Figure 5: *Comet P/Halley on March 16, 1986, 7:56 UT from La Silla. Flat-Field Camera 1:4/760 mm, filter IF λ 4260 (CO⁺), 103a–F hypersensitized, exposure time 60 minutes.*

Figure 6: *Comet P/Halley on March 16, 1986, 9:15 UT from La Silla. Flat-Field Camera 1:4/760 mm, filter IF λ 3880 (CN), 103a–F hypersensitized, exposure time 60 minutes.*

Figure 7: *Comet P/Halley near the radio galaxy NGC 5128 on April 15, 1986, 1:22 UT from La Silla. Flat-Field Camera 1:4/760 mm, filter GG 410, 103a–E hypersensitized, exposure time 20 minutes.*

the nucleus and the reactions with the solar wind, and (2) determination of abundances, production rates, and lifetimes of certain molecules as a function of the heliocentric distance of the comet. But these procedures are expected to take some time . . .

(Further information about the Bochum Halley campaign has been given in *Sterne und Weltraum* **25,** pages 221 (4/1986), 280 (5/1986) and 298 (7–8/1986).

Spectroscopy, Photometry and Direct Filter Imagery of Comet P/Halley

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The return of Comet P/Halley, as well as the related space missions, added to the intrinsic interest of comets and their importance in connection with the cosmogony of the Solar System, no doubt explain the high level of activity devoted to the study of these celestial bodies in recent years. While considerable progress has been achieved in this field, thanks to the use of new observational techniques and to numerous theoretical works, we are forced to admit that quite a long way remains ahead before a satisfactory understanding of the nature and origin of comets is to be reached. The unique opportunity offered by Comet Halley to gather an unprecedented wealth of original data of all kinds has given rise to a truly worldwide mobilization and we in Liège wanted very much to participate in this remarkable enterprise, in view of the continued interest shown by our institute in cometary physics and spectroscopy, ever since Professor Swings' pioneering work. When it was realized that our plans had so much in common with those of our colleagues from the Universities of Michigan, Texas, and Brussels, we decided all together to join our efforts.

The principal aim of our programme is to derive some information on the physical characteristics of the cometary atmosphere (distribution laws of densities, temperature and velocity as functions of the distance to the nucleus) by analyzing in detail the relative intensities of the molecular emissions, their variation with the position on the comet's image, as well as the evolution of these properties as the distance from the Sun, r, changes. The procedure followed to interpret the relative intensity distributions is to construct synthetic spectra integrating through the coma and taking into account radiative processes (resonance-fluorescence excitation by the solar radiation, sensitive to the radial velocity of the molecules relative to the Sun – the so-called "Swings effect") as well as collisional effects which may be significant in the innermost regions (Arpigny, 1976). The modelling of the structure of the coma indeed represents a necessary step towards the ultimate goal of the study of comets, namely the determination of the chemical composition of the basic material in the nucleus.

First Announcement

A conference organized by ESO on

VERY LARGE TELESCOPES AND THEIR INSTRUMENTATION

will be held from **21 to 25 March 1988** at Garching bei München, FRG. The programme will include the following topics:

- Fabrication of Large Mirrors
- Support Systems
- Active and Adaptive Optics
- Telescope Environment
- Atmospheric Turbulence
- Infrared and Optical Instrumentation
- Remote Control

For more information please write to M.H. Ulrich, European Southern Observatory, Karl-Schwarzschild-Str. 2, D-8046 Garching bei München, Federal Republic of Germany.

We have selected a number of specific observations or special problems related to this general programme and we shall outline these briefly here, grouping them according to the various instruments we used at La Silla during the post-perihelion phase of Comet P/Halley, essentially from mid-March to the beginning of June 1986.

