Modelling the coexistence of a nuclear cluster and a SMBH surrounded by a massive torus (update)

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Nuclear Star Clusters

...in galaxies and in the Milky Way

- located at the dynamical centers of the majority of galaxies
- dense and massive
- NSC in SgrA*: a unique template
- formation scenarios: migration via dynamical friction vs. in-situ star formation

...in active galaxies: embedded in gaseous environment

- quasi-spherical inflow/outflow
- disk-like or toroidal

(Schödel et al.; Neumayer et al.; Boeker; Kormendy et al; ...)

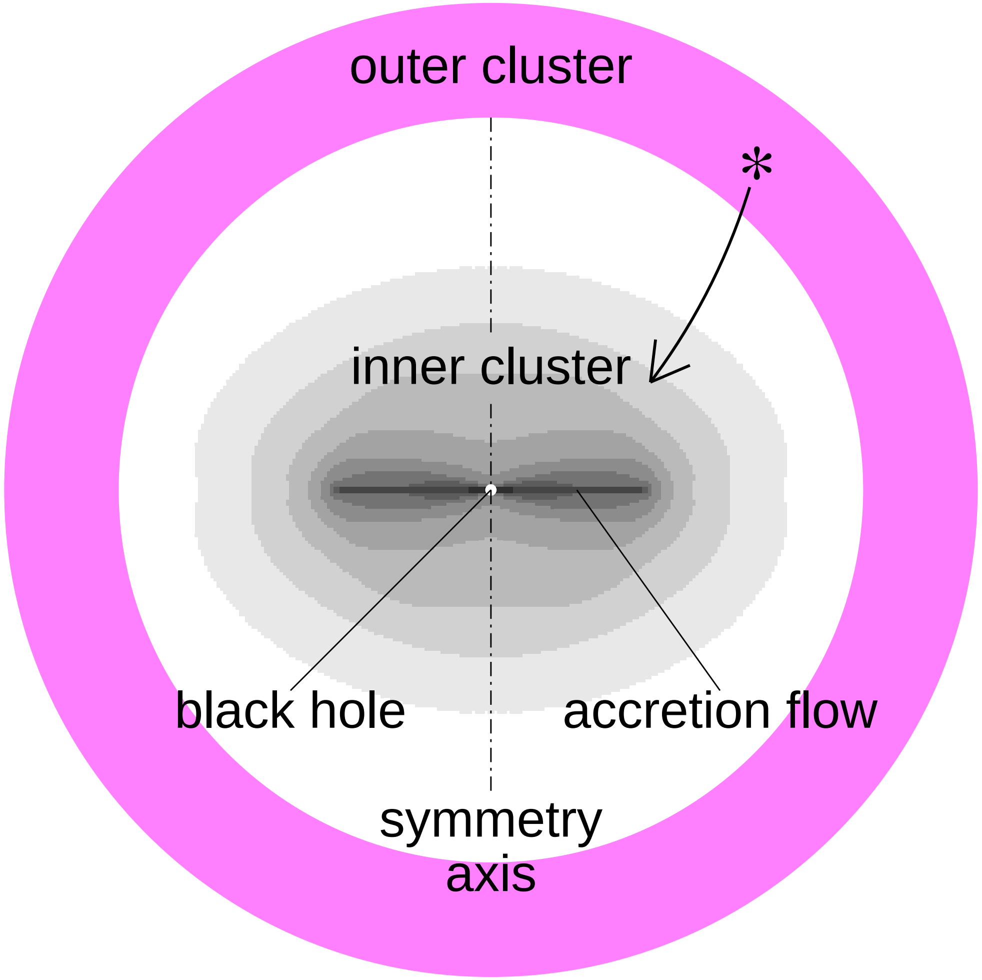
Nuclear Star Clusters

NSC structure and evolution

- is it spherically symmetric?
- how is the extended mass distributed in the central parsec?
- segregation of stellar types?
- is there a central cusp of compact stellar remnants?

