Relaxation and black hole feeding rates in non-spherical galactic nuclei

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Plan of the talk

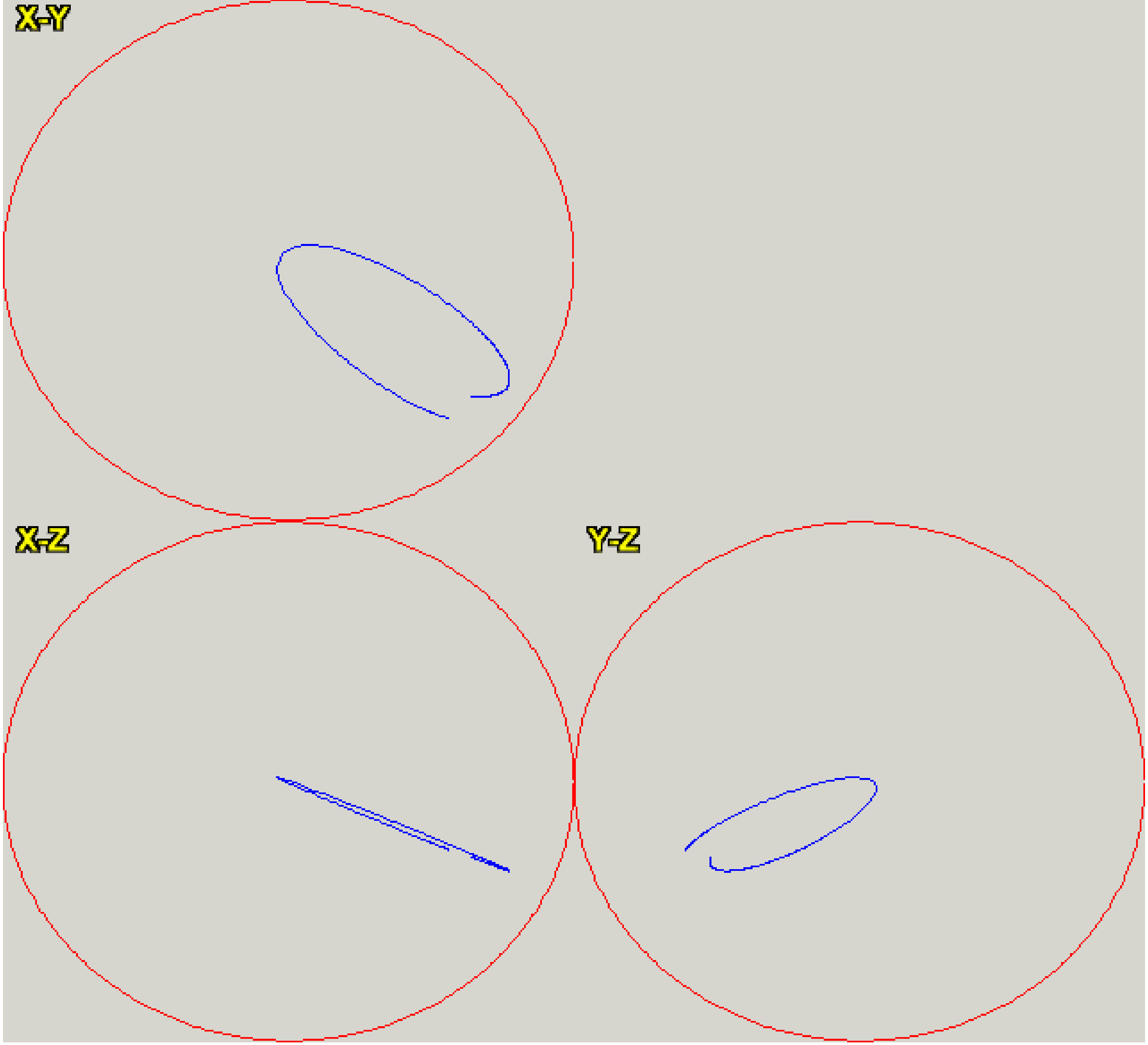
- Orbits around black holes in non-spherical nuclei
- Difference between spherical, axisymmetric and triaxial nuclear star clusters
- Two-body relaxation in galactic nuclei
- Empty and full loss cone regimes
- Fokker-Planck models and N-body simulations
- Predictions for realistic galaxies; conclusions.

