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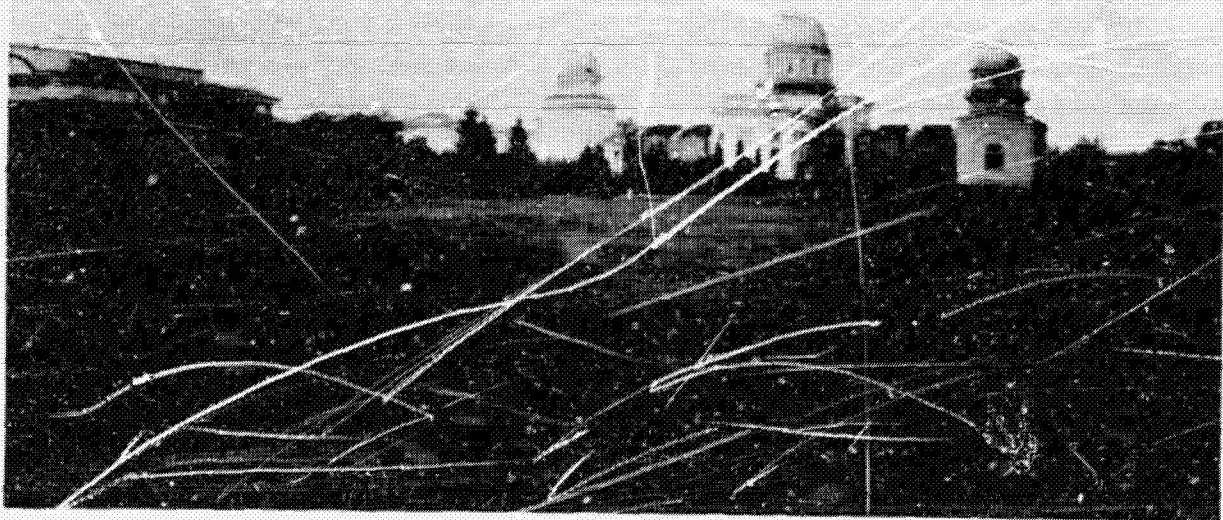
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PULKOVO OBSERVATORY

An essay on its history and scientific activity

ALEKSANDR NIKOLAEVICH DADAEV

Translated from the Russian by Kevin Krisciunas



TRANSLATOR'S PREFACE

In May of 1974 I visited Pulkovo Observatory near Leningrad, a visit which conjured up images of a time when the observatory was the "astronomical capital of the world." A century ago positional astronomy was the principal activity of astronomers. The foundation of modern astronomy was being built. It was Pulkovo Observatory itself that set the standards for a great deal of nineteenth century astronomy: the determination of fundamental constants, the compilation of fundamental catalogs of stellar position, the determination of proper motions and trigonometric parallaxes of stars, the discovery and measurement of double stars, the development of instrumentation and methods of observation for increased accuracy. To study the history of Pulkovo Observatory is to study the development of astronomy in all of Russia over the past century and a half; it has been the Principal Astronomical Observatory of the country since the time of its founding.

During my visit to the observatory I was given a tour of the grounds and a copy of A. N. Dadaev's 1972 work on the history of the observatory. As a result of the friendly attitude with which I was received, I have since wanted to make available to readers of English the historical treatise that was given to me. The start of this project took over two years. Though a 1958 version of Dadaev's history was translated into English (coinciding with the IAU meeting in Moscow), the second

edition of his history is three times longer and contains much more information on the post-World War II activities of the astronomers at Pulkovo. Besides, the English version of 1958 is not readily available. Because Pulkovo Observatory ranks today with institutions such as Yerkes, Lick, Hale and Greenwich, the histories of which are important to modern astronomy, I felt that my translation project would be worthwhile, both as a service to those interested in the topic and as a thank you to the Pulkovo astronomers K. N. Tavastsherna and G. S. Kosin.

In addition to the translation I have added a name index (containing full names and dates where available), a table of the observatory's directors and to the list of references some reading material in English.

The Library of Congress scheme for transliterating the Russian alphabet has been used throughout. This may make for some confusion, as Deĭch is also known as Deutsch, Ganskiĭ as Hansky, and Oskar Andreevich Baklund is also Jöns Oskar Backlund.

I would like to thank Professor S. Vasilevskis (retired Lick Observatory astronomer) for help in clarifying a number of passages. The ultimate responsibility for the translation, of course, is mine.

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At the present time Pulkovo Observatory bears the name of Principal Astronomical Observatory of the Academy of Sciences of the USSR,¹ but for a very wide circle of people in our country as well as outside its borders, it is known by the first of its names.

Founded more than 130 years ago, Pulkovo Observatory, in the first decade of its existence, acquired a reputation among scientists of the whole world as a first class scientific-investigative establishment, and the title of astronomical capital of the world was already attached to it then. The world-wide reputation and universal recognition of the observatory came as a result of its own distinguished works in different areas of astronomy, to astronomical observations of an exceptionally great precision, and to the carefully thought out organization of the observations and the continued perfection of methods and means of astronomy.

The observatory is situated to the south of Leningrad, 19

¹Throughout the extent of its history Pulkovo Observatory has had several official names: Principal Astronomical Observatory at Pulkovo (1839-1855), Nikolaevskaia Principal Astronomical Observatory (1855-1918), Principal Russian Astronomical Observatory (1918-1927), Principal Astronomical Observatory of the USSR at Pulkovo (1927-1945), and Principal Astronomical Observatory of the Academy of Sciences of the USSR (since 1945).

kilometers from the center of the city, on a hill 75 meters above sea level. A straight and level highway runs almost along the meridian from the city to the observatory, the domes of which are visible at a distance from Moskovskii Prospect in Leningrad. At the foot of the hill the highway forks: one branch goes to the city of Pushkin (formerly Tsarskoe Selo), the other to the main entrance of the observatory and on to Gatchina, Pskov, and Kiev.

The fame of Pulkovo stems not only from the scientific activity of the astronomers, but also from the battles fought by the defenders of the city of Lenin, the cradle of the proletarian revolution. Three times in the years of Soviet power Pulkovo was the scene of a bitter, bloody struggle against the enemies of the revolution and socialist state. On the third day after the achievement of the revolution in Petrograd, in November of 1917, a confrontation took place on the Pulkovo heights between the Red Guard forces and the troops of the Provisional Government, which were routed there. In October of 1919 the White Guard army of General Udenich was stopped and routed at Pulkovo. Finally, the Germano-fascist troops, advancing towards Leningrad in 1941, were held back here. From the Pulkovo heights began the all-out offensive of Soviet troops on the Leningrad front.

From September of 1941 till January of 1944 the southern boundary of besieged Leningrad was defended and held one and a half kilometers to the south of the main building of the obser-

vatory. Intensive artillery and mortar fire from the enemy positions and bombardment from the air brought total destruction to all buildings of the observatory. General damage done to the observatory was estimated at 137 million rubles (or 26 million American dollars, in 1944 currency).

The year 1953 was the year of the second birth of Pulkovo Observatory. It was not simply restored, but rebuilt from the ground up. Present cost estimates for this exceed prewar ones. The scientists at Pulkovo worked on diverse problems in astronomy and related disciplines, and according to the variety of undertakings by a number of people, Pulkovo Observatory presents itself as one of the most important scientific-investigative astronomical institutes in the world.

Pulkovo played a significant role in the creation and development of a number of observatories in our country and beyond the border: Simeiz, founded in 1908, Kislovodsk Mountain Station (1948), Blagoveshchensk Latitude Station (1958), Shemakha (1959), Zelenchukskaia (1968), Ulanbatar (Mongolian People's Republic, 1960), Chile (near Santiago, in 1962 transferred to a new place), and others. Pulkovo Observatory has branches at Nikolaev (Ukraine), Kislovodsk (North Caucasus), Blagoveshchensk-on-the-Amur (Far East), and investigative bases at the three points. From 1960-1964 the number of investigative expeditionary bases organized by the observatory reached 10, and of these, two- Zelenchukskaia and Novosibirsk- stand now as investigative centers.

The significance of Pulkovo Observatory in the development

of modern astronomy is great. The activity of Pulkovo astronomers in the past and present includes almost all branches of observational astronomy, with the exception of the monitoring of meteors, which to an equal extent can be considered an astronomical, as well as an atmospheric, phenomenon. In the line of workers at Pulkovo were such prominent scientists as Wilhelm von Struve, F. A. Bredikhin, A. A. Belopol'skii, A. A. Ivanov, and G. A. Tikhov. Their works have long been considered classical. The history of the observatory is closely connected in purpose with the history of astronomical science, and its modern activity falls in line with the demands of science and life.

*Struve is better known by the German form of his name (Friedrich Georg Wilhelm von Struve) than by the Russian form (Vasilii Iakcvlevich Struve). (Tr. note)

THE FOUNDING OF THE OBSERVATORY

The date of founding of the astronomical observatory at Pulkovo is considered to be the day of its official inauguration—7 (19) August 1839. The opening took place in the presence of members of the Academy of Sciences (the full delegation), high dignitaries, foreign officials, eminent scientists and astronomers from other observatories of Russia. The event had a great significance attached to it.

The construction of a large, well-equipped astronomical observatory near Saint Petersburg, at that time the capital, by direct authority of the Academy of Sciences was dictated by practical necessity. Russia stood on the path of capitalistic development, which signified the expansion of production and a fuller utilization of resources. The use of the country's natural resources was tied to the geographical studies of its vast territories, and the construction of geographical maps in the end depends on astronomical observations and a knowledge of precise stellar coordinates.

So, the practical objective of astronomy at that time was—precise stellar coordinates. But this goal was not easy. Achieving it required the development of astronomy as a science. Astronomy, precise positional astronomy, which, according to the term, by definition deals with positions of celestial bodies, had to make a step forward, which is to say, a leap in its development. This "leap" was manifested in the activity of the Pulkovo

Observatory in the first ten years of its existence. Precisely this was typified in the exceptional merit of the founder and first director of the observatory, W. von Struve (1793-1864), who by right was one of the greatest astronomers of the world.

W. Struve was not only a talented administrator and reformer, but was also an immutable ideological inspirer of the transformations contemplated by him in observational astronomy. Permanent concerns to him were to organize not only areas of positional astronomy. These concerns had a non-negligible significance for the development of all areas of astronomy, and in general preserve their significance to the present day.

Let us take a cursory look at the state of astronomy during that epoch. Of course, the Copernican paradigm was accepted by scientists everywhere. But the system of Copernicus received confirmation in view of the discovery of stellar parallax (or the measurement of the distance to stars) just in the years when the observatory at Pulkovo was built.

The discovery of annual stellar parallaxes (which are very small displacements of the stars on the sky due to the annual motion of the Earth around the Sun) was made, independently from each other, by a trio of astronomers: Wilhelm von Struve at Dorpat (now Tartu in Estonia), where he graduated from the university and began his scientific activity; F. Bessel in Germany; and T. Henderson at the Cape of Good Hope. In a number of European countries at that date, and in Russia, there already existed sufficiently equipped observatories, where systematic

observations were being carried out and, as it happened, the discovery was made. Observations for the most part were of the Moon and planets, double stars, comets (when they were visible), "fogs," according to the modern concept, remote star congregates, galaxies and gaseous nebulae. Along practical lines, in particular for navigation, star catalogs were periodically made up lists of stars with their coordinates. Of purely theoretical works, such as celestial mechanical investigations or cosmogonical hypotheses, these were not yet dealt with, as far as they were not directly tied to observations.

In any case, from the evidence of annual parallaxes to the discovery of quasars and pulsars, astronomy once again had to travel a long road. For complete and final proof of the Copernican system it took almost 300 years. What a fast tempo it has developed at, in order to reach the present state in 130 years! And in this development of astronomy an important role belongs to Pulkovo scientists.

Stellar coordinates are fundamental astronomical data, and this fundamental nature is necessarily permanent. Confronting a principal problem of the new observatory- the production of high-precision catalogs- W. Struve pursued not only practical, but also purely scientific goals. The stellar catalogs which were used up to the founding of the Pulkovo Observatory could not provide a hopeful basis for the subsequent development of astronomy. Having been made familiar with all previous catalog production efforts, W. Struve used all aspects of a new method,

called the "science of observation," founded the Pulkovo school of astrometry. In essence, modern astronomy, as an important branch of astronomy, dealing with various astronomical measurements, originated together with Pulkovo Observatory. It is needless to say that at Pulkovo the "art of observation," which Pulkovo astronomers and also their predecessors made famous, was successfully combined with "scientific observation."

Struve's method tied together in itself the elaboration of theory, the construction of instruments, and a program of observing nearby and distant objects, and a comprehensive investigation of instrumental and personal observational errors. The theoretical basis of the method might seem at first glance paradoxical, as is described briefly by the following: a considerable test of previous observations, completely ignoring the results. In other words, on the basis of the observations W. Struve decided to create such stellar catalogs which would not depend on data of previous catalogs, and the objective would be to build on the results of his own observations. In astronomy two methods of observation are distinguished: relative, when the stellar positions on the sky are measured with respect to fundamental stars with known coordinates, associated with some catalog, and absolute, when the position of every star is determined separately, independently from other stars, in an agreed-upon system. But it is necessary to define the very system of coordinates. The fixing of this depends on knowledge of the Earth's motion, which in astronomy characterizes itself as a so-called astronomical constant.

An astronomer must always remember that, while carrying out observations, he is not situated at a fixed point in space, rather, on a moving Earth, determining his "dozen motions," owing to the action of gravity and other laws of mechanics (in time he knows "eleven" motions). The measurement of the coordinates of celestial bodies consists in determining two quantities—right ascension and declination. They are analogous to the geographical coordinates on the Earth's surface, longitude and latitude, and in astronomy there are the concepts of a "celestial pole," a "celestial equator," and a zero point on the equator—the "vernal equinox." These three concepts give an idea of the system of coordinates for celestial objects. But the coordinate system, tied to the observations, changes all the time, as the observer moves together with the Earth. It is necessary to find some "fixed" system or at least one which would move transversely, always remaining parallel to one's self. In physics such a system is called inertial, and it is, according to the theory of relativity, equivalent to an absolutely fixed frame of reference. In order to have the desired coordinate system it is necessary to eliminate all motions of the Earth, especially rotational ones. This consists of the problem of determining astronomical constants. Of course, in this problem there also enters the determination of refraction, which is not connected to the Earth's motion, but to the refraction of light in the Earth's atmosphere.

So, in order to achieve the objectives, it was necessary to ignore the results of others' observations, not only to necessarily

forget other catalogs, but to determine astronomical constants all over again. In this was involved an absolute method of determining the coordinates of celestial bodies. Struve's method was an absolute system. All the advantages of his method were agreed upon much later, when, after his death, the so-called fundamental stellar catalogs were beginning to be created, about which we will have more to say.

In order to increase the accuracy of the observations W. Struve proposed a method of separately determining both coordinates. For this purpose he ordered from Germany instruments of two types: a transit instrument (objective diameter $D = 150$ mm, focal length $f = 260$ cm) for the determination of right ascension, and a vertical circle ($D = 150$ mm, $f = 195$ cm)- for the determination of declination. The instruments were manufactured in Munich according to Struve's plan by the master Ertel, and were the largest in the world for the purpose of meridian observations. Repeatedly modernized, they work up to the present time, carrying out a program of absolute observations.

Struve also planned a large project of relative, or differential, stellar observations, for which he obtained a Repsold meridian circle ($D = 150$ mm, $f = 215$ cm), also manufactured in Germany. Repsold's transit instrument ($D = 155$ mm, $f = 235$ cm) was used for the determination of astronomical constants (aberration and nutation), it being fixed on the prime vertical, i.e., the plane perpendicular to the plane of the meridian.

All instruments were situated in special parts of the main

building of the observatory, built according to the plan of the well-known Russian architect A. P. Briullov (1798-1877). The main structure (as it appears even today) consisted of two stone buildings, a west one and an east one, and a central observational part, united by corridors to the east and west buildings. Above the central part stood three wooden octahedral towers with conical roofs. In the middle the largest of these contained a 15-inch refractor, the work of the German opticians Mers and Mahler, successors to the famous Fraunhofer. This refractor, intended for the measurement of double stars, was for a long time the largest in the world. Thus, the equipment at Pulkovo Observatory was most modern for its time.

W. Struve took special care in the selection of the observers. Besides himself, the scientific staff of the observatory consisted of four astronomers: his son Otto Struve, G. Sabler, G. Fus, and F. Peters. This staff would be able to ensure the implementation of the selected program.

Already, in 1842-1843 appeared the work of O. Struve, F. Peters, and W. Struve on the determination of the constants of precession, nutation, and aberration.² Whereas for the deter-

²Precession and nutation are periodical motions associated with the rotation of the Earth and consisting of the change of position of the Earth's axis in space, or the change of position of the "celestial pole" with respect to a "fixed" Earth. Precession operates with a period of about 26,000 years, nutation

mination of the first two, characterizing the Earth's rotation, it required the use of observations carried out earlier at Greenwich and Dorpat, for the determination of aberration W. Struve utilized his own observations made at Pulkovo during the years 1840-1842 with the help of the transit instrument, fixed on the prime vertical. As far as the constant of aberration is associated with the velocity of light in space, these observations of W. Struve allowed him to conclude that light from all stars travels with the same velocity of 288,433 versts per second, with an error no greater than 150 versts (previous determinations contained errors greater than 3000 versts per second).³

with a period of 18.6 years. Therefore, their determination requires a number of observations, taken over a considerable span of time. Only having begun work at Pulkovo, the astronomers were not able to make the determinations solely with their own observations. This was supposed to be done later.

The phenomenon of aberration arises from a sum of velocities: the velocity of the spreading out of light, and the orbital velocity of the Earth. The constant of aberration was able to be determined on the basis of observations carried out over a period of approximately one and a half years.

³If versts are converted into kilometers, the velocity of light, according to Struve, is 307,700 km/sec. From this it is obvious that Struve did not quite correctly estimate the accuracy of the determination of the velocity of light. Of course,

Until the work at Pulkovo, the best determination of aberration belonged to Bessel ($20''.475$). In the year 1896, by suggestion of the American astronomer S. Newcomb, in the capacity of an international expert, it was customary to adopt the value of $20''.470$ for aberration, close to the determinations of Bessel and W. Struve. However, the average of its values from all determinations at Pulkovo from 1840-1880 ($20''.493$), also known to Newcomb, was almost in agreement with the modern (Hamburg, 1964) accepted value ($20''.496$). The same can be said about the constant of nutation: the customary value ($9''.210$), which we use by international agreements of 1896 and 1964, is very close to the value obtained by F. Peters in 1842 ($9''.214$). Such an objective characteristic of Pulkovo results is now cleared up in full measure.

Consequently, quite objective is the recognition of Pulkovo

its value was determined much more precisely than before, but it still was further from the true value than Struve supposed. His determination depended on the accuracy of determining the constant of aberration, but into this value to an uncertain degree enters one other constant, the so-called solar parallax, or distance to the Sun, which was known also with considerable uncertainty. However, not only a more precise determination of the velocity of light, but also the establishment of the fact of the constancy of this velocity, which already does not depend on the solar parallax, deserves special attention.

star catalogs as being the highest precision of all original catalogs containing first-hand observational facts. Confronting a basic problem of observatories, generations of Pulkovo astronomers created absolute catalogs of right ascensions and declinations of stars for the epochs 1845, 1865, 1885, 1905, and also 1930 and 1955. At first the catalogs contained 374 stars down to fourth magnitude, then the number was increased to 558, and in the catalogs of 1955 the number of stars contained exceeds a thousand. Already brought to light with the catalogs of 1845 and 1865, arose the possibility of creating fundamental catalogs on their basis, with the assimilation of observations from other observatories.

The fact is that from the comparison of two initial (original) absolute catalogs for different epochs it is possible to obtain "stellar proper motions," because with the absolute method of catalog construction the motions of the Earth are eliminated (all except the transverse motion), and the changes of stellar positions in two catalogs, compared by us after the decades separating one epoch from another, give evidence for the motion of most stars, also including the transverse motion of the Sun, i.e., the motion of the Sun among the stars.⁴ These are catalog proper

⁴Strictly speaking, the initial catalogs contained not only the "transverse motion" of the Sun, but, as a rule, the precession of the Earth's axis. Therefore, to obtain "absolute proper motions" of stars it was necessary to eliminate precession, which

motions and not peculiar, or "properly proper" motions, as far as the motion of the Sun enters into catalog proper motions in an uncertain manner. To precisely determine the velocity of the Sun's motion relative to the stars was possible only later on, and for the 1870's the determination of "catalog proper motions" in great quantity was a huge undertaking, more so, as for all practical purposes, just such proper motions were necessary. Pulkovo observations were furthered to a considerable degree with this undertaking.

Fundamental catalogs of stellar positions contain, besides coordinates, also the proper motions. Thanks to this they remain suitable for every epoch and, really, represent the very foundation of astronomy. Such catalogs are made up, originating from the results of observations of many observatories. Works for the creation of fundamental systems received their development in America and Germany (S. Newcomb, A. Auwers, L. Boss). But with all the constructions of fundamental systems, Pulkovo catalogs, displaying great precision, were invariably given the greatest weight. So it was, S. Newcomb wrote, that one observa-

was fully possible with the sufficiently large difference in the epochs of creation of the catalogs. As was found out in the years 1925-1927, with the discovery of the rotation of the Galaxy, the motion of the Sun together with the system of planets was not strictly transverse. This in general complicates matters, though practically does not enter into the calculation.

tion on the Pulkovo vertical circle was equivalent to twenty, thirty, or even forty observations made by average observers on a meridian circle. Newcomb himself caught the gist of it and brought to use the words of his compatriot and contemporary, B. Gould, calling Pulkovo the "astronomical capital of the world."

One of the first works of Pulkovo astronomers that deserves mention is the investigation published in 1848 by F. Peters concerning the parallaxes of 8 bright stars, based on observations made with the vertical circle. Peters confirmed the results of Struve and Bessel and proved once and for all that parallaxes of stars are exceedingly small, and, consequently, the distances to them are enormous. Struve himself described this work of Peters, "as a genuine standard of precision and inherent perfection."

W. Struve's classical work, Etudes d'Astronomie Stellaire, published in 1847 as a separate book, assumes a special place. It was not directly connected to the rest of the works at Pulkovo and, according to its title, did not pertain to positional astronomy, but rather to the realm of stellar astronomy. From his profound analysis of available data concerning the distribution of stars it is possible to conclude how intricately W. Struve understood the problems of astronomy and the significance of Pulkovo observations for following its development. Struve in particular demonstrated the absorption of starlight with its passage through space. This result had an important consequence for the development of stellar astronomy, and also for a resolution

of Olbers' paradox (ca. 1826), which concerned the realms of cosmology and philosophy.

This paradox may be formulated as follows. With a uniform distribution of an infinite number of luminous objects in the universe, the brightness of the sky must be infinitely great, something we do not observe in reality. The sky is dark, but it should appear blindingly bright. This means either that the universe is finite, or some other thing keeps the sky from being infinitely bright. W. Struve found the "other thing" in the form of the cosmic absorption of light. Of course, as the end of the century the paradox took on another form, and even with the help of cosmic absorption it was impossible to resolve it.

Raising a number of philosophical problems (the relativity of motion, an infinite universe) Pulkovo scientists at that time were still aware of the practical value of the results of their investigations and they did not ignore the practical problems of astronomy which also concerned them and the regulations of the observatory. In accord with the regulations, the Pulkovo Observatory scientists assumed an active participation in geodesical and geographical undertakings going on in Russia. Any and all important work of an astronomical-geodesical character was carried out under their leadership, and the director of the observatory, not without reasons in his reports, enumerated the works produced by the General Staff and other departments.

From 1816 to 1855, field works and observations on a vast scale were carried out under the direction of Wilhelm von Struve,

with the aim of measuring the different meridians between the Danube and the Arctic Sea, with a total range of $25^{\circ} 20'$. This "Russo-Scandinavian arc," or "Struve's arc," presented at that time a very large measurement of a degree on the terrestrial surface. It even now has a great value for the determination of the Earth's figure; even by modern standards it ought to rank as a great undertaking. In the years 1899-1901, sponsored jointly by the Russian and Swedish Academies of Sciences, Pulkovo astronomers participated in degree and gravimetric determinations on the Spitzbergen Islands, in a most northerly triangulation of the Earth.

To Pulkovo belonged a great role in the training of geodesists and topographers in Russia. At first the lessons with the topographers were conducted by the director of the observatory himself, then to the General Staff was granted the means which provided the prescription of a special assistant director, instructors with the lessons, and the purchase of necessary instruments. In the year 1856, to the northeast of the main observatory building, was built a small military department educational observatory. From 1863 the corps of military topographers suspended the sending of its officers to Pulkovo, but the practical training of geodesists continued right up to 1917 and even later. Beginning with the year 1898, naval officers-hydrographers were regularly commandeered to Pulkovo for the taking of practicals, having finished the course at the Naval Academy. For their lessons an observing tower was built next to the

General Staff's observatory, which was restored in postwar times, and preserved on it is the name "naval tower."

Soon after the October Revolution of 1917, in connection with an unusual range of geodesical, topographical, and gravimetric works in the country and, first of all, with the appearance of many socialized institutions, the broad scientific and educational activity for geodesy gradually began to diminish at Pulkovo. However, for newcomers to Pulkovo, the training of Russian and foreign astronomers continues to the present time.

THE ASTRONOMICAL CAPITAL OF THE WORLD

In October of 1861, in view of serious illness and on the grounds of overwork, W. von Struve retired from official service. Already in 1858 the activities of the observatory were managed by his son Otto Struve (1819-1905), who was selected by the Academy of Sciences in 1862 for the post of observatory director. In the very same year, according to a new law, Pulkovo Observatory was transferred from the management of the Academy of Sciences to immediate subordination to the Ministry of Public Education. The special role of the observatory was accentuated by the passage of the new law, as far as it was made equivalent to the Academy of Sciences, which was at that time subordinated to the same ministry. Allocations for the maintenance of the observatory were considerably increased, almost doubling its scientific estate. For opinions concerning scholarly matters and the decisions of questions of an important nature for the activities of the observatory was established the Committee of the Principal Astronomical Observatory, under the chairmanship of the president of the Academy of Sciences, and made up of representatives of departments, to which the activity of the observatory had a direct relationship.

The change of directors took place during Pulkovo Observatory's period of flourishing, during its worldwide recognition and fame. Also at that time considerable events were taking place in physics and astronomy, opening new paths for the devel-

oment of science. These events forced Pulkovo to improve its methods of work, in order to keep up with the times.

The beginning of the 1860's was marked by the invention of spectral analysis. The application of it to astronomy, side by side with the invention of photography,¹ prompted the development of a new branch of astronomical science, astrophysics (the science concerning the nature of celestial objects), for which the second half of the XIX century was characterized by the accumulation of observational material; numerous determinations of luminosity (brightness) and color of stars, the classification of stellar spectra and the search for the most rational classification, the study of spectra of comets and nebulae, and the measurement of the velocities of celestial bodies along the line of sight (the determination of radial velocities) from the displacement of the lines of their spectra.

¹The invention of photography by Daguerre (daguerrotypes) coincided with the year of founding of Pulkovo Observatory. Daguerrotypes soon after were used to obtain the first pictures of the Sun, Moon, and bright stars. A more important application was found for astronomy at the end of the 1850's, and since the 1880's, with the invention of extremely sensitive dry bromide-gelatin plates, photography superseded visual methods of observing for almost all areas of astronomy.

The solution of theoretical problems of astrophysics, which made this as precise as classical astronomy, was possible by the XX century, thanks to the successes of theoretical physics, in particular the theory of radiation and atomic physics.

In essence, astrophysical investigations were conducted at Pulkovo Observatory from the time of its founding. Of such can be considered the determination of the velocity of light from the constant of aberration (see above), and W. Struve's conclusion concerning the existence of cosmic absorption of light. From observations of a total solar eclipse in 1851 O. Struve reached the conclusion that prominences and the corona were not optical phenomena caused by the Moon as assumed earlier, rather, they were formations inherent to the Sun.

In several articles of the postwar period the thought was expressed that in the 1860's astrophysics at Pulkovo developed slowly, and the reason for this seemed to be a negative attitude of the director C. Struve towards it. This was not so. In two papers published by O. Struve for the Academy of Sciences in February of 1866 ("Photography for use in astronomy" and "Concerning the role of astrophysics in astronomy"), it is possible to see that the director correctly understood the problems of astrophysics of that time, and the purpose of the papers consisted in the justification of a new direction included in the sphere of the observatory's activity. Some restraint was called for by Struve with the fear that the enthusiasm for novelty and if it is possible to say, the search for discoveries withdrew

astronomy from its "life purpose" of scientific exactness and mathematical precision. Later, in 1889 Struve wrote: "As far as astrophysics is concerned, its acceptance into the circle of the observatory's activity was a necessity of the time, because without this our work in practical astronomy would soon become incomplete. Also, this (i.e., astrophysics) in some of its parts is a completely new branch of investigation, and it is still far from that accuracy in observing and from conclusions based on this observing compared with precise astronomy, which represents almost rigorously mathematical motions of celestial bodies, but the rapid development of astrophysics in the last two decades and its successes in the mentioned direction (i.e., increased accuracy) clearly show its value for astronomy, and the successes serve as a guarantee of further improvement regarding accuracy."²

The high precision of the observations made the fame of Pulkovo. The concern about its preservation was the business of many of the observatory's directors of prestige. Like his father, O. Struve was a talented administrator, successfully directing the observatory longer than other directors- more than 30 years. If astrophysics at Pulkovo exhibited considerable progress in the twenty years following his retirement, it was his doing. Any new field of science cannot develop without existing capital investments. Astrophysics was especially

²To the Fiftieth Year of the Nikolaevskaia Principal Astronomical Observatory, Saint Petersburg, 1889 p. 5.

demanding in this respect, as for its development powerful telescopes and other expensive equipment was necessary. Otto Struve himself secured the apportionment of the necessary funds from the government and purchased the required equipment, beneficially bestowed upon the observatory at the end of the century. But the technical backwardness of Russia on the whole, forced to put in orders for equipment from beyond the border, did not promote a constant material base maintenance for Pulkovo Observatory at a high level. The observatories of other countries, particularly the USA, surpassed it in equipment, and the foremost character of Pulkovo investigations was preserved basically for the calculation of an abundance of unsettled questions and in the ingenuity of the astronomers.

However, in the 1860's and 1870's at Pulkovo, as at other observatories, astrophysics did not go beyond the accumulation of observational results. In the years 1868-1869 P. Rosen, a Swedish astronomer-geodesist, formerly in practice at Pulkovo, made estimates of stellar luminosities by means of a Zöllner photometer (the observatory owned two such instruments then). He devoted special attention to the accuracy of the results and the study of the influence in them of possible errors of observation. The technical secretary of the observatory, E. E. Lindemann, continued these works after 1870, using the same method. Besides stars of constant brightness, variable stars were included in the program of observation. Producing a great number of observations during the extent of more than a quarter century,

Lindeman thoroughly studied the errors in his estimates, which included his work in a number of investigations of paramount importance executed at standard of the time.

The striving towards a preservation of the "life principle" of strictness and accuracy in astronomy was an unquestionable virtue of O. Struve. His "outmodedness" was reported by others. Fervently dedicated to scientific progress in Russia, he however did not draw the Russian intelligentsia to work. As before, vacant posts at Pulkovo were filled by Baltic Germans- pupils at Dorpat University and foreigners. But for the sake of justice it follows to say that Struve was not mistaken in the scientific capabilities of those he invited. For example, in 1872 he invited to Pulkovo the astrophysicist B. Hasselberg from Stockholm, who introduced photographic methods into practical observations. At that time a Dallmeyer photoheliograph was purchased, at once adopted for the observation of a transit of Venus across the disk of the Sun in December of 1874, in an expedition outfitted at Vladivostok. Hasselberg made the observations with the photoheliograph. He manufactured the photographic plates by hand, requiring for it a great effort.³ The results of his photographic observations, although requiring a long wait, surpassed in precision the results of other authors, who used visual methods in

³At that time dry plates did not exist and they used wet, colloidal plates, which were prepared before their use.

their observations.

