

Three Stars, Three Rings



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with Nienke van der Marel, Rebecca Martin, et al.

The GW Ori Triple System

A: $\sim 2.7 M_{\odot}$

B: $\sim 1.7 M_{\odot}$

A-B binary:

$a \sim 1.25 \pm 0.05$ AU

$e \sim 0.13 \pm 0.01$

$i \sim 23^{\circ} \pm 1^{\circ}$

C: $\sim 0.9 M_{\odot}$

AB-C binary:

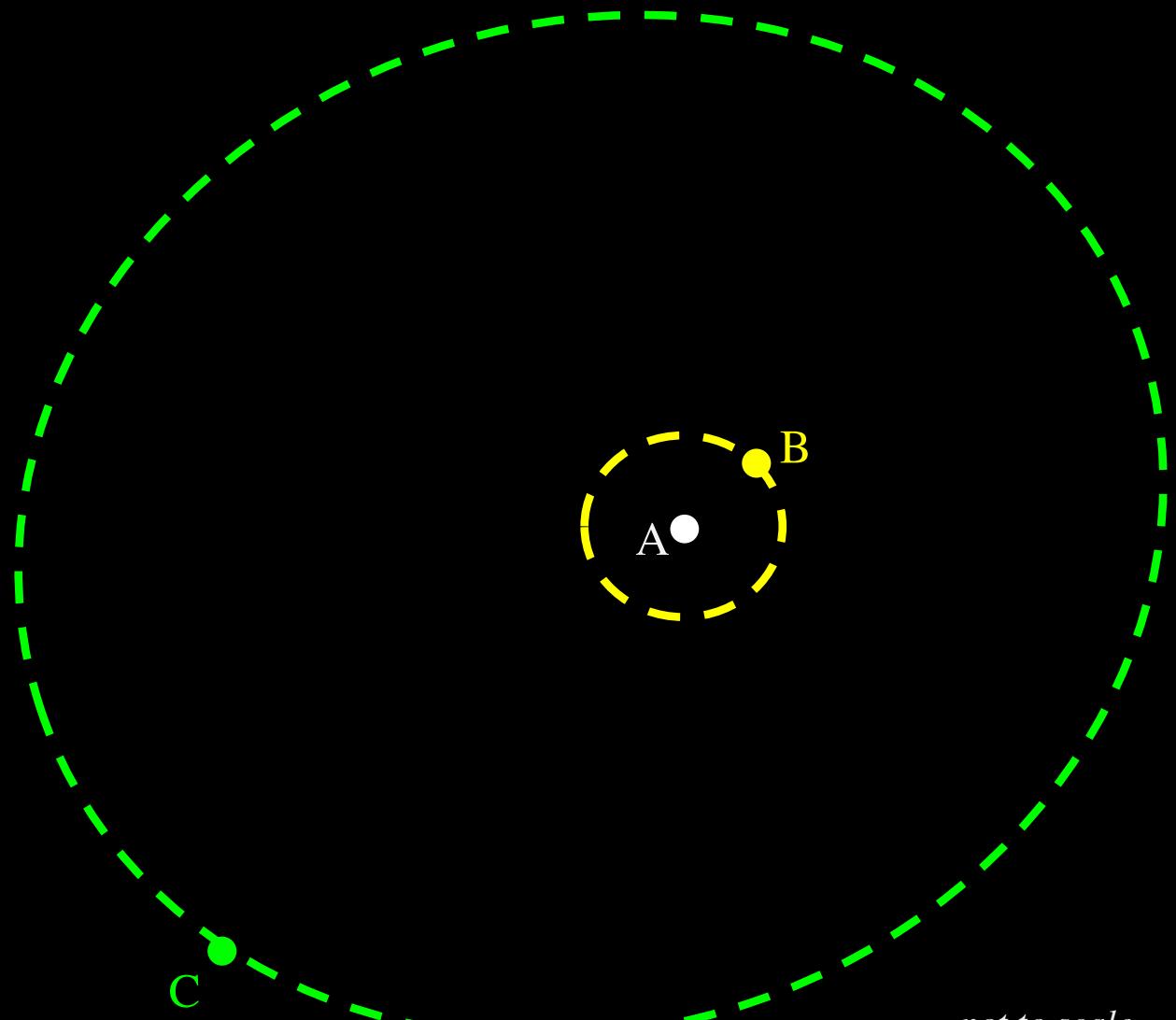
$a \sim 9 \pm 0.3$ AU

$e \sim 0.2 \pm 0.1$

$i \sim 30^{\circ} \pm 10^{\circ}$

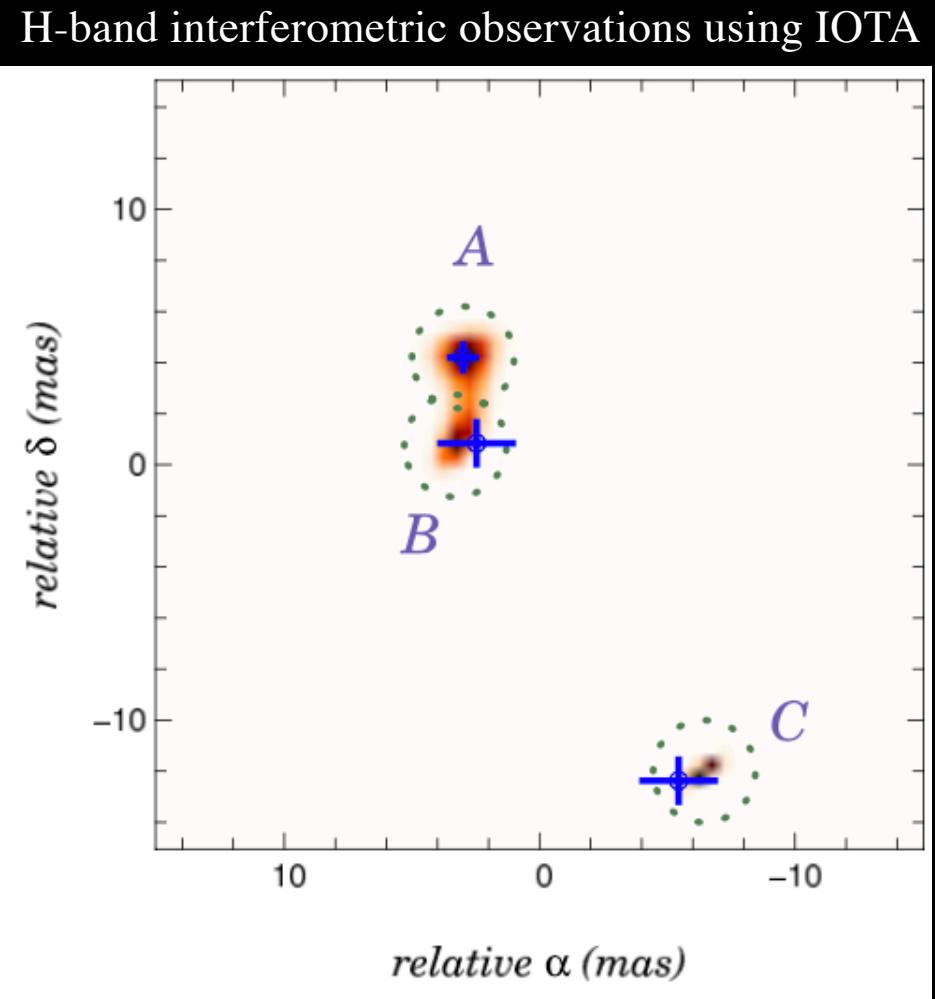
Czekala + 17

Berger + 11, Mathieu + 91



The Discovery of the Stars

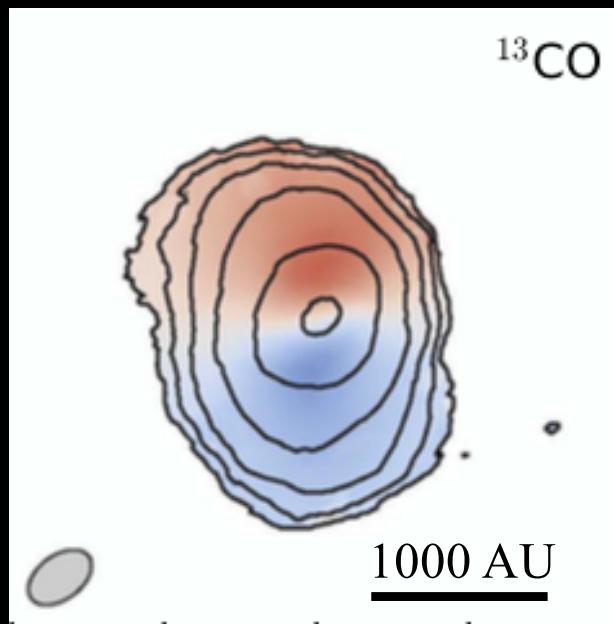
- A-B: spectroscopic binary
(Mathieu + 91)
- C: infrared interferometry
(Berger + 11)
- Distance: 400 pc
- Age: ~ 1 Myr



