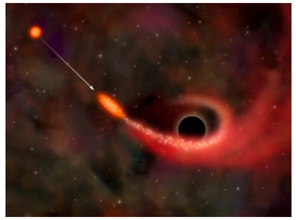
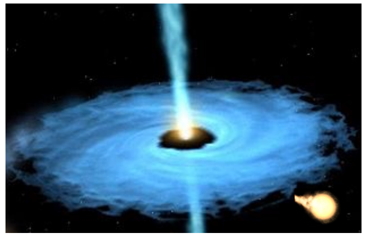
Dynamics of Stars @ Galactic Centers

- What sets the slope of the stellar cusp?
- What is the rate of Tidal Disruption Events?
  - how many deep penetrators?
  - what is the history before disruption?



- What is the rate of Extreme Mass Ratio Inspirals?

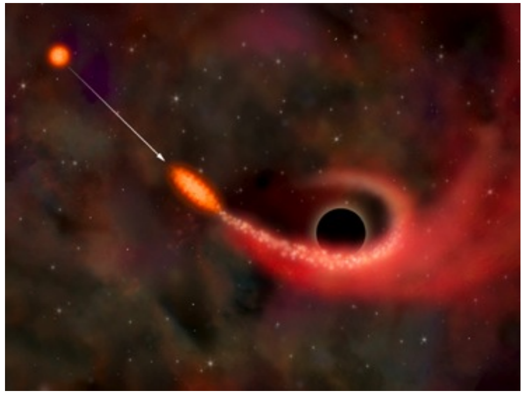


- Which events are more common?

$$\frac{\mathcal{R}_{\mathrm{EMRIS}}}{\mathcal{R}_{\mathrm{TDEs}}} = ?$$

Galactic Tidal Streams vs. TDEs

- Tidal streams dE/E <<1

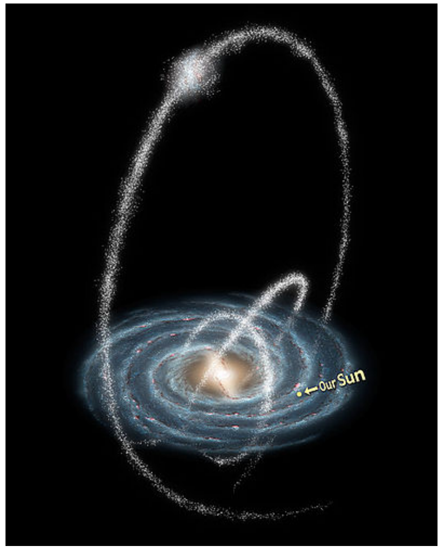


- Tidal Destruction Events dE>>E

$$dE \sim v_{esc} v_{orb,t} \sim \left(\frac{M}{m}\right)^{1/3} v_{esc}^2$$

$$E \sim v_{orb,t}^2 \, (a/r_t)^{-1} \sim \left(\frac{M}{m}\right)^{2/3} (a/r_t)^{-1} \, v_{esc}^2$$

$$\frac{dE}{E} \sim \left(\frac{a}{r_t}\right) \left(\frac{M}{m}\right)^{-1/3}$$



Setup

- BH embedded in a thermal bath of stars
- Some given velocity dispersion.
- Radius of influence of black hole: R_h
  - orbital velocity equals velocity dispersion
  - mass of stars equals mass of black hole.
  - we focus on $r<R_h$
- Simplifications:
  - All stars have the same mass
  - Ignore resonant relaxation
  - Spherical symmetry
  - Ignore finite stellar sizes: no collisions, no binary formation.

Slopes

- Peebles: constant stellar flux

$$\rho \propto r^{-9/4}$$

$$partical\ flux \sim \rho(r) r^3 \times \rho \times \left(\frac{Gm}{v^2}\right)^2 \times v \propto \frac{\rho^2 r^3}{v^3} \propto \rho^2 r^{9/2}$$

