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OPTOPUS Observations of Halley's Comet

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Introduction

At the beginning of the month of December 1985, the ESO multi-object spectrograph OPTOPUS was used for the first time by regular visitors to La Silla, yielding in 9 nights roughly 1,000 independent spectra from sources ranging typically from the 17th to the 19th magnitude. These include quasar candidates (of which approximately 40 have been spectroscopically confirmed), carbon stars in Fornax, planetary nebulae (approximately 30 identified) and compact H II regions in the SMC, galaxy clusters, a diffuse optical jet in a star burst galaxy, and selected regions in the coma of Halley's Comet.

Indeed, the first OPTOPUS observation run happened to be programmed at an opportune time for obtaining what are thought to be the first spatially distributed multiple spectra of Halley's comet. Although it can be rather difficult to accurately guide the entrance slit of a conventional spectrograph onto the outer part of a diffuse object, OPTOPUS enabled the telescope to be autoguided with ease onto the luminosity centroid of the comet, while 36 independent optical fibres sampled light from the outer regions of its hazy head (coma).

The spectral frames thus obtained from the comet, such as that shown in Figure 1, clearly show the sharply cut-off molecular emission bands arising from Halley's coma.

In the following paragraphs, a description is given of OPTOPUS and its characteristics, and a brief analysis of the extracted Halley spectra is presented.

Description of the Instrument

OPTOPUS, depicted in Figures 2 and 3, is designed to enable conventional use of the Boller and Chivens spectrograph to be extended to simultaneous spectroscopy of multiple or large extended objects. Here, the main features of the instrument are briefly described. Further details and characteristics can be found in the *Messenger* No. 41, page 25 (1985).

At present, OPTOPUS is available for use only at the 3.6-m telescope, and is intended to be used with the ESO # 3 (RCA) CCD detector. The fibre component of the instrument consists of 54 separately cabled optical fibres which enable light to be guided from freely distributed points in a 33 arcminute

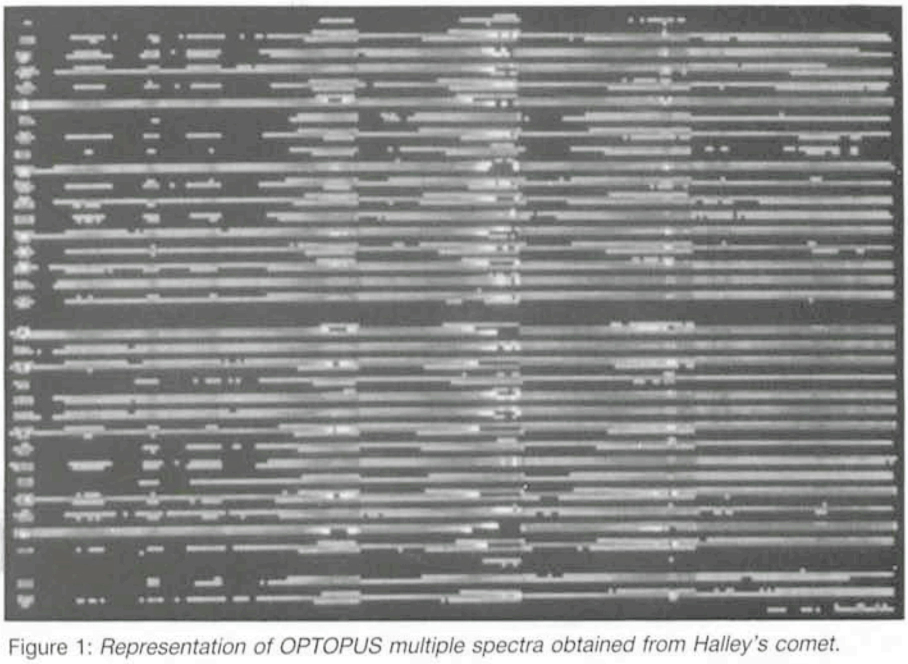

Figure 1: *Representation of OPTOPUS multiple spectra obtained from Halley's comet.*

* Also, "Chercheur Qualifié au Fonds National de la Recherche Scientifique" (Belgium).

