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Niels Bohr Institute



香港大學  
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# Tidal disruption events under the grid

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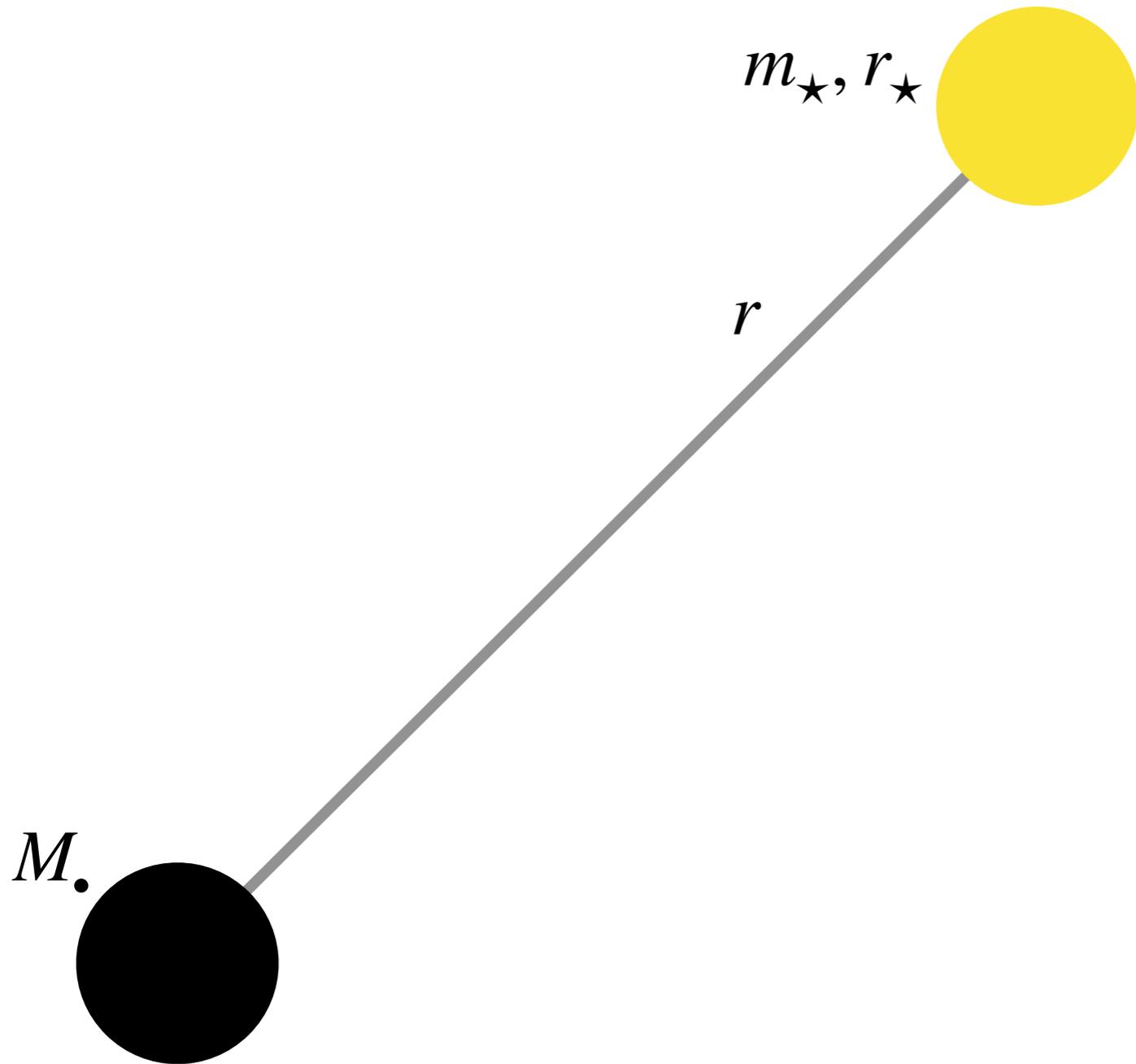
**Hugo Pfister - [pfisterastro@gmail.com](mailto:pfisterastro@gmail.com)**

with J. Dai, M. Volonteri, K. Auchettl, M. Trebitsch and E. Ramirez-Ruiz

Zoom - Sept. 27 2021

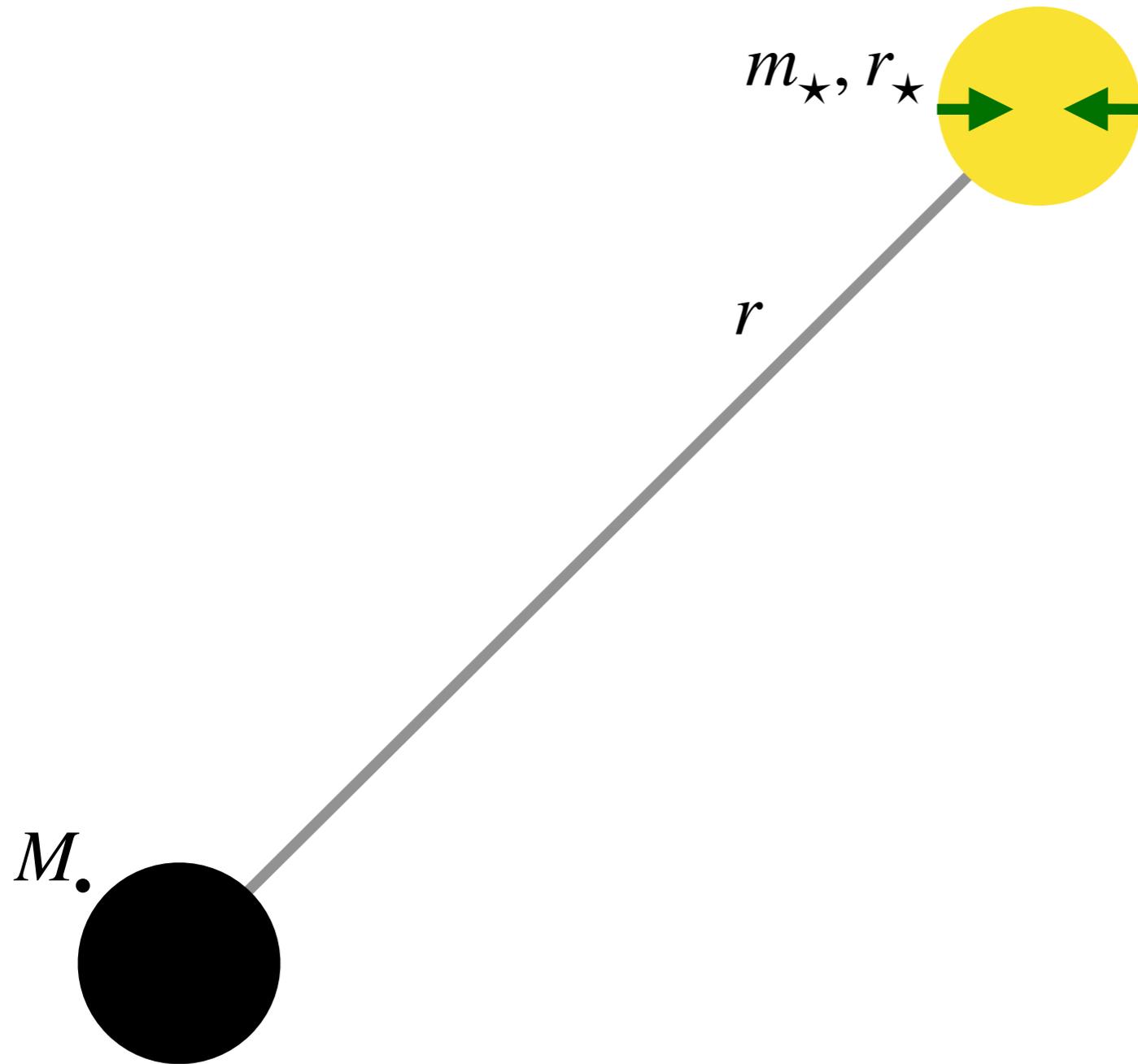
# Tidal disruption events

Hills+75



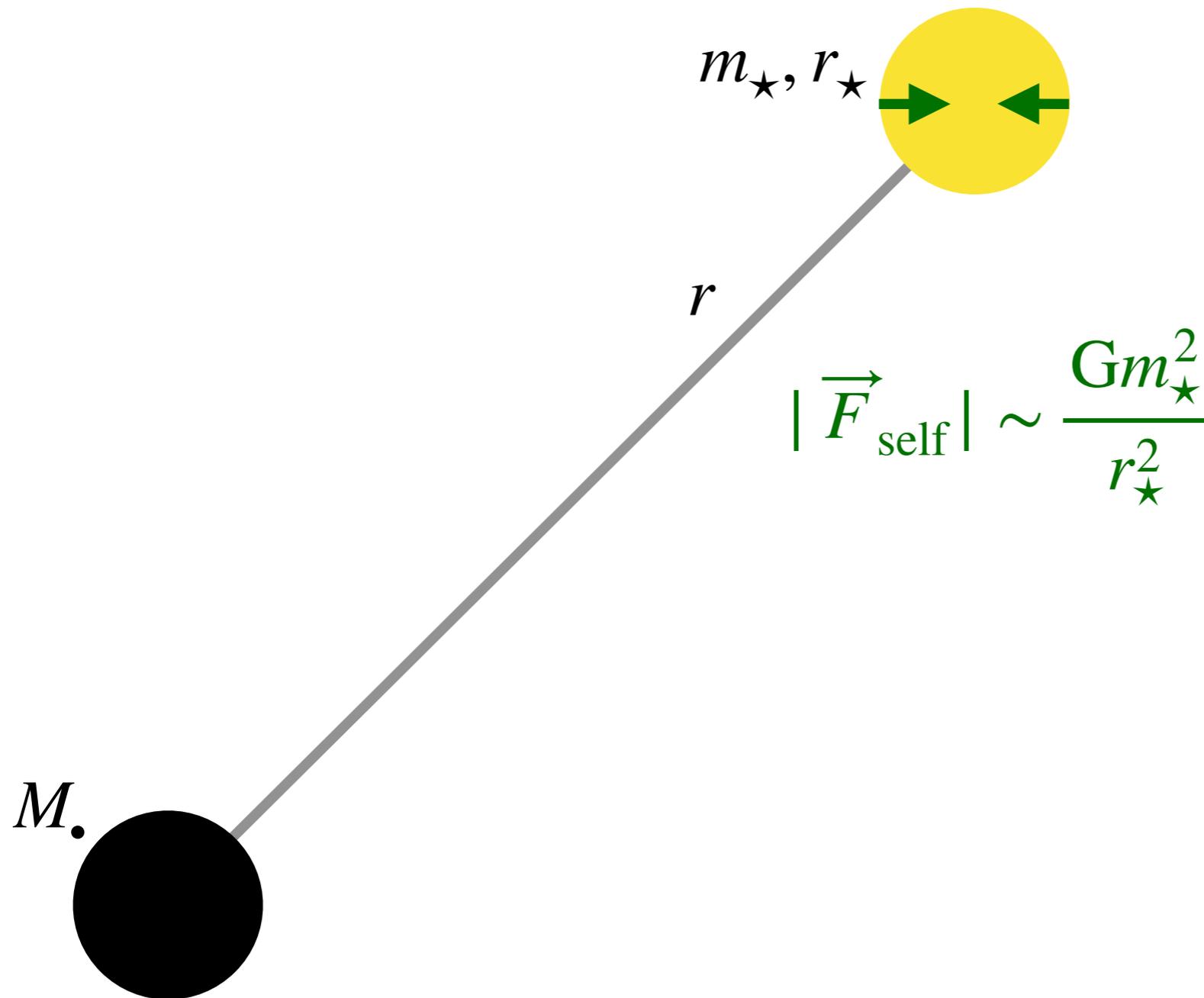
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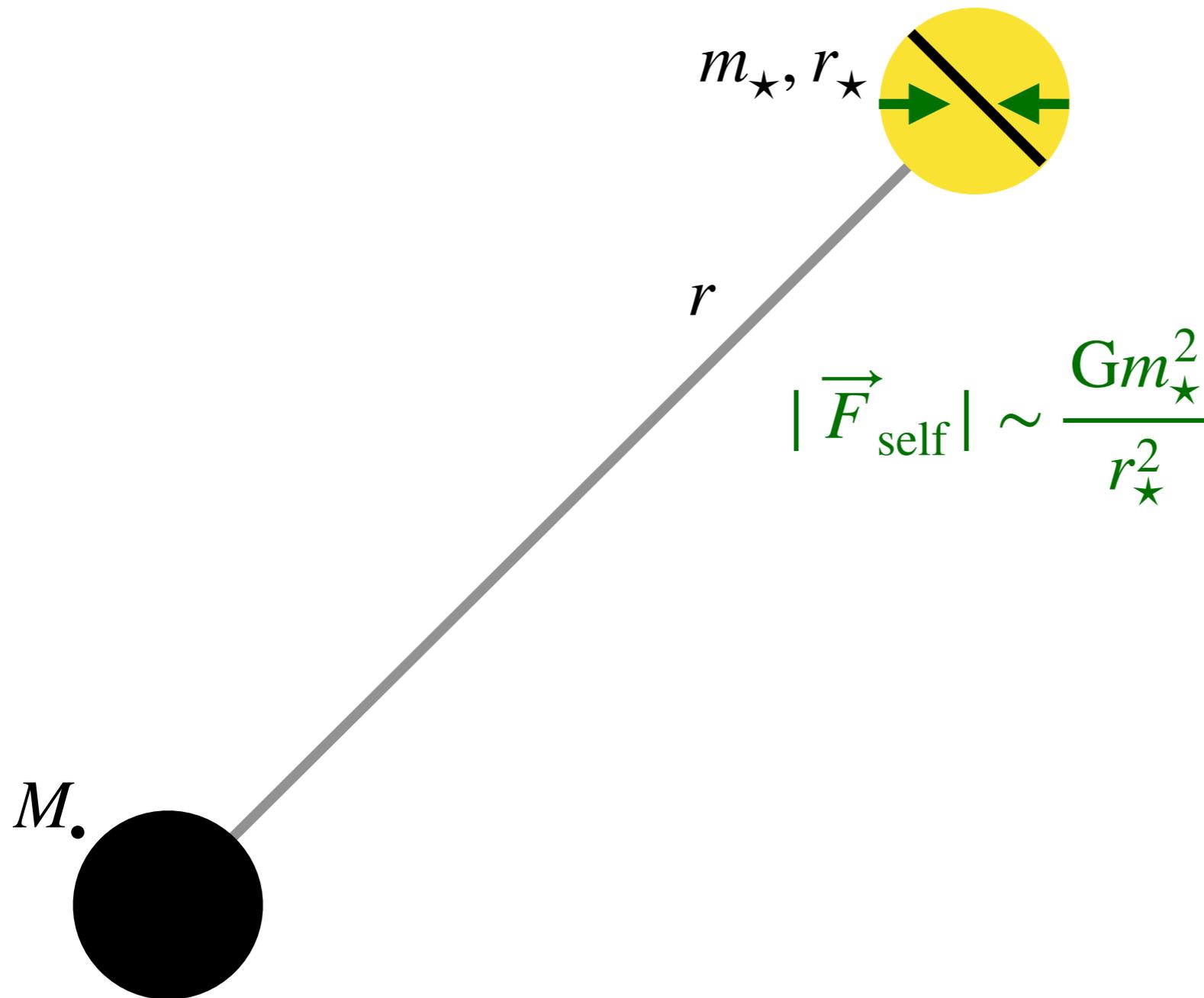
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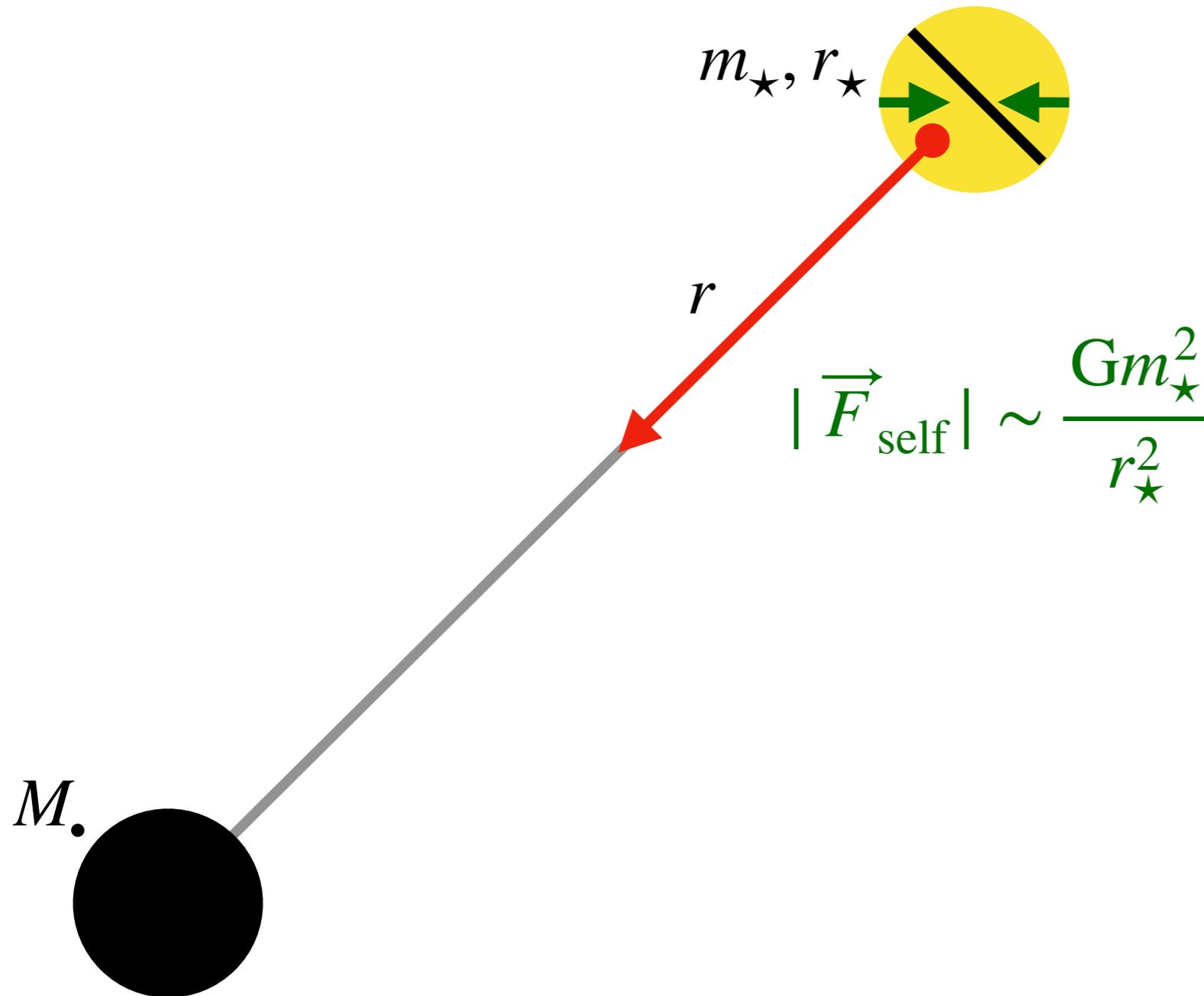
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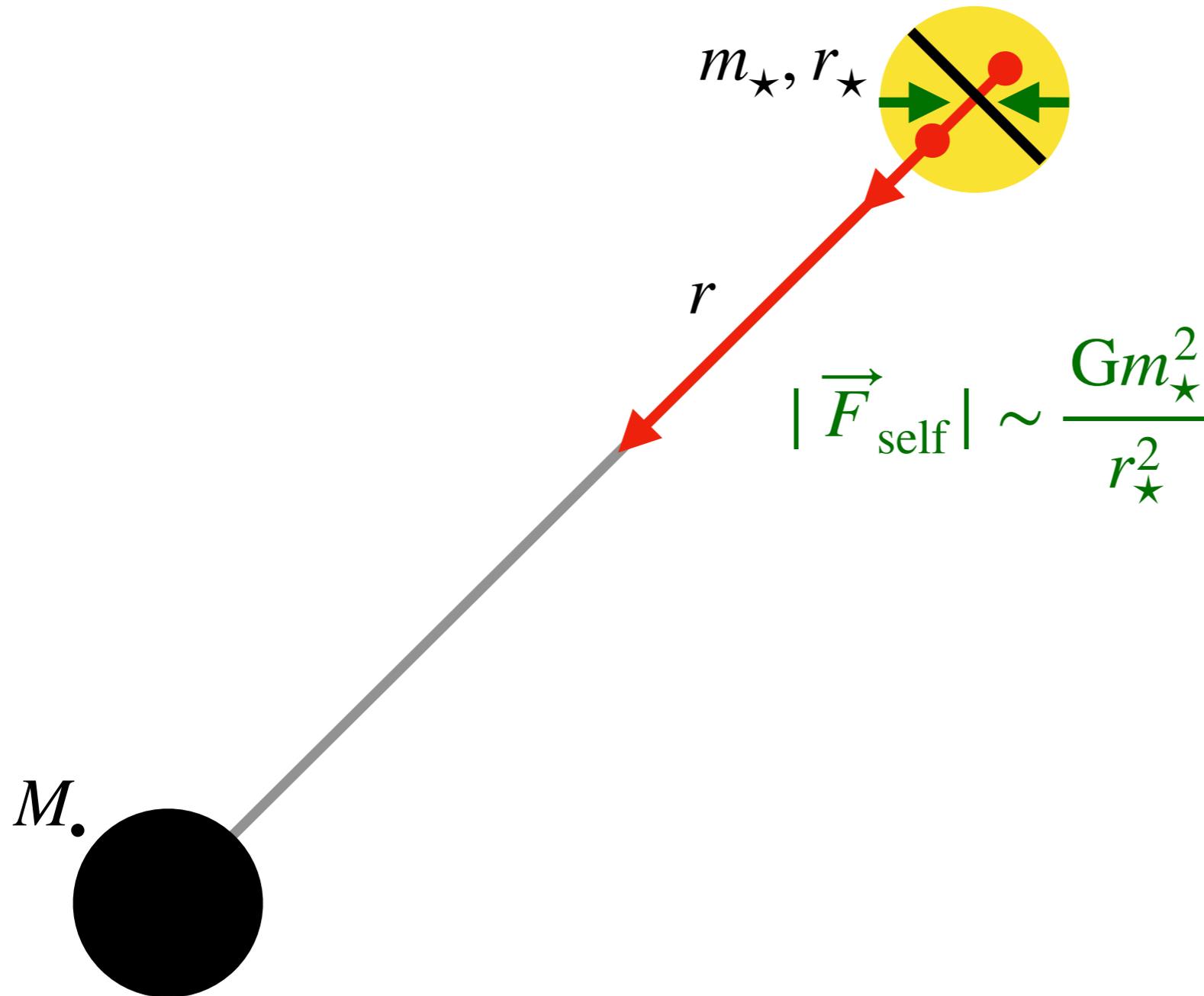
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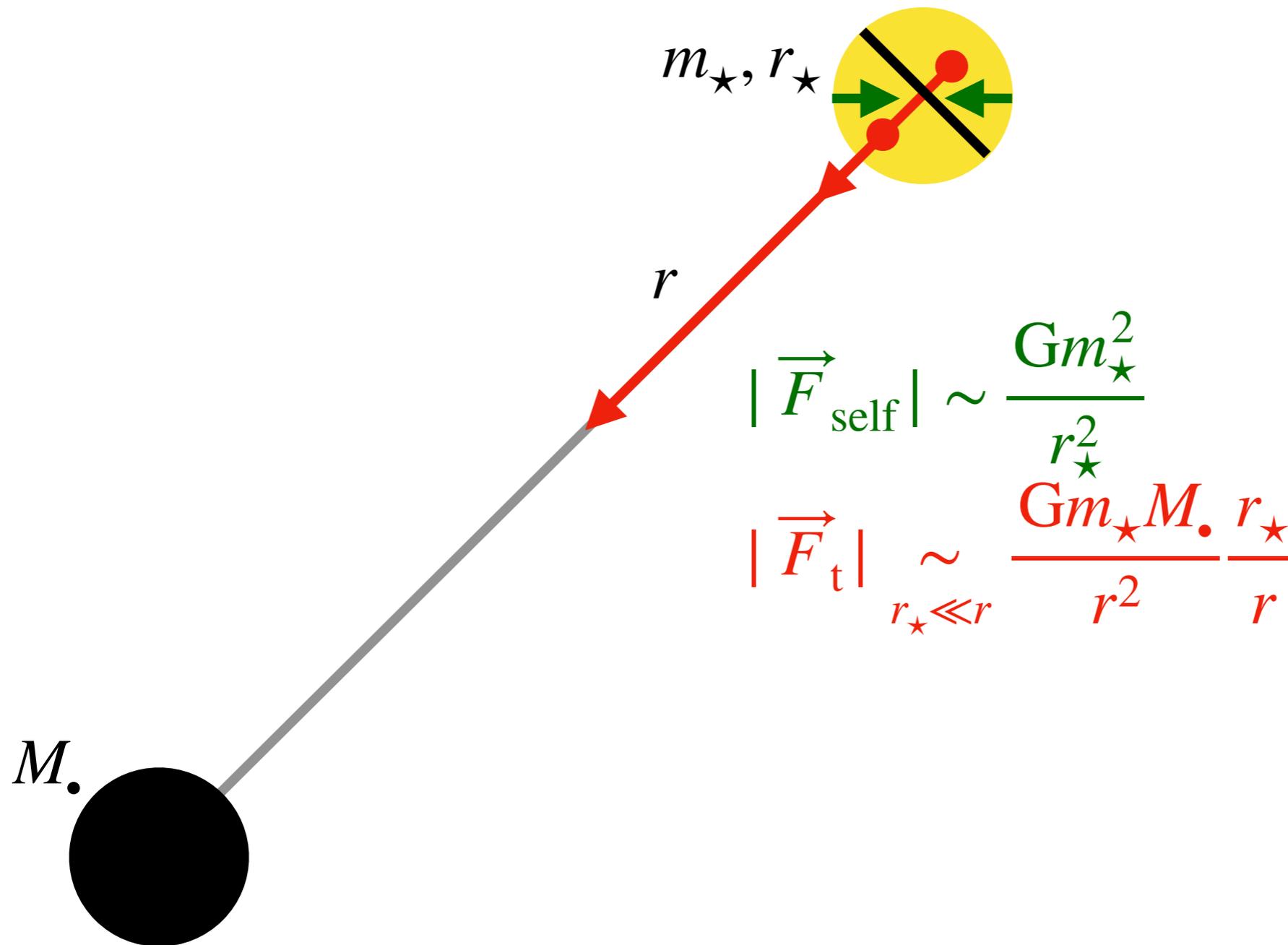
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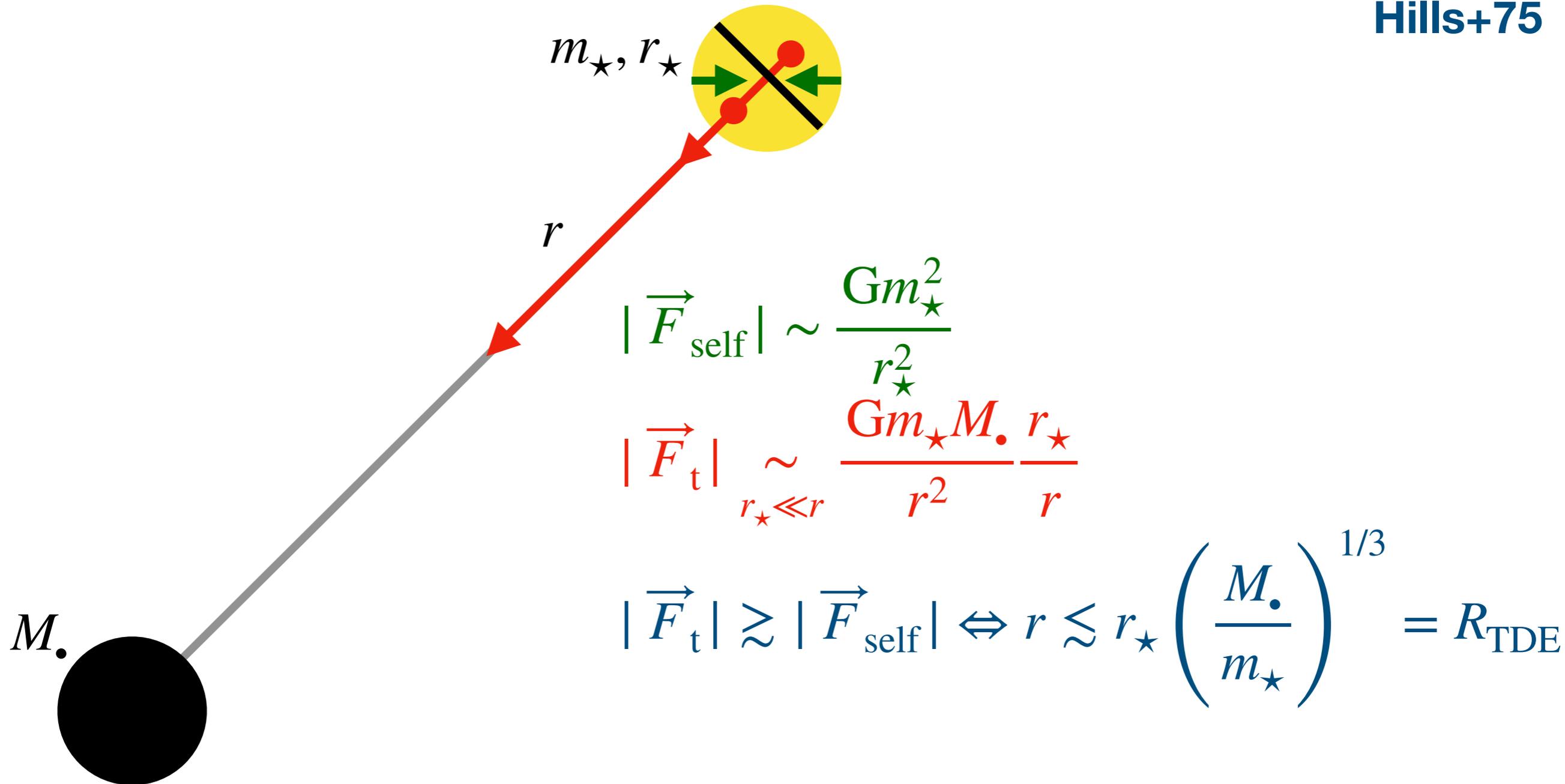
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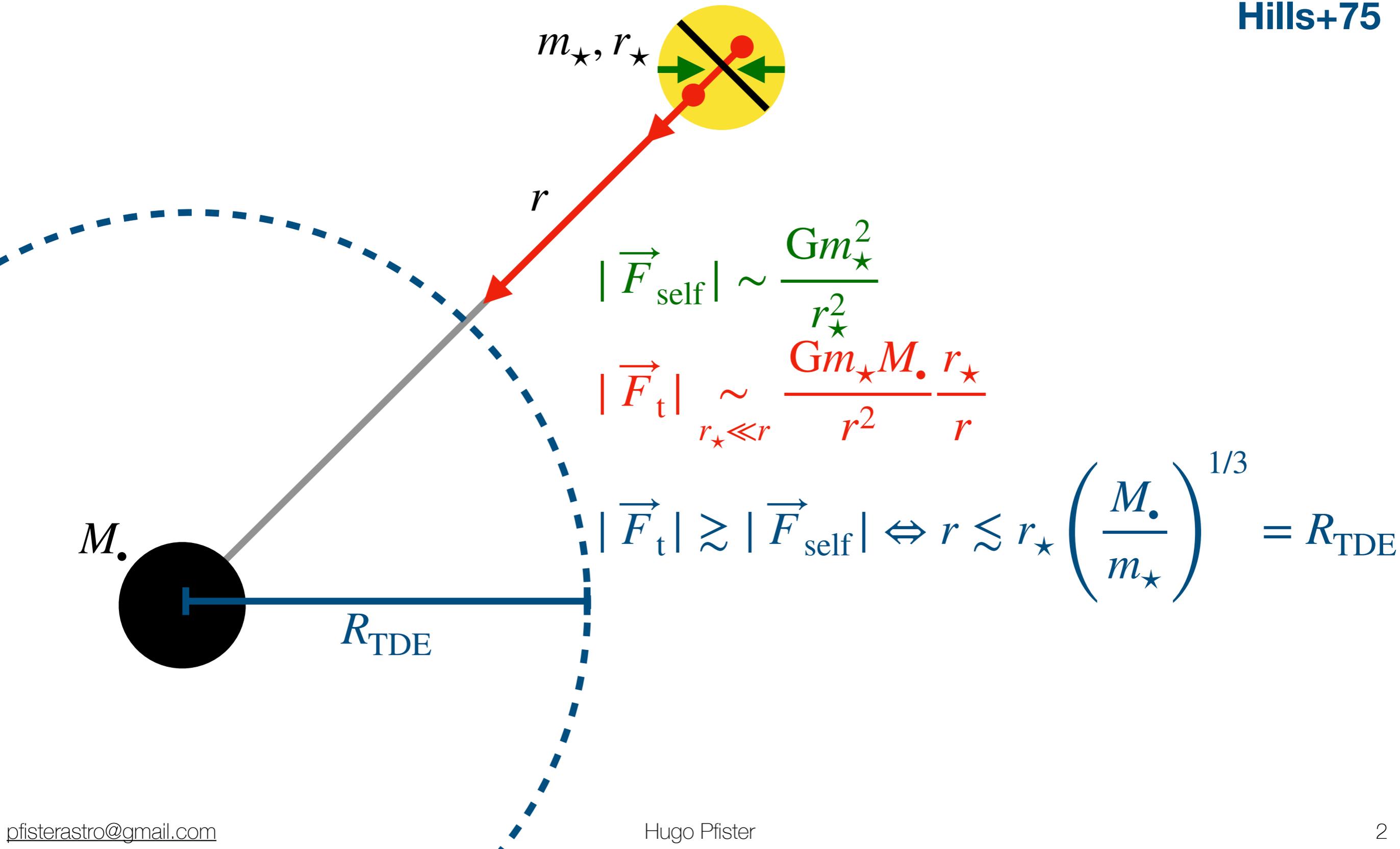
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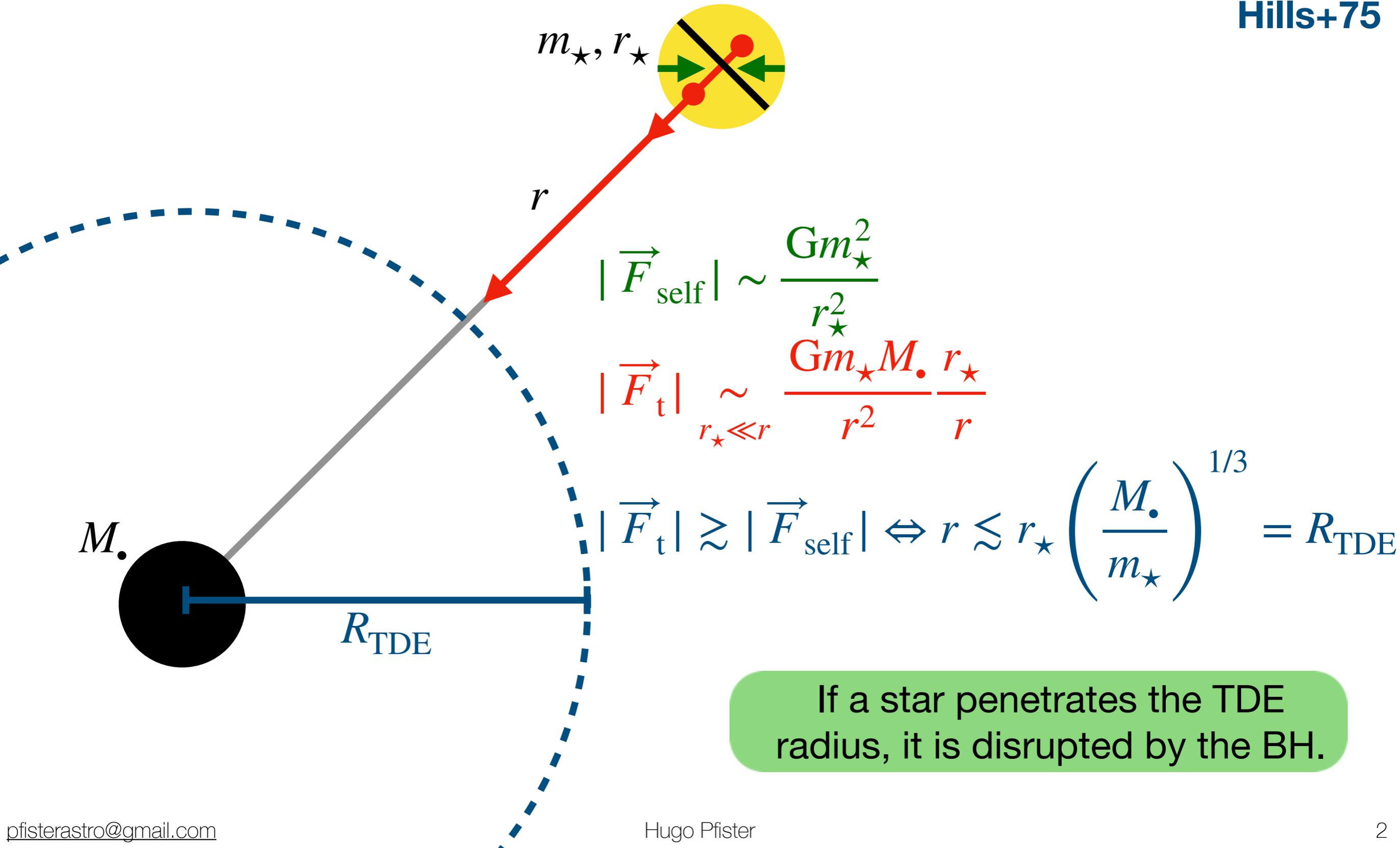
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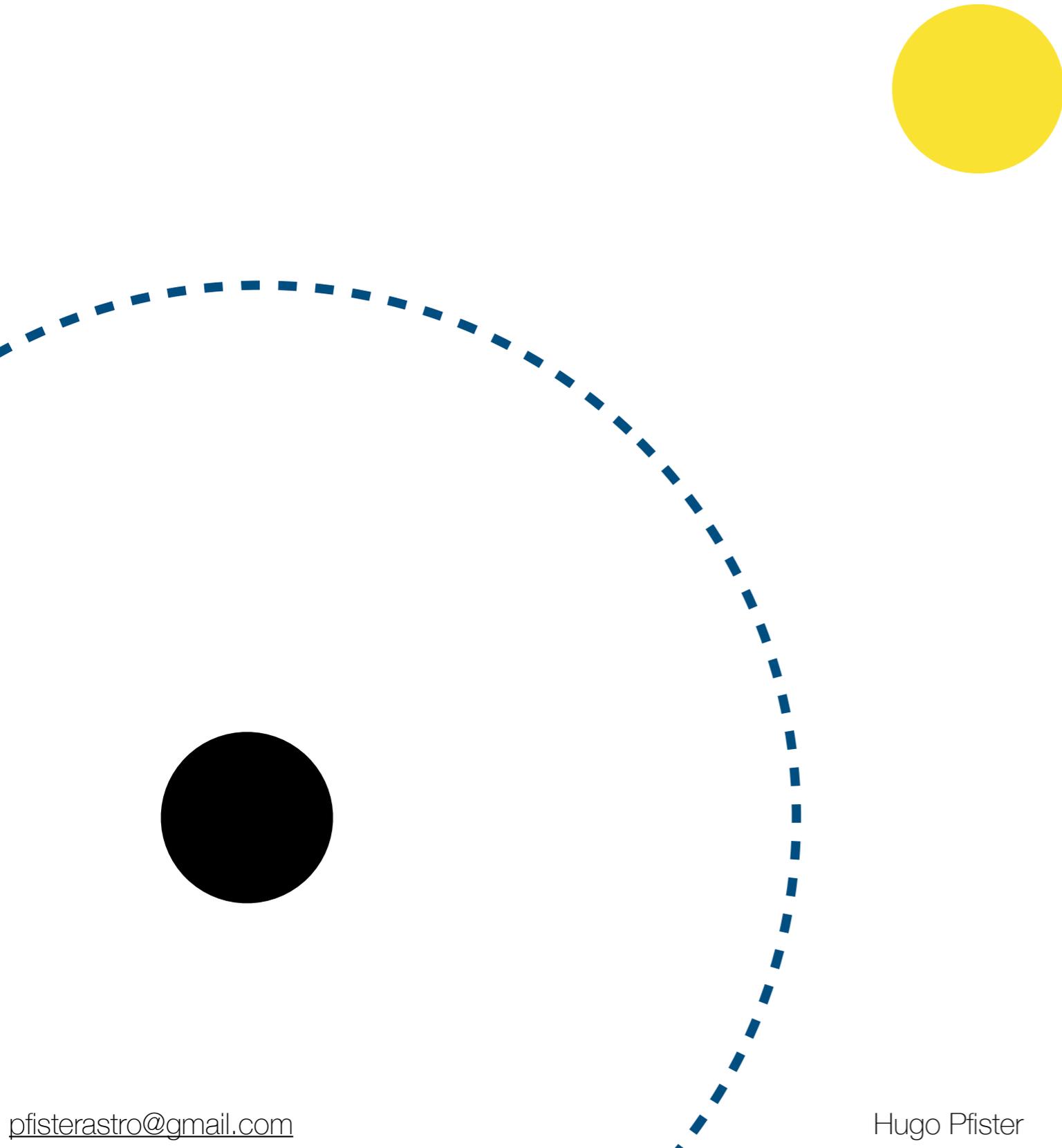
Hills+75



If a star penetrates the TDE radius, it is disrupted by the BH.

