The near-pericenter self-instersection of the debris stream in TDEs by a misaligned Kerr black hole

Rong-Feng Shen (申荣锋)

&

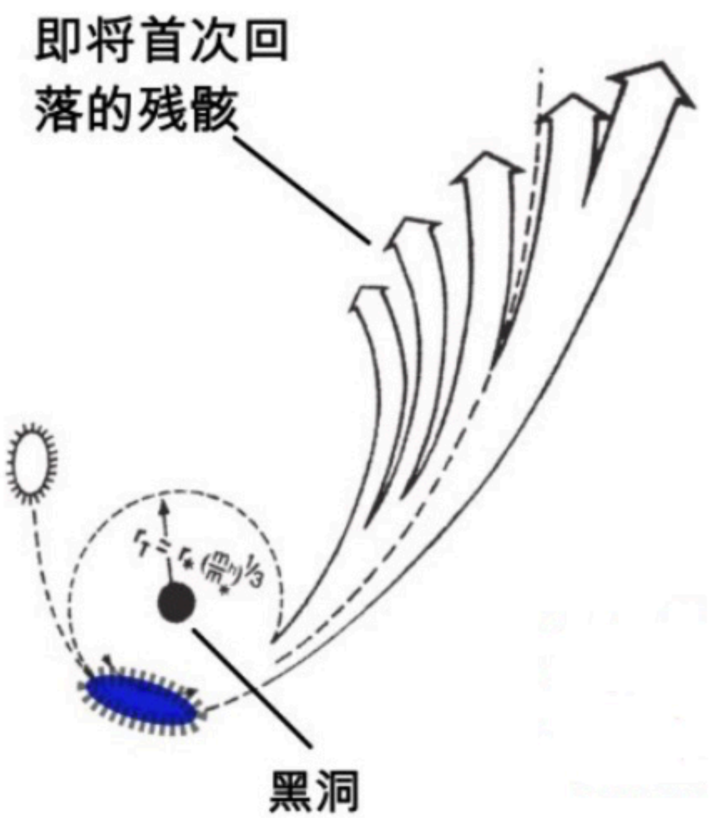
Yan Song (宋燕)

Sun Yat-sen University

(中山大学)

Key question in TDEs

- How does debris stream dissipate its orbital energy?



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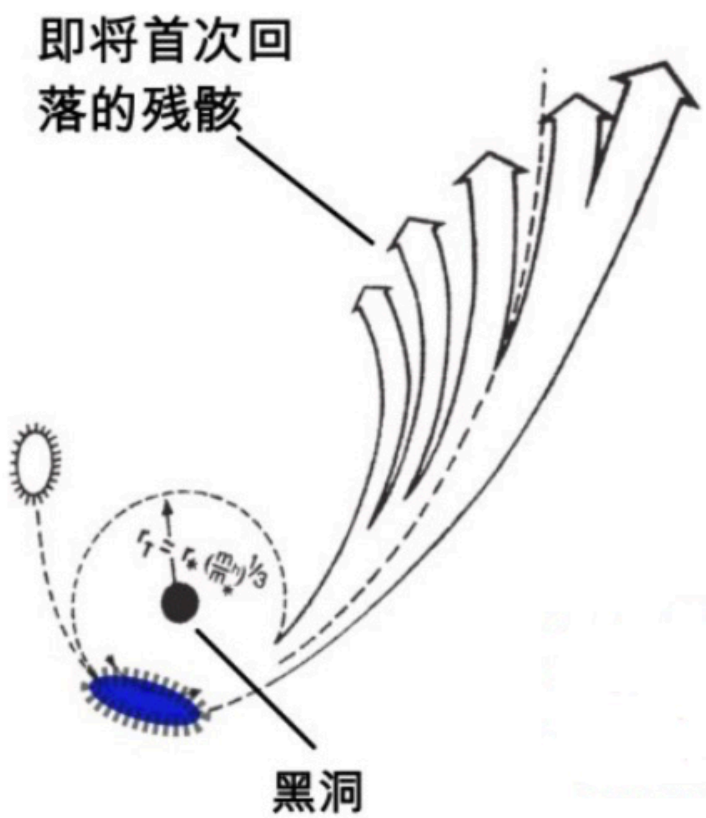
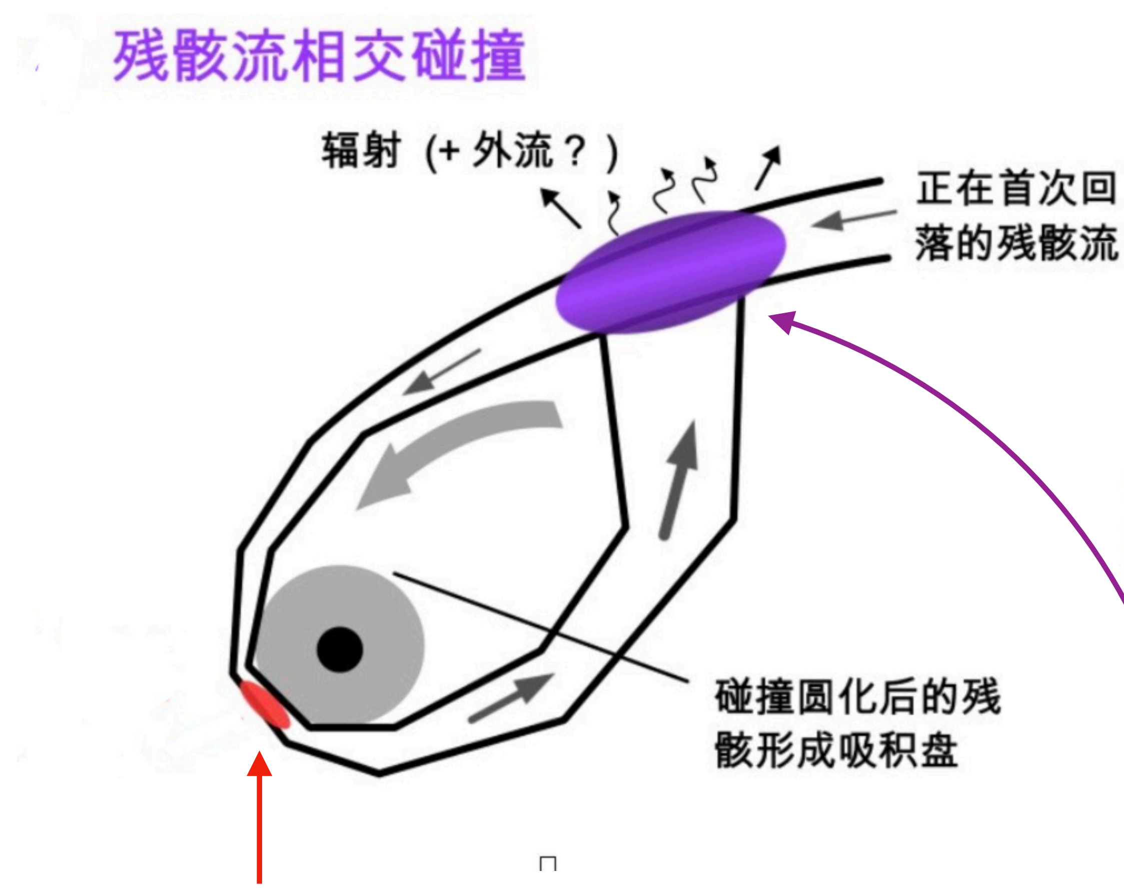
Apsidal precession（GR）





- Most likely early dissipation channels:

