Young Stars and Intermediate-mass Black Holes in the Galactic Center

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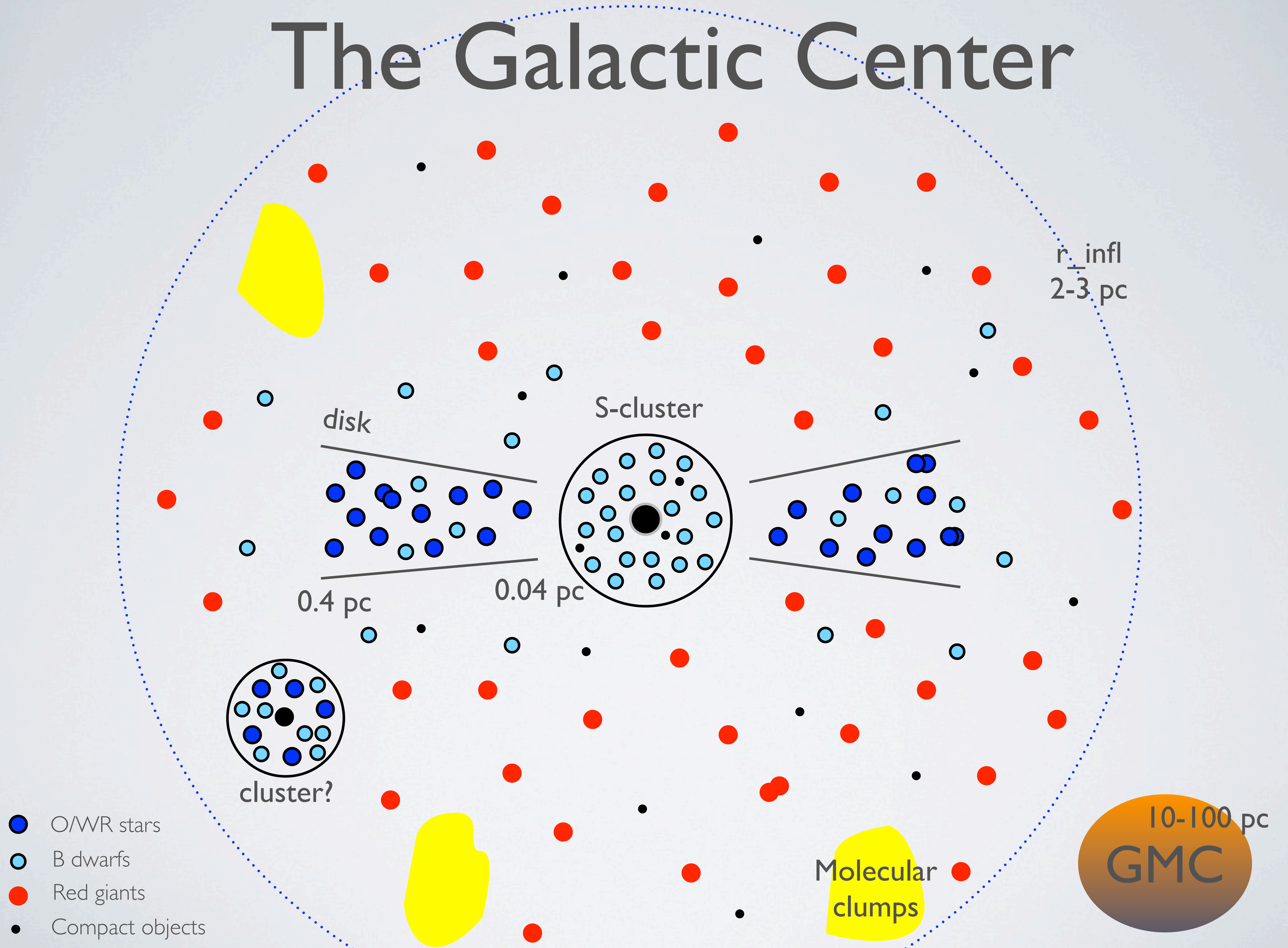
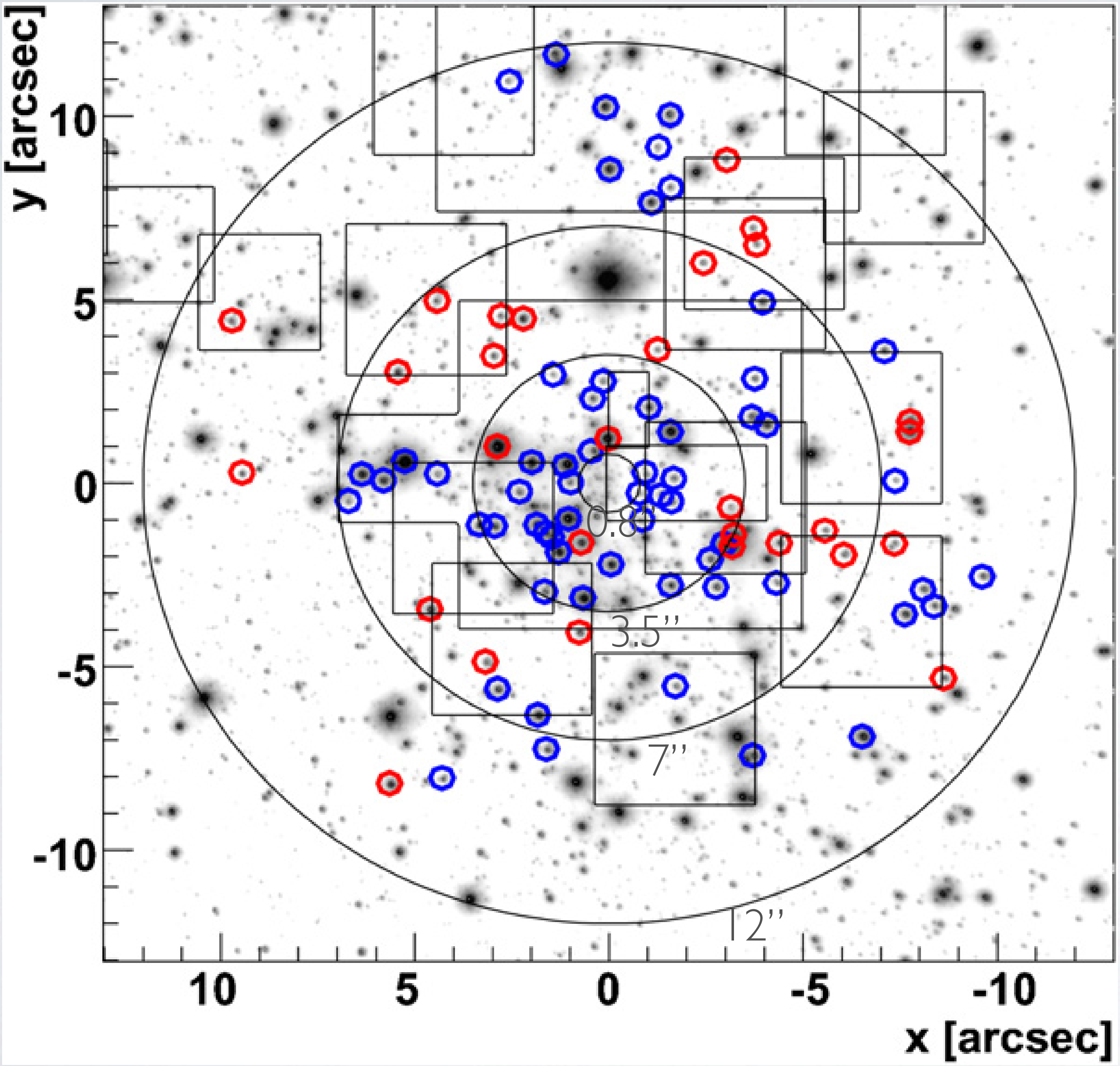
Central Massive Objects, ESO Garching, 22-25 June, 2010

The Galactic Center



The stellar disk(s)



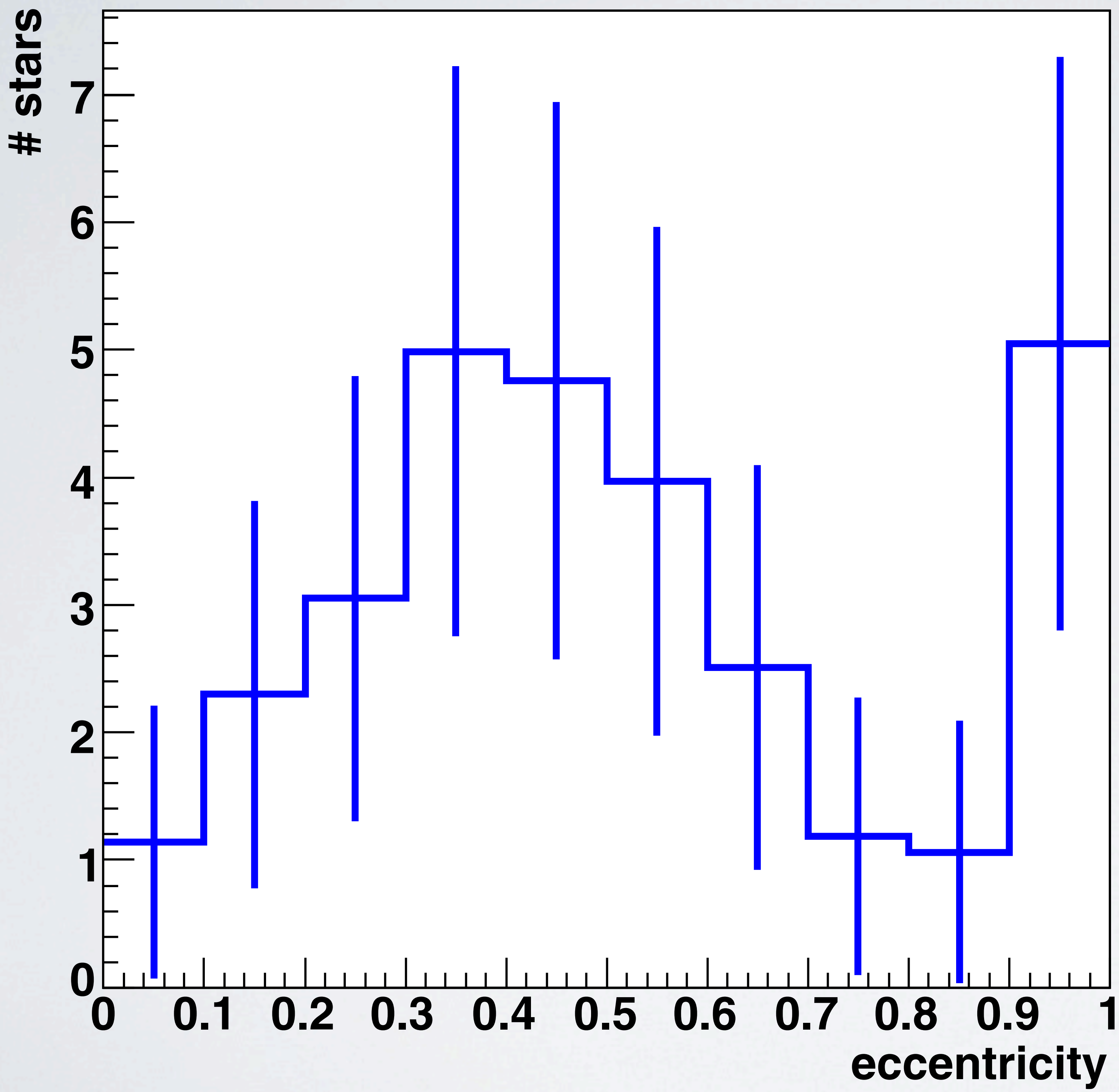
90 O/WR stars
$M_K < 14$

- clockwise orbits
- counter-clockwise orbits

Bartko et al. (2009)

