Warped protoplanetary discs

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Warping Away Gravitational Instabilities in Protoplanetary Discs

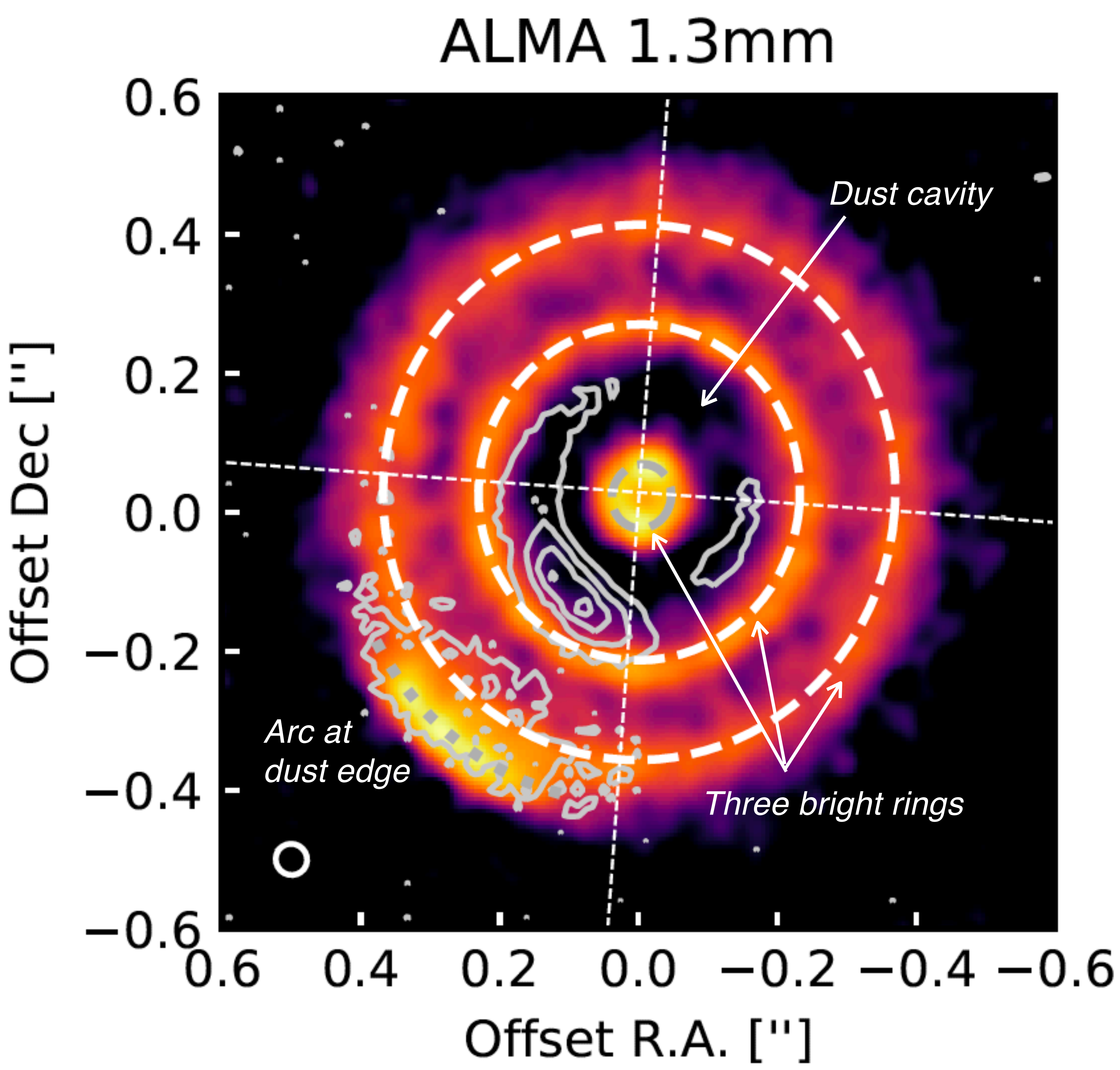
AVAILABLE ON THE ARXIV TODAY!

Sahl Rowther, Rebecca Nealon and Farzana Meru

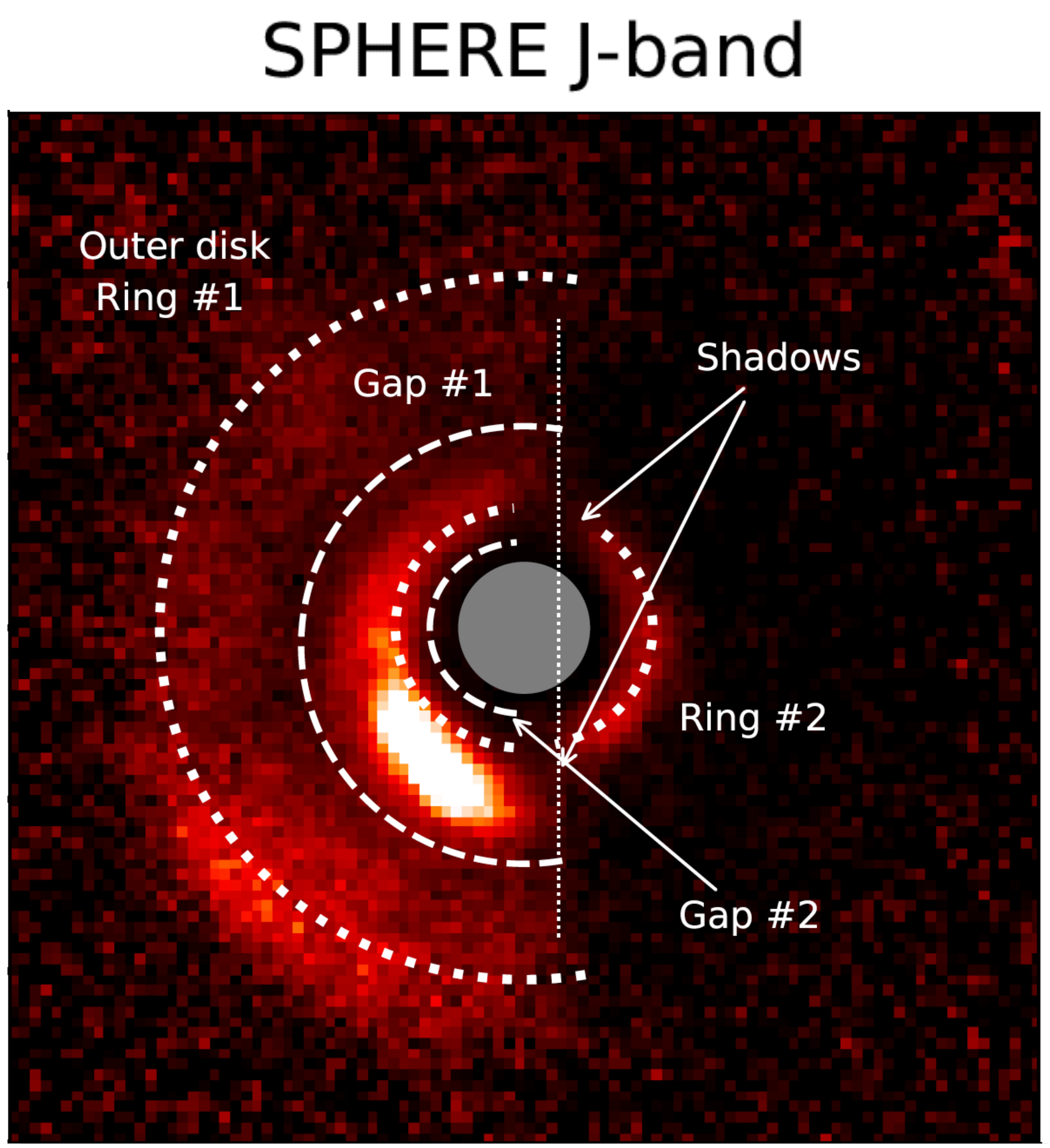
HD143006: CIRCUMBINARY PLANET OR MISALIGNED DISC?

Giulia Ballabio, Rebecca Nealon, Richard Alexander, Nicolas Cuello, Christophe Pinte and Daniel Price

HD 143006: OBSERVATIONS



Perez et al. 2018

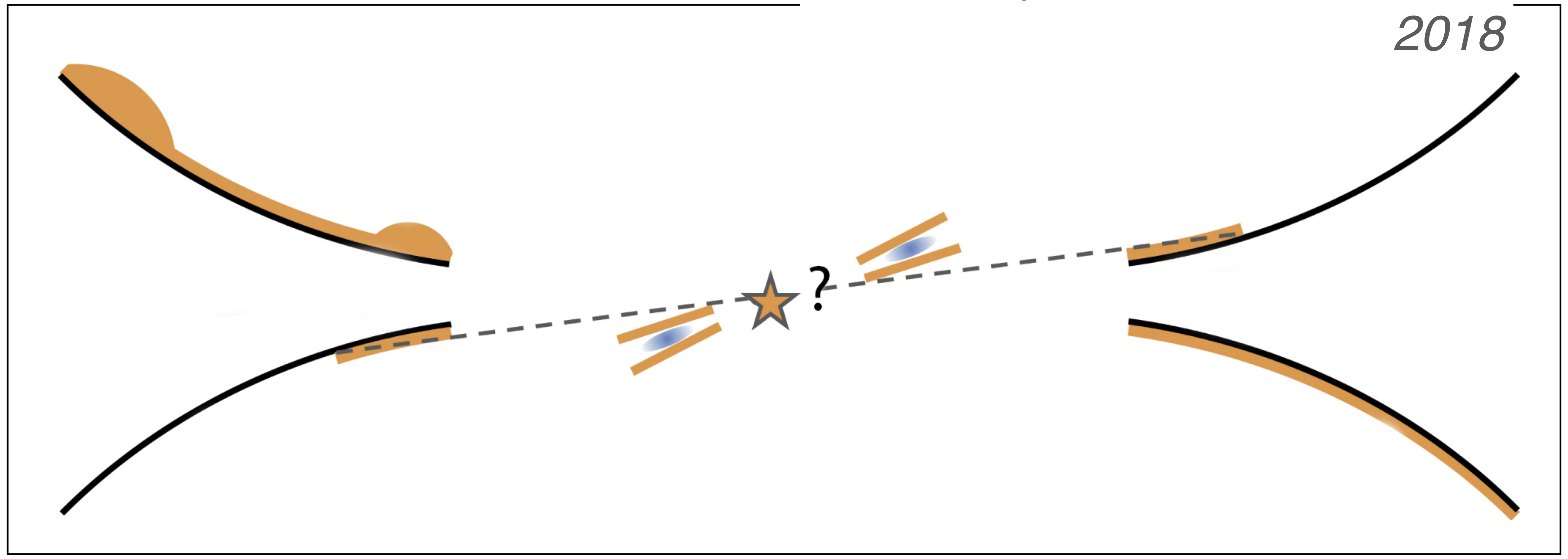


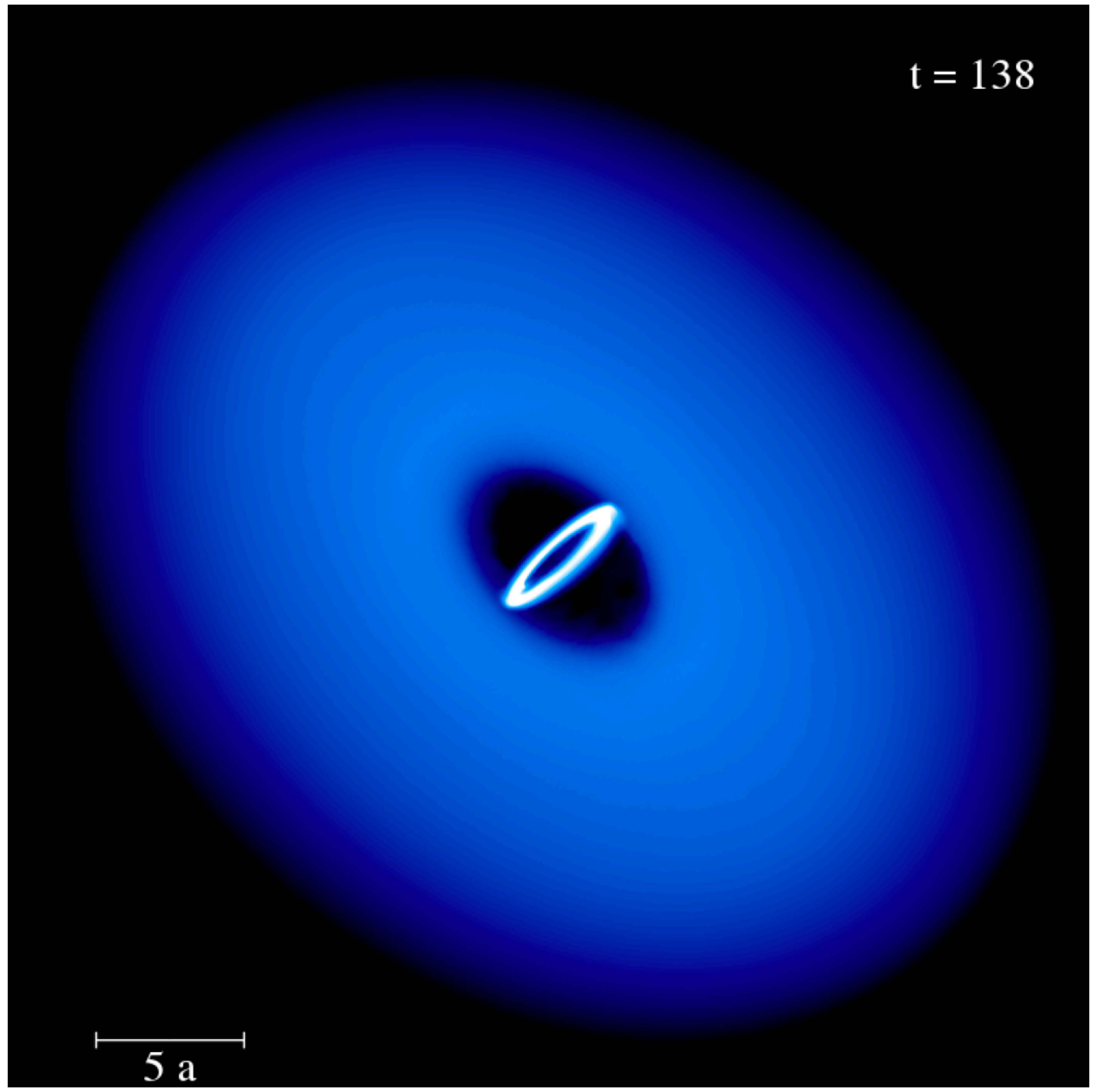
Benisty et al. 2018

PROPOSAL 1: A CIRCUMBINARY DISC

The proposed scenario: a binary at the centre breaks the disc and drives the misalignment.