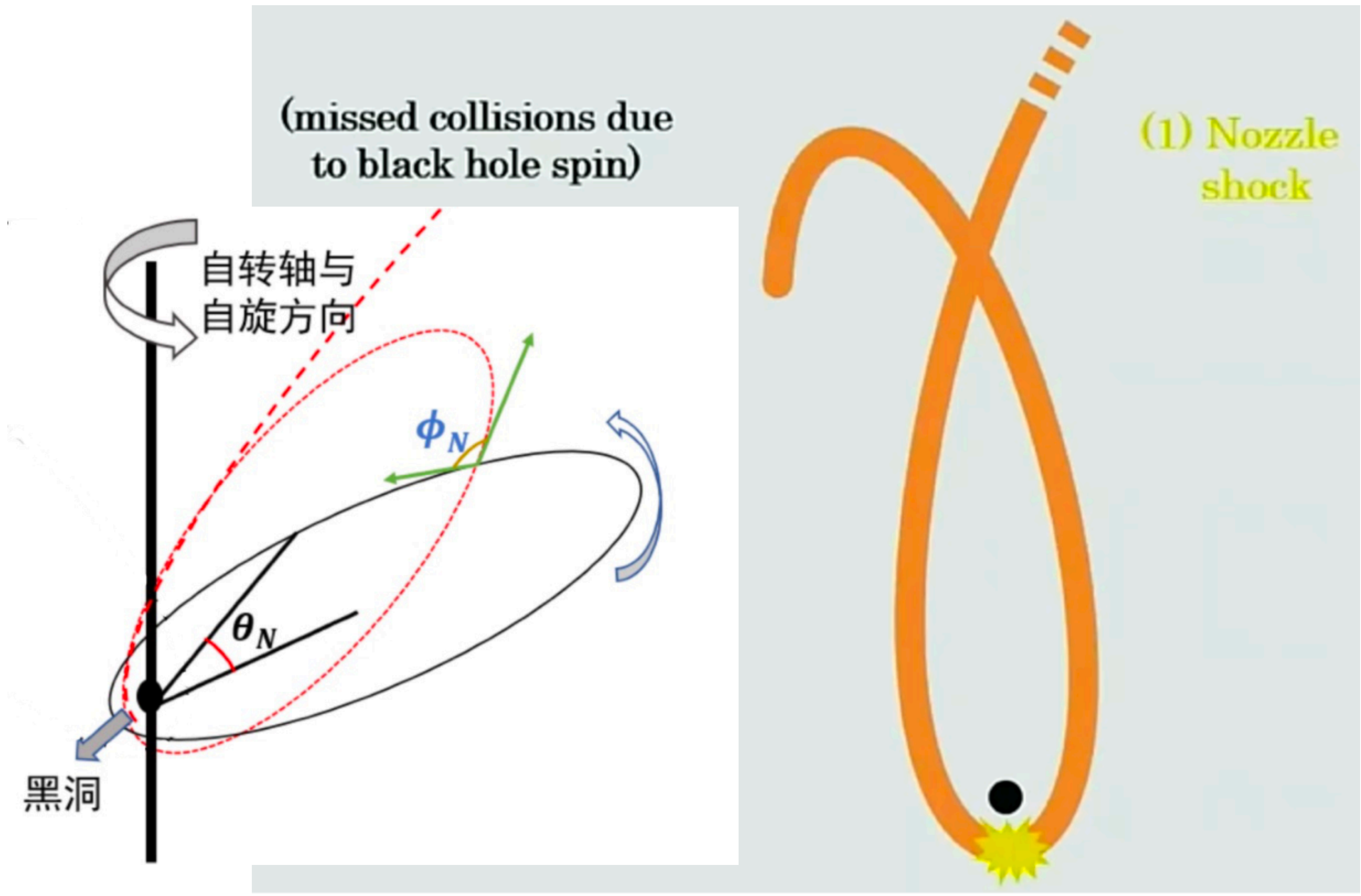
1) Peri-center nozzle shock: too weak!

2) Apo-center self intersection.

However, when BH is spinning and misaligned with stellar orbital plane …

- Stream might miss itself at apocenter.

Dai et al. (2013); Guillochon et al. (2015)



