NASA SP-91

Significant Achievements in

Space Astronomy

1958-1964

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Foreword

THIS VOLUME IS ONE OF A SERIES which summarize the progress made during the period 1958 through 1964 in discipline areas covered by the Space Science and Applications Program of the United States. In this way, the contribution made by the National Aeronautics and Space Administration is highlighted against the background of overall progress in each discipline. Succeeding issues will document the results from later years.

The initial issue of this series appears in 10 volumes (NASA Special Publications 91 to 100) which describe the achievements in the following areas: Astronomy, Bioscience, Communications and Navigation, Geodesy, Ionospheres and Radio Physics, Meteorology, Particles and Fields, Planetary Atmospheres, Planetology, and Solar Physics.

Although we do not here attempt to name those who have contributed to our program during these first 6 years, both in the experimental and theoretical research and in the analysis, compilation, and reporting of results, nevertheless we wish to acknowledge all the contributions to a very fruitful program in which this country may take justifiable pride.

HOMER E. NEWELL
Associate Administrator for
Space Science and Applications, NASA

Preface

STELLAR ASTRONOMY IS DEFINED as including all galactic and extragalactic objects except those normally associated with the solar system (the Sun is excluded from this discipline) and is divided according to methodology into gamma-ray and X-ray astronomy, ultraviolet astronomy, infrared astronomy, and radio (millimeter and kilometer wave) astronomy. Study of stars and galaxies at visual wavelengths would normally be included in this category also; however, no work has been done in this area in space during the period 1958–1964.

In all the fields covered in the astronomy discipline, the 6-year period from 1958 to 1964 has been one of discovery and development of the tools and techniques of space astronomy in contrast to the extensive, detailed observing programs of ground-based astronomy. The use of instruments carried above the Earth's atmosphere has enabled astronomers to study parts of the electromagnetic spectrum which before had been inaccessible to them. Significant consequences to astrophysical theory have already occurred from the new information, resulting in a more accurate knowledge of the evolution of the universe.

Contents

Introduction

ASTRONOMY, THE OLDEST OF THE SCIENCES, probably has more to gain from the use of space technology than any other science. A better understanding of the universe—its birth, history, and future—depends upon answers to the fundamental questions of stellar evolution and galactic structure. To answer these questions fully, a study must be made of information from all parts of the electromagnetic spectrum: gamma rays, X-rays, and ultraviolet, visible, infrared, and radio radiation (fig. 1). Electromagnetic radiation can be characterized by its wavelength, by its frequency, or by the quantum of energy, $h\nu$, which is emitted or absorbed when radiation of a given frequency interacts with matter. Thus a quantum of energy of 1 electron-volt is associated with a wavelength of 1.2396×10^{-4} centimeters or a frequency of 2.4184×10^{14} cycles per second.

Gamma rays and X-rays from celestial objects are completely unobservable from the Earth's surface. The first observations of this part of the electromagnetic spectrum were obtained from rocket flights in 1949 when X-rays emitted by the Sun were detected. Since then, steadily improving rocket methods have been used to map the sky and to search for other discrete sources of X-rays and gamma rays. As of 1964, there were 10 known galactic X-ray sources, which were far brighter than expected on the basis of the intensity of the X-rays emitted by the Sun.

Gamma-ray astronomy has been less fruitful than X-ray astronomy because the sources are weaker and therefore more difficult to detect. Instruments to detect very faint sources of gamma rays were developed, primarily by physicists, during the period from 1948 through 1964. It was concluded from the results of initial experiments that a diffuse gamma-radiation background does exist in the galaxy; however, no discrete sources have been discovered as yet.

The early-type supergiant stars, though less numerous than older stars such as the Sun, are of great importance in cosmological studies because of their youth and association with the hydrogen gas of the galaxy. Since most of their radiation occurs at short wavelengths unobservable from the Earth's surface, it was quite natural that the first rocket work in stellar astronomy was on this part of the spectrum. These studies were at first limited to mapping the sky in the ultraviolet region from 1225 to 1350 Å.

There have been extensive photometric studies of hot stars. The intensity of these stars in the ultraviolet was much lower than had been predicted. Resolution of this discrepancy has led to a revision of the stellar temperature scale.

Balloon observations of celestial objects in the infrared confirmed the few existing ground-based results. The limitations of available instruments restricted the initial efforts to bright objects such as planets. However, by 1964 detector design had so improved that some of the brightest red supergiant stars could be observed: they were found to have water-vapor bands at 1.4 μ and 1.9 μ.

Absorption by oxygen and water vapor in the troposphere sets a high-frequency limit on ground-based radio astronomy. At the low-frequency end, the cutoff is determined by reflection, absorption, and scattering in the ionosphere. Limitations on the size of antennas which could be carried on rockets and satellites have restricted

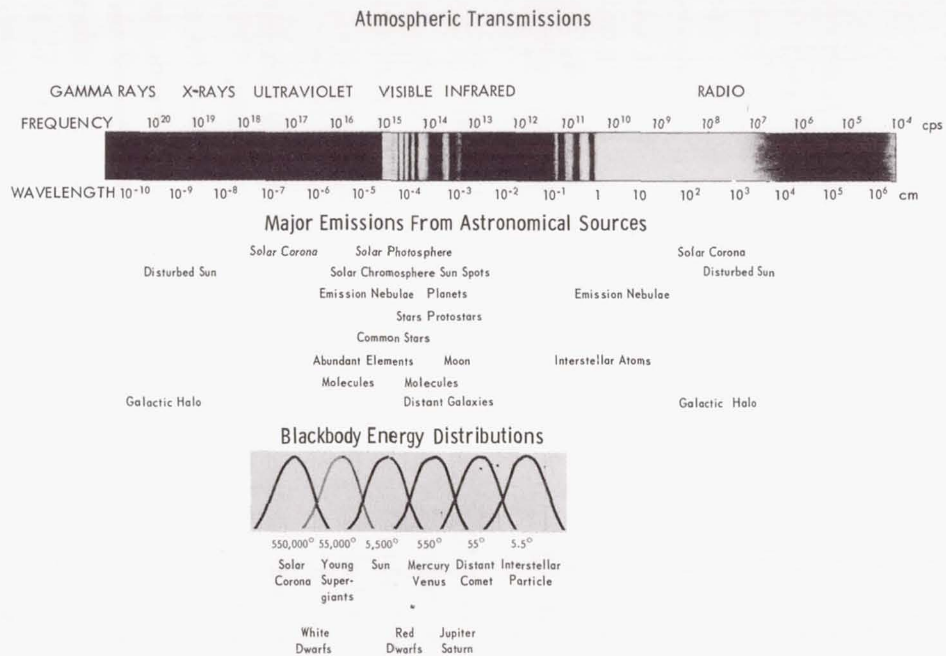

Figure 1.—Atmospheric transmissions, major emissions from astronomical sources, and blackbody energy distributions.

radio observations to coarse resolution. As a result the detected signals are actually composites of those from the galaxy, extragalactic sources, planets, and the Sun. The average cosmic-noise background shows a decrease at long wavelengths as predicted by astrophysicists.

Measurement of radio flux at high frequencies is not possible at present because of the lack of suitable instruments. The first reported low-frequency satellite radio-astronomy measurement was made in 1960 by a Canadian group, who used the Transit 2A satellite to measure the cosmic noise background at 3.8 million cycles per second. Two years later, a University of Michigan group used a Journeyman rocket with a 12.2-meter dipole antenna to determine the mean cosmic background at 0.75, 1.225, and 2.0 Mc/sec. A large drop in intensity between 1.225 and 2.0 Mc/sec was interpreted as resulting from absorption by a local concentration of interstellar gas. Cosmic radio emission between 1.5 and 10 Mc/sec was measured by the Alouette I satellite launched in 1962 (fig. 2). At 2.3 Mc/sec, the brightest region of sky appears to be centered on the south galactic pole.

In ultraviolet astronomy, the era of satellite observations is just beginning. A successful flight of the first Orbiting Astronomical Observatory (figs. 3 and 4) is expected to provide basic data necessary to plan future observations, as well as the first ultraviolet spectral energy distributions for a variety of normal and unusual stars and nebulae. Experiments are also being planned which will utilize the X–15 rocket plane to carry ultraviolet cameras (fig. 5). In X-ray astronomy, the major problem is to discover the nature of the X-ray "stars." Within a few years we should be able to locate the brightest ones with sufficient accuracy to permit their identification with photographed objects — an important step in determin-

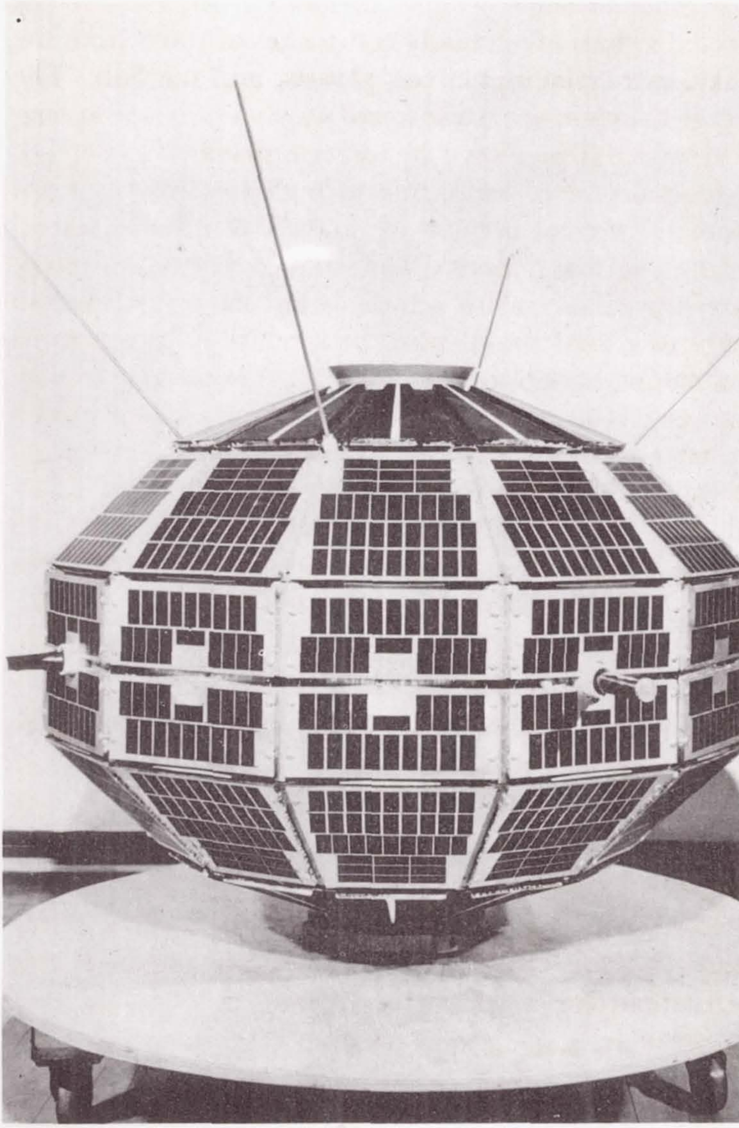

Figure 2.—The United States–Canada satellite Alouette.

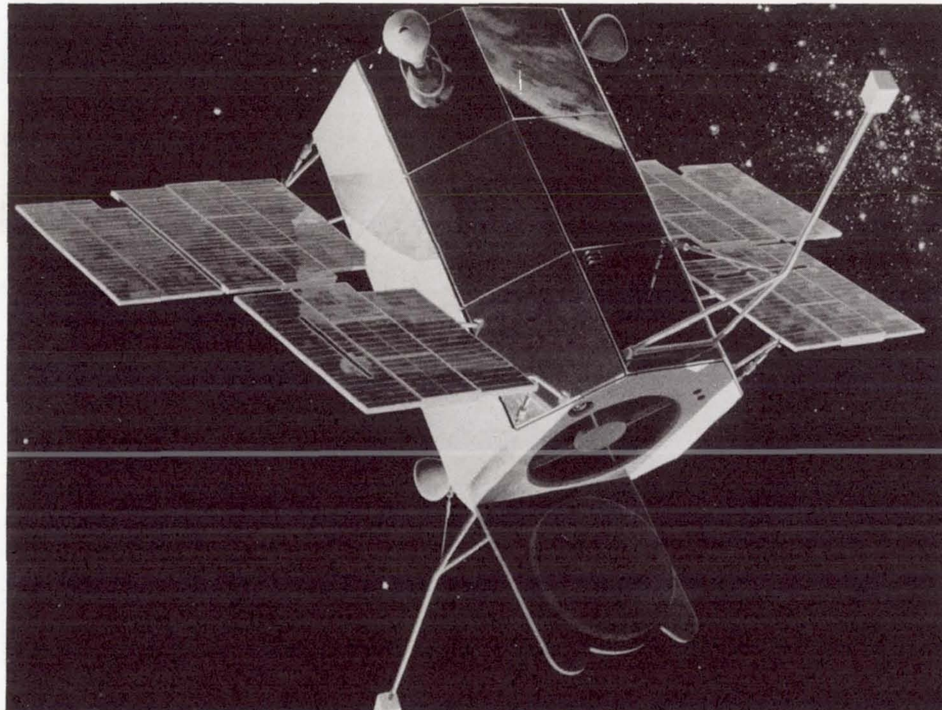

Figure 3.—Artist's drawing of the Orbiting Astronomical Observatory.

