2,500 interested persons through the building, compared to about 500 the years before. Whatever the reason, an unprecedented number of persons had decided to take the opportunity to visit our organization and learn about our work. Each of them was welcomed at the entrance and received an ESO brochure. The models of the Very Large Telescope and the New Technology Telescope were much admired and the auditorium was filled to the very limit when the ESO film was shown every 30 minutes. In the terminal room, the advanced image processing systems caught the eyes of computer-minded persons and the children enjoyed the instantly plotted TV pictures. The names and orbits of minor planets again attracted much interest and the major pictorial exhibition about ESO and the science which is done at La Silla led to extensive discussions. At the exit, there was a hectic sale of ESO pictures and slides and many orders were received during the following days from people who had taken along the Picture and Publications Catalogue.

The overwhelming, but extremely welcome influx may be taken as a sign of the greater visibility of ESO.

New Light on the Binary Planet Pluto-Charon

M. W. PAKULL and K. REINSCH, Institut für Astronomie und Astrophysik, Technische Universität Berlin

Earthbound observers currently witness a rare celestial phenomenon that will only recur in about 120 years. Presently the plane of Charon's inclined orbit around Pluto is sweeping over the inner solar system allowing mutual occultations and transits of the planetary disks to be observable from earth (cf. Fig. 1).

Since the shapes of the resulting light curves reflect the geometry of the system, we may hope to determine the relative sizes and albedos of the two bodies with much better accuracy than previously possible. This technique is of course well known in astronomy as much of our knowledge of stellar radii for instance has been derived from the analysis of the light curves of eclipsing binaries.

Due to the expected errors in the rel-

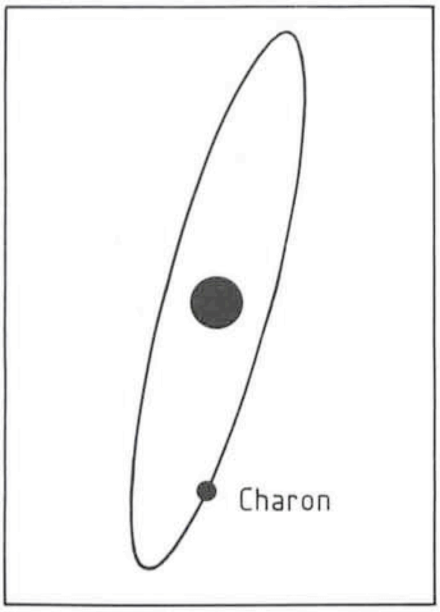

Fig. 1: *The 6^{d}.4 orbit of Charon around Pluto as seen from earth a few years ago. The orbital inclination with respect to the plane of the sky is now near 90 degrees.*

