CURRENT TRENDS IN METEOR SPECTROSCOPY

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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

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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/Giacobini-Zinner
Taurid	30	P/Encke
Ursid	35	P/Tuttle
Geminid	36	
Quadrantid	43	
δ Aquarid	43	
Lyrid	49	1861 I Thatcher
Perseid	60	P/Swift-Tuttle
η Aquarid	66	P/Halley
Orionid	67	P/Halley
Leonid	72	P/Tempel-Tuttle

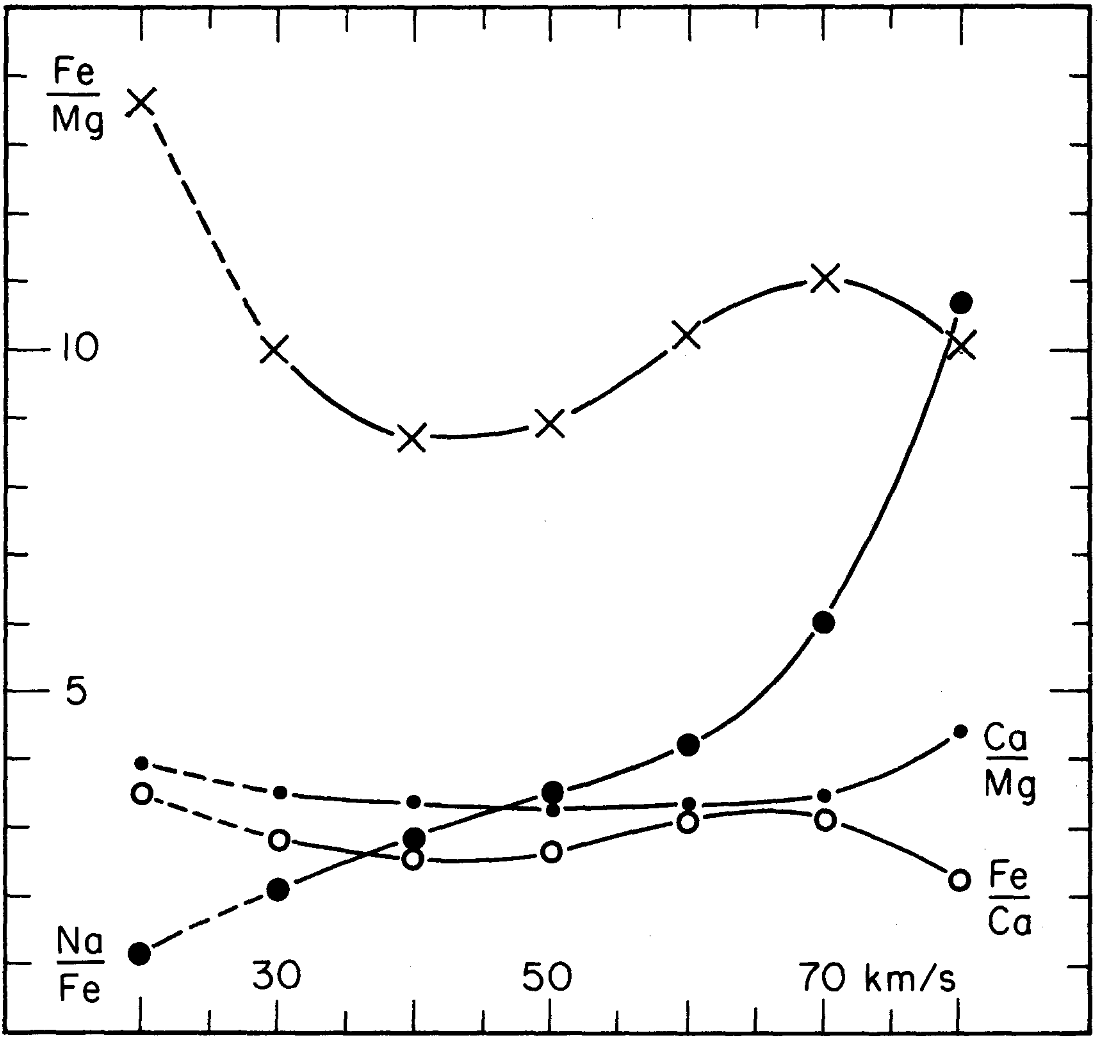
abundances for the four elements Na, Mg, Ca, Fe are close to Cameron's (1973) values for the solar system and agree with abundances in interplanetary dust found by other independent techniques (Millman 1979).

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,

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.

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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?

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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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