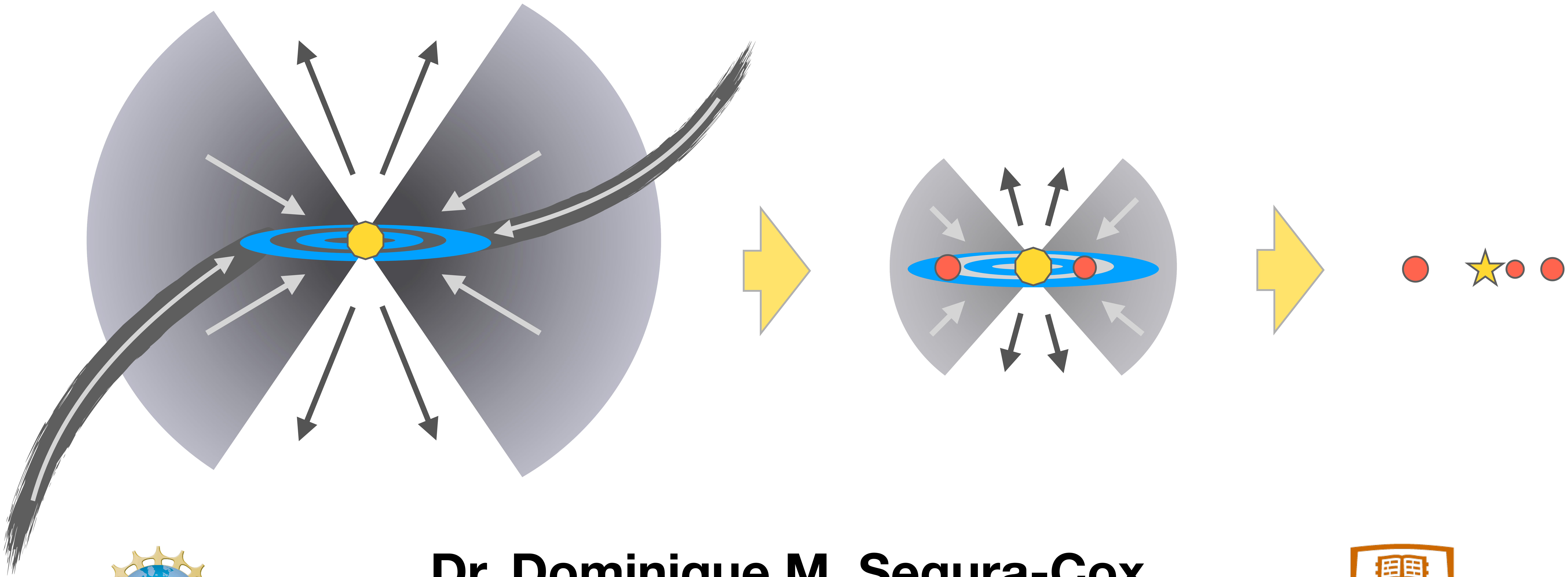
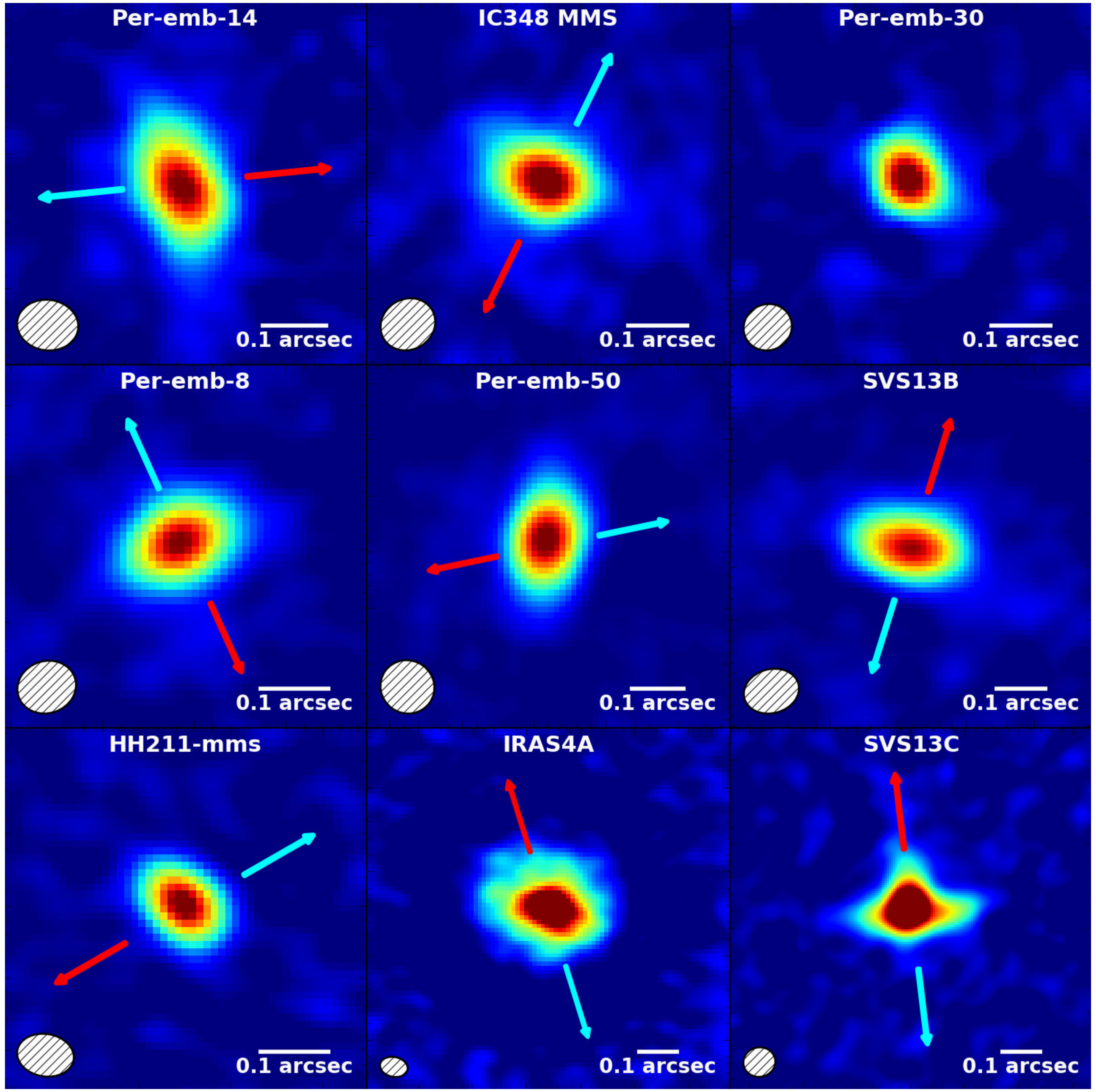
Observing Embedded Disks and the Onset of Planet Formation



Dr. Dominique M. Segura-Cox
NSF Astronomy and Astrophysics Postdoctoral Fellow at UT Austin
dominique.seguracox@austin.utexas.edu 25/10/21

Dominique Segura-Cox

Most 0/I Disks are Small: VLA

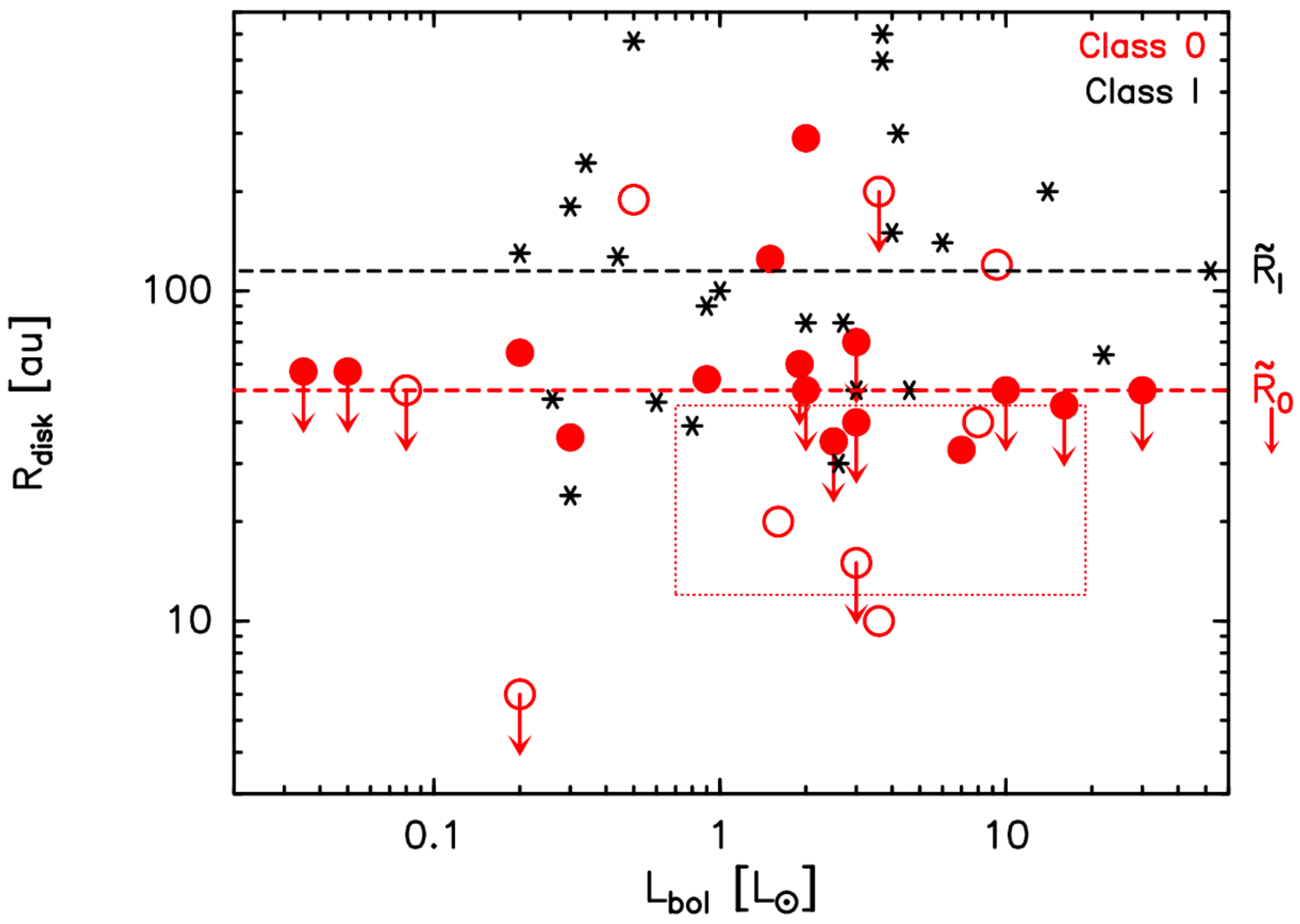


- VANDAM Survey
- 8 mm, 12 au resolution
- 80 Class 0 & I protostars
- 76% of targets have disks with R < 12 au

Segura-Cox et al. (2016, 2018)

Dominique Segura-Cox

Most 0/I Disks are Small: PdBI



- CALYPSO Survey
- 1 & 3 mm, ~130 au resolution
- 16 Class 0 protostars + more 0 & I from literature
- 75% of Class 0 protostars have disks with R < 60 AU

Maury et al. (2019)

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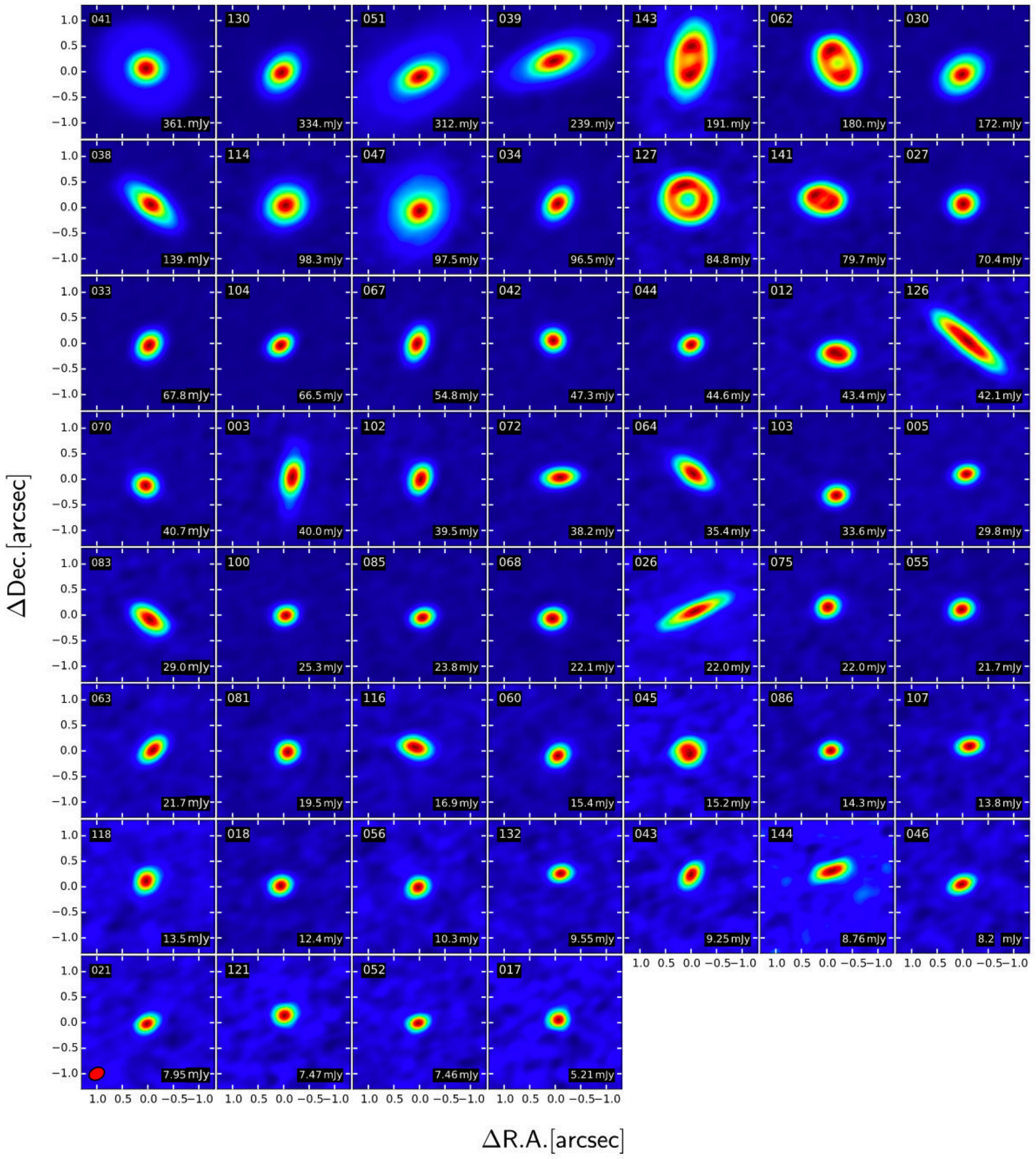
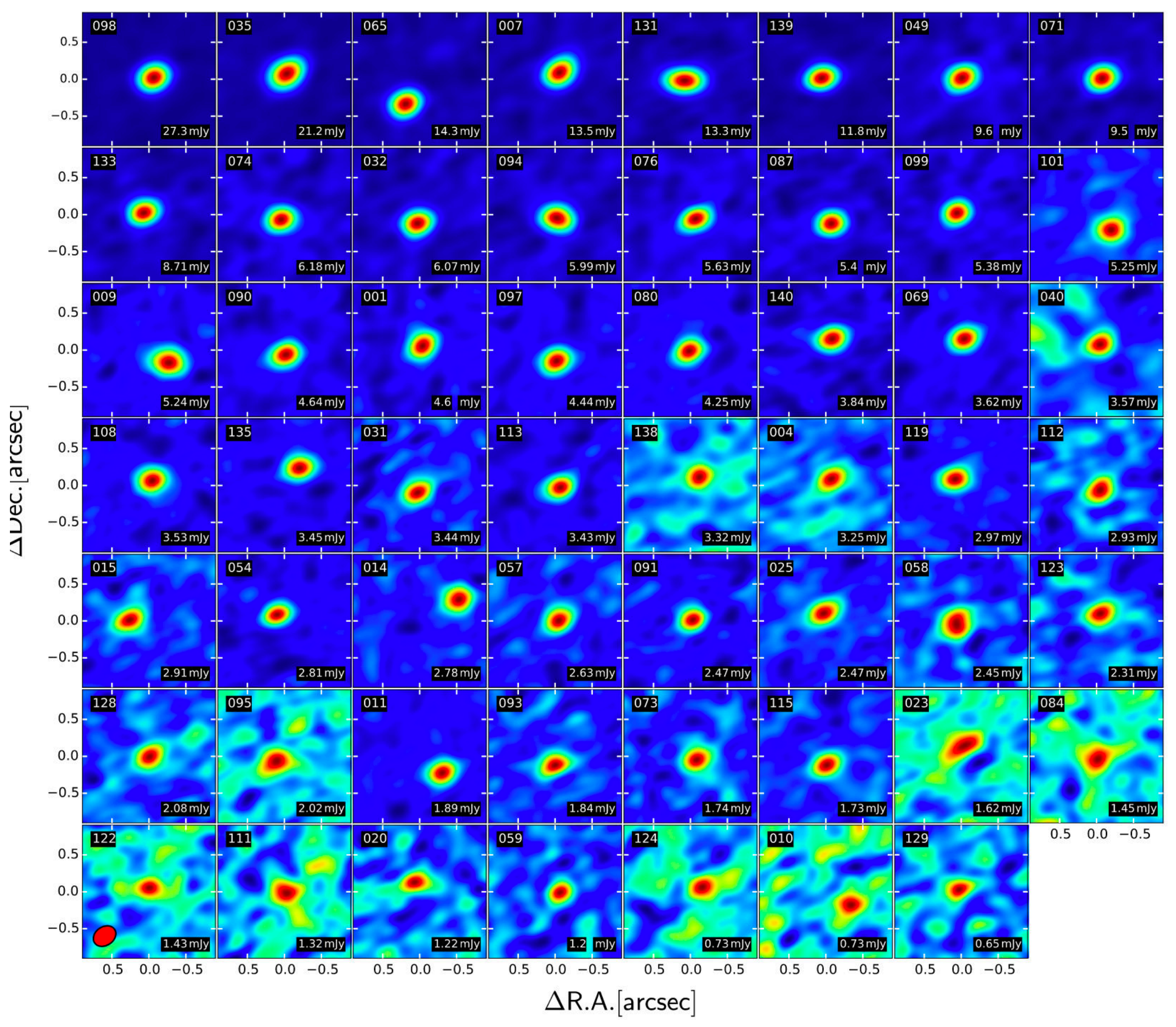
Most Disks are Small: ALMA

Resolved Disks



Unresolved Disks



- ODISEA Survey
- ~300 Class I, II, III, & flat spectrum targets
- 85% of 133 detected targets have disks with R < 30 AU

Cieza et al. (2019)

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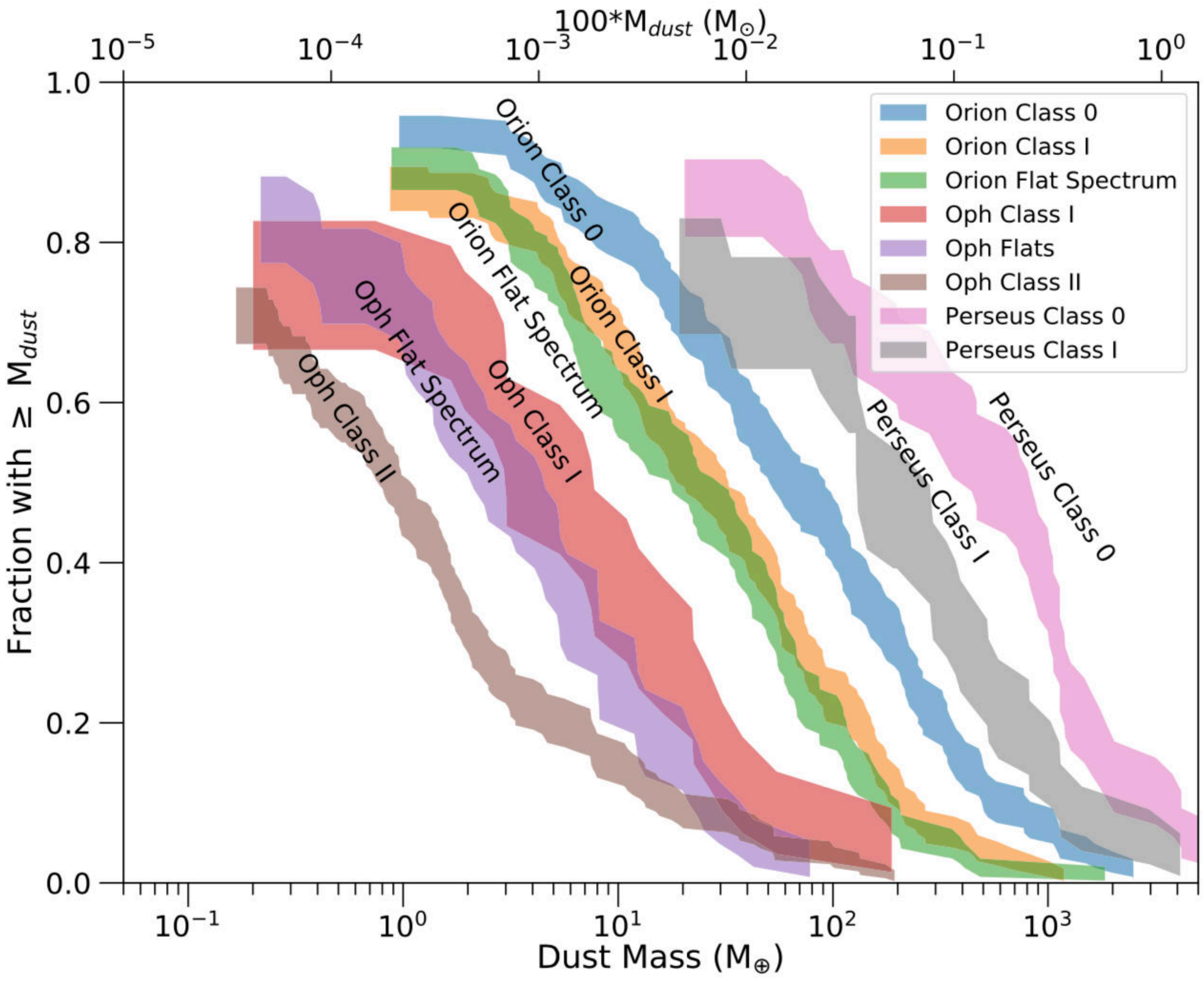
Young Disk Demographics, Mass



