bhint the Galactic Centre

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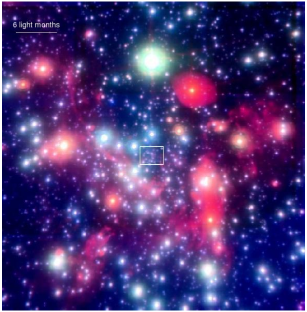
Stellar systems around super-massive black holes are a unique environment.

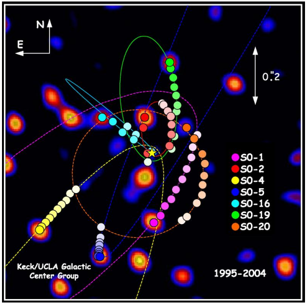
The stellar system around the SMBH in the Galactic Centre is similar to a star cluster:



- Large number of similar mass stars
- Wide ranges of eccentricities and central distances

Stellar systems around super-massive black holes are a unique environment.

However, stellar systems around SMBHs also behave like a planetary system:



- SMBH dominates motion
- Stars move along weakly perturbed Keplerian orbits
- Resonances play an important role

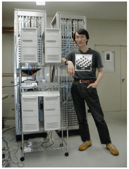
bhint – a Black Hole INTegrator.

Kepler's equation solves the two-body motion exactly.

$$H = \frac{p^2}{2m} - \frac{\mu}{r} \qquad\qquad M = E - e \sin E$$

Idea: Combination of

- High precision of Keplerian orbital motion and
- High speed and flexibility of N-body integrators, including GRAPE and GPU special purpose hardware.



Features of `bhint`

- Special treatment of close encounters and fast approaches
- Post-Newtonian extension
- External potentials

Observations of young stars in the Galactic Centre show two stellar discs at high inclination.

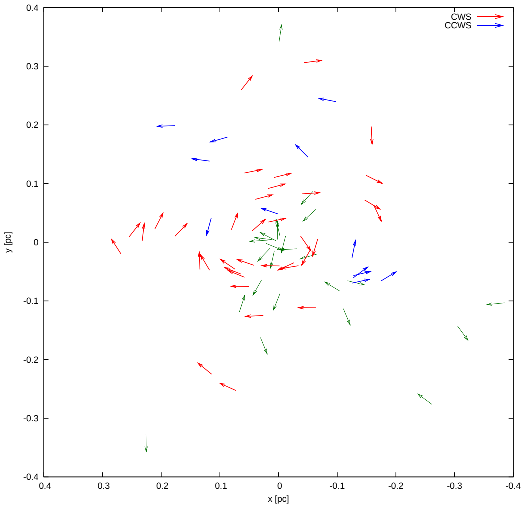


Illustration of stellar discs

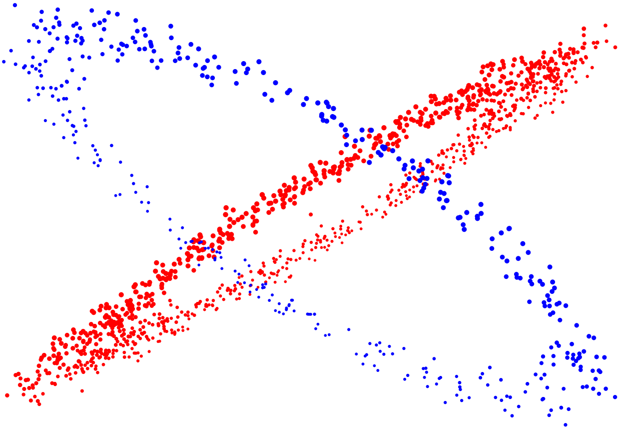


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Illustration of stellar discs

