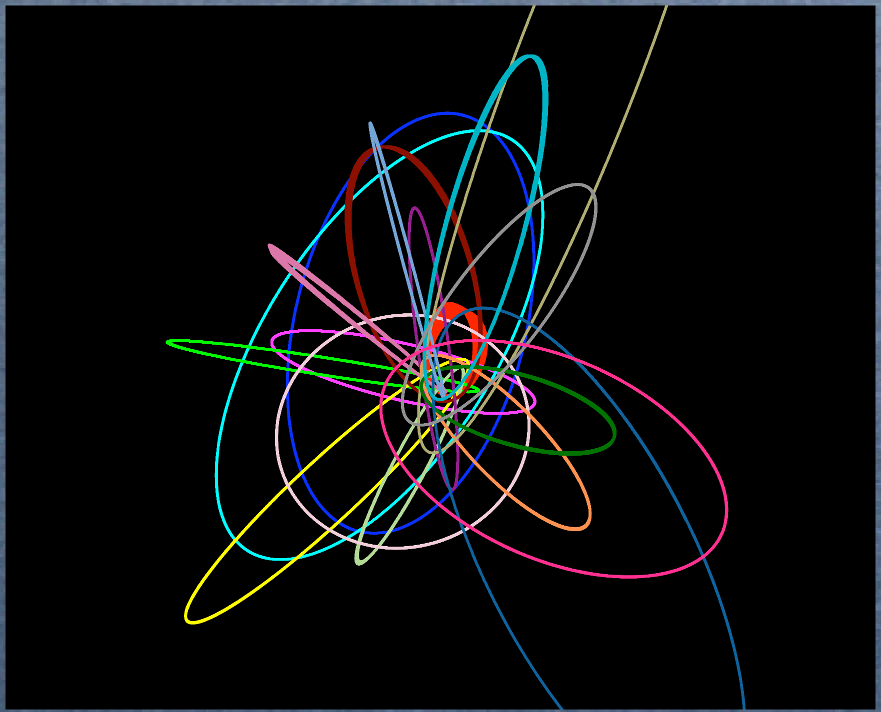
Evolution of the nuclear star cluster



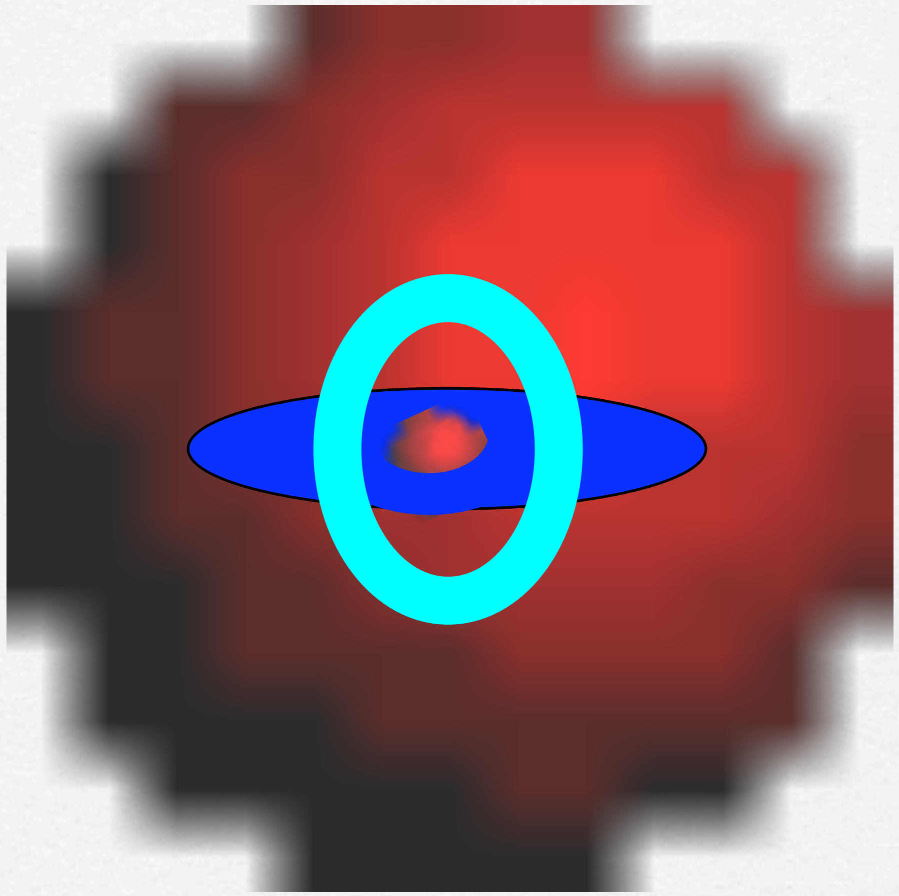
Alessia Gualandris

Rochester Institute of Technology

Collaborators: Stefan Harfst, David Merritt, Seppo Mikkola, Hagai Perets

The Galactic center

- SMBH $M = 4 \times 10^6 M_\odot$
- Stellar cusp $d \lesssim 3$ pc
- CW stellar disk
  scale 0.05 - 0.5 pc, mass 10^3-10^4 $M_\odot$,
  OB stars, age ~ 5 Myr
- ? CCW inclined disk
- S-cluster N ~ 20 B-type stars
  5-50 mpc, random orientations



Simulating the Galactic center

- φGRAPE: parallel direct summation N-body code, 4th order Hermite integrator, predictor-corrector scheme, GRAPE support

Harfst, Gualandris, Merritt, Portegies Zwart, Berczik (2007)

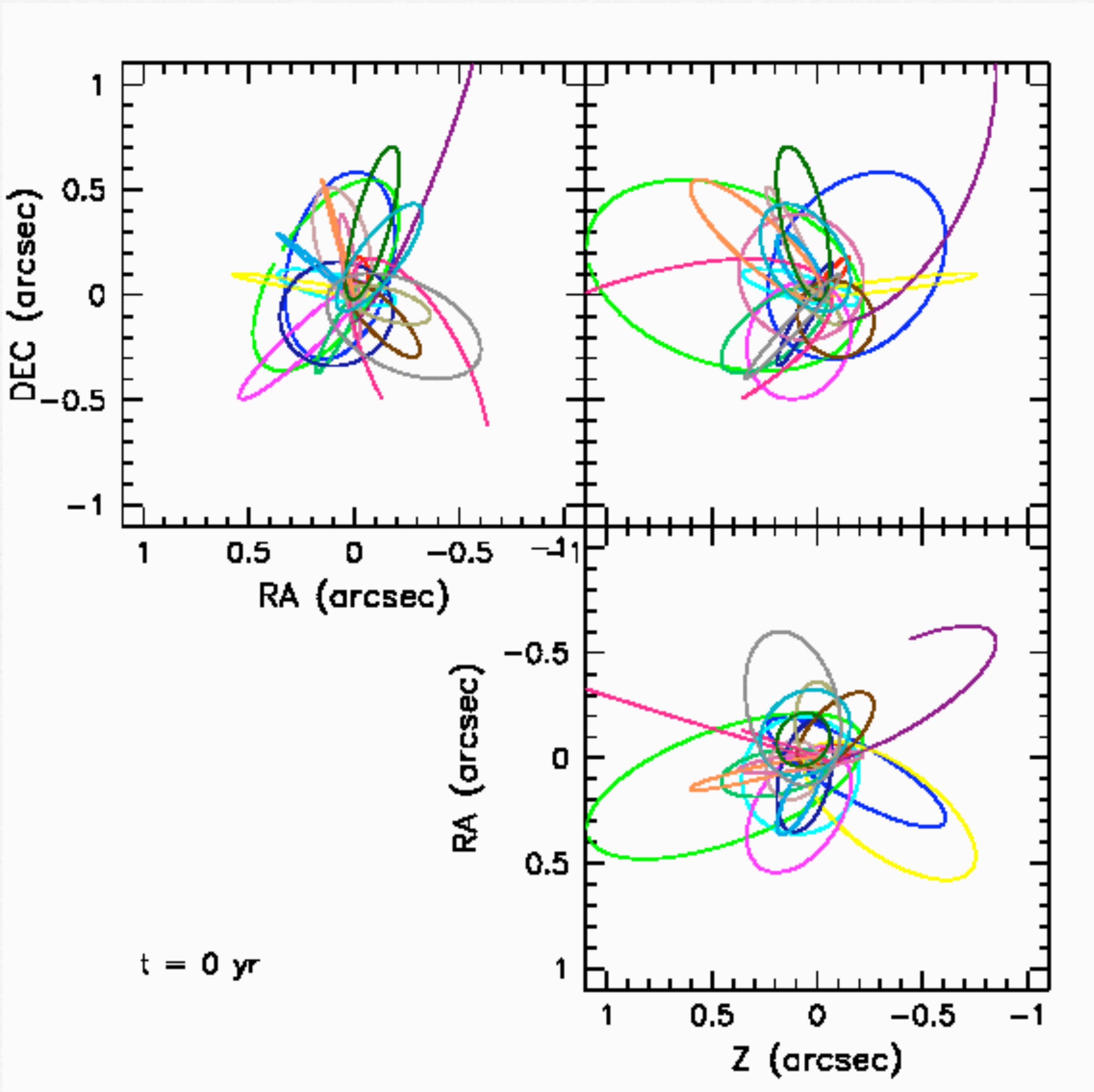
- AR-CHAIN: algorithmic regularization code with PN terms up to order 2.5

