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Science and Technology Facilities Council

Leading and Trailing Spiral Arms in a Nearly Broken Disc

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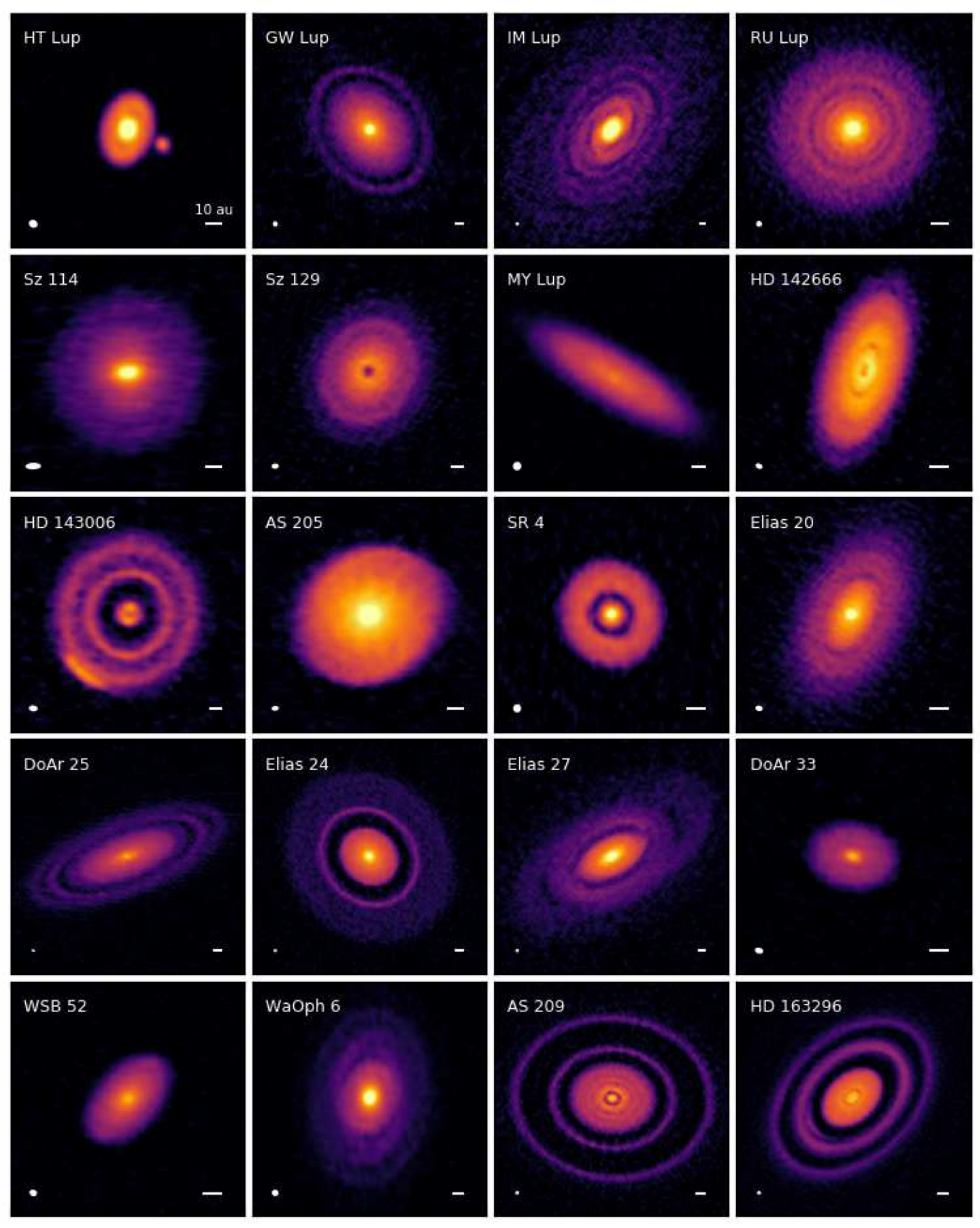
ALMA Observations

- Discs are highly structured.
- The variety of sub-structures also have a variety of explanations.



Andrews+ 2018

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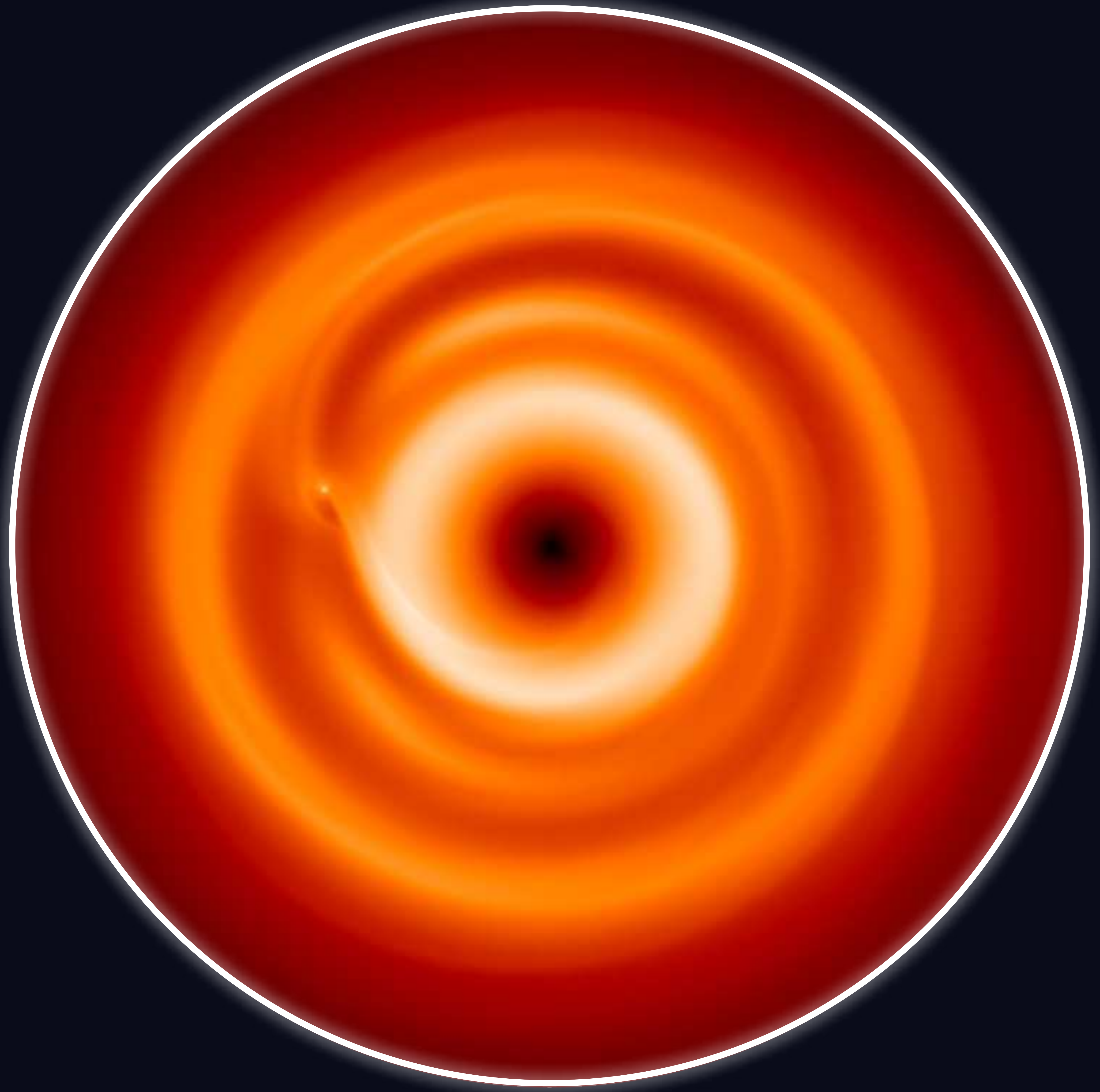
Ring & Gaps: Planets

Massive planets can carve open a gap in the disc.



Spirals: Gravitational Instability

For massive discs, gravitational instabilities occur due to the disc self-gravity.

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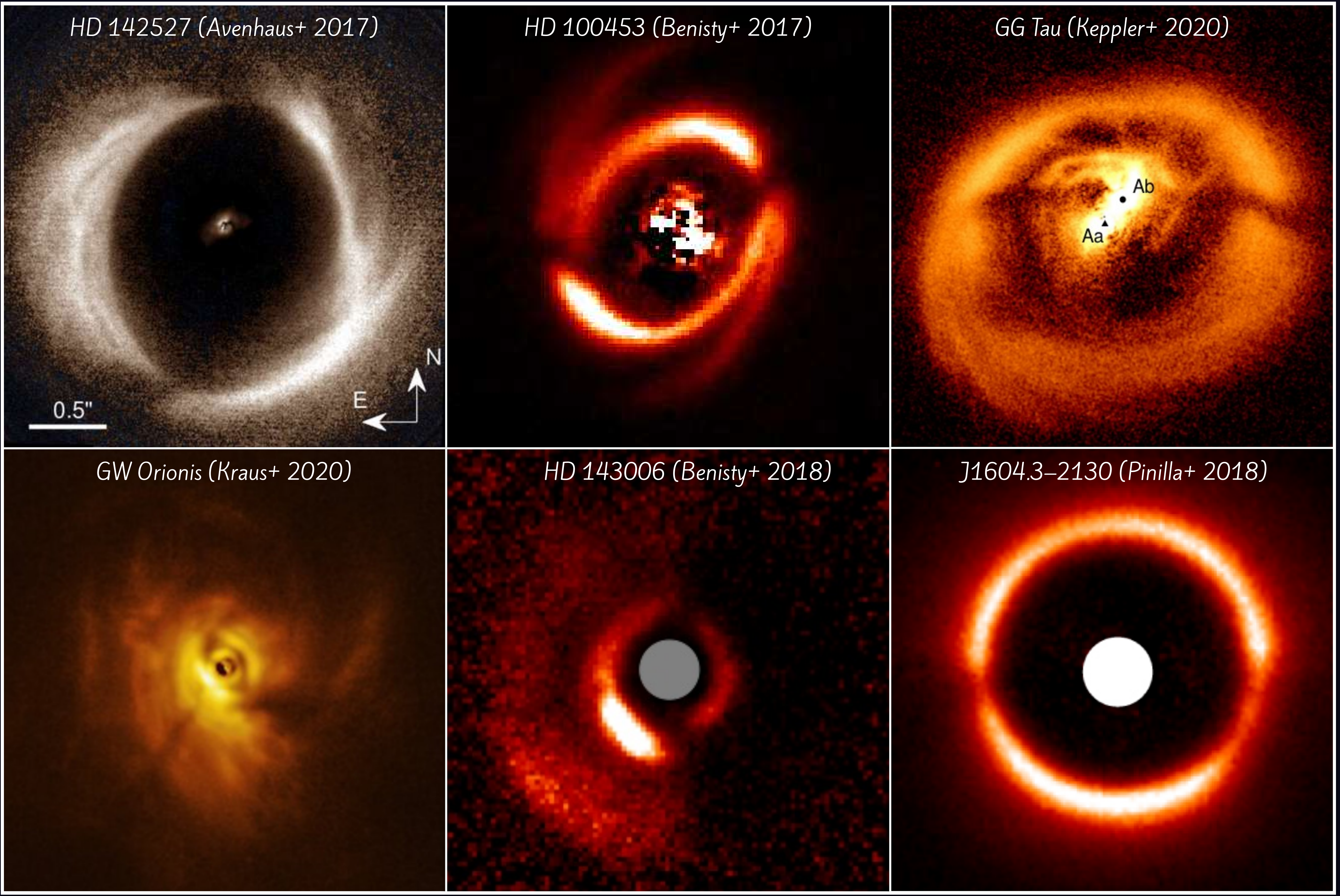
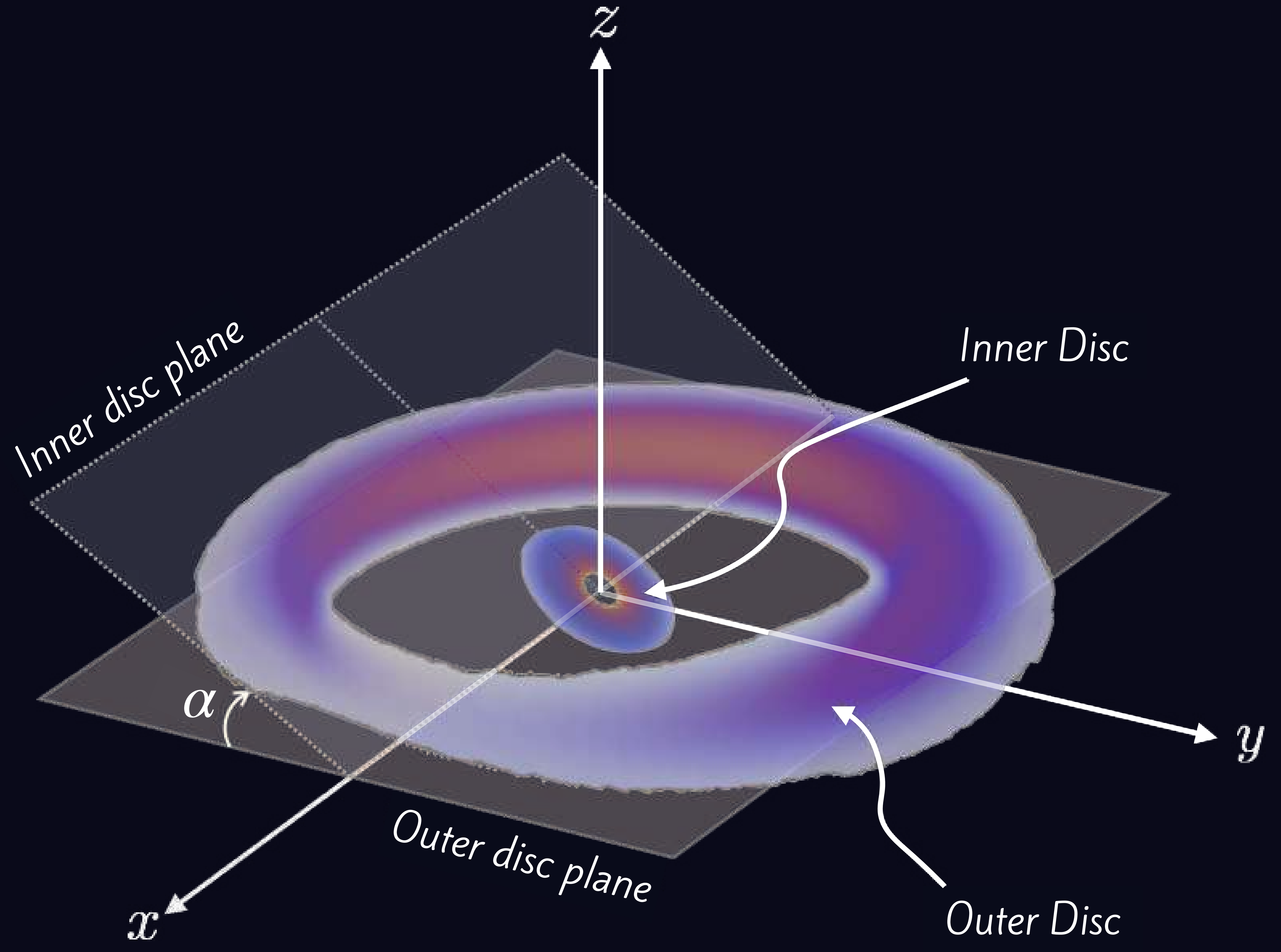
Observations of Shadows



