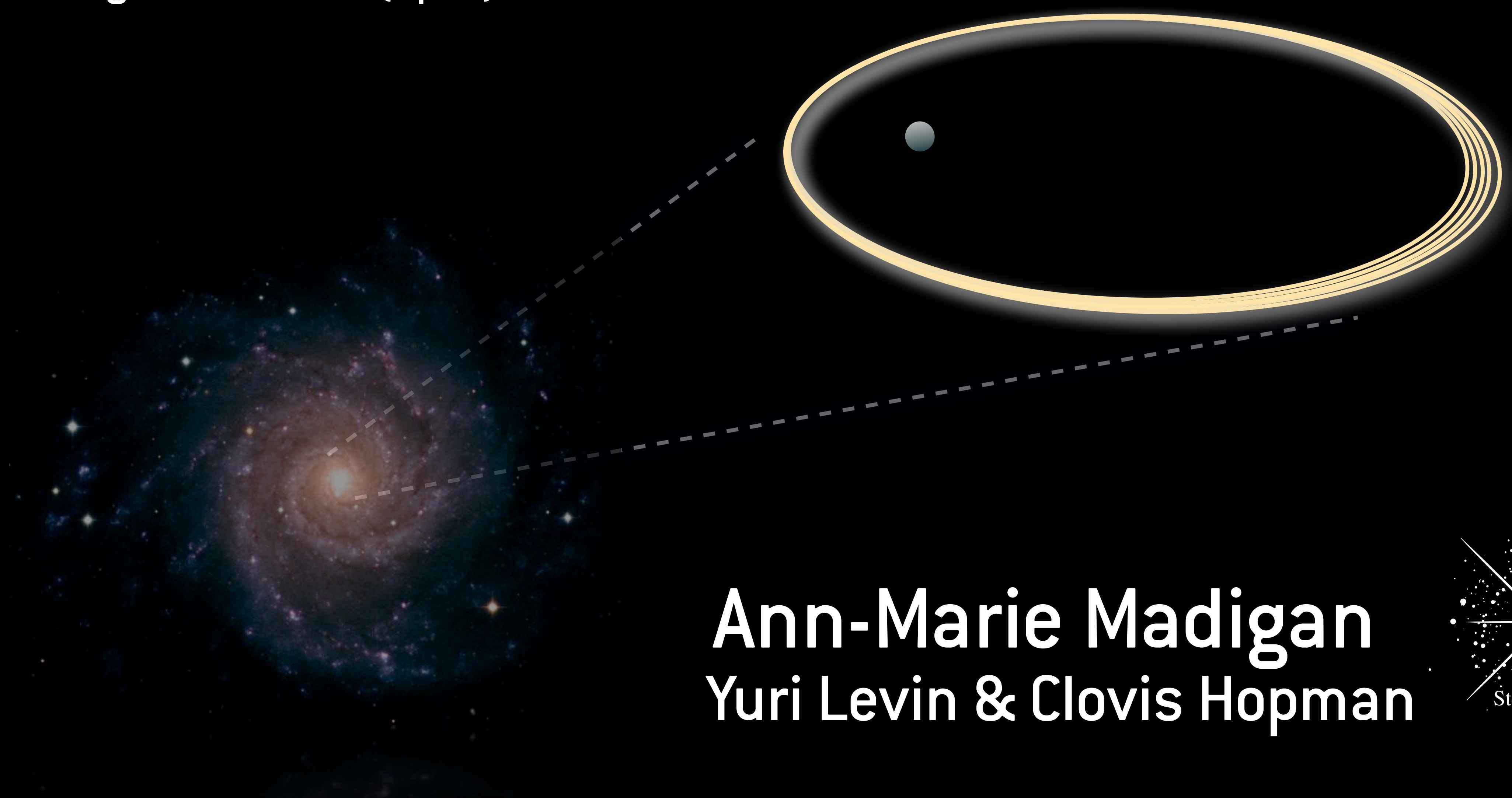
A New Secular Instability in Eccentric Stellar Disks around Massive Black Holes

Madigan et al. 2009 (ApJL)



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Outline

- Introduction to Galactic Centre
  - Motivation
- Physics of Instability
  - Simulations
- Applications

