What causes the dust's asymmetric emission in the inner parts of protoplanetary disks seen by the VLTI?

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astrophysique & planétologie

LAGRANGE

SF2A - 24/06/2026

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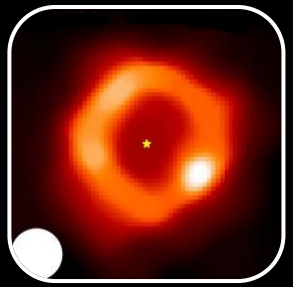
Observations of arc-shaped structures

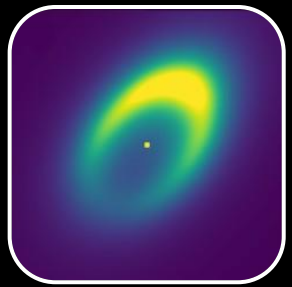
HD 142527
at 1 mm (ALMA)
Boehler+ 2021

660 AU



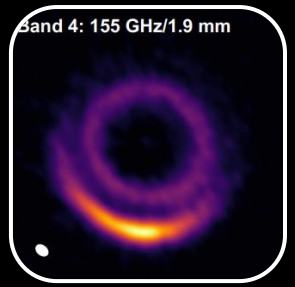
HD 190073
at 1.6 μm
(CHARA/PIONIER)
Ibrahim+ 2023

4.5 AU



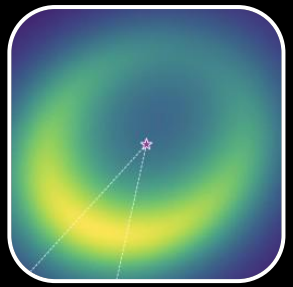
HD 163296
at 3.2 μm
(MATISSE)
Varga+ 2021

1.2 AU



HD 135344B
at 2 mm (ALMA)
Cazzoletti+ 2018

260 AU



HD 98922
at 2.1 μm
(GRAVITY)
Ganci+ 2024

3 AU

HD 163296
at 1.6 μm
(CHARA/PIONIER)
Setterholm+ 2025

0.8 AU

Observations of arc-shaped structures

Legend : Disk's outer parts (> 100 AU) / sub-millemetric observations

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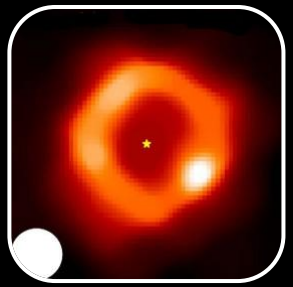
at 1 mm (ALMA)
Boehler+ 2021

660 AU



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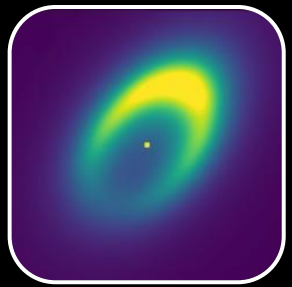

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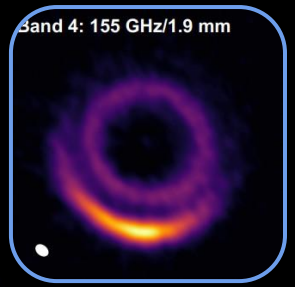

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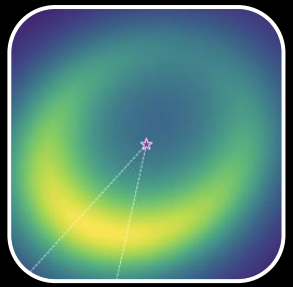

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Observations of arc-shaped structures

Legend : Disk's inner parts (< 5 AU) / near-infrared observations

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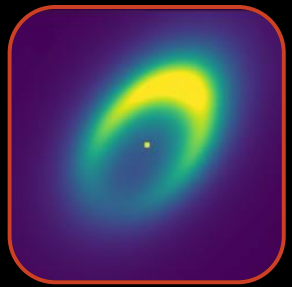

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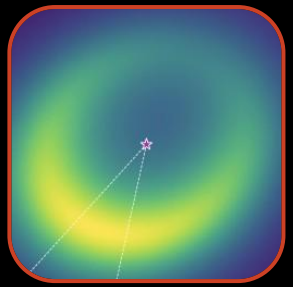

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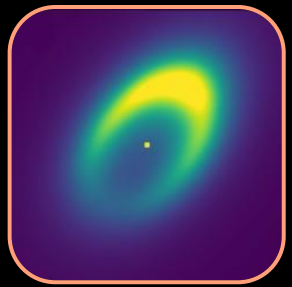

