OBSERVATIONS OF THE GIOTTO TARGET COMET P/GRIGG-SKJELLERUP AT THE CALAR ALTO OBSERVATORY

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Abstract. CCD images of comet P/Grigg-Skjellerup, obtained for astrometric purposes with the 3.5 m telescope at the Calar Alto Observatory/Spain, were used for an analysis of the activity status of the nucleus and for a search of faint coma structures. The nucleus was found essentially inactive beyond 2.7 AU solar distance both inbound and outbound (observations on 12–13 August, 1986, 21–23 October, 1986, 22 August, 1988, 18 October, 1988, 9 and 12 September, 1991 and 3 December, 1991). The coma of the comet was well developed in May and July 1987 with a diameter of at least 190 000 km on 24 May, 1987 and of at least 80 000 km on 24 July 1987. The coma showed a cone of diffuse brightness enhancement in the sunward hemisphere. The orientation of the cone axis changed from the Sun direction in May 1987 towards about North in July 1987, i.e., it was almost perpendicular to the projected Sun-nucleus line on the sky. The cone opening angle became smaller from about 100° in May to about 50° in July 1987. A weak and narrow plasma tail was found in the images of May 1987.

1. Introduction

On 10 July 1992 15.25 UT ±10 min the GIOTTO space probe of the European Space Agency ESA (Schwehm *et al.*, 1991) will fly by the periodic comet P/Grigg-Skjellerup. It is expected that after the end of its hibernation period in May 1992 and a successful check-out of the platform and the research instruments, GIOTTO will send another wealth of scientific data to Earth like it did during the Halley encounter in 1986. Because of the GIOTTO fly-by the target comet will certainly focus many scientific efforts and will attract public interest in 1992.

In the following we shortly characterize the GIOTTO target comet by a summary of the results so far published on P/Grigg-Skjellerup. We furthermore describe CCD direct images of the comet with respect to the coma activity status and the appearance of coma structures.

2. The Target Comet

Comet P/Grigg-Skjellerup was discovered on 22 July 1902 by J. Grigg in New

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Zealand and – after three perihelion passages without observations – it was recovered by J. F. Skjellerup in South Africa on 17 May 1922 (Vsekhsvyatskii, 1964; Belyaev *et al.*, 1986). Most likely, it was also observed by J. L. Pons (1829) in Marseilles on 6–9 February 1808, as identified by Kresák (1987). Since the recovery in 1922 the comet was observed during each perihelion passage and astrometric data of the comet were collected for orbit determination purposes. However, only very little is known on the physical characteristics of the comet.

With an orbital period of about 5.1 years comet P/Grigg-Skjellerup belongs to the Jupiter family of short-periodic comets. After a major perturbation by Jupiter in 1964 the orbit remained rather stable (Belyaev *et al.*, 1986). The non-gravitational forces were small and almost constant over the last few returns (Belyaev *et al.*, 1986; Schwehm *et al.*, 1991: the latter authors also give updated orbital elements of the comet for 1992). The cometary orbit was recently also determined using radar tracking data obtained from Earth (Yeomans *et al.*, 1992).

Nakano and Green (1991) and Green (1991) quote a faint intrinsic brightness of 12 mag for P/Grigg-Skjellerup, a late onset of significant coma activity (just 3 months before perihelion passage) and a very steep ($n = 30$ to 40) brightness increase before, but a normal ($n = 10$) decrease after perihelion. However, these conclusions are based on brightness estimations which were mostly obtained within 60 days around perihelion. For the 1992 apparition the authors predict a lightcurve increase from the nucleus level of about 20 mag in April to about 13 mag maximum brightness during the perihelion passage in mid July. The small intrinsic brightness (about 9 mag fainter than P/Halley) and the weak non-gravitational forces point to a much lower activity level of P/Grigg-Skjellerup during the perihelion orbit arc compared to that of P/Halley.