Nuclear star clusters

- Supermassive black hole M_{bh}
- Stellar cusp (for example, a power law density profile $\rho \sim r^{-\gamma}$)
- Total gravitational potential:

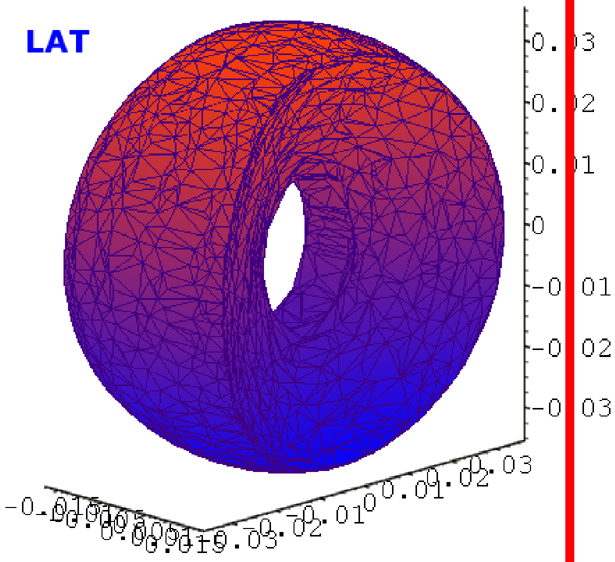
$$\Phi(\vec{r}) = -\frac{GM_{bh}}{r} + \Phi_\star \left(\frac{r}{r_0}\right)^{2-\gamma} \left(1 + \varepsilon \frac{z^2}{r^2} + \eta \frac{y^2}{r^2}\right)$$

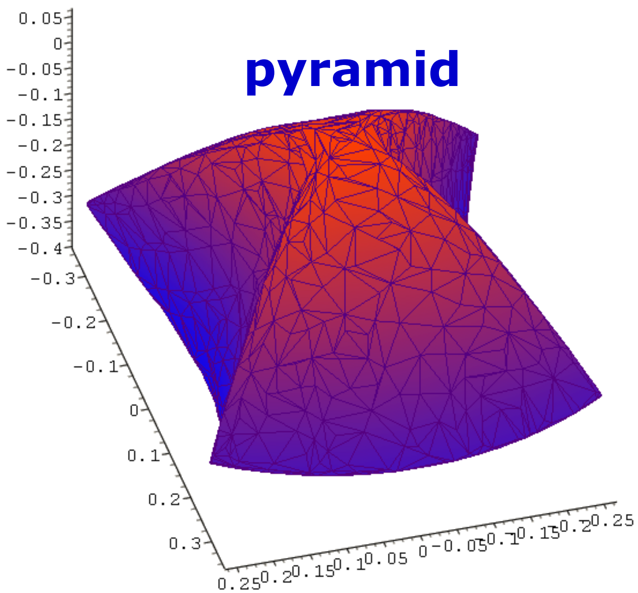
- Consider motion inside radius of influence r_{infl} =>
  dominant contribution is from SMBH =>
  orbits are perturbed Keplerian ellipses
  which precess due to torques from stellar potential
  (motion outside r_{infl} is discussed towards the end of talk).
- Orbital time t_{orb} << precession time $t_{prec} \sim r_{infl}/\sigma$


