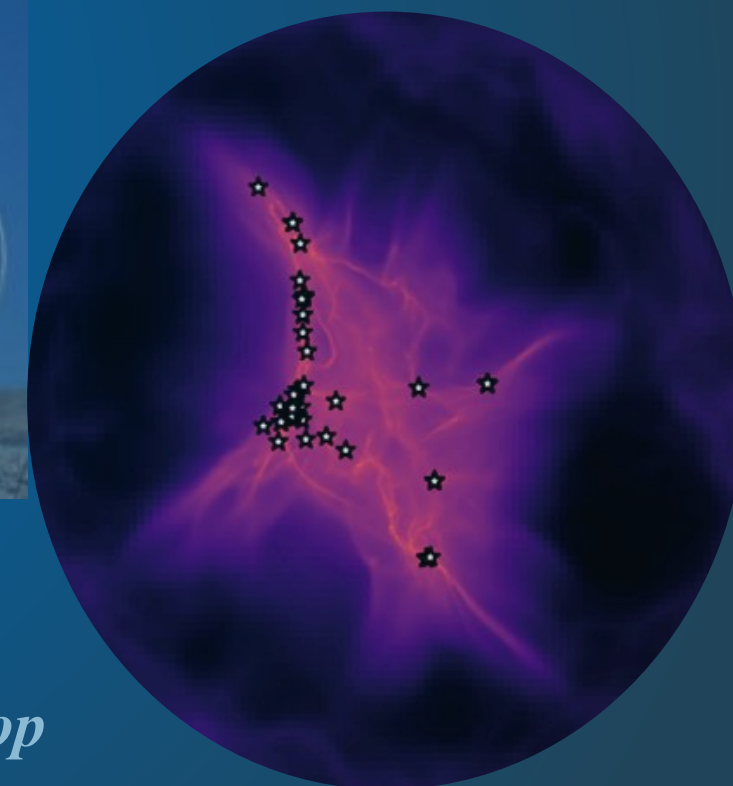
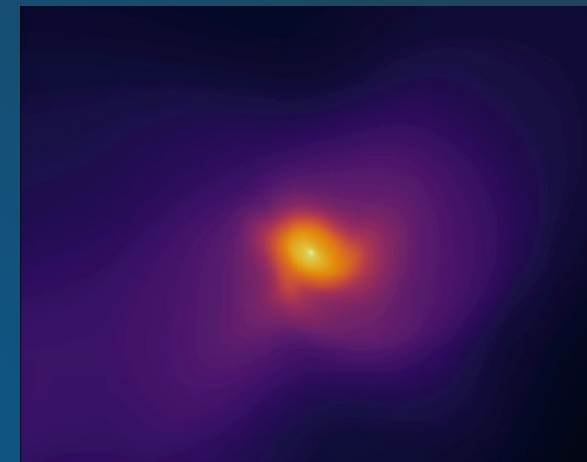


# RECOVERING THE MASS OF CLASS 0/I DISCS THROUGH BAND 2/3 CONTINUUM



**G. Columba**

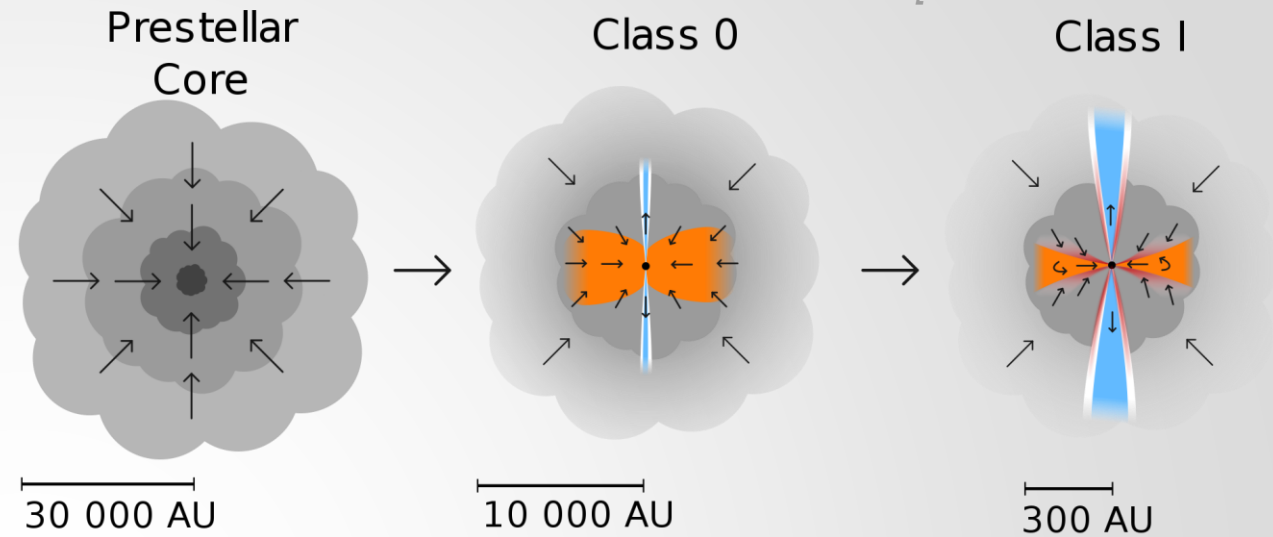
L. Testi, U. Lebreuilly, D. Tung, A. Maury, et al.



*Unveiling ALMA Band 2 workshop*  
*Bologna 26/02/2026*

# SCIENTIFIC CONTEXT

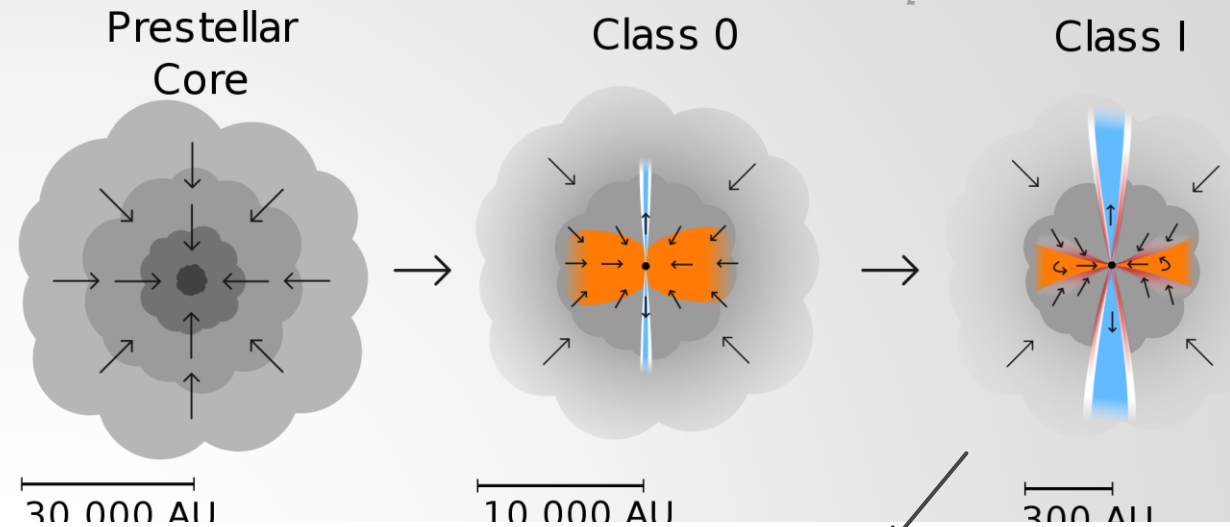
Stars and planet formation starts from collapsing large **molecular clouds**  
(e.g. Williams & Cieza 2011, Tsukamoto+ 2023)



After the **gravitational collapse** of a cloud core, the infalling material quickly forms an **accretion disk**, supported by angular momentum.

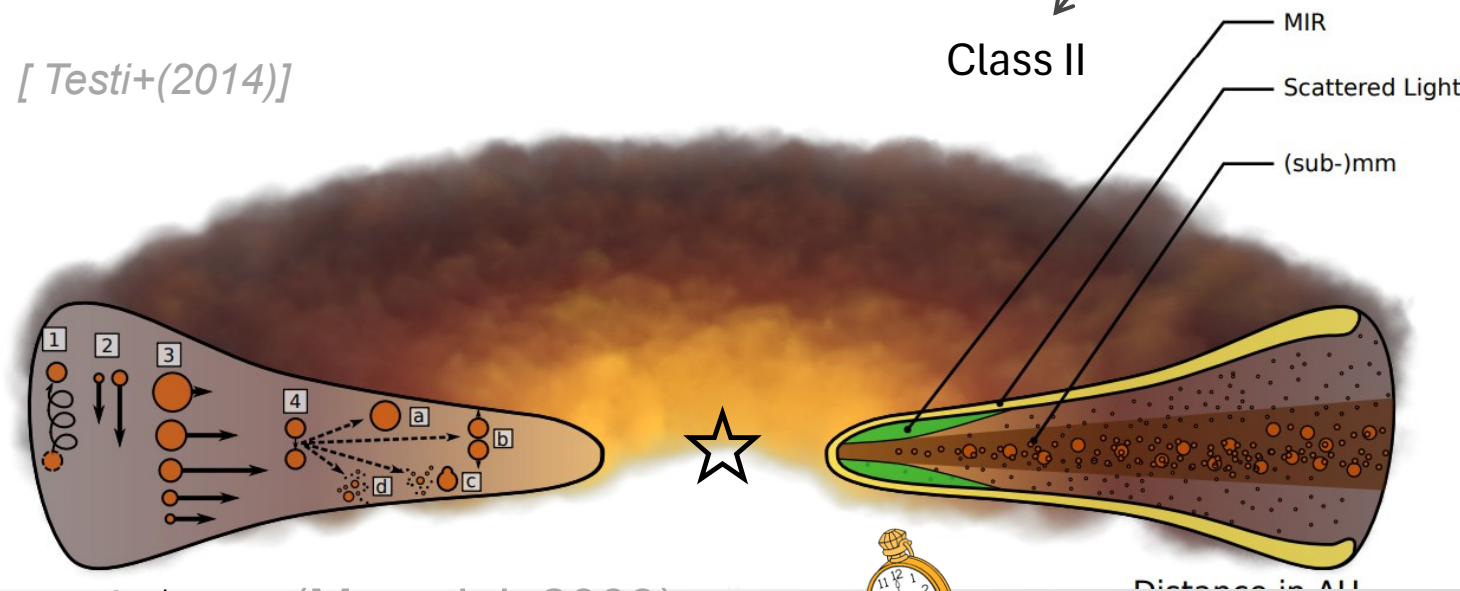
# SCIENTIFIC CONTEXT

Stars and planet formation starts from collapsing large **molecular clouds** (e.g. Williams & Cieza 2011, Tsukamoto+ 2023)



After the **gravitational collapse** of a cloud core, the infalling material quickly forms an **accretion disk**, supported by angular momentum.

[ Testi+(2014)]

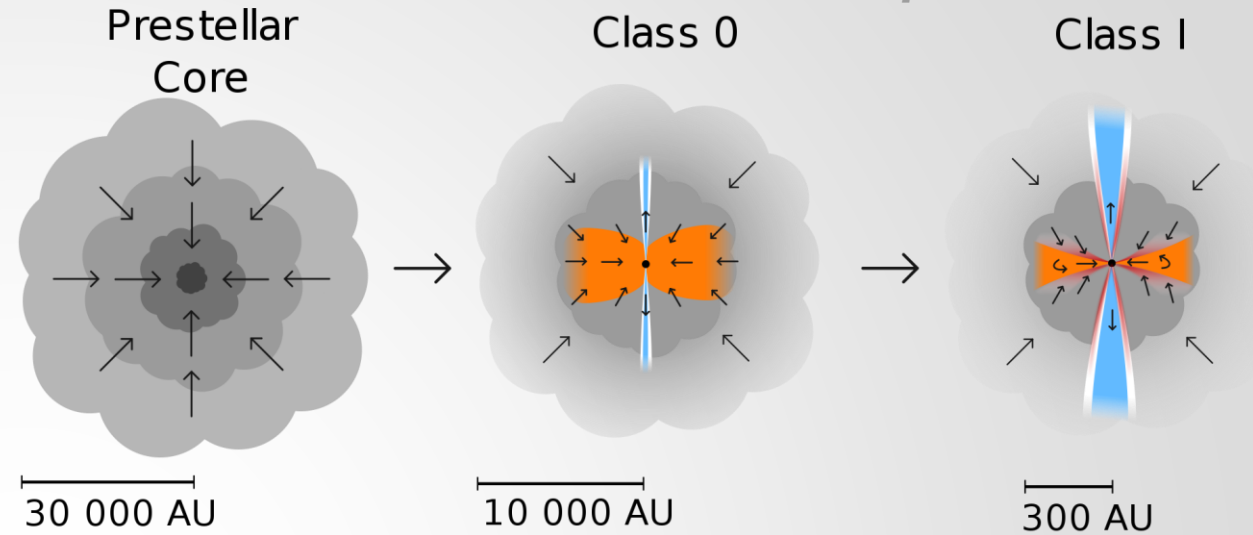


- Median lifetime of circumstellar disks:  $\tau \sim 2.5$  Myr (Mamajek 2009)
- Almost no disk observed after 10 Myr
- **Planet formation** *must* happen within this short time span!



# SCIENTIFIC CONTEXT

Stars and planet formation starts from collapsing large **molecular clouds**  
(e.g. Williams & Cieza 2011, Tsukamoto+ 2023)



Understanding of **PPDs evolution** requires to consider many processes at once  
*Early stages YSO Class 0/1 are more challenging to characterise due to their envelopes*



Necessity of **large-scale modelling** to bridge the galactic environment to the disk populations



Owen Wilson did not actually endorse ALMA in any way. Images adapted from "Marley and Me" © 2008 20<sup>th</sup> Century Fox and from a picture of ALMA antennas by the © Institut de radioastronomie millimétrique (IRAM), for educational purposes only. All rights belong to the original owners.

# OBJECTIVES

- Generate ALMA mock interferometric observations in **band 2/3 and 1** (3mm and 7mm) and analyse the sample with **survey-like** fitting methods.

*(Extending the work of Tung et al. 2024 in Band 7 or 0.9 mm)*

- Assess observables relations (and biases) to the underlying properties (**Class 0/1**)

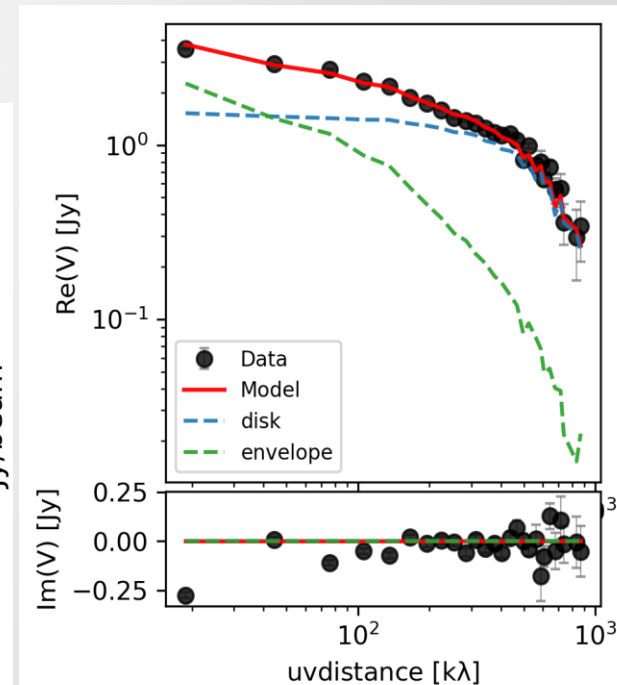
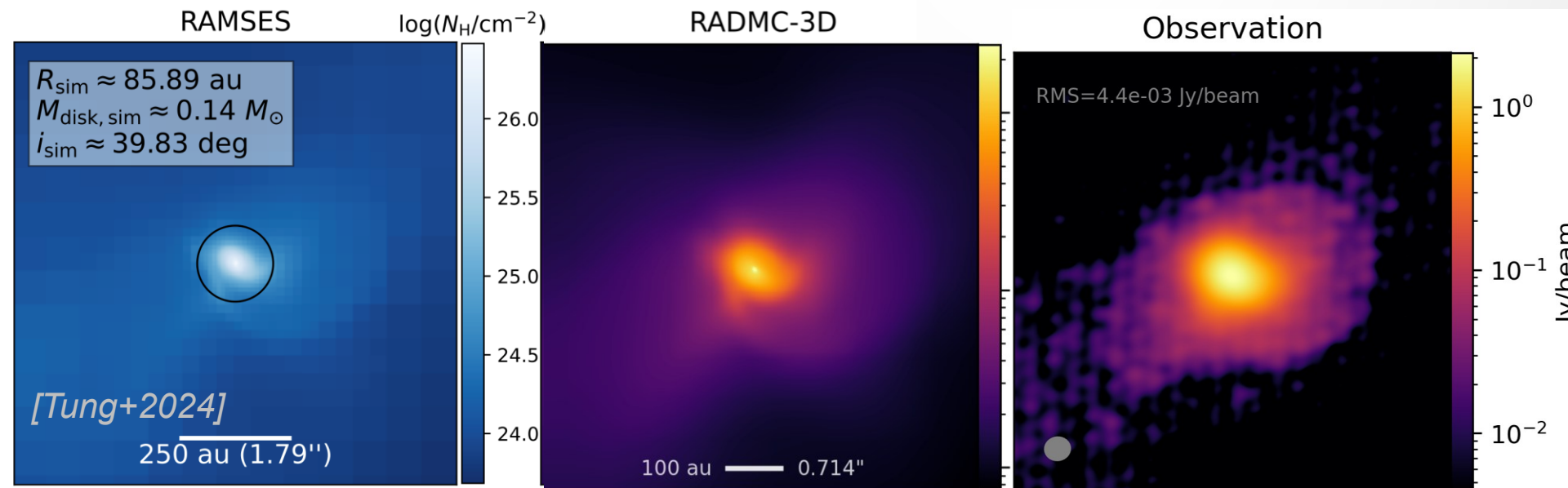
- **Can we retrieve the dust mass from the continuum?**



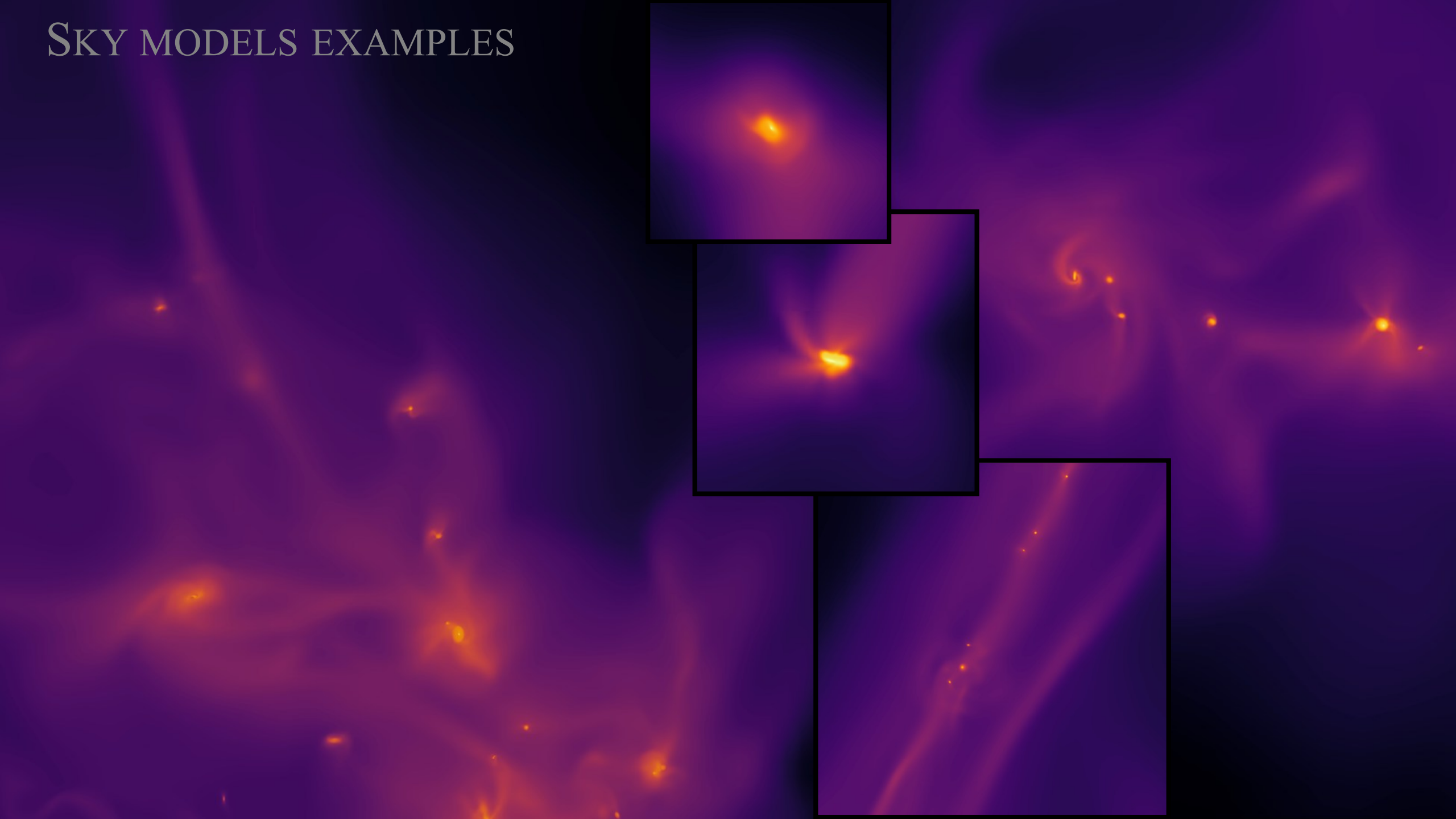
# METHODS: OVERVIEW

- Magneto-HydroDynamic **simulations** of *Lebreuilly+(2024)*: RAMSES
- **Radiative transfer** processing of simulations (*Tung+2024*): RADMC-3D
- Mock **interferometry** with ALMA antennas: CASA
- Model **fitting** and visibility sampling: **emcee**, GALARIO

