New telescope reveals first detailed image of a planetary system in formation

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The first detailed images of a planetary system in the process of formation have been revealed by the Atacama Large Millimeter Array (ALMA), a new international telescope beginning scientific operations. Studies of the gas and dust that surround the young star HL Tauri have revealed a series of gaps in the material that are strong evidence of planets slowly coalescing.

The origins of the Earth and of planetary systems in general have attracted the attention of natural philosophers since antiquity. The accepted model was introduced in conceptual form by the philosopher Immanuel Kant in his 1755 work *General History of Nature and Theory of the Heavens*.

The mathematician Pierre-Simon Laplace independently arrived at this model in his *Exposition of the System of the World* of 1796, which also developed mathematical physics for the model. In this schematic, gaseous clouds slowly collapse, their initial spin preventing full collapse in two dimensions, producing a pancake-shaped disk that further organizes itself into planets. Modern observational and theoretical work has confirmed and developed this model in considerable detail, but until now the best telescopes have produced only crude images of the process.

This has been a large part of the motivation in the development of millimeter-wave astronomy, a worldwide effort spanning decades. It has been known for a long time that dense clouds of gas and dust are opaque to visible light, and only in the past several years have we been able to pierce that veil, for the first time looking at both the formation of galaxies and planetary systems, such as HL Tauri, in detail.

HL Tauri is a Sun-like star 450 light years from Earth. Evidence of its protoplanetary disk was first found in 1975 through infrared observations. Further data was collected in 1985-86 at the Owens Valley Radio Telescope, when the disk itself was imaged, revealing part of its composition to be ice particles, iron, carbon monoxide and diatomic hydrogen.

The ALMA image shows a series of bright concentric rings separated by gaps. These features are the product of the gravitational effects of planets, slowly forming, accumulating matter in their paths and also sweeping remaining matter into preferred orbits. A similar instance in which a ring is organized into structure by local mass concentrations can be seen around the planet Saturn, where inner moons organize the Saturn ring system into a rich system of ringlets.

HL Tauri is known by other observations to be a very young star, approximately one million years old. Approximate models of the evolution of these young systems have long suggested a timescale of roughly 10 million years for the initial formation of protoplanets and the development of structure within the disk. A study led by astronomer Paola D’Alessio with the Spitzer Space Telescope in 2004 also suggested evidence for organization and clearing from the inner parts of a disk around a similarly young star, but from indirect evidence—not a direct image.

ALMA Deputy Program Scientist Catherine Vlahakis commented, “When we first saw this image we were astounded at the spectacular level of detail. HL Tauri is no more than a million years old, yet already its disc appears to be full of forming planets. This one image alone will revolutionize theories of planet formation.” Already, there have been suggestions that the disk’s magnetic field was somehow able to accelerate the planet-forming process, something that until now has not had a great deal of evidence.

Even more exciting is the scale of the disk. The total radius of the disk is about 12 billion kilometers, twice the distance of the Sun to Pluto. However, if one places an image of the Solar System side by side to HL Tauri and its protoplanetary disk, the gaps closely align to the orbits of our own planets. Given the mass of the star and the composition of the disk, it is speculated that by viewing HL Tauri, we are looking at what the Solar System looked like just after the Sun began to shine.

ALMA itself is a remarkable instrument. It consists of a constellation of 66 movable radio dishes linked to one another across 16 kilometers in the Atacama desert of northern Chile at an elevation high enough to negate a great deal of atmospheric interference that occurs in astronomical observations at sea level. The dishes detect electromagnetic radiation with wavelengths of millimeters, a part of the spectrum which is dominated by radiation arising from gas and dust in the universe. The array is run by an international team from Canada, Chile, Europe, Japan, South Korea, Taiwan and the United States. Since it began collecting data in 2011, ALMA has provided new insight into planetary formation, the composition of molecular clouds and the physics of the early universe.

An individual millimeter-wave telescope, due to the longer wavelength of radiation compared to optical light, reveals only a blurry image. To compensate, networks of telescopes must collect the incoming radiation and combine them through banks of supercomputers. This enables astronomers to mimic the performance of a vast telescope the size of the entire array of dishes without the otherwise colossal expense that would be needed.

The sharp image of HL Tauri's protoplanetary disk is due to this technique. ALMA's effective size is 16 kilometers across, a factor of eight greater than the previous generation of millimeter telescopes.

At $1.4 billion in cost, the ALMA telescope is the most expensive ground-based telescope in operation. Many such innovative telescopes are proposed—the increasing impoverishment of fundamental research ensures that few are built. Many more discoveries are expected from ALMA, which is only beginning to reveal its capabilities. These discoveries are just a foretaste of what the organized labor of the working class is capable of producing, in a social system that gives only limited scope to the quest for scientific understanding of our origins and future.