~100-89
140955
P-4

CCD-photometry of comets at large heliocentric distances

B.E.A. Mueller, Kitt Peak National Observatory, 950 N. Cherry Avenue, Tucson, AZ 85719

N93-19213

INTRODUCTION

CCD imaging and time series photometry are used to determine the state of activity, nuclear properties and eventually the rotational motion of cometary nuclei. Two extreme examples of quite different behavior of activity are P/Halley and P/Tempel 2. On one hand P/Halley had a rather surprising outburst at 14.3 AU (Hainaut et al. 1991, Meech 1991), on the other hand P/Tempel 2 had an activity onset during its last apparition at only 1.9 AU (Boehnhardt et al. 1990). Cometary activity at large heliocentric distances and mantle evolution are not yet fully understood. What is the difference between the nuclei of different comets? How does this influence the activity? It is thus very important to understand the temporal evolution of comets and therefor the differences between new and old comets and a possible relation to asteroids.

OBSERVATIONS

The observations were carried out at the 2.1 m telescope on Kitt Peak April 10–12 and May 15–16, 1991. The TI2 chip (binned 2 × 2) with a resolution of 0".38/pixel and the Tek2 with 0".34/pixel were used as detectors, respectively. The standard Kitt Peak Harris filter set for V, R and I (Cousins system) was used. The observational circumstances for the objects are given in table 1.

Table 1: Observations of Comets and Asteroids in 1991

Object	$^1\Delta$ [AU]		^{2}r [AU]		$^3\alpha$ [degree]	
	April	May	April	May	April	May
P/Churyumov-Gerasimenko	3.91	4.01	4.87	4.97	4.1-3.6	15.5-15.6
P/Giacobini-Zinner	2.92	2.60	3.75	3.53	9.9-9.5	6.4-6.6
P/Tempel 2	–	5.07	–	4.74	–	9.3-9.2
(2060) Chiron	10.38	–	10.44	–	5.5	–
(951) Gaspra	1.74	1.48	2.53	2.49	17.2	3.2-4.0
1991 JR	–	0.06	–	1.07	–	17.7

1 geocentric distance, 2 heliocentric distance, 3 phase angle

PHOTOMETRIC RESULTS

Landolt stars (Landolt 1983) and the Clusters NGC 4147 and M 92 (Davis, private communication 1991) were used as magnitude standards. (2060) Chiron in April and P/Giacobini-Zinner in May both showed clearly a coma. Digital apertures of 10 pixels ($\doteq$ 3".8) and of 6 pixels ($\doteq$ 2".0) were used for their photometry, respectively, minimizing (but not nullifying) the coma contribution. Magnitude variations of the objects are mostly smaller than the errors except for P/Giacobini-Zinner in May which is definitely variable. Because variability can neither be confirmed nor excluded, mean values and the maximal differences for the R-filter are given in tables 2 and 3.

In table 4 mean colors of the objects are given. Single measurements for P/Giacobini-Zinner in May are V-R = 0.57±0.12, 0.47±0.12, 0.52±0.11, R-I = 0.58±0.14, 0.60±0.12, 0.33±0.14, V-I = 1.15±0.15, 1.06 ± 0.12, 0.84 ± 0.13. Their variability can be attributed to different coma contribution.

The colors corrected for solar values (Scheffler & Elsässer 1974) are plotted in a (V-I)/(R-I) diagram (figure 1). The near earth approacher 1991 JR is the bluest object followed by (951) Gaspra, an S-type (Tholen 1989). 1991 JR was classified as a C-type asteroid by E. Howell (1991, private communication), the first one ever photometrically measured in this size range ($\approx$ 170 m, cf. Rabinowitz 1991). The colors of P/Giacobini-Zinner differ considerably in April and May, but this is most probably due to the coma present in May. P/Giacobini-Zinner in April is the reddest "nucleus" in this sample. An existing coma affects the measured colors because of the emitting gas and dust and molecule emission lines. Hartmann &

Table 2: Mean R-magnitudes of Comets and Asteroids in April 1991

Object	10		11		12	
	R	ΔR_{max}	R	ΔR_{max}	R	ΔR_{max}
[1]P/CG	21.55 ± 0.12	0.29	21.99 ± 0.15	0.55	21.38 ± 0.12	0.10
P/Giacobini-Zinner	21.30 ± 0.09	0.33	21.13 ± 0.09	0.28	20.90 ± 0.17	0.41
(2060) Chiron	16.16 ± 0.01	0.00				
(951) Gaspra	15.22 ± 0.01	0.03	15.21 ± 0.01	0.02	15.05 ± 0.02	0.02

1 P/Churyumov-Gerasimenko

Table 3: Mean R-magnitudes of Comets and Asteroids in May 1991

Object	15		16	
	R	ΔR_{max}	R	ΔR_{max}
P/Churyumov-Gerasimenko	22.04 ± 0.09	0.29	21.79 ± 0.08	0.19
P/Giacobini-Zinner	20.57 ± 0.12	0.43	20.39 ± 0.05	0.14
P/Tempel 2	20.98 ± 0.13	–	21.02 ± 0.09	0.10
(951) Gaspra	14.40 ± 0.03	0.07	14.40 ± 0.02	–
1991 JR			17.42 ± 0.03	0.01

