Forming super-Earths by ultraviolet stripping

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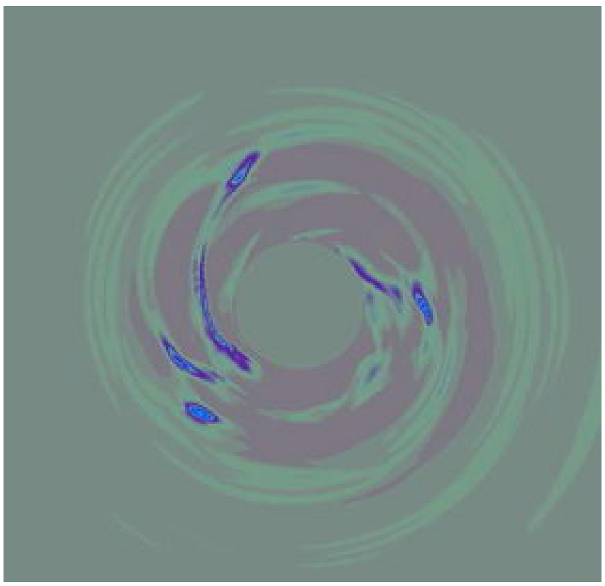

Four Jupiter-mass clumps formed on Saturn-like orbits after 215 years of evolution of an initially smooth disk of gas and dust in orbit around a red dwarf star with a mass half that of our Sun. Purple denotes regions with high gas density in the midplane of the planet-forming disk, while red regions denote low gas density. The red dwarf lies unseen at the center of the disk. These protoplanets would all be stripped down to super-Earths if this planetary system formed close to a massive star.

A new explanation for forming "super-Earths" suggests that they are more likely to be found orbiting red dwarf stars--the most abundant type of star--than gas giant planets like Jupiter and Saturn. The theory, by Dr.

Alan Boss of the Carnegie Institution's Department of Terrestrial Magnetism, describes a mechanism whereby UV radiation from a nearby massive star strips off a planet's gaseous envelope exposing a super-Earth. The work, published in the June 10, 2006, *Astrophysical Journal Letters*, explains recent extrasolar planet discoveries by the microlensing method.

Super-Earths have masses that range between those of Earth and Neptune but have unknown compositions. "Of the 300 stars closest to the Sun, at least 230 are red dwarf stars, with masses less than half that of our Sun," Boss says. "Because nearby stars are the easiest places to look for other Earth-like planets, it is important to try to predict what types of planetary systems they might have, and that means trying to figure out how their planets can form."

Recently, evidence was presented for perhaps the lowest-mass planet found to date in orbit around a main sequence star like the Sun. It was found by an international consortium of astronomers via a microlensing event, where a foreground star amplifies the light from a much more distant star by bending the light of the background star in our direction, an effect predicted by Einstein. In addition, they observed a secondary brightening as well, consistent with the presence of a roughly 5.5-Earth-mass planet orbiting the foreground star at a distance similar to the asteroid belt in our Solar System. While the identity of the foreground star is unknown, it is most likely a red dwarf (M dwarf) star. Evidence for microlensing by a 13-Earth-mass planet around another red dwarf was subsequently presented.

The microlensing detection teams interpreted their discoveries as evidence that super-Earths can form around red dwarf stars by the same process that led to the formation of the Earth and other terrestrial planets in our Solar System, namely collisions between progressively larger solid bodies. This process is so slow, however, that it is unlikely to lead to the formation of gas giant planets around red dwarfs, because the disk gas is likely to disappear before the solid bodies can grow large enough to capture any gas. However, microlensing teams had previously found evidence for two gas giant planets with masses similar to that of Jupiter around two other red dwarf stars. Given that equal numbers of both giant and super-Earth-massed planets have been detected by microlensing, yet the former are easier to detect, they argued that there must be far fewer giant planets than super-Earths.

Boss was pondering these discoveries while sitting in a hotel lobby in Houston when a new explanation for the four microlensing planets occurred to him. He had previously shown that red dwarf stars are likely to form gas giant protoplanets rapidly by the disk instability mechanism, whereby the gaseous disk forms spiral arms and self-gravitating protoplanets that would become Jupiters in the absence of any interference. However, most stars form in regions where massive O stars eventually form. Such stars emit immense amounts of ultraviolet (UV) radiation, which strips off the disk gas around young stars, exposing their outer protoplanets to UV and stripping away their gaseous envelopes. In 2002 Boss and his Carnegie colleagues, George Wetherill and Nader Haghighipour (now at the University of Hawaii), proposed this explanation for forming Uranus and Neptune, which have masses similar to those of the super-Earths.

"It dawned on me that because UV stripping depends on the mass of the central star, super-Earths should be found on much smaller orbits around a red dwarf than around the Sun," Boss says. "This idea naturally predicts red dwarfs that form close to massive stars will end up with super-Earths orbiting at the distances where super-Earths have been found by microlensing." Red dwarfs that form in the absence of massive stars will not suffer UV stripping and hence will form gas giant planets at these distances, instead of super-Earths. Such stars are in the minority so red dwarfs should be orbited mostly by super-Earths at asteroidal distances and beyond. This prediction agrees with the microlensing detections to date.

It remains to be seen if Boss's theoretical predictions will be verified by the ongoing microlensing searches and by the space-based planet detection missions being planned by NASA and the European Space Agency. Determining the compositions of super-Earths will be a major challenge with important implications for their habitability.

Source: Carnegie Institution

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