Spatial Distribution of Constituents in the Coma of Comet Halley, an Observing Programme at the ESO 1-m Telescope

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1. Scientific Objective

When a comet visits the inner solar system the sun's radiation sublimates part of the nucleus' matter. The liberated gases drag some dust particles with them and form the coma of the comet. It has an approximately spherical shape and an extent of several hundred thousand kilometres. The sublimated gas particles are dissociated and ionized by solar UV radiation, charge exchange and, in the inner coma, by collisions. In the inner coma chemical reactions between the different coma species will form new types of radicals and ions. Ultimately, all gas molecules and their daughter products will be ionized and swept away by the solar wind into the cometary ion tail. The dust particles are removed from the coma by solar radiation pressure and form the dust tail.

The observing programme to be described in the following was devoted to a study of the different constituents in the cometary coma. Such a study should give information on the chemical composition of the cometary nucleus. The neutral radicals, which are observable from the ground like CN, C_2, C_3, CH, NH and NH_2, are chemically processed and therefore relate only indirectly to the so-called mother substances of the nucleus. Many ions, however, e.g. CO^+, CO_2^+ and H_2O^+, are ions of presumable nucleus constituents. Consequently, the interest concentrated on the cometary ions. Their behaviour, however, is influenced by their interaction with the solar wind, which leads to the formation of ion rays and streamers. Therefore, a study of cometary ions must include their kinematical behaviour. As Comet Halley was investigated by an armada of space probes, we have the unique opportunity to compare the ground-based observations with *in situ* measurements.

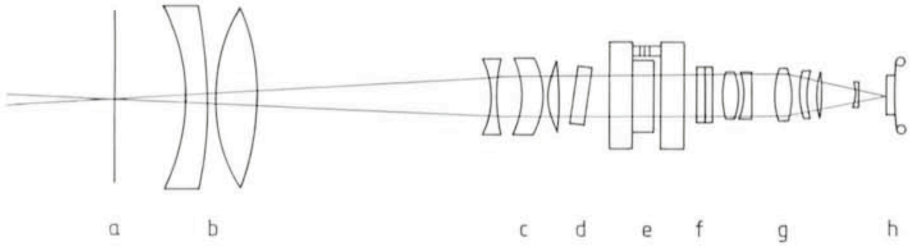

Figure 1: *Optical arrangement of the focal reducer in the imaging mode. a: Cassegrain focus; b: field lens; c: collimator lens; d: coloured glas prefilter; e: tunable Fabry-Perot filter; f: interference filter; g: camera lens f/2.8; h: two-stage image intensifier.*

2. The Instrument

For the observations the focal reducer of the Observatory Hoher List was used at the ESO 1-m telescope. For the comet observations the Max-Planck-Institute for Aeronomy supplemented this instrument with two dioptric cameras (Carl Zeiss, Oberkochen) for the near UV (365–500 nm) and visual (425–660 nm) spectral ranges. A two-stage proximity-focused image intensifier (Proxitronic, Bensheim) with bialkali cathode was attached to the UV camera and the image was recorded on plates (mostly hypersensitized IIIa-F) pressed against the exit window of the intensifier. The optical arrangement is shown in Figure 1. The telescope beam behind the Cassegrain focus (a) is recollimated via a field lens (b) and a collimator triplet (c), and a new image, reduced in size by a factor of 5, is formed by the lens (g) on the photocathode of the image intensifier (h). At the 1-m telescope a field of 25 arcminutes is obtained which corresponds at Comet Halley to about 10^6 km (depending on its geocentric distance).