1.5-m Telescope Coudé Spectrograph

One appreciable advantage offered by this instrument is the possibility to use a rather long slit (approximately 3.5 arcminutes) and hence to study the variation of the spectral intensity distributions over a fairly large projected distance (ϱ), a feature essential to the construction of model cometary atmospheres. Thus, radial profiles B (ϱ), i.e. the distributions of the surface brightness along a diameter of the apparent cometary disk, can be established for the various species. Assuming negligible optical thickness, which is valid in most cases, this gives also the column densities N (ϱ) and these, when compared with the profiles predicted by the models, should yield clues relevant to the production mechanisms of the observed radicals. For the same reason, possible spatial variations of the ionic emissions related to the accelerations of the carriers, OH$^+$, CO$^+$, CH$^+$ . . . ("Greenstein effect") can be searched for, which may throw some light on a long-standing enigma: "bulk versus wave motions in the plasma tail". Besides, observations with this configuration will allow a direct comparison with similar spectra secured with the twin 1.5-m telescope at the Haute-Provence Observatory (HPO) on several comets, notably on Bennett (1970 II). It will also be possible to relate these observations to a series of pre-perihelion spectra of P/Halley taken by some of us at HPO from the middle of November 1985 to the beginning of January 1986.

Approximately three hours exposures, one on each night, from 15 to 18 March produced three good spectra in the blue, and one rather weak in the visual spectral region. The best spectrogramme, covering the range from the NH (0,0) band to the C$_2$ Swan (0,0) band is reproduced in Figure 1. The orientation of the slit was in the general antisolar direction, while the telescope was guided in such a way as to keep the central part of the comet near the sunward end of the slit. As a result, the tail emissions show up quite well and are seen over about 125,000 km. The extreme weakness of the solar radiation scattered by the dust tail also makes the identification of some of the molecular tail emissions easier than in the case of Comet Bennett, for example. Especially noteworthy are: (a) the well-known CO$^+$ Comet-Tail bands and several bands due to the Fox-Duffendack-Barker System of CO$_2^+$, indicating a CO$_2^+$/CO$^+$ ratio somewhat higher in P/Halley near $r =$ 0.95 A.U. than in Bennett at comparable heliocentric distances; the CO$_2^+$ bands are $^2\pi-{}^2\pi$ doublets and here as in a number of other comets (see Festou et al., 1982), the 1/2–1/2 component is systematically stronger than the 3/2–3/2 component in the various bands, for some unknown reason (we have verified that this peculiar coincidence is not a Swings effect associated with the comet's orbital velocity); (b) the OH$^+$ (0,0) and (0,1) bands, the latter identified for the first time; furthermore, the (1,0) band of this ion may have some weak contribution near the short-wavelength edge of the NH (0,0) band; (c) the CH$^+$ (0,0) and (1,0) bands, a few lines of which are also seen for the first time; (d) some fairly strong ionic features at 371.48, 372.79, 410.95, 412.34, 414.59, and 416.01 nm, for which we have not found any satisfactory assignment.

Figure 2 illustrates at higher magnification a particularly rich section, 390–430 nm, from the same spectrum, where we can appreciate the remarkable spectral definition, in the CO$^+$ and CN bands. The quality achieved undoubtedly pleads for maintaining this instrument, which can still provide quite valuable data indeed. This material will enable us to carry out elaborate studies of the rotational intensity distributions of the various molecular bands.

1.4-m CAT, Coudé Echelle Spectrometer, Reticon

There are quite a few very important problems on which progress is possible only thanks to high-resolution observations (of the order of one hundredth of a nanometer). In this category we have chosen to try and evaluate the isotopic abundance ratio ^{12}C/^{13}C, which was given high priority in our cooperative project.

