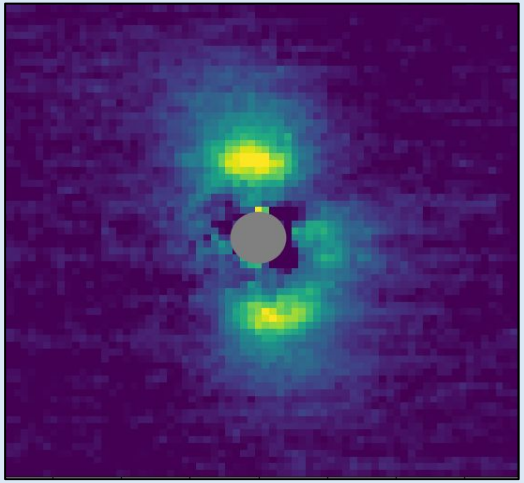
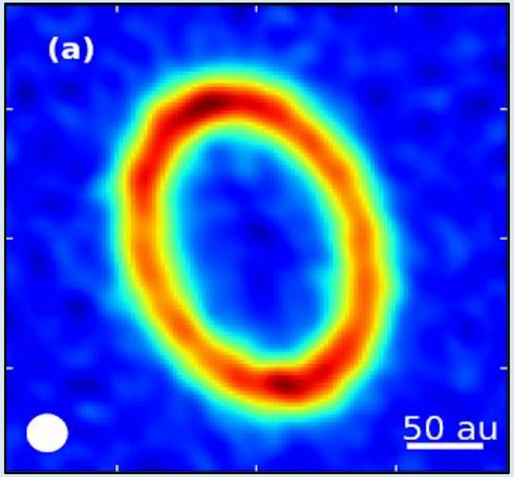
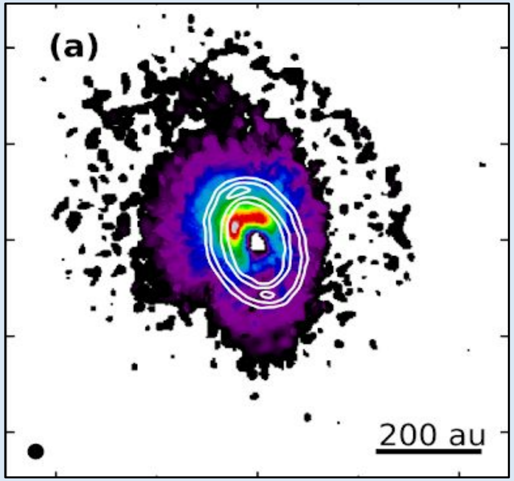
NACO polarimetric observations of Sz 91 transitional disk

A REMARKABLE CASE OF DUST FILTERING







Karina Maucó (Postdoc at U. Valparaíso)

Johan Olofsson, Hector Canovas, Matthias R. Schreiber, Valentin Christiaens, Amelia Bayo, Alice Zurlo, Claudio Caceres, Christophe Pinte, Clement Perrot, Eva Villaver, Gwendolyn Meeus, Julien H. Girard, Lucas Cieza, Mathias Montesinos

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Palm Cove, Queensland, Australia

Sz 91: a compact TD

- Lupus III molecular cloud
  - Distance = **159 pc** (GAIA DR2)
- Mdot ~ $10^{-8.8}$ Msun/yr (Alcalá et al. 2017)
- M0 Spectral type

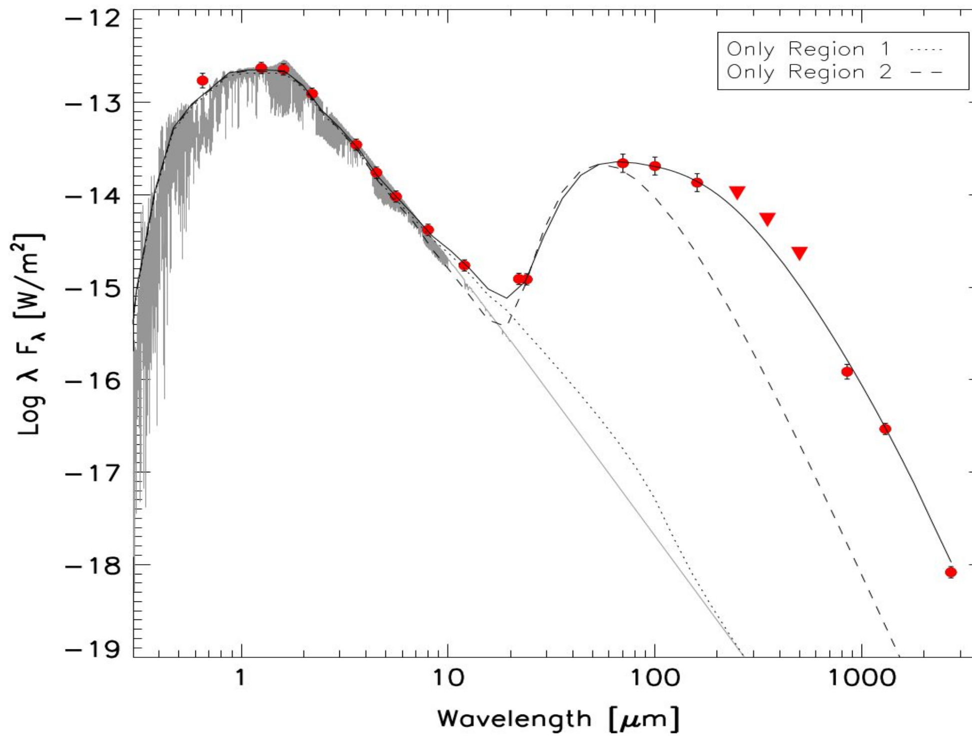
- (Bayo et al. (2008)

VOSA
VO SED Analyzer

optical-mm photometric data

Parameter	Value	Uncertainty
$T_{\rm eff}$ (K)	3800	[3750, 3850]
Log L_* ($L_\odot$)	-0.59	[-0.63, -0.56]
R_* ($R_\odot$)	1.18	[1.16, 1.18]
M_* ($M_\odot$)	0.58	[0.51, 0.62]
Age (Myr)	5.0	[3.6, 7.4]
$A_{\rm v}$ (mag)	1.65	[1.58 1.72]

