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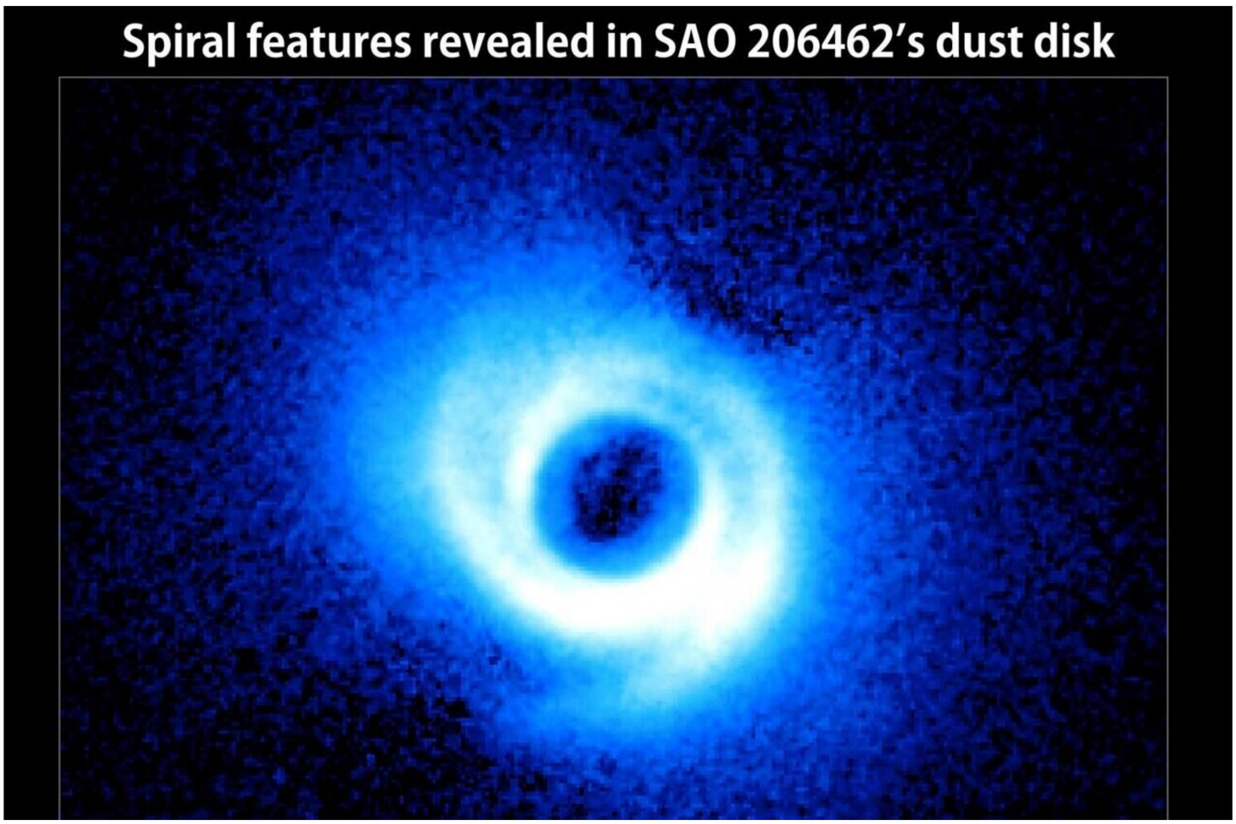
Astronomers conduct first search for forming planets with James Webb Space Telescope

March 27 2024, by Morgan Sherburne



Two spiral arms emerge from the gas-rich disk around SAO 206462, a young star in the constellation Lupus. This image, acquired by the Subaru Telescope and its HiCIAO instrument, is the first to show spiral arms in a circumstellar disk. The image traces the light emitted by the star and scattered on the disk surface. The disk itself is some 14 billion miles across, or about twice the size of Pluto's orbit in our own solar system. Credit: NAOJ/Subaru

Planets form in disks of dust and gas called protoplanetary disks that whirl around a central protostar during its final assembly. Although several dozens of such disks have been imaged, just two planets have been caught in the act of forming so far. Now, astronomers are aiming the powerful instruments aboard the James Webb Space Telescope at protoplanetary disks to try to find early clues about the ways in which planets form, and how these planets influence their natal disk.

A trio of studies led by the University of Michigan, University of Arizona and University of Victoria combined JWST's images with prior observations made by the Hubble Space Telescope and the Atacama Large Millimeter Array, or ALMA, in Chile. Based on the ancillary observations, the team used JWST to observe protoplanetary disks HL Tau, SAO 206462 and MWC 758 in hopes of detecting any planets that might be forming.

In the papers, published in The *Astronomical Journal*, the researchers pieced together previously unseen interactions between the planet-forming disk and the envelope of gas and dust surrounding the young stars at the center of the protoplanetary disks.

To catch a planet

The U-M study, led by U-M astronomer Gabriele Cugno, aimed JWST at a disk surrounding a protostar called SAO 206462. There, the researchers potentially found a planet candidate in the act of forming in a protoplanetary disk, but it wasn't the planet they expected to find.

"Several simulations suggest that the planet should be within the disk, massive, large, hot, and bright. But we didn't find it. This means that either the planet is much colder than we think, or it may be obscured by some material that prevents us from seeing it," said Cugno, also a co-author on all three papers. "What we have found is a different planet candidate, but we cannot tell with 100% certainty whether it's a planet or a faint background star or galaxy contaminating our image. Future observations will help us understand exactly what we are looking at."

