On the origin of the « Horseshoes » seen by ALMA in Transition Disks

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ALMA transformational science: Dust traps

To form a planet, dust needs to grow… a lot

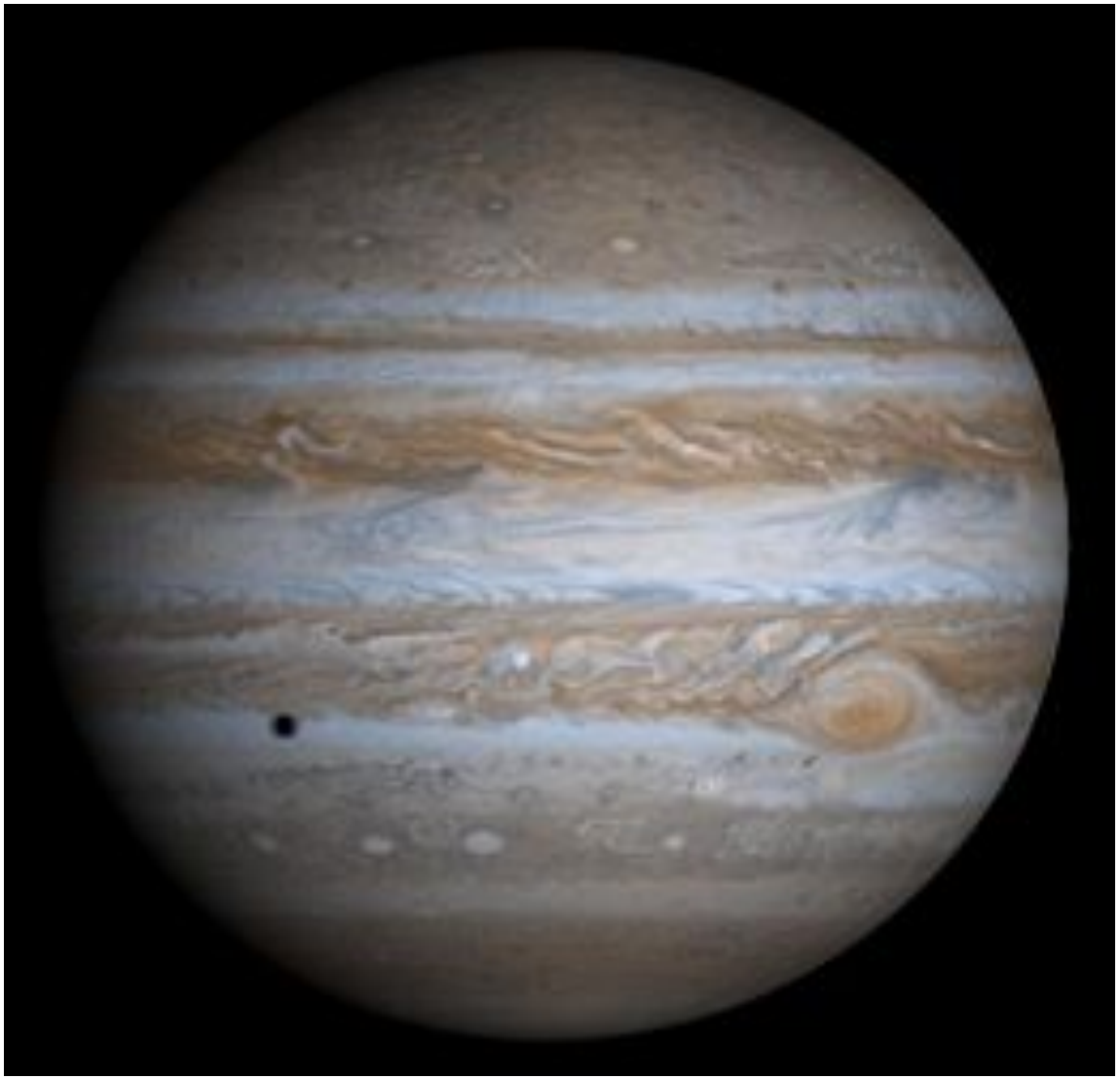
- small particles do stick and grow
- Big bodies do collide and grow into planetesimals

We have a problem for «meter sizes»

- radial drift too fast… boulders don't stay in disk long enough to grow « passed » that barrier.
- Need a way to overcome

- Pressure maxima and RWI have been proposed to serve as « dust traps » before
  - 1996 Barge & Sommeira
  - 1999 Lovelace et al.
  - 2006 Varniere & Tagger
  - 2009 Lyra et al.
  - 2011 Regaly et al.
  - … and the recent work by Birnstiel, Pinilla, Dullemond …

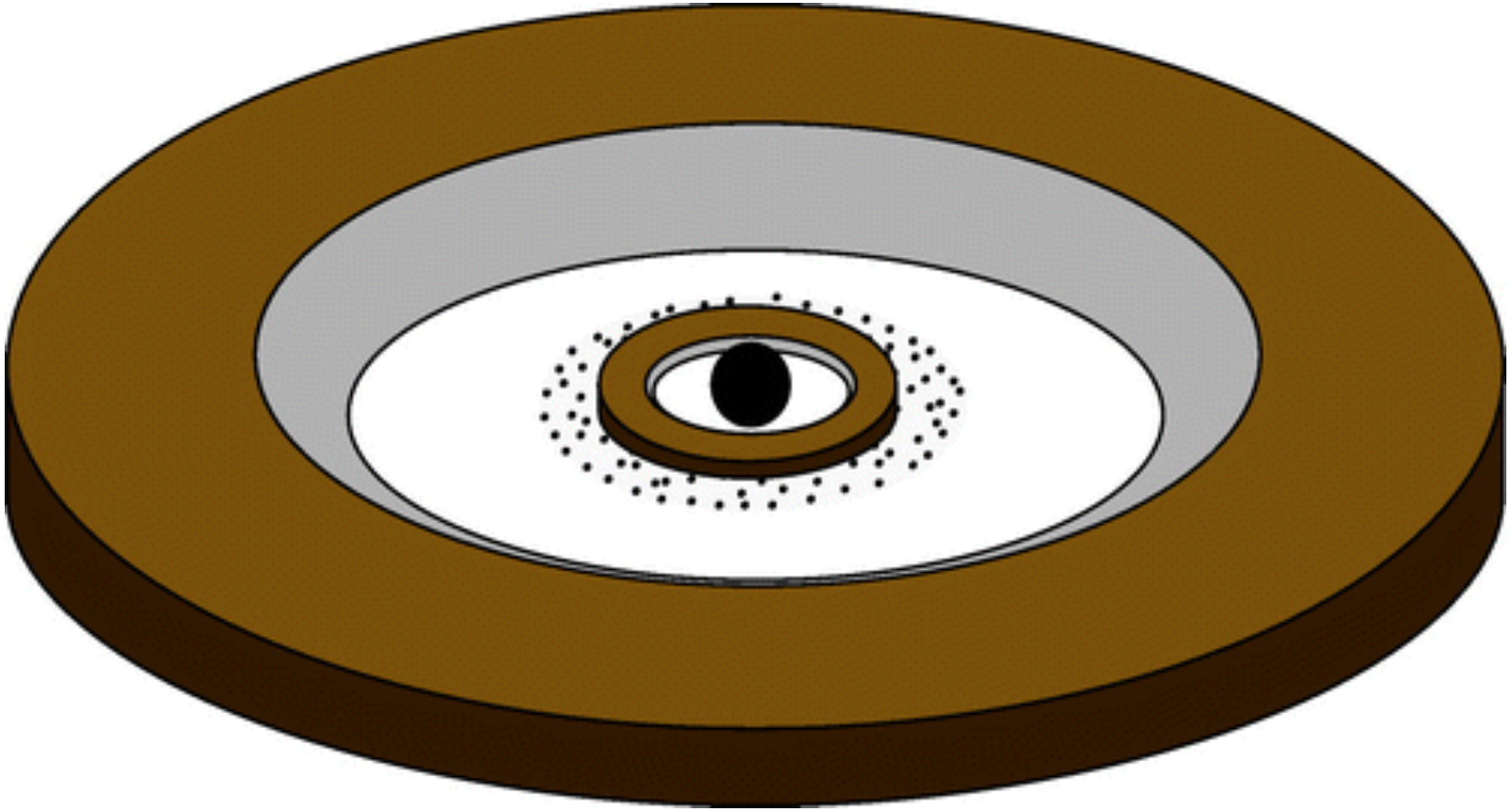
Long-lived vortices do exist !



