Slow Mass Segregation at The Galactic center

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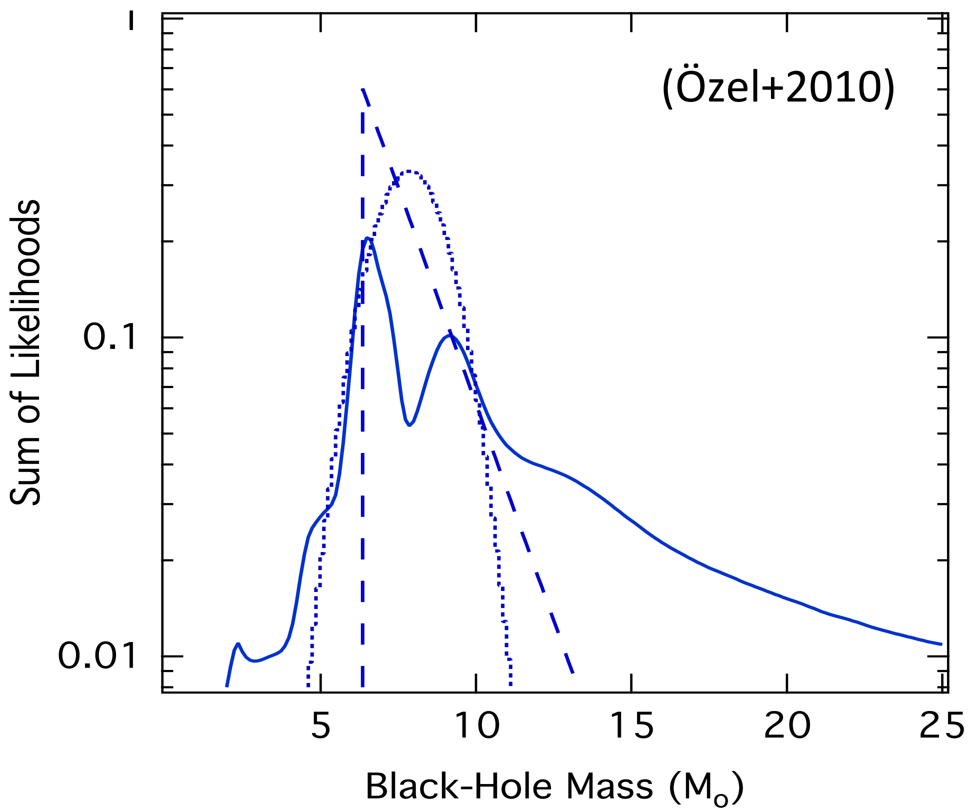
CITA–ICAT

Stellar black holes: number fraction and mass



TYPICAL FRACTIONS

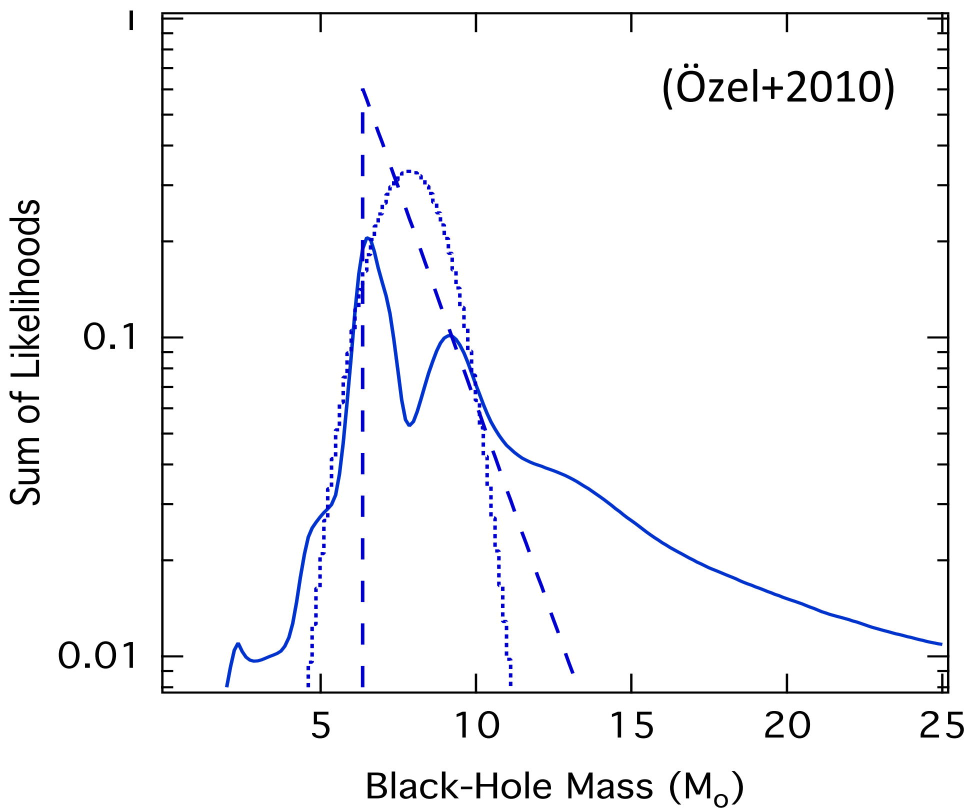
Standard IMF:

$$N_{\rm MS}:N_{\rm WD}:N_{\rm NS}:N_{\rm BH} \approx 1:0.1:0.01:0.001$$

Top-Heavy IMF:

$$N_{\rm MS}:N_{\rm WD}:N_{\rm NS}:N_{\rm BH} \approx 1:0.2:0.02:0.005$$

Stellar black holes: number fraction and mass



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Top-Heavy IMF:

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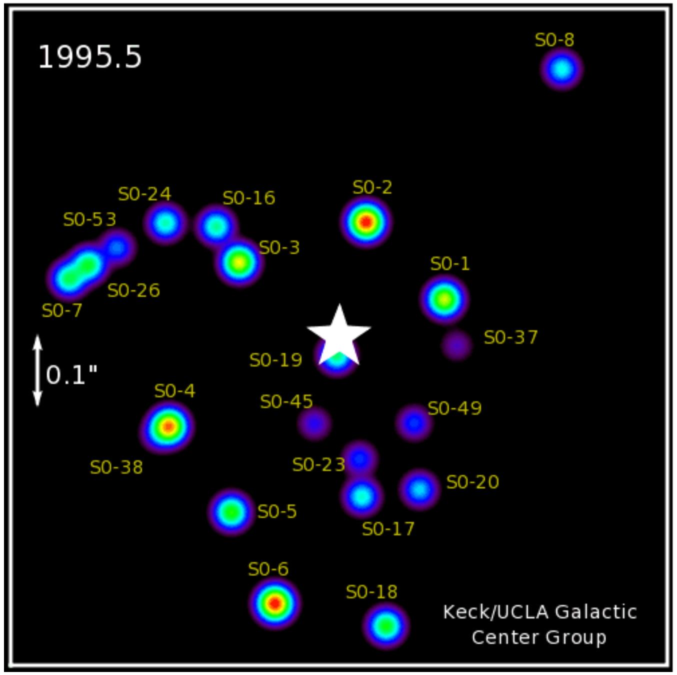
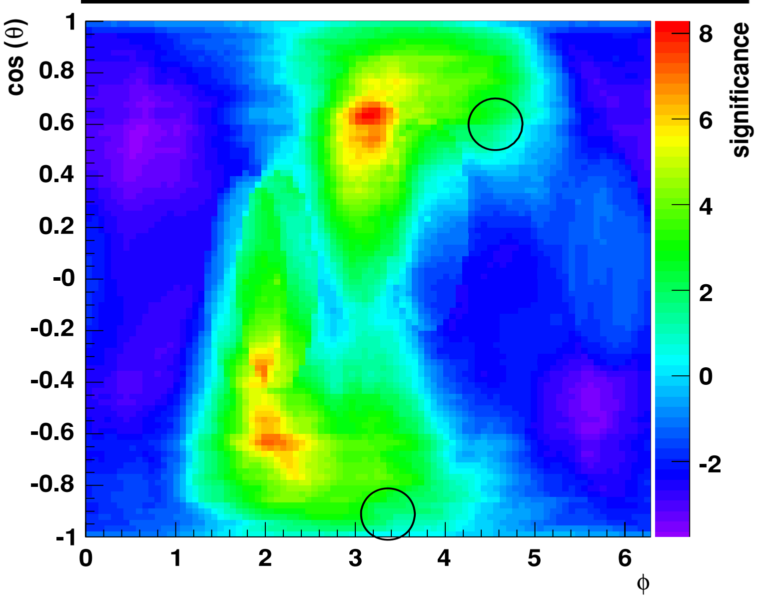
1) BHs are 10 times more massive than a typical field star
2) 1% of the cluster mass is in the form of BHs

The number of BHs at the Galactic center

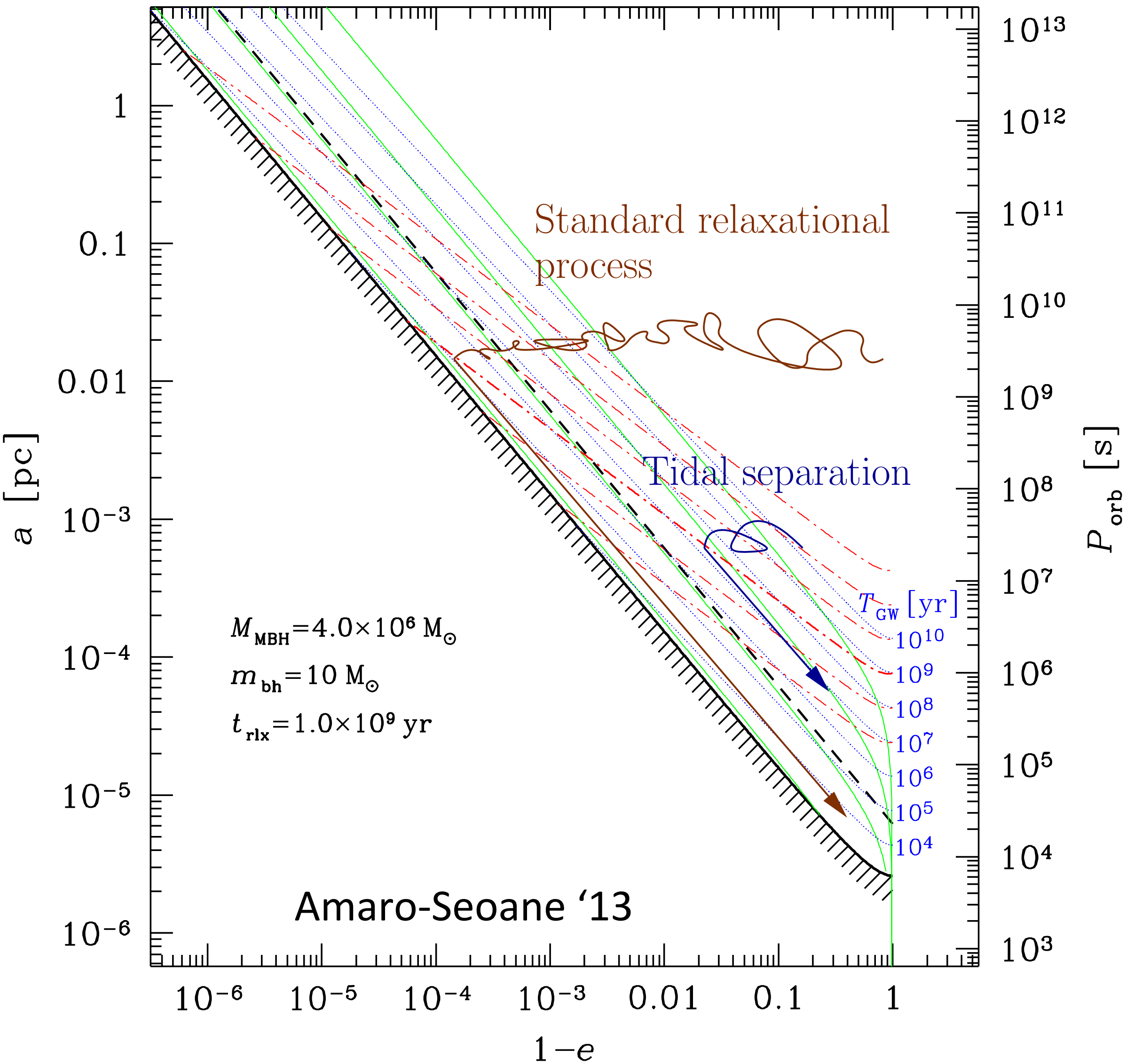


Randomization of the S-star orbital eccentricities (Antonini and Merritt '13, Antonini '14)



Warping of the young stellar disk (Bartko et al. '09; Kocsis & Tremaine '11)

Extreme mass-ratio inspirals



The inspiral of BHs into MBHs is as a promising source of GW for eLISA (Sigurdsson and Rees '97, Barack & Culter '04 Amaro-Seoane et al. '12)

