The protoplanetary disk HD164192

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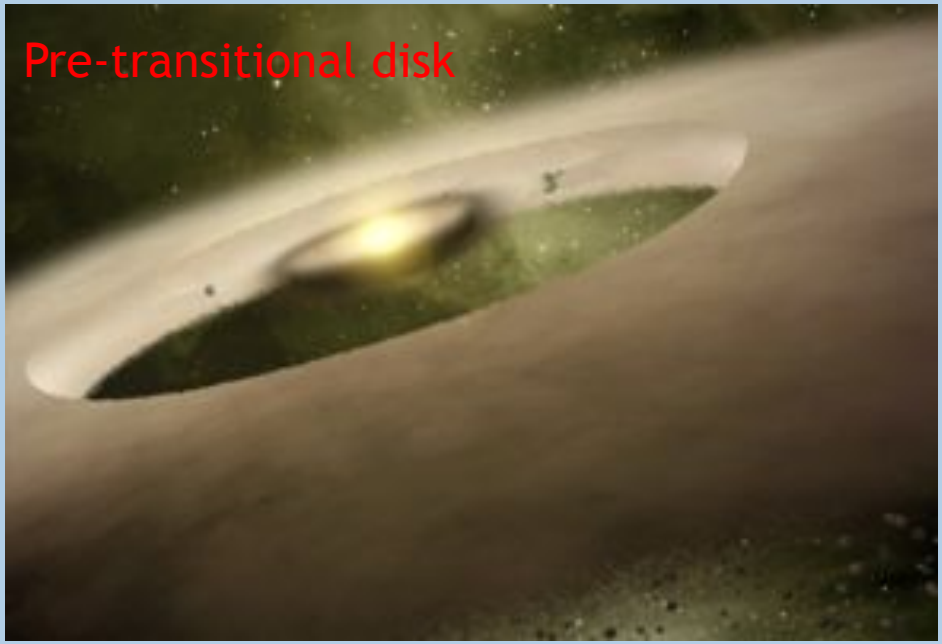
Transitional disks

Transitional disks have a deficit of flux in the near and mid infrared range and large fluxes at long wavelengths (Calvet et al 2002, 2005). They dot no have dust grains in the inner region, but this region is full of gas because the star is still accreting.
Espaillat et al. (2007, 2008) noted that a number of these disks have a small inner disk of dust inside the central gap and called these objects **Pre-transitional disks**.



Inner holes have been explained by several mechanisms:

- Photoevaporation of the disk (Alexander et al. 2006).
- Geometric shadowing (Dullemond & Dominik 2004).
- Grain growth in the inner disk (van Boekel et al 2005).
- The presence of another body that dynamically creates a gap and decouples the inner disk from the outer disk (Augereau & Papaloizou 2004).

In most cases, the presence of gaps has been inferred from the modelling of the SED in the mid-IR.

Spitzer IRS has been crucial to do that.

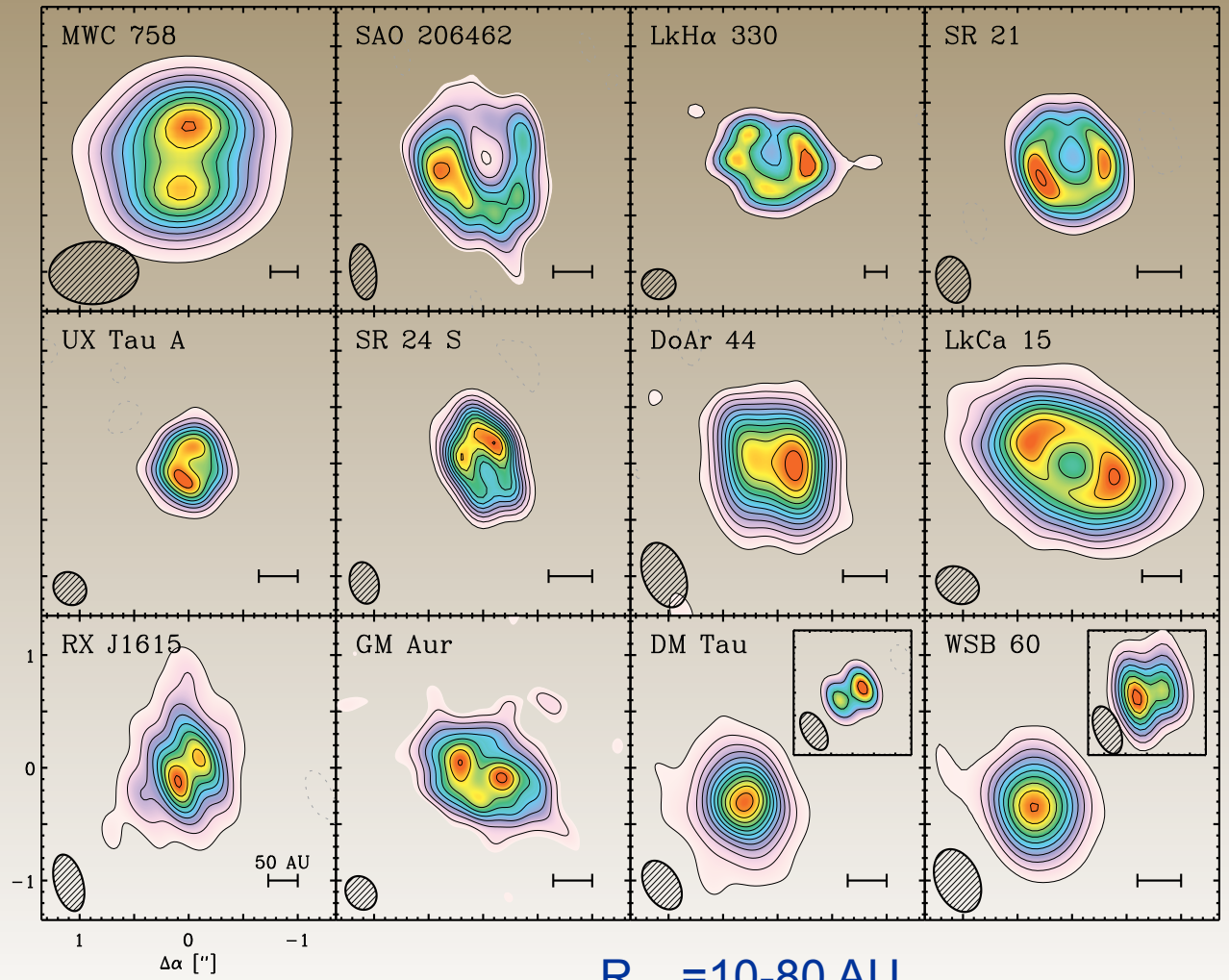
Disks and planet formation

Holes and cavities observed at radio wavelengths

Only a few cases have been identified through direct imaging.

SMA (880 μm)

Andrews et al (2011)



R_{cav}=10-80 AU

HD 169142

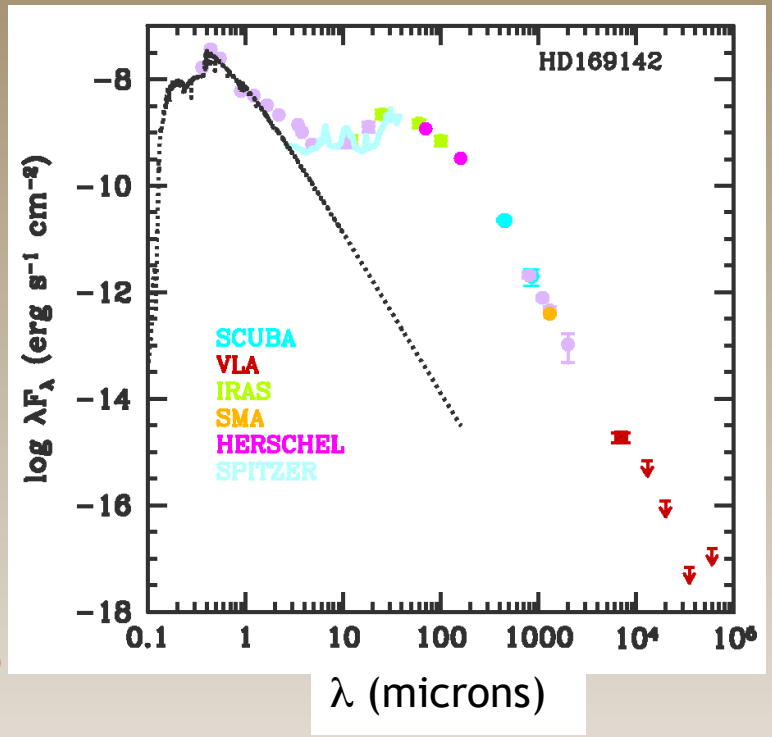
Relatively isolated Herbig Ae/Be star (nearest star at ~9”)

Stellar mass = 2 $M_\odot$

Spectral type: AV5 (Grady et al 2007)

Age = 2-10 Myr (Meeus et al 2001)

Distance = 145 pc (Sylvester et al 1996)

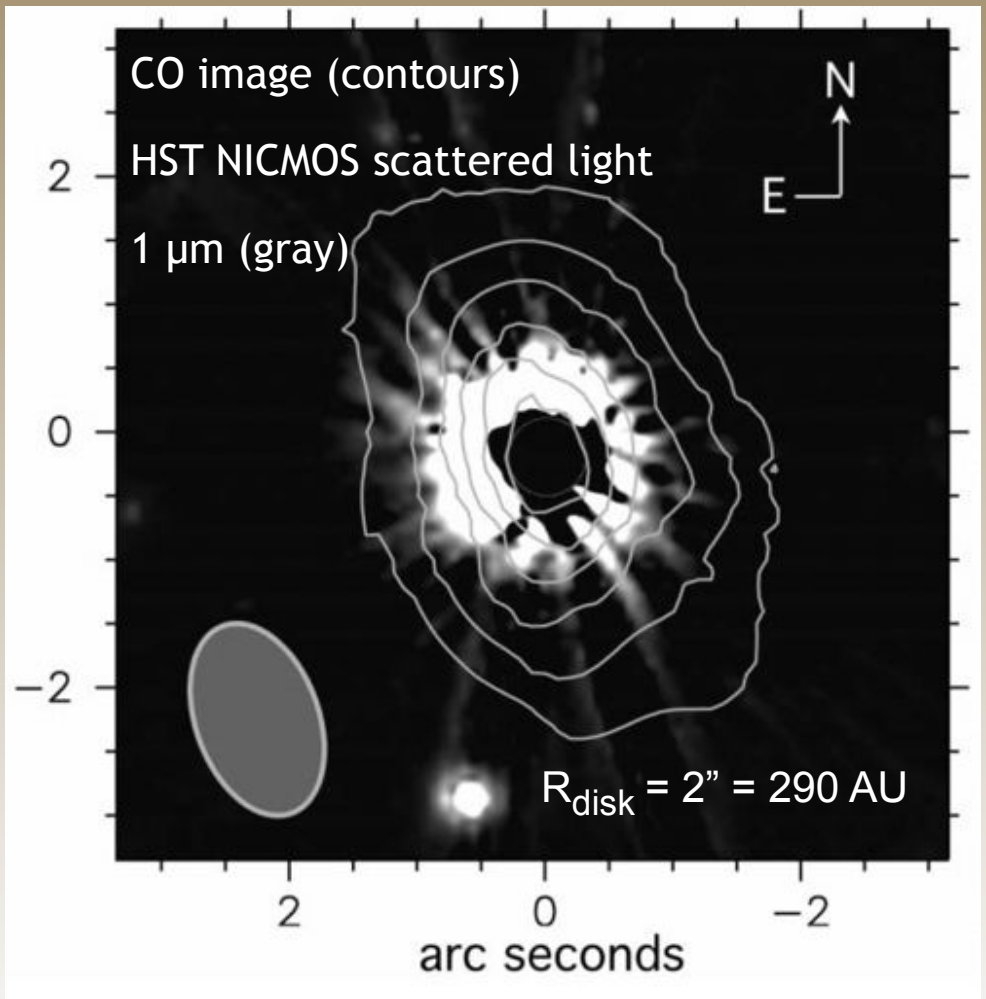


Characteristics of the observed SED:

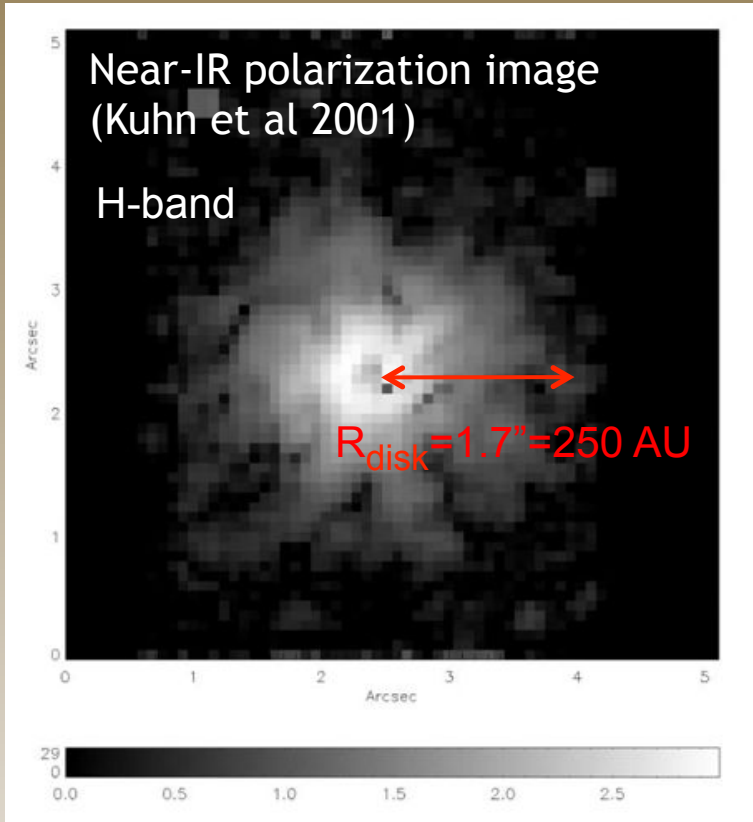
- Infrared excess.
- A spectral index of ~2.5 in the mm-submm range, implying a shallow dependence of dust opacity with frequency ($\kappa_\nu \propto \nu^{0.5}$)=>large grains.
- Absence of 10 μm Silicate absorption=>large grains.
- No cm emission according to our data. Therefore, no radio jets and negligible free-free contamination.
- Because a radio jet is not detected, the mass infall/ outflow is likely halted.
- The absence of large-scale nebulosity suggests that the envelope is gone and that the far-IR emission is dominated by the disk (Meeus et al. 2001).

Previous imaging of the HD 169142 disk

Previous observations suggest a nearly face-on disk extending up to a scale of 250 AU.

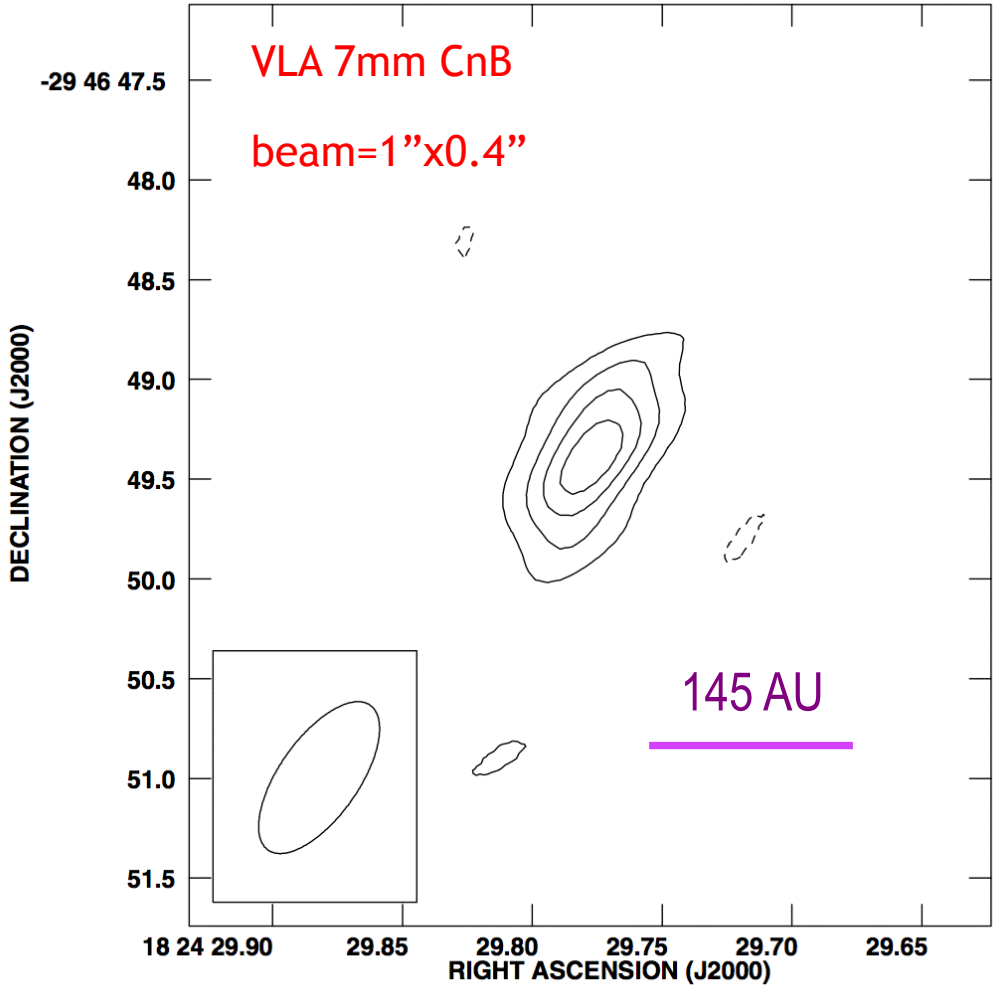


(Raman et al. 2006; Grady et al. 2007)



2006, Panic et al. 2008, Grady et al 2007

VLA observations at 7 mm (epoch 2002)



Epoch: 2002 (Dent et al. 2006)

- Relatively strong (4mJy) 7mm emission.
- Source unresolved (< 1”). Emission at 7 mm corresponds to the central part of the disk (r < ~80 AU, while R_{disk}=250 AU)
- Problem: elongated beam because of poor uv coverage and low declination of the source.
- At 3.6 cm the source was not detected

HD 169142 disk SED

In Dent et al. (2006) we also modeled the SED, including photometric data from the literature and our 7mm measurements, using irradiated accretion disk models (tabulated in D'Alessio et al. 2005).

The observed SED can be understood in terms of a single disk with a scale ranging from 3 $R_\odot$ to 300 AU. The emission at λ <10 μm is dominated by the stellar and the wall contributions (T=1400 K).

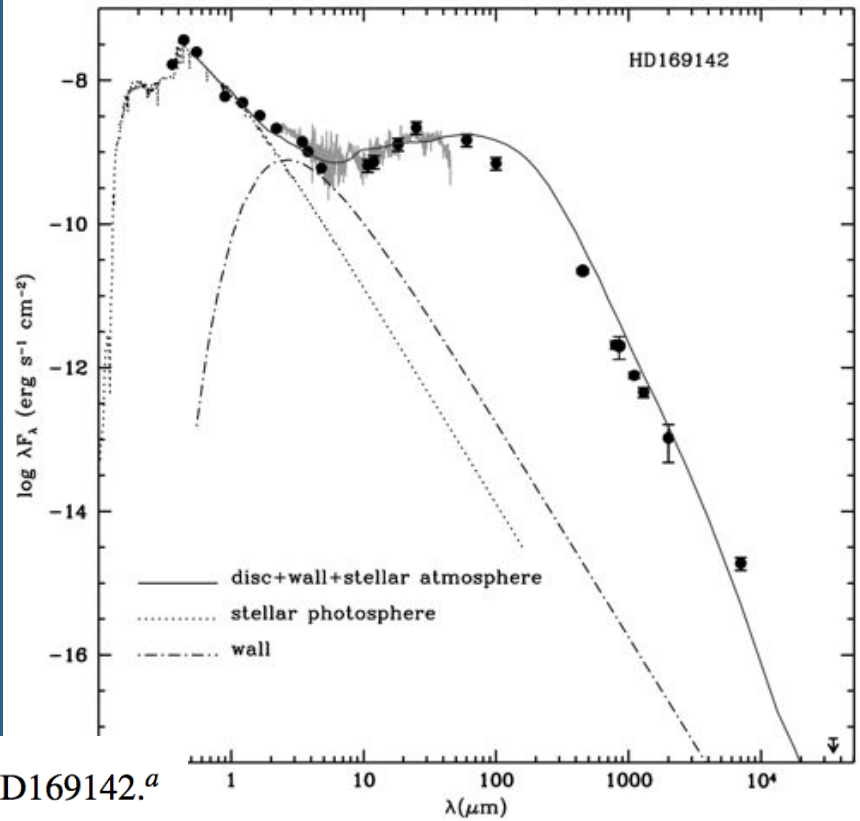


Table 3. Adopted parameters of the circumstellar disc around HD169142.[a]

Age (Myr)	$\dot{M}_{acc}$ ($M_\odot$ yr^{-1})	L_{acc} ($L_\odot$)	R_{wall} (au)	R_{disc} (au)	M_{disc} ($M_\odot$)	i (deg)	a_{max} (mm)	z_{wall} (au)
10	10^{-8}	0.37	0.35	300	0.04	30	1	0.018

[a]Obtained by modelling the observed SED (see Section 3).

Dent et al. 2006

Later UV observations indicate a lower mass accretion rate (Grady et al. 2007)

VLA observations (2012)

In order to get a high quality image of the disk at 7mm, in 2012 we requested several VLA configurations to combine all the data together to obtain an image where all scales are well sampled.

Because the source has a very low declination we requested for hybrid configurations.

We benefited from the large BW and improved sensitivity of the Expanded VLA.

SUMMARY OF 2012 VLA CONFIGURATIONS:

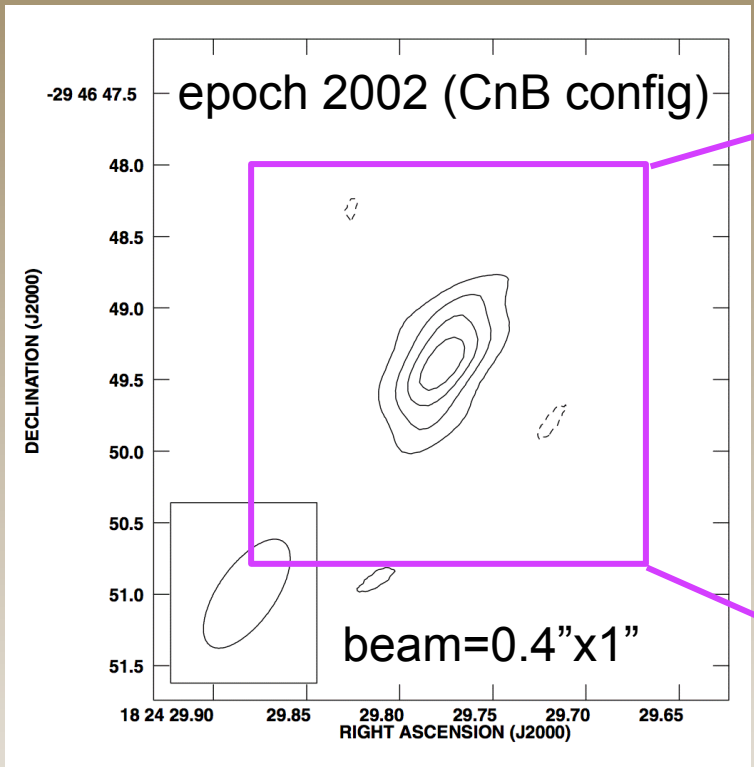
CnB configuration (beam ~0.5”)