The instrument was used in three modes. In the imaging mode (Figure 1) pictures of the comet were obtained through interference filters combined with a tunable narrow-gap Fabry-Perot filter (Queensgate Instruments, Sunbury near London, B. Halle, Berlin). The Fabry-Perot works in the wavelength interval of 350–430 nm. It has a bandpass (FWHM) of about 6 Å and a free spectral range of about 100 Å. In the field spectroscopy mode (Geyer et al., 1979) a slit mask with a pattern of 70 0.2 mm wide slits was inserted into the Cassegrain focal plane. Instead of the Fabry-Perot filter a direct vision grating prism was put into the parallel beam to produce 70 simultaneous spectra at different places in the cometary coma. The resulting saving of observing time was essential for the success of the programme, in particular when the comet was still close to the sun. Two gratings with 300 and 600 lines/mm were used and gave an inverse dispersion of 207 and 103 Å/mm, respectively. One plate was obtained with a double grating prism. The resulting pairs of inverted spectra should allow the determination of radial velocities (Geyer and Nelles, 1985). The field spectroscopy mode is in some sense similar to the octopus spectrograph introduced recently at the ESO 3.6-m telescope (Lund and Surdej, 1986). In a third mode, another Fabry-Perot etalon with a fixed plate separation of 0.5 mm was added to the optical arrangement of Figure 1 in an attempt to derive Doppler velocities of the cometary ions. A few very weakly exposed interferograms were obtained in the light of the CO^+ and CH^+ ions. It seems questionable if they will allow derivation of ion speeds. Most plates exposed in the direct imaging and field spectroscopy modes were photometrically calibrated with the ESO spot sensitometer, with exposures of the bipolar nebula NGC 6302 and with a set of mercury standard lamps. Besides the focal reducer, three

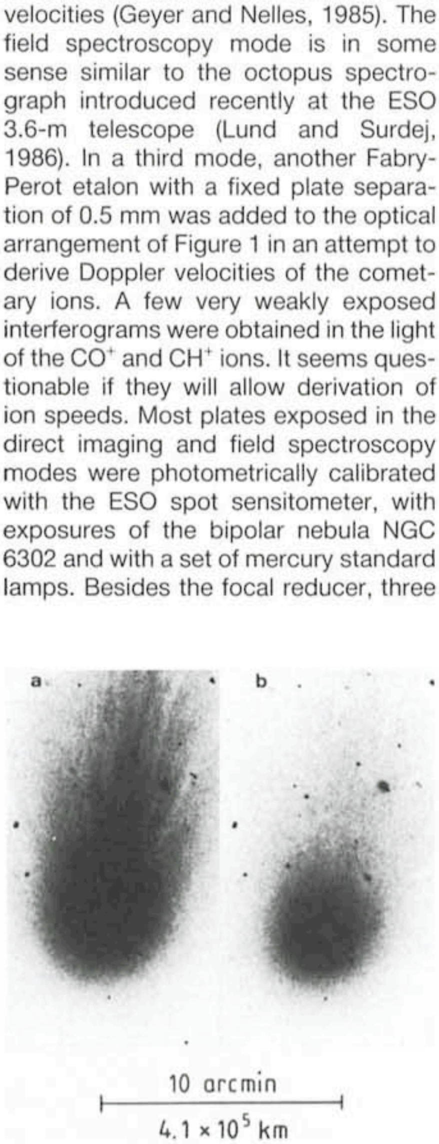

Figure 2: *Images of Comet Halley obtained March 15. a: CO^+ at 367.4 nm; b: "continuum" at 365.0 nm. Exposure times: 10 minutes.*