200 pc before → **1-2 Myr**
older than 3 Myr

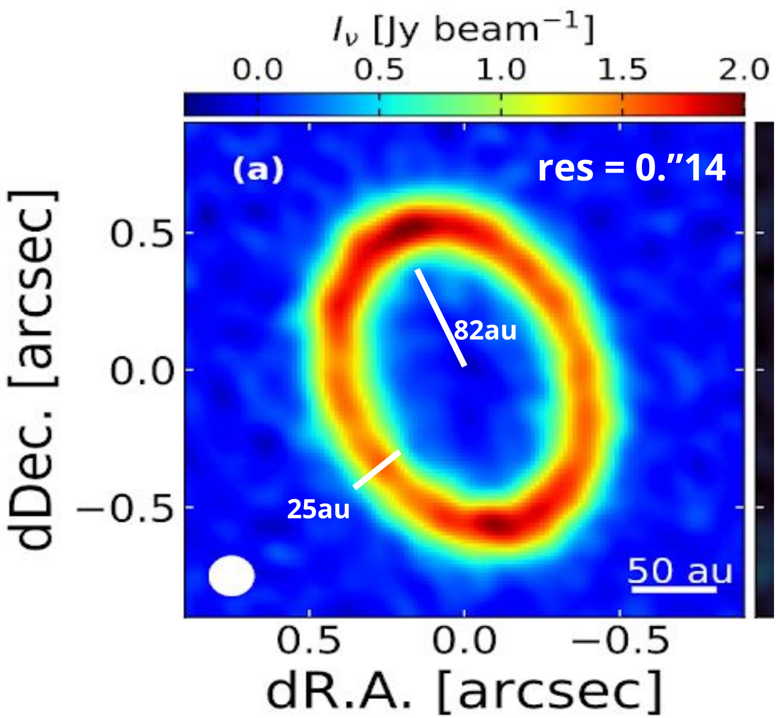


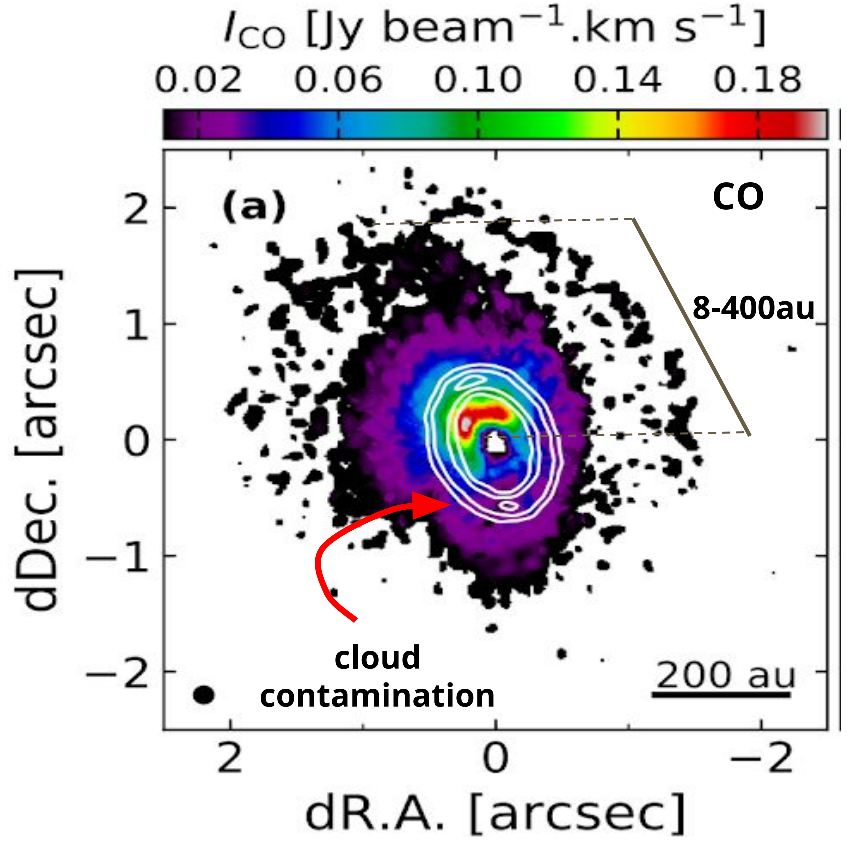
Maucó et al. in prep

Canovas et al. 2015

OBSERVATIONS

- **ALMA** band 7 (870μm) continuum and ^{12}CO and HCO+ line observations
- narrow ring (25 au width), ring-like structure, peaking at **~95 au** (**the largest** submm-dust cavity around a low-mass star)
- ^{12}CO emission **~8 au** to **~400 au**





modified from Tsukagoshi et al. (2019)

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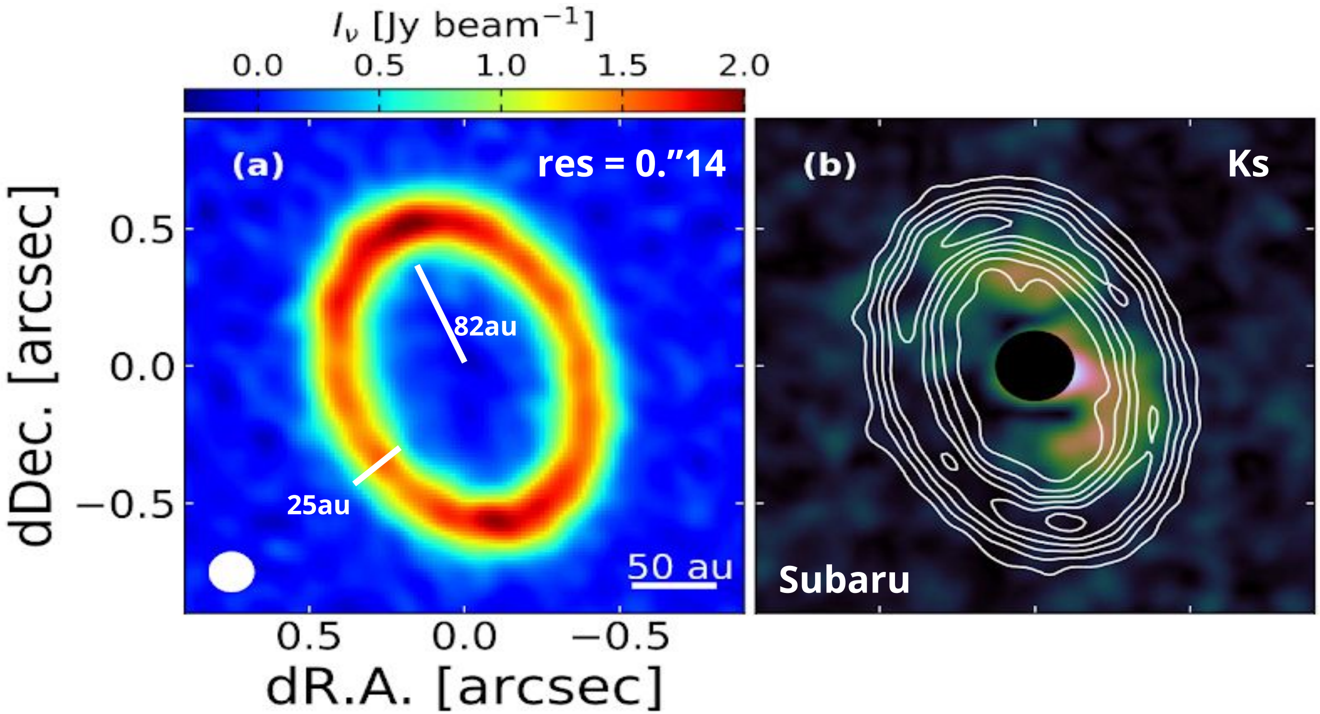


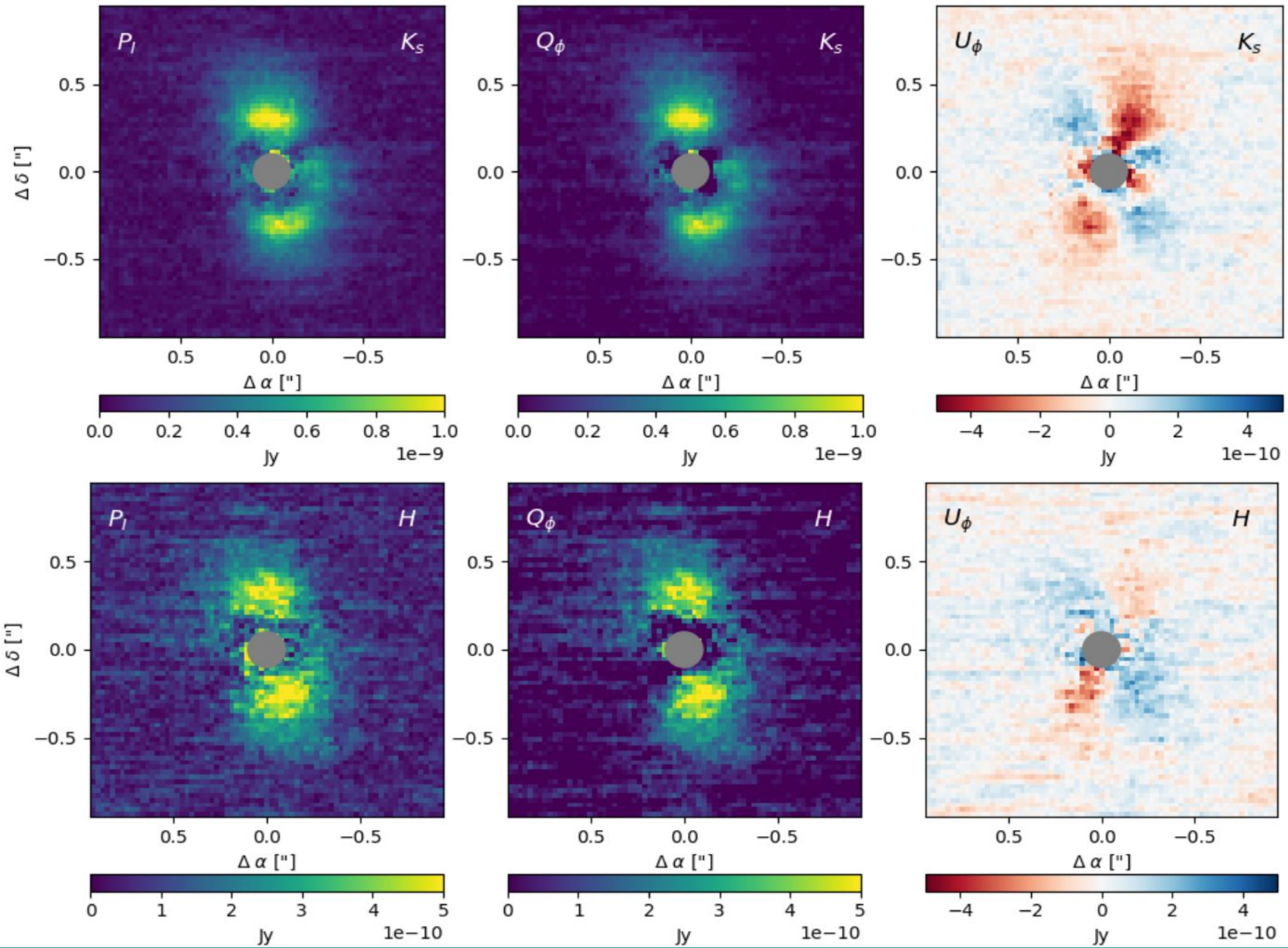
modified from Tsukagoshi et al. (2019), Tsukagoshi et al. (2014)