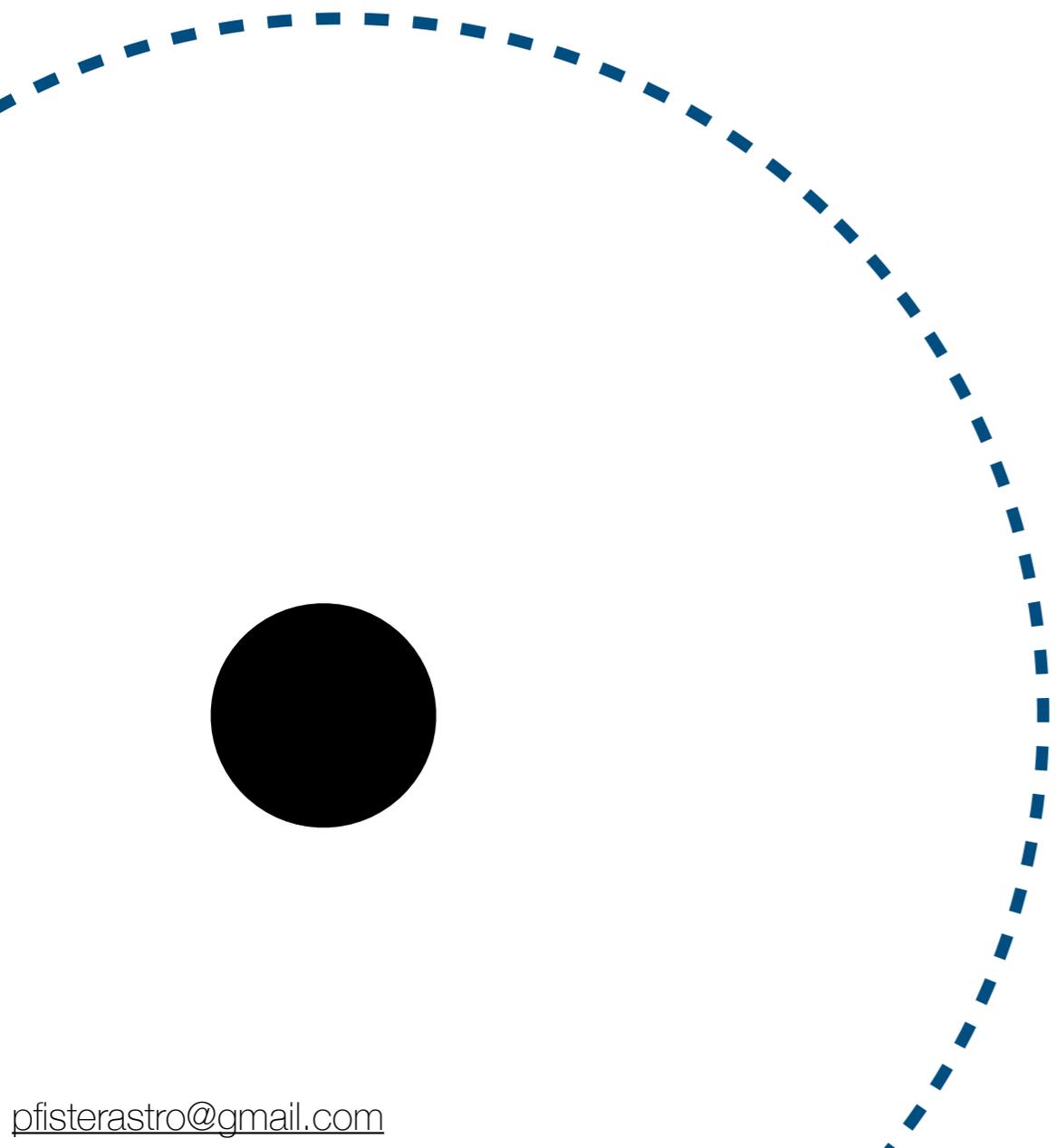
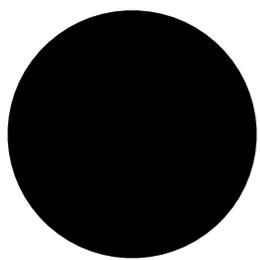
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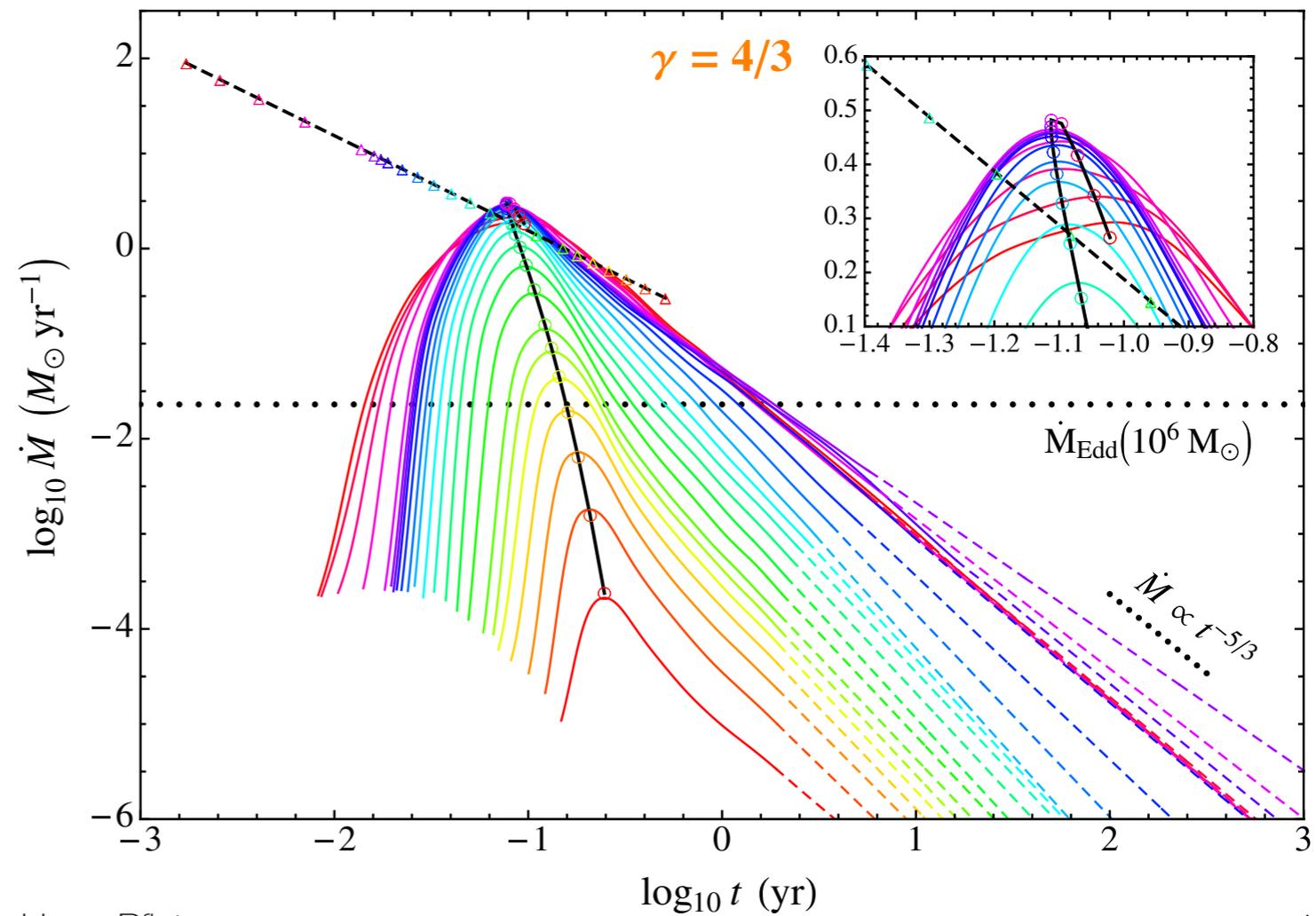
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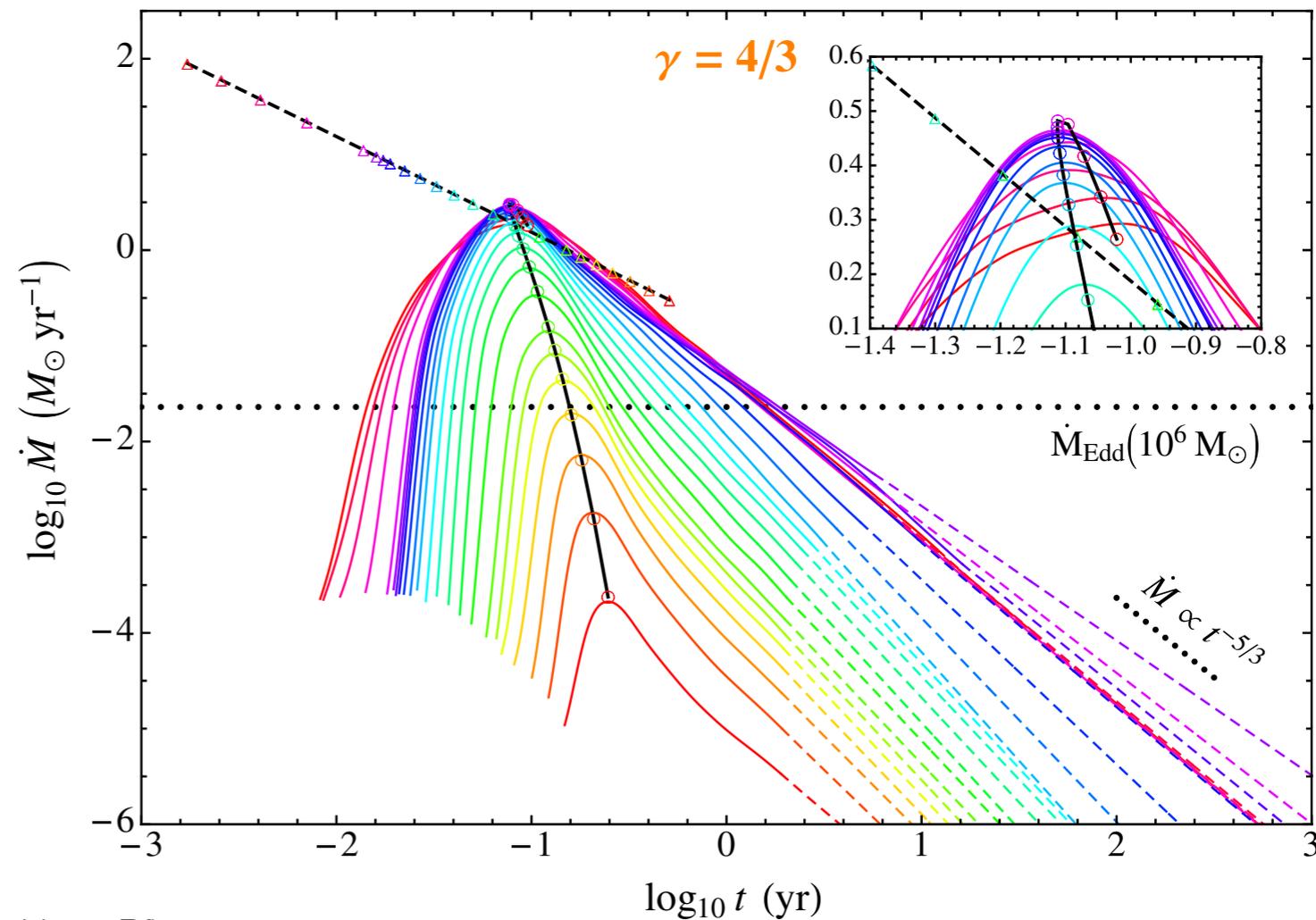
## Guillochon+13 (Theory)



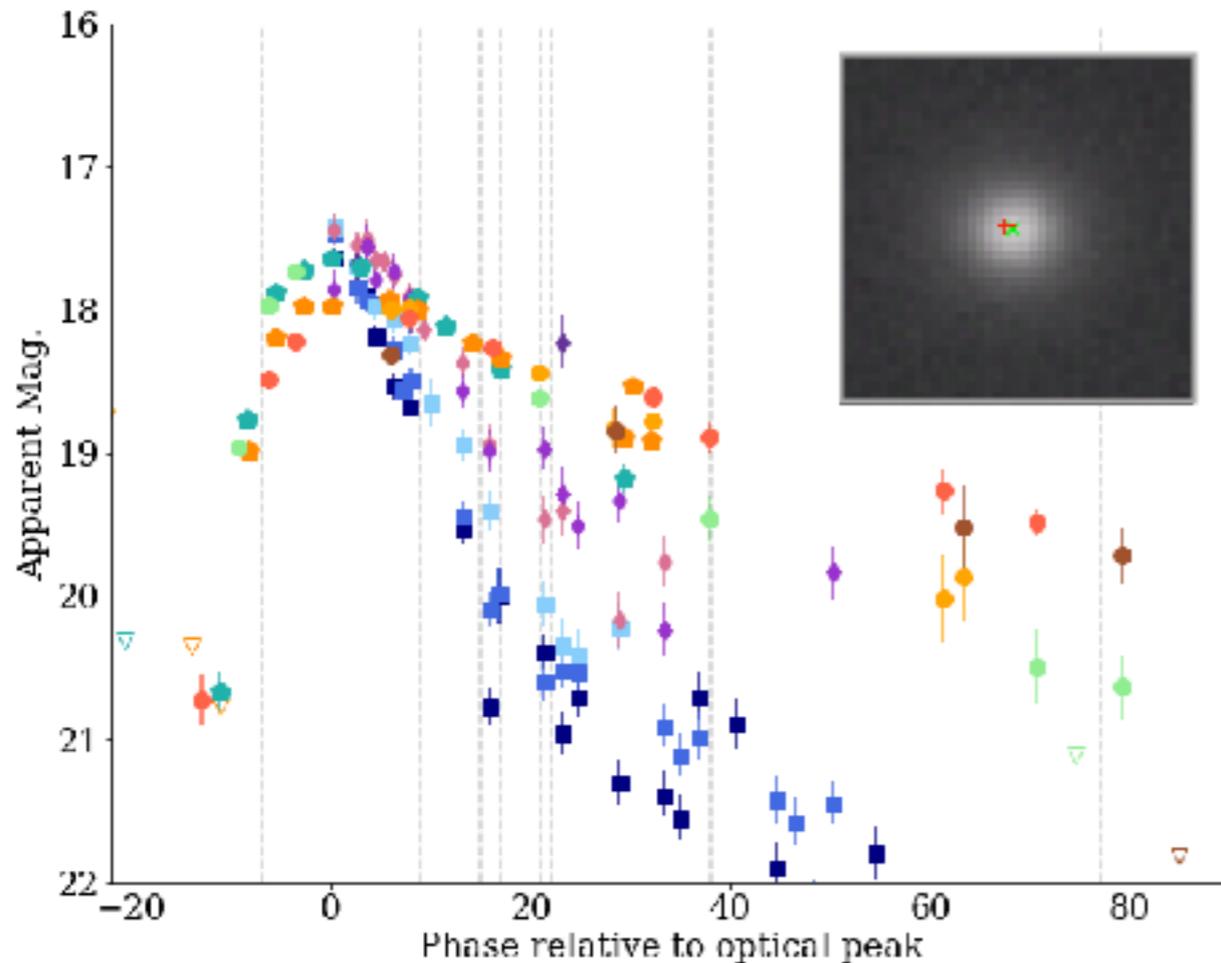
# Tidal disruption events

$$\text{Mag} \propto \log L \sim \log \dot{M}.$$

## Guillochon+13 (Theory)



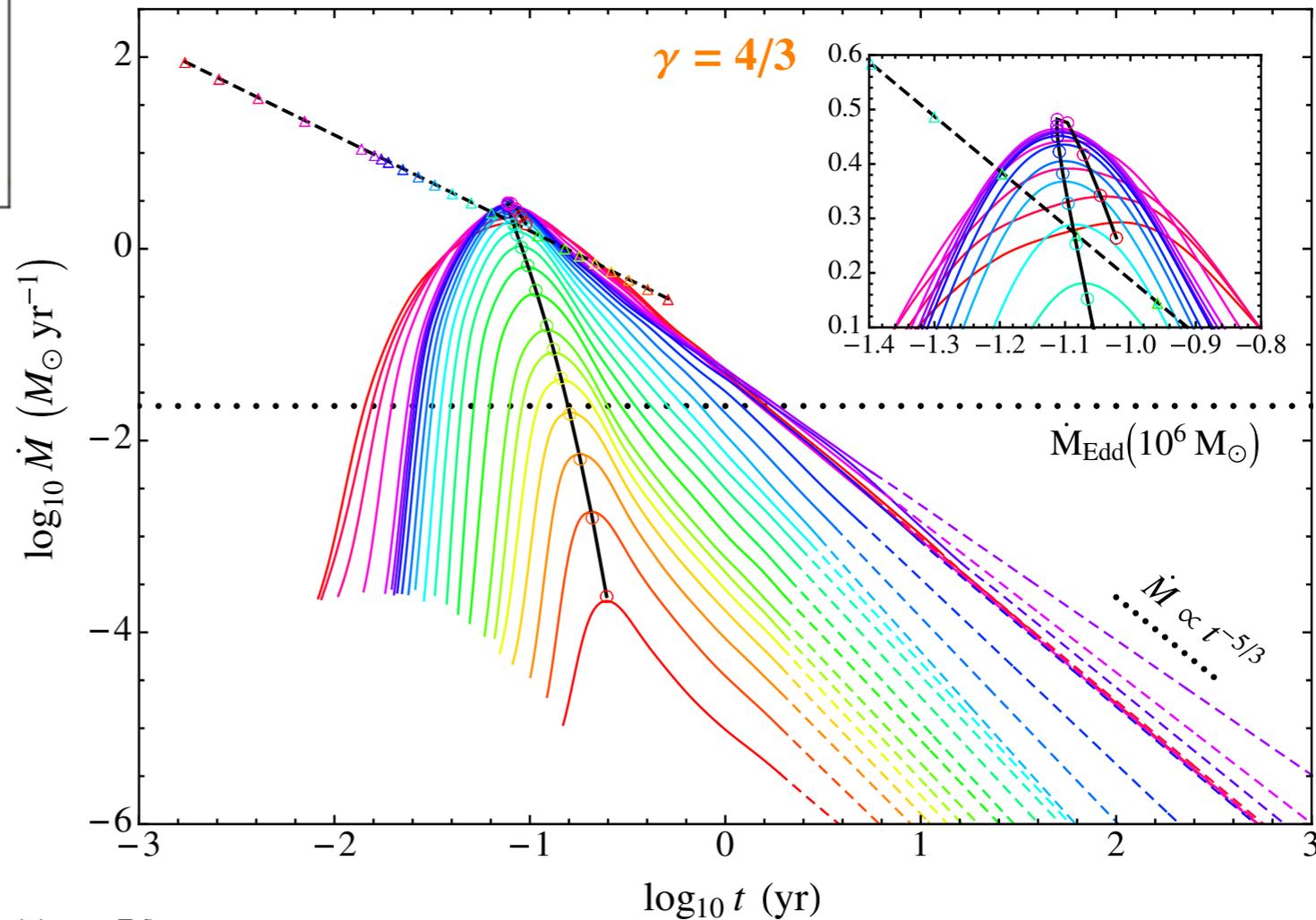
# Tidal disruption events



Angus in prep. (incl HP)  
(Observations)

$$\text{Mag} \propto \log L \sim \log \dot{M}$$

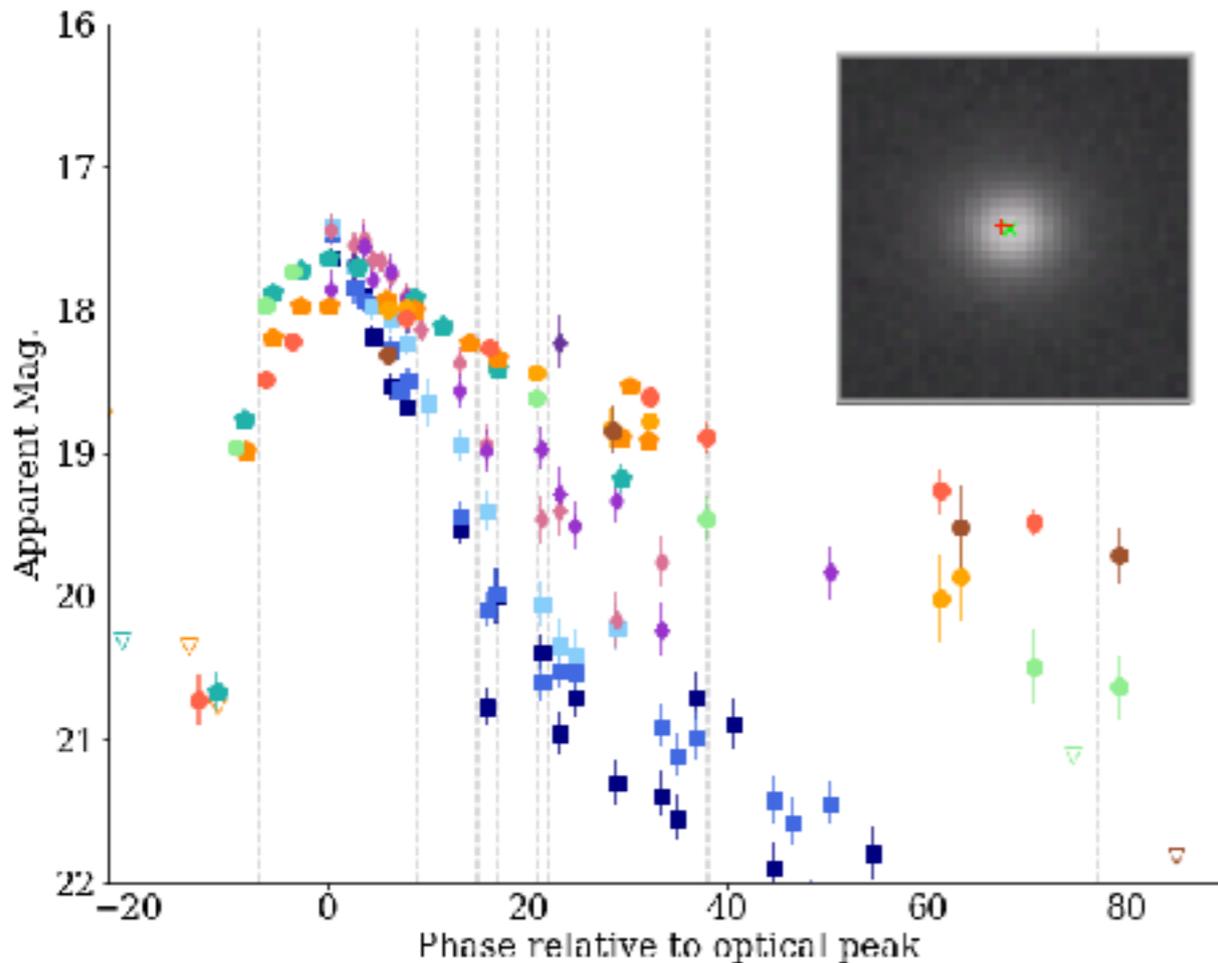
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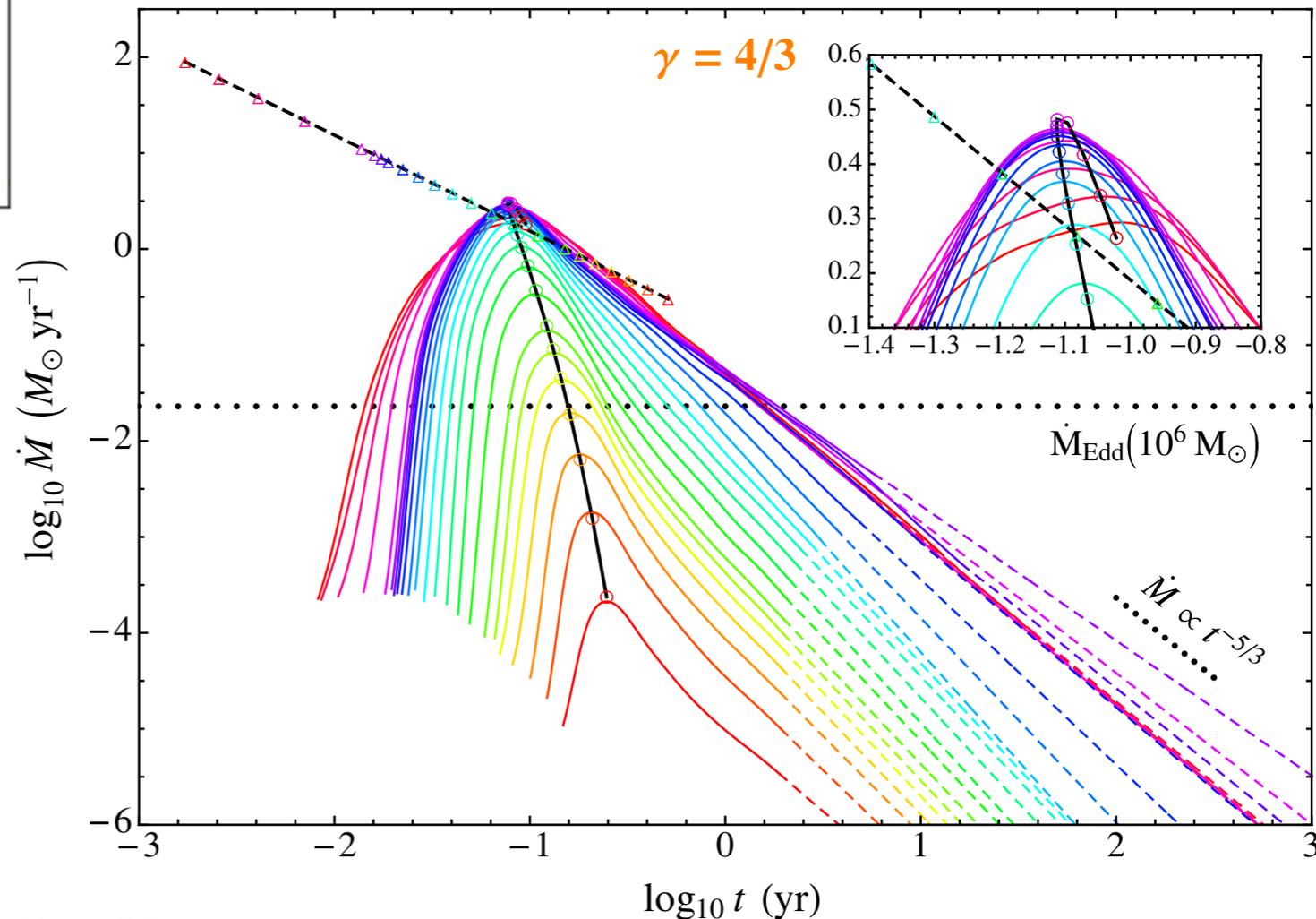
The details of the luminosity curve depend on the exact properties of the system such as masses, orbits, age and metallicity of the star etc...:  
**We can study BHs with TDEs!**

**Guillochon+13** (Theory)

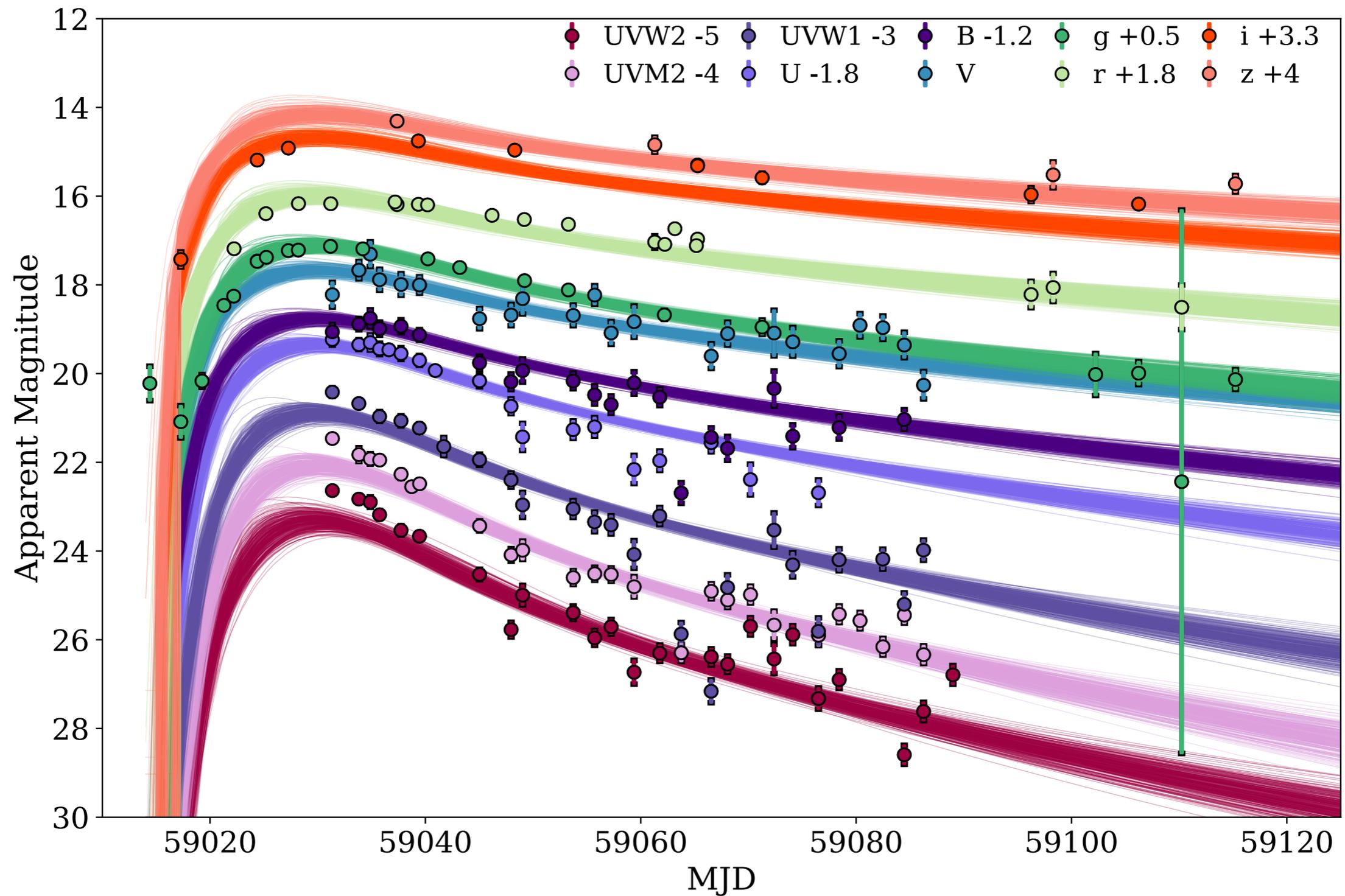


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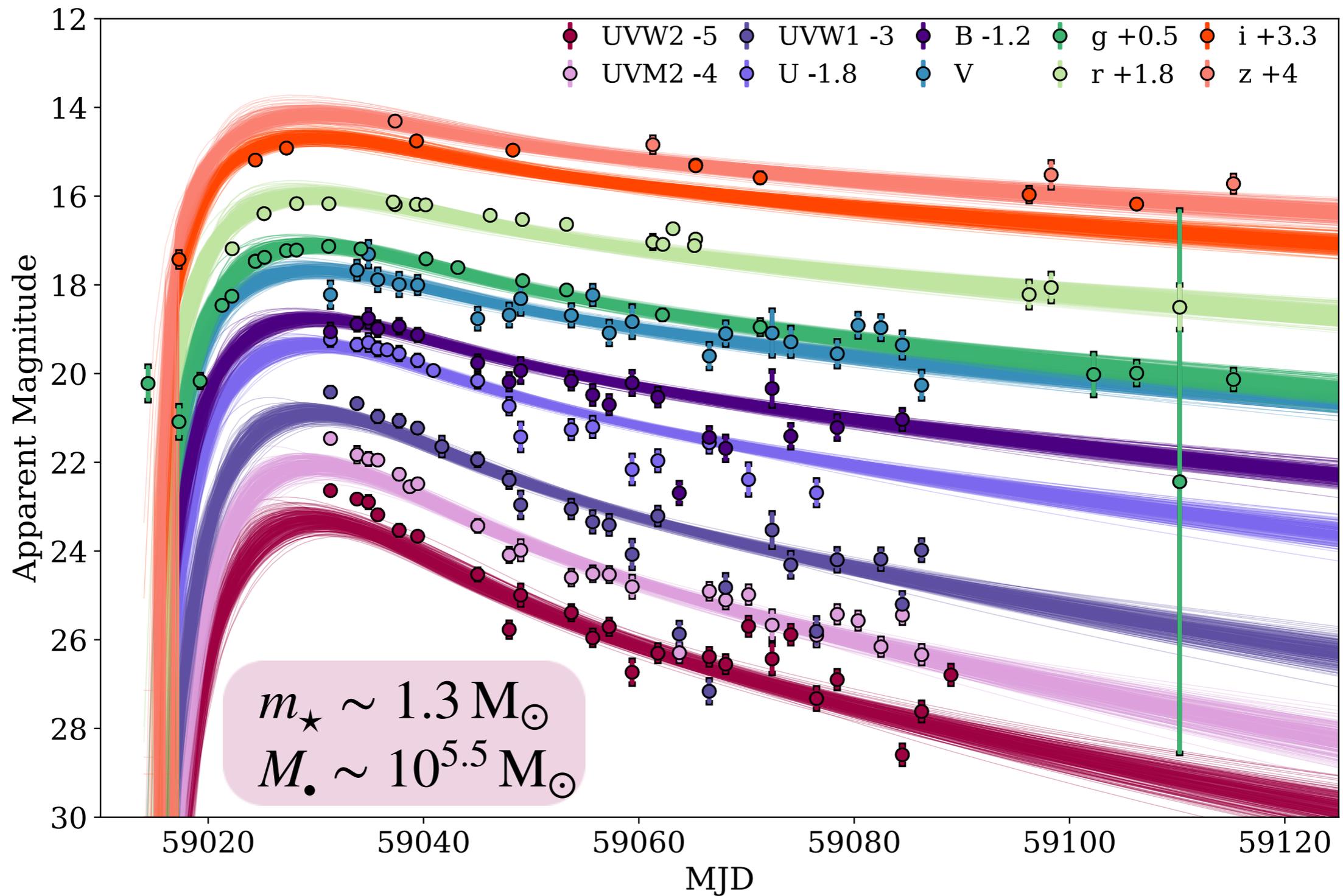


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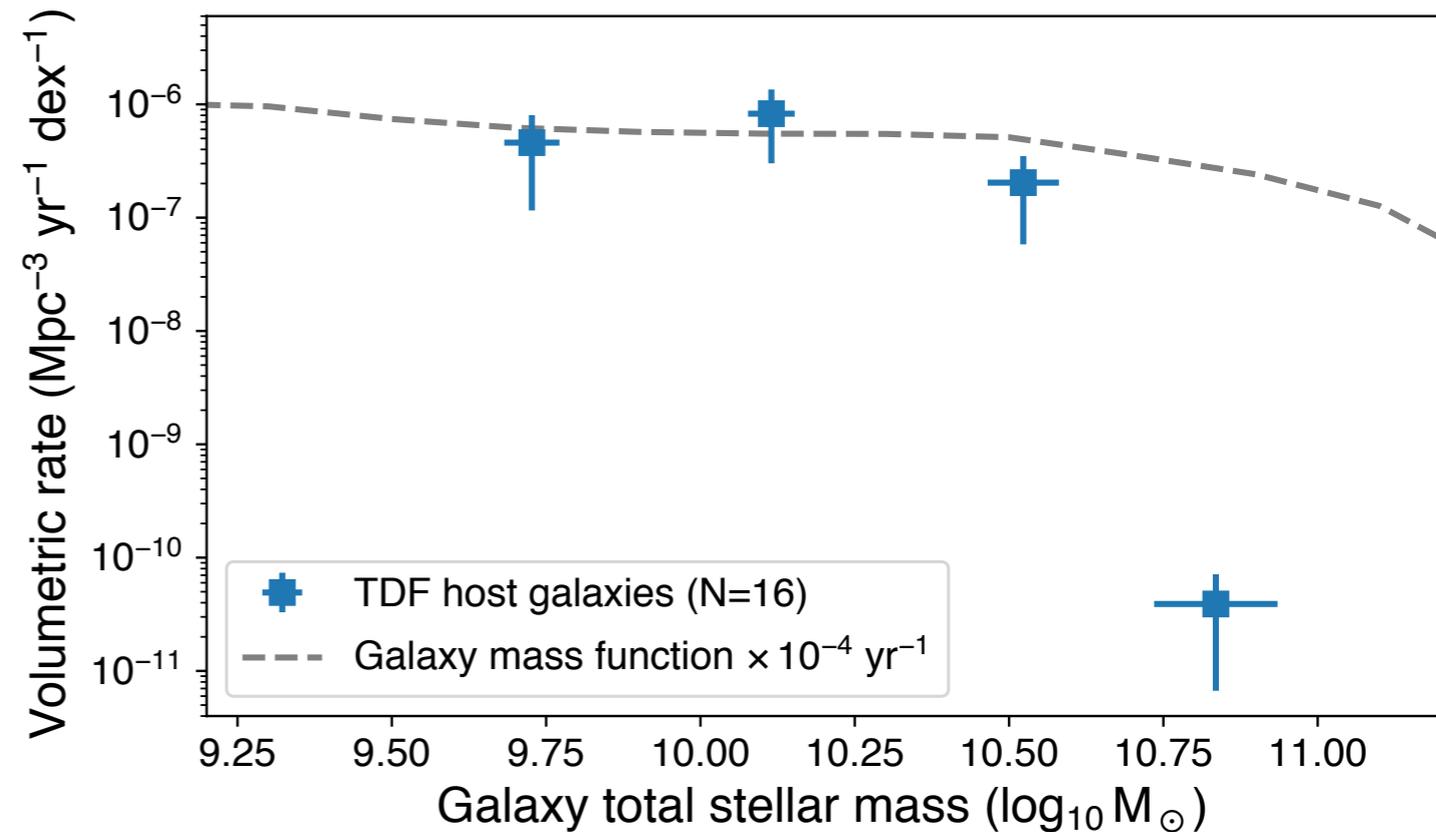
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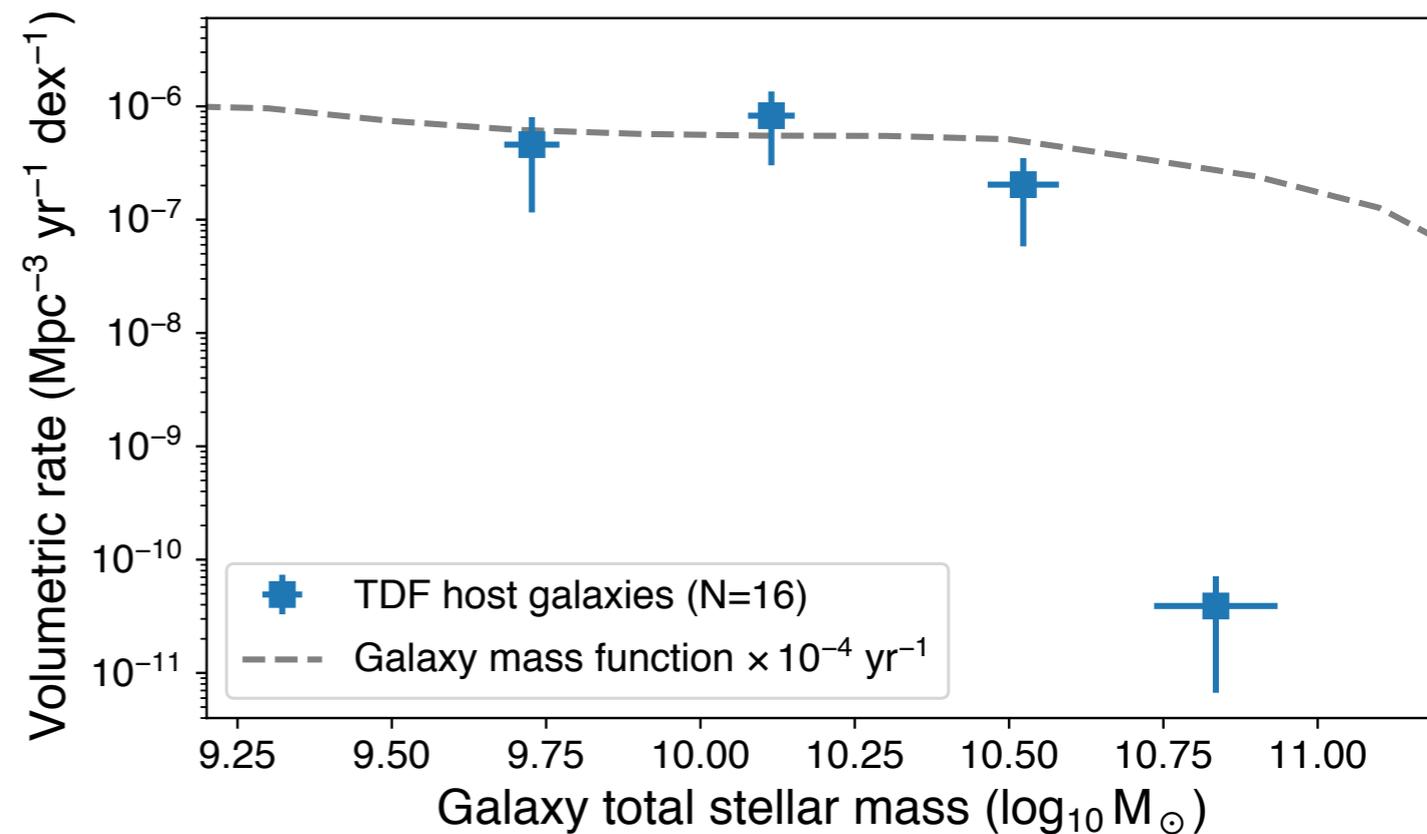


**VanVelzen+18**

# Some questions

How many events per year (rate)?

Typically 1 event every 10,000 yr



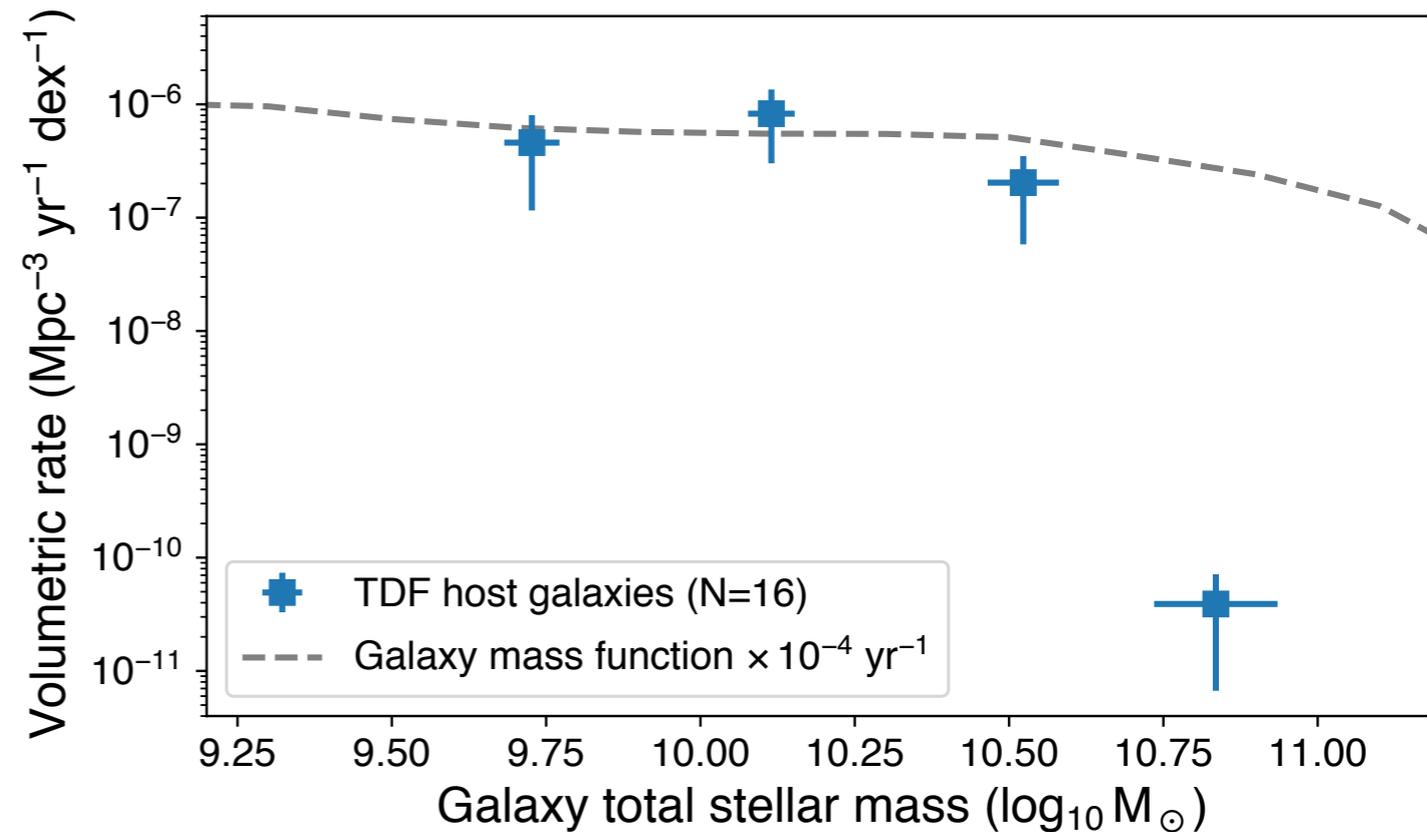
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Distributions of events?

