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THE NASA LRC FAINT METEOR SPECTRA PATROL

by Gale A. Harvey

Langley Research Center

Hampton, Va. 23365

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16. Abstract

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SUMMARY

A description of the instrumentation, facilities, and patrol technique used by the NASA LRC Faint Meteor Spectra Patrol is given. The primary purpose of the patrol is to provide data for composition and mass analysis of meteoroids in the 1-milligram to 1-gram mass range. The spectral data are also used for study of faint meteor radiation processes. The primary spectrographs are 15-cm-aperture, f/1.3 Maksutov slitless spectrographs with fused silica transmission elements. A photoelectric meteor detection shutter system is used with the spectrographs. A list of the 319 meteor spectra obtained in the first 2 years of operation is included, and four representative types of spectra obtained by the patrol are briefly described.

INTRODUCTION

Meteor spectra are extremely valuable in studies of meteoroid composition, meteoric processes (ref. 1), and atmospheric composition and processes (ref. 2). Unfortunately, because of the short duration of meteor events, high-quality meteor spectra are difficult to obtain. The first meteor spectra were actually obtained unintentionally on objective-prism stellar-spectroscopy plates. More recently a number of patrols have been operated specifically to obtain meteor spectra, and most spectra have been obtained by these patrols.

The world list of meteor spectra (ref. 3) as of April 1969 consisted of 1039 spectra (excluding the NASA faint meteor spectra). The largest contribution of spectra to the list was obtained by Canadians under the direction of Dr. Peter M. Millman (National Research Council of Canada). Millman has been an active meteor spectroscopist since 1930 and was one of the first astronomers to do serious analysis of meteor spectra. The Canadian meteor spectra are characteristically from bright, fast shower meteors, such as Perseids, Leonids, and Orionids of -3 to -8 magnitude. Additional information concerning Canadian meteor spectra can be found in references 4 to 8.

The second largest contribution to meteor spectra by early 1969 was made by Czechoslovakians, primarily under the direction of Dr. Zdeněk Ceplecha at Ondřejov Observatory. The most significant Czechoslovakian spectra are from fireball meteors

(-8 magnitude or brighter) of intermediate meteor speed (approximately 35 km/sec). (See refs. 9 to 11.) One of the Czechoslovakian spectra is an extremely high quality meteor spectrum with over 900 separate spectral features identified. Good ballistic data in addition to their spectral data are one of the most valuable attributes of the Czechoslovakian meteor patrol.

The U.S.S.R. has long been active in meteor spectroscopy (ref. 12) and has obtained approximately 200 meteor spectra. However, the details of their spectra are not generally well known, and it is believed that their spectra are not comparable with the Canadian and Czechoslovakian spectra. Japan has become active in meteor spectroscopy in recent years and has obtained several high-quality Leonid spectra comparable with the better Canadian Leonid spectra. (See ref. 13.)

The United States contributed 94 of the 1039 spectra in the 1969 world list. The major U.S. contribution consisted of a number of good Perseid spectra obtained by Dr. John Russell of the University of Southern California in the 1950's and early 1960's. (See refs. 14 and 15.) During the middle 1960's, the number of U.S. meteor spectra registered in the world list declined to a few per year.

The purpose of this paper is to describe a meteor patrol effort by the NASA Langley Research Center (LRC) to obtain a statistical number of spectra of suitable quality for quantitative analysis of faint (+1 to -3 magnitude) meteors. This patrol, the NASA LRC Faint Meteor Spectra Patrol, is operated primarily by Smithsonian Astrophysical Observatory (SAO) personnel under contract to Langley Research Center. The patrol direction, data reduction, and analysis are done by LRC. The instrumentation and patrol techniques evolved from instrumentation and techniques developed at LRC to obtain spectra of artificial meteors for the NASA Meteor Simulation Project. (See refs. 16 to 18.) The present report contains a listing of the spectra obtained in the first 2 years of the patrol and briefly discusses some of the more interesting spectra.

LOCATION AND FACILITY

The Faint Meteor Spectra Patrol site is located 0.8 km south of route U.S. 70 just east of San Augustin Pass in the Organ Mountains of south-central New Mexico, as shown on the map in figure 1. The coordinates of the site are longitude $106^{\circ}33'09''$ W, latitude $32^{\circ}25'24''$ N, and the elevation is 1610 meters. The site, which is about 20 km east of Las Cruces, was originally used as an SAO Super Schmidt meteor station (ref. 19) and was later used as a Baker-Nunn satellite-tracking and laser-ranging station (ref. 20). The diurnal temperature variation averages about 10° less than that of the surrounding lower elevations. However, the wind exhibits greater variability and force than at lower elevations. On the basis of a study conducted during the selection of sites for the original Super Schmidt meteor patrol (ref. 21), an average of 6 hours of observation per night can be expected. The best predicted observation period is in November, December, and January, with an average of 9 hours of observation per night. The worst predicted observation period is in late July and in August, when thunderstorm activity reduces the average number of hours of observation to 3 per night.

A photograph of the station facilities, which was taken looking east, is shown in figure 2, and a floor plan of the main building is shown in figure 3. The movable metal roof of the west observation room is the most distinguishing feature of the main building. The east observation room, which is about 50 percent larger than the west observation room, contains all the spectrographs mounted on permanent benches. Two rooms separate the observation rooms. The westernmost of these rooms contains the spectral sensitometer and is the area where most of the optical adjustments and calibrations are performed. The other room houses the office area and the control console for all the spectrographs. The console is used to adjust the operating level and to monitor the operation of the automatic shutters discussed in the section entitled "Instrumentation." The main shop area contains a drill press, a small lathe, and numerous work benches and storage bins. Two darkrooms complete the facility. Commercial power and a telephone are available at the site, but water must be trucked from Las Cruces.

INSTRUMENTATION

The effective exposure time for a photographic emulsion as a meteor image trails across it is typically 10^{-2} second. The time and space coordinates of meteors are unknown until the meteors appear, and hundreds of hours of operation per spectrograph are required for each good (10 or more identifiable spectral features) meteor spectrogram. These restrictions require fast spectrographs and a complex patrol program to yield a significant statistical number of meteor spectra.

Over the past 4 years the NASA Langley Research Center has developed entirely new instrumentation with greater detectivity and spectral range than that previously available for spectral patrols. This instrumentation consists primarily of fast, ultraviolet-transmitting slitless spectrographs and an automatic meteor detection system. These are primarily f/0.83 to f/1.3 Maksutov optical systems with apertures of 12.5 cm, 15 cm, and 20 cm and with fused silica transmission elements. Pertinent optical parameters of the spectrographs are listed in table I. A sketch of the optical system of an f/1.3 Maksutov is shown in figure 4, and a photograph of a Maksutov spectrograph is shown in figure 5. The primary elements of the optical system are the spherical mirror, the spherical-segment focal surface, the corrector lens, and the transmission diffraction grating.

The focal surface of the f/1.3 systems is a 21° diameter segment of a sphere. Accordingly, the film plates are required to accept a moderate curvature. During the design of the instruments, it was determined that 0.2-mm (thick base) acetate-base film could be pulled down by a threaded film-retaining ring to conform to the focal surface, especially if the film plates were given a small initial set by storing them in containers with the general shape of the focal surfaces. Because of the general trend to produce films on the more dimensionally stable ESTAR Base, many delays have been encountered in obtaining the highest speed emulsion available on 0.2-mm acetate base. However, the presently used special-order film SO-153 Kodak Meteor Tracking Recording Film satisfies the curvature requirement.

Although a complete description of the spectrographs is given in reference 16, some of the unique features of these spectrographs should be mentioned. The spacing and alinement are maintained by three 1-cm invar rods. Housings for the corrector lens and the diffraction grating are made of high-density expanded polystyrene sandwiched between 1.6-mm-thick aluminum. To minimize the effects of thermal expansion, the internal optics are not rigidly attached to the case, which was fabricated from Bakelite tubing with a 1-cm-thick wall.

The basic optical parameters of the spectrographs now on patrol are presented in table I. The spectrographs in table I consist of three types: seven low-resolution (inverse dispersion > 200 Å/mm) spectrographs, which were used in the Meteor Simulation Project; 11 high-resolution (inverse dispersion < 200 Å/mm) spectrographs, which are the primary spectrographs; and six special-purpose spectrographs, which were constructed specifically for this patrol. All the spectrograph systems were designed and fabricated at the Langley Research Center.