Galactic Centre

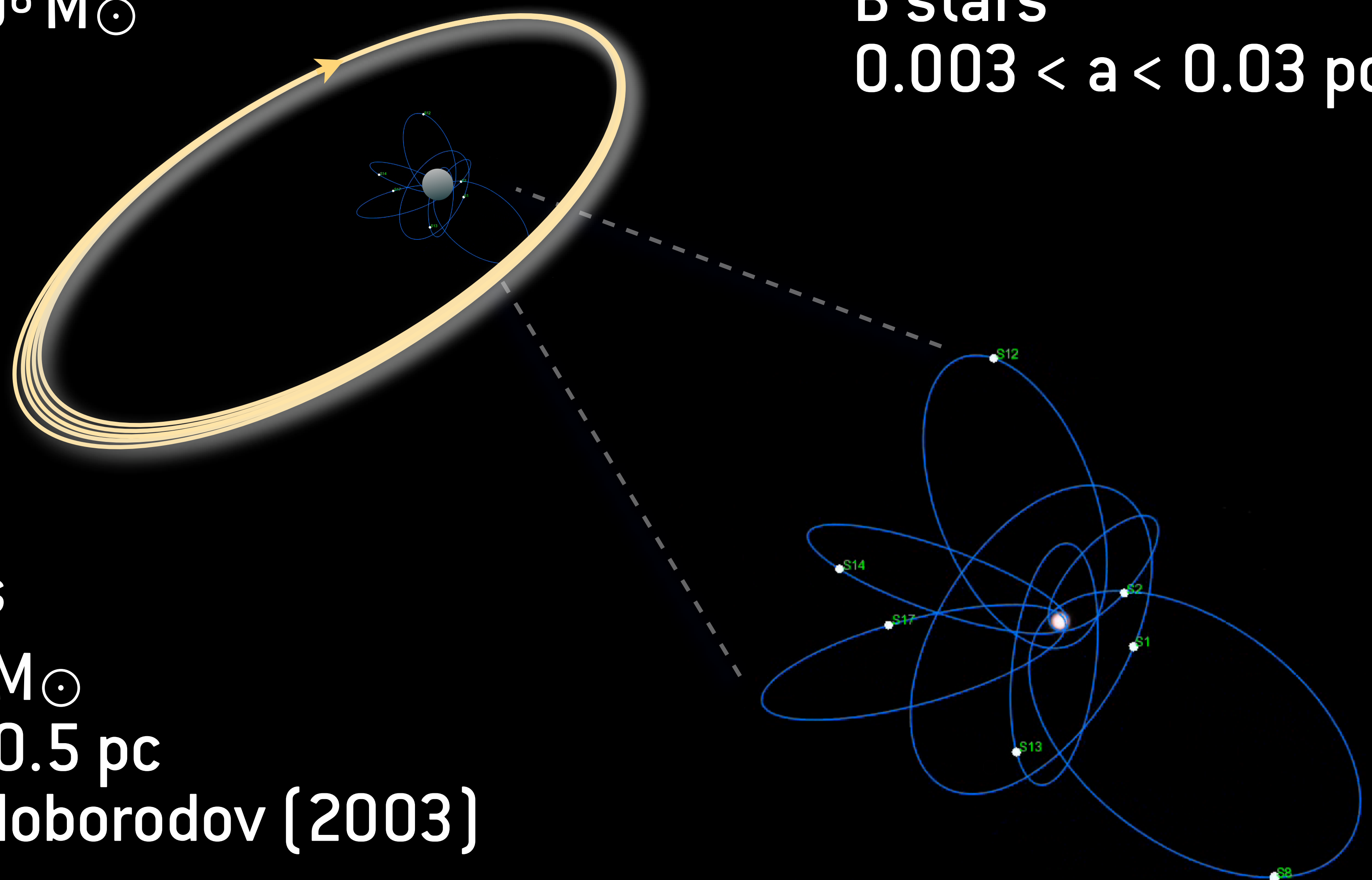
Credit: ESO/S. Gillessen et al. 2009

Galactic Centre

1. SgrA* Black Hole

   $M_\bullet = 4 \times 10^6 M_\odot$

3. S-stars:
   B stars
   $0.003 < a < 0.03$ pc

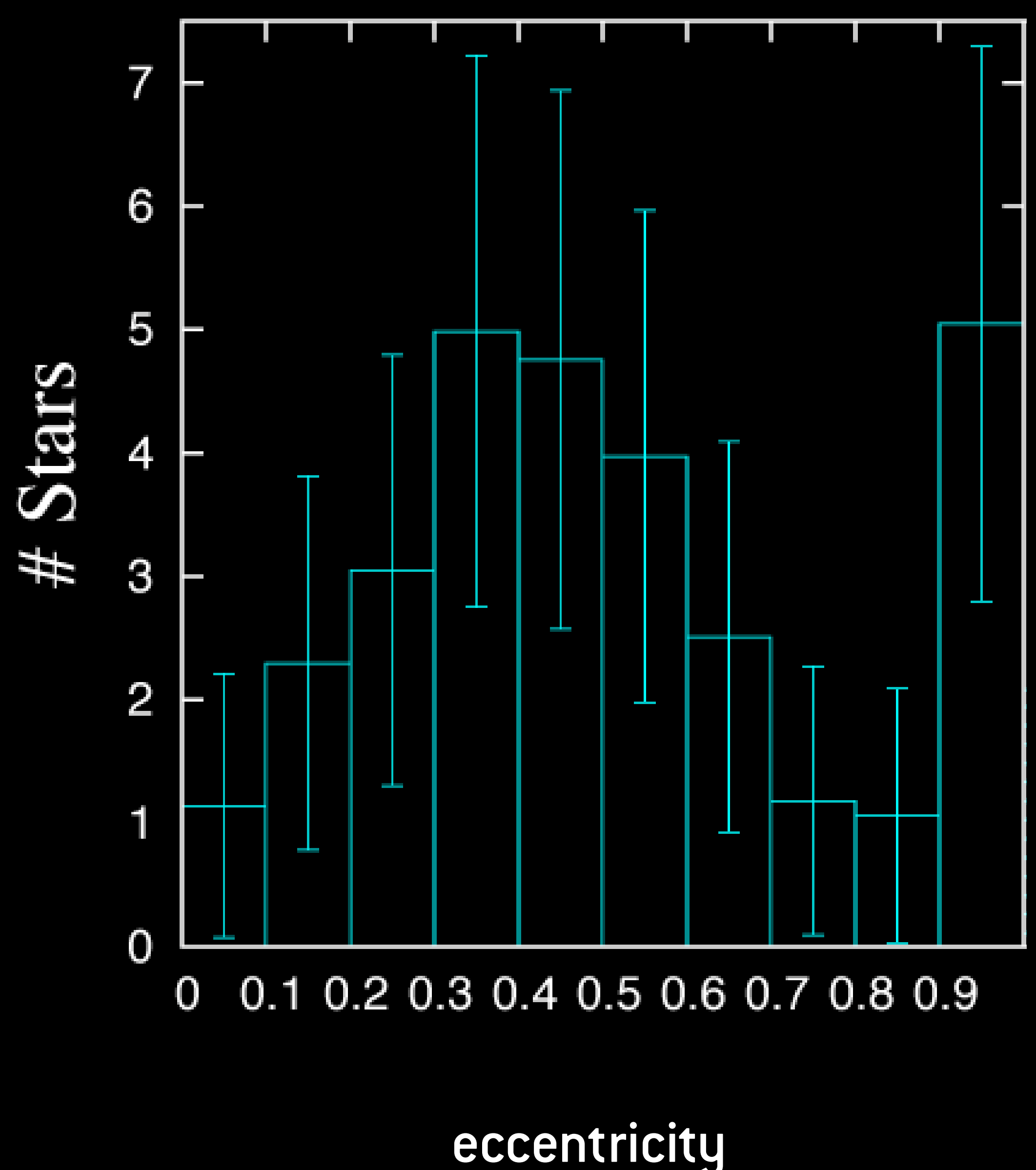


2. Disk:
   O/WR stars

   $M_{disk} = 10^4 M_\odot$
   $0.05 < a < 0.5$ pc
   Levin & Beloborodov (2003)

2 Puzzles...

Bartko et al. (2009)



