Comet P/Grigg-Skjellerup Observations at ESO La Silla During the GIOTTO Encounter Period

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Introduction

On July 10, 1992, the GIOTTO spacecraft of the European Space Agency (ESA) became the first satellite to pass within 500 km of the nucleus of a comet. GIOTTO encountered the periodic comet P/Grigg-Skjellerup and returned a wealth of interesting *in situ* measurements of the cometary coma to Earth. After the fly-by of comet Halley on March 14, 1986, the spacecraft completed the first ever Earth gravity assist manoeuvre on July 2, 1990, placing it on course for an encounter with comet P/Grigg-Skjellerup. At launch, operations after the fly-by of comet P/Halley were unforeseen but the remarkable performance of the spacecraft and its instrumentation allowed the extension of the mission. GIOTTO has now completed 7 successful years in space.

Unlike comet P/Halley, comet P/Grigg-Skjellerup was previously a largely unexplored comet (for a summary of the results published so far see Birkle and Boehnhardt, 1992; additional information can be found in Osip et al., 1992, Schmidt and Wegmann, 1992). ESO has supported the GIOTTO fly-by at comet P/Grigg-Skjellerup by providing urgently needed astrometric positions before the encounter and by granting observation time to four authors of this article for physical observations. In this article we give a preliminary account on these observations and provide some highlights of the spacecraft encounter.

The Observing Programme

The main scientific goals of our observing programme at ESO-La Silla were: to determine production rates of the very abundant H_2O molecules and other gaseous coma species, to provide direct images of the comet for the encounter period which could be used for an analysis of the coma geometry and overall dust environment, and to collect information on the cometary ion tail. Because of the damage of two important onboard experiments (the Halley Multicolour Camera and the Neutral Mass Spectrometer) GIOTTO was unable to collect detailed data on the questions addressed by our observing programme.

In total 4 half nights (from 7/8 to 10/11 July 1992) at the ESO 3.6-m telescope and at the ESO 1.5-m spectroscopic telescope were devoted to observe comet P/Grigg-Skjellerup. Two evenings were lost due to clouds over La Silla. In the night July 9/10, 1992 some direct images could be obtained through cirrus clouds. Only the last night of July 10/11, 1992 gave reasonably good atmospheric conditions for our observations. However, the small elongation of the comet from the Sun (about 45 deg.) restricted the observing window to just 1 hour after evening twilight with the comet positioned low above the western horizon (below 25 deg. elevation). In fact, special precautions were needed to operate the 3.6-m telescope at such large zenith distances and even then guiding on the comet with nonsiderial rate was not at optimum.

Comet P/Grigg-Skjellerup reached its perihelion of 0.99 AU on 22 July 1992. It was predicted to show a late onset of its nuclear activity and to exhibit a steep brightness increase (Green, 1991) before perihelion. Actually, it looks as if the comet only initiated significant coma development by the beginning of June 1992 (that was 1½ months later than expected) when it was already at a heliocentric distance of about 1.2 AU. However, the steepness of the lightcurve was approximately as predicted (n of about 30 to 40). Before perihelion the total coma brightness was estimated to be about 1 mag fainter than the lightcurve prediction published by Green (1991). At a wavelength of 620 nm the brightness of the comet in a square aperture of 20 arcsec was 15.5 mg on July 11, 1992.

In the night July 9/10, 1992, just 15 hours before the GIOTTO encounter with P/Grigg-Skjellerup, 4 broad-band R filter CCD images were obtained with the ESO 3.6-m telescope at La Silla through cirrus clouds low at the western horizon (below 20 deg. elevation). The images were processed at La Silla and immediately transmitted via satellite link to ESO-Garching. The co-added coma image of these exposures is shown in Figure 1. Thanks to the night work of people from the ESO Information Service and by staff at ESO-La Silla a hardcopy version of Figure 1 could be distributed only 10 hours after the observations and about 5 hours before the encounter to the GIOTTO experimenters, to the scientists and to the press who were following the fly-by at the GIOTTO control centre, the European Space Operations Centre (ESOC), in Darmstadt/Germany (Jockers, 1992).

