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30 September, 1982 File Référence

Final Report on the Research Study of:-

Meteors and Meteor Spectra Analysis

(NASA Contract/Order No. H-43052B (NRC 40-814))

This Final Report is further to:-

ITEM-A Progress Report dated 17 June, 1981
ITEM-B Abstract of Final Report dated 29 March, 1982.

The initial phase of the photometry, as noted in ITEM-B, has involved 17 meteor spectra consisting of 8 Geminid spactra, 6 Orionid spectra and 3 Eta Aquarid spectra. These have been chosen out of a data bank of SEC and SIT vidicon records of some 2000 meteors observed at Mt. Hopkins, Arizona, and at Springhill, Ontario (see ITEM-A). Among these 17 spectra (listed in the APPENDIX, page 1) the Geminid spectra are of the best quality and are being used primarily for the identification of the atomic lines and molecular bands that normally appear on video-tape spectra. The Geminid records are also the data used for developing calibration techniques in photometry. The Orionid and Eta Aquarid spectra have been chosen for early analysis because of the current interest in all physical and chemical data relating to Comet Halley. Work on examples of spectra from other showers is also in progress and will be proceeded with as rapidly as possible.

One of the best spectra among the 17 chosen for the initial study is No. 74G 658/1242V, which exhibits sixty identifiable features. The atomic multiplets and molecular bands which are the major contributors to this spectrum are listed in the APPENDIX, pages 2 - 5.

The first calibration curves for use in measuring the luminous intensity of meteor-spectrum features were based on measures of zero-order star images (see Sky and Telescope, vol. 57, p. 22, 1979). A more reliable technique is to use the spectra of standard stars. A typical calibration curve, based on 7 star spectra recorded at the same time as meteor spectrum No. 74G 209/1042V, has been reproduced in the APPENDIX page 6. Once the general form of video-tape calibration curves has been established we can carry out relative photometry even if suitable standard stars are absent from the record of a given meteor spectrum.

The general rule for extrapolation from the detailed spectra, representing the bright meteors, to the less-detailed spectra, representing faint meteors, has been followed throughout this investigation.

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For example, at the beginning of this investigation it was important to understand the relation between the individual pixels of the video tape and the spectrum features being measured. Contours of grey-scale numbers were drawn manually as illustrated in the APPENDIX, page 7. More recently a small-computer program plots the grey-scale values along the star spectra or the meteor spectra, thus speeding up the analysis.

At the recent XVIII General Assembly of the International Astronomical Union in Patras, Greece, 17-26 August, 1982, a paper titled "Current Trends in Meteor Spectroscopy" was presented at Joint Discussion V. This paper is now in press in "Highlights of Astronomy", volume 6. A copy has been attached to this report, along with copies of four other papers previously published and related to this research project.

Signed:- Peter M. Millman
Peter M. Millman

Attached:- APPENDIX, 7 pages
ITEM-A
ITEM-B
Published Papers - Quadrantid Meteors from 41,000 feet
Video Techniques in Comet-Debris Studies
115 Years of Meteor Spectroscopy
Summary of IAU Symposium 90
Current Trends in Meteor Spectroscopy

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List of Meteor Spectra being studied in the initial phase of the Photometry

Spectrum Number	Date			Time (UT)			Shower
				h	m	s	
74G 188/1029V	12/13	December,	1974,	06	53	27	Geminid
74G 209/1042V	"	"	"	07	22	29	"
74G 299/1106V	"	"	"	09	21	12	"
74G 500/-----V	13/14	"	"	07	14	04	"
74G 658/1242V	"	"	"	10	21	14	"
74G 708/1273V	"	"	"	11	07	40	"
74G 909/1418V	14/15	"	"	10	07	39	"
74G 946/1436V	"	"	"	10	54	41	"
74O 9V	18/19	October,	1974,	06	29	20	Orionid
74O 11V	"	"	"	07	44	20	"
74O 12V	"	"	"	08	03	18	"
74O 17V	19/20	"	"	05	15	39	"
74O 18V	"	"	"	05	17	34	"
74O 19V	"	"	"	05	52	16	"
75E 10V	06/07	May	1975,	07	36	26	Eta Aquarid
75E 11V	"	"	"	07	36	49	"
75E 23V	09/10	"	"	05	17	57	"

Meteor 74G 658/1242 V 1.

Grade	No.	λ from inter. plot max light	λ from pixel plot	main contributor λ standard [——]	secondary contributors	Grey Scale Peak	WIDTH (½ point) Ent. Å
D	0	3390		N_2 2nd+		69	60
C	1	3480	3496	Fe 6		80	50
C	2	3590	3595	Fe 23	N_2 2nd+ CN I	77	70
D	3	3700	3707	Fe 5	N_2 2nd+	73	30
D	3a	3750		Fe 21	Fe 5 N_2 2nd+	81	20
D	4	3815	3850	Mg 3	Fe 4 Fe 21	81	20
B	5	3890	3913	Fe 4	CN II	104	70
D	6		3945	Fe 4		90?	
C	7	3980	3976	N_2 2nd+	Fe 43	93	40
C	8	4050	4045	Fe 43	N_2 2nd+ Mn 2	100	40
A	9	4230	4226.7	[Ca 2]	CN III Fe 3 Fe 42	118	100
C	10	4360	4337	Fe 2	Fe 41 Fe 42	109	30
B	11	4420	4427	Fe 2	Fe 41	116	60
B	12	4500	4492	Fe 2		110	25
C	13	4590	4594	Mg 1		100	50
C	14	4680	4697	Mg 11	Mg 10	98	70

2/

Meteor 74G658/1242 V

Grade	No.	λ inten. plot max. light	λ pixel plot	main contributor λ standard [ ]	secondary contributor	Grey Scale Peak	WIDTH (½ point inten.) Å
D	14a	4755		C_2 II?	Na 11?	93	
D	15		4846	Fe 318?		93	
D	16		4888	Fe 318		101?	
C	17	4900.	4913	Fe 318		106	40
C	18	4990	4970	Fe 16		108	50
C	18a	5080		Fe 1	Fe 16	108	70
A	19	5170	5176.8	[Mg 2]	Fe 1 Fe 37	130	75
B	20	5260	5274	Fe 15	Fe 37 Ca 22	118	75
B	21	5350	5344	Fe 15	Fe 37	116	80
D	21a	5405		Fe 15		108	20
C	22	5440	5458	Fe 15		110	20
B	23	5530	5539	Mg 9		110	40
A	23a		5577.4	[O 3 F] (delayed)			
D	24	5610	5604	Ca 21		100	50
C	25	5705	5729	Mg 8	Na 6? N_2 1st$^+$?	104	30
C	26	5790	5814	N_2 1st$^+$		103	50

Meteor 74G 653/1242.V

Division between ------- main N_2 band

Grade	No	λ inten plot max light	λ pixel plot	main contributor λ standard [ ]	secondary contributor		Grey Scale Peak	WIDTH (½ point inten) Å
A	27	5880	5892.9	[Na 1]	N_2 1st+		112 (sk)	$80<^{20}_{60}$
D	28		5941	N_2 1st+			104?	
D	29	6650	6035	N_2 1st+			91	50
B	30	6160	6177	Ca 20	Ca 3	0 10	106 (sk)	$100<^{40}_{60}$