Relation between massive black holes and NSCs is not clear

Model



- Black hole
  $M_{\rm BH} \approx 10^3 - 10^8 M_\odot$
- Accretion flow
  $\Sigma_{\rm d} \propto r^s$
  $R_{\rm d} \approx 10^4 R_{\rm g} \approx 1\,{\rm pc}$
- 'Outer' cluster
  $n(r) = n_0 (r/r_{\rm h})^{-7/4}$
  $r_{\rm h} \approx 10\,{\rm pc}$
  $n_0 \approx 10^6\,{\rm pc}^{-3}$
- 'Inner' cluster…

Time-scales

$$T_{\rm K} = \frac{4}{3}\frac{M_{\rm BH}}{M_{\rm d}}\left(\frac{R_{\rm d}}{a}\right)^3 P$$

$$T_{\rm E} = \frac{1}{3}\frac{a(1-e^2)}{R_{\rm g}} P$$

$$\frac{T_{\rm K}}{T_{\rm E}} = 4\frac{M_{\rm BH}}{M_{\rm d}}\left(\frac{R_{\rm d}}{a}\right)^3 \frac{R_{\rm g}}{a(1-e)} \sqrt{1-e^2}\,(1+e)$$

inclination $T_{\rm inc} \simeq M_8 \frac{\Sigma_\star}{\Sigma_\odot}\left(\frac{a_0}{R_{\rm g}}\right)^{3/2-s}$ yr

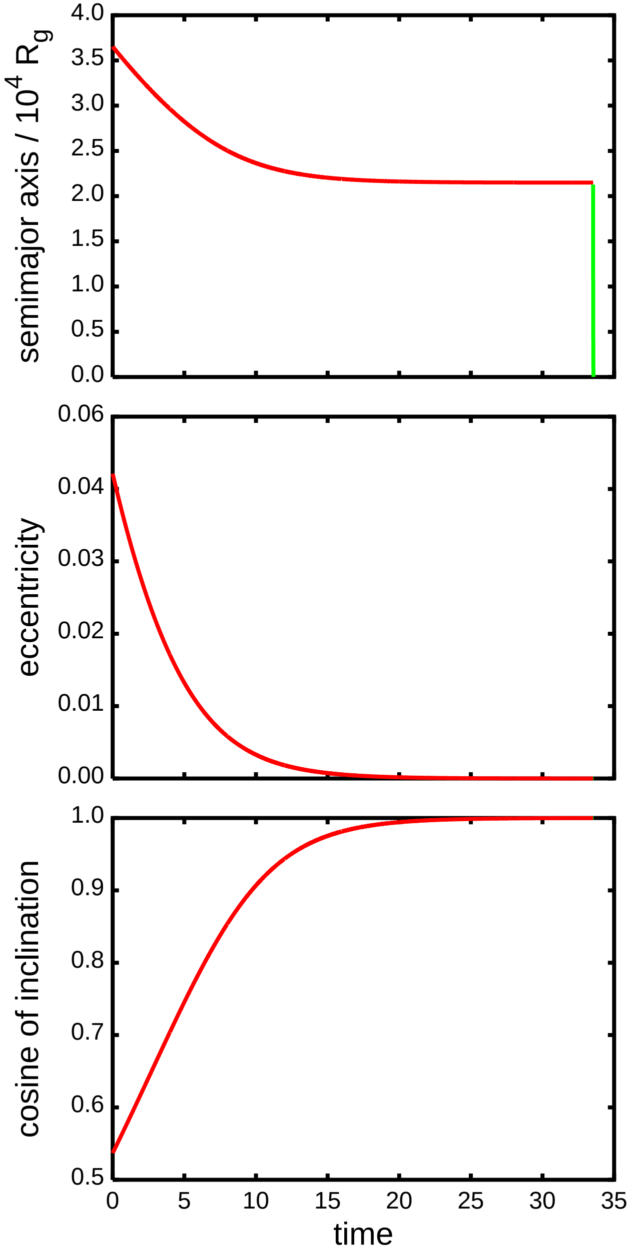
pericentre $\lesssim 3R_{\rm t}\,,\ R_{\rm t} \equiv (M_{\rm BH}/M_*)^{\frac{1}{3}} R_*$

relaxation $T_{\rm r} \simeq \frac{\sigma^3}{G^2 C\ \ln\Lambda\, M_\star 2\, n_\star}, \quad n_\star \sim (r/R)^{-7/4}\, n_0$