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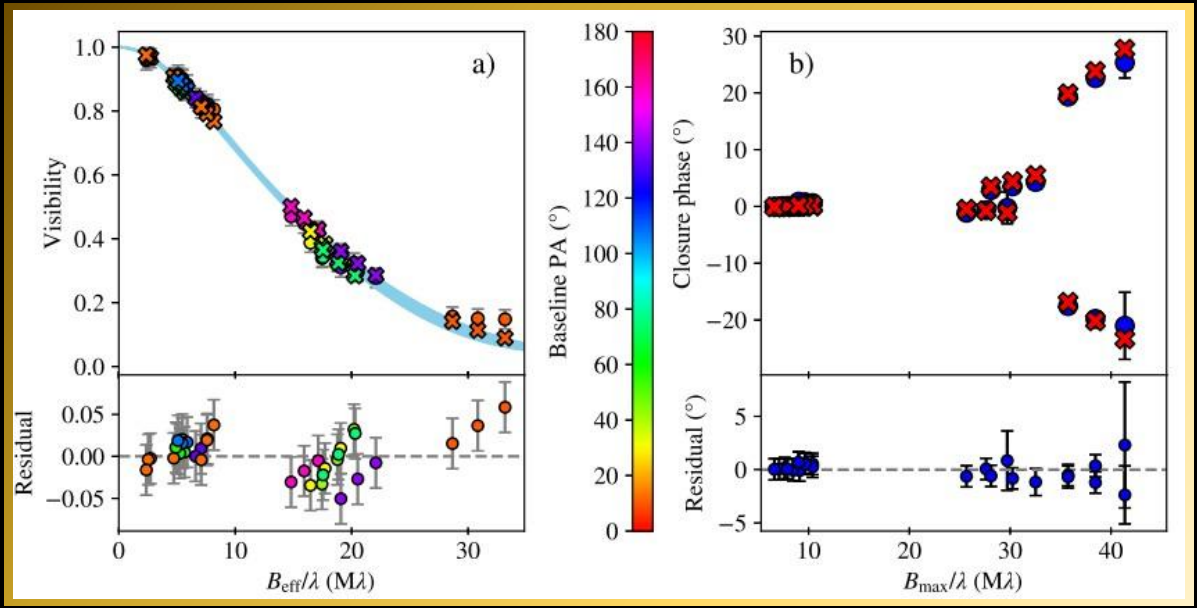
Interferometric observations

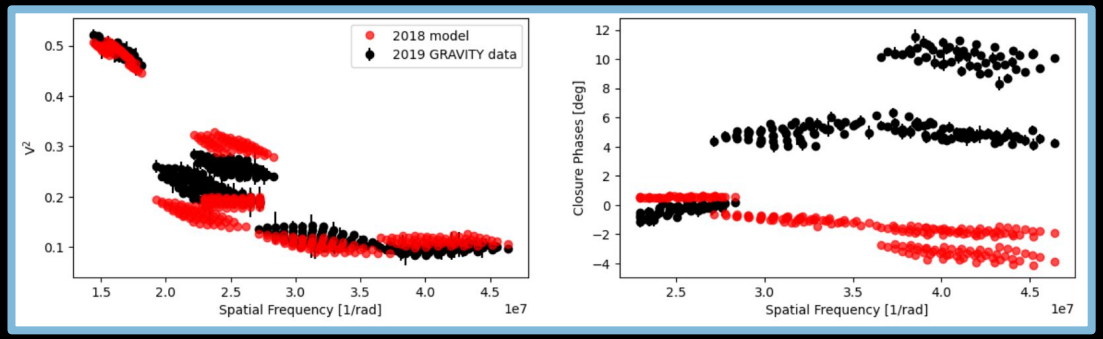
Interferometric data from the observation of HD 163296 (Varga et al. 2021)



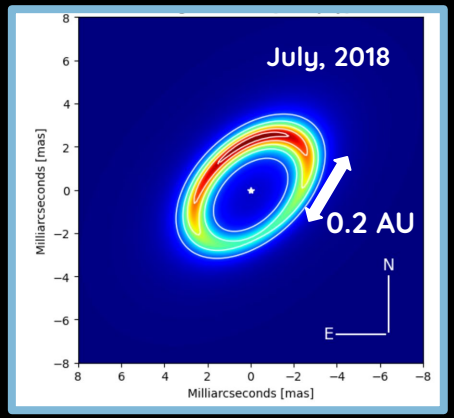
Visibility → the radial distribution of the emission flux