Tobin et al. (2020)

Overall trend that younger disks contain more dust mass than more evolved sources

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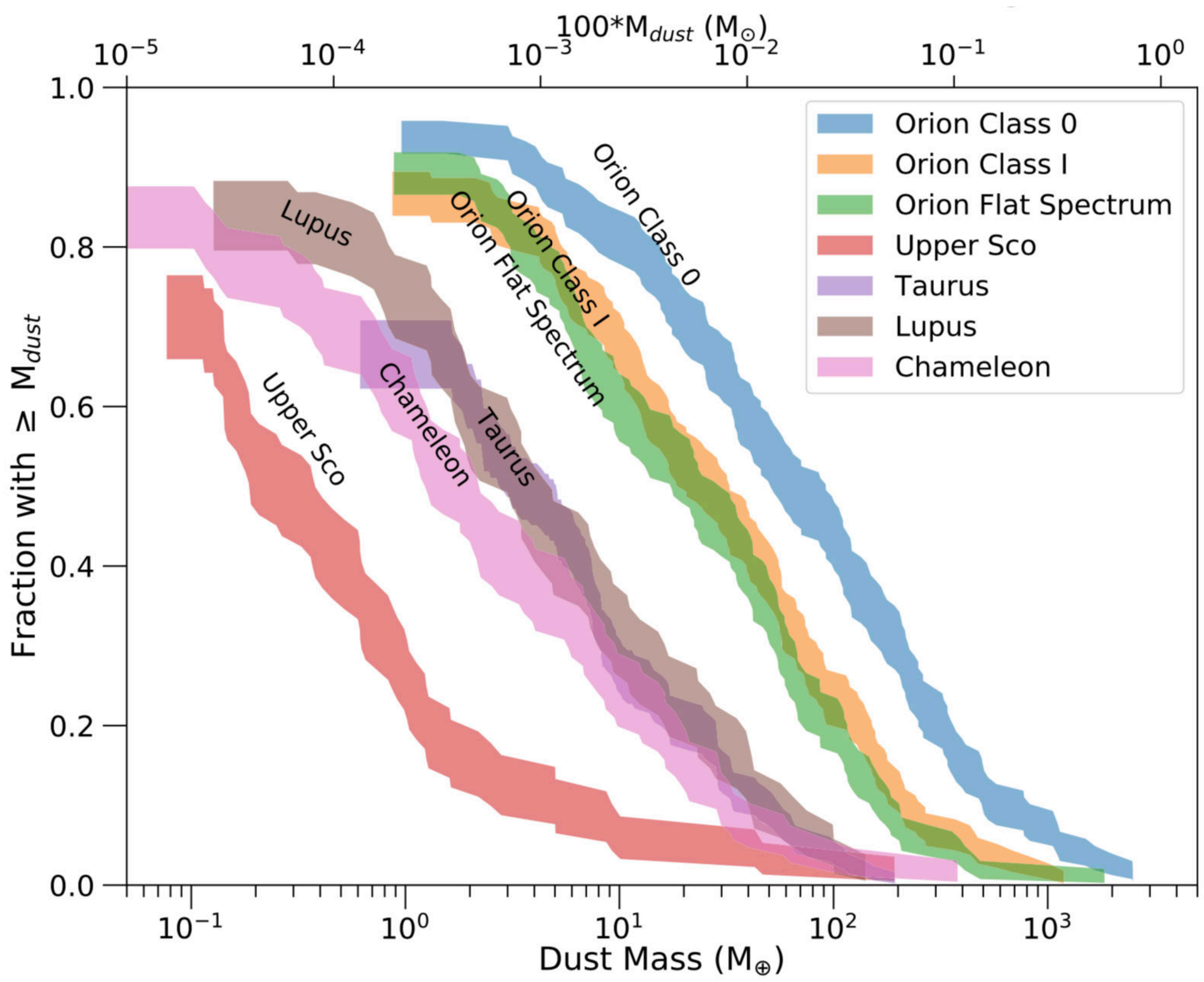
Young Disk Demographics, Mass



Younger star forming regions have higher disk masses than older star forming regions

Tobin et al. (2020)

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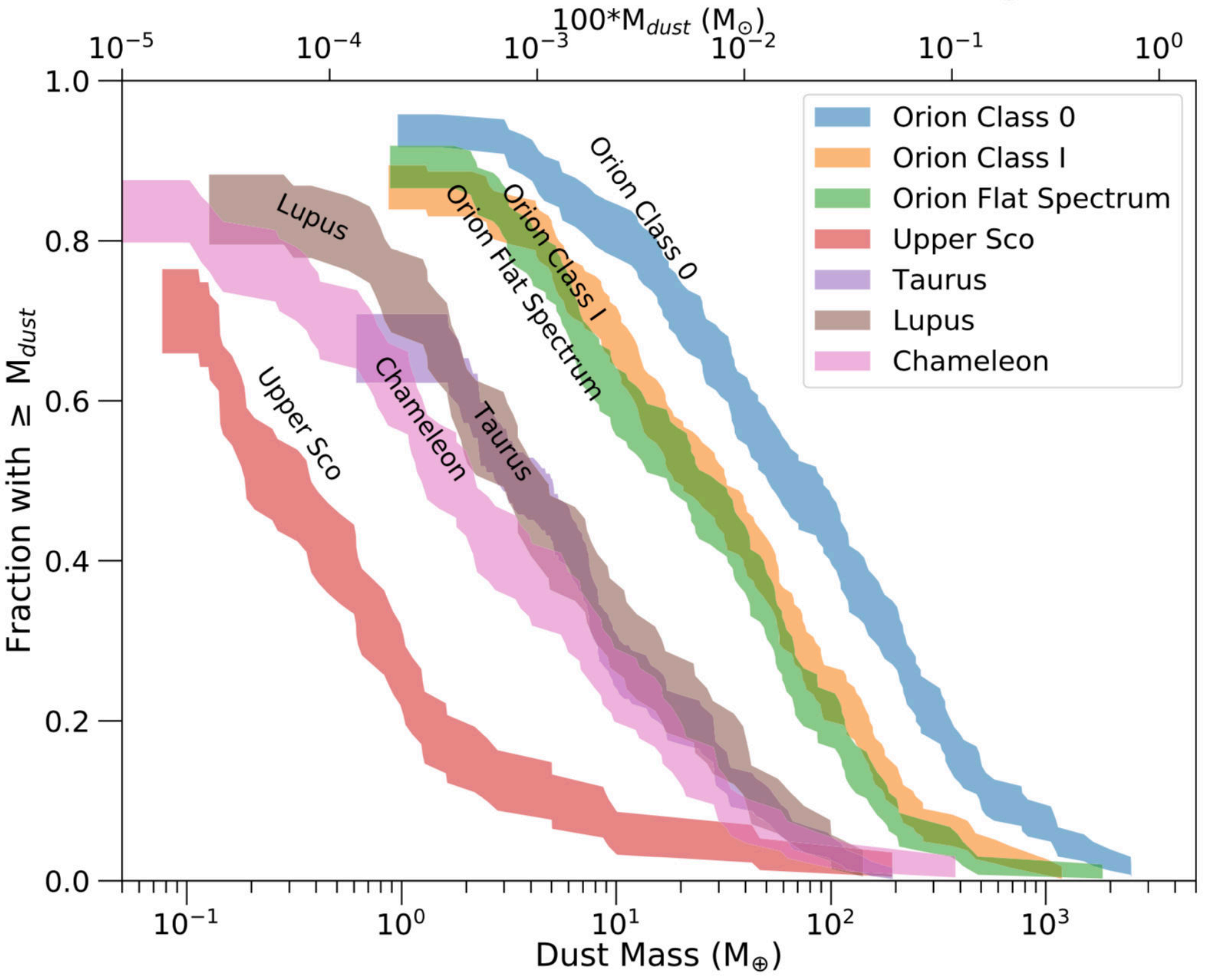
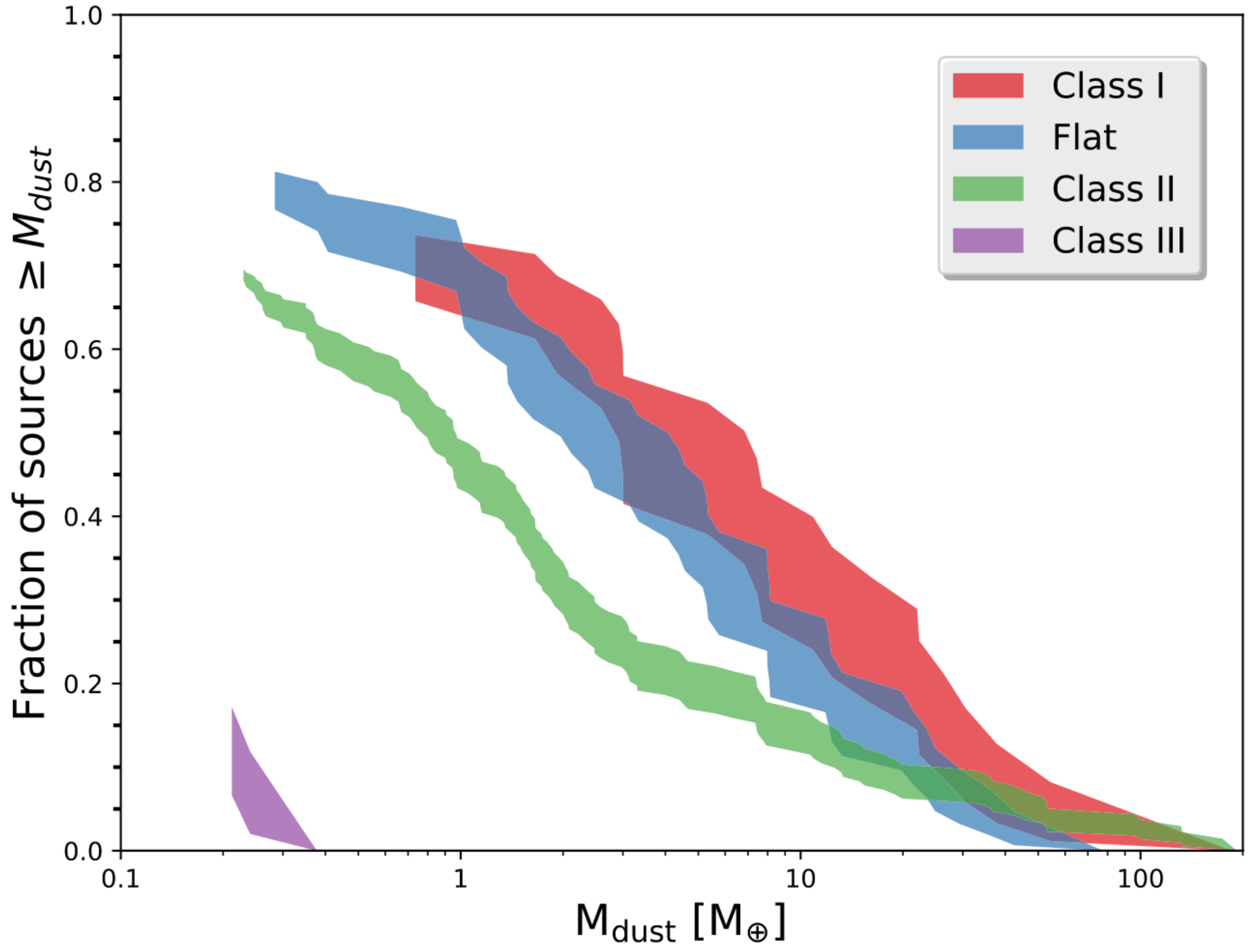
Young Disk Demographics, Mass



Tobin et al. (2020)



Williams et al. (2019)

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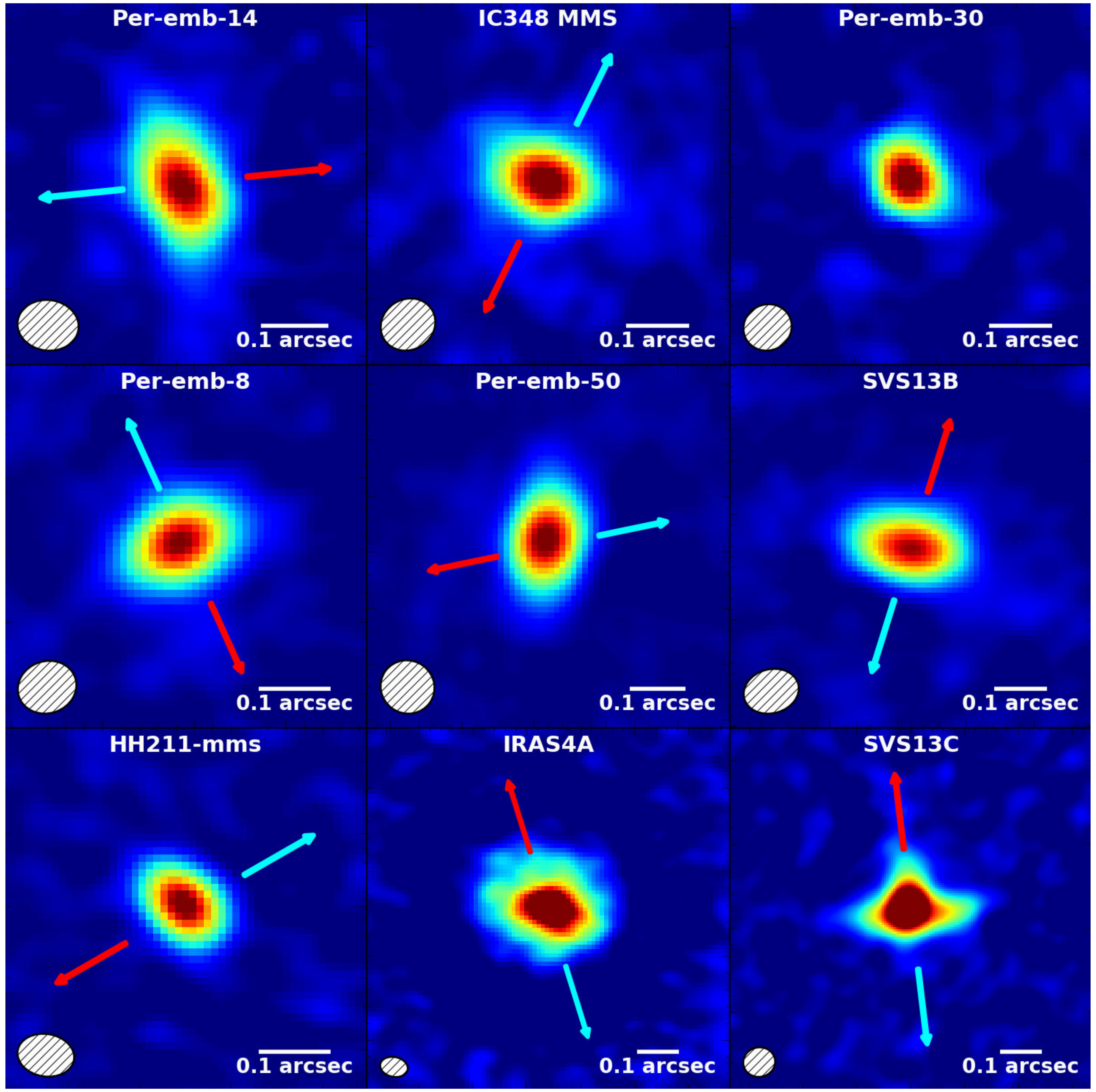
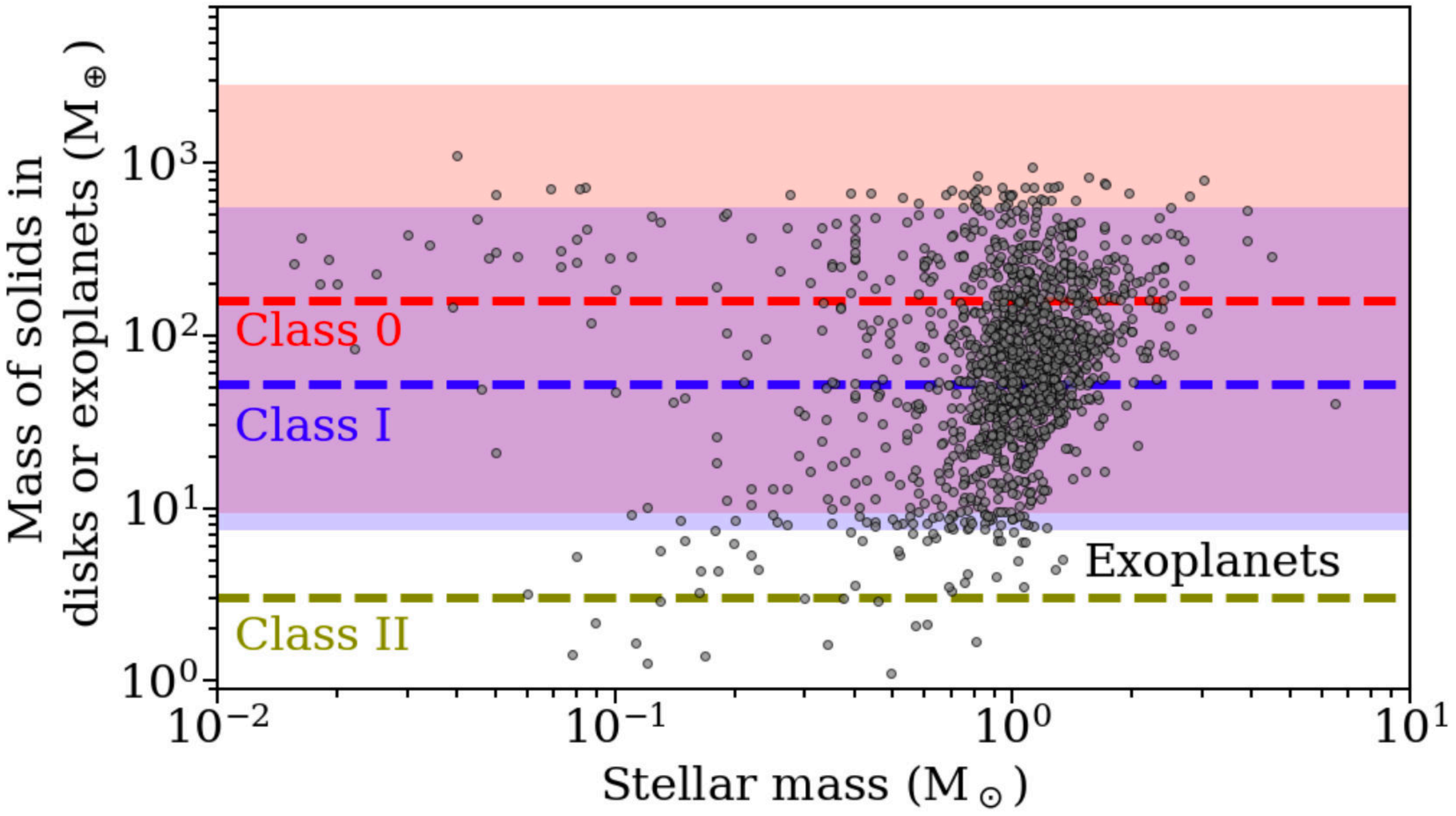
Embedded Disks can be Large and Massive



Segura-Cox et al. (2016, 2018)

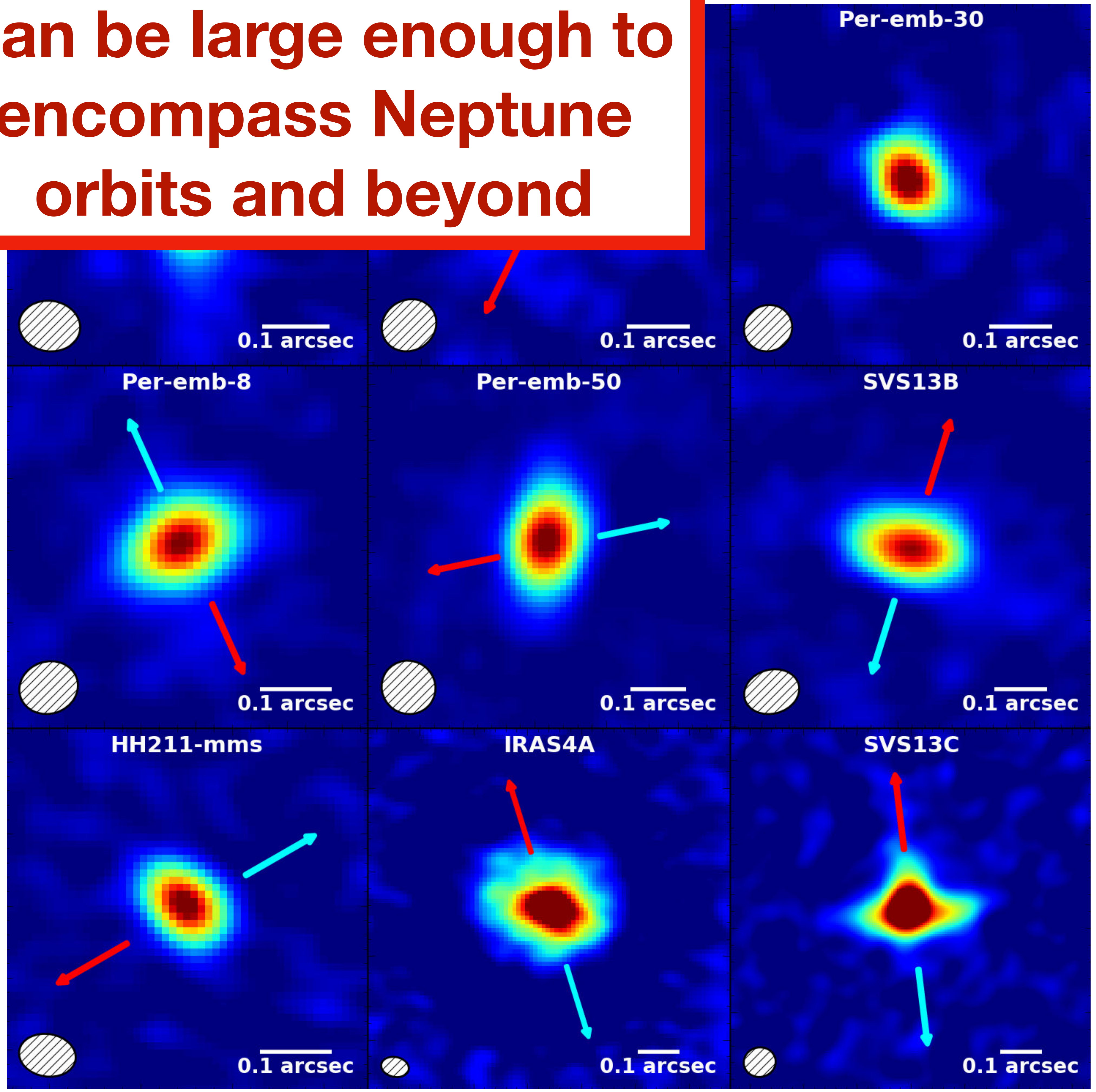


Tychoniec et al. (2020)