D	31		6273	N_2 1st+?			90?	
B	32	6310	6328	N_2 1st+	Mg 23?		105	60
A	33	6440	6439.1	[Ca 18]	N_2 1st+	0 9	116 (sk)	$80<^{20}_{60}$
B	34	6570	6580	Ca 1	N_2 1st+		110	70
C	35	6700	6703	N_2 1st+			97	20
C	35a	6765	6802	N_2 1st+			96	30
D	36		6812	N_2 1st+			80?	
C	37	6870	6877	N_2 1st+			72	40

D	37a	6960		N_2 1st+			63	30
C	38	7040	7045	N_2 1st+			77	40
B	39	7140	7131	Ca 30	N_2 1st+		101	60
C	40	7240	7272	N_2 1st+			85	50

Meteor 74G 658/1242 V

Grade	No.	λ inten. plot max (light)	λ pixel plot	main contributor λ standard [ ]	secondary contributor	Grey Scale Peak	WIDTH (½ point inten.) Å
D	41	7340	7351	N_2 1st$^+$?		86	30
C	41a	7380	7384	N_2 1st$^+$		96	60
B	42	7440	7469	N 3	N_2 1st$^+$	102 (sk)	$100<^{20}_{80}$
C	43	7570	7564	N_2 1st$^+$?		82	40
D	44	7705	7680	N_2 1st$^+$?		81	30
A	45	7770	7773.8	[O I]		121 (sk)	$100<^{20}_{80}$
D	46		7860	N_2 1st$^+$?		86?	
D	47		7984	O 19		66?	
D	47a	8050		N_2 1st$^+$		41	30
B	48	8200	8208	N 2	N_2 1st$^+$	48	60
B	49	8440	8456	O 4		34	50
B		(8682) from low dispersion		N 1			

Summary

A	- features	6
B	- "	13+1
C	- "	20
D	- "	20
	Total	59+1

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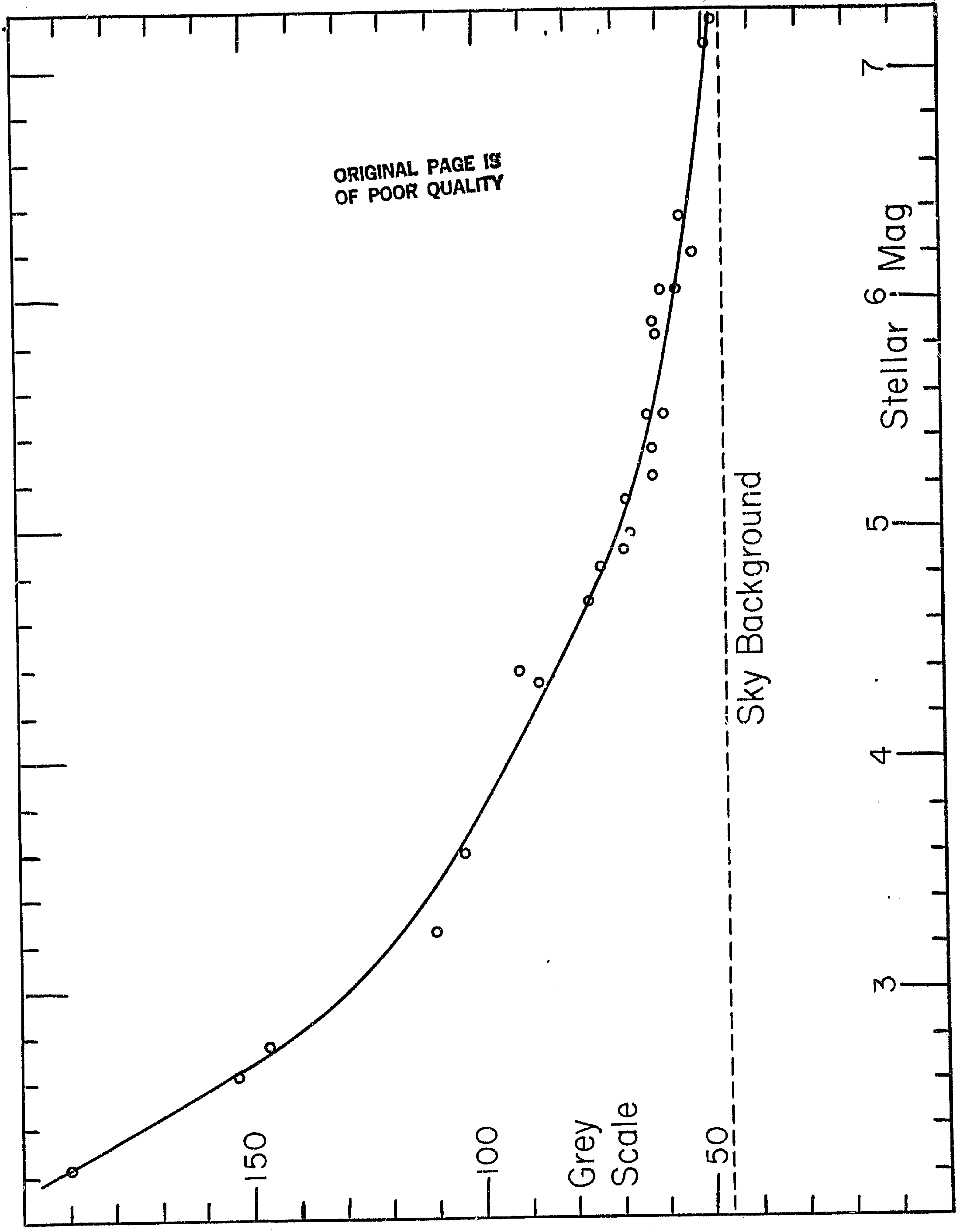
150
100
Grey Scale
50
Sky Background
3
4
5
6
7
Stellar Mag