From the published photometry of the cometary nucleus in the optical wavelength region (Birkle, 1986; Wehinger and Belton, 1987; Spacewatch, 1988; Meech 1991) the equivalent radius of the nucleus can be estimated to be within about 0.2 and 1.5 km (assuming an albedo of 0.025; Wehinger and Belton (1987) report weak spectral features of gas emission on 1–2 February 1987). From the measurements it is not clear whether this scatter in the estimated nucleus size is due to an elongated nucleus and/or due to albedo variations of the nuclear surface. Hughes (1991) has inferred a nucleus size of just 0.23 km from an analysis of the coma activity of the comet. Radar observations support a nucleus size of 0.2 km (Kamoun, 1983). Beside the uncertainties of the nucleus size, the rotation period and axis orientation, the albedo and the number and distribution of active regions on the nucleus of the comet are unknown as well. The fraction of nuclear surface active was estimated by Rickman *et al.* (1987) to about 0.8%, the bulk density of the nucleus to just 0.04 g/ccm. From optical spectra obtained on 6 June 1982 the gas and dust production was derived by Newburn and Spinrad (1989) to 1.66E24 mol/s for CN, to 1.35–1.57E24 mol/s for C_2, to 1.20E23 mol/s for C_3, to 2.09E26 mol/s for O[1D], to 2.93E27 mol/s for H_2O and to about 4.5 kg/s for the dust. A'Hearn *et al.* (1979) give production rates of 1.1–1.2E25 mol/s for CN and 0.68–1.0E25 mol/s for C_2 in mid April 1977 when the comet was at about 1 AU solar distance. The authors note variations in the apparent gas-to-dust ratio in P/Grigg-Skjellerup during their observation period. A comparison of the gas production rates derived by both author groups has to take into account the slightly different solar distance of the comet during the respective observation intervals and the different model constants for the applied Haser model calculations. Hanner *et al.* (1984) analyzed an IR spectrum of the comet obtained on 22 June 1982. The spectrum can be fitted by a 300 K black body or by a size distribution of absorbing dust grains. An emission at 10 micron wavelength was not found in the spectrum.

3. The Calar Alto Observations and the Data Reduction

The CCD observations of comet P/Grigg-Skjellerup, presented in this paper, were obtained in 1986, 1987, 1988 and 1991 at the Calar Alto Observatory in Spain. Together with a parallel series of Schmidt exposures the CCD campaign on the comet was mainly dedicated to the astrometry programme in preparation of the forthcoming GIOTTO fly-by at P/Grigg-Skjellerup. The CCD images were taken with the 3.5 m telescope at Calar Alto. Different filters and CCD equipment (RCA and GEC chips of 15 and 22.5 micron pixel size, respectively) were used depending on the actual requirements of the main observing programmes of this telescope. Table I lists the schedule of the CCD observations of the comet together with some additional data on the respective observing geometry. During all exposure intervals the telescope tracking was adjusted to the cometary motion. Therefore, stars appear as extended trails in the CCD images (see Figures 1–3).

Beside the astrometric data reduction the available CCD frames of the comet were also calibrated by astronomical standard reduction procedures, i.e., by BIAS level subtraction, flat field division and sky level subtraction. To a subset of the images the so called radial renormalization method was applied. This method reduces the general coma background and enhances inherent faint coma structures like jets and fans. It consists out of four steps of image processing: the determination of the position of the light centre in the coma to 0.1 pixel accuracy by two-dimensional Gaussian fits of the very inner coma region, the calculation of the mean radial coma brightness distribution in concentric rings of 0.5 pixel width around the light centre (the contribution of stars and image artefacts are widely suppressed by kappa-sigma-clipping), the construction of the two-dimensional images of the radial mean coma brightness distribution and the coordinate alignments of the original and constructed images, the normalization of the original image by the mean coma brightness frame either by division or subtraction of the images. The normalization by division allows the direct determination of coma magnitude variations relative to the mean radial coma brightness, while the subtraction option provides in some cases a higher dynamical range of the coma structures in particular in the inner coma region.

