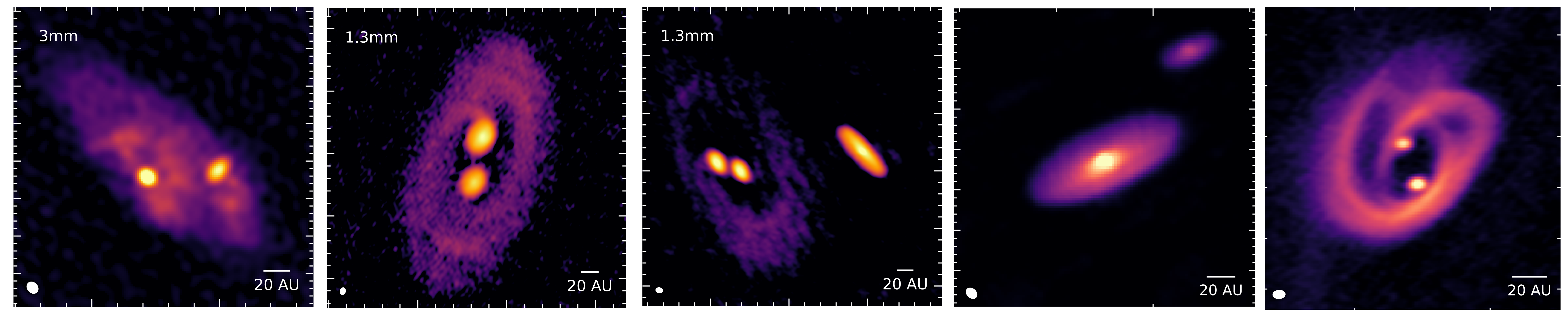
Observations of multiple body systems with ALMA

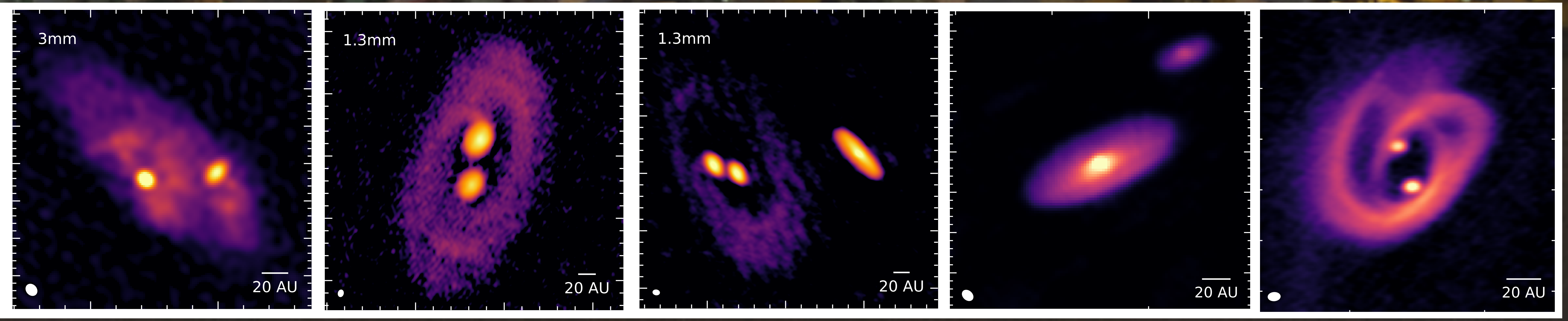


María José Maureira
Postdoc at MPI for Extraterrestrial Physics

Collaborators: Babobab Liu, Paola Caselli, Hector Arce, Jaime E. Pineda, Leonardo Testi, Munan Gong, Felipe Alves, Chenghan Hsieh, Dominique Segura-Cox, Joaquin Zamponi and *the ALMA-CAMPOS, FAUST ALMA Large Program, and NOEMA-PRODIGEE teams.*

Observations of multiple body systems with ALMA

Very Young



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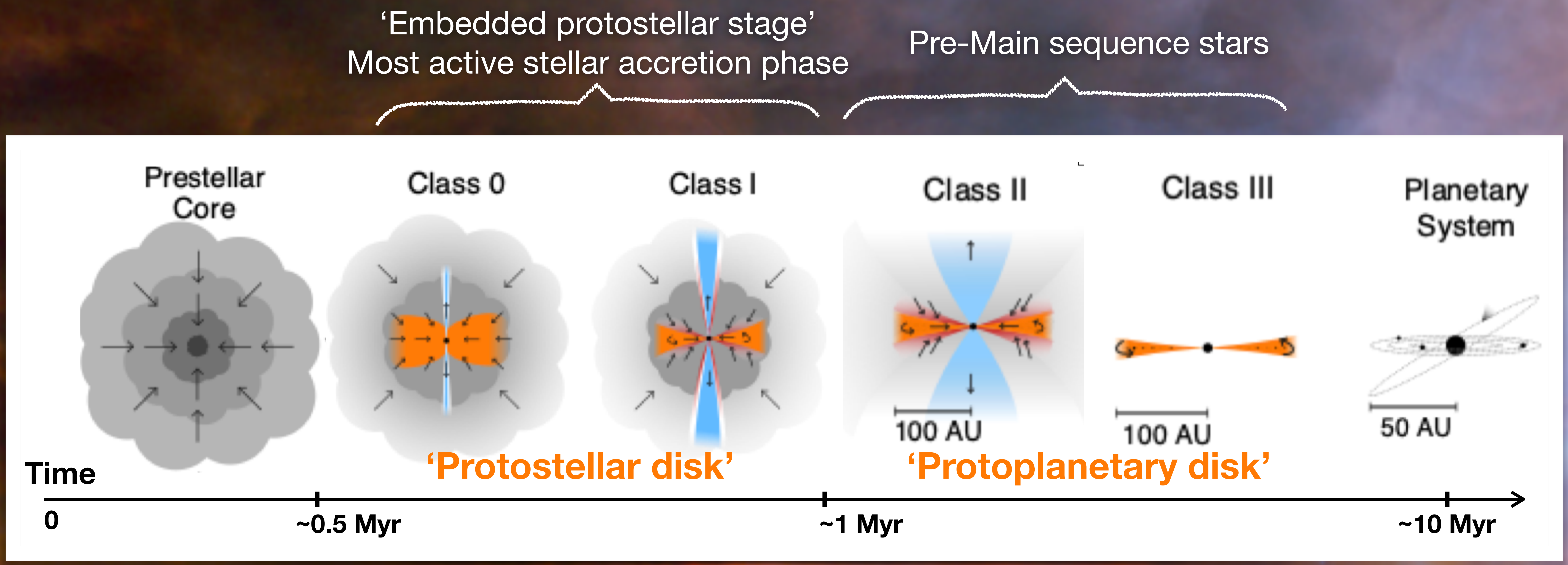
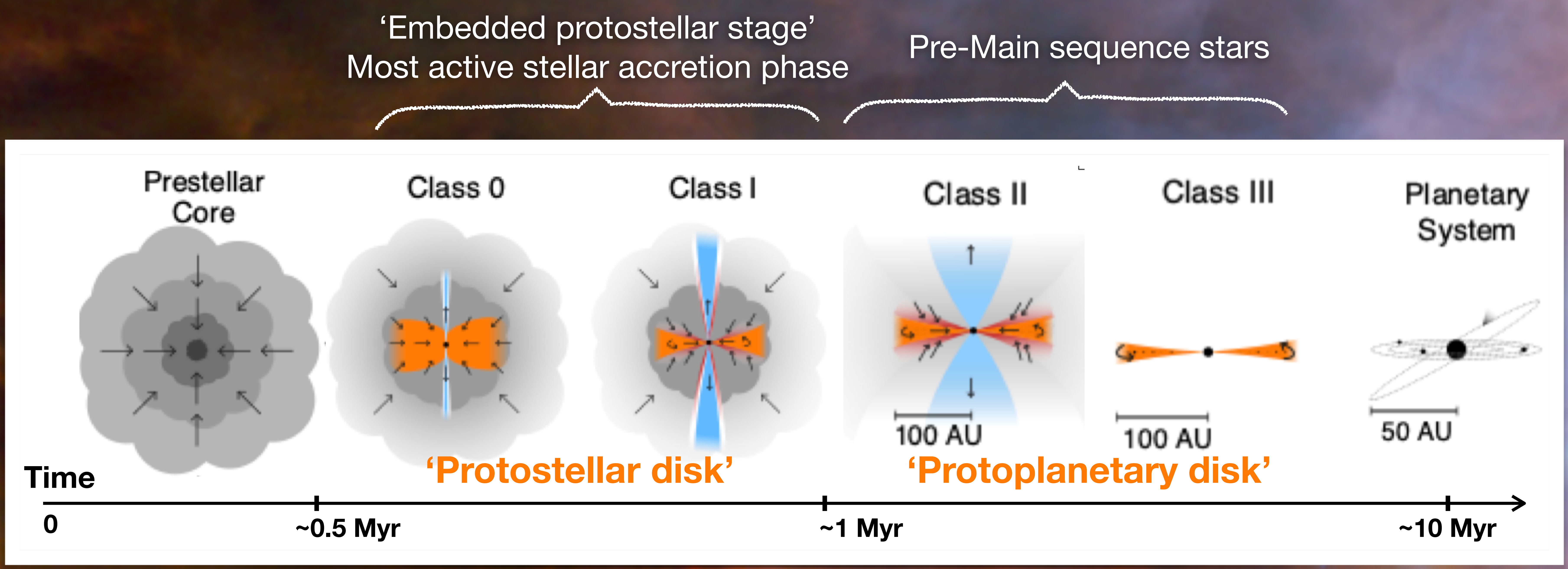
From dense clouds to protostars and planets



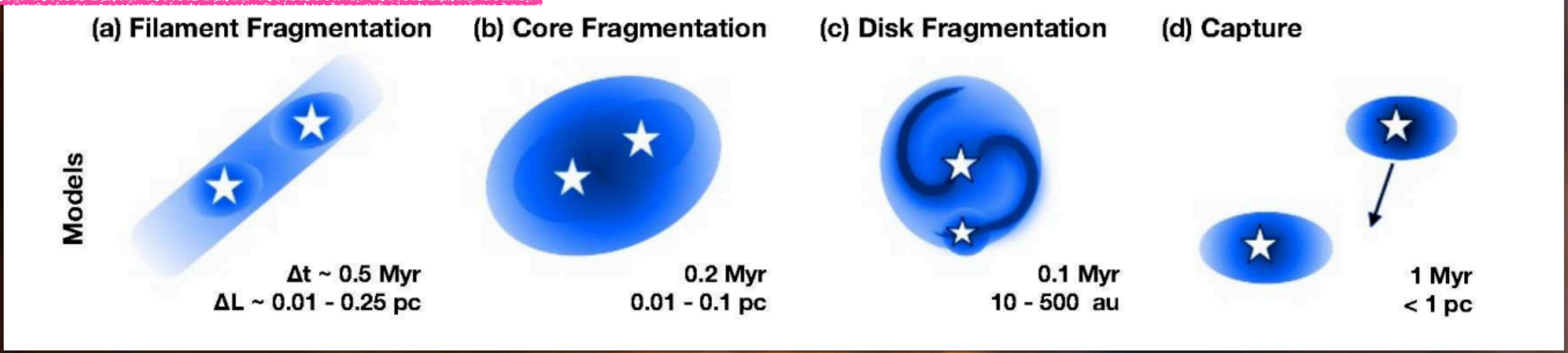
Credit: M. Persson

From dense clouds to protostars and planets



Credit: M. Persson

Mechanisms for the formation of multiple systems



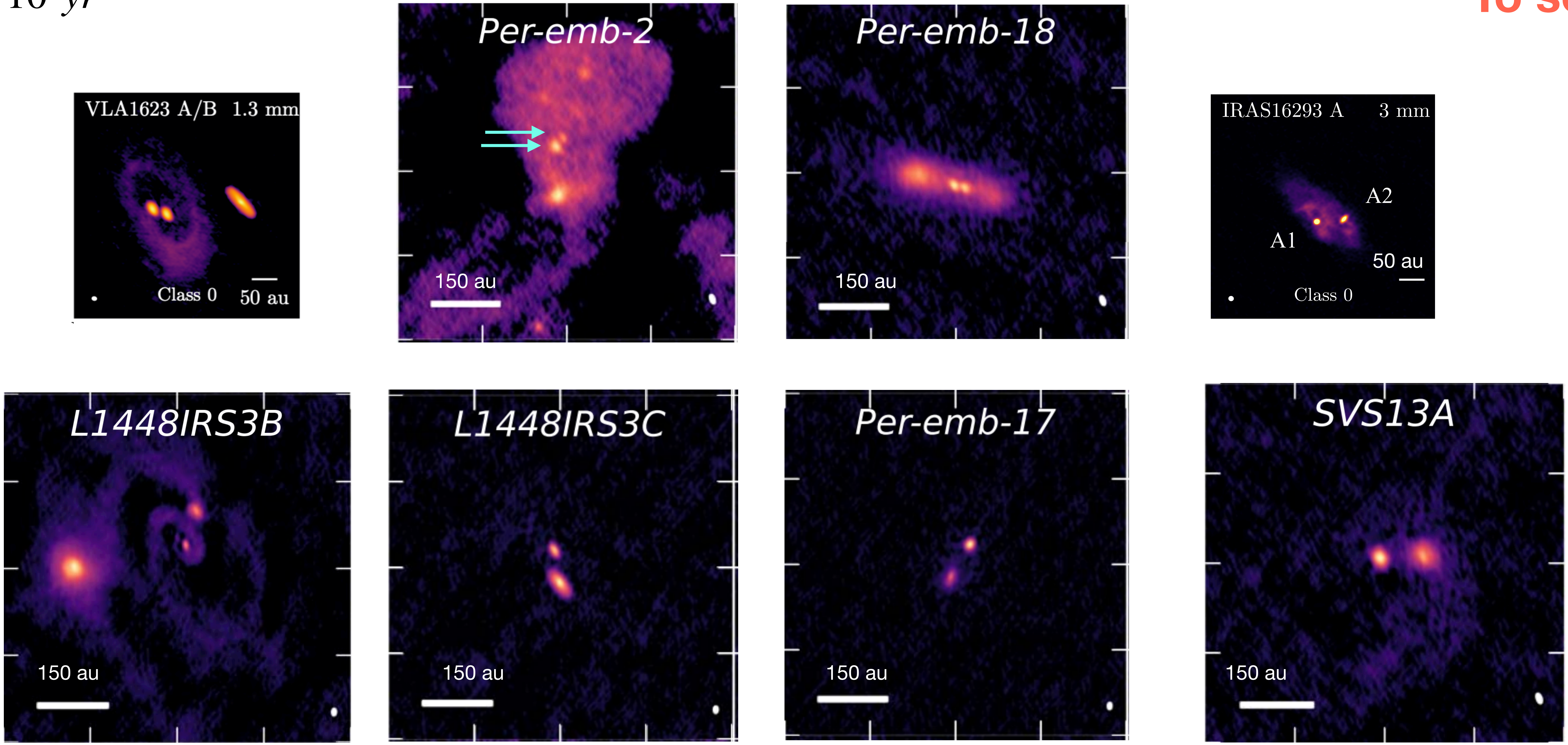
Offner et al. 2023 (PPVII)

Class 0 binaries with sep < 100 au resolved down to 6-8 au

Dust emission

$t \lesssim 10^4 - 2 \cdot 10^5 yr$

***To scale**



References: Maureira et al. 2020a, Reynolds et al. 2024, Maureira et al. in prep

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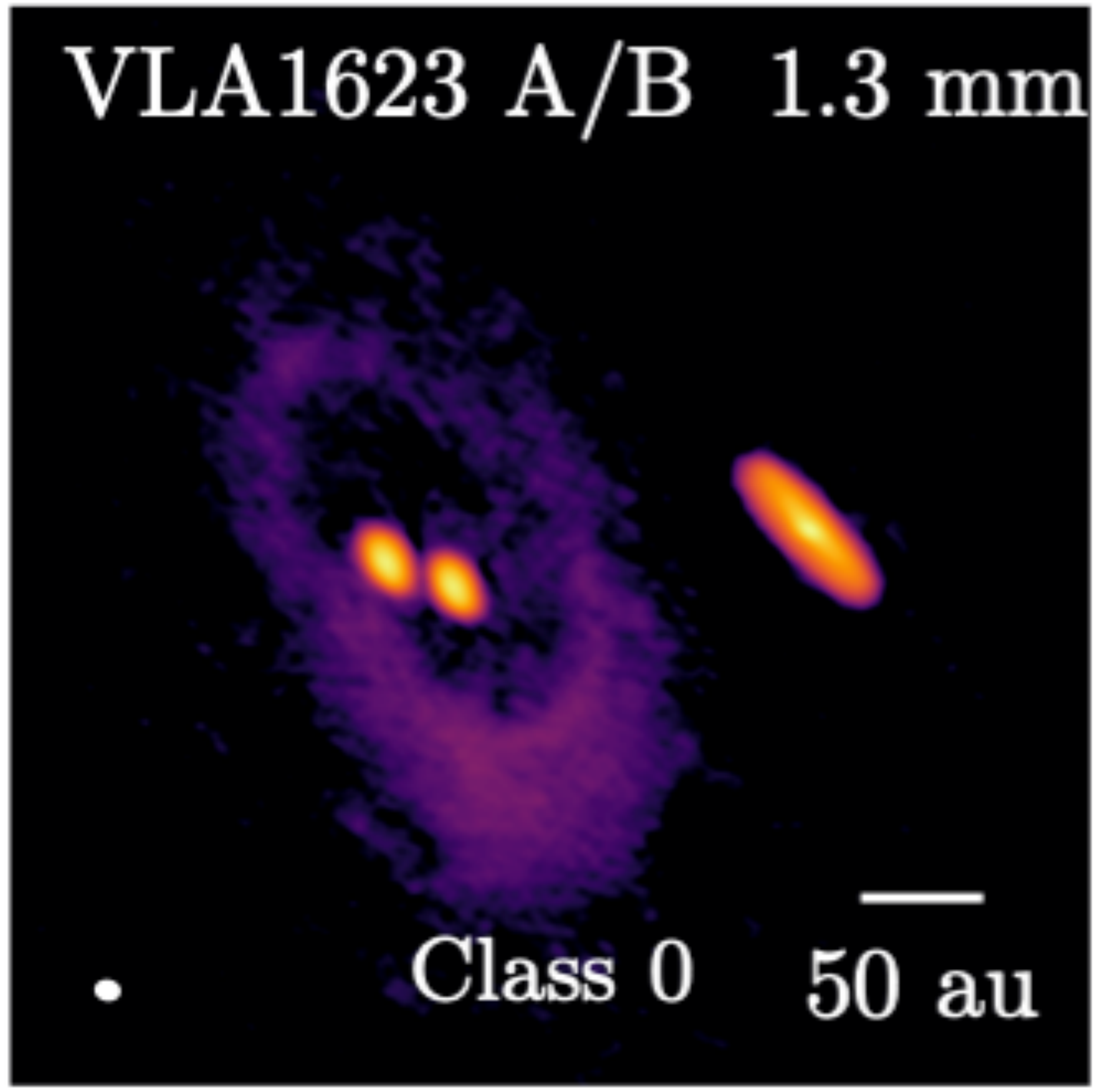
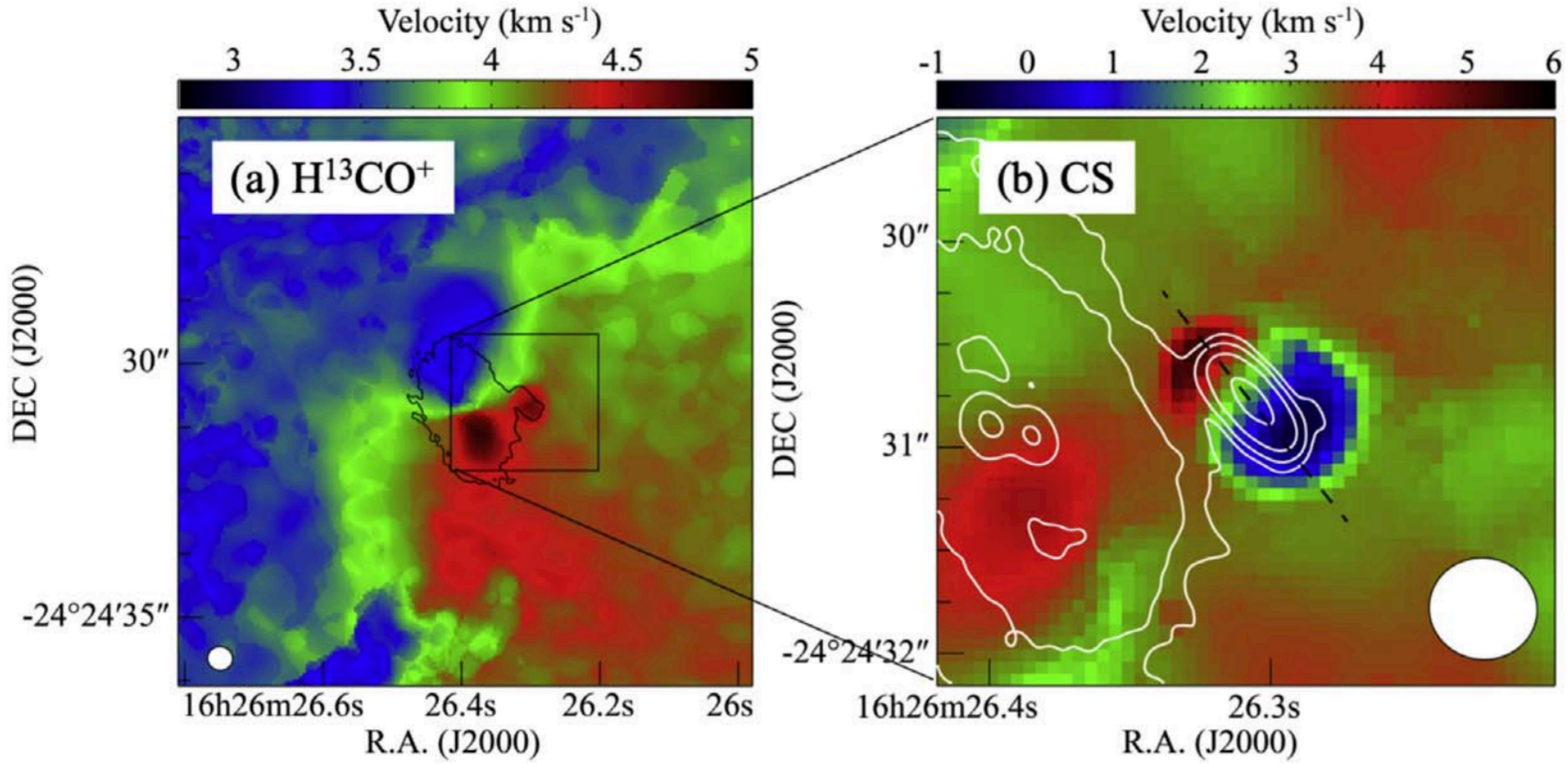
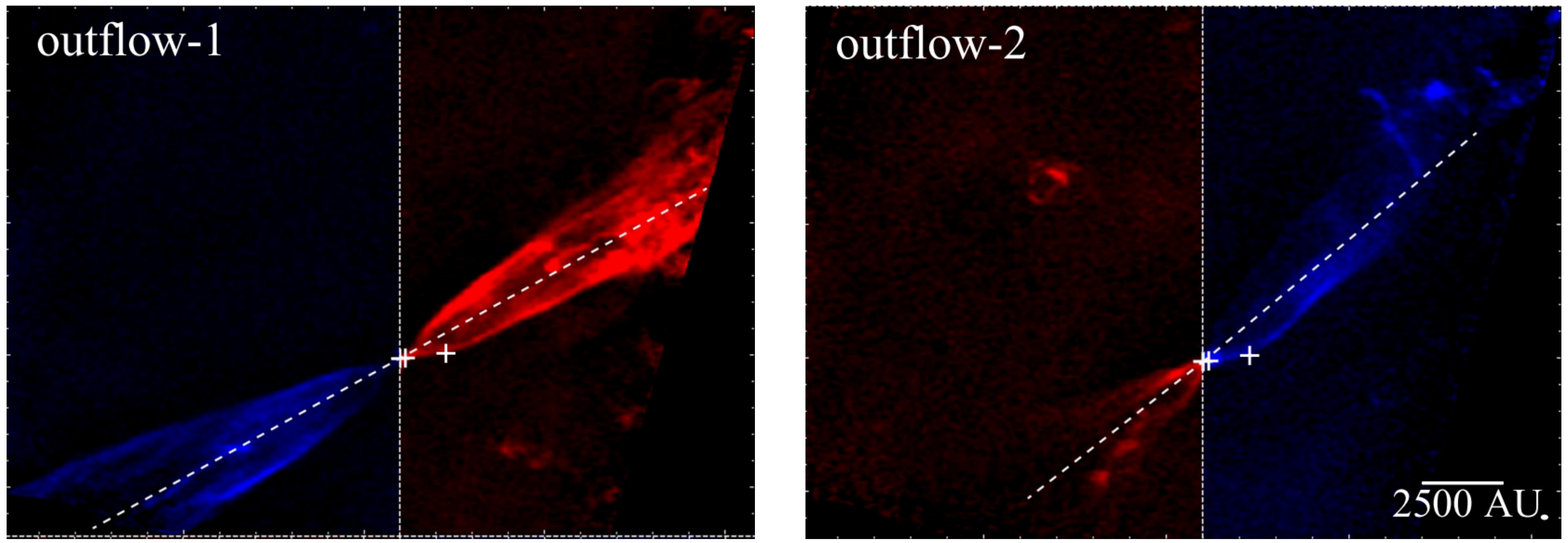