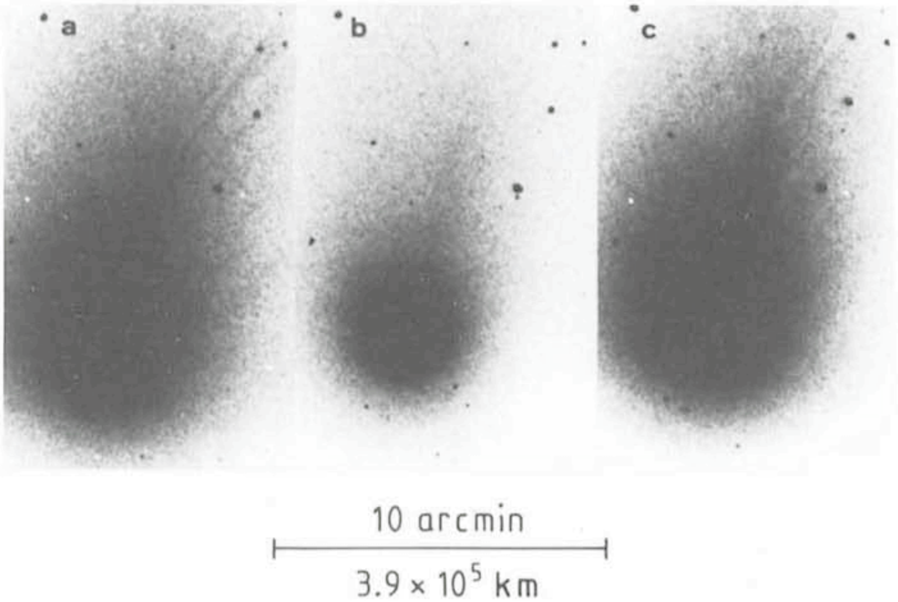

Figure 3: *Images of Comet Halley obtained March 16. a: CO^+ at 401.9 nm; b: "continuum" at 407.4 nm; c: N_2^+ at 391.2 nm. Exposure times: a and b: 1 minute; c: 4 minutes.*

cameras, attached to the top ring of the telescope, were used to obtain wide-field images and slitless wide-field spectra in the visible and UV spectral ranges.

3. The Observations

The observations were performed in the two periods March 10–16 and April 4–11, 1986. As there has not been enough time yet for a detailed quantitative analysis of the data, only some raw data are presented. Figure 2 shows a pair of images taken on March 15 at 367.4 nm (CO_2^+) and 365.0 nm ("continuum"). Both images were taken through the same interference prefilter but correspond to different settings of the Fabry-Perot filter. Comparison of the two images indicates a strong signal at the wavelength of CO_2^+. The weak ion features present in the "continuum" picture may be caused by weak plasma emissions in the "continuum" window or, more likely, by spectral impurity of the Fabry-Perot filter. Note the regular pattern of ion streamers surrounded by a plasma envelope which is missing in the continuum picture. In Figure 3 we see three images, obtained at 401.9, 407.4 and 391.2 nm respectively, corresponding to the 3-0 $A^2\,\pi_{3/2} - X^2\Sigma^+$ transition of CO^+, "continuum" and the O-O $B^2\Sigma^+_u - X^2\Sigma^+_g$ transition of N_2^+. The N_2^+ emission is present but weaker than CO^+ and N_2^+. There is a neutral gas coma visible in the CO^+ and N_2^+ pictures which is due to C_3 and CH, respectively. In the second observation period the comet was observable almost all night. The development of the inner tail of the comet during 6 hours is illustrated in Figure 4. Dramatic changes are seen in the light of the CO^+ and CO_2^+ ions. The images in the light of the two molecular ions look similar but there seem to be systematic differences. They need not to correspond to differences in column density ratio but may be caused by Greenstein effect (change in fluorescence efficiency caused by Doppler shift of the solar spectrum as seen by the moving cometary ions). An example of a multi slit spectrum is presented in Figure 5. It covers the region between 350 and 430 nm. To show the location of the comet relative to the slits, with most spectra a calibration exposure was obtained by removing the grating and taking a double exposure. Direct images of the slits were exposed, then the slit mask was removed and an image of the comet was taken through an interference filter of 10 nm passband centred at 369 nm. The spectra show all major ions except H_2O^+ which has no emissions between 350 and 430 nm. Note the varying line ratios in the different spectra. The ion emissions are also seen in spectra which do not correspond to a visible ion streamer. CO^+ ions are even seen upstream of the comet, confirming the notion of an extended CO^+ ion source region.

Figure 6 shows an example of a wide-field slitless tail spectrum taken with the Zeiss UV Sonnar with 104 mm focal length. The spectrum was taken through a UG 5 filter and covers the wavelength range from 309 to 395 nm. A direct, unfiltered, blue image of the comet is presented at the same scale for comparison. The wide-field images were taken simultaneously with the two latest