The method of operation for older meteor patrols is to continuously expose slitless spectrographs to a selected sky area. Chance occurrences of a bright meteor in the spectrograph field of view during the exposure result in the meteor spectra. This approach takes advantage of very high reciprocity failure of panchromatic films for long exposures to discriminate against background sky radiation. However, the Maksutov spectrographs used in the Faint Meteor Spectra Patrol become fogged from night sky and star radiation in approximately 0.5 minute. Thus, a different mode of operation was required for this patrol.

In 1966, during the study phases of the patrol, a high signal-to-noise ratio was recorded on a photomultiplier system used for accurate real-time event information. (See ref. 22.) The radiation was produced by a zero-magnitude artificial meteor of the Meteor Simulation Project. This relatively unexpected result led to a design study for detecting meteors photoelectrically and actuating a shutter from the photomultiplier tube output. This study resulted in the automatic shutter system shown in block diagram in figure 6.

This shutter system can open in approximately 0.1 second when a meteor of zero magnitude occurs in the field of view. A characteristic operating level for a typical shutter system is 0.6-μA photomultiplier tube current due to background radiation for a 21^{o} diameter field on an RCA 6199 photomultiplier tube. The shutter opens when the current is increased to 0.7 μA by the additional radiation from the meteor. The photomultiplier tube current is amplified a thousand times by two transistors and drives a relay solenoid which controls power to the shutter circuit. Induced currents of the same magnitude as the signal are eliminated by careful grounding and shielding measures. Experience has shown that the detectivity of the shutter system is well matched to that of the spectrographs, although there are differences in response of the shutter systems of different spectrographs.

A study of the spectral energy distribution of meteors from available spectrograms indicated that the near-ultraviolet region (3500 Å to 4000 Å) is the most energetic optical meteor radiation region. Fortunately, the night sky radiation decreases from the red toward the blue and ultraviolet region, and the response of the photomultiplier tube is a maximum in this region. In order to utilize these conditions fully, an ultraviolet filter is placed in front of the photomultiplier tube on clear, moonless nights. Scattered moonlight shifts the night sky radiation back toward the blue region of the spectrum. Fortunately, scattered moonlight is a problem only when the moon is near full phase.

A much more serious situation exists due to scattered light from lightning. The photomultiplier tubes are very sensitive to the scattered near-ultraviolet radiation from lightning. If a lightning flash is just barely visible on the horizon in the east, spectrographs facing west will operate. During periods of cloudless or nearly cloudless sky but with thunderstorm activity in the vicinity (the usual late-summer condition in the Southwest), the shutters actuate several times a minute. Thus, lightning causes many overexposed film plates even though each single exposure is limited to 2 seconds by a time delay in the circuit.

Other related equipment at the main patrol site includes ballistic cameras with occulting shutters, a real-time event recorder, and a spectral sensitometer for absolute spectral irradiance calibration (ref. 23).

PATROL OPERATION

The patrol was initiated when seven low-resolution spectrographs were transported to New Mexico in late July 1968. The high-resolution and special-purpose spectrographs have been gradually phased in since that time. All the high-resolution spectrographs were in operation by October 1969, and all the special-purpose spectrographs were in operation by August 1970. A photograph of the spectrographs taken in August 1969 is shown in figure 7. The photograph was taken looking down into the east observation room from the roof of the main building.

The spectrographs are positioned at elevation angles of 45°, 65°, and 80°. This orientation provides nearly complete sky coverage above 35° elevation. The image-intensifier and infrared spectrograph fields coincide with Maksutov spectrograph fields.

The number of meteor spectra expected to be photographed by the patrol can be estimated in several ways. One of these ways is just to equate the meteor acquisition rate of the Maksutov spectrographs to that of the modified aerial camera-spectrographs used by the Canadians. The faster optics of the Maksutovs (f/1.3 compared with f/2.5 of the aerial camera-spectrographs) essentially cancel the larger field of view of the aerial camera-spectrographs (1600 sq deg compared with 380 sq deg for the f/1.3 Maksutovs). However, the higher ultraviolet transmission and faster emulsions of the Maksutov spectrographs should increase their spectra acquisition rate, and faulty or poor shutter operation will tend to decrease it. The spectra acquisition rate of the aerial camera-spectrographs is about one meteor per 100 hours of operation per spectrograph. (See ref. 24.) During the last quarter of 1970, 136 spectra were acquired on 21 Maksutov spectrographs for 250 hours of observation time (with no coverage of the Geminid shower because of bad weather). This corresponds to 40 hours of operation per spectrograph per spectrum. This rate was reached only after many operational problems had been overcome.

Meteor velocity and altitude are fundamental parameters which are required in a detailed analysis of meteor spectra. In general, a meteor must be photographed with ballistic cameras from two stations in order to measure velocity and position. However, if the velocity is known (as it is for identified members of meteor showers) and altitude of one point along the trail can be estimated (from the occurrence of the auroral green line or from beginning heights), the altitude can be computed from measurements of the spectroscopic plates, star field identification, and spectrograph pointing angles. Uncertainties in estimated heights are typically 5 km. This approach was used in the analysis of meteor spectra acquired prior to September 1970. By September 1970 spectra were being acquired of meteors which were also photographed on ballistic cameras (modified aerial camera-spectrographs with occulting shutters). From these ballistic data, measurements can be made to compute the altitude of shower meteors and the effective exposure time of nonshower meteors. By the end of 1970 sequence ballistic cameras for complete triangulation data were in operation at a second station approximately 20 km west of the main station.

The Faint Meteor Spectra Patrol is operated on a routine nightly basis, with the two observers having alternate nights off. Special emphasis is on optimum operation during major meteor showers. The patrol is generally operated when cloud coverage is less than 50 percent.

RESULTS AND DISCUSSION

A list of the 319 meteor spectra obtained in the first 2 years of operation is presented in table II. The increased productivity with time and the enhanced productivity during meteor showers can be noted. The date is that of the evening of the start of the observation period. The type of film emulsion is included to indicate the range of the spectrum. Shower designation is based on date of occurrence, spectral characteristics, and in some cases, visual correlation or projected trail and radiant intersection. The number of features resolved in the spectrum with a visual comparator is also given. The classification was established by Millman (ref. 4). The number of features in a "d" spectrum is 9 or less, in a "c" spectrum is 10 to 19, in a "b" spectrum is 20 to 49, and in an "a" spectrum is more than 49. The spectrum plates are available to qualified persons for analysis at Langley Research Center. Additional information concerning the spectra may be obtained from the Space Physics Branch of the Langley Research Center.

Experience has shown that a- or b-quality spectra are needed for spectroscopic composition measurements, and a-quality spectra are needed for studies of radiation processes. Thus, of the spectra obtained in the first 2 years of the patrol, almost 100 percent are useful for general statistical classification of meteor spectra into composition and/or velocity groups, 15 percent are useful for spectroscopic composition measurements, and 4 percent are useful for meteor radiation studies.

Some of the types of spectra obtained from the patrol can be seen in figures 8, 9, 10, and 11. The first good meteor spectra were obtained in November 1968. These two spectra were photographed on the same plate and are shown in figure 8. The meteors have been classified as Leonids on the basis of the date of their occurrence (November 20, 1968), their spectral characteristics, and because their radiant passed through the Leonid radiant. These two spectra are characterized by high-energy excitation lines and are in general agreement with four other spectra obtained during the 1968 Leonid shower period. However, the spectra of figure 8 are not similar to meteor spectra of comparable quality obtained by earlier patrols discussed in the "Introduction." The most salient feature of Leonid and other fast meteor spectra obtained by these earlier patrols is the extreme dominance of the calcium H- and K-lines, which are only of moderate strength in the spectra of figure 8. This same general observation, that is, the much weaker strength of the H- and K-lines in spectra from the Faint Meteor Spectra Patrol, has been observed in all but the brightest spectra of Leonid, Perseid, Orionid, and Lyrid meteors. In addition, the development or growth of these calcium lines from the relative levels of figure 8 to levels comparable with those observed by the Canadian patrols (refs. 3 and 5) can be seen on several plates for meteors of -3 magnitude or brighter. Hoffman and Longmire (refs. 25 and 26) have suggested that the mechanism of the anomalously large H- and K-radiation characteristic of bright meteors is a result of resonant charge exchange between

N_2^+ (11 eV ionization energy) which ionizes (6.4 eV) and excites (4.2 eV) the H- and K-lines of calcium. The spectra from the Faint Meteor Spectra Patrol support this type of hypothesis and indicate that the region in which this phenomenon occurs is rather well defined. (See ref. 27.)

