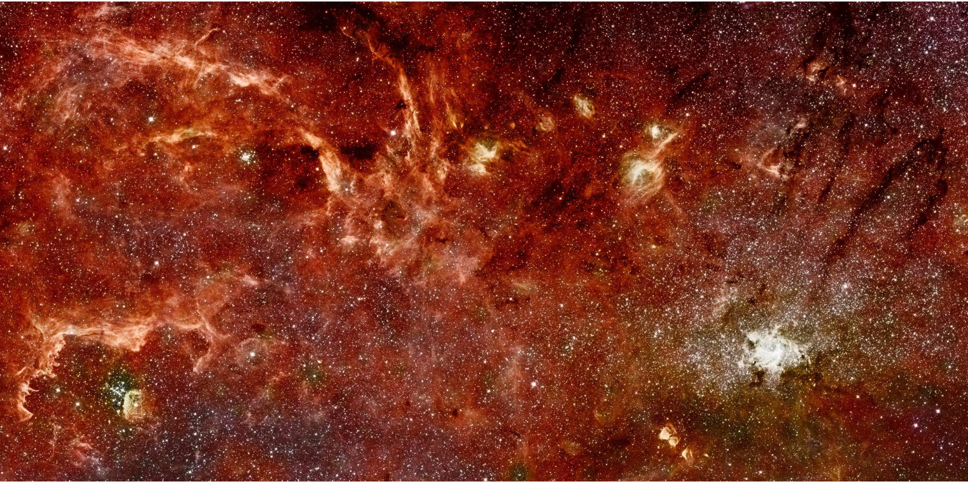
Dynamics of a stellar disc around an SMBH



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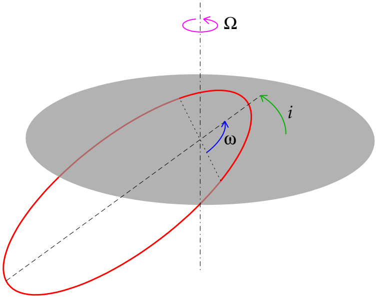
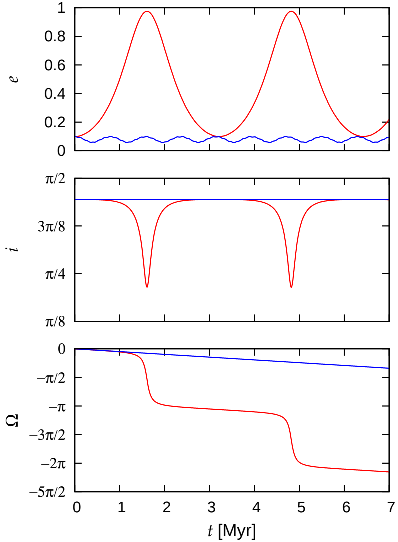
The stage

- numerous population (≈ 200) of young ($\lesssim 6\,$Myr) massive stars within $\lesssim 0.5\,$pc from the SMBH; several tens of them form a well defined disc (Levin & Beloborodov 2003)
- several tens of B-type stars within $0.04\,$pc on randomly oriented and highly eccentric orbits
- young stars embedded in a roughly spherical cluster of late-type stars
- properties of the numerous population of young stars in the Galactic centre indicate non-standard star formation process.
- hypothesis of fragmentation of gaseous disc apparently fails to explain origin of stars outside the stellar disc (including the S-stars)
- ...and, at the same time it motivates study of dynamical evolution of such flattened stellar structures per se

Kozai-Lidov oscillations

Broken spherical symmetry → angular momentum is not an integral of motion → oscillations of eccentricity and inclination
(Kozai 1962, Lidov 1962)





Šubr et al. 2009

Octupole level of the Kozai-Lidov approximation

Higher order expansion of perturbing potential – applies in particular when axial symmetry of the perturbing potential is lost. (see e.g. Katz et al. 2011, Lithwick & Naoz 2011, Li et al. 2014)

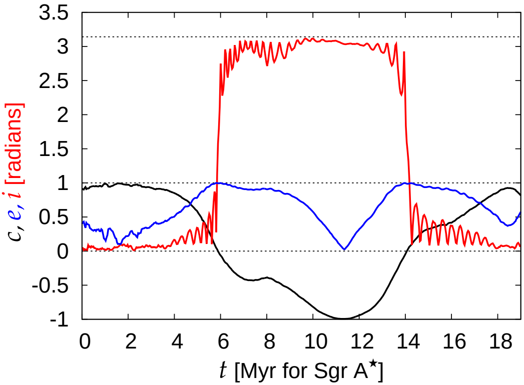
- Secular evolution still possible when the perturbing potential is sufficiently weak
- no conservation of any component of angular momentum $\Rightarrow$ more degrees of freedom
- adiabatic change of Kozai-Lidov ‘integral’, $c \equiv \sqrt{1 - e^2} \cos i$ leads to classical Kozai-Lidov oscillations modulated on long time-scale.

Possible application to the Galactic centre: initially eccentric disc of young stars as a source of perturbing potential influencing dynamics of its individual members.

