See you **next week**
in Garching!

Using ALMA multi-wavelength observations to study grain growth in the Lupus discs: implications for dust substructures

Marco Tazzari

Institute of Astronomy, Cambridge

Tazzari+ (2021) MNRAS 506 5117

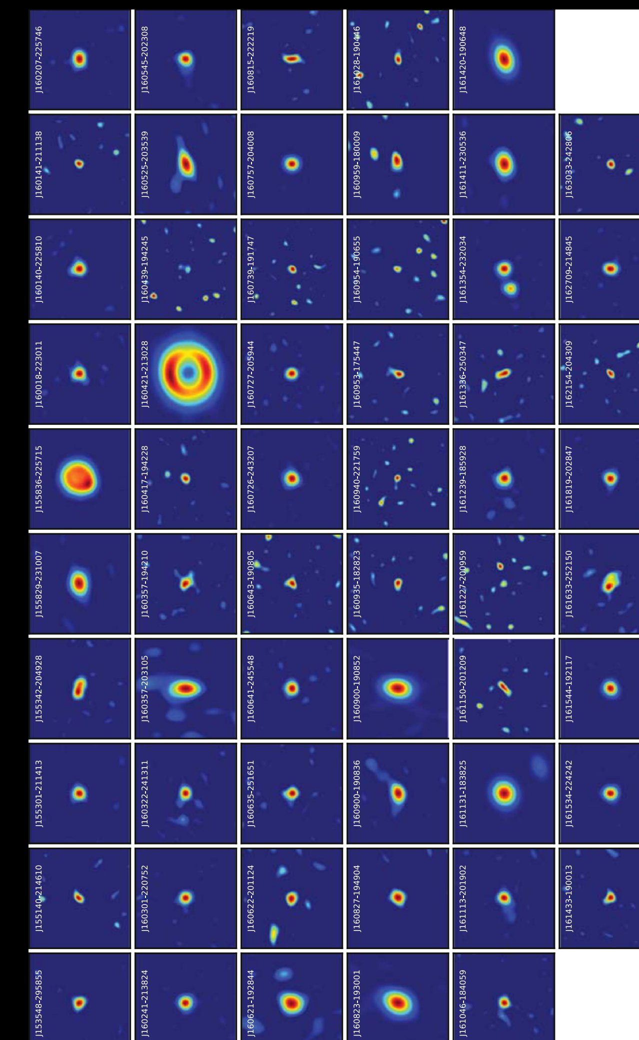
Tazzari+ (2021) MNRAS 506 2804

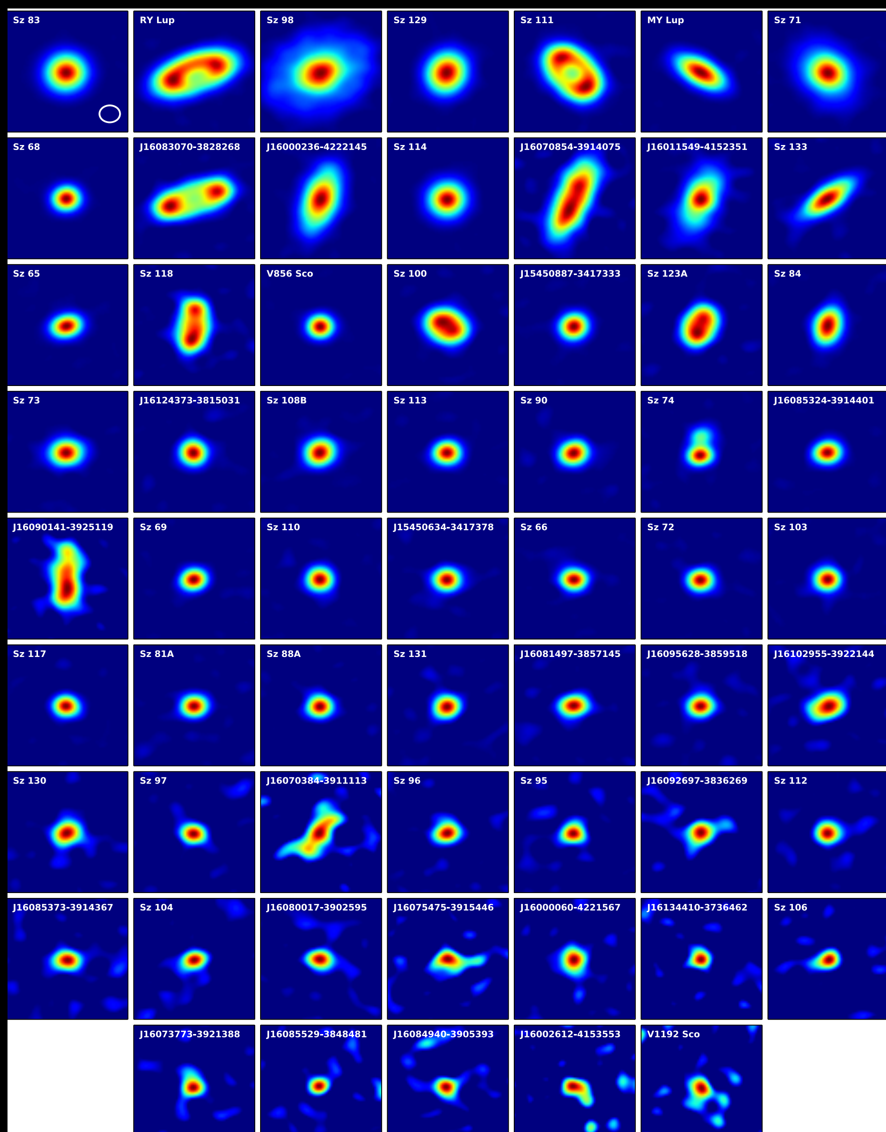
With:

C. Clarke (IoA, Cambridge), L. Testi (ESO), J. Williams (IfA),
S. Facchini (UniMi), C. Manara, A. Miotello (ESO) & t**he ALMA Lupus team**

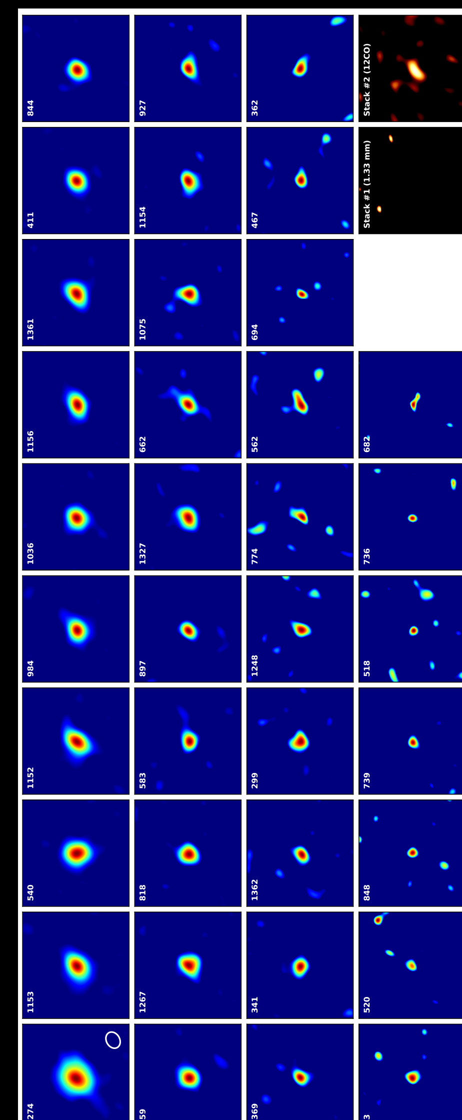
ALMA enables disc demographics

Upper Sco I
(58) Barenfeld+ 2016

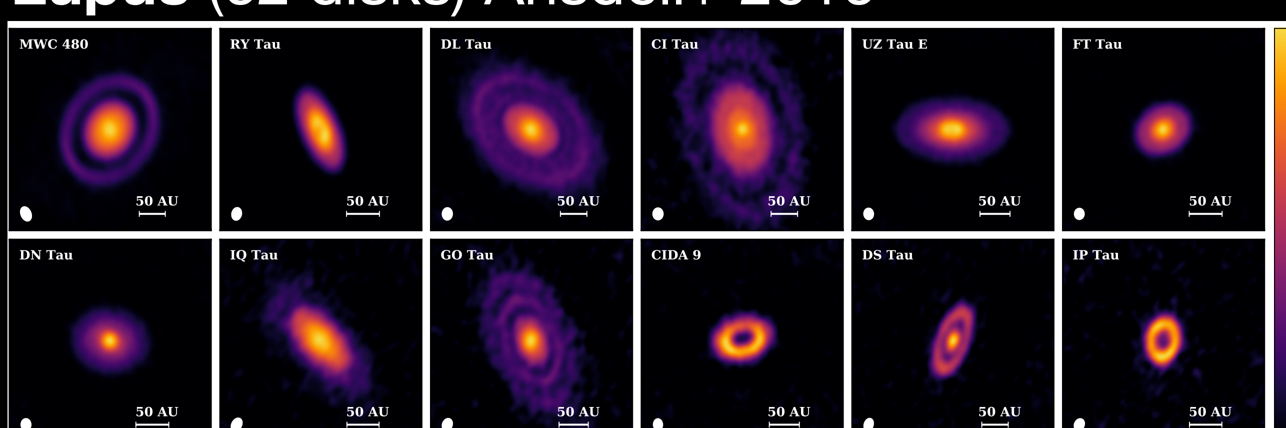




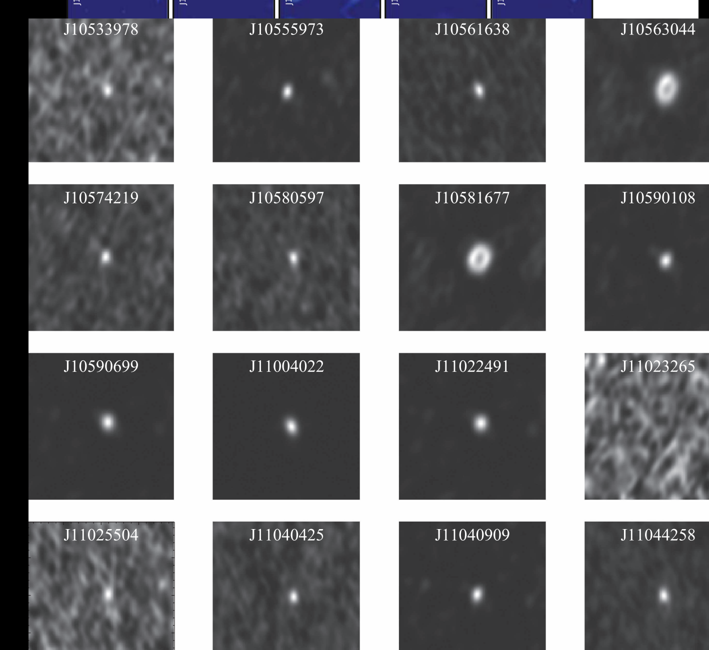
Lupus (62 disks) Ansdell+ 2016



σ Ori (37)
Ansdell+ 2017



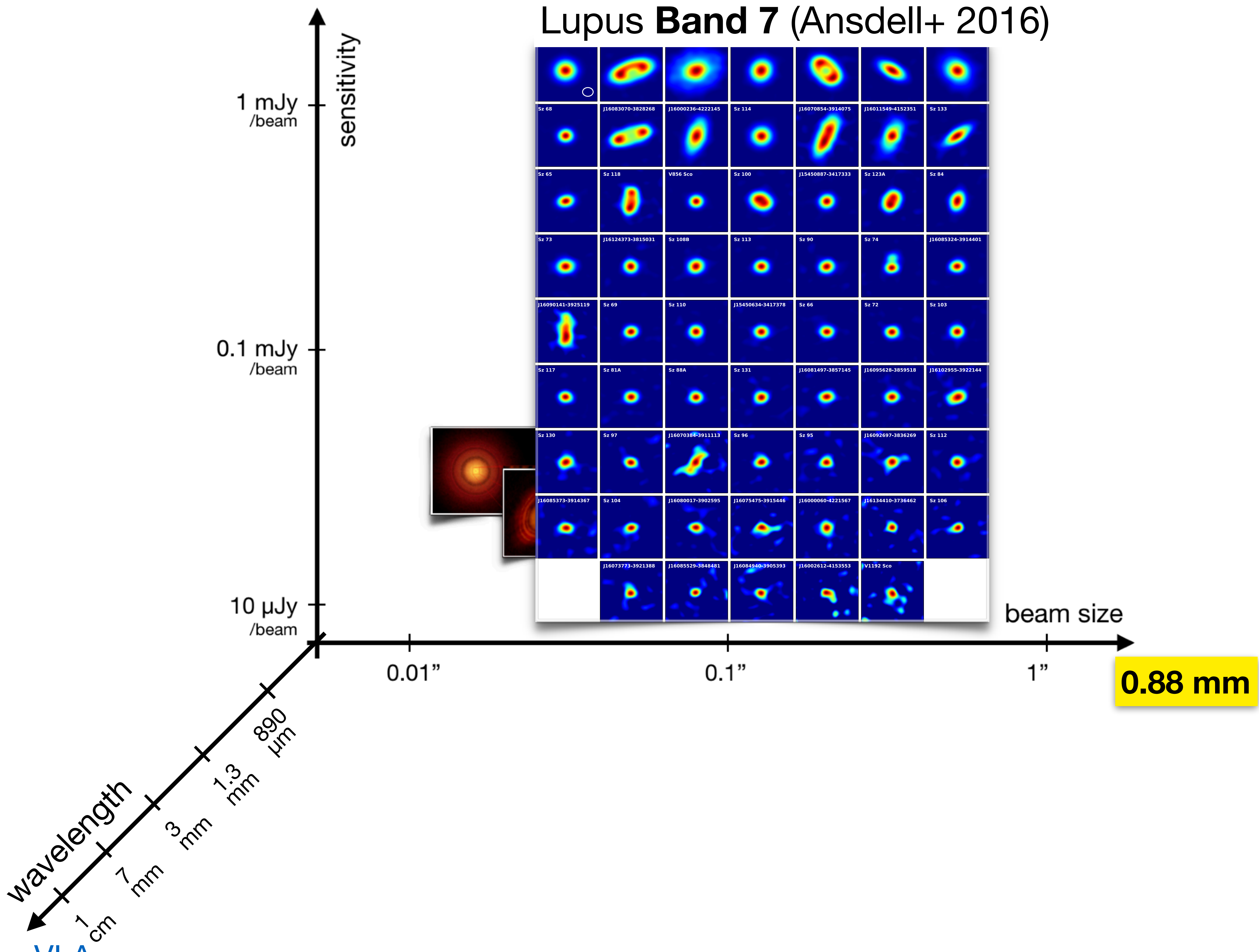
Taurus,
Long + 2018



Cha I (66) Pascucci+ 2016

mtazzari@ast.cam.ac.uk

ALMA enables *multi-wavelength* disc demographics



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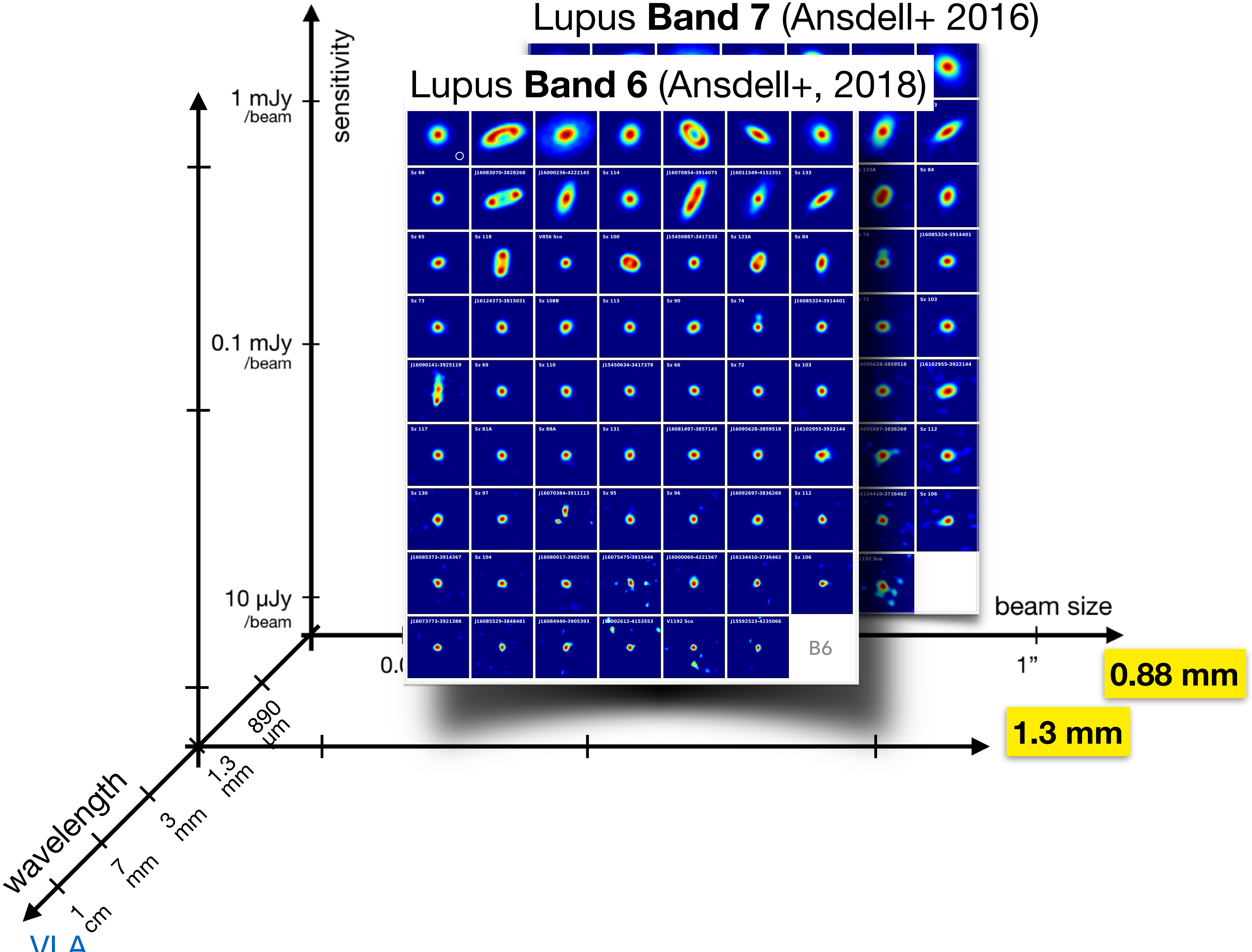
ALMA enables *multi-wavelength* disc demographics



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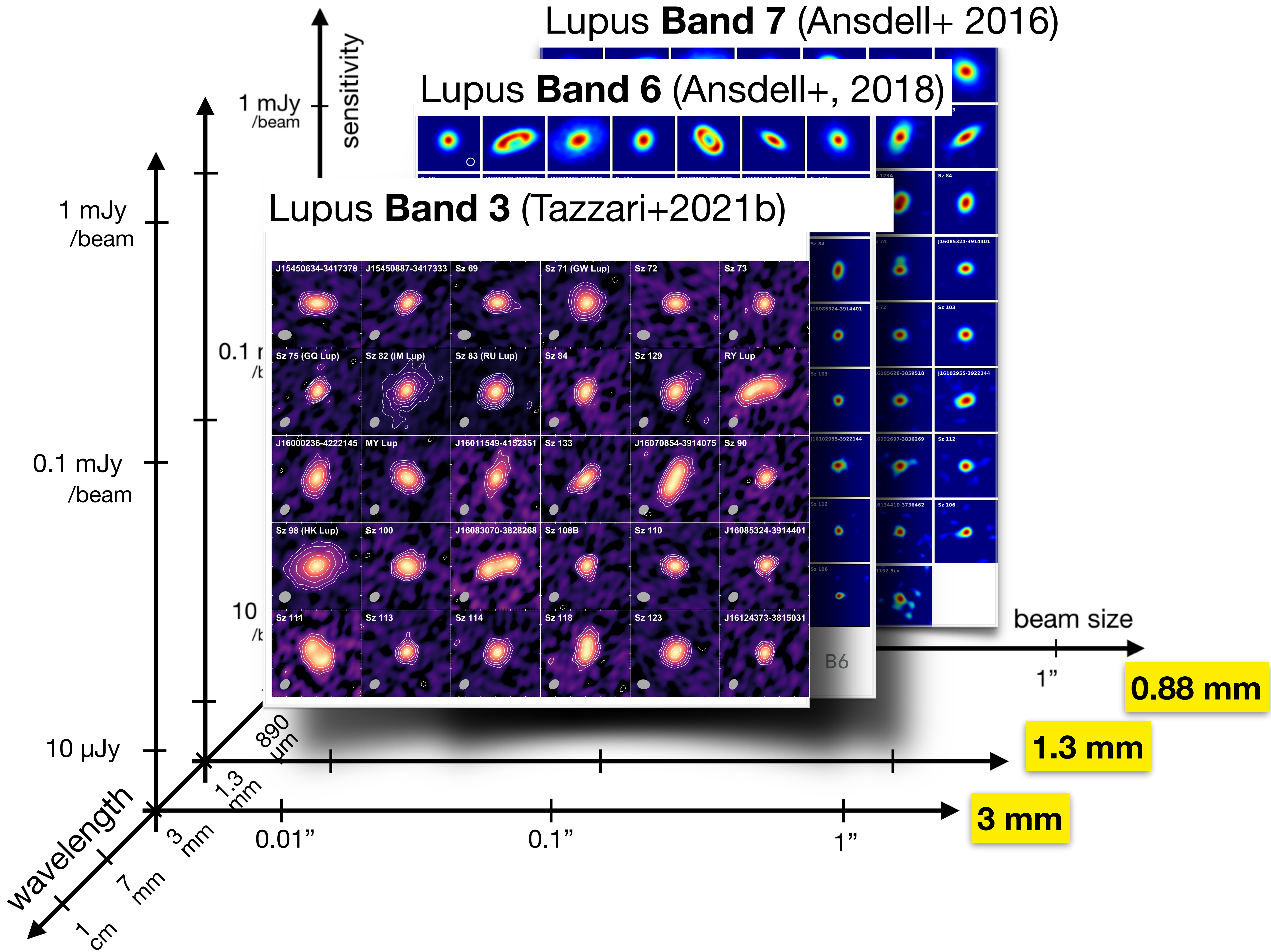
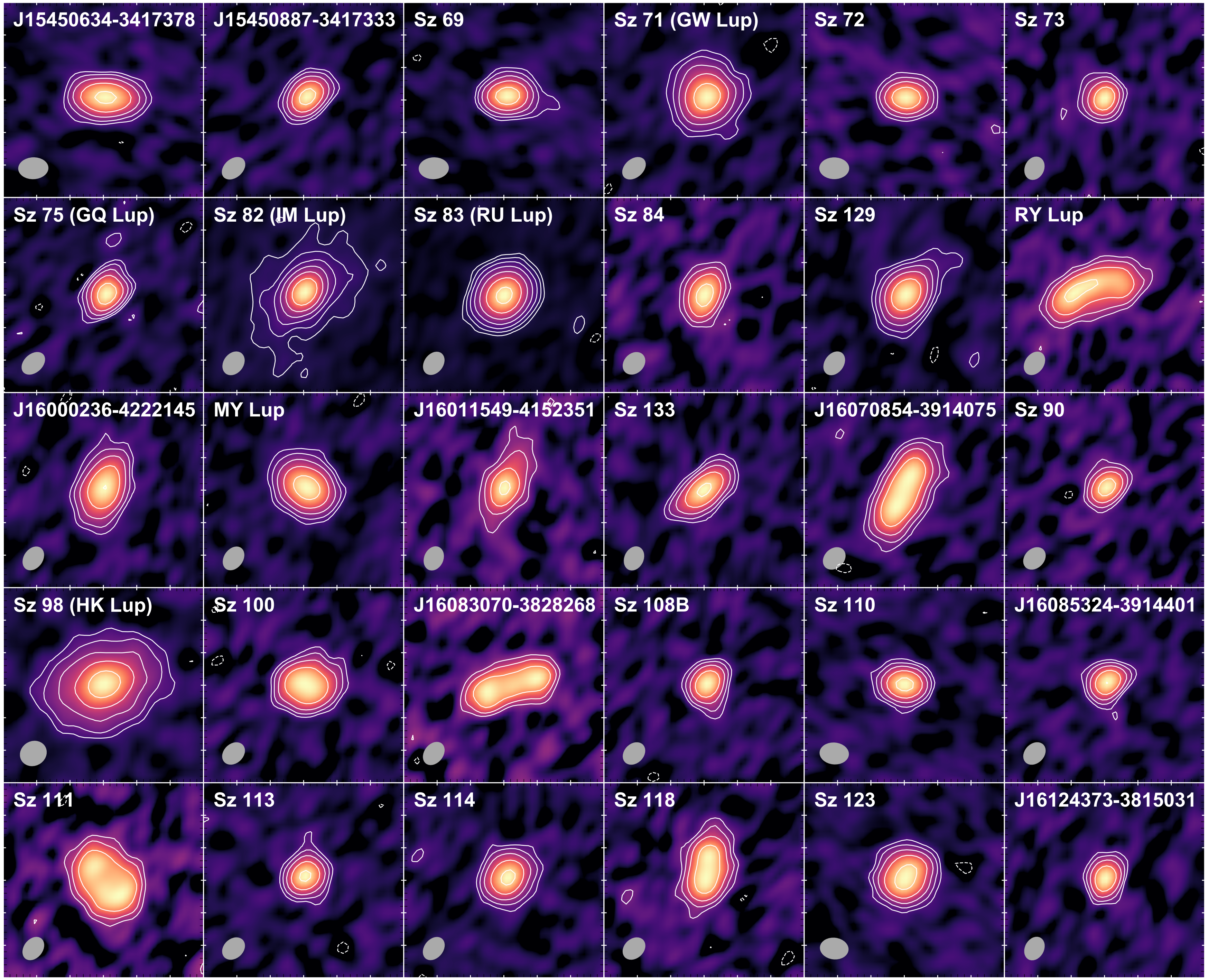
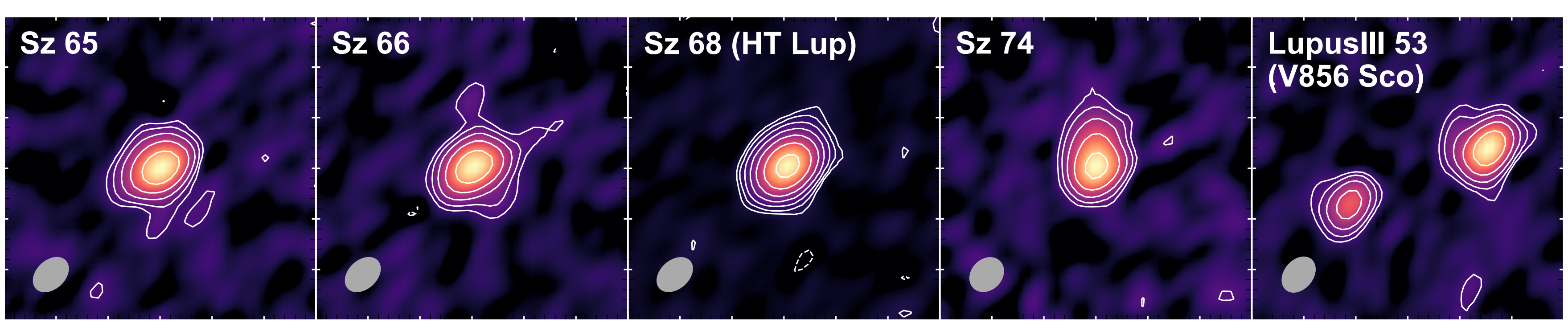


First ALMA Band 3 disk survey: Lupus discs



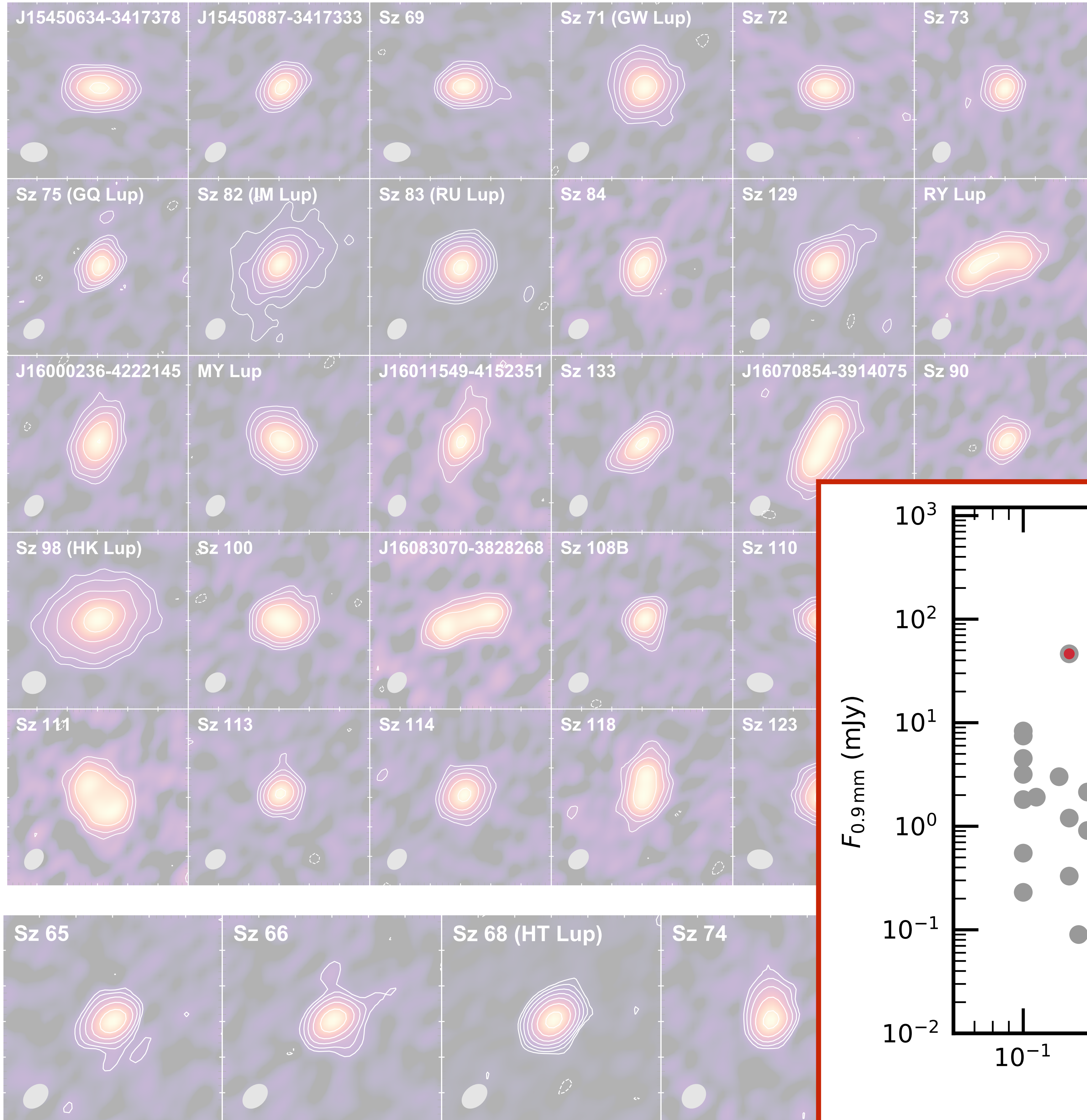
[Tazzari+ (2021) MNRAS 506 5117]