The spectrum of the shorter meteor shown in figure 8 has been analyzed to determine the relative composition of calcium, magnesium, sodium, and iron. (See ref. 28.) The mass of this meteor was determined to be 10 milligrams. The analysis also indicated that most of the radiation is produced by a gas with an energy-level population close to that of a Boltzmann distribution.

Figure 9 is reproduced from a spectrum of a predominantly iron meteor that was obtained during the night of April 9, 1969. The spectrum was produced by a very bright meteor of estimated -7 magnitude. The spectrum was recorded on a blue-sensitive emulsion and covers a maximum spectral interval of 3100 Å to 4600 Å. The third-, fourth-, and fifth-order spectra with inverse dispersions of 41 Å/mm, 31 Å/mm, and 25 Å/mm were recorded.

Figure 10 is reproduced from the spectrum of a meteor of estimated visual magnitude +2. This spectrum was recorded on an extended-red panchromatic film during the night of April 18, 1969. One wide feature near 3700 Å is superimposed on a low, broad continuum in the near ultraviolet. The inverse dispersion is 500 Å/mm. This spectrum is interesting because the dominant radiation is not line radiation and is presently unidentified. As can be seen in figures 8, 9, and 11, optical meteor radiation is almost exclusively line radiation although there are an increasing number of molecular band and continuum radiation meteors now being recorded.

Figure 11 is reproduced from the spectrum of a Taurid meteor. This identification is based upon the date of the meteor, the meteor radiant, and similarity of this spectrum to the spectra of several Taurid meteors obtained in Czechoslovakia. The strongest lines in this spectrum are multiplets 4, 5, and 20 of iron in the near-ultraviolet region of the spectrum. Multiplet 2 of magnesium in the green region of the spectrum and the sodium D-lines in the yellow region of the spectrum are also very strong. Over 300 features have been identified in this spectrum.

Most meteor spectra in the world list (April 1969) were photographed with modified aerial camera-spectrographs. These optical systems are characterized by refractive optical elements with one or more flint elements of low ultraviolet transmittance. Since these optical systems are refractive and were designed primarily for photography in the visible region, the chromatic aberration is severe for wavelengths less than 4000 Å. This chromatic aberration coupled with the low ultraviolet transmittance has generally limited meteor spectra to the region of wavelengths greater than 3800 Å. One notable exception exists (ref. 8). As can be seen in figures 8, 9, 10, and 11, the use of fused silica and mirrors in the Maksutov spectrographs has essentially opened a new and important spectral region (3100 Å to 3800 Å) to meteor spectroscopy.

CONCLUDING REMARKS

The NASA LRC Faint Meteor Spectra Patrol has demonstrated that statistical quantities of faint meteor spectra can be photographed. These spectra are from meteors of approximately a factor of 100 less in limiting radiation intensity than previously available spectra. The useful wavelength region for meteor spectroscopy has been extended by 700 Å into the near-ultraviolet region. In the first 2 years of the Faint Meteor Spectra Patrol, 319 spectra were photographed with specially designed Maksutov slitless spectrographs and an automatic meteor detection shutter system. Thus, the feasibility of operating a high-acquisition-rate meteor spectra patrol with a limited number of personnel has been demonstrated. The meteoroids which produced the photographed meteor spectra were in the mass range (1 milligram to 1 gram) of direct interest for spacecraft meteoroid protection. Some of the spectra have been analyzed and allow the first direct chemical composition measurements of meteoroids in this mass range. The spectra have also allowed the first detailed spectroscopic analysis of faint meteor radiation.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., April 29, 1971.

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TABLE I.- OPTICAL PARAMETERS OF FAINT METEOR SPECTROGRAPHS

Type	f/number	Aperture, cm	Field diameter, deg	Inverse dispersion, Å/mm	Number of spectrographs	Comments
Low resolution	f/0.83	15	20	500	1	
	f/1.0	15	28	900	2	
	f/1.0	15	28	450	1	
	f/1.3	12.5	21	800	1	
	f/1.3	12.5	21	1300	1	SiO_2 prism (dispersion for 3500 Å)
	f/1.3	20	21	500	1	
High resolution	f/1.3	15	21	123	5	
	f/1.3	15	21	165	6	
Special purpose	f/1.3	20	21	600	2	SiO_2 prism UV spectrographs
	f/1.3	7.5	15	1350	2	Image intensifier for +4-mag meteors
	f/0.87	9	30	1800	2	IR spectrographs

TABLE II.- NASA LRC FAINT METEOR SPECTRA LIST

(a) Key to film types and quality classes

Film type	Wavelength, Å
X-ray film	3100 to 4600
2485 High Speed Recording Film	3100 to 7000
SO-153 Kodak Meteor Tracking Recording Film	3100 to 7000
ROYAL-X Pan Recording Film	3100 to 6400
Infrared film (IR)	4000 to 9000

Class	Number of features
a	>49
b	20 to 49
c	10 to 19
d	<10

TABLE II.- NASA LRC FAINT METEOR SPECTRA LIST – Continued

(b) Spectra

Date	Film	Class	Shower
8-20-68	X-ray	d	
8-20-68	X-ray	c	
8-20-68	2485	d	
10-22-68	X-ray	c	
11-17-68	2485	c	Leonid
11-17-68	X-ray	b	Leonid
11-18-68	X-ray	d	Leonid
11-18-68	2485	d	Leonid
11-20-68	2485	a	Leonid
11-20-68	2485	a	Leonid
12-7-68	X-ray	d	
12-7-68	X-ray	d	
12-12-68	X-ray	d	Geminid
12-12-68	X-ray	d	Geminid
12-12-68	X-ray	c	Geminid
12-12-68	ROYAL-X Pan	d	Geminid
12-12-68	2485	d	Geminid
12-12-68	2485	c	Geminid
12-13-68	IR	d	Geminid
12-15-68	2485	d	Geminid
12-15-68	2485	d	Geminid
12-21-68	X-ray	d	
12-21-68	2485	b	
12-21-68	2485	d	
12-27-68	X-ray	b	
12-27-68	X-ray	a	
1-12-69	X-ray	b	
1-15-69	X-ray	d	
1-17-69	2485	d	
1-18-69	2485	d	
1-18-69	X-ray	c	
1-21-69	X-ray	d	
2-19-69	2485	d	
2-19-69	2485	d	
2-21-69	X-ray	d	
3-13-69	X-ray	d	
3-17-69	X-ray	d	
3-20-69	X-ray	d	
3-25-69	X-ray	d	
4-9-69	X-ray	d	
4-9-69	X-ray	a	
4-9-69	X-ray	d	
4-16-69	X-ray	c	
4-18-69	X-ray	d	
4-18-69	2485	d	
4-18-69	2485	d	
4-20-69	2485	d	Lyrid
4-20-69	X-ray	d	Lyrid
4-21-69	X-ray	d	Lyrid
4-22-69	X-ray	a	Lyrid
4-22-69	2485	d	Lyrid
4-22-69	2485	b	Lyrid
5-9-69	2485	d	
5-9-69	2485	d	
5-10-69	2485	d	
5-13-69	2485	d	
5-13-69	2485	b	
5-14-69	2485	d	
5-14-69	2485	d	
5-25-69	2485	c	
6-5-69	X-ray	d	
6-5-69	X-ray	c	
6-5-69	IR	d	
6-5-69	2485	d	
6-5-69	2485	d	
6-8-69	2485	d	
6-13-69	2485	d	
6-13-69	2485	d	
6-14-69	2485	d	
6-17-69	2485	d	
6-17-69	2485	b	
6-17-69	2485	d	
6-18-69	2485	b	
6-18-69	2485	d	
6-24-69	2485	d	
7-6-69	2485	d	
7-12-69	2485	d	
8-8-69	X-ray	d	Perseid
8-8-69	X-ray	d	Perseid
8-8-69	2485	d	Perseid

