SMBH Feeding and Star Formation in Massive Accretion Discs

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The Central Kiloparsec:
Active Galactic Nuclei and Their Hosts

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Black hole – Gas – Stars

Gaseous structures (discs, tori)

- gravitational influence on stellar orbits (Kozai oscillations, precession)
- hydrodynamical interaction (energy dissipation)
- 'causal' influence (star formation)

SMBH

- feeding via star tidal disruptions
- gravitational waves emission

Stars

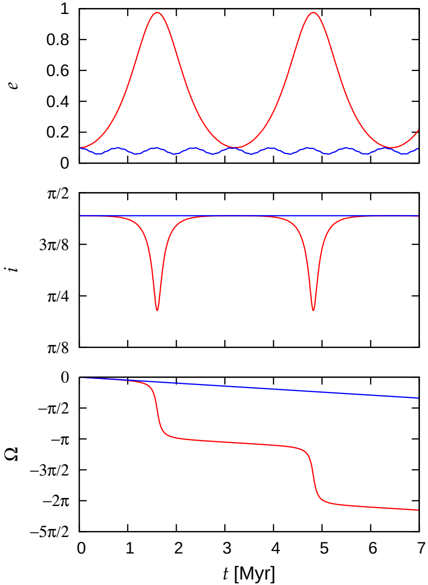
- strong radiating sources

Kozai oscillations

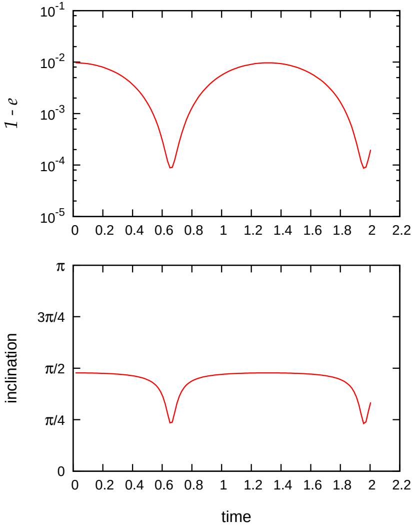
Broken spherical symmetry $\rightarrow$ angular momentum is not an integral of motion

Example:

- $M_{\rm BH} = 3.5 \times 10^6 M_\odot$
- $M_{\rm CND} = M_{\rm BH}$,
  $R_{\rm CND} = 1.5{\rm pc}$
- $a_0 = 0.1 R_{\rm CND},\ e_0 = 0.1$
  $i_0 = 80^\circ,\ \omega_0 = 0,\ \Omega_0 = 0$
- $M_{\rm c} = 0.1 M_{\rm BH}$



A way to tidal disruptions



In the Galactic Centre

molecular torus (CND; ring):

$$M_{\rm d} = 0.1 M_{\rm BH}$$
$$R_{\rm d} = 1.6\,{\rm pc}$$

star cluster:

$$\rho(r) \propto r^{-1.75}$$
$$n(e) \propto e$$
$$M_{\rm c}(1.6{\rm pc}) = M_{\rm BH}$$

$$\mathcal{F}(R_{\rm t}) \approx 3 \times 10^{-4}$$
$$N \approx 100$$

(clockwise) stellar disc:

$$M_{\rm d} = 0.01 M_{\rm BH}$$
$$R_{\rm in} = 0.03\,{\rm pc}$$
$$R_{\rm out} = 0.3\,{\rm pc}$$
$$\Sigma(r) \propto r^{-2}$$

star cluster:

$$\rho(r) \propto r^{-1.4}$$
$$n(e) \propto e$$
$$M_{\rm c}(0.4{\rm pc}) = 0.2 M_{\rm BH}$$

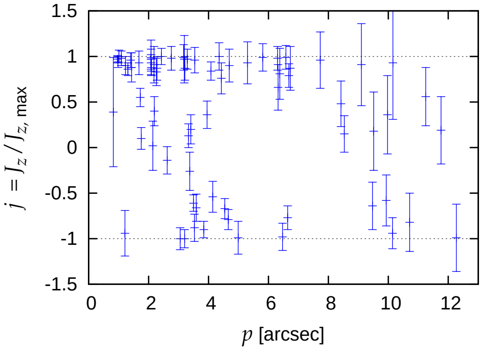
$$\mathcal{F}(R_{\rm t}) \approx 2 \times 10^{-3}$$
$$N \approx 100$$