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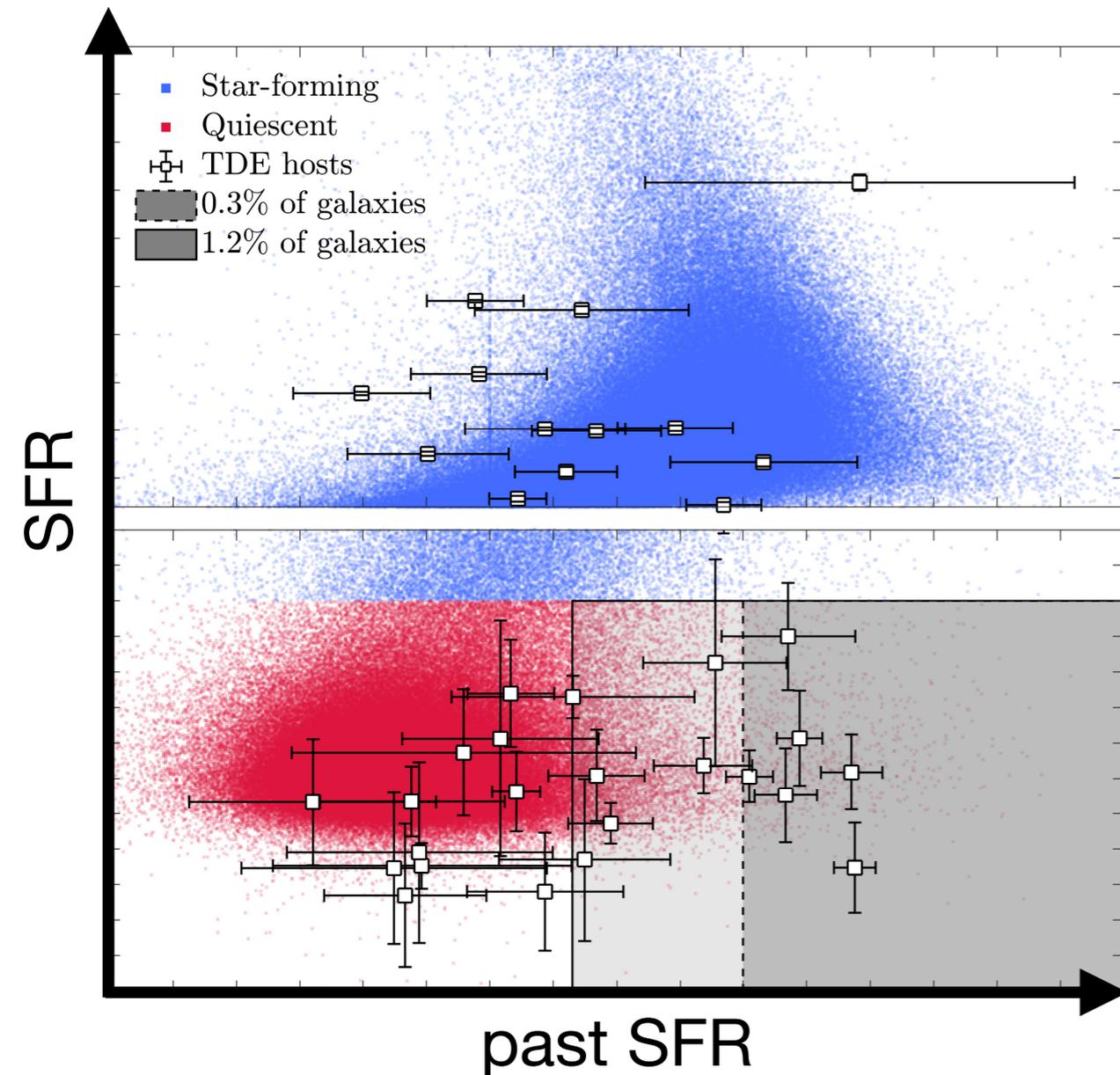
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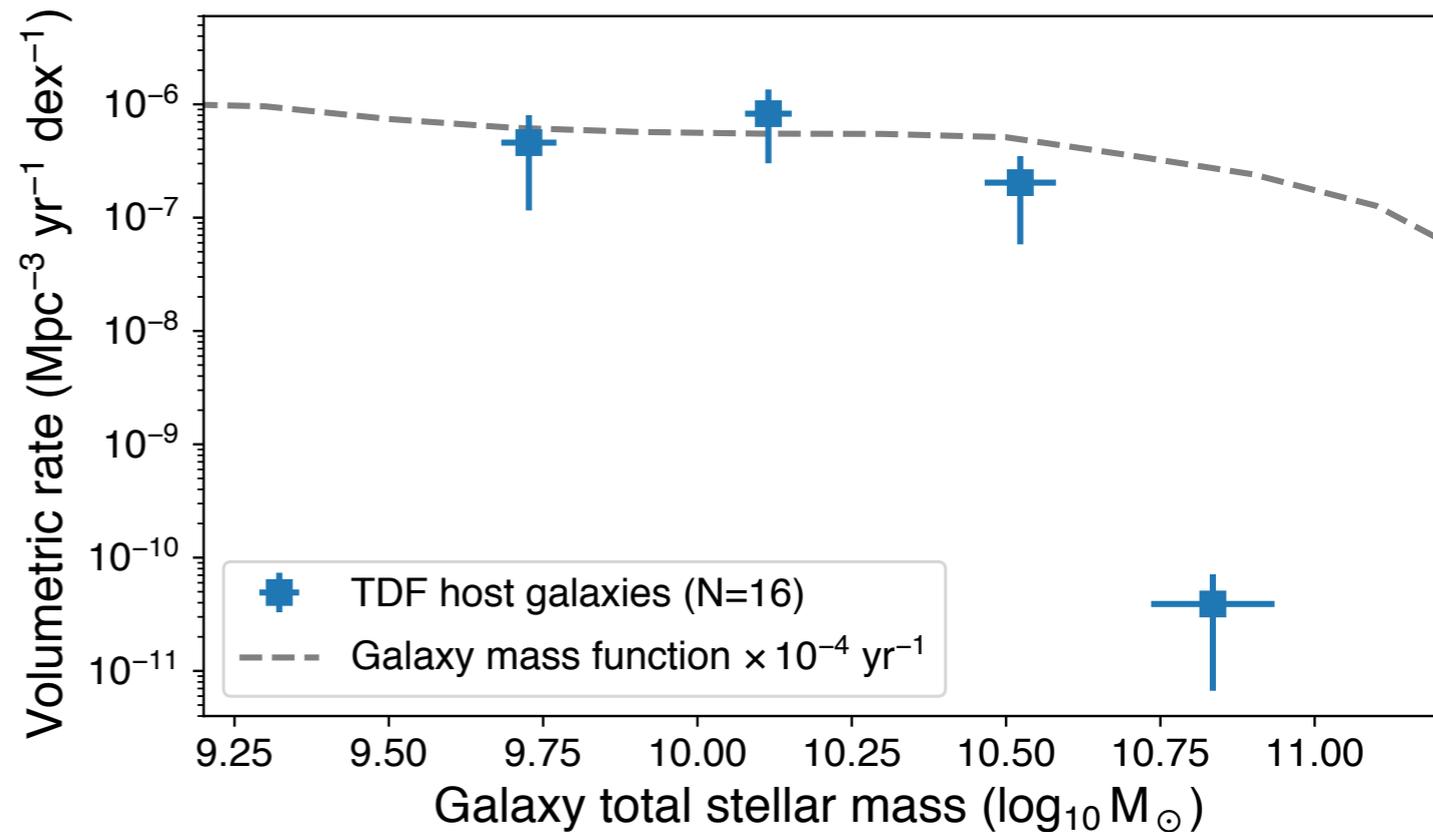
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DeckerFrench+16



VanVelzen+18

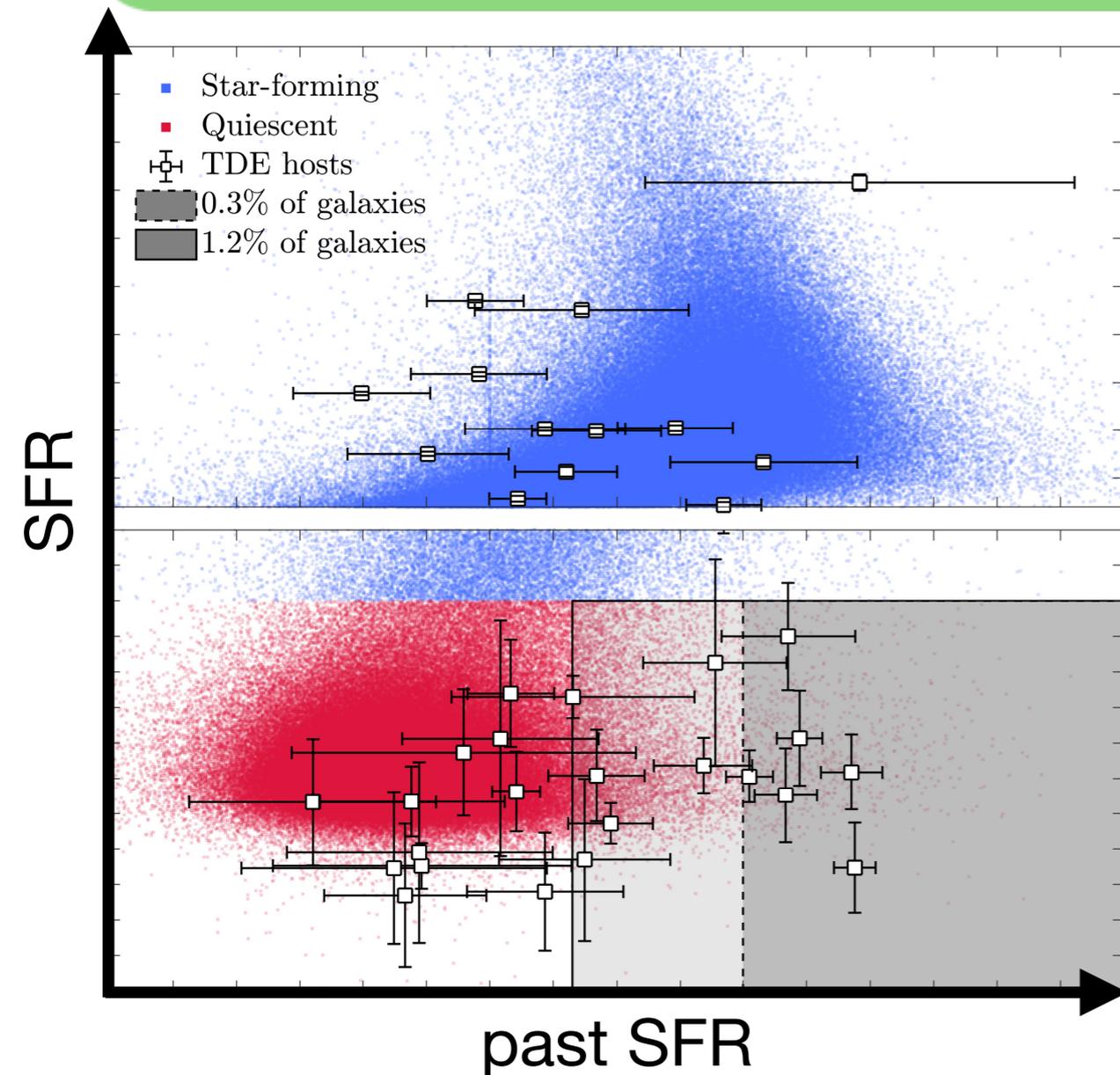
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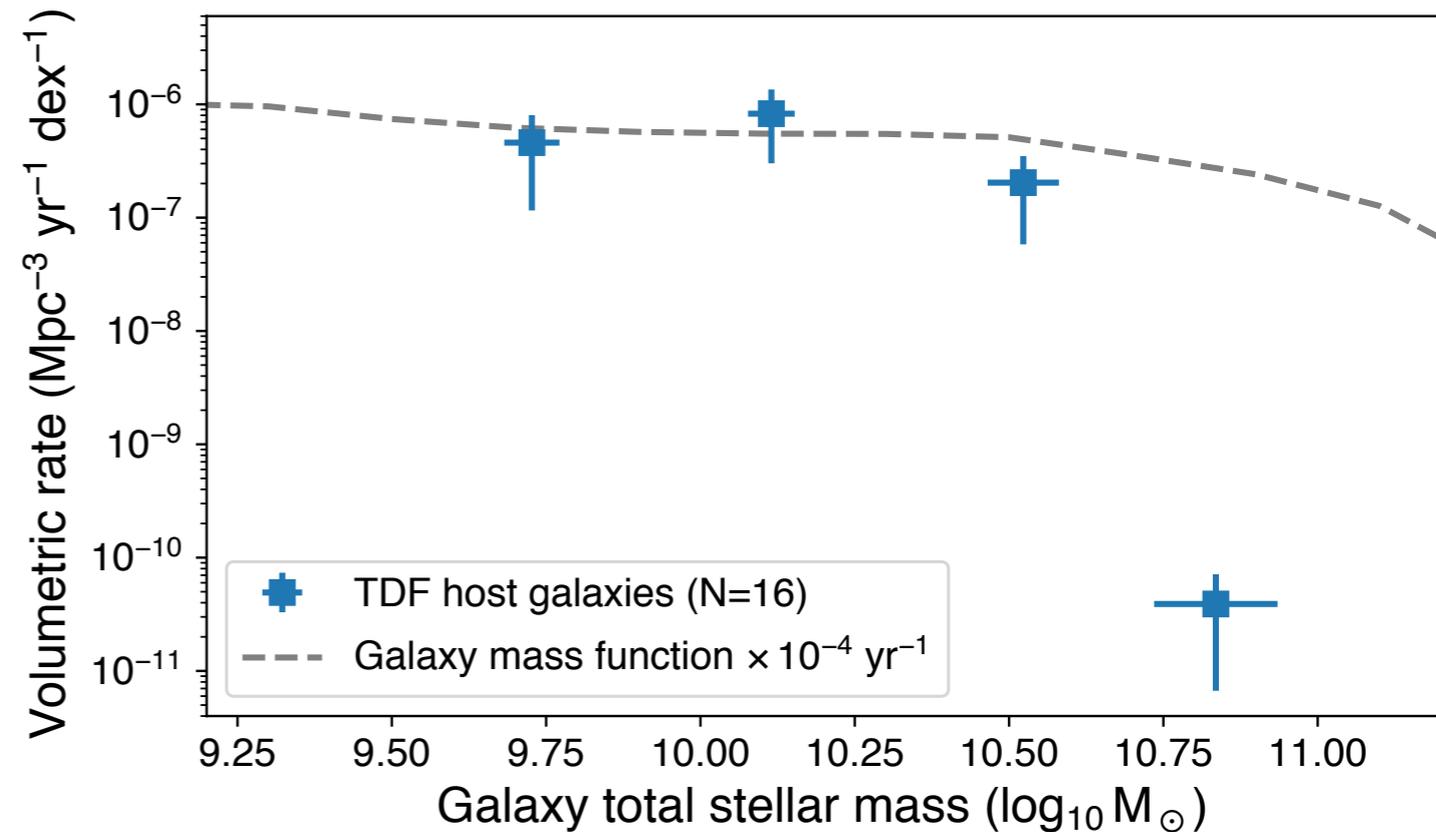
- 20% of events in 1% of galaxies

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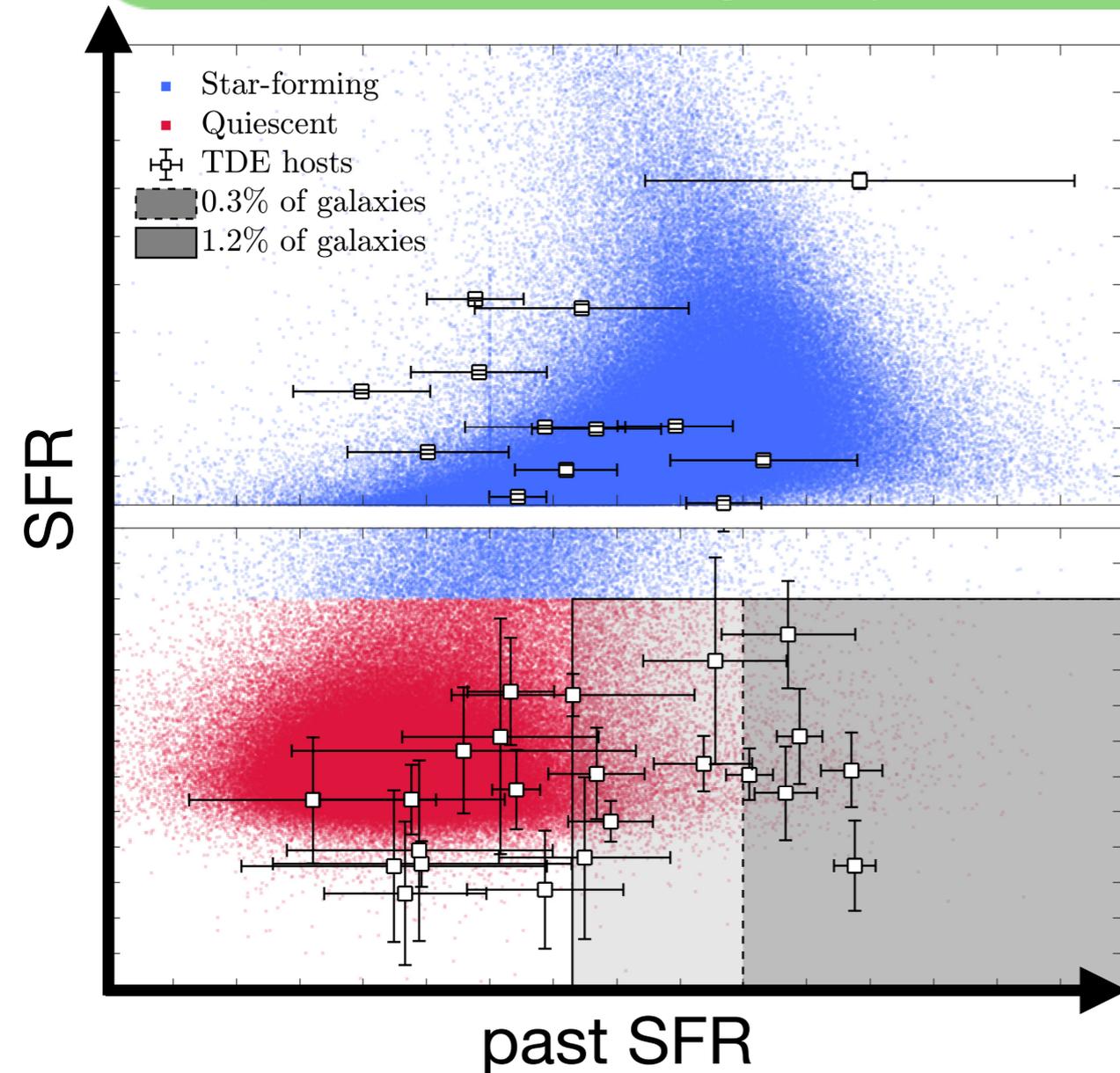
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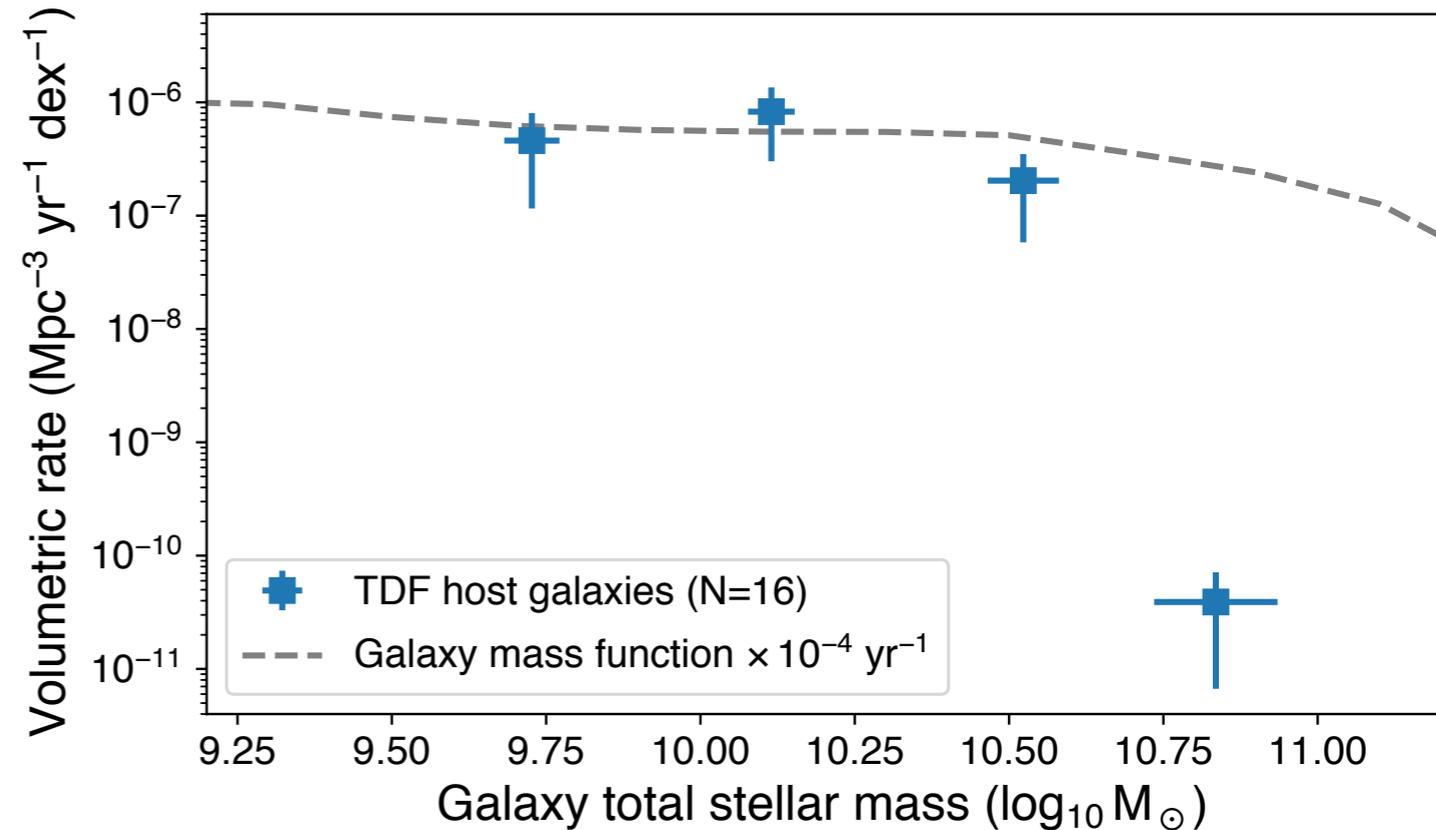
- 20% of events in 1% of galaxies
- Dependence with galaxy/BH mass

How many events per year (rate)?

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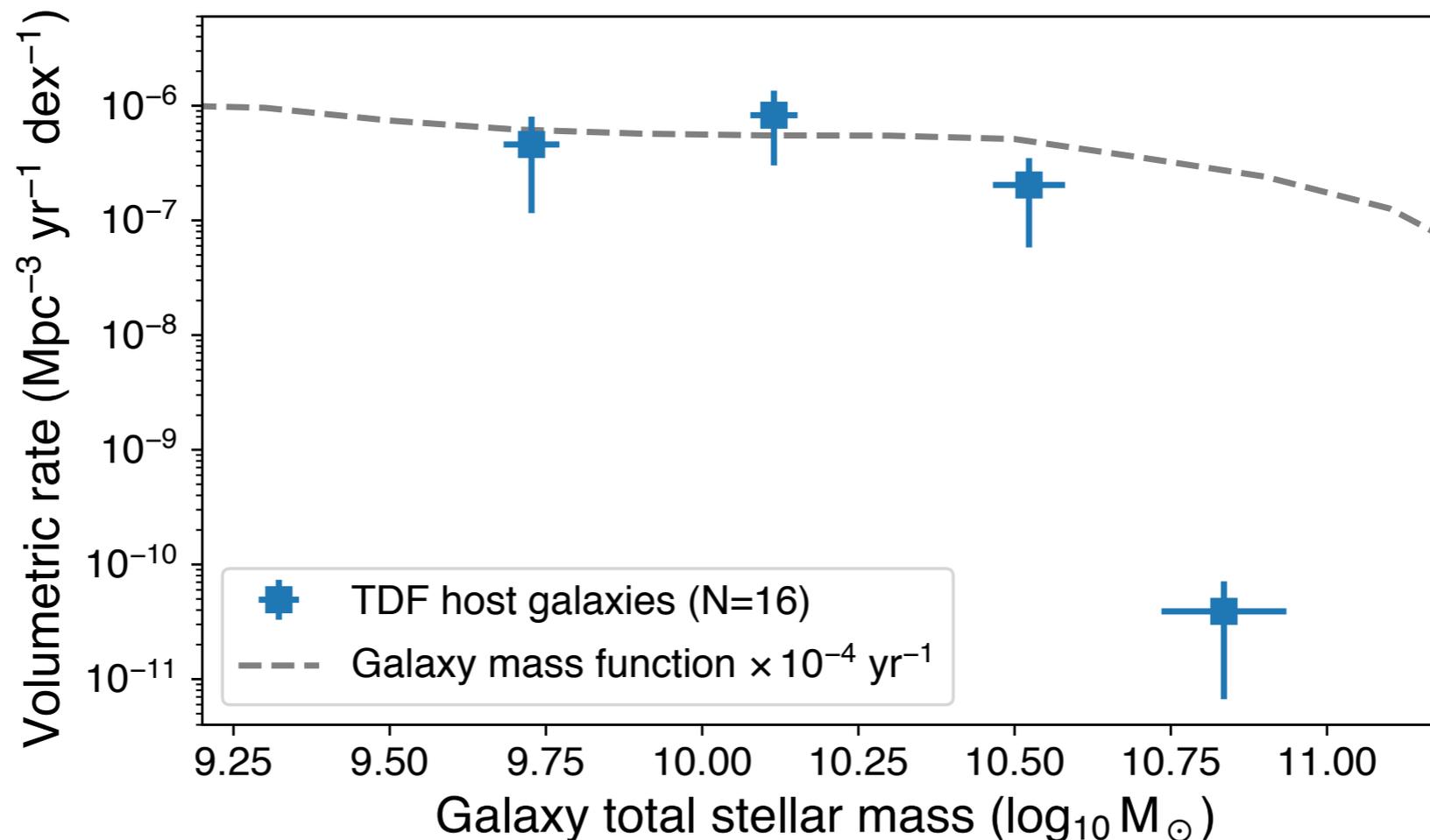
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# Outline

- I. Rate of TDEs in our Universe (**Pfister+20b**)
- II. Rate of TDEs during mergers (Pfister+19)
- III. Rate of TDEs in a mock universe (Pfister+20c)

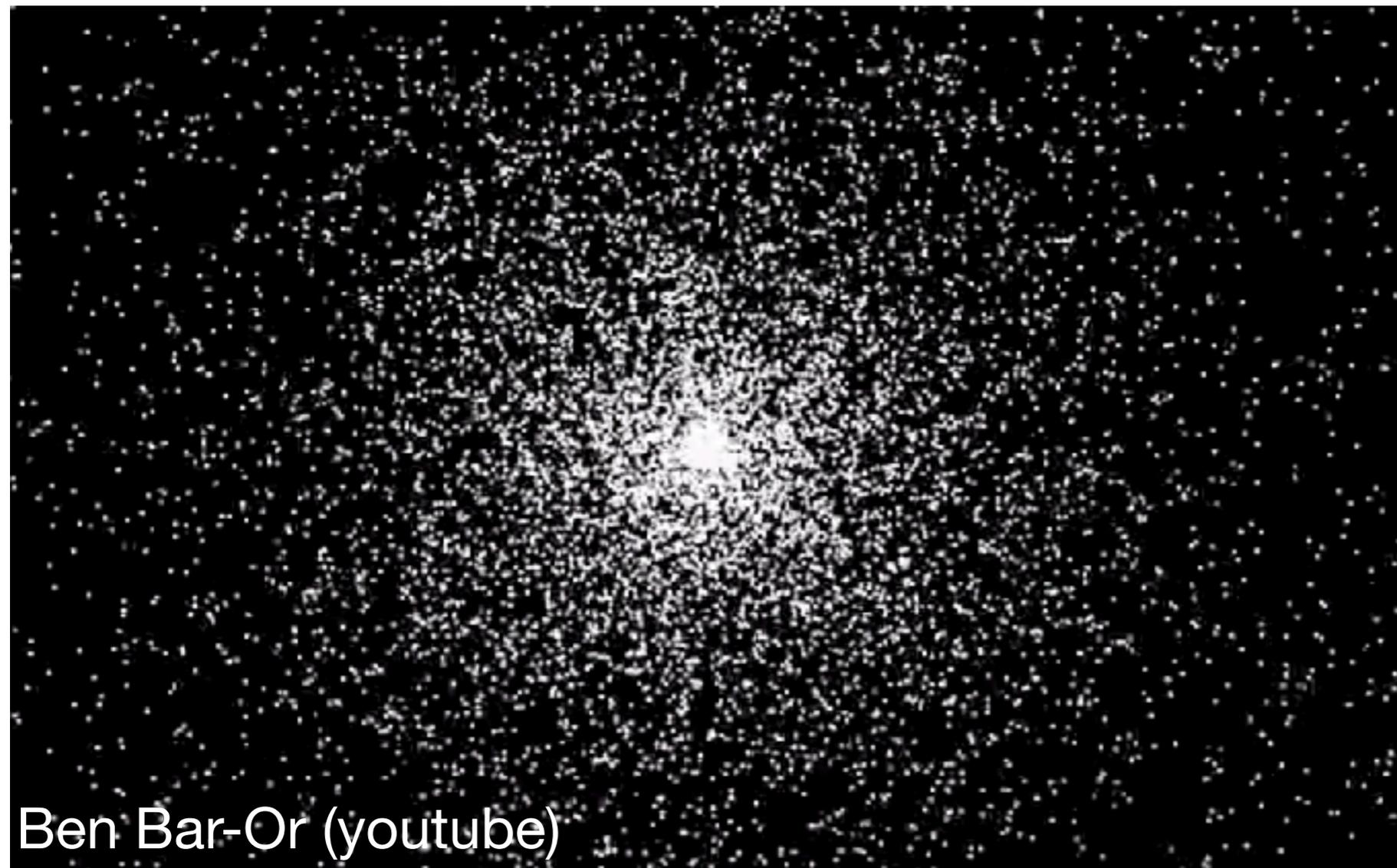
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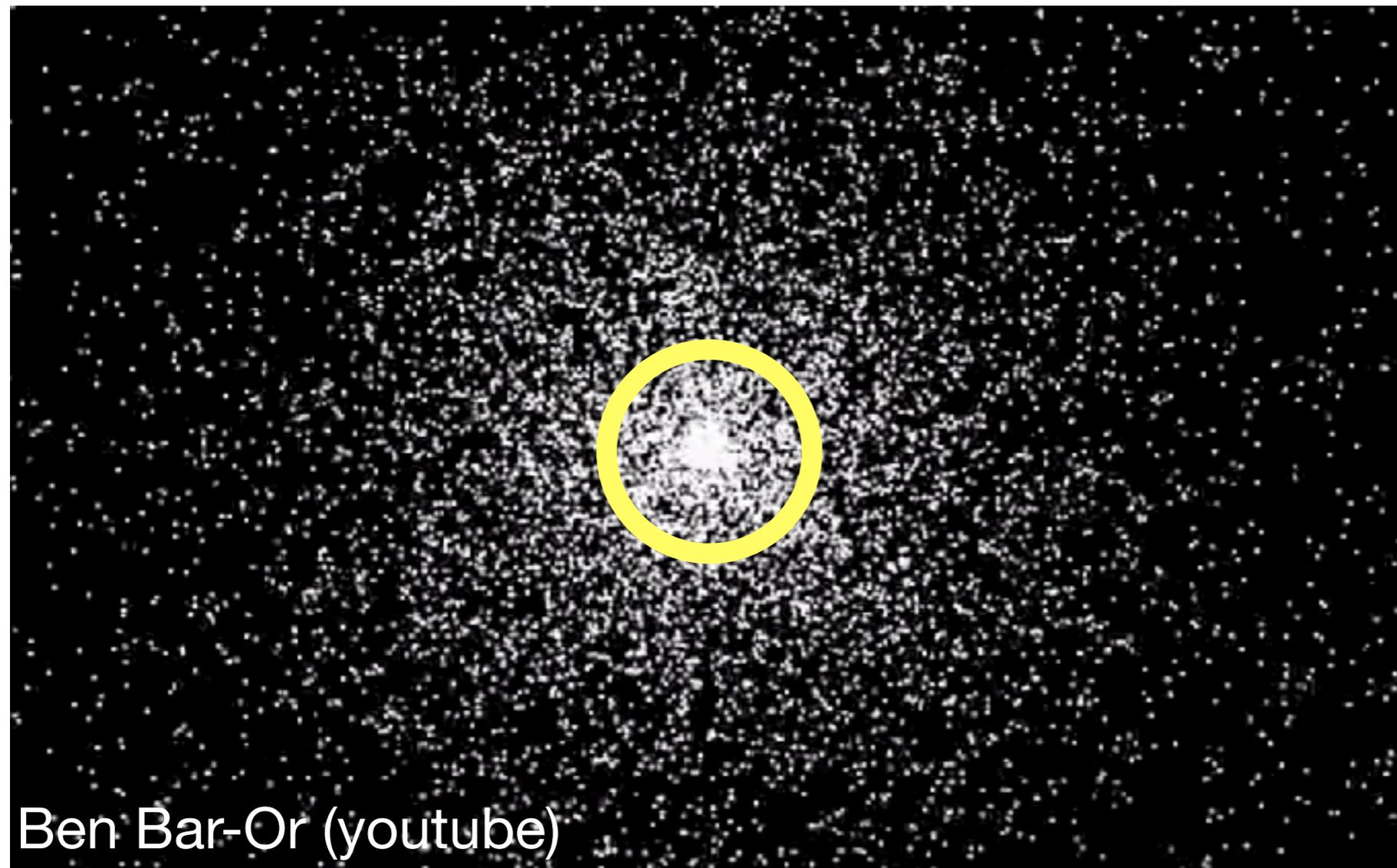
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# Rate of TDEs in our Universe



Count the rate at which stars penetrate the TDE radius.

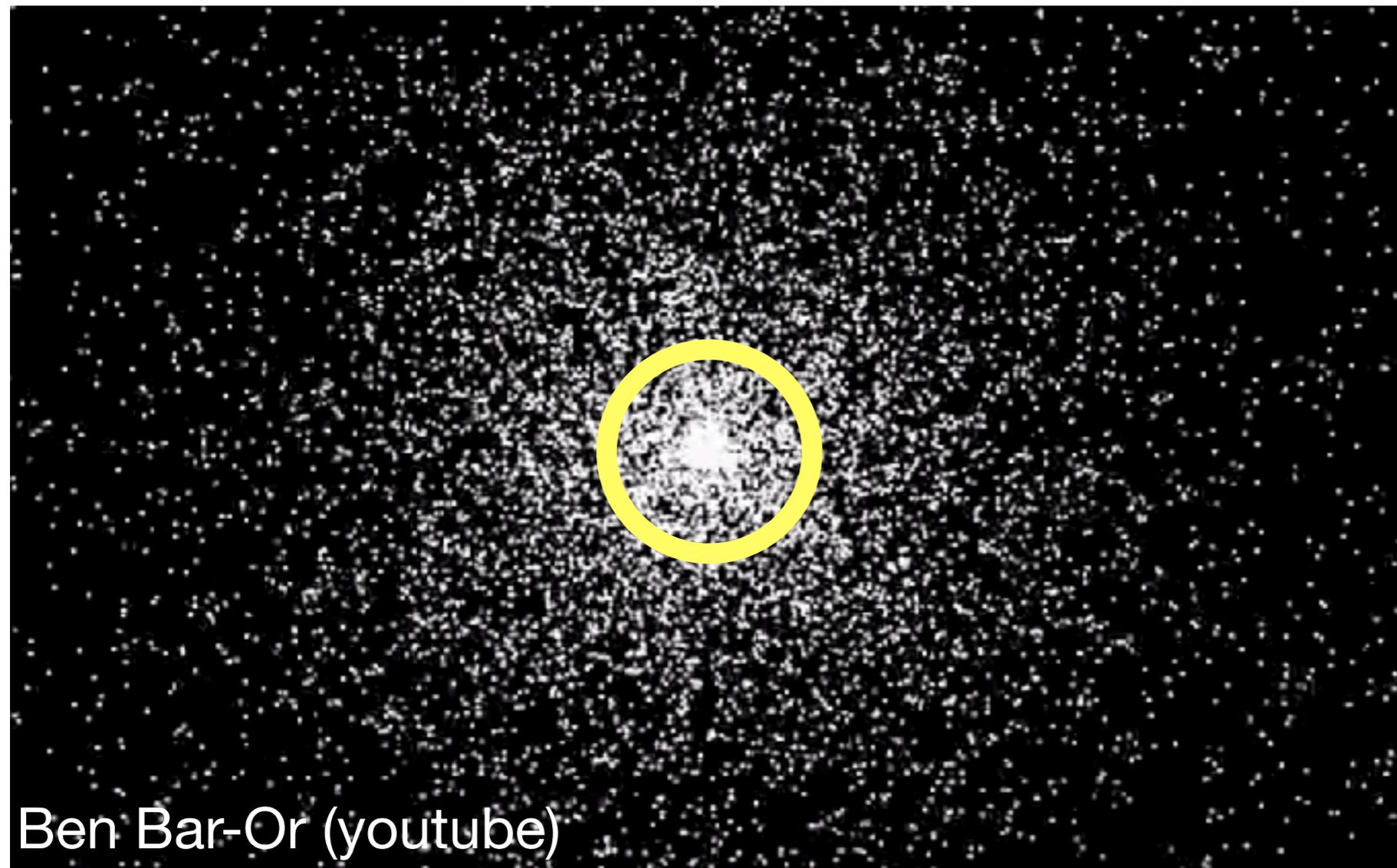
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Ben Bar-Or (youtube)

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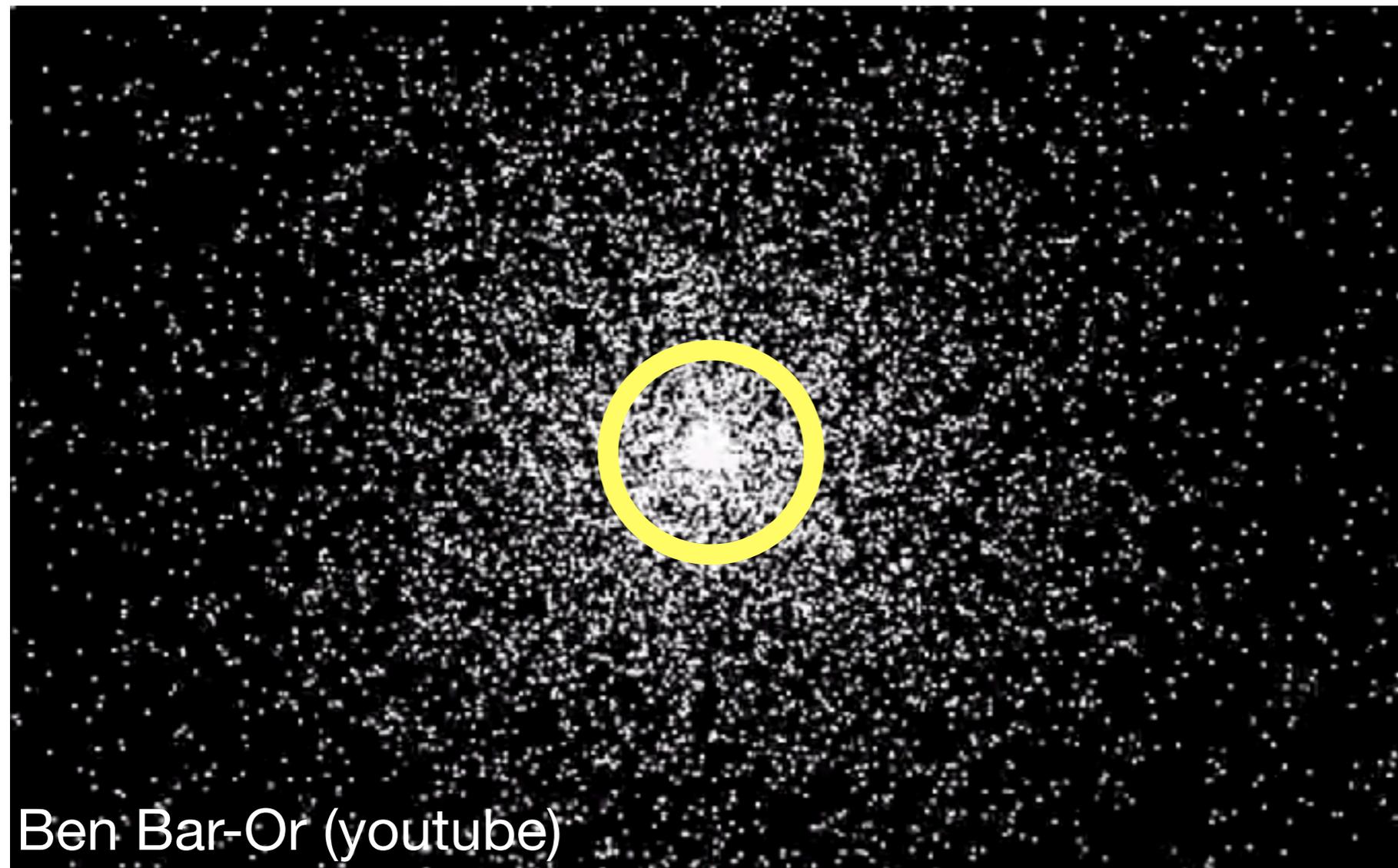


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# Rate of TDEs in our Universe

$$R_{\text{TDE}} = r_{\star} \left( \frac{M_{\bullet}}{m_{\star}} \right)^{1/3} \sim 10^{-6} \text{ pc} \left( \frac{r_{\star}}{R_{\odot}} \right) \left( \frac{M_{\bullet}}{10^6 M_{\odot}} \right)^{1/3} \left( \frac{m_{\star}}{M_{\odot}} \right)^{-1/3}$$

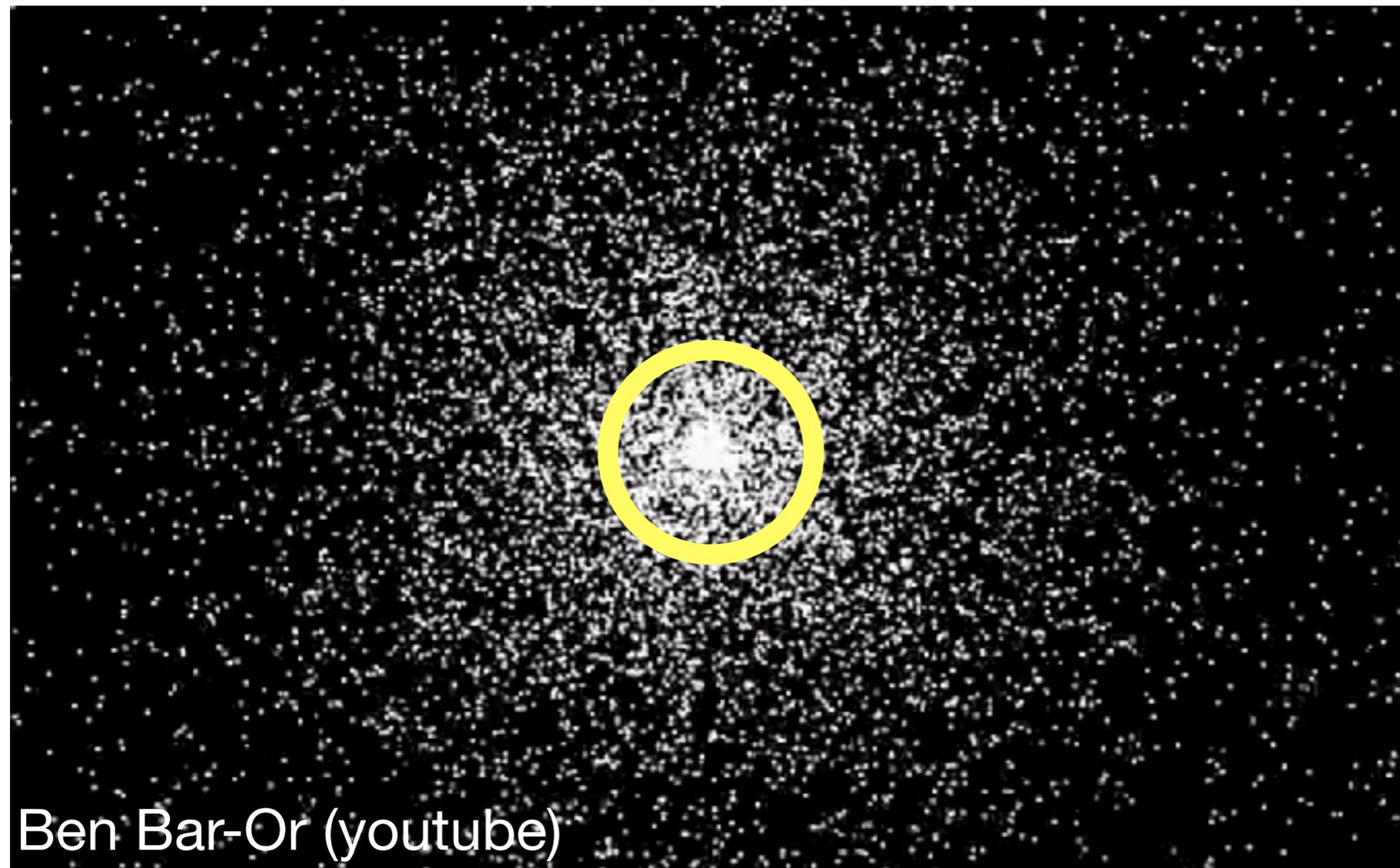


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Count the rate at which stars penetrate the TDE radius.

