the chimpanzee lineage has no fossil record whatsoever. One explanation has been that chimpanzees have always lived in forested environments, and that forest creatures are rarely preserved as fossils. Hominids only become (relatively) abundant as fossils after they moved from forests to more open habitats. However, this argument is turned on its head by strong evidence that *Orrorin*[3] and *Ardipithecus*[7] lived in woodland. The fossils of animals such as monkeys and small antelopes found alongside the hominids, as well as palaeobotanical and isotopic evidence, suggest that *Ardipithecus* lived in a relatively well-forested and high-altitude environment. Indeed, this creature may have been confined to such a habitat: as WoldeGabriel and colleagues[7] show, searches for early hominids in geological settings indicative of the open-country habitats associated with later hominids were less rather than more likely to produce results. So it may be that hominids were woodland creatures until about 4.4 million years ago[8,13].

Given that chimpanzees today live in environments rather like those inhabited by *Ardipithecus* and *Orrorin*, could it be that at least one of these early hominids is actually more akin to chimpanzees? Questions have been raised about the status of *Orrorin* as a hominid[5,6]. For their part, Senut and colleagues[2] defend the hominid status of *Orrorin* and propose that *Ardipithecus* is an ancestor of chimpanzees. But they do not discuss the implications of this view for the history of chimpanzees, as distinct from that of hominids.

Sadly, I doubt that the status of these creatures can be resolved to general satisfaction. Some researchers have suggested[14] that the dental and skeletal traits conventionally used as the basis for hominid systematics are unreliable guides for reconstructing evolutionary history, in that the phylogenies created using these traits differ from those based on molecular information from living primates. Given that bones and teeth are, for practical purposes, all there is to go on, uncertainty is likely to reign for some time, leaving the nature of the latest common ancestor — and the general course of early hominid evolution — as mysterious as ever.

Is the outlook completely gloomy? Perhaps not. The accumulating data on palaeoenvironments should at least improve our understanding of the lives and times of early hominids (and perhaps of early chimps), even though the evolutionary relationships remain murky. ■

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Planetary science

Saturn saturated with satellites

Douglas P. Hamilton

Advances in detector technology have led to a rash of newly discovered moons around the giant planets. Saturn currently has the most known satellites — but for how long?

Parents of small children are expected to know the answers to questions like "Which planets in the Solar System have the most moons?" But a surge of discoveries of distant planetary companions in the past five years has left beleaguered parents everywhere hard pressed to answer this query correctly. Today, the planets with the most known natural satellites are Saturn with 30 moons, Jupiter with 28, Uranus with 21 and Neptune with 8. But this list had a different order last year, and was different again the year before that. Not since the Voyager fly-bys of the 1980s have so many moons been discovered so quickly. On page 163 of this issue[1], an international team of astronomers led by Brett Gladman announces the discovery of a dozen new kilometre-sized satellites — the culmination of their highly successful observations of Saturn.

The new discoveries have come not from telescopes in space, nor from the largest telescopes on Earth, but rather from medium-sized ground-based instruments (3–5 m diameter), which can efficiently scan large regions of the sky. Ground-based surveys are sensitive to small moons far from planets, but fail to spot nearby satellites owing to light scattered from the planet. They complement spacecraft measurements, which can easily find small moonlets close to their parent planet, but cannot efficiently search for distant satellites.

Rapid improvements in detector technology have made systematic ground-based searches much more tractable than even a decade ago. Today, digital CCD (charge-coupled device) arrays with $10{,}000 \times 10{,}000$ pixels can cover a quarter-square-degree patch of sky (roughly equivalent to the area of the full Moon) in a single exposure. Equally important are improvements in computers, which allow data to be analysed in real time, and the development of sophisticated algorithms that can automatically detect faint, slowly moving objects.