Adapted from Perez et al. 2018





Facchini et al. 2013, 2018

PROPOSAL 1: A CIRCUMBINARY DISC

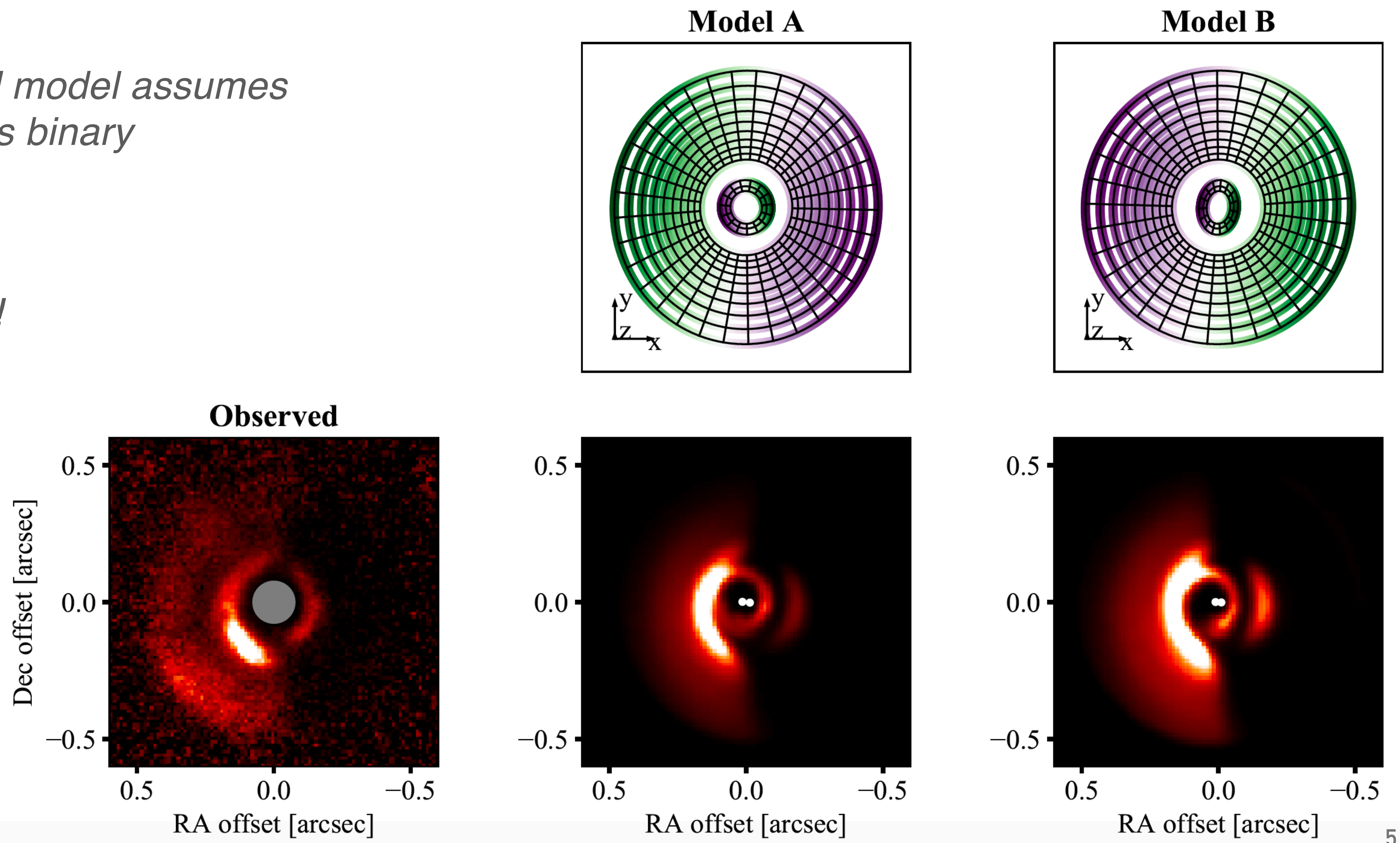
The proposed scenario: a binary at the centre breaks the disc and drives the misalignment.

Benisty et al. 2018

The proposed model assumes an equal mass binary companion.

BUT..

Not observed!



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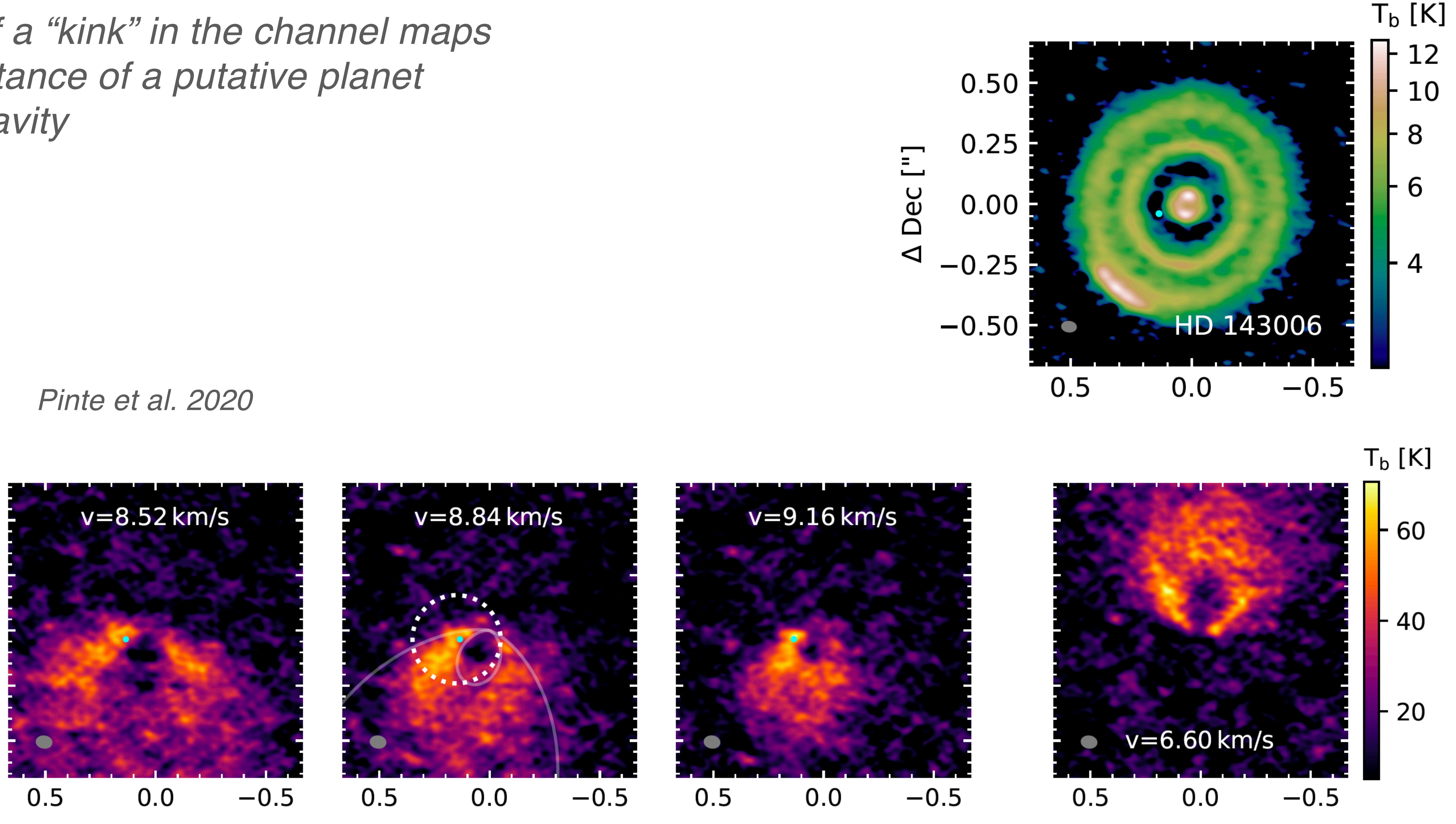
HD 143006: WE ALSO HAVE CHANNEL MAPS

Presence of a "kink" in the channel maps at radial distance of a putative planet within the cavity

Pinte et al. 2020

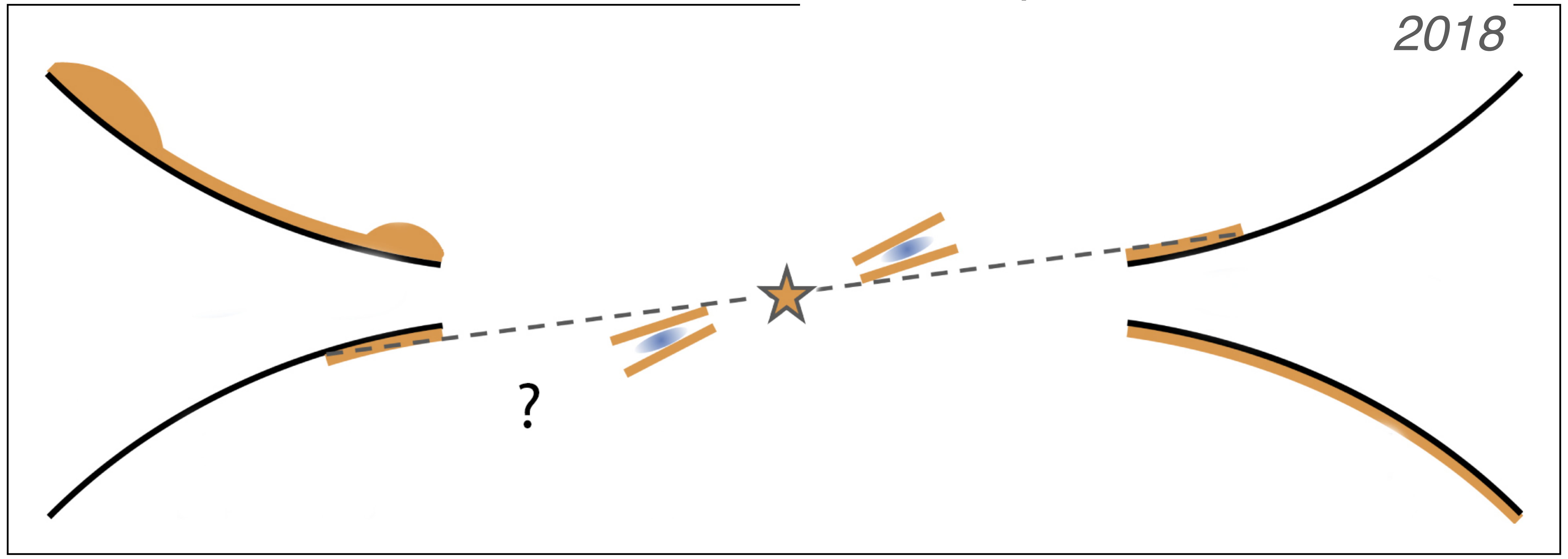


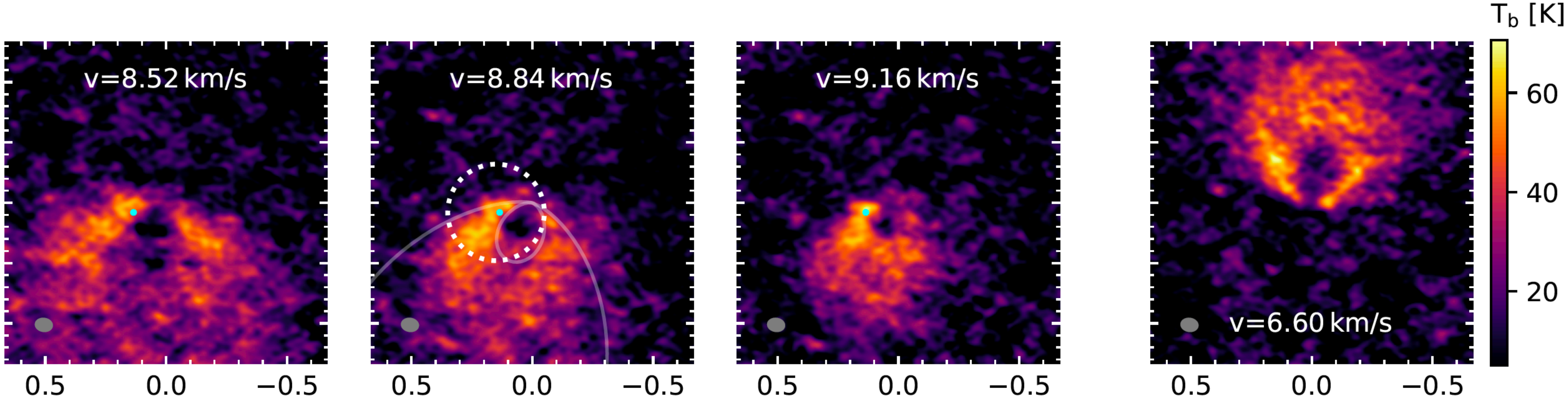
PROPOSAL 2: A DISTANT MISALIGNED COMPANION

Companion further out in the disc.

