*T*idal *D*isruption *E*vents & *SN remnant* evolution in galactic nuclei

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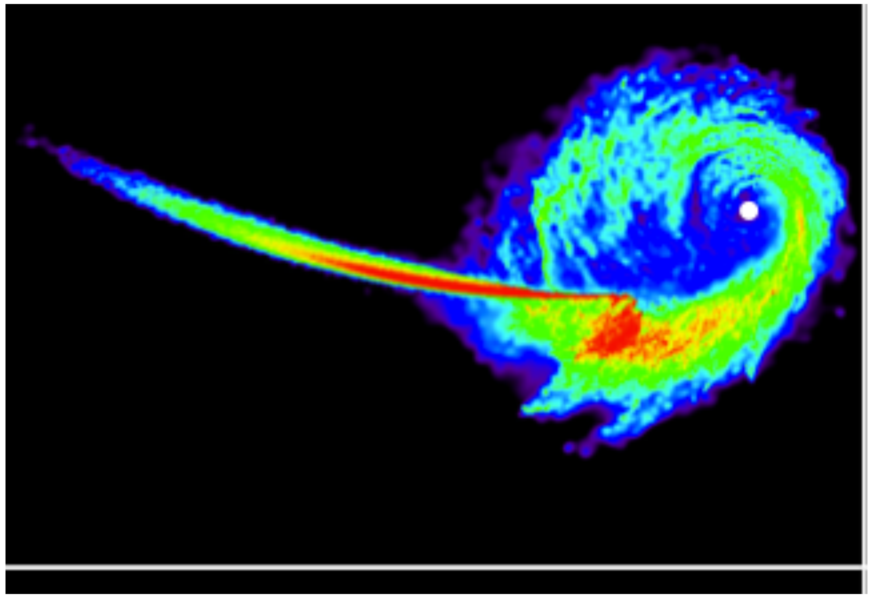
Aspen meeting, January 22, 2015

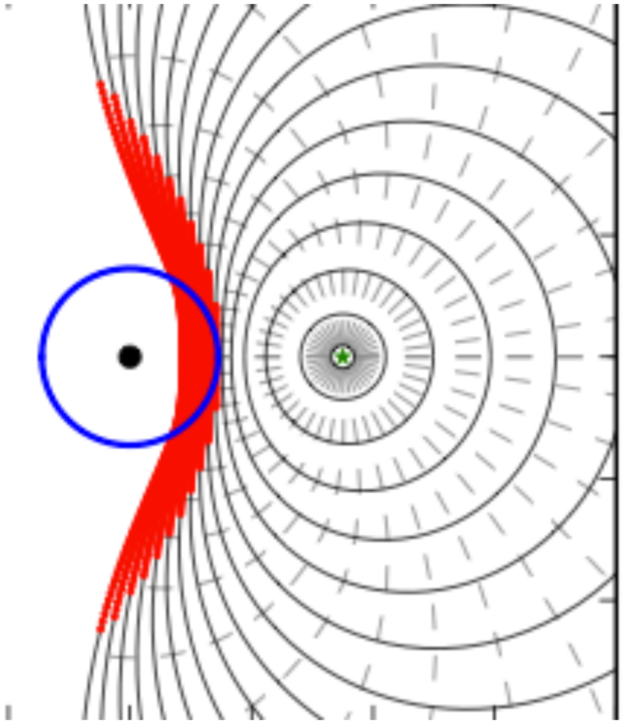
Disc formation in TDEs

PhD student C. Bonnerot



SN remnant evolution

PhD student A. Rimoldi

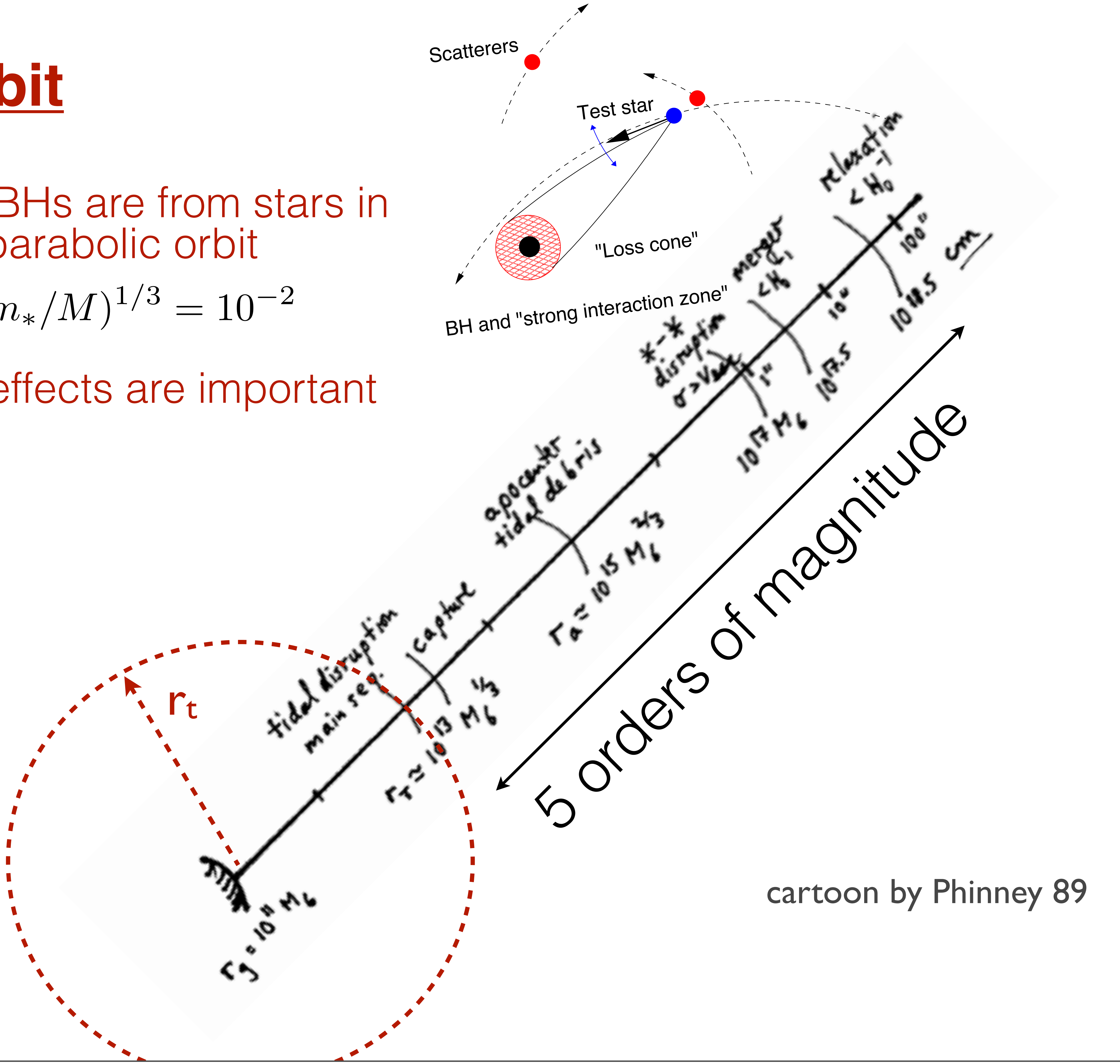


TDE Orbit

- TDEs by SMBHs are from stars in quasi-parabolic orbit

$$|1-e| \ll (m_*/M)^{1/3} = 10^{-2}$$

- Relativistic effects are important



cartoon by Phinney 89

Relativistic Effects

- BH size: Whether a star is swallowed whole or disrupted strongly depends on actual geodetics (Kesden 2012, **Emilio's talk**)
- Pericenter precession (Hayasaki, Stone & Loeb; Hotaka et al.; **Roseanne's talk**)
- Lense Thirring (e.g. Stone & Loeb; Hayasaki, Stone & Loeb; **Emilio's talk**)

Parabolic orbit are computationally challenging

- M/m_* >>1 implies large spread of semi-major axis ==> low density, resolution challenge
- Least bound matter takes an infinite time to come back ==> large range in timescales
- ``Solutions"
- **Consider smaller M/m_*** (e.g. talks by MacLeod, Hotaka et al. 15)
- **consider highly eccentric orbits** (Hayasaki et al.13,15)

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A study of “Disc” formation

Bonnerot, EMR, Lodato & Price (2015):

- **Highly eccentric orbit, $M = 10^6\ M_{sun}$, $M/m = 10^6$**

A study of "Disc" formation

Bonnerot, EMR, Lodato & Price (2015):

- Highly eccentric orbit and $M/m = 10^6$
- **Non-rotating black hole**
- **Use Keplerian and relativistic potential**

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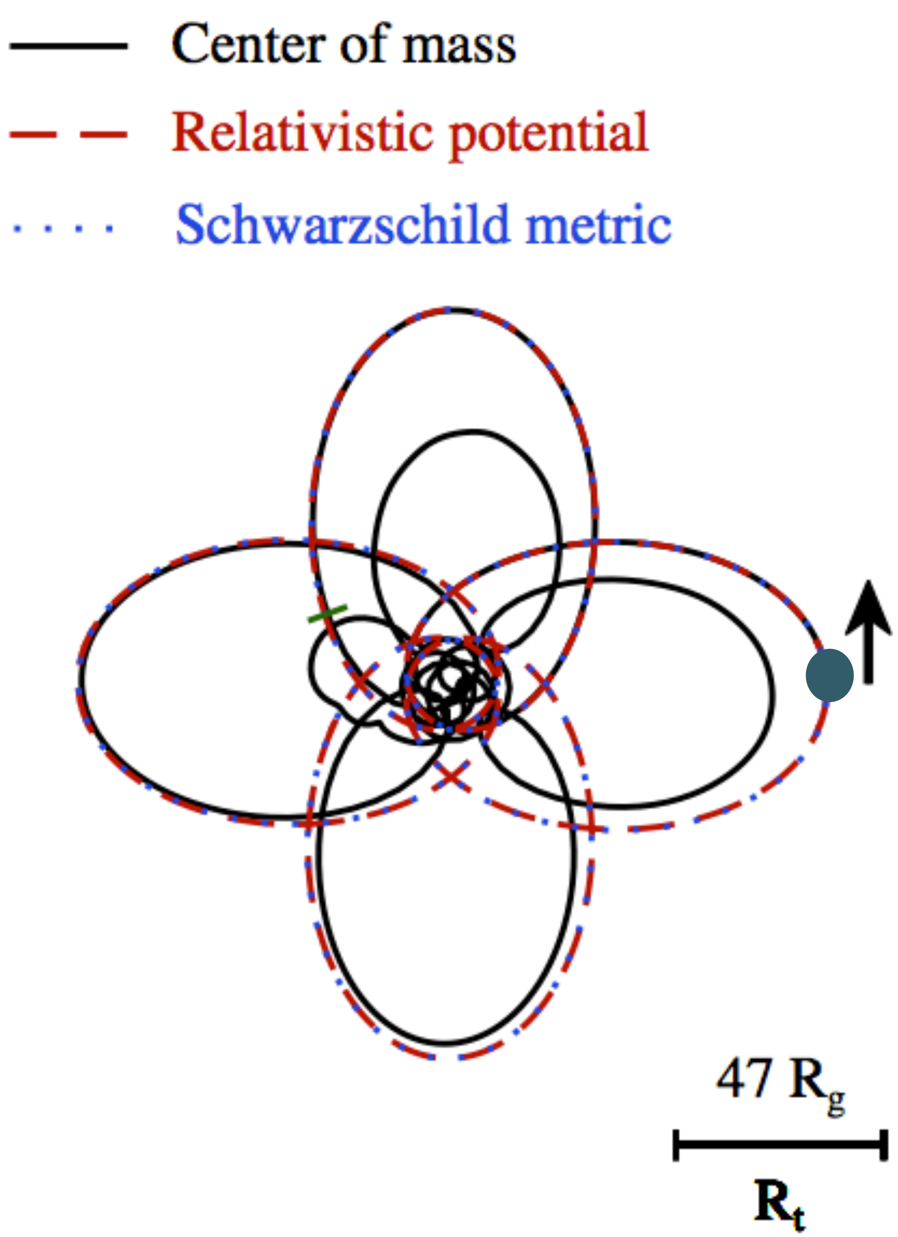

Tajeda & Rosswog 13

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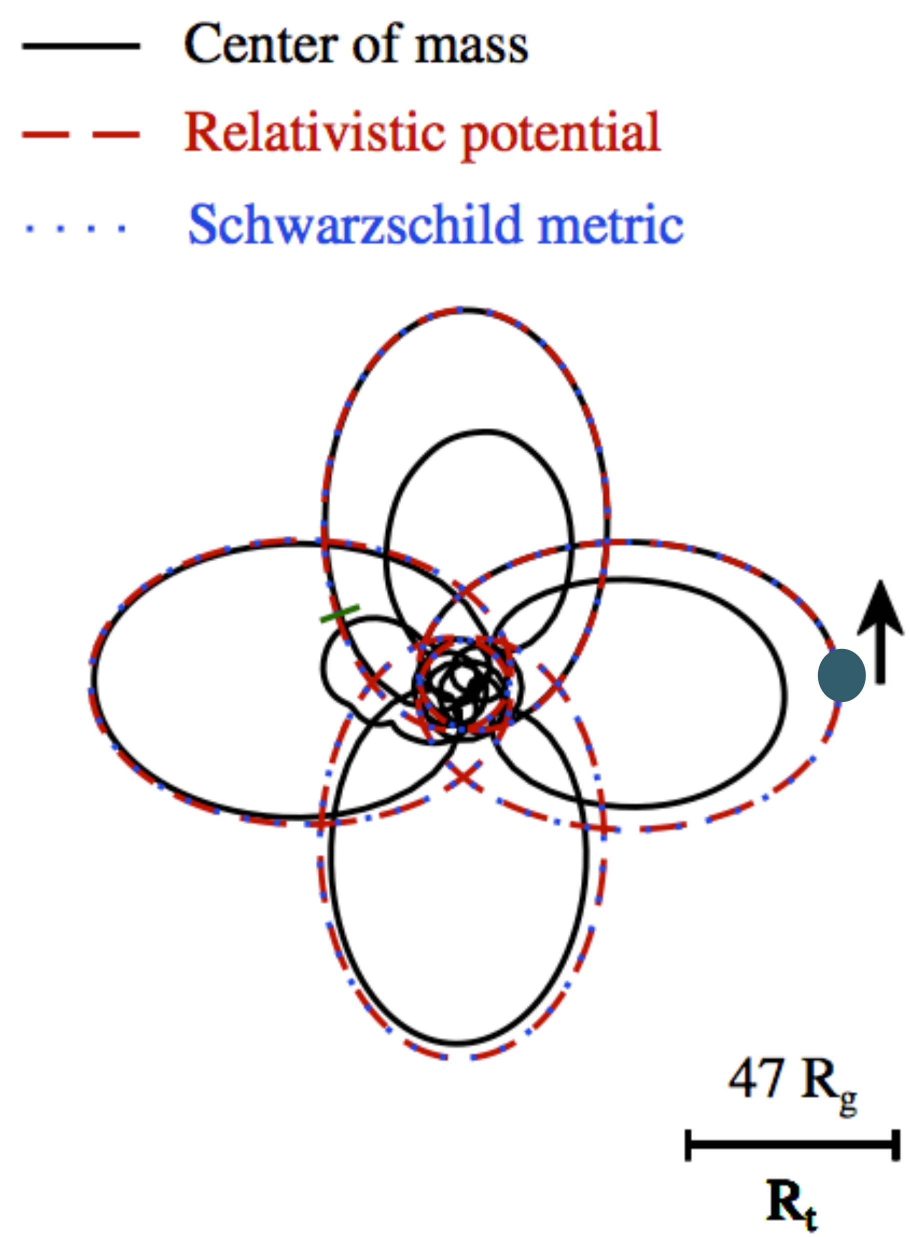
Tajeda & Rosswog 13