30 Single stars



5 Multiple systems

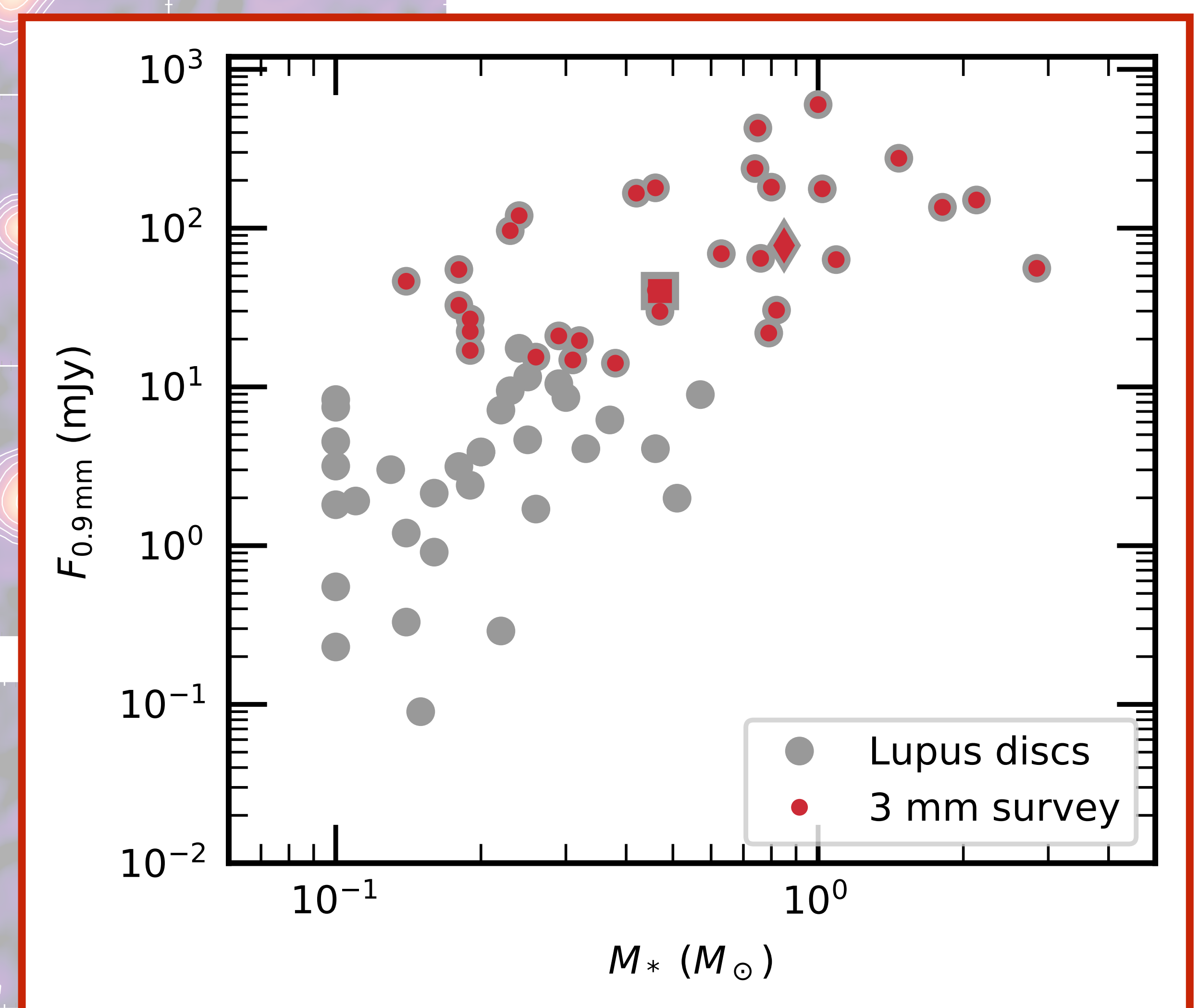
First ALMA Band 3 disk survey: Lupus discs



[Tazzari+ (2021) MNRAS 506 5117]

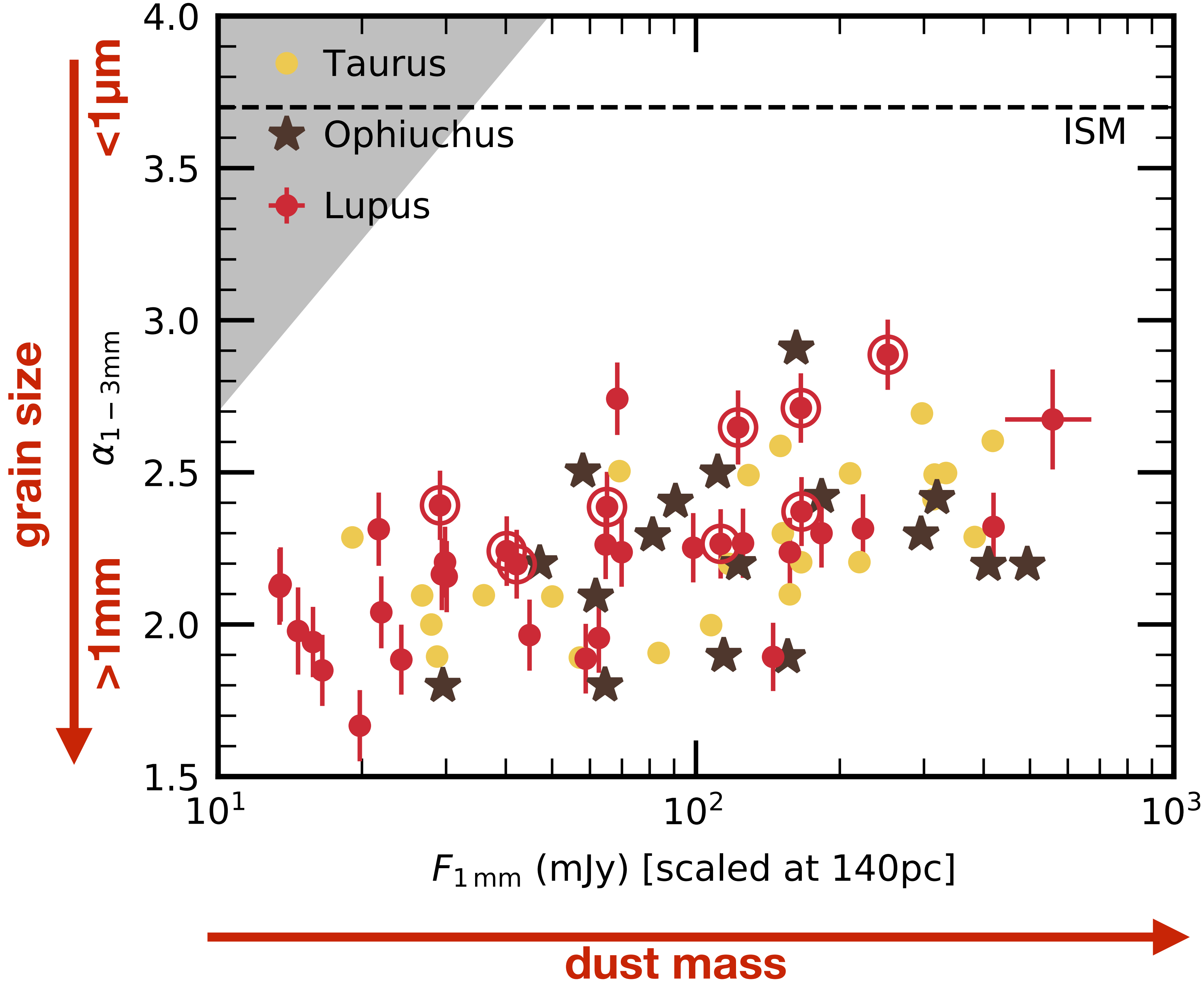
30 Single stars

Sample Completeness: 55%



First ALMA Band 3 disk survey: Lupus discs

[Tazzari+ (2021) MNRAS 506 5117]()



Literature data from: Rodmann+ 2006, Andrews and Williams 2005, 2007, Lommen+ 2009, Ricci+ 2010a,b, 2011, Mann and Williams 2010, Ubach+ 2012.

First ALMA Band 3 disk survey: Lupus discs

Tazzari+ (2021)
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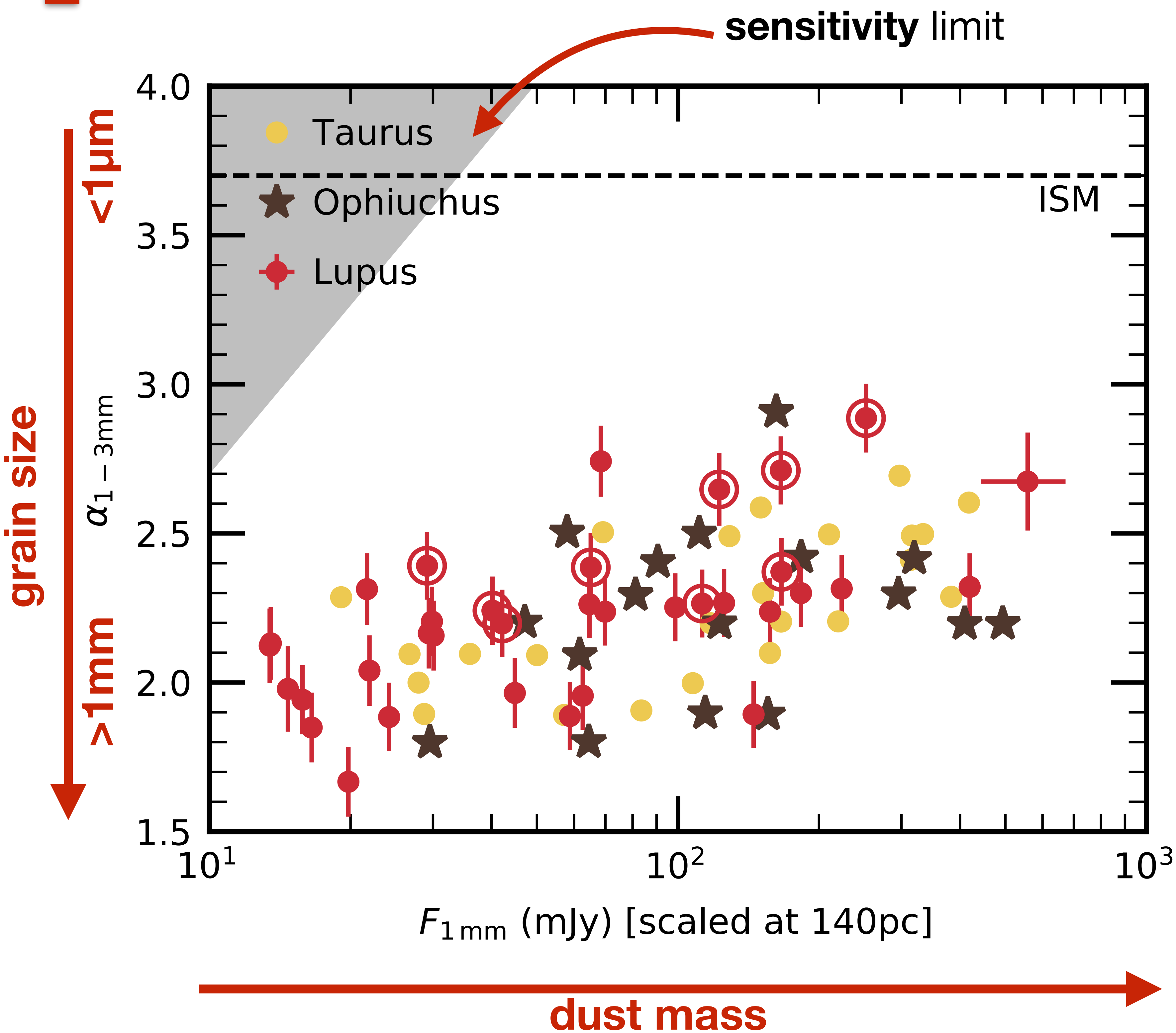

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First ALMA Band 3 disk survey: Lupus discs

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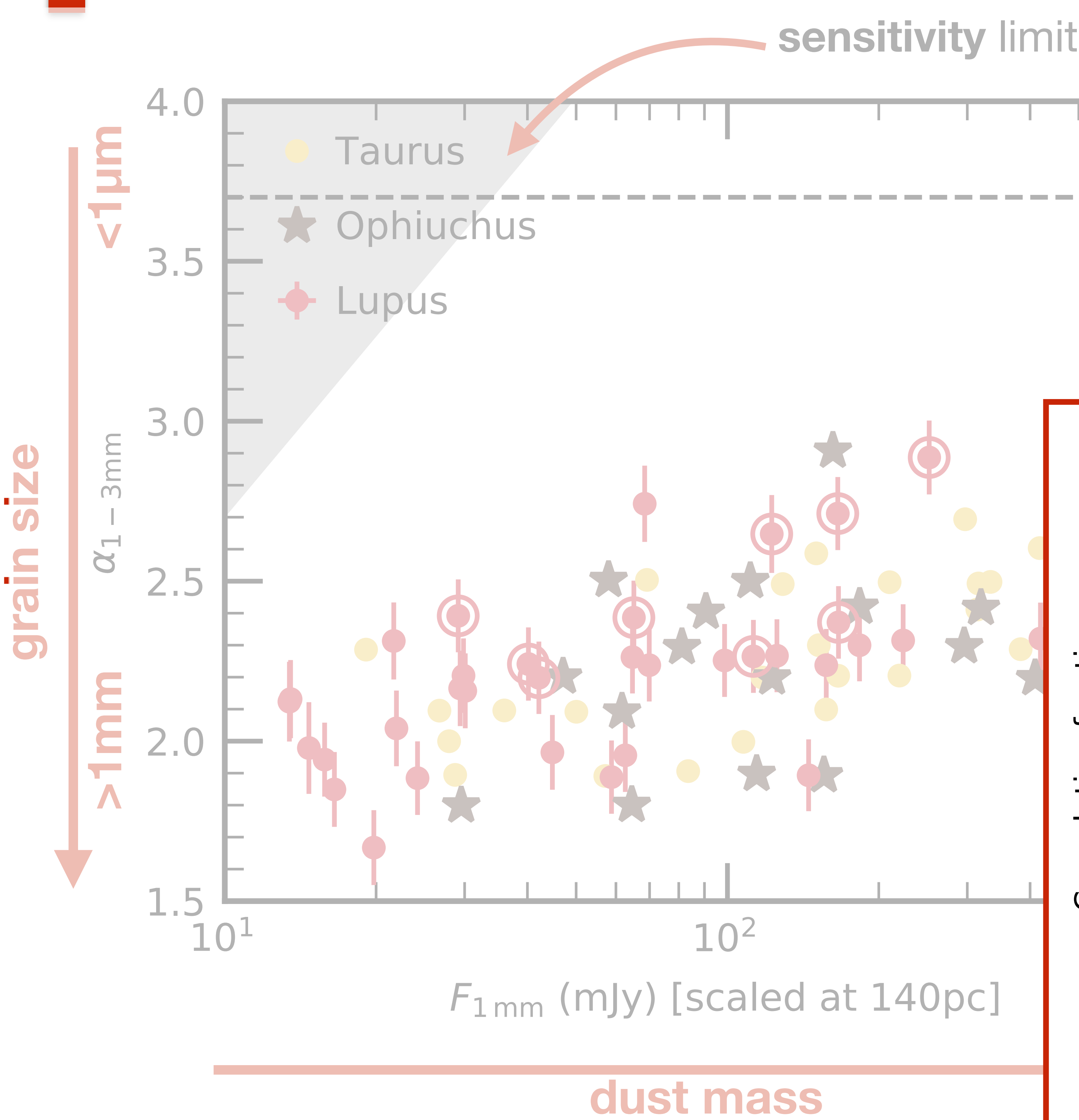
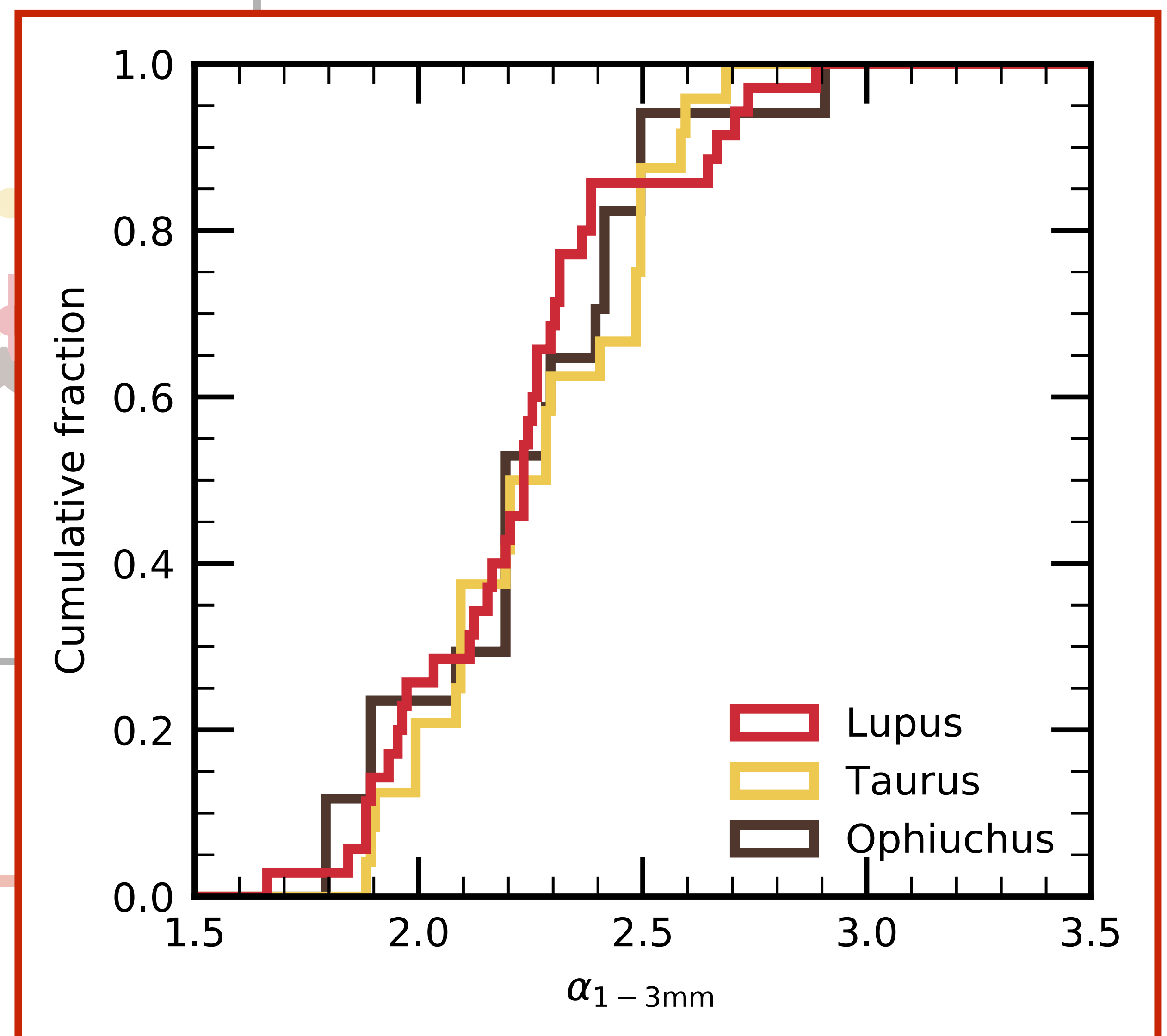


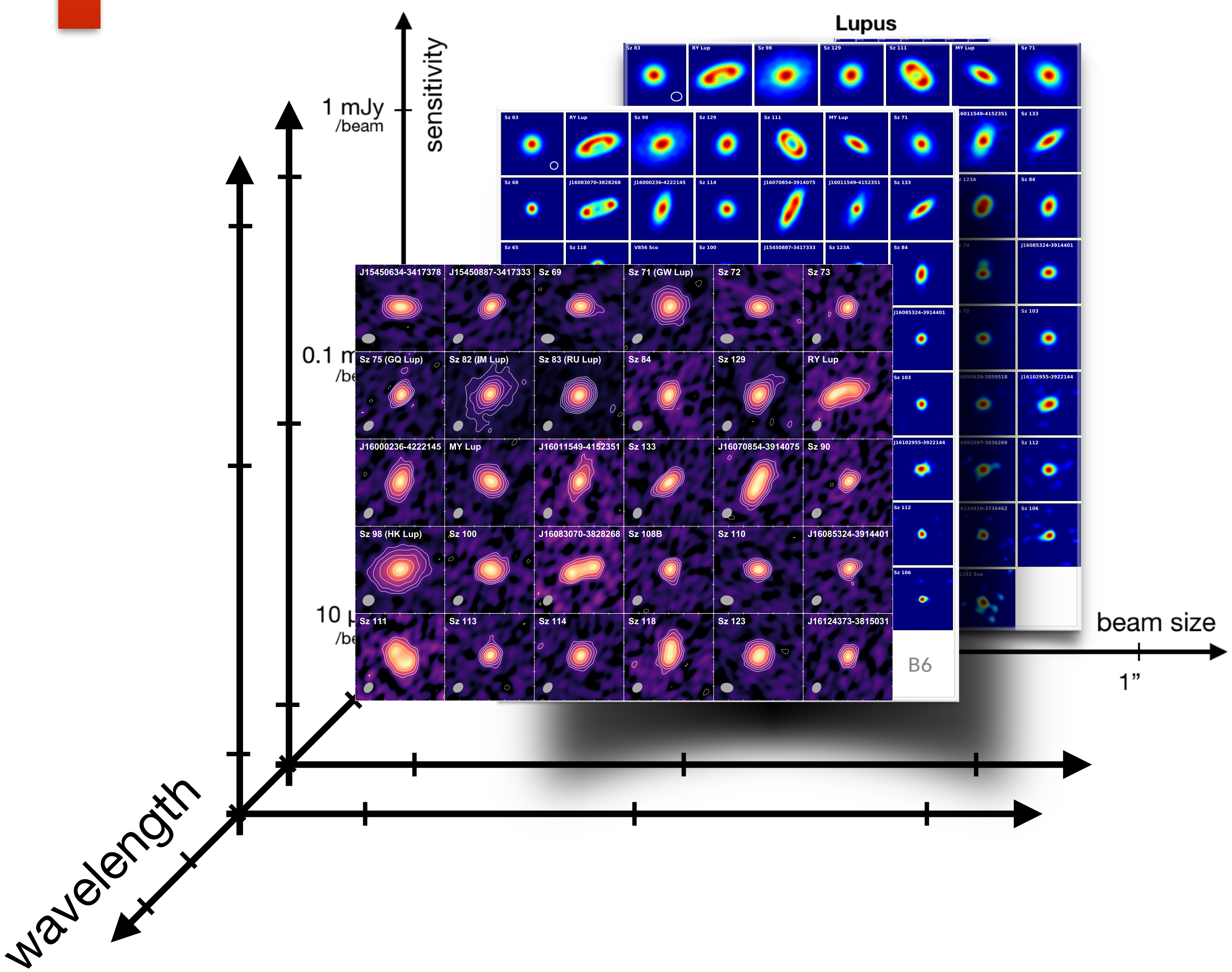
Similarity with other regions!



Literature data from: Rodmann+ 2006, Andrews and Williams 2005, 2007, Lommen+ 2009, Ricci+ 2010a,b, 2011, Mann and Williams 2010, Ubach+ 2012.

Multi-wavelength analysis

[Tazzari+ (2021) MNRAS 506 2804]



Method:

*Spatially-resolved analysis (**visibility** fits)*

Aims:
1. disc **size** vs obs **frequency**
2. disc **size** vs **mm flux**
3. disc **optical depth**
4. implications for grain growth (**substructures**)

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Results example: Sz 83

Tazzari+ (2021) MNRAS 506 2804

GALARIO

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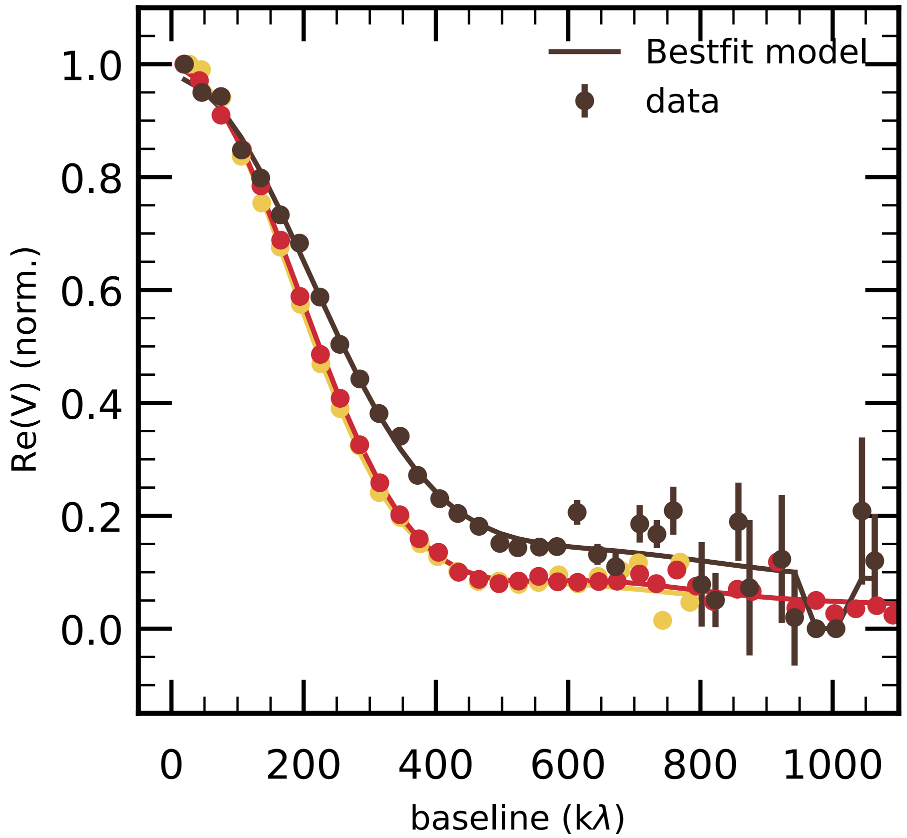
Tazzari+ (2021) MNRAS 506 2804

GALARIO

Visibililities:



Results example: Sz 83

[Tazzari+ (2021) MNRAS 506 2804]

GALARIO

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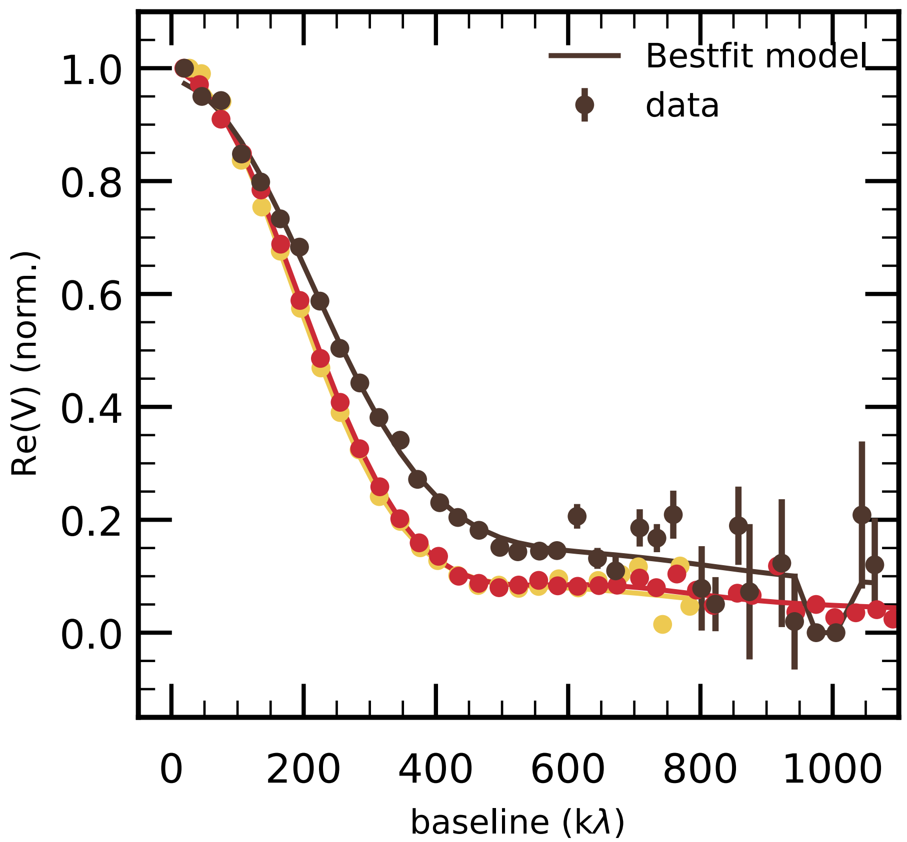
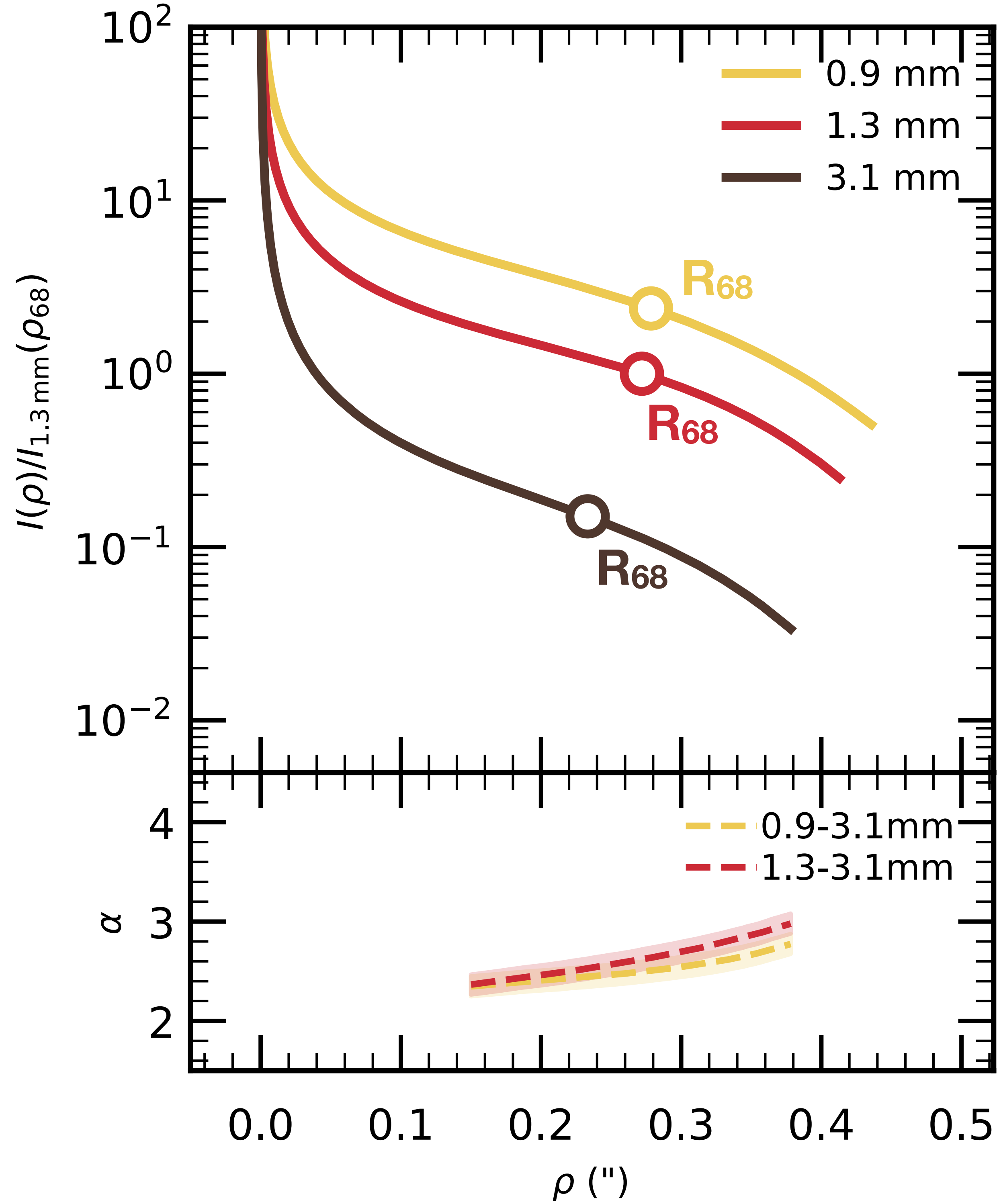