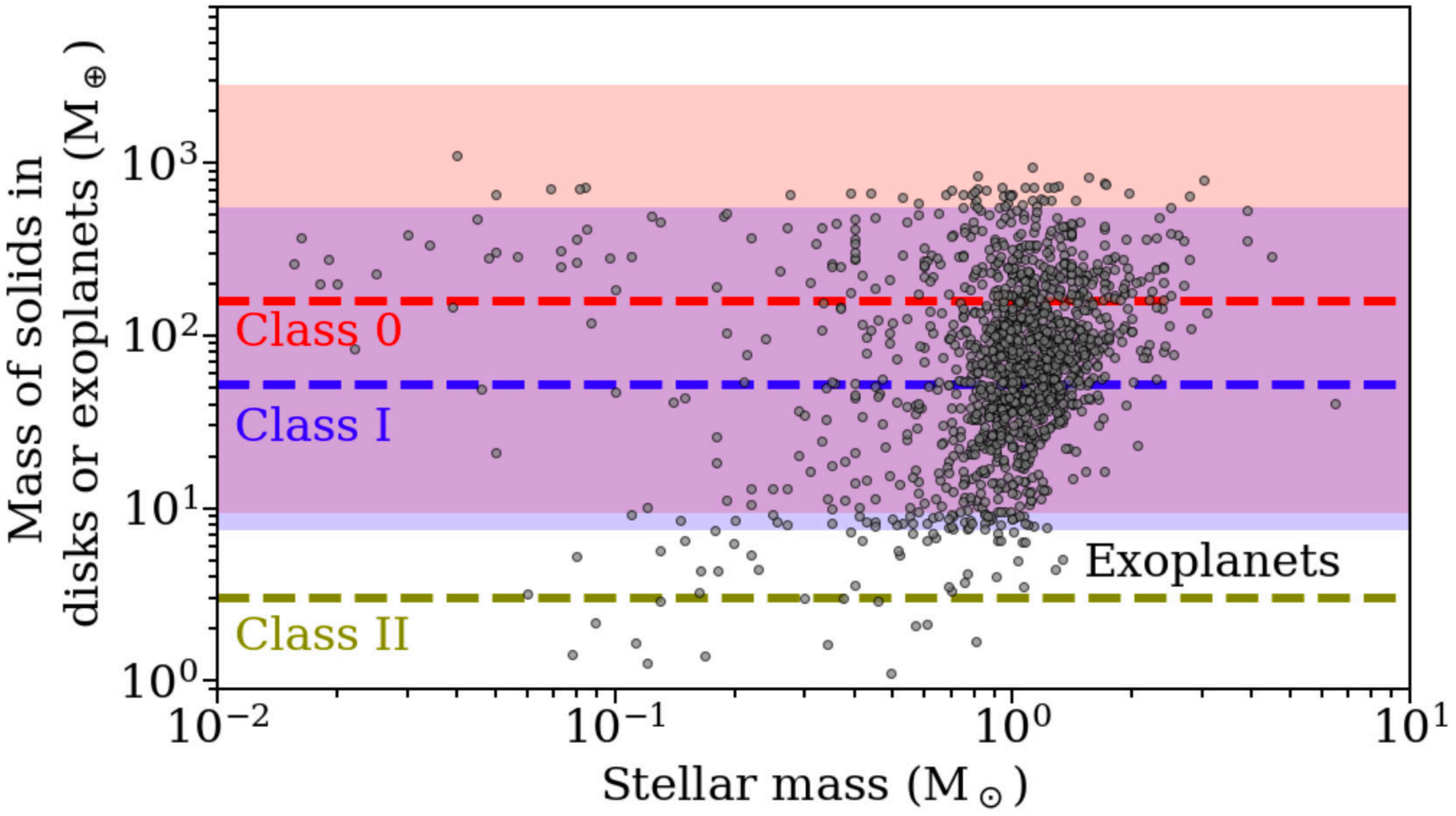
Dominique Segura-Cox

Embedded Disks can be Large and Massive

Can be large enough to encompass Neptune orbits and beyond



Segura-Cox et al. (2016, 2018)



Tychoniec et al. (2020)

Dominique Segura-Cox

Embedded Disks can be Large and Massive

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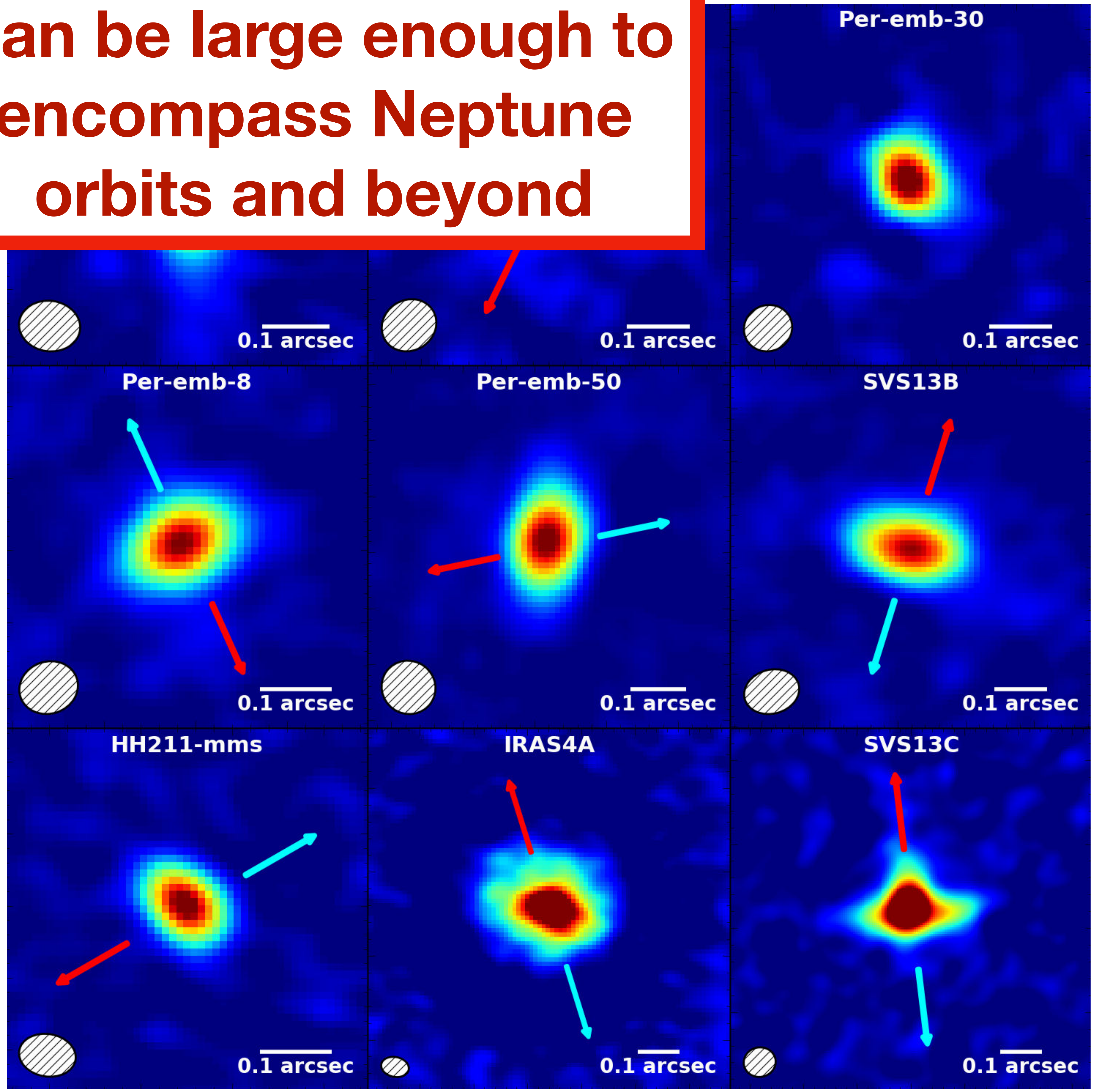
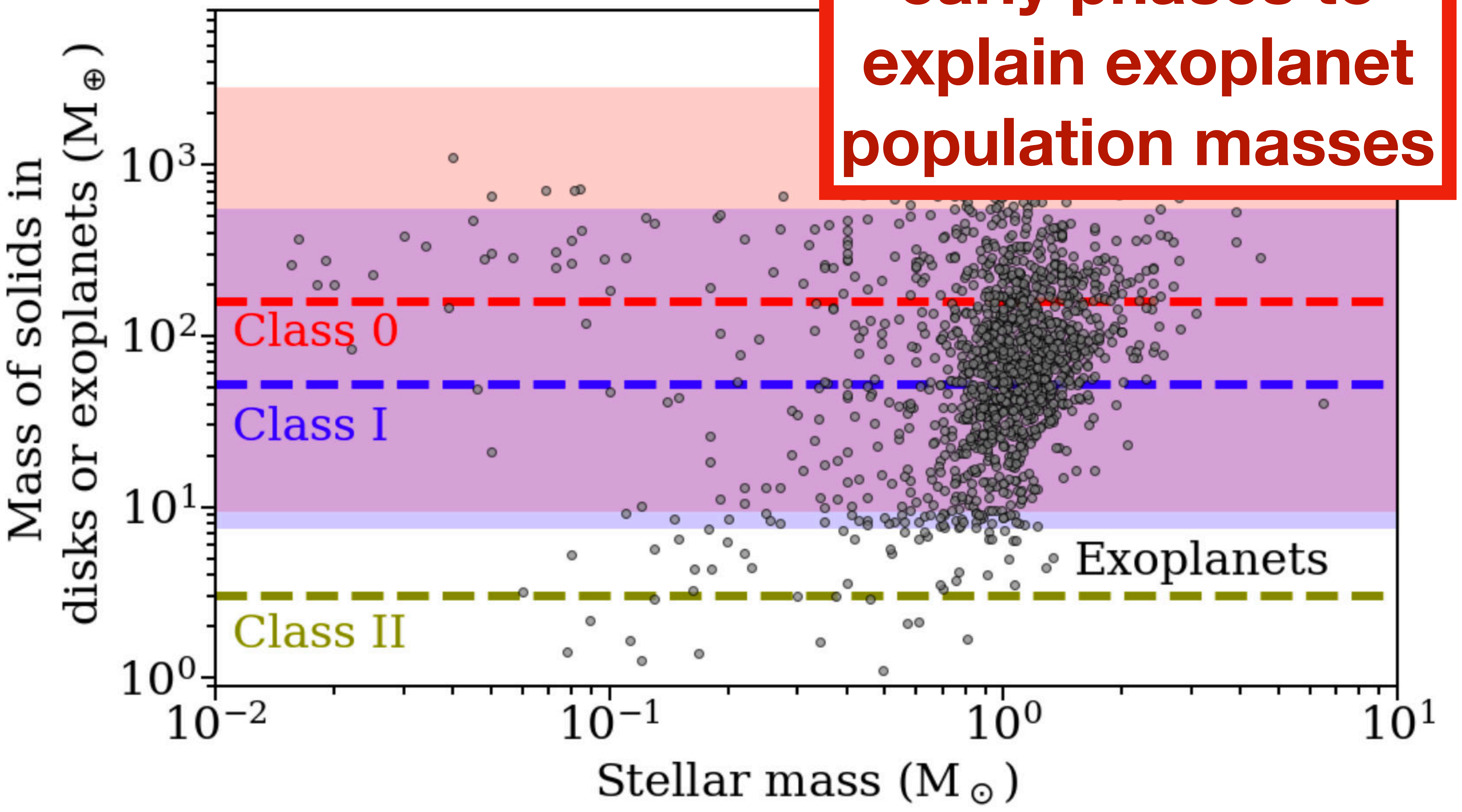


Segura-Cox et al. (2016, 2018)

Enough mass in early phases to explain exoplanet population masses



Tychoniec et al. (2020)

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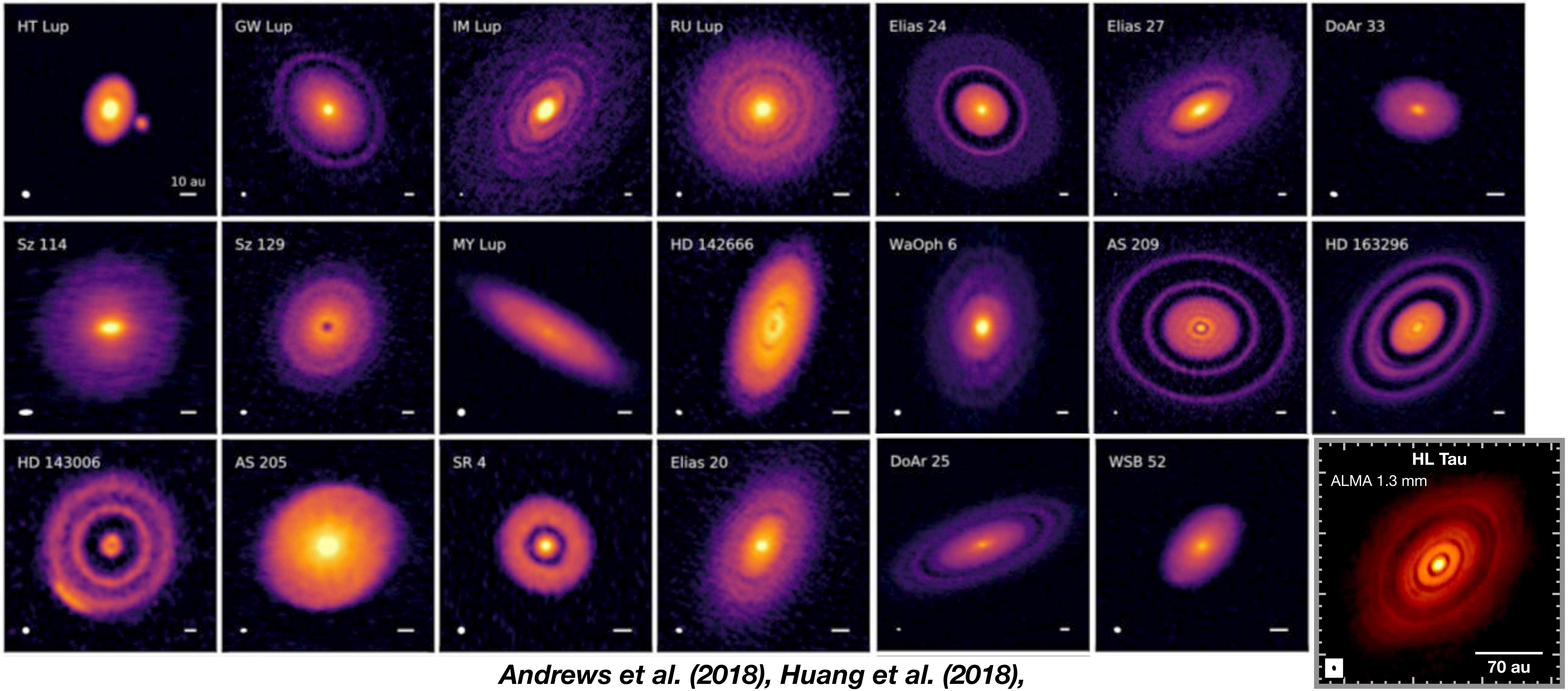
>1 Million Year Disks Have Rings

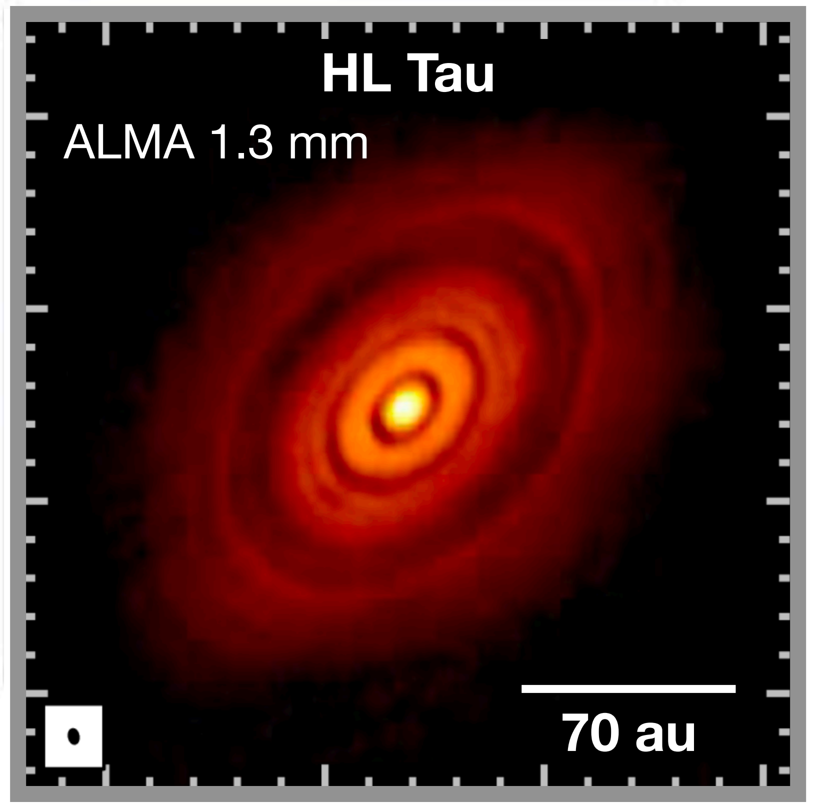


Andrews et al. (2018), Huang et al. (2018),
ALMA Partnership et al. (2015)

Dominique Segura-Cox

>1 Million Year Disks Have Rings

So when do these rings start to form?



Andrews et al. (2018), Huang et al. (2018), ALMA Partnership et al. (2015)

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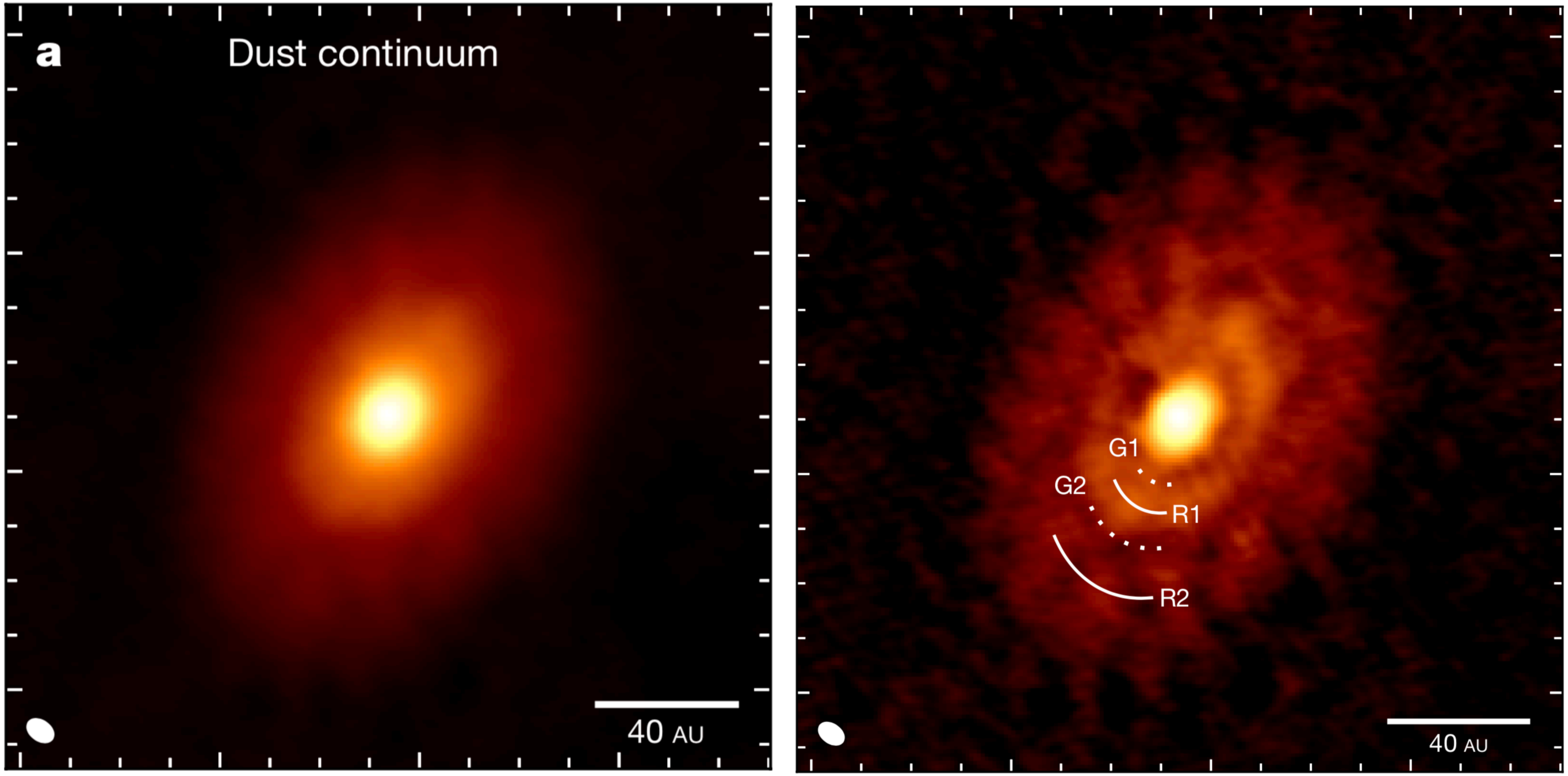
The Youngest Rings

IRS 63



Segura-Cox et al. (2020)

