FINAL TECHNICAL REPORT

ULTRAVIOLET COMETARY SPECTROPHOTOMETRY

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Submitted by:

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UNIVERSITY OF MARYLAND

DEPARTMENT OF PHYSICS AND ASTRONOMY

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Submitted by:

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During the observations at Goddard, this Principal Investigator participated intensively, being personally present at nearly all the observing sessions and by providing up-to-date ephemerides for the comet. Because of some differences in scientific goals among the three principal investigators, there was much discussion during and between the observing shifts to decide on priorities for exposures. In retrospect, this seems to have worked out very well to maximize the scientific returns from the observing. The collaboration with the Europeans was less satisfactory and will be addressed separately below.

During the 13 shifts dedicated to observations of Comet Bradfield (including the 2 European shifts), we obtained 5 high-dispersion exposures with the LWR camera, 27 low-dispersion images with the LWR camera, and 36 low-dispersion images with the SWP camera of which 5 were observations of the geocoronal background and 4 were taken in a serendipity mode while the nucleus of the comet was centered on the large aperture of the LWR camera.

The primary scientific results of the program were as follows.

1. The high dispersion spectra of the 0-0, 1-1, and 1-0 bands of OH could be reproduced with +10% accuracy using a pure fluorescence model. There

was no need to invoke molecular collisions in the inner coma or any other process to achieve this accuracy. On the other hand, the range of heliocentric radial velocities was small and the fluorescence varies drastically with heliocentric radial velocity. For this reason, it will be important to carry out further checks on future comets which can be observed at different heliocentric radial velocities.

2. The production rate of OH as measured with IUE is consistent with that measured from the ground using filter photometry. It is thus clear that routine monitoring of the OH production, at least for comets with relatively weak continuum, can be carried out from the ground. Dusty comets, however, will require monitoring with IUE.

3. The strengths of the H, O and OH features are all consistent with the widely accepted hypothesis that H_2O is the dominant volatile species in the nucleus.

4. The features indentified as being due to CO^+ by Jackson et al. in the IUE spectra of Comet Seargent were incorrectly identified. These features, also observed by us in Comet Bradfield, are due to second order Lyman-alpha and the Mulliken bands of C_2. The

presence of Lyman-alpha in second order is a totally new instrumental result of which other investigators should be aware although it is unlikely that any investigators will be observing objects in which the Lyman-alpha strength is relatively as great as it is in comets. The identification of the Mulliken bands of C_2 enabled us to estimate the strength of the transition moment for the forbidden intercombination transitions between triplet and singlet states of C_2.

5. The variation of OH production with heliocentric distance was inconsistent with any models of equilibrium vaporization of an icy surface, varying much more rapidly with distance than one would predict from such models.

6. The variations of CS production with heliocentric distance was much steeper than that of other species.

Several other scientific results from this program have also been reported but they are results in which this particular grant did not play any role (determination of a rotational temperature of CS, identification of new features longward of the 0-0 band of OH, etc.) and they are therefore not discussed here.

There was also one significant administrative result from this program. It is now clear that the administrative procedures for observing comets as targets of opportunity from Vilspa are entirely inadequate. The U.S. procedure of accepting specific proposals from different teams and requiring the different teams to work together has, from our point of view, worked very well. Particularly valuable, however, has been the policy of providing copies of the data tapes to each team. Collaboration with the Europeans has been continuously difficult because of disputes over who should participate from the European side and because copies of the Vilspa tapes were not available to the American investigators. It appears that M. Festou has been working hard to resolve these problems, many of which are internal to the European approach, but it is clear that the problems have not yet been solved. Since many of the future cometary observations are likely to require use of Vilspa shifts, it is essential that we be able to collaborate with the European investigators efficiently and it may be that direct negotiation between NASA and ESA will be required. We suggest that the IUE administrators consider in some detail possible future relationships between European and American observers of targets of opportunity.

Publications resulting totally or partially from this grant are as follows.

A'Hearn, Michael F.: 1980, Correlated Ground-based and IUE Observations, in "Modern Observational Techniques for Comets", eds. J.C. Brandt, B. Donn, J.M. Greenberg, and J. Rahe (JPL Publ. 81-68), pp. 138-140.

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A'Hearn, Michael F., David G. Schleicher, Bertram Donn, and William M. Jackson: 1980, Fluorescence Equilibrium in the Ultraviolet Spectra of Comet Seargent (1978m) and Bradfield (1979ℓ), in "The Universe at Ultraviolet Wavelengths", ed. R.D. Chapman (NASA CP-2171), pp. 93-81.