Gas Velocity





References: Ohashi et el 2022, Hara et al. 2021, Maureira et al. in prep

Class 0 binaries with sep < 100 au resolved down to 6-8 au

Dust emission

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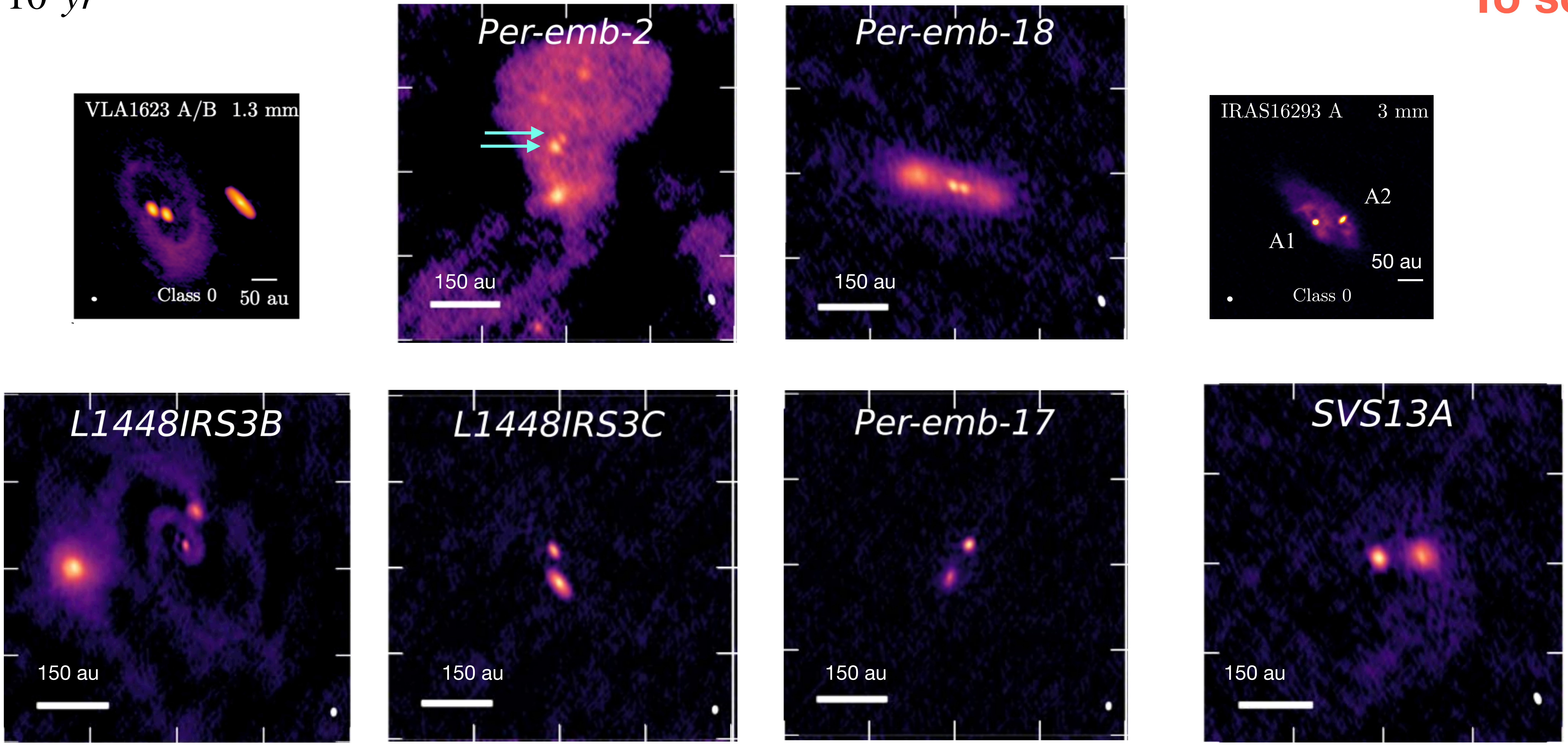
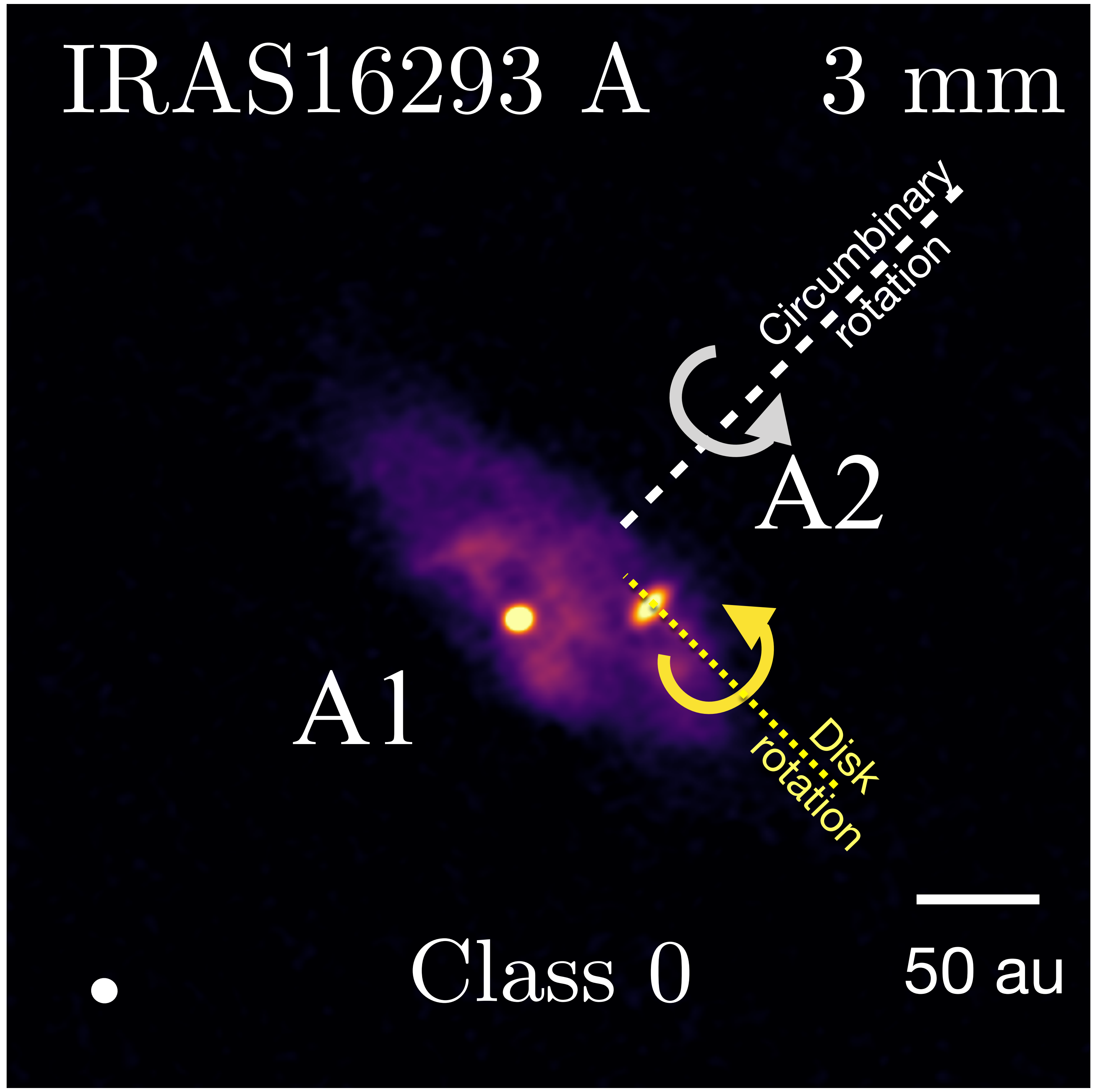
*To scale



References: Maureira et al. 2020a, Reynolds et al. 2024, Maureira et al. in prep

Class 0 binaries with sep < 100 au resolved down to 6-8 au

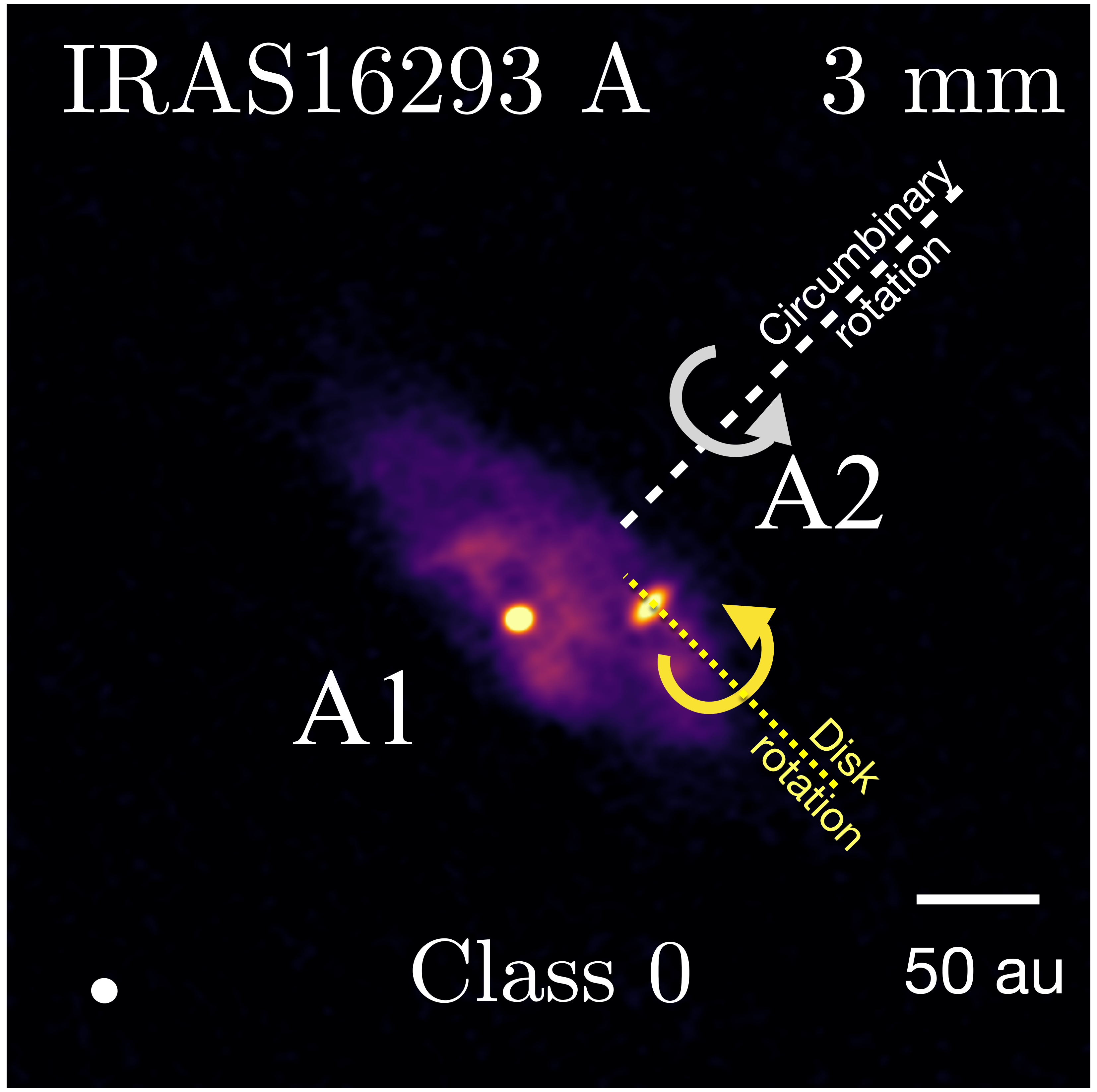
Dust emission



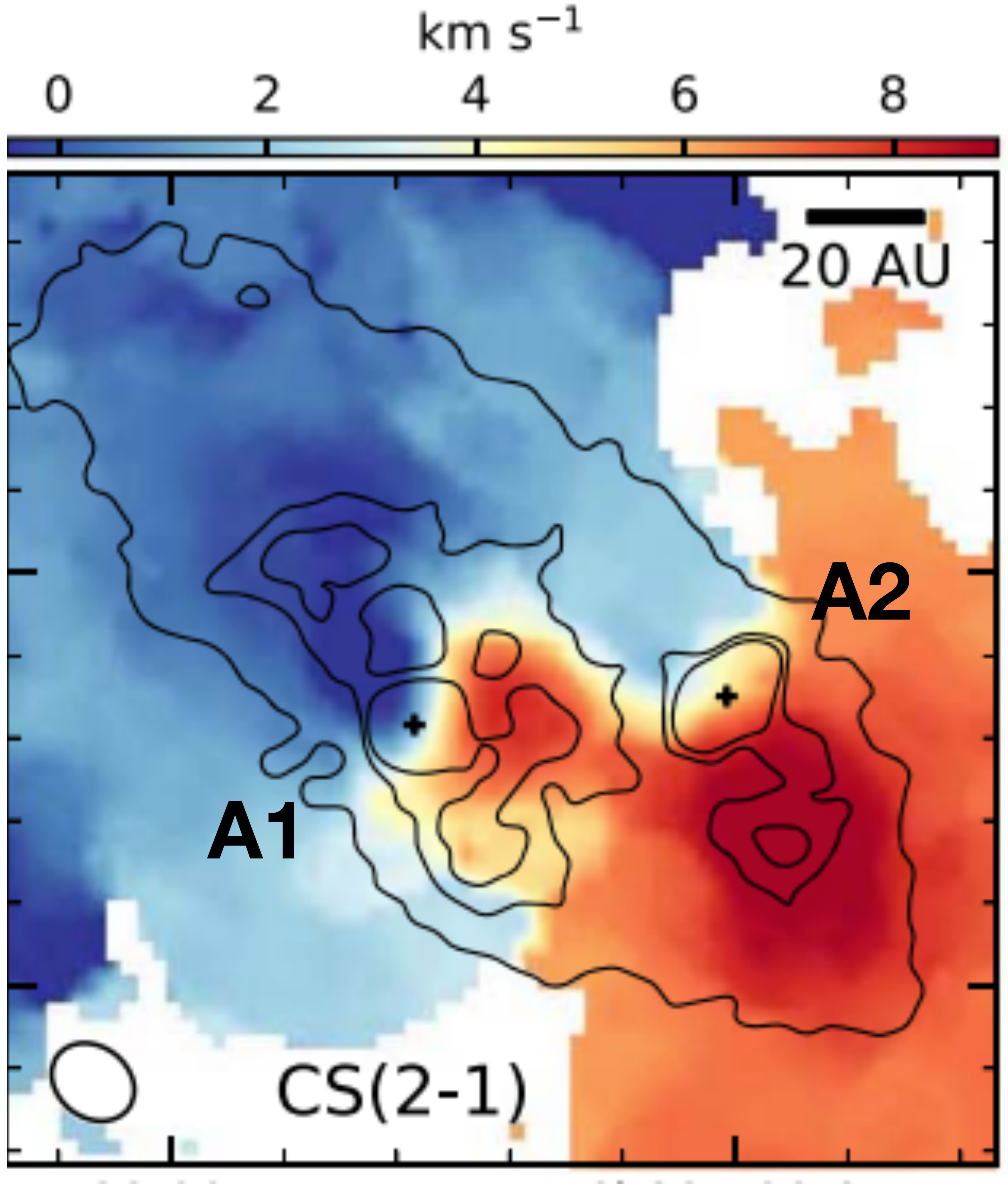
References: Maureira et al. 2020a, Maureira et al. 2022

Class 0 binaries with sep < 100 au resolved down to 6-8 au

Dust emission



Gas velocity



References: Maureira et al. 2020a, Maureira et al. 2022

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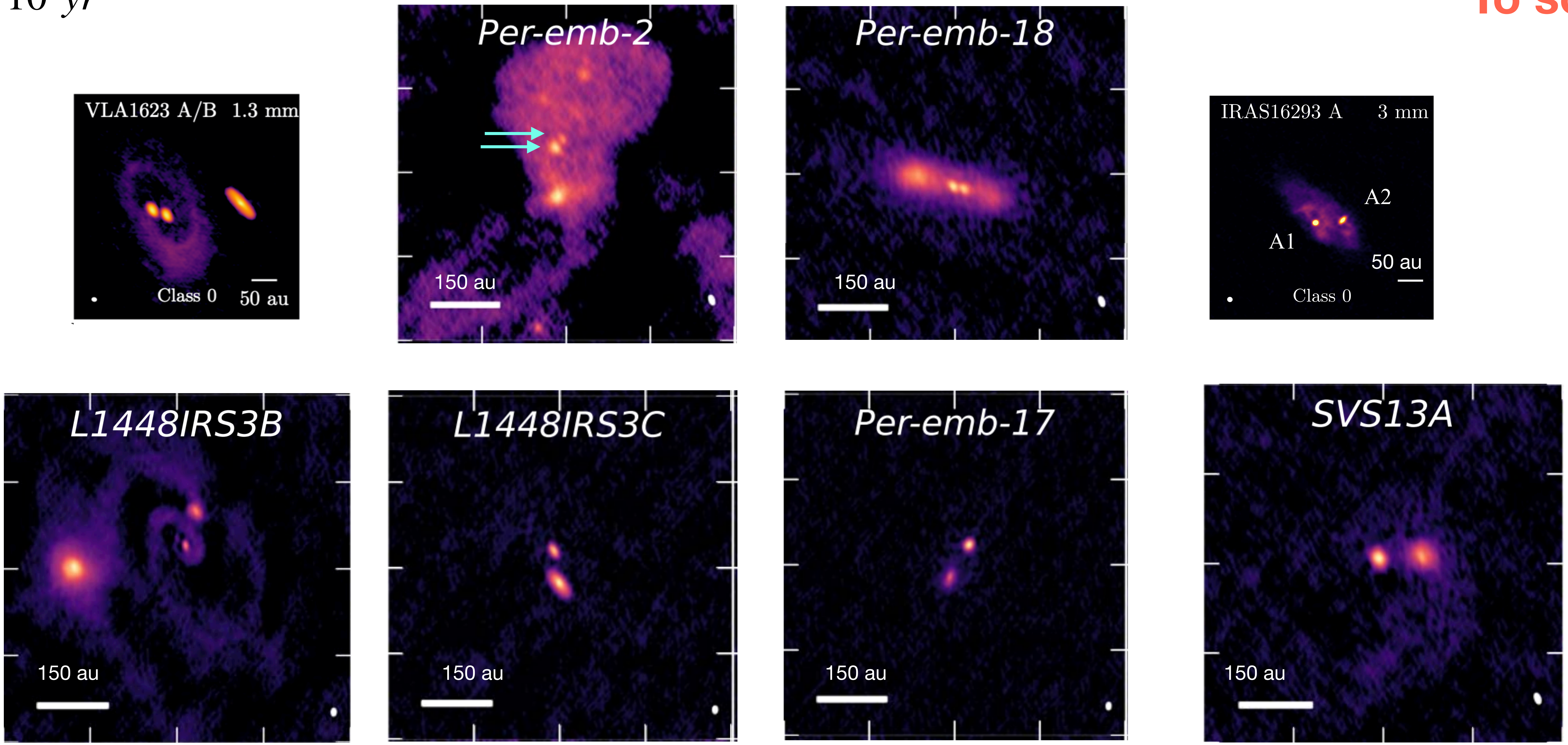
*To scale



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Class 0 binaries with sep < 100 au resolved down to 6-8 au

Dust emission

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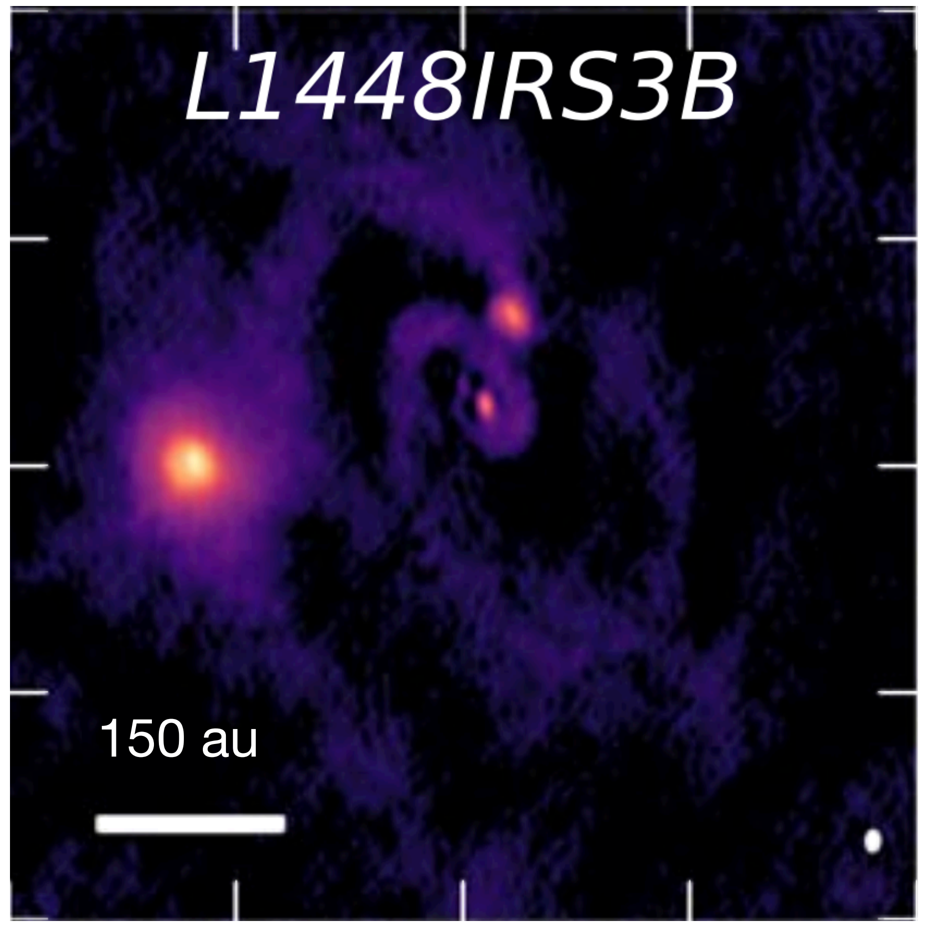
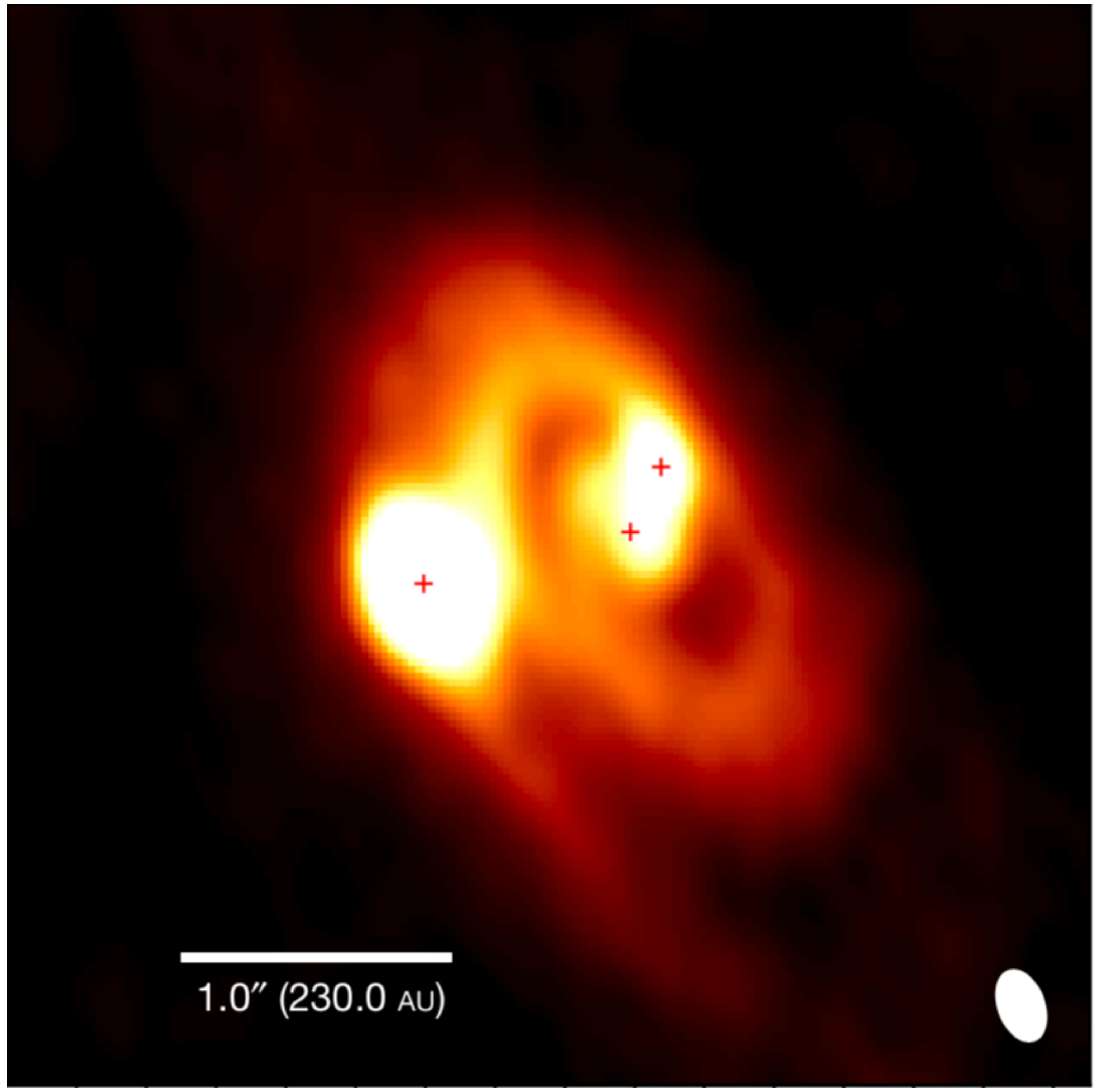
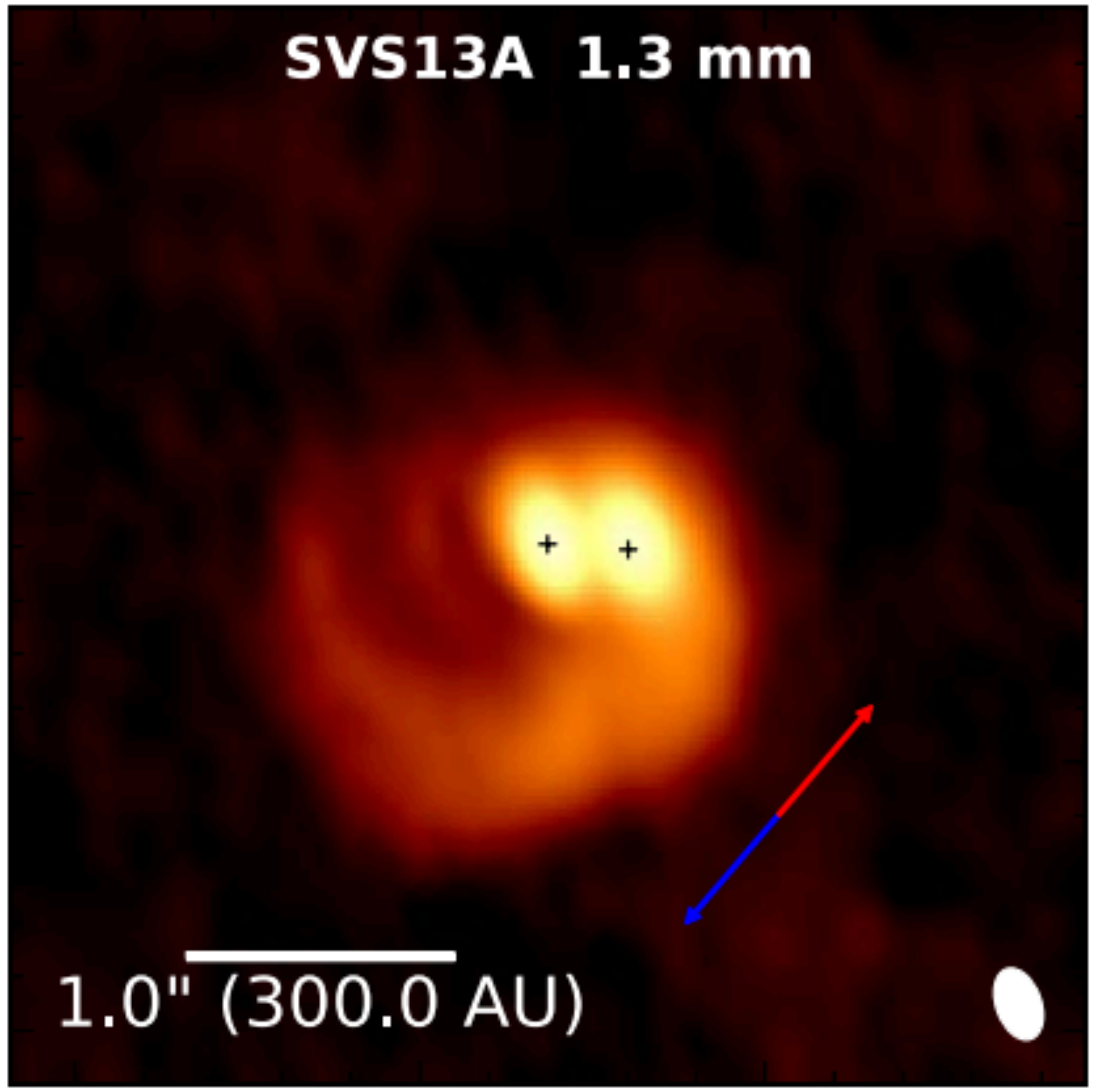
*To scale