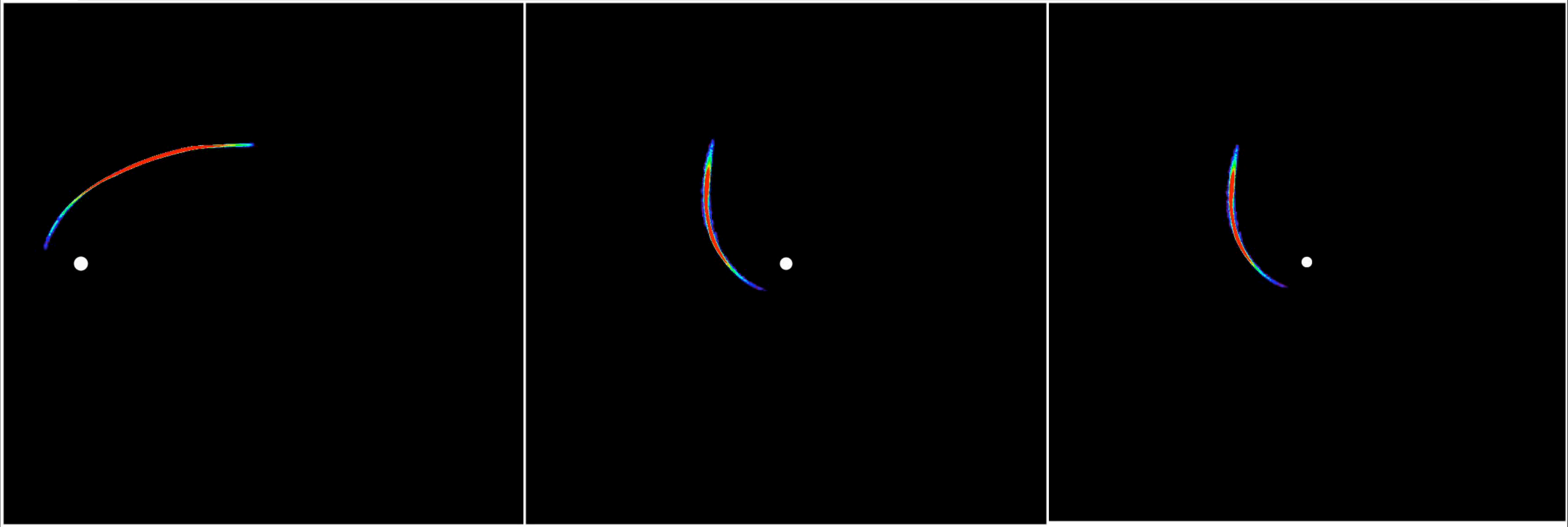
it reproduces exactly pericenter precession : simulations are as precise but less costly than with full GR code

A study of “Disc” formation

Bonnerot, EMR, Lodato & Price (2015):

- Bonnerot, EMR, Lodato & Price (2015): detailed investigation of the circularization process
    - Non-rotating black hole
    - Use Keplerian and relativistic potentia
    - **Use isothermal or adiabatic EOS**

Disc formation: e=0.8, $R_p = R_t/5 \sim 10\ R_g$



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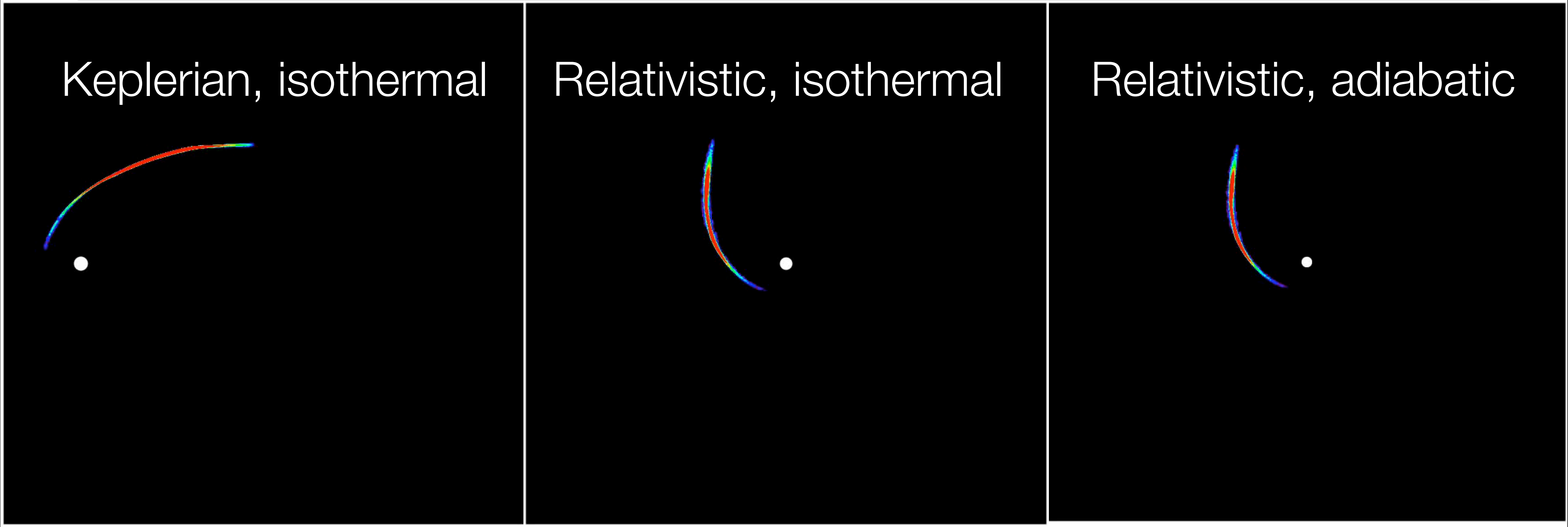

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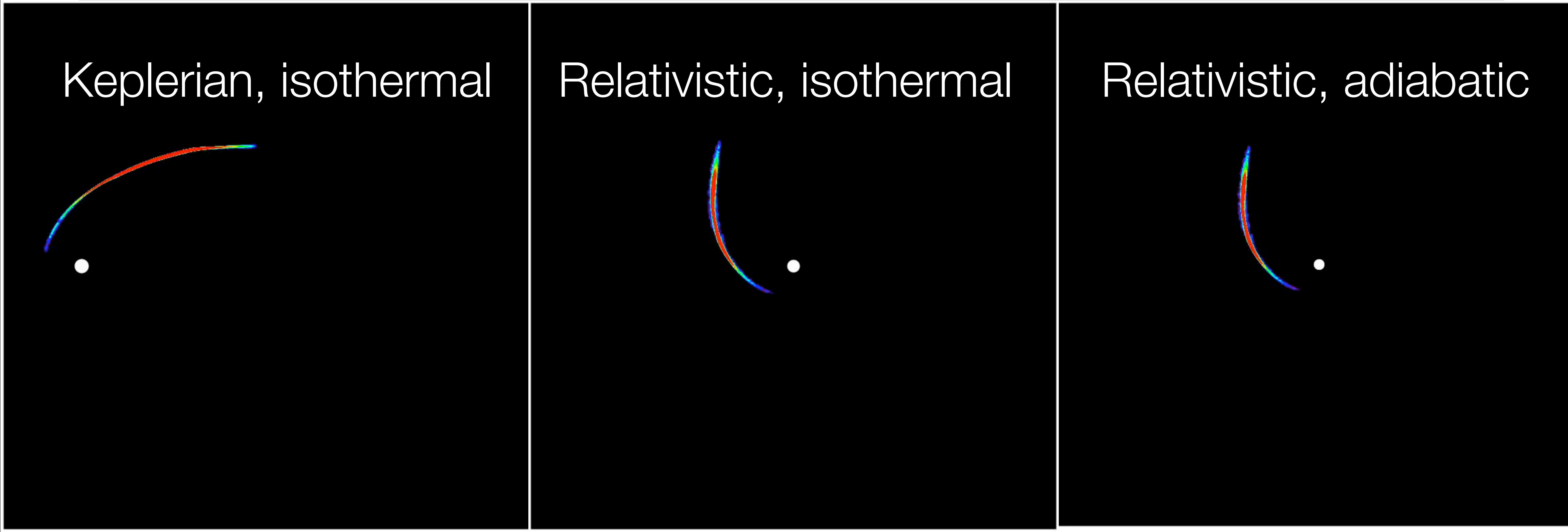


circularization: NO

circularization: YES

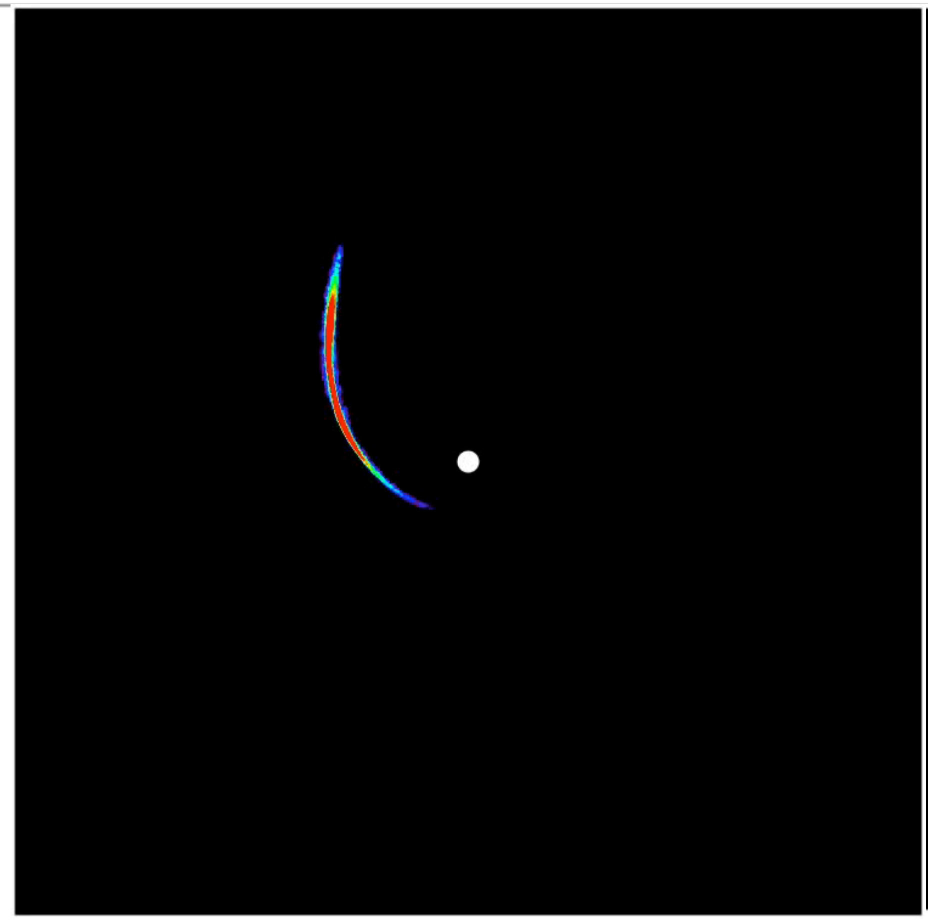
circularization YES

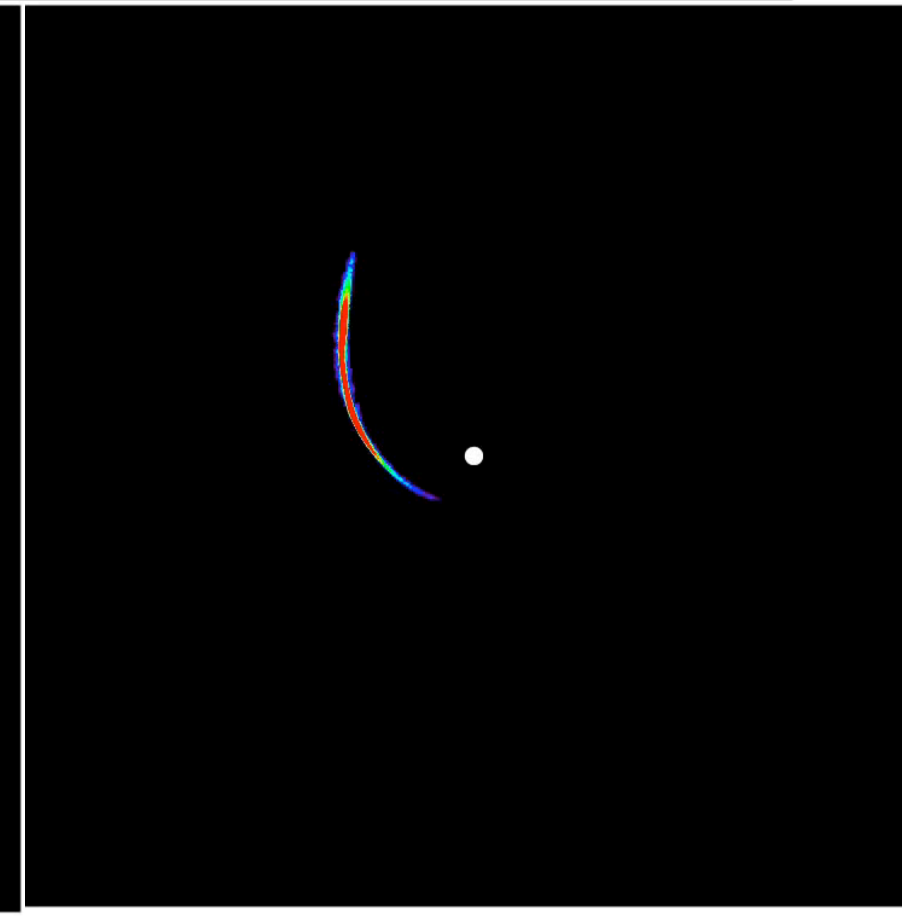
Disc formation: e=0.8, $R_p = R_t/5 \sim 10\ R_g$

circularization radius

$$R^{\rm K}_{\rm circ} = \frac{R_{\rm a}^2 v_{\rm a}^2}{G M_{\rm h}} = (1+e) R_{\rm p}, \quad (14)$$

$$R^{\rm R}_{\rm circ} = \frac{R_{\rm a}^4 v_{\rm a}^2 + (R_{\rm a}^4 v_{\rm a}^2(-12 G M_{\rm h}(R_{\rm a} - 2R_{\rm g})^2 R_{\rm g} + R_{\rm a}^4 v_{\rm a}^2))^{1/2}}{2 G M_{\rm h}(R_{\rm a} - 2R_{\rm g})^2}$$





circularization: YES

$t_{circ} \sim 5 \times P_* \sim 15$ h

thin ring @ Rc

negligible accretion

circularization YES

t_{circ} similar to is

thick torus

~20% accretion

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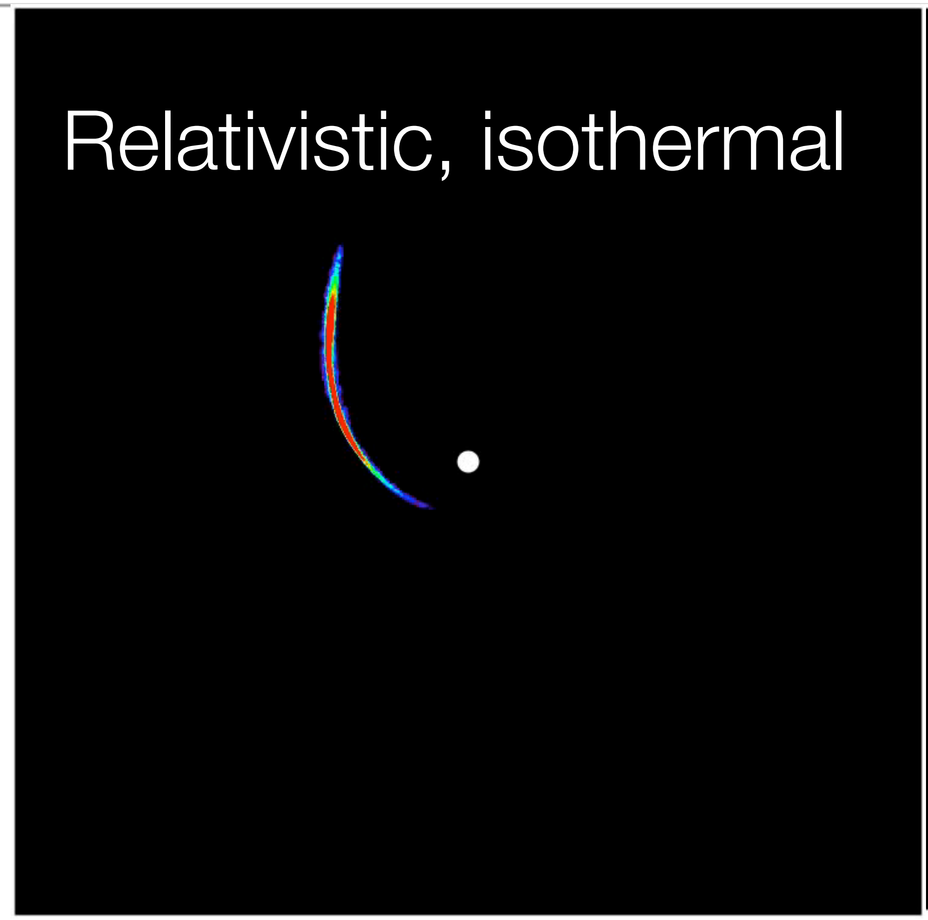

