Ongoing flyby in the young multiple system UX Tauri

Witnessing a stellar rendez-vous

Threats from the Surroundings
ESO Workshop
10 November 2020

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IPAG – Grenoble, France

Talk outlook

Dynamical & observational signatures of stellar flybys
Cuello et al. (2019, 2020)

Ongoing flyby in the multiple stellar system UX Tauri
Ménard, Cuello, Ginski et al. (2020)

More flyby candidates: SR 24, AS 205, ZCMa
—> Implications for planet formation

Collaborators:
François Ménard, Daniel Price, Christophe Pinte, Rebecca Nealon, Ruobing Dong, Giovanni Dipierro, Fabien Louvet, Daniel Mentiplay, Valentin Christiaens, Andrew Winter, Jorge Cuadra, Giuseppe Lodato, Guillaume Laibe, Richard Alexander, Gerrit van der Plas, Myriam Benisty, Laura Pérez, Nicolás Kurtovic, Marion Villenave, Jean-François Gonzalez, Christian Ginski, Matías Montesinos, Pedro Poblete, Baobab Liu, Sebastián Pérez

Stellar flybys in a nutshell

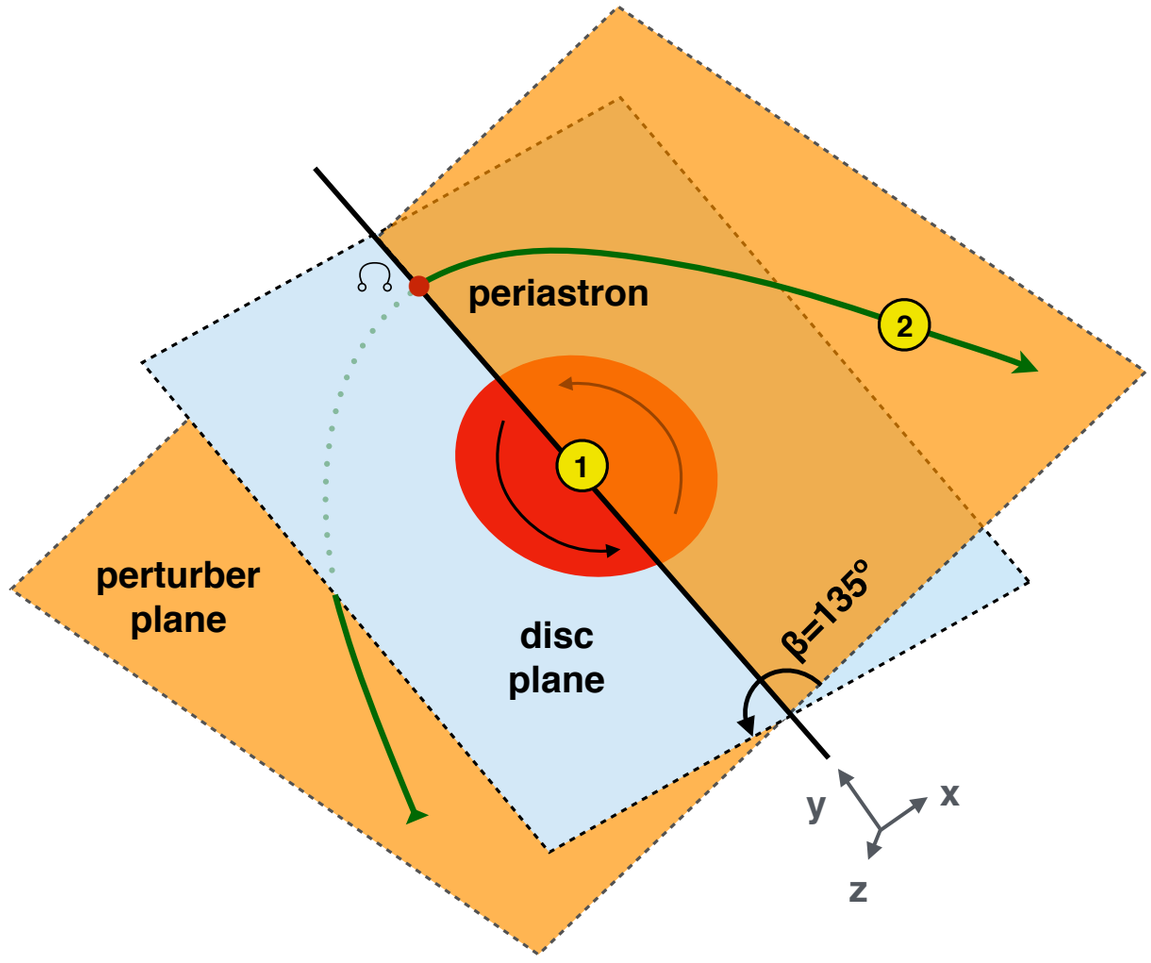
What is a stellar flyby ?
interaction between 2+ stars with e ≥ 1
at a reasonable 100 < d < 1000 au

Why do flyby occur ?
Chaotic nature of star formation
Hierarchical decay in multiples
e.g. Bate (2018), Reipurth & Mikkola (2015)

What is the encounter probability ?
Eq. 2.1 in Davies (2011)

$$\tau_{\rm enc} \simeq 33\ {\rm Myr}\left(\frac{100\ {\rm pc}^{-3}}{n}\right)\left(\frac{v_\infty}{1\ {\rm km\,s}^{-1}}\right)\left(\frac{10^3\ {\rm AU}}{r_{\rm peri}}\right)\left(\frac{M_\odot}{m}\right)$$

What is a "probable" perturber like ?
e ~ 1 & M_p < 1 M_{sun}
see Figs. 6 & 7 in Pfalzner (2013)



Probability for ≠ stellar environments ?
ex: d < 300 au & n_c = 500 - 50.000 pc^{-3}
10 % < P(x_{min} < 300 au) < 100 % after 3 Myr
see Fig. 7 in Winter et al. (2018b)

Take away message: flybys occur in (young) regions of high stellar density

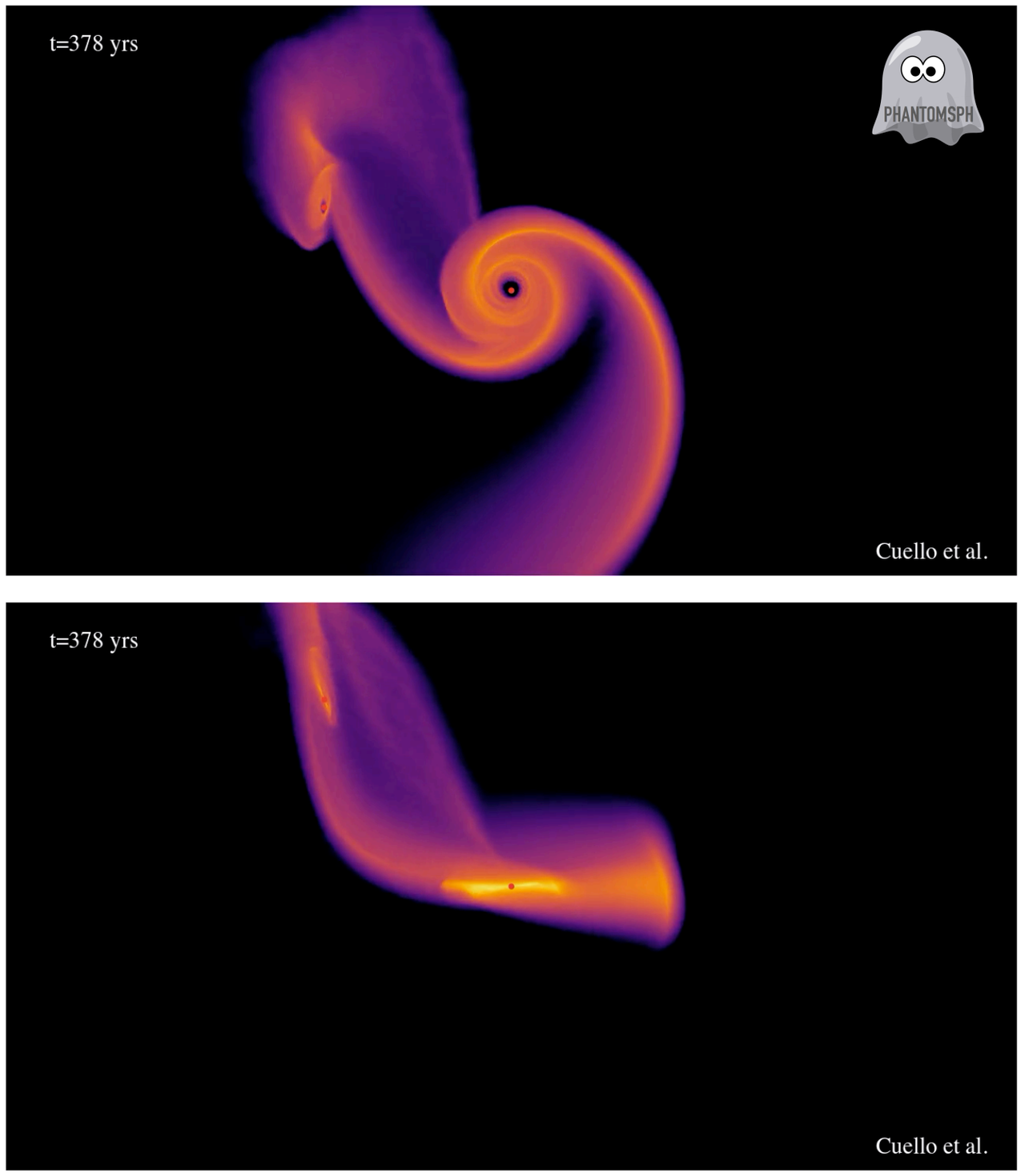
Dynamical signatures (1/2)

Flyby-induced spirals:
Clarke & Pringle (1993)
Ostriker (1994)
Pfalzner (2003)

Disc truncation:
Breslau et al. (2014, 2017)
Vincke et al. (2015)
Bhandare et al. (2016, 2019)
Winter et al. (2018b)

Warps and inclined discs:
Xiang-Gruess (2016)
Marzari & Picogna (2013)
Nealon, Cuello & Alexander (2020)