X-Y
X-Z
Y-Z

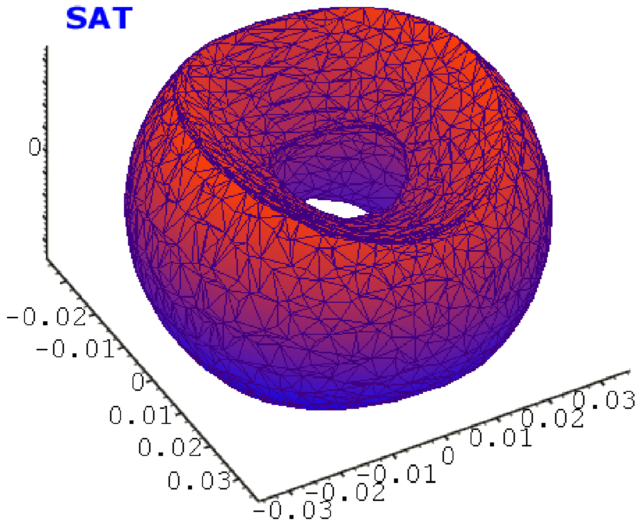
Types of orbits in non-spherical star cluster around a supermassive black hole

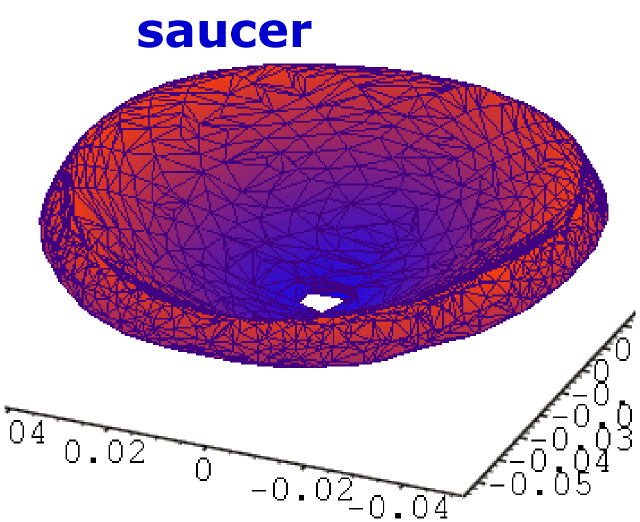
Triaxial cluster:





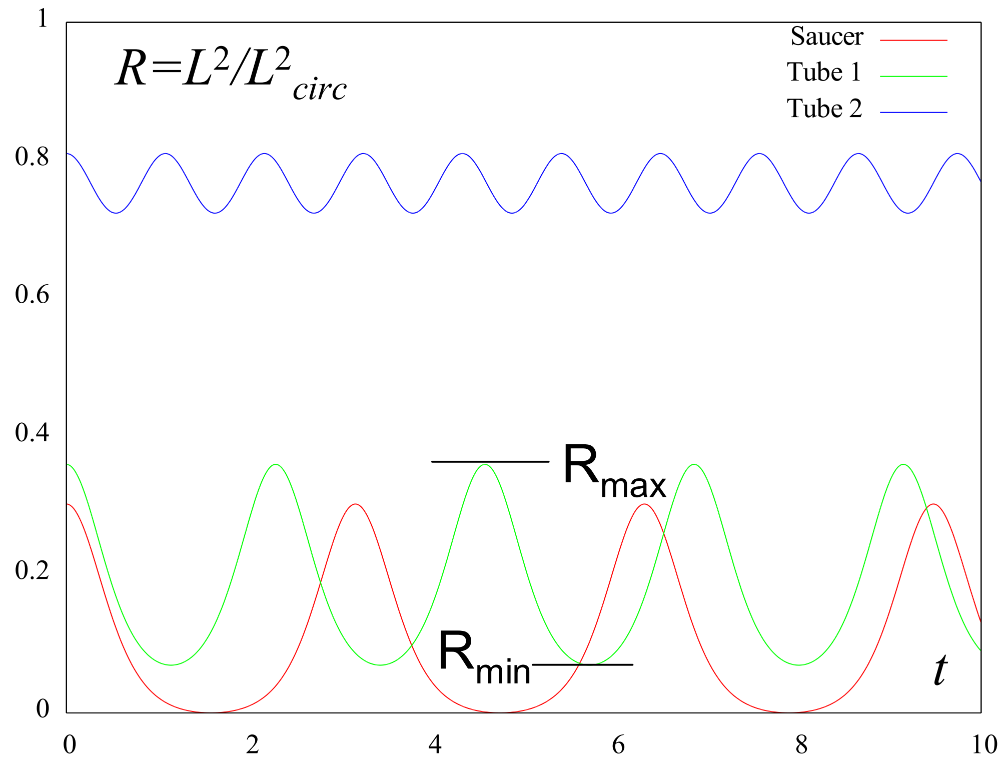
Axisymmetric cluster



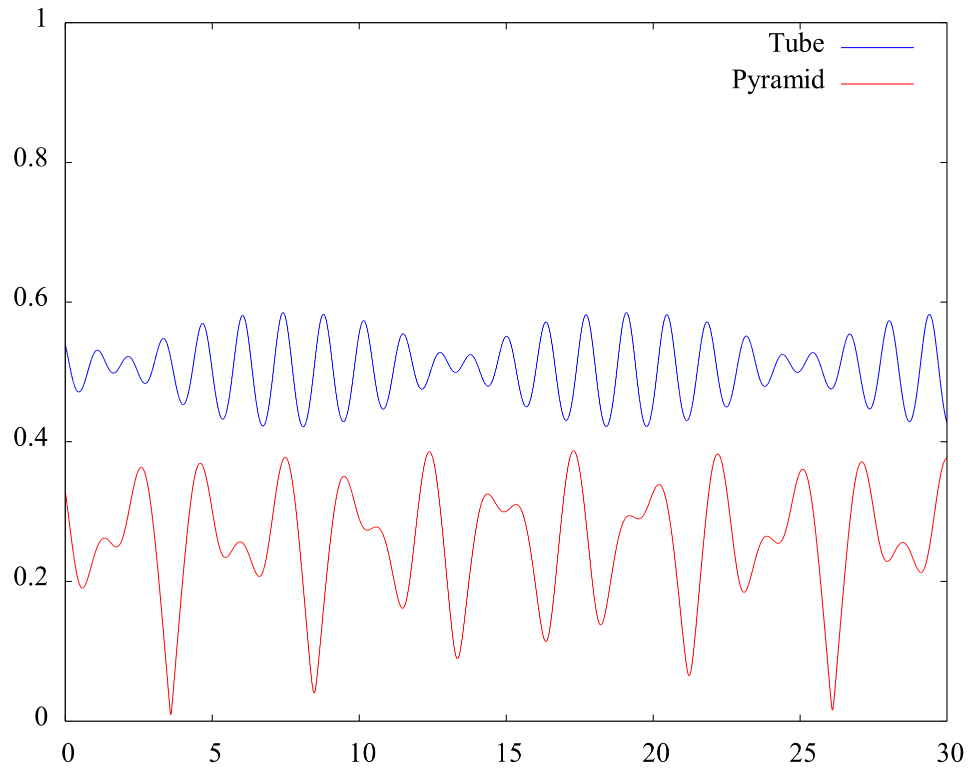


Evolution of angular momentum of an orbit in a non-spherical nuclear star cluster

Three integrals of motion: total energy E, secular hamiltonian H, and a third integral which is reduced to z-component of angular momentum L_z in axisymmetric systems. Total angular momentum squared, L^2, is not conserved but experiences oscillations between R_{min} and R_{max} with characteristic period $T_{osc} \sim T_{prec}$, and amplitude $\sim \varepsilon$.



Axisymmetric system



triaxial system

Difference between spherical, axisymmetric and triaxial nuclear star clusters

	Spherical	Axisymmetric	Triaxial
Fraction of stars with $L^2_{min} < X$	$\propto X$	$\propto \sqrt{X\varepsilon}$	$\propto \varepsilon$
Fraction of time that such a star has $L^2 < X$	1	$\sqrt{X}$	X
Survival time of such stars (assuming they are captured immediately after reaching $L^2 < R_{capt}$)	T_{rad} (10^{1-5} yr)	T_{osc} (10^{5-6} yr)	may be longer than 10^{10} yr

(for MW nucleus)

but that may not be true
in the presence of relaxation

Two-body relaxation in galactic nuclei and the concept of empty/full loss cone

Relaxation time $T_{rel} = \dfrac{0.34\,\sigma(r)^3}{G^2\,\overline{m}_\star\,\rho_\star(r)\,\ln\Lambda}$ – timescale for diffusion in E and L