Closure phase → the (non-) axisymmetry of the emission flux

Time variability



GRAVITY Collaboration, 2021



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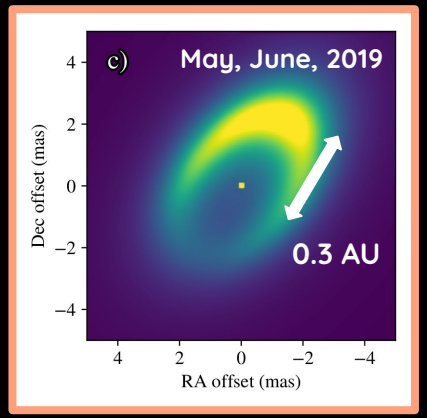
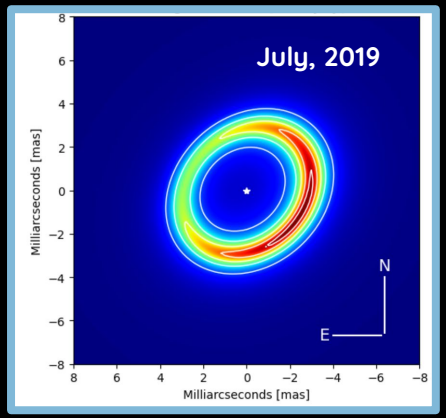
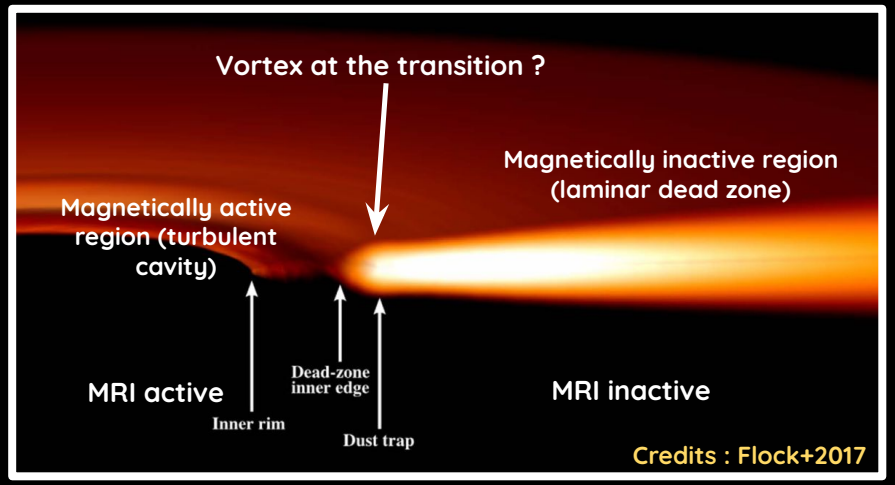


Varga et al., 2021



GRAVITY Collaboration, 2021

Objectives of the research work



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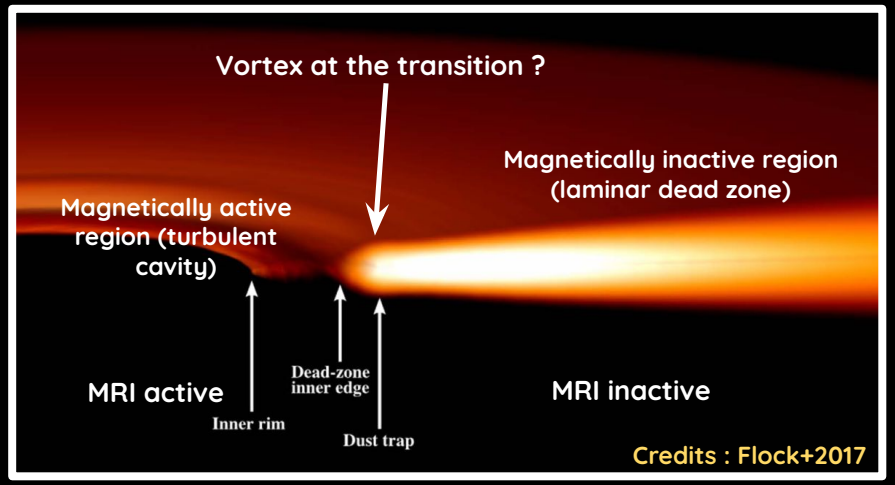

Hypothesis : a dust-trapping vortex at 0.3 AU ?

Sufficient condition to trigger the RWI :

$$min(\tilde{\kappa}) < 0.5$$

Chang&Youdin+2024

$$\tilde{\kappa} = \frac{\kappa^2}{\Omega^2}$$

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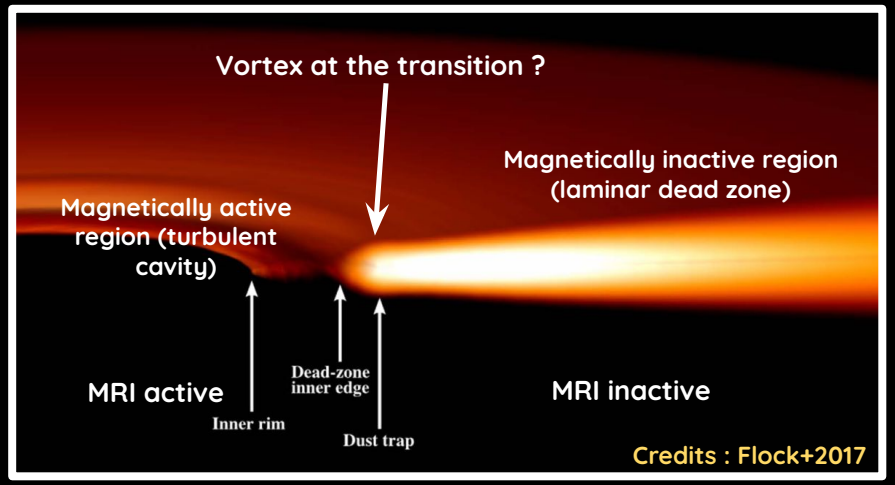

