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The Giotto Optical Probe Experiment

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Abstract

The Halley Optical Probe Experiment (HOPE) has been designed to provide in-situ photopolarimetric data on both the dust cloud and the gaseous atmosphere in Halley's coma. The Optical Probe's concept is presented here, together with a description of the instrumentation and the possibilities for cross-correlation between the HOPE results and those of other space and ground-based experiments. The instrument was turned on successfully on 13 September 1985.

1. Concept and Methodology

Cosmic dust observations from space probes are traditionally classified as either remote-sensing (essentially optical) or in-situ (typically mass-spectrometers or impact detectors). A third type of observation is possible with the ESA Giotto mission to Comet Halley, namely optical measurements of cometary dust and gas parameters in volume elements centred on the moving probe (Levasseur-Regourd et al. 1981a).

The Optical Probe's concept is shown in Figure 1. An optical measurement of the polarized spectral radiance in the direction of motion is made at point M1 on the spacecraft trajectory; a second measurement is then made at point M2. If the two observations are made parallel to the direction of motion, then their difference is the spatial derivative of the radiance along the line of sight. It is a direct measure of the light scattered by the dust or emitted by the gas in a tube along the trajectory (Levasseur-Regourd et al. 1981b).

The only assumptions made are: (i) that the cometary atmosphere is optically thin (which is highly likely more than 500 km from the nucleus); and (ii) that the rapid motion of the spacecraft through the coma allows a quasi-steady-state from one measurement set to the next.

The polarized spectral radiance can be inverted only if the viewing direction is parallel to the trajectory, resulting in two possibilities, the direction of motion and the opposite one. The corresponding measurements differ only in scattering angle, which typically for the Giotto mission are 72.8 deg for the forward viewing direction and 107.2deg for rearward viewing. Typical scattering phase diagrams such as those obtained for the zodiacal cloud and in laboratory measurements are flat in the 70deg - 110deg range (Dumont 1976, Giese et al. 1978), implying that the ratio of the two polarized radiances would yield almost no information on the forward-to-backscattering ratio. A rearward-looking instrument has been selected, in view of the more critical demands of a forward-looking type.

Figure 1. Concept of an optical probe

2. Instrumentation

The Optical Probe Experiment requires the measurement of linearly polarized brightnesses in various colours in the direction opposite to the direction of motion of the spacecraft through the cometary coma. Since an instrument on board a cometary probe had to be relatively small and extremely reliable, we have chosen to have no moving parts, which has led to an instrument mass of only about 1.3 kg (Fig. 2).

The spectral discrimination in the seven-colour refracting photopolarimeter is achieved by imaging uniformly illuminated interference filters deposited on the objective lens onto a micro-channel plate detector. The polarization is determined by the spinning spacecraft rotation (15 r.p.m.) of the polaroid analyzer; simultaneous measurements are made for the seven channels in 0.5 s. One set of measurements, which allows the determination of the total intensities, the polarized brightnesses, the azimuths of the polarized components (i.e. the Stokes parameters) and their errors, corresponds to a 180 deg rotation of the analyzer; it is performed every 2 s.

Table 1. HOPE spectral response

Filter	Central wavelength (nm)	Bandpass 50% peak (nm)	Bandpass 1% peak (nm)
Continuum 1	443.5	4.5	9.0
Continuum 2	575.0	10.0	20.0
Continuum 3	717.5	3.5	7.5
OH	307.5	6.0	10.0
CN	387.0	4.0	10.0
CO+	426.0	4.0	8.0
C2	514.0	4.0	6.0

The layout of the optical system is illustrated in Figure 3. It is composed of an f/1.7 objective lens of 18 mm diameter, seven interference filters (Table 1), a polaroid foil, a field stop, a field lens and a micro-channel plate photomultiplier. The filter mosaic is designed to provide comparable intensities for the various channels and a partial correction of the aberrations. The field of view for each channel is 3 deg. Cross-talk may exist between the various channels, due to diffusion inside the filter mosaic, misalignment between optics and detector, or electronic cross-talk; total cross-talk has been found to be less than 3%.