(1) Bimodal eccentricity distribution of disk stars

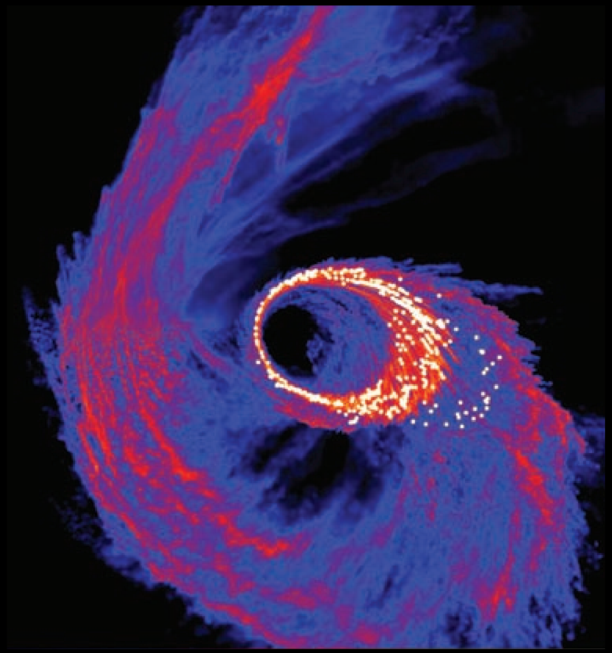
Age of disk ~ 6 Myr

Relaxation time ~ 1 Gyr

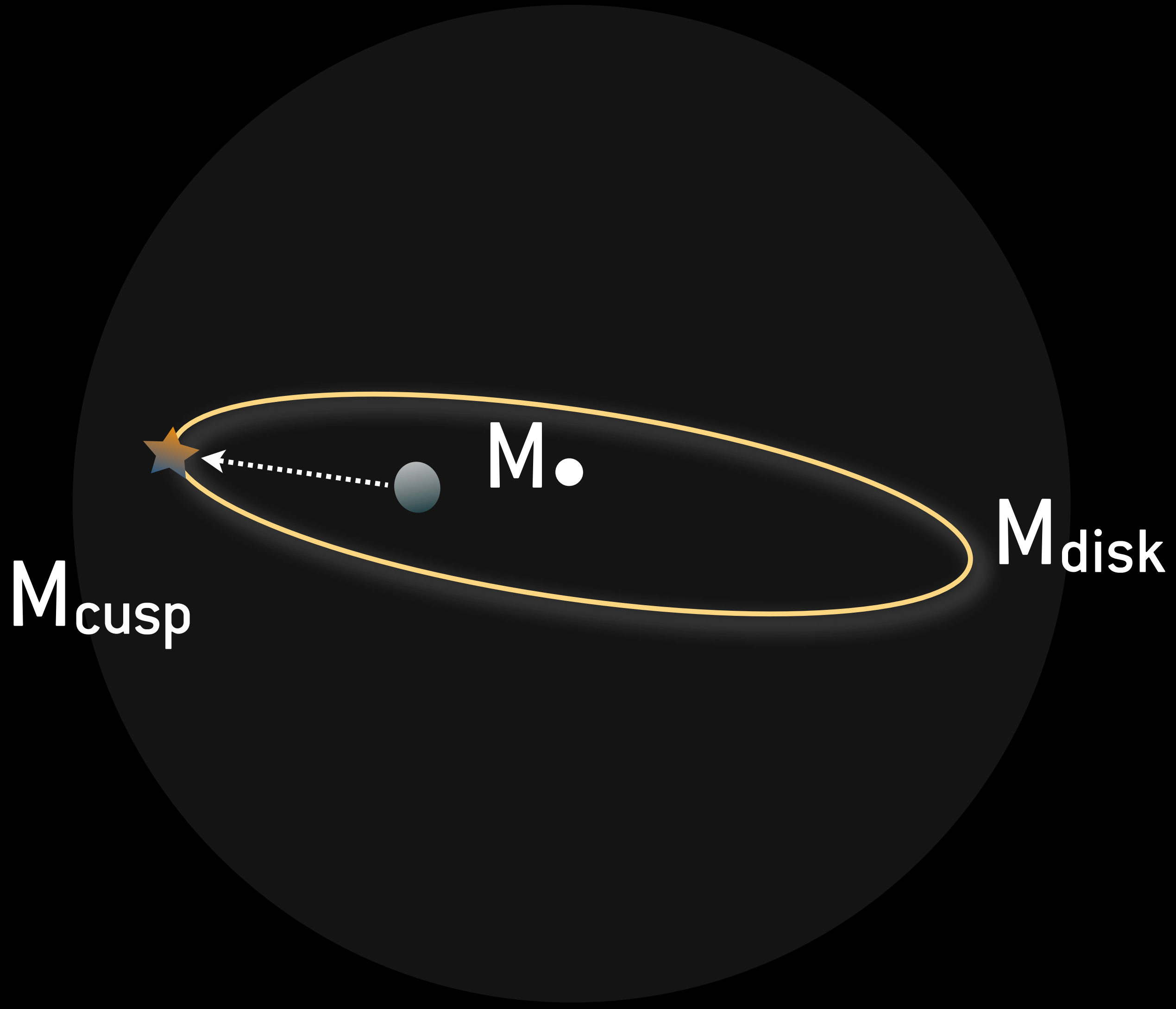
(2) Origin of S-stars

- In-situ formation ×
- Youth: Did not travel far from place of birth

Setup



Bonnell & Rice 2008



Assumptions:

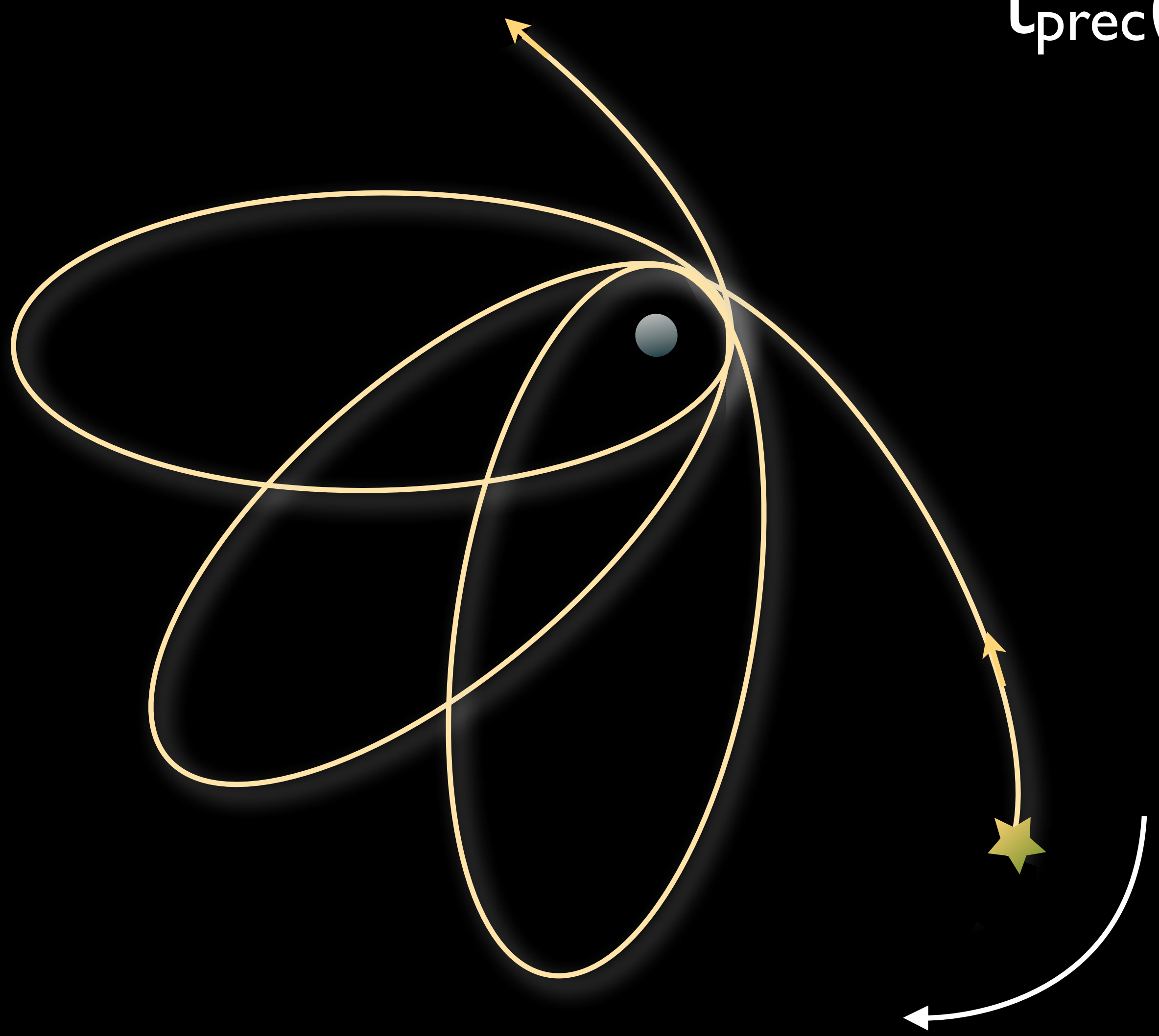
1) $M_{disk} << M_{cusp}$

2) Eccentricity vectors ($\bar{e}$) aligned, similar in magnitude

↪ vector which points to periapse

Precession

Retrograde Precession due to cusp:



$$t_{prec}(a,e) \sim [M_\bullet/M_{cusp}(<a)]\ t_{orb}(a)\ f(e)$$

$$\rho_{cusp} \propto a^{-\gamma},\ M_{cusp}(<a) \propto a^{3-\gamma}$$

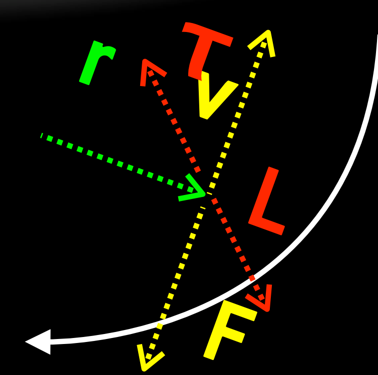
$$t_{orb}(a) \propto a^{3/2}$$

$$t_{prec} \sim a^{\gamma-3/2}\ f(e)$$

Fastest for low e orbits
Slowest for high e orbits

Instability (3)

$L \propto (1 - e^2)^{1/2}$



$\mathbf{L} = \mathbf{r} \times \mathbf{v}$

$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$

1. Higher **e** orbit precesses slower than other orbits
2. Feels strong, coherent torque from other stars in disk
   in opposite direction of angular momentum L
3. L is decreased, **e** is increased

Instability (4)

$L \propto (1 - e^2)^{1/2}$

$\mathbf{L} = \mathbf{r} \times \mathbf{v}$

$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$

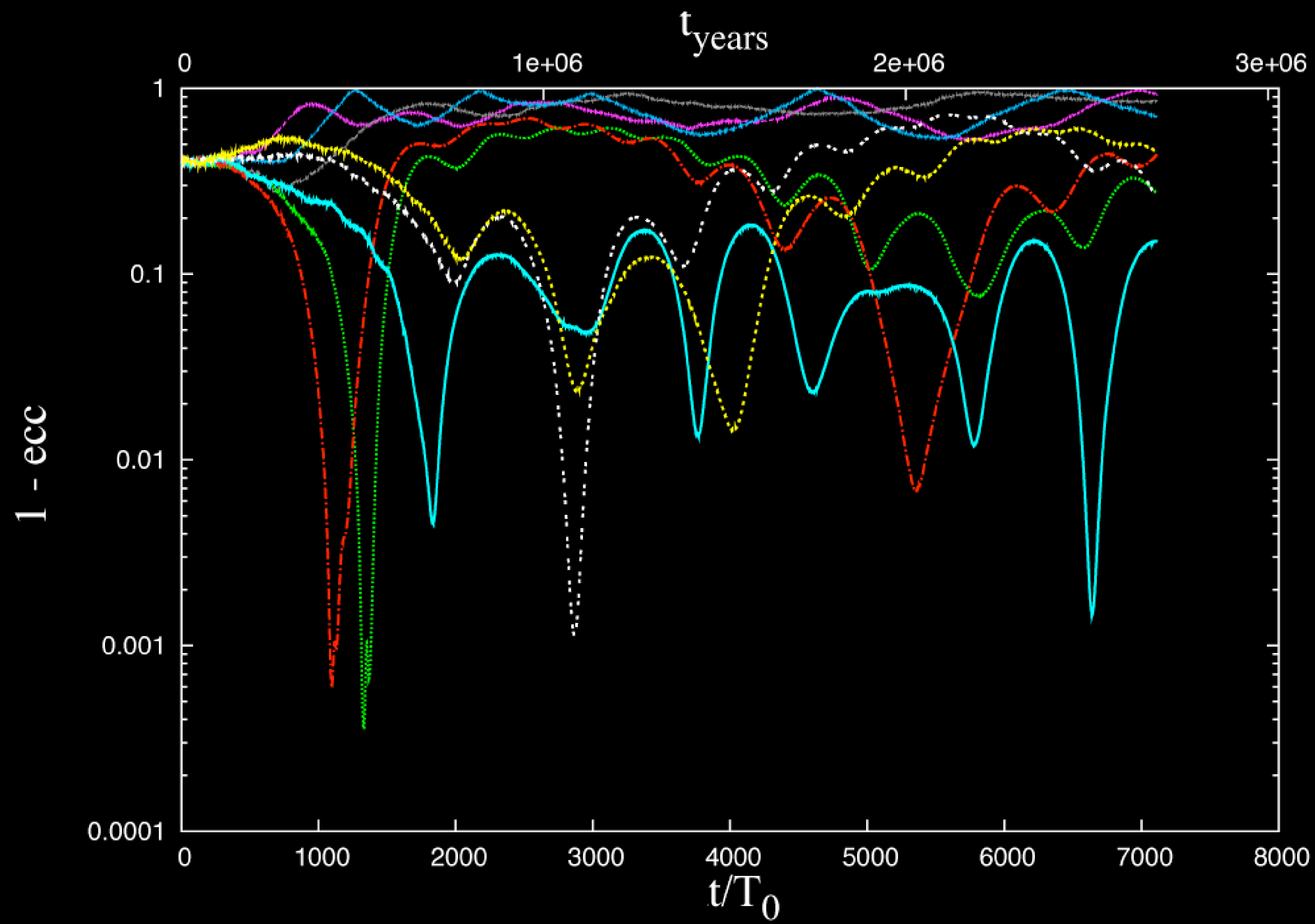
1. Lower **e** orbit precesses faster than other orbits
2. Feels strong, coherent torque from other stars in disk *in direction of angular momentum L*
3. L is increased, **e** is decreased