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(I)

Hydrodynamical simulations with FARGO3D

(II)

Dust radiative transfer calculation with RADMC-3D

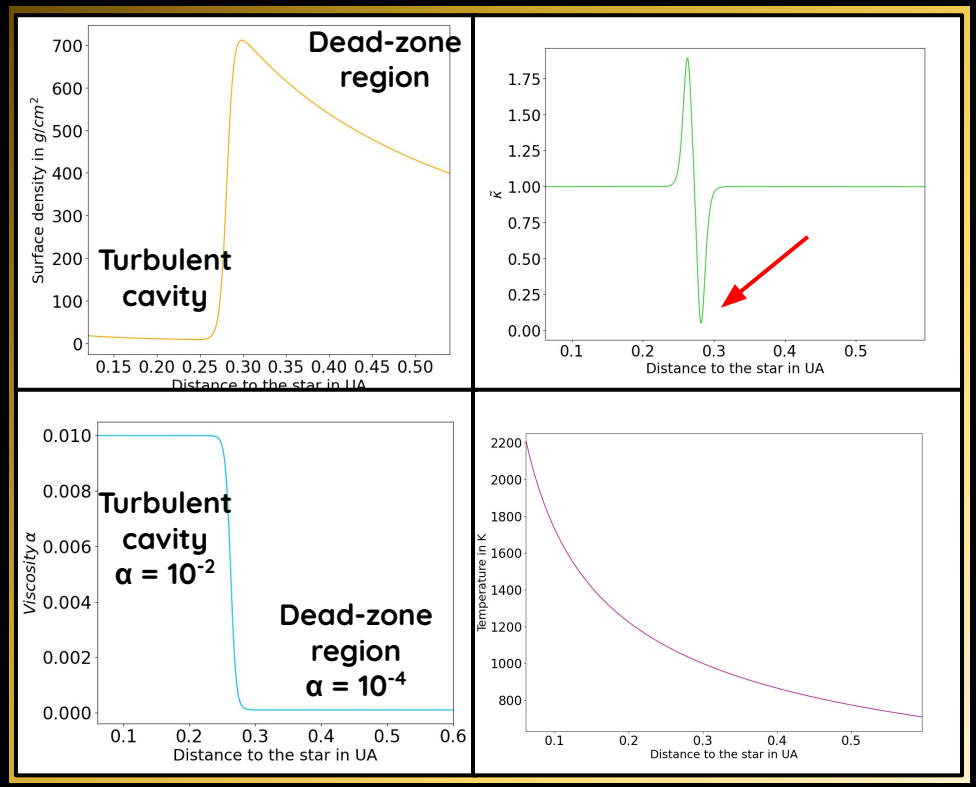
(III)

Computation of visibilities & closure phases with ASPRO2

The chosen model

Cavity profile = maximum density at the edge of the cavity

Corresponding viscosity transition



Minimum of $\tilde{\kappa}$ close to 5% : RWI triggering at ~0.3 AU

Power-law initial temperature profile + energy equation

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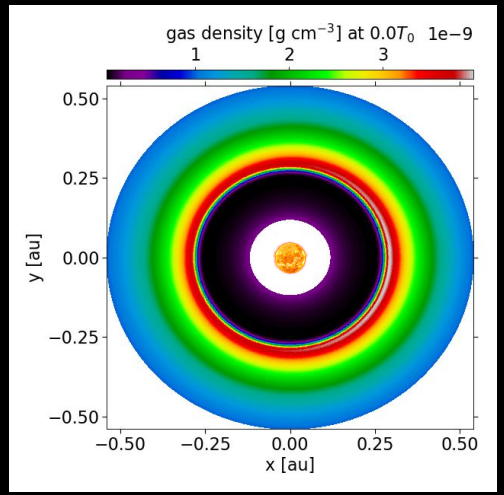
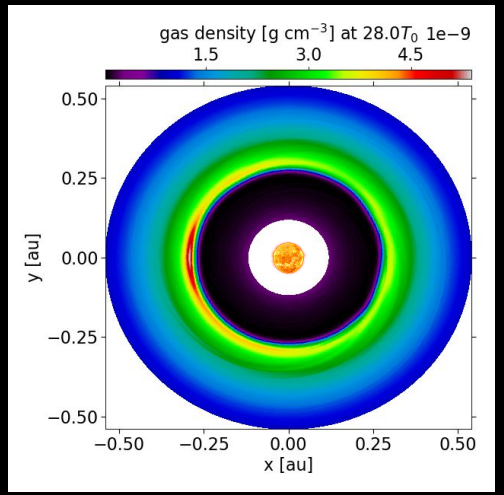
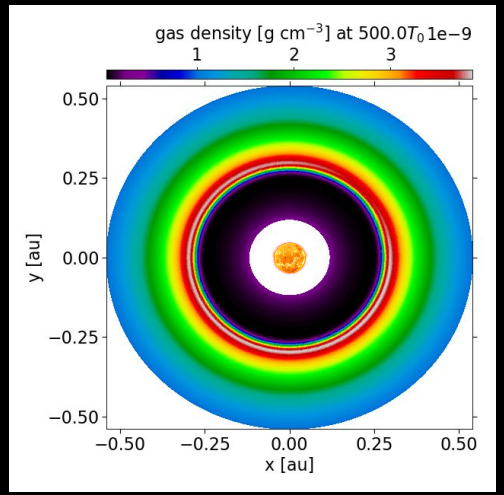
Results : lifetime of the vortex