Despite these improvements, finding small satellites is still a daunting task. The region of space that needs to be covered in a thorough search is a planet's 'Hill sphere' — the area within which satellites can orbit stably. The projected area covered by the Hill sphere is determined by the planet's mass: for Jupiter, Saturn, Uranus and Neptune, these areas are 48, 22, 6 and 7 square degrees, respectively. Even with a quarter-square-degree field of view there is a lot of space to be covered and, partly for this reason, Gladman and colleagues focused first on more distant Uranus and Neptune[2,3] before proceeding to Saturn[1]. To cover Saturn's entire Hill sphere, Gladman *et al.* planned a careful systematic campaign involving multiple telescopes and coordinated follow-up observations.

Remarkably, this new survey covered Saturn's entire Hill sphere down to a brightness limit of 23rd magnitude[1]. This means that, with reasonable assumptions for the reflectivities of the new moons, Gladman *et al.* have found all of the objects with radii larger than about 4 km that are circling Saturn (Fig. 1). They estimate that their previous studies of Uranus and Neptune are nearly complete, covering about 90% of the Hill sphere down to a similar brightness[3]. Although a complete survey of Jupiter's environs has not yet been undertaken, an impressive step in this direction was made earlier this year by Sheppard *et al.*[4], who added ten new moons to the one detected last year[5].

Because they shine by reflecting sunlight, satellites of equal brightness (23rd magnitude) around Jupiter, Saturn, Uranus and Neptune have very different radii: approximately 1, 4, 16 and 36 km, respectively. This makes it difficult to compare different satellite populations because the observations discriminate against the more distant planets. For example, all the new saturnian satellites are probably too small to have been detected if they had orbited Uranus or Neptune instead. Similarly, a group of three very faint objects that Gladman *et al.*[1] spotted moving near Saturn but then lost — when angling for moons, unlike when angling for fish, it is the small ones that get away — would have been more easily tracked had they circled Jupiter instead.

Nonetheless, complete surveys of satellite populations around individual planets can reveal important clues to the origin and

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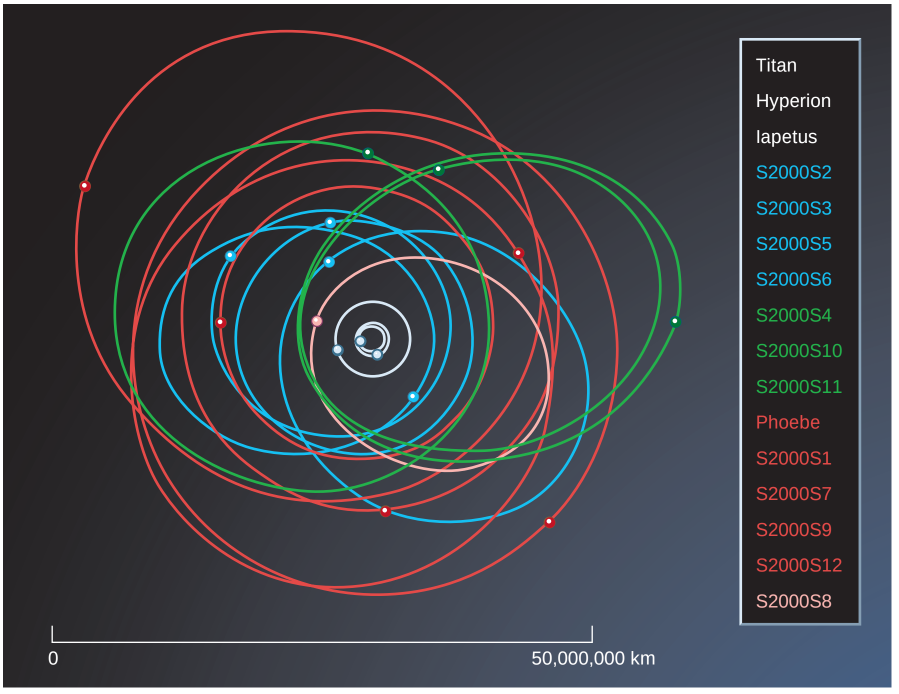