BnA configuration (beam ~0.2”=30 AU) BAD WEATHER

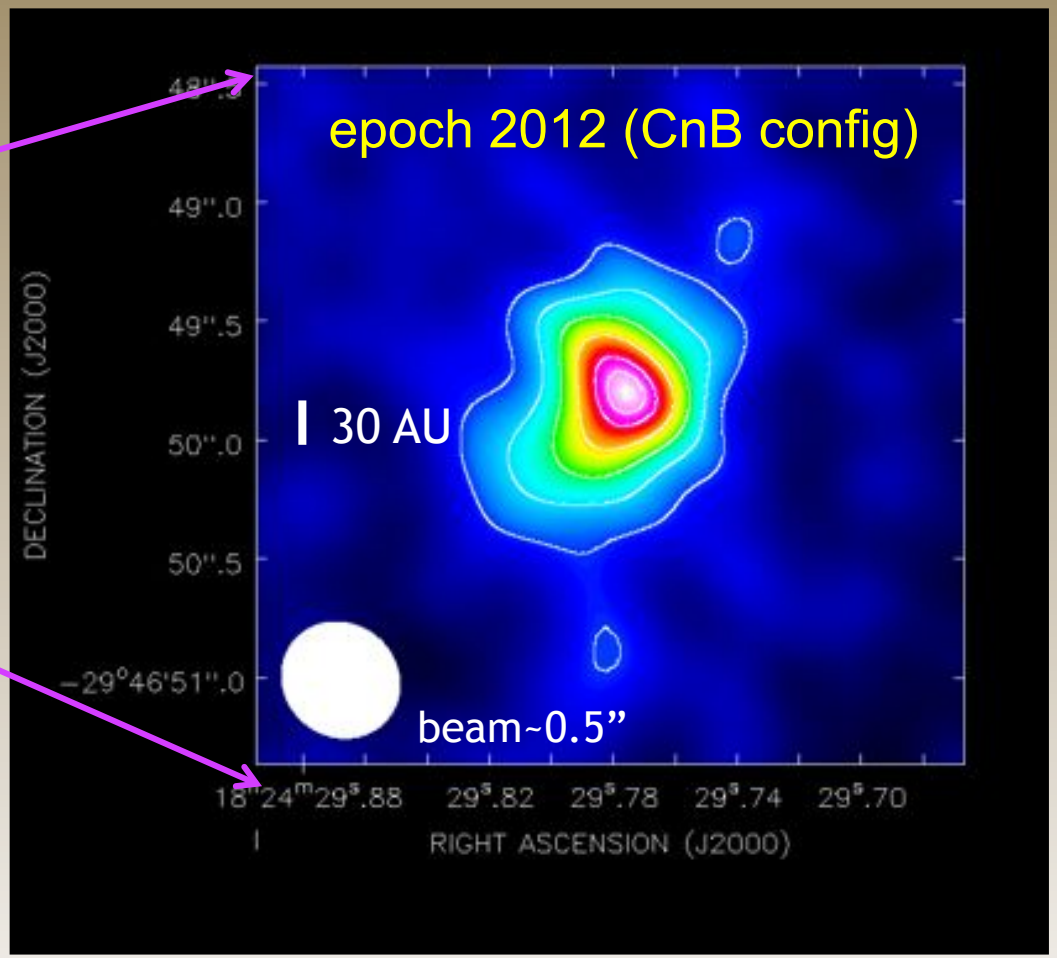
A configuration (beam ~0.1” (x0.05”)=15 (x8) AU)

We also carried out DEEP 6cm observations that show that there is no free-free contamination in this source.

VLA 7 mm observations epoch 2012

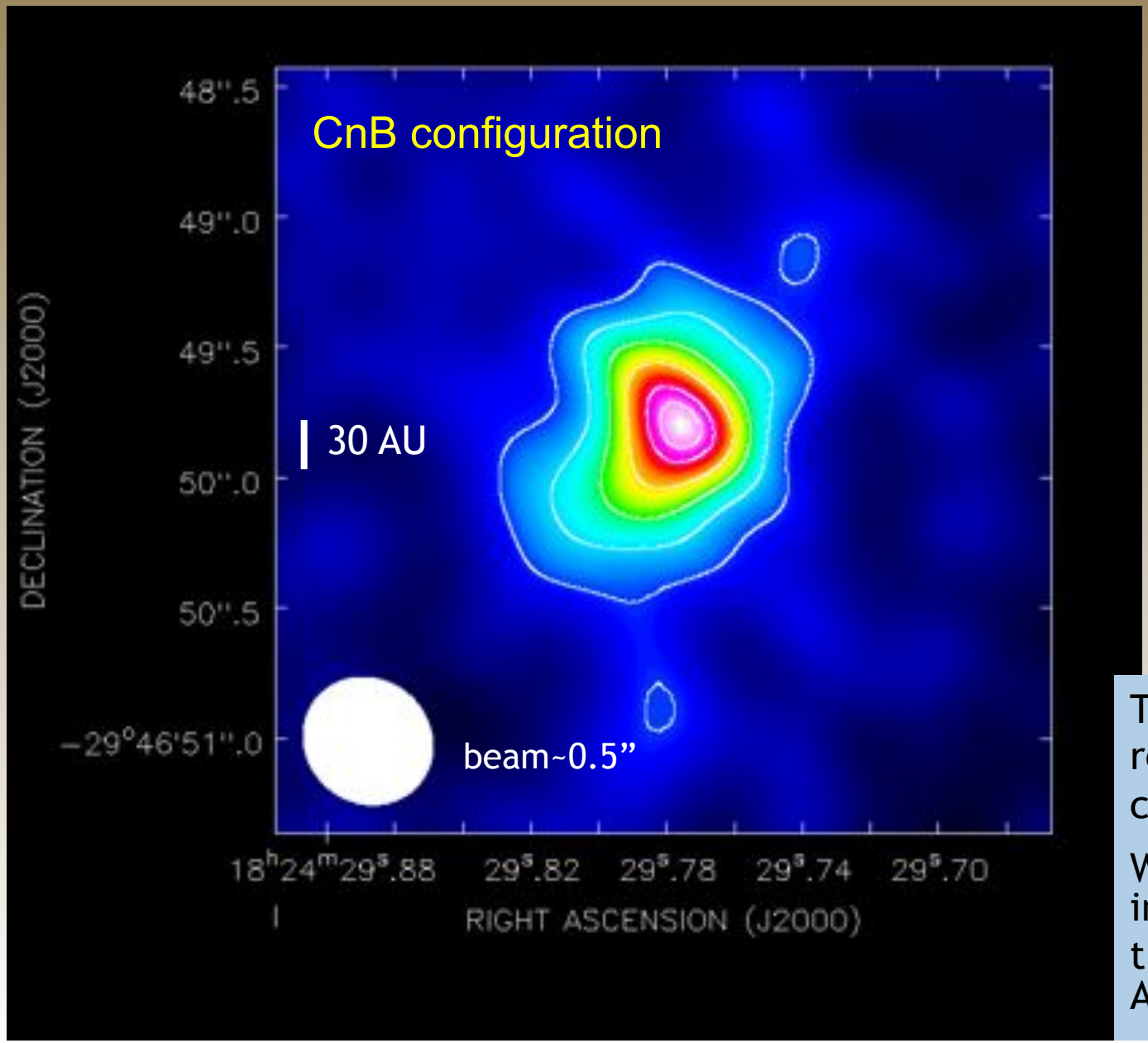


The beam of the 2002 CnB observations is very elongated.



The beam of the 2012 CnB observations is nearly circular (better uv coverage).

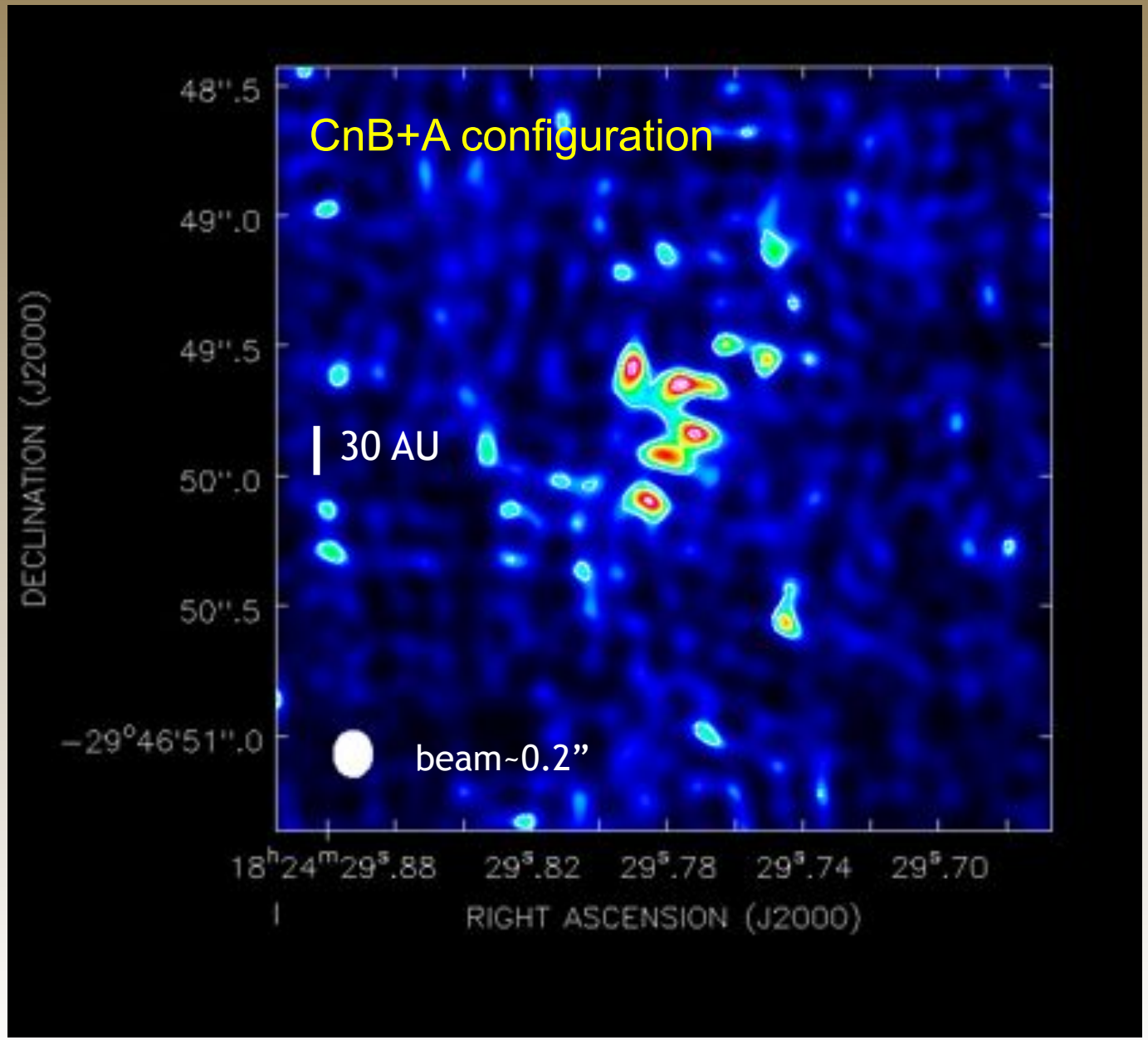
VLA 7 mm observations epoch 2012



The source is angularly resolved, suggesting a curved shape.

We are observing the inner part (r<90 AU of the disk; R_{disk} ~250 AU).

