REVIEW OF SPECTROSCOPIC & SPATIAL OBSERVATIONS OF COMETARY COMAE

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INTRODUCTION

During the past few years the field of comet spectroscopy has greatly expanded with observations of comets having nuclear magnitudes in the range of 10-19th magnitude. Although the total integrated magnitudes of several of the comets were brighter than 10th magnitude, the surface brightness of the coma of a comet is low and, with few exceptions, the night sky line at 5577A is brighter than any cometary emission line. The observational programs on which I will concentrate had their start under the P/Tempel 2 and P/Encke observing programs set up by R. Newburn at JPL.

Fortunately, the groups listed in Table 1 are regularly scheduled on large telescopes to observe comets. The regularly scheduled telescope time has enabled these groups to study systematically the activity of the available comets brighter than 20th magnitude. Observations have been made with respect to heliocentric distance and distance from the nucleus. The goal of the systematic study of comets is to acquire a uniform data set on comets. The great variety of comet spectra in the past did not provide a useful data base for statistical studies. These older observations ranged from high resolution spectra of brighter comets, to sporadic medium and low resolution spectra and filter photometry of the 10th magnitude comets, to nonexistent spectra of fainter comets.

During the past 3 to 4 years there have been several comets of medium brightness which M. A'Hearn's filter photometry program and the IUE uv spectroscopic program have been able to observe. This overlap will allow a valuable cross check between methods of determining cometary molecular abundances and extend the data base to fainter (mostly periodic) comets. Several publications will be forthcoming from these three groups.

Richard M. West (ed.), Highlights of Astronomy, Vol. 6, 713–717.

TABLE 1
SYSTEMATIC FAINT COMET OBSERVING PROGRAMS

Observers	Institution	Telescope	Instruments	Frequency
Barker, Cochran	UT-McDonald	2.7m,(2.1m)	IDS, (CCD)	3-4 Nights/Month
Spinrad	UC-Lick	3.0m	IDS	Monthly with Galaxies
Larson, S.	LPL-Catalina	1.54m	MCP	3 Nights/Month
Johnson, R.	LPL-Catalina	1.54m	CCD	5-6 Nights/ Bi-Monthly

PROGRAMS AND INSTRUMENTATION

The program carried out by S. Larson at LPL is based on the use of a microchannel plate (MCP) as a detector. Figure 1 illustrates a typical MCP spectrum which is in the form of a photographic emulsion and quite similar to classical long slit spectroscopy. Although the resulution of 11A is poorer than coude spectroscopy, it does contain continuous spatial information along the direction of the slit. A very important and unique feature is the almost simultaneous photograph of the comet at the same plate scale as the spectrum. The resolution is similar to that acquired by the CCD spectrograph used by the LPL group.

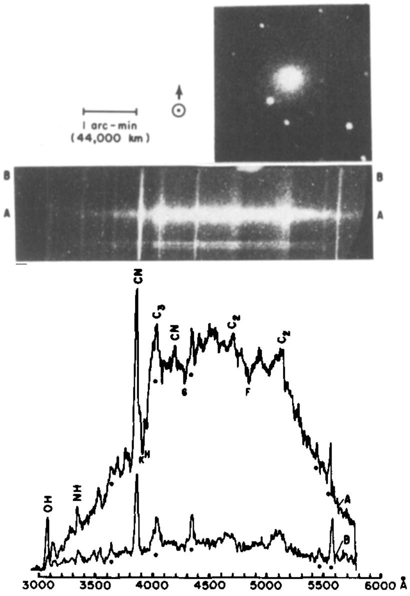

Figure 1: P/Stephen-Oterma (1980g), 1980, October 9.3, Ω = 1.74 A.U. Shown are the direct images to the same scale as spectrum and tracings through AA and BB.