OBSERVATIONS

- **NaCo/VLT H/Ks polarimetry**

Ks band
(2.2 um)
texp=2.5 h
seeing=0.”53

H band
(1.7 um)
texp=1.20 h
seeing=0.”76



Maucó et al. in prep

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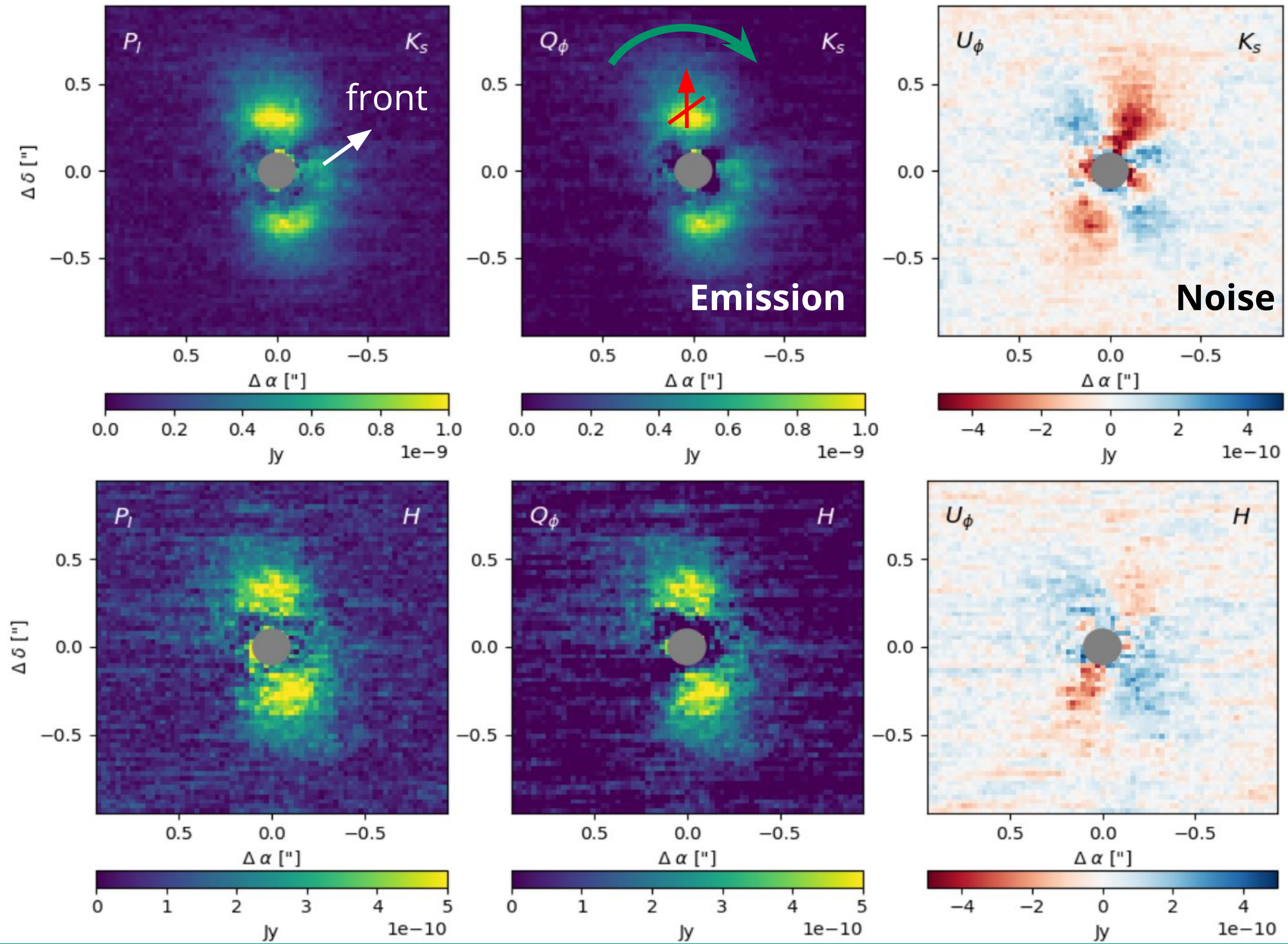

Maucó et al. in prep

MCFOST radiative transfer code

- We ran a grid of **13500** models
  - DHS grains → irregular shape
  - Pure silicate grains with small amount of carbonaceous particles (Draine & Lee 1984)
- PA ~ 18°, inclination ~50° (Tsukagoshi et al. 2019)

Parameter	Value
H_{100} (au)	5
γ	-1
ψ	1.15
$R_{\rm out}$ (au)	150
Parameter space	
$R_{\rm in}$ (au)	35-55, steps = 5
Porosity	0.1-0.9, steps = 1
$a_{\rm min}$ (μm)	0.05-0.175, steps = 0.025
δs (μm)	0.05-0.25, steps = 0.05
$m_{\rm dust}$ ($M_\odot$)	$10^{-6} - 10^{-7}$, steps = 1 (in log scale)

Notes. $a_{\rm max} = a_{\rm min} + \delta s$.

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MCFOST modeling

- **Bayesian approach**: we estimated PDFs of our model parameters using *VOSA 6.0* (Bayo et al. (2008)