Brightness profiles:

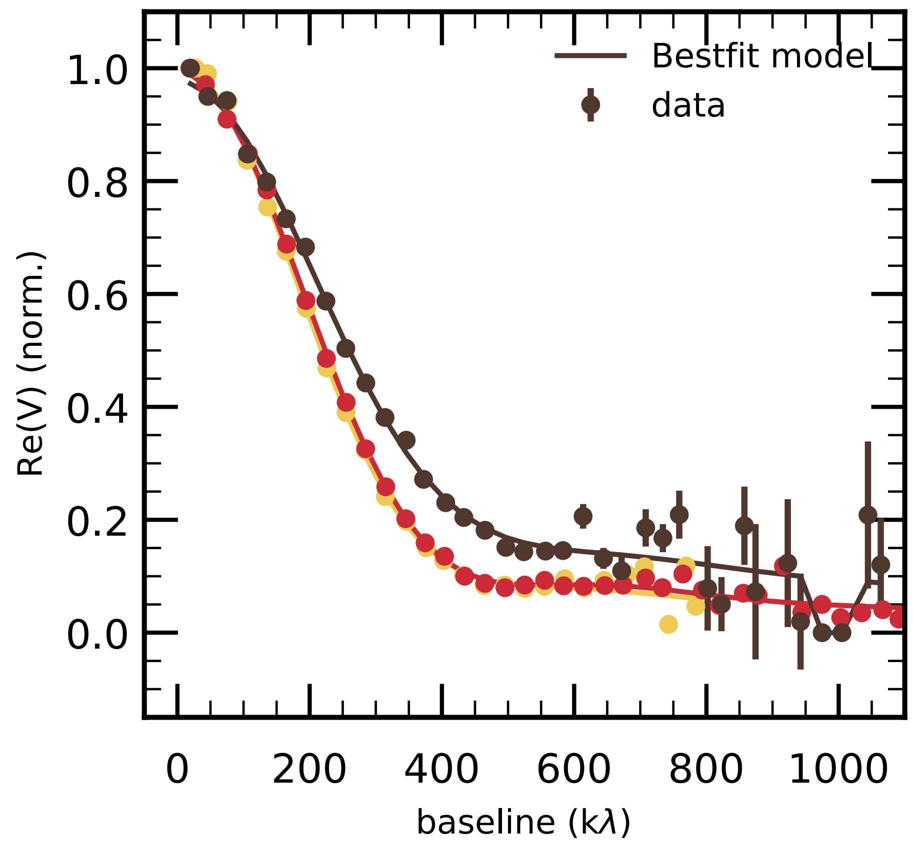


(modified self-similar or Gaussian profile)

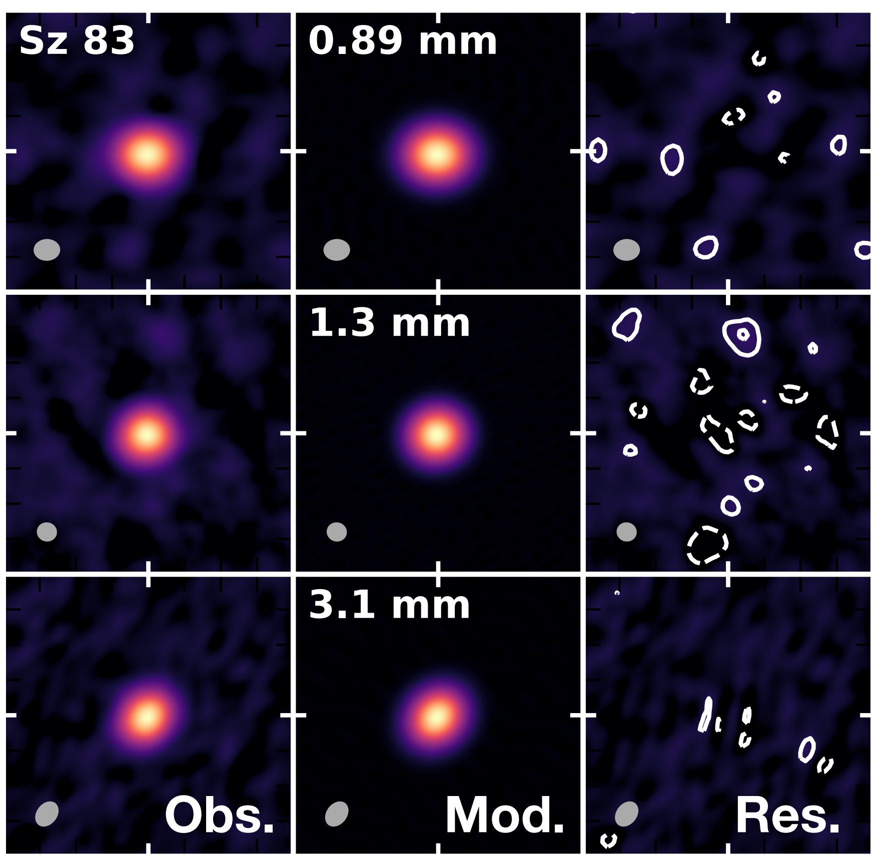
Results example: Sz 83

[Tazzari+ (2021) MNRAS 506 2804]

Visibililities:



Synthesized images:



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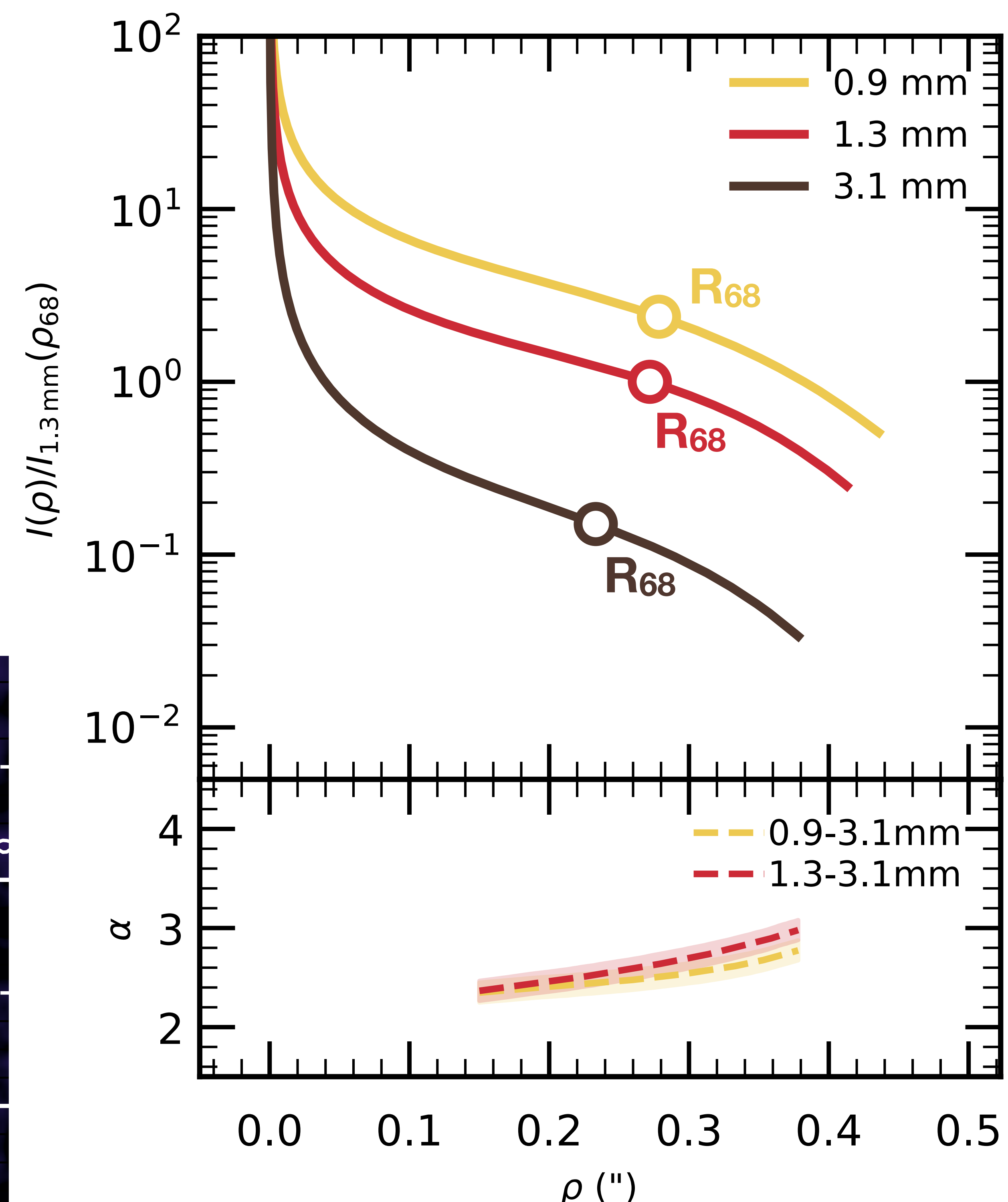

(modified self-similar or Gaussian profile)

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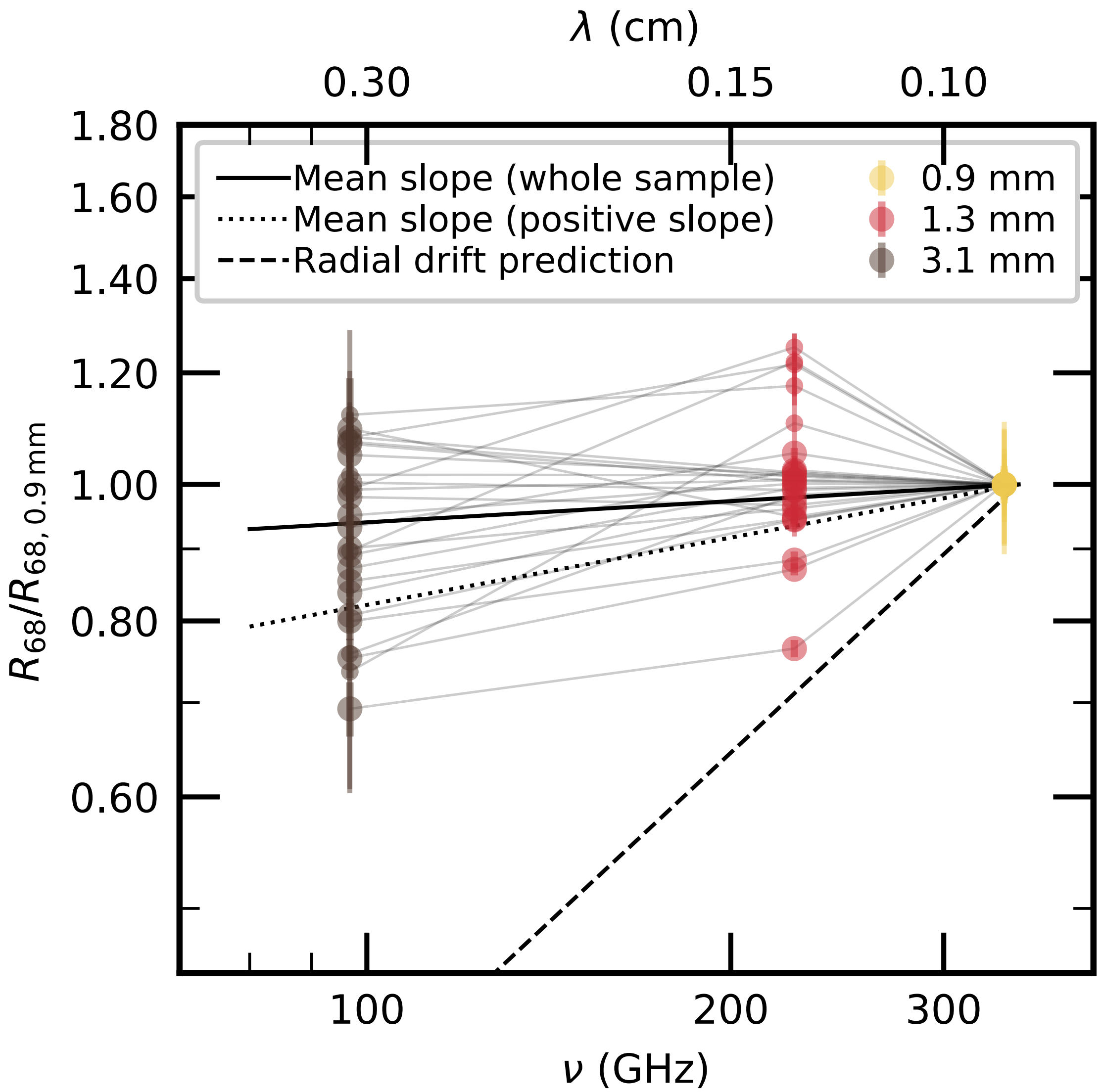
1) Disc size vs observing frequency

[Tazzari+ (2021) MNRAS 506 2804]

Lupus:



- Nearly identical radii
- R_{3mm} is ~90% $R_{0.9mm}$

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1) Disc size vs observing frequency

[Tazzari+ (2021) MNRAS 506 2804]

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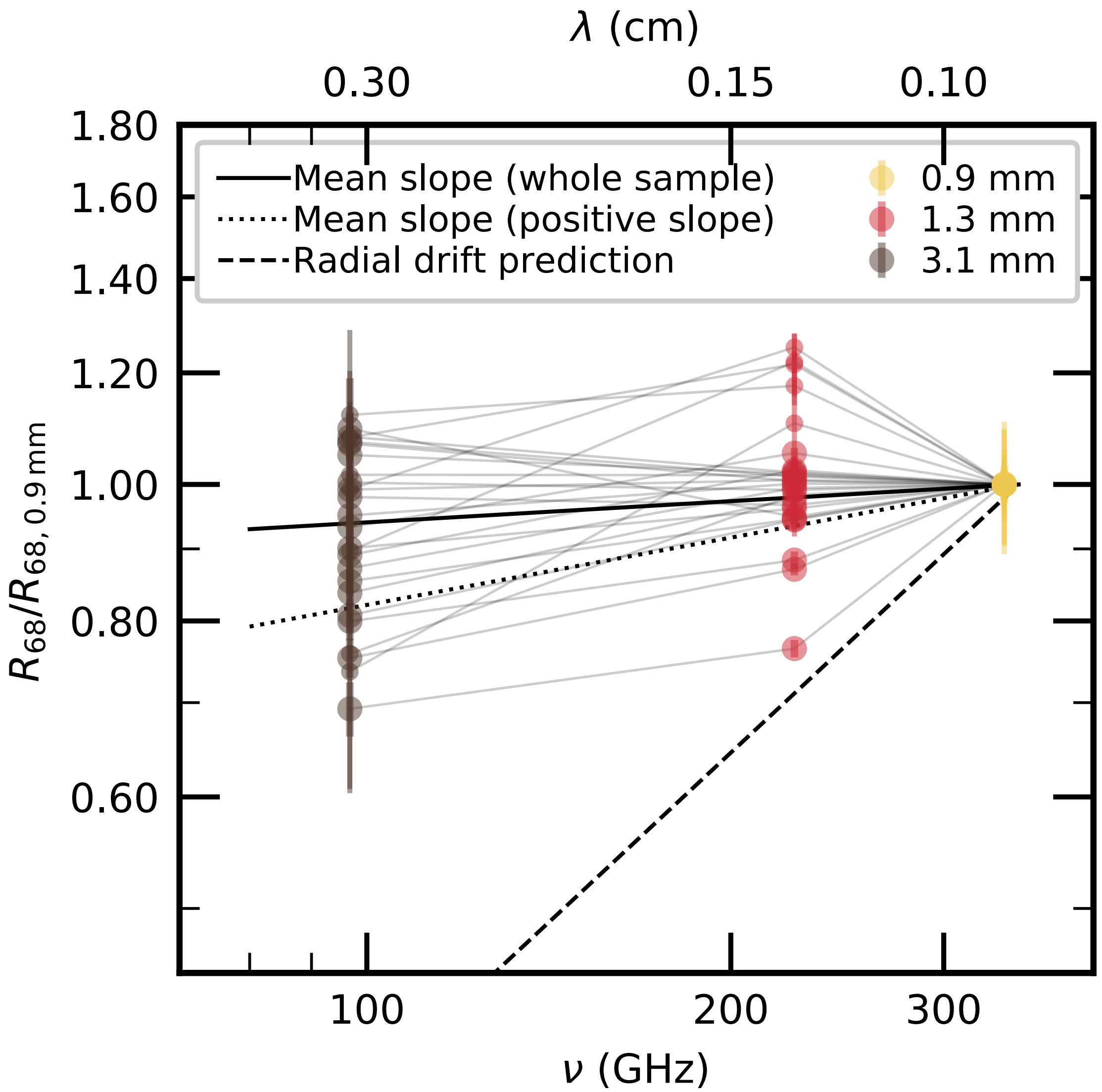
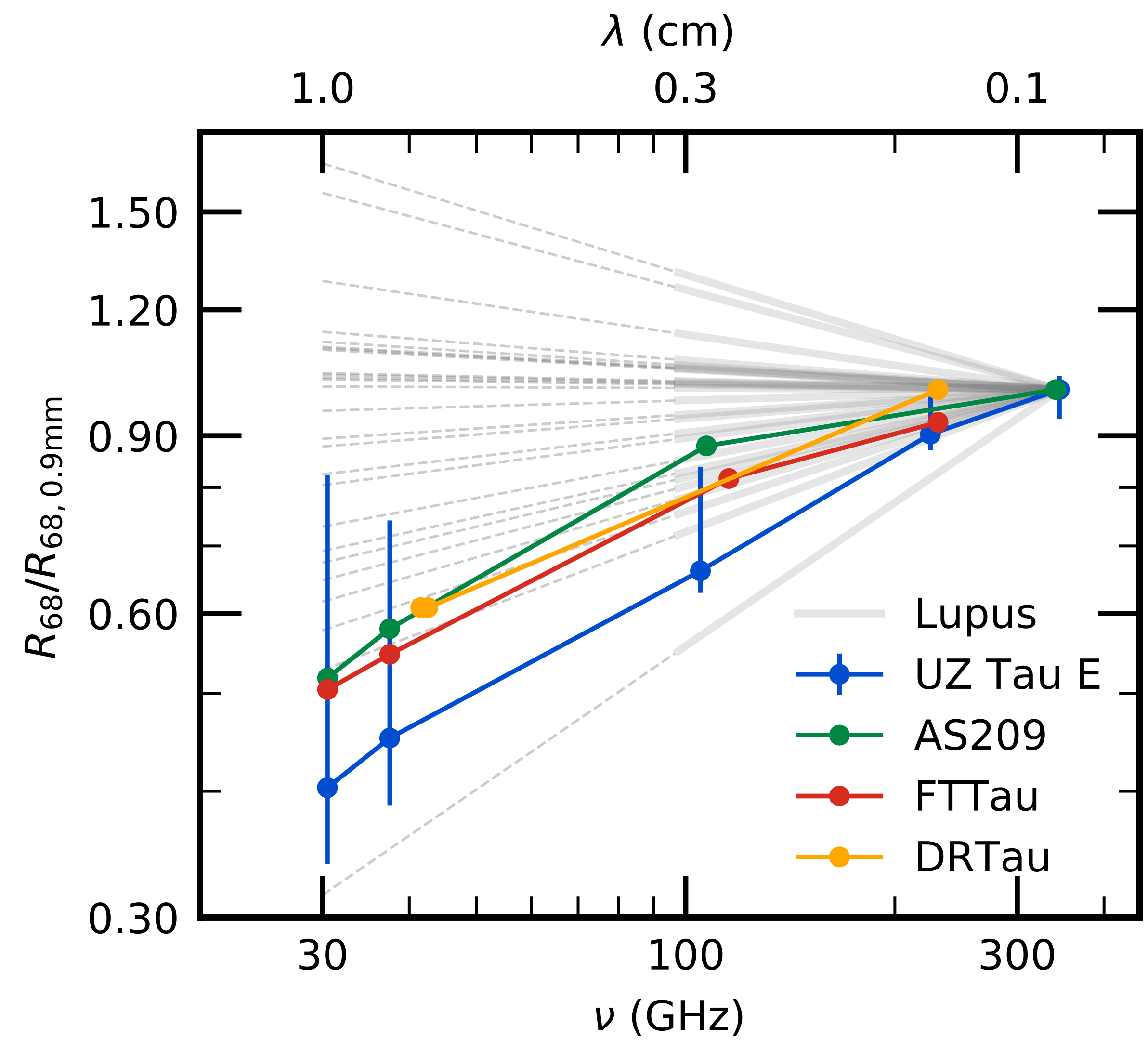


Comparison with literature:



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Tazzari+ (2021)
MNRAS 506 2804

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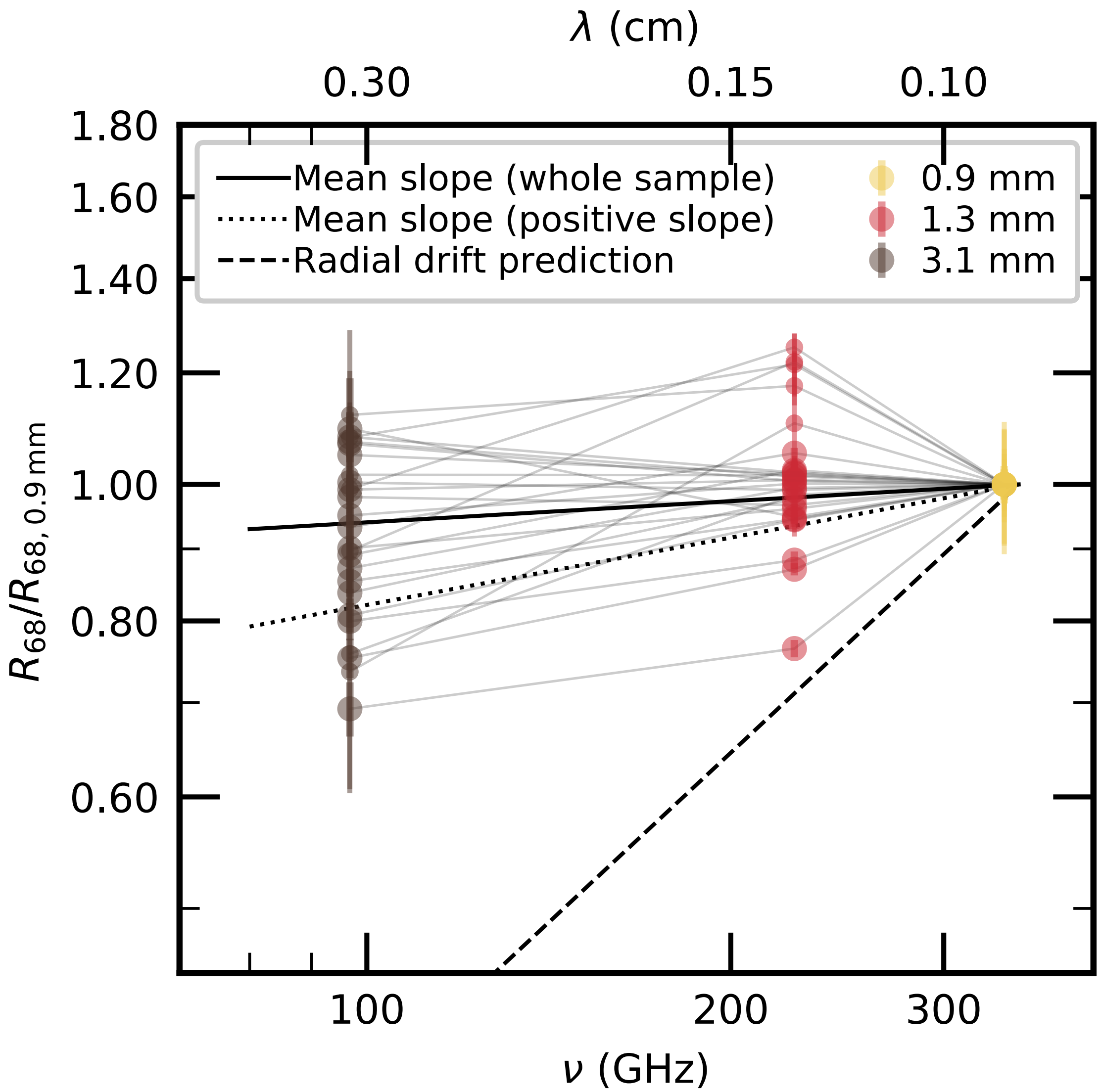

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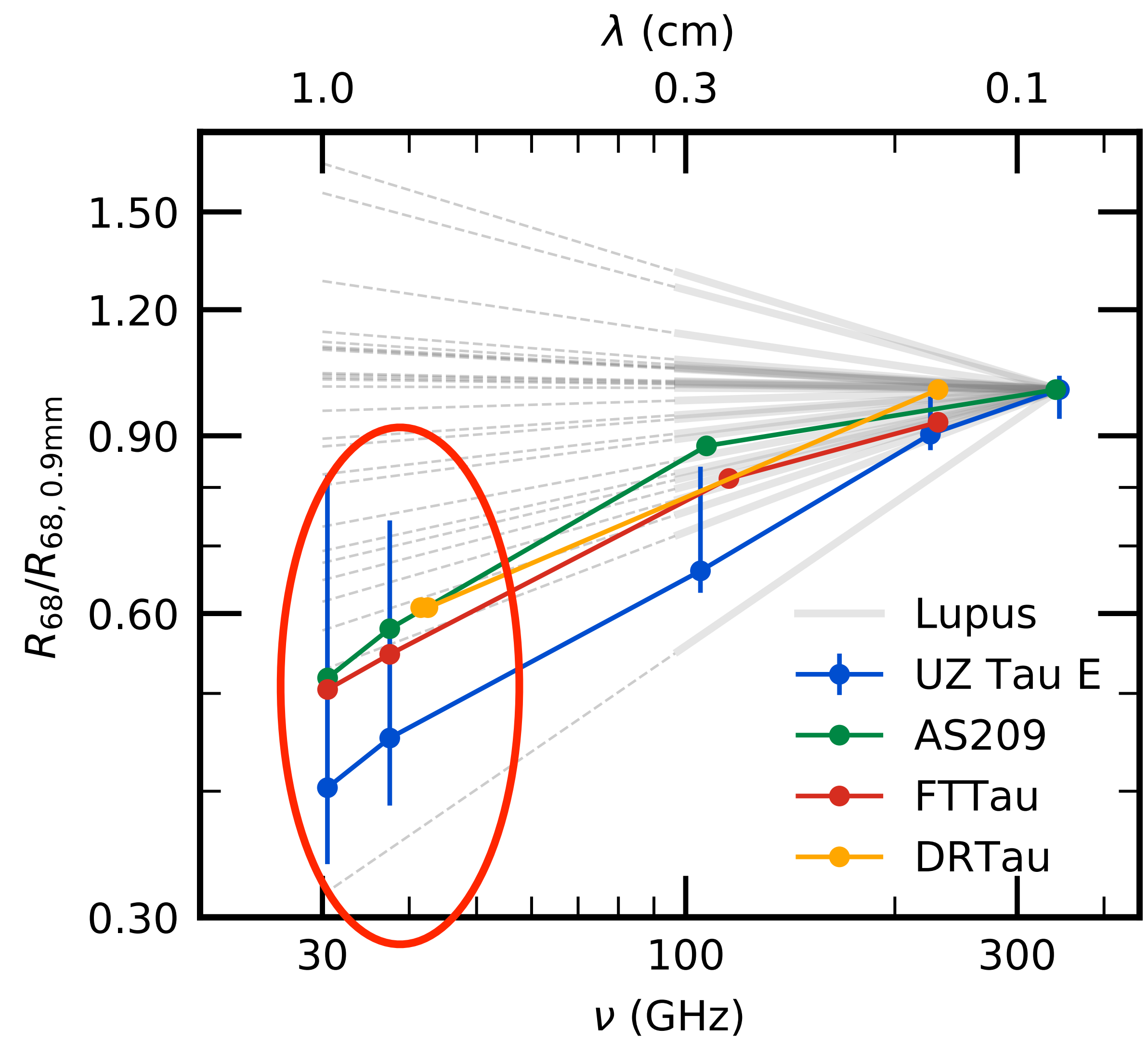