In 1876 B. Hasselberg founded an astrophysical laboratory at Pulkovo and was engaged with spectral investigations with the utilization of photographic plates, which he continued to manufacture. He conducted experiments with the luminescence of gases, studied the absorption spectra of chemical elements and compounds, determined and made more precise the wavelengths of spectral lines. On the basis of the study of comet spectra and carbon compounds he indicated the presence of the latter in comets. His monograph on this question was the first in the world's literature. A basic principle of astrophysical investigation was clearly reflected for the first time in the works of Hasselberg- the combination of spectral observations and a laboratory experiment. Only such a principle could provide the strictness and precision of results, as far as theory was lacking.

In 1882 a chair of astrophysics was established at Pulkovo Observatory, which was occupied by Hasselberg until his return to Sweden in 1889. On 1 January 1888 the Moscow astronomer A. A. Belopol'skii (1854-1934) was invited for one of the vacated positions of adjunct-astronomer. In 1890 he filled the position of astrophysics and until the end of his life remained the director of astrophysical work at Pulkovo. In 1886 a separate astrophysical laboratory building was built with an electrical station with it, which allowed laboratory investigations to expand much more widely. In astronomical observational technique, especially astrophysics and astrophotography, the lag behind foreign obser-

vatories had become apparent.

Already at the beginning of the directorship of O. Struve the 15-inch refractor, with which he himself made observations over the course of 40 years, had lost its place as the most powerful instrument in the world. Its mounting was noticeably out of date, something Struve became clearly convinced of on his trip abroad. At that time the Clarks (the father and two sons), American lens grinders, expanded their activity, having supervised the production of large objectives at Cambridge near Boston. In 1873 an objective of diameter 26 inches was manufactured at Clark and Sons for the refractor of the Washington (Naval) Observatory, with the help of which Hall discovered the moons of Mars in 1877. With the very same instrument was found a number of close double stars, difficult for observations by means of the 15-inch Pulkovo refractor. All this defined the necessity of ordering a new, more powerful telescope for Pulkovo. Thanks to the help of the Committee of the Observatory and the Ministry of Education 300,000 rubles was assigned for the ordering and manufacture of the instrument.

An objective with a diameter of 30 inches (76 cm) was ordered from the firm of the Clarks; the plant of Feil in Paris manufactured the glass for it and the firm of Repsold in Germany made the telescope mounting. In June of 1883 the objective was delivered to Pulkovo and the installation of the refractor in a special tower⁴ was completely finished in two years; the tower was built to the south of the main building of the observatory, according

to the plans, and under the direction of the engineer-general G. E. Powker, one-time Minister of Communication Means. In this way Pulkovo Observatory was for a second time the owner of the largest telescope in the world, but not for long: soon after, the Clarks manufactured two still larger lens objectives, with diameters of 36 and 40 inches (91 and 102 cm), for two American observatories- Lick (in 1888) and Yerkes (in 1896). The Yerkes 40-inch refractor to this date is the largest in the world. Lenses of larger diameter have not been made, for as the diameter is increased, so is the thickness, in which the light collected by the objective is absorbed.⁵

⁴The tower of the 30-inch refractor, greatly damaged in the war of 1941-1945, was demolished in 1953. Together with the tower perished the telescope's mounting, only the objective having been preserved, which is situated in the observatory's museum.

⁵Speaking of the diameters of telescopes, it follows to distinguish refractors (lens), reflectors (mirror), and mirror-lens telescopes. Large reflectors already existed at the end of the XVIII century. In 1789 William Herschel manufactured a telescope with a mirror diameter of 122 cm, and in 1845 W. Parsons (Lord Rosse) created a telescope with a metal mirror of 182 cm diameter. With the help of their telescopes Herschel and Rosse made many

In every case concerning the 30-inch refractor of Pulkovo Observatory it was destined to go down in history, not only at its observatory, but in worldwide astronomy. The first observations with it were made by the third son of O. Struve, Hermann Struve (1854-1920), who worked up to it from observations with the 15-inch refractor. In the first two years of observations H. Struve carried out an investigation of the instrument and made a large number of double star measurements. From his work, conducted with the help of the 30-inch refractor, the investigations of planetary satellites of Saturn, Mars, and other planets

discoveries. However, these gigantic telescopes were not perfect: their mirrors were made from copper and tin alloys, without special coatings, which is why they quickly tarnished and needed repolishing. Therefore, in the nineteenth century refractors with achromatic objectives for some time displaced reflectors. With the invention of thin coatings (at first silver, then aluminum) it became possible to polish mirrors of durable material- glass or pyrex, which possessed a small coefficient of thermal expansion. Then were created the largest reflectors: the 100-inch of Mount Wilson (1917) and the 200-inch at Palomar (1948). In the twentieth century mirror-lens systems were produced, and also systems with special correctional plates in front of the mirror instead of lenses (Schmidt and Maksutov systems).

produced a most important result. Being also a physicist and a theoretician, H. Struve utilized his observations for the establishment of a theory of motion of satellites. In the motion of the seventh satellite of Saturn, Hyperion, he discovered an extremely subtle phenomenon- libration (the tilting of the satellite), which was given a simple explanation with the help of the perturbation on Hyperion by the largest, sixth satellite in Saturn's system, Titan. This came to pass in 1888, and in 1892 he discovered the libration of the two satellites closest to Saturn- Mimas and Enceladus.*

In 1895 H. Struve, having received an invitation from Königsberg to occupy the post of director of the observatory and professor at the university, left Pulkovo. In 1904 he became head of the Berlin Observatory, for which a new building was built at Babelsberg. In that way he is considered the founder of the Berlin-Babelsberg Observatory.

It is now appropriate to speak of three more astronomers of world renown from the family of Struve. The fourth son of G. Struve, Ludwig Struve (1858-1920), was at first not on the staff at Pulkovo Observatory, but later on he was a professor at Khar'kov University and director of the university's observatory. Georg Struve (1886-1933), son of Hermann Struve, was an

*A tenth satellite, now known as Janus, was discovered by A. Dollfus at Meudon Observatory in 1966. It is now the closest known satellite to Saturn. (Tr. note)

astronomer-observer at the Berlin-Babelsberg Observatory. Particularly renowned as an important astrophysicist and administrator, the great-grandson of the founder of Pulkovo Observatory, the son of L. Struve, was Otto Struve (1897-1963), an American astronomer, director of two observatories- Yerkes (in the state of Wisconsin), and McDonald (in the state of Texas), president of the International Astronomical Union (IAU) from 1952 to 1955, and in the latter years of his life director of the new radio astronomy observatory at Green Bank (in the state of West Virginia).

Let us return to his grandfather O. Struve. In 1889, after the celebration of the fiftieth year of Pulkovo Observatory, the 70 year-old O. Struve, having served at the observatory since the day of its founding, went into retirement and soon after moved to Karlsruhe, where his relations and close friends lived. He did not lose his interest in science up to the end of his life. Concerning his work and interests it is possible to judge according to the publications of the observatory and from numerous letters preserved in the archives.⁶

⁶In the Archives of the Academy of Sciences of the USSR is kept, for example, the correspondence of O. Struve with the well-known Italian astronomer G. Schiaparelli, then director of Milan's Brera Observatory, and discoverer of the "canals" on Mars. This correspondence consists of greater than 500 items.

AT THE TURN OF THE CENTURY

The direction of activity of an institution and the condition of matters in it greatly depend on the director. This was clearly illustrated in the prerevolutionary history of Pulkovo Observatory. When, for example, G. A. Tikhov wrote a history of the observatory at its hundredth year, he subdivided the periods of its activity into: the new charter- a new director (O. Struve), the directorship of Bredikhin, the activity of the observatory under Baklund, etc. One has to almost precisely follow this scheme, for actually the election of a new director every time signified the beginning of a new period in the observatory's history. Of course, this did not carry with it the character of a revolution. On the whole traditions were preserved, but new distinctions appeared, characteristic of every period.

In the summer of 1890 F. A. Bredikhin (1831-1904) became the director of the observatory, elected in the same year as a regular academician of the Petersburg Academy of Sciences. He was already an important scholar, the investigations of whom on the theory of cometary forms acquired worldwide recognition. Over the course of 17 years he was director of the Moscow Observatory and a professor at the university. With the appointment of Bredikhin Pulkovo Observatory's "orientation to the west" was overcome. Pulkovo became a Russian center of astronomical investigations.

Bredikhin himself, in his first report to the Committee of

the Observatory, wrote the following: " At the very outset of the governing of the observatory it was clearly evident to me that theoretically oriented pupils of all Russian universities, feeling and declaring their calling to astronomy, must be given, within the limits of possibility, free access to complete practical training in this science, and then to the pursuit of all scholarly positions of the observatory." In accord with this he at once appointed four people as additional astronomers,¹ they having finished the course of mathematical sciences at the Petersburg and Moscow Universities at the head of the class. Three of them (S. K. Kostinskiĭ, A. A. Ivanov, and V. V. Serafimov) closely connected their fate with Pulkovo Observatory.

The drawing of people having graduated Russian universities to the observatory for additional positions was practiced after Bredikhin by his successor Baklund. For the calculation of the availability of "additional staff" the scientific personnel of the observatory increased itself almost one and a half times. With the aim of establishing scientific contacts, Bredikhin, in the very first year of his directorship, visited astronomical observatories in Moscow, ^KHarkov, Nikolaev, Odessa, and Kiev. Such visits he continued in following years. In 1894 he wrote: "The dealings with Russian university observatories, so lively now that it follows to rejoice from the soul, for a more or less prolonged period produced good people for us at Russian univer-

¹At present this position approximately corresponds to the post of junior scientific worker.

sities constantly- those who wish to improve one or another area of astronomy. With such a position of our business, observatories do not have to worry about a shortage of good talent, when they need it."²

Finally, for the sake of the goal of the unification of forces, in 1890 Bredikhin organized the Russian Astronomical Society and was its first chairman.

With the appointment of A. A. Belopol'skiĭ to the post of astrophysicist, astrophysical observations all assumed a great specific weight in the program of observations of Pulkovo Observatory. At first Belopol'skiĭ investigated the rotation of Jupiter on the basis of numerous observations of different observers. He reportedly discovered the differences of rotational period for the equatorial zone and in higher latitudes: Jupiter does not rotate as a solid planet. Along this line Belopol'skiĭ began a study of the Sun's rotation according to the motion of faculae, which are observable in numerous photoheliograms obtained by B. Hasselberg in 1881-1888. For the measurement of the plates he engaged the help of M. N. Morin. The result was analogous to the following: with the degree of moving off from the solar equator to its poles, one can clearly detect an increase of the rotational period. Later on, in 1905 and 1925 Belopol'skiĭ once again returned to a detailed investigation of the Sun's

²Report to the Committee of the Nikolaevskaia Principal Astronomical Observatory at Pulkovo, presented by its director, Saint Petersburg, 1894, p. 4.

rotation on a spectroscopic basis.

In 1891 Belopol'skiĭ was sent abroad for the ordering of necessary instruments- a stellar spectrograph and a photographic refractor, or a so-called normal astrograph. The normal astrograph with two objectives, a photographic ($D = 330$ mm, $f = 350$ cm) and a visual ($D = 250$ mm, $f = 360$ cm), was established at Pulkovo in the summer of 1893. The optics of this instrument were manufactured by the brothers Henry in Paris, and the mechanical parts by the Repsold firm. At the beginning the astrograph operated under the direction of Belopol'skiĭ, and after 1895 under the direction of Kostinskiĭ.

A. A. Belopol'skiĭ made the spectral observations by means of the 30-inch refractor, transferred to his complete direction with the departure of H. Struve. In 1895 Belopol'skiĭ began the implementation of an extensive program of observations of radial velocities of stars, the Sun, planets and comets. It is possible to measure velocities of stars along the line of sight from the displacement of lines in their spectra, in comparison with lines in the spectrum of a stationary light source: displacement to the red side signifies a receding source (positive velocities); displacement to the violet side, approaching sources (negative velocities). If the celestial object is not a star, rather, the Sun or a planet, the slit of the spectrograph can be placed at the edge of such an object to obtain evidence concerning the velocity of its rotation. In the foundation of the measurement of radial velocities lies a principle for oscillatory processes

in acoustics and optics, formulated in 1842 by the Austrian physicist and astronomer Christian Doppler.

According to Doppler, the frequency of oscillation detected by the observer from the source of sound or light depends on the relative velocity and the direction of motion of the observer and the source of oscillations; with their approach the detected frequency is increased; with recession it is decreased. On this basis Doppler unsuccessfully tried to explain in part the observed differences in color of the components (comprising) double stars. Independently from Doppler, the French physicist H. Fizeau discovered the very same principle for optical phenomena in 1848. Both arrived at this conclusion as a result of theoretical arguments. True, for sonant phenomena the validity of the principle is easily verified by experiment, even simply by ear. With the inclusion of spectral analysis into astronomy, the principle of Doppler-Fizeau was accepted unconditionally.*

A. A. Belopolskii proposed an experimental verification of this principle again in 1894, but he carried it out in 1900. The great exactness of Pulkovo astronomers is reported in the very execution of the experiment, in relation to the authenticity and precision of the results obtained.

The idea of Belopolskii's experiment was simple, but the

*One of the most important controversies in modern astronomy concerns the red shifts of quasars, which may not be due to their receding at velocities comparable to the speed of light, as the Doppler principle would imply. (Tr. note)

difficulties in the implementation were substantial, if we bear in mind the enormous velocity of light, the frequency of oscillation (or the wavelength), which is to change by means of the reflection of the stellar velocity, i. e., a velocity of order 20 km/sec. In any case Belopol'skii first conducted this experiment. Later on, B. B. Golitsyn, a Russian physicist and seismologist, founder of the seismological station at Pulkovo (1906), carried out a more precise determination of the experiment.

Successfully having carried out the experiment, Belopol'skii continued spectroscopic observations with renewed energy. The optics of the 30-inch refractor were meant for visual observations, and the displacements of spectral lines were determined from photographs. In order to adapt the instrument for photographic observations Belopol'skii ordered a special correction plate, the adoption of which allowed him to extend the length of the spectrum and noticeably expand the investigated region on both sides, in the red and violet. Belopol'skii achieved a great result in relation to accuracy of determination of radial velocities: as at other observatories, for example Potsdam (Germany) and Harvard (USA), already having made a considerable test of the observations, he determined velocities with errors of ± 2.6 km/sec, which amounts to approximately 10% of the observed stellar velocities. In this way he did much in the way of the elaboration of methods of determination of radial velocities and was one of the pioneers in this field.

Belopol'skii selected about 200 stars from 2½ to 4th magnitude for an investigation of the Sun's motion in space with a

statistical method.³ According to the measure of increase of stars observed by him, he placed among them many spectroscopic double stars, having numbered them in small quantity, but the important role of which was already fully realized. Like visual binaries, spectroscopic binary stars furnish information concerning the masses of their components (making up the stars), rotating one relative to the other according to the action of mutual gravity. The application of the law of gravity to the study of the orbits of these bodies allows the determination of their masses. But spectroscopic binary stars display themselves independent of distance, which is why, only thanks to their existence, do the masses of more distant stars become known.⁴

³It is possible to compute, in a rough approximation, that stars move in different directions with velocities approximately the same in magnitude. If, on that assumption a systematical deviation toward some direction with a determined magnitude is observed in the measured (radial or catalog proper) velocities of stars, this signifies the motion of the solar system not only in the opposite direction, but with the same magnitude of velocity.

⁴If a double star (implying a pair of stars, physically connected to themselves thanks to mutual attraction) is separated into components with the help of a telescope, then it would be called a visual binary, even in an instance when the most powerful telescopes admit photography for the separation. Just visual binaries were the topic of study of Pulkovo astronomers until

Beginning in 1892 Belopol'skii failed to see a single outburst of novae, the spectra of which he studied during the extent of the period of minimum luminosity, while the observations were accessible to the instrument. Especially of interest was the discovery of periodical changes of radial velocity in variable stars of a special family, the so-called Cepheids. At the beginning Belopol'skii himself included them among double stars, but the Moscow professor N. A. Umov, formerly one of the opponents of Belopol'skii for the defense of his doctoral dissertation in 1896, expressed an idea concerning the pulsation of Cepheids. This idea later on was completely confirmed by both theories of phenomena and subsequent observations. In 1912 Belopol'skii suspected a change of the intensity of the spectral lines in Cepheids, and in 1913 his student I. N. Lehman confirmed this variation which confirmed the idea of pulsation.

After twenty-five years of observations with the 30-inch refractor, A. A. Belopol'skii had obtained a thousand spectrograms of stars, the Sun and other bodies of the solar system. He devoted much attention to the study of the rotation of planets, the physics of comets and their tails. On the basis of an investigation of the rotation of the rings of Saturn he established

the appearance of astrophysical methods. Astrophysics clearly defined the concept of photometric binaries and spectroscopic binary stars. Those and many others still cannot be separated with telescopes.

in 1895 the meteoric character of their structure, which comes across in accord with the mathematical theory of the stability of the rings, elaborated by S. V. Kovalevskaja.

The works of Belopol'skii achieved wide recognition. In 1903 the Petersburg Academy of Sciences elected him an extraordinary, and in 1906 an ordinary academician. In 1907 the Italian Society of Spectroscopists chose him as a member, and in 1910 the Royal Astronomical Society (in London) chose him as a member-correspondent; in 1908 the Paris Academy of Sciences awarded him the gold medal of Janssen.⁵ The Russian Astronomical Society awarded him many honors. In 1908 the Academy of Sciences elected Belopol'skii to the post of vice director of Pulkovo Observatory. But the events just described took place far from the limits of the "epoch of Bredikhin."

In a number of astronomical endeavors of F. A. Bredikhin the agreement between Pulkovo Astronomical Observatory and the Magnetic Observatory at Pavlovsk, concerning the simultaneous observations of magnetic storms and special phenomena on the Sun's disk, deserves mention. The performances of such observations were conducted in 1892; they confronted difficulties of

⁵J. Janssen (1824-1907) was a French astronomer and one of the founders of spectroscopic analysis. In 1868 (a month earlier than N. Lockyer) he devised a spectral method of observation of solar prominences outside of eclipse, and in 1870 developed the method of quantitative spectral analysis.

an administrative nature, which regretfully they did not attempt to overcome. In the observations there are definite implications for the existence of a correlation of magnetic storms and the Aurora Borealis with the passage of a group of spots across the central meridian of the Sun. It is possible they might have achieved the establishment of a purposeful "solar service," the origin of which at Pulkovo was associated with the systematic observations of the Sun by means of a photoheliograph, which was made by Hasselberg and Belopol'skii from 1881 to 1895. The solar service was finally formulated at Pulkovo in 1932.

Other observations of an unorthodox nature point towards the notion of a latitude service, which almost from the start was maintained at Pulkovo. In 1888 F. Küstner in Germany established the fact of the change of latitude of several European observatories, which could only be understood having allowed motion of the Earth's poles. The verification of this assumption by means of the organization of latitude observations in Europe and at the Hawaiian Islands in 1891-1892 confirmed it. Besides that we remember that the Pulkovo astronomers F. Peters and M. O. Nyren both closely approached the discovery of latitude changes from materials of their own observations. Acknowledging that the matter was concluded with the change of latitude of Pulkovo, they unsuccessfully attempted to corroborate the 305 day period of oscillation of the pole predicted by L. Euler (ca. 1765). Such a period in general was not found.

The American astronomer S. Chandler showed in 1891, on the

basis of an analysis of a large quantity of observations (about 30,000), that in the displacement of the Earth's poles there exist two periods- a yearly and a 14 month, or 428 day period, which received the name Chandler period. S. Newcomb explained the discrepancy from the Euler period by the fact that in his theory Euler started from a representation of the Earth as an absolutely solid body. In fact the phenomenon depends on a non-solid Earth core, the presence of the oceans on the surface and the atmosphere around the Earth, and even on the seasonal shifts of air masses, snow covers, etc., that produce the cyclical changes of the planet's moment of inertia and the position of the axis of rotation inside its body.

In this way the oscillations of the axis of rotation of the Earth are manifested in the oscillatory motions of the Earth's poles, which "trace" irregular spiral-looking curves in the boundaries of a square with a side of 22 meters (or 0:7), influencing their displacements over the whole coordinate grid and especially for geographical latitude, being measured from the equator (or at the poles, which is equivalent because the equator can be determined as the geometric locus of points equidistant from the poles). Nevertheless, all this was understood after a great number, and a continued span of observations, and also as a result of serious theoretical investigations.

In 1891, after the discovery of Küstner, S. K. Kostinskii began latitude observations at Pulkovo by means of the transit instrument on the prime vertical. Other observers continued

these observations till 1911, periodically publishing the results. Also in 1891, I. E. Kortazzi at Nikolaev made a determination of latitude by means of a portable vertical circle. Simultaneously, a thorough reduction of previous groups of Pulkovo observations on the large transit instrument and the vertical circle was undertaken and important theoretical investigations were carried out (A. P. Sokolov, M. O. Nyren, and A. A. Ivanov). Analogous observations and investigations were conducted by other European observatories.

With the result of all these works appeared the organization in 1898 of the International Latitude Service, which from the next year established six stations (later on only five), arranged on one parallel ($39^{\circ} 8'$), but scattered over different longitudes, in order to be able to make an accurate map of the motion of the pole from changes of latitude being observed at these stations. In 1899 the Russian station of the International Latitude Service began to function at $\widehat{\text{Chardzhou}}$ (in 1930 the station was moved to Kitab, where it operates even now). The motion of the poles is irregular; it defies description by mathematical formulas, but as it is influenced by the accuracy of astronomical observations and geodesic determinations, the marked importance of uninterrupted surveys of coordinates of the pole, or latitude surveys, remains.

At Pulkovo, besides regular latitude observations with the transit instrument on the prime vertical, which were carried out from 1891 to 1911, in 1904 a zenith telescope ($D = 135 \text{ mm}$, $f = 175 \text{ cm}$), manufactured by the Pulkovo mechanic G. A. Freiberg, was

established for the objective of a continuous latitude survey.

This instrument functions even now, exhibiting a standard of precision in the skillful hands of several generations of observers.

THE EXPANSION OF PROGRAMS OF INVESTIGATION

Declining health, "greatly disproportionate to an ardent and diligent attitude toward business," compelled P. A. Bredikhin to leave the post of director. In April of 1895 O. A. Baklund (1846-1916), who was not an absolutely new person at Pulkovo, assumed control of the observatory: from 1879 to 1887 he worked as an adjunct-astronomer at the observatory. Some time later, after his election as an academician in 1883, he left the observatory with the intent of devoting himself to theoretical pursuits. He devoted almost his whole life to an investigation of the irregularities in the motion of Encke's Comet, the cause of which many theoreticians tried to elucidate since the time of its discovery by Pons in 1818, but they have not succeeded even yet. This comet has now received the designation Comet Encke-Baklund.¹ Although the area of scientific interests of Baklund lay severally on the side of basic directions of activity at Pulkovo Observatory, his knowledge, energy and administrative talent promoted the successful development of the observatory's work.

The activity of Baklund at the post of director seemed a direct continuation of the activity of Bredikhin. Basically, Bredikhin only exhibited skill in a number of reforms at the

¹At Pulkovo, before O. A. Baklund, H. Gylden and E. Asten devoted themselves to the theoretical problem of Comet Encke.

observatory, and the realization of them fell to Baklund's lot. But the "epoch of Baklund" has its own boundaries.

First of all O. A. Baklund himself implemented a highly controversial arrangement for that time: from 1895 he began to invite to computational work a number of women having finished the Higher Bestuzhev women's courses in the mathematics section. Concerning the determination of them in state service, i.e., concerning being put on the staff, it was out of the question: pay for work was set up by the job, without the right to a pension. Ever the special collaboration of the president of the Academy of Sciences did not allow "official rights" of the observatory's women colleagues to be gained.² Three of the first women colleagues having maintained a bond with the observatory till the end of their lives were M. V. Zhilova, E. P. Milorado-

²Those having finished the Bestuzhev courses acquired the right of teaching in women's intermediary educational institutions, but to obtain a position was difficult. In 1895 Baklund invited two women to work at Pulkovo (M. A. Bronskaia and M. V. Zhilova), and in 1909 the number of women trained for computation and the processing of observations reached 14 (with a constant scientific staff of 18 people). Obviously, for that, in order to veil the true position of the matter, the director, in his report to the Committee of the Observatory, dispersed the mentioning of temporary women colleagues throughout the whole report. In 1897 the works of Pulkovo women collaborators began to be published in the transactions of the State Astronomical Society.

vich, and S. V. Voroshilova (Romanskaia).

O. A. Baklund obtained an increase of staff and the colleagues' rates of pay in July of 1909, and even the essential increase of allocations for scientific and economic needs. For this it was often necessary for him to complain in reports and other official documents of the deficiency of means which did not provide for the expansion of work: "Observatories in Germany, France, and especially in America have achieved such development that our observatory has to strain every nerve in order to occupy a proper place in line with them."³

Of special merit of O. A. Baklund it follows to discuss the organization of the branches of Pulkovo Observatory in southern states- in Nikolaev and Simeiz. The geographic position of the observatory did not favor the development of many projects, therefore the question concerning the organization of a southern branch was brought up by Baklund at the very beginning of his activity at the post of director. Thanks to his persistence of the projected task, already in 1900 a branch came into existence at Odessa, where, under the leadership of A. R. Obinskiĭ, observations were made by means of a transit instrument and a vertical circle with an observance of the fundamental principles of Pulkovo astrometry. The northern position of Pulkovo allowed stars to 10° south declination to be successfully observed; observations at Odessa allowed the determination of stellar coordinates with

³Report to the Committee of the Observatory for 1899-1900.

declinations to -30° . Stars of this zone have a significance for the reliable determination of the celestial equator and the point of the vernal equinox, which establish the system of use. Besides that, observations of southern stars were important for the construction of a uniform catalog of stellar positions over the whole sky. The idea concerning the construction of such a catalog occupied Baklund in the course of the whole period of his directorship.

Observations at Odessa continued from 1901 to 1910. They showed the possibility of preserving a precision of results with the spread of Pulkovo methods to southern observatories. The Odessa branch was situated on the grounds of the Novorossiiskaia University. The question concerning the purchase of its own land, formerly then vital, suddenly dissolved, thanks to a proposal of the Naval Department to transfer the Nikolaev Naval Observatory, founded in 1821, to Pulkovo Observatory. In May of 1909 the Pulkovo astronomer B. P. Ostasheiko-Kudriavtsev left for the management of the observatory at Nikolaev. However, the final registration of the Nikolaev branch was delayed in higher circles.

Almost simultaneously with this, in 1908 Pulkovo Observatory achieved the possibility of establishing a branch at Simeiz (Crimea) on the grounds of a small private observatory. The initiative of the building of the Simeiz branch belonged to A. P. Ganskiĭ (1870-1908). He carried on negotiations with the owner of the observatory, N. S. Mal'tsev, concerning the use

of it for scientific purposes. Mal'tsev expressed the desire to transfer his observatory to Pulkovo as a gift, together with the land, buildings and instruments. The notarial registration of the transfer took place on 17 (30) November 1908, after the tragic death of Ganskiĭ, who drowned while swimming in the Black Sea.

The law concerning the establishment of the branches of Pulkovo Observatory at Nikolaev and Simeiz was only passed in 1912. Together with this, staffs of the branches (four people for Nikolaev and two for Simeiz), the allocation for their maintenance, and the ordering of additional equipment was organized. N. S. Mal'tsev thought to establish the Simeiz observatory as an astrophysical one, and it preserved that character. As before, the Nikolaev observatory remained astrometrical. In 1912, in accord with this, an order from the firm of Grubb (England) for the construction of two large instruments was made: a 32-inch refractor for Nikolaev and a 40-inch reflector for Simeiz.

The volume of work at Pulkovo had increased everywhere. With an unprecedentedly fast tempo observations were made for the next (after 1885) catalogs of absolute right ascensions and declinations of stars⁴ for the epoch 1905.0. The following

⁴As far as the coordinate system in which the determinations of stellar positions are made, does not remain fixed, every catalog is characterized by "its own epoch" - the epoch of creation (of observations).

catalogs were supposed to be for the epoch 1925.0 (actually the catalogs were created for the epoch 1930.0). But Baklund, besides that, organized observations with absolute methods for extensive intermediate catalogs: the catalog of 1900 contained 1213 stars from 5th to 7th magnitude and the catalog of 1915 contained 1631 stars of Baklund-Hoff's list (the absolute catalogs of 1930 contained only 558 fundamental stars). Faint stars appearing for the first time in the catalogs allowed the precision of observations to be increased, in comparison with the brighter fundamental stars; besides that, they could be used for a "link" to plates with astrophotographic determinations. Precisely in this period astrophotographic works received a wide development.

The second intermediate catalog was created as a result of an international agreement passed in 1909 in Paris at the Fifth Congress for Mapping the Sky.⁵ For works to a compilation of the

⁵In 1887 the First International Congress for Astrophotography, in which from Pulkovo O. Struve and B. Hasselberg participated, approved a decision concerning the compilation of a photographic map of the sky and an accompanying catalog. In the work, according to their membership, the participation of 21 observatories of different countries was assumed. The photographic atlas, including all stars to 15th magnitude, was supposed to be made up from 22,000 lists. The work is still unfinished.

photographic Carte du Ciel, fundamental determinations of coordinates of a large number of stars, uniformly distributed over the entire sky, were required: on the average one star for every 25 square degrees. The list of stars in the northern sky (to declination -30°) was proposed by Baklund, resulting from the 1900 catalog with an appendix of stars having been observed at the Odessa branch. This list was accepted with a few changes. The list of stars of the southern sky was compiled by S. Hoff, director of the Cape Observatory (Cape of Good Hope). For the implementation of general programs of observations S. Hoff visited Pulkovo in May of 1909; a month later, with the same purpose, the American astronomer L. Boss, an important specialist in the compilation of fundamental stellar catalogs, came to Pulkovo. So arose the list of Baklund-Hoff, which played an important role in astronomy. The catalog of 1915 was put together on the basis of observations at the Pulkovo and Nikolaev branches.

Just as extensive as for absolute observations were programs of differential determinations of stellar coordinates. As already said, W. Struve envisioned the implementation at Pulkovo not only of absolute, but also of relative, observations. However, his program of observations with the meridian circle was not carried out. After a significant curtailment of it, observations for a catalog of only 3542 stars for the epoch 1855.0 were finished in 1869 (published in 1889). Five observers participated in its creation. A subsequent catalog of 5634 stars for the epoch

1875.0 was created with the work of only one observer, H. Romberg, who made over 22,000 observations in the years 1874-1890. He made observations (about 34,500 in number) for a catalog of 6000 stars for the epoch 1885.0, processed and prepared for printing by I. A. M. Zeibot (they were published in 1909).

In 1896 the meridian circle observers M. P. Dichenko and A. S. Vasil'ev began the reobservation of 8834 stars from the catalog of Schjellerup⁶ in the zone of declination from $+15^{\circ}$ to -15° . Their observations were processed by Zeibot and were published in the form of a catalog of 4301 stars for the epoch 1900.0. The observations were continued by M. N. Morin and A. A. Kondrat'ev and were finished in 1909. The processing of all observational material was only completed by V. V. Serafinov in 1939. Having finished the reobservations of Schjellerup's catalog, these observers proceeded to a great new work, connected with the astrophotographic Carte du Ciel (the observation of 3396 reference stars of the Helsingfors zone).

A substantial modernization of the large transit instrument and the meridian circle preceded the observations for the extensive

⁶Ch. Schjellerup (1827-1897) was a Danish astronomer. The reobservation of his catalog of 1865, containing equatorial stars, has a great significance, in particular for the determination of the constant of precision. This was done by I. A. M. Gordon in 1950 on the basis of a comparison of the catalogs of Schjellerup and Morin-Kondrat'ev.

programs (since 1897 the registrations of stellar transits were produced by means of an "impersonal micrometer"), and also a basic change of method of observation on the vertical circle (1911) was implemented.