This ratio changes depending on the degree of nuclear processing that has taken place and a wide range of values is seen in different astrophysical sites, from ~89 in the Solar System to ~25 in the Galactic Centre, down to ~5 in some late-type stars. Knowledge of its value in comets is of great interest in connection with the origin of these bodies. Now this question of how, when and where comets were formed is still a matter of animated discussions. Various hypotheses envisage that they originated within the Solar Nebula, just beyond the Uranus-Neptune zone, or further out, 10^3 to 10^4 A.U. from the centre, or at the outskirts, in associated disks or fragments of the Nebula, or else in interstellar clouds from which they were captured by the Sun. Whatever their birthplaces, the determination of their isotopic (and chemical) composition will have implications upon the history of the Solar System, upon the conditions in an interstellar cloud, or eventually even upon some of our ideas concerning star formation. That comets

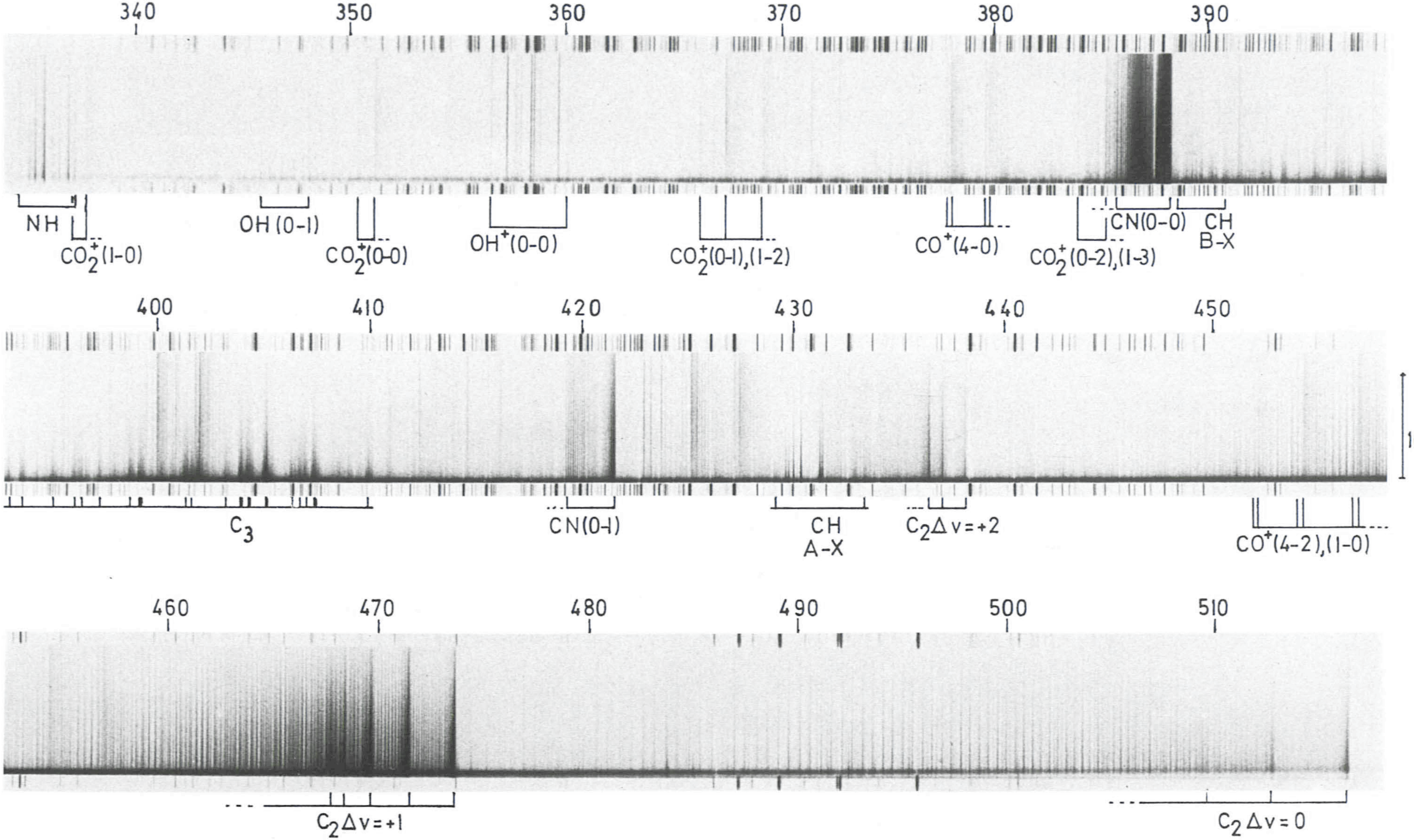

Figure 1: *Spectrum of Comet P/Halley (r = 0.96 A. U.) obtained with the coudé spectrograph at the 1.5-m telescope (sensitized IIa–O emulsion; original reciprocal dispersion 20 Å/mm; exposure time 3 h 25 min). The continuous strip at the bottom is due to the scattering of the solar radiation by small solid particles forming a halo around the nucleus. The tail of the comet is in the upward direction; the angle between its axis and the slit of the spectrograph varied from 55° to 5° during the exposure. The rotational structure of the various molecular emissions is well resolved thanks to the remarkable optical quality of this spectrograph. The vertical bar on the right represents 10^5 km projected on the comet.*