(Columba+, in prep)



# SKY MODELS EXAMPLES



# METHODS: MODELS

Gaussian component:

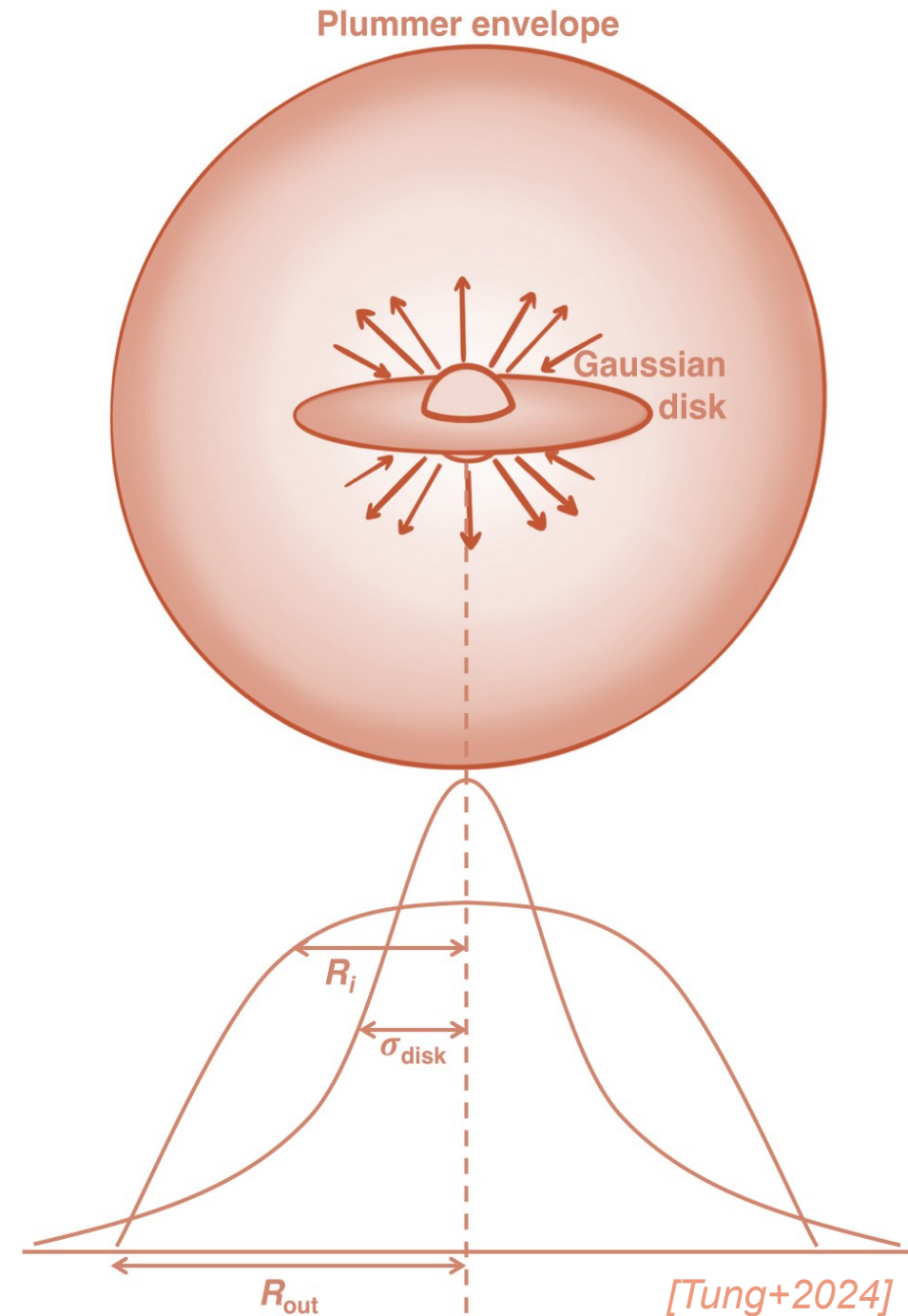
$$I_{\text{disk}}(r) = I_{0,d} \cdot \exp\left(-\frac{r^2}{2\sigma^2}\right) + \begin{matrix} inc \\ PA \end{matrix}$$

Plummer component

$$I_{\text{env}}(r) = I_{0,e} \cdot \left(1 + \frac{r^2}{R_i^2}\right)^{-(p-1)/2} \quad \forall r < R_{\text{out}}$$

Free parameters (2c):

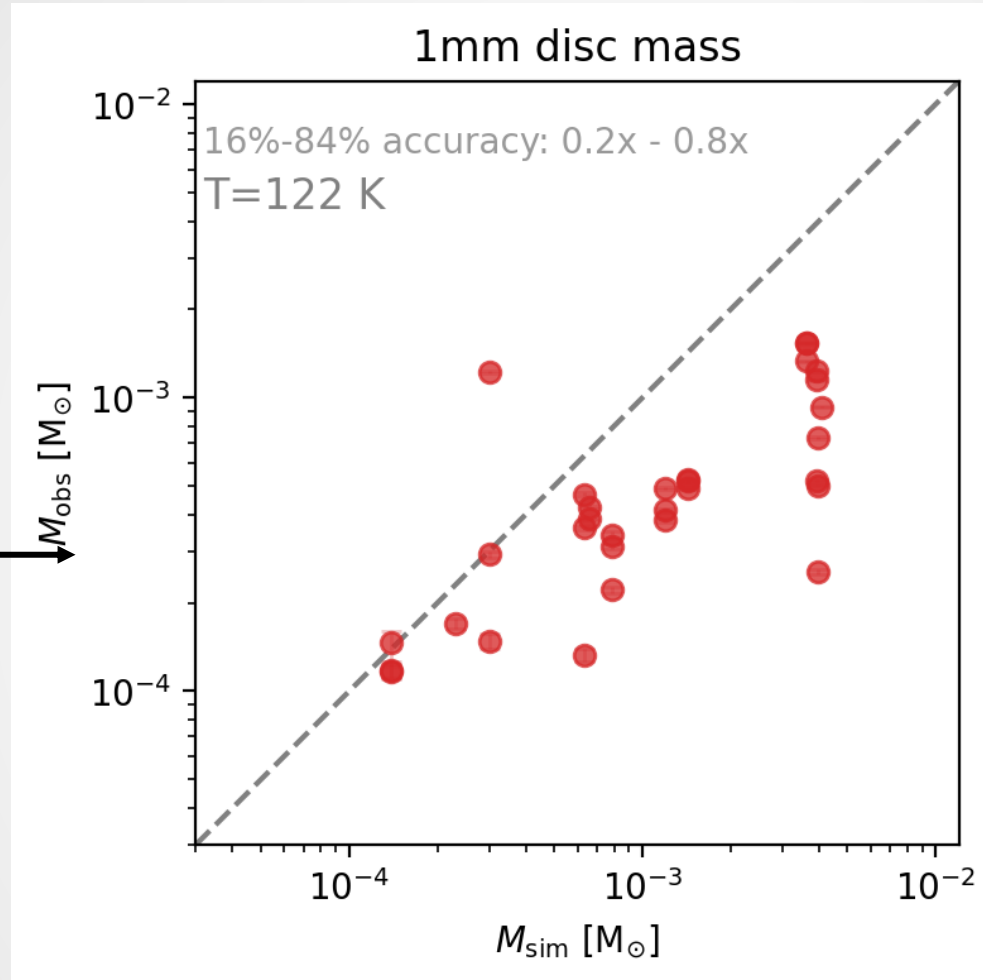
$$I_{0,d}, I_{0,e}, \sigma, R_i, R_{\text{out}}, p, inc, PA, dRA, dDec$$



# 1MM MASS ISSUE

using an average  
T=122 K (Tung+2024)

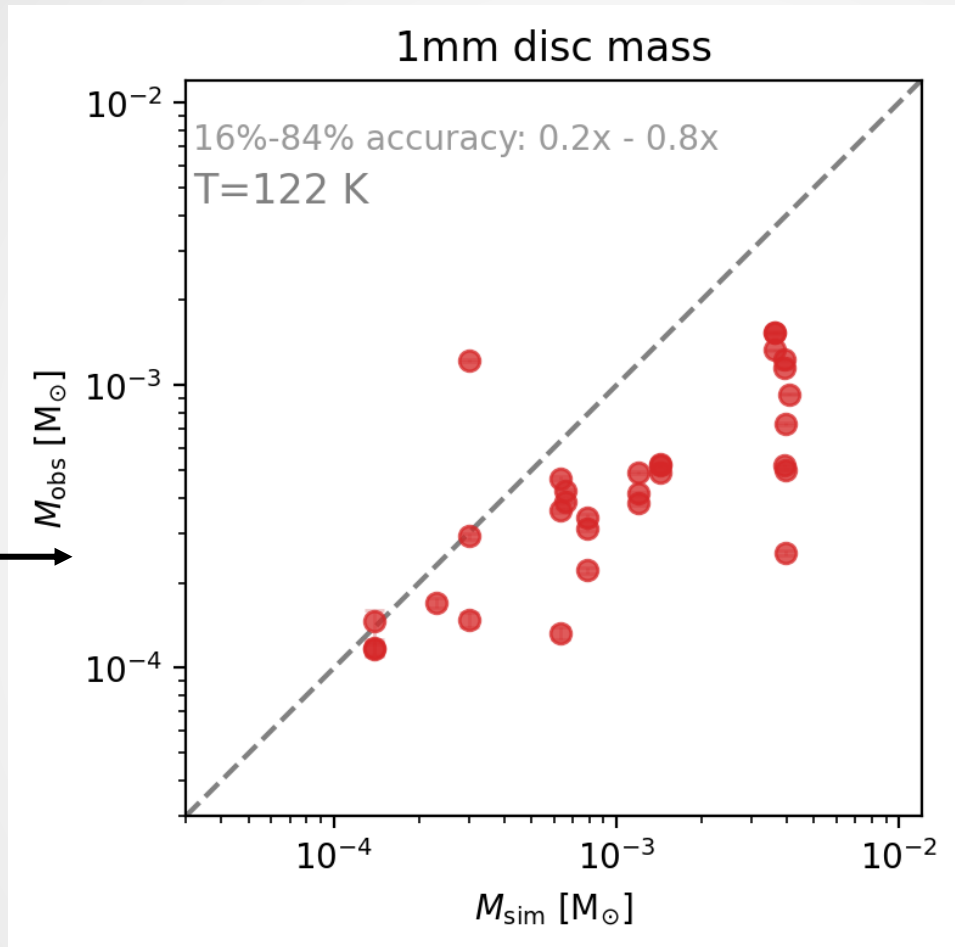
$$M_d = \frac{F_\nu}{B_\nu(\bar{T})} \frac{d^2}{\kappa_\nu} \rightarrow M_{\text{obs}} [M_\odot]$$



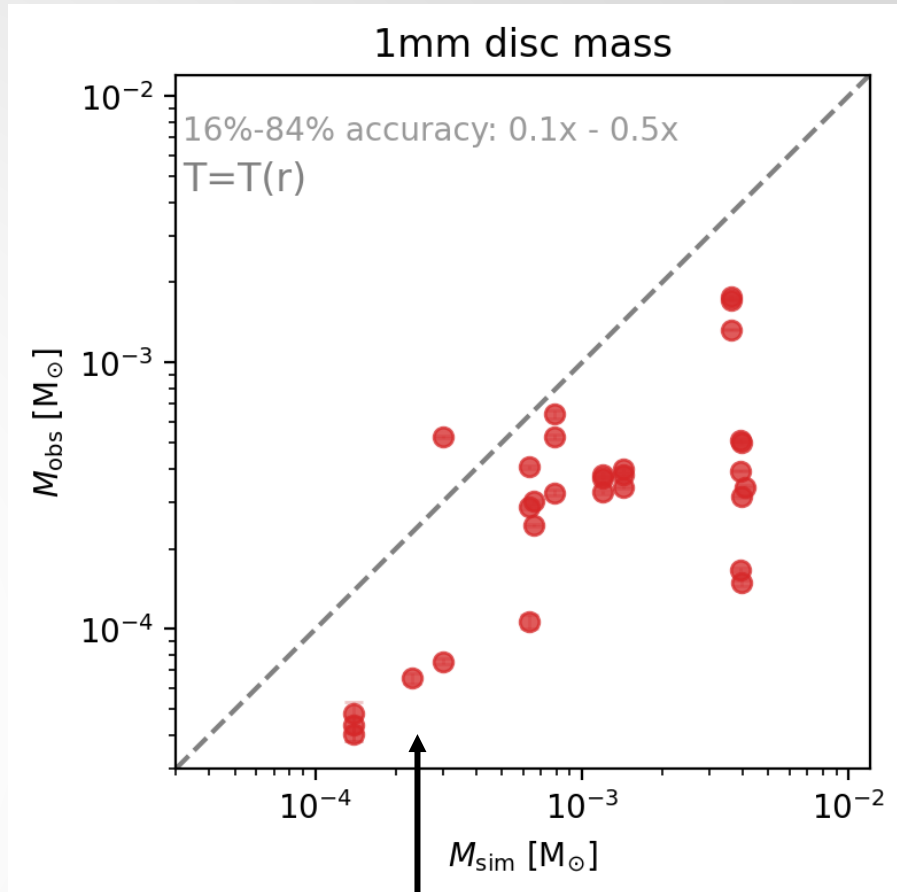
# 1MM MASS ISSUE

using an average  
 $T=122\text{ K}$  (Tung+2024)

$$M_d = \frac{F_\nu}{B_\nu(\bar{T})} \frac{d^2}{\kappa_\nu} \rightarrow M_{\text{obs}} [M_\odot]$$



Disc mass partially invisible!



$$M_d = \int \frac{dF_\nu(r)}{B_\nu(T(r))} \frac{d^2}{\kappa_\nu} dr$$

$$T(r) = 71 L_*^{0.25} \cdot r^{-0.52} \text{ [K]}$$

[Tung+2024]

BAND 2\* RESULTS

# ***MOCK-SURVEY AT 3MM***

Fiducial run info:

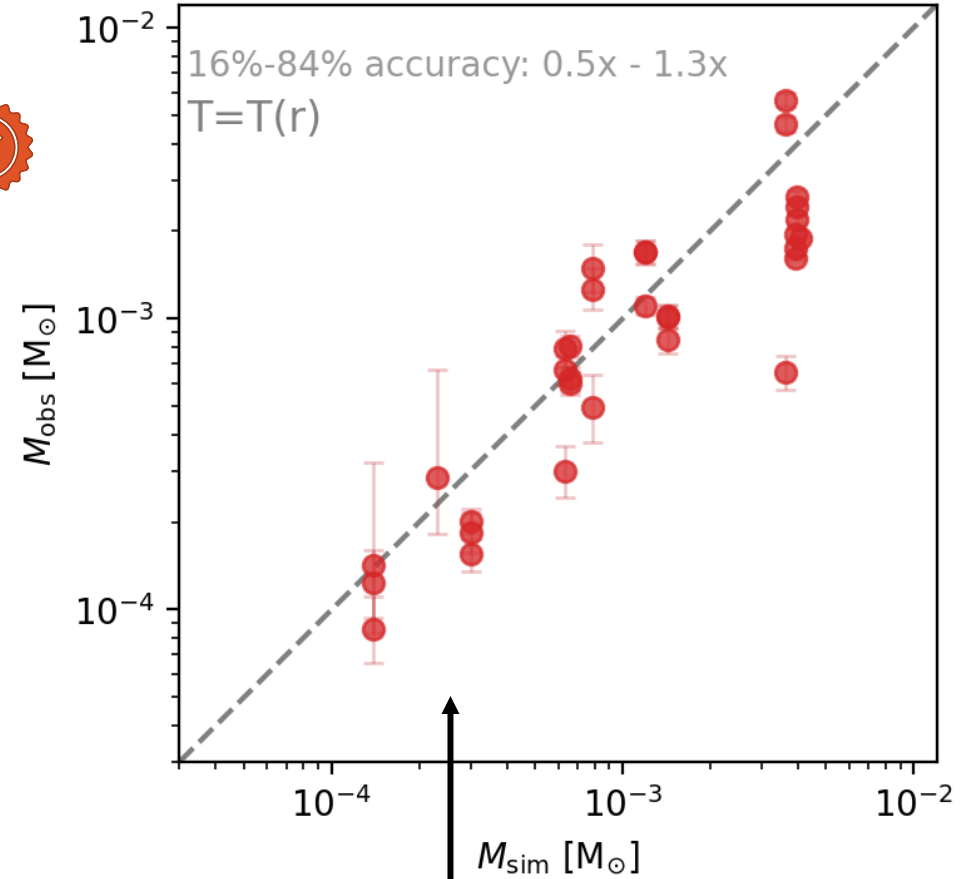
- On-target integration time  $T_{\text{exp}} = 1\text{h}$
- $\nu_c \approx 100\text{ GHz}$
- Model fit: Gauss + Plummer (2c)
- Antenna configuration (single): C7
- Spatial resolution  $\theta_{\text{res}} \approx 0.21''$  (30au)



*\*overlapping with existing Band 3 as well*

# RESULTS: MASS

3mm



$$M_{\text{d}} = \int \frac{dF_{\nu}(r)}{B_{\nu}(T(r)) \kappa_{\nu}} dr$$

$$T(r) = 71 L_{*}^{0.25} \cdot r^{-0.52} \text{ [K]}$$

[Tung+2024]

The **temperature profile** plays a role in estimating the correct disk mass

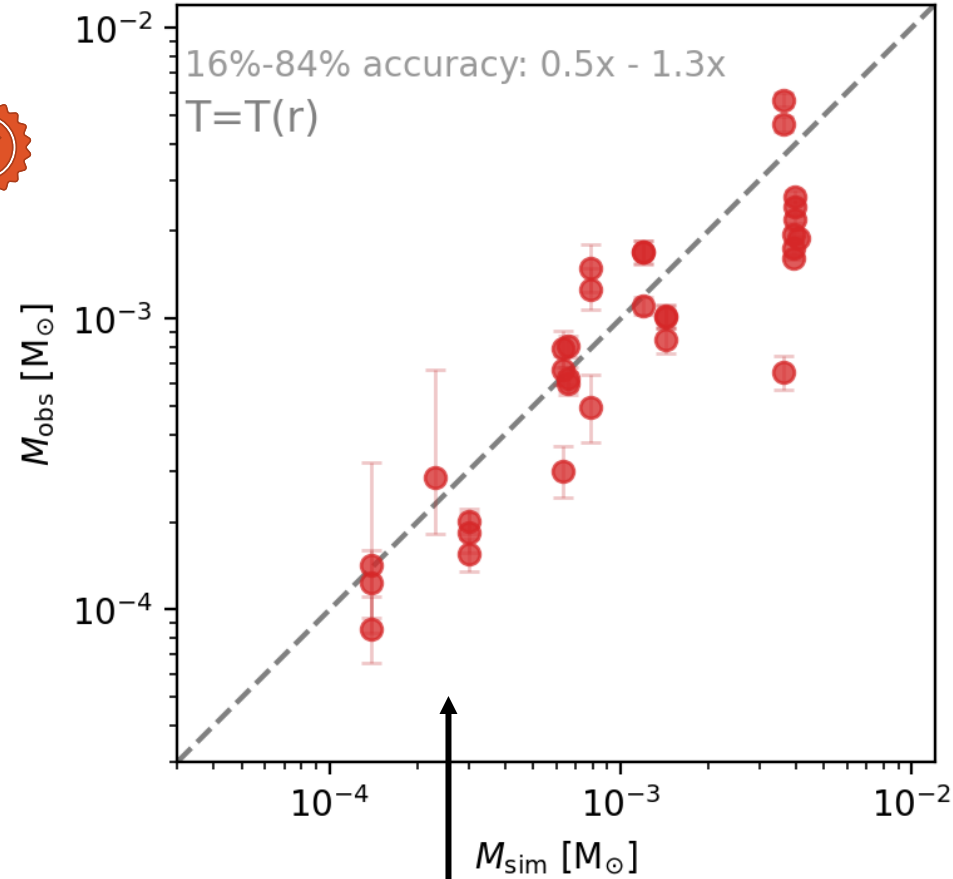
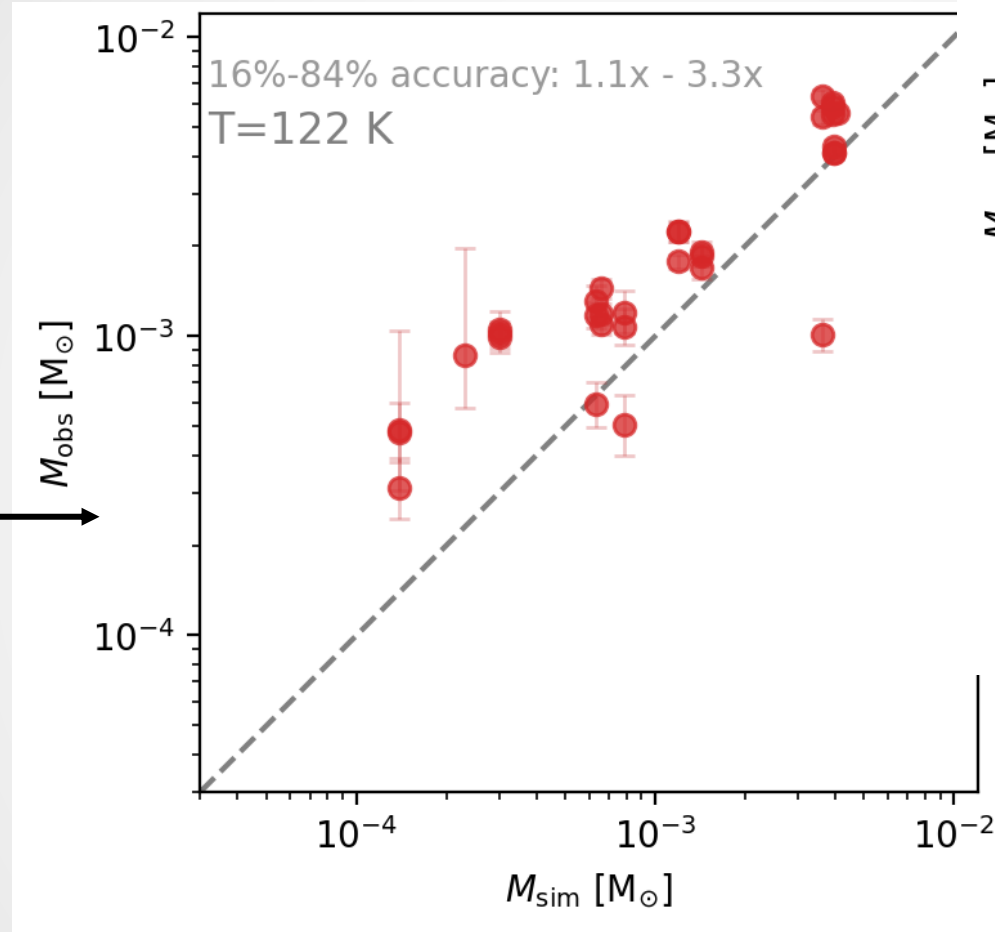
# RESULTS: MASS