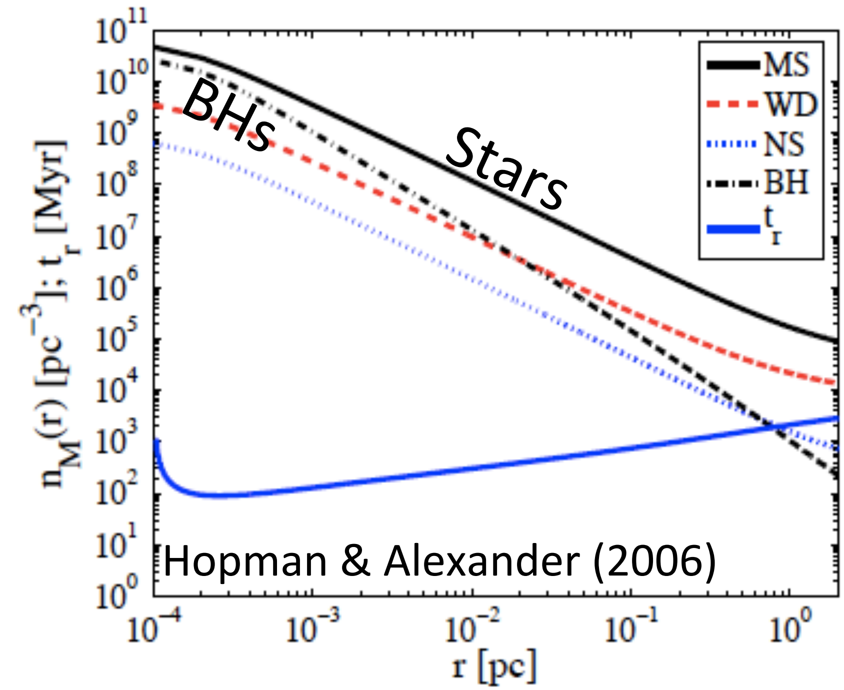
The inspiral rates are highly dependent on the *number* of BHs near the center of galaxies (e.g., Merritt '10)

The density distribution of late type stars

Theoretical (dynamically relaxed) models

steep density cusp
(Bahcall & Wolf '76)

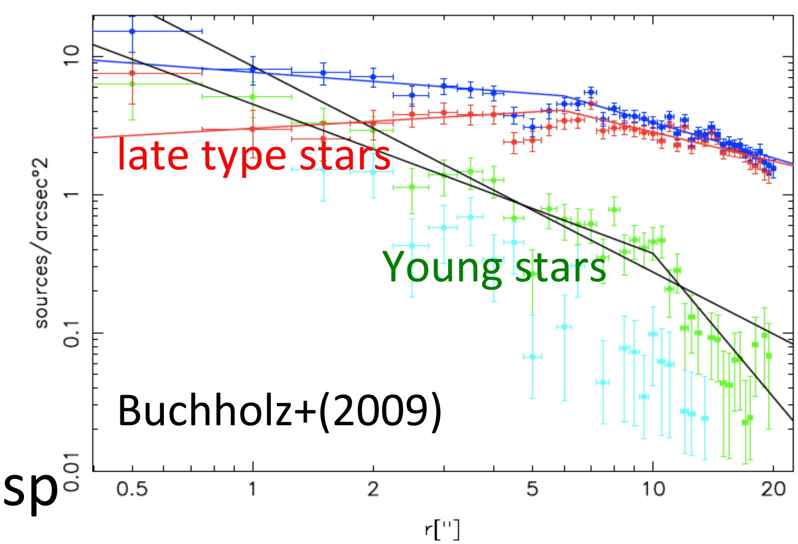
The BHs dominate within 0.1pc



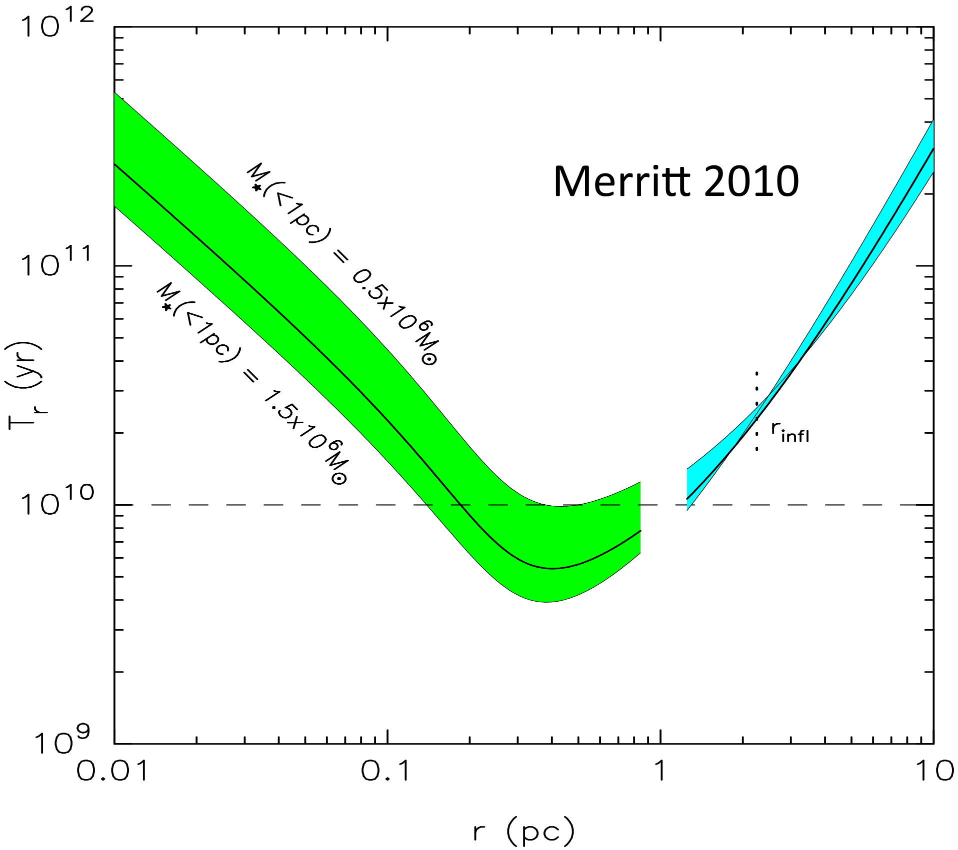
Observed distribution

flat core or shallow cusp!!
(Buchholz+'09; Do+ '09, '13; Bartko+ '09)

core radius ≈ 0.5pc
only the young stars have a density cusp

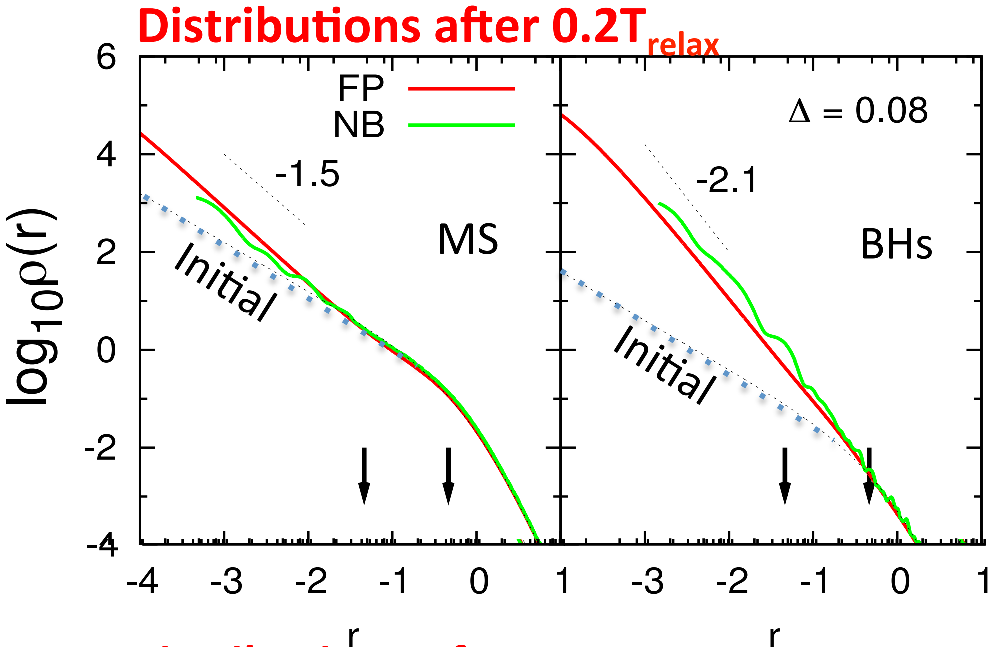


The distribution of stars at the Galactic center

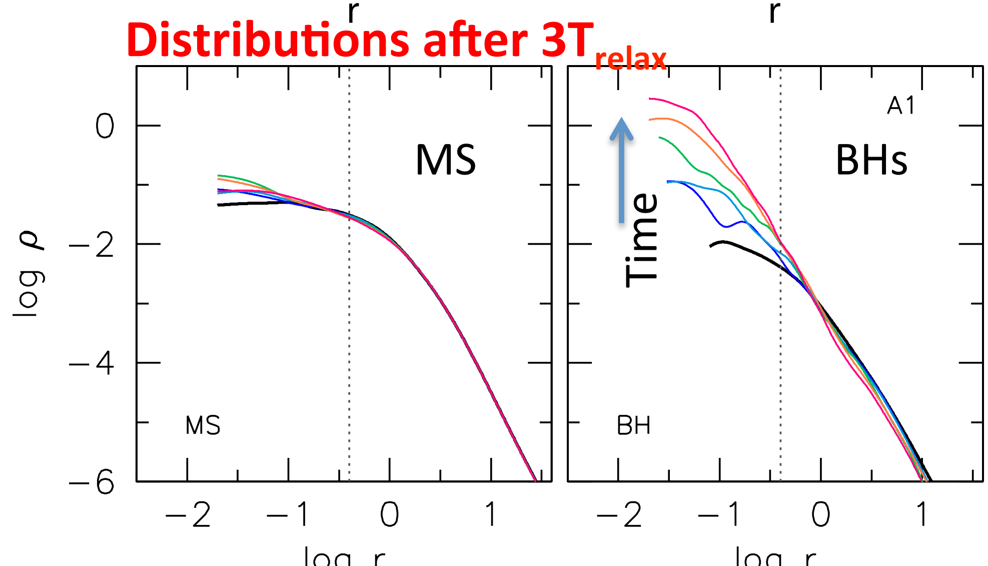


Relaxation time of order 20Gyr

Mass Segregation at the Galactic center: recent work

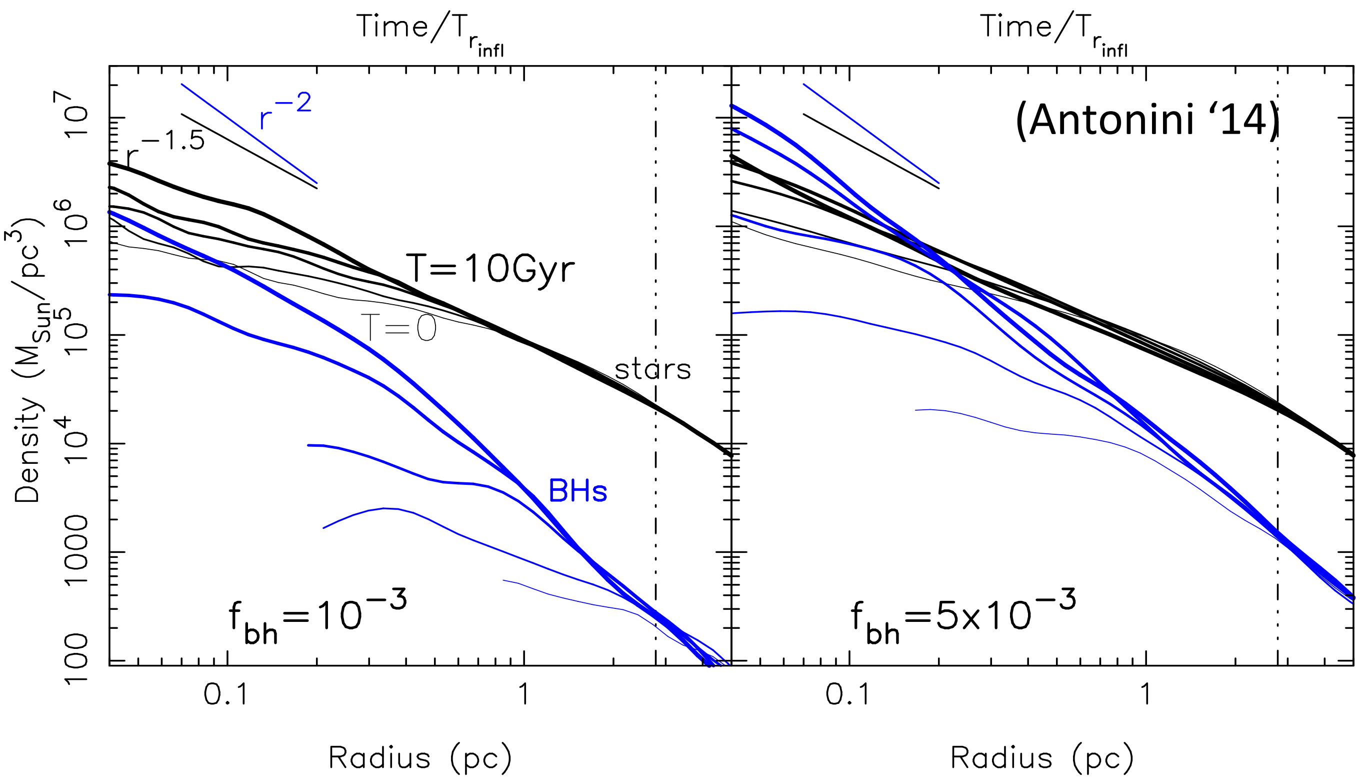


Preto and Amaro-Seoane '10:
"Mass segregation speeds up cusp growth by factors ranging from 4 to 10"



Gualandris and Merritt '12:
"Adding a heavy component has relatively little effect on the growth of a Bahcall-Wolf cusp in the MS component"