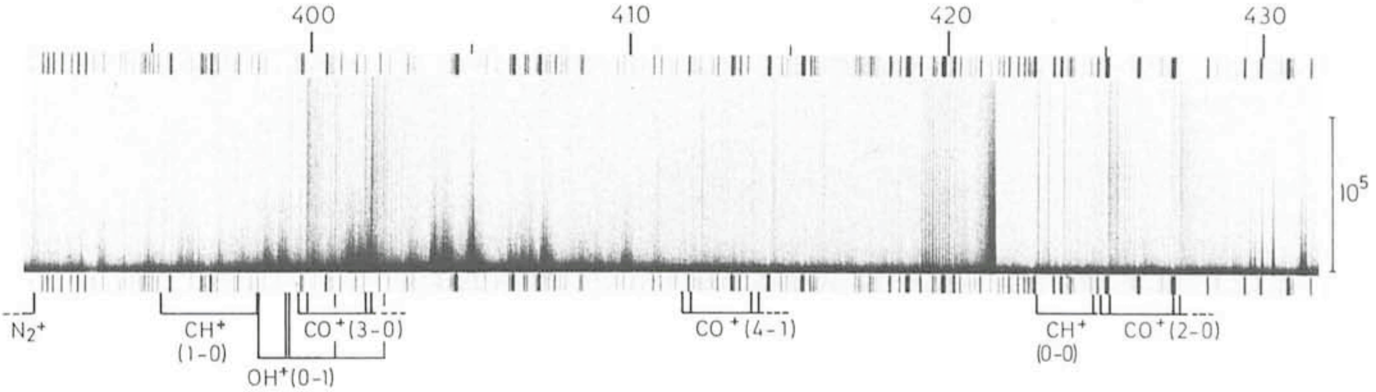

Figure 2: *Enlarged section from the spectrum appearing in Figure 1. For the sake of clarity, only the ionic emissions in this region are identified here, the neutral emissions in the same region being marked in Figure 1.*

may be regarded as primitive, essentially unfractionated bodies is due to their very long stay in very cold environments far from the Sun as well as to their very small mass, typically $\sim 10^{14}$ kg.

Measurements of the carbon isotopic ratio have been performed in half a dozen comets so far generally using the C_2 (1,0) Swan band. The Swan system is strong in comets and the 473.7 bandhead would in principle offer easy measurement of the $^{12}C/^{13}C$ ratio, as the introduction of the ^{13}C atom shifts the isotopic bandhead to 474.5 nm. Unfortunately, however, the $^{12}C^{13}C$ (1,0) bandhead happens to be severely blended with NH_2 features, which makes the extraction of the isotopic ratio rather delicate (Danks et al., 1974). In Comet West (1976 VI) another candidate, the C_2 (0,0) band, was tried. This band is appreciably stronger but has a much smaller isotopic shift; in that case, one has to look at individual rotational lines rather than at a bandhead and it turns out that very weak satellite lines of the normal $^{12}C_2$ molecule must be separated out (Lambert and Danks, 1983). Values from ~ 135 to ~ 50 with quite large error bars have been found for $^{12}C/^{13}C$ in the comets studied so far (see e.g. Danks, 1982).

