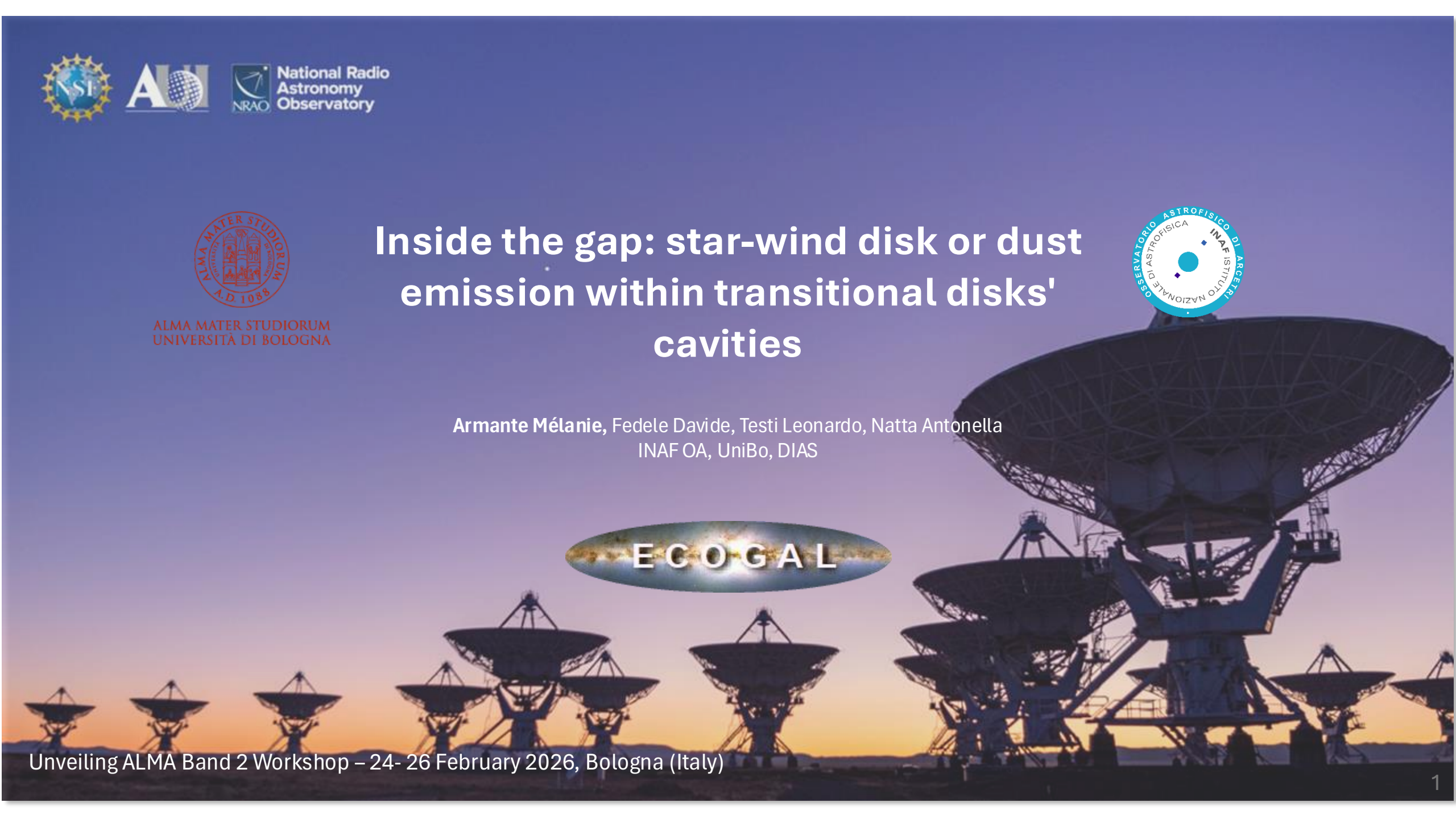
Inside the gap: star-wind disk or dust emission within transitional disks' cavities

Armante Mélanie, Fedele Davide, Testi Leonardo, Natta Antonella
INAF OA, UniBo, DIAS



Unveiling ALMA Band 2 Workshop – 24- 26 February 2026, Bologna (Italy)