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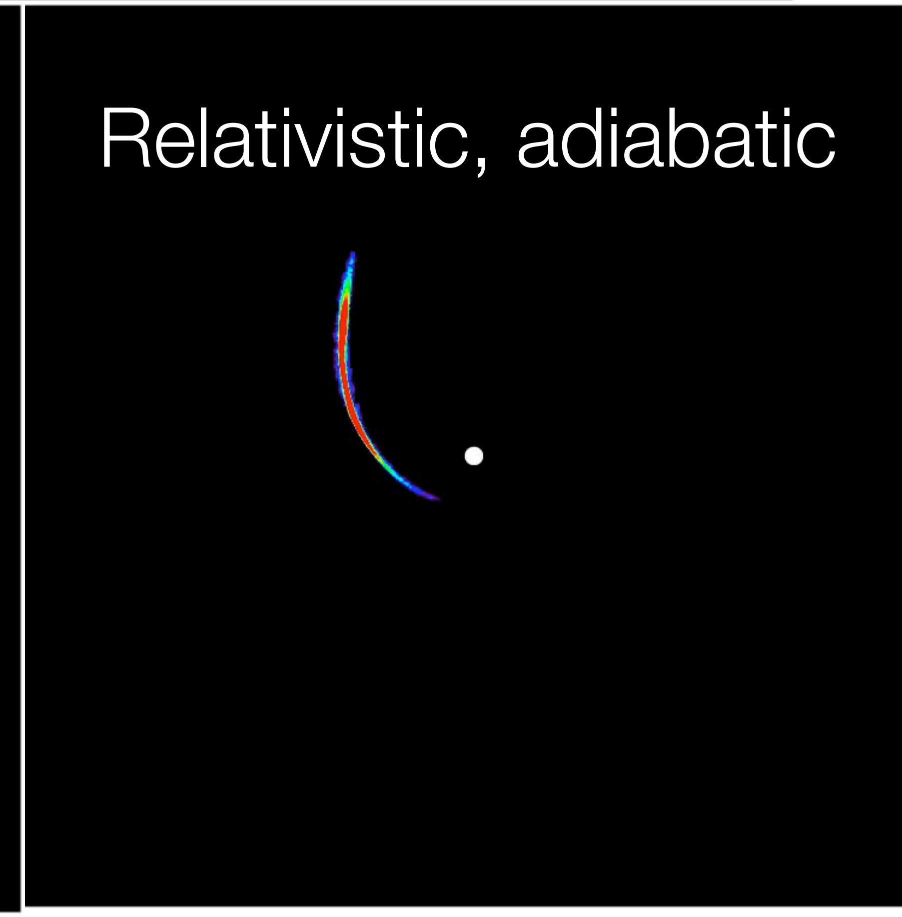

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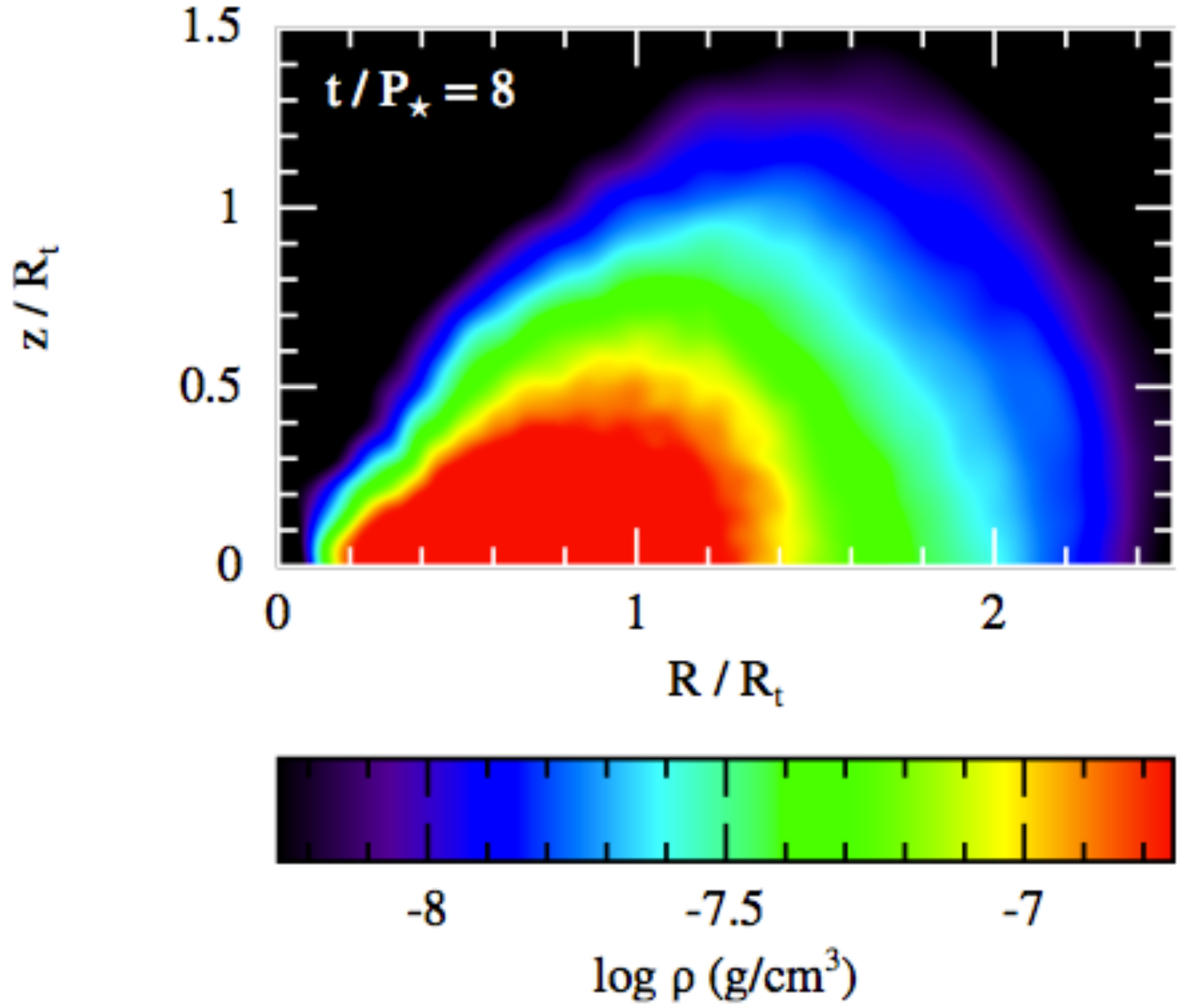
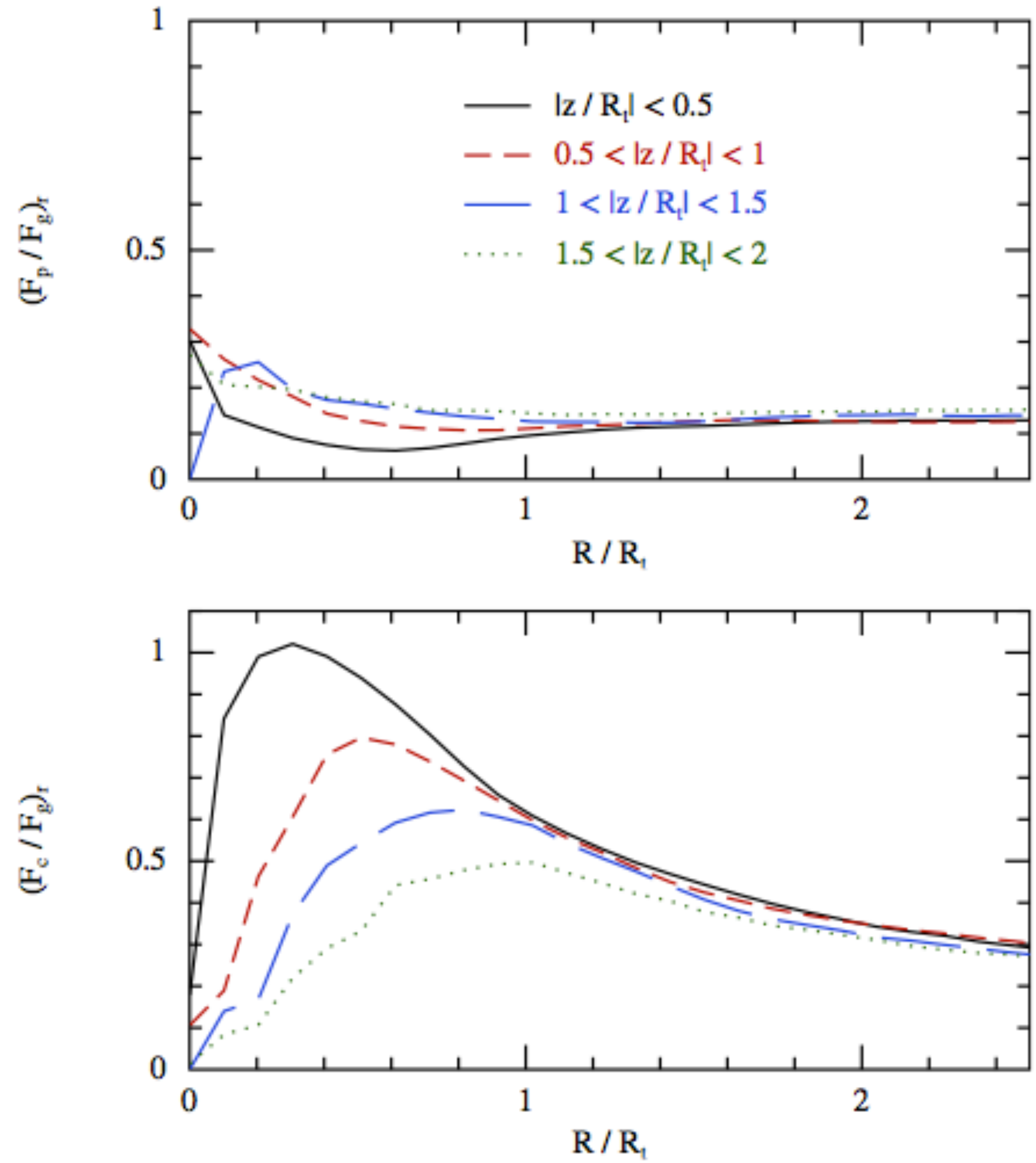
Torus Structure in the adiabatic case



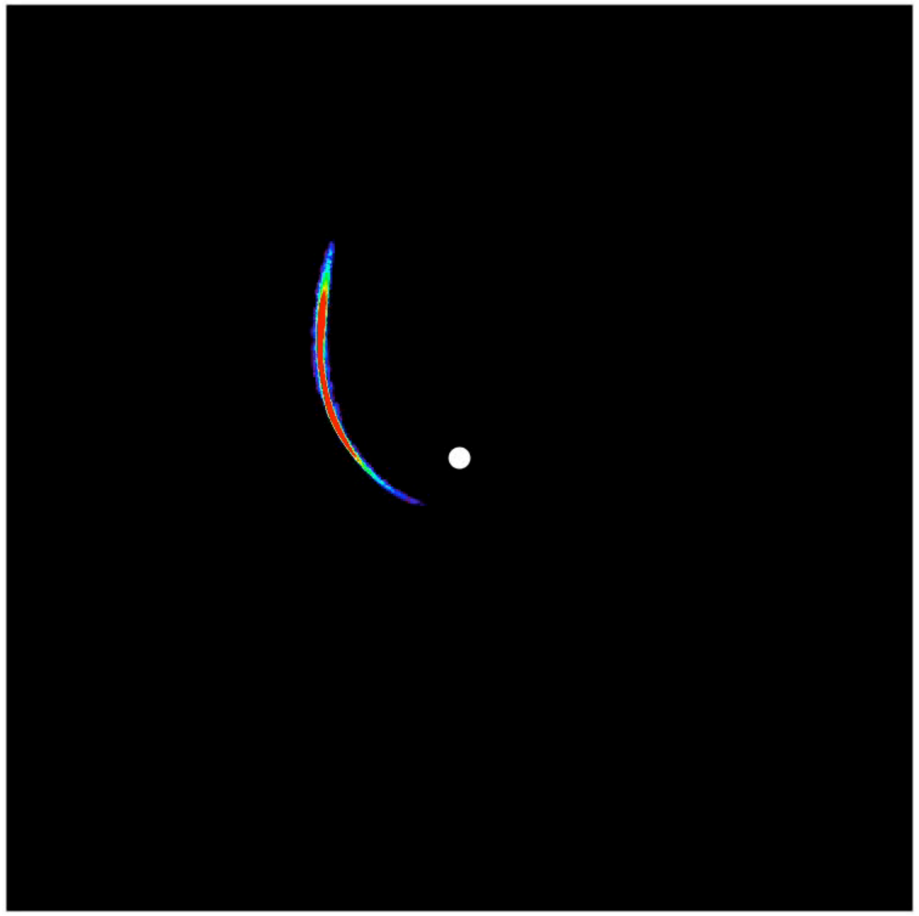


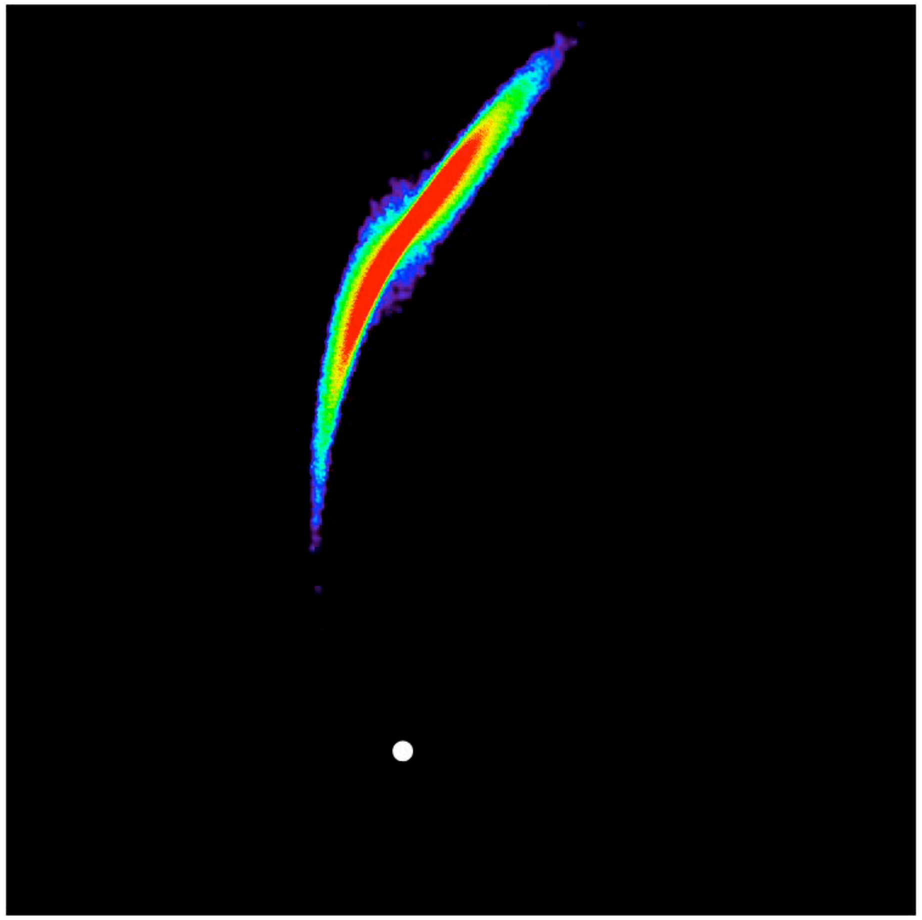
Rotationally supported,
Pressure support only at 10% level

