THE ASTROPHYSICAL JOURNAL, 379:L37–L40, 1991 September 20

OBSERVATIONS OF COMET LEVY (1990c) WITH THE HOPKINS ULTRAVIOLET TELESCOPE

P. D. FELDMAN,[1] A. F. DAVIDSEN,[1] W. P. BLAIR,[1] C. W. BOWERS,[1] W. V. DIXON,[1] S. T. DURRANCE,[1]
H. C. FERGUSON,[2] R. C. HENRY,[1] R. A. KIMBLE,[3] G. A. KRISS,[1] J. W. KRUK,[1] K. S. LONG,[4]
H. W. MOOS,[1] O. VANCURA,[1] AND T. R. GULL[3]

Received 1991 May 28; accepted 1991 June 21

ABSTRACT

Observations of comet Levy (1990c) were made with the Hopkins Ultraviolet Telescope during the Astro-1 Space Shuttle mission on 1990 December 10. The spectrum, covering the wavelength range 415–1850 Å at a spectral resolution of 3 Å (in first order), shows the presence of carbon monoxide and atomic hydrogen, carbon, and sulfur in the coma. Aside from H I Lyman-β, no cometary features are detected below 1200 Å, although cometary O I and O II would be masked by the same emissions present in the day airglow spectrum. The 9.4 × 116 arcsecond aperture corresponds to 12,000 × 148,000 km at the comet. The derived production rate of CO relative to water is 0.11 ± 0.02, compared with 0.04 ± 0.01 derived from *IUE* observations (made in 1990 September) which sample a much smaller region of the coma. This suggests the presence of an extended source of CO, as was found in comet Halley. Upper limits on Ne and Ar abundance are within one order of magnitude of solar abundances.

Subject headings: comets — ultraviolet: spectra

1. INTRODUCTION

Over the past two decades vacuum ultraviolet spectroscopy of comets has provided a wealth of new information regarding the atomic and molecular composition and the physical and chemical state of the gaseous atmosphere, or coma, of comets (Feldman 1983, 1990). Systematics of comet spectra as well as the study of long-term evolution and short-term ultraviolet variability of comets was made possible by the *International Ultraviolet Explorer* (*IUE*) satellite observatory (Festou & Feldman 1987) which has to date observed over three dozen comets. The Hopkins Ultraviolet Telescope (HUT) (Davidsen et al. 1991) offered the possibility of additional enhancements by providing spectral response between 500 and 1200 Å, medium high spectral resolution ($\Delta\lambda \approx 3$ Å) and two orders of magnitude improvement in sensitivity over the low-dispersion mode of *IUE*. This, coupled with the unique instrumental capabilities of the two other Astro-1 ultraviolet instruments for cometary science, led to an initial Astro-1 launch date chosen to coincide with the spacecraft encounters of comet Halley (1986 III) in 1986 March. The *Challenger* accident caused a postponement to 1990, but fortuitously, two moderately bright comets, Austin (1989c$_1$) and Levy (1990c) made their apparitions during the several shuttle launch attempts in 1990 May, September, and December, so that the opportunity for unique cometary observations was not lost.

2. OBSERVATIONS

Comet Levy was observed on 1990 December 10 for 20 minutes beginning at UT 14:53 as the last target of the Astro-1 mission for the ultraviolet instruments mounted on the Instrument Pointing System (IPS). At the time of the observation, the heliocentric distance of the comet, r, was 1.24 AU, the heliocentric velocity, $\dot{r}$, was 18.7 km s^{-1}, the geocentric distance, Δ, was 1.76 AU, and the visual magnitude, as reported on IAU Circular 5145, was ≈ 7.5. The $9\farcs4 \times 116''$ aperture was used for the HUT observations, but the orientation of the aperture was inadvertently rotated 30° from the Sun-comet line that had been requested. Although the comet rose ~9 minutes before orbital sunrise, delays in spacecraft maneuvering led to the observation being done completely in daylight with the result that strong dayglow emissions, particularly of atomic and ionic oxygen, masked the much weaker emission of these species from the comet. To assess the airglow, after 10 minutes with the center-of-brightness of the comet in the aperture, the payload specialist manually moved the IPS so as to offset the comet position by approximately 2′. After 5 minutes the IPS was manually returned to its initial position. This is illustrated in Figure 1 where the observed H I Lyman-α and C I λ1657 count rates are shown as a function of time. Since the scale lengths of both hydrogen and carbon exceed the projected distance of 2′ at the comet, 150,000 km, there is still significant cometary contribution to the observed count rate at the offset position. The fluctuation in the C I λ1657 curve reflects both jitter in the pointing and a low count rate (less than 1 count s^{-1}). The spectral data were processed in approximately 5 minute segments, 3 segments on and 1 segment offset from the center of brightness of the comet.

