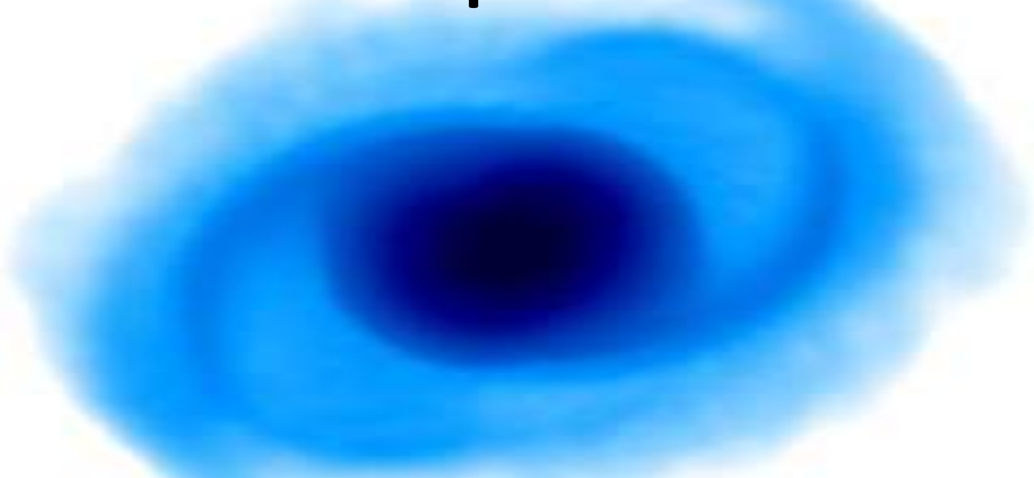
# The role of stellar rotation in Tidal Disruption Events



Andrea Sacchi (Pavia), Giuseppe Lodato (Milano)

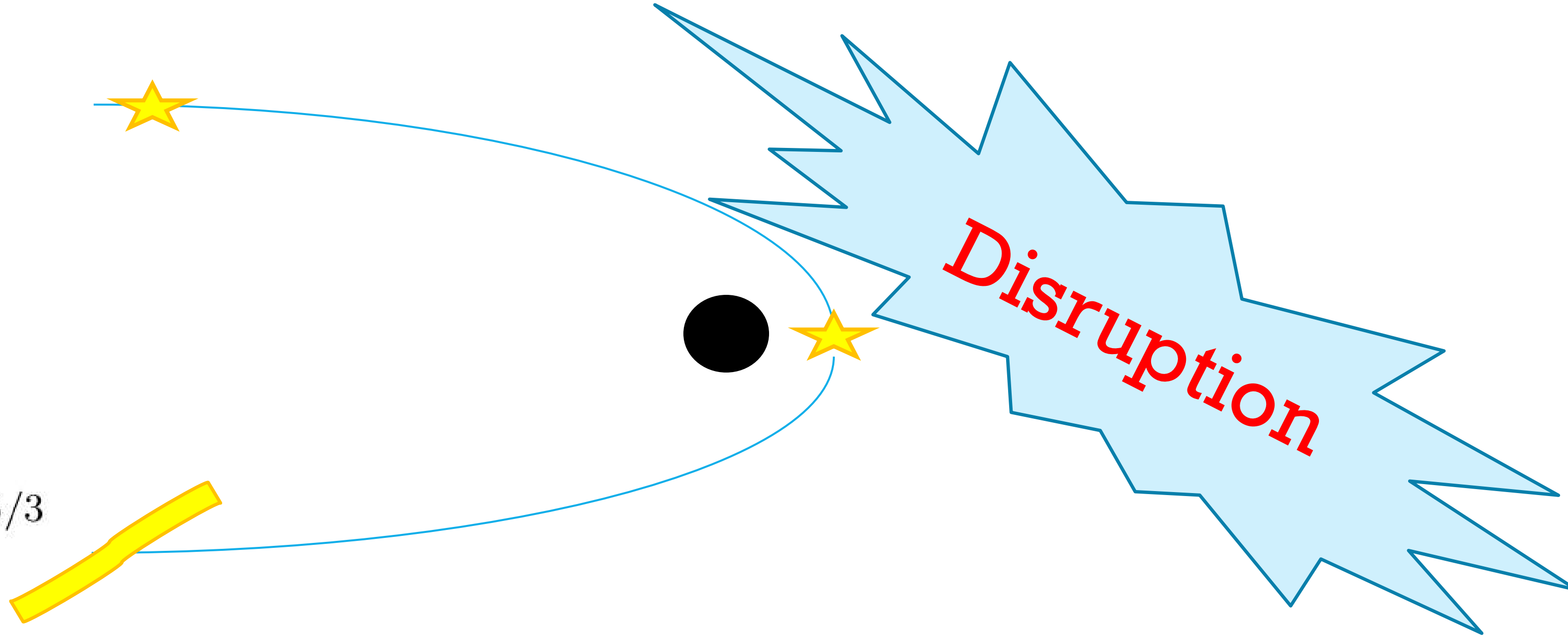
*1st Phantom European Users Workshop, 18th June 2018, Milan*

# Outline

- Introduction to Tidal Disruption Events
- Analytical estimates of stellar rotation effects
- Setting up a rotating star
- Simulations of TDEs with rotating stars
- Conclusions and future horizons

# Introduction to Tidal Disruption Events (1)

- $R_t = R_\star \left(\frac{M_h}{M_\star}\right)^{1/3}$
- $T = 2\pi G M_h (2E)^{-3/2}$
- $\Delta E \simeq \left.\frac{\mathrm{d}E}{\mathrm{d}r}\right|_{R_p} \Delta r$
- $\dot{M} = \frac{\mathrm{d}M}{\mathrm{d}E}\frac{\mathrm{d}E}{\mathrm{d}t} \approx \dot{M}_p \left(\frac{t}{t_{min}}\right)^{-5/3}$




(Rees 1988)

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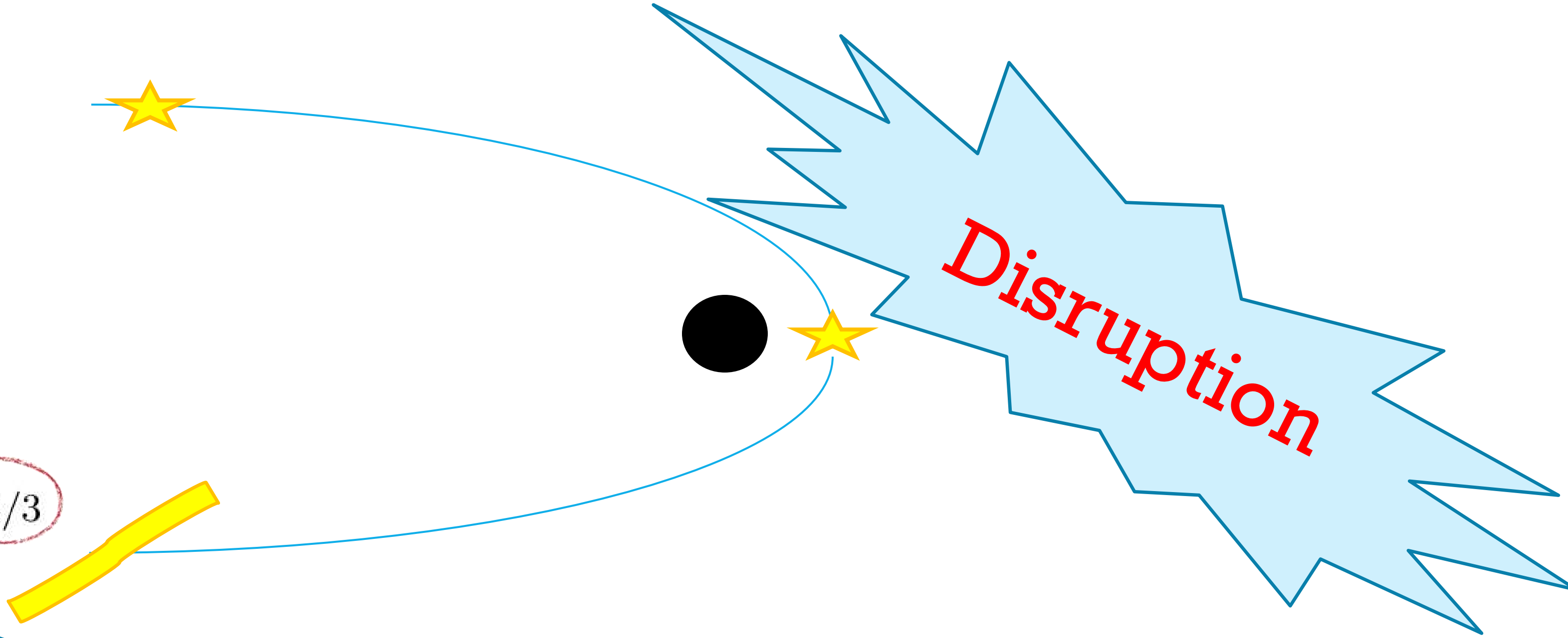
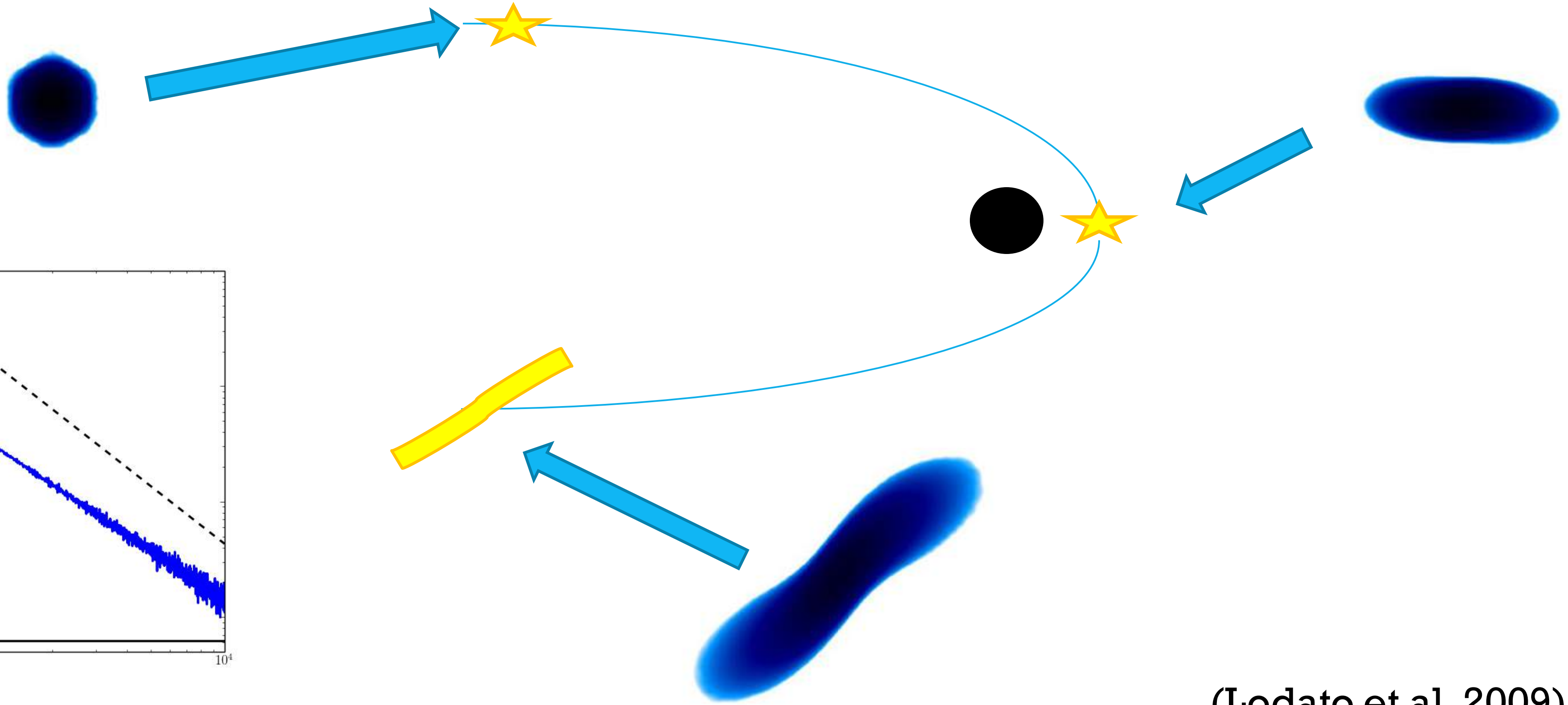