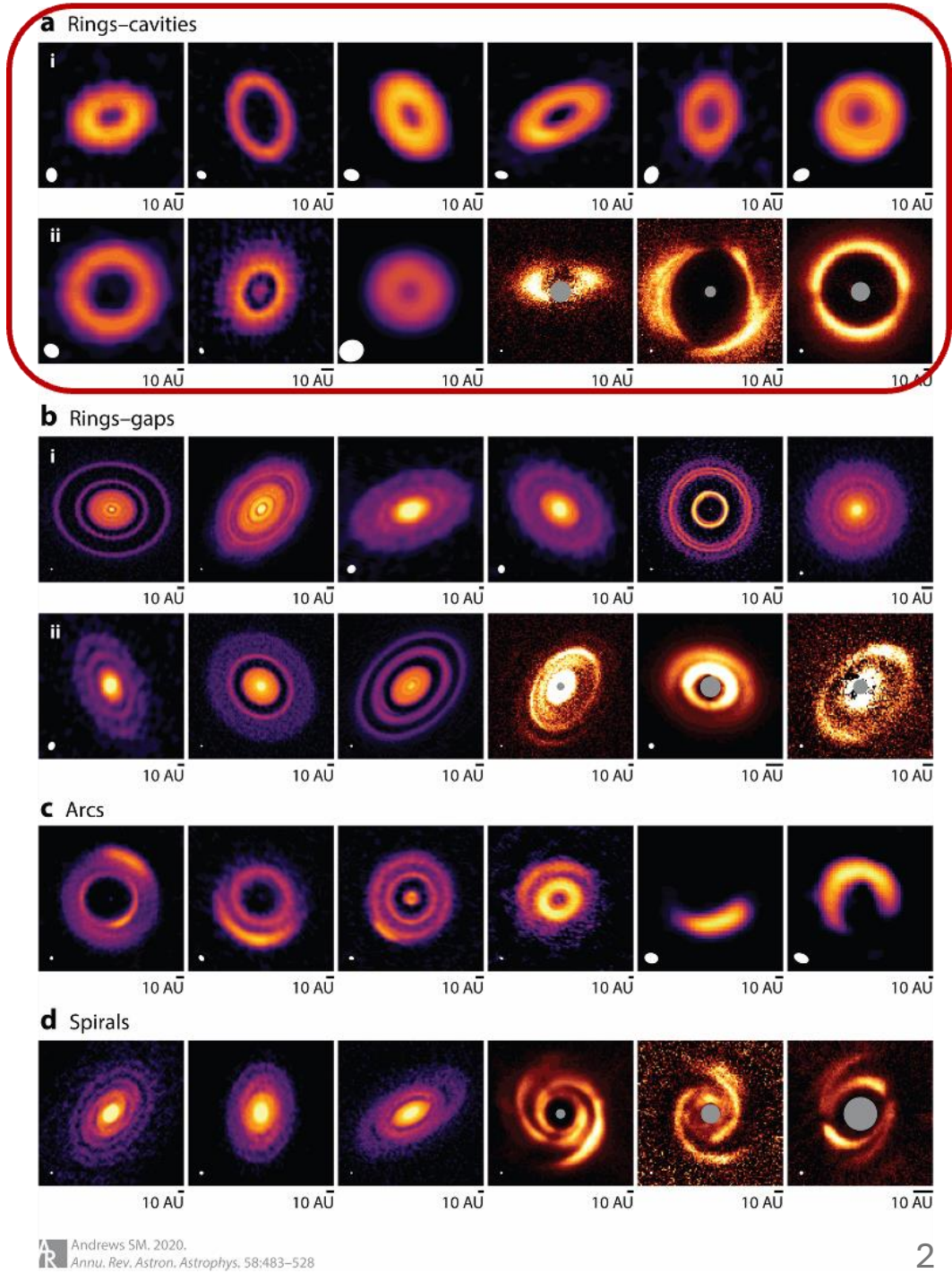
Transitional Disks

TD : protoplanetary disk presenting an inner cavity **depleted from dust and gas** surroundded by a ring

- This cavity is supposed to be the result of the formation of one or more giant planets (as it is the case for PDS 70)
- Passage of material only through the planet: small accretion
- & Modification of the pressure profile creating this ring-like structure where large grains are confined
- Emission around the protostar is observed at mm wavelength for ~50% of TDs

→ Is this compact emission due to the **presence of pebbles ?** or due to non-thermal emission related, e.g., **an ionized wind**

→ What's in the inner cavity of transitional disks ?



Andrews SM. 2020. Annu. Rev. Astron. Astrophys. 58:483–528

CQ Tau

Dataset : 6 maps, 2 ALMA, 4 VLA between 0.9mm and 6cm

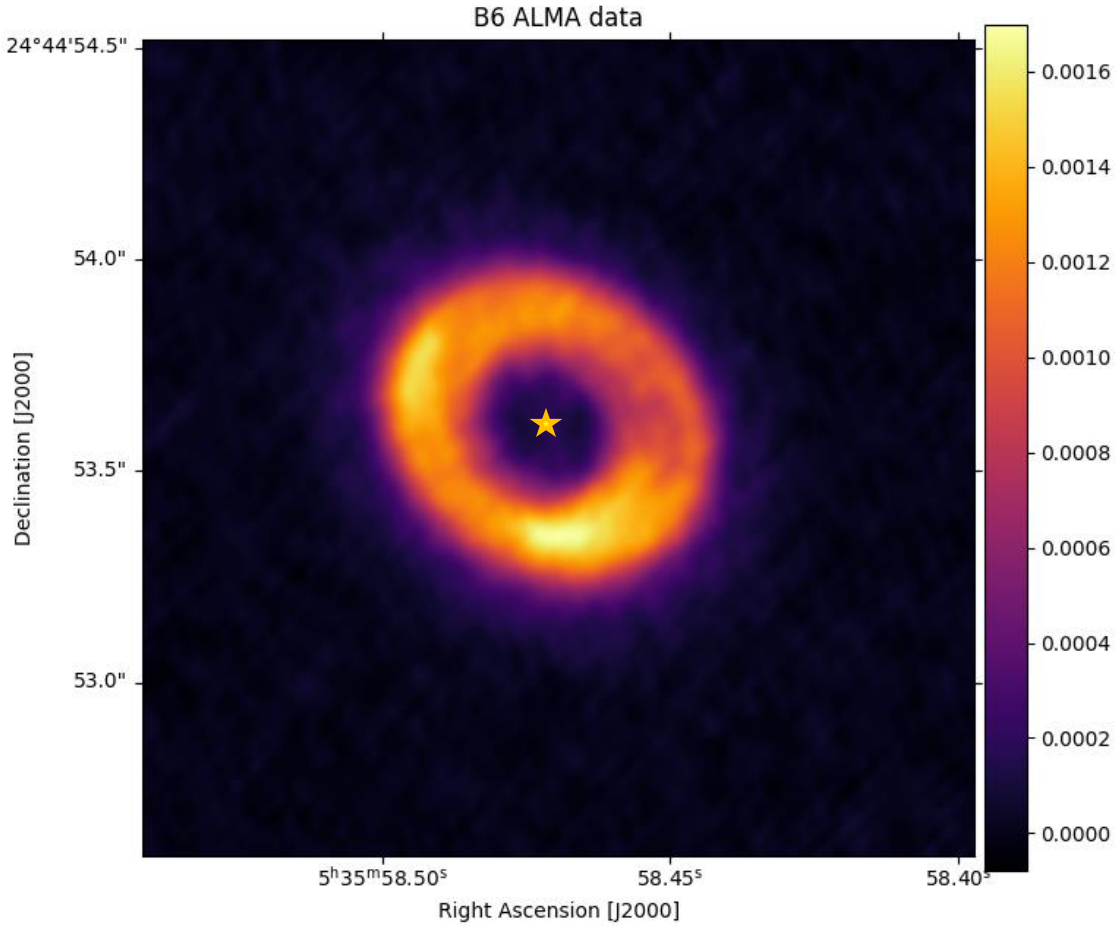
Transitional disk around a :

- Nearby (d=162 pc)
- Intermediate mass ($M_\star$=1.67 $M_\odot$, $L_\star$=10 $L_\odot$)
- Approximate age of ~ 10 My
- Pre-main sequence star of spectral type F2