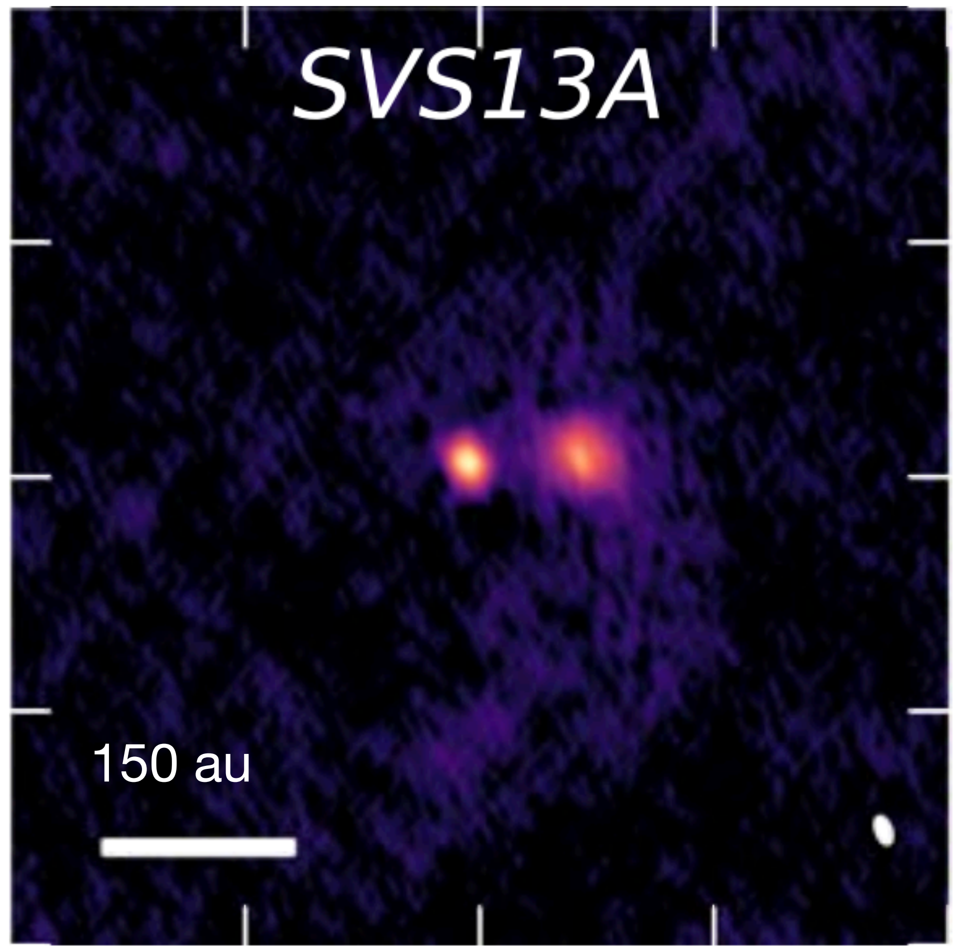
Zoom out







Zoom out



Individual circumstellar disks are nearly aligned

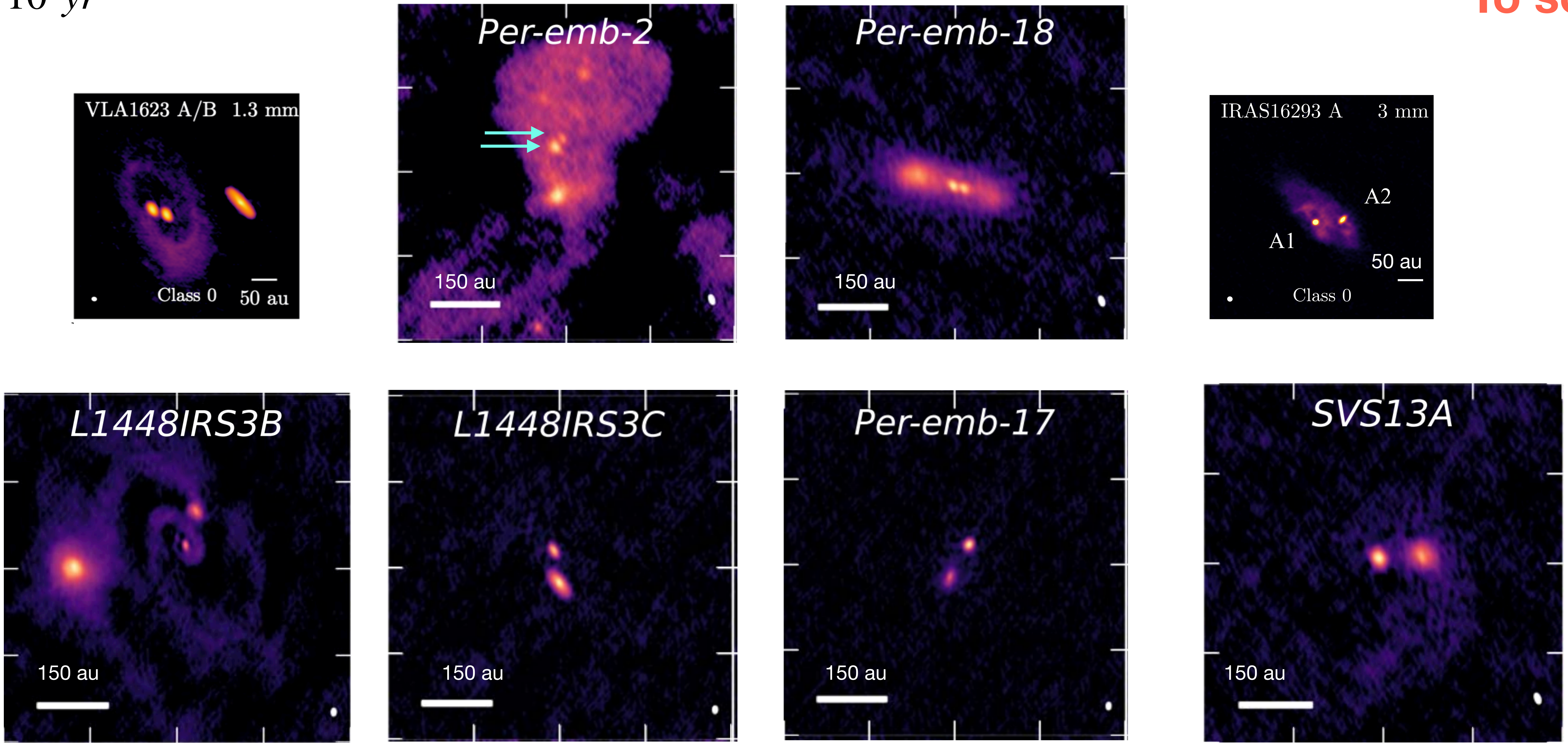
References: Tobin et al. 2018, Reynolds et al. 2024

Class 0 binaries with sep < 100 au resolved down to 6-8 au

Dust emission

$t \lesssim 10^4 - 2 \cdot 10^5 yr$

*To scale



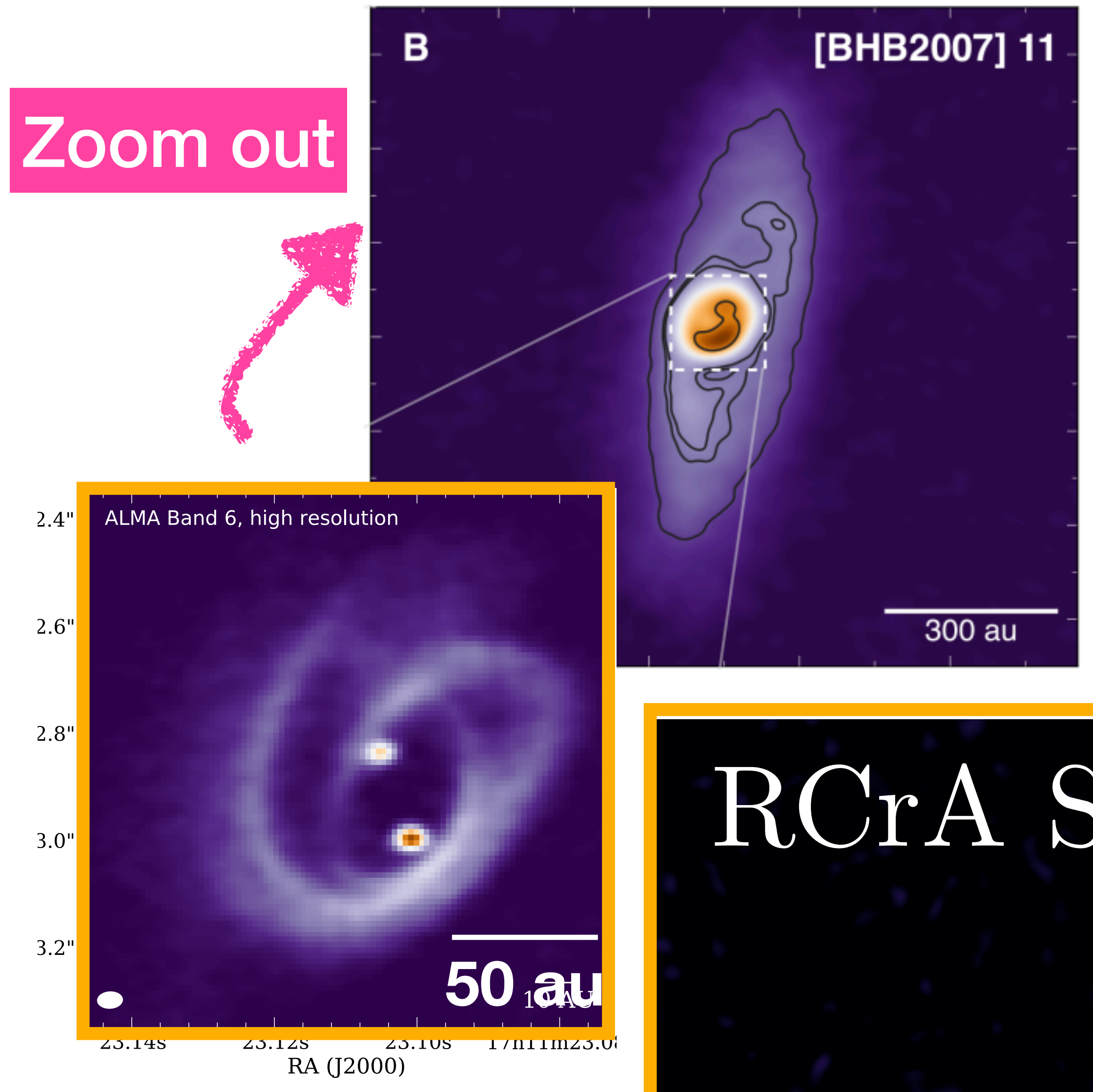
References: Maureira et al. 2020a, Reynolds et al. 2024, Maureira et al. in prep

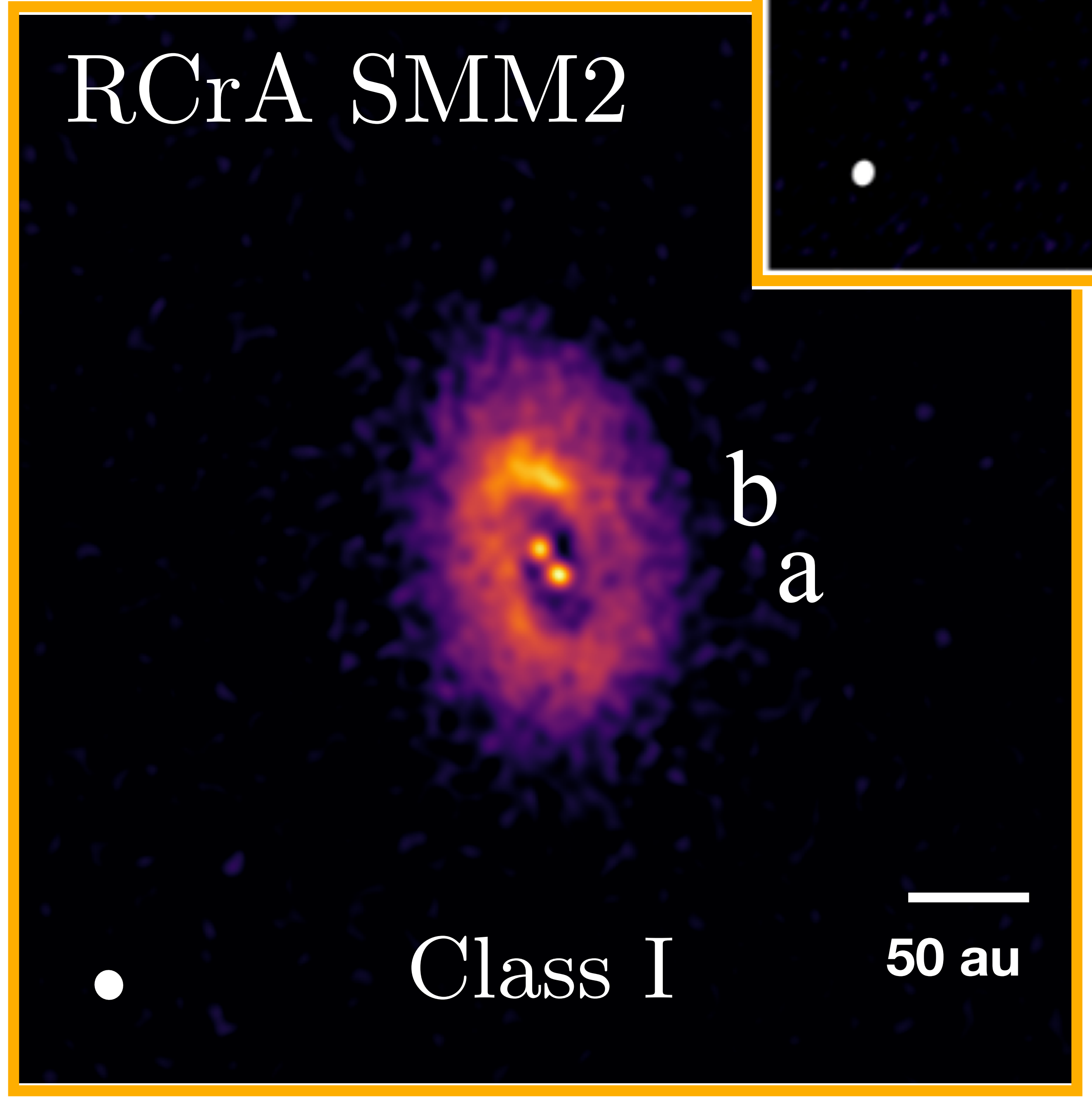
Class I binaries with sep < 100 au resolved down to 6-8 au