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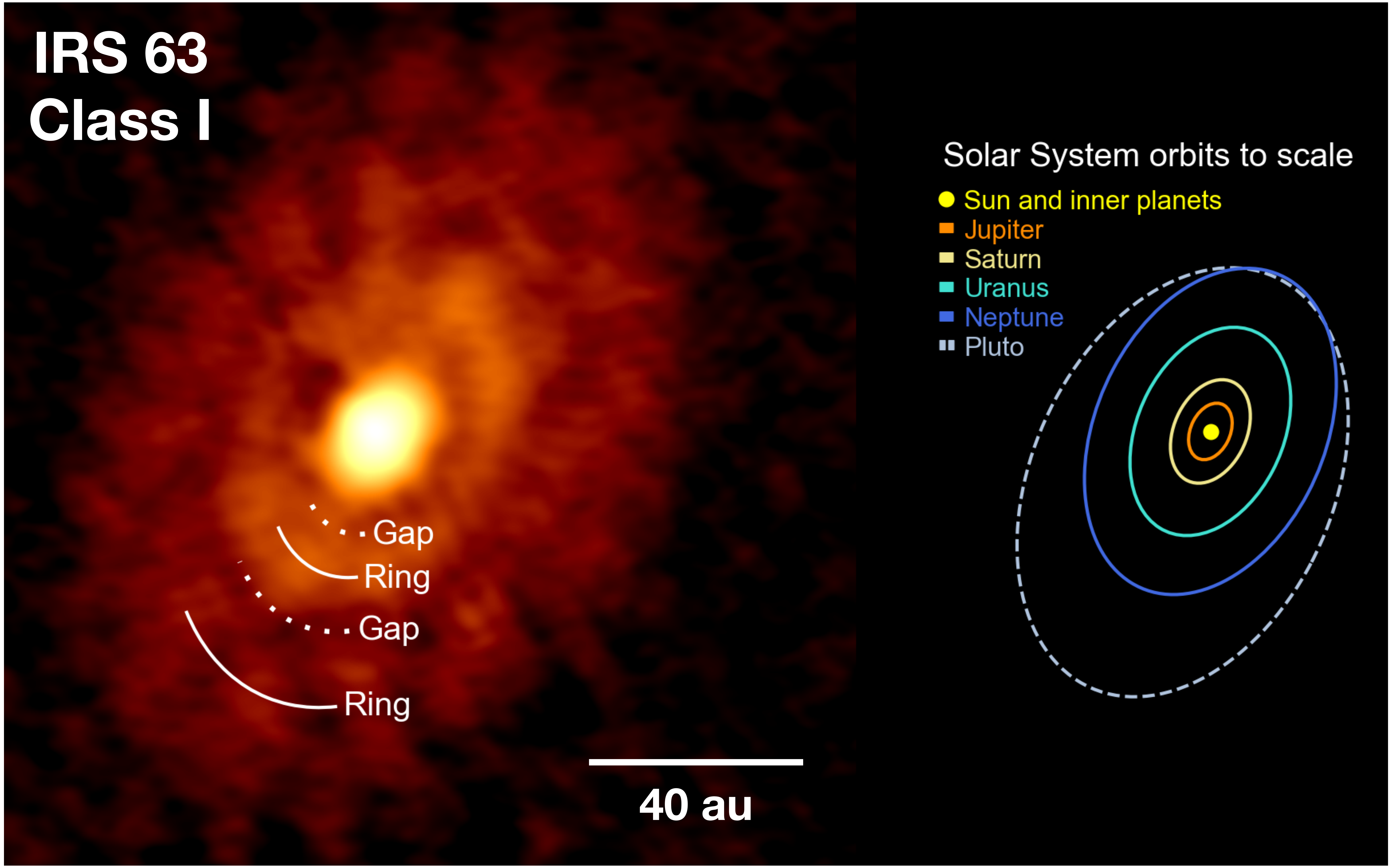
A Solar System Scale Class I Disk



Segura-Cox et al. (Nature 2020)

Enough mass in solid material in the rings to form multiple giant planet cores

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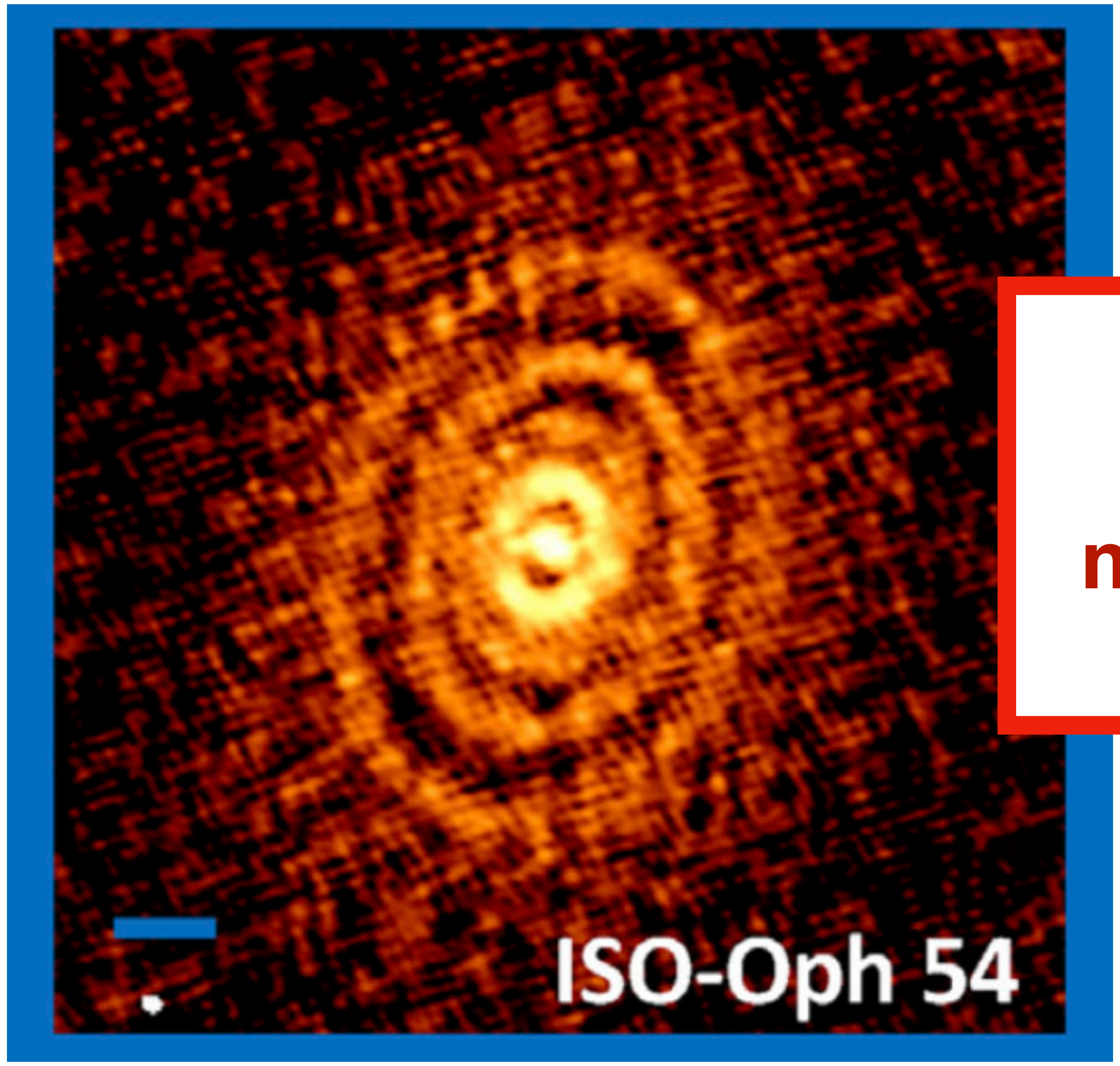
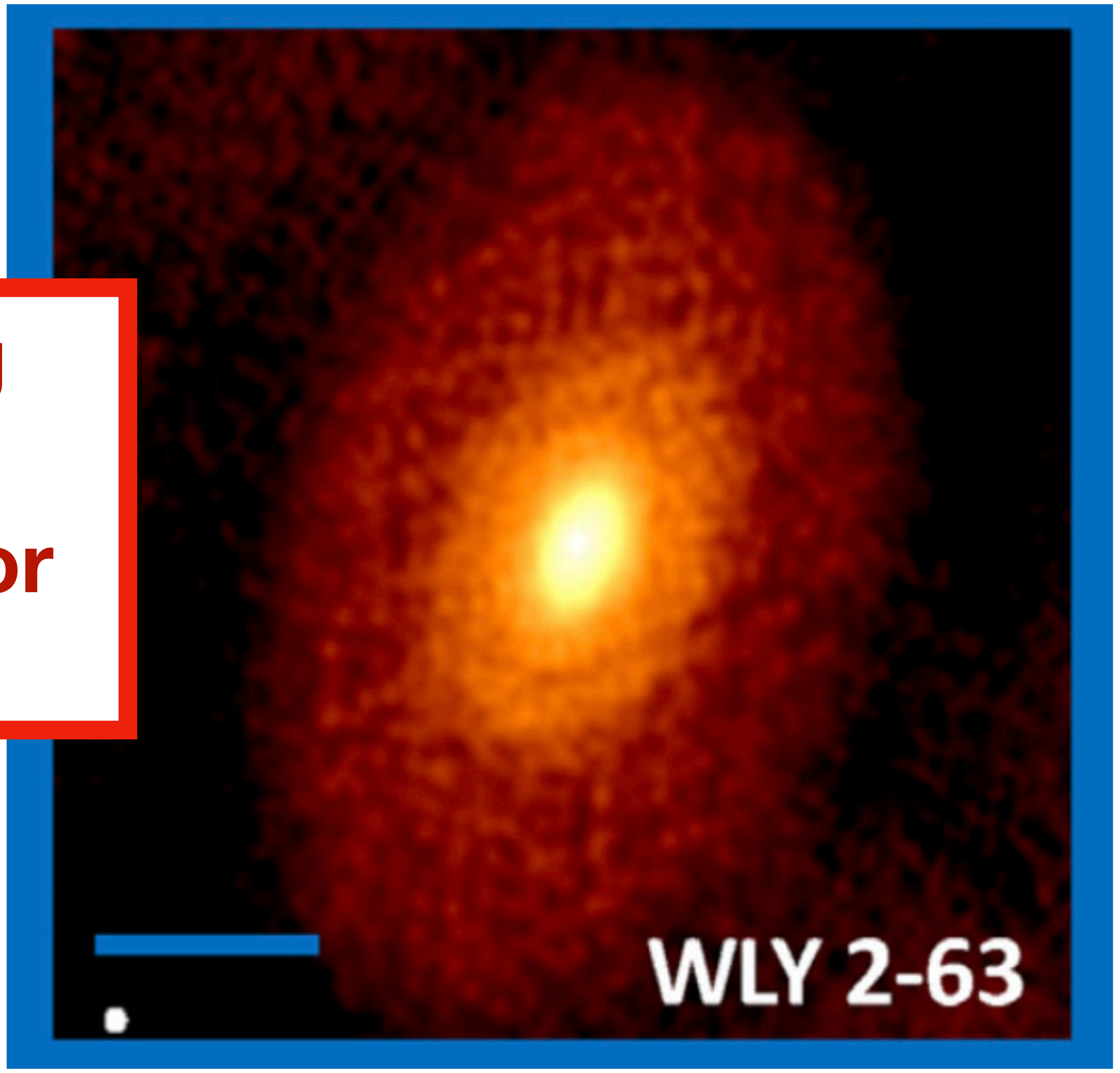
Young Rings: Deep vs. Shallow



Different ring formation mechanisms or timescales?



Cieza et al. (2021)

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Young Rings: Multi-wavelength View

Sheehan et al. (2018)

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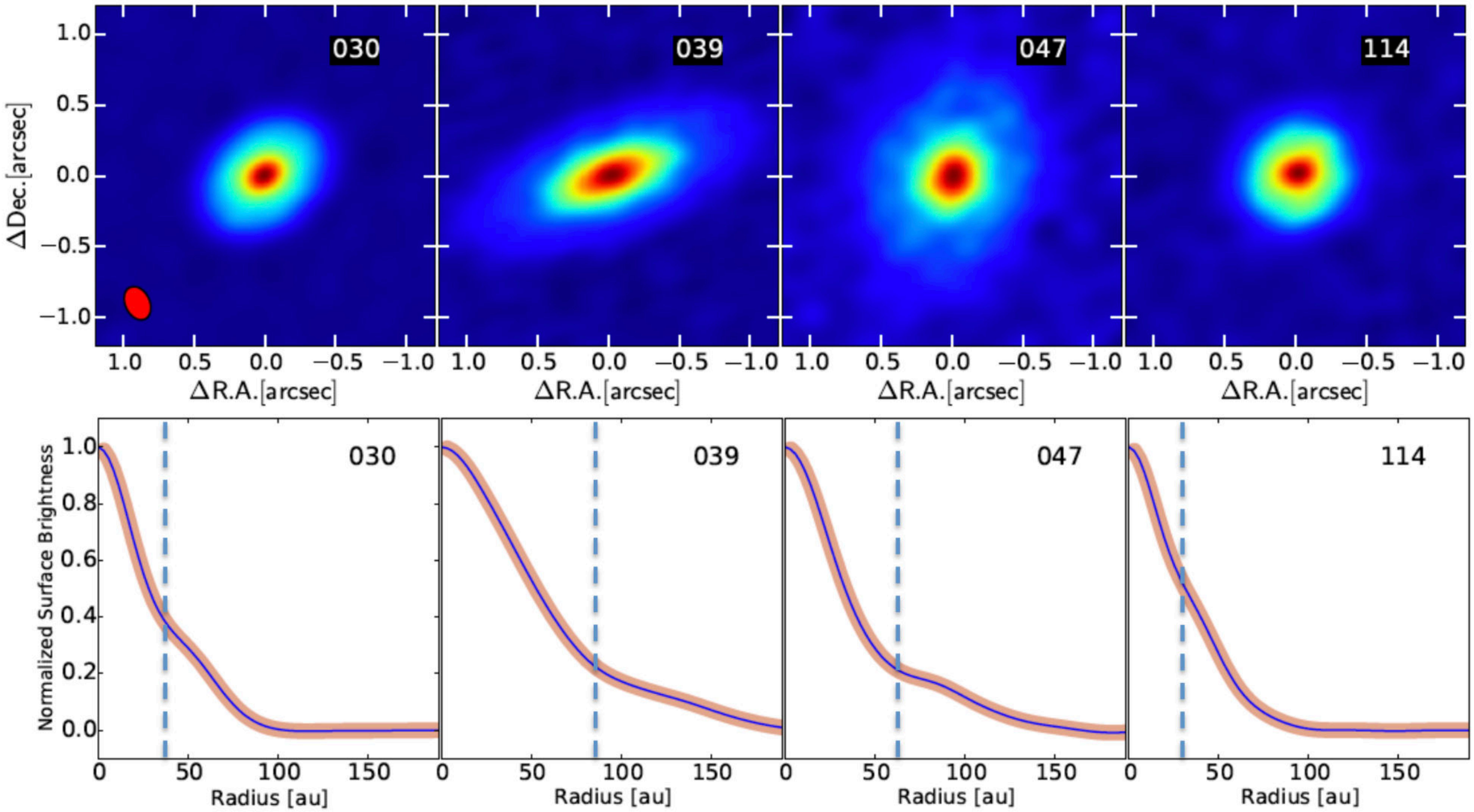
Radial Profiles Hint at Substructures



Cieza et al. (2019)

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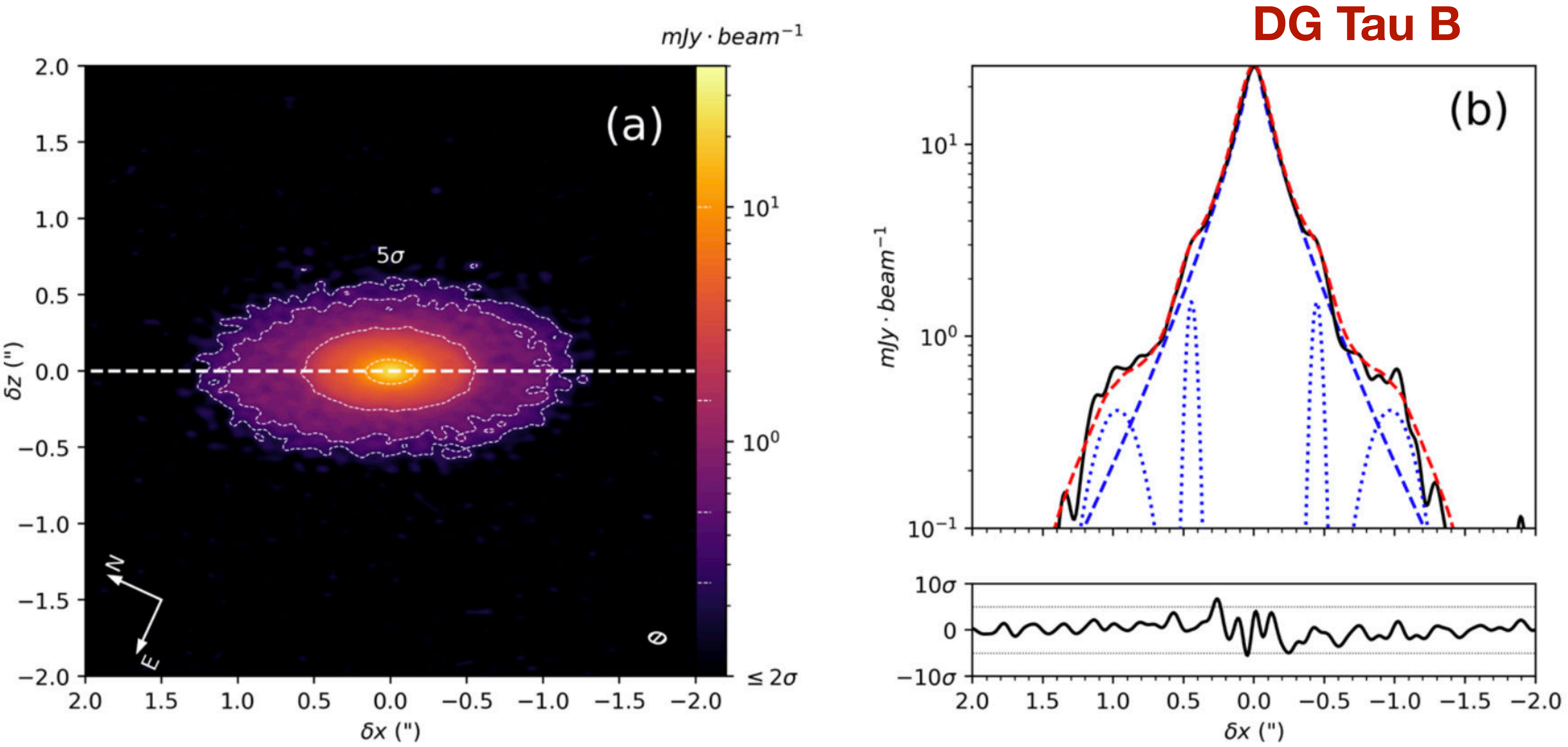
Radial Profiles Hint at Substructures



de Valon et al. (2020)

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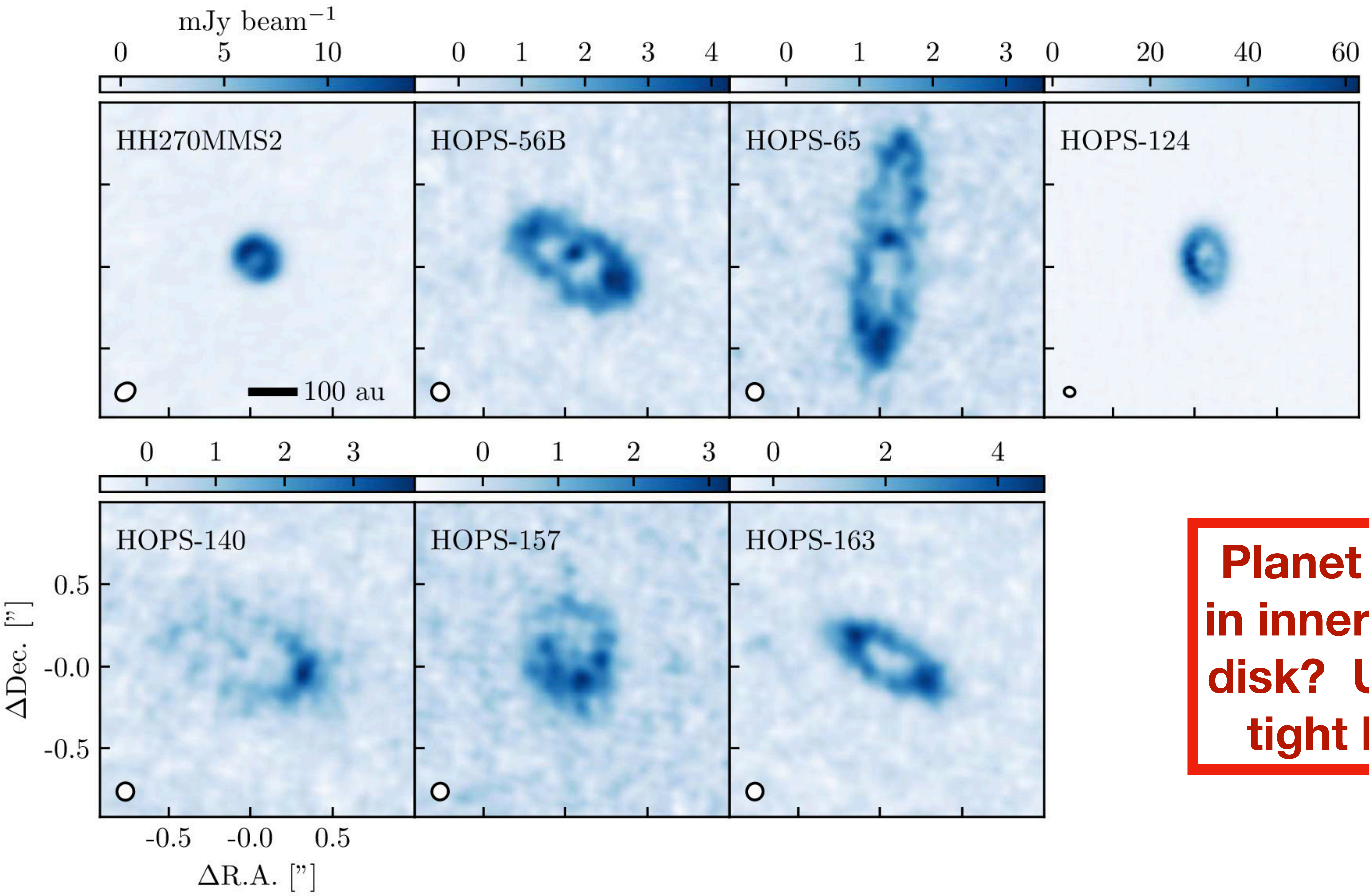
Young Cavities



Planet formation in inner regions of disk? Unresolved tight binaries?