Portions of the data are shown in Figures 2–4. These spectra are the sum of the three on segments and total 885 s of data. Figure 2 shows the region from 1000 to 1160 Å which is dominated by strong dayglow emissions of O I, N I and N II and, except for the H I Lyman-β and O I λ1026 blend, contains no obvious cometary features. The spectral region longward of 1400 Å is shown in Figure 3 and clearly shows C I λλ1561, 1657 and S I λλ1807–1826, well known from *IUE* comet spectra, as well as the airglow features identified in the figure. Figure 4 expands this region to show the fit of the weak features between 1400 and 1650 Å to a synthetic spectrum of the CO

---

[1] Center for Astrophysical Sciences, Department of Physics and Astronomy, Johns Hopkins University, Baltimore, MD 21218.

[2] Institute of Astronomy, Cambridge University, Observatories, Madingley Road, Cambridge CB3 0HA, England.

[3] Laboratory for Astronomy and Solar Physics, NASA Goddard Space Flight Center, Greenbelt, MD 20771.

[4] Space Telecope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218.

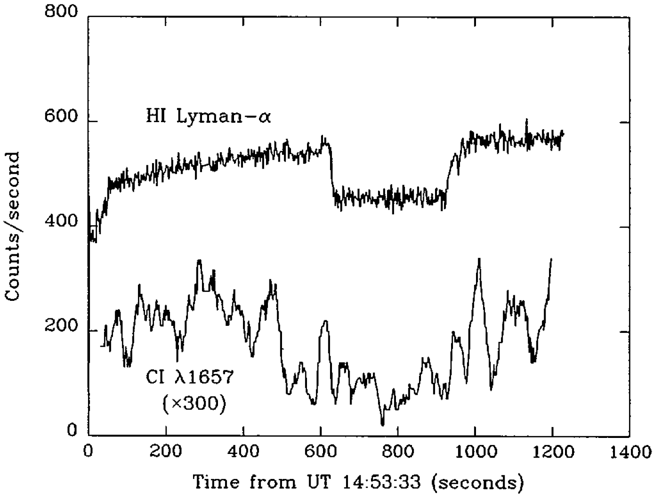

FIG. 1.—Observed count rate as a function of time from comet Levy for H I Lyman-α and C I λ1657. For the latter, the vertical scale is reduced by a factor of 300 and the data are smoothed over 30 s.

Fourth Positive system assuming pure resonance fluorescence and the calculated relative fluorescence efficiencies (*g*-factors) of Durrance (1981). The fit includes the apparent continuum of grating scattered Lyman-α radiation. Also indicated are two atomic sulfur features, S I λλ1425 and 1474, usually observed in comets only at low heliocentric velocity as they are excited by narrow S I emission lines in the solar spectrum (Roettger et al. 1989). Their presence suggests a change in line shape of the exciting solar lines at the time of solar maximum. Analysis of the sulfur emissions will be deferred to a subsequent paper.

3. DISCUSSION

3.1. *Carbon Monoxide*

The synthetic spectrum of the CO Fourth Positive system gives an excellent fit to the observed spectrum of Figure 4 with the exception of the intensity of the (0, 0) band at 1545 Å relative to that of the (1, 0) band at 1510 Å. This anomaly has also been noted in *IUE* spectra of comet Halley (Roettger 1991) where it had been postulated to arise from the CO column density becoming optically thick in the near-nucleus region that the *IUE* aperture samples. This would lead to absorption in the strongest bands, (1, 0) and (2, 0), with subsequent re-emission to higher vibrational levels of the ground electronic state, reducing the (1, 0) and (2, 0) band intensities relative to the rest of the system. In the present case this is unlikely, but the apparent enhancement of the (0, 0) band may result from changes in the line structure present near 1545 Å in the solar spectrum associated with solar maximum. For the present analysis, we use the brightness of the (1, 0) band, which is excited purely by solar continuum, to derive a CO production rate. The average brightness of this band in the slit,