1 arcsec ~ 0.04 pc

The CW stellar disk



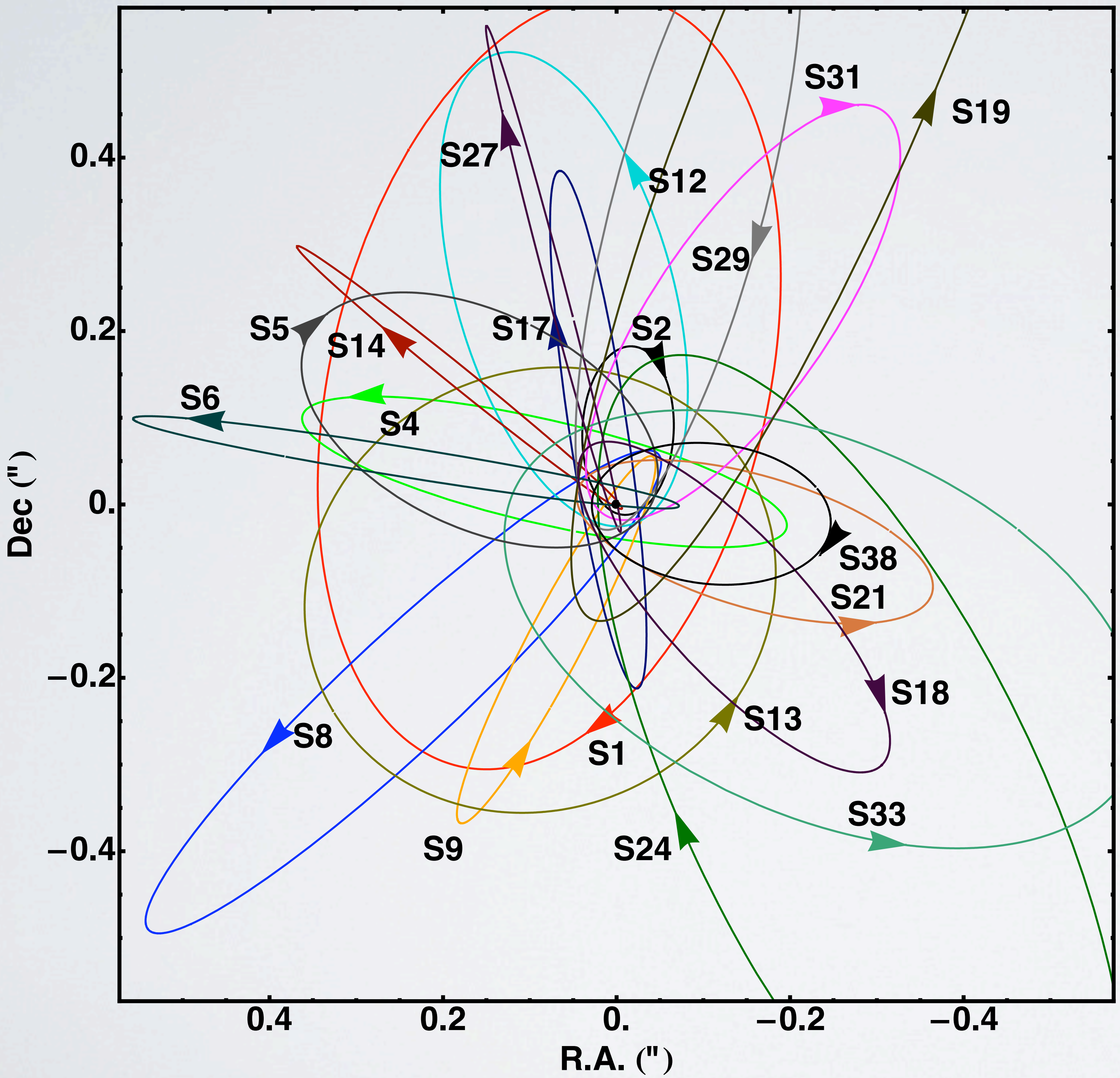
1 arcsec ~ 0.04 pc

Clockwise disk
O/WR stars
0.8” < r < 12”

Bartko et al. (2009)

Alessia Gualandris, ESO Garching, 22/06/2010

The S-star cluster

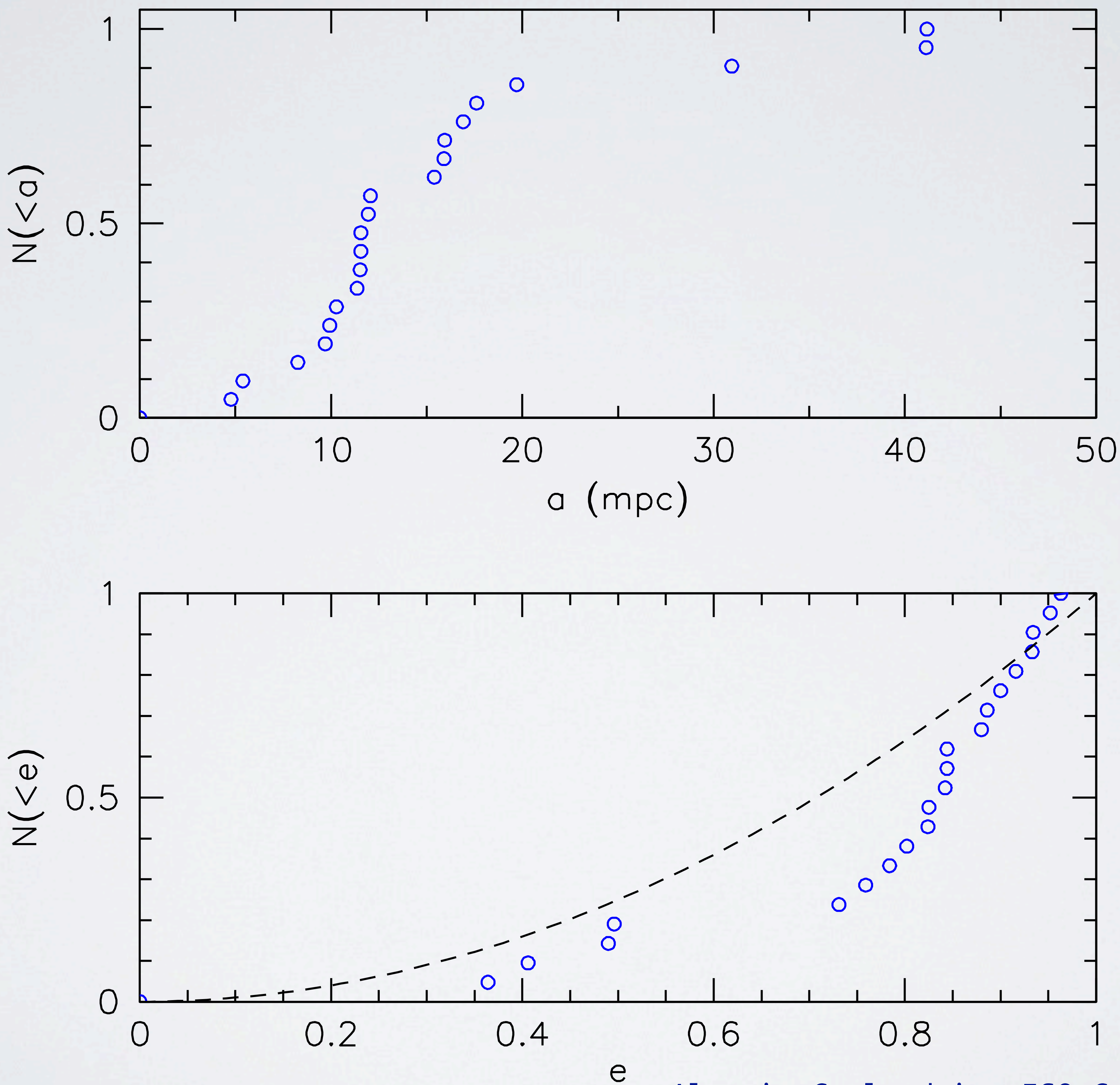


2009
N = 20 stars
15 early-type stars
5 late-type stars

Gillessen et al. (2009)

1 arcsec ~ 0.04 pc

The S-star cluster



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Origin of the young stars

NO Standard star formation!

critical density:

$$n_{crit} = 10^7 \mathrm{cm}^{-3} \left(\frac{1.6\,\mathrm{pc}}{R} \right)^{1.8}$$

while observed densities: 10^4 - 10^5 cm^{-3}

$\Downarrow$

- In-situ NON standard star formation
- Outside formation + migration

Origin of the young stars

Common formation scenario for disk stars and S-stars?

DISK

$0.8'' < r < 12''$

O/WR stars

disk

$\langle e \rangle \sim 0.3-0.4$

top-heavy MF

S-STARS

$0.1'' < r < 0.8''$

B-type MS stars

isotropic

$\langle e \rangle \sim 0.7$

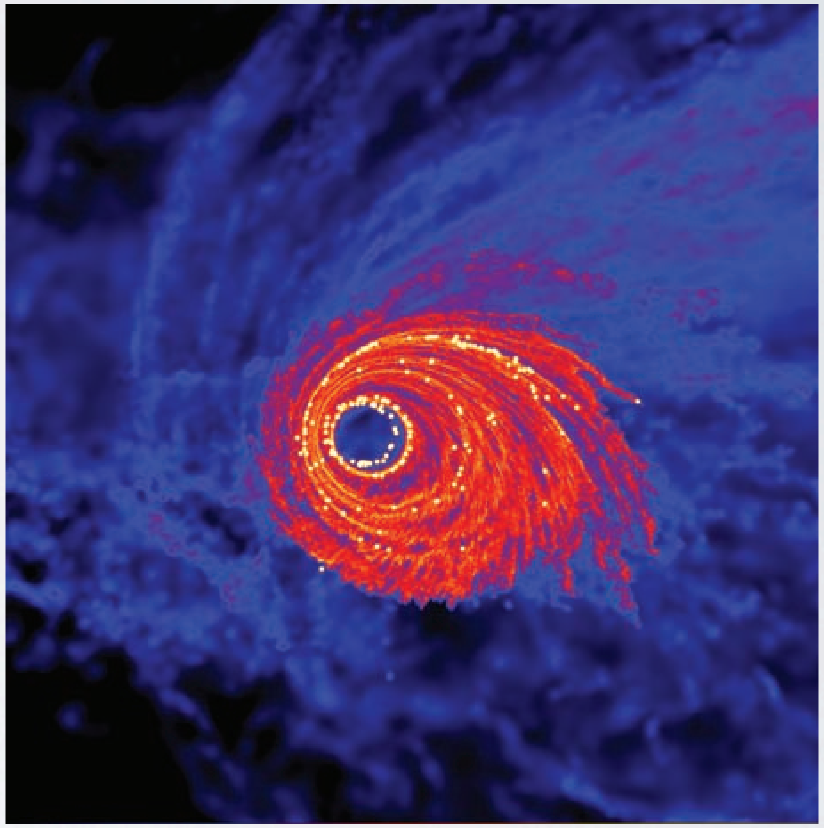
standard MF

Different properties argue for different scenario

Origin of the young stars

Proposed models:

(1) ***In-situ formation from infalling and/or colliding gas clumps***
Star formation from fragmenting gas disks/streams => production of disk structures in the range 0.01-0.1 pc.



Bonnell & Rice (2008)

Origin of the young stars

(1) *In-situ formation from infalling and/or colliding gas clumps*

Pros: Can reproduce properties of the disk stars: radial distribution, eccentricity and top-heavy mass function.

Cons: Can not produce stars closer than ~ 0.1 pc. Can not explain isotropic B-stars population.

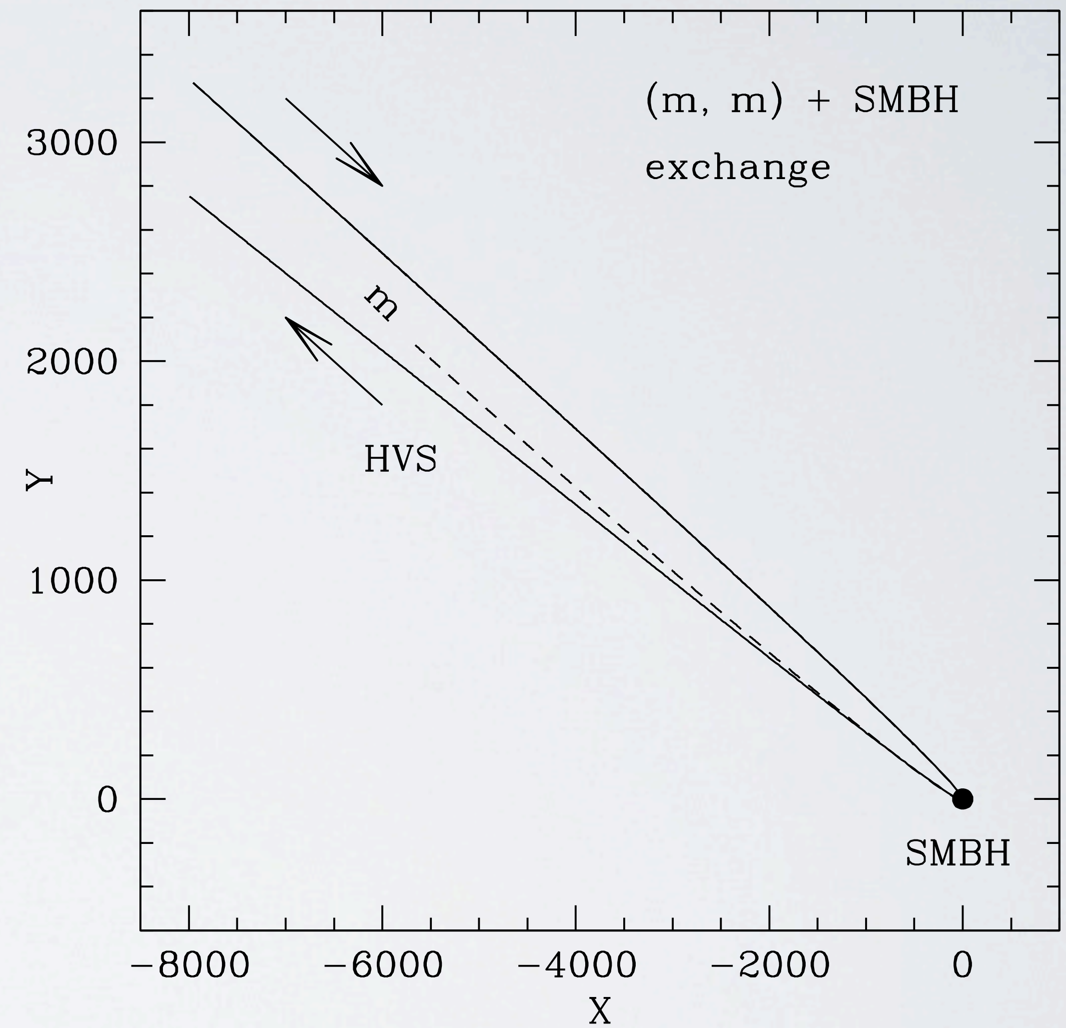
✔ Disk(s)

✗ B-stars

Origin of the young stars

Proposed models:

(2) ***Binary capture***
Binary formation at large distance + scatter to radial orbits (need massive perturbers) + interaction with MBH => capture of one star and ejection of companion + resonant relaxation



Gualandris, Portegies Zwart, Sipior (2005)

Origin of the young stars

(2) ***Binary capture***

Pros: Can reproduce properties of observed B-stars.