VLA 7 mm observations epoch 2012



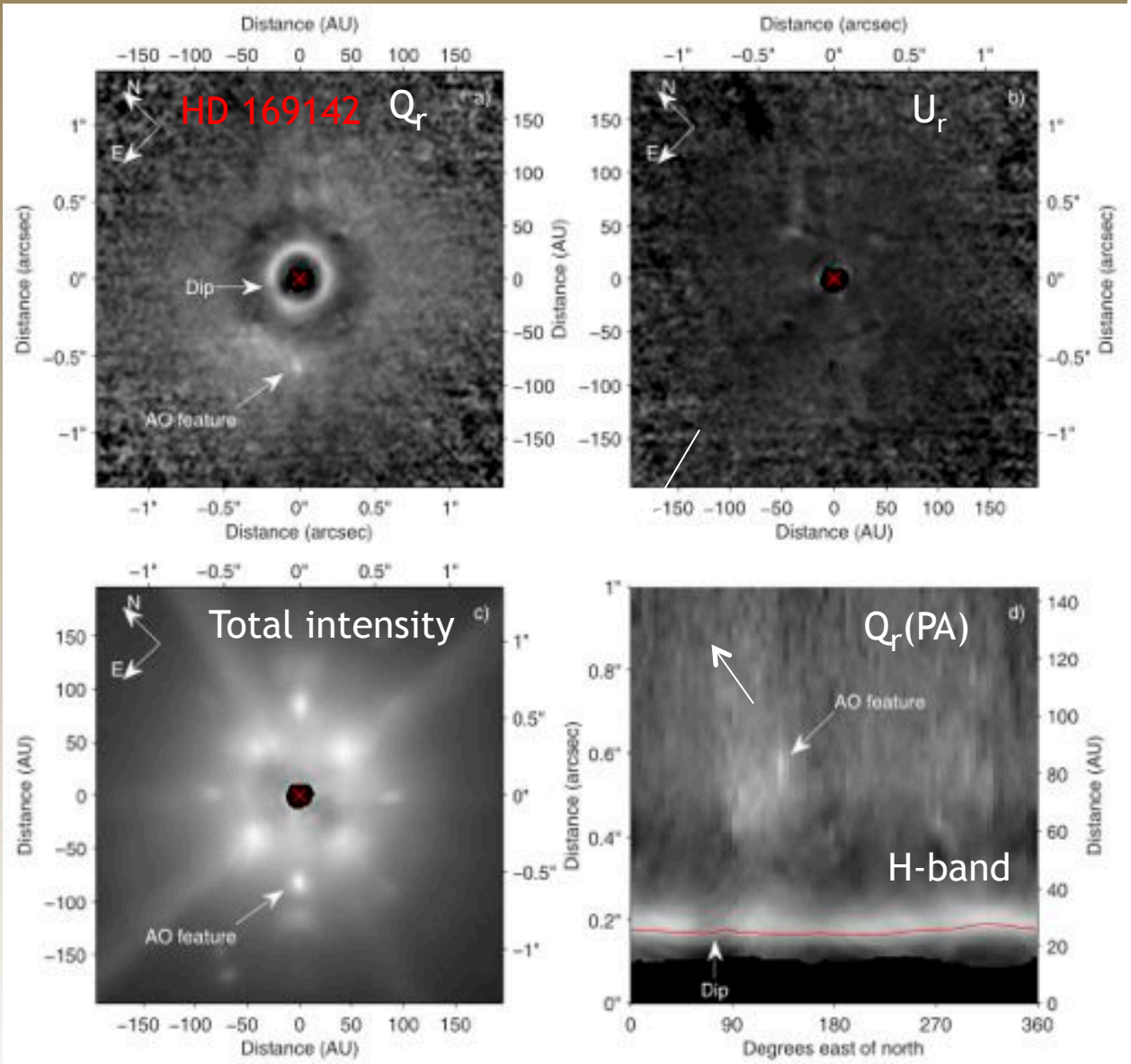
The CnB+A map shows a clumpy substructure, at scales ~20 AU that roughly follows the CnB map shape.

H-band VLT/NACO polarized light images (Quanz et al 2013)

Very recently, Quanz et al. (2013) reported IR polarimetric imaging of HD 169142 with the VLT.

Our VLA and the VLT observations were almost simultaneous.

These observations trace a face-on disk extending up to 1.7” (250 AU).



H-band VLT/NACO polarized light image

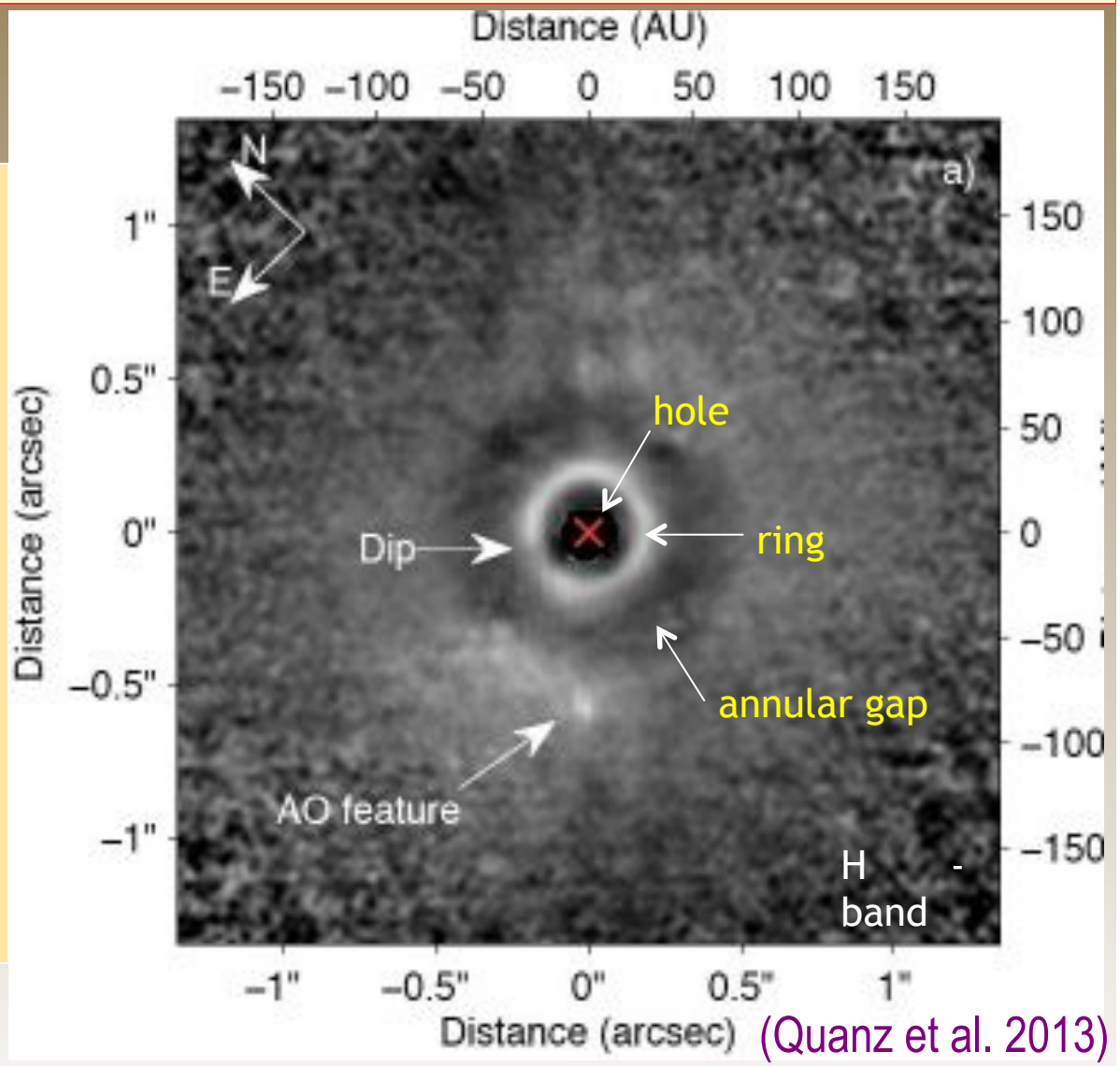
-Hole: r<20 AU (but the central part is hidden by the mask)

-Bright ring: r=20-25 AU

-Dip (real or due to properties of dust grains)

-Annular gap: 40 AU<r<70 AU

All these features might be signposts of planet formation



(Quanz et al. 2013)

poster 2.12 by A. Garufi

COMPARISON IR – 7mm

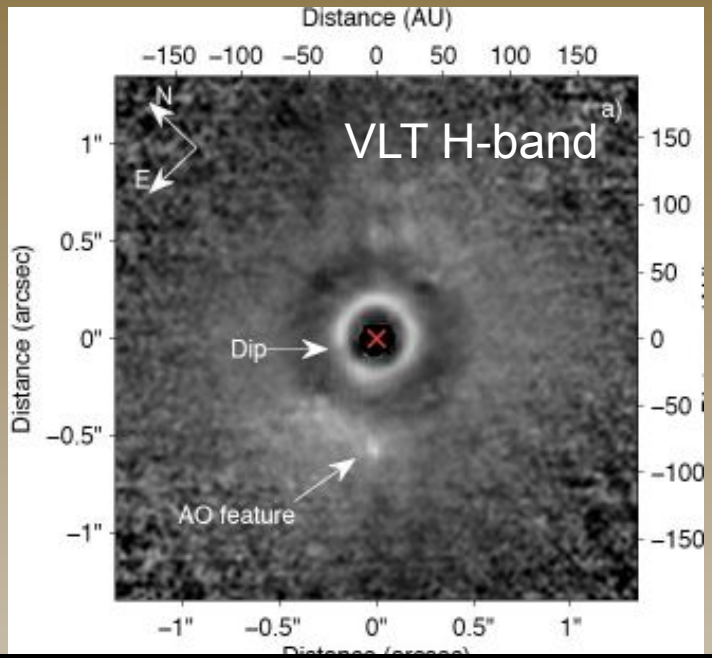
At 7 mm we do not detect directly the star. In order to compare our VLA image with the IR polarized image, we need to know very precisely the absolute coordinates of the star.

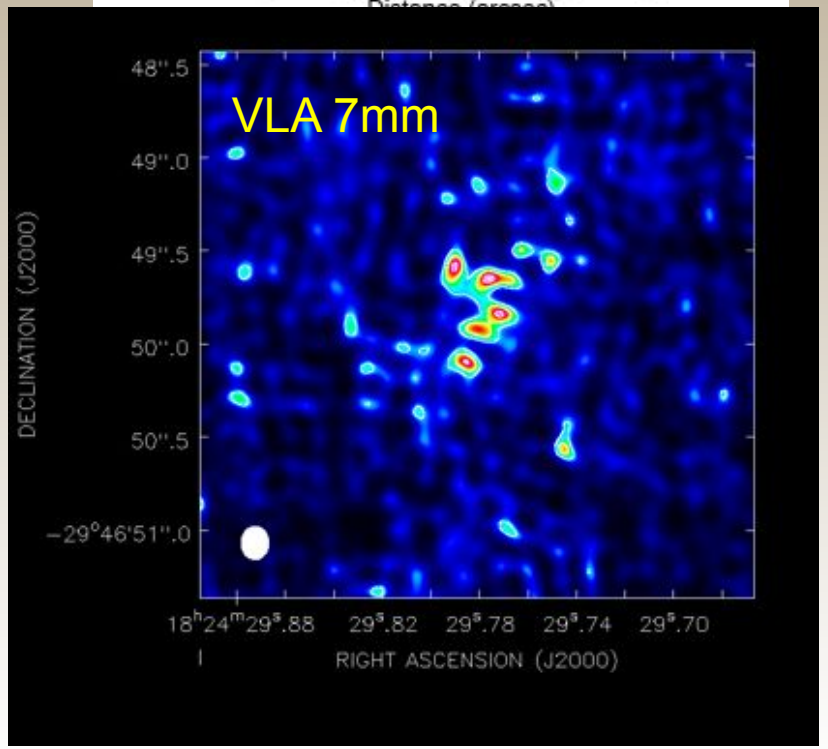
However, catalog positions have nominal errors of ~0.05” (~8 AU).

Optical (Tycho-2) and 2MASS positions differ by ~0.1”.