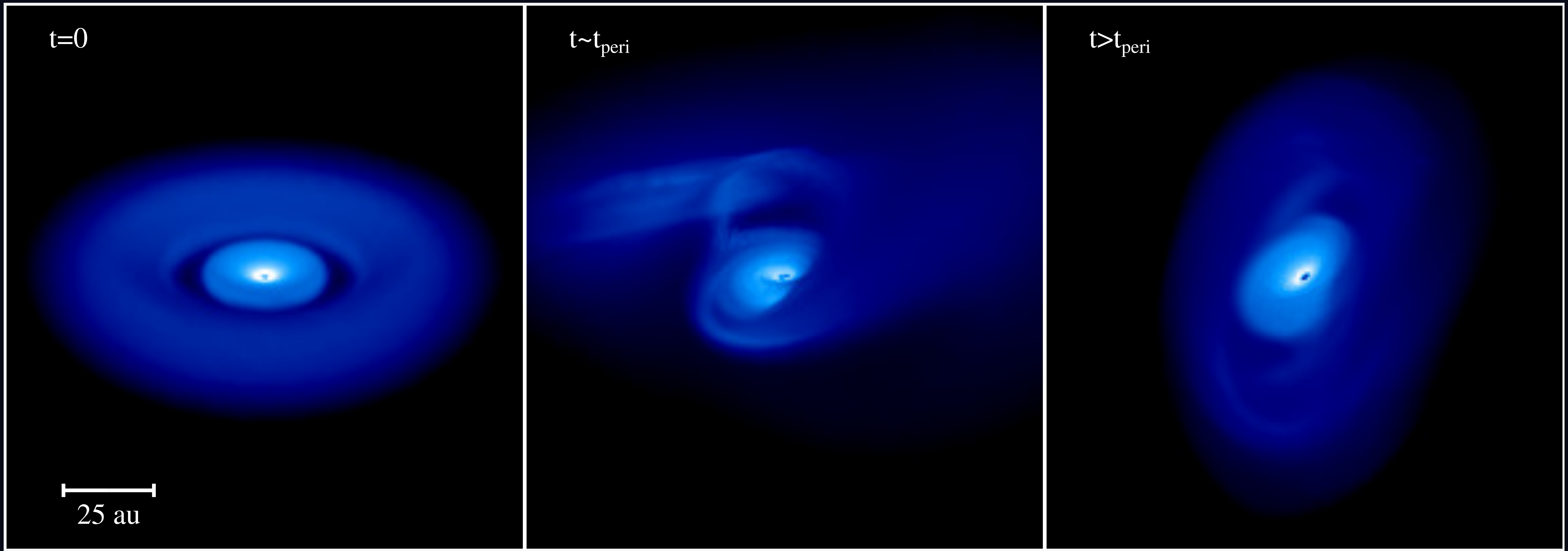
Origin of Shadows

A misaligned inner disc casts a shadow onto the outer disc.



Marino+ 2015

Flyby Induced Misalignment



Nealon+ 2020

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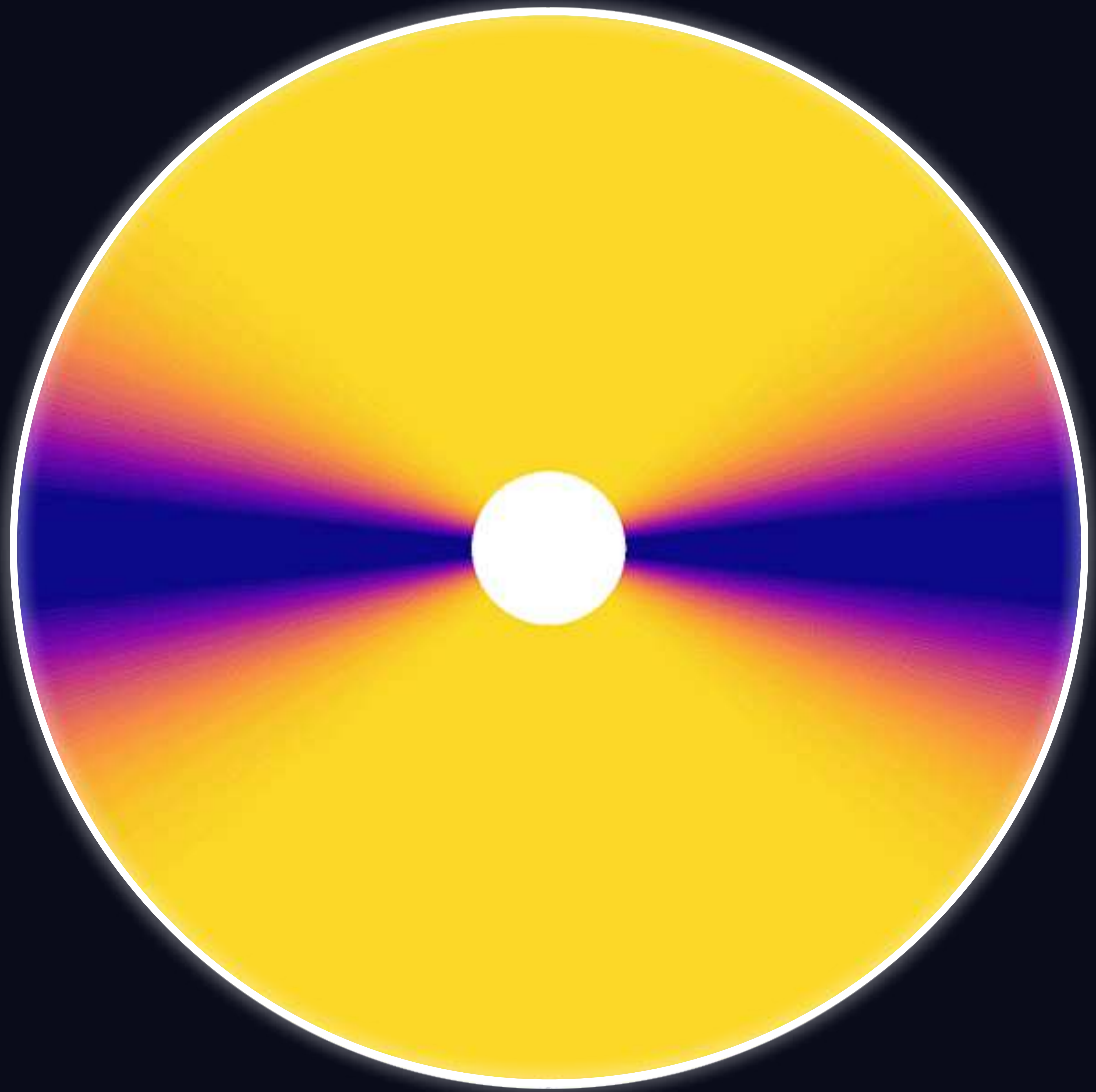
Shadows can also create spirals

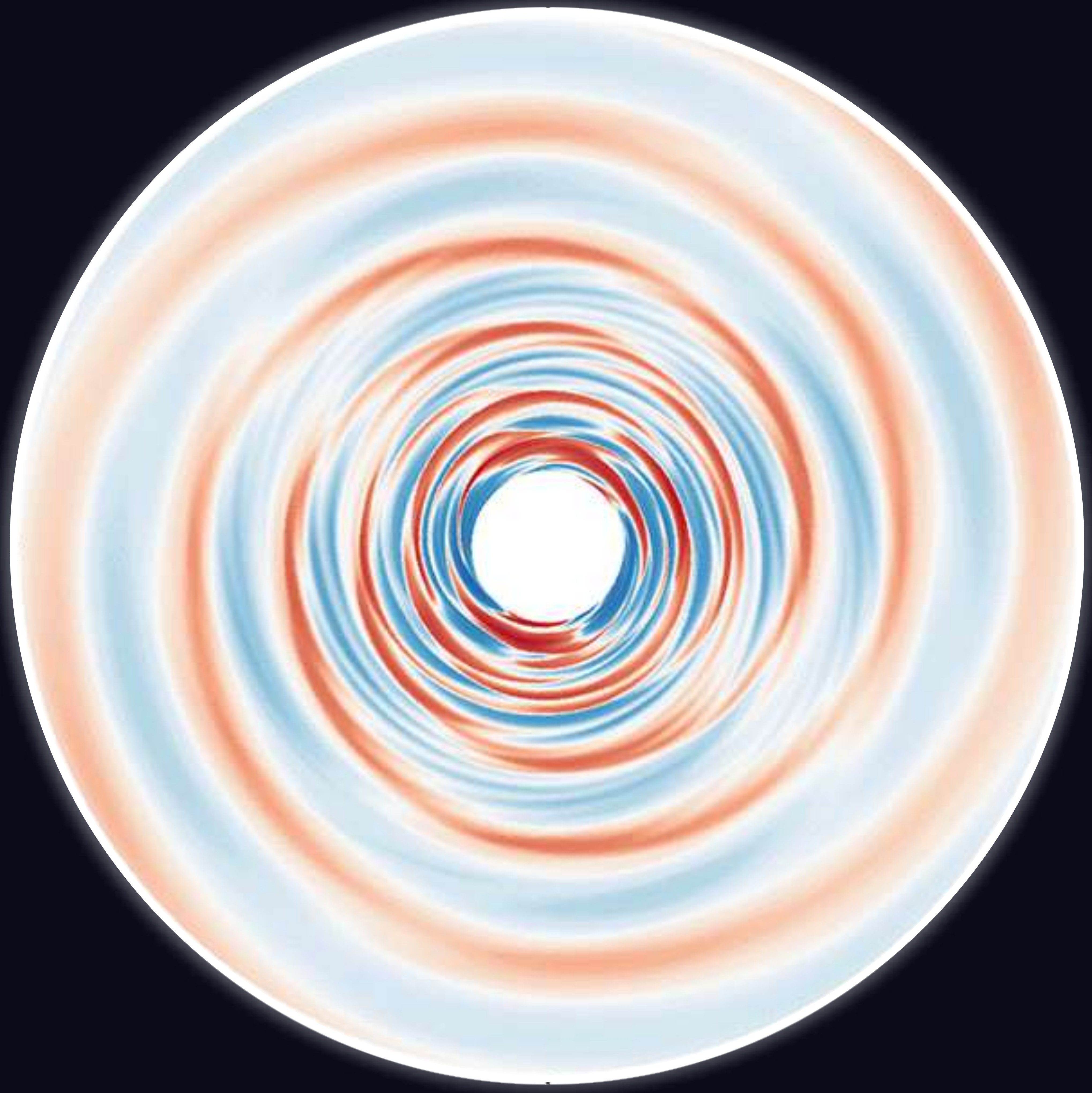
Temperature



Su+ 2024

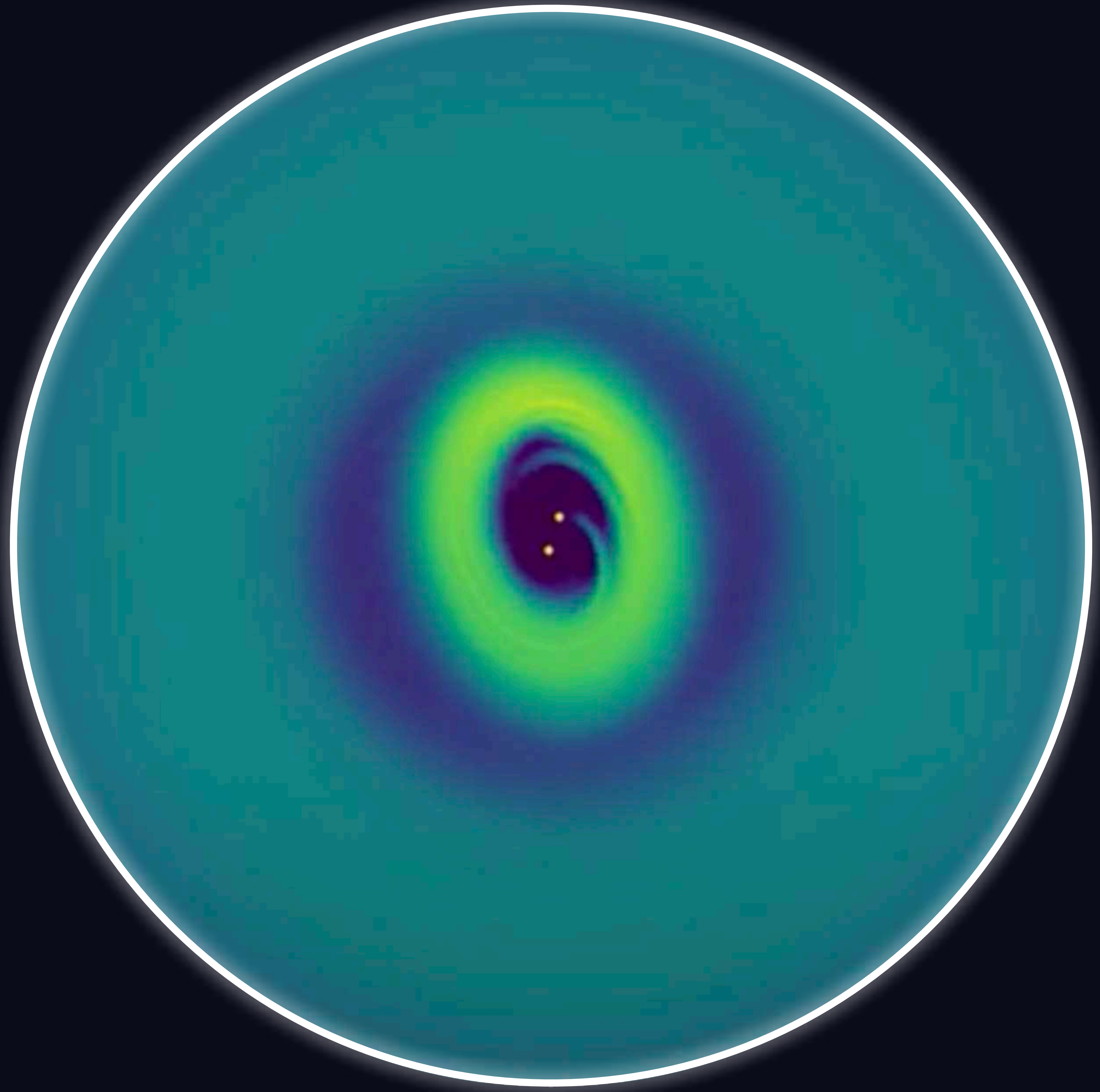
Shadows can also create spirals

Surface Density



Su+ 2024

But when the hydrodynamics of the inner disc is included, spirals were not seen.