We attempted to repeat these observations on Comet Halley with the CES, which provides the very high resolving power necessary to disentangle or at least reduce the blending problems involved here. Several trials on the C_2 (1,0) bandhead proved disappointing, the comet being fainter than anticipated. Thus we decided to concentrate upon the C_2 (0,0) band near 516 nm, the brightest emission in the visible. One single exposure of about one hour at a resolution of ~ 0.005 nm revealed the rotational structure of the band, however the intensities of the $^{12}C^{13}C$ lines are very low, of the order of 1 % those of the corresponding $^{12}C_2$ features, so that repeated measurements were needed in order to bring these lines above the noise. Ten integrations were made in total (10 March, 23–30 March; 45 to 60 minutes each, with resolutions of 80,000 to 100,000). One of these spectra is shown in Figure 3; this is one of the first and few spectra obtained on Comet Halley at this high resolution. It is also the first time such a resolution is used to record a molecular cometary spectrum. Let us hope there will be more opportunities of this kind on future bright comets! Naturally, from night to night Comet Halley was changing velocity, introducing a wavelength displacement in the observed bands. Therefore, before coadding data, each image frame has to be shifted slightly.

To aid interpretation and to act as a reference source, we managed to persuade the TRS and Mr. Van Howard to illuminate the slit area with an acetylene torch. At the high temperature of the C_2H_2 torch we could produce the emission spectrum of C_2 which also exhibits the terrestrial ratio of $^{12}C/^{13}C$, ~ 89. These lines are useful for different reasons. In particular, they are not superimposed on the scattered solar continuum, as are the comet lines and on the other hand, their intensities are due to thermal excitation, whereas the comet lines are excited by the resonance-fluorescence mechanism. Elimination of the underlying continuum in the cometary spectrum is effected by dividing by a solar type spectrum. In our case the most convenient body was the planet Mars, of which several short exposures were made.

These observations were successful, given the comet's brightness, and reduction of the data is in progress. We should be able to give both a measure of the $^{12}C/^{13}C$ ratio and a value for the rotational temperature of C_2 in Comet Halley in the near future.

Another item in this part of our programme was concerned with the forbidden atomic oxygen lines already mentioned above. Indeed, the stronger, shortward component of the [O I] doublet is perturbed by HN_2 emissions at low resolution and the oxygen abundances

