Symbiotics Stars, Prague - June 2024

DRIVING ASYMMETRIC RED SUPERGIANT WINDS WITH BINARY INTERACTION

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OF MATHEMATICS
AND PHYSICS
Charles University

Red supergiants

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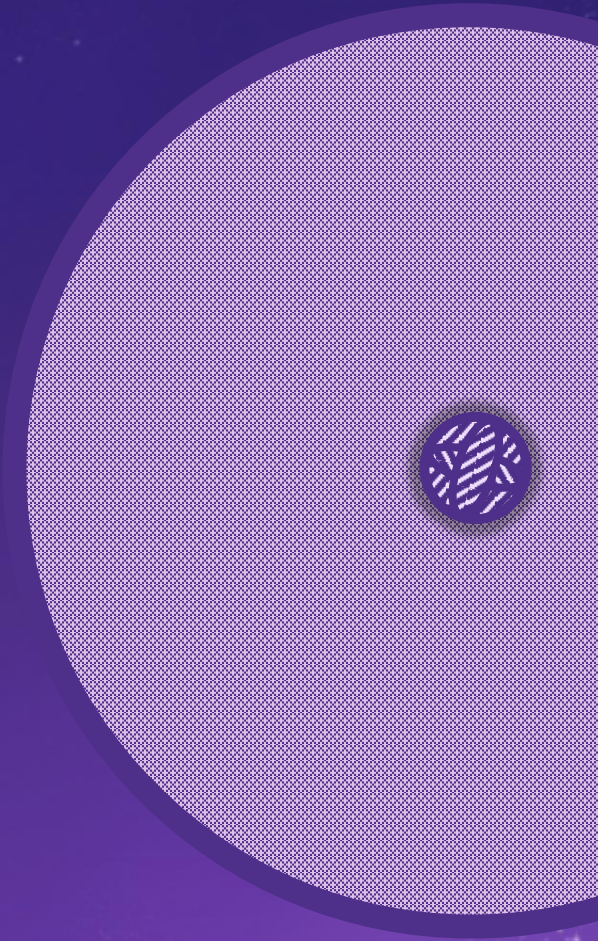
Post main sequence stars between 8 - 30$M_\odot$



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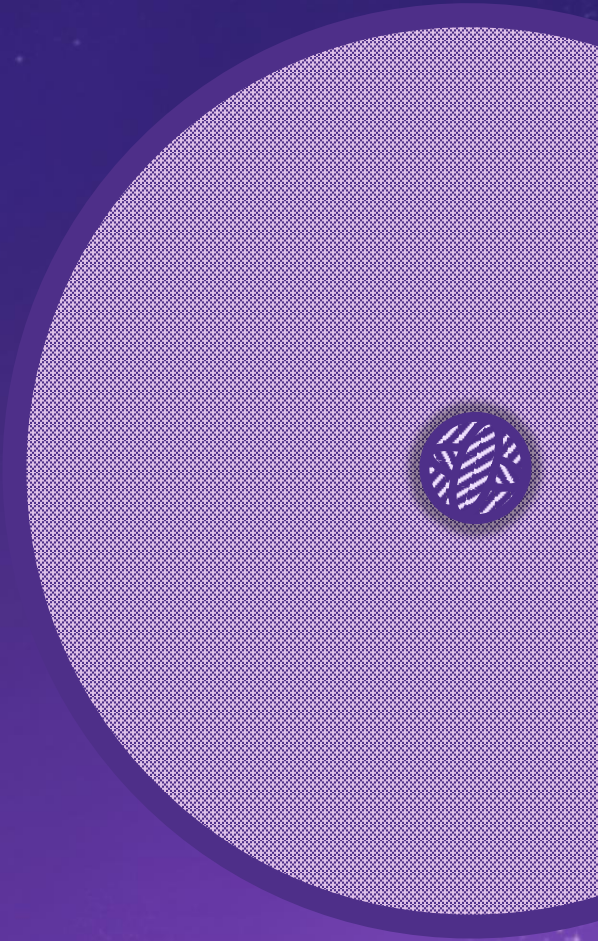

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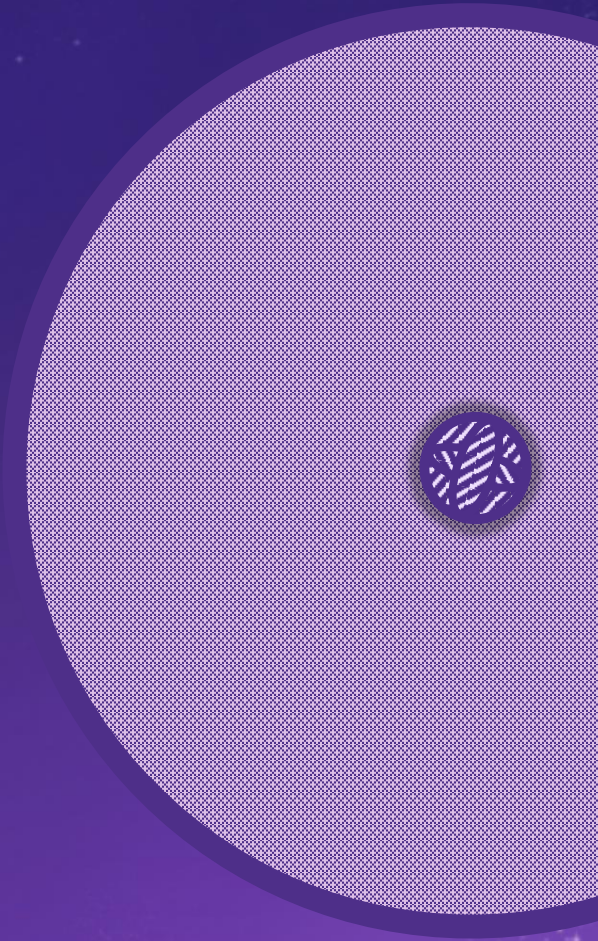

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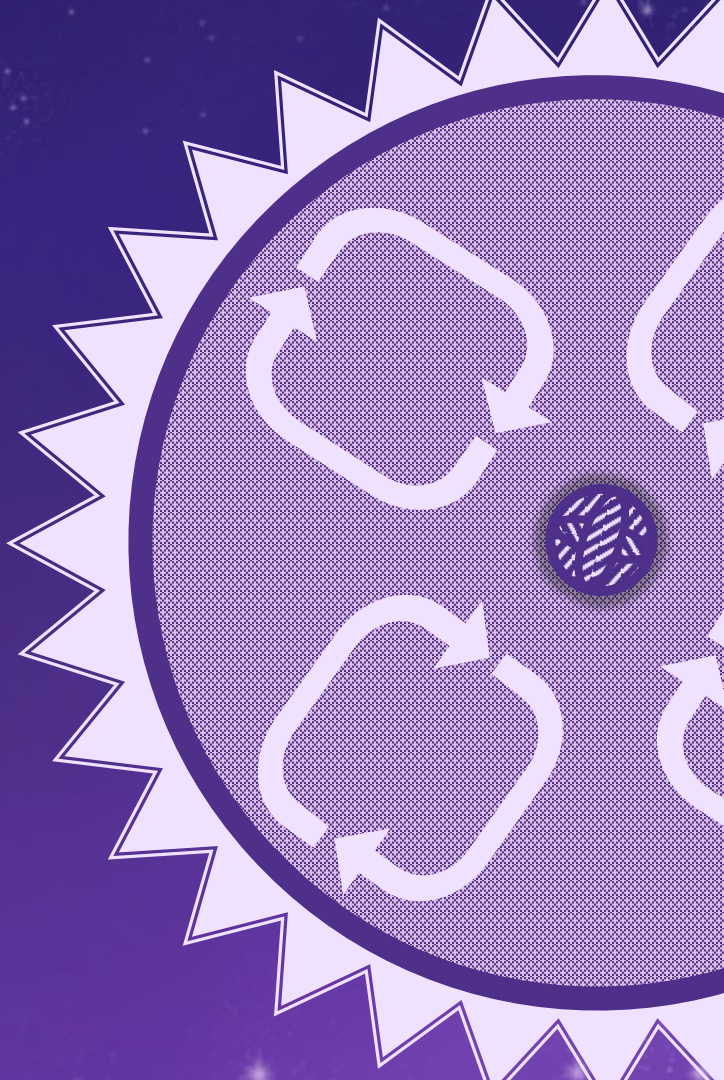

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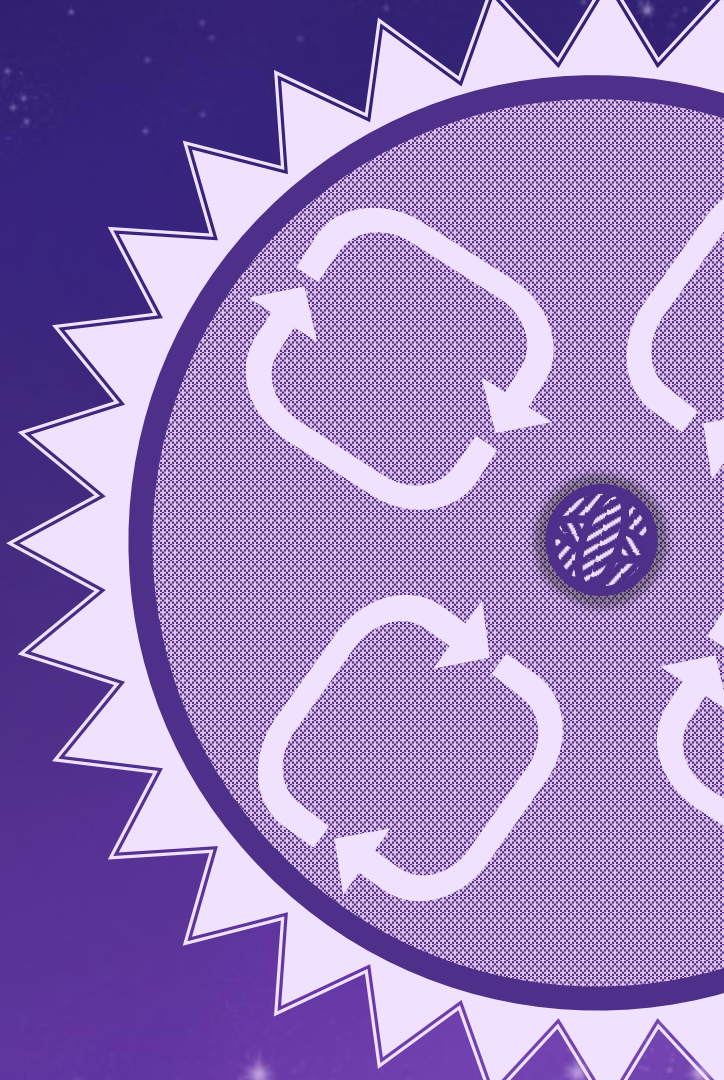
Important problem of stellar evolution



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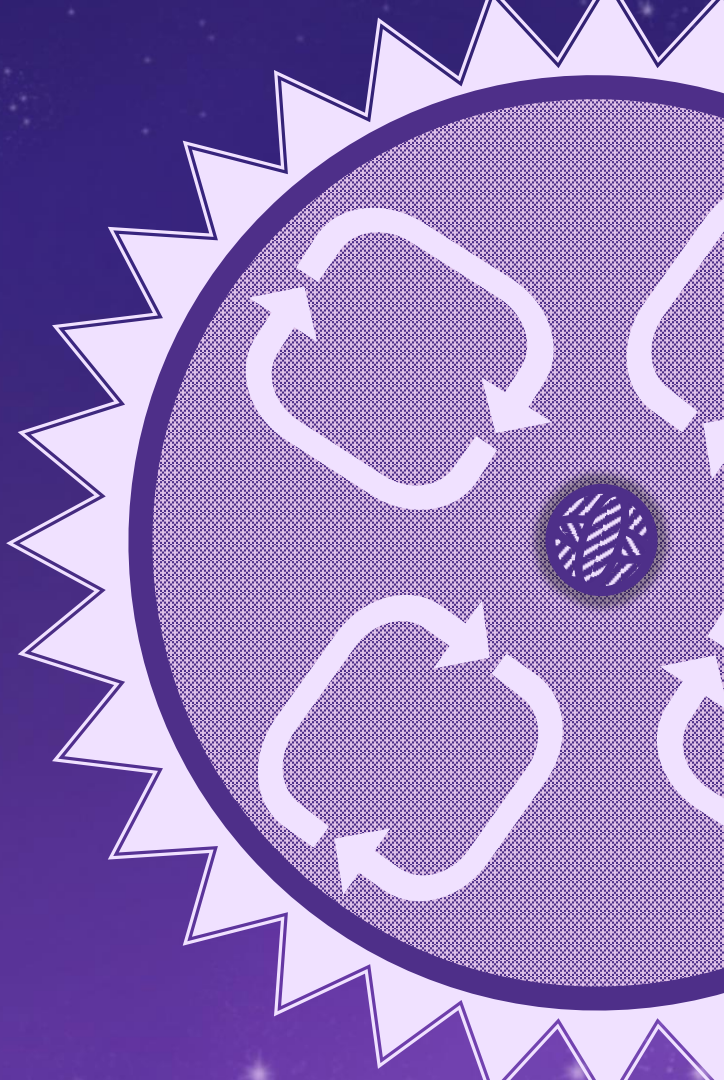

