A SYSTEMATIC PROGRAM OF COMETARY SPECTROSCOPY

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Some early results of a systematic program of observing the spectroscopic behavior of comets as a function of heliocentric distance are presented. An ultraviolet sensitive microchannel plate intensifier spectrograph is used to record the 3000-5000Å spectrum of comets brighter than magnitude 17 with a spectral resolution of 8 or 16Å, followed by a direct image for better interpretation of the spatial distribution of spectral features. Although the goals of the program require much more time and data, some interesting results from Comets Schwassmann-Wachmann 1, Bradfield and Bowell have thus far been obtained.

Past studies have qualitatively established the fact that comets exhibit individual spectrophotometric behavior and general statements can be made regarding the appearance of particular spectral emissions at various heliocentric distances. Yet, there has not been enough quantitative data to understand the significance of either the similarities or differences between comets that may result from either intrinsic compositional differences, or evolutionary changes that take place when the comet is in the vicinity of the inner solar system. This information would also be useful in the intelligent design of spacecraft experiments as well as being able to interpret spacecraft data in the context of the general comet population.

The problem has been the lack of a single or coordinated systematic program of observing comets at a variety of heliocentric distances with consistent instrumentation to facilitate a statistical study. There is not even enough data to identify the significant parameters. Past data exist in a variety of forms that make intercomparison difficult, if not impossible (Swings and Haser, 1957). There are high resolution spectra of the brighter comets, sporadic medium and low resolution spectra of fainter comets with a variety of instrumental configurations, and photoelectric photometry with a variety of filters and telescopes. Groundbased observations of comets are most often dictated by opportunities to share time with previously scheduled programs. The far ultraviolet observations with the IUE provides one of the most homogenous data sets available.

Although there are several approaches to observing the brightness behavior of comets, we felt that the single most productive would be to obtain medium resolution slit spectra of comets brighter than total magnitude 12. From this one can: (1) measure the total brightness of all emissions within a broad spectral region, (2) measure the dust component and thus properly correct its contribution to the emission brightness, and (3) measure brightness profiles and spatial distribution of the observed molecular and ionic species.

The program of cometary spectroscopy carried out at LPL has been aimed at securing a homogenous series of spectra of all comets observable on a monthly basis as a means of systematically obtaining cometary spectra, including faint and distant comets, and following the heliocentric-distance spectral variations on a uniform basis. These observations then can be used to characterize the emission/continuum (gas/dust) ratio distribution at different stages of cometary evolution (Donn, 1977).

The spectrograph design was predicated on the characteristics of an available 40 mm blue sensitive microchannel plate (MCP) intensifier, and the requirements of mechanical and optical stability. Other desirable characteristics included all reflecting optics, the ability to guide