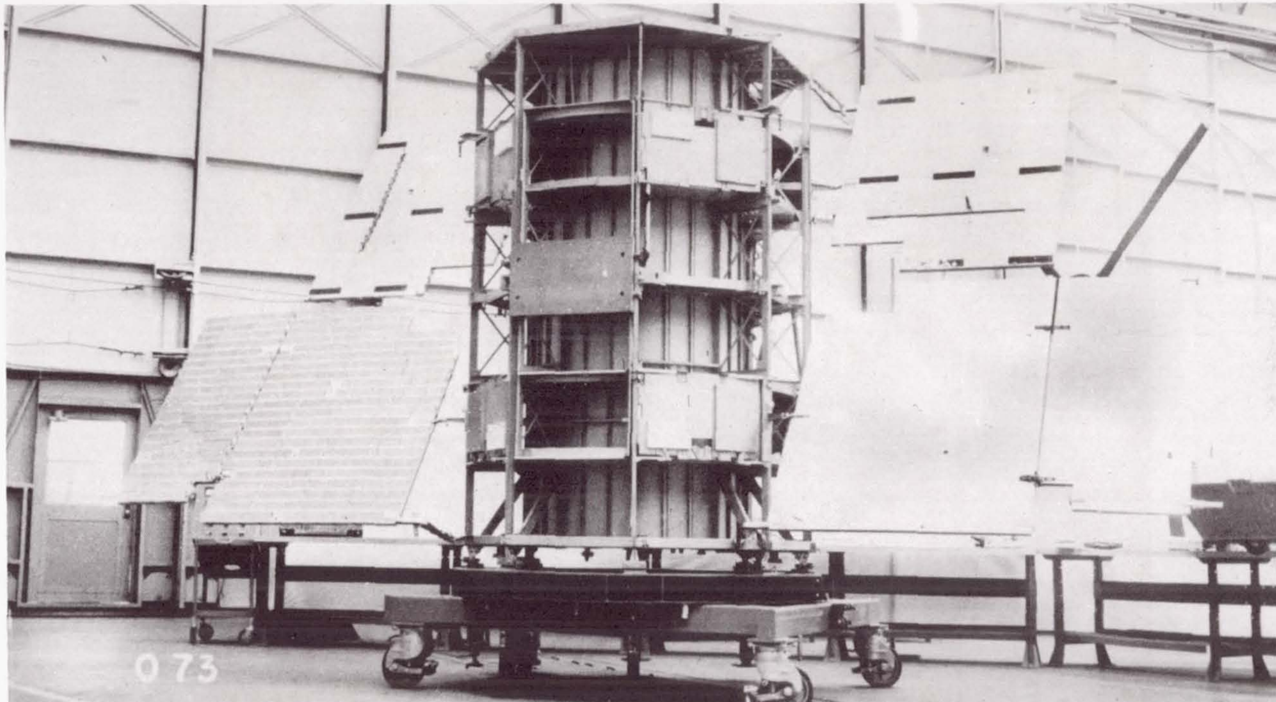

Figure 4.—Inertial model of the Orbiting Astronomical Observatory.

ing their nature. We should soon learn whether gamma-ray stars exist and, if so, what sort of objects they may be.

Current observations indicate that the brightness of the radio sky decreases at the longest observable wavelengths. An interpretation of this decrease must await at least the minimal resolution which the Radio Astronomy Explorer (figs. 6 and 7) will provide in 1967. The use of ionospheric focusing to provide this resolution will be investigated during 1965 with a receiver on the Polar Orbiting Geophysical Observatory.

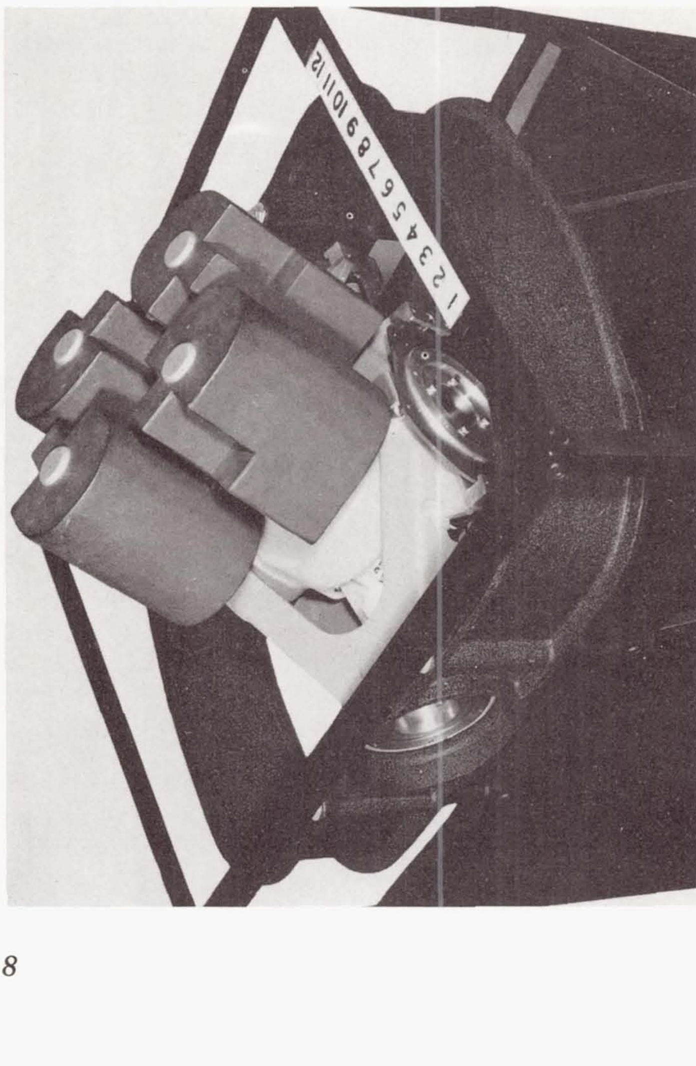

Figure 5.—Mockup of stellar cameras on inertial platform for X–15 experiment.

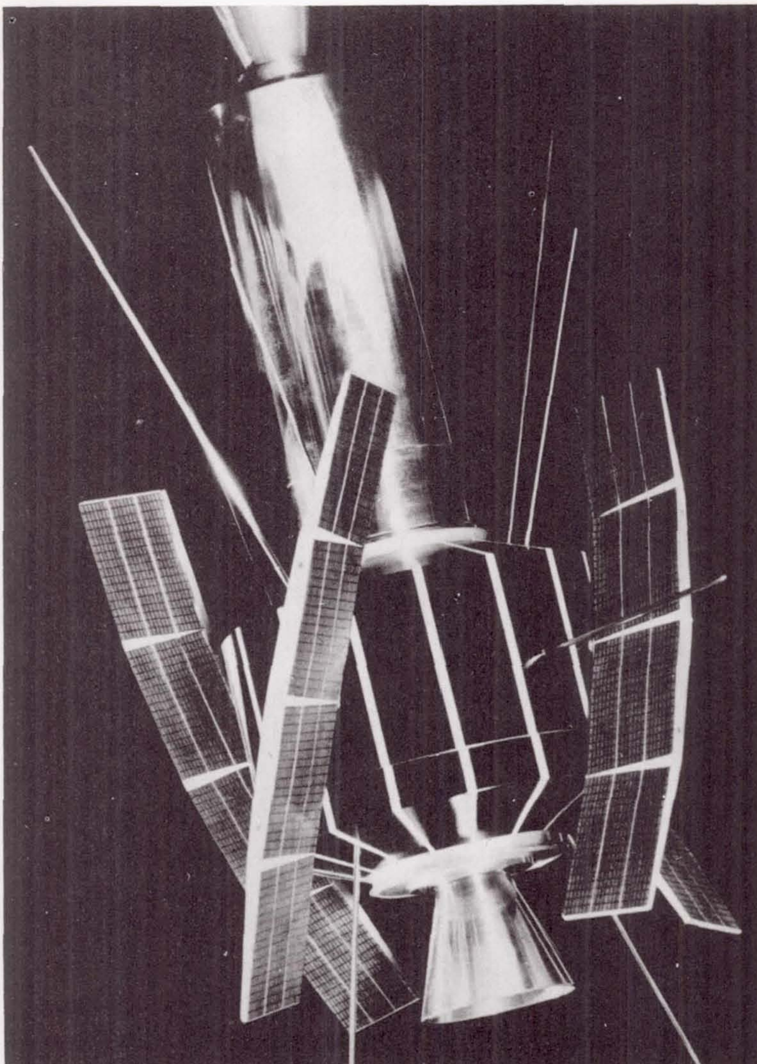

Figure 6.—Model of the Radio Astronomy Explorer.

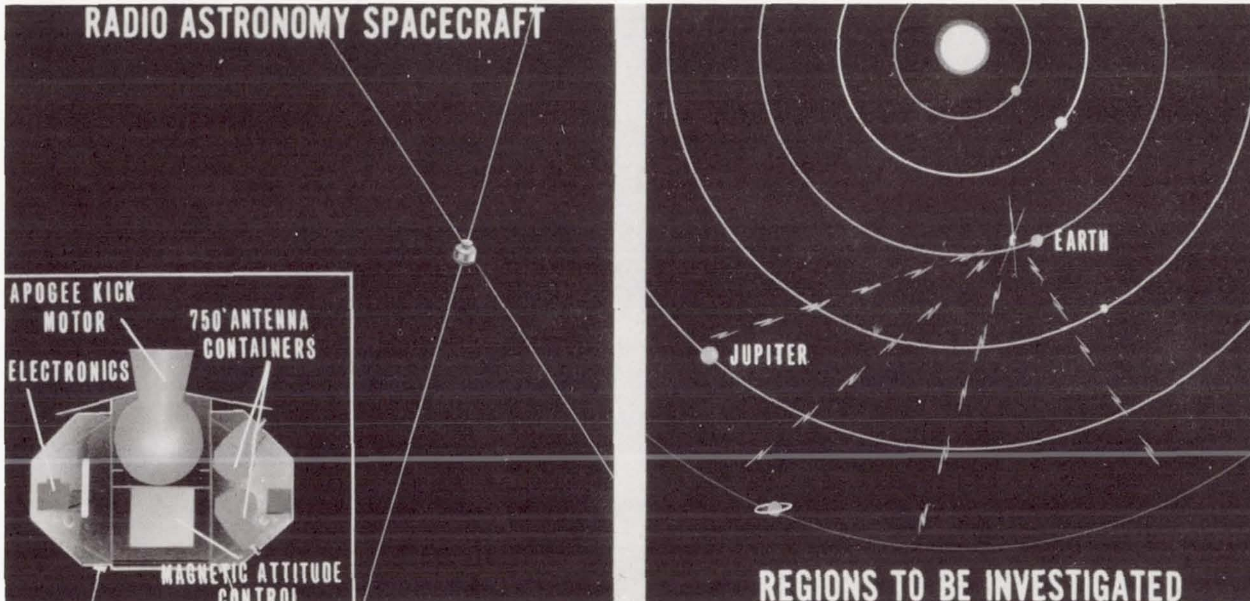

Figure 7.—Characteristics of Radio Astronomy Explorer planned for launch in 1967. The launch vehicle will be a thrust-augmented, improved Delta. The spacecraft will attain a 3700-mile circular orbit with a 50° inclination and will be gravity stabilized. Planned to carry five experiments, the spacecraft is to have a gross weight of 285 pounds, an antenna weight of 70 pounds, and a power of 22 watts.

X-RAY AND GAMMA-RAY ASTRONOMY

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X-Ray and Gamma-Ray Astronomy

X-RAY ASTRONOMY

Introduction

THE PRESENCE of large amounts of neutral hydrogen in space will prevent stellar ultraviolet astronomy observations at wavelengths shorter than 912 Å. This is the ionization threshold for neutral hydrogen, and more energetic photons will cause ionization of the neutral hydrogen in interstellar space and will be very rapidly absorbed. At still shorter wavelengths, ionization thresholds for heavier atoms will be reached, and hence interstellar space will be very opaque to electromagnetic radiation until wavelengths considerably shorter than 100 Å are reached. According to calculations of Strom and Strom (ref. 1), the interstellar medium becomes reasonably transparent to distances of hundreds of parsecs only for wavelengths shorter than 20 Å. The entire galaxy becomes relatively transparent to X-rays in the wavelength region near 3 Å.

Detection and Identification of X-Ray Sources

The earliest X-ray studies in space were carried out with detectors scanning the Sun. A review of the solar X-ray results has been given by de Jager (ref. 2). The early measurements gave upper limits on the X-ray fluxes in space; Friedman (ref. 3) found an upper limit of 10^{-8} ergs/cm^2/sec/Å for the influx of X-rays from beyond the solar system.

The first X-rays detected from sources outside the solar system were found in an experiment of Giacconi, Gursky, Paolini, and Rossi (ref. 4). They flew a rocket, from the White Sands Missile Range, containing uncollimated, thin-window Geiger counters with some 60 cm^2 of sensitive area. Discrimination against energetic particles was achieved with an anticoincidence scintillator. The windows of the Geiger counters had thicknesses of 1.7 and 7 milligrams per centimeter squared. Their transmission, together with that of the filling gas, gave a band of sensitivity for X-rays of wavelengths between 2 and 8 Å. This rocket experiment detected a soft X-ray source from a direction near the galactic center. This very intense source was later determined to be in the constellation Scorpio. There was also an indication of a second source in the neighborhood of Cygnus.

Further X-ray measurements were reported in 1963 by Gursky, Giacconi, Paolini, and Rossi (ref. 5). In these flights the Geiger-counter windows were made of beryllium 0.002 inch thick. These counters were supplemented by sodium iodide and anthracene scintillation counters which were intended to measure the more energetic X-rays and any electrons which might be present. The flights confirmed the presence of the source in Scorpio, reinforced the evidence for a source in Cygnus, and suggested the presence of the third source in the general direction of the Crab Nebula.

Further evidence of celestial X-rays was given by Fisher and Meyerott (ref. 6). Their analysis suggested that a multitude of X-ray sources is present in the sky, but these sources are not statistically well established (refs. 7 and 8).

Meanwhile, Bowyer, Byram, Chubb, and Friedman flew an instrumented rocket in April 1963 which carried proportional counters containing 65 cm^2 of sensitive area having a field of view of 10° at half-maximum sensitivity (refs.

9 and 10). These counters had beryllium windows 0.005 inch thick, and were sensitive to X-rays from 1.5 to 8 Å. The source in Scorpio was confirmed and its position located at RA 16^h15^m, decl $-15°$, the uncertainty in the position was stated to be about 2°, and the angular diameter was less than 5°. This flight also located a source in the direction of the Crab Nebula with a strength only one-eighth as great as that of the Scorpio source.

An extremely important advance was made by Bowyer, Byram, Chubb and Friedman (ref. 11) on July 7, 1964, when they launched a stabilized Aerobee rocket (fig. 8) guided to point Geiger counters with 114-cm^2 area at the Moon during the critical 5-minute phase in which the Moon was occulting the central portion of the Crab Nebula (fig. 9). There were two counters having Mylar windows, coated with 60 Å of Nichrome, one 0.001 inch thick and the other 0.00025 inch thick. The difference in counting rates between the counters was expected to indicate something about the spectral distribution of the X-rays in the low energy range. Both counters recorded essentially the same number of counts, which led Bowyer et al. to conclude that the X-rays from the Crab Nebula were concentrated below 5 Å. However, Friedman reported at the Symposium on Relativistic Astrophysics held at Austin, Tex., in December 1964 that it had rained on the day of the flight until nearly flight time and the moisture had apparently degraded the performance of the lower energy counter sufficiently to distort the results. Consequently, the data obtained from the July 1964 flight are open to question. This flight gave the very important result that the angular width of the X-ray source in the Crab Nebula was about 1 minute of arc. This indicated a diameter of about 1 light-year.