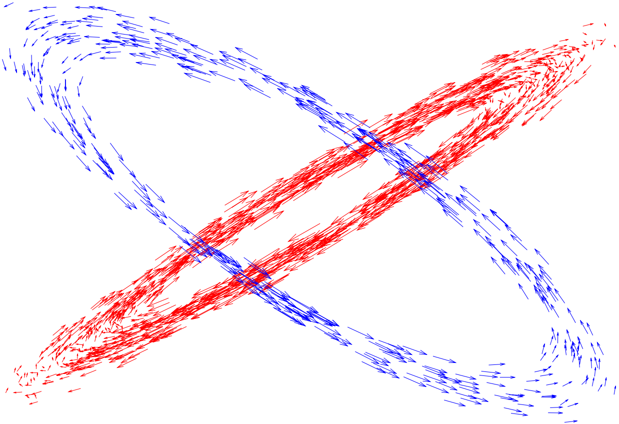


Illustration of stellar discs

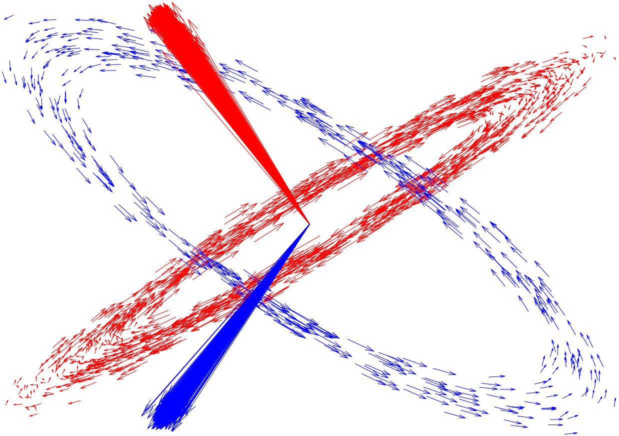
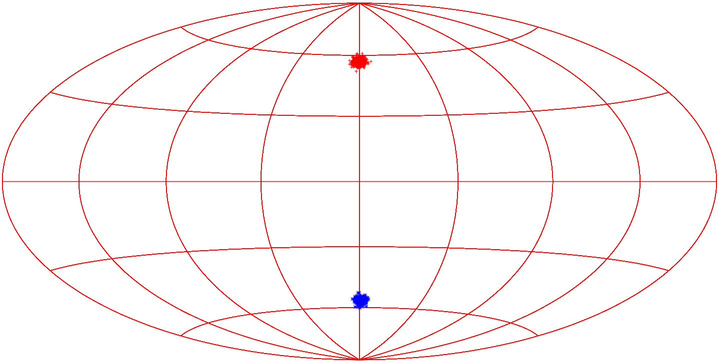


Illustration of stellar discs



Two interacting discs evolve due to mutual torque.

The torque exerted by a ring on a disc particle at radius R is

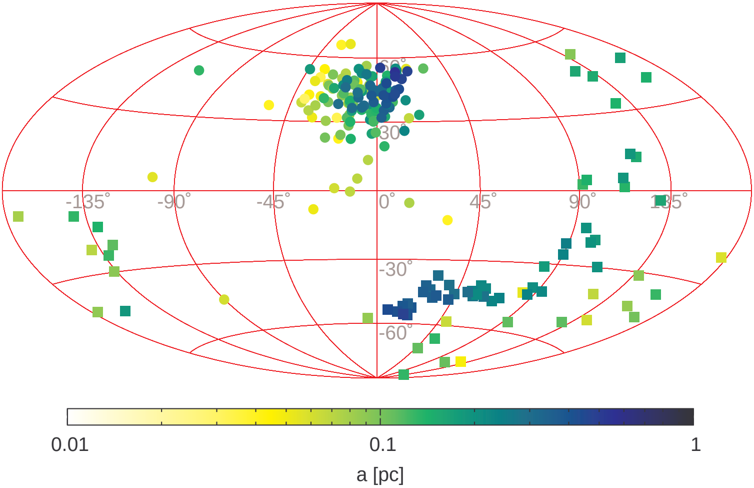
$$\tau = G M_{\text{disc}} M_{\text{ring}} R R_{\text{ring}} \int_0^{2\pi} \frac{\mathrm{d}\phi_1}{2\pi} \int_0^{2\pi} \frac{\mathrm{d}\phi_2}{2\pi} \frac{\mathbf{r}_1 \times \mathbf{r}_2}{|\mathbf{r}_1 - \mathbf{r}_2|^3}$$