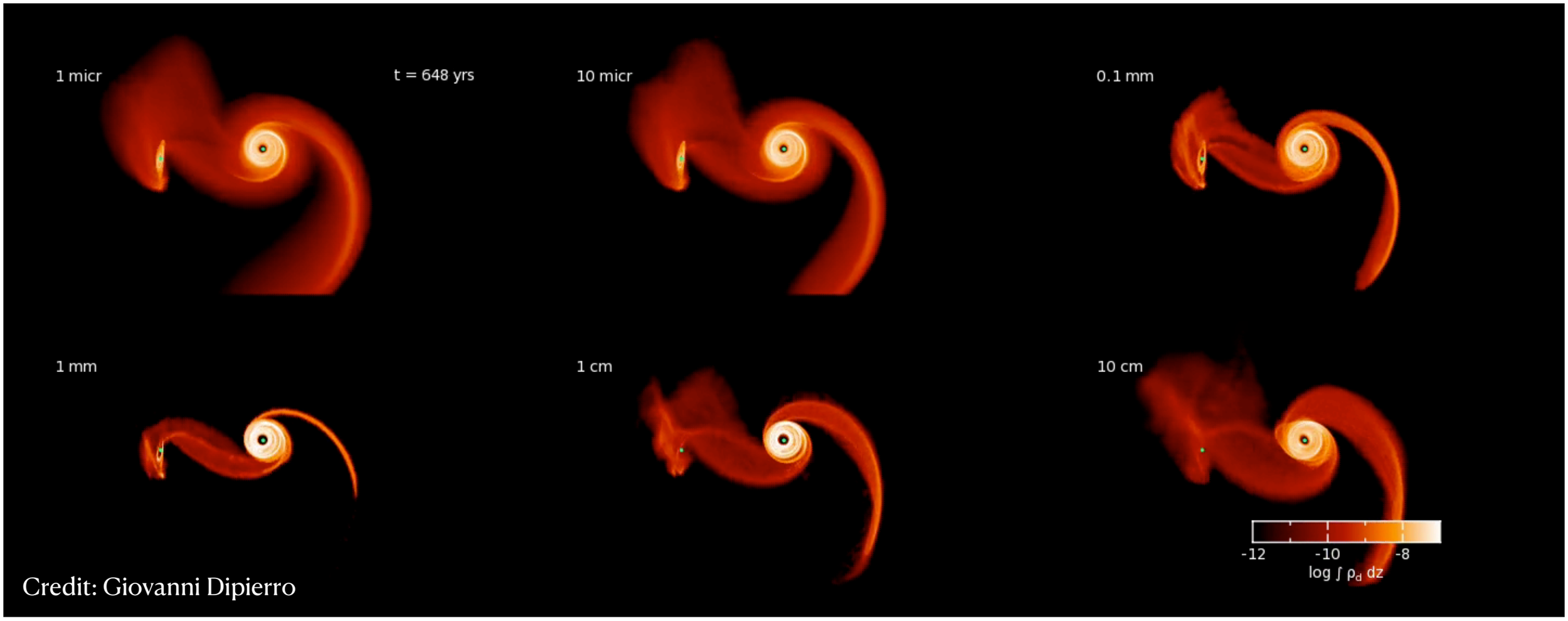
Accretion events
Bonnell & Bastien (1993)
Pfalzner (2004, 2008)
Takami et al. (2018)
Vorobyov (2015, 2020)
Cuello et al. (2019)



Phantom SPH code: Price et al. (2018)

Dynamical signatures (2/2)

Dust trapping & radial drift for different type of stellar flybys
Inclined & prograde flyby (e=1, q=M2/M1=1, β=45°) from Cuello et al. (2019)

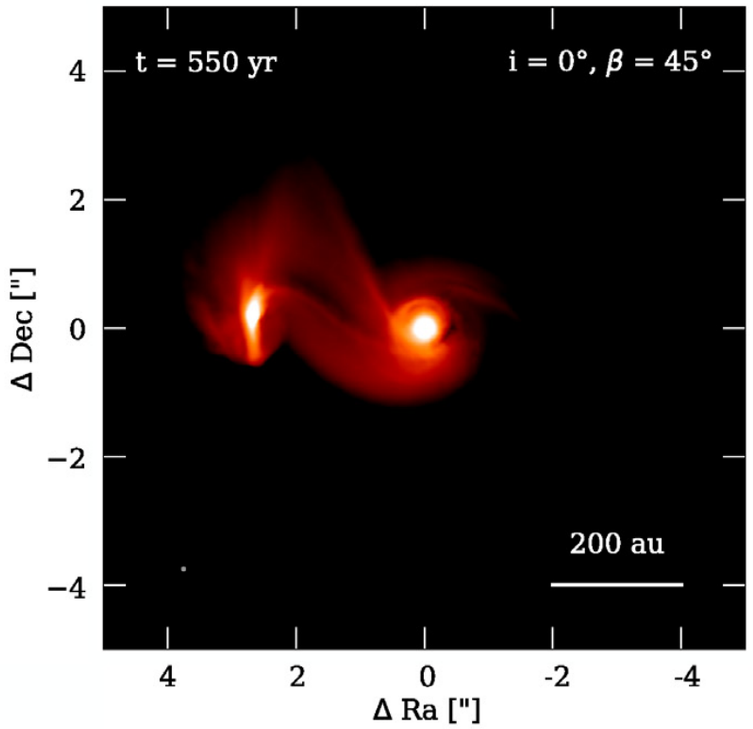


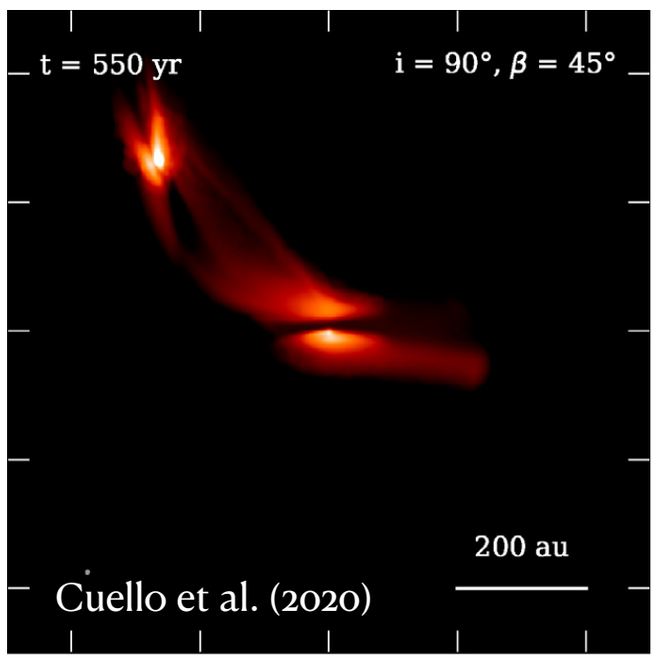
Flyby orbit <—> Disc morphology

Planetesimal formation ($v_{rel} < v_{frag}$) vs. disruption ($v_{rel} > v_{frag}$) ?
Do flybys speed up or prevent the process of planet formation ?

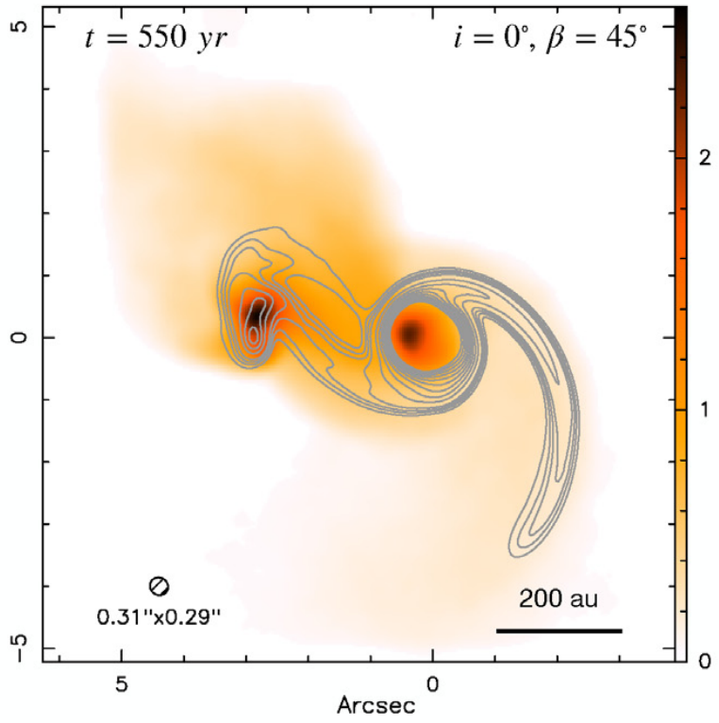
Observational signatures

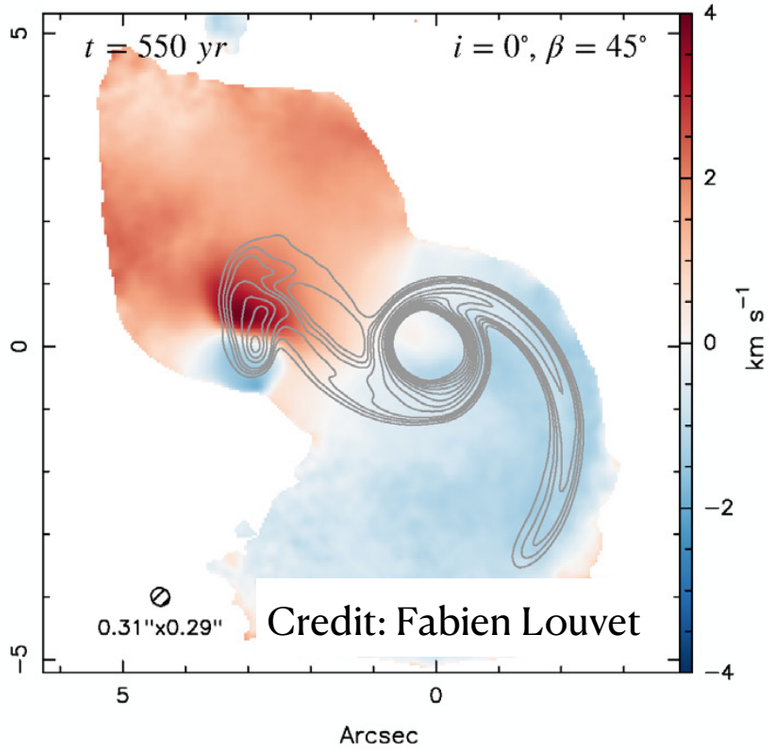
SPHERE or Subaru obs.