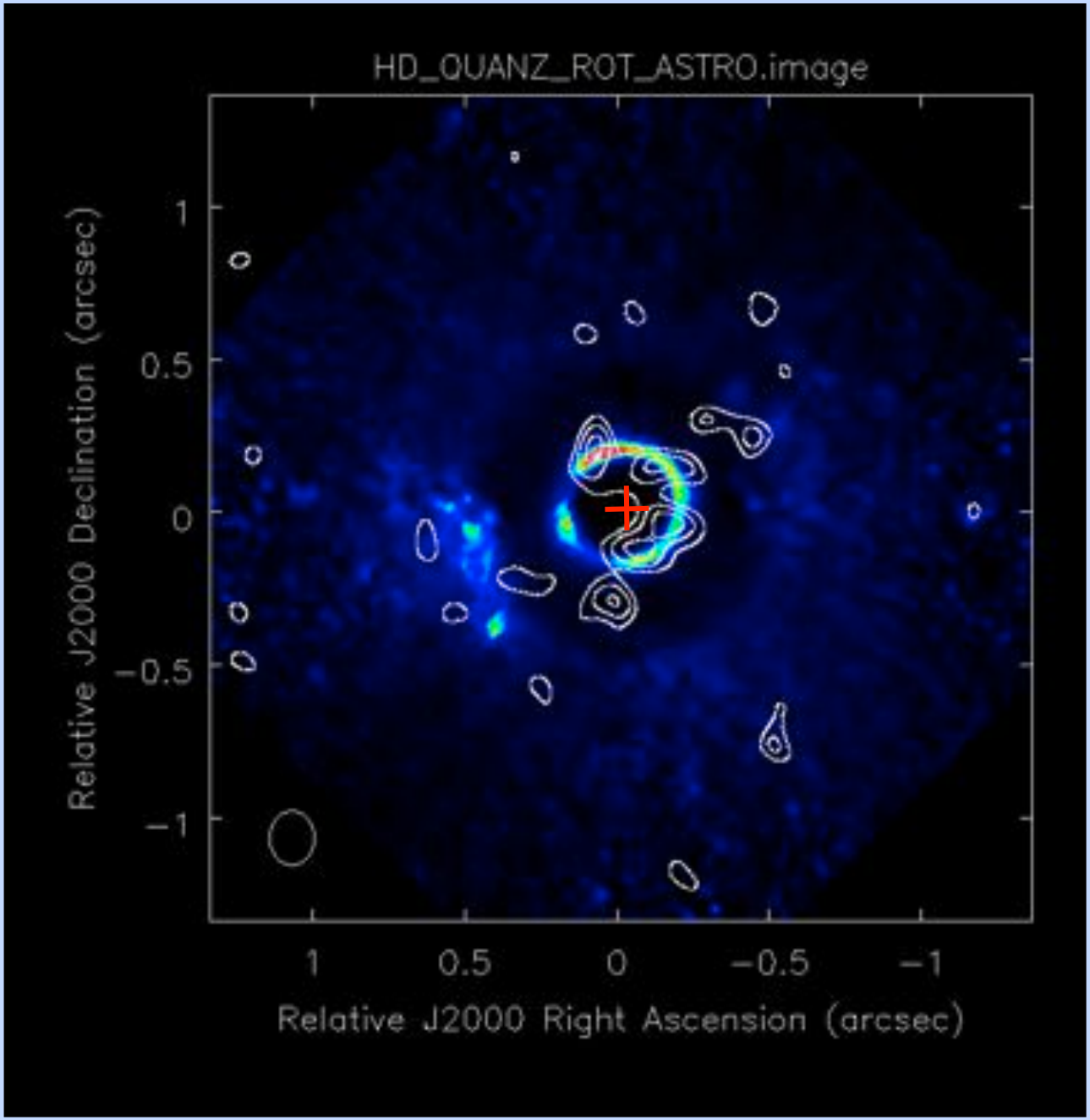
The star has significant proper motions (-2.1±1.5, -40.2 ±1.5 mas/yr) that must be taken into account to extrapolate the catalog positions to epoch 2012.9.

➔We adopt the 2MASS position corrected for proper motions as the star coordinates.

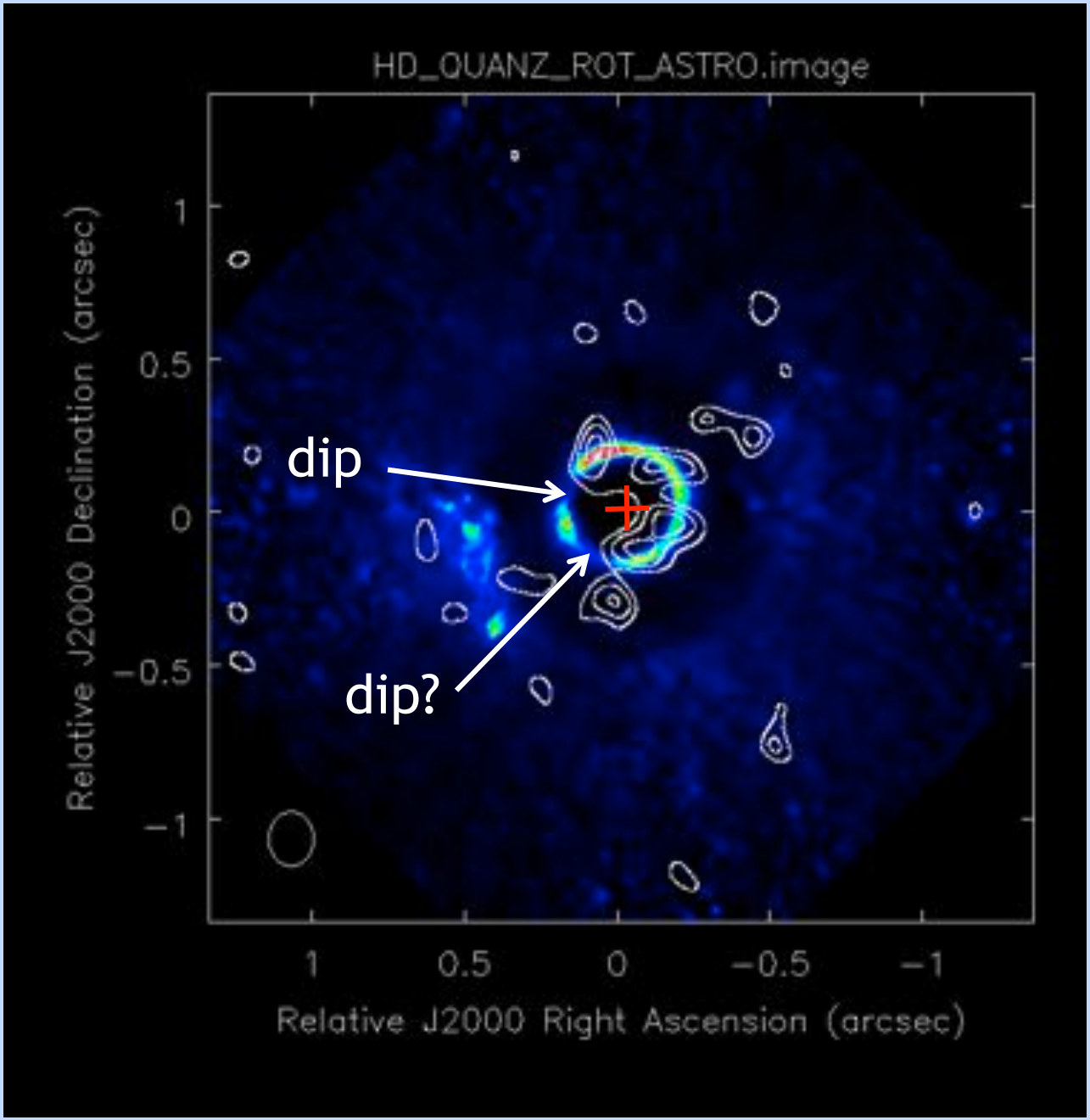




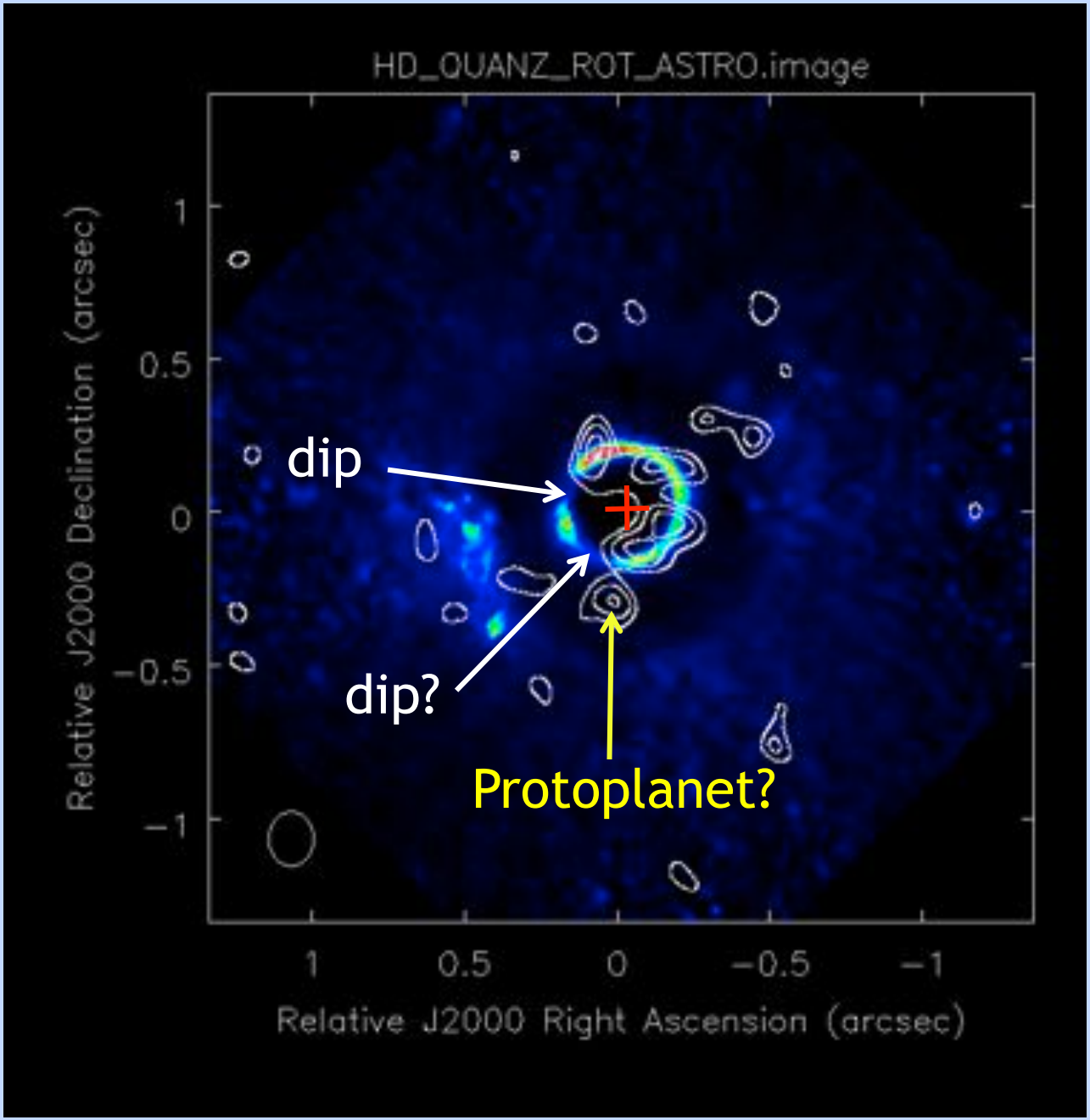
Centered on 2MASS position, corrected for proper motions



Centered on 2MASS position, corrected for proper motions



Centered on 2MASS position, corrected for proper motions



Centered on 2MASS position, corrected for proper motions

CIRCUMPLANETARY MATERIAL PROPERTIES:

$Flux_{7mm}$=0.15 mJy (5σ)