How can we do that realistically?

Ben Bar-Or (youtube)

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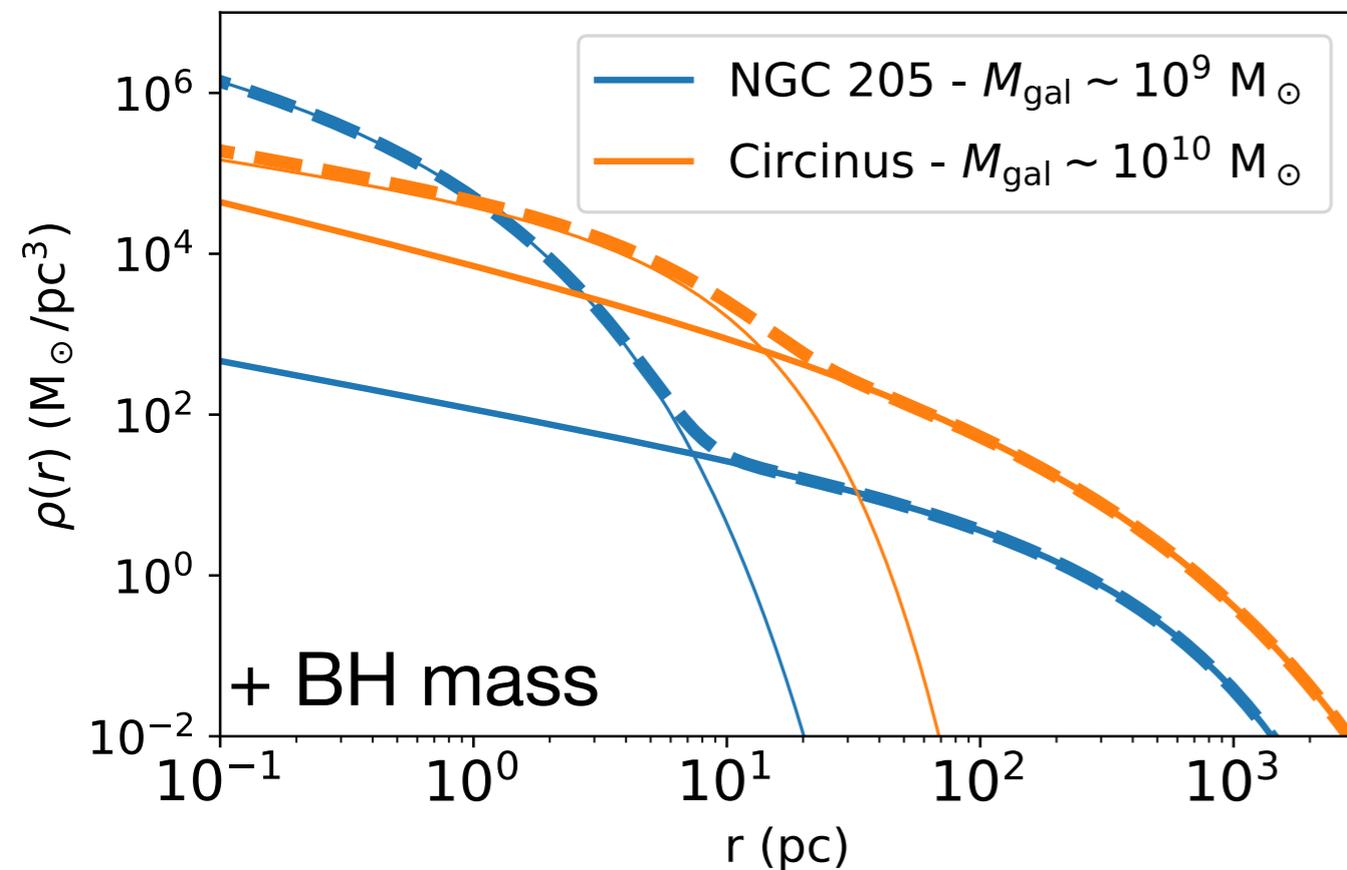
The rate of TDE should depend on the stellar density profile ( $\rho$ ) and BH mass ( $M_{\bullet}$ ): this is the "Loss Cone Formalism"

**Lightman+77, Strubbe+11, Merritt+13, Vasiliev+17, Pfister+21**

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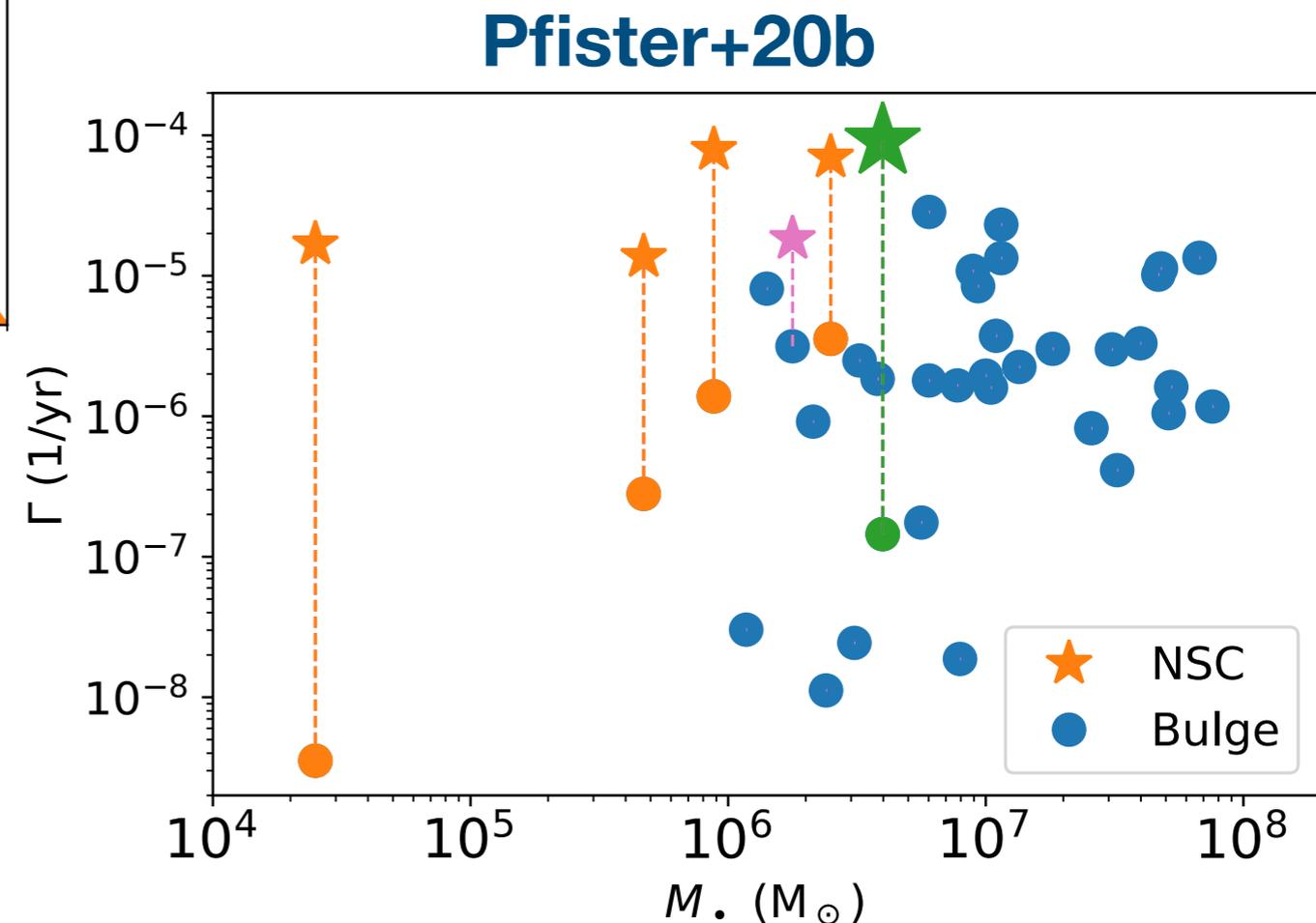
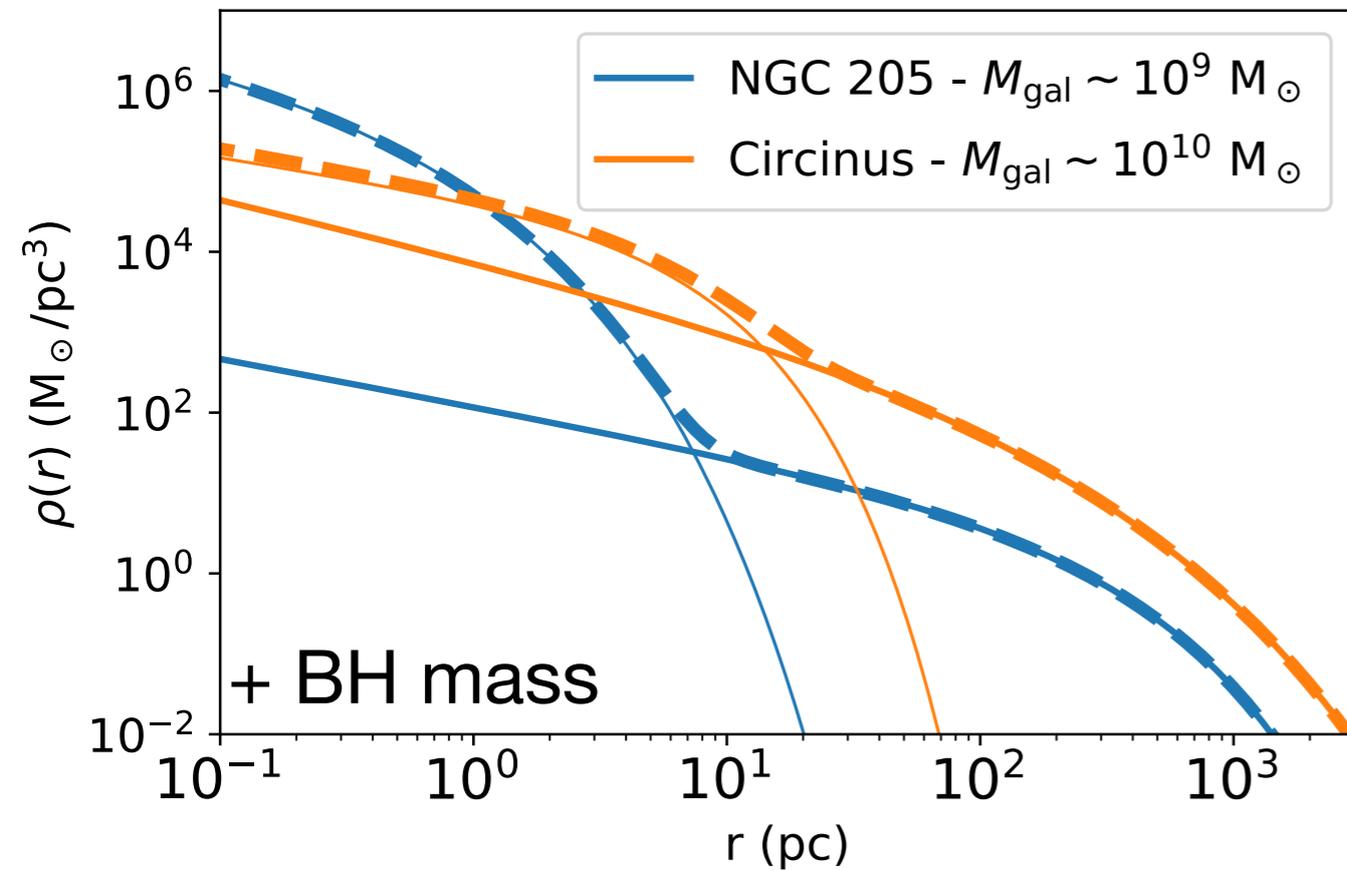
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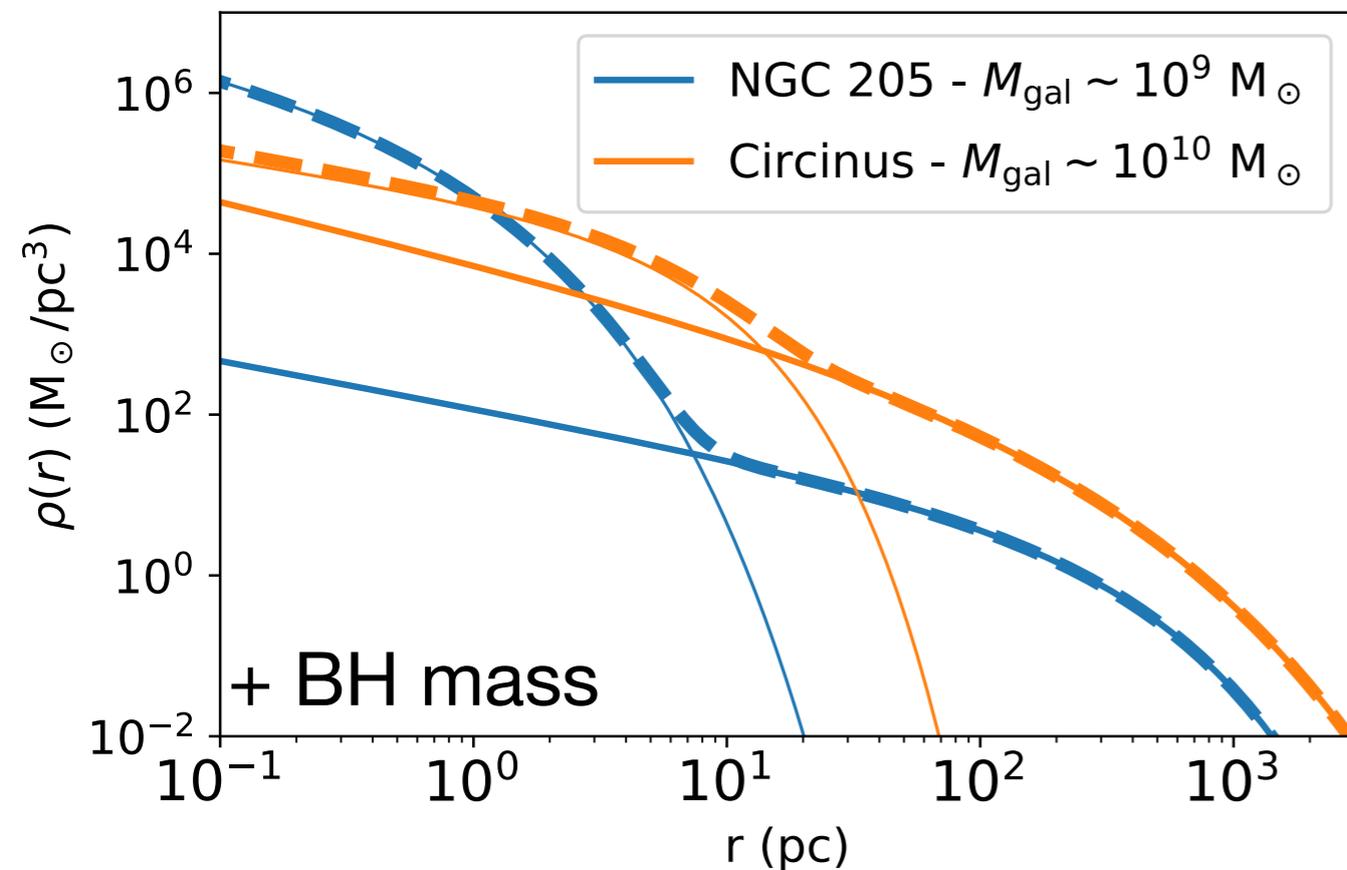
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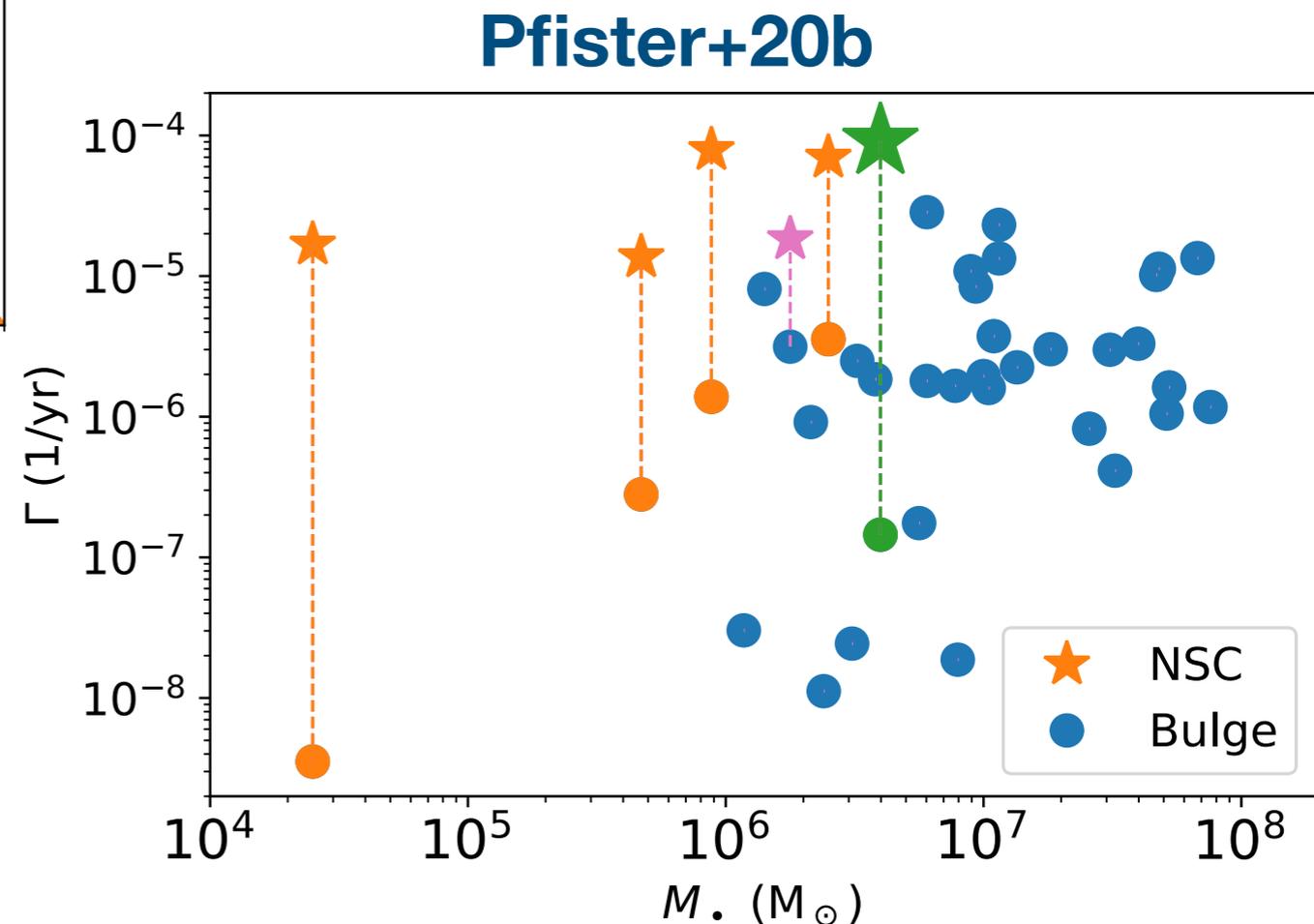
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**Lightman+77, Strubbe+11, Merritt+13, Vasiliev+17, Pfister+21**



We can understand the typical rate of  $10^{-5} - 10^{-4} \text{ yr}^{-1}$  with the Loss Cone Formalism

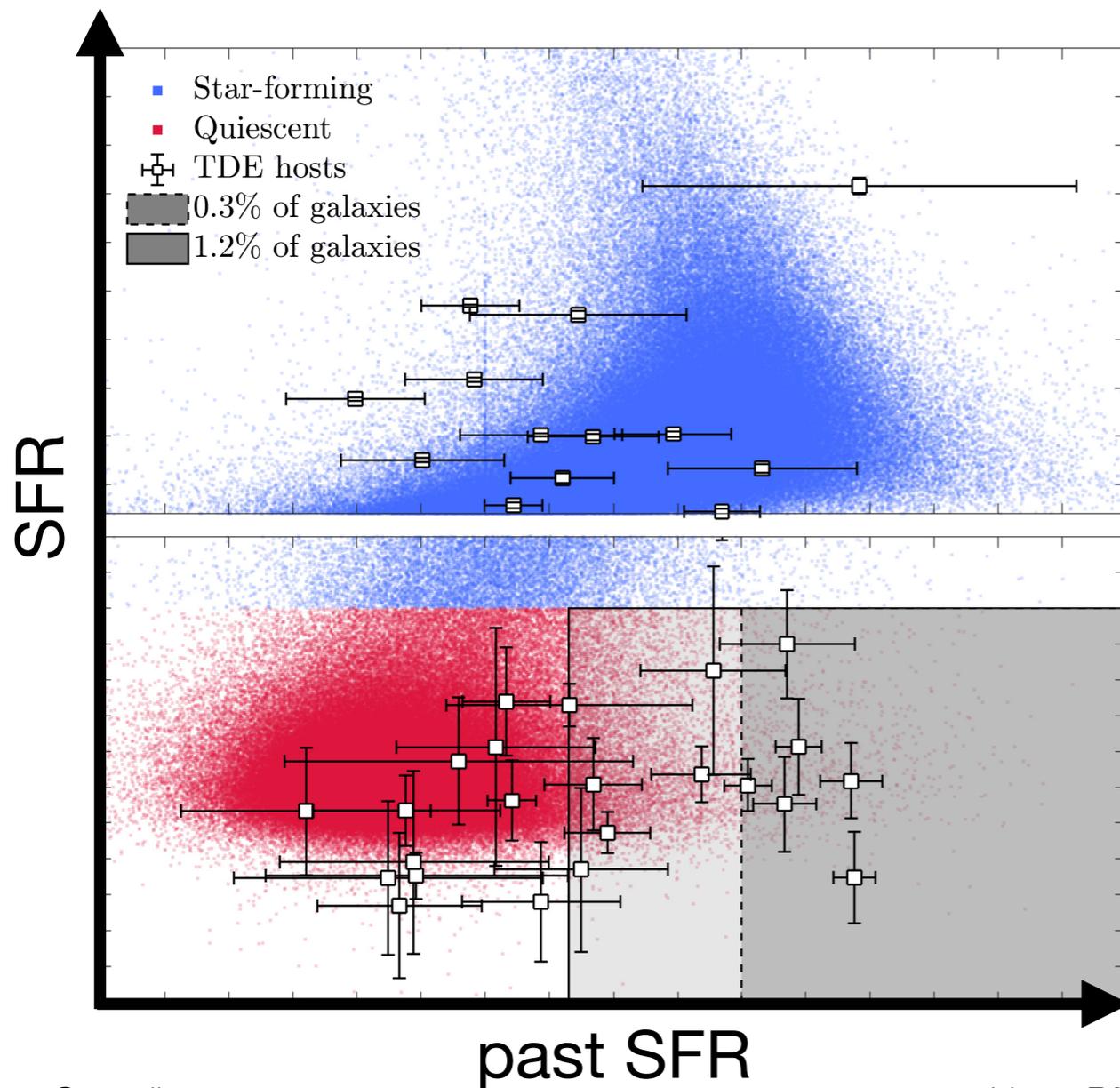


# Outline

- I. Rate of TDEs in our Universe (Pfister+20b)
- II. Rate of TDEs during mergers (**Pfister+19**)
- III. Rate of TDEs in a mock universe (Pfister+20c)

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Over-representation of TDEs in post-starburst galaxies?

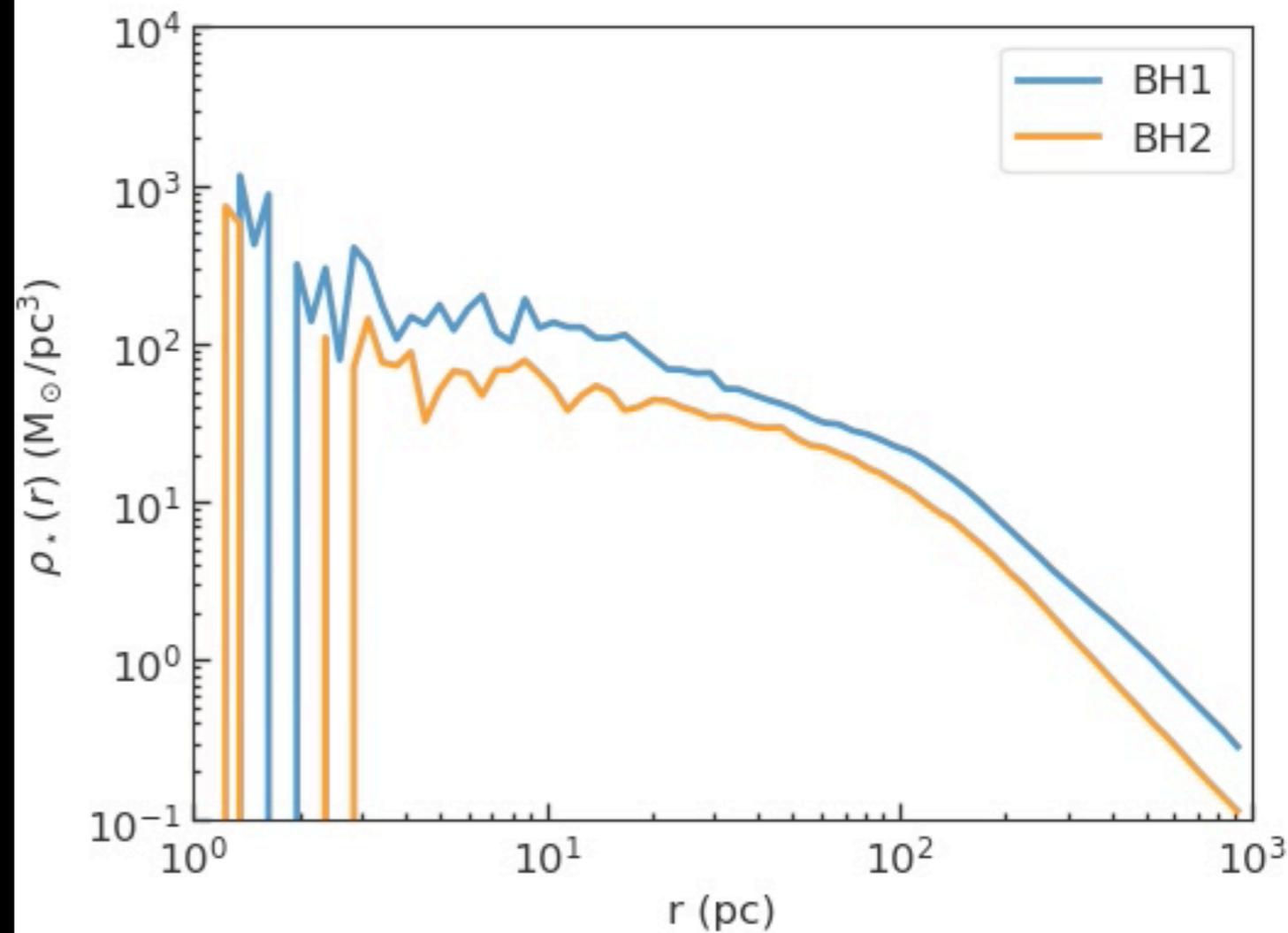
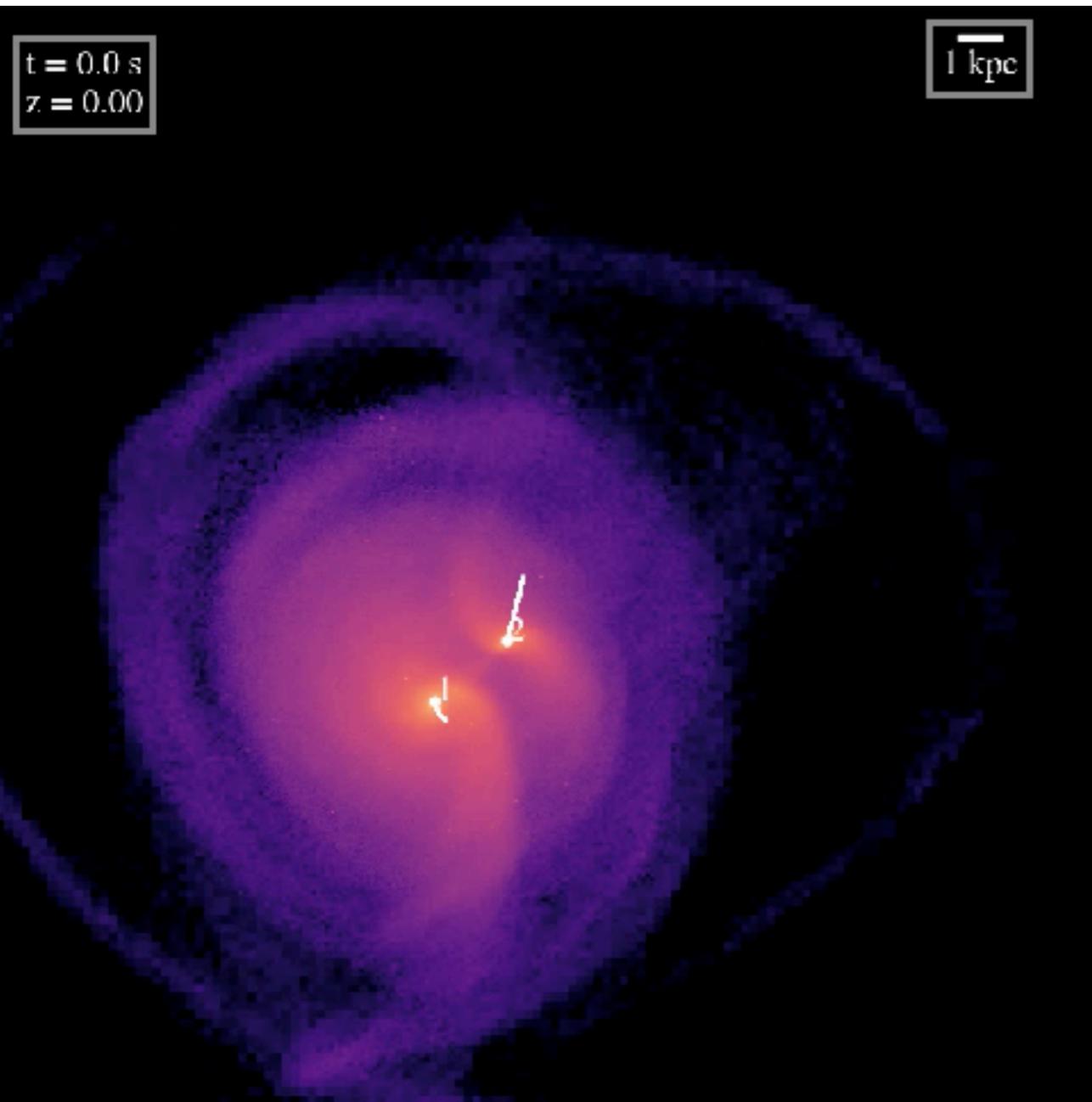
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During mergers, there is a starburst. We can run a simulation, measure the density profile, apply the Loss Cone Formalism, and compare the TDE rate with the SFR.

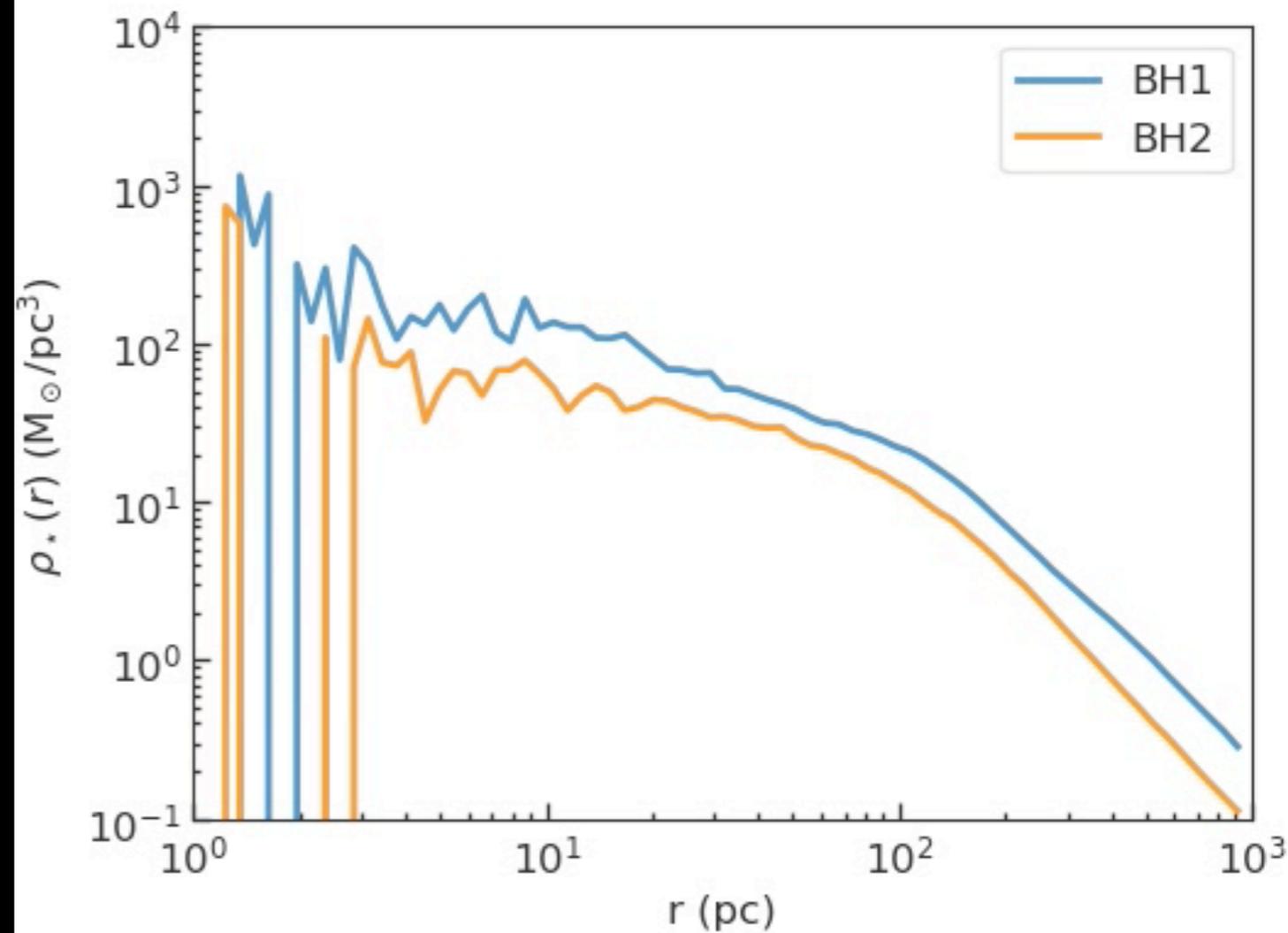
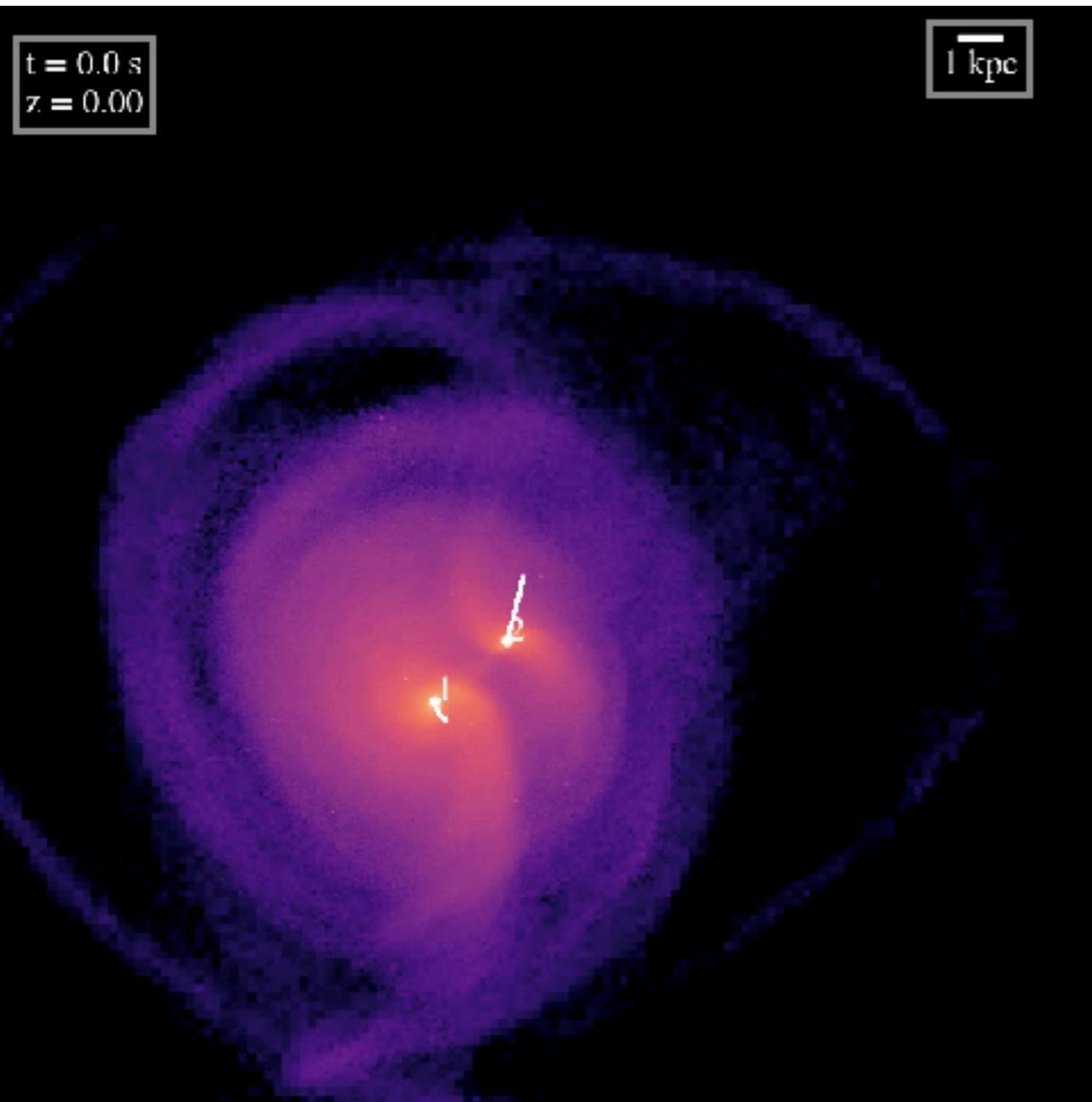
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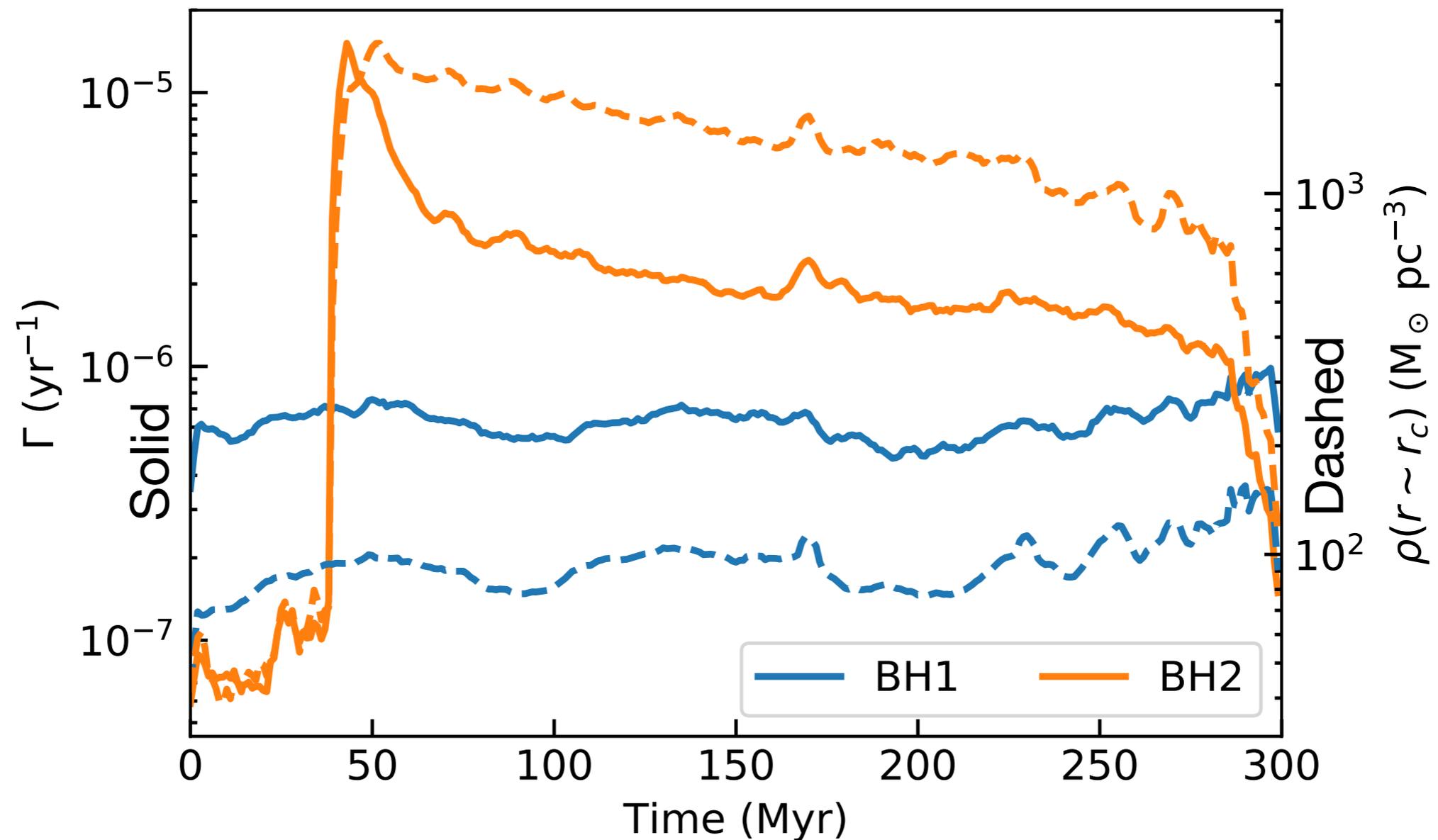
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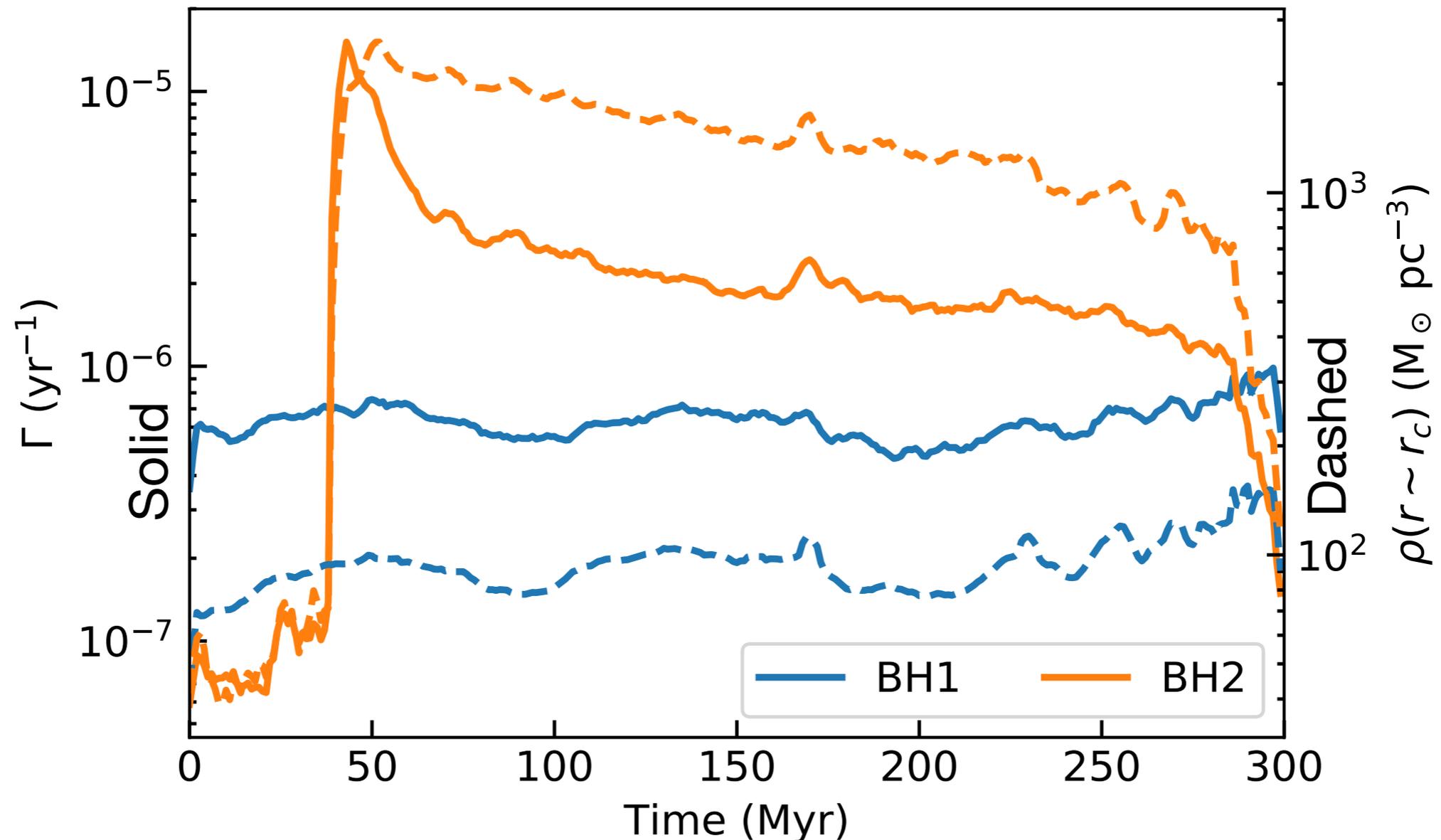
Pfister+19