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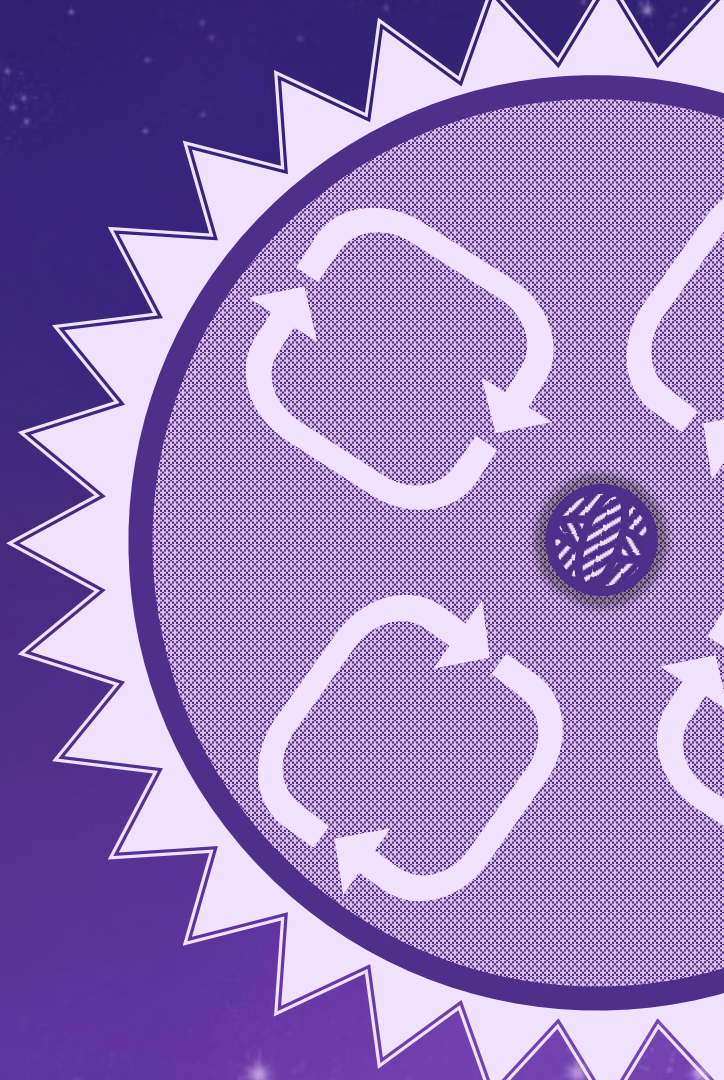

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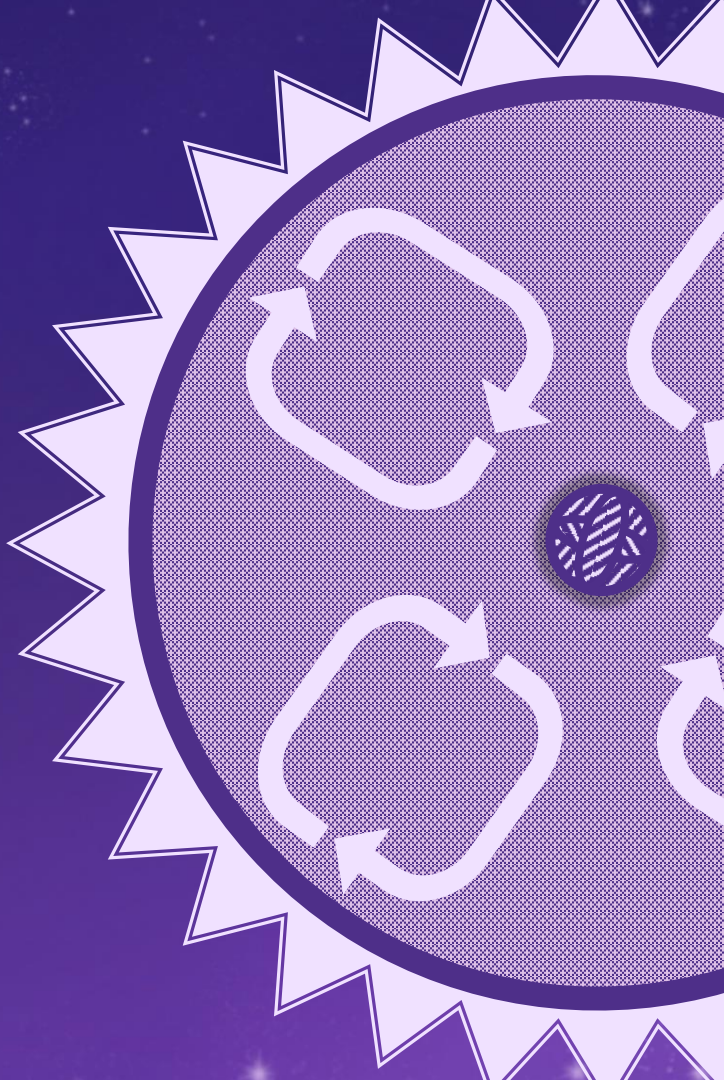

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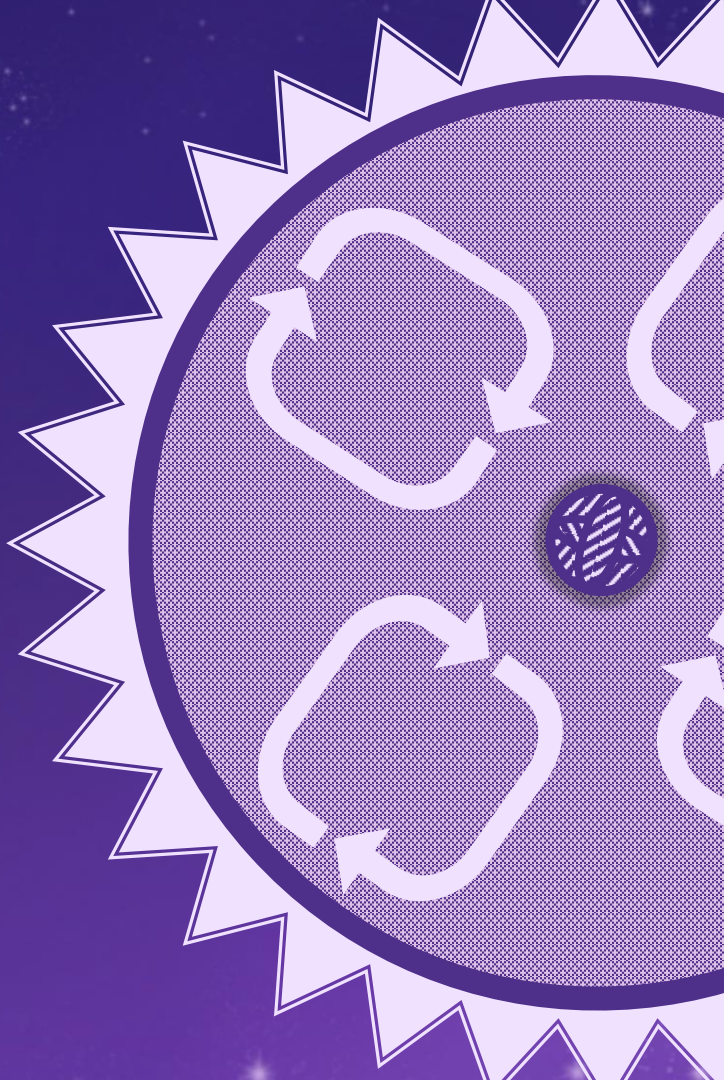

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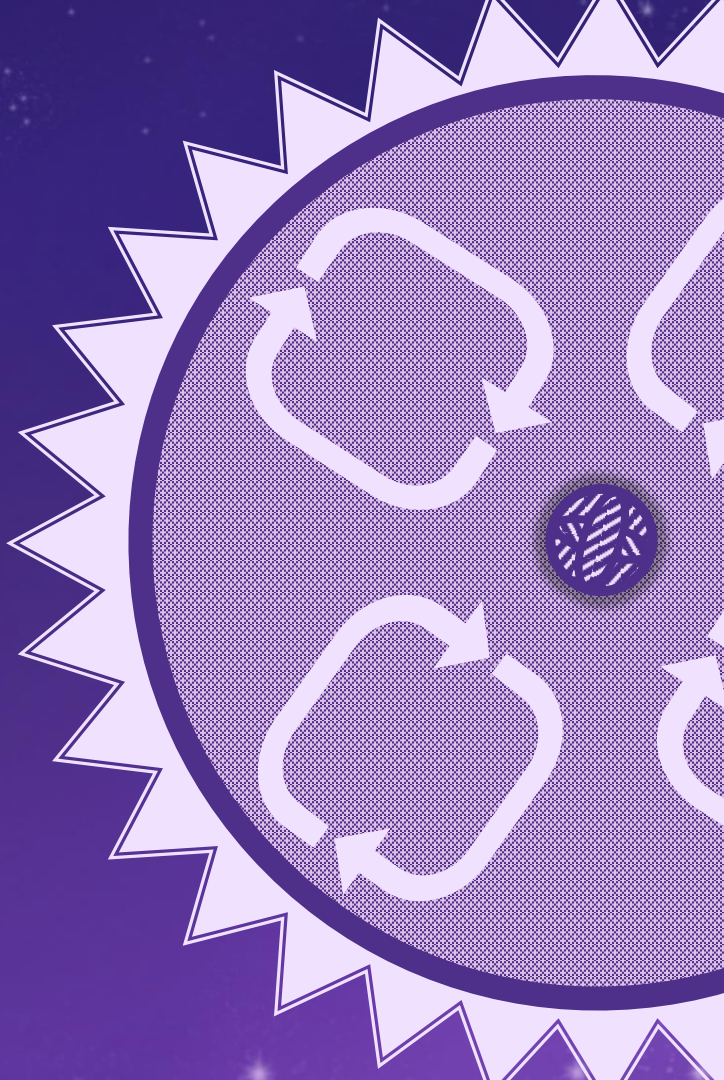

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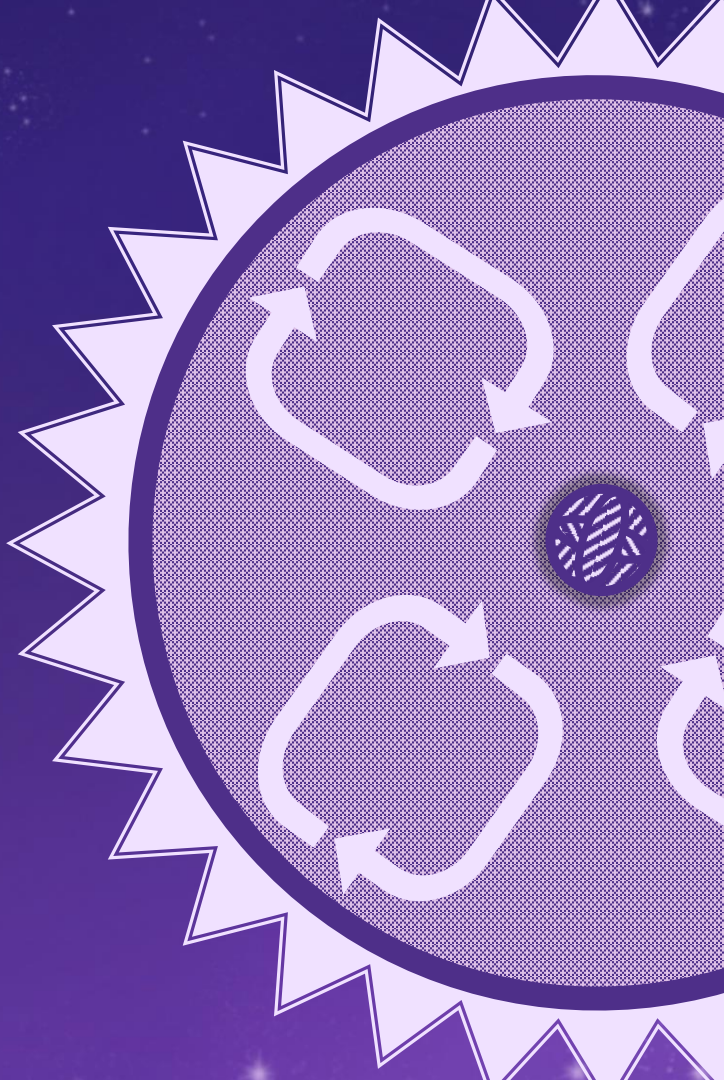

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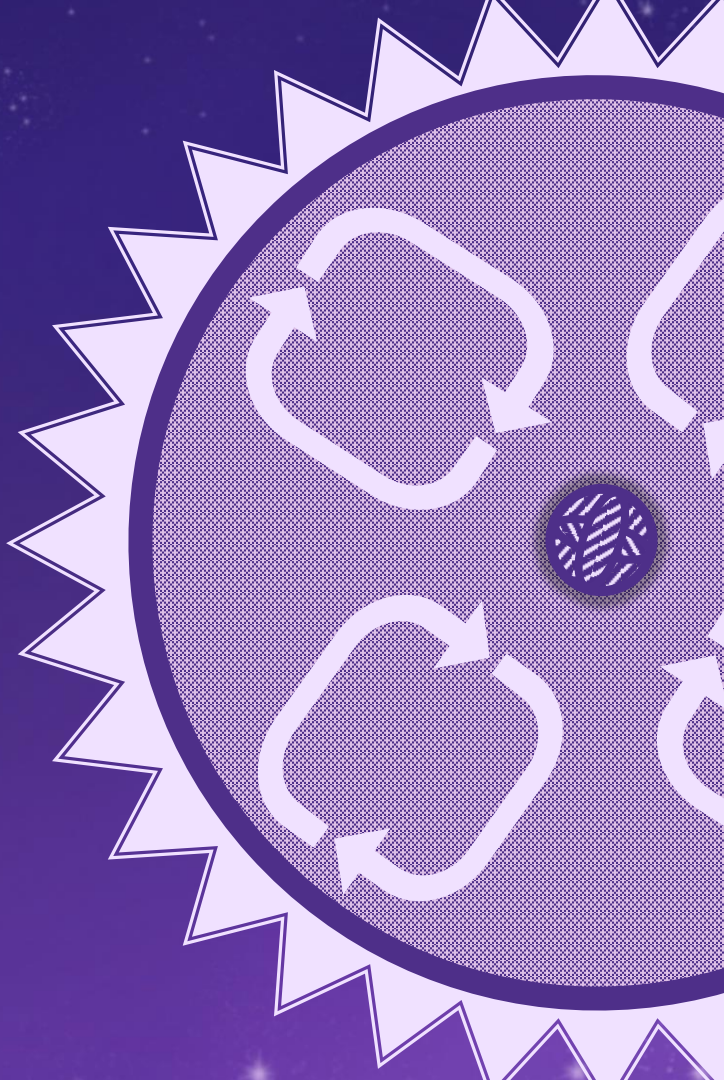