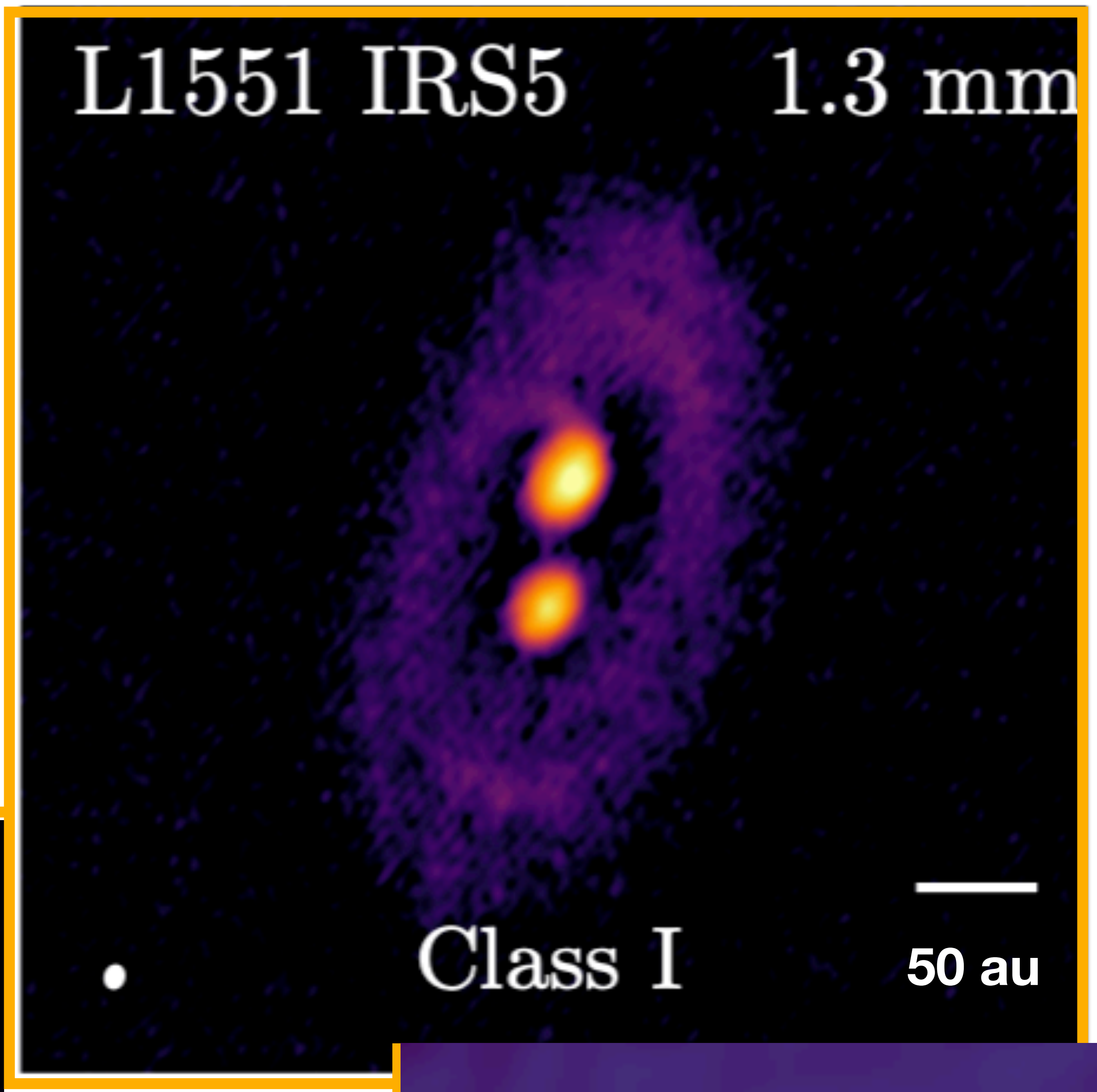
Dust emission

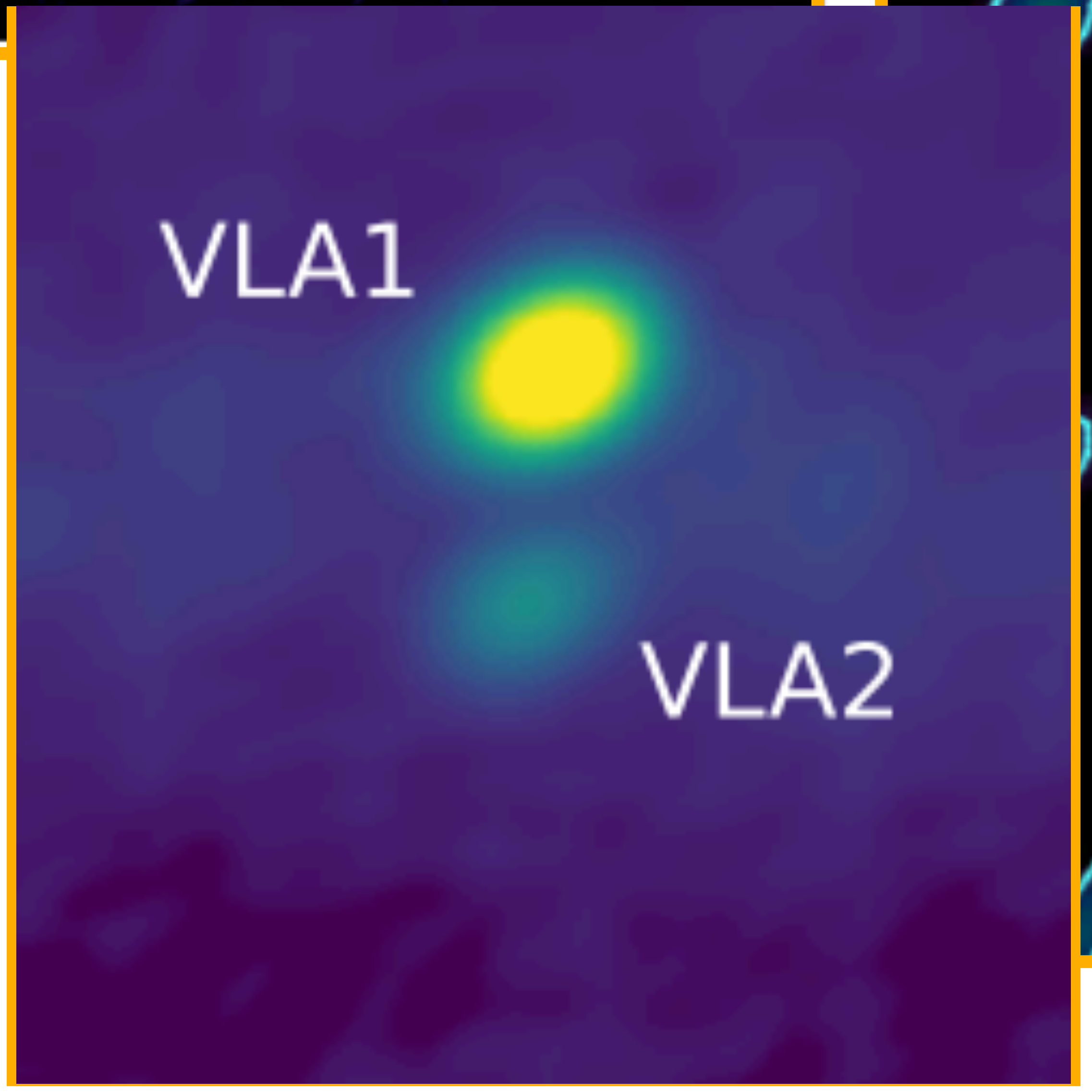
$t \lesssim 2 \cdot 10^5 - 10^6 yr$

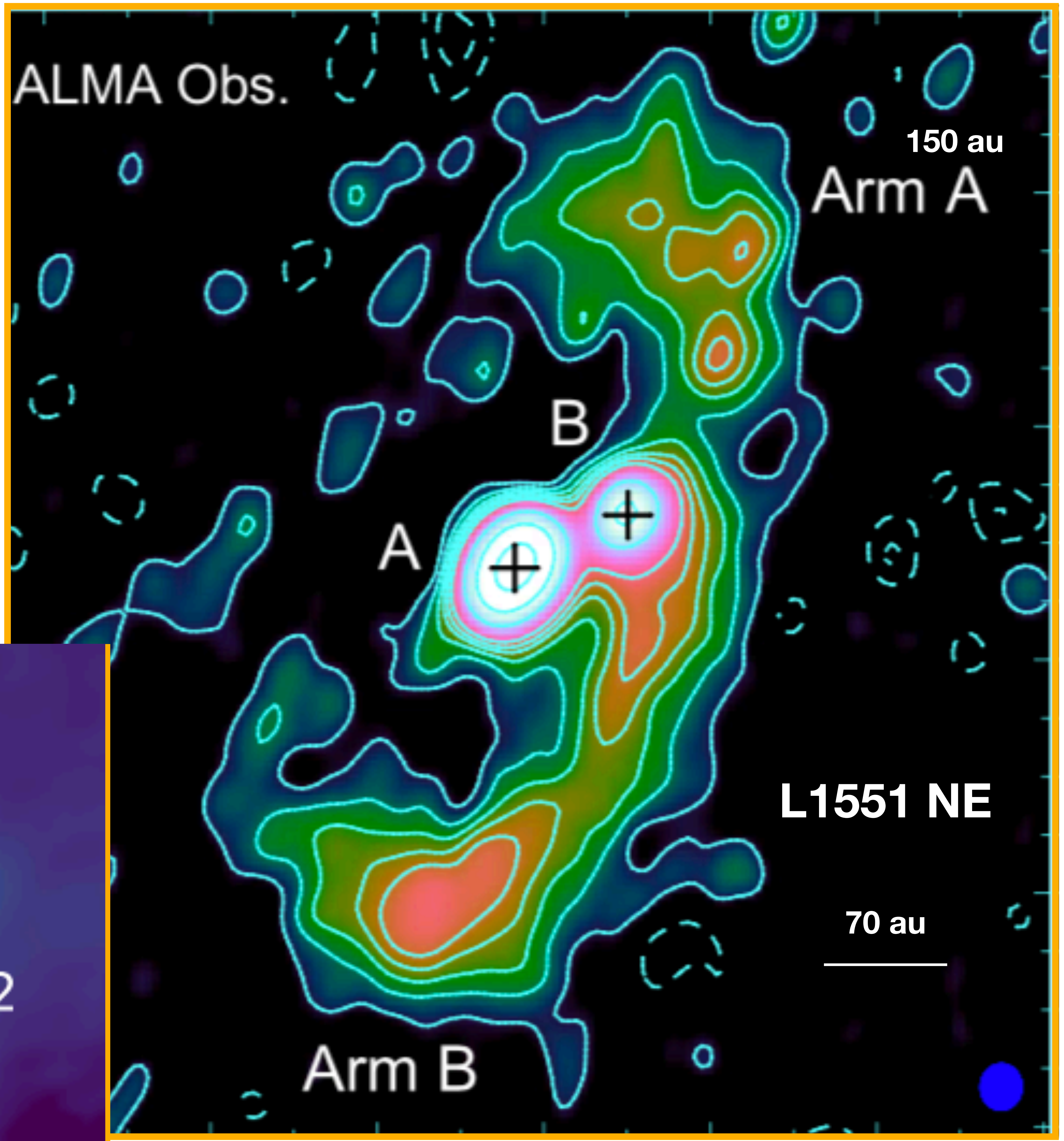
Zoom out











*To scale

References: Takakuwa et al. 2017, Alves et al. 2019, Narayanan et al. 2023, Brinch et al. 2016, Maureira et al. in prep

Class I binaries with sep < 100 au resolved down to 6-8 au

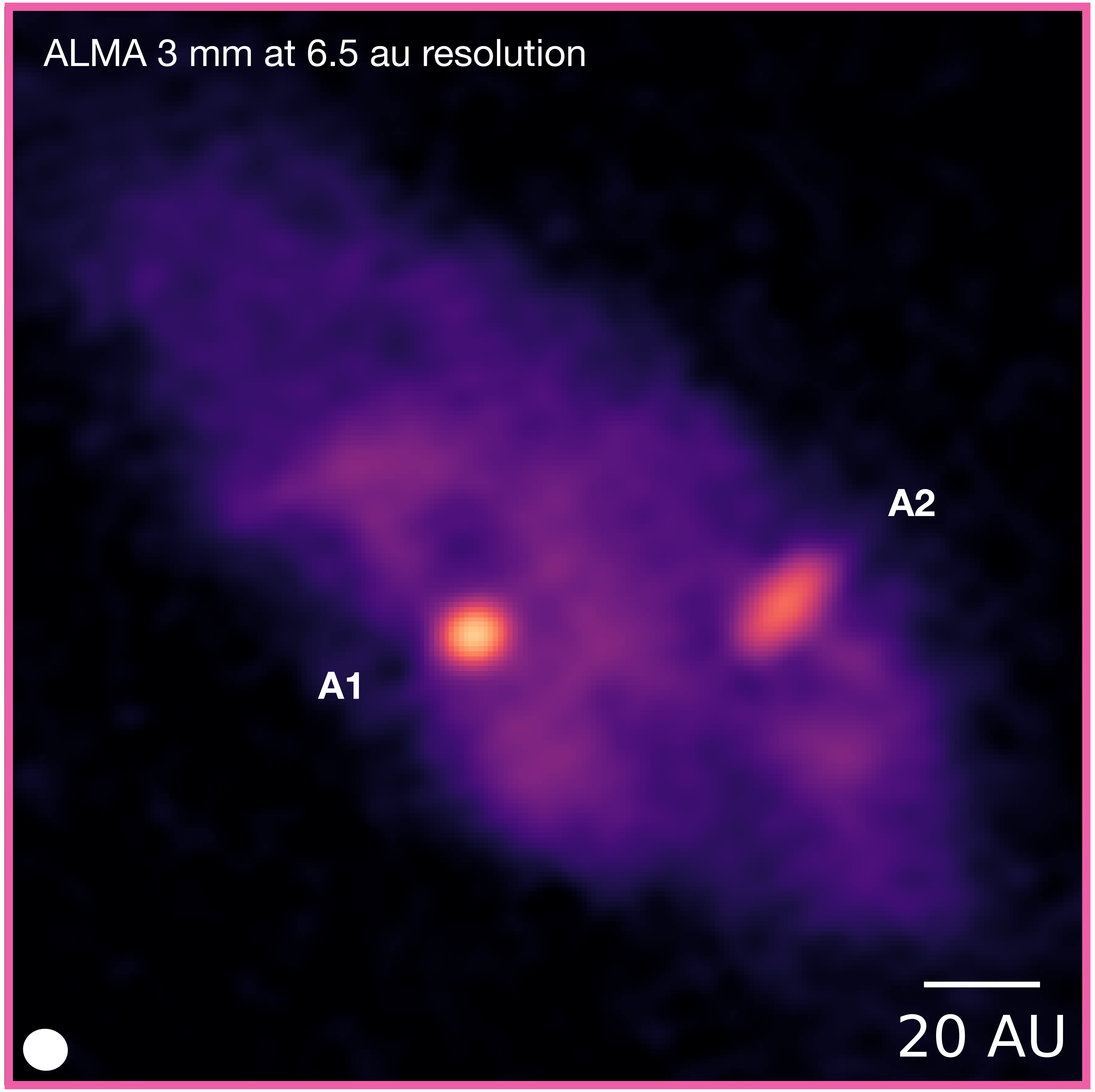
References: Takakuwa et al. 2017, Alves et al. 2019, Narayanan et al. 2023, Brinch et al. 2016, Maureira et al. in prep

Class 0/I binaries with sep > 100 au

*To scale

References: Ohashi et al. 2023, Reynolds et al. 2024, Maureira et al. 2022, Encalada et al. 2024, Jorgensen et al. 2022

Hot dust and gas spots in Class 0 circumbinary disk



References: Maureira et al. 2020a, Oya et al. 2020, Maureira et al. 2022

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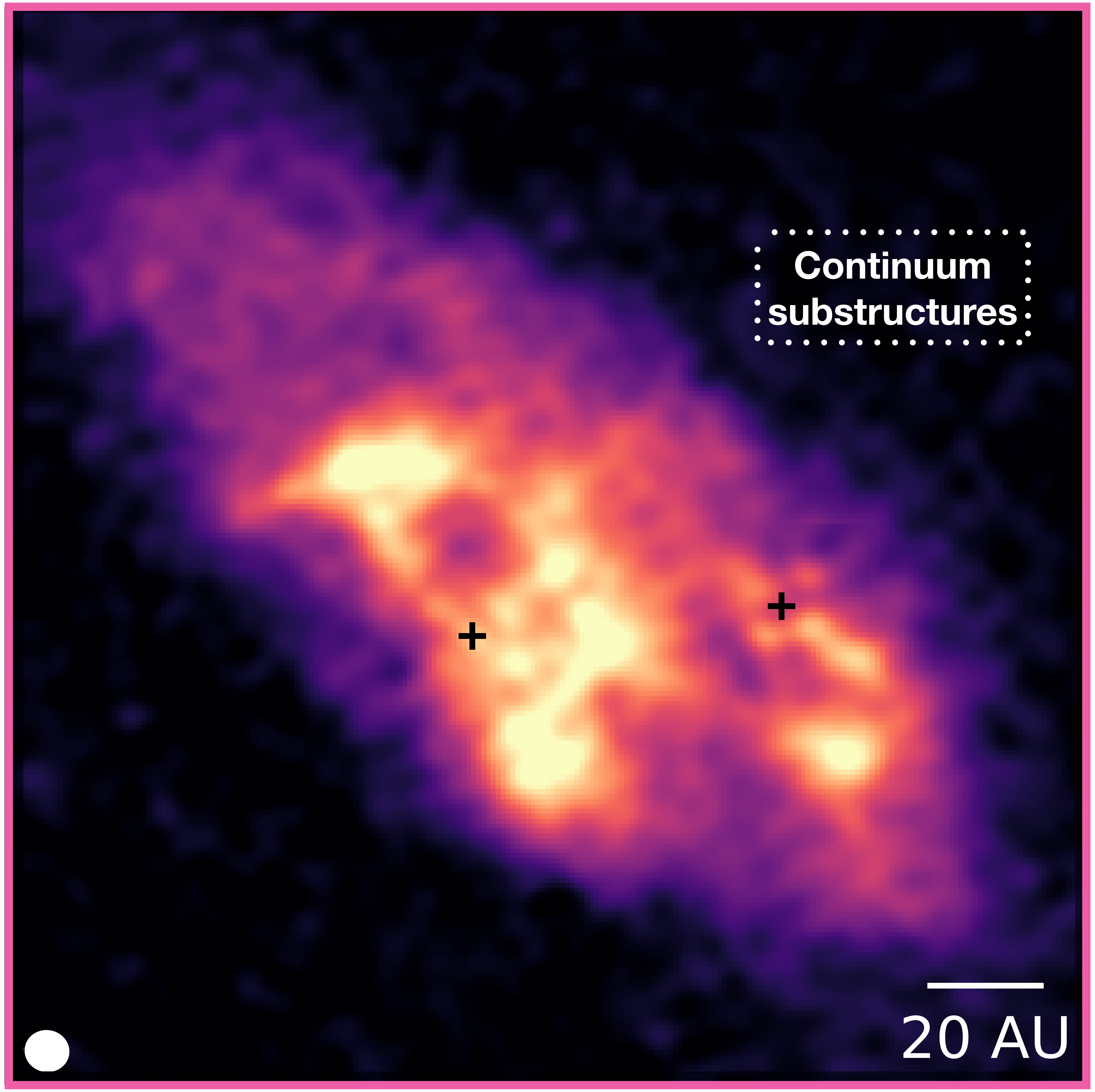

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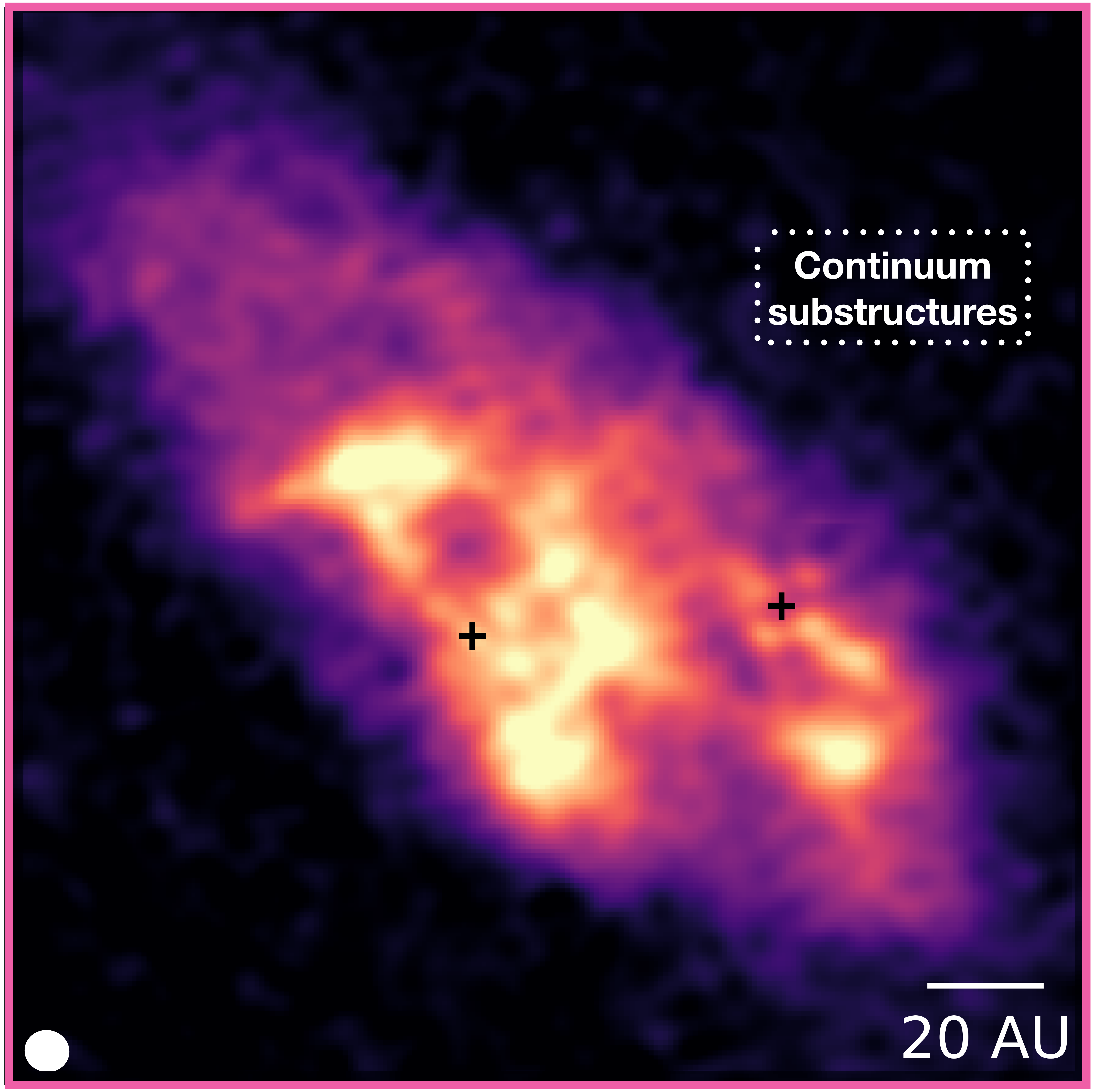