Nealon+ 2020

Misaligned Circumbinary Discs

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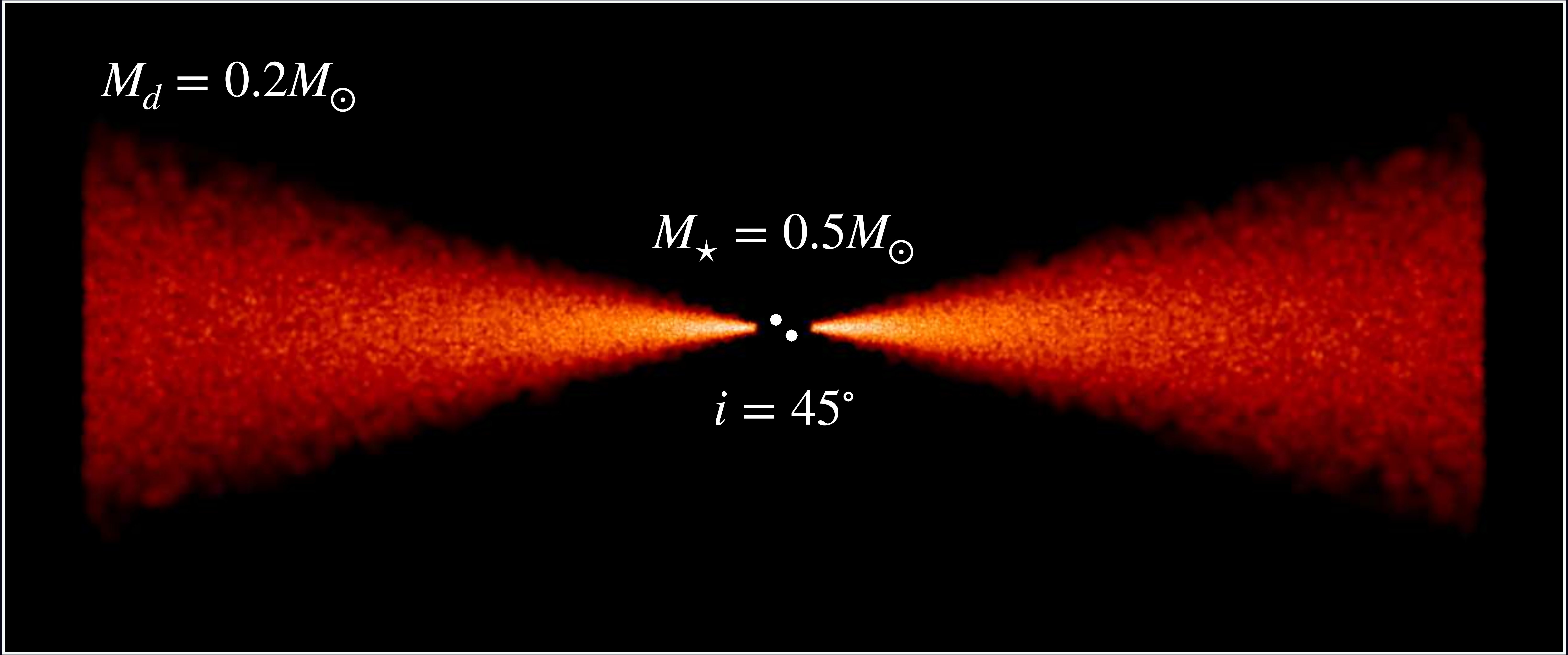
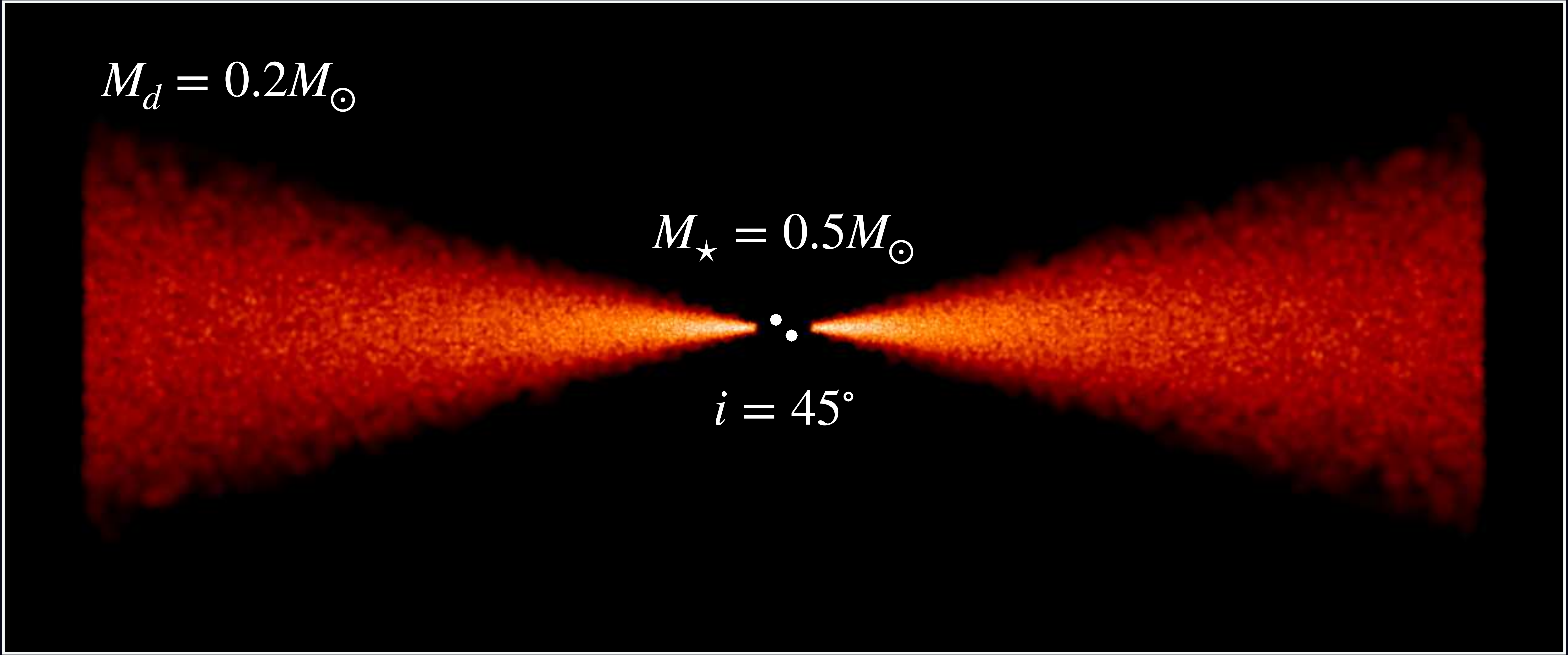
Initial Disc Setup