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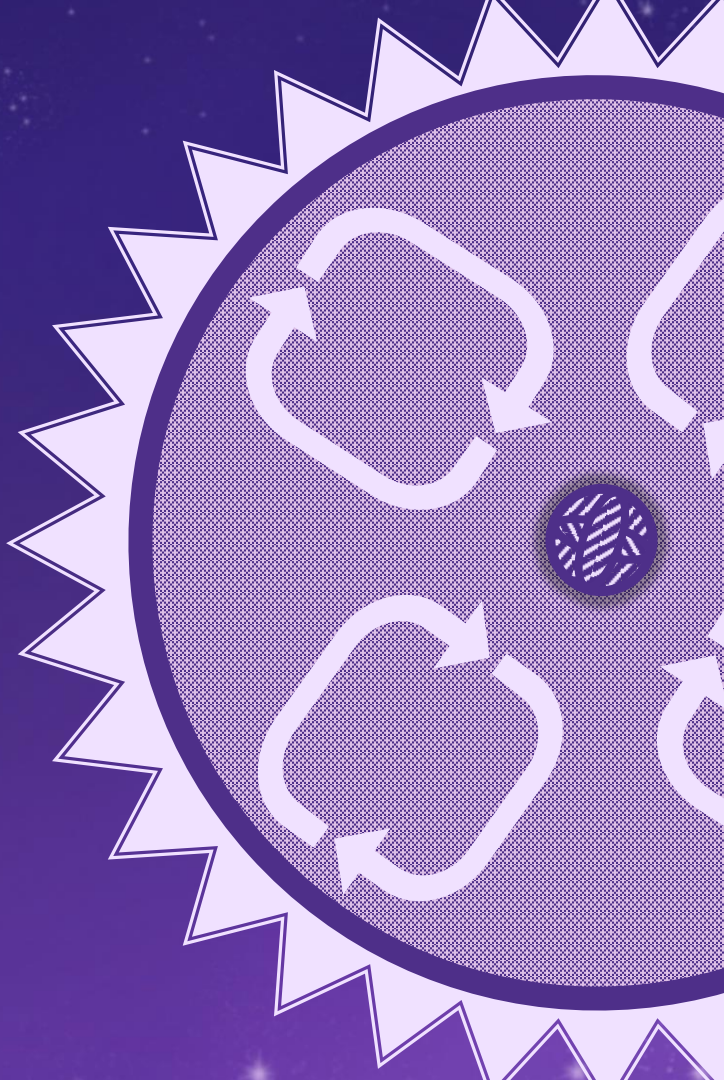
Some outflows around RSGs are very complex and asymmetric.



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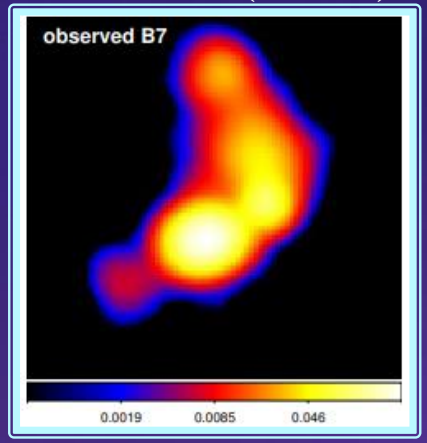
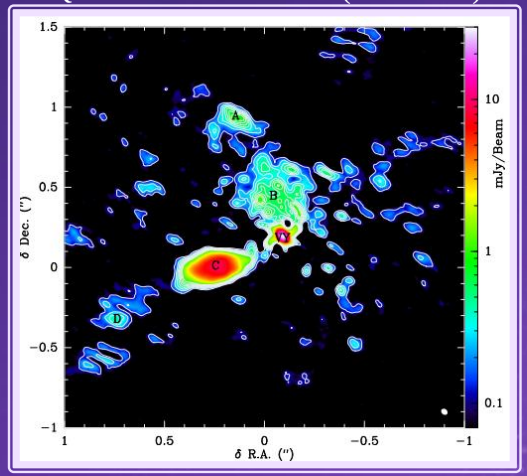
Kaminski 2019 (~350 GHZ)



Quintana-Lacaci 2023 (~300 GHZ)



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Discrete mass ejections thought to be due to magnetic activity and convection
(Humphrey 2022, Quintana-Lacaci 2023)

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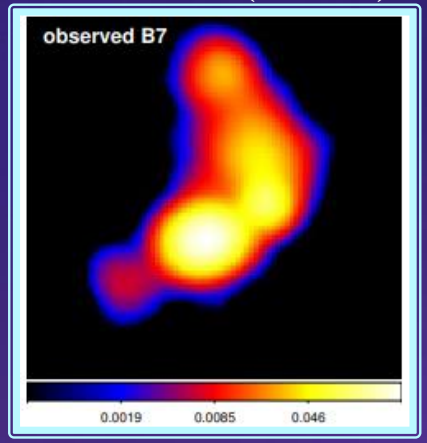

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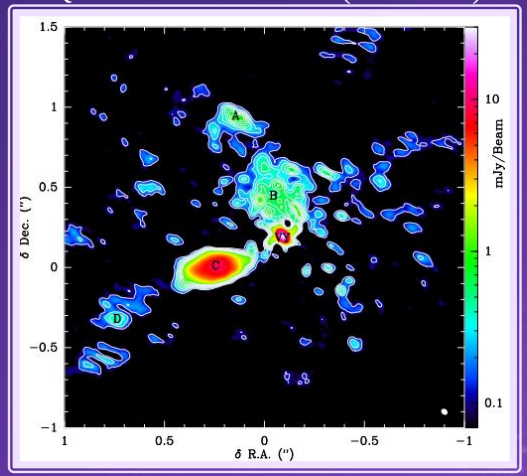

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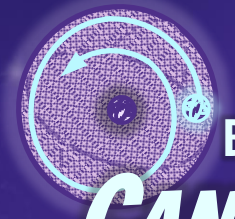
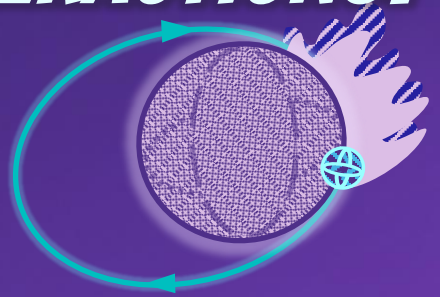
CAN WE EXPLAIN SOME OF THESE MASS LOSS EPISODES WITH BINARY INTERACTIONS?





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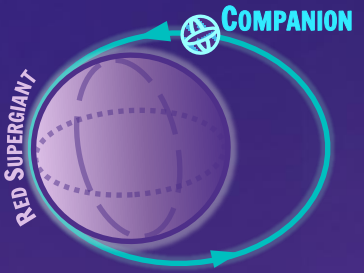

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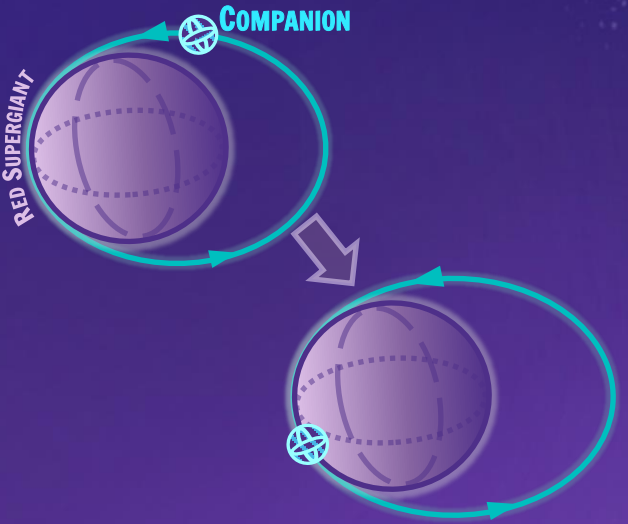
Shock through the outer envelope



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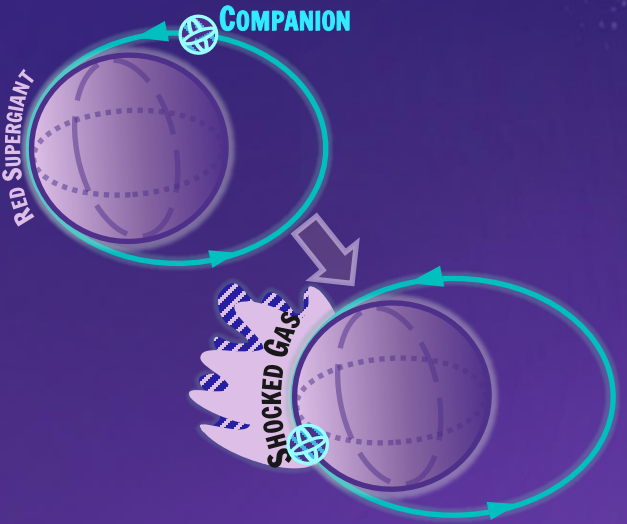
Matter is ejected asymmetrically



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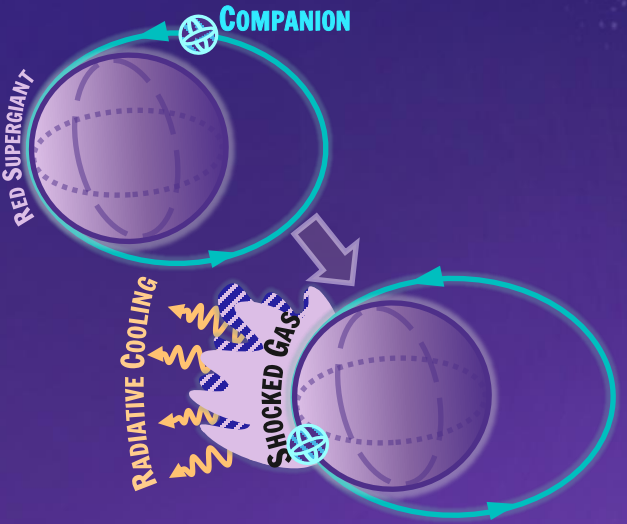

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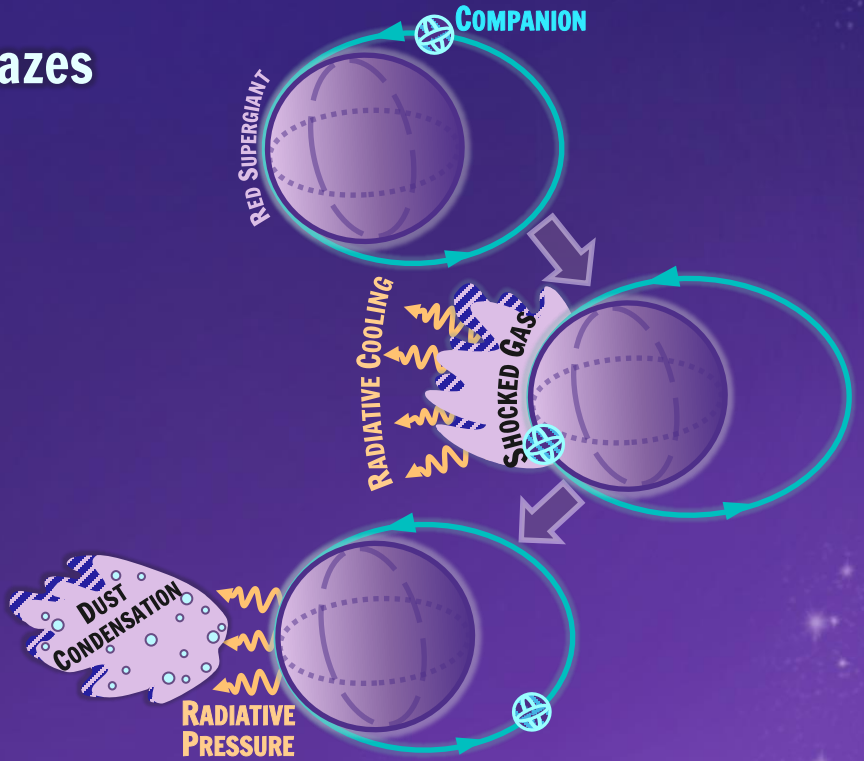