Sheehan et al. (2020)

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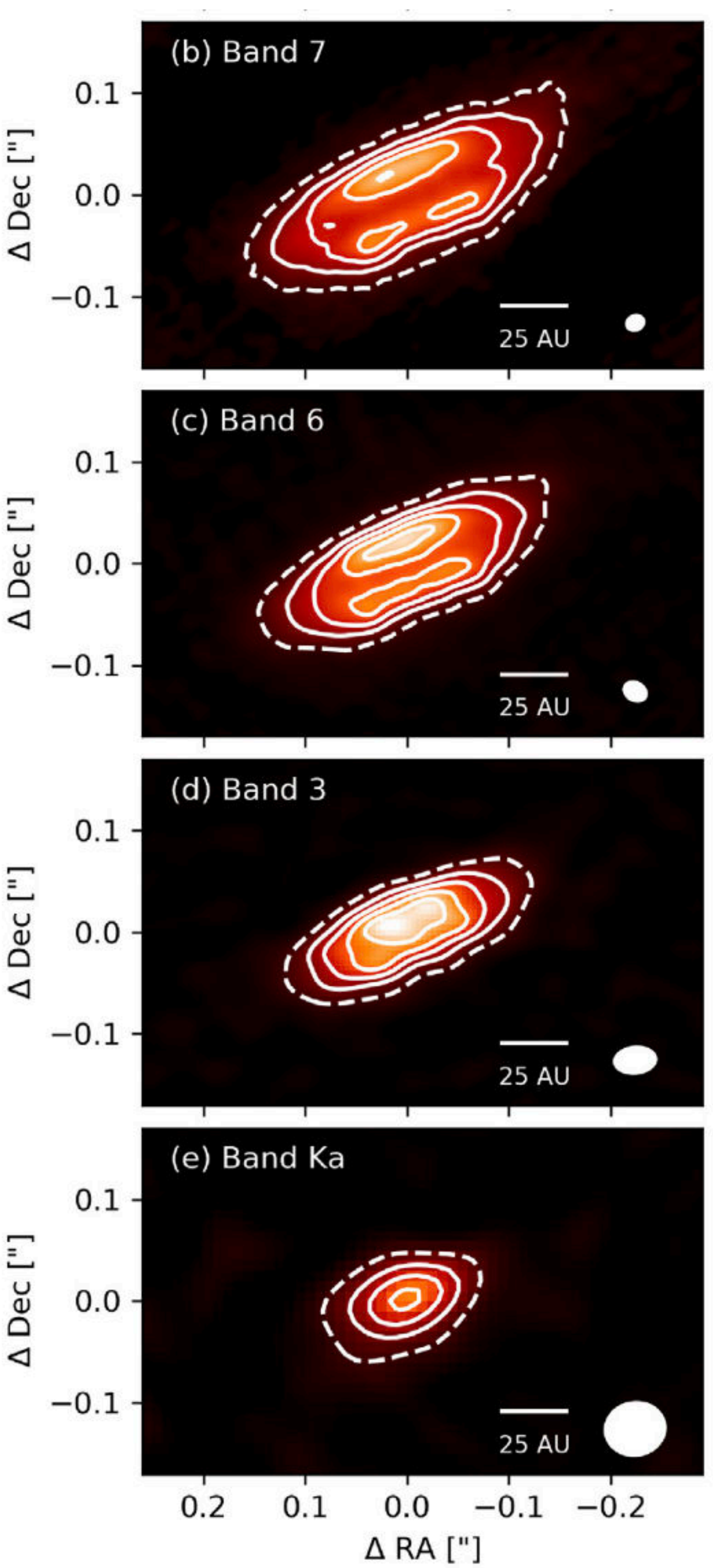
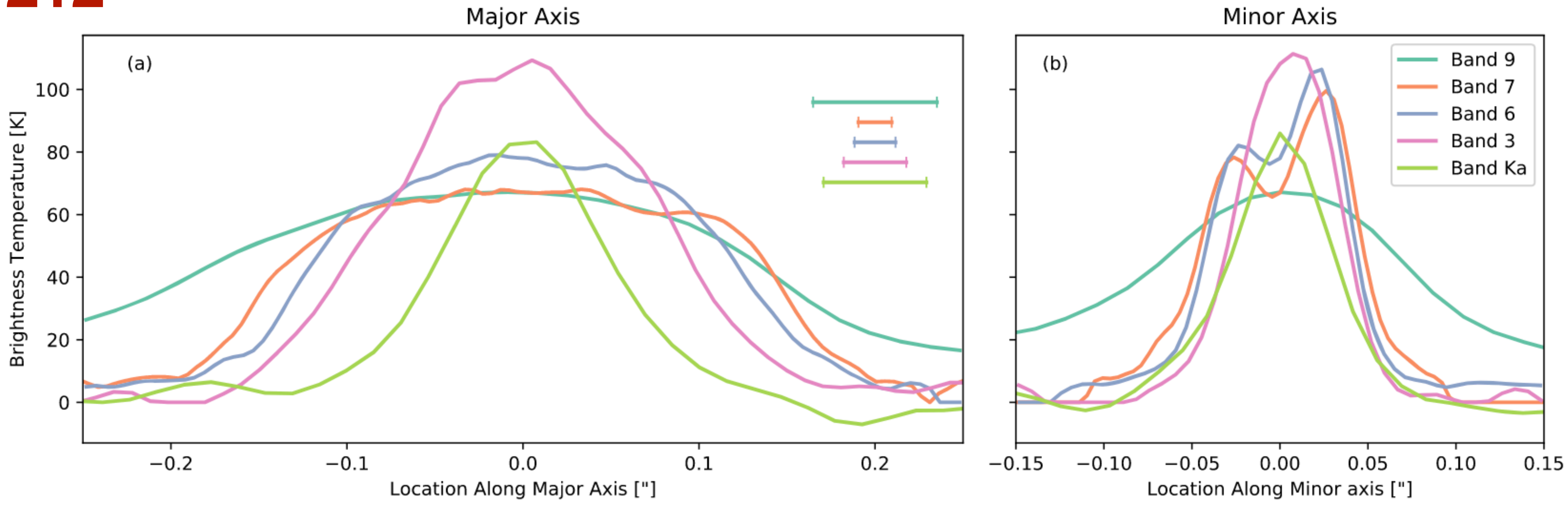
Continuum Shows Warm Disks



Modeling the continuum at multiple wavelengths show disk temperature > 20 - 30 K

HH 212



Lin et al. (2021)

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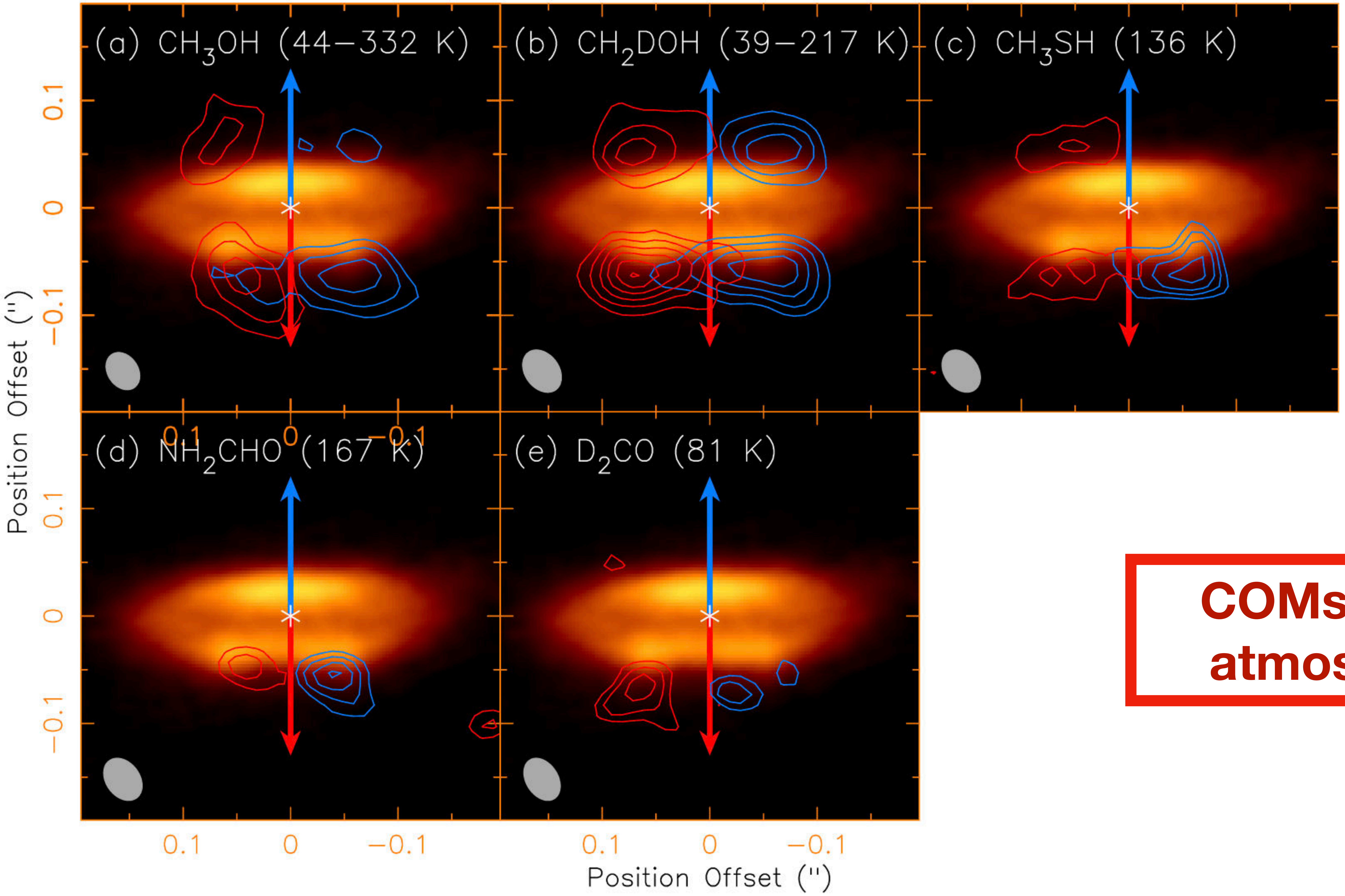
Chemistry Shows Warm Disks

HH 212



Lee et al. (2017)

COMs in disk atmosphere.

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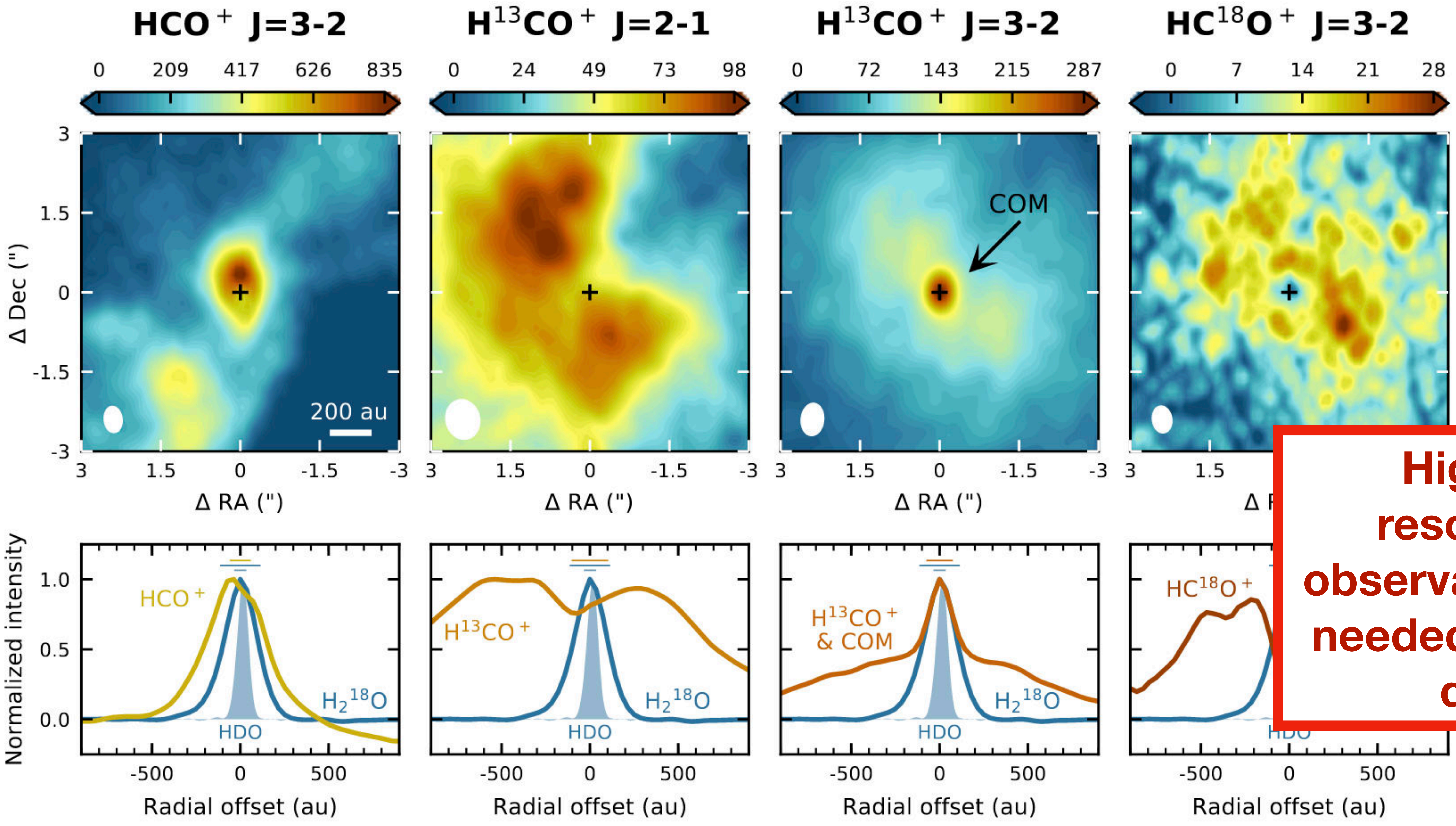
Snowlines Reveal Warm Disks

B1-c



Highest resolution observations not needed to show disk

van 't Hoff et al. (2021)

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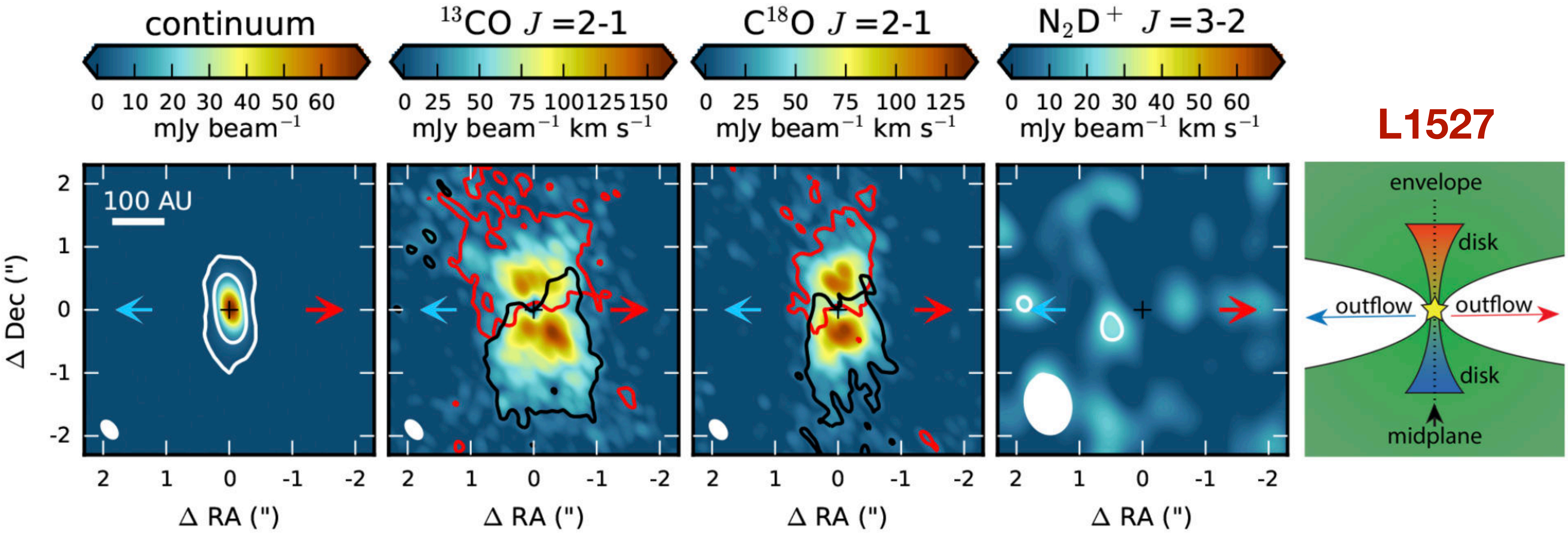
A Warm Edge-on Disk



van 't Hoff et al. (2018)

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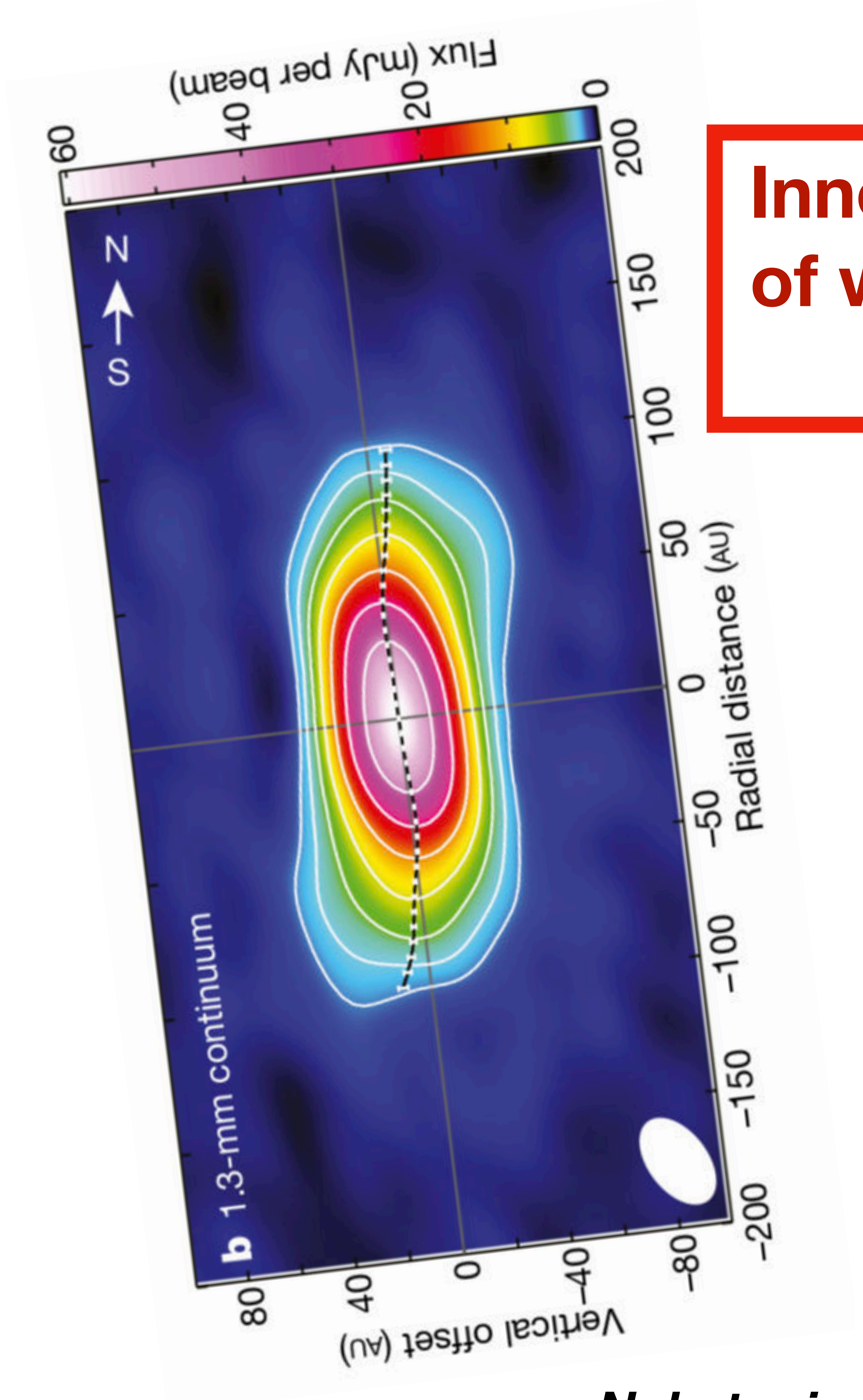
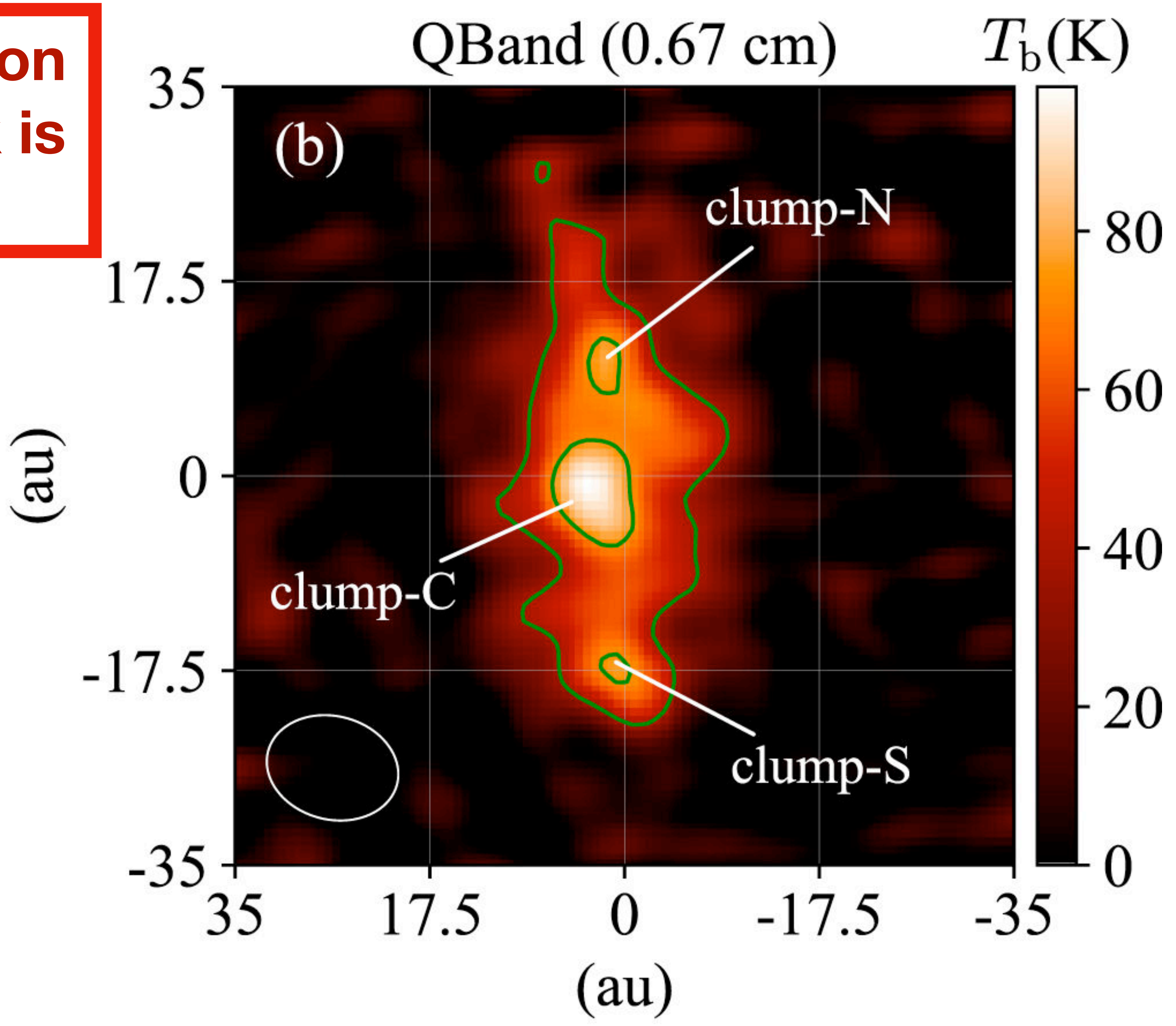
An Warm Edge-on Disk with Substructures



Innermost region of warped disk is clumpy.