In August 1964, Giacconi et al. (ref. 12) flew another rocket carrying a number of different counters. This flight

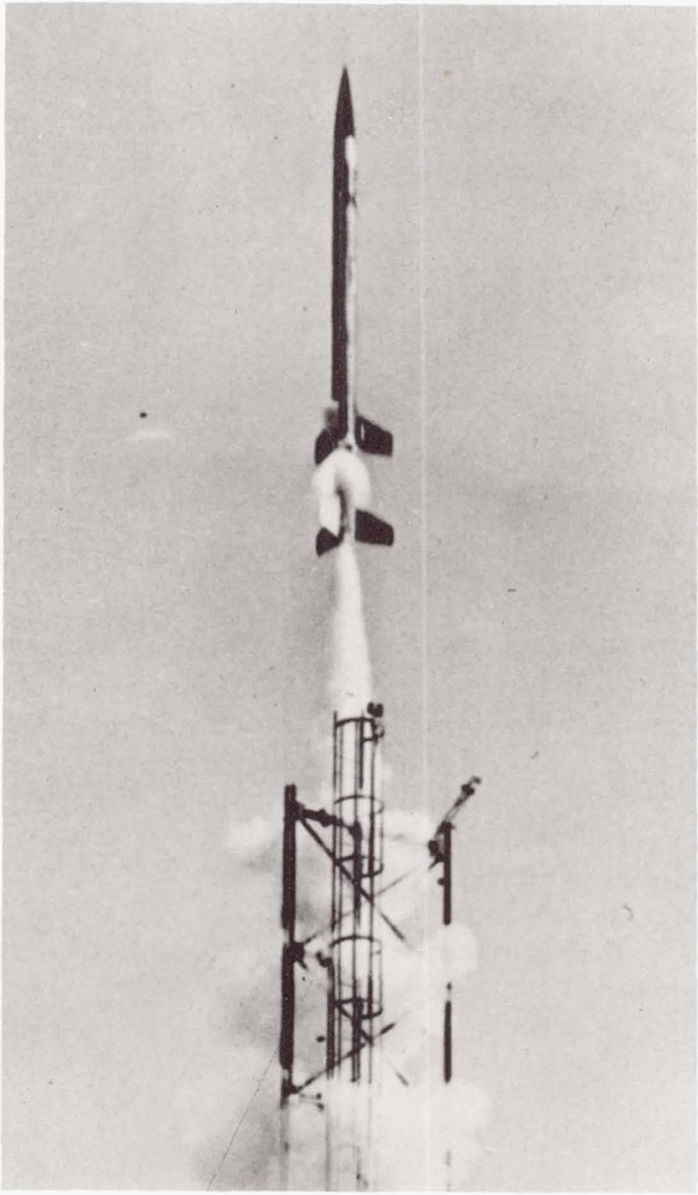

Figure 8.—Launch of an Aerobee 150 rocket.

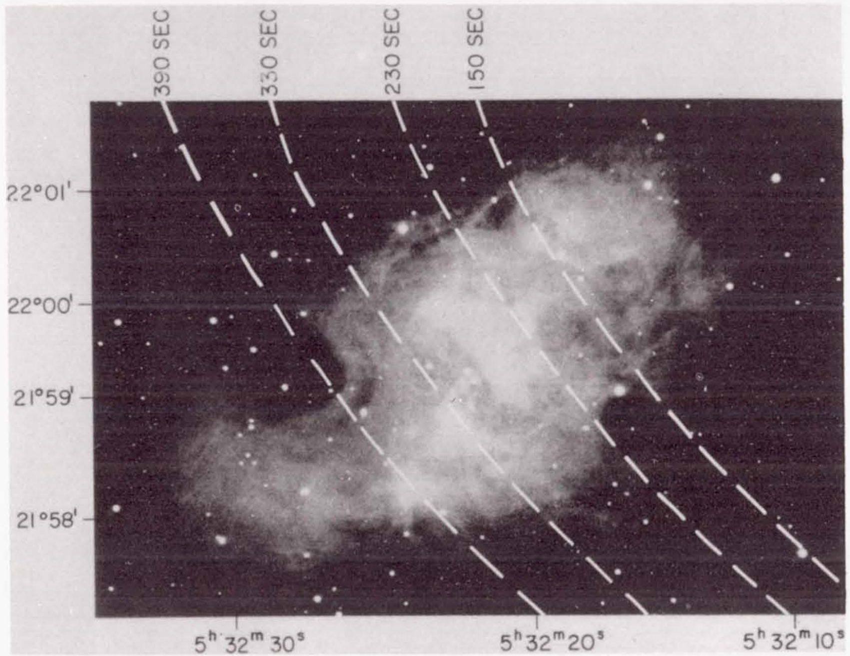

Figure 9.—Progress of the occultation of the Crab Nebula measured in seconds of time after launch of the rocket from White Sands Missile Range. The dashed curves represent the postions of the edge of the Moon. A maximum rate of decrease in X-ray flux was observed at about 230 seconds.

indicated a source in Sagittarius, in addition to the well-determined Scorpio source.

In February 1965, Oda, Clark, Garmire, Wada, Giacconi, Gursky, and Waters (ref. 13) reported some important data on the angular sizes of the X-ray sources in Scorpio and Sagittarius. They used an ingenious X-ray collimation system consisting of two grids of parallel wires. These wires were separated by slightly less than one wire diameter. The two grids were mounted one behind the other 1.5 inches apart. As the collimator scans across a point source, the shadow of the front set of wires will fall alternately on the back wires and on the intervals between the back wires. Hence a point source gives a modulated signal, whereas an extended source gives a more nearly continuous signal.

Oda et al. concluded that the Scorpio source extended in a direction approximately parallel to the galactic plane definitely less than 30 minutes of arc and probably less than 8 minutes of arc. They were also able to conclude that the Scorpio source did not extend more than 1° perpendicular to the galactic plane. They further concluded that the Sagittarius source was either extended in space or consisted of more than one point source. The X-ray source is spread over a region more than 30 minutes of arc in diameter.

The number of known X-ray sources was considerably extended as a result of two flights of Bowyer, Byram, Chubb, and Friedman (ref. 14), one on June 16, 1964, and the other on November 25, 1964. Geiger counters were mounted facing outward through the skin of an unguided Aerobee rocket. Aluminum-honeycomb collimators were used, limiting the field of view to 8.4° at half-maximum transmission. The rolling and precession of the rocket caused Geiger counters to scan a large portion of the sky. The counters were sensitive to X-rays in the range 1 to 15 Å. The effective area for X-ray detection was 906 cm^2.

These flights detected eight new X-ray sources. The positions, designations, and flux intensities of these sources are listed in table 1, taken from Bowyer et al. (ref. 14). It must be emphasized that the shape of the X-ray spectrum is extremely uncertain, as may be seen from the differences between the two methods of listing the flux in table 1. The positions of the sources are shown in the sky map of figure 10, taken from the same paper.

Table 1.—*X-ray sources. Flux is uncorrected for atmospheric absorption. It was measured with a ¼-mil Mylar window. Column A is the flux (10^{-8} erg/cm^2-sec) computed for a blackbody at 2×10^7 °K, 1.5 to 8 Å, and column B is that for a blackbody at 5×10^6 °K, 1.5 to 8 Å.*

[From ref. 14]

Source	1950 Epoch		Flux		
	RA	Declination, deg	Observed, counts/cm^2/sec	A	B
Tau XR–1[1]	$05^h31.5^m$	22.0	2.7	5.5	1.1
Sco XR–1[2]	16^h15^m	−15.2	18.7	38	7.9
Sco XR–2	17^h8^m	−36.4	1.4	2.9	.6
Sco XR–3	17^h23^m	−44.3	1.1	2.3	.5
Oph XR–1[3]	17^h32^m	−20.7	1.3	2.7	.6
Sgr XR–1[4]	17^h55^m	−29.2	1.6	3.3	.7
Sgr XR–2[5]	18^h10^m	−17.1	1.5	3.0	.6
Ser XR–1	18^h45^m	5.3	.7	1.5	.3
Cyg XR–1	19^h53^m	34.6	3.6	7.3	1.5
Cyg XR–2	21^h43^m	38.8	.8	1.7	.4

[1] Within 1′ of optical center of nebula.
[2] Previous measurement 12×10^{-8} erg/cm^2-sec computed as for col. A.
[3] 1.1° from SN1604.
[4] 2.3° from galactic center.
[5] 1.2° from M 17.

The source Taurus XR–1 is associated with the Crab Nebula; the lunar occultation experiment showed that it was within 1 minute of arc of the center of the nebula.

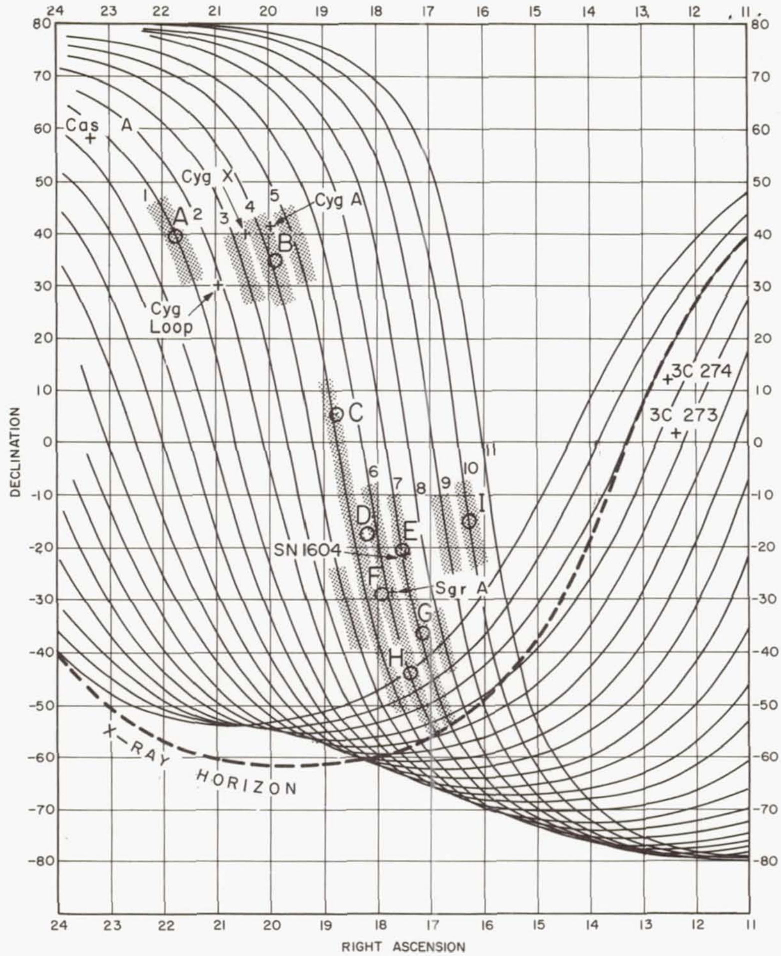

Figure 10.—Map of sky scanned by X-ray detectors in Aerobee flight June 16, 1964. Thin lines trace path of view vector across celestial sphere on successive rolls. Shaded segments indicate portions of scan in which clearly detectable X-ray signals were observed above background. Circles are positions at which discrete sources have been identified.

The source Ophiuchus XR–1 corresponds to the position of the Kepler supernova of 1604 to within 1.5°, which is comparable to the error of observation. However, Bowyer et al. (ref. 14) failed to find an X-ray source corresponding to the position of the Tycho supernova. All the X-ray sources lie rather close to the galactic plane and within 90° of the galactic center. This suggests that the X-ray sources are galactic rather than extragalactic, and they may be associated in some way with the newer disk population of stars in the galaxy. Type I supernova remnants are similarly associated with disk population stars.

Little information is yet available about the presence of higher energy X-rays from these sources. In July 1964, Clark (ref. 15) flew a balloon carrying an X-ray detector in the form of a scintillation counter with a sodium iodide crystal of 97 cm^2 in area and 1 mm thick. This detector was collimated to provide a field of view of 16° in one direction and 55° in the other. Clark detected X-rays in three energy channels between 15 and 60 keV.

Summary

There have been many explanations of these X-ray sources. Among the suggested source mechanisms we may mention are:

(1) Bremsstrahlung from a hot plasma

(2) The inverse Compton effect in which energetic electrons scatter starlight photons

(3) Synchrotron radiation produced by energetic electrons spiraling in a magnetic field

(4) Thermal emission of a Planck spectrum from the surface of a hot, compact, neutron star.

These mechanisms make different predictions about the spectral shape, angular width, and possible polarization characteristics of the sources. More refined experiments which can be made as X-ray astronomy develops are needed to determine which, if any, of these mechanisms is correct. It has, however, been possible to conclude that intergalactic space is not filled with a very hot plasma such as has been suggested in some cosmological models (ref. 16).

GAMMA-RAY ASTRONOMY

Introduction

Gamma-ray astronomy is intrinsically more difficult than X-ray astronomy, because of the low counting rates involved. The low counting rates require the use of large detectors with large collimation angles. However, the experiments which have been carried out appear to indicate that celestial gamma rays exist and may be detected in space experiments.

Difficulties Involved in Gamma-Ray Detection

Gamma rays of energy near 1 MeV were detected in an experiment on the Ranger III spacecraft by Arnold, Metzger, Anderson, and Van Dilla (ref. 17). Their detector was a 3-inch sodium iodide crystal surrounded by a plastic scintillator. One gamma-ray spectrometer was carried on the end of a boom and one was placed near the spacecraft and the counting rates of the two were compared. The two detectors subtended spacecraft solid angles differing by a factor of 20, but the gamma-ray intensity was greater by a factor of less than 2 near the spacecraft than remote from it, thus demonstrating that the majority of the gamma rays detected in the extended position came from space. Most of the gamma rays detected by Arnold et al. lay near 0.5 MeV, the lower energy limit of their detector. However, they detected no gamma-ray lines which might be attributed to positron annihilation or neutron capture by hydrogen.