In the future, the LPL group using the blue sensitivity of the MCP to augment the red sensitivity of the CCD system will provide spatial coverage of all cometary emissions between 0.3 and 1.1 µm on subsequent nights. The MCP system is limited to comets brighter than 18.5 mag, primarily by the TV acquision system. As with all photographic systems, the accurate conversion of plate density to observed flux is the prime problem affecting this program. Larson hopes to provide an independent crosscheck on other determinations of the production rates and gas-to-dust ratios. The detection of CO+ when P/Schwassmann-Wachmann 1 (SW 1) was near minimum started a long monitoring program (Larson, 1979). CO^+ emission has been observed at all stages of an P/SW 1 outburst by all three groups, but no correlations have been found with comet or solar activity (Cochran, et. al., 1982).

Both the McDonald and Lick Observatory programs use Intensified Dissector Scanners (IDS) as detectors behind similar spectrographs. The IDS spectrographs yield two independent simultaneous spectra 2500A long at a resolution of 10A. These digital systems are capable of doing automatic sky subtraction on a rapid time scale by moving the object between two apertures (35 arcsec apart for Lick and 52 arcsec for McDonald). Due to the extended nature of a developed cometary coma, the "sky" slit detects another portion of the coma. Hence, automatic sky subtraction is used during the data reduction steps for comets which do not display any cometary emission in the "sky" slit. A clean sky spectrum is obtained at a matching airmass and moon condition after making a set of measurements on an extended comet. We have been able to accurately remove the night sky missions and the sky color to better than the 5 percent level at McDonald. Systematic calibration uncertainties range from 10 to 20 percent, depending on the distribution of standards, instrumental stability, and quality of the atmospheric seeing.

The superb TV acquisition and guiding systems (SEC Vidicons) on the IDS spectrographs are valuable in detecting and identifiying an 18-20th magnitude comet. On nights of good seeing, these TV systems can reach fainter than 21st magnitude. A useful spectrum of a 19.5 magnitude comet can be obtained in about two hours under good seeing conditions using a 4 arcsec entrance aperture.

Spinrad, et al., (1979) observed P/Tempel 2 when it was quiescent at 2.66 AU and determined that the coma was slightly redder than the Sun. A few weeks later P/Tempel 2 underwent a two magnitude outburst during which CN emission was detected at 2.97AU by Johnson, et al., (1981). Recently, Spinrad (1982) has submitted a paper on "The Red Auroral Oxygen Lines in Nine Comets", in which he derives oxygen production rates. By comparing his observations of oxygen to production rates derived for H_2O from IUE observations of the same comets, he argues that the red auroral lines $O(^1D)$ of oxygen come from photodissociation of H_2O and not from CO_2 photodissociation.

Since we began observing comets under the P/Tempel 2 program at McDonald, we have observed 30 comets (over 700 individual spectra) to date. [P/Encke, P/Stephan-Otherma (1980g), P/Brooks 2 (1980f), P/Forbes (1980a), Cernis-Petrauskas (1980k), P/Tuttle (1980h), Bowell (1980b), P/SW1, P/SW2, (1979k), P/Borrelly (1980i), P/West-Kohoutek-Ikemura (1980r), P/Longmore (1981a), Panther (1980u), Meier (1980q), Bradfield (1980l), Bradfield (1980t), P/Gehrels 2 (1981f), P/Slaughter-Burnham (1981i), P/Swift-Gehrels (1981j), P/Howell (1981k), P/Kearns-Kwee (1981h), Bus (1981d), P/Smirnova-Chernykh (1975e, 1975VII), P/Gunn, P/DuToit-Hartley (1982c), P/Grigg-Skjellerup (1982a), P/d'Arrest (1982e), P/Churyumov-Gerasimenko (1982f) P/Peters-Hartley (1982h), Austin (1982g)]. To be able to handle the large amount of data uniformly, a blind analysis program has been developed which produces a table of line strengths for the various cometary emission features delineated in Figure 2 on typical spectrum of Meier (1980q) and a plot of the relative reflectance or color of the continuum. A. Cochran has developed her Ph.D. dissertation from the P/Stephen-Oterma data taken during this period and will be presenting these data and time dependent chemical models at the 1982 DPS meeting in Boulder, Colorado. P/Stephan-Oterma has been a difficult comet to work with because it was so dusty, but it may be the only truly symmetric comet among our sample. The flux calibrated, digital nature of the data has made it possible to remove the solar spectrum from the cometary emission spectrum.