TABLE II.- NASA LRC FAINT METEOR SPECTRA LIST – Continued

(b) Spectra – Continued

Date	Film	Class	Shower
8-8-69	2485	c	Perseid
8-8-69	2485	d	Perseid
8-8-69	2485	d	Perseid
8-8-69	2485	d	Perseid
8-9-69	X-ray	d	Perseid
8-9-69	2485	d	Perseid
8-9-69	2485	d	Perseid
8-9-69	2485	d	Perseid
8-9-69	2485	d	Perseid
8-10-69	X-ray	d	Perseid
8-10-69	X-ray	d	Perseid
8-10-69	X-ray	d	Perseid
8-10-69	2485	d	Perseid
8-10-69	2485	d	Perseid
8-10-69	2485	d	Perseid
8-10-69	2485	c	Perseid
8-11-69	2485	d	Perseid
8-11-69	2485	d	Perseid
8-11-69	2485	d	Perseid
8-12-69	X-ray	d	Perseid
8-12-69	X-ray	d	Perseid
8-12-69	X-ray	d	Perseid
8-12-69	2485	d	Perseid
8-12-69	2485	d	Perseid
8-12-69	2485	c	Perseid
8-12-69	2485	a	Perseid
8-12-69	2485	a	Perseid
8-12-69	2485	a	Perseid
8-12-69	2485	b	Perseid
8-14-69	X-ray	d	Perseid
8-15-69	2485	d	
8-20-69	2485	d	
8-20-69	X-ray	d	
9-3-69	2485	d	
9-15-69	2485	d	
9-15-69	IR	d	
9-15-69	2485	d	
9-15-69	2485	d	
9-16-69	X-ray	d	
9-16-69	X-ray	c	
9-16-69	2485	d	
9-16-69	2485	d	
9-16-69	2485	c	
9-16-69	2485	d	
9-16-69	2485	d	
10-4-69	2485	d	
10-5-69	2485	c	
10-6-69	2485	c	
10-9-69	2485	c	
10-9-69	2485	d	
10-9-69	2485	c	
10-12-69	2485	d	
10-14-69	2485	d	
10-14-69	2485	d	
10-15-69	2485	d	
10-15-69	2485	d	
10-16-69	X-ray	d	
10-16-69	X-ray	d	
10-18-69	X-ray	d	
10-19-69	2485	d	Orionid
10-19-69	2485	d	Orionid
10-31-69	2485	d	
11-2-69	2485	d	
11-3-69	X-ray	d	
11-3-69	SO-153	d	
11-4-69	2485	a	
11-4-69	2485	b	
11-4-69	2485	b	
11-4-69	SO-153	d	
11-4-69	SO-153	d	
11-5-69	X-ray	d	
11-5-69	SO-153	c	
11-6-69	X-ray	c	
11-7-69	X-ray	d	
11-7-69	2485	c	
11-7-69	2485	d	
11-9-69	X-ray	b	
11-9-69	2485	d	
11-9-69	2485	c	
11-9-69	2485	c	

TABLE II.- NASA LRC FAINT METEOR SPECTRA LIST – Continued

(b) Spectra – Continued

Date	Film	Class	Shower
11-9-69	2485	a	
11-11-69	X-ray	b	
11-11-69	2485	d	
11-11-69	2485	b	
11-11-69	2485	b	
11-11-69	2485	b	
11-11-69	SO-153	c	
11-12-69	2485	d	
11-12-69	2485	d	
11-13-69	X-ray	d	
11-13-69	2485	b	
11-13-69	2485	d	
11-13-69	SO-153	d	
11-14-69	SO-153	d	
11-16-69	X-ray	d	
11-18-69	X-ray	d	
11-18-69	2485	d	Leonid
11-18-69	2485	d	
11-18-69	2485	a	
11-30-69	X-ray	d	
11-30-69	2485	d	
12-1-69	SO-153	d	
12-6-69	SO-153	d	
12-9-69	X-ray	d	
12-9-69	SO-153	d	
12-10-69	X-ray	d	Geminid
12-10-69	2485	d	Geminid
12-10-69	SO-153	d	Geminid
12-10-69	SO-153	c	Geminid
12-10-69	SO-153	d	Geminid
12-11-69	X-ray	c	Geminid
12-11-69	SO-153	c	Geminid
12-11-69	SO-153	d	Geminid
12-11-69	SO-153	d	Geminid
12-11-69	SO-153	d	Geminid
12-11-69	SO-153	c	Geminid
12-11-69	SO-153	b	Geminid
12-11-69	SO-153	d	Geminid
12-11-69	SO-153	d	Geminid
12-11-69	SO-153	d	Geminid
12-12-69	X-ray	d	Geminid
12-12-69	X-ray	d	Geminid
12-12-69	2485	d	Geminid
12-12-69	2485	d	Geminid
12-12-69	2485	d	Geminid
12-12-69	SO-153	a	Geminid
12-12-69	SO-153	c	Geminid
12-12-69	SO-153	c	Geminid
12-12-69	SO-153	c	Geminid
12-12-69	SO-153	d	Geminid
12-12-69	SO-153	c	Geminid
12-12-69	SO-153	d	Geminid
12-12-69	SO-153	c	Geminid
12-12-69	SO-153	c	Geminid
12-12-69	SO-153	d	Geminid
12-12-69	SO-153	d	Geminid
12-12-69	SO-153	d	Geminid
12-12-69	SO-153	d	Geminid
12-12-69	SO-153	d	Geminid
12-12-69	X-ray	d	Geminid
12-13-69	X-ray	d	Geminid
12-13-69	X-ray	c	Geminid
12-13-69	X-ray	c	Geminid
12-13-69	X-ray	d	Geminid
12-13-69	2485	d	Geminid
12-13-69	2485	d	Geminid
12-13-69	2485	d	Geminid
12-13-69	SO-153	c	Geminid
12-13-69	SO-153	d	Geminid
12-13-69	SO-153	d	Geminid
12-13-69	SO-153	d	Geminid
12-13-69	SO-153	d	Geminid
12-13-69	SO-153	c	Geminid
12-13-69	SO-153	d	Geminid
12-13-69	SO-153	b	Geminid
12-13-69	SO-153	b	Geminid
12-13-69	SO-153	c	Geminid
12-13-69	SO-153	c	Geminid
12-13-69	SO-153	b	Geminid
12-13-69	SO-153	d	Geminid

TABLE II.- NASA LRC FAINT METEOR SPECTRA LIST – Concluded

(b) Spectra – Concluded

Date	Film	Class	Shower
12-13-69	SO-153	d	Geminid
12-13-69	SO-153	d	Geminid
12-13-69	SO-153	d	Geminid
12-13-69	SO-153	d	Geminid
12-13-69	SO-153	d	Geminid
12-14-69	SO-153	d	Geminid
12-14-69	SO-153	b	Geminid
12-14-69	SO-153	d	Geminid
12-15-69	SO-153	c	Geminid
12-15-69	SO-153	d	Geminid
12-30-69	X-ray	d	
1-2-70	IR	d	
1-4-70	X-ray	b	
1-4-70	IR	d	
1-4-70	SO-153	c	
1-4-70	SO-153	d	
1-4-70	SO-153	c	
1-6-70	2485	d	
1-6-70	2485	d	
1-6-70	SO-153	b	
1-6-70	SO-153	d	
1-6-70	SO-153	d	
1-10-70	SO-153	c	
1-10-70	SO-153	c	
1-10-70	SO-153	d	
1-13-70	2485	d	
1-13-70	2485	d	
1-13-70	SO-153	d	
2-5-70	SO-153	d	
2-6-70	SO-153	b	
2-7-70	SO-153	d	
2-10-70	SO-153	c	
2-14-70	SO-153	d	
2-25-70	SO-153	d	
2-28-70	SO-153	d	
3-4-70	SO-153	b	
3-4-70	SO-153	d	
3-4-70	SO-153	d	
3-6-70	SO-153	c	
3-6-70	SO-153	d	
3-6-70	SO-153	d	
3-6-70	SO-153	b	
4-28-70	2485	c	
4-28-70	SO-153	b	
4-28-70	SO-153	d	
5-6-70	SO-153	c	
5-9-70	SO-153	b	
5-9-70	SO-153	b	
5-11-70	SO-153	d	
5-12-70	SO-153	b	
5-28-70	SO-153	c	
5-29-70	SO-153	b	
6-2-70	2485	d	
6-7-70	SO-153	d	
6-7-70	SO-153	d	
6-8-70	2485	d	
6-8-70	SO-153	d	
6-26-70	SO-153	d	
6-27-70	SO-153	b	δ Aquarid
6-27-70	SO-153	c	δ Aquarid
6-27-70	SO-153	d	δ Aquarid
6-27-70	SO-153	b	δ Aquarid
7-31-70	SO-153	d	
8-3-70	SO-153	c	
8-11-70	SO-153	d	Perseid
8-11-70	SO-153	b	Perseid
8-11-70	SO-153	d	Perseid
8-11-70	SO-153	c	Perseid
8-11-70	SO-153	d	Perseid
8-11-70	SO-153	d	Perseid
8-11-70	SO-153	c	Perseid
8-11-70	SO-153	b	Perseid
8-11-70	2485	d	Perseid
8-11-70	SO-153	d	Perseid
8-11-70	SO-153	d	Perseid
8-11-70	IR	d	Perseid
8-11-70	SO-153	c	Perseid
8-11-70	SO-153	d	Perseid
8-11-70	SO-153	d	Perseid