L1527



Nakatani et al. (2020), Sakai et al. (2018)

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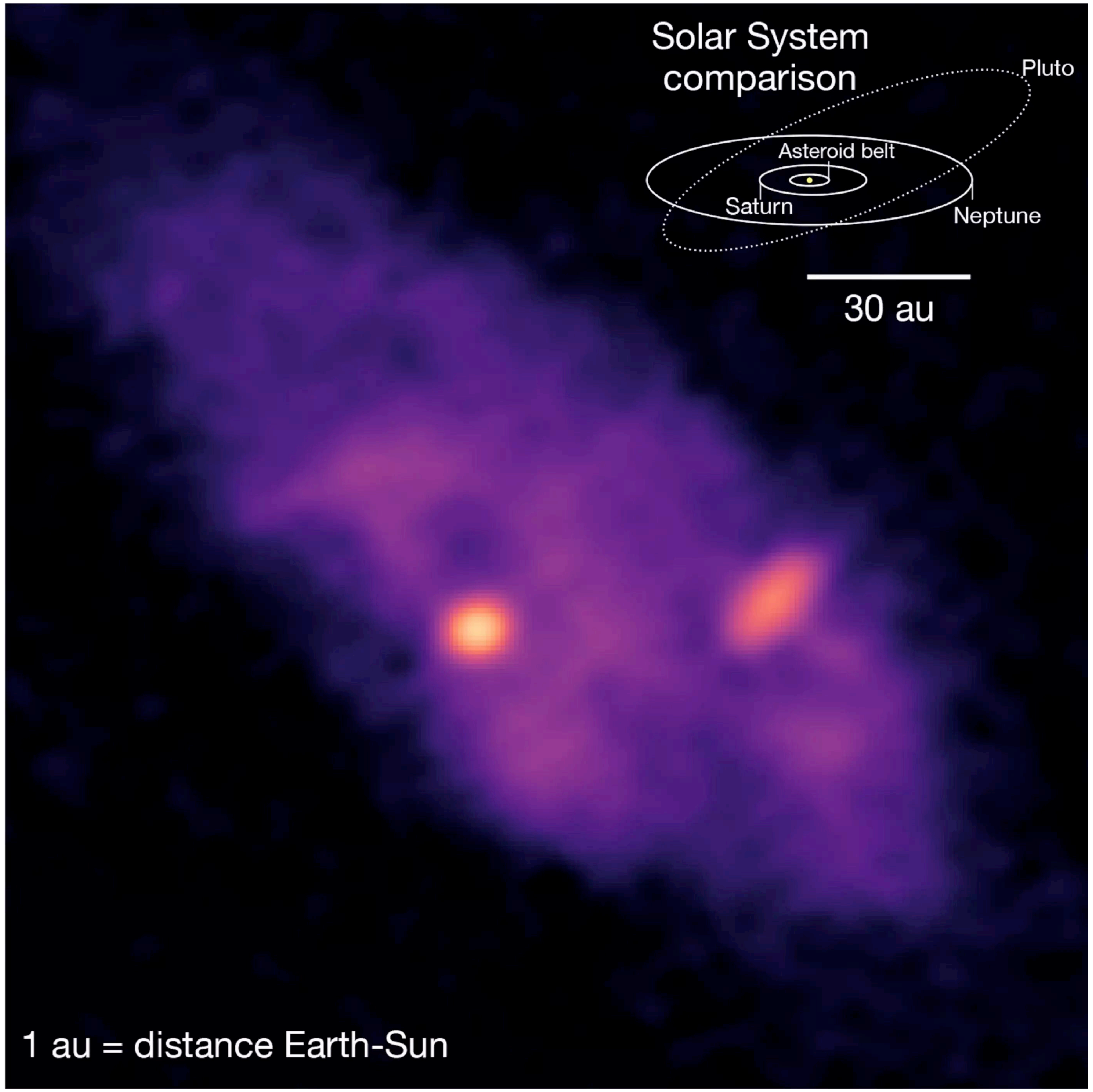
More Warm Disks



IRAS 16293 A

Close multiples can also have warm disks at solar-system scales.

Maureira et al. (2020)

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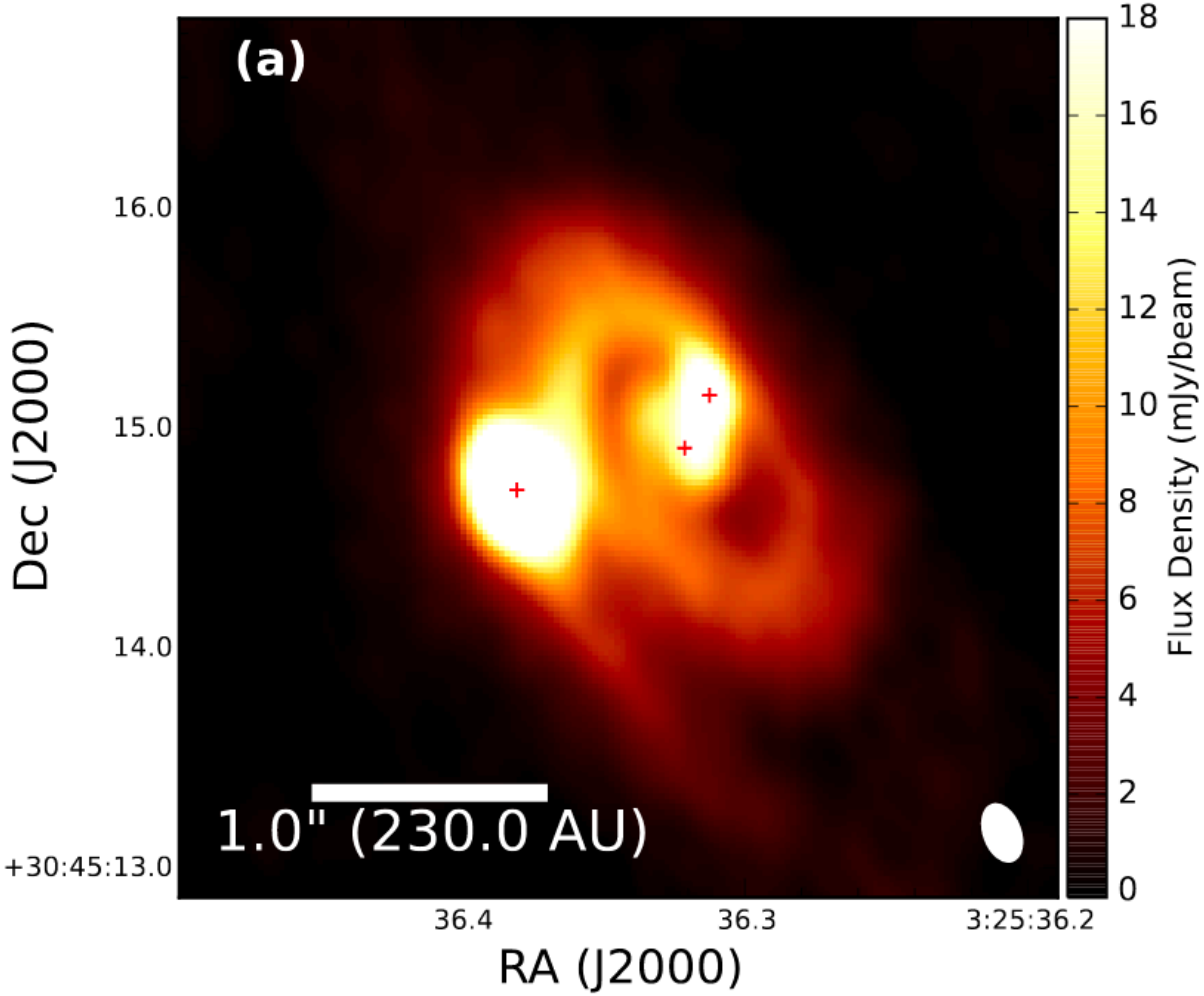
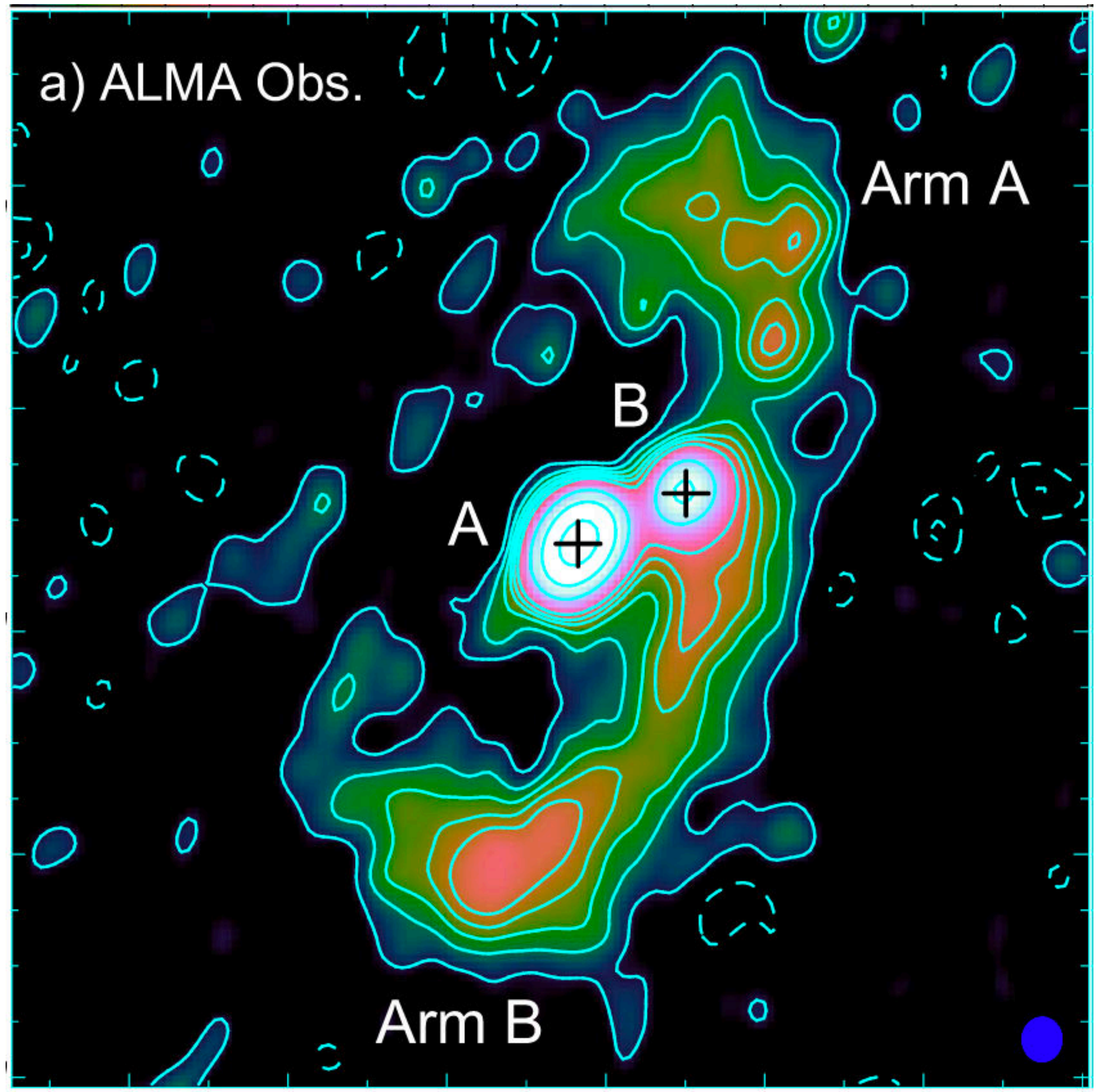
Close Multiples

L1448-IRS3B



Tobin et al. (2016)

L1551 NE



Takakuwa et al. (2017)

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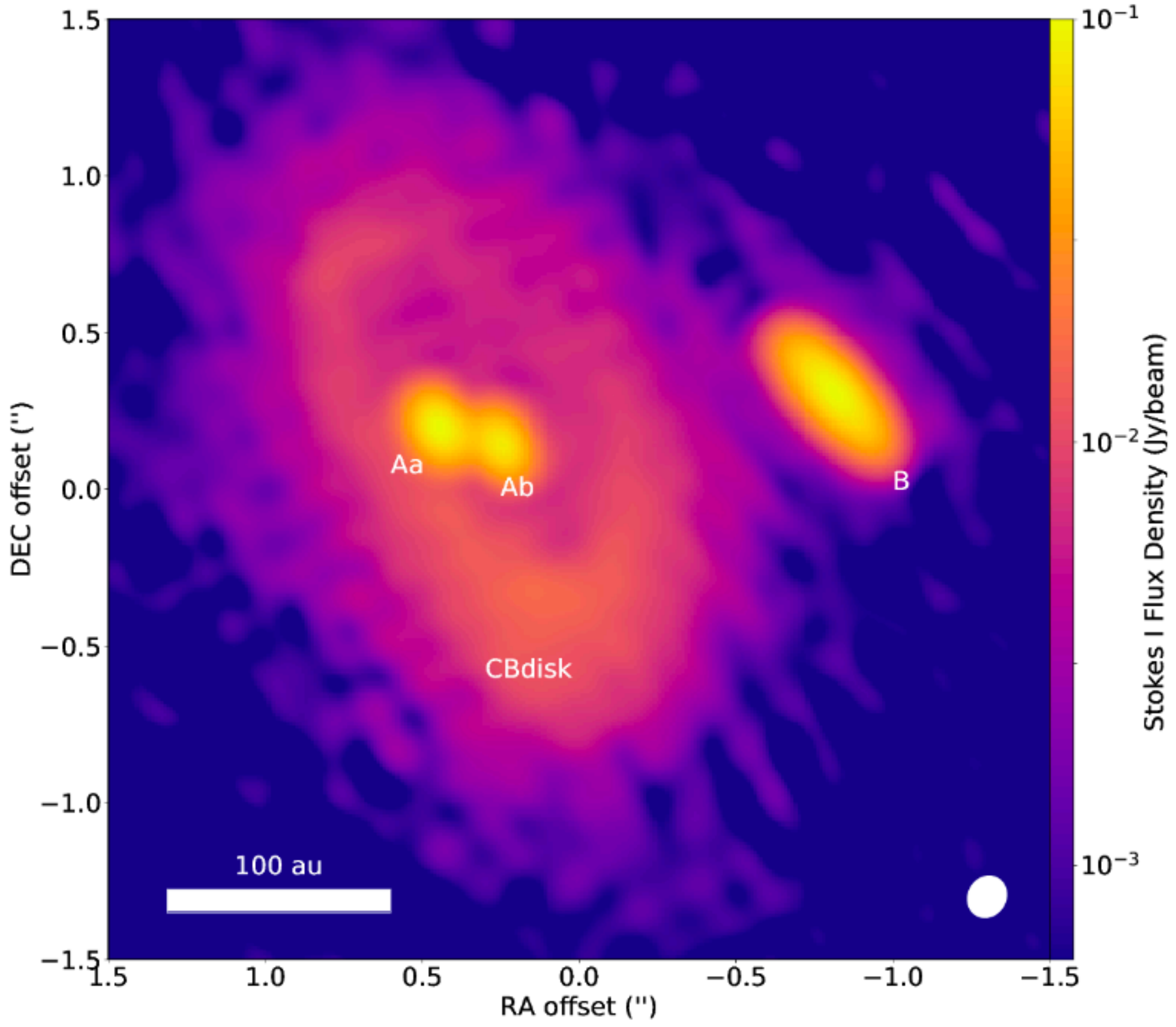
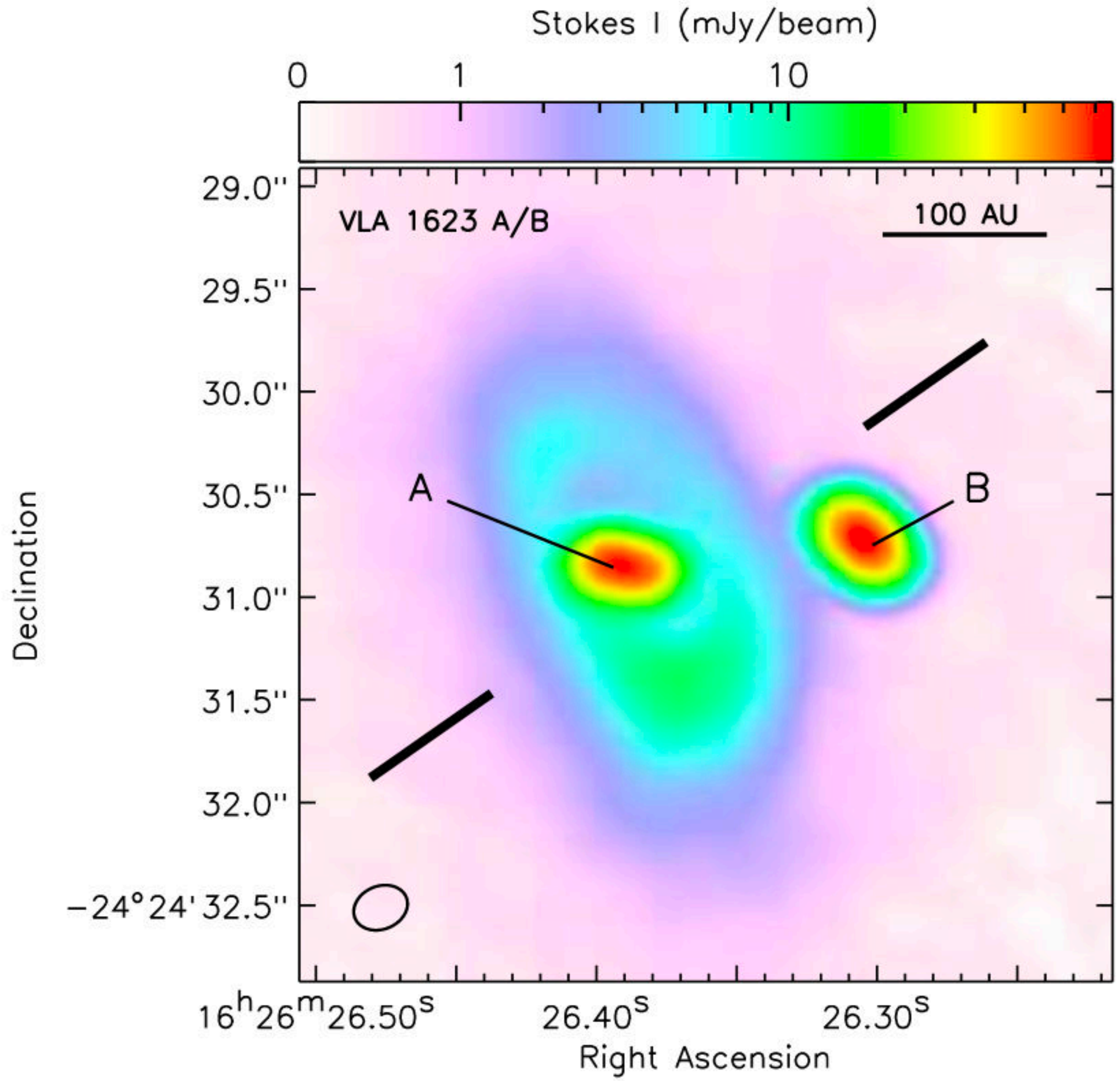
Close Multiples

VLA 1623



Harris et al. (2018)



Sadavoy et al. (2018)

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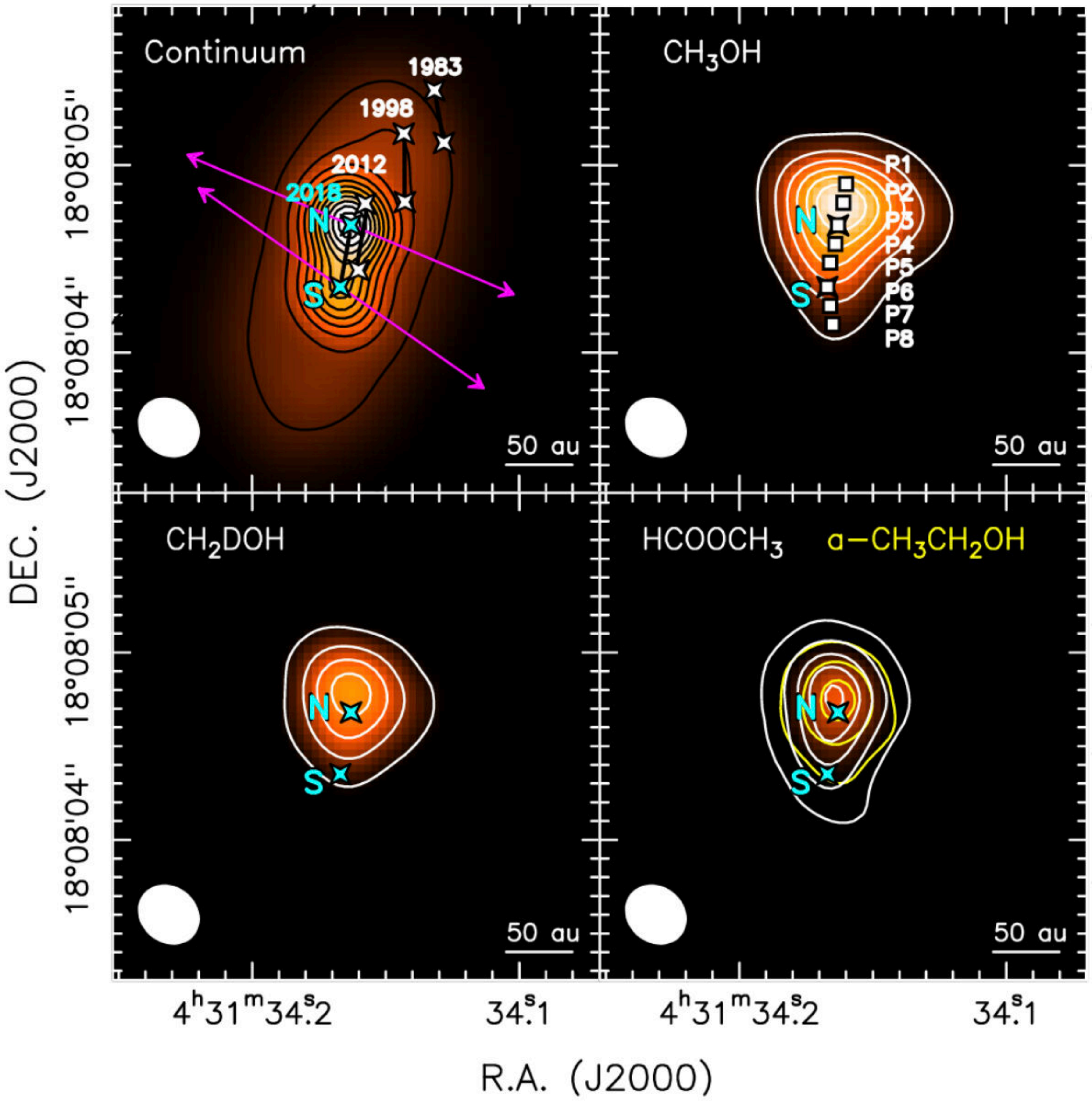
Close Multiples



L1551 IRS5

Clear chemical differentiation between the two sources. True differentiation? Optical depth?