3mm



using an average  
T=122 K (Tung+2024)

$$M_d = \frac{F_\nu}{B_\nu(\bar{T})} \frac{d^2}{\kappa_\nu}$$



$$M_d = \int \frac{dF_\nu(r)}{B_\nu(T(r))} \frac{d^2}{\kappa_\nu} dr$$

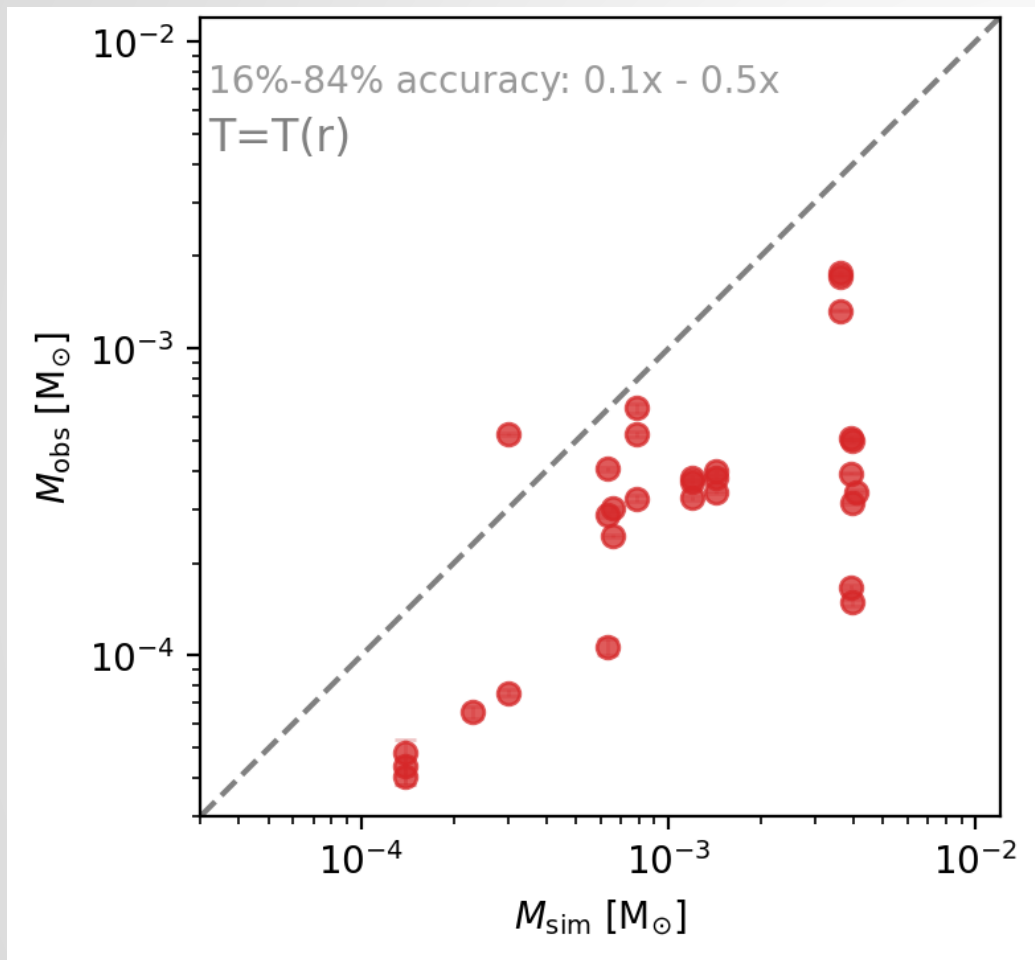
$$T(r) = 71 L_*^{0.25} \cdot r^{-0.52} \text{ [K]}$$

[Tung+2024]

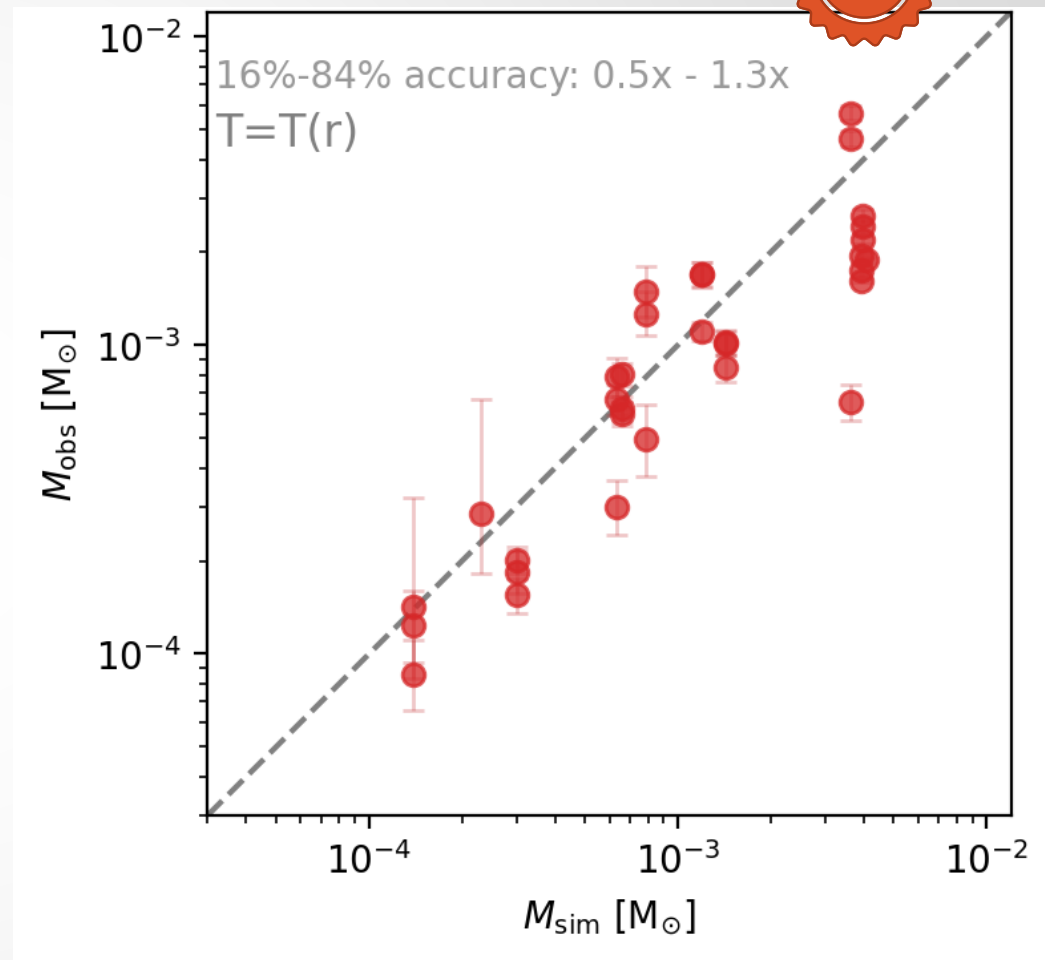
The **temperature profile** plays a role in estimating the correct disk mass

# RESULTS: MASS

## 0.9mm

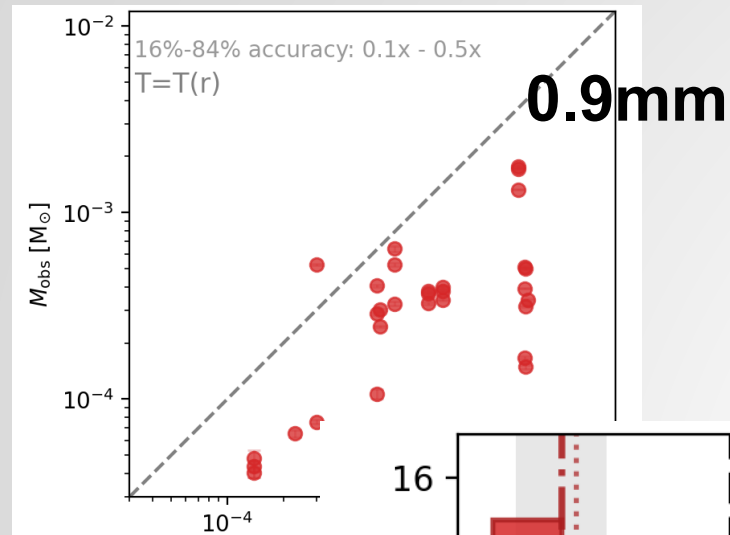


## 3mm

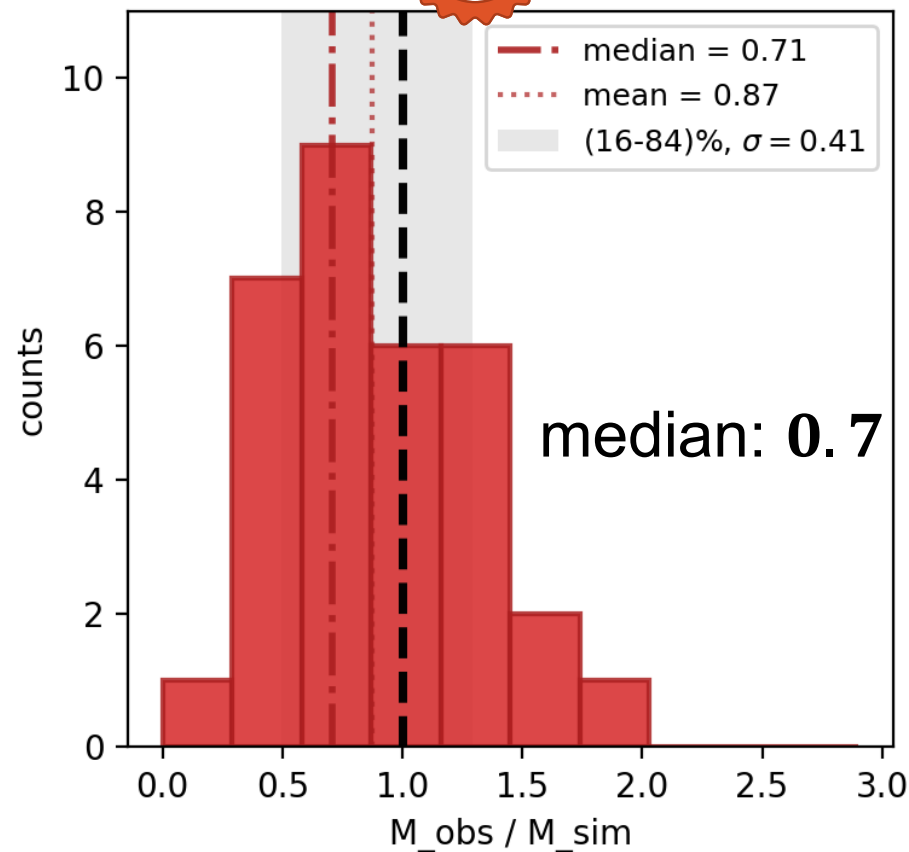
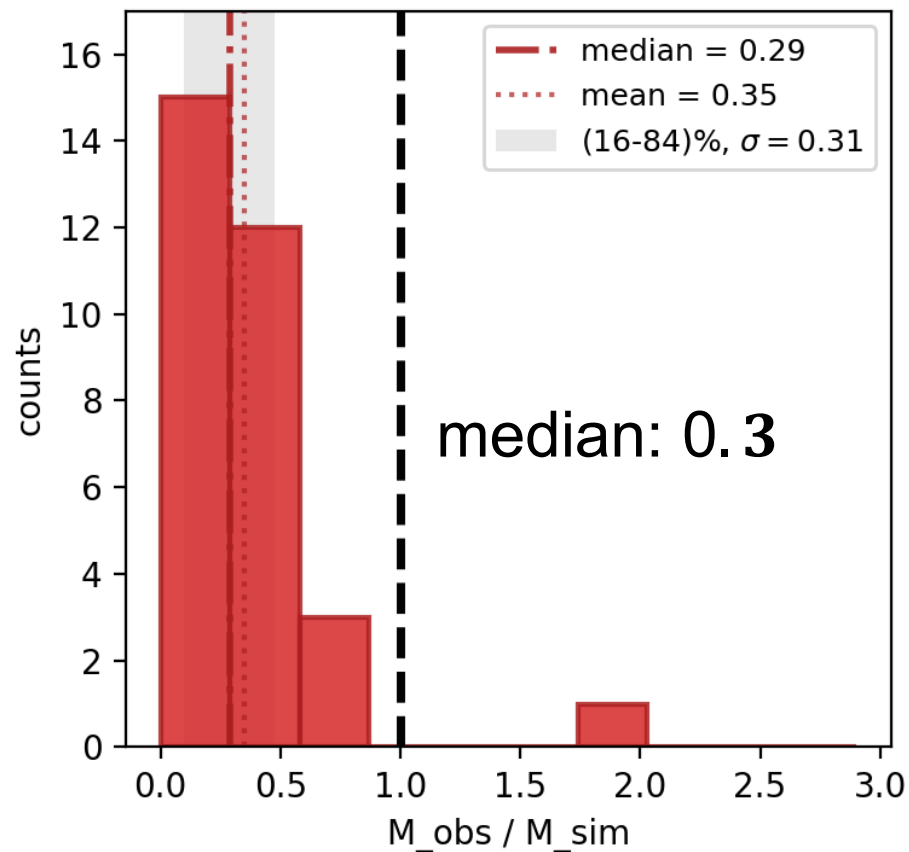
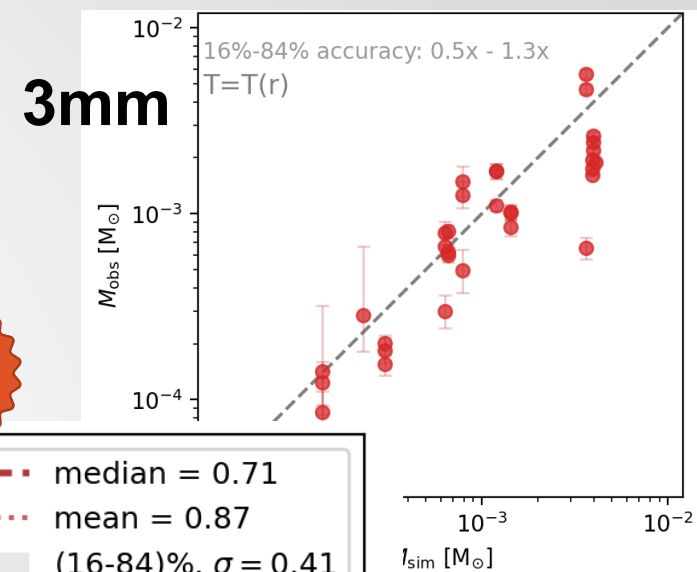


