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# **Xtreme progenitors of Gamma-ray bursts**

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**Los Alamos National Laboratory**

**Scientific Undergraduate Laboratory Internship - 2023**

# Vela Missions

# Vela Missions

- Classified missions led by the United States Air Force. Operable from 1963 - 1985
  - Purpose - monitor Soviet Union and any possible nuclear tests
- Scientists at LANL and Sandia were ones to monitor Vela and create its instrumentation
- The Vela satellites detected ~70 gamma-ray burst (GRB) during their deployment.
- Controversy behind if Vela detected missions here on earth.

# Vela Missions

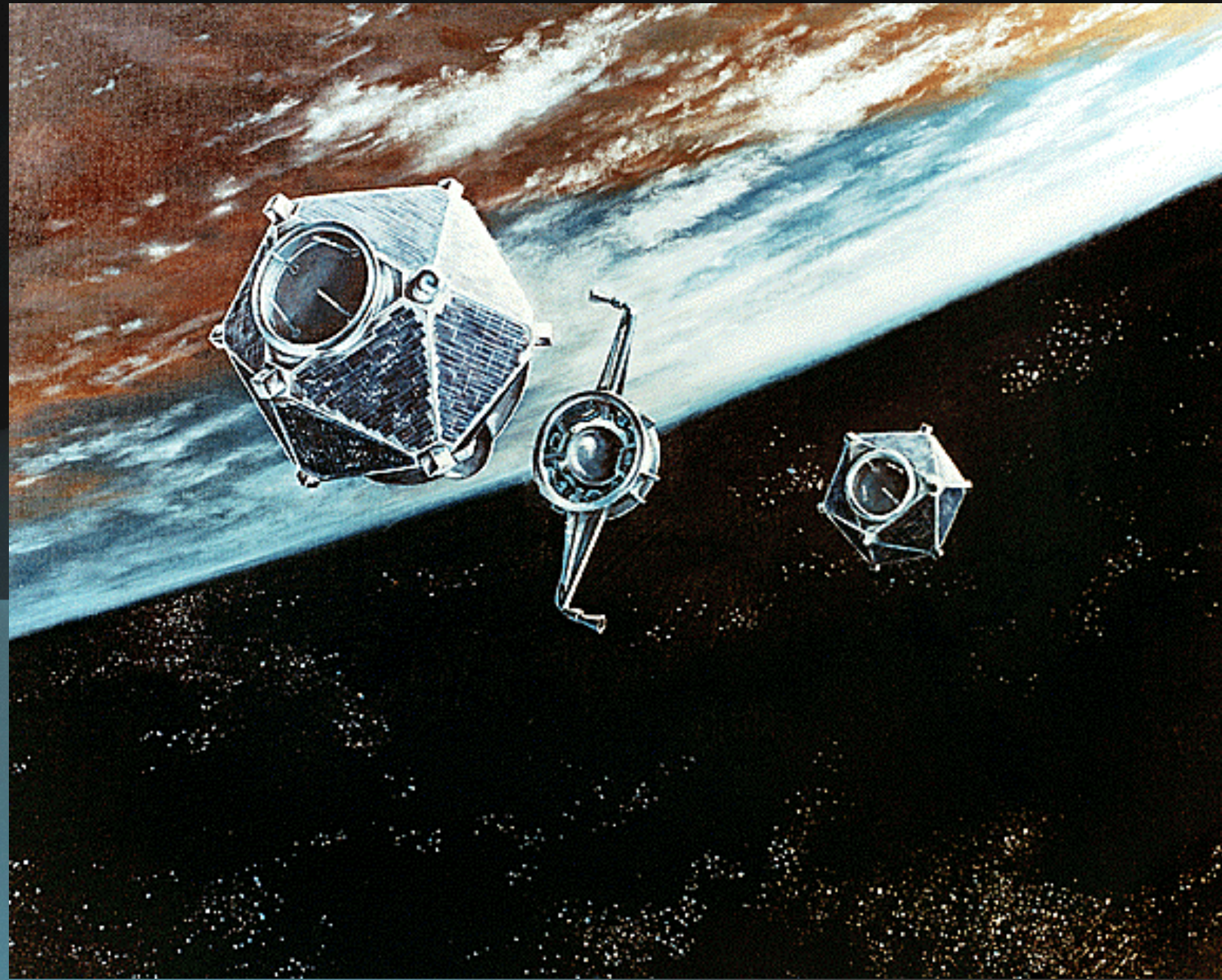


Image credit: NASA

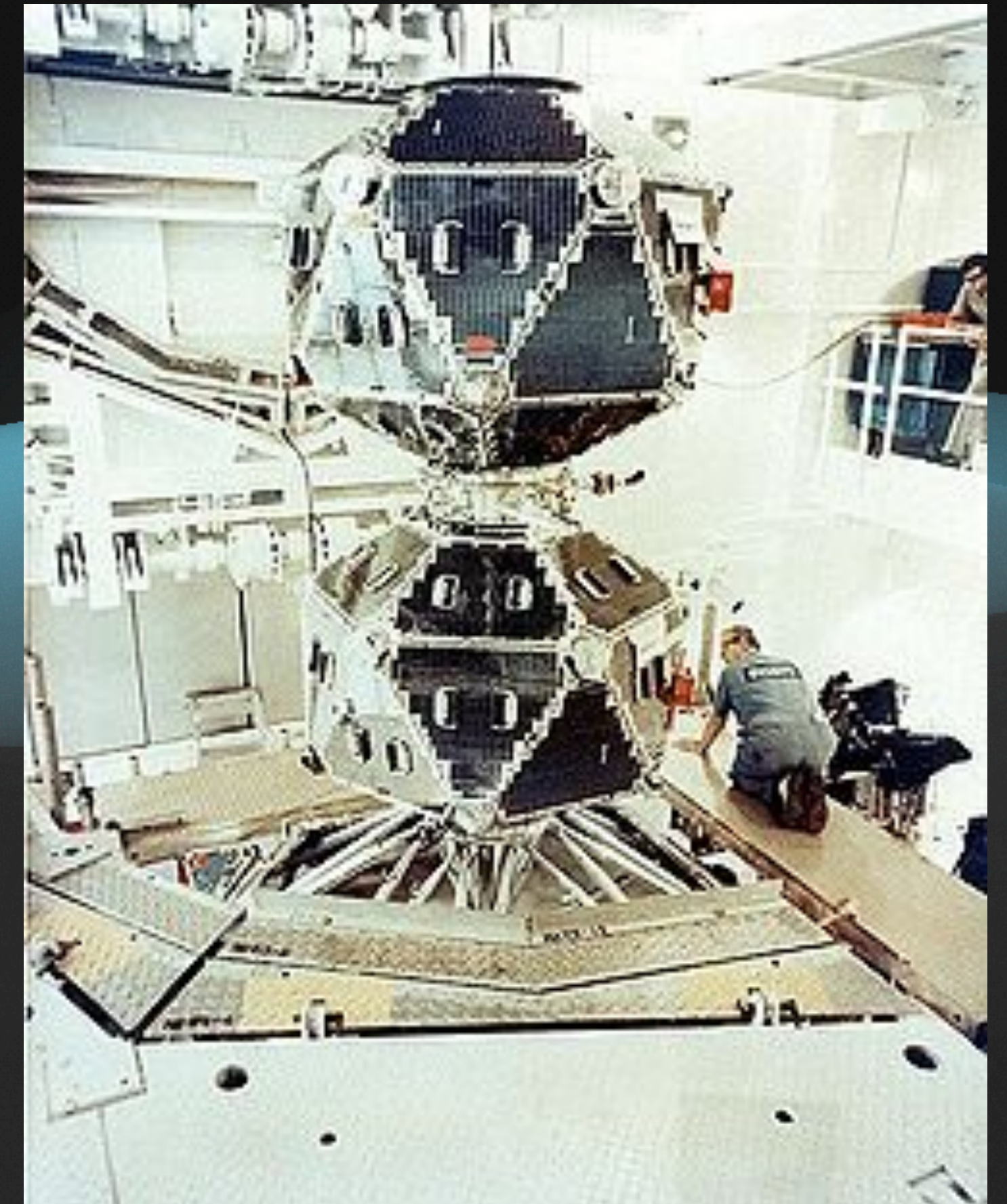
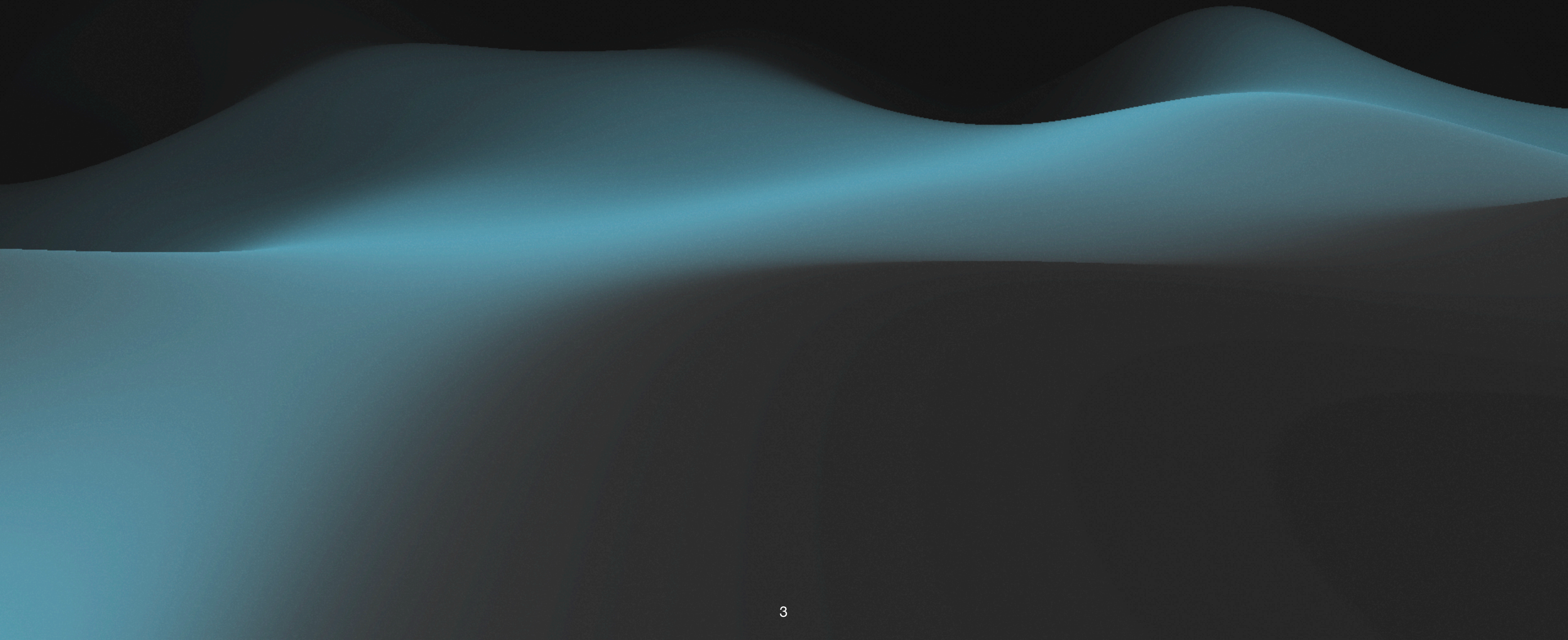


Image credit: Los Alamos National Laboratory

# Gamma-ray bursts



# Gamma-ray bursts

- Gamma-ray bursts are typically classified as “short” or “long”
- They are categorized by their gamma ray emission, Short GRBs have gamma-ray emission less than 2 seconds and long GRBs are greater than 2 seconds.
- Within long GRBs, further categorized as radio-loud or quiet. Radio loud are more energetic and have longer gamma-ray emission,
- Uncovering the progenitors of radio-loud GRBs, see Lloyd-Ronning et al. (2021, 2022)
- We’re studying a binary system with a massive star and black hole.

# Gamma-ray bursts



Image credit: Carl Knox



Image credit: Science Photo Library - Mehau Kulyk

# Massive star and black hole progenitor

- We choose an orbital separation far enough to study the tidal interaction prior to core collapse and black hole merge.
- The mass of the massive star is larger than the black hole. Allow us to model black hole as point mass.  $25 M_{\odot}$  and  $15 M_{\odot}$ , respectively
- Behavior of gas, self-gravity, tidal interaction, magnetic field, and “puffing” of star.
- Time scale is on 10M years, with various stopping conditions. Model this system until the star’s demise,