Presence of an inner disk both in the VLA and in the ALMA maps

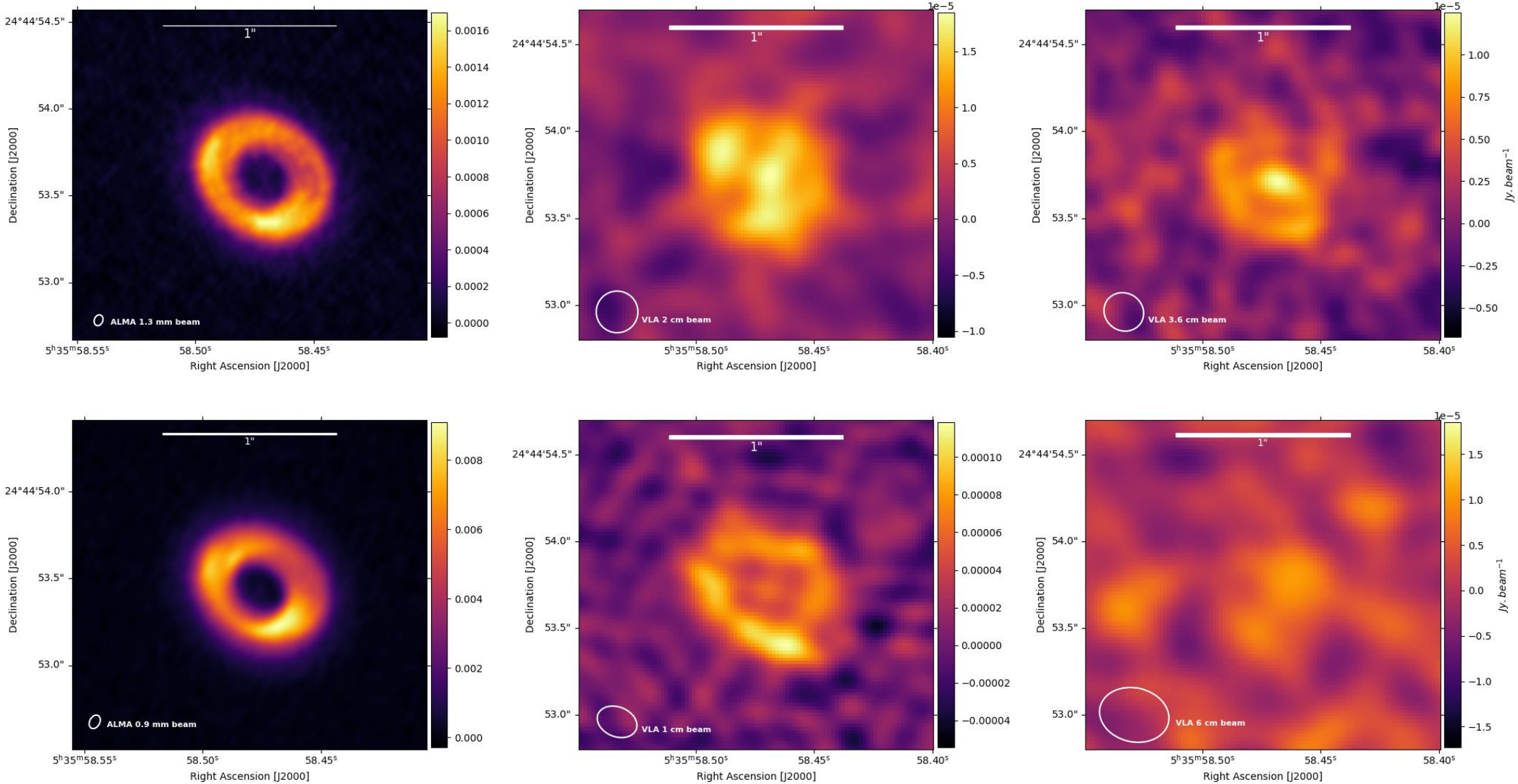
Match between ALMA and VLA maps' emissions for the inner disk and for the ring

→ Question the nature of these emissions !