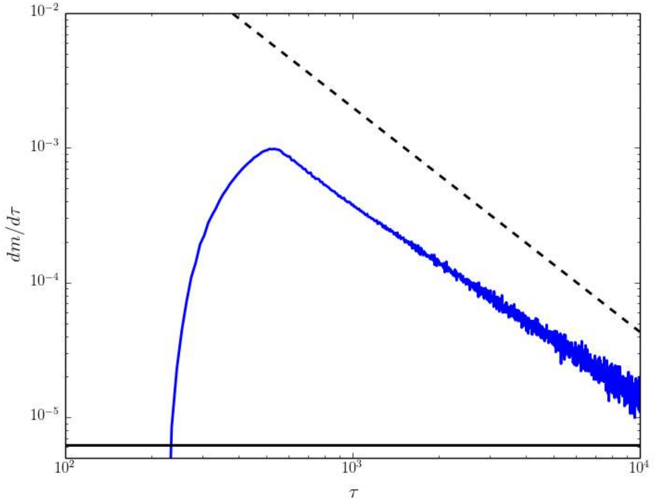

- Several Times super-Eddington luminosity
- Roughly 40 days time-scale
- Peculiar time dependency

(Rees 1988)

# Introduction to Tidal Disruption Events (2)

Polytropic index $\gamma = 5/3$






(Lodato et al. 2009)

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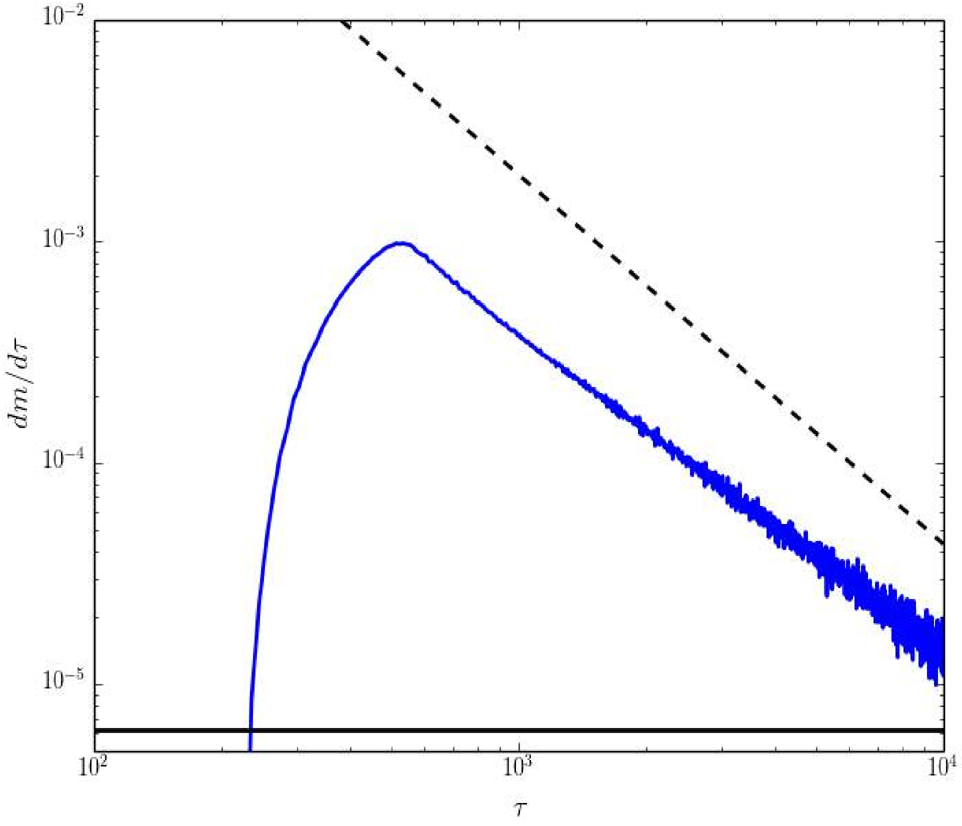
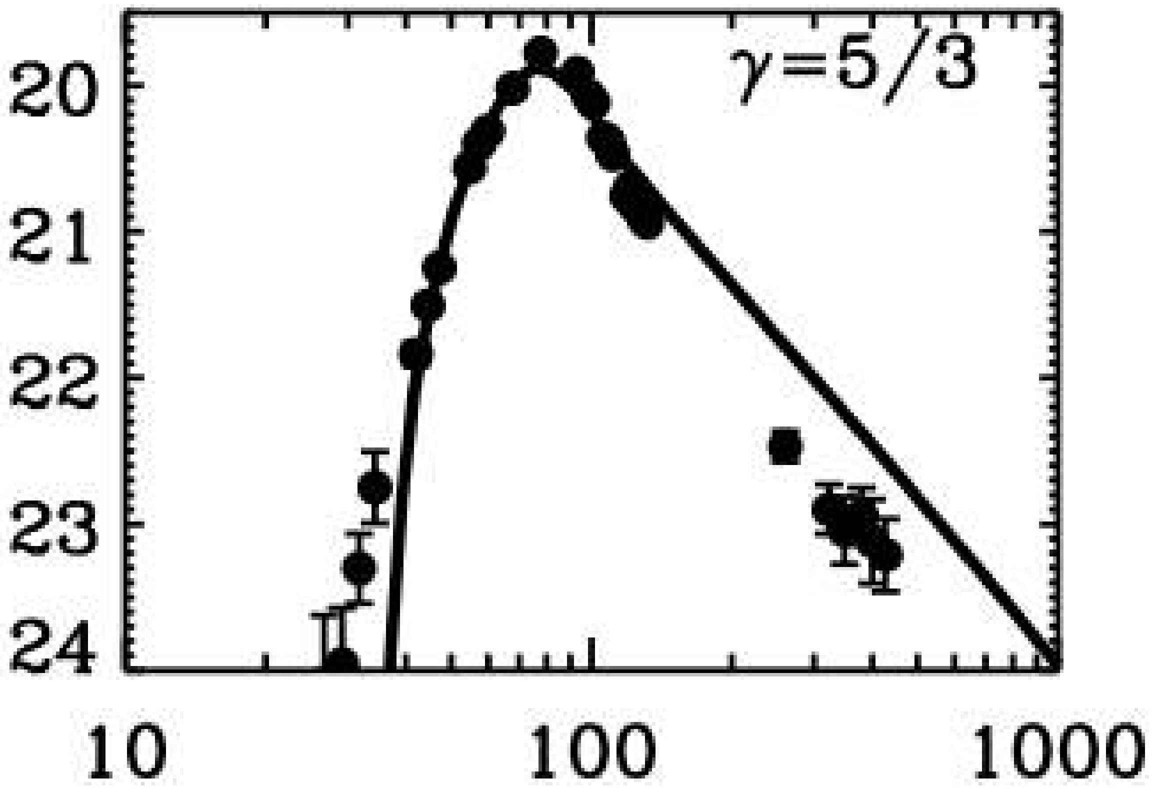



(Lodato et al. 2009)




(Gezari et al. 2012)

# Analytical estimate of stellar rotation effects

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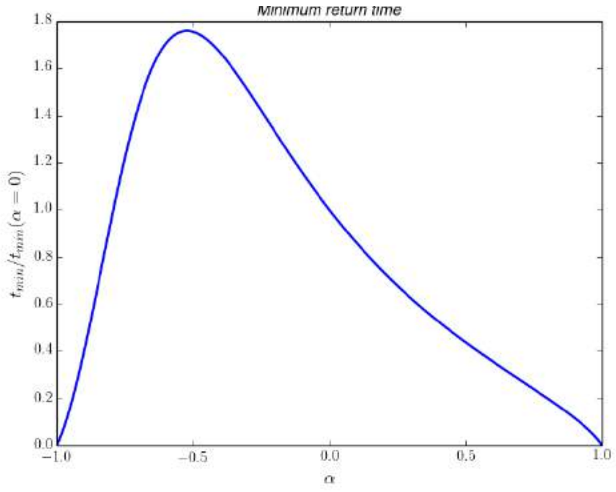
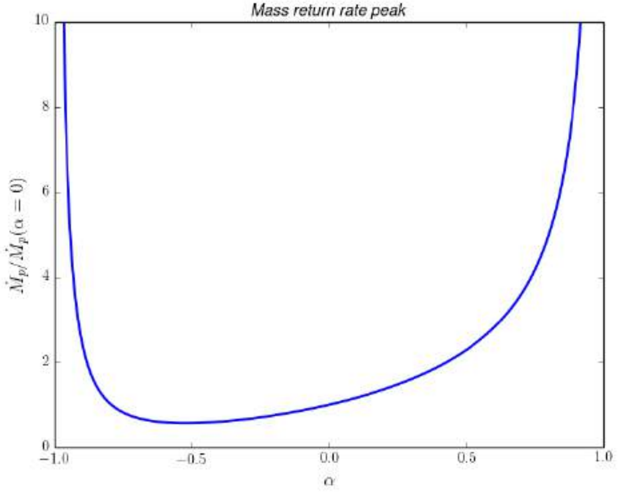
$$\omega_b = \sqrt{\frac{2GM_\star}{R_\star^3}}$$

