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IUE observations of comet P/Halley: evolution of the ultraviolet spectrum between September 1985 and July 1986

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Summary. The ultraviolet spectrum of comet P/Halley (1982 i) was monitored with the International Ultraviolet Explorer (IUE) satellite observatory between 1985 September 12 and 1986 July 8 ($r < 2.6$ AU pre- and post-perihelion) at regular time intervals except for a two-month period around the time of perihelion. A complete characterization of the UV spectrum of the comet was obtained which allows us to derive coma abundances and to study the light emission mechanisms of the observed species. IUE observations at the time of the Giotto encounter provide a unique opportunity to compare the *in situ* measurements with remote observations of the principal coma species. The Fine Error Sensor (FES) camera of the IUE was used to photometrically investigate the coma brightness variation on time scales of the order of hours. Spectroscopic observations as well as FES measurements show that the activity of the nucleus was highly variable, particularly at the end of December 1985 and during March and April 1986. The production rates of OH, CS and dust are derived for the entire period of the observations. The total water loss rate for this period is estimated to be $3\,10^8$ metric tons.

Key words: comet P/Halley – spectroscopy – ultraviolet

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1. Introduction

The IUE was used in an extensive joint US-European program to monitor the spectral characteristics and evolution of comet Halley between September 1985 and July 1986, corresponding to heliocentric distance $r < 2.6$ AU both pre- and post-perihelion. Observations, from both Goddard Space Flight Center and Vilspa, were made at regular intervals during this period except between January 1 and March 8, 1986 when the solar elongation angle of the comet was too small. A special observing technique, developed by the GSFC IUE staff, made possible the almost daily observations during the week of the Vega-2 and Giotto encounters.

An unexpected benefit of the IUE program was the use of the Fine Error Sensor (FES) as a photometric monitor over relatively long time periods of short-term fluctuations in cometary activity. Large amplitude variations in brightness (in the 18" square central region of the coma) were particularly evident the last week of December 1985 and throughout March and April 1986. These variations are attributed to a combination of nucleus rotation and outburst of individual jets or active areas on the surface of the nucleus. Contiguous observing shifts have made it possible to study the behavior of the UV emissions during several periods of outburst activity.

This report presents a summary of the observations made through July 1986 and a preliminary analysis of the long-term evolution of the gaseous coma of P/Halley. The highlights of the observations made during the spacecraft encounters have been presented by Festou et al. (1986). In this regard it is worth noting the excellent agreement obtained between the water production rate based on IUE measurements of OH emission and the vectorial model of Festou (1981) and that based on the *in situ* neutral mass spectrometer data from Giotto (Krankowsky et al., 1986). The *in situ* measurements also showed the validity of the inverse square distribution and radial outflow velocity ($0.9 \pm 0.2\,\mathrm{km\,s^{-1}}$) of the H_2O parent molecules used in the coma models, even though some question remains concerning the value of the photodestruction lifetime of H_2O.

2. Spectroscopy

The first spectrum of comet Halley ever recorded from space, a long wavelength three-hour exposure taken on 1985 September 12.0, is shown in Fig. 1. The OH (0, 0) band at 3085 Å is readily apparent, indicating a significant H_2O production rate already at 2.59 AU. Typical of the period following perihelion is the exposure from 1986 March 11, shown in Fig. 2, which displays all of the known neutral cometary emission features in this spectral range as well as a very strong component of sunlight reflected by particulate grains in the coma. Comparison with the measured solar spectrum (Mount and Rottman, 1981), shown as the dotted curve in Figure 2, indicates that the reflected spectrum is more reddened (7% per 100 Å) than that of more distant, dusty comets observed previously by the IUE (Feldman and A'Hearn, 1985). The source of the reddening remains uncertain and is contrary to the behavior expected from the large population of small grains detected by the *in situ* dust experiments. The strong solar component tends to mask the emission from the CO_2^+ doublet near 2890 Å. However, when a properly reddened solar spectrum is subtracted from a spectrum such as in Fig. 2, the resultant CO_2^+ emission suggests an abundance relative to OH comparable to that found in other comets (Festou et al., 1982). The absence of detectable CO^+ First Negative band emission near 2200 Å probably results from a combination of lower fluorescence efficiency for these transitions (relative to the blue Comet Tail bands) (Magnani and A'Hearn, 1986) and the poor sensitivity of the LWP camera in this spectral range.