Apsidal precession+ Lense-Thirring precession

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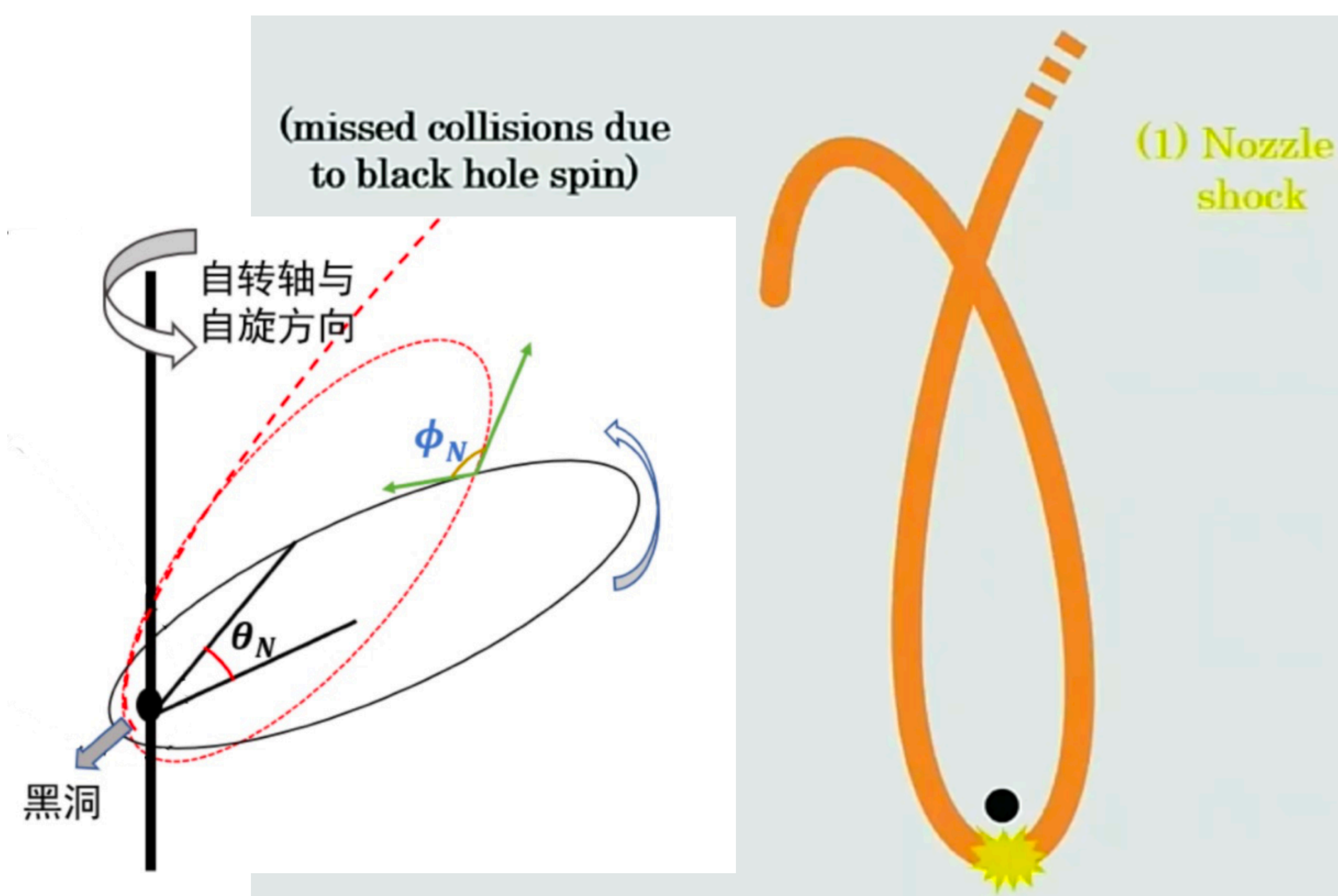
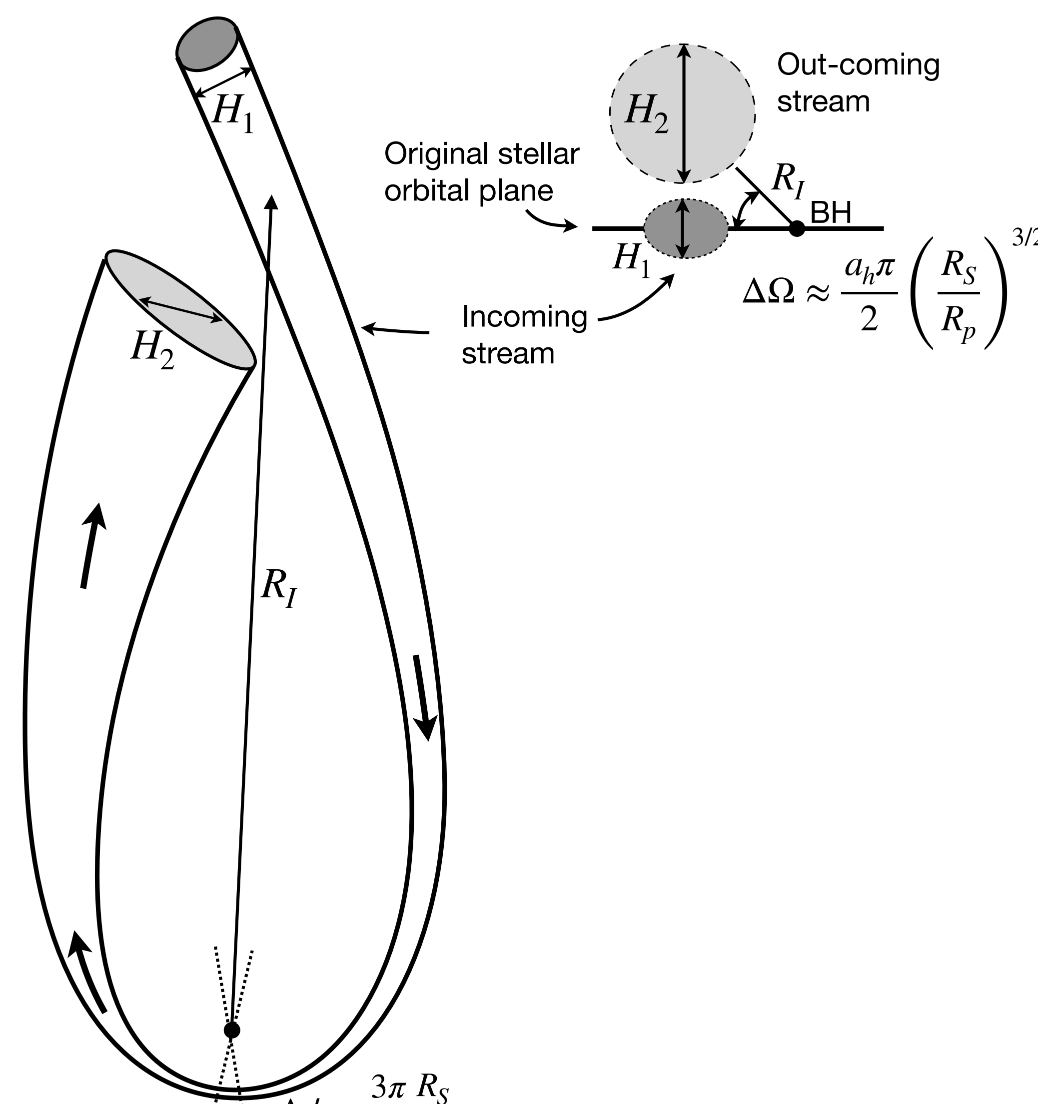
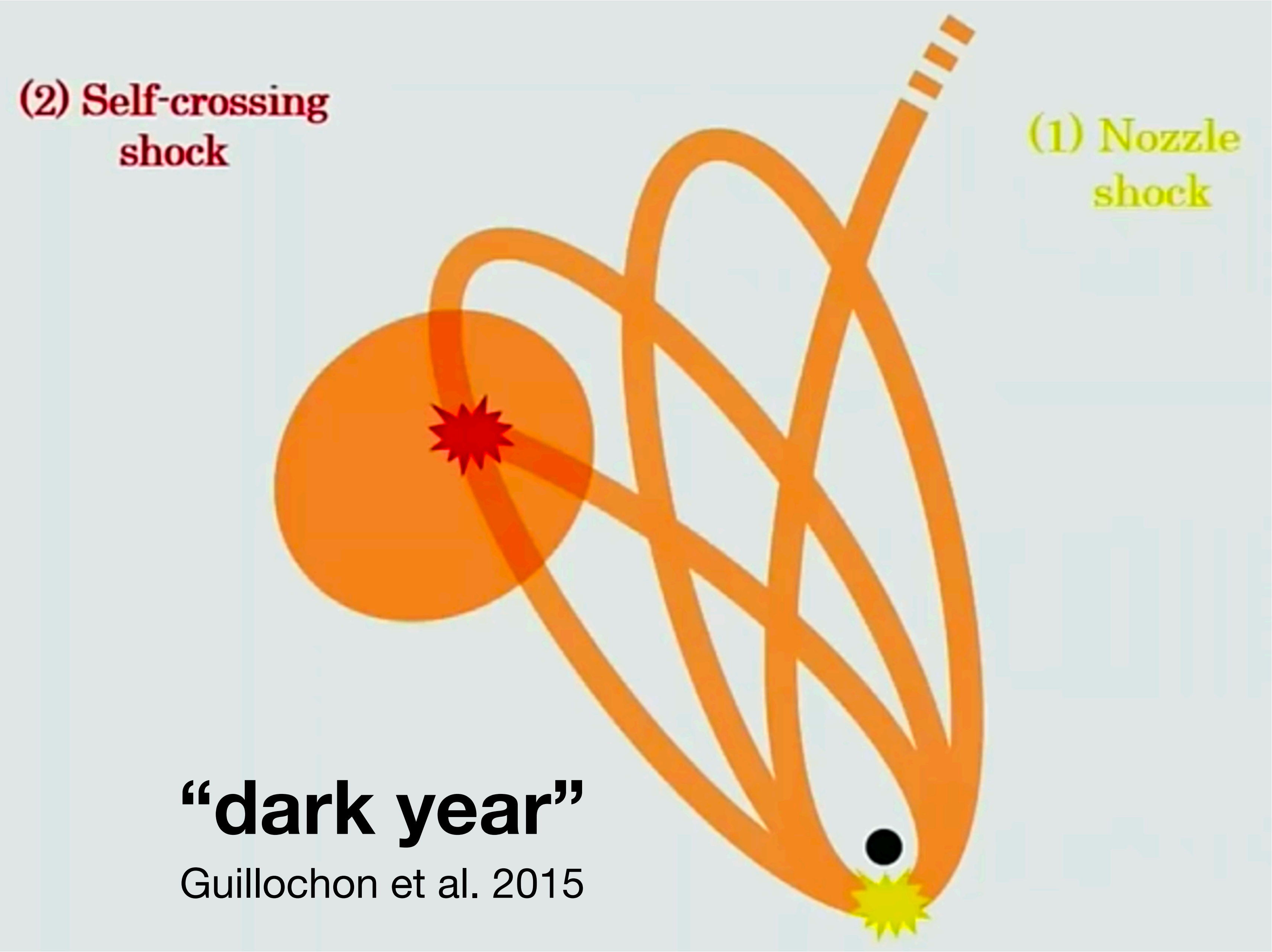