Break up velocity:
centrifugal force equal
to self-gravity

# Analytical estimate of stellar rotation effects

- Rigid rotation $\alpha = \omega/\omega_b$
- Tidal radius $R_t(\alpha) = R_t(0)(1-\alpha^2)^{-1/3}$
- Energy spread $\Delta E(\alpha) = \Delta E(0)\left[\frac{1+\alpha\sqrt{1-\alpha^2}}{(1-\alpha^2)^{2/3}}\right]$



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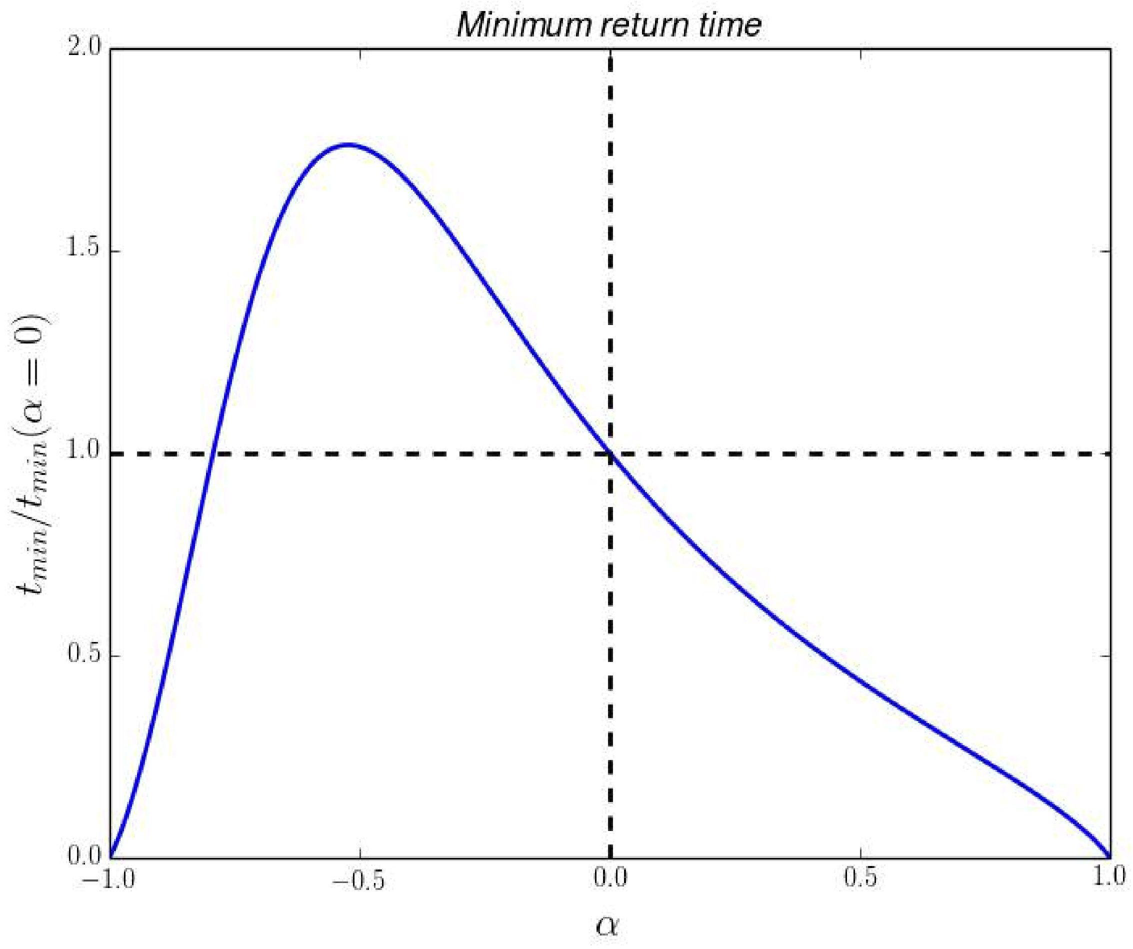