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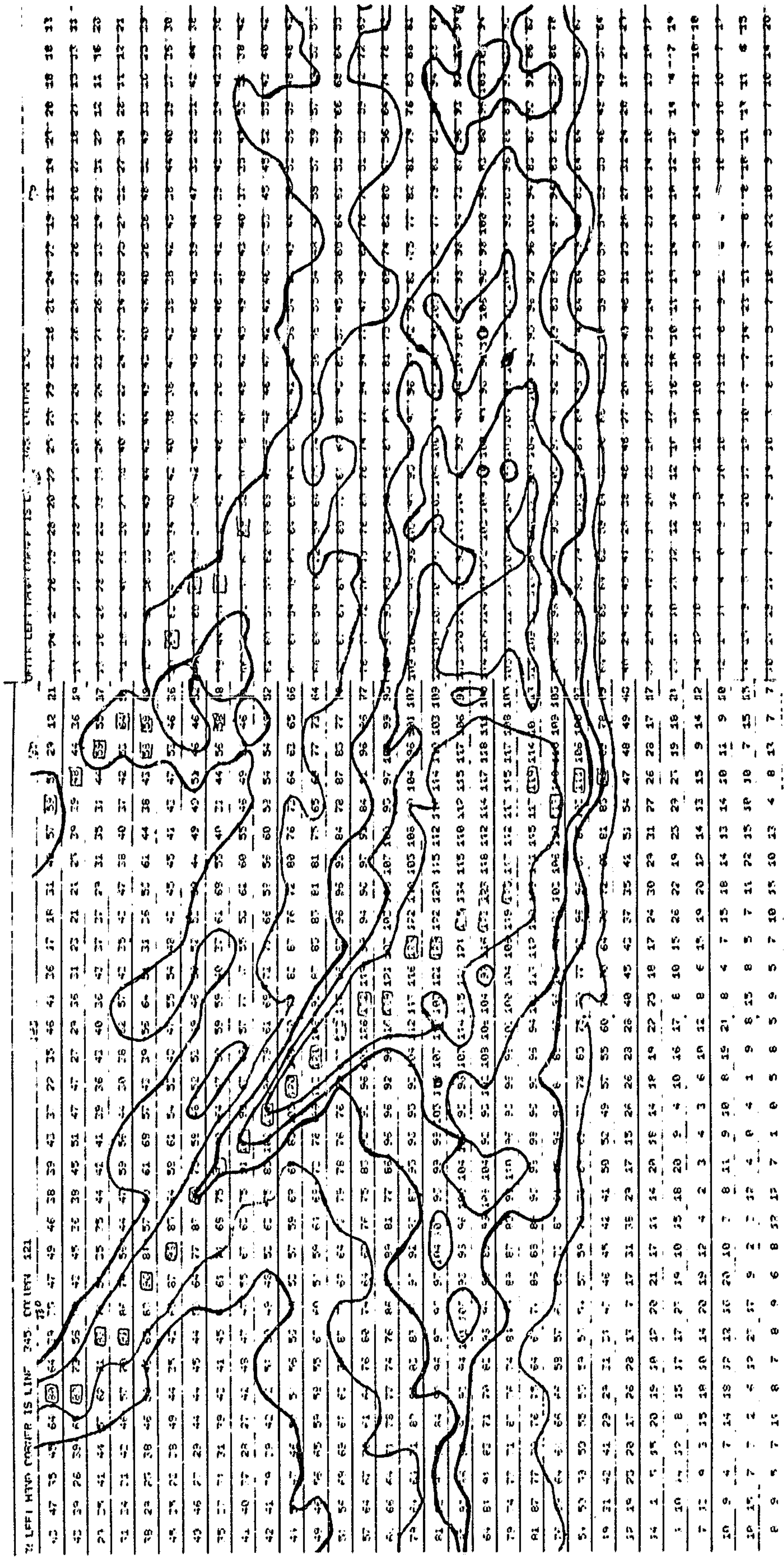

Example of manually drawn intensity contours for Meteor Spectrum 74G 658/1242V to study the relation between the pixel numbers and the resolution possible in the case of video-tape records.
(Compare with illustration in Sky and Telescope, vol. 57, p. 23, 1979.)

ITEM-A

Progress Report on the Research Study of Meteors and Meteor Spectra Analysis

(17 June, 1981)

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INTRODUCTION

For a study of the chemistry of the cometary meteoroids, those small solid particles in interplanetary space that are fragments of comets, the use of closed-circuit television type observing systems has greatly improved the statistical possibilities of quantitative abundance estimates. Equipment such as SEC or SIT Vidicon cameras can produce basic data on standard video tape and make possible the recording of the spectra of faint shower meteors, which are always more numerous than the bright meteors. As a result we can extend our chemical study to smaller particles and we have a larger data bank than is available from the more conventional method of recording meteor spectra by photography.

The two main problems in using video-tape meteor-spectrum records are;-

(a) the video-tape recording in its present form has a much lower resolution than the photographic technique,

(b) video tape is a relatively new type of data storage in astronomy and the methods of quantitative photometry have not yet been fully developed in the various fields where video tape has been used.

The first problem can be solved to a great extent by using the most detailed photographic meteor spectra to calibrate the video-tape records and to make positive identification of the more prominent chemical elements appearing in the spectra. To solve the second problem good progress is being made in developing standard photometric techniques for the analysis of video tape records of meteor spectra. This work is active primarily at the Marshall Space Flight Center in Huntsville, Alabama, and at the Herzberg Institute of Astrophysics in Ottawa, Ontario.

OBSERVATIONAL MATERIAL

Two primary data banks have been used in this research study. The first consists of upwards of 1600 spectroscopic records of meteors secured by the Marshall Space Flight Center in the middle seventies at Mt. Hopkins, Arizona. The second data bank has resulted from a cooperative program of the Dudley Observatory, Albany, N.Y.; the Smithsonian Astrophysical Observatory; Cambridge, Mass., and the Herzberg Institute of Astrophysics, Ottawa, Ont.; operated during the years 1974 to 1977 inclusive and supported in part by the National Science Foundation, Washington, D.C. This cooperative program has resulted in some 340 spectroscopic meteor records. The quantity and quality of the data in the first bank is higher, while the coverage of various cometary showers is broader, and records of the same meteors observed by other methods are available, in the second bank (see Appendix, pages 1 and 2).

For the initial photometric study examples have been chosen from these two data banks on the basis of both the quality of the chemical information contained and the breadth of coverage of the meteoroids fragmented from different comets (see Appendix, page 3). The seven meteor showers from which data is being processed for photometry give us a reasonably good variety of sources. These vary from showers with denser meteoroids that penetrate relatively lower in the atmosphere, Class B*, and for which the parent comets have apparently disintegrated or are invisible, to the more fragile meteoroids that appear higher, Class C_2, and for which the parent comets are known. It is of interest to note that among the 5 meteor showers in this study for which the comets are known, two are from Comet Halley.

PHOTOMETRIC PROCEDURES

In developing the photometric techniques for reducing these data emphasis has been placed on finding automatic read-out methods, after the initial reductions have been made. The latter inevitably involve a good deal of manual plotting. The first requirement is to be able to digitize the original video tape, which is normally in analogue form. We have generally used the 8-bit digitization system giving a total of 255 steps on a grey scale from one extreme to the other. Repeat read-outs of the pixel gray-scale values are in perfect agreement, and reasonable averaging of multiple readings of various locations on the record for parameters, such as background sky values for example, are generally within a small number of gray-scale steps. There seems to be no reason why video-tape records cannot be used for relative photometry among the various meteor showers and quite possibly also for absolute photometry when good standard stars are available for calibration.

As a by-product meteor heights can be calculated from single-station video-tape records of meteor spectra if a standard shower velocity and radiant position are assumed for each meteor observed. Preliminary examples of meteor heights are given (see Appendix, page 4). Publications that have appeared since my last final report, made in March, 1978, are also listed (see Appendix, page 5). Typical examples of video-tape meteor spectra from six cometary sources are attached in four plates.

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* Major height differences for meteor trails result from the different velocities with which the meteoroids enter the earth's atmosphere. In determining the Class of the meteoroids of a shower, A, B, C_1, C_2, etc., the velocity-of-entry of the meteoroid is first allowed for.

The Marshall Space Flight Center
Program of Meteor Observation

Prior to 1972 Meteor Spectra were
recorded with the SEC Vidicon equipment
during the Perseid Shower at the
Springhill Meteor Observatory, Ontario.

1972 – 137 meteors were recorded at Mt. Hopkins,
Arizona, with the SEC Vidicon, during
the Geminid Shower. see Can. J. Phys.
53, 1939–1947,
1975.