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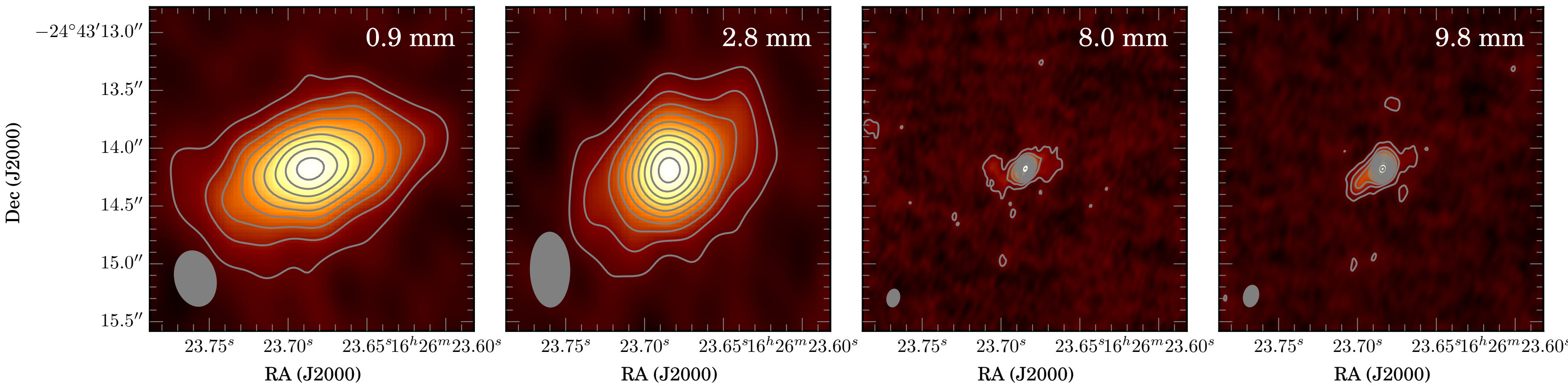
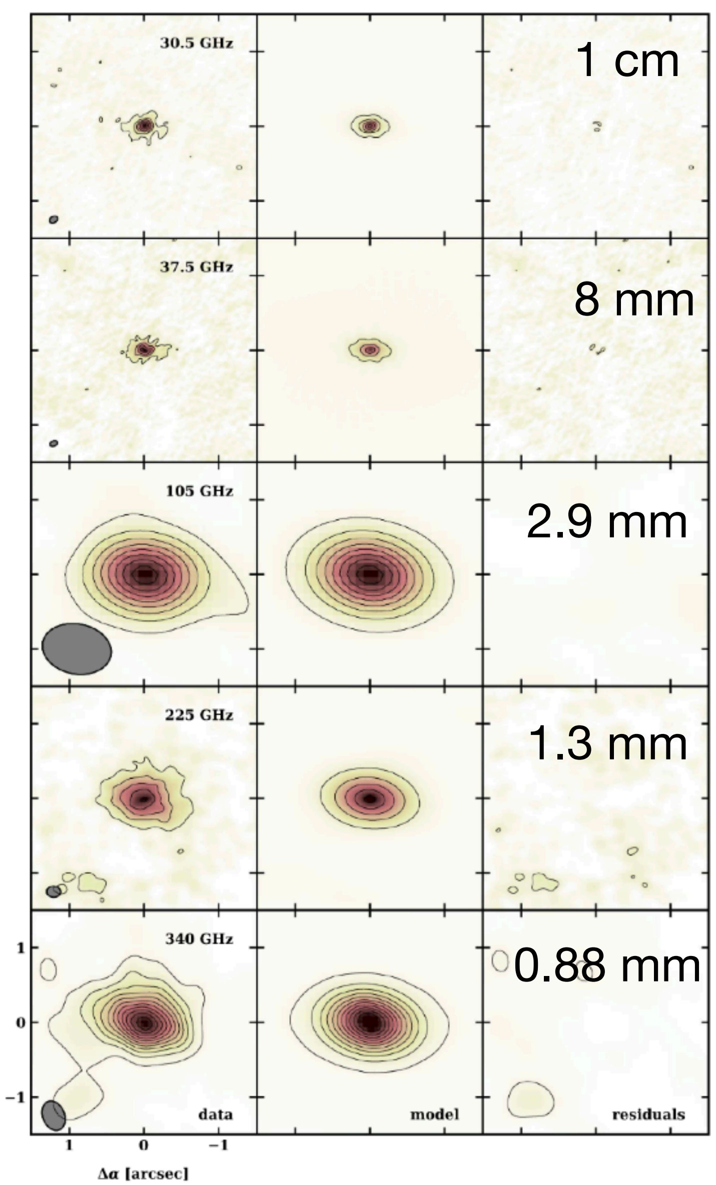
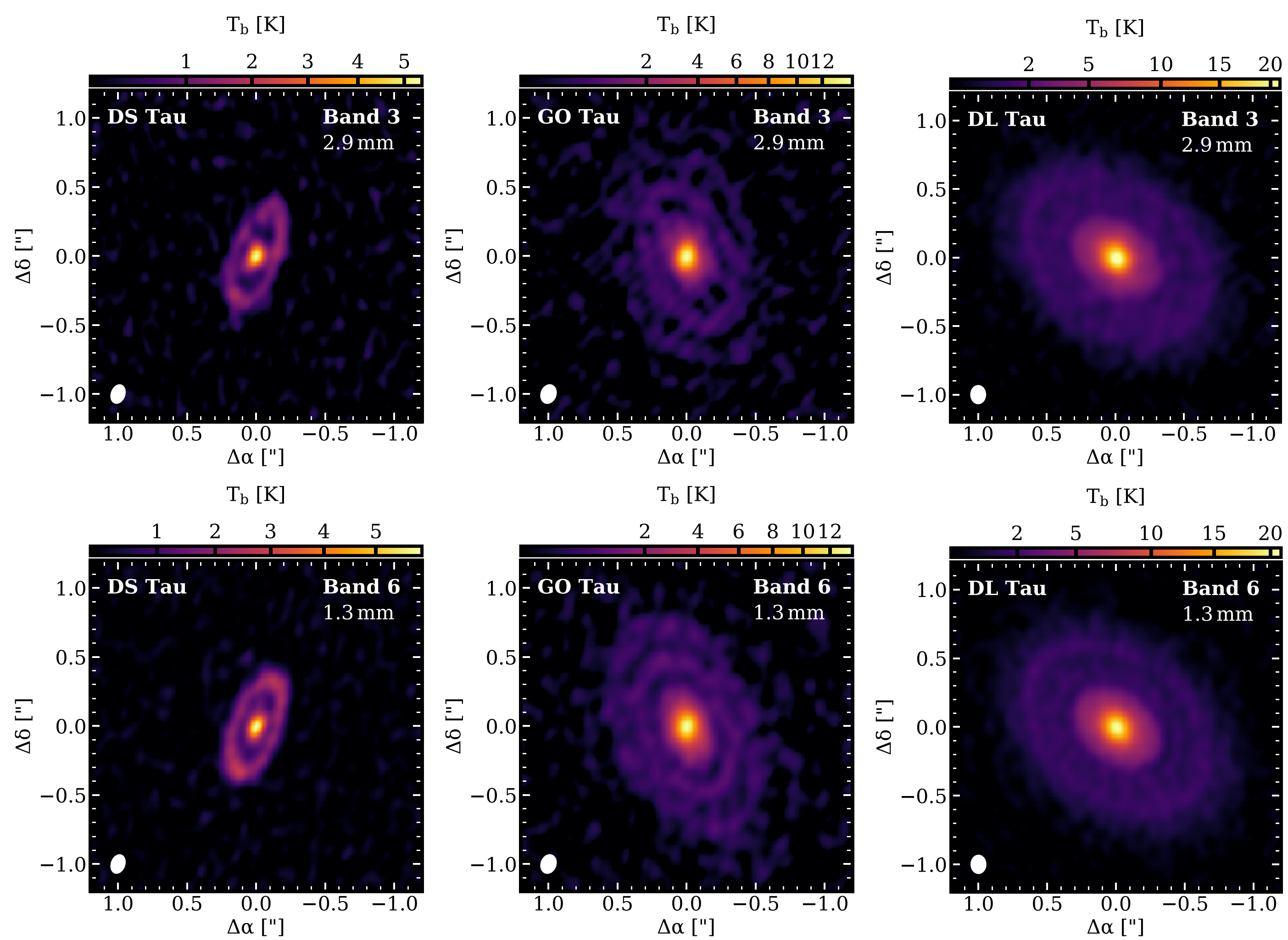


- Do Ar 25 (Pérez 2015)

- UZ Tau E (Tripathi+ 2018)



- DS Tau
- GO Tau
- DL Tau



2.9 mm

1.3 mm

(Long+ 2020)

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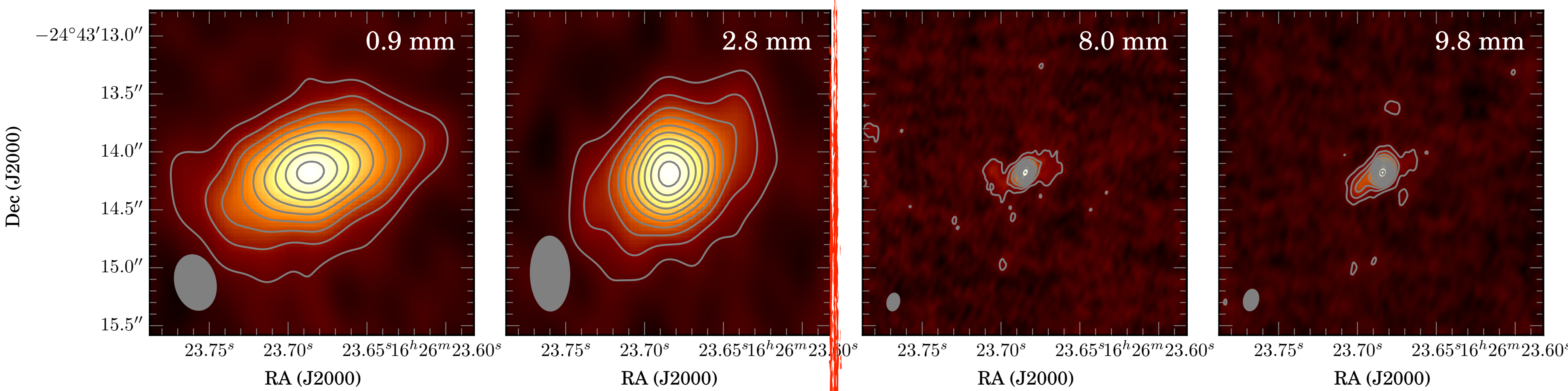

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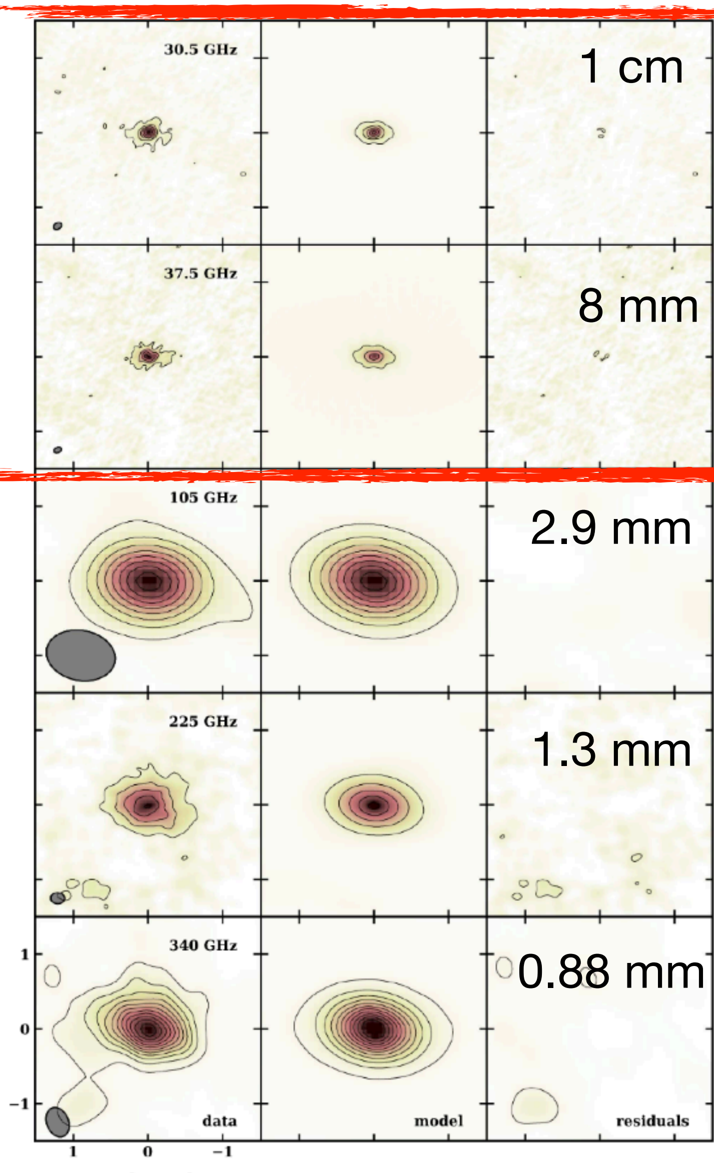

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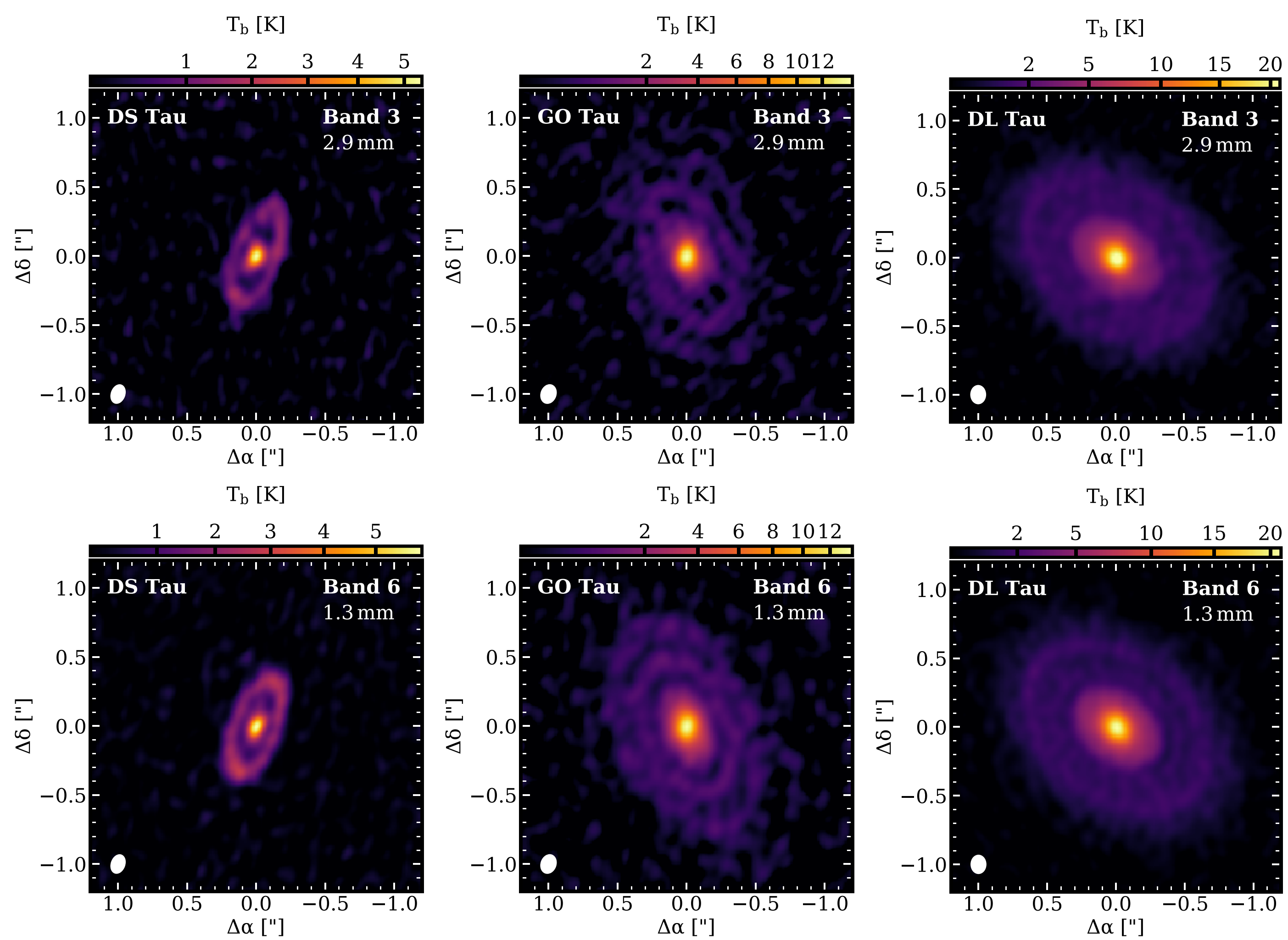

(Long+ 2020)

1) Disc size vs observing frequency

[Tazzari+ (2021) MNRAS 506 2804](#)

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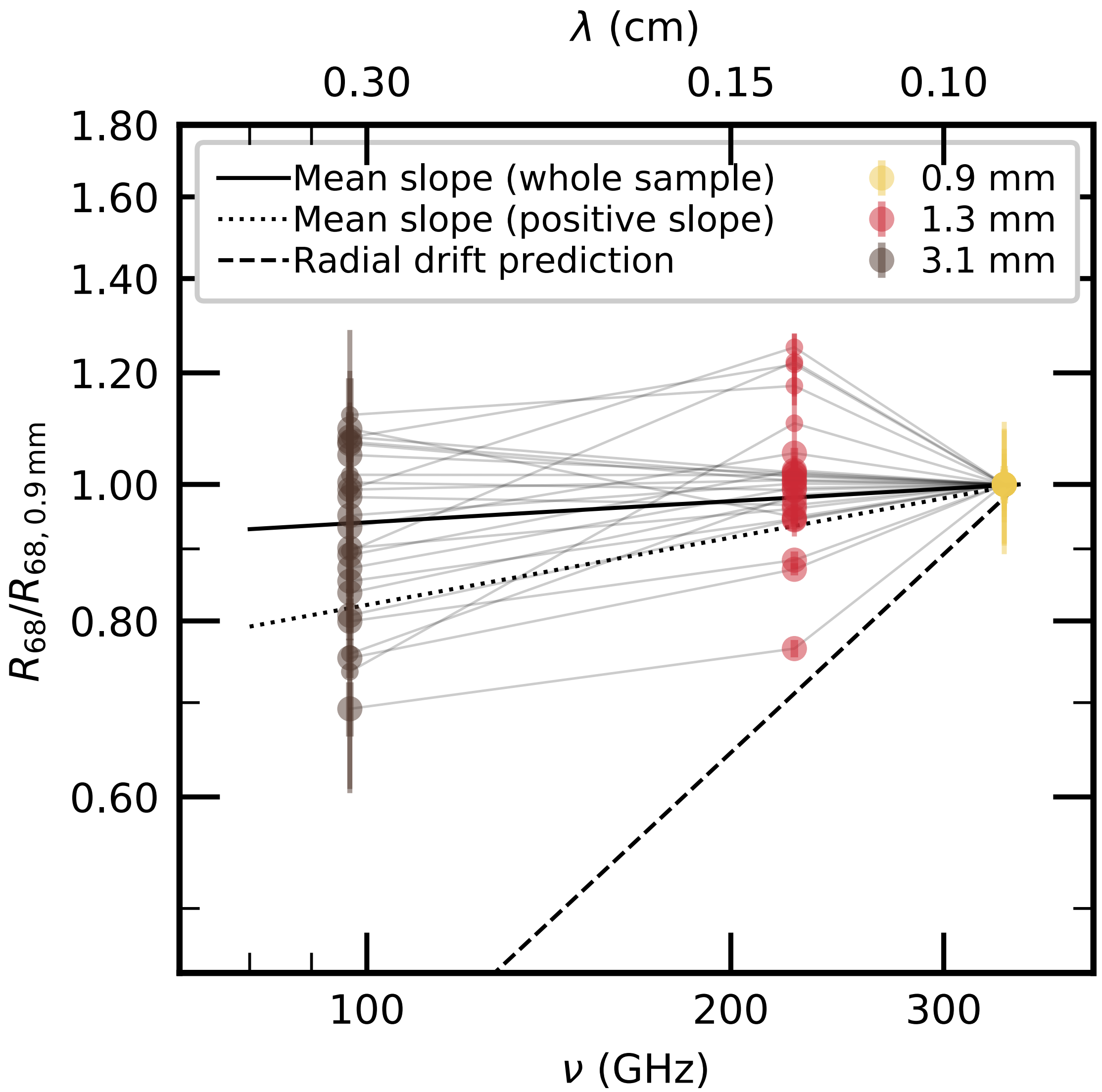

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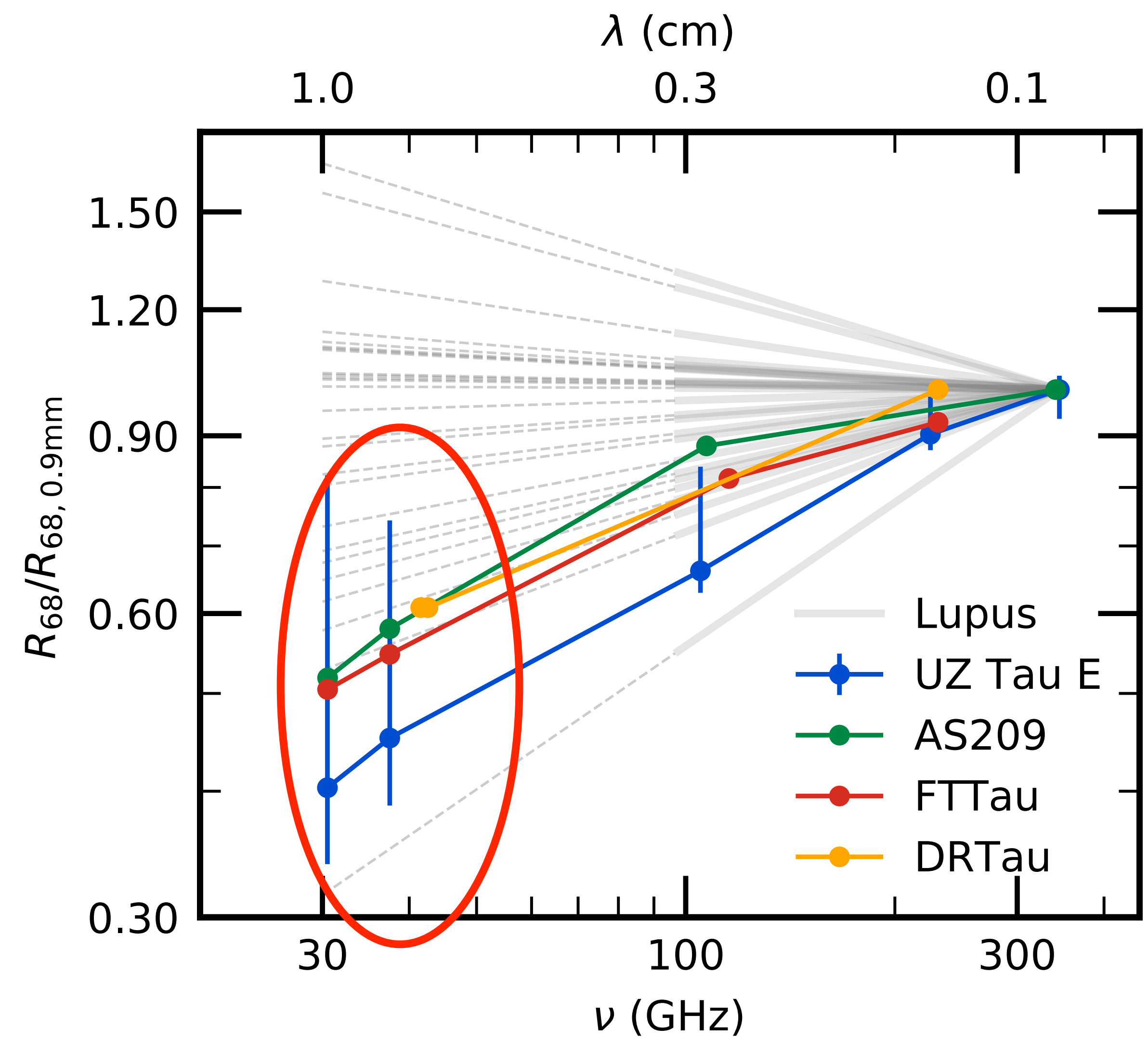

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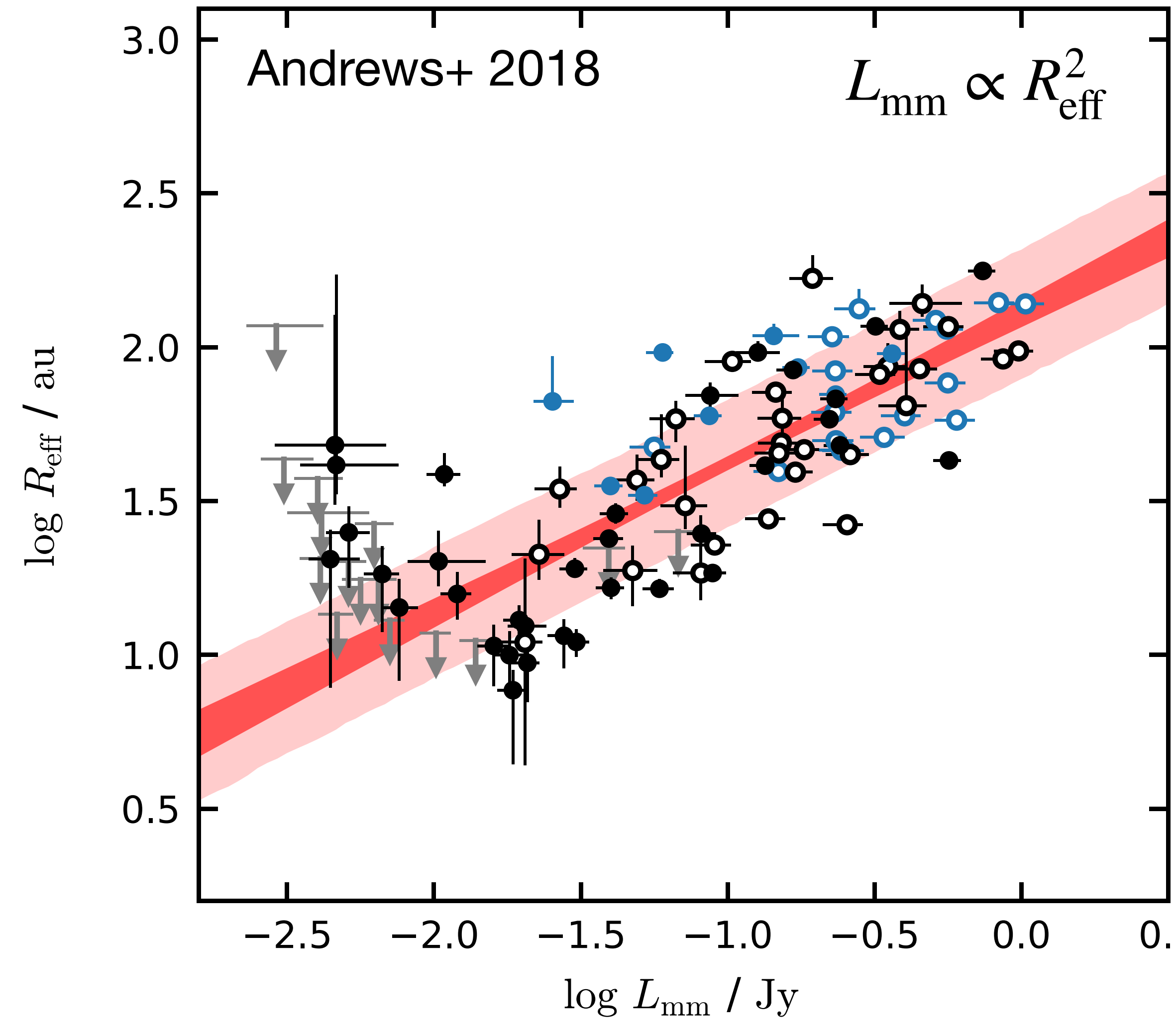
2) Disc size vs mm luminosity

Tazzari+ (2021) MNRAS 506 2804

- found in **Lupus** and **Taurus**
  Tripathi+ 2017, Andrews+ 2018
- found also in **Upper Sco** (Hendler+ 2020)
- so far: from SMA and ALMA obs at **0.9 mm**
- suggestive of **constant column-density**