Kraushaar and Clark (ref. 18) searched for primary cosmic gamma rays with an energy greater than 50 MeV. Their gamma-ray detector, together with a final rocket stage, constituted the satellite Explorer XI (figs. 11 and 12). The detector consisted of a sandwich crystal scintillator with alternate slabs of cesium iodide and sodium iodide. The solid angle of the detector was about 17° half-

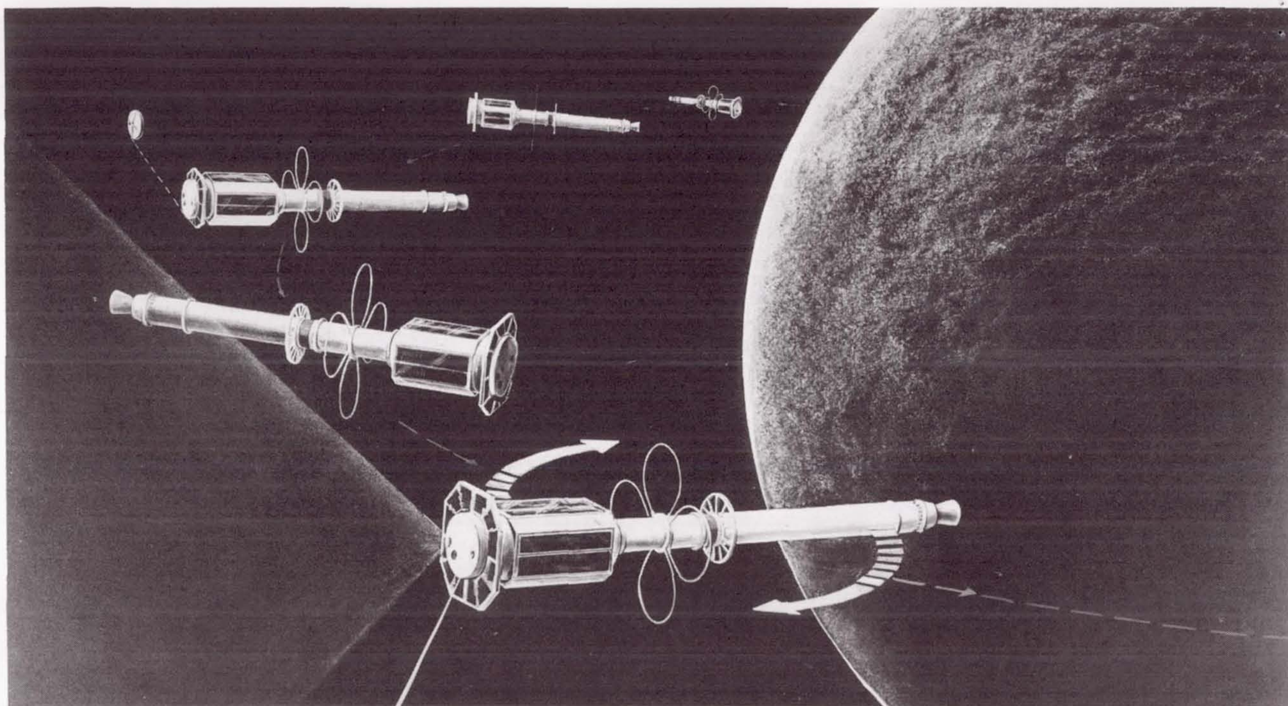

Figure 11.—Artist's drawing of Explorer XI gamma-ray experiment.

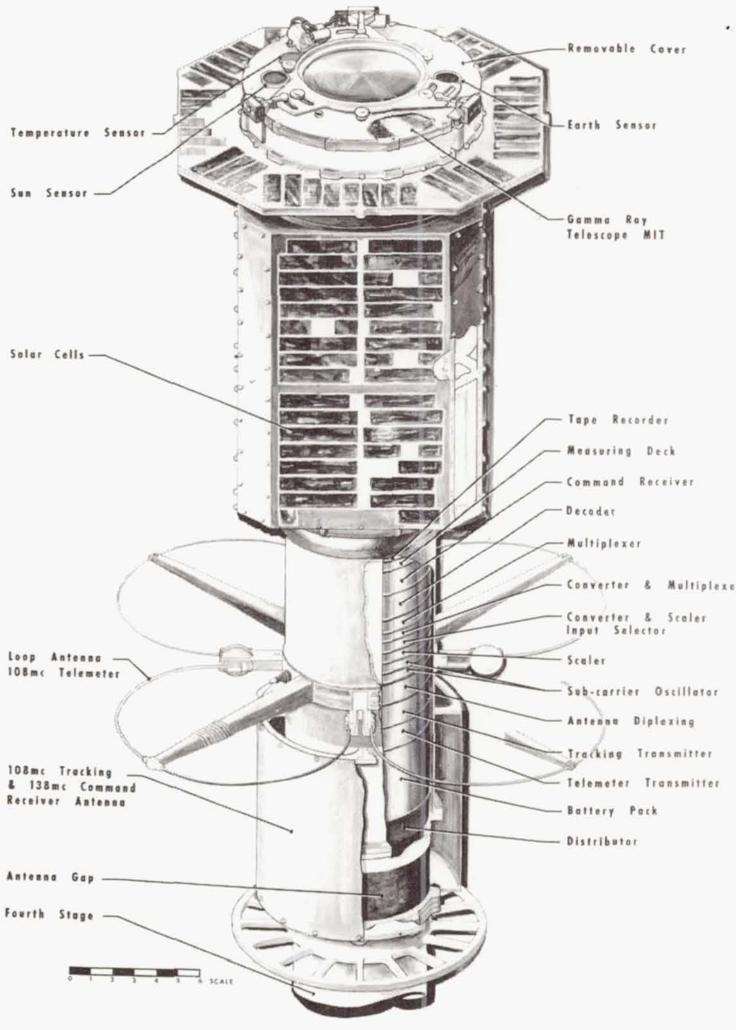

Figure 12.—Cutaway drawing of Explorer XI.

angle. There was a plastic anticoincidence detector surrounding the crystal.

These investigators detected a finite flux of gamma rays in this high-energy region; however, they were uncertain of the background flux and decided to consider their result only an upper limit to the high-energy gamma-ray flux from space.

A significantly higher flux of high-energy gamma rays was obtained in high-altitude balloon flights by Duthie, Hafner, Kaplon, and Fazio (ref. 19). Their principal detector element was a Cerenkov counter. There is at present no indication of the source of the discrepancies between the data of Kraushaar and Clark and those of Duthie et al.

Summary

These high-energy gamma rays are believed to be produced by the decay of neutral pions produced in collisions of cosmic rays with the interstellar medium. For this reason an early attempt was made to measure them. Felton and Morrison (ref. 20) have suggested that these high-energy gamma rays, as well as the low-energy gamma rays and the X-rays, may be explained by the inverse Compton effect. Because of the uncertainties in the experimental measurements of high-energy gamma-ray fluxes, no positive conclusions can be drawn at present. However, it is possible to draw the negative conclusion that the galaxy contains very little antimatter. This rules out certain types of matter creation in a steady-state universe.

ULTRAVIOLET AND INFRARED ASTRONOMY

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ULTRAVIOLET ASTRONOMY

Introduction

THE 6 YEARS since the founding of NASA have been marked by the development of rocket techniques for mapping the sky in the ultraviolet. The only data that had been obtained previously were from two rockets flown by the Naval Research Laboratory. Results were limited to the wavelength region from 1225 to 1350 Å (refs. 21 and 22). The first experiment, in 1955, was a crude survey with a 20° field of view; the second flight used mechanical collimators to narrow the field of view to 3°. Both indicated that detectable radiation was received from the direction of hot, bright stars.

In the intervening period, most observations have been made from spinning rockets. This technique is inefficient for studying individual sources. It also furnishes the data in a form which is difficult to interpret, thus most publications have followed the flights by 2 years or more. During the past year, a three-axis stellar pointing control has been used for some flights, although no data from these flights have been published to date. Such pointing controls will probably be used for most astronomy rocket flights in the future.

In 1958, the Naval Research Laboratory (NRL) was the only scientific group active in this field. Since then, not only has the Goddard Space Flight Center (GSFC) (NASA) been very active but the University of Wisconsin and Princeton University have flown rockets for ultraviolet astronomy. At least three groups are active in Great Britain and several groups are developing on the European continent.

Ultraviolet Nebulosities

The early flights, in spite of their poor angular resolution, indicated that emission in the wavelength range 1225 to 1350 Å was being received from several extended areas of the sky. These areas included regions in Orion and in Vela in which many hot stars and H II regions are located and from which strong ultraviolet signals were expected. However, they also included a puzzling strong nebulosity around the high-latitude B star, α Virginis (Spica). The individual stars did not seem to stand out against these nebulosities.

A partially successful rocket flown by Boggess, at GSFC in May 1960, seemed to confirm this result (refs. 23 and 24). Although the rocket rotated much too rapidly for good photometric data or angular resolution to be obtained, the α Virginis source was clearly observed on 58 consecutive scans covering an angle of 9°. On the other hand, a rocket-borne instrument with 1.5° angular resolution flown by the NRL group late in 1959 (ref. 25) showed sources of about the same maximum intensity as were observed earlier, but in the Orion region, showed no indication of angular extension.

To reconcile these results, Friedman suggested that temperature effects had modified the short-wave limit of the calcium fluoride optics (which were known to be temperature sensitive) to such an extent that Lyman-α was being received by the detector on the early flight. This led to the problem of explaining why Lyman-α formed such a bright halo around a star like Spica.

The early observations are not understood, but these extended nebulosities have never been observed since. Chubb and Byram (ref. 26) suggest that the original observation may have been of a patchy, upper atmosphere airglow; however, the contributing molecule is not obvious. It probably suffices to say that the α Virginis region was scanned with a detector identical to that used on the 1957 flight by Byram, Chubb, and Friedman (NRL) in April 1963 (ref. 27). The star appeared as a point source and an upper limit of one-tenth the value previously reported was placed on the intensity of the diffuse glow. Another telescope-photometer combination sensitive to the region from 1050 to 1350 Å also showed Spica as a point source and eliminated changes in filter transmission as an explanation of the earlier results.

Stellar Photometry

Observations of stars in the ultraviolet have been made by two techniques: broadband photometry and low-resolution spectrophotometry. In the first technique, filter and detector cutoffs are used to isolate bands 100 to 200 Å in width; in the spectrophotometric experiments, a grating is used to disperse the light and the extent of the spectrum is cleanly limited by a slit. The spectrophotometers flown to date have had bandwidths (or resolutions) of either 50 Å or 100 Å.

Most of the observations of stars in the ultraviolet have been photometric. Chubb and Byram published data for about 50 stars observed near 1427 Å (1350 to 1550 Å) and about 80 stars observed near 1314 Å (1290 to 1350 Å) on 2 flights in 1960. Each rocket carried a set of 4-inch and 6-inch paraboloidal mirrors which focused the radiation on a gas-gain ionization chamber with a view angle of about 2½°. The systems were calibrated before flight with an estimated absolute uncertainty of less than a factor of 2. Most of the stars fall below the brightness pre-

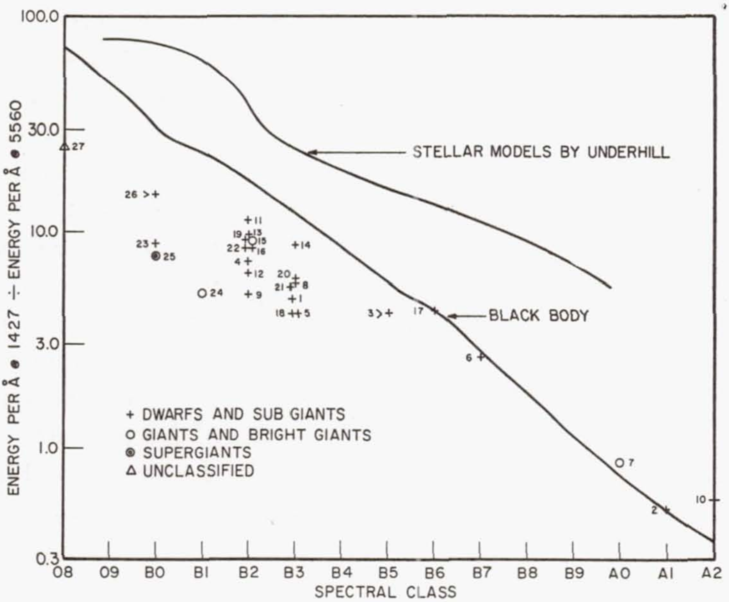

Figure 13.—A plot of the ratio of the ultraviolet brightness of stars observed at 1427 Å to their visible brightness at 5560 Å as a function of spectral type. The numbers adjacent to each data point permit identification of the stars corresponding to individual data points. Also shown are curves describing the ultraviolet-visible brightness ratios predicted by stellar atmospheric theory and by blackbody approximations to stellar spectral emission.

Plot no.	Star	Spectral type	Plot no.	Star	Spectral type
1	45 ε Cas	B3 IVp	15	σ Lup	B2 IV
2	66 α Gem A	A1 V	16	α Lup	B2 II
3	π Cen	B5 V	17	o Lup	B6 V
4	o Cen	B2 Ve	18	π Lup	B3 V
5	ρ Cen	B3 V	19	δ Lup	B2 IV
6	5κ Dra	B7 V	20	d Lup	B3 IV
7	γ Cen	A0 III	21	τ Lib	B3 V
8	f Cen	B3 V	22	η Lup	B2 V
9	ξ^2 Cen	B2 IV	23	δ Sco	B0 IV
10	79 ζ U Ma	A2 V	24	σ Sco	B1 III
11	ν Cen	B2 V	25	μ Nor	B0 I_b
12	μ Cen	B2 V:pne	26	τ Sco	B0 V
13	υ^1 Cen	B2 V	27		08ep
14	ι Lup	B3 V			

dicted either from blackbody curves or from stellar models (figs. 13 and 14). However, these are a few stars which appear much brighter than most.

Bogges published (m_{2200}–m_{2600}) colors for 13 well-observed, unreddened stars (ref. 28). The magnitudes were measured with either 60-mm refracting or 150-mm reflecting telescopes. The bandpasses of the 2200 Å and 2600 Å filters were 210 Å and 250 Å, respectively, with the overlapping region of the spectrum subtracted from the intensity measured with the 2200 Å filter. The estimated uncertainties in the measured intensities for the multiply observed stars is less than 20 percent. In general, the correlation of these colors with spectral type is good; 10 of the 13 stars lie within 0.1 magnitude of the mean line.