✔ B-stars

X Disks

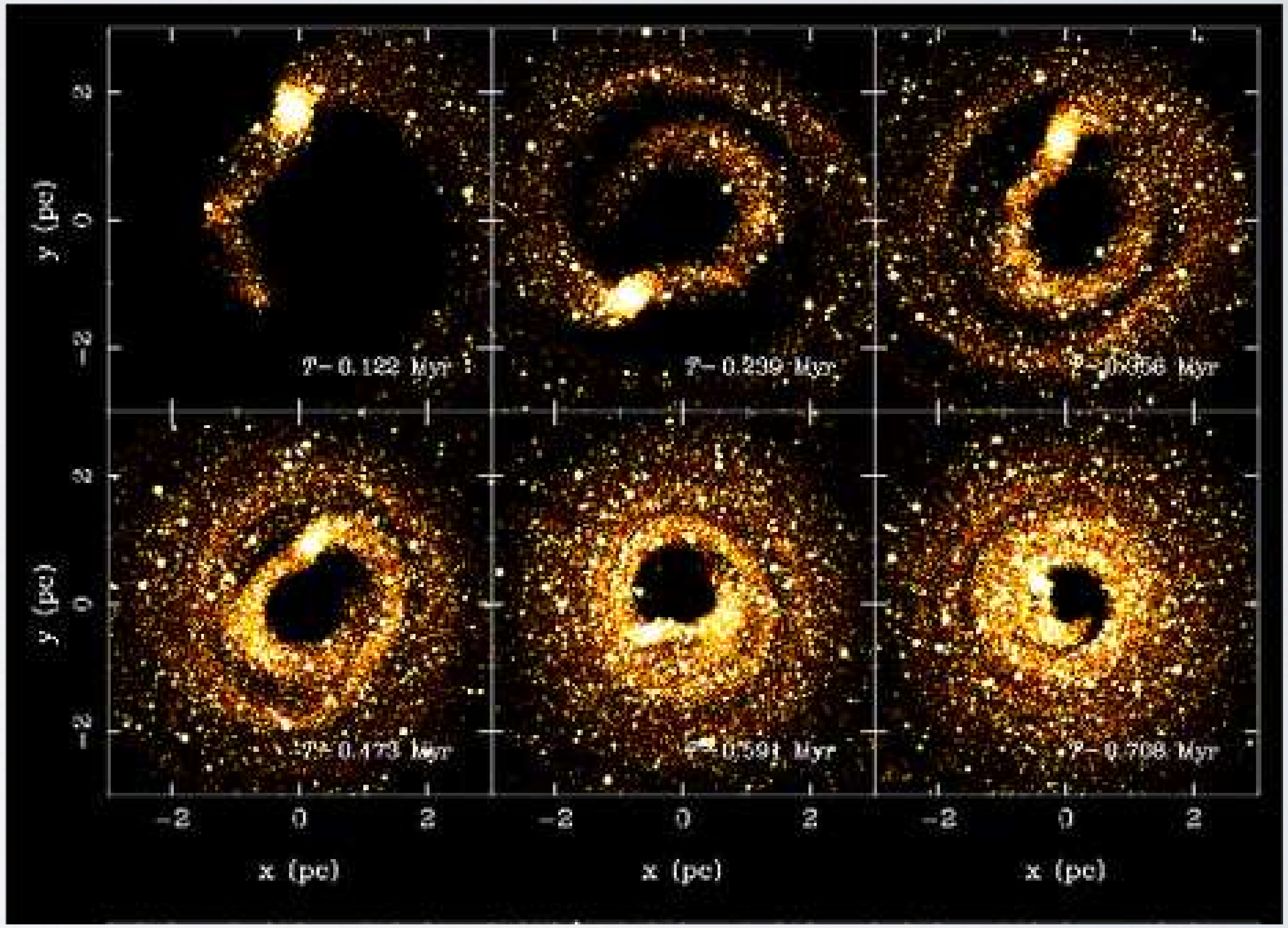
Cons: Many steps scenario. Requires large reservoir of binaries, efficient scattering by massive perturbers, tidal interaction with MBH, randomization of eccentricities by resonant relaxation.

Origin of the young stars

Proposed models:

(3) ***Cluster infall (+IMBH)***

Cluster formation outside central pc with runaway merger => IMBH + inspiral + tidal disruption => deposition of a disk



Fujii et al. (2008)

Origin of the young stars

(3) *Cluster infall (+IMBH)*

Pros: IMBH quickly randomizes orbital planes and thermalizes eccentricities. Explains bias towards massive stars. IMBH ejects stars and produces a core.

Cons: Formation of massive IMBHs may be difficult. Inspiral time-scale may be too long. Expected number of B-stars deposited outside S-cluster much larger than observed.

? B-stars

Origin of the S-star cluster: cluster infall with IMBH

BBH initial conditions:

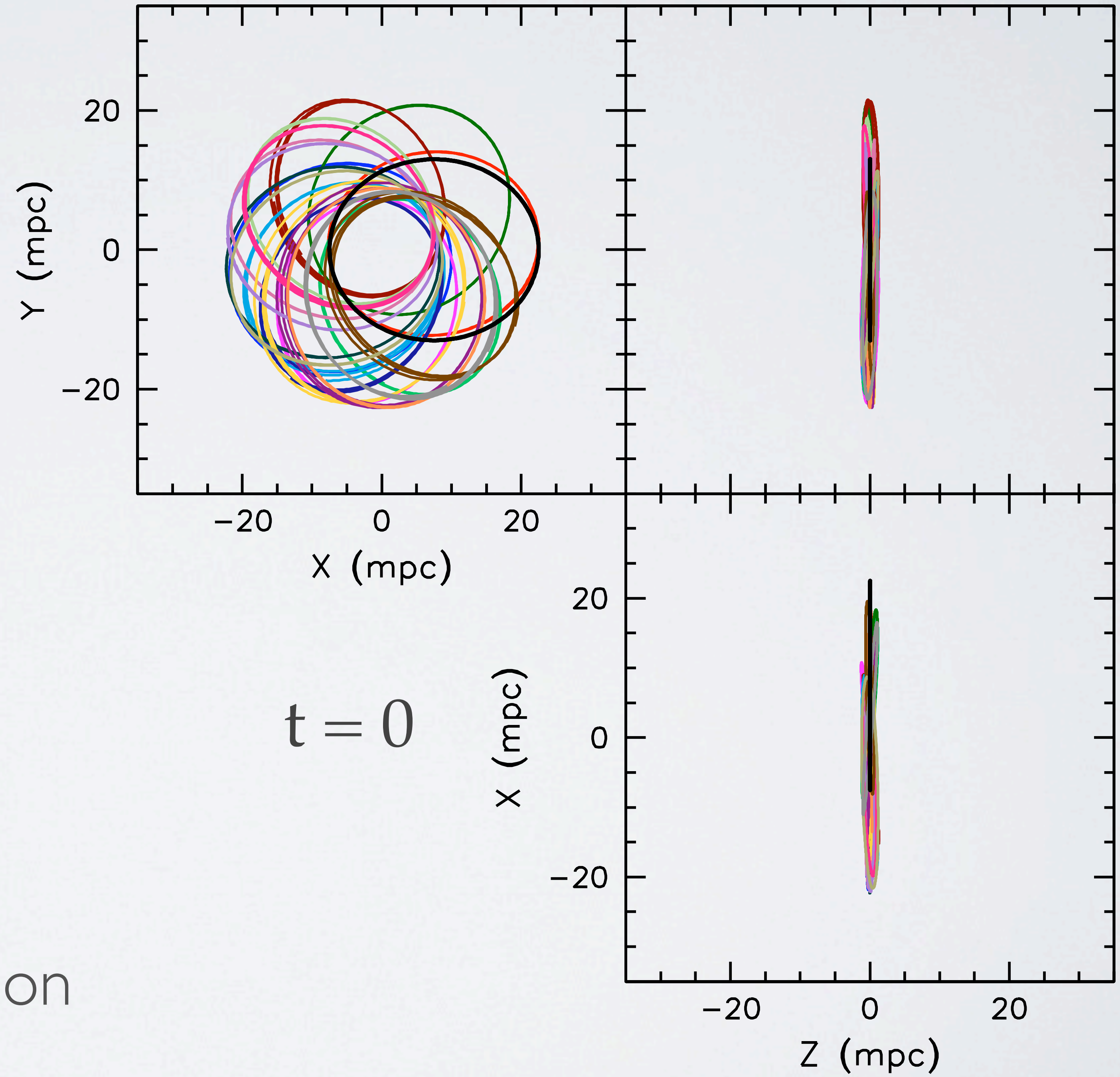
* $M_{SMBH} = 4.5\times10^{6}\ M_{\odot}$
* IMBH $q = 10^{-4} - 10^{-3}$
* a = 10 - 80 mpc
* e = 0.2 - 0.5

Stars initial conditions:

* orbits similar to those of tidally stripped stars, with a small thickness

Numerical method:

* Regularized direct summation method (AR-CHAIN)



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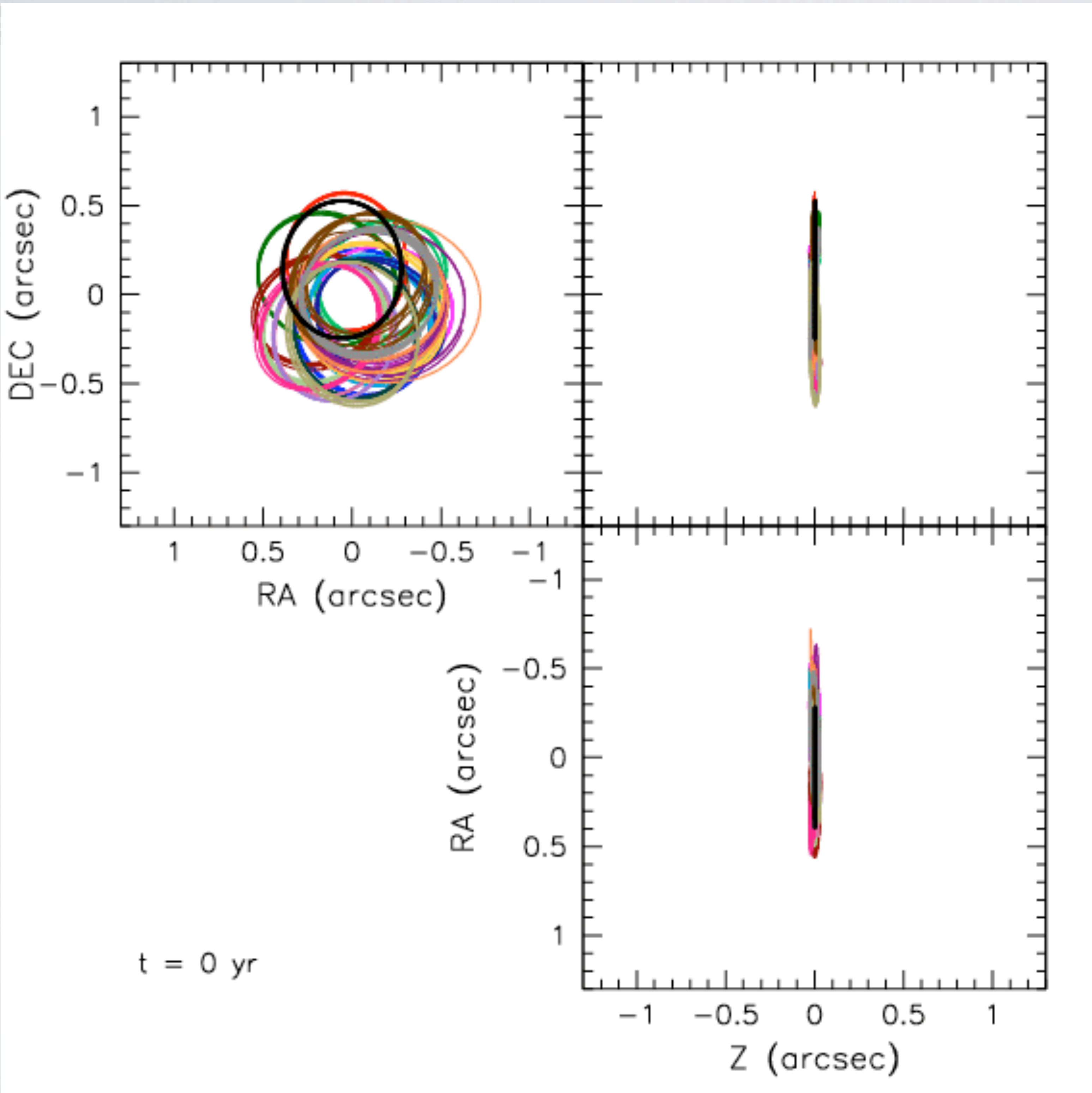
Stellar disk + IMBH evolution