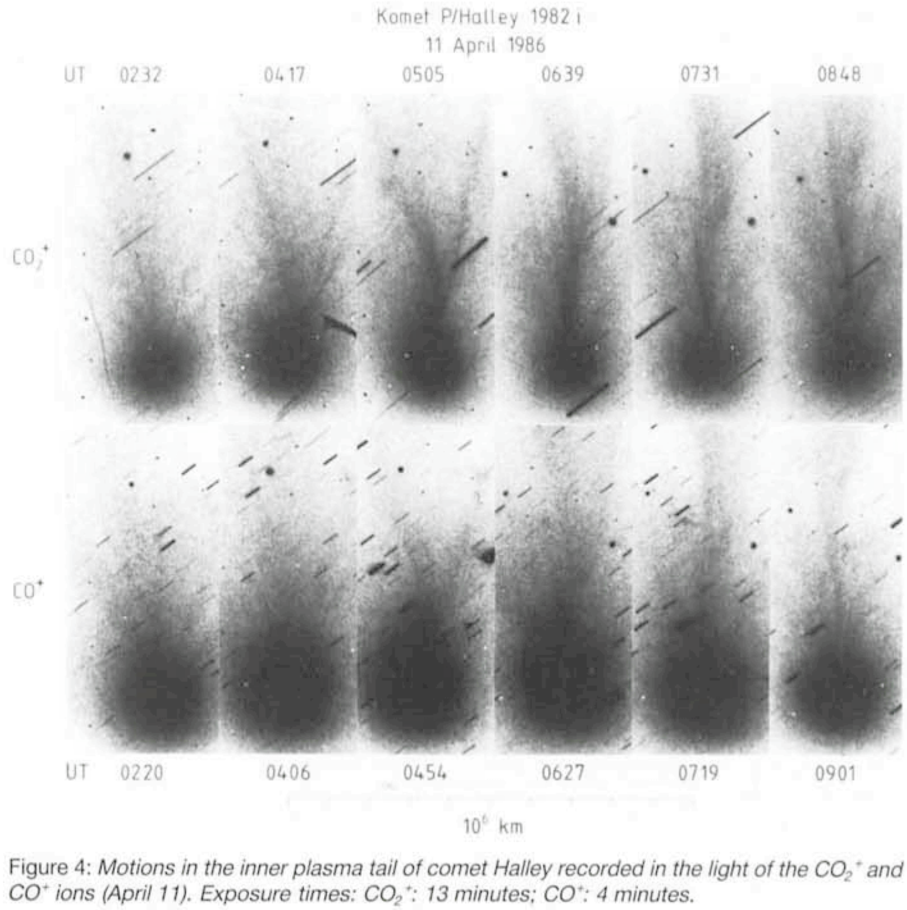

Figure 4: *Motions in the inner plasma tail of comet Halley recorded in the light of the CO_2^+ and CO^+ ions (April 11). Exposure times: CO_2^+: 13 minutes; CO^+: 4 minutes.*