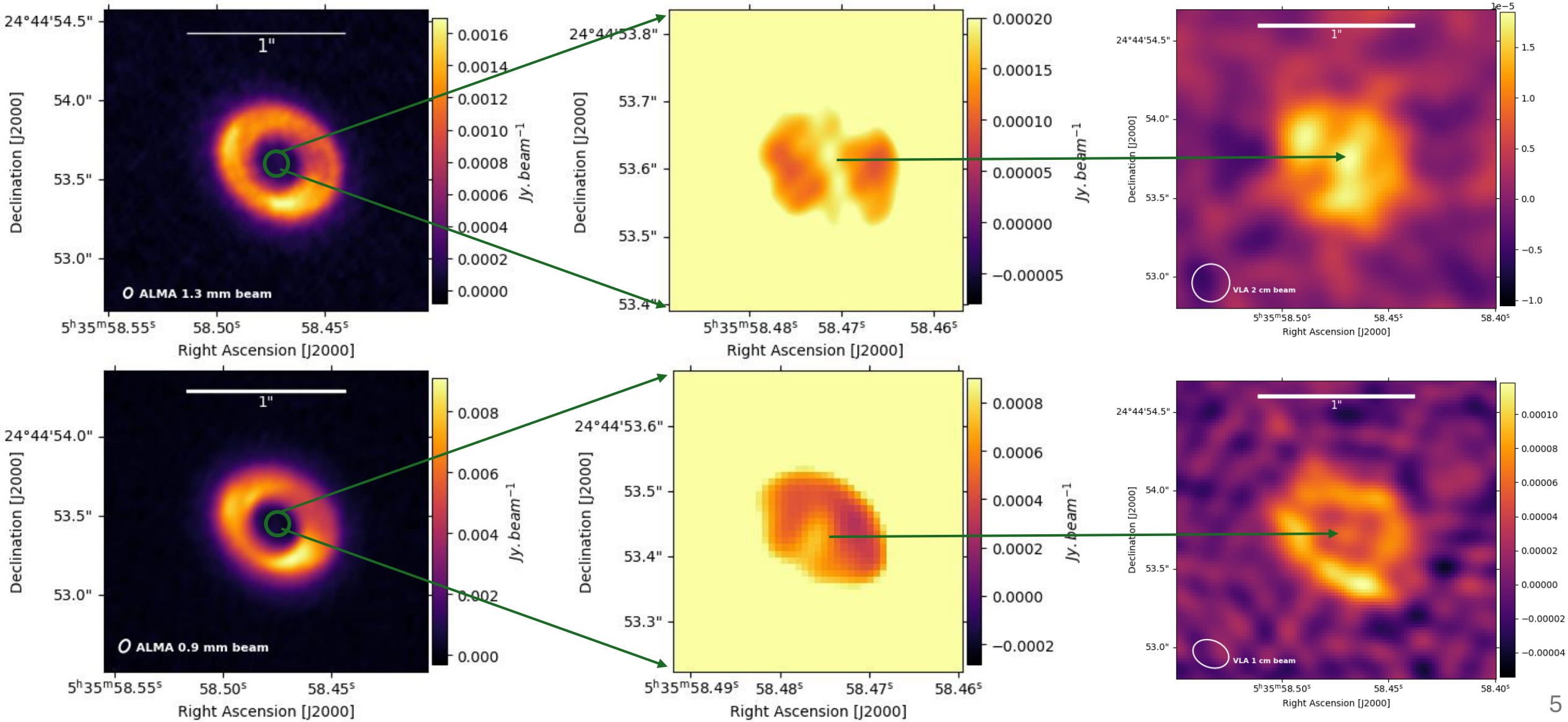


Band6 ALMA map, @224.68 GHz

CQ Tau's dataset



CQ Tau's dataset



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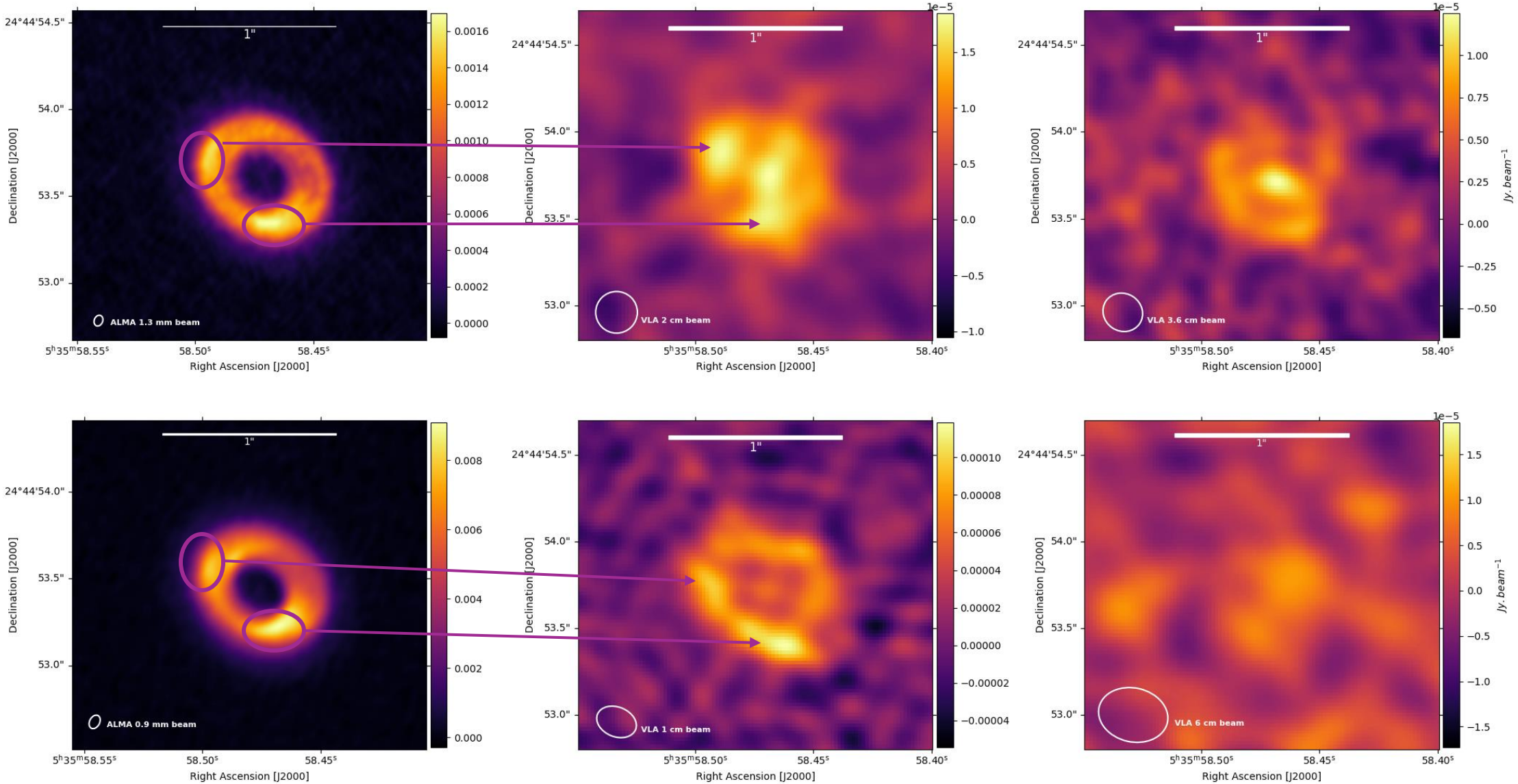


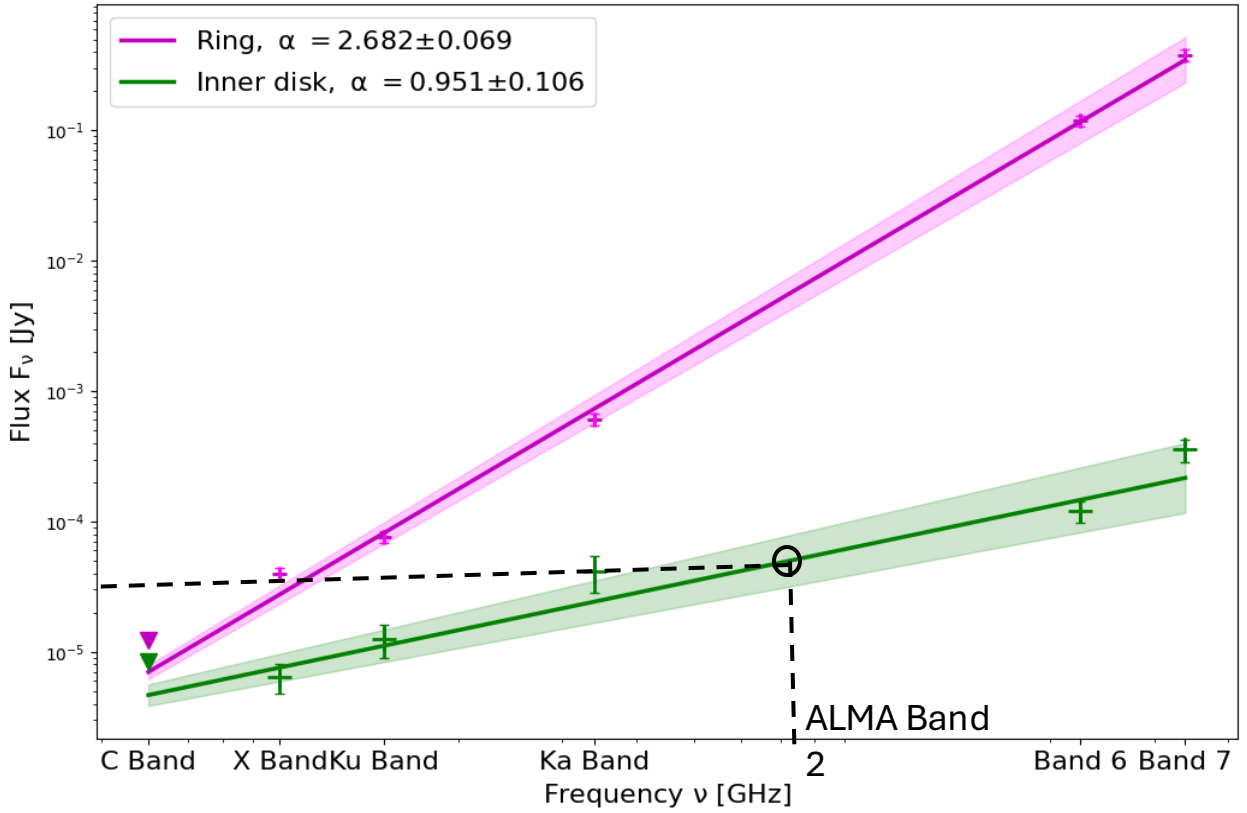
Spectral Energy Distribution (SED)