Inferred disk mass vs true mass

# RESULTS: MASS

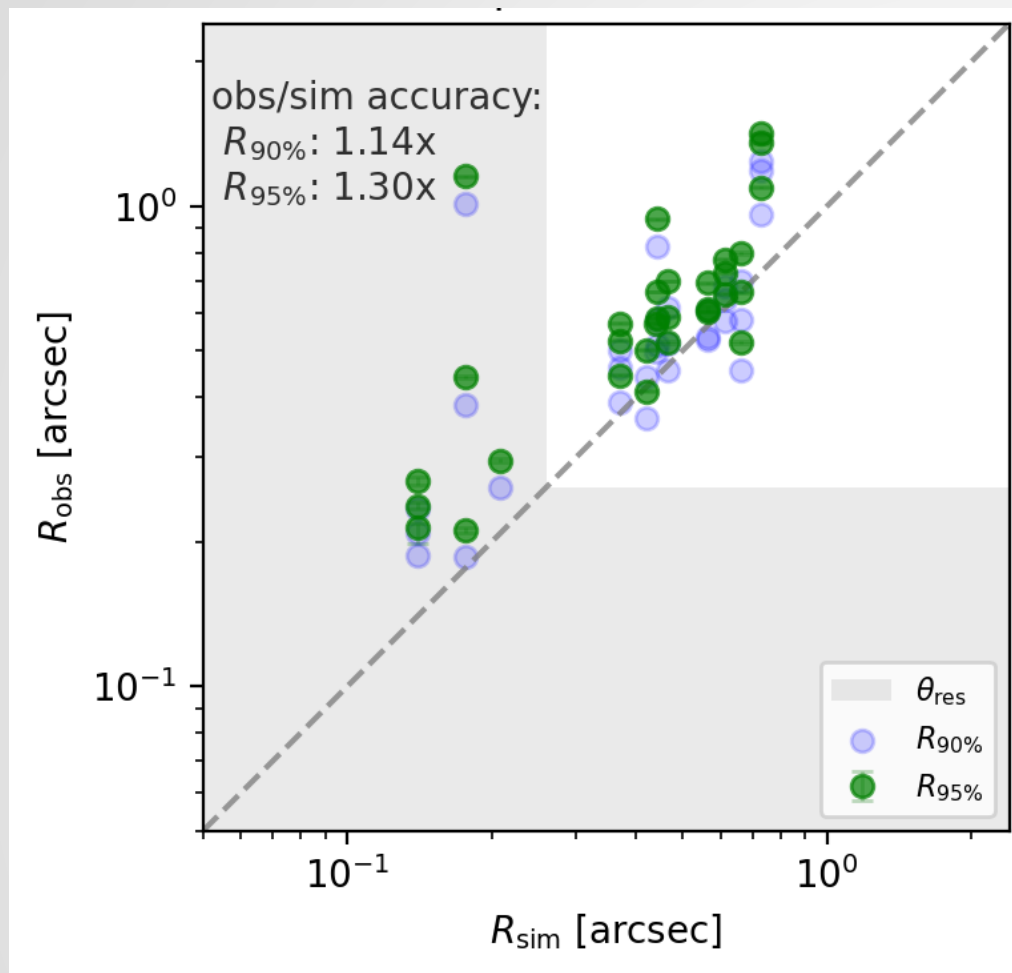


$\frac{M_{obs}}{M_{sim}}$  distributions

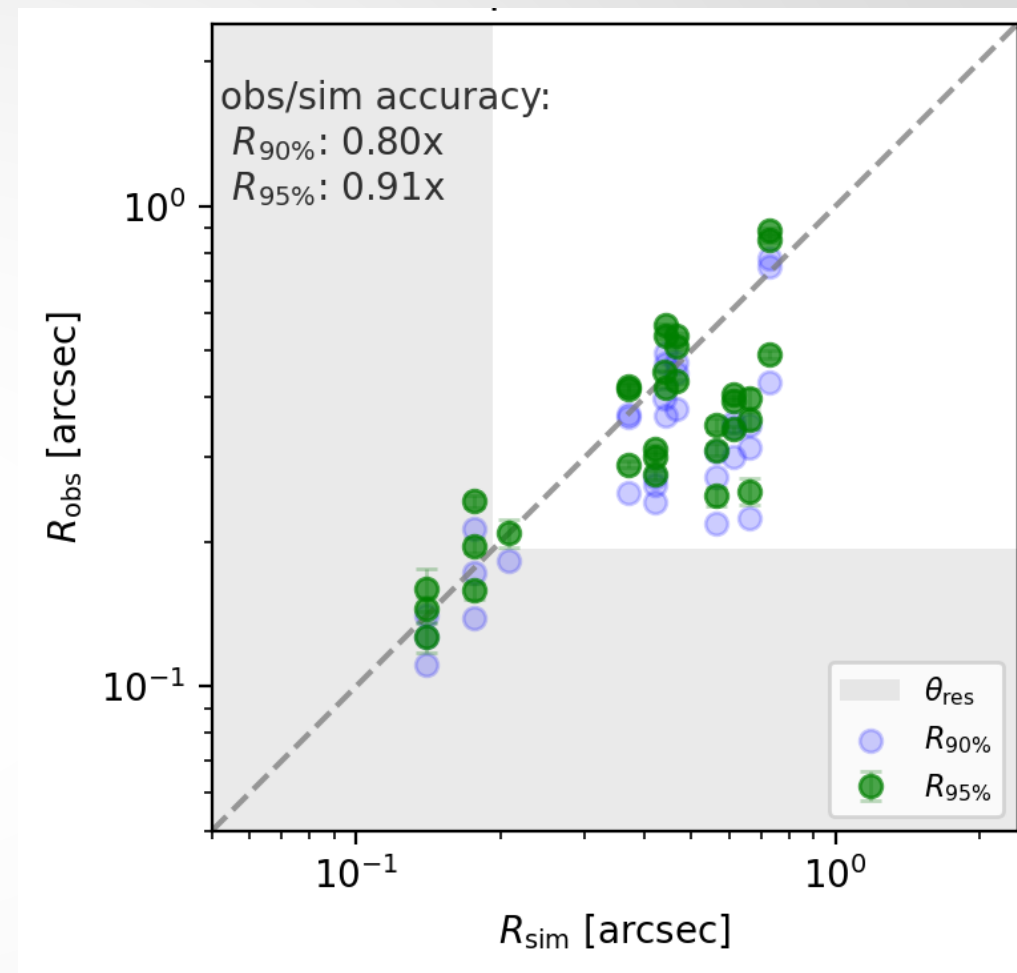


# RESULTS: RADIUS

0.9mm



3mm

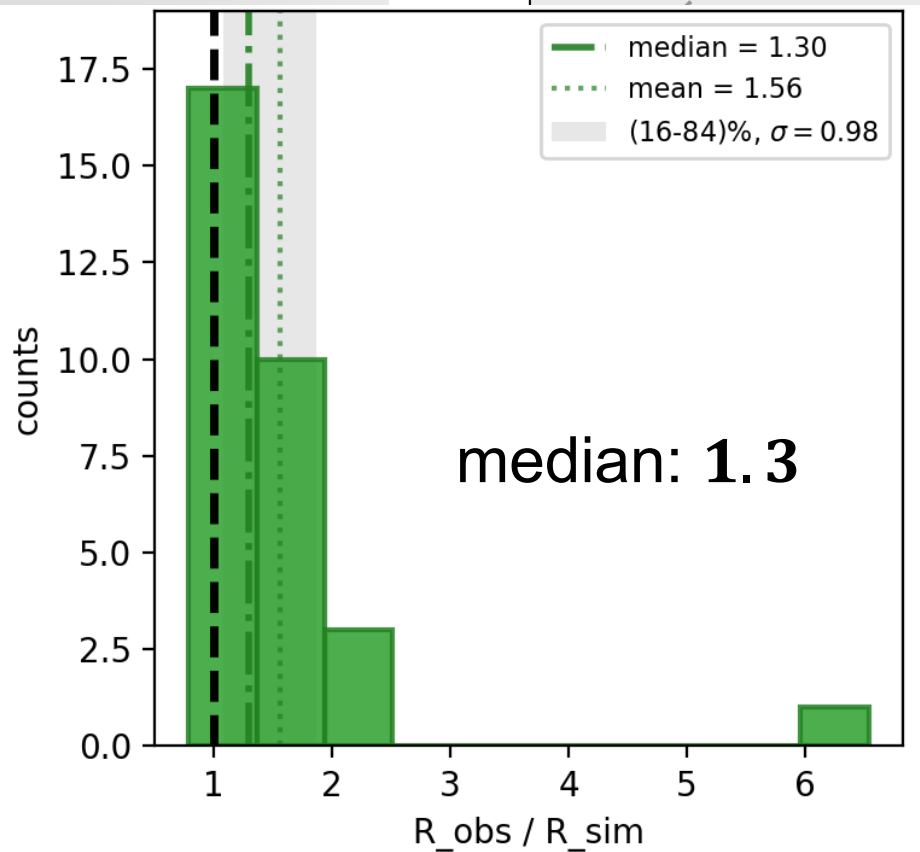
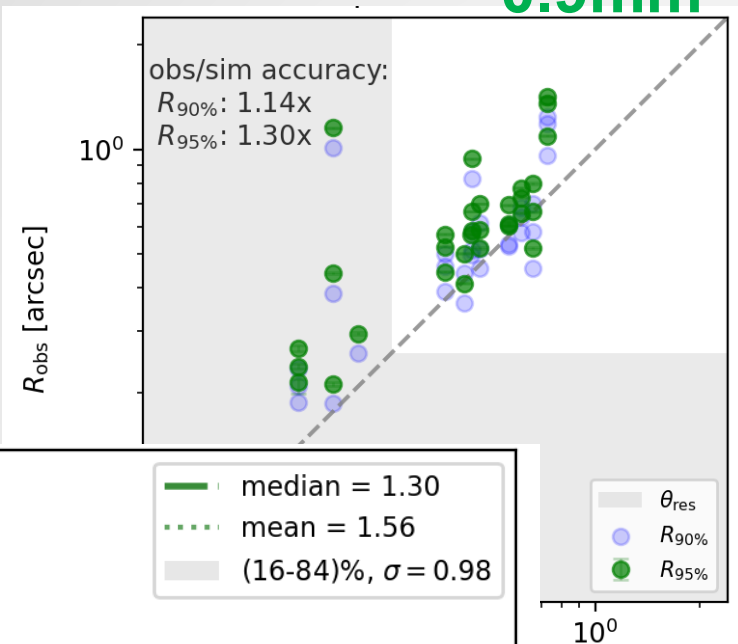


Observed disk radius vs true radius (simulation, kinematic)

90% and 95% brightness radii as reference metrics

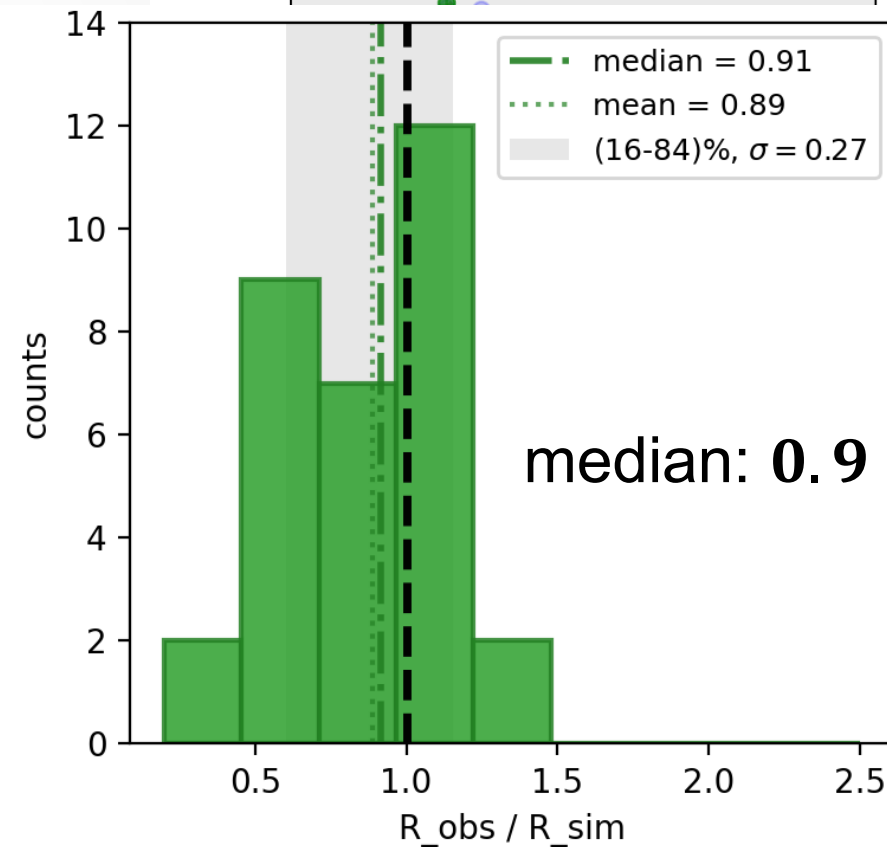
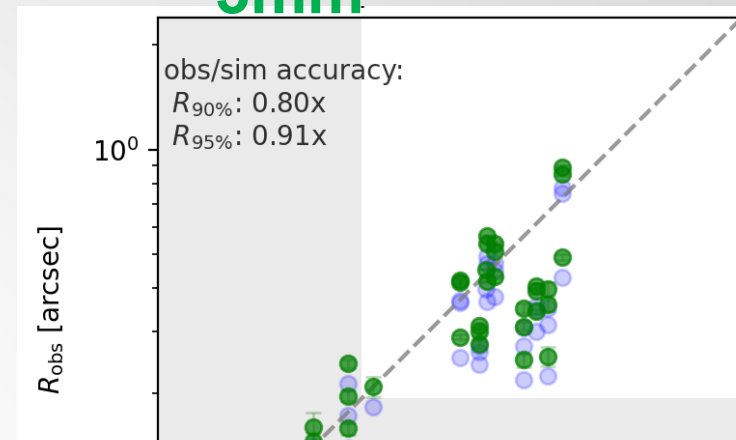
# RESULTS: RADIUS

0.9mm



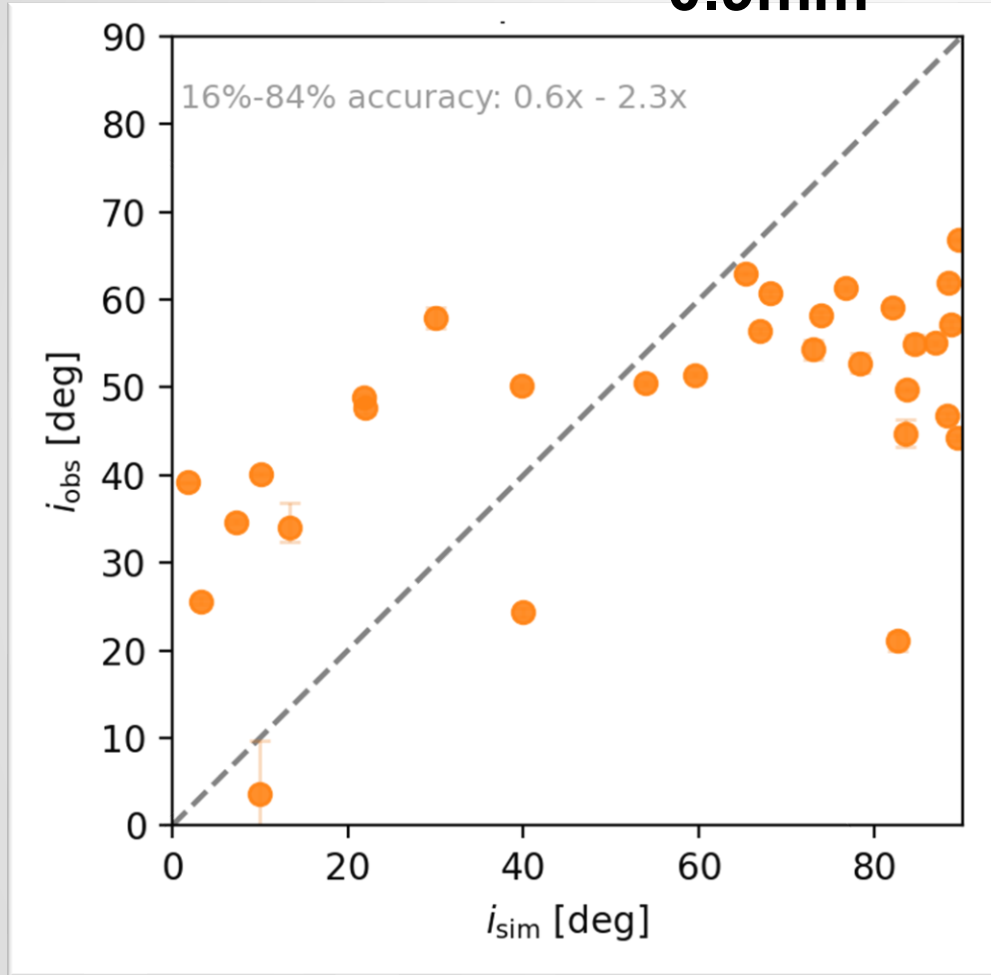
$\frac{R_{\text{obs}}^{95}}{R_{\text{sim}}}$   
distributions

3mm

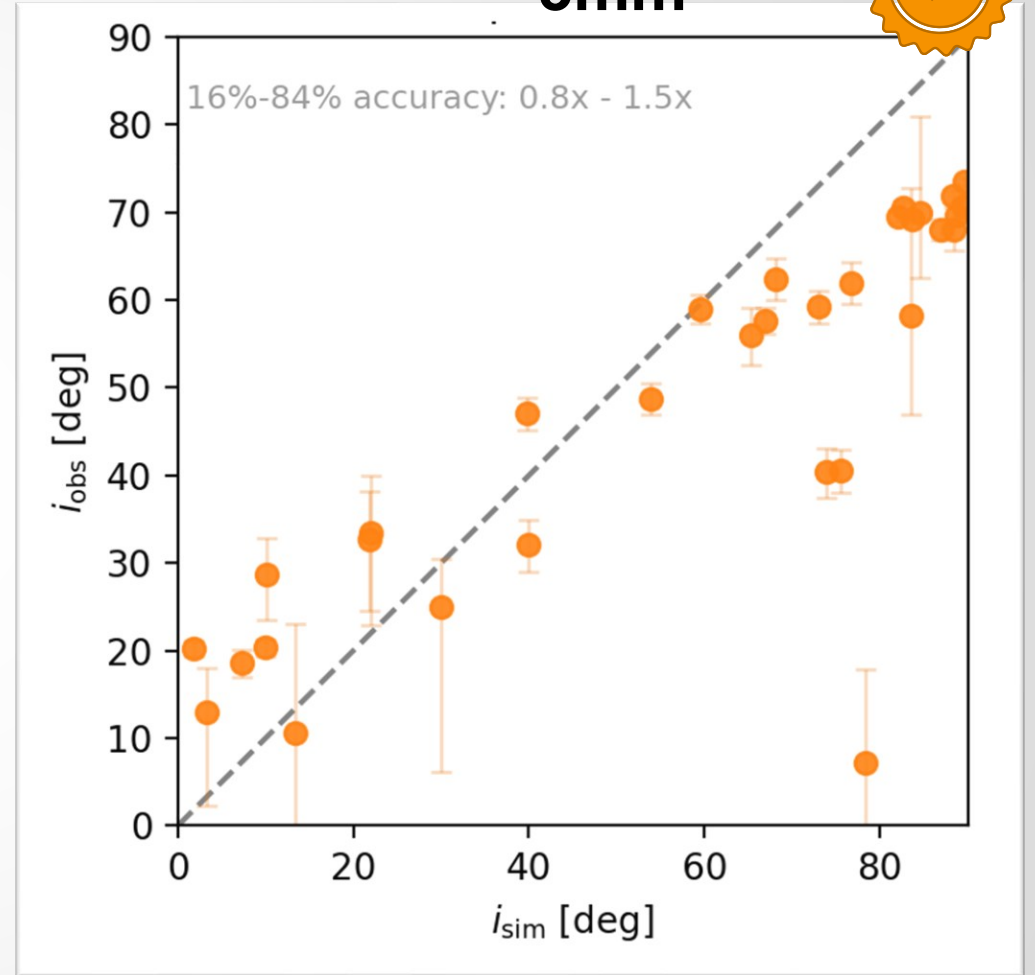


# RESULTS: INCLINATION

## 0.9mm



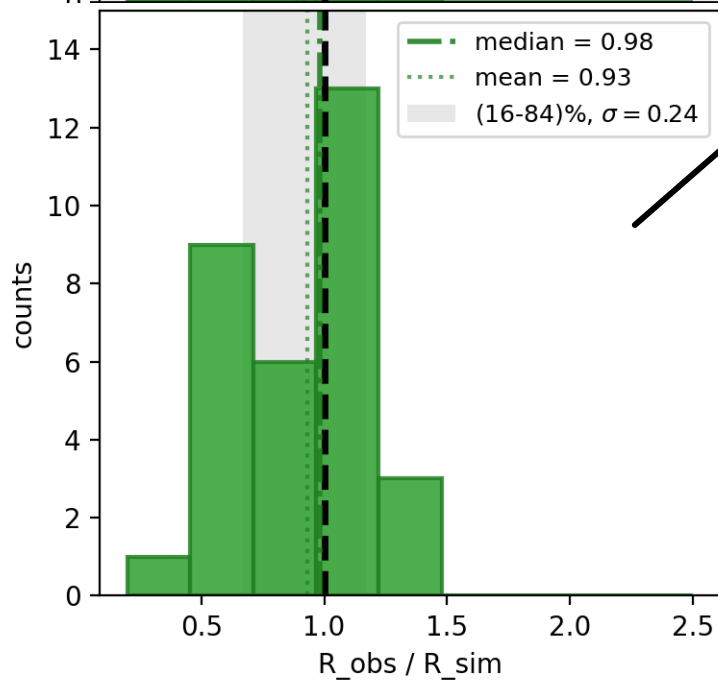
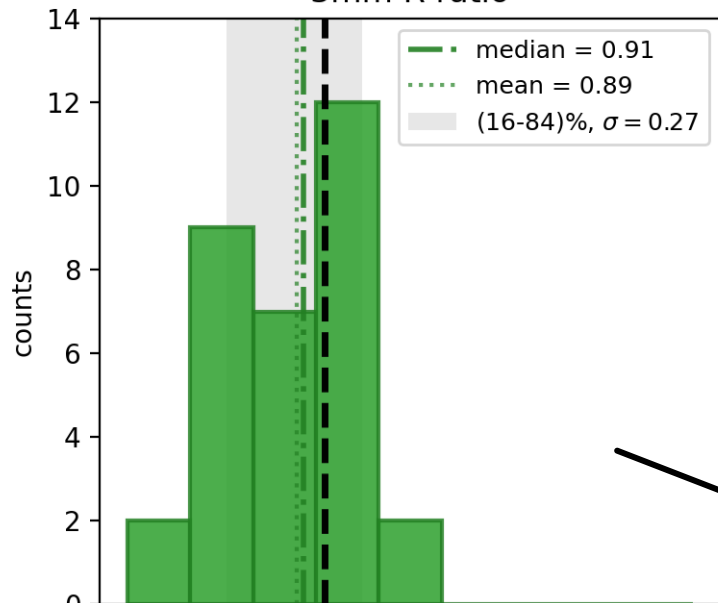
## 3mm



Observed disk inclination vs true inclination

# GOING WIDER: + COMPACT, 3MM

3mm R ratio

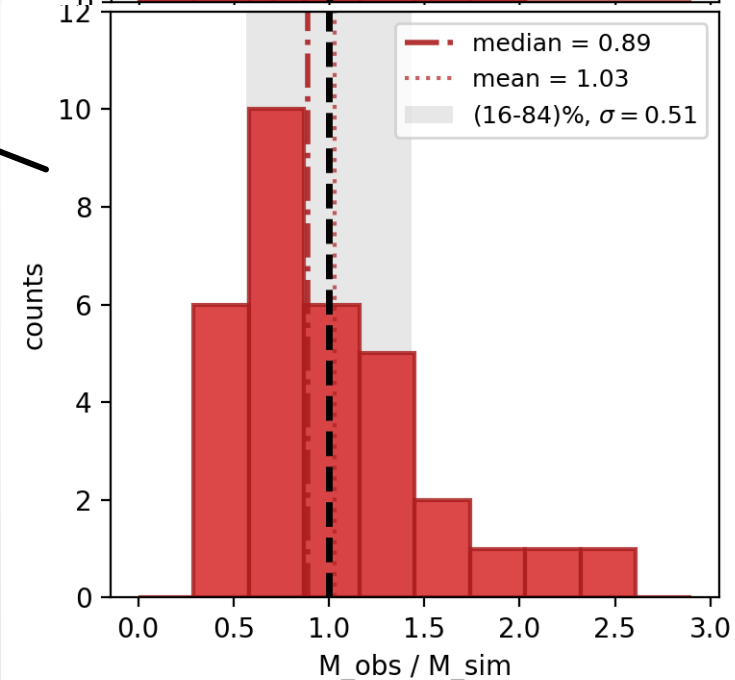
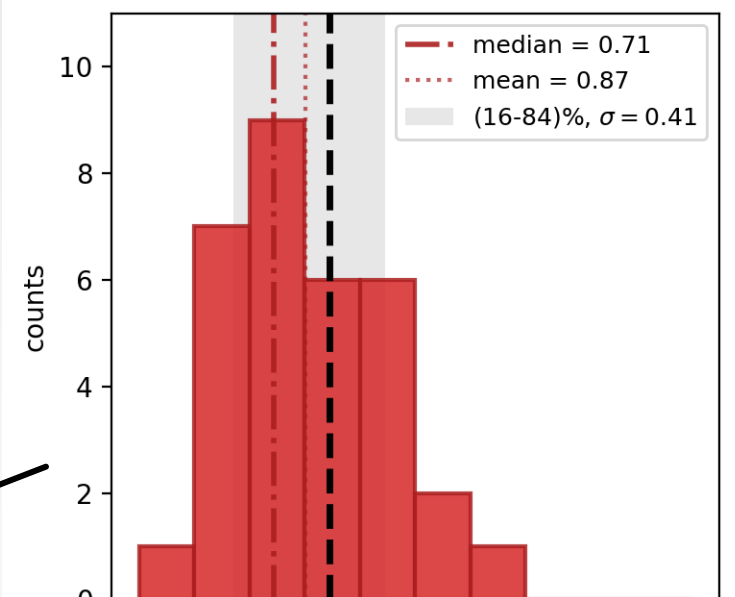


What if you also add a more compact antenna configuration?

	$\frac{R_{obs}}{R_{sim}}$	$\frac{M_{obs}}{M_{sim}}$
Mono config	0.9	0.7
<b>+ compact</b>	<b>1.0</b>	<b>0.9</b>

Medians improve!

3mm M ratio



# SUMMARY

- **3mm** (Band 2/3) best compromise between observing setup and accuracy to recover the **disk mass and radius**, with good sample accuracy. **4mm** sweet spot ??
- The **temperature** profile of YSOs has a critical impact on the disk masses recovered at all wavelengths.
- **Envelopes** require more than one observation type to be constrained, which slightly impacts disks parameters too.



GO ALMA Band 2!!  
Thank you!

**Backup slides**

# DATA: SIMULATIONS (GAS)

Full details: see [Lebreuilly et al. \(2021, 2024\)](#)

AMR code **RAMSES** (Teyssier 2002; Fromang+2006)  
Solves the MHD equations using the finite volume method.

