Origin of the emission at centimeter wavelengths in the transitional disk surrounding T Chamaleontis

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Abstract

In this work we present an attempt to characterize the emission at centimeter wavelengths in T Chamaleontis, one of the most intriguing transitional protoplanetary disks of the southern hemisphere. Transitional disks are considered as the missing link between disks surrounding young stars and planetary systems. They are characterized by the presence of gaps in their radial dust distributions, which may be originated by photo-evaporative winds, close stellar companions, planets in formation, and grain growth, among other mechanisms. Emission at 0.7 cm and 1.7 cm can be produced by the contribution of different phenomena involving dust emission from large dust grains and free-free radiation from an ionized jet, ionized winds, accretion shocks near the central protostar, non-thermal synchrotron emission from the stellar chromosphere, or photoevaporative winds. Radio interferometers working at centimeter wavelengths offer the possibility for resolving the population of large dust grains on disks and provide insights on the origin of free-free emission. Using the Australia Telescope Compact Array (ATCA) observations we resolve the continuum emission at 0.7 cm and 1.7 cm surrounding T Chamaleontis, the first T Tauri star with observational evidences of planetary formation inside a disk gap. In this contribution we discuss on the possible nature of this emission at centimeter wavelengths.

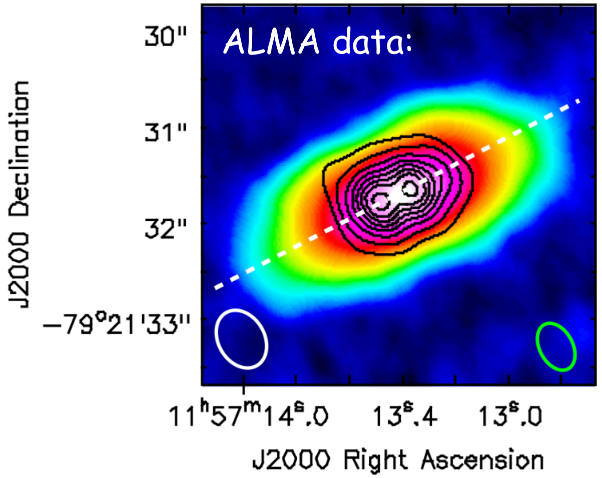
Context of the research

The source

- Young (7 MYr) T Tauri at 107 pc distance. SED typical of a transitional disk (small IR excess between 1-10 μm , steep rise between > 10 -30 μm).
- A **very low mass young companion** candidate at 6.7 AU from T Cha central star was detected by Huélamo et al. (2011). The companion candidate was well withing the gap predicted by models.
- A good characterization of the disk properties was needed.
- SED modelling → **dust gap predicted** between 0.2-15 AU (Brown et al. 2007).
- Detection of Ne II line in the mid-IR→ **Evidence of photoevaporation** (Pascucci & Sterzik 2009)

The ALMA era

- Huélamo et al (2015) **resolved the disk of dust and gas** at 850 microns and CO(3-2) using ALMA data.
- Dust disk Radius=80 AUs, with an inner **dust gap of 40AU size** was confirmed.
- Gaseous disk Radius=230AU; i=67º;PA=113˚ in Kepplerian rotation, which provides a dynamical mass of the central protostar of 1.5 M_{sun}



Colors → CO(3-2). Contours → Continuum at 850 μm. (Huélamo et al. 2015)

The path from dust to planets

- Understanding the path of dust grain growth to planet formation needs observations in the centimeter regime, where "pebbles" emit more efficiently.
- Centimeter-size dust grains do not stick efficiently and grain collisions can fragment those "pebbles" instead of favor the grain growth process.
- The presence of proto-planets may generate pressure bumps where dust can accumulate and grow to large grains beyond the centimeter size barrier.
- High-angular resolution and high-sensitivity observations at centimeter wavelengths are needed to understand and characterize grain growth and dust migration mechanisms in protoplanetary disks.

Description of the work / project / methodologies

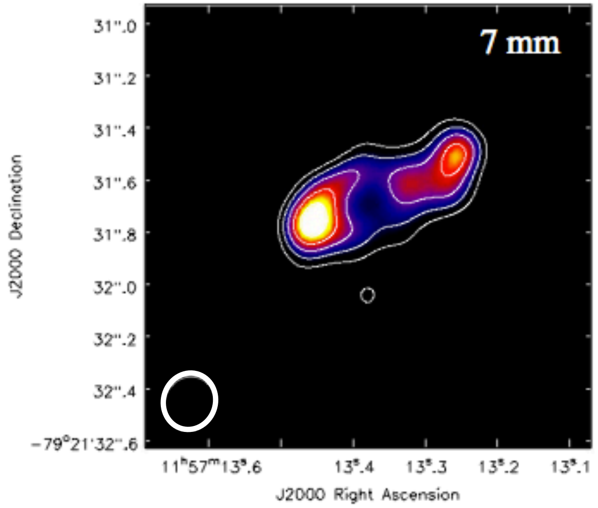
ATCA high-angular resolution observations at 0.7 cm and 1.7 cm