The integrated intensity at each wavelength for each part of the disk : $\mathbf{F_\nu = \Sigma\, I_\nu \Delta v \times \theta_{Beam}}$, with θ_{Beam} the beam size of each map
Each map is at their native resolution
The estimated error for each flux is defined as : $\mathbf{\sqrt{(F_\nu \times 10\%)^2 + (rms)^2}}$

Spectral index computation :
$\mathbf{F_\nu \propto \nu^\alpha}$, **α is the spectral index**

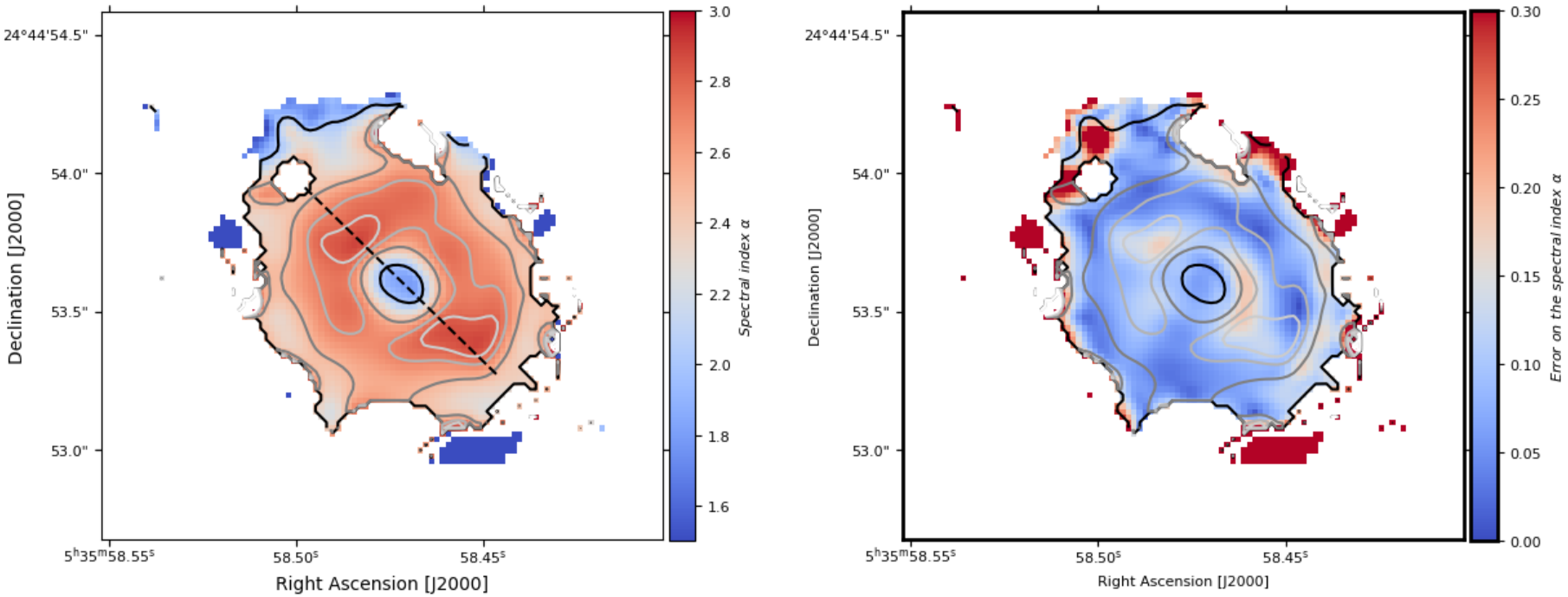
Results :
α = 2.682 ± 0.069 for the ring
α = 0.951 ± 0.106 for the inner disk
Significantly different values

- a dust dominated ring
- at least a free-free contaminated inner disk



Analysis of the ring

Computation of a spectral index map (left) and the associated error (right)



Mean value over the ring α = 2.67 ± 0.08

Values of α over the ring from 2.0 to 2.9

➔ Confirmation of a dust dominated ring

➔ Variations over the ring that seems to trace the asymmetries seen in all maps

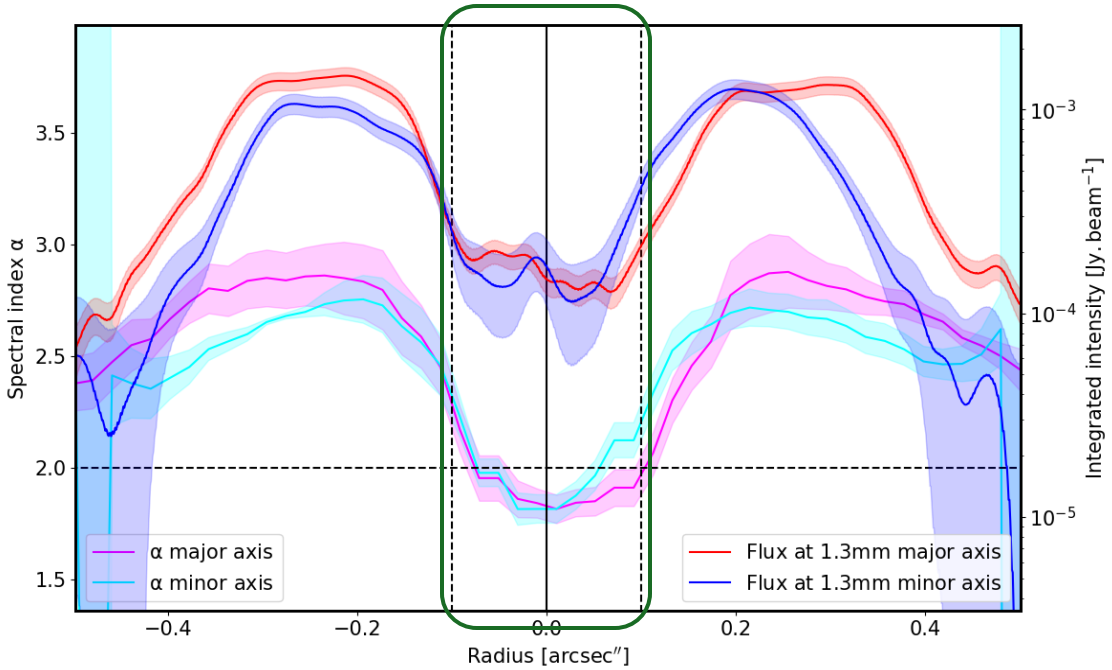
➔ **Weird pattern:** Increase of the value of the spectral index with the asymmetries ➔ **we need new data (ALMA Band 2)**