Vary the eccentricity

same: ios (isothermal) and $R_p = R_t/5 \sim 10\ R_g$

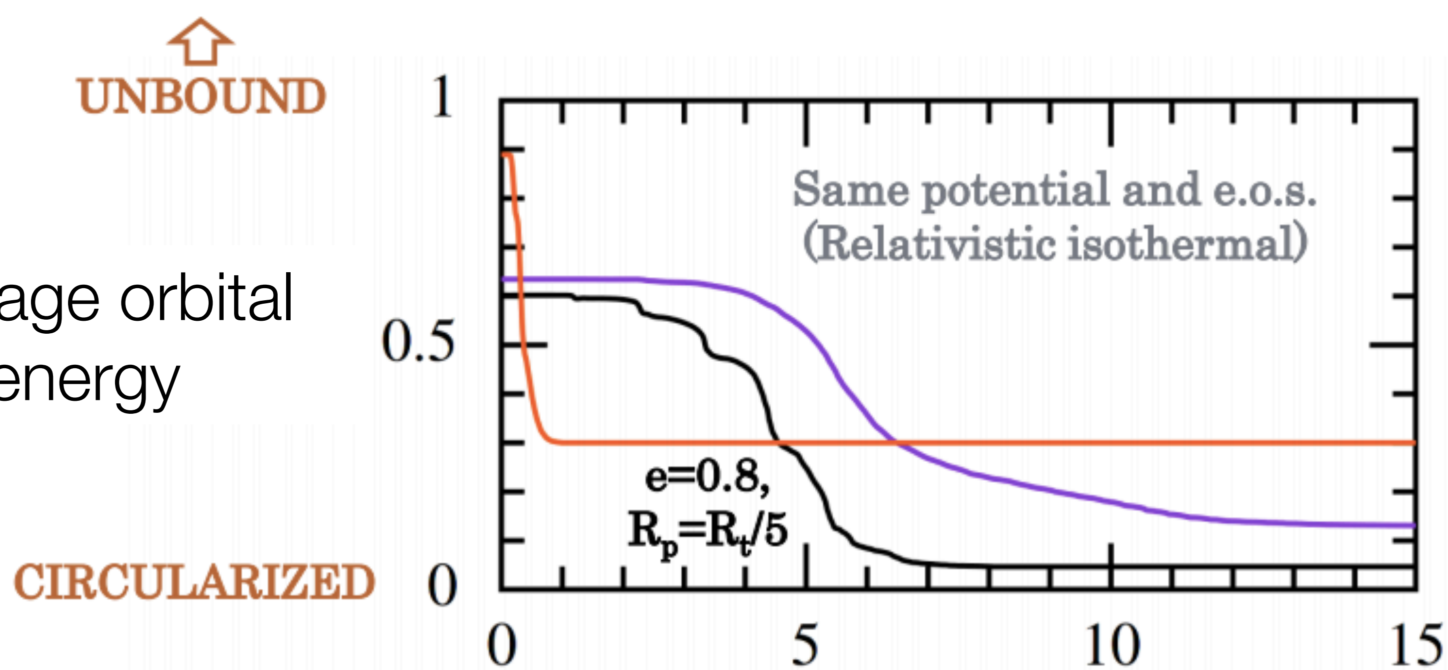
90 deg precession





80 deg precession

average orbital energy



$P_* \sim 3$ h, e=0.8

$P_* \sim 22$ h, e=0.95

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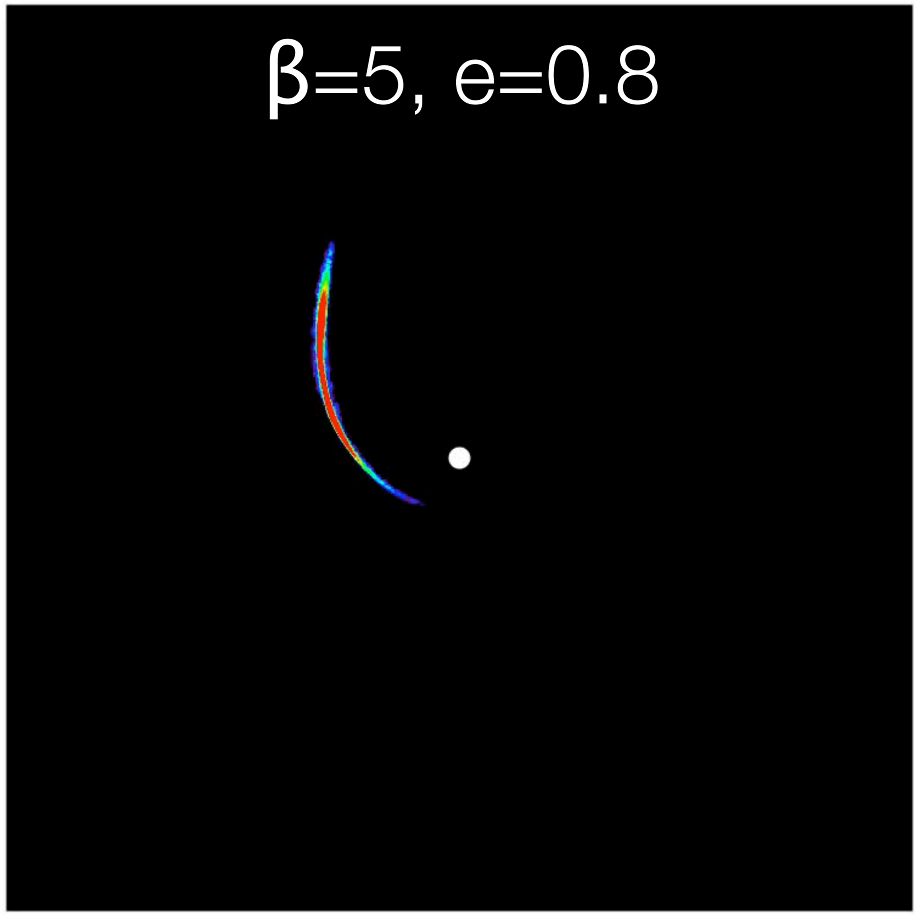

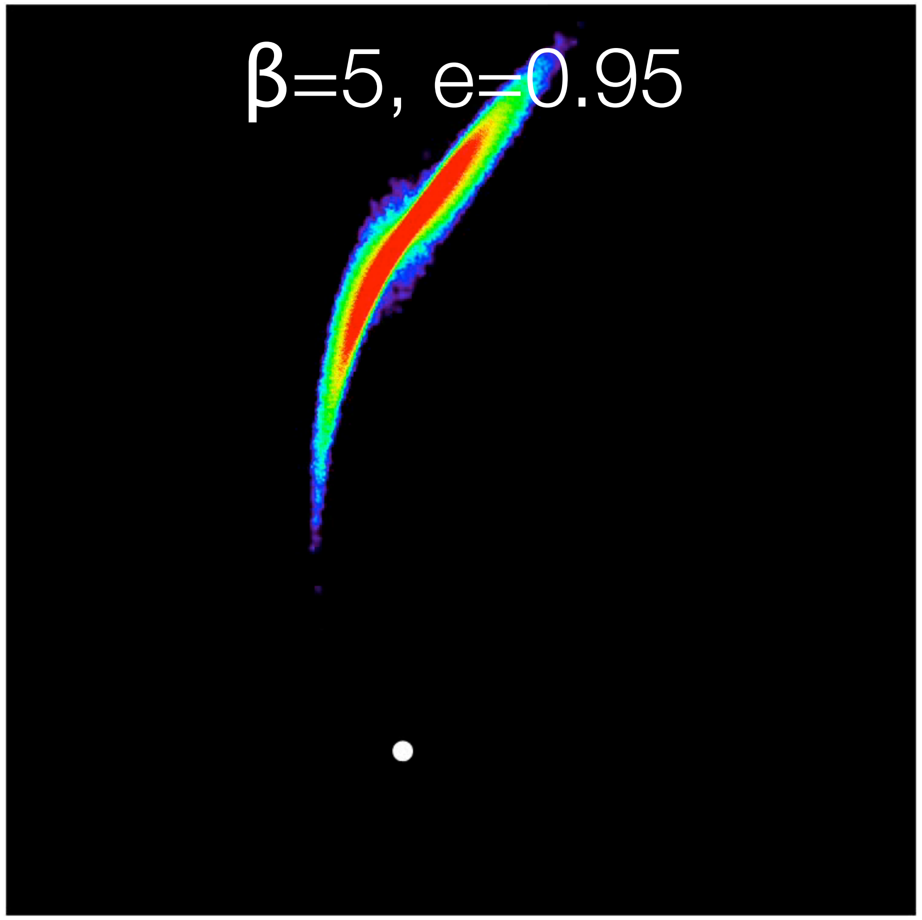

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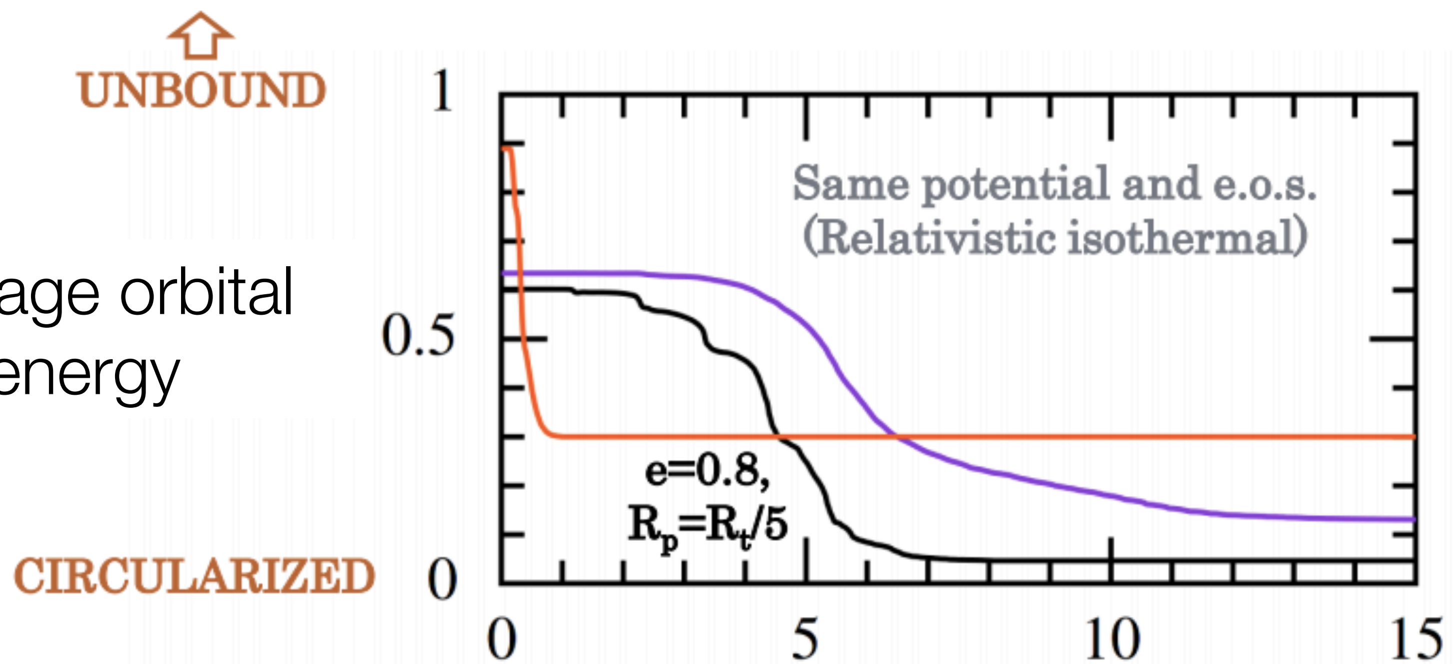