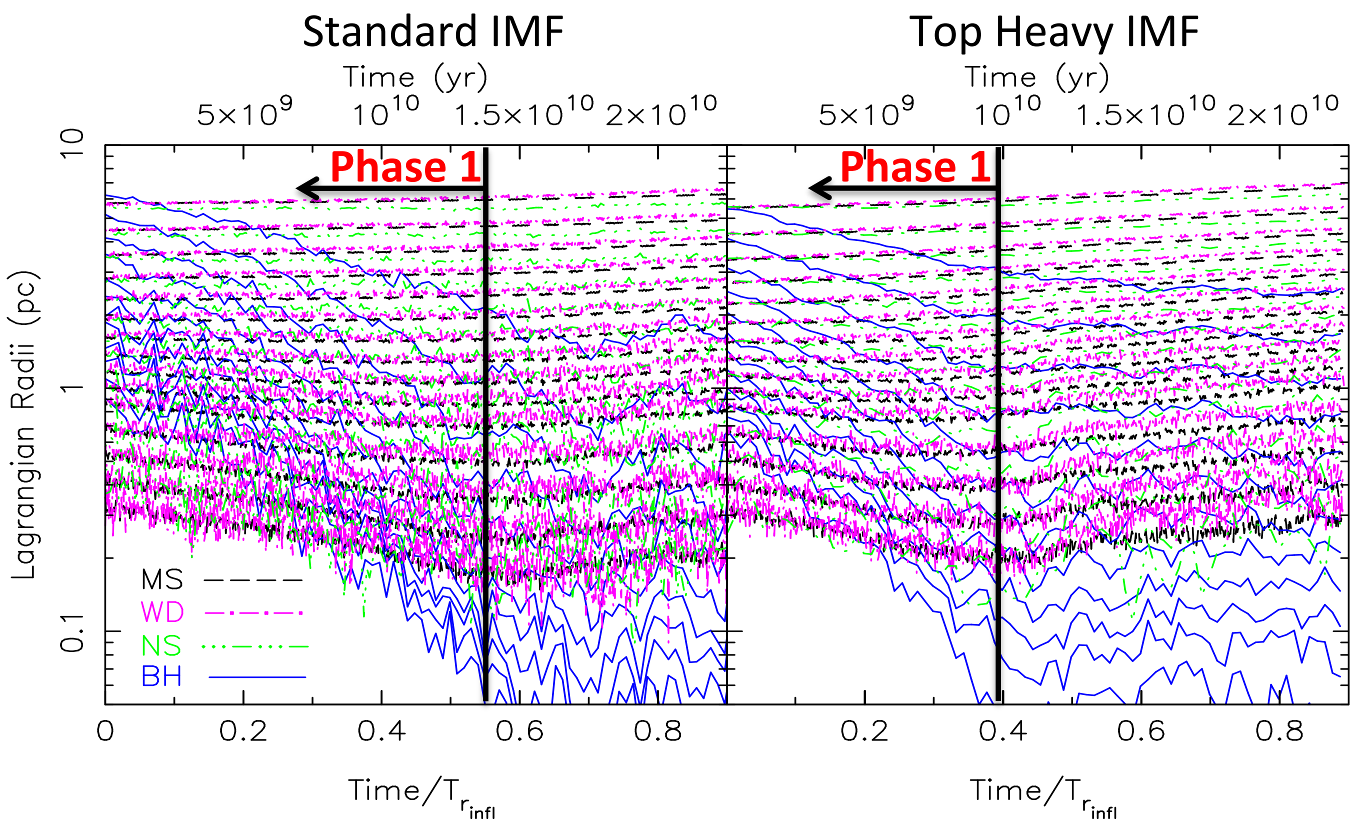
Mass Segregation at the Galactic center



The regrowth of a stellar cusp can take more than one Hubble time

Mass segregation is ***slow***: after 10Gyr the density of BHs remains below that of stars at all radii

The Two Phases of Mass Segregation

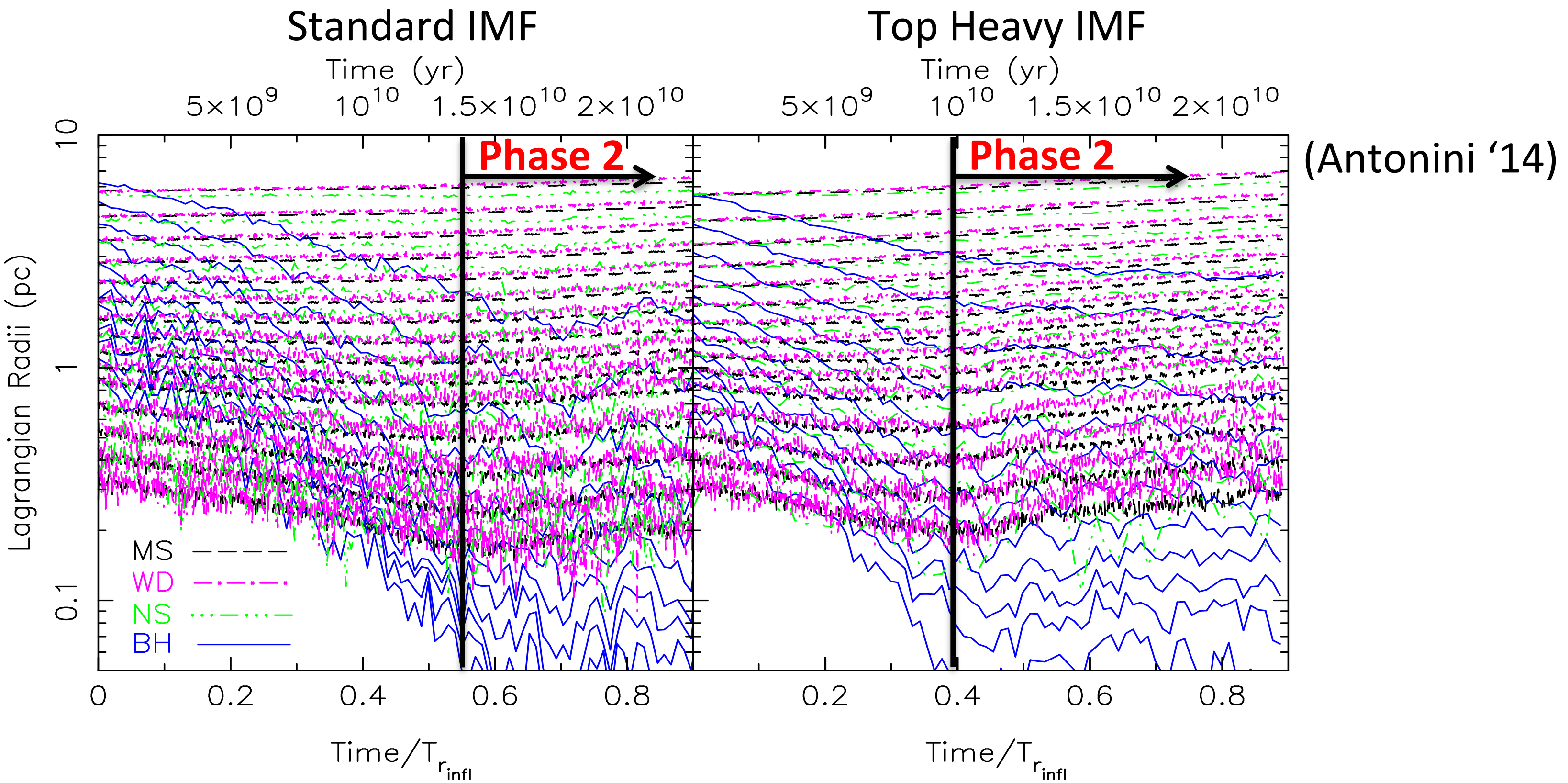


(Antonini '14)

TWO PHASES OF MASS SEGREGATION:

1) THE DENSITY OF BHS IS SMALLER THAN THE DENSITY OF STARS: dynamical friction drives the inspiral

The Two Phases of Mass Segregation

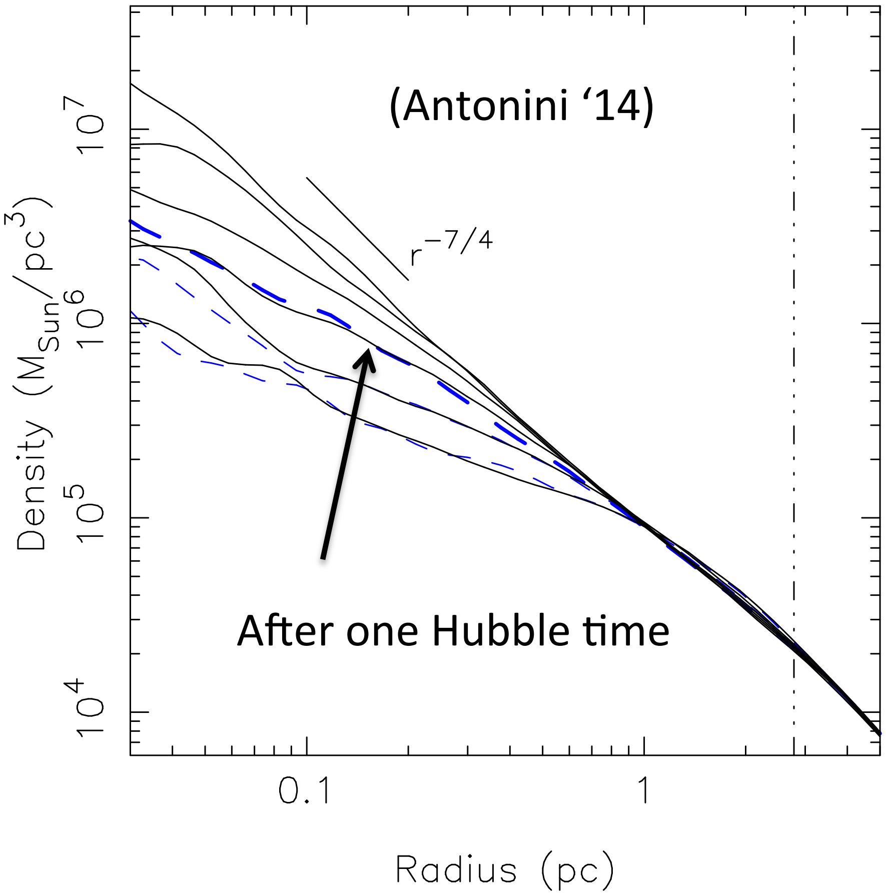


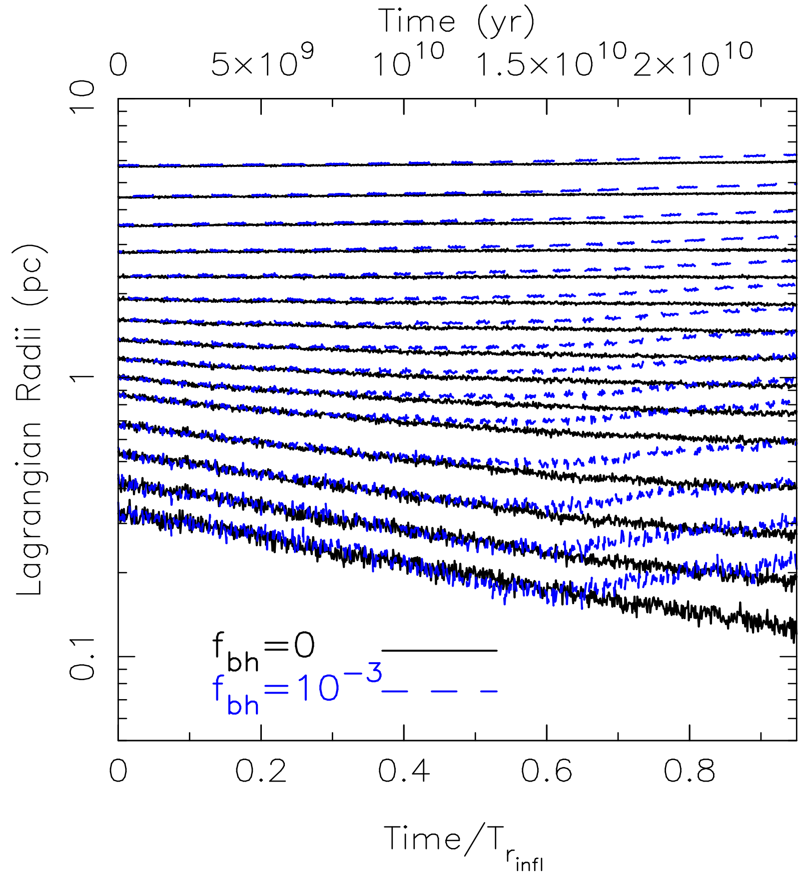
TWO PHASES OF MASS SEGREGATION:

1) THE DENSITY OF BHS IS SMALLER THAN THE DENSITY OF STARS: dynamical friction drives the inspiral

2) THE BHS DENSITY BECOMES LARGER THAN THE DENSITY OF STARS: self-scattering of the BHs and scattering of the MS off the BH population becomes the dominant process

