In a distant stellar system, the JWST sees the end of planet formation

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This artist's illustration shows what gas leaving a planet-forming disk might look like around the T Tauri star T. Cha. Credit: ESO/M. Kornmesser CC BY

Every time a star forms, it represents an explosion of possibilities. Not for the star itself; its fate is governed by its mass. The possibilities it signifies are in the planets that form around it. Will some be rocky? Will they be in the habitable zone? Will there be life on any of the planets one day?

There's a point in every stellar system's development when it can no longer form planets. No more planets can form because there's no more gas and dust available, and the expanding planetary possibilities are truncated. But the total mass of a stellar system's planets never adds up to the total mass of gas and dust available around the young star.

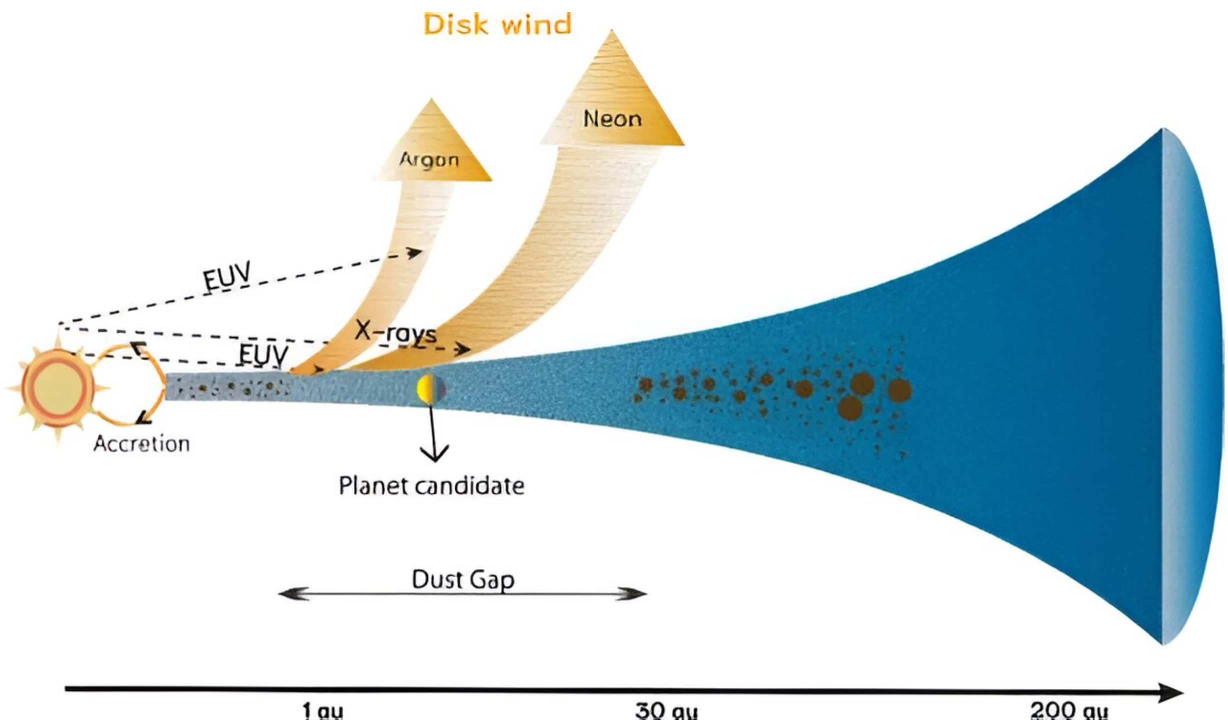
What happens to the mass, and why can't more planets form?

When a protostar forms in a cloud of molecular hydrogen, it's accompanied by a rotating disk of gas and dust called a circumstellar disk. As material gathers into larger and larger bodies, planetesimals form, and eventually, planets. At that point, the disk is referred to as a protoplanetary disk. But whatever we call it, the rotating disk is the reservoir of material out of which planets form.