- Bahcall-Wolf: constant energy flux

$$Energy\ flux \sim E(r)\rho(r) r^3 \times \rho \times \left(\frac{Gm}{v^2}\right)^2 \times v \propto \rho^2 r^{7/2}$$

$$\rho \propto r^{-7/4}$$

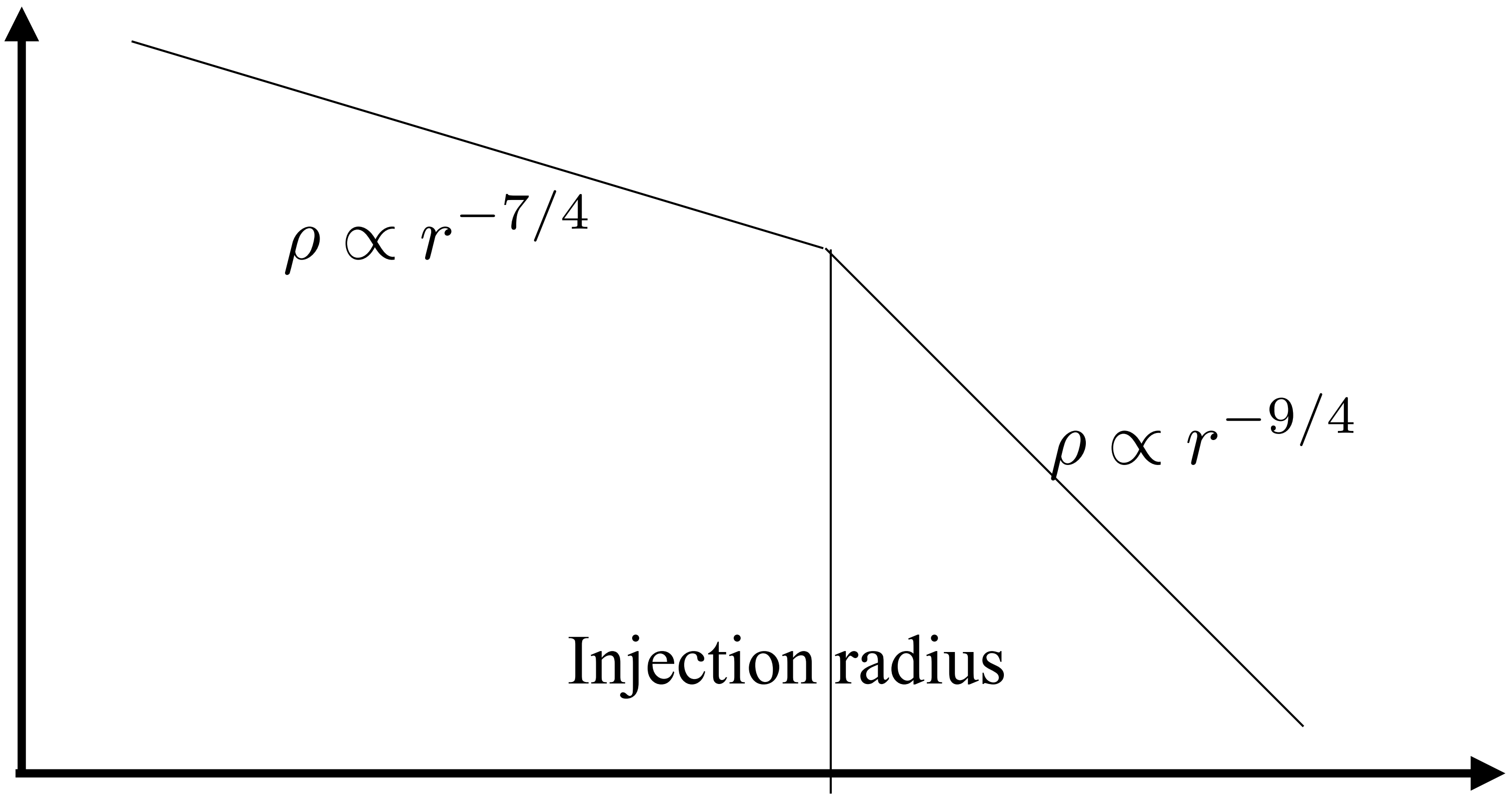
Slopes - Injection @ $r_i < R_h$

- Peebles: constant stellar flux

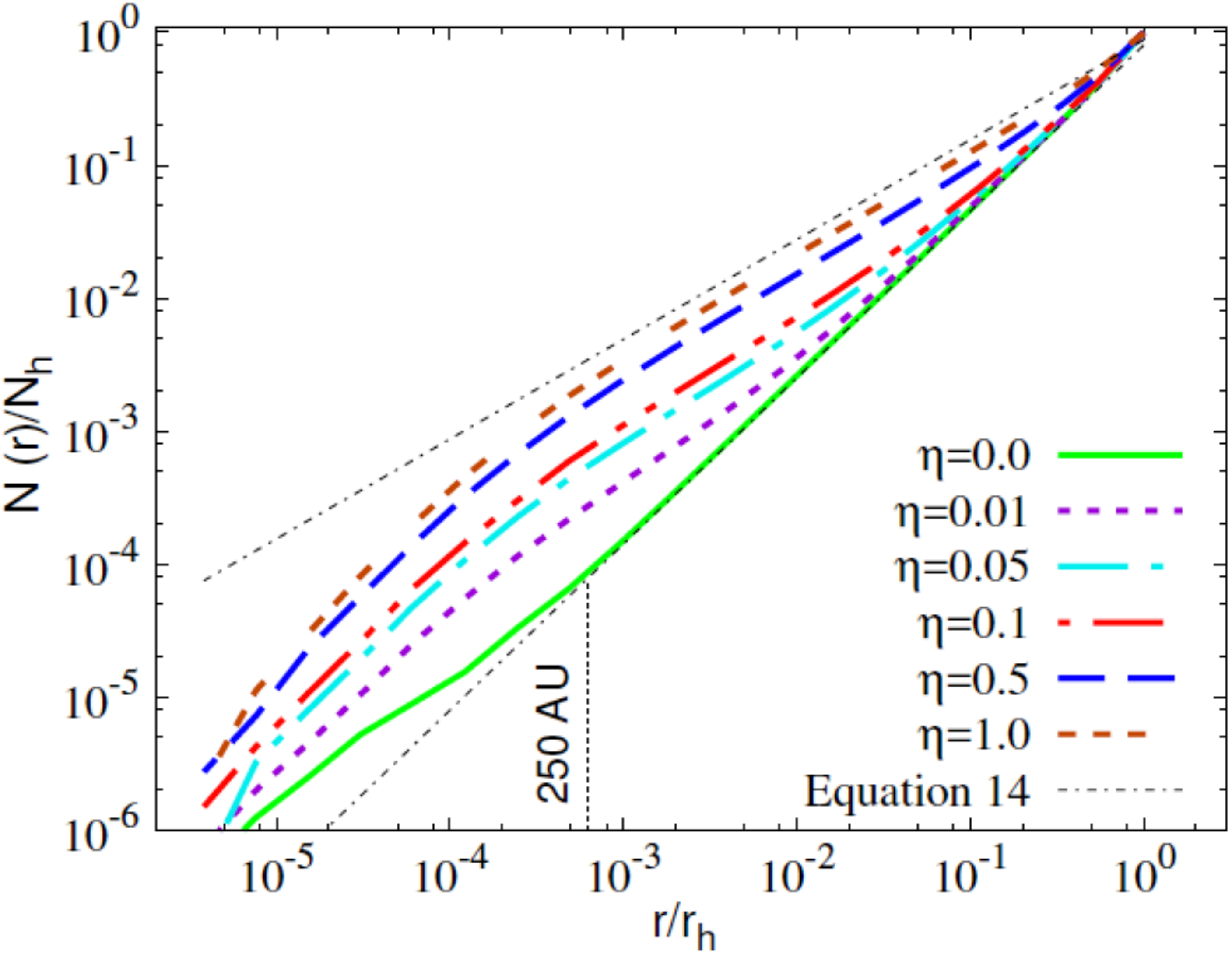