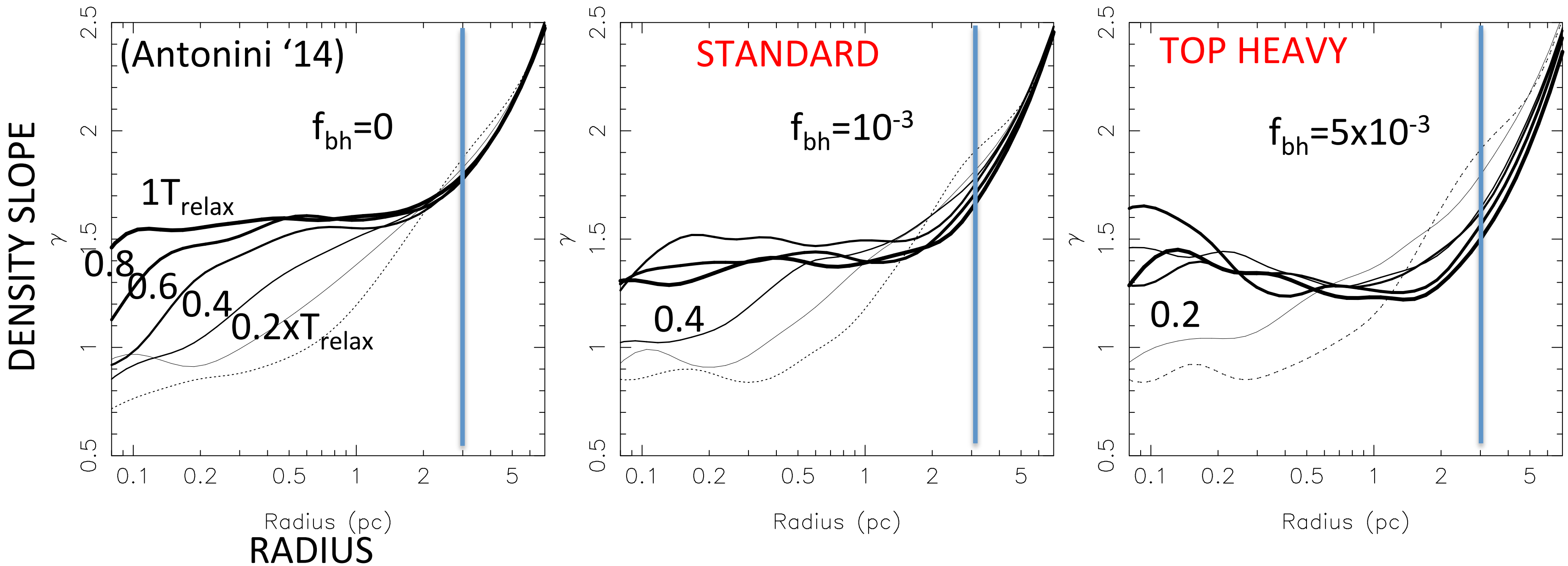
Effect on the MS population





The dynamical friction phase is *very slow* and even after one Hubble time the presence of the heavy component has little effect on the density of stars (Antonini '14)

Effect on the MS population



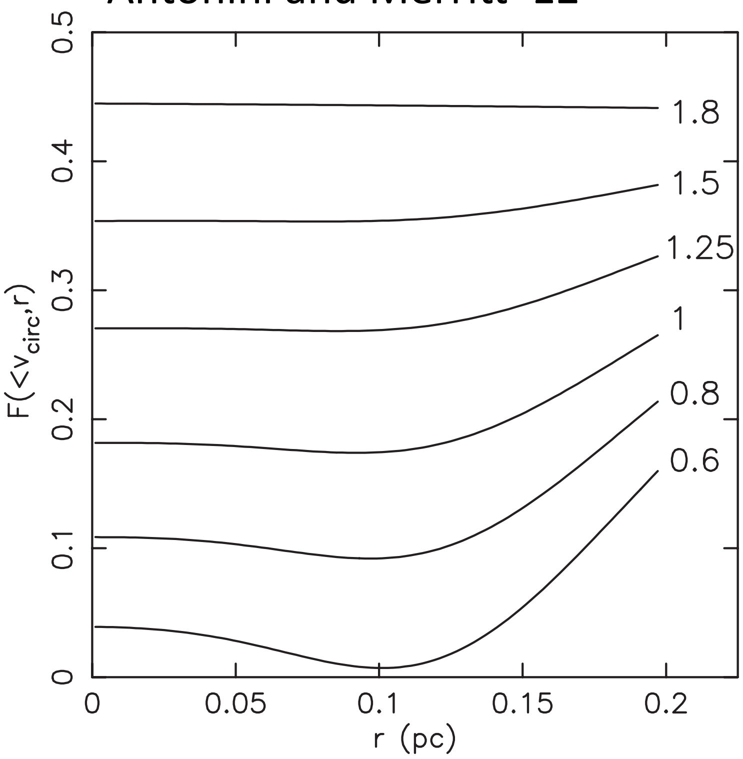
IN PHASE II SCATTERING OF THE MS OFF THE BH POPULATION CAUSES:

(i) the mean density of stars to decrease (the point stressed by Gualandris and Merritt '12)

(ii) and accelerates the redistribution of stars in phase space toward the steady state (as found in Preto and Amaro-Seoane '10)

Dynamical friction around a MBH: a failure of Chandrasekhar's formula

Antonini and Merritt '12



According to Chandrasekhar:

$$a_{\rm df} \propto \rho F(< v)$$

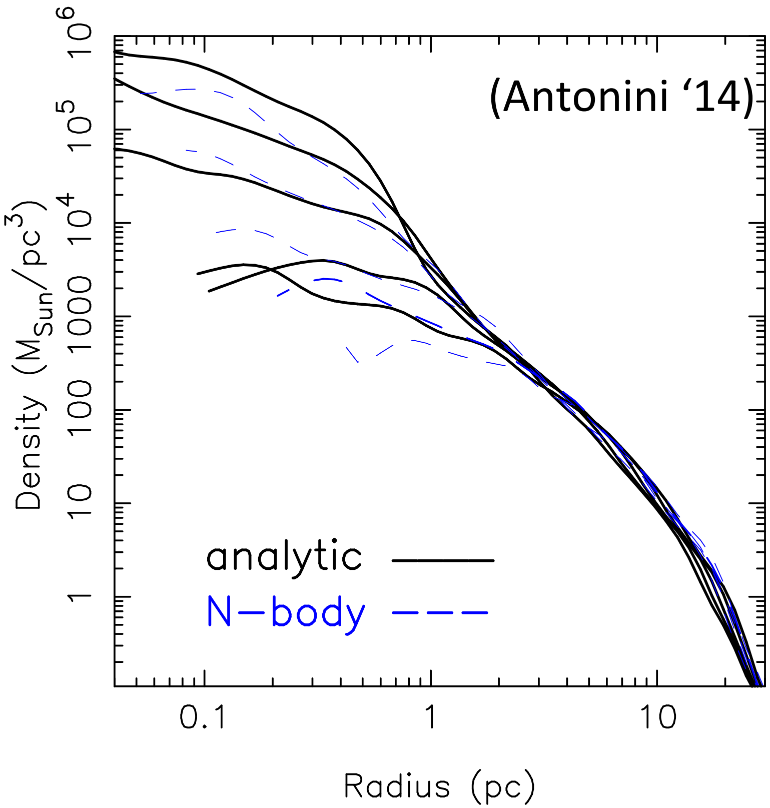
where $F(<v)$ is the number of stars moving **more slowly** than the massive body.

But when γ **= 1/2**, $f = 0$ for

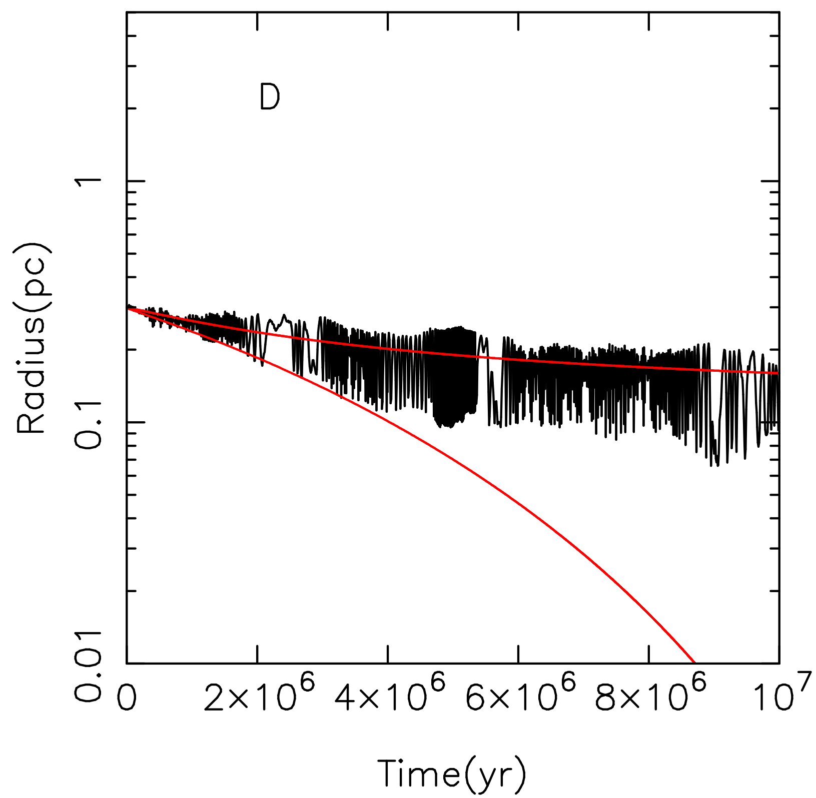
$$E = v^2/2 + \Phi(r) < E_{\rm core}$$

Dynamical friction tends to 0 for gamma → 1/2 !!

Slow Mass Segregation

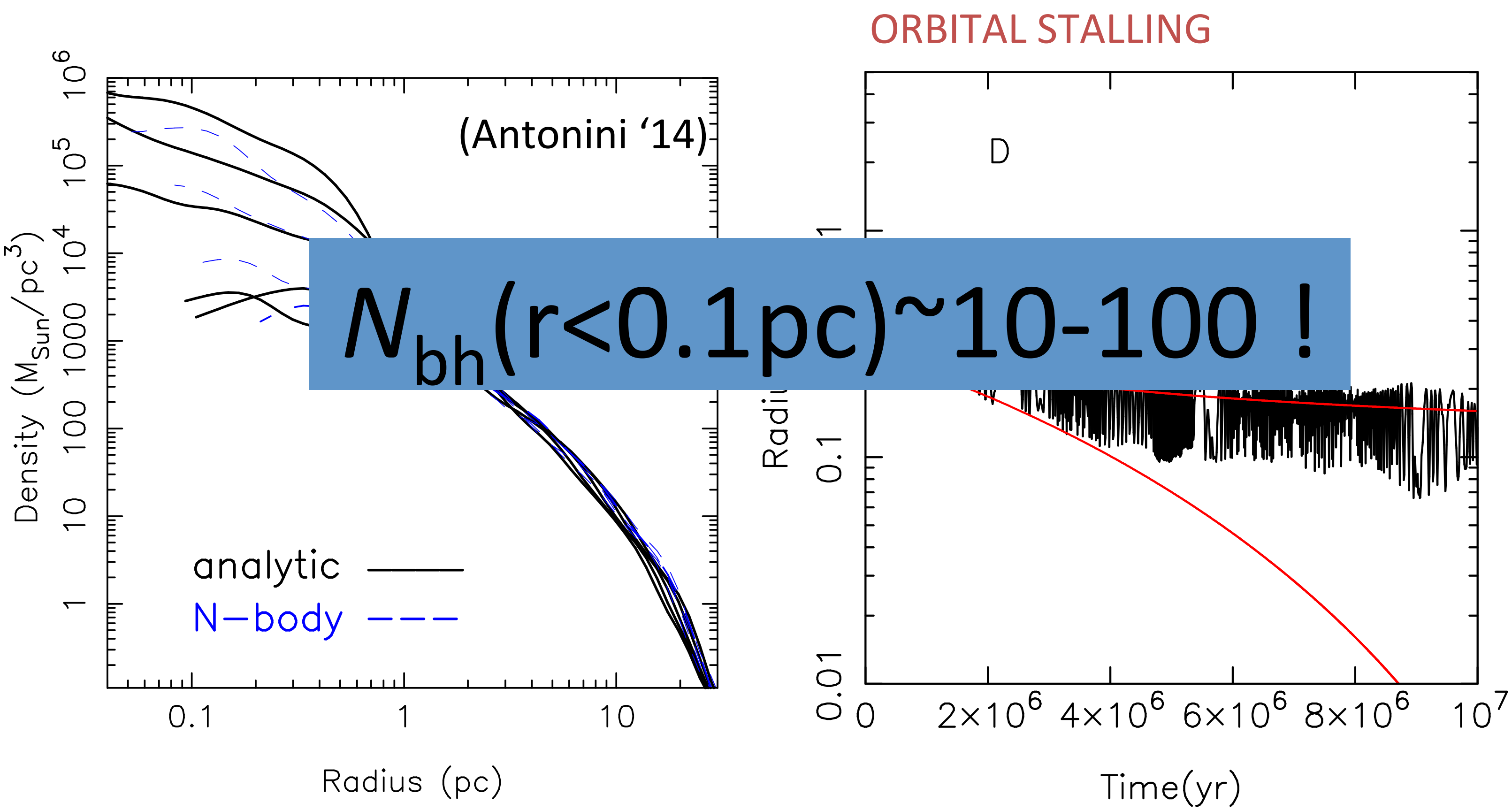


ORBITAL STALLING



$$\boldsymbol{a}_{\mathbf{fr}} \approx -4\pi G^2 m_{\rm bh}\rho(r)\frac{\boldsymbol{v}}{v^3}\times\Big(\ln\Lambda\int_0^v dv_\star 4\pi f(v_\star)v_\star^2 + \int_v^\infty dv_\star 4\pi f(v_\star)v_\star^2\left[\ln\left(\frac{v_\star+v}{v_\star-v}\right)-2\frac{v}{v_\star}\right]\Big)$$