Individual orbits

Two phases of orbital evolution:

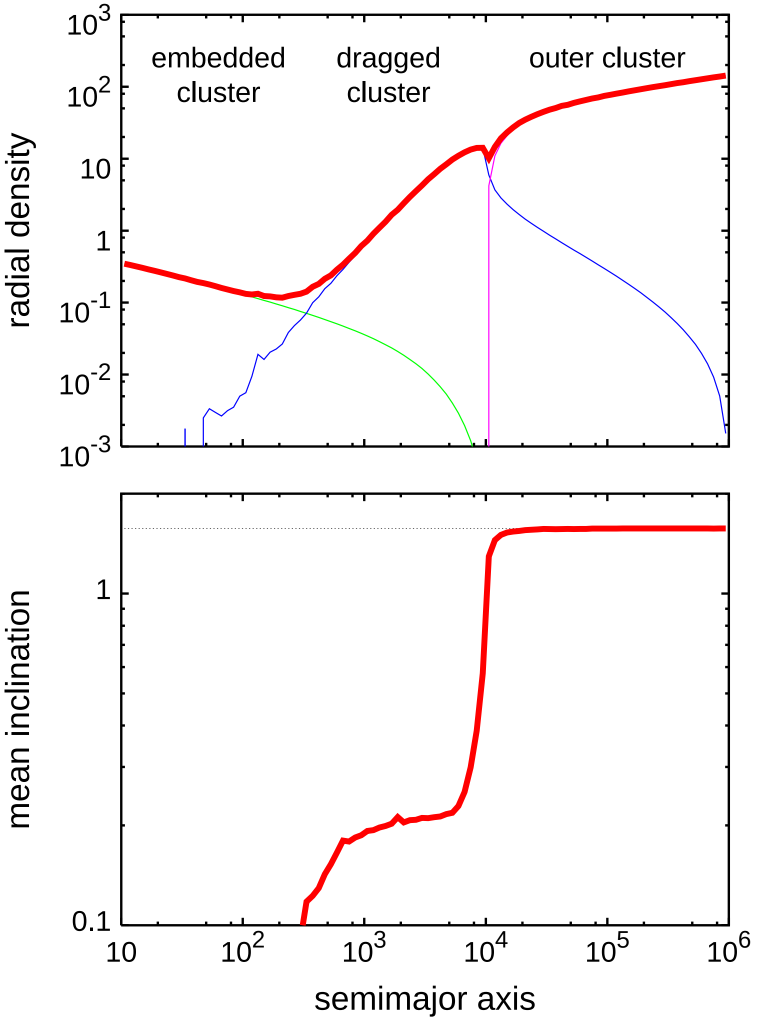
- Star-disc collisions → gradual decay towards a circular orbit and corotation with the disc
- Different modes of migration of orbits embedded in the disc
  - opening a gap (large stellar masses, thin disc)
  - accretion onto star (stronger interaction → faster decay)



Syer, Clarke & Rees (1991); Šubr, Karas & Huré (2004)

A stationary cluster

- Outer cluster: a reservoir
- Inner cluster: becomes flattened
- Size of the inner cluster $\simeq$ the disc outer radius
- Distribution of semi-major axes: a broken power-law