Outline

- ALMA continuum data for Transition Disks
- The Rossby Wave Instability
  - Calculation set-up
- Results of calculations
  - + qualitative comparison with data
- Future prospects

I- What are Transition Disks ?



Sketch from C. Espaillat

I- Transition Disks with ALMA

- HD 142527
- Recall previous talks by Simon Casassus, Misato Fukagawa & Henning Avenhaus

Image courtesy of Hector Canovas (in prep. 2013)

- Image removed

I- Transition Disks with ALMA

- HD 142527
- Band 7 data (cycle 0)

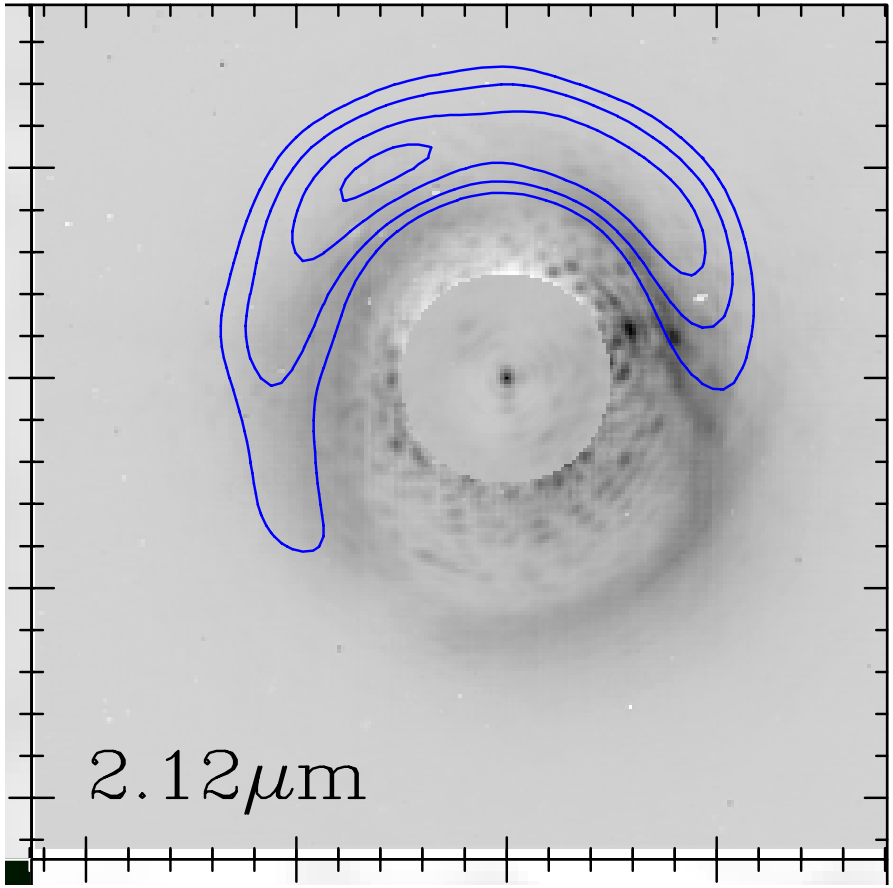
- Image removed

Image credit: Misato Fukagawa et al.

I- Transition Disks with ALMA

The « horseshoe » is located at the disk rim…

… where conditions are met for RWI to grow



Casassus et al. (2012, 2013)

I- Transition Disks with ALMA

- A variety of them…
- Image removed

Here, IRS 48

- See Nienke van der Marel's talk on Friday
  - Cycle 0
  - Band 9

UNDER EMBARGO !

Image credit: N. van der Marel

I- Transition Disks with ALMA

- SR 21
  - See Laura Perez' talk in a few minutes.
    - Band 9
    - Cycle 0
- Image removed

Image credit: Laura Perez

I- Properties of the Horseshoes

- Contrast (in surface brightness)
  - Wide range, from a few to ~100
- For HD 142527 (from Casassus' data set)
  - Azimuthal extent
    - Wavelength dependent
  - Radial extent
    - Unresolved with current array,
      - marginally in Band 9.

II- The Rossby Wave Instability

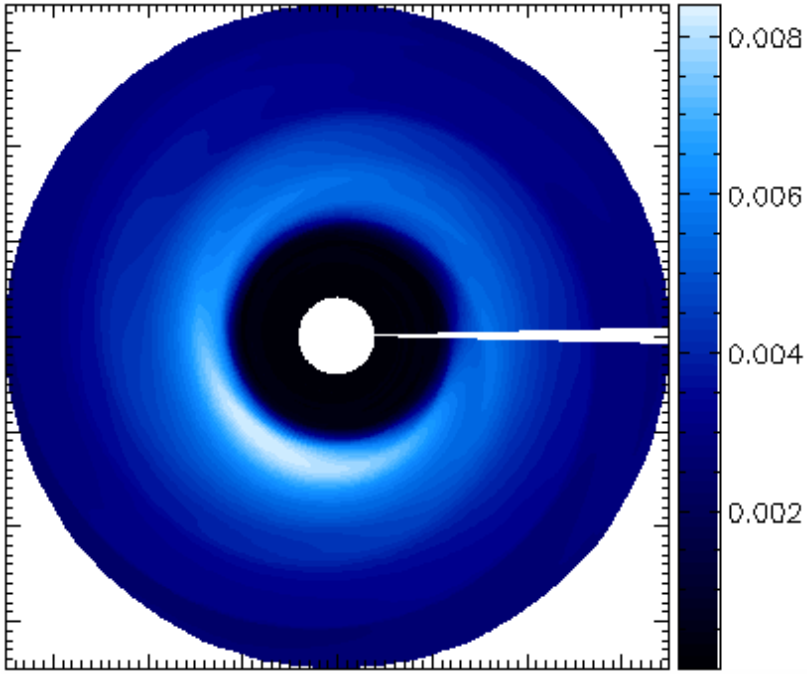
- 2 quantities: Vorticity (curl v), density (Σ)
  - New word: Vortensity = vorticity / density
- Conditions will be met for RWI to develop at position of extremum in gradient of vortencity.
  - Was used at boundaries of dead zones
  - Here we use at Inner Rim of Transition Disks
- In other words:
  - Keplerian disks are good places to find large vorticity
  - Transition disks are good places to find large density gradient with pronounced extrema…