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Schleicher, David G., and Michael F. A'Hearn: 1982, OH Fluorescence in Comets: Fluorescence Efficiency of the Ultraviolet Bands, Astrophys. J., 258, 864 - 877.

Weaver, H.A., P.D. Feldman, M.C. Festou, and M.F. A'Hearn: 1981, Water Production Models for Comet Bradfield (1979X), Astrophys. J., 251, 809 - 819.

The above list includes only papers published in their entirety. It does not include papers presented at meeting and published only as abstracts.

7 March 1983
MFA:msb

CORRELATED GROUND-BASED AND IUE OBSERVATIONS

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In this talk I will not really be discussing a new observational technique but rather something which deals primarily with the psychology of cometary observers and of those who schedule telescope time for cometary observers. My goal is to point out the great value of coordination among different observers, particularly those working in different wavelength regions. This coordination, which has already been mentioned yesterday, is more important among observers of comets than among observers of almost any other class of astronomical object. The basic reason for this is that comets are highly time-variable, often erratically so, and observations of a particular comet usually cannot be repeated. As a result, some uncoordinated observations cannot be interpreted at all while others are susceptible to misinterpretation. I will discuss several specific examples of coordinated observations based on recent experience. In some of these the coordination was deliberate while in others the coordination was a fortunate, accidental circumstance. Although I was involved to some extent in many of these observations, it should be obvious from the nature of the talk that many other people were also involved, some of them to an even greater degree than I was.

OH Production Rates in Comets

A first example was discussed yesterday by Millis when he compared the OH production rates derived from ground-based, filter photometry with those derived from IUE Spectrophotometry. The ground-based results could easily have been criticized either on the grounds of inadequate treatment of atmospheric extinction or on the grounds of inadequate absolute calibration. The IUE results, on the other hand, could have been criticized because they are based on observations of only a very small fraction of the comet and are thus quite model sensitive. The fact that the two methods are subject to unrelated sources of error and still yield results in reasonably good agreement gives much greater confidence that both methods are reliable.

In one sense, this is a relatively trivial example since one can carry out the relevant science using either technique alone. The second technique merely corroborates the first. In other cases, the science simply cannot be done without the coordination of observations.

HCN and CN Production Rates

A much more critical need for coordinated observations exists in the area of radio spectroscopy of comets. The only universally accepted observations of radio lines are those of OH and even here there appear to be discrepancies between the results derived from radio observations and those derived from optical and ultraviolet observations. More important, however, are the many negative searches for other spectral lines and the tentative detections of a few species (HCN, CH_3CN, H_2O). How should one interpret the many negative results? It seems that the only sensible approach is to compare the upper limits to abundances obtained from optical observations of chemically related species.

When Comet Bradfield (1979l) was first discovered, we were able to use the experience of previous ground-based photometry of comets and the apparent magnitude to estimate the production rate of CN that we would observe for this comet (c.f., A'Hearn and Millis, 1980). Since the comet would make an unusually close approach to Earth, it would also significantly alleviate the problem of beam dilution that plagues most radio observations. We then estimated that if the comet behaved normally and if HCN were really the parent of CN, then the HCN should be observable because of the favorable geometry. Zuckerman obtained observing time with the 36-foot telescope at Kitt Peak and searched for HCN as well as several other species. All searches were negative. Using the inner coma rotational temperature (kinetic temperature) determined for CS by Jackson et al. (1980) and using a Gaussian to approximate the spatial distribution of HCN, we were able t set an upper limit (5σ) on the production rate of HCN at a few times 10^{26} sec^{-1} and on the

