Time for gas planets to grow

Jack J. Lissauer

Giant planets like Jupiter need a large reservoir of gas to grow to full size. New observations indicate that such planetary nurseries last twice as long as previously thought.

Until now, astronomers have believed that giant gas planets, such as Jupiter and Saturn, must form in a few million years or less — quite fast in astronomical terms. On page 60 of this issue, however, Thi *et al.*[1] report evidence to the contrary. They have detected substantial amounts of molecular hydrogen (H_2) gas around three youngish nearby stars in spectroscopic measurements taken by the Infrared Space Observatory spacecraft.

These stars were already known to possess dust disks, so why is it surprising that they are also surrounded by molecular hydrogen, the most common of all the elements, and why should anyone not specializing in stellar environments care? We care because hydrogen is the main ingredient needed to make the giant planets in our own Solar System, and its discovery around other stars means that giant-planet formation may be more common than previously thought. The result is surprising to astronomers because very little carbon monoxide gas orbits these stars. Although it is far less abundant, carbon monoxide is much easier to observe than hydrogen, and has even been detected around a very distant quasar, as described by Papadopoulos *et al.*[2] on page 58 of this issue.

Models of planet formation have been developed primarily to explain the existence of planets and smaller bodies within our Solar System[3]. The major planets have almost circular orbits in roughly the same plane, suggesting that they formed from a disk of material orbiting the Sun. The inner planets, moons and asteroids have a rocky composition, whereas most moons and small bodies beyond the asteroid belt are rich in ice. All of these bodies grew by condensing the material around them. The variation in composition implies that the temperature of the disk material decreased away from the centre of the Solar System.

The four jovian planets (Jupiter, Saturn, Uranus and Neptune) have large masses but low densities, so they must mainly be composed of light materials, such as hydrogen and helium. The most popular models for the formation of giant planets begin with the accumulation of a core of rock and ice roughly ten times the mass of Earth. The core grows into a giant planet by gravitationally accumulating hydrogen and helium gas from the surrounding protoplanetary disk. These models generally require a few million years to form a Jupiter-like planet (Fig. 1; blue curve). Although this is rapid compared to the 20–100 million years believed necessary to form Earth-like planets[3,4], giant planets require a substantial gas reservoir to complete their growth, whereas rocky planets can keep growing in a gas-free environment like that of our Solar System today. So according to current models of planet formation, these giant planets must accumulate gas fairly rapidly.

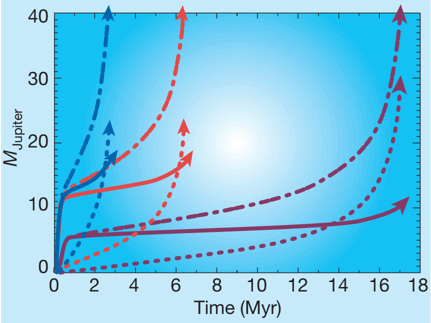

Figure 1 **Three models of the growth of Jupiter, calculated as in ref. 10. The vertical scale gives the mass of a growing Jupiter, in units of Earth's present mass. The curves show the gaseous (dotted) and solid (solid) components of Jupiter, as well as the mass of the entire planet (dot-dashed). Initially, the planet accumulates nearly all of the small planetary masses within its gravitational reach. When the planet is massive enough, it contracts and rapidly accretes all nearby gas. The planet's rate of gas accumulation is governed by its ability to radiate away energy that is released by gravitational contraction. The red curves assume that the dust-to-gas ratio within the planet's atmosphere is the same as the interstellar ratio; the blue curve assumes a clearer atmosphere with 2% of the interstellar value, so the planet can radiate energy and accumulate gas faster. The purple curves also assume a low dust atmosphere, but less rock and ice available for the core, so the planet's gravity is weaker. The new observations of Thi *et al.*[1] can accommodate models with a broader range of atmospheric dust abundance and core sizes, some of which predict long formation times for the giant planets (red and purple curves).**