PHANTOM

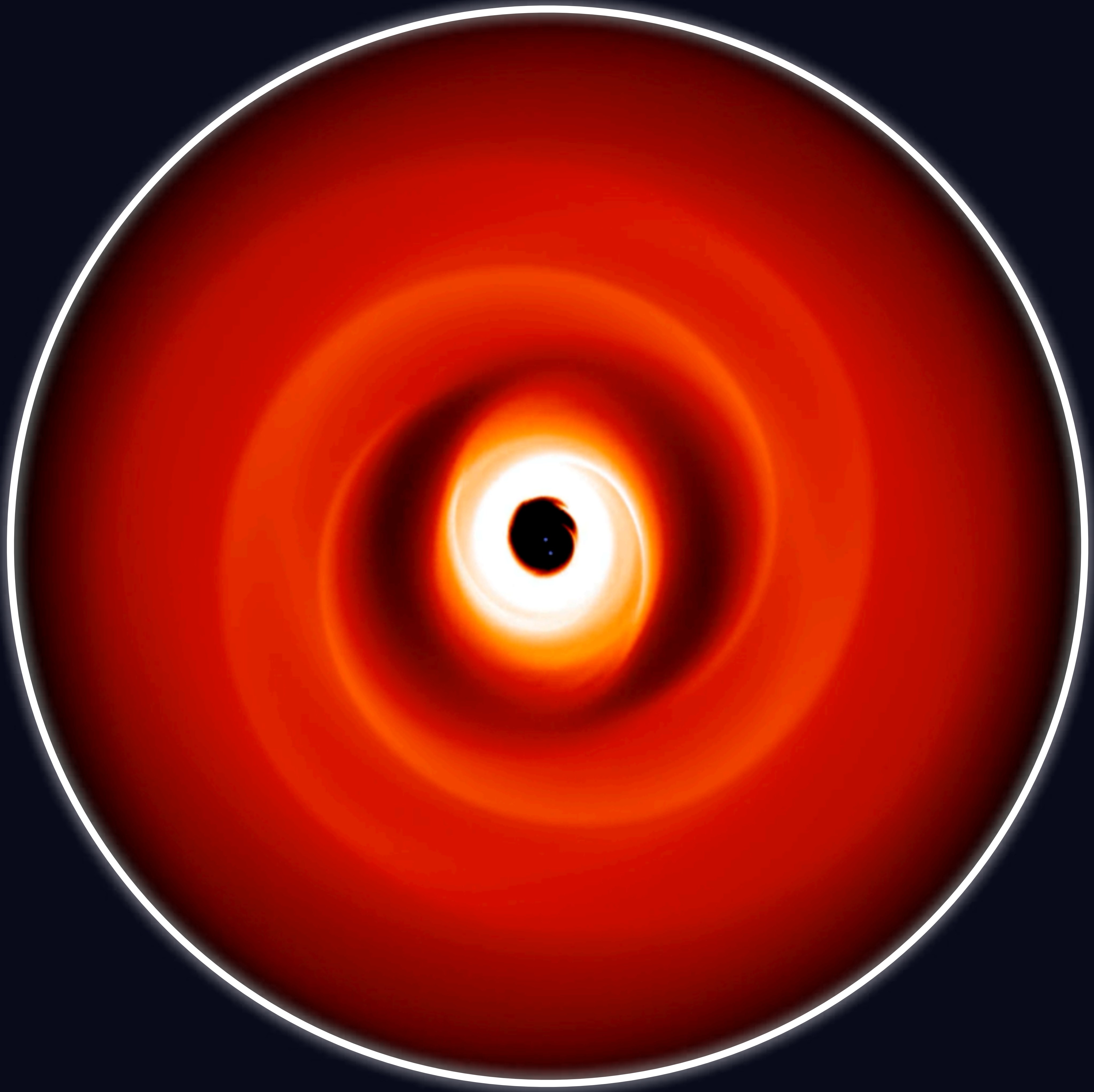


Initial Disc Setup



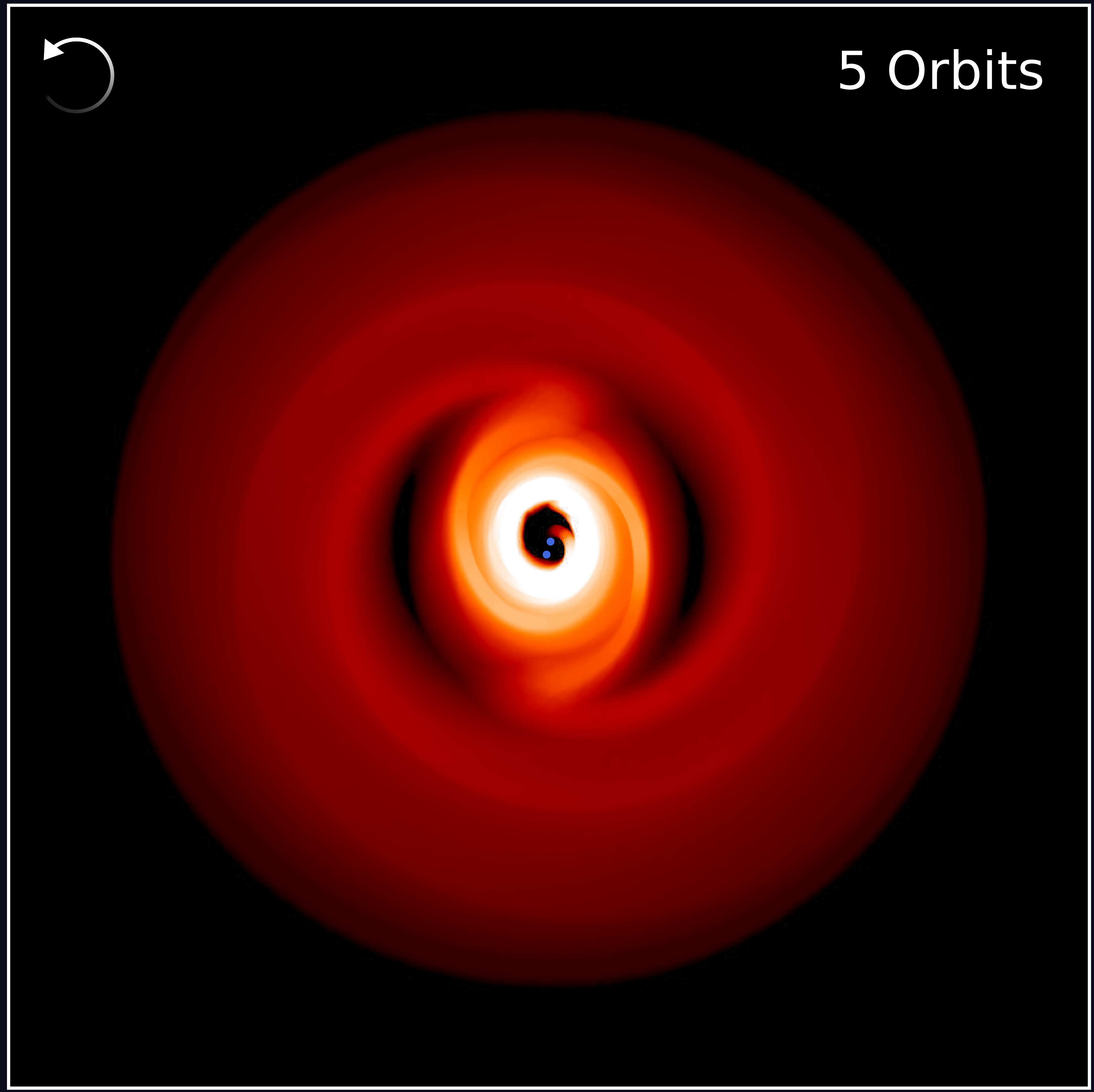
Isothermal, and without self-gravity

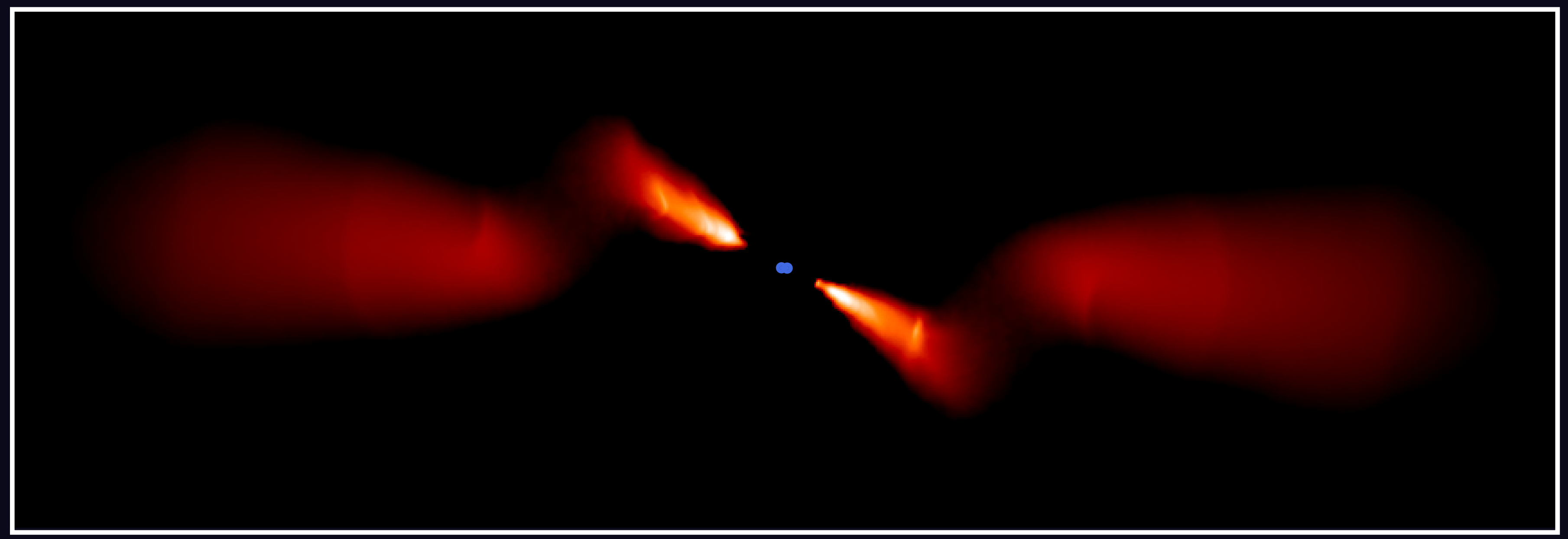
The Formation of Leading Spiral Arms



A Misaligned Disc

Leading spiral arms are launched where the misaligned inner disc connects to the outer disc.





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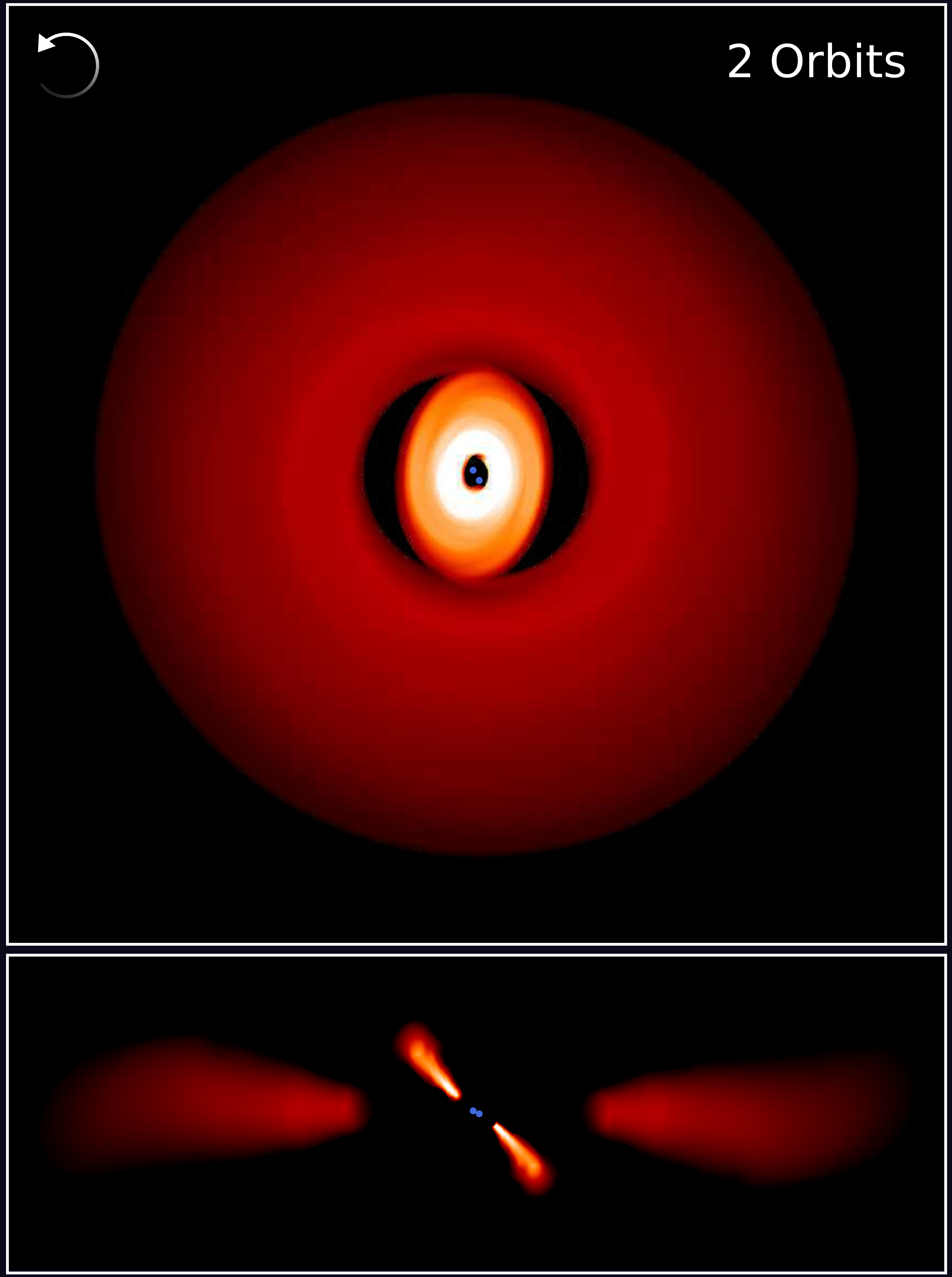
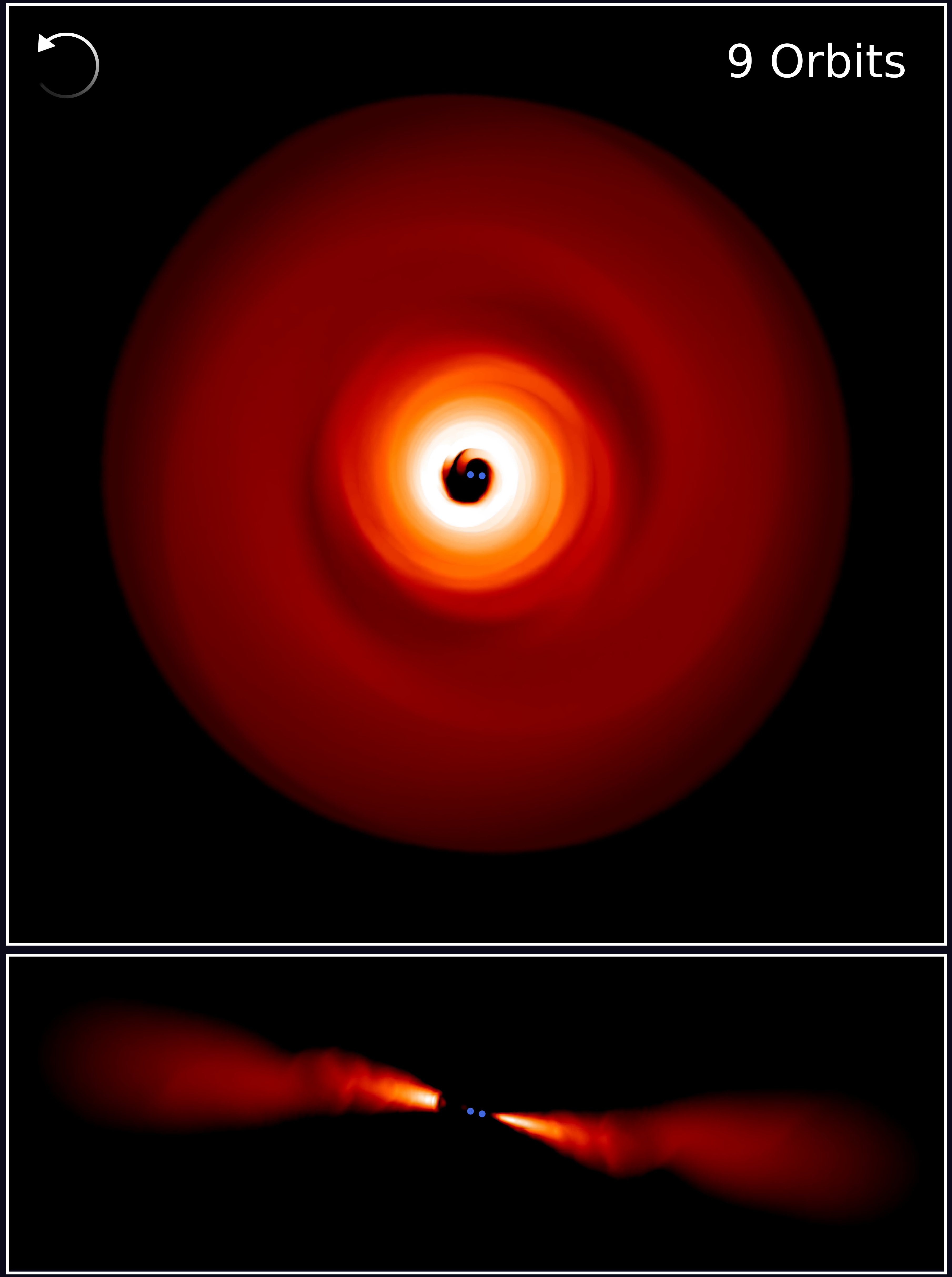
A Broken Disc

The inner and outer disc are disconnected. Hence, there are no leading spiral arms.



An Aligned Disc

The two connecting nodes no longer exist. Hence the leading spirals also disappear.