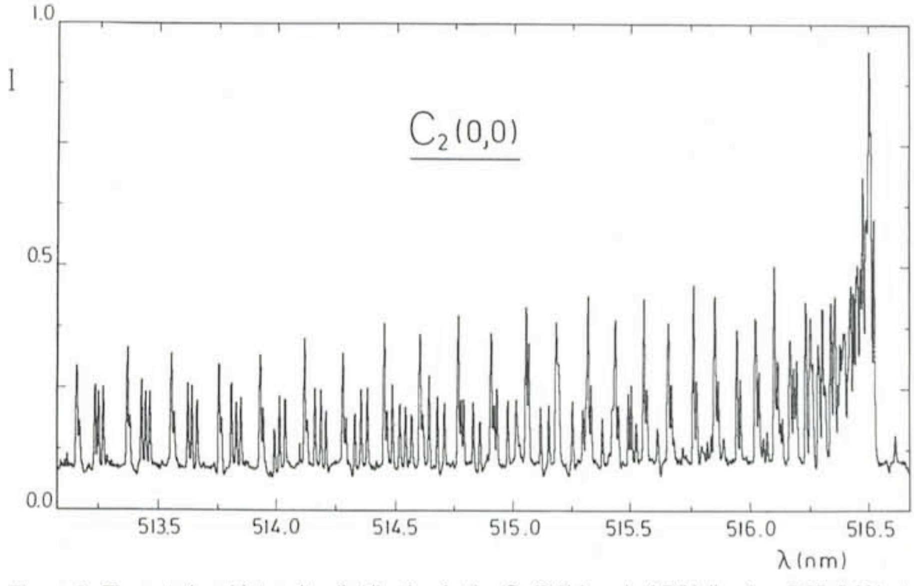

Figure 3: *The rotational intensity distribution in the C_2 (0,0) band of P/Halley (r = 0.85 A.U.) at 100,000 resolution (Coudé Echelle Spectrometer at the 1.4-m CAT).*

reported so far depend upon an assumption regarding the strength of these NH_2 emissions that needs to be checked by resolving the blend. We obtained eight spectra covering the range 628.5–633.5 nm (24 March, 5, 7, 8, 27 April; resolution 50,000); some of these were taken at different positions in the sunward and anti-sunward directions in order to study the mechanism by which the oxygen atoms are formed.

50-cm ESO Photometric Telescope

Photometry is also an efficient tool in cometary studies. A glance at a typical spectrum (see Fig. 1 and 2) shows that normal U, B, V or even intermediate bandpass photometry is of little help in such an intricate superposition of molecular emissions and solar continuum. To overcome these difficulties, special filters like those defined by the IAU have to be used. These filters have narrow bandpasses, typically a few nanometers. They isolate characteristic features such as the CN 387 nm emission, or a particular emission-free zone of the spectrum so that the continuum is readily accessible.

The advantages of photometric observations are the usual ones:

- accurate and relatively easy absolute calibration;
- simple and reliable instrumentation;
- fast observation;
- theoretical availability of a large number of telescopes, mainly of small size, all over the world (Europe being underrepresented in that respect).

Observations have been carried out at La Silla and in many other places, first of P/Giacobini-Zinner during the trial run of the IHW, and then of P/Halley. Diaphragms of different sizes are used in order to analyze the radial distribution of the various emissions. Combination of the observations made at different observatories, with a wide distribution in longitude, will eventually give an almost continuous monitoring of Comet Halley's activity both before and after perihelion.

Our first P/Halley observing run at La Silla was of 12 nights (27 March–7 April), when the comet was still relatively bright and moving swiftly in front of the Milky Way background. This stellar background proved to be a problem as it was not easy to evaluate the exact sky brightness affecting the comet measurements. One striking result of these observations was the important fluctuations exhibited by the comet, by factors of 2 or more, from one night to the next, in agreement with many other reports of such variability. In addition, on several nights a few hours were devoted to differential observations with a single diaphragm. Measurements were performed in quick succession alternatively of a comparison star and of P/Halley so that more rapid variations could be detected.