II- The numerical set-up

- A disk « similar » to the outer disk of HD 142527 is used
  - Surface density profile $\alpha \quad r^{-1}$
  - Rim of Outer disk located at 130AU
    - Sharp Surface density drop
  - Total disk mass: $0.1 M_{sun}$
    - Global G/D ratio = 100
      - Not true locally after RWI sets in
  - Central star mass: $2.0\ M_{sun}$
- grid for hydro calculations:
  - 512 cells radially (between 30 and 350 AU)
  - 128 cells in azimuth direction

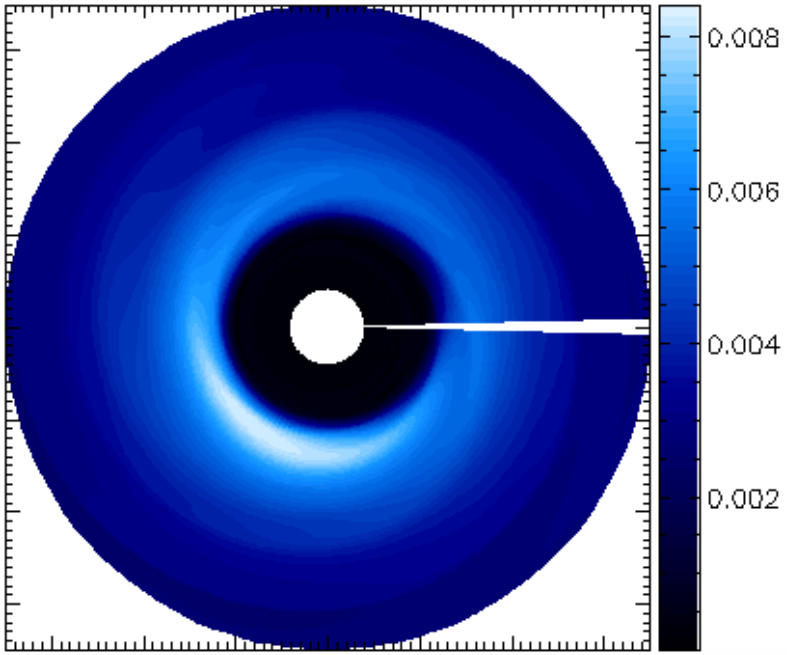
III- Results and Comparison

- Gas structure is modified azimuthally by RWI.
  - Long-lived vortex is created
    - At R ~ 135AU,
    - inner edge
  - Survives several 100's of orbits, as long as conditions are present
  - Rotates at ~keplerian period
    - See Ataiee et al.
- Gas density contrast of a factor of ~2.

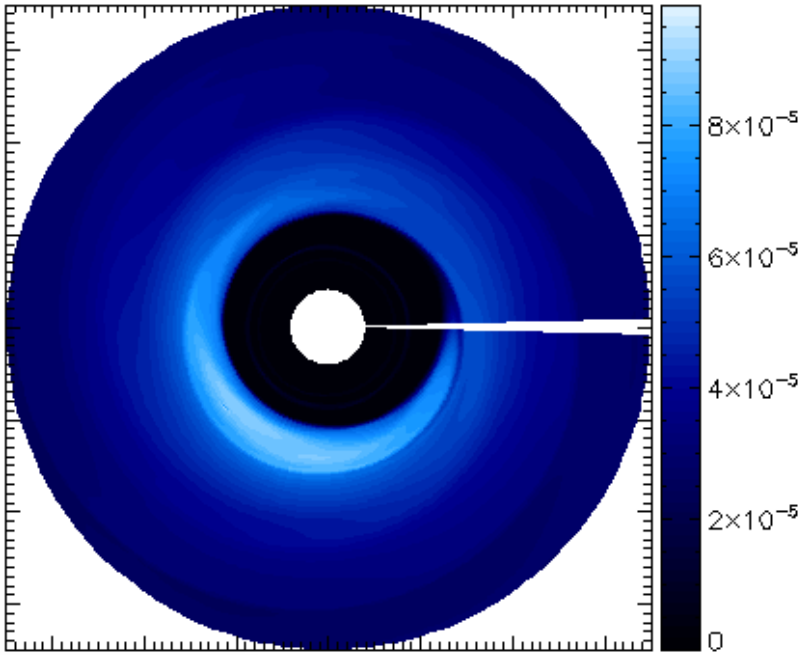


Gas Surface density map

III- Adding dust to the gas.

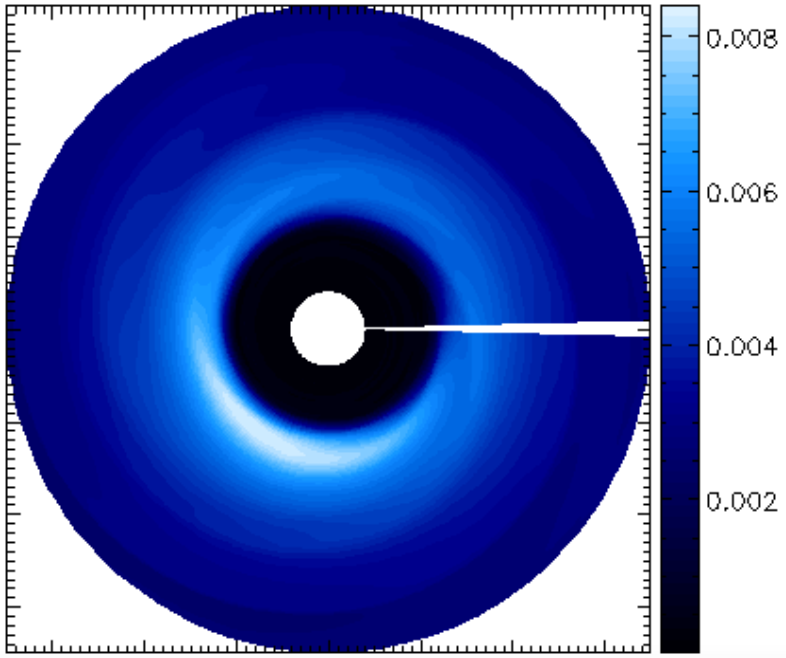


Gas Surface density map

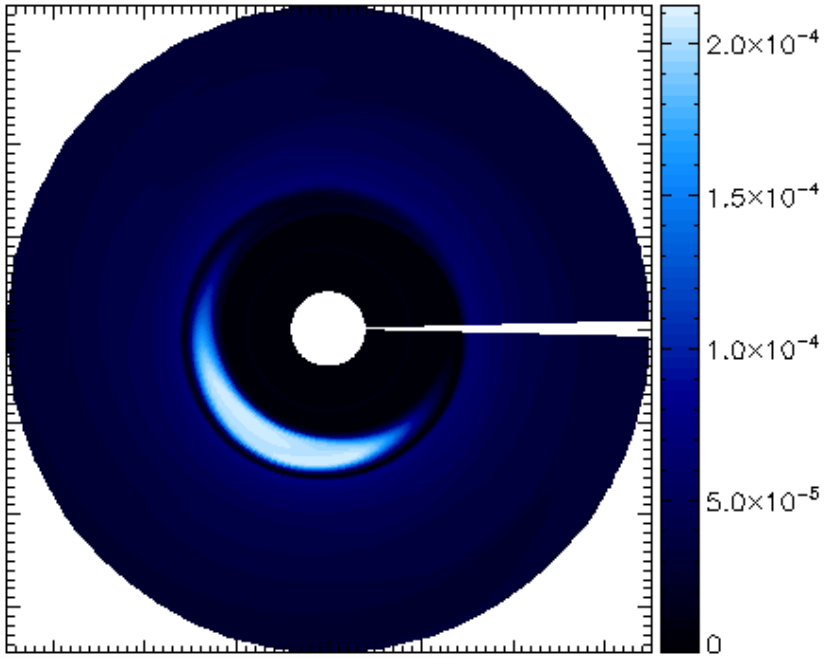


Dust: 10 µm

III- Adding dust to the gas.