ALMA continuum & moment maps





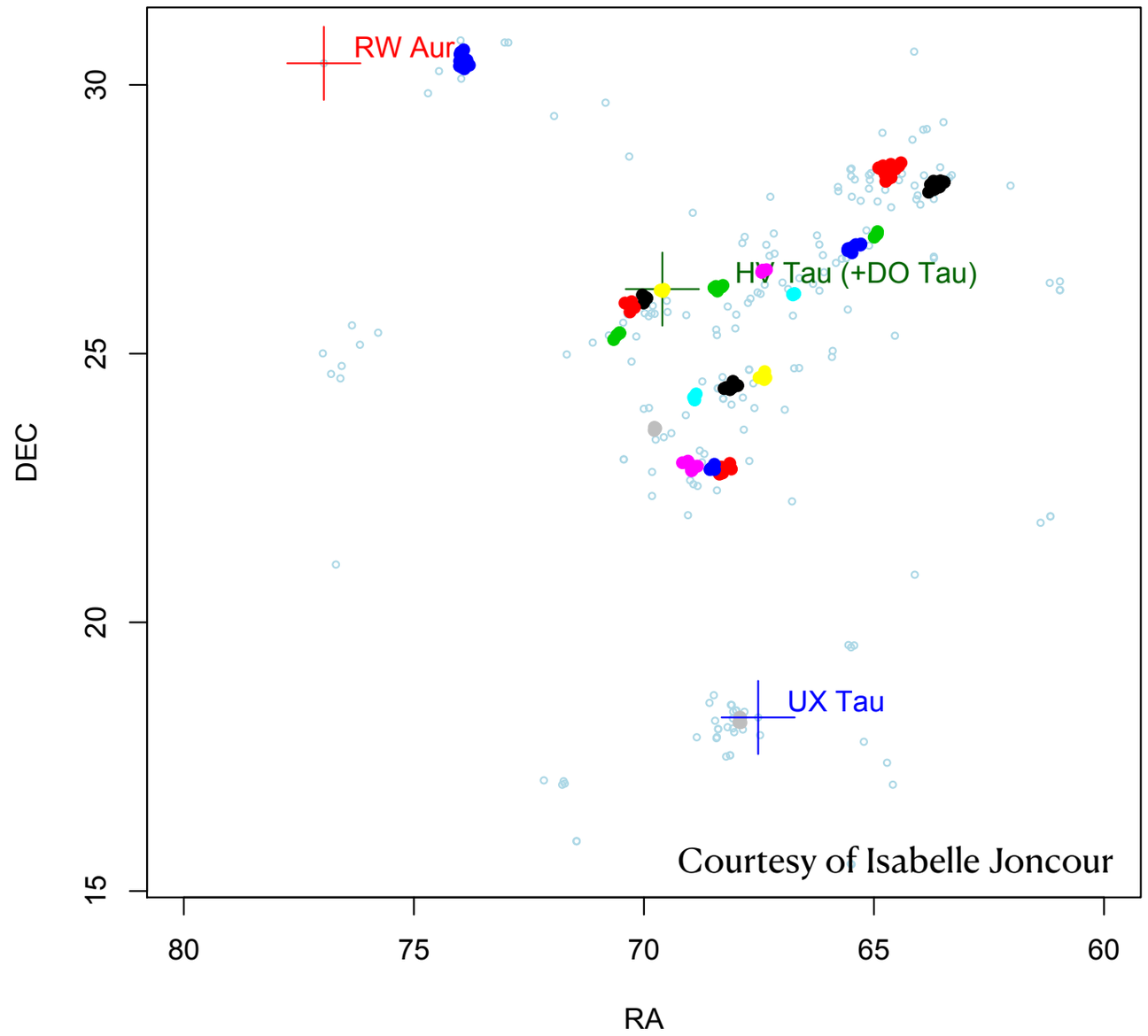
- Spirals in scattered light
gaseous “bridges”

- Compact emission in the continuum
dust trapping & segregation

- Non-coplanar structure in CO emission
e.g. warps & inclined discs
—> search in the channels maps

Flybys & environment

Hyp: flybys preferentially occur in regions of high stellar density
—> **Any link with the stellar environment ?**



Close to a stellar nest ? Hierarchical decay ? Random encounters ?

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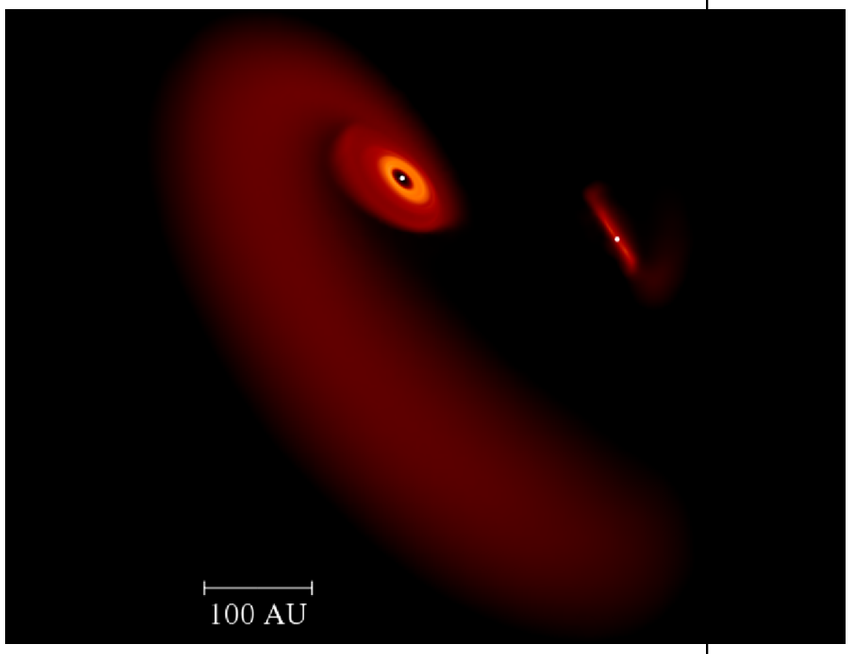
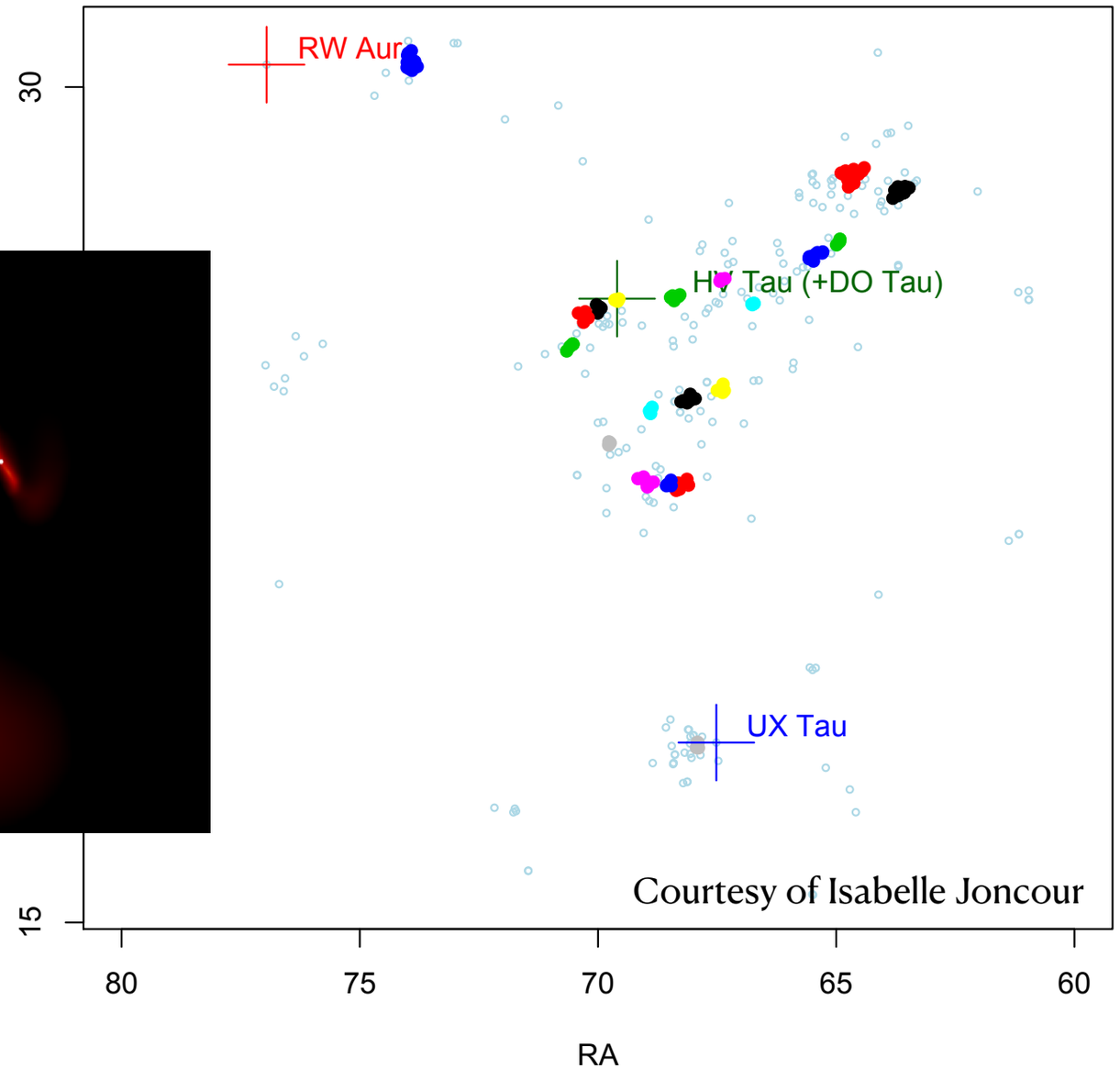
RW Aur A & B:
Dai et al. (2015)
Rodriguez et al. (2018)