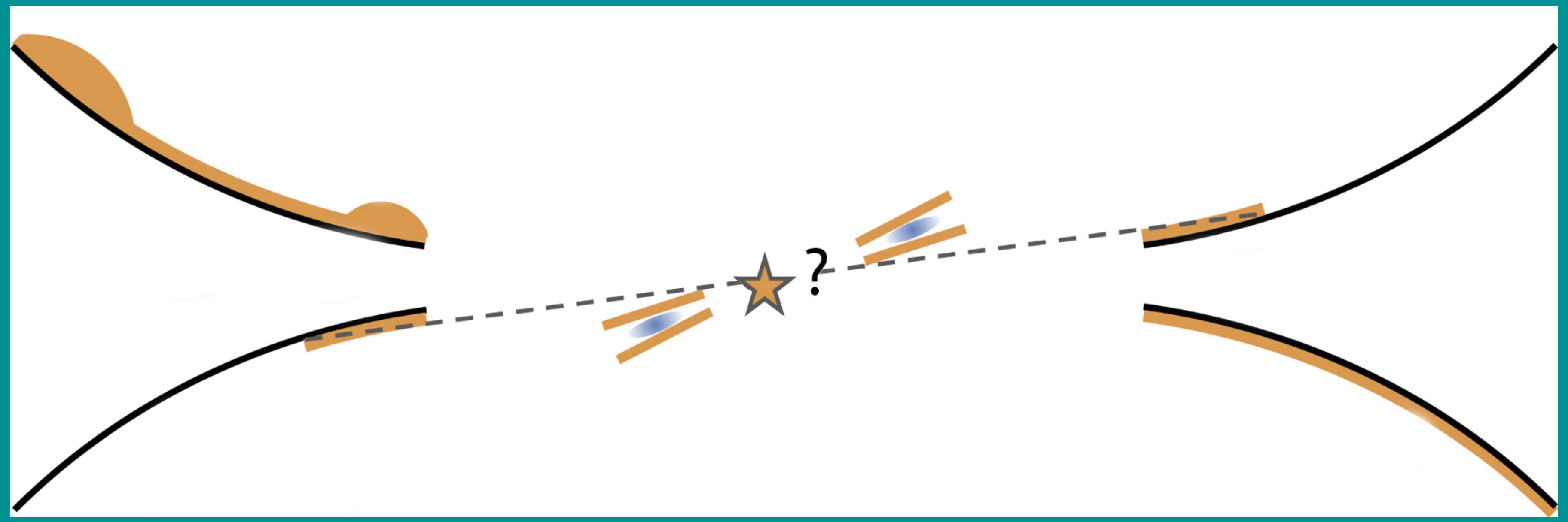
Constraint on the mass ratio q<0.2

Adapted from Perez et al. 2018





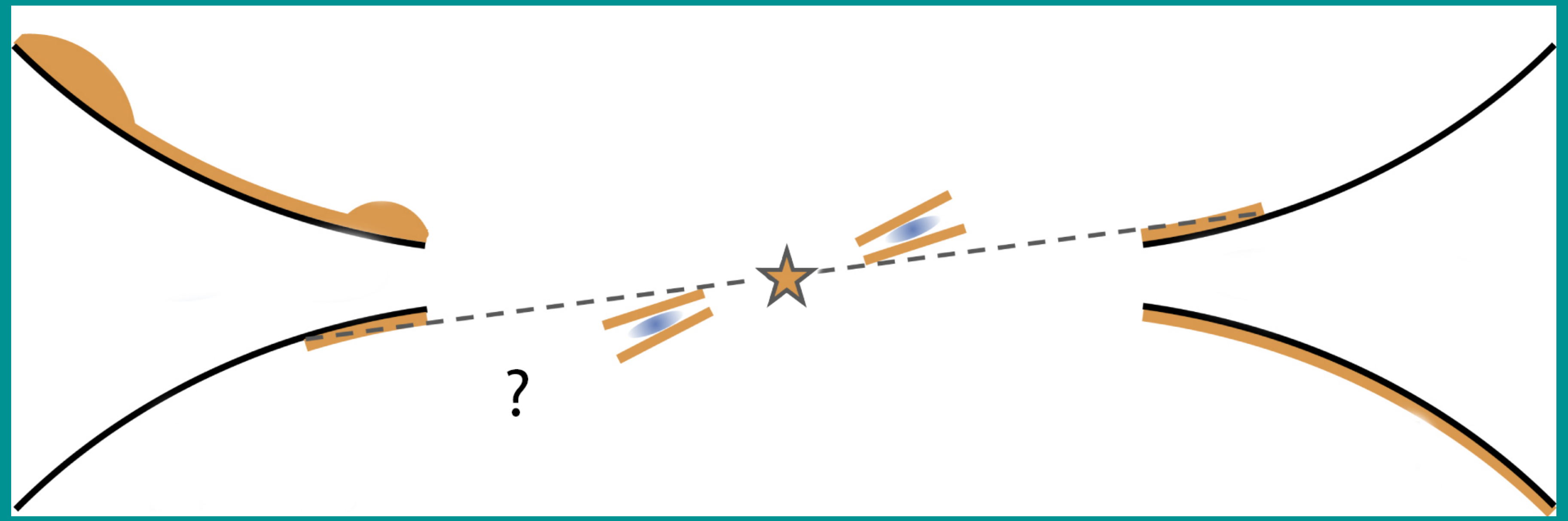
SO, WHAT CAUSES THE MISALIGNMENT?



Binary scenario…

…. or …..

… a distant outer companion?



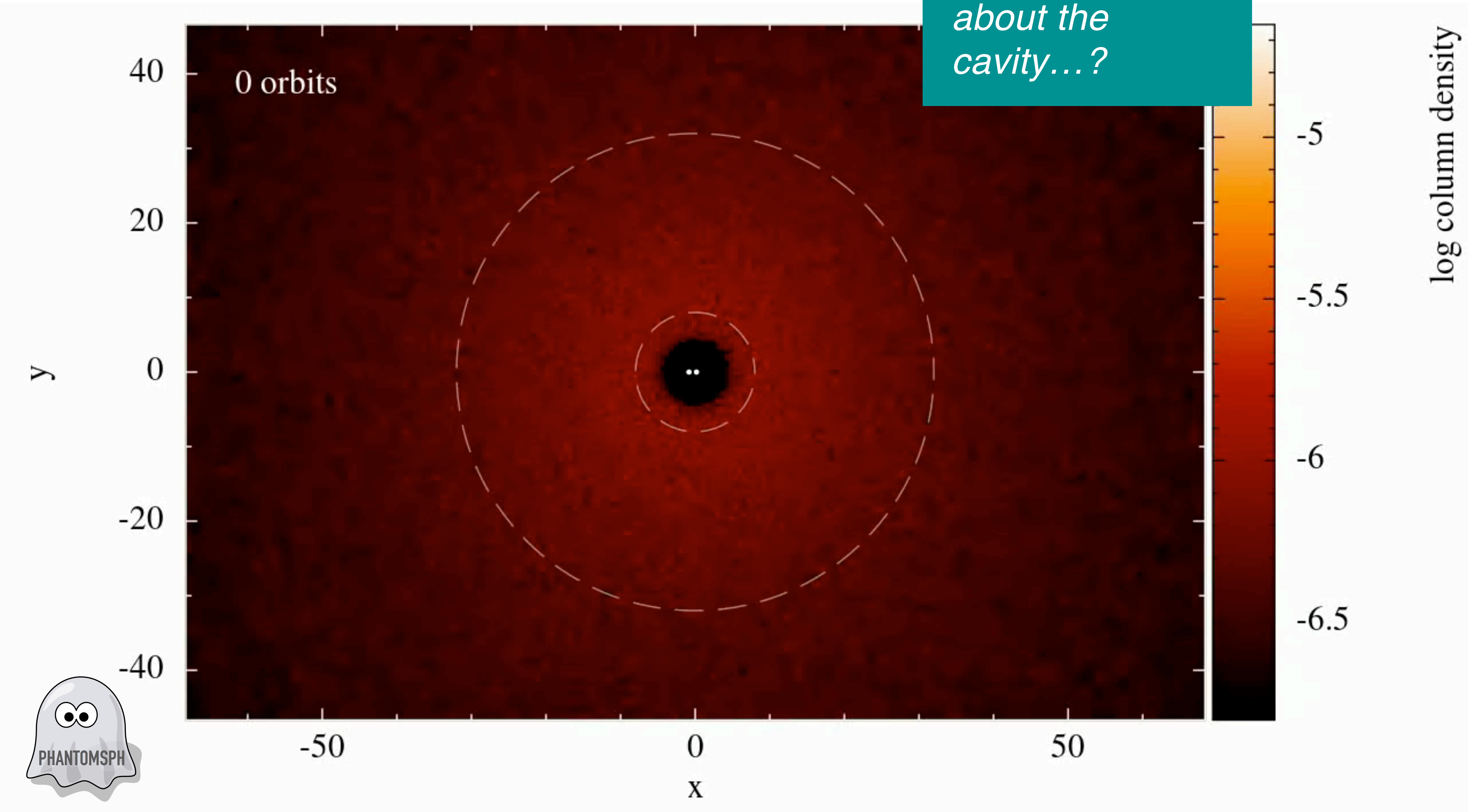
CONSTRAINTS FROM OBSERVATIONS:

1. *Misaligned gas < 8 au*
2. *Extent of cavity 8-32 au*
3. *Relative misalignment ~30-40 degrees*
4. *Mass ratio 0.1-0.2*
5. *Consistent with kinematics*

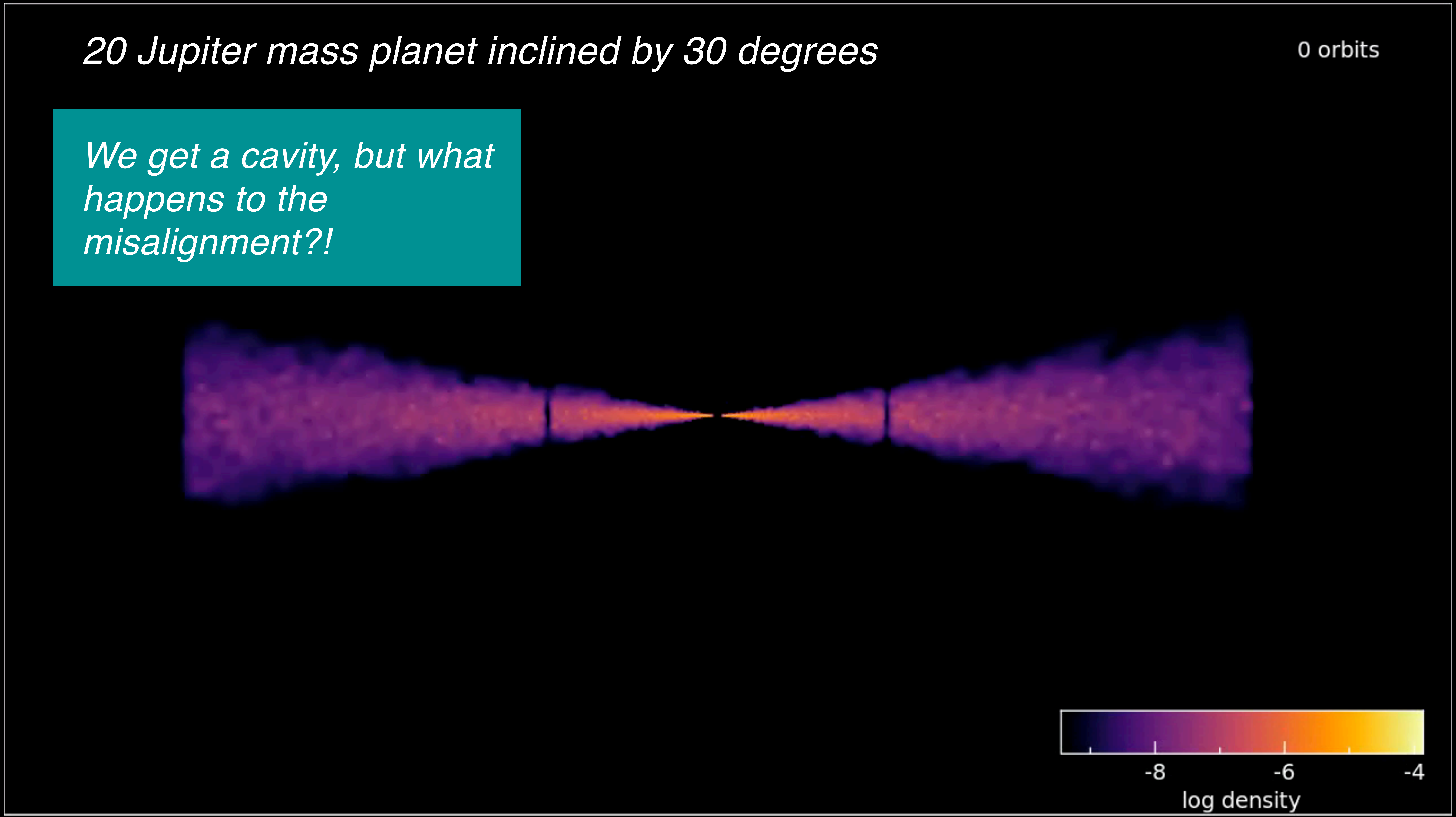
1. AN INCLINED BINARY

Simulations of a binary inclined by 60 degrees.

OK! But what about the cavity…?

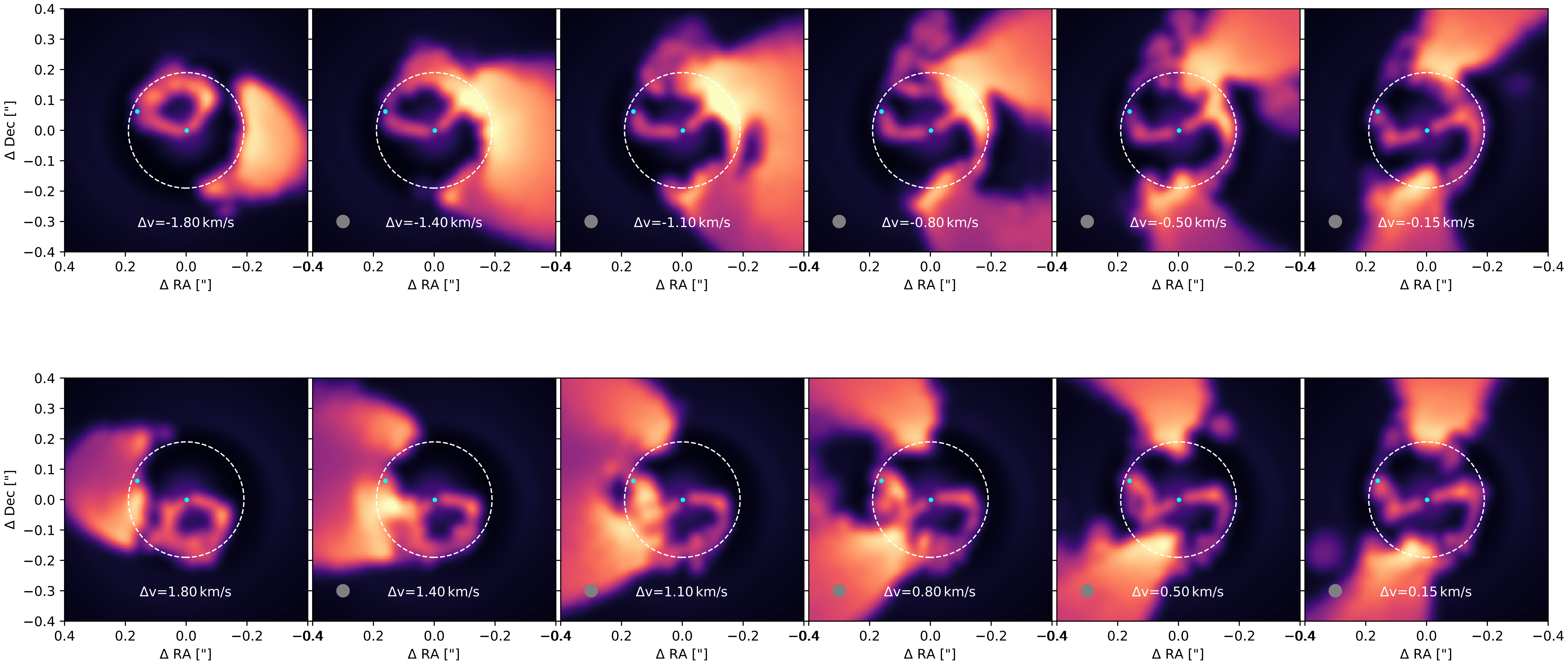


PROPOSAL 2: A DISTANT MISALIGNED COMPANION



PROPOSAL 2: A DISTANT MISALIGNED COMPANION

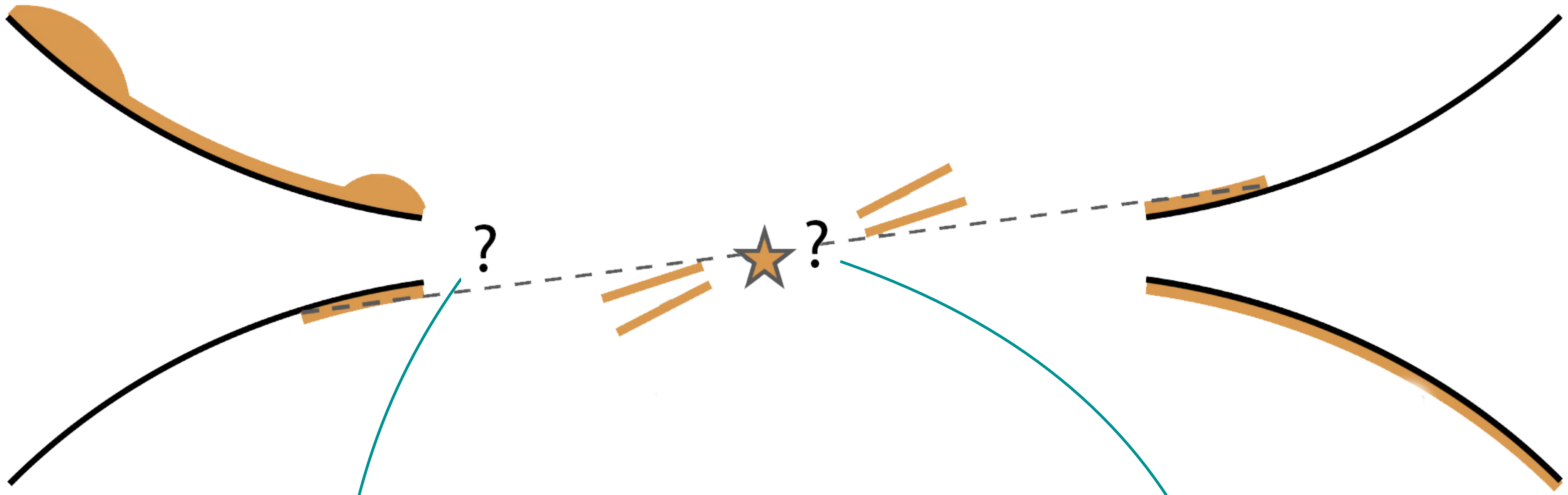
20 Jupiter mass planet inclined by 30 degrees