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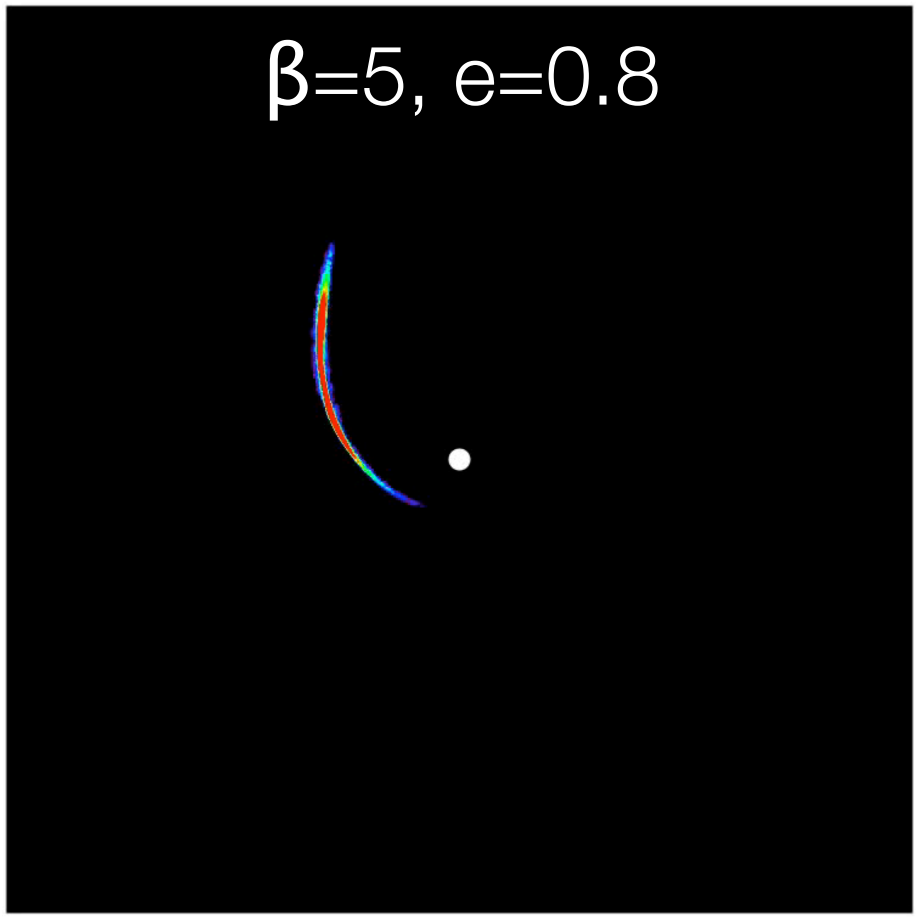
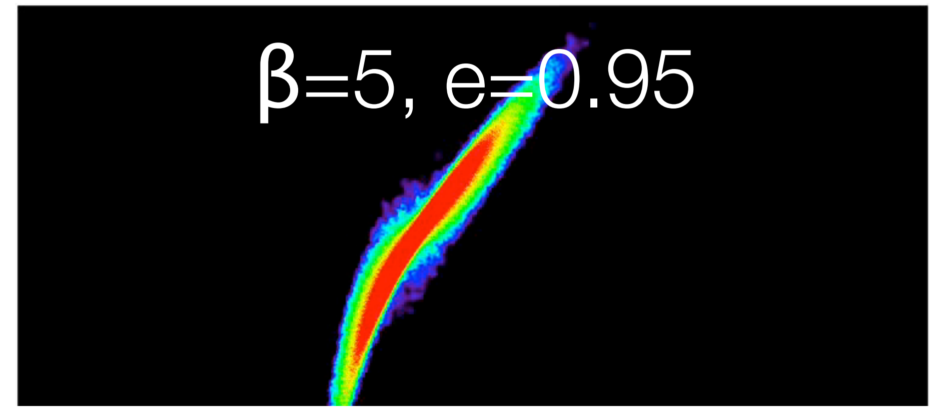
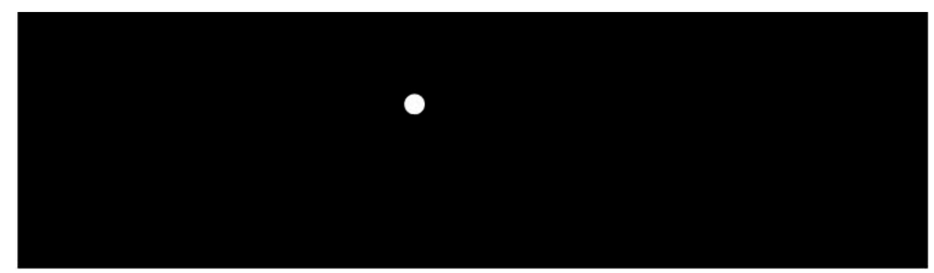




true for any e >0.9, also parabolic case!



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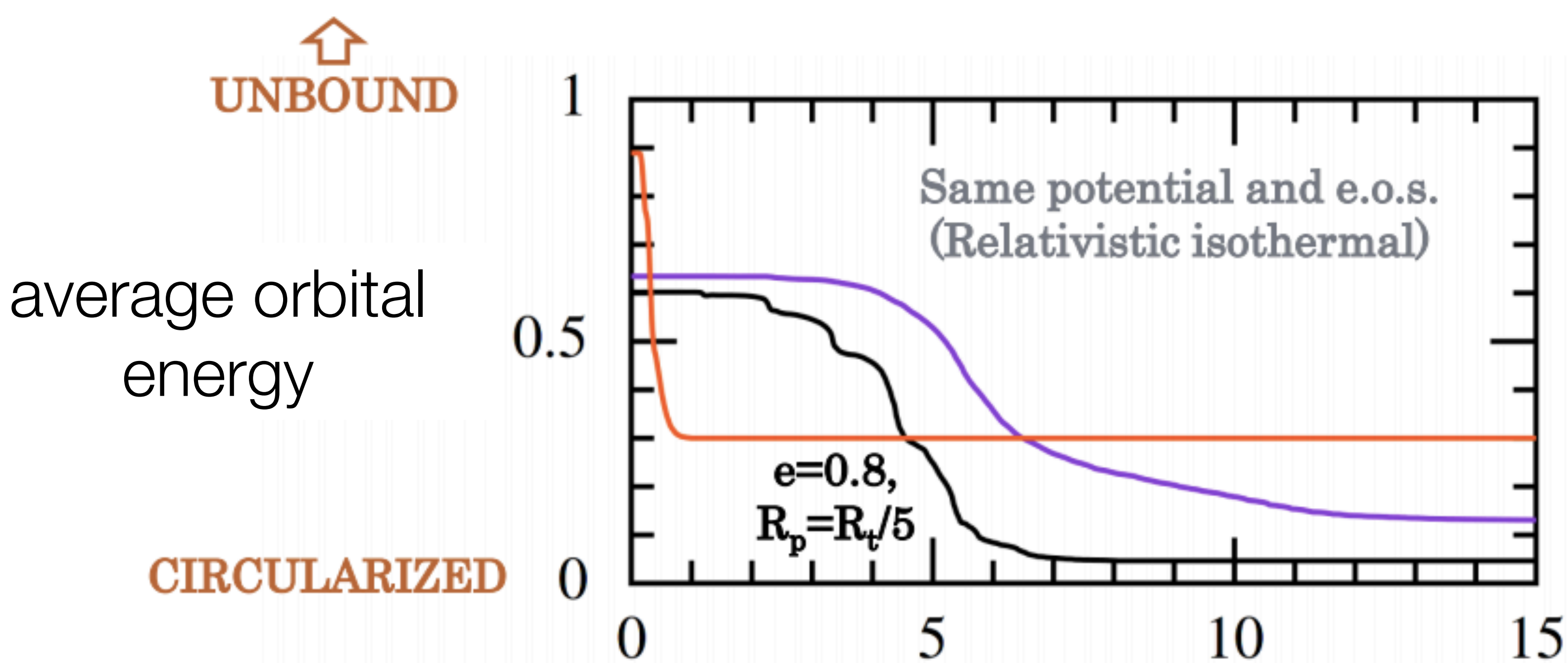

$P_* \sim 3$ h, e=0.8

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Viscous accretion : **isothermal** case

Thin ring, t_{visc} @ circularization radius $R_c \sim (1+e)\, R_p \sim (1-e^2)\, a$

$$\frac{t_{\rm visc}}{t_{\rm circ}} = 700 \left(\frac{n_{\rm circ}}{5}\right)^{-1} \left(\frac{\alpha}{0.1}\right)^{-1} \left(\frac{H/R}{10^{-2}}\right)^{-2} \left(\frac{1-e^2}{0.36}\right)^{3/2}$$

=> the accretion is not set by fall back

$$\dot{M} \simeq M_*/t_{\rm visc} \approx 40 \dot{M}_{\rm Edd}$$

Towards a parabolic orbit

$e > 0.9$, $n_{circ} = t_{circ}/P_* = 1$ and for $e > 0.9992$ $t_{visc} = t_{circ}$

=> in the parabolic case you should expect fall back to dictate the accretion rate as $t^{-5/3}$

Viscous accretion : **adiabatic** case

Thick torus, that extends out to semi-major axis ``a”: t_{visc} @ a

$$\frac{t_{\rm visc}}{t_{\rm circ}} = 0.3 \left(\frac{n_{\rm circ}}{5}\right)^{-1} \left(\frac{\alpha}{0.1}\right)^{-1} \left(\frac{H/R}{1}\right)^{-2}$$

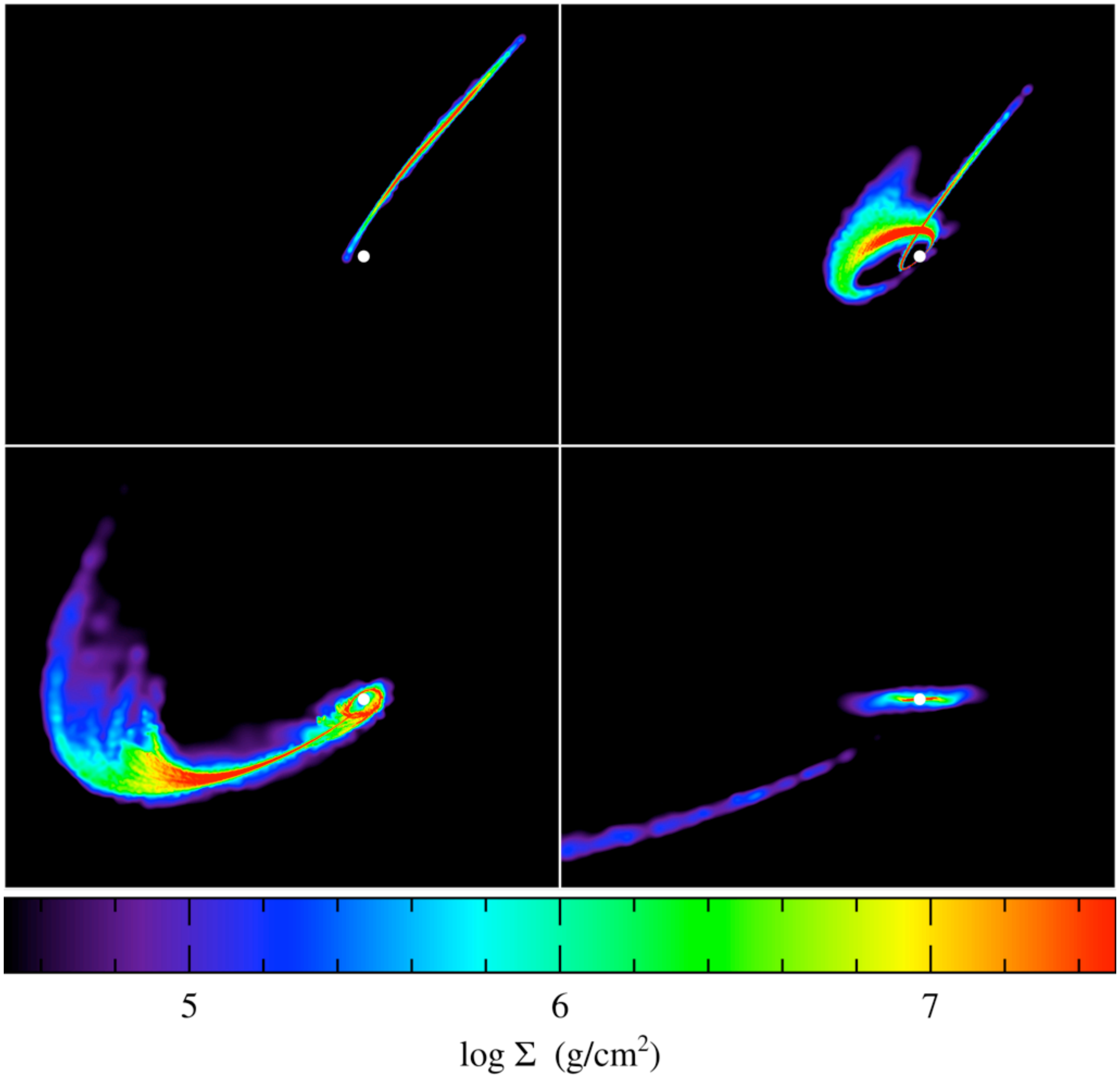
=> marginal: viscous accretion may drain torus while circ.
depending on H/R and viscous properties

Towards a parabolic orbit

the ratio is independent of ``e” (and a)

=> in the parabolic case MAYBE $t^{-5/3}$

Spinning Black holes, inclined orbits



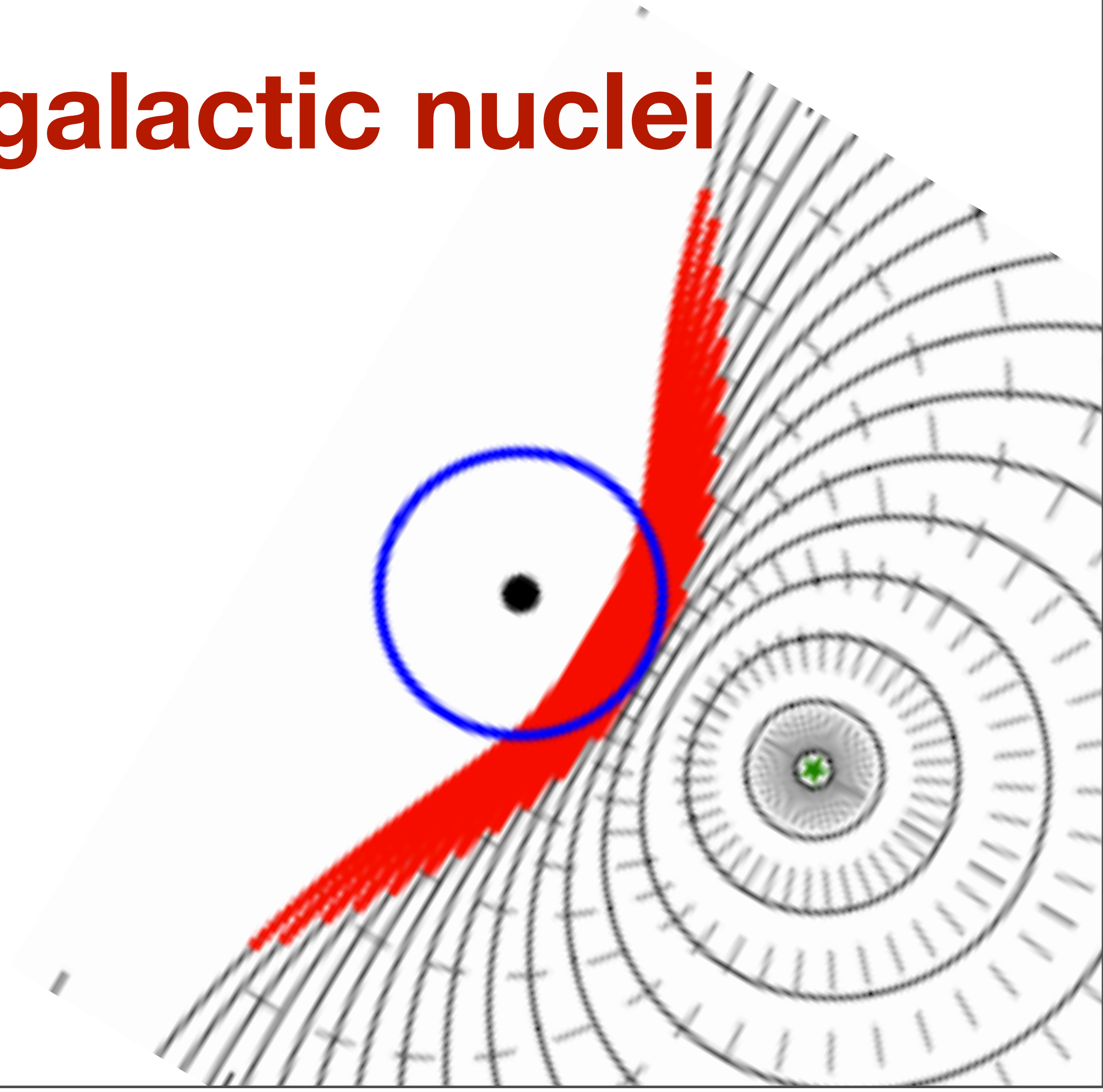
crossing **happens** and closer to the black hole

e=0.95
inclination of 45 deg
$R_p = R_t /5$
a = 1
isothermal

Bonnerot, EMR in prep

Rimoldi, EMR, Piran & Portegies Zwart (2015)

Supernova explosion in galactic nuclei



Supernova explosion in galactic nuclei

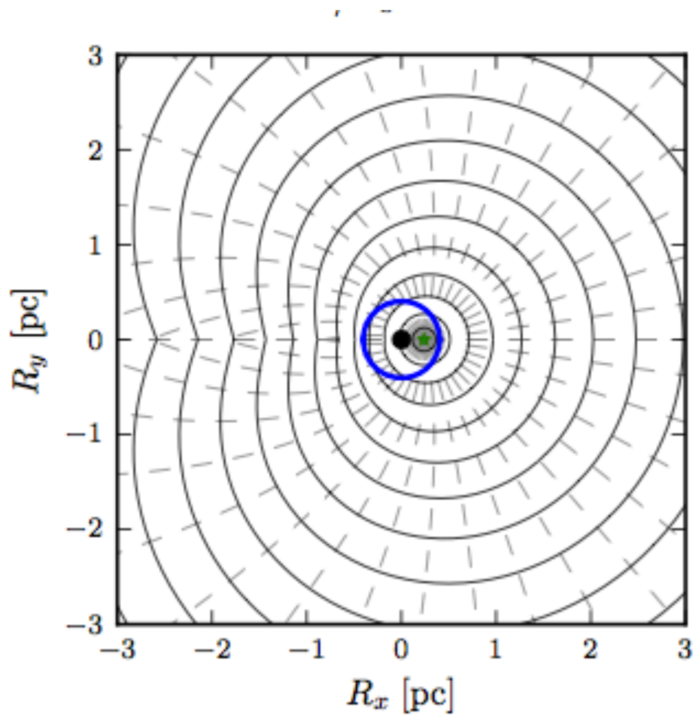
- With have heard that stellar nuclear clusters and GC have **massive stars** (many talks earlier in the week)
- Galactic nuclei have **Supermassive Black Holes** (yep, we know...)
- Quiescent Supermassive Black Holes have **radiative inefficient accretion disc**, fed by winds from massive stars

How do supernova remnants evolve in such hostile environment? Do they ``live” less?