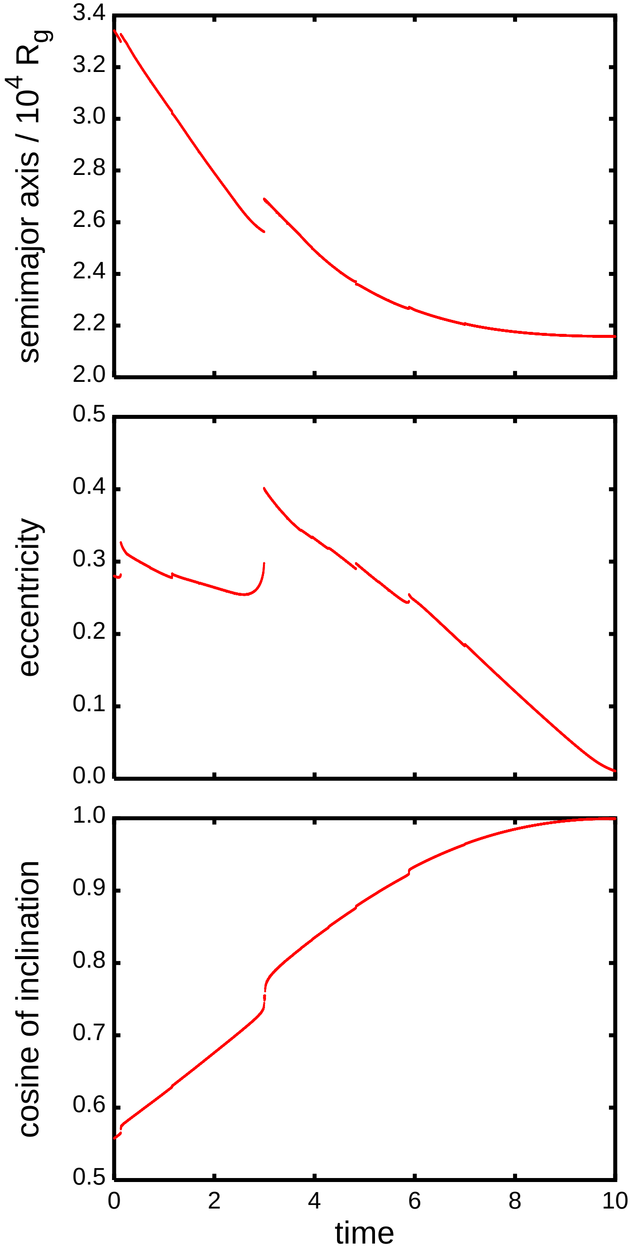


Effects of the disc gravity

. . . with the gravitational effect of the disc taken into account.

New features:

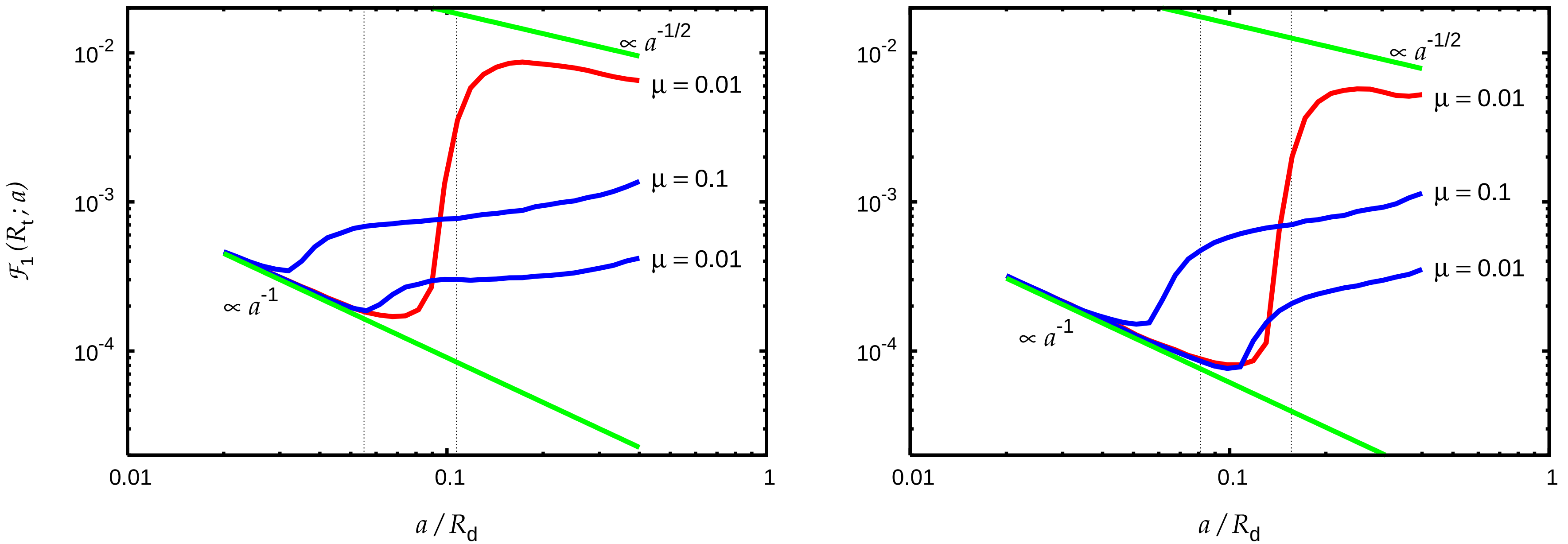
- Jumps of orbital parameters occur in resonance.
- Passages through the disc are more frequent.