1974 – 1300 meteors
recorded on 4 nights
at Mt. Hopkins during the
Geminid Shower, using the SEC Vidicon

Other recordings of the Quadrantid
meteor shower etc. are also
available

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The Dudley - Herzberg - Smithsonian Program of Meteor Observation (1974-1977) at Springhill Meteor Observatory and Shiels Meteor Station

45° 11'.8 N
75° 28'.3 W

45° 15'.0 N
76° 18'.3 W

Total Nights on which some observations were made

YEAR	NIGHTS
1974	37
1975	37
1976	47
1977	35

Grand total nights:- 1974-1977 $\boxed{156}$

Grand Totals of Data Secured

Vidicon (SIT) spectroscopy (Springhill)	341	meteors in 128 hrs
Photographic spectroscopy (Springhill)	1354	camera-hours
" " (Shiels)	5145	camera-hours
Meteor photographs	40	
High-power Meteor Radar records	344	hours
Low-power Meteor Radar records	2472	"
Visual Meteors recorded	833	

Shower Meteoroids Processed for Photometry

	No. Spectra	ORBIT			Class	Comet
		a	q	q′		
Geminids	25	1.4	0.14	2.6	B	
Quadrantids	12	3.1	0.98	5.2	B	
Ursids	6	5.7	0.86	11.		Tuttle
Orionids	6	15.	0.57	30.	C_2	Halley
η Aquarids	2	13.	0.55	25.		Halley
Perseids	4	28.	0.98	55.	C_2	Swift-Tuttle
Lyrids	2	28.	0.90	55.		Thatcher

a = semimajor axis (in astronomical units-au)
q = perihelion distance from ⊙ " " "
q′ = aphelion " " " " " "

Class B = meteors whose luminous paths begin at medium heights

Class C = meteors whose luminous paths begin relatively high

GEMINID METEOR HEIGHTS

Meteor	Beginning	End	Maximum Light
74G209/1042V	107.5 km	84.9 km	93.5 km
74G267/1080V	105.2	85.7	
74G278/----V	100.1	80.4	
74G299/1106V	106.4	87.2	92.0
74G461/----V	100.2	93.9	95.0
74G552/----V	99.8	80.2	
74G636/1233V	101.2	22.0	
74G638/----V	104.2	87.0	
74G658/1242V	100.6	80.8	
74G708/1273V	106.1	88.3	
Means	103.1	84.8	93.5

QUADRANTID METEOR HEIGHTS

Meteor	Beginning	End
76Q002V	101.0 km	93.1 km
76Q016V	101.7	95.0
76Q052V	103.3	87.5
76Q061V	106.9	99.9
Means	103.2	93.9

Publications issued since Final Report on Meteor Spectra Analysis(W 14425)

(dated 31 March, 1978)

Video detection and analysis techniques of transient astronomical phenomena

1979 by Clifton, K.S., Reese, Jr., R., and Davis, C.W.
Optical Engineering vol. 18, pp. 291-297.

Video Techniques in Comet-Debris Studies

1979 by Millman, P.M., and Clifton, K.S.
Sky and Telescope vol. 57, pp. 21-23.

Interplanetary Dust

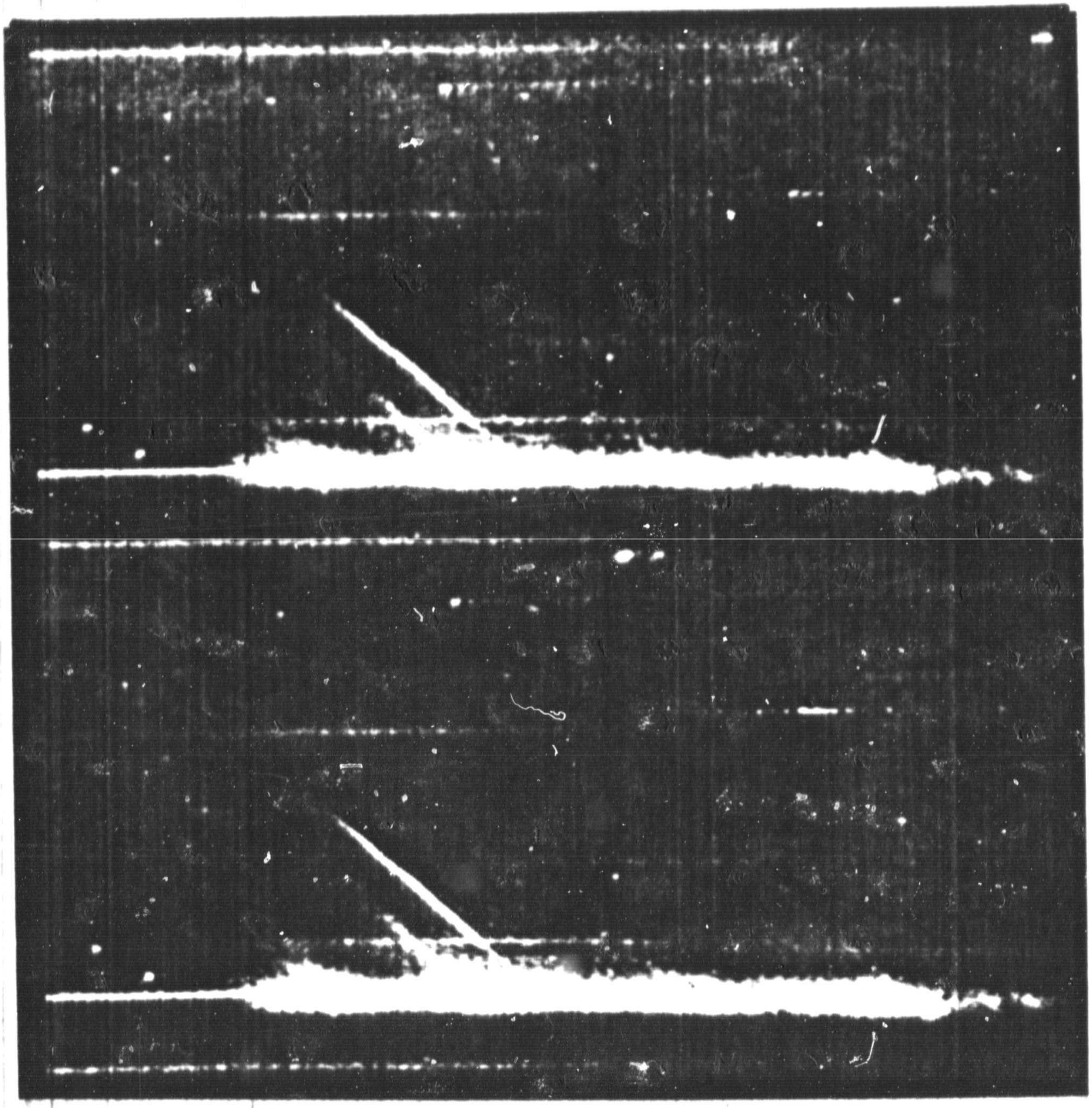
1979 by Millman, P.M.
Naturwissenschaften vol. 66, pp. 134-139.

One Hundred and Fifteen Years of Meteor Spectroscopy

1980 by Millman, P.M.
"Solid Particles in the Solar System" eds. I. Halliday & B.A. McIntosh,
D. Reidel Pub. Co., pp. 121-128.