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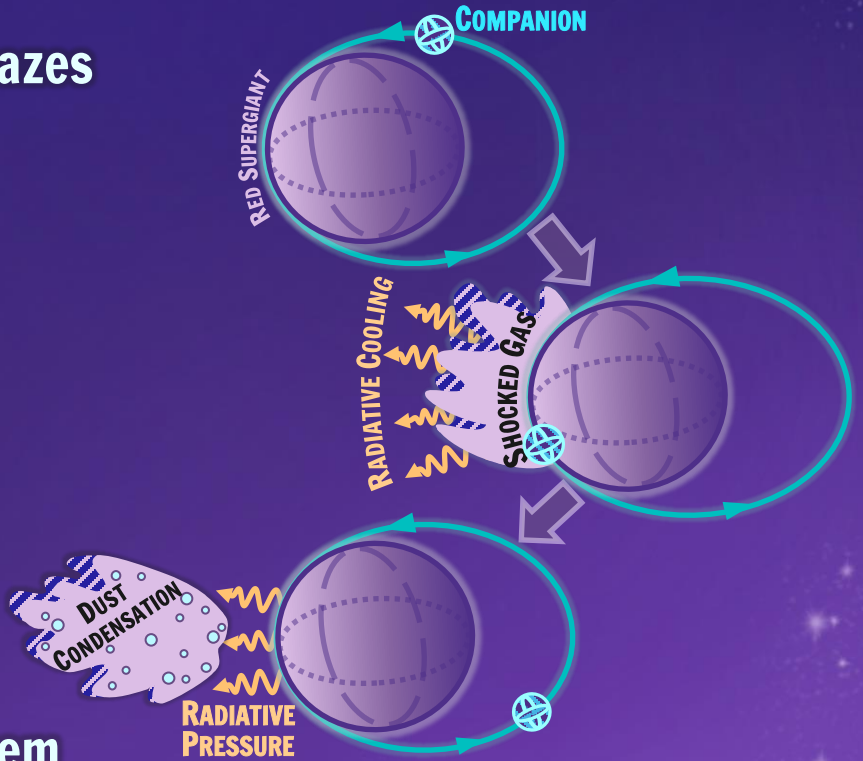
⇨ Run 3D hydro simulations of this system



Simulations

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$R_1 = 1500\ R_\odot$
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$Z = 0.02$
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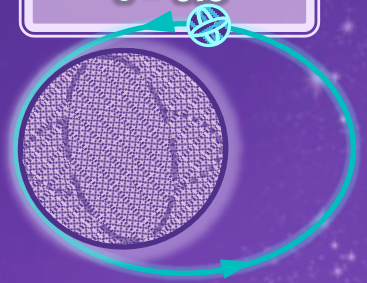

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Evolve this binary system in 3D smoothed particle hydrodynamics

Phantom
(Price et al., 2018)

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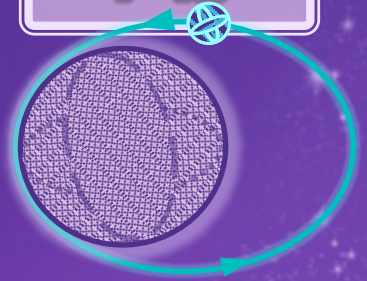

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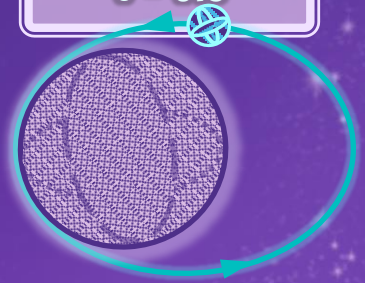

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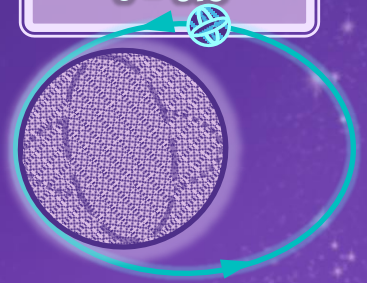

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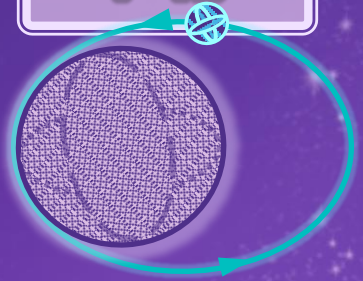

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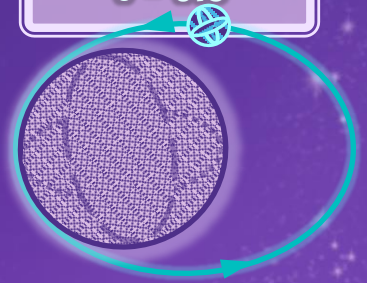

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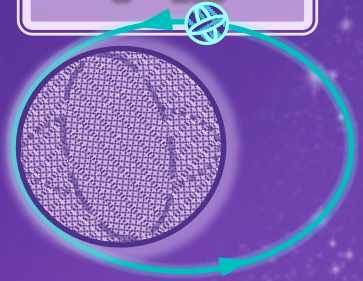

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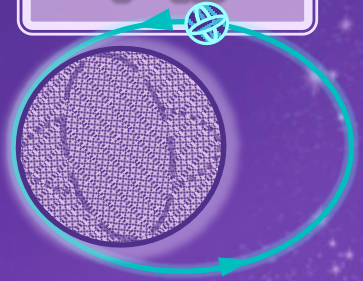

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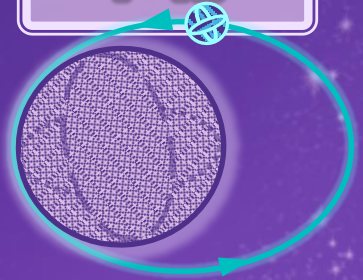

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⇨ Emulate the effect of radiative cooling by implicitly cooling to the equilibrium value

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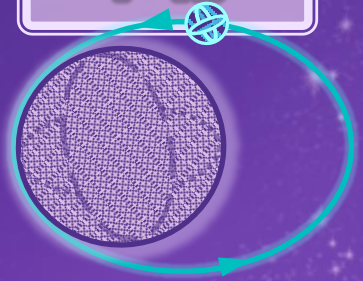
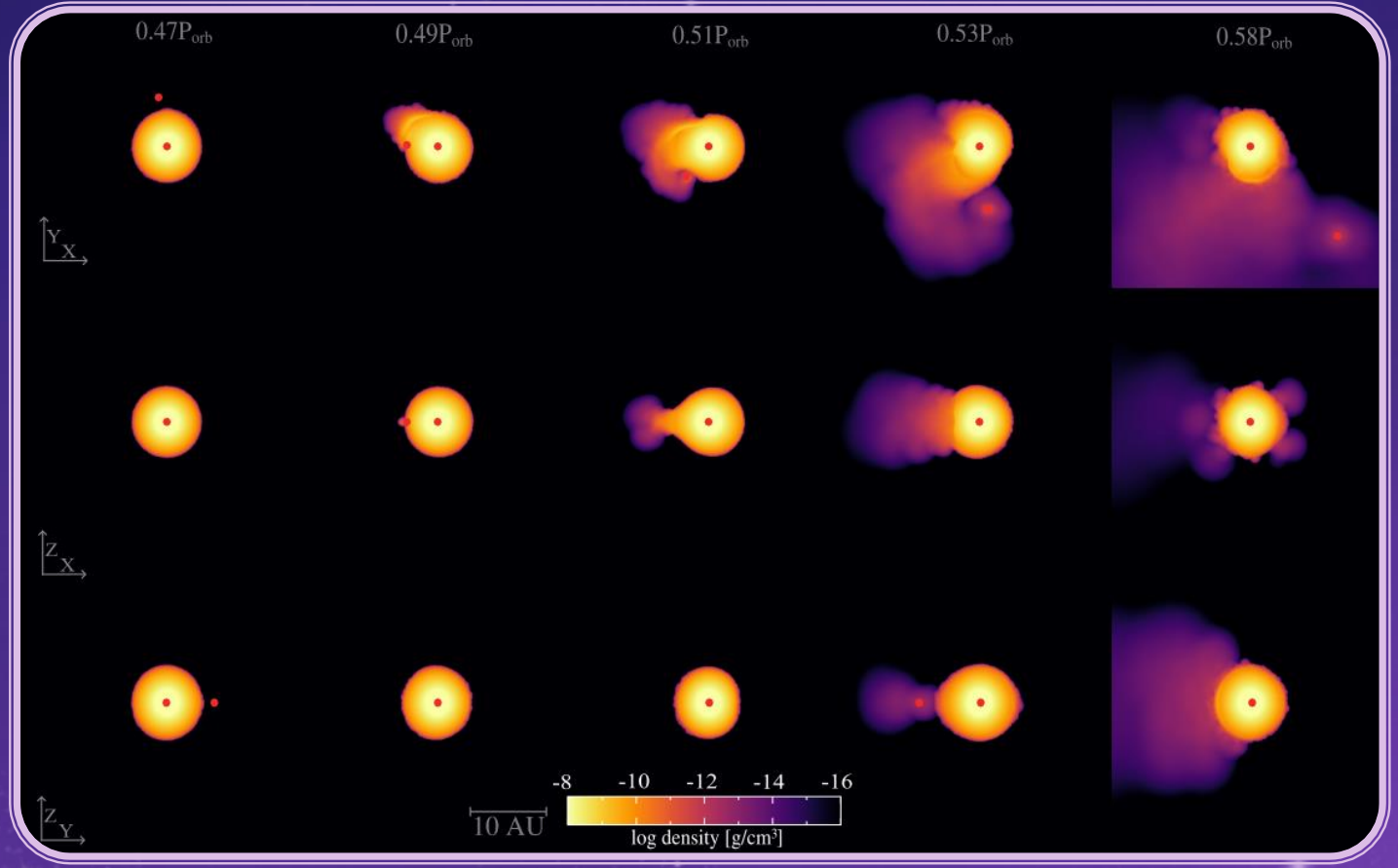


Results

RESULTS

One interaction

(Landri & Pejcha 2024)



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P = 43.91yrs
2 million particles

Orbit decay and mass loss

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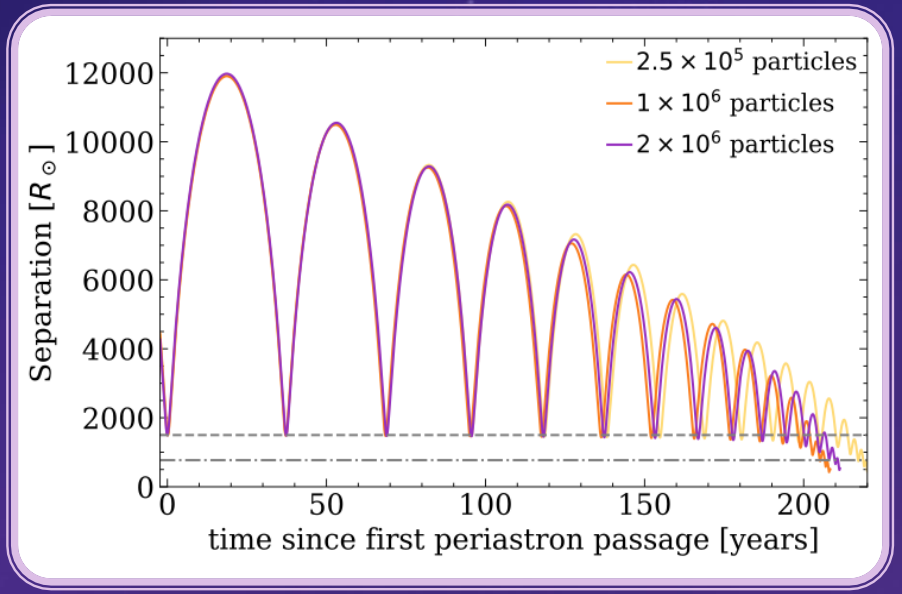
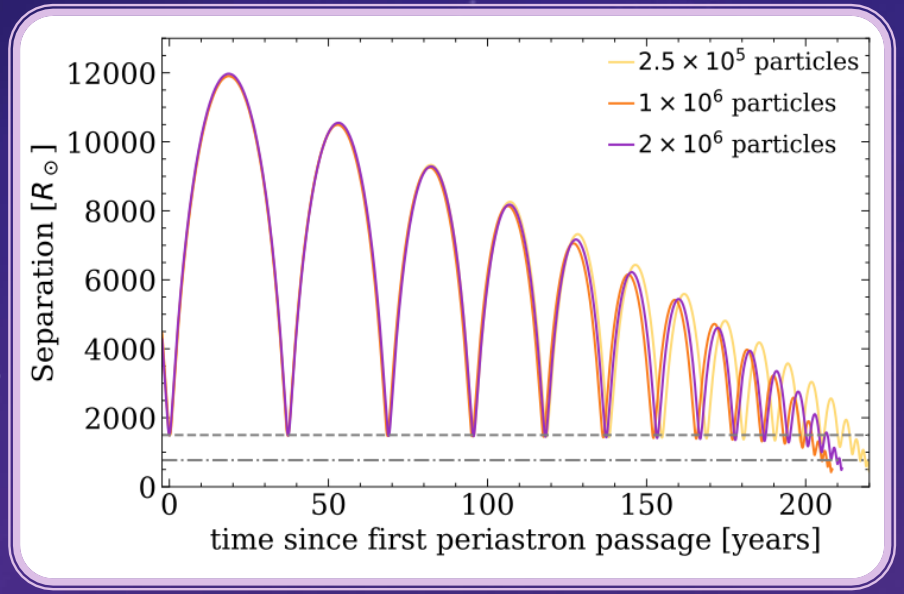


(Landri & Pejcha 2024)

Evolution of binary separation

Orbit decay and mass loss



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Evolution of binary separation