Young stars in the Galactic Centre

- ≈ 100 young stars observed so far
- OBs, Wolf-Rayets, LBVs
- $M_* \gtrsim 20 M_\odot$
- age $\approx 6\mathrm{Myr}$

Clockwise stellar disc (Genzel et al. 1996, Levin & Beloborodov 2003)

- $N \approx 30$
- $0.03\mathrm{pc} \lesssim R \lesssim 0.3\mathrm{pc}$
- opening angle $\approx 15°$



Genzel et al. 2003, Paumard et al. 2006

Star formation in a massive gaseous disc

Infalling gas cloud $\longrightarrow$ tidal circularization $\longrightarrow$ gaseous disc $\longrightarrow$ fragmentation due to self-gravity (Levin & Beloborodov 2003, Nayakshin 2006, Alexander et al. 2008)

- \+ acceptable model of star formation in the vicinity of a supermassive black hole
- \+ stars formed in a coherently rotating disc
- × model gives small orbital eccentricities (perhaps solvable by more elaborated model of an eccentric disc)
- × cannot explain young stars apparently not beloning to the disc (perhaps solvable by L.Š.)

Orbit precession

Gravity of the circum-nuclear disc causes precession of stellar orbits, i.e. monotonical change of the longitude of the ascending node:

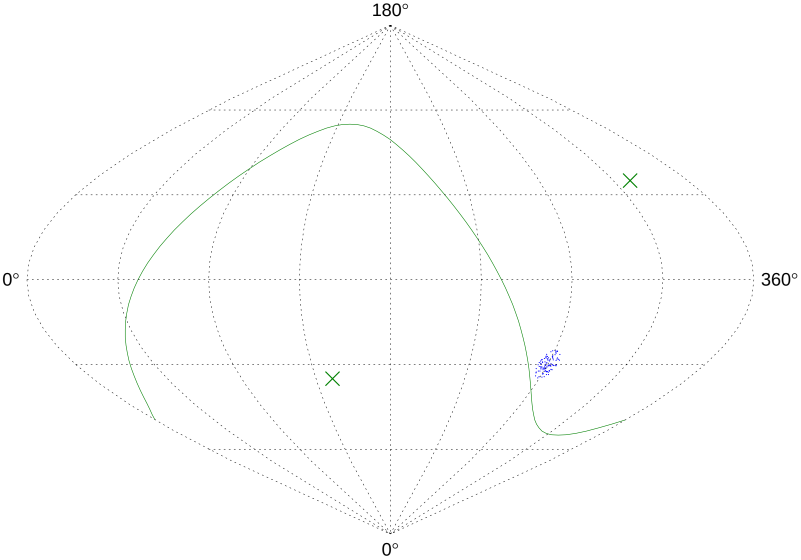
$$\frac{\Delta\Omega}{\Delta t} = -\frac{3}{4}\cos i\; a^{3/2}\,\frac{\sqrt{GM_{\rm BH}}}{R_{\rm CND}^3}\,\frac{M_{\rm CND}}{M_{\rm BH}}\,\frac{1+\frac{3}{2}e^2}{\sqrt{1-e^2}}$$

For $R_{\rm CND} = 1.5{\rm pc},\; M_{\rm CND} = M_{\rm BH},\; \Delta t = 6{\rm Myr}$ and $e = 0$:

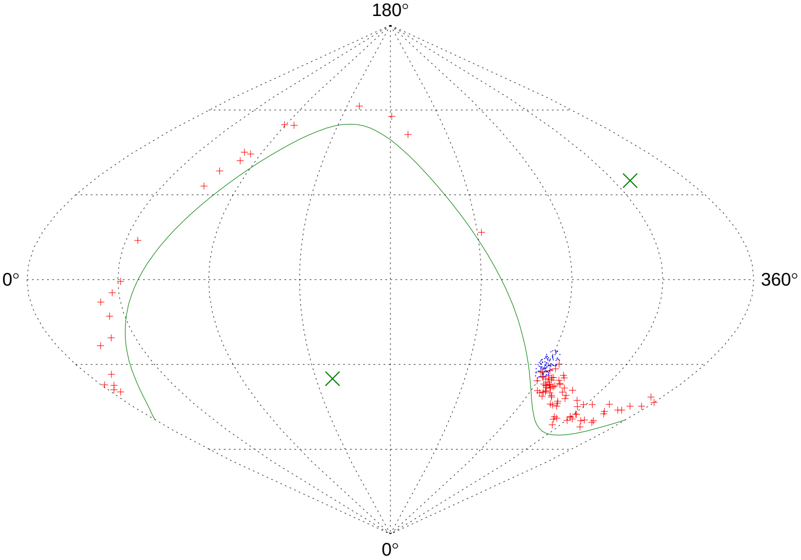
$$\Delta\Omega = -560^\circ\;\cos i\left(\frac{a}{0.1R_{\rm CND}}\right)^{3/2}$$

$\cos(90^\circ) = 0\,,\quad \cos(89^\circ) = 0.017\,,\quad \cos(80^\circ) = 0.17$

Thin stellar disc



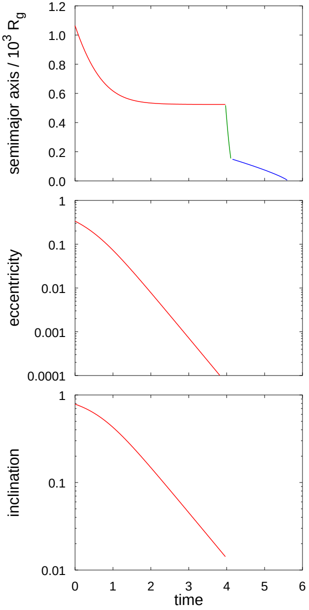
Warped stellar disc



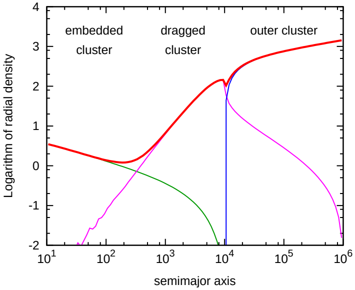
Hydrodynamical drag

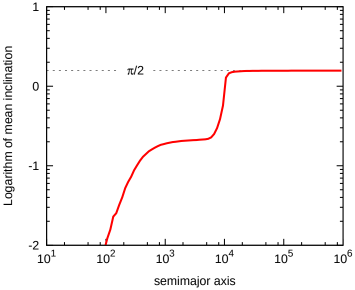
Thin disc: $\Sigma_{\rm d} \propto r^{-\rm s}$, $\rm s \approx 3/4$

- Hypersonic passages through the disc $\longrightarrow$ energy dissipation, circularisation, inclination decay
- $R_{\rm L} = (M_*/M_{\rm BH})^{1/3}\, r < h$: induction of density waves in the disc medium $\longrightarrow$ strong interaction
- opening of gap for larger stellar masses and/or thinner discs $\longrightarrow$ migration coupled to the accretion flow



Stationary cluster





$$t_{\rm relax} = 4\times 10^8 n_6 \left(\frac{M_*}{M_\odot}\right)^{-2} \left(\frac{\sigma}{300\,{\rm km/s}}\right)^{\frac{7}{2}} \left(\frac{r}{r_{\rm g}}\right)^{\frac{1}{4}} {\rm yr}$$

$$t_{\rm drag} \approx M_8 \left(\frac{\Sigma_*}{\Sigma_\odot}\right)^{-1} \left(\frac{a_0}{r_{\rm g}}\right)^{\frac{3}{2}+{\rm s}} {\rm yr}$$

$$\dot{N} \approx 10^{-3} M_8^3\, n_6^2 \left(\frac{M_*}{M_\odot}\right)^{2} \left(\frac{\sigma}{300\,{\rm km/s}}\right)^{-7} \left(\frac{R_{\rm d}}{10^4 r_{\rm g}}\right) {\rm yr}^{-1}$$

Conclusions

- Axisymmetric gaseous structures influence stellar dynamics in the central parsec
- Potentially detectable via
  - tidal disruptions
  - gravitational waves emission
  - dynamics of young stars in the Galactic Centre