(Computed with MCFOST)

PROPOSAL 3: WHY DON'T WE HAVE BOTH?

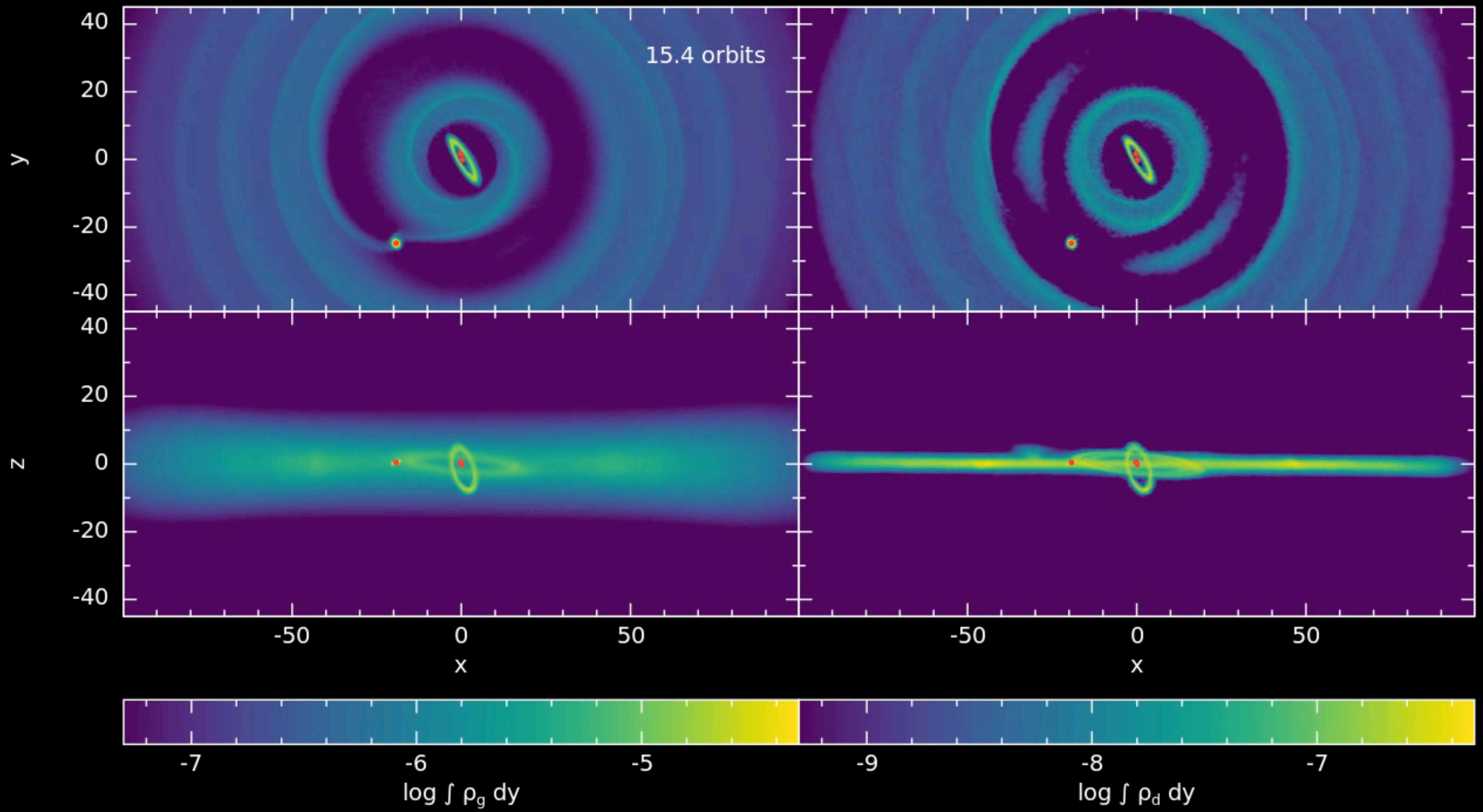
We propose a scenario in which there is an inclined binary at the centre and a planetary companion co-planar with the outer disc.



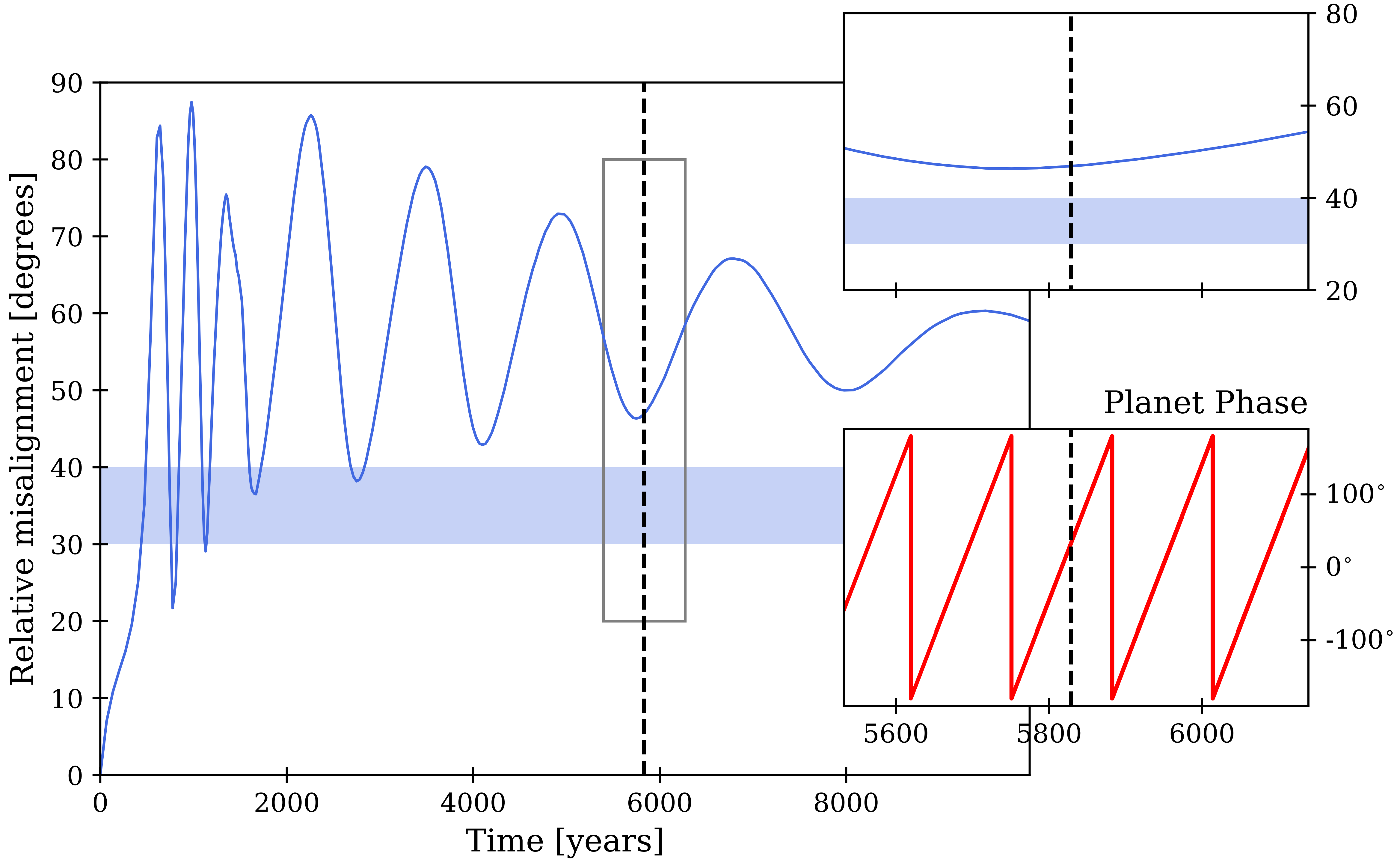
Outer companion aligned with outer disc: opens the gap effectively breaking the disc

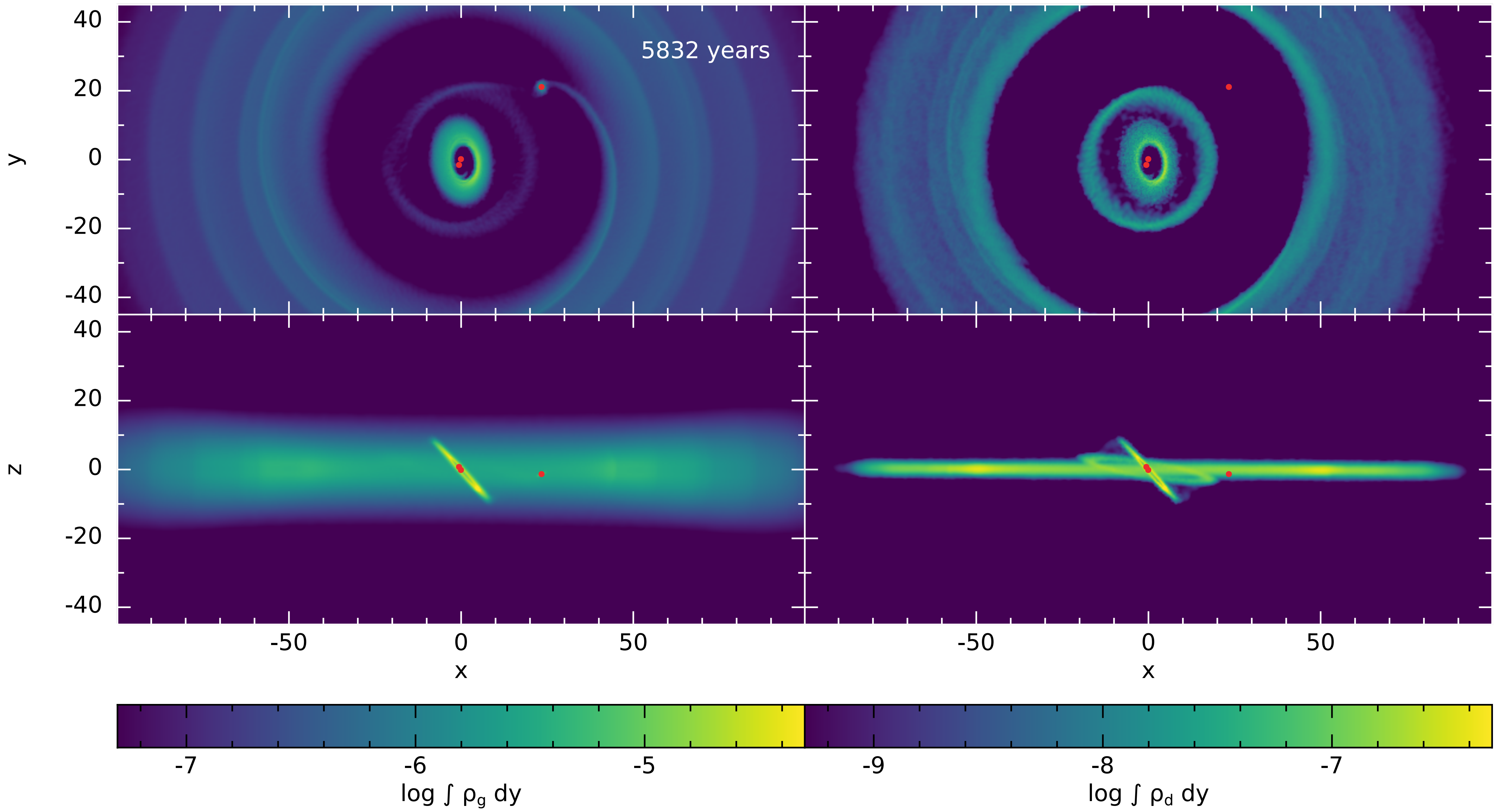
Inclined binary: causes the misalignment of the inner disc