Apsidal precession+ **Lense-Thirring** precession

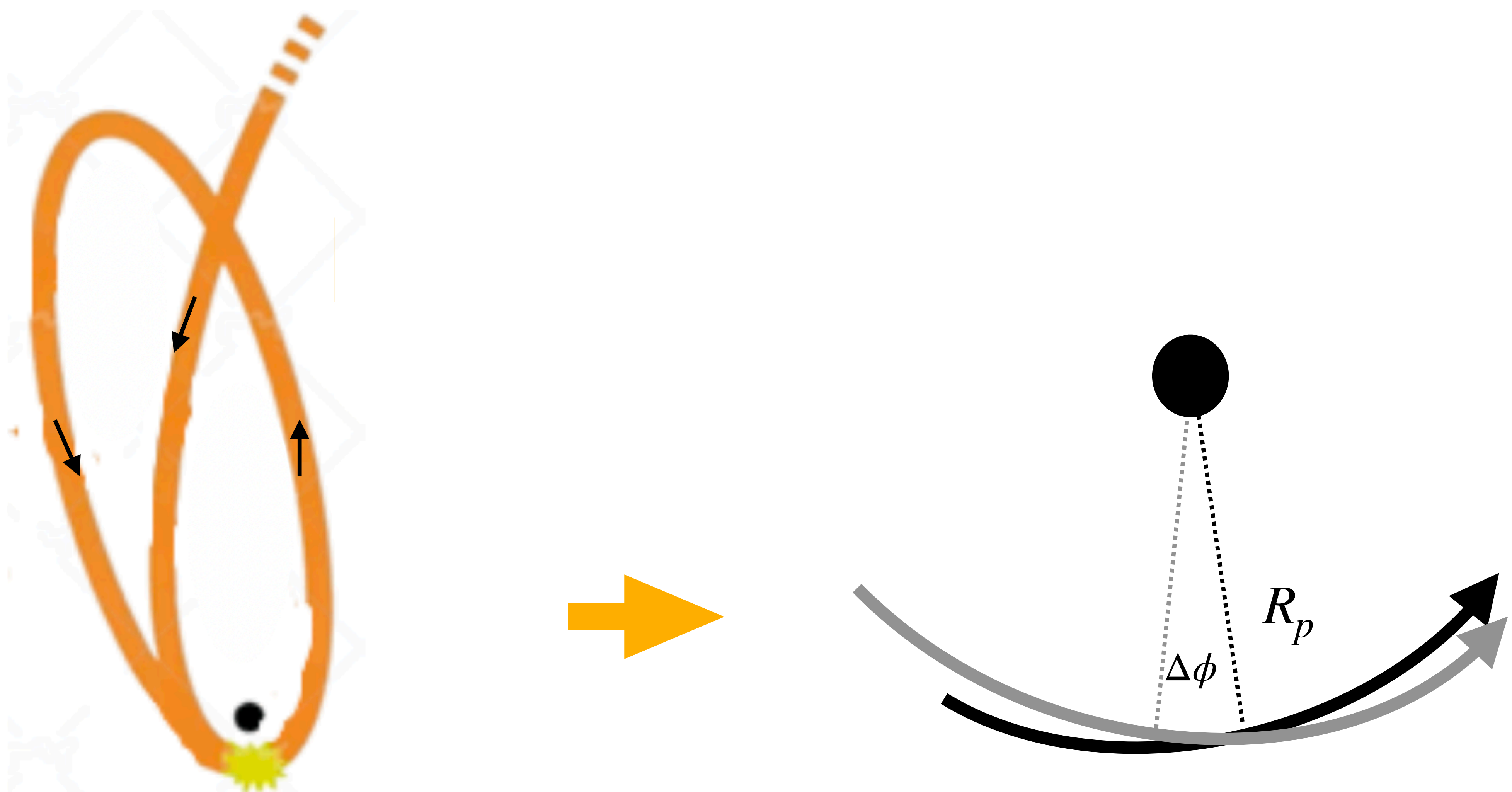
→ Delayed stream dissipation and TDE signal



Apsidal precession+ Lense-Thirring precession

We study the small-angle collision at peri-center

- May be the earliest collision, for the misaligned Kerr BH case.

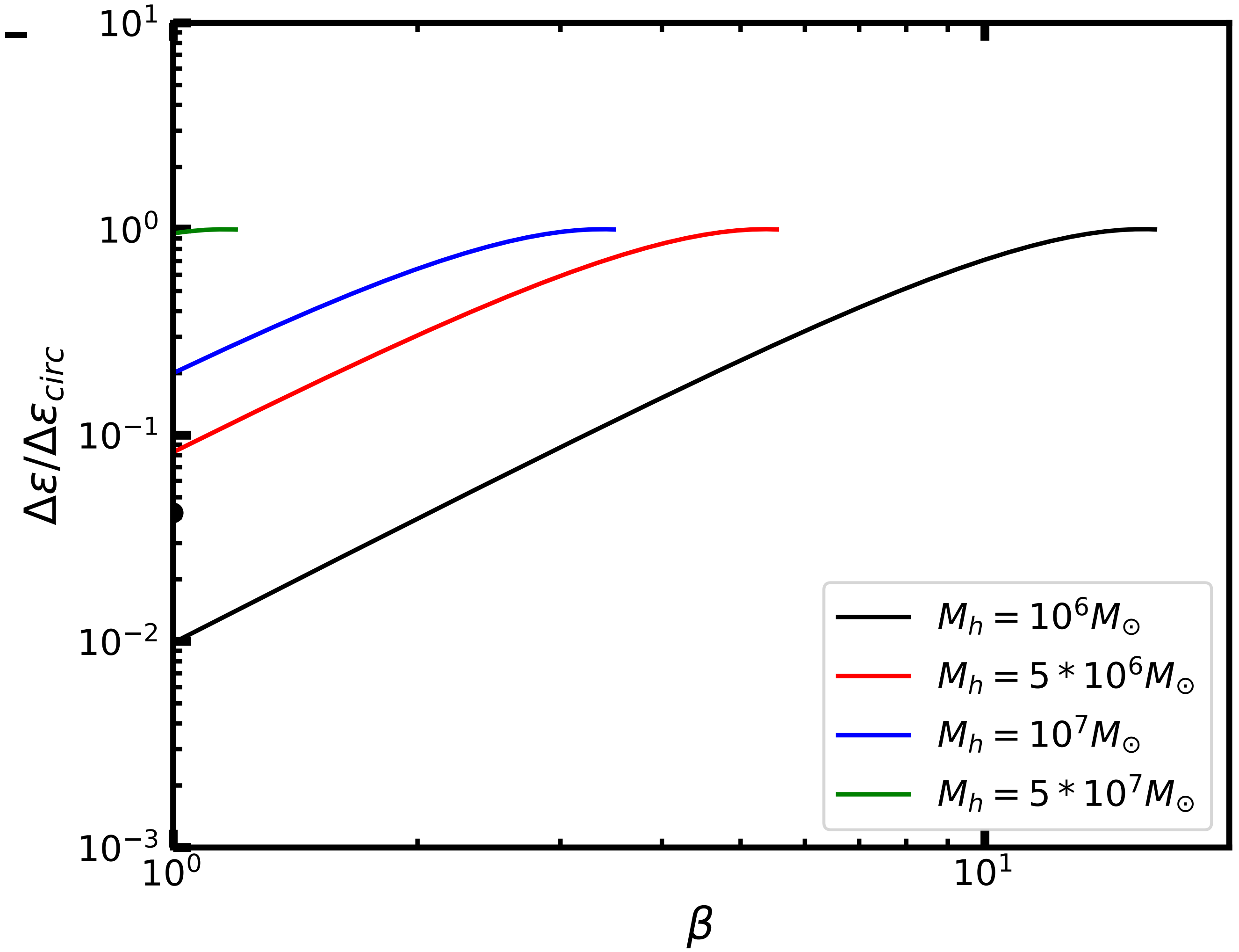


Order-of-magnitude estimate

- Specific energy dissipation at peri-center：

$$\Delta\epsilon = 2\frac{GM}{r_\mathrm{c}}\sin^2(\theta_\mathrm{c}/2),$$

- Comparable to that of apsidal collision.



- However, **L-T precession causes a vertical offset** between streams at their peri-center encounter.