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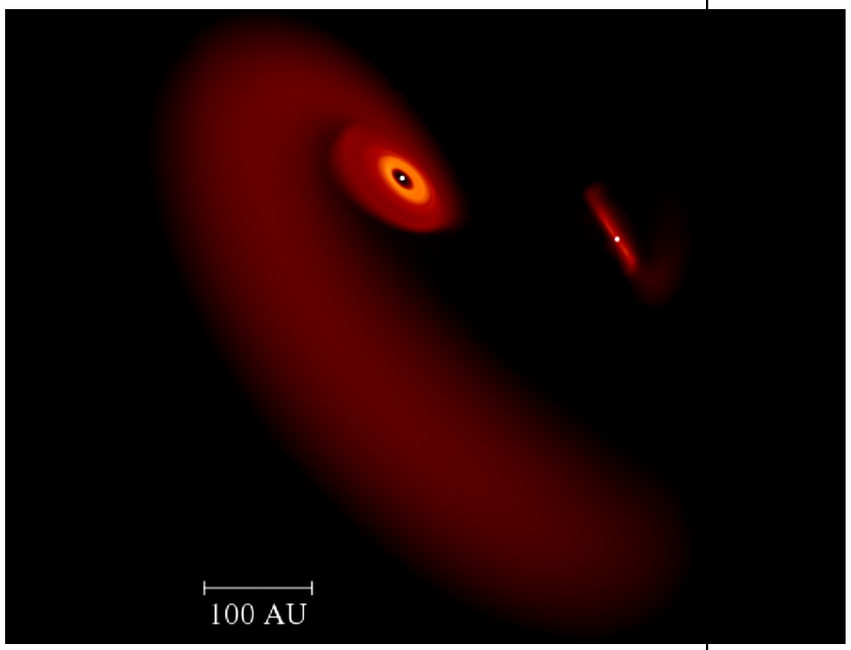
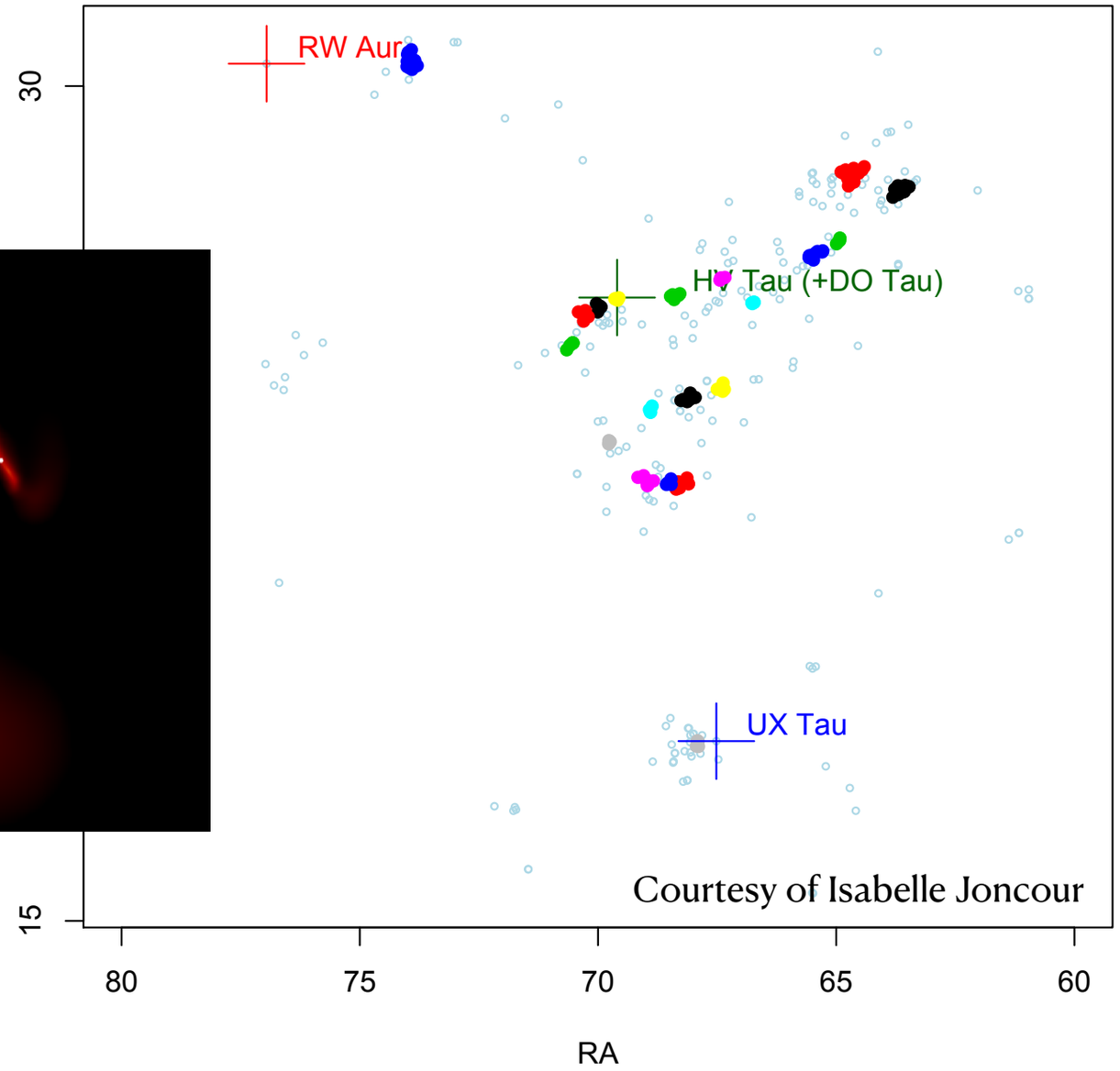
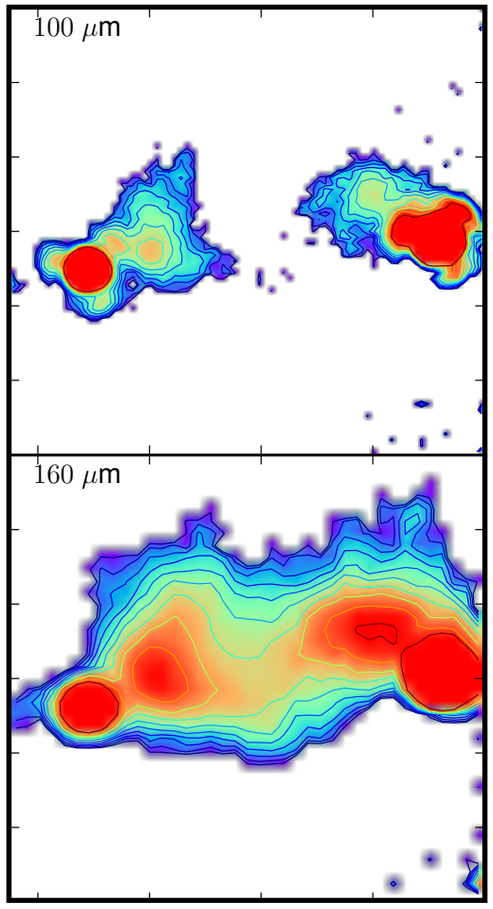




HV Tau & DO Tau:
Winter et al. (2018c)



Close to a stellar nest ? Hierarchical decay ? Random encounters ?

The case of UX Tauri

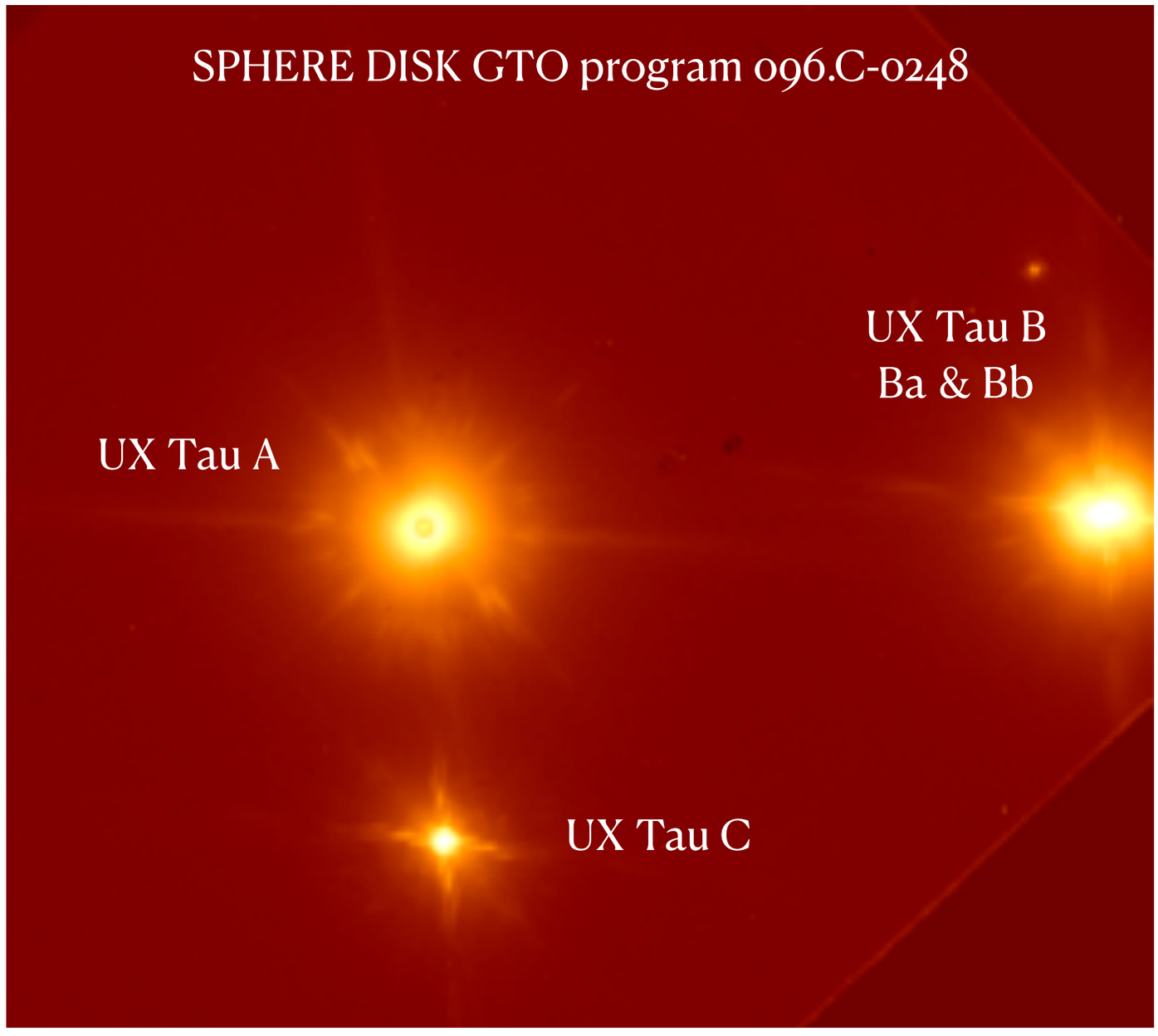
UX Tauri ID card

age: 1-2 Myr old
distance: 147 ± 2 pc
Gaia Collaboration (2018)

stars: 4 (1+2+1)
B is a tight ~0.''1 binary
Correia et al. (2006)