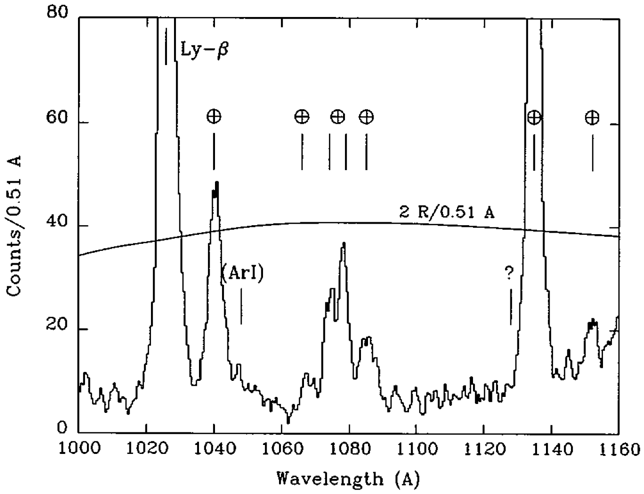

FIG. 2.—Spectrum of comet Levy from 1000 to 1160 Å, smoothed over 1.5 Å. The principal day airglow emission features, indicated in the figure, include O I λλ1040 and 1152, O II λ539 and He I λ537 (both in second order), N II λ1085 and N I λ1134. The position of Ar I λ1048 is indicated, as is the position (denoted by "?") of a forbidden oxygen transition reported in a spectrum of comet Austin (1989c$_1$) by Green et al. (1991). The solid line shows the instrument response to a source of uniform surface brightness of 2 Rayleighs per 0.51 Å spectral element.

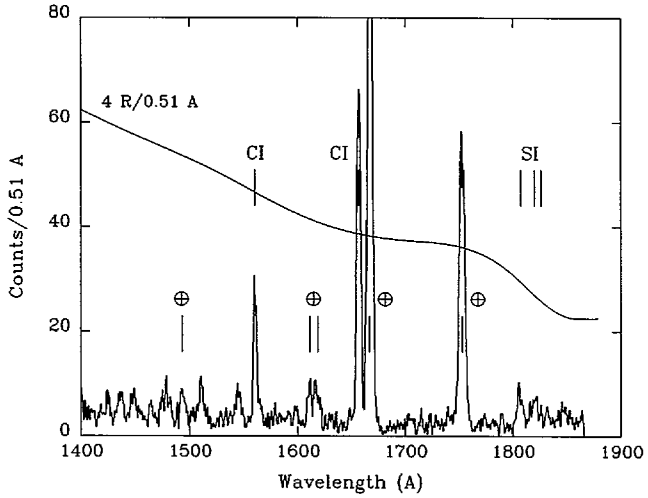

FIG. 3.—Spectrum of comet Levy from 1400 to 1850 Å, smoothed over 1.5 Å. The principal day airglow emission features, indicated in the figure, include O II λ834 (in second order), O II λ539 (in third order), N I λ1493 and He I λλ584 and 537 (in third order). The solid line again shows the instrument response.

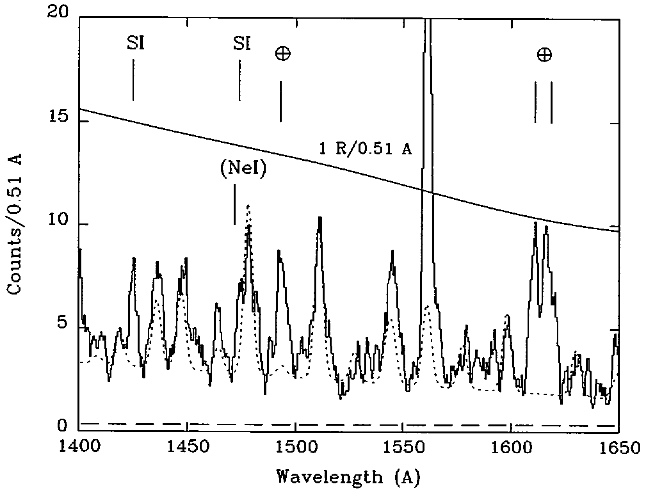

FIG. 4.—Spectrum of comet Levy from 1400 to 1650 Å, smoothed over 2.5 Å. The short dashed line is a synthetic spectrum of optically thin fluorescence of the CO Fourth Positive system superimposed on a quasi-continuum of grating scattered Lyman-α radiation. The long dashed line is the detector dark count rate.

using the flight calibration (Davidsen et al. 1991) is 5.5 ± 1.1 Rayleighs.