O. HUBICKYJ

Do giant planets form only in unusually long-lived protoplanetary disks, or can they accumulate around most stars? The measurements of Thi *et al.*[1] suggest that gas remains in many protoplanetary disks long enough to form Jupiter-like planets. Massive dust disks are known to occur around most stars less than 1 million years old, but few stars older than 5 million years possess such disks. Thi *et al.* have now measured the amount of H_2 gas in the smallish dust disks found around three stars between 8 million and 30 million years old. Previous observations of these stars, based on measurements of carbon monoxide gas, suggested that there is surprisingly little gas left around the star, giving a much lower gas-to-dust ratio than found in the interstellar medium (which is mostly hydrogen). But Thi *et al.*'s hydrogen measurements show that these stars have around one Jupiter mass of H_2 in their dust disks, with gas-to-dust ratios similar to that in the interstellar medium. One of the three disks may still have enough gas for the growth of Jupiter-mass planets. The presence of H_2 but not carbon monoxide may be explained by carbon monoxide condensing onto dust grains in icy conditions, or being destroyed by ultraviolet starlight.

More generally, Thi *et al.*'s results suggest that dust is a good indicator of hydrogen in disks around young stars. The discovery of larger amounts of gas in the disks of older systems suggests that jovian planets can form on timescales of up to 10–20 million years within some disks (Fig. 1; purple curve). This means that the formation of giant planets is likely to be fairly common, at least around isolated Sun-like stars. The situation will be different in a star-forming cloud that is producing luminous massive stars, whose bright ultraviolet radiation could destroy nearby protoplanetary disks[5].

What else can be learned from observations of this kind? Since 1995, giant planets have been discovered around 50 other stars. Although the masses of these planets are all Jupiter-like, their orbits are not. Jupiter is more than five times the Earth–Sun distance from our star, whereas most known extrasolar planets are less than two Earth–Sun distances from theirs. Extrasolar planets at Jupiter's distance are difficult to detect, so they may be quite abundant. Nonetheless, the observed orbits are hard to explain because it is unlikely that such large planets formed so close to their star.

Further measurements of hydrogen on dust disks around a wide range of stars (both young and old) may be the key to new insights in this area. For example, the manner in which gas is removed from a protoplanetary disk could have as much influence on the ultimate configuration of the planetary system as does the lifetime of the disk. A planet gravitationally tugs surrounding disk material, and this interaction can alter planetary orbits substantially. Although the possibility of significant planetary migration was predicted more than two decades ago[6], this type of interaction was largely ignored, because theory suggested that a planet would move faster as it approached a star. Planets capable of migrating a significant distance were therefore expected to spiral inwards to a hot death.

The discovery of the first Jupiter-mass planet orbiting at only one-twentieth of the Earth–Sun distance from its star[7] (with an orbital period of 4.2 days) led to the suggestion that planetary migration could be stopped very close to the star. This could happen either because the planet enters a gas-free orbit, cleared by magnetic processes close to the star, or because the planet experiences counterbalancing forces resulting from tidal motion on the star that is induced by the planet[8]. But these models do not account for the many giant planets subsequently discovered with intermediate orbital periods ranging from a few weeks to a few years[9]. Such planets are still too close to their star to have grown *in situ*[10], yet too far away for the proposed stopping mechanisms to operate. Might these giant planets have been migrating inwards only to be stranded as the star cleared away disk material from the inside outwards? The Space Infrared Telescope Facility[11], to be launched by NASA in 2002, will be able to observe disks containing hydrogen at much higher resolution, so hundreds of nurseries will soon be available to test this and other ideas of giant-planet formation. ■

Jack J. Lissauer is at the NASA Ames Research Center, Moffett Field, California 94035, USA.
e-mail: lissauer@ringside.arc.nasa.gov

---

1. Thi, W. F. *et al. Nature* **409,** 60–63 (2001).
2. Papadopoulos, P., Ivison, R., Carilli, C. & Lewis, G. *Nature* **409,** 58–60 (2001).
3. Safronov, V. S. (Nauka, Moscow, 1969) [in Russian]. Transl.: *Evolution of the Protoplanetary Cloud and Formation of the Earth and Planets* (NASA TTF-677, 1972).
4. Wetherill, G. W. *Annu. Rev. Earth Planet Sci.* **18,** 205–256 (1990).
5. Johnstone, D., Hollenbach, D. & Bally, J. *Astrophys. J.* **499,** 758–776 (1998).
6. Goldreich, P. & Tremaine, S. *Astrophys. J.* **241,** 425–441 (1980).
7. Mayor, M. & Queloz, D. *Nature* **378,** 355–359 (1995).
8. Lin, D. N. C., Bodenheimer, P. & Richardson, D. C. *Nature* **380,** 606–607 (1996).
9. http://exoplanets.org/
10. Bodenheimer, P., Hubickyj, O. & Lissauer, J. J. *Icarus* **143,** 2–14 (2000).
11. http://sirtf.jpl.nasa.gov/