N-body model description

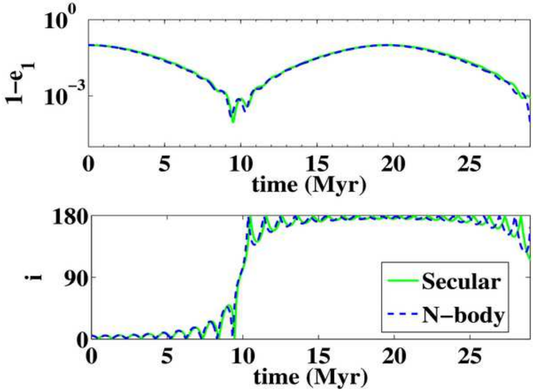
- SMBH treated either as a masisve particle, or fixed Keplerian potential
- disc of 2000 stars on Keplerian orbits around the SMBH
  - semi-major axes in $\langle 0.04\,\mathrm{pc}, 0.4\,\mathrm{pc}\rangle$
  - eccentricity gradient: $e = 0$ at the inner edge $\rightarrow$ $e = 0.9$ at the outer one
  - common direction of eccentricity vectors (nested ellipses)
  - half-opening angle of 2°
  - either zero or 100% binary fraction
- direct N-body integrator NBODY6 (with some tunings)
- see Haas & Šubr 2016 and Šubr & Haas 2016 for more details

‘Eccentric’ Kozai-Lidov oscillations



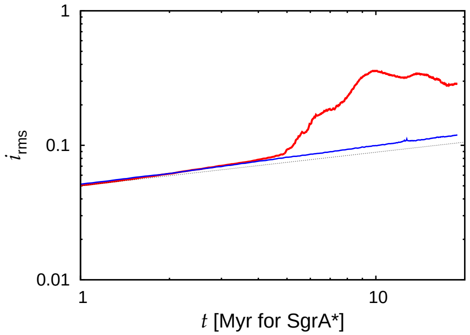
- flips from co-rotation to counter-rotation and vice versa
- extreme values of eccentricity during the flips

‘Eccentric’ Kozai-Lidov oscillations



- flips from co-rotation to counter-rotation and vice versa
- extreme values of eccentricity during the flips
- c.f. Fgr 2 in Li et al. 2014, ApJ, 785, 116

Mean inclination growth

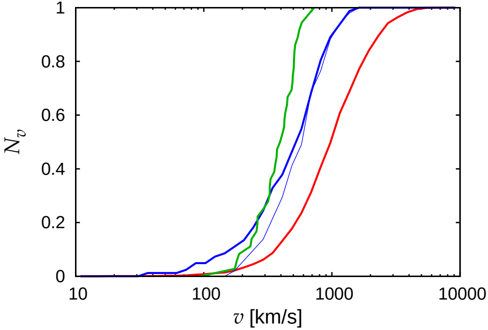


- accelerated growth if $i_{\rm rms}$ due to (relatively coherent) octupole Kozai-Lidov oscillations
- due to geometry of flipping orbits, the large value of $i_{\rm rms}$ does not correspond to large geometrical thikness of the disc

Observational intermezzo – hypervelocity stars

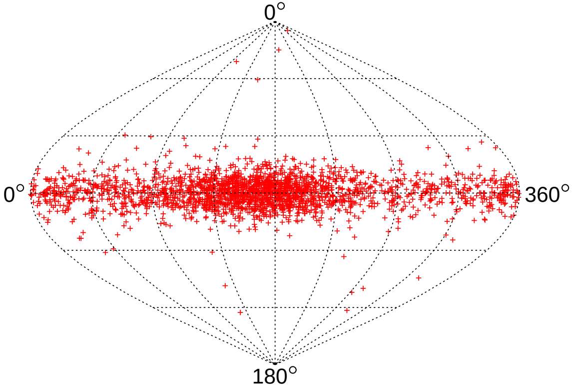
- B-stars observed in the Galactic halo with heliocentric velocity $300\,\mathrm{km\,s^{-1}} \lesssim v \lesssim 1000\,\mathrm{km\,s^{-1}}$ (e.g. Brown et al. 2014)
- about 20 known so far (but large list of possible candidates exists; Vickers et al. 2015)
- velocity vectors indicate Galactocentric origin
- statistically significant spatial anisotropy (incomplete sky syrvey, however)
- predicted already by Hills in 1988 as a consequence of tidal break-up of binary stars passing close to the SMBH in the Galactic centre; their initial companions remain tightly bound to the SMBH $\rightarrow$ unique hypothesis for origin of the HVSs and the S-stars
- the question: Where do the binaries come from?

HVSs formed in the N-body model



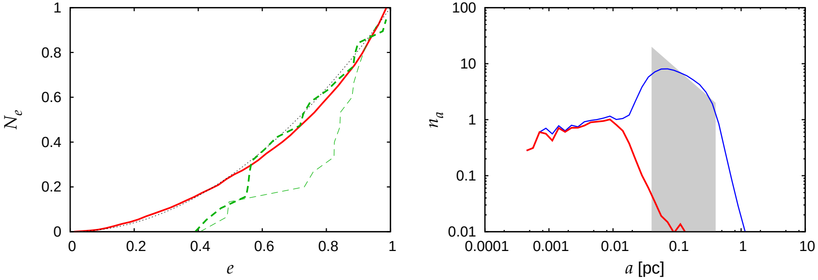
- strong (and non-trivial) dependence on binary semi-major axis distribution and shape of the Galactic potential (our default model – Kenyon et al. 2008)

Spatial anisotropy of the HVSs



- strong anisotropy – both lattitude and longitude

S-stars in the N-body model



- All stars in the disc and the S-stars

  S-star ≡ what remains after the Hills break-up

- Observed S-stars below 1″

  (Gillessen et al. 2009; Gillessen et al. 2016)

Summary

- ‘disc scenario’ of formation of stars in galactic nuclei implies resonant dynamics (not only of the young stars!)
- secular dynamics depends on many parameters of the system
- observational data really great(!), but still leave us with only few stars with well determined orbits (including the HVSs)
- need to search for features characteristic for individual dynamical processes
    - ◇ positive example: anisotropic distribution of HVSs
    - ◇ not so positive example: distribution of orbital elements of the S-stars