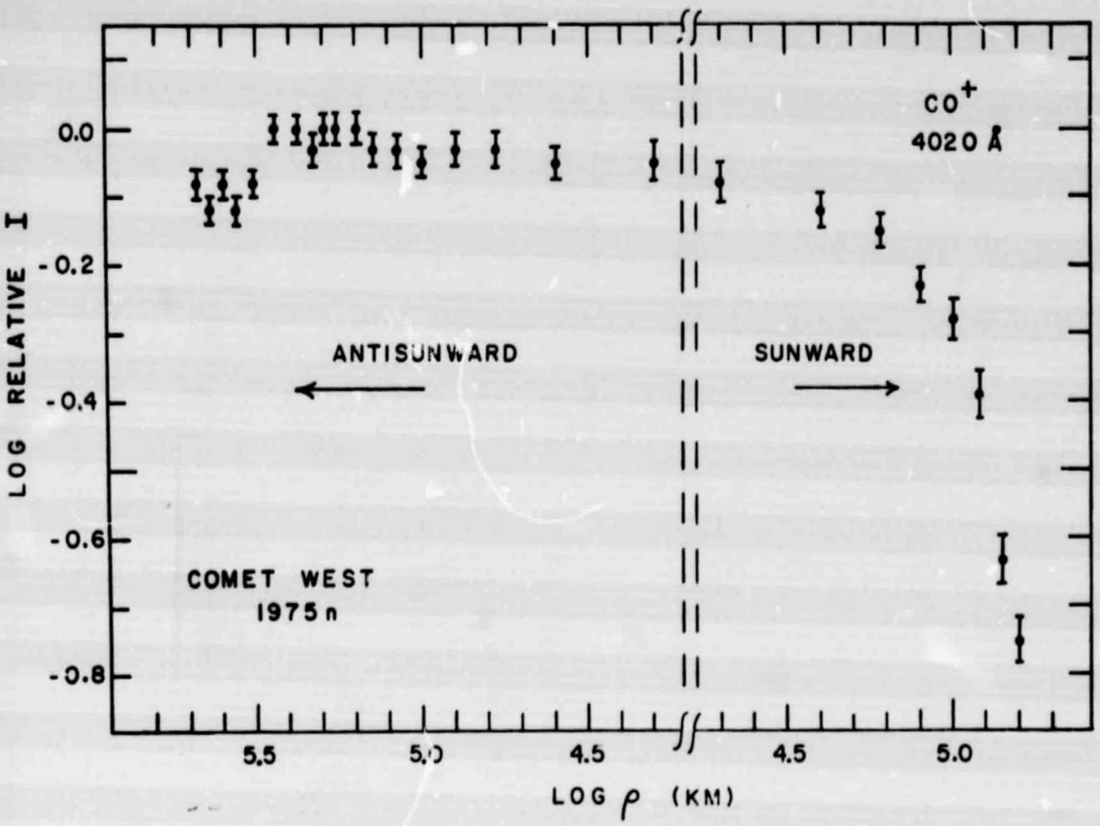

Figure 9. Monochromatic intensity profiles of CO$^+$ (3-0) band emission at 4020Å (continuum subtracted) in comet West. Data from Fig. 8. Note the pronounced asymmetry in the sunward and antisunward intensity profiles.

With the general use of modern detectors such as the Image Photon Counting System (IPCS) developed by Boksenberg and the Charge Coupled Device (CCD) now being used by several groups, two-dimensional spectra of comets can be obtained. These new detectors have both high spectral and spatial resolution as well as much higher quantum efficiencies than photographic plates. Also because they are linear devices, the new two-dimensional detectors will permit relatively accurate absolute calibrations of cometary data. In essence the new generation detector which is just now beginning to be used regularly with ground-based spectrographs will improve immensely the quality of optical cometary spectra in ample time for observing the return of comet Halley.

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peak column density at 8×10^{12} cm^{-2}. These numbers are an order of magnitude lower than those found for Comet Kohoutek (Huebner, Snyder, and Buhl, 1974) and the molecular production rate is less than the expected CN production rate. In the absence of any other information we would have concluded that HCN could not be the parent of CN. Fortunately, we did have other information because Millis was carrying out filter photometry of the comet from Hawaii within 6 hours of the radio observations as well as on numerous other nights. It subsequently turned out that the CN production rate in Comet Bradfield had varied approximately as r^{-4} rather than the r^{-2} that we had observed in some previous comets (A'Hearn, Millis, and Birch, 1980). The upper limit for HCN production then turned out to be somewhat larger than the observed CN production rate rather than smaller. Although we might ultimately have recognized this variation in CN production from the visual magnitude light curve of the comet, it is quite possible that we would have drawn a totally invalid conclusion if we had not had nearly simultaneous radio and optical observations.

Although this was a relatively straightforward case, because there are several pieces of indirect evidence suggesting that HCN might be the parent of CN, it was also a particularly significant one because of the rather low upper limit achieved. There have been numerous other searches for radio spectral lines both of species observed in other spectral ranges and of species not previously observed in comets. Even negative results in some of these searches might have significance if properly related to optical results.