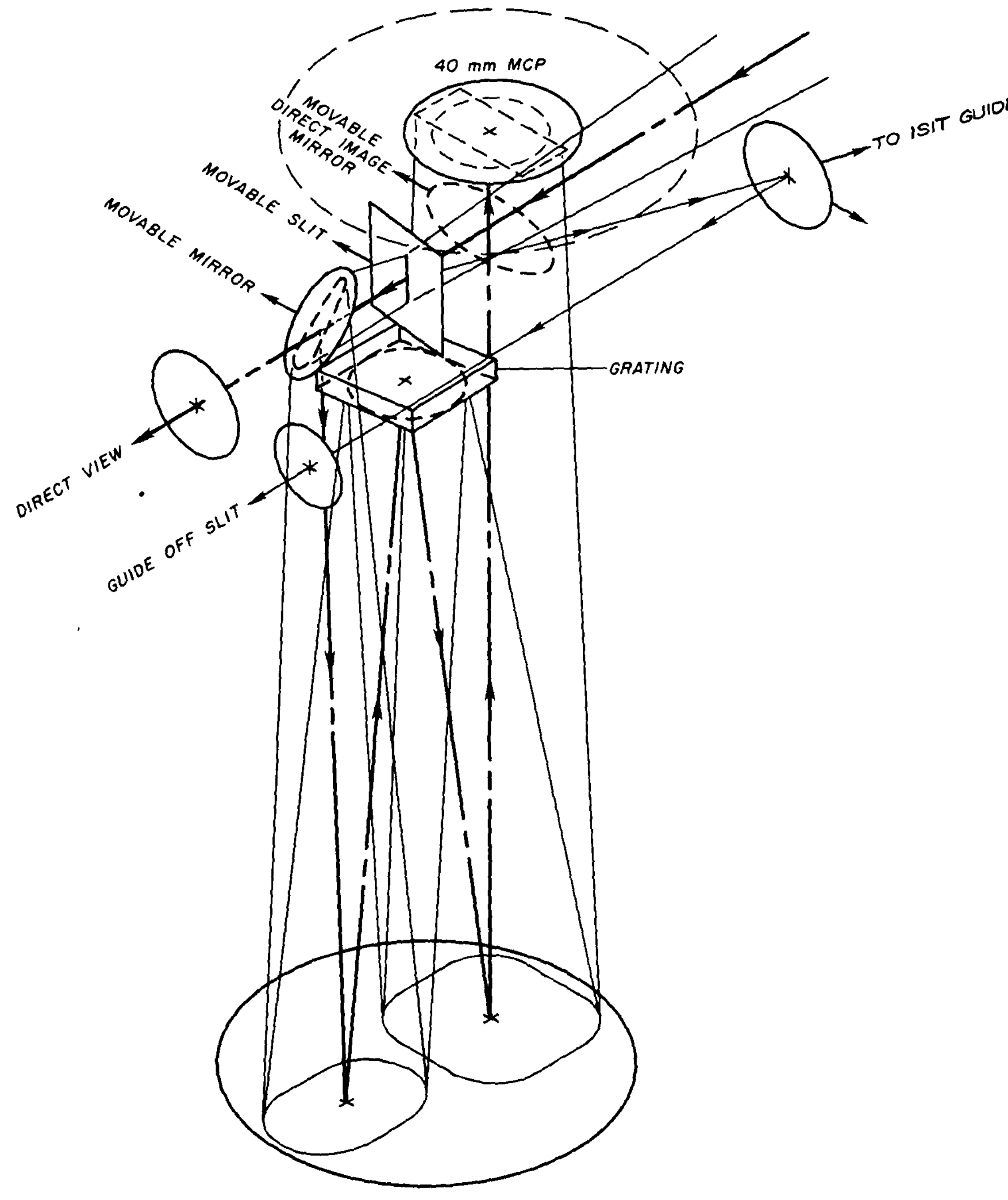

Figure 1. Schematic optical diagram of the microchannel plate spectrograph and direct imaging camera. Insertion of the mirror in front of the MCP allows direct imaging without changing focus. The f/9 telescope beam enters in from the upper right.

off of the entrance slit and having the capability to quickly convert to a direct imaging mode. The wavelength interval from the atmospheric cutoff near 3000Å to 5800Å is covered with either 8 or 16Å resolution. This resolution is adequate to distinguish C_3 emissions at 4050Å over the Mercury line at 4046Å caused by city lights.

Direct imaging is facilitated by moving the slit on a carriage and folding the beam directly onto the intensifier. In the direct imaging mode with no filter, the dark sky background is usually recorded in 30 seconds. Spectra of the faintest objects detectable in the ISIT acquisition system ($M_R \sim 17$) of the 154 cm Catalina Observatory telescope can be obtained with a one hour exposure. Guiding on very faint objects requires periodic interruptions with the ISIT system, while guiding objects brighter than $M_V \sim 13$ directly off of the slit is possible with the aid of an 18 mm MCP intensifier in place of the eyepiece. Fig. 1 shows an optical schematic of the spectrograph, and Fig. 2 an example observation.

The drawbacks of the system are primarily those associated with the calibration problems inherent in the photographic process.

