Where stars form

Hale Observatories

Protostars form in the shade of interstellar dust with the help of hydroxyl masers

by Dietrick E. Thomsen

When it comes to the formation of new stars astronomers have supposed for a long time that the interstellar dust clouds are where it's at. It seemed right and proper that stars should form where the matter of the universe appeared to be thickest.

The discovery that the dust clouds are inhabited by aggregations of quite a number of different chemical compounds, some of them fairly complex organic sustances, has greatly stimulated study of the dust clouds in the last few years. Information resulting from those studies serves to bolster the idea that stars are formed in the clouds, and some theoreticians are putting forward suggested scenarios of stellar formation in which the new discoveries, especially the so-called interstellar masers, play significant roles.

The first question about stellar formation in the dust clouds is whether the matter there is dense enough for the formation process to begin. Stars are supposed to form from the collapse of a cloud of gas under the influence of its own gravity. Gradually the contracting gas heats up until nuclear burning begins and a star is born.

For the collapse process to begin, the gas must have a sufficient density to make the mutual gravitational forces strong enough to start the atoms or molecules moving toward each other on the average. By studying the brightnesses of the emissions from the different molecules astronomers can get some idea of the density.

The stability of such gas clouds is one of the subjects of interest to William J. Welch of the University of California at Berkeley. He dealt with it in a talk at the recent American Physical Society meeting in San Francisco. Observation shows the clouds to have densities greater than 100 atoms or molecules per cubic centimeter. This, he says, is "at least thinking about collapse." Furthermore such large over-all densities increase the possibility that there might be denser, more unstable clumps here and there. Infrared observations have shown a number of sources apparently buried in such clouds, and some theorists suppose that these might be the unstable clumps: hot, collapsing protostars.

The great variety of chemical compounds found in the clouds leads some astronomers to suggest that not only stars form there but also their attendant planetary systems. This hypothesis is economical: It preserves the results of the chemical activity that formed the different compounds. If the compounds collapsed into stars they would be dissociated. Then, if planetary systems were formed out of material ejected by stars (as some hypotheses have held), the compounds would have to be formed all over again.

If some of the gas collapses directly to planets, the compounds have a much better chance of survival. In that case too they would endow the planets at birth with organic compounds out of which living creatures might be built. Whether or not this hypothesis holds, the recent studies of the interstellar clouds have answered one important philosophical question about the origins of life: The formation of organic compounds, complex as they are, is neither chancy nor rare, but continuous and ubiquitous. In the words of Patrick Thaddeus of the Institute for Space Studies, "Nature has an urge to make organic molecules."

Accompanied by planets or not, the collapsing protostar must radiate a good deal of energy as it goes. Gravitational collapse generates more energy than is needed for the ignition of nuclear burning and if the excess is not radiated, the protostar is likely to explode. However, the configuration of a protostar at this stage of its evolution would seem to ensure that the necessary radiation would have a hard time getting out. As William D. Gwinn of the University of California at Berkeley describes it, when a protostar's density begins to get high, radiation pressure keeps the dust grains (which are supposedly carbon) out of it. The grains form a shock wave around the protostar. "It is completely dark," he says. Radiation in visible wavelengths cannot get through the carbon veil.

As an escape hatch to save the protostar Gwinn and other students of the problem invoke the interstellar hydroxyl maser mechanism. The story of the maser began in 1966 when Harold Weaver of UC Berkeley discovered emission from interstellar hydroxyl radicals at 1,665 megahertz. Eventually it developed that there were two lines, 1,665 and 1,667 megahertz. Both showed maser-like characteristics: They were very bright and very narrow.

To get these lines and to produce the anomalous ratio of brightness between them and other hydroxyl lines requires some mechanism that pumps hydroxyl radicals to particular energy levels whose decay produces these particular wavelengths. Gwinn, Barry Turner (now at the National Radio Astronomy Observatory) and Miller Goss (now at the Max Planck Institute for Radio Astronomy in Bonn) developed a possible model. It starts with a water molecule adsorbed on a carbon grain. Along comes a proton and knocks a hydrogen atom out of the water. This leaves a hydroxyl radical. The hydroxyl is in a highly excited state of rotational energy. According to the calculations of Gwinn, Turner and Goss it will radiate this rotational energy very quickly as infrared, and that activity will put it into a state where it will preferentially radiate either the 1,665 or the 1,667 line.

As Gwinn puts it, the theory "did not meet instant success." Astronomers were at first reluctant to believe that there is water there. Gwinn was vindicated by the discovery of water in the same clouds as the hydroxyl. Nevertheless critics still argue against his ideas on the ground that the intensity of the water sources varies more rapidly than that of the hydroxyl, making a connection between the two difficult to envision. "We've had quite a few arguments," says Gwinn.

Gwinn sees his mechanism taking place inside a protostar, turning the heat it must dissipate (expressed in motion of protons) into maser radiation. Whether they agree with the details of Gwinn's mechanism or not, a number of astronomers see the maser as "a sink for energy in protostars," as Thaddeus puts it. The maser has the advantage of being strong radiation in the radio range, and this can get through the veil of dust. In its turn, this general theory is not universally accepted, but it is a plausible way of permitting stars to form. □