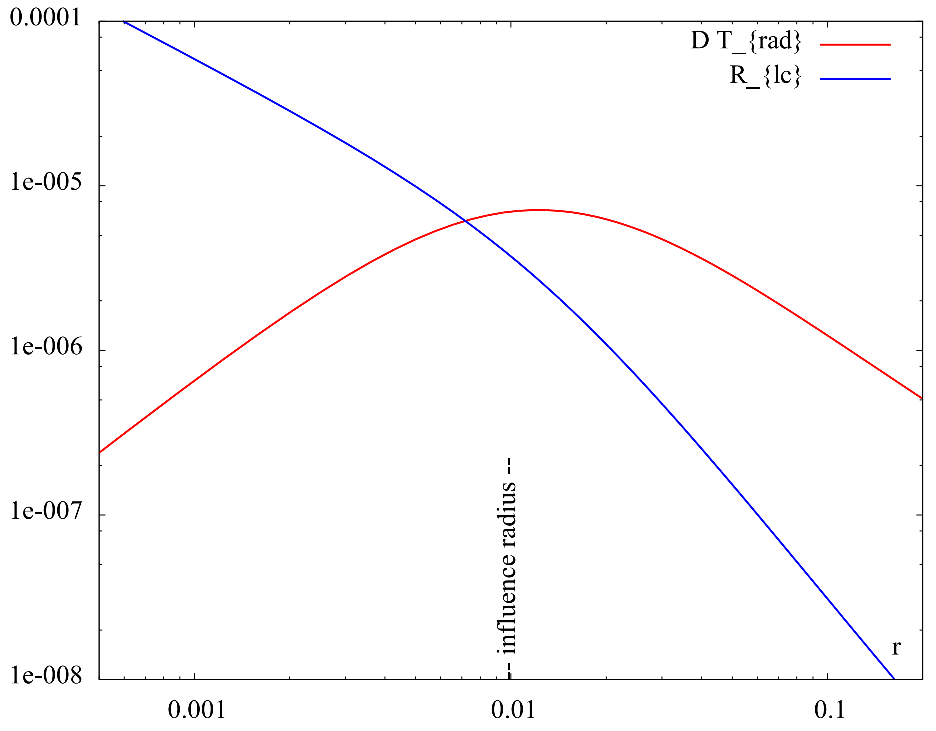
Loss cone is the region in phase space in which an orbit is captured on the nearest pericenter passage, i.e. at most within 1 radial period, having $L^2/L^2_{circ} = R < R_{lc}$.

The question is how fast the changes in L occur compared to radial period:

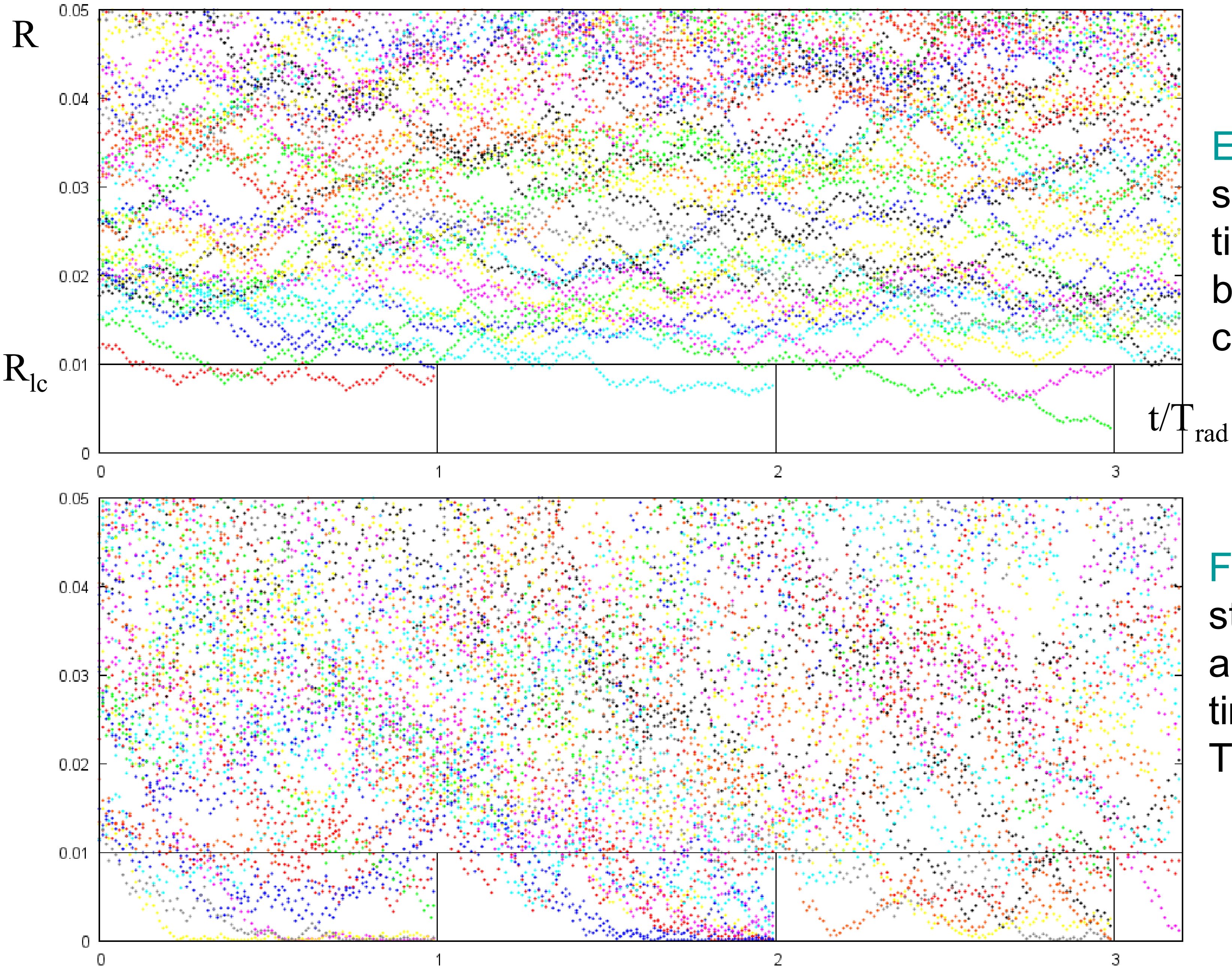
$q = \Delta R^2/R^2_{lc}$,

q << 1 – empty loss cone regime:
stars are captured as soon as they enter LC; population of stars with $L^2<R_{lc}$ is negligible

q >> 1 – full loss cone:
stars may move in and out of LC many times before being captured at the end of T_{rad}, d.f. of stars in LC is the same as elsewhere