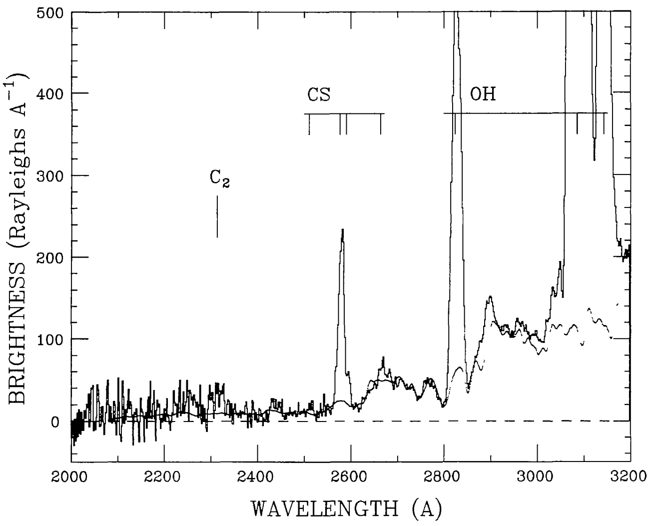

Fig. 2. A long wavelength 15 minute exposure of P/Halley (LWP 7773) obtained on 1986 March 11

As with the long-wavelength spectra, the short-wavelength spectrum (Fig. 3) does not show any previously undetected cometary emission features. In fact, the apparent weakness of O I, C I and S I, relative to those emissions in the spectrum of comet Bradfield (1979 X) (Weaver et al., 1981), may reflect lower fluorescence efficiencies and photodissociation rates due to the lower solar UV fluxes characteristic of solar minimum as compared with 1980 which was the year of solar maximum.

3. Variability

Visible light photometric monitoring of P/Halley was accomplished by using the Fine Error Sensor (FES) camera of the IUE (normally used for target acquisition and tracking) as a broadband (4000–6500 Å) photometer. In this mode, the FES samples a region approximately 18 arc-seconds square around the center of brightness of the comet. These observations are made auto-

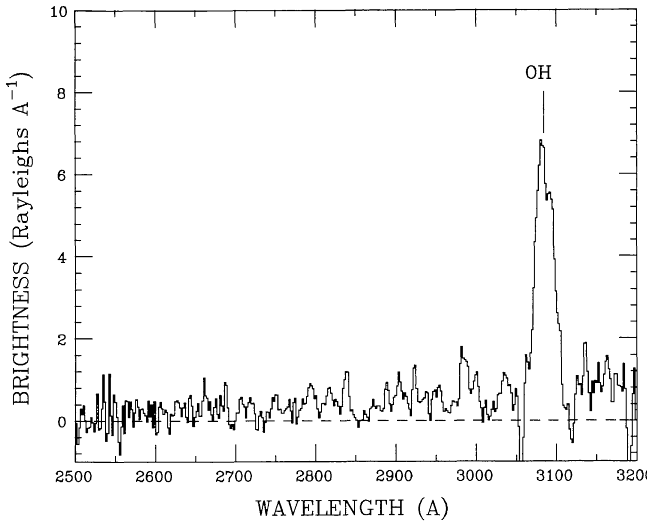

Fig. 1. Long-wavelength spectrum of P/Halley (LWP 6720) obtained on 1985 September 12. The exposure time was 180 minutes

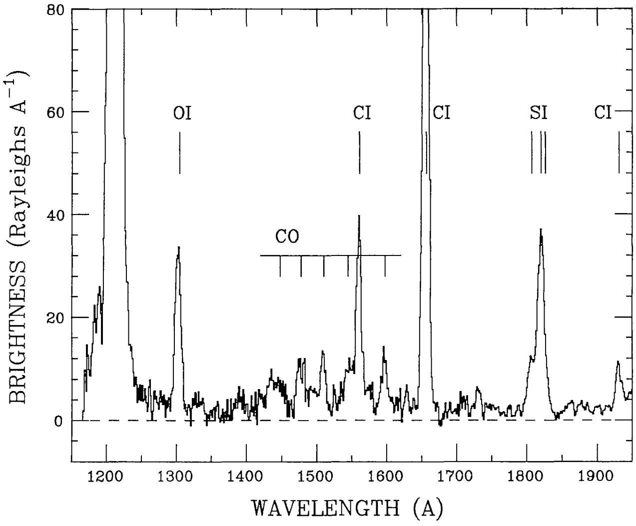

Fig. 3. Short-wavelength spectrum of P/Halley (SWP 27884) obtained on 1986 March 9. The exposure time was 45 minutes