M_A = 1.4 ± 0.6 M_sun
M_C = 0.16 ± 0.04 M_sun
Krauss & Hillenbrand (2009)
—> **q = M_C/M_A = [0.08, 0.22]**

d_{AB} = 5.''8 to the West
d_{AC} = 2.''7 to the South
—> **A-C separation: ~ 400 au**



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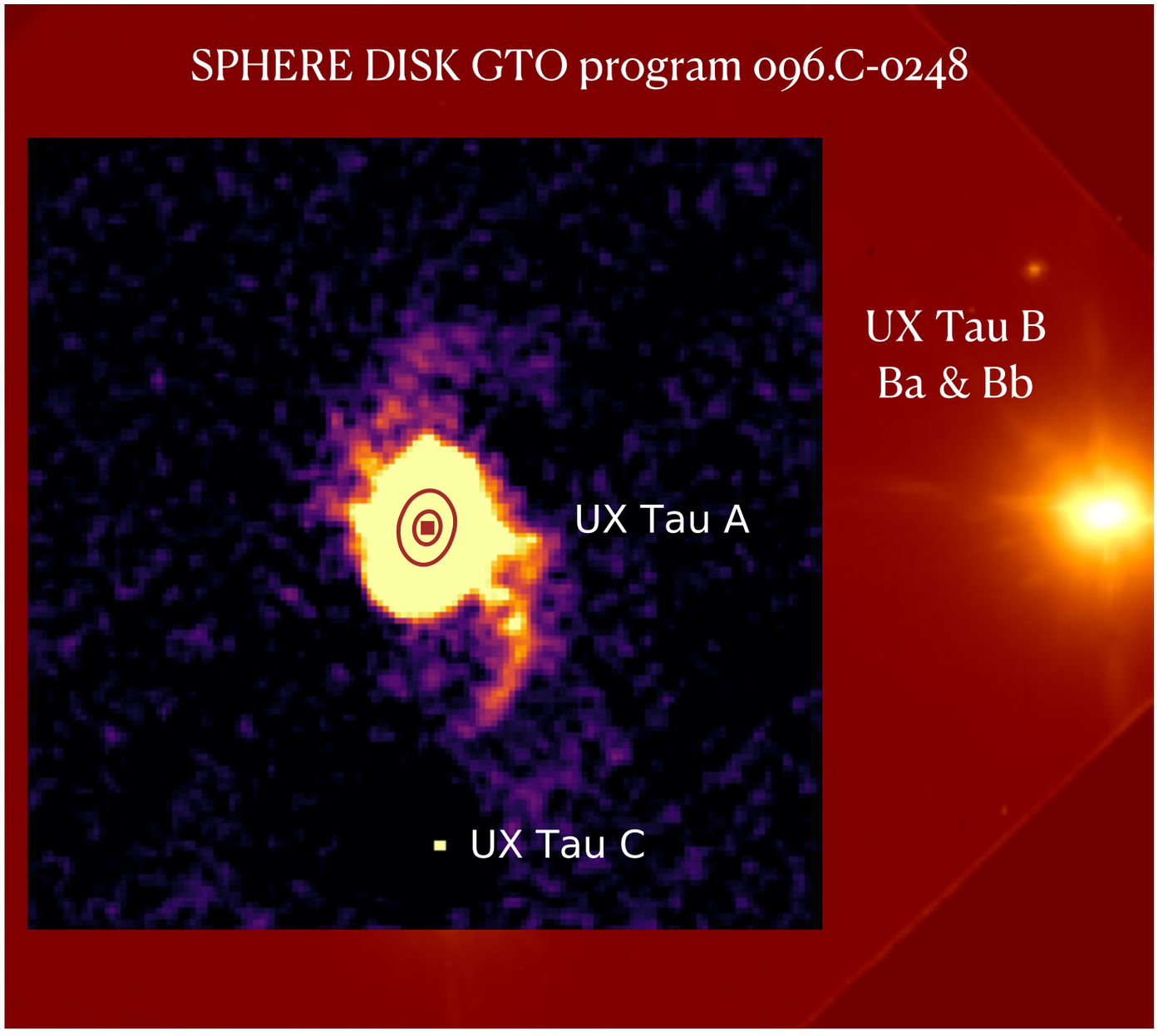

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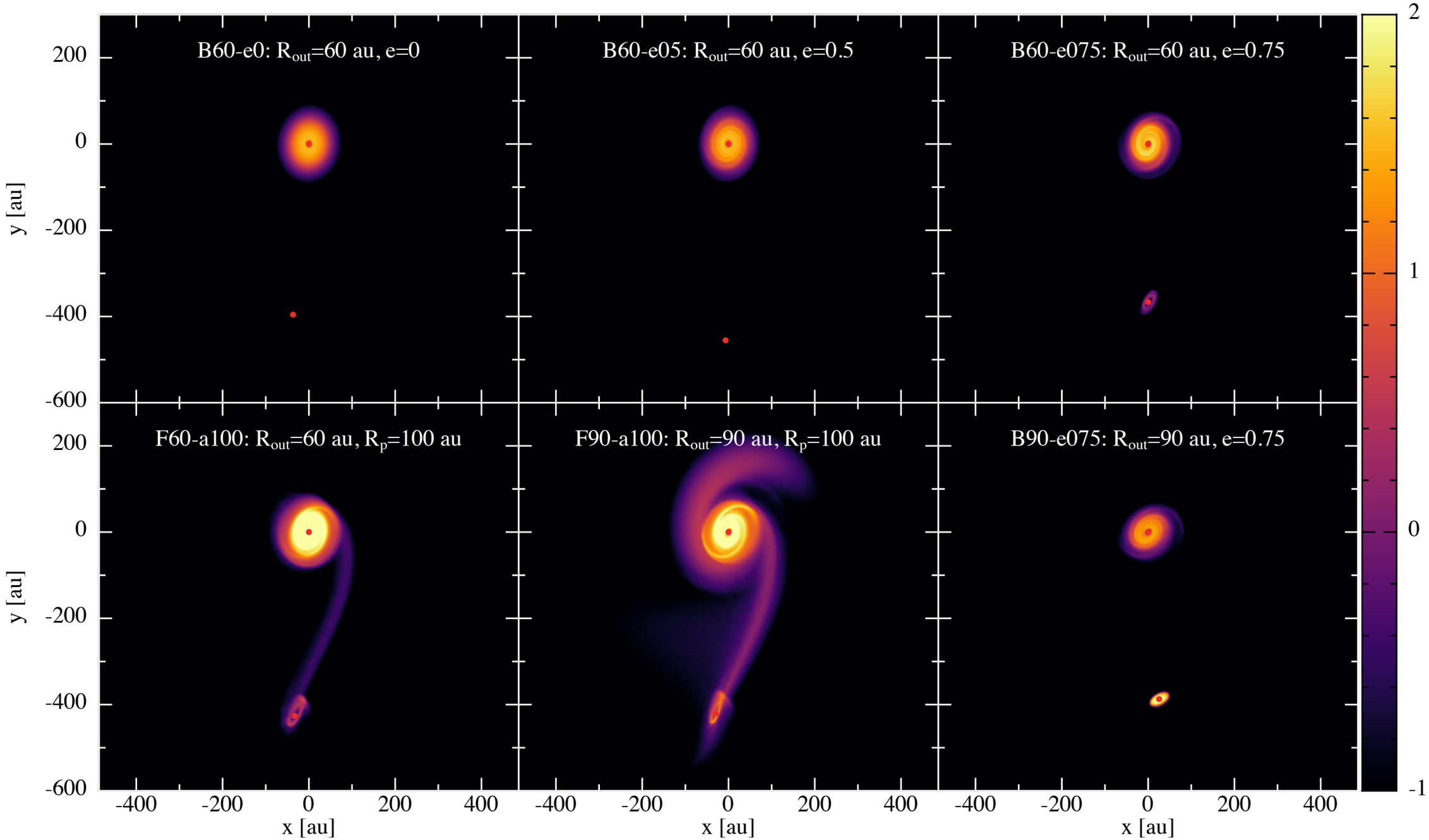
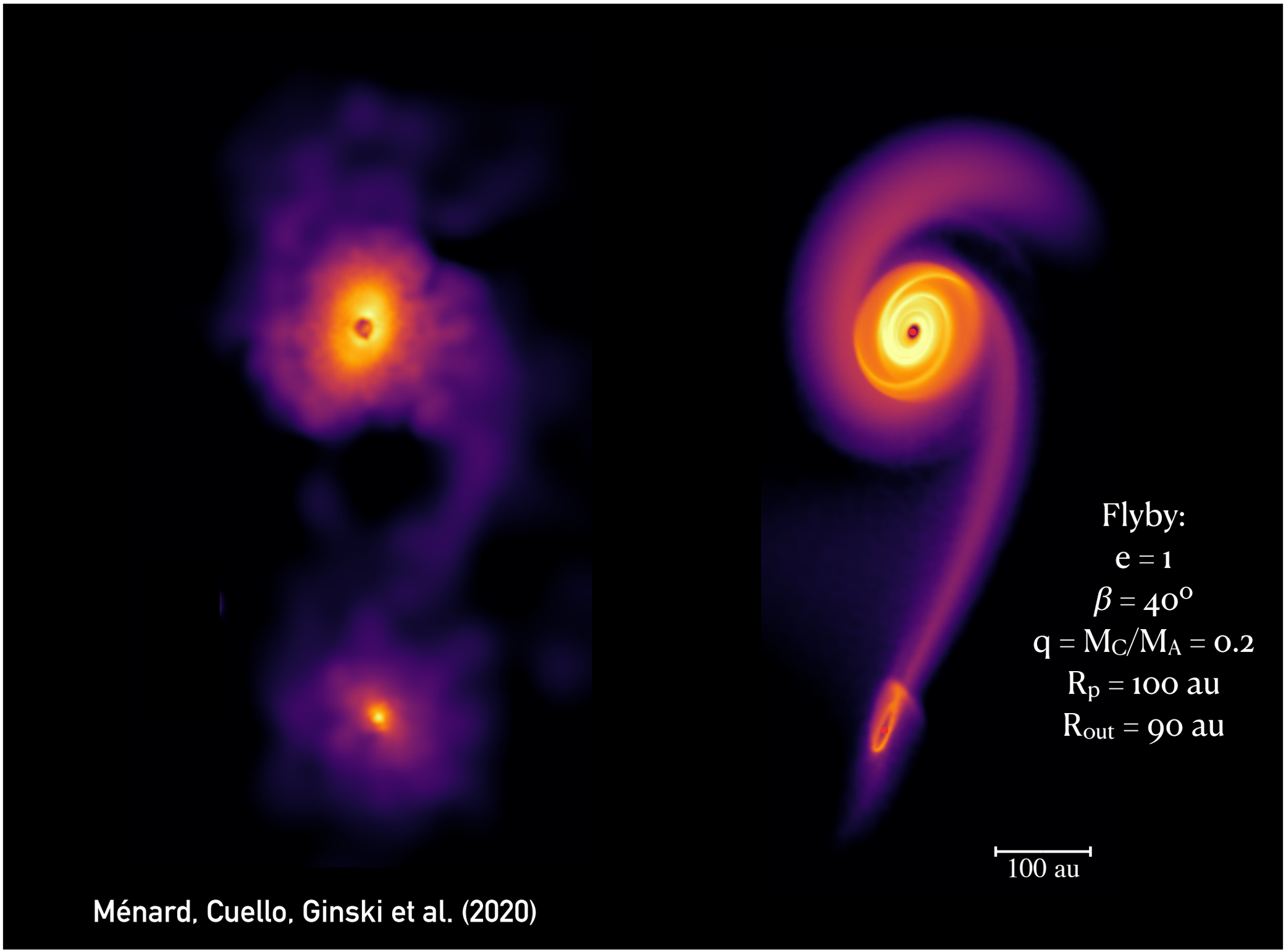
UX Tau C: bound or unbound ?