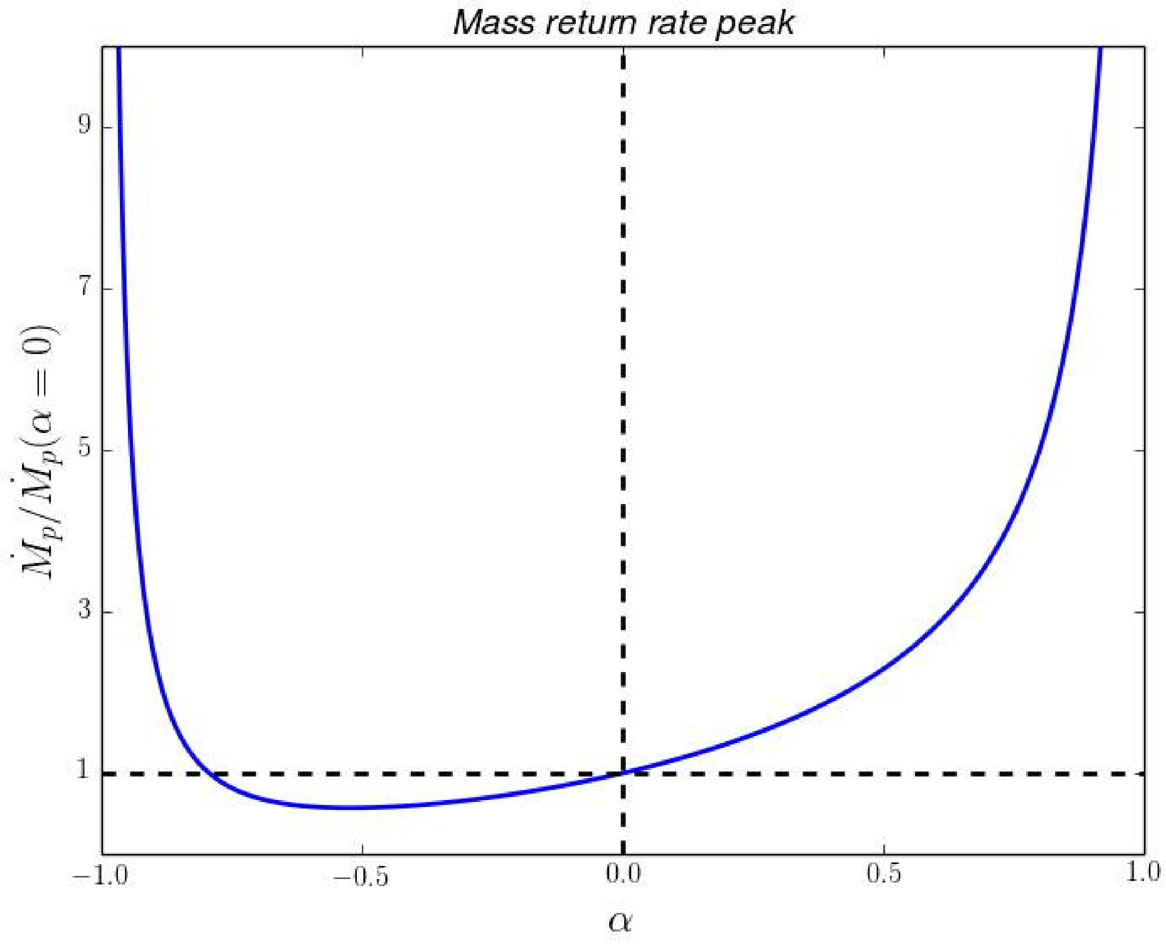

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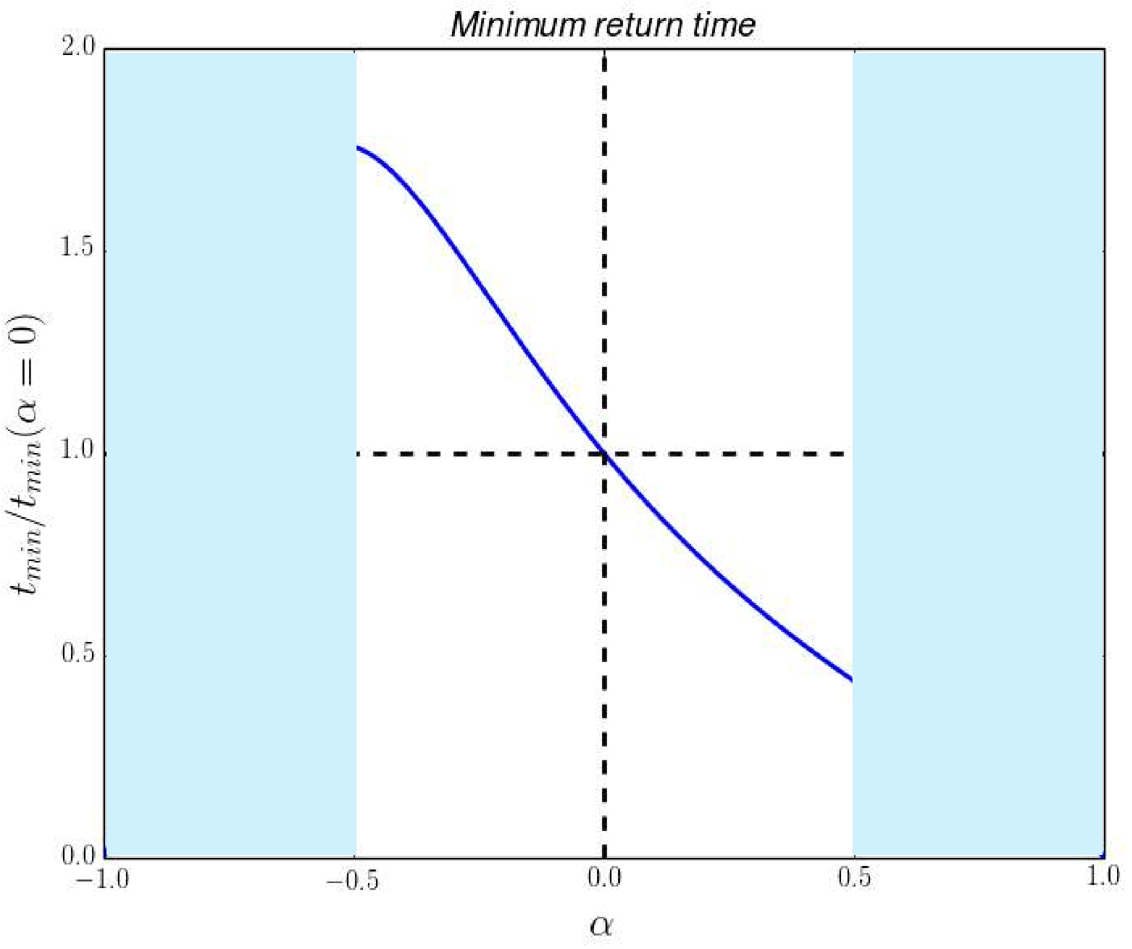
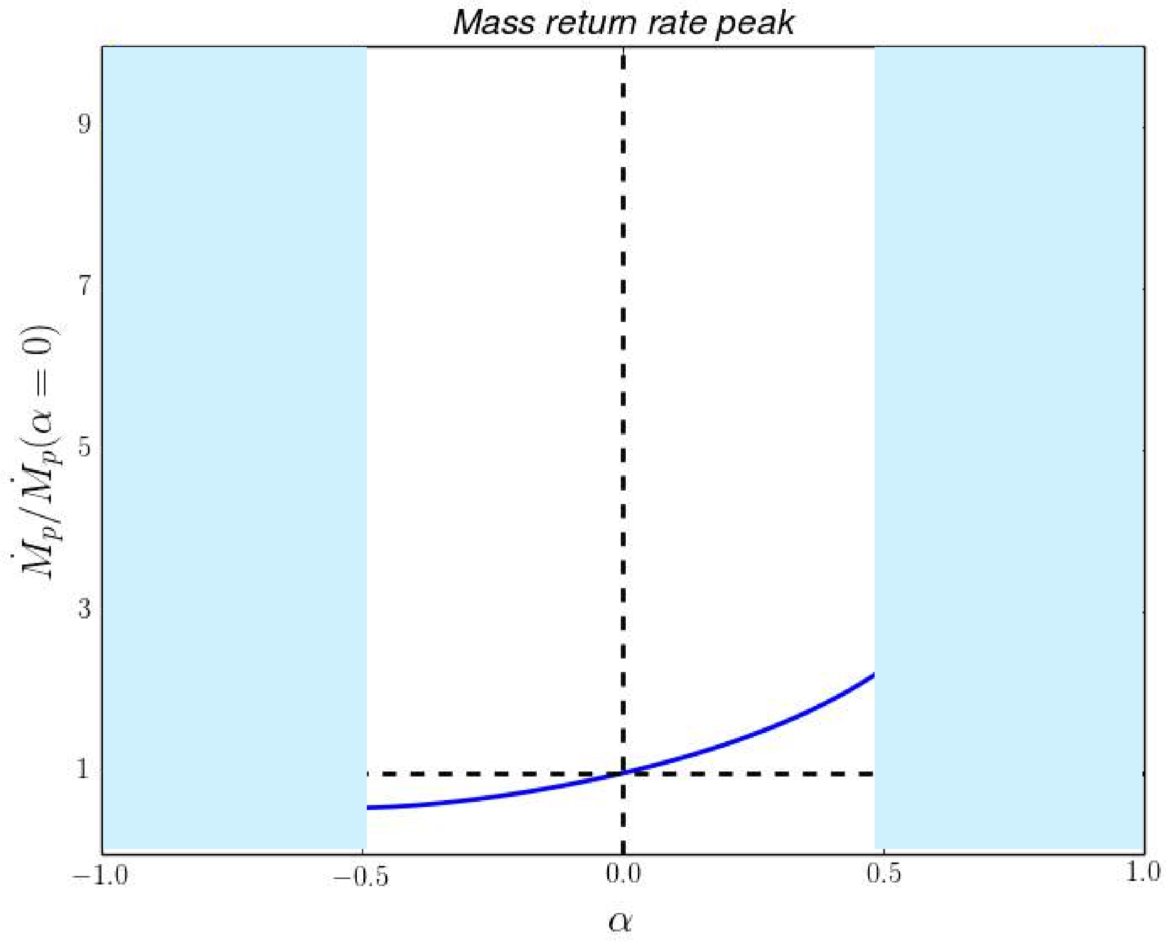
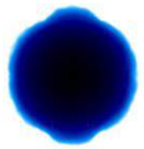


# Setting up a rotating star

- Polytropic sphere $\gamma = 5/3$



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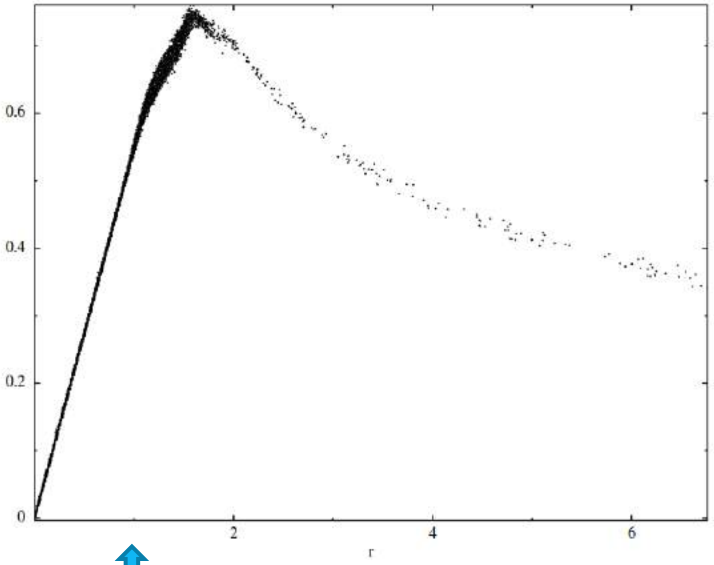
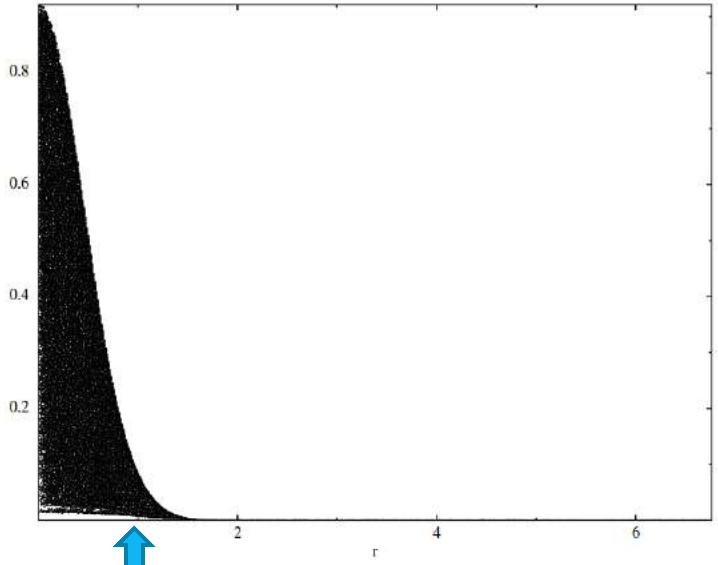
- Checking whether the rotation is still rigid and how fast the star spin

Azimutal velocity



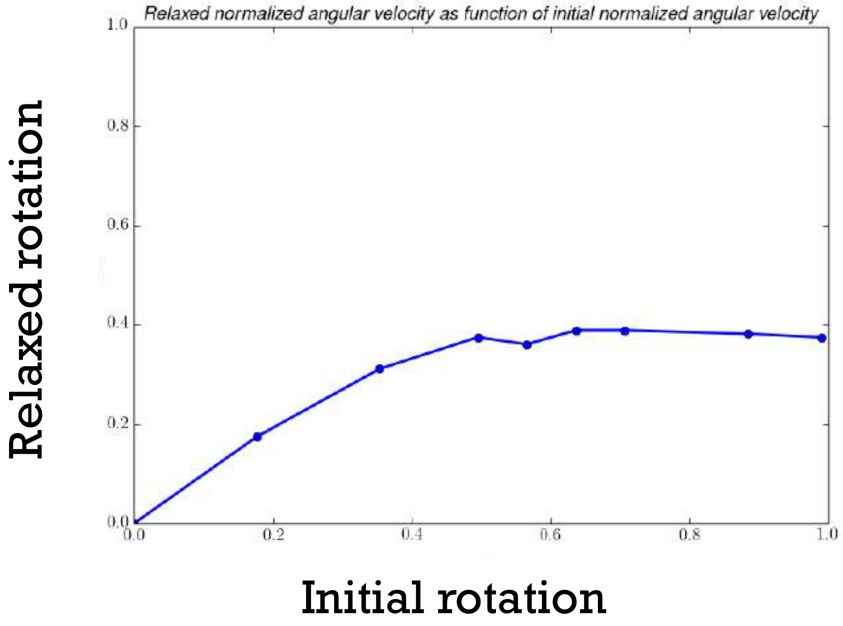

Density




Initial radius

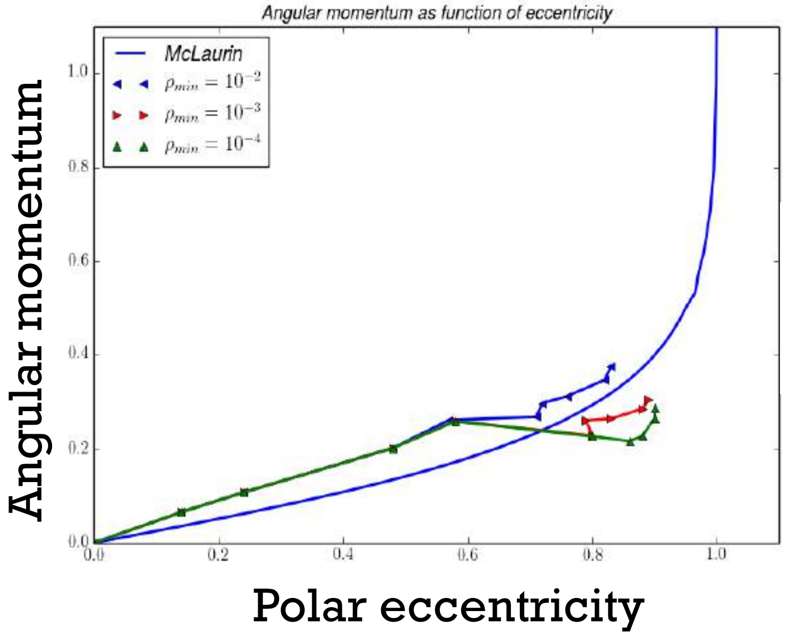
# Setting up a rotating star

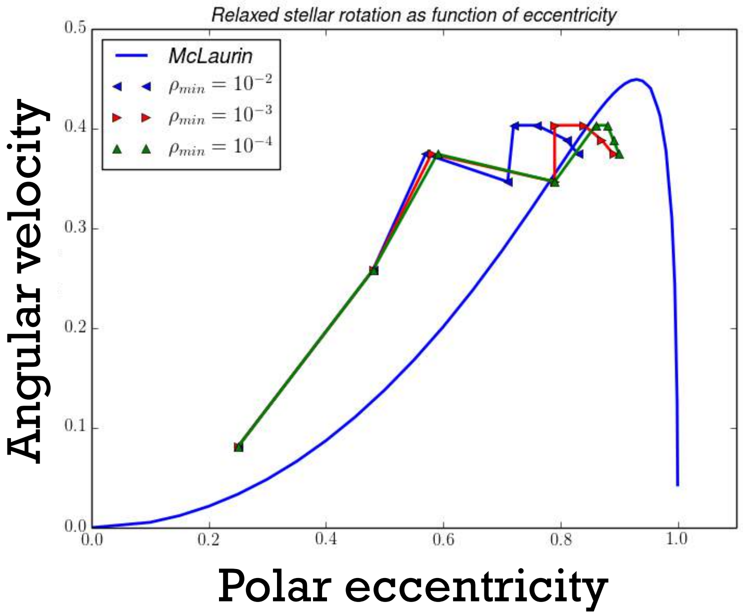
- Polytropic sphere $\gamma = 5/3$
- Rigid rotation $\alpha = \omega/\omega_b$
- Checking whether the rotation is still rigid and how fast the star spin
- Problem: saturation