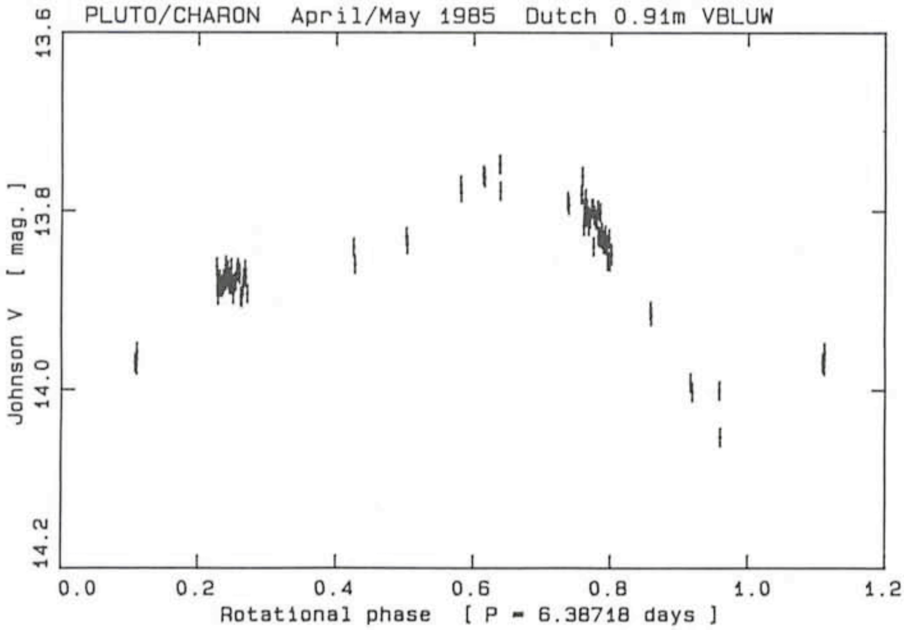

Fig. 2: *The rotational light curve of Pluto observed in 1985 April/May with the Dutch 90 cm telescope. Note the rapid decline in brightness between rotational phases 0.7 and 0.95. Conjunction of Pluto and Charon appear around phases 0.25 and 0.75 where the coverage is densest (cf. Fig. 4).*

evant systemic parameters of Pluto/Charon, the onset of the mutual eclipse series was uncertain until about 2 to 3 years ago.

We started to search for these events in 1982 with the Walraven photometer on the 0.9 m Dutch telescope on La Silla in the course of an observing programme which was mainly aimed at a photometric study of massive X-ray binaries and cataclysmic variables.

In a previous issue of the *Messenger* Baier, Hetterich and Weigelt (1982) reported on their speckle interferometry of Pluto and Charon which subsequently has allowed important refinements of the orbital parameters.

The Rotational Light Curve of Pluto

Although we did not observe any eclipses before April 1986, we have, nevertheless, been able to cover the relatively smooth but asymmetric rotational light curve of Pluto. As shown in Fig. 2, the planet's visual brightness presently varies between 13.8 and 14.0 in its 6.4 d cycle. This period has first been determined by Walker and Hardie (1955). Since then, the "absolute" mean magnitude V (1.0), which is related to the brightness the planet would have if it were placed one astronomical unit from both the sun and the earth, has increased by 0.3 mag. At the same time, the amplitude of the rotational light variations has become significantly larger.

This result has been interpreted by the fact that the rotational axis of Pluto is highly inclined with respect to its orbit around the sun and that some years ago we were looking more onto one of the relatively bright poles, whereas now we see Pluto in an equator-on configuration with dark and bright regions unevenly distributed over the surface of the planet.

To our surprise, Pluto's (synodic) rotational period, quoted in recent publications, has not been substantially refined from the value (6.3867 ± 0.0003) derived more than 20 years ago. Some authors did not even distinguish between the observed (more or less synodic) and sidereal (intrinsic) rotation rate.

For the determination of the sidereal value one needs to know the relative orientation of the rotational axis with respect to the orbital plane around the sun. Since there is now good reason to believe that Pluto's equatorial plane