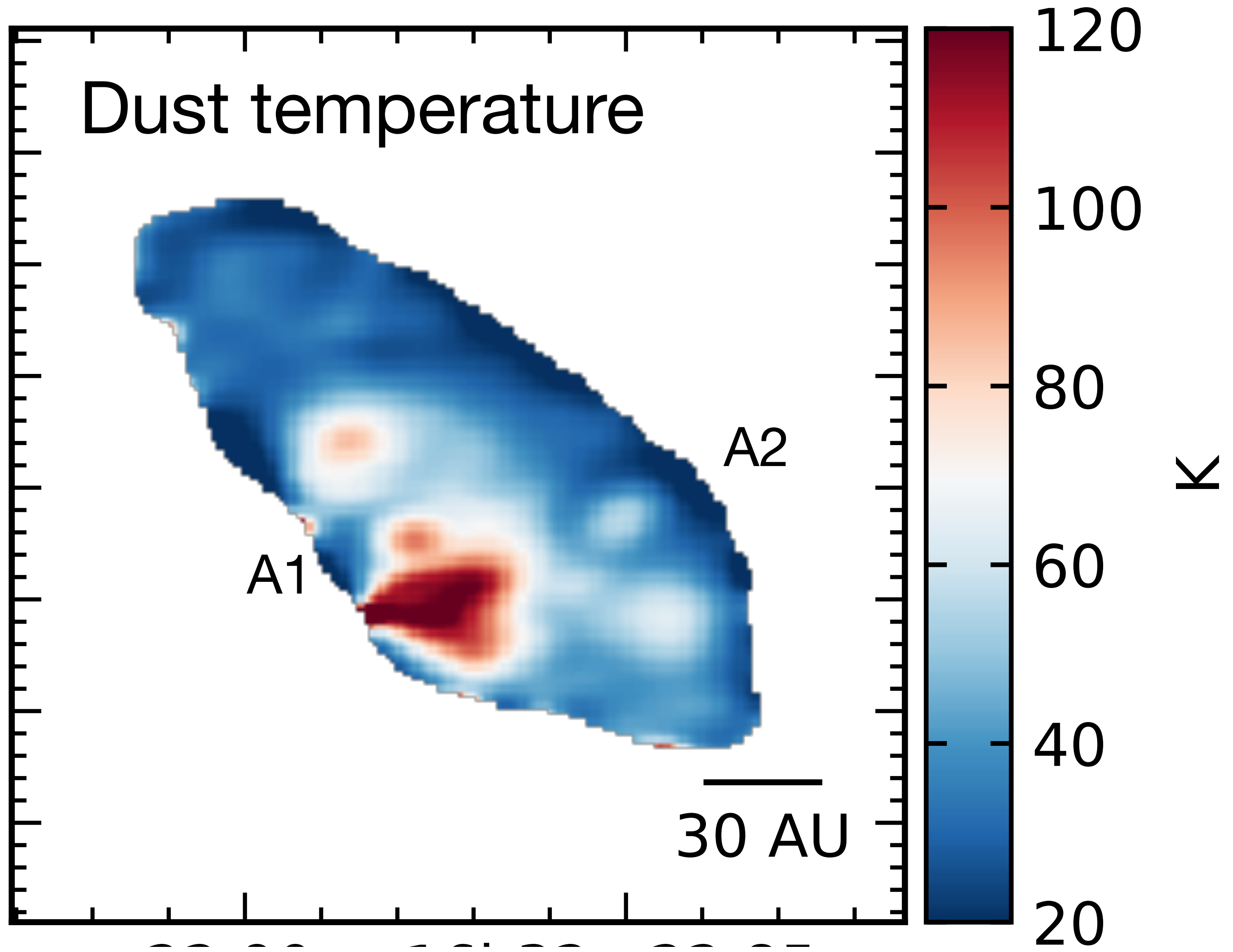

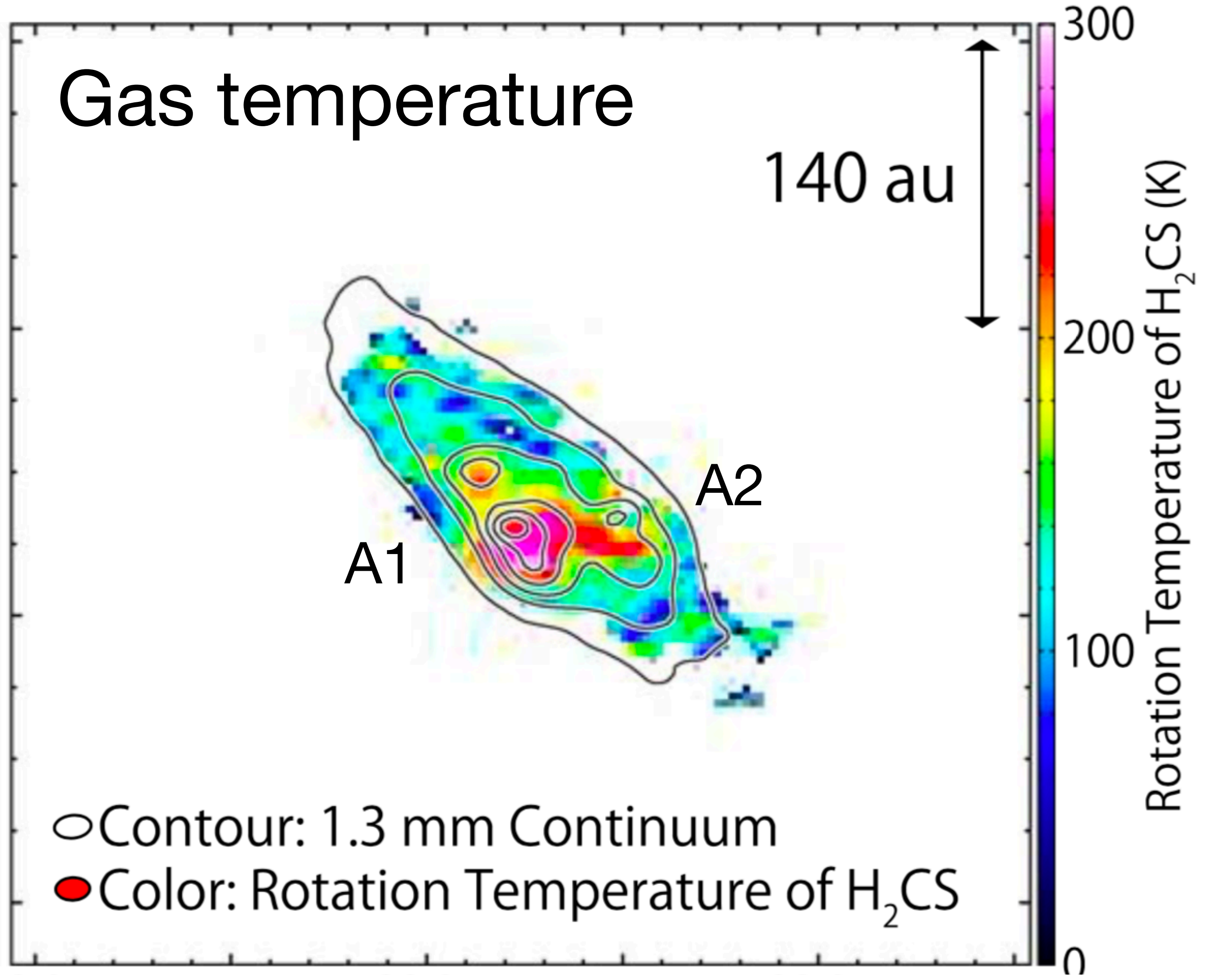

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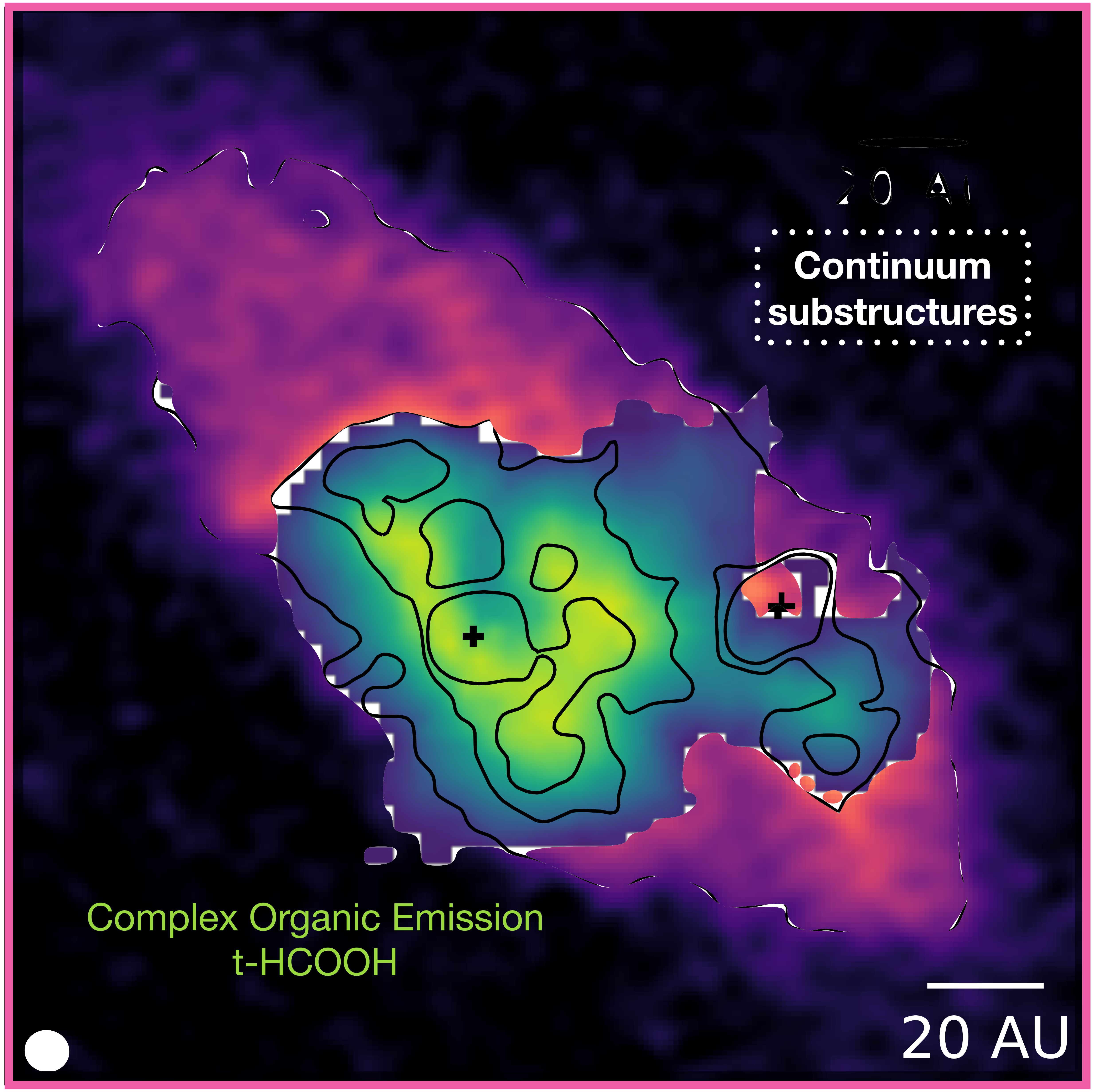
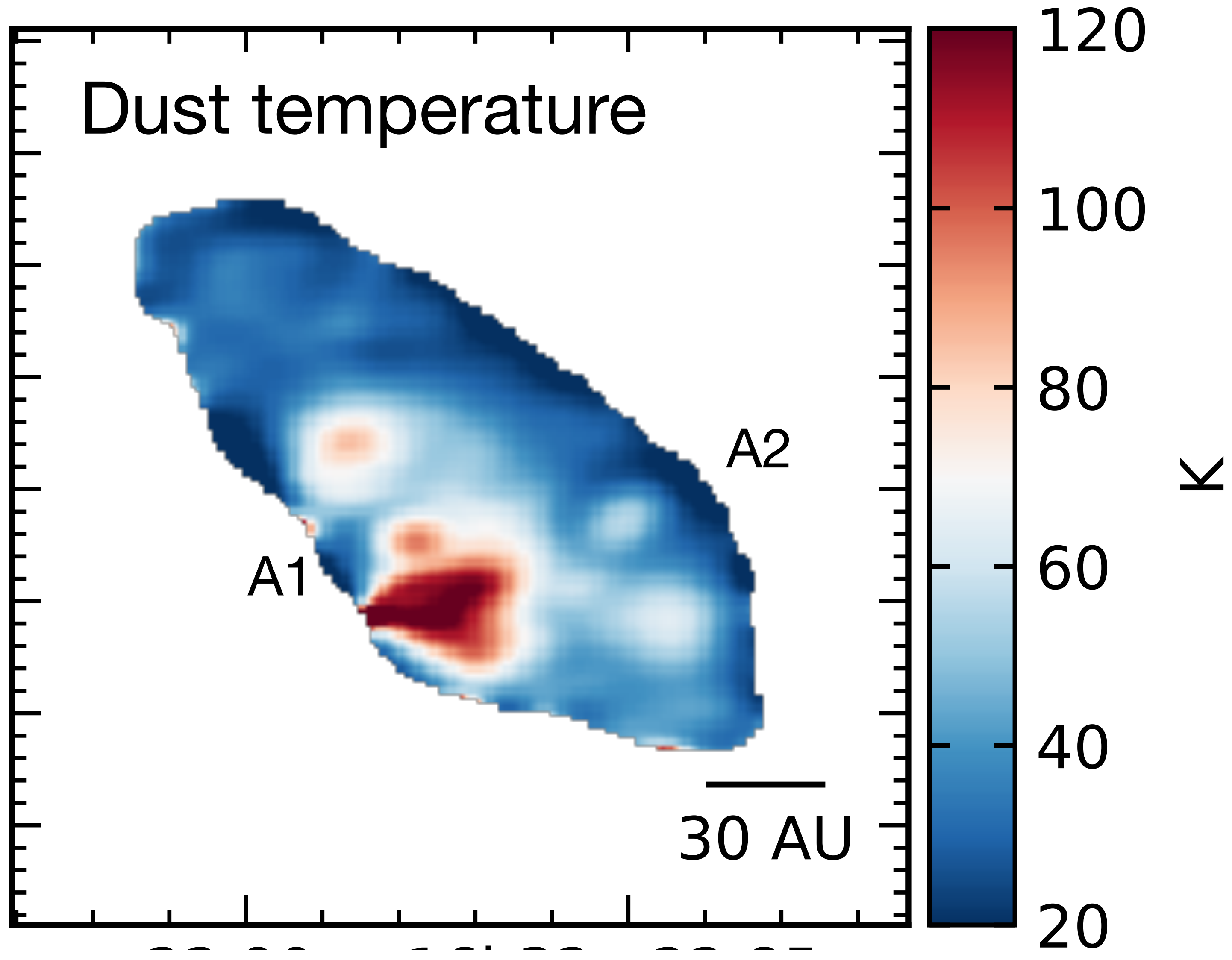
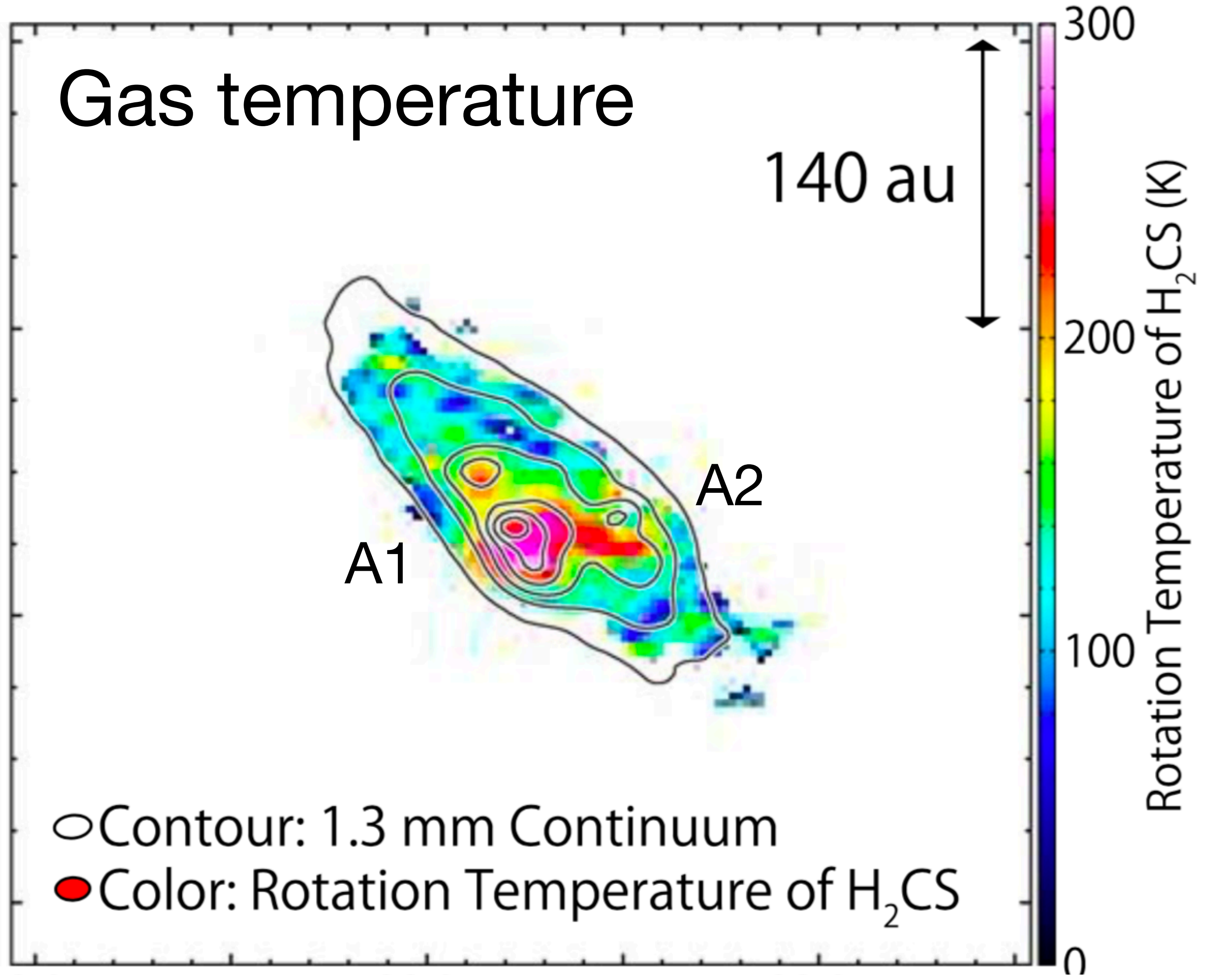
Hot dust and gas spots in Class 0 circumbinary disk







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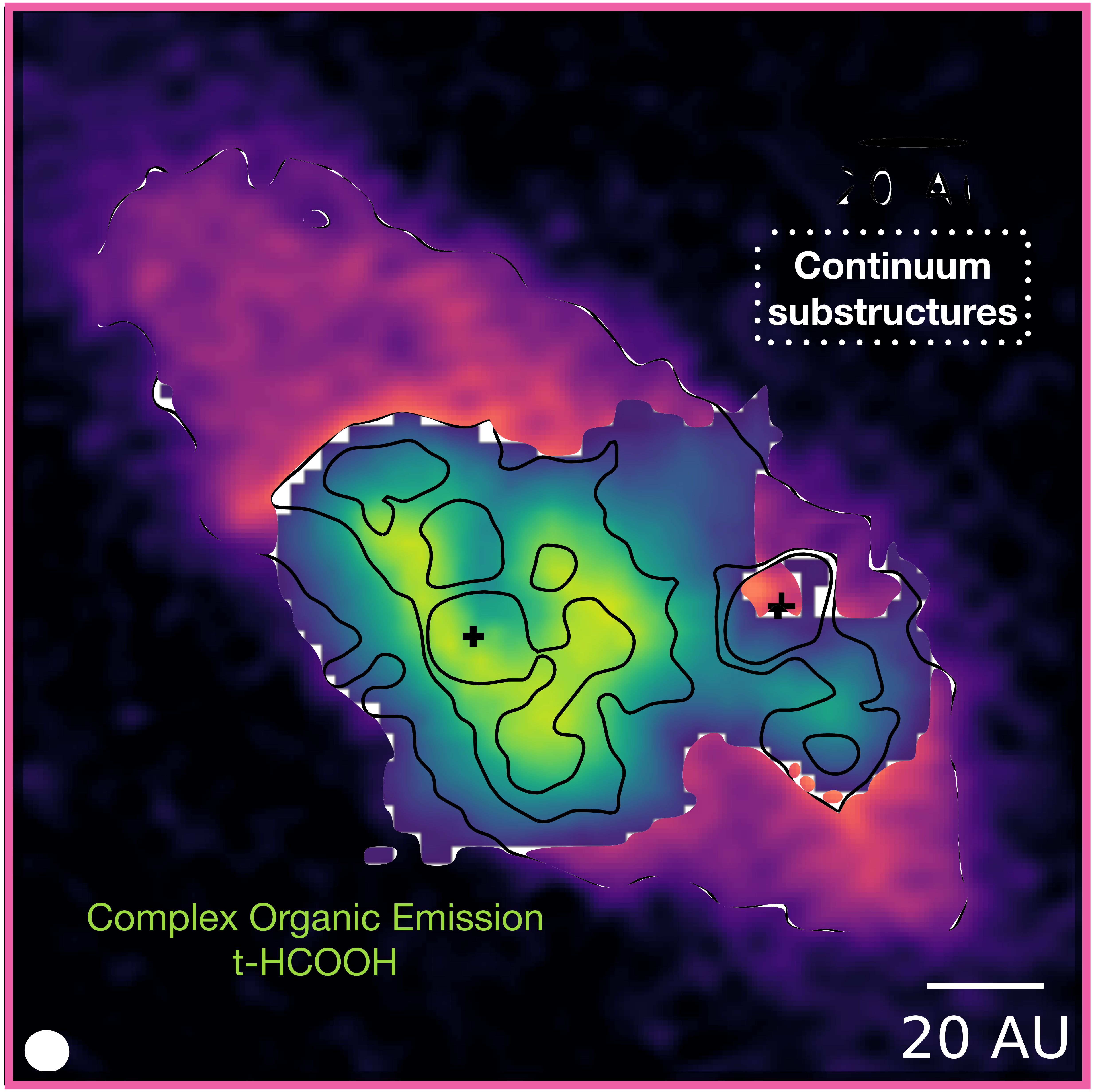
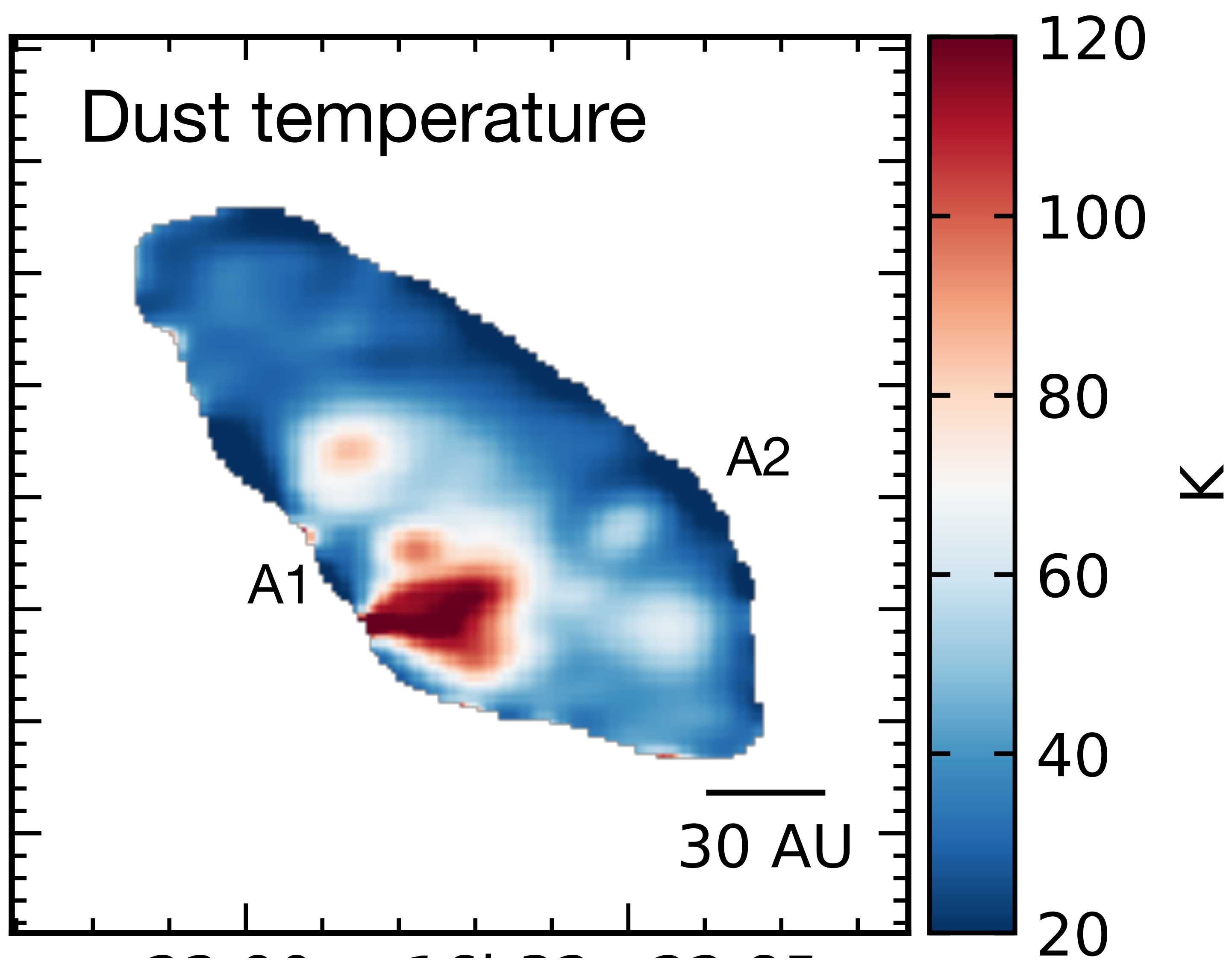
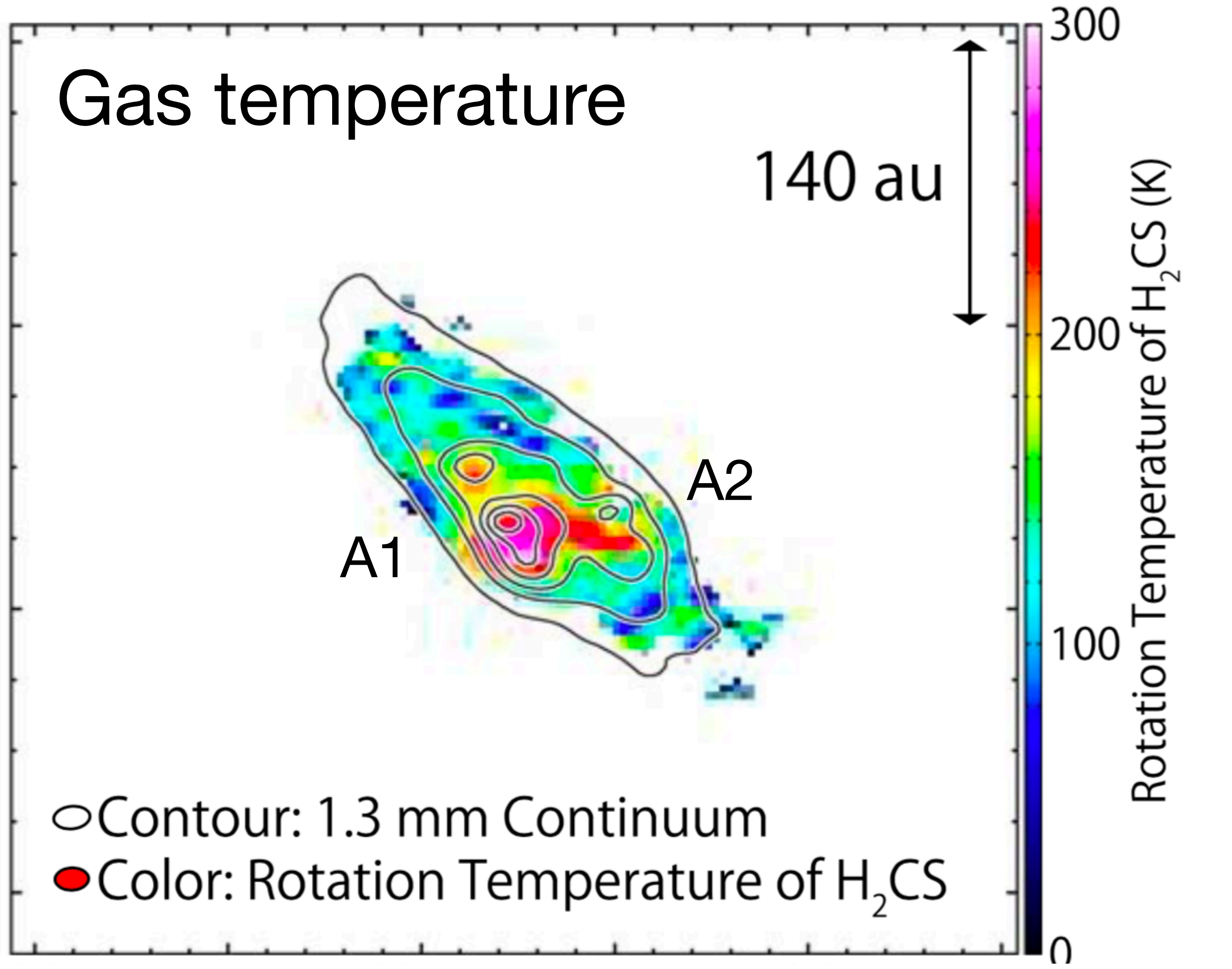