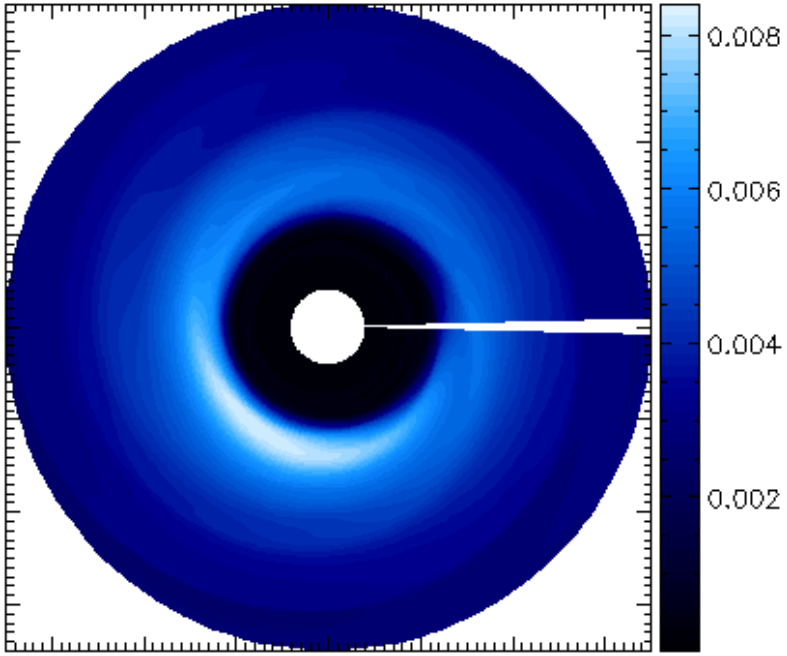


Gas Surface density map

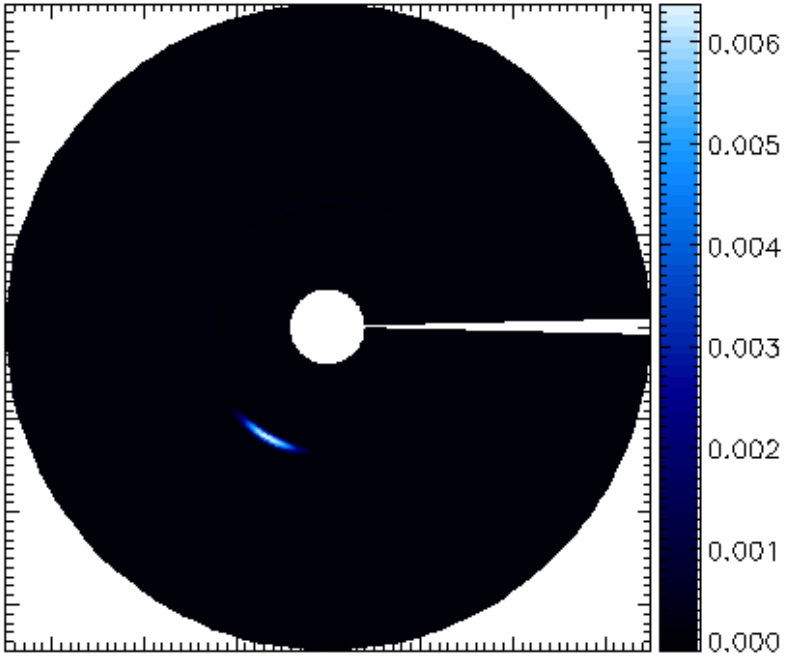


Dust: 100 µm

III- Adding dust to the gas.