-**Projected** into a grid with 0.027" pix-1

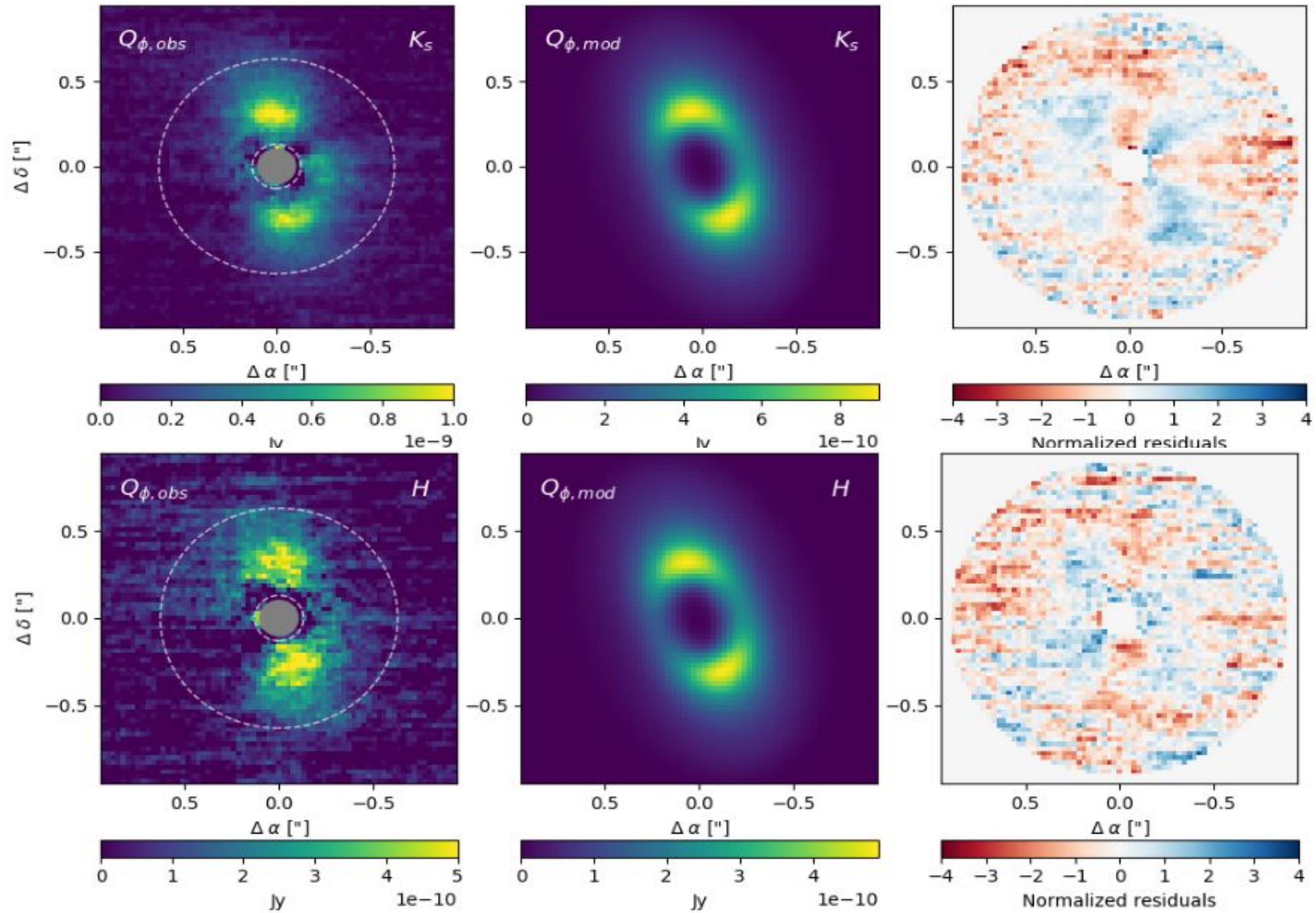
- **Scaled** using H/Ks 2MASS mag

- **Convolved** using a 2.5-px Gaussian PSF

- $W_i = \exp(-\chi^2/2)$

$$\chi^2 = \sum \frac{(Q_{\phi\mathrm{mod}} - Q_{\phi\mathrm{obs}})^2}{\sigma^2}$$

standard deviation in concentric anuii from the center of the **Uϕ image**



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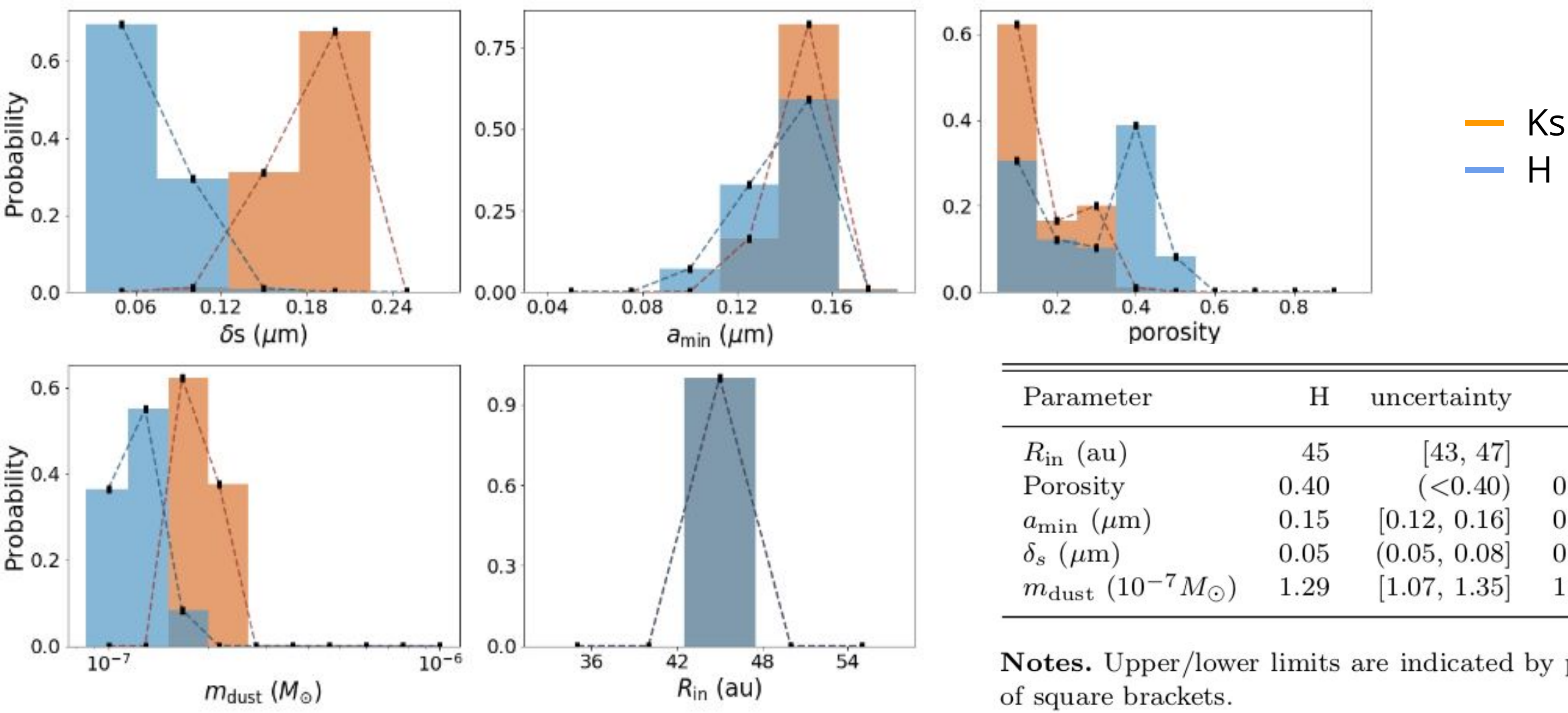
Results: MCFOST modeling

- **PDFs of our model parameters**



Parameter	H	uncertainty	K	uncertainty
$R_{\rm in}$ (au)	45	[43, 47]	45	[43, 47]
Porosity	0.40	(<0.40)	0.10	(0.1, 0.17]
$a_{\rm min}$ (μm)	0.15	[0.12, 0.16]	0.15	[0.13, 0.16]
δ_s (μm)	0.05	(0.05, 0.08]	0.20	[0.15, 0.22]
$m_{\rm dust}$ ($10^{-7} M_\odot$)	1.29	[1.07, 1.35]	1.67	[1.59, 2.27]

Notes. Upper/lower limits are indicated by parentheses instead of square brackets.

- small grains (**<0.4um**),
- porosity **< 40%**,
- Rin = **45 au** (submm ring @ ~95 au),

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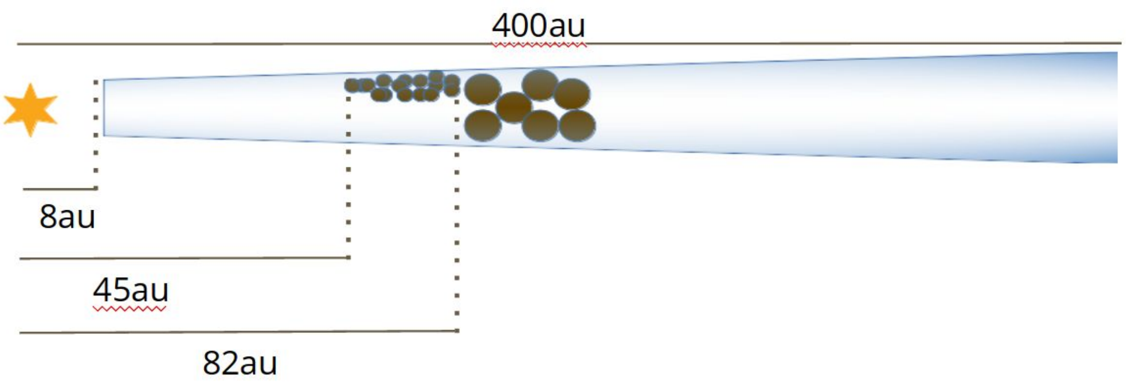
GAP OPENING MECHANISM?

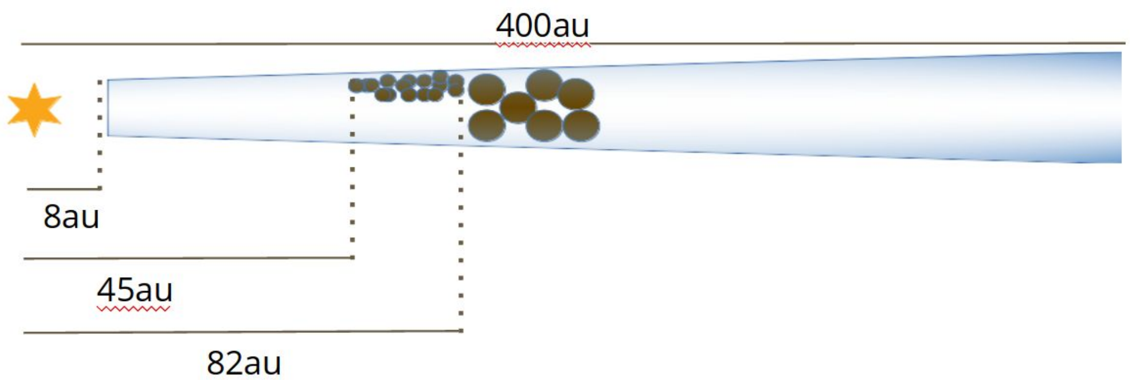
- Planets
- Dead zones
- Photoevaporation



GAP OPENING MECHANISM?