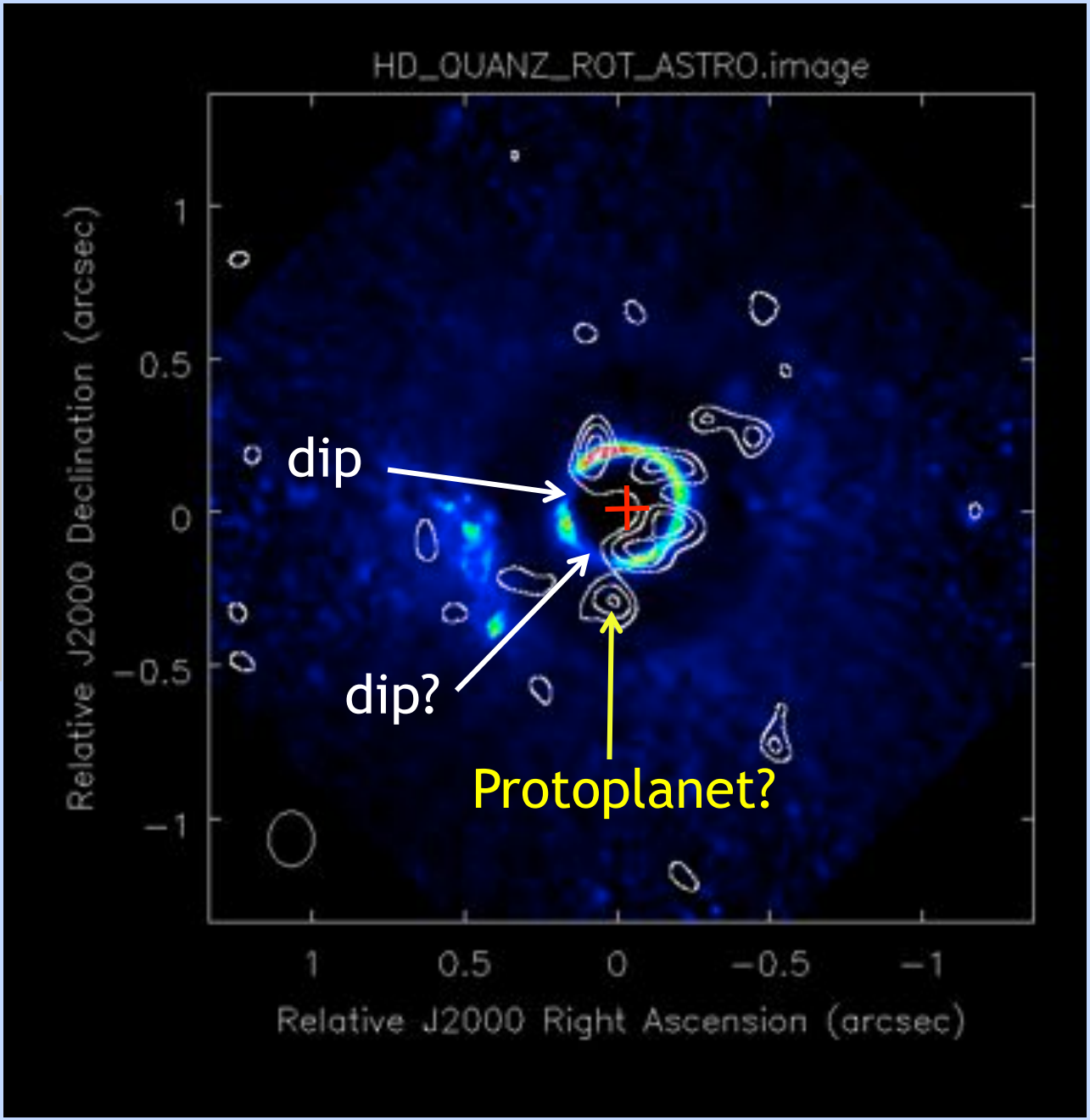
T_{dust}=100-300 K

κ_{7mm}=0.9-5 x 10^{-3} cm^2/g

Mass=2—0.2 M_J

For a 2 Msun star at 145 pc

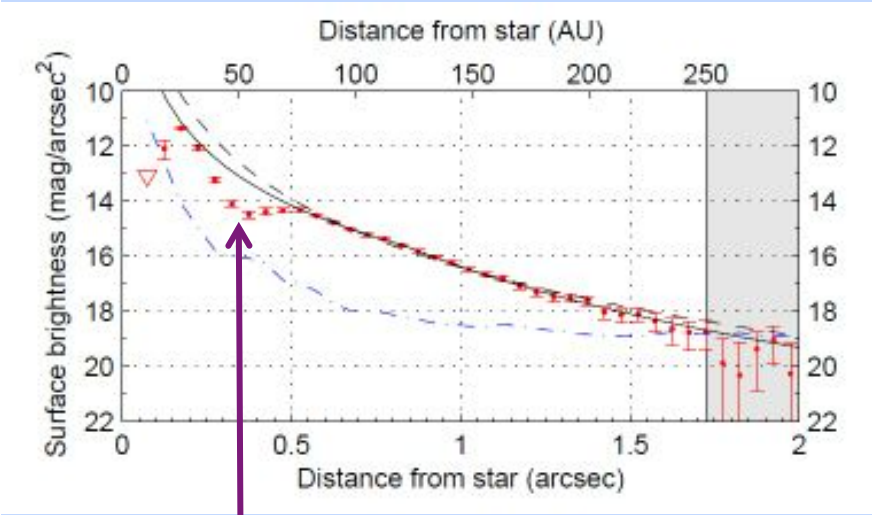
Orbital radius = 43 AU
Orbital period = 186 yr
Expected orbital proper motion in 5 yr = 0.3”

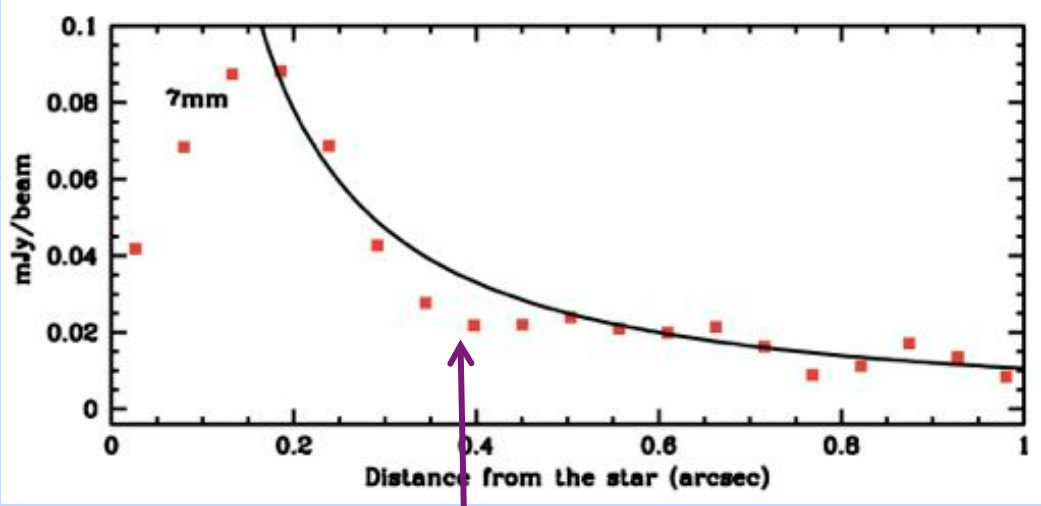


Radial intensity profile of the disk

Near IR azimuthally averaged surface brightness profile

7mm azimuthally averaged intensity profile





Quanz et al. 2013

40-70 AU gap

40-70 AU gap?

A model for the HD169143 disk

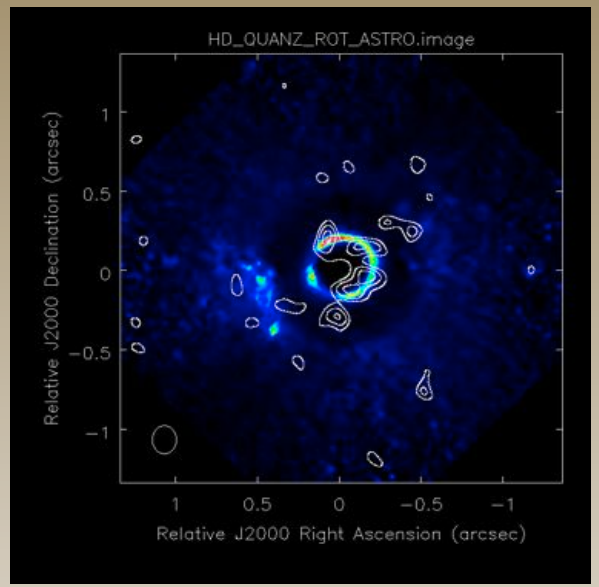
We need a disk that fulfills the following conditions:

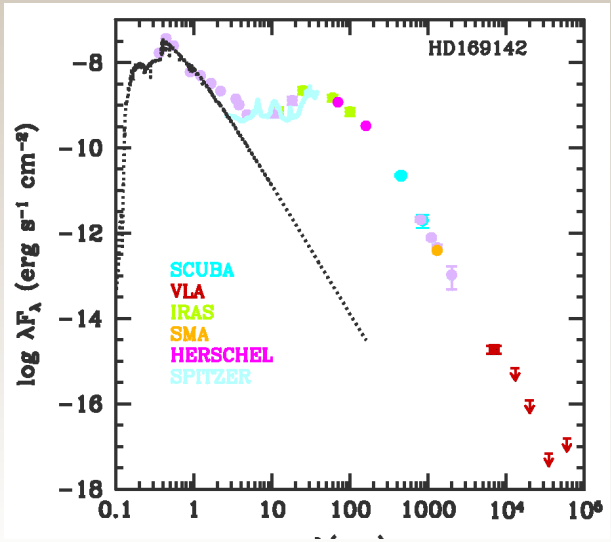
- No significant 7 mm emission (<0.06 mJy/beam) at r < 20 AU

- 7 mm emission at r=20 AU of 0.15 mJy/beam

- Fits the broad band SED

We did not attempt to reproduce the 40-70 AU gap, which probably is not completely empty (Quanz et al. 2013) and whose effects on the SED are probably small.





Flared irradiated accretion disk models (D'Alessio et al. 2006)

These models yield a vertical structure of the disk that is self-consistent with the stellar parameters (M_*, R_*, L_*), without using power-law approximations for the temperature and surface density profiles.

♣ The main heating mechanisms are:

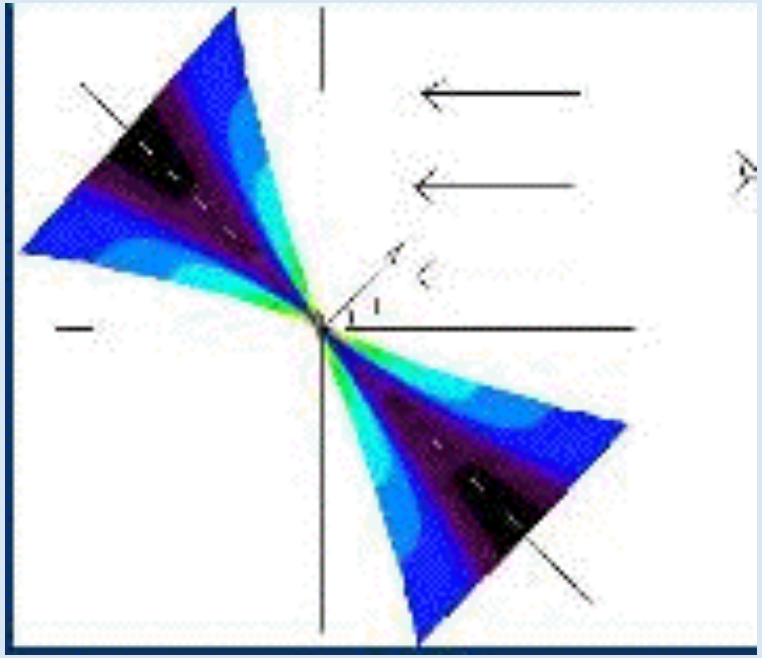
- Viscous dissipation
- Stellar irradiation

♣ The α-prescription (Shakura & Sunyaev 1973) is adopted:

$$\Sigma = M_{acc} / 3\pi\nu_{turb}$$

♣ Vertical settling of the particles in the disk mid-plane is included assuming a standard grain-size distribution $n(a) \sim a^{-p}$

- a_{min}=0.005 μm, a_{max}~1 μm (upper layers)
- a_{min}=0.005 μm, a_{max}~1mm-1cm (mid-plane)



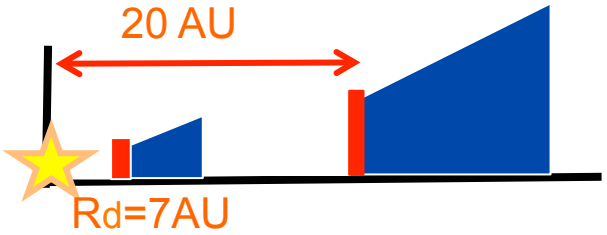
We have truncated the inner edge of the disk at a radius 20 AU, and added the contribution of a wall. Previous models have also considered a truncated disk for this source (Grady et al. 2007; Meeus et al. 2010; Honda et al. 2012)

Model should fulfill SED and 7mm constraints

Full disk (+wall)
+star

SED ✔
7mm ✗

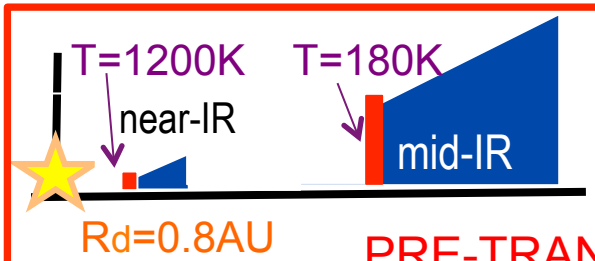
Predicts too much emission at r< 20 AU, in conflict with 7mm image!