Maximum resolution:  $\Delta x \sim 1.2$  au

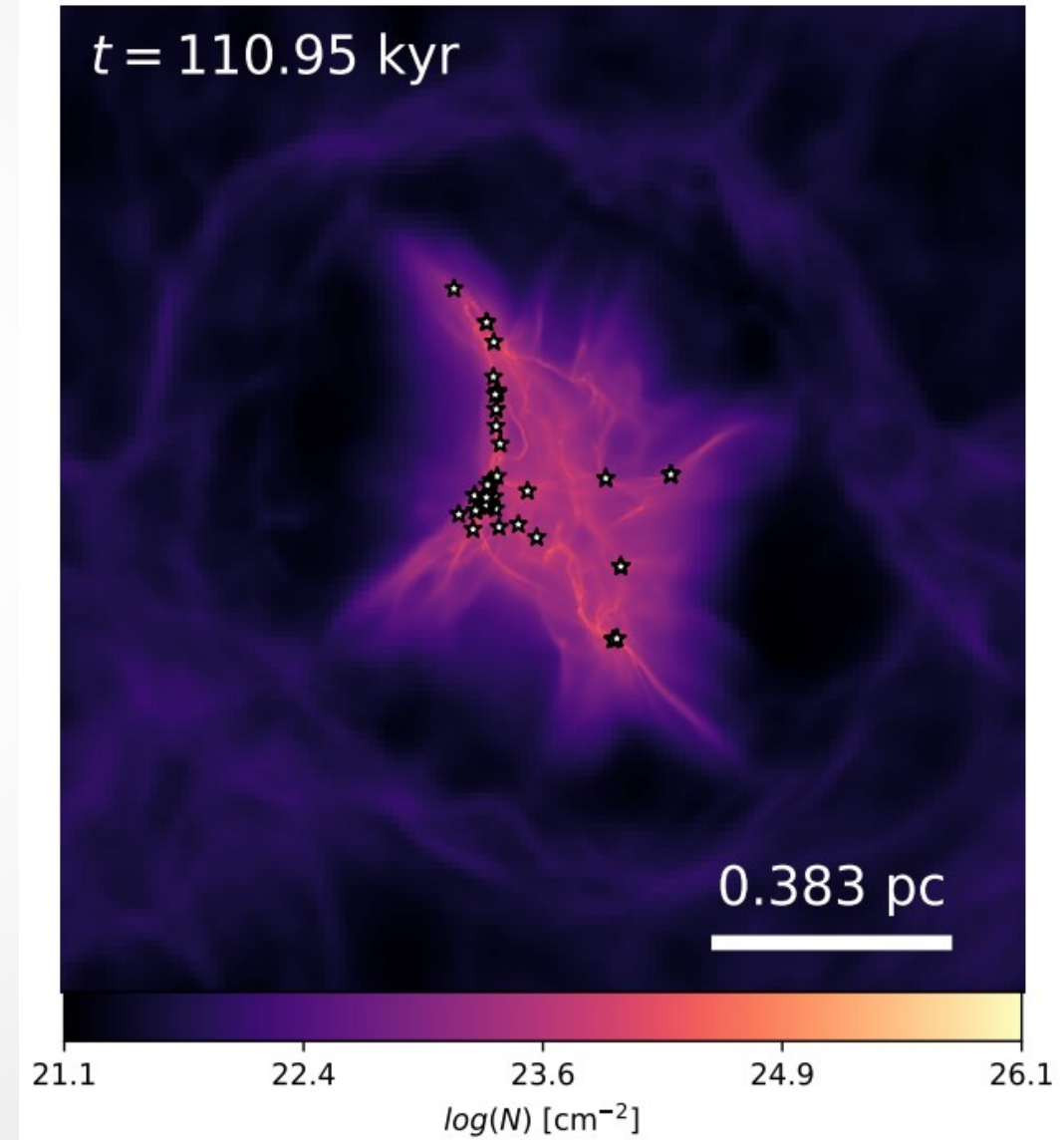
Initial conditions of the clump:

$$M = 1000 M_{\odot}$$

$$T = 10 K$$

$$R \sim 0.38 pc$$

*Lebreuilly et al. (2024)*



# DATA: RADIATIVE TRANSFER (DUST)

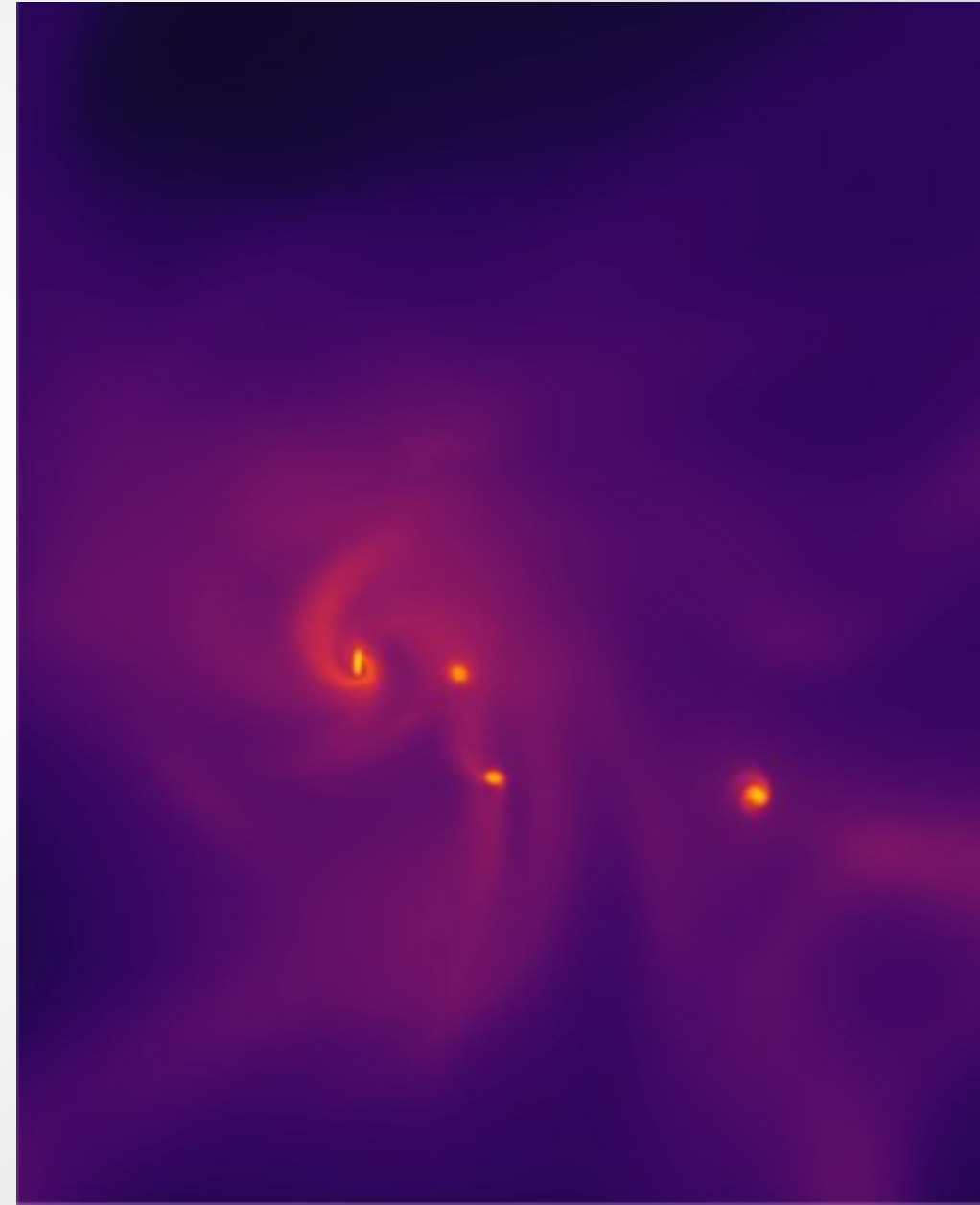
Full details: see [Tung et al. \(2024\)](#)

**RADMC-3D** code (Dullemond+) for the sky  
brightness models, assuming a distance  $d \sim 140$  pc

**1/100** dust to gas ratio assumed  
everywhere

**DIANA dust opacities** from OpTool (Dominik+2021)

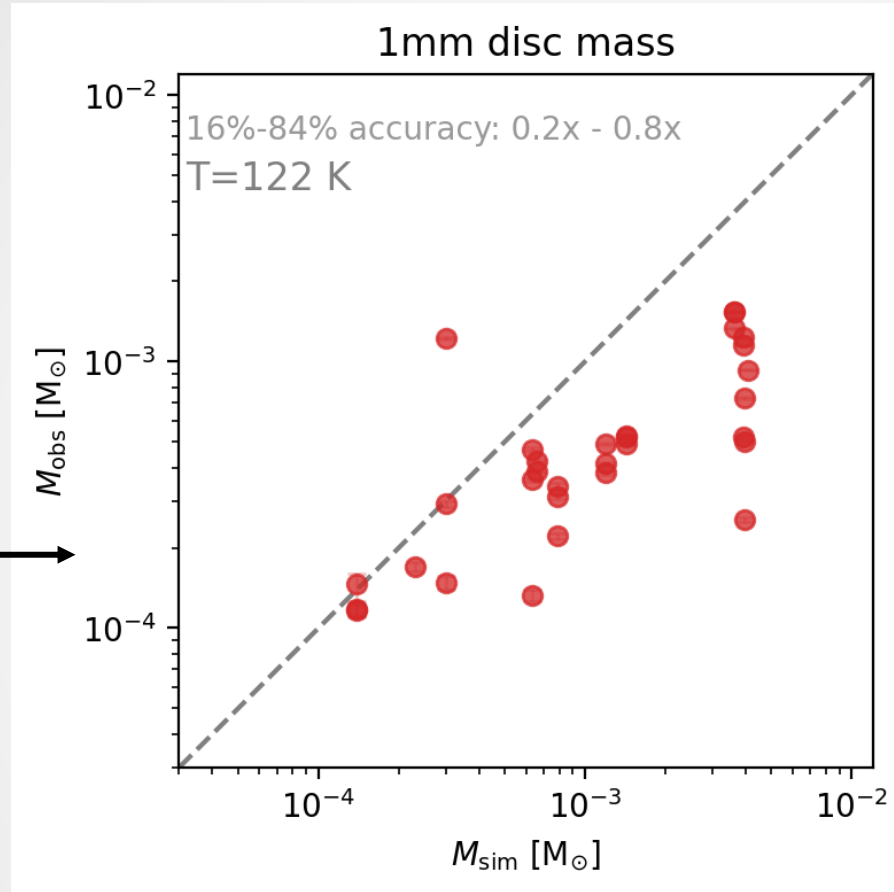
MRN power-law distribution with  
 $a_{\min} = 1$  nm ,  $a_{\max} = 10$   $\mu$ m ,  
averaged on single grain population



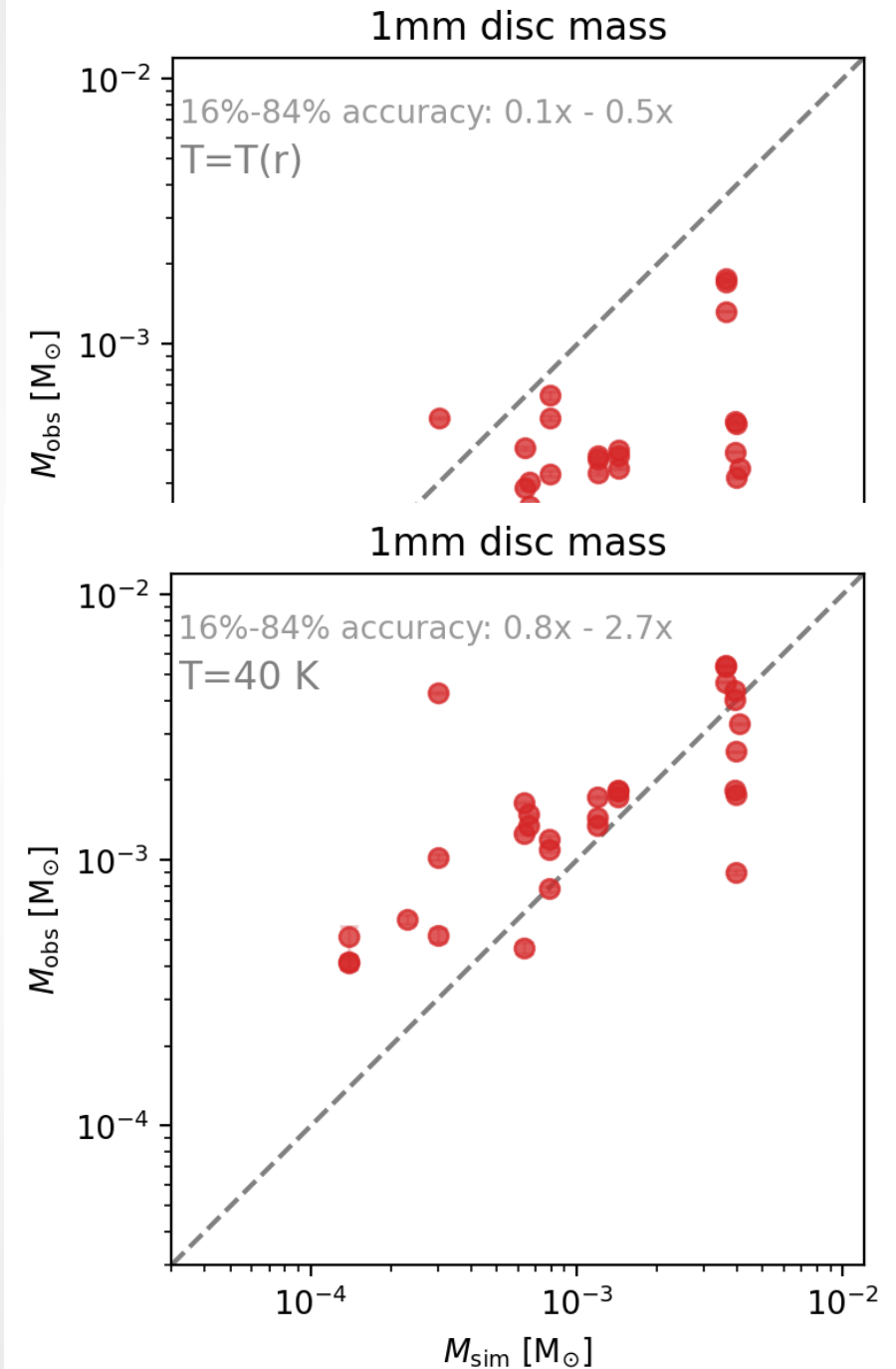
# 1MM MASS ISSUE

using an average  
 $T=122\text{ K}$  (Tung+2024)

$$M_d = \frac{F_\nu}{B_\nu(\bar{T})} \frac{d^2}{\kappa_\nu}$$



Disc mass does not correlate well at 1mm, even with  $T = 40\text{ K}$



## BAND 1 RESULTS

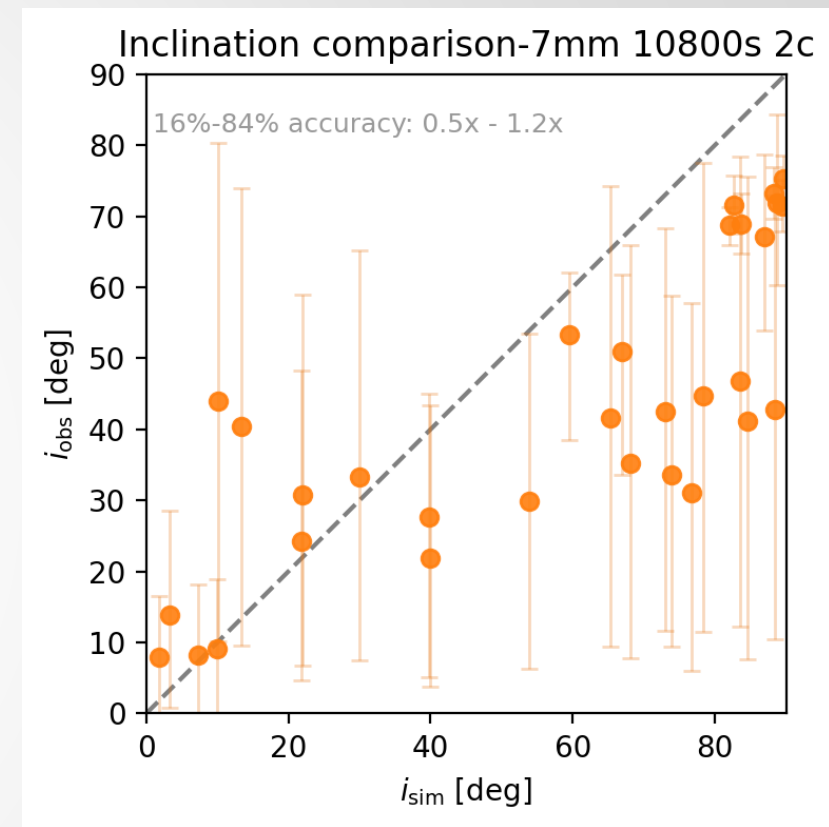
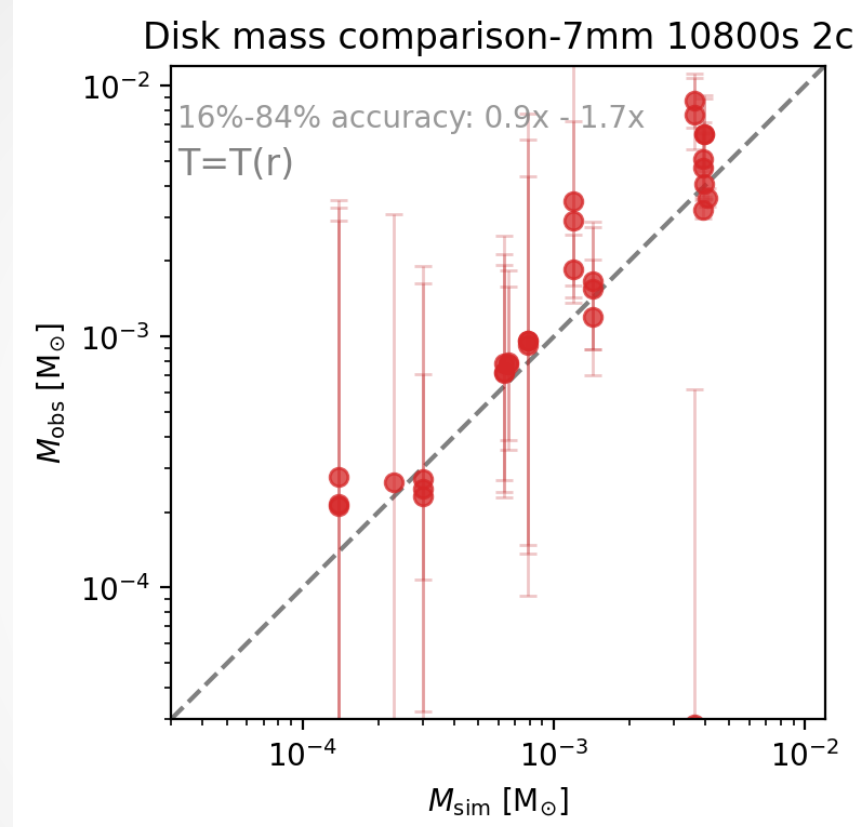
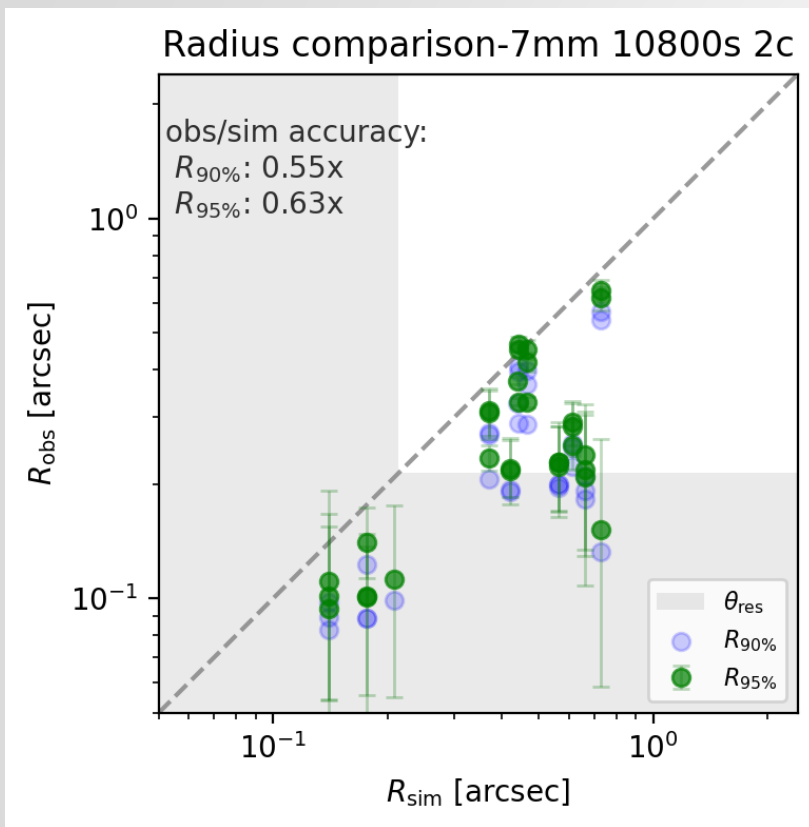
# *MOCK-SURVEY AT 7MM*

Fiducial run info:

- On-target integration time  $T_{\text{exp}} = 3\text{h}$
- $\nu_c \approx 42.8\text{ GHz}$
- Model fit: Gauss + Plummer (2c)
- Antenna configuration: C8
- Spatial resolution  $\theta_{\text{res}} \approx 0.22''$  (30au)



# RESULTS: 7MM SUMMARY

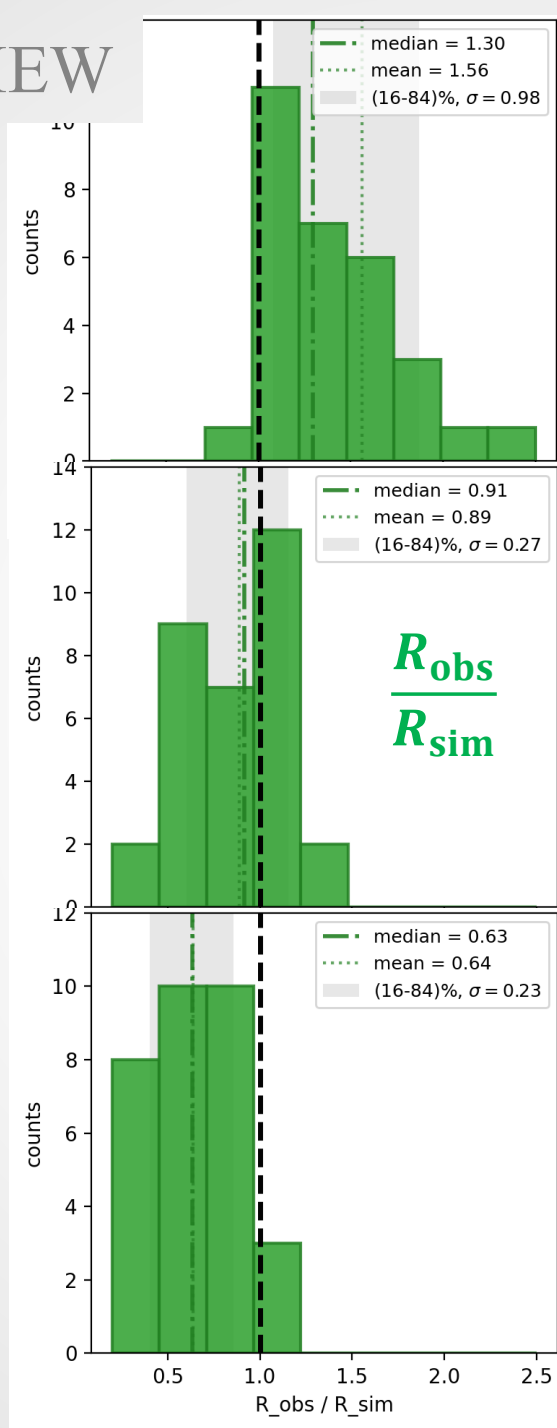


Non-negligible **underestimation** of disk radii, although with a contained dispersion.