Simulations

e = 0.9

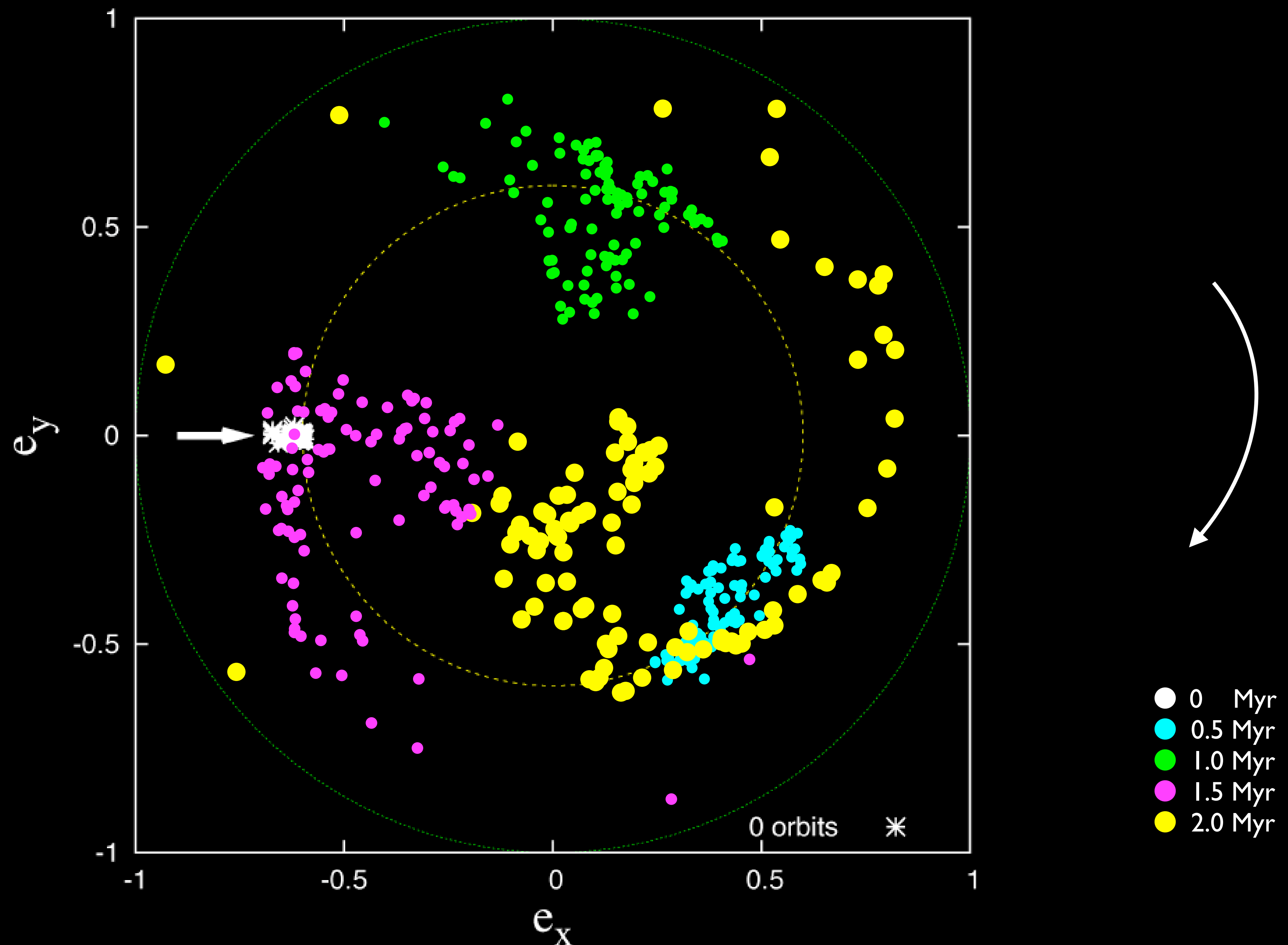
e = 0.99

e = 0.999

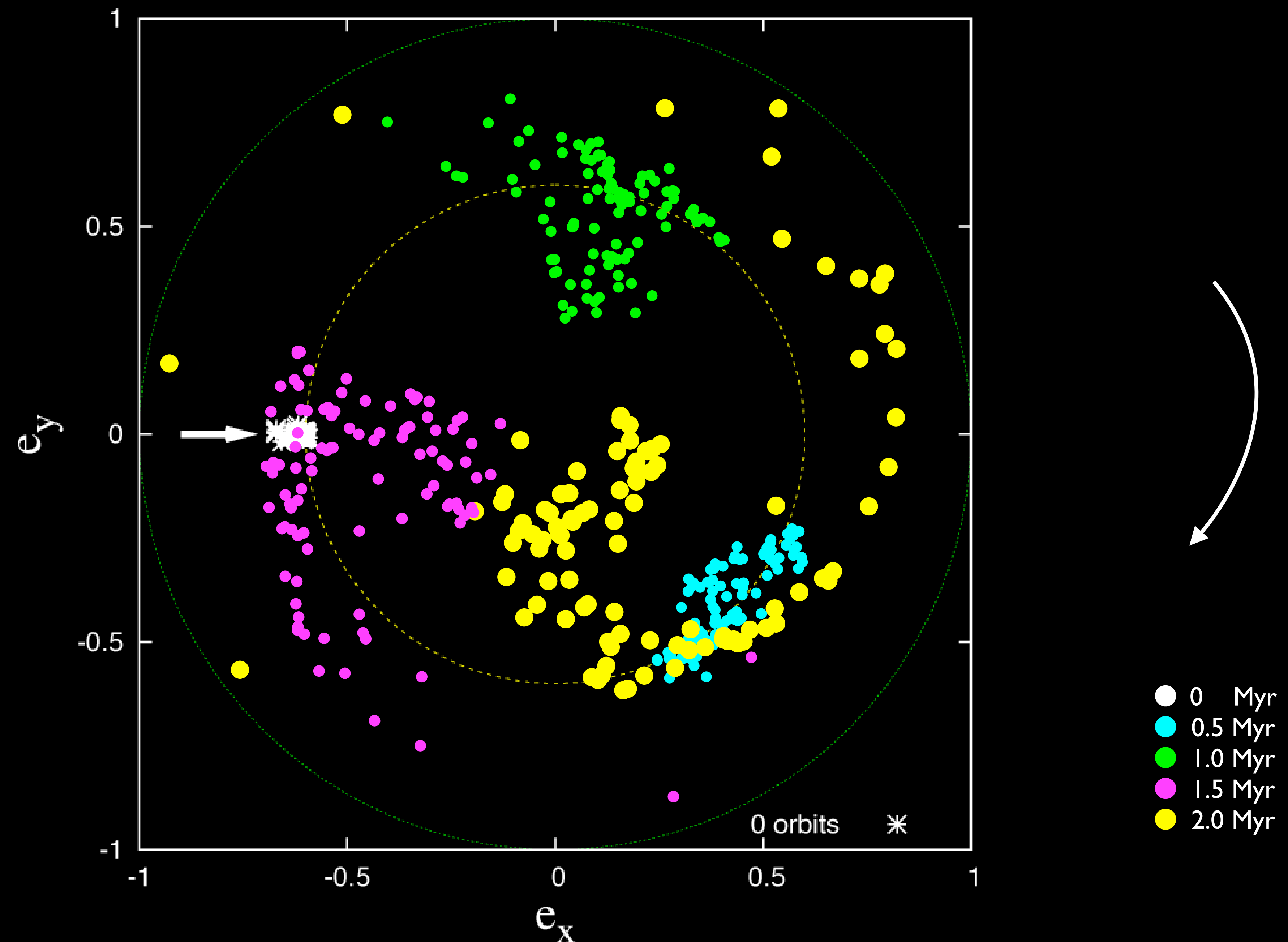


Relaxation time ~ 1 Gyr