  $\rho \propto r^{-9/4}$

- Bahcall-Wolf: constant energy flux

  $\rho \propto r^{-7/4}$



Slopes - Injection @ $r_i < R_h$



Giacomo Fragione

Slopes - Injection @ $r_i < R_h$

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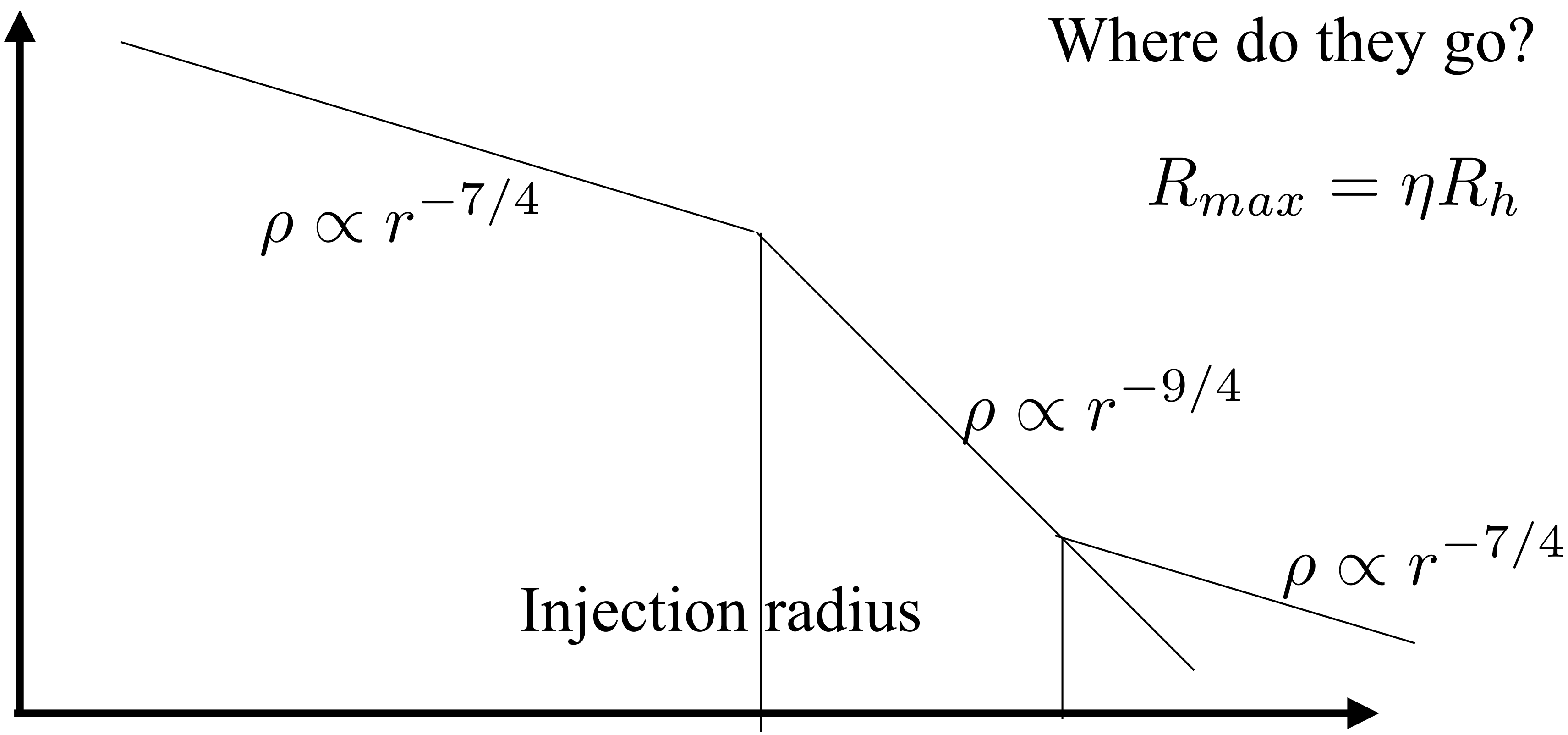
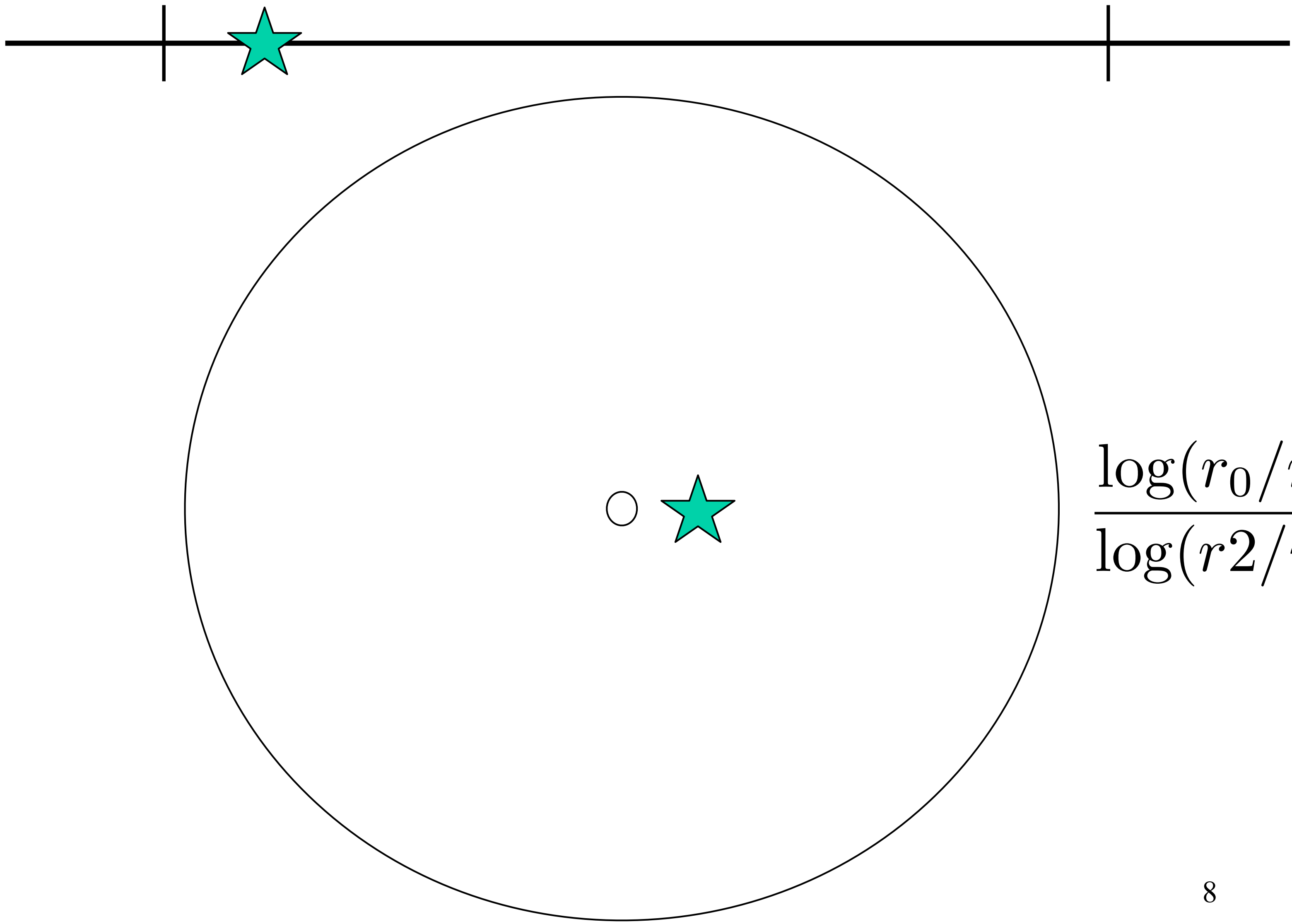