# Setting up a rotating star

- Polytropic sphere $\gamma = 5/3$
- Rigid rotation $\alpha = \omega/\omega_b$
- Checking whether the rotation is still rigid and how fast the star spin
- Problem: saturation, is it normal? Yes!
  (Chandrasekhar 1969)



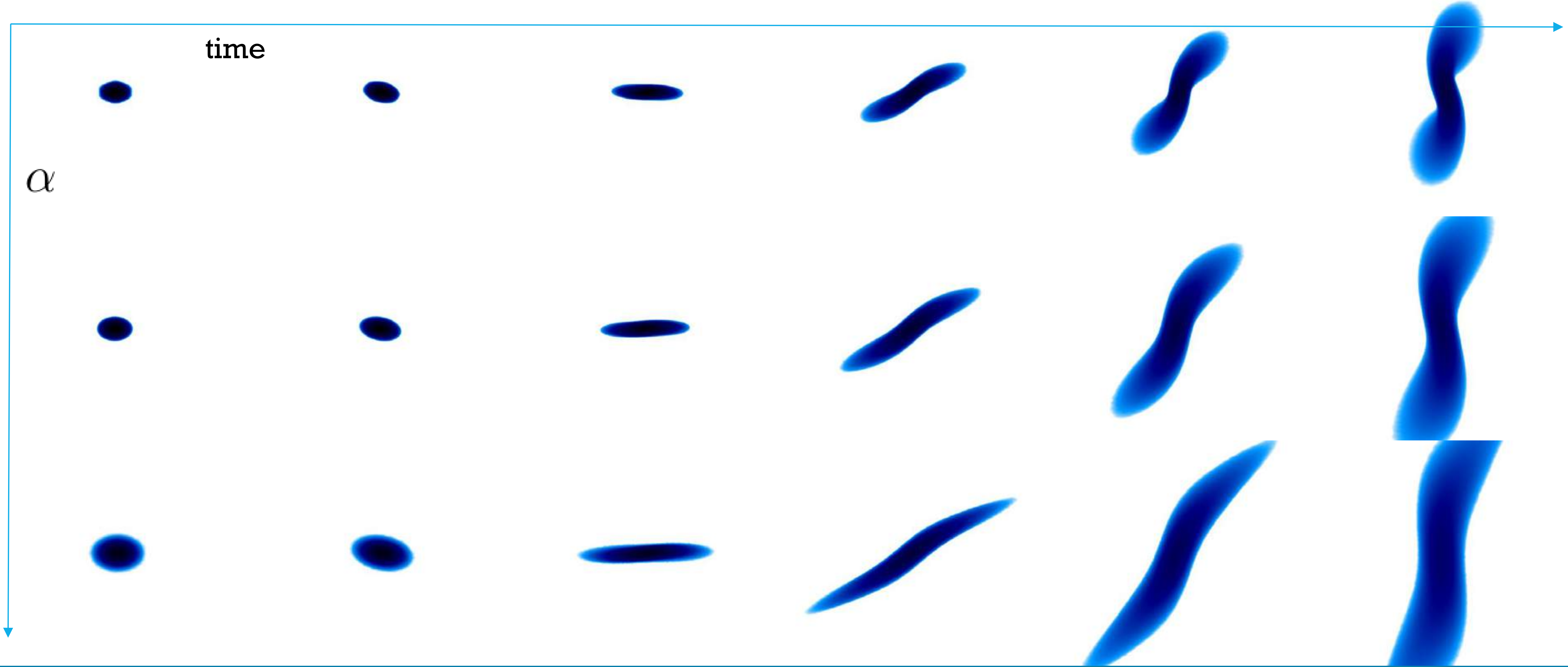
# Simulations of TDEs with rotating stars

- Parabolic orbit around a $10^6 M_\odot$ black hole
- Penetration factor $\beta = R_t(0)/R_p = 1$
- Two (three) possible configurations:

# Simulations of TDEs with rotating stars

- Parabolic orbit around a $10^6 M_\odot$ black hole
- Penetration factor $\beta = R_t(0)/R_p = 1$
- Two (three) possible configurations:
  1. varying $\alpha$ magnitude (prograde rotation)
  2. varying stellar spin orientation
  3. counter-rotation

# Case 1: prograde rotation



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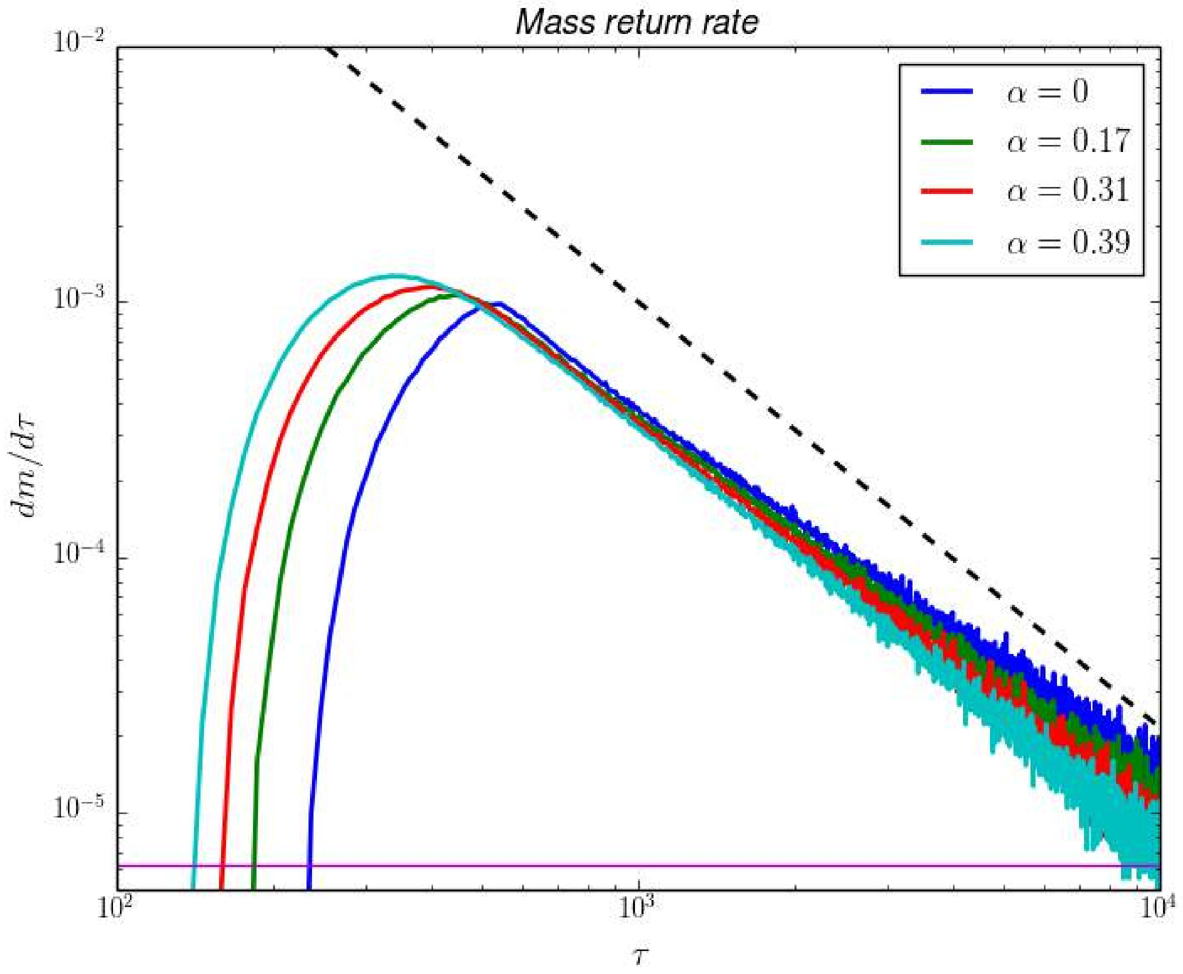