Mikkola & Merritt (2008)

- φGRAPEch: hybrid N-body φGRAPE + chain regularization

Harfst, Gualandris, Merritt, Mikkola (2008)

Evolution of the S-stars



19 S-stars

$M_{SMBH} = 4\times10^{6}\,M_\odot$

$m_{s\text{-}stars} = 10\,M_\odot$

Simulations performed with AR-CHAIN

Evolution of the S-stars

GR precession - PN terms

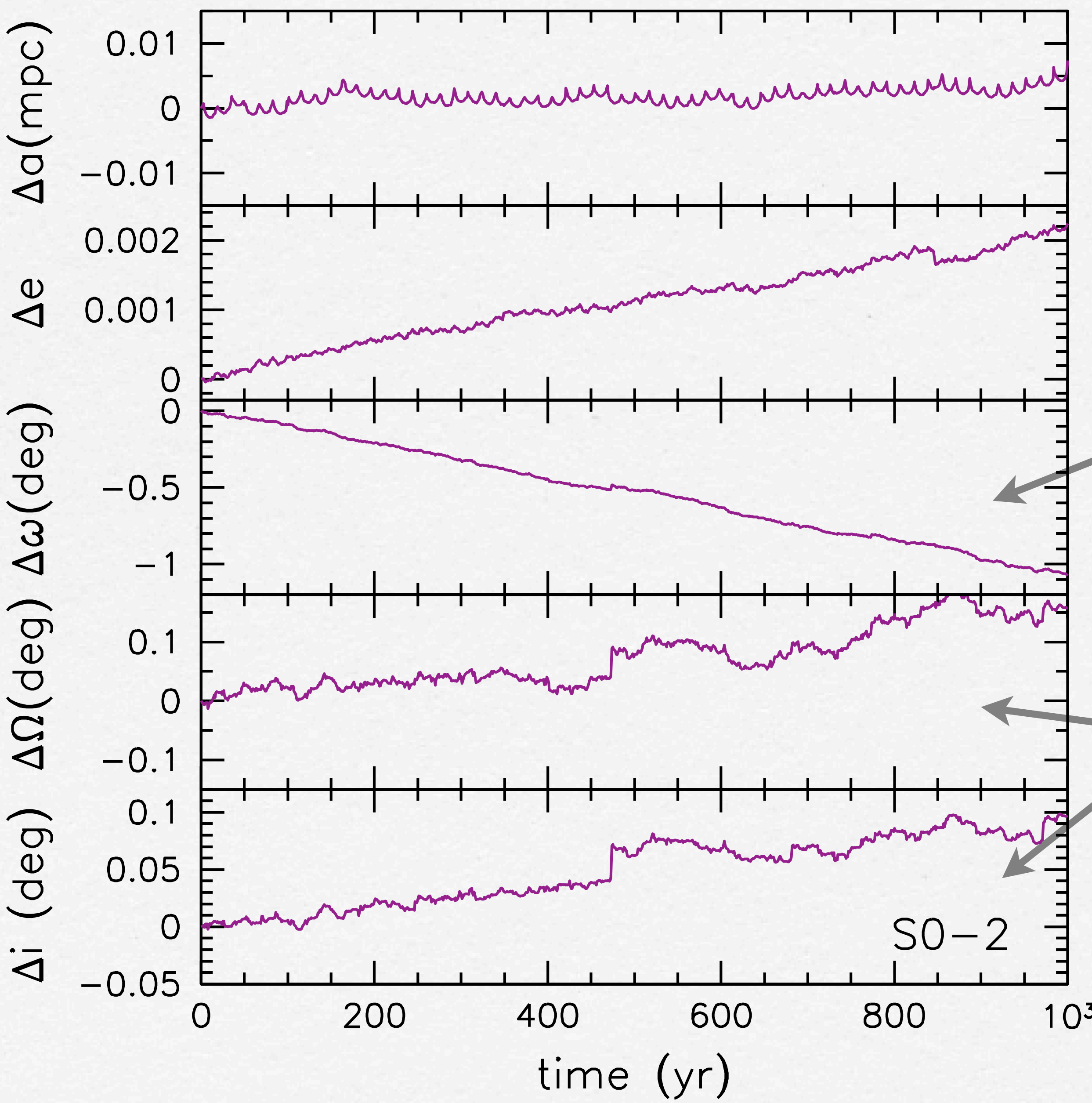
$$T_P = \frac{2\pi}{3}\frac{c^2}{G^{3/2}}(1-e^2)\frac{a^{5/2}}{M_{\rm BH}^{3/2}}$$

$$\simeq 8.2\times10^5\,{\rm yr}\left(\frac{\rm a}{10\,{\rm mpc}}\right)^{5/2}\left(\frac{4\times10^6{\rm M}_\odot}{\rm M_{BH}}\right)^{3/2}(1-{\rm e}^2)$$

Evolution of the S-stars in the stellar cusp

- Hopman & Alexander (2006) multi-mass model
  $N = 75000$ $r < 0.01$ pc
- SMBH $M_{SMBH} = 3 \times 10^6 M_\odot$
- MS stars $m = 1 M_\odot$, WD $m = 0.6 M_\odot$,
  NS $m = 1.4 M_\odot$, BH $m = 10 M_\odot$
- S-stars: S0-2, S0-16, S0-19, S0-20, S0-1
  $m = 15 M_\odot$