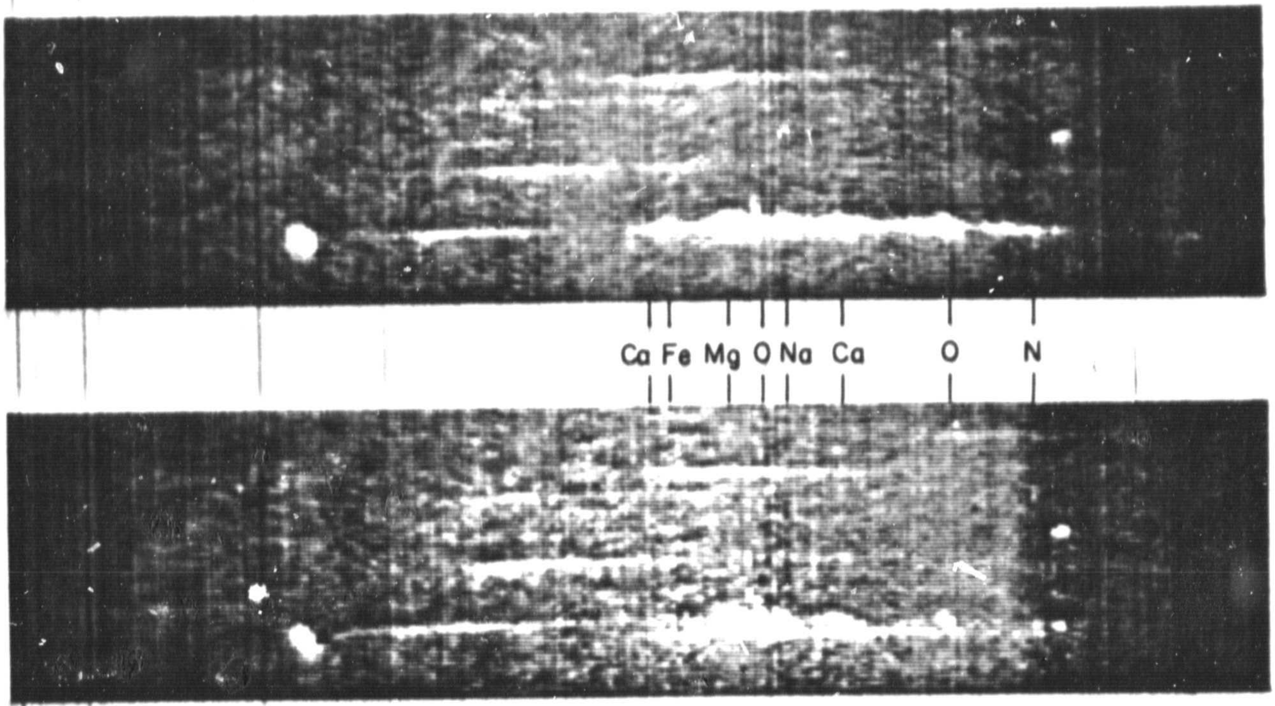
Summary of IAU Symposium 90

1980 by Millman, P.M.
"Solid Particles in the Solar System" eds. I.Halliday & B.A. McIntosh,
D. Reidel Pub. Co., pp. 429-431.