TABLE I

The CCD observations of comet P/Grigg-Skjellerup at the Calar Alto Observatory

Midpoint date (UT)	Duration (s)	Filter	r (AU)	d (AU)	Theta (deg)	Beta (deg)	Phi (deg)
1986/08/12.16108	900	R	3.23	3.75	52.1	14.4	259.8
1986/18/13.14881	900	R	3.22	3.73	52.3	14.5	260.0
13.16026	900	V					
13.16859	360	R					
13.17492	360	R					
1986/10/21.23058	300	R	2.77	2.39	101.8	20.6	280.0
21.23622	200	R					
1986/10/22.20219	900	R	2.76	2.37	102.6	20.6	280.4
22.21197	525	R					
22.22703	485	V					
1986/10/23.07743	900	R	2.76	2.35	103.4	20.6	280.8
23.08935	800	R					
23.10243	900	R					
1987/05/21.86354	20	Gunn g	1.06	1.04	57.5	62.5	108.5
21.86540	20	Gunn g					
21.86742	20	Gunn g					
21.87005	300	Gunn g					
1987/05/24.86278	15	Gunn g	1.05	1.02	61.9	58.9	109.0
24.86707	30	Gunn g					
24.87034	300	Gunn g					
1987/07/24.85562	15	V	1.12	0.89	71.4	59.6	107.2
24.85777	30	V					
24.86176	300	V					
1988/08/22.14492	358	V	3.86	3.10	133.1	11.0	233.1
22.15613	900	V					
22.16806	600	V					
1988/10/19.11372	600	H-alpha	4.10	3.18	154.8	5.9	93.2
19.12425	600	H-alpha					
1991/09/09.18206	600	V	3.27	3.36	75.6	17.4	273.5
12.18236	600	V	3.25	3.30	78.1	17.6	272.6
12.19242	600	V					
1991/12/03.98325	400	R	2.70	1.82	147.0	11.4	221.8
03.98953	400	R					

Explanations: r = Sun distance of the comet in AU; d = Earth distance of the comet in AU; Theta = Sun-Earth-comet angle in deg; Beta = Sun-comet-Earth angle in deg; Phi = Position angle of the extended radius vector Sun-comet projected onto the sky in deg; (North = 0, East = 90).

4. The Cometary Coma

An extended coma was found in the May (Figure 1a) and July 1987 (Figure 2a) observations, i.e., 25 to 28 days before and 36 days after the perihelion passage of the comet (see Table I). During these observations the solar distance of the comet was only slightly larger than it will be during the GIOTTO encounter which will take place about 12 days before perihelion. All cometary images show a regular coma with almost circular isophotes. It is assumed that, particularly in the inner coma section, the brightness in the V filter of July 1987 is caused by Sun illuminated dust particles. This can be inferred from the linear increase (exponent