Berger + 11

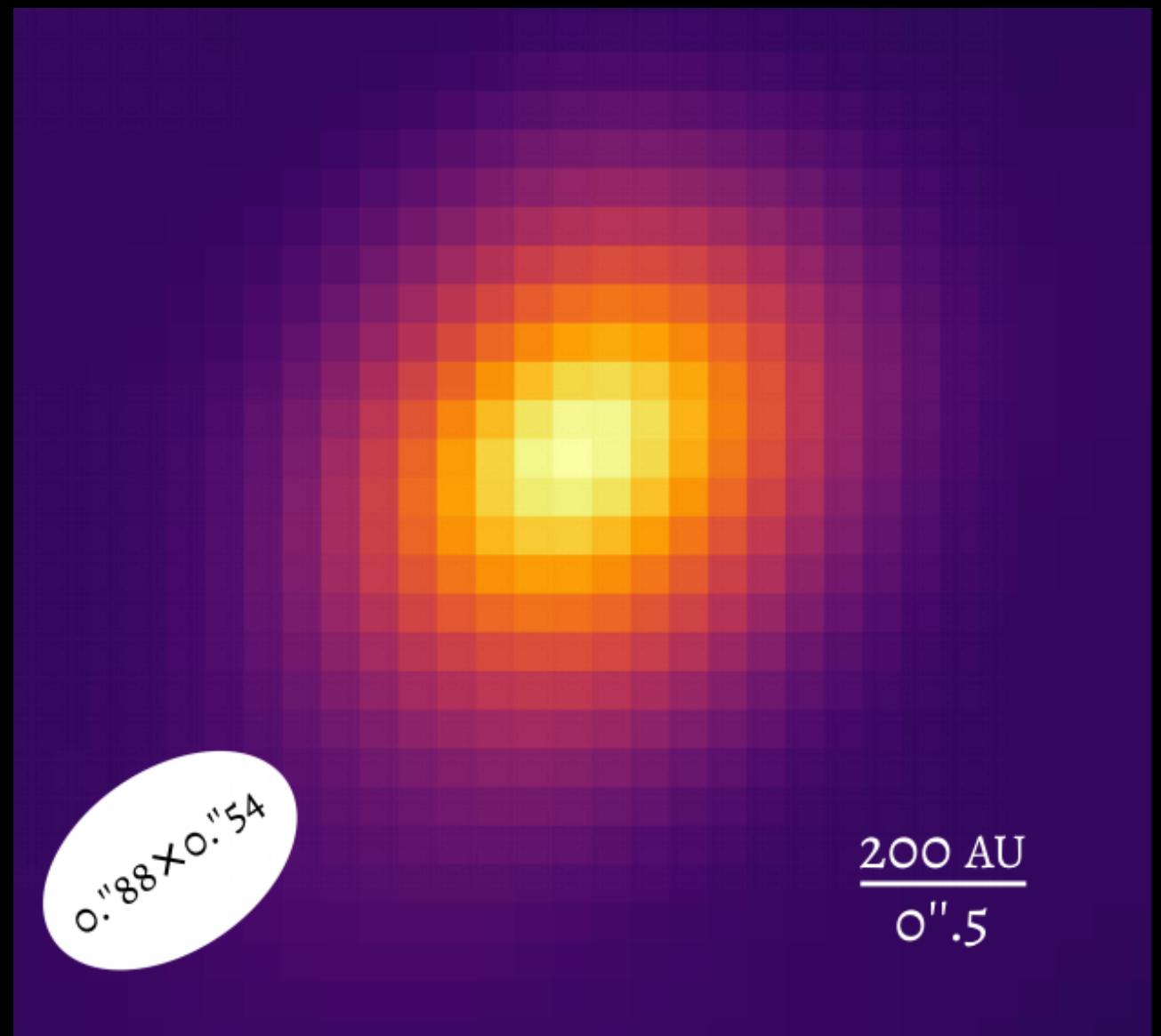
The GW Ori Disk

- Dust disk radius: ~ 400 AU
- Gas disk radius: ~ 1000 AU



Czekala + 17

1.3 mm continuum ALMA observation

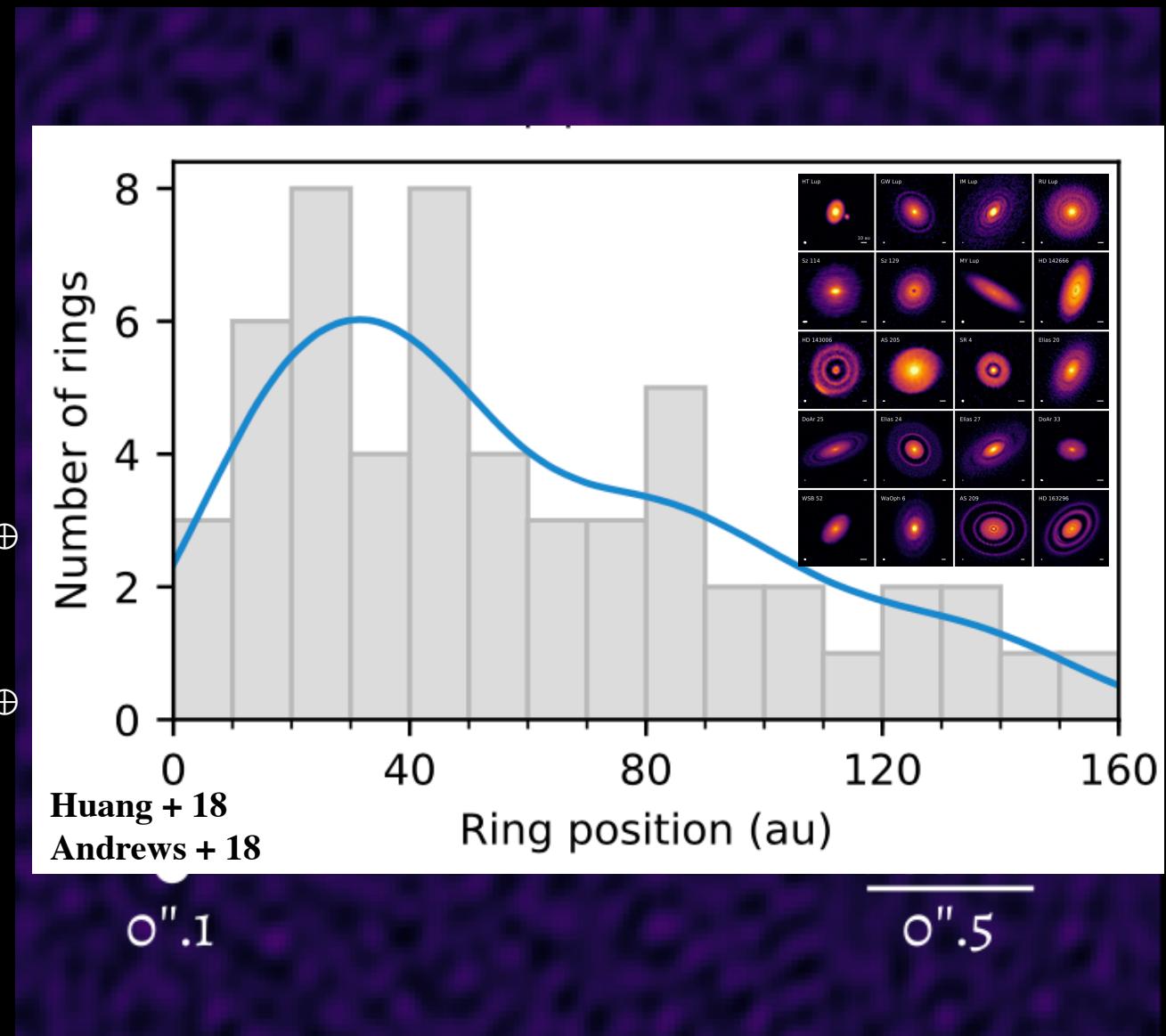


Czekala + 17

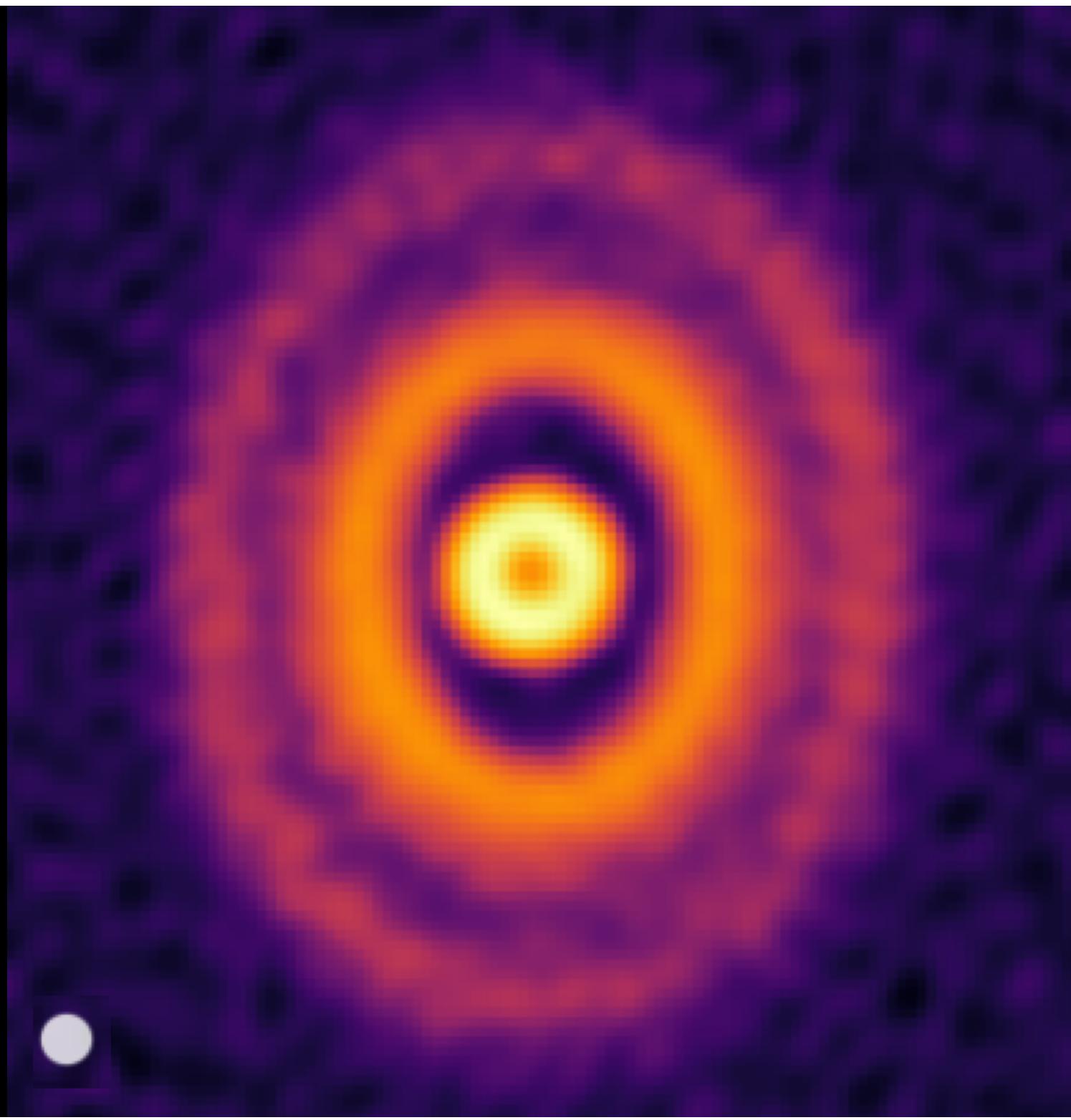