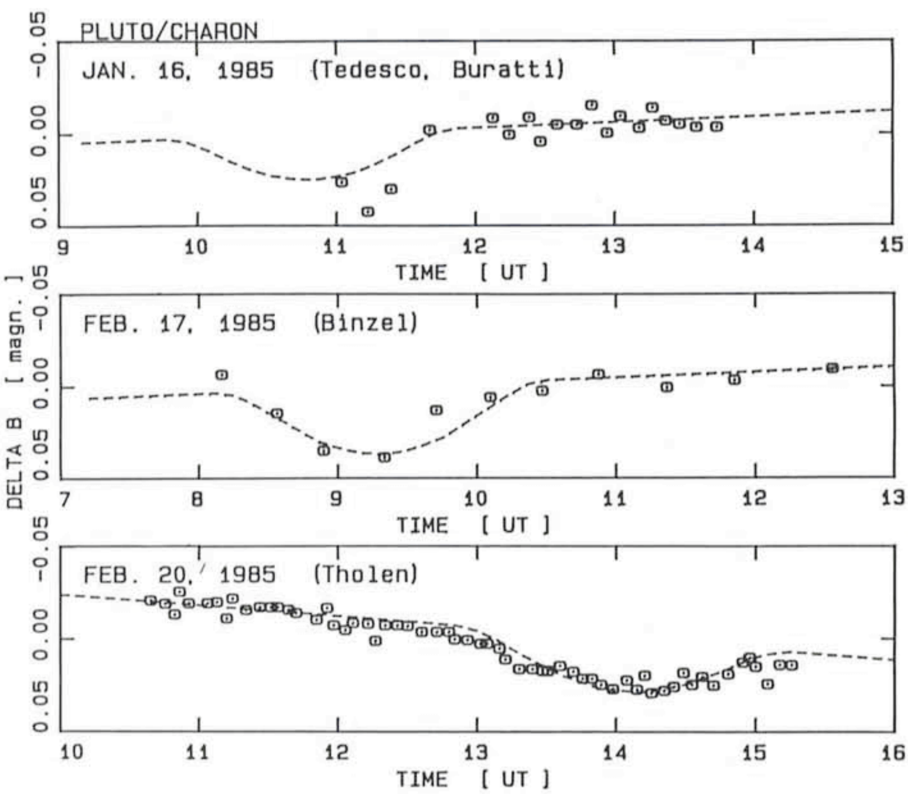

Fig. 3: *The first mutual eclipses of Pluto and Charon reported by Binzel et al. (1985) in early 1985. The dashed line represents our model light curve.*

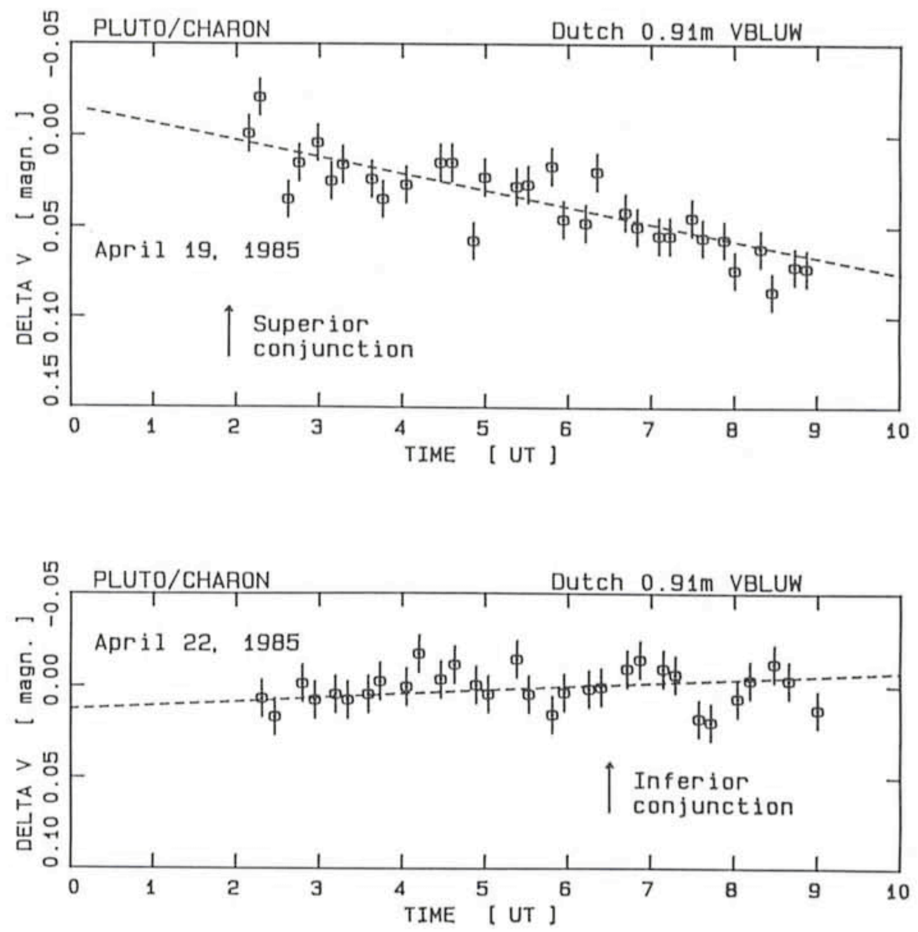

Fig. 4: *The light curve near expected eclipses on 1985 April 19 and April 22. Note that no events appear to be present only 2 months after the last observations by Tholen (cf. Fig. 3).*

coincides with that of Charon's orbit, this exercise can easily be done.