An important result for the increase of precision in the determinations of declinations were the works of O. A. Baxlund and I. V. Bonsdorf on a study of the phenomenon of refraction, which was given special attention since the time of the observatory's founding. The reduction of observations on a vertical circle directed H. Gylden to the creation in the 1860's of a theory of astronomical refraction, on the basis of which A. I. Gromadzskii built the Pulkovo tables of refraction, published in 1870. These tables, republished without changes in 1905 and 1930, achieved a wide distribution; for the fourth publication in 1956 the tables were redone by B. A. Orlov. Thanks to the work of Bonsdorf arose the concept of local refraction, which at once played an important role.⁷

Works of an astrophysical nature displayed themselves with such completeness, that they permitted the allocations and

⁷The refraction of light with its passage through the terrestrial atmosphere makes up the principal part of astronomical refraction. Besides that, with the differences of temperatures outside and inside the dome, in which the instrument is situated, light experiences an additional refraction, called local refraction, with its entry into the dome. It also enters into the precision of observations but does not lend itself to calculation.

the set of instruments of the observatory. Besides the works of A. A. Belopol'skii, the astrophysicist on the job, and according to the character of his investigations, it follows before all to dwell on the works of A. P. Ganskii, who joined the observatory's staff only in 1905 at the post of additional adjunct-astronomer, but actually associated himself with the observatory 8-10 years earlier as a normal member.

In spite of the relatively short span of his scientific activity, Ganskii left a deep impression in astrophysics and by right ranks with a number of distinguished Russian astronomers. He participated in three distant expeditions for the observation of total solar eclipses, ^{and} was a participant at the Spitzbergen expedition, which was headed up by O. A. Baklund from Pulkovo. A. P. Ganskii organized and led an expedition to Spain for the observation of the solar eclipse of 17 (30) August 1905. He ascended in balloons several times and repeatedly scaled Mont Blanc for the execution of astrophysical observations. Ganskii determined the dependence of the appearance of the solar corona on the quantity of sunspots and predicted the form of the corona in 1900. This work is often referred to even now. He studied solar granulation (the "grainy texture" of the solar photosphere, observable when projected on a screen with good images or in photographs of high quality), the motions and lifetimes of existence of the granules. His photographs of sunspots and granulation, obtained at Pulkovo by means of the normal astrograph with an enlarging camera, have long remained

unsurpassed in quality.

Together with A. P. Ganskii, G. A. Tikhov (1875-1960), a well-known investigator of Mars and a steadfast advocate of the hypothesis of life on it, began his work at Pulkovo.⁸ Tikhov, already having distinguished himself in astrophysics, was put on the staff of Pulkovo Observatory in 1906. He received for his supervision the so-called Bredikhin astrograph, a gift of F. A. Bredikhin. This splendid instrument ($D = 170 \text{ mm}$, $f = 80 \text{ cm}$) was used in the Spanish expedition of 1905, and after its return to Pulkovo was utilized by Tikhov for photometric observations with filters.

Eclipsing variable stars were an object of observation which were photographed in different colors (through different filters). The purpose of the observations had to do with the search for the cosmic dispersion of light, or the difference of velocity of diffusion of light in space for different wavelengths. If such exists, then, with the observation of the beginning and end of eclipses of eclipsing binary stars, the displacement for different rays must be registered then: in blue light the eclipse must ensue later than in the red, which comports with the lesser (phase) velocity of diffusion for blue

⁸In his autobiographical narrative (G. A. Tikhov. Sixty Years at the Telescope. Moscow, 1959) it is possible to come across much of interest concerning his own works and the activities at Pulkovo Observatory, especially at the beginning of the twentieth century.

light (the normal dispersion of light). Tikhov actually observed the effect suspected by him. Almost simultaneously with him, the French astronomer Nordmann observed the same phenomenon for eclipsing variable stars. The phenomenon received the name of the Tikhov-Nordmann effect. But it was still not the discovery of the cosmic dispersion of light, which we would say concerns the presence of the interstellar medium: in 1909 phenomena were registered by S. I. Beliauskii at Dimeiz, and as a result by other observers, which were the reverse of the Tikhov-Nordmann effect, which contradicted "normal dispersion." In the same year of 1909 the renowned Russian physicist F. N. Lebedev attributed these effects to properties of the stellar atmospheres enveloping close binaries; the Soviet astronomer É. P. Mustel' in 1934 gave a new interpretation of the phenomenon. However, the Tikhov-Nordmann effect has hardly received a final explanation.⁹

⁹The member-correspondent of the Academy of Sciences of the USSR G. A. Mel'nikov thought that the cosmic dispersion of light, although negligible, had to exist, as far as interstellar selective absorption of light is observed, which testifies to the presence of, say, interstellar calcium. In G. A. Tikhov's and A. A. Balonch'skii's work of that period the significance of the cosmic dispersion was overestimated.

At the time of the great opposition of Mars in 1909 G. A. Tikhov photographed it through filters, utilizing the 30-inch refractor. On the basis of a study of approximately 1000 photographs of Mars Tikhov concluded that the polar caps on Mars were made up of frozen water (snow and ice), its famous "canals" had the same color as "seas", which over a long time were said to be the places of vegetation. This point of view is not accepted now, but is not completely repudiated. Tikhov discovered the resemblance of optical characteristics of the atmospheres of the Earth and Mars. Although this work represents his first step in the study of Mars, it was carried out at an advanced level and has important consequences.

Photography was adapted to astrometry with great success. With the installation of the normal astrograph at Pulkovo A. A. Belopolskii produced photographs of different objects by means of it: star clusters, nebulae, the moons of Mars, etc. Beginning in 1895 plans for the instrument were being made by S. K. Kostinskiĭ (1867-1936), one of the founders of photographic astrometry. In 1895 he set out on a foreign mission for a detailed familiarization with the experiment of photographic observations of stars. He passed several weeks at Potsdam with J. Scheiner, a well-known astrospectroscopist, then he familiarized himself with the methods of the Dutch astronomer J. Kapteyn. After his return to Pulkovo Kostinskiĭ carried on a large program of work with a perspective several decades ahead of the times.

First of all an extensive series of photographs of Jupiter's

moons was obtained for a study of their motion. F. F. Renz carried out the processing of the observations with the additional Helsingfors plates, the precision of the photographic results surpassing the precision of visual measurements with micrometers on large refractors. For this work the Academy of Sciences awarded Renz a gold medal.

The measurement of the satellites of planets led to the discovery of an effect which was thoroughly investigated in 1906 by S. K. Kostinskii on photographs of double stars and artificial stellar representations. The phenomenon has to do with the fact that with two very close images on a photographic plate it is as if the larger one pushes away its neighboring image, less according to size, the displacement being stronger, the closer the images are situated to each other. This phenomenon received the name of the Kostinskii effect. Subsequently, the reverse effect was discovered, having to do with the "attraction" of images. The character of the phenomenon depends on many factors, in particular on the method of development. In any case, this effect necessarily influences the measurement of an accurate separation of very close objects on a photographic plate.

The satellites of the more distant planets (Saturn, Uranus, Neptune) also were objects of observations. Neptune, with its satellite Triton,¹⁰ was observed by Kostinskii from 1899 to 1920,

¹⁰The second satellite of Neptune, having received the name

Saturn from 1906 to 1920 (over 100 plates of each planet). Uranus was situated at a position unfavorable for Pulkovo, and Kostinskiĭ only obtained the first successful plates of its satellites in 1919. Photography of the large planets have a significance not only for the study of the motion of their satellites, but also for a more precise determination of the orbital elements of the planets themselves. As far as the periods of revolution of the distant planets are great (for Neptune the period of revolution about the Sun is 165 years), photographs of these planets, in the representation of points against the background of stars, gain a special importance with the increase of the spans of time of their accumulation. Therefore, the photography of the distant planets of the solar system- Uranus, Neptune, and Pluto, discovered in 1930- continues at Pulkovo at the present time.

The program of observations of planets became prolonged. Prolonged, according to plan, was also the program of determination of the Earth's own motions. To photograph the whole sky with one instrument would be an inconceivable task. This apparently, though, would be of the volume of work for the international Carte du Ciel . Needless to say, the photographing of the sky for this purpose at Pulkovo was not carried out.

Nereid, was discovered by the American astronomer G. Kuiper in 1949. Remaining very faint ($19^m.5$), this satellite is not at all visible on Pulkovo photographs.

For the Carte du Ciel Pulkovo Observatory made fundamental determinations of the coordinates of reference stars. Kostinski's plan was the no less grandiose and no less interesting plan than that suggested by Kapteyn in 1906. The idea of Kapteyn's plan consisted in an objective not to study the whole immense stellar universe, rather, to organize 206 selected areas, distributed everywhere on the sky, and for stars situated in the selected areas, to obtain as far as possible more complete data: parallaxes (distances), proper motions, stellar magnitudes, colors, etc.

In order to determine the proper motions of the stars in a selected area with the photographic method, it is necessary to have two plates of the selected region of the sky with a difference of epochs no less than 20 years. Of course, both plates must be obtained with the same astrograph with identical or very similar conditions of observations.¹¹ For example, the plates must be taken on approximately the same calendar date: if a photograph is to be produced in a different time of the year, then annual parallax influences the stellar positions,

¹¹ Generally speaking, for the determination of proper motions of stars plates taken with different instruments can be used, but then the reduction of the observations is significantly complicated, and the accuracy of the results is diminished. Such happens with the non-observance of identical conditions of observation.

i.e., nearby stars are displaced on the plates because of the motion of the Earth in its orbit. But in the given example we are not interested in the annual parallactic displacements, rather, in the proper displacements of stars on the sky in their projections onto the photographic plate. True, these again are not "properly proper" (peculiar) stellar motions: as with "catalog proper motions," here the motion of the solar system, or, the parallactic secular displacement of the stellar positions, does not perceptively enter. Only having been freed from it, is it possible to obtain peculiar proper motions in the projection on the celestial sphere.

To take into consideration the motions of the Earth is now done as with fundamental determinations. When for determinations of stellar proper motions plates with a time span between them of 20-30 years are obtained, but at the same time of year, then with this it is as if they eliminate the motion of the Earth about the Sun; however, precession, nutation, and other motions remain. Therefore, the measurements and processing of photographic plates stipulates the "reduction of observations," i.e., the liberation of them from different distorting factors (the motion of the Earth, instrumental errors, atmospheric refraction, the difference of luminosity of the stars). Kostinskii worked out the method of measurement and of processing of astronomical negatives in detail and improved the formulas of reduction.

In the accomplishment of his program S. K. Kostinskii photographed selected areas of the sky and obtained "first epoch"

plates for the determination of proper motions of stars. He was founder of the Pulkovo "glass photo library," or "plate library," as it was more often called, which rendered an incalculable service to subsequent generations of astronomers. Having done the "second epoch" plates, students of Kostinskii achieved the possibility to determine proper motions of stars.

However, Kostinskii already was able to make a number of conclusions himself. It concerns the determination of stellar parallaxes. As is evident from previous discussions, for the determination of the so-called trigonometric parallaxes it is necessary to obtain plates of a part of the sky interesting to us with a time span of half a year. Usually, for every section not two, but three, plates are taken: the second six months after the first, the third a year after the first. Then every pair of successive plates will correspond to different positions of the Earth in its orbit, from which the stellar sky, generally speaking, must look differently. But it looks identical, because the majority of stars are situated very far from us, and only the closest stars will put parallactic displacement to the test with the motion of the Earth about the Sun. Precisely for nearby stars is there the hope to obtain parallaxes, and knowing the diameter of the Earth's orbit, it is already easy to compute the distance to a star with a known parallax.¹²

¹²The small angle (at the Earth) in an extremely drawn-out right angled triangle, one of the sides of which represents

As with the determination of stellar proper motions, so it is with the determination of parallaxes- the photographic method produces more accurate, and larger numbers of, observations in comparison with fundamental methods of meridian observations. No less a problem of determination of stellar parallaxes is one of the most difficult: even for the closest stars the displacement of them on photographic plates is minute, especially with a short focal length instrument.

S. K. Kostinskii determined the parallaxes of greater than 200 stars. True, in the majority of them the resultant parallaxes turned out to be within the limits of observational error ($\pm 0^{\circ}03$). This is explained by the insufficient focal length of the normal astrograph, owing to which a long focus photo-

the radius of the Earth's orbit, and the hypotenuse, the distance from the Sun to the star, is called the (trigonometric) stellar parallax. Even for very close stars this angle is less than one second of arc (for the nearest star- α Centauri- it is $0^{\circ}755$. the accuracy of modern determinations of trigonometric parallaxes is $0^{\circ}010$). It is not possible to measure the parallaxes of distant stars with the direct trigonometric method; with the utilization of other (indirect) methods of distance estimation the notions of spectral, dynamical, and other parallaxes are introduced. Often the word "parallax" is used in that case when one is simply speaking of the distance to a celestial object.

graphic refractor with an objective diameter of 32 inches (81 cm) and a focal length of 10.7 m was ordered. Besides that, the climatic conditions at Pulkovo hardly favor the determination of parallaxes. Because of the white nights in the summer and the continuous cloudy weather in the winter, significant periods were lost from ~~the~~ program of photographic observations.

Astrophotography played an important role in the works of the Simeiz branch in the first 10-15 years of its activity. According to the initiative of Baklund, from the beginning of 1912 Simeiz participated in the international program of observations of minor planets, having taken on itself the task of systematic determination of the photographic path of coordinates of 120 asteroids. The southern position of the branch favored the successful implementation of this task. In addition to that, the observers S. I. Beliaevskii and G. N. Neujmin discovered approximately 100 new asteroids and seven comets, six of the comet discoveries going to Neujmin. This is a lot for one astronomer, and not without reason was he called a "comet hunter."

In the period of his directorship O. A. Baklund organized investigations at the observatory in the area of celestial mechanics, and also for many theoretical problems of astronomy. Besides Baklund himself, serious theoretical investigations were implemented by A. A. Ivanov, G. Tseibel, and M. A. Vil'ev. For more than twenty years a large work for the determination of orbits and ephemerides (calculated positions) of minor planets

and short period comets was carried out (by M. V. Ẑhilova, E. A. Maksimova, L. L. Matkevich and many others).

Having finished the narrative of the "epoch of Bredikhin," it is necessary to mention the serious beginning of the time transmission service. In 1912, at the Paris conference on the questions of time transmission by means of a radio telegraph, O. A. Baklund was chosen chairman of the International Committee on Time. The transmission of time signals by radio seemed then a novelty, but soon after produced a radical change in the determination of longitude points on the terrestrial surface. Until this, differences of longitude were determined with a means of conveyance from one point of another chronometer, keeping accurate time, then for this purpose the wire telegraph was used. In 1914 a fundamental determination of the longitude difference of Pulkovo to Paris was undertaken with the help of radio. At first in Russia the transmission of accurate radio time signals was realized through the only equipped Petrograd radio station. The beginning of the First World War interrupted this important work.

On 16 (29) August 1916, while occupying the post of observatory director, O. A. Baklund passed away. The leadership of the observatory was assumed by the vice-director A. A. Belopol'skii, chosen in December of the same year as director. In his first report Belopol'skii summarized the activity of Baklund thusly: "The development of personnel strength of the observatory, the increase of the number of colleagues, the acquisition of new

instruments in accord with the motion of science forward, the creation of extensive themes for the activity of the observatory, combined scientific works with foreign establishments, a constant unity with scholars of the whole world, and on the other hand, the organization of an extensive investigation of the mysterious motion of Encke's comet- all this preserves for him the name of prominent director and significant scholar."

Just words, a merited appraisal.

POST-REVOLUTIONARY YEARS

The social events of 1917-1921, having awakened Russia and put her on a new, totally unknown path of political and economic development, could not pass over and did not pass over Pulkovo Observatory. The point cannot be only concerning the damages which shrapnel inflicted on the buildings, having exploded over the observatory at the time of the events of 10-12 November 1917. That, which carried with its revolutionary achievement of this great year, penetrated the deep inside of not only the buildings, but more importantly- into the consciousness of the people.

This happened, of course, not all at once. At first the old astronomers, deservedly having enjoyed several privileges, feared for their "modest comfort," especially when "new ideas, erroneously informed population" brought "lower service personnel at the observatory" to the presentation of demands to the administration concerning the increase of pay and "concerning the objection of quarters at the place having been situated beneath ground level." Complaining to local powers, who supported these demands, the director of the observatory was obliged to satisfy them. But was it not the same director, assuming the post, who wrote about the respect of every one of the colleagues for his comrades, among which there exist "no higher-ups or lower-downs"? Democracy revealed to him in words in March of 1917 was spread out with his business doings in March of 1919.

Not ashamed of some day being quoted, the director complained: "The scientific activity of the observatory proceeded in the reported year in a serious condition: the personnel were placed under the yoke of an indeterminate position, not being persuaded how the new government provides and supplies the means for the implementation of the tasks, provided to the institution with previous epochs."¹

Undoubtedly, the difficulties were immense: desperately needed repairs, insufficient fuel, strict rationing of electricity, absence of transportation- all did not further the development of work: and "one must be amazed that the scientific activity of the observatory did not sink to a minimum: the number of manuscripts submitted for publication, the number of scientific transactions, the intensity of observations remained almost in the same state as in much better times,"² although the exhaustion of the reserves of photographic plates, having been purchased abroad, necessarily curtailed some types of observations. Owing to starvation and exhaustion the scientific colleague B. A. Zemtsov, having returned from the armed forces, and chosen in 1918 for the post of scientific secretary, died prematurely on 2 November 1920.

¹Report for the Year 1918-1919, presented to the Committee of the Principal Russian Astronomical Observatory at Pulkovo by its Director. Petrograd, 1919, pp. 3-4.

²Ibid., p. 5.

Hardships fell not only to the lot of "eternal science" workers. The whole country was tested by hardships, carrying the burden of an imperialistic war and being subjected to foreign intervention. The scholars did everything in their power to withstand all tests. In December of 1917, "with the permission of the director," as a director of the observatory himself was assumed, an Astronomers Council was created at Pulkovo, to which in June of 1918 a general meeting of the Russian Academy of Sciences granted wide-ranging rights of governance of observatories and the selection of all staff to vice-director inclusively. The director chose a special commission consisting of representatives from the Astronomers Council and from the Academy of Sciences, under the chairmanship of its president. In June of 1919 A. A. Ivanov (1867-1939), rector and professor of the Petrograd University, astronomer at Pulkovo from 1890 to 1901, was chosen for the post of observatory director.

The Astronomers Council produced new staff of the observatory with a consideration of maximum gratification of its needs for computers, and with a consideration of an increase of personnel of the Nikolaev and Simeiz branches. The staff approved by the Academy of Sciences in August of 1919 consisted of 64 positions (of which 9 were for Nikolaev and 7 for Simeiz). This exceeded by more than a factor of two the staff of 1912 (27 people, including the staff of the branches), the largest which the director O. A. Baklund was able to achieve through the grand patron—the chairman of the Committee of the Observatory.³ During the

period of Baklund's directorship, in connection with the accepted volume of work, astronomers were so keenly needed for laboratory and computing work, that since 1917 a great volume of unprocessed photographic plates, spectrograms and catalog observations were generated.

The new civil rights and recently approved staff allowed women to be taken on as permanent help at the observatory. A few of the first to be put on the staff were I. N. Balanovskaia-Lehman, M. V. ZHilova, and S. V. Romanskaia. In February of 1918 S. V. Romanskaia became the first woman to obtain access to astronomical observations. In February of 1921 M. V. ZHilova and S. V. Romanskaia, chosen for the post of junior astronomers, joined the Astronomers Council.

The active recruitment to the observatory of highly educated women resolved the problem of qualified calculatory help. In November of 1920 the Petrograd branch of Pulkovo calculators was organized under the leadership of the experienced and erudite astronomer N. I. Idel'son. In 1924 the staff of the observatory (together with the branches) reached 95 people, and in 1925 it was increased to 107 people, 61 of which were scientific colleagues, and 36, technically qualified and junior technical

³From 1889 to 1915 the chairman of the Committee of the Nikolaevskaia Principal Astronomical Observatory and president of the Petersburg Imperial Academy of Sciences was Grand Duke Konstantin Konstantinovich Romanov.

colleagues, i.e., assistants and calculators. In such a way, as regards "tasks given to the institution with previous epochs," the strengths and means for their implementation must have sufficed with some left over.

However, the new epoch brought new problems. At that time a genuine revolution in physics and astronomy was taking place. The discovery of galaxies, the birth of relativistic cosmology, the establishment of the law of recession of galaxies- all radically changed the established view of the universe at the end of the last century. Jumping ahead, it is possible to say that many Soviet astronomers were literally "krocked off their feet" with the bombardment of observational facts and theoretical conclusions impetuously rushing in from abroad, where technique allowed astonishing discoveries to be made. But only facts were able to oppose the facts, or at least it was necessary to verify them, so as not to interpret them falsely. To obtain such a volume of facts was impossible with the lack of sufficiently powerful equipment.

Highly out of date instruments were furnished to Pulkovo in volume as a legacy from previous epochs, although the observatory again was considered the most wealthy among other observatories of the country in regard to equipment. The manufacture of two large, more powerful instruments, ordered from England, was suspended beginning with the World War of 1914-1918. The resumption of negotiations with the firm of Grubb-Parsons took place in 1920 when diplomatic relations with

Western Europe were not far from being resumed again. These negotiations were carried out through the Delegation of Foreign Trade (Vneshtorg) in London with the direct participation of the national commissar of foreign trade L. B. Krasin. For the completion of the work the firm demanded the additional payment of significant sums (over 24,000 pounds sterling, with an initial cost of the order of 17,000), which, in spite of the severe economic position of the country, the Soviet government allocated in 1922. In this way instruments were acquired for Pulkovo Observatory.

In December of 1924 A. A. Belopol'skii was commandeered to England for the inspection of the instruments on site. The 1-meter reflector was almost ready; arrangements for a refractor were relatively finished concerning the increase of its diameter from 32 to 41 inches, in order to have the largest refractor in the world. The decision concerning the increase of the diameter of the refractor ultimately resulted in the fact that the firm did not manufacture the objective. A photographic objective with a diameter of 32 inches was finally manufactured in Leningrad under the direction of D. D. Maksutov, but the refractor was not assembled; the mounting of the instrument, conveyed from England to Pulkovo, perished at the time of the war of 1941-1945. The objective of splendid quality was saved.

The reflector with the 1-meter mirror was transported to Simeiz in 1925 and was established in the same year. The quality

of the optics turned out to be excellent. The establishment of this telescope presented itself as a highly significant event in Soviet astronomy of the post-revolutionary period. The telescope, however, was destroyed in 1941 during the time of the occupation of the Crimea by Hitler's troops. The excellent mirror was disfigured by a direct hit, and the mounting, removed by the occupants to Germany, was used there for scrap metal.

A large Littrow system diffraction spectrograph of length 7 meters (with a dispersion of $0.76 \text{ \AA}/\text{mm}$ in the third order) also is of concern to large instrumental acquisitions. The spectrograph and the coelostat to it (a flat-mirrored solar telescope) was also acquired in England and received at Pulkovo in 1923. In 1924 investigations of the apparatus and systematic spectroscopic observations of the Sun were begun. The high dispersion of the apparatus allowed highly profound problems to be set up and resolved. With the help of the new spectrograph the 60 year-old A. A. Belopol'skii resumed his investigations of the law of rotation of the Sun with the purpose of the possible establishment of the connection between the rate of rotation and the activity of the Sun.

Again in 1921 the German Astronomical Society⁴ raised the

⁴For the international cooperation of the Carte du Ciel, the German Astronomical Society (Astronomische Gesellschaft, AG), founded in 1863, played the role of a single international organi-

question of repeated observation of all stars in the northern sky to 9th magnitude (the so-called zonal catalogs or AG Catalogs). The Astronomers Council of Pulkovo Observatory decided to participate in this work, in accord with which an order was made to the firm of Zeiss for the manufacture of a zonal astrograph. The program of work was discussed at a conference of

zation, which compiled the work of observatories of different countries, in particular, thanks go to it for the establishment of the AG Catalogs, undertaken in the 1870's with the participation of 20 observatories. These catalogs contained positions of stars to 9th magnitude (about 140,000 for the northern sky), measured with the differential method by means of meridian circles. The publication of the AG Catalogs was essentially completed at the beginning of the XX century. Often these catalogs are called zonal catalogs, as with a consideration of them the sky is divided into zones of declination, which were delegated to the observatories-participants of the work. The reobservation of the zonal catalogs undertaken in the 1920's employed a change to photographic methods for the determination of the positions of the majority of stars "attached" to reference stars, the positions of which were determined with meridian methods (meridian circles).

the Astronomical Society called in August of 1926 in Copenhagen and it took on an international character. From Pulkovo F. F. Renz participated in the work of the conference and the zonal commission. The commission distributed zones of observations among observatories, the photographic determination of stellar positions of the circumpolar zone and the observation with the meridian circle of 3700 reference stars in the zone 35-60° north declination falling to Pulkovo's lot. The zonal astrograph (D = 120 mm, f = 205 cm) with a four-element objective (for easy elimination of aberration and an enlarged working field of 5 X 5°) was received at Pulkovo at the end of 1926. In the following year they set about to the planned photography of the circumpolar zone of the sky.

It especially follows to mention the establishment at Pulkovo in July of 1940 of the horizontal solar telescope (mirror coelostat D = 500 mm; principal parabolic mirror D = 500 mm, f = 1700 cm), at that time the largest instrument in Europe for the investigation of the Sun. Manufactured by the State Optical-Mechanical Works (now LOMO), it was the first of that soviet industry. The construction of the telescope was supervised by the talented scientist N. G. Ponomarev , the first class optics manufactured under the direction of D. D. Maksutov. The manufacture of large telescopes in our country on the basis of the native production opened new perspectives in the development of Soviet astronomy.

Parts of the history of Pulkovo Observatory during the period

1918-1941 involved searches for new organizational forms. Such searches were inevitable, as far as the previous organization of work, with which everything was placed under the direct supervision of the Grand Chairman or the Committee of the Observatory, did not accord with the principally new form of state government.

As already mentioned, in December of 1917 at Pulkovo arose an Astronomers Council, which independently decided many vital questions. According to the Statute of 1921, with the resolutions of the council the general course of scientific activity of the observatory was determined. In the charter of the Astronomers Council stands a presidium consisting of: the director of the observatory, his assistant, and the scientific secretary. In large measure the selection of the director depended on the council, all the remaining positions being filled only through the council. The financial and economic activity was regulated by an economic committee consisting of the presiding director, three elected representatives from the Astronomers Council and three from the remaining personnel of the observatory, chosen for the year. As is evident, the chosen basis and the democracy in the government were then established at a high level.

Because of the great rights of the Astronomers Council the director of the observatory did not play that deciding role in the activity of the observatory which belonged to him in pre-revolutionary years, although for the "scientific face of the establishment," who assumed this position, as before, had significance. Fruitful in his activity at this post was A. A. Ivanov,

for whom A. D. Drozd was exchanged in 1931 for a short term. The directorship of the latter was an especially notable "break" from organizational beginnings. His own scientific activity was organized with observations on the zenith telescope in 1917-1920, and of the processing and discussion of these observations. At the beginning of 1933 the great scientific professor of Khar'kov University, B. P. Gerasimovich (1889-1937), headed up the observatory; Pulkovo astronomers knew him since 1915 in connection with his visit to Pulkovo for the carrying out of scientific work, and in 1931 he was the head of the astrophysical sector. During the period of Gerasimovich's directorship the scientific activity of the observatory was strongly revived and strengthened. From 1937 to 1943 the director of the observatory was S. I. Beliauskii (1883-1953), an untiring observer and the head of the Simeiz branch for the extent of almost two decades.

For the activity of Pulkovo Observatory, which until 1917, including the period of Bredikhin's directorship, remained to a significant degree secluded, in post-revolutionary years there existed a characteristically uninterrupted growth of scientific and business contacts with other astronomical participants of the country. Above all the connection was manifested in conferences of astronomers, the joint commissions and voluntary unions of scientists. Again with the life of O. A. Baklund in the company of Pulkovo astronomers a project arose concerning an organization of Russian astronomers. The project drew the support of many scientists, and in April of 1917 in Petrograd the consti-

tuent assembly of the Russian Astronomical Union was organized. Later on the union was renamed the Association of Astronomers of the RSFSR, which called three more meetings: in 1920, 1924, and 1927; after this its activity was discontinued. After the change there came about in 1932 a non-professional voluntary union of specialists and amateur astronomers- the All-union Astronomical-Geodesical Society (VAGO), which brought in local society, like the Russian Astronomical Society, consisting principally of Leningrad (Petersburg) astronomers and geodesists, and the Metropolitan Circle of Amateur Astronomers, founded in 1827, which was like the Moscow society (1908).

Especially important was the creation of an organization coordinating the activity of astronomical colleagues. Thus, in 1924, by decree of the Council of People's Commissars (Sovnarkom) of the USSR, the Joint Time Service Commission was created, under the chairmanship of the director of Pulkovo Observatory. This was the first serious effort for the coordination of the work, yet only in one narrow sphere. In 1937, with the Academy of Sciences of the USSR, was formed the Astronomical Council, as a directing and coordinating center of all astronomical investigations in our country, the standards of which have increased many times.

SCIENTIFIC ACHIEVEMENTS AND NEW SEARCHES

Traditional catalog observations, started at Pulkovo at the time of the founding of the observatory, were not discontinued until July of 1941. The observations and processing of the intermediate absolute catalogs of 1915 were just finished, when in 1920 observers with the large transit instrument and vertical circle set about to create the next catalogs, but not according to the plan of W. Struve, according to which the next catalogs were to be intended for the epoch 1925.0. Intermediate absolute catalogs of right ascensions and declinations of 558 bright stars were made up for the 1930.0 epoch. And this finished in itself a new program of observations having come into operation, only just having finished the previous one. The catalogs of 1925 were like the intermediate ones. In fact they presented themselves as a logical extension, and a rather extensive supplement to the intermediate catalogs of 1915. The fact is that the catalogs of 1915, consisting of stars of the Baklund-hoff list, were adopted for the special purpose of the maintenance of the basis of the photographic Carte du Ciel, and did not fully satisfy practical, in particular geodesical, problems. This insufficiency might have been eliminated by means of a replenishment of previous catalogs of stars to 6th magnitude. Thus arose the absolute catalogs of right ascensions and declinations of 1334 bright stars for the epoch 1925.0.

According to the meridian circle program (differential

observations) it was necessary again to finish the processing of numerous observations of a large number of stars of the Helsingfors zone and the catalog of Schellerup. But in 1929 the retiring A. A. Kondrat'ev, and also IA. I. Beliaev and N. V. TSimmerman, set about to the observations of reference stars of the zone $35-60^{\circ}$ for the international program of the AG Catalogs. The work was carried on to the end of 1934. However, in 1932 a new extensive program of observations was outlined, the implementation of which other observatories of the USSR took part in. The question here concerns the so-called "Catalog of Geodesical Stars," containing accurate positions of all stars to 6th magnitude from the pole to declination -10° .

This catalog contains almost all (with very few exceptions) stars of the absolute Pulkovo catalogs of 1915 and 1925, and according to the accuracy the new geodesical catalog must have had to exceed the resultant absolute catalogs. For stars of the Baklund-Hoff list (the catalog of 1915) this might have sufficed by means of a processing of all existing catalogs. As far as the Baklund Hoff list was recognized internationally, many observatories produced observations of stars on the list. The Astronomical Institute in Leningrad and Pulkovo Observatory made that processing, and the summary catalogs were finished in 1934-1935. Positions of the 1334 stars of the 1915 catalog stood to increase precision. For this all 1334 stars had to be observed with maximum thoroughness repeatedly by several Soviet observatories included in this cooperative work. N. V. TSimmerman (1890-1942)

worked out the method of observations; he supervised all the work. The observations and a general summary of them turned out to be finished in the autumn of 1939; a complete reduction of the catalog was delayed due to the war and the death of N. V. TSimmerman. The completion of all processing and the publication of the catalog was carried out by A. A. Nemiro and B. A. Orlov. The "Catalog of 2957 bright stars with declinations from -10° to $+90^{\circ}$ " was brought to light in 1948. For this work the Academy of Sciences posthumously awarded N. V. TSimmerman the F. A. Bredikhin prize.