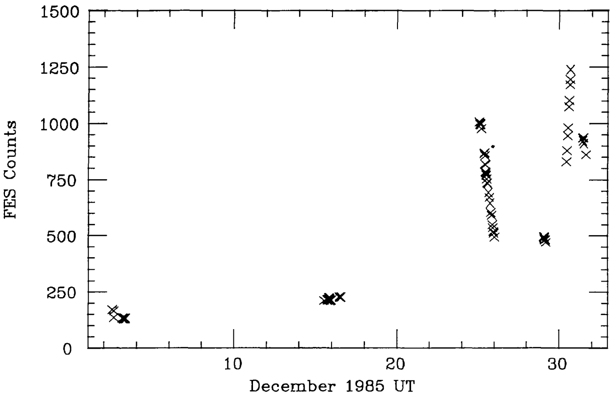

Fig. 4. FES photometry for December 1985

matically as the IUE tracking of the moving comet is verified at intervals of ~30 to 60 minutes. The short-term variability of comet Halley can be seen in Figs. 4 and 5 which show the FES data for December 1985 and March-April 1986, respectively. The FES responds to a mixture of gas and dust emission and a comparison with the ultraviolet spectra (taken at much less frequent intervals) indicates that both the UV continuum and the CS emission follow the changes in cometary activity more rapidly than does the OH emission, which arises from a parent molecule whose lifetime is about 1 day (McFadden et al., 1987). Amongst many apparent transient events seen in Fig. 5, a sharp outburst on March 18-19 was found to be correlated with CO_2^+ emission observed by IUE 150,000 km tailward from the nucleus during the outburst and with ground-based observations of a large detached CO^+ cloud on 20 March 1986 (Feldman et al., 1986). Otherwise, the variations in Fig. 5 are found to closely follow the 7.4-day period light curve derived from ground-based photometry by Millis and Schleicher (1986). However, it should be noted that IUE observations made after April did not show any significant variation in the FES count rate during an 8-hour observing shift.

4. Production rates

One of the principal goals of the IUE Halley program was the determination of the variation of gas production rate with heliocentric distance both before and after perihelion. The derivation of this rate from the observed surface brightness is generally achieved with the use of steady-state, spherically symmetric models. Although the validity of these assumptions is clearly questionable in light of both *in situ* and remote observations of P/Halley, they provide the only means of intercomparing observations made over a large range of heliocentric and geocentric distances. However, as noted above, the preliminary results from the Giotto neutral mass spectrometer experiment (Krankowsky et al., 1986) confirmed two of the basic assumptions of the models, the radial outflow velocity and the inverse square density distribution of the parent molecules. For the present, only the production rates of the parents of OH and CS are considered. For the grains, the production rate can be related to the quantity $Af\rho$, the product of albedo, filling factor and aperture radius (A'Hearn et al., 1984). The vectorial model (Festou, 1981) and OH fluorescence efficiencies of Schleicher (1983) are used to derive Q_{H_2O}, while Q_{CS}, assumed to be equal to the production rate of its short-lived parent, CS_2 (Jackson et al., 1986), is derived from a Haser model and the assumption of heliocentric velocity independent fluorescence efficiency. For the parent molecules, the outflow velocity was taken to be 1 km s^{-1}, while the photodissociation lifetimes of both H_2O and OH were taken from Festou (1981). The use of a shorter H_2O scale length, as suggested by Krankowsky et al. (1986) would yield values of Q about 60% of those shown in Fig. 6. In all three cases, the emissions are assumed to be optically thin. While this is not exactly so for the strongest lines of the OH (0, 0) band used in the analysis, the effect of resonance re-radiation on the derived production rates is estimated to be begligible.

The results, shown in Figs. 6-8, are somewhat surprising. Both the CS and the dust show larger short-term fluctuations with comet variability than does OH, but also exhibit a uniform decrease in production rate to larger heliocentric distance. The H_2O production rate, on the other hand, while increasing dramatically between 2 and 3 AU pre-perihelion, and then more gradually to 1 AU, did not begin to decrease appreciably until the comet was approaching 2 AU post perihelion. This behavior suggests that in P/Halley the CS and dust production are not totally controlled by the water vaporization, a conclusion already reached for two other comets previously observed by IUE, IRAS-Araki-Alcock (1983 VII) (Feldman et al., 1984) and P/Encke (A'Hearn et al., 1985).