Assuming that the rapid decline in brightness, which was also a prominent feature in the earlier light curves, corresponded to the same rotational phase, we derived a much improved sidereal rotation period of Pluto, namely 6.38718 ± 0.00009 d.

Eclipse Observations

In early 1985 the first shallow eclipse events were observed near preopposition quadrature (Binzel et al., 1985; cf. Fig. 3). We obtained quasi-continuous measurements with the Walraven photometer attached to the Dutch 0.9 m telescope on April 19, 1985, and on April 22, 1985, when Charon was suspected to be at superior/inferior conjunction. No eclipse-like event was seen in either of these observations to a limit of about 0.01 mag (cf. Fig. 4). Due to its yearly motion around the sun, the earth apparently had moved away from the Pluto-Charon orbital plane during Pluto's opposition period. Thus, the eclipse series ceased in 1985 and probably started again by the end of the year.

On April 2, 1986, a transit of Charon in front of Pluto, and on April 18, 1986, an occultation of Charon by Pluto were observed with the ESO/MPI 2.2 m and the Danish 1.5 m telescope, respectively, using CCD direct-imaging techniques which allow high precision intensity measurements even if sky conditions are not strictly photometric. Both observations started with the event near mid-eclipse (the ingresses occurred while Pluto was beyond airmass 2.0) and yielded unexpectedly deep minima (cf. Fig. 5).

The analysis of the light curves was done using models for eclipsing binaries with spherical components assuming no limb darkening.

Seven parameters are of importance: the ratio of the satellite's radius to the planetary radius, the planetary radius (in units of the distance between the centres of Pluto and Charon), the albedo ratio Charon/Pluto, the apparent inclination of the satellite's orbital plane with respect to the plane of the sky, the binary (sidereal) orbital period P and the times of inferior/superior conjunctions.

Due to the difference between the direction to the sun and to the earth as viewed from Pluto/Charon, the light curves may be complicated by shadow transits which occur displaced in time relative to the eclipse events. At the dates of our observations, the shadows of Pluto/Charon projected onto the celestial sphere preceeded the planetary disks. Thus, shadowing affected only the ingresses of the events which were not observed by us.

The observations were corrected for light time effects, the varying orbital longitude of Charon at superior conjunction and the variable apparent inclination of Charon's orbit.

Parameters of the Pluto/Charon System

Combining our observations with the early events reported by Binzel et al. (1985) we made a multi-parameter least-squares fit using the model light curves. It is interesting to note that the allowed range of parameters is also strongly restricted by the non-detection of eclipses in April 1985. The best solution yielded the physical parameters of the system given in Table 1.

The radii of (1100 ± 70) km derived for Pluto and of (580 ± 50) km for Charon are significantly lower than those found by previous observers using speckle interferometric techniques who reported radii of Pluto to be in the range of 1300 . . . 2000 km. On the other hand, our values are consistent with the Pluto upper limit (< 1700 km) obtained from far-infrared observations (Morrison et al., 1982) and the Charon lower limit of 600 km derived from stellar occultation work (Walker, 1980). Note that older textbooks quote values in excess of 2500 km!

From the planetary radii and the total mass of the system (0.0017 earth masses; Tholen, 1985 we find a systemic average density (2.1 ± 0.5) g/cm^3 which is comparable to that of the major satellites of the outer planets.