stars N=20

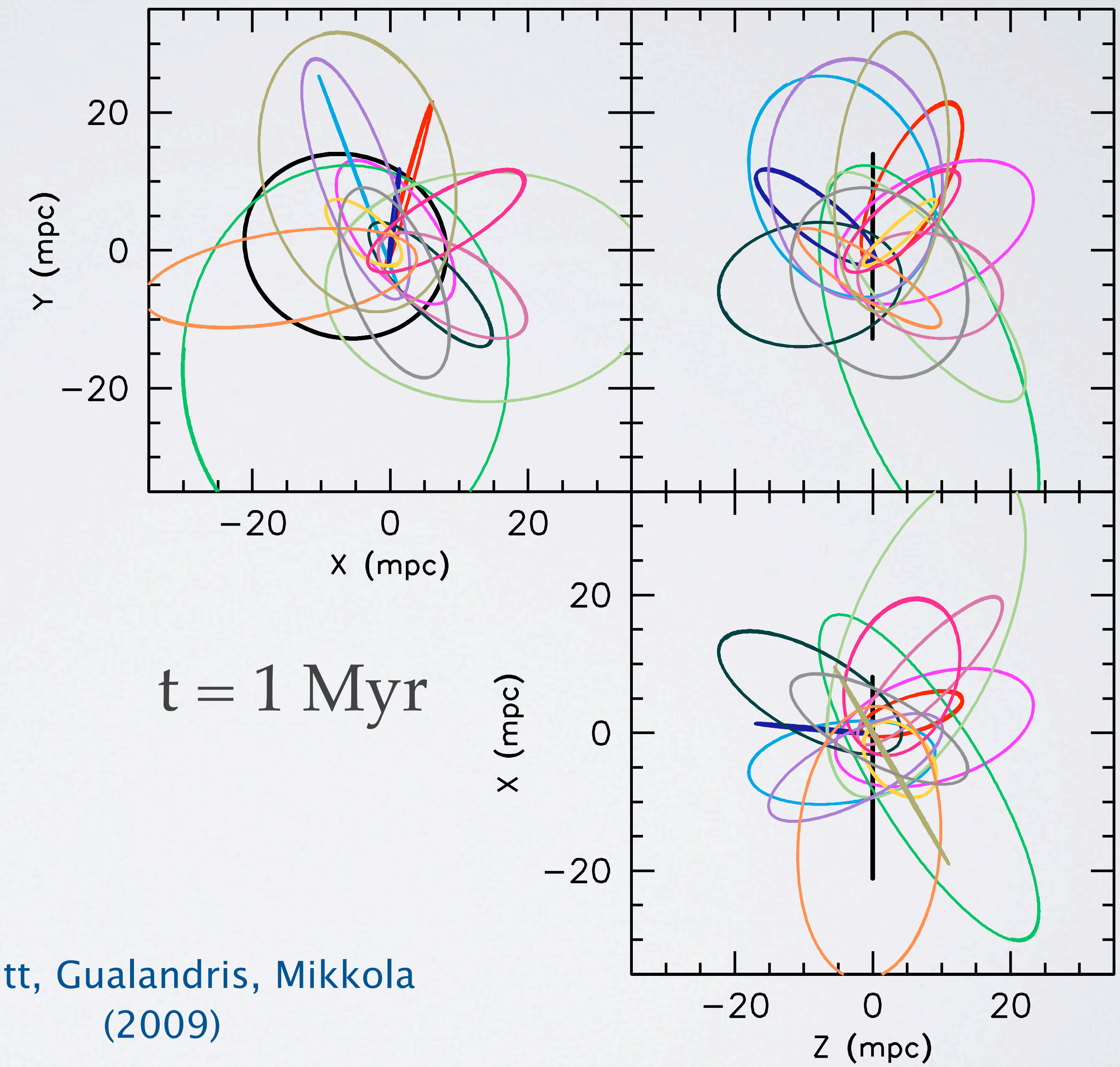
BBH
q = 0.001
a = 15 mpc
e = 0.5

Merritt, Gualandris, Mikkola (2009)

Stellar disk + IMBH evolution

stars
N=20

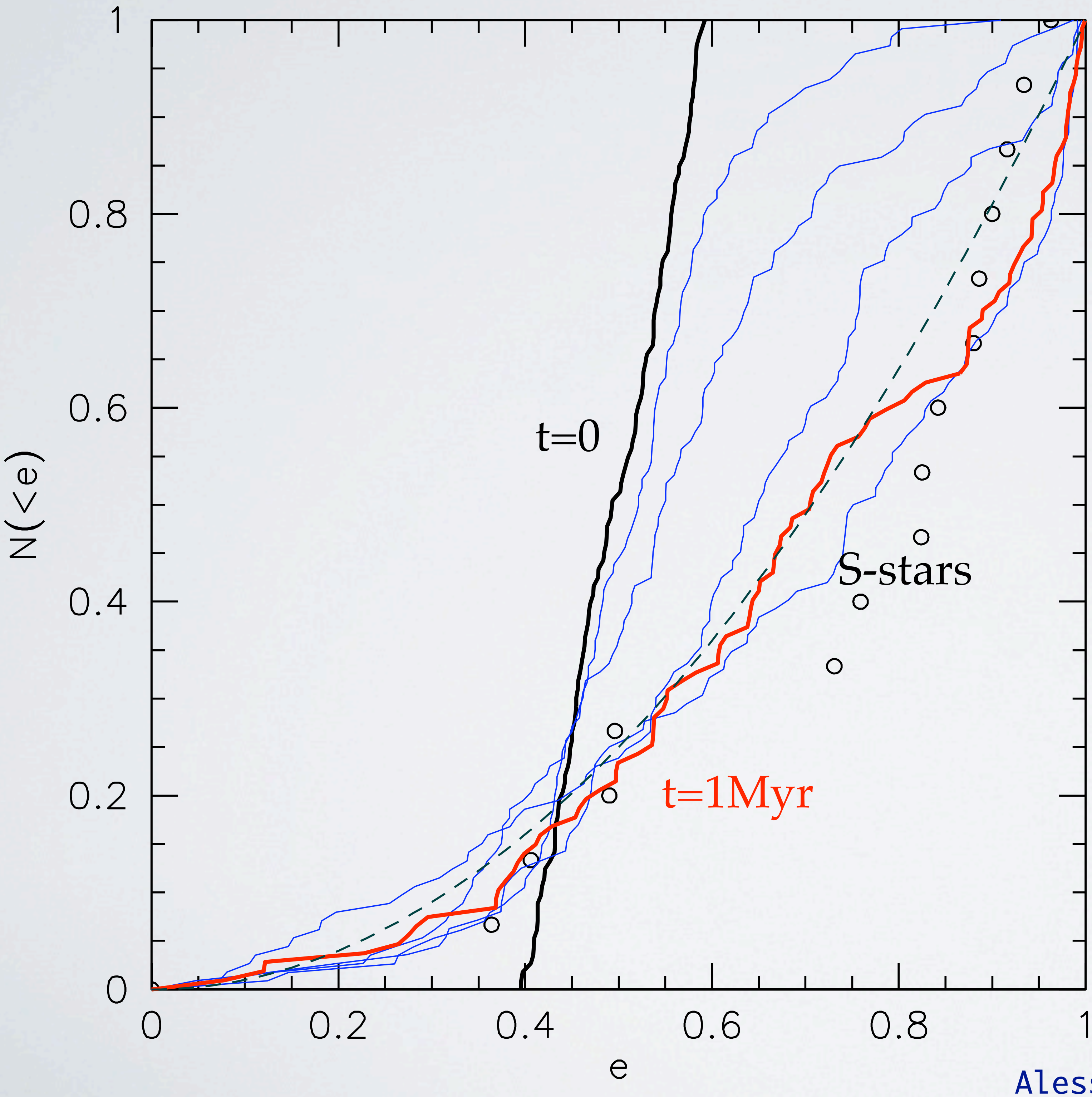
BBH
q = 0.001
a = 15 mpc
e = 0.5



$t = 1$ Myr

Merritt, Gualandris, Mikkola (2009)

Stellar disk + IMBH evolution

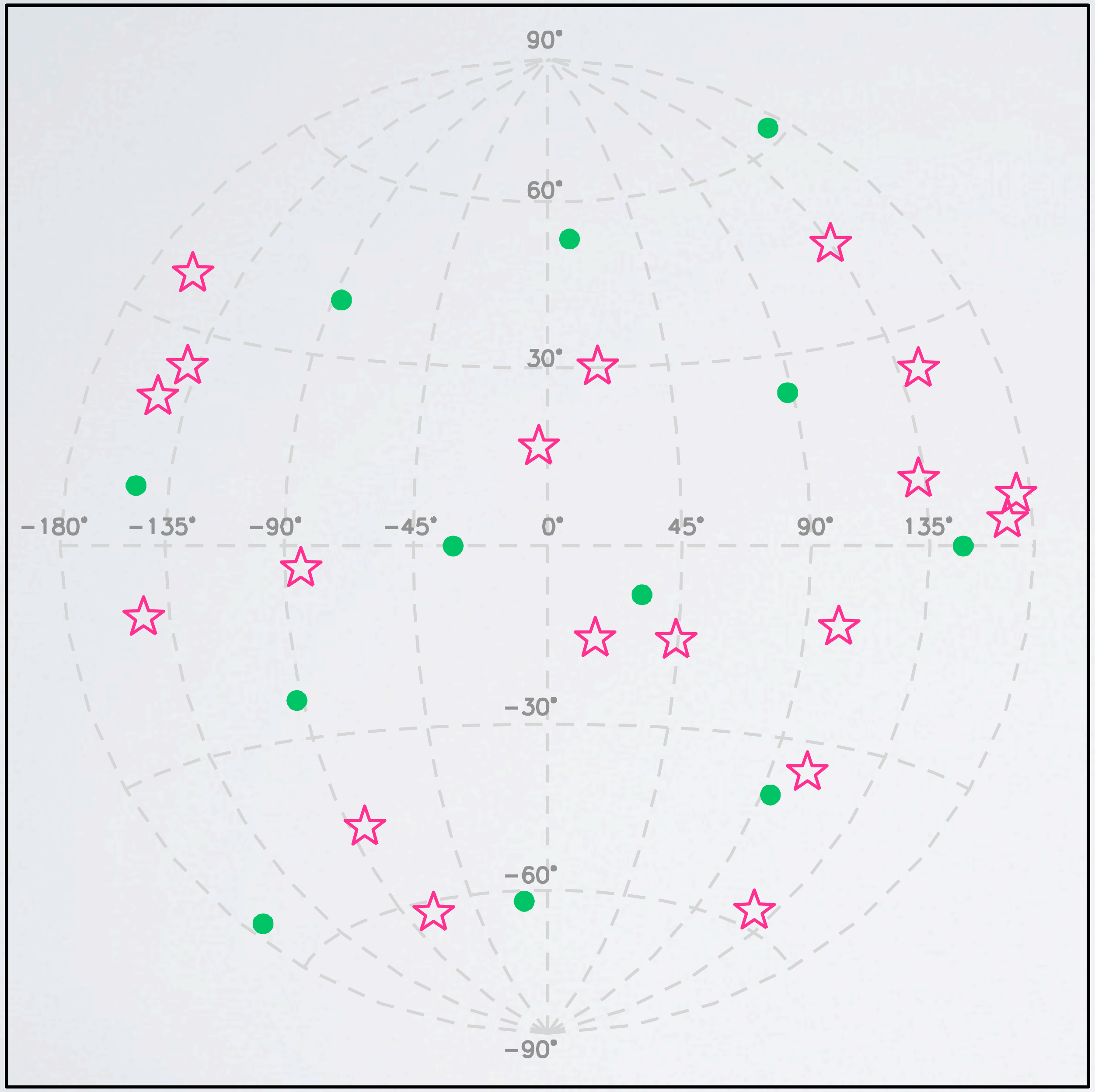


$M_{IMBH} = 4000\ M_\odot$
$a = 15$ mpc
$e = 0.5$

efficient thermalization of eccentricities

Merritt, Gualandris, Mikkola (2009)

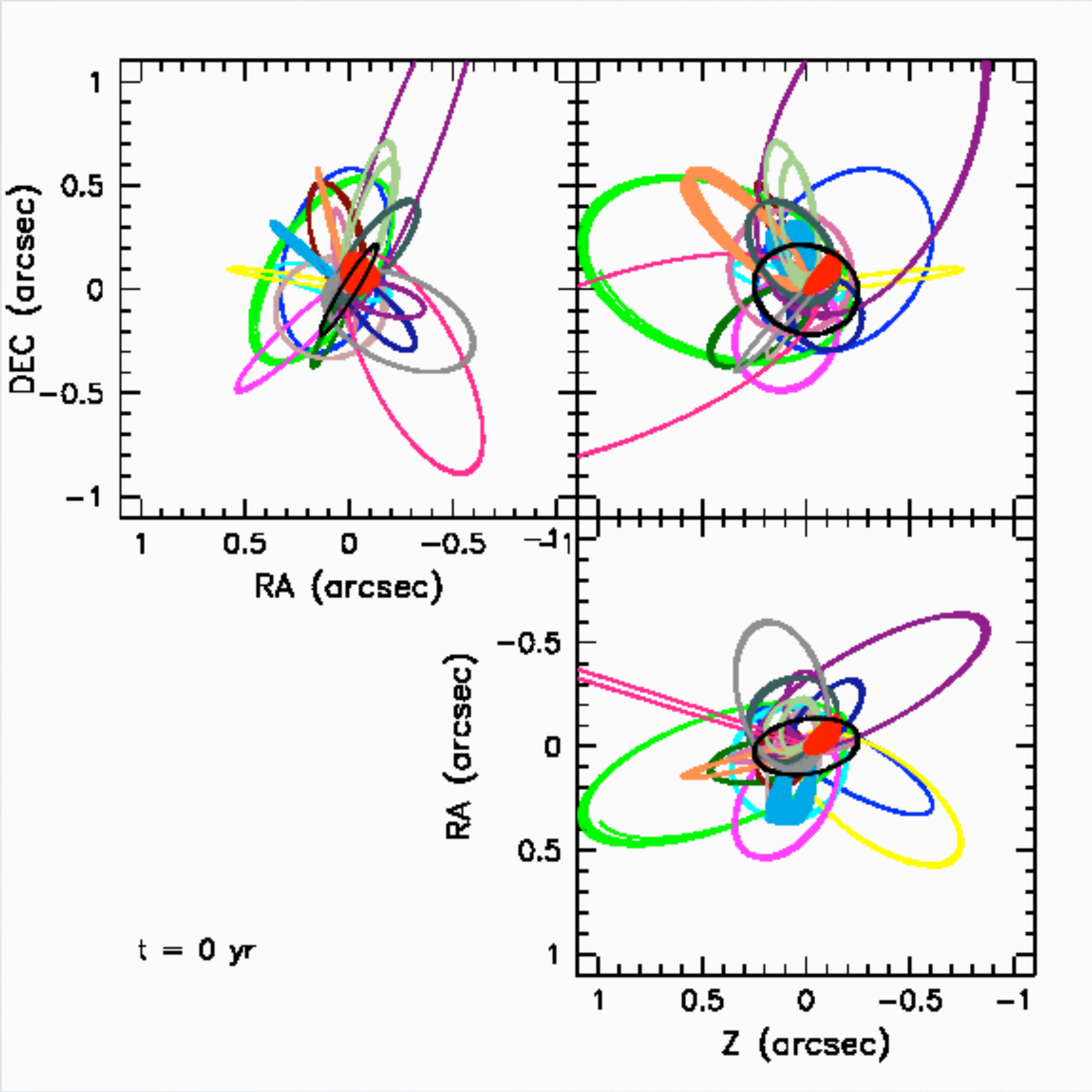
S-stars + IMBH evolution



Gualandris & Merritt (2009)