NEW

1.3 mm continuum ALMA observation

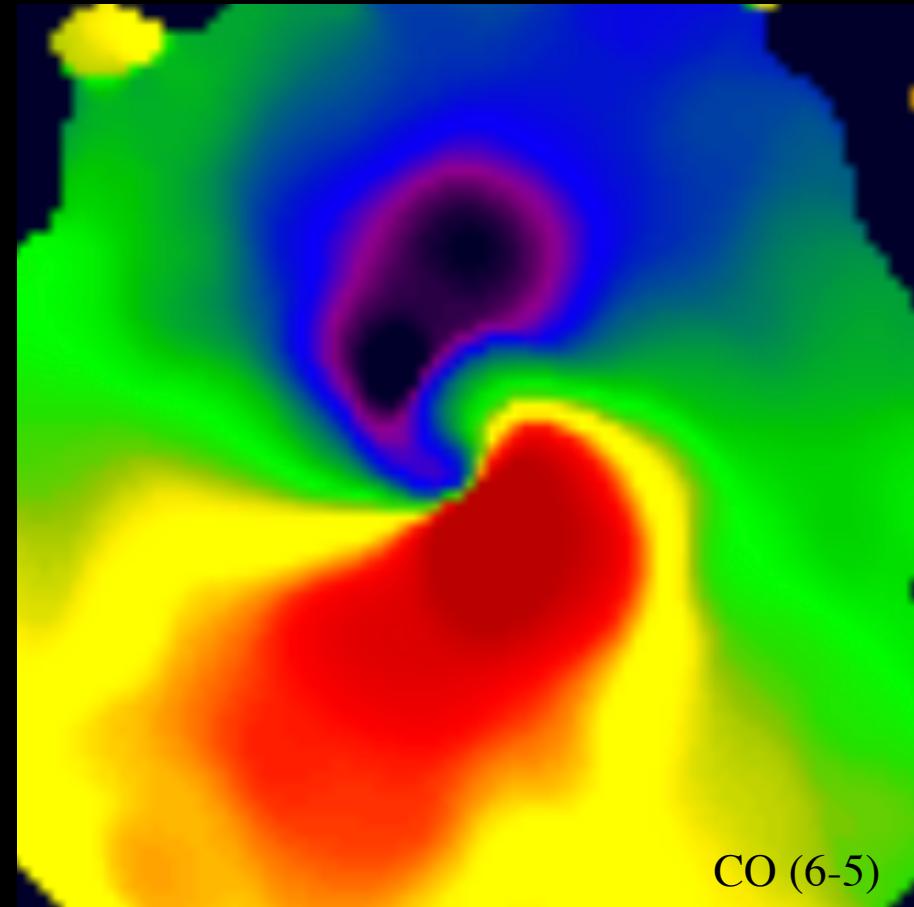
- Inner Ring:
Radius 45 AU, dust mass $70 M_{\oplus}$
- Middle Ring:
Radius 190 AU, dust mass $160 M_{\oplus}$
- Outer Ring:
Radius 340 AU, dust mass $230 M_{\oplus}$



Bi et al., in prep.