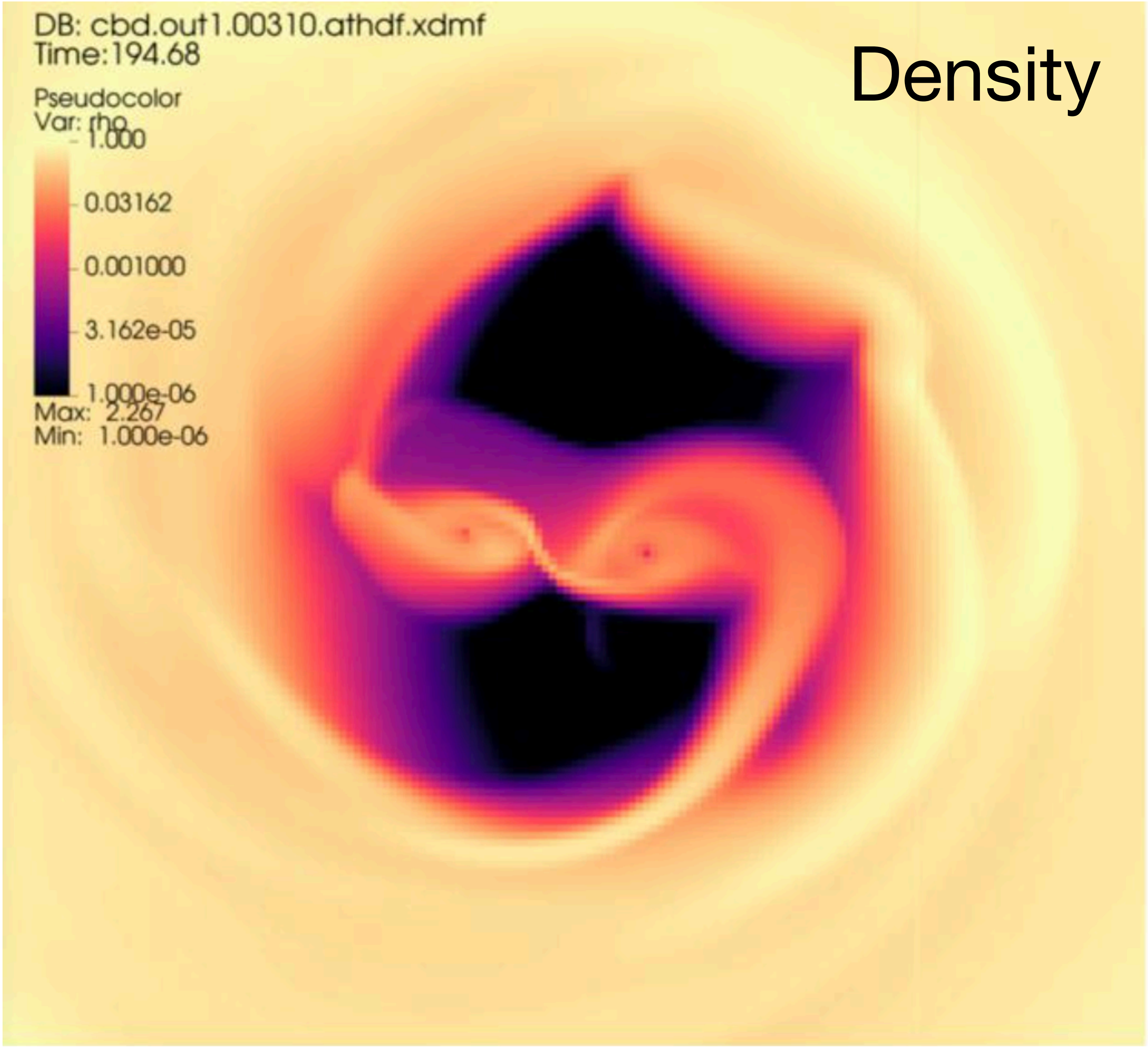


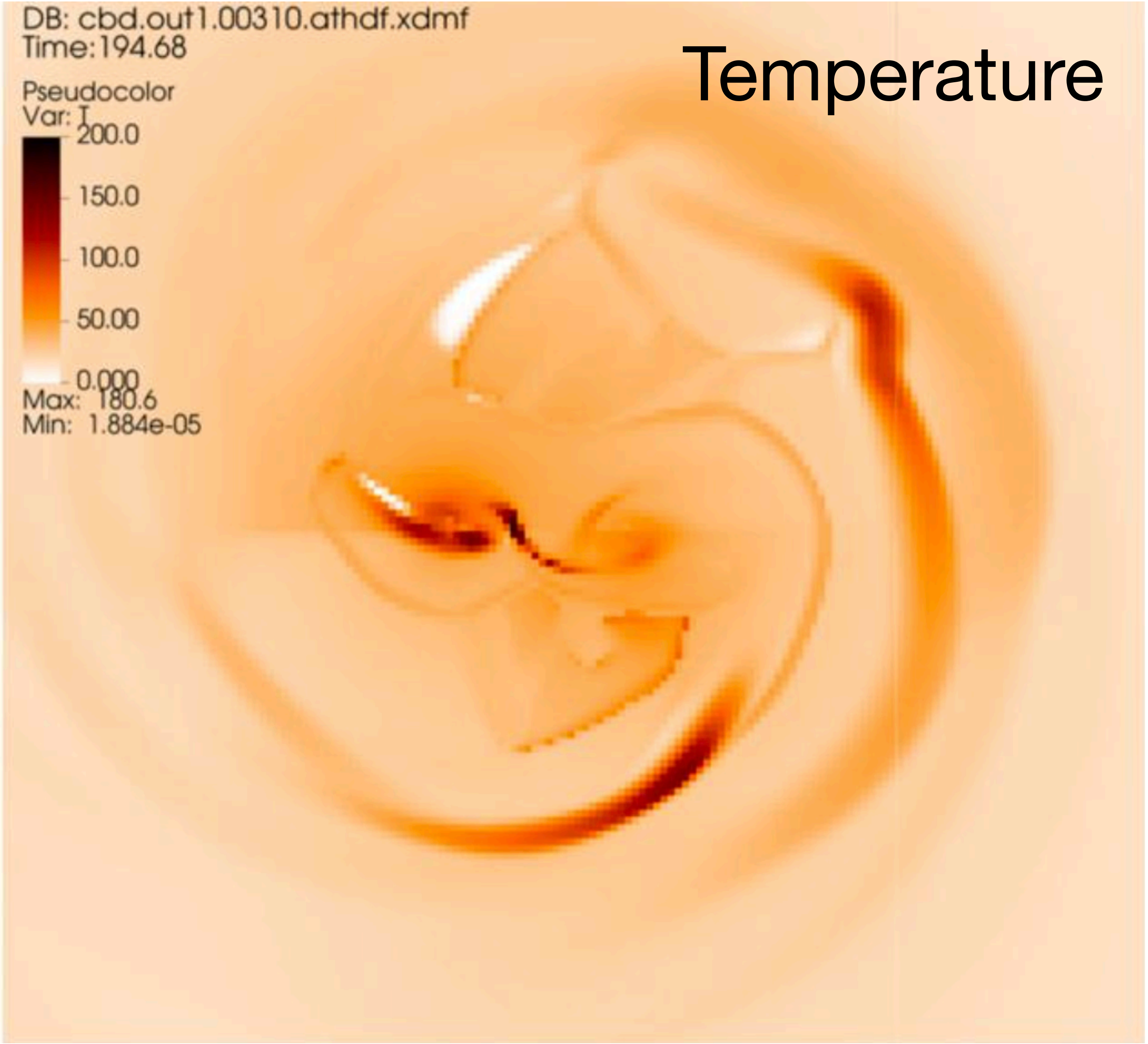


References: Maureira et al. 2020a, Oya et al. 2020, Maureira et al. 2022

Hot gas/dust spots due to shocks?

Numerical simulation



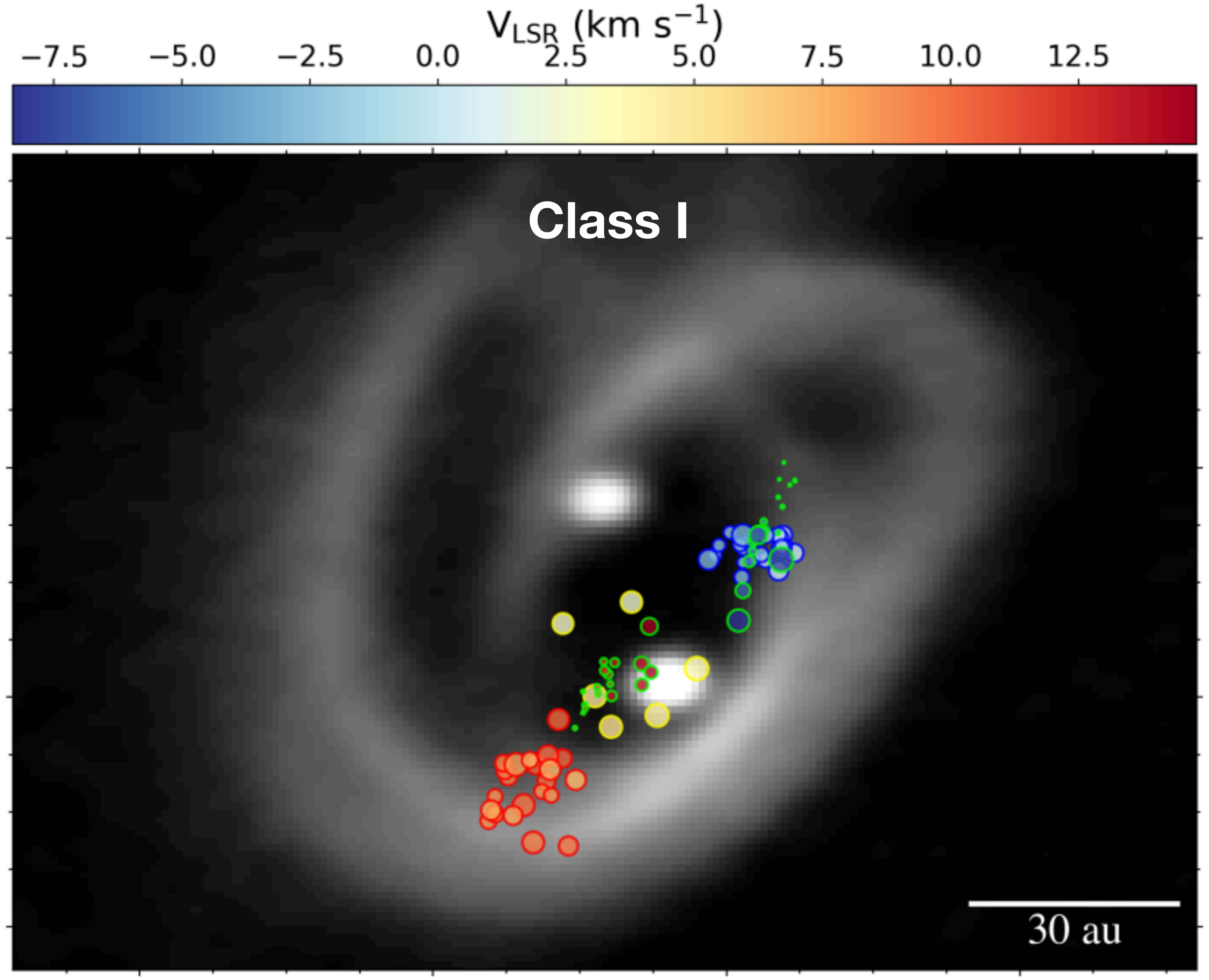


Gong, Maureira et al. in prep

More examples of hot 'shocked' regions in circumbinary material?

CH_3OCH_3 with temperatures 100-130 K

n(H2) ~ 10^7 cm^{-3}



Vastel et al. 2024, Alves et al. 2019

More examples of hot ‘shocked’ regions in circumbinary material?

CH_3OCH_3 with temperatures 100-130 K
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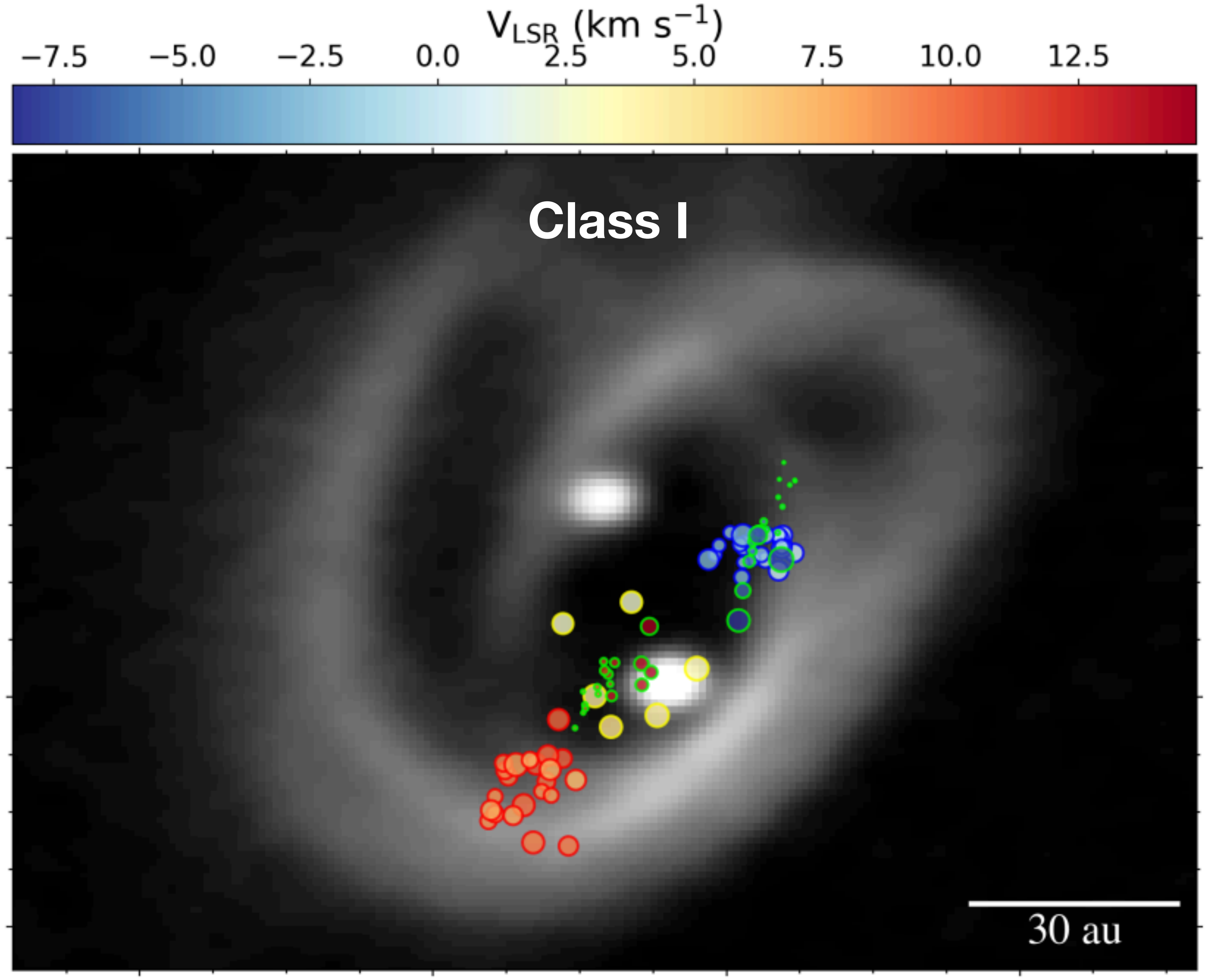
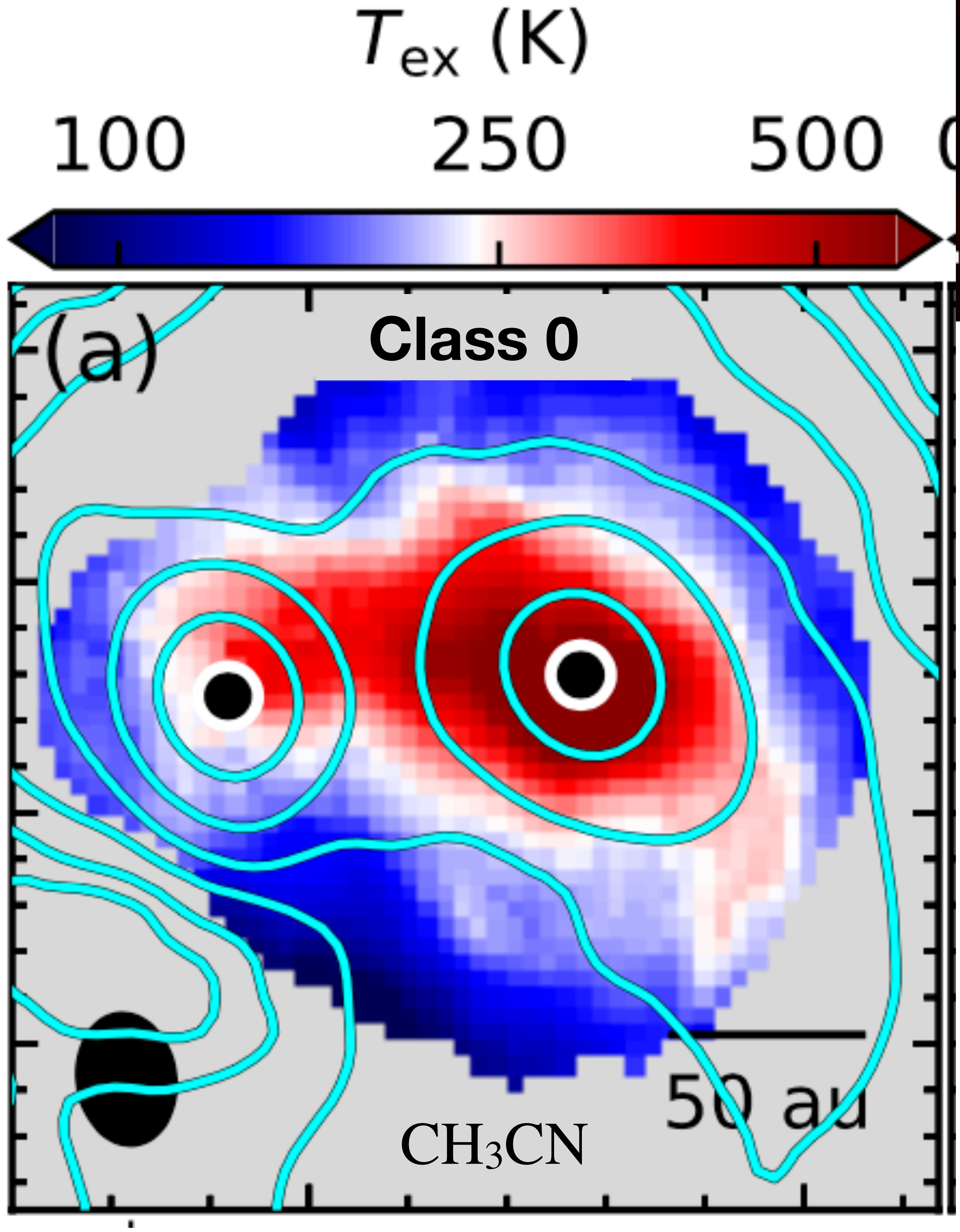
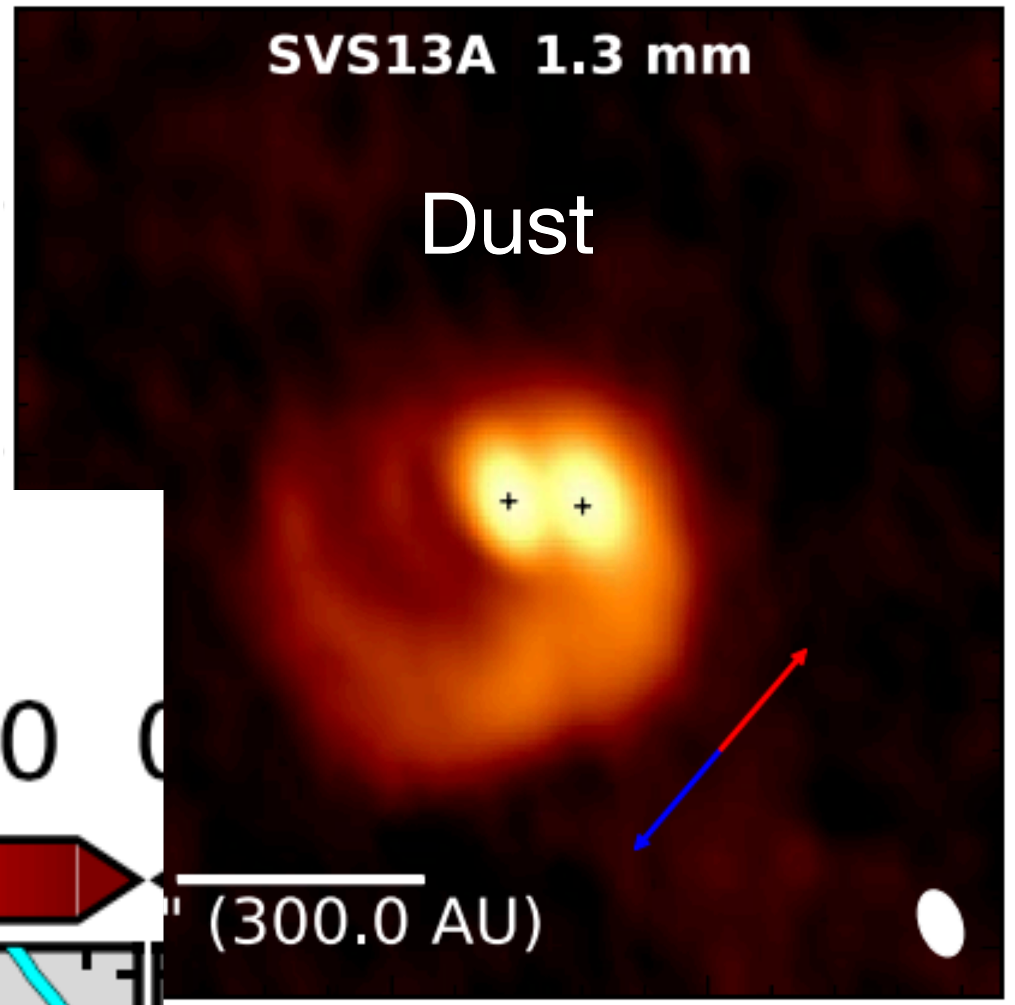


Vastel et al. 2024, Alves et al. 2019

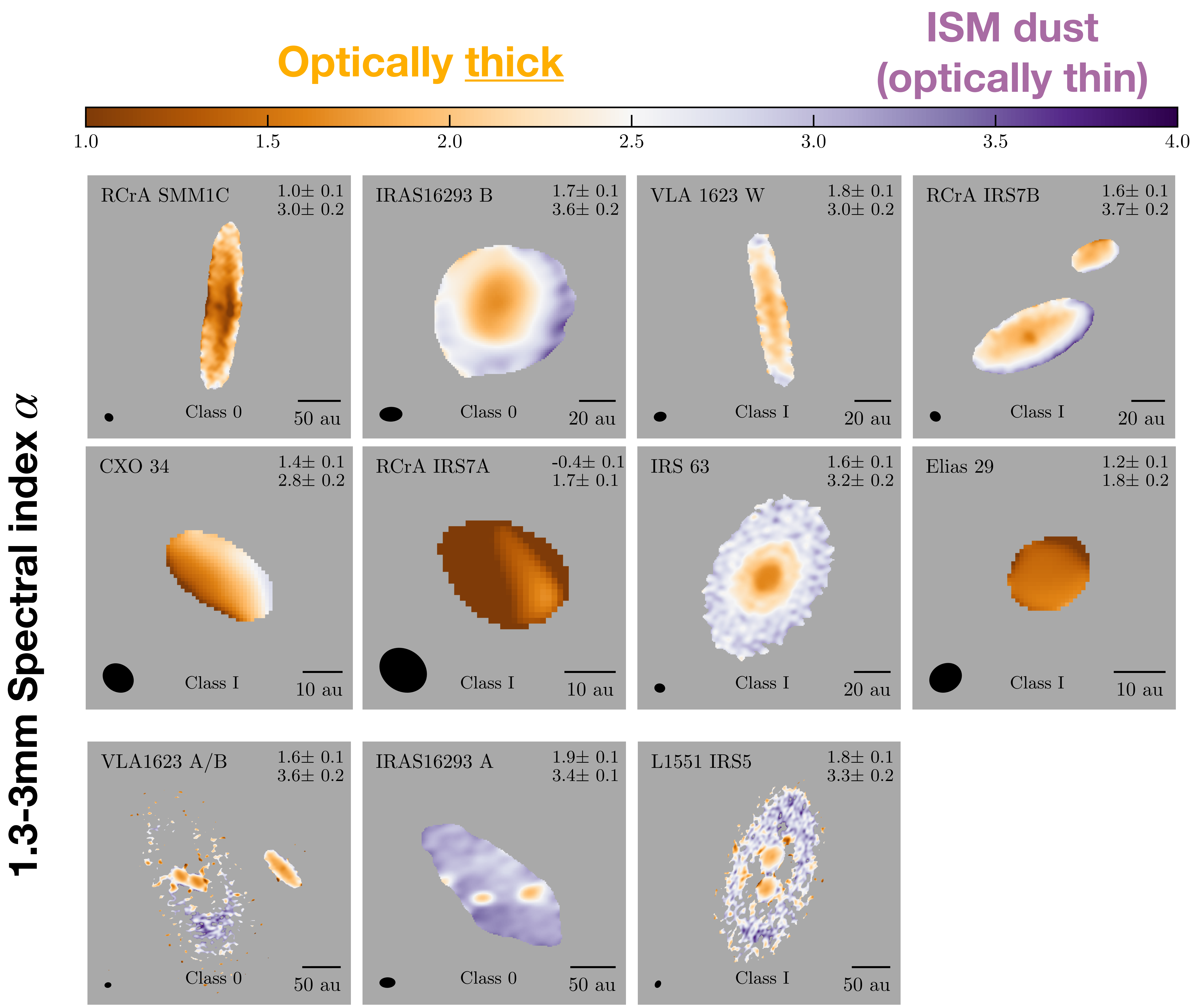


Hsieh et al. 2025 (submitted)