~ 3 yr

~ 55 yr



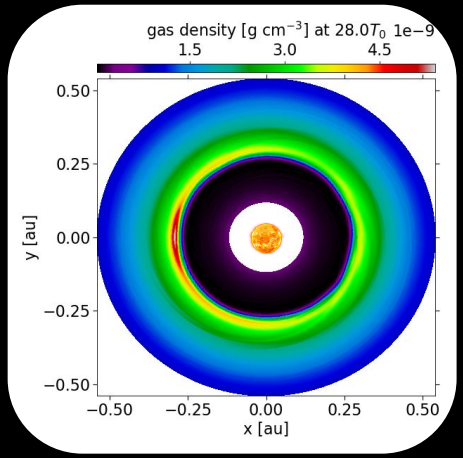




Gas midplane density
(3D simulations)

Results : dust radiative transfer calculations

Transfer code RADMC-3D : thermal Monte-Carlo + ray-tracing



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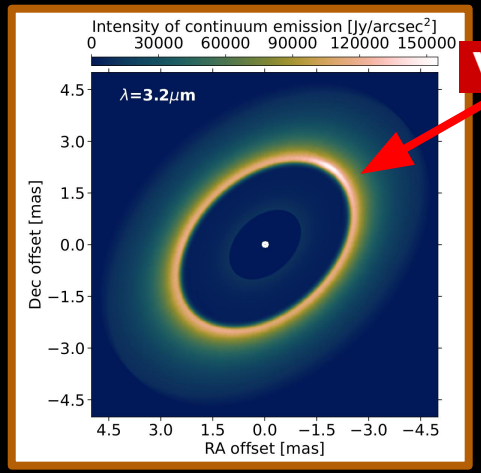


VORTEX !

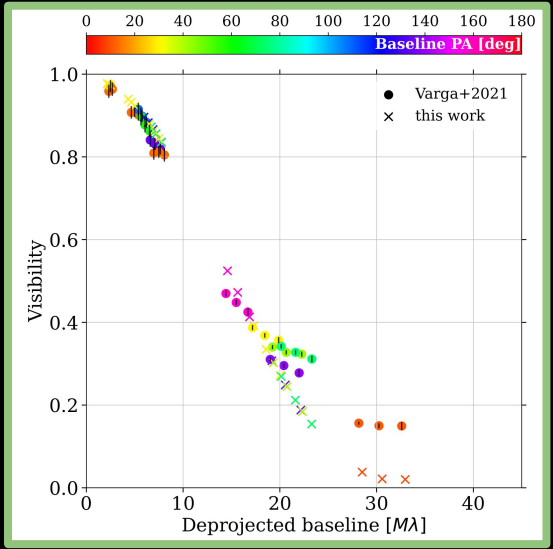
Synthetic dust emission map

Dust-to-gas mass ratio = 10^{-7}

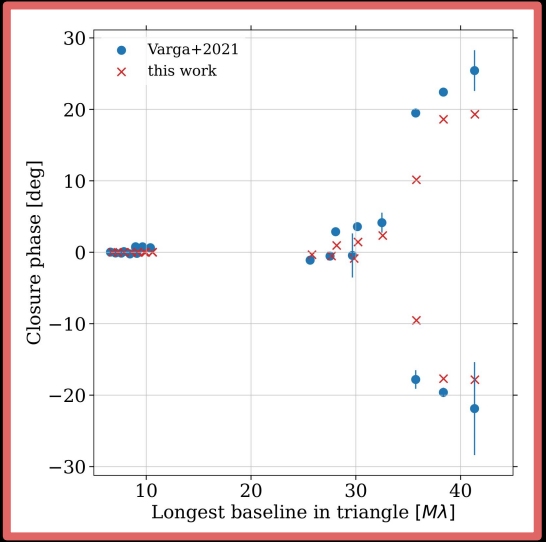
Star-to-disk flux ratio in the L-band : 9.8%

Results : a good fitting of visibilities and closure phases ?

ASPRO2 : compute synthetic interferometric observables with the same VLTI configuration used by Varga et al. 2021



Visibilities

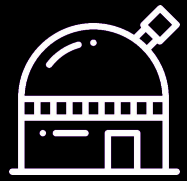


Closure phases

Conclusion

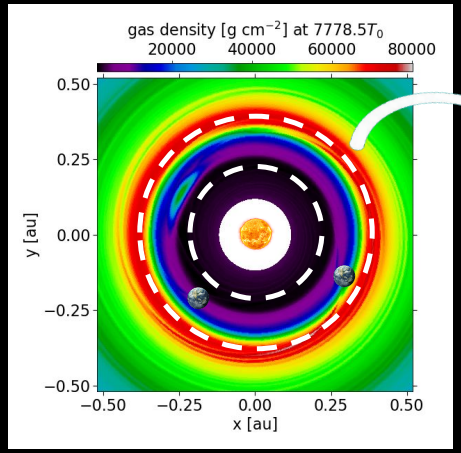
To explain the crescent-shaped structures in dust emission : Dust-trapping vortex at the edge of the turbulent cavity.