Evolution of the S-stars in the stellar cusp



$N = 7.5 \times 10^4$ stellar cusp

Newtonian precession

$\Delta\omega \propto M_*(<r)/M_{BH}$

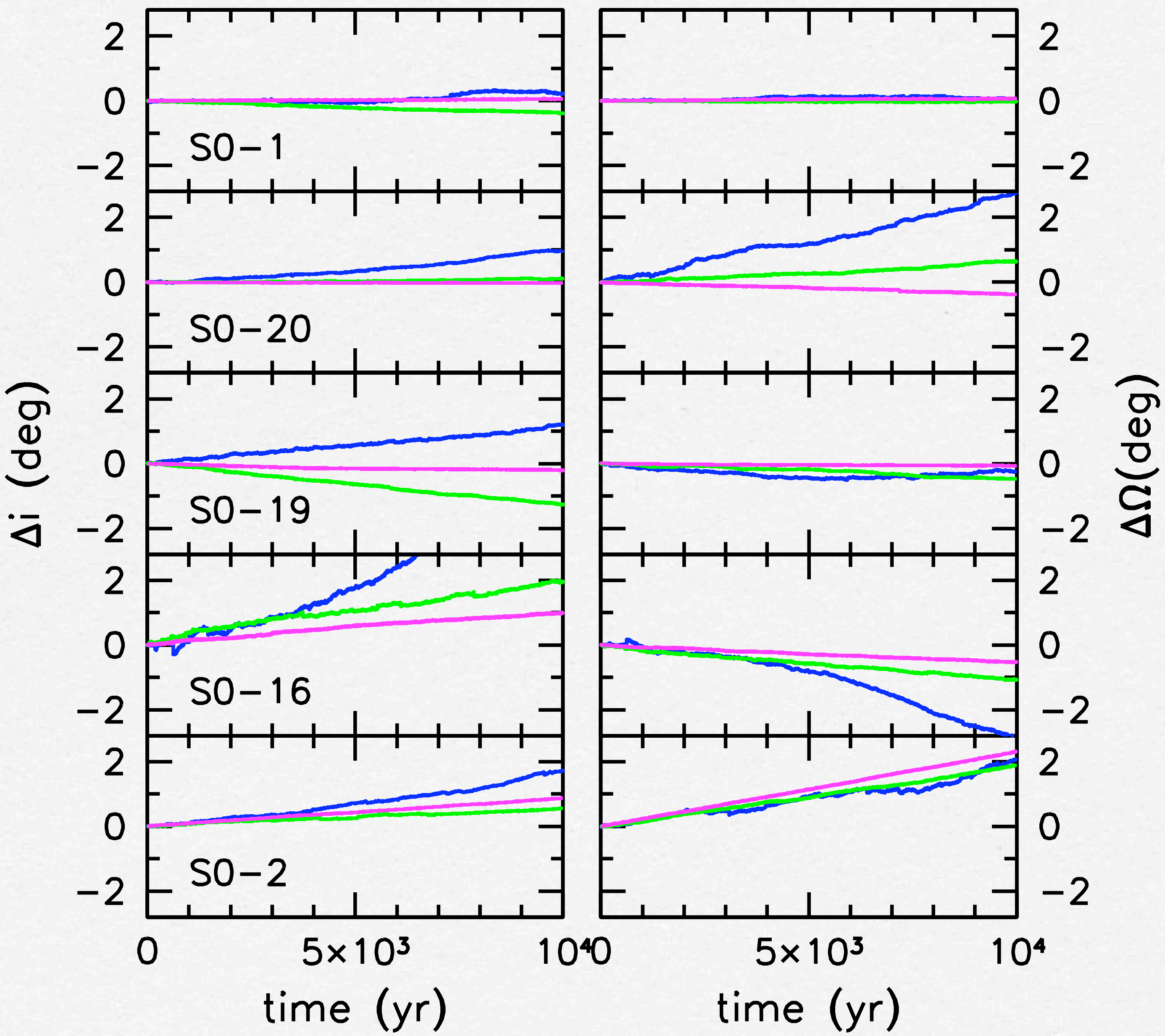
retrograde

Resonant relaxation

Simulations performed with
φGRAPEch

Harfst, Gualandris, Merritt, Mikkola (2008)

Evolution of the S-stars in the stellar cusp



Deviations of the potential from spherical symmetry

⇩

$$\Delta(i,\Omega) \approx A\frac{m}{M_\bullet}N^{1/2}\frac{t}{P}$$

$$\approx A\frac{m}{2\pi}\left(\frac{GN}{M_\bullet a^3}\right)^{1/2} t$$

Rauch & Tremaine (1996)