- Planets
- Dead zones
- Photo~~evaporation~~

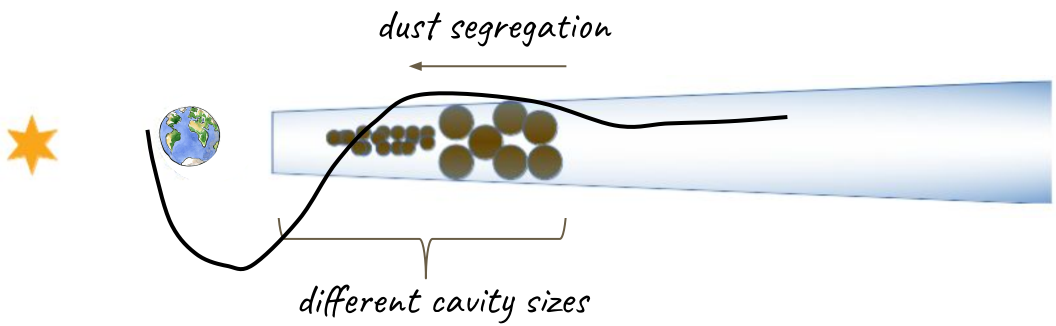
- *Large sub-mm cavity*
- *$10^{-8.8}$ Msun/yr (Alcalá et al. 2017)*



Owen et al. 2011; Ercolano & Pascucci 2017

GAP OPENING MECHANISM?

- **Planets**
- Dead zones

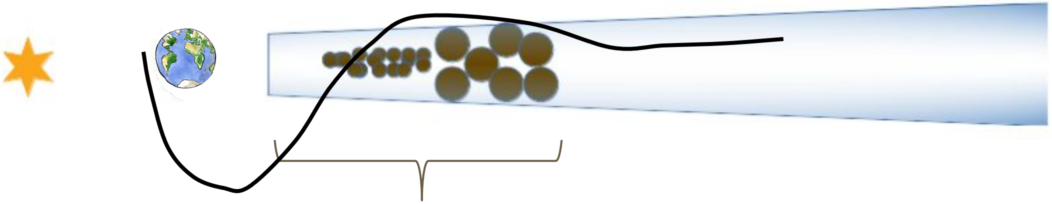


✓ Creates pressure bump (dust traps)
✓ Low-mass planets ⟶ Partial filtration of dust
✓ Different radii between gas and dust
? Gas emission down to innermost regions

e.g. Rice et al. 2006; Pinilla et al. 2016a,b; Gabellini et al. 2019

GAP OPENING MECHANISM?

- **Planets**
- Dead zones



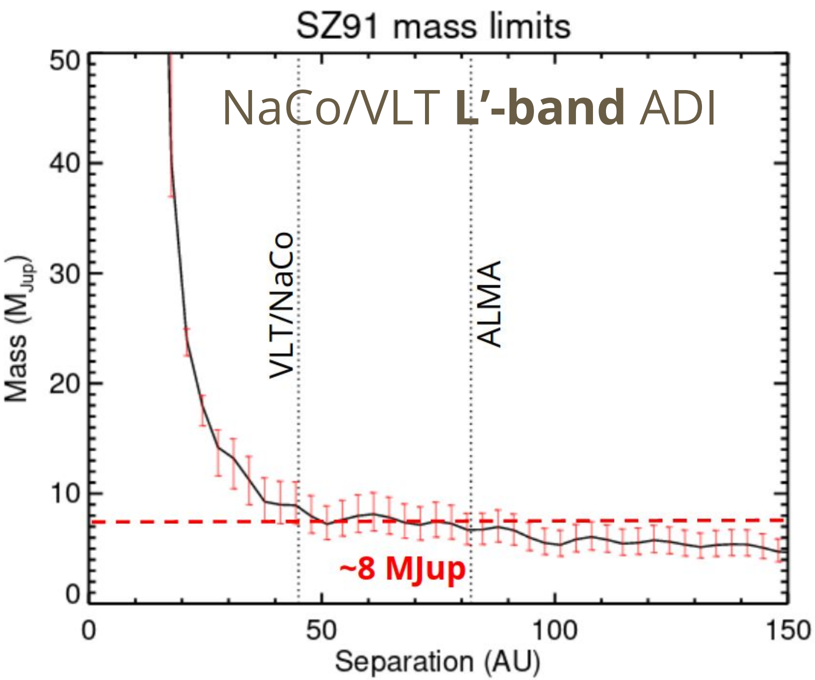
✓ Creates pressure bump (dust traps)

✓ Low-mass planets → Partial filtration of dust

✓ Different radii between gas and dust

? Gas emission down to innermost regions

multiple low-mass planets

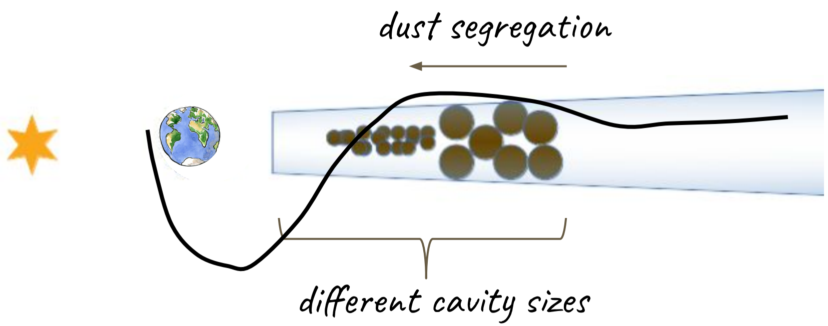


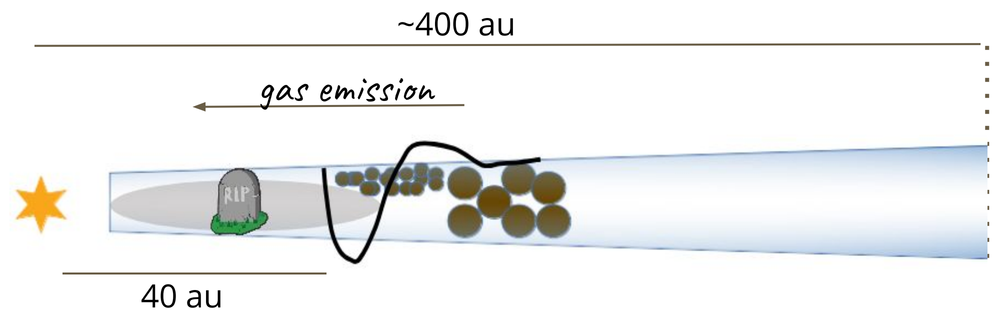
van der Marel's talk → mass of companion **>13 Mjup** (Rgas$_{cav}$ vs Rdust$_{cav}$)

e.g. Rice et al. 2006; Pinilla et al. 2016a,b; Gabellini et al. 2019

GAP OPENING MECHANISM?