Numerical method to solve shock in arbitrary density gradients

Analytical solutions only for power-law profiles (e.g. Sadov-Taylor). To investigate more complex environments => numerics

- We built a numerical method based on following flow lines along the shock front



- Kompaneets approximation:
  - Strong shock
  - Flow line velocity 90 deg to shock front
  - Uniform post shock pressure
  - Adiabatic evolution until Temperature < 10^6 K (~300 km/s)

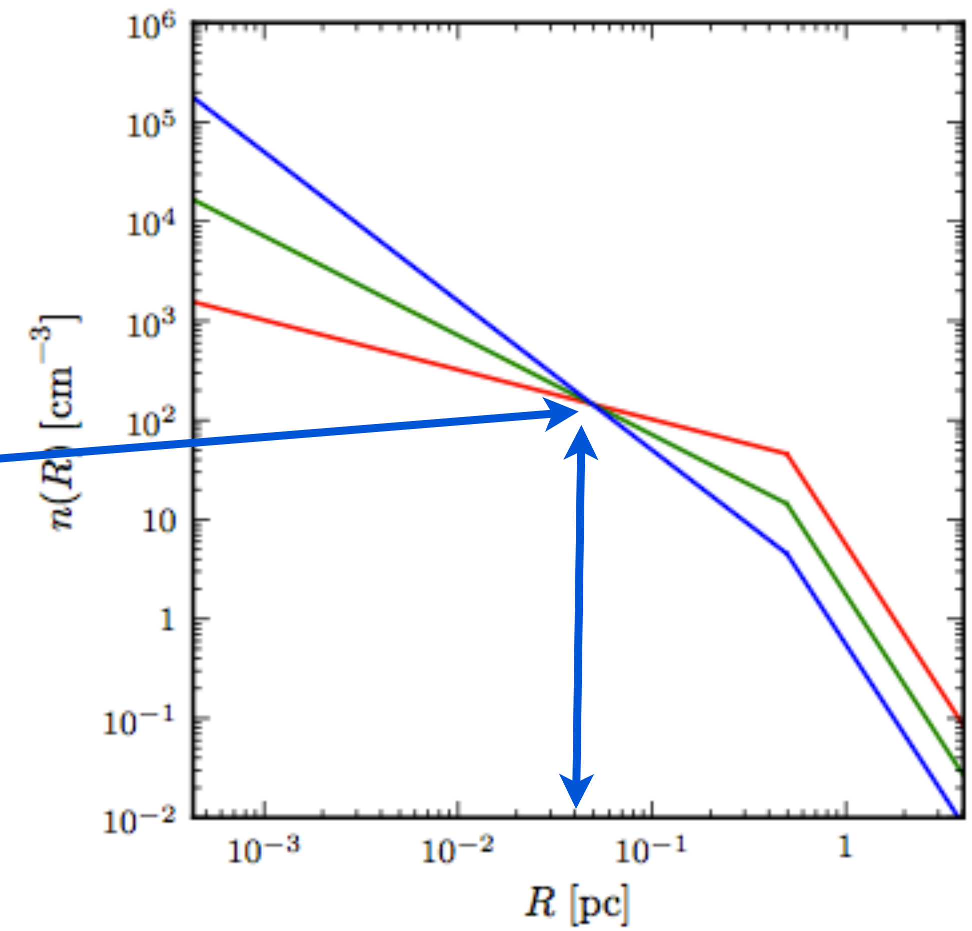
Galactic Center gas environment

- Shape: Radiative inefficient flow

e.g. Quataert 04 Cuadra et al. 06

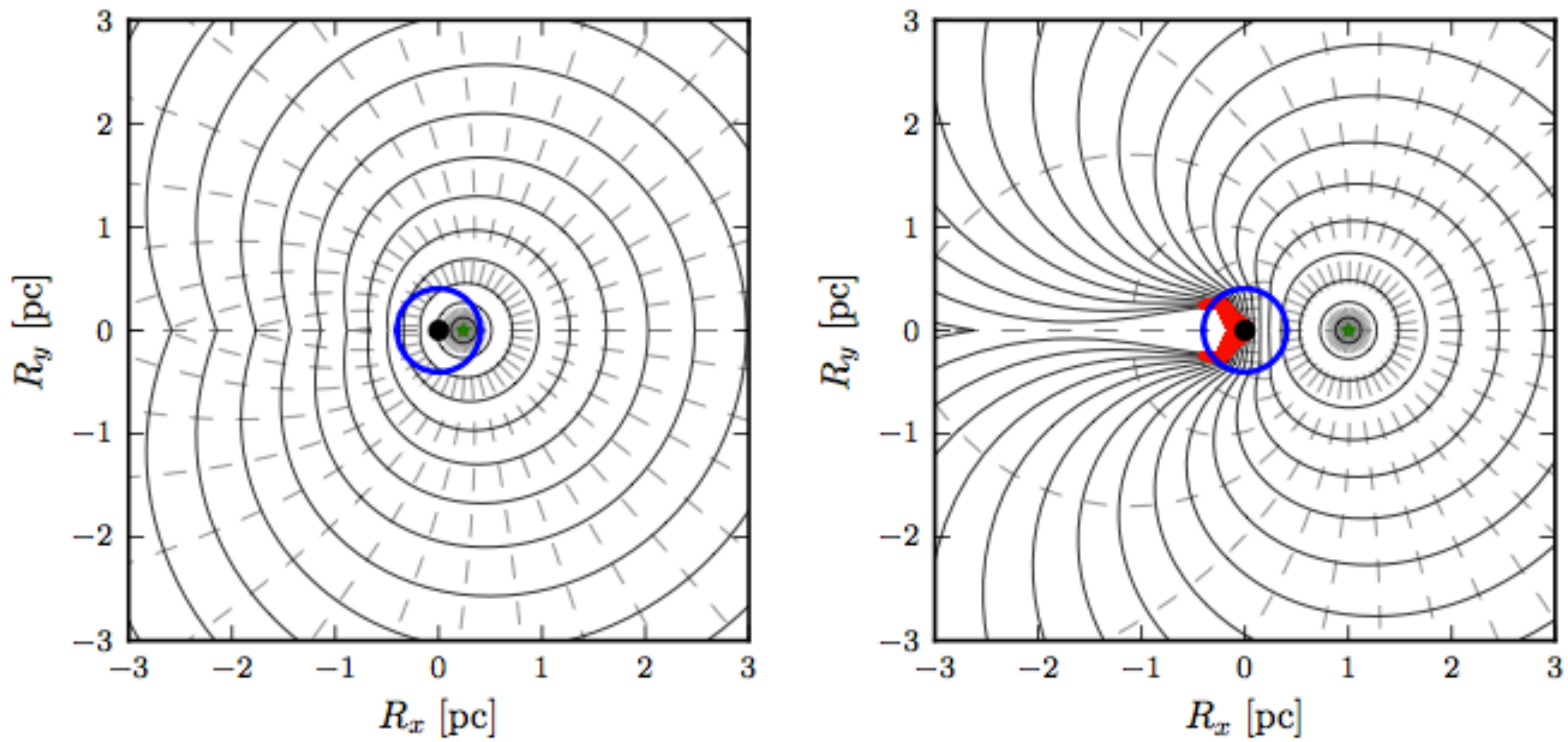
- Normalisation: Chandra observation @ 0.04 pc n~130 cm^{-3}

Baganoff et al. 03



Galactic Center

- For GC densities, deceleration and shearing should be never too severe to shorten the life of a SN remant. => Remnants should be indeed visible in X-rays for a few 10^4 yr



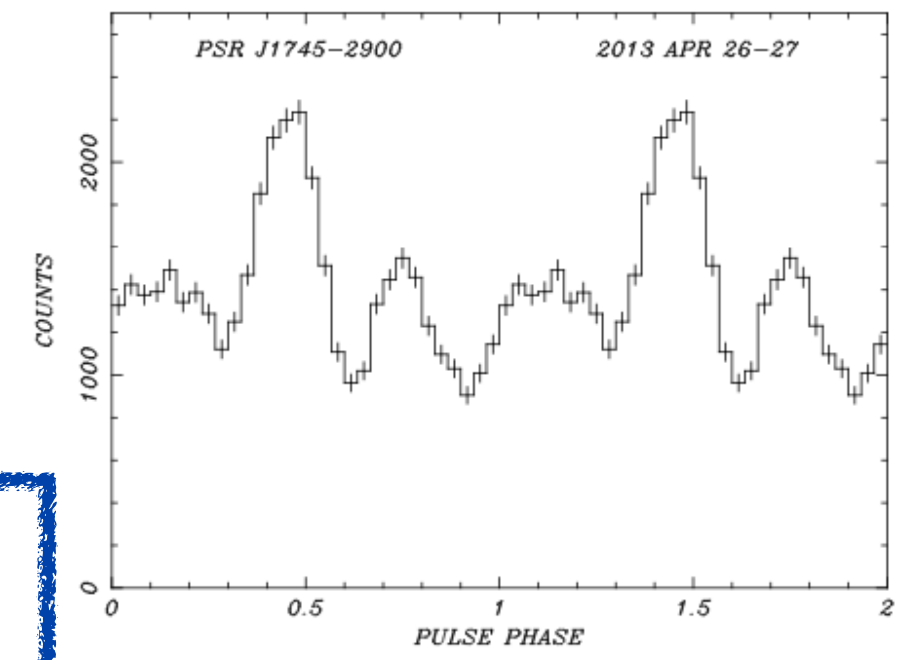
Magnetar in Galactic Center: where is the SNR ?

Magnetar SGR J1745-2900 discovered at ~1 pc from SgA*

Kaya Mori et al (2013) with NuSTAR

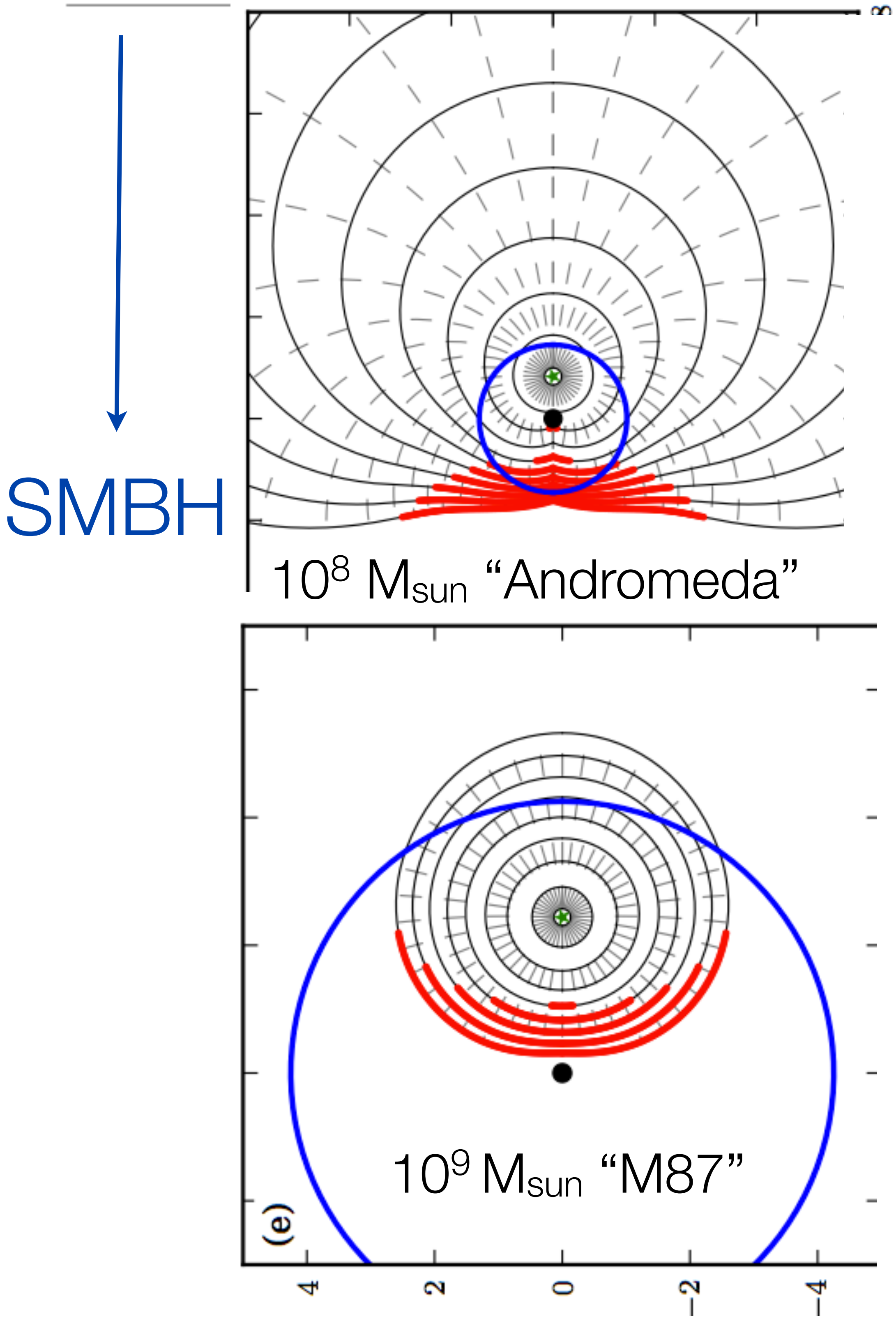
Its age is $P/2\dot{P} \approx 9 \times 10^3 yr$

but no X-ray remnant observed !!!