Evolution of $\bar{e}$

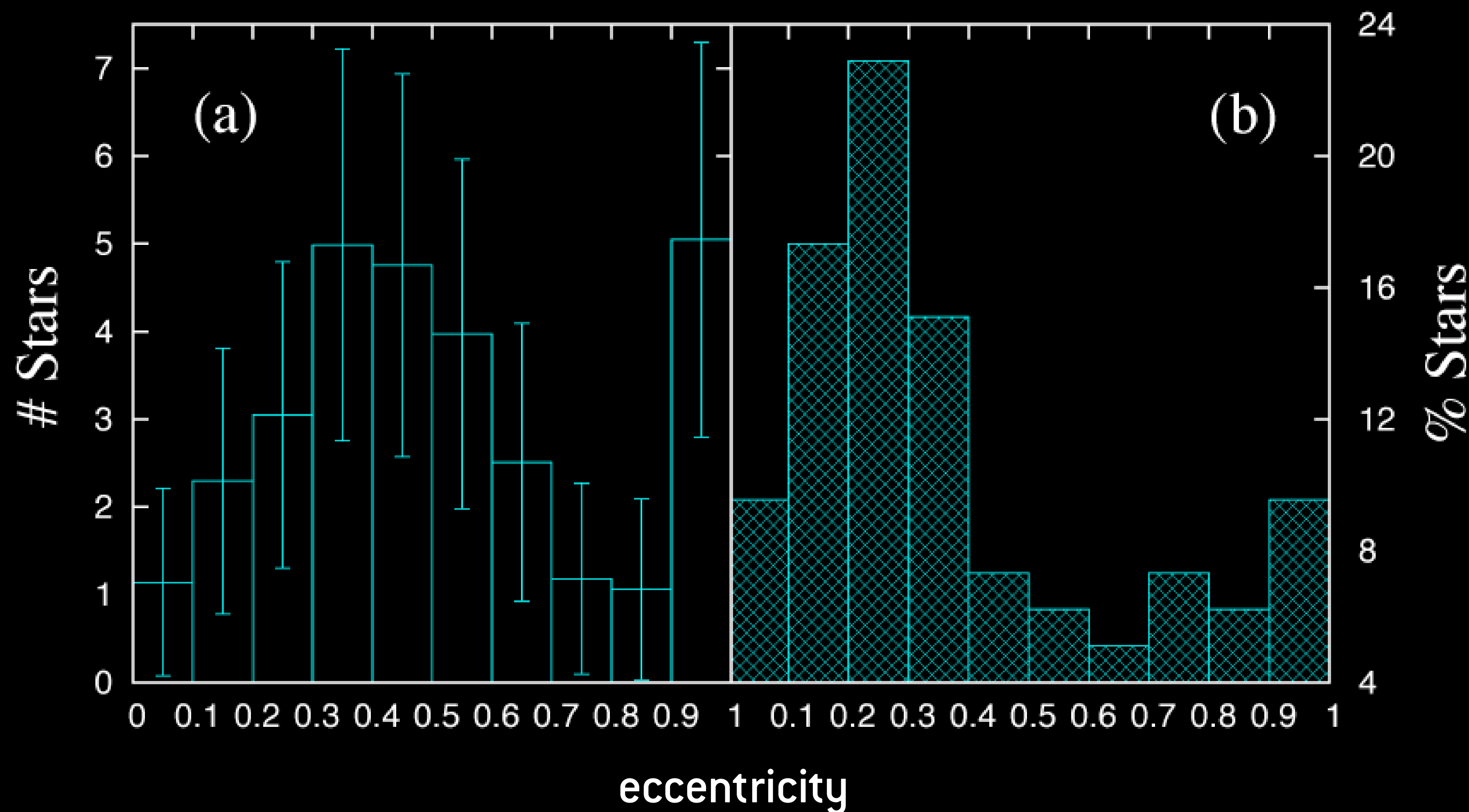


Evolution of $\bar{e}$



Observed vs Simulated Eccentricity Distribution

Bartko et al. (2009)