Assumption: stream width increment due to nozzle shock

- The width of stream after the N-th orbit:

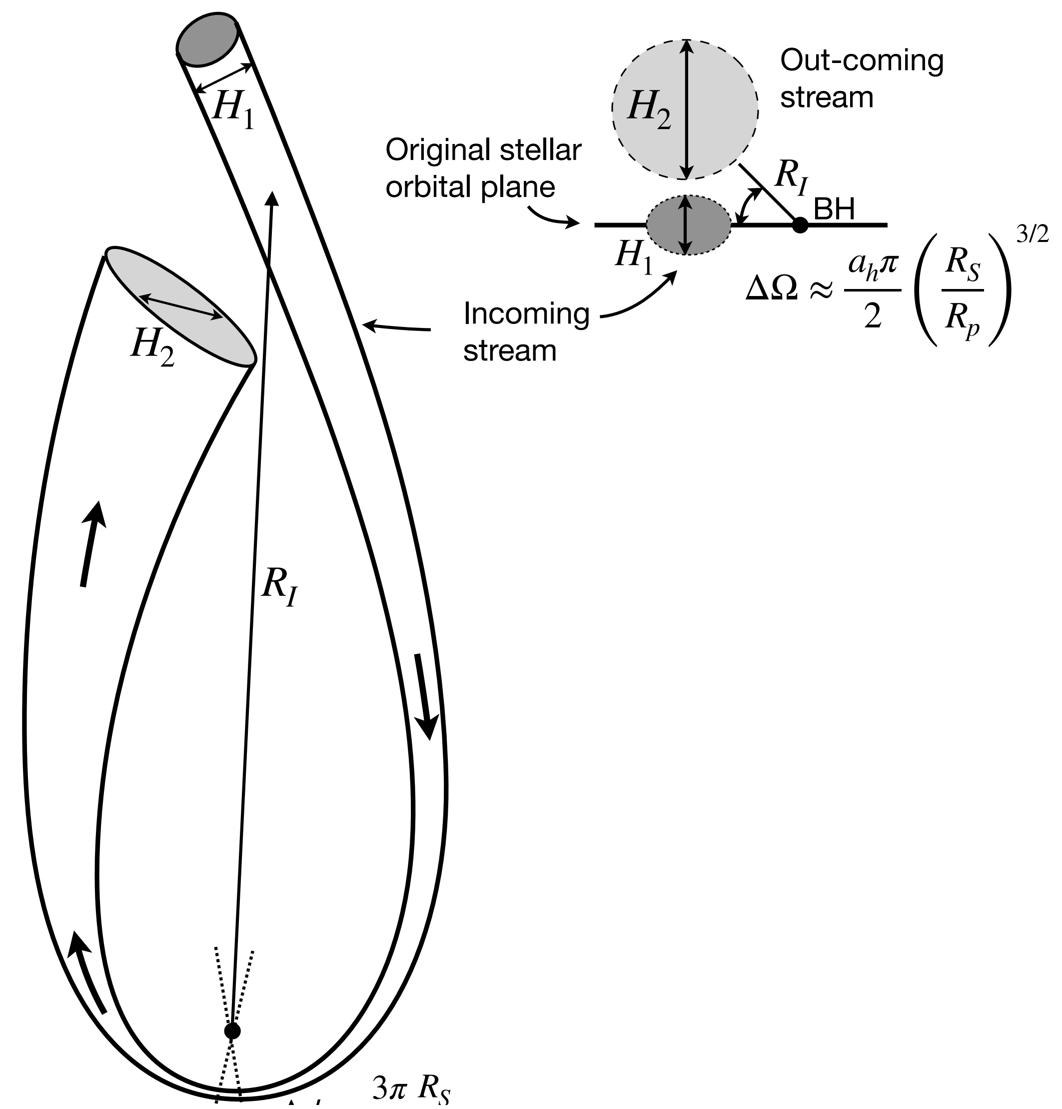
$$H \approx N R_{\rm int} \frac{R_*}{R_p}$$

- The vertical offset of two streams at their encounter:

$$\Delta z \approx R_{\rm int} \Delta\Omega$$

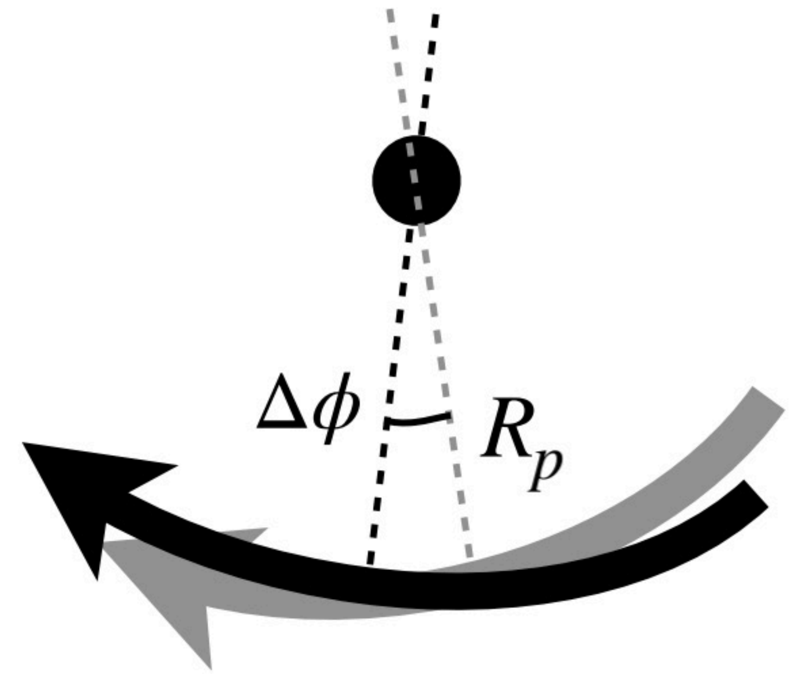
- Collision happens when:

$$\Delta z < H_1 + H_2$$



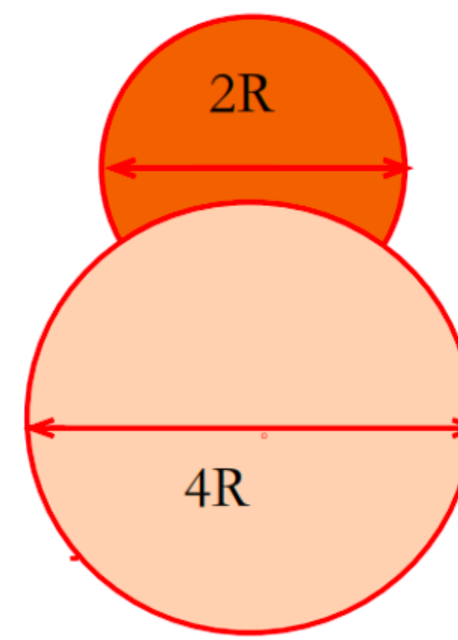
Methods

- Local 3-D hydrodynamical simulation with Athena++.
- Adiabatic index 4/3.
- Newtonian gravity.
- Spherical coordinates.