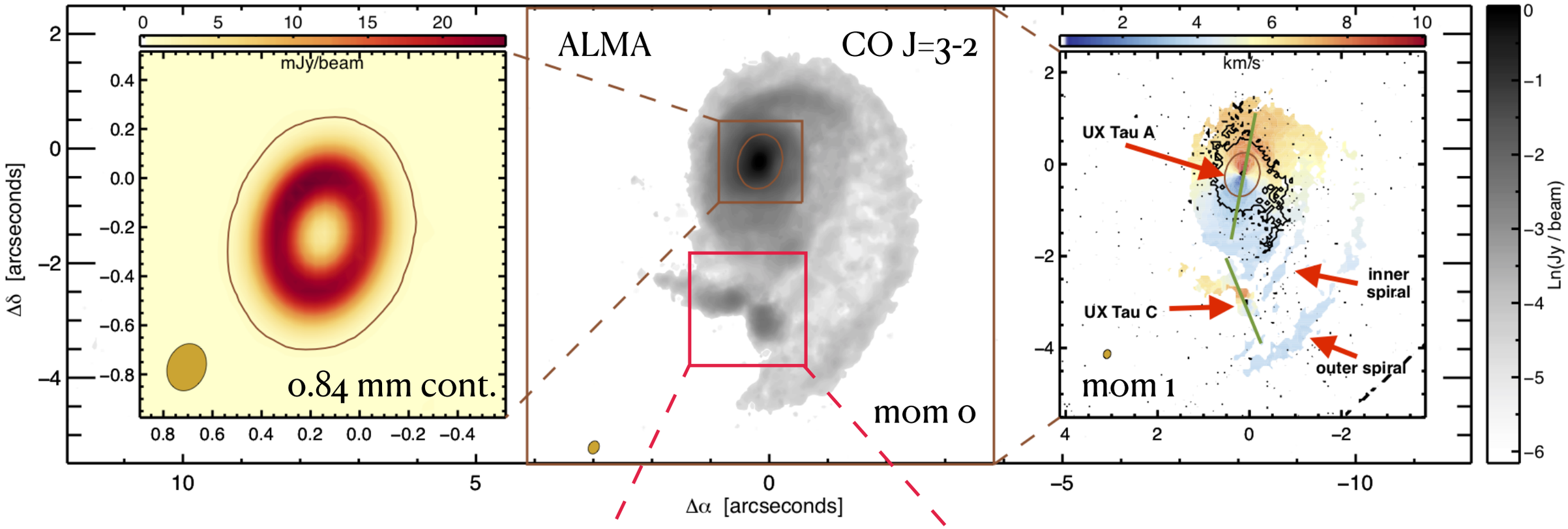
Unbound companions heavily truncate the disc after a few orbits

Prominent spirals only for flybys with $R_{out} \sim R_p$

UX Tau C: bound or unbound ?



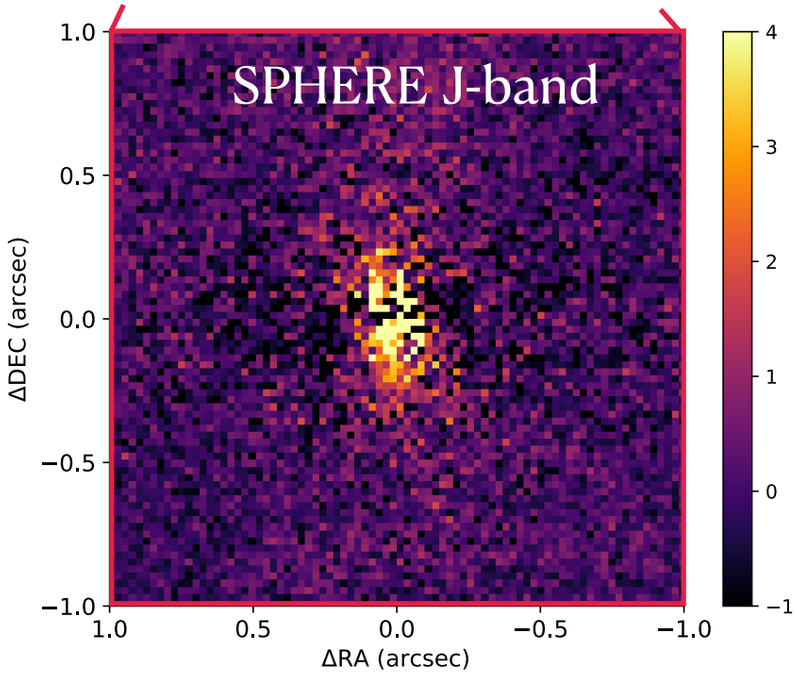
UX Tau C: captured disc ?



1st detection of disc around C
in scattered light
Disc also seen in CO

No continuum emission !
Misaligned discs

See also Zapata et al. (2020)



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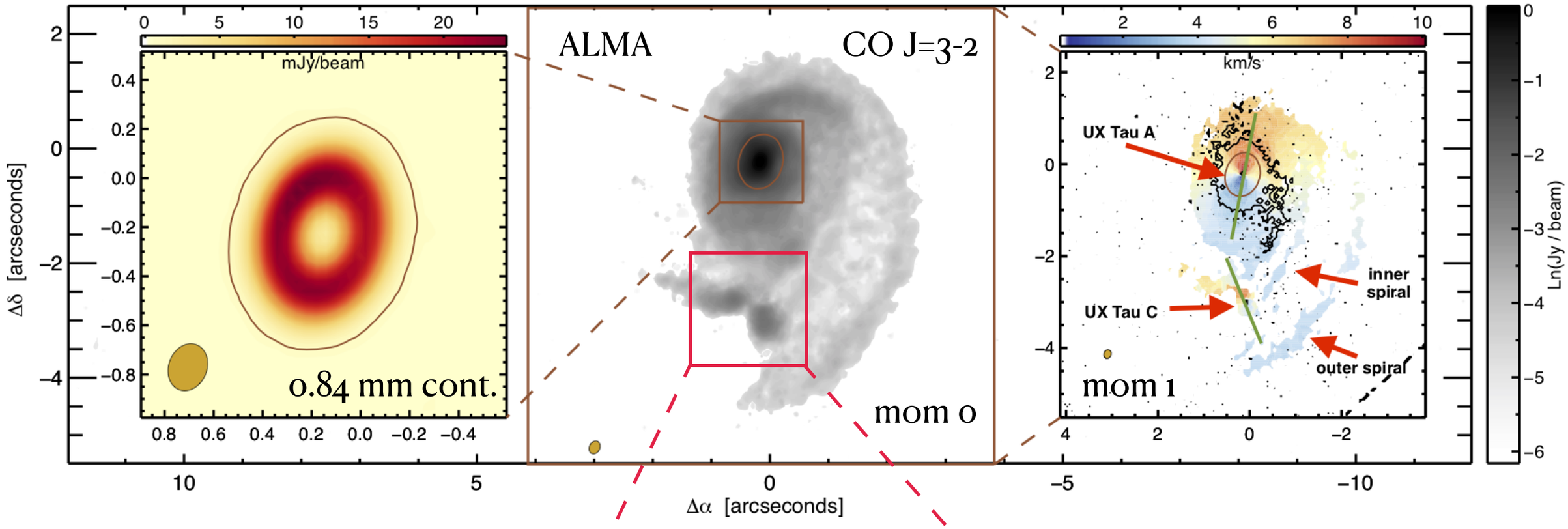