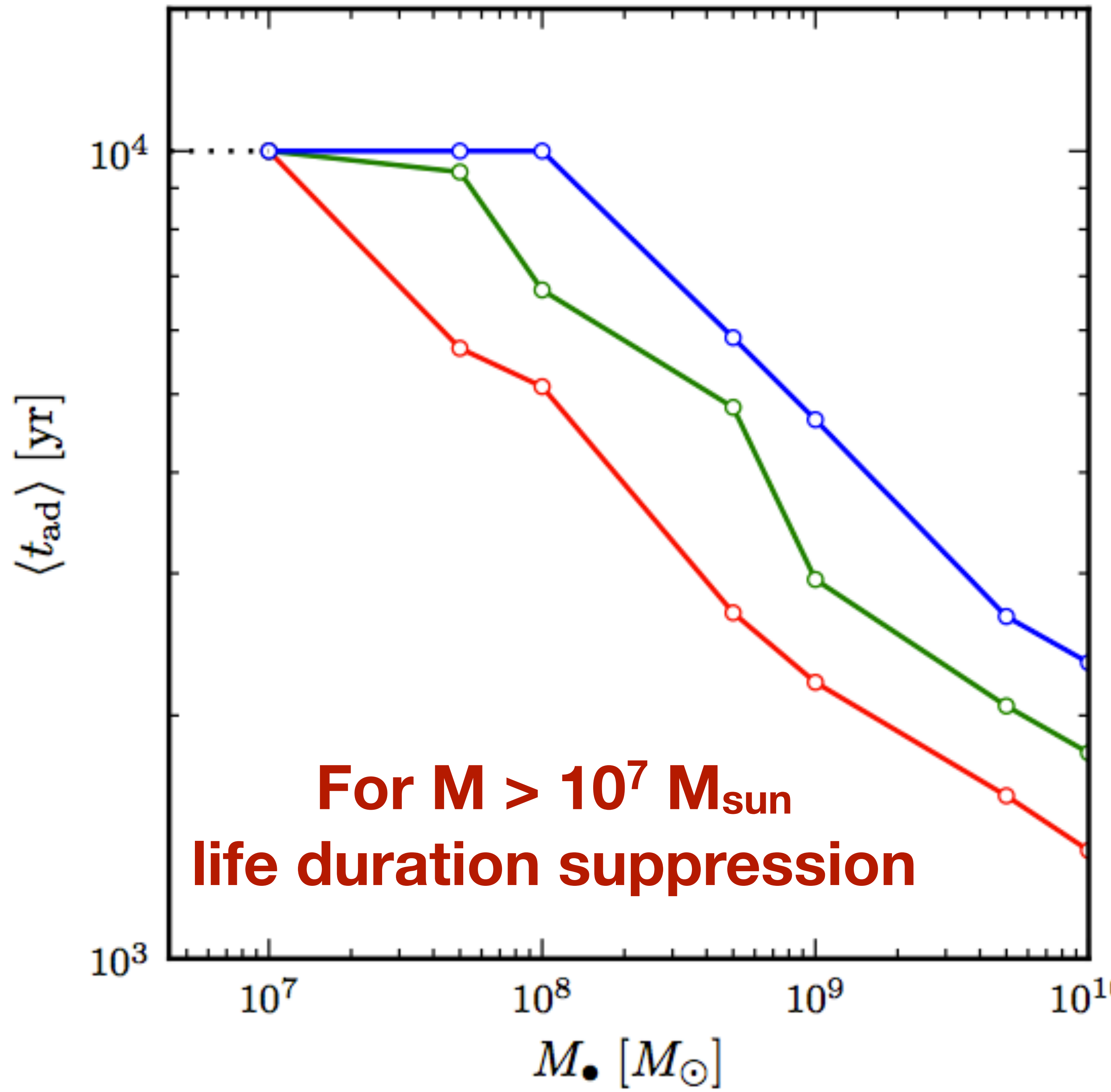


- Is the Magnetar much older?
- Are supernovae from magnetar different, slower ?

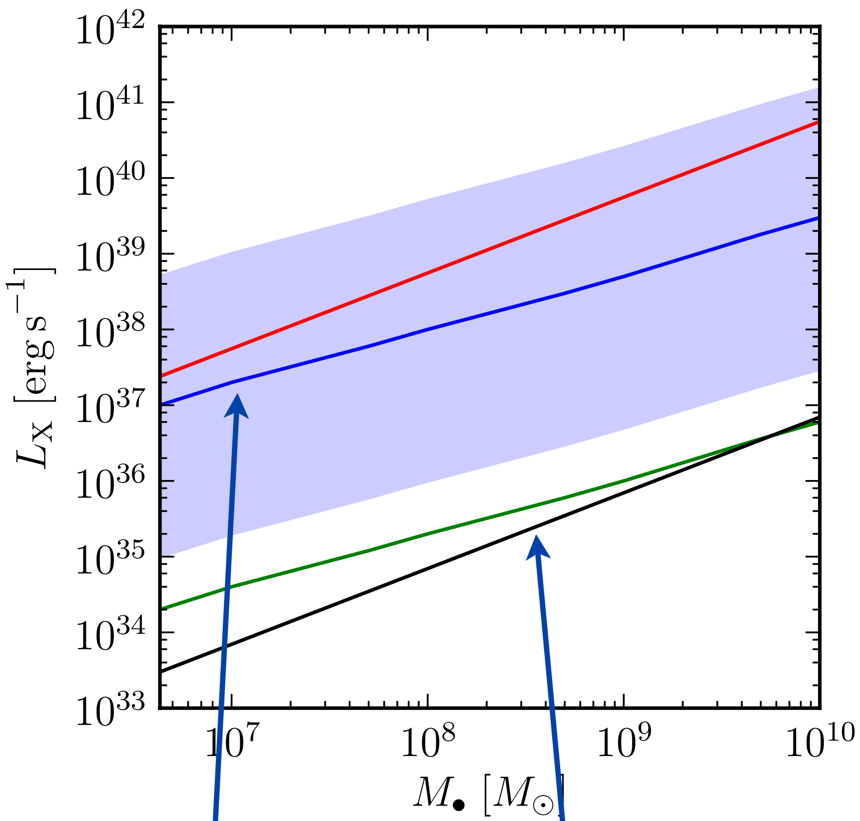
X-ray Lifetime in other nuclei



different lines = different gas slope

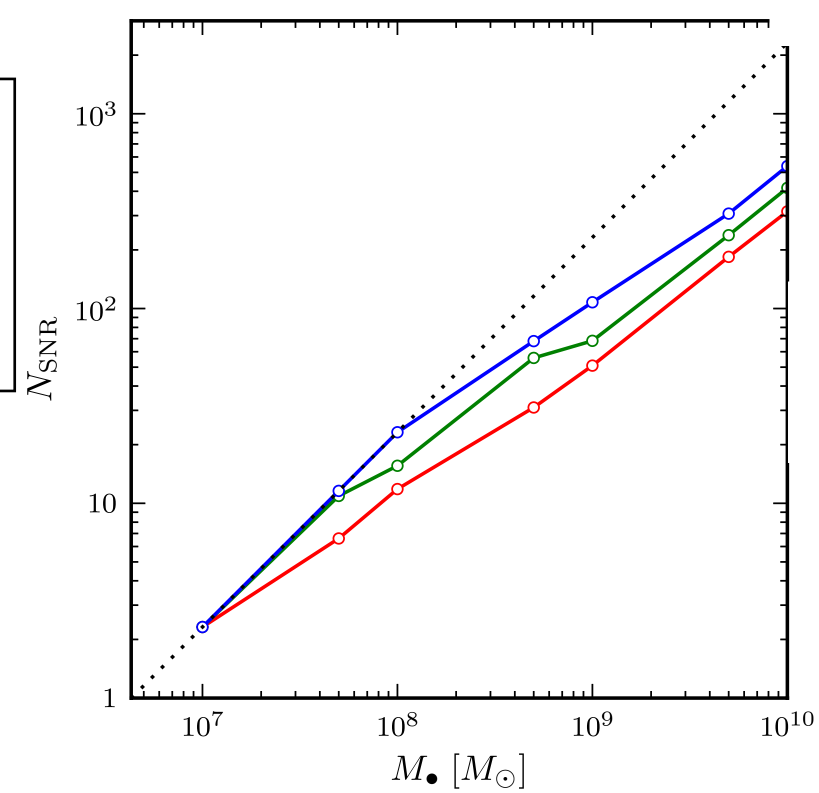


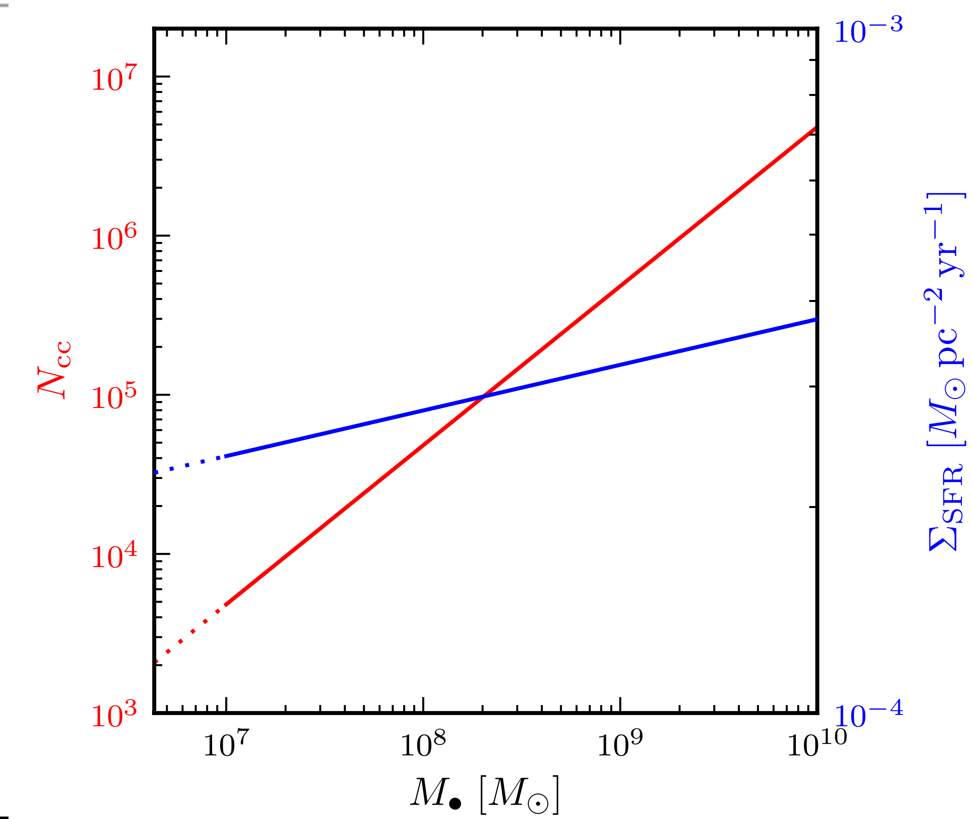
Observation Implications



Total X-ray luminosity expected: higher than that from accretion disc

Adiabatic remnants





$$N_{\rm SNR} = 4\pi \int_{R_{\rm sh}}^{R_{\rm SOI}} \frac{n_{\rm cc}(R)\, t_{\rm ad}(R)}{\langle t_*(M>8)\rangle} R^2\, {\rm d}R,$$

back up slides

Adiabatic or isothermal ?

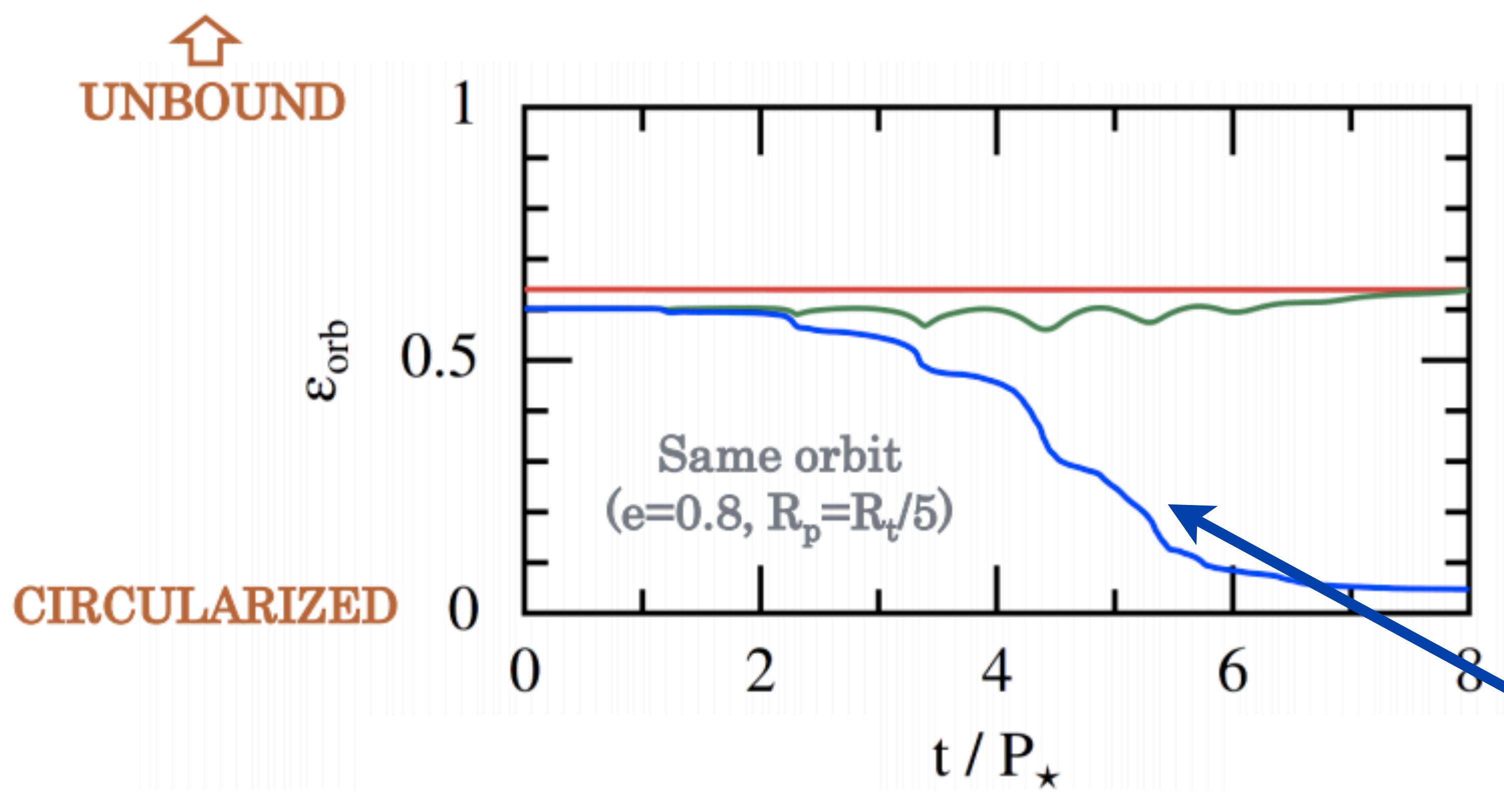
Isothermal if $t_{\rm diff} < t_{\rm circ}$

$$\rho_{\rm sh} < 8\times10^{-7}\,{\rm g\,cm^{-3}}\left(\frac{\rm n_{circ}}{5}\right)\left(\frac{\rm H_{sh}}{\rm R_\star}\right)^{-2}\left(\frac{\rm a_\star}{100\,\rm R_\odot}\right)^{3/2}$$