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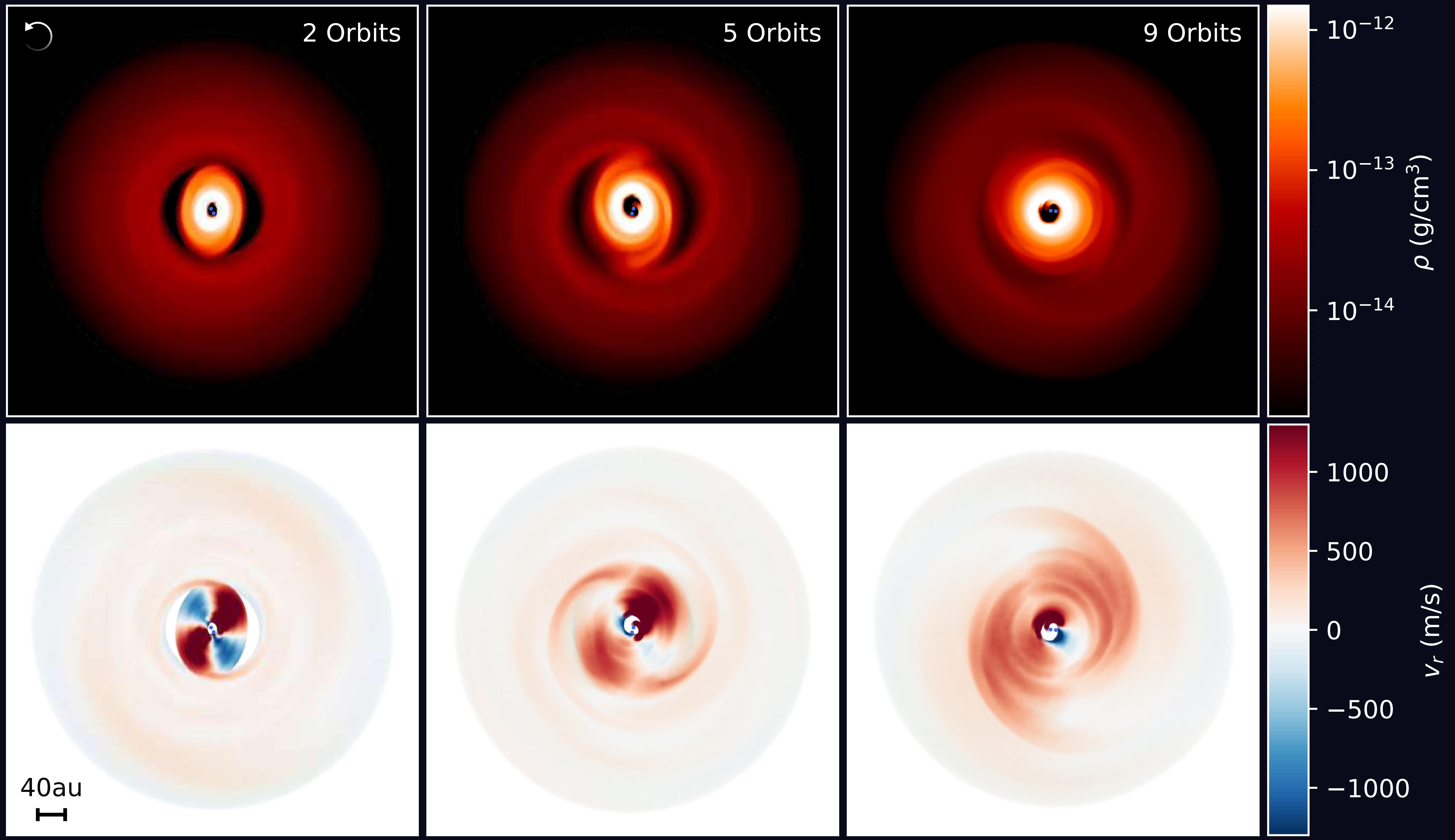
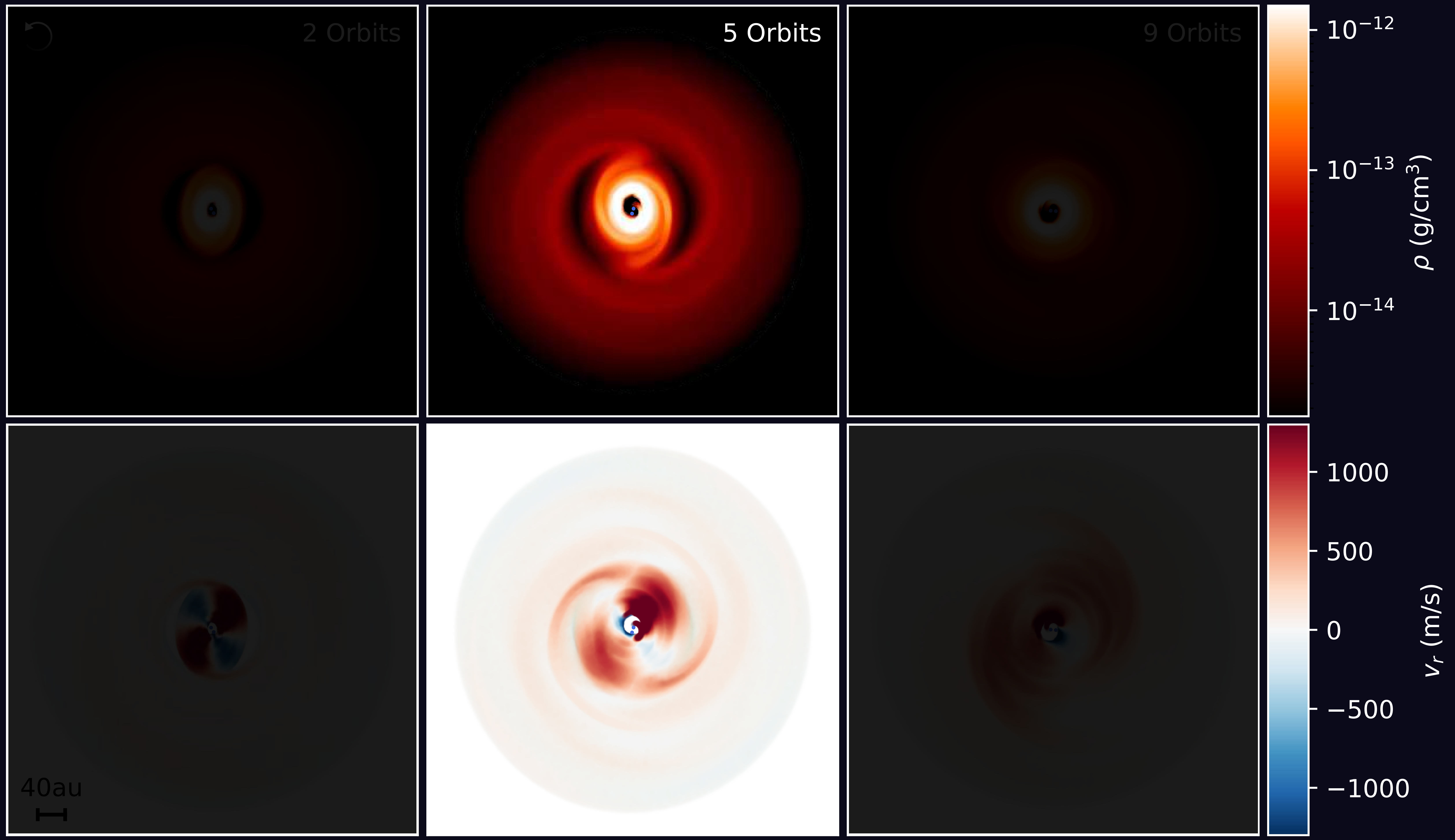
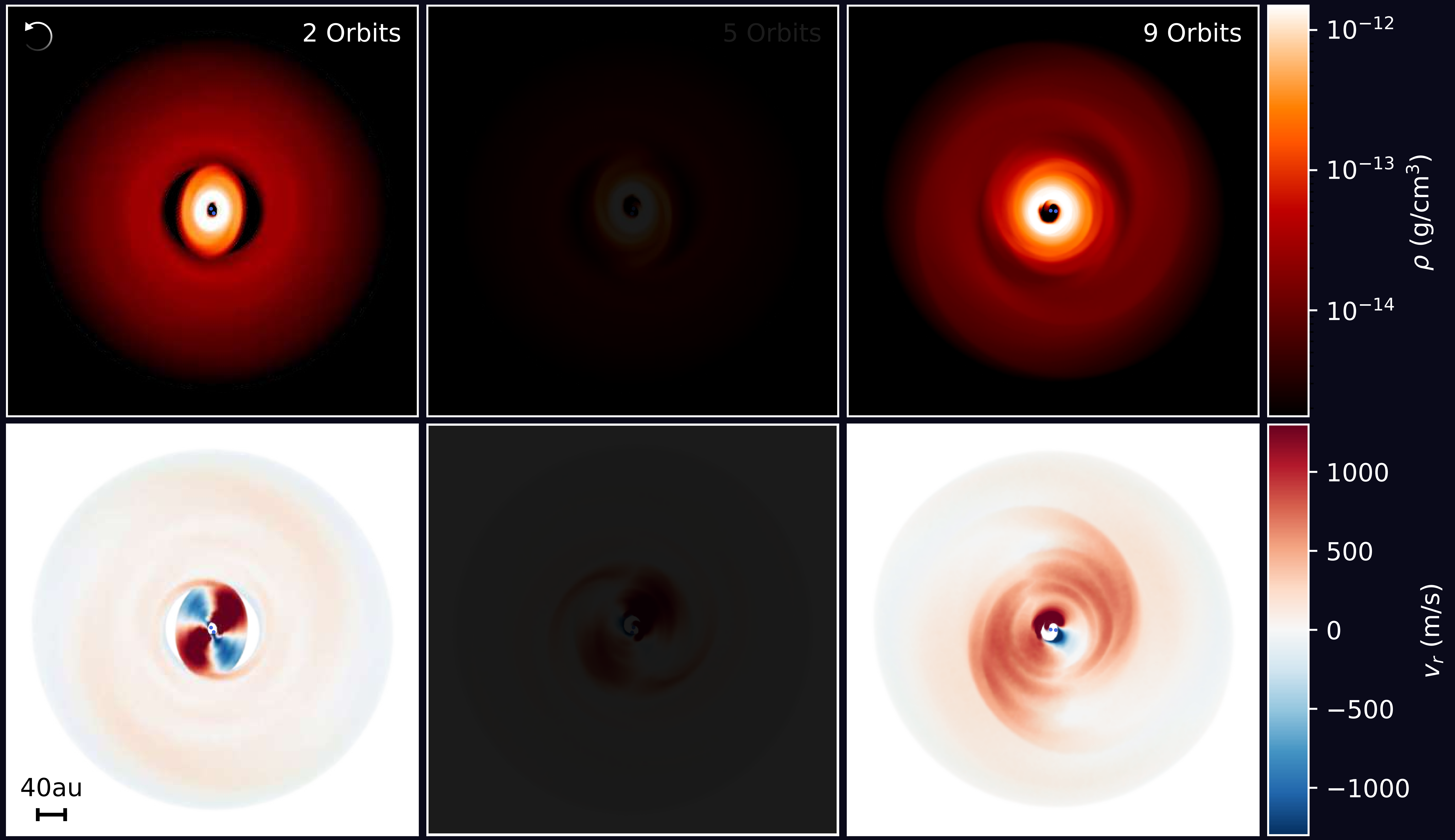
The Velocity Structure



The Velocity Structure



The Velocity Structure



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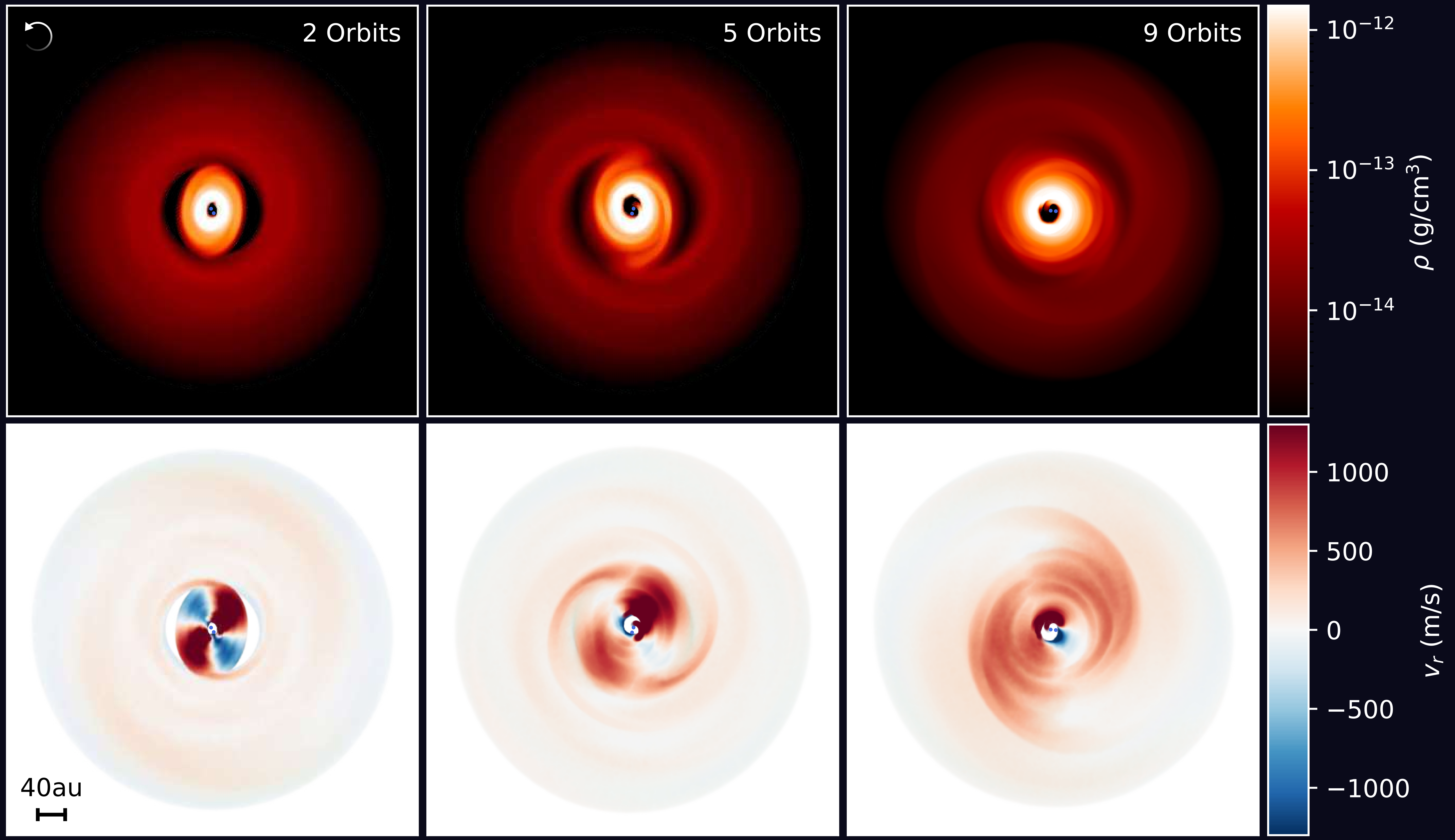
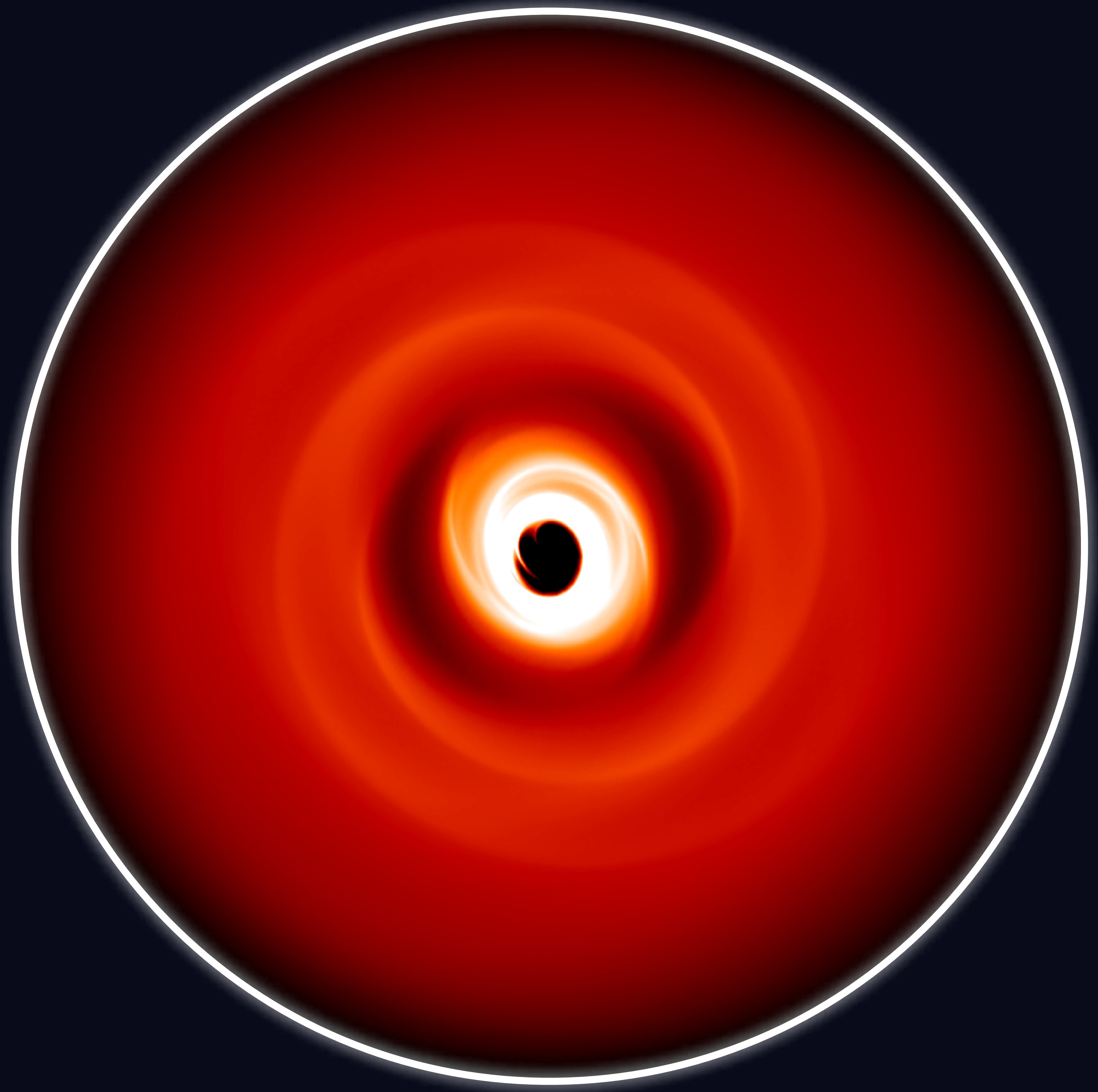
The Velocity Structure