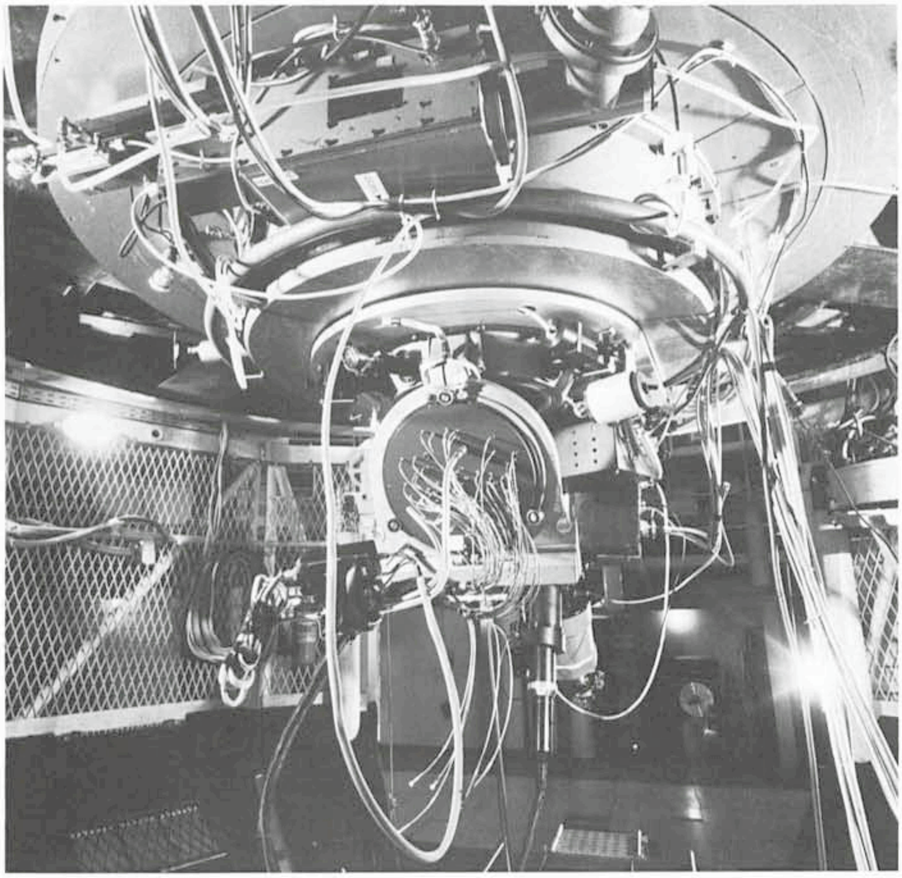

Figure 2: *Wide angle view of OPTOPUS when installed in the Cassegrain cage of the 3.6-m telescope.*

zone of the Cassegrain focal plane, to a common slit.

The fibre input ends are located in the focal plane by means of precision connectors which are plugged into drilled starplates (Figures 4 and 5). These are aluminium disks which are prepared in advance in Garching with the aid of a high-precision programmable milling machine.

The machine programmes, which are designed to include compensation for the field curvature of the telescope focal plane (by hole depth adjustment), and for the differential refractive effects of the terrestrial atmosphere, are generated from the astronomer's (alpha, delta) coordinate data by computer*.

When OPTOPUS is installed at the telescope, the Boller and Chivens spectrograph is laterally displaced by about 1.5 m from its usual position at the Cassegrain adaptor flange, and is fixed underneath the mirror cell. In this mode of use, the spectrograph only serves the purpose of a mechanical structure, holding the input beam, grating and de-

* A brief description of the data-transfer facility is given on page 30 in this issue of the *Messenger* ("The ESO VAX Computer's Largest Peripheral . . .").