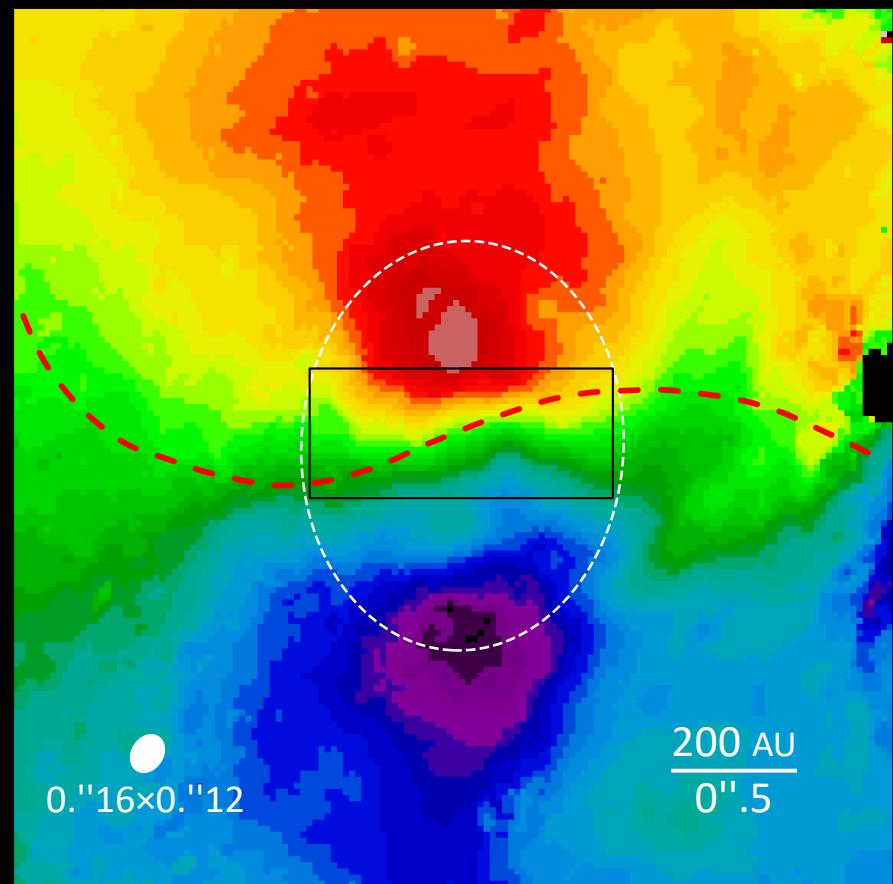


Gas Kinematics in a Warped Disk HD 142527

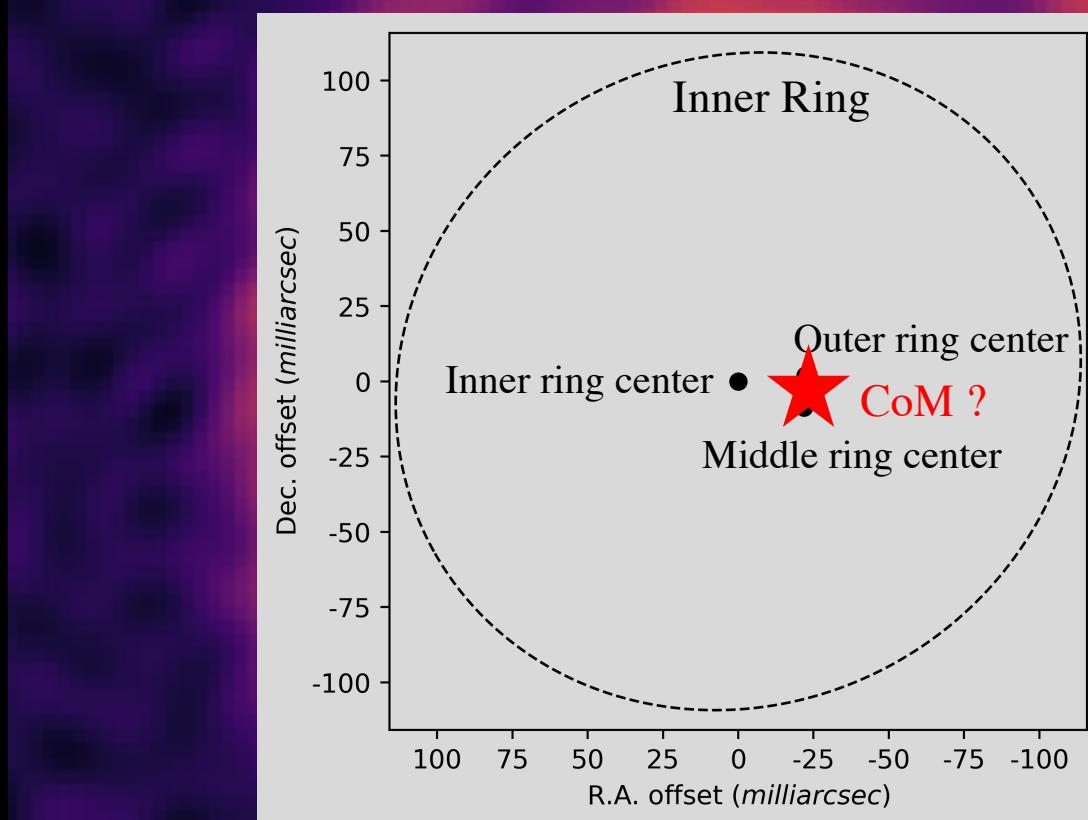


Casassus, Marino, Perez + 15