Calculating the Relative Disc Misalignment

$$\theta = \cos^{-1}\left(\hat{\boldsymbol{\ell}}_{\mathrm{inner}} \cdot \hat{\boldsymbol{\ell}}_{\mathrm{outer}}\right)$$

Unit angular momentum vector



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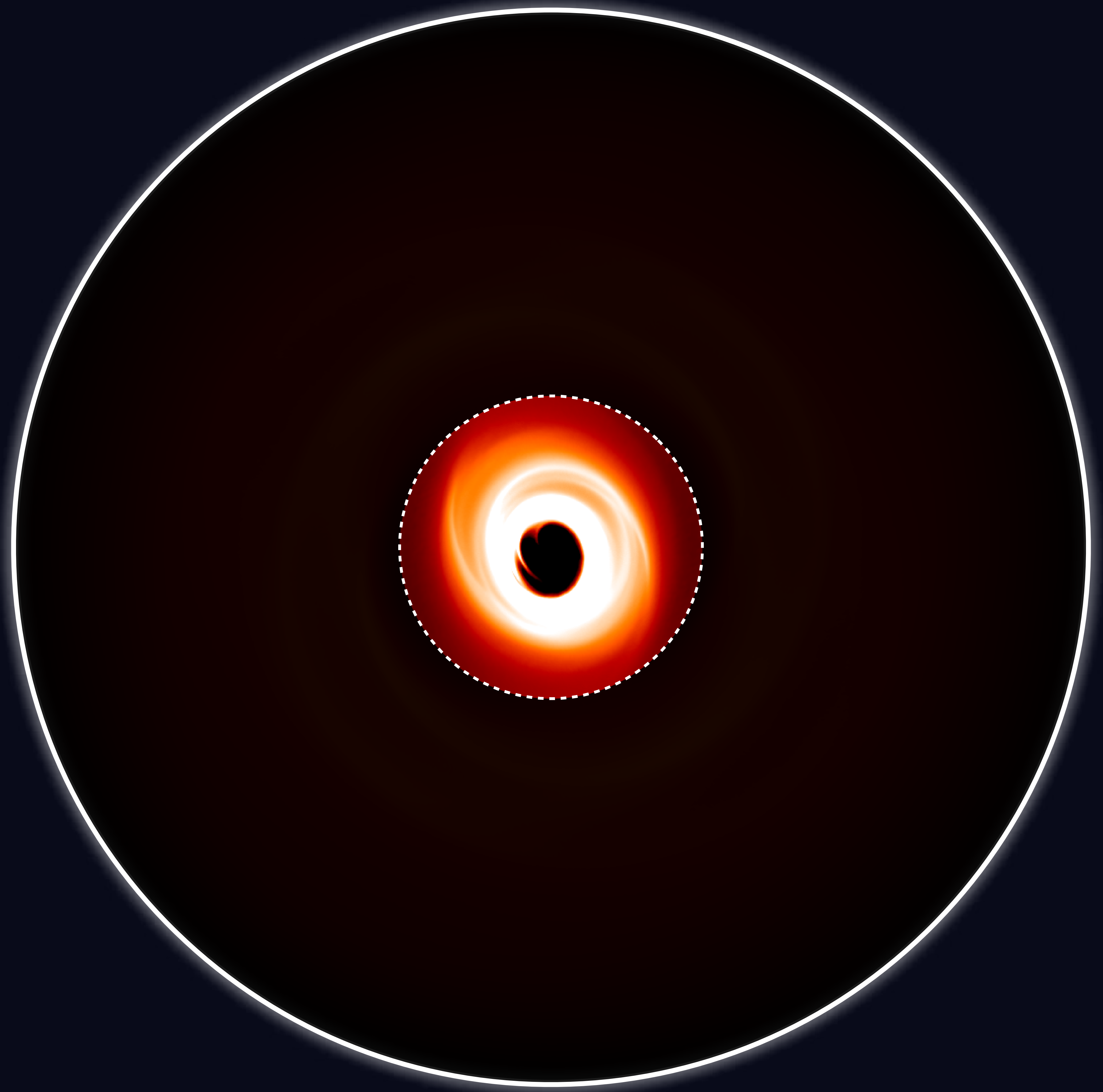

Calculating the Relative Disc Misalignment

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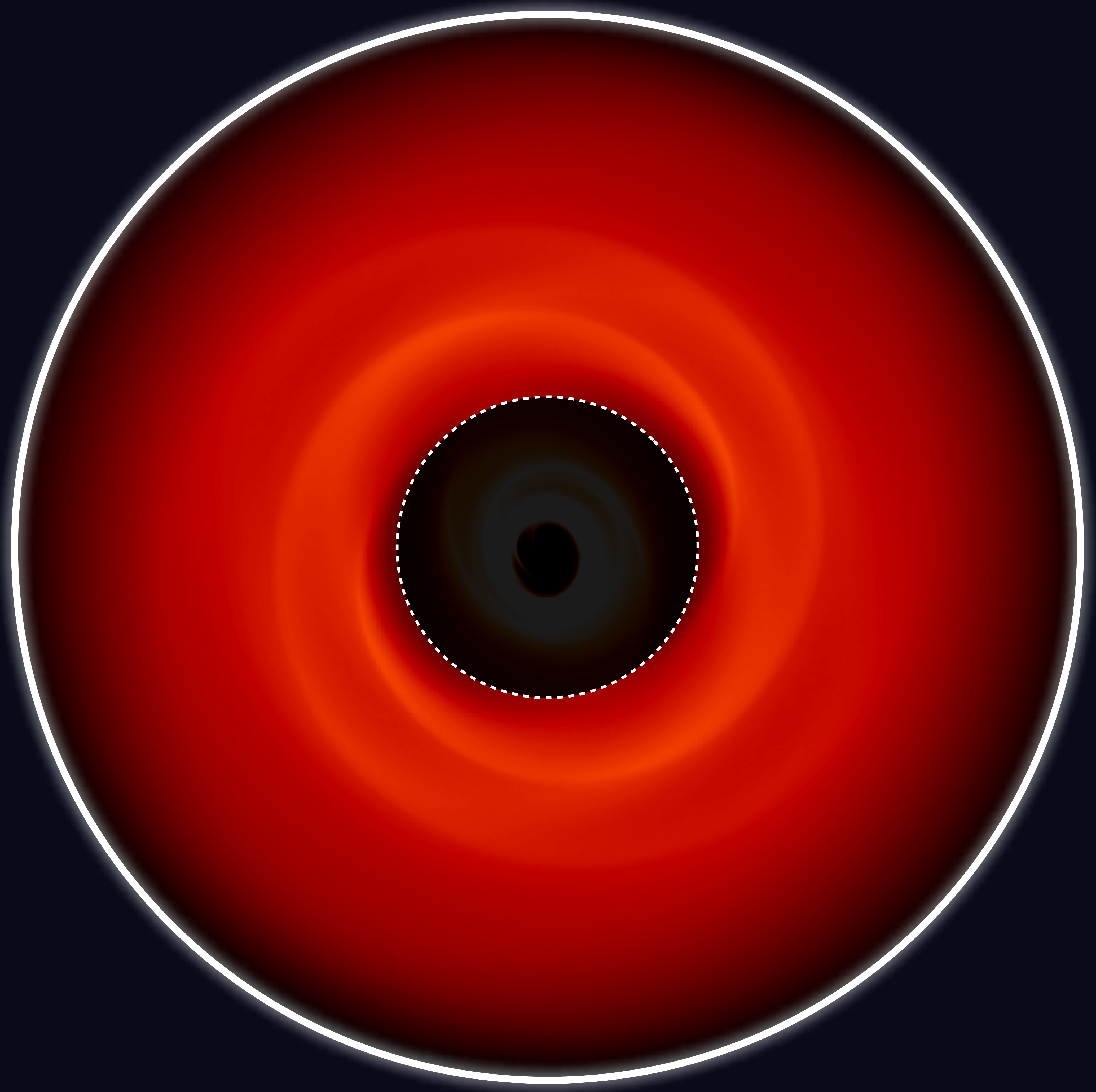
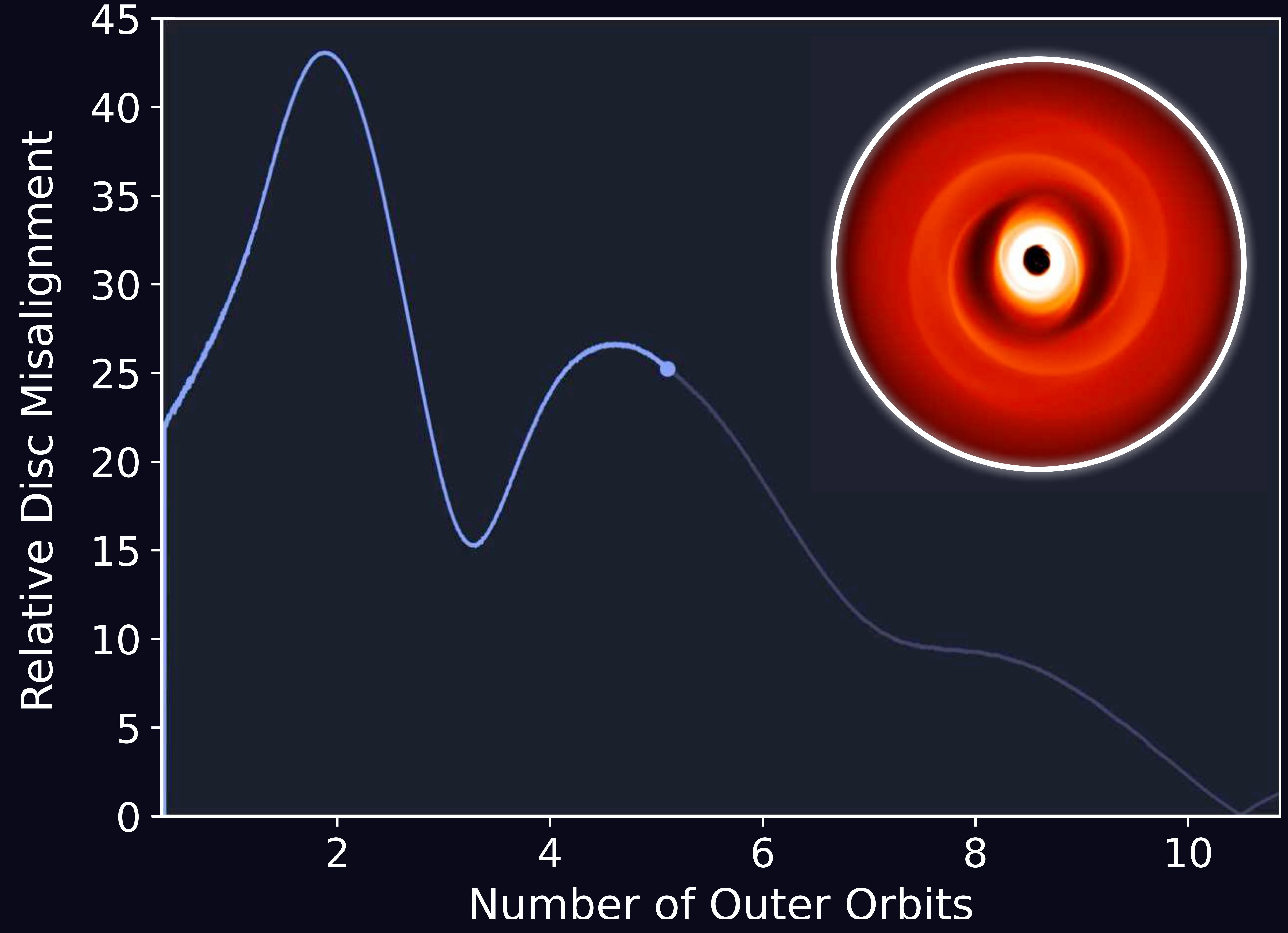
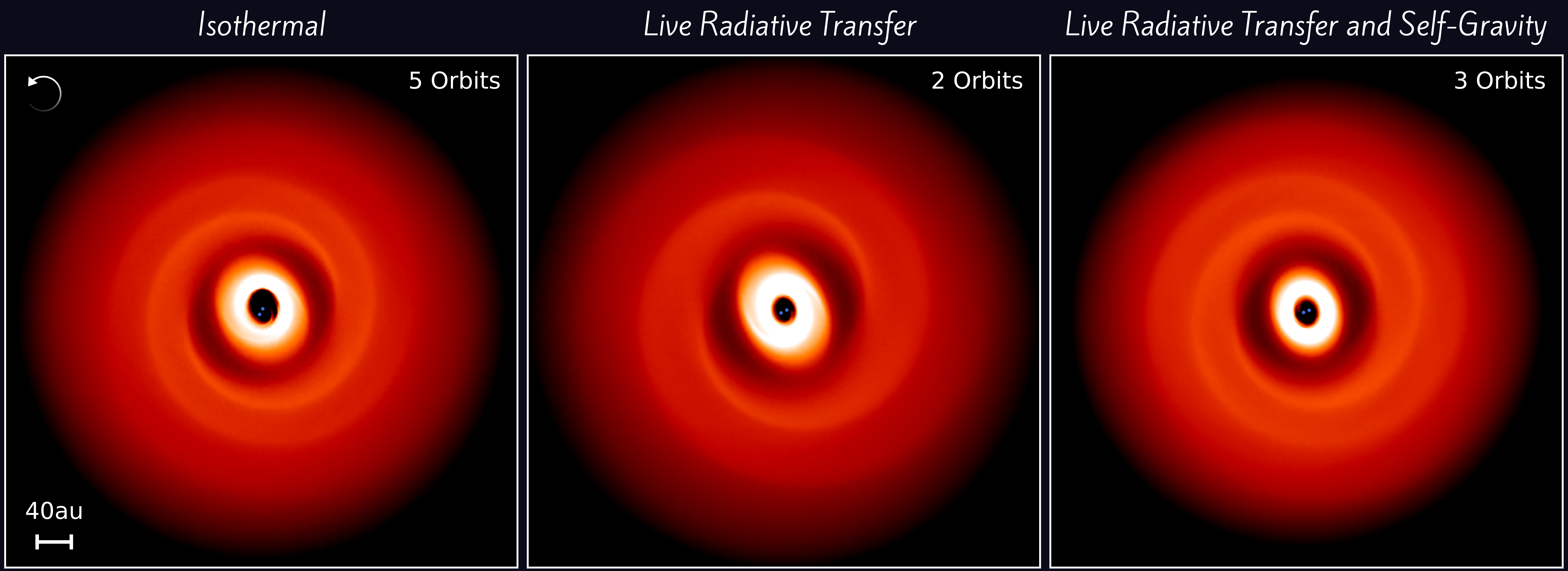