For a mutual inclination β, and in an approximation $R \ll R_{\text{ring}}$ or $R \gg R_{\text{ring}}$, this results in a precession frequency of

$$\omega_p = -\frac{3}{4} \frac{M_{\text{ring}}}{M_\bullet} \cos\beta \sqrt{\frac{G M_\bullet}{R^3}} \frac{R^3 R_{\text{ring}}^2}{\left(R^2 + R_{\text{ring}}^2\right)^{5/2}}$$

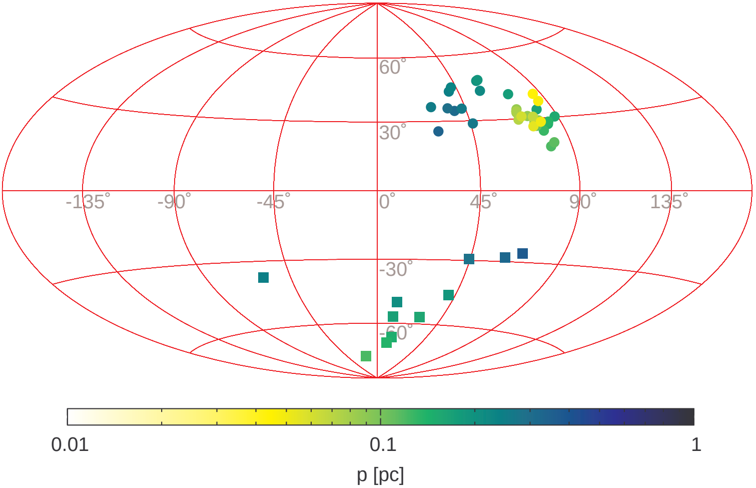
(Nayakshin 2005).

After 5 Myr of simulation, the less massive disc shows significant warping by the massive disc.



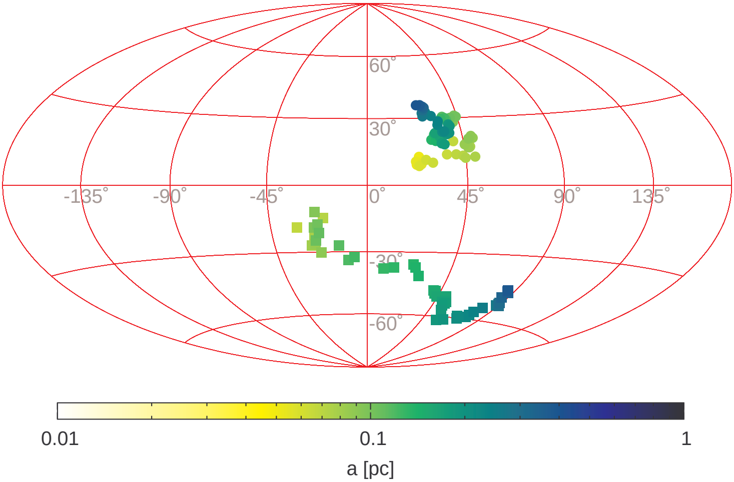
Löckmann & Baumgardt, 2008, MNRAS submitted

Observations of the Galactic Centre also show a warping of both discs. . .



Löckmann & Baumgardt, 2008, MNRAS submitted

. . . with an orientation suggesting an initial inclination $< 90^\circ$.



Löckmann & Baumgardt, 2008, MNRAS submitted

Resonant relaxation dominates GC dynamics. Stellar discs may decrease these time-scales.