Slow Mass Segregation



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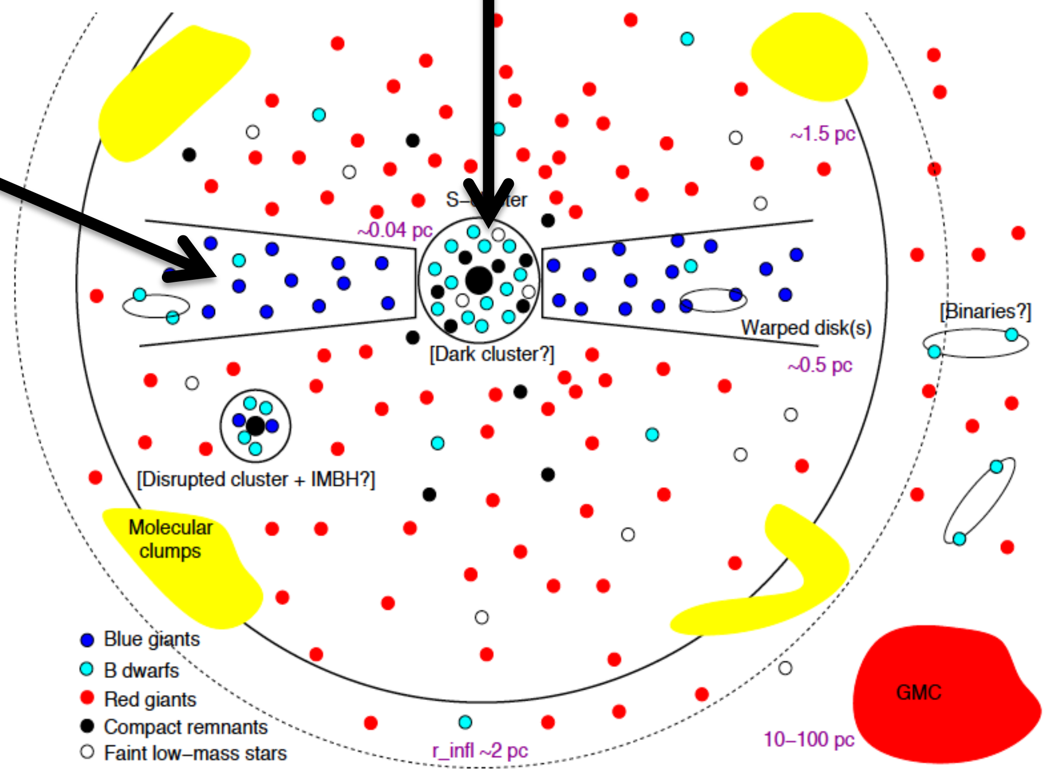
Dynamical structure at the Galactic center

S-star cluster: Few Myr old isotropiclly distributed stars with galactocentric radii from 1mpc to 0.05pc (Ghez et al. 2008)

Disk of young stars: O-B Giants and Super Giants. The disk extends from 0.05 to 0.5 pc from the center.

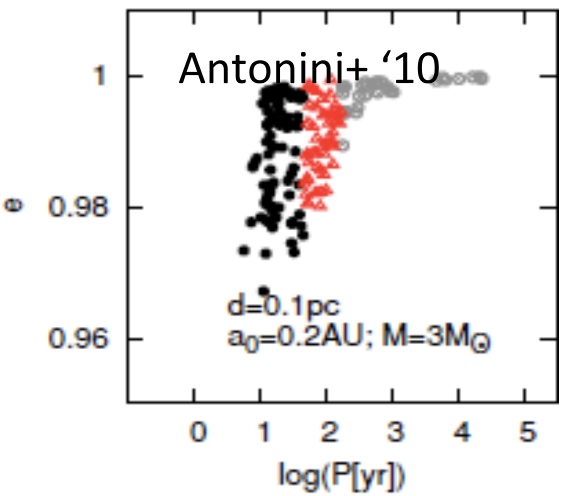


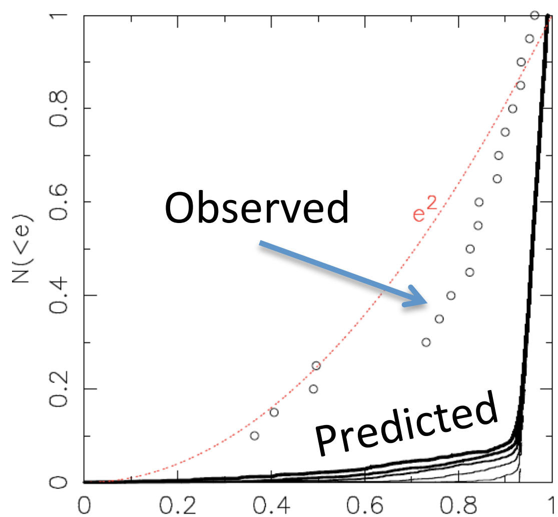
Alexander '10

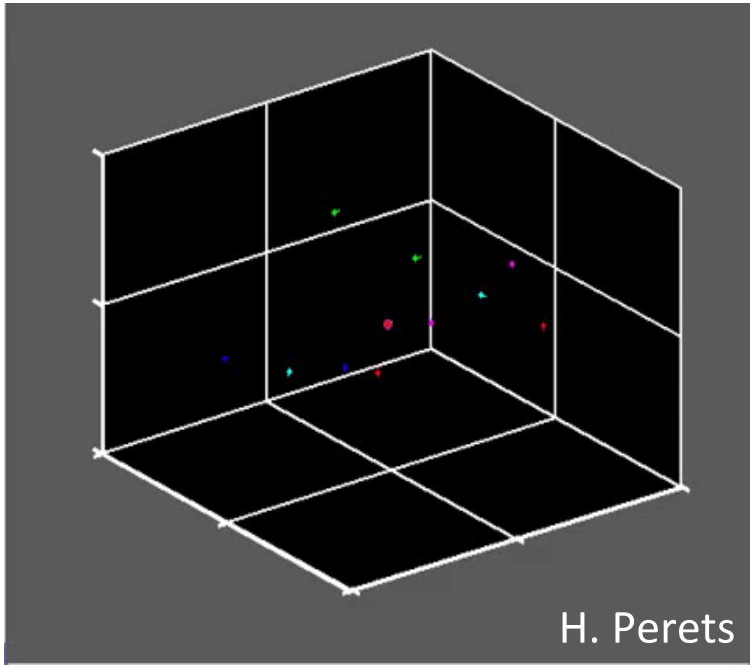
Old stellar population: while the central few arcseconds are dominated by massive early type stars the light of the low mass stars dominates the outer star cluster

Origin of the S-stars

Binary disruption scenario (Hills '98, Yu & Tremaine '03, Ginsburg&Loeb 2006). Too many high eccentricity orbits!







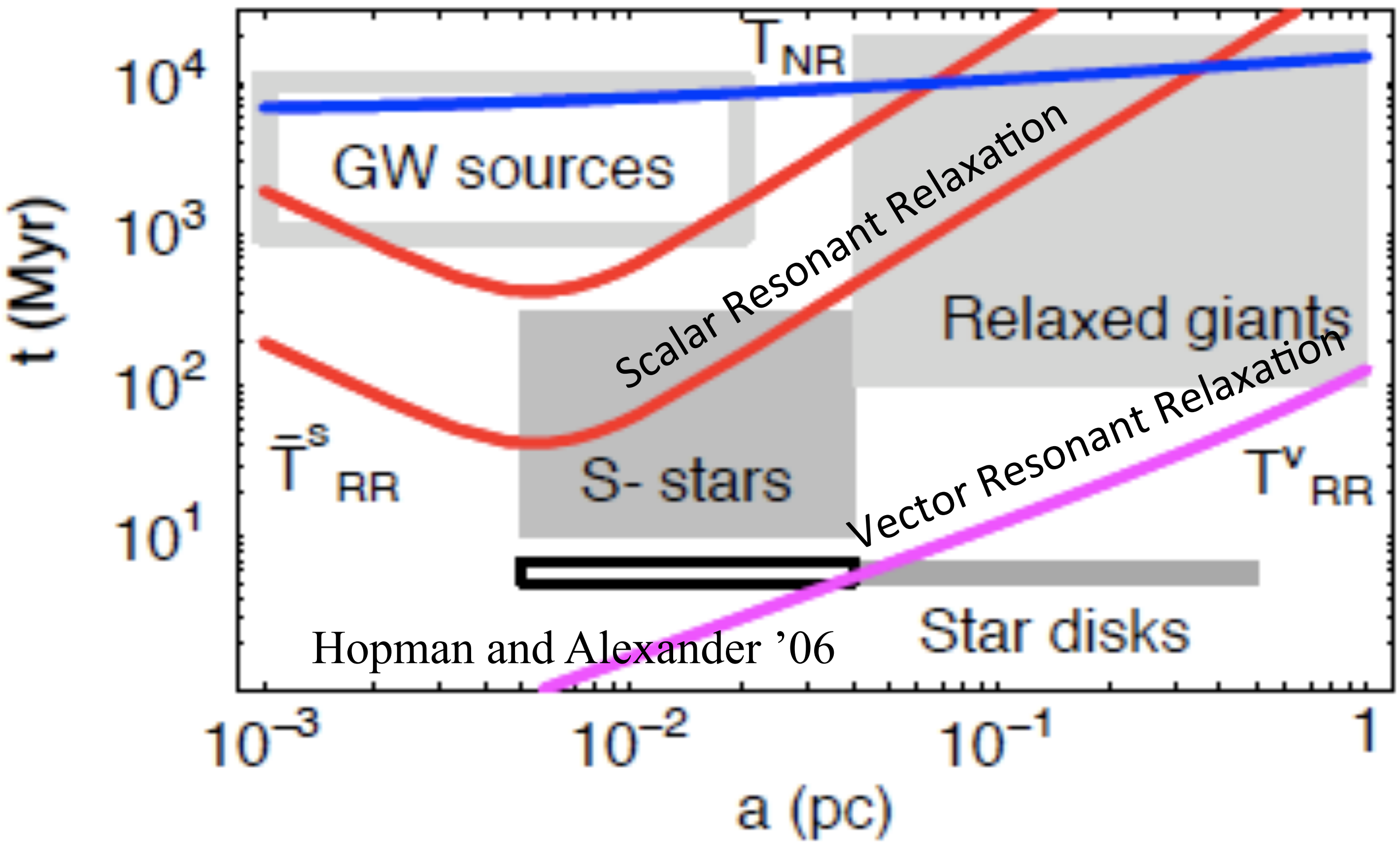
Binaries could originate from:

Initial inclinations:

1) The isotropic stellar cusp near the radius of influence of Sgr A* (e.g., Perets et al. 2007) → **Random**

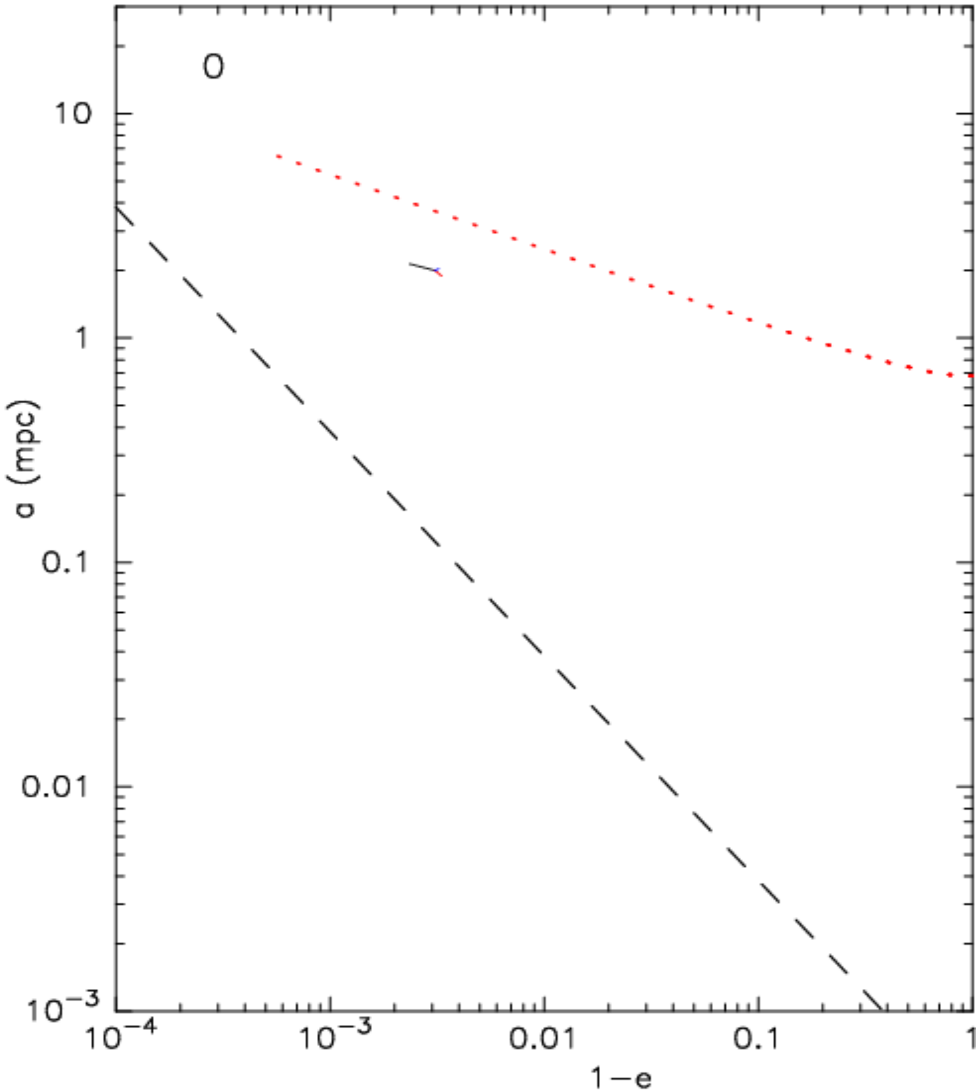
2) In a stellar disk, closer (<0.5pc) to the Galactic center (e.g., Madigan et al. 2009) → **Correlated**

Post capture evolution



(Rauch & Tremaine '96, Hopman & Alexander '06)