1,2&3D diffusion



$$\frac{x_1}{x_2}$$

$$\frac{\log(r_0/r_1)}{\log(r2/r_0)} \sim 1$$

$$\sim \frac{r_0}{r_1}$$

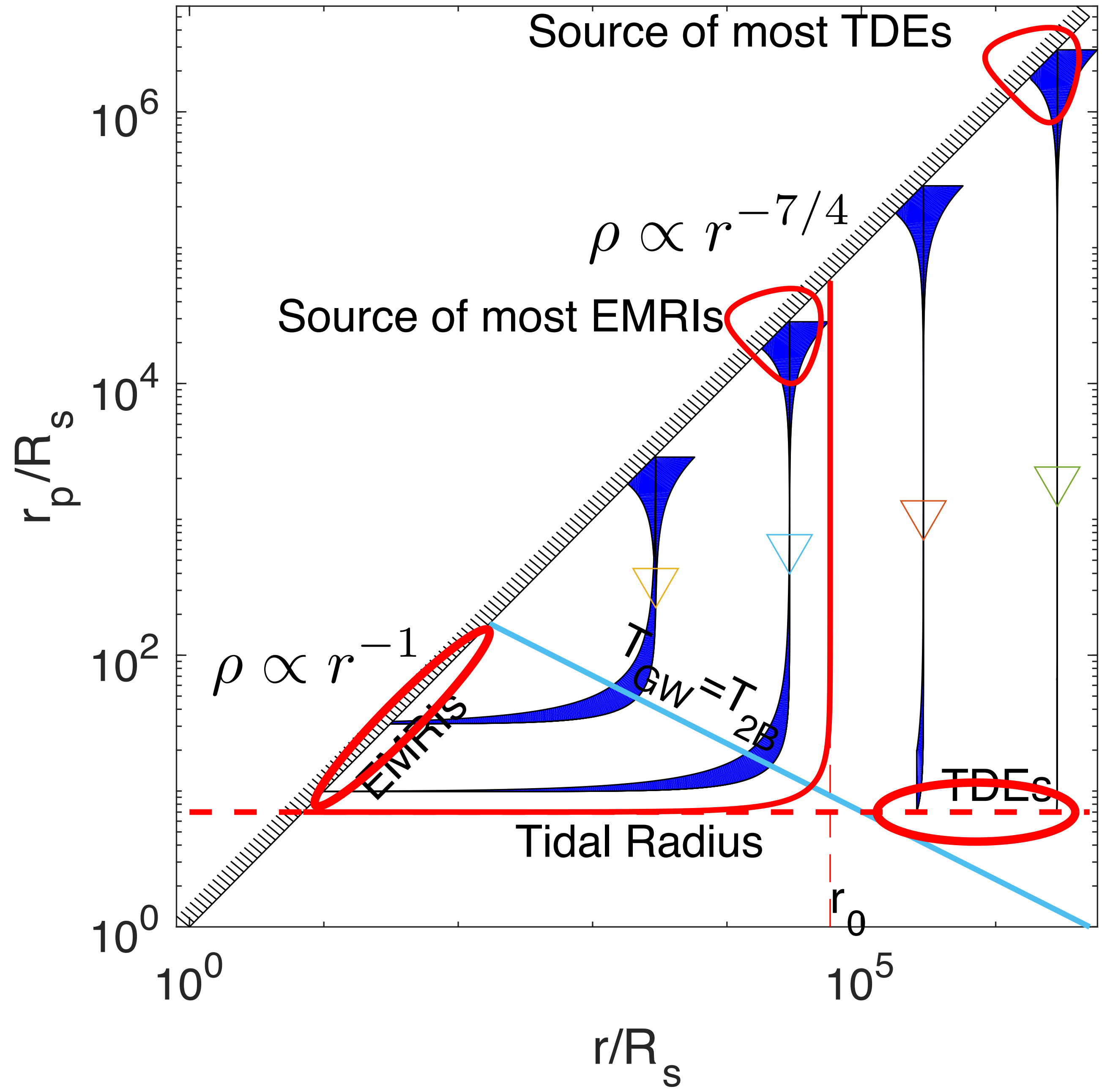
Gravitational Waves & Eccentric Orbits

$$T_{GW} = \frac{R_s}{c}\frac{M}{m}\left(\frac{r_p}{R_s}\right)^4\left(\frac{r}{r_p}\right)^{1/2}$$

$$T_{2B} = \frac{R_s}{c}\left(\frac{M}{m}\right)^2 N(r)^{-1}\left(\frac{r}{R_s}\right)^{3/2}\frac{r_p}{r}$$

$$T_{GW} = T_{2B} \quad \to \quad r_p = R_s\left(\frac{r}{R_h}\right)^{-1/2}$$

Scatterings & Gravitational Waves



$$r_0 = R_h \left(\frac{R_s}{R_t}\right)^2$$

$$\frac{\mathcal{R}_{\mathrm{EMRIS}}}{\mathcal{R}_{\mathrm{TDEs}}} = \left(\frac{R_s}{R_T}\right)^2$$