# Set up illustration

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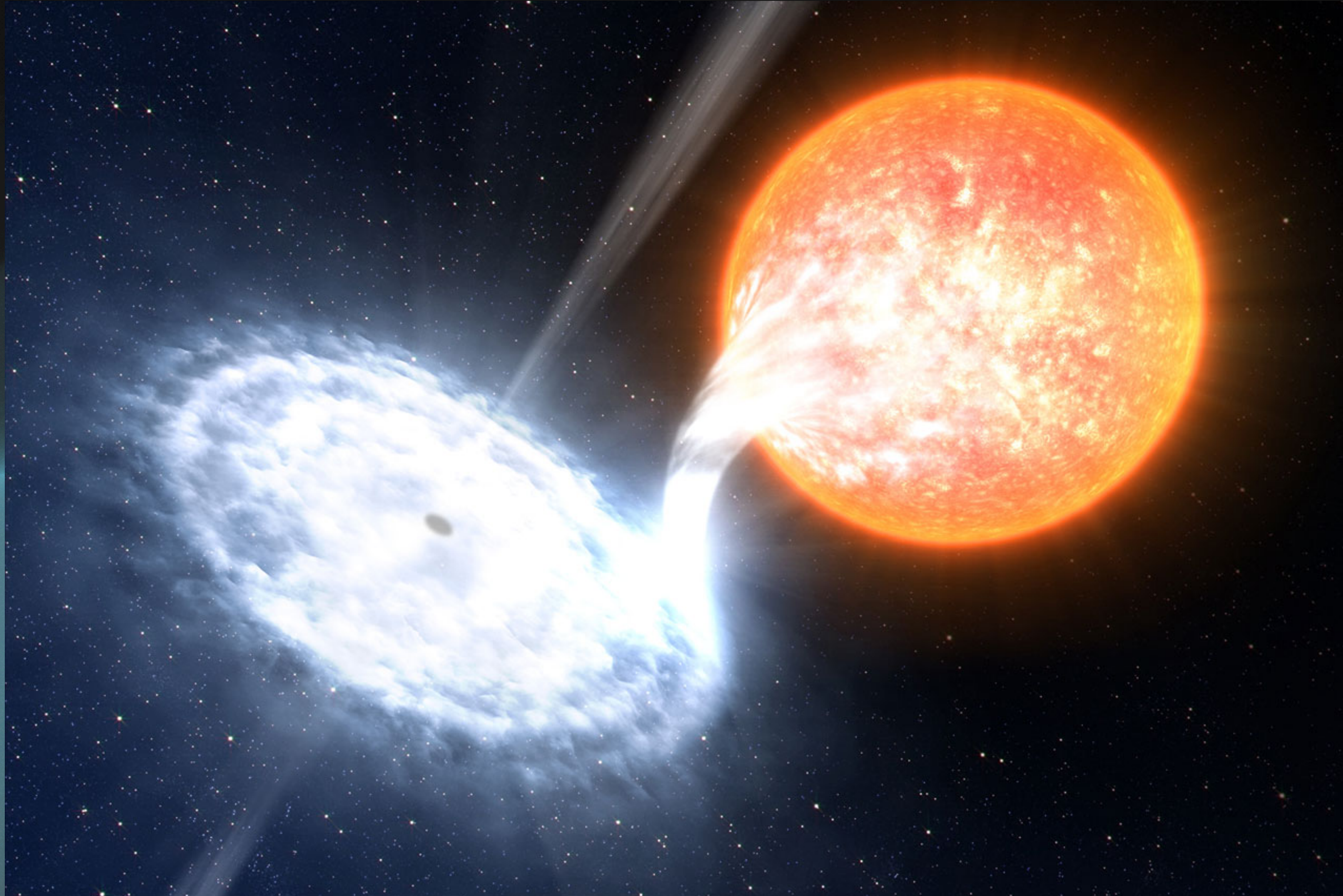
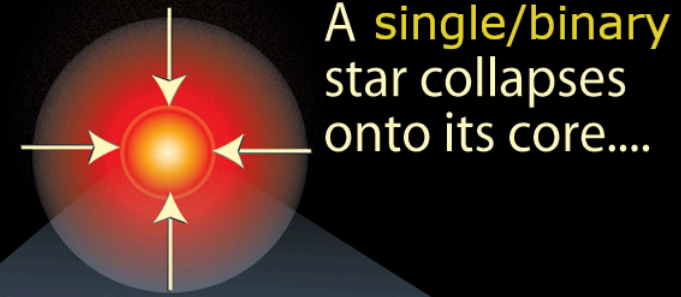


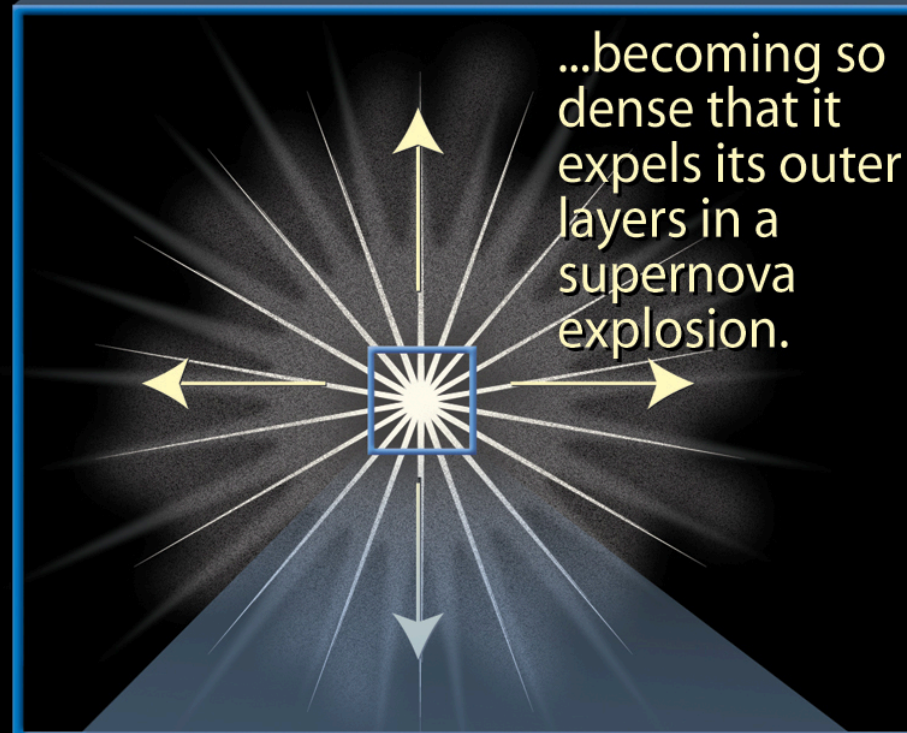
Image credit: ESO/L. Calçada  
5

# Set up illustration

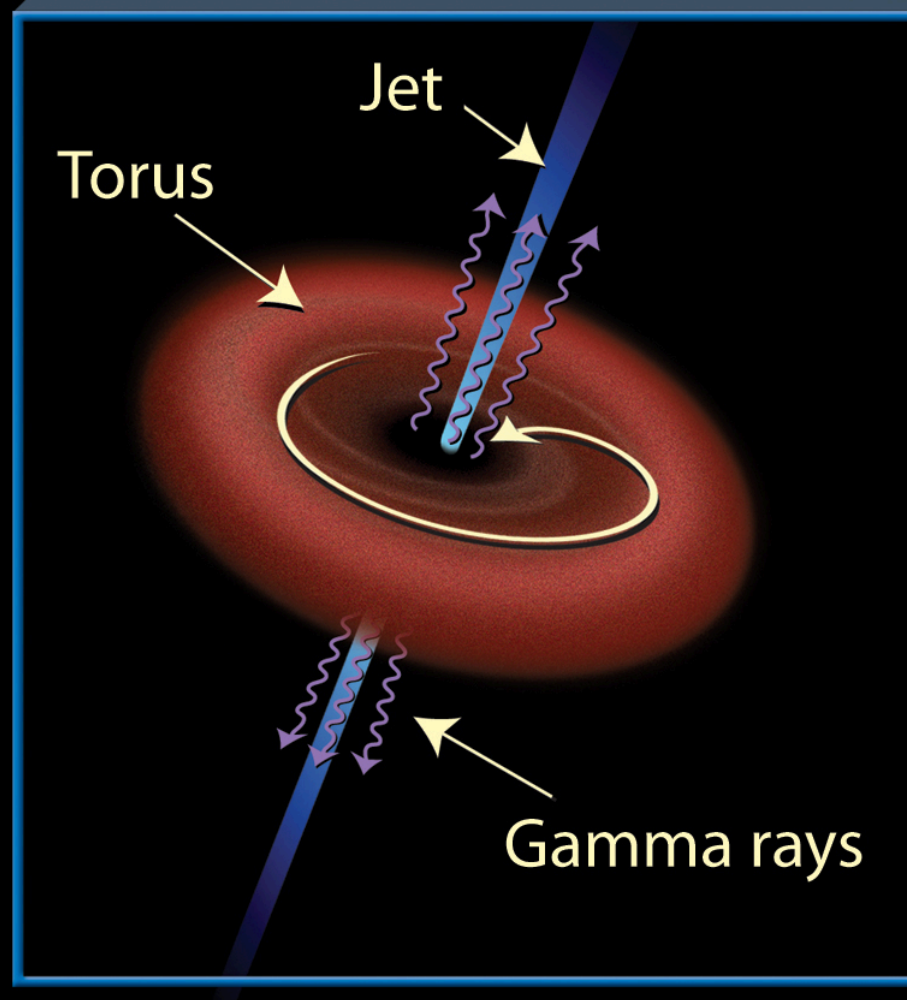
**Long gamma-ray burst**  
( $>2$  seconds' duration)



A *single/binary* star collapses onto its core...