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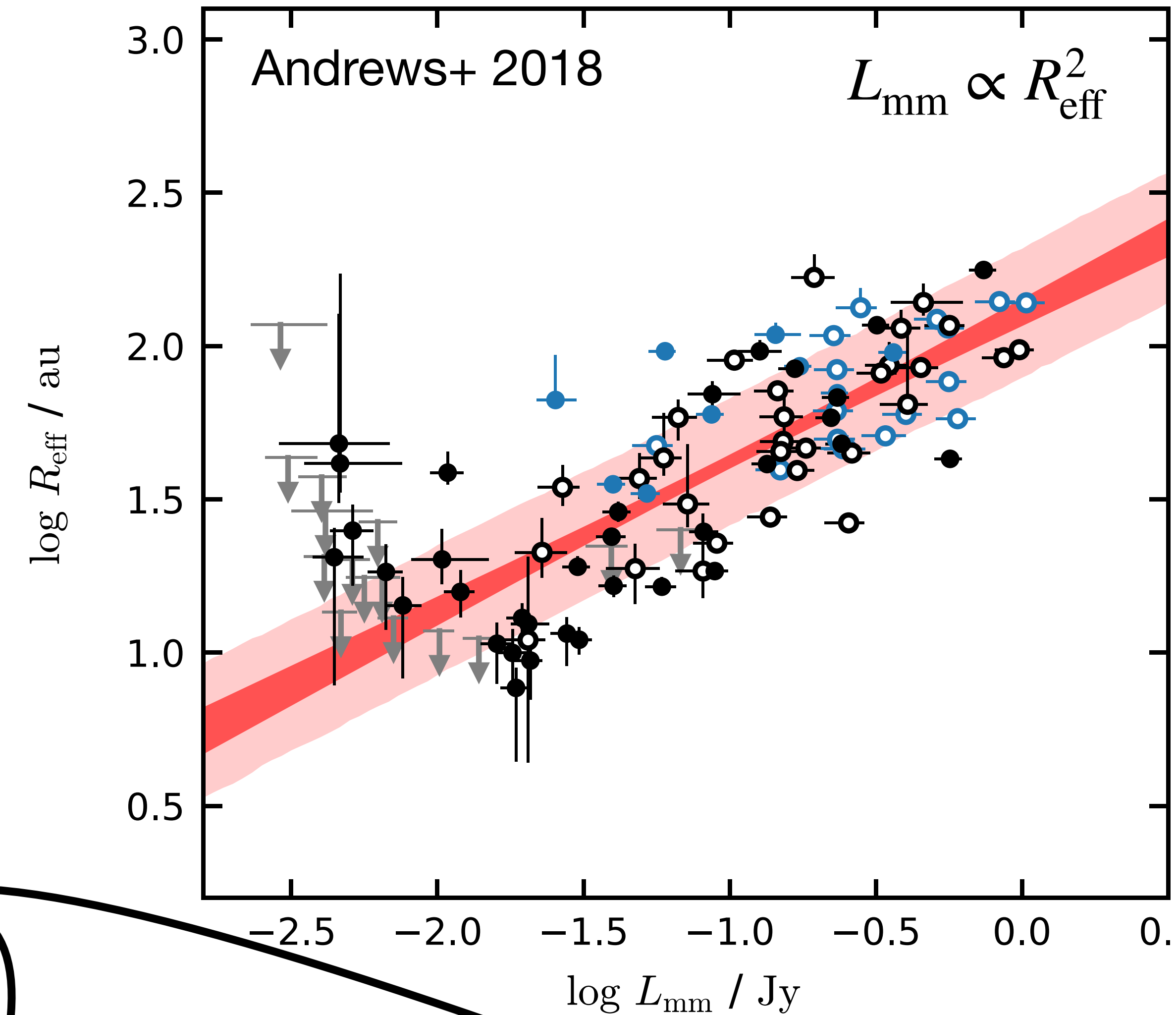
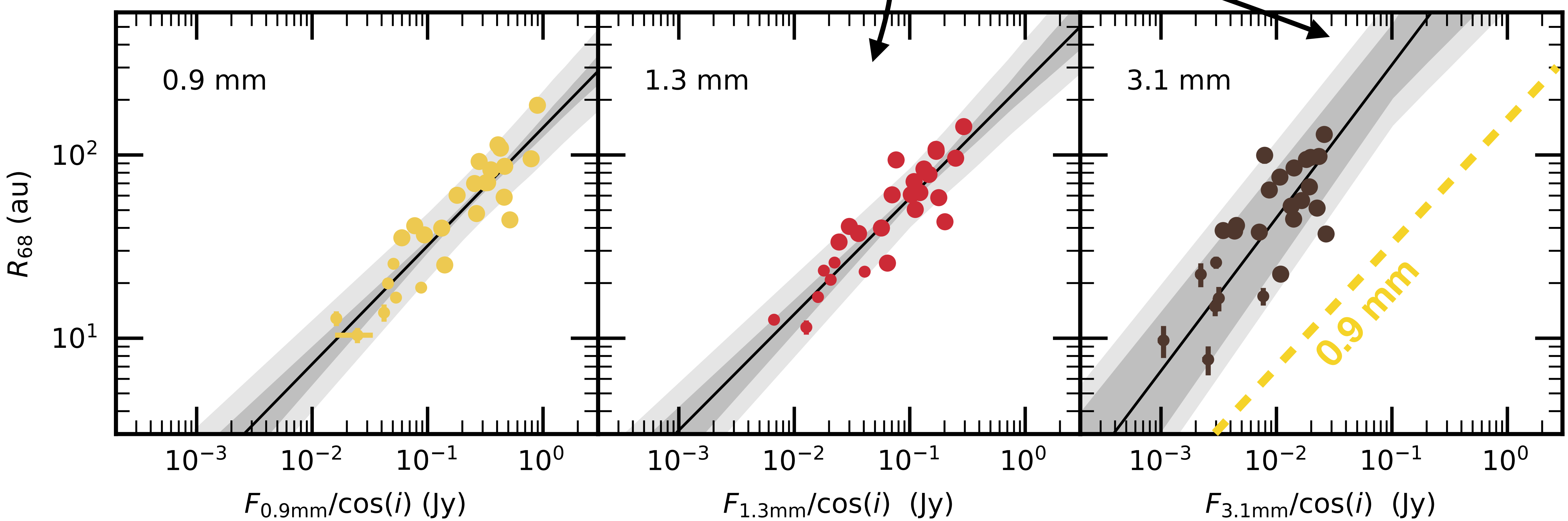


- in Tazzari+ 2021:
  - correlation found also at **1.3** and **3** mm!
  - at 3.1mm the correlation is steeper



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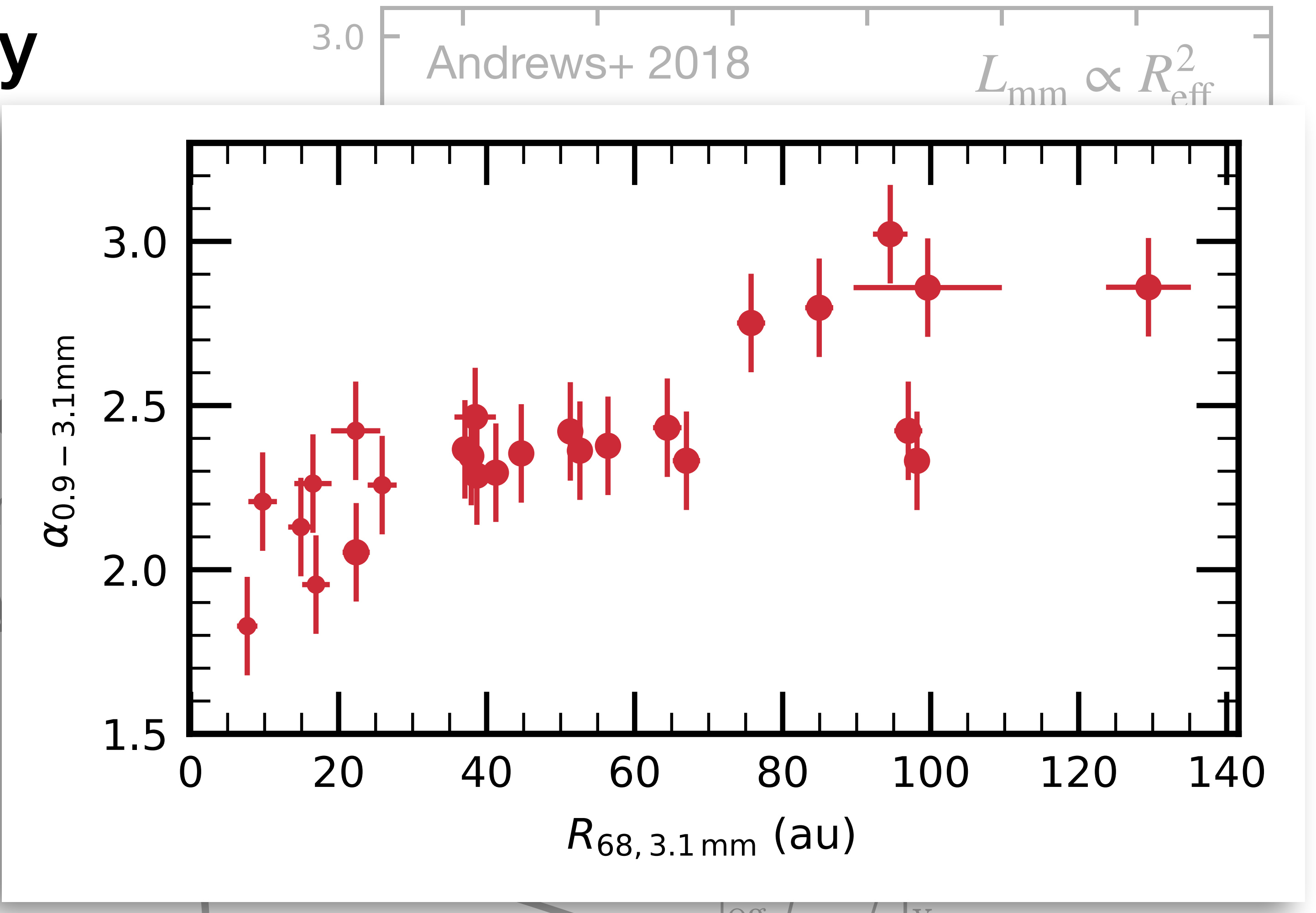

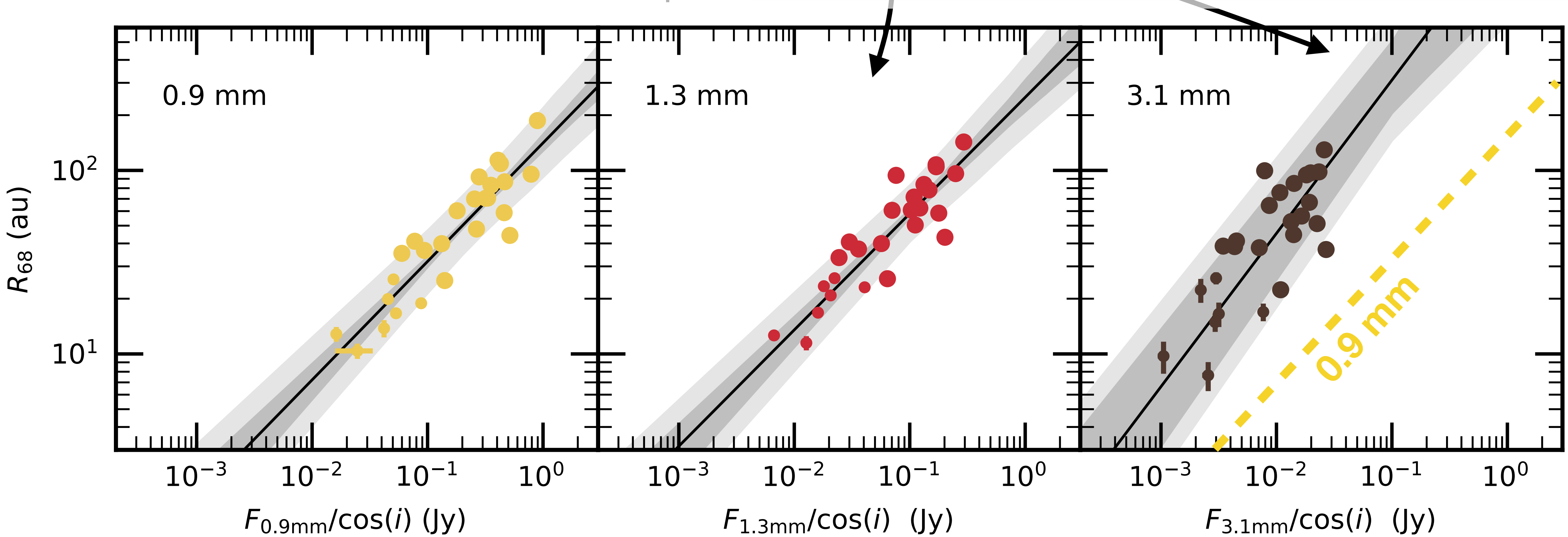

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3) Optical depth

Tazzari+ (2021) MNRAS 506 2804

Fraction of optically thick emission

$$\mathcal{F} = \frac{x F_\nu}{2\pi \cos(i) \int_0^{\rho_x} B_\nu(T) \rho' d\rho'} = \frac{x L_{\rm mm}}{2\pi \int_0^{\rho_x} B_\nu(T_{\rm d}) \rho' d\rho'} \qquad x = 0.68$$

Requires assumption of dust Temperature

$$T_{\rm d} = T_0 \left(\frac{L_\star}{L_\odot}\right)^{0.25} \left(\frac{R}{R_0}\right)^{-q}$$

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3) Optical depth

Tazzari+ (2021)
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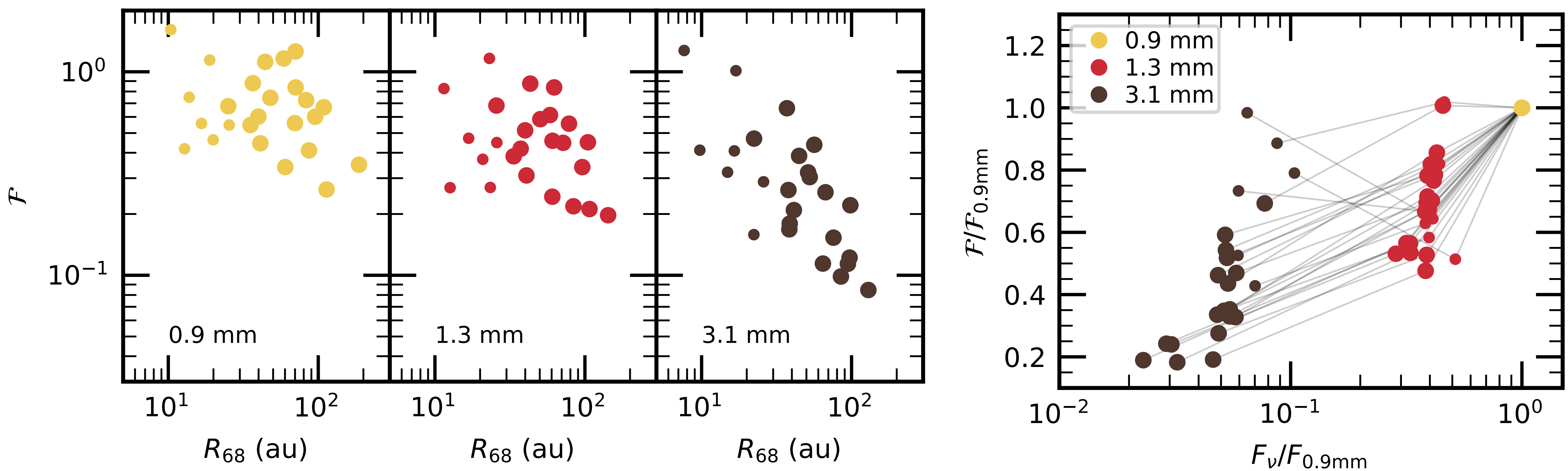

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4) Implications for grain growth?

Tazzari+ (2021)
MNRAS 506 2804

Observational constraints:

- radii

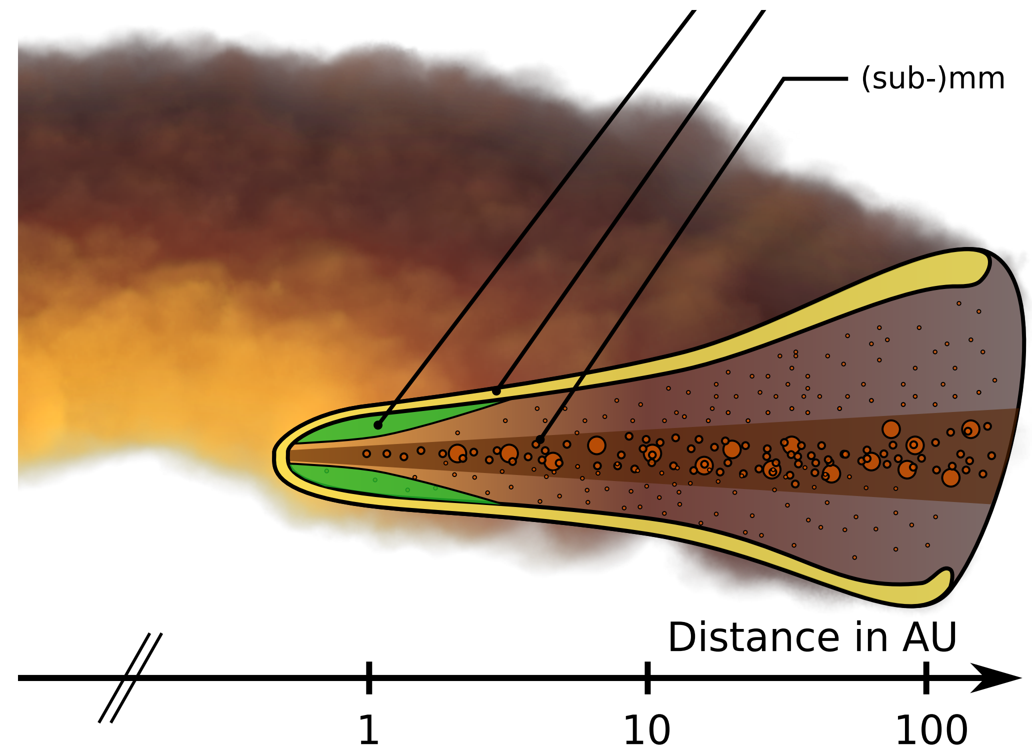
$$R_{68,3.1\,\mathrm{mm}}/R_{68,0.88\,\mathrm{mm}} \approx 1$$

- sp. index

$$2.4 \leq \alpha_{0.9-3.1\,\mathrm{mm}} \leq 3.0$$

- opt. thick fractions

$$0.2 \leq \mathscr{F}_{1.3\,\mathrm{mm}} \leq 0.6$$

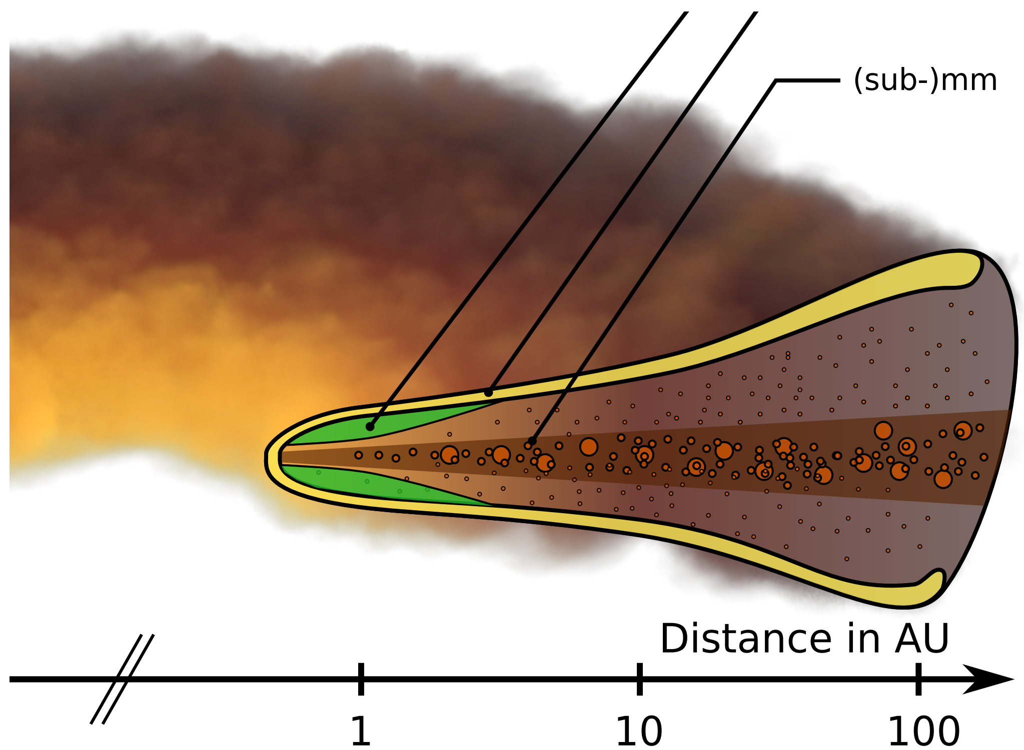


4) Implications for grain growth: building a toy model

[Tazzari+ (2021) MNRAS 506 2804]

We set:

- $\beta(R)$
- τ_0
- $T_\mathrm{d}(R)$



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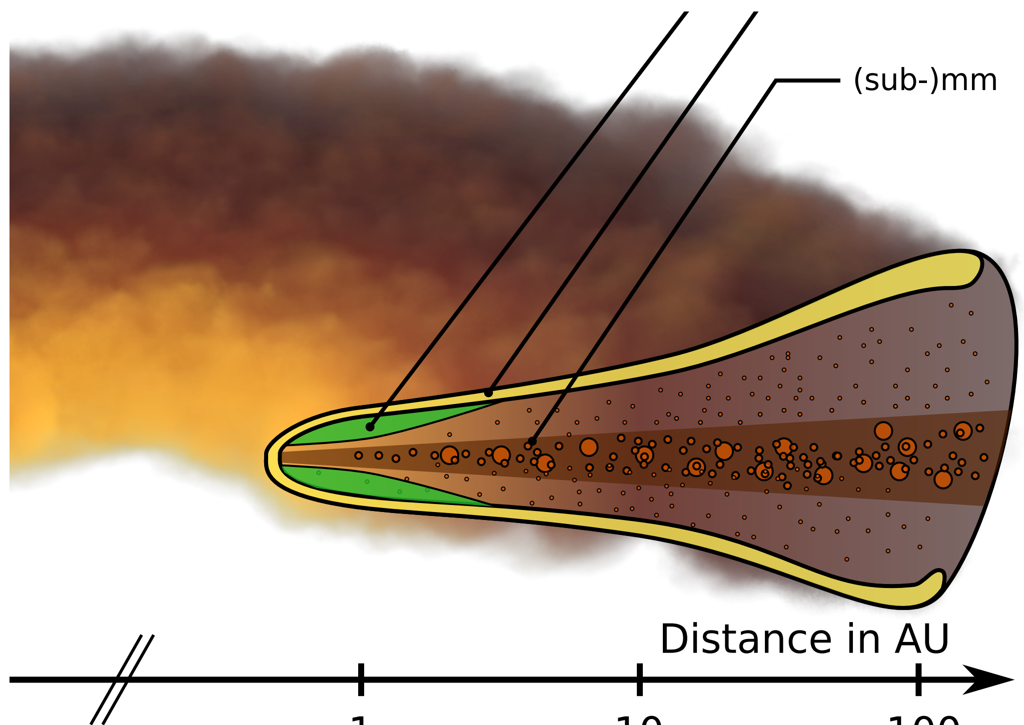
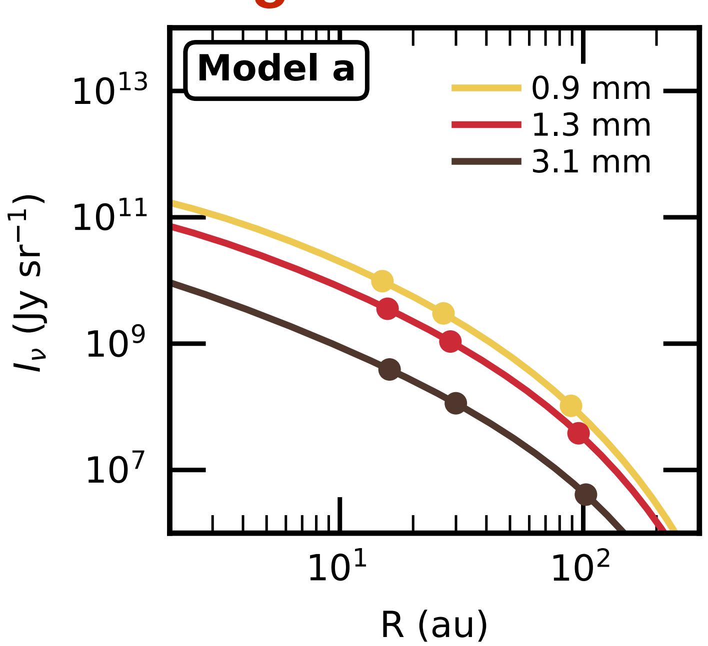
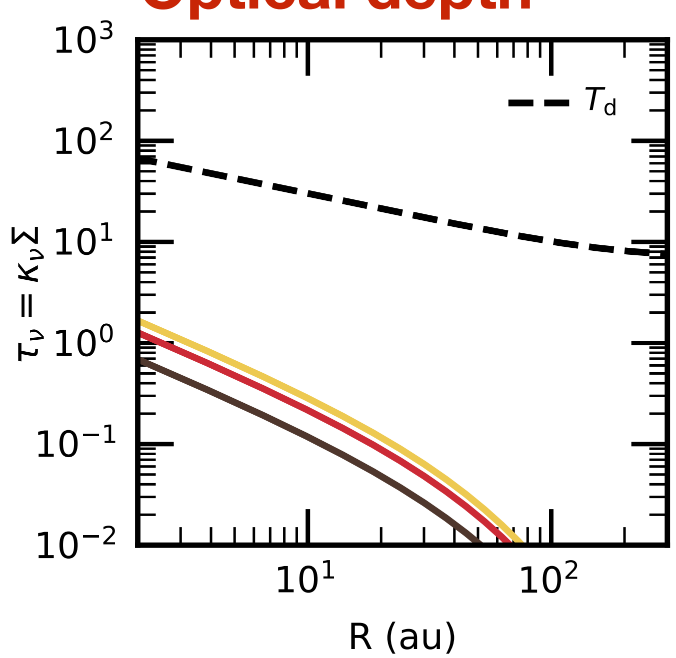


We get:

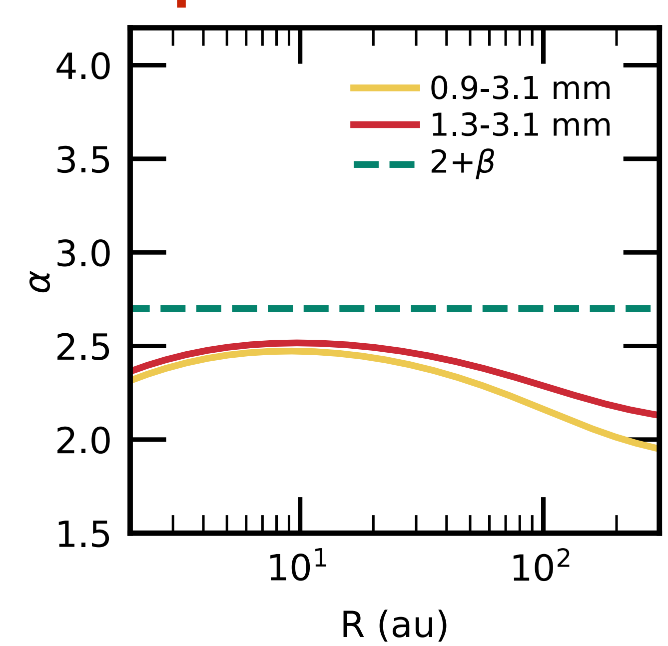
Brightness



Optical depth



Spectral index



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4) Implications for grain growth: building a toy model

[Tazzari+ (2021) MNRAS 506 2804]

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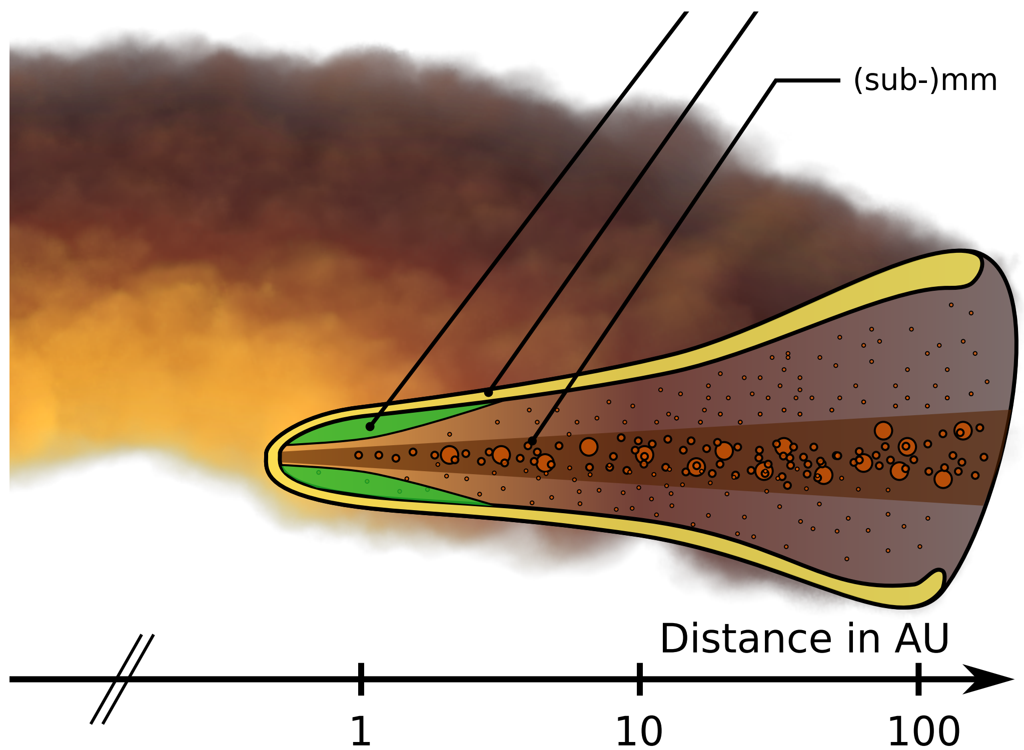
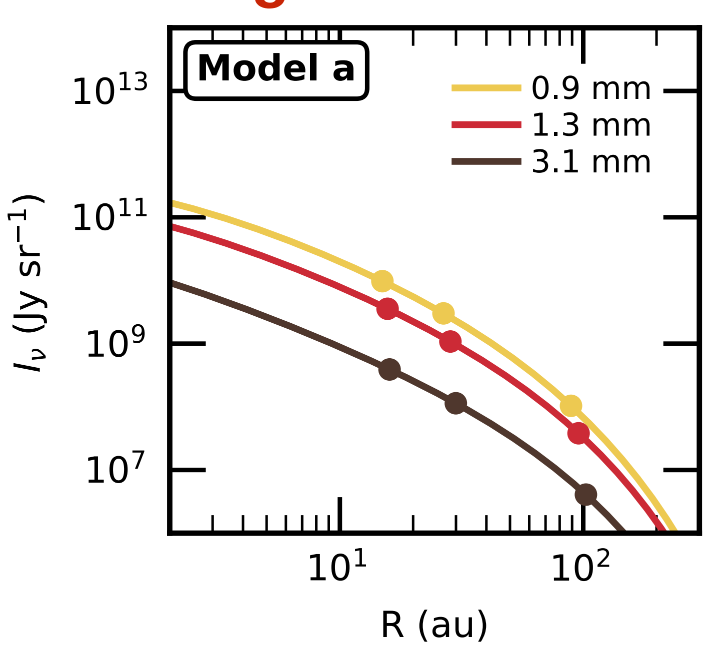


We measure:

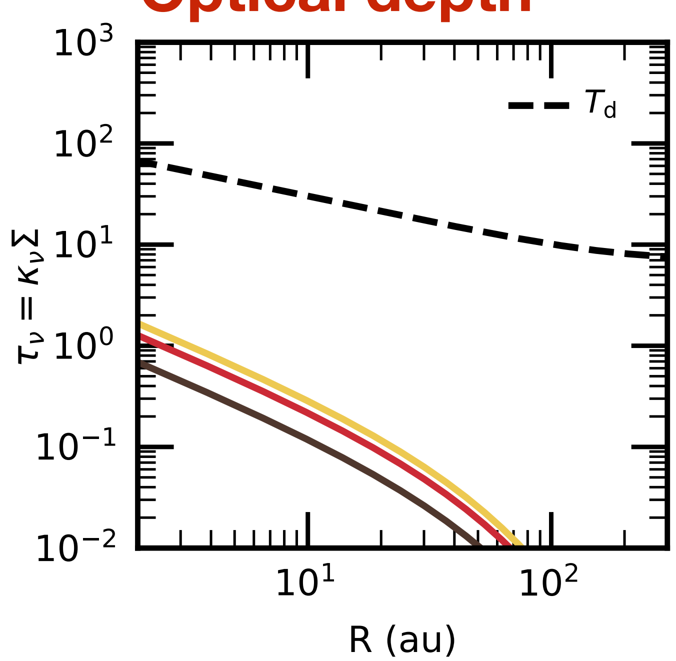
- $R_{68,3.1\,\mathrm{mm}}$, $R_{68,0.88\,\mathrm{mm}}$
- $\alpha_{0.89-3.1\,\mathrm{mm}}$
- $\mathscr{F}_{1.3\,\mathrm{mm}}$

We get:

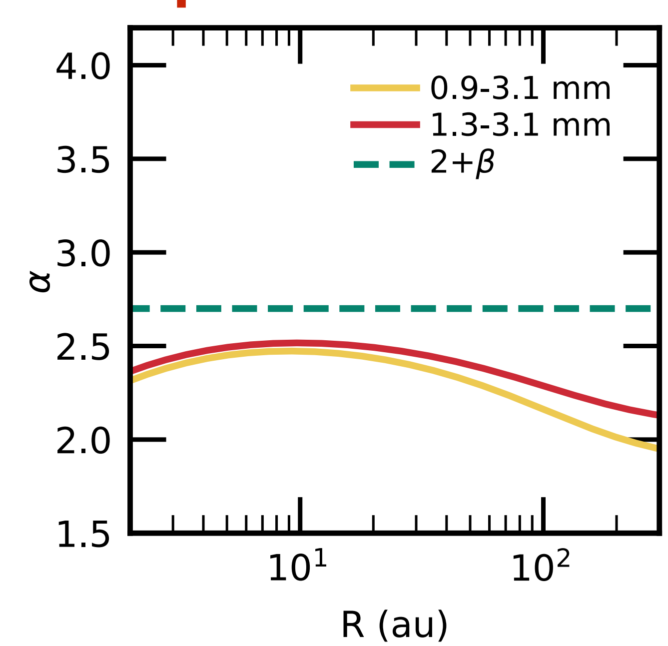
Brightness



Optical depth



Spectral index



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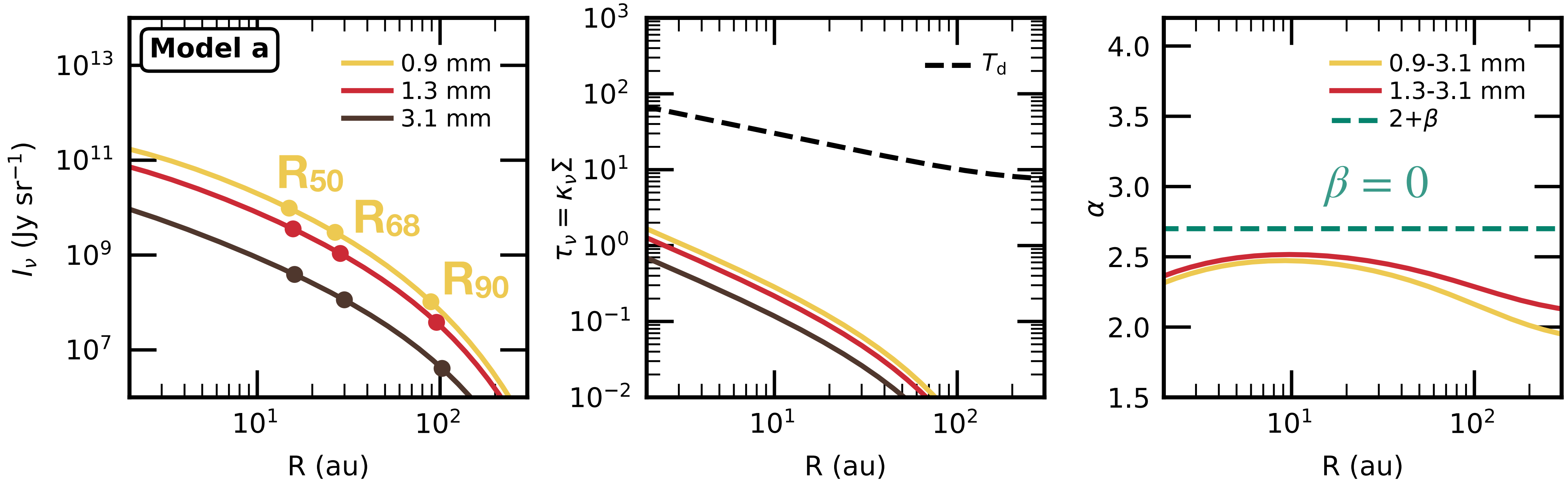
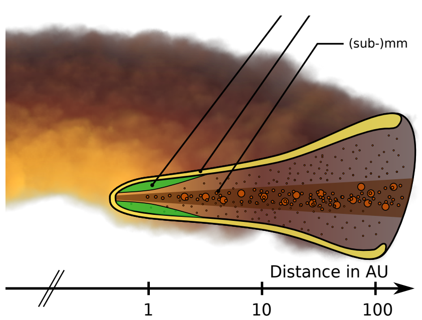
4) Implications for grain growth: building a toy model

[Tazzari+ (2021) MNRAS 506 2804]

Large grains

Brightness | **Optical depth** | **Spectral index**

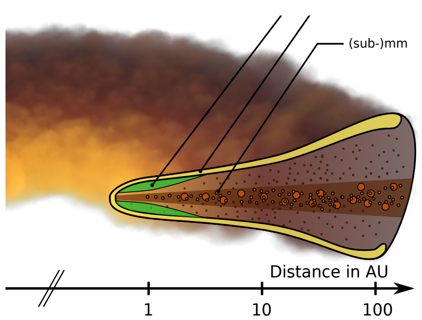


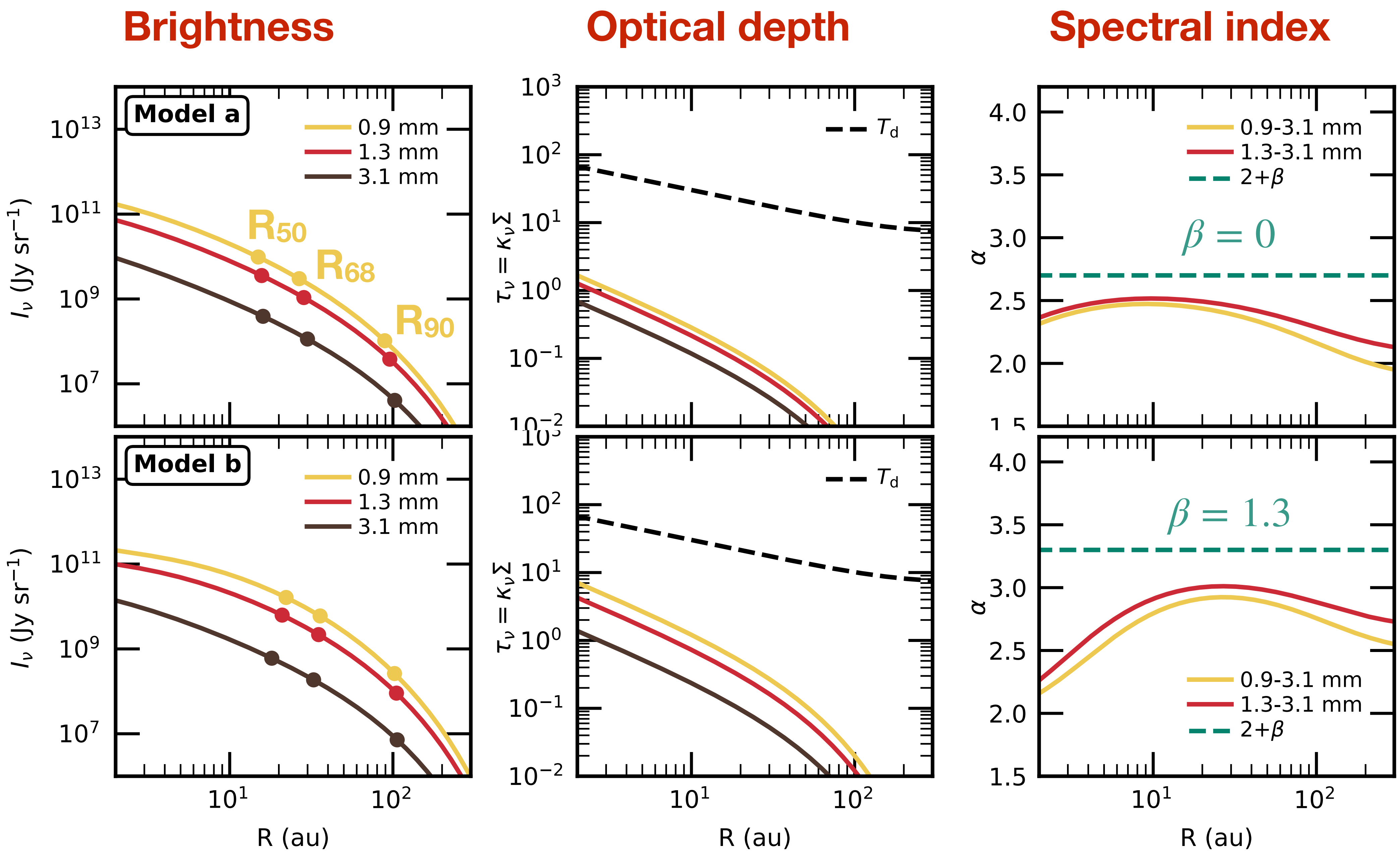


4) Implications for grain growth: building a toy model

Tazzari+ (2021) MNRAS 506 2804

Large grains





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4) Implications for grain growth: building a toy model

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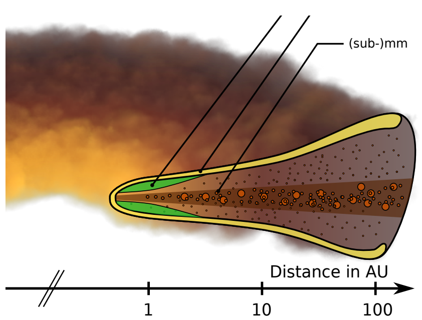
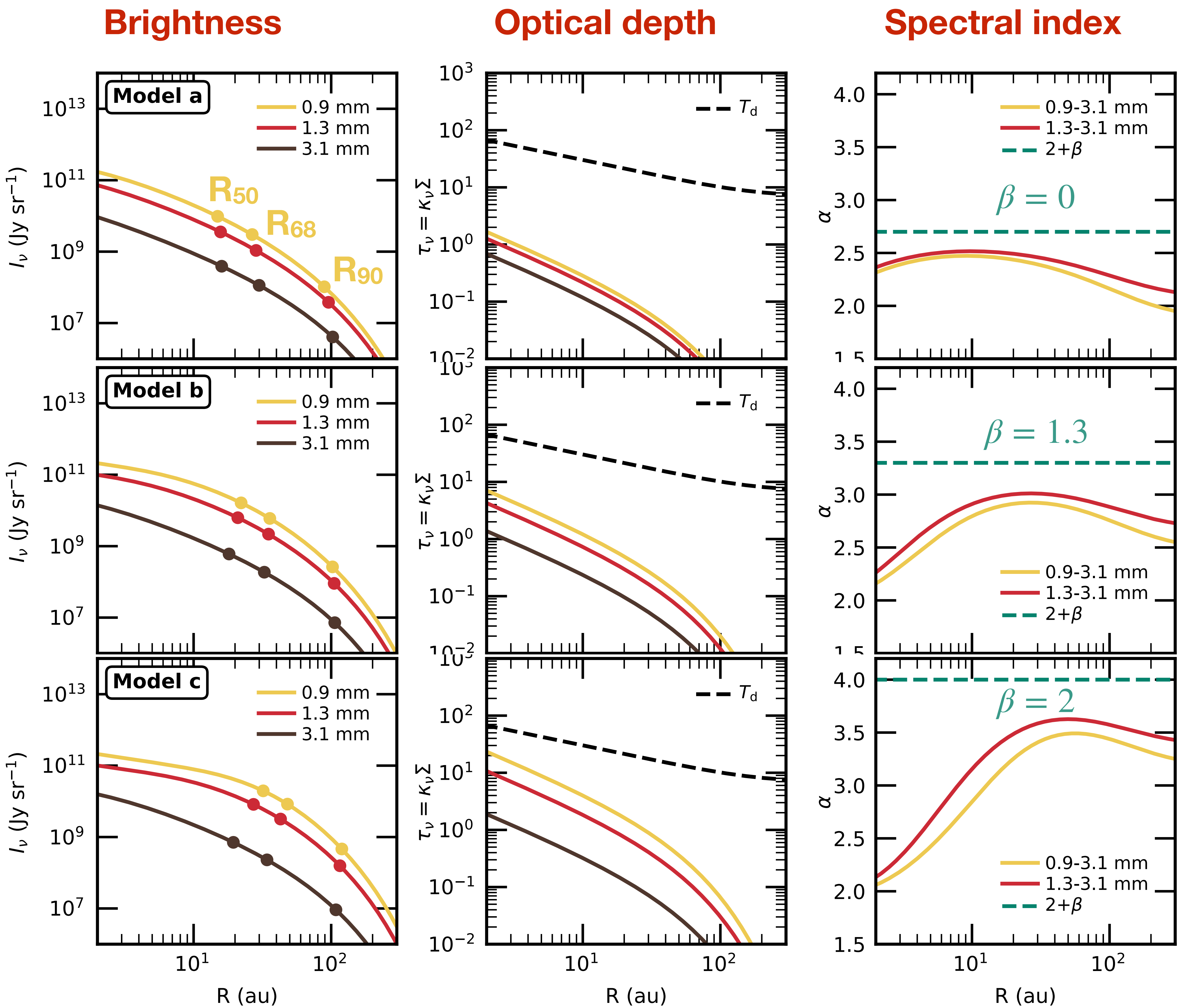
Large grains

Small grains





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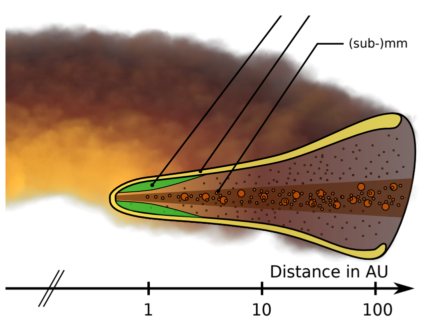
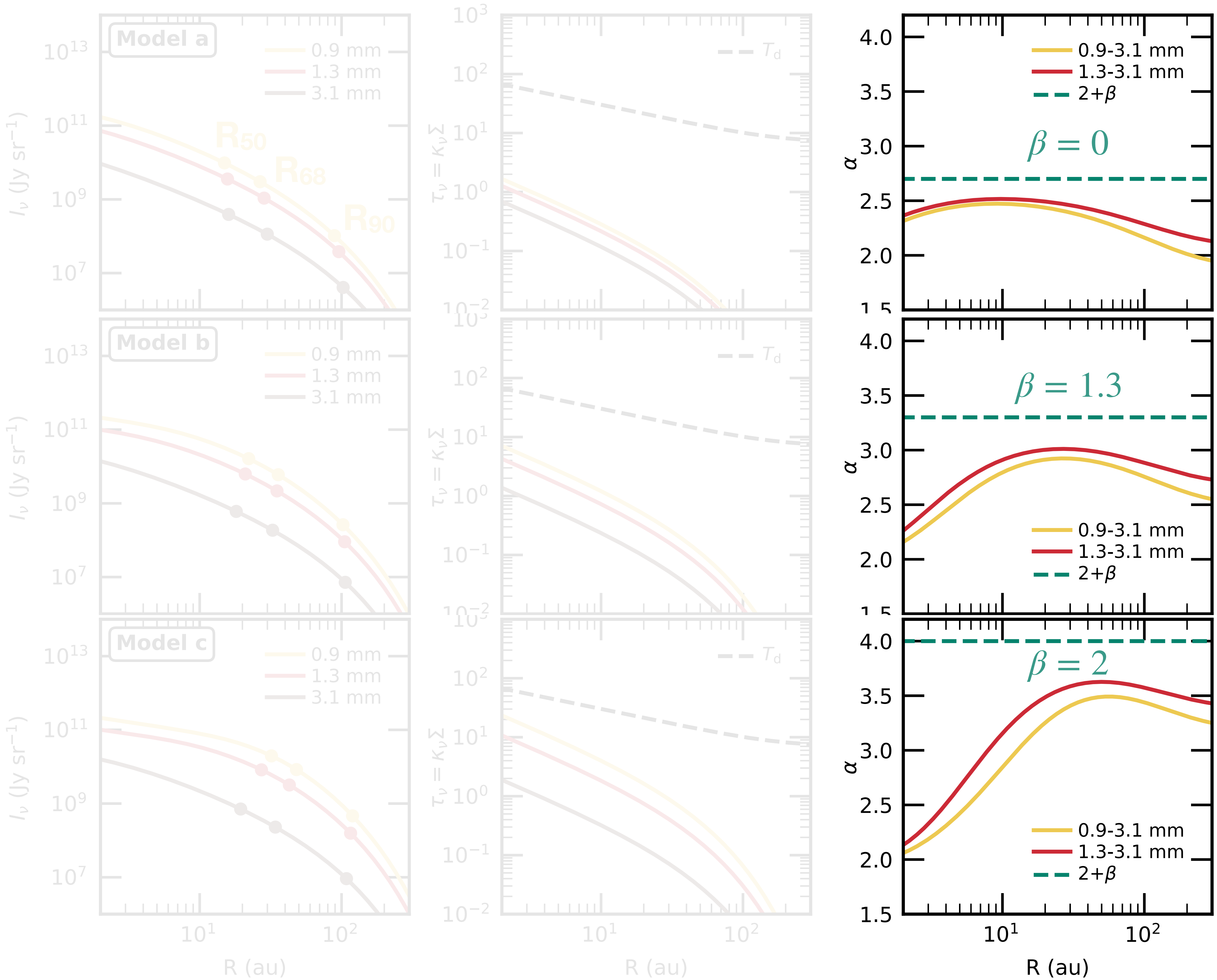


Small grains

Brightness | Optical depth | **Spectral index**



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4) Implications for grain growth: building a toy model

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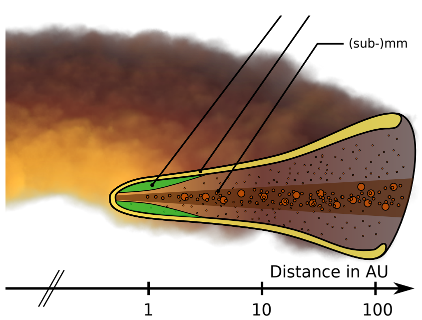
Large grains

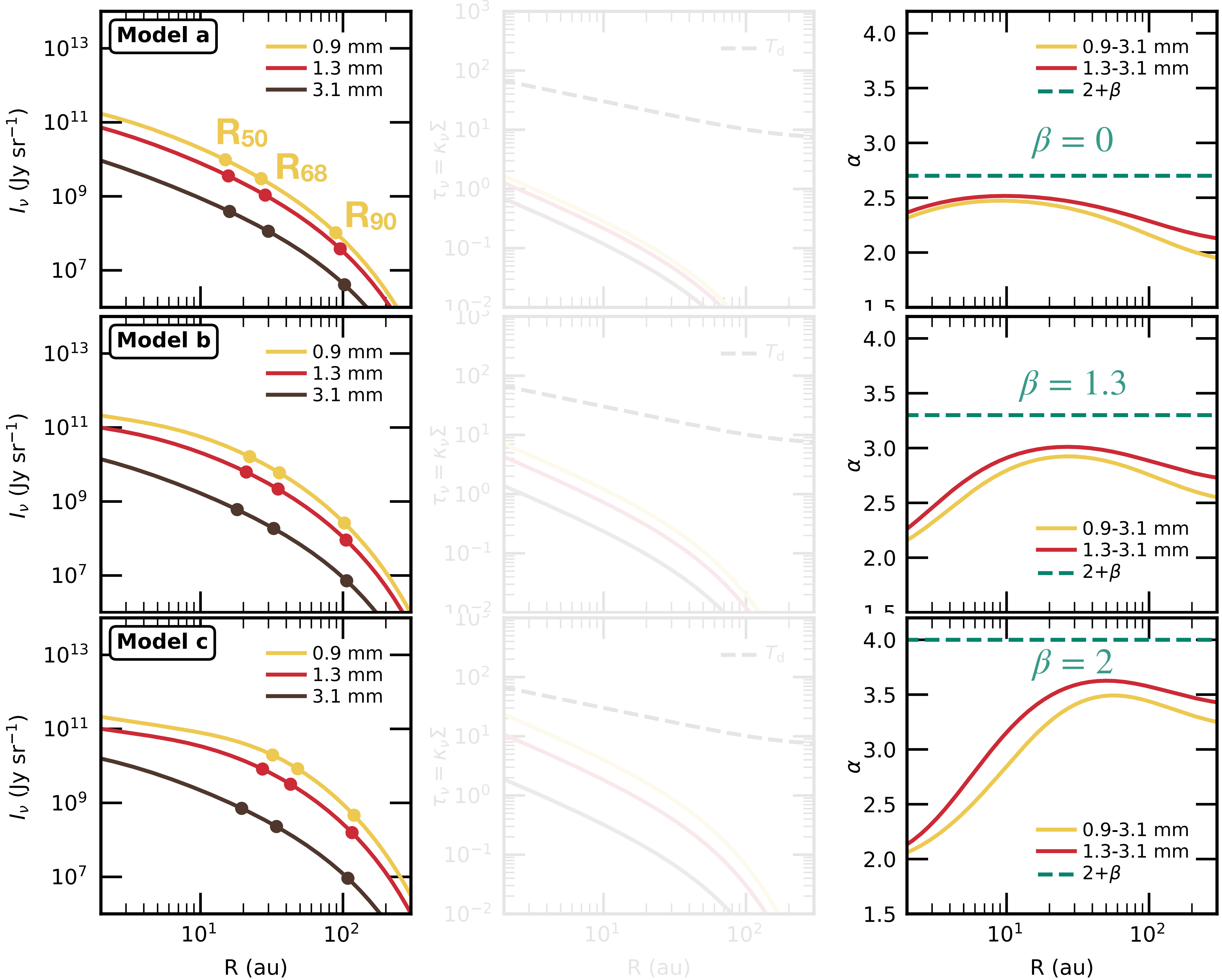


Small grains

Brightness

Optical depth

Spectral index



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[Tazzari+ (2021) MNRAS 506 2804]

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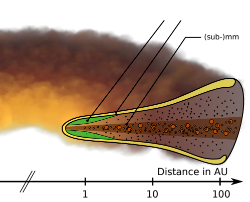
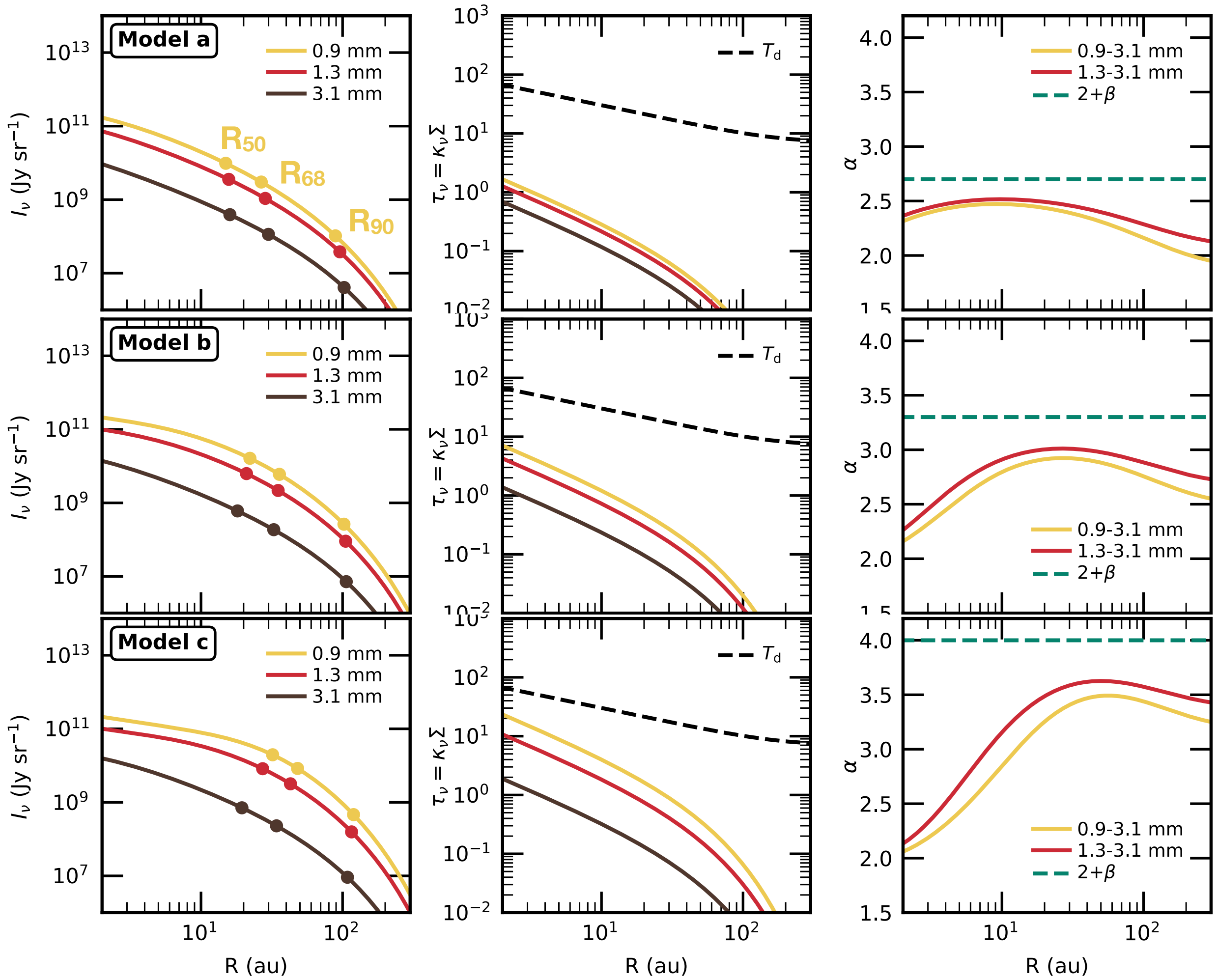


Small grains

Brightness **Optical depth** **Spectral index**



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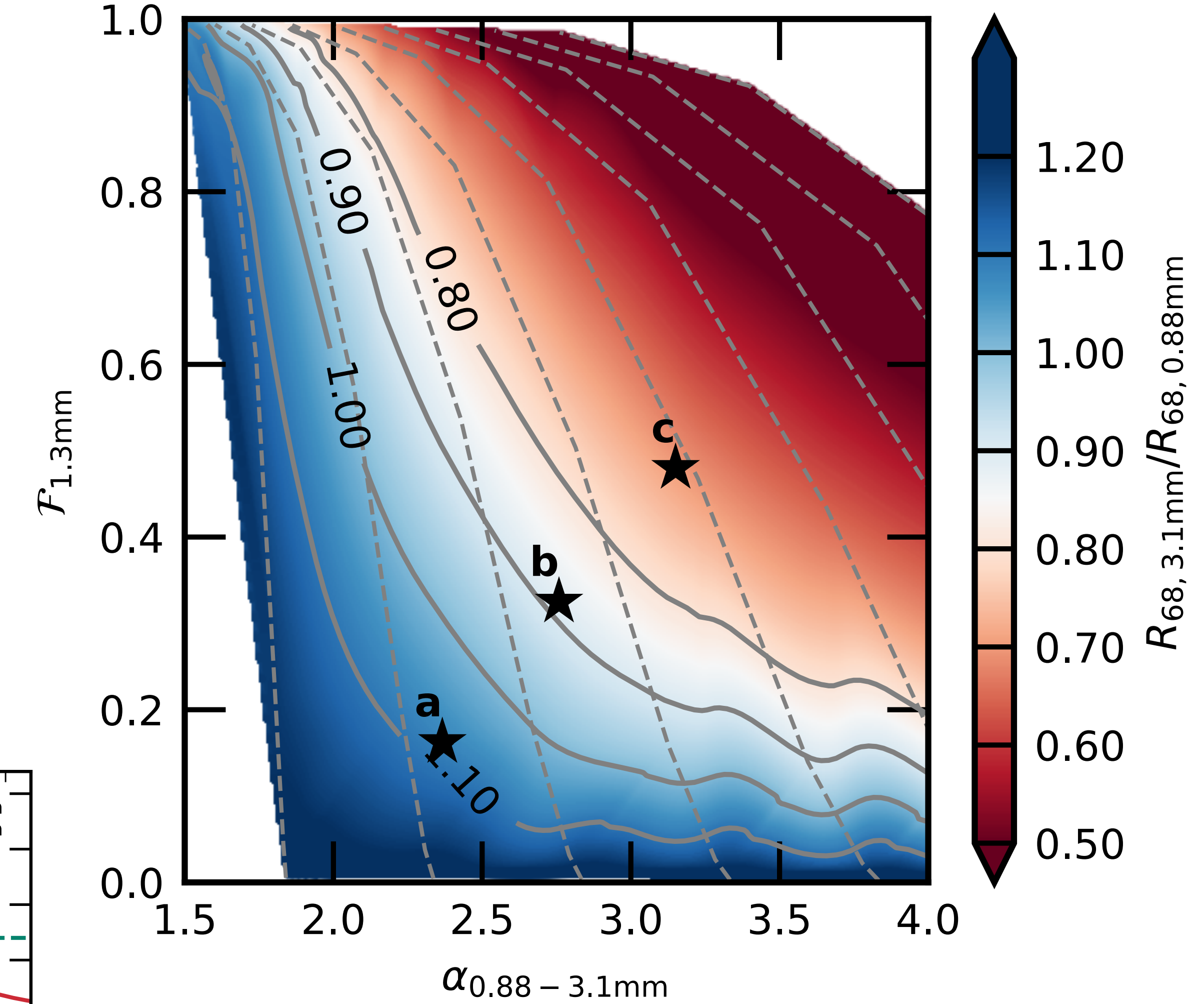
[Tazzari+ (2021) MNRAS 506 2804]