Tobin et al. 2018

Spectral index in circumbinary and circumstellar Class 0/I disks



$$I_\nu \propto \nu^\alpha$$

Optically thick — Optically thin

$$2 < \alpha < 2 + \beta$$

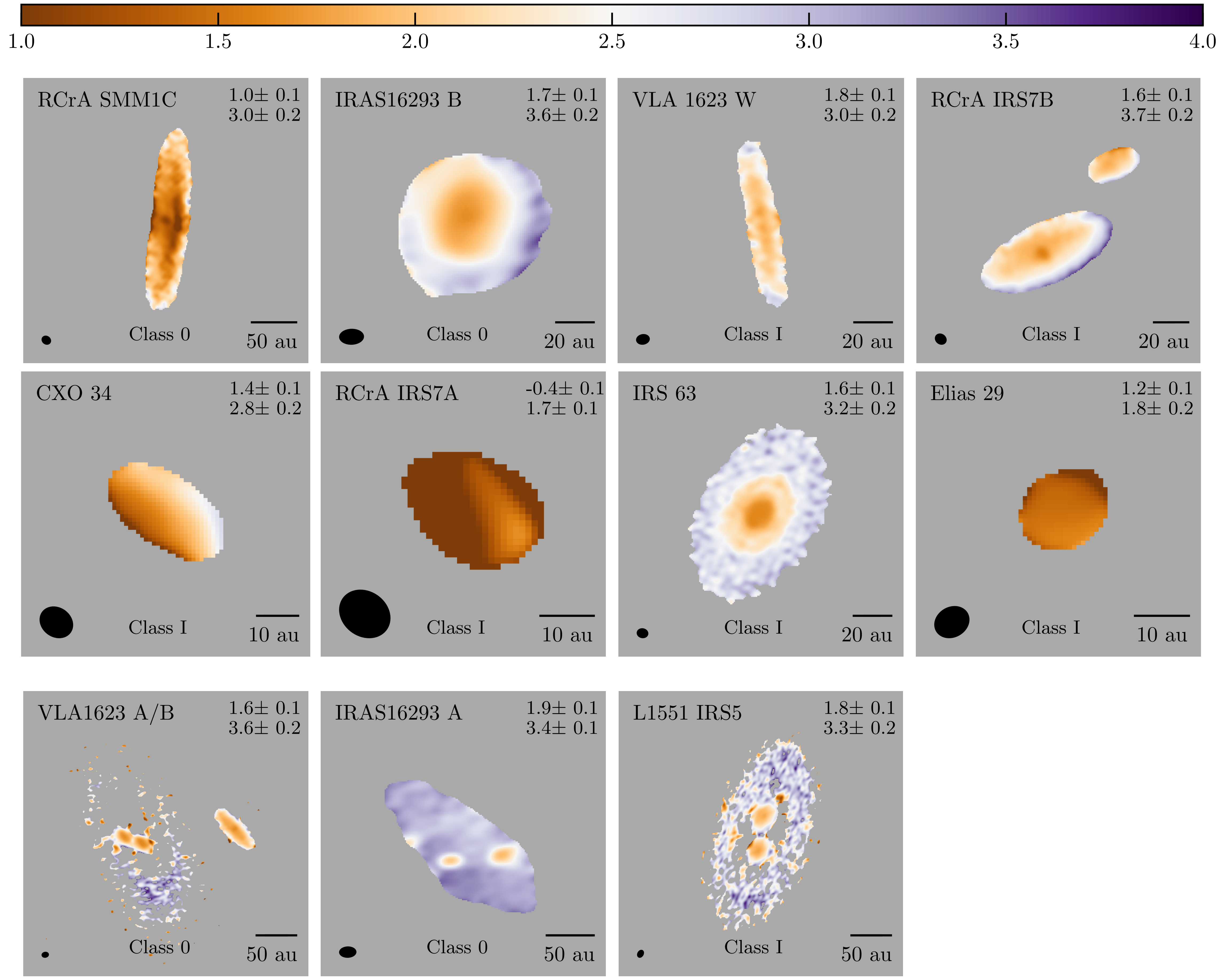
β changes depending on dust properties

Maureira et al. in prep

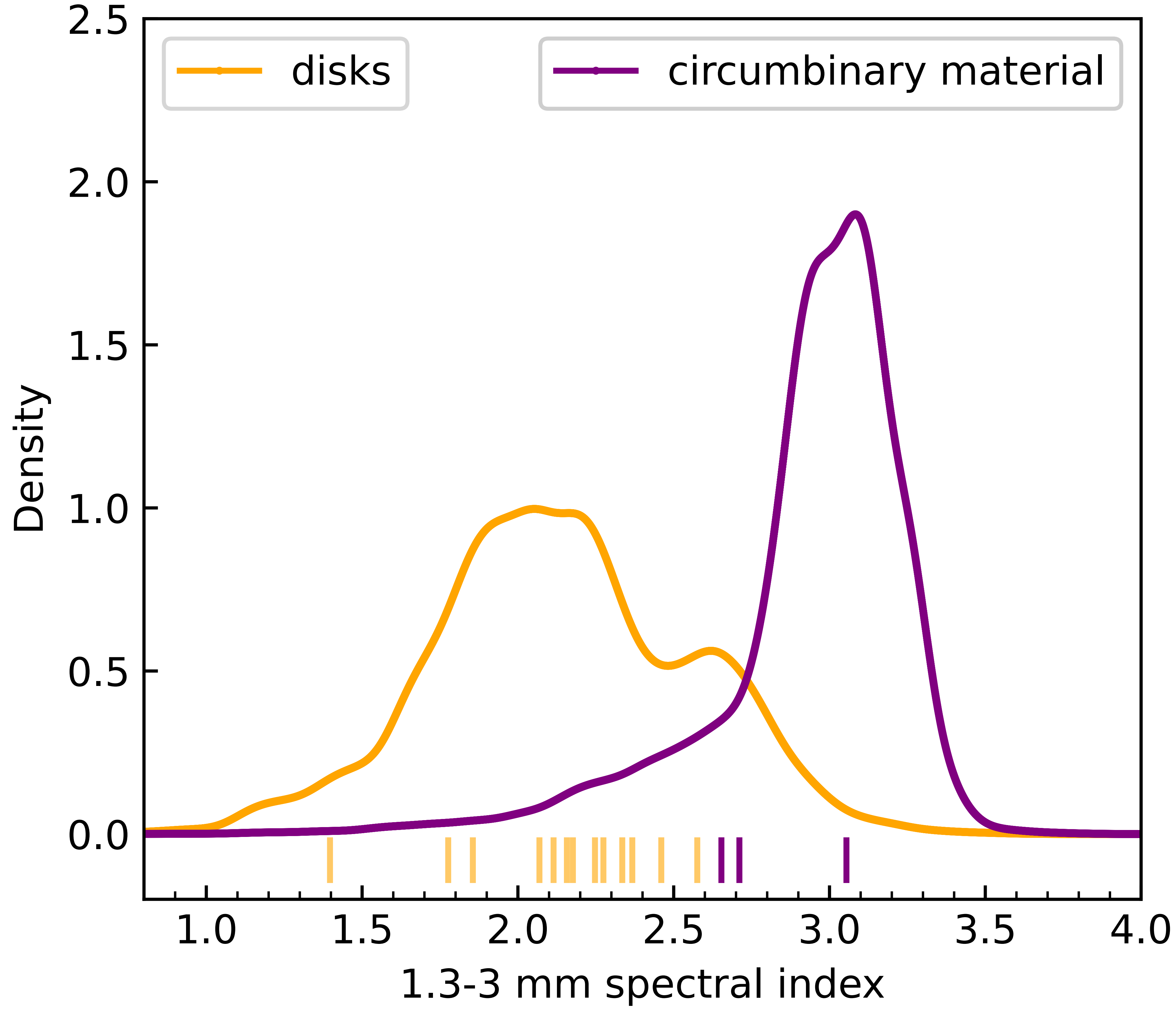
Spectral index in circumbinary and circumstellar Class 0/I disks

Optically thick | **ISM dust (optically thin)**

1.3-3mm Spectral index α

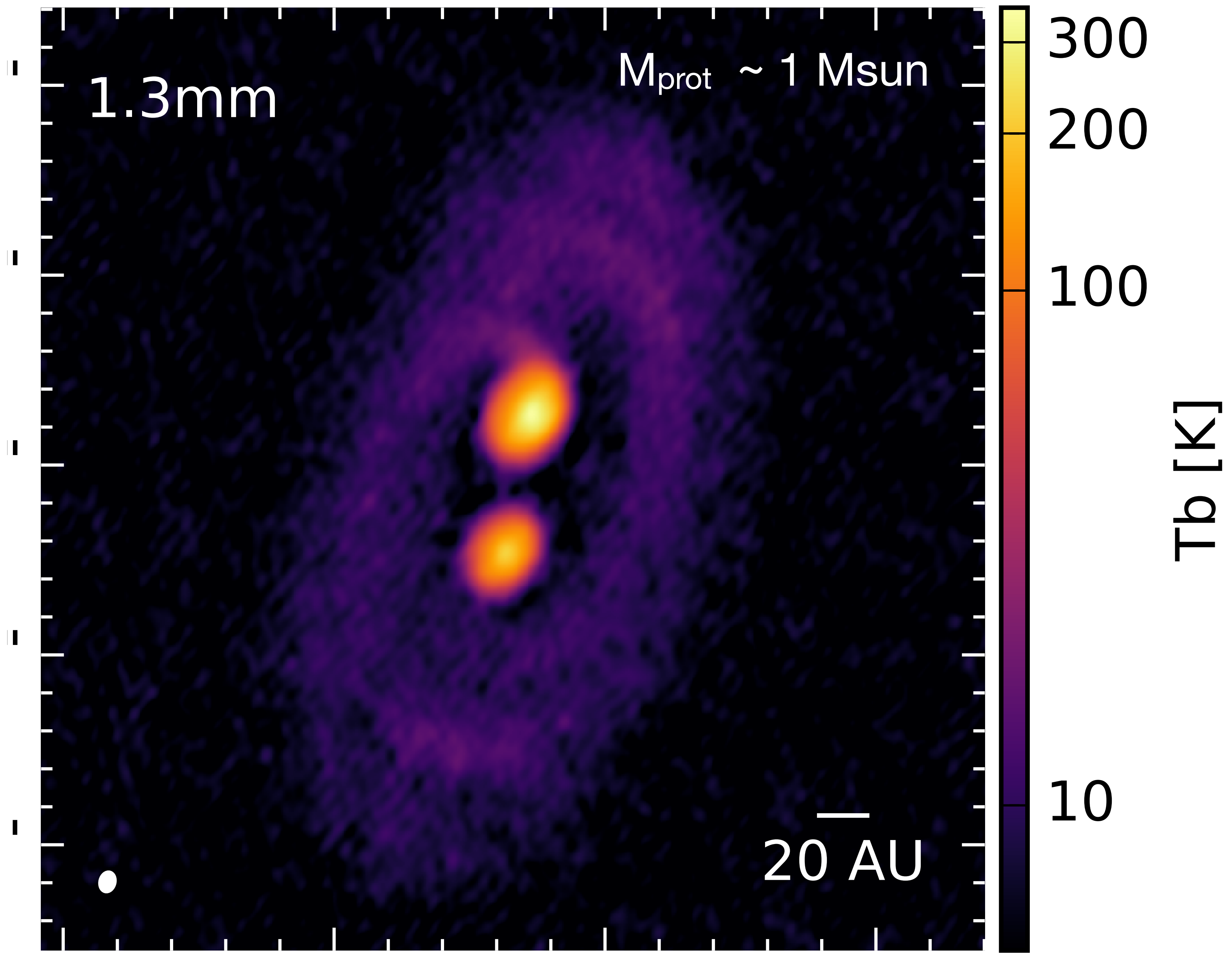


Individual disks versus circumbinary disks

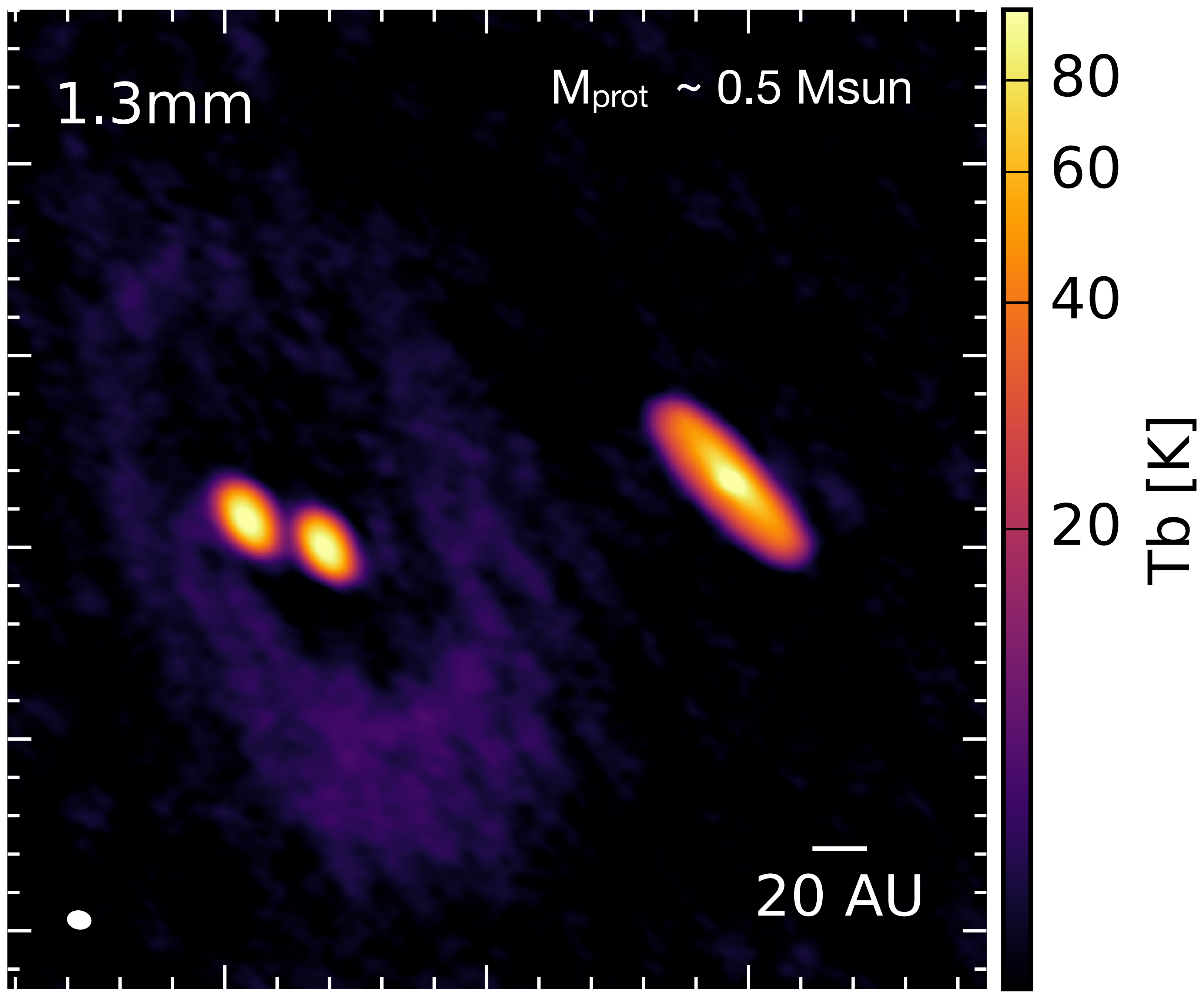


Maureira et al. in prep

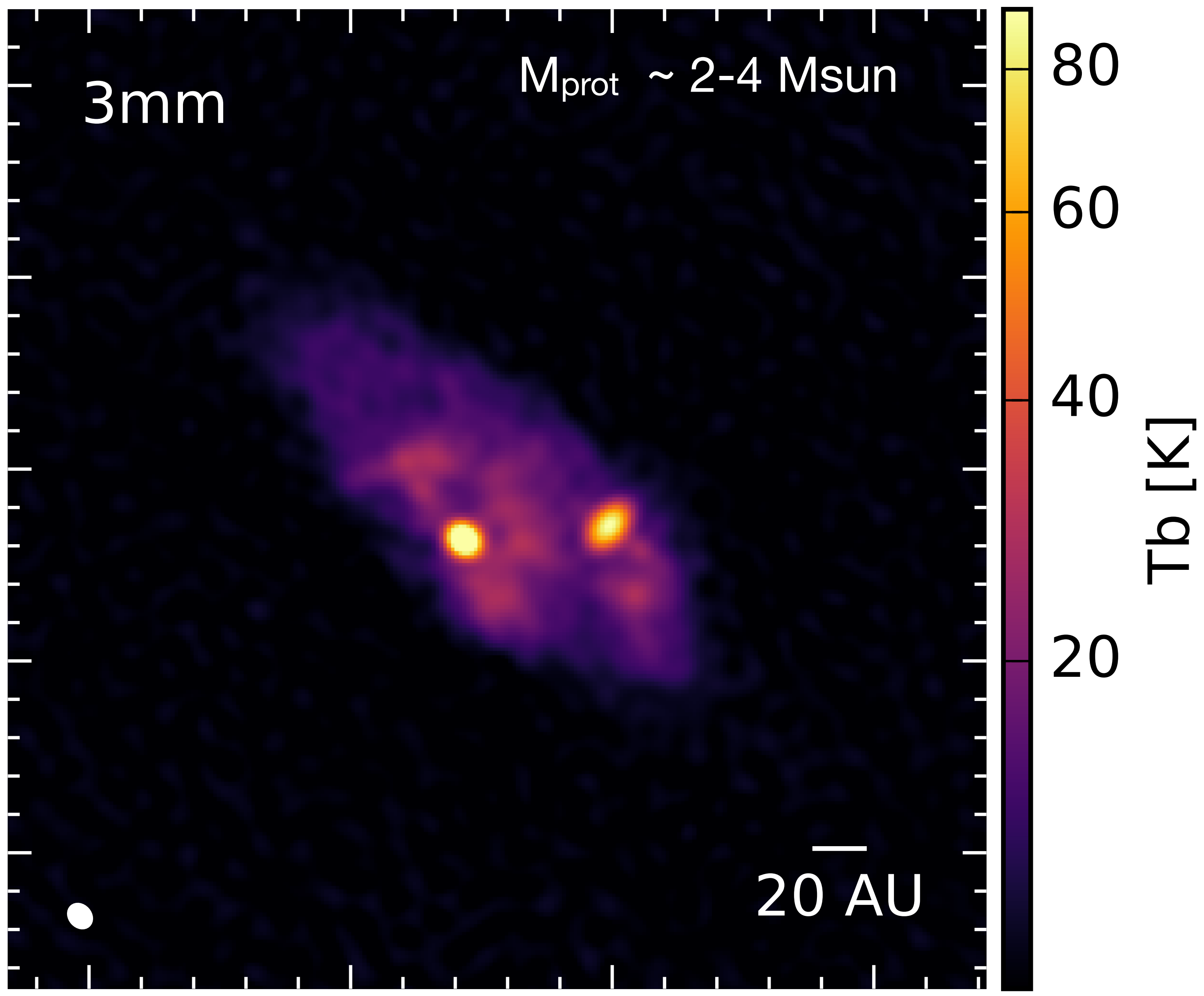
Mass estimates: Circumbinary and circumstellar disks



Mass CB disk
Gas ~ 0.07 M_{sun} (~70 M_{jup})
Dust ~ 180 M_{Earth}



Mass CB disk
Gas ~ 0.05 M_{sun} (~50 M_{jup})
Dust ~ 170 M_{Earth}



Mass CB disk
Gas ~ 0.1 M_{sun} (~100 M_{jup})
Dust ~ 300 M_{Earth}

Maureira et al. in prep

Mass estimates: Circumbinary and circumstellar disks

Mass CB disk
Gas ~ 0.07 M_{sun} (~70 M_{jup})
Dust ~ 180 M_{Earth}

Mass CS disks
Gas ~ 0.03 M_{sun} (~30 M_{jup})
Dust ~ 100 M_{Earth}

Mass CB disk
Gas ~ 0.05 M_{sun} (~50 M_{jup})
Dust ~ 170 M_{Earth}

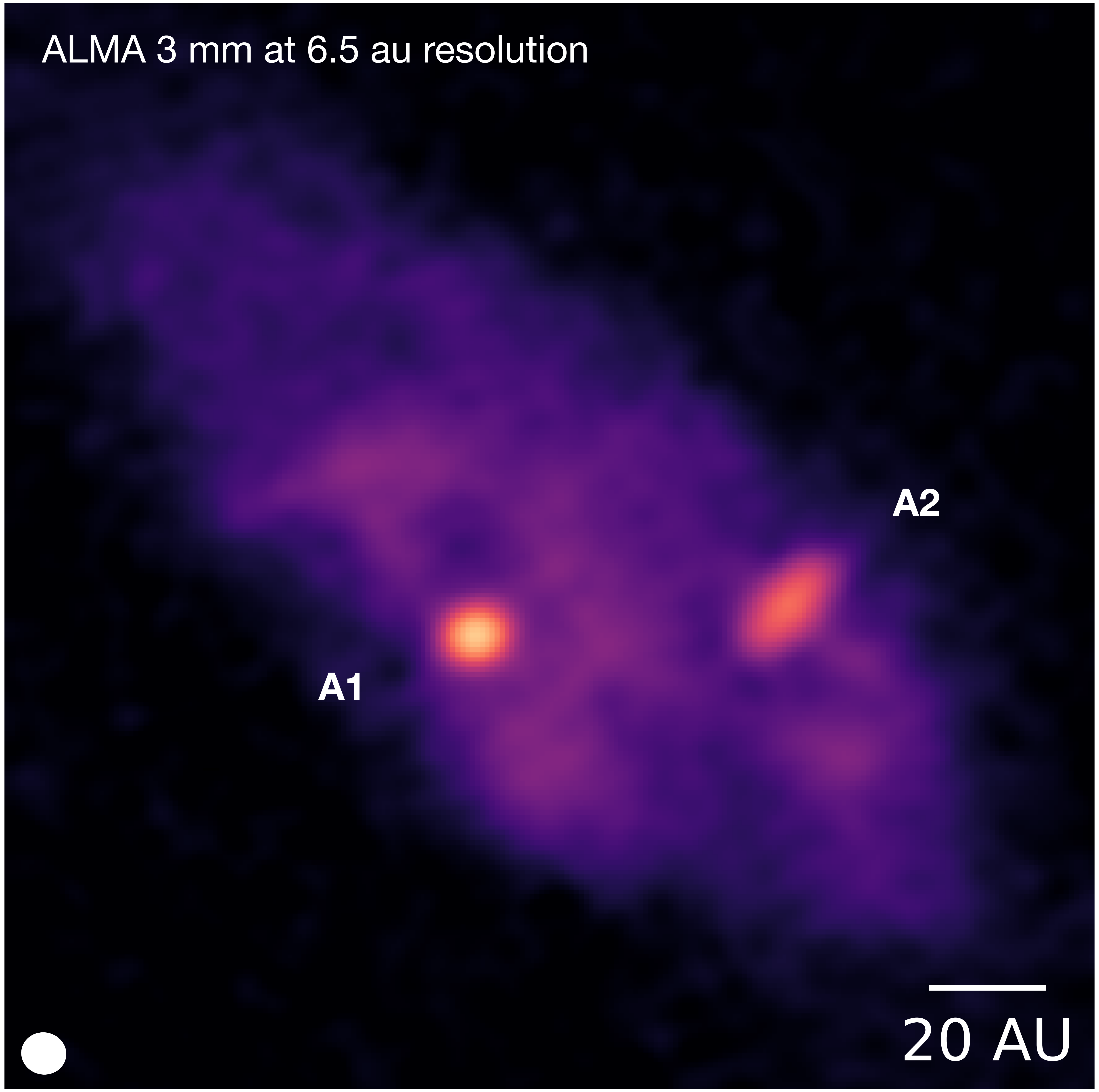
Mass CS disks
Gas ~ 0.02 M_{sun} (~20 M_{jup})
Dust ~ 80 M_{Earth}

Mass CB disk
Gas ~ 0.1 M_{sun} (~100 M_{jup})
Dust ~ 300 M_{Earth}

Mass CS disks
Gas ~ 10^{-3} - 10^{-2} M_{sun} (~1-10 M_{jup})
Dust ~ 2 - 40 M_{Earth}