PROPOSAL 3: BOTH AN INCLINED BINARY AND A PLANET FURTHER OUT



PROPOSAL 3: BOTH AN INCLINED BINARY AND A PLANET FURTHER OUT

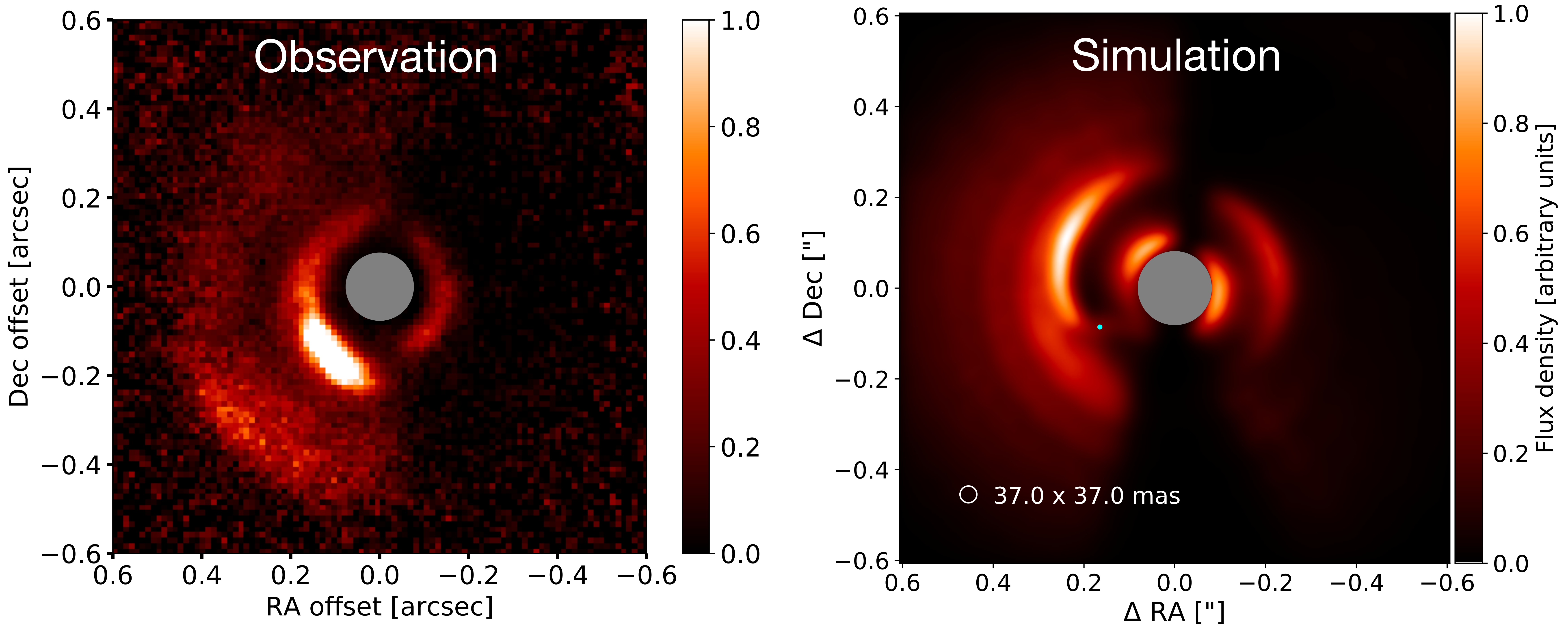




Best compromise:

43 planet orbits and 2766 binary orbits

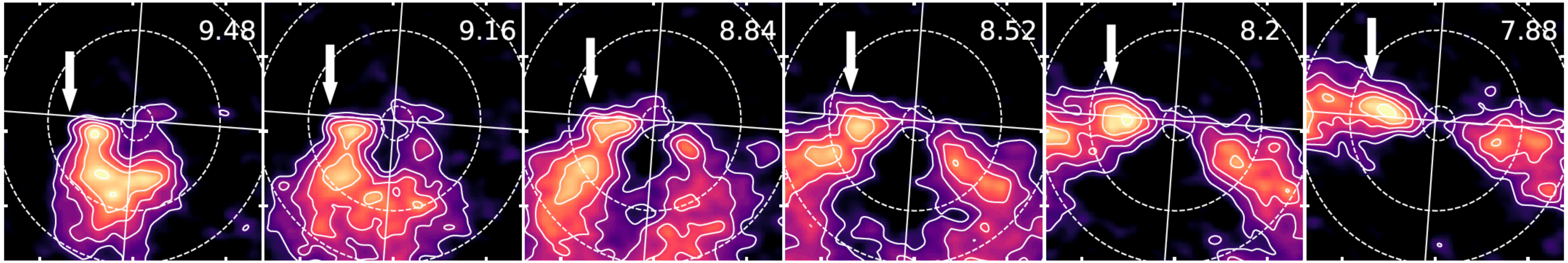
PROPOSAL 3: IN SYNTHETIC SCATTERED LIGHT



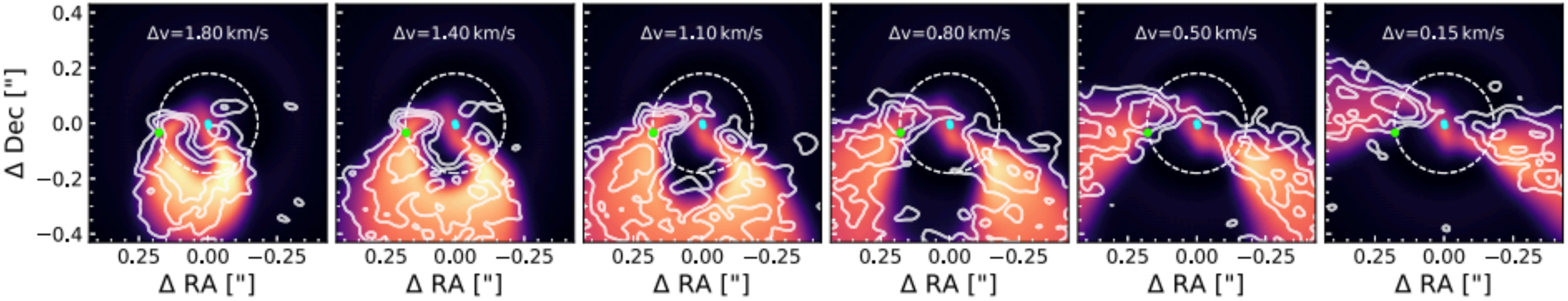
(Computed with MCFOST)

PROPOSAL 3: THE KINEMATICS

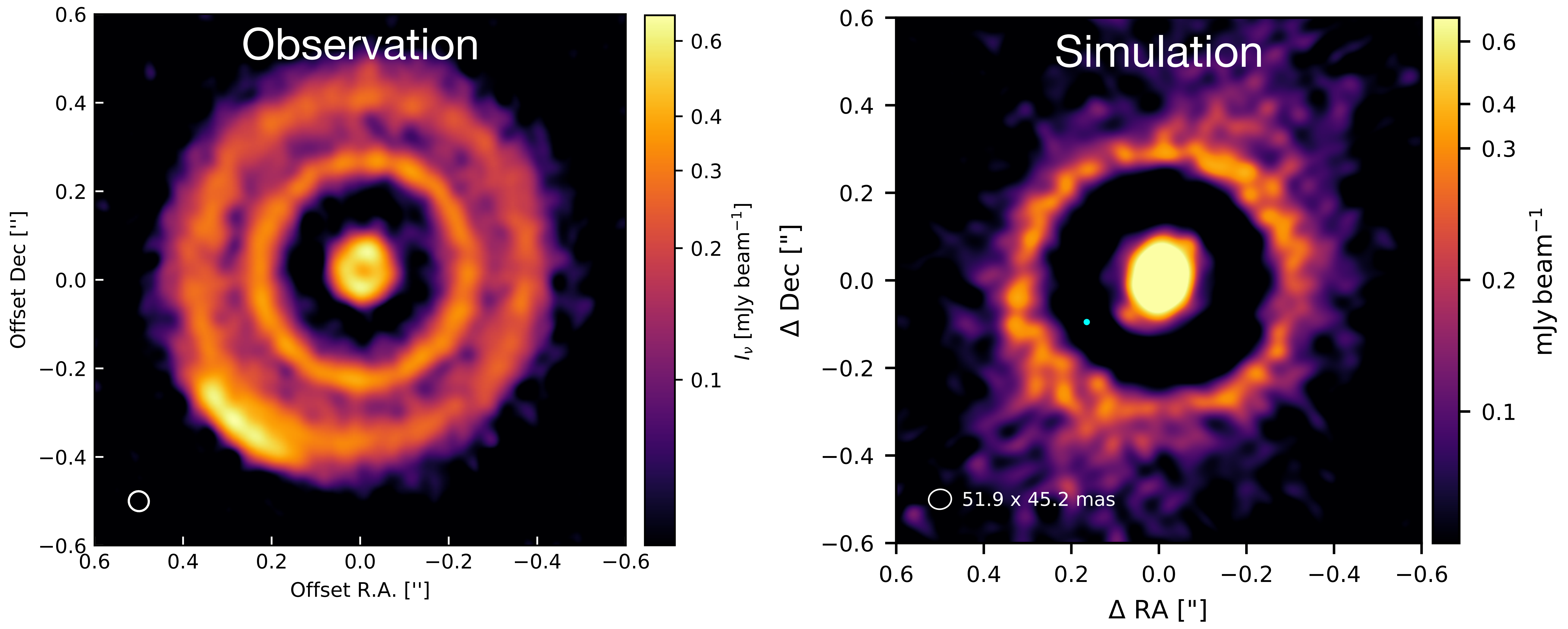
Observation



Simulation



PROPOSAL 3: IN DUST MM CONTINUMM



(Computed with MCFOST+CASA)

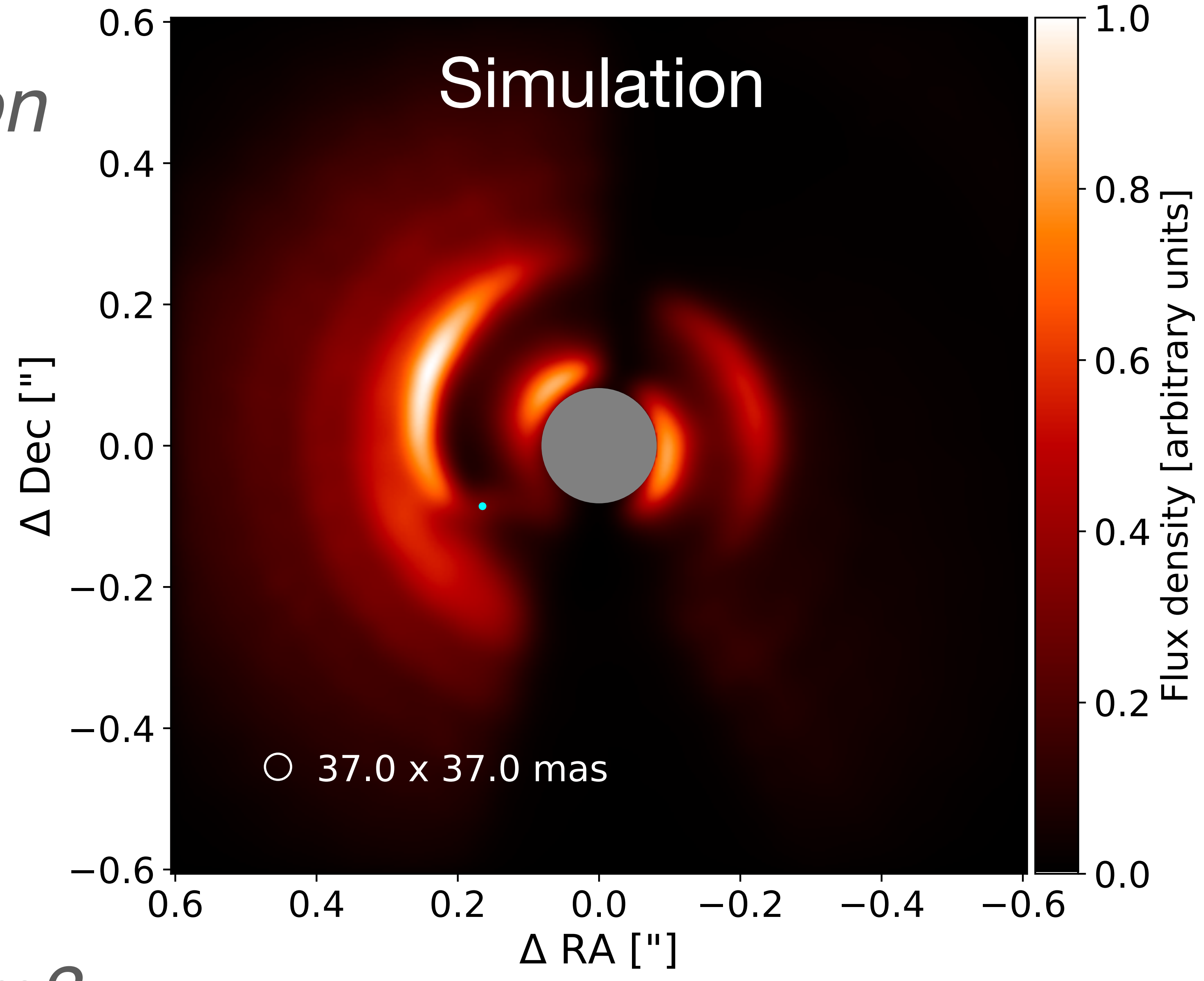
HD143006 LIKELY HAS BOTH AN INCLINED BINARY AND A DISTANT PLANET

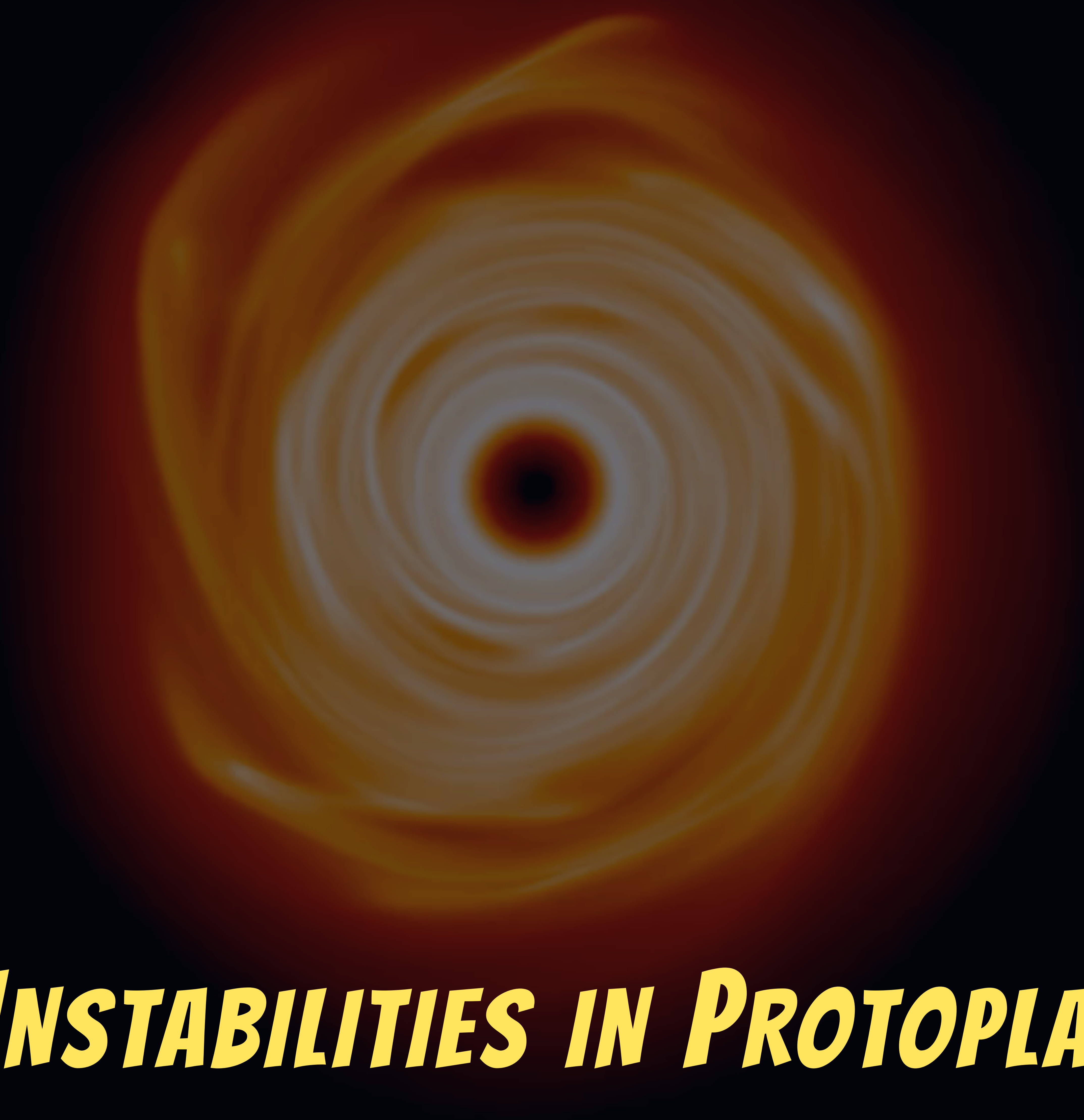
- *We found that the observations are best explained using a combination of an inner misaligned binary and a planet around 30-40 au*