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- We naturally reproduce the rate enhancement in post-starburst galaxies

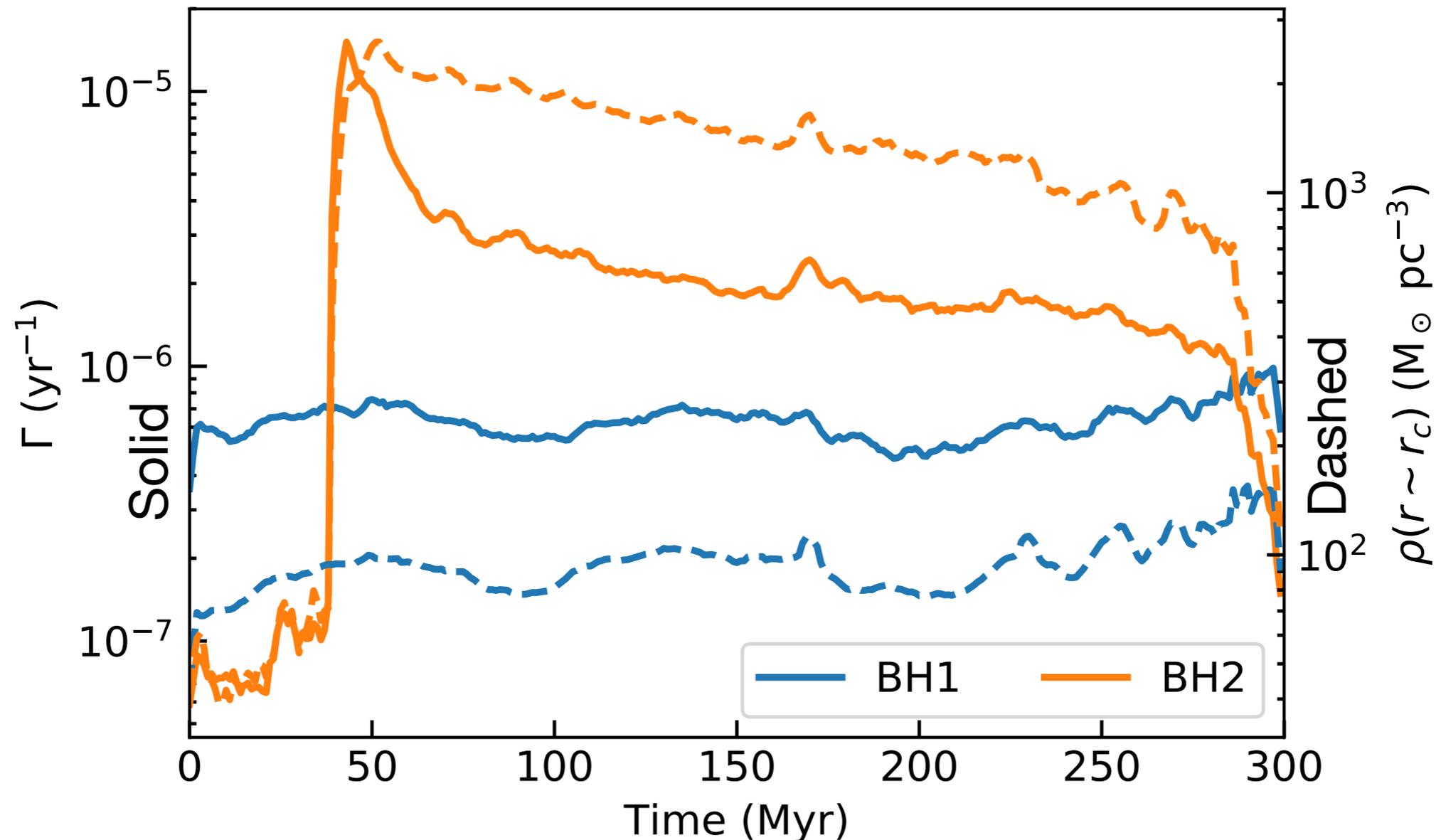
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# Rate of TDEs during mergers

- We naturally reproduce the rate enhancement in post-starburst galaxies
- This is due to an enhancement of the stellar density near the BH

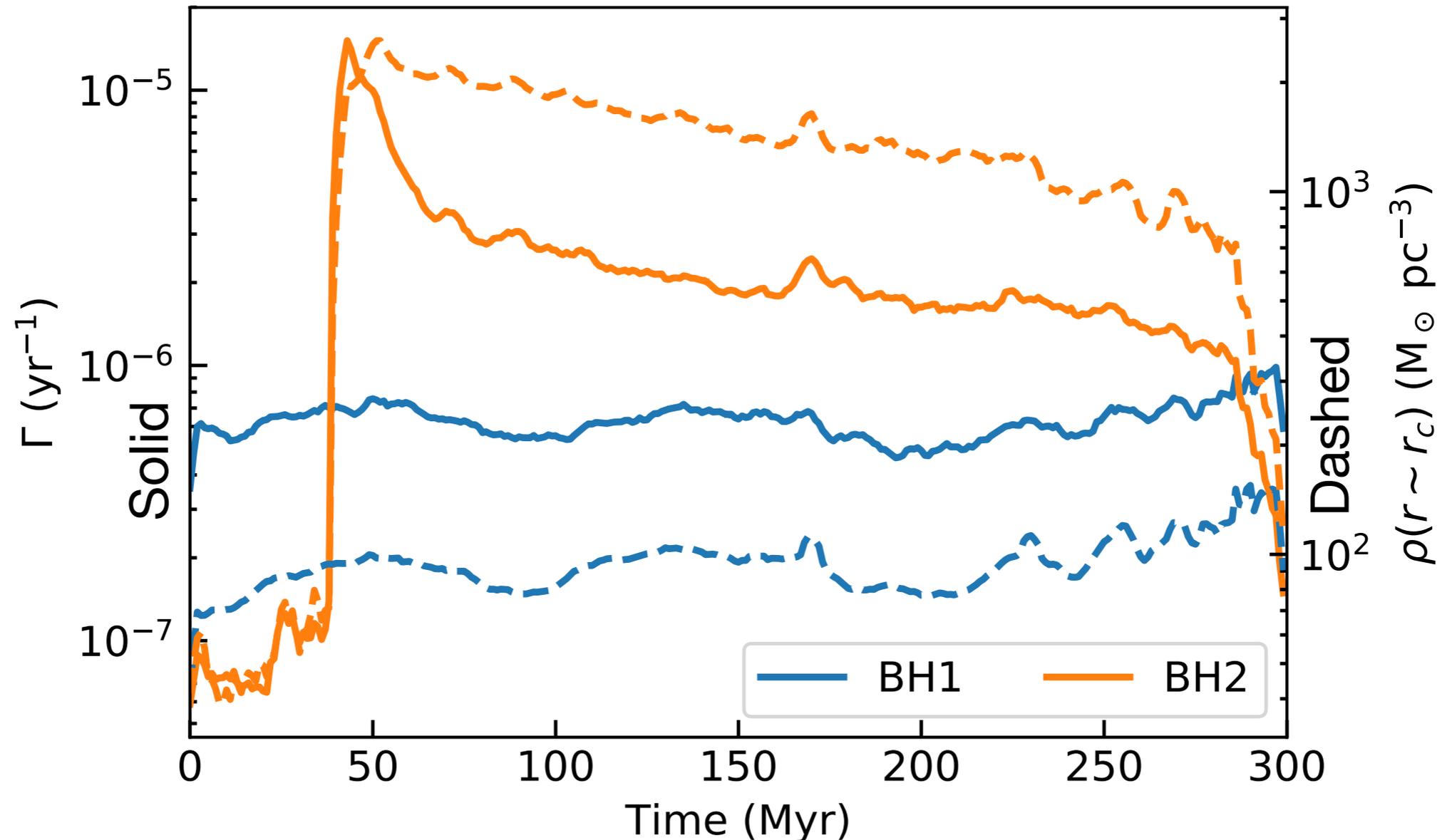
**Pfister+19**



# Rate of TDEs during mergers

- We naturally reproduce the rate enhancement in post-starburst galaxies
- This is due to an enhancement of the stellar density near the BH
- Here, the enhancement happens on the secondary BH

**Pfister+19**



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Around which BHs can we find TDEs? How does the rate evolve with redshift? Does "stellar accretion" affect the growth of BHs?

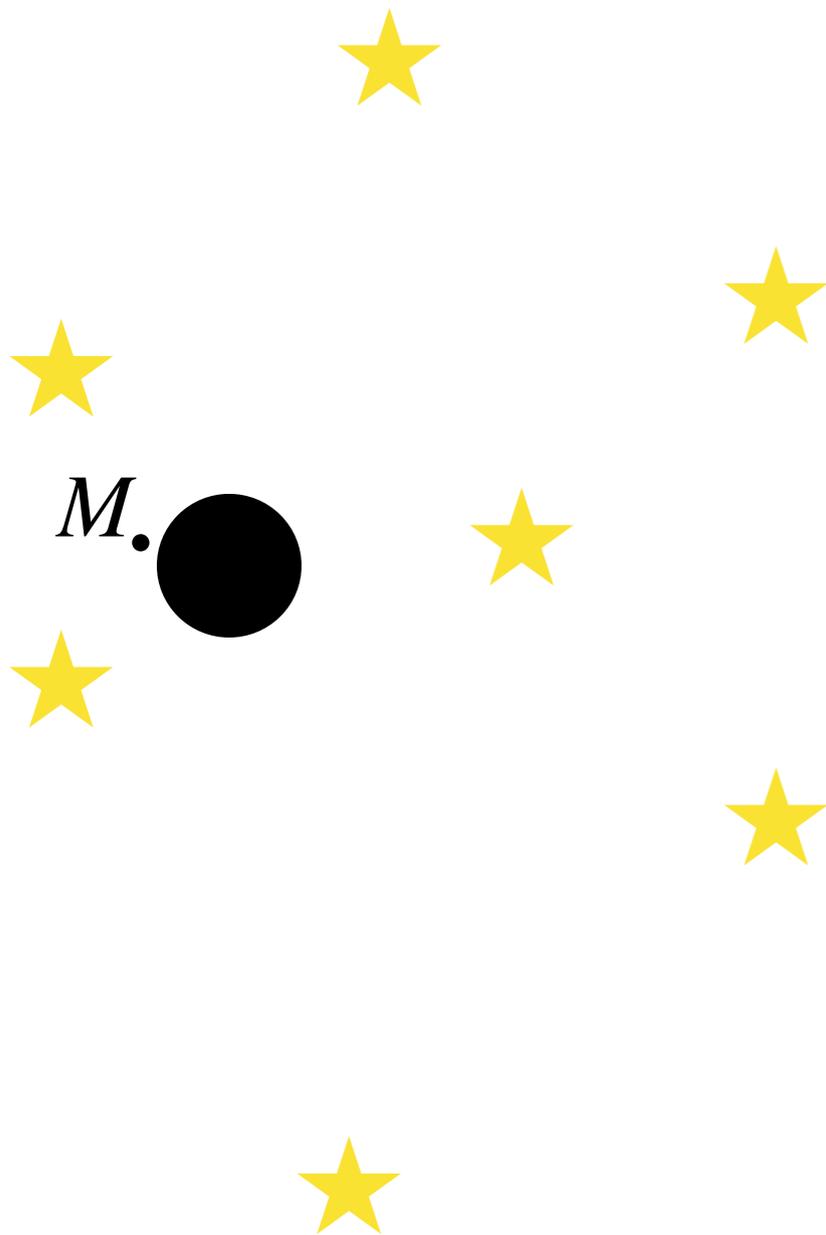
# Rate of TDEs in a mock universe

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We need to estimate self-consistently TDEs, on the fly, in a simulation.

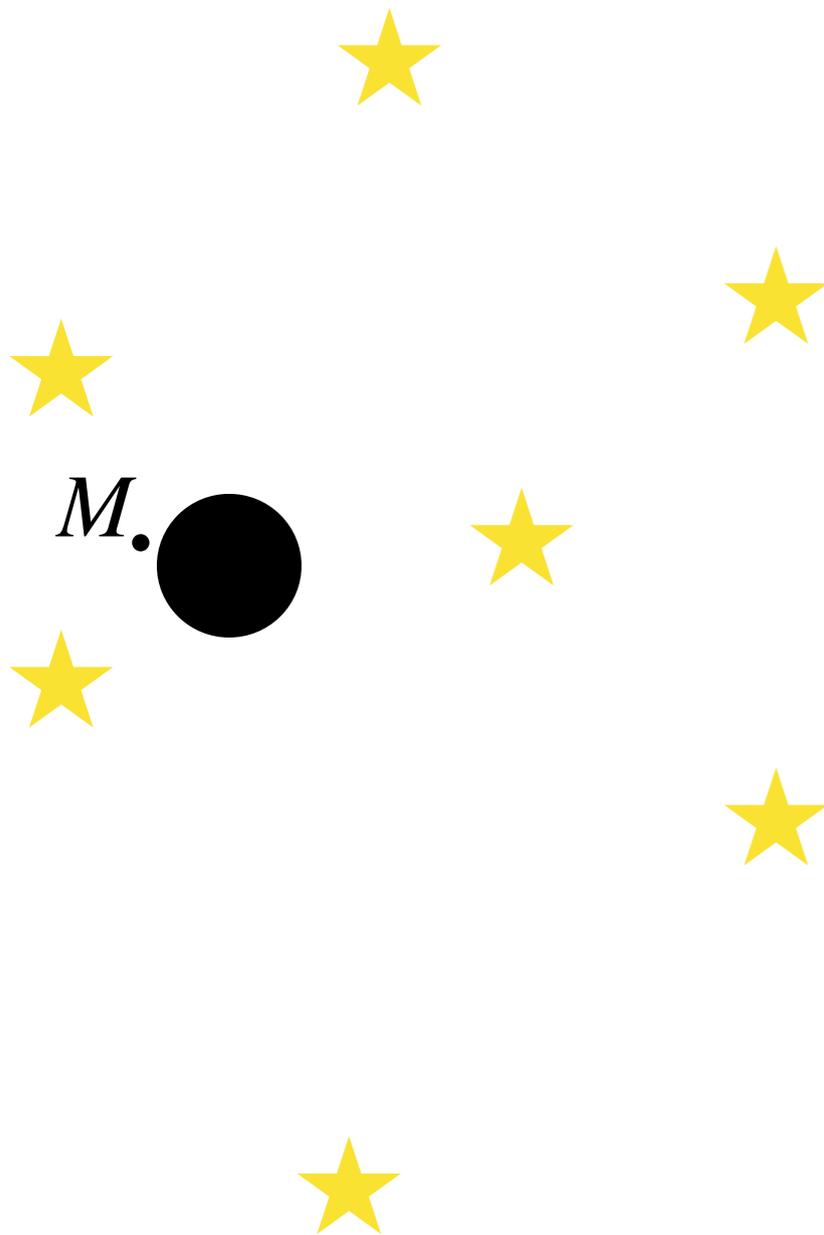
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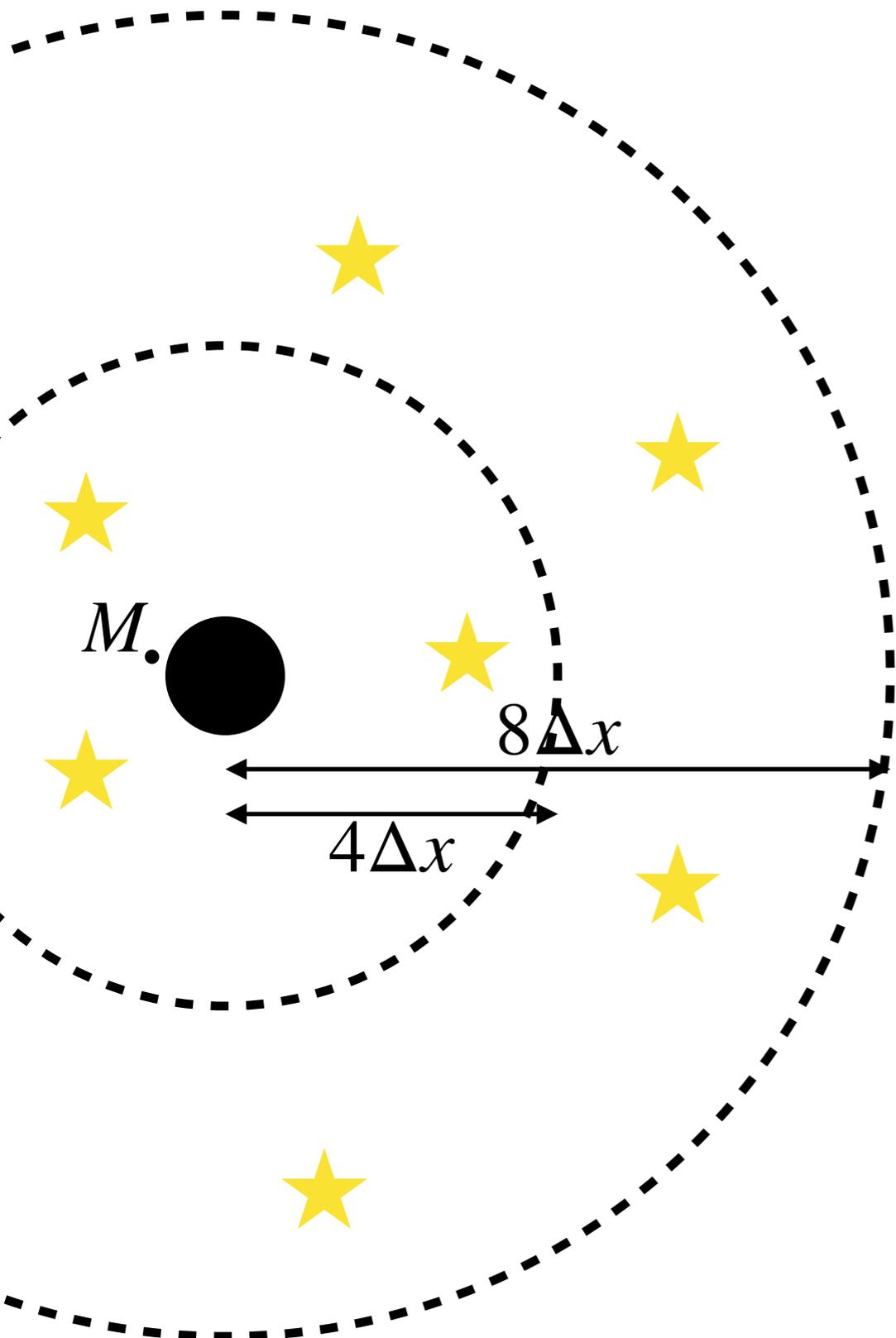


1. Power law density profile:

$$\rho(r) = \rho_0(r/r_0)^{-\gamma}$$

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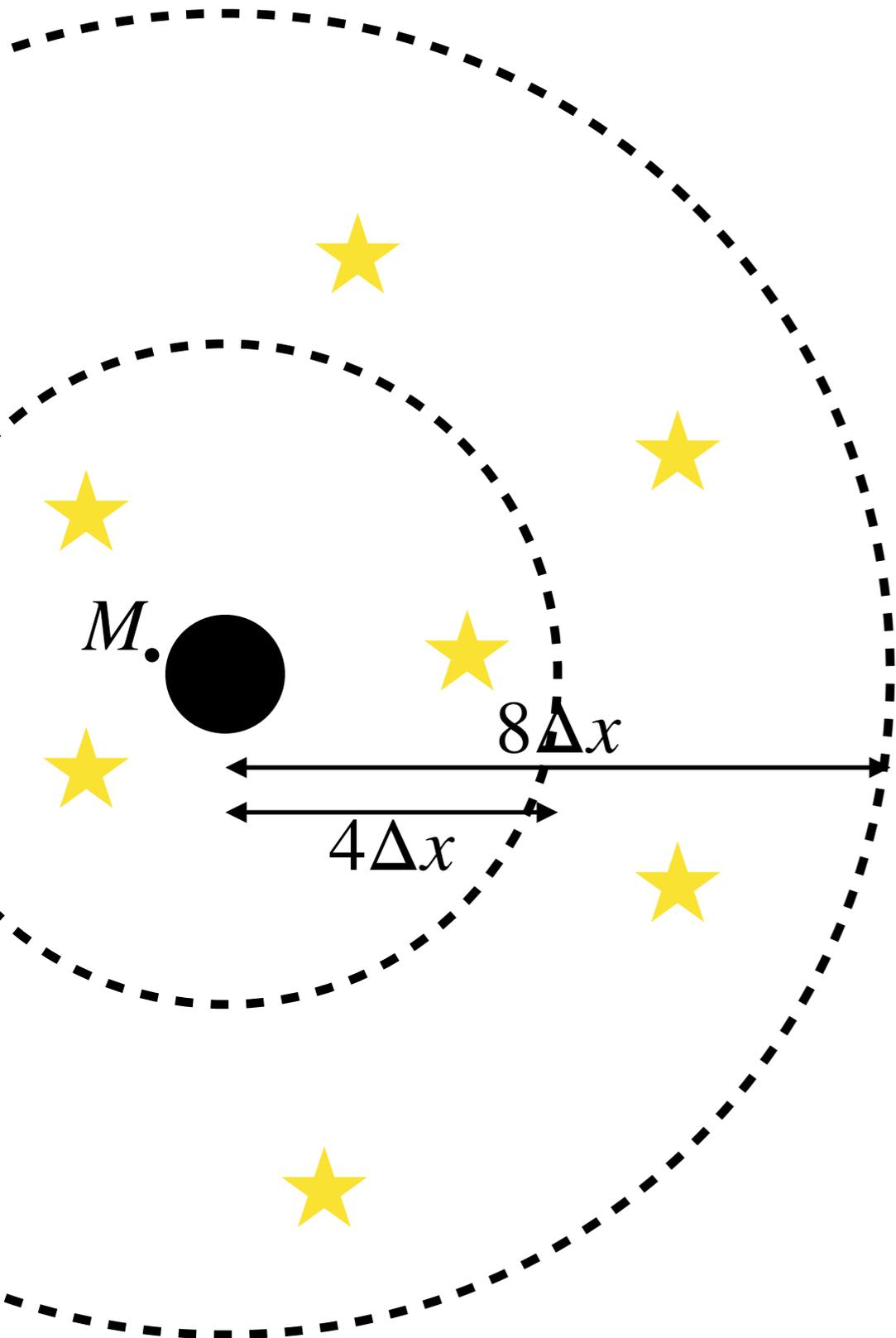


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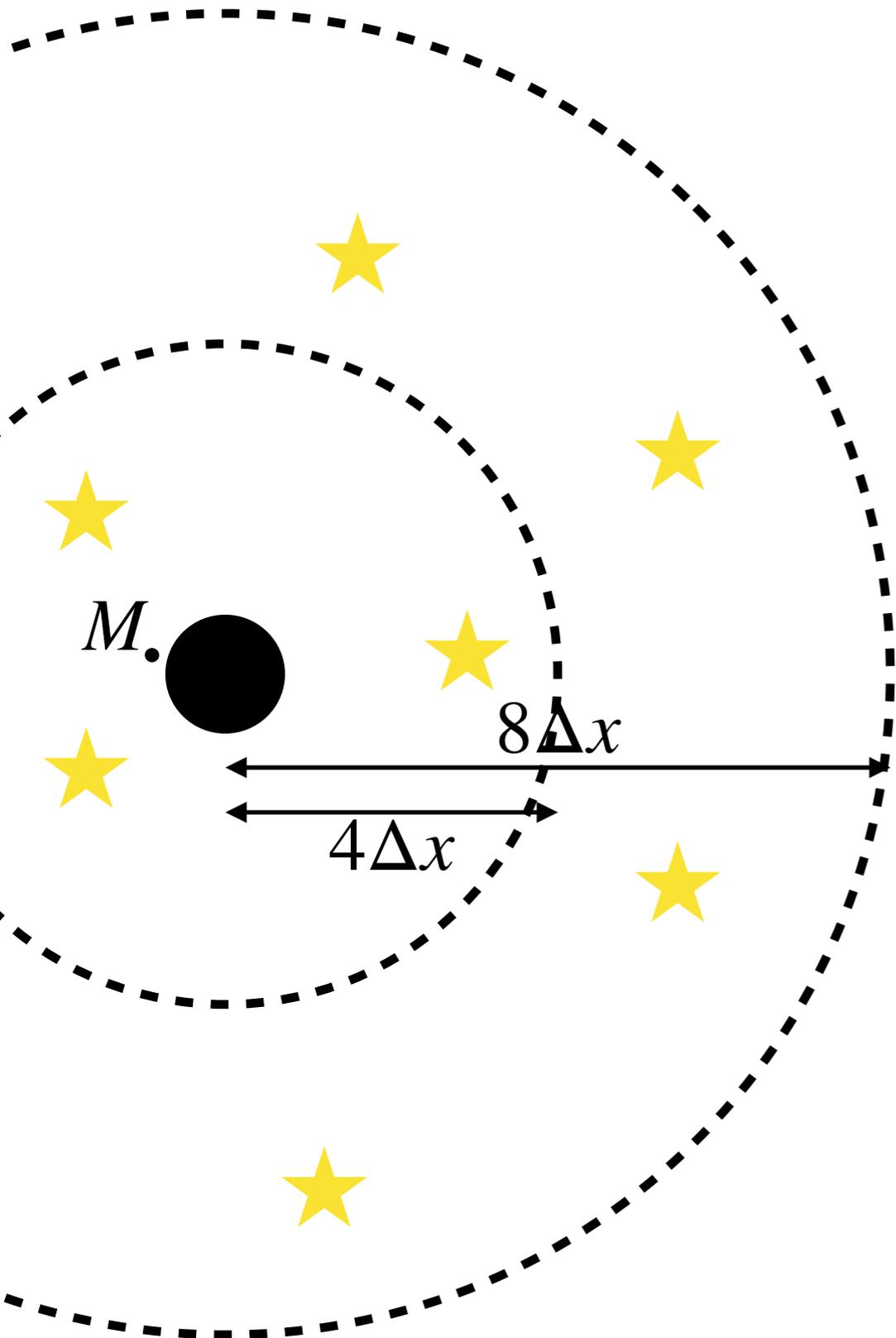


1. Power law density profile:
2. Results from **Wang+04** using the Loss Cone Formalism:

$$\rho(r) = \rho_0 (r/r_0)^{-\gamma}$$
$$\Gamma(M_\bullet, \gamma, \rho_0, r_0)$$

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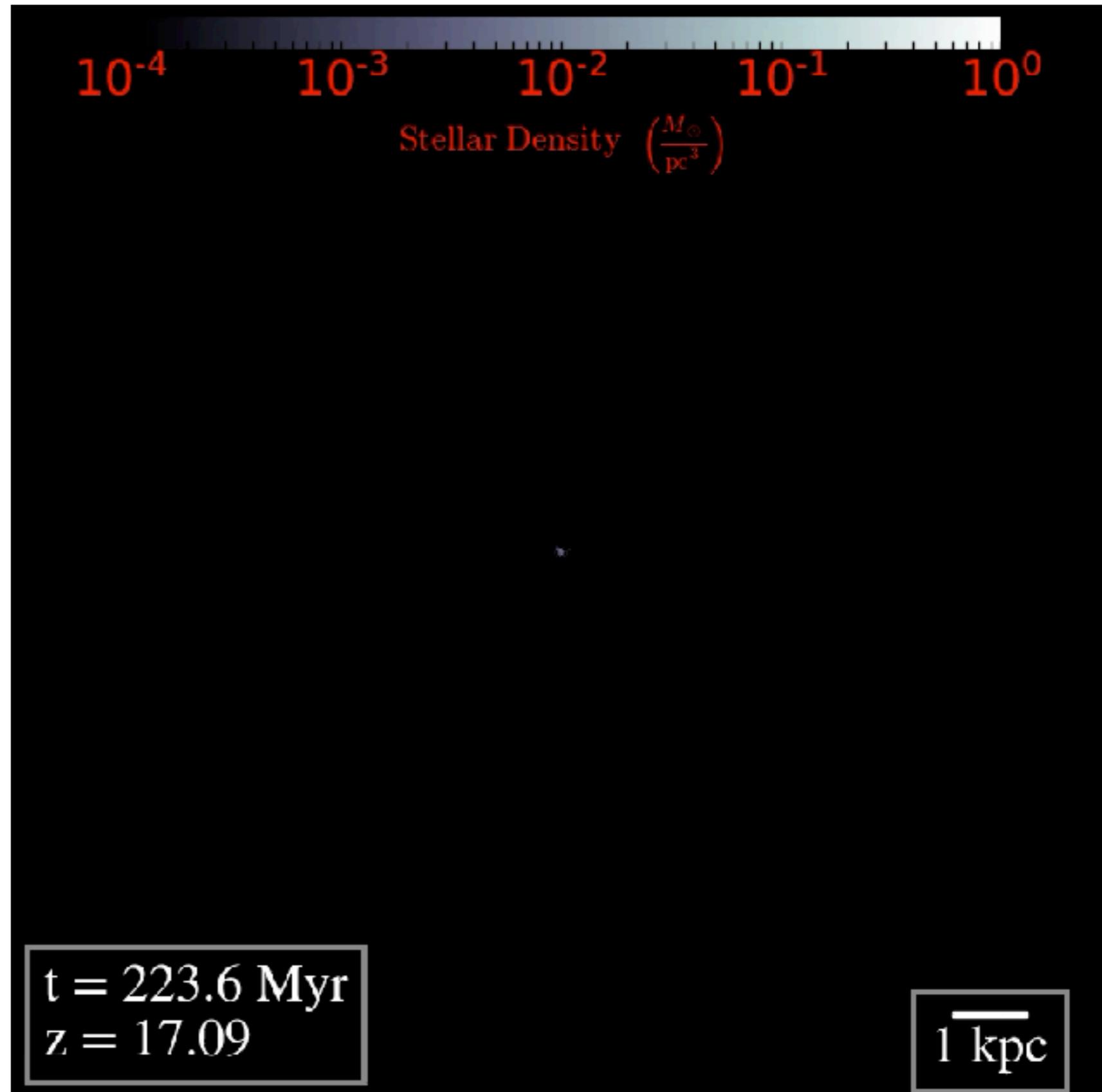
We need to estimate self-consistently TDEs, on the fly, in a simulation.



1. Power law density profile:
$$\rho(r) = \rho_0(r/r_0)^{-\gamma}$$
2. Results from **Wang+04** using the Loss Cone Formalism:
$$\Gamma(M_\bullet, \gamma, \rho_0, r_0)$$
3. Between  $t$  and  $t + dt$ :  $\Gamma dt$  is removed from surrounding stars,  $\Gamma(1 - f_a)dt$  goes back in the medium (gas),  $\Gamma f_a(1 - \epsilon_r)dt$  is accreted by the BH, and  $\Gamma f_a \epsilon_r dt$  is emitted as feedback. ( $f_a = 0.5$ ;  $\epsilon_r = 0.1$ )

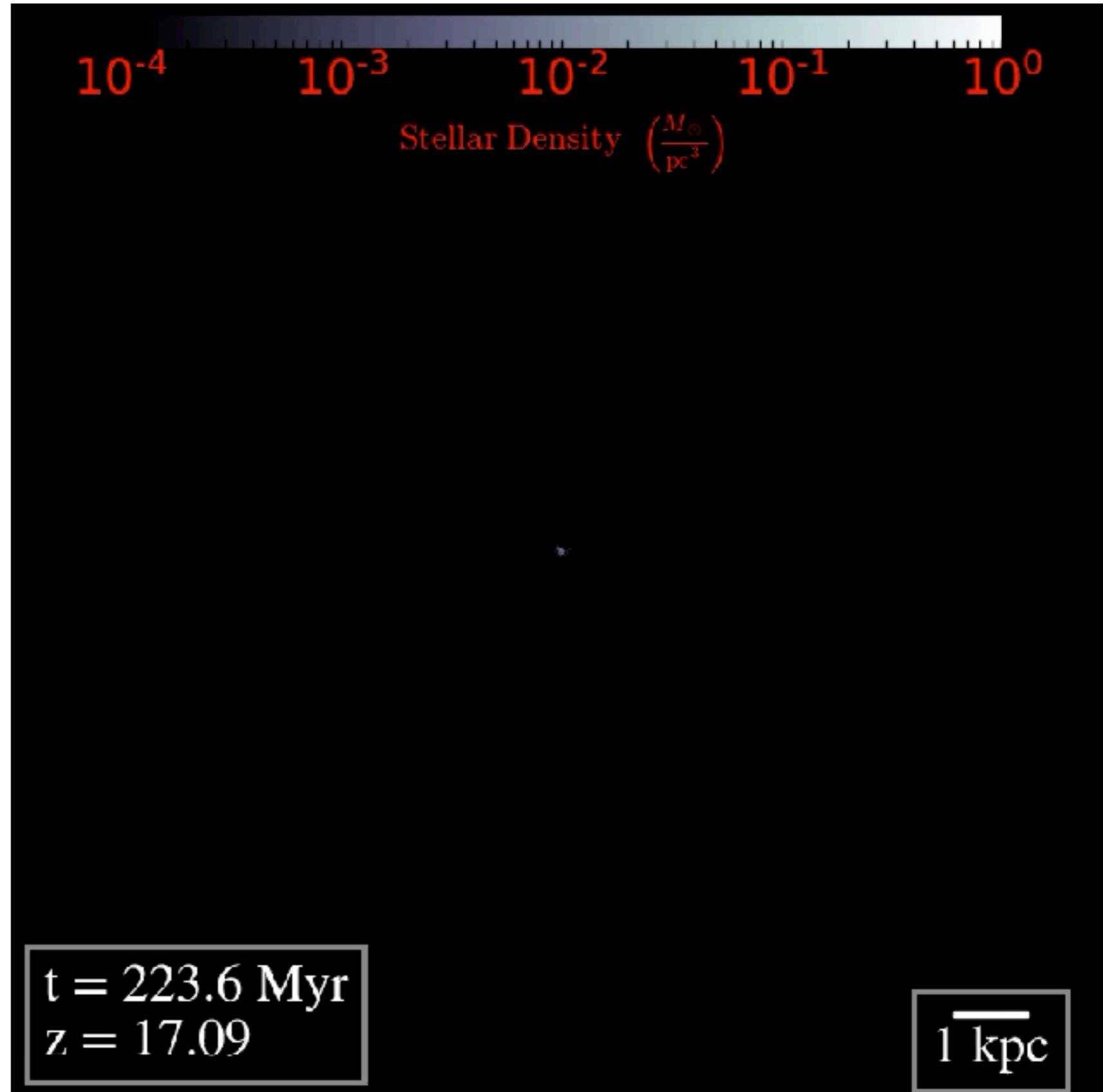
# Rate of TDEs in a mock universe

- Cosmological simulation of a  $10^{10} M_{\odot}$  galaxy at  $z = 6$ .
- State of the art subgrid physics: cooling, star formation, supernovae feedback, metal enrichment, BHs etc...
- Resolution of  $\Delta x = 7 \text{ pc}$ .
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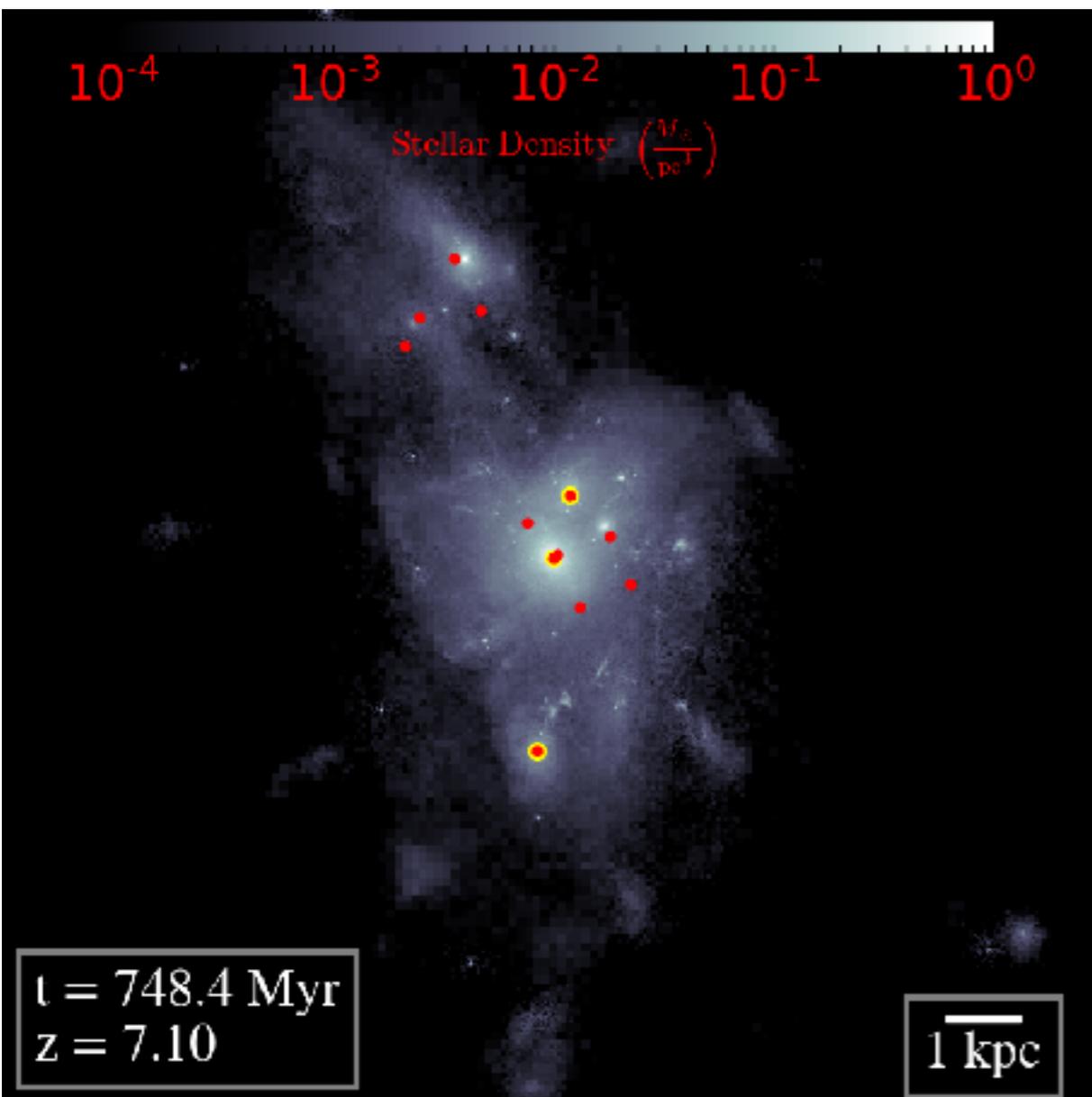


# Rate of TDEs in a mock universe

- Cosmological simulation of a  $10^{10} M_{\odot}$  galaxy at  $z = 6$ .
- State of the art subgrid physics: cooling, star formation, supernovae feedback, metal enrichment, BHs etc...
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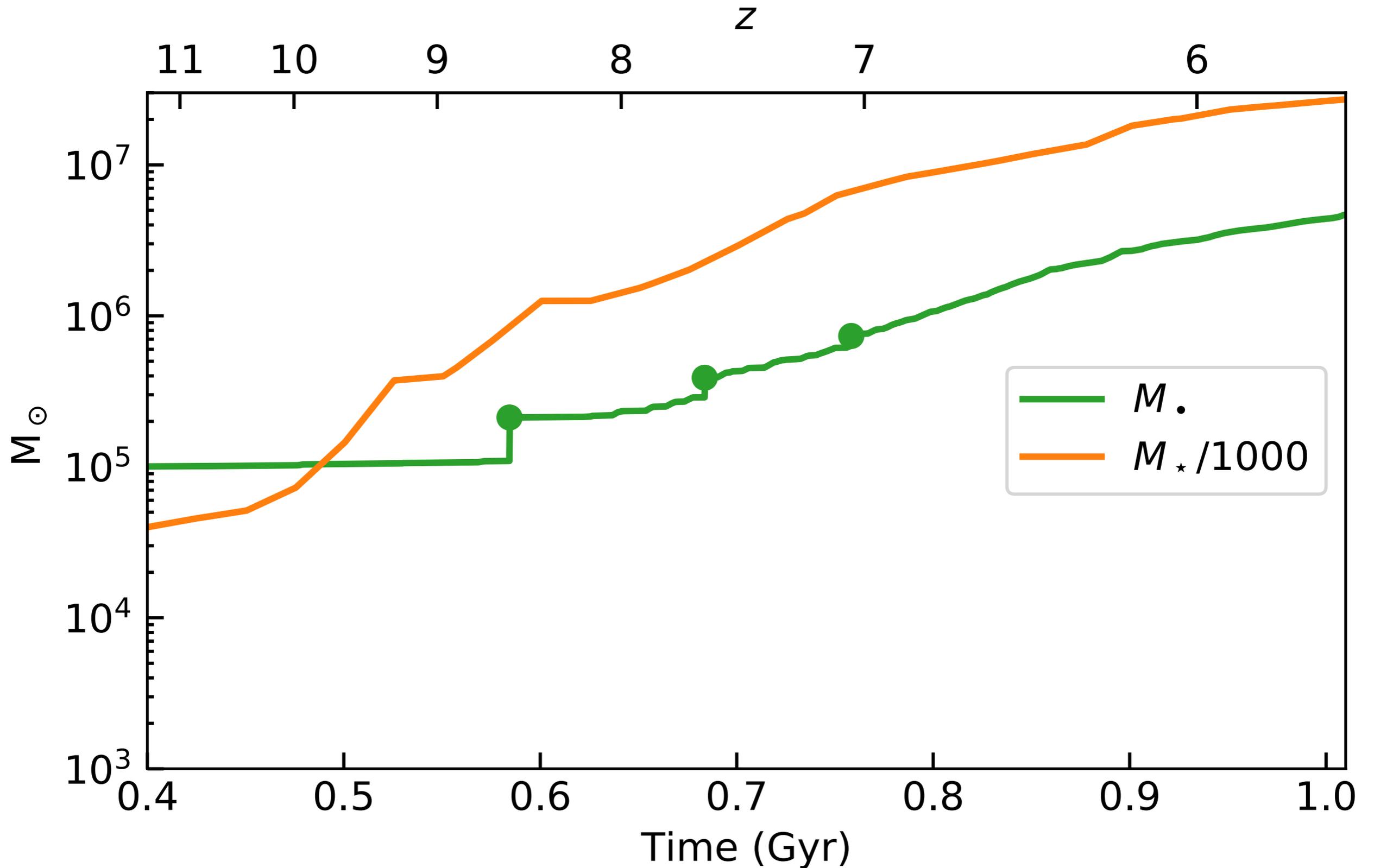


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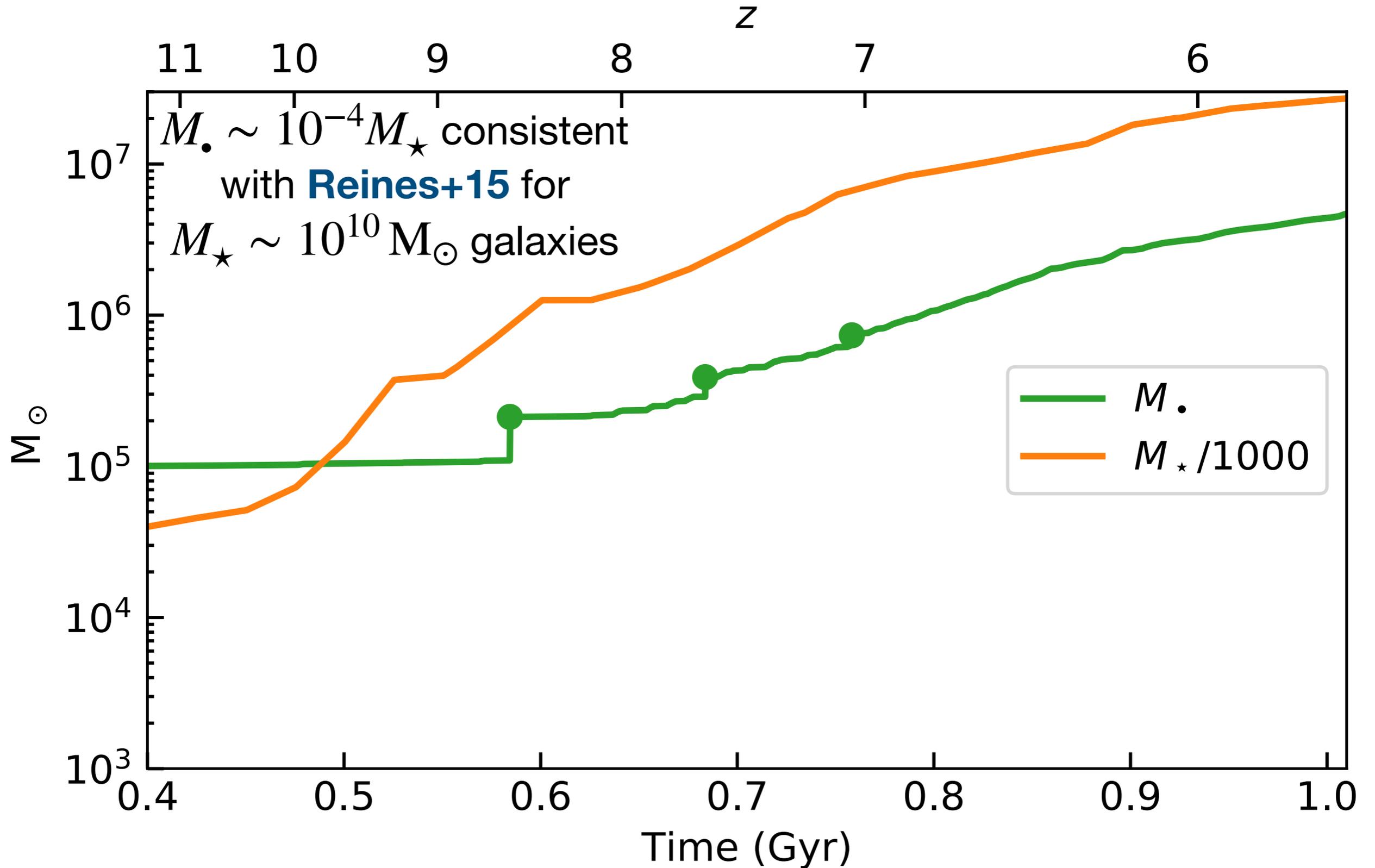


- There can be many BHs in the galaxy, they are inherited by mergers: the total TDE rate is not simply the one of the central BH.
- It can be that wandering BHs have a large rate ( $> 10^{-5} \text{ yr}^{-1}$ ).