Figure 1 **The current orbits of the outer satellites of Saturn. The radius of the Hill sphere is about 65 million km, which is equal to 1,100 Saturn radii, or 0.43 AU (1 AU is the mean Earth–Sun distance). Saturn is at the centre and the white objects on inner, nearly circular, prograde orbits are the classical satellites: Titan, Hyperion and Iapetus. Prograde objects circle Saturn in the same way as its classical satellites (anticlockwise when viewed from above), whereas retrograde objects orbit in the opposite direction (clockwise). The 12 new satellites discovered by Gladman *et al.*[1] can be grouped into families according to their orbital properties: cyan and green objects are the new prograde groups, whereas pink and red dots (including previously known Phoebe) are all retrograde satellites. Animations of these and all other Solar System satellites can be found at ref. 9.**

early history of the planets. Indeed, Gladman *et al.* observe that Saturn's moons are grouped into distinct families (Fig. 1) with similar orbital properties, just like asteroids and distant satellites of Jupiter. Families are thought to be formed either during cratering collisions that break fragments off parent bodies, or during more violent catastrophic collisions that completely destroy the parent.

Although the current orbits of the satellites (Fig. 1) hint at these relationships, clearer indications come from similarities in their long-term orbital properties (particularly the average tilt of the orbital plane)[1]. The existence of satellite families implies that there are substantial unseen populations of smaller bodies around all the giant planets, because collisions that chip 1-km fragments off 10-km moons occur far more frequently than collisions that produce 10-km fragments from 100-km moons. The three little ones that got away near Saturn are just the tip of the iceberg.

If each satellite family was derived from a single parent moon, where did the parents originate? It has long been believed that satellites were captured from independent orbits around the Sun early in the history of the Solar System. At that time, the Solar nebula, a large disk of gas and dust, still surrounded the Sun, and smaller disks circled each of the gaseous planets. There are several possible capture mechanisms involving interactions with the planet's gaseous nebula[6], collisions with other objects within the planet's Hill sphere[7], and expansion of the Hill sphere as the planet grows in size[8]. Although these mechanisms for capture have been investigated, the details are not well understood and the process of satellite capture remains an outstanding problem in planetary science.

The next observational challenge is a survey of Jupiter's entire Hill sphere down to 23rd magnitude. Such a survey is complicated by the large search area (more than for the other three giant planets combined), the potentially huge number of detectable 1-km-sized moonlets, the more rapid orbital motion of jovian satellites, and the greater likelihood of mistaking them for main-belt asteroids. Nonetheless, a multitude of jovian satellites probably lurk undetected in the vast region of space controlled by this giant planet. It will not be long before massive Jupiter regains the title of the Solar System's most-mooned planet. ■

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Apoptosis

Mostly dead

Douglas R. Green and Helen M. Beere

It has always been thought that once the process of cell suicide has passed a certain point, it is irreversible. Yet it seems that cells can recover — but only if they are not eaten by nearby 'phagocytic' cells.

In all animals, the process of programmed cell suicide (apoptosis) is coordinated by enzymes known as caspases, which cut up key substrates in the cell. The dying cell is then neatly packaged, engulfed by neighbouring 'phagocytic' cells, and cleared from the body without fanfare, leaving no evidence of the catastrophic events that preceded. It has always been assumed that there is a 'point of no return' in this death cascade — at or shortly before the time at which caspases are activated — beyond which the process of cell execution proceeds inexorably. This view is challenged by Reddien *et al.*[1] and Hoeppner *et al.*[2] on pages 198 and 202 of this issue. It seems that cells in which caspases have been activated can in fact progress through a state of being 'mostly dead', a stage that physically resembles the early phase of apoptosis but from which cells can fully recover.

During the development of the nematode worm *Caenorhabditis elegans*, 131 cells are destined to die by apoptosis. These cell deaths depend on the presence of a caspase, CED-3, and on a molecule called CED-4 that binds to and activates CED-3. In healthy cells, CED-4 is maintained in a functionally inactive state by its association with CED-9. The trigger for cell death is the protein EGL-1, which is expressed in response to developmental cues. EGL-1 binds to CED-9,