Table 4: Colors of Comets and Asteroids in 1991

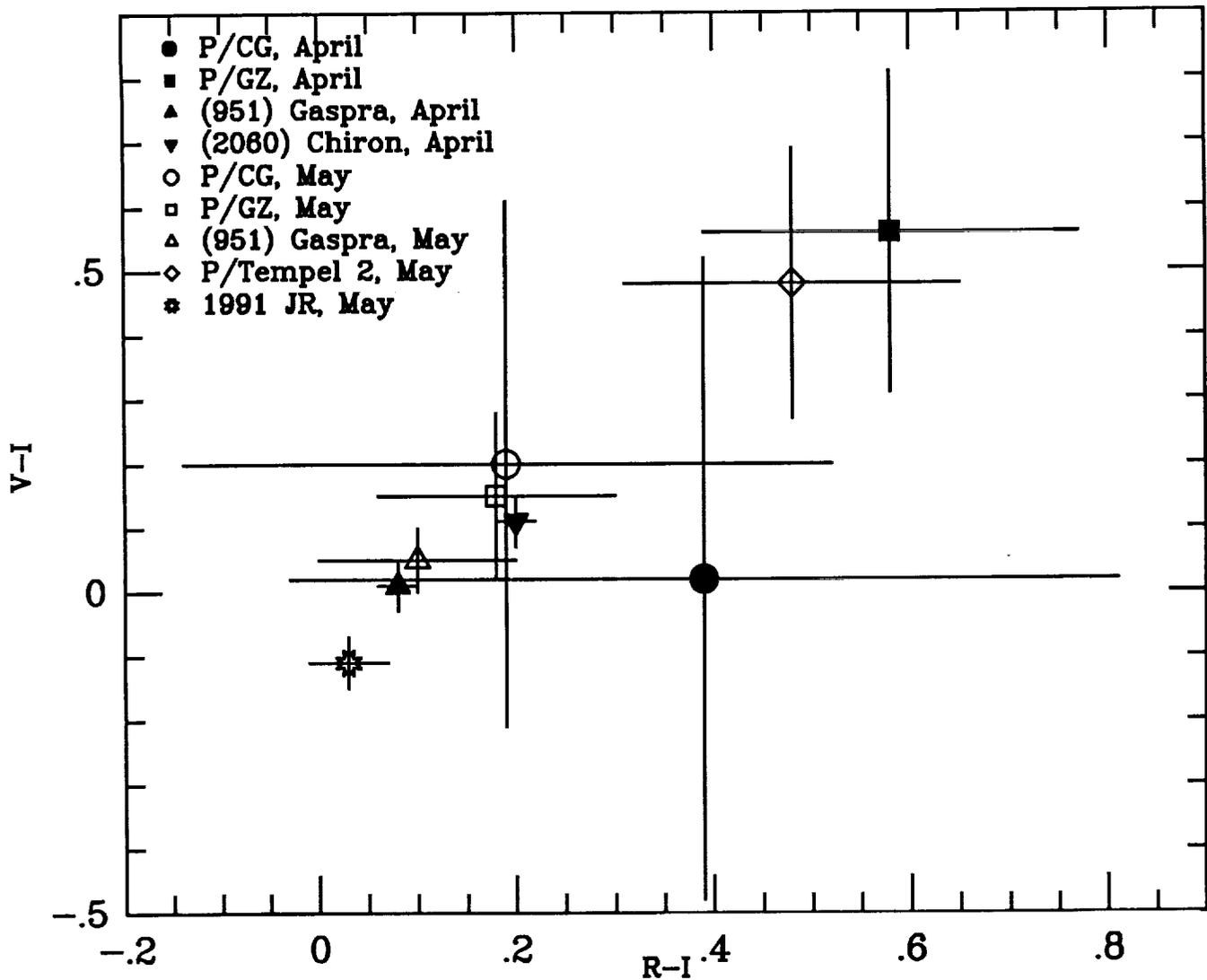| Object	April 10			May 16		
	V-R	R-I	V-I	V-R	R-I	V-I
[1]P/CG	0.16 ± 0.32	0.72 ± 0.42	0.88 ± 0.50	0.54 ± 0.26	0.52 ± 0.33	1.06 ± 0.41
[2]P/GZ	0.51 ± 0.20	0.91 ± 0.19	1.42 ± 0.25	0.52 ± 0.09	0.51 ± 0.12	1.01 ± 0.13
P/Tempel 2				0.53 ± 0.17	0.81 ± 0.17	1.34 ± 0.21
(2060) Chiron	0.44 ± 0.04	0.53 ± 0.02	0.97 ± 0.04			
(951) Gaspra	0.46 ± 0.04	0.41 ± 0.02	0.87 ± 0.04	0.48 ± 0.04	0.43 ± 0.10	0.91 ± 0.05
1991 JR				0.39 ± 0.04	0.36 ± 0.04	0.75 ± 0.04

1 P/Churyumov-Gerasimenko, 2 P/Giacobini-Zinner

Figure 1: (V-I)/(R-I) color-color diagram. The colors are corrected for the Sun.