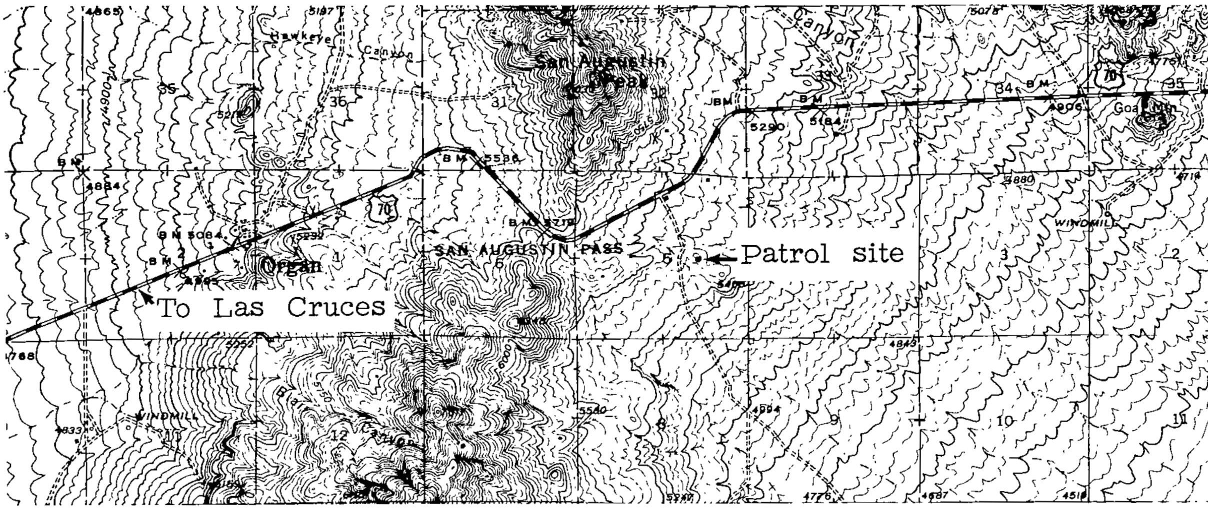
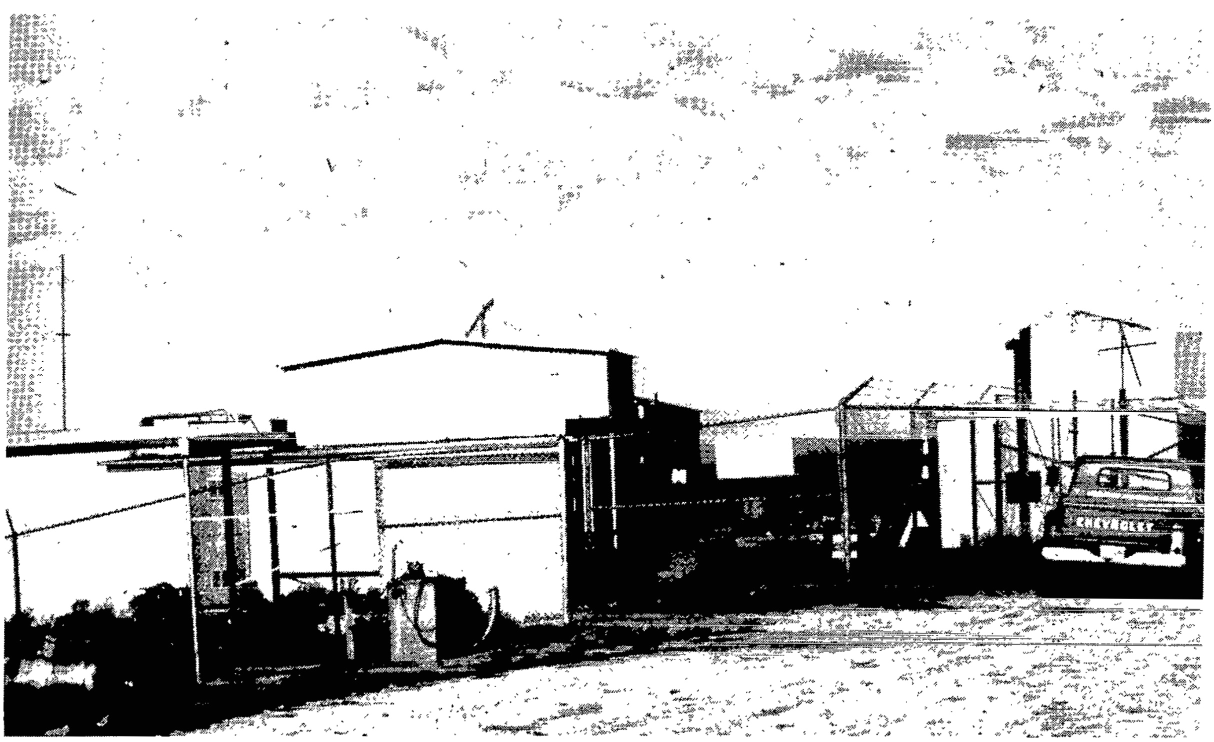


Figure 1.- Map showing Faint Meteor Spectra Patrol site.



L-71-581

Figure 2.- Photograph of spectral patrol facility (looking east, August 1969).

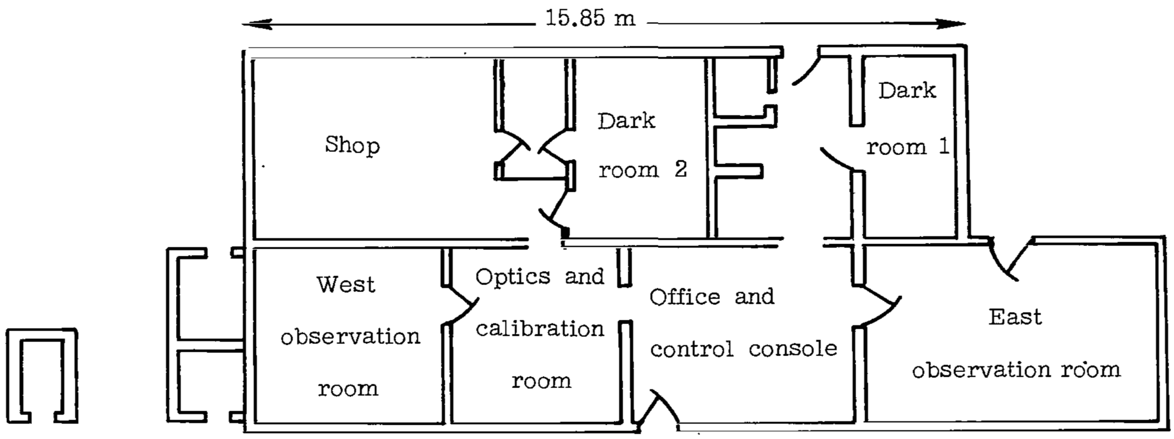


Figure 3.- Floor plan of main building.

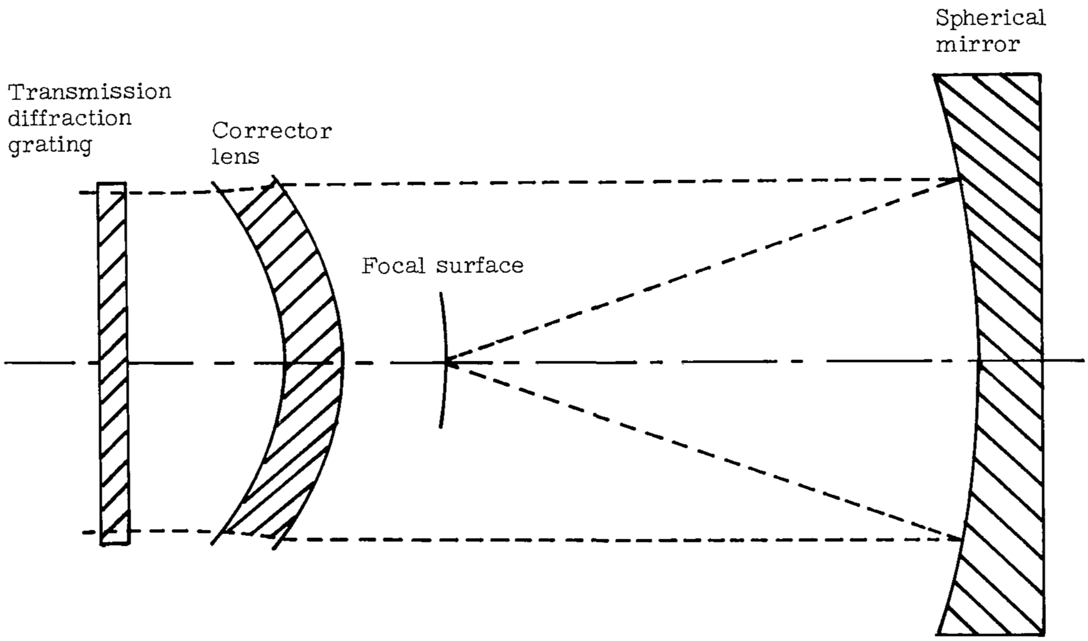


Figure 4.- Sketch of f/1.3 Maksutov optical system.