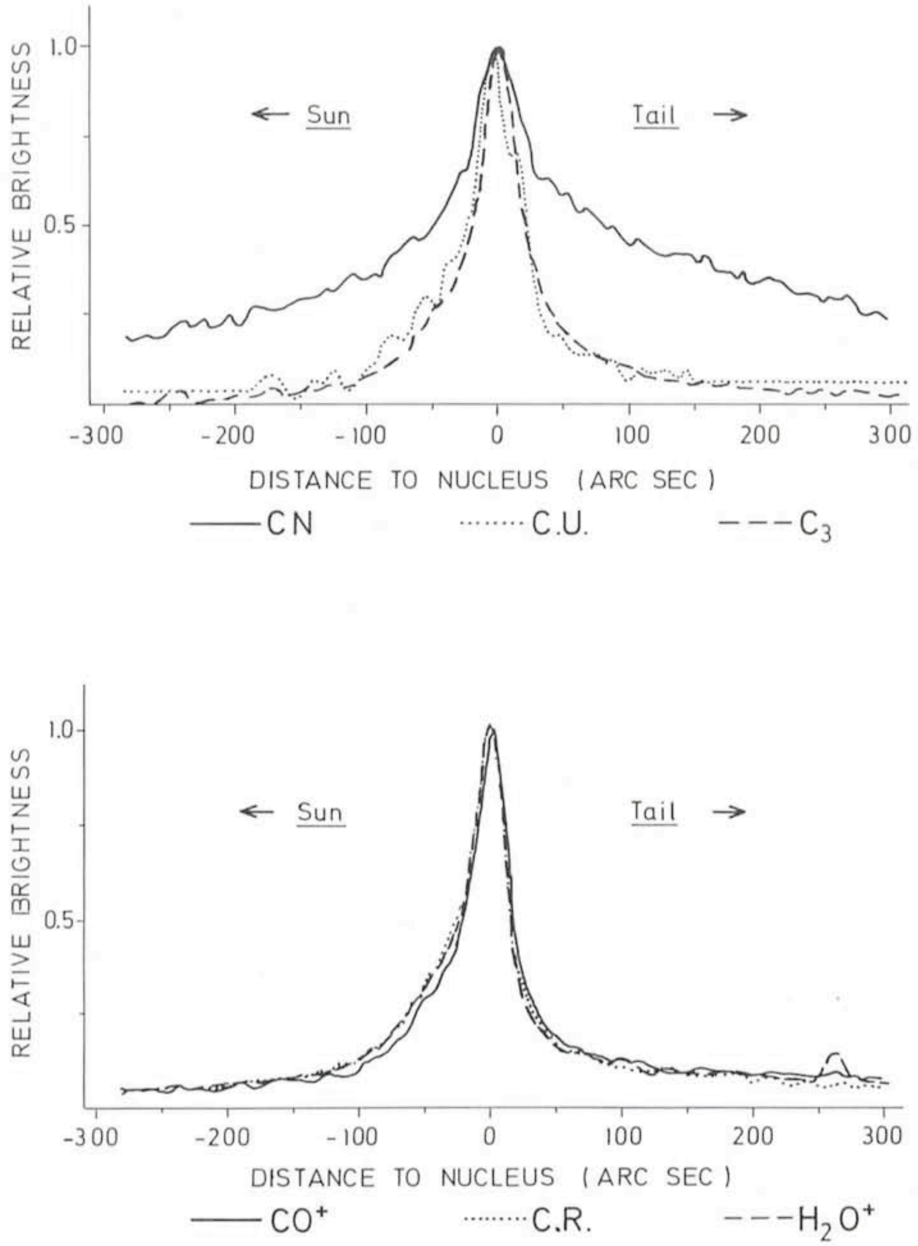

Figure 4: *Examples of photometric scans across P/Halley's coma along the Sun-antisun line, through various filters (C. U. = Ultraviolet continuum, 365 nm; C. R. = Red continuum, 684 nm). The asymmetry in the CN profile can probably be attributed to the effect of solar radiation pressure on radicals produced with a velocity dispersion. On the other hand, the asymmetry of opposite sign in the other molecular emissions, imitating the profiles in the continuum, seems to indicate contamination of these molecular emissions by scattered solar radiation.*

One difficulty arises from the limited choice of diaphragm sizes. Even small telescopes in the 0.5-m class rarely have diaphragms larger than 1 arcminute. For nearby objects this of course means small linear dimensions. Fortunately, the versatility of the ESO telescopes and in particular of the 0.5-m used for our study allowed to record the intensity in the various filters during radial scans across the coma. Figure 4 gives a few examples of such scans from the nucleus out to 5 arcminutes in the directions towards and away from the Sun. Thus the distribution of the different spectral contributions can be followed farther out and more accurately than with the classical method of multiple diaphragms.

During our second photometric observing period we were able to make one last set of measurements through all nine IAU-IHW filters (24 June).