Cruikshank (1984) found a color-distance trend in comets in the infrared, but this was disputed by Jewitt & Meech (1988). But these measurements were all taken of comets exhibiting a coma. It is not clear if a color-distance relation for nuclei exists and how it is connected to composition, shape, rotation and phase. The data are much too sparse to infer a color dependence of the orbit location of a comet of physical differences among different comets. Further observations of the same and new objects are planned in order to test a color-distance relation and to determine nuclear properties.

NUCLEAR RADII AND SHAPES

The size of the nucleus (R) can be estimated by the formula (Spinrad et al. 1979)

$$R^2 A = r^2 \, 10^{0.4(M_\odot - m(\alpha) + 5 \log \Delta)}$$

with $m(\alpha) = m_{obs} - c\alpha$ and $c \approx 0.03^m/$ deg (Jewitt & Luu 1989), α being the phase angle, r the heliocentric distance in km, Δ the geocentric distance in AU, $M_\odot$ the absolute solar magnitude and m_{obs} the observed magnitude in the respective filter, and A the albedo. For (951) Gaspra the formulae by Bowell et al. (1989) were used to derive a radius. The axes ratio of a nucleus can be simply calculated by (provided the amplitude of the magnitude difference is due to rotation)

$$I_{min}/I_{max} = 10^{-0.4(m_{min} - m_{max})} = b/a$$

with a, b the semi-major and semi-minor axis, respectively, I the intensity and m the magnitude in the respective filter. Because my data are incomplete and I certainly don't have complete light-curve coverage the values I get are lower limits. The derived radii and minimal axes ratios are given in table 5 along with the albedos which have been taken from the literature. The radii of P/Giacobini-Zinner, P/Tempel 2 and (951) Gaspra compare well with values from other authors. There are no published values for P/Churyumov-Gerasimenko but the size derived is similar to other comets. The minimal axes ratio for P/Giacobini-Zinner of 1:1.5 does neither confirm nor exclude Sekanina's (1985) value of 1:8.3.

Table 5: Size and Shape of Comets and Asteroids

Object	Albedo	R [km]	$(a/b)_{min}$
P/Churyumov-Gerasimenko	0.03	3.2	1.7
P/Giacobini-Zinner	0.05	1.9	1.5
P/Tempel 2	0.024	5.9	1.7
(951) Gaspra	0.186	8.0	–

REFERENCES

Boehnhardt H., Beisser K., Vanysek V., Mueller B. E. A., Weiss M., Jäger M., Reinsch K., and Grün E. (1990) Direct imaging and spectrophotometry of comet P/Tempel 2. Icarus, 86, 58–68.

Bowell E., Hapke B., Domingue D., Lumme K., Peltoniemi J., and Harris A. W. (1989) Application of photometric models to asteroids. In Asteroids II (R. P. Binzel, T. Gehrels, and M. S. Matthews, eds.), pp. 524-556. The University of Arizona Press, Tucson.

Hainaut O., Smette A., and West R. M. (1991) Periodic comet Halley. IAU Circ., 5189.

Hartmann W. K. and Cruikshank D. P. (1984) Comet color changes with solar distance. Icarus, 57, 52–62.

Jewitt D. C. and Luu J. X. (1989) A CCD portrait of comet P/Tempel 2. Astron. J., 97, 1766–1790.

Jewitt D. C. and Meech K. J. (1988) The absence of a color-distance trend in comets. Astron. J., 96, 1723–1730.

Landolt A. U. (1983) UBVRI photometric standard stars around the celestial equator. Astron. J., 88, 439–460.

Meech K. J. (1991) Periodic comet Halley. IAU Circ., 5196.

Rabinowitz D. L. (1991) The flux of small asteroids near the earth. In Asteroids, Comets, Meteors III (A. Harris and E. Bowell, eds.), submitted. Lunar and Planetary Institute, Houston.

Scheffler H. and Elsässer H., eds. (1974) Physik der Sterne und der Sonne. Bibliographisches Institut, Mannheim. 78 pp.

Sekanina Z. (1985) Precession model for the nucleus of periodic comet Giacobini-Zinner. Astron. J., 90, 827–845.

Spinrad H., Stauffer J., and Newburn R. L., Jr. (1979) Optical spectrophotometry of comet Tempel 2 far from the sun. Publ. Astron. Soc. Pacific, 91, 707–711.

Tholen D. J. (1989) Asteroid taxonomic classifications. In Asteroids II (R. P. Binzel, T. Gehrels, and M. S. Matthews, eds.), pp. 1139-1150. The University of Arizona Press, Tucson.