Already at the end of the 1930's the successful beginning and unquestionable progress in the implementation of the first large joint effort of soviet observatories allowed astronomers to set about to the realization of a far more grandiose plan—the establishment of a catalog of precise positions of faint stars. In 1932 B. P. Gerasimovich and N. I. Dneprovskii suggested a deeply and thoroughly thought out proposal concerning the creation of such a catalog. They did not have a narrowly practical objective, rather, an extensive long range scientific program: "The universe of Struve and Bessel accessible to measurement was contained in the sphere, depicted from the center of the Sun with a radius of a few parsecs; the universe of Shapley and Hubble took up the space of a hundred million parsecs. . ."¹ As an

¹Proceedings of the Astronomical Conference. Pulkovo, 5-9 March 1932. Pulkovo Observatory, Leningrad, 1933, p. 137. In

experimental strategy they did not propose to throw all powers "to the assault," for the achievement of new, unprecedented boundaries, for which no one had the means (high powered telescopes), and to concentrate the organized human reserves to it, in order to assimilate and secure the things achieved. For Soviet astronomy, only having started to play havoc with its forces, this program was especially reasonable: it allowed the most advantageous positions at the advanced borders of science to be taken.

the cited quotation human understandings concerning the universe of the 1840's and 1940's are compared. H. Shapley and E. Hubble were American astronomers who made especially significant contributions in the development of extragalactic astronomy. In particular, Shapley developed the method of determination of distances to Cepheids, which are called the "candle of the universe"; he studied the structural features of galaxies and their distribution in space. Hubble was the first to demonstrate the existence of extragalactic stellar systems, having resolved the most nearby galaxies into stars; he established the law of "red shift" (recession of galaxies). A parsec (parallax of a second) is a unit of distance equal to 3.26 light years ($1 \text{ pc} = 3.08 \times 10^{13} \text{ km}$). The latest astronomy and radioastronomy deal with distances not in the hundred millions, but in billions of parsecs, i.e., distances to 10^{23} km .

The program of Gerasimovich-Dneprovskii turned out as perspective and solely correct as the program of observations of W. Struve was in its own time.

The idea of a catalog of faint stars can be elaborated in the following way. The fundamental catalogs made at the end of the XIX and beginning of the XX centuries in essence contained in them bright stars, i.e., stars primarily near to us; stars contained in them were heterogeneous according to spectral make-up, and consequently, their positions and proper motions were affected by different accidental and systematic errors. In a significant number of cases one can avoid this, reasonably having picked up a sufficiently uniform complement of (faint) stars, faint stars being advantageous not only because the accuracy of the determinations of their coordinates is essentially increased, but also because they stand as resultant benchmarks for the distant and extremely distant probing of the universe, being more remote from us in comparison with bright stars. In order to obtain coordinates of the benchmarks, possibly more accurately, the coordinate system itself, connected with the "celestial equator" and the plane of motion of the Earth about the Sun- the ecliptic- must be "fixed" with all reliability, for which the observations of planets, and not the Sun, are to be advantageously utilized. Finally, the benchmarks must provide, as far as possible, "absolute values" of proper motions, which follow to be determined according to practically fixed objects- remote galaxies. All these points of a common

idea were new as an idea itself. The interlacing with them of astrometrical, celestial-mechanical, stellar astronomical, and astrophysical problems made the whole problem especially inviting.

Not by chance were the scientists ardently devoted to the program with enthusiasm. Moscow astronomers took to the matter particularly actively, having done the work under the direction of M. S. Zverev in such a manner as to correctly personify the ideological program (the selection of stars of the program, the exploitation of the method of observations, the arrangement of forces and means, the trial observations and other questions). The war interrupted the business which had begun. . .

Worrying about a number of scientific problems concerning anticipatory work in science, Pulkovo astronomers, as in previous times, did not forget about the practical problems having a national-economic significance. An example of such is the "Catalog of Geodesical Stars." However, it follows to also mention the organization of a time service on a wide scale, i.e., not only for the use of Pulkovo Observatory itself, but for all countries, expanding on a wide path of accelerated economic development, with which the precision in time plays a paramount role. Accurate time is especially necessary for the unfolding of geodesical work.

On 1 December 1941, a number of preliminary experiments, signals were to be regularly transmitted from Pulkovo to the Belgrade radio station "New

Hollandia," and on 25 May 1921- also through the Moscow (KHodynskaia) radio station. On 11 July 1923 "New Hollandia" was replaced by the Detskosel'skaia radio station, which did not break the regularity of transmission. Although the Moscow transmitting stations all were changed, the regular provision of all organizations and expeditions in the country with accurate time from Pulkovo continued until 12 July 1941. The discontinuance of transmission from Pulkovo did not affect the vital means of accurate time to the "consumer," as far as the broadcast of radio time signals was produced also from Tashkent since 1929, and in 1931 the P. K. Shternberg State Astronomical Institute (GAISH) in Moscow organized the regular transmission of rhythmical signals of accurate time.

The establishment of the Interdepartmental Time Service Commission in 1924 promoted the development of separate services: if in the first years of Soviet rule only two accurate time services operated (Pulkovo Observatory and the Principal Board of Weights and Measures), then in 1938 the number of them reached seven. In 1928 the Commission began to publish summary features of rhythmical radio time signals, which had an important meaning for "consumers." The Bureau International de l'heure set about to produce analogous publications in 1931.

The observations of longitude differences between Pulkovo Observatory and other points undertaken at Pulkovo Observatory had an important practical significance. Thus, in 1925, with the help of a radio telegraph, the longitude difference of

Pulkovo-Greenwich was determined by IA. I. Beliaev and N. I. Dnebrovskii.² An accurate value of the longitude of Pulkovo, rendered, as all longitudes, from the zero meridian of Greenwich, was especially important for geodesical and geographical investigations. In 1928 the Russian Geographical Society awarded a gold medal to the executors of this work. Then followed a series of determinations of longitude differences: Pulkovo-Nikolaev (1928), Pulkovo-Moscow (1930), and with the participation of Pulkovo astronomers or even with the unilateral method were determined the longitudes of Simeiz (1928), Sverdlovsk and Tbilisi (1930), Arkhangelsk (1932), Novosibirsk (1936), and other points. Pulkovo Observatory assumed participation in the determination of the longitudes of several points on the course of the Baltic Geodesical Commission (the USSR joined this commission in 1929), and organized a whole series of geodesical and gravimetric investigations "on the ring": Helsinki-Stockholm-Copenhagen-Potsdam-Riga-Tallin-Pulkovo-Helsinki.

²With such determinations astronomical observations were produced at both points with observers changing their places. The correlation of results of their observations (from which the difference of longitude was calculated) was attained as far as possible simultaneously thanks to the reception of accurate radio time signals by both observers from some prechosen radio station.

From September 1915 to December 1928 the latitude service of Pulkovo Observatory (systematic observations on the zenith telescope) produced observations for an extensive program "all night long," i.e., from sunset till sunrise. The new program covered a significantly greater quantity of stars than before. The purpose of such a program consisted of the fact that, besides the study of the general character of the pole's motion, it was to reveal short period changes, in particular a daily variation of latitude. During the 13-year period of the extensive program of observations over 27,000 latitude measurements, and during the period 1904-1941 about 58,000 determinations, were obtained. The analysis of this colossal material showed that Pulkovo determinations possessed a very high precision and allowed to serve even the control of the International Latitude Service. Observations for the extensive program revealed in the oscillations of latitude the existence of a daily term with a very small amplitude (0.04"), the nature of which even now is not understood.

Latitude observations were even revived on the transit instrument on the prime vertical. From 1917 to 1947 A. S. Vasil'ev (1868-1947) produced observations. His results, published in 1952, summed up the centennial observations of the transit instrument on the prime vertical, started by the founder of the observatory himself, W. Struve. The fundamental inference of A. S. Vasil'ev consisted of the fact that the daily oscillation of latitude discovered by him (with another

phase and with an amplitude of 0.16 , essentially greater than on the zenith telescope) resulted from abnormal refraction, with which, however, other authors did not corroborate. The magnitude of the daily oscillation obtained by means of the zenith telescope is taken as more reliable, but the overestimated value, determined from observations on the transit instrument, possibly characterized a property of the instrument, for example, its greater susceptibility to changes of temperature of the surrounding air.

Let us return to astrophotography and astrophysics. After the lapse of two decades photographic plates from the "plate library" of S. K. Kostinskii began to acquire a special significance. The repeated photography of Kapteyn's "selected areas" was undertaken in 1924 and 1932. On the basis of this was carried out the determinations of stellar proper motions with a difference between epochs of photography of 12 and 20 years. The trial work (with a difference of epochs of 12 years) was a catalog of proper motions of 3189 stars in 13 areas, published by A. N. Deich and E. I. A. Perepelkin in 1935. Then in 1940 a fundamental work of A. N. Deich concerning a catalog of proper motions of 18,000 stars in 74 selected areas was brought to light. The precision of the catalog stood at the level of modern demands, in spite of the fact that the normal astrograph was the smallest instrument of those which were used for the determinations of proper motions according to Kapteyn's plan.

Another large astrophotographical work was implemented in

connection with an international commitment- the participation in the reobservation of the AG Catalogs. The photography of the circumpolar region of the sky by means of a zonal astrograph was undertaken by I. A. Balanovskii; under his direction the processing all plates (about 200), their measurement, and the calculation of "plate constants" was carried out. Later on (for the calculation of stellar coordinates and summary results) the leadership was passed on to S. I. Beliaevskii. The result of the work was the "Astrographic Catalog of 11,322 Stars between 70° North Declination and the North Pole," published in 1947.

Kapteyn's plan found reflection in the astrophysical investigations of Pulkovo Observatory. In 1926 G. A. Tikhov undertook the determination of colors of stars in 91 Kapteyn areas with the method of the "longitudinal spectrograph." The essence of the method, suggested by one writer in 1916, consists in the utilization of a defect of the Bredikhin astrograph- uncorrected chromatic aberration. As far as rays of different colors do not collect at the focus identically (not at one point), the photography of stellar images will look circular on the plate, affected differently for stars of different colors, especially if the middle of the objective is masked from the incident beam with an opaque disk. Carrying out the calibration of stellar images for stars with known colors, it is then possible to determine the colors of other stars in great quantity, which was done. The results of the determinations were pub-

lished in the form of two catalogs in 1937 and 1951.

The interests of G. A. Tikhov brought him also to investigations in the area of atmospheric optics and observations of solar eclipses. In the summer of 1927 an expedition of Pulkovo astronomers with I. A. Balanovskii at the head departed for Malmberget (Sweden) for the observation of the total solar eclipse of 29 June 1927; among them G. A. Tikhov assumed participation, who obtained photographs of the solar corona through filters by means of the four-element coronagraph. On their basis he made an interesting conclusion concerning the fact that the corona of the Sun consists of two parts: a diffuse, reddish one, having a spherical form, and a radiant white one that is the same color as the solar photosphere. He successfully participated in the program of coronal and atmospheric-optical investigations in the observations of the solar eclipse of 19 June 1936, the total phase zone of which passed over territories of the USSR. Preparation for this eclipse also included the manufacture (at Soviet plants) of new instruments; the observations were associated with many expeditions. At the beginning of the Patriotic War G. A. Tikhov placed himself at the head of an expedition to Alma-Ata for the observation of the total eclipse of 21 September 1941. After the war Tikhov remained at Alma-Ata where he organized the Sector of Astro-Botany for the Academy of Sciences of the Kazakh SSR, and he entirely devoted himself to investigations of Mars.

In observations of the Sun at Pulkovo itself, except the

work of A. A. Belopol'skii, new directions of investigations were outlined. In 1928 E. I. A. Perepelkin began, and in 1933 jointly continued with V. P. Viazanitsyn, systematic observations of solar prominences by means of the 30-inch refractor (with the spectral method). In 1932 analogous observations of the chromosphere with the utilization of the Littrow spectrograph were carried on. If A. A. Belopol'skii measured the positions and displacements of lines in the solar spectrum, on the basis of which he based the law of rotation of the Sun, then E. I. A. Perepelkin provided the fundamental method for the photometry of spectral lines, i.e., the qualitative measurements within lines (the widths of the lines, their profiles and the strengths of absorption in them), which allowed the physical conditions in different layers of the Sun (photosphere, chromosphere, and prominences) to be more widely presented: the relative maintenance of different chemical elements in these layers, the velocities of different atoms producing the spectral lines, the electron density and electron pressure, etc. In relation to the law of rotation of the Sun, young scientists drew conclusions not only concerning the character of this law according to heliographic longitude (like Belopol'skii), but also depending on the depth of the layers of the solar atmosphere (from spectral lines of different chemical elements, not having an identical distribution with depth).³ They determined the exis-

³With depth (as far as the word is used concerning its

in the prom. . . and in the chromosphere, of large turbulent (mixing) velocities of atoms, which exceed their thermal velocities- the thermal velocities of atoms are characteristic of the given temperature.

One of the most important results of spectrophotometric investigations of prominences was the establishment of that fact, that the relationship of the intensity of the lines of hydrogen and calcium revealed significant fluctuations from prominence to prominence, and, on the average, for a large number of prominences this relation smoothly changed with the solar activity cycle. The intensity of spectral lines depends on the number of atoms participating in the formation of lines, and also on the quantity and quality of radiation passing through the cloud of atoms (gas). As the relative quantity of atoms (calcium and hydrogen) cannot be essentially different in separate prominences, and what is more, it does not change

relatively small change) not so much the chemical composition changes as the temperature conditions determining the degree of excitation of the atoms (the ability of them to emit or absorb radiation). The conditions of excitation strongly differ for atoms of different elements, and therefore, sometimes even with the relatively small change of temperature, lines of one element vanish in the spectrum of the mixture of gases and lines of other elements appear. This precisely is characteristic for the different layers of the Sun.

in the whole solar atmosphere, and as the quantity of solar radiation is also considered to be invariable (the "invariability" of it characterizes a so called solar constant),⁴ then depending on the phase of the Sun's activity the quality of radiation changes: with maximum activity (greatest quantity of spots) the role of the Sun's ultraviolet radiation increases. In that way was established the "ultraviolet index" of solar activity (ordinary indices of activity are pooled together from the observed number of sunspots and the number of groups of spots, and also of the general magnitude of their areas).

In 1932 E. I. A. Perepelkin organized a continually functioning solar service. This service was already conceived twice at Pulkovo. In essence, the photography of the Sun by Hasselberg and Belopol'skii in 1881-1895 already embodied the service itself. In 1921-1929 M. V. Zhiiova produced systematic

⁴The solar constant is the total quantity of radiation emanating from the Sun in 1 min to an area of 1 square cm which is located at the limits of the terrestrial atmosphere, perpendicular to the solar rays, at the average distance of the Earth to the Sun; it amounts to about 2 cal/cm² min. The 5 percent limits of uncertainty stipulate the difficulty of a complete estimate of infrared and ultraviolet radiation of the Sun. The attempt to establish the possible fluctuations of the solar constant depending on the Sun's activity was not brought to the determined results because of that difficulty of measurement.

observations of sunspots and faculae by means of a 3-inch Zeiss scope with projection of the solar image on a screen.⁵ However, only an acute need in the given service allowed "to set it on its feet" finally. This need arose first of all as a result of quickly developing needs of communication (telegraph and especially radio), the continuity and clearness of the work of which depends on the condition of the ionosphere (the electrically charged layer of the Earth's atmosphere) and the magnetic field of the Earth, and the condition of the latter in its own right is determined with solar activity. The practical significance of the solar service had not now failed to be demonstrated. Data of this service were not only utilized with the establishment of communication, as far as the activity of the Sun affected many geophysical phenomena, but also in various statistical investigations and even in medicinal practice, as was established the connection between the activity of the Sun and the condition of health of people suffering from various chronic diseases.

In connection with this great value, the forecast of solar activity was achieved, and the forecasting, more often of all

⁵In various reports of the Principal Astronomical Observatory during these years tables of the number of sunspots (and faculae) and the quantity of groups of spots per month were set forth. This is precisely that which follows for the working out of relative "Wolf numbers," which are widely used as the most obvious index of solar activity up till now.

more reliable in comparison with purely theoretical methods, again insufficiently exploited, was produced on the basis of statistical generalizations of results of previous observations. That is why the publication of the "Catalog⁵ of Solar Activity," started by Pulkovo Observatory in 1939 (the first catalog contained data for 1932-1937), has an important meaning. With the organization of the Pulkovo solar service (observations of the Sun with the photoheliograph produced at Simeiz) in essence arose the "United Solar Service" in the USSR: data of other observatories (Tashkent, Khar'kov, Abastumani) were received at Pulkovo and included in general summaries.⁶ Beginning in 1938 the reduction of data to a single system was produced by R. S. Gnevyshev, under whose direction the publication of the catalogs continued. Highly valuable were investigations of the influence of solar activity on the character of various terrestrial processes conducted by Pulkovo astronomers and collected in social monographs.⁷

Repeatedly in the 1930's came up the question of the organi-

⁶At the present time summary data of catalogs of solar activity are usually built on the basis of results of observations of 10 soviet solar services and 5 observatories of socialist countries.

⁷M. S. Eigenson, M. N. Gnevyshev, A. I. Ol', B. M. Rubashev. Solar activity and its terrestrial manifestation. Moscow, 1948.

zation in southern lands of an astrophysical branch of Pulkovo Observatory- a well-equipped base constructed in more favorable climatic and astro climatic conditions. Much of the attention was devoted to the selection of a suitable site, for which in 1935-1940 were equipped expeditions to the Crimea, Kakhetiia, and Central Asia; theoretical questions of the study of the astro-regime and astro-climatic conditions were pursued. Side by side with this remained special themes of a practical nature concerning the investigation with astrophysical methods of the terrestrial atmosphere, the luminescence of the night sky, and the polar aurora (G. A. Tikhov, D. I. Eropkin. N. A. Kozyrev).

With the establishment of the 1-meter reflector the Simeiz branch became one of the best equipped observatories in the country. By means of the new reflector highly sensitive astrospectroscopic investigations were implemented. In 1925 Simeiz was directed by G. A. SHain (1892-1956), who was chosen in 1939 as an academician. The discovery (1929) of the rapid rotation of stars of early spectral classes belongs jointly to him and Otto Struve. In the Crimea, by means of the 40-inch reflector, G. A. SHain and V. A. Al'bitskii determined the radial velocities of approximately 800 stars. They discovered about 30 new spectroscopic binaries, the majority of which were repeatedly observed, and were investigated in detail right up to the calculation of their orbits. G. A. SHain studied the peculiarities and abnormalities in spectra of stars of different types and proposed theoretical explanations of these features; in the

very same period the beginning of his work on gaseous nebulae took place.

From theoretical works of Pulkovo astronomers, among them can be singled out the investigations of B. P. Gerasimovich on the theory of stellar atmospheres, the interior structure of stars, and stellar statistics. V. A. Ambartsumian, a distinguished astronomer of our time, an academician since 1953, began his scientific activity at Pulkovo. There he carried out an investigation of the temperatures of Wolf-Rayet and ρ Cygni stars, which are distinguished by a rapid outflow of matter from their surfaces; he studied questions of radiative equilibrium of planetary nebulae and more exactly defined the method of determination of the temperatures central stars. Then at Pulkovo arrived N. A. Kozyrev, subsequently made famous with notable works on the physics of planets and the physical investigations of the properties of time. In 1934 he became distinguished thanks to decisions of an important and actual problem concerning radiative equilibrium of stars with extended atmospheres. V. A. Krat, the present director of Pulkovo Observatory, having become the head of its Astrophysics Section in 1938, studied the theoretical problem concerning figures of equilibrium of double stars. Later on this work took the form of a more general monograph.⁸ The investigations concerning cosmology and the

⁸V. A. Krat. Figures of equilibrium of celestial bodies. Moscow-Leningrad, 1951.

theory of relativity (V. A. Krat, A. P. Bogorodskii, M. S. Eigen-son) deserve mention.

The educational activity of Pulkovo astronomers was extensive and many-sided. Many of them are read in lectures at the Leningrad University and different universities. Students of universities and students of the geodesical faculty of the Military-engineering Academy passed their practicals at Pulkovo; young astronomers from many observatories worked on problems; post-graduate students and those working on their doctorates prepared themselves. In 1938 the number of them reached 11. On the basis of the lectures read through at the Bestuzhev courses at the Petrograd University, in 1921-1924 appeared the notable courses of A. A. Ivanov: Course on spherical astronomy, which ran into several editions; of A. A. Belopol'skii: Astrospectroscopy; G. A. Tikhov: Astrophotometry. The two last books were a prototype of the "Course on Astrophysics and Stellar Astronomy," published in two volumes by a collective of authors under the editorship of B. P. Gerasimovich in 1934-1936. The publication of such a course, written essentially by a new collective of authors, was once again carried out in 1951-1964 under the editorship of A. A. Mikhailov (in 3 volumes).

No less extensive was the popularized activity of the observatory. Starting with 1918 numerous delegations of workers and excursions visited Pulkovo Observatory. At the end of the 1930's the number of excursions reached 400 per year with the number of guests greater than 12,000 people. The

popularity of Pulkovo Observatory grew.

This widespread fame appeared as a result of not only the inclination of the population toward astronomical accomplishments, but also the versatile and selfless activity of the observatory's personnel. The staff of scientific and scientific-technical workers of the observatory on 1 January 1941 consisted of 72 people, of which 10 were doctors and 18 were candidates of science. This was in general a small collective for that vast work which is difficult to wholly survey in so short an essay.

A ceremonial anniversary session of the Academy of Sciences of the USSR was held on 3-6 June 1940 in connection with the 100th year of Pulkovo Observatory. No one surmised that in 14-15 months it was destined to be turned into a heap of ruins.

The war of 1941-1945, imposed on our country by the German Nazis, inflicted great damage to Soviet astronomy. Pulkovo Observatory was destroyed to the foundation; it lost all large instruments, a significant part of the library and many people. At the time of the blockade of Leningrad N. V. TSimmerman, N. G. Ponomarev, F. F. Renz, V. A. Elistratov, V. R. Berg, and many of the observatory's colleagues died; the post graduate student S. S. Petrov perished at the front; the post graduate student B. S. SHul'man and the manager D. E. Ezhov died from hostile bombardment. The Nikolaev branch suffered greatly, situated within German occupation. The Simeiz branch, ruined and burned down at the time of the occupation of the Crimea, lost its pearl—the first-class 1-meter reflector.

A great deal came to be created anew.

A SECOND BIRTH

In September of 1943, at the height of the war, an astronomical conference took place in Moscow, called by the Academy of Sciences of the USSR. All distinguished astronomers of the country assumed participation in the conference. The fundamental result of the conference was an estimate of the role and significance of Soviet astronomy in the development of world astronomical science and an outline of subsequent actual tasks in the upcoming period. The significance of Soviet astronomy was highly modestly appraised, which, in spite of notable accomplishments, "on the whole again did not manage to assume ^{the} a leading position in world science, which Russian astrometry played in the second half of the XIX century."¹ The progress of Soviet astrophysics was also impartially appraised: "The level of practical and theoretical astrophysics in our country is equal to the level in the principal European countries. . . However, we cannot presently compete with America in ability in the area of fundamental problems with a principal method, due to a lack of powerful equipment."² The insufficiency of equipment was discussed in astrometrical works, although the situation in astrometry was better by far than in astrophysics.

¹Astronomicheskiĭ Zhurnal, 1944, v. 21, pt. 1-2, pp. 57-66.

²Ibid.

As with the extensive damage, almost a push backwards, was the loss of two of the best equipped observatories- Pulkovo and Simeiz. It seemed imminently impossible to return even to the prewar condition. At the same time as the USA established a 5-meter reflector shortly after the Second World War, we were forced to recreate that which was destroyed in the years of the war. However, the participants of the conference confidently discussed plans for the future, before everything considering the problem of the restoration of the Pulkovo, Crimean, and Nikolaev observatories.

In the difficult conditions of the dissociation of all collectives, an acute shortage of materials, equipment and even foodstuffs, astronomers continued to work at Tashkent, Kitab (Uzbek SSR), Abastumani (Georgian SSR), Kazan and Alma-Ata, where the circumstances of the war and a forced evacuation brought them. Besides purely scientific problems, astronomers gave much attention to the working out of questions of defense thematics, having an important significance for the country at that time. The organization of scientific work in the war years was highly instructive and merits a wider illumination than is possible within the limits of the given book.

A conviction in the righteousness of its struggle, unprecedented courage and heroism led the Soviet nation to victory. Already in January of 1944 Leningrad was finally liberated from the blockade. The battles subsided at Pulkovo. In February of 1944 N. N. Pavlov was the first to return to Leningrad,

appointed scientific secretary of the observatory. In the beginning of March Pulkovo appointed a commission with G. N. Neumin at the head, who became director of the observatory in April of 1944. In May of the same year governmental instructions were obtained concerning the working out of plans and a general estimate of the expenses for the restoration and reconstruction of Pulkovo Observatory and its branches at Simeiz and Nikolaev.

The war was not quite finished, but astronomers, jointly with architects, worked over plans of Pulkovo Observatory's restoration. With a decision of the Presidium of the Academy of Sciences of the USSR from 24 October 1944, the Simeiz branch was chosen as an independent scientific-investigative establishment of an astrophysical nature. The profile of Pulkovo had to be determined primarily with astrometrical problems that took into account the projects of the reconstruction of the observatory. Later on life corrected all projects and created that profile which the observatory has now. As regards Simeiz, its actual apportionment was included in 1945. On its basis the Crimean Astrophysical Observatory was formulated, equipped at the present time with larger telescopes and situated in the Bakhchisaraiskii Region in the center of the Crimean peninsula. Simeiz at the present time is part of the Crimean observatory. With the selection of a place for this observatory, results of expedition investigations conducted during the war were utilized, and supplementary astro-climatic investigations were organized. Plans for the creation of a southern astrophysical observatory,

which Moscow and Pulkovo astronomers nurtured in the 1920's and 1930's, came to life.

Historical for Pulkovo Observatory was a decree of the Council of People's Commissars of the USSR of 11 March 1945, in which concrete legislative enactments for the restoration and reconstruction of the Principal Astronomical Observatory were determined. Restoration works were begun in the summer of 1945. Pulkovo was made anew. Before all it was necessary to clear the territory of mines and live shells which prevented construction works. This demanded a great deal of time and did not progress without human sacrifice. Accidents even happened in 1951-1952, when shells and mines of different caliber and type suddenly went off. However, general observations³ were already resumed at Pulkovo on 1 October 1947 with the help of the Freiberg zenith telescope (ZTF). The merit in this belongs as much to the builders as to the astronomers-observers.

However, all Pulkovo astronomers longed to begin observations. In May of 1945 a large group of the observatory's colleagues returned from the evacuation of Leningrad, in order

³Regular observations began on 1 September 1948, since in June observations were discontinued on time, and the instrument was dismantled in connection with the fact that with the drainage around the pavilion a live shell of large caliber (405 mm) was discovered.

to organize two expeditions for the observation of the total solar eclipse of 9 July 1945. One of the expeditions was directed to Mount Ivanova, where observations were hampered by cloudy weather, the other, more numerous expedition (22 people under the direction of V. A. Krat) was situated on Mount Sortavala (Kareliia). These observations were made with success and supplied abundant material for processing and discussion that took two and a half years.

The staff of the observatory, greatly thinned out in the years of war, already numbered 62 people at the end of 1946 (of which 11 were doctors and 12 candidate of science). After the re-evacuation, scientific departments and laboratories⁴ were dispersed to several locations scattered over the central part of Leningrad. The dissociation to a certain extent remained, but the colleagues had the opportunity to meet every day.

⁴The observatory was then systematically subdivided into six scientific departments: astrometry (N. I. Idel'son), photographic astrometry (A. N. Deich), time service (N. N. Pavlov), astrophysics (V. A. Krat), solar service (N. S. Eigenson), and the spectroscopic laboratory (O. A. Mel'nikov). All department heads had scientific degrees of a doctor of sciences and ranks of professor.

Leninrad quickly healed its wounds; life returned to normal. An especially gratifying phenomenon was the fact that the scientific works accumulated over several years were quickly published. A sad event of that year was the sudden death of the observatory's director G. N. Neumin, who energetically undertook the reconstruction of the observatory, but prematurely departed from life.

N. N. Pavlov temporarily directed the observatory. In June of 1947, in compliance with the regulations of the Academy of Sciences, the Moscow astronomer A. A. Mikhailov, member-correspondent of the Academy of Sciences of the USSR since 1943 (academician since 1964), was selected for the post of Pulkovo Observatory director. He⁵ already known then as a versatile astronomer, a specialist in the areas of gravimetry, geodesy, stellar cartography, the theory of eclipses, astrometry, and astronomical instrument making. From 1934 to 1960 he was chairman of the All-union Astronomical-Geodesical Society, from 1939 to 1963 chairman of the Astronomical Council, and from 1945 to 1948 vice-president of the International Astronomical Union.⁵ To the end of his directorship A. A. Mikhailov

⁵The International Astronomical Union (IAU) was founded in 1919 in Brussels. The Soviet Union joined the IAU in 1935. With the organization of the Astronomical Council in 1937 a national committee from the USSR was to represent the latter in the IAU. Basic membership in the IAU is collective (members of the IAU

had abundant experience as an administrator. More than once chosen director, he successfully directed the observatory in the course of 17 years. Having left the high post in December of 1964, he did not leave Pulkovo, and shortly thereafter placed himself at the head of the astronomical constants department.

The directorship of A. A. Mikhaïlov fell in a period of exceptionally stormy development and an unprecedented upsurge of activity of the observatory: its restoration, systematic reconstruction, the formulation of new branches and scientific departments, the birth of experimental astronomy, the building of large telescopes, the wide scope of expeditionary investigations, and the development of international scientific ties.

The project of restoration and reconstruction of Pulkovo Observatory was carried out under the direction of the prominent

make up a national committee); besides this exists individual membership. Of Pulkovo astronomers 11 scientists were members of the IAU in 1946, and among Pulkovo colleagues at the 1970 conference there numbered 42 members of the IAU. Conferences of the IAU take place usually every three years. An executive committee with the president of the IAU at the head carries out the leadership with the Union. Of Pulkovo scientists, V. A. Ambartsumian was chosen president of the IAU (1961-1964); A. A. Mikhaïlov, V. A. Ambartsumian, B. V. Kukarkin, and A. B. Severnyi were vice-presidents.

architect and academician A. V. SHCHusev (1873-1949). The Briullov-type classical features of the main building were preserved, only the form of the domes on the central part of the building being changed. Instead of polyhedrons of wood, which once topped the building, now stand three stone towers with hemispherical metal revolving domes on them. The interior layout of the eastern and western buildings was considerably altered. It subordinated the setting of both buildings: the eastern one a laboratory, the western one for administration. Originally, in pre-revolutionary times, these were in essence living quarters. A sight of the western building is the splendid two-color conference room, finished with red marble with bas-reliefs of prominent astronomers, Russian and foreign.

In harmonious accord with the main building is situated a scientific courtyard with observation towers and pavilions, layed out to the south of the main building. On the side of the Kiev highway the observatory is protected by a monumental cast-iron railing. The entrance to the territory of the observatory is designed with portals in Doric style, like the north portico of the main building. The portals are ornamented with bas-reliefs symbolizing the zodiacal constellations. From there the view is at once opened to the two story building of the hotel-hostel (architect D. KH. Enikeev). Encircled with stone railings with vase and flowers, fountains and flowerbeds in front of the facade, especially beautiful in summertime, this building resembles a Russian country estate of the last century.