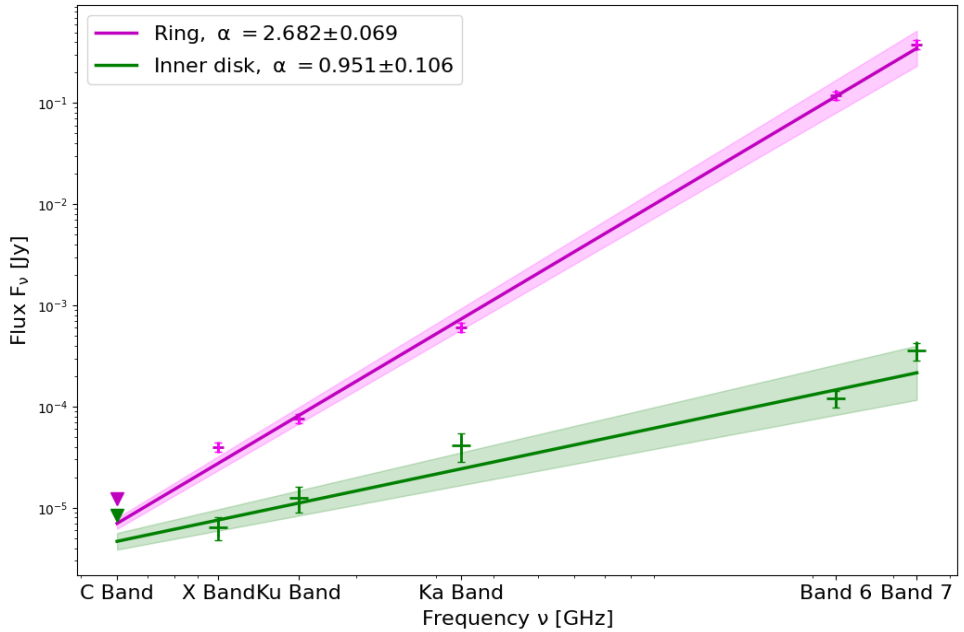
Analysis of the inner disk

Value : α = 0.951 ± 0.106

Lowest value of **α** corresponding to the peak in emission seen in the Band 6 and Band 7 maps (the inner disk)

Value of α ~ 0.9 : higher than optically thin free-free emission **(α = -0.1)**, and slightly higher than a partially optically thick ionized wind **(α ~ 0.6 - 0.7)**





→ Mix of free-free emission and dust thermal emission within the inner disk, most likely **partially optically thick stellar ionized wind**

Separation between free-free and dust

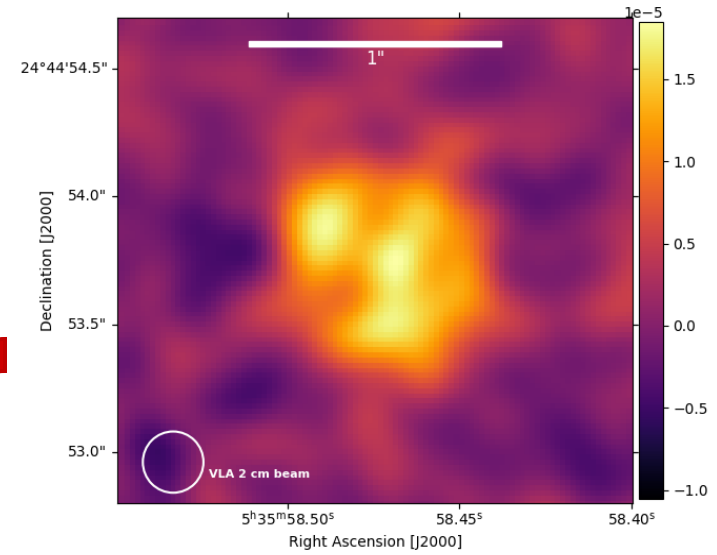
Comparison with models

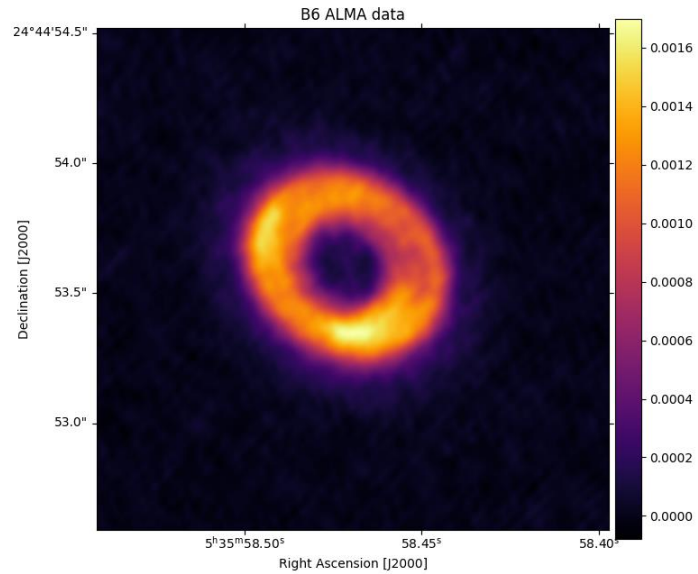
Using all VLA bands for which we have detection : X, Ku and Ka
And making the following hypothesis :

- Spectral index between an optically thin free-free dominated emission **(α = -0.1)** and a partially optically thick and ionized stellar wind **(α ~ 0.6-0.7)**
- Percentage of the flux in the VLA maps between **30% and 100%**

