Planetary science

Kuiper-belt interlopers

A. Morbidelli and H. F. Levison

Objects in the Kuiper belt, which lies beyond Neptune, occur as two distinct populations. One group may have migrated from a region closer to the Sun, caught by Neptune's gravity as it wandered in the early Solar System.

When astronomers first postulated the existence of a belt of small bodies beyond Neptune — now called the Kuiper belt — they imagined a disk of planetesimals (primordial icy bodies) in which the conditions of the early Solar System were perfectly preserved. But when these objects were finally discovered, astronomers realized that this is not so: the Kuiper belt is dynamically excited, as if something had kicked it very hard. The origin of this excitation is a central question in planetary astronomy today, because it could give vital clues to the origin of the planets. Writing in *Icarus*, Rodney Gomes[1] proposes a new mechanism that can explain a lot of what we see. If he is right, much of the structure of the Kuiper belt has been generated by a slow, outward migration of Neptune's orbit during the last phases of its birth.

A detailed analysis[2] of the orbits of objects in the Kuiper belt — and one that accounts for observational biases — shows that the vast majority of the bodies can be divided into two populations of roughly equal numbers: a 'cold' population whose orbits are inclined at only a few degrees to the average orbital plane of the planets (called the invariant plane); and a 'hot' population that has a broad distribution of orbital inclinations, extending up to 40°. The terms hot and cold do not refer to temperature, but rather to the level of dynamical excitation of the bodies (as seen in the inclinations and eccentricities of their orbits). The co-existence of these two populations in the Kuiper belt has puzzled astronomers.

Even more puzzling is the growing evidence that the bodies in the two populations are physically different. In the absence of detailed spectra, astronomers classify objects according to the colour of the light that they reflect from their surface. The colour distributions in the cold and hot populations are statistically different: the hot population has predominantly grey colours, whereas the cold population is almost exclusively made up of red objects[3,4]. In addition, all the largest Kuiper-belt objects seem to belong to the hot population[4], although the evidence for this is statistically weak.

Through simulations of planetary migration and the evolution of planetesimal orbits, Gomes has devised a mechanism[1] that explains the origin of the hot population and also implicitly accounts for the differences in its physical properties with respect to the cold population. The starting point is the migration of Uranus and Neptune. After their formation, these planets are generally believed to have moved further away from the Sun, because of the gravitational effect of the scattering of planetesimals in their vicinity[5,6]. Under the gravitational influence of Neptune, and to a lesser extent of Uranus, most of these planetesimals were transported closer to the Sun before being ejected from the Solar System through encounters with Jupiter or Saturn (Fig. 1). As energy and angular momentum had to be conserved, and as Neptune had sent most of the material inwards, that planet slowly spiralled outwards as a result.

However, some planetesimals were transported outwards by Neptune, on elliptical orbits. These orbits must have regularly crossed that of Neptune, and at each encounter the planetesimals would have been knocked into new orbits, at new mean distances from Neptune and new inclinations to the invariant plane. Occasionally, an object would have entered a resonance with the planet. Resonances are subtle dynamical phenomena that occur when, for example, the orbital period of the body is in a simple integer ratio with that of the planet. In a resonance, the ellipticity of the orbit can be modified without a planetary encounter.

If the ellipticity of a planetesimal's orbit decreases (becoming more circular), the sequence of encounters eventually stops and the planetesimal becomes 'decoupled' from Neptune, like a classical Kuiper-belt object. This process is reversible: eventually, the ellipticity increases again to the extent that the orbits of Neptune and the planetesimal again cross, and gravitational encounters restart. But Gomes has found that Neptune's migration away from the Sun broke this reversibility: as a result, some of the decoupled bodies escaped from their resonances and remained permanently trapped in the Kuiper belt.

Thus, the Kuiper belt is inhabited by two populations: the local population, which probably formed *in situ* and, never having had encounters with Neptune, essentially preserved its small-inclination distribution; and the population of bodies that immigrated from the region around Neptune, with large inclinations acquired during their Neptune-encountering phase. These two populations can be identified respectively with the cold and hot populations that are observed. Indeed, in Gomes' simulations, the inclination distribution of the immigrants matches that observed in the hot population very well. And, having originated in two different regions of the Solar System, the two populations naturally have different physical properties. The immigrant population would also be expected to host larger objects than the cold population: the accretion rate (at which planetesimals stick together to form larger bodies) would have been higher at smaller distances from the Sun.