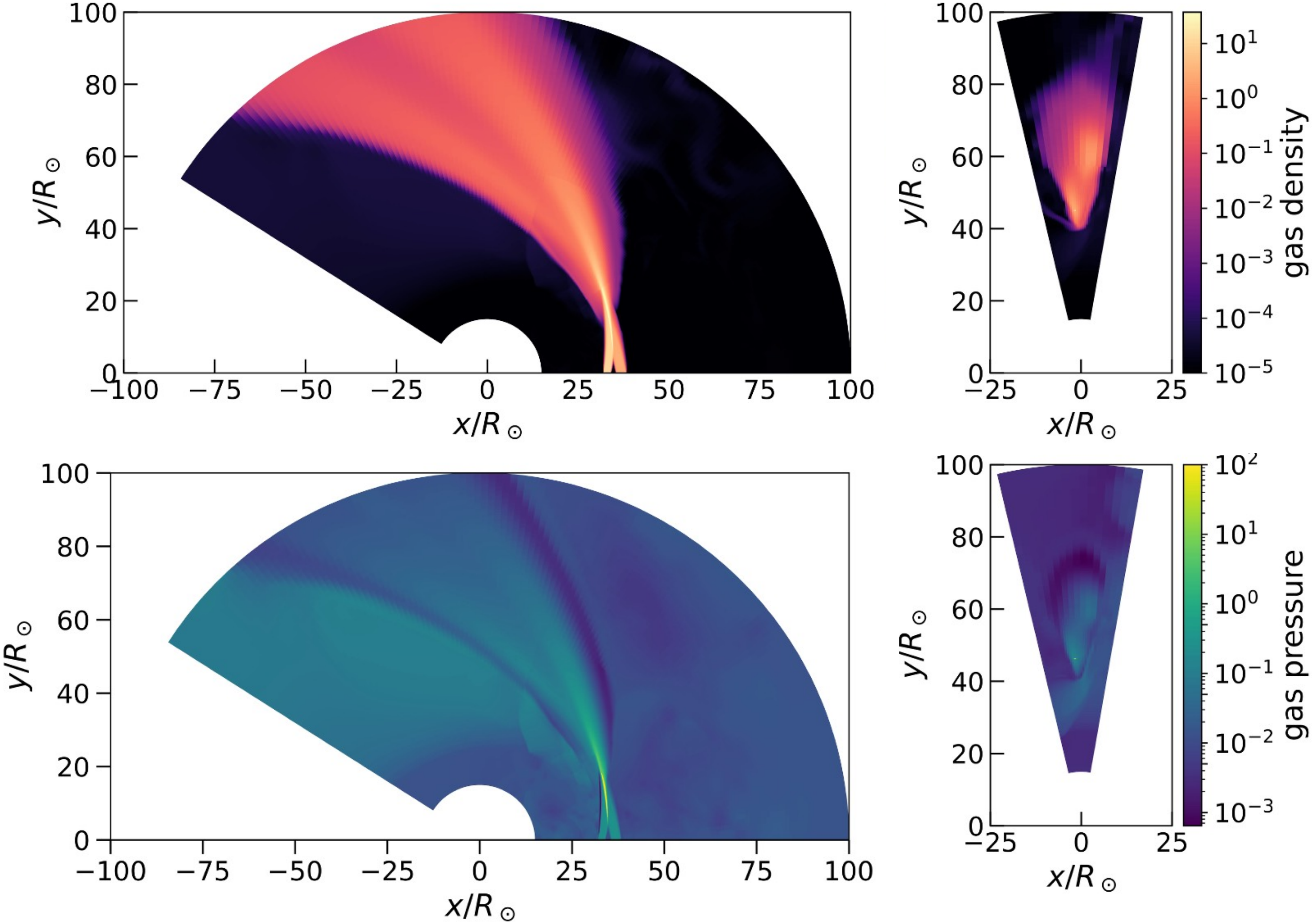
	Mbh (Msun)	Mstar (Msun)	Rstar (Rsun)	a	i	β
Run 1	10^6	1	1	0.9	pi/3	3

- **Two streams cross at small angle at R_c.**
- **Represent the ones which passed the nozzle shock once and twice, respectively.**