On the day of the GIOTTO encounter (see Figure 1) an ellipsoidal coma of about 30 × 20 arcsec apparent extension surrounded the central brightness condensation which contained the cometary nucleus. The major axis of the coma ellipsoid pointed towards position angle 130 deg. (counted east from north), i.e. about 15 deg. out of the antisolar direction. Numerical simulations of the dust tail orientation for the encounter day support the interpretation of the elongated coma as being formed mainly by cometary dust particles. No indications of a plasma tail were detected in any of our exposures. This is partly caused by the moon-lit sky which does not allow to reach the low surface brightness of the plasma tail (a plasma tail was detected by GIOTTO) and also limits the extent of the visible coma. The radial renormalization method was applied to the superimposed CCD image of P/Grigg-Skjellerup of Figure 1. However, apart from the dust tail extension no further structure was found in the otherwise symmetric cometary coma. An analysis of the radial profile of the integrated coma brightness exhibited a rather linear increase with aperture diameter. Both phenomena (the elongated coma towards the dust tail direction and the radial coma brightness profile) support ideas that most of the light in the R filter exposures of July 9/10, 1992 arose from sunlight scattered by the dust. An analogous image processing of the R filter CCD observation of P/Grigg-Skjellerup obtained on June 29, 1992 at the ESO New Technology Telescope NTT (Storm and Meylan, 1992) has been performed by one of the authors and led to similar results as for our images of July 9/10, 1992.

In the night July 10/11, 1992 7 images (exposure time 30 s each) through a wide-band red filter (dust + NH2) and 3 plasma filter exposures (10 minutes each, but trailed due to guiding problems) were obtained at the ESO 3.6-m telescope. The photometric calibration and the analysis of these data is still in progress. While the cometary imaging continued at the 3.6-m telescope, 2 CCD spectra in the 370 to 1000 nm wavelength range were exposed on July 10/11, 1992 at the ESO 1.5-m spectroscopic telescope. The spectra show the strong emission band of CN at about 388 nm and also the C2 emission around 517 nm. A weak dust continuum was found in the red part of the spectra. For the spectra the calibration and data analysis is presently performed.

ESO has also supported the fly-by targeting of the GIOTTO spacecraft by providing high-quality astrometric positions of the comet to ESO before encounter. The data were measured by Richard West from CCD frames obtained with La Silla telescopes. Post-fit residuals of 0.1 to 0.2 arcsec were derived for the ESO data from the comet orbit determination at ESOC Darmstadt. Astrometric positions of the comet were also determined from our CCD frames of July 9/10, 1992. These data were also transmitted to ESOC Darmstadt and can be used together with data from other observers for the post-encounter analysis of the GIOTTO fly-by trajectory at the comet.

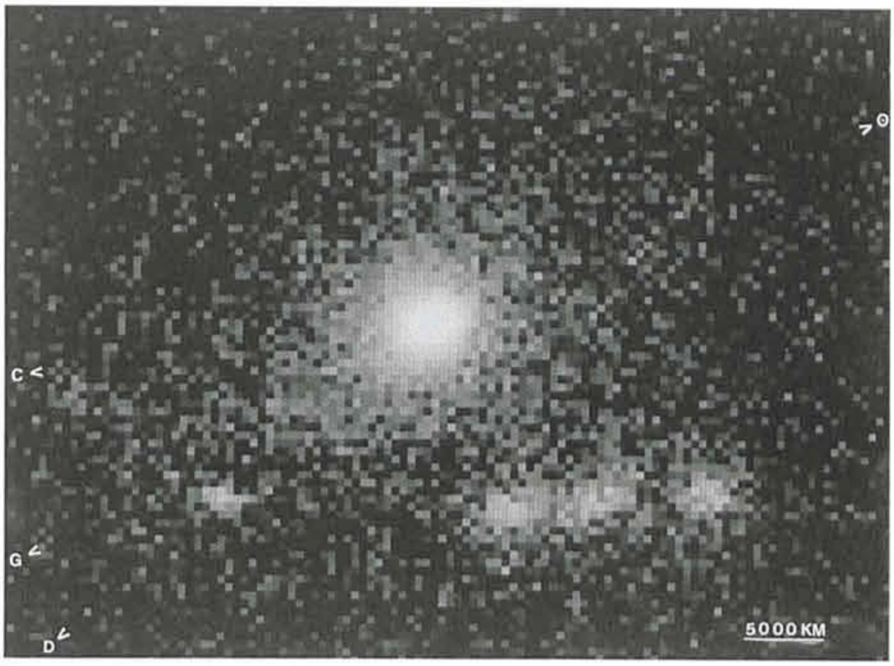

Figure 1: *Comet P/Grigg-Skjellerup on July 10, 1992, just 15 hours before the GIOTTO encounter.*

The image is a composite of 4 R filter exposures obtained at the ESO 3.6-m telescope. The field of view is about 70 × 50 arcsec (73,000 × 52,000 km at the comet). North is up and east to the left. The Sun direction is indicated by symbol O, that of the dust tail by symbol D. The direction of the cometary motion on the sky is given by symbol V, that of the GIOTTO spacecraft by symbol G. The four trails in the lower image section are background stars.