for $A = 1$ $t = 10^4$ yr

$\Delta(i,\Omega) = 0.5^\circ$ $a = 10$ mpc

$\Delta(i,\Omega) = 1^\circ$ $a = 2$ mpc

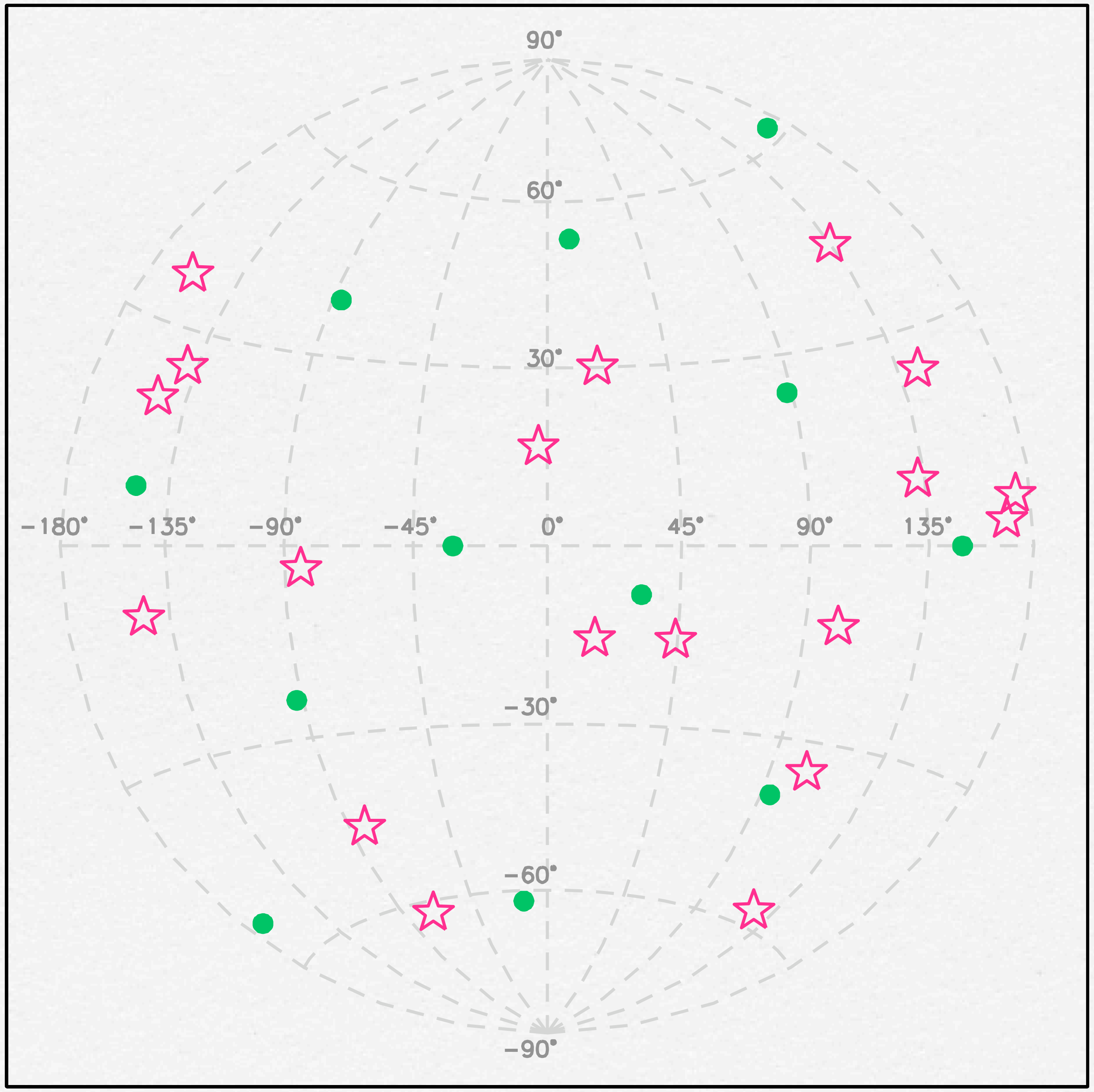
$2 < A < 3$

Simulations performed with

φGRAPEch

Wednesday, August 13, 2008

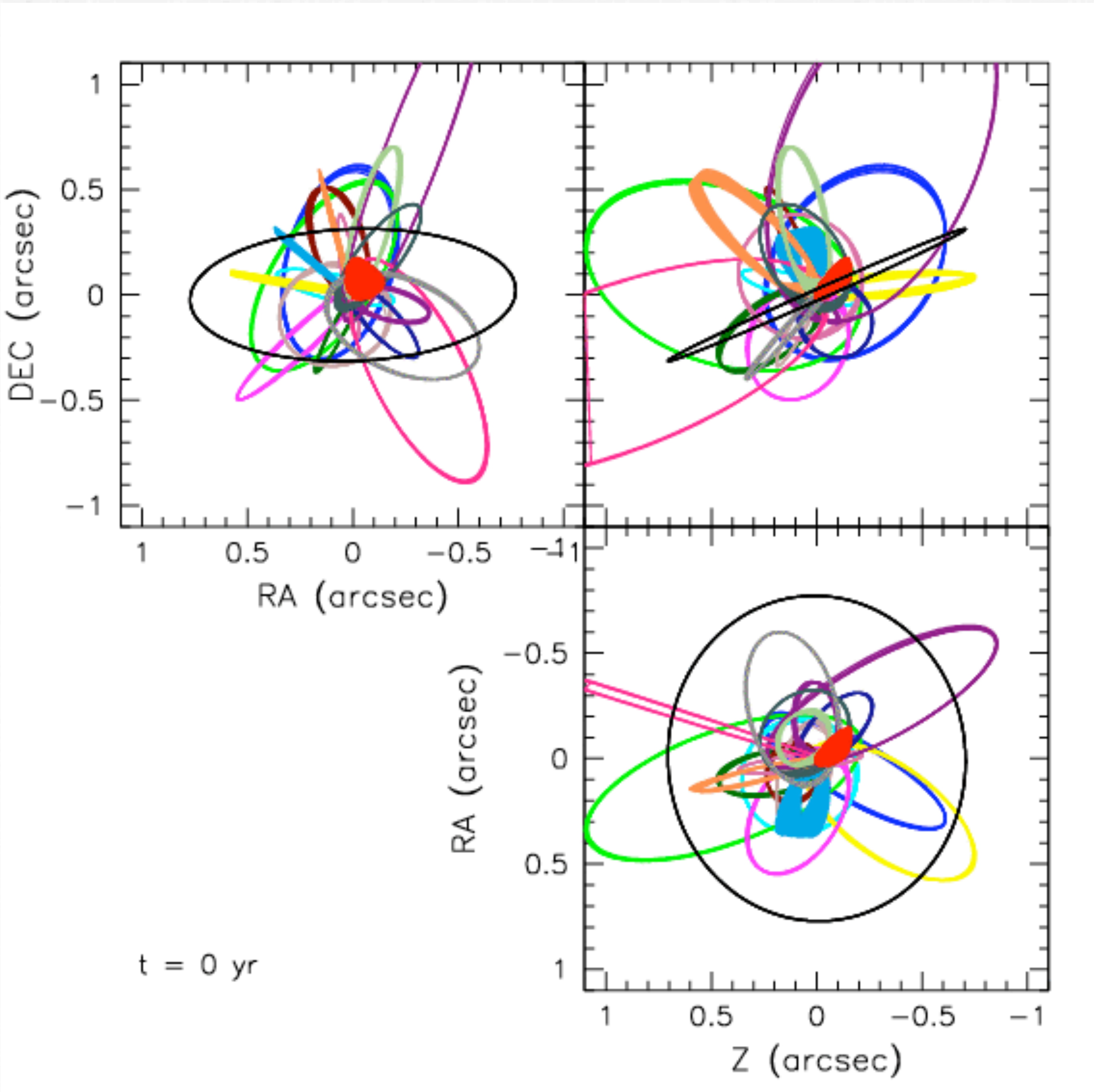
Evolution of S-stars + IMBH



- SMBH $M_{SMBH} = 4 \times 10^6 M_\odot$
- 19 S-stars $m = 10 M_\odot$
- IMBH $M_{IMBH} = 400, 1000, 2000, 4000 M_\odot$
- $a = 0.3, 1, 3, 10, 30$ mpc
- 12 positions on the sky
- $e_{IMBH} = 0$

Gualandris & Merritt (in prep.)