The LPL program utilizes two nights per month on the 154 cm telescope within one week on either side of new moon. To insure a high probability of obtaining data on all comets on a monthly basis actually requires about twice that time with Tucson's weather. Over 36 months, spectra of 7 short period and 3 long period comets have been obtained. This rate implies a very long time to obtain a statistically significant sample from which compositional or evolutionary classes might be identified. It is clear, as was the case with asteroids, that standardized data from several groups of observers will be needed to insure that all comets are observed, and with adequate temporal coverage. It appears that the spectral manifestation of compositional differences in comets result from water content, dust (silicates) and CO or CO_2 content. Recent groundbased photometry (A'Hearn et al., 1980) and spectrophotometry from IUE (Weaver et al., 1980) show that the OH emissions relate well with water production models, and may therefore allow a direct method of determining the water content from the ground. When our spectra are converted to intensities, it will be possible to determine relative production rates of OH, CN and C_2.

As observations are made, some interesting results have been obtained. The identification of CO^+ in periodic Comet Schwassmann-Wachmann 1 near quiescent state in this program (Larson, 1980) implies a high CO or CO_2 content that may be responsible for its irregular outburst activity. Continued monitoring of this comet may show spectral variations for different stages of outburst, and provide clues to the outburst mechanism.

Spectra were obtained of Comet Bradfield (1979l) on February 5, 1980 (r=1.1 AU), and showed a very high emission/continuum ratio. Emissions of CH, C_2, C_3, NH, OH and CO_2 were recorded. The conspicuous lack of CO^+ was also noted in the IUE data (A'Hearn et al., 1980). Some unidentified lines near 3460Å, sharing the spatial distribution character of an ionic species such as CO_2^+ was also recorded. CN was well recorded even 1.60×10^5 km in the tail direction from the nucleus. Poor weather prevented further observations until March 18 (r=1.8 AU) when it was considerably fainter, and only a solar reflection spectrum was recorded. On the following opportunity of April 10 (r=2.1 AU), the comet had faded to the extent that it could not be located with the ISIT acquisition system. This is consistent with the photometric results of A'Hearn et al. (1980b) which showed the production rates of the principal species varied as $r^{-4.0}$.

Comet Bowell (1980b), travelling in a hyperbolic orbit (Marsden, 1980) towards perihelion at 3.4 AU in March 1982, had a predominantly solar reflection spectrum at 7 AU on May 7, 1980. The well developed dust coma could be seen to 5×10^4 km from the nucleus. The great perihelion distance of this comet may limit observable emissions, but since it may represent a most primitive cometary body, it will be important to monitor it.

Period Comet Stephan-Oterma (r=1.7 AU) and Encke (r=1.3 AU) has shown CN, C_2, OH and C_3 emissions. Encke has a high emission/continuum ratio.