The GIOTTO Fly-by at the Comet

On July 10, 1992 15:30:36 UTC* (± 46 sec) GIOTTO passed within about 200 km of the nucleus of comet P/Grigg-Skjellerup. During the P/Grigg-Skjellerup encounter GIOTTO was actually overtaken by the comet in its orbital motion around the Sun. At the same time it passed through the orbital plane of the comet from north to south. The relative velocity during the fly-by was about 14 km/s which was almost 5 times slower than during the Halley encounter in 1986. The heliocentric distance of the comet at encounter was 1.01 AU, the Earth distance 1.43 AU. GIOTTO approached the nucleus from 11 deg. behind the terminator. For on-board power reasons and because of communications constraints (the high-gain antenna needed to be kept Earth pointing) GIOTTO had to fly through the coma of comet P/Grigg-Skjellerup almost side-on with the solar cells fully exposed to the cometary dust and gas environment (at comet P/Halley the bumper shields of the spacecraft were front-on in order to protect the experiments and the other satellite hardware from damage by cometary particles).

* All times in this section are station-receive times of the GIOTTO signals in UTC. The time for signals to reach Earth from GIOTTO at the time of the encounter was 11 minutes 52.6 seconds.

Further details on the GIOTTO Extended Mission to comet P/Grigg-Skjellerup have been given in Schwehm et al. (1991). Spacecraft orbit and attitude aspects of the fly-by have been described by Morley (1991).

The payload was switched on in the evening of July 9, 1992. 7 out of the original complement of 11 on-board experiments were operated during the encounter: the Magnetometer (MAG), the Johnstone Plasma Analyser (JPA), the Energetic Particle Analyser (EPA), the Optical Probe Experiment (OPE), the Reme Plasma Analyser (RPA), the Dust Impact Detection System (DID), the Ion Mass Spectrometer (IMS). In addition, the signals from the spacecraft were analysed for perturbations by members of the GIOTTO Radio Science Experiment (GRE) team.

At about 600,000 km from the nucleus (12 hours before closest approach), JPA detected the first presence of cometary ions. At a distance of 18,000–15,000 km both JPA and RPA reported what looked like a bow shock or a bow wave of the coma, much more distinct than had been predicted for such a faint comet. MAG measurements carried out during the inbound trajectory could not confirm this finding, but reported interesting wave phenomena not seen in a natural plasma before. However, on the outbound trajectory MAG saw clear indications of a shock.

OPE started to detect emissions from the gas coma about 50,000 km from the nucleus. The first indication of entering the dust coma occurred around 20,000 km from the nucleus (at about the same distance as the dust coma extent in our ground-based observations). Data from OPE provided the first estimate of the spacecraft-nucleus distance at closest approach. A value of approximately 200 km was derived. In combination with the MAG data, there is good evidence that GIOTTO passed the nucleus on the anti-sunward side, i.e. through the tail forming region of the coma. The data from OPE also suggested that closest approach occurred a few seconds after the nominal predictions.

DID reported its first impact at 15:30:56 UTC – probably after closest approach. A total of three impacts were recorded, the first being the largest. It is conceivable that the impacts occurred when GIOTTO crossed the orbital plane of the comet.

At 15:31:02 UTC, shortly after the first impact, the High-Gain Antenna of GIOTTO appeared to be oscillating slightly around its nominal value. An increase of the spin rate by 0.003 RPM was also observed while the solar aspect angle readings were fluctuating between 89.26 and 89.45 deg., indicating a nutation of about 0.1 deg. This was also recorded by the GRE and is awaiting further evaluation.

EPA saw clear indications of the acceleration regions and surprising differences in the structures between P/Halley and P/Grigg-Skjellerup. Last but not least IMS recorded good data; however, the data analysis for this instrument is quite cumbersome and complex, due to the comparatively low encounter velocity.