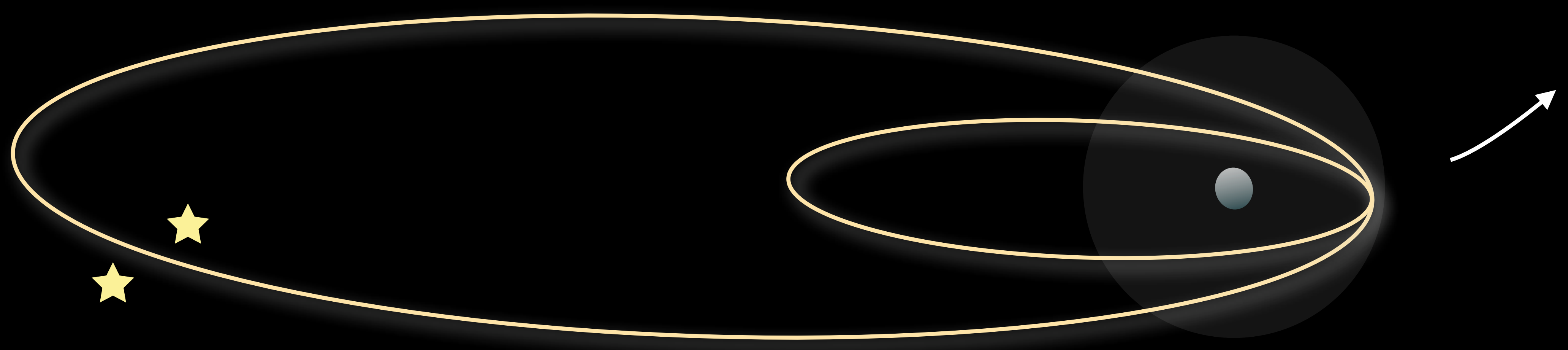


Madigan et al. (2009)

Bimodal distribution:
direct consequence of instability

Origin of S-stars

Instability in disk pushes binary system to high eccentricity orbit.



Binary system is disrupted (Hills' [1988] Mechanism) forming:
(1) hyper-velocity star
(2) bound high-eccentricity star = **S-star ?**

Summary

1) New Instability in Eccentric Stellar Discs

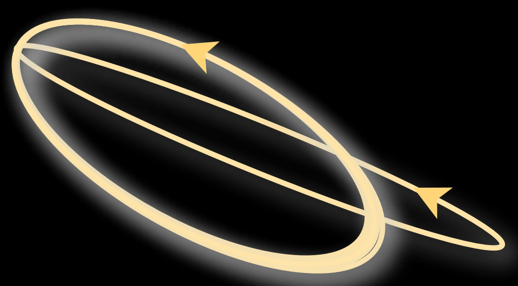
> Time-scale: Myr

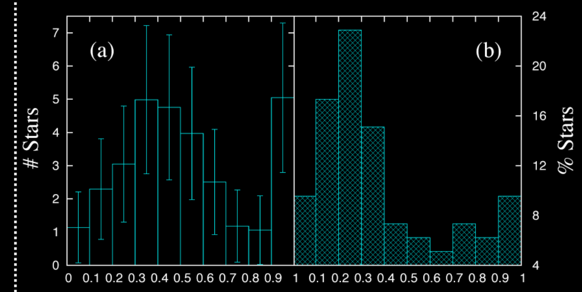
> Robust

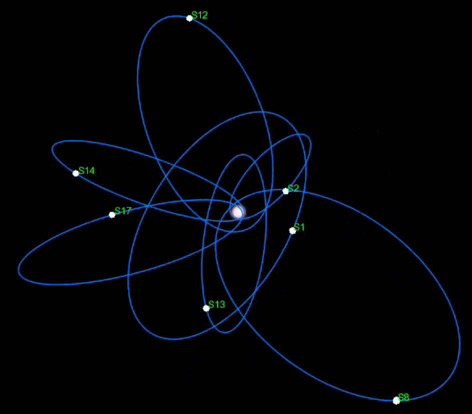
2) Application to Galactic Centre:

> Bimodal eccentricity distribution

> Origin of S-star population?