Example: Growth of MBH

Fraction of stars that plunge below the BH tidal radius.

$M_{\rm BH} = 10^4 M_\odot$ $M_{\rm BH} = 10^5 M_\odot$

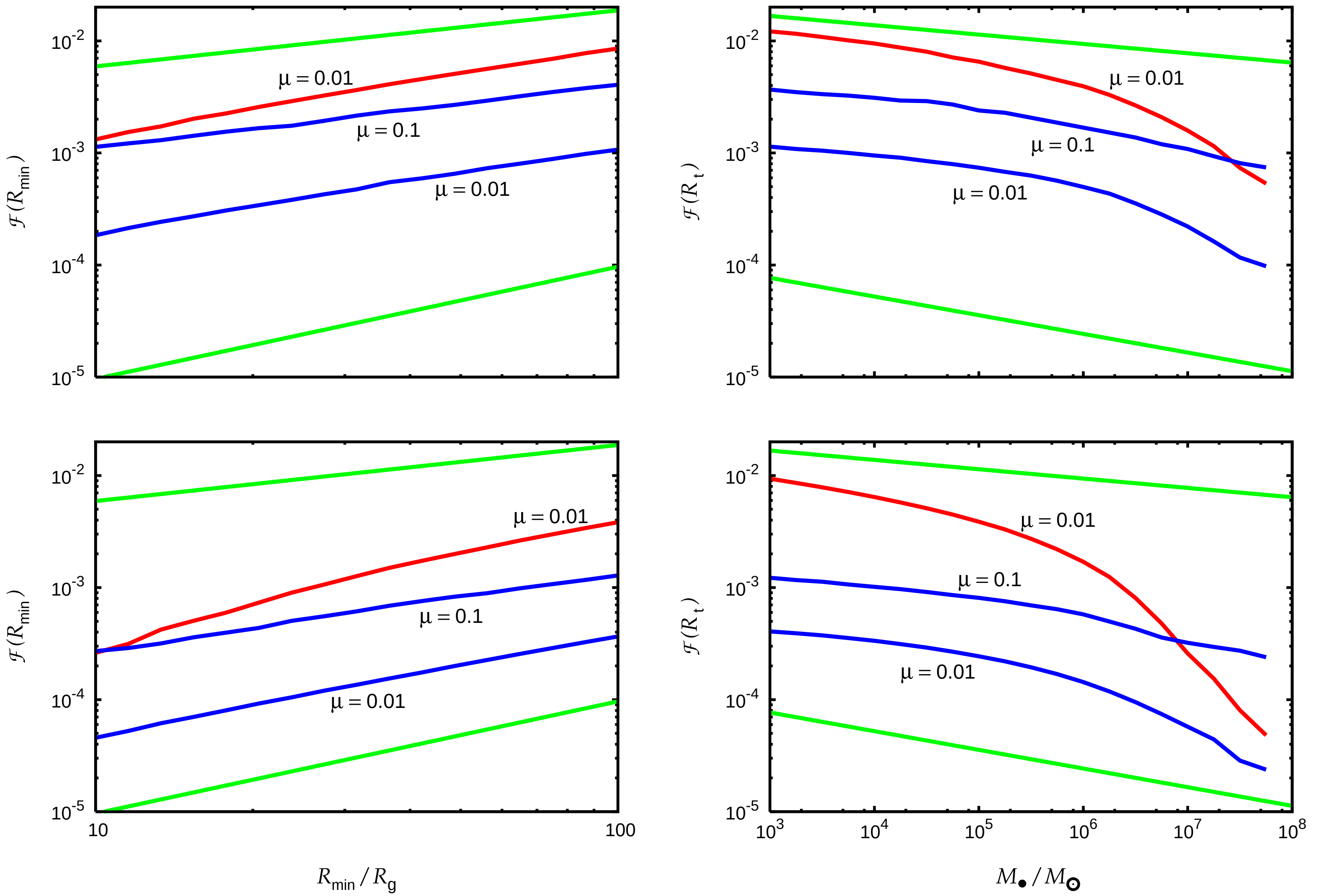