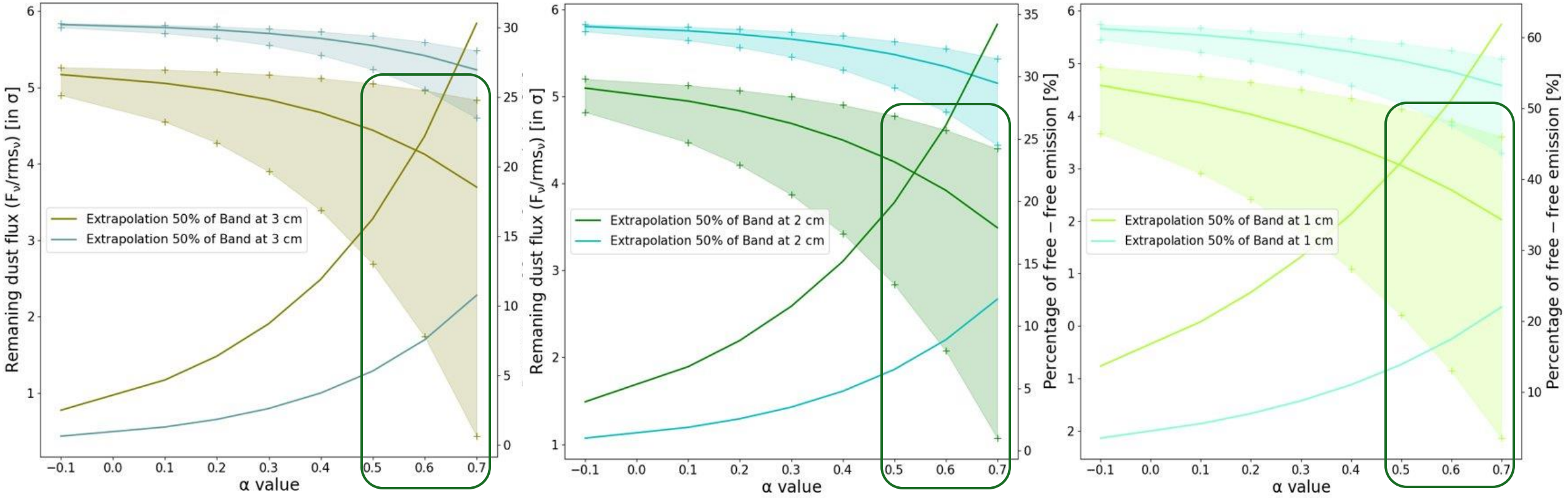
We extrapolate the equivalent "free-free emission" of the one at cm at 1.3mm and 0.9mm and remove the contribution to see what remains
→ **In theory : pure dust map**

$F_\nu \propto \nu^\alpha$





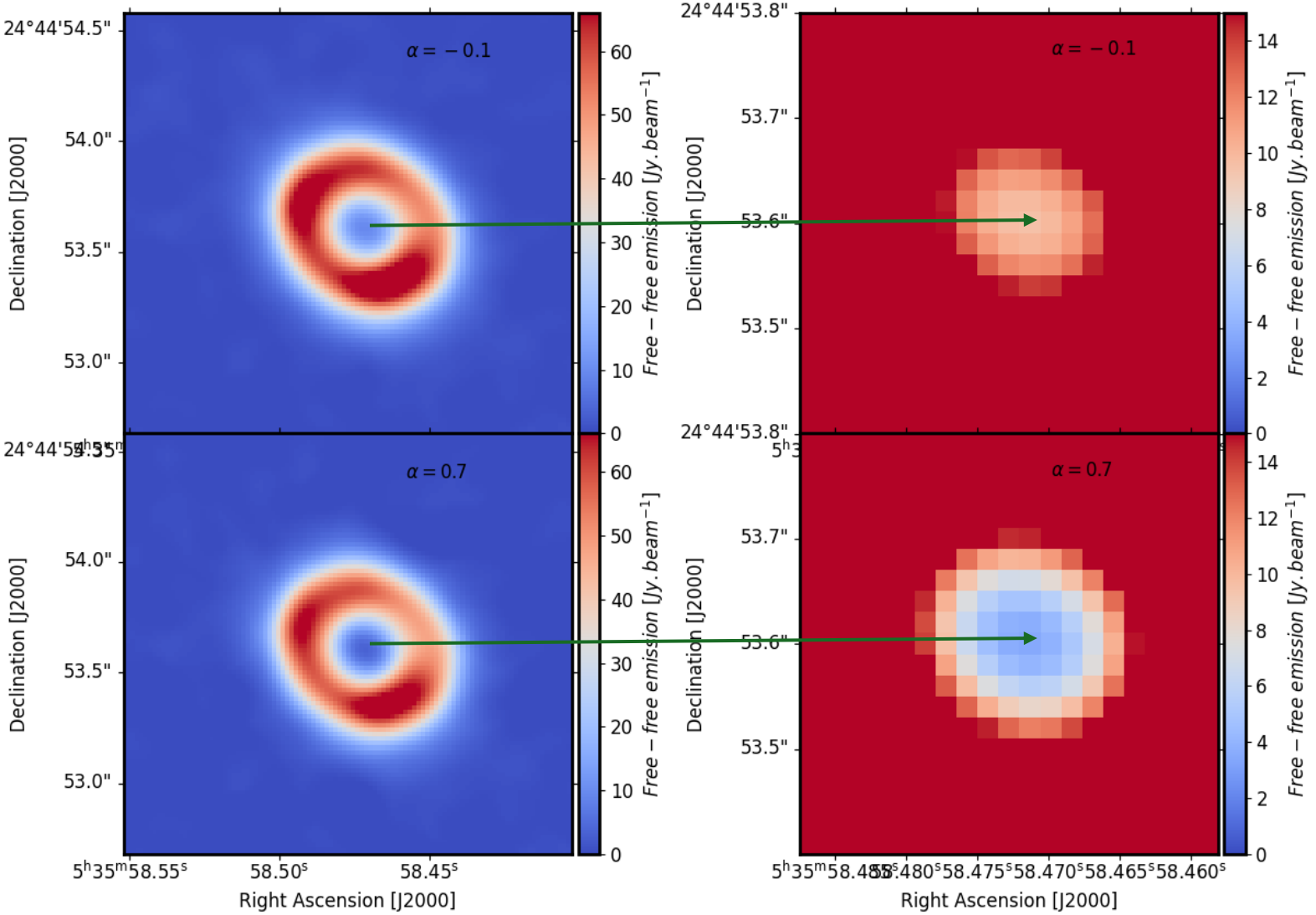
Free-free emission in the inner disk



When doing the computation only for the inner disk : for all VLA band, we can find a scenario that (fully) explains the emission at 1.3mm, which is not the case at 0.9mm.