. Each interaction tightens the orbit

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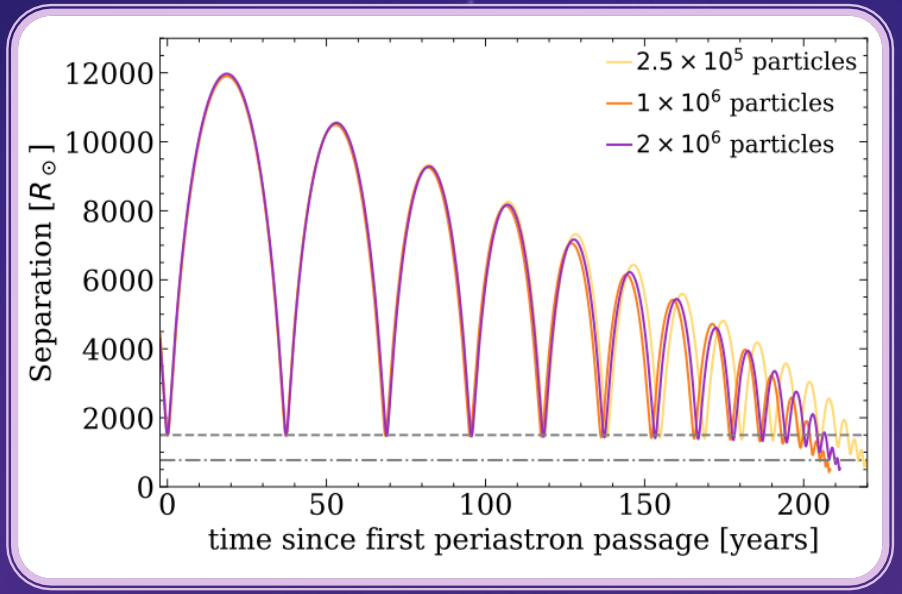

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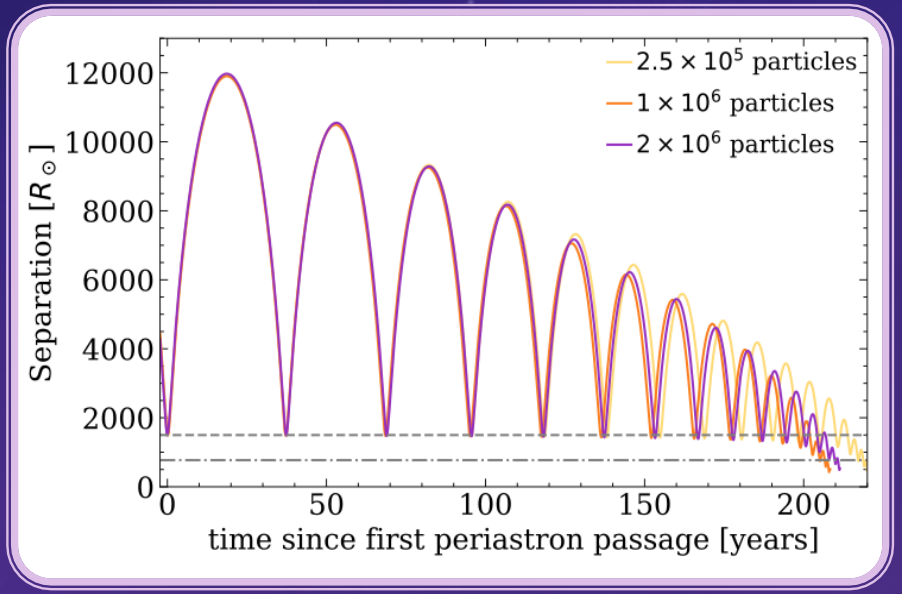

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Evolution of binary separation

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. CEE after 200 years (14 orbits)

Orbit decay and mass loss

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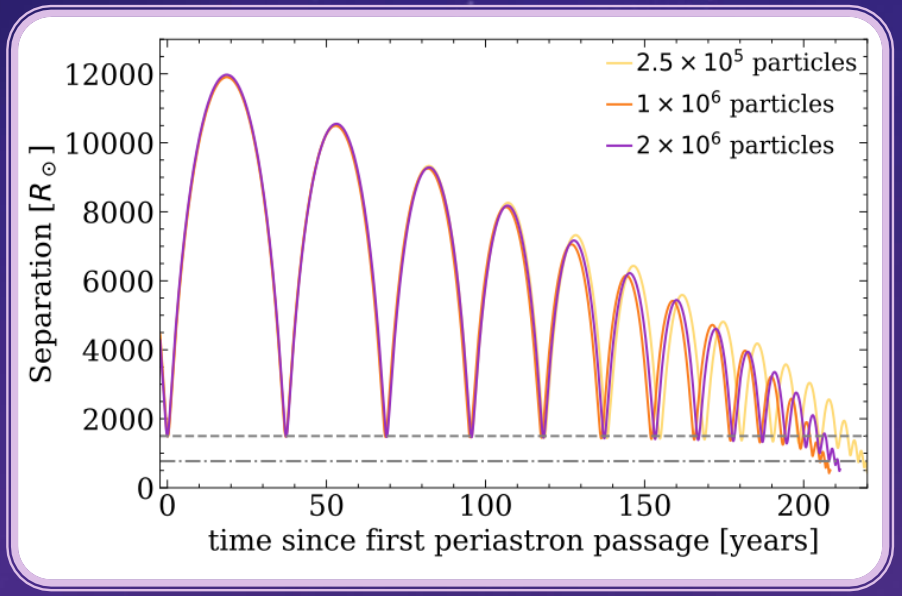

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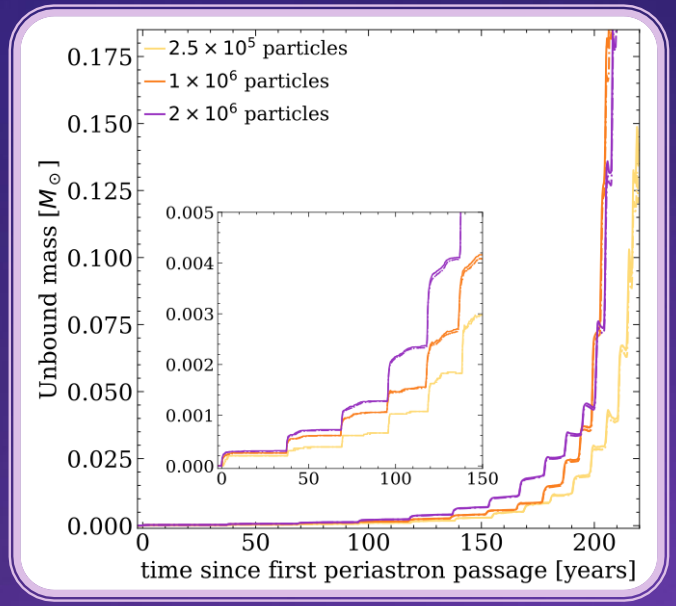

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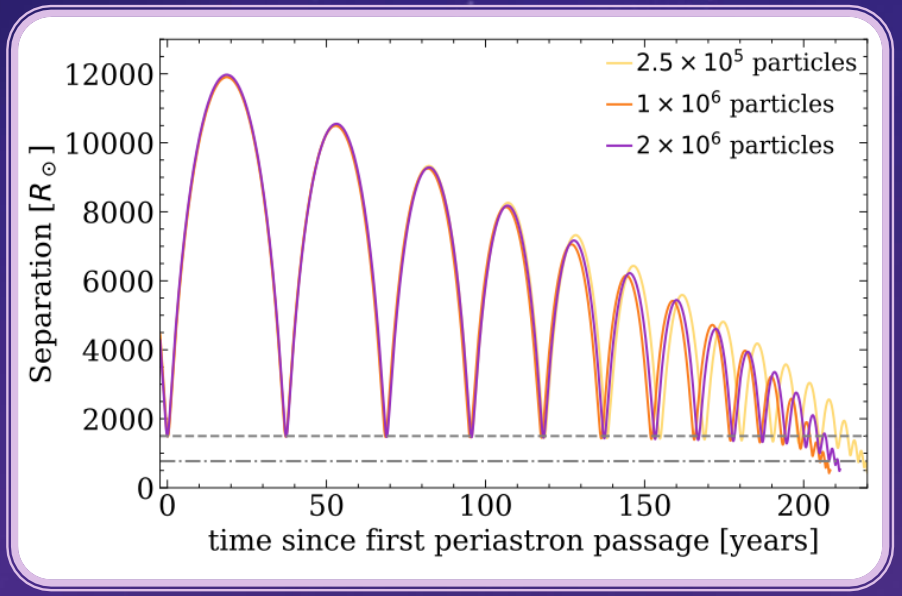

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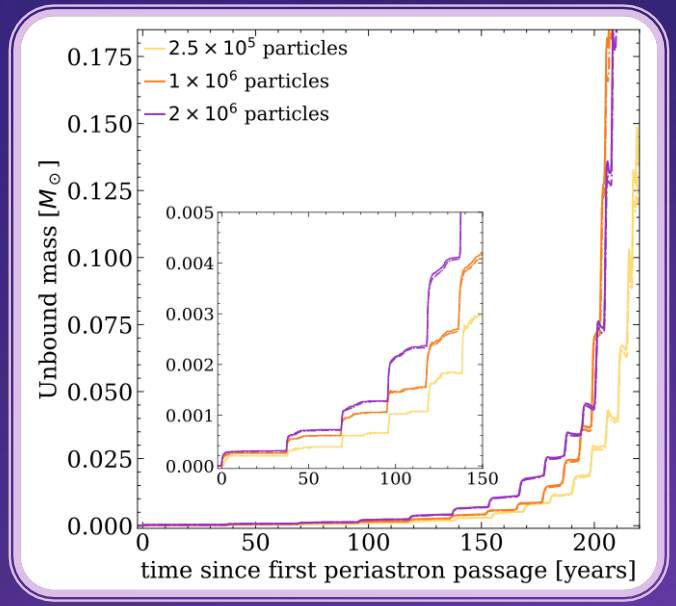
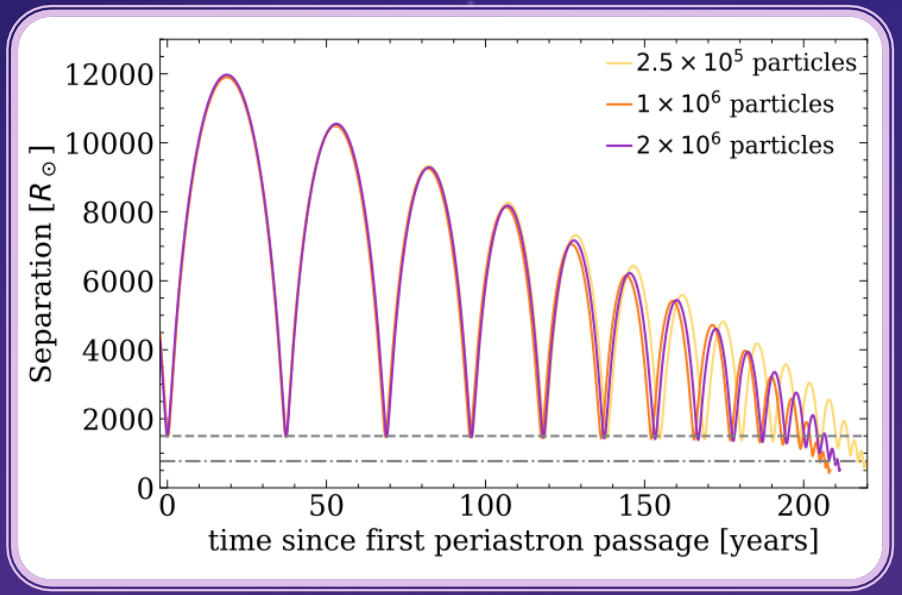


Evolution of mass loss

. Mass loss is episodic

Orbit decay and mass loss

(Landri & Pejcha 2024)



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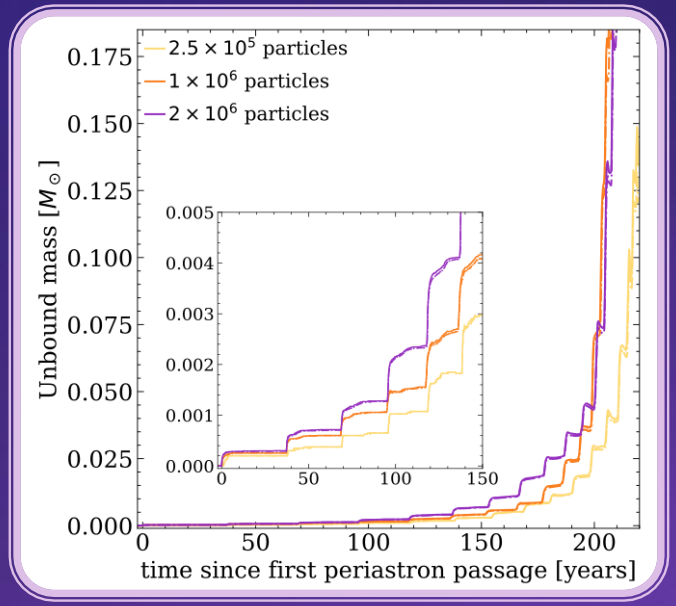