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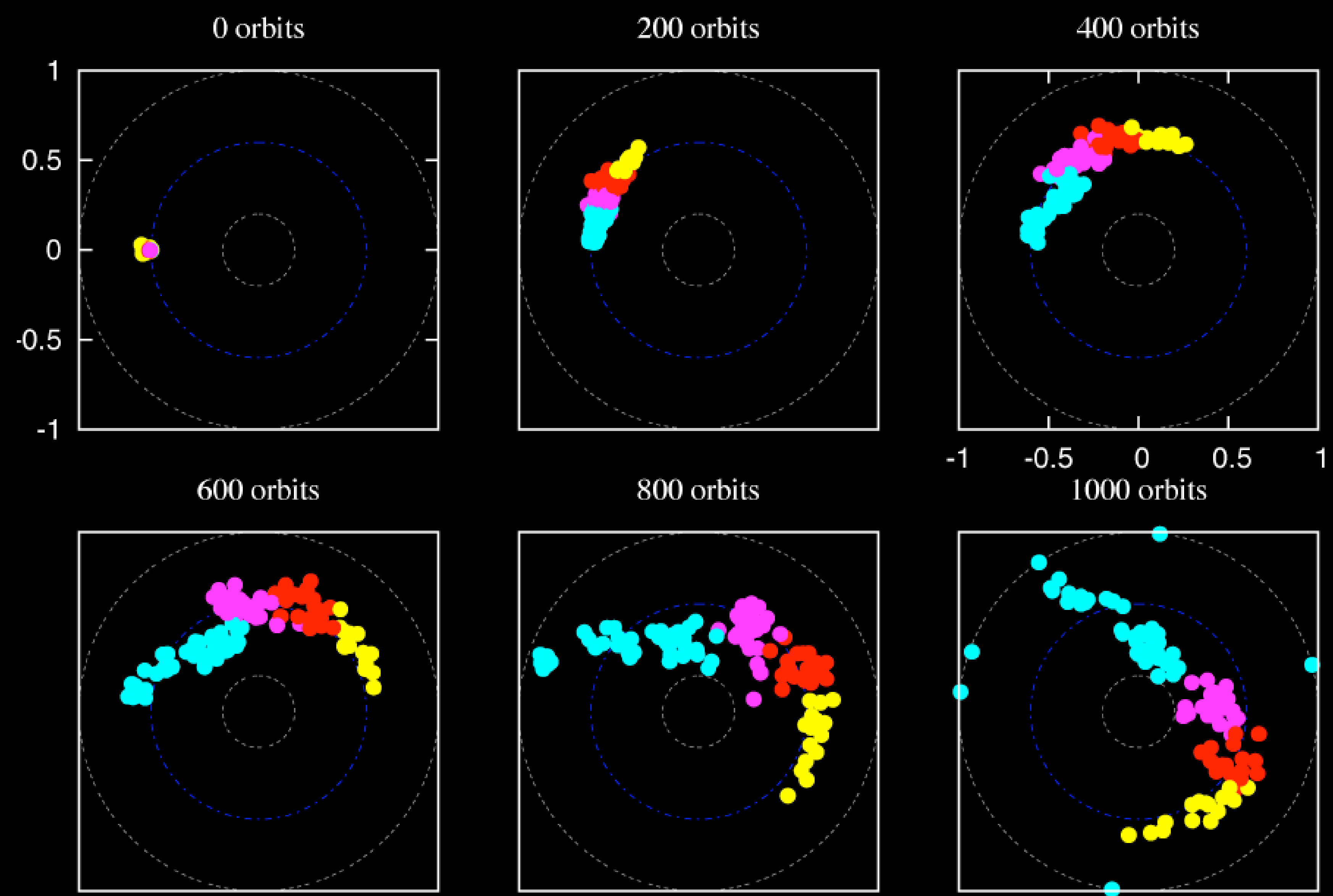
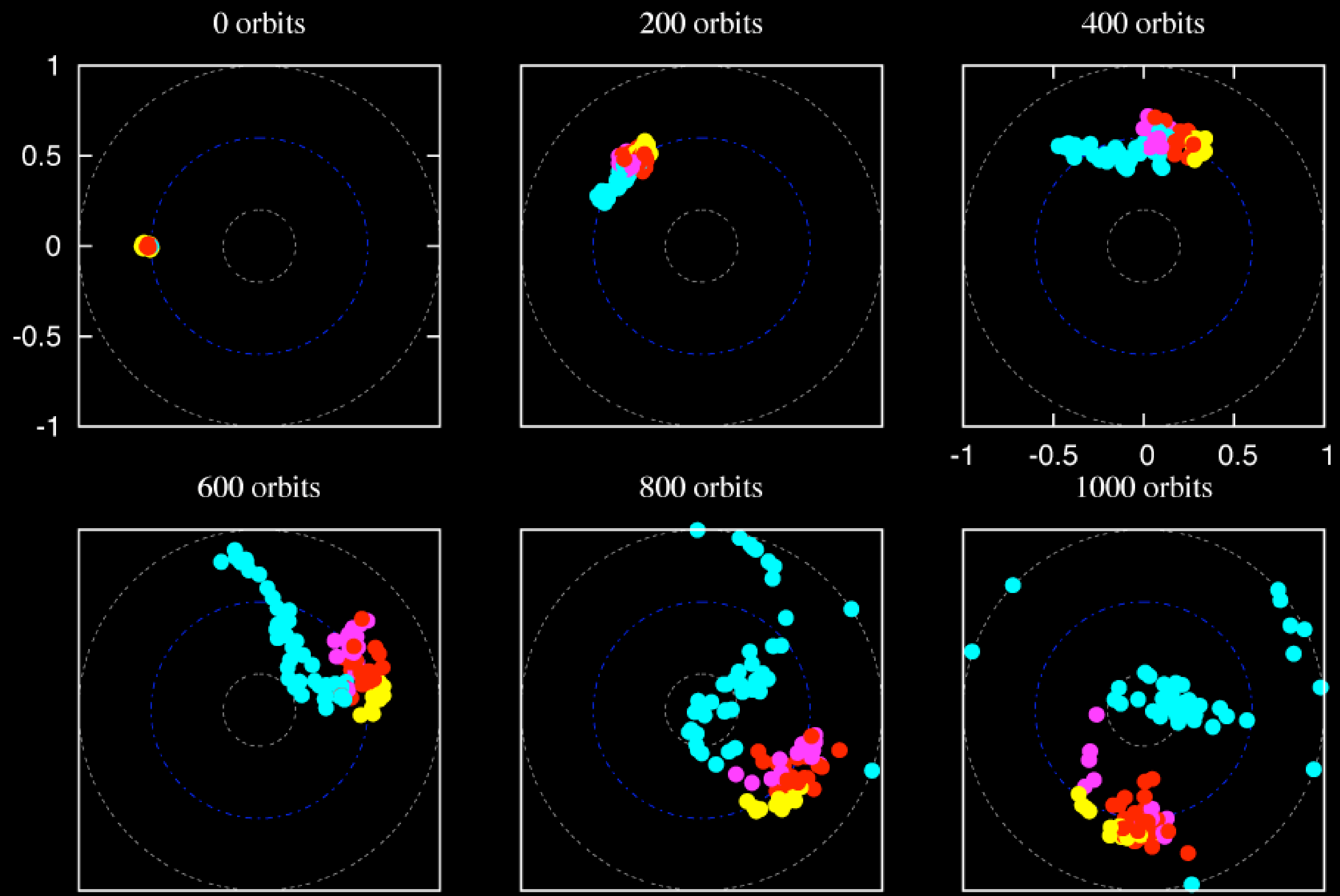
γ = 1.25

Evolution of $\bar{e}$



γ = 1.5

Evolution of $\bar{e}$



$\gamma = 1.75$

Evolution of $\bar{e}$