This scenario is always compatible with **an ionized stellar wind and a significant part of the VLA map due to free-free emission**

Free-free emission in the inner disk

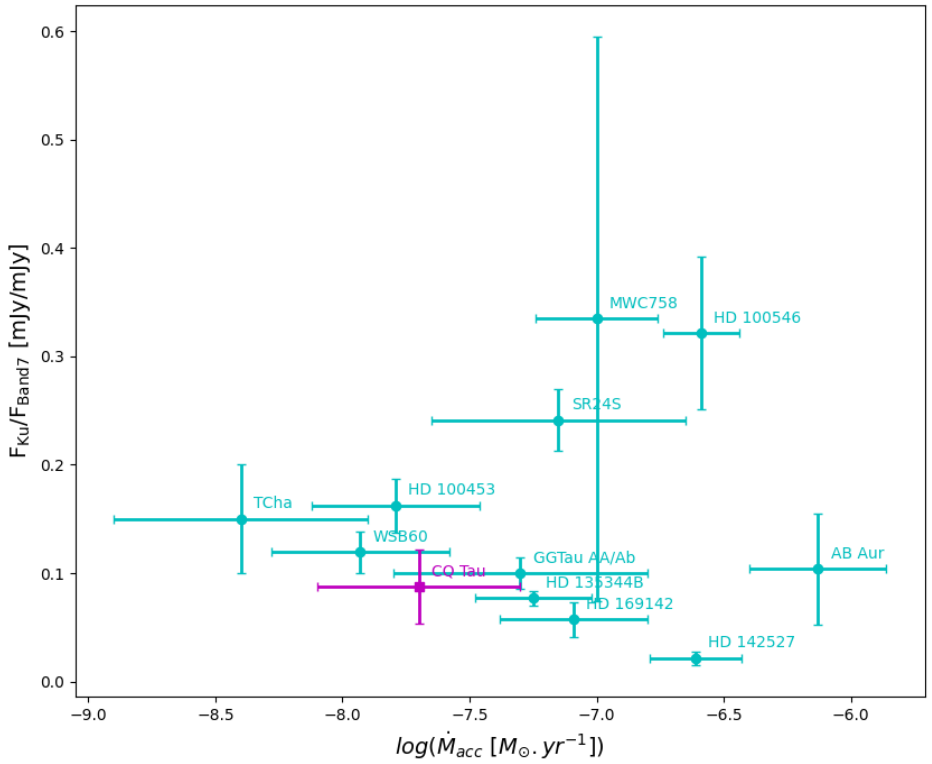


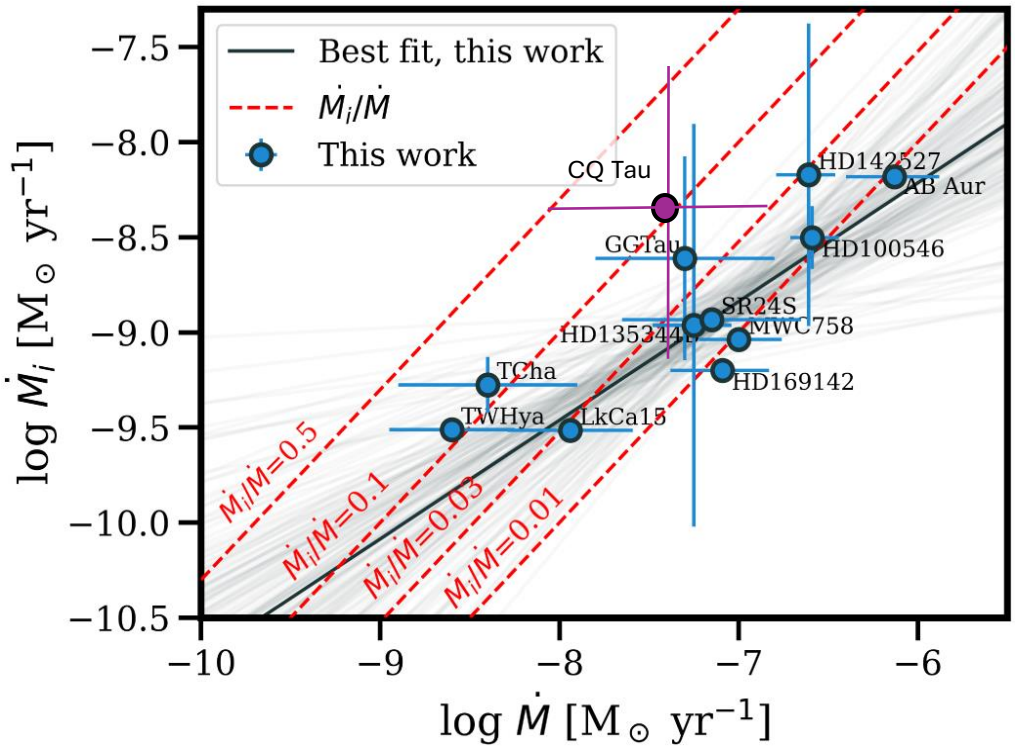
For the **Ku band at 2cm**, extrapolated at 1.3mm, and estimate that **100% of this band is due to free-free emission.**

In the inner disk, emission reamins for low values of the spectral index (optically thin free-free emission) but becomes not significant for higher value (α = 0.6-0.7)

→ **The emission seen is compatible with an ionized stellar wind, even for the convolved map at 1.3 mm**

Accretion and free-free emission





Rota et al., 2024

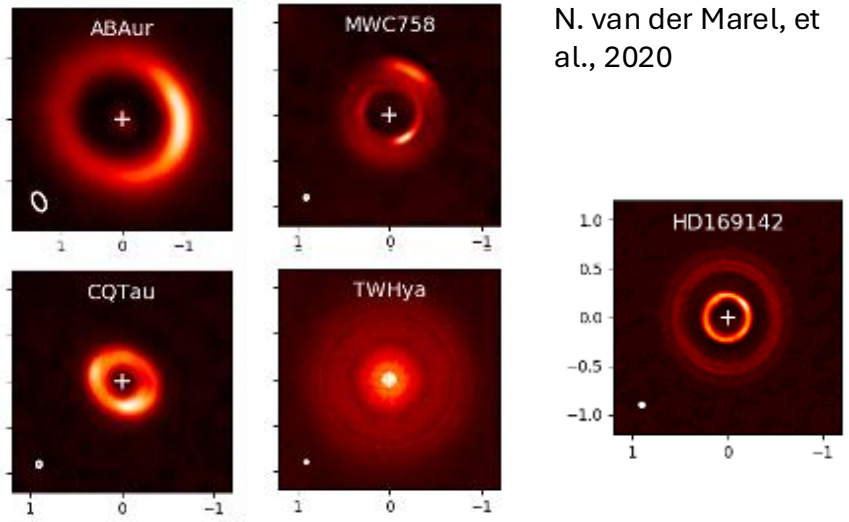
Derived values of the 1. mass accretion rate and 2. spectral index for the inner disk compatible with values found either for TDs or full disk (*Rota et al. 2024*, *Garuffi et al. 2025* & *Rota et al. 2025)*

→ **No matter the nature of the disk, the inner disk always have the same nature, what change is the efficiency of accretion and ejection**

→ **In any case, as soon as the protostar star starts ionizing the disk, the accretion becomes low**

Next steps …

- **Ask for observations :** fill the gap between ALMA and VLA observations with ALMA Band 2 (higher resolution, brighter, opt thin, RRL detection, …)
- **Extend to other objects**, at least the following 10 : AA Tau, AB Aur, DM Tau, GM Aur, Mwc758, HD 169142, SR 24A, V4046 Sgr, WSB60, TW Hya



N. van der Marel, et al., 2020

National Radio Astronomy Observatory

Thank you for your attention !