Red – PN1 approximation for the central mass; the outer cluster neglected.

Blue – the outer stellar cluster taken into account.

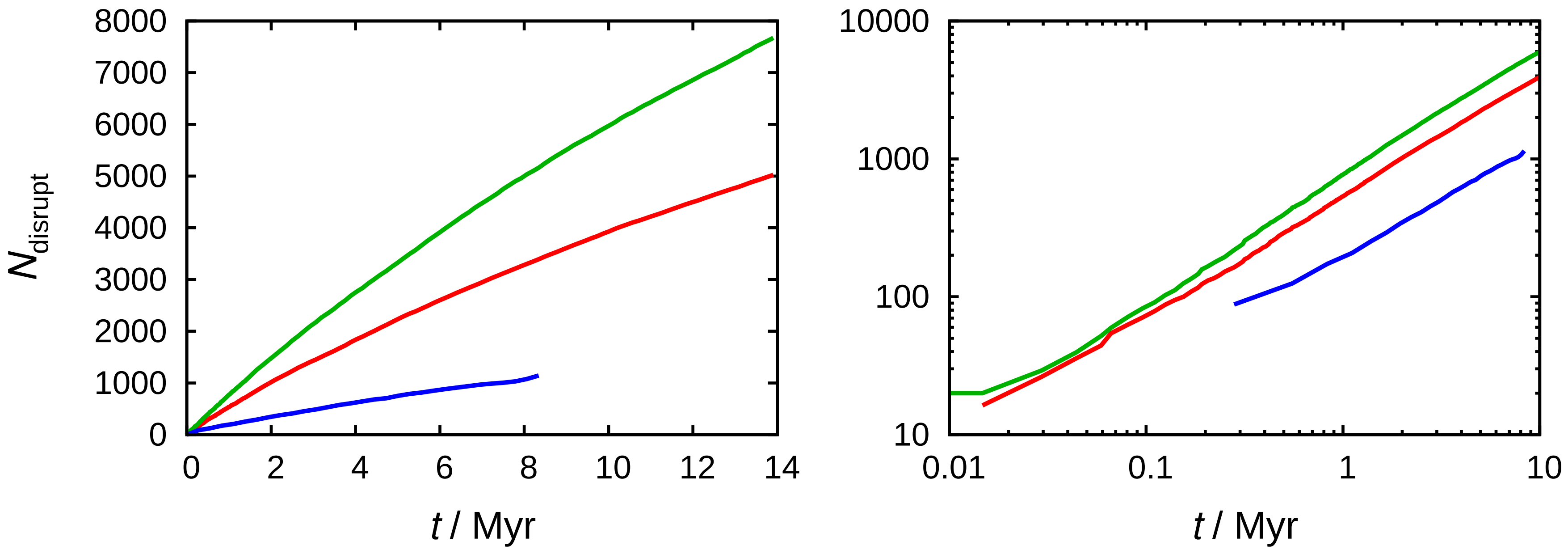
Green – analytical power-law estimates.

