of satellites in the Kuiper belt or among the asteroids, the Pluto–Charon system is a tightly bound pair whose angular momentum, if concentrated in a single object with the combined mass of the two, would produce an object rotating so fast that it approaches rotational break-up. This is similar to the Earth–Moon system and is an immediate consequence of an origin by impact: the parent object must have been a fleeting association between two planet-sized bodies that lost a substantial fraction of their initial energy during a brief, violent collision. The main result of such an impact is that a portion of the gravitational and kinetic energy of the bodies is converted into heat, robbing them of the ability to go their separate ways. As Canup found in her detailed simulations, this process is most effective when the relative velocity of the two approaching bodies is small, thus minimizing the difference in total energy between a bound pair and two separate bodies.

The major constraints on the collision process are the final angular momentum of the planet–satellite pair and the ratio of their masses. Whereas our Moon's mass is about 1% of Earth's, that of Charon is a huge 10–15% of Pluto's mass. Unfortunately, there are too many unknown factors to determine the precise conditions of the impact: the mass, structure and initial rotation states of both the participants in the collision, their relative velocity and the angle of impact. Canup's procedure is thus probabilistic by necessity. She examined a broad suite of different possible initial conditions and evaluated how many of these produced a final configuration similar to the Pluto–Charon system.

Her simulations use a method called smooth particle hydrodynamics, which incorporates a full three-dimensional geometry. In addition, the gravitational forces between each portion of both distorted planets must be taken into account. In agreement with earlier researchers[4], Canup found that torques exerted by the distorted mass that is the product of the collision are crucial for inserting a large amount of the mass into orbit to produce a moon. What is new about this work is that she discovered two basic scenarios for the creation of a satellite.

In the first scenario, the parent bodies are differentiated, which means they have dense cores overlain by a lighter mantle. Most of their mass merges into a new central body, while gravitational torques spin the remaining material out into a dispersed ring or disk. The satellite later condenses from the disk. This disk is mainly composed of intensely heated mantle material, and the ratio of the disk mass to the planet's mass is relatively small. This may be the process that created our Moon.

Undifferentiated bodies, on the other hand, which do not have a distinct core and mantle, remain more intact after collision. Although they again share angular momentum through gravitational torques, the satellite is essentially complete at birth. The ratio of satellite mass to final planet mass is much higher, and the bulk of the satellite is not strongly heated. This is the likely circumstance of the birth of Pluto and Charon. Each object retains nearly its initial chemical composition. Such a scenario would be a poor candidate for the Earth–Moon system because the Moon differs substantially from the Earth, especially in its content of metallic iron–nickel, and therefore its density. We know little of the composition of Pluto and Charon (current measurements[5] are not able to clearly discriminate between planet and moon), but the prediction that they are very similar in density can be tested by future spacecraft reconnaissance or by improvements in astrometric measurements.

What is the origin of the object that became Charon? Canup's simulations do not answer this question, but they do offer some clues. The need for a low approach velocity suggests that the two parents were in very similar initial orbits. Further, the present Pluto–Charon system is in a rather delicate resonance with Neptune that prevents a collision between Neptune and Pluto–Charon in spite of their crossing orbits: Neptune circles the Sun exactly 1.5 times faster than Pluto. Any scenario describing the giant impact that produced Pluto and Charon must yield a system that ends up in this resonance.

After evaluating a number of different possibilities, Canup concludes that the two parents could already have been trapped in a resonance with Neptune before colliding with each other. Trapping may have occurred during a time when the outer planets' orbits were evolving through interactions with a massive disk that became the Kuiper belt. As Neptune's orbit expanded, its orbital period would also have increased. The orbital periods of the parent bodies gradually synchronized with Neptune, trapping them in the stable 1.5 resonant configuration[6]. They remained in this resonance during and after the collision that produced the Pluto–Charon system.

As with all numerical simulations, future work at higher resolution and with better thermodynamic descriptions of the materials making up the colliding objects is always desirable. However, Canup has added a substantial amount of flesh to the skeleton of the giant-impact idea and made this catastrophic interpretation of the Pluto–Charon system far more plausible. Her elucidation of two distinct modes of satellite formation in large impacts has added reason and clarity to our ever-improving understanding of these processes. ■

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Animal behaviour

Meals sized up


CSIRO

Termites are fussy eaters. A particular piece of wood may be avoided because it is too hard or contains defensive chemicals that the termites can't detoxify. Different termite species also vary in their food requirements, and such selectivity may help to reduce competition, allowing different species to coexist in the same habitat. Even wood size matters — one species may specialize on entire timber-framed buildings, whereas another may have an appetite only for twigs.

Theodore A. Evans and colleagues have tackled the problem of how termites assess wood size (*Proc. Natl Acad. Sci. USA* **102,** 3732–3737; 2005). Worker drywood termites (*Cryptotermes domesticus*, pictured) are blind and so cannot judge wood size visually and do not survey the wood physically before starting to eat. The researchers considered another possibility. Termites often communicate with vibrational signals — soldiers, for example, may drum their heads against the wood to warn of impending danger — and they are also noisy eaters.

Evans *et al.* wondered whether termites use vibrations generated during foraging to judge the resonance frequency of the wood, which is related to its size. To test this possibility, they presented hungry worker termites with blocks of wood of different sizes. The workers preferred blocks of a particular size, but this preference could be specifically altered by playing them recordings of termites feeding, or by producing artificially generated vibrations. Remarkably, the vibrational signals also affected reproductive development in the species, suggesting that such signals might play a wider role in termite biology than has been appreciated. **Rory Howlett**