Heddle has measured stellar radiation at wavelengths near 2000 Å (ref. 29). His data were obtained as part of an experiment to measure the ultraviolet radiation of celestial objects in the Southern Hemispere. The experiment was flown on a Skylark vertical sounding rocket fired from Woomera, Australia. Identification of signals received by 2 scanning photometers was made for 22 stars. The observed ultraviolet flux, when compared with that predicted by stellar model atmospheres, showed that the models overestimated the ultraviolet radiation for early B stars by a factor of approximately 4.

Spectrophotometry

Narrowband photometry was introduced into rocket astronomy by Stecher and Milligan, who flew narrowband photometers on an Aerobee 150A rocket to obtain stellar spectra (fig. 15) in the ultraviolet (ref. 30). Similar instruments were subsequently used to study the reflectivity of Jupiter in the ultraviolet (fig. 16). Stecher and Milligan used four spectrometers (fig. 17), two instruments with

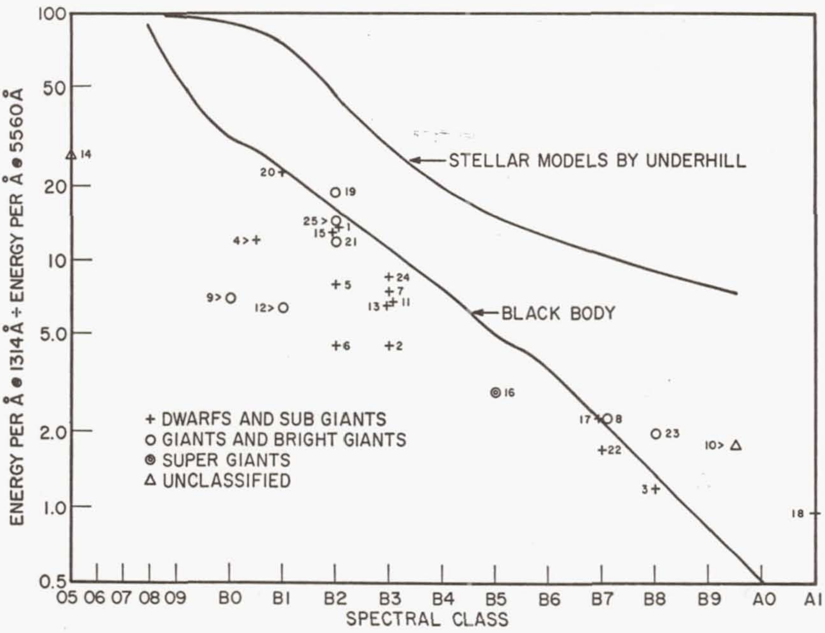

Figure 14.—A plot of the ratio of the ultraviolet brightness of stars observed at 1314 Å to their visible brightness at 5560 Å as a function of spectral type. The numbers adjacent to each data point permit identification of the stars responsible for the individual data points. Also shown are curves describing the ultraviolet-visible brightness ratios predicted by stellar atmospheric theory and by blackbody approximations to stellar spectral emission.

Plot no.	Star	Spectral type	Plot no.	Star	Spectral type
1	17 ζ Cas	B2 V	13	11 β Mon	B3 Ve
2	45 ε Cas	B3 IV:p	14	15 S Mon	Oe 5
3	26 β Per	B8 V	15	13 κ CMa	B2 Ve
4	45 ε Per	B0.5 V	16	31 η CMa	B5 Ia
5	3π^4 Ori	B2 IV	17	3 β CMi	B7 V
6	8π^5 Ori	B2 IV	18	66 α Gem A	A1 V
7	10 η Aur	B3 V	20	o Pup	B1 Ve
8	112 β Tau	B7 III	21	α Pyx	B2 II
9	53 κ Ori	cB0 II	22	32 α Leo	B7 V
10	37 θ Aur	B9.5pv	23	4 γ Crv	B8 III
11	1 ζ CMa	B3 V	24	85 ι Her	B3 V
12	2 β CMa	B1 II	25	8 β Cep	B2 III

a pair of 600-lines/mm gratings for the range 1225 to 3000 Å and two near-ultraviolet instruments with a pair of 500-lines/mm gratings for the range 1700 to 4000 Å. The four spectrometers were mounted in pairs 180° from each other in order to obtain the best sky coverage. One pair had 50-Å resolution, the other had 100-Å resolution. Signals from about 30 O-type and B-type stars were recorded by the two long-wavelength spectrometers, but the short-wavelength instruments were saturated throughout the flight. Every star observed (except α Carinae, spectral type FO Ia) was deficient in flux below 2400 Å compared with that predicted by model atmosphere theory, and by a factor considerably in excess of photometric errors or choice of models. This deficiency in flux could be an intrinsic property of the stars or caused by an absorber in the interstellar medium. The stars have little or no color excess, and so a mechanism that absorbs only at short wavelengths would have to be hypothesized. No such mechanism in the interstellar medium appears suitable, therefore, the observed ultraviolet absorption must be caused by some opacity in the stellar atmospheres.

Ultraviolet Deficiency

The discrepancy between the observed flux and the flux predicted from model atmosphere theory for ultraviolet wavelengths for early-type stars has been the subject of several investigations.

One study by Morton takes into account the effect of absorption lines on the ultraviolet stellar radiation (ref. 31). A total absorption of about one-third the total continuum flux is probable in the ultraviolet spectrum of B-stars. Morton finds that after correction for this line-blanketing effect, the discrepancy is reduced to a factor of 4 or even 2 at 1314 Å, but remains a factor of 5 at 1427 Å.

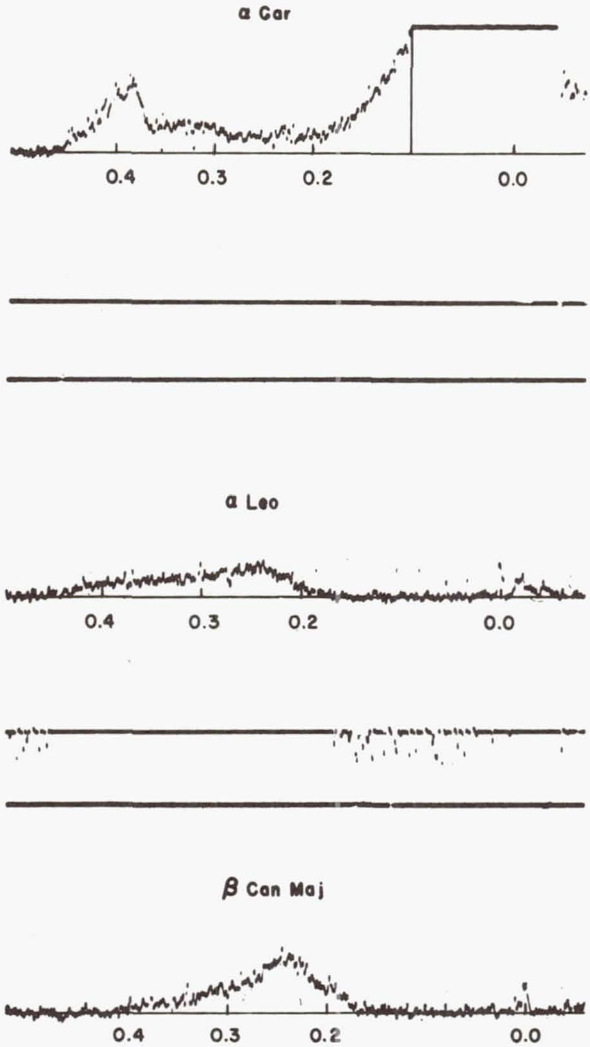

Figure 15.—FM–FM telemetry traces of ultraviolet spectra of α Carinae, α Leonis, and β Canis Majoris. The wavelength is given in microns. The resolution is 50 Å, and the scanning rate is 5000 Å/sec. The saturated signal to the right of α Carinae is the southern airglow horizon.

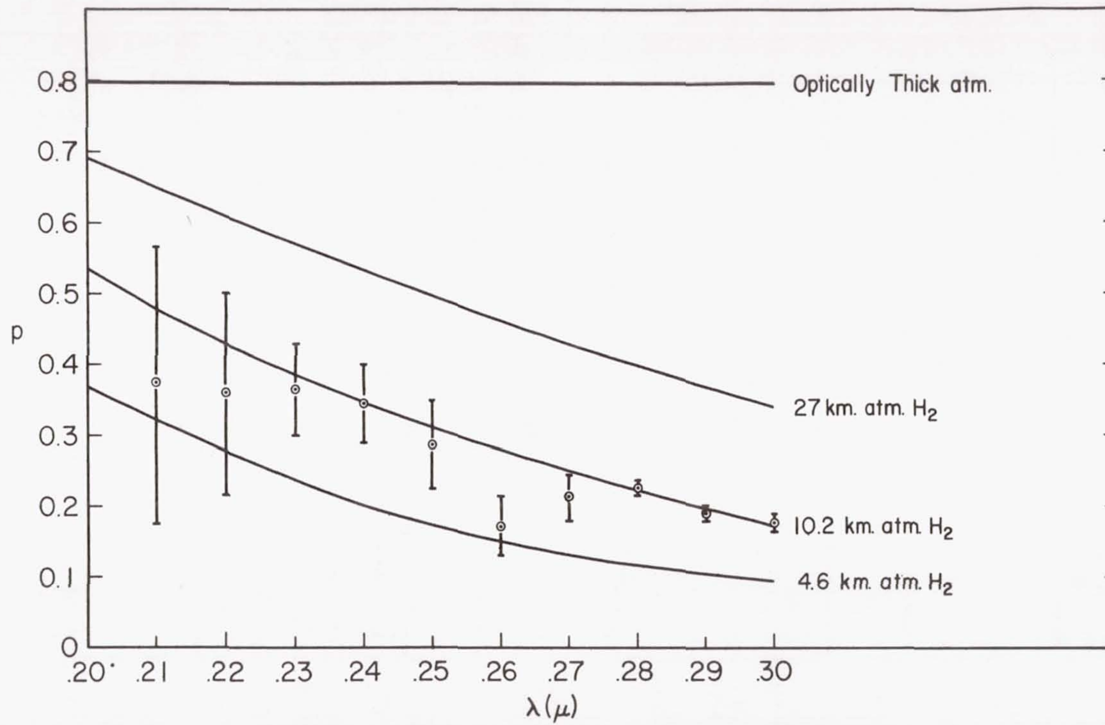

Figure 16.—Geometrical reflectivity of Jupiter.

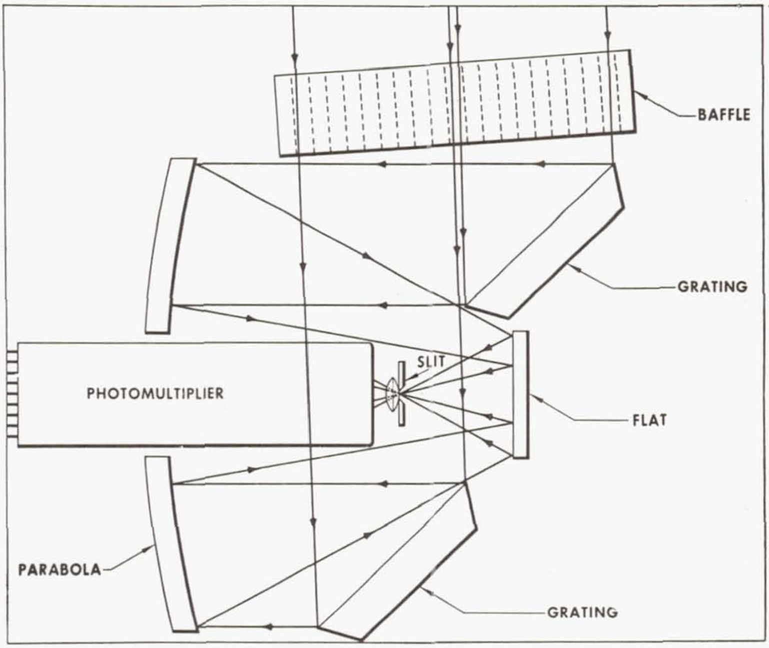

Figure 17.—Schematic of spectrophotometers.

However, if many weak lines contribute to the blanketing, these factors could be reduced even further.

Meinel pointed out that a mechanism exists which gives close agreement between the observed and computed spectral distributions for a B-type star (ref. 32). This mechanism is a molecular-recombination process involving collisions between ground-state and excited-state hydrogen atoms. A similar process involving excited helium atoms was proposed for the ultraviolet deficiency effect in O-type stars.

Another comparison between model atmospheres and observed spectra of early-type stars was made by Avrett and Strom (ref. 33). Their nongray model atmospheres were in strict radiative equilibrium, with effective temperature ranging from 10 000 to 20 000° K and surface gravities of 10^3 to 10^4. For three models they added blended wings of the higher Balmer and Lyman hydrogen lines and included an approximate correction for the ultraviolet line-blanketing effect. The effective temperatures derived from these models for B-stars closely agree with those determined observationally by Aller and Stecher for α Gruis (B5V), and hence they conclude that there is no longer a discrepancy in the ultraviolet between theory and observation.

Interstellar Extinction in the Ultraviolet

The first reliable estimate of interstellar extinction was obtained from rocket-based photometry of six stars at wavelengths 2600 Å and 2200 Å by Boggess and Borgman (ref. 34). These stars have a narrow spectral range of O 9.5 to B 1. It appears that the extinction can be represented by the usual reddening laws applicable to other wavelength regions. A plot of extinction observations for all wavelengths, together with Van de Hulst's dielectric-grain extinction curve No. 15, shows close agreement down to about 4000 Å, but the two new observations at 2600 Å and 2200 Å are not represented by this curve (fig. 18). A better fit can probably be obtained with extinction models based on composite particles.

INFRARED ASTRONOMY

Because the short-wavelength end of the spectrum is only accessible from above the Earth's atmosphere, it was only natural that astronomers turned their attention to that spectral region first when balloon and satellite astronomy became possible. This situation still exists today, though to a lesser extent, since plans are well underway to bring the infrared and visual regions of the spectrum under investigation.