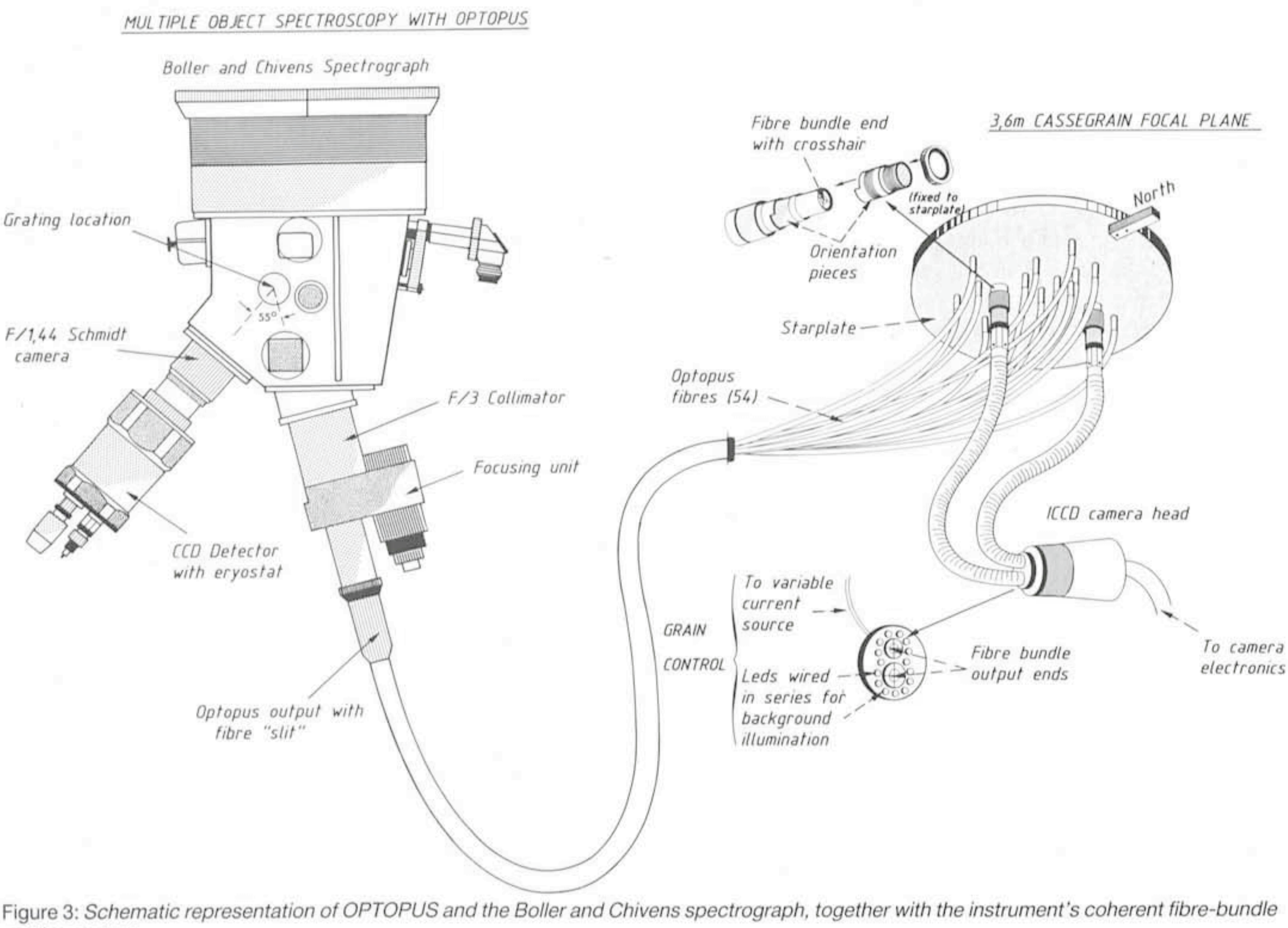

Figure 3: *Schematic representation of OPTOPUS and the Boller and Chivens spectrograph, together with the instrument's coherent fibre-bundle guiding system.*