- 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
- $e_{IMBH} = 0, 0.7$

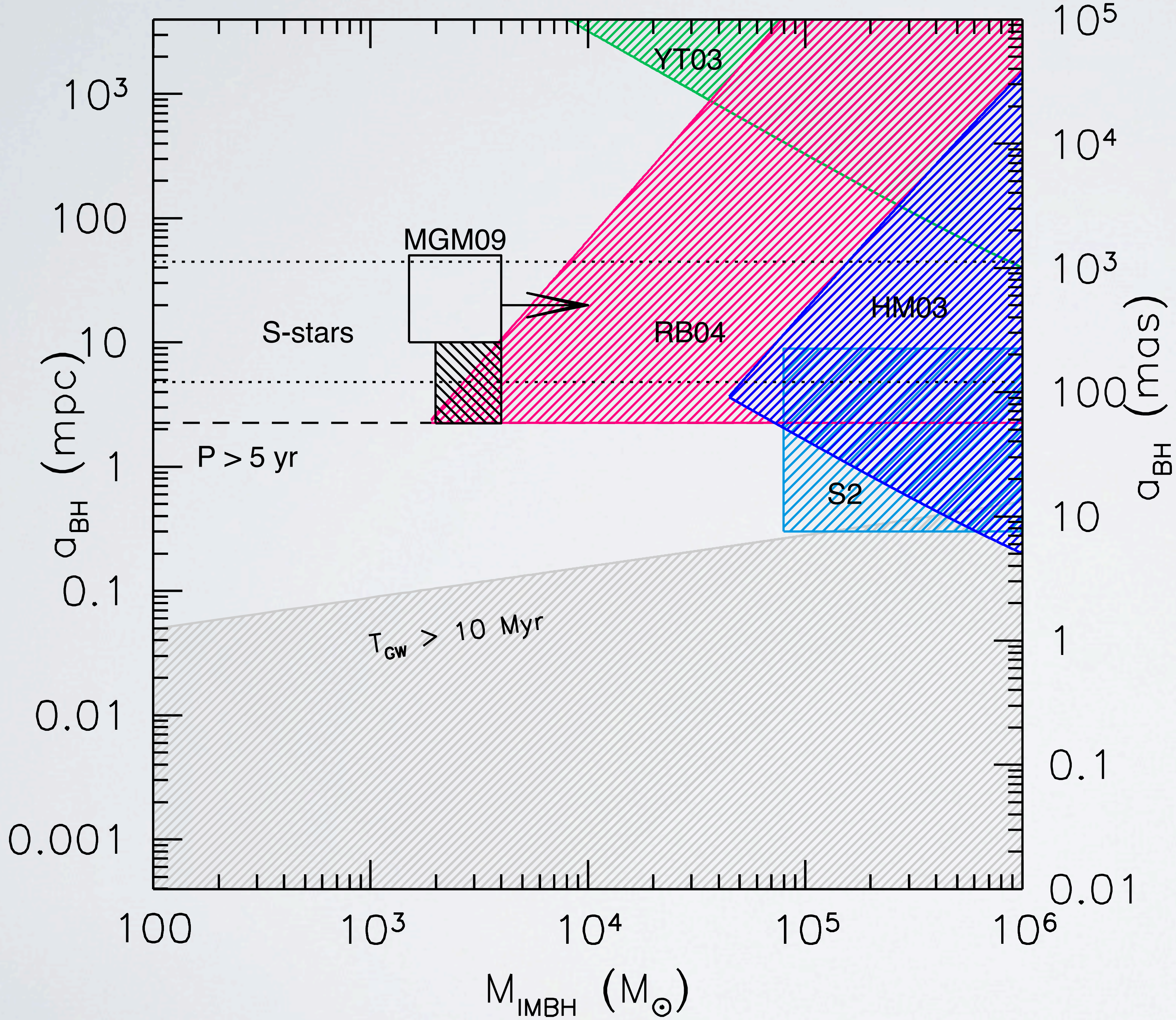
S-stars + IMBH evolution



$M_{IMBH} = 2000\ M_{\odot}$
a = 10 mpc
ejection

Gualandris & Merritt (2009)

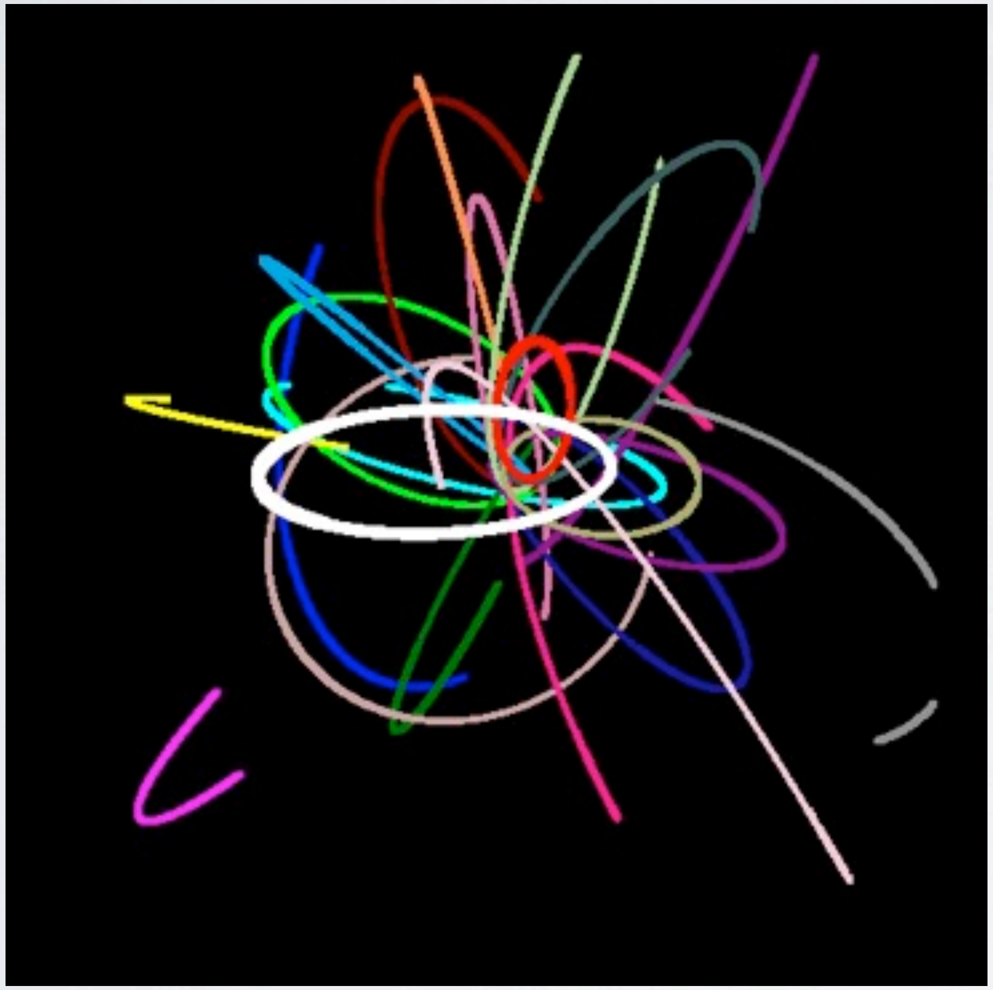
Constraints on IMBHs



- BBH com ~ peak stellar distribution within uncertainties (YT03)
- lifetime $T_{GW} > 10^7$ yr
- mass enclosed within orbit of S2 < 0.02 M_{BH}
- motion of SgrA* (HM03, RB04)
- stability of S-cluster

Gualandris & Merritt (2009)

IMBH effect on S2



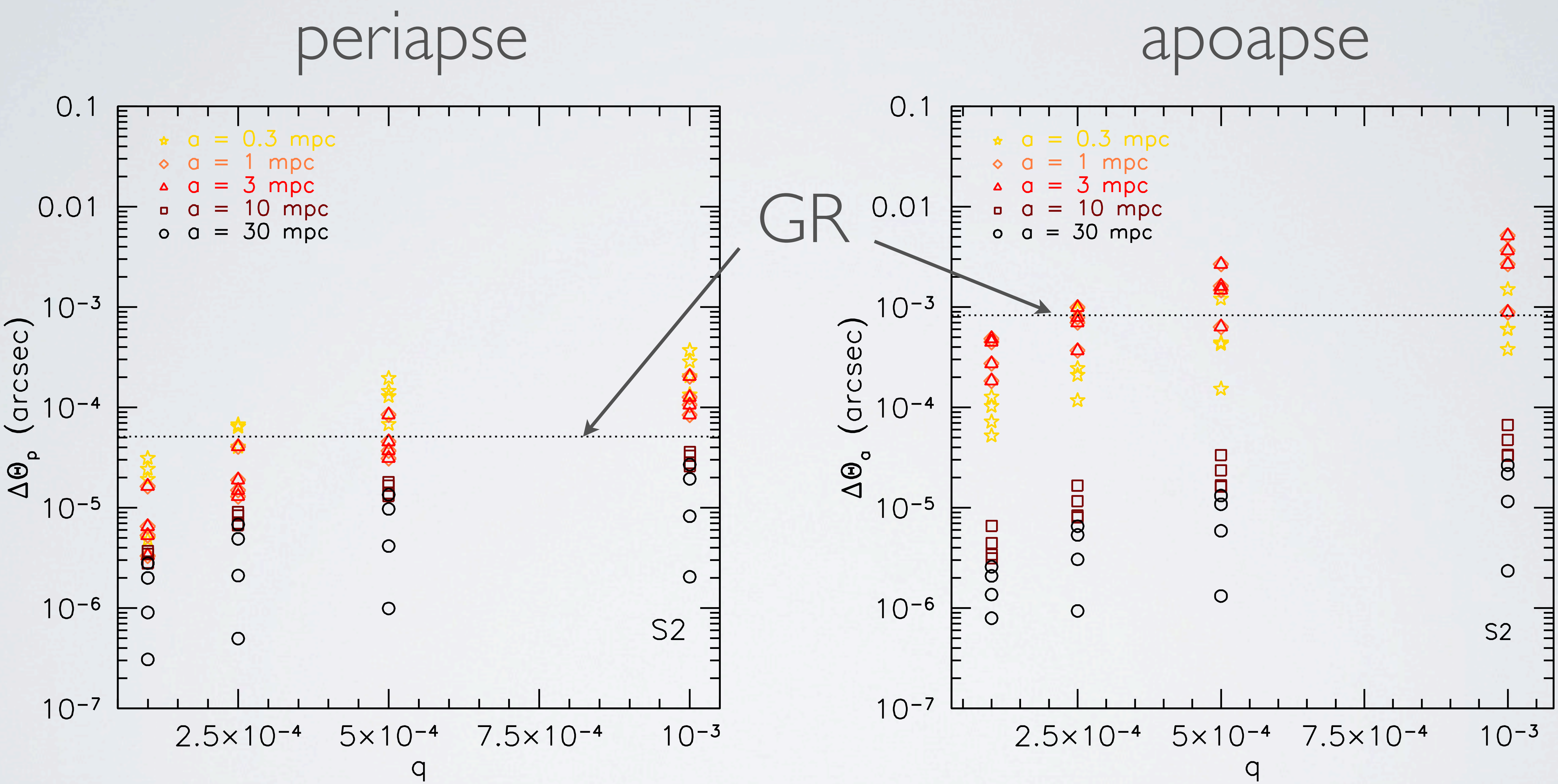
Gualandris, Gillessen, Merritt
astro-ph/1006.3563

SMBH $M=4.3\times10^6\ M_\odot$

IMBH: $q = 10^{-4} - 10^{-3}$
$a = 0.3, 1, 3, 10, 30$ mpc
$e = 0, 0.5, 0.7, 0.9$
21 S-stars