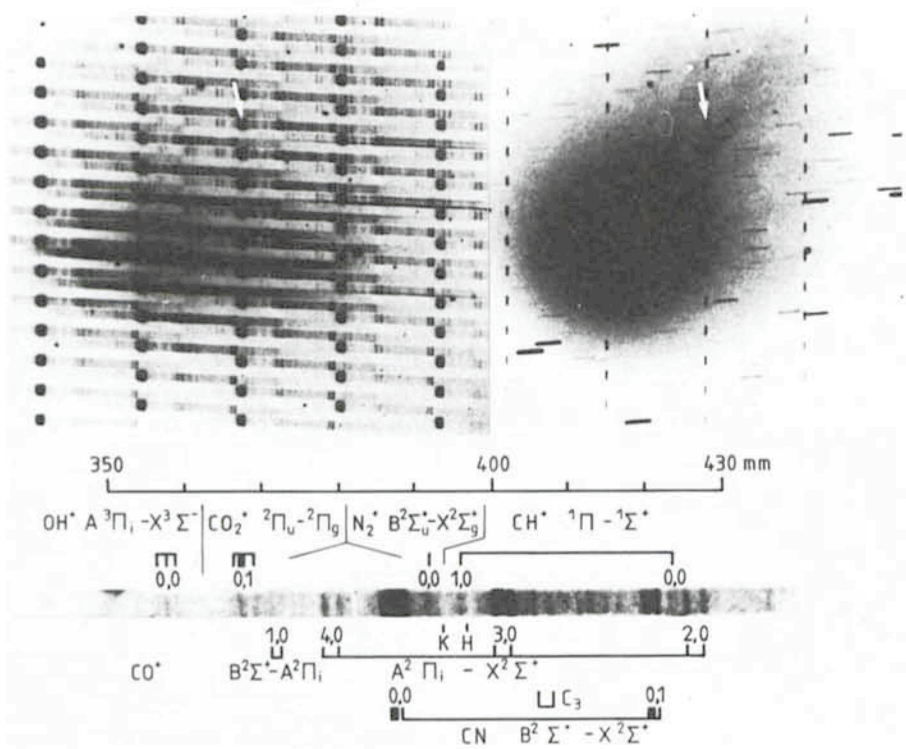

Figure 5: *Multi-slit spectrum of Comet Halley obtained on April 10. Top left: Spectrum plate; top right: slit position plate. The arrows point to the slit and the corresponding spectrum, which is reproduced in enlarged form in the bottom to explain the individual spectrum features. Exposure time of spectrum: 30 minutes.*

pictures of Figure 4 but the spatial scale is almost 10 times larger. The extended CN coma in the wide-field picture would cover almost half of the frames of Figure 4.

Acknowledgement

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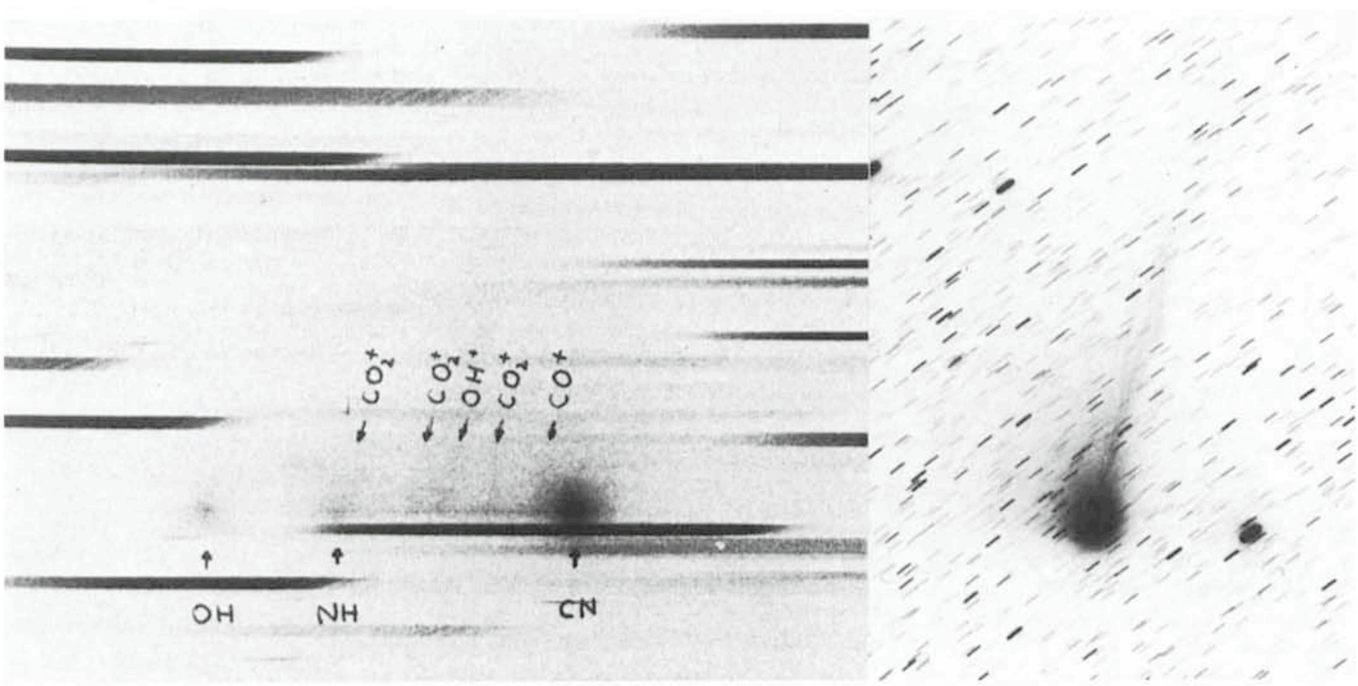

Figure 6: *Slitless wide-field spectrum and direct photograph of Comet Halley. Wavelength range of spectrum 309–395 nm. Dispersion E-W. Wavelength increases to the right. Exposure time of spectrum: 1 hour at f/4.5 on IIa-O plate.*

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