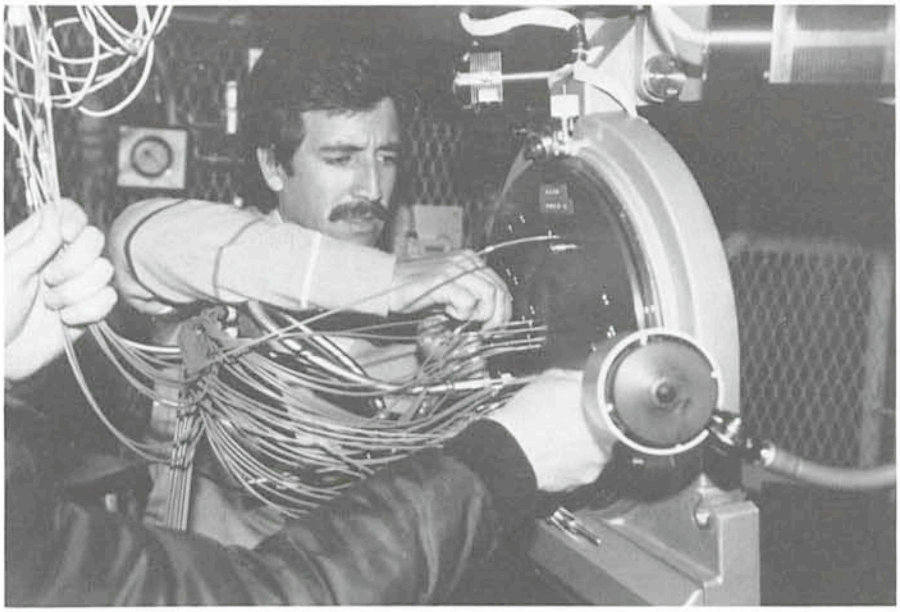

Figure 4: *View of the protected optical fibres being inserted into a starplate. The silver-coloured guide bundles can be seen at the lower left of the starplate.*

Tentative Time-table of Council Sessions and Committee Meetings in 1986

April 3–4	Committee of Council, Chile
April 24	Scientific Technical Committee
April 29–30	Finance Committee
May 21–22	Council, The Hague
May 26	Users Committee
June 10–11	Observing Programmes Committee, Lyon
November 18	Scientific Technical Committee
November 20–21	Finance Committee
December 8–9	Observing Programmes Committee
December 11–12	Committee of Council

All meetings will take place at ESO in Garching unless stated otherwise.

tector in rigid alignment. Since the Boller and Chivens shutter and order-sorting filter functions cannot intersect the beam path and can therefore not be used, they are duplicated within the OPTOPUS collimator structure. Spectral calibrations must be made via the fibres, and this is achieved by means of comparison sources which are built into the OPTOPUS adaptor. The calibration light beams are diverted upwards from the Cassegrain focal plane to the recently installed white diffusion screen, which provides an authentic simulation of the telescope pupil.

The spectrograph entrance slit is materialized by the fibre output ends, which are arranged in a straight, polished row in such a way as to simulate a classical "long-slit" arrangement. Each fibre output provides a circular spot of light, thus giving rise to a set of parallel, independent spectra at the detector (as shown in Figure 1).

The optics of the collimator are optimized for the Boller and Chivens plus F/1.44 Schmidt camera configuration, although in December a special adaption was made to enable the more luminous PCD camera to be used. At the expense of a slight reduction in the number of fibres and the spectral range available, an appreciable gain in sensitivity ($\lambda\lambda$ 3600–6100 Å) was achieved with this camera. Each fibre output is projected onto the detector with a monochromatic image size of 65 μm (2.2 pixels) or 90 μm (3 pixels) depending on whether the Schmidt or PCD camera is used.