Evolution of mass loss

. Mass loss is episodic
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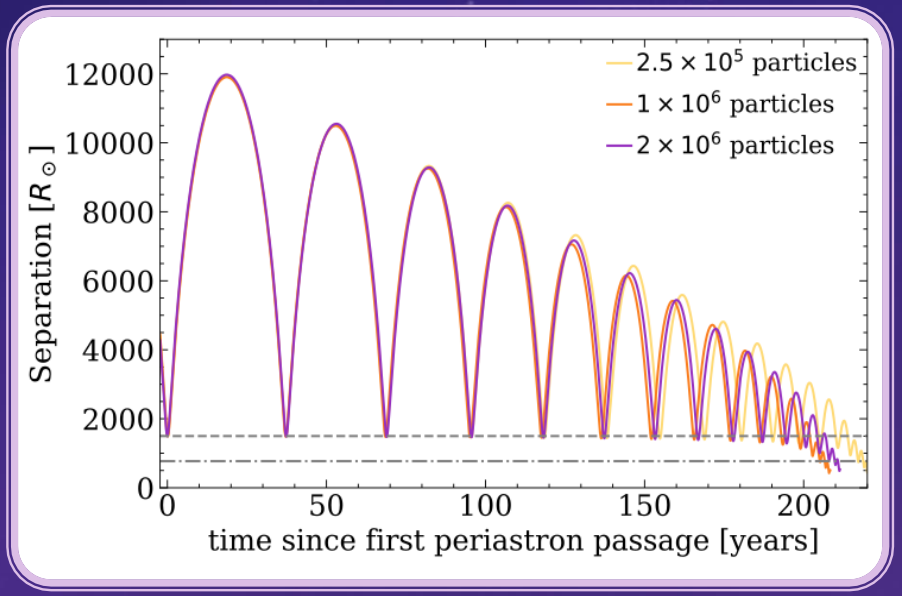

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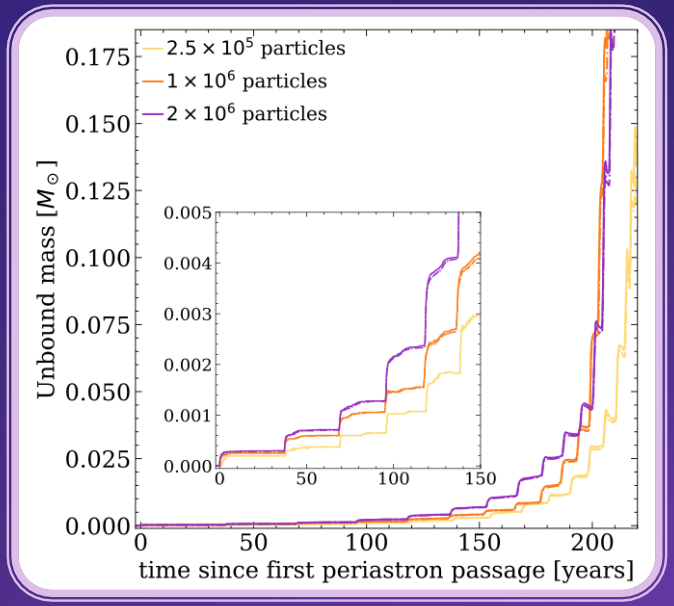


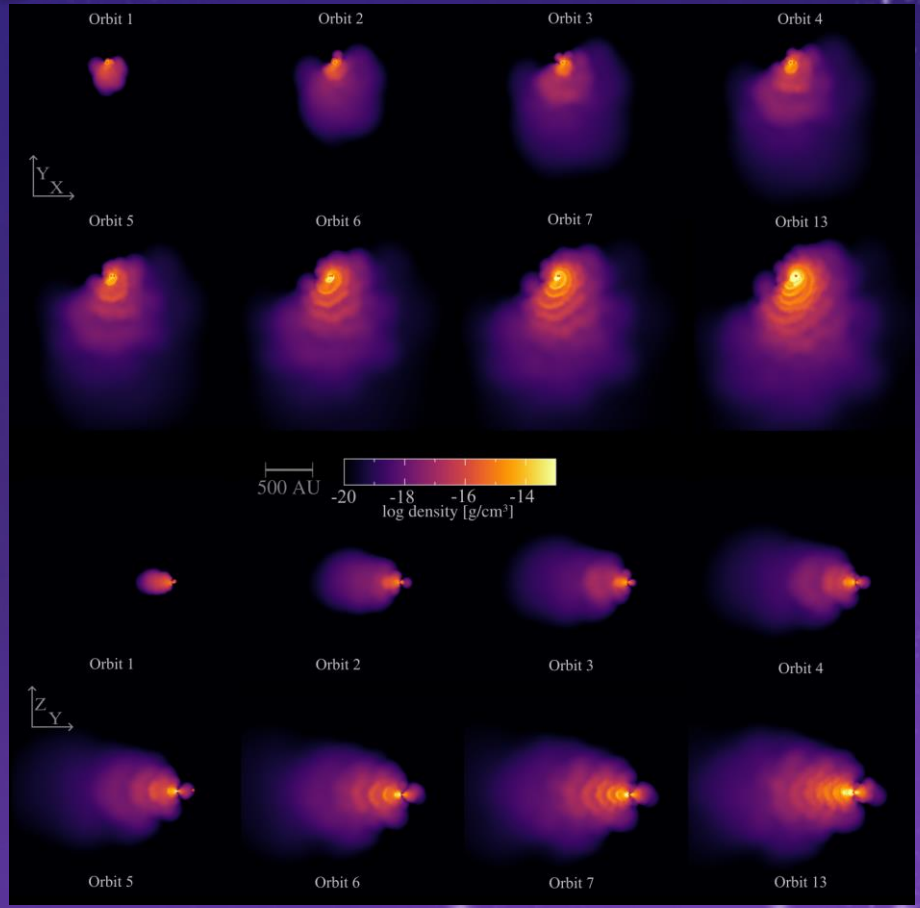
Evolution of mass loss

- Mass loss is episodic
- Enhanced after each interaction
- Loses 0.185 $M_\odot$ before CEE

Evolution of the ejecta

Evolution of the ejecta

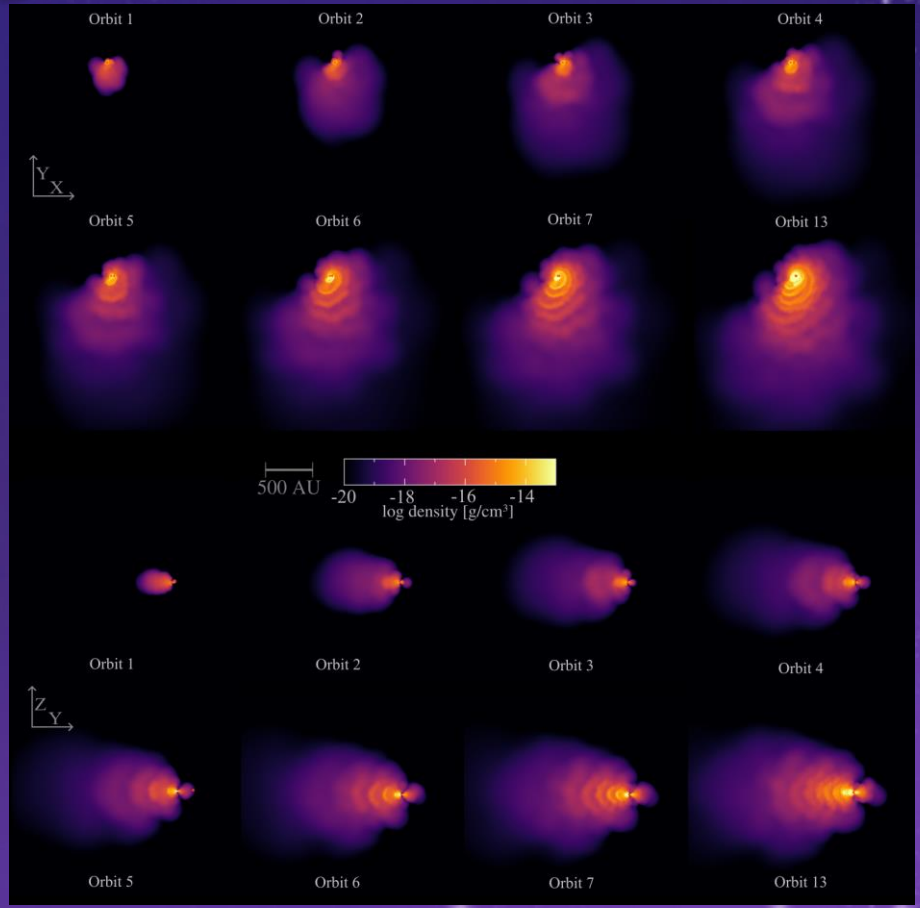
Density snapshots along the z=0 and x=0 planes
(Landri & Pejcha 2024)



Evolution of the ejecta

Slow evolution until 5th orbit (140 yrs):

Density snapshots along the z=0 and x=0 planes (Landri & Pejcha 2024)



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Slow evolution until 5th orbit (140 yrs):
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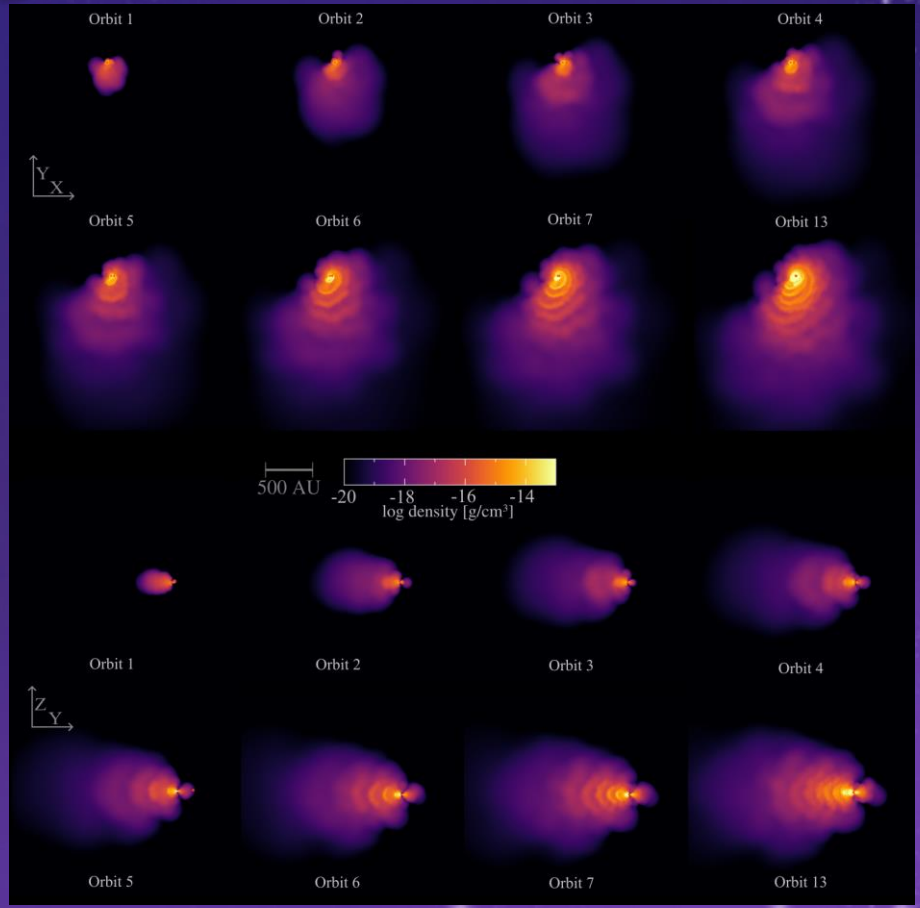

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Slow evolution until 5th orbit (140 yrs):
. broad, low-density spirals
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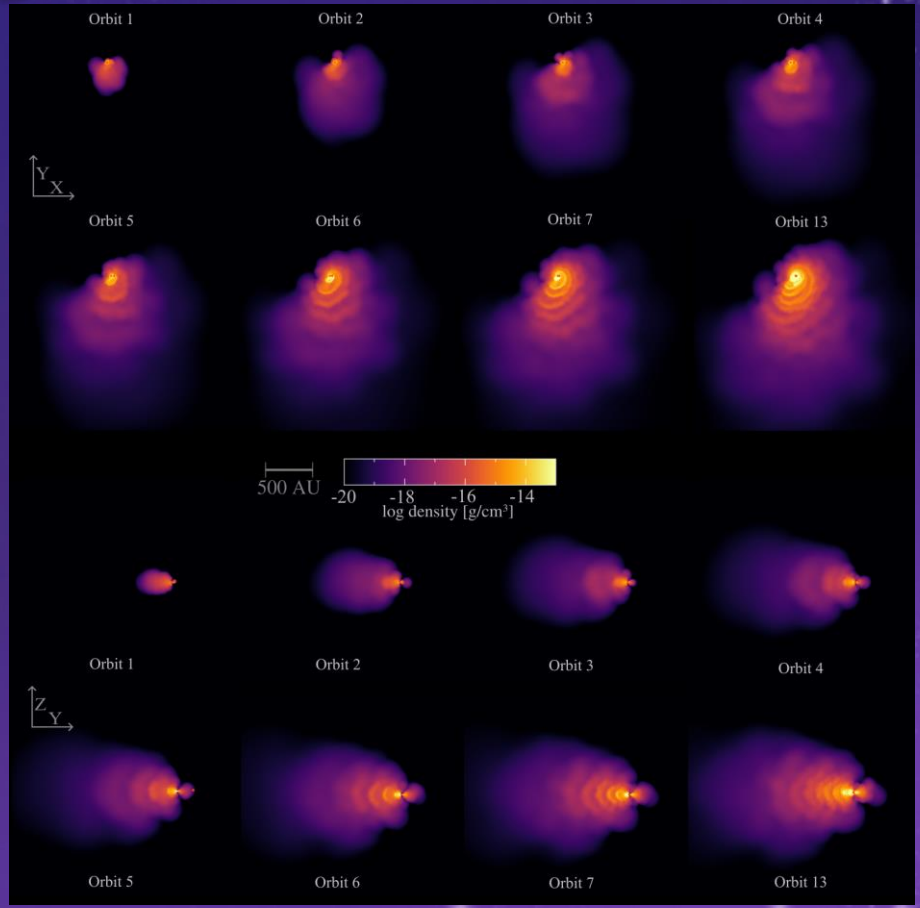