Evolution of S-stars + IMBH



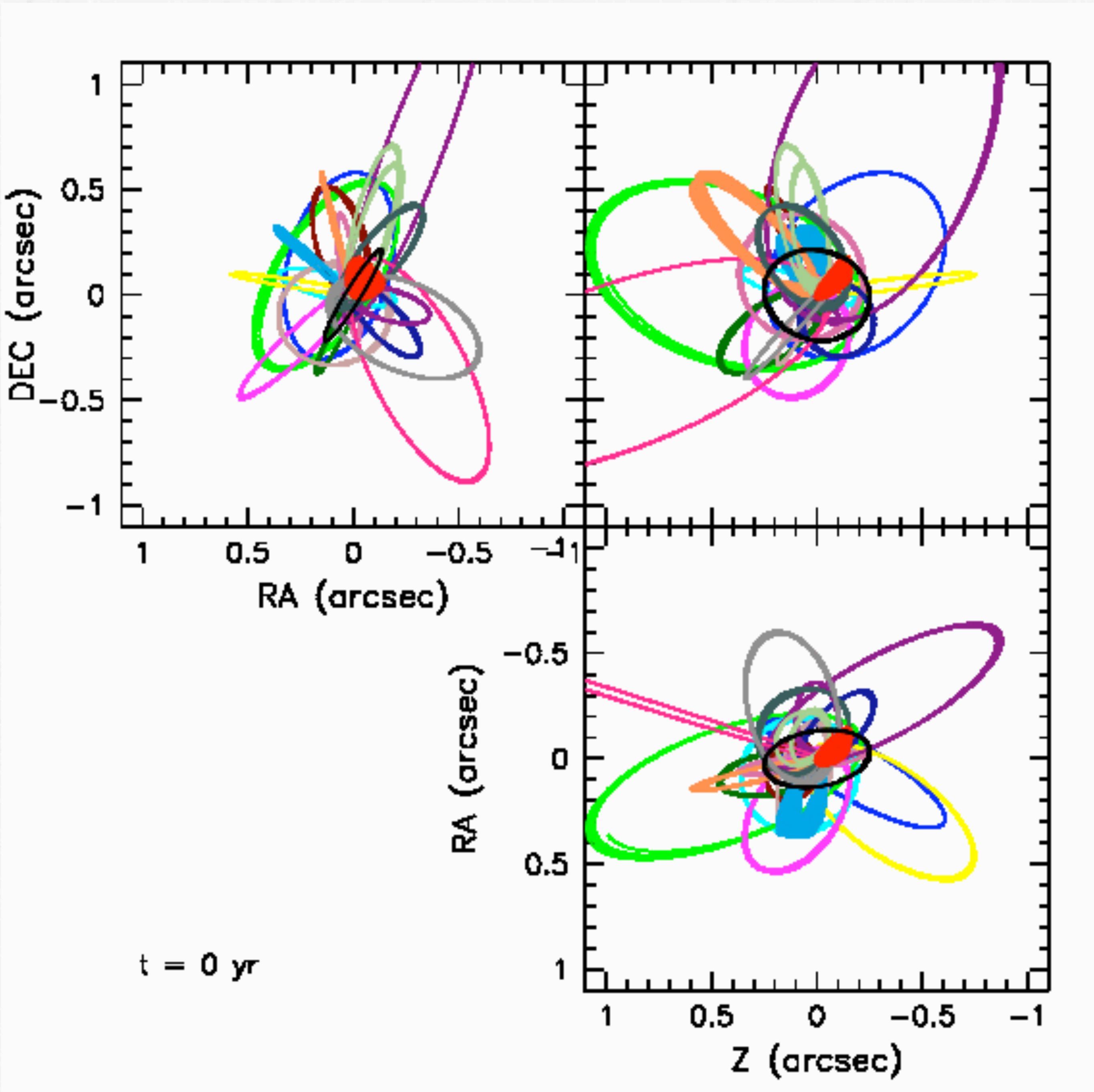
M_IMBH = 4000M⊙

a = 30 mpc

perturbations

Simulations performed with AR-CHAIN

Evolution of S-stars + IMBH



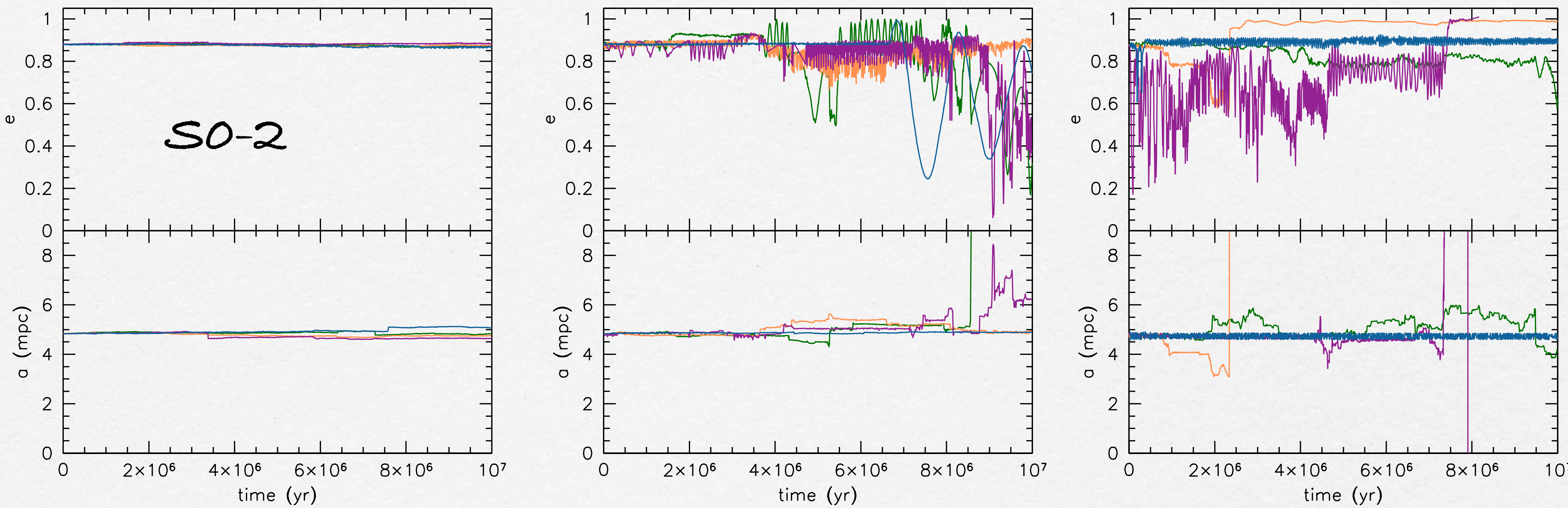
M_IMBH = 2000M☉

a = 10 mpc

ejection

Simulations performed with AR-CHAIN

Evolution of S-stars + IMBH

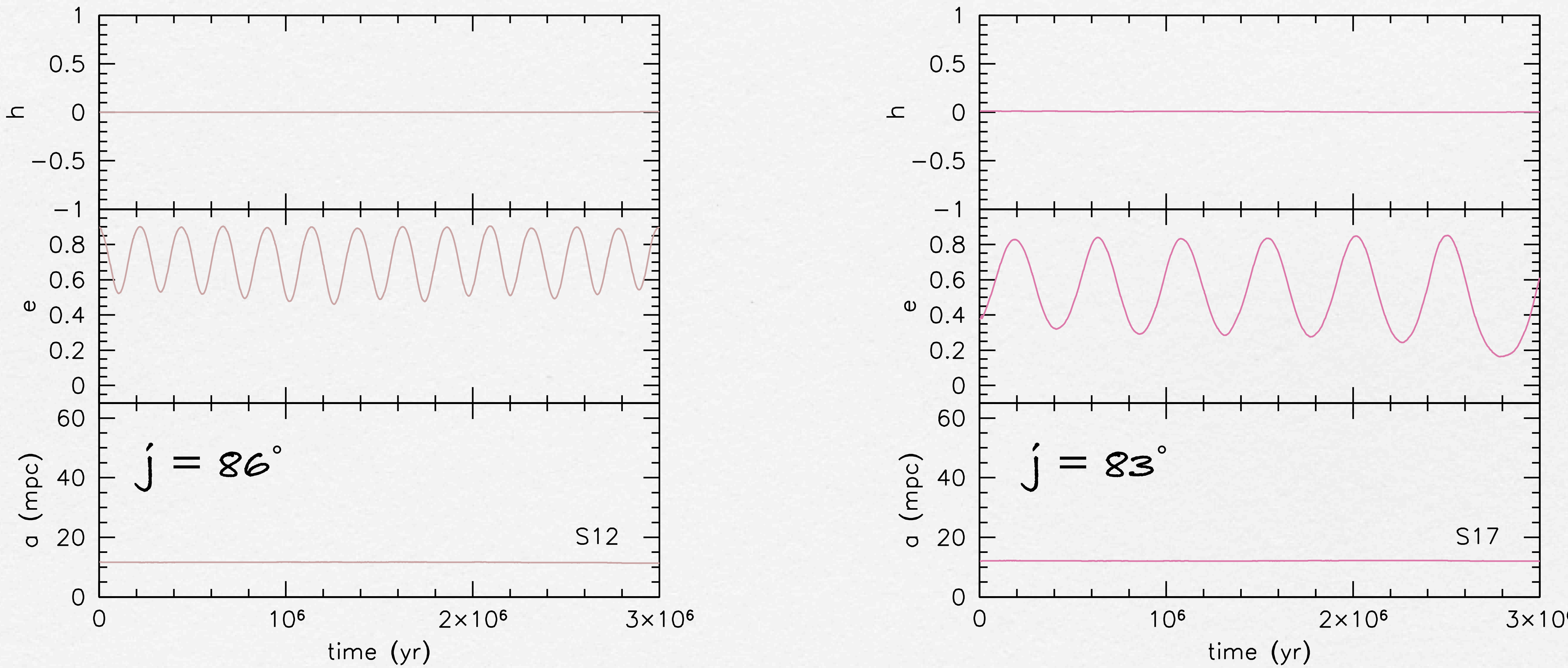


a_{IMBH} = 30 mpc a_{IMBH} = 10 mpc a_{IMBH} = 3 mpc

Simulations performed with AR-CHAIN

Gualandris & Merritt (in prep.)