Acquisition and guiding are important instrumental functions, which in the case of OPTOPUS are assured by a separate system, as depicted in Figure 3. The conventional slit-viewing camera cannot be used for guiding in this case, because the observed stars are not imaged onto the Boller and Chivens entrance slit. With OPTOPUS the guide star images are picked up and fed to a TV camera by means of two flexible coherent fibre bundles, for which holes with special orienting inserts are prepared in each starplate. The camera is of the (non-integrating) intensified CCD

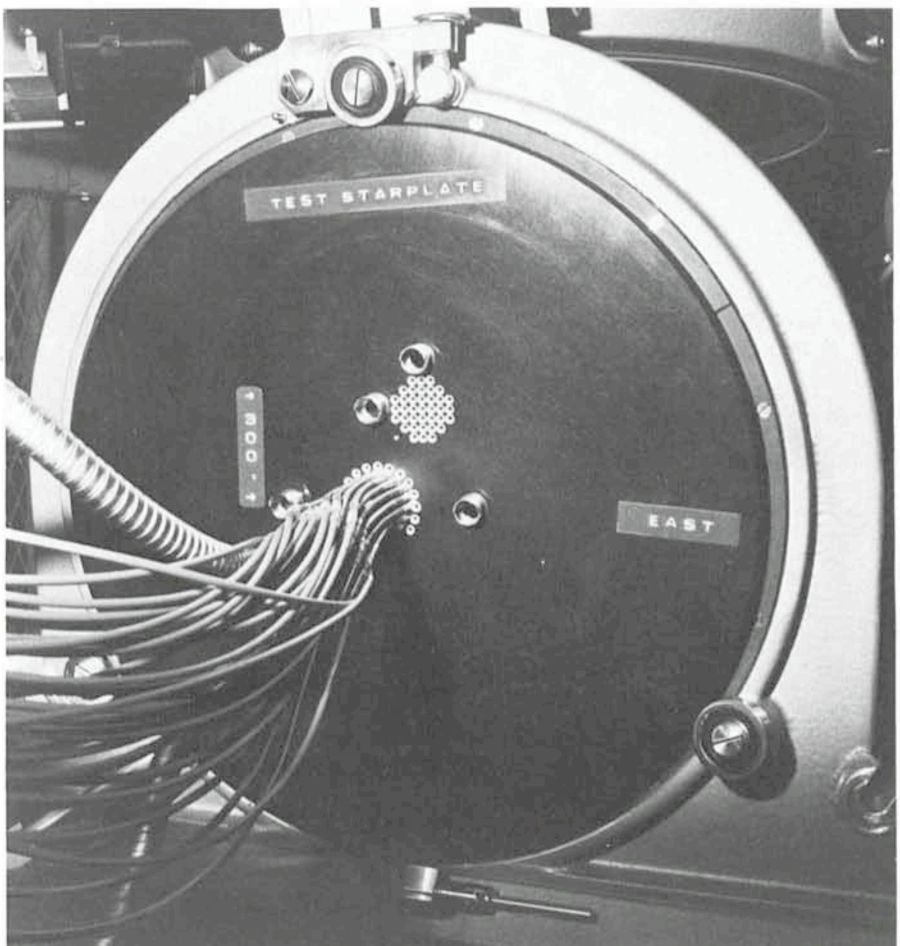

Figure 5: *Close-up view of the starplate used for observation of Halley's comet, showing the compact fibre arrangement. The diameter of the connectors imposes a minimum proximity corresponding to 25 arcseconds between adjacent fibre cores.*

type, and incorporates a fibre optic input window which permits direct image coupling without the use of transfer lenses. Engraved reticles cemented onto the input ends of each guide bundle enable the observer to simultaneously appreciate the correct alignment of both guide stars. The two-guide-star requirement arises from the need to bring the starplate into accurate rotational alignment (around the optical axis) with respect to the observed field. Rotational movements of the starplates are assured by a motorized drive, and can be controlled from the 3.6-m control room. In principle, very little adjustment is needed for successive starplates if their object coordinates have all been precession-corrected to the epoch of observation.