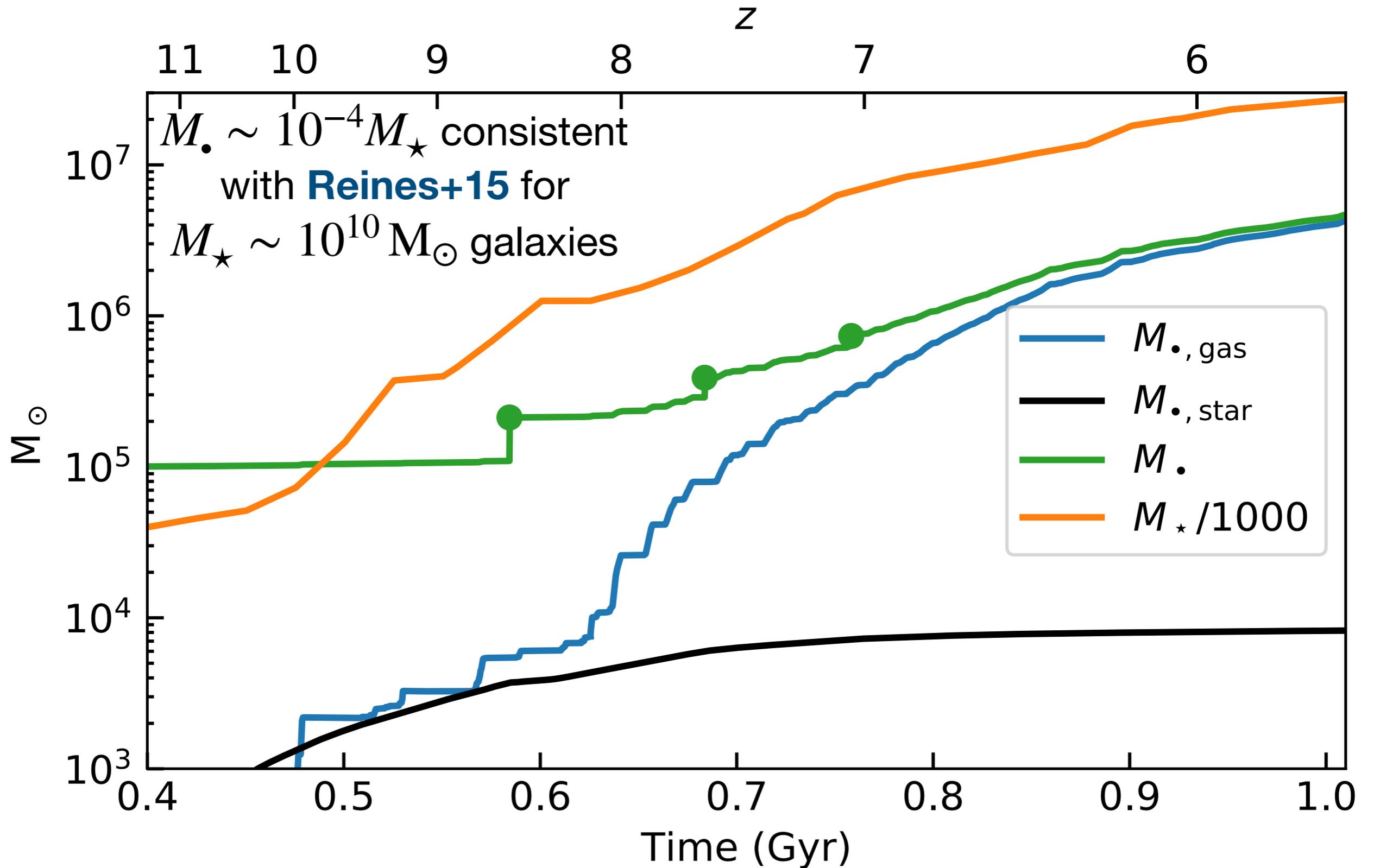
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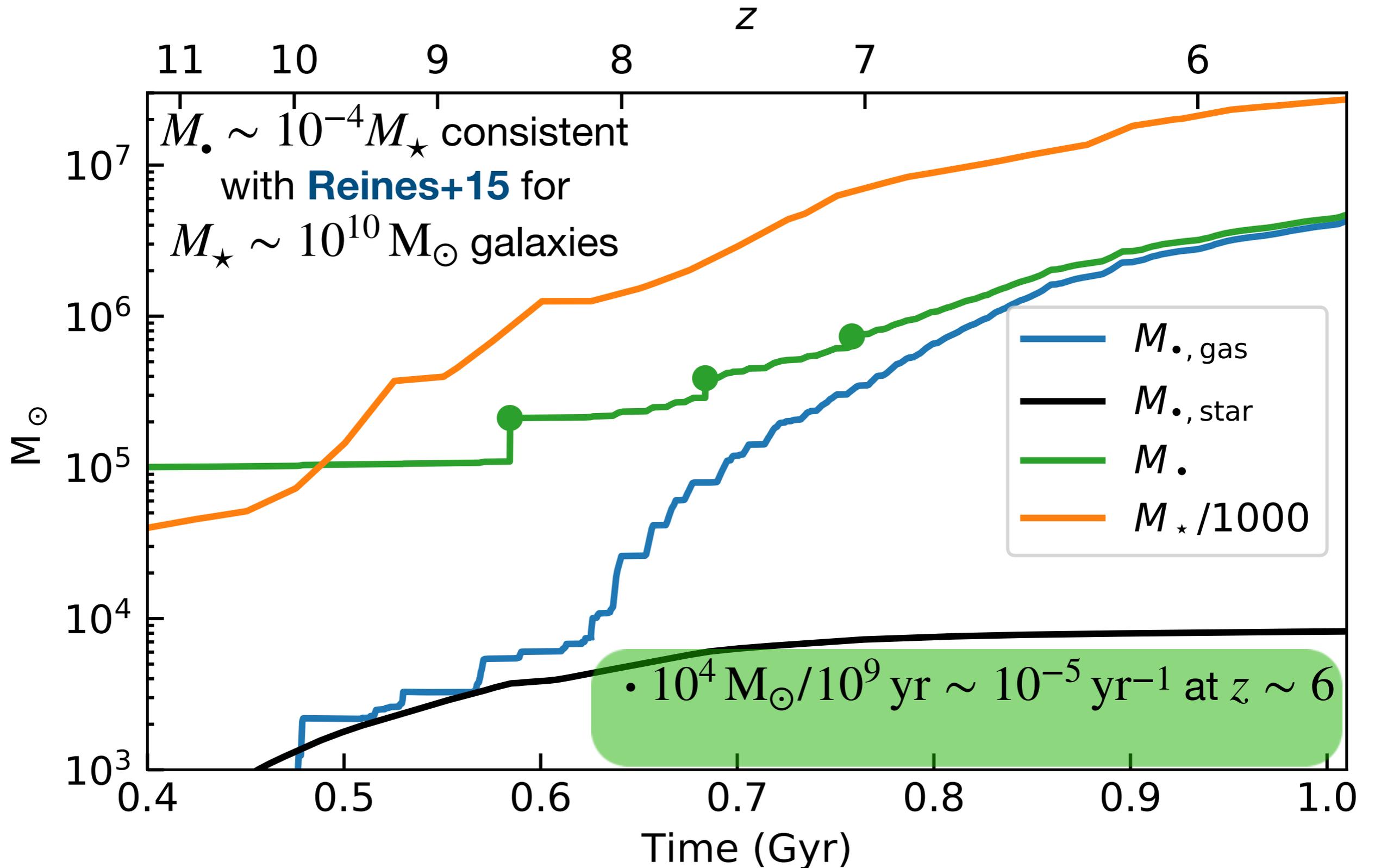
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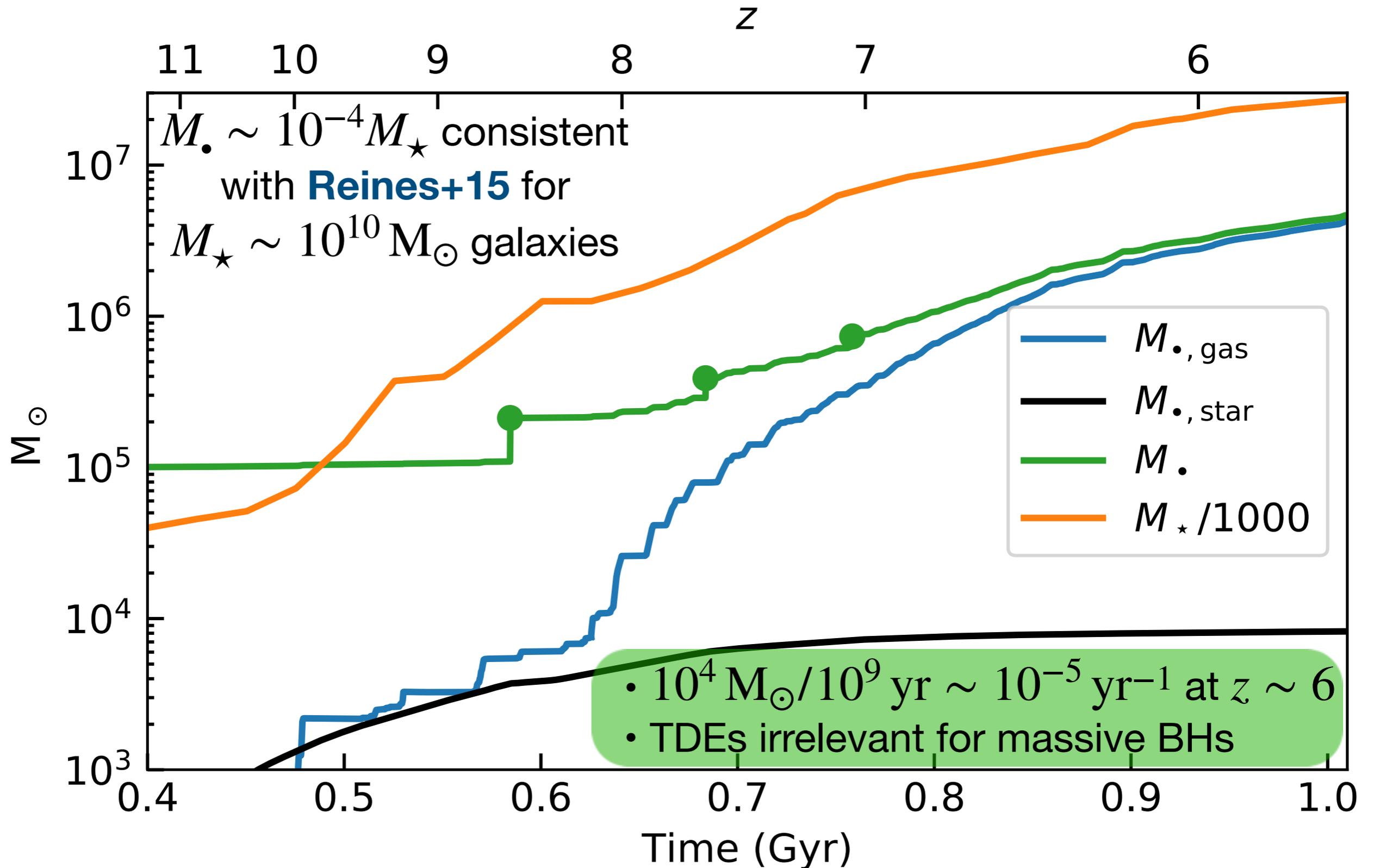
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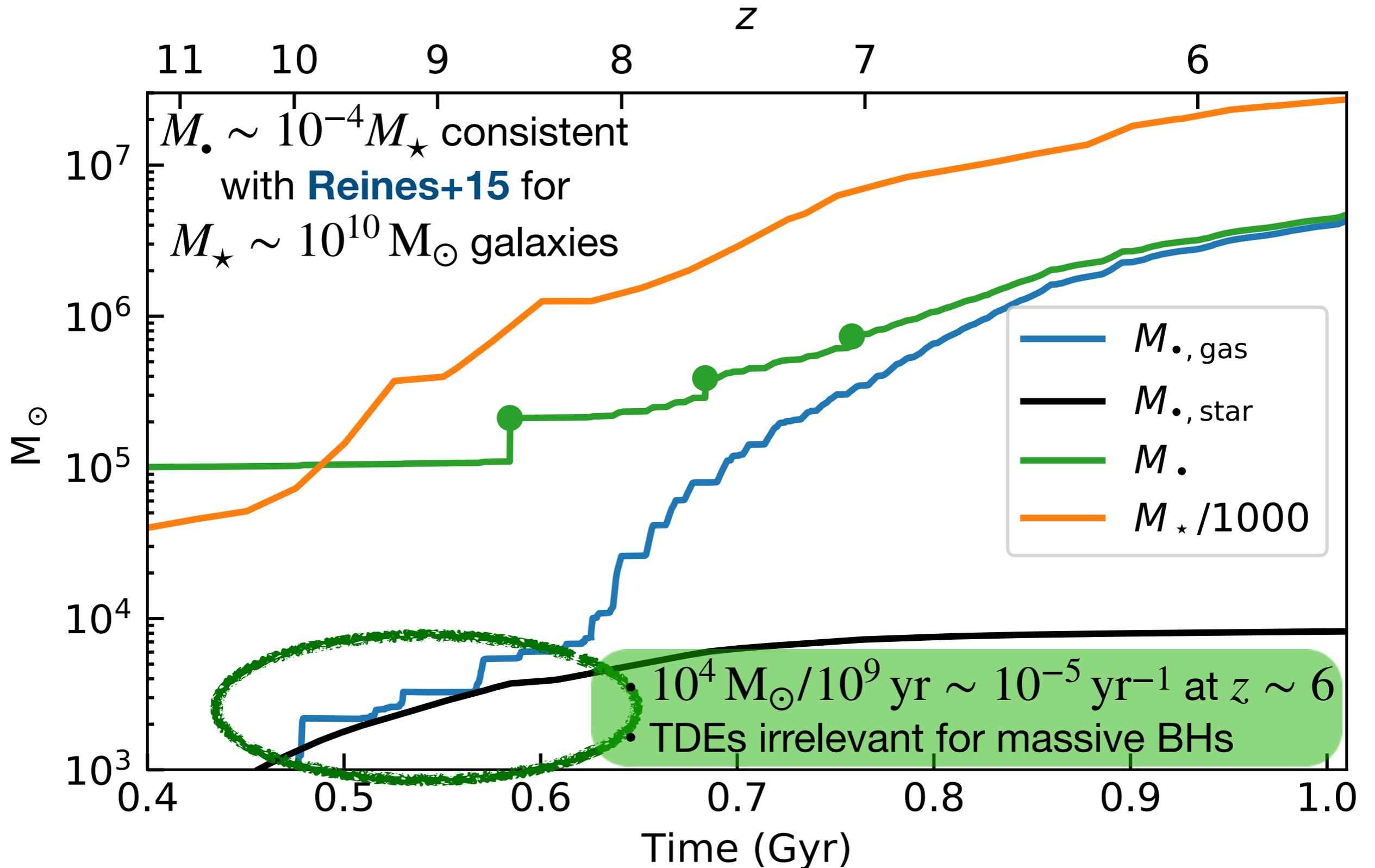
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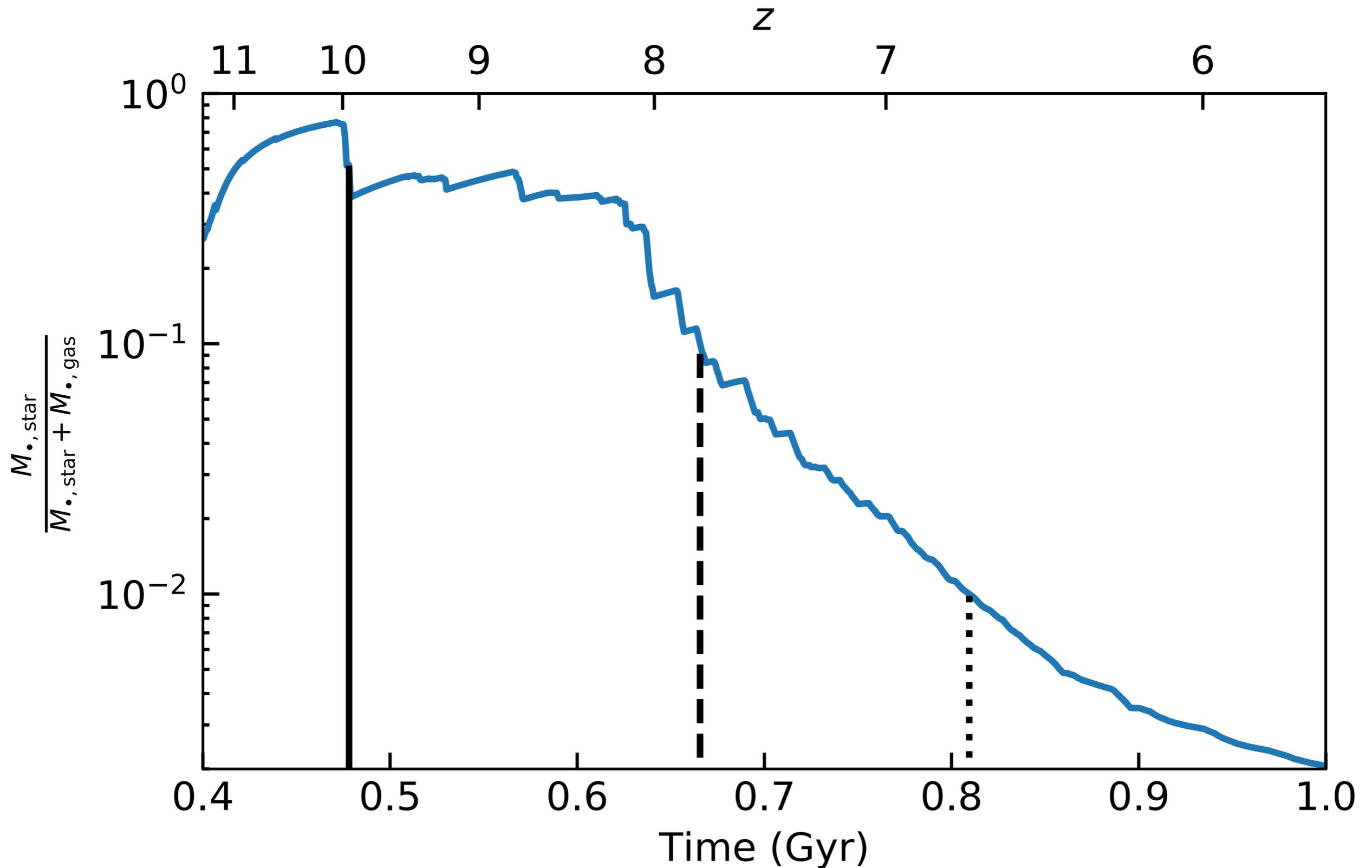
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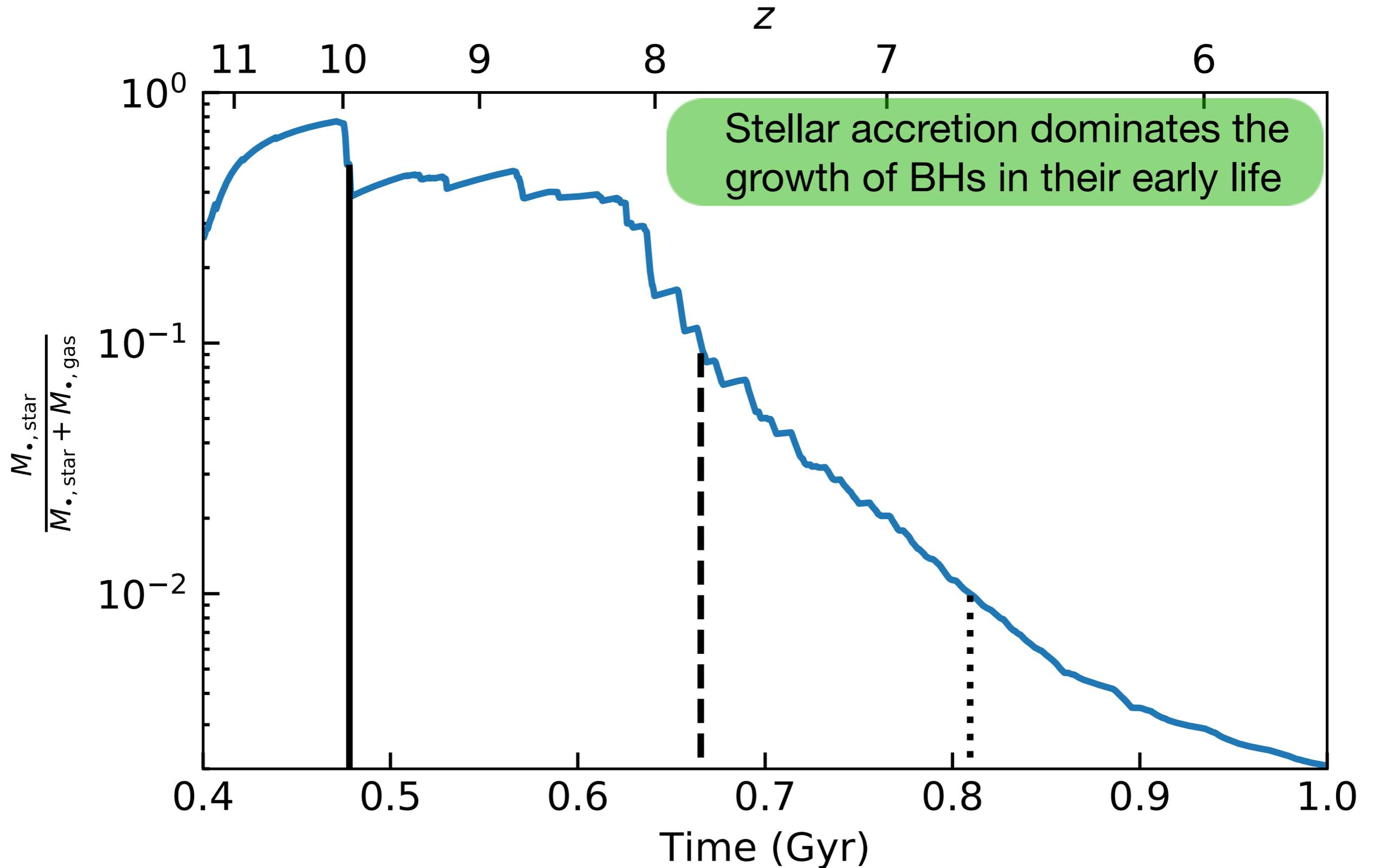
# Rate of TDEs in a mock universe



# Evolution of the BH mass



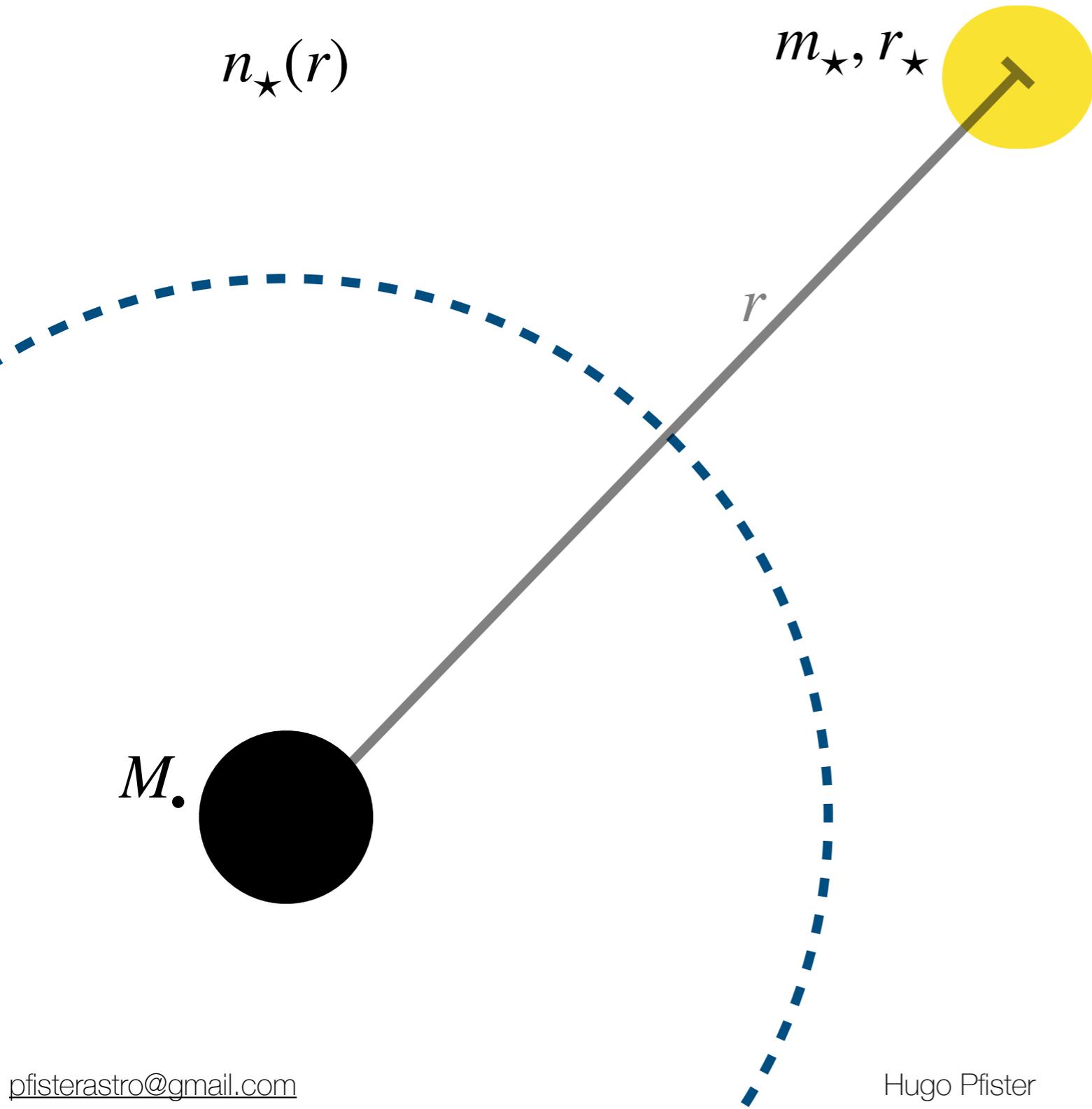
# Evolution of the BH mass



# Conclusions

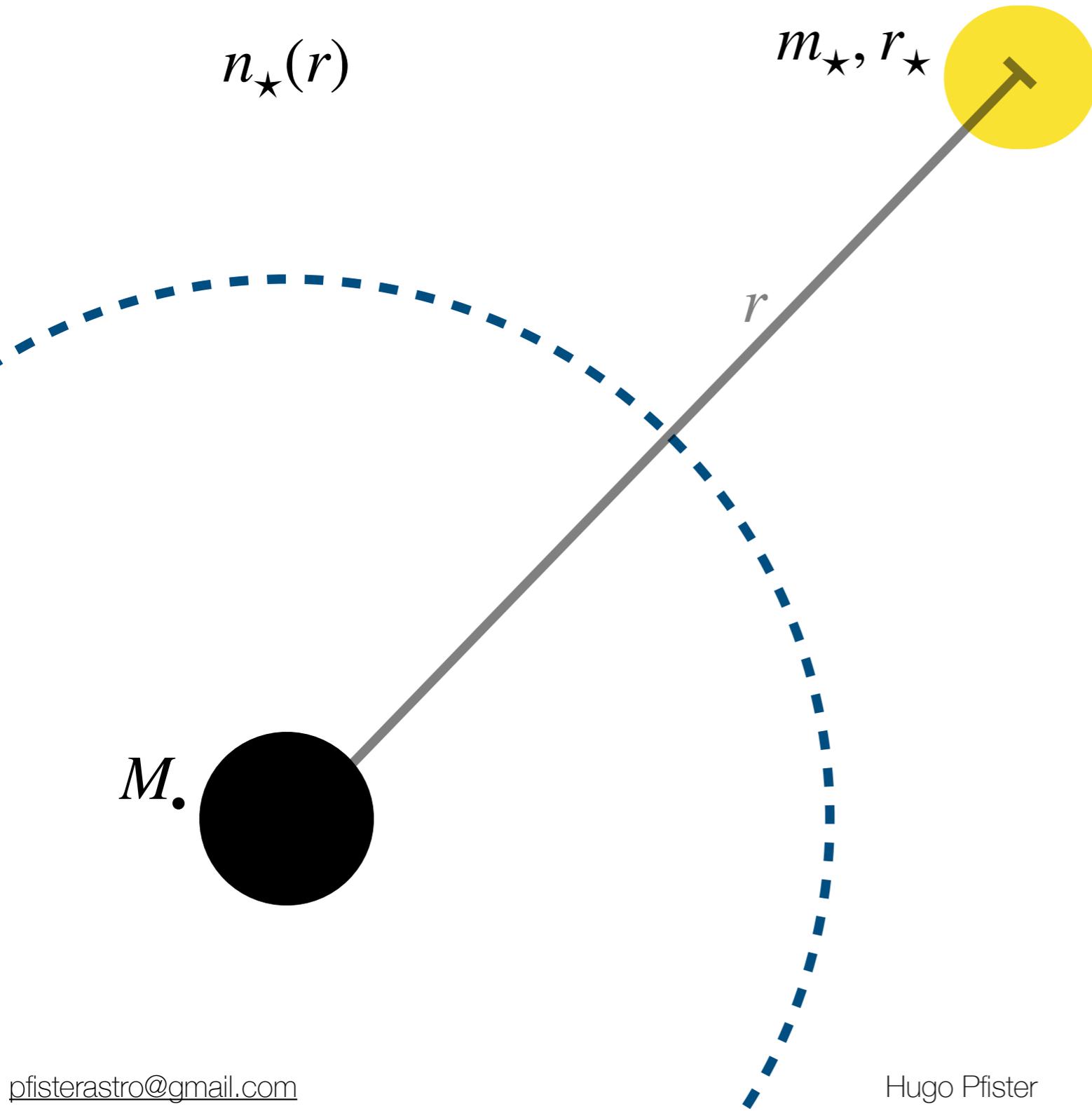
- Stars getting close to BHs can be tidally disrupted, resulting in a luminous flare: a tidal disruption event
- We have observed a dozen of TDEs to date, yielding an overall  $10^{-4} \text{ yr}^{-1}$  rate over-represented in post-starburst galaxies
- Using standard Loss Cone Formalism results, we recover this typical rate in "real" galaxies (**Pfister+20b**)
- Applying the Loss Cone Formalism, we find that the TDE rate is naturally enhanced in post-starburst galaxies due to the enhancement of the stellar density in the vicinity of the BH (**Pfister+19**)
- We develop a simple subgrid model to self-consistently take into account TDEs in simulations
- We find that the rate can be high for off-centered BHs
- We find that TDE subsequent stellar accretion can be important in the early life of BHs. (**Pfister+20c**)

# Loss cone formalism



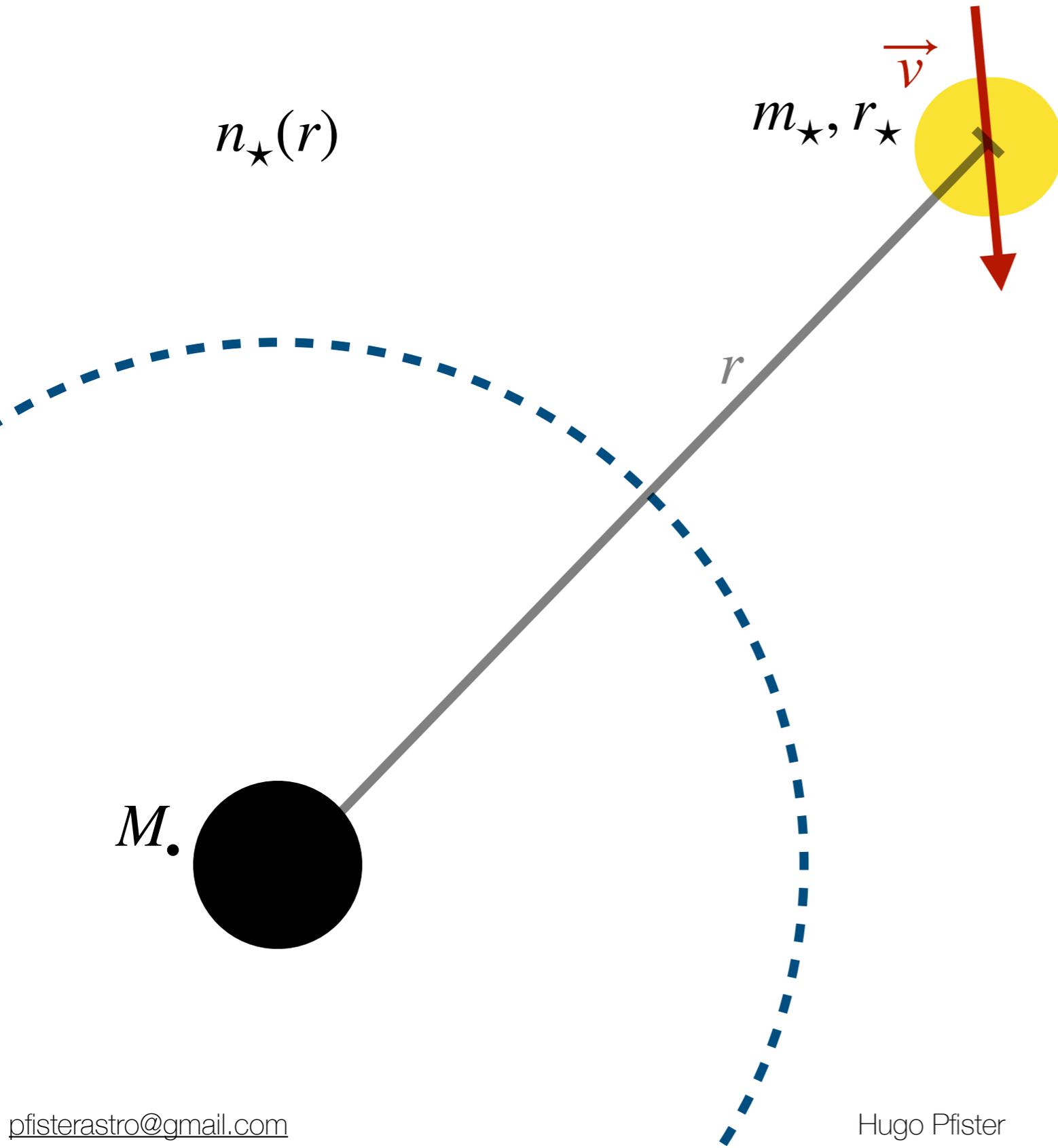
# Loss cone formalism

What is the rate at which stars are disrupted?