...becoming so dense that it expels its outer layers in a supernova explosion.



Jet

Torus

Gamma rays

# Modules for Experiments in Stellar Astrophysics (MESA)

MESA

- 1D open source, multiphysics, stellar evolution code.
- Allows users to create a binary model with various properties.
  - Orbital period, metallicity, mass, convection, and dynamo
  - We use the HPC chicoma platform to run our simulations and conduct our analysis with python

# Results - Angular momentum

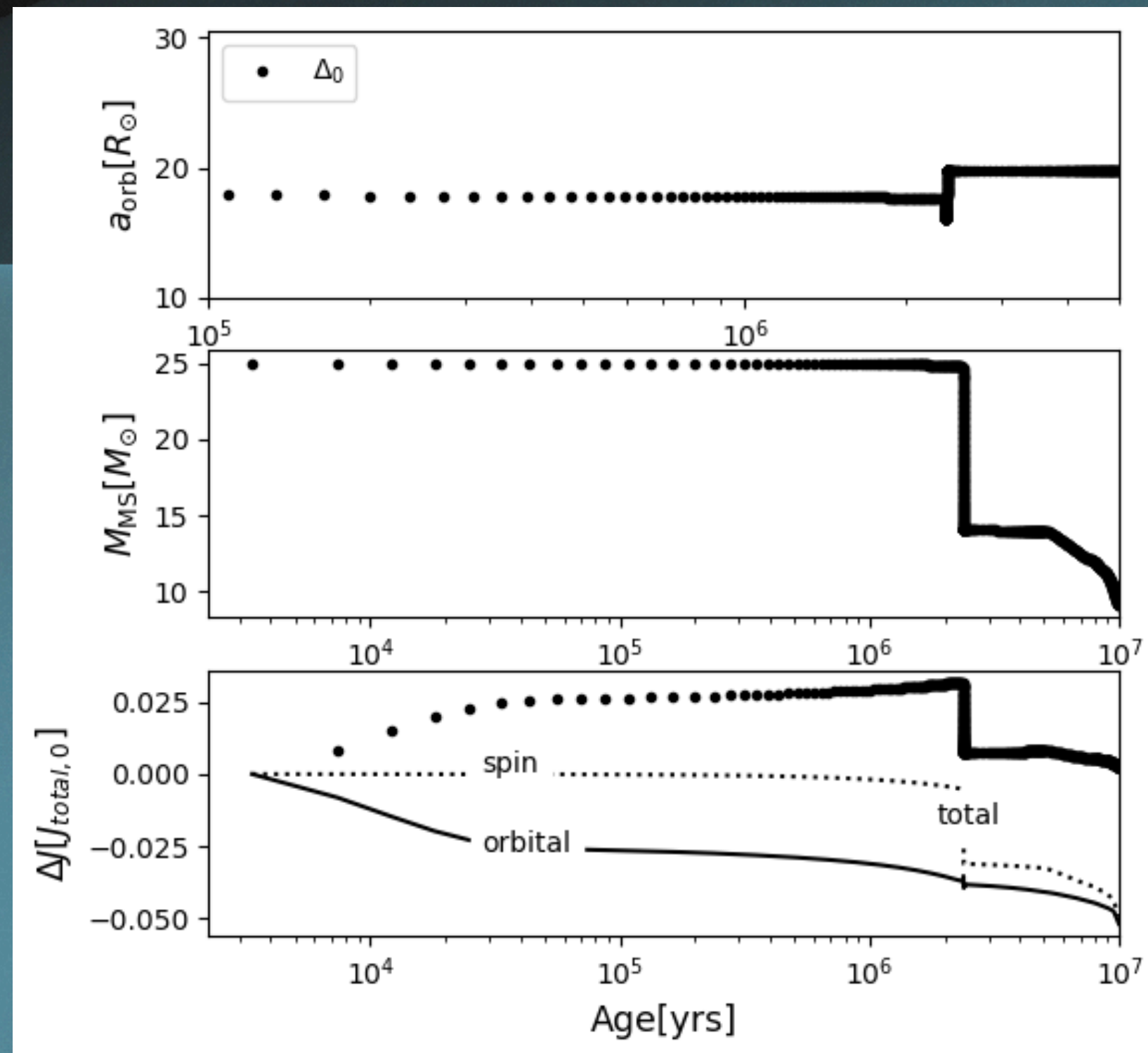
Massive star -  $25 M_{\odot}$  & Black Hole -  $15 M_{\odot}$

