From Dust and Gas to Planets and Stars

Star formation, one of the more complex processes in the universe, is linked inextricably to planet formation and thus to the origin and evolution of life. While the general outline of how stars and planets form has been known for years, understanding the process in detail has proven to be a slow but rewarding quest. New research tools promise to allow great advances in our understanding of this important process in the coming years.

We know that interstellar clouds of gas and dust fragment into clumps and the clumps can collapse gravitationally until their cores reach the temperatures and densities required to trigger nuclear fusion reactions. Outstanding questions about this process include what makes some clumps collapse and others fail to do so; and what are the roles of rotation, turbulence, and magnetic fields in the collapse process, and the chemical composition of the clouds.

Some observed facts remain difficult to explain. We know that the majority of stars are not single, like our sun, but rather are parts of binary or other multiple-star systems. Current theoretical models of star formation have difficulty showing how these multiple-star systems are produced. We also know that many stars are much more massive than the sun, but simple star-formation models indicate that intense radiation from a massive young star should blow away incoming material and stop further growth. Recent and planned observations will seek to learn how rotating disks of material surrounding these young stars and “jets” propelled from the poles of these disks can allow continued addition of material to produce stars with observed high masses.

Over the past decade or more, the discovery of hundreds of planets beyond our solar system has shown that planets are common companions to stars. The emerging picture is that material drawn toward a young star forms a flattened disk that rotates around it. Within the disk, tiny dust particles stick together and grow into pebble-sized objects that collide and form “planetesimals.” Eventually, the planetesimals grow into the cores of planets. Only recently have astronomers been able to confirm pieces of this picture observationally, and new instruments promise dramatic improvement in the ability to study this process.

Similarly, new and oncoming telescopes, particularly in the infrared, submillimeter and radio portions of the electromagnetic spectrum, will allow studying the process of star formation not just in our own Milky Way, but also in other galaxies. This development will provide the ability to study star formation in environments significantly different from those in our own galaxy, and across the vast reaches of cosmic time.

In other galaxies, we see evidence of “starbursts”—regions of frantic star formation as much as 10,000 times more powerful than any star-formation regions in our Milky Way. Such starbursts often appear to be linked to the formation of “super-star clusters,” objects unseen in the Milky Way. It remains unknown if such extreme star formation is basically similar to that of what we see in our galaxy or is somehow fundamentally different. It also is unknown if this extreme process forms stars like our sun, and other types, and how such prolific star formation affects its parent galaxy.

Studying star-forming regions in other galaxies also will help answer questions about the gas clouds that serve as stellar nurseries.

Outstanding questions scientists hope to learn the answers to include: What are the types of chemicals found in a variety of these gas clouds? What types preferentially form stars? What types produce super-star clusters? What is the role of the clouds in enriching the universe with the heavy elements produced in the cores of stars?

Finally, since looking outward from our own galaxy is looking back in time, studying distant galaxies can show us how star formation has changed as the universe aged. We have discovered that, less than a billion years after the big bang, galaxies already were enriched in heavy elements formed in the first generations of stars. It appears that the universe was much richer in the gas needed to form stars billions of years ago than it is today. Future studies will seek to understand how much gas was actually available in early galaxies and how it got into those galaxies; how efficient those galaxies were in forming stars from the gas; and just how quickly the first stars exploded as supernovae to significantly enrich their galaxies with heavy elements.

With the new generation of research tools coming online in the next few years, astronomers are on the verge of answering many of the tantalizing questions that surround the exciting and important topic of star and planet formation.