- *This still doesn't explain the over-brightness*

- *Identify a misaligned circumplanetary disc (as theoretically predicted)*

- *What does it mean to the planet evolution to be in this kind of a system?*





Warping Away Gravitational Instabilities in Protoplanetary Discs

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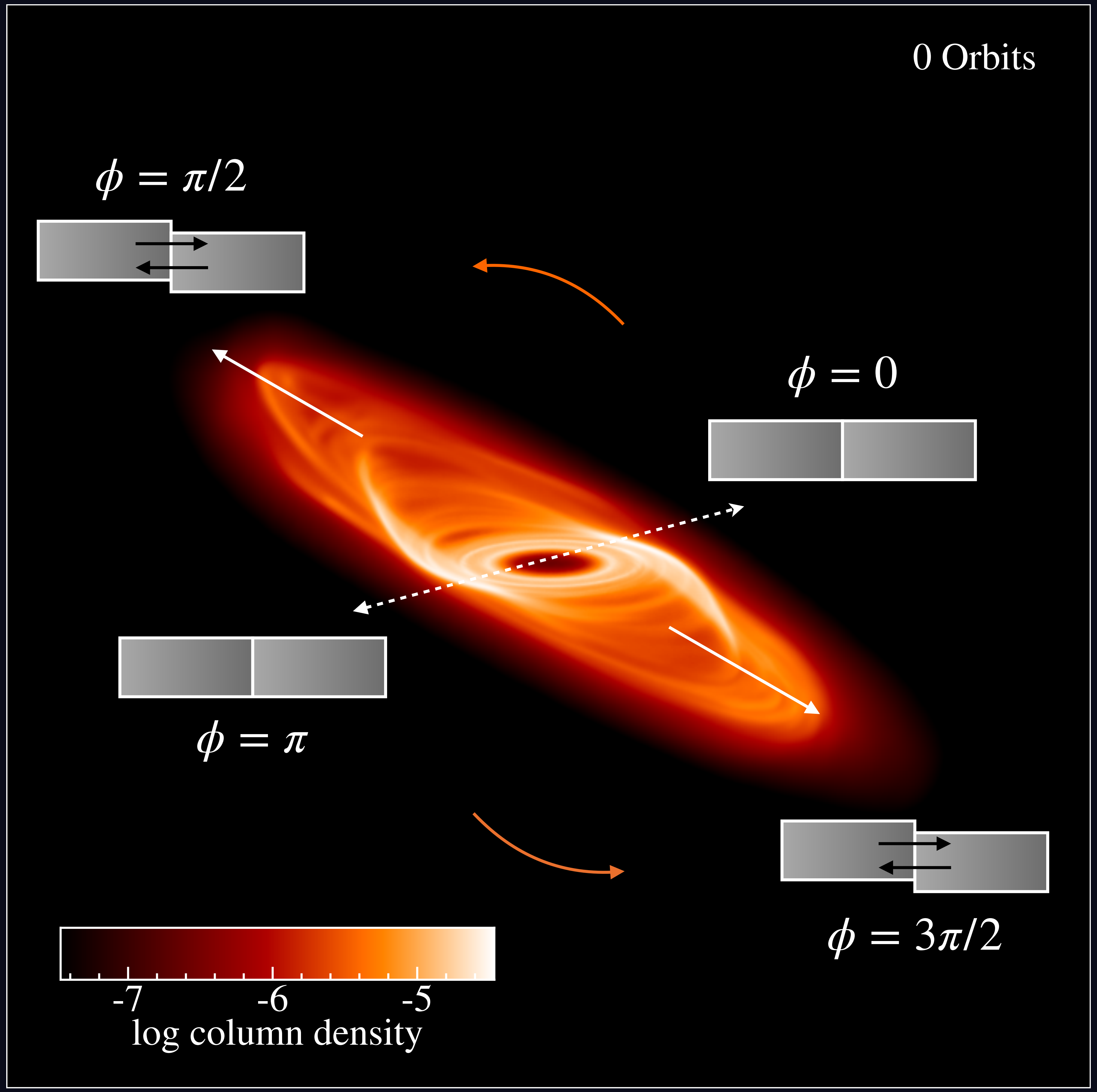
The role of the warp in the disc's evolution

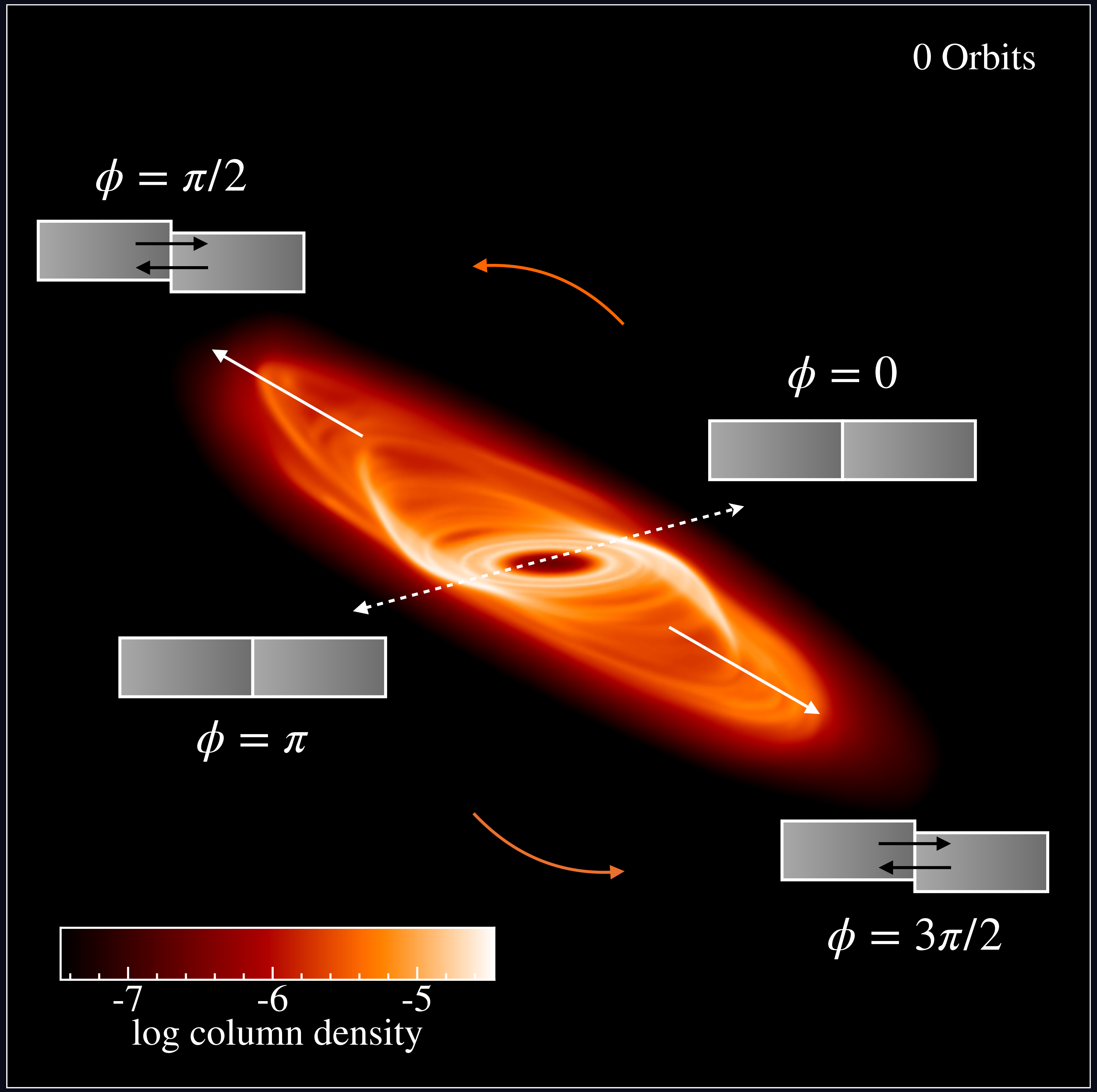
- Warp induces an oscillating radial pressure gradient (Lodato & Pringle 2007).

$$\frac{\partial p}{\partial R} \sim \frac{p\psi}{H}$$

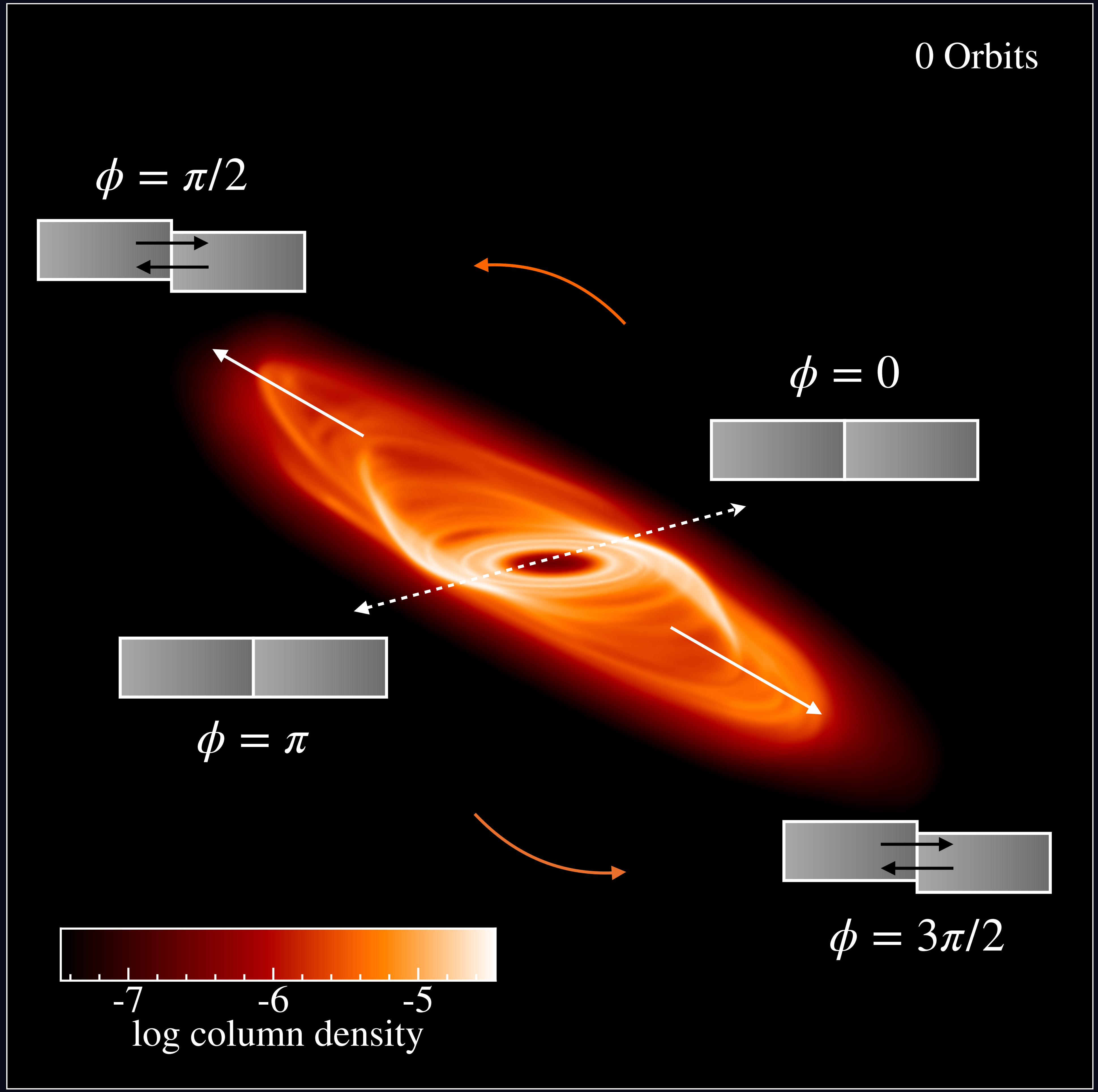


The role of the warp in the disc's evolution

- This induced pressure gradient can trigger a response in the velocity flow of the disc (Lodato & Pringle 2007).