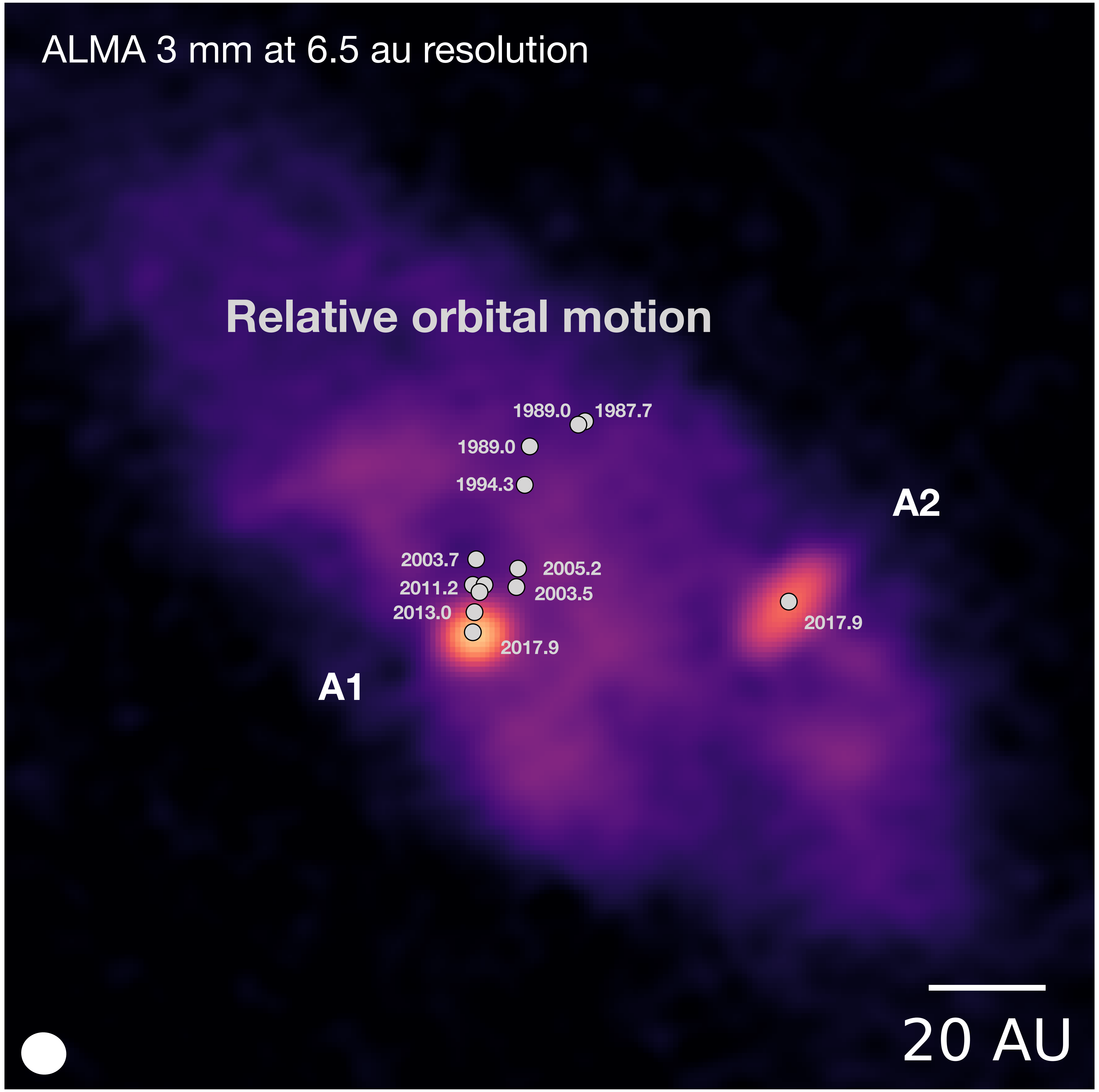
Maureira et al. in prep

Orbital motion of the Class 0 binary IRAS 16293 A



Maureira et al. 2020a

Orbital motion of the Class 0 binary IRAS 16293 A



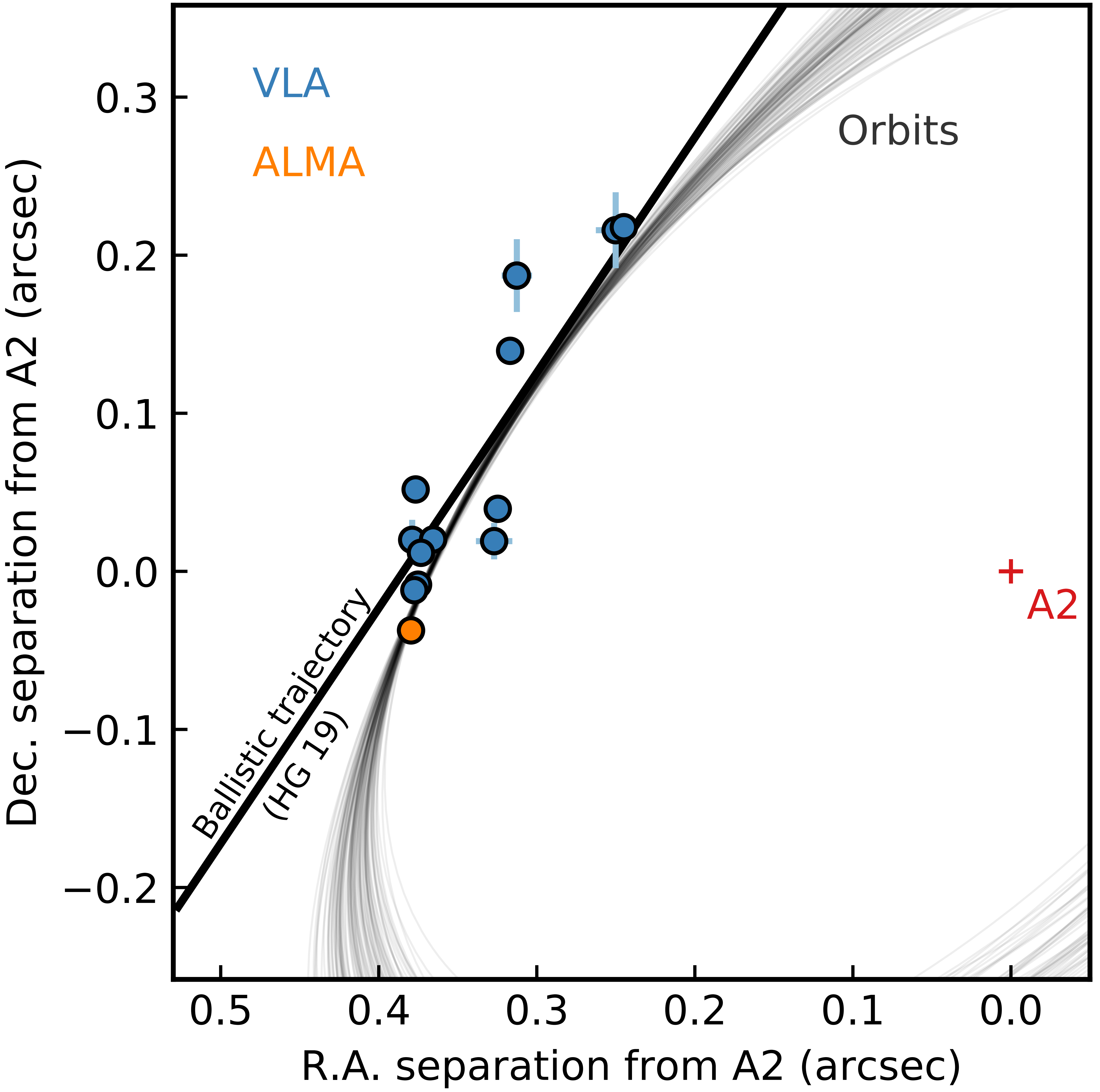
Bound system

At least 2 Msun in protostellar mass

Orbital period ~ 400 yr

Maureira et al. 2020a

Orbital motion of the Class 0 binary IRAS 16293 A



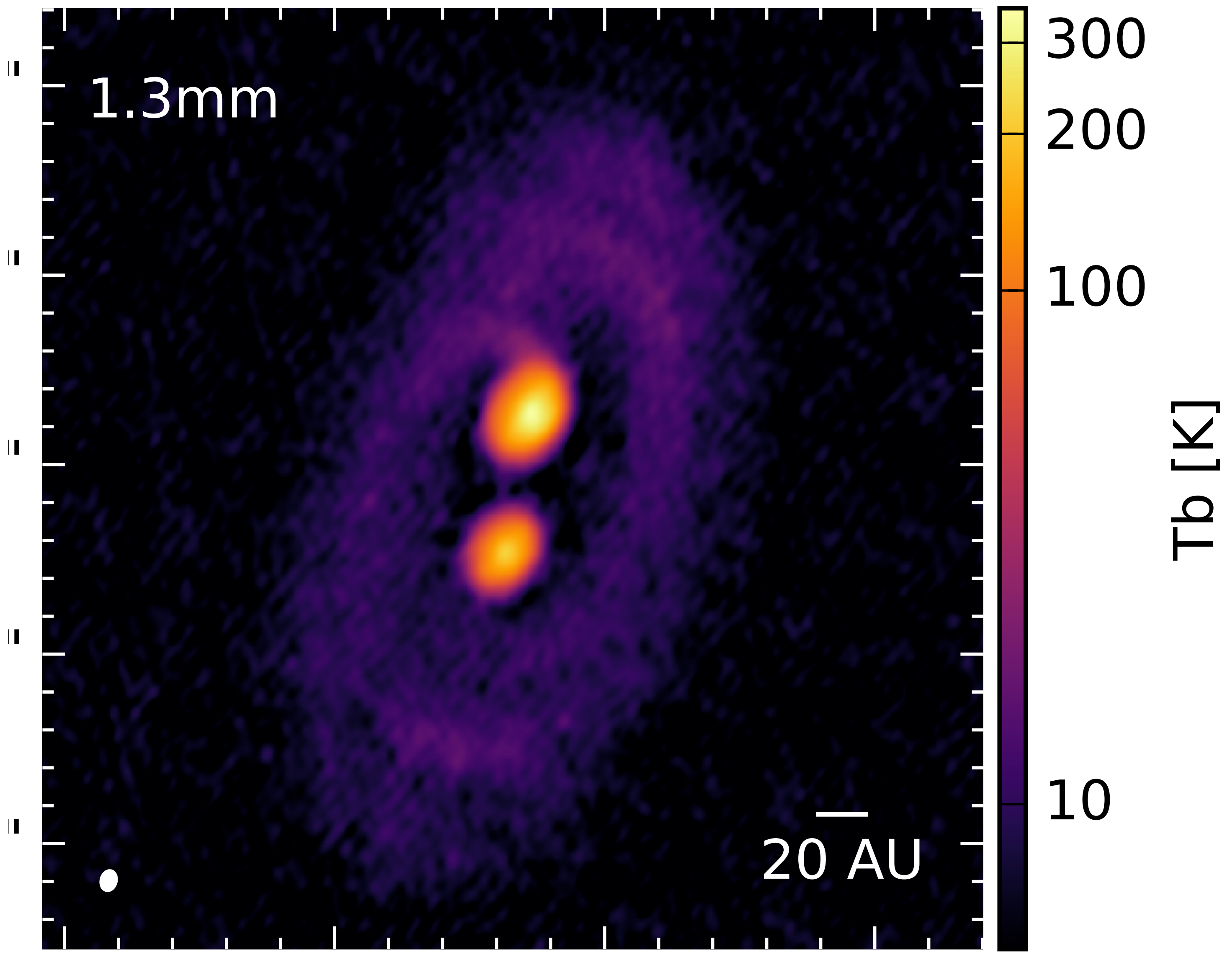
Bound system

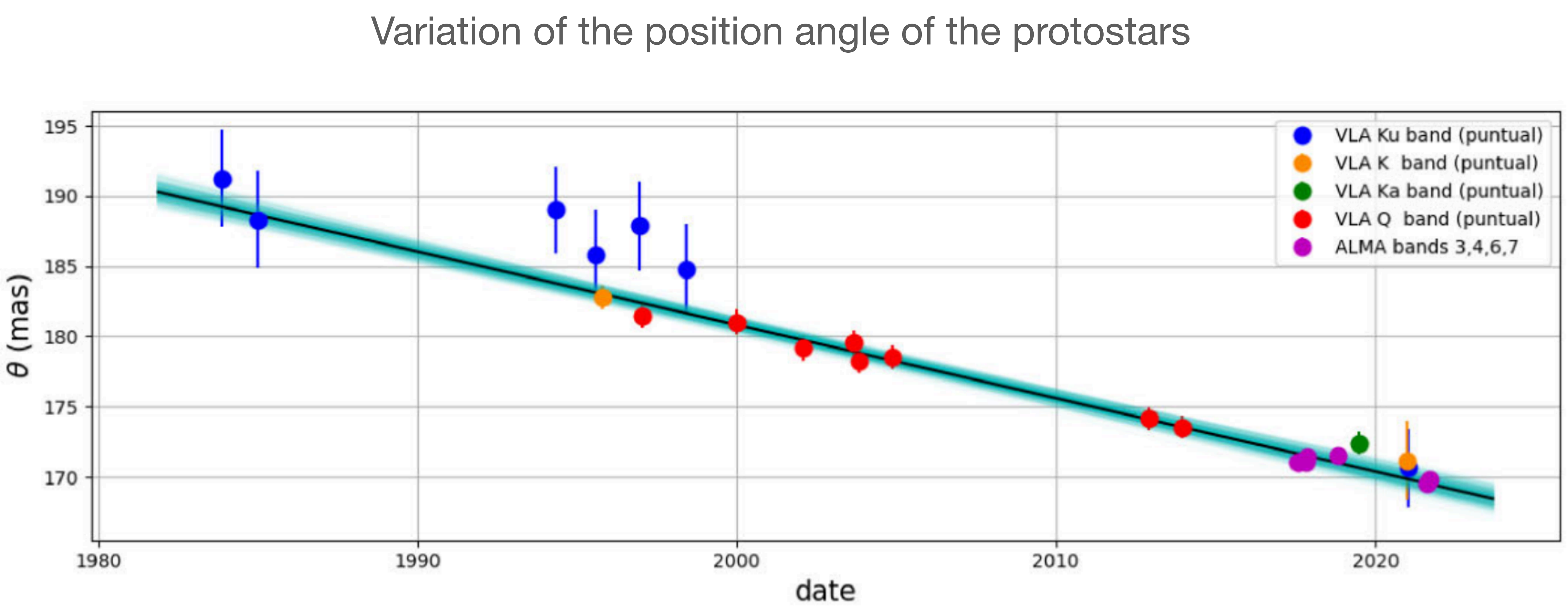
At least 2 Msun in protostellar mass

Orbital period ~ 400 yr

Maureira et al. 2020a

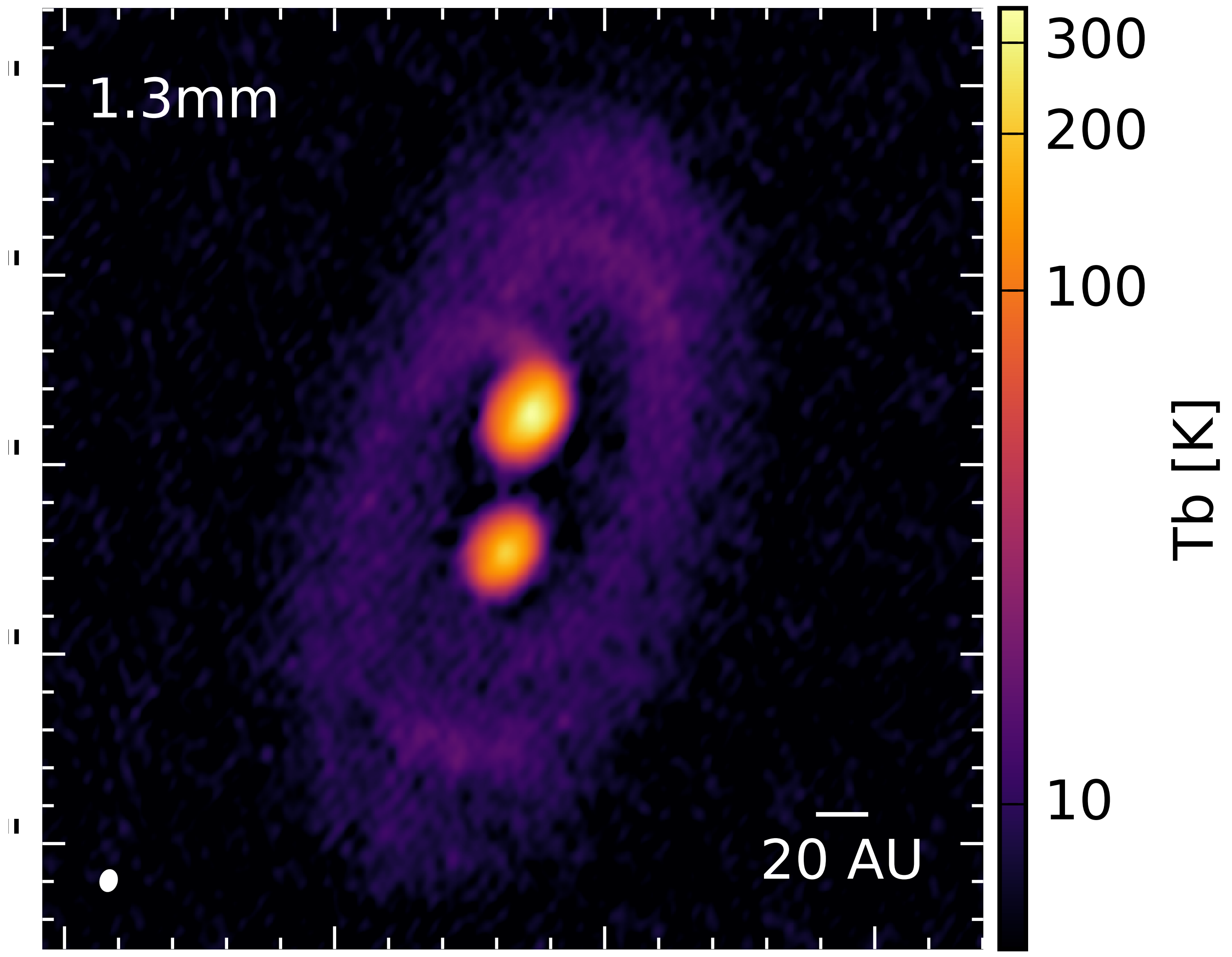
Orbital motion of the Class I binary L1551 IRS 5

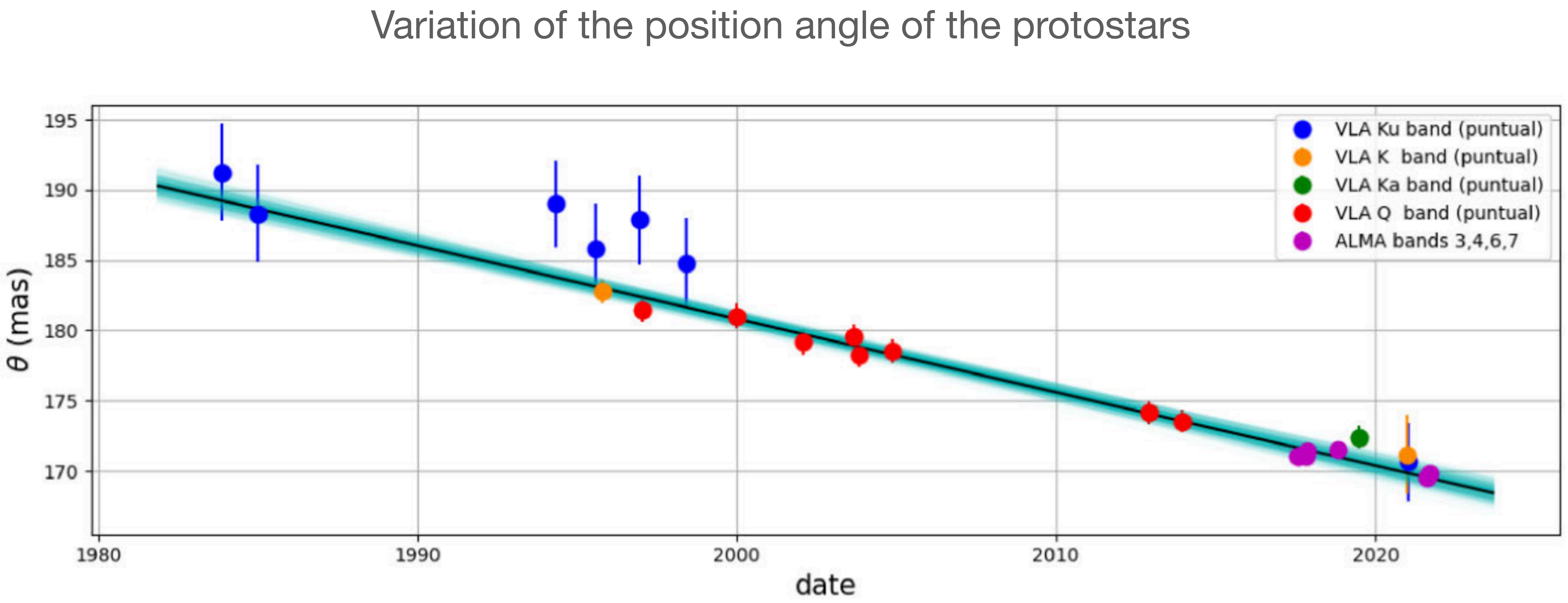




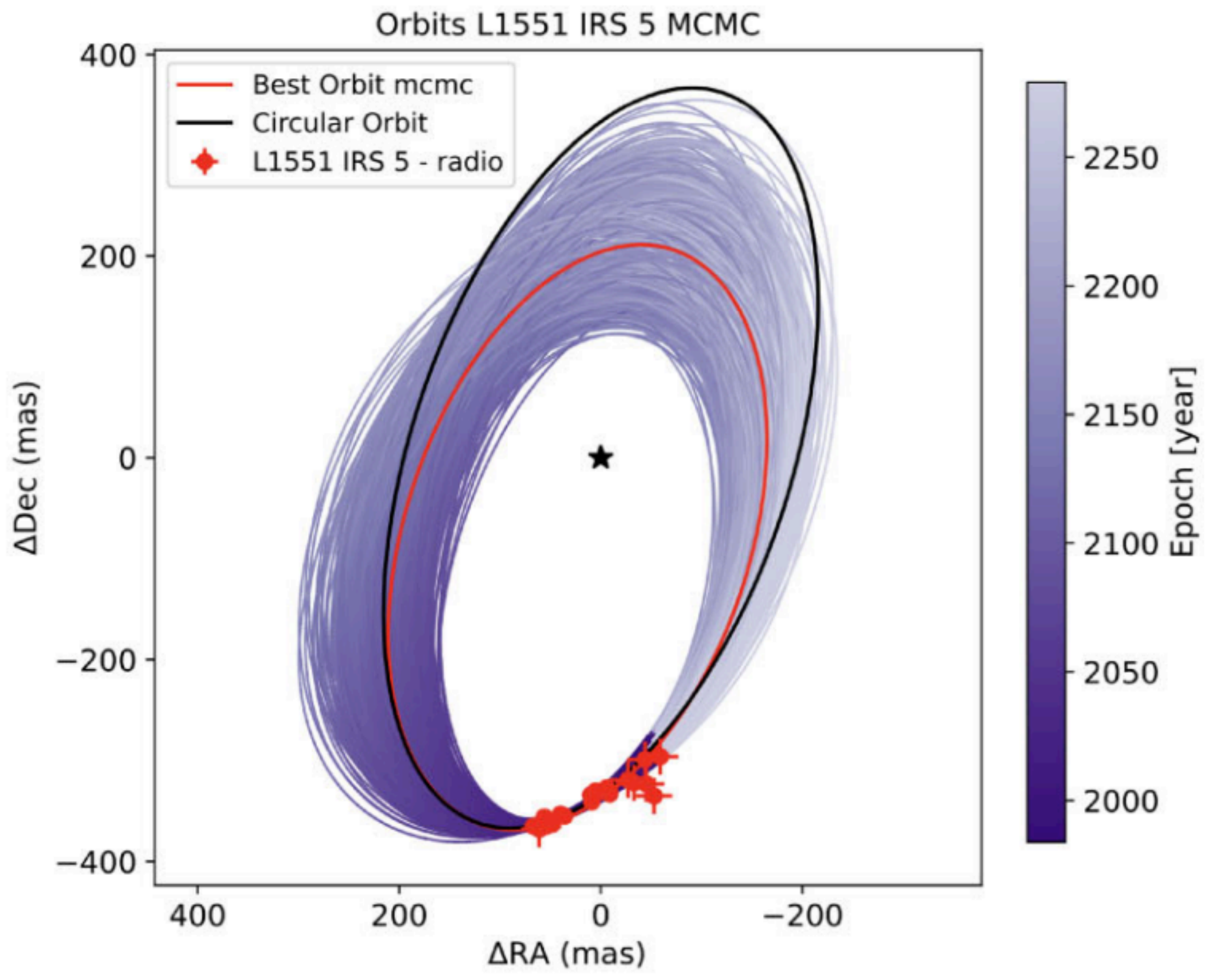
Hernandez Garnica et al. 2024

Orbital motion of the Class I binary L1551 IRS 5





Parameter	Value	Units
a	44.0±3.2	AU
e	0.27±0.09	
Ω	161.3 ±4.1	degrees
i	126.3 ±5.0	degrees
ω	175.9±15.1	degrees
T_0	2457329±28	
P	300±38	years
Total mass	0.96±0.17	$M_\odot$



Hernandez Garnica et al. 2024

Summary

- **Class 0/I binaries (sep < 100 au) show a variety of circumbinary disks sizes** (few 10 to few 100 au), **morphologies** (spirals, ring-like, disk-like, etc) and **misalignments** (CB vs CS disk)

  ….BUT not all show clear circumbinary disk structures (* in dust emission)

- **Filamentary structures connecting to the disks are observed for systems > 100 au separations**, possibly tracing accretion streamers.

- Presence of **localized and asymmetric enhancements of dust/gas temperatures (> 100 K) in circumbinary disks, interpreted as shocks** (origin: binary accretion, accretion streamers from envelope, outflows?)

- Circumstellar disks are optically thick at 1.3 and 3 mm (in singles and multiple systems), while circumbinary disks appear to be optically thinner (tau < 1).

- Mass estimates for CB disks: 10^{-2} - 10^{-1} M_{sun} (50-100 M_{jup}) in gas or tens to 100 ME_{arth} in solids.

- **Orbital parameters are starting to be constrained for embedded Class 0 and I** systems using ALMA and VLA, more will become available in the future!

Class 0/I binaries with sep > 100 au resolved down to 6-8 au

*To scale

References: Ohashi et al. 2023, Reynolds et al. 2024, Maureira et al. 2022, Encalada et al. 2024, Maureira et al. in prep, PRODIGEE team