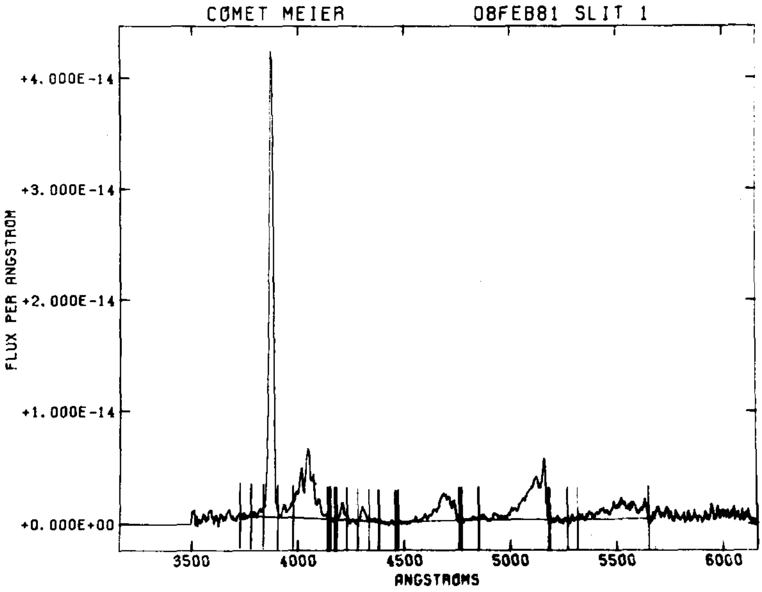

Figure 2: Comet Meier (1980q) at r=1.738AU and W=1.889AU with the reflected solar spectrum removed. The continuum regions and wavelength bounds of the CN,C_2 and C_3 bands are marked and column densities were calculated from the integrated fluxes.

One of the advantages of being regularly scheduled for many nights was the chance observation of a "ring-tailed snorter" outburst of SW 1 in February, 1981. By analyzing the color of the nucleus and the change in the color along the "one-armed" spiral shaped coma, were able to model the size distribution of particles in the coma. One of the positions observed during the outburst showed a spectrum similar to the quiescent state, but the other positions required the addition of a distribution of smaller sized particles. As the outburst progressed, more and more of the smaller particles were required to match the relative reflectance (Cochran, et al., 1982). This type of analysis was applied to several other dusty comets by Barker, et al., 1981. The conclusion of the inadequate Mie scattering analysis was that when a theory is developed to numerically represent the scattering by dirty, non-spherical grains, we will have a larger data base for comparison.

A detailed analysis is just beginning on the derived column densities for each molecular emission band in the 30 comets observed. The CN column densities when referred to the same heliocentric distance vary by more than a factor of 100 indicating significant differences between comets. CN and C_3 emission are not detected in 13 of the 30 comets observed. This reduces the number of comets to 17 in which we can compare the CN, C_3 and C_2 column densities. Unless we can observe several species in a comet, we cannot properly constrain chemical models. For only a few of the comets (P/Encke, P/Swift-Gehrels, P/Kearns-Kwee, Panther (1980u), P/Stephan-Oterma, and Meier (1980q) was the coverage of the dependence of the CN emission with heliocentric distance sufficient to determine a power law relationship. The derived exponents were respectively: -4.5, -7.2, -9.8, -2.6, -6.6 and -5.9.

The radial dependence or brightness profiles of a molecular emission will provide model constraints. We have good profiles sampled with a 4x4 arcsec aperture on at least one date for several comets. We see definite asymmetries in the column density distributions for P/Encke, P/Swift-Gehrels, P/SW 2, P/Grigg-Skjellerup, and Bradfield (1980t). Johnson, (1982) have studied the profiles of ions and neutrals in their CCD, longslit spectra of P/Tuttle.

In the future programs utilizing array detectors, CCD's in particular, will provide the next advances in coma spectroscopy. Longslit CCD spectroscopy or imaging through a standard filter sets onto a CCD detector will be used to study the radial symmetry in the physical processes taking place in the coma region.

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