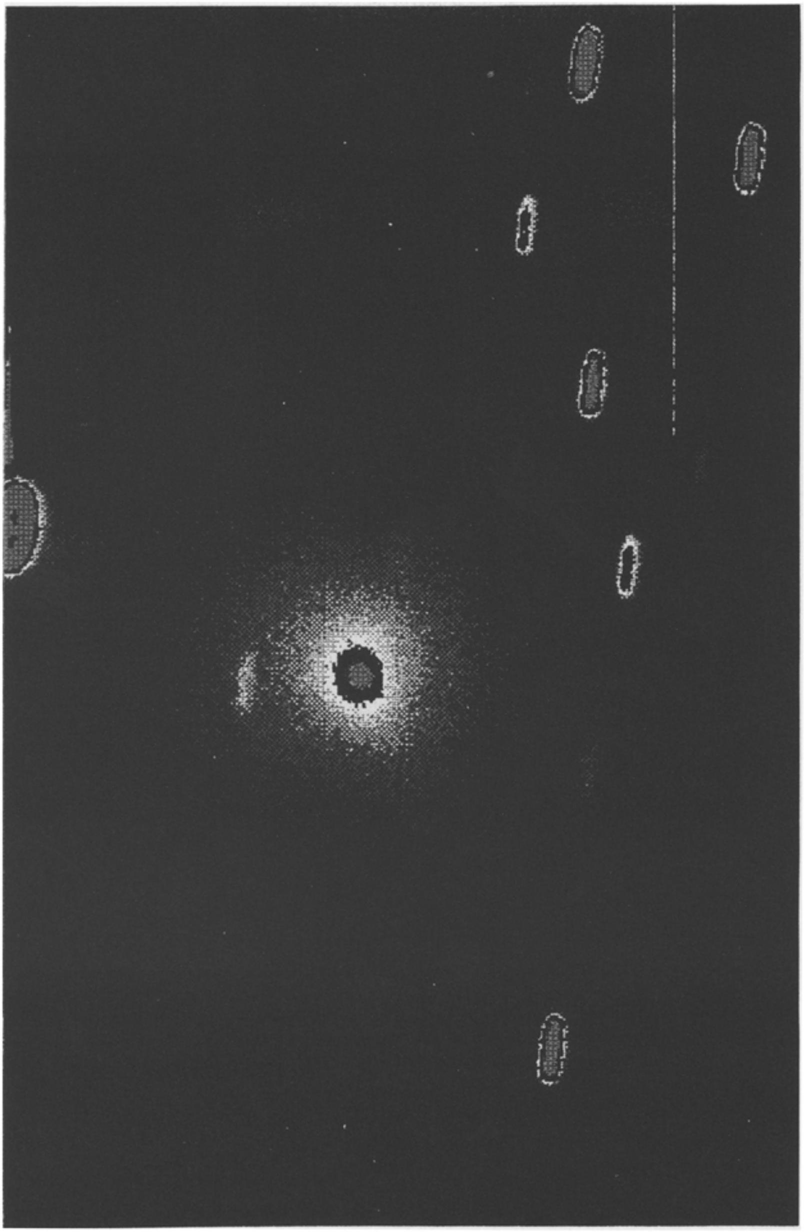

Fig. 1(a). Comet P/Grigg-Skjellerup on 24 May 1987. 300 s Gunn g filter exposure; field of view: 190 000 × 120 000 km. North is left and East is down. The stars are trailed because of the telescope tracking on the comet.