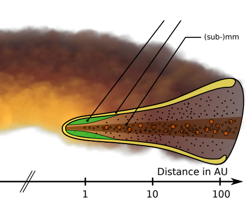


Spectral index

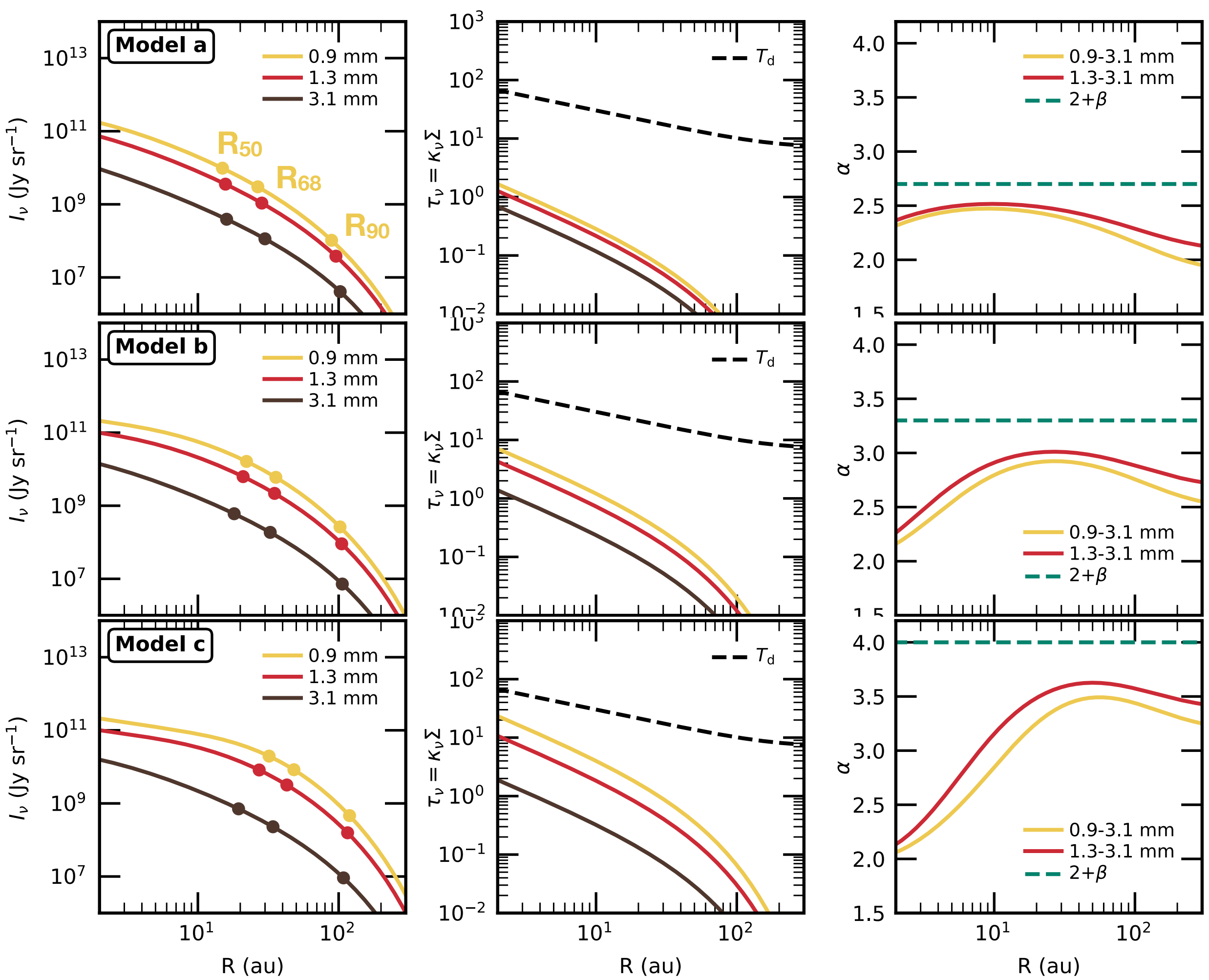
Brightness

Optical depth

Large grains



Small grains



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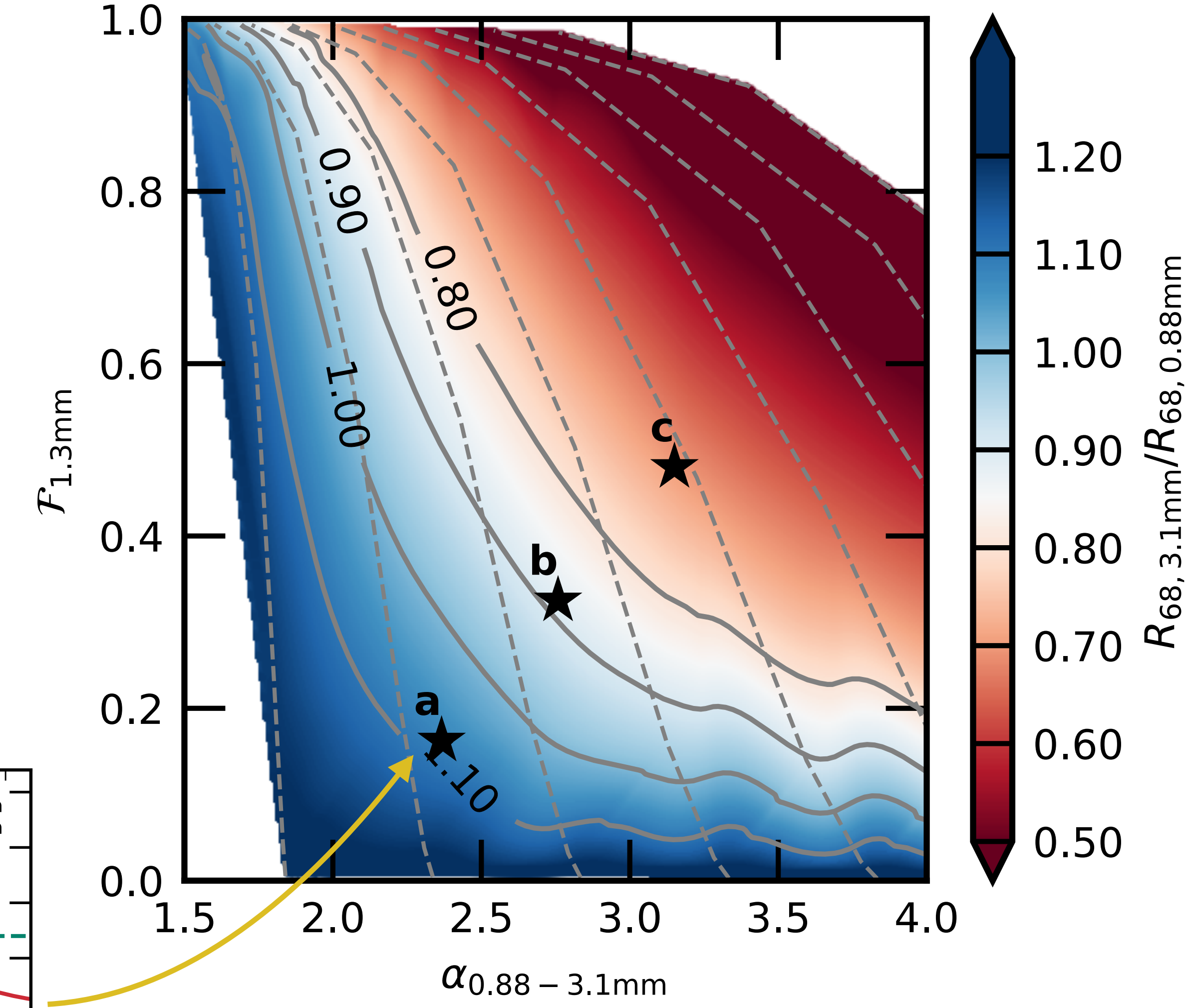

Brightness

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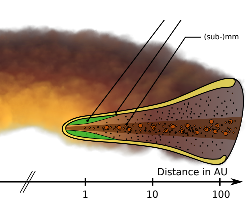
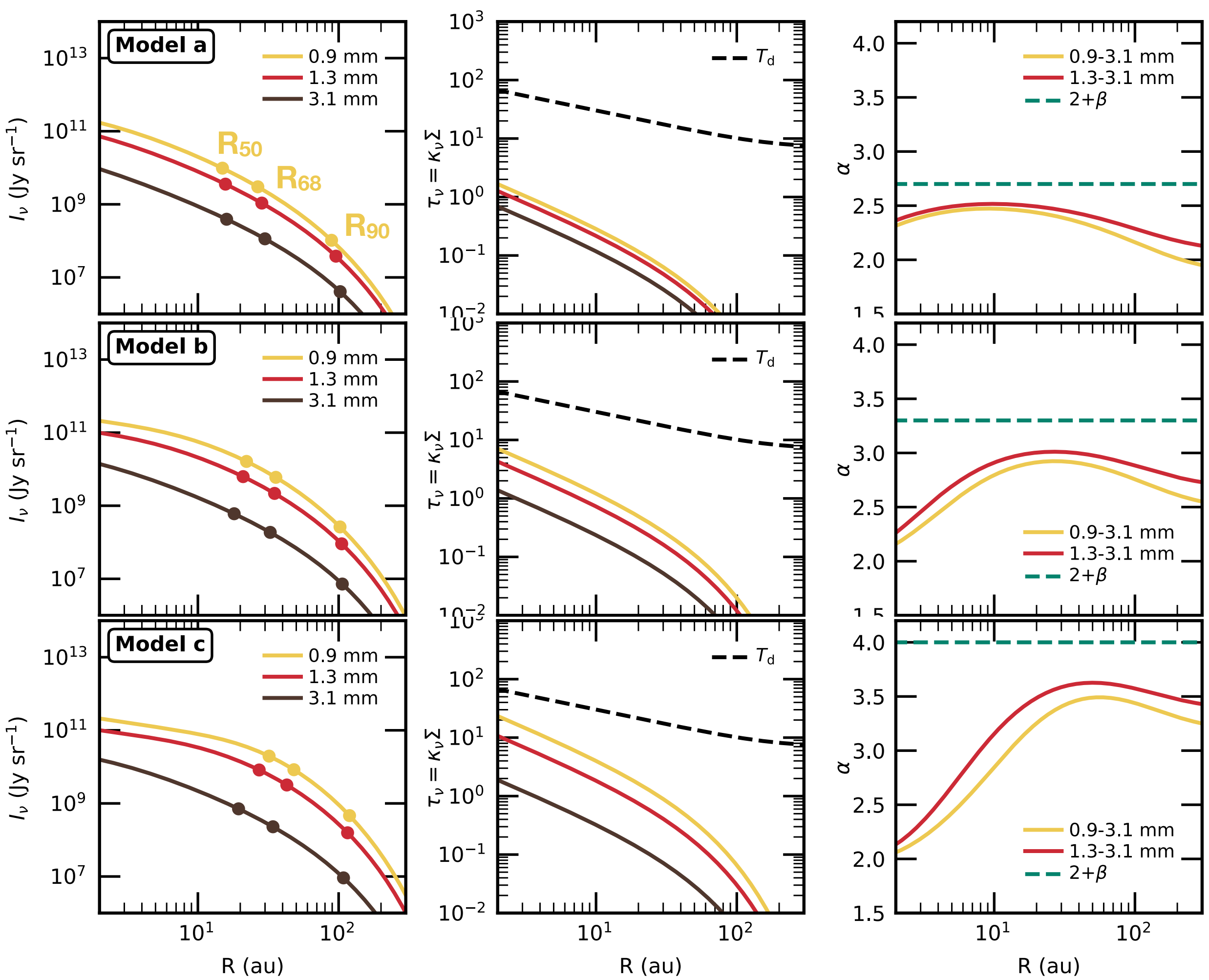
Large grains

Small grains





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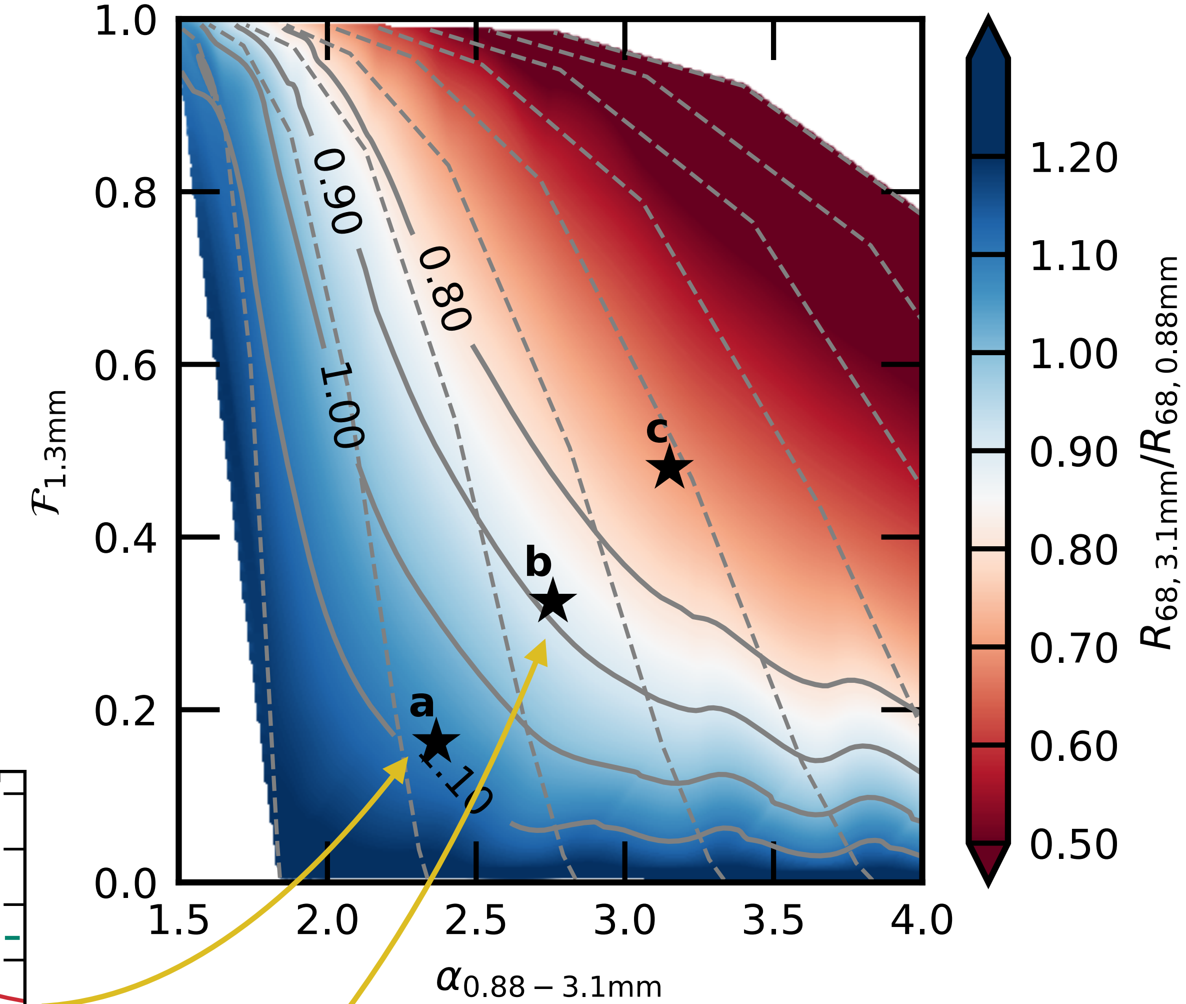

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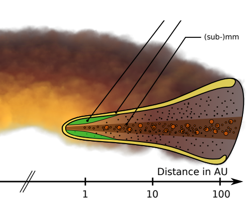

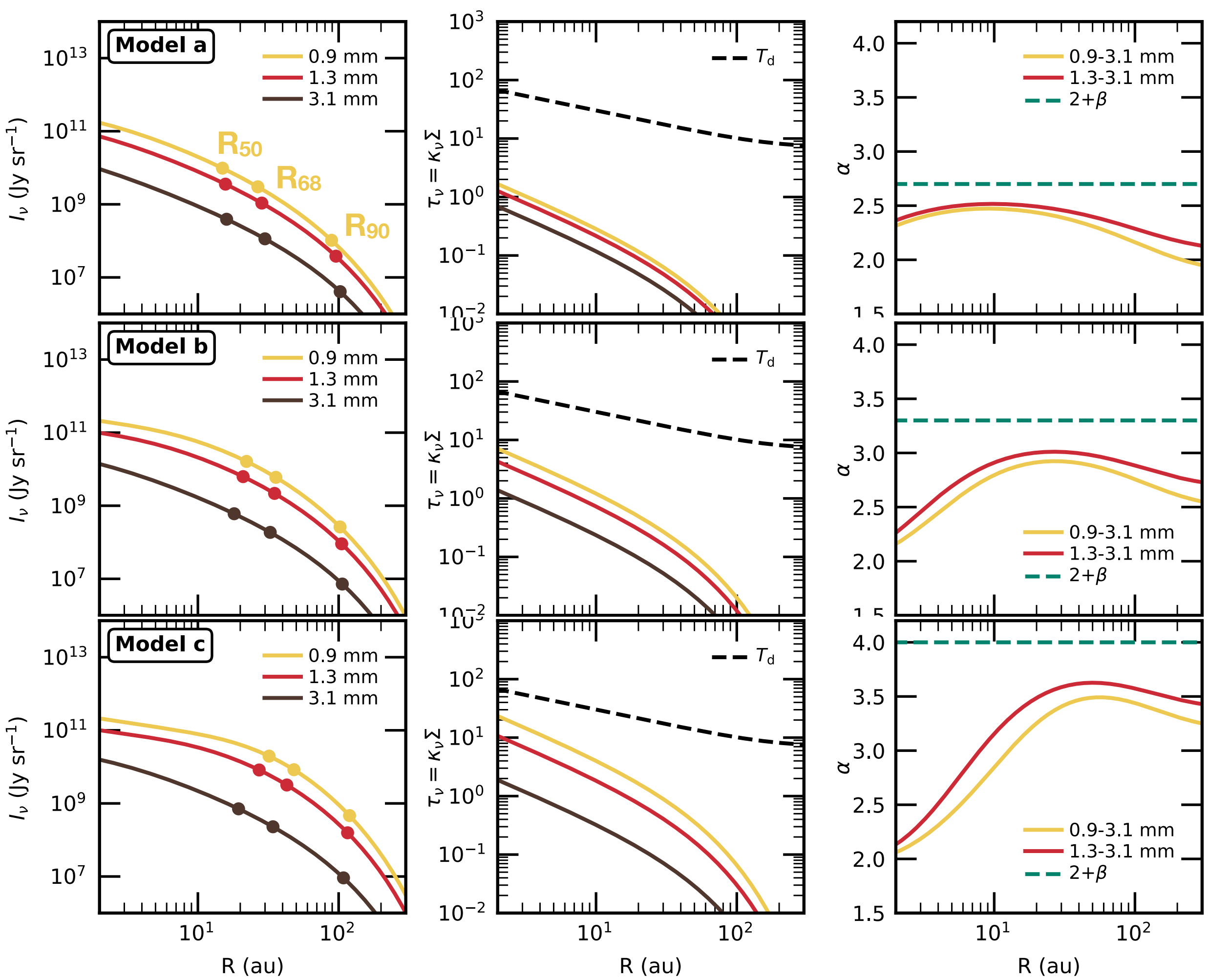

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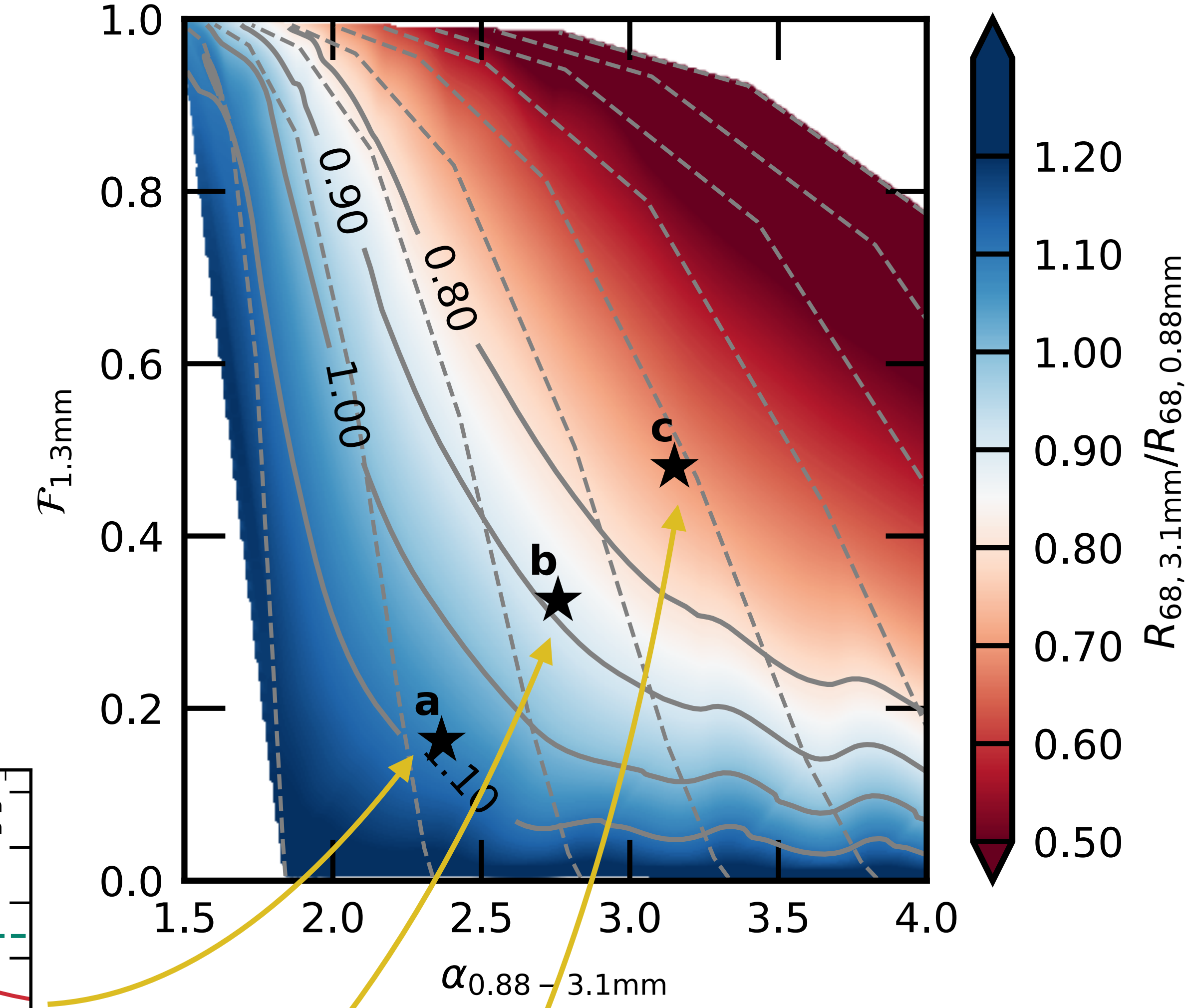

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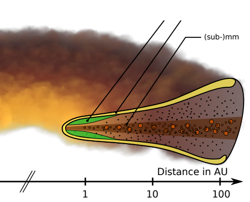

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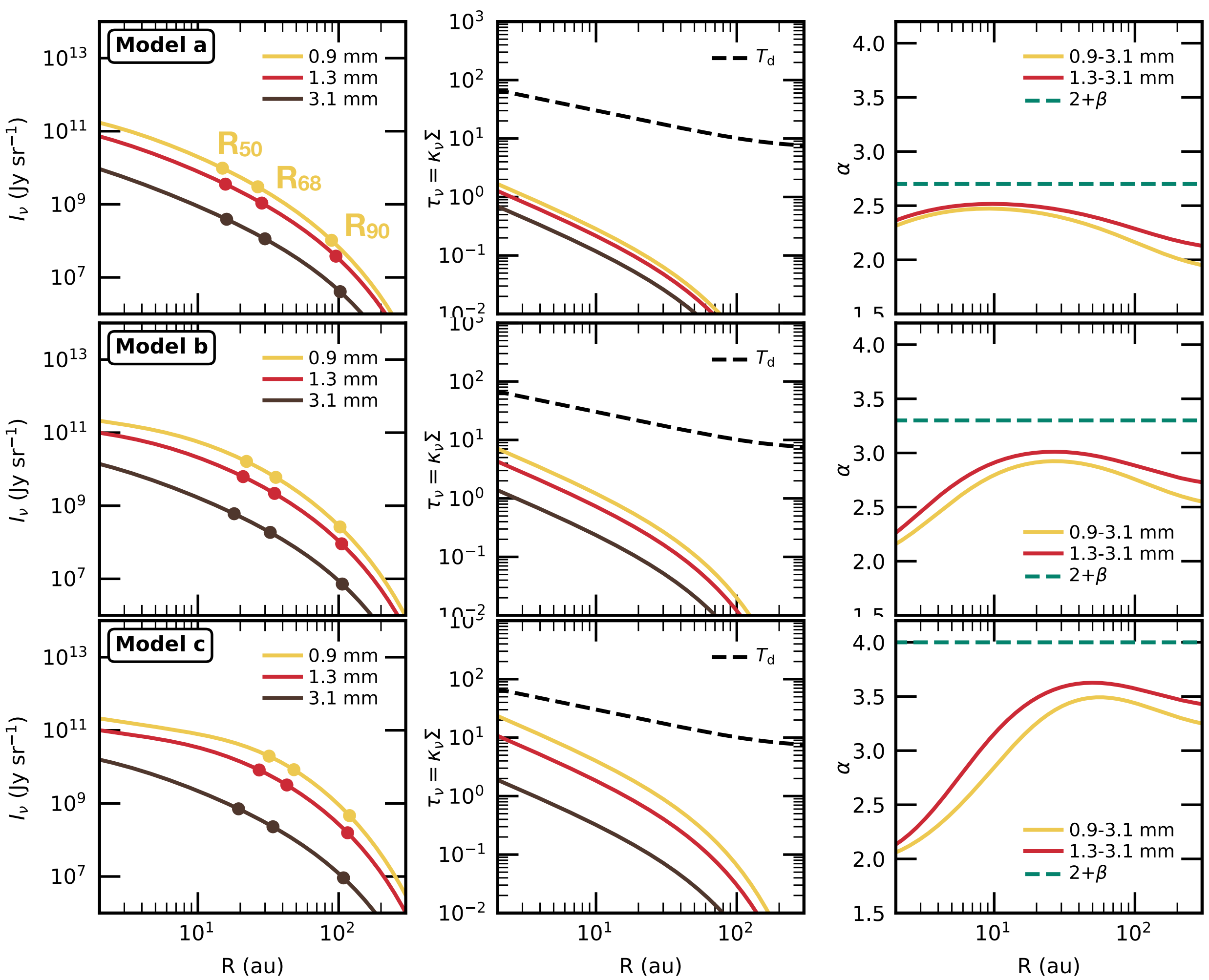

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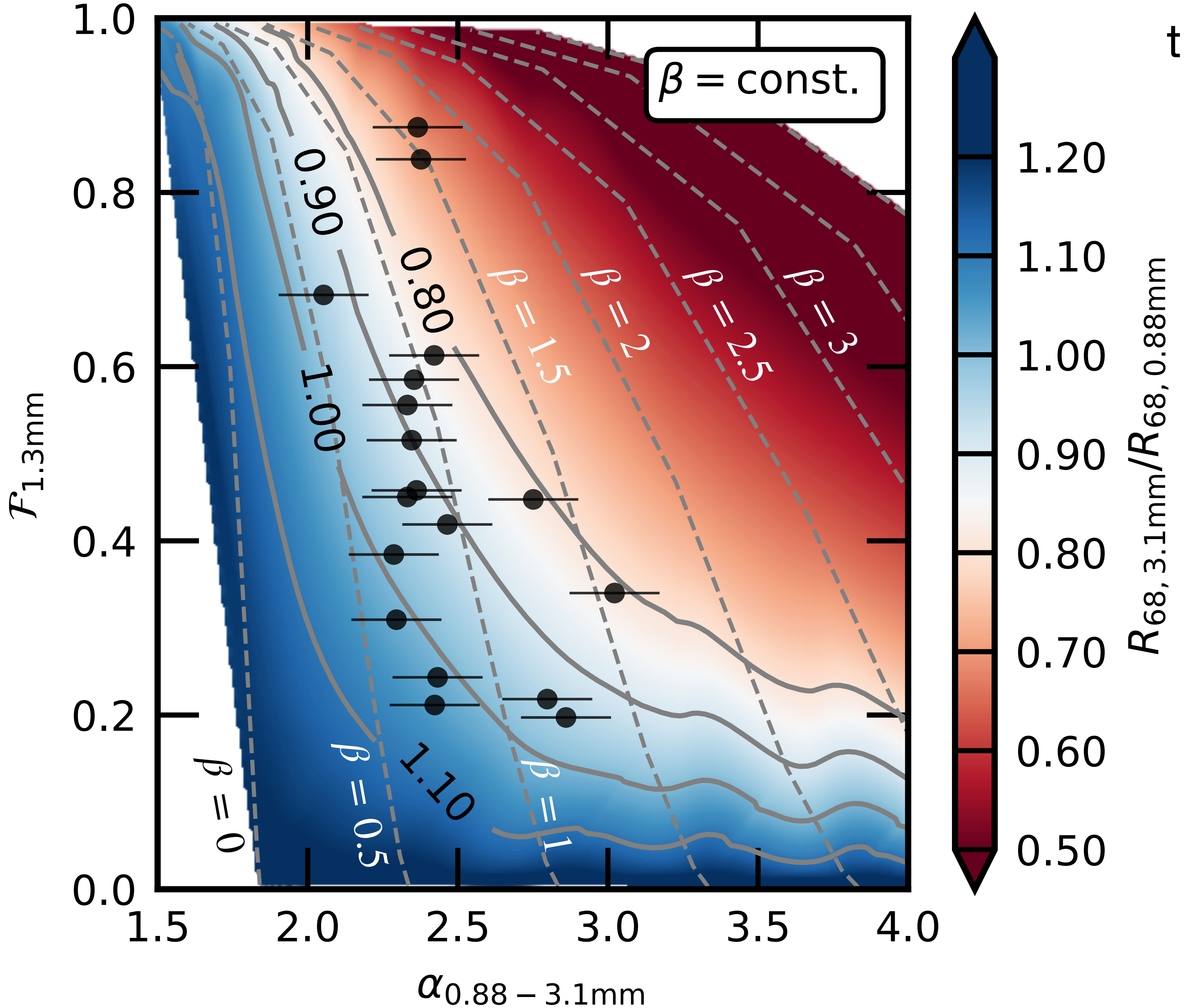
4) Implications for grain growth: evidence for large mm grains

Constant ß(R)



Grains must be **large** ($a_{\max} \geq 1\,\mathrm{mm}$) throughout the disc to reproduce:

- radii

$$R_{68,3.1\,\mathrm{mm}}/R_{68,0.88\,\mathrm{mm}} \approx 1$$

- sp. index

$$2.4 \leq \alpha_{0.9-3.1\,\mathrm{mm}} \leq 3.0$$

- opt. thick fractions

$$0.2 \leq \mathscr{F}_{1.3\,\mathrm{mm}} \leq 0.6$$

[Tazzari+ (2021) MNRAS 506 2804](#)