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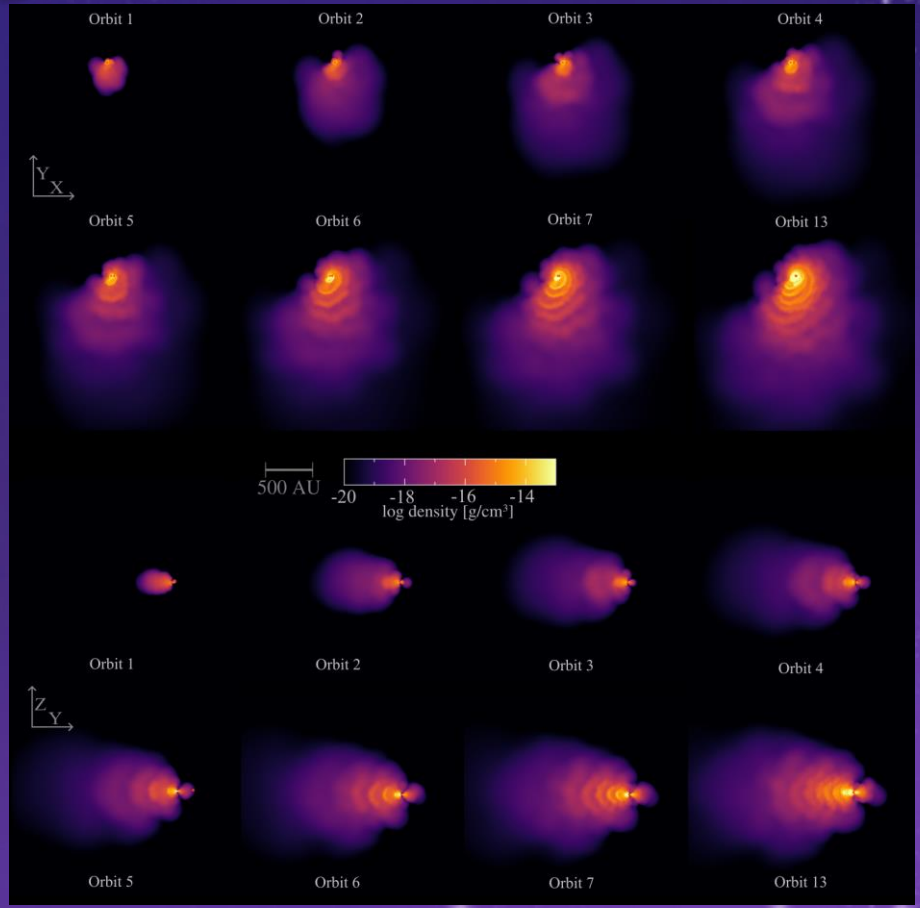

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Then strong orbit decay :
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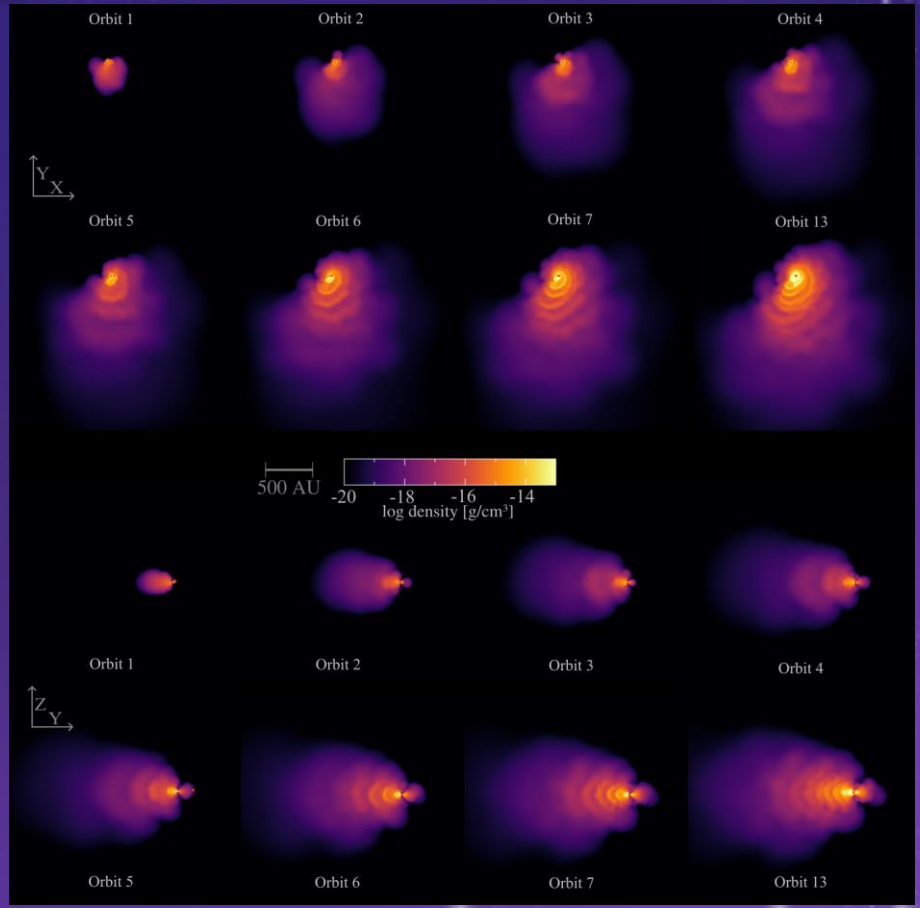

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Then strong orbit decay :
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. Tighter shell-like structure

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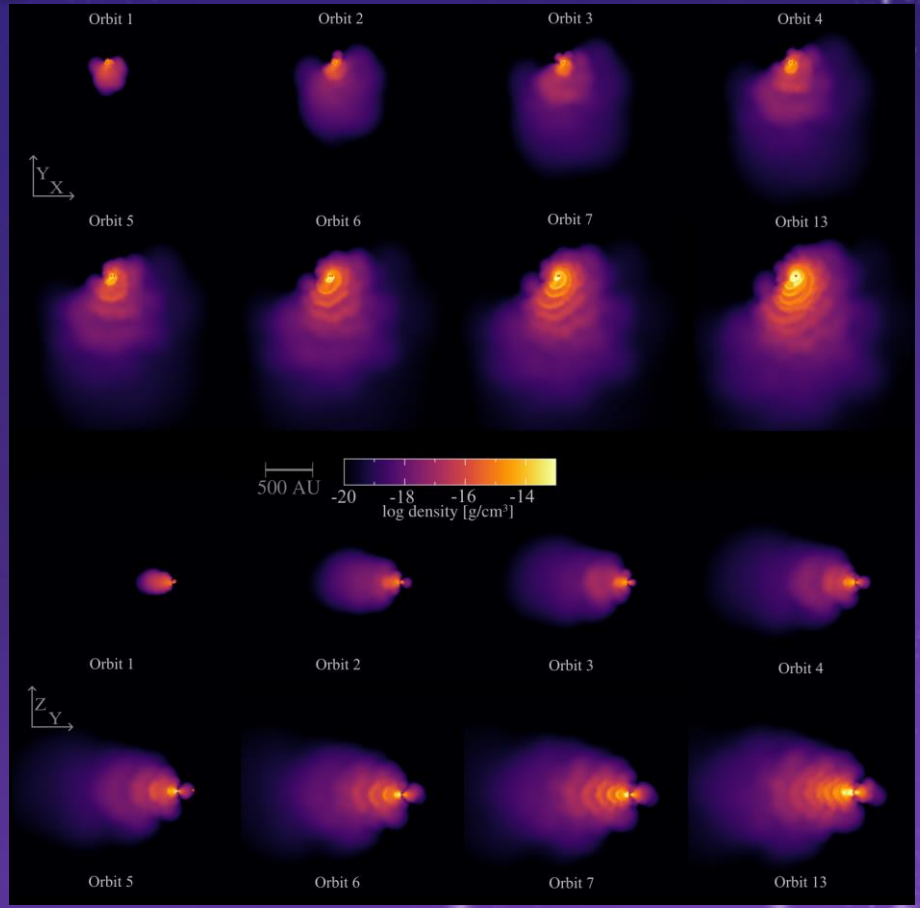

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Final outflow:

Density snapshots along the z=0 and x=0 planes
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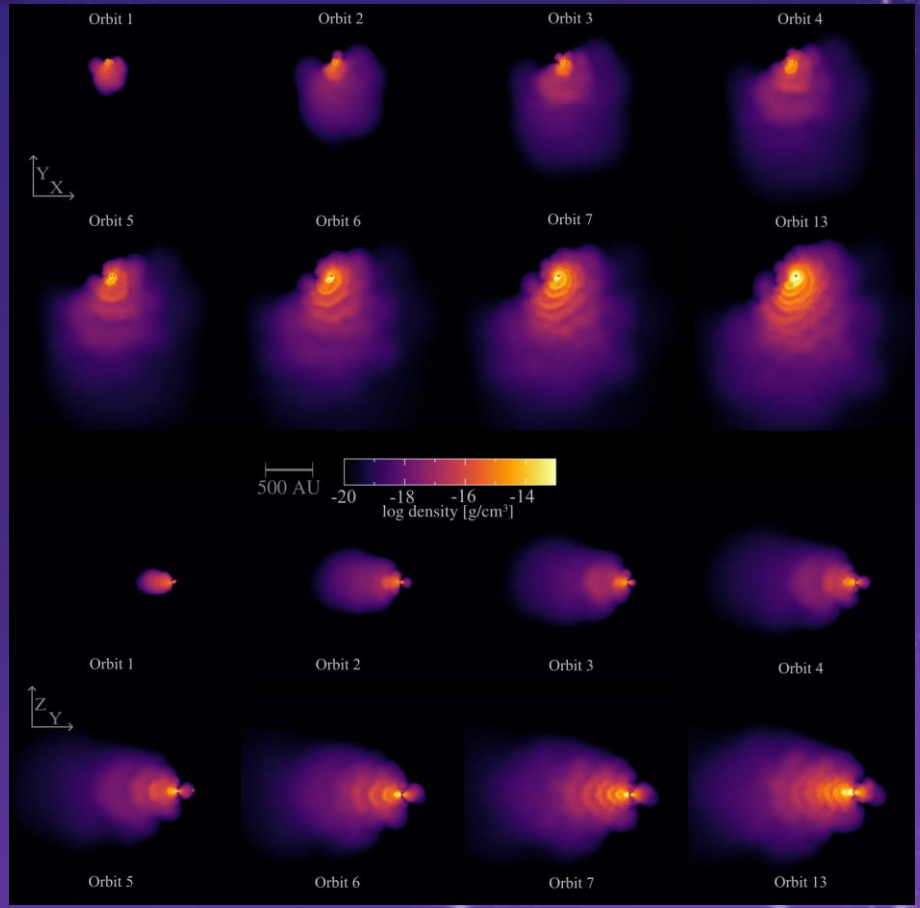

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Final outflow:
. dense inner region (0.15 $M_\odot$ extending up to ~100 au)

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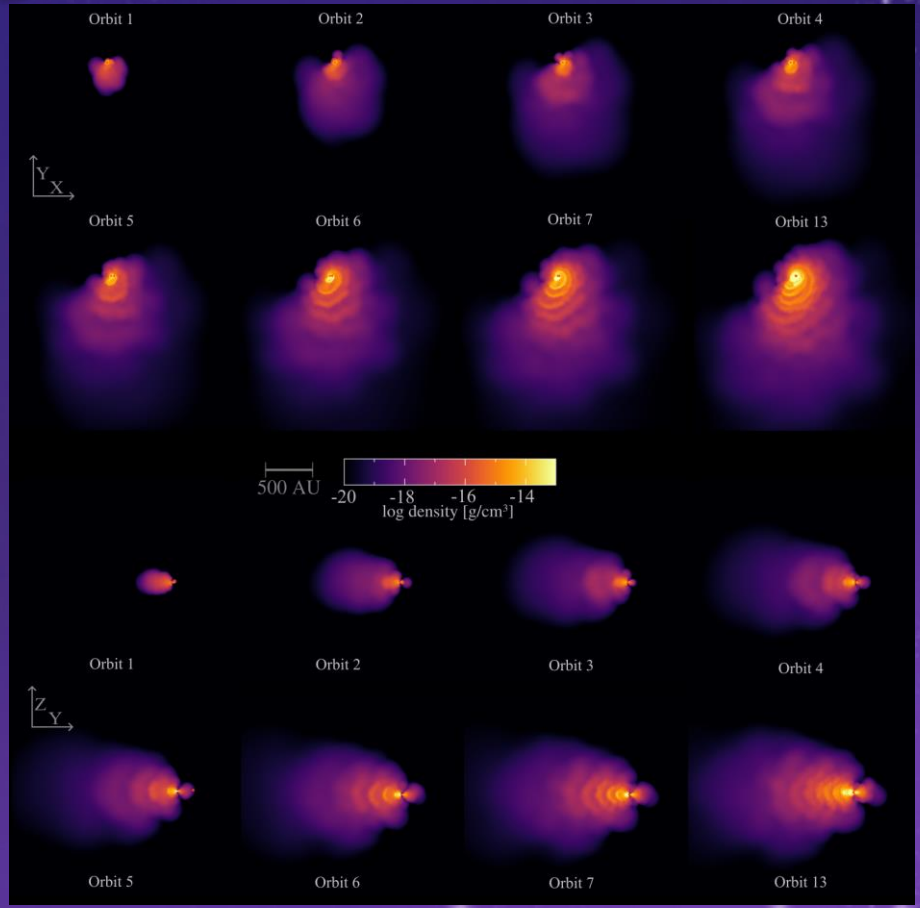