Tidally locked binary

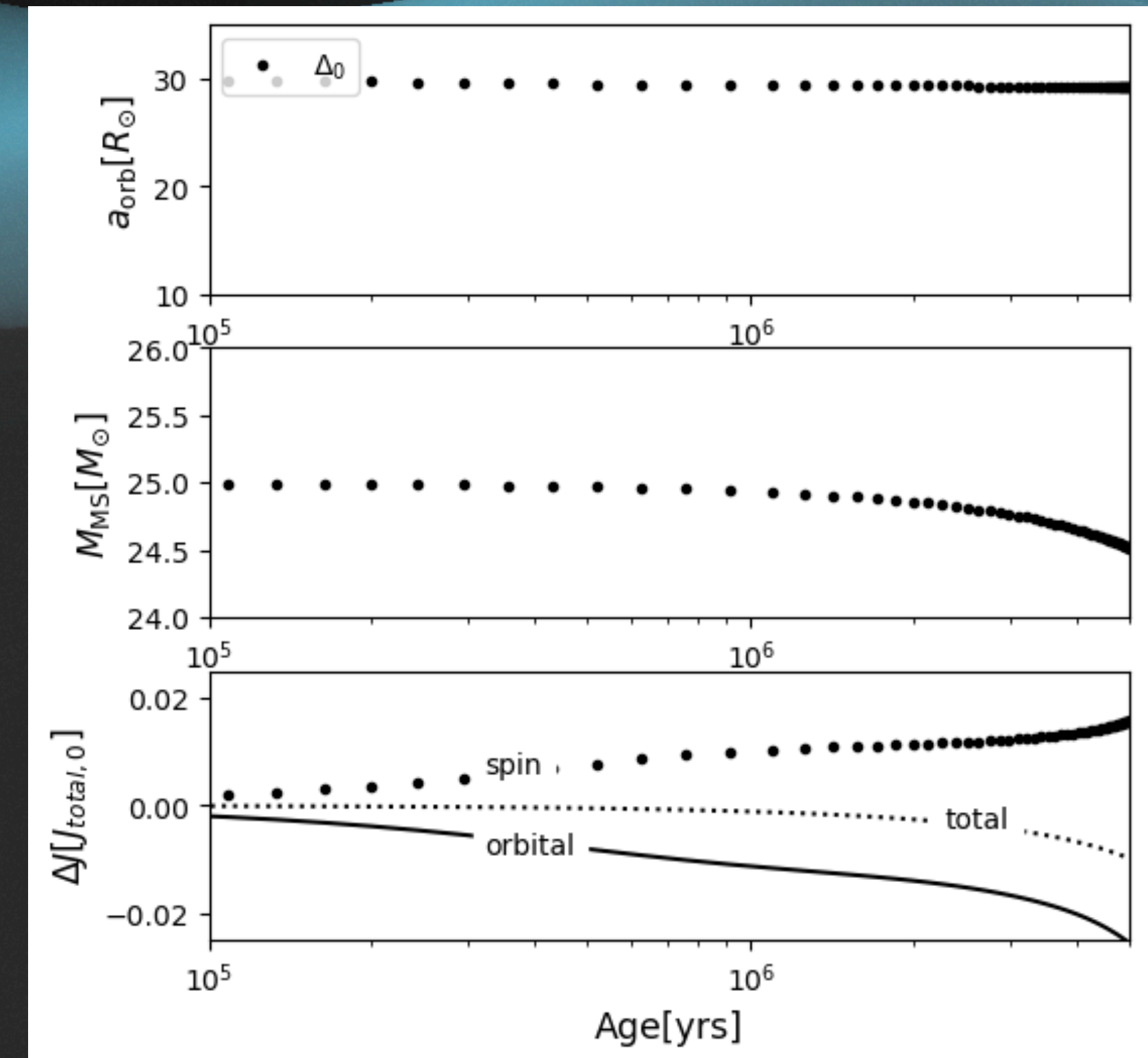
$z = 0.01$

No initial rotation on MS

1.5 day orbital period



3.0 day orbital period



# Results - density convergence

Massive star -  $25 M_{\odot}$  & Black Hole -  $15 M_{\odot}$

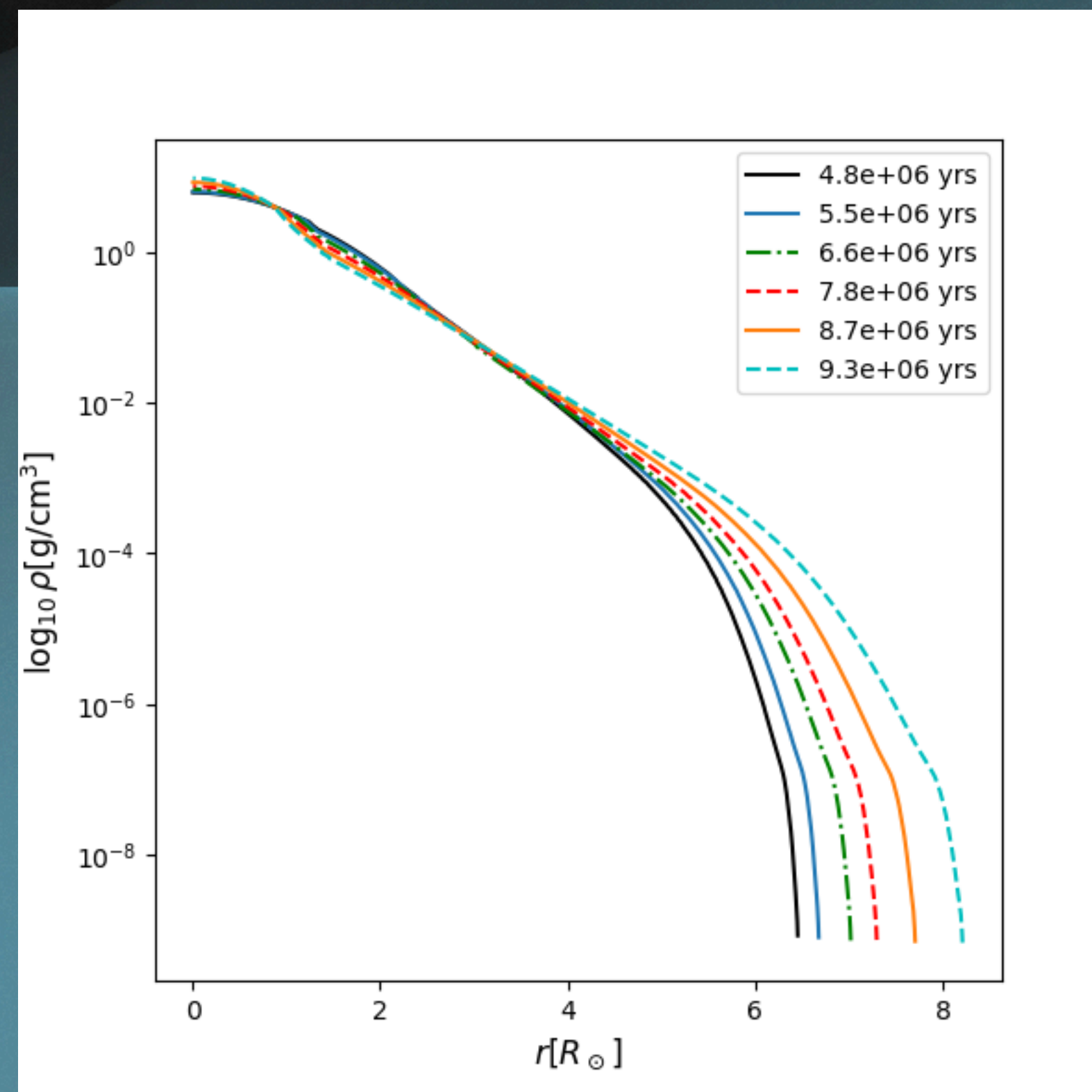
Tidally locked binary

3.0 orbital period

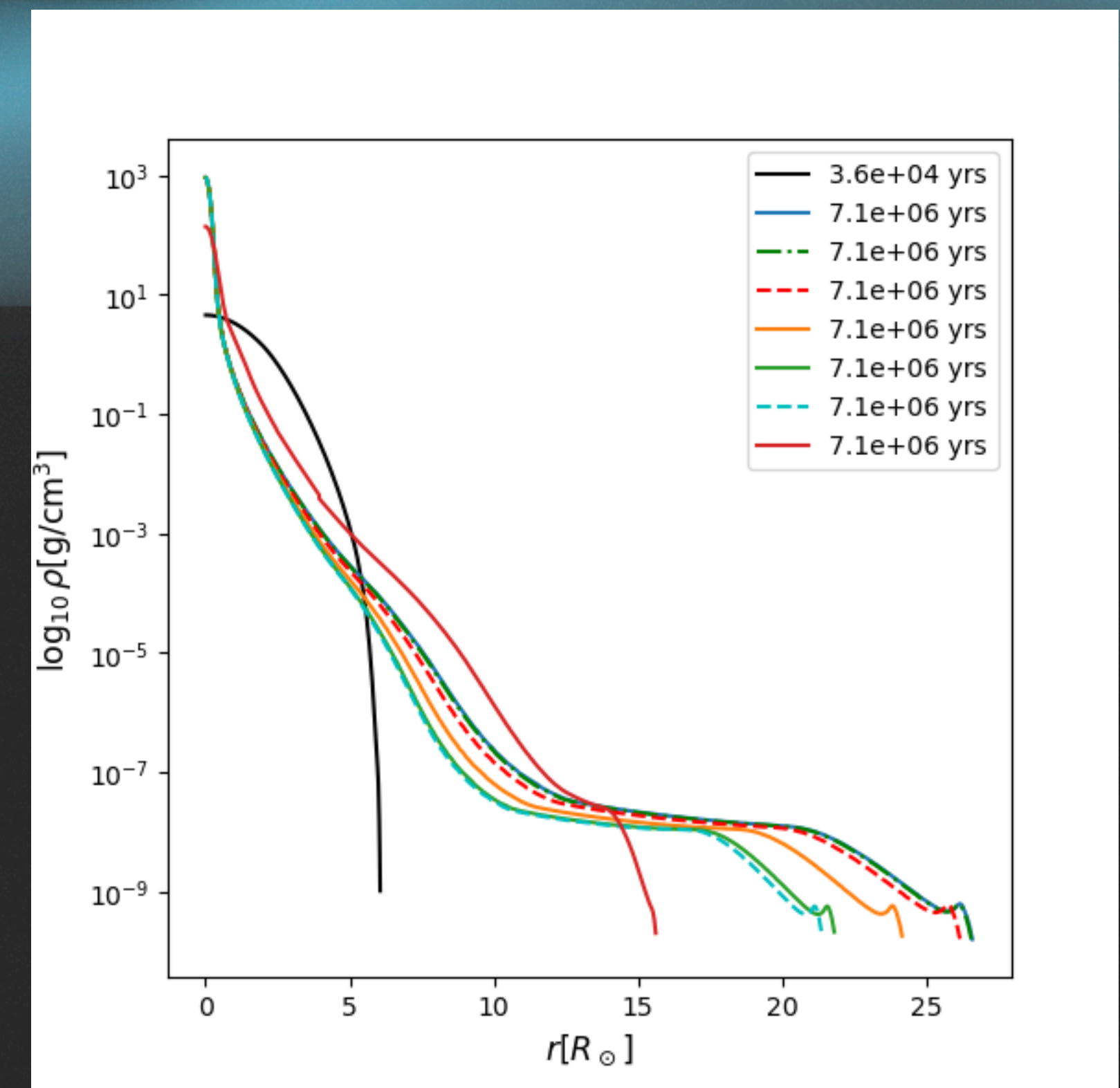
$z = 0.01$

No initial rotation on MS

## 1.5 day orbital period



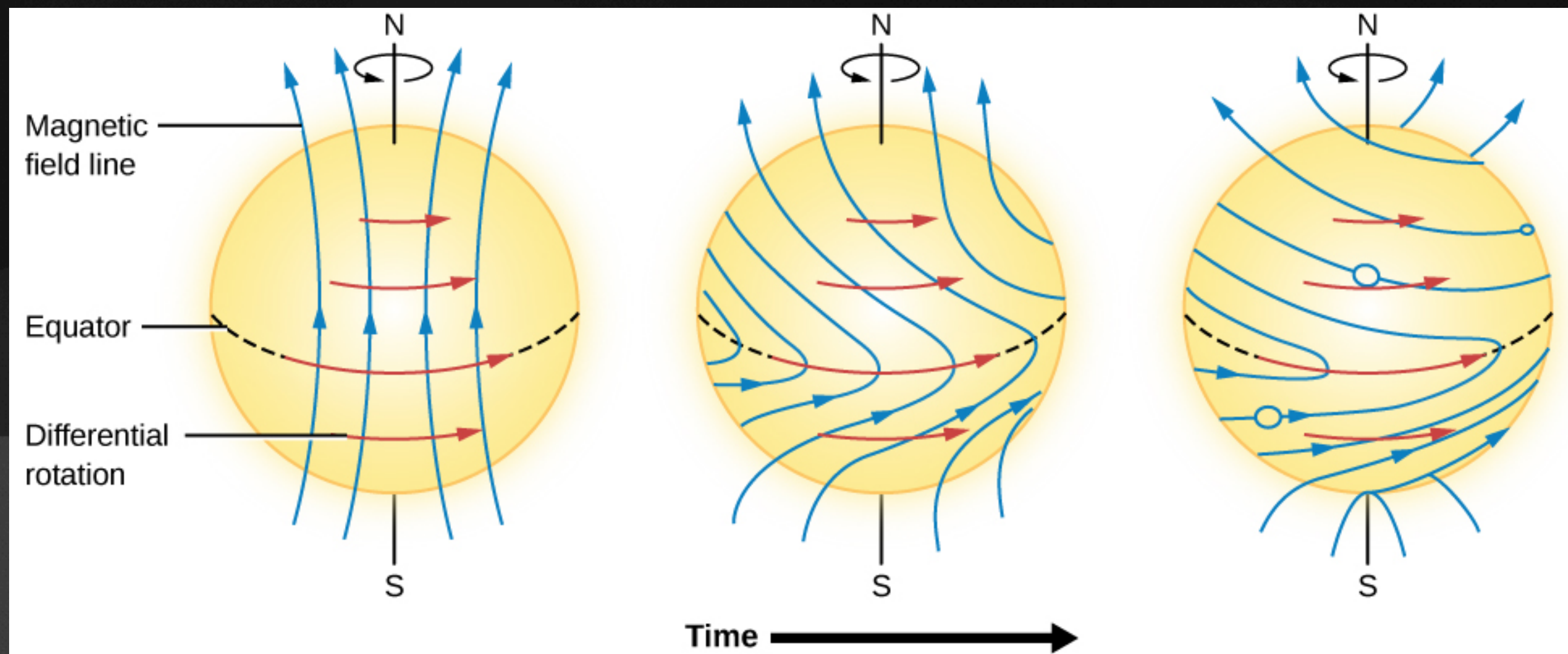
## 3.0 day orbital period



## Spruit-Taylor Dynamo

- Taylor instability - dense fluid lying on top of another fluid under the influence of gravity. Example - Oil on top of water. Disrupt this system and study.
- Spruit says - Magnetic field generated by a star's differential rotation but the fluid inside of the star experiences Taylor instability.
- Angular momentum transport supported by star's dynamo, and the dynamo must be able to support Taylor instability.
- External torques from stellar wind or interior of star could affect AM