$$\Delta z/(H_1 + H_2) = 0.68$$

Simulation run



$\theta = \pi/2$ plane

$\phi = 2\pi/5$ plane

Results

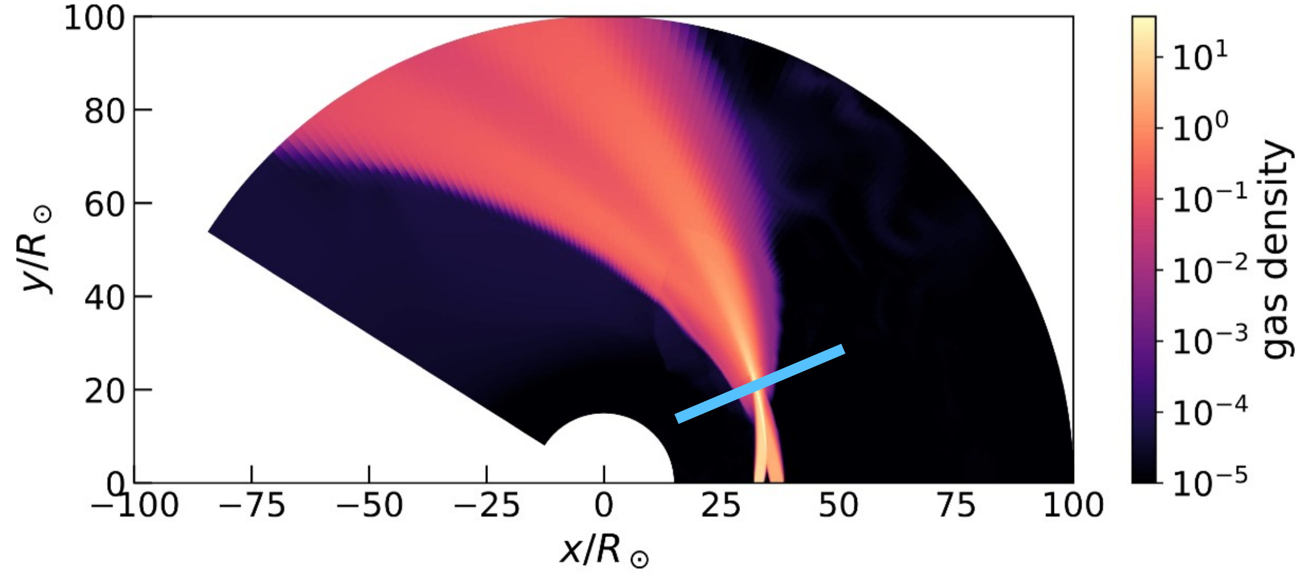
Energy dissipation

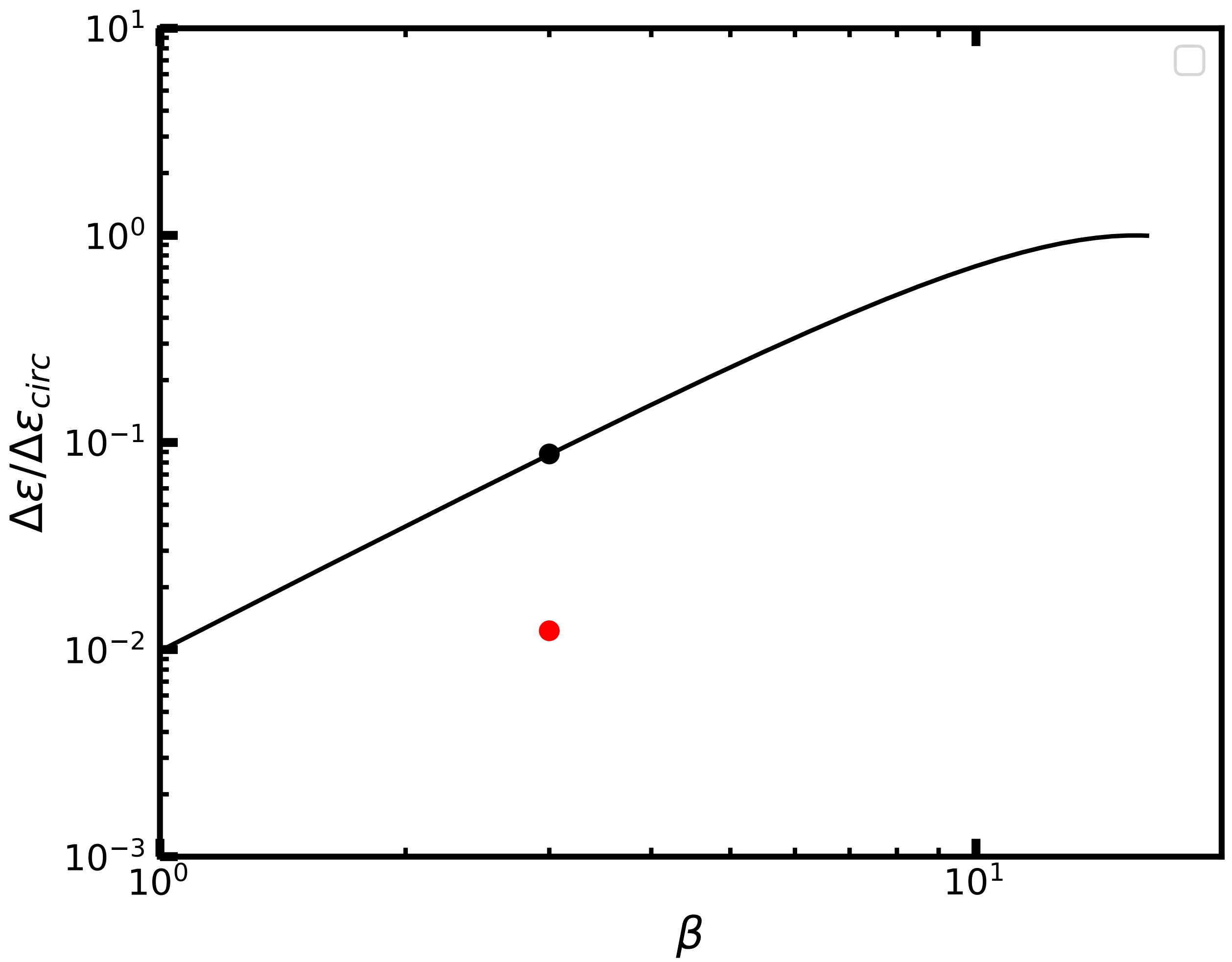
- Compute the internal energy flux through the cross section (blue line) $\dot{\epsilon}_{\rm int}$ / full-circularization required specific energy dissipation $\Delta\epsilon_{\rm circ} \times$ mass rate $2\dot{M}$) :

$$\frac{\Delta\epsilon}{\Delta\epsilon_{\rm circ}} = \frac{\dot{\epsilon}_{\rm int}}{2\Delta\epsilon_{\rm circ}\dot{M}}$$

- **Solid line**: theoretical expectation (assuming no stream vertical offset) ;

- **Filled cycles**: simulation results. **Black**: $\Delta z = 0$



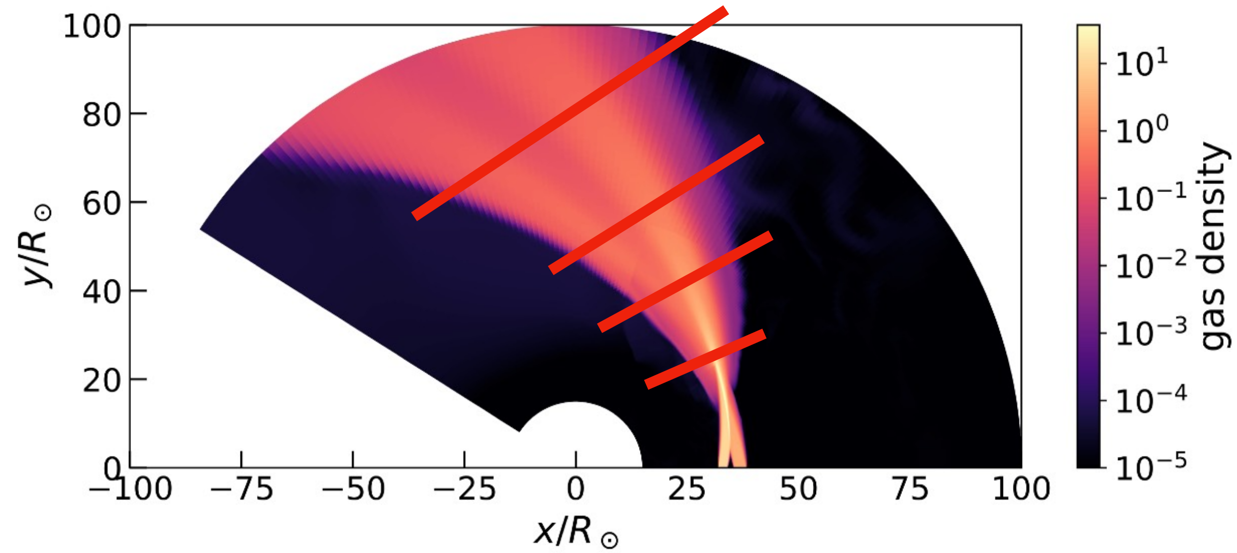


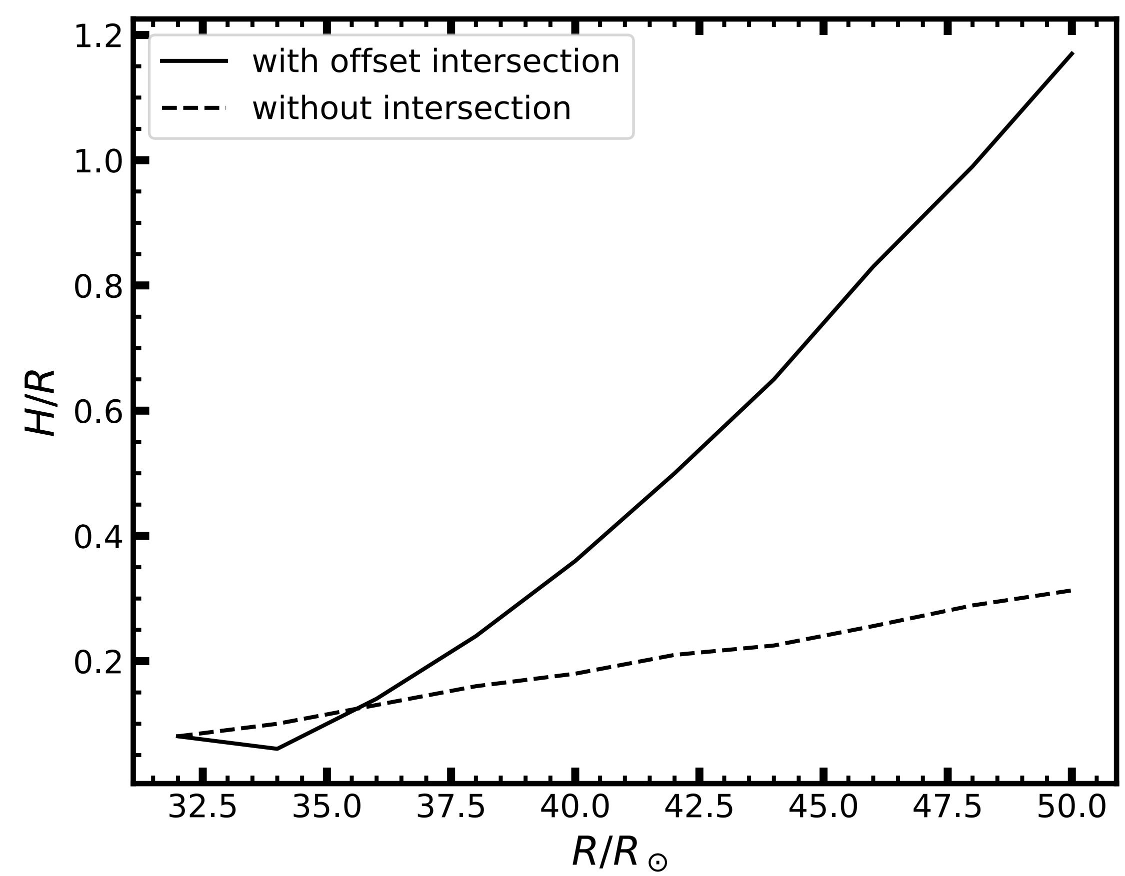
Results

Post-collision width expansion

- H is defined as for $(10^{-4} - 1)$ of ρ_{max}.