- Planets
- **Dead zones**





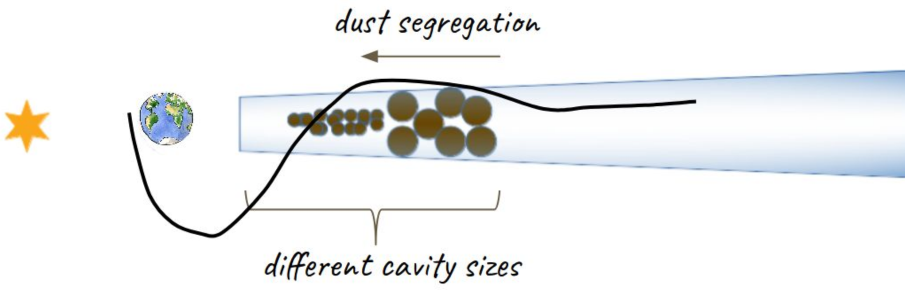
- ✓ Creates pressure bump (dust traps)
- ✓ Low-mass planets → Partial filtration of dust
- ✓ Different radii between gas and dust
- ? Gas emission down to innermost regions

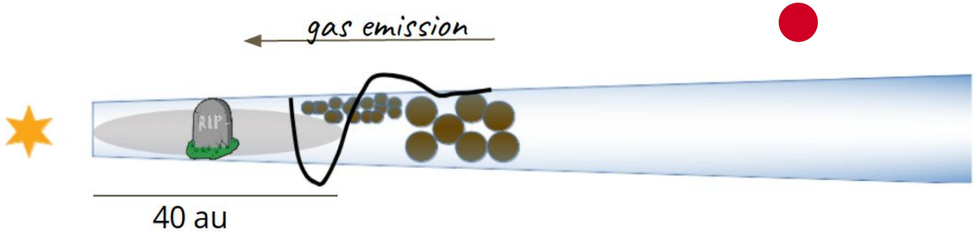
- ✓ Pressure bump @outer edge
- ✓ Presence of gas at the innermost regions
- ✓ Including a MHD wind → gas @ <10-20 highly depleted
- ? Can produce dust filtration?
- ✗ Gas outer disk significantly depleted

e.g, Flock et al. 2015; Pinilla et al. 2016

GAP OPENING MECHANISM?

- Planets
- Dead zones





Radially resolve the sub-mm ring.

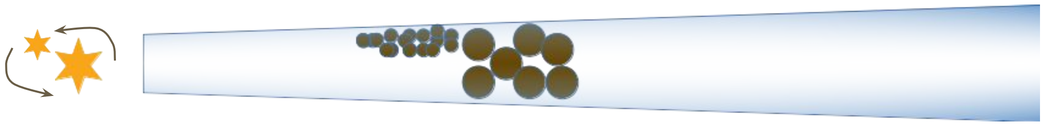
radially asymmetric ring with a wider outer tail

radially symmetric ring

e.g, Flock et al. 2015; Pinilla et al. 2016

GAP OPENING MECHANISM?

- **Binary**

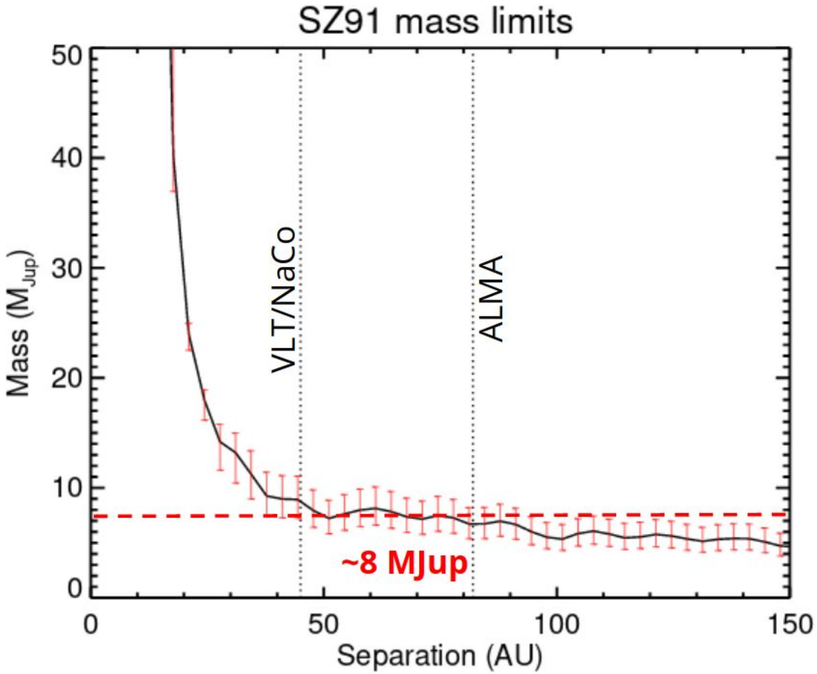


- *One epoch of MIKE spectra*
- *Discard SB2 nature*

equal mass binary *m1/m2 > 0.7*

- *Melo+2003 no evidence for a close-in binary companion (down to masses ~0.2Msun)*

Our Rv differed from Melo's by ~2.5sigma



WHAT ABOUT THE DUST?

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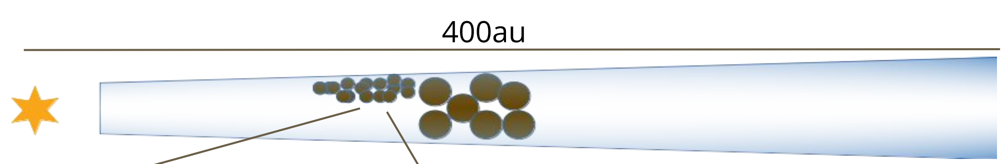
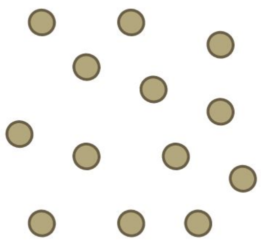
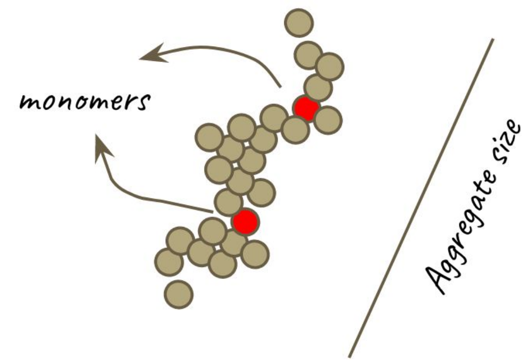
- Small dust (<0.4 um)
- Porous (<40%)
- Large aggregates



- Small grains



- Large aggregates
- Polarized emission dominated by small monomers



e.g., Min et al. 2016; Roy et al. 2017; Halder et al. 2018; Tazaki et al. 2019

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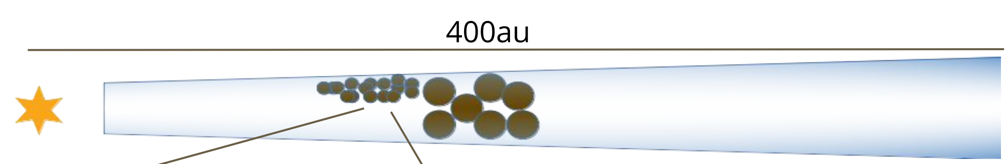

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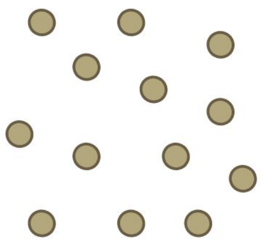
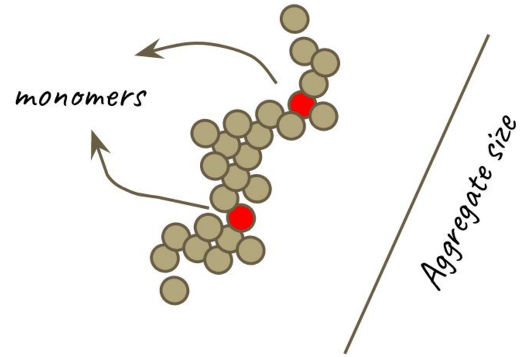


