New astronomical evidence for planets

Theoretical expectation

Stars form by gravitational collapse of gas & dust in cold interstellar clouds. Some rotation should be present, leading to a flattened disk orbiting the protostar. In this disk, further gravitational attraction, sticking and collisions among the solid particles may lead to the growth of planetisimals & planets. This certainly happened in our solar nebula (evidence from meteorites).

Protoplanetary disks

Disks were inferred to be present around protostars and T Tauri (pre-main sequence) stars by modeling of their infrared excesses and their bipolar outflows (Herbig-Haro objects). These disks have now been directly imaged using millimeter interferometers and the Hubble Space Telescope. It is now clear that most stars are born with protoplanetary disks, although this does not mean that all disks form stable planetary systems.

beta Pic type debris disks

Roughly 1/5 of main sequence A-type stars show an infrared excess. These include very bright well-known stars like Vega and beta Pic. Spectroscopy shows that many cometary bodies are continuously impacting beta Pic. It is argued that these are not protoplanetary disks during the formation process, but rather debris disks where infrared-emitting particles are produced by collisions among planetisimals (similar to our Asteroid Belt and zodiacal light).

Planets discovered via Doppler wobble (see exoplanets.org)

About 78 planetary systems discovered to date around nearby solar-type stars (4/1/02). Most are single Jovian systems with orbit sizes from 0.02 to 4 A.U.

Properties of the extrasolar planets

Planets found in ~10% of a nearly complete sample of ~1000 nearby solar-type stars. But the true fraction of stars with planets is undoubtedly larger, as the Doppler method is technologically limited to finding relatively massive stars with relatively close orbits.

Seven double planet and one triple planet system have been found. this demonstrates that multi-planetary systems like our own can occur. There may be many terrestrial-mass planets in any of these systems which we cannot detect by Doppler wobble.

Planetary masses range from ~0.3 to 15 M_J, and the frequency decreases with mass. The lower mass limit is due to limitations in the detection method. The reasons for the

absence of more massive planets, and the decrease in number as mass increases, are unclear.

Two types of planetary orbits found: `hot Jupiters' in circular orbits, and colder Jupiters with eccentric orbits. Possible explanations:

1. Gravitational interactions (scattering) among several Jovian-type planets. Can readily produce eccentric orbits. A reasonable explanation for Pluto's unusual orbit in our solar system.
2. Inward migration of Jovian planet due to gas drag and gravitational resonances with the ganeous disk. Can readily explain the close circular orbits. In such planetary systems, any inner terrestrial planets would be destroyed.
3. Gravitational scattering by nearby stars. Can produce eccentric Jovian orbits, but such encounters are rare except in very dense stellar clusters.

Stars hosting planets systematically have higher metallicities than stars without planets. The cause of this is unclear:

1. Stars born with more metals have disks with more interstellar dust which are more effective in forming planets
2. Stars with inner Jovian planets have already accreted other planets (via inward migration) which have contaminated their surfaces with additional heavy elements

A few planets found from Doppler wobble lie in the habitable zone of their host stars. In such cases, imoons like Europa would have liquid surface oceans and may be good sites for the development of life (Williams et al, Nature 1996, PSU faculty).

Conclusion: In the past decade, astronomical evidence has irrefutably shown that planets frequently form around habitable stars. However, the details of the planet formation process appear to be complex, and it is not clear that systems with a terrestrial planet at the right distance from the star are common.