Mass is inferred with **good accuracy** but large uncertainties

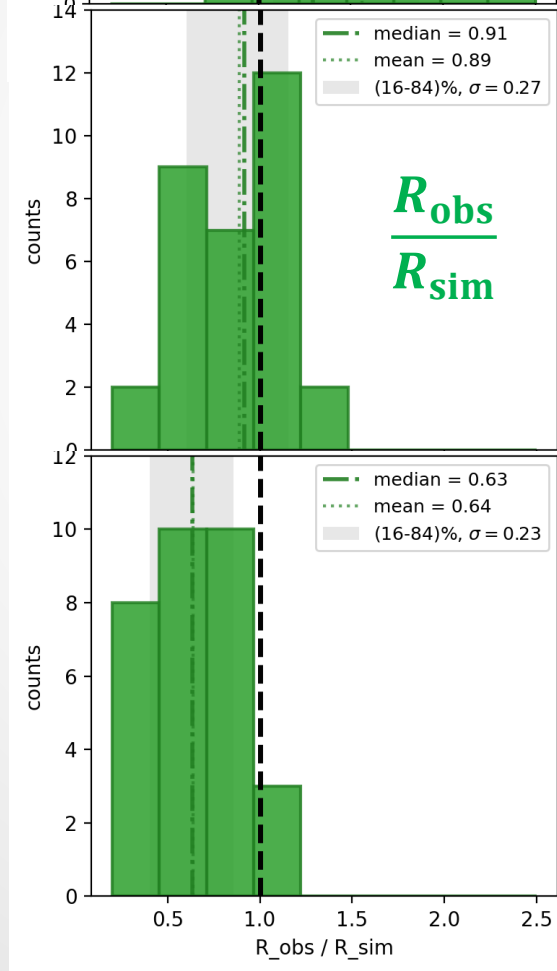
# SINGLE CONFIG OVERVIEW

0.9mm

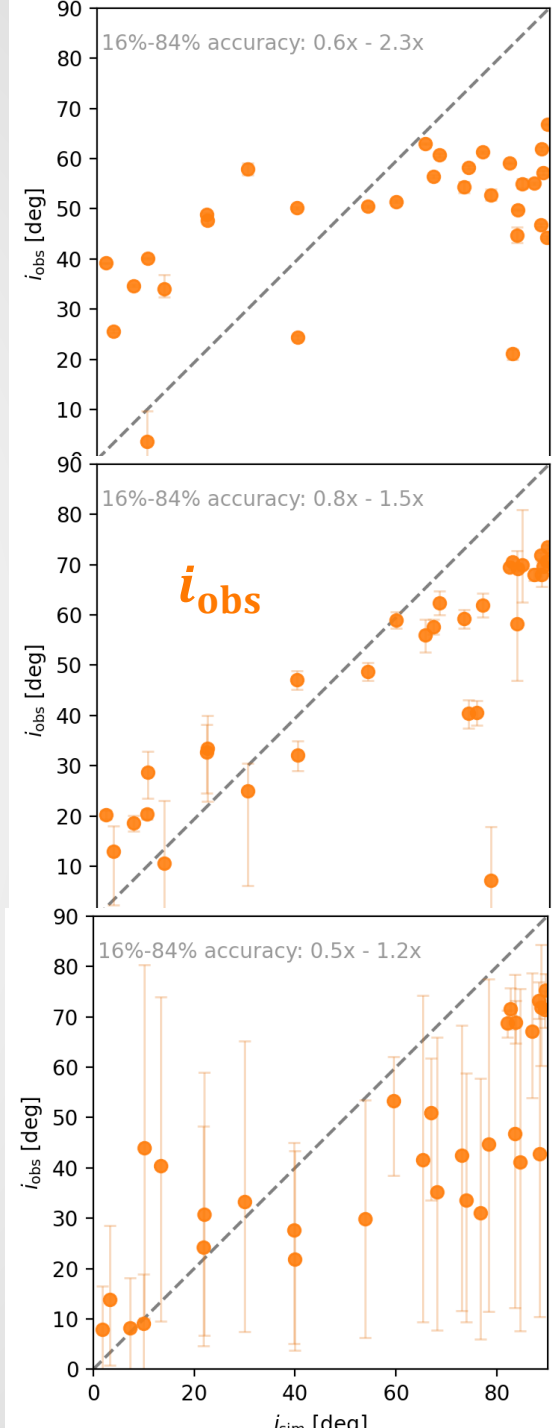
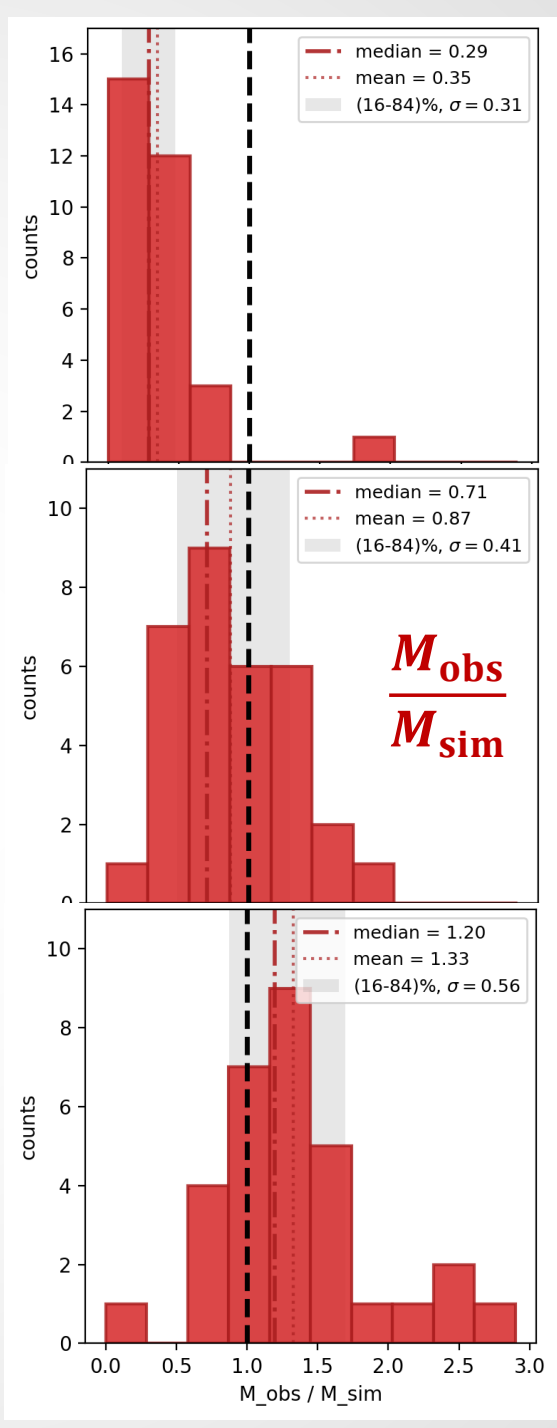
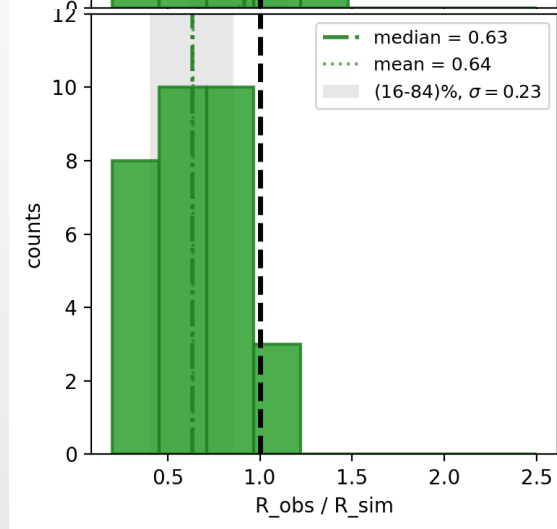


Best match !

3mm



7mm



# +COMPACT OVERVIEW

0.9mm

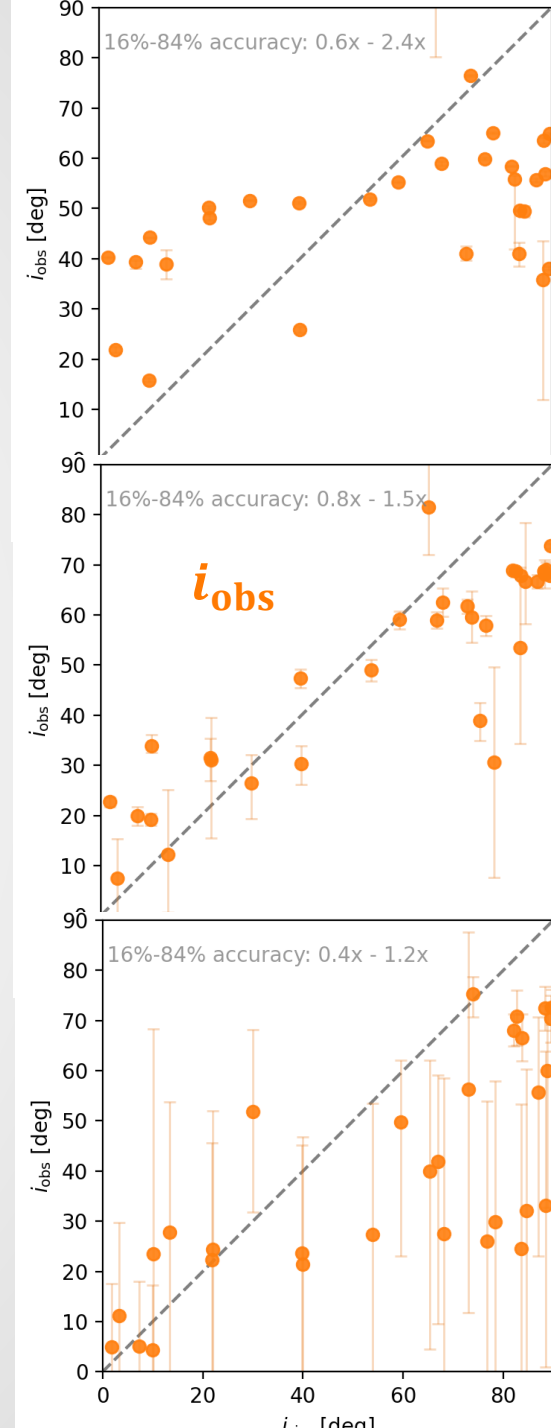
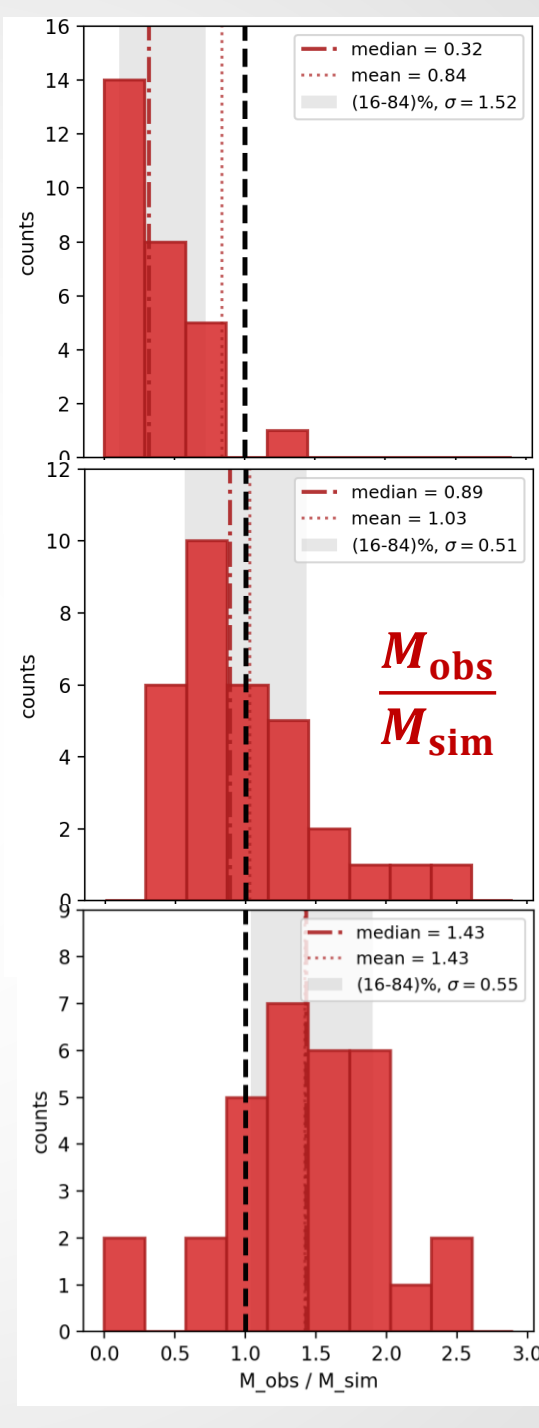
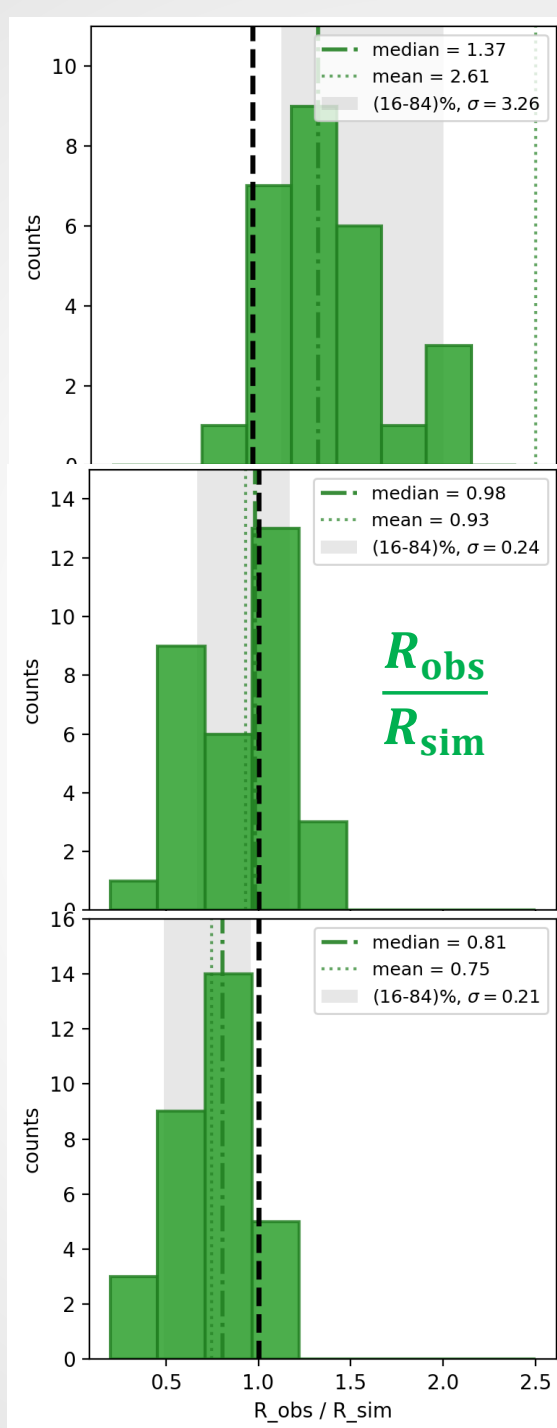
Observed  $R$  and  $M$  medians increase for all wavelengths.

Best match !

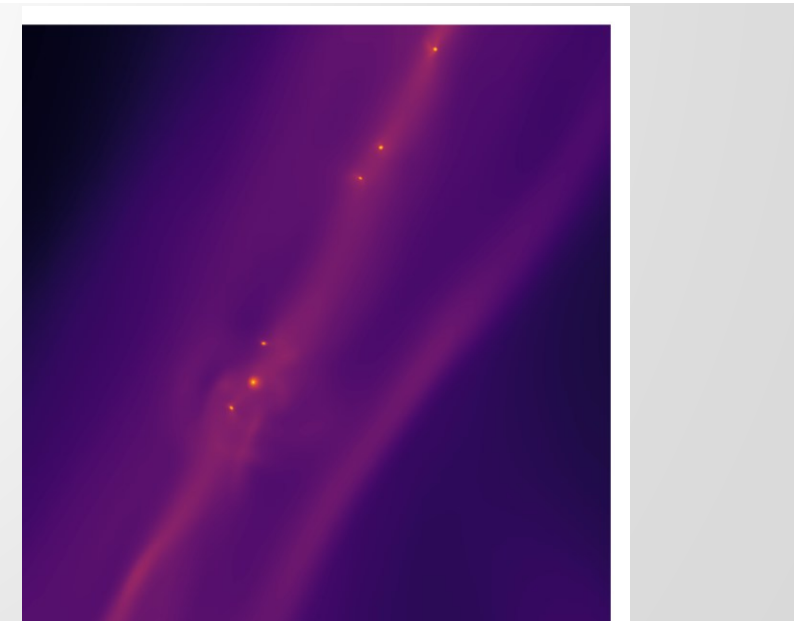
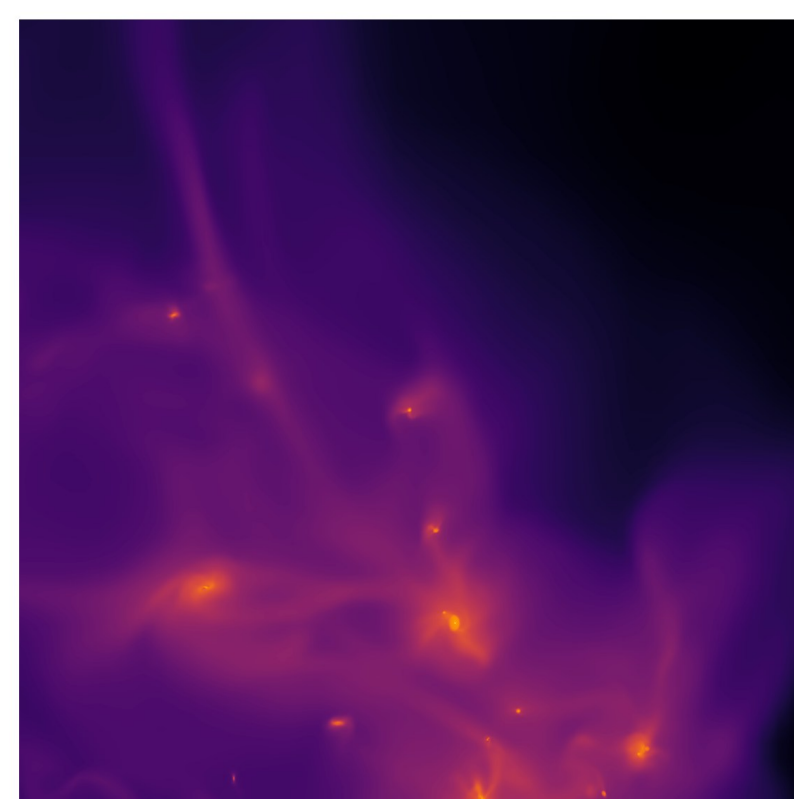
3mm