# Spruit-Taylor Dynamo



Credit: Libretexts

# Results - Spruit-Taylor Dynamo

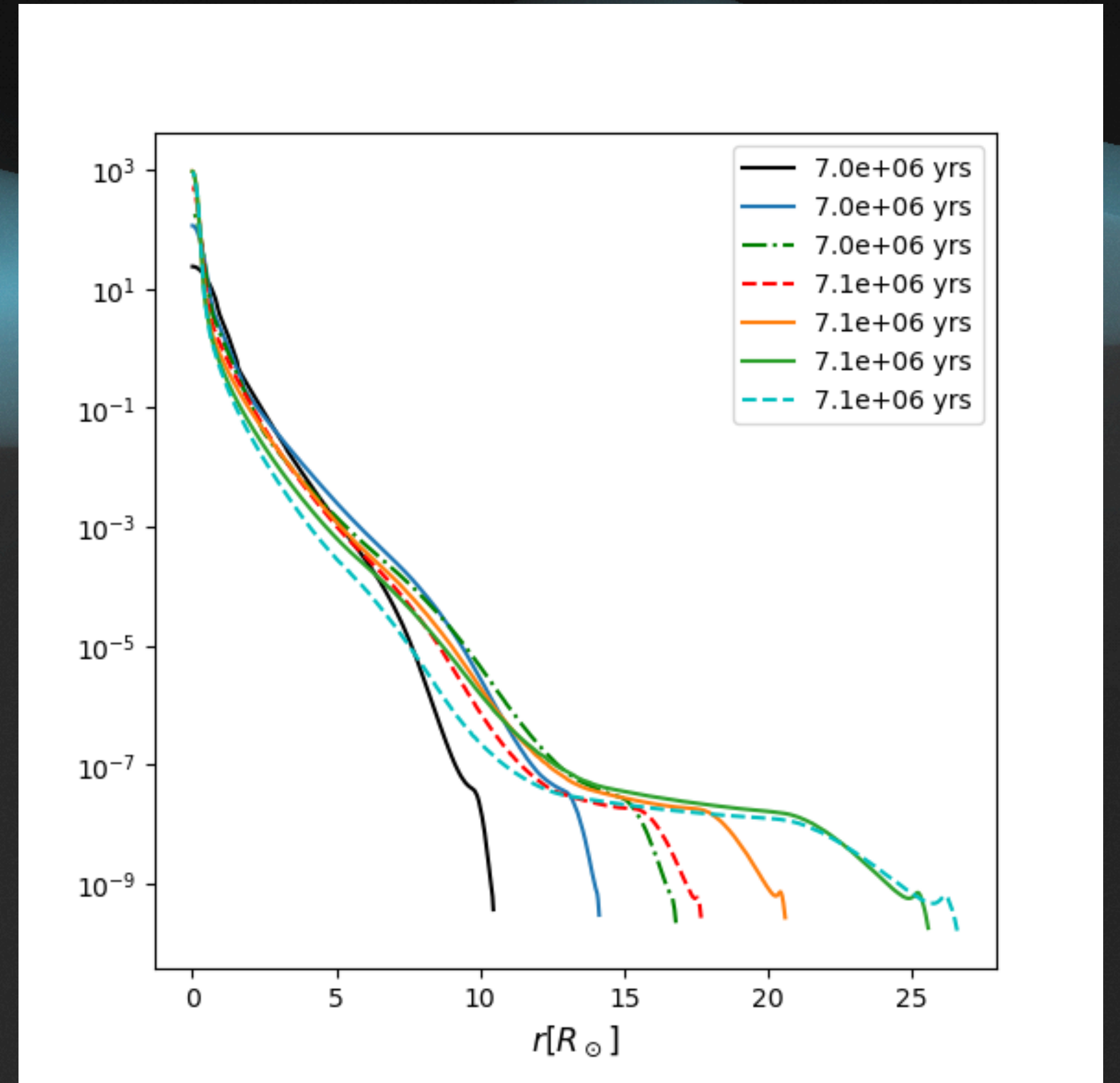
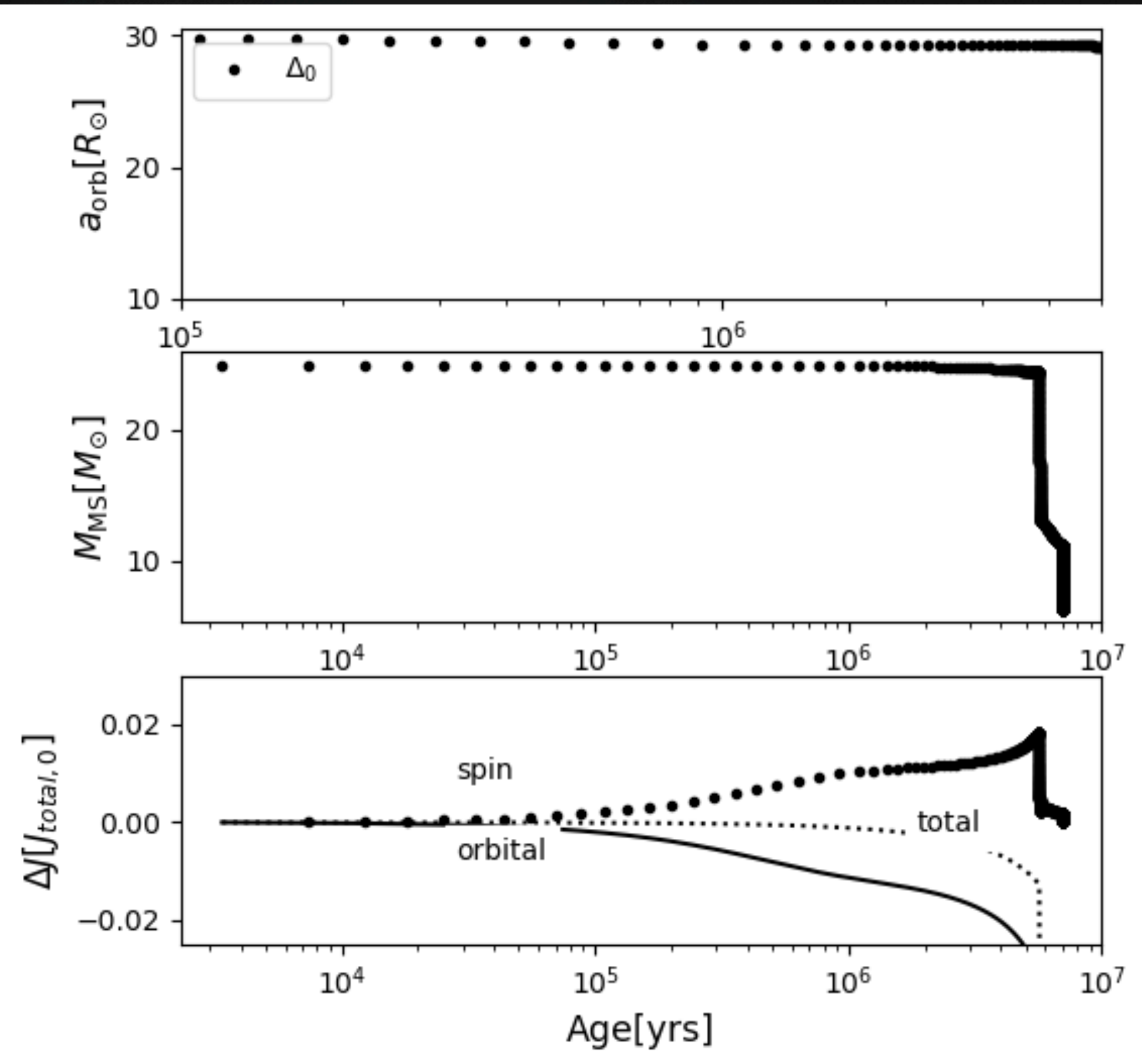
Massive star -  $25 M_{\odot}$  & Black Hole -  $15 M_{\odot}$