When do leading spirals form?

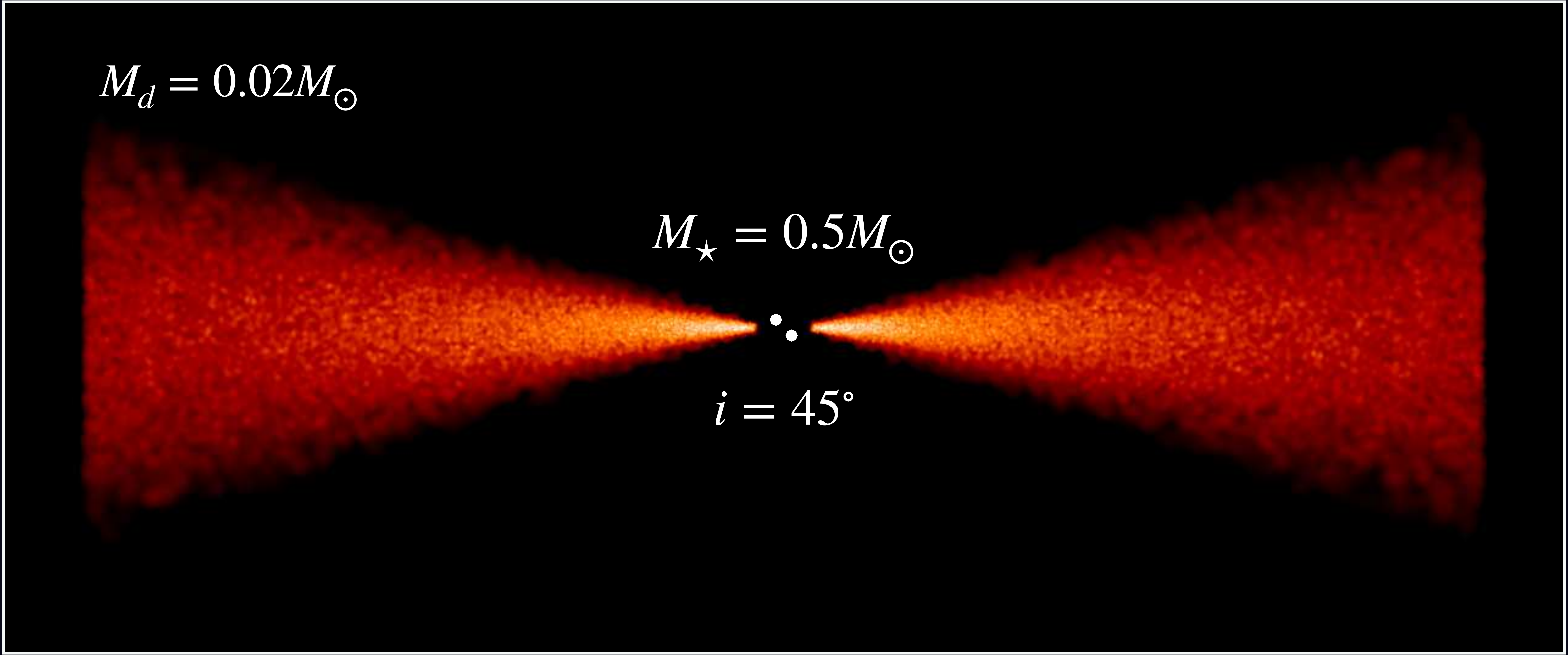


Leading Spirals are Independent of Disc Physics



A Lower Disc Mass

Initial Disc Setup



With live radiative transfer

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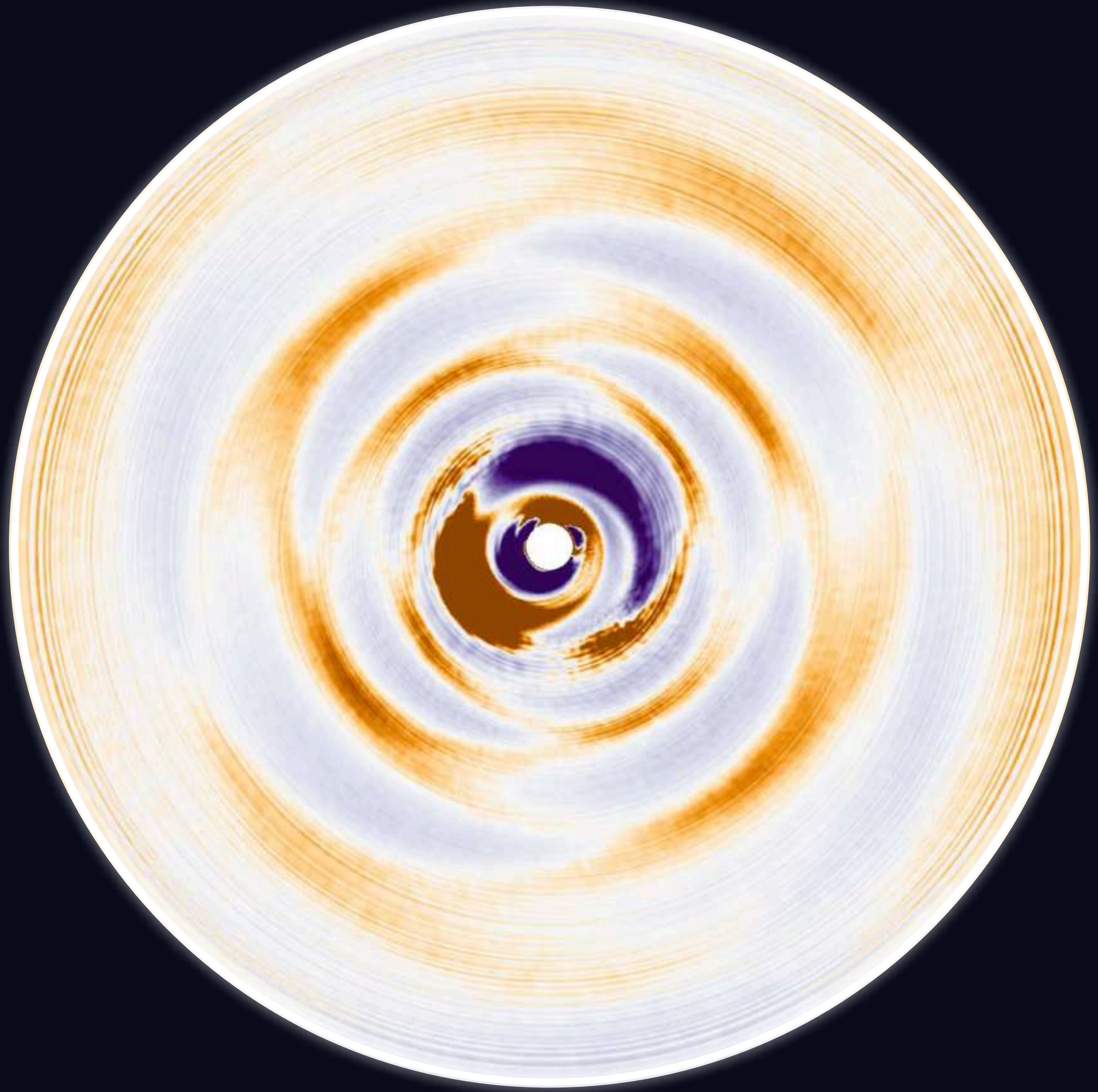
The Formation of Leading & Trailing Spiral Arms

$\Sigma/\bar{\Sigma}$



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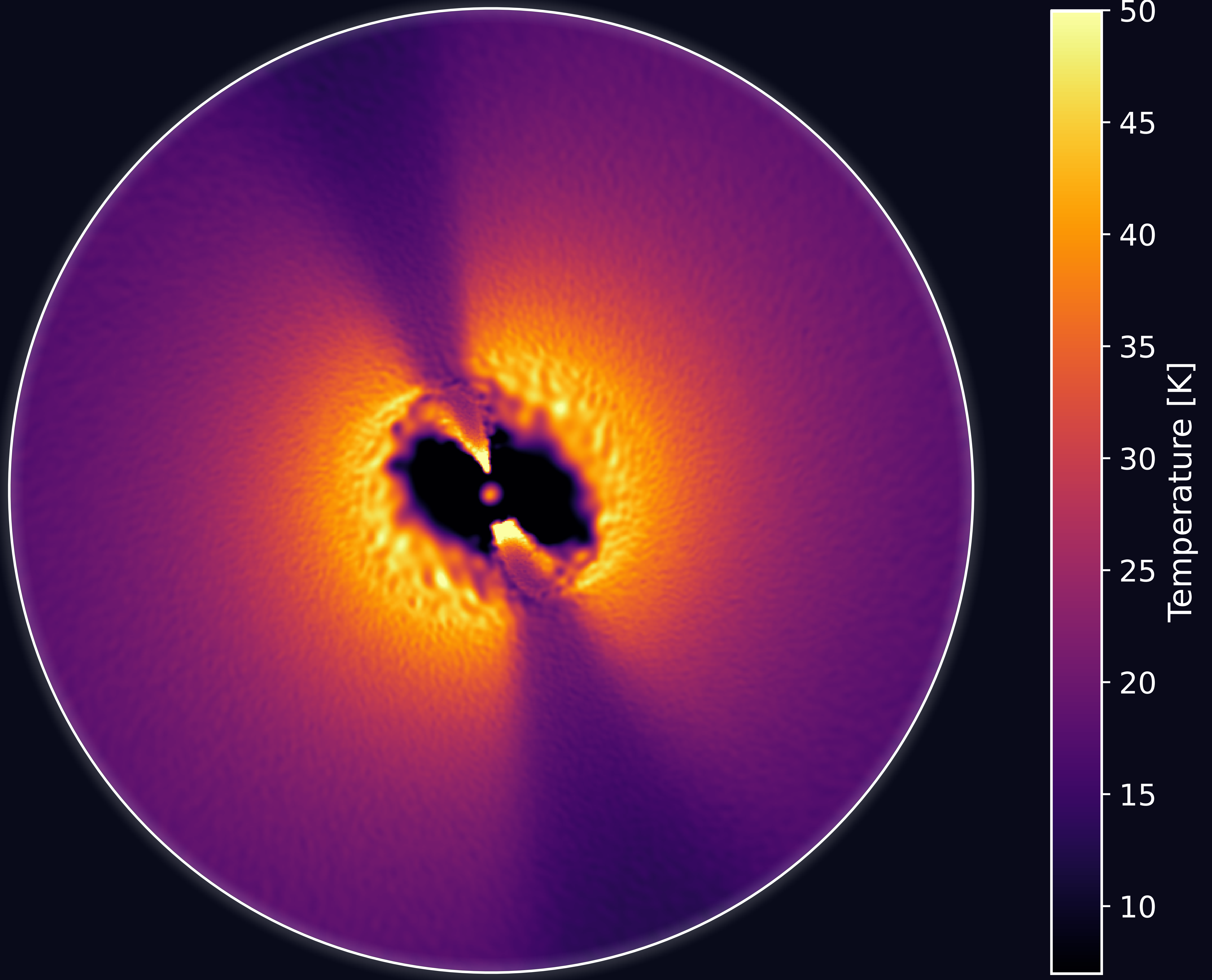
Shadows