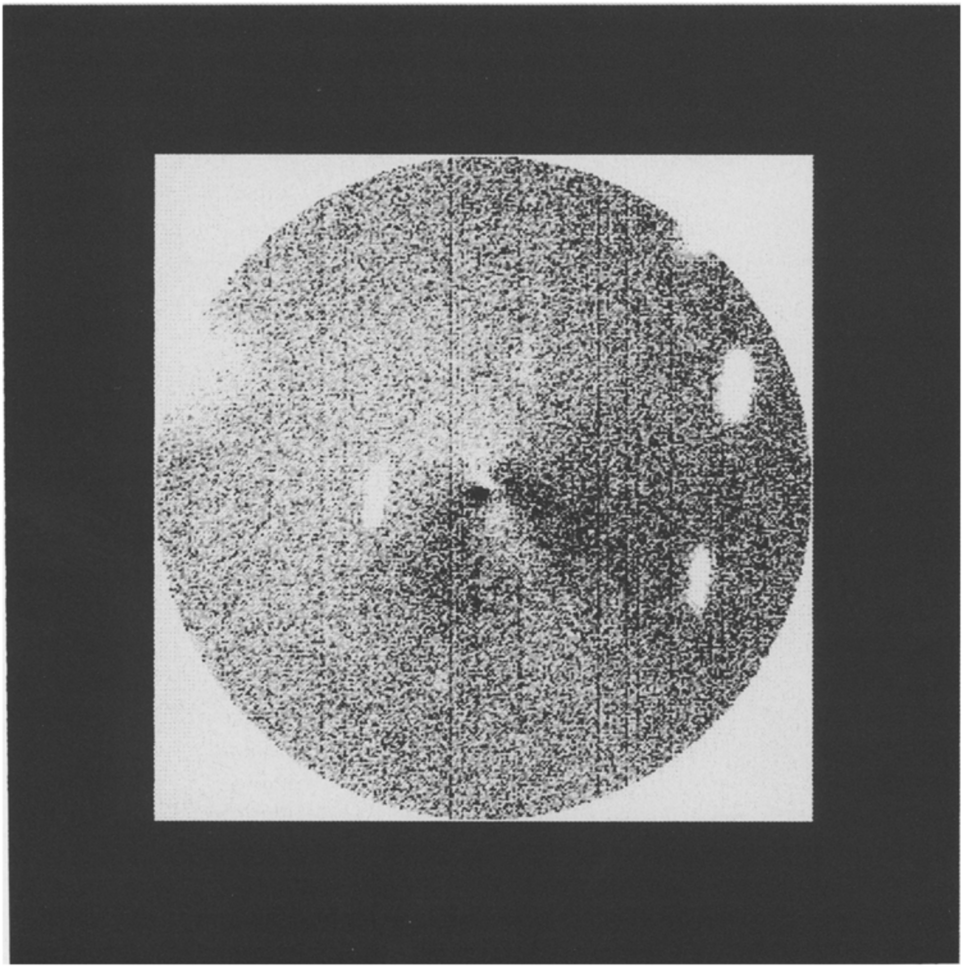

Fig. 1(b). Computer-processed image of Figure 1a (radial renormalization). Image orientation as in Figure 1a; field of view: 105 000 km diameter at comet. The centre of light in the coma is in the middle of the circular aperture.

1.06) of the mean coma brightness with increasing radius of a circular aperture as measured in the CCD images. The Gunn g filter observations of May 1987 may contain – beside the reflected sunlight from the dust – a considerable amount of light from gaseous coma species since a non-linear and steeper (exponent above 1.2) coma brightness increase with aperture radius was found in the images.

In the May 1987 images (Figure 1a) the focus points of the outer isophotes are systematically shifted towards the Sun. This may be due to the higher activity of material emission on the Sun illuminated part of the nucleus. A weak and narrow plasma tail is apparent in the anti-solar direction. The coma can be detected to at least 95 000 km nucleus distance in May 1987. Image processing by the radial