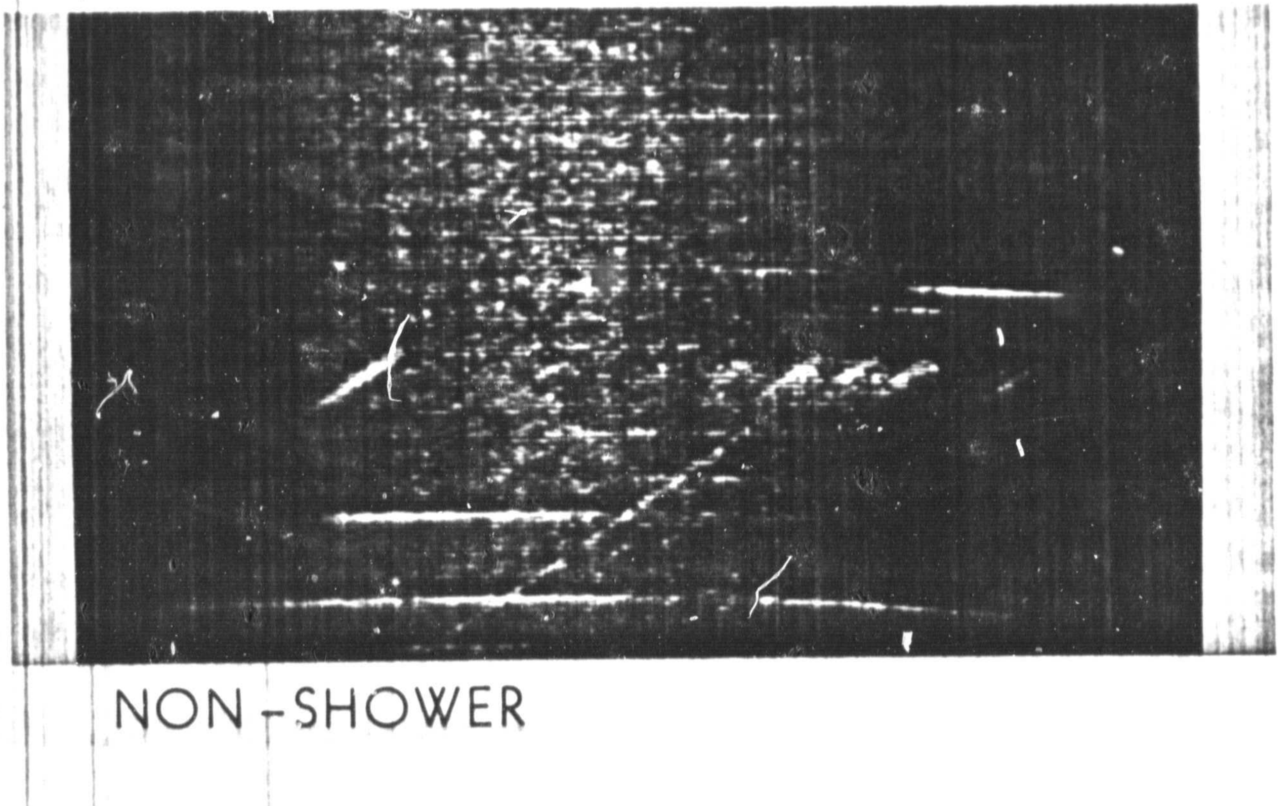


GEMINID SPECTRUM

74G 658/1242V



QUADRANTID



NON-SHOWER

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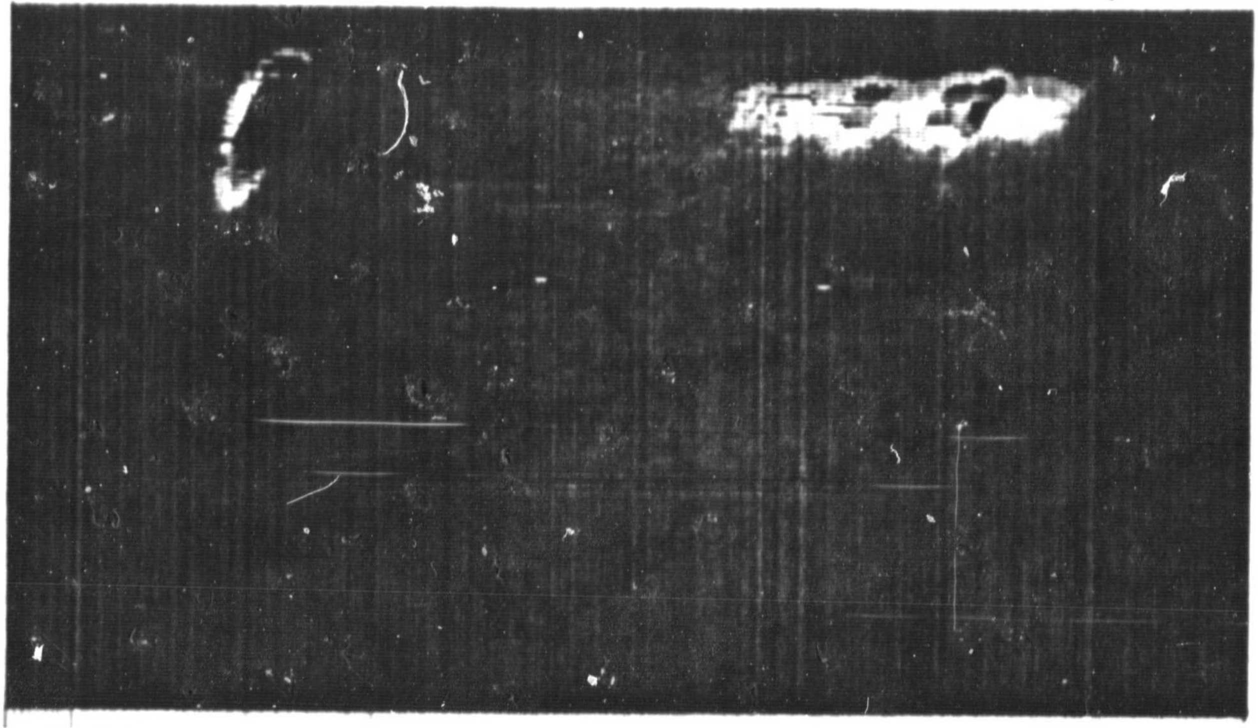
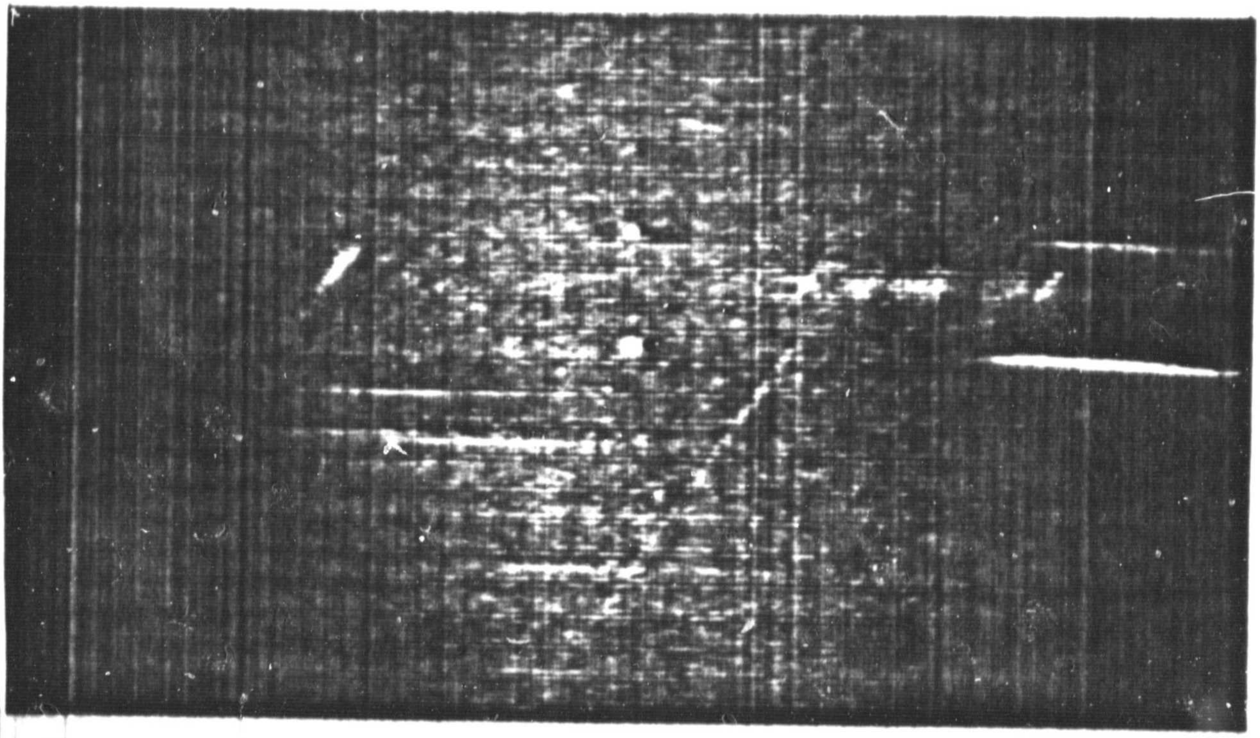


ORIONID



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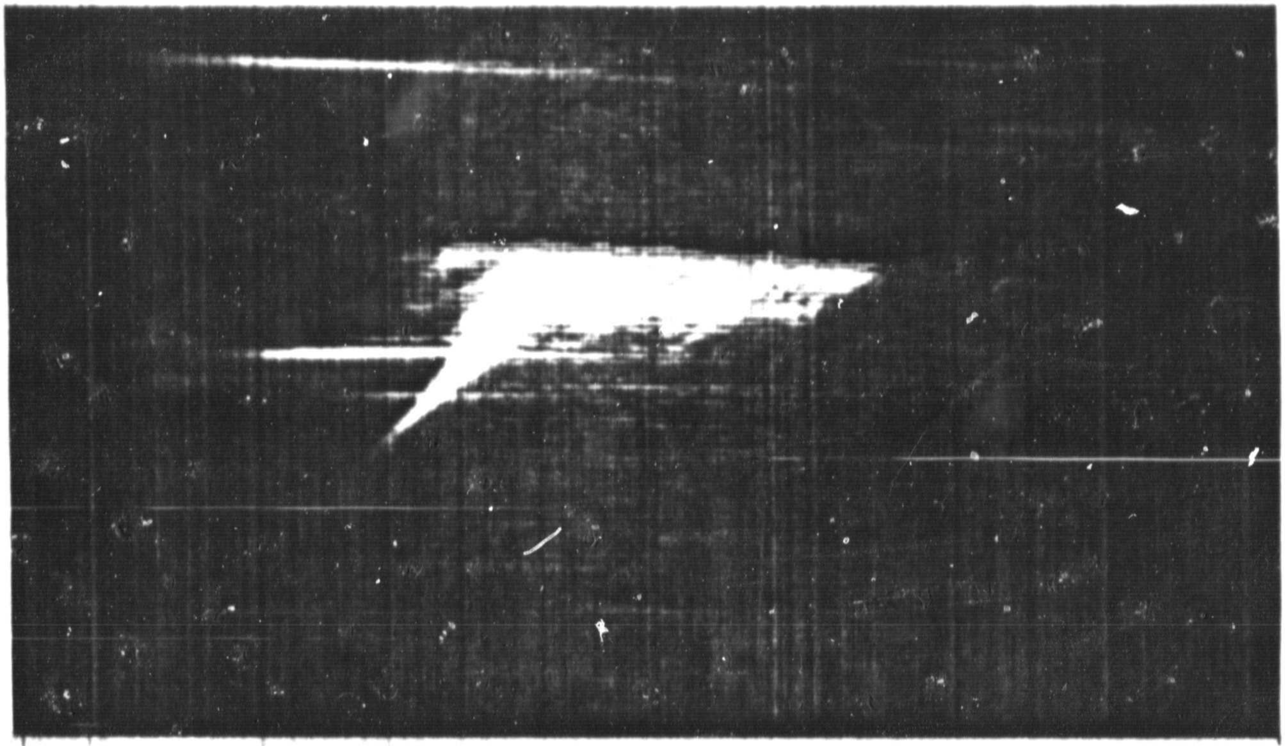