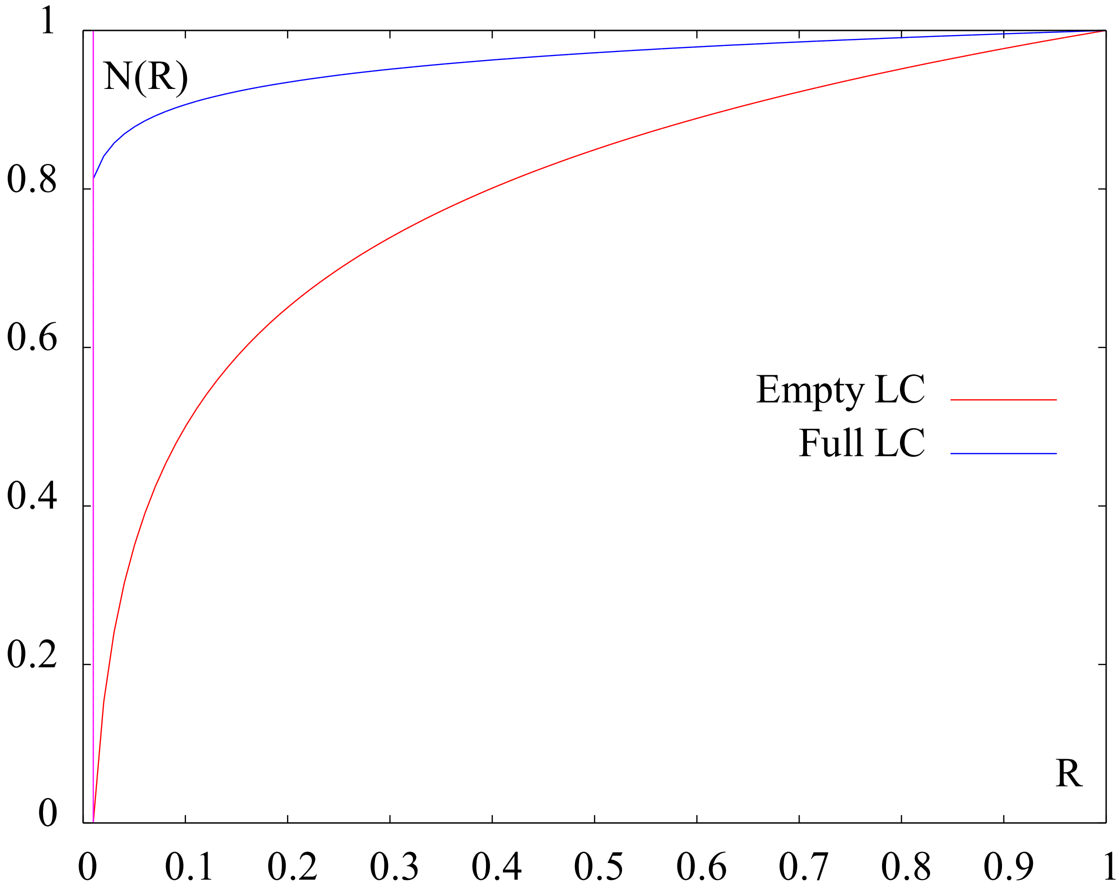
The concept of empty/full loss cone



Empty LC:
stars barely have time to enter LC before they get captured after T_{rad}