S2: $a = 5$mpc
$e = 0.883$
$r_p = 0.6$ mpc
$r_a = 9.4$mpc

IMBH effect on S2



Gualandris, Gillessen, Merritt
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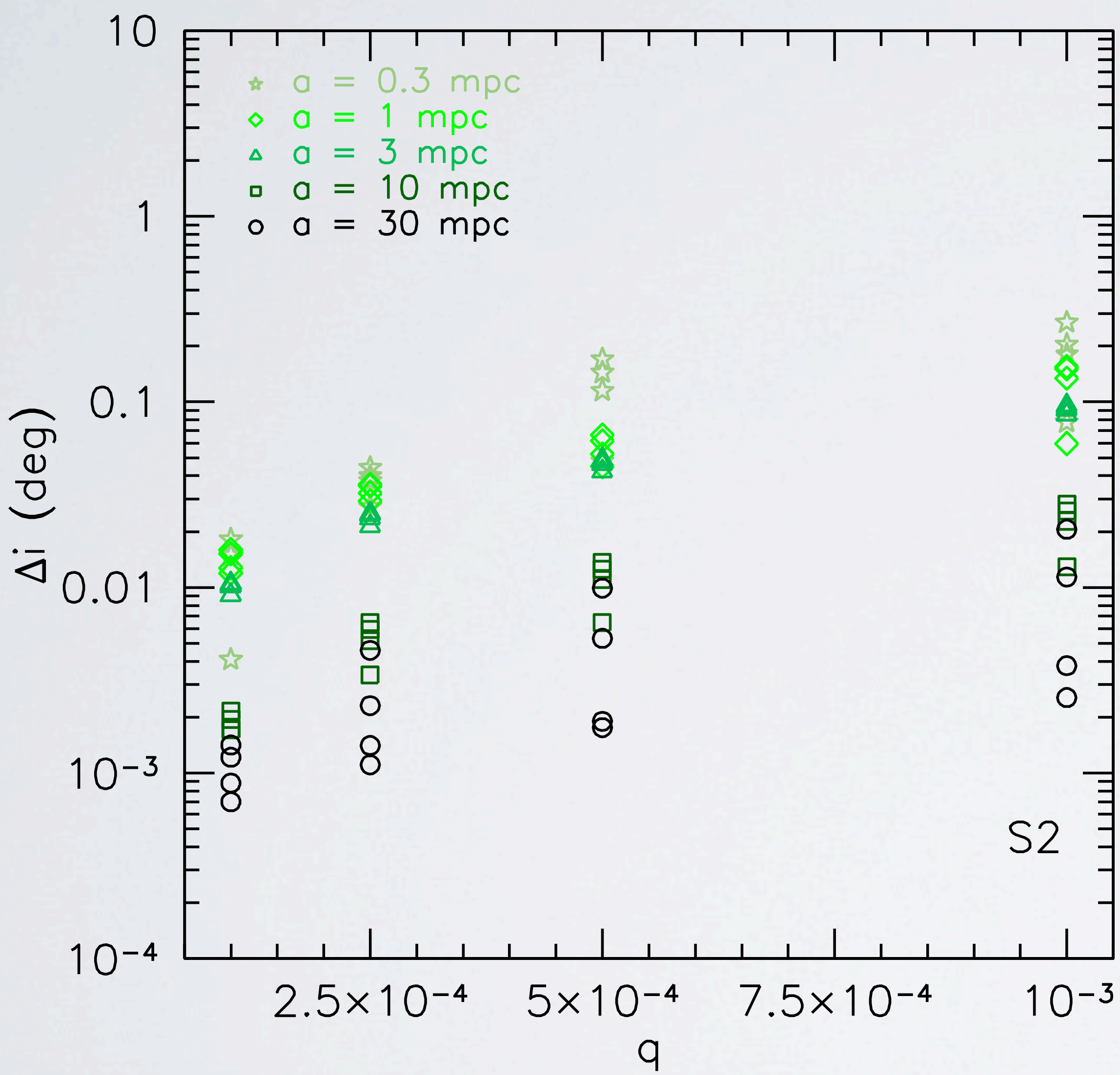
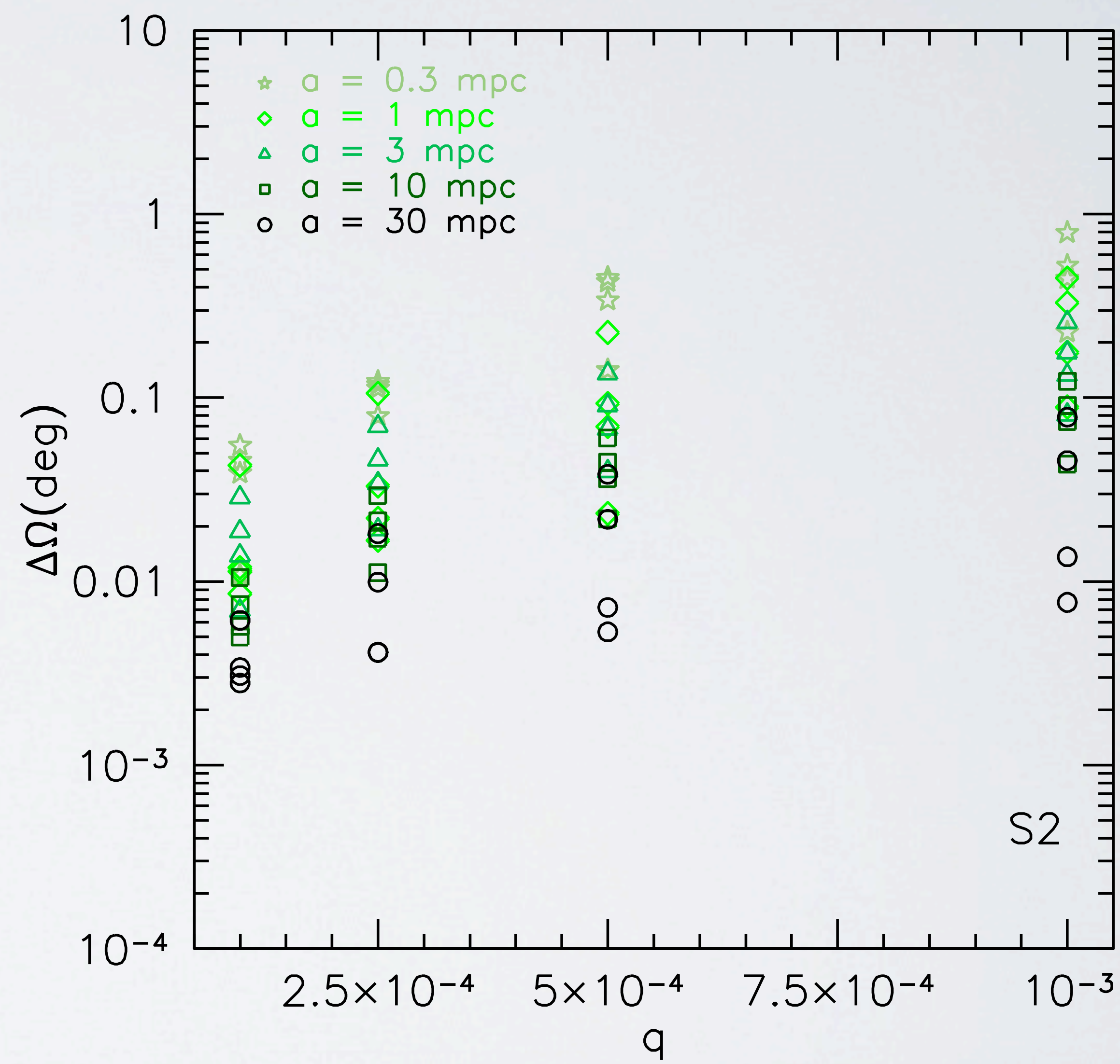
IMBH effect on S2

inclination



nodal angle



Gualandris, Gillessen, Merritt
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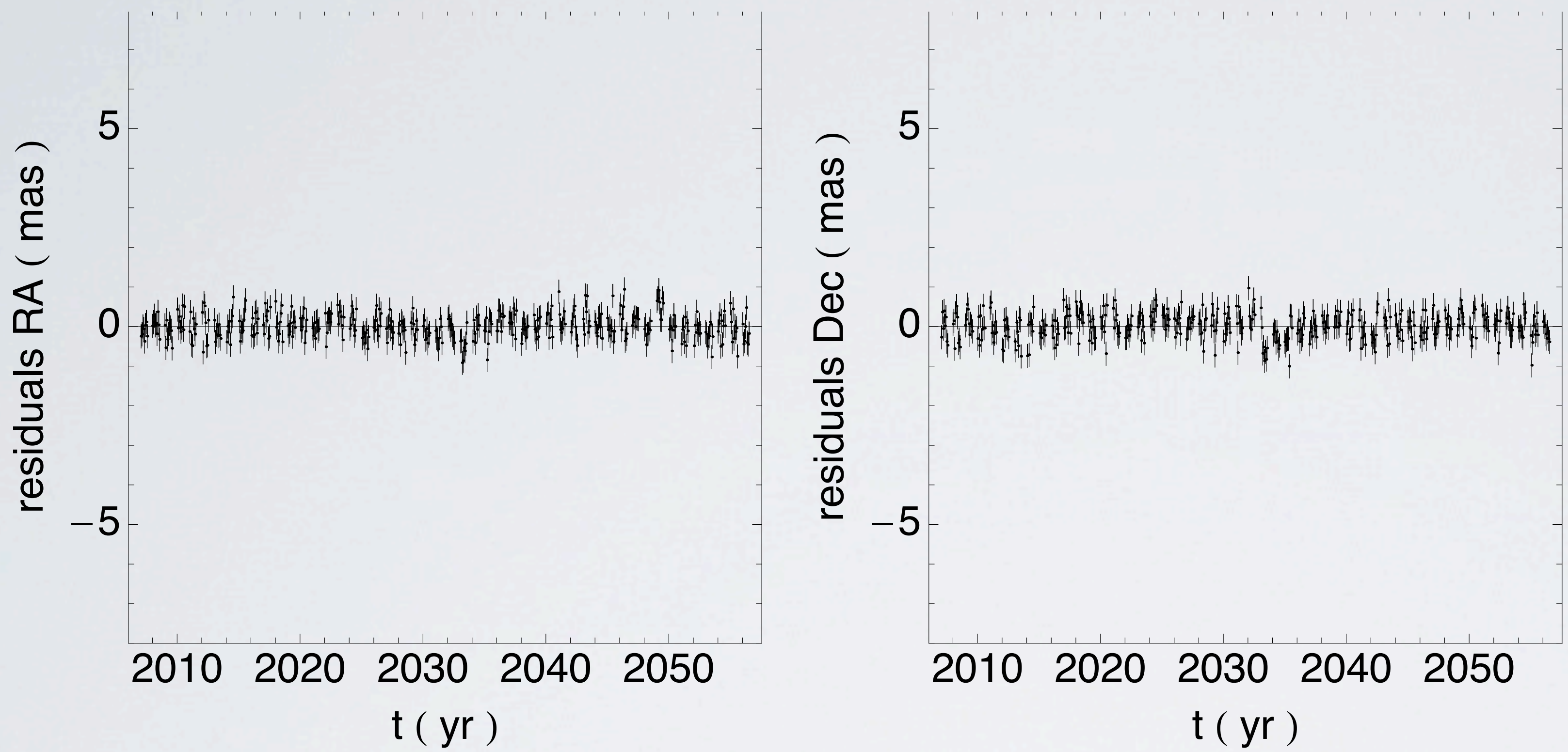
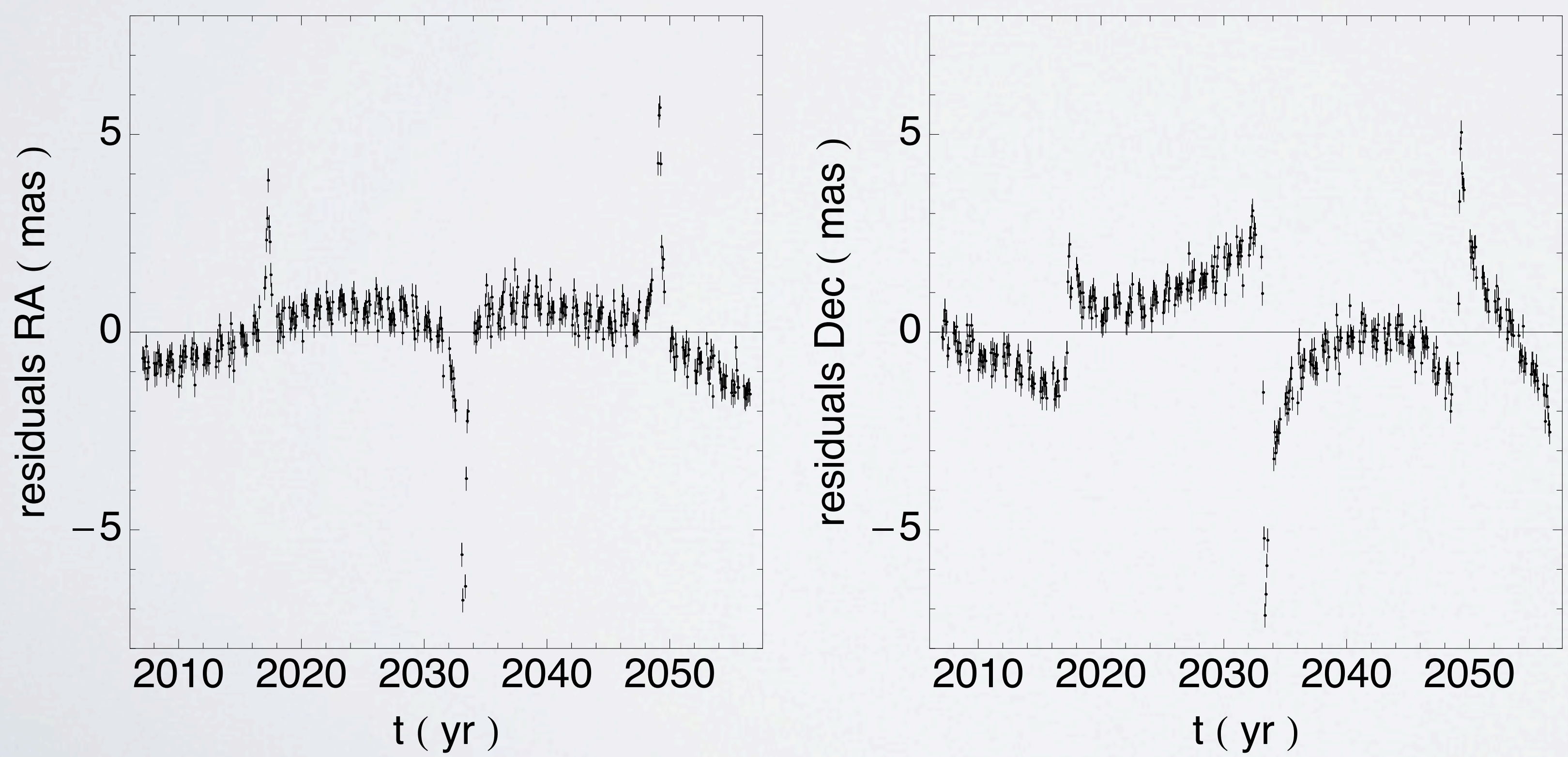
IMBH effect on S2