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ITEM-B

29 March, 1982

File Référence

NASA Contract/Order H-43052B (NRC 40-814)

Brief Abstract of the Final Report on the Research Study of Meteors and Meteor Spectra Analysis

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A high dispersion Geminid spectrum of good quality was studied in depth as a guide to the identification of features in other spectra of lower dispersion and poorer quality. Sixty individual features were measured in the high dispersion spectrum, resulting in the identification of 44 multiplets from 7 neutral atoms (N, O, Na, Mg, Ca, Mn, Fe) and 6 band systems from 3 diatomic molecules (CN, C_2, N_2). The spectra of some 30 standard stars, recorded at the same time as the meteor spectra, were used to produce calibration curves for the determination of the intensities of the atomic and molecular features in the meteor spectra. All stellar spectra were measured at 8 different wavelengths and this material was combined to produce satisfactory calibration curves. Further calibration checks resulted from the use at Springhill of a specially designed photometer and by the use of the zero-order star images on the video tape to produce curves similar to that published in Sky and Telescope, vol. 57, p. 22, 1979.

Work is now continuing in the application of the photometric techniques developed to the analysis of video-tape spectrographic records of both meteors and lightning. Additional showers which will be studied and for which video-tape data are available, include the Quadrantids, Ursids, Perseids and Lyrids. The last three showers represent particles from comets Tuttle, Swift-Tuttle, and Thatcher respectively. This entire program is a cooperative study among the three institutions - Marshall Space Flight Center, Smithsonian Astrophysical Observatory, and the H.I.A.

Signed:- Peter M. Millman
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ITEM-B
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29 March, 1982

File Reference

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CURRENT TRENDS IN METEOR SPECTROSCOPY

N83 14043

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INTRODUCTION

A detailed summary of the progress of meteor spectroscopy over more than a century has been published recently (Millman 1980), and only a few historical facts will be noted here. Serious research in this field was initiated by Alexander Stewart Herschel, a grandson of Sir William Herschel, in 1863 (Herschel 1865). Originally, the observational data were entirely visual records but, in the first decade of the twentieth century, a brief program for the photography of meteor spectra was carried out at the Moscow Observatory by S. Blajko (1907). Interest in this type of observation developed slowly and further programs were not attempted until the thirties. At the outbreak of World War II some 60 meteor spectra had been photographed. In the post-war period a general interest in the upper atmosphere led to the development of more efficient meteor cameras which employed replica gratings, and later electronic image-intensification systems recording on video tape (Hemenway et al. 1971; Clifton et al. 1979). As a result several thousand meteor spectra are now available for study.

GENERAL NATURE OF METEOR SPECTRA

The majority of these instrumental records have been produced by meteors which are members of one of the recognized meteor streams moving along comet orbits, and thus we have a large quantity of data produced by cometary fragments entering the earth's atmosphere. A unique feature is that each of these meteoroids can be identified with a specific comet, and this holds true even though, as is the case with the Geminid, the Quadrantid and the δ Aquarid meteor streams, the comets have not been observed. We thus have the opportunity of looking for possible differences in the chemical abundances among the various streams.

Meteor spectra exhibit the bright lines of the neutral and singly-ionized atoms present in the gaseous mixture of the vaporized meteoroid with the earth's atmosphere. Also present in meteor spectra are the band systems of some common diatomic molecules. The luminosity is produced essentially by collisional excitation of both atoms and molecules. If any continuum is present it is relatively faint and difficult to separate from the unresolved faint atomic lines and molecular bands.

RESOLUTION IN METEOR SPECTRA

The photographic data cover the wavelength range from 3100 A to 9000 A and have the higher resolution with wavelengths determined to one angstrom or better in some cases. The video-tape data are more numerous and extend to fainter meteors, but with lower resolution. Typically, the pixels of the television-type display are spaced between 15 and 20 angstroms apart, so that wavelengths in the video-tape meteor spectra can be determined to about five angstroms. However, positive identification of the various features in these spectra is possible by using the photographic data for wavelength calibration. As an example of the more detailed video-tape spectra the Geminid spectrum published by Millman and Clifton (1979) may be noted. In this example some 60 features were measured and these have been identified as resulting primarily from 44 multiplets of 7 neutral atoms (N, O, Na, Mg, Ca, Mn, Fe) and 6 band systems of 3 diatomic molecules (CN, C_2, N_2).

HEIGHTS AND VELOCITIES

A very important property of the video-tape data is that we are provided with 60 views of the meteor spectrum per second or, if we combine pairs of the television raster fields into frames, we have 30 pictures per second with higher resolution. This makes it possible to follow in detail the build-up and decay of individual spectrum features. The height in the atmosphere of each segment of a stream meteor trail can be computed by measuring the zero-order images of stars and meteor, provided we adopt a standard radiant and velocity for each meteor stream.

In the currently available data bank of meteor spectra eleven major meteor streams are well represented, see Table 1. These streams have been listed in order of increasing velocity of entry into the earth's atmosphere as this parameter has the greatest effect on the nature of the spectrum. Meteor spectra are, in general, of low excitation and exhibit abnormally high intensities of the intercombination lines arising from the ground energy level of the neutral atom. As we progress from the low-velocity meteor streams to the high-velocity streams the excitation level rises and the lines from the first-ionized state of the atoms appear.

CHEMICAL ABUNDANCES

For the stream meteors the most prominent features, apart from those of oxygen and nitrogen, are from the elements sodium, magnesium, silicon, calcium and iron. Savage and Boitnott (1973) have determined the absolute luminous efficiencies of Na, Mg, Ca and Fe in the laboratory under conditions of collisional excitation and free molecular flow in the upper atmosphere. Using their values for 16 meteor-stream spectra the relative

Table 1

Major Meteor Streams for which Spectra have been Recorded

Meteor Stream	Velocity of Entry into Earth's Atmosphere	Associated Comet
Giacobinid	23 km/s	P/Comet Giacobini-Zinner
Taurid	30	P/Comet Encke
Ursid	35	P/Comet Tuttle
Geminid	36	
Quadrantid	43	
δ Aquarid	43	
Lyrid	49	1861 I Thatcher
Perseid	60	1862 III Swift-Tuttle
η Aquarid	66	P/Comet Halley
Orionid	67	P/Comet Halley
Leonid	72	1866 I Tempel-Tuttle

abundances for the four elements Na, Mg, Ca, Fe are close to Cameron's (1973) values for the solar system and agree with abundances in interplanetary dust found by other independent techniques (Millman 1979).