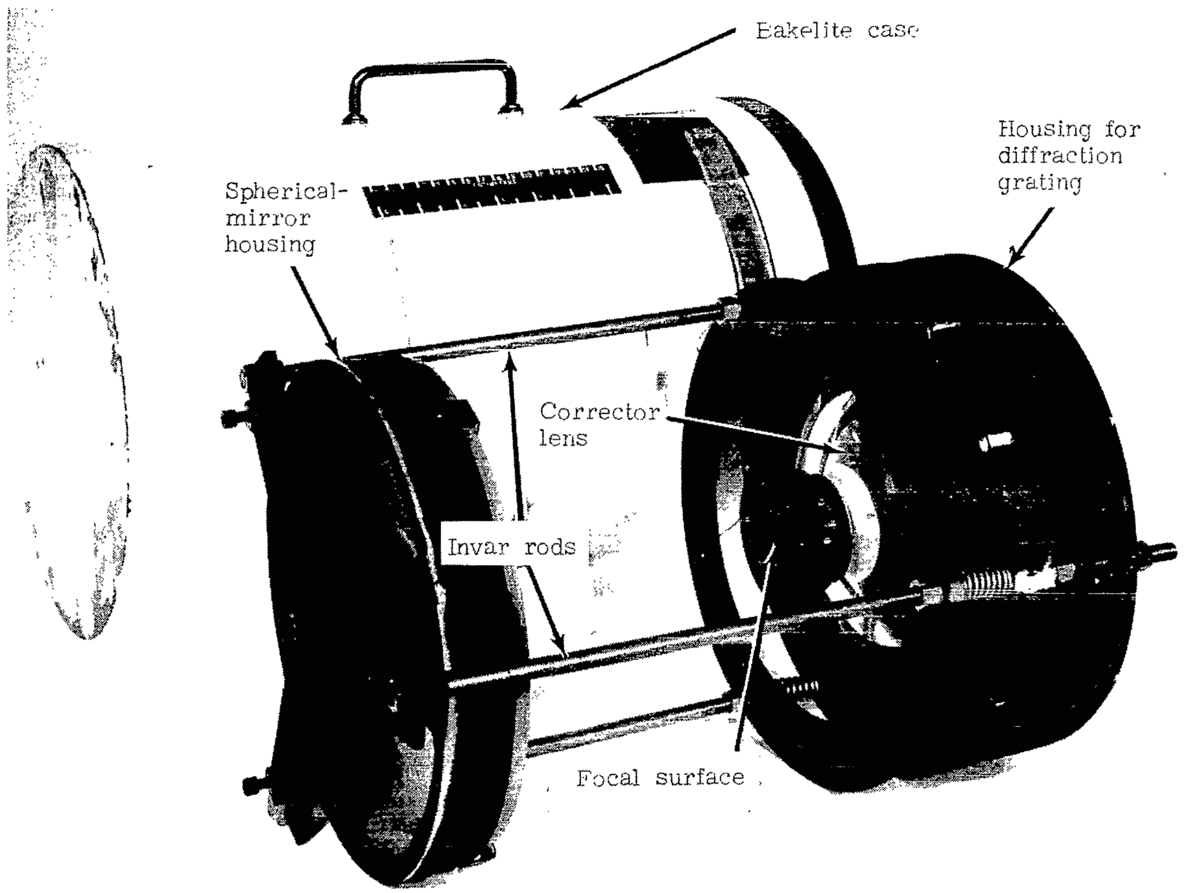


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Figure 5.- Case and optics of 15-cm-aperture, f/1.3 Maksutov slitless spectrograph.

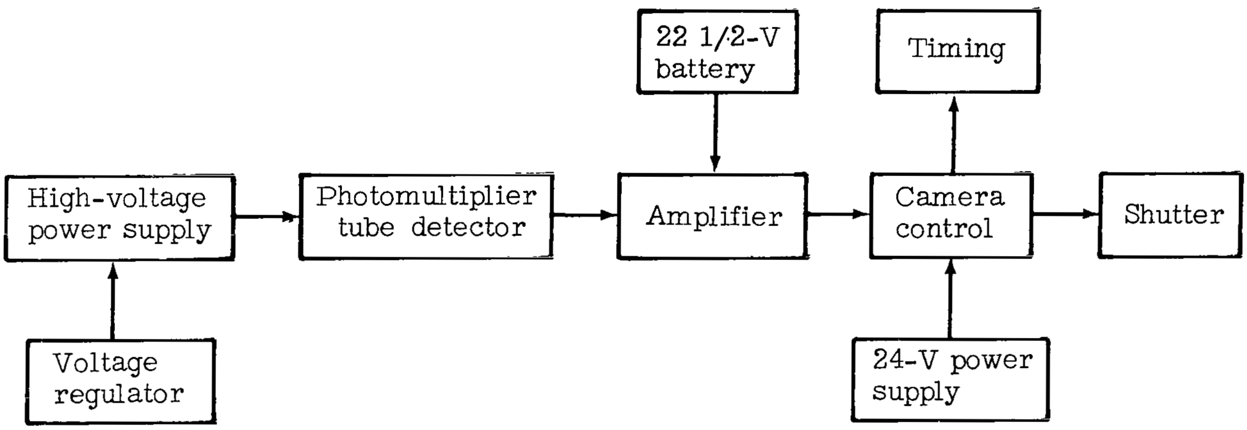

Figure 6.- Block diagram of photoelectric meteor detection shutter system.