A thorough test of the Halley Multicolour Camera (HMC) onboard GIOTTO on 7 July 1992 could only confirm that the optical path was very effectively blocked. However, on July 12, 1992 a number of tests were performed with the detectors of the MMC, which provided engineering and calibration data on the long-term behaviour of CCD's in space.

The Future of GIOTTO

About one week later than previously planned, on July 21, 1992, another major orbit manoeuvre put the spacecraft into an orbit that will bring it close to Earth (distance about 200,000 km) in July 1999. There are still 4 kg of fuel left onboard for attitude and further orbit correction manoeuvres. This leaves, though with rather hard constraints, the door open for some further activities in 1999. After a final orbit trim manoeuvre on July 23, 1992 at 17:07 UTC the GIOTTO spacecraft was put into hibernation for the third time.

Meanwhile, spacecraft experimenters and telescope observers have started the scientific evaluation of their data, which may still hold surprises. The next space exploration of comets, after cancellation of the American CRAF (Comet Rendezvous Asteroid Flyby) project will be ESA's ROSETTA mission which is supposed to bring a cometary sample back to Earth. It will take place in the next century. Meanwhile, cometary exploration will continue from the ground and we expect that, together with other branches of astronomy, it will profit from ESO's progress in telescope technology.

Acknowledgement

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A Minor Planet with a Tail!

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Minor Planet 1979 VA was discovered by Eleanor Helin at Palomar on November 15, 1979 as a "fast-moving object" of magnitude 11 (IAUC 3422). Further observations were made, and when a reasonably accurate orbit became available, it was found that 1979 VA belonged to the select "Apollo" class of Earth-crossing minor planets. Its perihelion was just inside the Earth orbit, at 0.98 AU, and it had passed within 0.1 AU, or less than 15 million km, of the Earth in late October 1979. The eccentricity was rather large, 0.63, and the orbit was therefore very elongated; the period was somewhat over 4 years.

After more observations had become available in the 1980's, 1979 VA was duly assigned the definitive number 4015, but it has not yet received an official name.

Nothing very exciting about that. But this August, Minor Planet (4015) suddenly became an object of intense interest among solar system astronomers!

The Palomar 1949 Observations

Extrapolating the motion of (4015) backwards in time in the hope of finding earlier recorded images of this object, Ted Bowell of the Lowell Observatory at Flagstaff, Arizona, USA, found that it should be visible on a pair of plates, obtained with the 48-inch Palomar Schmidt telescope for the first Palomar Sky Survey on November 19, 1949. These plates were some of the first obtained with this telescope, red-sensitive no. 9 (45 min; 103a-E + a red plexiglass filtre) and blue-sensitive no. 10 (12 min; unfiltered 103a-O).

The image of (4015) was easy to find, but Bowell and his colleagues were most surprised to discover that it did not look like a normal minor planet trail – it had a tail!

When a hint was passed to Brian Marsden at the Minor Planet Center (Center for Astrophysics, Cambridge, Mass., USA) that the earlier images were "unusual", he immediately recalled that an object on the Nov. 19 Palomar plates had already been catalogued in 1949 as Comet Wilson-Harrington (1949 III). There was also the strange circumstance, however, that this comet was described as having a point-like appearance on plates obtained the following nights.

So here was an object that was a seemingly normal minor planet in 1979 and thereafter, but which looked like a comet on a pair of plates in 1949. How could this be explained? Were the tails perhaps some kind of plate fault, or was this a real effect?

Brian Marsden asked about our opinion and we decided to have a very careful look at the glass copies of the POSS I Atlas plates, stored in the vault at the ESO Headquarters in Garching.

Our first conclusion was that the "tails" are unlikely to be photographic faults. Although a great variety of artificial dots, lines, etc. is often found on the very sensitive emulsions used in astronomy – the first Palomar Atlas contains many so-called "Kodak stars" – the emulsion structure around the "tail" is uniform on both plates and does not indicate any artificial origin. It is of course true that we were only able to study second-generation copies of the original plates in the plate vault at Caltech in Pasadena, but from our experience with many thousand Schmidt plates over the years, this conclusion still seems quite safe.

The tail is rather weak, especially on the red plate, and we therefore photographically enhanced the two Palomar plates in order to see the structure more clearly. The amplified images are reproduced in Figure 1a and 1b. There is no doubt that on both plates, the "tail" has the normal appearance of a cometary tail. It extends only to one side of the trail, is attached to the trail over the full