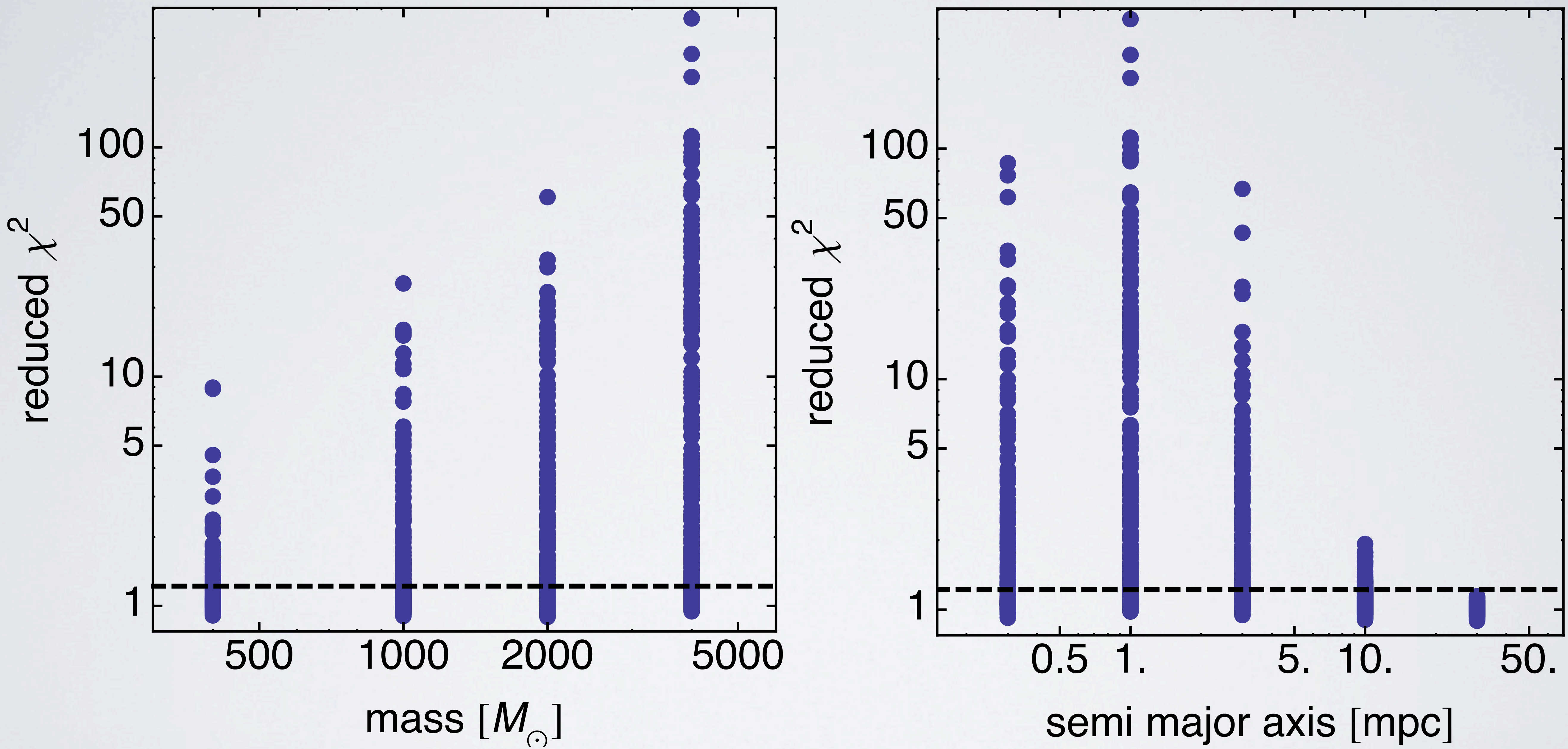
$q = 10^{-4}$
$a = 30$ mpc
$e = 0$



$q = 5\times10^{-4}$
$a = 1$ mpc
$e = 0$

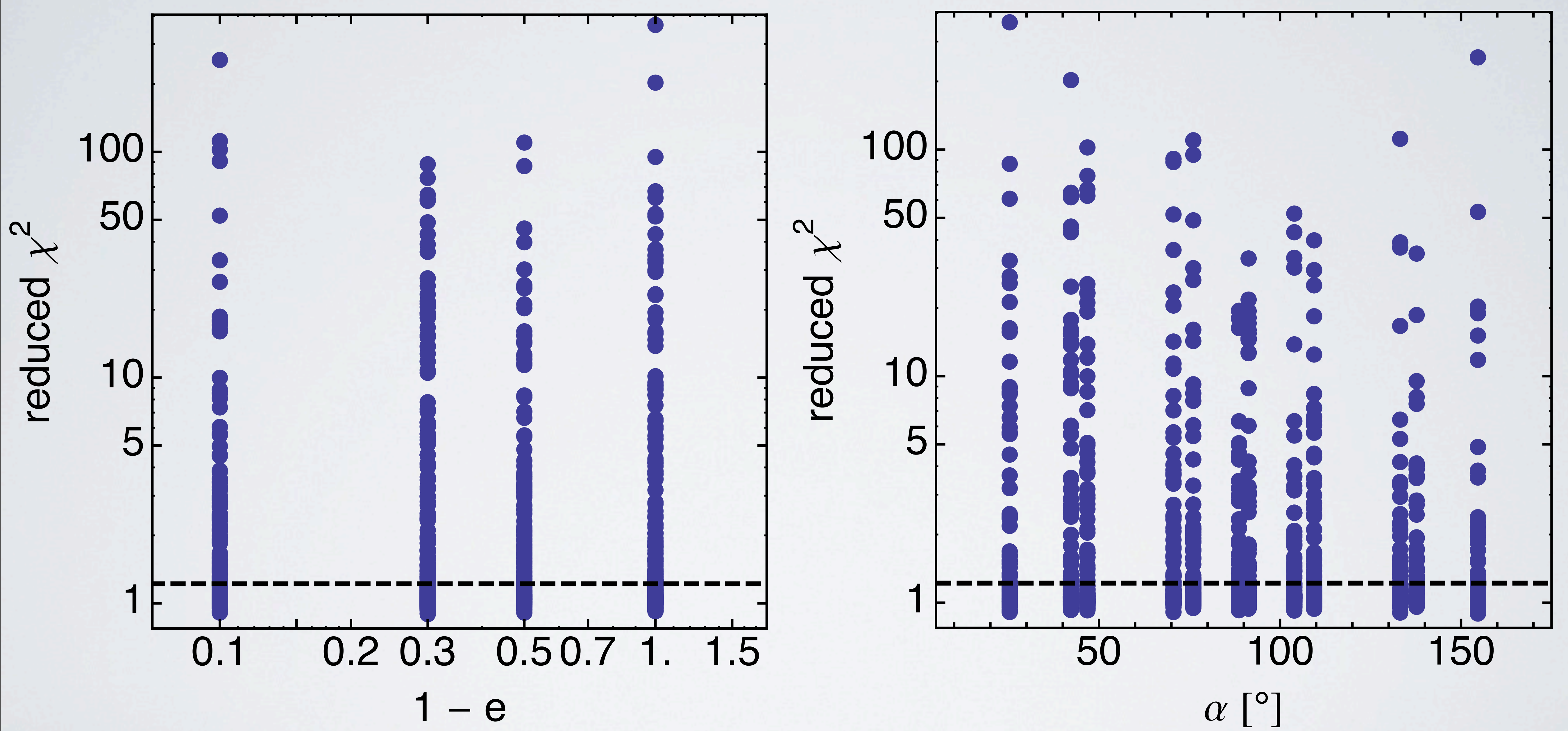
Gualandris, Gillessen, Merritt
astro-ph/1006.3563

IMBH effect on S2



Gualandris, Gillessen, Merritt
astro-ph/1006.3563

IMBH effect on S2



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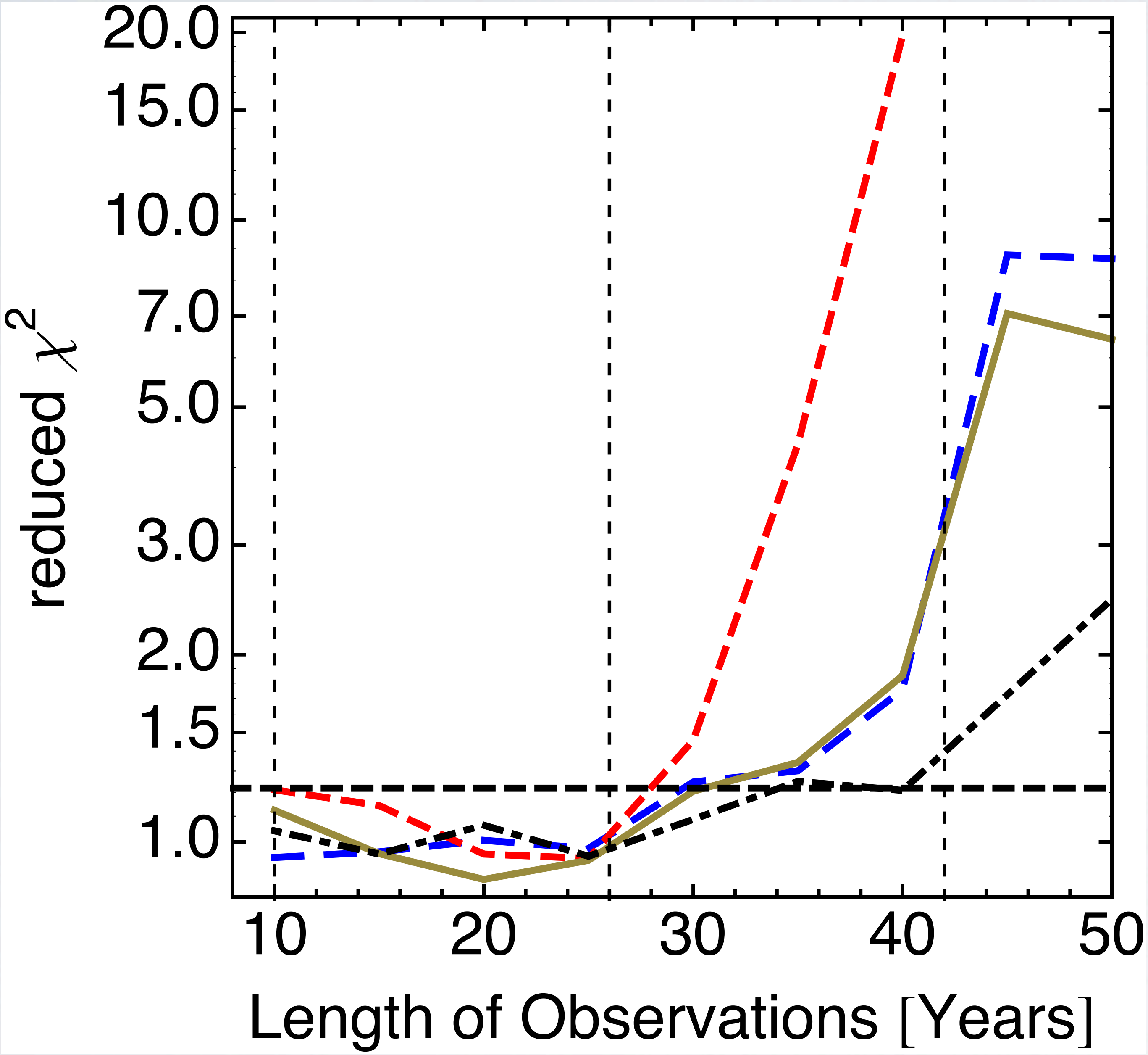
astro-ph/1006.3563