Evolution of S-stars + IMBH



$$h = (1 - e^2)\, cos^2(j)$$

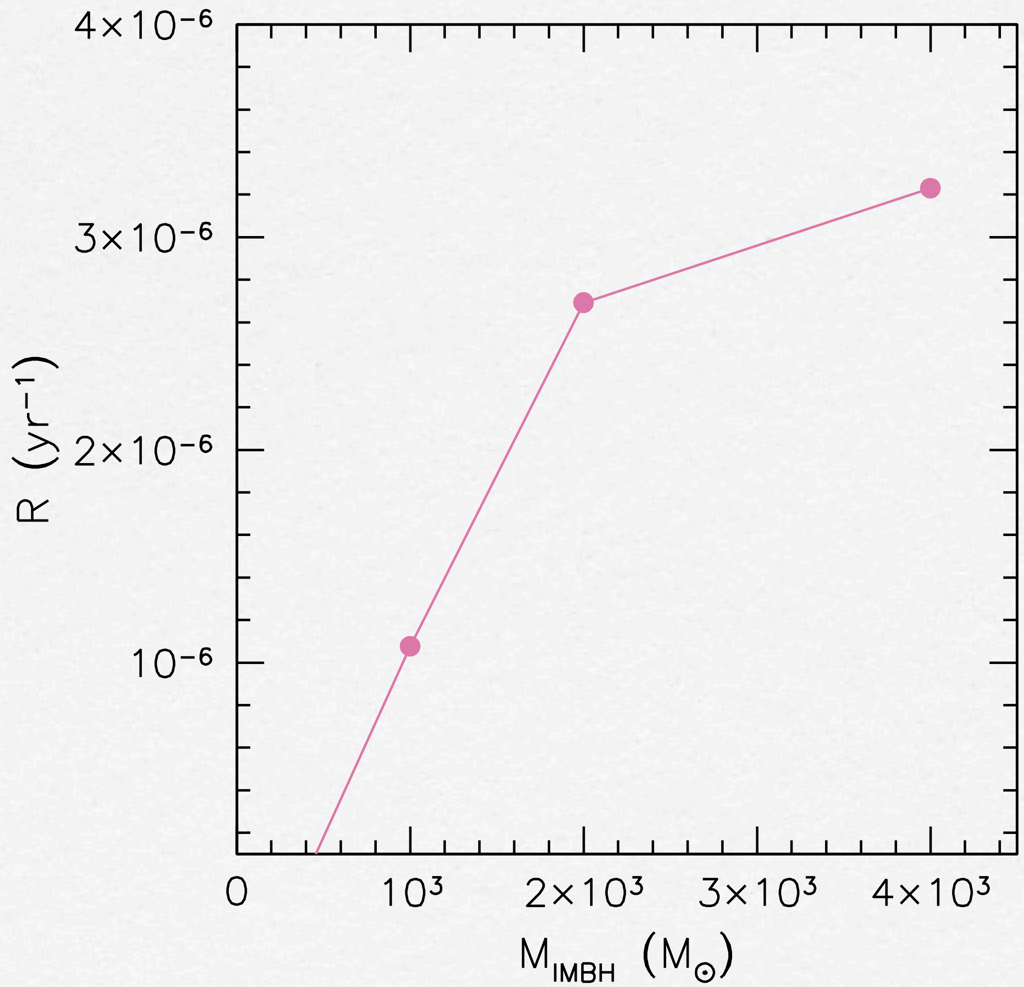
Kozai integral

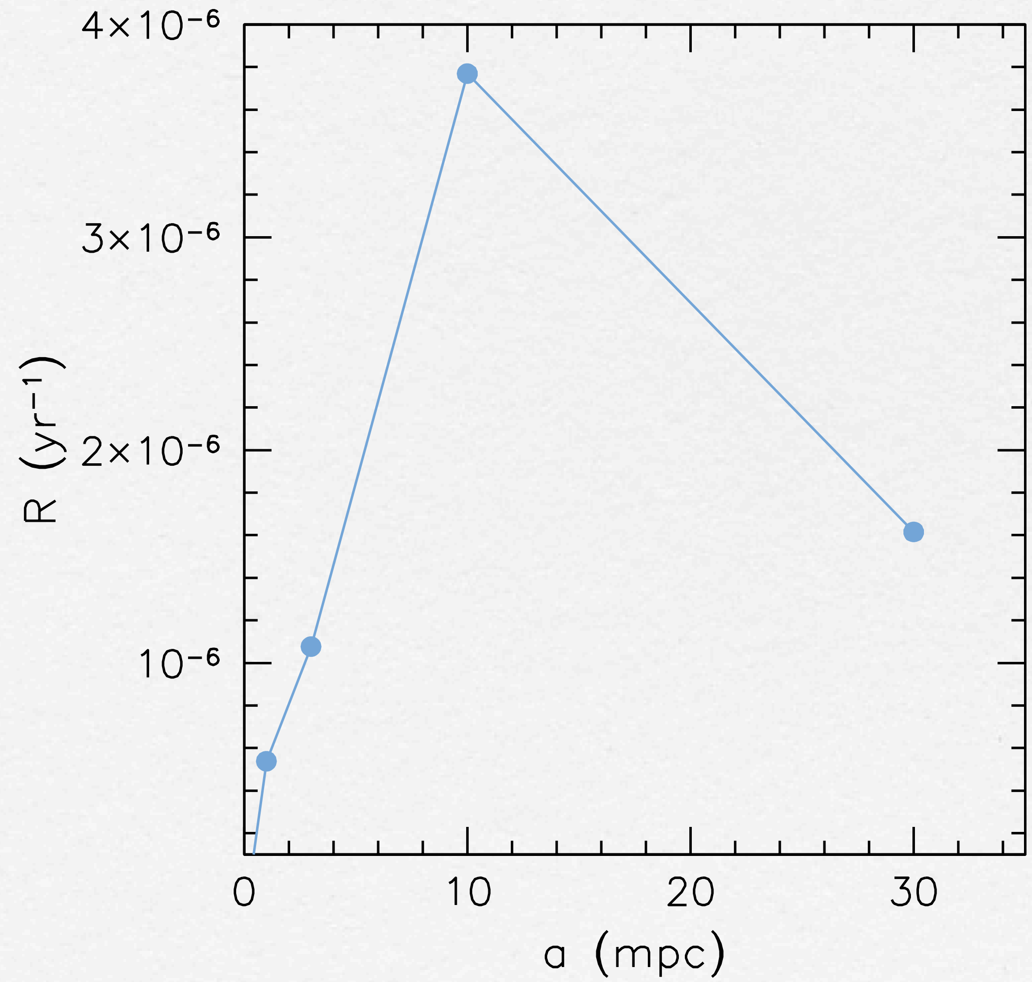
Evolution of S-stars + IMBH

Rate of stellar captures

(13/100) x (10^4/19) ~ 70 captures/10 Myr

R ~ 7×10^{-6} yr^{-1}





Origin of the S-stars

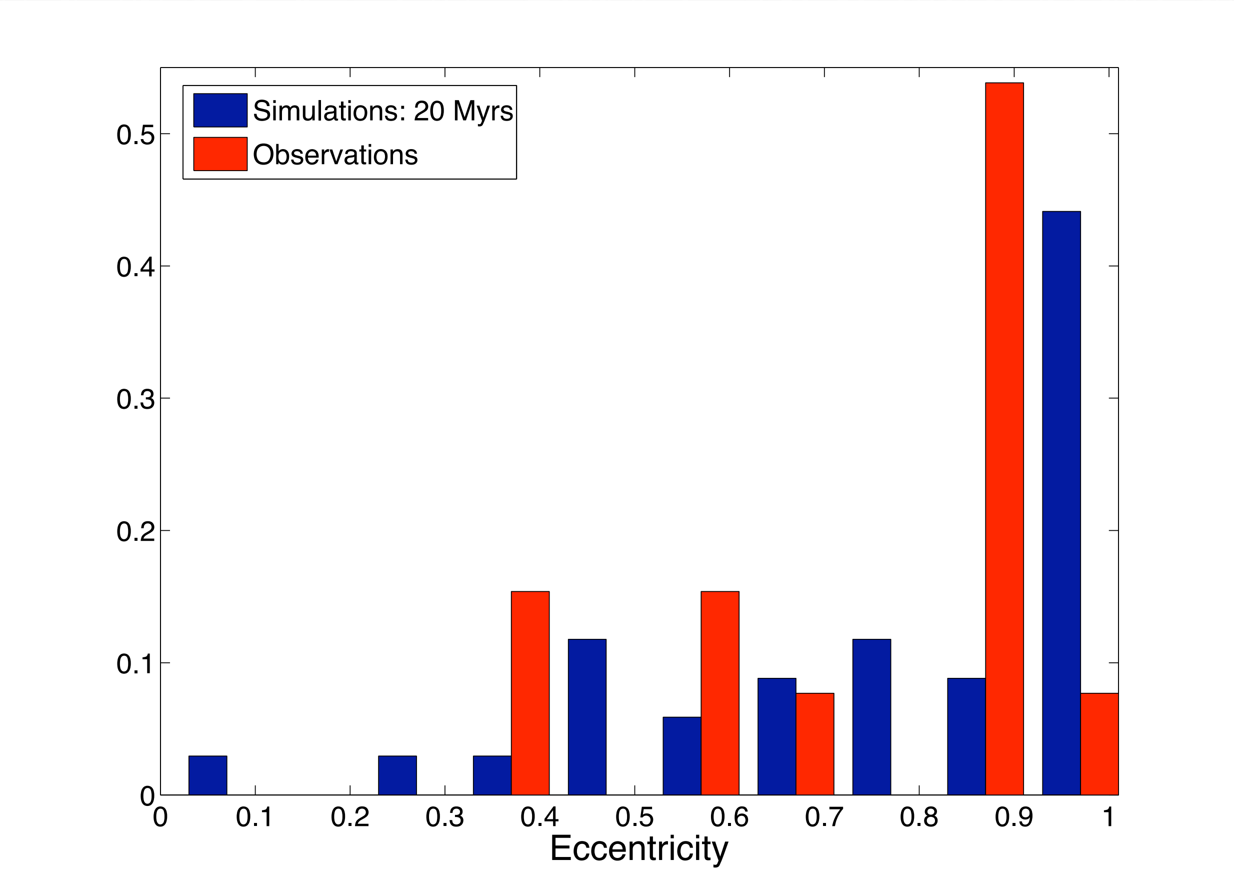
- captured during a 3-body encounter stellar binary + SMBH
  $\Rightarrow$ high eccentricity
- formed in a gaseous disk and migrated to current location $\Rightarrow$ low eccentricity