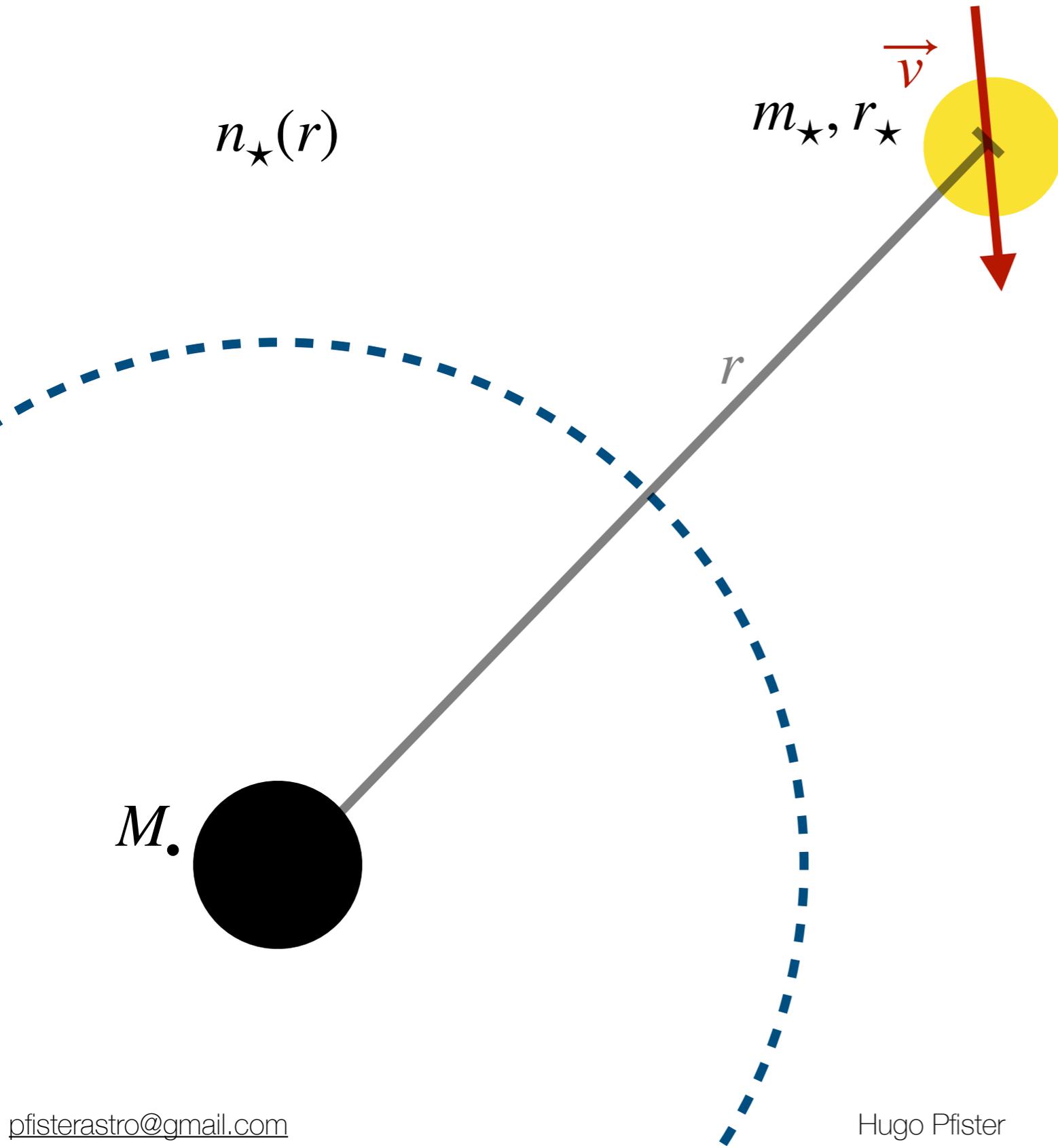
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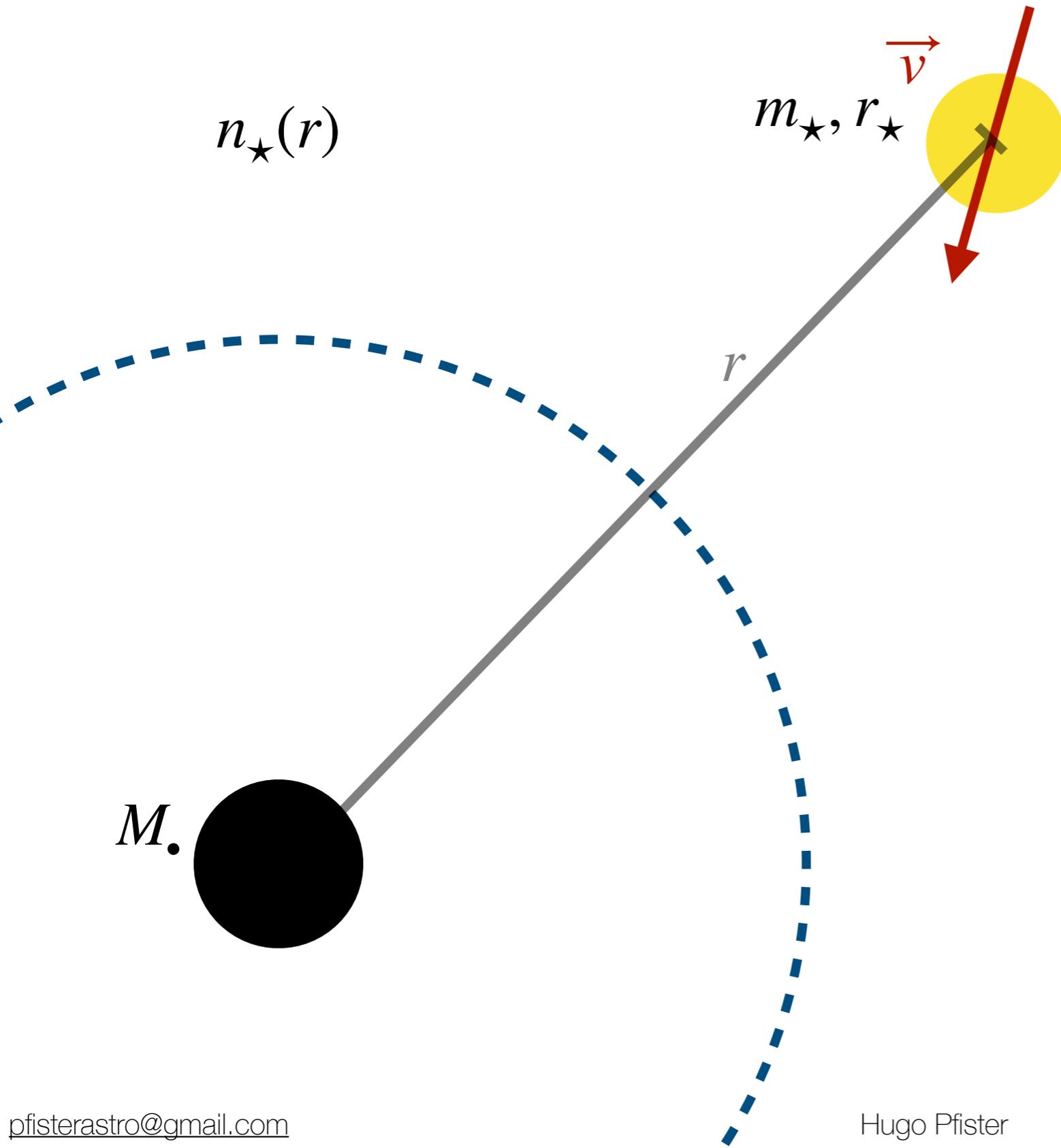
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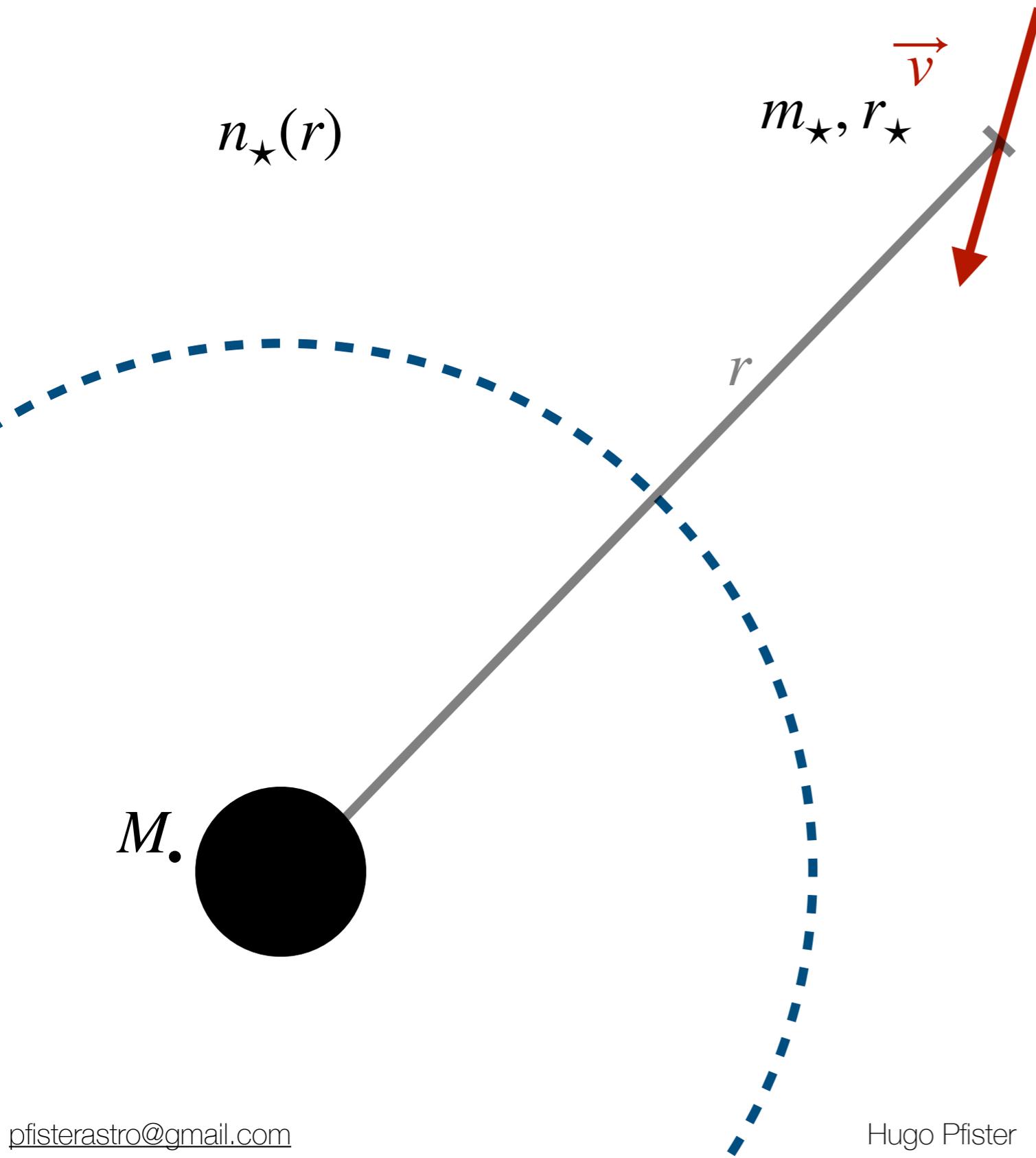
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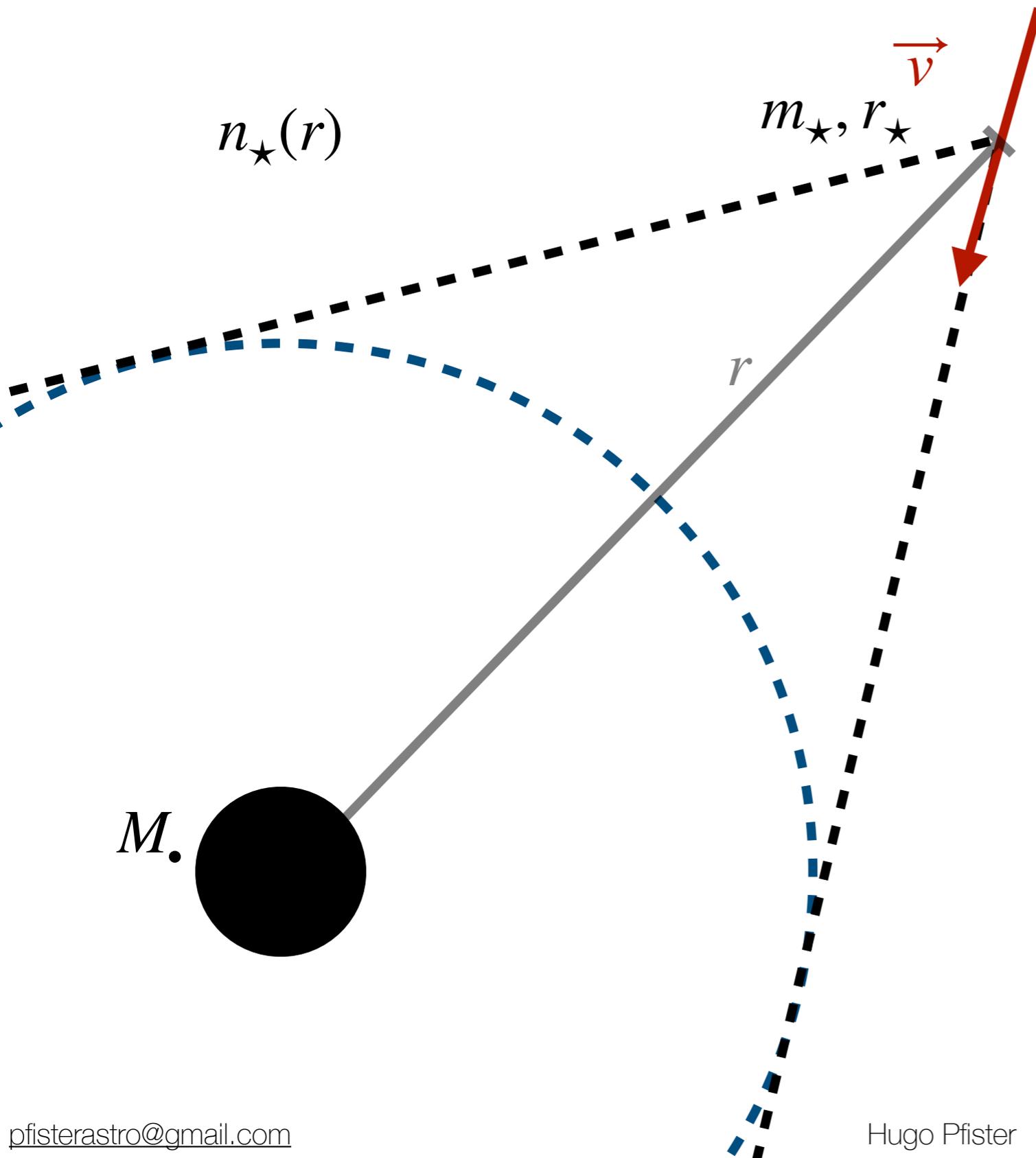
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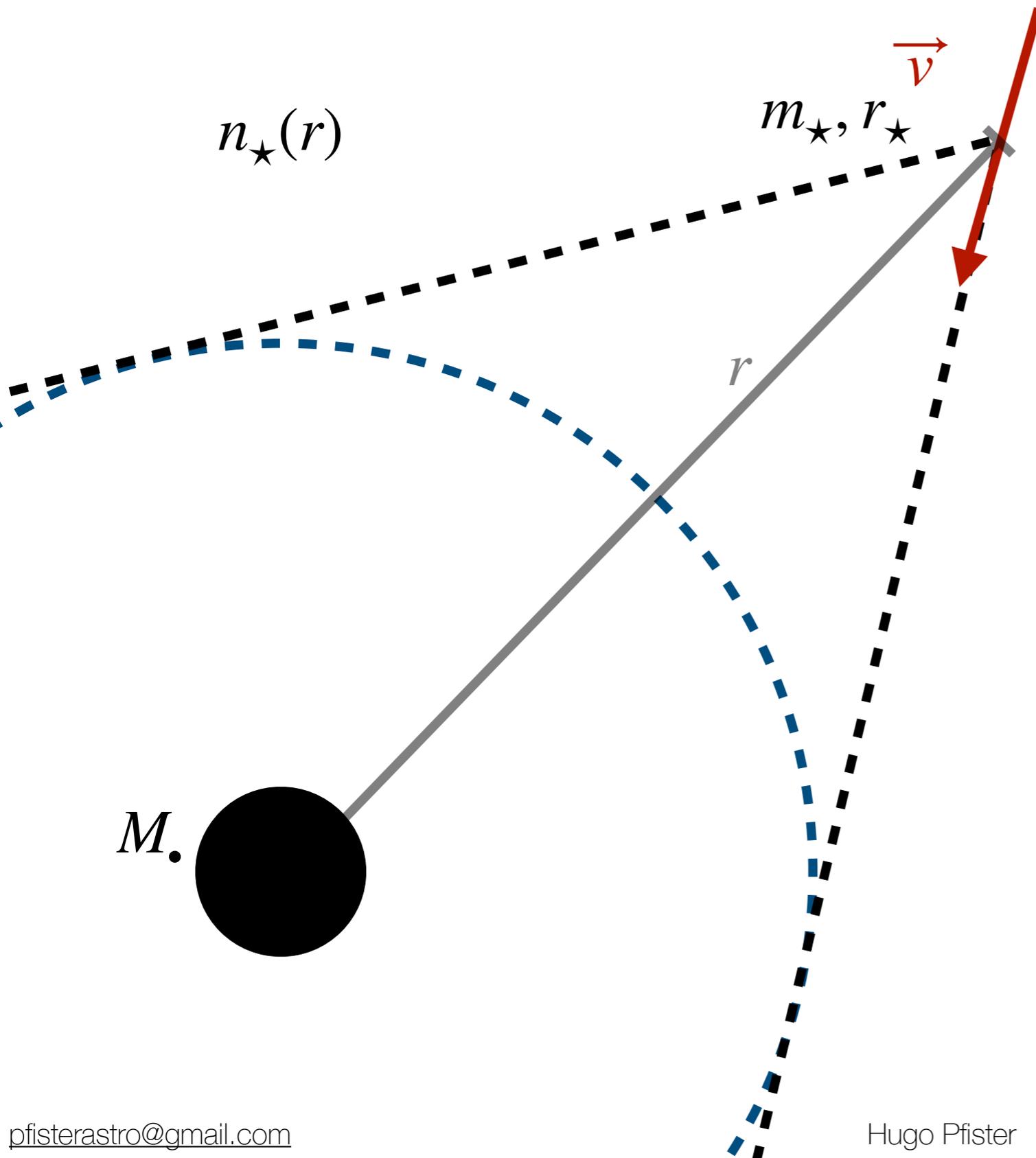


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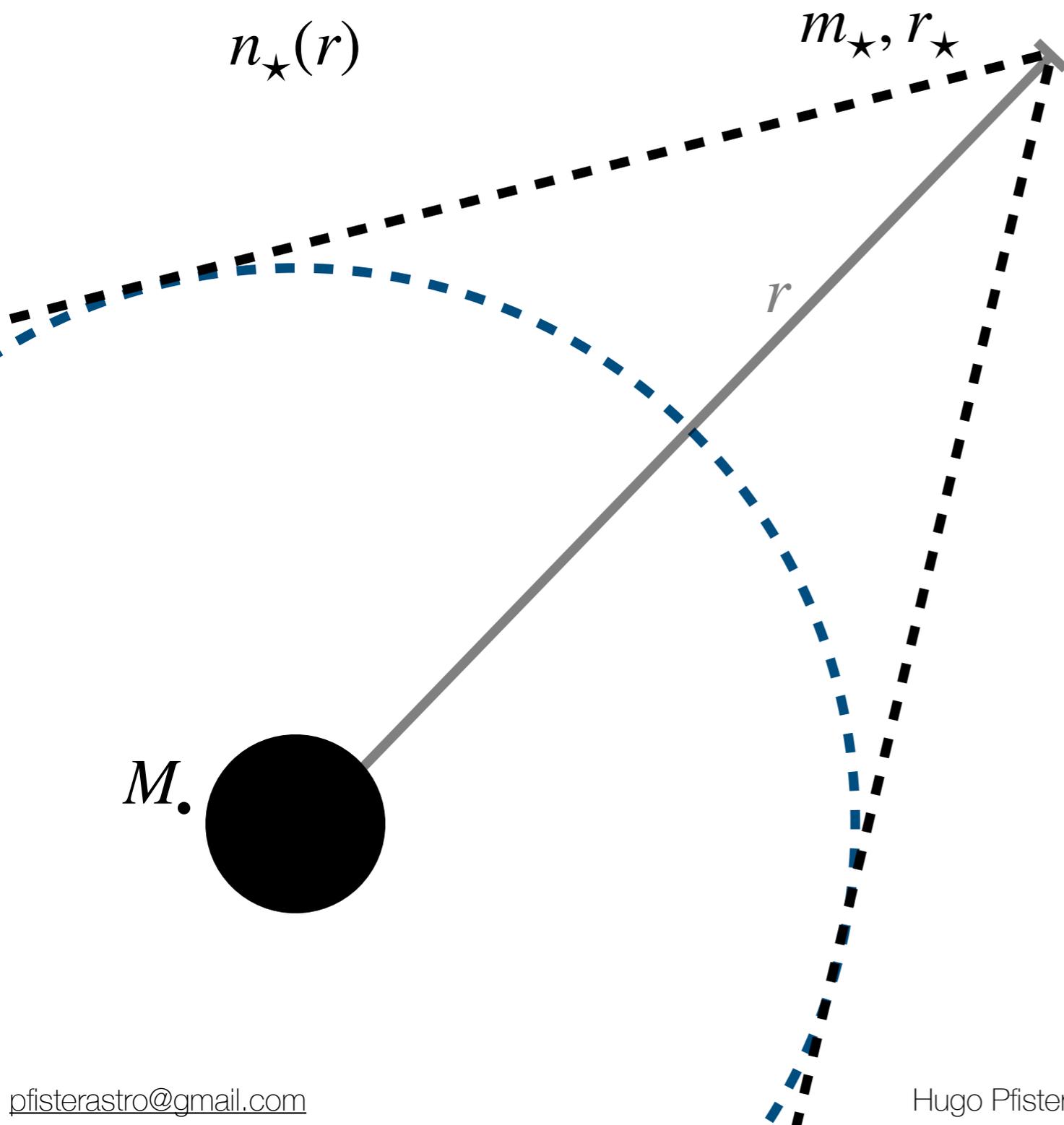
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# Loss cone formalism



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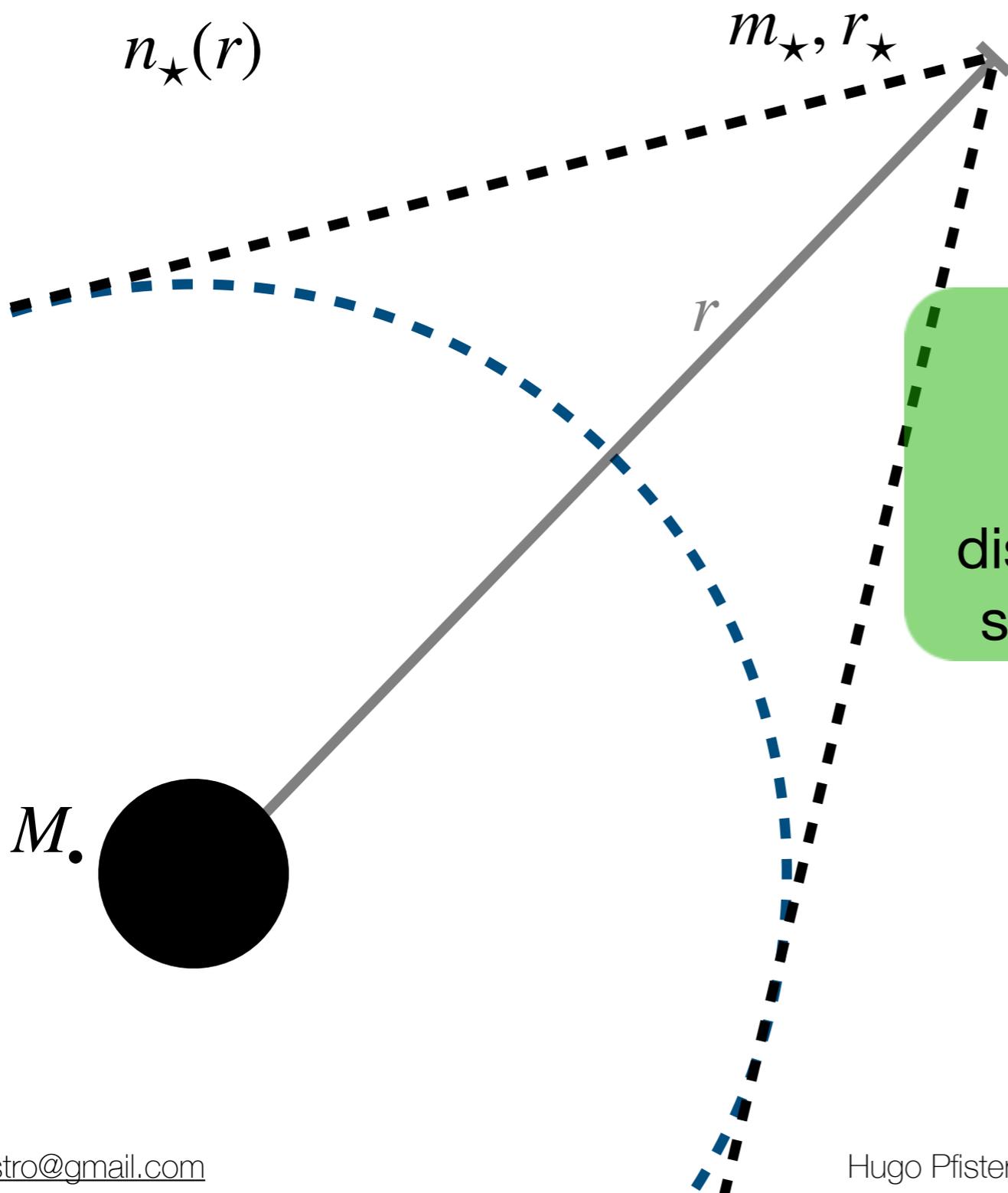
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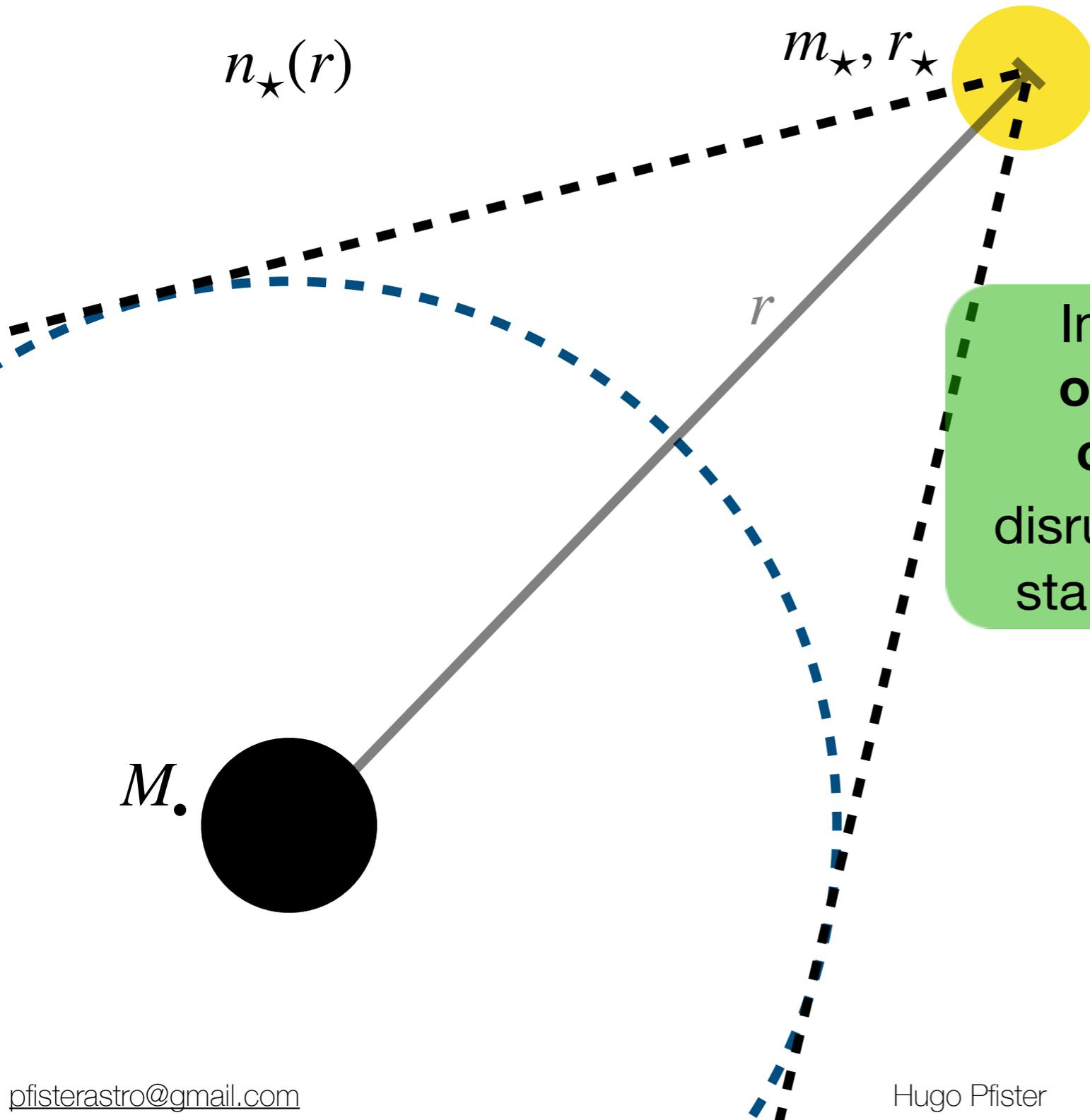
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In a smooth spherical potential, orbits have fixed peri- and apo-centers. If a star is doomed it is disrupted after one single period  $P$ , if a star is safe, it will never be disrupted.



# Loss cone formalism

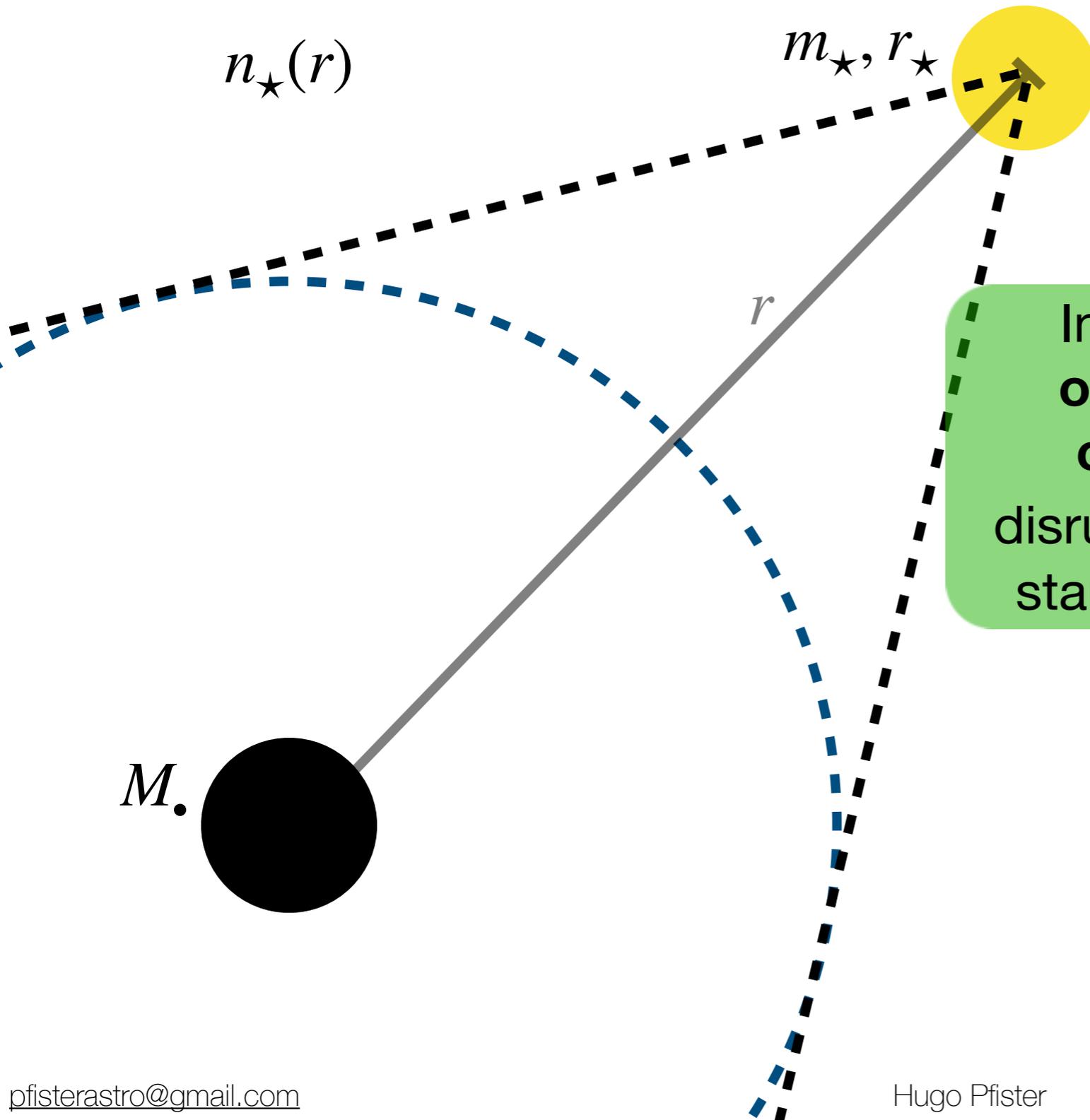


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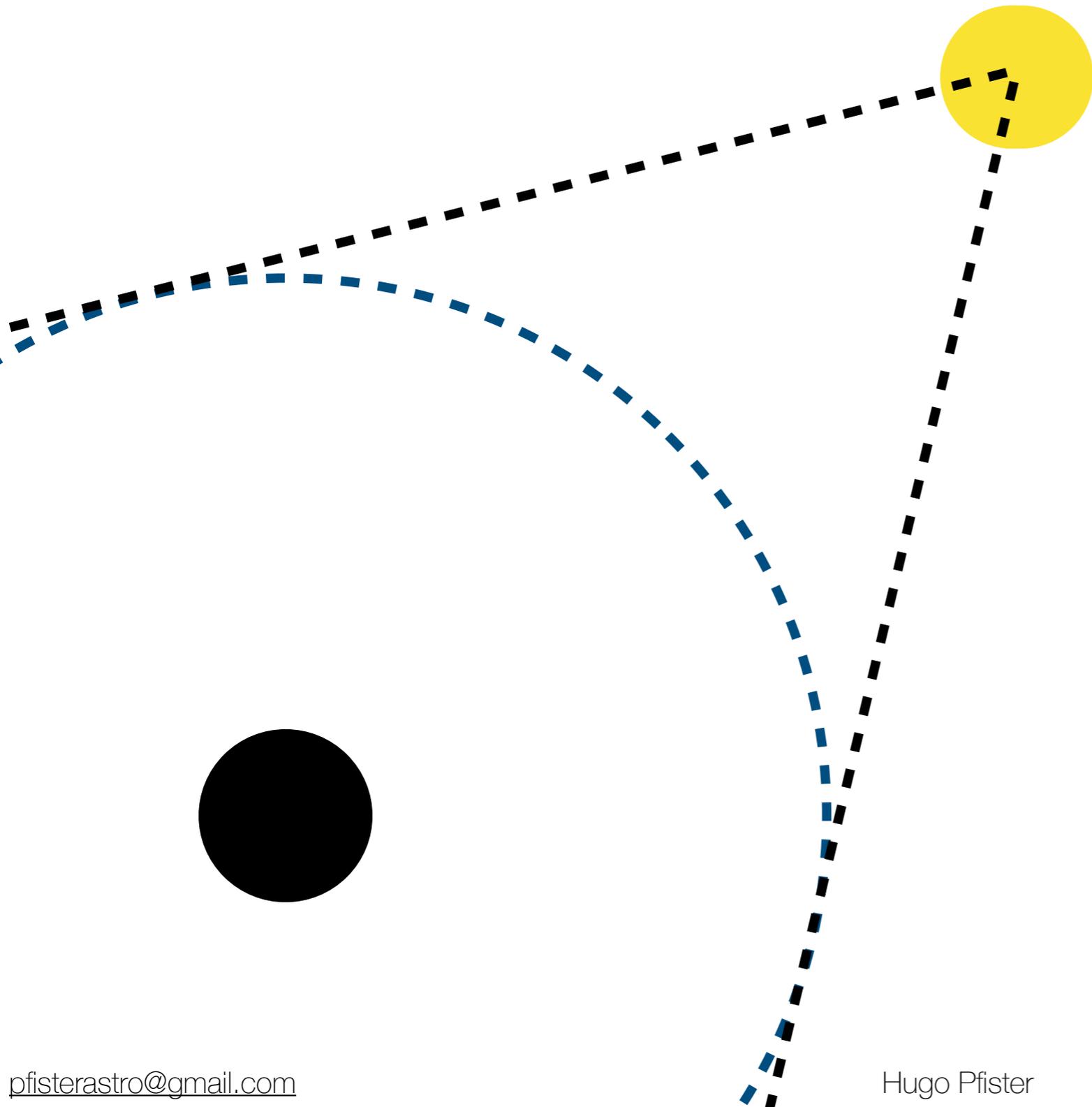
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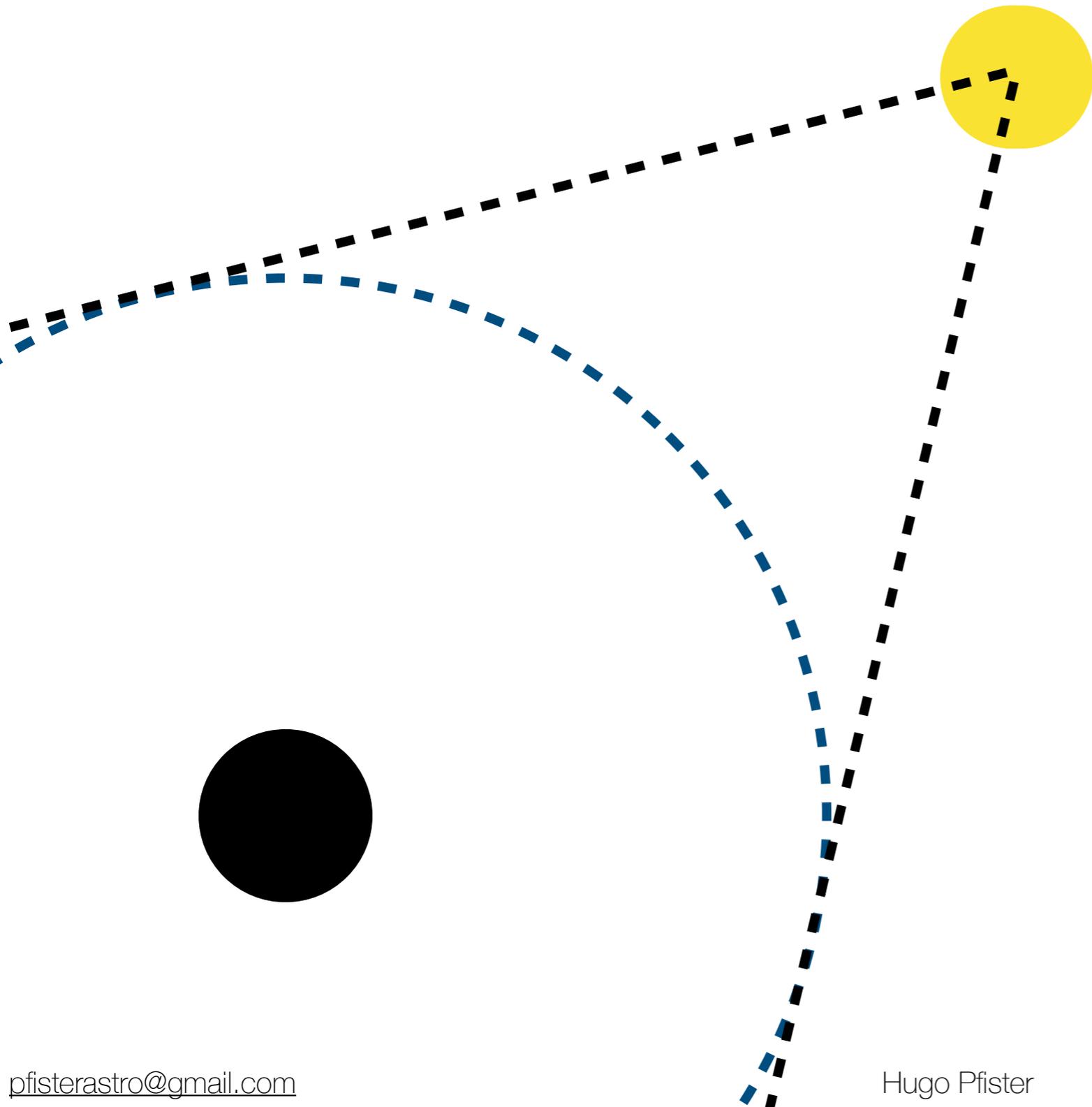
What is the rate at which stars are displaced from safe orbits to doomed orbits? and what causes this displacement?