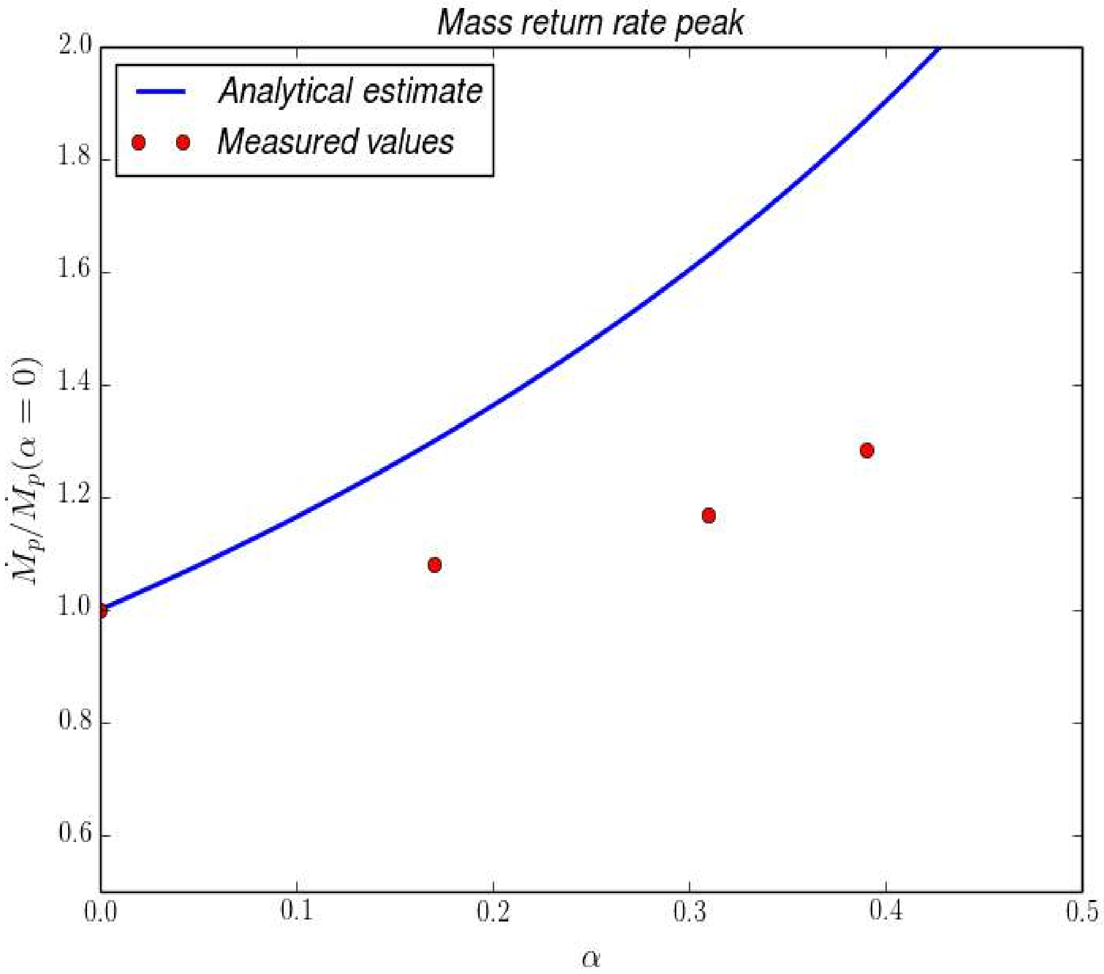

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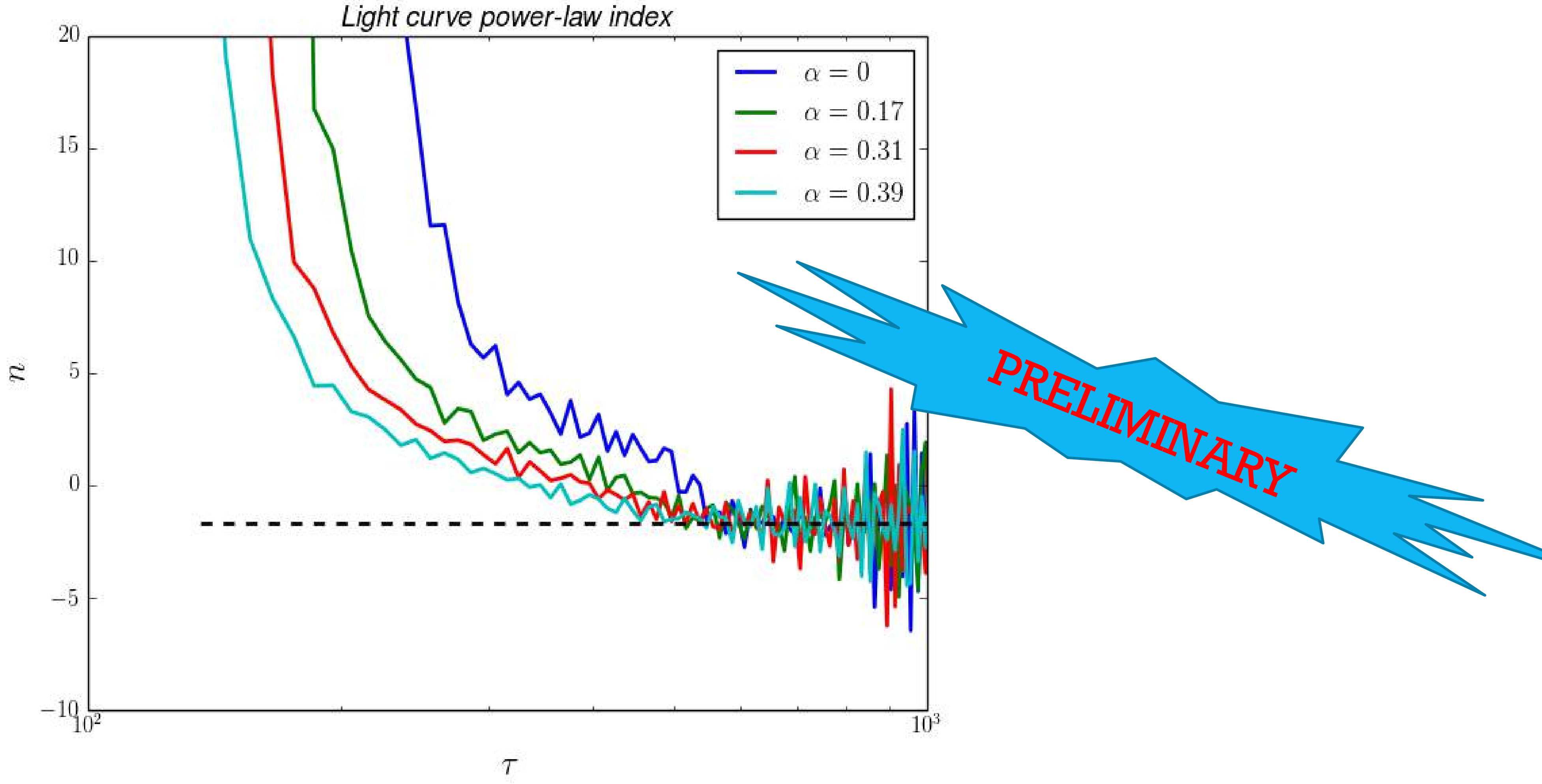
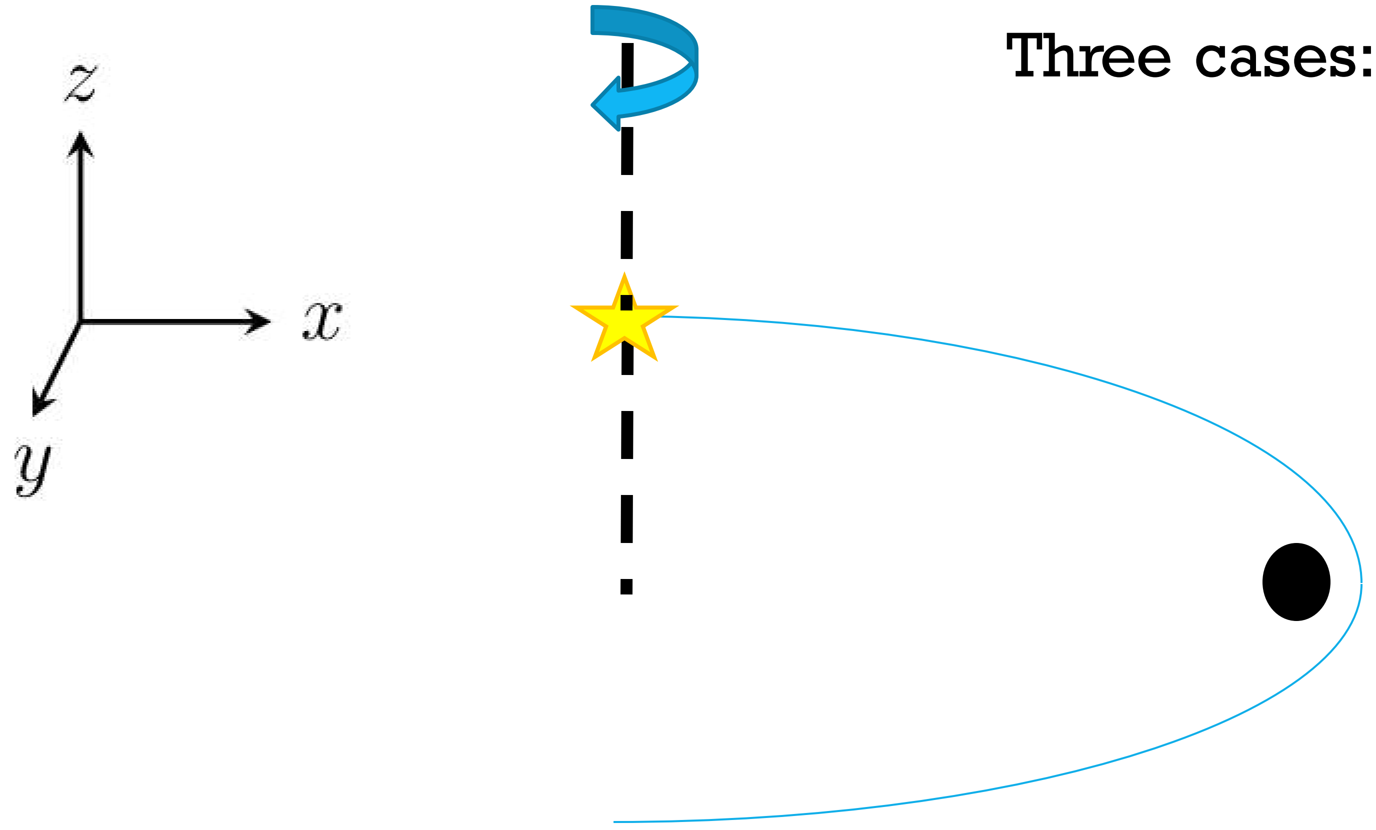
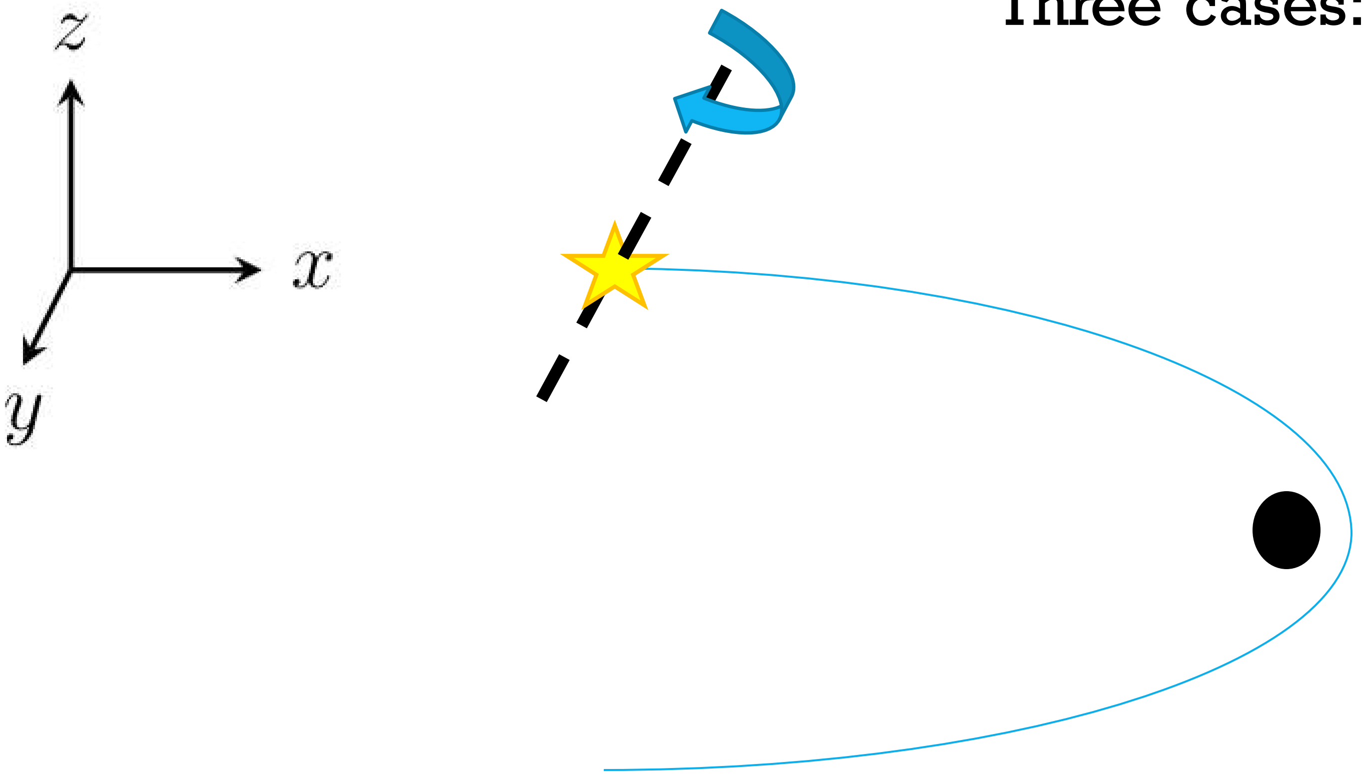