To model the average column density in the 9″.4 × 116″ HUT slit, the CO is assumed to originate in a point source and flow radially outward with a velocity of 1.0 km s^{-1}. This is the same model used in analysis of *IUE* data with which the HUT results will be compared below. However, because of the projected length of the HUT slit at the comet, 148,000 km, the model was evaluated over a range of CO dissociation lifetimes, from 1.4×10^6 s (Huebner 1985) corresponding to solar minimum, to 0.4×10^6 s for solar maximum. The latter was estimated using recent solar EUV fluxes measured by Woods & Rottman (1990). Note that the solar flux between 1400 and 1550 Å used by Durrance (1981) to derive the *g*-factors is that appropriate to solar maximum as well. The derived CO production rate is $1.4 \pm 0.3 \times 10^{28}$ s^{-1}, with only a 5% variation over the range of lifetimes used. The uncertainty quoted is statistical and, in fact, does not correctly represent the true uncertainty associated with the measurement. The model used assumes a point source centered in the spectrograph aperture, so that pointing jitter, not possible to quantify at the present time, leads to an underestimate of the brightness and thus a lower limit to the actual production rate.

The quantity of interest is the ratio of CO to H_2O in the coma, as this appears to be highly variable from comet to comet (Feldman 1986) and may be related to the gas/dust ratio, which is also highly variable (Feldman et al. 1988). Ultimately, the water production rate, Q_{H_2O}, for this observation will be obtained from simultaneous WUPPE measurements of OH band emission. For now, we use reported visual magnitudes and *IUE* measurements of comet Levy from 1990 September and 1991 January (Feldman et al. 1991). The visual magnitudes, taken from IAU circulars and reduced to a geocentric distance of 1 AU, appear to follow a slope of 5 log *r*, indicative of a constant average production rate, with the activity post-perihelion about half that preperihelion. The adopted value is $Q_{H_2O} = 1.25 \times 10^{29}$ s^{-1}, giving a ratio Q_{CO}/Q_{H_2O} of 0.11 ± 0.02. Again, this is best regarded as a lower limit to the true ratio. From two long *IUE* exposures taken on 1990 August 26 and 1990 September 18 ($r = 1.38$ and 1.13 AU, respectively) Feldman et al. (1991) found a value of 0.04 ± 0.01. The difference between these results may be due to a change in activity resulting from a change in the relative solar exposure of different volatile areas of the cometary surface between pre- and postperihelion. Alternatively, it may indicate the presence of an extended source of CO in the coma, not significantly contributing to the emission seen in the *IUE* aperture. Such a source, peaked about 10,000 km from the nucleus and contributing from one-half to two-thirds of the total CO in the coma, was detected in situ in comet Halley by the neutral mass spectrometer aboard *Giotto* (Eberhardt et al. 1987). A similar analysis for P/Halley, comparing nearly simultaneous *IUE* and long-slit sounding rocket spectra is completely consistent with the *Giotto* results and further suggests that this phenomenon was not unique to the time of the *Giotto* encounter (Feldman et al. 1988). Unfortunately, simultaneous *IUE* observations of comet Levy at the time of Astro-1 were not possible.

3.2. *Upper Limits to* Ar *and* Ne *Abundance*

The HUT has the unique spectral capability to detect fluorescent emission from the noble gases neon and argon in their strongest transitions at 735.9 and 1048.2 Å, respectively. He I λ584 is also detectable, in both second and third order, but, if present at all in the cometary spectrum, would be masked by geocoronal He emission. The positions of the Ne I and Ar I lines are indicated on Figures 4 and 2. For Ne I λ736, which appears in second order at 1472 Å, there is overlap with the S I λ1474 line, and a 1 σ upper limit of 2.4 Rayleighs is derived. Note that the second order effective area at 736 Å is about a factor of 3 lower than that for first order at 1472 Å. A positive detection of a line at the wavelength of Ar I λ1048 with a brightness of 2.0 ± 0.8 R is made, but this appears to be associated with the day airglow as it is present in the offset spectrum as well as in other HUT spectra. It is probably not Ar I airglow emission, as standard atmosphere models predict an argon column density above the spacecraft sufficient to produce only ~0.007 R of emission. Using the offset 5 minute segment and taking the difference with the two 5 minute segments on either side centered on the comet gives a net comet emission at 1048 Å of 0.0 ± 1.6 R.