Formation of vortex is possible but it has short lifetime. The addition of an energy equation or a temperature transition does not improve this lifetime.

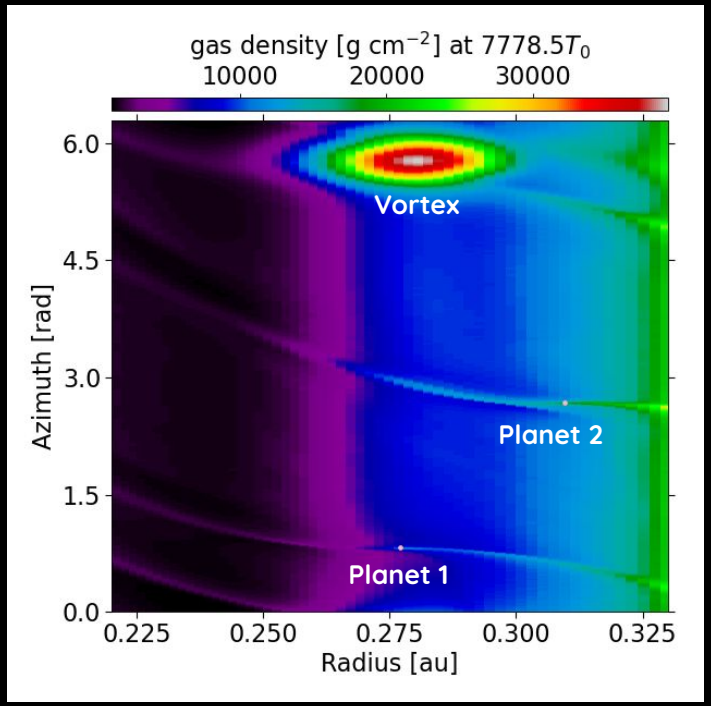


Difficult to reproduce all the visibilities but closure phases are nearly reproduced when the vortex is still present.

Perspectives



- 2D simulation
- 2 planets
- Vortex formation at L5 point of the 1st planet
- Subsists because of the spiral density wave of the 2nd planet



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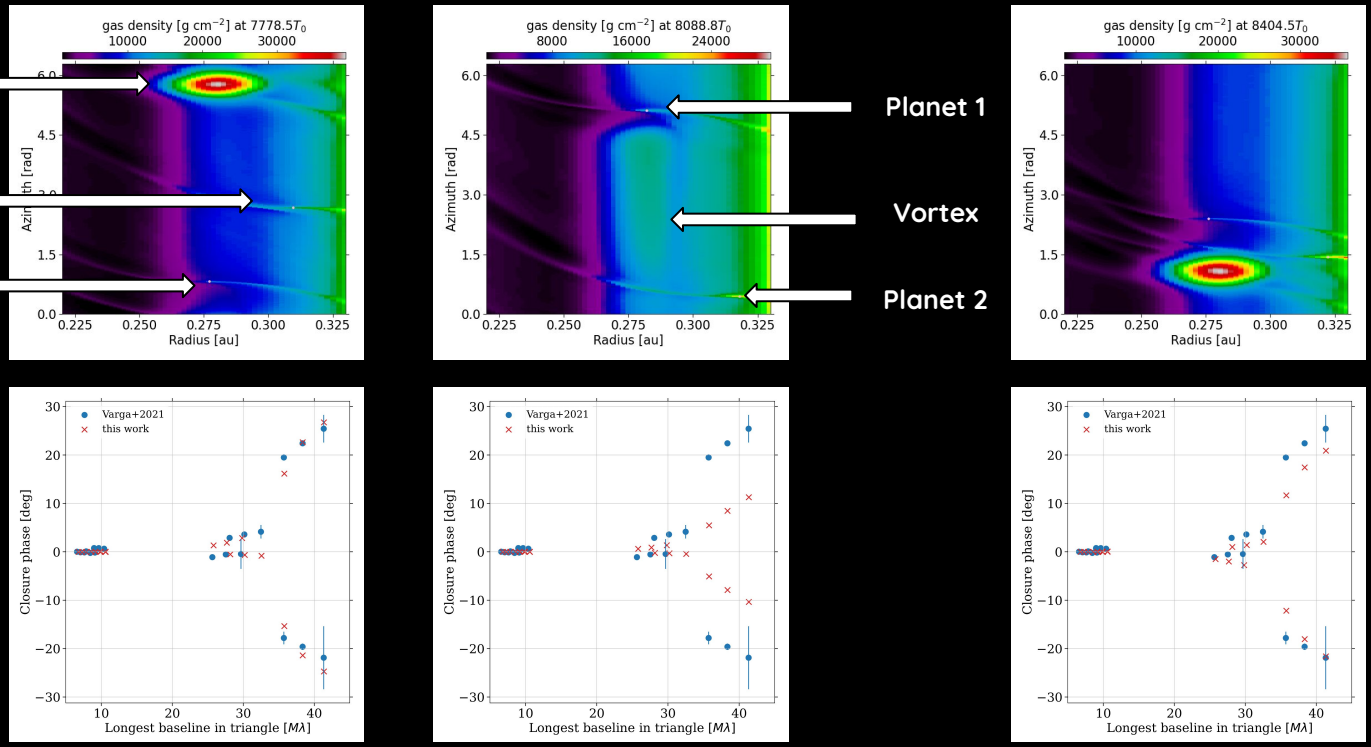