Spectroscopic Multi-Aperture Observations of Halley's Comet

At the time when OPTOPUS was last installed at the telescope, Halley's comet appeared as a near-symmetrically-shaped diffuse nebula, and it exhibited a relatively very faint tail. For this reason it appeared most interesting to sample the comet at mainly symmetrically distributed points in such a way as to enable the centre-to-edge variations in spectral emission to be put into clear evidence.

A special starplate (Figure 5), normally intended for standard star exposures, was used for these observations. A supplementary hexagonal patch of connector holes, seen in the picture, was also included in the starplate to enable fainter, more distant regions of the comet's coma to be analysed.

The loci of the analysis points finally selected to produce the 28 extracted spectra of Figure 7 are shown more clearly in the overlay of figure 6*, where the fibres are seen to have been placed in two concentric rings, and at 4 more distant locations. Here, the central circle represents the coherent fibre bundle used for guiding, and fibre positions are represented by the smaller open circles. The 4 outer fibre locations are indicated with white spots, in order to distinguish them from the darker background.

* The near-nucleus detail apparent in this picture (cf. p. 26 of the *Messenger* No. 42) was made possible thanks to a photographic masking technique developed by Mr. B. Dumoulin and Mr. J. Quebatte at the ESO Sky Atlas.

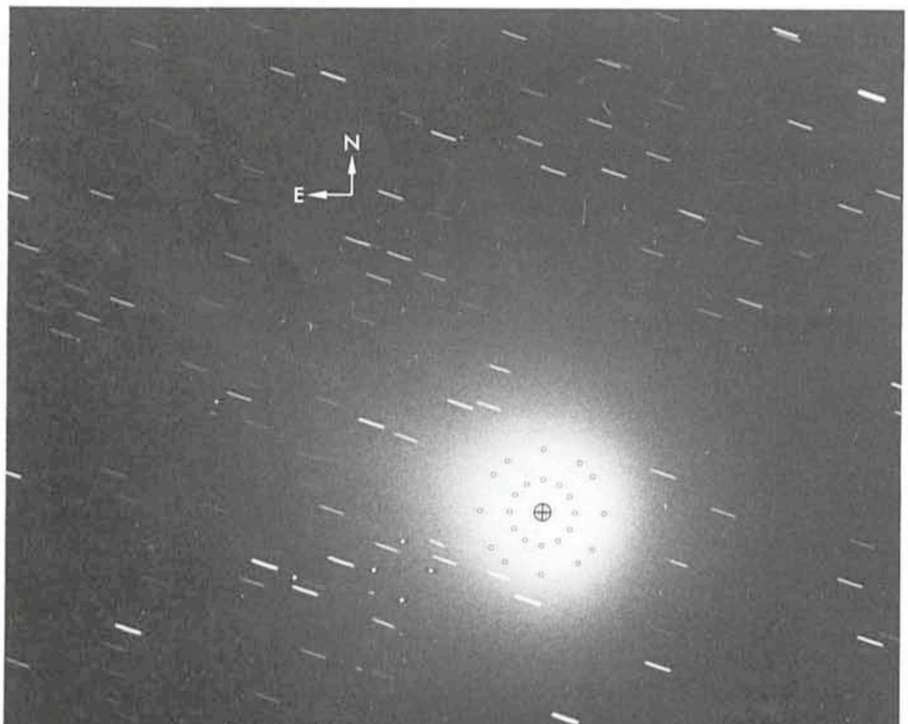

Figure 6: *View of the central region of Halley's coma, with an overlay representing the locations in which the fibres were positioned. The outermost fibre positions are represented here with white spots, in order to distinguish them from the darker background. The central "crosshair" represents the coherent fibre bundle used for guiding. The detail visible in this print was made apparent by the use of a photographic masking technique described on page 12 in this issue of the* Messenger.

The telescope tracking parameters were adjusted to compensate for the apparent movement of the comet, and residual errors were left to the care of the telescope autoguider. At a reciprocal dispersion of 170 Å/mm – corresponding to a spectral resolution of 13 Å (using an on-chip binning factor of 2) – an exposure of 10 minutes was largely adequate in order to record the 36 independent spectra across the coma of Halley's comet.