# Case 2: orientation




Three cases: 1. stellar spin along z

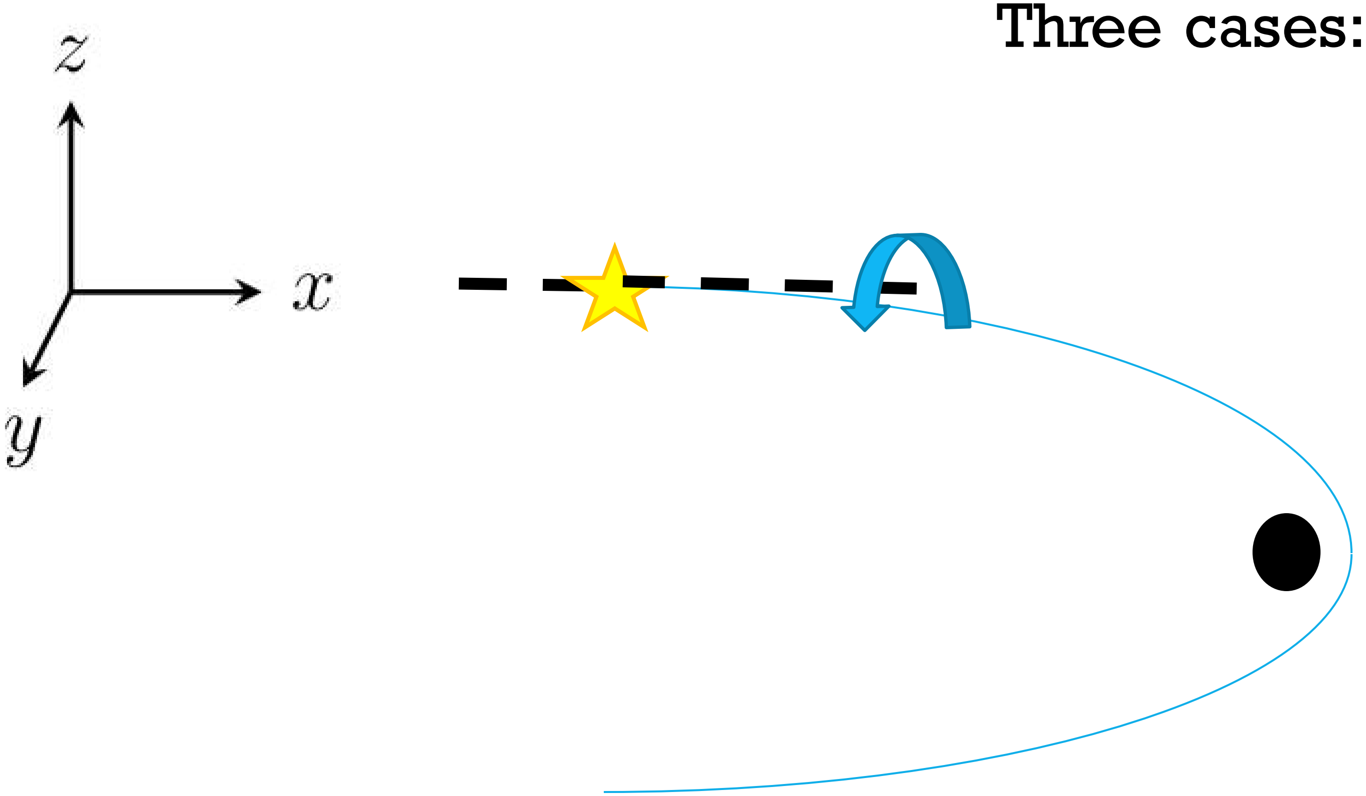
# Case 2: orientation




Three cases: 1. stellar spin along z

2. stellar spin along y

# Case 2: orientation




Three cases:
1. stellar spin along z
2. stellar spin along y
3. stellar spin along x

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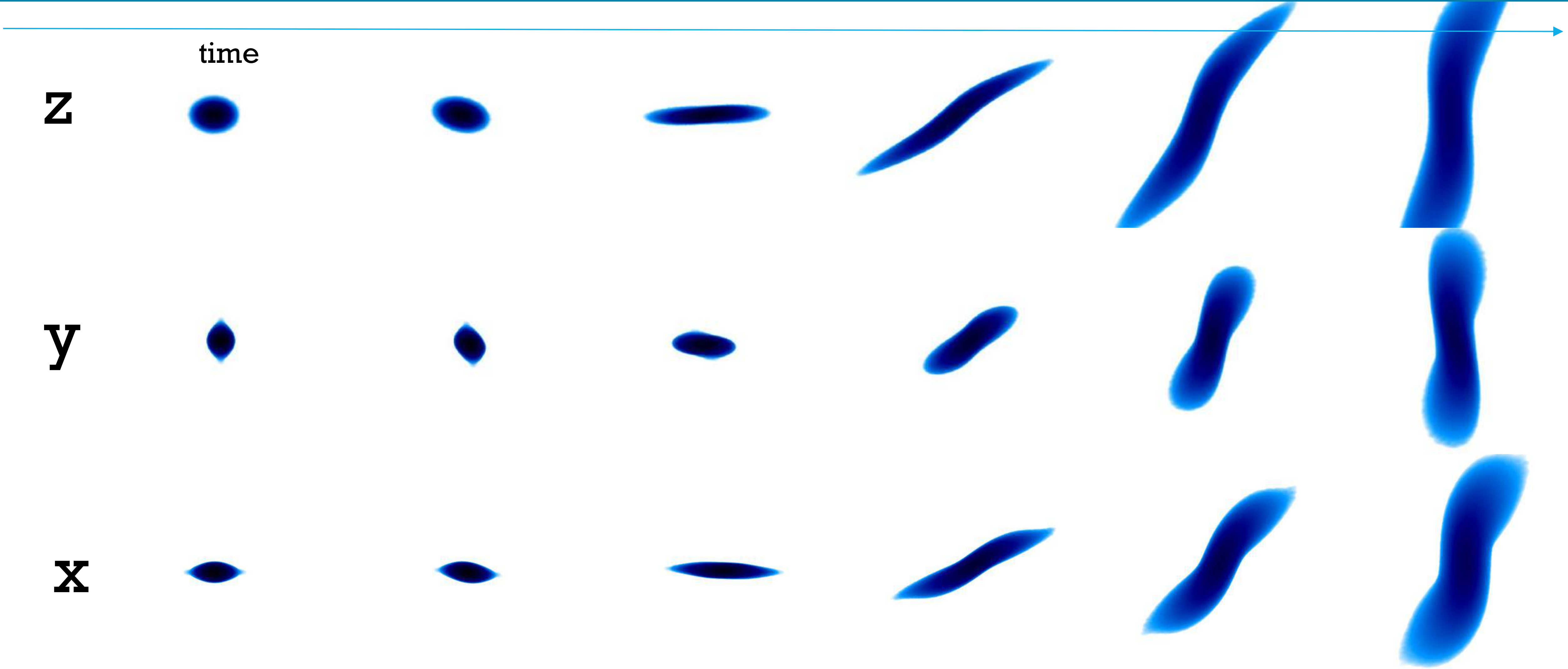