Also see in Kees' talk from yesterday



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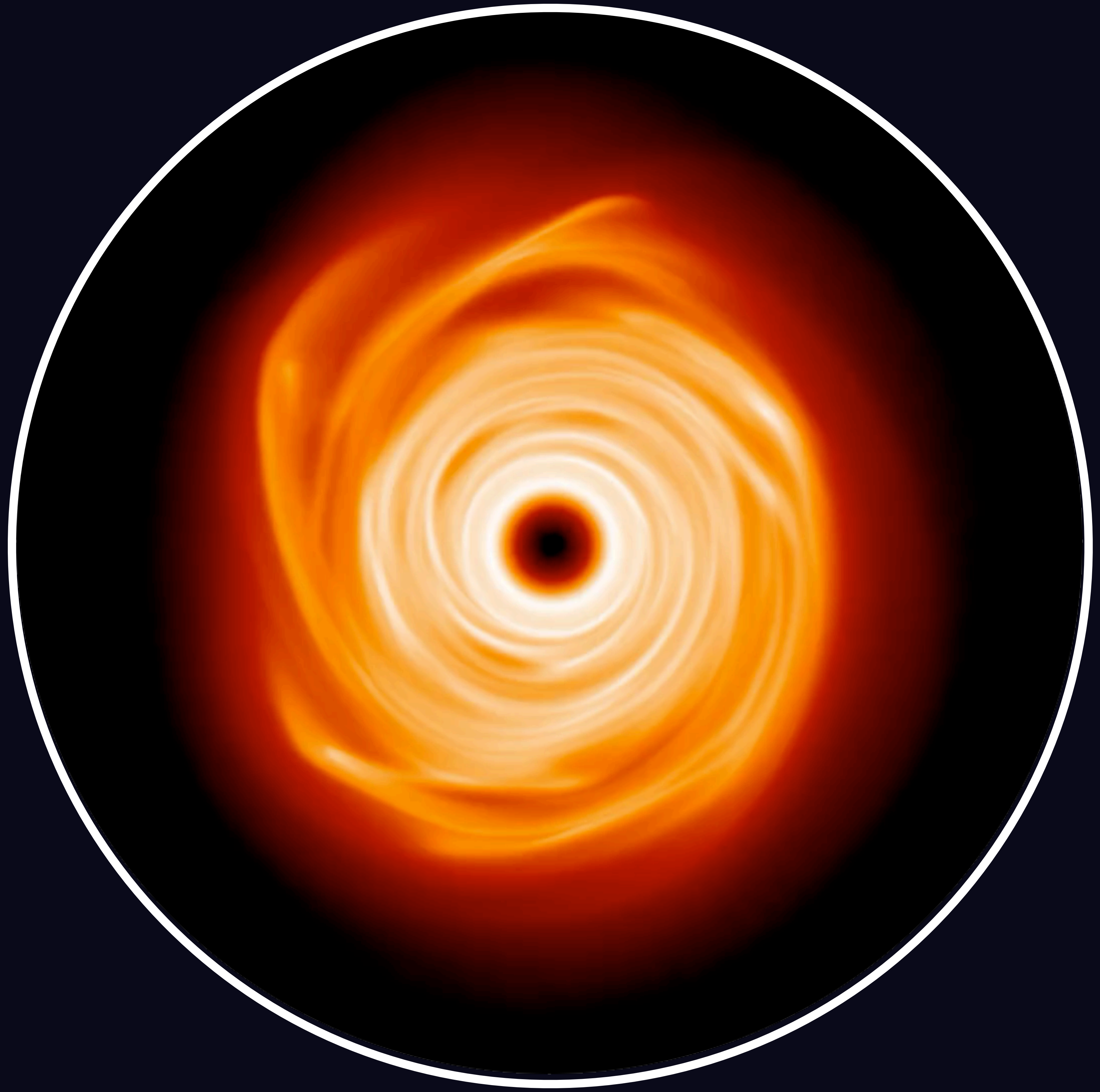
Evolution into a Gravitationally Stable Disc



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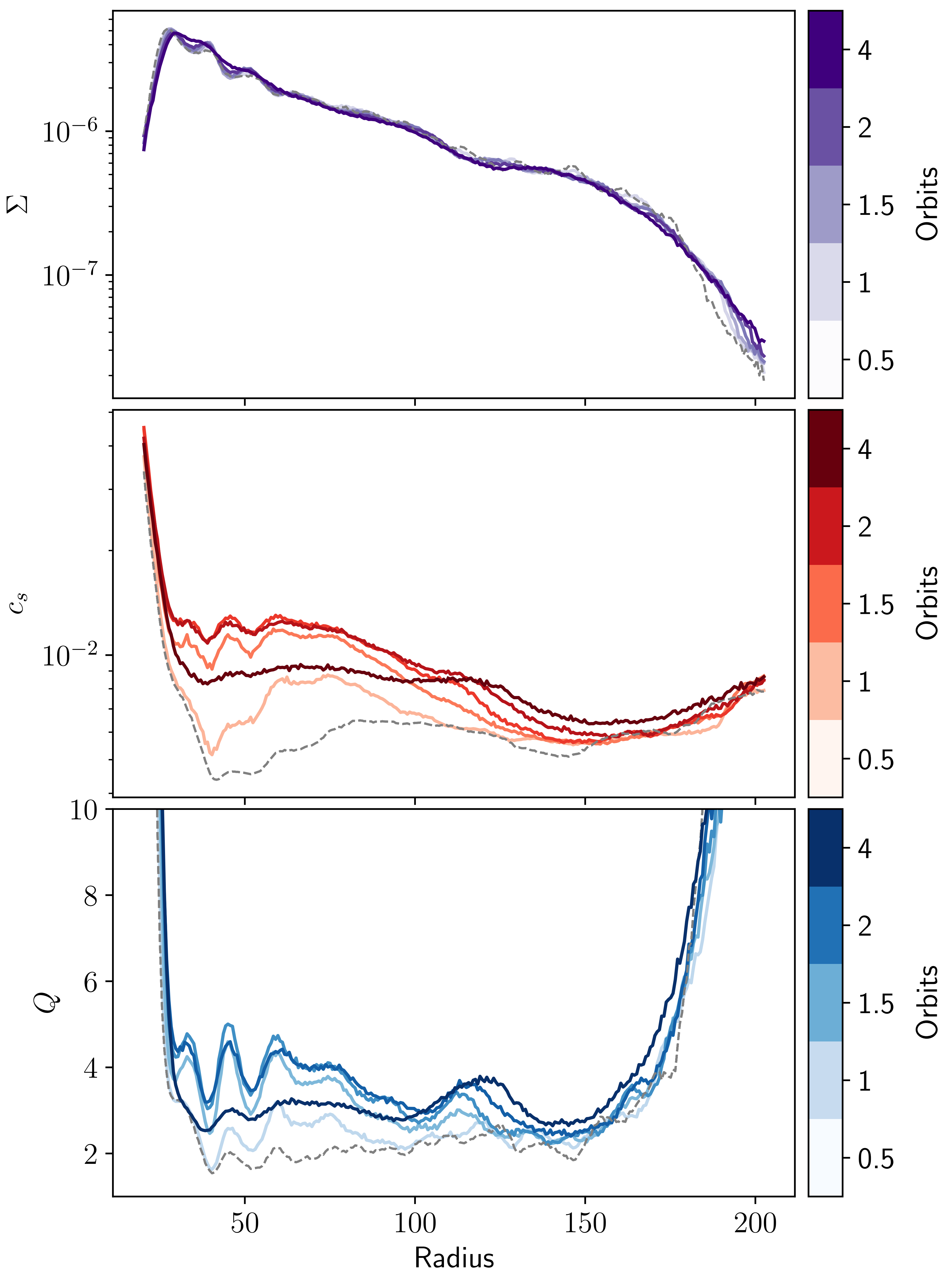
Why does the disc become gravitationally stable?

The warp heats up the disc pushing it towards stability.



The Internal Energy Equation

$$\frac{\mathrm{d}u}{\mathrm{d}t} = -\frac{P}{\rho}(\nabla \cdot v) + \Lambda_{\mathrm{shock}} - \frac{\Lambda_{\mathrm{cool}}}{\rho}$$

PdV Heating

Shock Heating

Cooling Term

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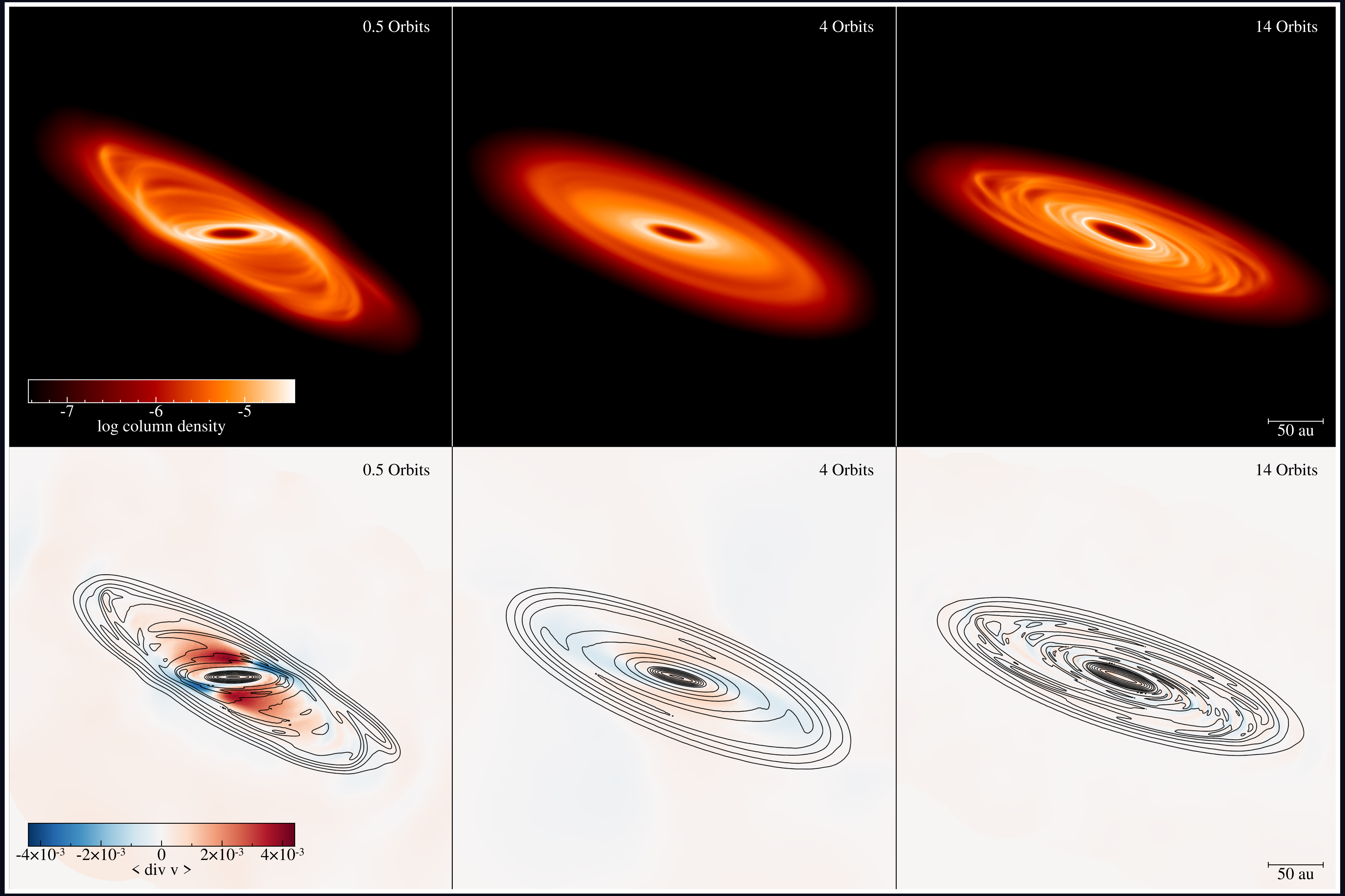
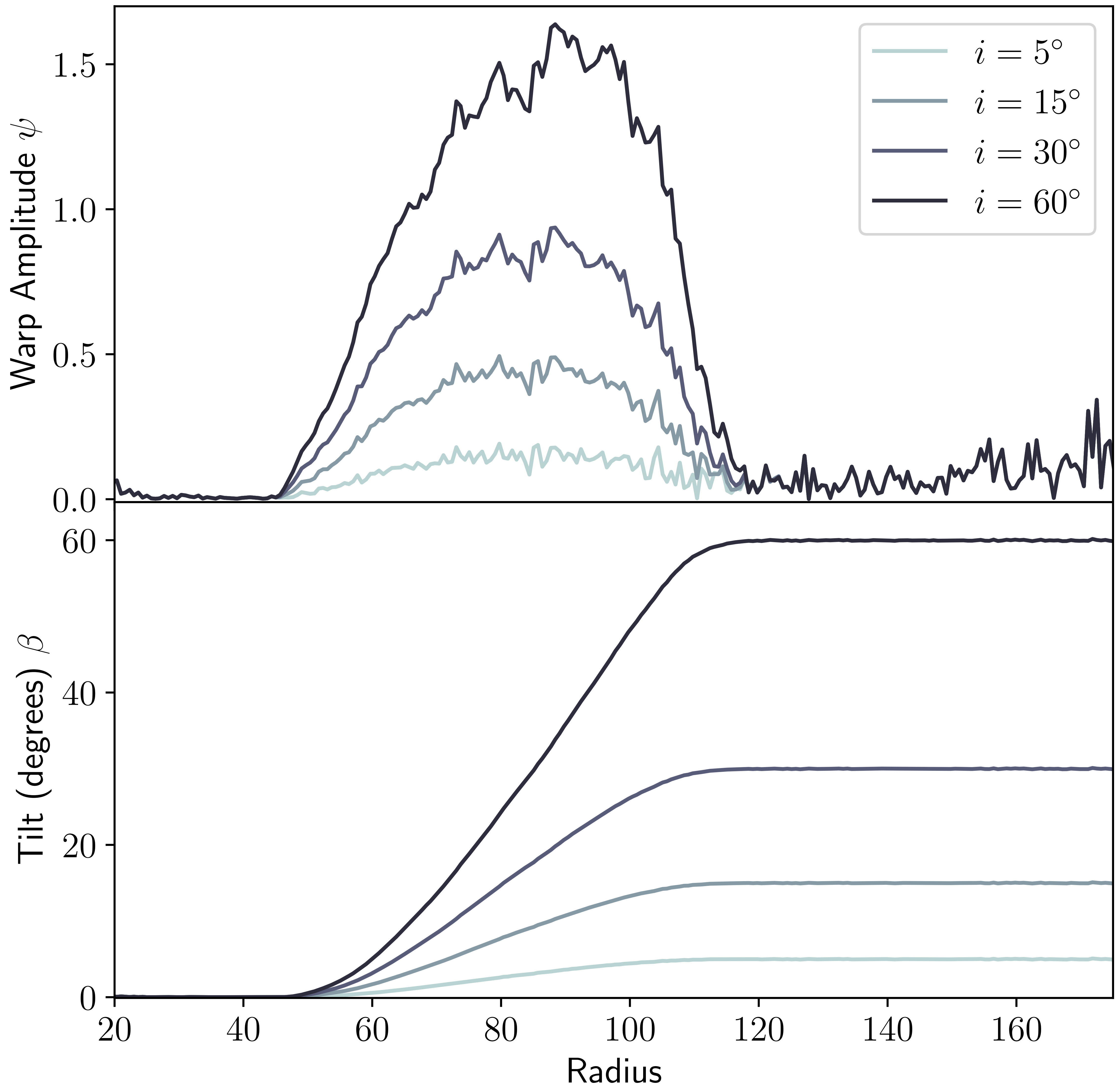
The warp triggers a strong response in the induced radial velocities