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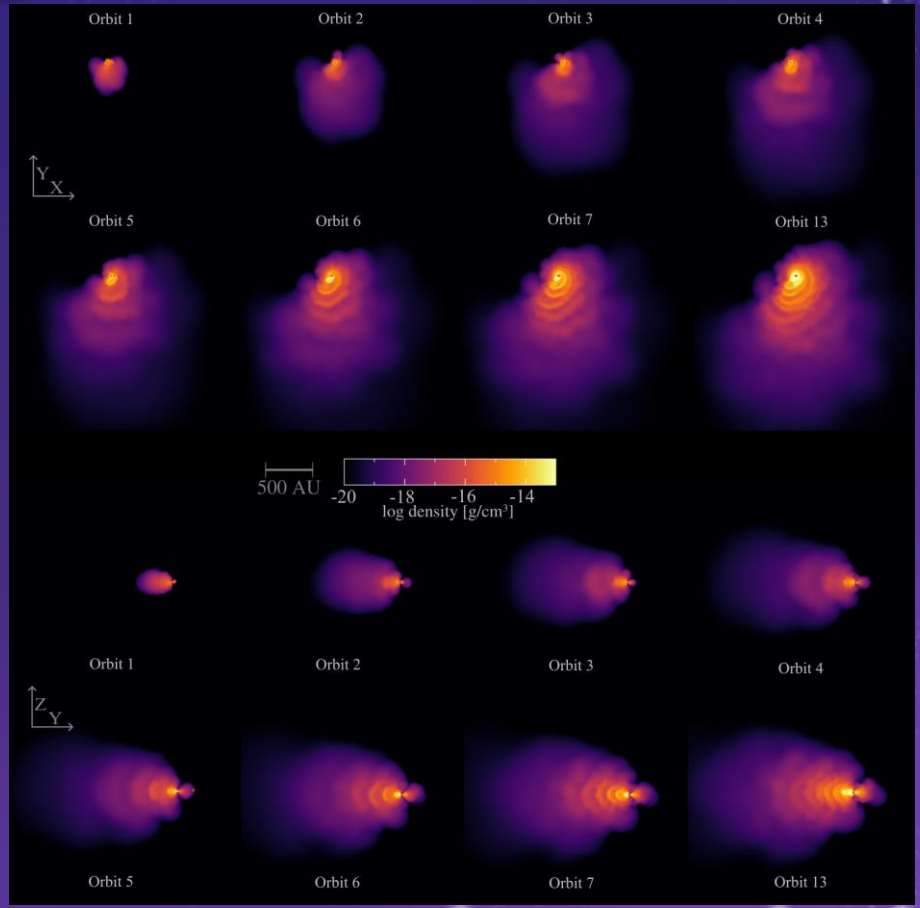
Final outflow:
- . dense inner region (0.15 $M_\odot$ extending up to ~100 au)
- . Intermediate region (3×10^{-2} $M_\odot$ up to ~500 au)



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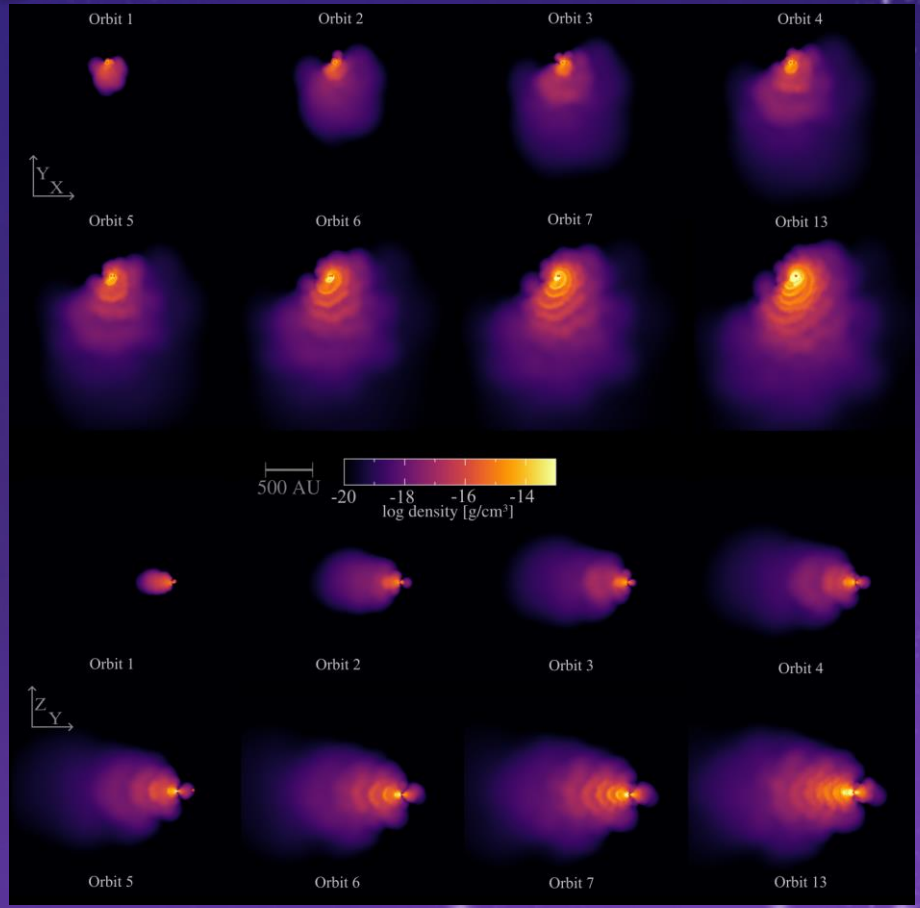
. Extended region (5×10^{-3} $M_\odot$ up to ~2000 au)

Density snapshots along the z=0 and x=0 planes (Landri & Pejcha 2024)



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Wind terminal velocities approach v_r ~ 60 km/s

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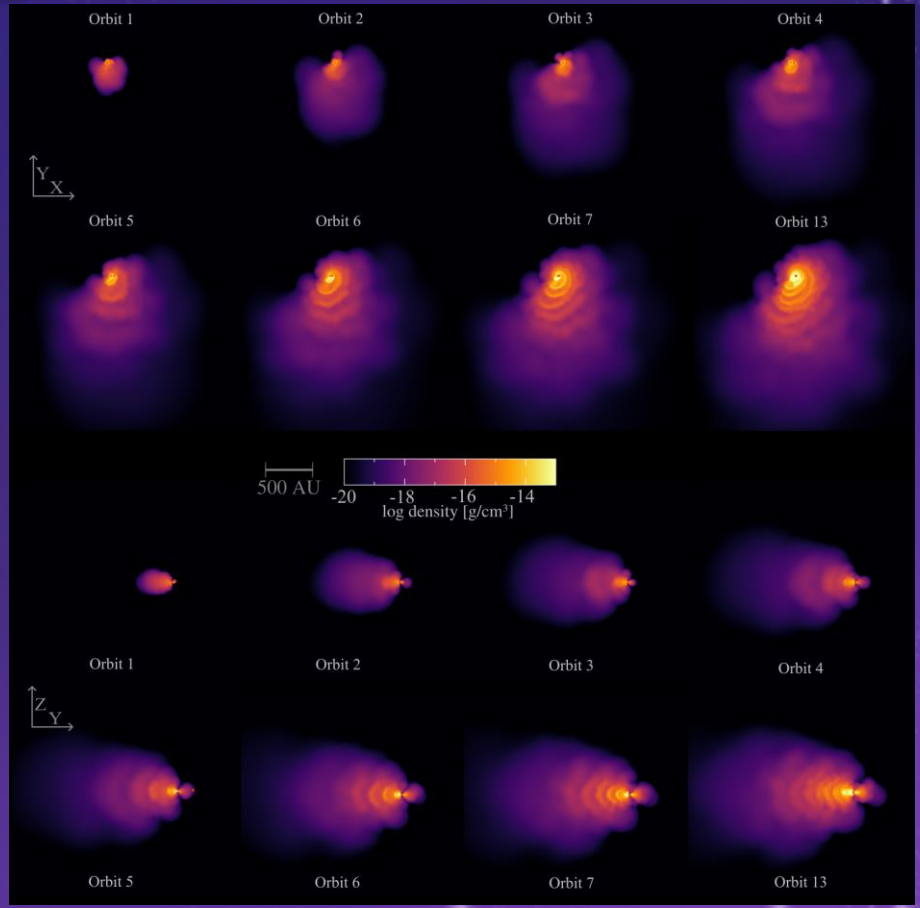

Conclusion

Binarity rate in RSGs is about 30% from observations (e.g., Neugent 2021, Patrick+2022)

→ Companion interaction could drive wide asymmetric winds around RSGs in close binaries

Winds are massive (extended ejecta carries $5 \times 10^{-3}\ M_{\odot}$)

→ dusty ejecta can be observed

Can only explain part of the asymmetric ejecta around VY CMa

→ there must be an interplay with other processes (convection, magnetic activity)

What's next?

- Produce synthetic observables
- Improvements on the accuracy of the simulations

References (RSG)

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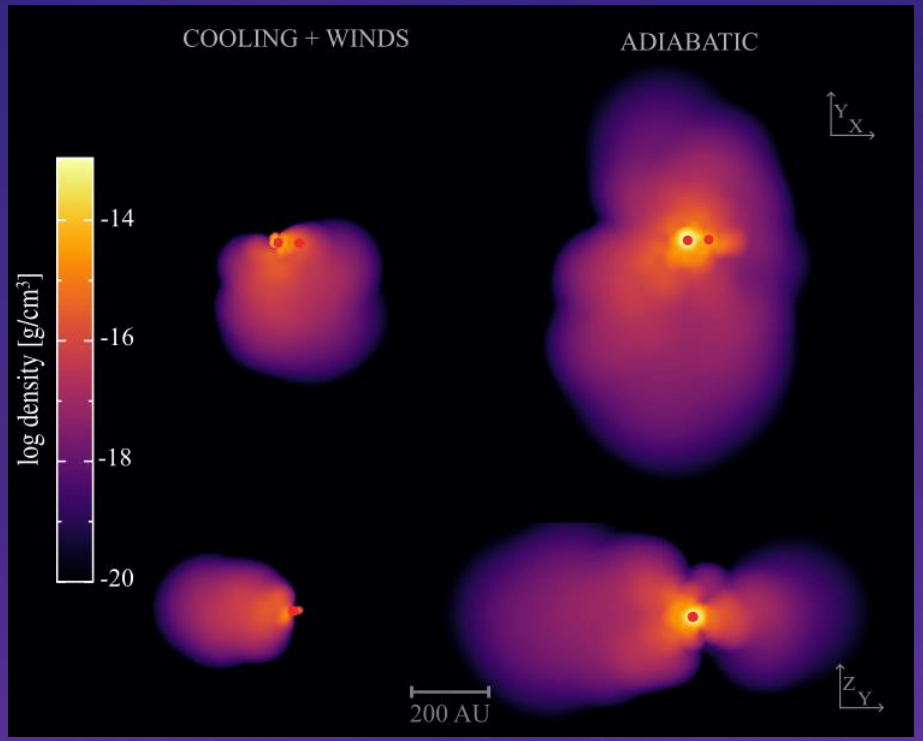
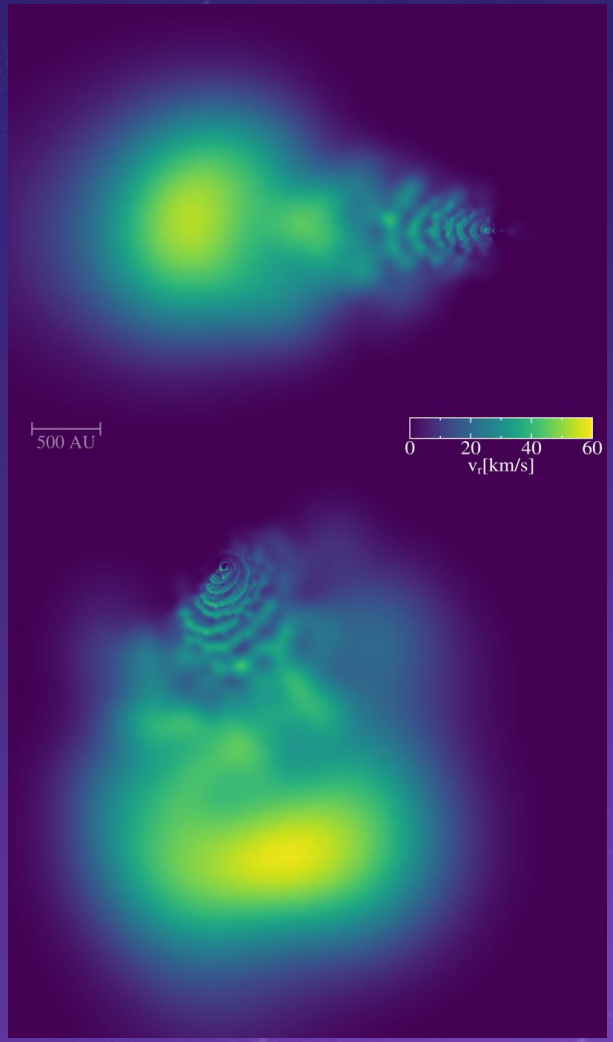
More snapshots





Stellar profiles