Example: Growth of MBH



Fraction of stars that reach their orbit pericentres below R_{min}.

Tidal disruption events



Number of TDEs per year. Parameters set as for Sgr A*

($M_\bullet = 4 \times 10^6 M_\odot$, $M_d \simeq 0.1 M_\odot$).

Conclusions

Kozai's mechanism increases the probability stars get close to MBH. More efficient for IMBH than for SMBH.

- Feeding the black hole

  Rate of stars getting into the MBH tidal radius

- Modifying the inner accretion flow

  Exchange of energy and angular momentum with star cluster)

- GW signal from inspiralling stars

  The effect of the drag acting on the 'satellite' stars

- Modifying the cluster structure

  Flattening the stellar cluster, changing the velocity dispersion near BH

Details of the method

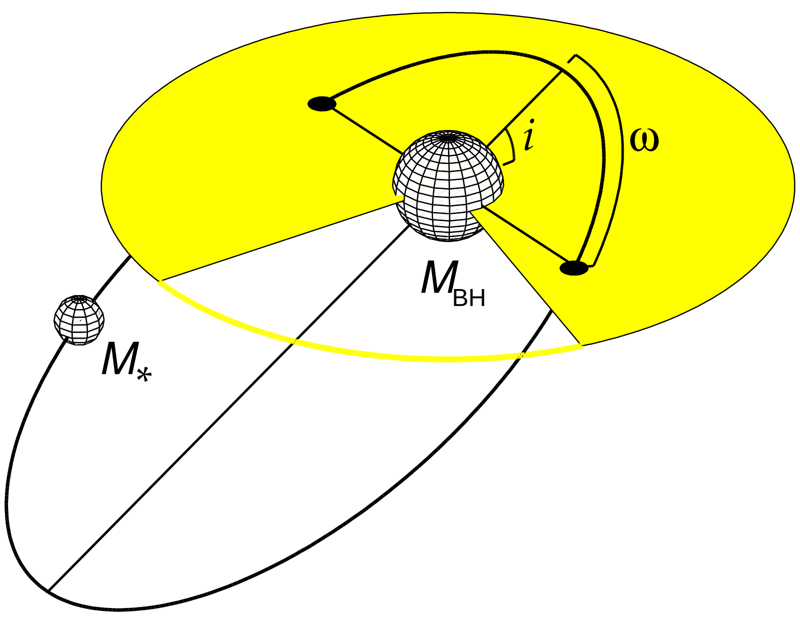
Two-body Hamiltonian,

Cartesian coordinates:

$$\mathcal{H} = \frac{1}{2}\left(v_1^2 + v_2^2 + v_3^2\right) - \frac{\mathcal{G}\,(m_0 + m_1)}{\sqrt{x_1^2 + x_2^2 + x_3^2}}$$