Before 1959 very little infrared astronomy of stellar or

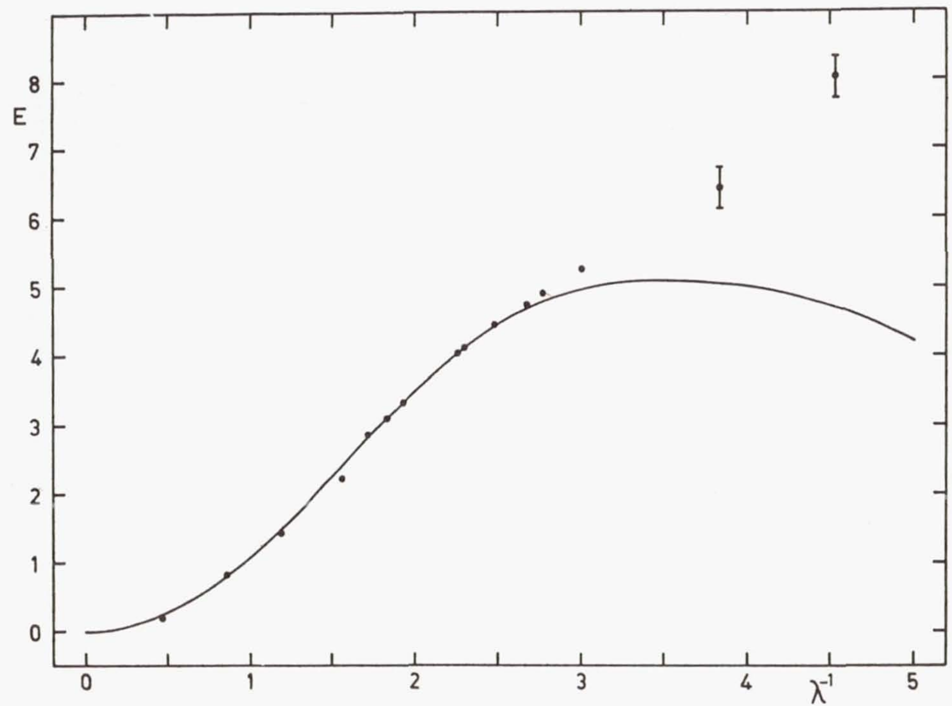

Figure 18.—Normalized extinction observations. Error bars at the 2600- and 2200-Å points indicate probable errors. The solid curve is the theoretical extinction curve No. 15 of van de Hulst.

galactic objects had been attempted from above the Earth's atmosphere. Rocket astronomy was completely involved with ultraviolet or X-ray wavelengths, and balloon astronomy was introduced in 1957 by the spectacular photographs of solar granulation by Stratoscope I (refs. 35 to 37). Not much work was done in the infrared from the Earth's surface, except for the extension of the fundamental magnitude and color standards to longer wavelengths. This is primarily because the data were difficult to obtain, even though the infrared transmission is quite high under the best conditions in certain restricted wavelength regions. The advent of balloons greatly facilitated the interpretation of ground-based observations. For example, Kuiper, Sinton, and Boyce discovered stellar water-vapor bands at 1.4 μ and 1.9 μ Mira Ceti, in spite of telluric bands at 1.3 μ and 1.8 μ. In November 1963 this discovery was confirmed by the spectra (fig. 19) taken by the Stratoscope II balloon telescope.

Stratoscope II (figs. 20 and 21) is a balloon-borne 36-inch telescope project of Princeton University directed by Martin Schwarzschild (ref. 38). It is the successor to Stratoscope I, a balloon-borne 12-inch telescope system, which, as mentioned previously, has given the highest resolution photographs of the Sun to date. The main purpose of Stratoscope II is to acquire high-resolution photographs of celestial objects. Two successful preliminary flights using infrared optics have been made; the first, in March 1963, gave valuable data on Mars, and the second, in November 1963, gave useful data in the range from 1 to 3 μ on Jupiter, the Moon, Sirius, and seven red giant stars. Two important results from this latter flight were: (1) the infrared spectrum of Aldebaran is relatively free of bands, though there is an intensity peak at 1.6 μ where the absorption coefficient of the negative hydrogen ion goes through a minimum; and (2) the strong water vapor

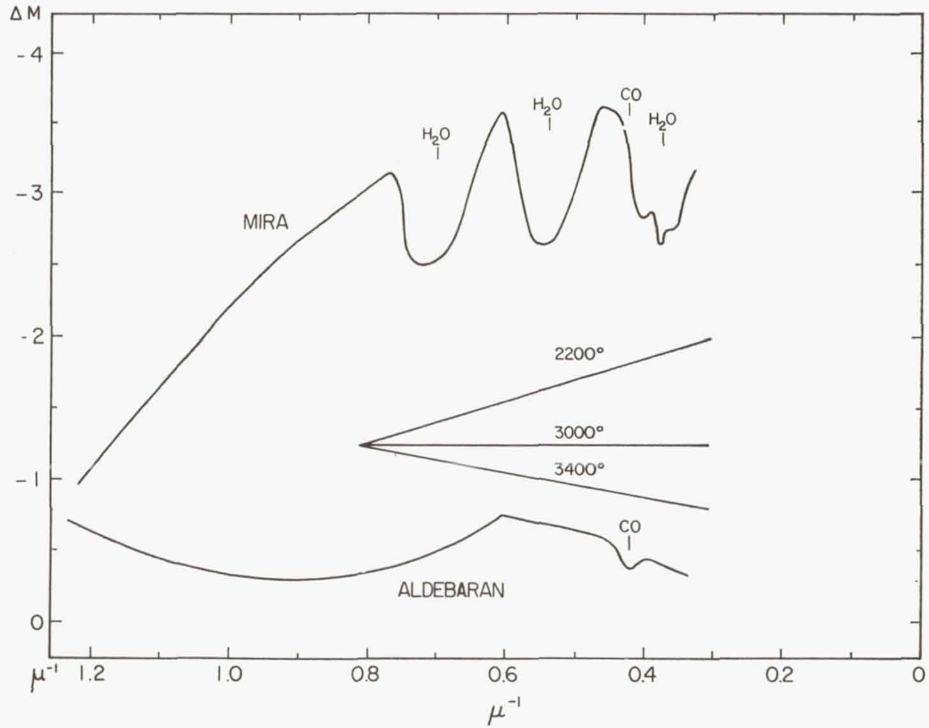

Figure 19.—**Deviations from blackbody radiation for Aldebaran and Mira.**

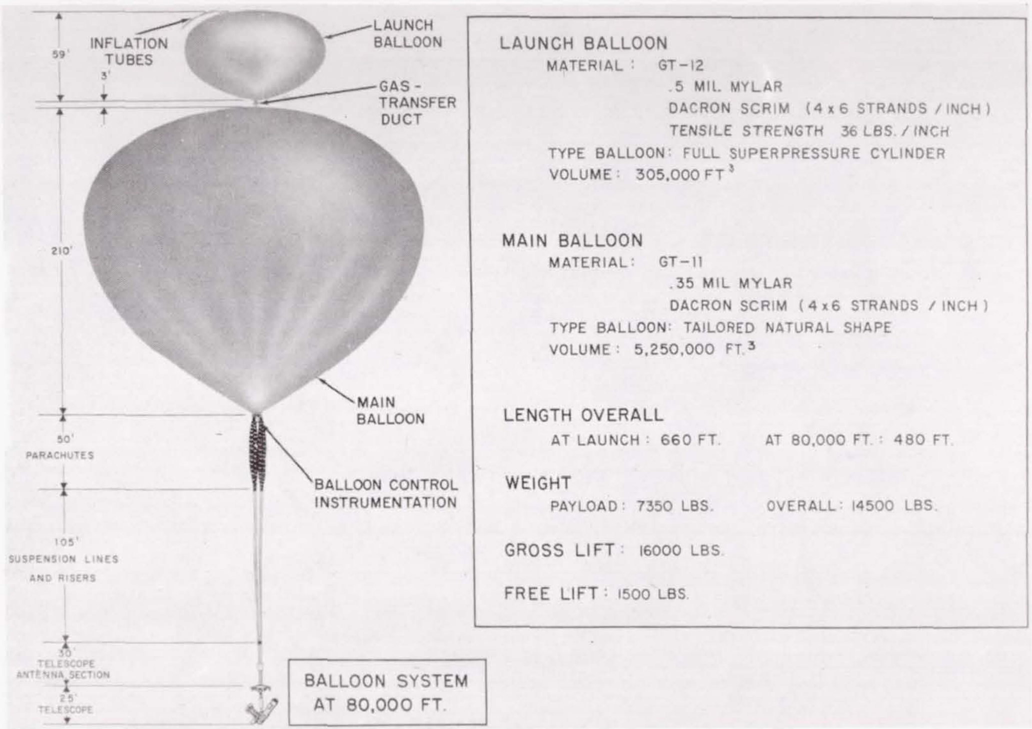

Figure 20.—Stratoscope II balloon characteristics.

bands in Mira at 1.4 μ and 1.9 μ mentioned previously are also strong in the spectra of Betelgeuse and R Leonis. Figure 22 shows the spectrum of α Orionis, obtained by Stratoscope II.

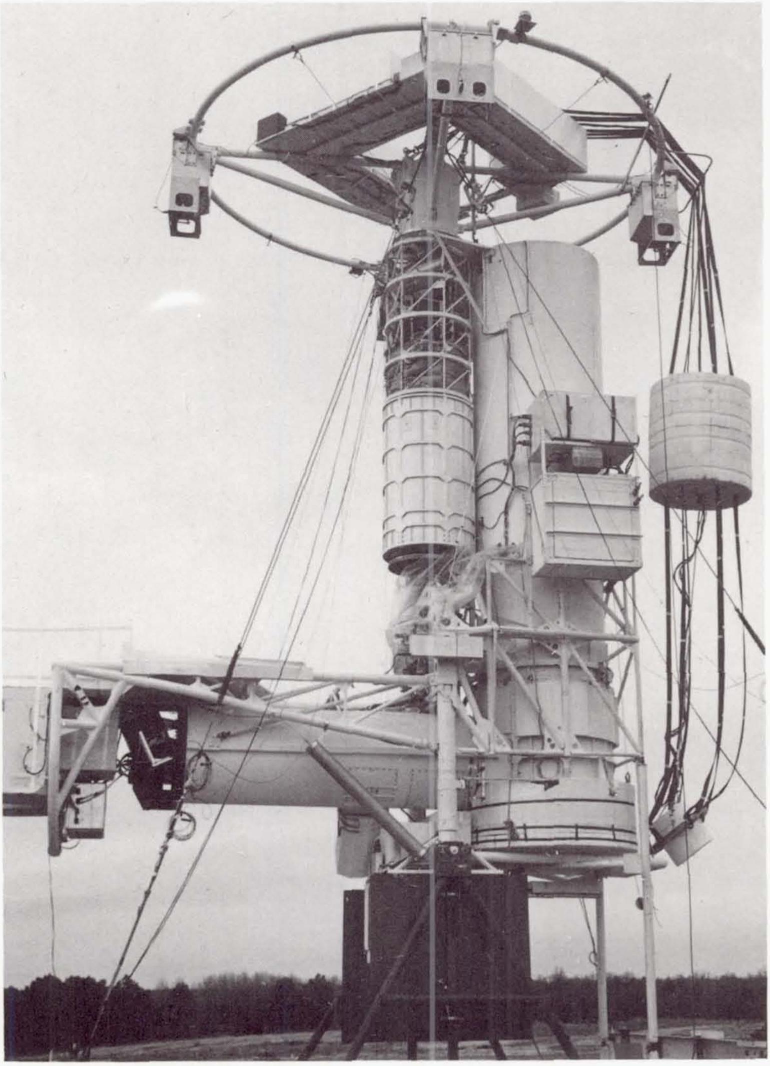

Figure 21.—**Stratoscope II 36-inch telescope before launch.**

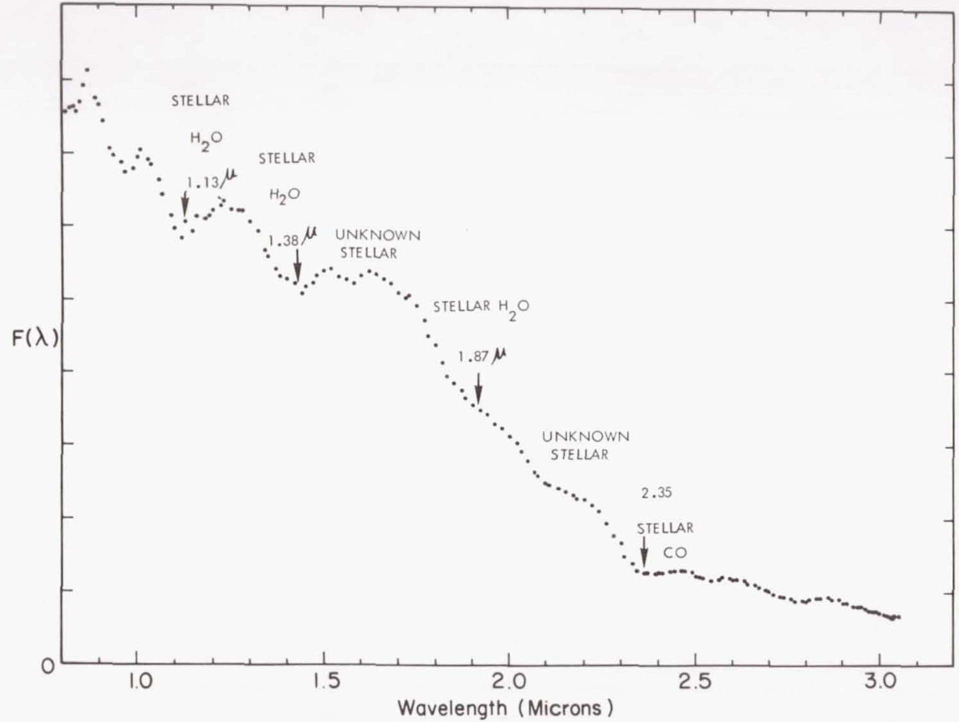

Figure 22.—Infrared spectrum of α Orionis obtained by Stratoscope II.

LOW-FREQUENCY RADIO ASTRONOMY

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Low-Frequency Radio Astronomy

APPEARANCE OF THE RADIO SKY AT LOW AND HIGH FREQUENCIES

AT THE LOW-FREQUENCY END of the radio window, the prominent features in the sky are as follows:

(1) Sporadic bursts of emission from the Sun and Jupiter
(2) A bright belt of radio emission in the galactic plane
(3) An overall glow from the entire sky
(4) Scattered bright regions of emission from distant radio galaxies
(5) Small quasi-stellar objects of extreme radio brightness
(6) A number of disk-like bright sources varying in size and concentrated along the galactic plane, identified with remnants of the supernova
(7) Dark interstellar clouds of ionized gas which absorb the general background emission; these also vary in size and are concentrated in the galactic plane.