In cases where absolute abundances of various elements may be difficult to calculate, a comparison of the relative abundances of pairs of elements among different stream meteoroids may be carried out. The curves in Figure 1 have been drawn using values from Figure 4 of Savage and Boitnott's paper. Figure 1 herewith plots ratios between the absolute luminous efficiencies of pairs of neutral atoms, based on the measurements made on specific emission lines and plotted against a range of collisional velocities. It is not difficult to compare relative abundances of pairs of elements between two meteor streams where these curves do not have too great a slope in relation to velocity.

PHOTOMETRY

Photometric techniques for the determination of absolute luminosities in the spectrum lines of photographic data have been long established and pose no great problem. The same is not the case for video-tape data as the use of this system of recording is relatively new in astronomy. In a paper already referred to (Millman, Clifton 1979) photometric calibration of the digitized video-tape records was carried out by using the zero-order images of stars in an area of the sky near the meteor trail. This procedure has now been refined by using the spectra of stars from the video tape that has recorded the meteor spectrum. Only the stars contained in the Thirteen-Color Star Catalogue (Johnson, Mitchell 1975) are used,

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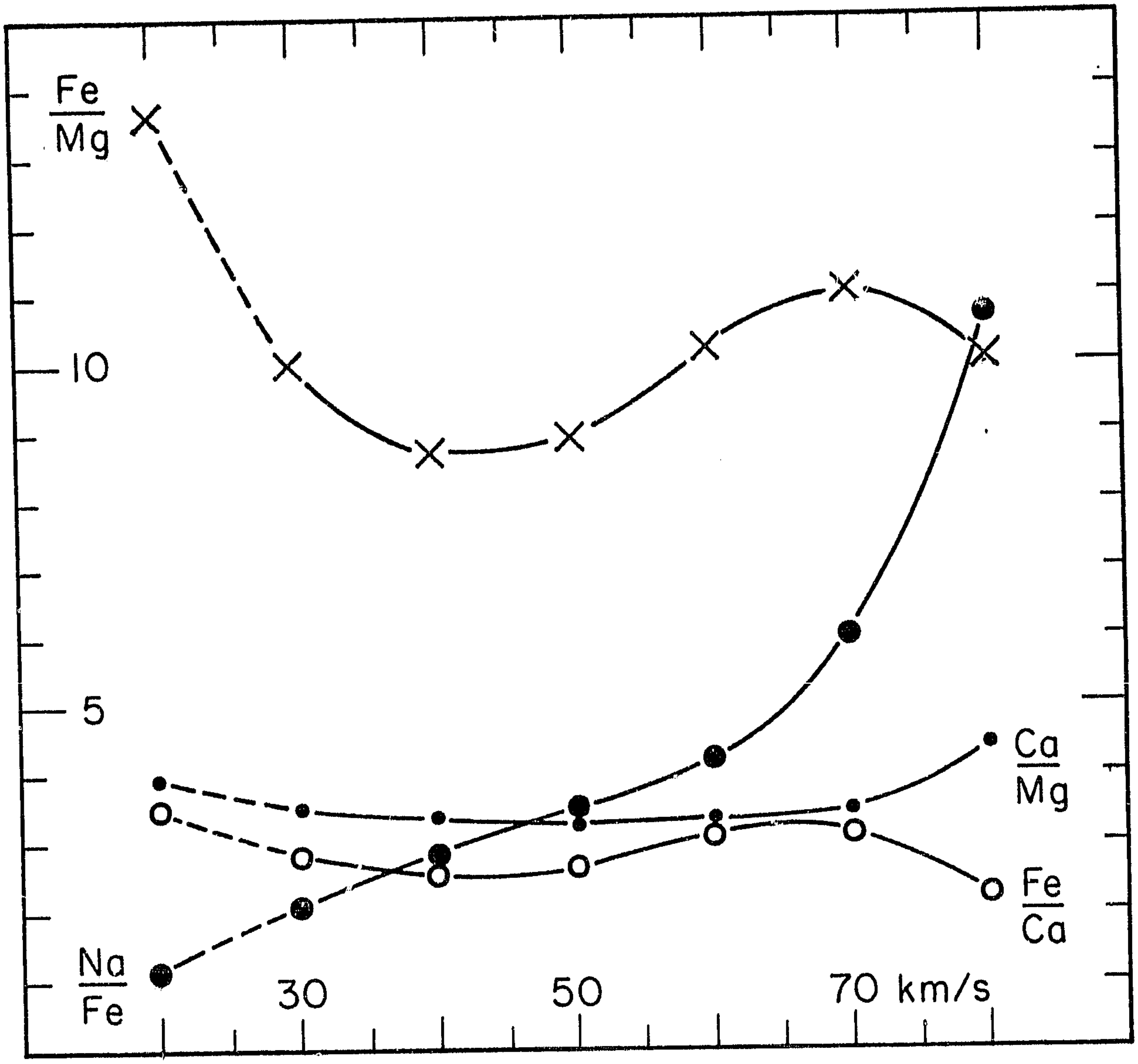
Figure 1



The ratio between the luminous efficiencies of pairs of elements in meteor spectra, plotted as ordinate, against the velocity of meteoroid entry into the earth's atmosphere, plotted as abscissa. These curves have been calculated from Figure 4 in the paper by Savage and Boitnott (1973). The values for velocities below 30 km/s have been extrapolated and are less reliable than the remainder. The atomic lines used in the measurements upon which these curves are based were:-

Na - the D lines at 5893 A,
Mg - the lines at 3835 A and 5177 A,
Ca - the line at 4227 A,
Fe - the lines between 3500 A and 5500 A.

and satisfactory photometric calibration curves can be developed by taking the pixel values along the stellar spectra at the same wavelengths as those tabulated in the star catalogue and combining them to form a general calibration curve. If necessary this can be modified slightly to fit the range of wavelengths being studied.

CONCLUSION

At the present time, with the expectation of the return of both Halley's Comet and Comet Swift-Tuttle, priority is being given to the study of spectra from the η Aquarid, the Orionid and the Perseid meteor streams. It is hoped that additional laboratory determinations of the collisional cross-sections of elements common in meteoroids will be made so that the study of chemical abundances in the cometary meteoroids may be extended. The author is continuing his work with Clifton at the Marshall Space Flight Center in Huntsville, Alabama in the reduction and analysis of video-tape meteor spectra recorded at Mt. Hopkins, Arizona and at the Springhill Meteor Observatory near Ottawa.

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DISCUSSION

CEPLECHA: How do you check on the free molecular flow?

MILLMAN: For the study of chemical abundances we use the upper part of the meteor trajectory and assume that free molecular flow conditions are usual at these heights.

DONN: The increase of the luminous efficiency of sodium relative to iron is somewhat curious. Sodium is rather readily released from solids, eg. heating glass produces a bright yellow glow. Could there be an abundance rather than a spectroscopic effect here?

MILLMAN: In the laboratory experiments conducted by Savage and Boitnott to determine collisional luminous efficiencies a beam of N_2 or O_2 molecules was intersected at right angles by a metal beam from an oven. In the case of the sodium beam the flux of sodium atoms was measured with a hot tungsten oxide surface ionizer. I assume that the densities of the colliding beams, and the energies involved, were correctly determined.

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