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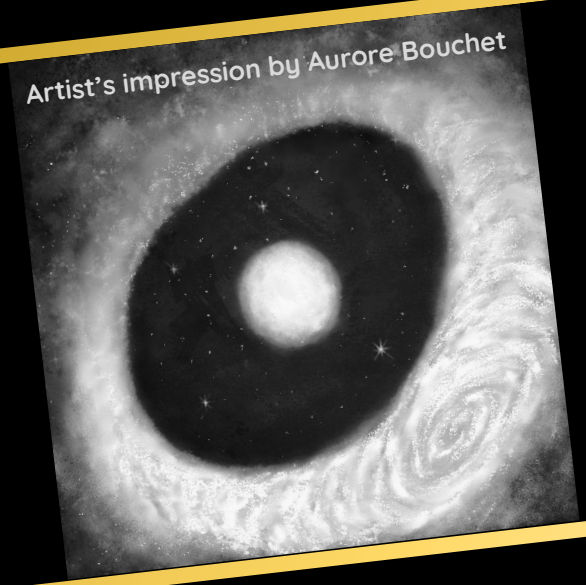
THANK YOU FOR YOUR ATTENTION !



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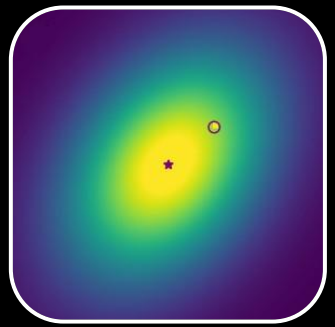
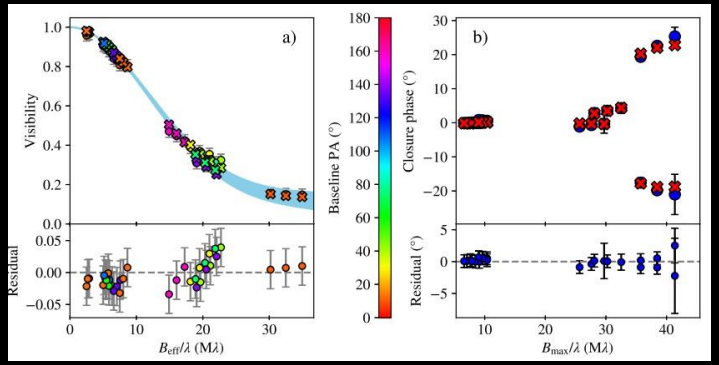
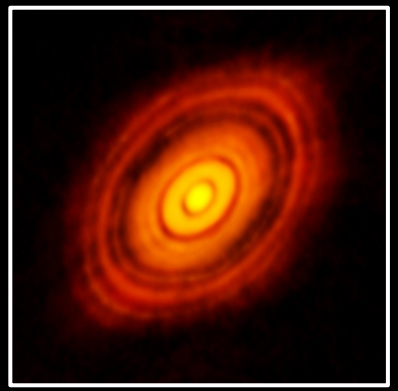
Bonus slide 1 : origine de l'asymétrie