Finally, we note that the water production rates shown in Fig. 6 can be integrated over the entire period from September 1985

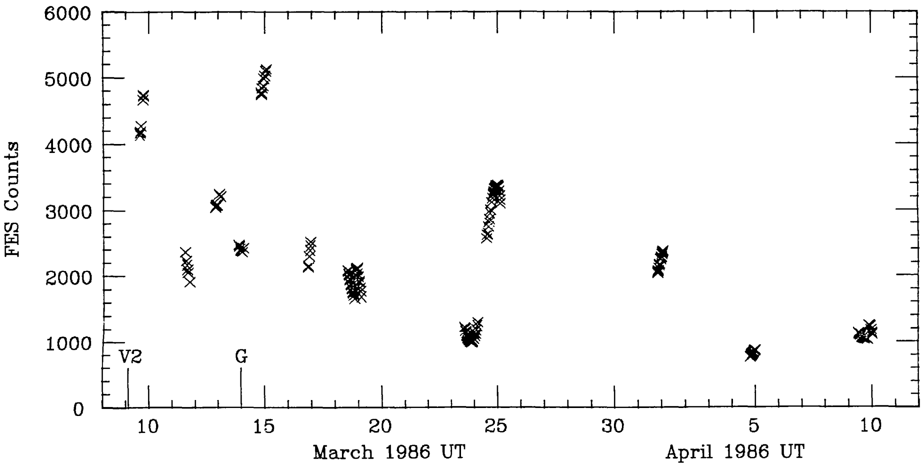

Fig. 5. FES photometry for March and April 1986. The times of the Vega-2 and Giotto encounters are indicated

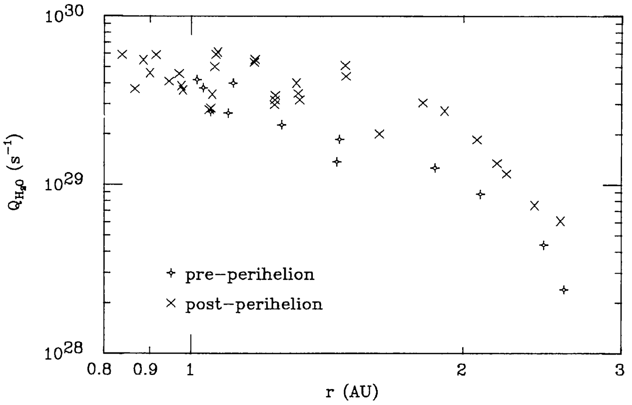

Fig. 6. Water production rate for comet Halley as a function of heliocentric distance as derived from IUE observations of OH

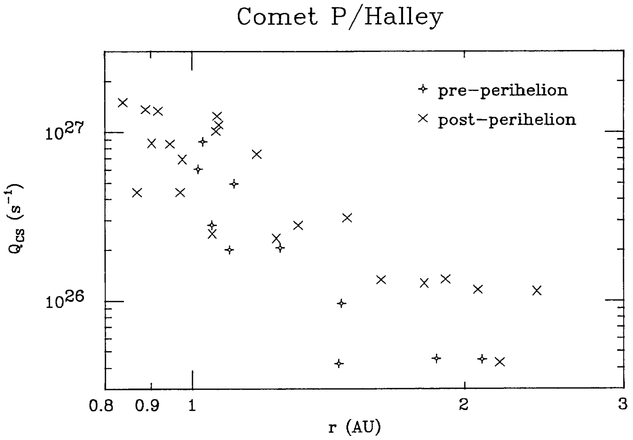

Fig. 8. Production rate of CS as a function of heliocentric distance

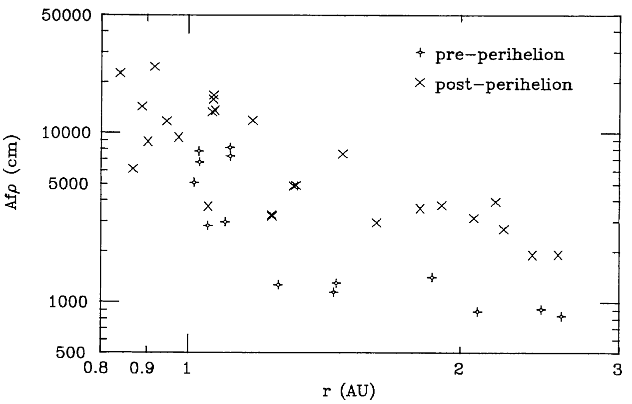

Fig. 7. Dust production rate variability as a function of heliocentric distance

through the beginning of July 1986 to estimate the total amount of water lost by P/Halley during this apparition. For the period around perihelion when there are no IUE observations, a constant value of $Q = 1\ 10^{30}$ molecules s^{-1} is used. This value is consistent with the H I Lyman-α observations made by the ultraviolet spectrometer on Pioneer Venus Orbiter during this period (Stewart, 1987). The total H_2O lost, estimated this way, is $3\ 10^8$ tons.

5. Conclusion

The IUE observations of comet Halley provide a unique source of information about the composition, evolution, and short-term behavior of the cometary coma, and establish a context for the inter-comparison of the *in situ* encounter snapshots of Halley and the large body of Earth-based observations of the comet.

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