The linearity calibration was performed at the Max Planck Institute for Astronomy in Heidelberg. It allowed determination of the degree of linearity for individual counts by a boot-strap method. This Individual Linearity Ratio (ILR) is defined for a given count as the ratio of counts measured to counts expected, i.e. if a stimulus results in a count C1, and another stimulus results in a count C2 (where C1 is approximately equal to C2), the combination of the first and second stimuli results in a count C3. Then if the system is behaving linearly, C1 + C2 = C3. The ratio of C3 to the sum of C1 and C2 defines the ILR for the count (C1 + C2)/2. These ILRs were determined for all channels. A least-squares curve was then fitted to the ILR vs counts for each channel. The product of successive values of the ILR yields the linearity ratio, which is then used to correct the measured counts of our system.

The cross-talk measurements were also mainly carried out in Heidelberg using a Jarrell Ash dual 1 m monochromator. In this set-up, a light beam is passed through the monochromator with a dispersion of about 0.1 nm and the response of the instrument noted in all channels. These measurements were repeated for numerous wavelengths. The results were integrated across each bandpass and then compared with the integrated signal received in the out-of-bandpass channels. The outband and inband counts were corrected by applying a preliminary linearity ratio derived as a composite of all channels. The outband and inband counts corrected in this way for linearity were then used to determine the preliminary cross-talk. This cross-talk was then used to correct the linearity ratios. The improved linearities were then used to correct the cross-talk. This cross-talk was subsequently used to correct the linearity ratios, and finally the improved linearity ratio was used to finalize the correction to the cross-talk. The application of this finalized cross talk to the linearity ratio did not result in any material change and the iteration process was therefore terminated.

Figure 2. The HOPE instrument

3. Wavelength Choice

Sunlight diffused by the cometary dust will be measured over a wide wavelength range, from the blue to the red, in three gas-free emission bands: 439-448 nm, 565-585 nm and 714-721 nm. Of great importance is the fact that there are two wavelengths in common between the Giotto HMC camera and the HOPE instrument, and one wavelength in common between the USSR Vega probe camera and HOPE (Fig. 4), providing the possibility of cross-checking.

Light emitted by the cometary gases will be measured in four spectral bands. The OH emission band at 307 nm has been chosen as a tracer of H2O molecules. CN at 387 nm and C2 at 514 nm are the dominant minor species emissions in the optical range; they could be representative of some carbon chemistry in the coma. CO+ at 426 nm will allow the penetration of the solar wind to be studied throughout the coma,

Figure 3. The HOPE optical system

Figure 4. Comparison of the continuum filter bands

and will provide new insight into ion formation processes. Polarization measurements are mainly aimed at the study of the optical properties of dust grains. They also carry information on the production processes of the gaseous species; ground-based observations have been found to be compatible with the fluorescence mechanism. Polarization measurements for OH, CN and C2 will help to assess the possibility of some of those species being produced in an excited state in the inner coma.

The rearward-looking photopolarimeter is located on the top platform of the Giotto spacecraft, in the shadow of the solar panels. It is, nevertheless, necessary to baffle the instrument against light coming from the cometary coma outside the field of view, and reflected by Giotto’s main antenna or tripod during the flyby. A 270 mm long baffle with seven vanes has therefore been designed and incorporated. The total system stray-light suppression is about 10**-12, as long as the flight sources are at least 1.5deg from the instrument’s optical axis. The possibility that specularly reflecting sources might direct sunlight into the baffle has been studied during solar simulation testing of the spacecraft.

A self-luminescent white source of moderate intensity is mounted on the back of the baffle cover; it has been used during the tests and during the Giotto spacecraft cruise phase. The cover was released in October 1985 by means of a pyrotechnic device. In-flight calibration is provided via this calibration source, and by the background sky radiation (zodiacal light + star light) to be observed immediately prior to encounter.