+ Observations

scattered-light → total intensity

@different λ → color

- Large aggregates
- Polarized emission dominated by small monomers



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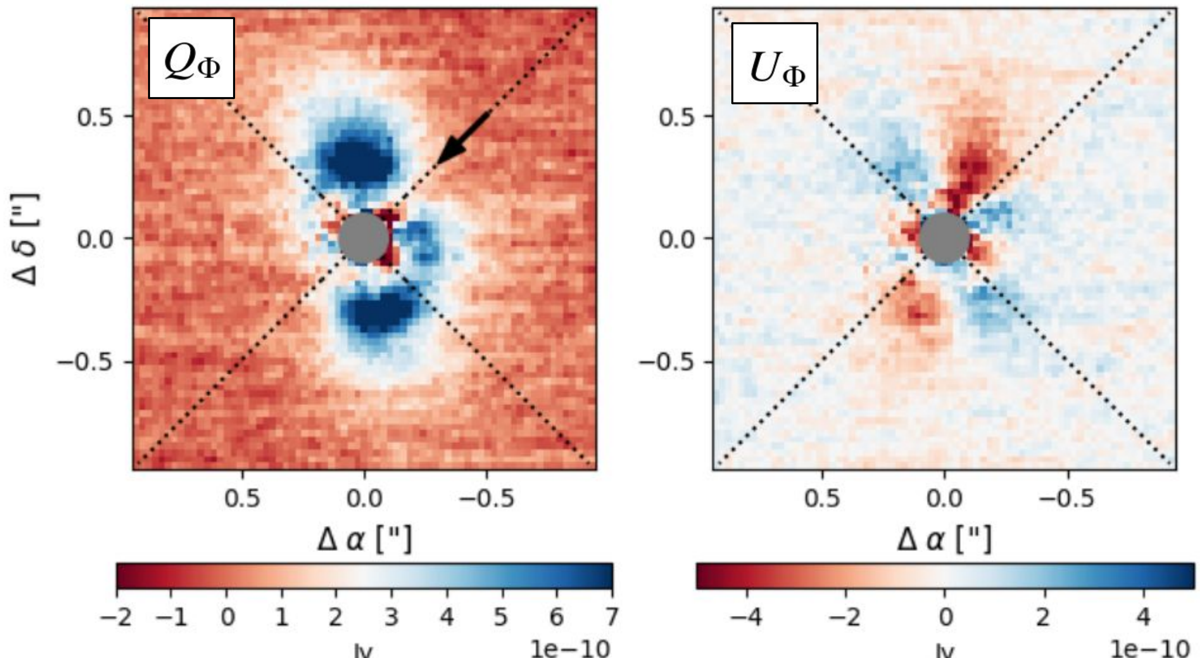
Apparent "dip"

- Very faint (1.2sigma)
- Located at 45° → image subtraction
- Negative values close to the center of the image → multiple scattering events (Canovas+2015, Pohl+2017)
- Centering effects



Maucó et al. in prep

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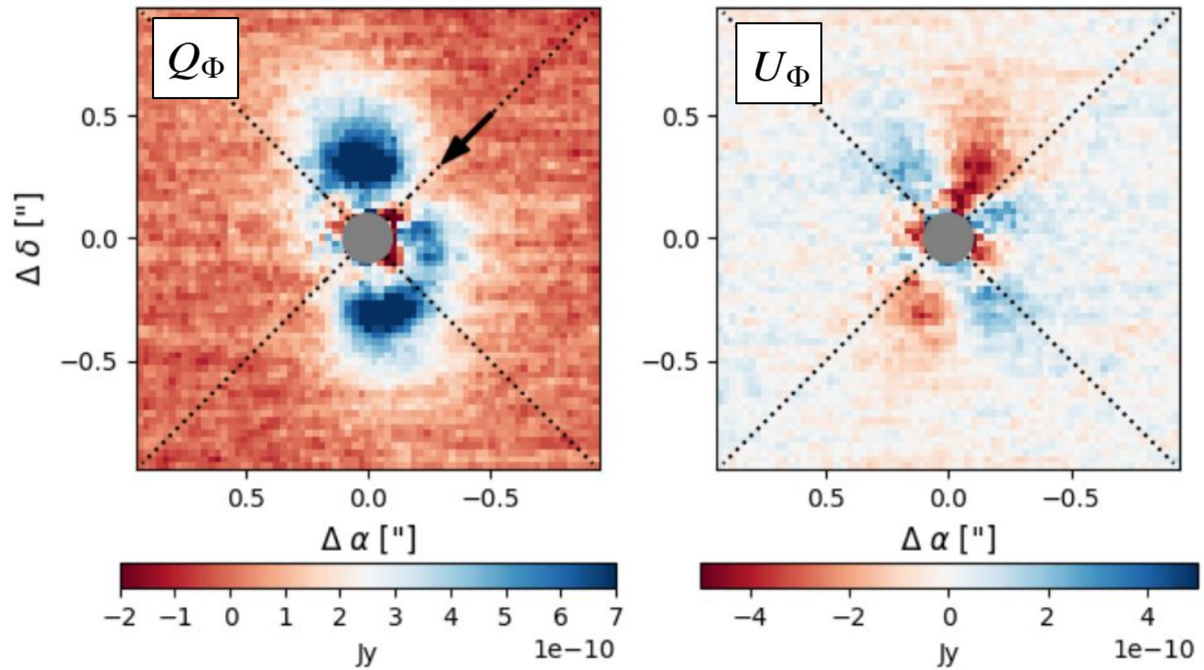
Hint → most likely related to the data reduction process and/or multiple scaterring events



Maucó et al. in prep

THANKS!

DUST BUSTERS

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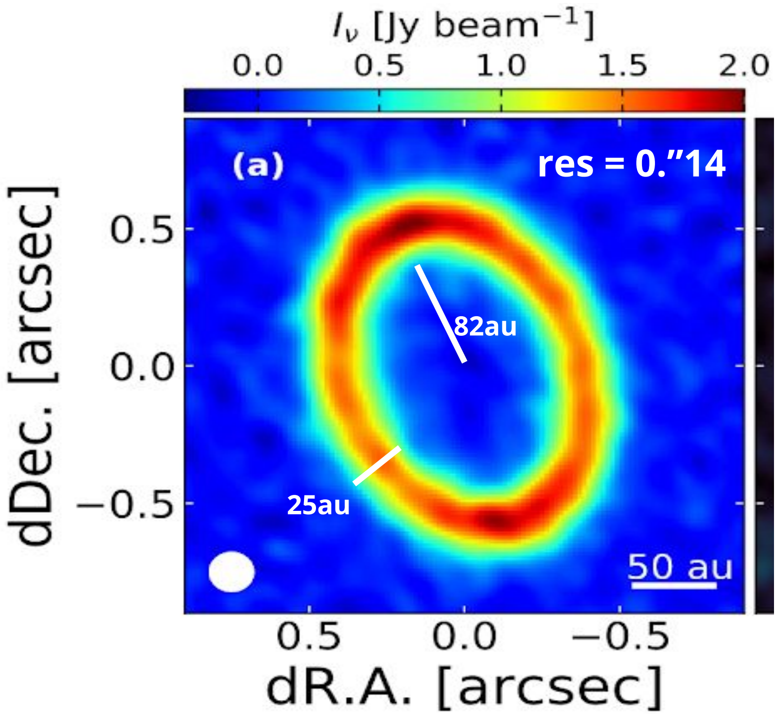
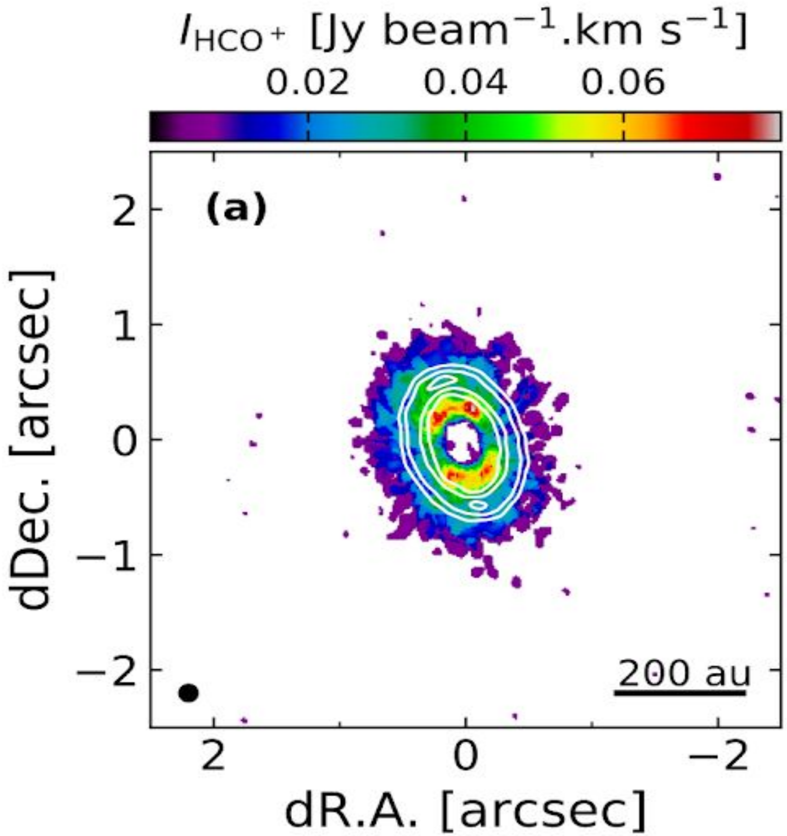
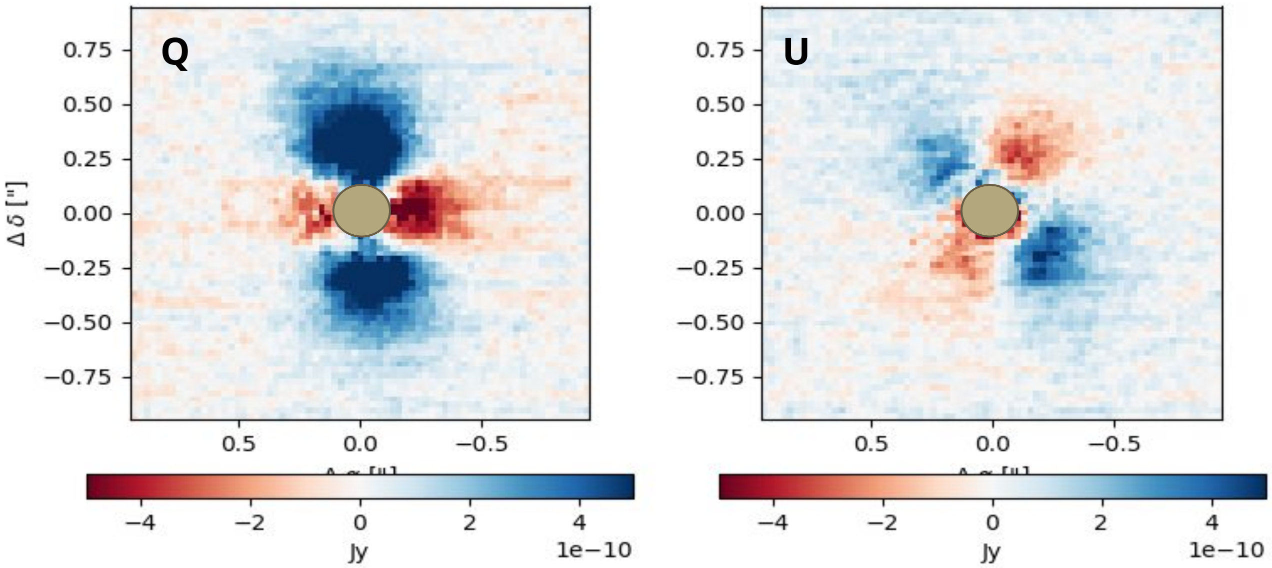