For a comparison with solar abundances (Cameron 1973), oxygen is used as a standard and the production rates of Ne and Ar relative to Q_O are used in the same radial outflow model described above to estimate the expected average brightness in the HUT slit. The quantity Q_O is taken to be 25% higher than Q_{H_2O} to account for additional sources of O in the coma such as CO and CO_2, and the fluorescence efficiencies are calculated using solar EUV fluxes appropriate to solar maximum scaled from the recent data of Woods & Rottman (1990) obtained at a spectral resolution of ~1 Å. Thus, for solar abundance ([Ne]/[O] = 0.16, [Ar]/[O] = 0.0054), the expected values are 0.5 R for Ne I λ736 and 0.15 R for Ar I λ1048. These are lower by factors of 6–10 than the HUT upper limits, but indicate that detection of these species is feasible with longer (nighttime) integration time, more favorable viewing geometry and/or a more active comet.

3.3. *Limits on Other Emission Features below* 1200 Å

As noted above, except for the H I Lyman-β, O I λ1026 blend, which decreased at the offset position, no cometary emission feature is identified below 1200 Å. This conflicts with the recent paper of Green et al. (1991) reporting features at 1042 and 1128 Å in a sounding rocket spectrum of comet Austin ($1989c_1$) which they attribute to highly forbidden transitions of O I produced by cascade from $O(2p^3 3d\ ^3D^0)$ excited by solar Lyman-β. These emissions are particularly difficult to understand since a comparison with O I λ1302 observed in a sounding rocket experiment a week earlier (Sahnow et al. 1990) implies branching ratios of forbidden to allowed transitions greater than 1. Moreover, the 1128 Å transition ($2p^3 3p\ ^3P$–$2p^4\ ^3P$) has never been seen in any laboratory or atmospheric spectrum of atomic oxygen (Kelly 1987). As can be seen in Figure 2, the region round 1128 Å is well isolated from the airglow N I λ1134 emission and no detectable emission, to a 1 σ limit of 0.8 R, is present. The 1040 Å region in Figure 2 is dominated by the electron-excited O I λ1040 airglow emission so that it is not possible to constrain the cometary emission at this wavelength.

For comparison with the 320 R of 1128 Å emission reported by Green et al. (1991), a simple scaling law is again possible as the angular slit sizes of both HUT and the Green et al. (1991) spectrographs were nearly equal. Detailed modeling, using spatial profiles of atomic oxygen measured in comet Halley by Dymond, Feldman, & Woods (1989), will be reported later. In this case, the average slit brightness is proportional to $r^{-4}\Delta^{-1}Q_{H_2O}$, where the additional factor of r^{-2} is needed to account for the rate at which the oxygen parent molecules are photodissociated. For comet Austin at the time of the observation of Green et al. (1991), $r = \Delta = 0.61$ AU, and $Q_{H_2O} = 8 \times 10^{28}$ s^{-1} (Budzien et al. 1990). Thus, for the HUT observation of comet Levy, 10 R would be expected, one order of magnitude above the derived limit. It is likely that the 1128 Å feature of Green et al. (1991) is an instrumental artifact.

As they suggest, a search for this feature for comparison with other O I forbidden transitions in optically thick oxygen environments is warranted, and such a search is possible with the HUT observations of the bright Earth. Using the model calculations of Meier et al. (1987) to estimate the brightness of the branching $2p^3 3d\,^3D^0$–$2p^3 3p\,^3P$ transition at 11290 Å in terms of the observed O I λ1026 line (which accounts for 80% of the emission at 1026 Å in the dayglow), the branching ratio $A(1128)/A(8446)$ is found to be ≤ 0.03. Moreover, this represents an upper limit, as the residual emission at 1128 Å seen looking down is most likely due to the $N_2\, b'\,^1\Sigma_u^+ - X\,^1\Sigma_g^+$ (1, 7) band (James et al. 1990). A detailed analysis of the N_2 band spectrum in the day airglow, to be published elsewhere, should permit this limit to be reduced further.