Astronomers have observed the disk in the past, notably with the Hubble Space Telescope, the Subaru Telescope, the Very Large Telescope and ALMA. These observations show a disk composed of two strong spirals, which are likely launched by a forming planet. The planet the U-M team expected to find is a type called a gas giant, planets composed mainly of hydrogen and helium, similar to Jupiter in our own solar system.

"The problem is, whatever we're trying to detect is hundreds of thousands, if not millions of times fainter than the star," Cugno said. "That's like trying to detect a little light bulb next to a lighthouse."

To peer more closely into the disk, the team used an instrument on JWST called NIRCam. NIRCam detects infrared light, and the astronomers used the instrument employing a technique called angular differential imaging. This technique can be used to detect both the thermal radiation of the planet, as the team has done to detect the planet candidate, and specific emission lines associated with material falling onto the planet and hitting its surface with high velocity.

"When material falls onto the planet, it shocks at the surface and gives off an emission line at specific wavelengths," Cugno said. "We use a set of narrow-band filters to try to detect this accretion. This has been done before from the ground at optical wavelengths, but this is the first time it's been done in the infrared with JWST."

This artist's impression shows the formation of a gas giant planet embedded in the disk of dust and gas in the ring of dust around a young star. A University of Michigan study, led by U-M astronomer Gabriele Cugno, aimed the James Webb Space Telescope at a protoplanetary disk surrounding a protostar called SAO 206462, hoping to find a gas giant planet in the act of forming. Credit: ESO/L. Calçada

Imaging the 'raw material' of planets

The University of Victoria paper, led by astronomy student Camryn Mullin, describes images of the disk surrounding the young star HL Tau.

"HL Tau is the youngest system in our survey, and still surrounded by a dense inflow of dust and gas falling onto the disk," said Mullin, a co-author of all three studies. "We were amazed by the level of detail with which we could see this surrounding material with JWST, but unfortunately, it obscures any signals from potential planets. "

HL Tau's disk is known for having several solar-system scale rings and gaps that could harbor planets.

"While there is a ton of evidence for ongoing planet formation, HL Tau is too young with too much intervening dust to see the planets directly," said Jarron Leisenring, the principal investigator of the observing campaign searching for forming planets and astronomer at the University of Arizona Steward Observatory. "We have already begun looking at other young systems with known planets to help form a more complete picture."

However, to the team's surprise, JWST revealed unexpected details of a different feature: the proto-stellar envelope, which is essentially a dense inflow of dust and gas surrounding the young star that is just beginning to coalesce, according to Leisenring. Under the influence of gravity, material from the interstellar medium falls inward onto the star and the disk, where it serves as the raw material for planets and their precursors.

The UArizona study, led by Kevin Wagner, a NASA Hubble/Sagan Fellow at UArizona Steward Observatory, examined the protoplanetary disk of MWC 758. Similar to SAO 206462, previous observations by the UArizona-led team revealed spiral arms forming in the disk, hinting at a massive planet orbiting its host star.

While no new planets were detected in the disk during the most recent observations, the sensitivity is groundbreaking, the researchers say, as it allows them to place the most stringent constraints yet on the suspected planets. For one, the results rule out the existence of additional planets in the outer regions of the MWC 758, consistent with a single giant planet driving the spiral arms.

"The lack of planets detected in all three systems tells us that the planets causing the gaps and spiral arms either are too close to their host stars or too faint to be seen with JWST," said Wagner, a co-author of all three studies. "If the latter is true, it tells us that they're of relatively low mass, low temperature, enshrouded in dust, or some combination of the three—as is likely the case in MWC 758."

The search for forming planets continues

Catching planets in the act of forming is important because astronomers can glean information not only about the formation process, but how chemical elements get distributed throughout a planetary system.

"Only about 15 percent of stars like the sun have planets like Jupiter. It's really important to understand how they form and evolve, and to refine our theories," said U-M Michael Meyer, U-M astronomer and co-author of all three studies. "Some astronomers think that these gas giant planets regulate the delivery of water to rocky planets forming in the inner parts of the disks."

Knowing how these disks are shaped by gas giants will help astronomers ultimately understand the properties and evolution of protoplanetary disks that later give rise to rocky, Earth-like planets, said Meyer.

"Basically in every disk we have observed with high enough resolution and sensitivity, we have seen large structures like gaps, rings and, in the case of SAO 206462, spirals," Cugno said. "Most if not all of these structures can be explained by forming planets interacting with the disk material, but other explanations that do not involve the presence of giant planets exist.

"If we manage to finally see these planets, we can connect some of the structures with forming companions and relate formation processes to the properties of other systems at much later stages. We can finally connect the dots and understand how planets and planetary systems evolve as a whole."

More information: Kevin Wagner et al, JWST/NIRCam Imaging of Young Stellar Objects. I. Constraints on Planets Exterior to the Spiral Disk Around MWC 758, *The Astronomical Journal* (2024). DOI: 10.3847/1538-3881/ad11d5

Gabriele Cugno et al, JWST/NIRCam Imaging of Young Stellar Objects. II. Deep Constraints on Giant Planets and a Planet Candidate Outside of the Spiral Disk Around SAO 206462, *The Astronomical Journal* (2024). DOI: 10.3847/1538-3881/ad1ffc

Camryn Mullin et al, JWST/NIRCam Imaging of Young Stellar Objects. III. Detailed Imaging of the Nebular Environment around the HL Tau Disk, *The Astronomical Journal* (2024). DOI: 10.3847/1538-3881/ad2de9

Provided by University of Michigan

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