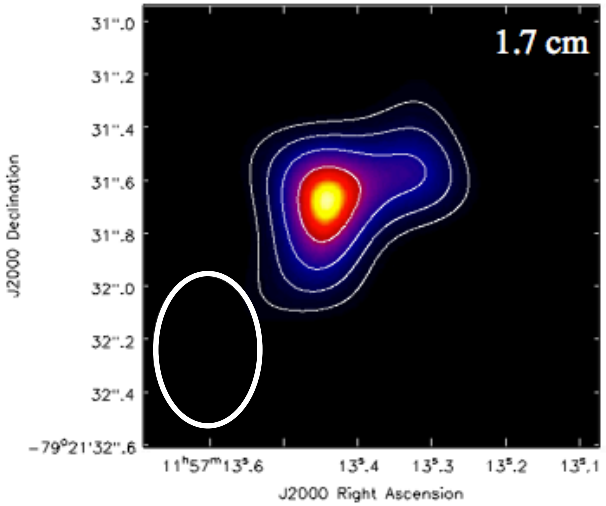
- We carried out 36 hours of observations with the Australia Telescope Compact Array (ATCA) at 0.7 cm and 1.7 cm at subarcsecond spatial resolution as a first attemp to resolve spatially the centimeter emission from T-Cha.

Australia Telescope Compact Array

- Continuum emission at millimeter and submillimeter wavelengths traces mainly thermal emission from the dust in the disk surrounding T Cha.
- Continuum emission at centimeter wavelengths comes mostly from free-free radiation produced by different phenomena: an ionized jet, ionized winds, accretion shocks near the central protostar, non-thermal synchrotron emission from the stellar chromosphere, and/or photoevaporative winds.
- Continuum emission at centimeter wavelengths can also be produced by a population of large dust grains on disks.
- **The aim of this work is to resolve spatially the emisison from T Cha at centimeter wavelengths and to study its nature.**

What is tracing 0.7 cm and 1.7 cm emission in T Cha?





At 0.7 cm observations:

- Disk spatially resolved (0.2" angular resolution) ; $S_{0.7cm}$=1.3+/-0.2 mJy
- Similar morphology than the dust observed with ALMA at 850 microns.
- External radius of 50 AU and presence of an inner gap.

At 1.7 cm observations:

- Disk barely resolved in its main axis (0.6"x0.4" resolution); $S_{1.7cm}$=0.26+/-0.06 mJy
- Similar morphology than the one observed at 0.7cm.

Spectral indexes study

From the literature **$\alpha_{1.2\text{-}3.0\,mm}$ = 2.9 ± 0.6** → **Traces thermal dust emission**

- Assuming optically thin emission, the dust opacity index ~β = α-2~1→ indication of the presence of large dust grains.
- Extrapolating to 0.7 cm and 1.3 cm we would obtain $S_{0.7cm}$=1.3 mJy and $S_{1.7cm}$= 0.1 mJy
- We see an excess of emission at 1.7 cm (predicted 0.1 mJy vs observed 0.26 mJy) that cannot be attributed to errors in flux measurements.

Conclusion:

Emission at 0.7 cm is coming from large dust grains, but what is producing the emission at 1.7 cm?

Results

What is producing the emission at 1.7 cm in T Cha?

1- Emission at 1.7 cm can be produced by free-free emission:

Using previous data at 6 cm for the literature, we derive a spectral index $\alpha_{1.7\text{–}6\,cm}$= **– 0.1** compatible with free-free optically thin emission. Various mechanisms can produce this free-free emission:

1. **Ionized jets** → but no presence or jets or molecular ouflows in T Cha.
2. **Accretion shocks near the central protostar** → would account only for few microJy in a star like T Cha
3. **Non-thermal synchrotron emission from the stellar chromosphere** → produces a negative spectral index and highly variable emission (not seen in previous variability studies in the literature).
4. **Photoevaporative winds driven by high-energy photons from the central star** → can account for hundreds of microJy

Conclusion: radio continuum emission at 1.7 cm could be explained by the presence of a photoevaporative wind

2- Could a population of large dust grains produce also the emission observed at 1.7 cm?

- Using the radiative transfer code MCFOST we modeled the deprojected visibilities profile and the surface brightness profiles at 0.7 cm as well as the SED with all photometric points until 1.7cm.
- To account for the observed fluxes at 1.7 cm wavelengths, **a population of "pebbles" with maximum grain size of at least 3 cm as well as the presence of refractory material** is required. Pure silicates, even with a very large maximum grain size, always underpredict the observed fluxes in the centimeter regime.
- The best fit model reproduces accurately the total integrated continuum flux, the continuum brightness profile at 0.7 cm and the SED including the two new datapoints at 0.7 cm and 1.7cm.

Conclusion: With this model we can explain the observed emission at both 0.7 cm and 1.7 cm by dust thermal emission.

Impact and prospects for the future

- Our measurements indicate that the bulk of the emission observed at **0.7 cm is coming from large dust grains** from the disk surrounding T Cha.

- The **nature of the emission observed at 1.7 cm is more uncertain** since two phenomena can contribute to it:

  1. Photoevaporative winds driven by high-energy photons from the central star
  2. A population of "pebbles" with maximum grain size of at least 3 cm as well as the presence of refractory material.

- The detection of Ne II line at 12.86 microns by Pascucci & Sterzik (2009), indicative of photoevaporation, and the variability in the emission at 1.7 cm seen in the literature (which points to a contribution of a free-free component) support the free-free emission nature. Nevertheless a contribution of both phenomena cannot be discarded.

Higher angular resolution and higher sensitivity observations in the centimeter regime are needed to disentangle the true nature of the emission at centimeter wavelengths in T Cha. Existing facilities in the southern hemisphere reached its limit in spatial resolution and sensitivity → **SKA is need to follow up this study.**