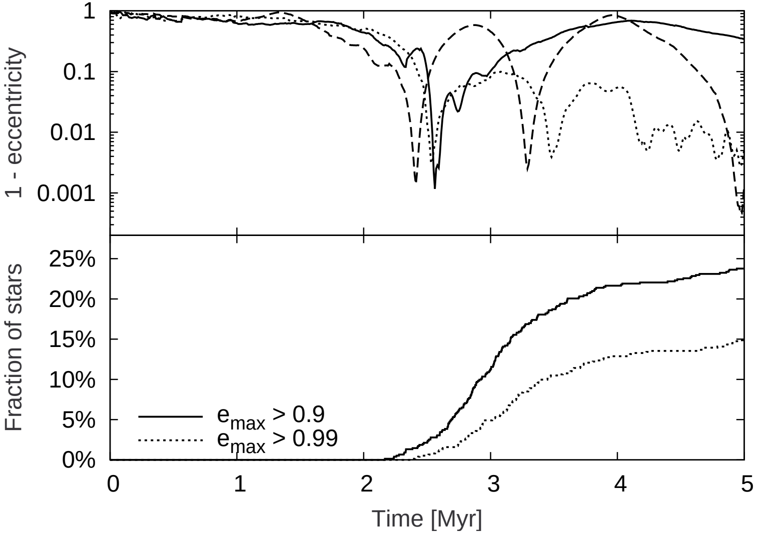
The time-scale on which orbits of $M_\star = 5M_\odot$ stars at 0.1 pc from Sgr A* are randomized by RR is (Rauch & Tremaine 1996)

$$t_{\mathrm{RR}} \sim P M_{\mathrm{SMBH}} / M_\star \sim 1\,\mathrm{Gyr}.$$

Instead of a sum of *random* forces, a disc exerts a force like one massive particle:

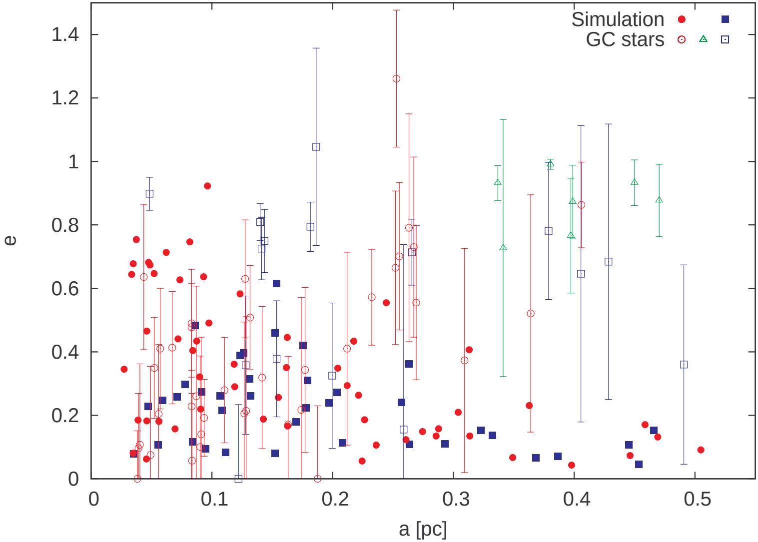
$$t_{e\mathrm{RR}} \sim P M_{\mathrm{SMBH}} / M_{\mathrm{disc}} \sim 1\,\mathrm{Myr}.$$

Even initially flat discs lead to high eccentricities by *enhanced* resonant relaxation within a few Myr.



Löckmann, Baumgardt & Kroupa, 2008, ApJL in press, astro-ph/0807.2239

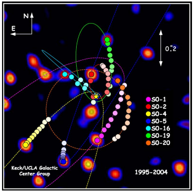
However, this only holds for the inner 0.3 pc or so.



Löckmann & Baumgardt, 2008, MNRAS submitted

At very high eccentricities, close binaries are disrupted.

- Gould & Quillen (2003): S-stars created by binary disruption
  *need very massive star clusters passing close to Sgr A**
- Perets, Hopman & Alexander (2007):
  large population of compact massive perturbers, many young stars on eccentric orbits
- Löckmann, Baumgardt & Kroupa (2008):
  natural result of the interaction of two massive discs



Summary

- Due to mutual torques, two discs warp and destroy each other with time.
- Observations show that both discs exhibit a warping.
- *Enhanced* Resonant Relaxation creates eccentric orbits, the Kozai mechanism can take over and lead to very high eccentricities.
- At very high eccentricities, binaries may get disrupted, leaving behind an S-star and a hyper-velocity star.

Disc warping and *E*RR:

Löckmann & Baumgardt, 2008, MNRAS, submitted

Creation of S-stars:

Löckmann, Baumgardt & Kroupa, 2008, ApJL 683, in press