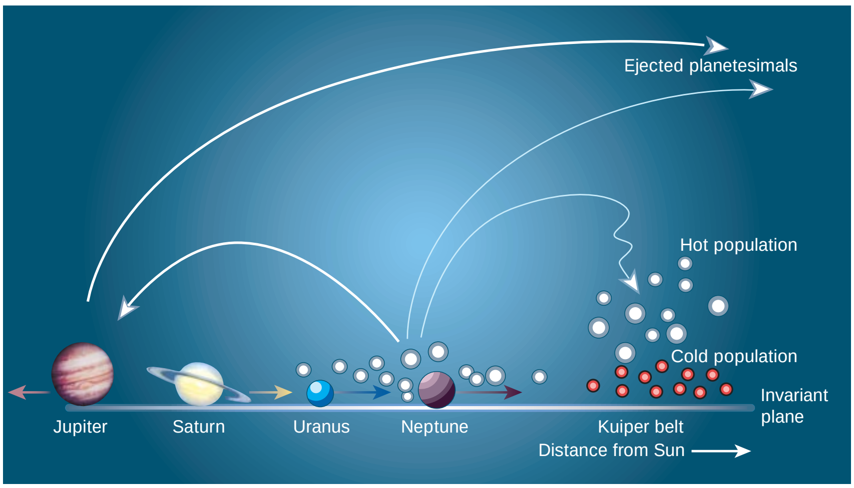

Figure 1 **On the origin of the 'hot' Kuiper-belt population. Gomes[1] proposes that this group of planetesimals, now in orbit beyond Neptune, originated in a region between the current orbits of Uranus and Neptune. Gravitational effects in the developing Solar System threw some of these primordial bodies out of the system completely; others were deflected towards Jupiter and Saturn before they too were ejected. But Neptune's migration away from the Sun (balancing the inward motion of planetesimals towards Jupiter and Saturn) trapped some objects that would otherwise have been lost. This mechanism explains why the properties of the hot population are different from those of the cold population that evolved *in situ* and is confined at small inclinations to the invariant plane.**

Ten years after the discovery of the first true Kuiper-belt object, Gomes' work gives a new perspective on these bodies. If the hot Kuiper belt is really a record of the Uranus–Neptune planetesimal population, a comparison of the detailed physical properties of the hot and cold objects could provide valuable information on the way in which the temperature and chemical properties of bodies varied with increasing distance from the Sun in primordial times. As astronomers slowly unlock these, and other, mysteries, we will learn more about the early life of our planetary system. ■

A. Morbidelli is at the Observatoire de la Côte d'Azur, 06304 Nice, France.
e-mail: morby@obs-nice.fr
H. F. Levison is at the Southwest Research Institute, 1050 Walnut Street, Boulder, Colorado 80302, USA.
e-mail: hal@boulder.swri.edu

1. Gomes, R. S. *Icarus* **161,** 404–418 (2003).
2. Brown, M. *Astron. J.* **121,** 2804–2814 (2001).
3. Trujillo, C. A. & Brown, M. E. *Astrophys. J.* **566,** 125–128 (2002).
4. Levison, H. F. & Stern, S. A. *Astron. J.* **121,** 1730–1735 (2001).
5. Fernandez, J. A. & Ip, W. H. *Planet. Space Sci.* **44,** 431–439 (1996).
6. Hahn, J. M. & Malhotra, R. *Astron. J.* **117,** 3041–3053 (1999).

Plant biology

Mobile plastid genes

Pal Maliga

The direct demonstration that chloroplast DNA can be incorporated into the nuclear genome of plants, even though it is unlikely that such DNA would be functional, will influence thinking in plant biotechnology.

Plastids are organelles found in the cells of higher plants, the best-known form being the chloroplast, the site of photosynthesis. They arose when, way back in time, plant ancestors assimilated photosynthetic prokaryotes — unicellular organisms such as bacteria which, in contrast to eukaryotes such as plants (and ourselves), typically lack a membrane-bound nucleus. The creation of functional plastids involved the migration of huge numbers of genes from the prokaryote genome to the plant nucleus. But is transfer of plastid DNA into the nucleus of higher plants still occurring?