Asphalt roads connect the auxiliary buildings with the business complex (the garage, boiler house of the central heating system, the gas controls, the materials warehouse and the workshops) and the living quarters, situated in the eastern part of the territory. The general area belonging to the observatory grounds consists of 150 hectares* (before the war 25 hectares). A significant part of it is covered by trees and shrubs and presents itself like a park in its basic landscape style. On the eastern side of the Kiev highway, where a part of the observatory grounds is also situated, the living quarters were built opposite to the entrance; south of them is a grammar school and a large laboratory building, erected in 1963. Here is situated the observatory's computer station, with an electronic calculating machine "Minsk-22" and a complex of other machines, but laboratory apparatus and new instrumental ideas of astronomers and engineers for the means of observations are mainly developed and realized here. Side by side with the laboratory building are arranged two astronomical towers of an experimental nature. They are there as if to underscore the belonging of all buildings to the observatory. In short, today's Pulkovo Observatory is a whole town, the appearance of which is especially impressive to the east or southeast (in the direction of Pushkin and in the direction of Aleksandrovka).

The construction-restoration works on the whole were com-

*1 hectare = 2.471 acres. (Tr. note)

pleted in 1953. One after another of the astronomical instruments were again put into operation up to their termination: the normal astrograph (1948), the mirror-lens camera system of G. G. Sliusarev (1949), a model of the chromosphere telescope of S. B. Ioffe, manufactured on the basis of interference-polarizing filters (1950), the completely restored horizontal solar telescope (1951), and others. Astronomers without delays began to produce observations, taking up residence in the completed south wing of the hotel-hostel with provisional heat, without water and sewers. They did not complain about the conditions of life, but it was impossible to call them normal.

In 1947 the Pulkovo time service set up work at Leningrad University's observatory. As far back as 1934-1939 N. N. Pavlov developed a method of photoelectric (automatic) registration of stellar transits, which essentially increased the accuracy of determination of astronomical clock corrections.⁶ In 1939-

⁶The time service took the form of three sections: the determination of the corrections from astronomical observations, the custody of time, and the transmission of accurate time signals to users. The first of those mentioned was the "weakest section" because of errors in the determination of the astronomical clock corrections, especially because of the so-called personal errors. The introduction of automatic registration of observations eliminated these, although it introduced new errors, however, comparatively more easily lending themselves to calculation.

1941 regular observations with the application of "impersonal" registration were produced at Pulkovo. Observations interrupted by the war were necessarily to be resumed as soon as possible for the purpose of the further improvement of the method (in 1947 N. N. Pavlov was honored with a State Prize) and were employed with other time services. In July of 1953 the Pulkovo time service shifted its base one and a half years after other departments and was safely based at Pulkovo itself.

Not long before the transfer of all scientific departments from Leningrad to Pulkovo, the structure of the observatory was subjected to reorganization in accord with the thematics of investigations having changed. Defense thematics were phased out; reconstruction tasks were moved away from in the second place; first and foremost, observational, and purely astronomical problems moved forward. At this time for the consolidation of the Nikolaev branch, the Pulkovo astronomer I. A. E. Gordon was directed there in the capacity of manager. In 1948 a new branch of Pulkovo Observatory was formulated- the Mountain Astronomical Station at Kislovodsk, founded by M. N. and R. S. Gnevyshev. The principal problem of the station in the establishment of systematic observations of the solar ^{Corona} by means of a Lyot coronagraph. These observations have been carried out since 1950. Together with that a whole series of observations of all layers of the Sun was organized with optical and radio-astronomical methods.

At Pulkovo itself the question concerning the equipment of the observatory for the measurement of observations was keenly

felt. The restoration of the old telescopes (like the 15- and 30-inch refractors) would take significant material expenditures and would divert the construction forces, but the out of date equipment would on the whole restore astronomers "morally." Several orders were supposed to be carried out in the USA and in England, where in 1946 O. A. Mel'nikov and B. A. Orlov went. However, it would have proved more reliable to utilize the possibility of native industry, which already before the war had carried out several experiments, especially after the manufacture of the large solar telescope. In essence, this telescope, with several improvements in its construction, introduced by P. V. Dobychnin, was made anew. Besides that, a whole series of small and medium sized instruments was manufactured, outfitted not only at Pulkovo, but at other observatories, and which provided the possibility of an optical-mechanical industry to build up experiments in order to begin the manufacture of large telescopes.

Among this series is the above-mentioned Sliusarev camera (the ASI-4; $D = 280$ mm, $f = 150$ cm), the meniscus telescope of Maksutov (MTM-500; $D = 500$ mm, $f = 650$ cm), the Ponomarev short-focus double astrograph (AKD; $D = 100$ mm, $f = 70$ cm), the Mel'-nikov-Ioannisiiani quartz spectrograph system (ASI-5; $D = 250$ mm, $f = 75$ cm), the Maksutov photoheliograph ($D = 100$ mm, $f = 880$ cm), the interferometric heliometer system of the academician V. P. Linnik, his stellar interferometer (first model), and other instruments. A large part of all this was the means of astro-

physical observations. As regards fundamental astrometrical problems, as in absolute determinations of the coordinates of celestial bodies, for the time being were revived the "old horses"- the large transit instrument and the Struve-Ertel vertical circle, and for relative determinations the observatory purchased the meridian circle of Töpfer ($D = 190 \text{ mm}$, $f = 250 \text{ cm}$), a more modern instrument than the previous meridian circle of Reibold, given to the Nikolaev branch.

The establishment of the normal astrograph at Pulkovo allowed astronegatives ("glass plates"), accumulated for decades and preserved in the war years, to be effectively utilized, being of great value for the massive determinations of stellar proper motions, the theory of motion of planets of the solar system, investigations of multiple stellar systems and planet-like companions of stars, and other problems. The largest Zeiss refractor in the USSR ($D = 650 \text{ mm}$, $f = 1050 \text{ cm}$), also established at Pulkovo, was intended for astrophotographic purposes.

The less all this satisfied astronomers, indeed it could not completely satisfy the demands presented to modern astronomy. Therefore, searches for new methods and means of observations and their reduction continued and continue. Several of the instruments established at Pulkovo were created in the optical-mechanical workshops of the observatory: the polar telescope of A. A. Mikhailov ($D = 200 \text{ mm}$, $f = 600 \text{ cm}$) for the determination of astronomical positions, a model of the hori-

horizontal meridian instrument of L. A. Sukharev, and the coronal spectrograph of I. A. Prokof'eva for observations of the solar corona. Laboratory measurement instruments and other equipment, created according to the plans of Pulkovo astronomers, were especially numerous: the original level trier of L. A. Sukharev, manufactured in five copies for different observatories of the USSR, the objective micrometer of A. V. Markov for accurate photometric measurement of plates, the self-registering isophotometer of N. N. Mikhel'son, N. P. Kuprevich's instrument for the automatic registering of the solar spectrum, the large diffraction spectrograph to the horizontal solar telescope (in place of the Littrow spectrograph), and the nozzle to the telescope (the receiver) of A. A. Kaliniak, with an image converter. This was only the beginning. If we were to enumerate all equipment created in the post-war years only in the construction bureau and the workshops of Pulkovo Observatory, then at first glance it can be said that to design and produce new instruments was the fashion. However, of that genre works were absolutely inevitable in certain areas characterized for the scientific-investigative plan of the observatory of the post-war period.

A new trend of investigations brought to realization in 1952 was the department of astronomical instrument making, which was headed up by the prominent Soviet optician, the inventor of the meniscus system, member-correspondent of the Academy of Sciences of the USSR since 1946, D. D. Maksutov (1896-1964).

The department had a great significance for the development of instrument making at Pulkovo, but the main purpose of its organization included the working out of technical jobs for the erection of a 6-meter telescope, the largest in the world.* A well known constructor of astronomical telescopes was drawn to these works, later on a recipient of a Lenin prize, B. K. Ioannisiani. A great role in the works also belonged to O. A. Mel'nikov and N. N. Mikhel'son, to whom was passed on the management of the department of instrument making after the sudden death of D. D. Maksutov. Also then were begun site searches for the erection of the future astrophysical observatory with the largest telescope. The early action taken was not unnecessary: expeditionary astroclimatic investigations carried out under the direction of N. I. Kucherov (1905-1964) took up more than ten years.

Seven scientific departments and two branches (Nikolaev and Kislovodsk), about 90 scientific and scientific-technical colleagues (with a general staff of 240 people), newly constructed buildings and outfitted laboratories, 20 operating instruments for the production of astronomical observations and ten having been implemented only during the post-war years of serious investigations- such was Pulkovo Observatory at its official opening after the restoration. At the same time was established the "Pulkovo" seismological station- one of the best equipped stations of the Institute of Physics of the Earth of the Academy of Sciences of the USSR.

*See *Sky and Telescope*, Nov. 1977, pp. 356-362. (Lr. note)

The ceremonial opening of the restored Principal Astronomical Observatory of the Academy of Sciences of the USSR took place in May of 1954. A special session of the Department of Physical and Mathematical Sciences⁷ of the Academy of Sciences of the USSR was devoted to this event, having taken place on 20-23 May in Leningrad and at Pulkovo. Besides members of the Department, over 500 astronomers and geodesists from different observatories and established countries, Pulkovo builders, representatives of the Leningrad public and academicians of the Union of Republics attended the session, and also 47 foreign scientists from 18 countries, including the general secretary of the IAU, P. Costerhoff, who read greetings of the then-time president of the IAU, O. Struve, great-grandson of the founder of Pulkovo Observatory. Those who assembled warmly saluted Pulkovo astronomers on the occasion of the second birth of their observatory.

⁷In 1963, from the structure of the Department of Physical and Mathematical Sciences, was formed a number of new departments: mathematics, general and applied physics, the department of Earth science, and others. The Principal Astronomical Observatory became a part of the Department of General and Applied Physics, which soon after was renamed the Department of General Physics and Astronomy.

TRADITIONS AND NOVELTY

Four years later Pulkovo Observatory again received visitors. In August of 1958 in Moscow the ^{Tenth} conference of the IAU took place, the largest of all previous conferences: over 1200 delegates and visitors from 35 countries, of them 778 foreign astronomers, who showed great interest in our country. The launching of the first artificial satellite of the Earth (ASE) in the world, realized on 4 October 1957, demonstrated the strength of Soviet industry, the high level of development of science and technology in the USSR. For astronomical science this signified the birth of a new area—experimental astronomy.¹ The peculiarity of the Moscow assembly was such that it happened in the period of the International Geophysical Year (IGY), the most grandiose scientific collaboration

¹Astronomy, the oldest of the sciences, for centuries remained primarily an observational science. Only meteorites having hit the Earth from interplanetary space can be touched. Everything else beyond the limits of the Earth remains inaccessible to direct study. To bring nearer the means of observation to celestial bodies became possible thanks to rockets, automatic stations in the cosmos, and piloted cosmic flights. What is more, by means of powerful rockets it became possible to create artificial celestial bodies. This signified the birth of experimental astronomy.

of scholars of all countries of the world.

The foreign delegates of the conference were invited to visit Leningrad and Pulkovo. By that time Pulkovo was even more rebuilt thanks to the organization of the station of optical observations of the ASE (1957), and the department of radioastronomy (1954). New instruments were established during the IGY, notable was the construction of the large Pulkovo radio-telescope (LPR, 1956), the largest radiotelescope in the world at centimeter wavelengths. To Pulkovo fell the great honor to receive the most notable astronomers in the world within its walls. In its guest book, opened by the president of the IAU, A. Danjon, appear hundreds of signatures and notes in many languages. A broad opportunity of establishing personal contacts with scientists of other countries was presented to Pulkovo astronomers in these days, and the establishment of the exchange of opinions, the reception of advice and critical remarks on the side of the greatest authorities in the world. But the criticism was exceptionally business-like and well-wishing. During the days of the conference and for a long time following it, testaments of thanks and articles filled the Soviet and foreign press. So the participants of the conference appreciated the hospitality of the Soviet government, the Academy of Sciences of the USSR, and soviet colleagues.

The wide contact and collaboration through the IAU, especially with scientists of socialist countries, became habitual for Pulkovo astronomers in post-war times. Many of them in turn were chosen

presidents and vice-presidents of different continually existing commissions of the IAU. In 1952, at the VIII conference of the IAU in Rome, a special symposium, "Problems of astrometry of faint stars," was conducted on the initiative of Soviet astronomers. Reports of the Pulkovo astronomers M. S. Zverev and A. N. Deich were presented at it which affected the state of the problem of the Catalog of Faint Stars (CFS) and which maintained proposals concerning international collaboration in the creation of this actual catalog. The proposals were settled by the General Assembly in the form of a recommendation of the conference to assume participation with observatories in this work. Scientists of socialist countries were the first to respond: Poland and Rumania. The Wroclaw and Bucharest observatories were included in the general program of observations.

The program of the CFS was recognized as international, but organizational arrangements were still discussed in corresponding commissions of the IAU. At the following conference of the IAU, which took place in Dublin in 1955, a final understanding was achieved on the basis of a merger of Soviet and American proposals: the program of the CFS was consolidated with an international undertaking according to the reobservation of reference stars of the zonal photographic catalogs. The consolidated program provided for the observation of over 30,000 stars, the coordinates of which were subject to determination from meridian observations. In the following several years these observations were intensively carried out at 11 observatories of different

countries (Washington, Greenwich, Paris, Heidelberg, Pulkovo, Nikolaev, and others). Especially important remained the organization of analogous observations at observatories of the Southern hemisphere. Because of the very small number of observatories in the Southern hemisphere, its sky was more incompletely investigated than the sky of the Northern hemisphere. Therefore, at the XI conference of the IAU, which took place in Berkeley (USA) in 1961, a resolution was passed which provided hope at the Washington (Naval) and Pulkovo observatories in relation to the development of observations of southern reference stars (SRS). One of the principal participants of this new work was the Chilean expedition of Pulkovo Observatory.

At Pulkovo itself, observational work developed in all directions. After a thorough investigation of the instruments, inevitable because of the prolonged interruption in their functioning, observers on the large transit instrument and the vertical circle set about to work on the compilation of the next absolute catalogs for the epoch 1955.0. As already stated, the new absolute catalogs contained almost twice as many stars as the previous ones: besides the bright stars of Struve's program, fundamental faint stars were included in the program of absolute observations. The general number of them was 1046. Thus, this traditional program was essentially renovated and would entail great difficulties for the CFS, which was pivotal for Pulkovo astrometry of the present period.

Almost simultaneously with this was begun observations with

the meridian circles at Pulkovo and Nikolaev of stars for the international program, the so-called AGK3R- reference stars of the northern sky for the reobservation of zonal catalogs. Pulkovo took on itself the determination of the coordinates of 11,500 faint reference stars; Nikolaev- 10,000 stars. The processing of the observations was carried out jointly at the Pulkovo and Washington observatories.

The question must arise: was the international cooperation with Soviet astronomers in the creation of the catalogs of faint stars required for it, if Pulkovo Observatory only, together with its branch at Nikolaev and the Chilean expedition, made observations of the whole sky and carried them out in a comparatively short time?

The point was not to "seize the initiative"; it was enough that it belonged to Pulkovo Observatory. The question, in essence, concerns the creation of the foundation of astronomy of the XXI century, and the majesty of the problem immensely increases responsibility. It is necessary to determine the coordinates of a huge number of stars with the greatest precision attainable in modern conditions. With the point of view of the next century the insufficient level of development of astronomical measurements could accommodate a large quantity of participants for the work. That is why the greatest number of observers possible was expediently drawn into the work. The substantial number of participants raised the accuracy and speed up all works. But this is even more important because the

determinations of stellar proper motions enter into fundamental determinations, except for the measurement of coordinates, and the sooner the first part of the program is carried out, the earlier the second stage can be started- ultimately- the reduction of proper motions. In 1964 the number of observatories-participants in the implementation of these tasks reached 25, on the whole globe, in the Northern and Southern hemispheres.

Pulkovo Observatory solidly retained the initiative not only in an organizational mode (through a commission of the IAU and the Astrometrical Commission with the Astronomical Council of the Academy of Sciences of the USSR), but in a constant display of a "personal example" in the work. Before all of this was the scope of astrometrical and astrophotographic works: the quantity of observations, their reduction, the organization and production of observations in the Southern hemisphere. Many facts of no small consequence were dealt with. In 1956 the "Preliminary Summary Catalog of Fundamental Faint Stars with Declinations from +90 to -20" (PFCFS) was produced by M. S. Zverev and D. D. Polozhentsev, based on observations over the course of 15 years at 10 observatories, of which two were foreign- Bucharest and Wroclaw.² This catalog, computed in a short time span with the participation of the Institute of Theoretical Astronomy (ITA) in Leningrad, made manifest the fact that it had a direct relation to the problem of the CFS (one more sample for duplication)

²Transactions of the Principal Astronomical Observatory, v. 72, 1958.

and compared with a number of the first fundamental catalogs directly produced at Pulkovo. Until then the "monopolies of production" of fundamental catalogs belonged to German and American astronomers (A. Auwers, A. Kopf, L. Boss, B. Boss, H. Morgan).

A year earlier a complete series of fundamental catalogs for one coordinate- right ascension- was completed. These catalogs were the result of processing undertaken by A. A. Nemiro of the 100-year sequence of observations (1839-1939) on the large transit instrument. For the first time fundamental catalogs were created on the basis of observations of great precision, produced on one instrument. The dream of W. Struve was indeed realized! True, advancing the plan of creation of strictly absolute catalogs of stars, the founder of Pulkovo Observatory supposed that this task would be accomplished on one instrument. But the task (human practice in the rather wide sense) was carried out by many followers of the Pulkovo undertaking, and A. A. Nemiro, for the construction of the catalogs themselves, of course utilized summarized experiments of other observatories. In particular, it was advisable to utilize generally accepted international values of fundamental astronomical constants, but corrections to them were outlined concerning the necessity of improvement of these conventional values, precisely in the direction to which they were subsequently changed by the Hamburg assembly of the IAU.

For the determination of astronomical constants a joint

analysis of absolute observations of right ascensions and declinations would be especially valuable. B. A. Orlov (1906-1963) undertook to carry out analogous work on the generalized 100-year sequence of observations with the Struve-Ertel vertical circle (absolute observations of declinations). His death interrupted the work, which had not reached the mid-point of the projected task. The work awaits another executor. It generously returns his kindness, all the more now that, with the publication of a new absolute catalog of declinations of 1955 (G. S. Kosin, B. K. Bagil'dinskiĭ), material became far more extensive and richer.

One theoretical investigation again merits attention- one more fact of the "personal example." After the example of the PFCPS, over several years it would be possible to set about to the construction of a fundamental system of stellar coordinates covering the whole sky. However, for the southern sky the observational material was clearly insufficient. Considering this deficiency, Pulkovo Observatory took on itself the completion of the processing of absolute observations carried out in 1928-1941 at the Melbourne Observatory (Australia), which in 1944 ceased to exist. The proposal concerning their reduction originated from R. Woolley, present director of Greenwich Observatory, through which all material of observations was obtained. The program of Melbourne observations on the whole contained stars of the Baklund-Hoff list (almost 2250), and also stars of other lists. K. N. Tavastsherna directed the processing of

material. The first part of the work was completed and published in the form of a separate publication.

In 1960 the observations of 11,500 stars of the international program and the absolute determinations of the coordinates of the 1046 bright and faint stars were completed. Several years were required for the final reduction of the observations and discussion. More quickly of all this was done according to the works of an international character, regulated obligation, and strict time constraints. However, the observers on the large transit instrument and the vertical circle almost at once were involved in new crucial observations with the aim to determine the positions of the large planets, which was dictated by the necessity of a more precise determination of their orbits and the theory of their motion, so important for a calculation of accurate trajectories of flights of interplanetary space stations. The practical significance of the astrometrical investigations regenerated earthly goals: astrometry became useful for cosmonautics.

Together with that a serious problem of the further increase of accuracy of astronomical observations stood before astronomers. In spite of the fact that the accuracy of the observations produced at Pulkovo was sufficiently high, new problems presented scientists the necessity to accomplish a 10-15 fold increase in accuracy in a single bound. This was possible only on the basis of a radical reformation of methods and a complete replacement of instrumental equipment. Along this line several works were

already conducted at Pulkovo: the manufacture of the horizontal meridian circle of L. A. Sukharev (at first in the form of a model, then- a working design), the photographic vertical circle of M. S. Zverev, the large transit instrument for the Chilean expedition with constructional improvements introduced by A. A. Nemiro. It is possible to determine the subsequent progress of the ideas of the methodical and instrumental character peculiar to Pulkovo.

Indeed, traditions at Pulkovo Observatory are contained not only in an attachment to several problems (for example, the compilation of stellar catalogs or the determination of astronomical constants), but also in a constant perfection of the methods of approach to these old problems. Perhaps Struve had not found a completely new method of approach to them. This was a particular tradition because the novelty inwardly inherent to it was this tradition of novelty. However, here is no passion for novelty for the sake of novelty: everything was subordinated to the "vital principle" of strictness and accuracy- the principal demand of the Pulkovo astrometrical school.

Let us turn to another traditional problem- the determination of astronomical constants. As is evident from the foregoing, some astronomical constants are obtained from "themselves," in essence, from any number of observations, but still W. Struve presented the task of their special determination from observations with the transit instrument on the prime vertical. The polar telescope of A. A. Mikhailov served this very purpose at

post-war Pulkovo. After improvements introduced by K. I. Potter into the method and the progress of observations (a semiautomatic control with the photographing of the circumpolar region of the sky, a differentiated measurement of temperature, and a maintenance of the stability of the instrument), the processing of a 7-year sequence of observations (1953-1959) resulted in a value of the aberrational constant of $20^{\circ}4965$, which is extremely close to the value recommended by the Hamburg assembly of the IAU ($20^{\circ}4958$). Later, in turn, it was based on the results of radio location observations of Venus,³ carried out in the USSR and USA in 1960-1962.

The aberrational constant was repeatedly determined at Pulkovo by several authors (V. S. Bedin, N. M. Bakhrakh, N. N. Pavlov, G. V. Staritsyn) from diverse observations, in particular from sequences of observations of the time service. The constant of nutation was sufficiently dependably determined from latitude observations. Thus, as a result of the processing of an extensive sequence of observations on the Pulkovo zenith telescope in 1915-

³The radio location of Venus allowed an accurate distance from the Earth to Venus to be determined, consequently, to more accurately determine the measure of the solar system. As follows from the concept of aberration, an accurate value of the distance from the Earth to the Sun and the magnitude of the velocity of light gives the possibility to calculate the aberrational constant, which was done on the basis of radio location observations.

1941. S. V. Romn'skaia (1886-1969) obtained a value of the constant of nutation of 9.2041 , which approximates the best determinations, for example the determination of E. P. Fedorov (Poltava), and, probably indicated the necessity of a more precise determination of the international conventional value. However, the question concerning the improvement of astronomical constants is not decided only on the basis of astronomical data. Constants are related through their mathematical dependences. An example of the most simple connection is the reciprocal dependence of the aberrational constant and the solar parallax. A more complicated theory connects the constants of precession and nutation with the mass of the Moon. The determination of the generally accepted values for these quantities can be mutually in accord. This problem proved to be exceptionally difficult and still remains unsolved.

The determination of astronomical constants was closely connected with the study of the Earth's rotation. This problem acquired a special importance during the IGY. The systematic study of the Earth's rotation produced two services- time and latitude. At the beginning of the IGY both services were "ready for action": the staffs were made up and trained, instruments were acquired, observations were produced according to the comprehensive program. With the aim of the investigation of instrumental errors and the influence of them on the results of latitude determinations, a second zenith telescope (the ZTL; $D = 180$ mm, $f = 236$ cm) was established at Pulkovo in 1957, manufactured in

Leninrad on the basis of constructional plans of V. I. Sakharov and I. P. Korbut. The idea of parallel observations with two zenith telescopes, presented and for the first time realized by Pulkovo astronomers, won recognition in a number of observatories (at Poltava, Kazan, Kitab, then at foreign observatories).

In 1967 a 19-year sequence of uninterrupted latitude observations by means of the ZTF, started in 1948, was finished. After this time, covering a whole nutational period (18.6 years), 48,000 measurements of latitude were obtained, a good half of which were taken in the 6-year time span (1955-1961) of observations for the comprehensive program. The "density of observations" after this time span exceeded the density of observations of 1915-1928 by a factor of two, also carried out for the comprehensive program. But the principal thing was not the quantity of the observations. The traditions of Pulkovo were kept sacredly; the Pulkovo latitude service produced the best results in the world: the accuracy of its observations was almost twice as great as the accuracy shown in any of the stations of the International Polar Motion Service (IPMS), the number of observatories of which now taking part is about 40, scattered over the whole terrestrial globe.

Observations of "high density" play an important role in the study of short-period variations of latitude. So, from observations of 1915-1928 a "daily term" with an amplitude of $0^{\circ}04$ was revealed. The processing of a new set of data, begun by L. D. Kostina, led to the reduction of the amplitude of the daily

to 0:015. This processing was carried out under the direction of V. I. Sakharov with the application of a new method, according to the utilization of a more precisely determined value of the aberrational constant and with the calculation of all possible corrections recommended by the Astronomical Yearbook according to the execution of a reform of 1960 in the computation of the so-called reduced magnitudes. All results of the processing of the new 19-year sequence of observations are still difficult to foresee but they undoubtedly will be interesting.

The results of the observations of the latitude survey were regularly communicated to the Soviet center (Poltava) and the international centers of the IPMS (Mizusawa, Paris). However, latitude observations for a long time exceeded the limits of purely "social goals." These observations give broad scientific material for the decision of such profound (in the direct and figurative sense of the word) problems as the study of the "viscosity of the Earth," or, for example, the interaction between the terrestrial core and the mantle of the "solid" Earth, set in rotation. So the practice gave birth to a theory, the development of the theory was subsequently required, more often of all of the modified practice, and a new practice suggested new theoretical problems.

Such transformations continuously happened with another astronomical practice- the time service. According to a number of reasons the Pulkovo service was not resumed with radio transmission of accurate time signals, rather, concerning its activity

on the reduction and perfection of methods of the astronomical determination of time. There existed the difficult task of the assimilation of the "lagging section." Here arose a number of almost insurmountable difficulties, which turned out to be quickly circumvented, rather than to be overcome, changing the methods of combination of theory and practice. With the introduction of an automatic method of observations, attention was directed to the study of instrumental errors and the influence of surrounding conditions on the accuracy of observations. With the works of V. M. Vasil'ev, the influence on the precision of observed clock corrections of the differences of temperature of separate parts of the instrument was proven, and also the local difference of temperature in the dome. As with other authors, the specific role of local refraction and the effect of wind was shown. To create the theory, to calculate and introduce corresponding corrections in the observations was not shown possible. It remained to be attempted to change the conditions of observations, in order to decrease errors, of course, having in view the determination of a "theoretical state of affairs."

With this aim N. N. Pavlov proposed and built a new (in the constructional sense) transit instrument (PTI) with thermal insulation and other improvements.⁴ In 1959 observations by

⁴The Pulkovo transit instrument (PTI) was constructed and manufactured in the mechanical workshops of the Principal Astronomical Observatory with the utilization of the main parts from a

means of the PTI came to be produced in a large separate dome with a powerful exhaust ventilation. The flow of air exiting through an open hatch of the dome and flowing around the instrument eliminates local differences of temperature in the dome and partly reduces the influence of outside wind. In order to avoid local refraction the instrument is raised under the roof such that the objective end of the instrument is situated at the limits of the dome slit in the presence of the open hatch. These arrangements curtailed errors of observations almost by a factor of three. Such an important practical result influenced the determination of theoretical questions in an astronomical aspect.

The high precision of the observations was also the result of a restoration of their quantity. The more determinations of some magnitude that are produced, the more trustworthy and accurate would be the knowledge about them. After only 10 years (1954-1963) the time service at Pulkovo observed over 82,000 stars. At the time of the IGY the program of observations produced by the Pulkovo service and carried out by many time services of the USSR contained about 500 stars. The list of stars was specially expanded for the calculation of catalog purposes. At

Hildebrand transit instrument. Presently the manufacture of another, more modern transit instrument construction has been completed, the idea of which was also introduced by N. N. Pavlov and carried out in the workshops of Pulkovo Observatory.

this time the collective of the department of time service already had gained the experience of the compilation of stellar catalogs. In the process of the "service" with the photoelectric method, passages of the same star were systematically observed, thanks to which it was possible to reveal the errors of the catalog positions (for right ascension) of the observed stars. The objectiveness of the method and the repetition of the process of measurements allow these errors to be determined exceptionally accurately. In such a way eight of the "photoelectric catalogs" (F1-F8) were put together, which were distinguished by a high precision. Especially valuable was the summary catalog of right ascensions of 807 stars put together by N. N. Pavlov, G. V. Staritsyn, and P. M. Afanas'eva and based on twenty separate catalogs of nine time services of the USSR. The number of observations used in it exceeded 185,000, of which 80,000 were produced by the Pulkovo time service. According to its precision this catalog exceeds the best modern fundamental catalogs by approximately an order of magnitude, i.e., by ten times.

Catalogs of stellar positions were a traditional aim of scientific investigations conducted at Pulkovo since the day of the founding of the observatory, but in the given case this was not an end in itself. As far as observations of the time service directly reflect the phenomenon (fact) of the Earth's rotation, that opens the possibility of study of the means of Earthly rotation. "Clock corrections," which were obtained from astro-

nomical observations may characterize both the irregularities of the motion of the clocks and the irregularities of the Earth's rotation. It is necessary only to be assured that the laboratory clocks are sufficiently accurate. Until comparatively recently there was no such assurance, and the direct method of study of the irregularity of earth's rotation by means of a comparison with laboratory clocks remained inapplicable, although the irregularity itself was an established fact.

Thus, from the theory of tides and tidal friction, elaborated by G. Darwin at the end of the XIX century, it followed that the Earth must have a secular retardation of rotation. It was really manifested in the form of a lack of coincidence of theoretically calculated moments of the beginning of solar eclipses with the factually observed moments, from which the magnitude of slowing down was calculated. The secular retardation was manifested in a gradual increase of the period of the Earth's rotation (a day) which amounts to 0.0023 seconds in a century- the magnitude still inaccurate in direct verification. On the basis of the theory of motion of the Moon and several planets with an analogous method, i.e., from the comparison of precalculated positions of celestial bodies with observed values, uneven variations of velocity of rotation of the Earth in different years were suspected. The greatest (to 0.004 sec) deviations of period from the "normal" were observed in 1897 and 1920. It was supposed that such variations happened with a "leap" on the side of an acceleration or a deceleration of rotation with a gradual return

to the normal tempo, however, the "leap" itself was not revealed at once on account of its minuteness (the change of the period of rotation did not exceed 0.001 sec in 24 hours), and was revealed over some time as the result of the accumulation of error due to the "abnormal" velocity of the Earth's rotation.

After the invention of quartz clocks (in the 1930's), seasonal variations of the velocity of rotation of the Earth were discovered with a direct method. As it turned out, the duration of a day could deviate from the average value by more than 0.001 sec, the Earth rotating faster in June-August than in December-February. Quartz clocks kept time much more reliably than the best pendulum clocks used up to that time. The daily change of quartz clocks did not exceed 0.0001 sec. A new stage in the investigation of the irregularity of earthly rotation was begun with the introduction of the more accurate, high precision atomic (or molecular) clocks, the first examples of which were constructed in 1954-1956. The IGY program stimulated these investigations.

The precision of the motion of laboratory clocks is now confidently controlled with the help of "atomic standards." Changes of the duration of the day on the order of 0.0001 sec can be easily registered, if a method of comparison is allowed- astronomical observations which give an accuracy of only 0.01 sec. That is why this "intermediate link" came to lag behind, and the success in the perfection of astronomical observations opens the path to a detailed investigation of the irregularities of the rotation of the Earth. However, the study of the character of seasonal and

uneven irregularities, especially the cause of their origin, was shown to be a confusion of phenomena. The French astronomer A. Danjon (1890-1967) attempted to coordinate the uneven changes of the velocity of rotation of the Earth with the outbursts on the Sun observed in 1958 and 1959, or accompanying phenomena - solar coronal winds and earthly magnetic storms. The connection with outbursts and solar activity has now been demonstrated. In earlier works N. Stoyko (France) discovered changes of the longitude differences between Europe and North America, which bore a seasonal character, and also were associated with the period of solar activity. Near the maximum of the activity Europe and America were closer, near the minimum further away from each other by several meters.