See also HD 143006, Perez, Benisty + 18

GW Ori CO (2-1)

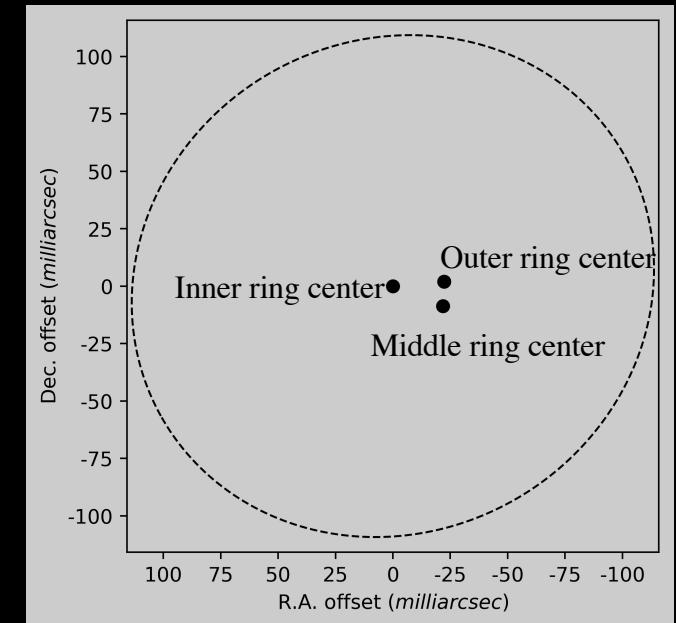
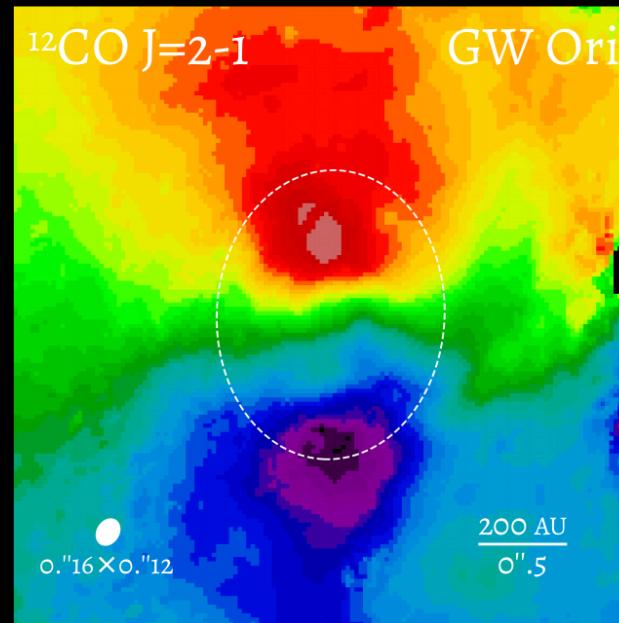
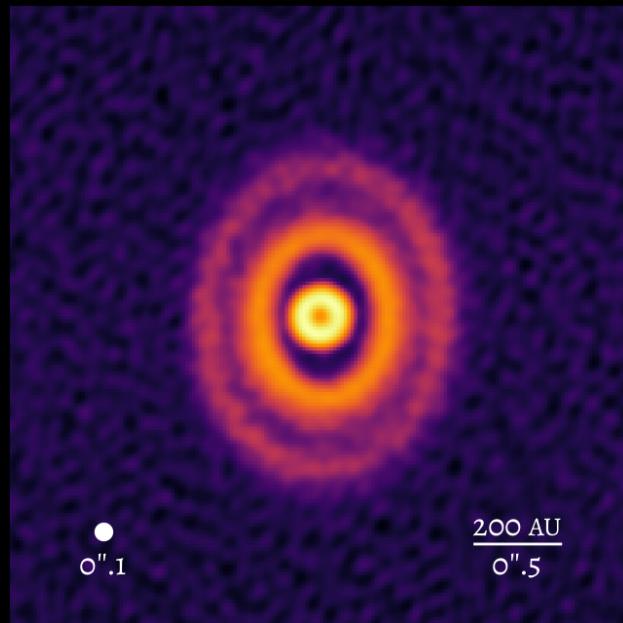