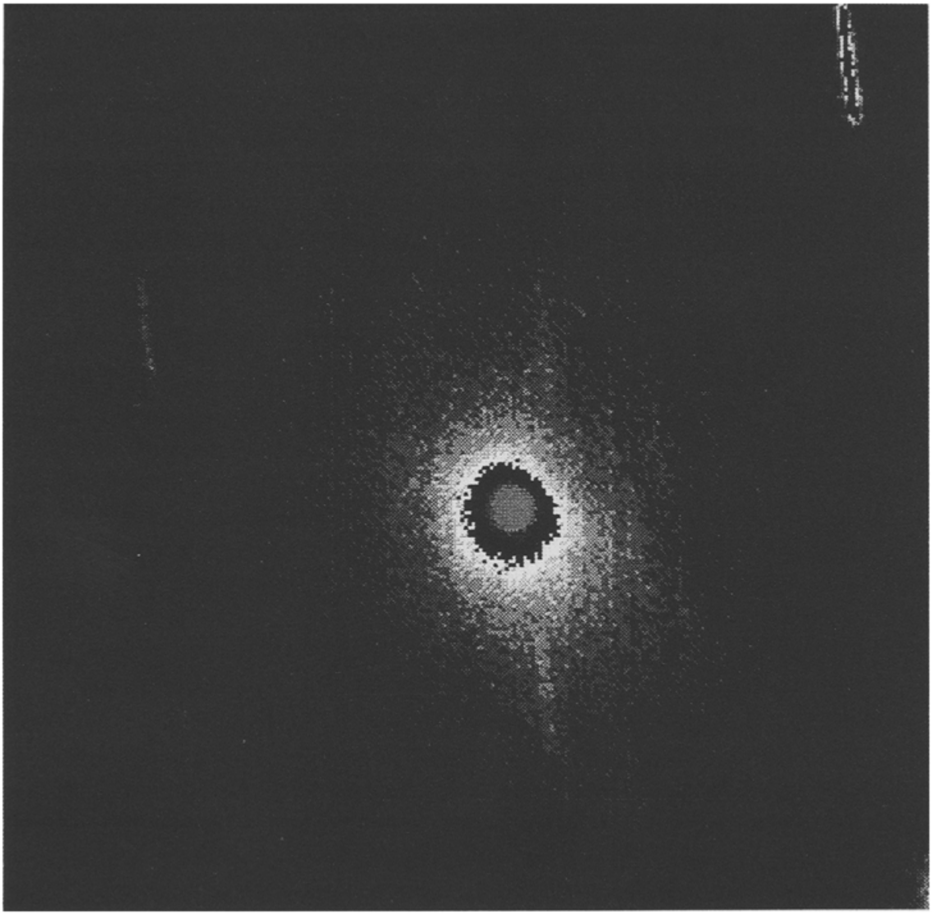

Fig. 2(a). Comet P/Grigg-Skjellerup on 24 July 1987. 300 s V filter exposure; field of view: 83 000 × 83 000 km. Image orientation as in Figure 1a.

renormalization method confirms the brightness asymmetry in the coma (Figure 1b): in all May 1987 observations a broad cone (100° opening angle) of enhanced activity (with respect to the mean radial brightness) can be found on the sunward coma side and a reduced brightness level on the tailward side. The tail pointed almost exactly into the direction of the projected extended radius vector and had an opening angle of below 5°. The brightness excess and deficiency in the coma were symmetric with respect to the Sun-tail axis and showed no changes from 21 to 24 May 1987.

On 24 July 1987 the brightness enhancement in the coma was less pronounced and located in the North-East quadrant of the coma (Figure 2a). The coma radius was at least about 40 000 km. The radial renormalization of the images reveals a diffuse activity increase (opening angle of about 50°) in the northern direction of the coma – almost perpendicular to the projected Sun-comet line on the sky –