N. N. Pavlov turned his attention to this curious result and confirmed it in modern, more accurate and more extensive material, offering data of observations of time services scattered over different continents. What does it mean? Time services gather astronomical observations and, in the limits of their accuracy, systematically register the duration of the period of rotation of the Earth. The result shown depends on the time of year, the phase of solar activity and, finally, on which continent the observations are produced. If the velocity of rotation of the Earth is registered differently on different continents, then before all it is necessary to find some average velocity, taking into account that fact that all services do not observe identically accurately. The problem has many

uncertainties. N. N. Pavlov attempted to refine the material, after which he was convinced that the oscillation of the differences of longitude between continents did exist. Supposing the phenomenon to be real, he explained the mobility of the earthly continents, which is expressed in their "oscillatory" displacement from a relatively average position. This "oscillatory motion" was connected with the acceleration or deceleration of earthly rotation and, probably, is explained as a result of an exchange of rotational energy between the earthly core and the atmosphere, the condition of which is characterized by changing circulations, depending on the time of the year and on stormy processes on the Sun.

Going further, N. N. Pavlov compared the detected displacements of the continents with large earthquakes and discovered that the catastrophic Chilean earthquake in May of 1960, according to European and American time services, was preceded by an abnormal shift of the American continent in the direction of the South Pole and amounting to 14 meters towards the Chilean coast of the Pacific Ocean. Does this not mean that data of the Earth's network of time services (which further amounts to the title of "Earth rotation service"), it is possible, some time can be utilized for the prediction of earthquakes?

From the foregoing discourse it is evident that for the measurement of times it is possible to avail oneself of other periodical phenomena, for example, the motion of the Moon. But here also arose the question about the precision of the observa-

tions; as far as the observations would be accurate, as far as long intervals can be reliably "measured off." Of course, the significance and the theory of motion of the Moon are part of this question. Consequently, side by side with the measurement of time, such observations can be used for a more precise determination of the theory. For these purposes the positions of the Moon are observed by a photographic method with a special camera. The camera which gave the best results was invented by the American astronomer V. Markowitz. An instrument of that type was manufactured in the mechanical workshops of the Principal Astronomical Observatory; the method of observations was worked out by KH. I. Potter. The accuracy of the observations at Fulkovo was shown to be high. The probable error of a determination of the coordinates of the Moon from observations on one night amounted to $\pm 0^{\circ}15$.

Observations of the positions of the Moon can also be used for geodesical purposes for the measurement of large arcs on the terrestrial surface (the distances between remote points). According to an idea of KH. I. Potter, an expeditional astrograph was built in 1962 by the Principal Astronomical Observatory for photographic observations of the Moon; it was utilized in a number of expeditions. For the measurement of the coordinates of the Moon on photographic plates, an automatic measuring engine was designed by N. P. Bystrov, which gives the results of the measurements on punch cards for subsequent computational reduction by means of a computer.

Except for our natural satellite- the Moon- observations of

artificial satellites of the Earth (ASE's) are used for the measurement of large arcs on the terrestrial surface. Created by the hands of people, these "celestial bodies" are distinguished from the remaining celestial objects not only by their artificial origin, but by other features, in particular, the quickness of motion on the firmament. The first observations of them presented themselves an unusual matter. The photography of their tracks was especially complicated: these were faint, but quickly moving, celestial bodies. Because of their small dimensions they were faintly illuminated by reflected sunlight, but because of their nearness to the Earth it was only possible to observe them in twilight, when the sky was still comparatively light. The effort of photographing the paths of meteors was almost inapplicable: for ASE's a high precision of the determination of their coordinates follows, otherwise the observations lose their meaning.

Originally observations of ASE's were produced on the whole by a visual method with the help of a special scope (a small telescope), possessing a substantial field of view ($D = 50$ mm, 11° field of view with 6X magnification). The Astronomical Council of the Academy of Sciences of the USSR organized over 70 stations of optical observations of ASE's in the territory of the USSR and socialist countries. Such a station, containing up to 20 observers-volunteers, was created at Palkovo. In order to assure the best survey of the assumed route of an artificial satellite, observations were produced simultaneously by 6-10

observers. The satellite, "picked up" by one of the observers, was "attached" to any star observed in the scope at that very moment. The time of the "attachment" was registered with a chronograph by means of a pressure key. The error of the observations from the best observatories amounted to 0.1 in angle and 0.2 seconds of time. Perhaps this is too great an inaccuracy, if we consider that in one second the ASE travels a distance of about 8 km.

For the first time the photographic program of an artificial satellite (more accurately, the rocket-carrier of the first Soviet ASE) was obtained by T. P. Kiseleva at Pulkovo on 10 October 1957 by means of the short focus astrograph AKD, which subsequently used for systematic observations of ASE's. But these observations demonstrated the necessity of the creation of a special camera with a fast acting shutter. In the capacity of such devices light gathering cameras were utilized with special mechanisms for the accurate registering of time. Although the work for the organization of the observations of ASE's was produced on the whole by the Astronomical Council, a large role in the matter of the improvement of apparatus and the increase of precision of observations belonged to Pulkovo astronomers (A. A. Mikhaïlov, D. E. SHCHegolev, L. A. Panaiotov, B. A. Figaro, G. V. Panova). The method of reduction of the photographic observations of ASE's was proposed by A. N. Deïch and A. A. Kiselev; the laboratory of scientific photography, directed by I. I. Breïdo, was occupied with questions of the

increase of sensitivity of photoemulsions. In 1965 the number of photographs of satellites produced at Pulkovo still exceeded a thousand. The precision of the registrations of the moments of observation reached 0.002 sec, and the error in the determination of the position of a satellite did not exceed $\pm 4''$.

Such an accuracy allowed them to avail themselves of observations of satellites for a so-called cosmic triangulation. The geodesical connection between two or more points on the Earth is accomplished with the help of triangles, the bases of which are based on the Earth, and one of the vertices, common to all triangles, is situated in space. This is an orbiting satellite, observed from those points which we can "connect," i.e., determine the distance between them. According to this the main thing is the synchronization of observations, then a picture at the moment of the observation makes it stationary, which simplifies the calculation. The synchronization could have been ensured with the help of special geodesical satellites with impulse lamp flashers, however, this method is still insufficiently worked out. Some methods were suggested by D. E. SHCHEgolev and other authors, and what it came to is that "mechanical" synchronization was replaced by "mathematical" synchronization, i.e., the special methods in the reduction of observations were not implemented quite simultaneously, but were related to a common scale of time-standard time of the USSR. With the participation of the geodesical service, expeditional stations and many observatories of the USSR and socialist countries, the carrying out of a method

of cosmic triangulation was done on the space from the Kiril Islands to East Germany with a general extent of over 10,000 km.

Traditions instilled by the founders of the observatory continue in the area of geodesy.

"HIGH MATTERS" AND EVERYDAY WORK

The opinion has been expressed that astronomers occupy themselves only with "high matters." Undoubtedly, astronomy is an ideological science; it to a significant extent is connected with philosophy, in particular with dialectic materialism. But before that, to indulge in philosophical reflections, it is necessary to create a firm basis for them, otherwise they can be shown to be erroneous. Already from previous chapters it is evident that astronomy is also closely connected with practical activity of people: for example, accurate time and coordinates are equally necessary for the orientation both on the sky and on Earth, procured as a result of "celestial observations" produced on the Earth. More often of all this role of ground astronomy remains unnoticed, and its importance is spoken of, although it would seem that half of the scientists and scientific departments of Pulkovo Observatory give principal attention precisely to it.

The other half (astrophysicists, radioastronomers, rather than stellar astronomers) is more closely contiguous to "high matters," as far as it is connected with observations of astronomical phenomena and it is possible to say "performs discoveries." However, to "discover a new star," or "count stars on the sky," to measure the distances to them, to broaden the frontiers of the surveyed universe, to discourse about the goings-on of the world, is not at all a simple matter. In order to discover

something new in astronomy, as in any other area of accurate knowledge, one generally has to begin with a creation of apparatus. Of course, modern telescopes are constructed and manufactured chiefly by factories, but not without the participation of astronomers, who still "nurture the idea" to the expression of the thought concerning the construction of new equipment and work out the method. Then, after the realization of the idea, a thorough investigation of the instrument and the improvements of method, prolonged observations and the processing, labor-consuming to them, falls to the share of astronomers.

The division of labor was a natural phenomenon. Collective investigations were especially fruitful, but in the collective not everyone has to collide with a "high matter." Nevertheless, an astronomer looks on it like on a working topic, without shyness, in exactly the same way as a worker of any other profession considers a topic of his activity.

Let us return to photographic astrometry. Laying the foundation of this area of science, S. K. Kostinskii determined its program for Pulkovo more than decades ahead. A disciple and a successor of Kostinskii, A. N. Deich completed in 1942, and in 1947 published, a discussion of a catalog of proper motions of 18,000 stars. Besides an ordinary (for such investigations) determination of the direction (apex) and velocity of motion of the Sun in space, A. N. Deich deduced the so-called secular parallaxes of various groups of stars, which allowed the distances to them, their true luminosity, and the total absorption of light

in the galactic plane to be estimated. Significant was the discovery of a new subclass of stars- subdwarfs, the name of which was suggested by the American astronomer G. Kuiper, who also discovered them and earlier published a short note himself. According to identical proper motions, A. N. Deich revealed a significant quantity of double stars and discovered that, of every 33 stars, one turned out to be double. The question is concerning the widely separated stars not observed visually in the form of doubles, but presenting themselves as physically connected pairs, or wide stellar pairs.¹

¹The nearest stars to the Sun, Alpha and Proxima Centauri, are an example of a wide stellar pair. The first- Alpha- is itself a visual double with a distance of 17".6 between the components and a total luminosity of almost 0 magnitude. The second- Proxima- is a star of 11th magnitude, displaced from the bright pair by an angular distance of $2^{\circ} 11'$. It was discovered in 1915 by R. Innes (1861-1933), the director of the observatory of Johannesburg (South Africa), on the basis of the total magnitude and direction of proper motion. A subsequent measurement of the parallax of Proxima confirmed the presence of the physical connection of it (through gravity) to Alpha Centauri. After the discovery by Innes, Kostinskiĭ put together a special program of photographing bright stars and their surroundings with the aim of revealing wide stellar pairs.

The "first epoch" plates of Belopol'skii and Kostinskii now acquired a greater value. With the establishment of the normal astrograph in the postwar period, a second series of plates came to be obtained with a difference of epochs of 50-70 years with regard to the first series. The richest material for the determination of stellar proper motions was obtained, and the study of the motion inside star clusters and gaseous nebulae (according to the illuminated "nodules" on photographs of these remote objects). Only in the postwar years were proper motions of several tens of thousands of stars determined, the determinations being distinguished by a high precision thanks to the great difference of epochs. An extensive investigation was carried out by V. V. Lavdovskii. The proper motions of 13 open star clusters and the stars in their environs were studied by him; over 14,200 stars were measured. Data of modern three-color colorimetry of stars was drawn to the investigation. As a result, not only the peculiarities of the motions were studied, the measure of the clusters and the quantity of stars in them made more accurate, but the composition of the "stellar population" of the clusters was also revealed.

The study of the proper motions of globular clusters was undertaken by N. V. Gamalei (1914-1954). Globular star clusters are the most remote objects of our galaxy, and their proper motions (angular displacements on the firmament), in spite of the relatively large space velocities, are very small; none the less the result was shown by Gamalei that with a large difference

of epochs such measurements make sense. Z. I. Kadla successfully continued the work. A group of students of A. N. Deich (G. V. Akhundova, N. M. Bronnikova, L. V. Zhukov, L. S. Koroleva, A. A. Latypov, A. B. Onegina, O. N. Orlova) occupied themselves with a determination of the proper motions of various objects, including, for example, such things as stellar associations, and planetary nebulae, for which expansion is characteristic.

The investigation of the star 61 Cygni was especially interesting on methodological and ideological grounds. The photographing of this double star, possessing a rapid proper motion, was begun at Pulkovo by means of the normal astrograph at the end of the XIX century. Thanks to the perturbations in the motion of a component of 61 Cygni, a dark, invisible companion of it was suspected. Only in 1943 did the American astronomer K. Strand manage to calculate the perturbing mass of this companion, which was shown to equal 0.016 solar masses. Strand had available a comparatively small number of observations, and at Pulkovo material was accumulated over 60 years. A. N. Deich carried out the reduction and analysis of all material and confirmed the existence of the invisible companion from one (just from the brighter) of the components of 61 Cygni with a mass of 0.012 solar masses and a period of revolution of 4.9 years. As far as the mass of the companion of 61 Cygni only exceeds the mass of Jupiter by a factor of 11, it can be regarded as a planet-like body. In this way the possibility of the exis-

tence of other planetary systems was demonstrated. In modern times the presence of planet-like bodies is established or suspected for at least a dozen stars.

Observations with the normal astrograph continue. Another photographic instrument- the 26-inch refractor- has a similar program. By means of it open star clusters, stellar associations and their nuclei, and stars with invisible companions were systematically photographed, and a principal part of the program includes the determination of trigonometric parallaxes of stars and the photographing of double stars with the aim of a study of the elements of their orbits. The instrument was improved; the automation of the observations took root; this happened with the direct participation of the observers I. I. Kanaev, A. A. Kiselev, and G. A. Pliugin. Their names probably will be remembered through many decades, such that with gratitude they are called the ^{primary} observers of the normal astrograph.

Also, it is difficult to imagine Pulkovo after fifty years, still amongst instruments of the future there still will be such "archaic" telescopes as the 26-inch refractor, the attitudes towards which will be the same as it is now toward the normal astrograph. Nevertheless, the normal astrograph still has served for a long time. Works for the problem of the Catalog of Faint Stars presented themselves with a guarantee to it. With the normal astrograph was produced the photographing of "areas with galaxies" with the aim of subsequent utilization for the construction of an absolute system

of stellar proper motions. On the basis of extensive material A. N. Deich, V. V. Lavdovskii, and N. V. Fatchikhin put together a catalog of 1500 galaxies in 157 areas $2^{\circ} \times 2^{\circ}$ (the field of the normal astrograph) from the North Pole to -5° declinations; of them 600 galaxies were shown to be suitable for accurate astrometrical measurements. The accumulation of plates "of the first epoch" was completed in 1958 (in all 900 plates obtained); for plates of the second epoch of time, it is possible, it is still to be done: the more the decades pass, the greater the accuracy of the subsequent measurements. However, it was of interest to obtain them for the observers themselves although it would be a preliminary result. Therefore, the repeated photographing of the same areas and the joint measurement of the plates of the first and second epochs has already begun. Works acquired not only an all-union (Moscow, Kiev, Tashkent), but an international, character (Bucharest, Bordeaux, Toulouse, San Fernando, Shanghai, and also observatories in the Southern hemisphere: Santiago, Perth, Cape, LaPlata and Cordoba). With the establishment of the new astrograph in Chile Pulkovo Observatory obtained factual material over the entire sky.

The other part of that grandiose work was the observation of minor planets for the orientation of the system of coordinates. A large group of observers systematically produced photographs of selected minor planets with the normal astrograph at Pulkovo (since 1949) and the zonal astrograph at Nikolaev (since 1961); the results of the observations are published in the form of

precise coordinates of the planets in Soviet and international circulars. The participation of observatories of the Southern hemisphere is also assumed in this work.

At restored Pulkovo photographic observations of the outer planets of the solar system- Uranus, Neptune, and Pluto- were resumed. In connection with the development of cosmonautics and the necessity of a more precise determination of the orbits of the large planets, attempts were made for the determination of the coordinates of the bright planets (Venus and Mars) with a photographic method, which before gave results essentially lower in precision than meridian observations. The special method, applied by T. P. Kiseleva for the observations of Mars, produced the desired result: the accuracy was shown to be even somewhat higher, in comparison with meridian observations. Astrophotographic observations and measurements were utilized, for example, for such problems as the decision of the question about the asymmetry of the discs of the planets Jupiter and Saturn (K.H. I. Potter and B. N. Strugatskii), which gave, however, a negative answer, in spite of the assumptions of N. A. Kozyrev concerning the asymmetry of the form of the northern and southern hemispheres of the rapidly rotating planets. The study of the form of the Earth, on the basis of an analysis of the orbits of artificial satellites, apparently confirms this assumption, expressed long before the appearance of ASE's.

We now consider astronomical problems in real earnest.

The interest for the nearest celestial bodies- the Moon and planets- first weakened, then grew in relation to the development of the means of observations. At the present moment it is impossible to speak of its slackening, but several works of Pulkovo astronomers in some measure anticipated the advance of the cosmic era. Before all it follows to mention the works of A. V. Markov (1897-1968) and his group (N. S. Orlova, E. K. Kokhan, I. N. Chistiakov and others) on the investigation of the physical characteristics of the lunar surface on the basis of comparative photometry, polarized and radiometric measurements, as a result of which the deduction about the temperature of separate formations, the roughness of the relief and the characteristics and age of lunar rocks were procured or determined more accurately. These investigations acquired a special significance in combination with the radio location of the Moon and radio astronomical observations produced at Pulkovo under the direction of N. L. Kaïdanovskii.

In 1960 an interesting collection, "The Moon," was published under the direction of A. V. Markov, which enriched methodological questions and results of ground observations. In December of that same year the IAU, imparting a special significance to the achievements of Soviet scientists, organized an international symposium at Pulkovo which was devoted to investigations of the Moon.² Of course, the principal things in the notice of the day

²The materials of this symposium were published by Pulkovo

were the reports concerning the results of the photography of the back side of the Moon by means of the third Soviet interplanetary rocket, which was launched on 4 October 1959 and which later received the name "Luna-2." In the deciphering of the first photographs of the surface of the Moon invisible to the Earth, ^{Several} Pulkovo astronomers assumed participation (A. A. Mikhailov, A. V. Markov, I. I. Breido, D. E. Shchegolev). Later on they also participated in the processing of the photographs obtained by the space probes "Zond-3," "Luna-9," and "Luna-13."

It seemed as if ground-based astronomy would have ^{almost} nothing to do in relation to the Moon, especially after flights of people to the Moon. However, such an opinion is not quite correct, and the works of the Pulkovo astronomer N. A. Kozyrev proved this. On 3 November 1958, while taking observations at the Crimean Astrophysical Observatory by means of the 50-inch reflector, he discovered a phenomenon which was interpreted by him as volcanic. The search for active processes and changes on the Moon was carried out during all periods of telescopic observations, but even in the last century the opinion was established that the Moon was a dead body. Convinced of the activity of the Moon, Kozyrev persistently sought an indirect manifestation of interior orogenic forces, in particular, igneous gas from the interior, the emergence of which on the lunar surface can be observed with

Observatory in Russian under the general editorship of A. A. Mikhailov.- New things concerning the Moon. Moscow-Leningrad, 1963.

a spectral method. The unique spectrogram obtained by him precisely testified to that phenomenon. His interpretation was called into question for a duration of ten years. Only in December of 1969 did the Committee for the Business of Inventions and Discoveries of the Council of Ministers of the USSR award N. A. Kozyrev a diploma for the discovery of lunar volcanism, and in October of 1970 the International Academy of Astronautics rewarded him their gold medal with imprinted diamonds portraying the constellation of Ursa Major.

Essentially, N. A. Kozyrev introduced something new into the investigation of planets. For example, for the study of the chemical composition of the atmosphere of Venus he proposed (1953) to observe the spectrum of the luminescence of its dark side, *i.e.*, that part of the Cytherian atmosphere which is situated above the clouds escaping from the lower atmosphere and surface of the planet. In this way he detected nitrogen in its atmosphere, the presence of which was confirmed with the direct investigations of the interplanetary probes "Venera-4"-"Venera-7" with the entry of them into the dense atmosphere of this mysterious planet. In accord with the observations of Kozyrev (1954) and his interpretation, the polar caps of Mars to a significant degree present themselves as atmospheric formation (snow clouds). Later on other planetary experiments confirmed this.

The articles of Kozyrev, side by side with the results of the observations, contained profound and elegant theoretical discourses, without the cumbersome calculations given to original

treatments. Thus, he theoretically proved (1963) the possibility of the existence of a rarified hydrogenous atmosphere for Mercury, although his observations in favor of the proper theory called into question other authors who spoke of an atmosphere of carbonic acid. Observations and theories of another type, the wrong way around, have stood the tests. The question here is one of the observations of the rings of Saturn (1968). Kozyrev detected water vapor in their presence and explained this as a phenomenon of photosublimation- the rarification of a crystal lattice of ice, a fraction of which makes up the rings of Saturn, under the action of photons of solar radiation.³ The work of Kozyrev stood in contradiction to the investigations of the American astronomers G. Kuiper and D. Cruikshank, who interpreted their observations as the presence of ammoniac ice in the rings. However, at the beginning of 1970 these authors rescinded from their previous interpretation and came over to the explanation completely corresponding with the results of the Pulkovo astronomer.

Kozyrev carried out his observations with the use of the instrument^а of the Crimean observatory. Because of the white nights in the summer, partly also because of the low altitudes of planets above the horizon at times favorable for observations, large telescopes were unsuitable to be established at Pulkovo. They are situated in southern states.

³The concept and term "photosublimation" has not been used in physics until now.

Observations in the Crimea allowed A. A. Kaliniak, another Pulkovo astrophysicist, to carry out a highly complex investigation of the Galilean satellites of Jupiter in search of atmospheres suspected for them.⁴ The search was carried out by means of a specially constructed spectrograph in combination with an image converter. In the neighborhood of wavelength 5300 Å (the visual portion of the spectrum) in the first three satellites, and especially clearly for Ganymede, spectral lines were observed which did not belong to the Fraunhofer solar spectrum. Their appearance could relate to the calculation of the presence of atmospheres of the observed satellites, although for a number of reasons a question concerning their atmospheres still remains to be resolved.

The use of image converters in the capacity of receivers of

⁴The four bright satellites of Jupiter (Io, Europa, Ganymede, and Callisto) were discovered by Galileo in 1610. The dimensions and masses of three of them (Europa excepted) exceed that of the Moon. In particular, Ganymede is greater than the Moon by more than a factor of two in mass and almost one and a half times in diameter. This circumstance and several others led to the idea concerning the possible existence of atmospheres for them.

light extended the possibilities of telescopes. Thanks to the transformation of a beam of light into a flow of electrons, it is possible to transmit invisible radiation (for example, infrared radiation with wavelengths to 1.3 microns), for which ordinary plates are insensitive, into a visible radiating image. The luminescence can be intensified, dispersing electrons with an electric field, which even more so can extend the power (aperture) of the telescope. Especially advantageous is the direct action of electrons on the film located inside a vacuum tube, where the electron flow forms. The laboratory headed up by A. A. Kaliniak worked over this in the course of a number of years. As a result of prolonged experimental searches the construction of an electron camera for inter-vacuum photography was worked out, which markedly differed from the camera of S. Fallier (France), the first to create a device for that purpose.

An analogous effect led to the application of television in astronomy. A transmitting tube (IR-vidicon) located at the focus of the telescope reforms the invisible IR radiation of a luminous body into a visible image on the screen of the television. The electronic scheme allows the brightness of the image to be intensified. To some measure this is equivalent to the enlargement of the entrance aperture of the telescope. Photographing the Moon, more correctly, separate details of it by means of a television system, N. F. Kuzevich achieved a total increase of the intensity of the image by a factor of 300, which allowed the exposure to be shortened (to 1/50 sec) and which also allowed the influence of

atmospheric turbulence to be reduced. But the most important thing consisted of the fact that television observations of the Moon in infrared rays (about 2.3 microns) led to the visible increase of the relief of the images. As is well known, the relief and contrast of the images at full moon are washed out at visible wavelengths. The effect of relief (also at full moon) probably happens on account of extra infrared radiation (luminescence) of separate details. With this the appearance of details on the television of infrared photographs is explained, which are not observed on ordinary photographs of the Moon.

Works on the installation of television technique in the carrying out of astronomical observations, begun at Pulkovo in 1956, have attained a broad scope at the present time. One channel and two channel television telescopes were constructed which were successfully used for observations of celestial bodies, the study of the characteristics of atmospheric disturbances and the creation of an automatic system for the struggle against them. V. L. Lentsman worked out the method of intensification of the contrast of television images of faint details for the decrease of internal apparatus complications, i.e., for the increase of the signal to noise ratio. Having shown a positive result with testing under laboratory conditions, the method promised much in the discernment and detection of objects, which were blended with the diffuse background of the sky.

The results of radio astronomical observations of planets are of special interest. With the help of the large Pulkovo

radio telescope (LPR) in 1962, observations of Venus and Jupiter were undertaken at wavelengths of 3 and 10 cm with the aim of studying the distribution of "radio brightness" on their disks. For Venus this was equivalent to a resolution of where its radio radiation comes from, to which a high temperature (about 600 °K) corresponds. If its surface is heated, then the radio brightness must increase toward the center of the disk; if the radio radiation results from the atmosphere (ionosphere), then the "brightness" must increase toward the edges. However, the resolving power of the LPR is 1' (at 3 cm wavelength); such a value is much greater than the visual diameter of Venus. In order to obtain the distribution of radio brightness over the planet's disk, I. U. N. Pariiskii developed a special method of exposing small variations from a uniform distribution. A low-noise parametric (molecular) amplifier, constructed by D. V. Korol'kov and G. M. Timofeeva, was used for the observations. A decrease of radio brightness toward the edges of the disk was established by the observations, which corresponds to a heated planetary surface. This result was announced to the Scientific Council of the Pulkovo Astronomical Observatory in November of 1962, months before the American probe "Mariner-2," which flew close by Venus, established the same fact by direct measurement of the distribution of radio brightness. Observations of Jupiter delivered much information concerning the means of its radiation zones. Later, in 1967, with observations at millimeter wavelengths, a still greater resolution was reached, thanks to which data about the distribution of the radio brightness over

the Cytherean disk were gathered together with rocket probes and were of much higher quality. For Jupiter, interior zones of radiation and a temperature gradient in its atmosphere were discovered.

The creation of a powerful experimental base in an astrophysical laboratory can promote the development of planetary and other astrophysical investigations after its construction and the putting into operation of new equipment. In particular, a functioning 100-meter gas tube is to be utilized for the modeling of planetary atmospheres and the study of the spectral characteristics of gaseous mixtures with the registration of selective absorption; when light passes through them, variations of pressure and the attainment of a large number of passages of light beams through the mixture which are studied give the possibility of imitating the atmospheres of planets and comparing the spectra obtained in the laboratory with spectra of the planets themselves, for the establishment of their chemical composition, trustworthy information concerning which is had only in relation to Venus, thanks to direct investigations of interplanetary probes.* At the present time extensive data have already been obtained (L. A. Mitrofanova, V. D. Galkin, L. N. Zhukova) concerning the behavior of the absorption lines of atmospheric oxygen with different

*With the landing of the American probes Viking 1 and Viking 2 on Mars in the summer of 1976, analogous data for the Red Planet are also available. (Tr. note)

pressures and different optical depths, i.e., with the change of the general path of light passage in the tube by means of repeated reflections, the number of which has now reached 20, which signifies a 2 kilometer depth of gas.

In post-war times, thanks to the energetic activity of V. A. Krat, who headed up the Pulkovo heliophysicists, a wide range of investigations of the Sun was carried out.⁵ In the

⁵For an understanding of terminology connected with solar investigations, we are reminded of several terms about the Sun. The Sun presents itself as a gaseous sphere with a diameter of about 1,400,000 kilometers. Being of gas, the substance of the Sun, however, is highly opaque: observers possessed with various means penetrate to a depth in it of not more than 400 km. Therefore, the solar disk precisely appears to be sharply outlined. The visual diameter of the Sun amounts to 1920", hence, 1" = 725 km on its surface. The external border of the sphere (about 0.5) appears somewhat darker at the edge of the disk because of the fact that the edge rays pass through a significantly greater thickness of gas than the central rays. The luminous surface of the Sun is called the photosphere. Its average temperature is 6000 °K. The photosphere is heterogeneous; it is completely made up of luminous spots, spread out like a view of "rice grains" against a dark background. This heterogeneity bears the name of granulation. Sunspots and faculae (long luminous formations) also have to do with the photosphere. Higher than the basic surface

years of restoration of the observatory attention was concentrated on the completion of the processing of materials from 1936-1941 and the observations of solar eclipses with the help of preserved equipment. Except for the eclipse of 1945, expeditions were organized: to Brazil (1947), to Chile in the Kazakh SSR (1952), in the Southern Caucasus and in Kuban' (1954). Several expeditions only partly carried out their programs. For example, in Brazil,

are situated layers (at about 7000 km height) which can be observed only under special conditions (at the times of a solar eclipse or with the use of special apparatus) and visually appear like "fiery grass" of red light, which is called the chromosphere. Above it appear the prominences (ejections of material), which reach altitudes of 50-100,000 km. The outer envelope itself is the solar corona, having a radiant texture. Observations of prominences and the corona also require special apparatus.

Knowledge about the interior of the Sun is given only by theory, but its conclusions lead themselves to practical verification. The temperature of the center (about 20 million degrees) results in thermonuclear reactions, which represent the source of solar energy. The transfer of energy from the interior to the surface of the Sun happens by means of radiation, although theoretically the existence of a skin-deep zone of convection just under the photosphere has been proven. Many authors have written that it carries away the photosphere and granules present themselves as separate "convection elements."

because of cloudy weather, it was proposed to carry out only radio astronomy observations. However, the preparation for the expedition and all of their organization demanded, in any case, much time and energy.

The processing of materials of observations obtained at Pulkovo until the war, and in Tashkent during the war, led to the spelling out of a series of articles on the investigation of sunspots and faculae (T. V. Krat), prominences and filaments (V. N. Kucherova), and luminous flocculi (V. N. Zuikov).⁶

⁶Filaments are prominences projected on the solar disk which are observed under definite conditions in absorption (as dark formations); at the edge of the solar disk prominences are observed in emission (as luminous formations). Flocculi are extensive luminous formations in the chromosphere, sometimes called chromospheric faculae, but which are observed in monochromatic light, for example in the lines of ionized calcium and hydrogen, then, as photospheric faculae, are visible in general (integrated) light. Photographs of the solar surface, obtained in monochromatic light, are called spectroheliograms. Filaments and flocculi appear on precisely such photographs. Of course, a spectroheliogram shows the features of the distribution over the disk of the Sun of that chemical element in the rays of which it is taken, on account of which solar formations themselves obtain the names of calcium or hydrogenic flocculi or filaments.

Observations of eclipses were utilized for the study of the chromosphere and corona. V. P. Viazanitsyn (1908-1960) carried out a thorough investigation of the chromosphere from materials of the eclipses of 1941, 1945, and 1952, obtained with the large prism camera with the photographing of so-called solar flares (the the moments of the interior contacts of the lunar and solar disks during total solar eclipses).⁷ These were spectra of the

⁷"Flares" near the second and third contacts of an eclipse consist of the sudden transformation of the dark Fraunhofer lines (which characterize absorption) into bright emission lines. The layer in which such a transformation takes place was earlier called the "reversing layer"; according to modern notions, there is no intermediate layer whatever between the photosphere and the chromosphere, rather, the reversing of the lines takes place principally in the lower chromosphere.

The term "flare" (for an eclipse) must be distinguished from a similar, outwardly sometimes identical term, "chromospheric outbursts," or simply "outbursts." Chromospheric outbursts (in popular literature they are often called "explosions on the Sun") can be picked out on spectroheliograms taken in the line of hydrogen H_{α} as the brightest formations on the Sun which do not exist for a prolonged period. They are observed by means of spectrohelioscopes or spectral telescopes, which are furnished with an interferometric-polarizing filter (IPF), intended for the passage of monochromatic light (in a narrow wavelength range) in the line of H_{α} .

most external layers of the solar atmosphere, basically the chromosphere. All material was investigated with particular thoroughness and Pulkovo-style conscientiousness, which allowed valuable data concerning the physical conditions in the chromosphere to be extracted. This very material was used for a spectrophotometric investigation of prominences (V. N. Zuikov) and for the photometry of the green line of the solar corona (T. V. Krat), which resulted in the discovery of formations in lower parts of the corona, later on called "coronal condensations."