Inner disk (+wall)
+ outer disk (+wall)
+ star

SED ✔
7mm ✗

Predicts too much emission at r< 20 AU in conflict with 7mm, image!

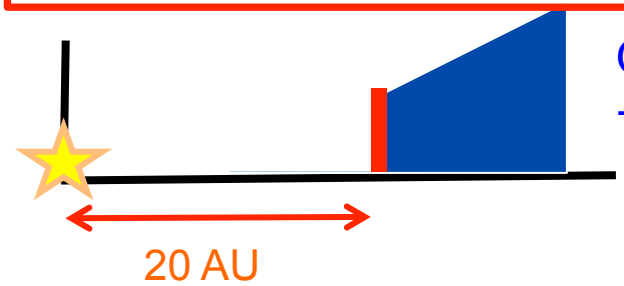


Small inner disk (+wall)
+outer disk (+wall)
+star

SED ✔
7mm ✔

Predicts little emission at r< 20 AU, consistent with the 7mm image

PRE-TRANSITIONAL DISK (as defined by Espaillat et al. 2007, 2008)



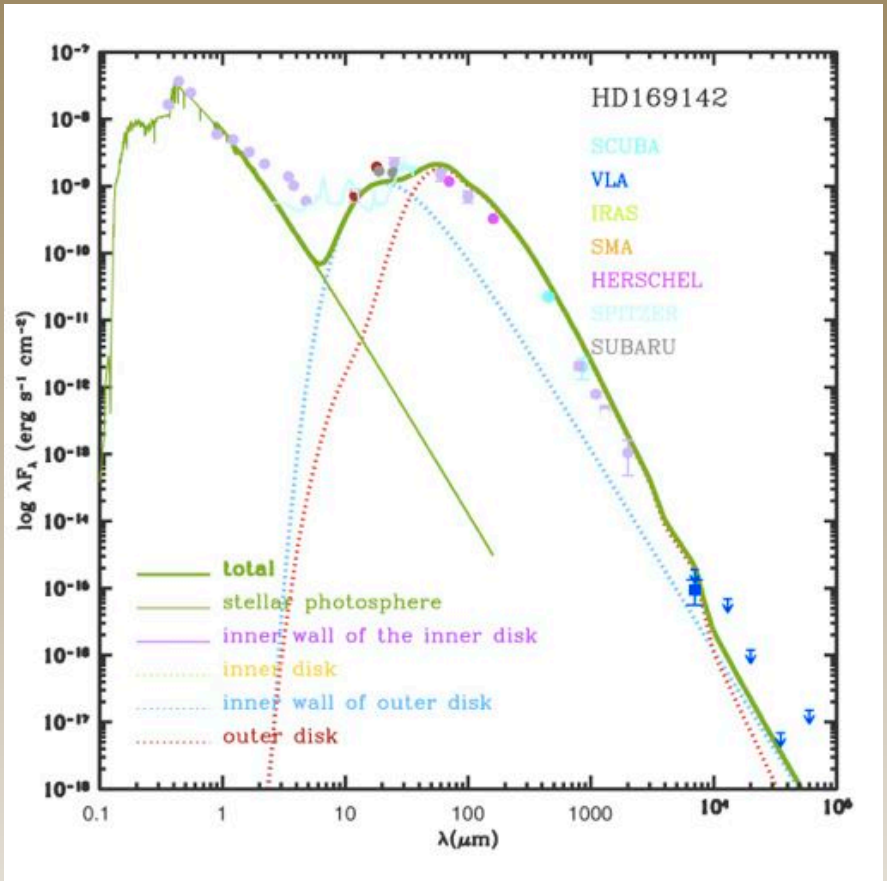
Outer disk (+wall)
+ star

SED ✗
7mm ✔

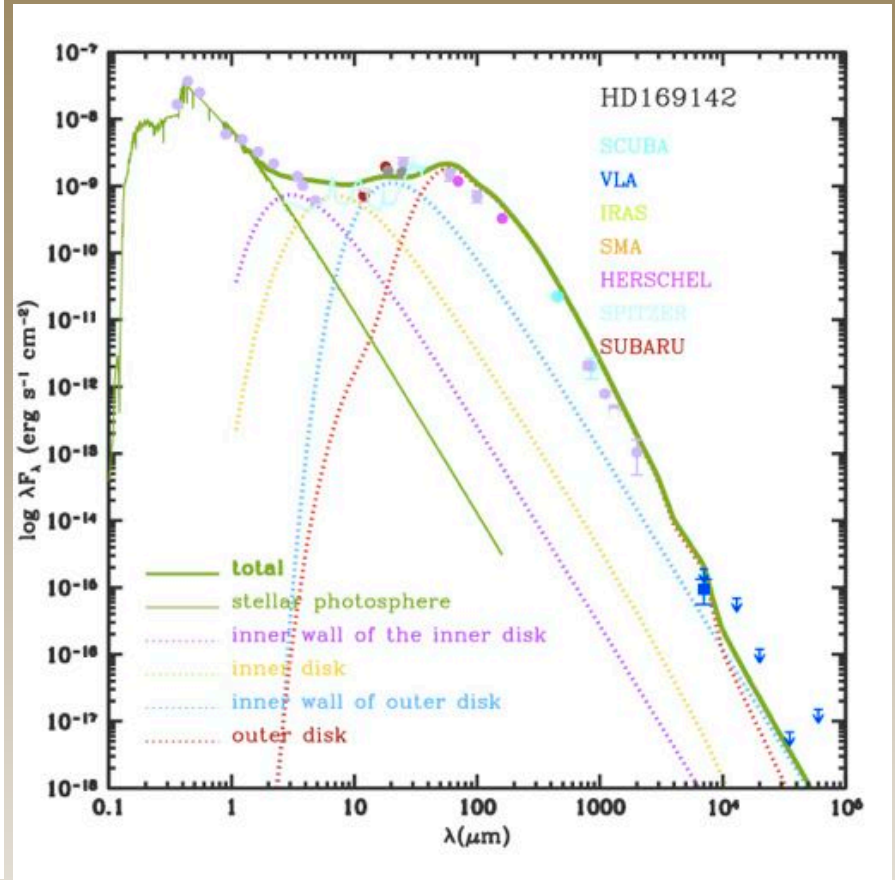
Predicts too little near-IR emission, in conflict with the observed SED!

(we did not attempt to include the 40-70 AU gap in our model)

Without small disk and its wall



With small disk and its wall



A small inner disk and its wall (i.e., a pre-transitional disk) are needed to explain the 2-10 μm emission. These components do not produce detectable 7 mm emission because of the small sizes and high T.

The inner wall of the outer disk is needed to explain the emission at 20 μm.

Parameters of a plausible disk model

Outer Disk:

- $i=13^o$ low inclination according with the images

-$M_{acc}=3.5x10^{-9}\ M_\odot/yr$ according with $M_{acc}\sim10^{-9}\ M_\odot/yr$ < UV excess (Grady et al 2007)

-$R_d=240$ AU outer radius according with the images (200-300 AU)

-$M_{outer\ disk}=0.1\ M_\odot$

-$\alpha=0.0008$ (viscosity parameter), $\Sigma=M_{acc}/3\pi\nu_{turb}$

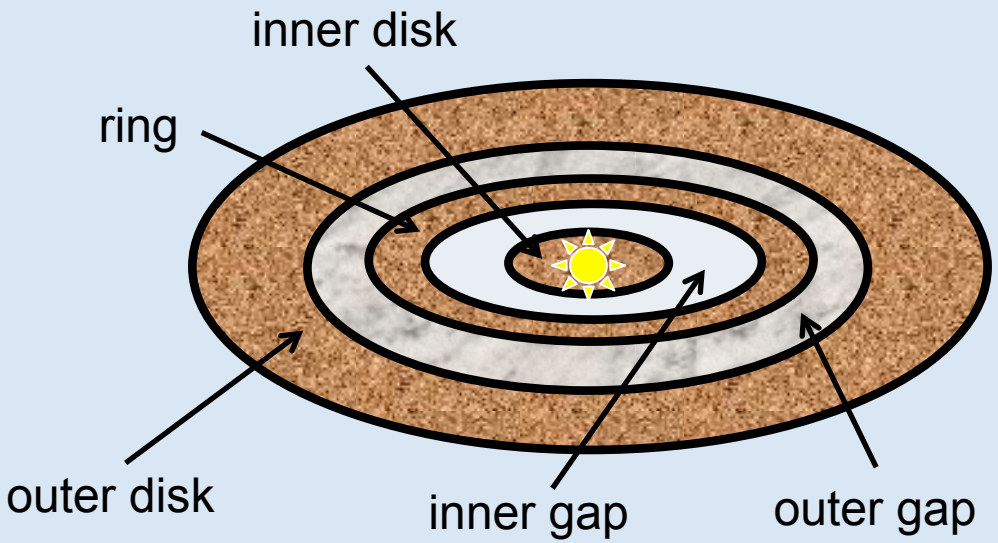
To fit the long wavelength fluxes, the model requires a large population of big grains (1mm) in the disk mid-plane

Inner Disk (not well constrained):

-inclination, M_{acc}, opacities and viscosity are assumed similar to those of the outer disk

-$R_d=0.7$ AU

-$M_{inner\ disk}=10^{-4}\ M_\odot$



SUMMARY AND CONCLUSIONS

- We obtained a high angular resolution 7mm VLA image of the inner structure of the HD 169142 protoplanetary disk. The morphology of the 7 mm emission is well correlated with the VLT IR scattered light image (Quanz et al. 2013).

- The SED fitting and the VLA/VLT data indicate that the HD 169142 disk is a pre-transitional disk, with a small inner disk of radius 0.7 AU surrounded by a gap extending from ~0.7-20 AU. The outer disk has a radius of 240 AU and shows a second, probably less developed, gap extending from 40-70 AU.

- Inside the 40-70 AU annular gap we detect a 7mm emission knot, that we tentatively interpret as tracing the dust associated with a protoplanet candidate. We estimate a mass of 0.2-2 M_J for this proposed circumplanetary dust structure.

- We interpret these results as evidence of possible planetary formation in the disk of HD169142. This hypothesis can be further tested with new VLA, VLT and ALMA observations.

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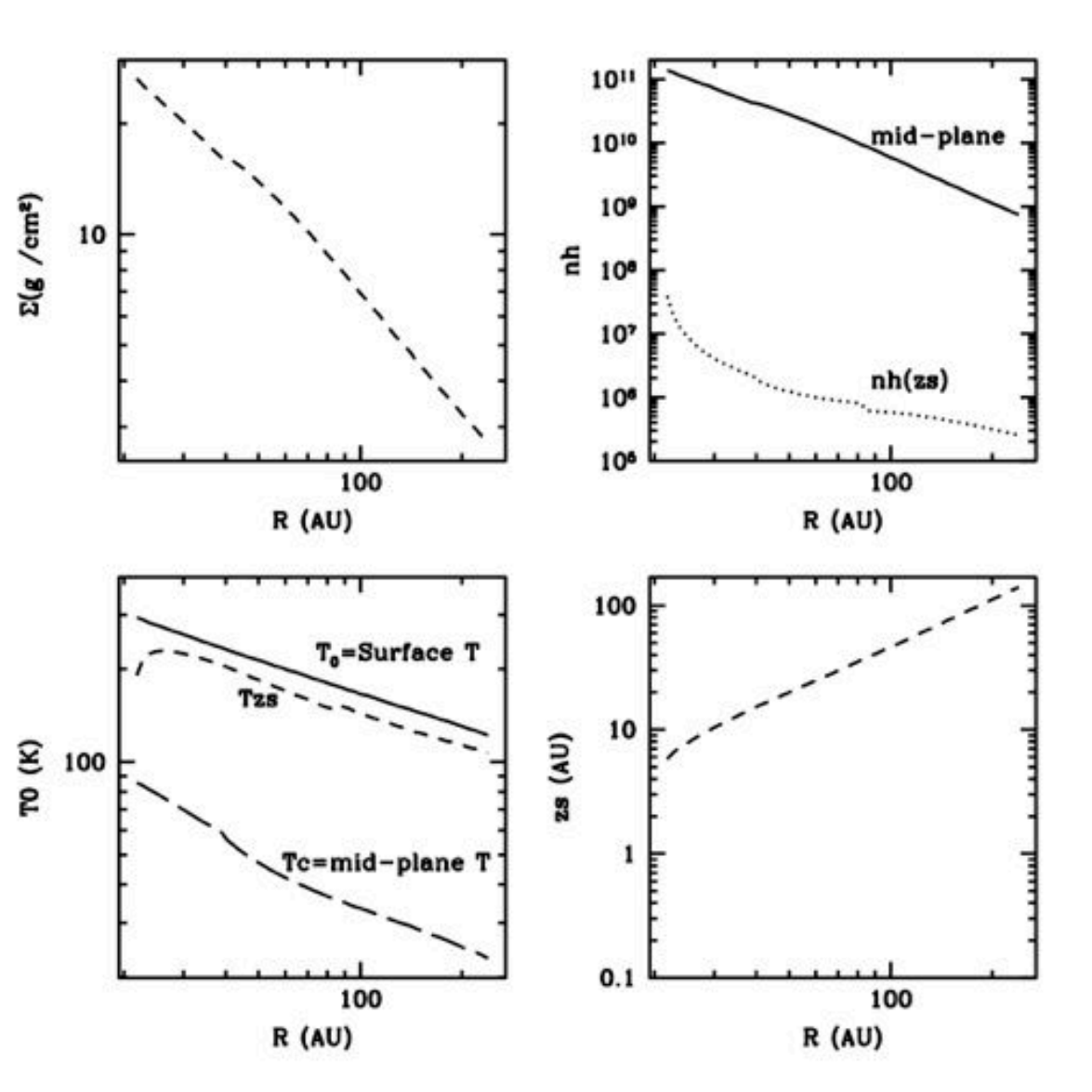
W.R.F Dent (ALMA)