Full LC:
stars may enter and exit LC many times during one T_{rad}

The concept of empty/full loss cone



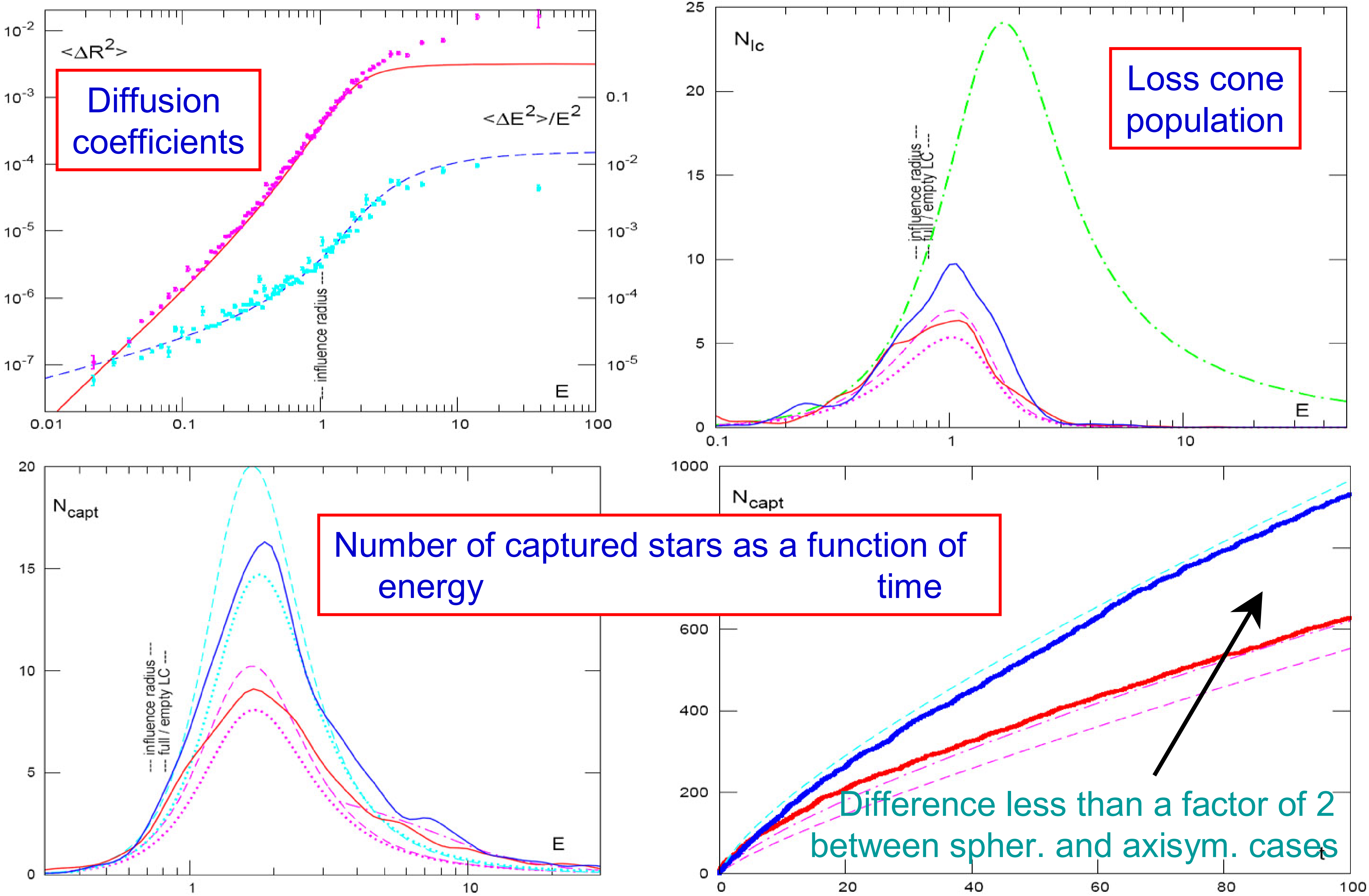
- In the empty LC regime, $N(R_{lc}) \sim 0$, $N(R) \sim \log R$, capture rate is limited by diffusion (gradient of $N(R)$): $F \sim T^{-1}_{rel} / (\log(1/R_{lc}) - 1)$ for standard 2-body relaxation
- In the full LC regime, $N(R_{lc}) \sim N(R) \sim 1$, capture rate is $F \sim R_{lc}/T_{rad}$

does not depend on diffusion coefficient or even on the mechanism of LC refill as long as it is efficient enough to keep it full!

Loss cone draining vs. relaxation

- Regular precession may shuffle stars in angular momentum more efficiently than 2-body relaxation
- The capture rate cannot exceed $F_{full\ LC}$, but can be larger than in the spherical case if it was in the empty loss cone regime
- After all orbits with $L^2_{min}<R_{capt}$ have been drained, the influx of stars from higher L is still limited by diffusion (relaxation in angular momentum)
- For triaxial nuclei, the draining time of pyramid orbits may be >1010yr. For axisymmetric systems, adequate description of relaxation is needed (in terms of Fokker-Planck equation in terms of the variables which are integrals of motion in the absence of relaxation).
- Comparison with N-body simulations to determine applicability of F-P description; extrapolation of F-P results into the range of parameters inaccessible for direct N-body.

Comparison of Fokker-Planck models with N-body simulations



Conclusions

- In non-spherical nuclear star clusters the star angular momentum L is changed not only due to 2-body relaxation, but also due to regular precession
- This facilitates the capture of stars at low L:
  the "expanded" loss region is where $L^2_{min}<L^2_{capt}$, not just $L^2<L^2_{capt}$
- Draining time of this region is $\sim T_{prec} \sim 10^{5\text{-}6}$ yr in axisymmetric case and much longer, comparable to Hubble time, in triaxial case
- Compared to the spherical case, the difference in total capture rate for axisymmetric case is relatively small (~factor of 2) and is important only in the transition regime between empty and full loss cone
- For giant elliptical galaxies, which are deeply in the empty loss cone regime for a spherical case, the enhancement may be more dramatic