In the observations of the eclipse of 1952 V. A. Krat utilized a slitless meniscus diffraction-prism spectrograph of his own design and carried out absolute spectrophotometry of the chromosphere. The photometry of the solar corona, according to direct plates of it at the time of the eclipses of 1945 and 1952, was carried out by A. V. Markov and N. N. Mikhailson, for which a special isochotometer was constructed for this purpose. In 1948 N. F. Kuorevich constructed an instrument for the automatic registration of the profiles of the lines in the solar spectrum - a photoelectric spectrophotometer, which produced a record in "intensities." This was significantly more advantageous than the measurement of spectra on photographs, which registered "darkenings" and not "intensities," which directly characterize a quantity of energy; for the transformation of the darkenings into intensities labor-consuming work is required with the utilization of the characteristic curves (calibrations), which at first are necessary to be formed with the calculation of their individualities for every

photographic plate. Much later an improved model of Kucrevich's spectrophotometer has been regularly used to the present time. A great amount of material was collected by T. E. Dervis, L. N. Zhukova, and L. A. Mitrofanova, covering one and a half cycles of solar activity. In their publication in 1960 a change of the central intensity of several lines with the phase of solar activity was noted: the higher the Wolf number, the lower the central intensity. This result gave rise to doubts (no changes whatever in the spectrum of the Sun had previously been observed), yet American astronomers did not confirm it in 1969.

A number of theoretical-experimental and theoretical investigations was carried out in the first post-war years. O. A. Mel'nikov redetermined the temperature of the reversing layer. According to laboratory intensities of lines of ionized iron, L. A. Mitrofanova made a "curve of growth" for the Sun- a graphical representation of the dependence of "equivalent widths" of spectral lines on the number of absorbing atoms. V. A. Krat published several articles on general solar circulations, questions of interpretation of spectroheliograms, the development of the forms of formations in the solar atmosphere resulting from a principle formulated by him, "electrostatic stationariness" in the photosphere and chromosphere, the constancy of electric fields in the plasma.⁸ These

⁸A plasma is the "fourth state of matter" (solid, liquid, and gas excepted), a highly ionized gas, in which positive and negative charges, which are created by electrically charged particles (ions

works were the theoretical basis for subsequent investigations.

In the ~~summer~~ of 1950 I. A. Prokof'eva established a small telescope with an interference-polarizing filter (IPF) in the "naval tower" (see p. 19), which was designed and manufactured by S. B. Ioffe. This telescope was the first model of a standard instrument, the chromospheric telescope "taken to arms" by the solar services at the beginning of the IGY. Observations with an IPF were later produced in the dome of the horizontal solar telescope; the material obtained was used for a study of chromospheric heterogeneity and served as one of the stimuli for the creation of a theory of the heterogeneous chromosphere.

Observations of the Sun extended in different directions with the reconstruction of the horizontal solar telescope in the spring of 1951: direct photography at the prime and secondary foci (with focal distances of 17 and 60 meters and solar image diameters of 16 and 56 cm, respectively), spectral observations by means of quartz (prism) and diffraction spectrographs, the automatic registering of solar spectra, and the chromospheric observations with an IPF. Observations of the Sun allowed the features of the Pulkovo astroclimate and its advantages for the performance of delicate investigations to be determined. The mild and damp marine climate ^{and} the relatively low heat of the

and electrons), are identical or almost identical in any volume considered. The substance of the Sun and stars actually is not a gas, but rather, is a plasma.

soil in summer days create favorable conditions for daytime observations. Often the "washed out" images do not exceed several tens of seconds of arc, and sometimes it is close to $0''.2$, the limit of resolving power which the atmosphere generally allows at the given altitude above sea level. Observations were intensively continued till the summer of 1954, when the wooden dome burned down due to defective electrical wiring. Observations were only resumed in the autumn of 1955 in a newly constructed dome of "fireproof" construction.

The series of pictures of solar granulation were an important result of the first period of observations (1951-1954). If Ganskii succeeded to fix granules with a visual diameter of about $1''$, then on the new pictures granules were discovered which were twice as small in size (to $0''.4$). This led V. A. Krat to the suggestion that still smaller granules exist, and the observed sizes would be characterized by only the resolving power of the instrument (jointly with the atmosphere). Although the thought was not taken as a prediction, it came true. In 1957-1959 the American astronomer M. Schwarzschild obtained exceptional pictures of granulation, according to clarity, with the ascension of a telescope into the stratosphere, and confirmed the prognosis of V. A. Krat. In 1966-1970 Soviet stratospheric solar stations supplied pictures on which the smallest granules did not exceed 100-150 km (less than $0''.2$) in diameter.

The confirmation of the prognosis led to results of great significance. In 1954 V. A. Krat again set down the hypothesis

concerning the wave nature of granulation despite the widespread conviction that granules present themselves as convective elements. The hypothesis was converted into theory. Indeed, if there were no standard elements, if granules of vanishingly small sizes were encountered, then the phenomenon of granulation was indeed similar to waves in the ocean, where the bright places were the crests, and the darker spaces were the places between the waves. The ideas of V. A. Krat concerning the wave nature of the phenomena of the solar photosphere penetrated many investigations of Pulkovo heliophysicists, who advanced like a single front against this mystery.

A powerful diffraction spectrograph was established in 1956 in the new dome of the solar telescope. Constructive ideas of the capable young scientist, V. N. Karpinskii, were used in its construction. The new spectrograph granted observers wide possibilities. Investigations of the chromosphere, prominences, and chromospheric outbursts continued with enthusiasm. Cinematography was applied to the study of granulation by M. Kerimbekov; the "duration of life" of granules confirmed an already expressed point of view on their nature. The photoelectric observations of V. A. Krat and I. V. Udina bore witness to this very fact. The practical impossibility of measuring the horizontal motions of granules (in the pictorial plane on the surface of the Sun) created difficulties. But these difficulties were overcome with the placing into operation of the original automatic magnetograph of L. M. Kotliar (1959). The magnetograph allowed the intensity

of the magnetic field (the longitudinal component) and the radial velocities to be simultaneously recorded; after improvements on the instrument (1963) it again became possible to register the brightness of the measured strip, which is equivalent to the heliographical "binding" of it to sunspots and chromospheric formations (flocculi, filaments). The first works of G. I. A. Vasil'eva and G. P. Bialshin with the use of the magnetograph led to results deserving attention. The observations obviously could be interpreted in favor of the existence in the photosphere of phenomena which resemble sound (transverse) waves and gravity waves (longitudinal oscillations resembling the agitation in a water glass in which a stone is dropped). Superposition (interference) of these waves gives the observed picture. "Thus, the photosphere of the Sun is this continuously churning ocean of gas," as summarizes the referred-to works of the author of the theory himself.

Another direction of work was the development of the ideas of the Pulkovo astrophysicist E. I. A. Perepelkin (1906-1937) concerning the heterogeneity of the chromosphere. Although the first observers (in the middle of the XIX century) compared the chromosphere with a "fiery prairie," emphasizing its heterogeneity, they theoretically considered it to be a uniform layer in which the "barometric formula" or a law similar to it operates. Perepelkin was the first to try to build a theory with the consideration of the fact that "the chromosphere appears like a gathering of a large number of separate filaments- prominences," which only

because of their great number statistically "form a continuous shell at first glance." This representation was obtained in the subsequent development in the works of V. A. Krat, T. V. Krat, and V. M. Sobolev on the basis of modern knowledge about the characteristics of plasma. The chromosphere is considered to be a transitional layer, not in equilibrium, from the photosphere to the corona; it consists of currents of gas moving upward and downward in the magnetic field, which is "wound" into the plasma and forms with it a single, whole entity, because of which the chromosphere is presented as being in quasi-equilibrium. Its discrepancy consists of this, its "dialectic." What is more, as far as the expansion and pressure of the gas (with the ascending and descending streams) in the magnetic field results in strong oscillations of temperature, a difference of temperature can be observed in the chromosphere (in that very same layer) at the determined moments of time; therefore, lines of such atoms and ions can exist in the spectrum of the chromosphere, the spectral indications of which appear in non-identical physical conditions. The theory of the chromosphere in non-equilibrium was not only worked out quantitatively, it was led there for the calculation of numerical values of different parameters in their comparison with observed data.

A significant quantity of work (V. N. Zuikov, M. N. Stoianova and others) was devoted to the analysis of spectra of flares and prominences. In 1958 V. A. Krat and L. N. Pravdiuk observed bands of continuous emission (a bright glow), the source of which

is placed in the photosphere. The phenomenon resembled chromospheric outbursts, however, the outbursts were in the photosphere. Hence, the inference was suggested that outbursts can arise in both layers of the solar atmosphere. The presence in the faculated areas of the dissemination of hot gas with a temperature of about $50,000^{\circ}$ was established by the same authors according to observations of the lines of helium; such formations are called "hot spots." In 1956 T. V. Krat detected previously unknown formations in the chromosphere in the form of dense clots, resembling dense prominences- "chromospheric condensations."

A third direction of work was the solar service. On the whole these works were concentrated at the Mountain Station of the Principal Astronomical Observatory. Systematic observations at Pulkovo have been conducted since 1957 in connection with the IGY, they being organized at once with observations of the magnetic fields of sunspots according to a method worked out by G. F. Vial'shin. A year earlier the coronagraph of I. A. Prokof'eva began to work at Pulkovo, which was manufactured in the optical-mechanical workshops of the observatory (to the inclusion of the diffraction grating spectrograph) and which was markedly different than the Lyot coronagraph, the essential details of which (the "artificial Moon," playing that role which the Moon does during a total eclipse, and the "field lens," also connected with its objective) were absent in the coronagraph of Prokof'eva. The image of the Sun was formed directly by the curved slit of the spectrograph, which fulfilled the role of the "Moon." In other

respects, care was taken concerning the elimination of scattered light inside the instrument. Since the time of its establishment, the new coronagraph, much simpler in design, allowed photography of the green and red lines of the solar corona to be carried out. The observations were regularly conducted, practically at sea level (together with the tower, the height of the installation was about 90 meters above sea level), which by itself testified to progress. These observations were not included in the solar service, but the coronagraph was successfully utilized for the study of the characteristics of coronal lines, weak spectral lines of prominences and chromospheric outbursts. In particular, coronal condensations, which T. V. Krat first detected in 1949, were investigated in detail by I. A. Prokof'eva.

The publication of the monthly bulletin "Solnechnye dannye" (edited by I. I. Vitinskii), in which, besides urgent data of the services of the USSR and socialist countries, short scientific reports are published, has a direct relation to the solar service. The bulletin has been published since 1954 by Pulkovo Observatory jointly with the Commission for the Investigation of the Sun of the Astronomical Council of the Academy of Sciences of the USSR. Appendices to the bulletin have appeared every half month since 1962: detailed maps of the magnetic fields of sunspots are circulated to observatories and interested participants in the form of a separate brochure. Pulkovo continues the publication of the "Catalogs of Solar Activity."

A fourth direction of work was the creation of new instruments.

Concerning many works of this genre, we have both already spoken in general and in connection with solar investigations, but attention must once more be turned to them, as these works undoubtedly have to do with a number of important achievements of the observatory, which stimulated all its subsequent observational and investigational activity. In 1967 one more solar telescope was put into operation at Pulkovo, the ATSU-5 (diameter of the coelostat mirror, the supplementary and main mirrors $D = 440$ mm, the focal distance of the main mirror $f = 1750$ cm, the secondary focus of 60 meters, the path of rays horizontal), placed in a special stone room not far from which was situated a separate laboratory location, but which was connected with it by communications. The telescope was supplied with a four-chamber isothermal diffraction spectrograph of high resolving power, the design of which was worked out at the ^{Principal} Astronomical ^{Observatory}; the spectrograph was constructed and built by the staff of the observatory. In accord with the name of the apparatus, four portions of the spectrum can be simultaneously photographed. A second feature of it consists of "scanning" the solar surface. The image of the Sun from one edge of the disk to the other passes over the slit of the spectrograph, which cuts out a portion of the surface (with a size up to $45'' \times 180''$). The photographing of spectra is automatically carried out over different spans of time. In such a way the spectrograph gives information of the physical conditions of the determined region of the solar atmosphere in three measurements: the slit cuts out an area, and the picture of the phenomena

according to height is determined by the instrument in one or another portion of the spectrum. A spectrum obtained with high dispersion contains abundant information about the magnetic field, radial velocities, relative intensities in the spectral lines and the "continuous background," from which the reductions and calculations infer diverse physical characteristics.

The creation by V. N. Karpinskii and N. I. Pechinskaia of a double diffraction spectrograph with digital read-out in 1969 was another achievement in this realm. Works on the construction of a photoelectric monochromator for the double diffraction instrument were begun by Karpinskii at the end of the 1950's; the first results were published in 1961-1963. The new instrument allowed "ghosts" (imaginary spectral lines peculiar to diffraction gratings) and scattered light in the spectrograph to be practically completely eliminated. Thanks to this, contours of the Fraunhofer lines were obtained in clear view, which, undoubtedly, promoted the study of weak spectral lines which make up the basis of the solar spectrum. The subsequent improvement of the instrument in combination with a calculatory-deciding mechanism led to the creation of a completely original spectrophotometer.

On a principally different basis, with the use of image converters, A. A. Kaliniak developed a differential method of determining spectral distinctions in the photosphere. His method was applied to the exposure of very faint Fraunhofer lines and to the study of all sorts of space-time variations on the Sun and in the solar spectrum. The striving towards multi-

regularity of information led to the realization of a model of a two-chamber coronagraph (on the basis of the coronagraph of Prokof'eva), which allowed synchronized observations of the solar corona to be produced in two wavelengths with an arbitrary time span between them. For monochromatic observations of the surface of the Sun A. V. Merkulov worked out a scheme and constructed a model of a "static spectroheliograph." Especially important was the participation of Pulkovo astronomers and inventors in the creation of stratospheric astronomical stations and their outfitting, intended for direct pictures of the Sun (granulation) and the photographing of solar spectra (ultraviolet and visible spectra of the central and edge portions of the Sun, corresponding to the photosphere and chromosphere).

fifth direction of work was radio astronomical observations. Investigations of the Sun with the use of radio telescopes were carried out at the time of eclipses (partial, total, and annular) on site (at Pulkovo with the GPR) and with the departure of expeditions to regions of eclipses. Attention was concentrated on the study of bursts of solar radio radiation, which happen at the beginning of chromospheric outbursts, and local sources, which are differently called "radiospots." The study of the latter is especially favorable at the time of eclipses since, with the hiding of them by the lunar disk (then with the emersion) one can confidently determine (localize) their locations on the disk of the Sun and compare them with objects observed optically. Such a method increases the possibilities of small radio telescopes. The

large Pulkovo radiotelescope, possessing a significant resolving power, allows observations and the localization of sources to be carried out at any time (outside eclipses, but during the passage of the Sun through the meridian- the directional layout of the antenna of the radiotelescope). Therefore, the GPR is used especially at the time of the IGY for the organization of simultaneous observations of chromospheric outbursts and bursts of radio radiation with optical and radio astronomical methods. Both methods give similar results for the determination of the average temperature of the solar corona, but do not always agree on the identification of local sources. Thus, according to data of V. N. Ikhsanova, radiosoots often do not coincide with sunspots.

As a result of diverse observations, theoretical estimates and fervent discussions, Pulkovo radio astronomers (G. B. Gel'freikh, V. N. Ikhsanova, N. S. Soboleva, A. P. Molchanov and others) "constructed a model" of local sources in the form of condensations of coronal gas, disposed above the photosphere to a height of 0.05-0.07 solar radii, and which do not coincide with coronal condensations observed optically. Investigations of bursts led A. F. Dravskikh and G. B. Gel'freikh to the conclusion that the bursts of radio radiation arise in regions with a strong magnetic field and a temperature which significantly exceeds the average temperature of the corona (about 1 million degrees) and which reach tens of millions of degrees. The result seemed unlikely, but soon after it was confirmed. According to data of measurements of X-ray radiation of the Sun obtained by rocket, it turned

out that zones of exceptionally high heating can arise above the visible flares. Pulkovo radio astronomers were the first to note this. The mechanism of formation was obvious: with the strong heating, portions of the coronal gas acquire velocities on the order of 1000 km/sec, which exceeds the velocity of escape for the Sun (619 km/sec).

A sixth direction of work was the investigation of the nature of solar activity and its manifestation in the solar system. It follows here to mention the works of B. M. Rubashev and his group. At the present time it is quite evident that a convection zone is the main cause of all active formations on the Sun. Therefore, proceeding to a working out of a theoretical method of predicting relative Wolf numbers, B. M. Rubashev began with a detailed study of the characteristics of the convective zone and subphotospheric stratification. Having created a theory of the convection zone as a boundary layer, he found a new method of determining the thickness of the convection zone. In principle, the thickness of it is fixed by the sizes of sunspots: the larger they are, the deeper they lie. Hence a rough calculating method of prediction came about, however, it still did not give the Wolf numbers. These works continue.

Empirical-statistical methods of prediction of solar activity were simultaneously worked out and improved at Pulkovo (A. I. Ol', I. I. Vitinskii). They turned out to be less crude than the calculatory method. Predictions of Wolf numbers, made up on their basis, were used by geophysical and radiophysical institutes. A

large quantity of work on the problem of the "Sun-Earth" belonged to B. M. Rubashev. In particular, he proposed a method of calculation of the heating of the lower ionosphere (with a height of 100 km above the terrestrial surface) according to the observed characteristics of magnetic storms. As far as meteorological phenomena are connected with the heating of the upper atmosphere, the method, besides other applications of it, was used for the elucidation of the character of the influence of solar activity on weather. Rubashev showed a direct manifestation of solar activity in the lower layers of the atmosphere (troposphere), having established the connection of the intra-yearly fluctuations of solar activity with types of atmospheric circulation. The presence of such a connection helped in the working out of long-term meteorological predictions on the basis of the predictions of Wolf numbers. Finally, Rubashev detected a manifestation of solar activity in the variations of brightness of the planets Jupiter and Saturn, periodic changes of the zonal rotation of Jupiter, etc.⁹

Thus, from "high matters," from solar matter in its burning hot conditions (in the "fourth state"), together with them, a

⁹The examined questions are summarized in detail in the literature: B. M. Rubashev. Problems of solar activity. Moscow-Leningrad, 1964; I. I. Vitinskii. Predictions of solar activity. Moscow-Leningrad, 1963; The morphology of solar activity. Leningrad, 1966.

rather insignificantly small part of it, having parted company with the Sun in the form of a sea of highly agitated charged particles, we mentally return to our Earth. The value of science, especially natural science, is often measured by its practical applications. This was proven in full measure by the example of solar investigations.

MYSTERIES AND PROFOUND SPECULATIONS

Modern astronomy contains two extensive realms of investigations especially closely related to philosophy. They are cosmogony and cosmology. They do not correspond to that division of astronomy which was formulated in the middle of the XIX century and was severally enlarged till the middle of the present century, in accord with which all sciences concerning the sky were subdivided into astrometry, celestial mechanics, stellar astronomy, astrophysics, and radio astronomy. Enveloping all areas of astronomy, cosmogony and cosmology simply advanced as two immense problems because of the immensity of their objects—the whole universe.

Truly, cosmogony, not following from the literal meaning of its name (the origin of the universe), divides up the universe into separate, characteristic "cosmic forms," in which material in the universe exists, and studies questions on the origin and development of celestial bodies and their systems, and not the entire universe. Cosmology does not divide up the universe and considers the universe as a single whole. Literally, very little had been devoted to this subject; the twofold presentation of the question was connected with the General Theory of Relativity, worked out by A. Einstein in 1915-1916. Models of the universe as a whole appeared after 1917 on its theoretical basis (the first model belonged to Einstein himself), which, thanks to and only thanks to such a presentation, questions led in general to a pic-

ture of the ultimate universe in space and in time, in spite of the historically assembled representation concerning the limitlessness of the universe.

The contradiction challenged many arguments. At times they flared up and intensified, taking on an ideological coloring, at times they subsided but did not come to an end. Cosmogony, breaking into pieces its own object of knowledge, was the arena of less violent battles, but, in essence, if the limit of the universe were to be proven by cosmology, the problem of its origin would quickly arise, and this problem would signify cosmogony in that primary and direct meaning of the word, as it is understood in myths concerning the origin of the universe reaching us from many ancient countries (Indians, Egyptians, Jews, Greeks and others). Both problems for a long time were organized on a scientific basis. However, the decision of diverse questions of cosmology and cosmogony in an essential way depends on the accumulation of facts, observed data.

Generalizations of the achievements of astrophysics, stellar statistics and stellar dynamics led to definite conclusions concerning the age and directions of development of stellar systems of different classes, several types of stars and other forms of cosmic matter. Here it is sufficient to mention the works of the Soviet astrophysicist and academician V. A. Ambartsumian on the investigation of stellar associations, the stability (and disintegration) of stellar systems and multiple systems of galaxies and other things. His conclusion (1947) concerning the

fact that, "the formation of stars continues in the galaxy at the present time," forced the models of the universe to be improved, according to which the birth of galaxies and stars is computed as occasional and is unambiguously connected with an "act of creation."

The newest achievements in radio astronomy- the discovery of quasars (1963) and the background radiation (1965)- led to arguments over the use of the cosmological model of an expanding, hot and overdense universe in the past. Now it is possible to quote the words of the academician I. A. B. Zel'dovich: "the theory of the expanding universe is one of the most important achievements of science of the XX century."¹ Radio astronomical observations confirmed the predictions of a theory that shows a criterion of truth in any theory or hypothesis (at the borders of its applicability).² Born with the theory of relativity, it

¹I. A. B. Zel'dovich and I. D. Novikov. Relativistic astrophysics. Moscow, 1967, p. 387.

²The theory of the expanding universe depicts the Metagalaxy- the supersystem uniting all galaxies- in its present state in a phase which, evidently, was preceded by a state with a significantly higher temperature. Only the cosmic microwave and radio radiation confirms this and the calculated number density of the distribution of quasars, if they are considered, which is highly likely, as a pregalactic form of matter. Observations never say anything

also demonstrated the power of its parent. Henceforth, relativistic theory took its stand with a method of cognition of the universe. On this basis arose, and in a very short time developed, a new realm of astronomical science- relativistic astrophysics (or rather, the modern theory of gravity) in the capacity of a principal element for the decision of astrophysical problems, especially problems of cosmology and cosmogony.

However, it does not follow to overstate the all-embracing meaning of it. The mathematical apparatus of the modern theory of gravity brilliantly justified itself as the means of knowledge of the Metagalaxy. It follows to once again emphasize how telescopes and radio telescopes reached the boundaries of this indeed immense supersystem, and how the theory described the scales of it along general lines, qualitatively. Quantitative corrections (they were also essential) brought in the results of observations.³ Observations also allowed a suitable

about the fact that the superdense state was primal, consequently, they do not serve as a confirmation of the primary phases of the state of the universe, which the theory calculates in detail and affirms.

³In the 1930's, on the basis of theory, the "radius of the universe" was computed to equal 1.8 billion light years. At that time it was thought that the 100-inch Mount Wilson telescope penetrated to a depth of the universe to one half of its "theoretical radius." In order to reach its "border" a telescope with

choice among various theoretical models of the universe to be made. In this way much information concerning the Metagalaxy, in particular, the confirming observations, could be considered as sufficiently proven. This confirms the theory of an expanding universe, although on the whole it still is far from being completed. All the more erroneous was the assertion of the advocates of the universality of the new theory concerning the fact that it includes the whole universe. It depicts the Metagalaxy, and not the universe, and there was no necessity to identify these two different concepts. If the theory led to the conclusion about the limited nature of the universe, then it says, of course, nothing about its weakness concerning the limited nature of the sphere of its applicability. Any physical and mathematical theory is precisely such, because a theory builds on the basis of limited practice and does not allow a limitless extrapolation. Only a correct combination of theory with practice (the verifica-

twice the size was constructed. Soon it was established that measured distances must be doubled and in this way it turned out that the new 200-inch telescope detected objects (galaxies) at distances to 4.25 billion light years. Naturally, the "theoretical radius" had to be adjusted to those things which were observed. Then it once more had to change, when objects (quasars) were detected by radio telescopes at distances of 9-10 billion light years.

tion of theoretical conditions of observations) and methodology (the theory of knowledge of dialectical materialism) can lead to the disclosure of yet unknown mysteries of the infinite universe.

Science does not repudiate, and has no basis by which to repudiate the existence of other metagalaxies. It is possible, there already is some set of observational data in favor of their existence, only we are not able to presently examine all of the abundance of facts, and are not able to decipher their authentic meaning. Thus it was, for example, with galaxies. Scientists pondered the existence of other galaxies. In the 1840's A. Humboldt expressed thoughts on "world islands," or "island universes," as those objects were called in the first third of the XX century. Astronomers even made available observational data. As far back as the end of the XVIII century W. Herschel observed "unresolvable" nebulae," among which were galaxies. However, only in 1916-1920 were they deciphered, as a result of which it was proven that astronomers for a long time had come into contact with extragalactic objects- other galaxies. The accumulation of facts and new, powerful means of observations were required for the proof.

Works of Pulkovo Observatory in a large part related precisely to the accumulation of observational facts. Its role in the decision of cosmogonical and cosmological problems can be described as modest: the role of any observatory is such, if a scientist does not have to work on theoretical generalizations.⁴ However, at Pulkovo they had and have a place. As far back as

W. Struve, one of the problems of cosmology- the photometrical paradox- was come into contact with and was successfully handled at that time by them. Later, in 1929, A. A. Belopol'skii attempted to uncover the non-Doppler explanation of the "red shift."⁵ In

⁴The more significant investigations in the realm of cosmology and cosmogony are connected with the names: A. Einstein, A. Eddington, G. Lemaitre, J. Oort, F. Hoyle, and also Soviet scientists: A. A. Friedmann, V. A. Ambartsumian, B. V. Kukarkin, V. G. Posenkov, O. I. Schmidt, I. P. Zel'dovich and others.

⁵The "red shift" is the displacement of the spectral lines in the spectra of galaxies toward the red end, which, in accordance with the Doppler principle, signifies recession. For galaxies it means literal "recession," as the velocity of their recession is proportional to distance: the further they are observed to be, the faster they recede. Precisely this law (Hubble's law) served as an experimental basis for the "idealistic" theory of the expanding universe. Belopol'skii attempted to give a material explanation of the "reddening" of the light on the basis of the "aging" of quanta, robbing them of energy: quanta traveling in space for hundreds of millions of years lose energy, which is equivalent to an increase of the wavelength of light (a displacement toward the red wavelength side). The explanation of Belopol'skii, however, met insurmountable difficulties of purely physical means.

the 1930's Pulkovo astronomers (B. F. Gerasimovich, A. F. Bogorodskii, M. S. Eigonson and others) carried out a whole series of works of a serious theoretical nature. In the post-war years V. A. Krat published some quantity of diverse investigations on the questions of cosmogony ("On the development of stars," "The origin of the solar system," etc.).

In 1953 V. A. Krat suggested a proper hypothesis of the origin of the solar system which, in his opinion, was formed from a cloud of solid particles of comet-like type. The Sun itself at the time of formation of the planetary system had passed through several stages in its development. The formation of the outer planets took place in that period when the Sun was a hot B-type star with a mass of 5.5 presently solar masses. All material inside the orbit of Jupiter evaporated because of the high temperature of the Sun. Subsequently, the star (Sun), according to V. A. Krat, underwent evolution through the Wolf-Rayet, ρ Cygni and red giant stages. The star passed through these stages (from B star to red giant) in 10 million years, i.e., "very quickly," according to the age scale of the Sun. As stars of Wolf-Rayet and ρ Cygni type are distinguished by a powerful outflow of matter from the surface, that Sun passing through the corresponding stages had to have "lost" a fundamental part of its matter, and its mass at the red giant phase could not have exceeded 2.2 times that of the present. The red giant phase was also not prolonged because of the loss of matter for a different reason (with the large radius

of the red giant, the "velocity of escape" of particles was not great). The inner planets (planets of the terrestrial group) were formed from the rest of the dusty cloud, brought nearer to the Sun thanks to an inhalation of material thrown out from the Sun during the star's Wolf-Rayet stage. After the formation of the planets and the dissipation of the fundamental mass of matter with the Sun, the "life" of the solar system over the course of billions of years lapsed into a "tranquil situation," reminiscent of the present.

A positive aspect in the hypothesis of V. A. Krat was the fact that he was the first to attempt to take into account the possible change of the Sun itself during the period of formation of the planetary system and in the early period of its evolution. With this, the formation of the planetary system, according to his hypothesis, happened more or less simultaneously with the process of formation of the central luminous object. In his articles V. A. Krat expressed original understandings as regards the formation and evolution of the galaxy, gaseous-dusty nebulae and stars. A "corpuscular instability" plays an essential role in the development of stars (a principle formulated by him in 1948), consisting of an accelerated dissipation of the atmosphere of stars possessing gigantic sizes and a high temperature. Super-massive hot stars, subsequently losing mass, quickly undergo evolution. They follow to be related to young objects which formed "not long ago." At the present time such stars are observed only because they still have not succeeded to undergo evolution

and advance in their development to the class of "later" stars. The age of young stars estimated by V. A. Krat was in agreement with estimates of V. A. Ambartsumian, V. G. Pessenkov and other authors on the basis of different considerations.

As regards works which were contributing to the accumulation of data of observations, any astrophysical and stellar-astronomical investigations were of interest for cosmogony. Work on the physics of planets and stellar astronomy were elucidated in the previous chapter; now the question is one of works on the physics of stars.

The work of O. A. Mel'nikov attracted great interest in this area. In 1944 he completed an extensive spectrophotometric investigation of Cepheids on the basis of observations at Pulkovo and Simeiz in 1936-1939. Because of the circumstances of war time, the work was only published in 1950. In several senses O. A. Mel'nikov continued the line of investigations of A. A. Belopol'skii and I. N. Lehman-Balanovskaia. However, he gave a profound analysis of the physical conditions in the atmospheres of Cepheids and a complete picture of complex phenomena in them, on the basis of which several inferences of a cosmogonical nature could be made. A second part of the work contained a statistical investigation of long-period Cepheids. The fundamental result of Mel'nikov's investigation was a more precise determination of the magnitude of cosmic absorption of light and the zero-point of the "period-luminosity" curve.⁶

In accord with the new zero-point, the measured distances

in the universe had to be increased by approximately 1.3 times. It followed to increase the linear size of the Andromeda Nebula

⁶For several classes of so-called physical variable stars, for classical Cepheids, cluster-type variables, etc., there exists a dependence, established by observations, between the period of variability and the brightness, or more precisely, the luminosity, i.e., with the general quantity of radiated stellar light. Thanks to this dependence of the period of change of the brightness, which is comparatively easy to observe, it is not difficult to establish an absolute brightness of a star. But the absolute brightness would bear witness to the true luminosity of a star if all stars were situated at an identical distance. As the light of the star decreases proportional to the square of the distance, the observed brightness of a star (the apparent stellar magnitude), in comparison with its absolute brightness, allows the distance to the star to be determined. In this way the "period-luminosity" dependence allows the distance to variable stars to be determined on the basis of the observed stellar magnitude and the period of variation of brightness. This dependence is also confirmed theoretically, only from observations it follows to determine the zero-point of the "period-luminosity" curve, but for this it is necessary to know several initial distances, which often have to be estimated with indirect methods, and besides this, it is necessary to determine the magnitude of the cosmic absorption of light. "All intricacies" of this method are contained in this.

in the same proportion, which still more (not only by structure, but also by the actual size) made it similar to our galaxy. Some time later, in 1952, W. Baade, utilizing results of proper observations with the help of the 200-inch Palomar telescope, established that intergalactic distances had to be doubled, which was agreed by international decree.