These results do not confirm suggestions based on earlier density estimates of less than 1 g/cm^3 that Pluto consists mainly of frozen volatiles. The geometric albedos of the occulted areas of Pluto and Charon (0.63 ± 0.10, 0.49 ± 0.10, respectively) are similar to those reported for Triton and the icy satellites in the Jovian and Saturnian systems (Klinger, 1985) and are, furthermore, consistent with the detection of methan ice on Pluto.

Assuming that the derived albedos are typical for the whole surfaces, we find Charon should be covered with slightly darker material than Pluto.

The sidereal orbital period of Charon resulting from our eclipse analysis agrees within the error limits with the sidereal rotational period of Pluto. The deviation from corotation must be less than 0.003 %! The orbit of Charon seems to be perfectly circular with an upper limit to the eccentricity (e cos ω) of 0.002. This confirms that the Pluto-Charon system is completely tidally evolved.

The present series of eclipses is estimated to continue until 1990 with central eclipse events expected for 1987. Further observations of mutual eclipses will improve the determination of the physical parameters of the system and allow to analyse the influence of non-uniform albedo distribution on the form of the eclipse/transit light curves. Combining all available eclipse observations will yield gross albedo maps of one hemisphere of each component.

Since no planetary mission to Pluto is scheduled in the near future, this kind of investigation will remain the only opportunity to improve our knowledge about the outermost known planet in the solar system. Even Space Telescope will hardly provide the resolution to observe surface structures on Pluto or Charon.

Comparison with Recent Results Reported by Other Groups

After submission of our investigation to *Astronomy & Astrophysics* and publication of the ESO press release PR 09/86 we have learned that (not unexpectedly) several groups of American astronomers have also analysed their eclipse observations in a similar fashion.

Dunbar and Tedesco (1986) derived the radii of Pluto and Charon to be 1150 ± 50 and 750 ± 50 km, respectively.

On the other hand, according to the Dec. 1986 issue of *Sky and Telescope*, Tholen and Buie estimated radii of 740 and 420 km which, however, were later revised (Tholen, private communication) to be 1145 ± 46 and 642 ± 34 km.

In particular the latter results are in excellent agreement with our findings.