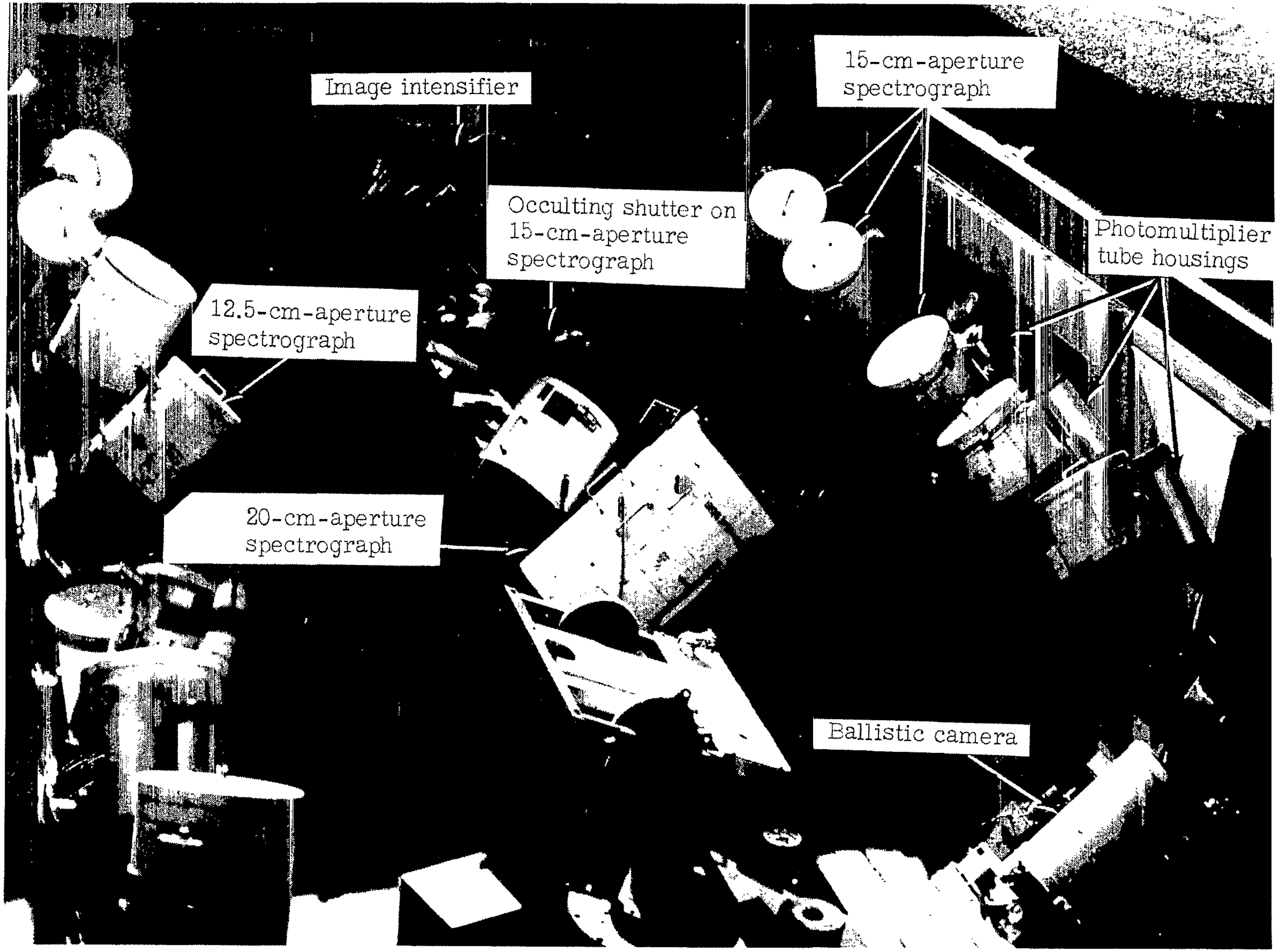

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Figure 7.- Meteor spectrographs in east observation room (August 1969).