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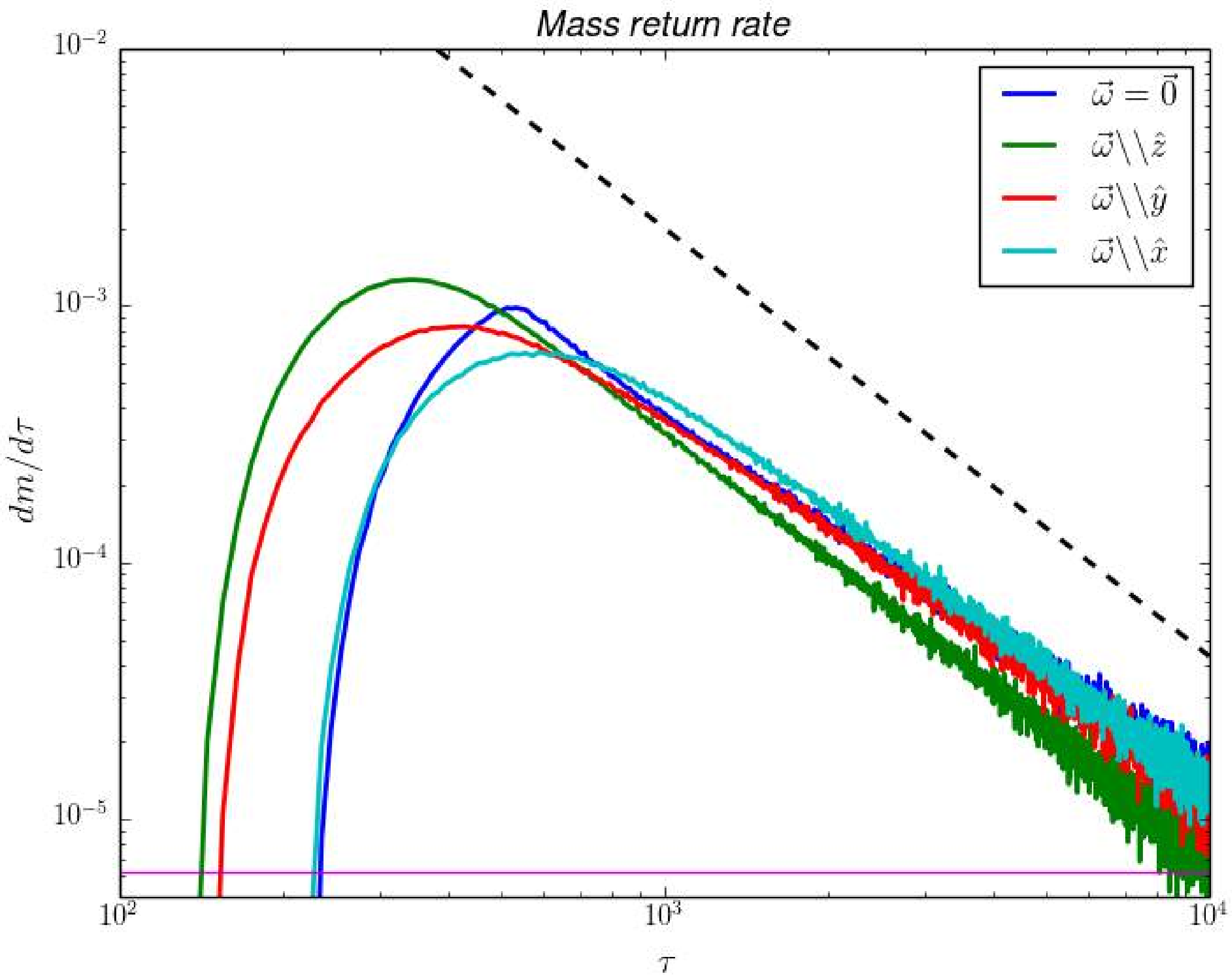

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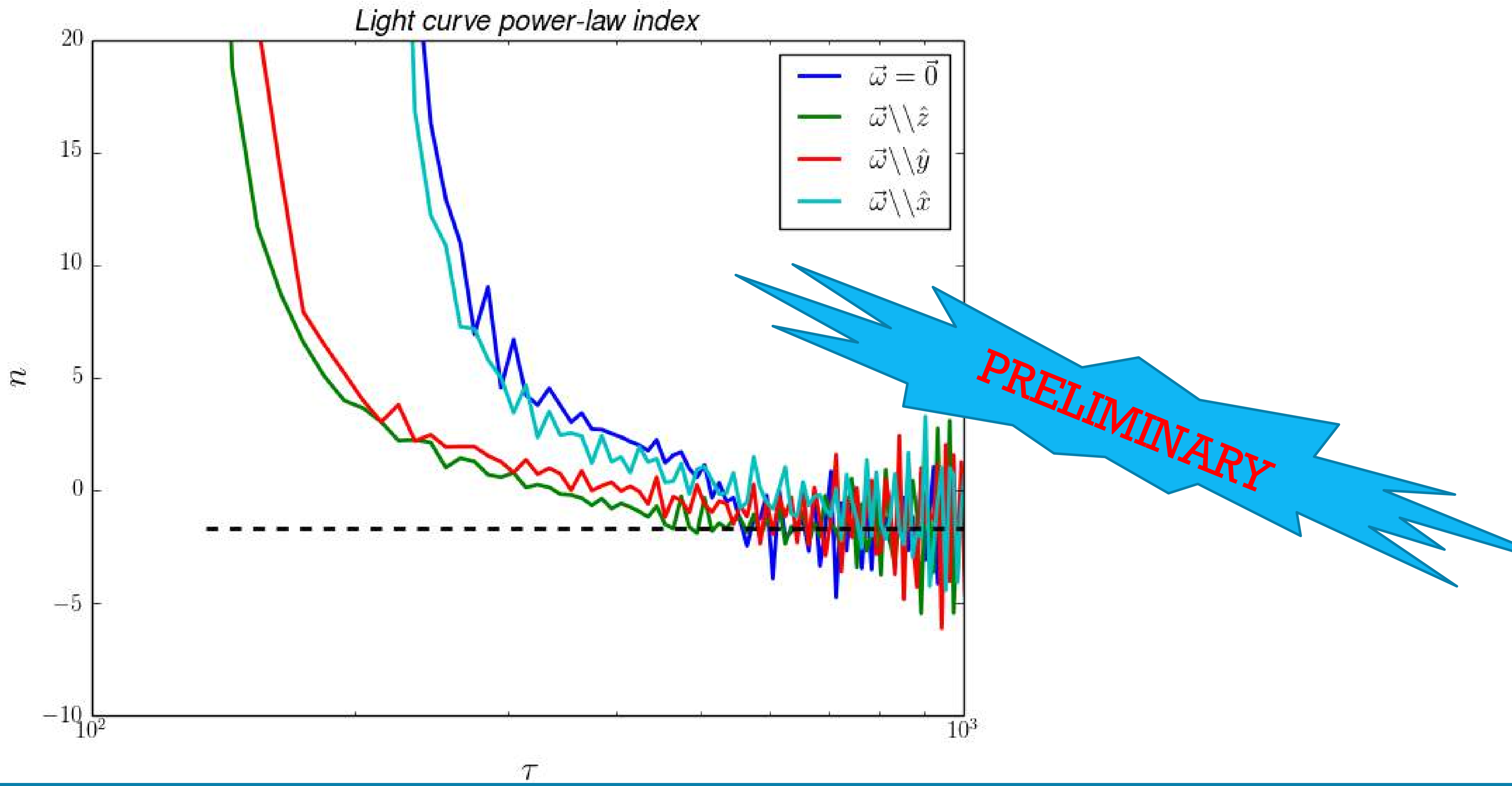
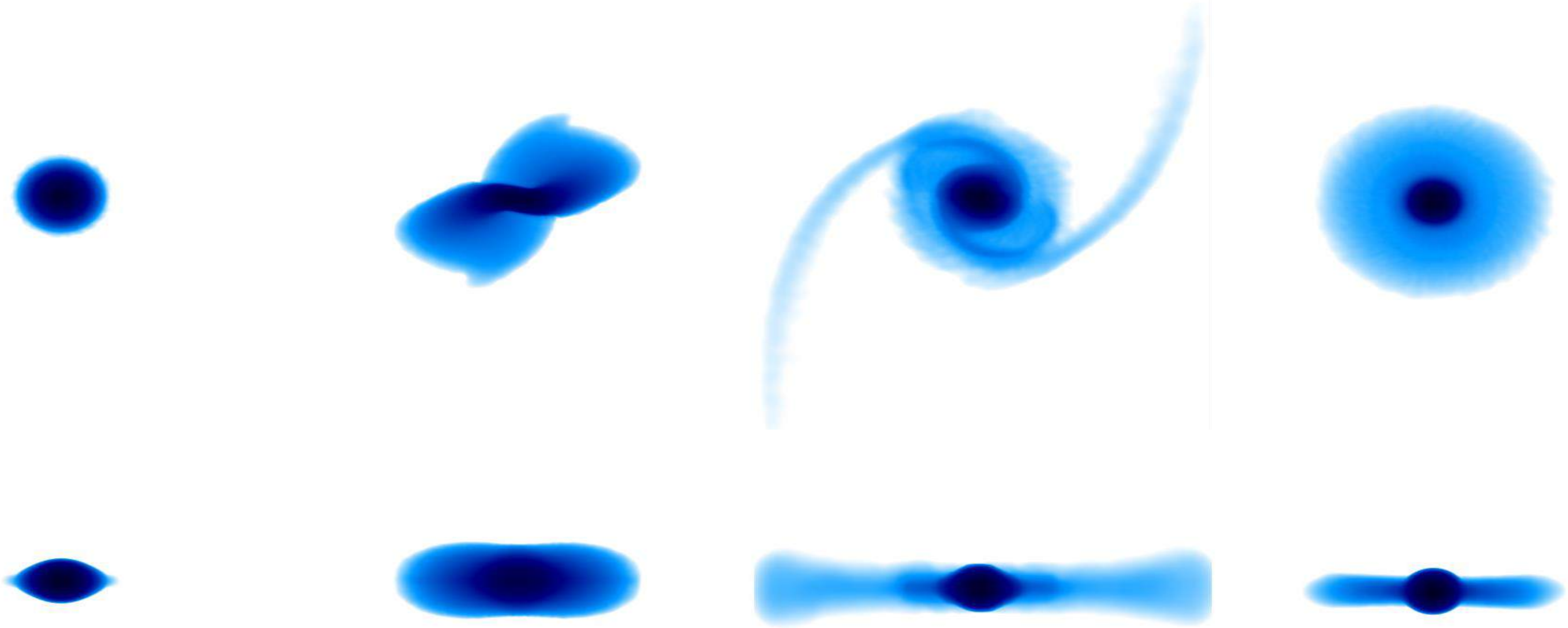


# Case 3: counter-rotation

- Stellar spin aligned with z-axis
- Retrograde rotation
- Analytical estimates predict fainter TDEs
- What do we observe?

# Case 3: counter-rotation



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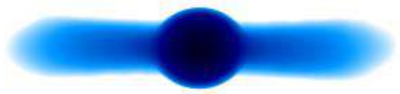


$$\frac{H}{R} = 0.3$$

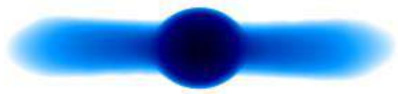
$$\alpha = 0.1$$

$$R_{out} = 4.69\ R_{\odot}$$

Main characteristics:

- Luminosity: several times super-Eddington (for the star)
- Duration: few tenths of days
- Spectrum: peaked in the x-ray band
- And then?

# Case 3: counter-rotation



The non-disrupted star is on a Keplerian orbit:

- Period: 80 years
- Apocentrum: 4000 AU

Prediction: brighter TDE when the star passes again near the black hole.

# Conclusions and future developments

Resume:

- Stellar rotation can brighten, dim or distort TDE light curves
- Counter-rotating stars could survive the black hole flyby and generate new events

Future:

- Exploring other parameters (penetration factor, black hole binaries, stellar structure)
- Modification to the rate of these events

That's all folks!

Thanks for the attention!