$\sim 1\%$

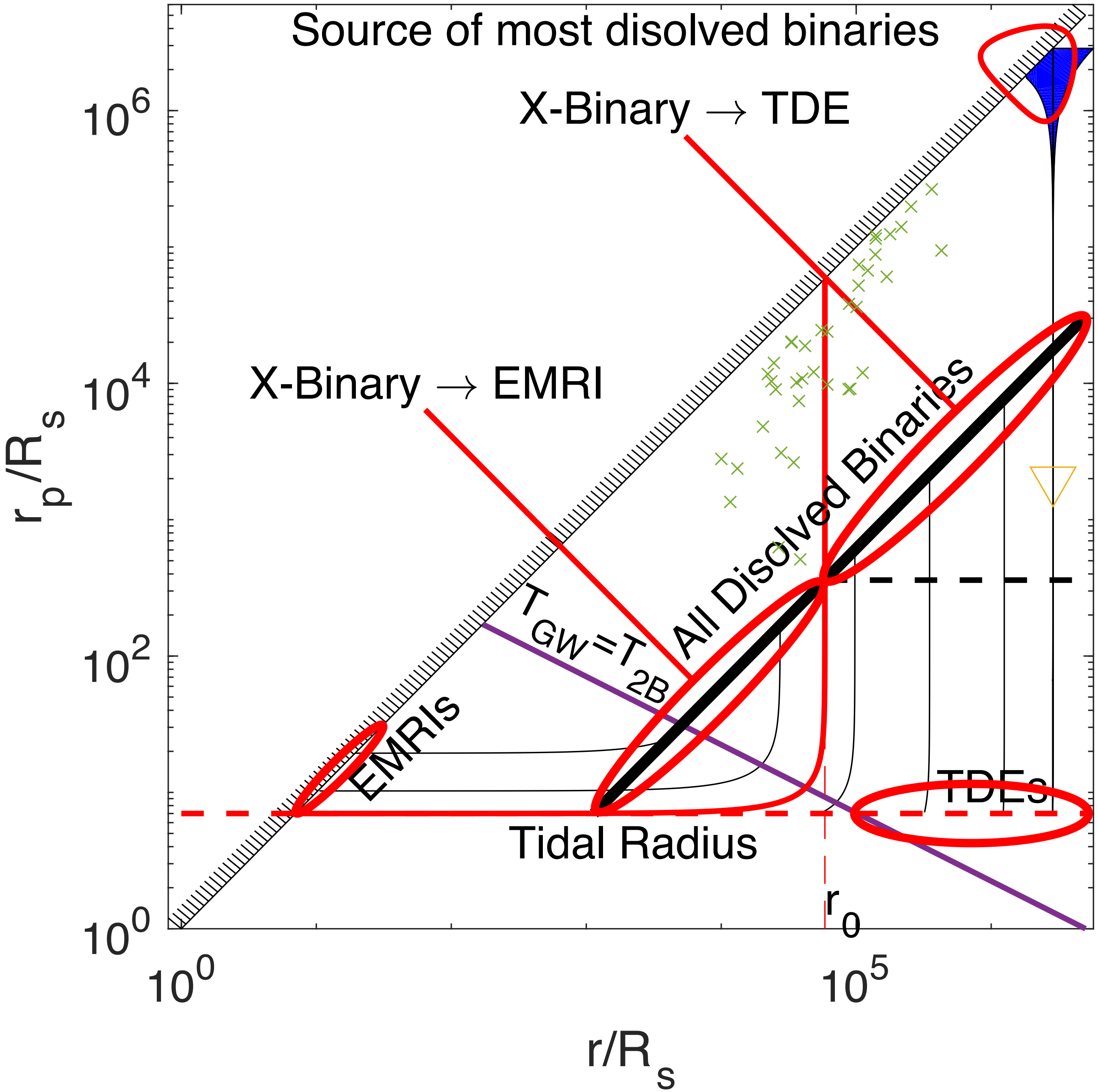
Galaxy mass
Stellar mass
Compact objects

Resonant Relaxation

- Related to **secular theory** in planetary dynamics.
- Not important close to Rh (fast precession by other stars)
- Not important close to Rs (fast precession due to GR)
- May farther decrease