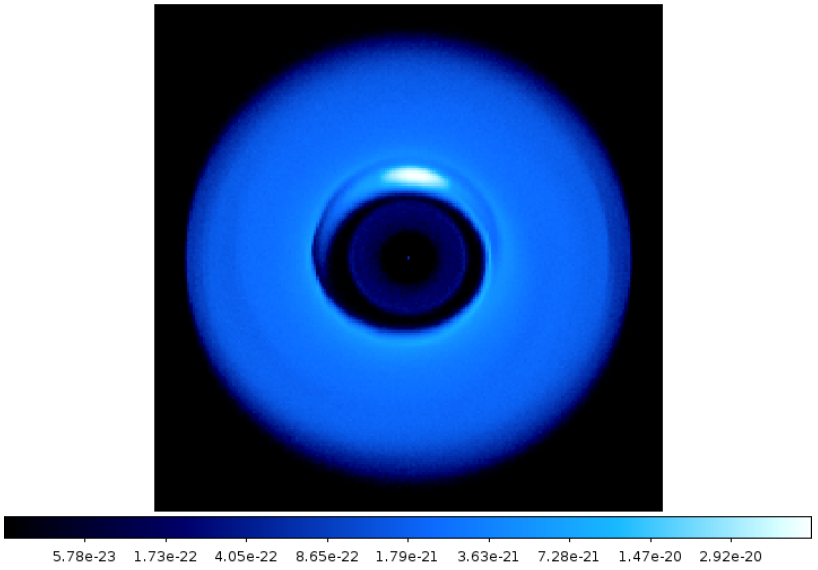
Gas Surface density map



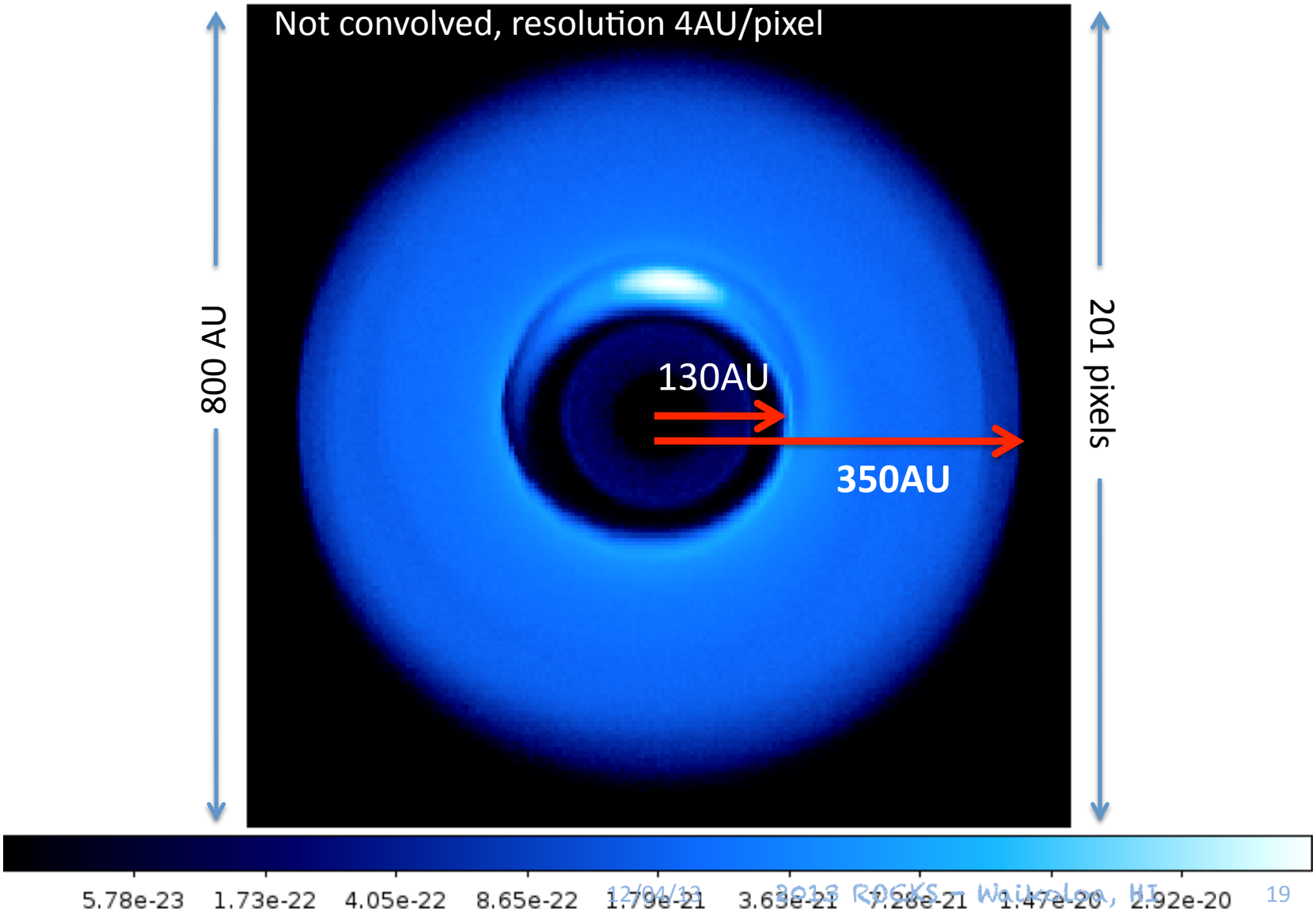
Dust: 1 mm

III- Preparing for Radiative Transfer

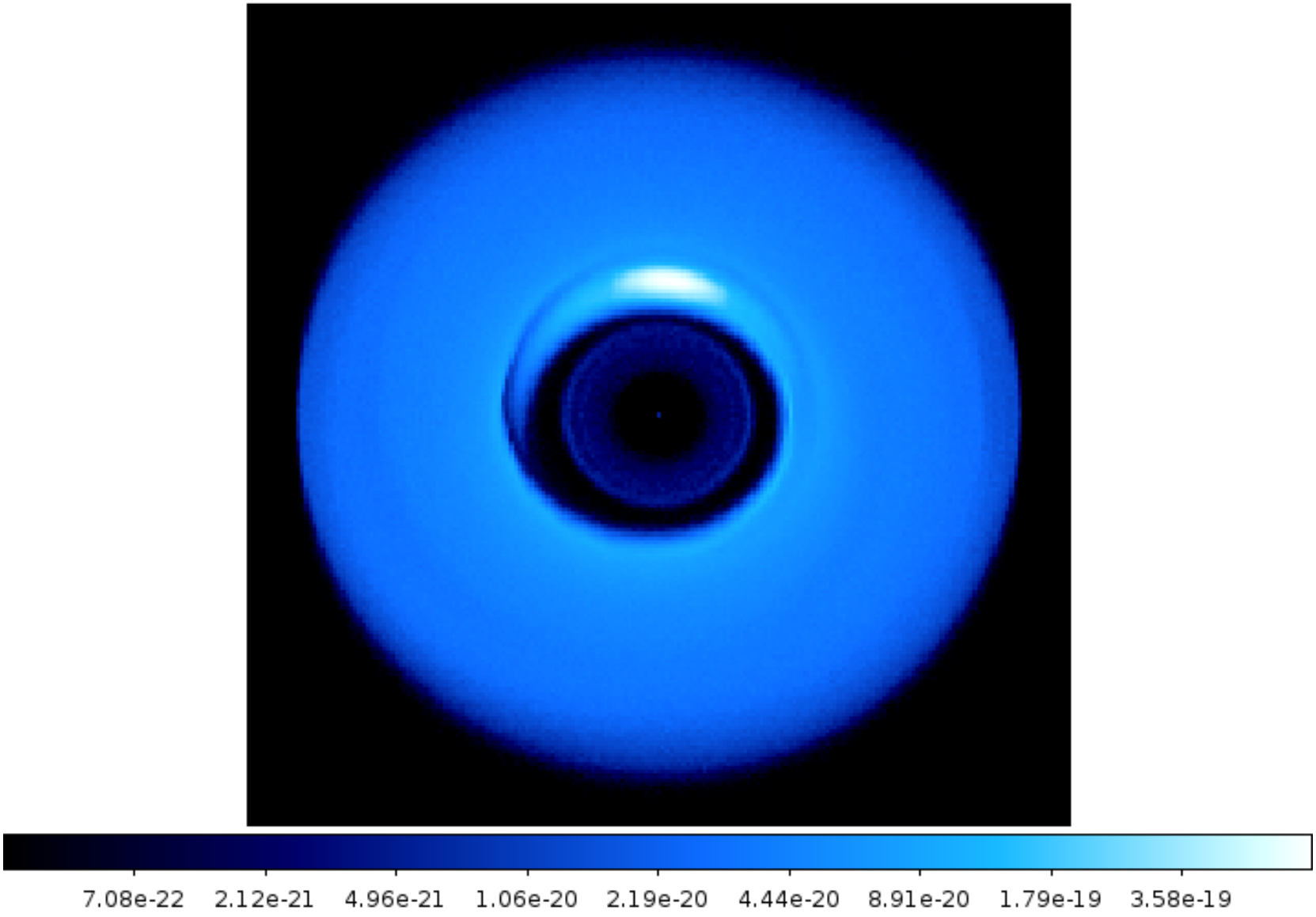
- 2-fluid Hydro sims' are combined to produce one single density grid.
  - 1 gas profile
  - 5 dust profiles
    - 1,10,100,1mm,1cm
  - Interpolate in between to build complete dust population in each grid cell
    - Assuming a_{min}, a_{max}, & slope
    - 3rd dimension is hydrostatic equiibrium