Acknowledgments

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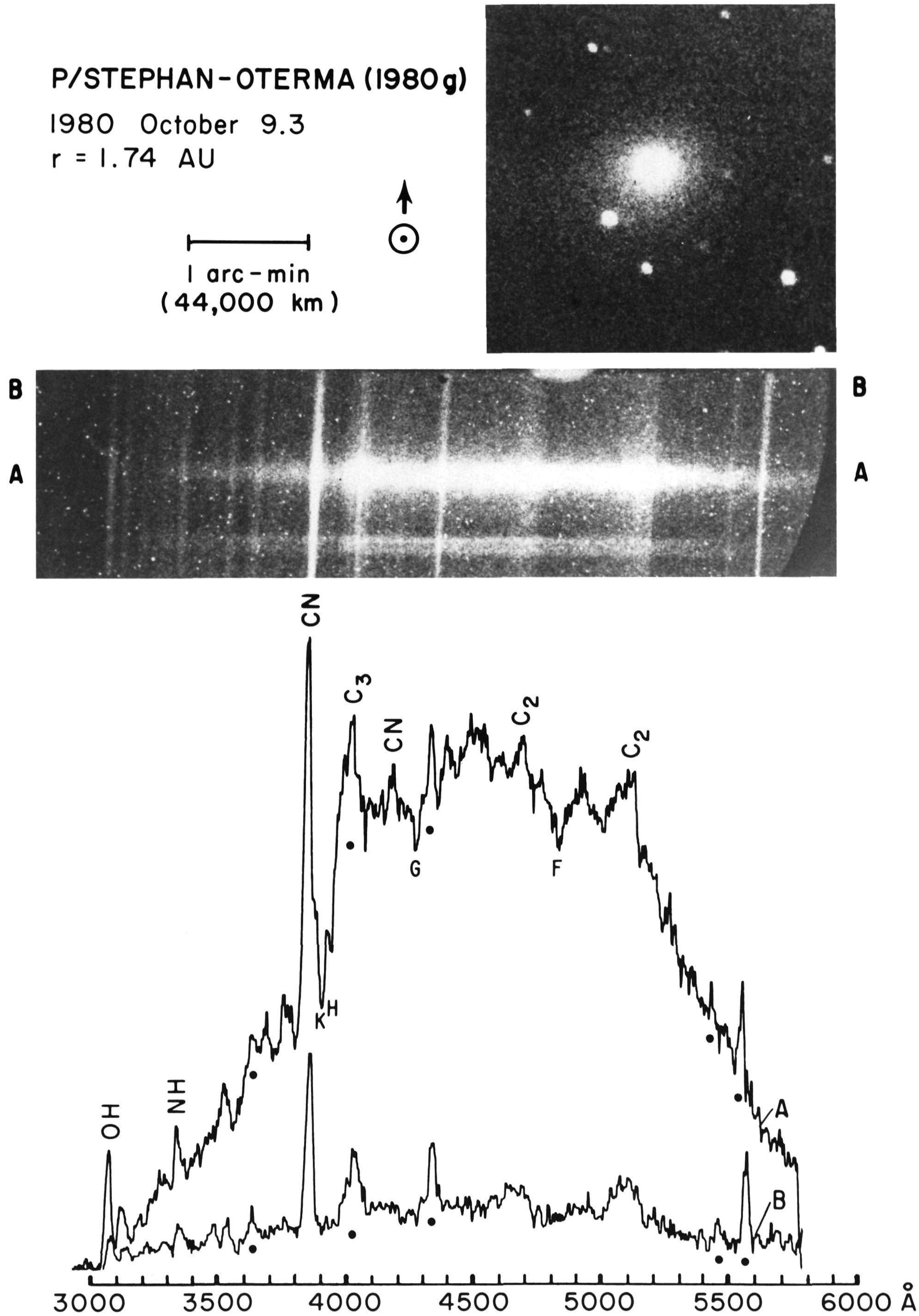

Figure 2. Example of an observation. The direct image of P/Stephan-Oterma (upper right) is the same scale and orientation as the spectrum (middle). Note that the CH and C_3 emissions appear more asymmetric than C_2 emissions. The direction to the sun is towards the top. The two small spectra below the comet were produced when the two stars below the comet passed across the slit as the telescope followed the diagonal motion of the comet. The density tracings (below) were at the nucleus (upper) and 3×10^4 km sunward (lower). Dots below the tracings are positions of mercury emissions from city lights, and letters are Fraunhofer lines.

References

A'Hearn, M. F. and Feldman, P. D. 1980a, On the Absence of CI^+ in Comets Seargent and Bradfield, BAAS Abstract 12, No. 3, 751.

A'Hearn, M. F., Millis, R. L. and Birch, P. V. 1980b, Photometry of Comet Bradfield 1979l, BAAS Abstract 12, No. 3, 730.

Donn, B. 1977, Comets, Asteroids, Meteorites, Interrelationships, Evolution and Origins. (Toledo: University of Toledo Press), p. 15.

Larson, S. M. 1980, CO^+ in Comet Schwassmann-Wachmann 1 Near Minimum Brightness, Ap. J. 230, No. 1, part 2, L47.

Marsden, B. G. 1980, IAU Circular 3468.

Swings and Haser, 1957, Atlas of Cometary Spectra, Liege.

Weaver, H. A., Feldman, P. D., Festou, M. C., A'Hearn, M. F. 1980, Water Production Models of Comet Bradfield (1979l), BAAS 12, No. 3, 737.