IMBH effect on S2



IBH potentially detectable at next pericenter passage in 2018

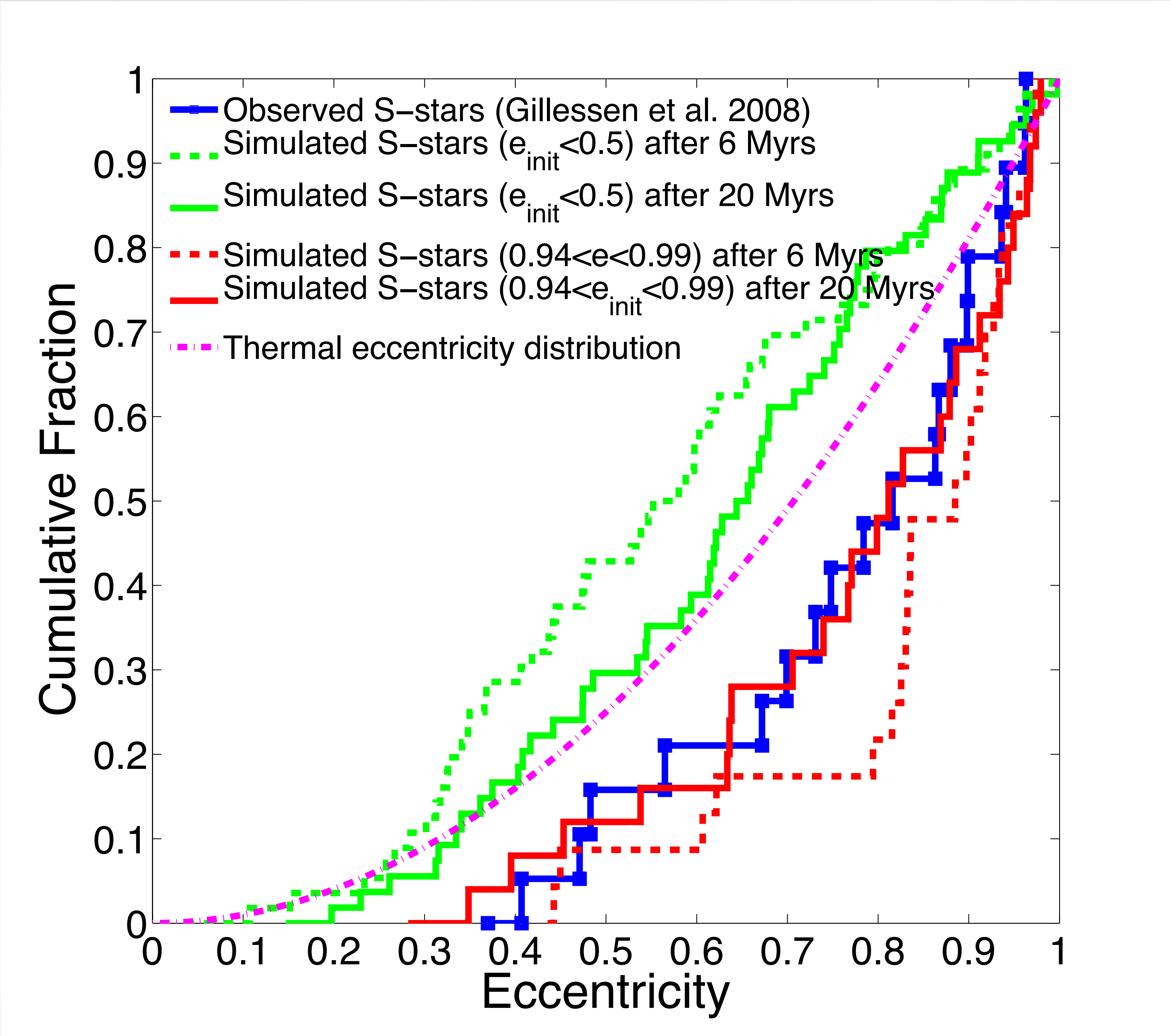
optimum cut

Gualandris, Gillessen, Merritt
astro-ph/1006.3563

Origin of the S-star cluster: in-situ vs binary disruption

- Isotropic cusp $N = 1200$ $r < 0.3$ pc
- $N_1 = 200$ $N_2 = 1000$
- $m_1 = 3\ M_\odot$ S-stars, $m_2 = 10\ M_\odot$ bhs
- $M_{BH} = 3.6\times10^6\ M_\odot$
- Power-law distribution $r^{-\alpha}$
  $\alpha = 2$ for bhs , $\alpha = 1.5$ for stars

Origin of the S-star cluster: in-situ vs binary disruption



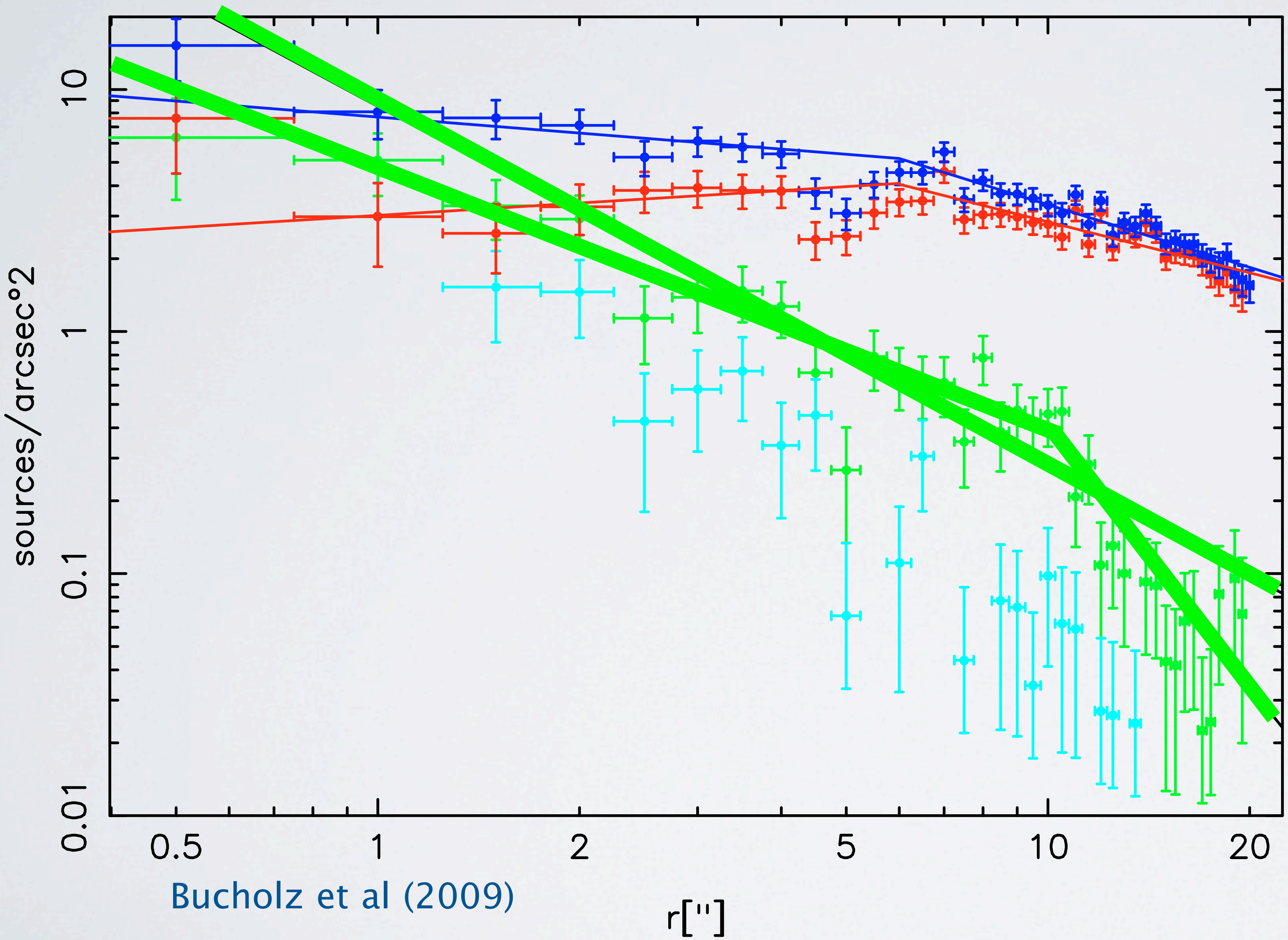
high initial eccentricities (e>0.96) binary disruption

low initial eccentricities (e<0.5) disk origin

Binary disruption t = 20 Myr is the favored model

Perets, Gualandris, Merritt, Alexander (2009)

The B-stars population



Bucholz et al (2009)

Detection of early-type stars out to ~0.8 pc
=>
Continuous population of B-stars

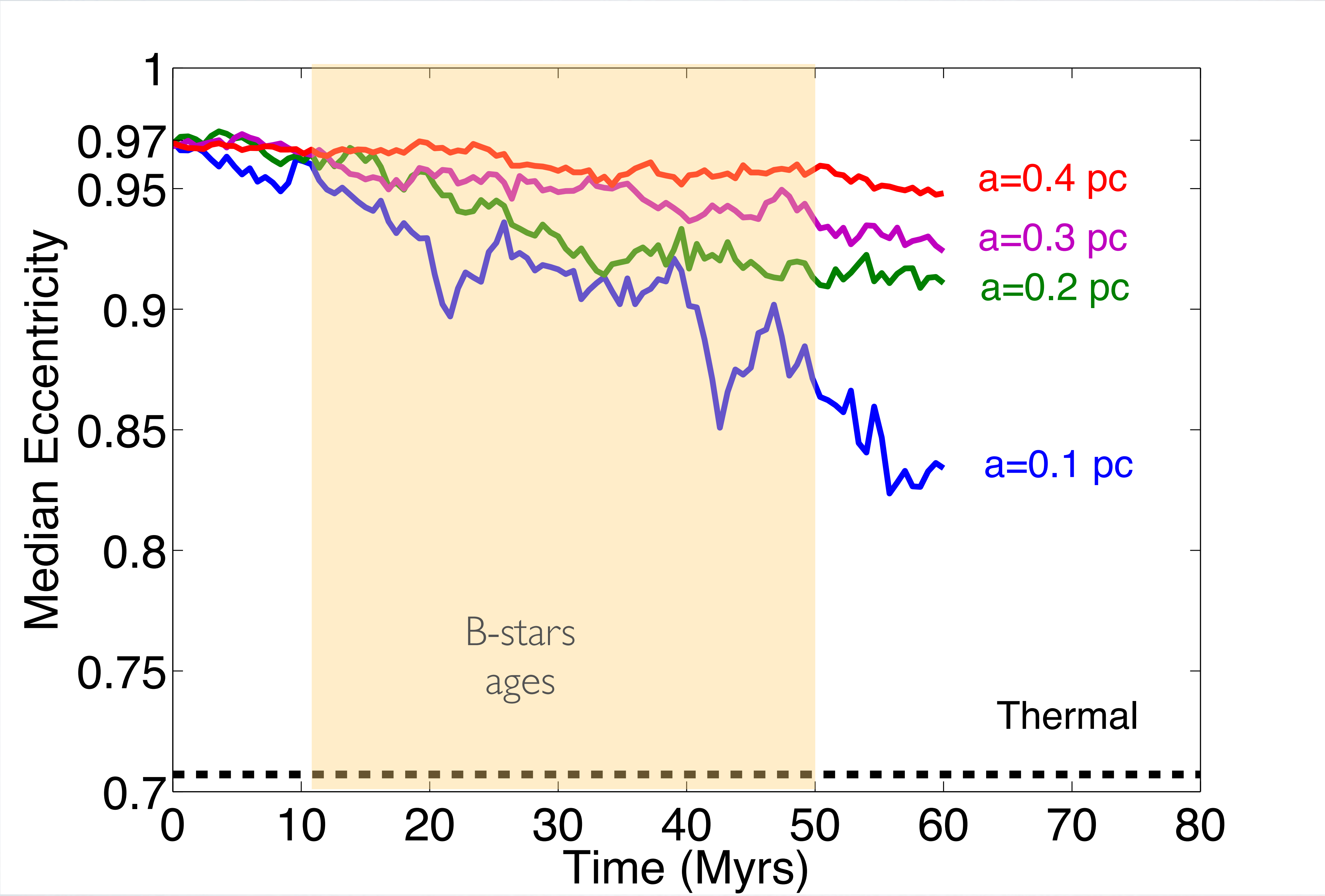
1 arcsec ~ 0.04 pc

The B-stars population

- $M_{BH} = 3.6 \times 10^6\ M_\odot$
- Isotropic cusp $N = 16000$ $m = 10\ M_\odot$ stars
- Power-law distribution r^{-2}, $0.04 < r < 0.8$ pc

follow stars with initial eccentricity $0.94 \leq e \leq 0.99$
representative of binary disruption stars

The B-stars population



Perets & Gualandris
arXiv:1004.2703

Conclusions

Models for origin of the young stars in the Galactic center:

* In-situ formation consistent with stellar disk(s), not the B-stars.
* Binary disruption scenario consistent with the properties of the B-stars population, but requires chain of events. It predicts dependency of eccentricity on distance.
* Cluster infall scenario with IMBH consistent with all observed properties of the B-stars, but difficulties in the IMBH formation and inspiral and predicted number of B-stars outside central arcsecond.
* Short-term effects from an IMBH potentially detectable for star S2 at next pericenter passage.