Neurobiology

Background inhibition to the fore

Ivan Soltesz and Zoltan Nusser

Investigations of a neurotransmitter receptor required for 'background' neuronal inhibition in mice show the importance of such inhibition in keeping neuronal excitability under control.

Why would you put microphones outside a concert hall to record the music inside? All they would pick up is muffled noise, although the sound would vary according to the music's highs and lows. On the other hand, with sufficiently sensitive microphones you could monitor several concert halls simultaneously, and thus keep an ear on the musical life of the whole town. The festival halls of the nervous system are the tiny junctions, called synapses, between nerve cells. And the molecular microphones — neurotransmitter receptors — are indeed found outside synapses, as well as inside them, on the surface of nerve cells[1,2] (Fig. 1). In fact, there might be more receptors outside synapses than inside[3]. But despite their abundance, the function of these 'extrasynaptic' molecular microphones has been elusive. Writing on page 89 of this issue, Brickley and colleagues[4] make a significant contribution to deciphering their importance.

Brickley *et al.* have studied inhibitory neuronal signalling mediated by the neurotransmitter γ-amino-butyric acid (GABA). Inhibition takes place as a consequence of GABA binding to its receptors — the so-called GABA_A receptors (Fig. 1). The result is a decrease in the probability that a neuron reaches its threshold for firing an action potential, the signal of a nerve cell. In an earlier study[5], the same group described two distinct types of inhibition in a group of neurons — the cerebellar granule cells — that are involved in coordinating movements. 'Phasic' inhibition of these cells is mediated by discrete pulses of high concentrations of GABA released at synapses, where GABA acts on synaptic GABA_A receptors. In contrast, 'tonic' (continuous) inhibition is due to the persistent activation of extrasynaptic GABA_A receptors by the low concentrations of GABA in the extrasynaptic space — rather like the continuous, muffled music from many concert halls picked up by the microphones.

The GABA_A receptors underlying these two forms of inhibition differ in terms of their molecular composition and proper-

100 YEARS AGO

Science is cosmopolitan. Electricity abolishes time and envelops both hemispheres with a new idea as soon as it has emerged from the brain of the Thinker. Mechanics, by its space-annihilating power, has reduced the surface of the planet to such an extent that the human race now possesses the advantage of dwelling, as it were, on a tiny satellite. Both these agencies, then, combine to facilitate a rapid exchange of new ideas and commodities, as well as of those who are interested in them in whatever capacity. These considerations indicate some of the most momentous changes which have occurred in the world's history since the last century dawned … The enormous and unprecedented progress in science during the last century has brought about a perfectly new state of things, in which the "struggle for existence" which Darwin studied in relation to organic forms is now seen, for the first time, to apply to organised communities, not when at war with each other, but when engaged in peaceful commercial strife. It is a struggle in which the fittest to survive is no longer indicated by his valour and muscle and powers of endurance, but by those qualities in which the most successful differs most from the rest.

From *Nature* 3 January 1901.

50 YEARS AGO

During the past hundred years or so a variety of techniques has been devised for transmitting messages electrically from one point to another. It is only of recent years, however … that means have been provided for assessing quantitatively the commodity which is transmitted, namely, the 'information' content of messages, and of determining the extent to which existing techniques fall short of what may be attainable. This recent work proves to have a significance beyond the sphere of electrical communications. A new branch of science is emerging which reveals and clarifies connexions between previously largely unrelated fields of research concerned with different aspects of the processes by which living organisms — in particular man — collect, classify, convert and transmit information. A confluence of different fields of investigation is, of course, no new phenomenon in the history of science, but the wide recognition of a new connecting link can seldom have been so rapid as in the present case.

From *Nature* 6 January 1951.