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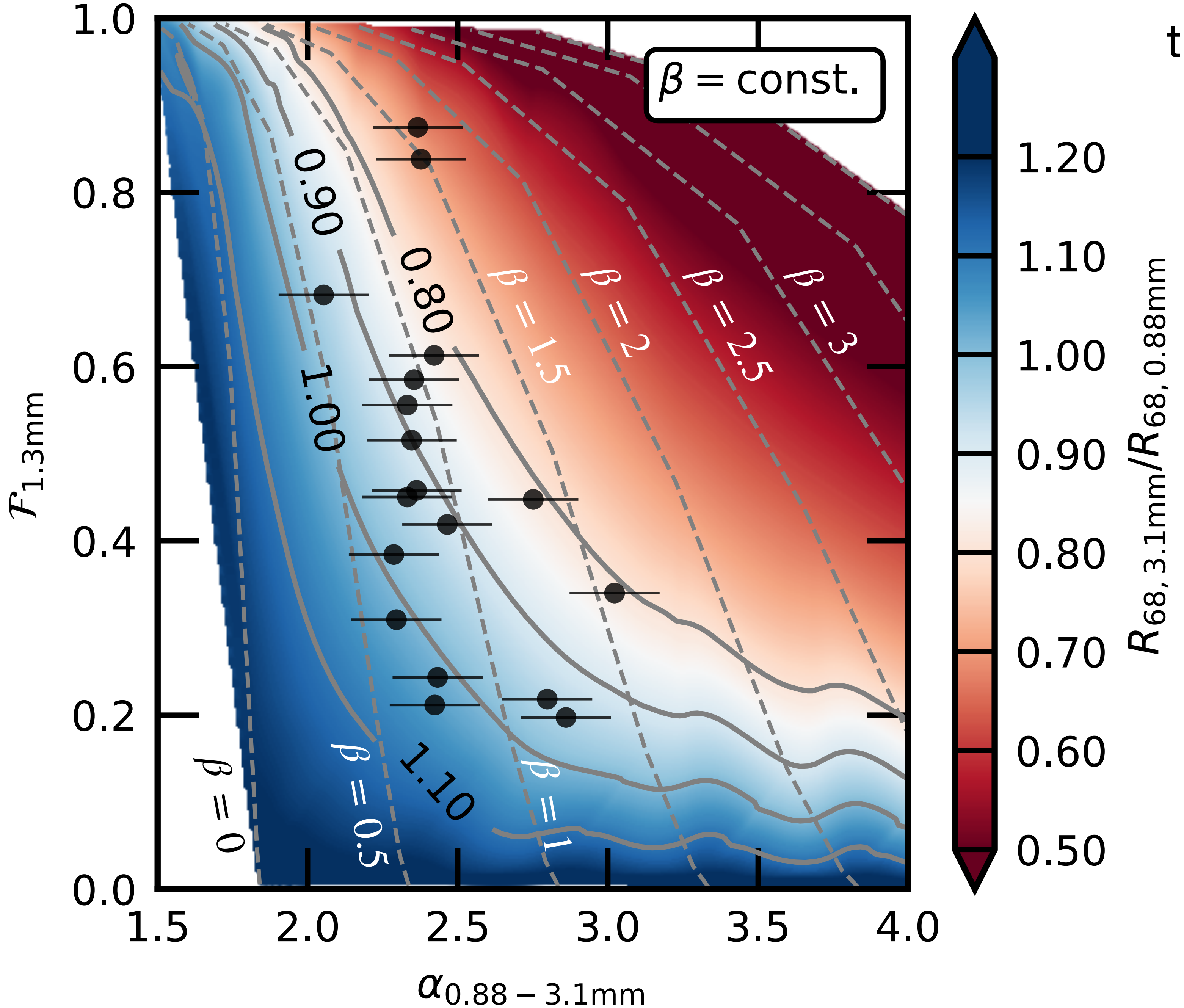

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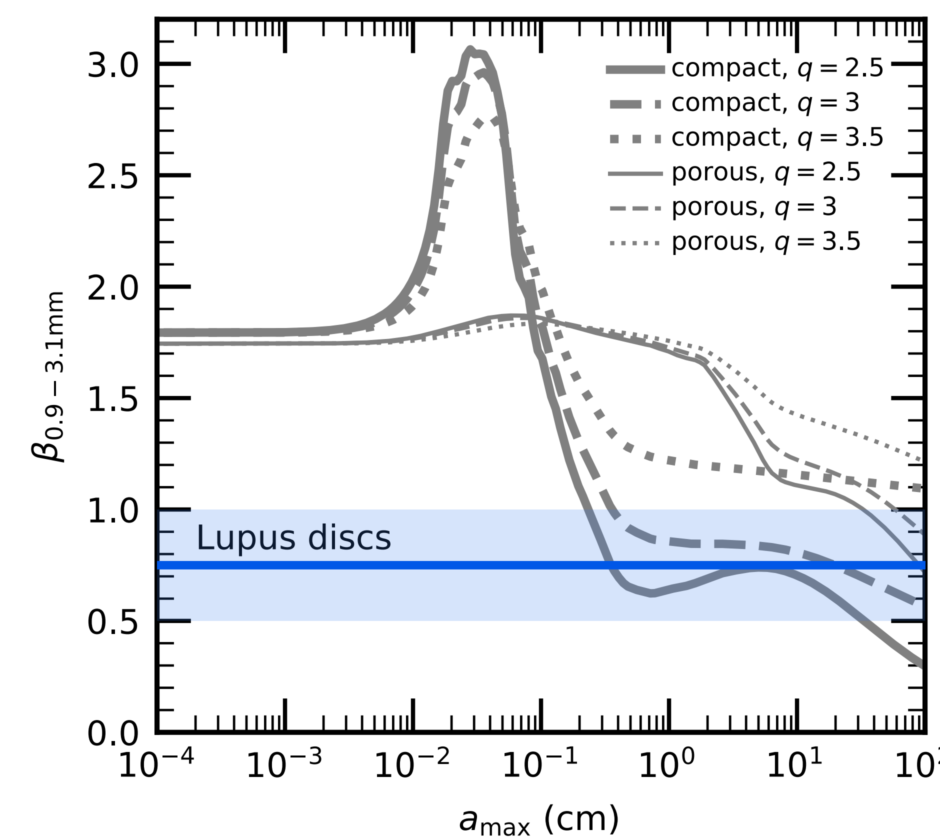

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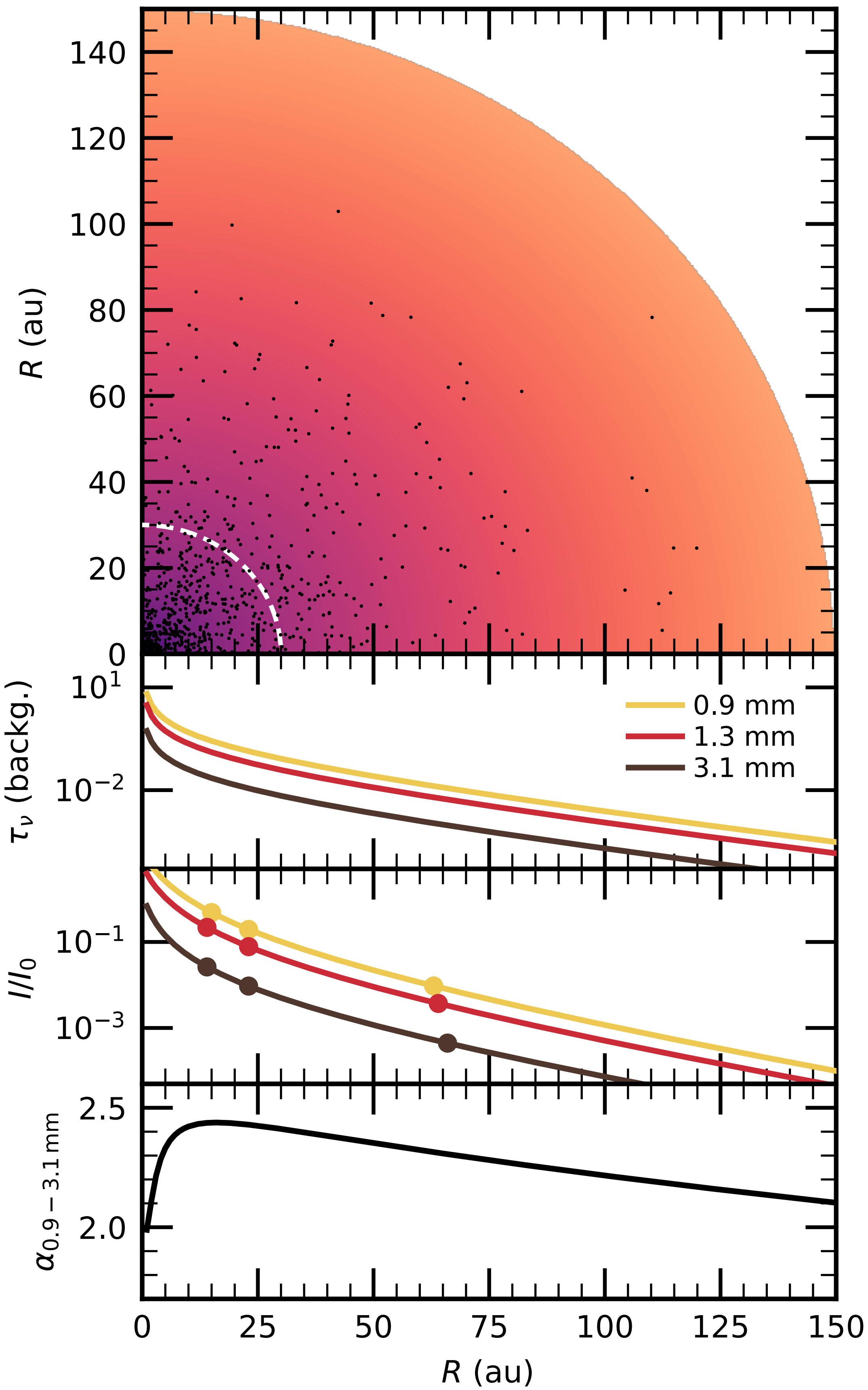
4) Implications for grain growth: room for small grains?



[Tazzari+ (2021) MNRAS 506 2804]

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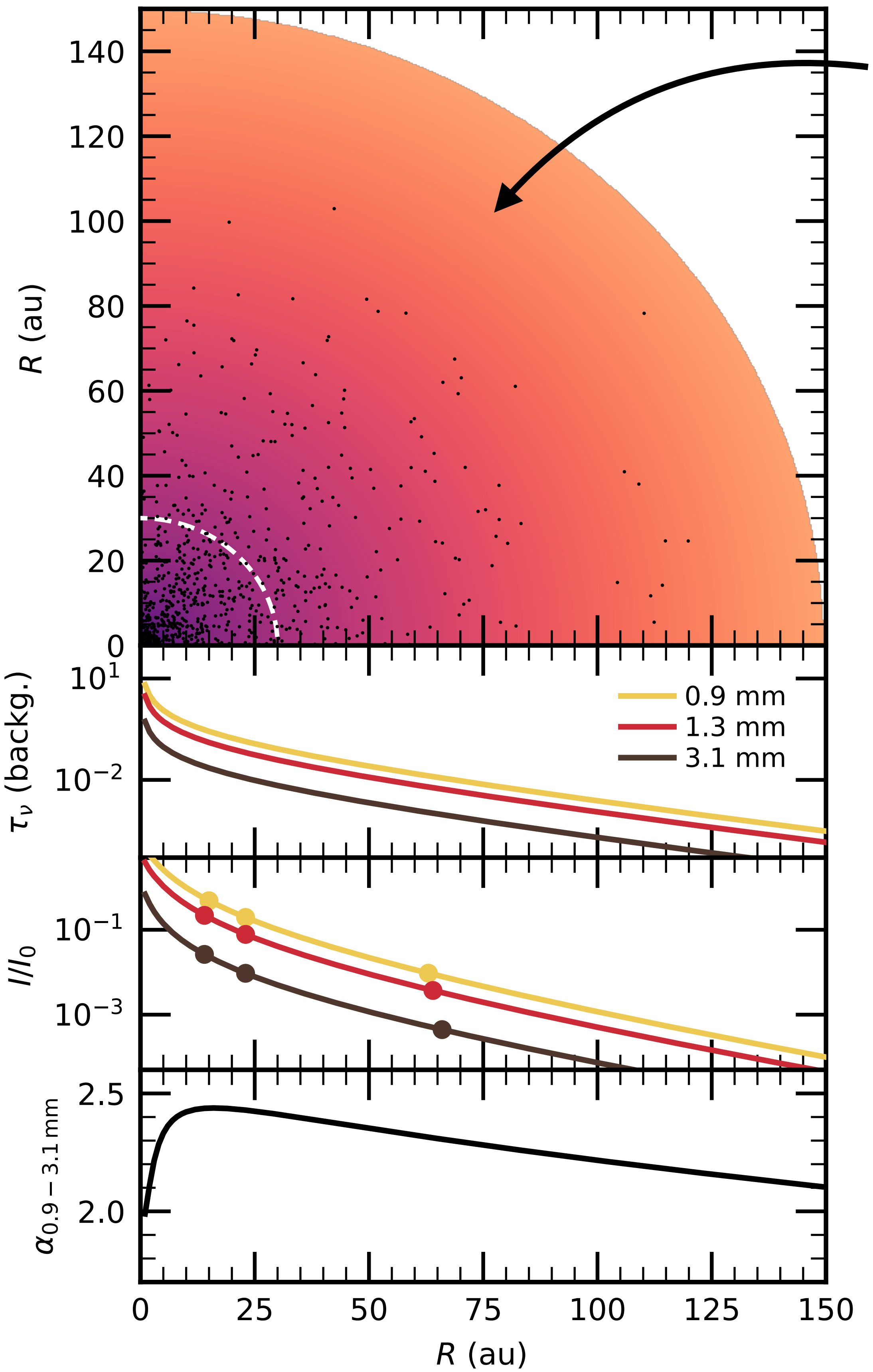

opt. thin background
$\alpha \approx \alpha_{\rm ISM} \simeq 3.7$

[Tazzari+ (2021) MNRAS 506 2804]

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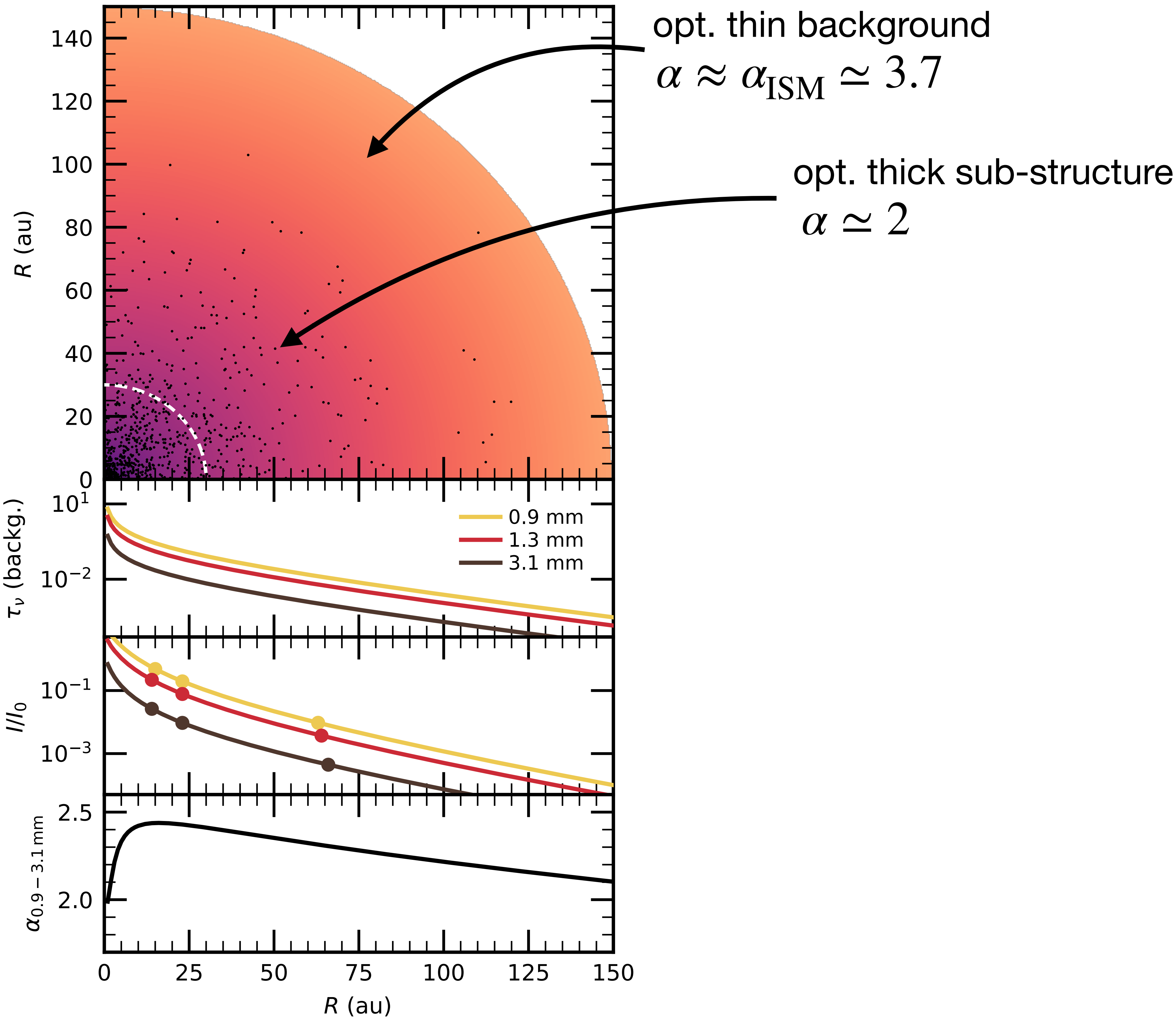

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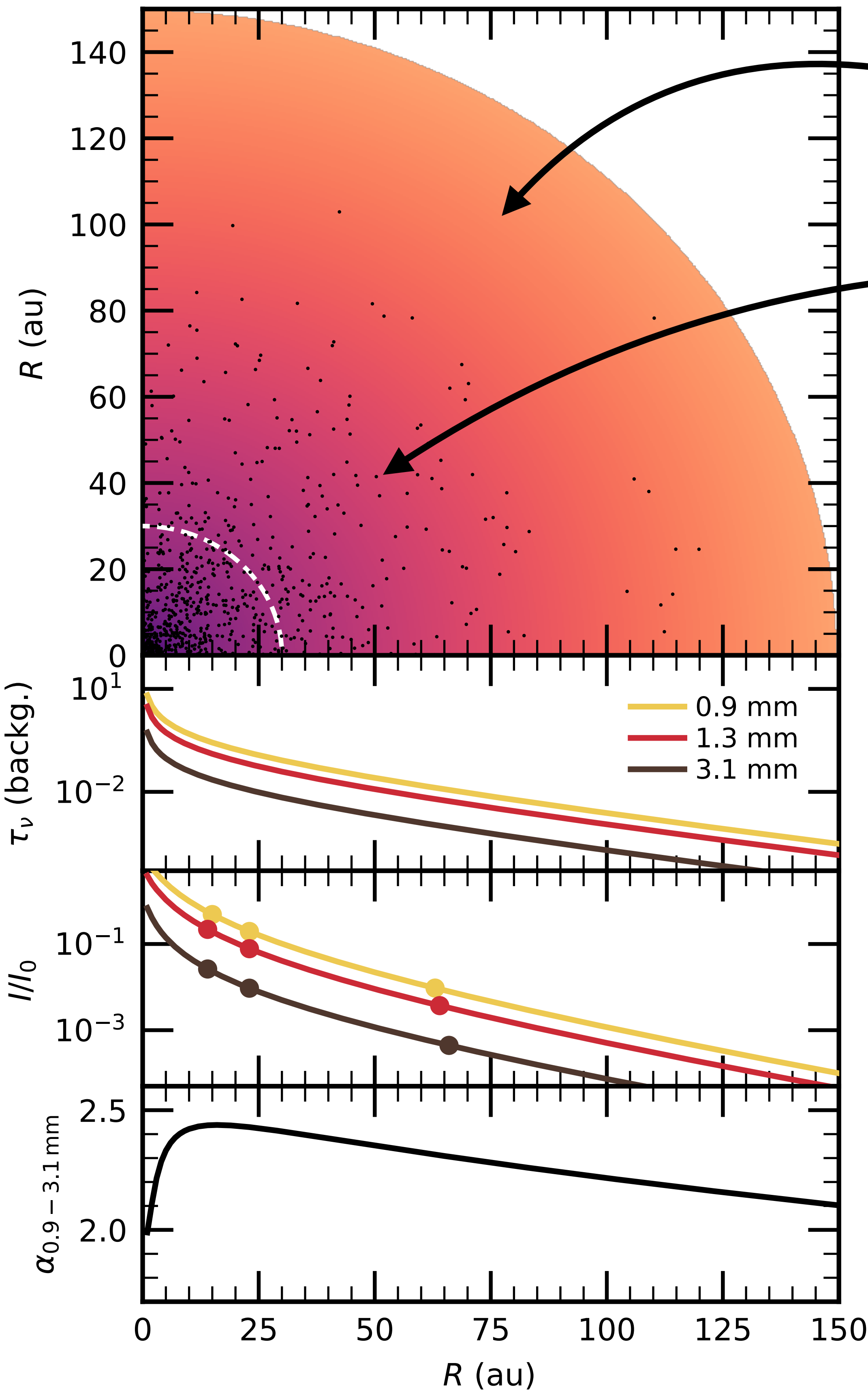

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opt. thick sub-structure

$\alpha \simeq 2$

[Tazzari+ (2021) MNRAS 506 2804]

Results:

Very narrow set of solutions can reproduce observational constraints:

- roughly equal balance between opt thick and thin emission
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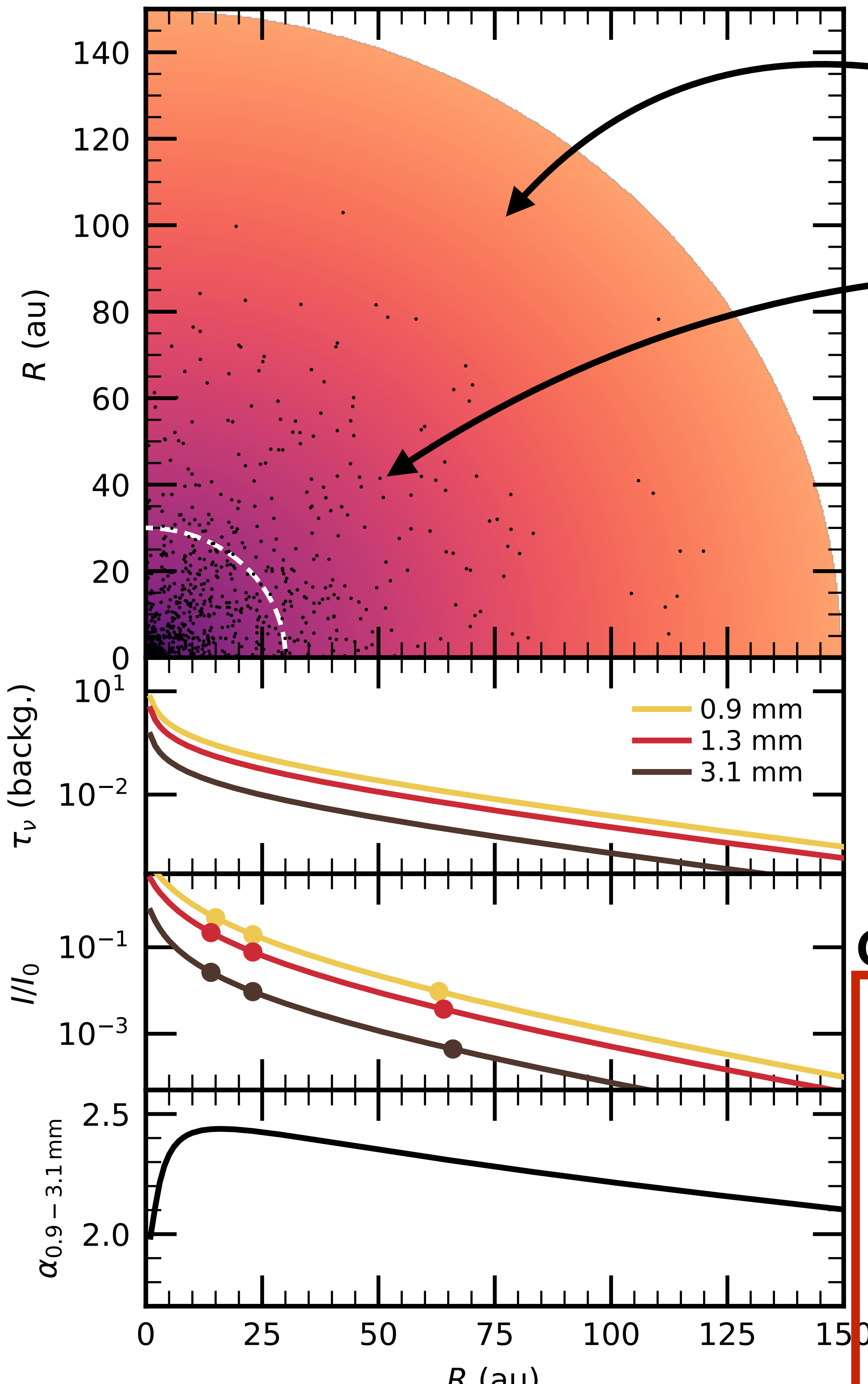

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Conclusions:

Opt thick sub-structures is not disfavoured in *general,* but:

- opt thick structures + small grains (beta~2): contrived
- opt thick structures + larger grains (beta~1): possible
- opt thick strucutres **of** large grains (high albedo): possible and do not require opt thin background
  - $\lambda \geq 7\,\mathrm{mm}$ observations will help discriminate

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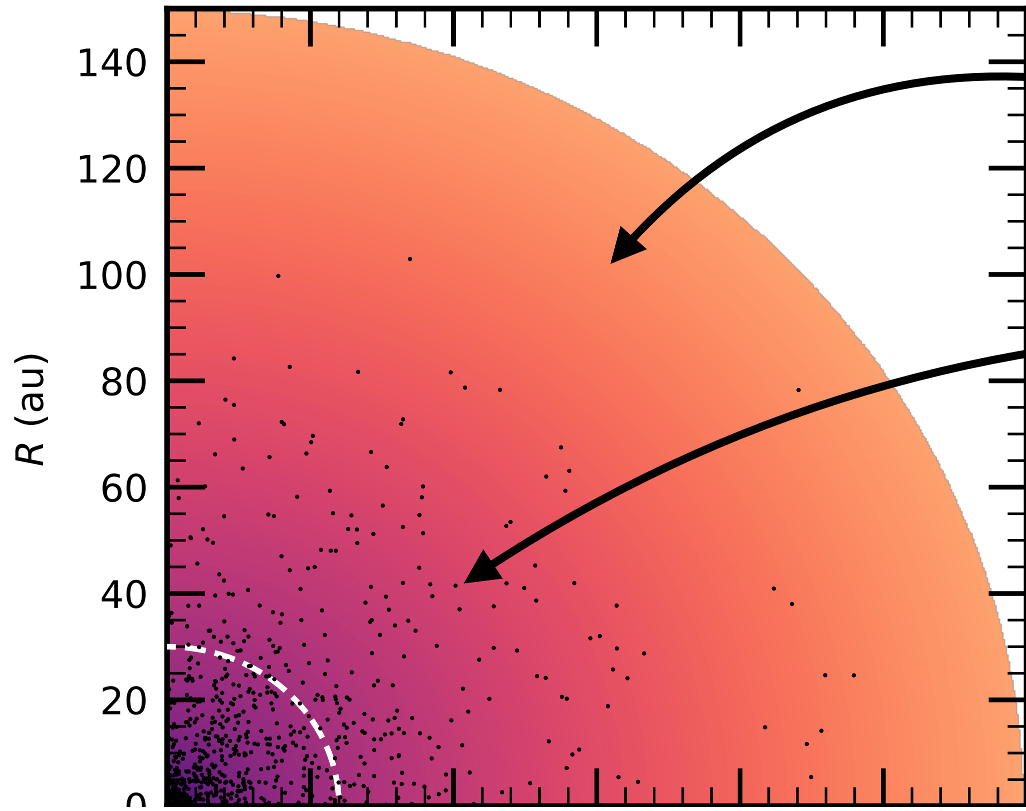

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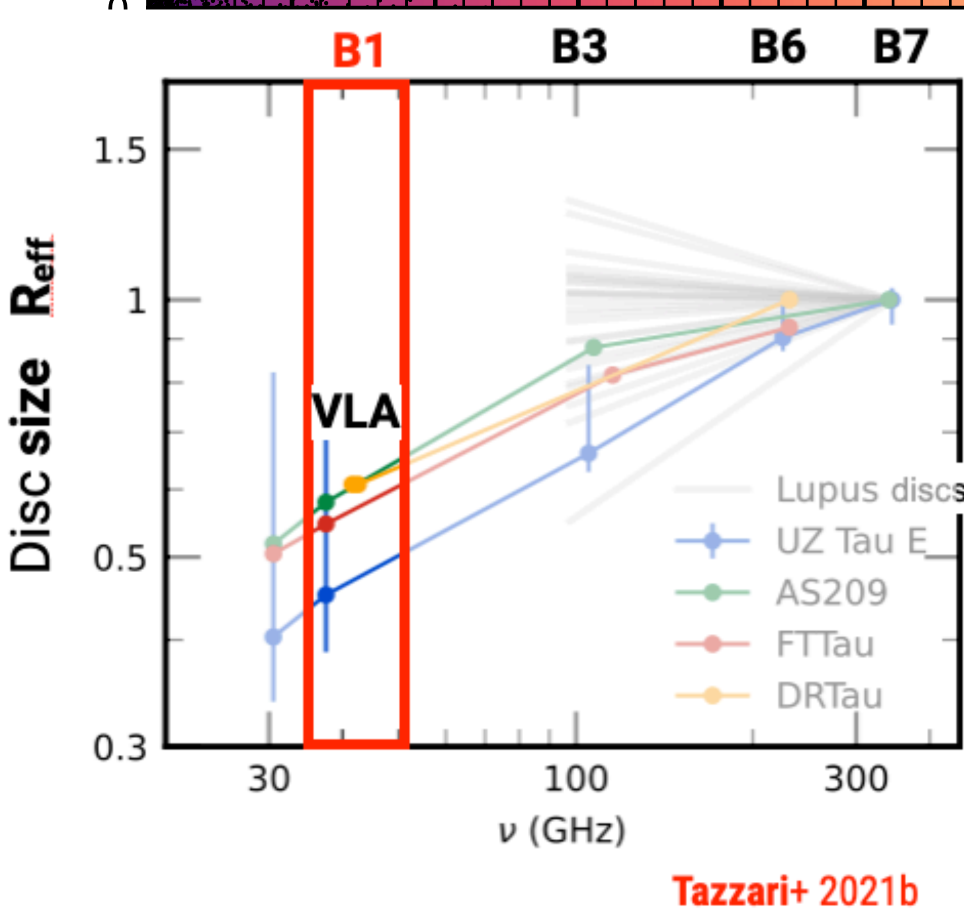

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Data is public online: get it & use it!

zenodo

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June 21, 2021

Dataset | Open Access

Data from "Multi-wavelength continuum sizes of protoplanetary discs: scaling relations and implications for grain growth and radial drift"

Tazzari, Marco

Table 1, Table 2, and Table 3 from Tazzari et al., 2021, "Multi-wavelength continuum sizes of protoplanetary discs: scaling relations and implications for grain growth and radial drift", Monthly Notices of the Royal Astronomical Society, arXiv:2010.02249

Both tables are available in IPAC format, which is in human- and machine-readable:

```
from astropy.io import ascii
tb = ascii.read('Table1.txt', format='ipac')
```

Table comments (stored at the beginning of the ASCII file as lines starting with "/") can be read as:

```
tb.meta['comments']
```

Multi-wavelength:
(0.88, 1.3, 3.1 mm)

- fluxes
- spectral indices
- dust masses
- disc sizes
- opt. depth fraction

uv-plane analysis:

GALARIO

github.com/mtazzari/galario

[Tazzari+ (2021) MNRAS 506 5117](#) https://zenodo.org/record/4756282

[Tazzari+ (2021) MNRAS 506 2804](#) https://zenodo.org/record/4756381

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