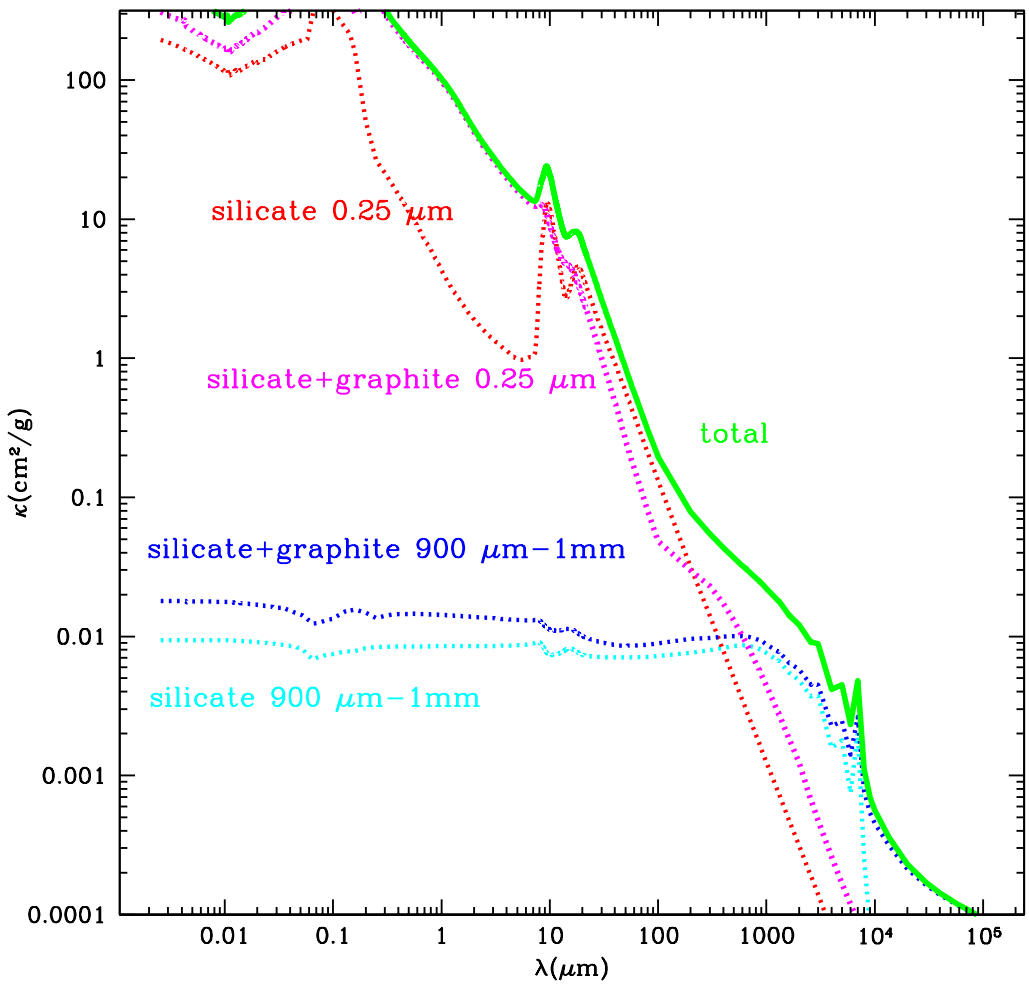
IAU Symposium 299, Virginia B.C. June 4, 2013

Parameters of the successful disk model

Properties of the outer disk



Parameters of the successful disk model



Walls

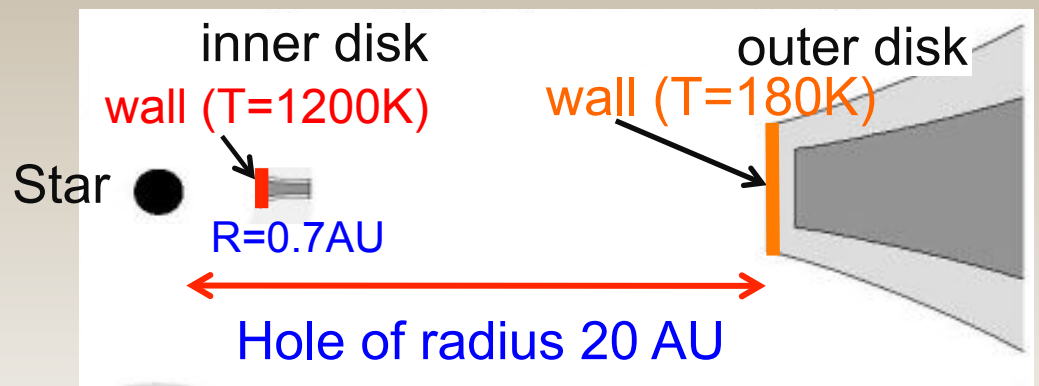
Wall emission of outer disk: computed as a cylindrical surface with R=20 AU, and height H_{outer}. The wall emits as a Black Body at a temperature T such that:
$17\ L_{sun} = 4\ \pi\ \sigma\ (20\ AU)^2\ T^4$.

T_{outer}=180 K, H_{outer} =0.6 AU

Wall emission of inner disk:
Black Body at a radius such that
$17\ L_{sun} = 4\ \pi\ \sigma\ R^2\ (1200K)^4$.

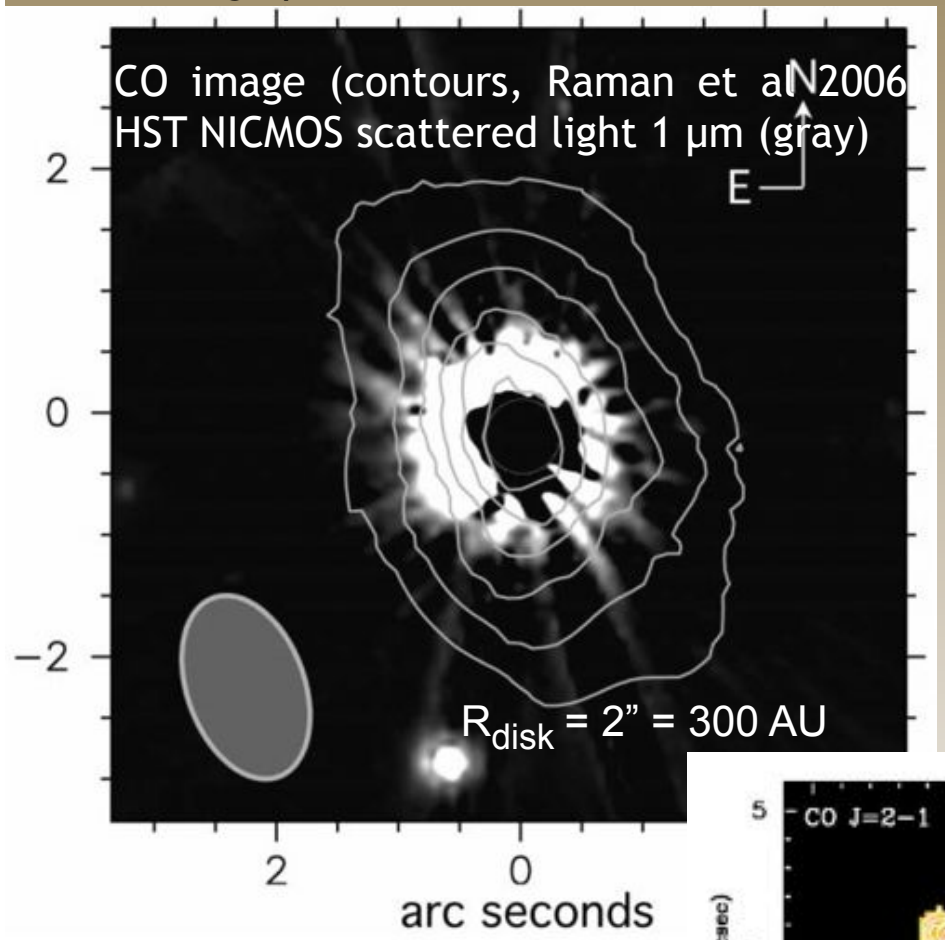
R_{inner}=0.4 AU , H_{inner} =0.01AU

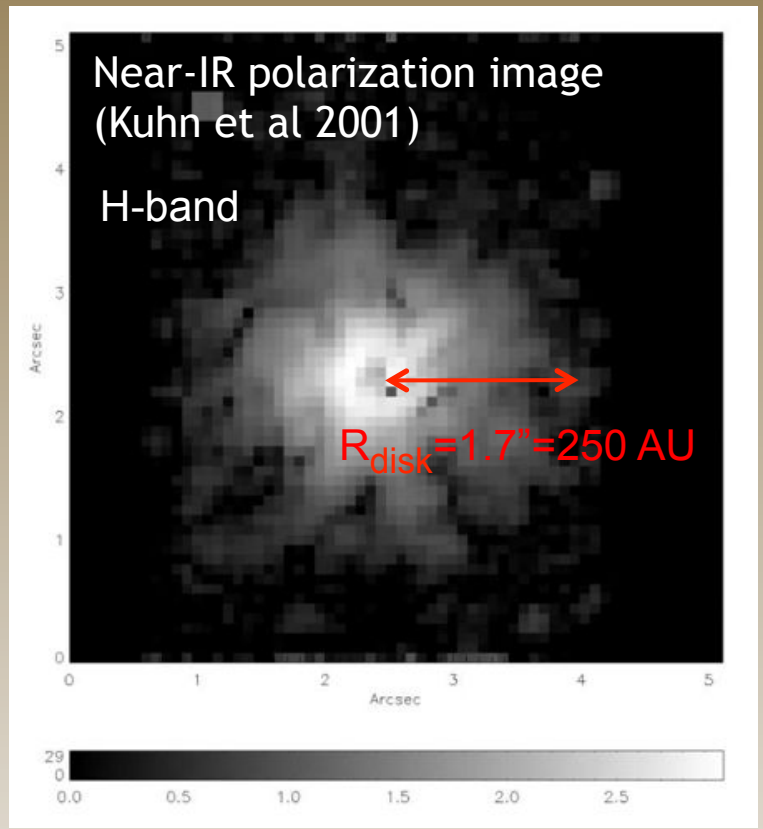
Geometry for HD169142



Previous imaging of the HD 169142 disk

Previous observations suggest a nearly face-on disk extending up to a scale of 250 AU.





Raman et al 2006, Panic et al. 2

Panic et al 2008