Bi et al.

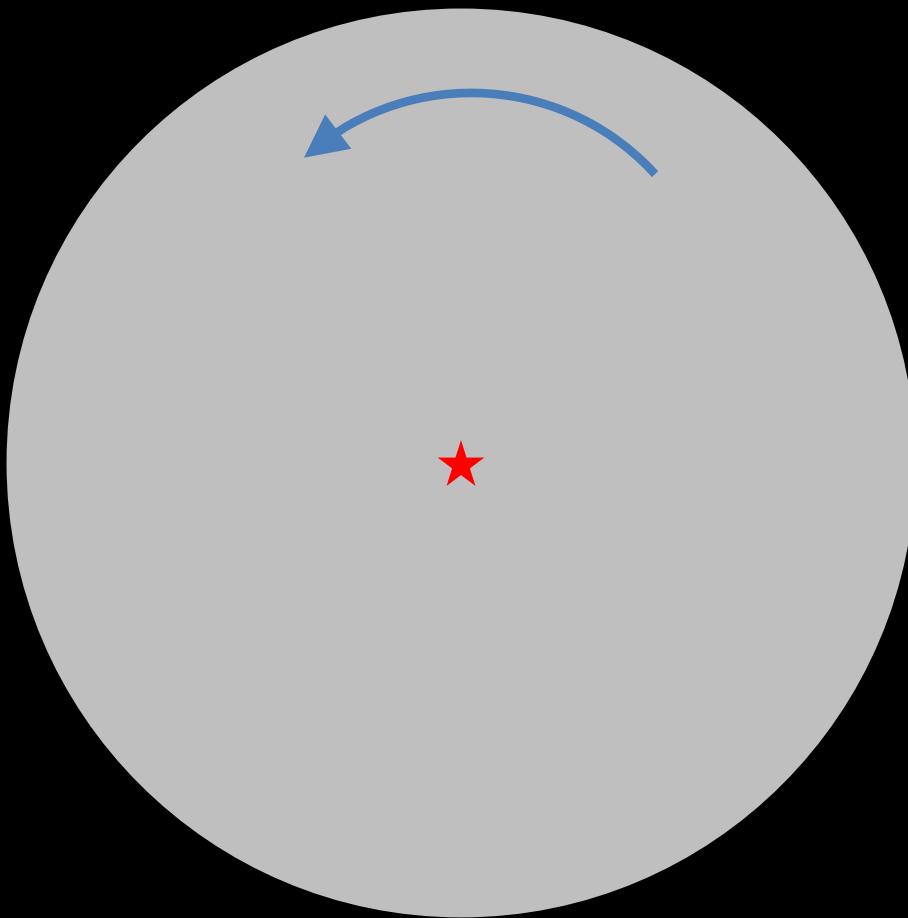


GW Ori

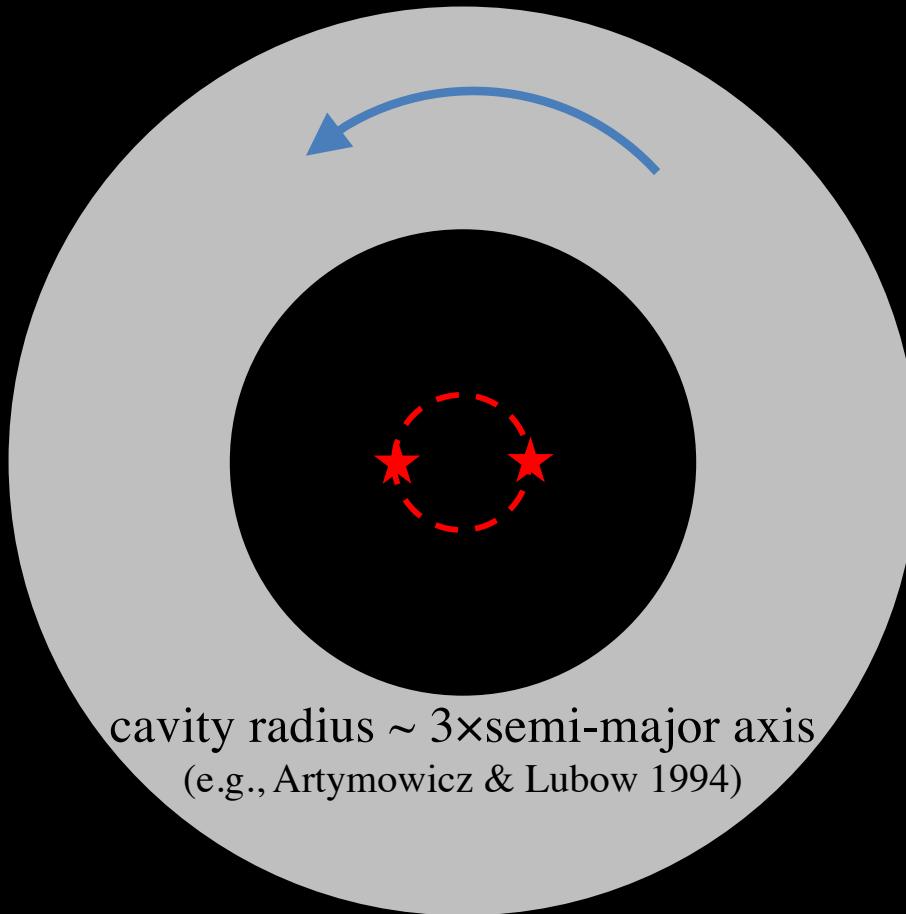
Misalignment and Eccentricities in the Rings