In our solar system, there are more rocky objects than gaseous ones. Not by mass but by number. Scientists think that systems similar to ours form similar numbers of rocky and gaseous objects.

But in the solar system's early days, there was way more gas than there was solids. This contradicts the fact that the disks around young stars contain 100 times more gas than they do solids. Where does all the gas go?

New research based on JWST observations provides an answer. The study is "JWST MIRI MRS Observations of T Cha: Discovery of a Spatially Resolved Disk Wind." It's published in *The Astronomical Journal*, and the lead author is Naman S. Bajaj, a doctoral student at the University of Arizona's Lunar and Planetary Laboratory.



This schematic from the research shows T Cha, the dust gap, the planetary candidate, and the EUV and X-rays that ionize the noble gases, creating the disk wind. Credit: Bajaj et al. 2024

T Chamaelontis (T Cha) is a young T Tauri star located about 335 light-years away. T Tauri stars are less than about 10 million years old and haven't entered the main sequence yet. At this point in their development, the disks around T Tauri stars are dissipating. The gas in the disk is being actively dispersed into space.

"Knowing when the gas disperses is important as it gives us a better idea of how much time gaseous planets have to consume the gas from their surroundings," said lead author Bajaj. "With unprecedented glimpses into these disks surrounding young stars, the birthplaces of planets, JWST helps us uncover how planets form."

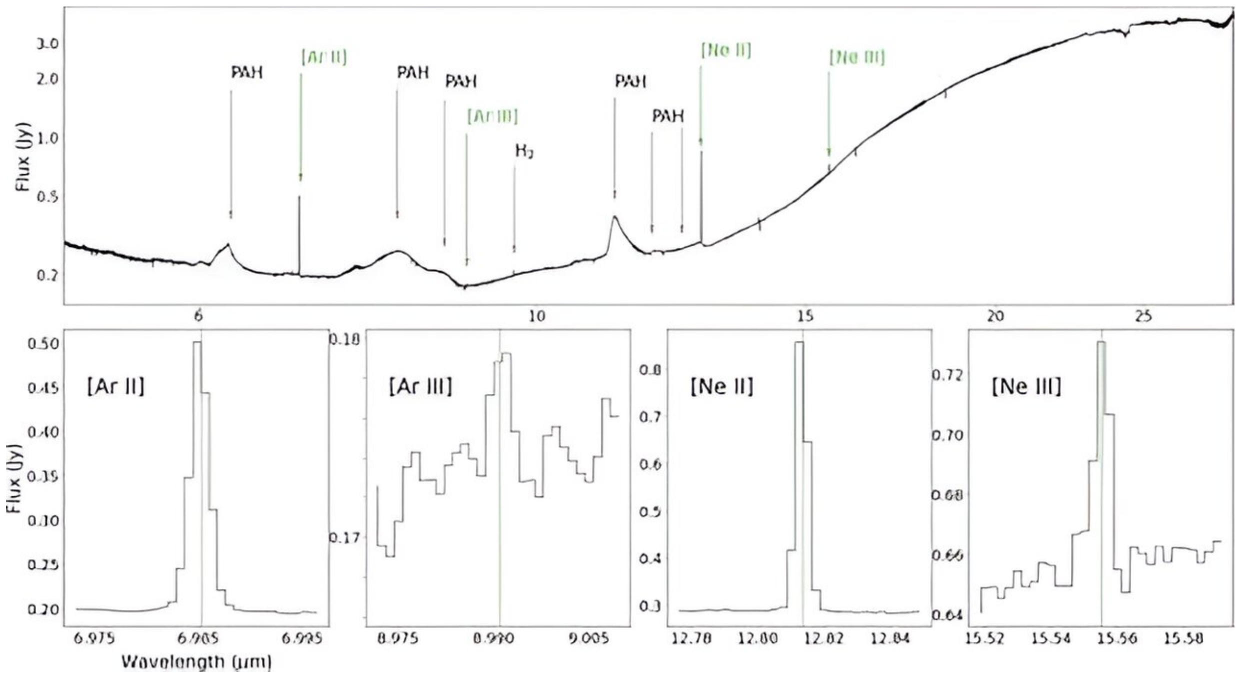
Since the type and number of planets formed in a disk around a star depends on how much gas and dust are available, knowing how and when it disperses is foundational to understanding the eventual stellar system.