On Saint Nicholas's day, the comet was at a distance of a mere 0.68 A.U. from the earth, and could already be distinguished with the naked eye ($mV \simeq 6.3$ mag.).

Some Preliminary Results from the Multi-Aperture Analysis of Halley's Comet Spectra

After correction of the raw OPTOPUS data for wavelength and flux calibrations as well as for the relative sensitivity of the individual optical fibres, we observed that within measurement uncertainties, spectra recorded at the same projected radial distance from the luminosity centroid of Halley's comet appeared to be essentially the same. This result gave us considerable confidence in the reliability of the instrument's performance as well as in the consistency of the rather long reduction procedure adopted within the IHAP system. Therefore, in Figure 7 we have presented the AVERAGE spectra of Halley's comet observed at the approximate angular separations of 1.1 arcminutes (spectrum I), 2.0 arcminutes (spectrum II) and 5.0 arcminutes (spectrum III) from the centre of the coma. These apparent angular separations correspond to projected radial distances of $4.7\ 10^4$ km, $8.8\ 10^4$ km and $2.4\ 10^5$ km respectively. Each optical fibre spanned a circular region on the comet approximately 1,280 km in diameter.

The spectra thus shown in Figure 7 reveal the presence of a very faint continuum, which is due to the scattering of solar line photons in the inner region of the coma. On this solar-like continuum are superimposed the bright emission bands of various molecules (CN, C_2, C_3, NH_2, etc.). It is nowadays well known that these cometary emissions are produced by a resonance-fluorescence mechanism: the pumping of solar radiation at frequencies characteristic of a given molecule is followed by a re-emission process of line photons at the same as well as at other discrete frequencies. The exact profiles of the observed emission bands critically depend on the spectral shape of the underlying solar continuum, on the distance and radial velocity of the comet with respect to the sun (the so-called Pol Swings effect), and to a lesser extent on other secondary phenomena. The presence of "chemically" very unstable molecules such as CN, C_2, C_3, NH_2, etc. in the head of comets suggests that the cometary atmospheres are regions of very low density where collisions between particles are very rare. This spectroscopically established result may also be visually confirmed by close inspection of Figure 6; indeed, it is because of the very tenuous nature of the cometary atmosphere (typically 10^5 molecules/cm^3 at a distance of 10,000 km from the centre) that trails of very distant stars can be seen through Halley's coma. The OPTOPUS spectra also clearly show that the brightness decrease of molecular bands as a function of the projected radial distance is not the same for different molecules (see for instance CN and C_3 in spectra I, II and III). We are convinced that a more detailed analysis of the presently obtained data will contribute to a better understanding of the physics of Halley's comet. These results will soon be reported elsewhere.

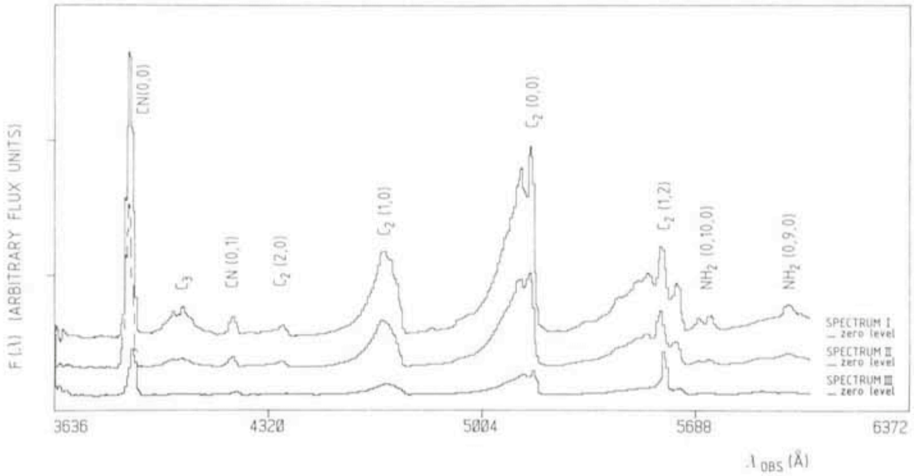

Figure 7: *Averaged OPTOPUS spectra of Halley's comet, observed at the approximate projected radial distances of 47,000 km (spectrum I). 88,000 km (spectrum II) and 240,000 km (spectrum III) from the centre of the coma (see text).*