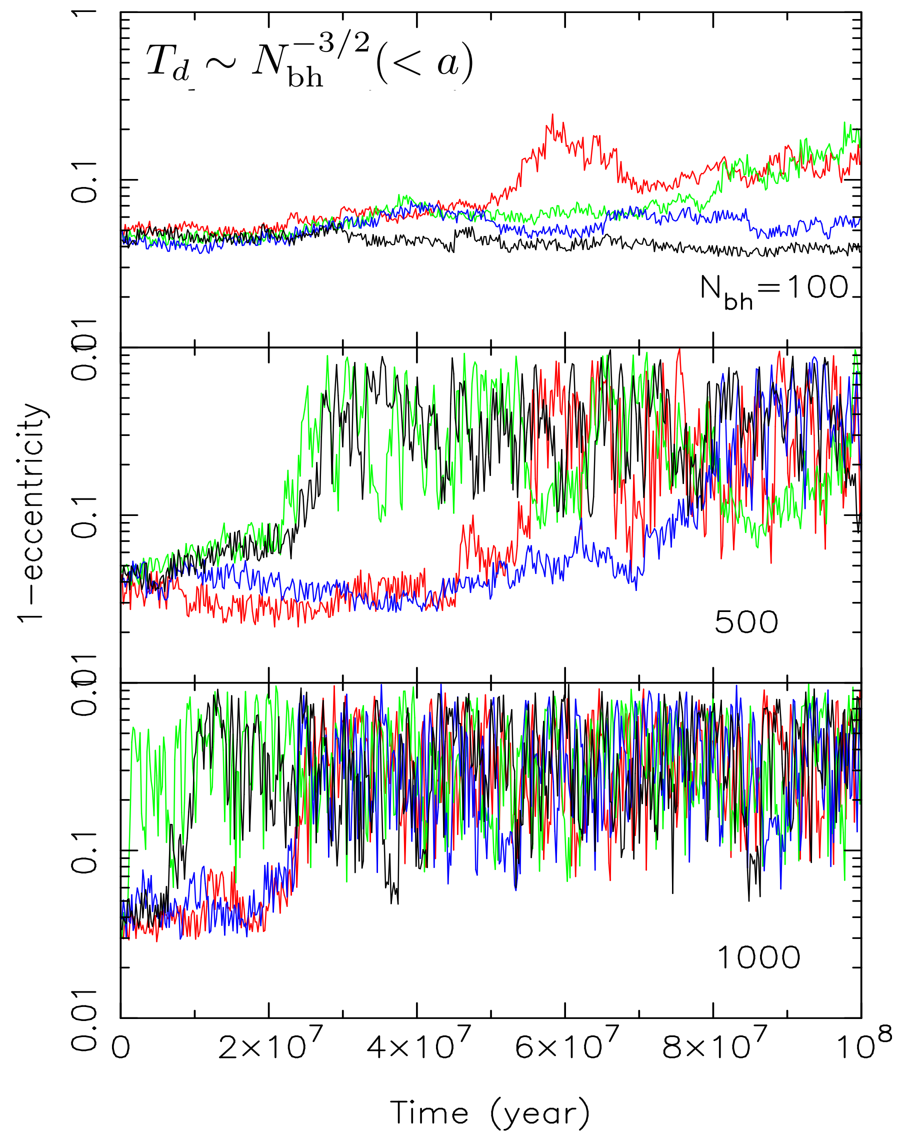
The Schwarzschild barrier as a one-way permeable membrane



The SB is permeable to orbits that approach it from below but impermeable to orbits that approach it from above.

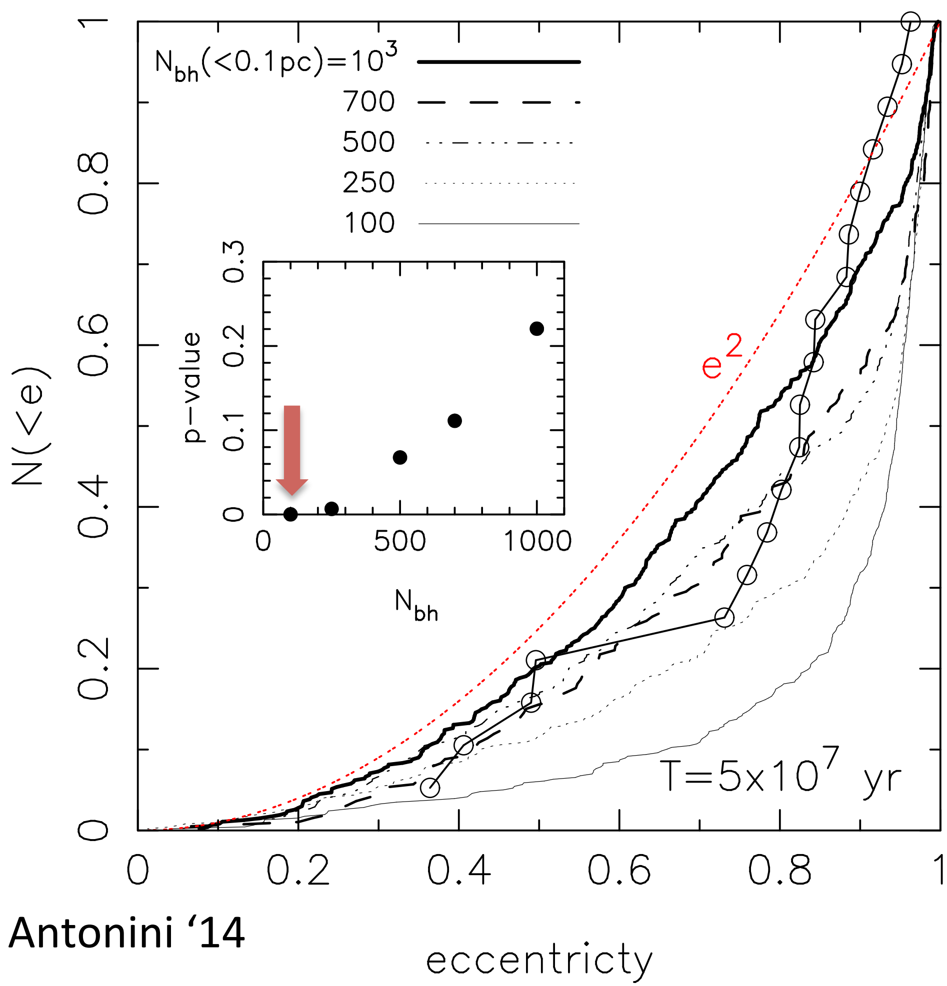
(FA & Merritt '13)

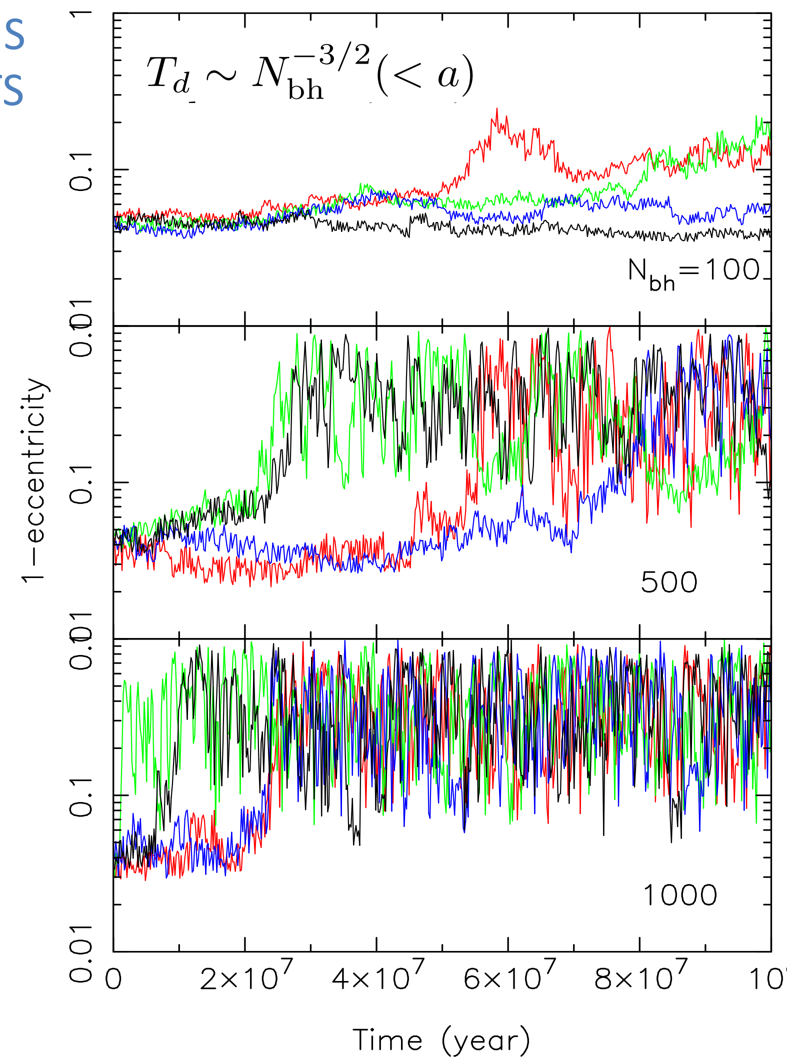
Dependence on the number of perturbers



Constraining the number of BHs at the Galactic center

DYNAMICAL EVOLUTION OF THE S-STARS FOLLOWING THEIR CAPTURE ON ECCENTRIC ORBITS





Antonini '14

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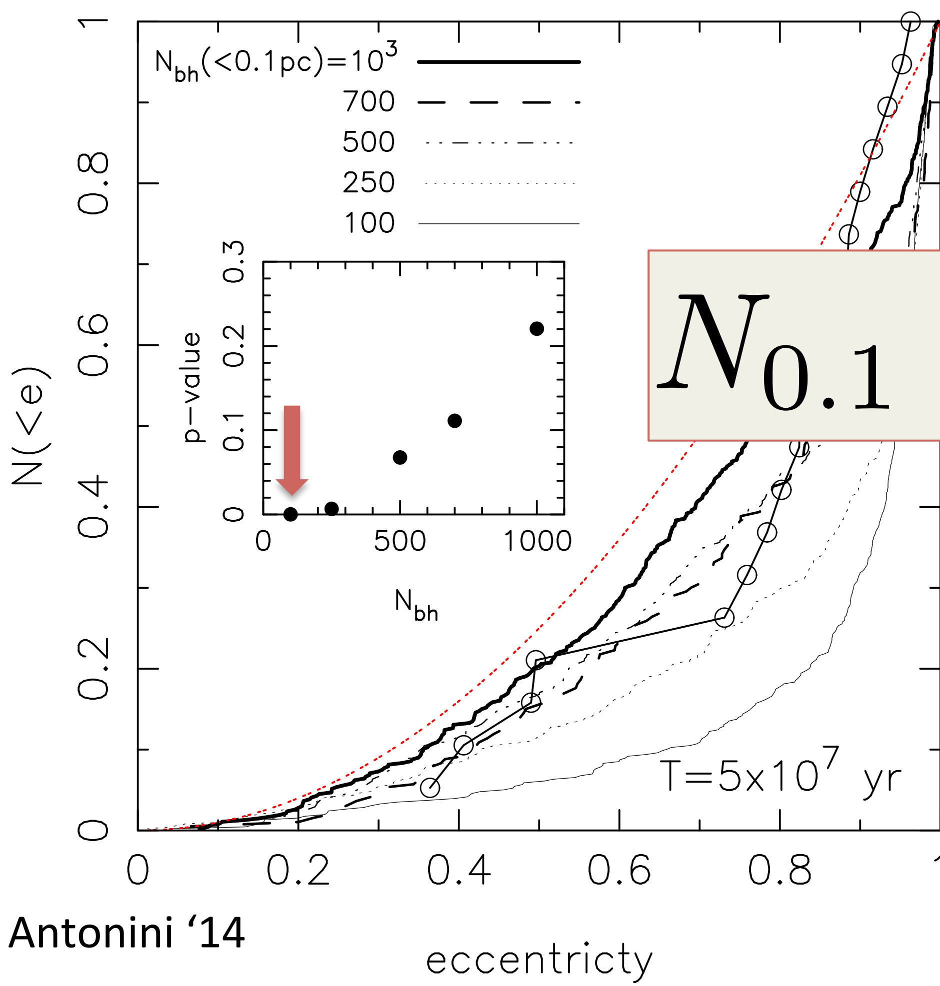
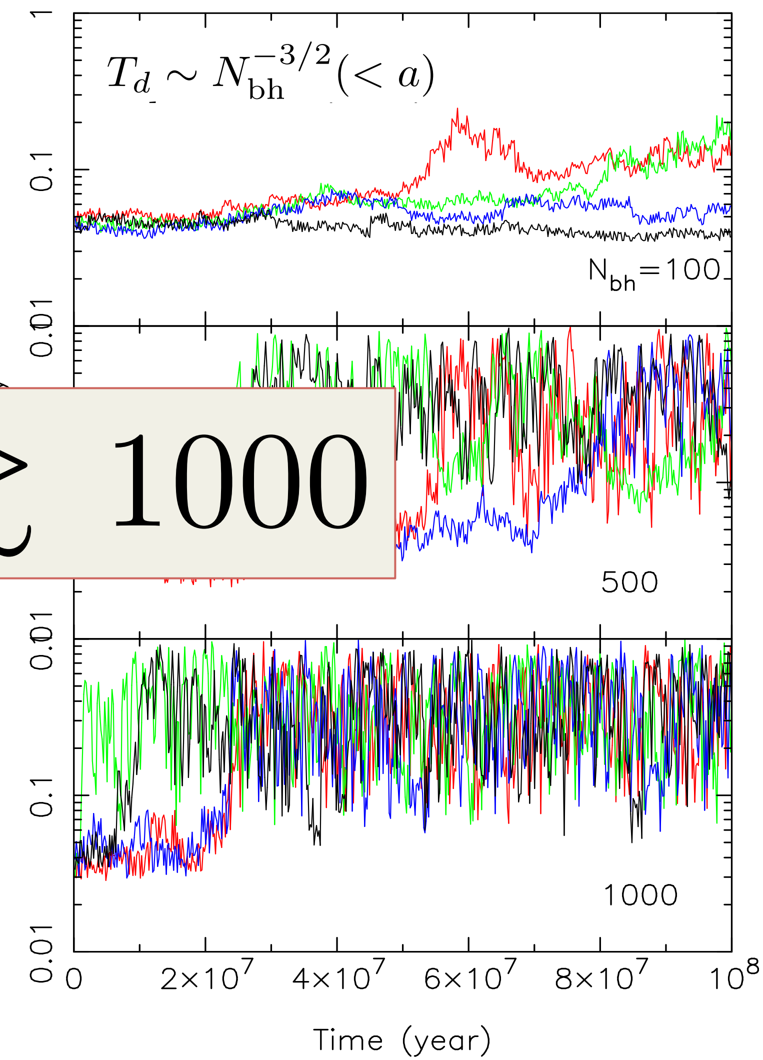
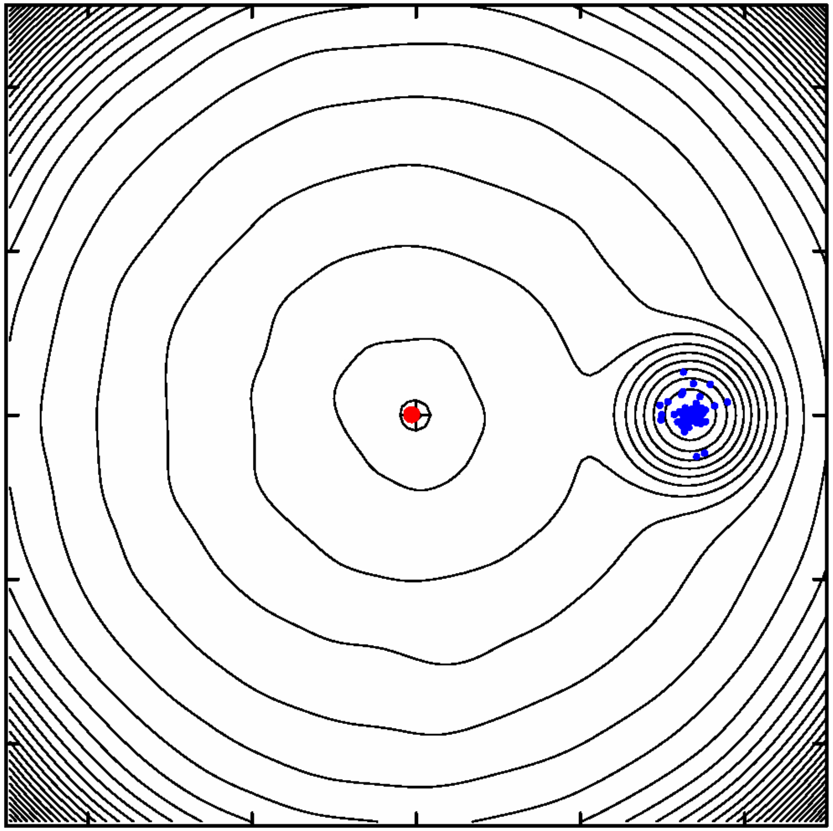