$$\frac{\mathcal{R}_{EMRIS}}{\mathcal{R}_{TDEs}}$$

Scatterings + GW + BINARIES



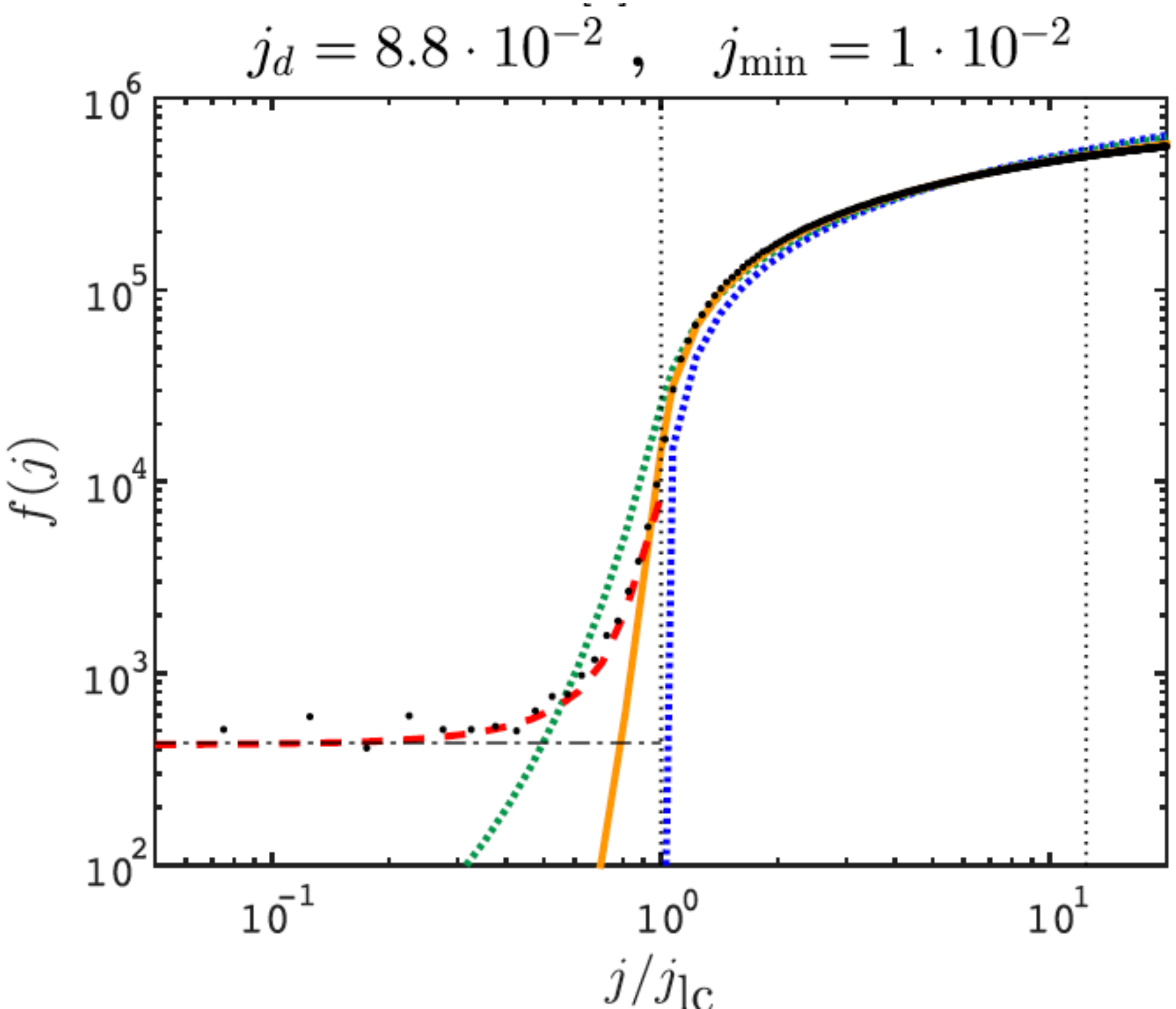
$$r_0 = R_h \left(\frac{R_s}{R_t}\right)^2$$

$$\frac{\mathcal{R}_{\mathrm{EMRIS}}}{\mathcal{R}_{\mathrm{TDEs}}} = \eta_b$$

~10%

Empty Loss Cones

- Deep penetrators
  - common in full loss cone
  - extreme compression inside tidal radius
  - shock breakout/nuclear reactions.
- How common in empty loss cone?
- Rare large kicks.



Amir Weisbein

Summary

- Stellar density slopes
  - particle flux $\rho \propto r^{-9/4}$
  - energy flux $\rho \propto r^{-7/4}$
- Breakup of Binaries:
  - Creates hyper velocity stars
  - Injects stars deep in the BH potential
- Bound x-binary stars:
  - source of most EMRIs.
  - Creates outward stellar flux.
  - Steeper cusp slope.
- Emris Gravitational Wave signal:
  - Both chirp and prich
  - Reflects stellar properties.
  - More than prev. thought.