Observations at La Silla of Comet Halley after Perihelion

R. M. West, ESO

Comet Halley passed through its perihelion on 9 February. At that moment it was only 8 degrees from the sun and it could therefore not be observed with optical telescopes. However, radio and infrared observations, which started in late 1985, continued to be made during daytime.

The first observations of the comet after perihelion were performed at La Silla on 15 February in the bright morning sky, when Halley still was only 15 degrees from the sun. Here, ESO astronomer R. M. West and Belgian visiting astronomer H. Debehogne photographed the object with the 40-cm GPO double astrograph, just after it rose above the eastern horizon. A 30-second exposure on a red-sensitive plate, when the comet was only 15 arcminutes above the Cordillera, enabled the astronomers to measure the accurate position. The data were immediately telexed to the spacecraft control centres in Darmstadt, Tokyo, Moscow and Pasadena as well as to the IAU Telegram Bureau in Cambridge, Mass., USA. The ESO observation proved that Halley was very near the orbit which had been predicted on the basis of pre-perihelion measurements. It was good news for the spacecraft navigators that Halley had behaved normally while "behind" the sun. As we witnessed in early March, all five spacecraft en route to Halley indeed managed to pass the comet nucleus within the prescribed distances.

Following the initial observations with the GPO, other telescopes at La Silla and other observatories soon joined in. The full story will only be available after some years, when the archive comprising all Halley observations has been put together by the International Halley Watch. In the meantime, here are some details about the early activities at La Silla.

Here, the GPO continued to deliver astrometric positions until 6 March, the day of the Halley fly-by of the Soviet Vega-1 spacecraft. Other exposures with this telescope showed dramatic changes from morning to morning in the innermost few thousand kilometres of the coma. Thanks to very stable weather and excellent seeing, the rather unique time-series has been continued by P. Monderen. Until the time of writing (18 March), not a single night has been lost since 15 February and it is the intention to continue as long as possible. This observational material will provide a most valuable record of the near-nucleus events, including several violent outbursts during which the innermost part became totally obscured by dense dust clouds. It would be tempting to produce a short movie, once the plates have been digitized and calibrated.

The first exposures with the specially designed Wide-Field CCD Camera were made already on 17 February. This instrument uses a 640 × 1,024 pixel RCA CCD chip as detector behind a 100 mm Canon lens at aperture f/2.8. The field is 5.5 × 9 degrees and each pixel measures 31 arcseconds on the sky. Until the full moon started to seriously interfere on 23 February, exposures were made through a GG 495 filter, i.e. covering the 5000–11000 Å spectral interval. Of particular interest was the spectacular tail structure, that was first seen on 18 February. At least seven tails emerged from the coma which could be theoretically explained by consecutive outbursts in the period when Halley was nearest to the sun.

During the moon period, which lasted until 8 March, this camera explored the ion tail(s) by means of narrow interference filters, which suppress the sky background light. The observations, which were made by ESO astronomer H. Pedersen with the help of R. Vio and B. Gelly, documented in detail the development of a more than 15 degrees long CO^+ tail, necessitating two shifted exposures to cover most of it. Daily changes were recorded and on 5 March the first of several disconnection events was seen. As Halley moved higher in the sky, exposures in other filters could be made as well, corresponding to other major constituents of the ion tail(s). Also these observations were blessed by the marvellous weather and now provide a unique record of the tail changes.

Infrared observations at ESO started already in late 1985. From 16 February to 3 March only one night was lost and ESO astronomer Th. Le Bertre recorded the comet's brightness in the standard