Pluto's strange orbit

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THE planets in the Solar System are believed to have accumulated in a dusty gaseous disk, where internal dissipative processes caused the disk material to be flattened and relaxed into circular motion around the Sun. As a consequence, most have orbits that are near-circular and nearly coplanar. But Pluto is an oddity, as Bill McKinnon recently pointed out[1]; not least among its peculiarities is its orbit, which is inclined by 17° to the plane of the ecliptic, and is so eccentric that it overlaps that of Neptune (see box).

How could such a bizarre orbit have come about as the planets formed in the plane of their dusty disk? Renu Malhotra[2], on page 819 of this issue, suggests that Pluto was born with the usual circular orbit in the plane of the disk. Then, she says, Neptune's orbit expanded as it scattered unaccreted planetesimals out of the region, and its decreasing orbital angular velocity approached 3/2 that of Pluto (for such a ratio of two small integers, the orbital angular velocities are said to be commensurate). Pluto was captured into the first of the orbital resonances described in the box, and it was subsequently pushed out ahead of Neptune, staying within the resonance while its eccentricity continued to grow as long as Neptune's orbit continued to expand.

The unique feature of this explanation is that it does not rely on a collision between Pluto and another planetesimal to push Pluto directly into the stable librating state. It readily produces the observed eccentricity of orbit and amplitude of libration, provided that Neptune's orbit expanded by about 5 or 6 astronomical units (1 AU is the mean distance from the Earth to the Sun). This migration is typical of that given by numerical models of the scattering of planetesimals by the four major planets during the last phases of planet formation[3].

Orbital resonances abound in the Solar System, mostly among the satellites of the major planets, and capture of two bodies into this sort of resonance as their orbits approach one another through some dissipative process is well understood[4]. For satellites of the major planets, that dissipative process causing differential expansion of the orbits is tidal friction in the primary. Here Neptune's orbit approaches that of Pluto because some fraction of those planetesimals that Neptune scatters inwards are scattered out of the Solar System by Jupiter or Saturn, and the energy and angular momentum that Neptune gains by this process is more than the energy and angular momentum it loses by scattering planetesimals outwards. As Neptune approaches commensurability with Pluto, capture is assured if Pluto's initial orbital eccentricity is less than 0.03, and is still possible for larger eccentricities.

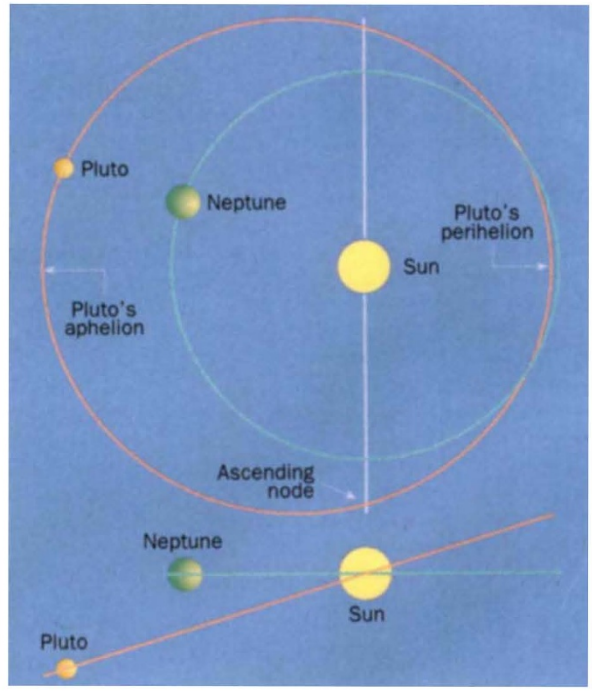
Malhotra's explanation is not complete, as the inclination of 17° is not produced, nor is the resonance that keeps the aphelion 90° away from the ascending node evident. But her numerical integration shows Pluto's inclination increasing, so there is a real possibility that some combination of initial conditions will yield all the properties of Pluto's orbit. Growth in the inclination might be due to another resonance associated with the 3/2 commensurability, but affecting the inclination rather than the eccentricity. Alternatively, it may be due to a 'secular' resonance, where the motion of the longitude of Pluto's ascending node is commensurate with one of the fundamental frequencies of the Solar System. This process of inclination growth within resonances has been used to explain the 4° inclination of the orbit of Uranus's satellite Miranda in an otherwise planar system of satellites[5,6].

What of other explanations? The old theory that Pluto was a satellite of Neptune that escaped in a close encounter with Neptune's large satellite Triton[7] is now thought to be unlikely[8,9]. But Pluto could have been one of a swarm of similar planetesimals, some fraction of which were continuously scattered into and out of the 3/2 orbital resonance with Neptune by their mutual collisions. Pluto was simply left behind in its protective resonances after the others were scattered from the region by close approaches to Neptune.

This idea has gained support from calculations by Holman and Wisdom[10] and by Levison and Stern[11]. They independently find that if test particles are started in circular orbits nearly coplanar with Neptune's orbit with a range of semimajor axes near that corresponding with the 3/2 orbital resonance, the particles rapidly and chaotically evolve to eccentricities and inclinations like Pluto's. Some of these test particles are actually librating within the 3/2 resonance, but with such large amplitudes that they are chaotically unstable. A necessary collision between

Avoiding close encounters

PLUTO is usually the most distant planet from the Sun, but its orbit is so eccentric that it overlaps that of Neptune (in fact, Pluto is currently closer to the Sun). The two have avoided close approaches because Pluto's orbital period is almost exactly 3/2 that of Neptune and the planets are in conjunction when Pluto is near its aphelion, far away from Neptune's nearly circular orbit. The figure shows a typical conjunction between Neptune and Pluto. Rather than the longitude of the conjunction drifting away from Pluto's aphelion, it is pulled back by restoring accelerations from Neptune. This causes stable libration (oscillation) of the conjunctions about Pluto's aphelion and the system is said to be in an orbital resonance.



A second orbital resonance keeps the aphelion roughly 90° away from Pluto's 'ascending node' (the point where Pluto's orbit rises through the plane of Neptune's orbit). So at conjunction, Pluto is close to its maximum distance below Neptune's orbital plane, and further still from Neptune.

Without at least the first of these resonances, Pluto would not now exist. The inevitable close approach to Neptune would either have produced a collision or thrown the smaller, lighter Pluto out of the Solar System. S.J.P.