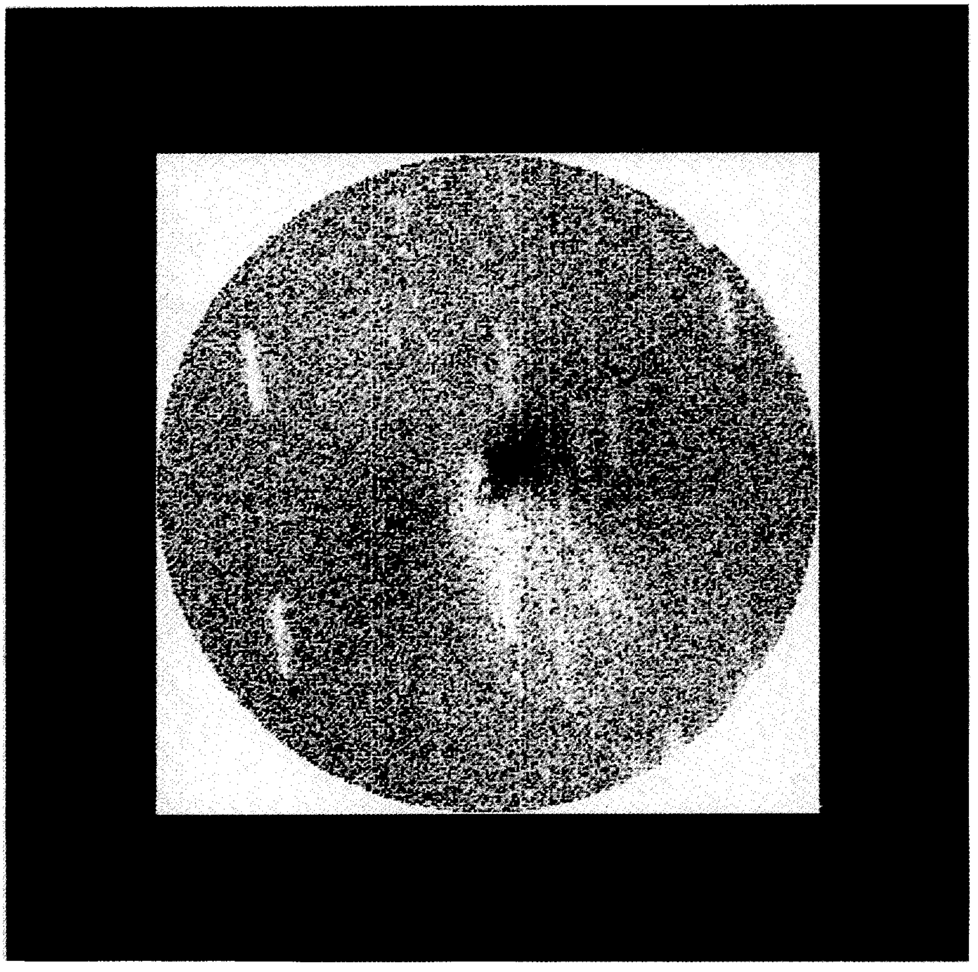

Fig. 2(b). Computer-processed image of Figure 2a (radial renormalization). Image orientation as in Figure 1a; field of view: 91 000 km diameter at comet. Location of the centre of light as in Figure 1b.

and a reduced brightness on the opposite side (Figure 2b). However, no clear evidence for the presence of other coma structures like jets, fans or a plasma tail can be seen in the processed images. Compared with the May 1987 frames, the brightness asymmetries were turned away from the Sun direction by about 90°. From the available images no clear decision can be drawn on the physical reasons for the changes in the orientation and opening angle of the coma emission cone. It can be speculated that the illumination geometry of the active regions on the nucleus was different in May and July 1987 since the comet passed about 73° in true anomaly during this time interval. In part also the altered viewing angle of the comet from Earth may have contributed to the changes in the overall coma appearance.

5. The Nucleus Observations

Contrary to the 1987 images no coma can be seen by visual inspection of the P/Grigg-Skjellerup observations obtained in August and October 1986, August and October 1988, September and December 1991. During these observations the solar distance of the comet was larger than 2.7 AU (in 1986 and 1991 inbound, in 1988 outbound). The activity status, if any, must have been very low. Only for the December 1991 observations (Figure 3) the signal-to-noise-ratio of the comet image was high enough to analyze the presence of a coma in or around the seeing disc of the comet. Different methods were applied: deconvolution of the cometary image by a stellar image, radial renormalization, subtraction and division of the normalized comet image (maximum in seeing disc = 1, sky level = 0) by an equally normalized star image, two-dimensional Gaussian fits to the cometary image and comparison with a fit to a stellar image, comparison of one-dimensional Gaussian fits to linear traces in four directions through the centre of the seeing disc of the comet and through a stellar source. All methods provided negative results for the presence of a cometary coma on 3 December 1991. Therefore, we conclude that the activity of comet P/Grigg-Skjellerup had not yet onset by that time or might have been below the detection limit of the imaging observations even for CCD equipped larger telescopes. In any case, it can be assumed that on 3 December 1991 the cometary brightness was dominated by sunlight reflected on the nucleus surface. The estimated brightness (20 to 21 mag) is within the range predicted by Green (1991) for the nucleus in December 1991.

6. Conclusions

In CCD images, originally collected in the context of the astrometry campaign on the comet P/Grigg-Skjellerup for the GIOTTO Extended Mission, the status of the coma development of the comet was analyzed. Close to the 1987 perihelion passage a diffuse brightness asymmetry (enhancement towards the Sun) and a weak narrow tail (in late May 1987) was found in the coma. The orientation and the opening angle of the cone of enhanced material emission in the coma changed from late May to late July 1987. However, no further coma structures were detected, which can be used for an assessment of the rotation motion of the nucleus. In our 1986, 1988 and 1991 images most likely the bare nucleus only can be seen.