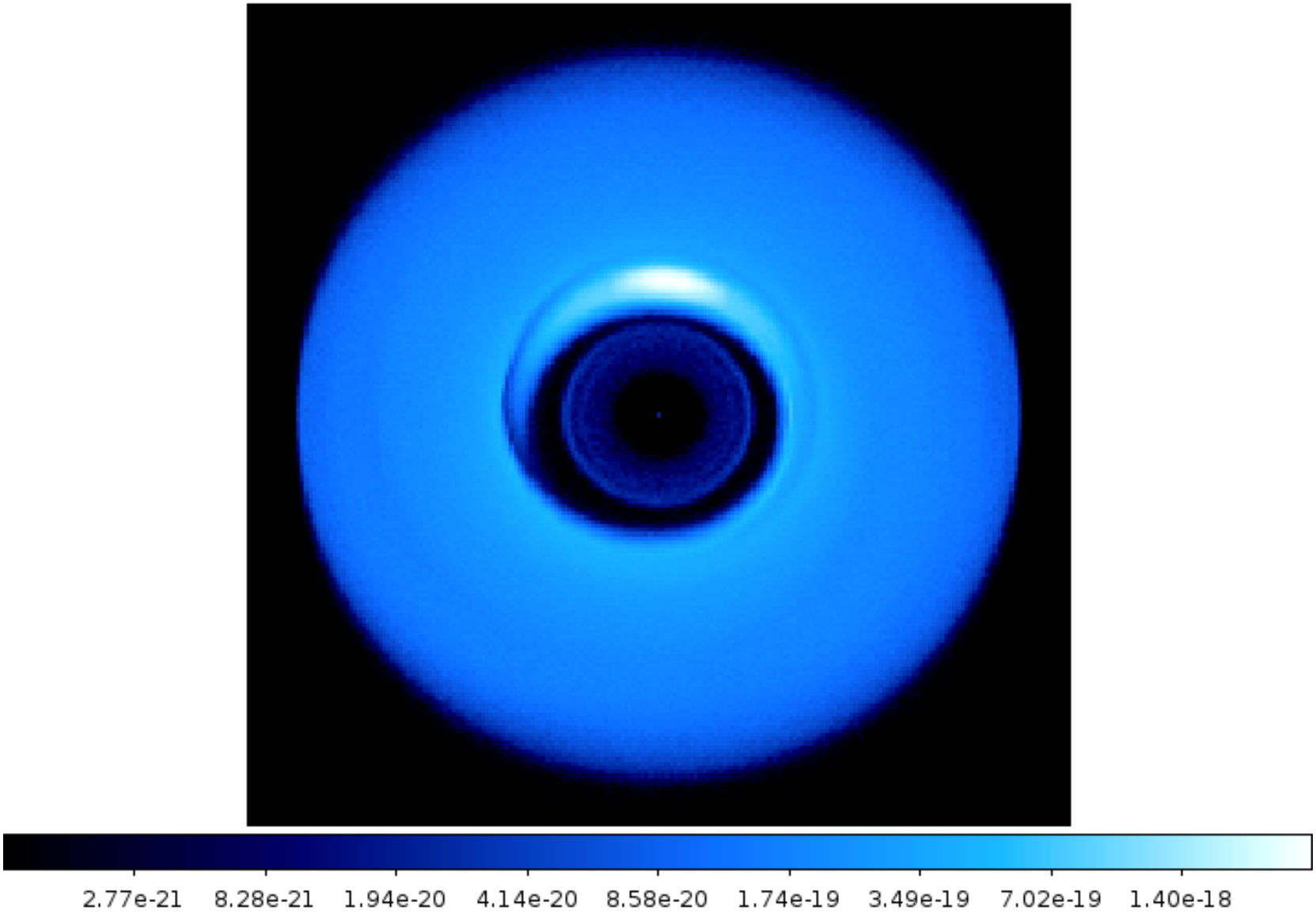
III- Synthetic images: 2,7 mm (band 3)



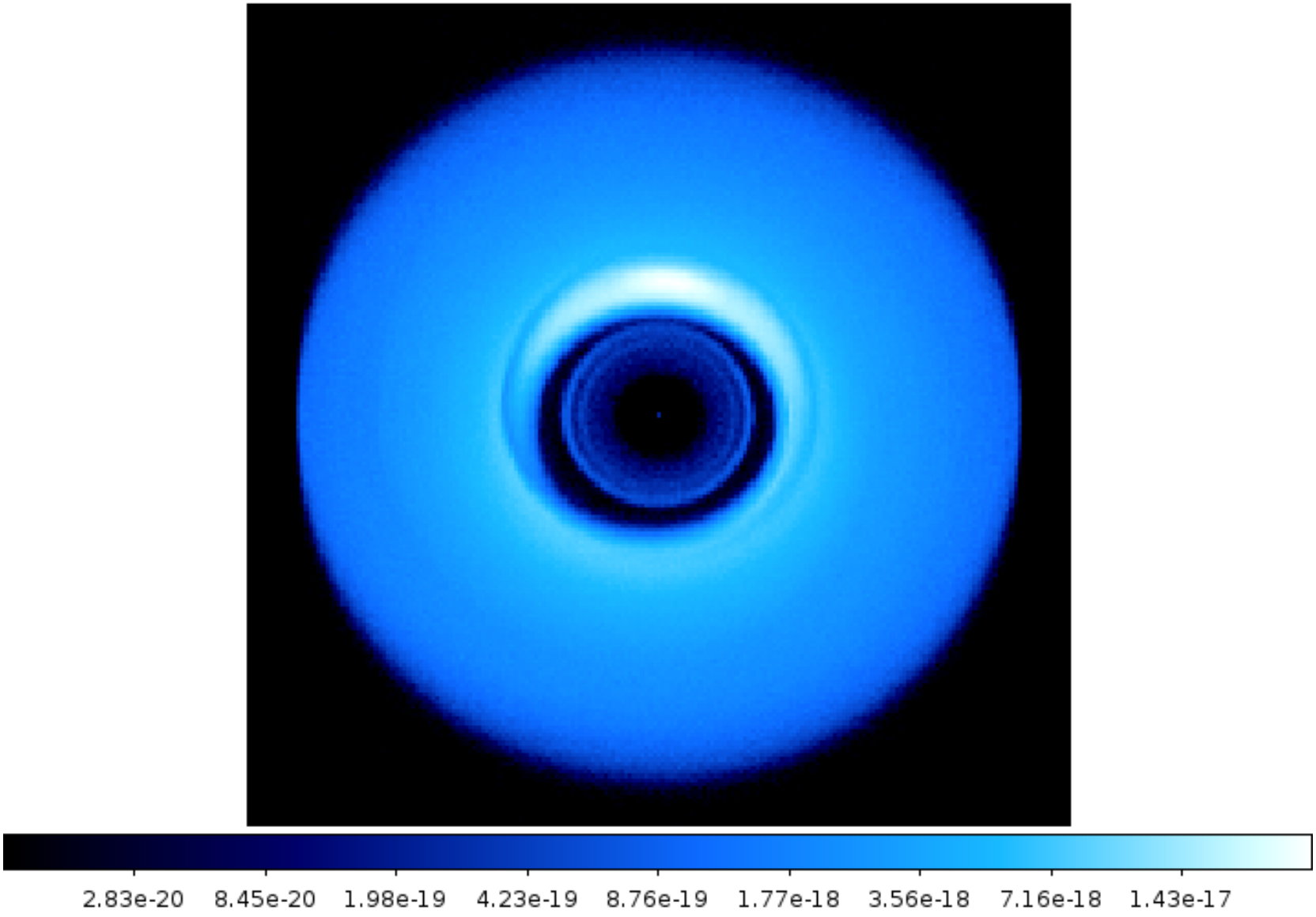
III- Synthetic images: 1,3 mm (band 6)