Tidally locked binary

3.0 orbital period

$z = 0.01$

Initial rotation - 91.77 km/sec



# Results - Spruit-Taylor Dynamo

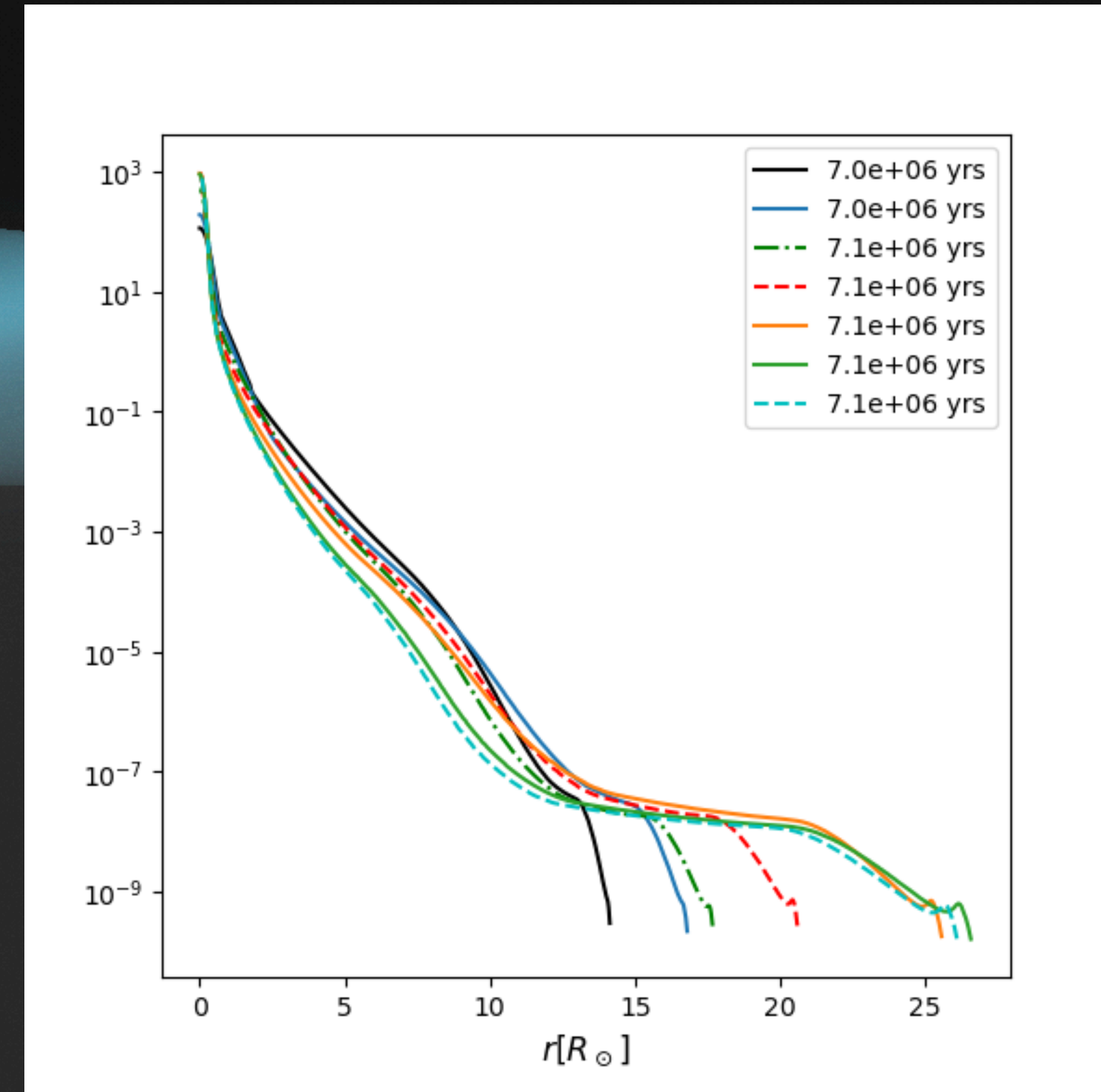
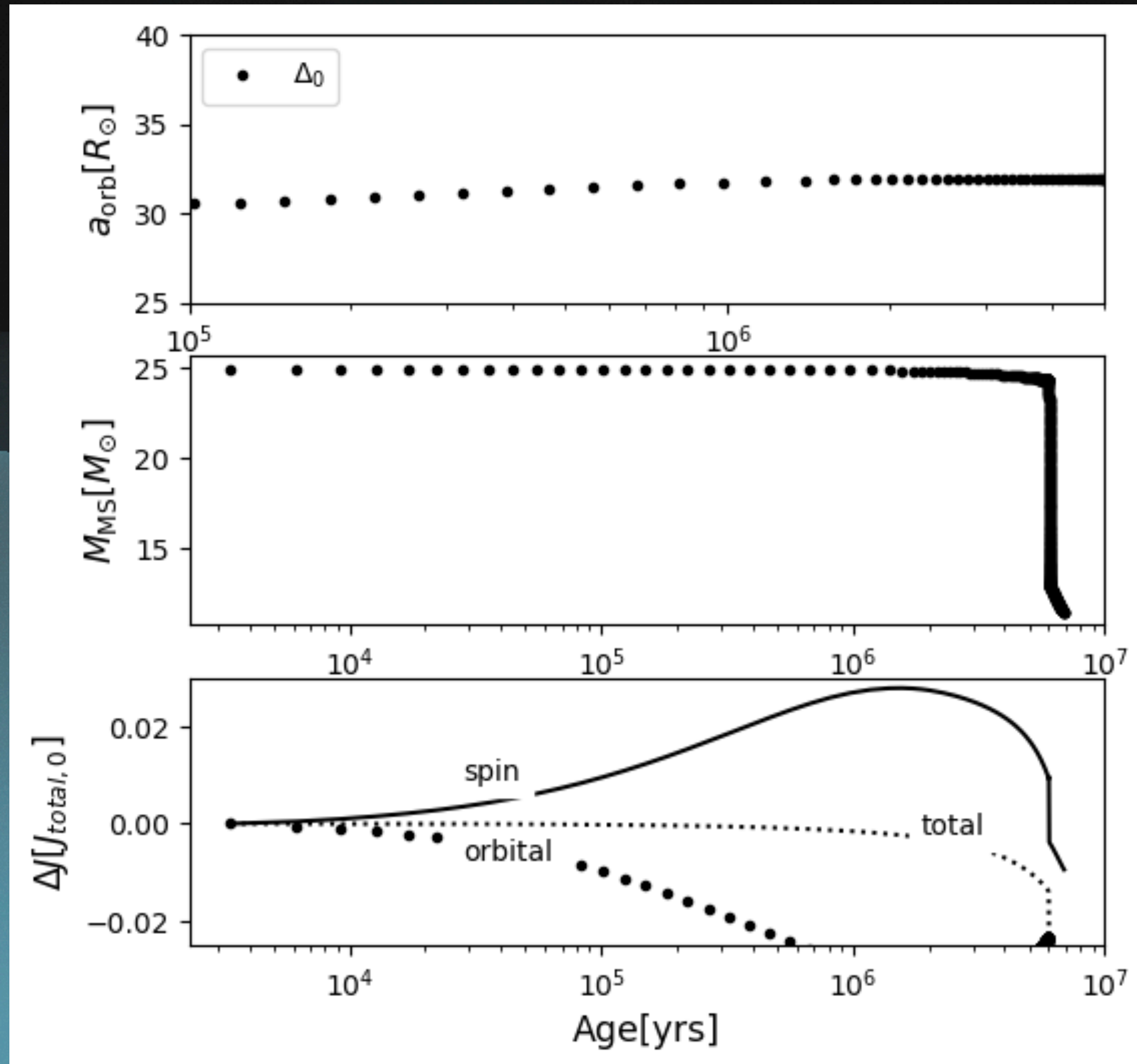
Massive star -  $25 M_{\odot}$  & Black Hole -  $15 M_{\odot}$

Tidally locked binary

3.0 orbital period

$z = 0.01$

Initial rotation - 45.89 km/sec



# Current Investigation & Future

- Continue to study binary and star profile.
- Study output that could produce a radio-loud GRB.
- Spruit-Taylor dynamo, rotating convection, and MS with an initial rotation. *Oh my!*
- Follow-up, GRMHD study of the relativistic jet that is emitted from the binary based on parameters that are being investigated.

# Acknowledgments

- Nondimensional numbers
- Osborne Reynolds
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A black and white photograph of a modern architectural interior. The scene is dominated by curved, light-colored concrete walls and a ceiling. A bright opening in the distance creates a strong light source, casting long, soft shadows across the curved surfaces. The overall atmosphere is minimalist and dramatic.

**Thank you!**