# Loss cone formalism



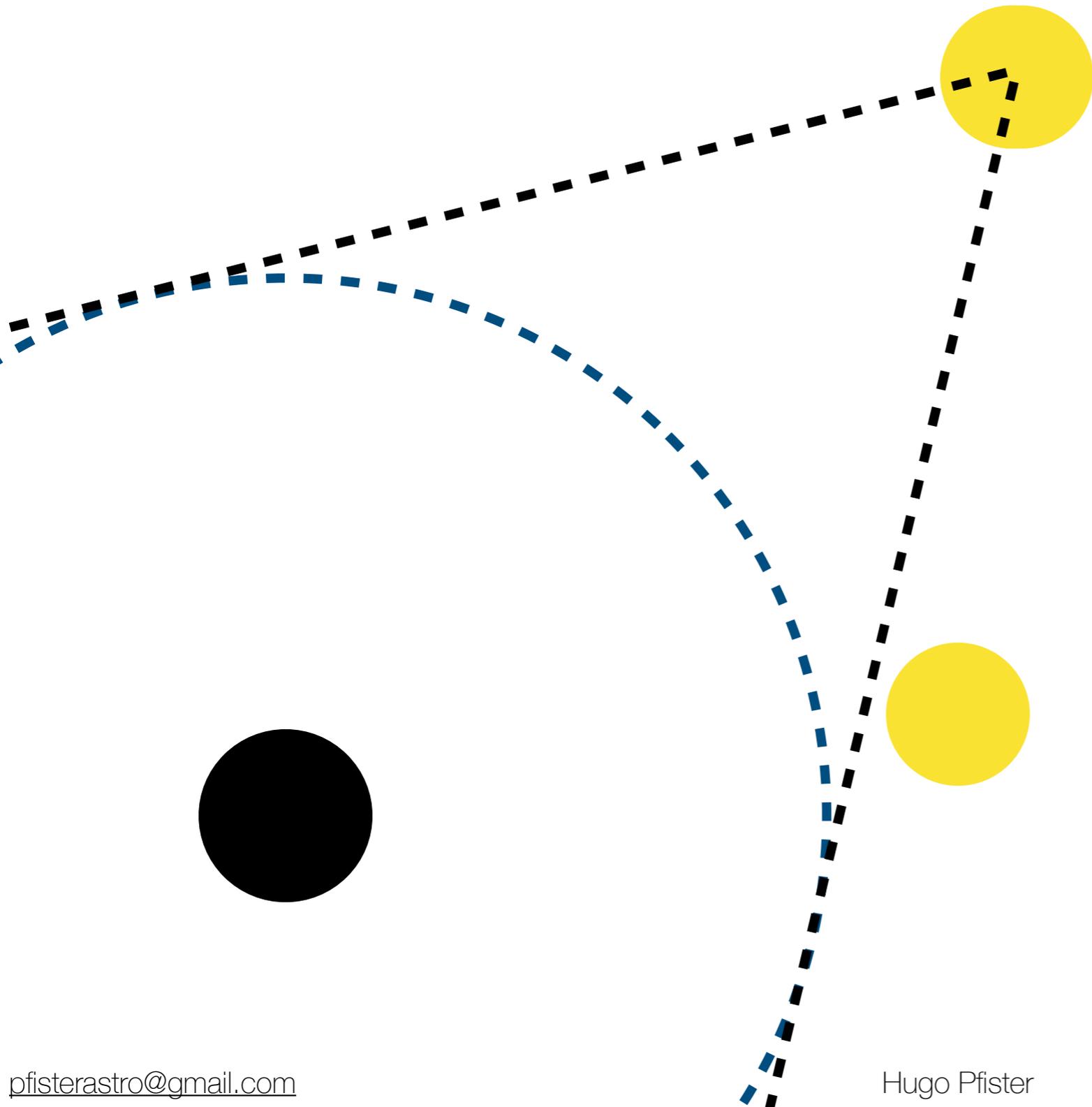
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The potential is spherical,  
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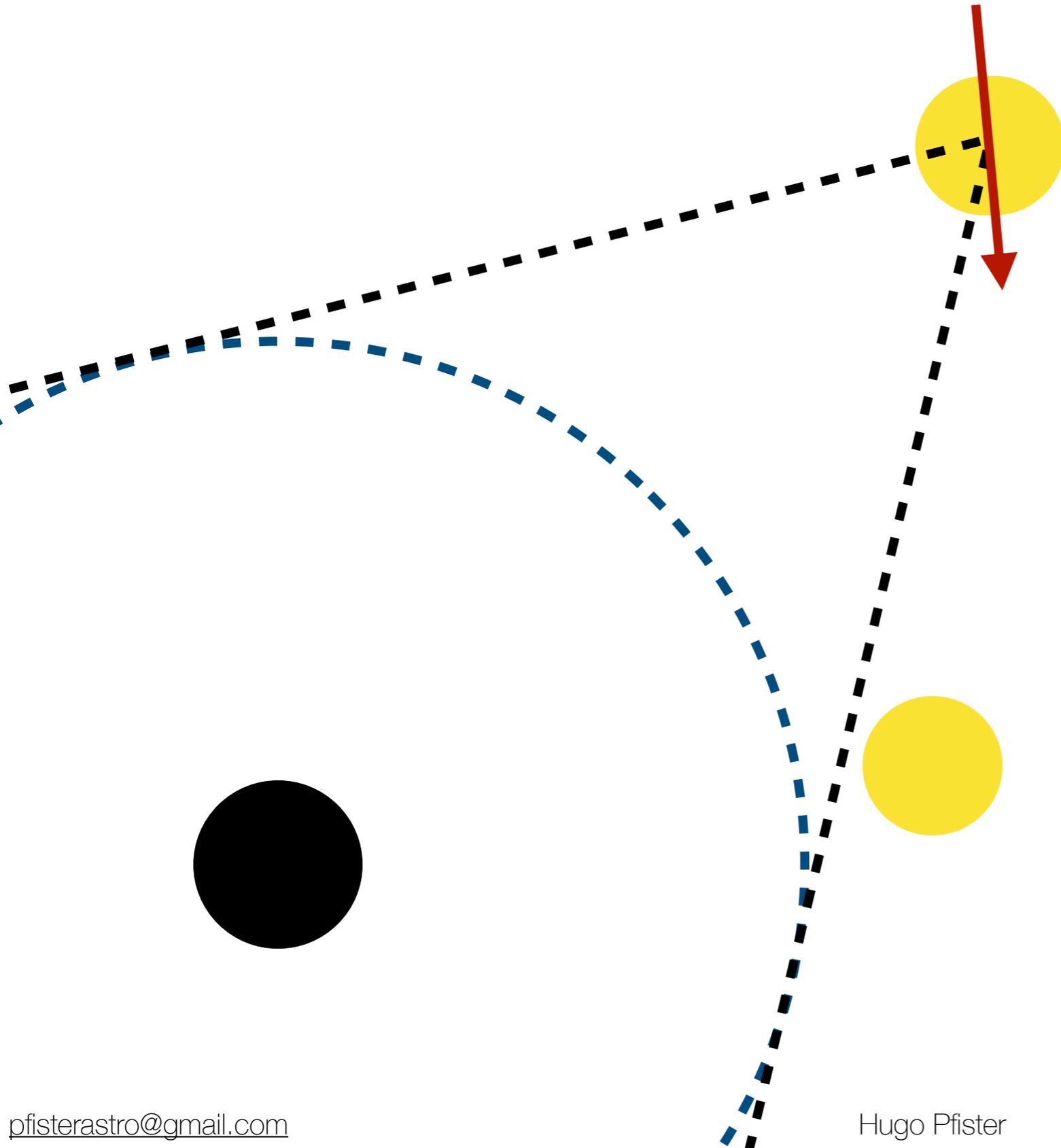
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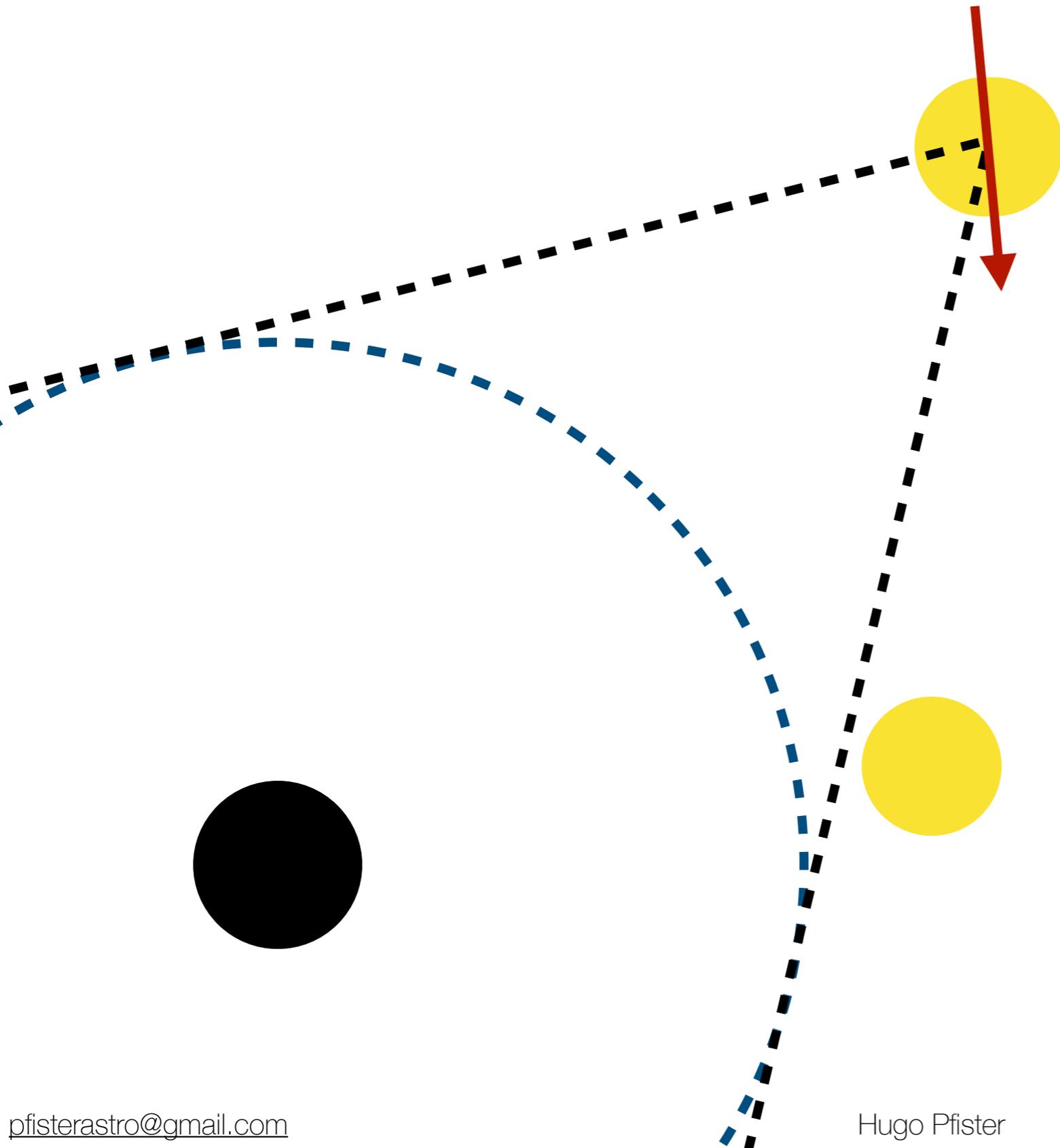
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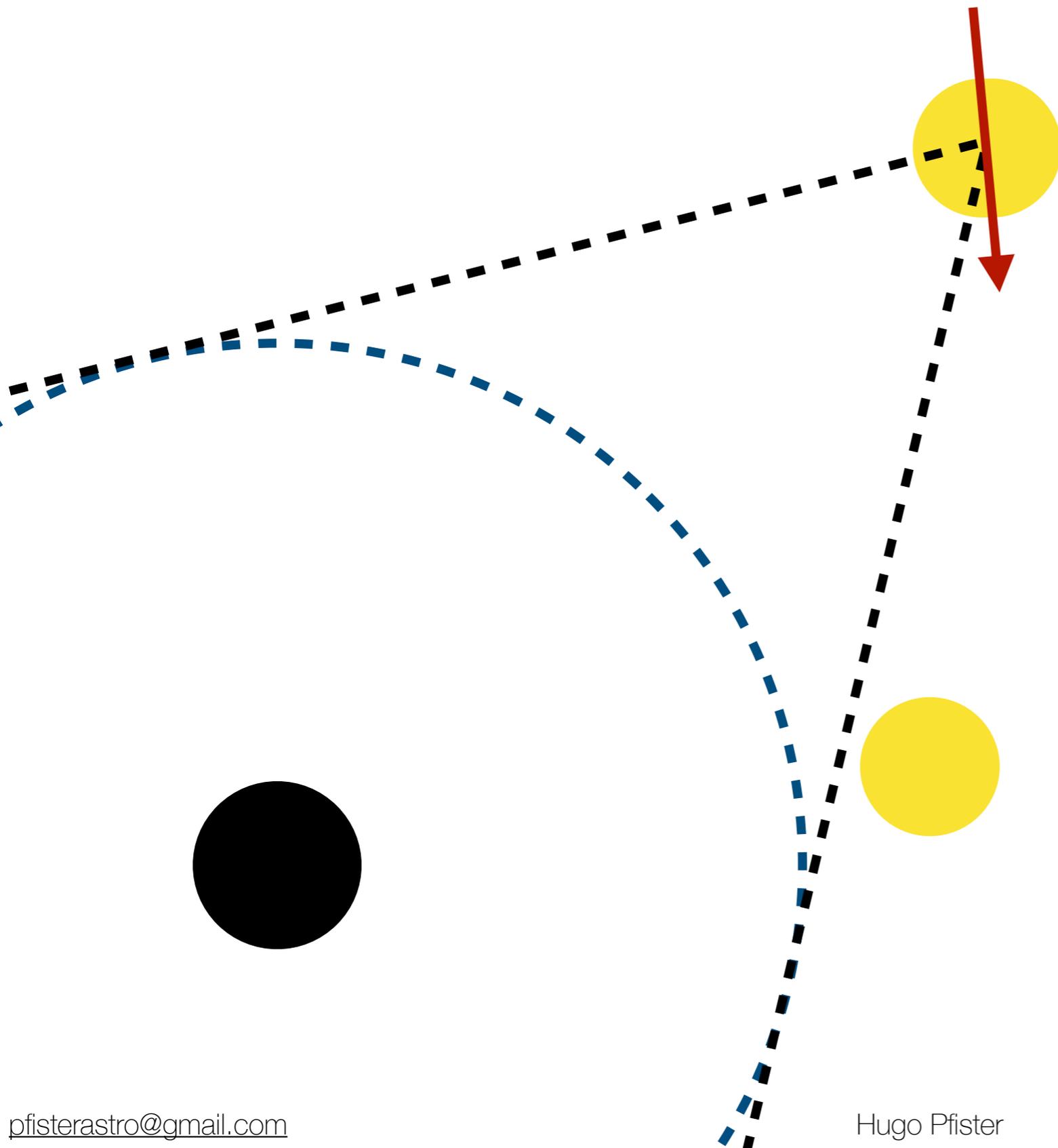


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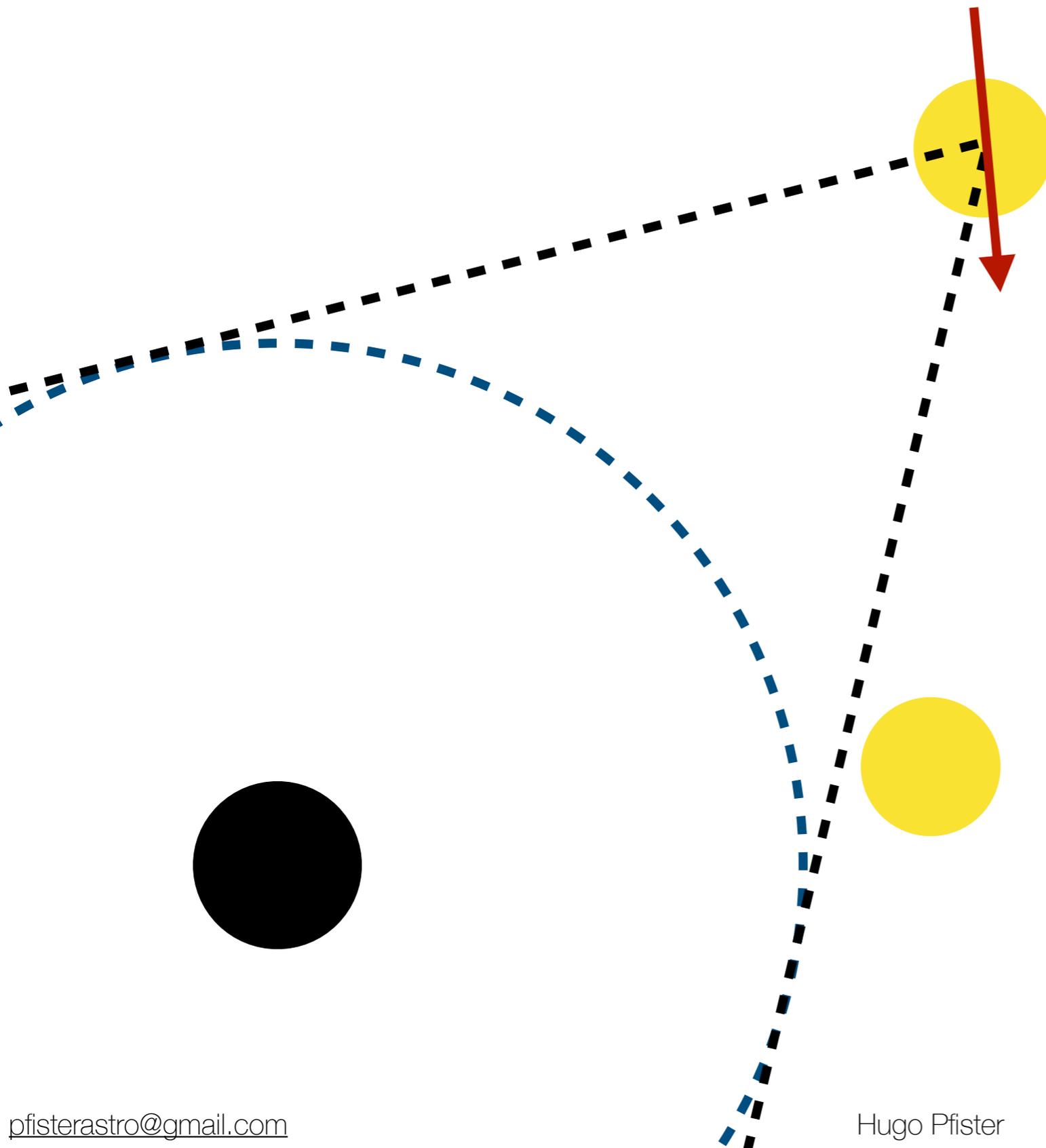
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The potential is spherical, but **not smooth**.

There is two-body relaxation. This can scatter stars and repopulate doomed orbits.

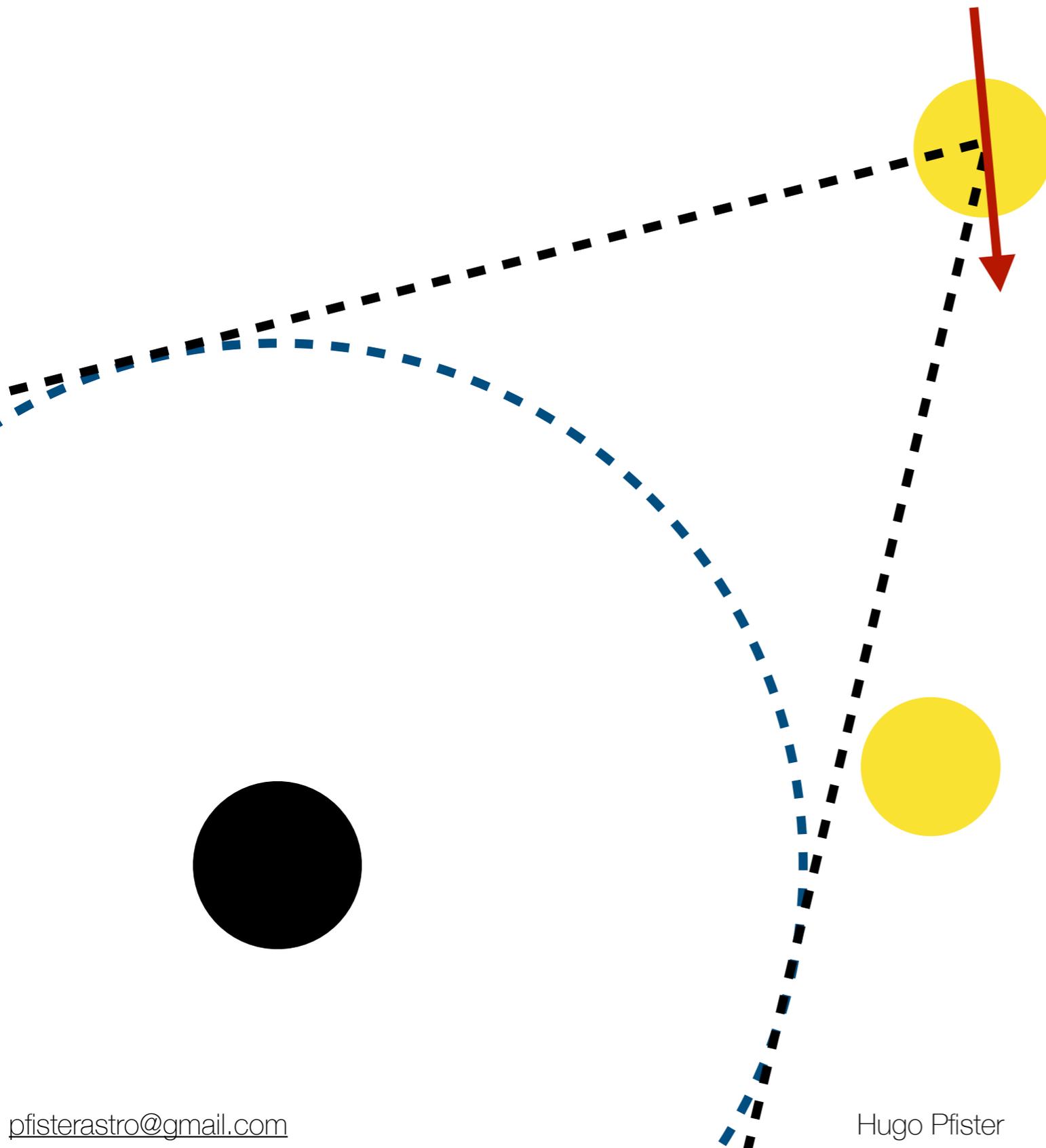
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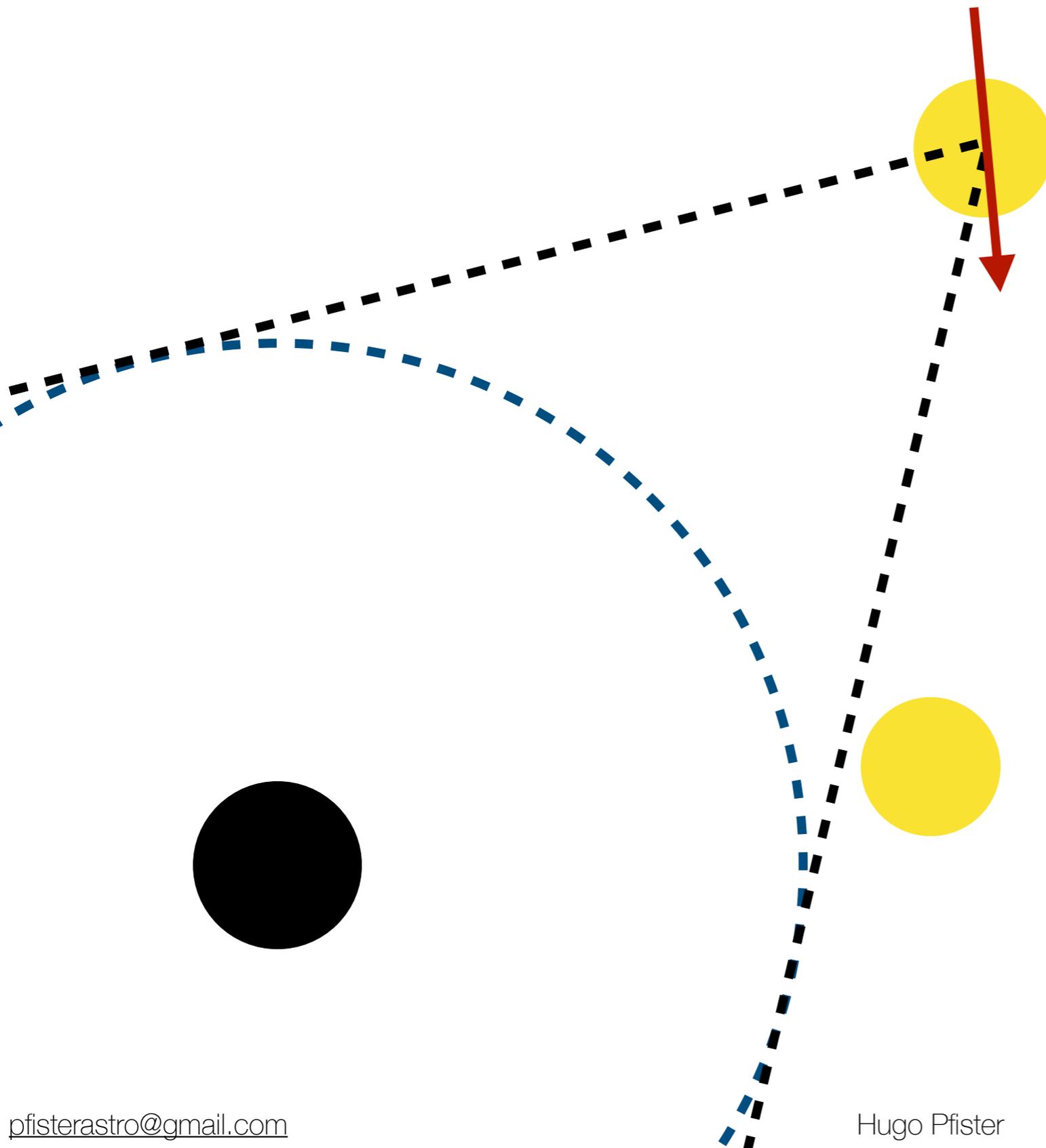


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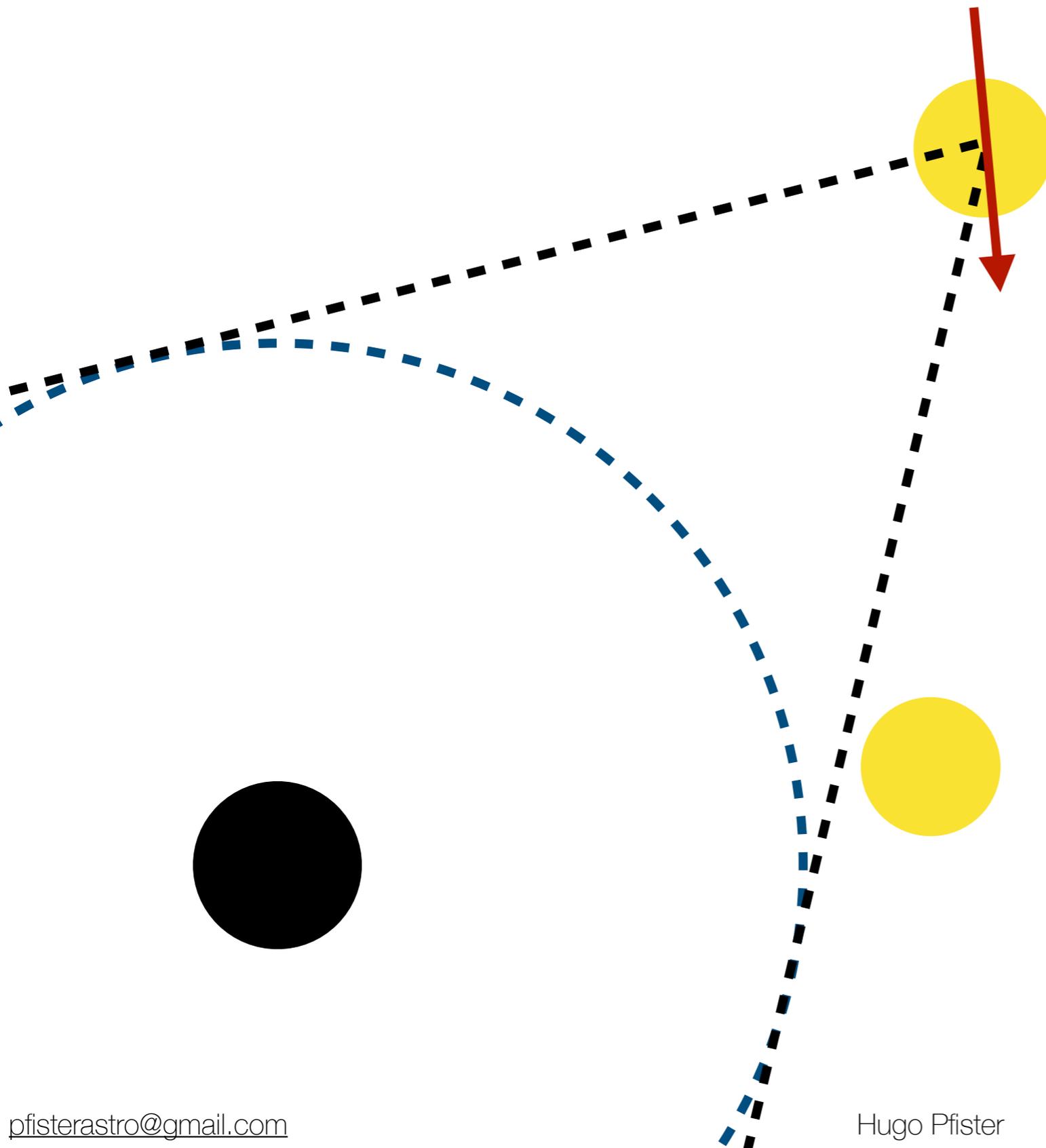
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There are two important timescales:

- The orbital period  $P$  corresponding to the time it takes to go from pericenter to apocenter.
- The relaxation timescale  $T_r$  corresponding to the time to significantly change the orbit

# Loss cone formalism

- If  $T_r \ll P$  then it is very fast to repopulate doomed orbit, the loss cone is always full. We talk about the **full loss cone regime** (or the pinhole regime).

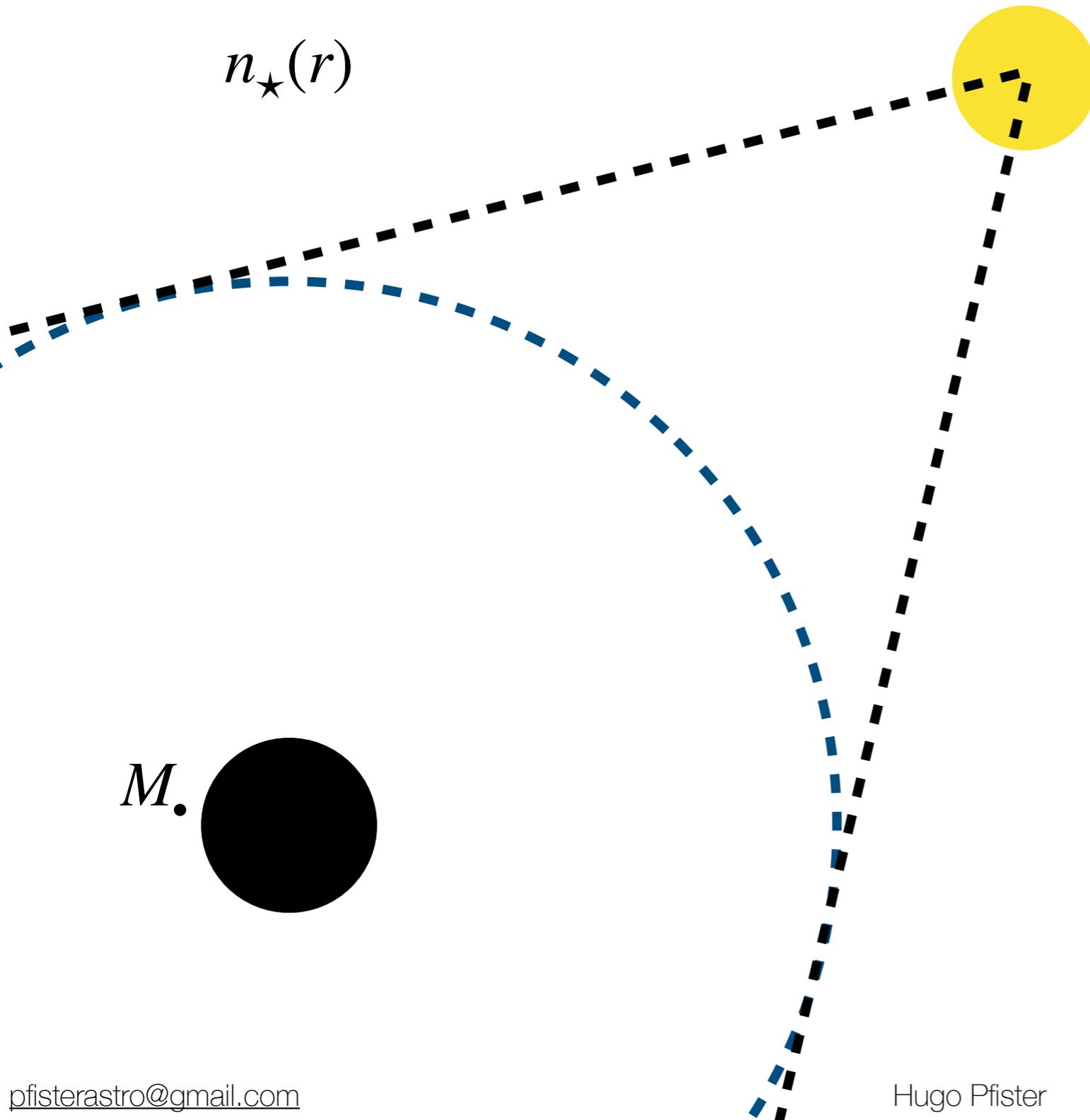
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- If  $P \ll T_r$  then, during one orbit, everything happens as if the potential was perfectly smooth. Orbits are slightly changed during one period such that stars *diffuse* onto doomed orbits. We talk about the **diffusive regime** (or empty loss cone).

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- If  $P \sim T_r$  then calculations are complicated, but doable  
(**Lightman+77, Strubbe+11, Merritt+13, Vasiliev+17, Pfister+21**)

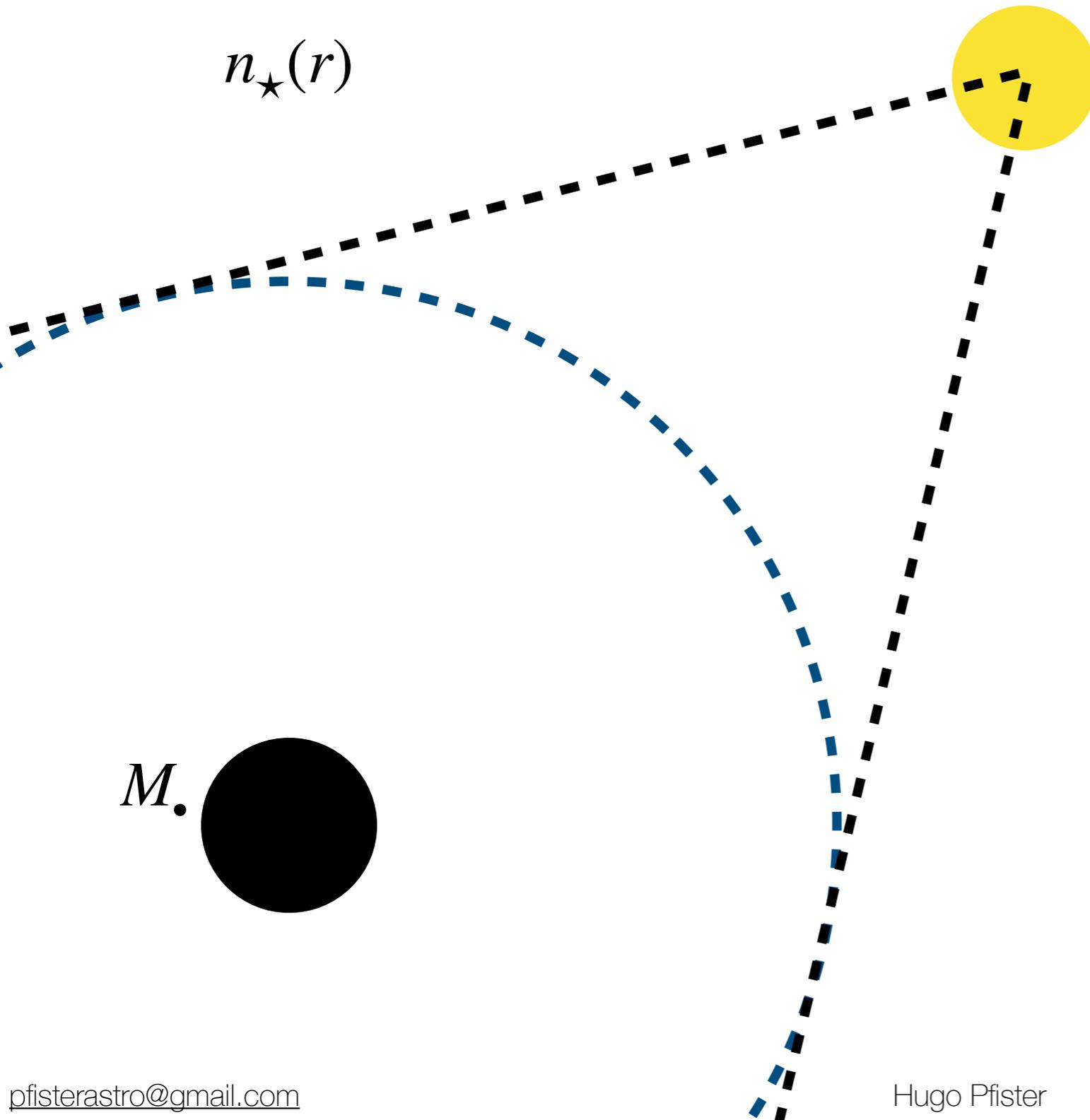
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1. Estimate the number density of stars going in the cone:

$$n_\star(r) \times \epsilon(r)$$

# Loss cone formalism



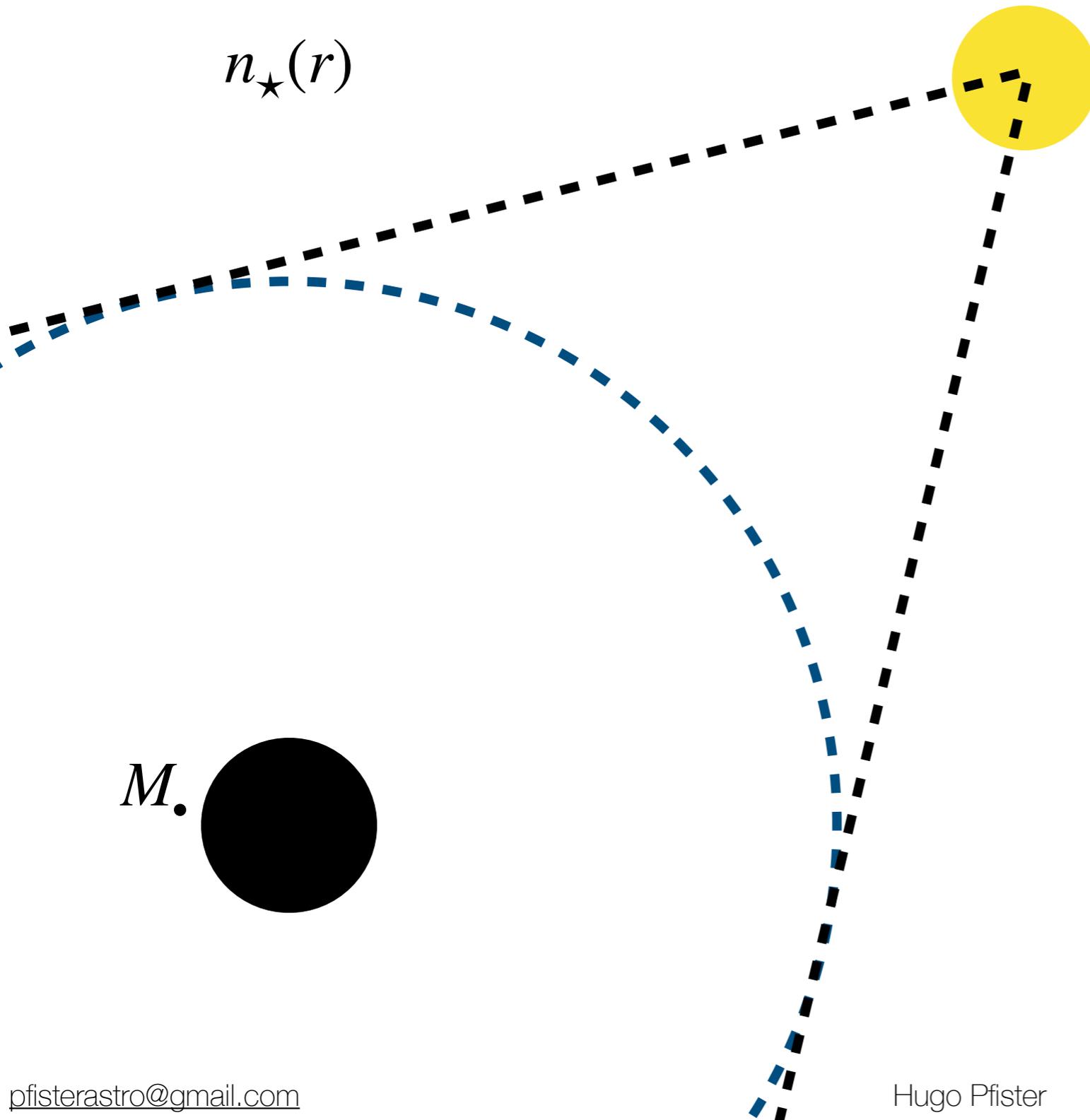
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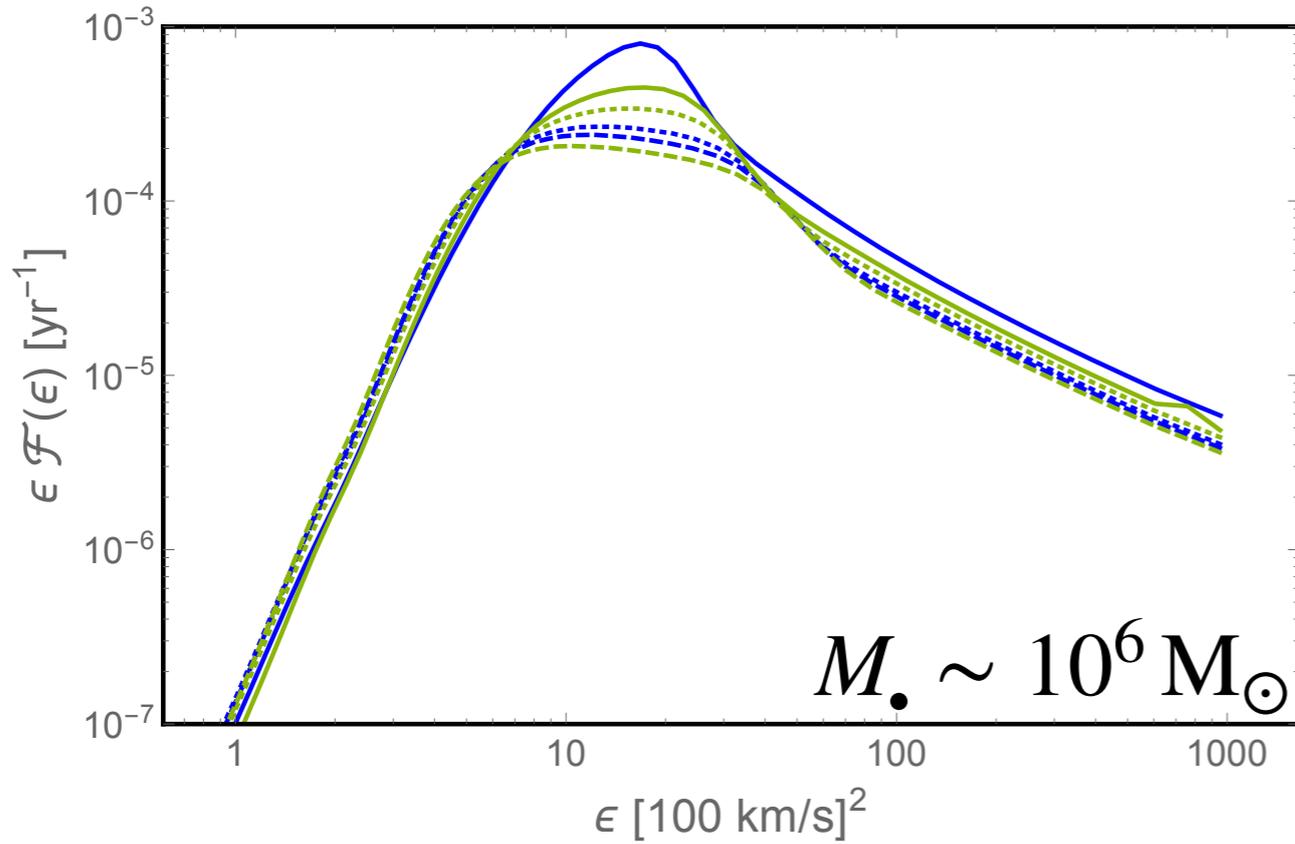
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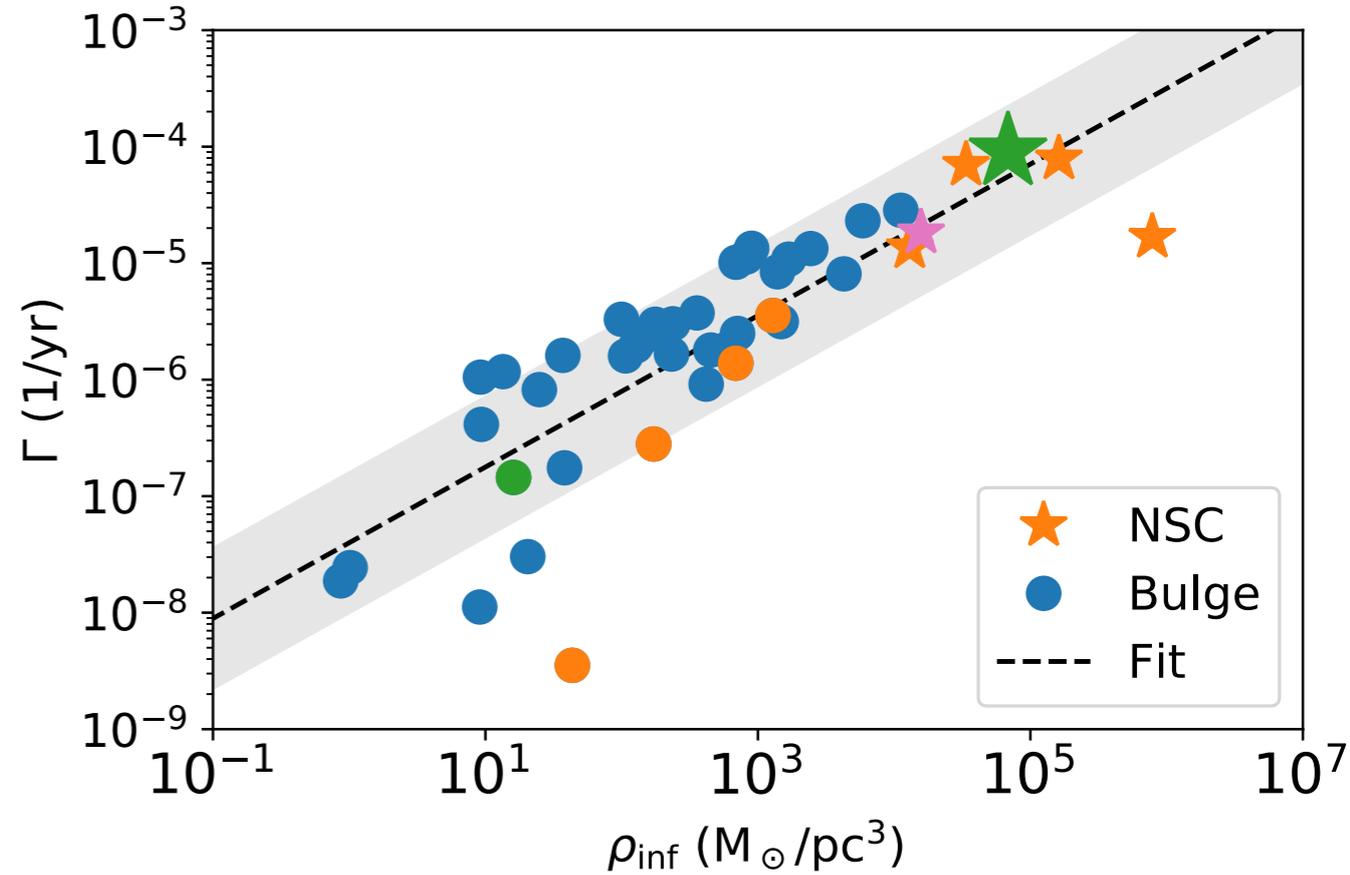
3. TDE rate:

$$\Gamma \sim \int \frac{\epsilon n}{\tau} \times 4\pi r^2 dr$$

# TDEs' stars origin



**Stone+16**



**Pfister+19**

$$a \sim \frac{GM_{\bullet}}{2\epsilon} \sim 2 \text{ pc}$$

$$\Gamma \sim 10^{-7.4} \text{ yr}^{-1} \left( \frac{\rho_{\text{inf}}}{M_{\odot} \text{ pc}^{-3}} \right)^{0.65}$$