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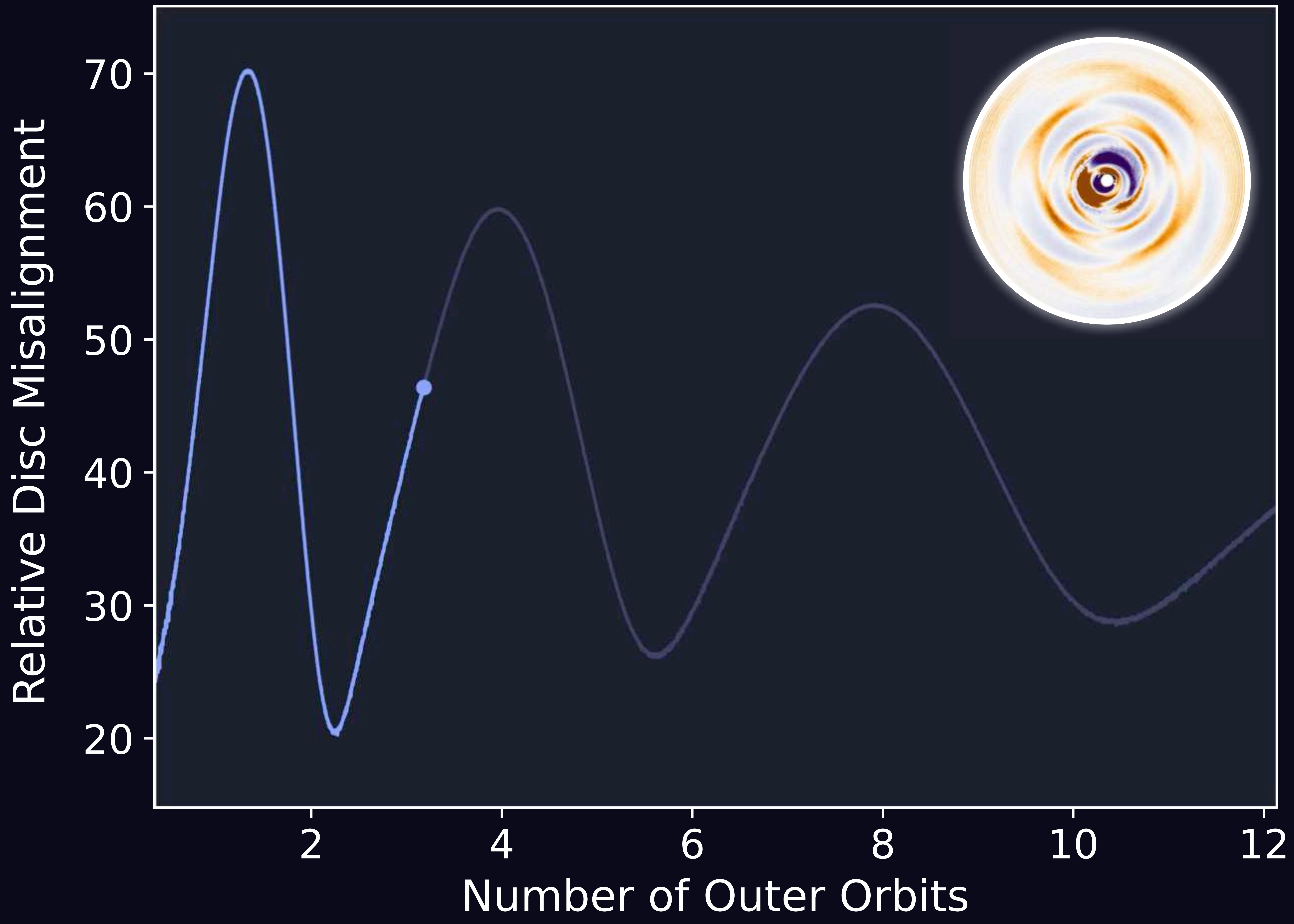
When are trailing spirals seen?



Leading Spirals

Due to the dynamics of the inner and outer disc at moderate misalignments

Trailing Spirals

Due to shadows cast by a highly misaligned inner disc

Conclusions

- *In a misaligned cicumbinary disc, there are two mechanisms that can generate spiral structures.*

- *At moderate misalignments, the inner disc remains connected to the outer disc at two nodes from which leading spirals are formed.*

- *Shadows are able to launch trailing spirals when the inner disc is disconnected from the outer disc.*

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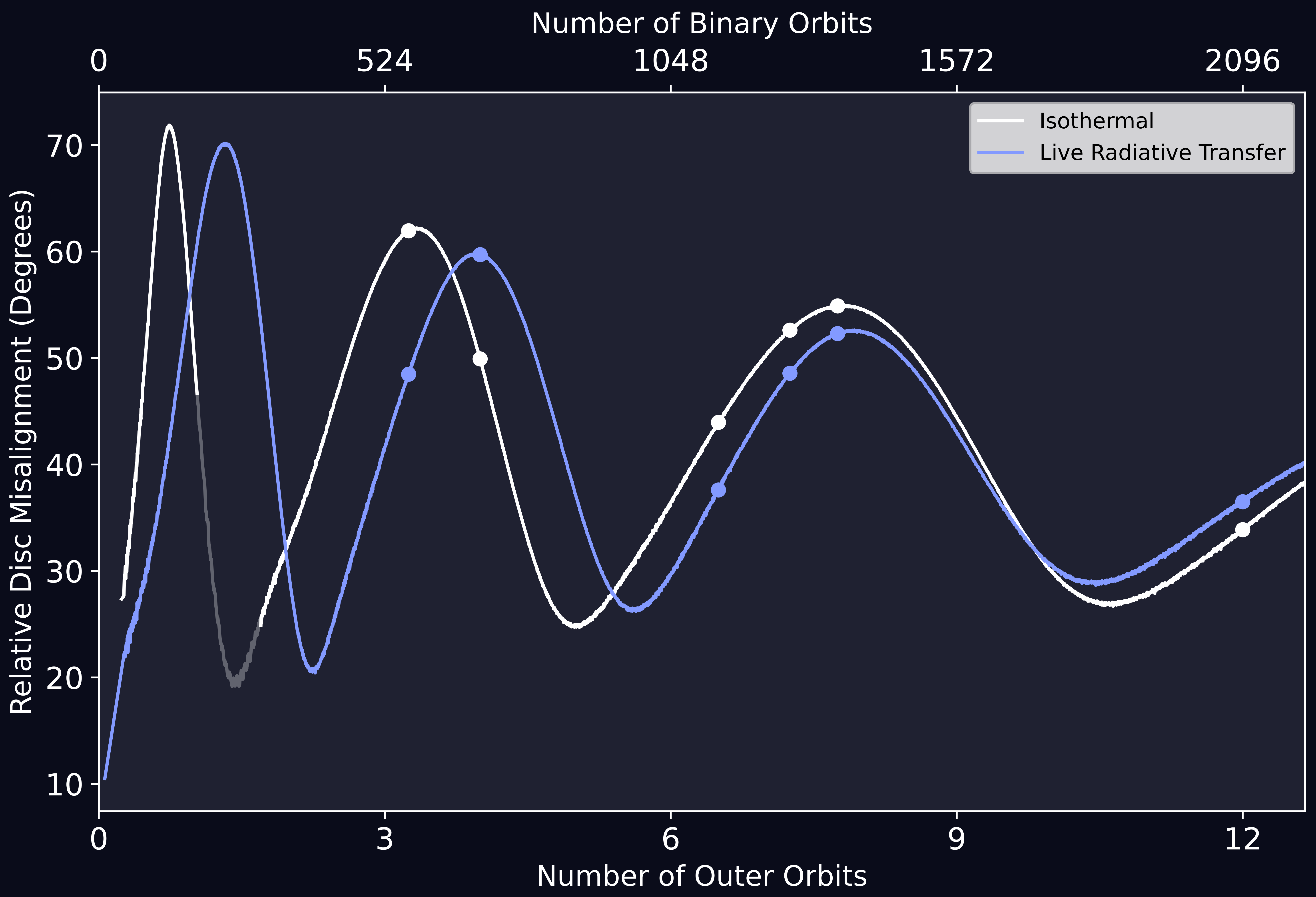
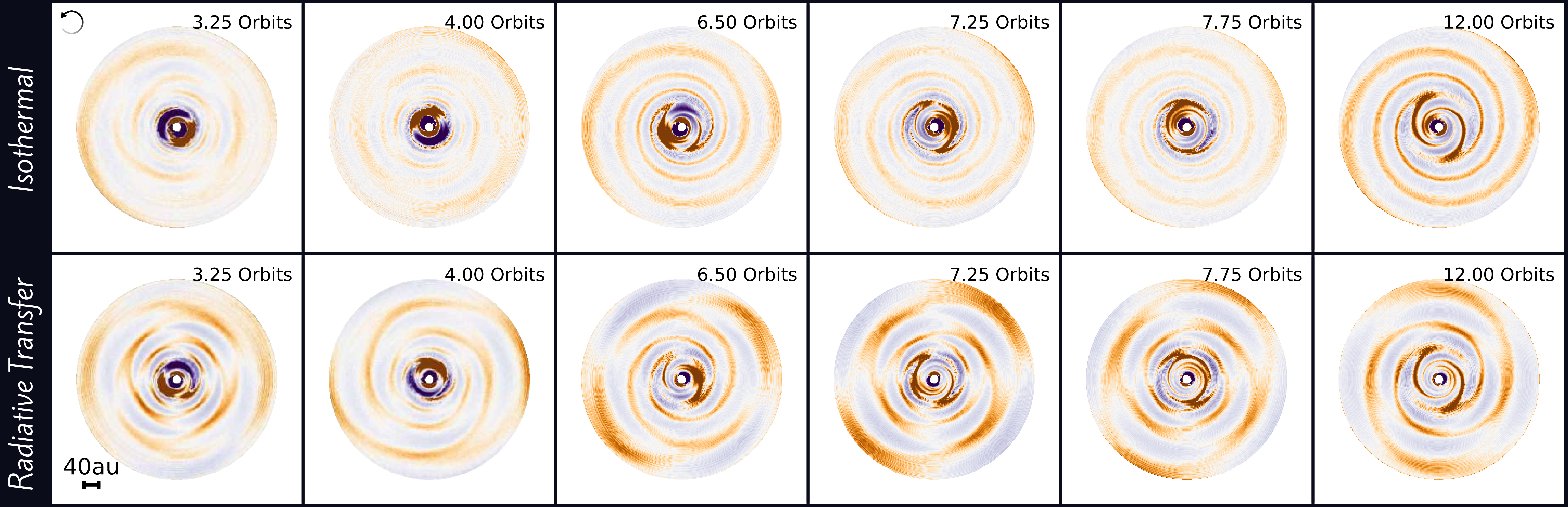
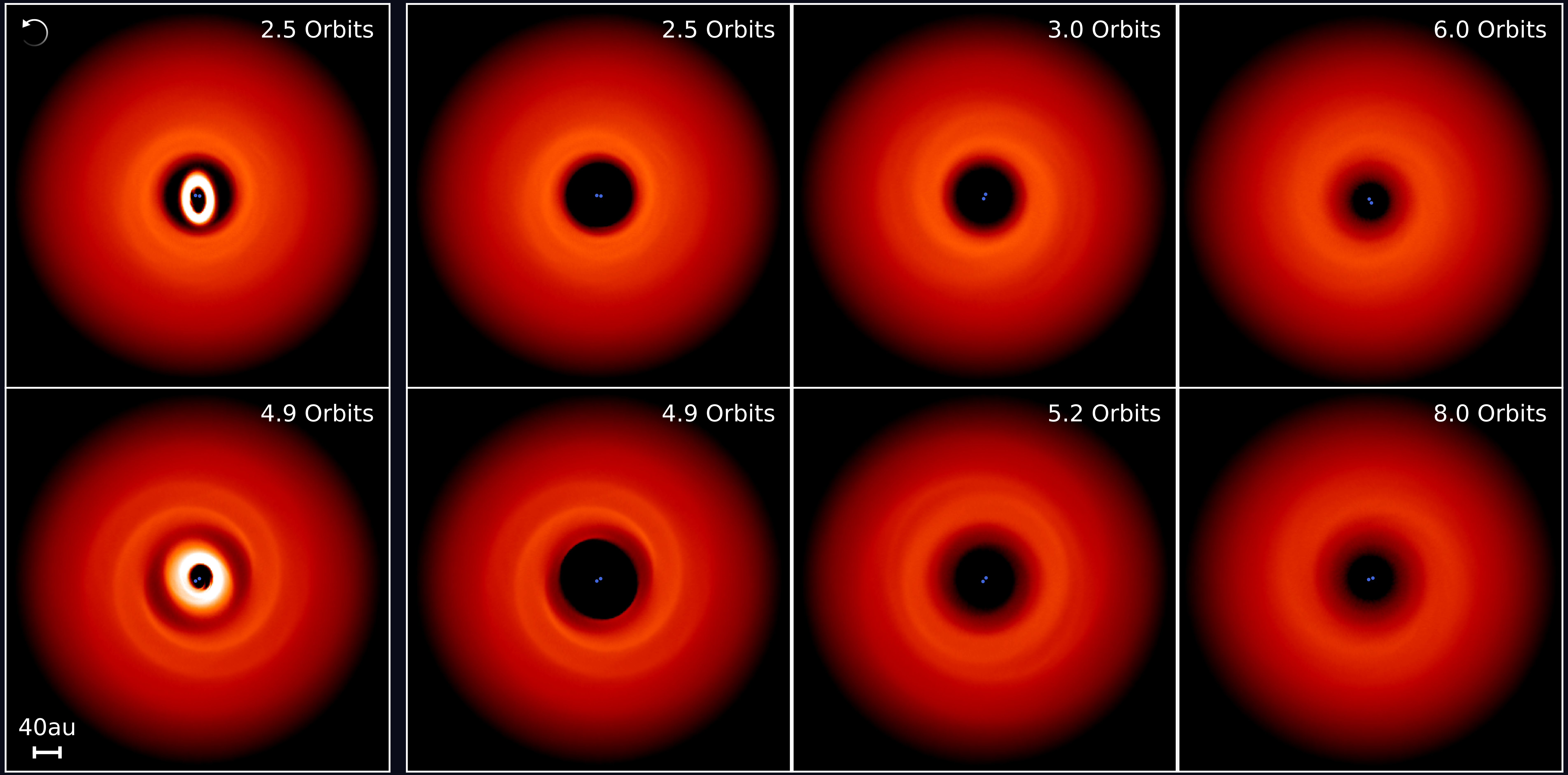
Similar evolution of the relative disc misalignment



No trailing spirals in the isothermal simulation



Removing the inner disc



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Resolution Test

The formation of leading spirals is consistent