- Expanded stream may be easier for later apsidal collisions.





Summary

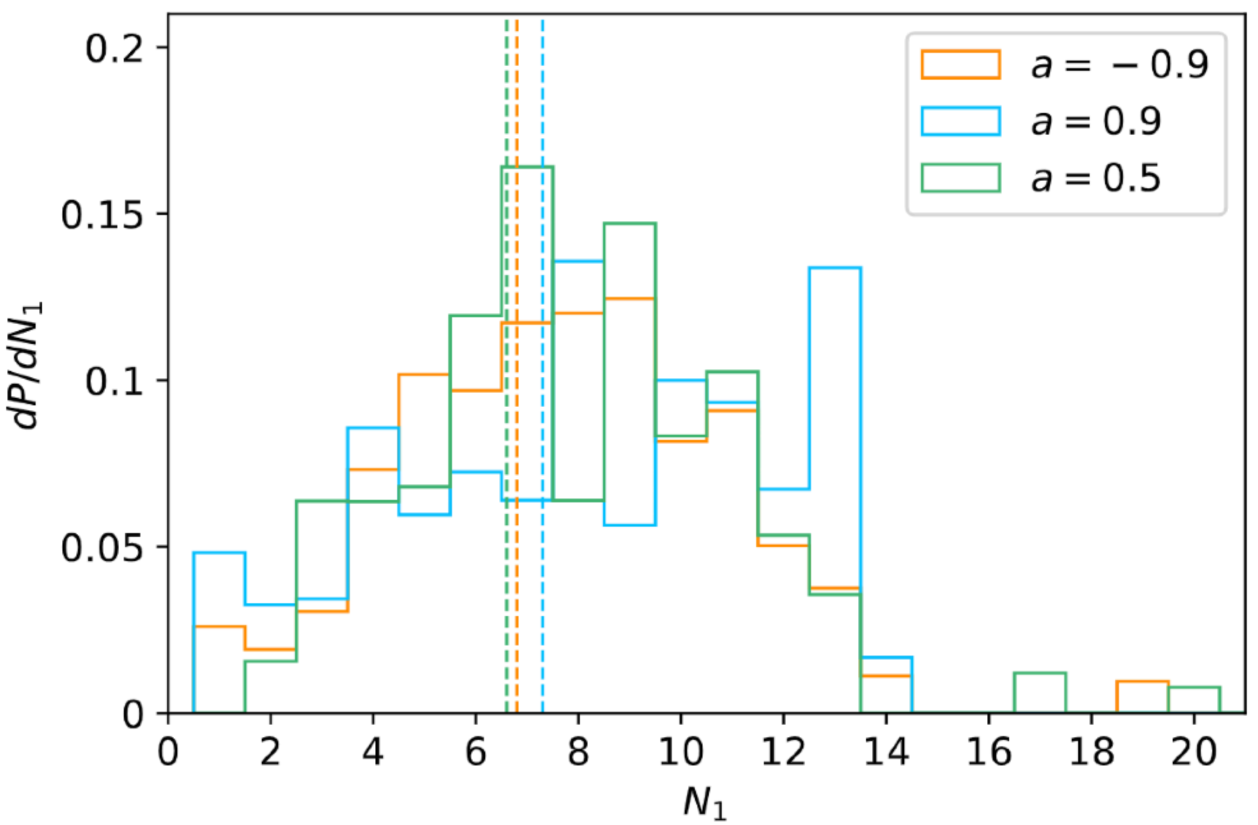
- The near-pericenter collision dissipates very little energy, ~ 0.5% of stream kinetic energy, due to the vertical offset nature of the collision.

- After the collision, the stream experiences a lateral expansion, making its width to increase with distance more quickly than the case without a peri-center collision.

- This width expansion likely promotes collisions in subsequent orbits and accelerates the disk formation.

近心点附近残骸流自交叉

- 根据 (Batra, G et al. 2021)的半解析分析，自旋黑洞情况下自交叉首次发生在近心点还是远心点的概率各占一半



(Batra, G et al. 2021)

近心点附近残骸流自交叉

- 因此我们认为有必要研究自旋黑洞情况下的心点自交叉
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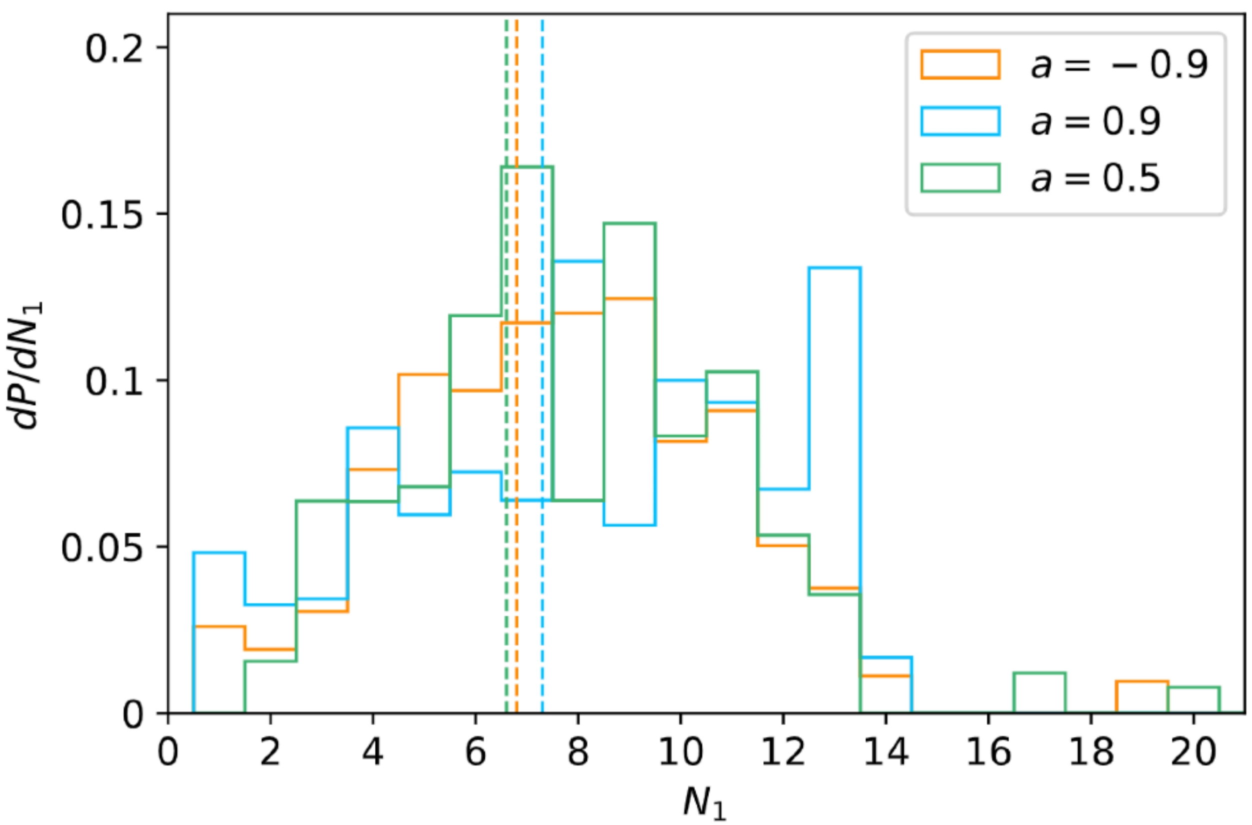

(Batra, G et al. 2021)

模拟结果

质量加权的角动量和能量分布

- 我们讨论近心点自交叉造成的碰撞后残骸流角动量和能量分布