One Star, One Disk



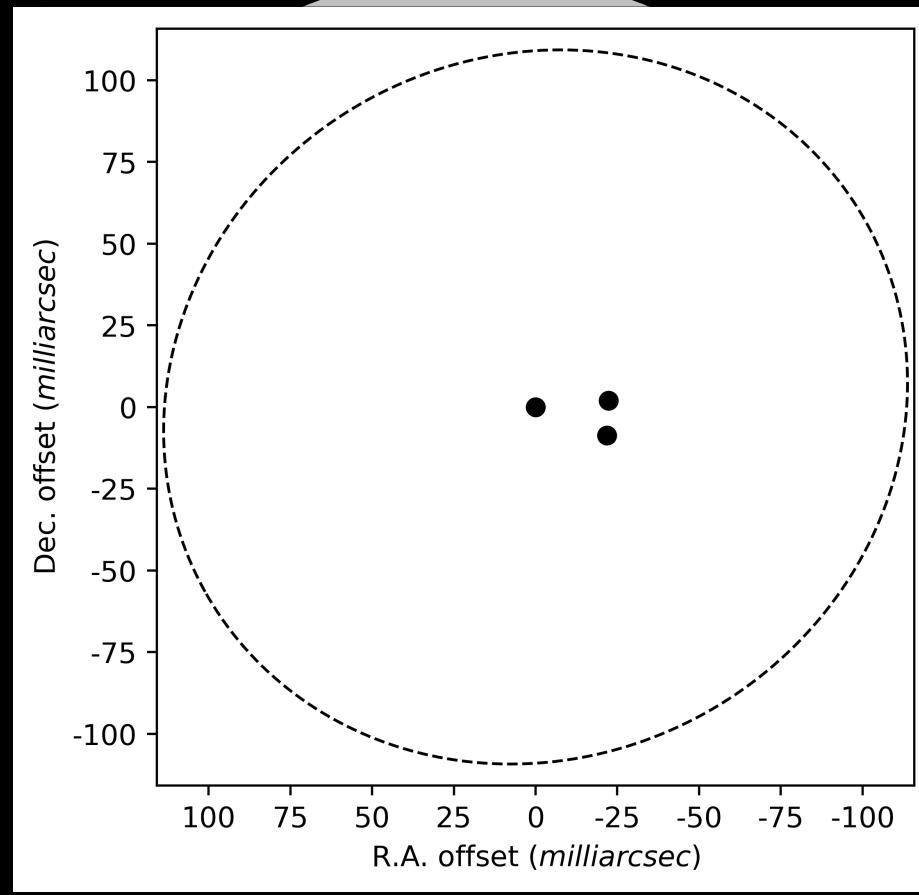
Two Stars, One Disk



cavity radius $\sim 3 \times$ semi-major axis
(e.g., Artymowicz & Lubow 1994)

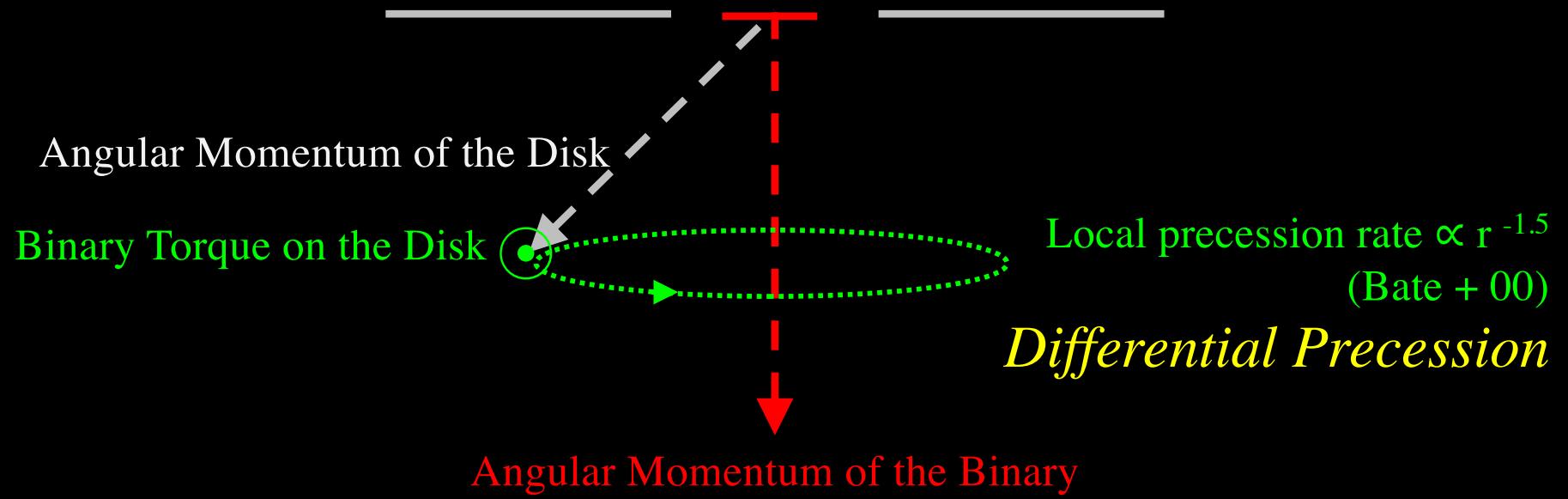
Two Stars, One Disk

E. Ragusa's Talk



Munoz & Lai (2016)

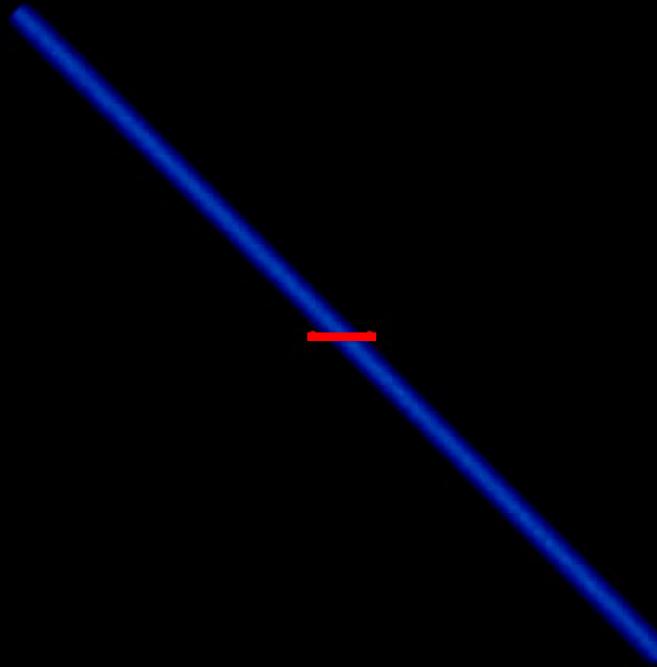
Two Stars, One Misaligned Disk



Two Stars, One Misaligned Disk

Situation #1:

Differential Precession → Warp (+ Break)
Diffuse Regime ($h/r < \alpha < 1$)

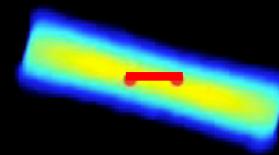


Nixon, King & Price (2013)

See also Facchini, Juhasz & Lodato (2018), Nealon, Dipierro + 18; Zhu 19, etc

Situation #2:

Precess as a Rigid Body
Wave-disk Regime ($\alpha < h/r < 1$)



Smallwood et al. (2018)

Two Stars, One Misaligned Disk

Radial communication timescale < Precession Timescale



$$t_c \approx \frac{8}{5\Omega_b(h/r)_{\text{out}}} \left(\frac{r_{\text{out}}}{a_b} \right)^{3/2}$$

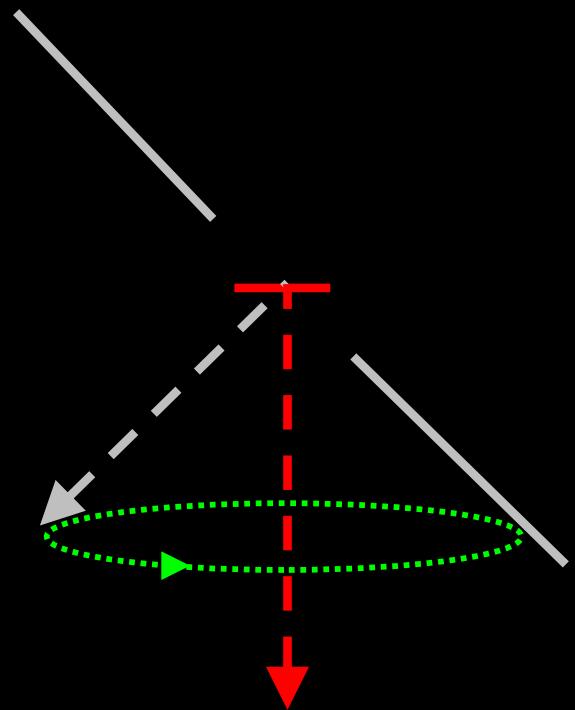
Lubow & Martin (2018)



$$\omega_p = \frac{3}{4} \sqrt{1 + 3e_b^2 - 4e_b^4} \frac{M_1 M_2}{(M_1 + M_2)^2} \frac{\int_{r_{\text{in}}}^{r_{\text{out}}} \Sigma r^3 \Omega (a_b/r)^{7/2} dr}{\int_{r_{\text{in}}}^{r_{\text{out}}} \Sigma r^3 \Omega dr} \Omega_b$$

Smallwood + 19 (Global Precession Rate)

Situation #2:
Precess as a Rigid Body



Differential Precession

vs

Radial Communication

Two Stars, One Misaligned Disk

Radial communication timescale < Precession Timescale



$$t_c \approx \frac{8}{5\Omega_b(h/r)_{\text{out}}} \left(\frac{r_{\text{out}}}{a_b} \right)^{3/2}$$

Lubow & Martin (2018)



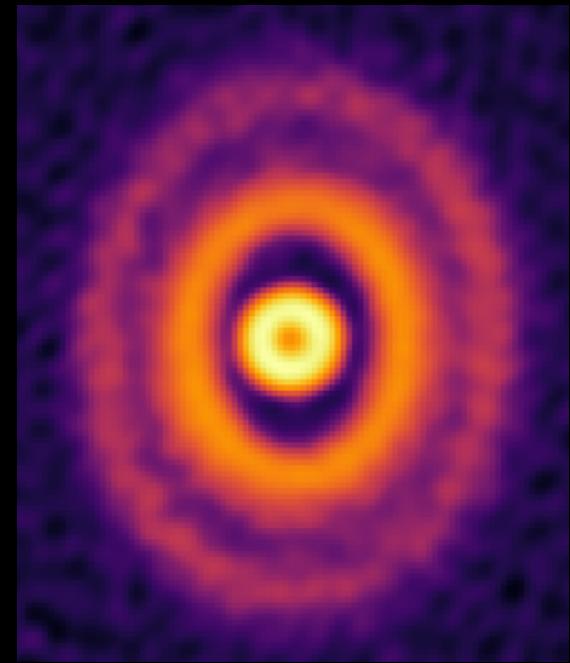
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Smallwood + 19 (Global Precession Rate)



GW Ori: ~ 0.1 Myr $<$ ~ 1 Myr
(treat the entire disk as one body)

Situation #2:
Precess as a Rigid Body



Differential precession cannot significantly warp the disk

Two Stars, One Misaligned Disk

Situation #1:

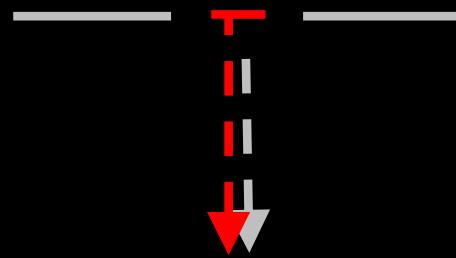
Differential Precession → Warp (+ Break)

Situation #2:

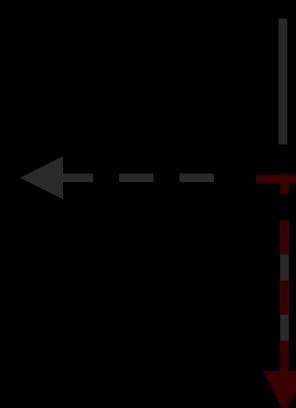
Precess as a Rigid Body

Viscous Dissipation Causes the Disk Inclination to Evolve

Disk-binary Coplanarity
(alignment or counter-alignment)



Polar Alignment



Sufficiently high initial disk-binary misalignment and binary eccentricity

Three Stars, Three Rings, Two Misaligned Disks, One Eccentric Cavity