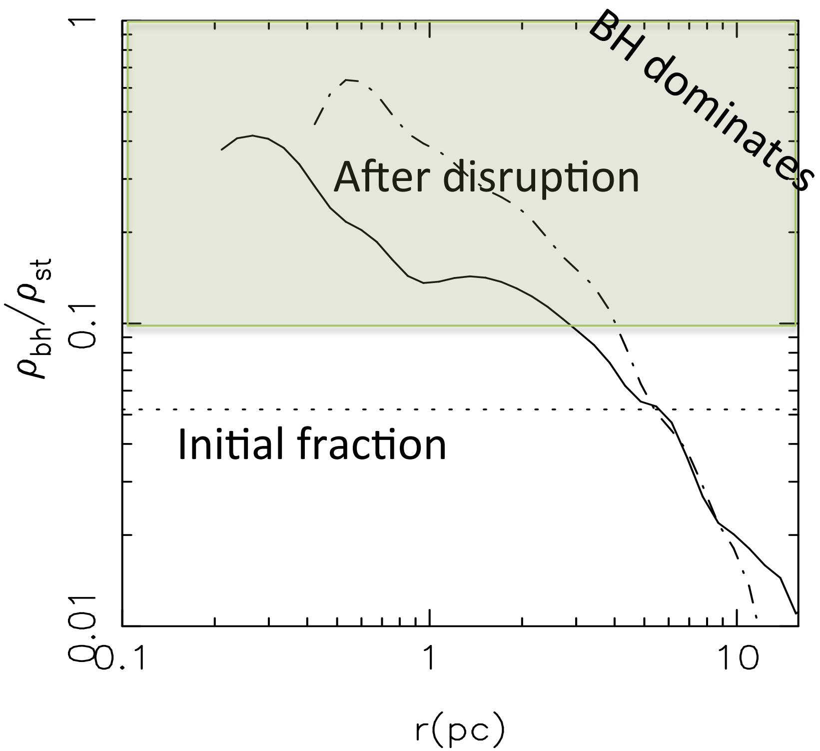
$$N_{0.1} \gtrsim 1000$$

Antonini '14

Black hole cusp formation



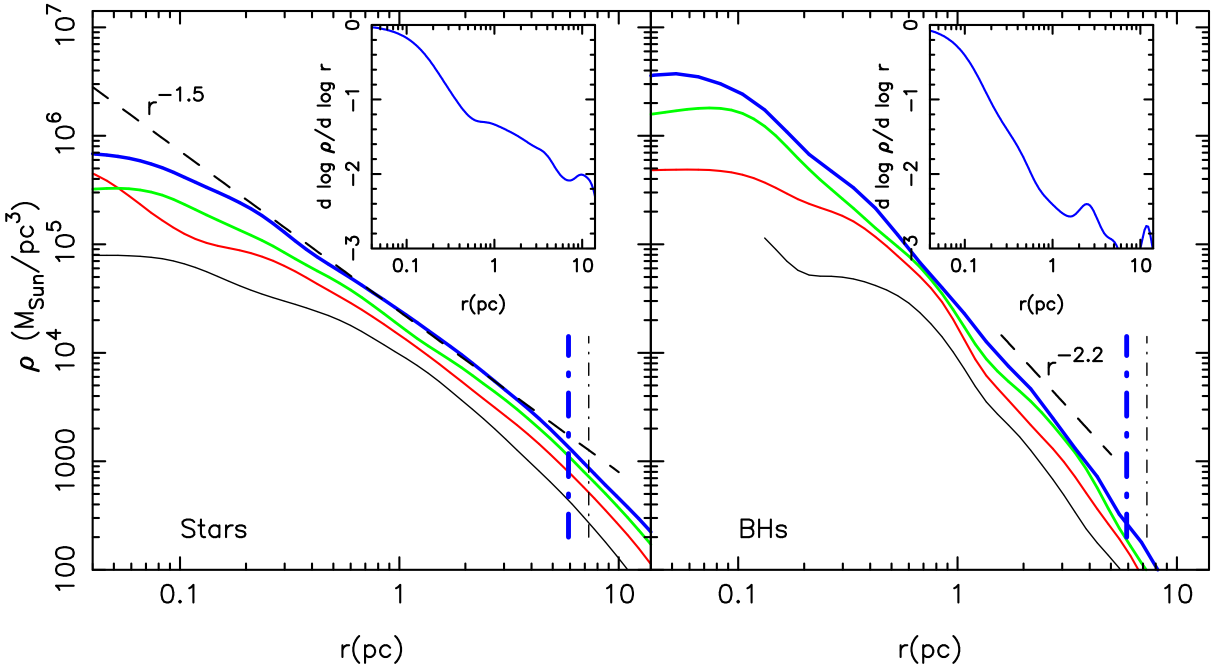
Antonini '14



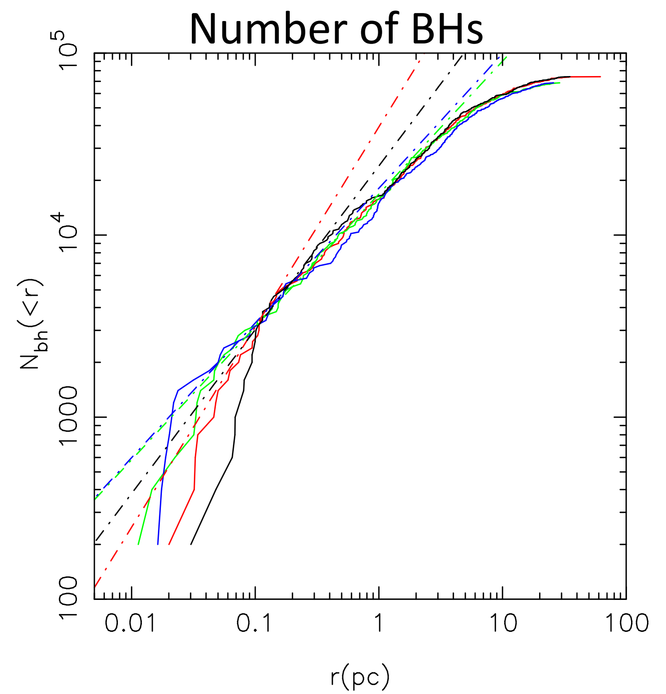
After the NSC has formed the BHs dominate the mass density inside ~0.5pc

IN THESE MODELS THE DISTRIBUTION OF BHS IS VERY DIFFERENT THAN THAT PREDICTED BY STANDARD MODELS

Black hole cusp formation



Antonini '14



Main properties of the mass distribution:

1) The stellar distribution has a pc-scale core
2) High central densities of BHs

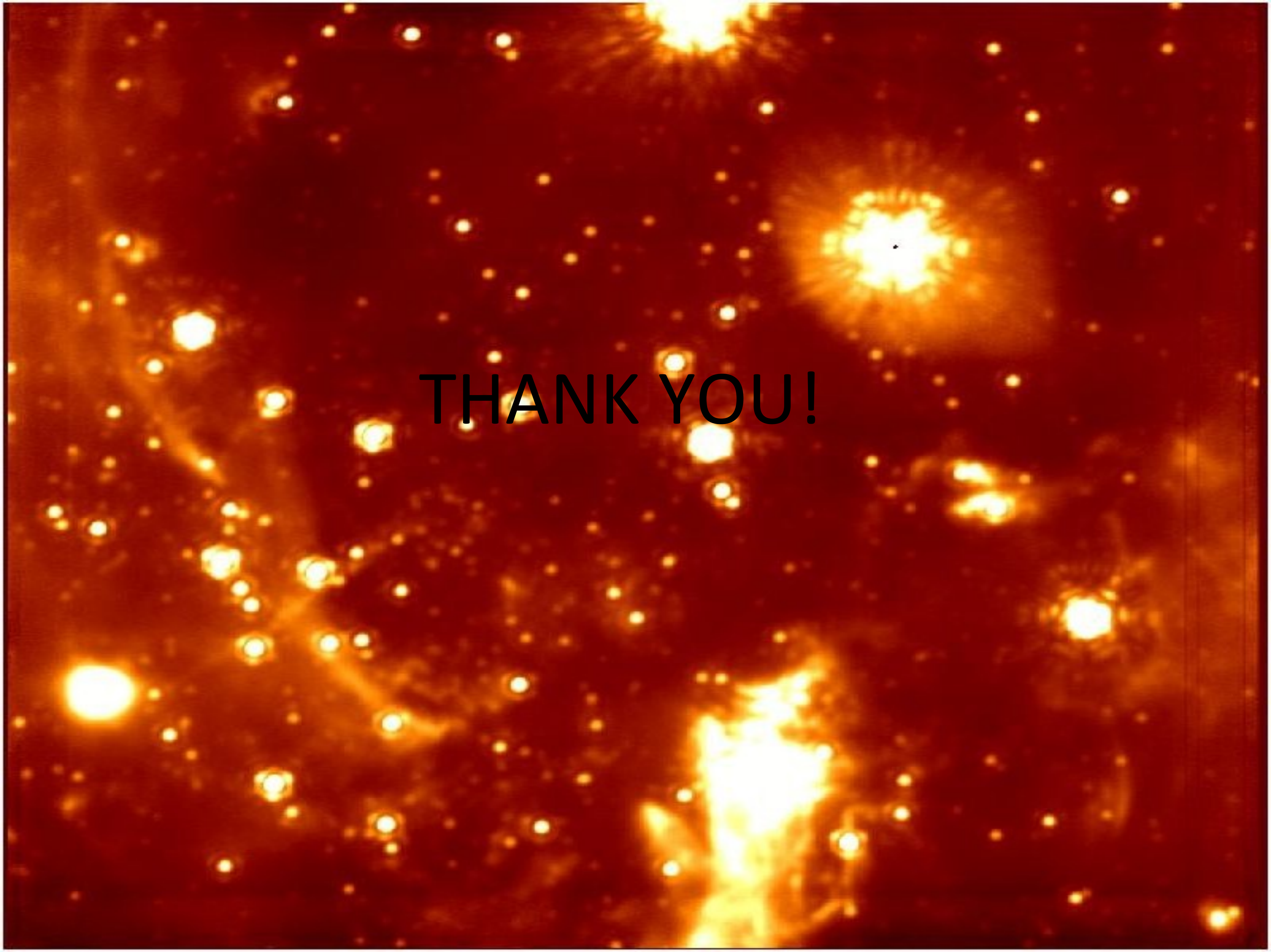
CONCLUSIONS

1) Dynamical friction in a low density core around a MBH can be extremely inefficient.