Bianchi et al. (2020)

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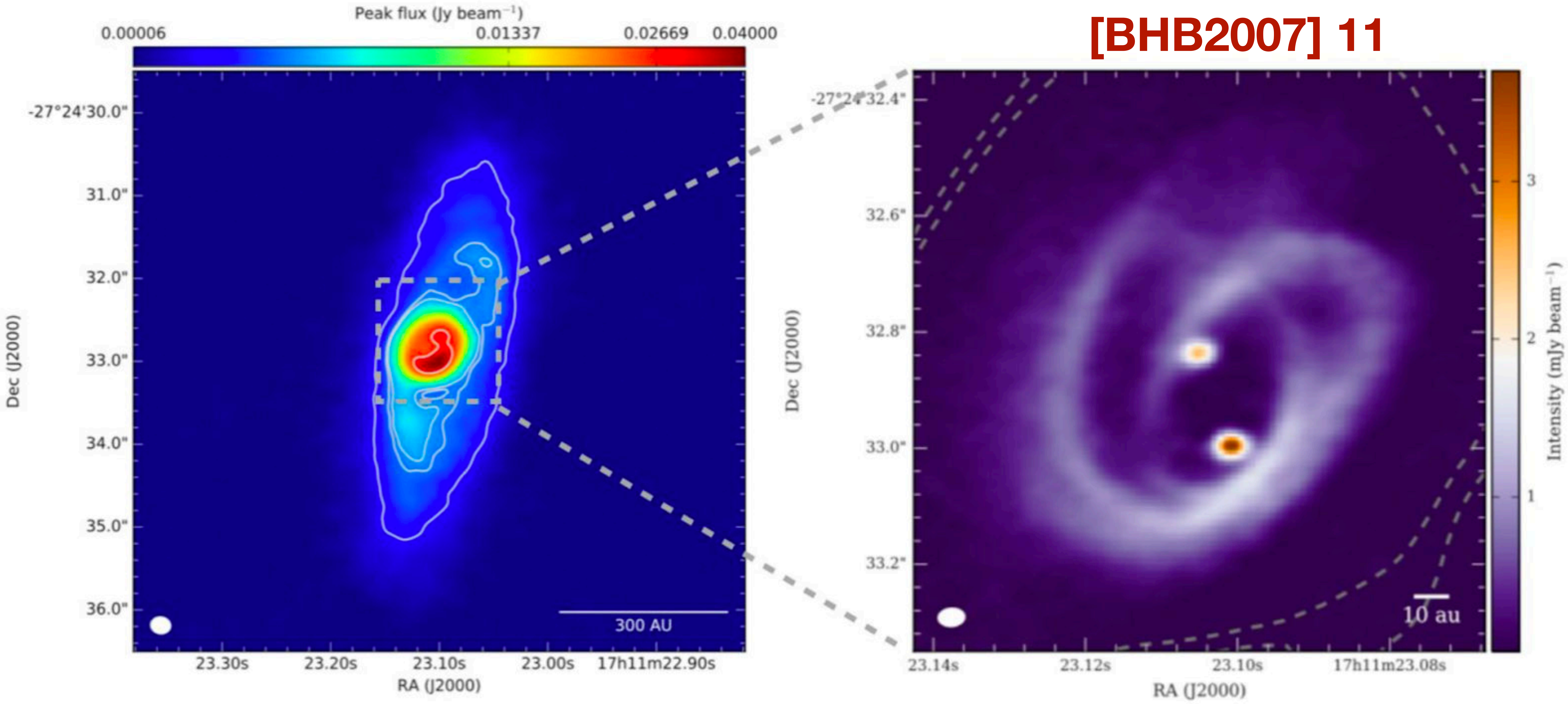
Close Multiples, Multi-scale Complex Structures



Alves et al. (2017, 2019)

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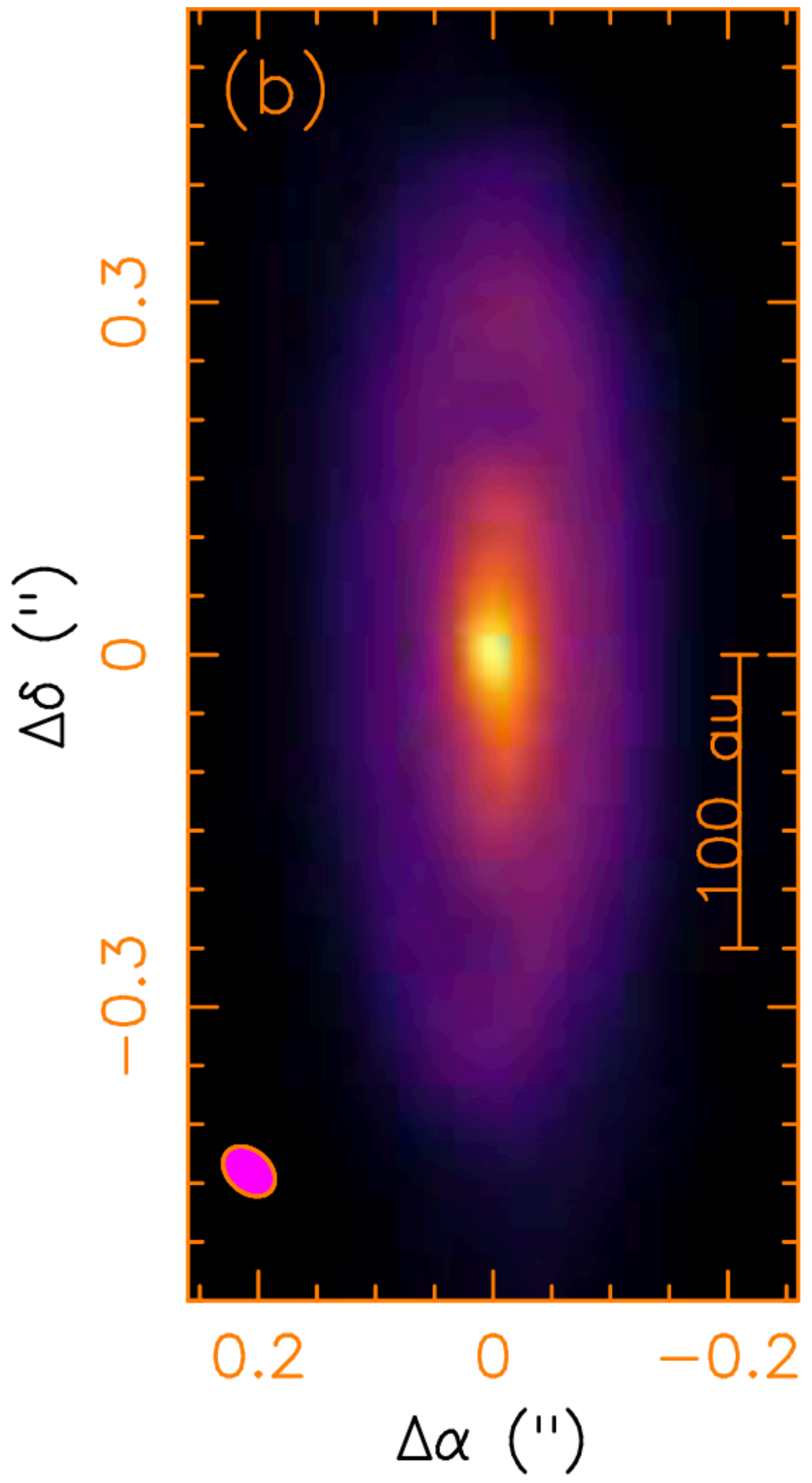
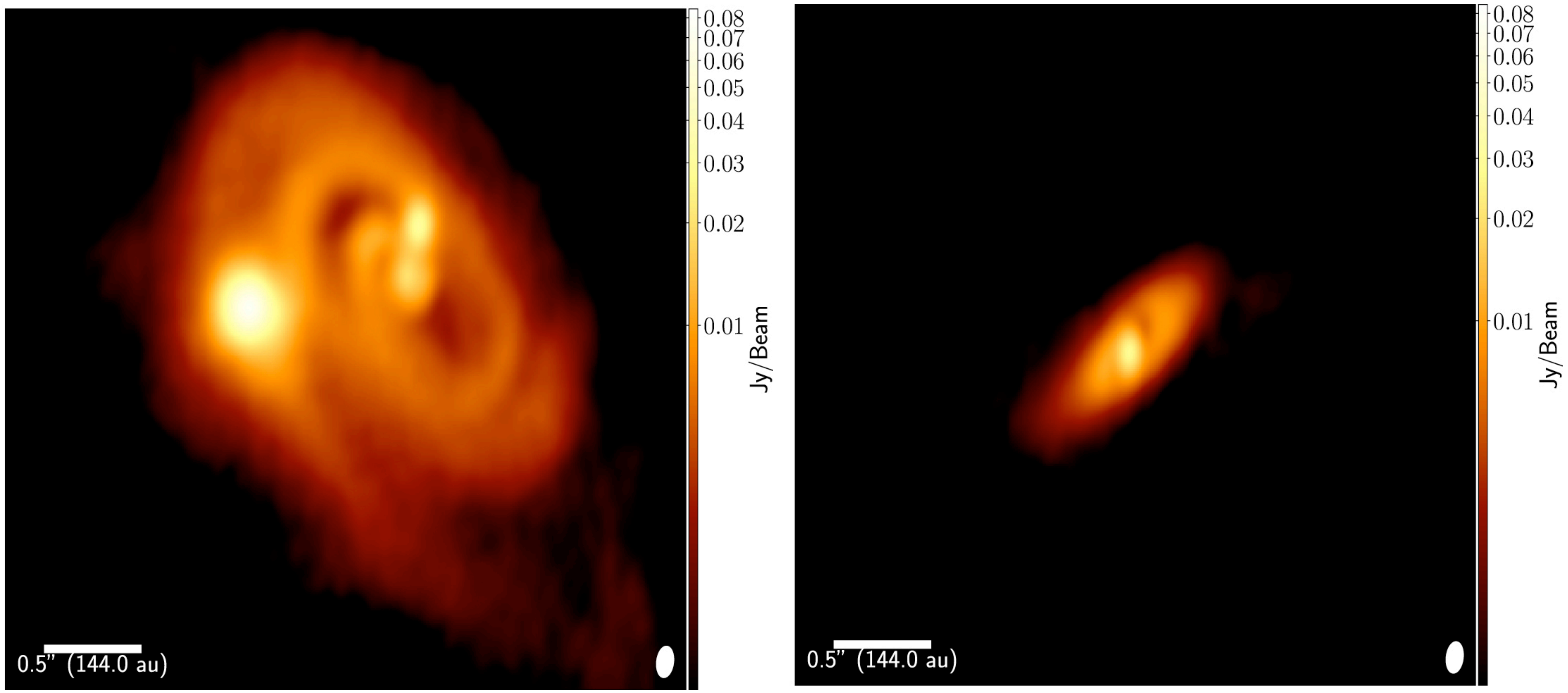
Spirals



HH 111 VLA 2



L1448-IRS3B & L1448 IRS3A

Lee et al. (2020), Reynolds et al. (2021)

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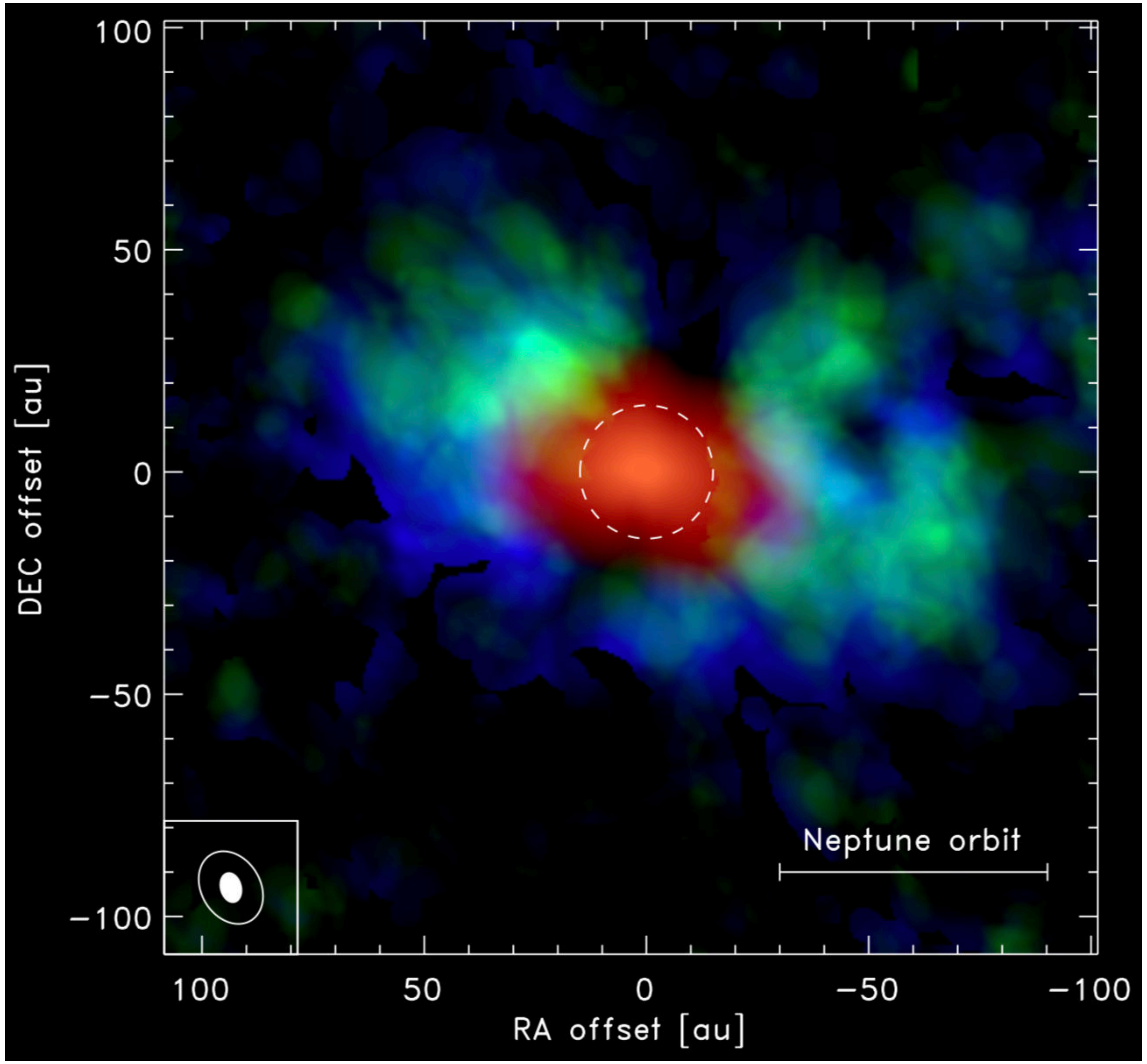
Observing Grain Growth



TMC1A

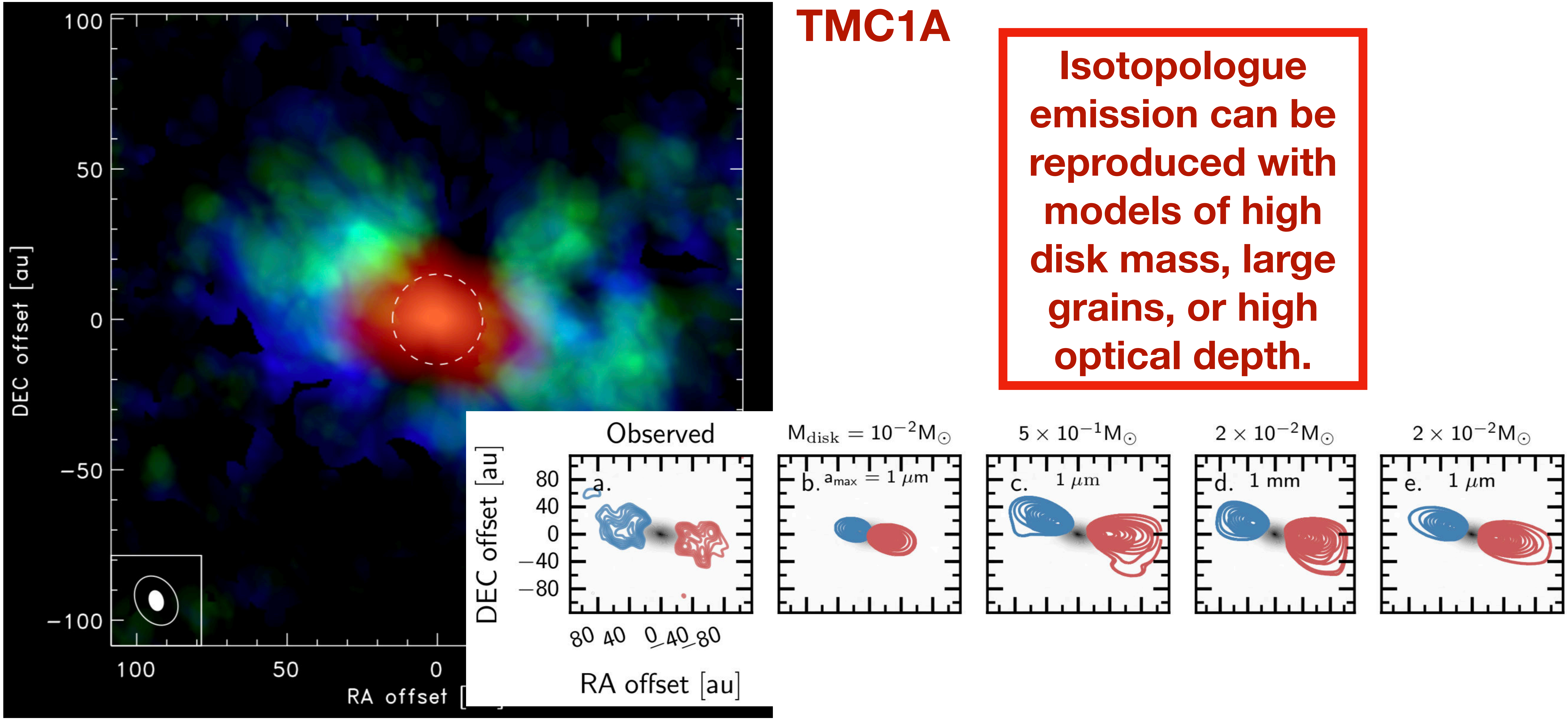
CO isotopologues disappear where the continuum emission peaks.

Harsono et al. (2018)

Dominique Segura-Cox

Observing Grain Growth

TMC1A



Isotopologue emission can be reproduced with models of high disk mass, large grains, or high optical depth.