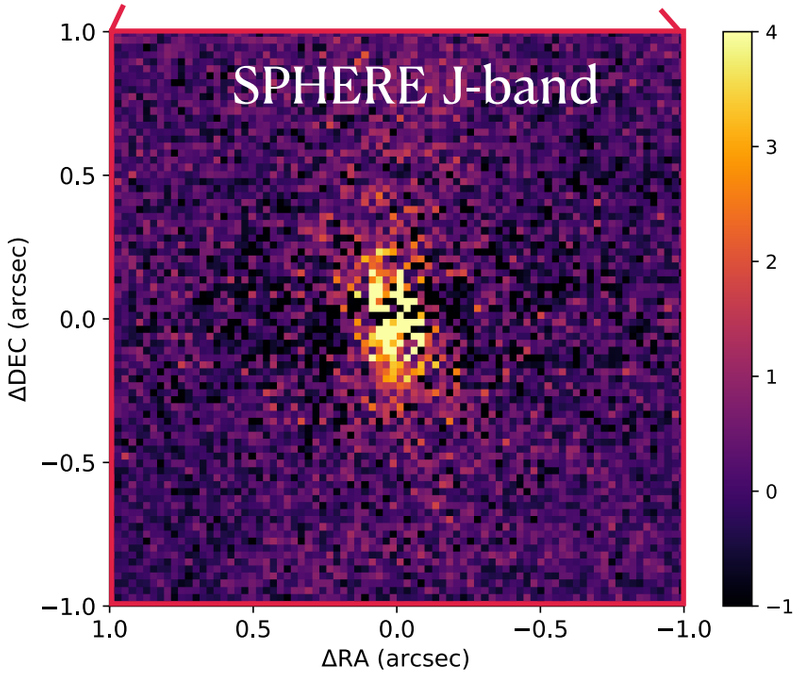

1st detection of disc around C
in scattered light
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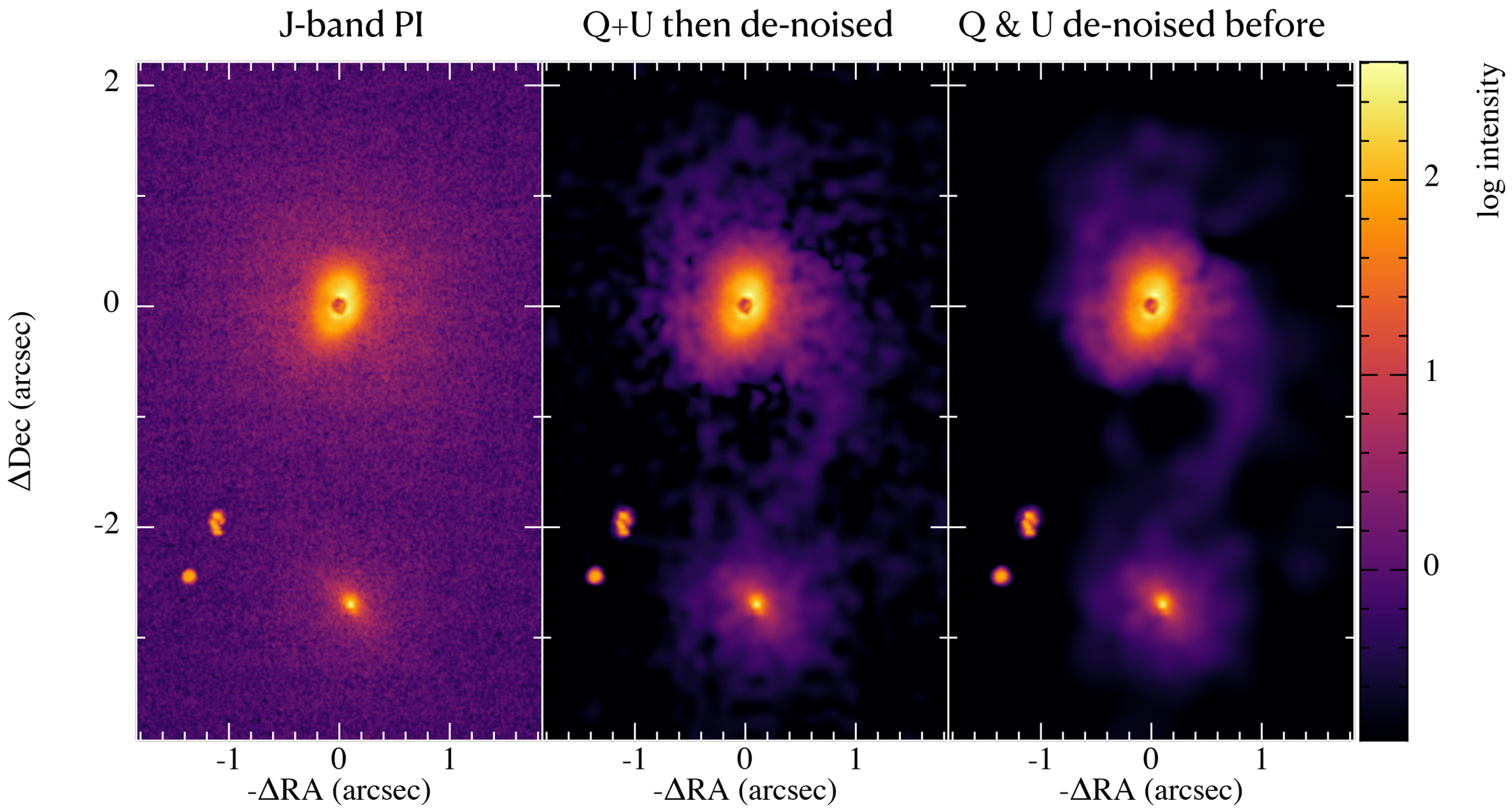
Was this disc captured during the encounter ?
First dust radial drift
then flyby + gas capture

Further constraints on C orbit
gas + dust modelling

Ejected from UX Tau B ?

De-noising tool: SPH cleaning

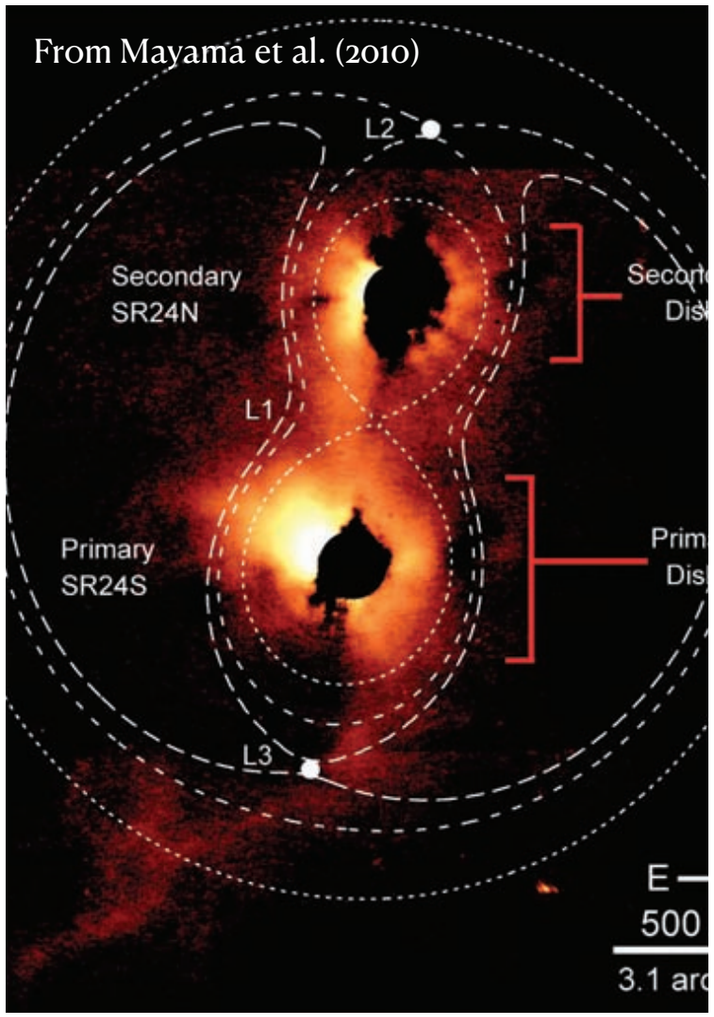


Fast and cheap way to recover “hidden” signal close to noise level
Better results if de-noising before PDI

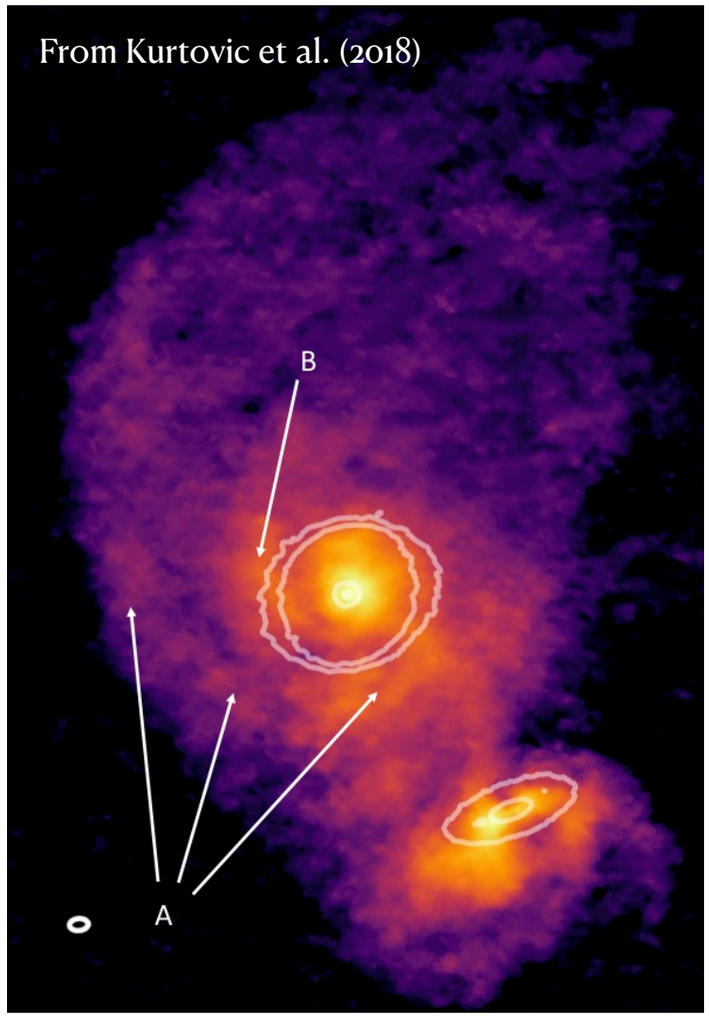
See Appendix C in Ménard et al. (2020)
Available in SPLASH (Price 2007)