Triplet/Singlet Ratio of C_2

A third example will show that purely serendipitous results can be achieved if different observers happen to make relevant observations nearly simultaneously. When analyzing the CO^+ bands in the IUE spectra of Comet Bradfield, we discovered that the bands were not due to CO^+ at all and that the strongest of these bands was the $\Delta v = 0$ sequence of the Mulliken bands of C_2 (A'Hearn and Feldman, 1980). Although C_2 triplets have long been observed in the optical (the well known Swan bands), this was the first unambiguous observation of C_2 singlets from which convincing fluxes could be derived. Fortunately Birch in Australia and later Millis in Hawaii had been observing the Swan bands and, by coincidence, some of their observations were on precisely the same dates as the IUE observations. This enabled us to derive the triplet-to-singlet ratio for C_2 and, using the theory of Krishna-Swamy and O'Dell (1979), to derive the absolute transition moment for the forbidden transition $a\,^3\Pi_u - X\,^1\Sigma_g^+$.

Observations of "Bare" Nuclei.

Recently there has been much interest in attempting to observe the nuclei of comets, particularly to determine whether they bear any similarity to the asteroids. Comet Arend-Rigaux, at two previous apparitions, had appeared to exhibit a purely asteroidal behavior and at the 1977 apparition Paul Weissman stimulated a number of observers to attempt observations with the filter systems used successfully on asteroids. Fortunately, other observers were also stimulated to carry out the more usual cometary observations in the same time period. Degewij (197[illegible]) obtained a spectrum showing the typical cometary emission bands of CN and C_3 while I (1978) obtained Schmidt photographs indicating the presence of both a gaseous coma and a short, dusty tail. These observations showed quite clearly that the photometry of the asteroid filter sets could not be related in any simple way to the true nuclear properties.

More recently Ray Newburn has stimulated efforts to observe the nucleus of Comet Tempel 2 when it is relatively far from the sun. In this case a number of different observers carried out filter photometry (much of it not yet published) which should have led to a determination of the color of the nucleus. Other observers obtained spectral scans which should have described the nucleus. Most of these observers had carried out their observations on a simple, one-shot basis. When the observations of the photometrists were compared with each other (Zellner et al. 1979; Millis, private communication), it was clear that this comet had undergone unexpected outbursts. This makes it rather difficult to be sure, for example, that the spectrophotometry carried out by Spinrad et al. (1979) refers to the nucleus rather than to a halo of grains.

Although these various observers were not explicitly coordinated in the usual sense of the word, they were all stimulated to obtain data in the same general time period. If there had not been several observers active at this time, the outburst phenomena of Tempel 2 might have been suspected depending on which observers happened to get data, but might also have entirely escaped detection. It seems clear that somewhat greater coordination, perhaps involving UBV photometry in the week preceding and the week following the spectrophotometry, would have gone far to determining whether the spectrophotometry was relevant to the nucleus itself.

Infrared and Optical Albedo

We have already heard in this meeting about the attempts to determine the albedo of the grains in the cometary coma during the discussions by Gradie and Campins. Determination of the albedo involves comparison of the reflected solar continuum with the thermal emission, both of these quantities being measured by broad-band photometry. Although there is some evidence that the broad-band photometry in the infrared is dominated by true thermal, continuum radiation, it is certain that the broad-band photometry in the optical includes a large contribution from fluorescent emission lines. It appears to me that a significant improvement in these albedo estimates might result if the infrared photometrists were in closer coordination with the optical photometrists who use narrow-band filters specifically to isolate the reflected continuum.

Interpretation of Continuum/Emission Ratios

As a final example in which coordination might lead to improvements in understanding, I would mention the case of continuum/emission ratios measured to estimate the dust/gas ratio. The standard programs of narrow-band filter photometry of comets, such as that discussed yesterday by Millis but also including programs by a number of other observers, usually include a method for determining the continuum/emission ratio in whatever diaphragm is being used for observation. In some cases these measurements are made in a variety of different diaphragms but in general this is not the case. Direct interpretations of the continuum/emission ratio as a measure of the dust/gas ratio can be very misleading. For some comets, the continuum might be predominantly from a strong, nuclear condensation while for other comets the continuum might be spread out over the entire diaphragm (as is usually observed for new, dusty comets). It seems clear that the usual photometric results could be very profitably combined with contemporaneous spectra of the type described just a few minutes ago by Larson. The photometry would provide the absolute calibration while the long-slit spectra would provide the information on spatial variation of the continuum/emission ratio. This should considerably enhance our ability to interpret both sets of data.

In summary, I think we have a large number of different examples in which coordinated observing has led or could lead to significant, scientific gains. In the past, such coordination has been largely hit-or-miss although a few observers have made specific attempts for special projects. Coordination of this type has been discussed in the context of the International Halley Watch, which will be described tomorrow by Newburn, but the coordination is not a widely accepted procedure for cometary observing. I strongly urge that this coordination be more widespread than it is at present.

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