The coma images presented in this paper might be useful for the planning of forthcoming observation campaigns on the GIOTTO target comet or even for the fly-by targeting of the spacecraft itself. It is evident that more observations (either CCD images, Schmidt plates or spectra of previous and forthcoming apparitions) are needed in order to evaluate detailed results on the appearance and changes of coma features and on the activity onset of the comet. Since the camera onboard the GIOTTO space probe is no longer functioning, coma images obtained from

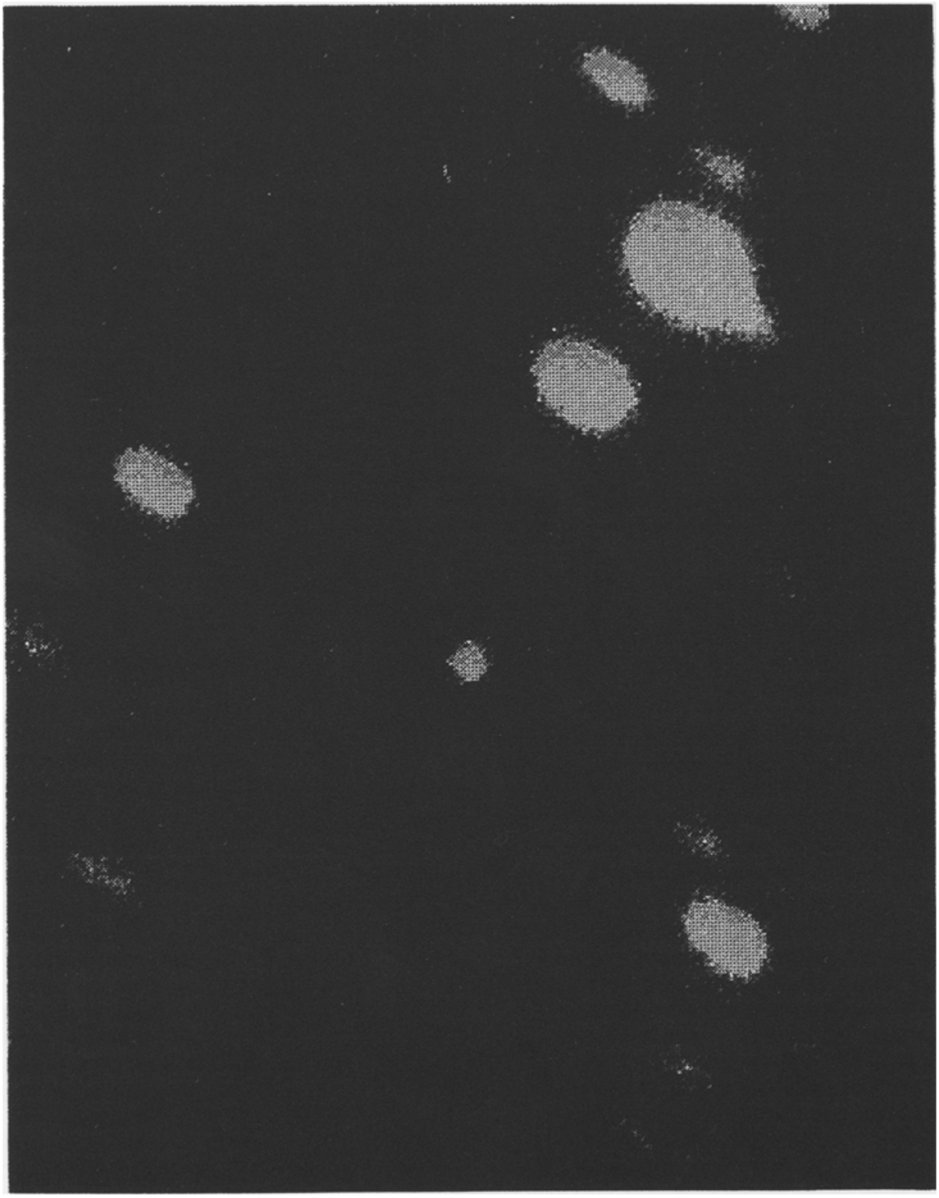

Fig. 3. Comet P/Grigg-Skjellerup on 3 December 1991. Image orientation as in Figure 1a. The comet is the point-like source in the centre of the image; field of view: 50 × 40 arcsec.

Earth within 30 days before perihelion might support the analysis and interpretation of the GIOTTO measurements at comet P/Grigg-Skjellerup on 10 July 1992.

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