Delaunay variables:

$$\mathcal{H} = -\frac{\mathcal{G}^2 (m_0 + m_1)^2}{2L^2}$$

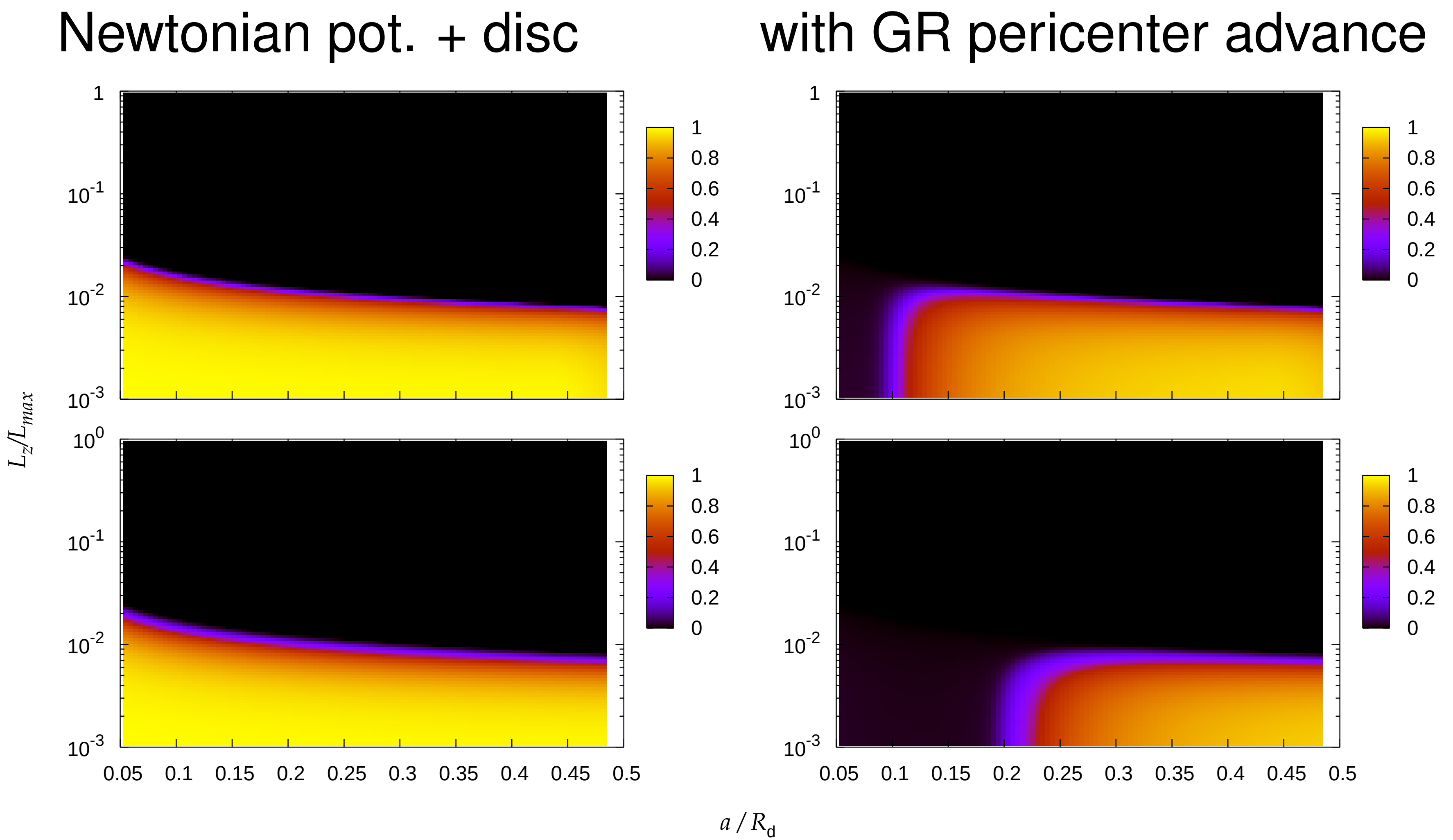


$$L = \sqrt{\mathcal{G}(m_0 + m_1)a} \qquad l = M$$

$$G = L\sqrt{1 - e^2} \qquad g = \omega$$

$$H = G\cos i \qquad h = \Omega$$

Effect of pericenter advance



Fraction of stars getting in the loss cone because of eccentricity oscillations.

Contour analysis, $\bar{V}(e,\omega) = \text{const}$