Celestial mechanics

Arcs around Neptune

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PLANETARY rings now form such a menagerie that it had little need for any new attractions — given the diversity of the ring systems of Jupiter, Saturn and Uranus, with their associated dynamical problems. However, the latest addition to the collection is the planet Neptune. Recent occultation results by Covault *et al.*[1] appear to confirm the presence of incomplete rings or 'arcs' around the planet and a new model by Goldreich *et al.*[2] attempts to provide an explanation for a series of puzzling observations.

Since the fortuitous discovery of the rings of Uranus in 1977 when a star was occulted by ring material, Neptune became an obvious target for studies to detect a ring system. A series of peculiar results began with the claimed detection of a small new satellite by Reitsema *et al.*[3] in 1981. Further occultations failed to detect any ring material (that is, a feature observed before immersion — the disappearance of the star behind the planet — and after emersion — its reappearance) until Hubbard *et al.*[4] observed a single feature from more than one site. As the feature was only observed on one side of the planet they believed that they had detected an 'arc' of material some 13–15 km wide at a radial distance of between 63,000 and 69,000 km.

The occultation on 7 June 1985 (Fig. 1) by Covault *et al.* produced a new twist to the story as the star to be occulted was actually a binary. Although no pre-immersion event was observed there was a single post-emersion event but only one of the binary pair was occulted. Using this information the authors calculated that the feature must be discontinuous over several thousand kilometres. There is no independent confirmation of their result but they estimate a width of 8 km and their accurate orbital radius of the feature also lies within the limits set by Hubbard *et al.* There were no further detections during a subsequent occultation on 25 June 1985. Given the number of negative results to date it now appears that the current observations can be explained by at least one narrow, partial ring composed of one or more arcs covering about 10 per cent of the orbital path. How can such as ring system be maintained?

Theorists had already considered the dynamical problems posed by arcs in connection with the rings of Uranus. It was originally thought that the outermost ε ring was actually two distinct arcs because occultation features on each side of the planet had different orbital radii. Although it is now known that this is due to the strong ellipticity of the ε ring, the original observations led Dermott and Gold[5] to propose a ring theory involving arcs of material trapped in 'co-rotation' resonances with pairs of Uranian satellites. Resonant phenomena, a common feature in the Solar System, can occur when the periods of two or more objects have a simple ratio and mutual perturbations are enhanced. Lissauer[6] proposed that arcs around Neptune could be explained by the resonant actions of two satellites. The first maintains ring particles in orbits at the classical Lagrange equilibrium points L_4 and L_5 (which precede and trail the satellite by 60°). The second satellite, which lies interior or exterior to the first, provides an additional confinement mechanism to counteract the tendency for the ring to spread due to collisions and other effects.

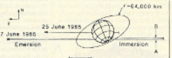

Fig. 1 The apparent paths of stars relative to Neptune for two occultations observed by Covault *et al.*[1] in 1985. Paths A and B refer to the individual stars of the binary pair observed on 7 June. The ellipse shown represents an equatorial radius of 64,000 km, which is a possible location for ring arc occultation events. (Copyright Academic Press.)

Goldreich, Tremaine and Borderies have now produced a model for the arc rings of Neptune which relies on the resonant effects of a single satellite in an inclined orbit. The satellite, which may have already been discovered by Reitsema *et al.* in 1981, produces a resonance mechanism which is much more intricate than in previous ring models. They first claim that the arcs lie at one of the strong co-rotation resonances of the satellite. Their location is determined by comparing the orbital periods of a ring particle and the satellite, and also taking into account the longer nodal precession period of the satellite orbit resulting from the oblateness of Neptune. It turns out there will always be an even number of equilibrium positions at the resonant locations and that the ring particles oscillate about each of these positions, forming arcs of material. Goldreich *et al.* then claim that the associated 'Lindblad' resonances involving the orbital periods of the ring particle, the satellite and the pericentre precession period of the ring particle will re-supply the energy lost from the arc through particle collisions. The end result should resemble a series of warped arcs (Fig. 2).

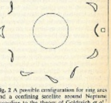

Fig. 2 A possible configuration for ring arcs and a confining satellite around Neptune according to the theory of Goldreich *et al.*[2] Radial variations have been enlarged by a factor of 200. (Copyright American Astronomical Society.)

Given the paucity of hard facts about Neptune's ring system, the model of Goldreich *et al.* seems premature. However, they do make a prediction: the proposed satellite will be found to be in a significantly inclined orbit because otherwise the necessary confining resonances would be too weak. High inclination orbits are the exception rather than the rule for planetary satellites but the most notable exception happens to be Triton, the large satellite of Neptune. The authors speculate that a single event may have produced unusual orbits for all Neptune's satellites.

The study of the dynamics of ring arcs is still in its infancy with many problems still to be tackled. The field will only reach maturity when further observations provide tighter constraints on ring theories. When Voyager 2 reaches Neptune in 1989, the rings of Neptune may be revealed to be even more exotic than we could have imagined. ☐

1. Covault, C.E., Glass, I.S., French, R.G. & Elliot, J.L. *Icarus* 67, 126–133 (1986).
2. Goldreich, P., Tremaine, S. & Borderies, N. *Astr. J.* 92, 490–494 (1986).
3. Reitsema, H.J., Hubbard, W.B., Lebofsky, L.A. & Tholen, D.J. *Science* 218, 289–291 (1982).
4. Hubbard, W.B., Brahic, A., Sicardy, B., Elicer, L.-R., Roques, F. & Vilas, F. *Nature* 319, 636–640 (1986).
5. Dermott, S.F. & Gold, T. *Nature* 267, 590–593 (1977).
6. Lissauer, J.J. *Nature* 318, 544–545 (1985).

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