7mm

Envelopes still not totally constrained at 7mm CC



# METHODS: MULTIPLICITY



# METHODS: MULTIPLICITY

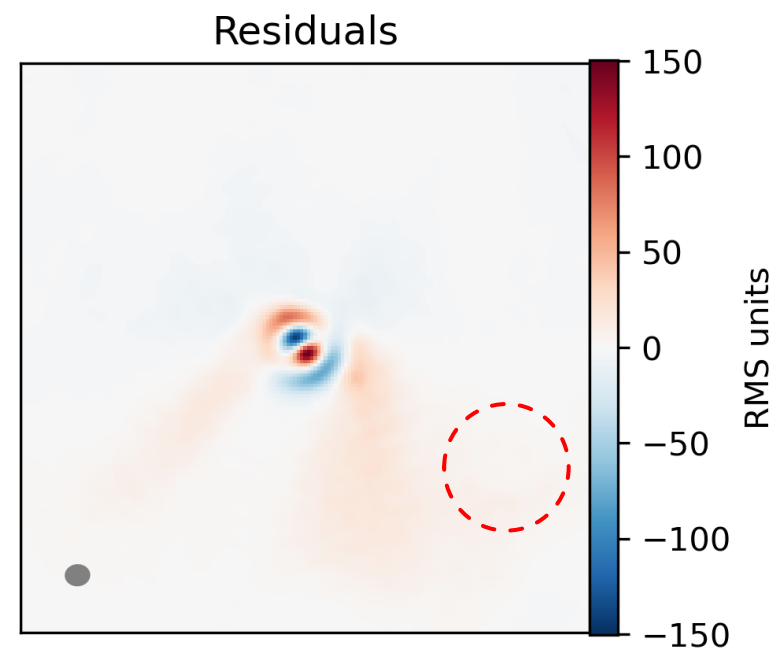
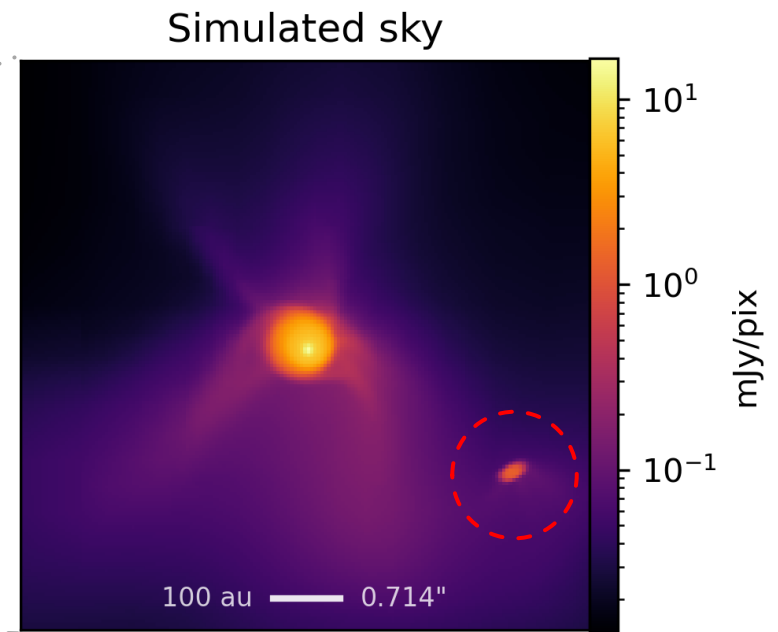
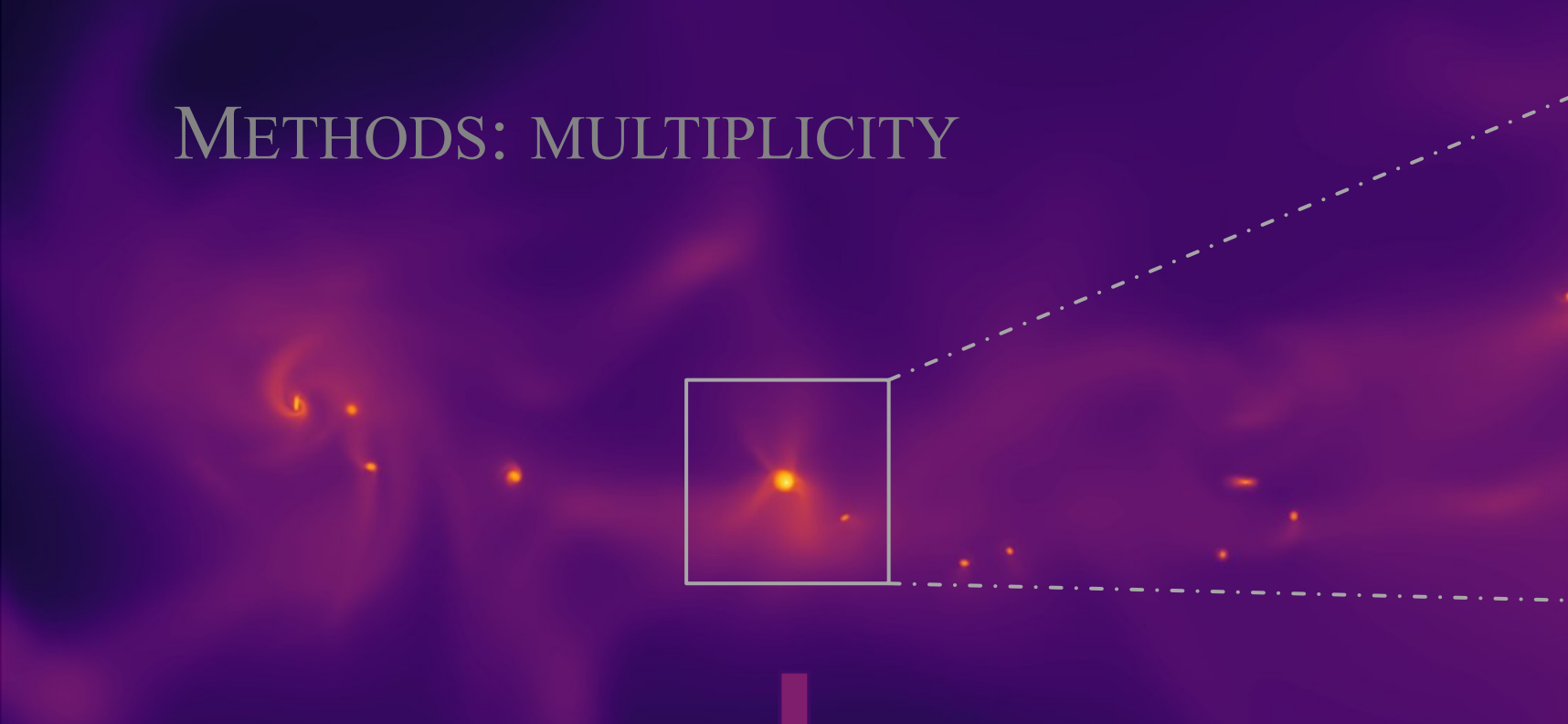


Extra sources detected on the **observed** sky image (cleaned)

**RMS** thresholding criterion

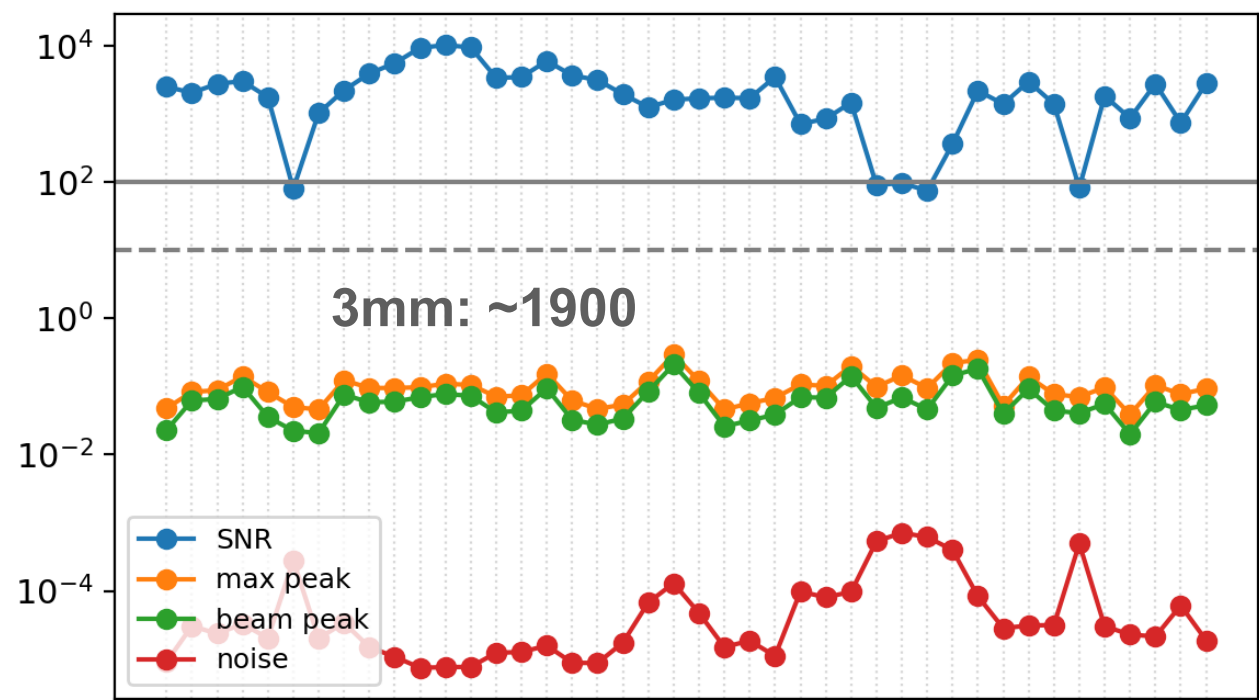
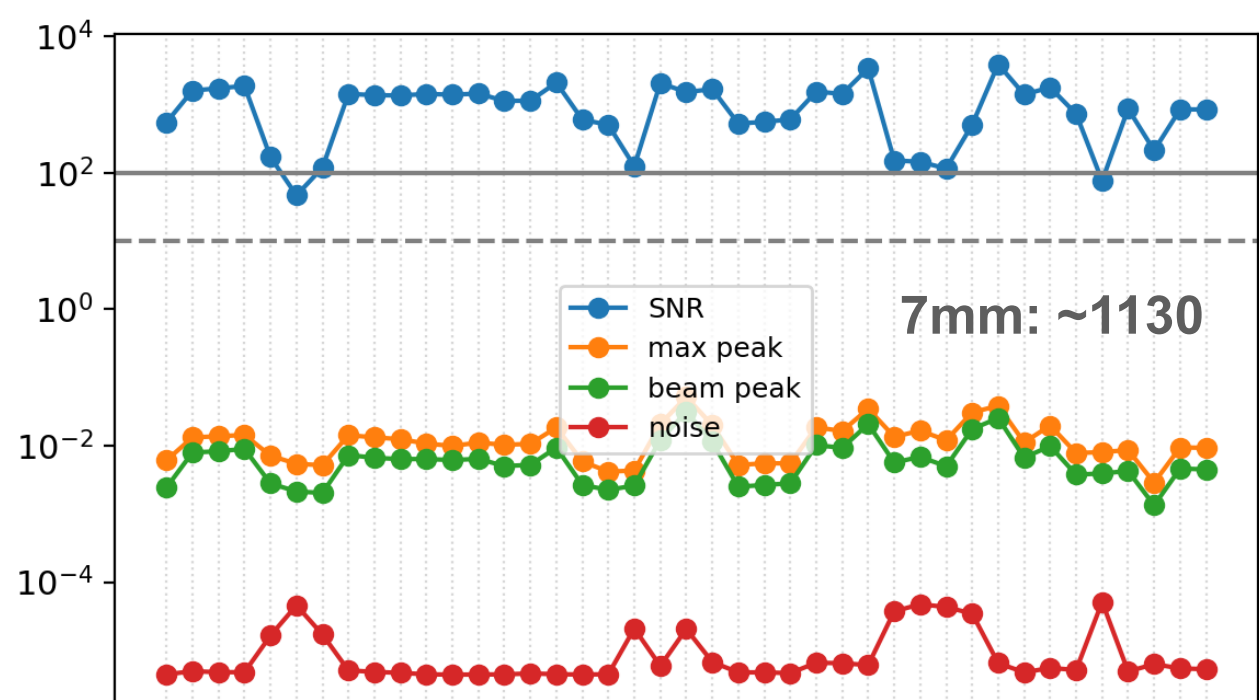
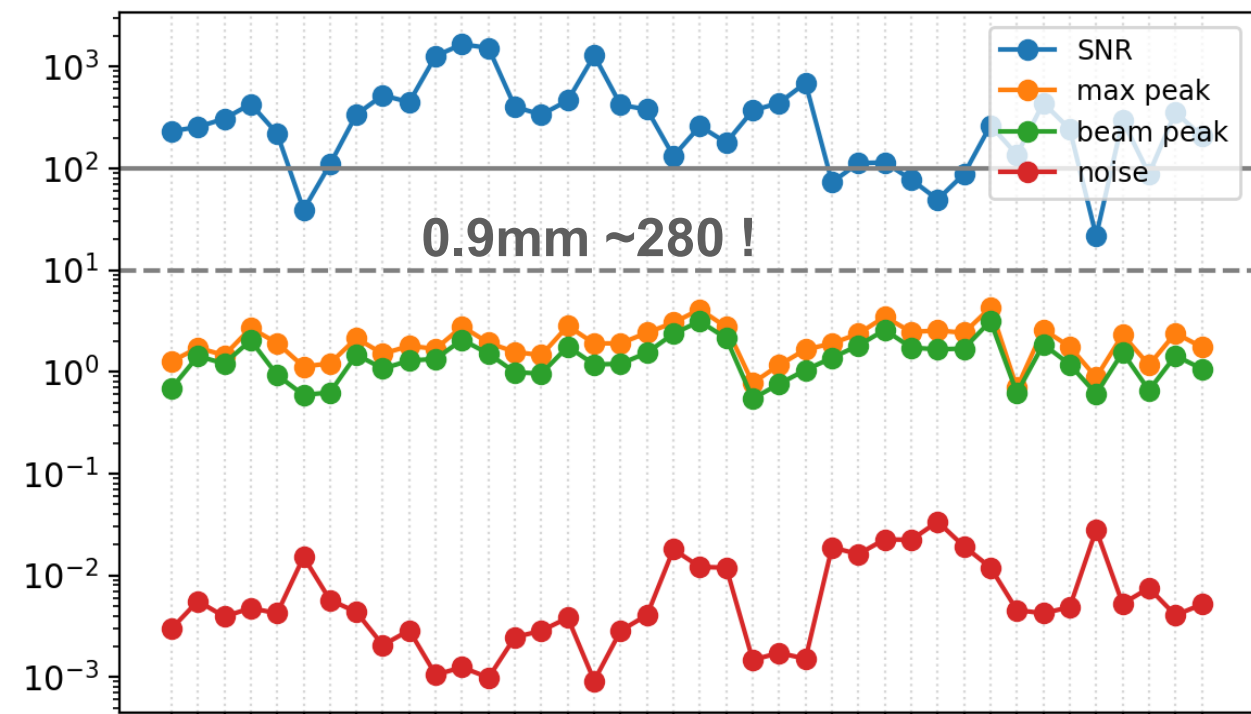
The clean components in the selected regions are translated to complex visibilities and **subtracted** from the original dataset

# METHODS: MULTIPLICITY

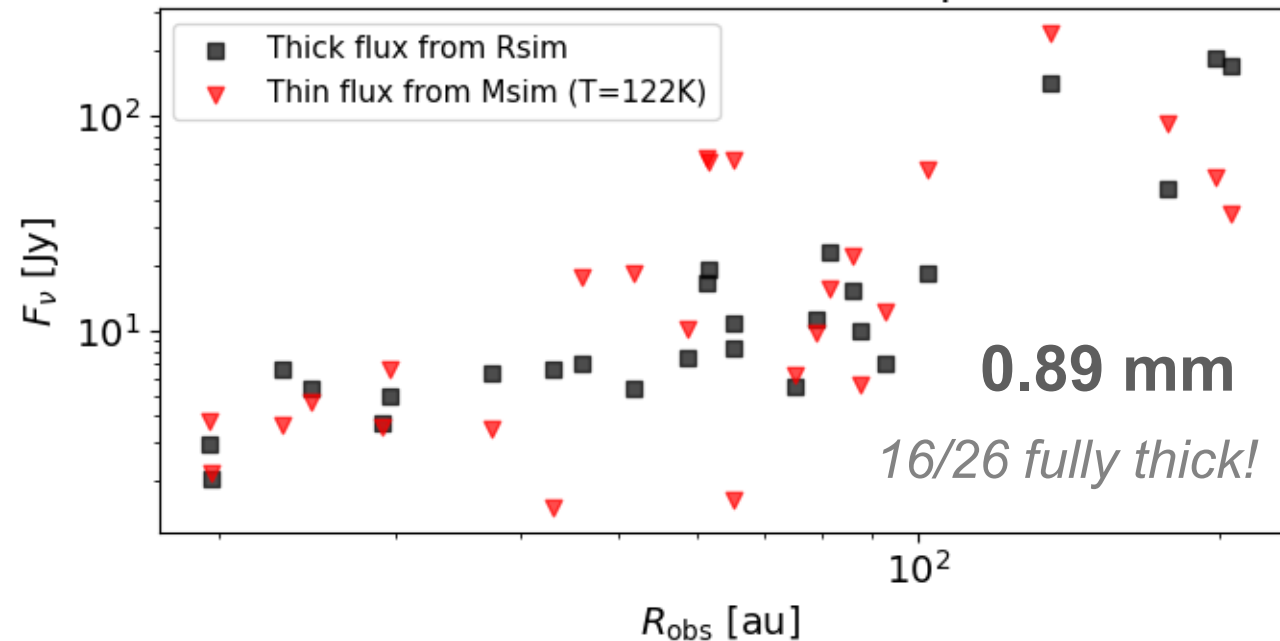


# RESULTS: SNR

(different integration times)



Simulation thin vs thick spread



thick



thin

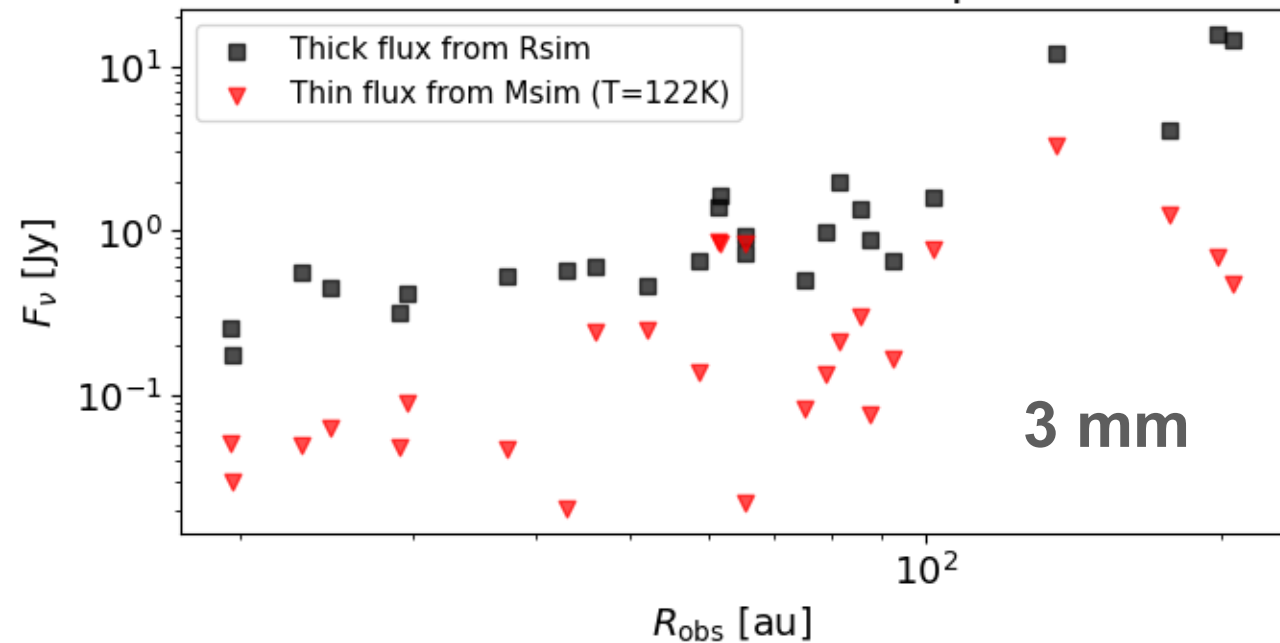


$$F_{\nu, \text{th}} = \frac{1}{d^2} \int_0^{R_{\text{sim}}} B_\nu(T_{\text{dust}}) 2\pi r dr.$$