"So, in short, the outcome of planet formation depends on the evolution and dispersal of the disk," Bajaj said.

T Cha is noteworthy for another reason beyond its young age. Its eroding circumstellar disk has a vast dust gap in it about 30 astronomical units wide. On the inside of the gap is a narrow ring of material close to the star, and on the outside of the gap is the remainder of the disk material. A planetary candidate is in the gap but isn't part of this research.

The force that disperses gas is called the disk wind. In this research, the scientists involved used the JWST to probe the disk and discover what drives the wind. This is the first time that scientists have imaged the disk wind.

Ionization plays a large role in disk dispersion. Ionization happens when energetic photons from a star strike an atom and remove one or more electrons. Ionization of different types of atoms releases particular light that the JWST can see and that scientists can use to trace the activity in the disk. In this research, the JWST detected two noble gases being ionized: argon and neon. The JWST also detected double-ionized argon, the first time it's ever been detected in a disk.



This figure from the research shows some of the JWST’s observations. The upper panel is the JWST MIRI MRS spectrum of T Cha plotted between showing PAH (polycyclic aromatic hydrocarbon) features and other data, including the forbidden noble gas emissions in green. The lower four panels further highlight the four forbidden line emissions, [Ar ii], [Ar iii], [Ne ii], and [Ne iii], which are especially important in this study. The presence of doubly ionized Argon (Ar iii) has never been observed before. Credit: Bajaj et al. 2024

Astronomers have known for a decade that Ne ii traces disk winds. Scientists working with NASA's Spitzer Space Telescope discovered that. At T Cha, the Ne ii traces emission away from the disk, which is compatible with a disk wind.

"The neon signature in our images tells us that the disk wind is coming from an extended region away from the disk," Bajaj said. "These winds could be driven either by high-energy photons—essentially the light streaming from the star—or by the magnetic field that weaves through the planet-forming disk."

It's critical to understand the source of the ionization. To dig into it, the researchers relied on simulations. The researchers simulated the intense radiation coming from the young star and compared it to the JWST observations. There was a good match showing that the energetic stellar photons can drive the disk dispersal.

"Our discovery of spatially resolved neon emission—and the first detection of double ionized argon—using the James Webb Space Telescope could become the next step towards transforming our understanding of how gas clears out of a planet-forming disk," said Ilaria Pascucci, a professor at LPL who helped discover that neon traces disk winds. "These insights will help us get a better idea of the history and impact on our own stellar system."

As a young T Tauri star, T Cha is changing rapidly. Previous observations about 17 years ago with Spitzer revealed a different spectrum than these observations with the JWST. The differences can be explained by a small inner disk of material near T Cha that has lost noticeable mass in the intervening 17 years. In specific scientific terms, the MIRI [Ne ii] flux is 50% higher than the Spitzer flux obtained in 2006. Future studies can help shed even more light on these wind diagnostic lines.

Chengyan Xie, a second-year doctoral student at LPL who's involved in the research, thinks that we're watching disk dispersal in real time and that things will continue to change rapidly.

"Along with the other studies, this also hints that the disk of T Cha is at the end of its evolution," Xie said. "We might be able to witness the dispersal of all the dust mass in T Cha's inner disk within our lifetime."

Planet formation could be about to stall at T Cha, and the JWST is helping us see it happen.

More information: Naman S. Bajaj et al, JWST MIRI MRS Observations of T Cha: Discovery of a Spatially Resolved Disk Wind, *The Astronomical Journal* (2024). DOI: 10.3847/1538-3881/ad22e1

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