Origin of the S-stars

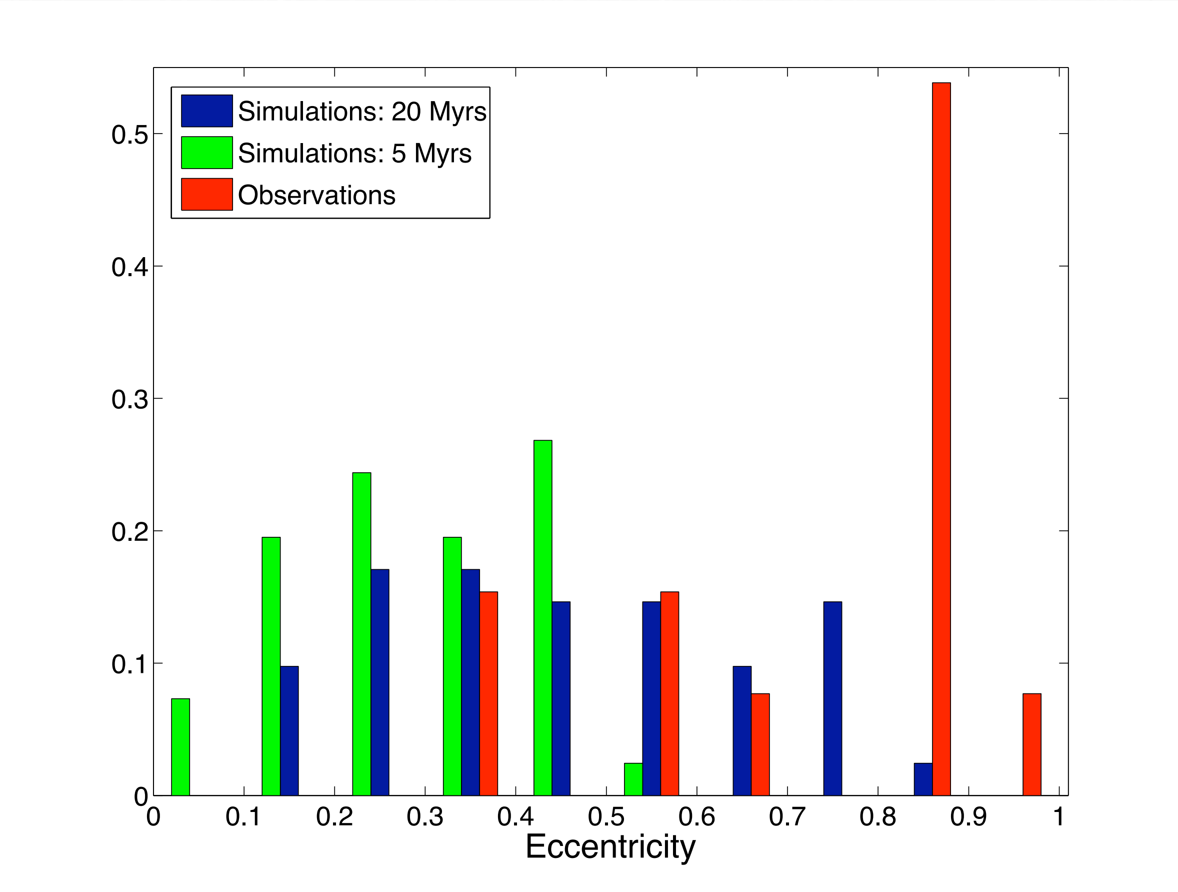
- Isotropic cusp $N = 1200$
- $N_1 = 1000$ $N_2 = 200$
- $m_1 = 3\ M_\odot$ S-stars, $m_2 = 10\ M_\odot$ bhs
- $M_{BH} = 3.6\times10^6\ M_\odot$
- Power-law distribution $r^{-\alpha}$, $0.001 < r < 0.05$ pc
  $\alpha = 2$ for bhs, $\alpha = 1.5$ for s-stars

Origin of the S-stars

Eccentricity distribution



high initial eccentricities (e>0.96) binary disruption



low initial eccentricities (e<0.3) disk origin

Simulations performed with φGRAPE

Perets, Gualandris, Merritt, Alexander (in prep.)

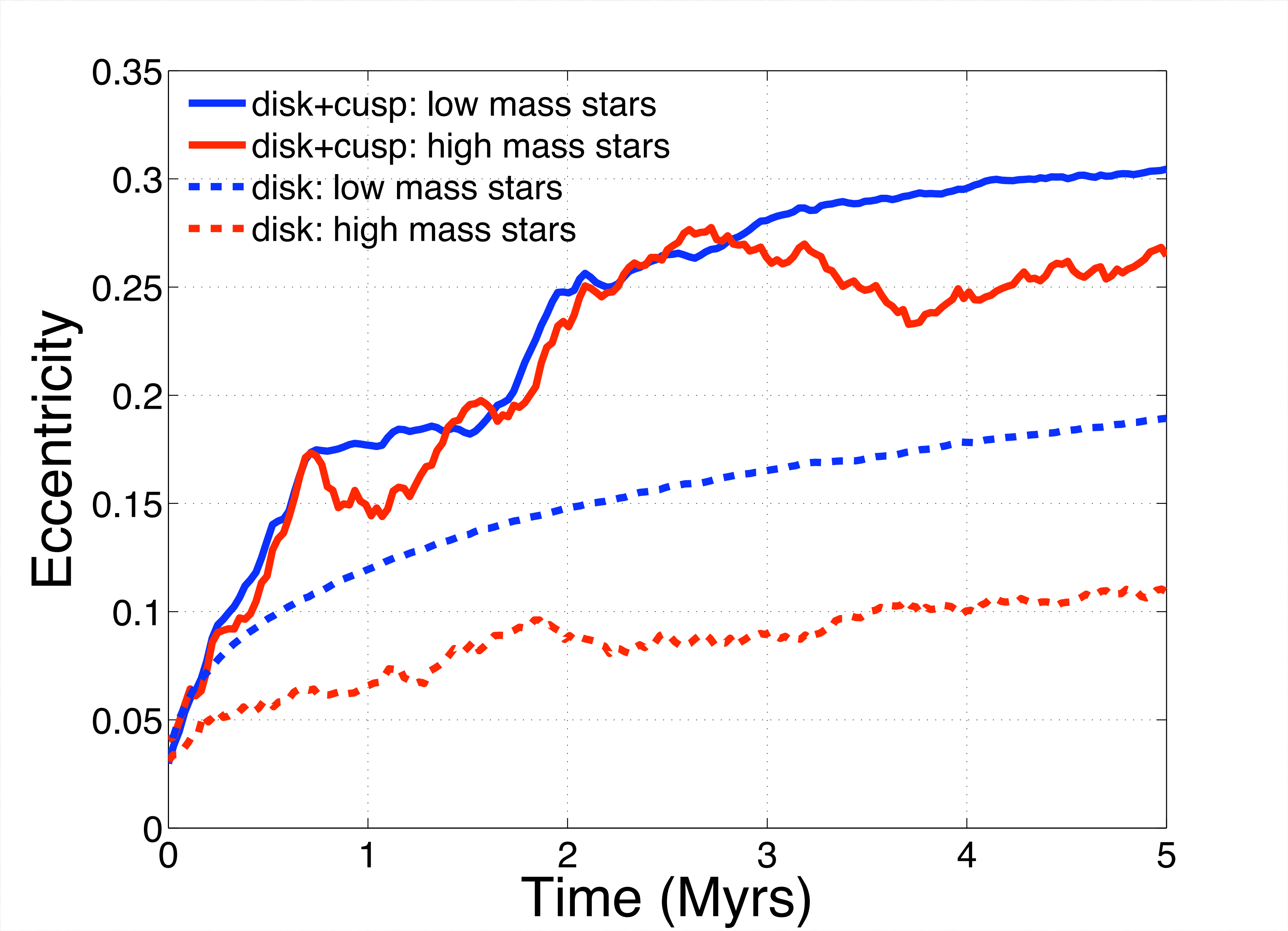
Evolution of the stellar disk

- Stars in the CW disk have significant eccentricities: $e > 0.2$ (Paumard et al. 2006), $e > 0.4$ (Lu et al. 2006)
- Stars in the CCW disk $e > 0.8$ (Paumard et al. 2006)
- Origin of disk stars: in situ formation from an accretion disk

Evolution of the stellar disk

- Single stellar disk $M = 5000\ M_\odot$
  - $N = 5000$ equal mass stars
  - $N = 2500$ stars with Salpeter mass function
- thin disk ($H/R \sim 0.01$), all stars $\sim$ circular ($e \lesssim 0.01$), surface density $\sim r^{-2}$
- $M_{BH} = 3.6\text{x}10^6\ M_\odot$
- with/without stellar cusp ($1.6\text{x}10^4$ black holes $m = 10\ M_\odot$, r^{-2} power-law distribution between 0.01-0.8 pc)