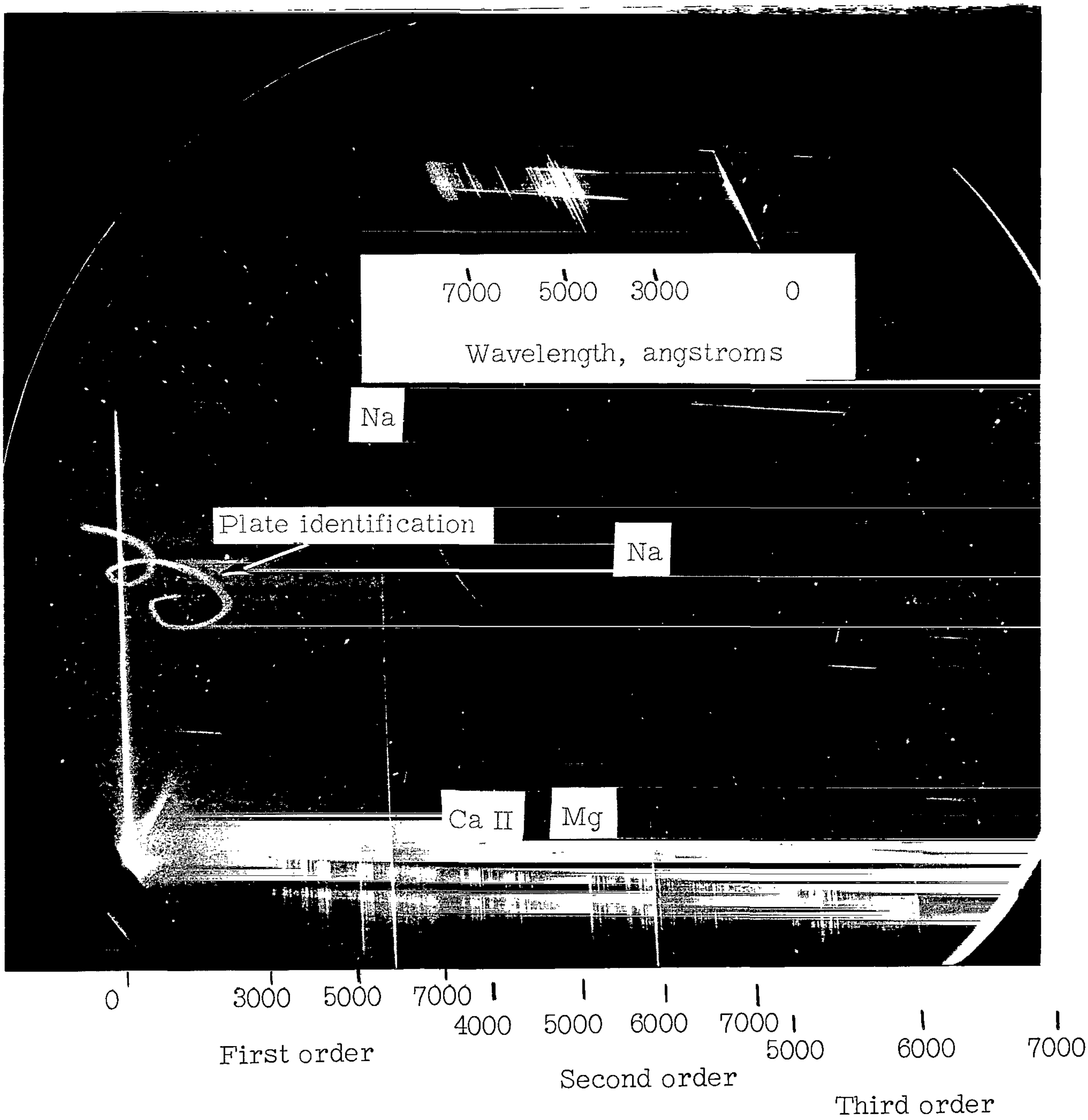

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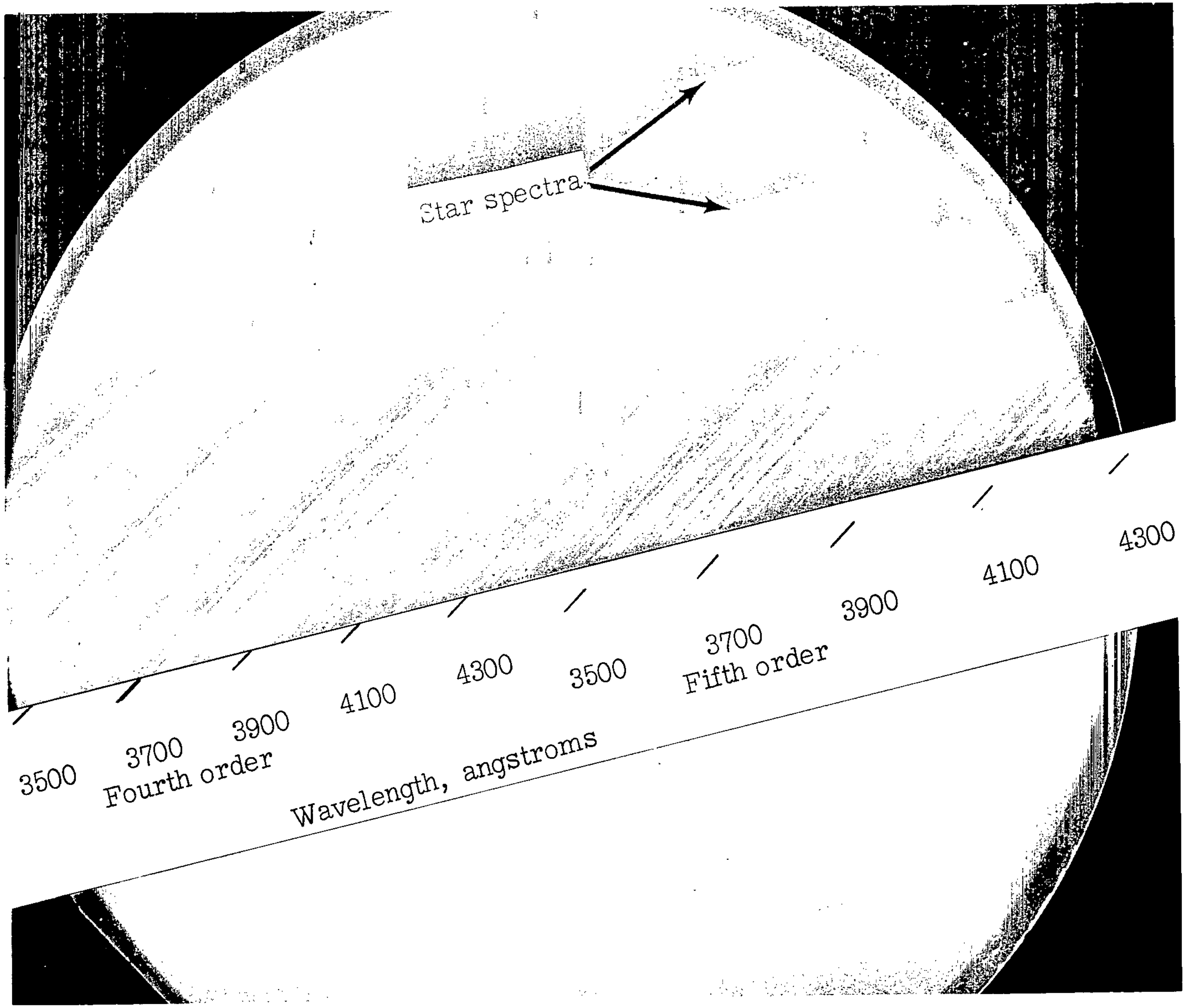
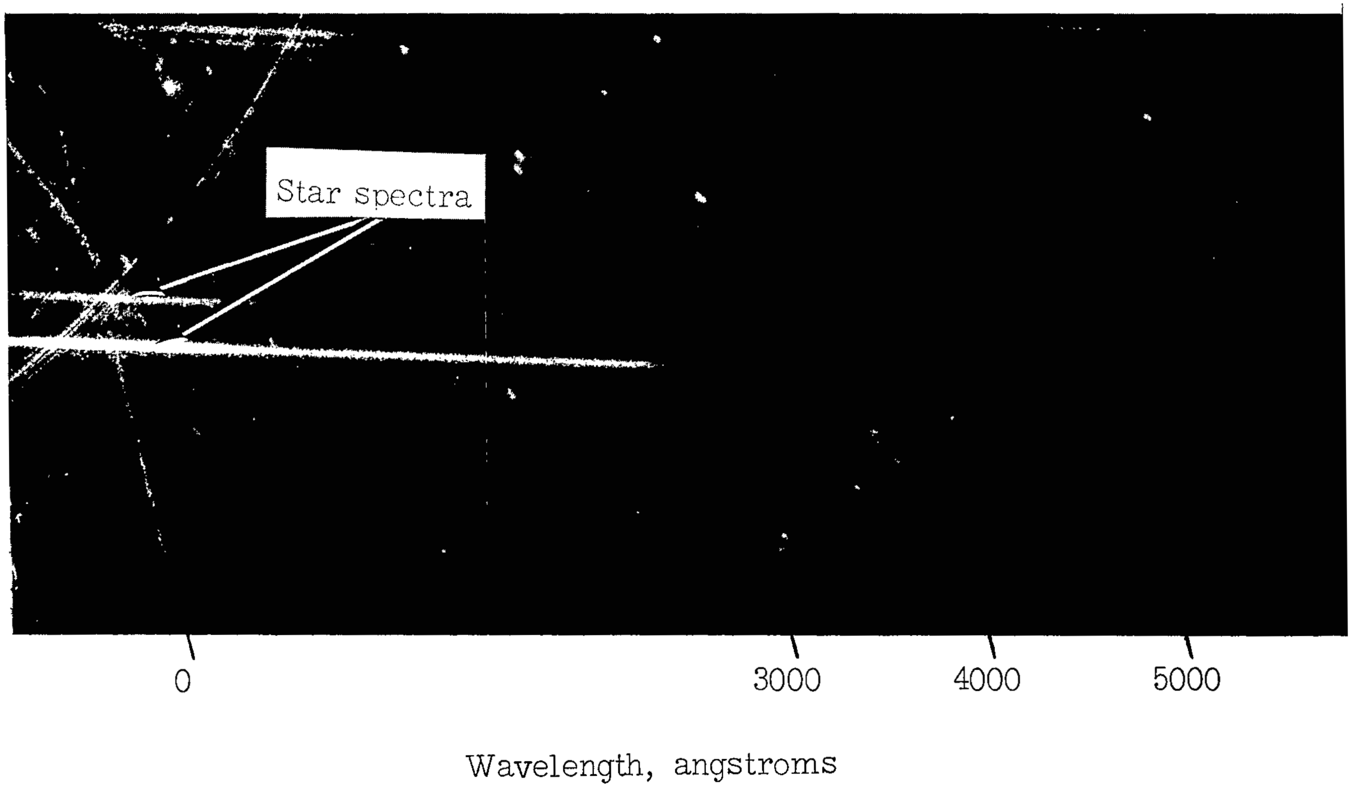
Figure 8.- Enlargement $\left(\times 3\frac{1}{2}\right)$ of spectra of two Leonid meteors.



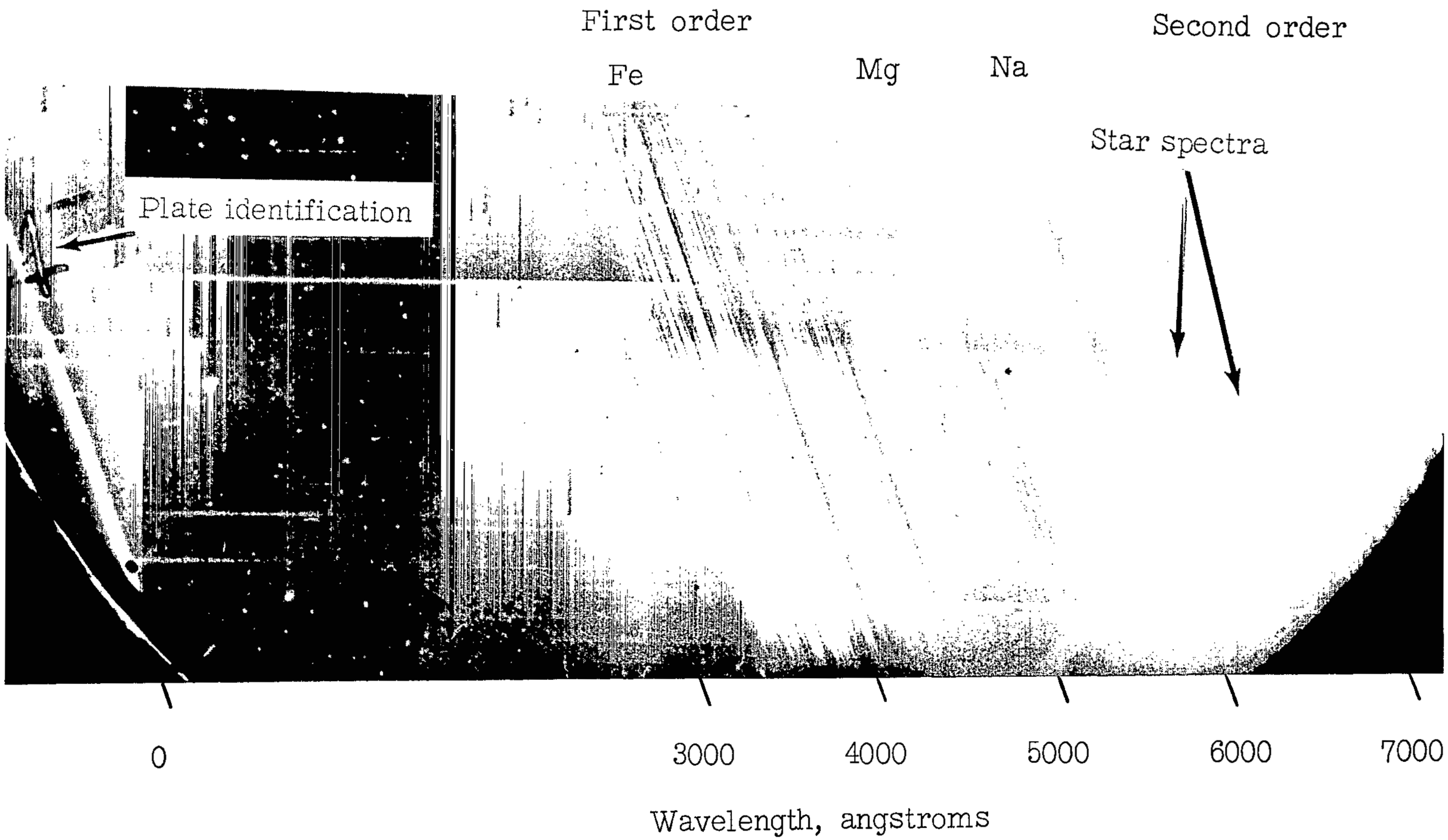
L-71-584

Figure 9.- Enlargement (× 2) of spectrum of an iron meteor.



L-71-585

Figure 10.- Enlargement (× 10) of spectrum of a faint continuum radiation meteor.



L-71-586

Figure 11.- Enlargement (× 3) of spectrum of a Taurid meteor.

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