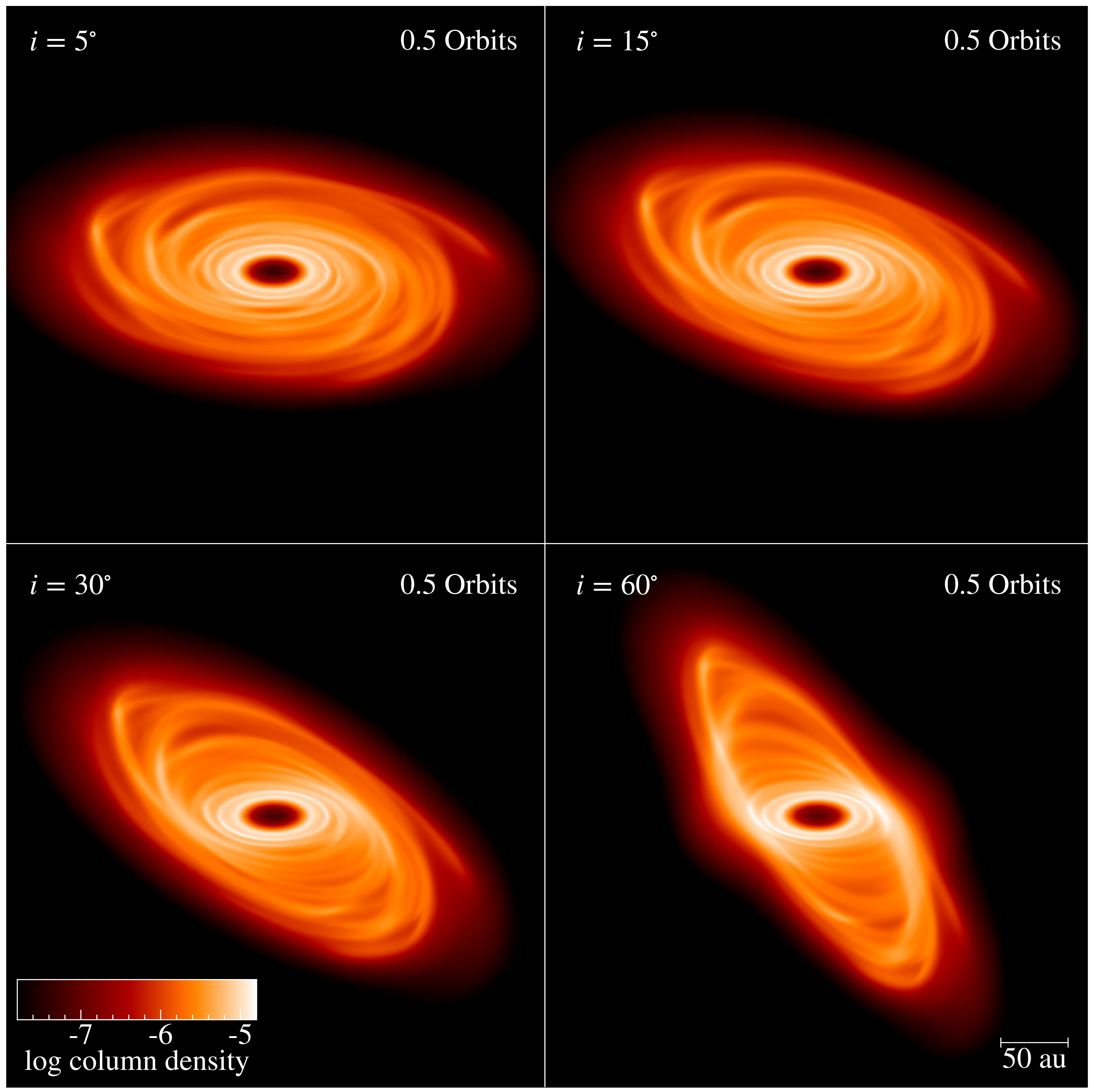


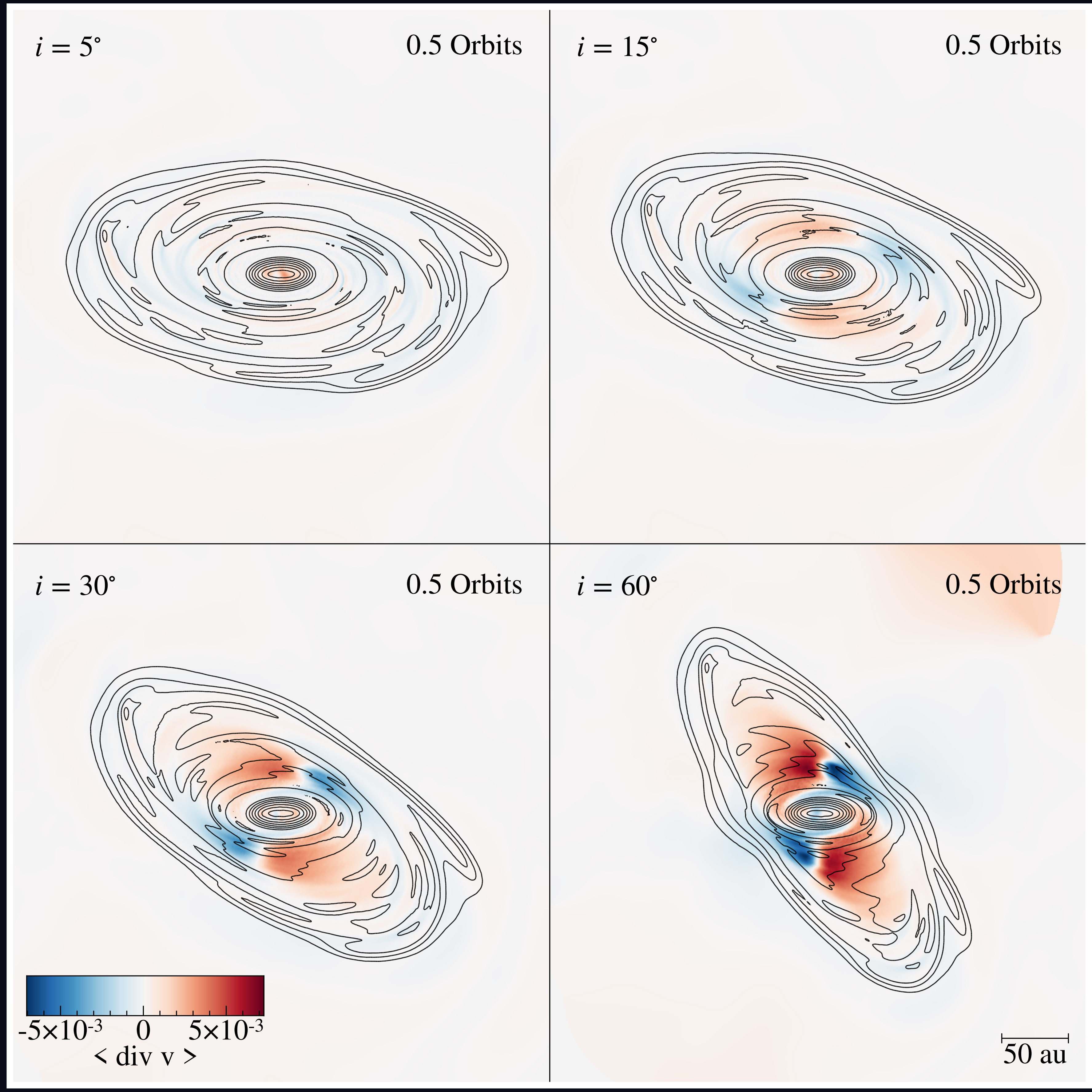
Changing the Warp Inclination

Warp amplitude is largest for greater misalignments.



Changing the Warp Inclination





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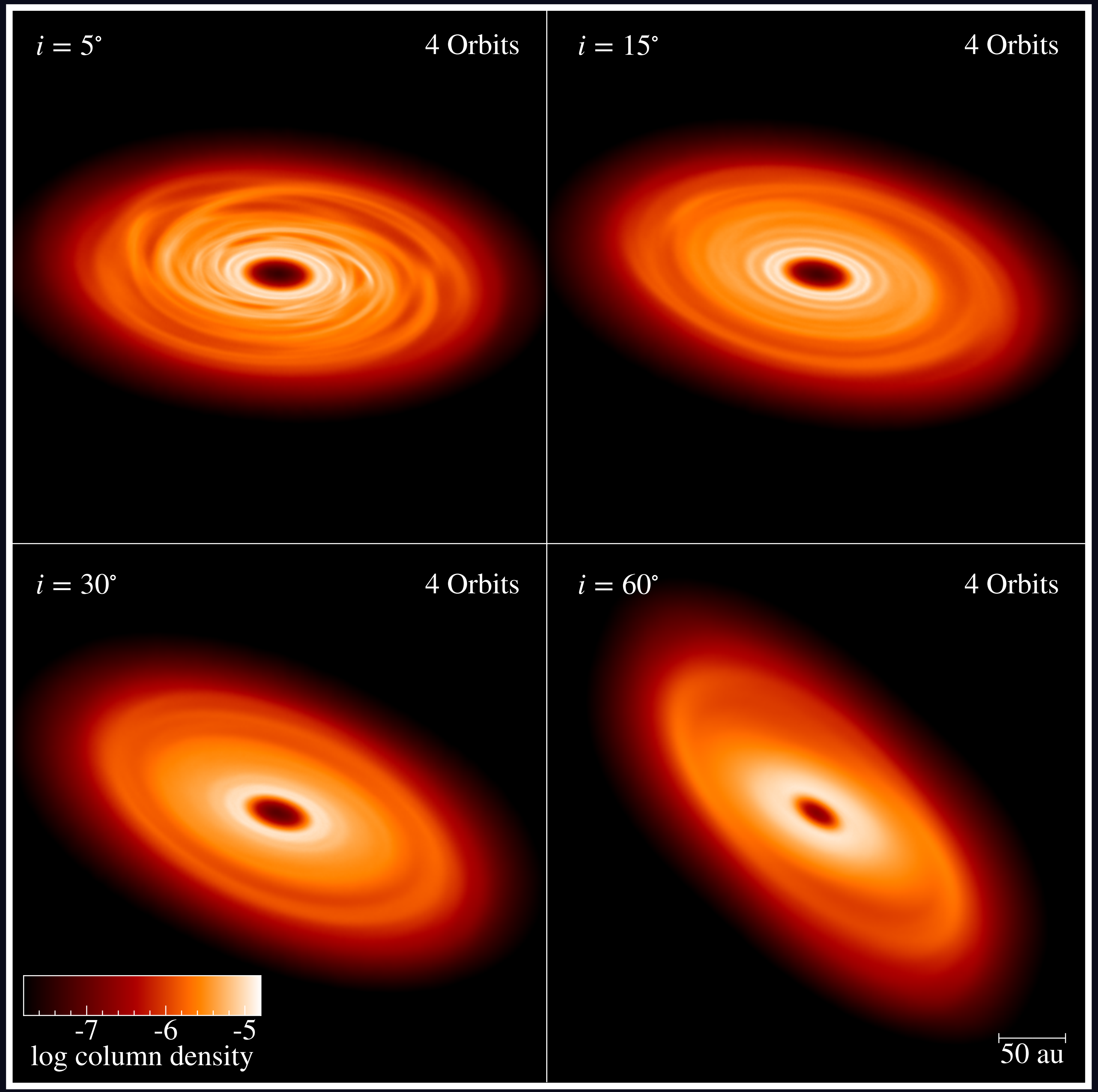

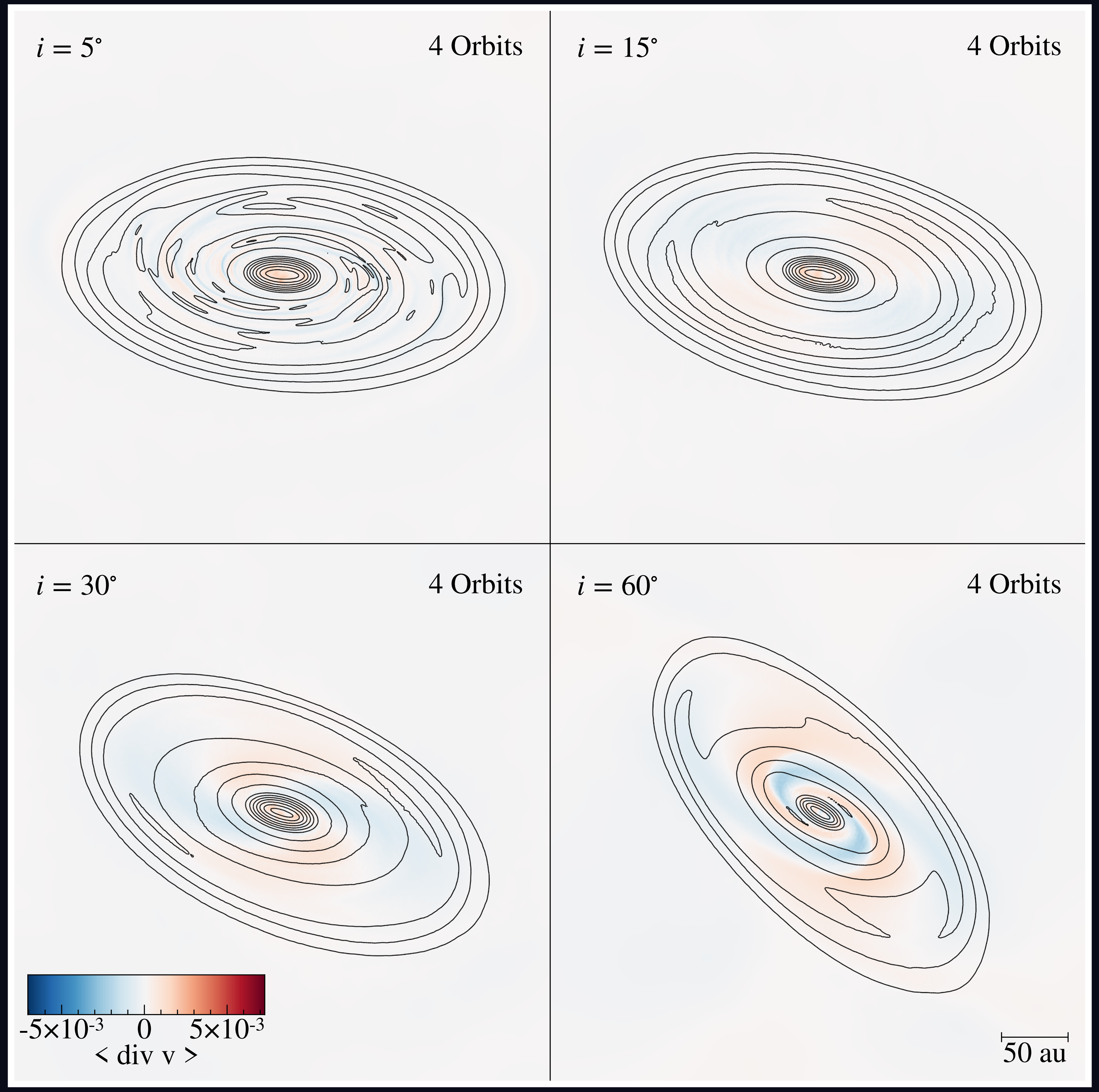

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- *If the warp is strong enough it can push discs into the gravitationally stable regime suppressing spiral structures.*
- *This is due to the oscillating radial pressure gradient induced by the warp which triggers a response in the velocity flow of the disc. This causes the disc to heat up and become gravitationally stable.*
- *In some cases, the disc evolves to form ring & gap structure.*