As they describe on page 72 of this issue[1], Timmis and colleagues conclude that it is, at a rate comparable to spontaneous mutation of the nuclear DNA. There are various implications here, not least for plant biotechnology. One proposed strategy for the future is to engineer genes for some trait or other into chloroplasts, rather than nuclei, because — in principle — those genes will affect the characteristics of the individual plant and will be transmitted to future generations by the maternal parent, but not 'escape' in pollen and spread uncontrollably.

The extent of gene migration during evolution becomes clear when we consider that the plastids of higher plants today contain only about 120 genes, compared to the 3,000–4,000 thought to have been present in the genome of the ancient photosynthetic prokaryote. Plastid function depends on some 3,000 nuclear genes, the products of which are transferred to complement those of the remaining plastid genes[2]. We have a relatively good idea about the identity and gene content of the organisms that were involved when the original eukaryotic plant ancestor took in the prokaryotic forerunner of the plastid[3]. But little is known about the evolutionary process of gene transfer from the plastid to the nucleus.

This is what Timmis and colleagues[1] set out to study by designing a smart screen to estimate the rate of plastid-to-nucleus DNA transfer in tobacco plants. Their system involved measuring the transfer rate to the plant nucleus of a gene (*neo*) — which confers resistance to the antibiotic kanamycin — that had been engineered into the tobacco plastid genome (along with a marker gene, *aadA*, of which more later). The kanamycin-resistance gene was endowed with the various signals, including a promoter sequence, required for eukaryote-type expression in the nucleus. Plastids, in general, have a prokaryotic-type gene-expression machinery[4], so the nuclear kanamycin-resistance gene was not expected to be expressed there (Fig. 1a, overleaf).

Timmis's group found that transfer of *neo* to the nucleus took place in a total of 16 heritable events in 250,000 seedlings — that is, at an incidence of around 6×10^{-5} — and was detected by testing for kanamycin resistance in the tobacco plants (Fig. 1b, c). Molecular analyses confirmed that the *neo* genes, together with flanking plastid DNA of variable size, had indeed been incorporated into the tobacco nuclear DNA at different genomic locations.

Another cellular organelle found in eukaryotes is the energy-generating mitochondrion. Previous work[5] with yeast has shown that here, too, there is transfer of organelle DNA to the nucleus, and the rate (about 2×10^{-5} per cell per generation) is comparable to that found by Timmis *et al.* in tobacco. In yeast, the fragments of mitochondrial DNA were incorporated into the chromosomes by a mechanism known as 'double-strand-break repair'[6,7], which is

100 YEARS AGO

All inquirers have perceived that great men are of two types, and it would conduce to clear thinking if we could accustom ourselves to classify them under different names… The first class, to which I should prefer to restrict the name genius, may be described primarily as men of fine, delicate, sensitive, impressionable constitution, and strong, restless innate tendencies which appear early in life, as a rule, and take their own shape. These men work energetically, often at high pressure, and in general die comparatively young… The second class I would describe as men of talent. When preeminent they exhibit striking aptitude in learning and in imitation, and develop extraordinary powers of work… In nature there is great variety, and genius, so far, is one of the varieties which often recur, but scarcely ever survive even for two generations. It is a rare and delicate thing, and the utmost we can hope for it is that endeavours may be made to collect and preserve it like some hot-house plant, in order that it may suggest combinations which men of talent may put to practical account. The position of the second type in the struggle for existence is beyond doubt. The stability of a country and its place among the nations depend upon the number and ability of men of this stamp.
From *Nature* 5 March 1903.

50 YEARS AGO

There has been a progressive increase, both absolute and relative, in the proportion of old people in the population, this increase being the result of the decline in infant and young adult mortality produced by the medical and social advances that have been made possible by the application of the scientific method during the past century. As a result of this, more old people must be supported by a diminished proportion of wage earners. There is a corresponding increase in the numbers of elderly invalids to be cared for, who are suffering from the degenerative disease of old age which medical treatment may ameliorate, but not cure. Meanwhile, the expense of medical treatment, especially hospital treatment, has risen enormously and continues to rise, and it has been suggested that the community is faced with a gloomy prospect of unlimited 'medicated survival' to be met by diminishing resources.
From *Nature* 7 March 1953.