4. Anticipated Results

Multicolour brightnesses and polarizations will be obtained in volume elements along the trajectory of the Probe throughout Halley’s coma. The tubes will be 140 km long (corresponding to 2 s in the encounter data take) and 7 km wide (corresponding to the 3 deg field of view of the instrument). For the dust, HOPE provides six values (three wavelengths X two states of polarization) of the product of the local density and the differential scattering cross-section. It should be possible to distinguish changes in density from changes in cross-section and five values of the normalized cross-section are obtained. One has, nevertheless, to be aware of possible ambiguities in order to arrive at proper interpretation of the data, especially in the regime of large irregular dust grains which might show similar relative scattering functions, somewhat independent of size (Weiss-Wrana K, 1983). Generally, however, if the normalized cross-sections do not vary from one point to the next, any change in the local polarized radiance is a direct measurement of a change in the dust number density; discrete features (jets) will be obvious if the optical properties do not change dramatically in these jets. If the normalized cross-sections vary, severe constraints will be imposed on optical properties. Dust number densities will be derived from laboratory results on dust scattering properties and modelling, developed at Ruhr Universitat, Bochum, Laboratoire d’Astronomie Spatiale, and the Space Astronomy Laboratory (Levasseur-Regourd et al. 1983).

Figure 5 shows how various grain-size intervals contribute to the brightness integral. The lower curve obtained using Mie theory indicates that the size intervals (0.121 - 1.5 micro m) and (1.5-70 micro m) contribute equally to the overall integral; the upper curve, obtained using a combination of Mie theory for small grains (</= 70 micro m) and the Perrin-Lamy model (Perrin J M & Lamy P L, 1983) of rough particles for larger grains, suggests that grains larger than 70 micro m may contribute to enhance the brightness integral. Table 2 shows how colour should behave for three HOPE dust channels, taking the fourth one (445 nm) as a reference. The red channel indicates the possibility of distinguishing between

Figure 5. The cumulative brightness integral as a function of grain radius

Table 2. Colour dependence (left: Mie model; right: Mie + rough model)

Distance to the comet (km)	Lambda = 368.0nm		Lambda = 575.0 nm		Lambda = 717.5 nm	
1.08 x 10**4	100	1.02	1.19	1.19	1.30	1.23
1.06 x 10**3	1.01	1.02	1.19	1.19	1.30	1.25
5.06 x 10**2	1.01	1.04	1.19	1.19	1.30	1.25

smooth and rough grains and/or the possible presence of submicron-sized particles.

A simulation has been made to prepare the restitution method. For the dust, the Perrin-Lamy model was used, while for gases a Festou-Zucconi model was employed (Festou M & Zucconi J M, 1984). The solar flux scattered along the rearward-looking line of sight was integrated every 0.5 s. Then, the zodiacal background was added and the overall intensity was partially modulated to simulate the polarization. Afterwards, the stellar background and, for the gas channels only, the estimated polarized gas signals, were added. We also included stray light, cross-talk, telemetry noise and telemetry breakdown. Typical results are presented in Figure 6. This simulation allows the ultimate precision of the inversion technique to be estimated as a function of the global noise level.

In conclusion, with the HOPE experiment we seek to:

- determine the changes in both number density (including inhomogeneities) and the grain-size distribution as a function of the Probe's position inside the coma
- determine the spatial distribution along the trajectory of emissions due to OH, CN, C2 and CO+, in order to derive the production rates of the parent species, as well as their nature, and to obtain information on the physical processes leading to the formation of the observed radicals by means of the study of the polarization of their emissions as a function of the distance of the nucleus
- investigate the dynamical coupling of gas and dust by determining the gas-to-dust mass production ratio as a function of the distance and the possible correlations with grain sizes
- compare the optical properties of cometary dust with those of interplanetary and interstellar grains, in an effort to understand the histories and mutual interactions of all three dust complexes.

The experiment should also provide the necessary link between in-situ and remote measurements with regard to spatial changes through the coma. It has been suggested to the International Halley Watch (IHW) that ground-based observations should be made at HOPE wavelengths: in addition HOPE team members will make supporting grounf observations.

Figure 6. Typical brightnesses for two continuum wavelengths and two gas wavelengths

From a comparison of in-situ dust-detector measurements and HOPE experiment results, the following relationships should be determined: dust number density and bulk density, mass distribution and grain size, species abundances and gaseous emissions. These relationships should allow remote (and future) observations of comets to be interpreted in terms of physical processes.

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