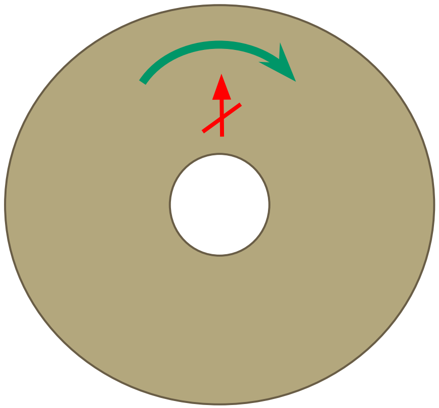


modified from Tsukagoshi et al. (2019)

Polarized emission

- Stokes **Q** and **U** parameters
- Single scattering → polarization in the **tangential** direction





Polarized emission

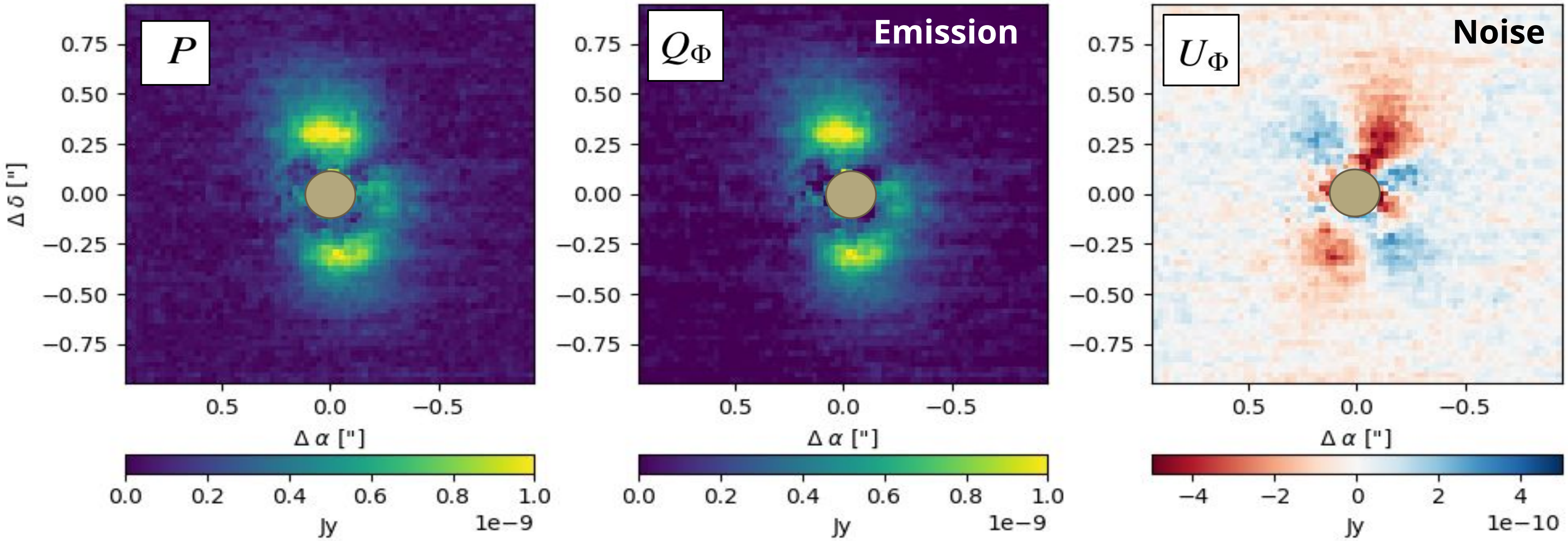
- **Polar-coordinate Stokes parameters:**

$$P = \sqrt{Q^2 + U^2},$$

tangential $Q_\Phi = +Q\cos(2\Phi) + U\sin(2\Phi),$

radial $U_\Phi = -Q\sin(2\Phi) + U\cos(2\Phi),$

$$\Phi = \arctan\frac{x - x_0}{y - y_0} + \theta.$$



Dust properties

Min+2016

M. Min et al.: Multiwavelength optical properties of compact dust aggregates in protoplanetary disks

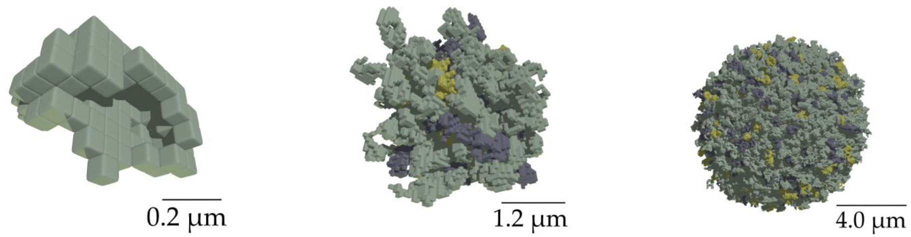


Fig. 1. Images of the particles used in the DDA computations. The *left image* shows a single monomer, containing approximately 100 dipoles, the *middle image* is an aggregate containing 216 of these monomers, and at the far *right* we show the largest aggregate we consider, containing 8000 monomers. The horizontal line indicates the scale in each image.

Tazaki+2019

Scattered-light images of fluffy dust discs 4953

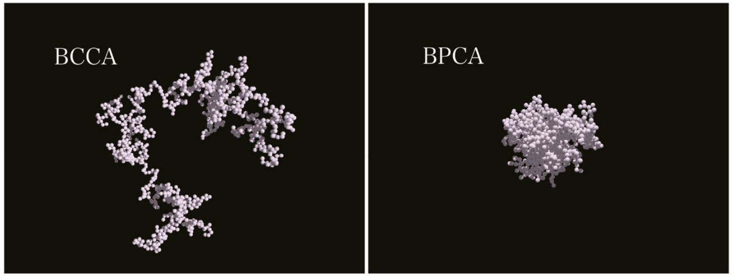


Figure 1. Morphology of porous dust aggregates. Left- and right-hand panels correspond to the BCCA and BPCA models, respectively. The number of monomers is 1024 and the monomer radius is set as $R_0 = 0.1\,\mu$m, and hence the characteristic radii of the BCCA and BPCA models are $R_c = 4.8\,\mu$m and 1.9 μm, respectively. Both dust aggregates have the same volume equivalent radius $R_V \simeq 1\,\mu$m. Hence, BCCA and BPCA have porosity of 99 per cent and 85 per cent, respectively.