It is necessary to mention that the determination of the scale of distances, or the zero-point of the "period-luminosity" curve, depends on the fact that this holds for any group of stars as far as they can belong to different "population types," which can lead to different results.⁷ "Cluster-type variables," which, however, are not observed in neighboring galaxies, as far as they are very faint, give a more certain result. Therefore, it is

⁷In 1943 Baade showed the diverse make-up of "stellar population." All stars in the galaxy (and other stellar systems) can be subdivided into two types: I- the "population of the planar component," which is found in the arms of spiral galaxies and in irregular form galaxies; II- the "population of the spherical component," characteristic for the nuclei of galaxies, globular clusters and elliptical galaxies. The works of Soviet astronomers (B. V. Kukarkin, V. A. Ambartsumian and others) of that period showed earlier that types of "stellar population" were more diverse, and that the affiliation of stars to one or another type is determined by their "genetics"- the community of "genealogical lines."

desirable to have reliable scales "graduated" for different types of physical variables. O. A. Mel'nikov often returned to work on a more precise determination of the zero-point of the scale of distances with the calculation of all sorts of circumstances, in particular, the make-up of "stellar population."

The works of the astrophysical school of V. A. Krat and O. A. Mel'nikov were diverse. On the whole they were carried out with the methods of spectrophotometry and electrophotometry. The objects of study were stars of different spectral classes, situated at different stages of evolution and on different paths of development. Highly complex physical characteristics were obtained for stars making up photometric binaries. Concerning the abundance of material, a list, though short, is as follows: spectrophotometry of the eclipsing variables α Herculis and RS Vulpeculae (N. M. Gol'dberg-Rogozinskaia), an investigation of hot supergiants in eclipsing binary systems (A. N. Dadaev), electrophotometry of subgiant stars (A. V. Sofronitskii), colorimetry and spectrophotometry of subdwarfs (K. Kalchaev, A. N. Demidova). Quantitative analysis of the continuous spectrum and spectral lines (spectrophotometry)- a more productive method of study of the physical conditions in the atmospheres of single stars- was applied in all cases when the means of observations were allowed, in particular for the study of "white" and "yellow" supergiants (T. M. Fofanova), stars in the Coma Berenices and Pleiades clusters (N. N. Gorokhova), "pseudocolors" (V. S. Ponomov),

and magnetic-variable stars (T. N. Kuznetsova). This method was utilized for the study of the interstellar absorbing medium (N. V. Bystrova). Now it is possible the time has come to somehow summarize this material, which was obtained over two and one half decades.

Two more investigations were closely related to these works, which were connected with the working out of methods, but which were implemented side by side with observations taken for the verification of the methods: the determination of stellar radial velocities by means of a direct vision objective prism (L. A. Panaiotov) and a photometric study of 15 spiral galaxies (D. E. SHCHEGOLEV). the result of the latter merits special attention. The investigated galaxies have, according to the photometric data, similar structure: the primary part of the radiation is created by stars of the "spherical component," which forms the continuous background of the nebula; the spiral arms consist of stars of the "planar component." Absorbing material is concentrated in the galactic plane less strongly than stars of the spiral arms, but more strongly than stars of the background. Our galaxy probably looks like that from outside.

The works of N. A. Kozyrev stand by themselves, in which the problem of the interaction of one body (of a mechanical complex) with another is studied as a principal theme through the change of the properties of time on account of the goings-on in their irreversible (cause and effect) processes. Only with such an interaction, according to Kozyrev's opinion, can the physical

features of the components of double stars be explained, which were discovered by him on the basis of a statistical investigation and which consists of the fact that that the components of small mass and size seek to come closer, according to their means, to the more massive components, and this is made noticeable because of the deviation from fundamental stellar-statistical regularities, before all from the "spectrum-luminosity" diagram.⁸ Kozyrev attempted to investigate the universal properties of time, determined in astronomical processes, experimentally and in laboratory conditions. The appendix to his "causal mechanics," incidentally speaking, contradicting physical canons, was highly diverse.⁹

⁸The "spectrum-luminosity" diagram is one of the fundamental laws of conformity of stellar astronomy and astrophysics. It was first constructed by E. Hertzsprung (Holland, 1911), and some time later, and independently from him, by H. N. Russell (USA, 1913), which is why it is often called the Hertzsprung-Russell diagram in previous literature. The modern diagrams are unusually involved and are strongly distinguished from the originals, but on all, as before, one can pick out the main sequence branch of stars, on which the stars of greater mass and luminosity correspond to the hotter stars (stars of the earlier spectral classes). This diagram undoubtedly has a "genetic" and evolutionary meaning for all classes and subclasses of stars.

⁹The problem of the properties of time was set forth by N. A. Kozyrev in the book: Causal or non-symmetric mechanics in the

At last, from the investigations in the area of optical astronomy, it follows to mention the work of A. A. Kaliniak, carried out jointly with V. I. Krasovskii and V. B. Nikonov, according to photography of the galactic center in infrared light. The existence and location of the galactic nucleus was established on the basis of the rotation of the galaxy, observed for stars. However, such a mighty and compact stellar cluster at the center, which theory prescribes and which is visible on photographs of other spiral galaxies, we do not visually observe in our galaxy because of clouds of absorbing matter (in the constellation of Sagittarius), which obstruct the galactic center from us. Photography carried out in 1948 with image converters at a wavelength of about 1 micron, distinctly show the structure of the galactic nucleus.

The young science of radio astronomy thrust open a new "window to the universe," which impetuously developed in the years after World War II and which made at this time important discoveries of great significance. Before all, radio astronomy decisively changed the previous view of the universe as something which stands its ground, changes extremely slowly,

linear approximation. The ^{Principal} Astronomical ^{Observatory}, Leningrad, 1958, and an article published in the collection: The history and methodology of natural science, v. II. Physics. Moscow State University, 1963, pp. 92-106. An astrophysical supplement contains more special articles.

invariable over the extent of billions of years, and is almost unfathomable in its evolution. Undoubtedly, the discovery of violent, energetic and short-lived processes has an influence on the success of modern cosmogony and cosmology. Not quite so fantastic now, as it was perceived in 1948, seems the thought, expressed by V. A. Ambartsumian concerning the possible existence of "protostellar bodies," from which the observed stellar associations are born by means of an explosion. Explosions in galaxies, far more powerful than had been supposed, were established by radio astronomical methods. The Friedmann-Lemaître model of the expanding universe came to be preferred in place of the stable-equilibrium cosmological models of the universe. This very model was transformed from the theory of a one-time formation of all galaxies and stars ^{into} the "big bang" theory, or the "catastrophe which appeared at the beginning of all catastrophes" in the universe.

Radio astronomical investigations still have that significance for cosmology, thanks to the colossal power of the energy sources with which radio astronomy deals; they allow the depths of the universe to be penetrated at significantly greater distances than optical astronomy. Truly, quasars (quasi-stellar radio sources), which allow this to be done, at first were also taken to be the objects (massive superstars) predicted by F. Hoyle and W. Fowler in 1963, precisely on the eve of the discovery of quasars. The displacements of the lines observed for quasars can be interpreted not only as cosmological (Doppler-like),

but also as gravitational, being calculated for collapsing superstars.¹⁰ In this case we would be dealing with objects situated comparatively nearby, although beyond the limits of the galaxy, and which would sooner be of interest for cosmogony than for cosmology. However, there almost remain no doubts now, that the displacement of the spectral lines for quasars have the Doppler-like interpretation and that these objects are situated at cosmological distances.

¹⁰Gravitational collapse, understood till now only theoretically, is the fall of the mass of a superstar towards its center with the velocity of light or near the velocity of light, if the radius of the star for some reason is less than the critical gravitational radius for the phenomenon of collapse. Principally, however, a collapsing superstar cannot be observed: it closes not only matter inside its volume (with a radius equal to the gravitational radius), but also radiation. It can be produced, but the material inside such a sphere must undergo a degree of compression such that the gravitational radius for the Sun (or a body possessing its mass) equals 1 km, and for the Earth, 1 cm. The concept of gravitational radius (sometimes it is called the Schwarzschild radius) was introduced by the German astronomer Karl Schwarzschild (1873-1916), and had made significant theoretical enrichments in different areas of stellar astronomy and astrophysics, in particular, those which led to the theory of radiative equilibrium in stellar atmospheres and which advanced

When in 1954 a department of radio astronomy was organized at Pulkovo Observatory,¹¹ already over 20 observatories and institutions on the terrestrial globe (of which 4 participants were from the USSR) had been producing radio astronomical observations. S. E. Khaikin (1901-1968), a well-known specialist in the areas of mechanics and radio physics, created and headed up the new section of the Principal Astronomical Observatory. Since 1968 the talented young scientist I. N. Pariiskii has directed the section. Still, up to the organization of observations at Pulkovo, naturally, a question arose concerning the choice of working wavelengths at the limits of the "window of transparency" for radio waves, which was defined by the characteristics of the terrestrial atmosphere, which lets in radio waves in a range from millimeter to decameter lengths. With this choice was connected another question- concerning the most rational construction

the first theory of the interior structure of the Sun and stars (1905).

¹¹ At the end of 1969 the department of radio astronomy had an influence of the SAO (Special Astrophysical Observatory of the Academy of Sciences of the USSR, Zelenchukskaia village, Northern Caucasus), for the time being remaining at Pulkovo. Only a group of radio astronomers-heliophysicists making up the department of solar physics was retained with the Principal Astronomical Observatory.

of radio telescopes. Almost all observational stations worked then at the most advantageous meter wavelengths. According to a series of considerations for the work at Pulkovo a range of centimeter wavelengths was chosen. It to some degree "pre-determined" the construction of the radio telescope, the original decision for which was made by S. È. KHaïkin and N. L. Kaïdanovskii.

With the erection of the Pulkovo radio telescope it was sought to achieve the maximum possible resolving power (about one minute of arc at the chosen wavelength of 3 cm). The resolution of a radio telescope (reflector), as for an optical telescope, is proportional to the wavelength and inversely proportional to its diameter; given both quantities (the resolving power and the wavelength), the third can be calculated- the size of the reflector.* To construct a bowlshaped steerable telescope (with a diameter on the order of 100 meters) with a high precision parabolic surface (the flexure cannot exceed 0.5 cm over its whole area) was not technically possible. Therefore, the construction of a non-steerable fan-type antenna was chosen, made up of separate flat elements of sheet duraluminum. On the whole they approximate the surface of the shape of a paraboloid with a variable

*For a circular reflector the resolution α (measured in radians) is equal to $1.22 \lambda/D$, where λ and D , respectively, are the wavelength of radiation gathered and diameter of the reflector, both measured in the same units. The larger α is, the "smaller" the resolving power is, i.e., the ability to separate close sources of radiation. (Tr. note)

profile (an antenna of variable profiles- AVP), the profile depending on the altitude of the object (radio source), which is observed on the meridian with its passage through the "directivity diagram" of the radio telescope. The variability of the profile (the change of the parameters of the paraboloid) can be achieved accordingly, calculated beforehand in a stipulated program of observations with the displacement of every element of the antenna. In principle, automation is possible by a computer which makes the calculations and gives the "command" for the corresponding shift.

As far as the horizontal and vertical sizes of the antenna are not equal (the length of the band is nearly 60 times greater than the height), its appearance is like a "knife blade" stood on edge; the horizontal resolution of the radio telescope amounts to $1'$, and the vertical resolution, 1° (for a wavelength of 3 cm). The radio telescope (with a measure of 130 m by the chord, a radius of about 100 m, and a variable focus, depending on the form of the antenna) does not move and is directed to the south. Observations are carried out at the moment of passage of a radio source through the meridian, without tracking after the source. If the object of observation is not a point source, the "knife-like array" cuts it into "vertical strips" (with a width of one minute of arc), the signals from which are registered by the receiving apparatus; the "slice" of the radio source is obtained in right ascension. In such a way it is possible to note (localize in one coordinate) the position of increased radio radiation

in extensive objects, for example, on the disks of the Sun and Moon, the visible diameters of which are about 32'-31'. For complete localization of sources (in both coordinates), observations must be taken in two azimuths. The radio telescope allows observations to be carried out with shifts of 15-20° to the east and west of the meridian.

So arose the large Pulkovo radio telescope (LPR) in 1956, the most powerful radio telescope in the world at centimeter wavelengths. The utilization of it for radio astronomical observations warranted all estimates and hopes which were led by it. After 14 years of the radio telescope's use (with several interruptions in connection with the removal of moving parts of the supports soon after its establishment and reconstruction in 1965-1967 with a change-over to millimeter wavelengths), a series of significant results was obtained; a number of them were mentioned in the previous chapter. The inspirer of almost all of the investigations up to the end of July 1968 was S. É. Khaikin. In 1965, for work in the area of radio astronomy, the Academy of Sciences of the USSR awarded him the A. S. Popov gold medal. Constructional ideas for the LPR were used as the basis of the design of the gigantic reflecting radio telescope at centimeter and decimeter wavelengths, the RATAN-600, the construction of which on the Zelenchukskaja plain, begun in 1967, has already progressed a great deal (I. U. N. Pariiskii and N. L. Kaidanovskii embody the general scientific leadership with this undertaking). A circular fan-shaped antenna (AVP) with a diameter

of 600 meters and semi-automatic control allows observations to be simultaneously carried out in three azimuths with a resolving power three times greater than for the LPR; the use of the whole ring and the tracking after an object of observation over the extent of 4 hours will be possible.

Observations at centimeter wavelengths with a substantial resolving power were made at first. Therefore, it was necessary to have started with an exploitation of the receiving apparatus and all methods of observations, for which a great deal of trouble was taken. Defects of preliminary versions were removed and replaced by new constructions and the working out and subsequent improvement of methods. The whole united collective of the radio astronomy department was constantly required for this.

The LPR was highly effectively used by I. N. Pariiskii and his group for a detailed investigation of "discrete sources" of radio radiation. The substantial resolving power of the LPR since the very beginning of its work allowed the sizes of radio sources and the distribution of the "radio brightness" in them to be determined, and to obtain their coordinates (by means of observations at two azimuths) with the purpose of identifying the radio sources with optical objects. The first significant result was the detection of the galactic nucleus, the intensity of which sharply increases toward the center, the determination of its size and mass being made according to observations at wavelengths of 3, 10, and 30 cm. The double-peaked distribution of the radio radiation in the source Cygnus A was finally estab-

lished, and it revealed the erroneousness of the interpretation of several results regarding this source, which were obtained by means of a radio interferometer.¹² A detailed investigation was carried out on "radio nebulae" which coincided with optical observations of gaseous clouds, such as the Crab Nebula in the constellation of Taurus, the Great Nebula in Orion, and the "Omega" Nebula in the constellation of Sagittarius; distinctive traits were found in the character of the distribution of "radio brightness" for typical gaseous (or gaseous-dusty) nebulae and nebulae which present themselves as supernova remnants (for example, the Crab Nebula). The coordinates of a large number

¹²High resolution can be reached not only with an increase of the size of the telescope (reflector), but also with the help of a radio interferometer- two antennas separated by a known distance and connected to each other with a "high frequency tract," so that the radio signals brought in by both antennas are added up in one receiving apparatus. The directivity diagram of the radio telescope has a "multi-petalled" form. Its "petals" are greater (and also the resolving power), the larger the base of the interferometer is, i.e., the further the antenna are separated. At the present time interferometers are used without connecting tracts. Observations are synchronously registered on magnetic tape and then deciphered by computer and "added up," thanks to the strict synchronization. Here the high precision time service (see p. 134) finds an application with the utilization of atomic standards.

of radio sources of galactic and extragalactic origin were determined. After the reconstruction of the LPR (1967), new measurements were carried out and a high precision morphological catalog of galactic sources of radio radiation was put together.

Observations were made in parallel fashion of linearly-polarized radio radiation of nebulae at wavelengths of 3.2 and 6.3 cm (N. S. Soboleva and others). The polarization of radiation testifies to its non-thermal character; for example, the radiation of the Crab Nebula partly has this character, and the radio source Cygnus A, where a noticeable portion of the radiation is polarized, does also. According to Pulkovo data, about 4.5% of the radio radiation for the Crab Nebula at a wavelength of 3.2 cm is polarized. From observations of both the just-mentioned objects (galactic and extragalactic) it follows that the percentage of polarization increases with the decrease of the wavelength of the radio radiation; therefore, observations at short wavelengths are especially useful. As far back as 1953 I. S. SHklovskii set down the proposition concerning the presence for the Crab Nebula of an intensive magnetic field, which must decelerate electrons and force them to emit synchrotron radiation in the optical and radio-microwave ranges (magnetobrehmstrahlung or the synchrotron effect). The Leningrad astronomer V. A. Dombrovskii confirmed this assumption by detecting the polarized light of the Crab Nebula; radio astronomical results confirm this. Polarizational observations in the millimeter and submillimeter

ranges could become a means of searching for supernova remnants, the outbursts of which were not earlier observed.

Investigations, conditionally called "spectral" investigations, accrued great interest. Observations were also conducted at distinct wavelengths, but in the given case it corresponds to a discrete spectral line of some chemical element or compound. Its choice depends on the purpose of the investigation. For systematic observations at Pulkovo by N. P. Ryzhkov, T. M. Egorova, N. V. Bystrova, and I. V. Gosachinskiĭ, two lines were selected: the lines of neutral hydrogen with a wavelength of 21 cm, and the hydroxyl molecule (OH)- 18 cm. Since the time of the discovery of the 21 cm hydrogen line in 1951, radio astronomers at once realized what a powerful means of investigation they had obtained in the discovery itself, namely the means and not the object, although at first hydrogen was a topic of investigation. Cold, neutral hydrogen is found everywhere in the galaxy; to distinguish what regime of space it belongs to, it is indeed possible according to its velocities, which are observed as a rule by the displacement of spectral lines (in the given case by the 21 cm line). Thus, a map of the distribution of hydrogen was put together, which graphically showed that our galaxy, indeed, presents itself as a spiral system, the arrangement of the spirals (arms) and the direction of motion of hydrogen in them now being known, although in need of being more accurately determined. In passing, it is indeed possible to more accurately determine the map. The fundamental problem of Pulkovo radio astronomers consists

of utilizing the known distribution of hydrogen, in order to obtain accurate information concerning other sources of radio radiation, their arrangement or structure (if the source is extended). In this case interstellar hydrogen is also used as a means of investigation. Its line at a wavelength of 21 cm, considered till now "a mess" because of its irregular contour and the washed-out appearance of its breadth, was shown to be extraordinarily "advantageous" for the investigators. This line presents itself as a whole assemblage of frequencies, which corresponds to hydrogen moving with different velocities observed along the line of sight. Tuning in several frequencies nearby the frequency of 1420 Mhz (wavelength 21 cm) and simultaneously taking information in several channels (in the Pulkovo installation there are 10), radio astronomers "lock through" all of the galaxy's space in the direction of the strips of observation. If an object is encountered along the line of sight which possesses "continuous spectrum" radio radiation, then it gives the line of hydrogen in absorption (hydrogen absorbs if situated between the observer and the radiating object). Looking along such a direction, sections of the "washed-out" line of 21 cm are shown in absorption, concerning which, the corresponding channels of the receiver make it possible to determine in what part of space the "continuous radio radiation" object is situated, i.e., it is possible to estimate the distance to it, and its coordinates are determined with the direction of observation. The substantial resolving power of the LPR allows this to be

done with sufficient accuracy (the resolving power for a wavelength of 21 cm is seven times "worse" than at 3 cm). If the investigated source appears to be double, the "Pulkovo method" allows the determination of whether both sources are physically connected to each other (they are situated in one volume of space), or whether they accidentally lie on top of each other along the line of sight.

In such a way a large number of radio sources was investigated. Of course, the first object of investigation was the galactic nucleus, and in a more recent representation of it as a source possessing strict symmetry relative to the direction toward the galactic center, essential amendments to the representation came to be introduced. At first other observers, in particular, Australian radio astronomers, could not verify the results of the Pulkovo radio astronomers. But the result was also confirmed with the observation of the hydroxyl molecule lines at 18 cm at the very same Pulkovo installation. The hydroxyl molecule, like neutral hydrogen, is also used in the capacity of a means of investigation, but its distribution in space has still hardly been studied, and therefore, it presents itself, except for what was just mentioned, as an object of investigation. According to Pulkovo data, clouds of hydroxyl molecules possess different motions in space and do not match those of hydrogen. Most likely, this is not accidental: hydroxyl molecules are very energetic oxidizers; they "readily" enter into reaction with almost any chemical element (in combination

with hydrogen they make water). In other words, the hydroxyl molecule is the "building material" in the galaxy. But from whence it comes and into the creation of what it goes, is not well known at present; not without reason, it has been called "mysterium."¹³ Attempts to unravel the mysteries of cosmic hydroxyl clouds, and at least find some approximate answers to the questions, continue at Pulkovo.

Another direction of spectral (radio astronomical) investigations consists of the detection of new lines of monochromatic radio radiation. In 1958 N. S. Kardashev (GAISH) calculated the "energetic transitions" of a series of radio lines of excited hydrogen and indicated the possibility of their being observed. In 1963 the ^{Principal} Astronomical ^{Observatory} colleagues A. F. and Z. V. Dravskikh detected one of those lines with a wavelength of 5.1 cm in the radio radiation of the "Omega" and Orion Nebulas. Some time later R. L. Sorochenko and E. V. Borodich (FIAN, Moscow) observed one more line of the same series with a wavelength of 3.4 cm. The report of both of these discoveries at the IAU conference in Hamburg (1964) was met with great approval. All five authors were honored with a diploma for the discovery, registered in 1966 by the Committee for

¹³There are now many such "mysteriums." Except for OH, a variety of "building materials" has been observed by radio astronomical methods in interstellar space: water, formaldehyde, several alcohols, etc.

Business of Inventions and Discoveries of the Council of Ministers of the USSR.

A "quasars service" was systematically put into operation with the help of the LPR, which was conducted on an international scale for the study of their radio variability. In 1963 optical variability was shown on old photographic plates by two Moscow astronomers (A. S. $\widehat{\text{S}}\text{Harov}$ and $\widehat{\text{I}}\text{U. N. Efremov}$), and simultaneously by two American astronomers (H. Smith and D. Hoffleit), soon after the discovery of the red shift of the lines in the spectrum of the quasar 3C 273 by M. Schmidt. The displacement of the spectral lines toward the red end (if it is to be interpreted as Doppler-like) indicates the recession of the source. The size of the displacement (the velocity of recession) testifies to the enormous distance to a quasar. From the apparent stellar magnitude and the known distance, the absolute stellar magnitude (luminosity) can be calculated, on the basis of which it can be concluded that a quasar radiates 100 times more energy in the optical part of the spectrum than our whole galaxy. On the other hand, the variability of its brightness indicates that this is a single body, and not a conglomerate. The explanation of the variability of quasars with the periodical and coordinated outbursts of a hundred supernovae was rejected. From the period of variability (from several days to one year) it follows that the diameter of a typical quasar does not exceed 1 light-year. The sizes, indeed, are small for a body with 100 billion solar masses. These sizes

are confirmed by measurements at the time of occultations of a quasar by the Moon and in the features of radiointerferometric measurements: the diameters of quasars seem to be significantly smaller than the visible sizes of the most distant galaxies.

Till 1967 the radio variability of quasars remained in doubt: the periods, not observed with certainty, did not coincide with those detected optically on photographs. At Pulkovo N. M. Lipovka obtained a most prolonged series of radio observations of the quasar 3C 273. A 10-day period of radio variability was found for it, although the radio observations of the variability were more complicated than the optical observations because of obstacles which arise in the cosmos itself, in interplanetary and interstellar space. Confident series of radio observations of quasars could be obtained on the basis of international cooperation. "Closely spaced series" of observations are necessary for the revealing of short period variations. Observations of several quasars are conducted at Pulkovo at a wavelength of 6 cm (1963-1967) and at 4 cm (since 1967); at times they were taken every day with each passage of the quasar through the meridian. The joint study of the variability of quasars with radio astronomical and optical methods probably sheds light on their nature.

Finally, let us take one more look at radio observations which are important for cosmology. Lately at Pulkovo attempts have been made to discover fluctuations in the background radiation. As mentioned earlier (see p. 181), the discovery of the

background thermal radiation was taken as indisputable evidence in favor of a non-stationary model of the universe, which was hot in the past. Indeed, if the universe was formed as a result of a big bang, with which the temperature reached billions of degrees, then with the expansion it must have cooled down. The remainder of the radiation which is observed in the present epoch at different wavelengths of the radio spectrum leads to a single background temperature of about 3° K (3 degrees above absolute zero), i.e., this is not some kind of special radio radiation and is precisely thermal radiation. In the optical range of the spectrum the radiation has such a low temperature that it cannot be observed at all- another advantage of radio astronomy. Probably, the background registered by radio telescopes brings us information from the most ancient period of the universe (Metagalaxy), during which the formation of quasars and galaxies began. But is this background continuous? Is it impossible to pick out separate fluctuations, "clumps of energy," from it? Galileo also roughly viewed the mysterious Milky Way, layed out in stellar clouds and separate stars with the only difference being that he "did not look" so far into the past universe. In other words, is it impossible to observe that which came before galaxies and quasars- protogalaxies and protoquasars?

Having asked such questions, Pulkovo radio astronomers obtained a negative answer. With great precision it was possible to show that the background has a structureless character. Apparently, between us and our most distant past, is situated a

"continuous fog" in the form of an "electron gas undergoing Thomson scattering." Such was the result of the observations and its unexpected interpretation.

CONCLUSION

We return to our life.

Arriving at Pulkovo Observatory with a tour or alone, the conglomeration of towers is astonishing, the fantastic outlines of the domes, like the originals, used with some fantasy, as in abstract art, although this is no abstraction and no fantasy, rather, an expedient realization of concrete projects with strictly scientific objectives. The strikingly flat metallic "semi-circular fence" - the fan-like antenna of the Pulkovo radiotelescope with multiply repeating tuning mechanisms on the back side - attracts one's attention. And nearby are the bowl-shaped metal-constructions of radiotelescopes of different sizes with retina or continuous reflecting surfaces. Almost all the structures are original, every one of interest.

At Pulkovo there are architectural and historical monuments. Already at the entrance at the foot of Pulkovo hill one's attention turns to a stone arbor-fountain (architect Thomas deThomon, 1809) standing to the right of the highway. This is one of three remaining ponds, some time ago standing on the Saint Petersburg-TSarskoe Selo road (two of the others were transferred to the city limits). On the ascent of the Kiev highway one meets another architectural structure - an ancient grotto, made in 1807 according to a project of A. N. Voronikhin from Gatchina limestone.

In the Circular Reception Hall of Pulkovo Observatory there is a portrait gallery of distinguished astronomers of the XVIII-

XX centuries. A portion of the portraits is situated in the reading gallery of the science library. A collection of pictures (about 50) fills up the extent of the whole history of the participants. In the majority of them the portraits, painted in oils, are originals and were executed by well known masters or present themselves as good copies of the originals. Among them are two portraits of Wilhelm von Struve: one in the library, made from a photograph of 1864 by N. L. Tiutriumov, the other, the work of the notable Danish portraitist Christian-Albrecht Jenser. Several copies from portraits of foreign astronomers, located in the Circular Reception Hall, came from his brush. There are portraits of: A. P. Briullov (original?), in a rendition of his brother K. P. Briullov; Otto Struve, and A. N. Savich (originals)- works of the distinguished Russian painter I. N. Kramskoi; O. A. Baklund, in a rendition of another artist-copyist, N. P. Bogdanov-Belskii; H. Gylden, the work of the great Swedish artist O. Björck; D. Gill, in the original impressionist brush style of El'za Baklund, oldest daughter of O. A. Baklund, a well known artist, especially in the period of her life in Sweden since 1916; B. P. Gerasimovich, made in 1957 by the Leningrad artist N. G. Lopakin; and many others.

In the very same Circular Reception Hall (the form of the circle has only a stone floor in the interior part of the hall, separated by massive columns from the exterior part in the form of an octahedron, where, in essence, exhibits take place) a photographic show was placed, which was devoted to the history and scientific activity of Pulkovo Observatory and its branches,

and also there is situated the museum of astronomical observational equipment, various clocks, demonstrating the development of measurement of the "custody of time," visual receivers and laboratory apparatus, several manuscripts and a few books, periodically having been presented for review. Having existed until the war, the museum of old instruments was entirely destroyed; the present day collection was created anew in 1965. In the central part of the hall, on the Pulkovo meridian, in 1964, at the one hundredth anniversary of the death of Wilhelm von Struve, was placed his marble bust, in a rendition of the Leningrad sculptor A. Teplov.

Outside the premises, in the niches of the northern facade of the main building of the observatory, are established the sculptures of the most notable astronomers who destroyed geocentrism and who gave expression to the development of modern representations of the cosmos- Nicolaus Copernicus and Galileo Galilei (the sculptors were L. Iŭ. Ėidlin and L. N. Barbash). Opposite to the entrance in the small building of the seismological station, having an attractive view of the metropolitan dachas or private summer homes, in the neighborhood of the painted Petrov stone mound, on a pedestal of red granite, towers a bronze bust of the founder of the station, the academician Grand Duke B. B. Golitsyn (sculptor N. Kochutov, 1955).

To the northeast of the main building, on a steep slope of the hill, is situated a memorial cemetery of astronomers. Here is buried the founder of the observatory Friedrich Georg

Wilhelm Struve, next to him his wife Johanna Franciska Struve-Bartels¹ (1807-1867), O. A. Baklund, A. A. Belopol'skii, S. K. Kostinskii, G. N. Neuimin, S. I. Beliaevskii and many workers

Pulkovo, whose memory and business science and the history Pulkovo Observatory preserves.

On the northern slope of the hill, since the time of the last war, a military cemetery with communal graves was formed, on which those who perished were enumerated and with nameless graves, which also are reverently protected. A large communal grave of the guardsmen is situated on the Pulkovo meridian, on the summit of the hill, in front of ^{the} a facade of the main building of the observatory. On the cemetery lawn is a modest monument of grey granite with a marble slab and the laconic inscription, carved in gold: "Eternal memory to the heroes-guardsmen having perished in defense of the city of Lenin. January- 1944."

That unforgettable January cost so many lives! Sacrifices were made but not in vain: drawing here, the enemy found then only its destruction, as they found it on other fields of battle in the war which undid them. Yearly, thousands of people from

¹This was the second wife of W. Struve. His first wife, Emily Wall (1796-1834), died in Dorpat, having left after her eight children. The necessity to bring them up was left to the second marriage. Of the second wife of W. Struve his son Otto Struve spoke not only concerning the suitable choice of his father, but about the mother dear to all the children.

different corners of the country visit Leningrad and Pulkovo, in order to see the place of the bloody battles and to bow their heads for the bravery and those who perished with courage and did not prevail.

Traces of the last battles are preserved to the south of the observatory in the appearance of an anti-tank ditch, having eroded in places, passing over the Kiev highway to the large radio telescope through orchards and gardens now occupying this territory, some time ago having been named the "line of defense." On both sides of the highway, which crosses the Pulkovo River, stand two rectilinear form structures of solid concrete, with the deeply embedded figures "1941-1944." The stone massifs one and a half kilometers from the south gates of the observatory designate the one-time boundary of the front, having stabilized after 28 months. Within three hundred meters of the very gates, on the left side of the road, a grandiose monument was built in 1967, in the form of a mural with mosaic designs, portraying the heroic victory of the Leningrad troops in the Great Patriotic War. The project of the monument was worked out at the Leningrad Higher Artistic-Industrial Academy by V. I. Mukhina, under the leadership of its rector I. A. N. Lukin.

And an even more sublime monument to the heroes-defenders of Leningrad is Pulkovo Observatory itself, restored at the fork in the road and prospering to the glory of Russian science and to the glory of the heroic city and its Motherland.

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DIRECTORS OF PULKOVO OBSERVATORY

Friedrich Georg Wilhelm von Struve (1793-1864)	1839-1861
Otto Wilhelm Struve (1819-1905)	1862-1889
Fedor Aleksandrovich Bredikhin (1831-1904)	1890-1895
Oskar Andreevich (Jöns Oskar) Backlund (1846-1916)	1895-1916
Aristarkh Apollonovich Beloev'skiĭ (1854-1934)	1916-1919
Aleksandr Aleksandrovich Ivanov (1867-1939)	1919-1931
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