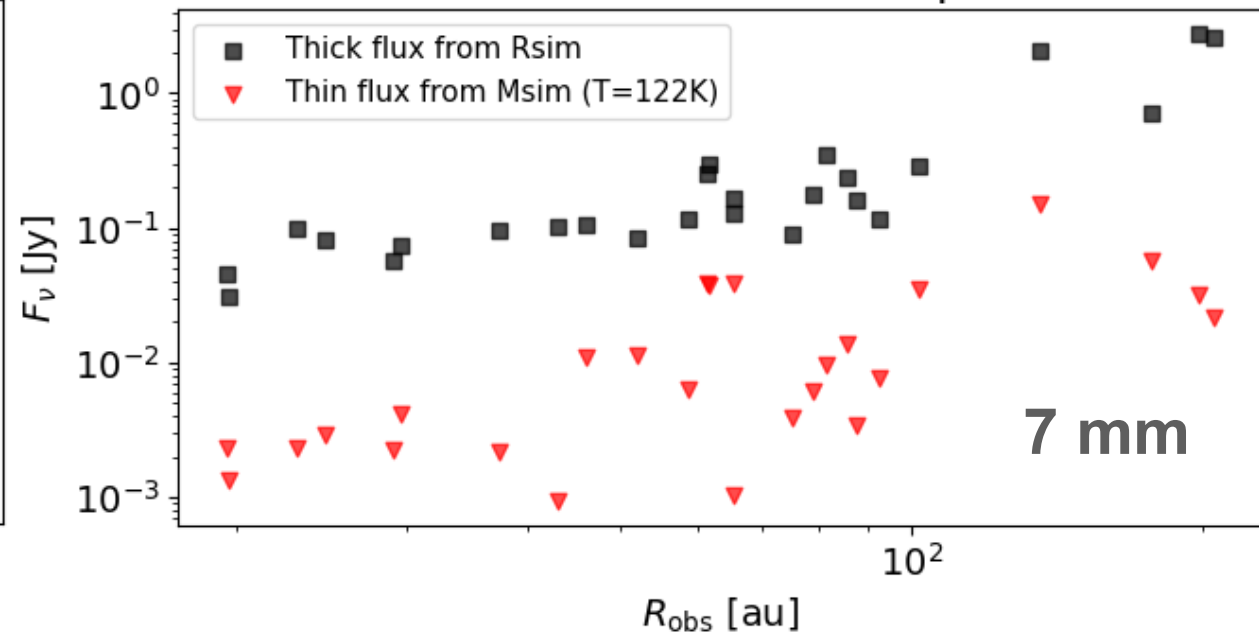
$$F_\nu = M_{d, \text{sim}} \cdot \frac{\kappa_\nu B_\nu(T)}{d^2}$$

$$M_{\text{dust}} = \frac{F_\nu d^2}{\kappa_\nu B_\nu(T_{\text{dust}})},$$

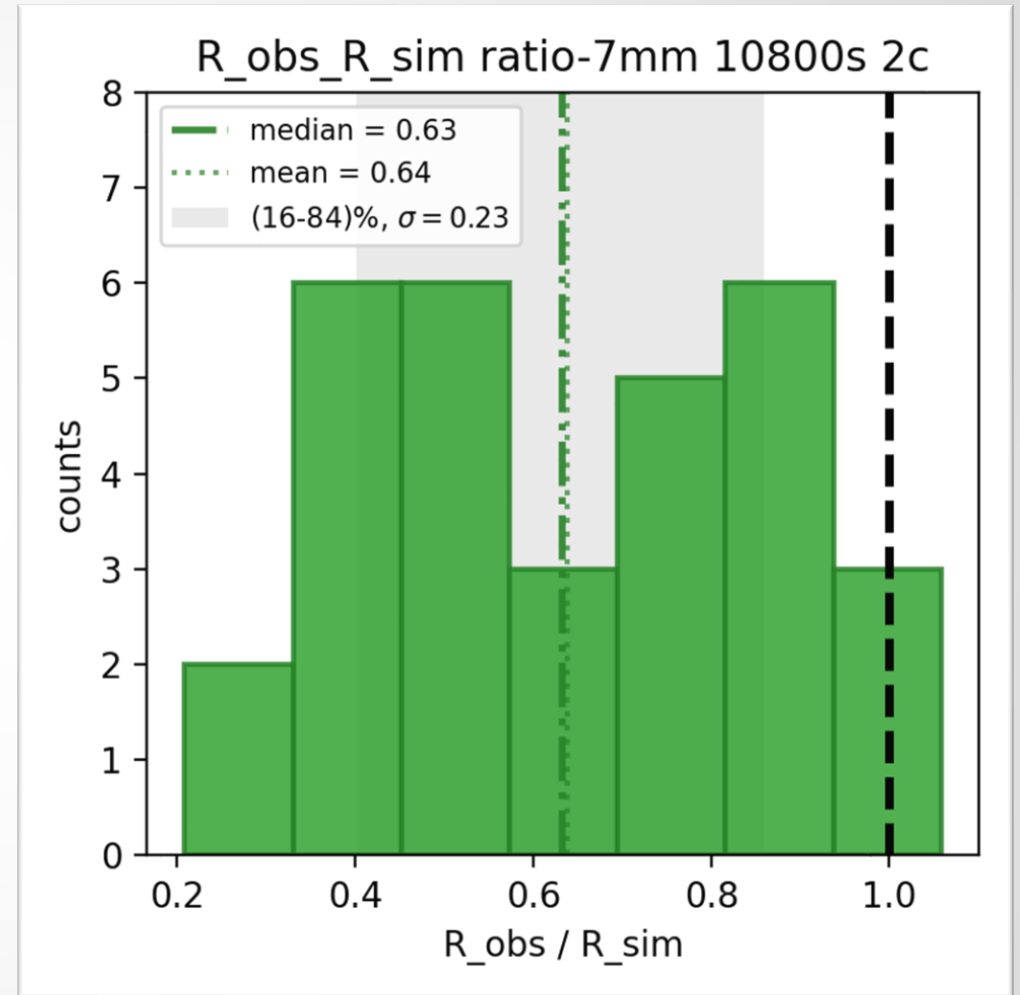
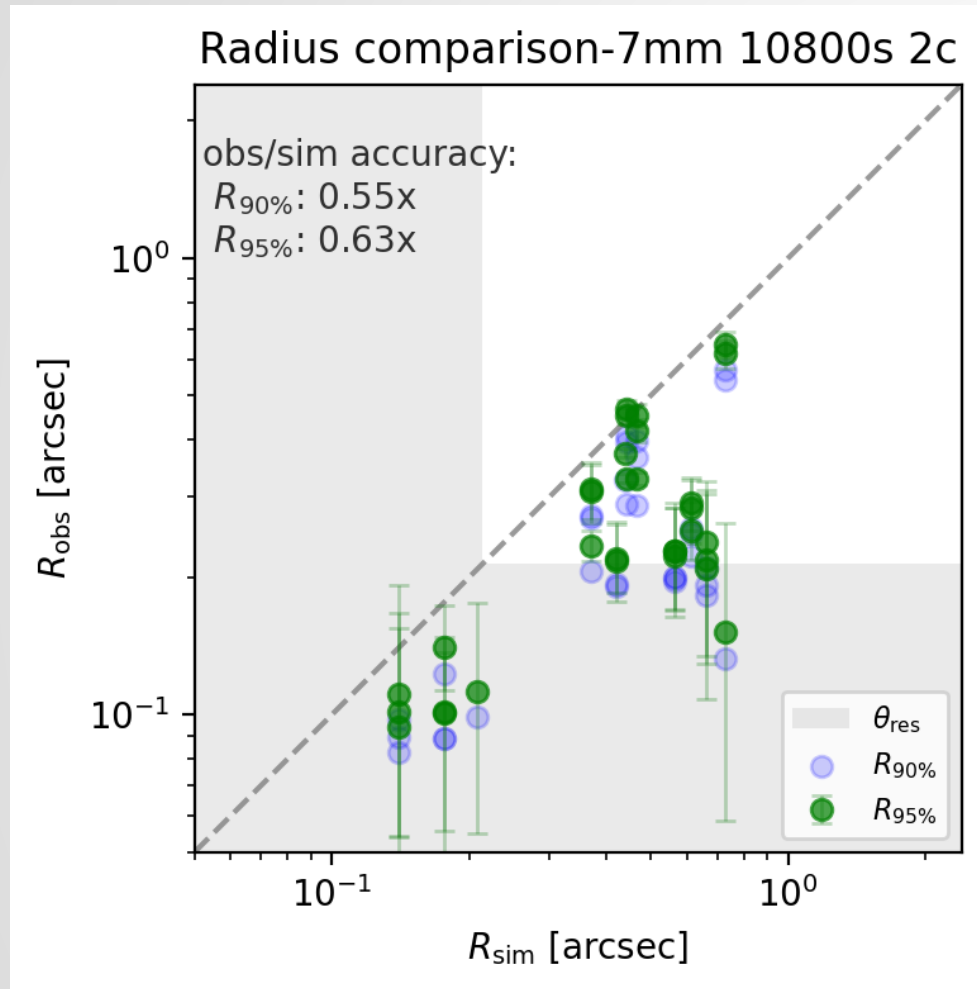
Simulation thin vs thick spread



Simulation thin vs thick spread



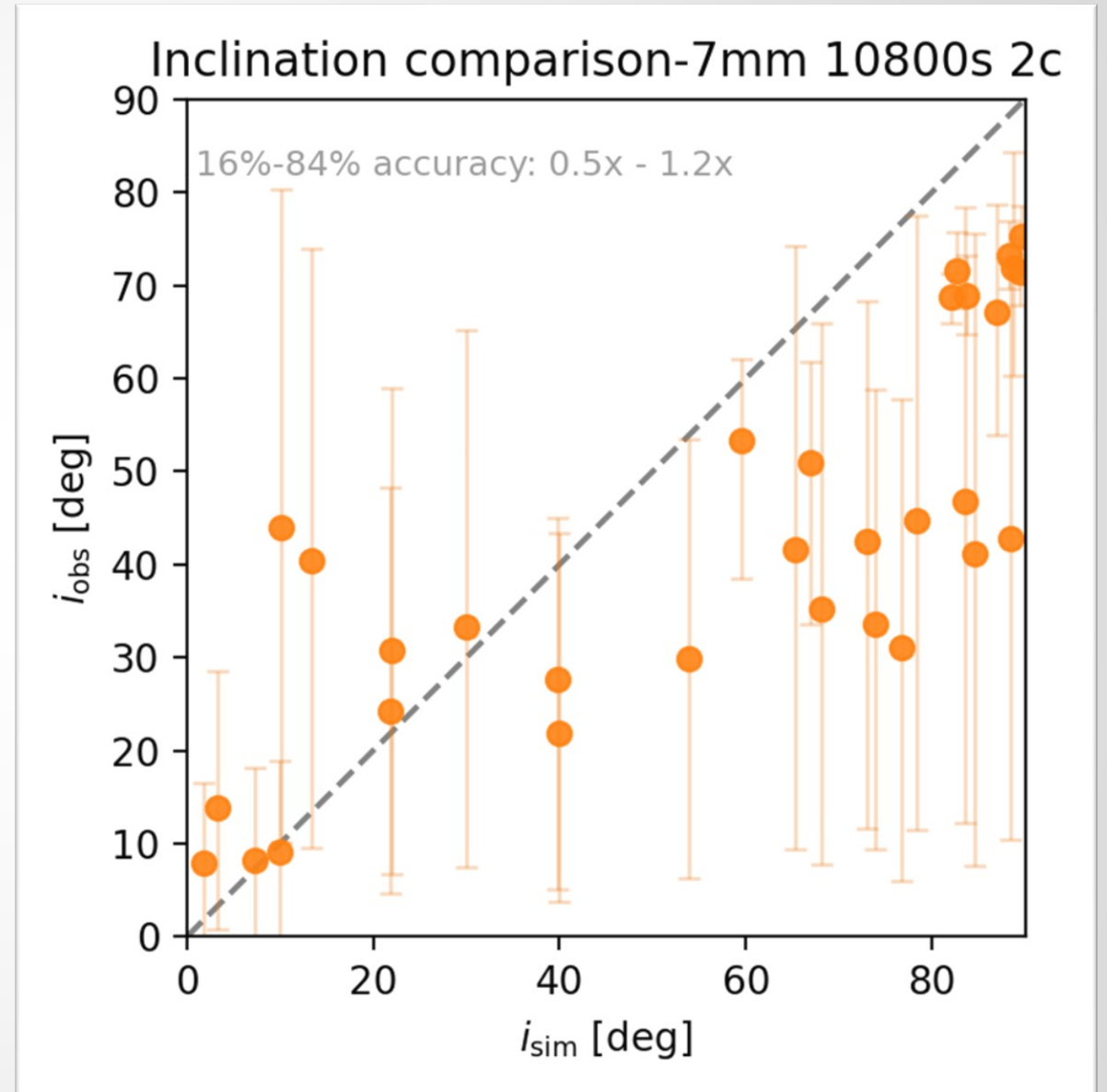
# RESULTS: RADIUS



Non-negligible **underestimation** of disk radii, although with a contained dispersion.

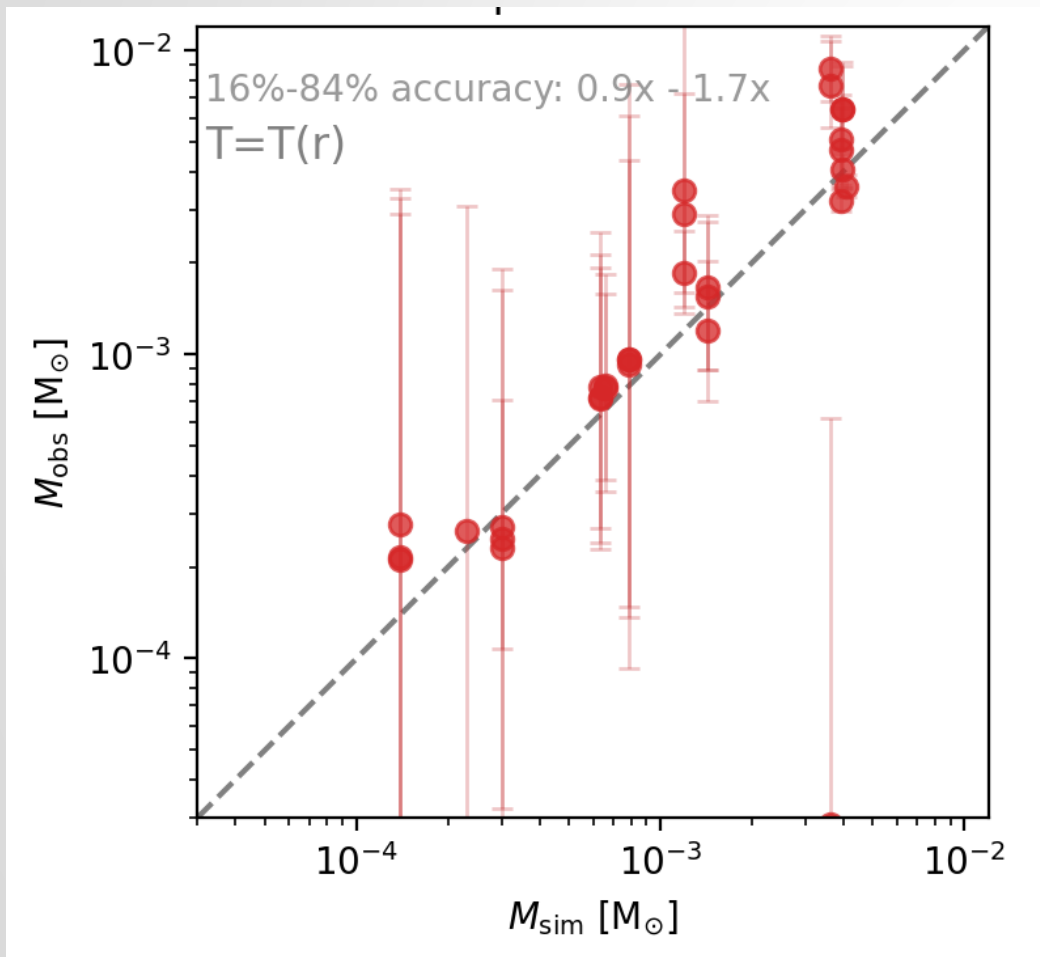
# RESULTS: INCLINATION

Inclination poorly constrained:  
low accuracy and large spread.



# RESULTS: MASS

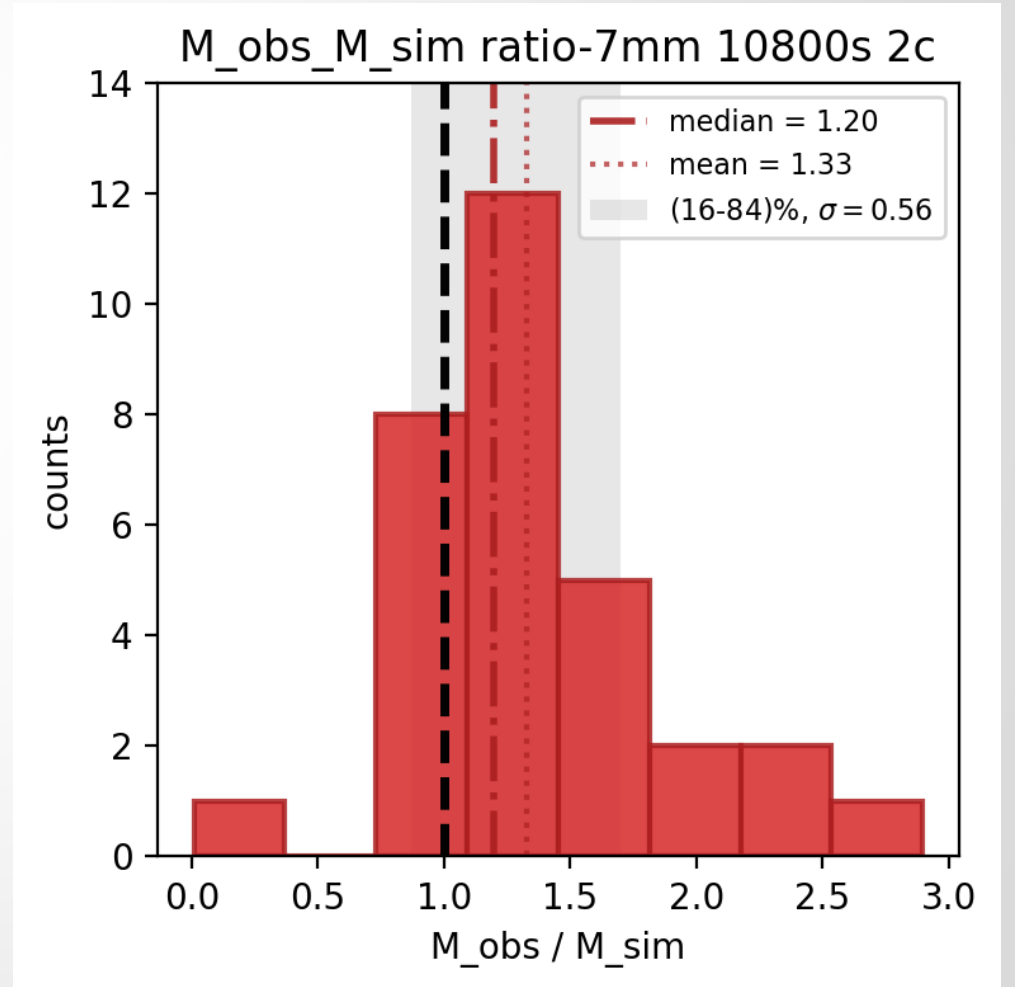
Mass is inferred with **good accuracy** but large uncertainties



Obs/sim ratio distribution

peaks closer to 1

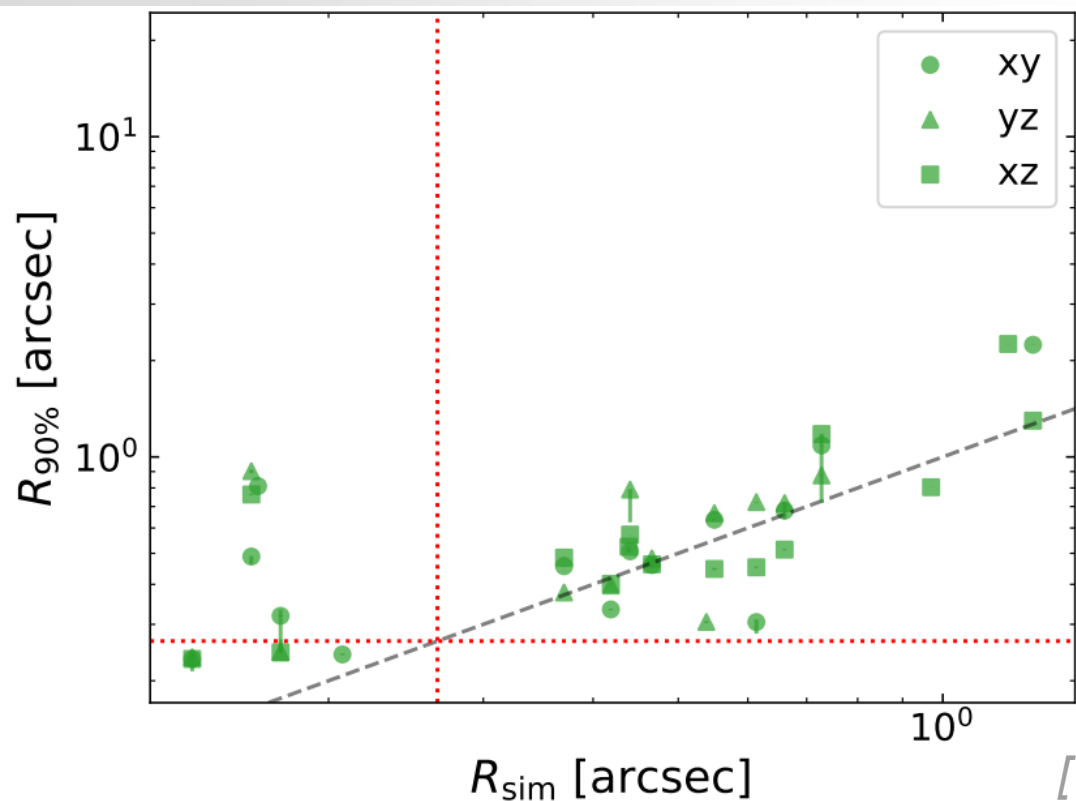
A few disk masses are overestimated notwithstanding the *underestimated* radii !



# RECAP: BAND 7 PROPERTIES

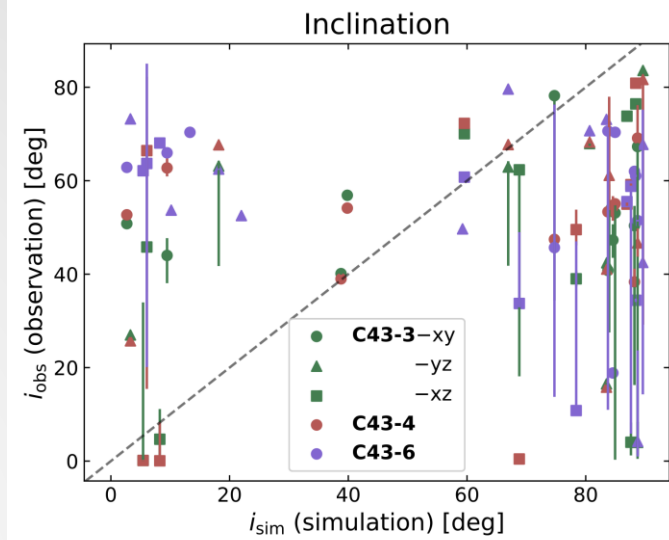
How were the **main properties** of the sample recovered at **0.9mm**? (Tung+ 2024)

## Radius



[Tung+2024]

## inc



## Mass