Figure 23 shows the radio spectra of a variety of these celestial objects, and illustrates how the radio picture of the sky changes when seen in bands of the radio spectrum. Figure 24 is a photograph in visible light of the radio source in Virgo A.

The appearance of the radio sky at high frequencies is generally dark and shows the following features:

(1) Strong emission from the Sun, Moon, Venus, and Jupiter

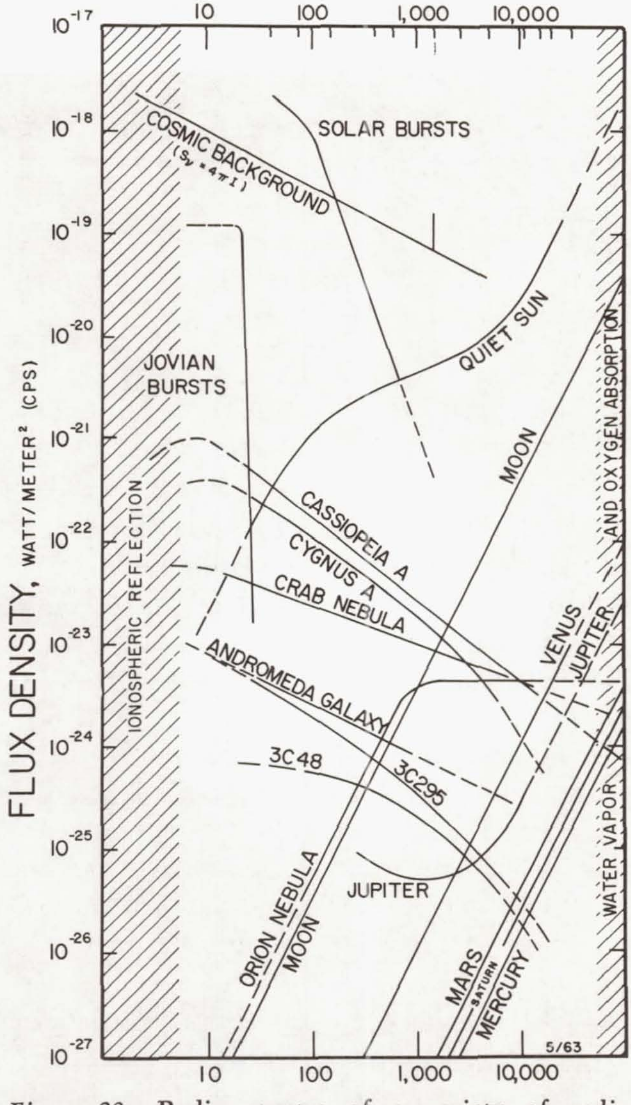

Figure 23.—Radio spectra of a variety of radio sources obtained from ground-based observations through the radio window in the Earth's atmosphere. The curves for solar and Jovian bursts are only roughly indicative of these highly variable phenomena. The level of the spectrum for the cosmic background with respect to the other spectra depends on the collecting area of the observing antenna.

Figure 24.—Photograph in visible light of radio source in Virgo A.

(2) Occasional bursts of radiation from the Sun
(3) A steady narrow belt of emission along the galactic equator
(4) A few bright sources
(5) Many faint sources scattered over the sky.

In contrast, we expect to find from low-frequency observations from large orbiting or lunar-based radio telescopes operating in the band around 1 Mc/sec that the radio sky will show the following:

(1) A very bright overall glow
(2) A wide dark band distributed along the galactic equator, becoming very wide toward the galactic center
(3) A large number of bright sources of emission distributed over the sky but because of strong absorption by interstellar gas rather sparse in the Milky Way
(4) Frequent strong outbursts of radio waves from Jupiter
(5) Occasional radio outbursts and noise storms from the Sun. The undisturbed Sun and most of the planets will be inconspicuous.

RESTRICTIONS ON SPACE RADIO OBSERVATION

Because very large structures with the required dimensional stability for resolution at low frequencies are not yet available, space radio observations are restricted to very coarse resolution. To date, there have been no rocket or satellite observations with an angular resolution of less than a large fraction of the whole sky. Since the intensity of radio signals at low frequencies is generally stronger than the receiver noise, accuracy is generally not limited by receiver sensitivity for sufficiently large antennas, but by low angular resolution if there is adequate preflight calibration and inflight monitoring of antenna impedance and receiver gain. Adequate angular resolution is required to discriminate between the various sources of emission in the same region of the sky in order to obtain useful data. With low angular resolution, the antenna output is the composite of signals from the galaxy, extragalactic sources, the planets, and the Sun. With the resolution available at present, it is possible to study only a few important astronomical problems: the average cosmic-noise background spectrum and the dynamic spectra of radio bursts from the Sun and planets.

LOW-FREQUENCY MEASUREMENTS FROM SPACE

The scientific potential of low-frequency radio measurements from space was discussed over 6 years ago by Getmantsev, Ginzburg, and Shklovski, by Haddock, and by Lovell. Although many observations of the cosmic background noise have been made from the ground for the past two decades, quantitative data for frequencies below 10 Mc/sec are still available only from the measurements by Reber, by Ellis and his colleagues, and by Parthasarathy, Lerfald, and Little (refs. 39–47). These observations were made from Tasmania where conditions for radio propagation through the ionosphere are exceptional.

The first reported radio-astronomy measurement at low frequencies was by a Canadian group (ref. 48) who obtained a measurement of cosmic-noise background at 3.8 Mc/sec from the Transit 2A (1960 Eta-1) satellite, which was launched in June 1960. These measurements were first discussed by Chapman and Molozzi (refs. 48 to 50) and later, independently, by F. G. Smith (ref. 51). The cosmic brightness temperature deduced by Smith was lower by a factor of 6; this discrepancy was caused by differences in interpretation of the effect of the local ionospheric medium on the receiver sensitivity. No inflight receiver or antenna calibrations were made. The first value reported is shown on figure 25.

The next reported measurements were by Walsh, Haddock, and Schulte of the University of Michigan (refs. 52 to 55). They used rocket-borne equipment (fig. 26) designed to measure the absolute value of mean cosmic

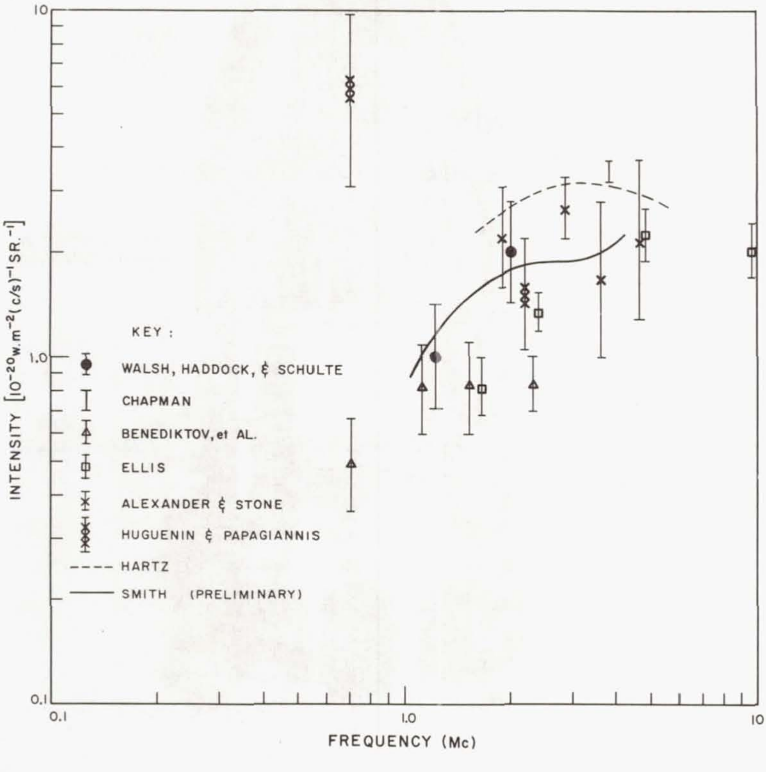

Figure 25.—Measured values reported for the mean cosmic background noise. All points represent measurements from rockets or satellites, except those of Ellis. The solid curve is from the Ariel II satellite and has not been corrected for local plasma effects. The broken curve represents relative values only, deduced from uncalibrated sweep frequency measurements. The high value at 0.7 Mc/sec is believed by Huguenin and Papagiannis to be caused by locally generated noise, not cosmic noise.

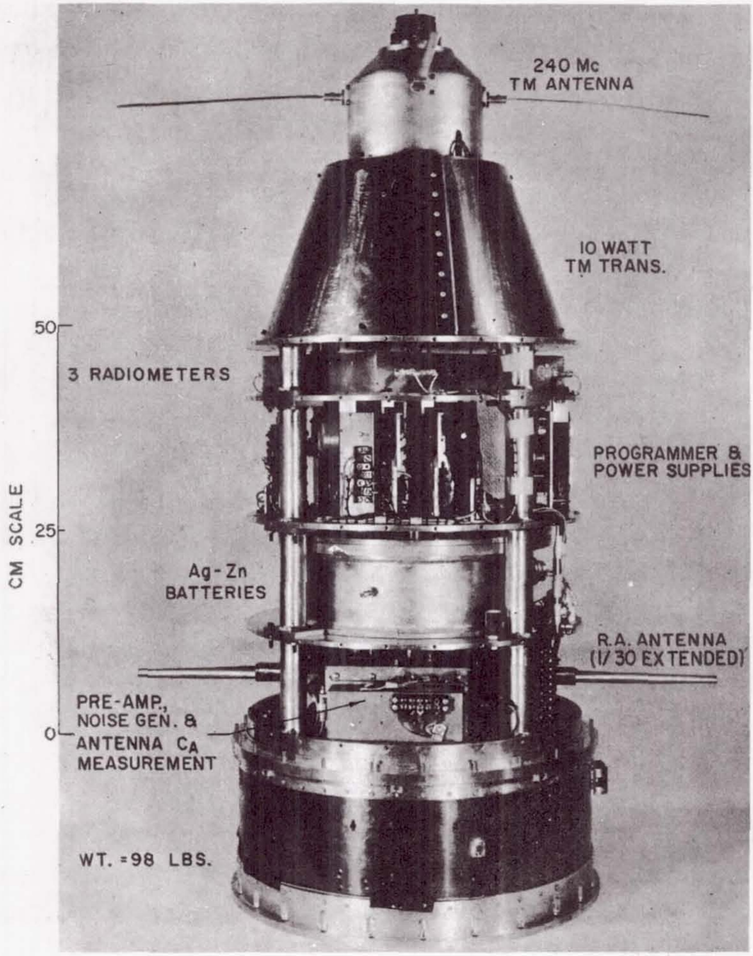

Figure 26.—Payload of rocket for cosmic radio noise measurements.

background at 0.75, 1.225, and 2.0 Mc/sec. The experiment included inflight calibration of the antenna and receiver characteristics, required for the interpretation of the effects of the local ionosphere on system sensitivity. A 12.2-meter electric-dipole antenna was used. The payload was launched from Wallops Island on a four-stage

Journeyman rocket on September 22, 1962, shortly after midnight. The rocket and all components on the payload performed well and over 20 minutes of data were obtained. An altitude of 1691 kilometers was reached which was somewhat lower than originally planned.

The mean intensity of cosmic-noise background, averaged over a celestial hemisphere centered on new galactic latitude of 144° and longitude of −19°, was derived at 1.225 and 2.0 Mc/sec. The system sensitivity was too low to derive a useful value at 0.75 Mc/sec. The corresponding intensities obtained were 1.0×10^{-20} W/m^2/cps/sr, and 2.0×10^{-20} W/m^2/cps/sr, respectively, with an estimated uncertainty of 40 percent in the absolute values but with half this uncertainty for the ratio of the two values. The large drop of intensity between 2.0 Mc/sec and 1.225 Mc/sec was rapid enough to require the assumption that it was caused by free-free absorption by a local concentration of ionized interstellar gas. The magnitude of the absorption can be accounted for if it is assumed (ref. 56) that the absorbing gas is concentrated within 200 parsec of the Earth and the mean electron density is 0.14/cm^3.

Unexpected intense noise signals also detected are believed to originate in the ionosphere (ref. 57). A criterion for the occurrence of this noise was obtained in terms of the propagation characteristics (the local gyro frequency and plasma frequency) in the ionosphere at all three observing frequencies (figs. 27 and 28). This region of local noise occurs where the refractive index tends toward infinity, in the absence of collisions. The effects of the magnetoionic medium on the radiation resistance were also determined and measured quantitatively for the first time. Variations in the radiation resistance during the disappearance of the extraordinary radio wave were consistent with theoretical expectations (refs. 58 and 59).

It was thus demonstrated that antenna behavior in the

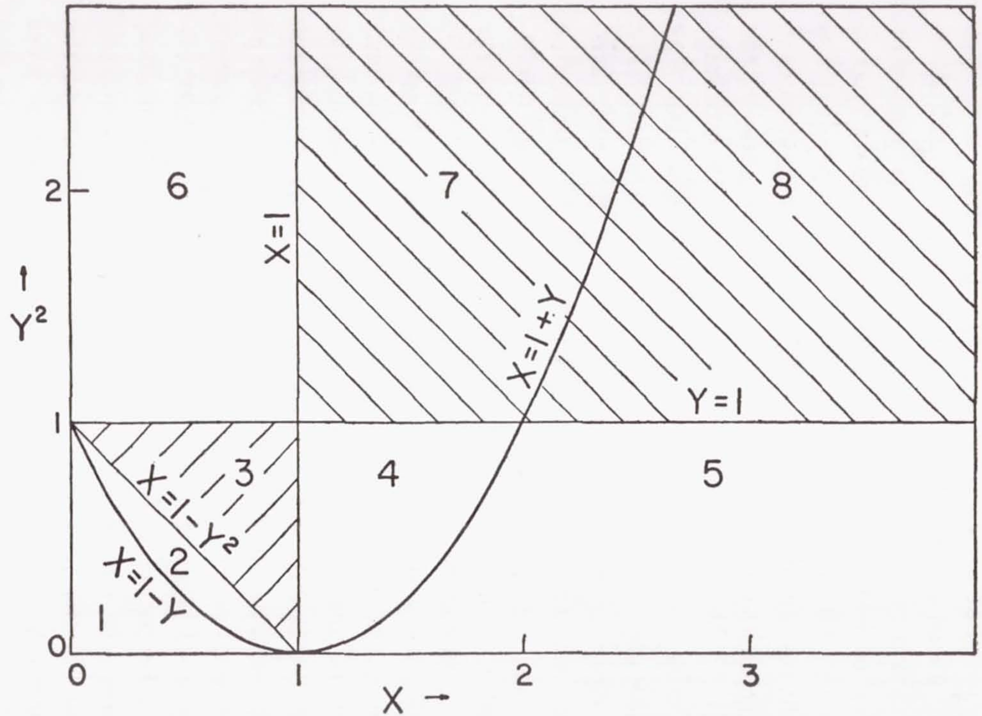

Figure 27.—The X–Y^2 plane. X is (plasma frequency/wave frequency)^2, cosmic (gyro frequency/wave frequency).