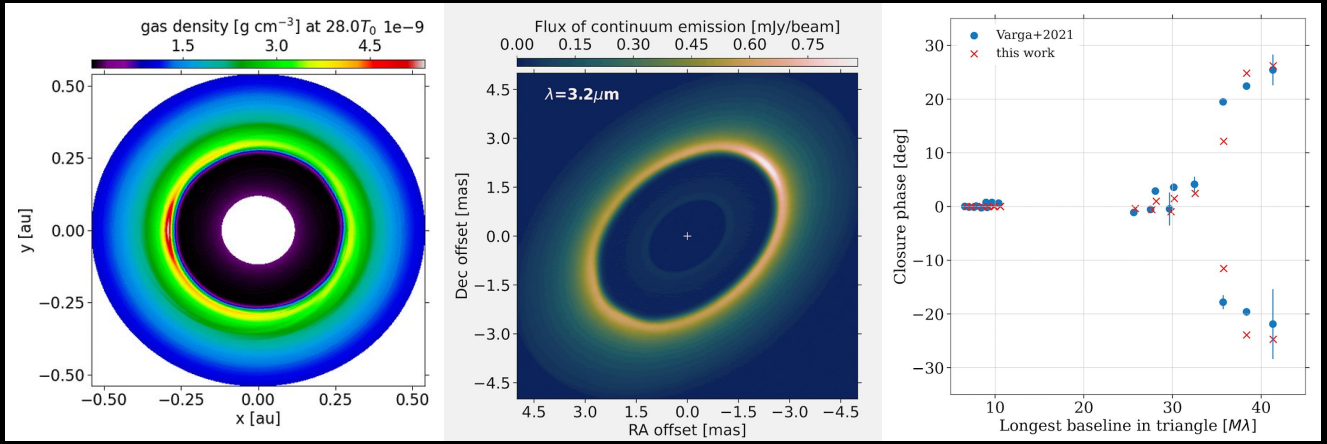




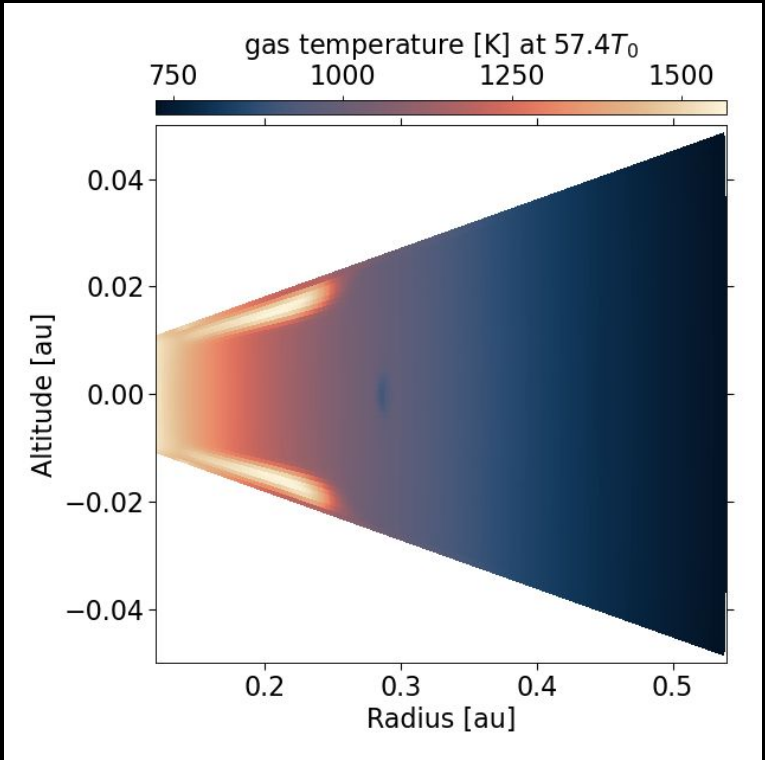


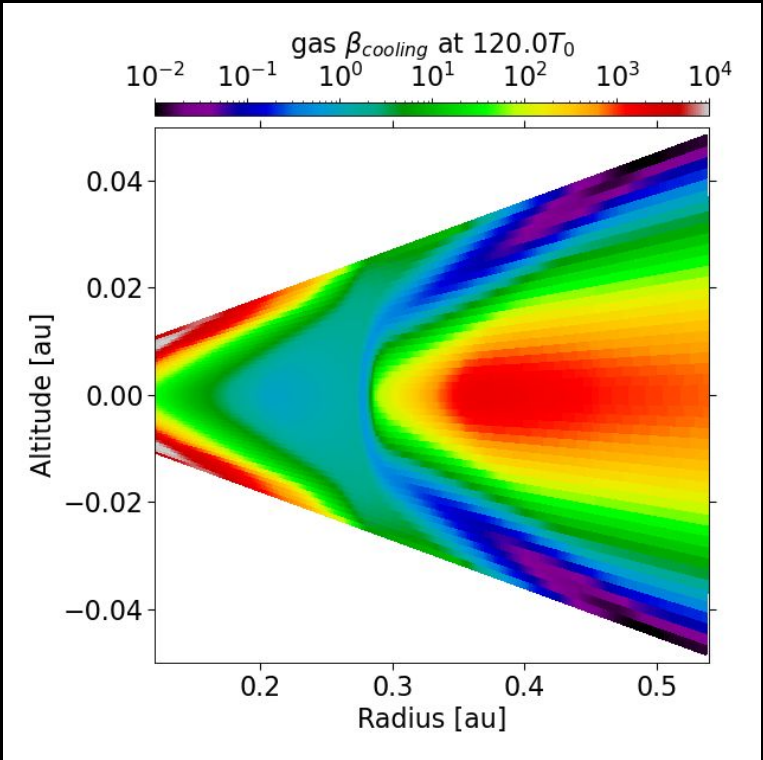
HL Tauri seen by ALMA
Credits : ESO

Bonus slide 2 : variabilité



Bonus slide 3 : simulations 3D





Bonus slide 4 : résultats RADMC-3D