Finally, we note that the daytime observation precluded one of the original goals of this program, the detection of the oxygen ion tail in a comet via emission of O II λ834. For an estimate of the expected brightness, the O^+ column density was scaled from the CO_2^+ column density measured in comet Wilson (1987 VII) at roughly the same values of r and Q_{H_2O} (Roettger et al. 1989) using the CO_2/H_2O ratio of comet Halley (Krankowsky et al. 1986), and the *g*-factor was taken from Meier (1990). The result is of the order of a few Rayleighs, which would have been detectable at night, but is masked by the ~1 kR of O^+ day airglow emission.

4. SUMMARY

HUT observations of comet Levy (1990c) show the presence of carbon monoxide and atomic hydrogen, carbon and sulfur in the coma. The abundance of CO relative to H_2O, compared with the same ratio derived from *IUE* observations (which sample a much smaller region of the coma), suggests the presence of an extended source of CO, as was found in comet Halley. Upper limits on Ne and Ar abundance are within one order of magnitude of solar abundances. Future analyses will compare the extended H and C emissions measured at the 2′ offset position with existing models.

It is a pleasure to thank the Spacelab Operations Support Group at Marshall Space Flight Center for their support during the Astro-1 mission, with special thanks to Becky Bray and the mission planning team for making the observation of comet Levy possible. We also thank our many colleagues at Johns Hopkins University and the Applied Physics Laboratory for all of their contributions to the success of the Hopkins Ultraviolet Telescope. T. N. Woods kindly provided detailed solar EUV flux data. This work was supported by NASA contract NAS 5-27000 to Johns Hopkins University.

REFERENCES

Budzien, S. A., Feldman, P. D., Roettger, E. E., A'Hearn, M. F., & Festou, M. C. 1990, in Workshop on Observations of Recent Comets, ed. W. F. Huebner et al. (San Antonio: SWRI), 64

Cameron, A. G. W. 1973, Space Sci. Rev., 15, 121

Davidsen, A. F., et al. 1991, in preparation

Durrance, S. T. 1981, JGR, 86, 9115

Dymond, K. F., Feldman, P. D., & Woods, T. N. 1989, ApJ, 338, 115

Eberhardt, P., et al. 1987, A&A, 187, 481

Feldman, P. D. 1983, Science, 219, 347

———. 1986, in Asteroids, Comets, Meteors II, ed. C. I. Lagerkvist et al. (Uppsala: Uppsala Univ.), 263

———. 1990, in Chemistry in Space, ed. J. M. Greenberg & V. Pirronello (Dordrecht: Kluwer), 339

Feldman, P. D., Budzien, S. A., A'Hearn, M. F., Festou, M. C., & Tozzi, G. P. 1991, in preparation

Feldman, P. D., Roettger, E. E., Dymond, K. F., & Weaver, H. A. 1988, BAAS, 20, 827

Festou, M. C., & Feldman, P. D. 1987, in Exploring the Universe with the *IUE* Satellite, ed. Y. Kondo (Dordrecht: Reidel), 101

Green, J. C., Cash, W., Cook, T. A., & Stern, S. A. 1991, Science, 251, 408

Huebner, W. F. 1985, in The Photochemistry of Atmospheres, ed. J. S. Levine (Orlando: Academic Press), 438

James, G. K., Ajello, J. M., Franklin, B., & Shemansky, D. E. 1990, J. Phys., B23, 2055

Kelly, R. L. 1987, J. Phys. Chem. Ref. Data, 16, Suppl. 1

Krankowsky, D., et al. 1986, Nature, 321, 326

Meier, R. R. 1990, Geophys. Res. Letters, 17, 1613

Meier, R. R., Anderson, D. E., Paxton, L. J., McCoy, R. P., & Chakrabarti, S. 1987, J. Geophys. Res., 92, 8767

Roettger, E. E. 1991, Ph.D. thesis, Johns Hopkins University

Roettger, E. E., Feldman, P. D., A'Hearn, M. F., Festou, M. C., McFadden, L. A., & Gilmozzi, R. 1989, Icarus, 80, 303

Sahnow, D. J., Feldman, P. D., McCandliss, S. R., & Martinez, M. E. 1990, in Workshop on Observations of Recent Comets, ed. W. F. Huebner et al. (San Antonio: SWRI), 55

Woods, T. N., & Rottman, G. J. 1990, J. Geophys. Res., 95, 6227