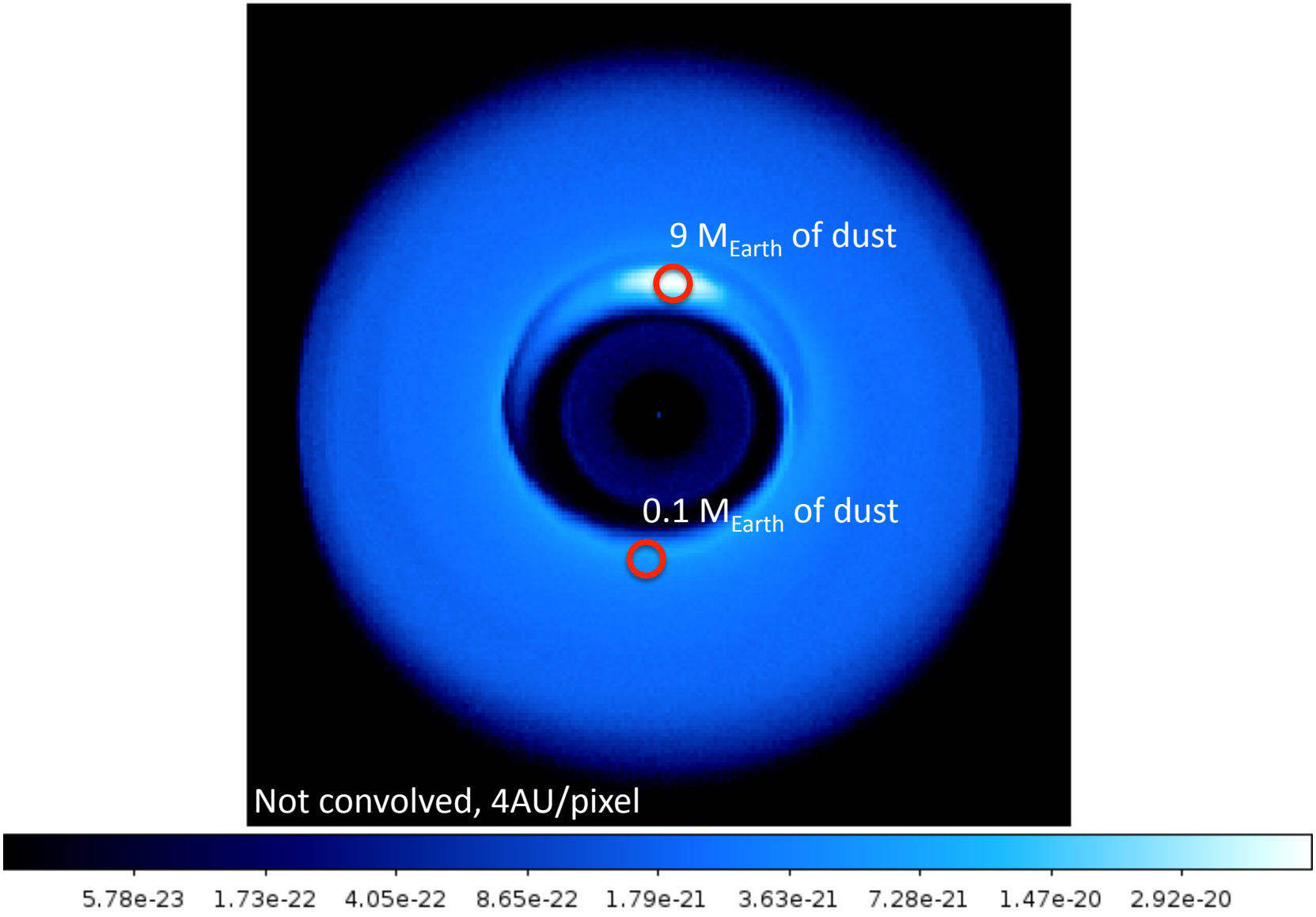
III- Synthetic images: 850 μm (band 7)



III- Synthetic images: 350 μm (band 10)

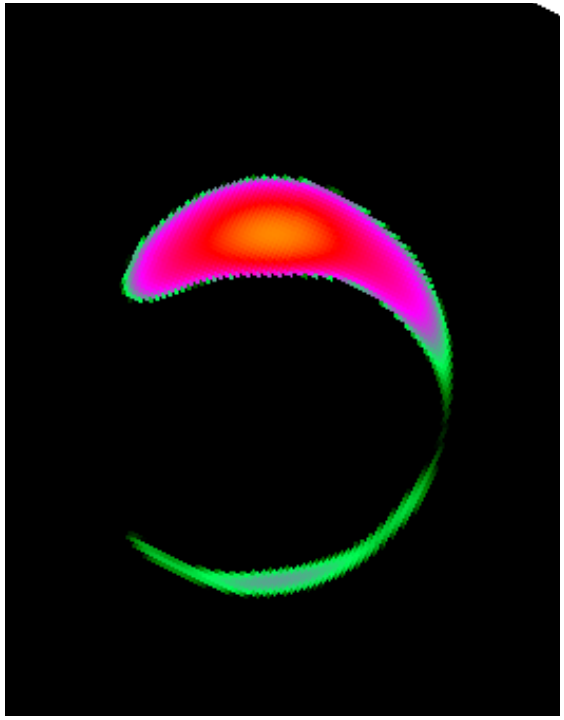


III- Synthetic images: 2,7 mm (band 3)