More flyby-shaped discs

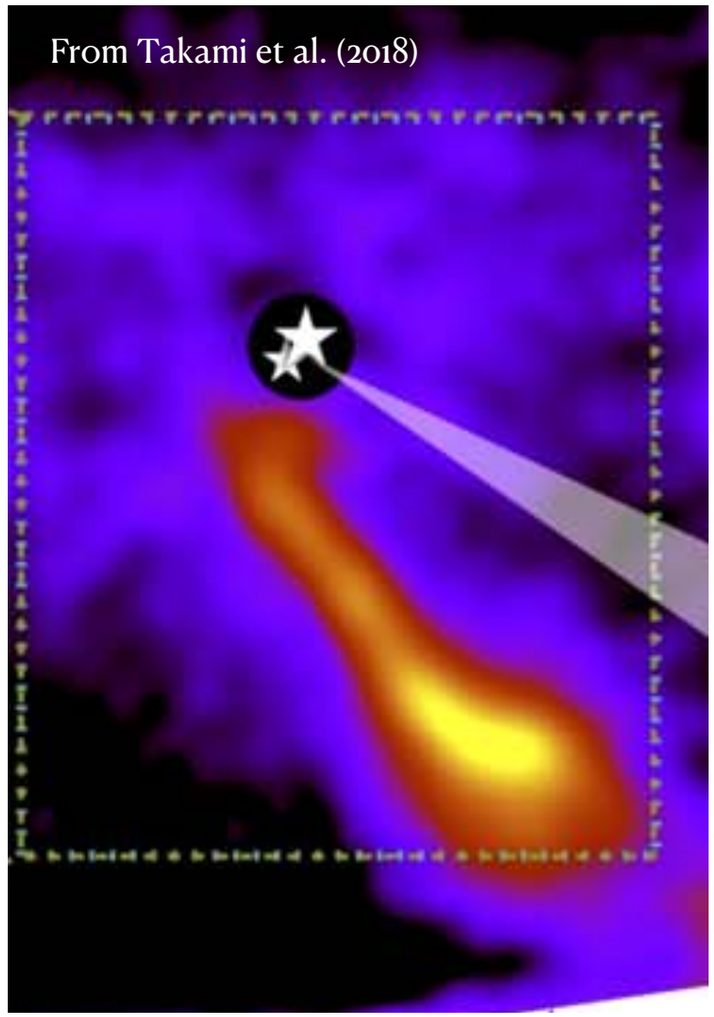
SR 24: Na+Nb & S



AS 205: N & Sa+Sb



Z CMa: A+B & C



Common point ?

More flyby-shaped discs

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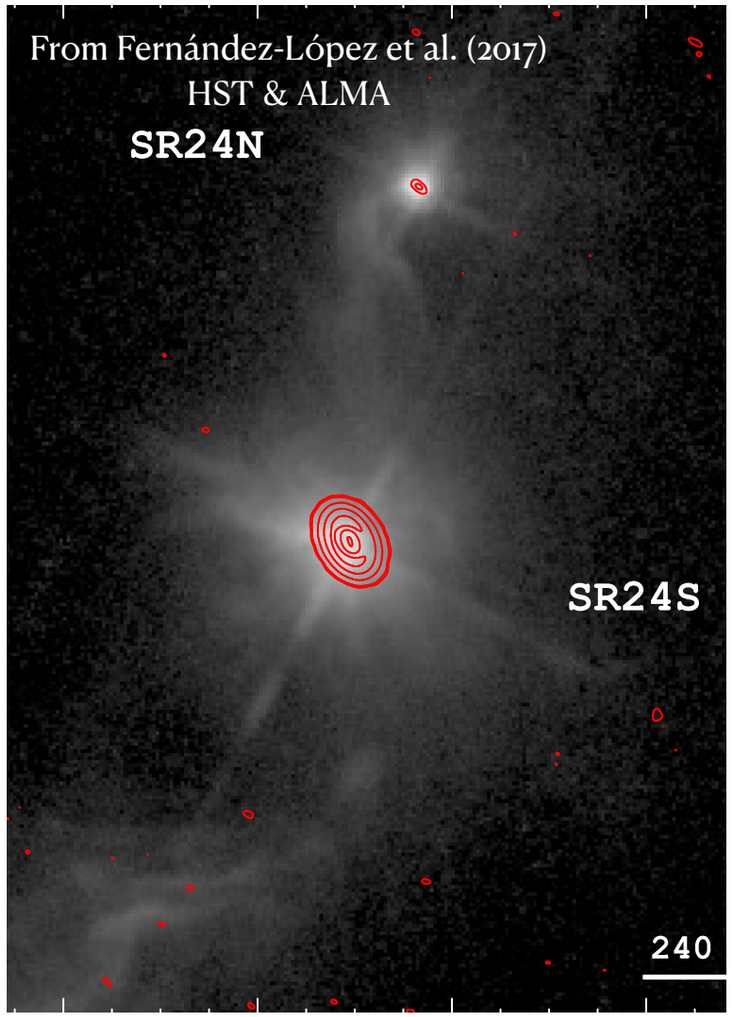

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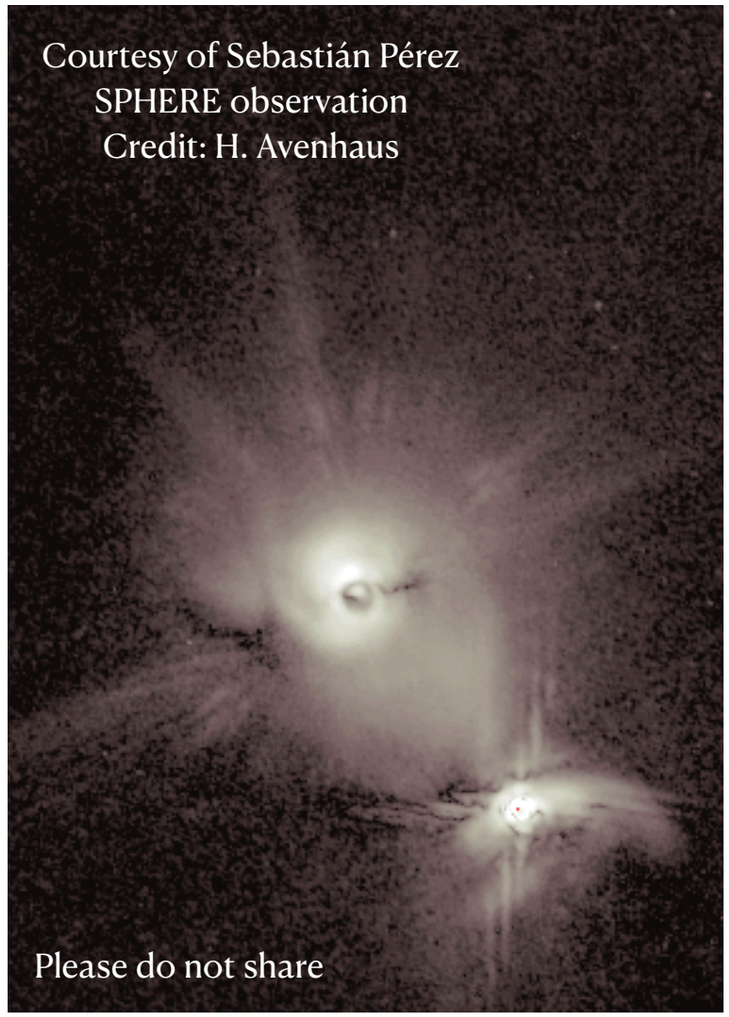

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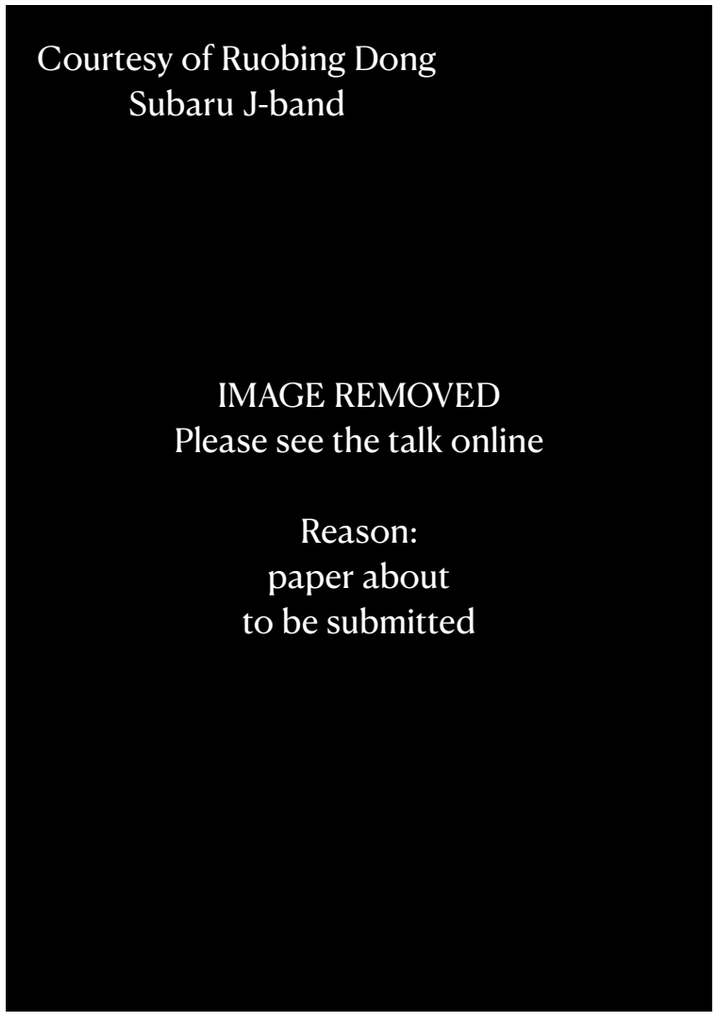

Common point :

Triple stellar systems in “hierarchical” configuration

—> hierarchical ejection or random encounter ?

—> flybys are able to reproduce disc morphology

Flybys & planet formation

Flyby parameters <—> disc morphology
e.g. orbital inclination, q=M2/M1, and R_{out}/R_p

Multi-wavelength observations are key
Possible to reconstruct past & ongoing flybys
—> bound companions tend to fail

UX Tau: ongoing prograde & inclined flyby
discovery of gaseous spirals with SPHERE & ALMA
captured gaseous disc around C ?

<u>To be discussed:</u>
- Connection with FU Ori events
- Effects on planetesimal formation
- Resulting planetary architectures