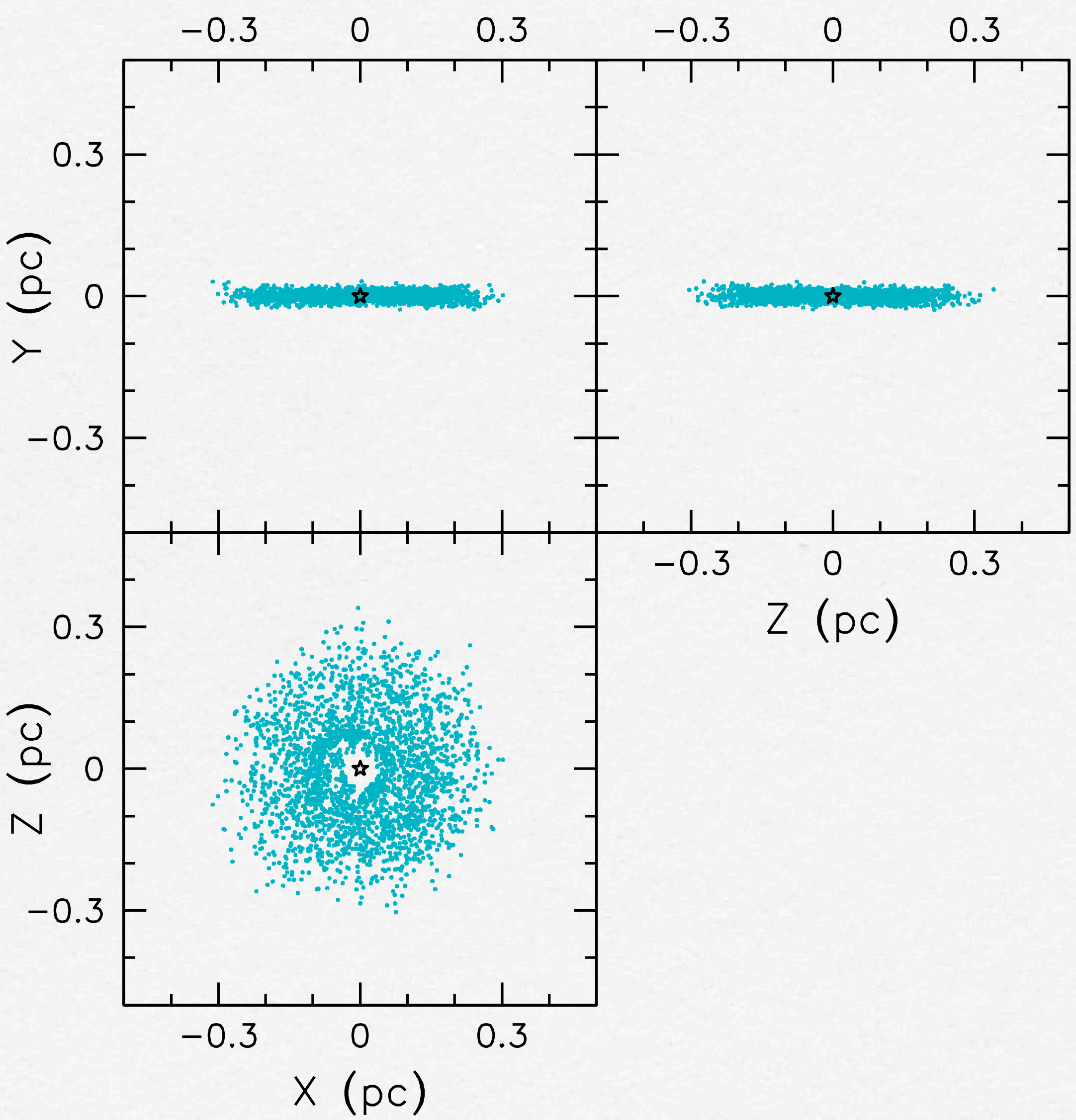
Evolution of the stellar disk



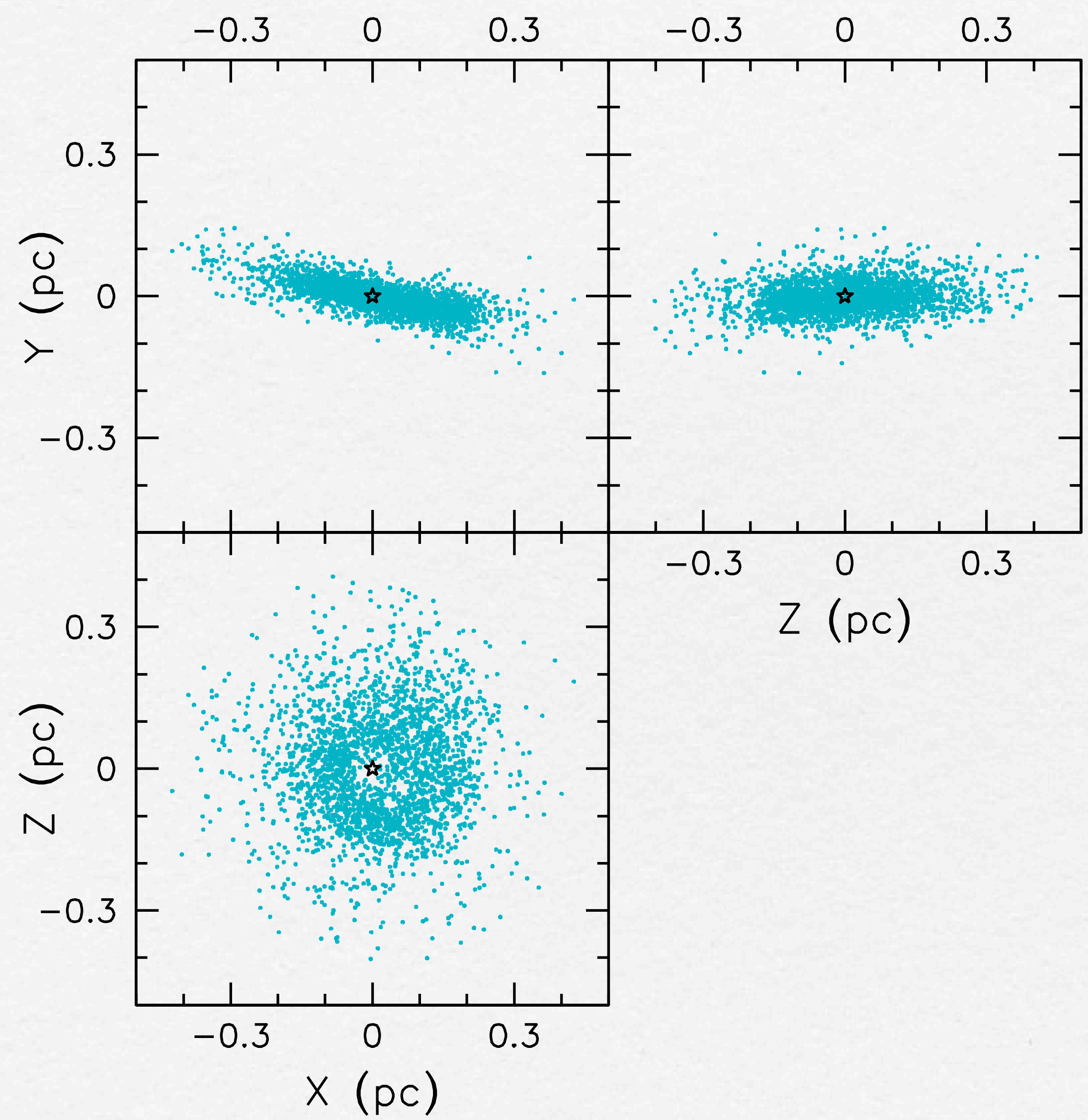
Simulations performed with
φ GRAPE

Perets, Gualandris, Merritt, Alexander (in prep.)

Evolution of the stellar disk



without black hole cusp



with black hole cusp