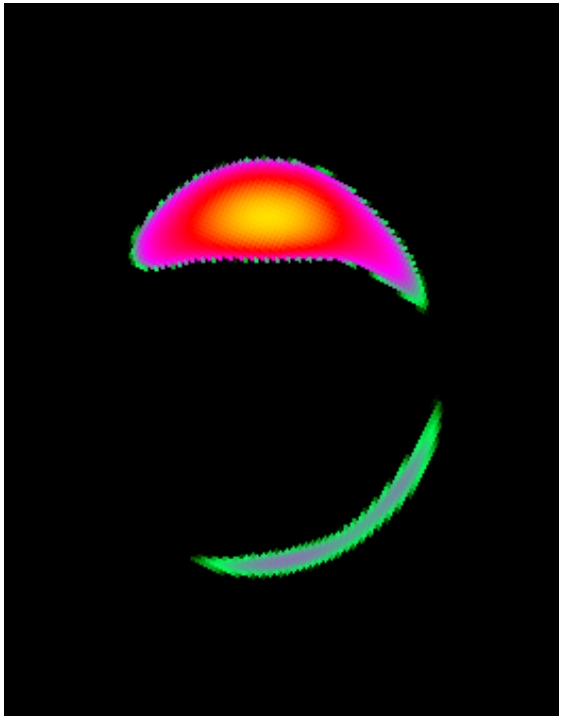


III- further comparison

Band 7

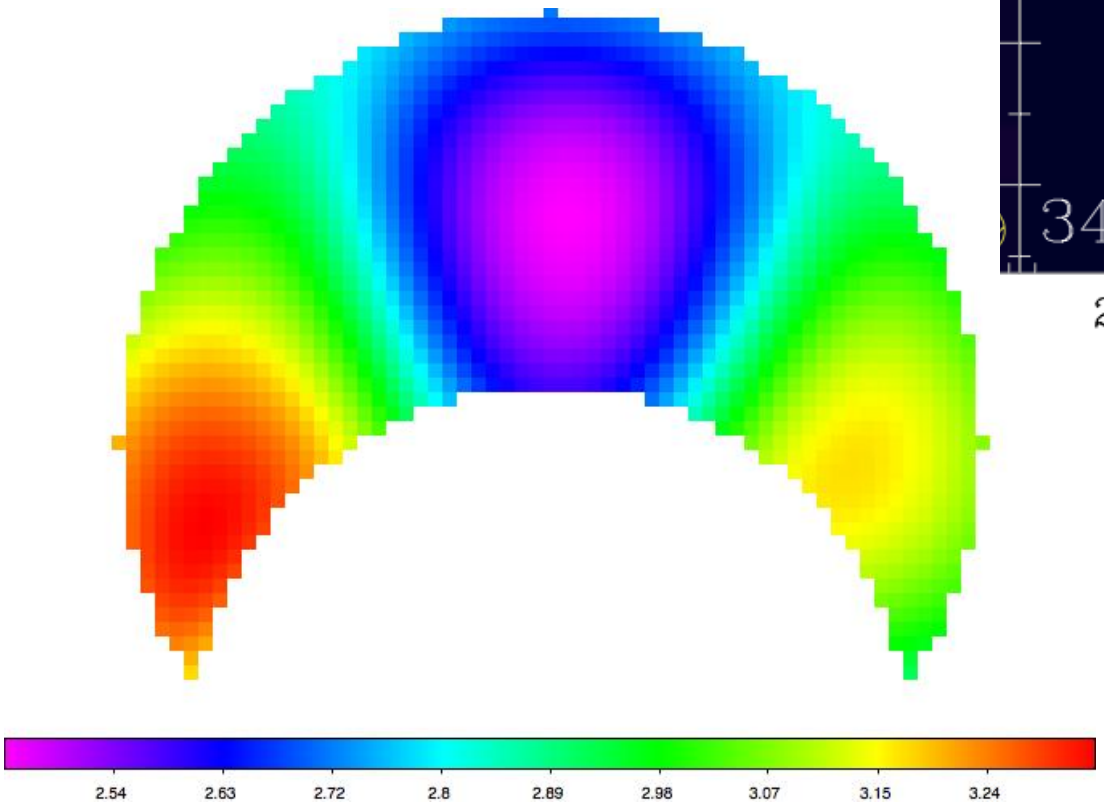


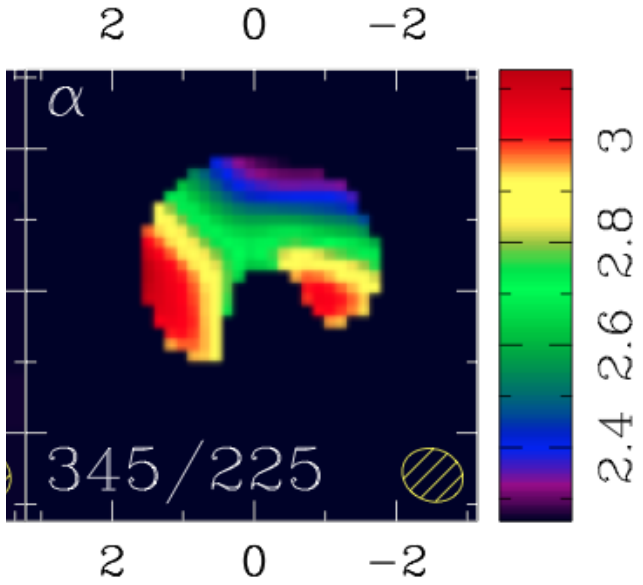
Band 6



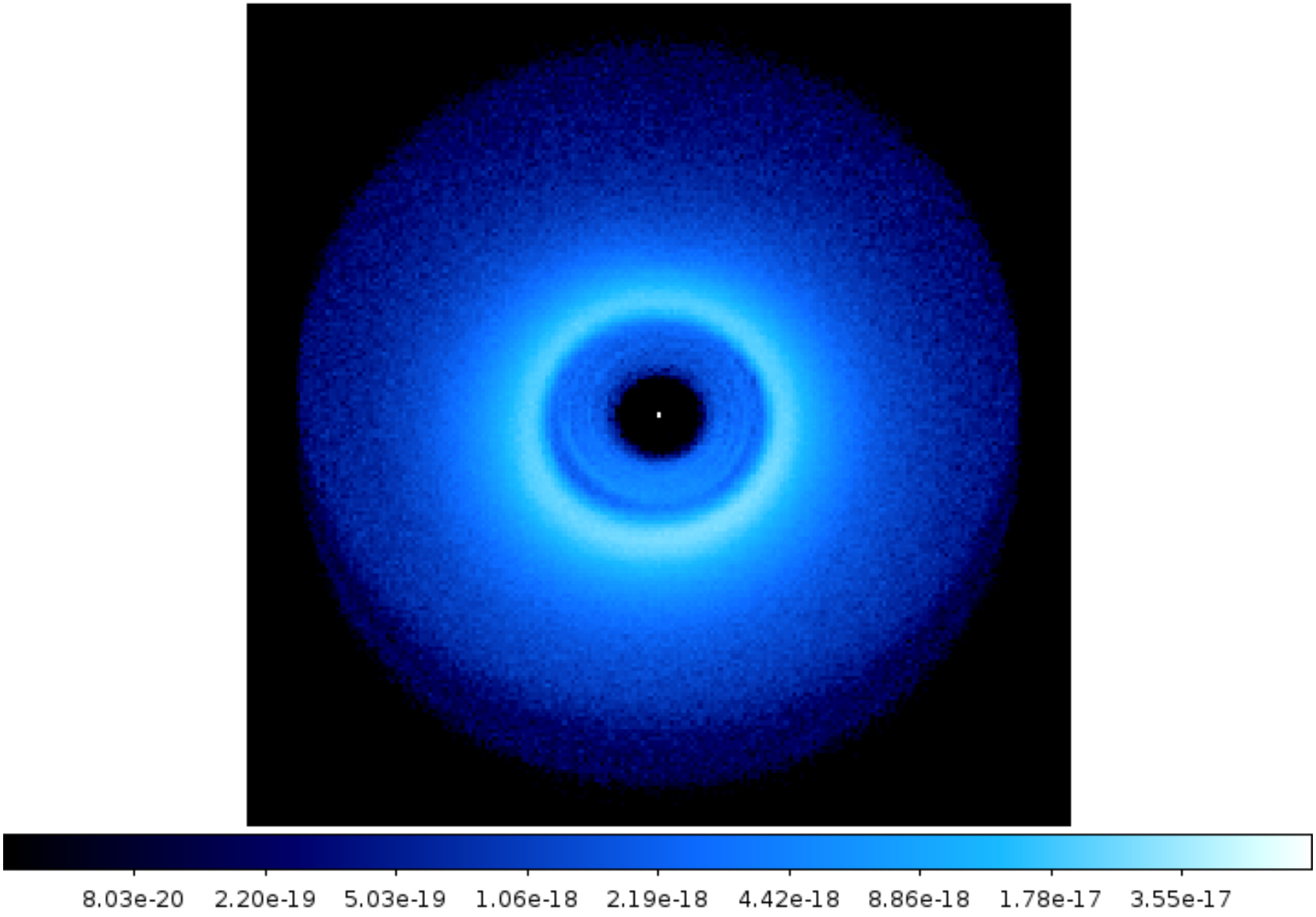
Images are convolved by round 0.4arcsec beam ,
Detection limit added : 0.05 mJy/beam

III- Map of emissivity index





III- Synthetic images: 1.6 µm (scattered light)



IV- Wrapping up

- For Transition disks observed with ALMA
  - Hydro calculations of the Rossby Wave Instability captured the broad features of the observations and their behaviour with frequency
    - for an object similar to HD 142527
    - Contrast, azimuthal extent, emissivity
- 3D version of the calculations is underway

IV- To do list (partial)

To confirm presence / role of RWI:

- Behaviour with time
  - RWI = ~ keplerian rotation
  - Resonance with Planets will be different
- Behaviour of « Horseshoes » with size of inner hole
  - RWI expected to produce larger density asymetries
- Estimate radial extent of vortex
- Use (A)symmetry of vortex and Emissivity maps
  - Broad range of wavelength needed

DATA FITTING will be required (not done here)

- need proper treatment of uv coverage