Planet formation

Enigmatic emission

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The detection of infrared emission from the dusty disk around a distant star signals the presence of the H_3^+ ion. The finding may provide a vital clue to how hydrogen and helium condense into gas-giant planets.

Although there is some consensus on how stars form from interstellar matter, how planets form is less certain. Observations of infrared and radio emissions from dust in protostars have established the presence of protoplanetary disks — regions where dust particles accumulate to form rocky planets like the Earth. But it's a different story for giant planets like Jupiter and Saturn. How the primordial gas of hydrogen and helium in the region condenses to form giant planets is still a mystery, although it is generally believed that the condensation occurs within a short period.

On page 57 of this issue, Brittain and Rettig[1] report their observations of a protoplanetary disk around the star HD 141569, 320 light years from Earth, in which a giant planet might be in the process of forming. Particularly startling is the detection of strong emission of the hydrogenic ion H_3^+, which, according to one model, might originate from a gas-giant protoplanet. If the findings are confirmed, Brittain and Rettig have discovered a new astronomical object, opening up a new avenue for the study of the formation of giant planets.

A crucial question is whether protoplanetary disks contain sufficient raw material, H_2 and He, to form Jupiter-like planets. Observations have been controversial, even on this most fundamental issue. Zuckerman, Forveille and Kastner[2] observed radio emission from CO molecules in the disks surrounding many young stars that are considered to be going through the period of planet formation; assuming the standard ratio of H_2 to CO (about 10^4), they concluded that the amount of H_2 available was far short of that needed for the formation of a giant planet. However, using data from the Infrared Space Observatory, Thi *et al.*[3,4] reported an abundance of H_2 in some of the same stars, as much as a mass equivalent to that of Jupiter. But this finding was subsequently challenged for one of the stars, β-Pictoris, by Lecavelier des Etangs *et al.*[5] using data from the Far Ultraviolet Spectroscopic Explorer. More recent infrared observations by Richter *et al.*[6] also seem to negate the claim of Thi *et al*.

Does this mean that Jupiter-like planets cannot form around those stars? Or have giant planets or protoplanets already formed[5] in those systems, so that there is little H_2 left over in the disk to observe? Giant planets are clearly present in our Solar System and are also observed as extra-solar planets orbiting other stars. Are these giants exceptional? Questions abound.

Brittain and Rettig[1] introduce a new observational tool in this field — the infrared vibration–rotation spectrum of H_3^+ at a wavelength of 4 μm. The H_3^+ ion is an H_2 molecule with an extra proton attached. The third hydrogenic species (after H and H_2), it has only recently been introduced into astronomical observations, but its excellence as an astrophysical probe is rapidly being recognized[7].

The H_3^+ spectrum has been seen in a wide variety of objects: in the giant planets

Jupiter[8], Saturn and Uranus; in molecular clouds[9]; in the diffuse interstellar medium[10]; and possibly even in a supernova and an extragalactic object. The observations by Maillard *et al*.[8] of intense H_3^+ emission in the auroral regions of Jupiter show a spectacularly pure spectrum: all the spectral lines seen are due to the H_3^+ ion and the spectrum is practically free of background radiation[11]. The purity of the spectrum is such that it can be used to study plasma activities in the Jovian ionosphere from ground-based observatories simply by using an infrared camera with a proper filter.

So it seems natural to think of using the same spectrum to detect extra-solar giant planets, and indeed several projects are underway[12]. The detection by Brittain and Rettig of H_3^+ in the protoplanetary disk of HD 141569 is therefore big news. Although HD 141569 is so far away (320 light years) compared with Jupiter (40 light minutes), the dilution of the signal with distance (by a factor of around 10^{-13}) might be compensated for by the larger amount of gaseous H_2 available in a gas-giant protoplanet. (In Jupiter most of the H_2 molecules are locked up in its interior as a high-density metallic fluid, so the planet has a high magnetic field[11].) Nevertheless, questions remain as to how H_2 gas is ionized and how H_3^+ ions are excited to the higher energy state of the emission.

How convincing is Brittain and Rettig's claim to have detected H_3^+ emission? Frequency matching between astronomical and laboratory spectra has been the cornerstone of identifying molecules in space. The discriminative power of high-resolution spectroscopy is so great that the discoveries of important molecules such as H_2O, H_2CO, CO and HC_5N in space were all claimed on the strength of the detection of just one spectral line, and confirmed later by the observation of other lines. In view of this, Brittain and Rettig's observation of two spectral lines (shown in Fig. 2a and Fig. 2b on page 58), at the right frequencies, seems more than sufficient. The latter line is perhaps less convincing, but the authors' subsequent observations have confirmed this line with a higher signal-to-noise ratio (T. Rettig, personal communication).

However, a few enigmas remain. In particular, Brittain and Rettig note that another H_3^+ line is missing from their spectrum. This is in stark contrast to the data from Jupiter, in which that line was observed with an intensity comparable to that of one of the lines that Brittain and Rettig do see. There are also a few other details in the data that I find difficult to explain — more observations are needed to firmly establish H_3^+ emission in HD 141569.

Brittain and Rettig's findings will certainly stimulate interest in the formation of giant planets and H_3^+ spectroscopy. No doubt many of the world's infrared telescopes will be pointed towards HD 141569 and other young stars this year. It will be wonderful to see H_3^+ promoted as an essential probe for the studies of gas-giant protoplanets. ■

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