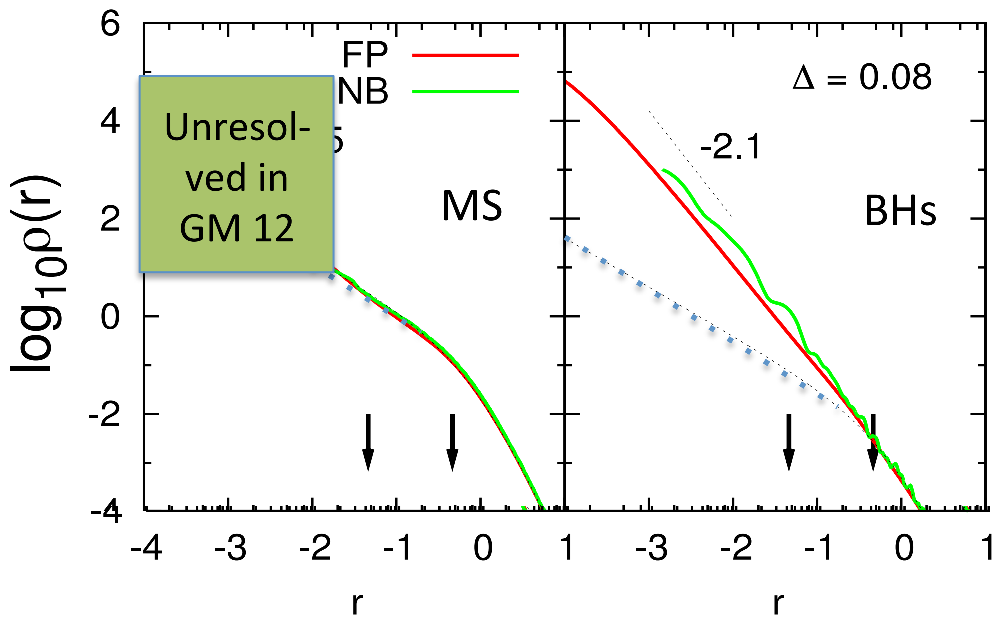
2) Adopting a parsec scale initial core, the time to regrow a cusp in the density of BHs and stars can be much longer than one Hubble time.

3) After one Hubble time standard models of mass-segregation give a number of BHs which is too low to be consistent with a binary disruption origin for the S-stars.

4) The stellar and BH distribution in galaxies like the Milky-Way can still reflect the formation process of the NSC. This motivates studies that start from initial conditions which correspond to well defined physical models.

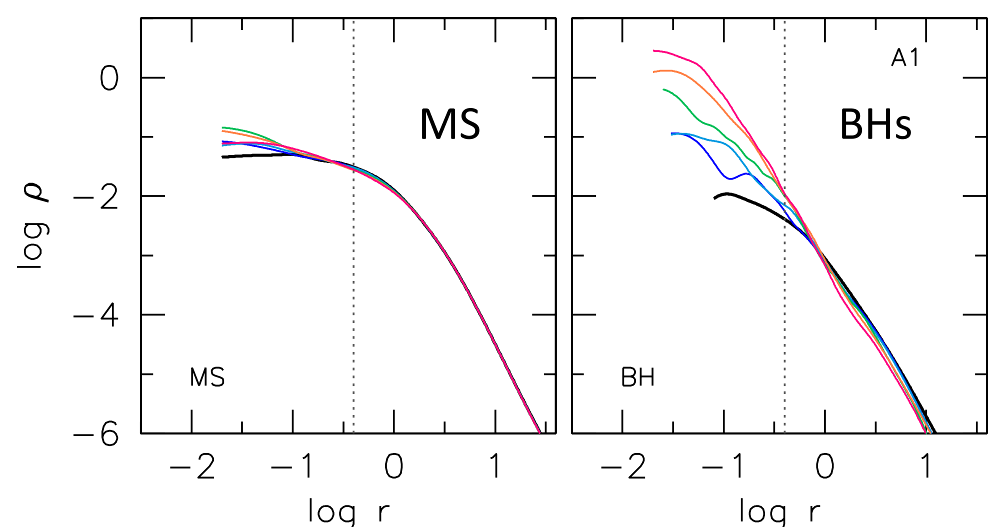

THANK YOU!

Mass Segregation at the Galactic center: previous work



Preto and Amaro-Seoane '09:

1) "Mass segregation speeds up cusp growth by factors ranging from 4 to 10"
2) Stellar and BH cusps can regrowth in less than one Hubble time for galaxies similar to the Milky Way

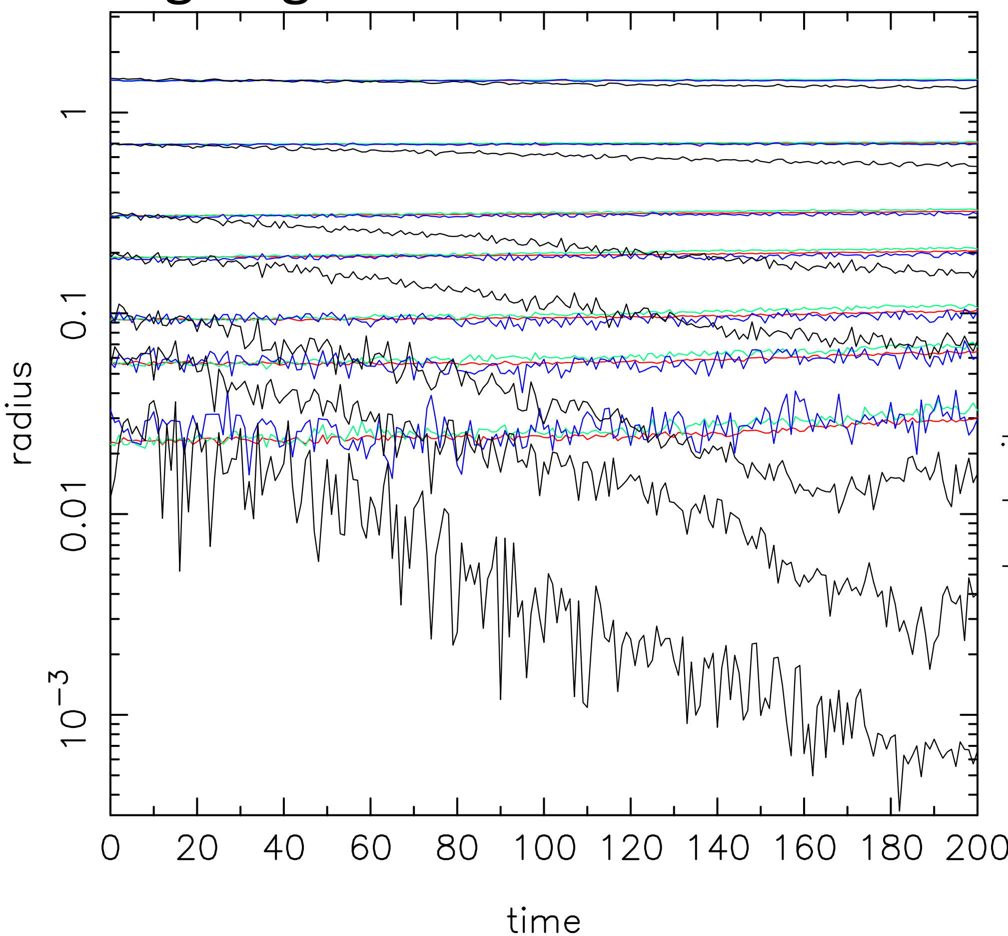


Gualandris and Merritt '12:

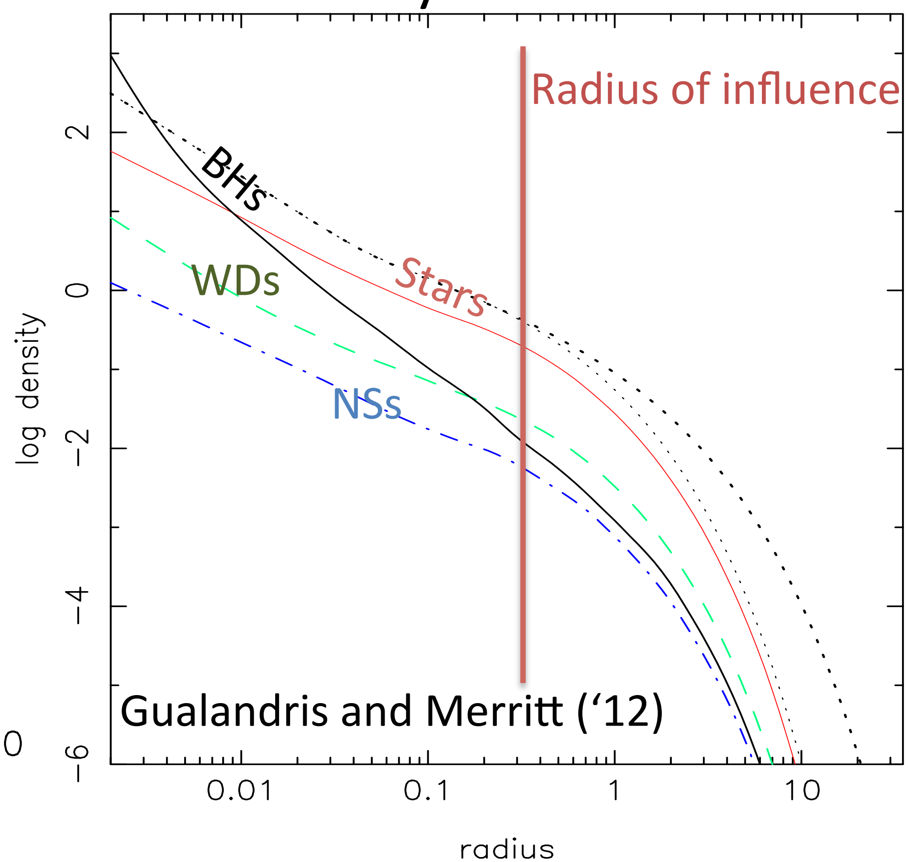
1) "Adding a heavy component has relatively little effect on the growth of a Bahcall-Wolf cusp in the MS component"
2) A stellar cusp cannot reform in less than one Hubble time

Mass Segregation around a Massive Black Hole

Lagrangian Radii evolution

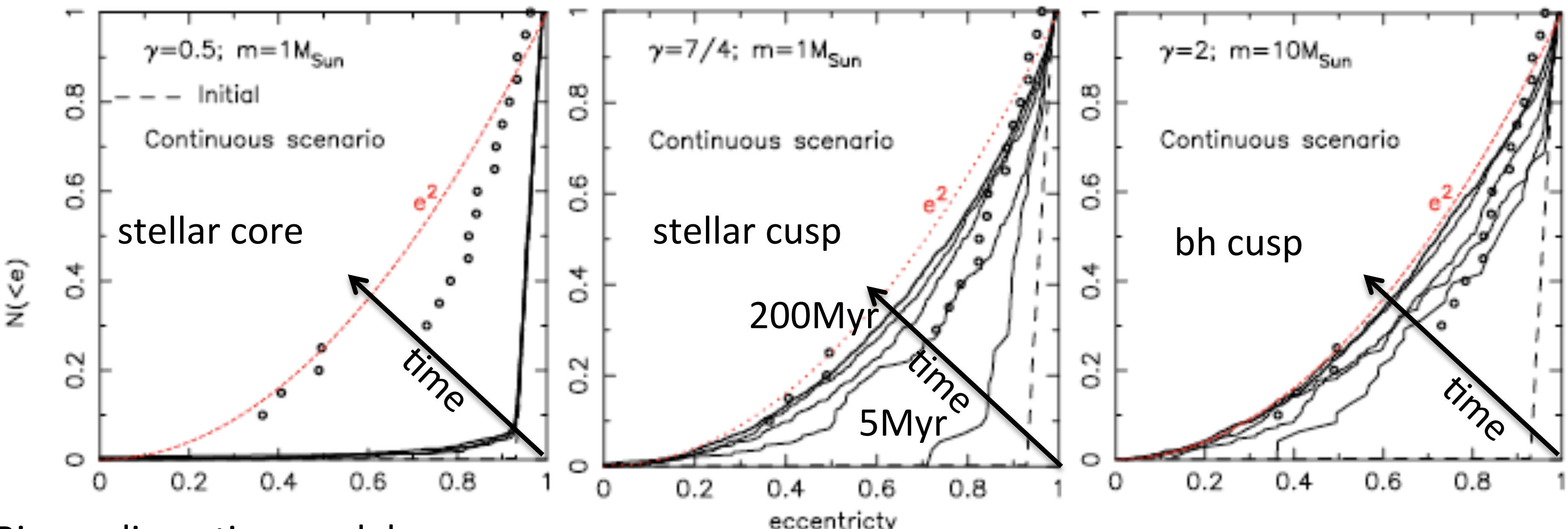


Final Density Distributions



See also Freitag et al. '06 and Hopman and Alexander '09

Comparison with the observed *e*-distribution



Binary disruption model

Binary Disruption Continuous scenario[d]	p[a]					TDs[b](%)
	5 Myr	20 Myr	50 Myr	100 Myr	200 Myr	
$\gamma = 0.5; m = 1\ M_\odot$	7.21×10^{-13}	6.41×10^{-13}	5.32×10^{-13}	1.33×10^{-13}	1.267×10^{-13}	0
$\gamma = 7/4; m = 1\ M_\odot$	3.14×10^{-5}	0.147	0.645	0.819	0.660	0.16
$\gamma = 2; m = 10\ M_\odot$	8.07×10^{-2}	0.108	0.410	0.499	0.310	0

[a] Probability value of the two-sample Kolmogorov-Smirnov test.
[b] Percentage of stellar tidal disruptions after 200 Myr.
[c] Orbits initialized at $t = 0$.
[d] Orbits initialized at random times between [0,200 Myr].

Good match to observations obtained after ~10 Myr (roughly the age of the S-star cluster).
However, **steep density cusp models are required!**

Schwarzschild Barrier in the Galactic center

In any formation scenario, the physics of the SB is important for the evolution of the S-stars!

(FA & Perets '12, FA & Merritt '13)