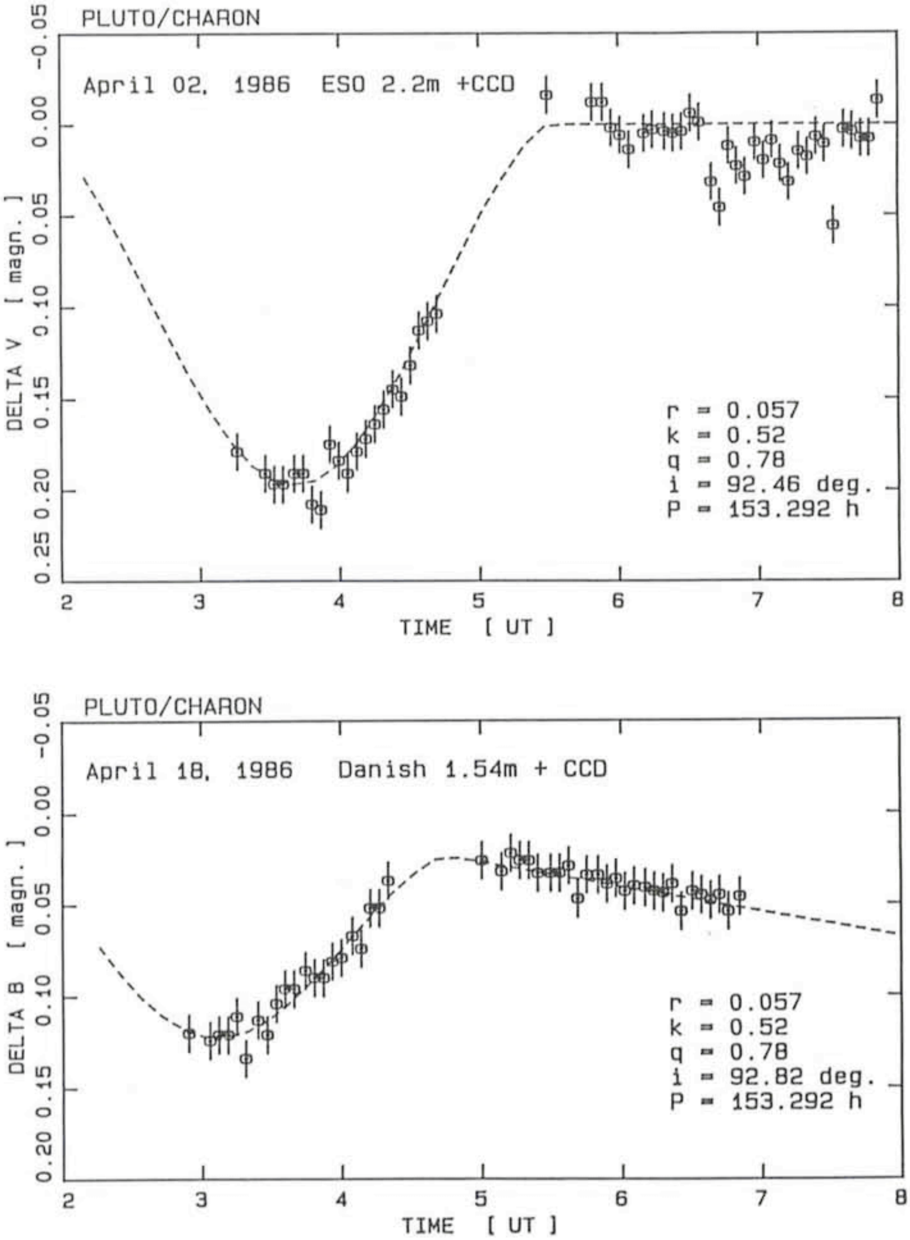

Fig. 5: *Mutual eclipses with depths of 0.20 and 0.13 mag, respectively, are visible in our CCD light curves on 1986 April 2 (transit of Charon in front of Pluto) and April 18 (occultation of Charon by Pluto). As in Fig. 3 and 4 our model is superimposed on the observed light curve.*

	Pluto	Charon
Radius (km)	1100 ± 70	580 ± 50
Orbital radius (km)	19130 ± 460 (Tholen, 1985)	
Average density (g/cm^3)	2.1 ± 0.5	
V (1.0)	– 0.56 ± 0.10	1.10 ± 0.10
Mean geometric albedo	0.63 ± 0.10	0.49 ± 0.10
Bond albedo	0.19. . . 0.25	
Sidereal rotational period (d)	6.38718 ± 0.00009	
Sidereal orbital period (d)	6.38718 ± 0.00013	
Inclination (degrees)	94.3 ± 1.5 (Tholen, 1985)	
Ascending node (degrees)	222.04 ± 0.13	
Orbital longitude (degrees)	79.2 ± 0.3	
Eccentricity (e cos ω)	< 0.002	
Epoch (JED)	2445000.5	

Table 1: *Physical parameters and orbital elements of the Pluto/Charon system adopted from our "best fit".*

References

Baier, G., Hetterich, N. and Weigelt, G.: 1982, *The Messenger* **30,** 23.
Binzel, R. P., Tholen, D. J., Tedesco, E. F., Buratti, B. J. and Nelson, R. M.: 1985, *Science* **228,** 1193.
Dunbar, R. S. and Tedesco, E. F.: 1986, *Astron. J.* **92,** 1201.
Klinger, J.: 1985, in J. Klinger et al. (eds.), Ices in the Solar System, p. 621.
Morrison, D., Cruikshank, D. P. and Brown, R. H.: 1982, *Nature* **300,** 425.
Tholen, D. J.: 1985, *Astron. J.*, **90,** 2353.
Walker, A. R.: 1980, *Mon. Not. R. Astron. Soc.* **192,** 47 P.
Walker, M. F. and Hardie, R.: 1955, *Publ. Astron. Soc. Pc.* **69,** 224.