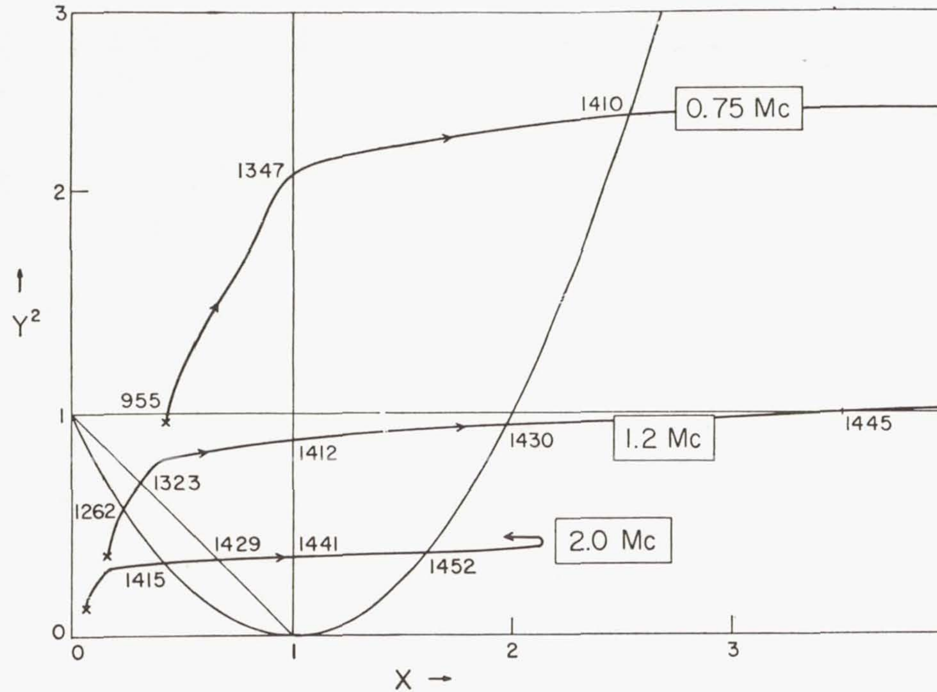

Figure 28.—Trajectories of radiometer frequencies on X–Y^2 plane. Flight times, in seconds, are marked at region boundaries.

ionosphere is theoretically predictable and that corrections to obtain the free-space cosmic noise intensity values are possible except for those regions where the index of refraction is infinite (ref. 60).

As expected, there was no evidence of manmade radio signals leaking through the ionosphere during this experiment. There was also no evidence of radio emission from the artificial radiation belt injected in the magnetosphere on July 9, 1962.

At the IAU Symposium No. 23 in Belgium during August 1964, Huguenin and Papagiannis (ref. 61) reported results of measurements made during the summer of 1962 from a pickaback scientific payload on the satellite 1962 $\alpha\beta$. The polar orbit had a perigee of 200 kilometers and an apogee of 370 kilometers. Because of the short life, only about 1 day's worth of data was obtained on cosmic-noise levels at 4 and 7 Mc/sec, on antenna impedance, and on magnetic field. The background noise levels recorded were a million times greater than expected, and are attributed to Earth-generated noise when the satellite was below the maximum ionospheric electron density. The noise levels obtained in the nighttime phases over the south geomagnetic pole where the terrestrial interference level was low and the critical frequency of the F_{max} was below 7 Mc/sec "probably represent the cosmic background." The value deduced was 1.5×10^6 °K (± 2 dB), which is in general agreement with the previously reported values. The descriptions of this work are not clear, and details of the calibration, instrumentation and data reduction procedure have not been published.

Huguenin and Papagiannis (refs. 61 and 64) reported measurements of the cosmic background noise averaged over the whole sky at frequencies of 0.7 and 2.2 Mc/sec. The instrumentation was carried by a Blue Scout Jr. (AP–3) high-altitude rocket probe which was launched from Cape Canaveral on July 30, 1963. It reached an altitude of 11 100 kilometers. Although the antenna impedance probe did not work, the high altitude insured that the measurements were made at essentially free-space conditions. There were unexpectedly intense bursts of radio emission which are attributed to terrestrial noise generated in the exosphere. There was no significant leakage of ground noise through the ionosphere, for a strong ground component of emission would have shown a change of intensity by a factor of 20 over the range of altitudes of the experiment. The measured fluxes for the average cosmic noise over the whole sky are:

(1) At 0.7 Mc/sec, $S=8\times10^{-19}$ W/m^{-2}(cps)$^{-1}$, with an estimated uncertainty of 2 to 3 dB.

(2) At 2.2 Mc/sec, $S=1.8\times10^{-19}$ W/m^{-2}(cps)$^{-1}$, with an estimated uncertainty of 1.4 to 2 dB.

The sky brightness obtained at 2.2 Mc/sec is in general agreement with previously reported values, but the brightness at 0.7 Mc/sec is about 15 dB higher than that expected from the trend of the radio spectrum. The experimenters state that the previously reported low-altitude observations, as well as these high-altitude observations at frequencies below 2 Mc/sec, are both possibly correct. They suggest that the differences may be caused by strong radio emission in the Earth's exosphere and perhaps arise from harmonic gyroradiation from the Van Allen belt or the artificial belt created by the high-altitude nuclear explosion.

Hartz (refs. 62 and 63) has reported observations of cosmic radio emission between 1.5 and 10 Mc/sec obtained from the Alouette I satellite (1962 $\beta\alpha$ 1) which was launched September 28, 1962. A nearly circular polar orbit at an altitude of 1000 kilometers and an inclination of 80.5° was obtained. Five hours a day of sweep-frequency records covering the band from 0.5 to 12 Mc/sec was obtained, but only a small portion of the data was analyzed to obtain an estimate of the cosmic radio spectrum from 1.5 to 5 Mc/sec. No provision was made for absolute gain calibration of the receiver in flight, and the largest uncertainty in the data results from the unknown effect of the ionosphere on the antenna impedance and its effect on receiver gain. Evaluation was made, by a rather involved method, under a variety of ionospheric and magnetic field strength values to extrapolate the measured values to free space values. At 2.3 Mc/sec, the brightest region of the sky is centered on the south galactic pole with reported radio brightness temperature of 1.8×10^7 °K. The lowest temperature was 5.0×10^6 °K centered on RA 9^h, decl +75°. The spectral slope of the brightness temperature spectrum was −1.7 at 1.5 Mc/sec. Because this experiment was designed for ionospheric sounding work and not for the measurement of cosmic background noise, no receiver gain or antenna impedance calibration instrumentation was available. The method of analysis appears to be open to uncertainty. Apparently the absolute level of the reported values was adjusted to previously published values.

On March 27, 1964, the satellite UK II (Ariel 2) was launched into an elliptical orbit with apogee of 1360 kilometers and perigee of 290 kilometers; the inclination of the orbit to the equator was 52°. A sweep-frequency receiver, covering 0.65 to 3.5 Mc/sec, was designed by F. G. Smith and Hugill of Cavendish Laboratory, Cambridge University. Its antenna consisted of an electric dipole 40 meters tip to tip, held taut by centrifugal force. Smith reported at the Liège meeting (ref. 65) provisional flux density values which were obtained without correction for ionospheric effects on the sensitivity of the receiving system. The curve shown in figure 25 is without correction for the ionospheric effects. The intensity is nearly constant at a level of 1.4×10^{-20} W/m^2-cps-sr from 2 Mc/sec to about 1 Mc/sec but decreases to 0.7×10^{-20} units at 1.2 Mc/sec. The values at 1.2 and 2 Mc/sec are about 30 percent below those obtained by the University of Michigan group.

Smith also reported that the antenna impedance effects and the detection of locally generated noise in the Earth's exosphere confirm the findings of the Michigan group. Smith and Harvey also reported noise in region 4 where the magnetoionic parameters X and Y have values given by $1 < X < (1+Y)$ and $Y < 1$ (refs. 65 and 66).

Alexander and Stone of the Goddard Space Flight Center reported (ref. 67) the measurement of cosmic radio noise intensities at four frequencies below 5 Mc/sec, using equipment on a Javelin rocket launched from Wallops Island on October 23, 1964, which attained an altitude of 1070 kilometers. A short electric dipole antenna and four tuned-RF receivers with a reference noise source and an antenna impedance probe made up the payload. Figure 24 shows the reported intensities at the four frequencies: only 1.9, 2.85, 3.6, and 4.7 Mc/sec. These are average intensities referring to the hemisphere centered near the north galactic pole. The authors state that their results were not inconsistent with the Michigan results.

PLANS FOR THE FUTURE

The Goddard Space Flight Center has recently completed the design of a Radio Astronomy Explorer satellite which is specifically for medium- and low-resolution observations of cosmic background noise and low-frequency observations of bursts from the Earth, the Sun, and Jupiter. The 380-pound payload will include V-antennas of beryllium copper, one-half inch in diameter, extending in opposite directions from the spacecraft, four special radiometers designed to cover 10 frequencies between 0.1

and 10 Mc/sec, two rapid-response receivers for recording noise bursts from the Sun and planets, two antenna impedance probes for measuring the changing ionospheric environment and the antenna boom distortions, a probe for measuring the local electron density, aspect sensors, magnetometers, magnetic tape recorders, telemetry system, and batteries.

A special feature of this satellite is the stabilization by differential gravity forces to maintain the antenna beams along the Earth-satellite line while in a circular orbit of approximately 4400-kilometer altitude with an orbital inclination of about 50° and a period of almost 4 hours. The antenna will be broadband to permit measurements over a range of frequencies in spite of the distortions caused by the differential gravity forces and the uneven solar heating of the booms. The acute angle at the root of the V-antenna will be about 60°, a value chosen so that the distortion effects on the booms will tend to compensate one another. A small television camera on the satellite will monitor the tips of these booms which will contain point sources of light. This is necessary in order to compute the resultant antenna patterns for the changing shapes of the booms. It seems therefore that the data-reduction problem will be somewhat complicated. In order to obtain measurements over an appreciable fraction of the sky, it is necessary to make observations over a period of a year during which time the orbit precesses 180°. The first launch is scheduled for early 1967 with an expected 1-year life.

Summary and Conclusions

X-RAY AND GAMMA-RAY ASTRONOMY

THE EARLIEST X-RAY STUDIES in space were carried out with detectors scanning the Sun. In 1962 the first X-rays from sources outside the solar system were detected. They were found to come from the direction of Scorpio in the direction of the galactic center. A second source was found in the neighborhood of Cygnus. An important advance in X-ray work was made by NRL scientists in 1964 when they used the Moon as an occulting disk to locate to within 1 minute of arc a source near the center of the Crab Nebula. By the end of 1964, 10 X-ray sources had been detected and their positions located to within a degree or two. All the sources lie rather close to the galactic plane and within 90° of the galactic center. Hence they appear to be galactic rather than extragalactic objects, and may be in some way associated with the newer disk population of stars in the galaxy.

Gamma-ray astronomy is intrinsically more difficult than X-ray astronomy, because of the low counting rates involved. Experiments to date indicate that celestial gamma rays exist, though no discrete sources have yet been detected. Gamma rays of energy near 1 MeV were detected by an experiment on Ranger III. Explorer XI searched for primary cosmic gamma rays with an energy greater than 50 MeV and established an upper limit on the high-energy gamma-ray background flux of 3.7 to 11×10^{-4}/ergs/cm^2-sr-sec. In addition, upper limits for the gamma-ray flux from several individual objects were also estimated.

Many of the problems of both gamma-ray and X-ray astronomy can be resolved by improvements in techniques such as larger and more sensitive detectors and longer observation times. The immediate goals will be to map the general background radiation more accurately, and to detect and identify discrete sources.

ULTRAVIOLET AND INFRARED ASTRONOMY

An early result from ultraviolet rocket photometry was the suspected presence of ultraviolet nebulosity around the high-latitude B-star, α Virginis (Spica). This was observed on two separate flights, and was tentatively explained as a Lyman-α halo around Spica. Subsequent observations, however, failed to confirm this and Spica has since been observed as a point source rather than as an extended nebular one.

Both broadband photometry and low-resolution spectrophotometry have been used in making ultraviolet observations of stars. Most of the stars fall below the brightness predicted from blackbody curves or stellar models. It is not known at present whether this is an intrinsic property of the stars or is caused by an absorber in the interstellar medium, but it probably results from the earlier failure to take adequate account of line-blanketing in computing model stellar atmospheres.

The advent of the first stabilized, accurately pointed satellite specifically designed for astronomical observations will permit ultraviolet investigations at a higher level of accuracy and thus aid in resolving problems such as those previously mentioned. Eventually, observations in the visual region of the spectrum from large satellites will be possible with a higher resolution than from ground-based telescopes.

Infrared studies, although plagued by equipment and technological difficulties, have just begun to provide data on stars and to confirm terrestrial observations of brighter objects on the existence of water vapor in stellar spectra. Extension of these techniques will enable the astronomer to obtain energy-distribution curves for all parts of the spectrum, and thus improve the accuracy of stellar models.

RADIO ASTRONOMY

Low-frequency radio observations have been carried out aboard various rockets and satellites. The main purpose of these experiments has been to study the cosmic background noise below 10 Mc/sec, which is normally prevented by the ionosphere from reaching surface-bound radio telescopes. To date, the radio-astronomy experiments have not usually been the prime objective of a satellite mission, but development is underway of Radio Astronomy Explorer satellites designed specifically for medium- and low-resolution measurements of the cosmic background and observations of low-frequency radio bursts from the Sun and planets.

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