Shocks that happens close to the SMBH do not satisfied this requirement

Circularization timescale

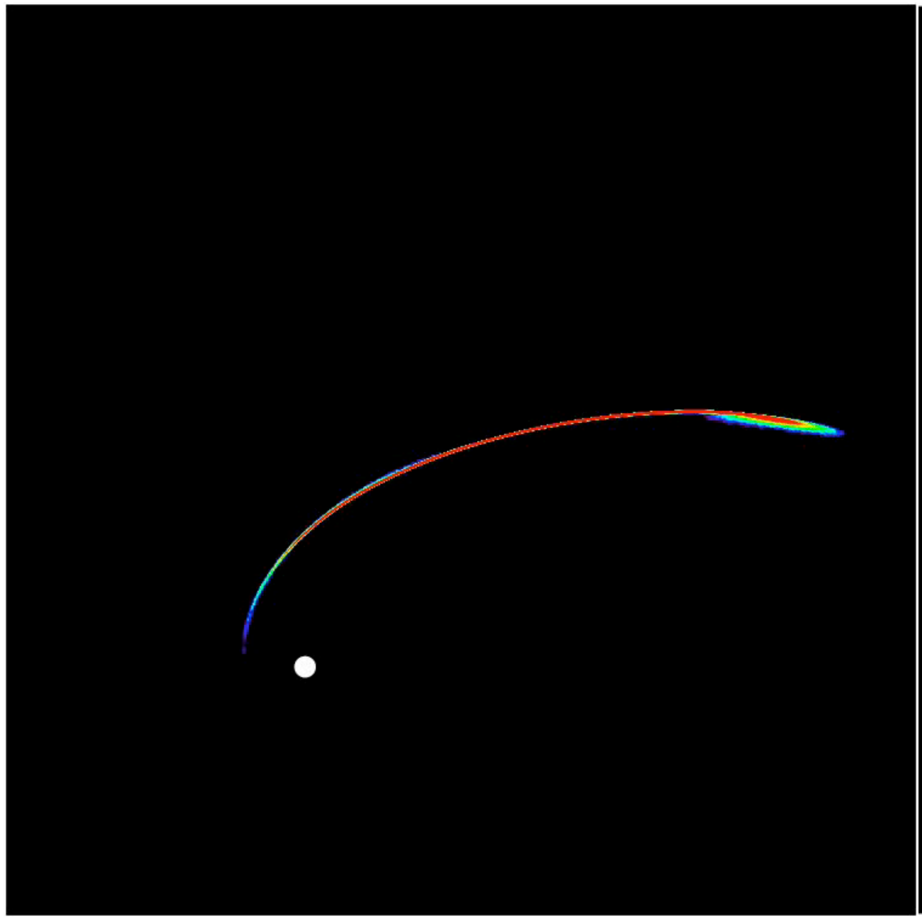
P* = 2.8 h



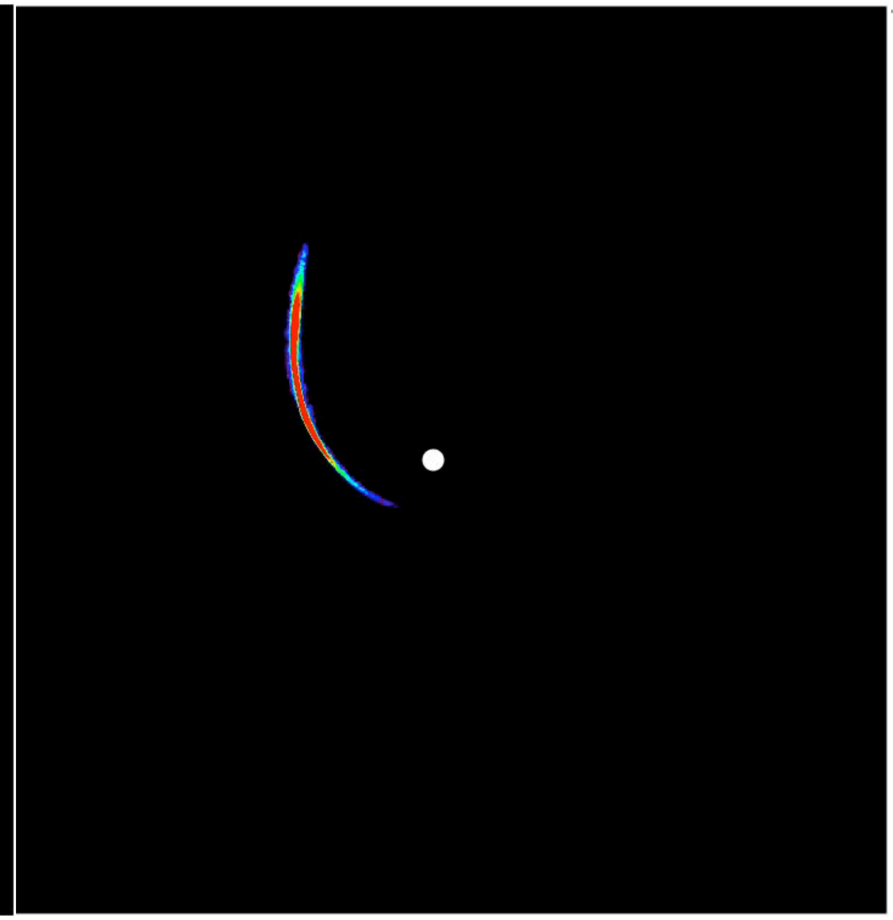
isothermal case

Vary beta

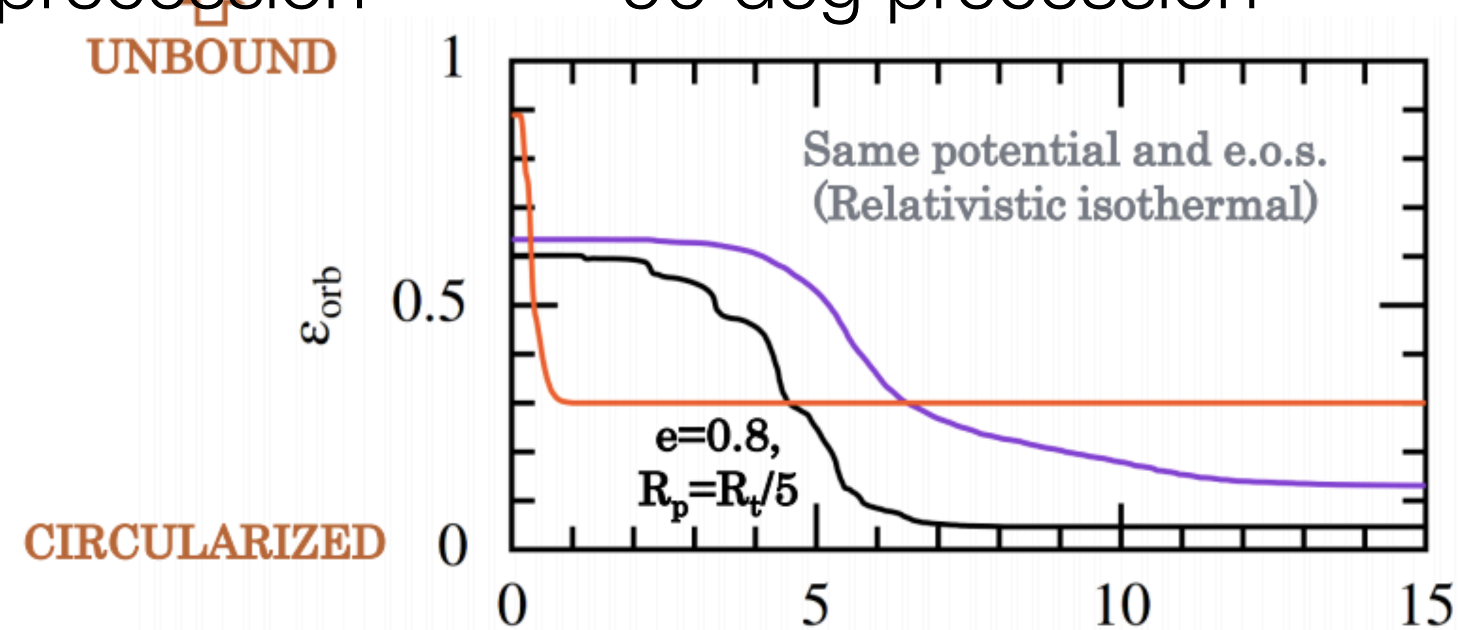
same: ios (isothermal) and e=0.8



13 deg precession



90 deg precession



$P_\star = 2.8$ h

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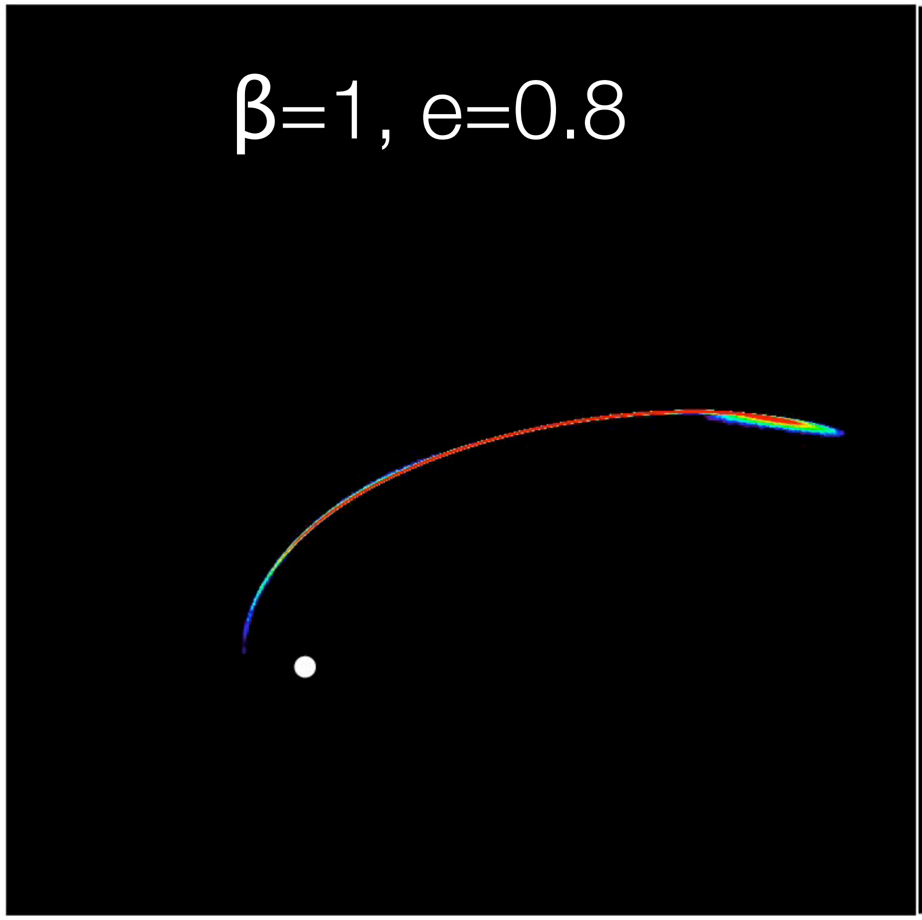

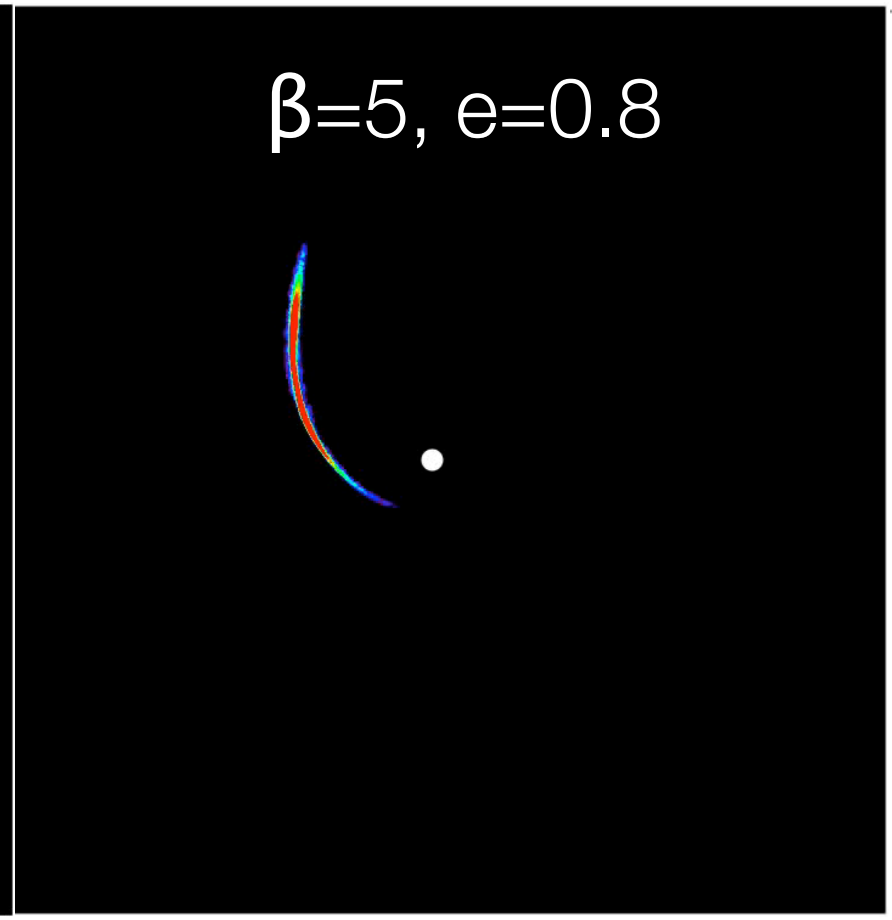

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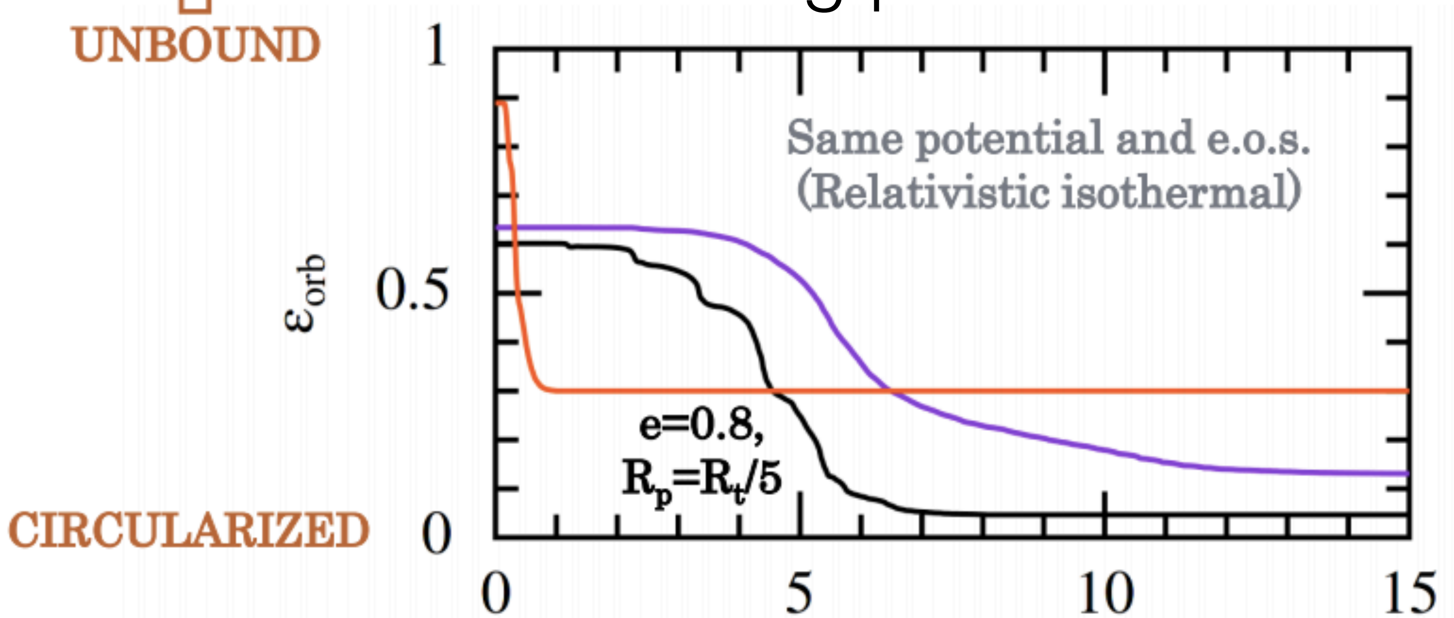

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