1.5-m Danish Telescope, CCD Camera

Having acquired a set of IHW imaging quality filters which isolate the same molecular emissions and continuum windows as the photometric filters (with the exception of the OH filter), we wanted to take advantage of the favourable conditions near the perigee of P/Halley and obtain high spatial resolution pictures. Thus a total series of about forty frames were secured on 8 and 9 April, when the geocentric distance of the comet was ~0.42 A.U. The exposure times ranged from 1 minute with the red filters to 10–20 minutes near 400 nm.

Now, the nearness of the comet to the Earth also has a drawback in that it causes a troublesome very rapid apparent motion of the object. Indeed, at a rate of some 16"/min the autoguiding system had a hard time in trying to follow the comet perfectly. Therefore we decided to split the longest exposures into several shorter ones in order to preserve the excellent spatial resolution (a few 100 km), the more so that the image quality itself was quite good (seeing ~0."9). This will of course require delicate image processing. We hope to end up with valuable "monochromatic" bidimensional data, covering a field of about 45,000 × 70,000 km projected on the comet. The resulting spatial distributions of the various components may provide useful information bearing upon the enigmatic question of how they are produced in the inner coma.

Let us mention here that we were struck by the similitude between some of the pictures, especially the red ones, H_2O^+ and red continuum, suggesting that the solar radiation scattered by the dust may have a predominant contribution even in a filter centred on a molecular emission and that careful treatment will be necessary in order to derive significant results from images taken through such filters.

We all enjoyed living and working in a very hospitable and dynamic observatory and we appreciated very much the efficient help we received on many occasions in the course of our activities at ESO. Our heartiest thanks to all who contributed to make our respective stays in La Serena and in La Silla so pleasant and fruitful!

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The PHEMU 85 International Campaign

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1. Introduction

The mutual phenomena of the Galilean satellites of Jupiter take place every six years, when the Earth and the Sun cross the equatorial plane of Jupiter which coincides with the orbital planes of the satellites. At that time, mutual occultations and eclipses may occur. However, the only favourable situation for observing such phenomena is when the crossing of the equatorial plane occurs simultaneously with the opposition of Jupiter. These phenomena are often observable only once every twelve years. In 1985, during the latest opposition of Jupiter, its declination was between −19 and −15 degrees, which made La Silla one of the best places to observe them.

In order to improve the theory of the motion of the Galilean satellites, two kinds of observations have been made so far: photometric observations of the eclipses by Jupiter yielding a positional accuracy of 1,000 km and photographic astrometry giving an accuracy of 300 km. However, as the satellites have no atmosphere, an even higher accuracy can be achieved by observing mutual phenomena, that are eclipses and occultations of the satellites by themselves. These observations are the most precise that can be made of those bodies and lead to a precision of about 100 km, which explains why international campaigns have been organized to carry them out.

Is such a precision for a position of the Galilean satellites necessary? The answer is yes for several reasons. First, the exploration of Jupiter and its satellites by space probes requires a very accurate knowledge of the orbital motions of these bodies. This will especially be the case when the Galileo probe in a few years will be put in orbit around Jupiter. Secondly, the motion of the Galilean satellites around Jupiter, affected by several so far little understood perturbations, is one of the most complex problems of celestial mechanics. The system of moons is submitted to very fast changes and by studying these we may hope to detect non-gravitational effects. Io, for instance, is suspected to have a secular acceleration due to energy dissipation. It is a very inconspicuous effect which cannot be observed easily, but observations of mutual phenomena over a couple of Jupiter oppositions should allow us to explore it.

Therefore, an international campaign, PHEMU 85, has been organized by the Bureau des Longitudes (France), bringing together theoreticians working in celestial mechanics and observational astronomers (which does not happen so often!). As part of this campaign, ESO allocated a large amount of observing nights to the programme at the ESO 50-cm and 1-m telescopes. In total we were able to observe 46 mutual phenomena, during 32 nights (or half-nights).

2. The Observations

The observations were carried out in fast photometry mode, generally with a time resolution of 50 ms. This mode of observing is briefly described in the present issue of the *Messenger* and has been extensively used already in the