Harsono et al. (2018)

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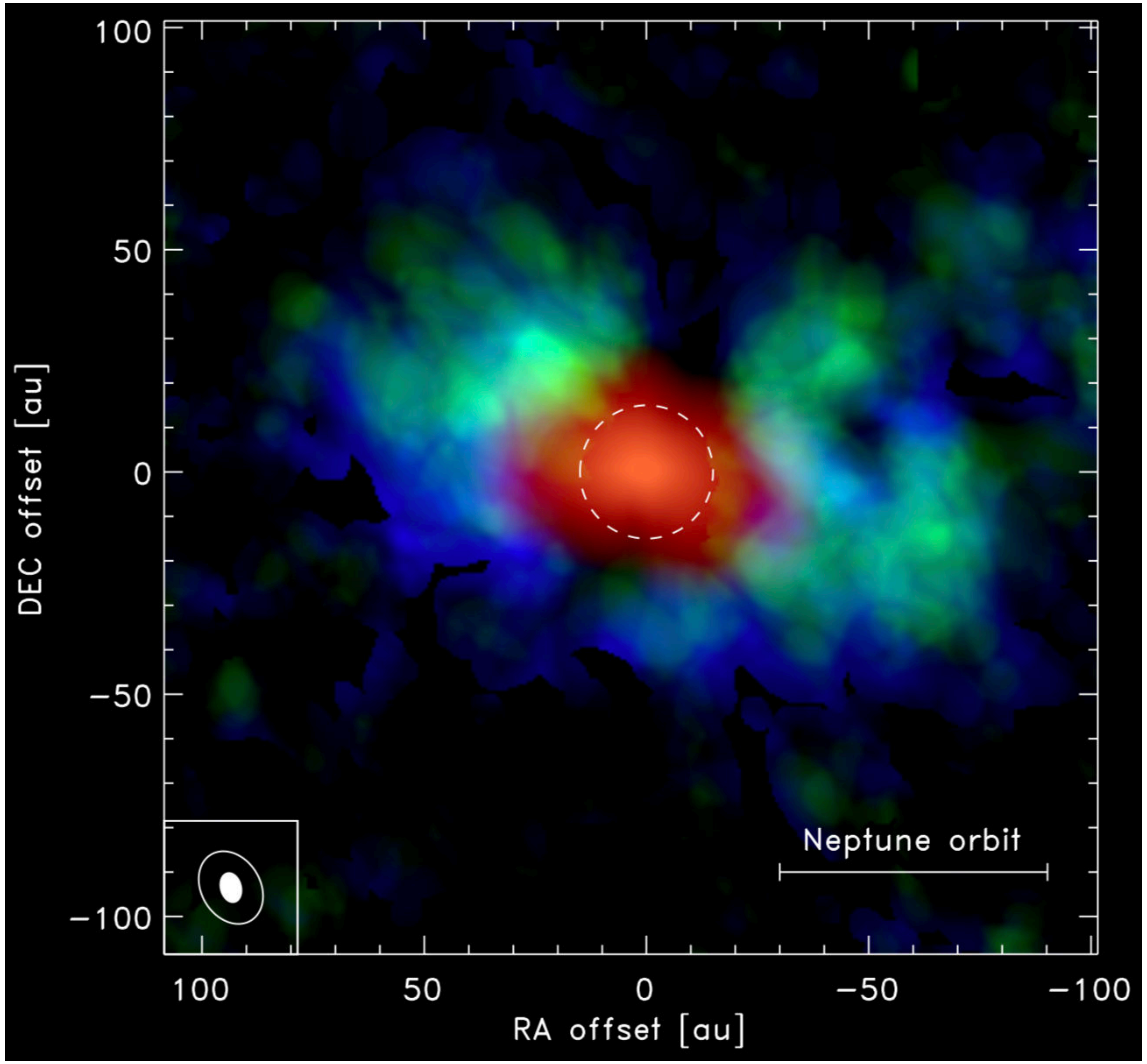
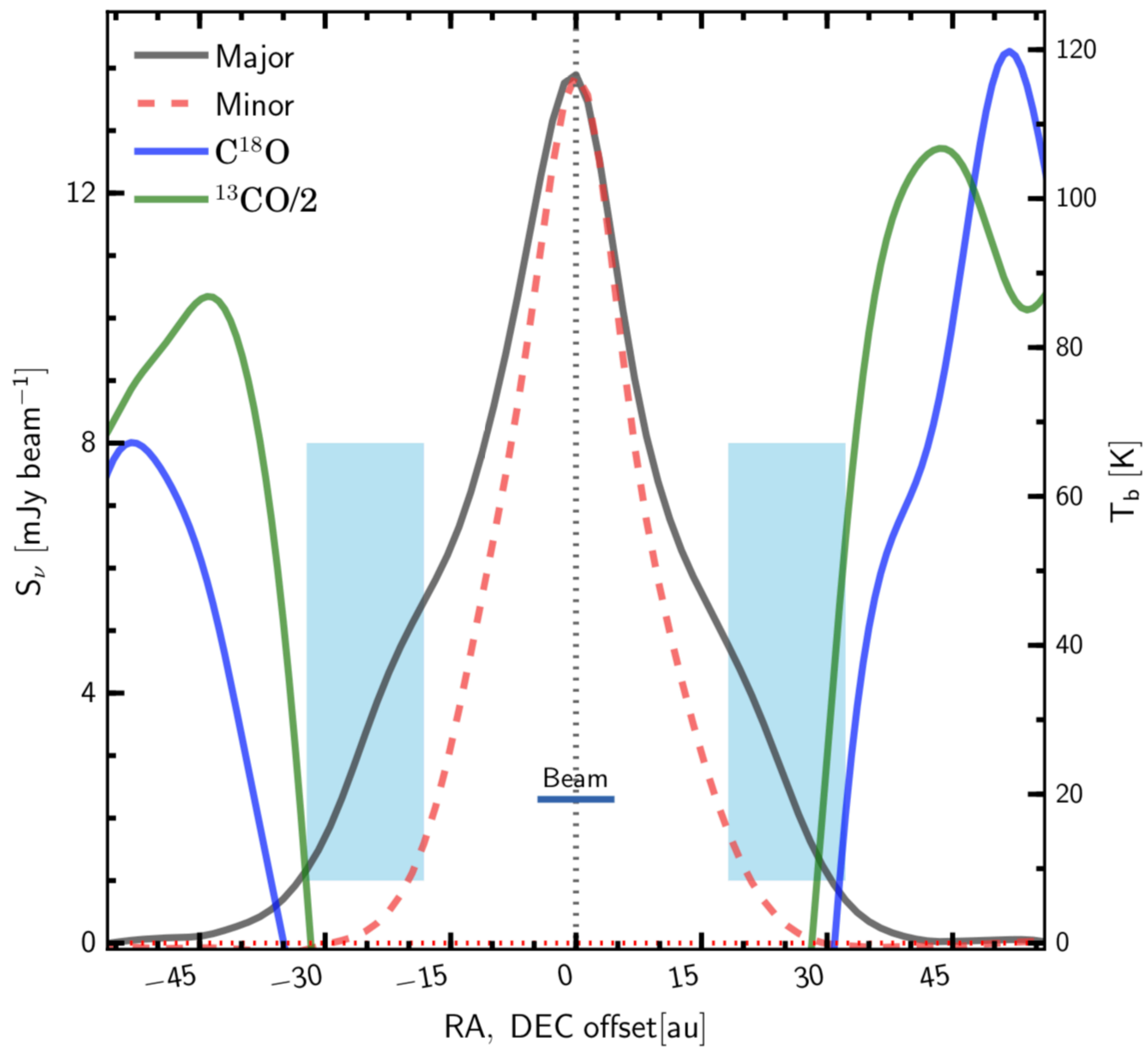
Hidden Substructures?



TMC1A



Harsono et al. (2018)

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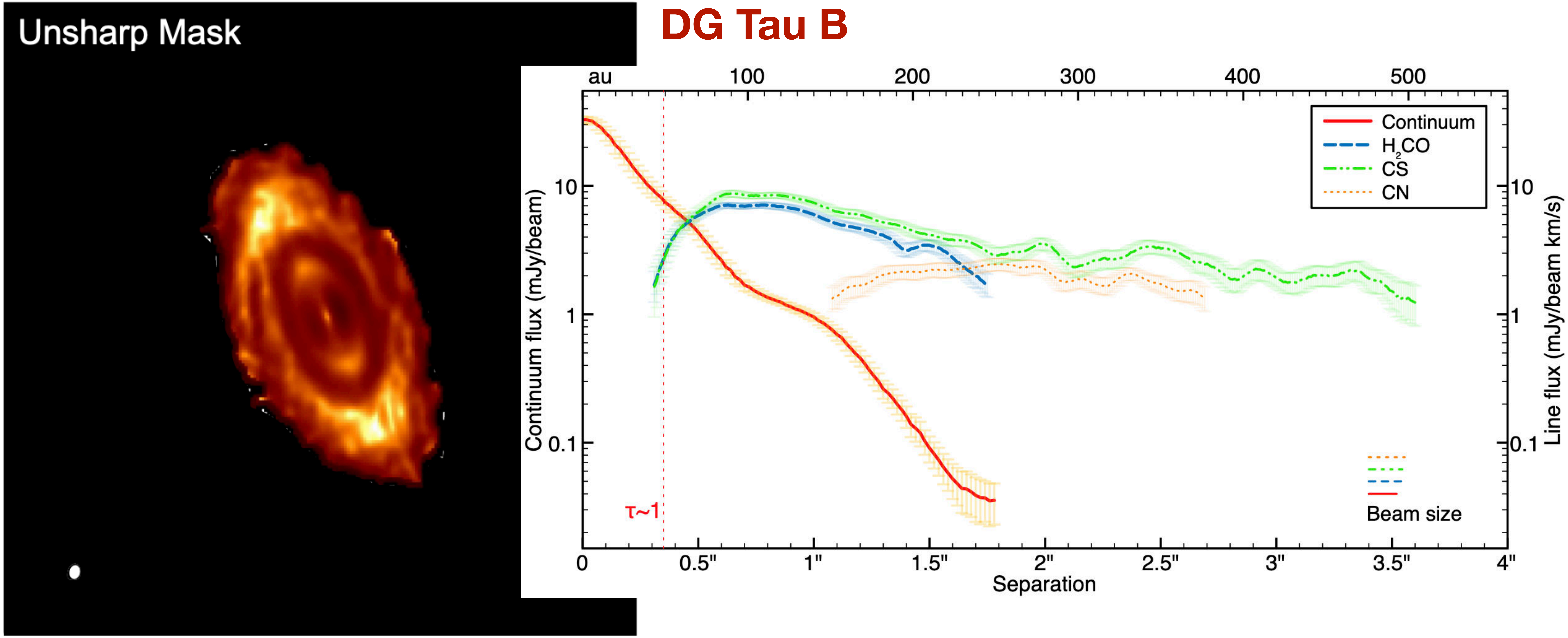
Another Disk with Hidden Mass?



Garufi et al. (2020)

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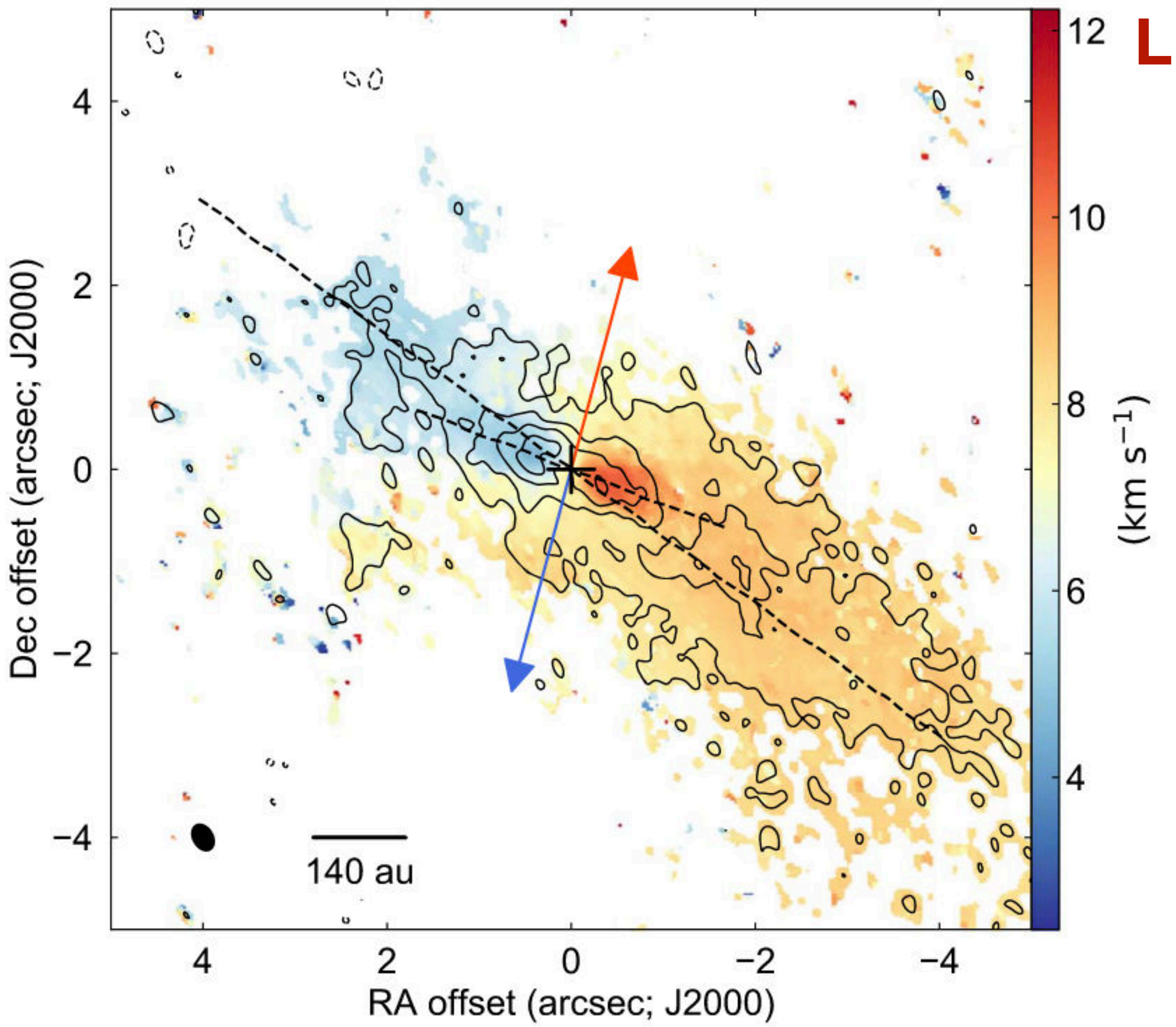
Connections to the Envelope



L1489 IRS

Sai et al. (2020)

An asymmetric kinematic connection reaches from the disk to envelope scales.

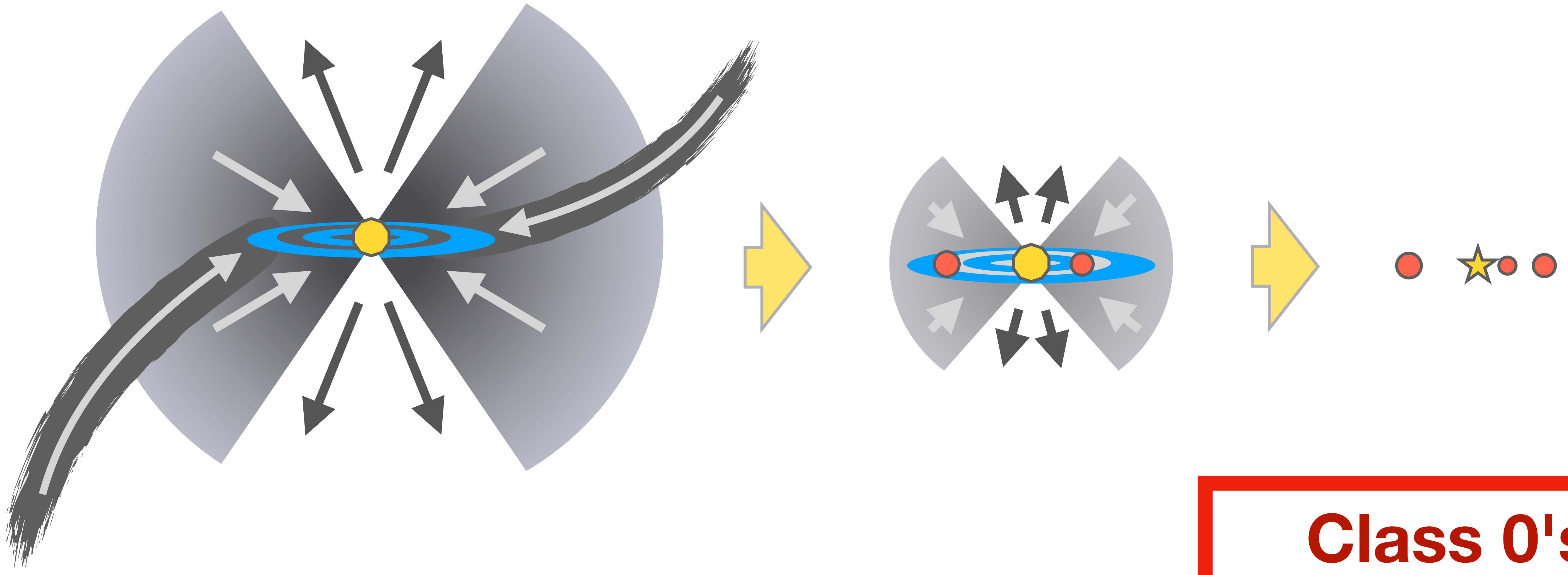
Dominique Segura-Cox

Connections to Even Larger Scales

Per-emb-2

Sadavoy et al. (2012, 2014) **Pineda et al. (2020)** **Reprocessed from Tobin et al. (2018)**

Summary: Embedded Disks Might Jump-Start Planet Formation



Dust rings are present in the Class I phase. Conditions for planet formation satisfied early?

Class 0's have warps and asymmetries.

Class 0 and I disks are still embedded in their envelopes! Does planet formation start while the disk material is replenished?

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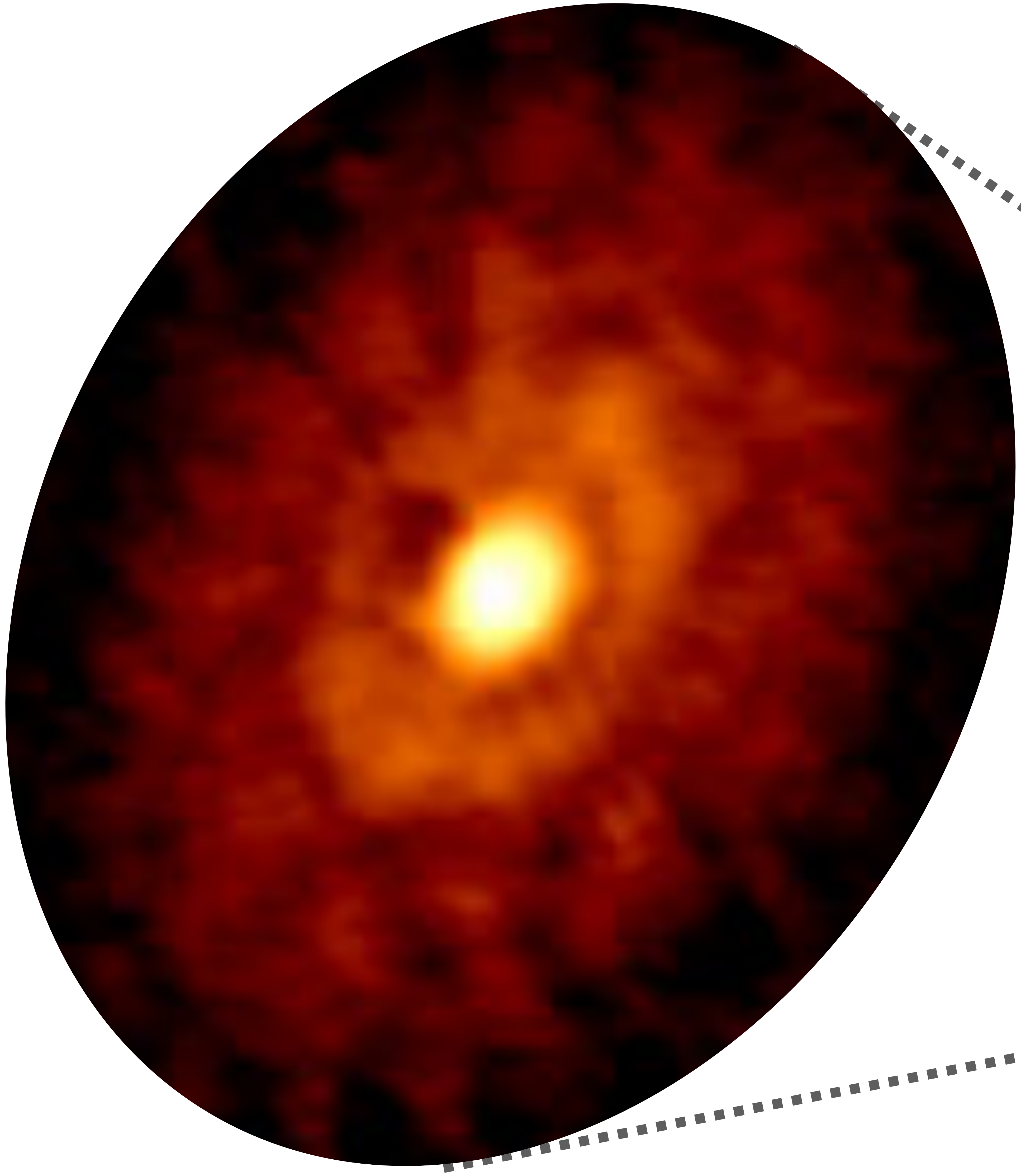
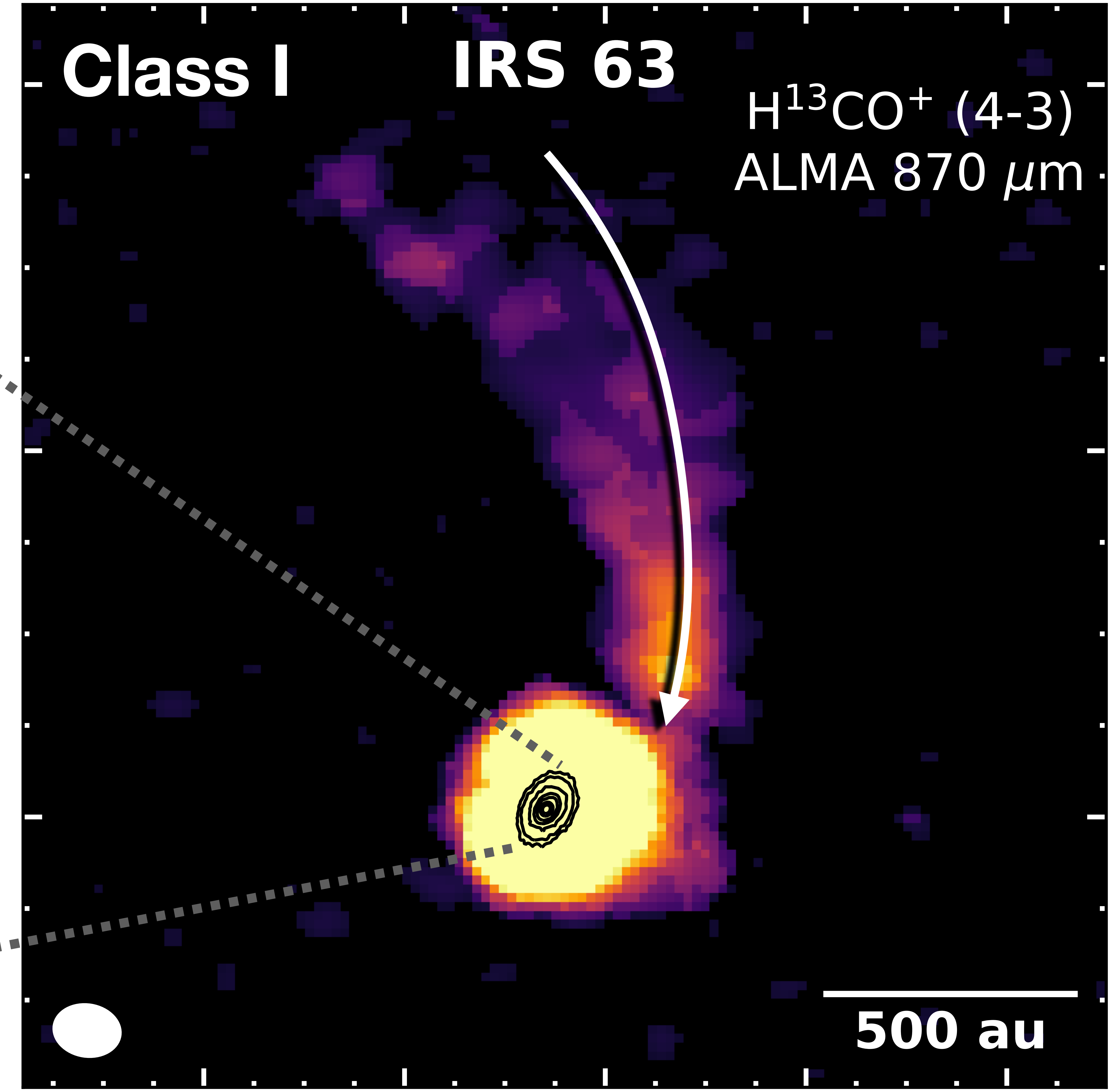
Connections to the Envelope



Segura-Cox et al. (2020)



Segura-Cox et al. in prep