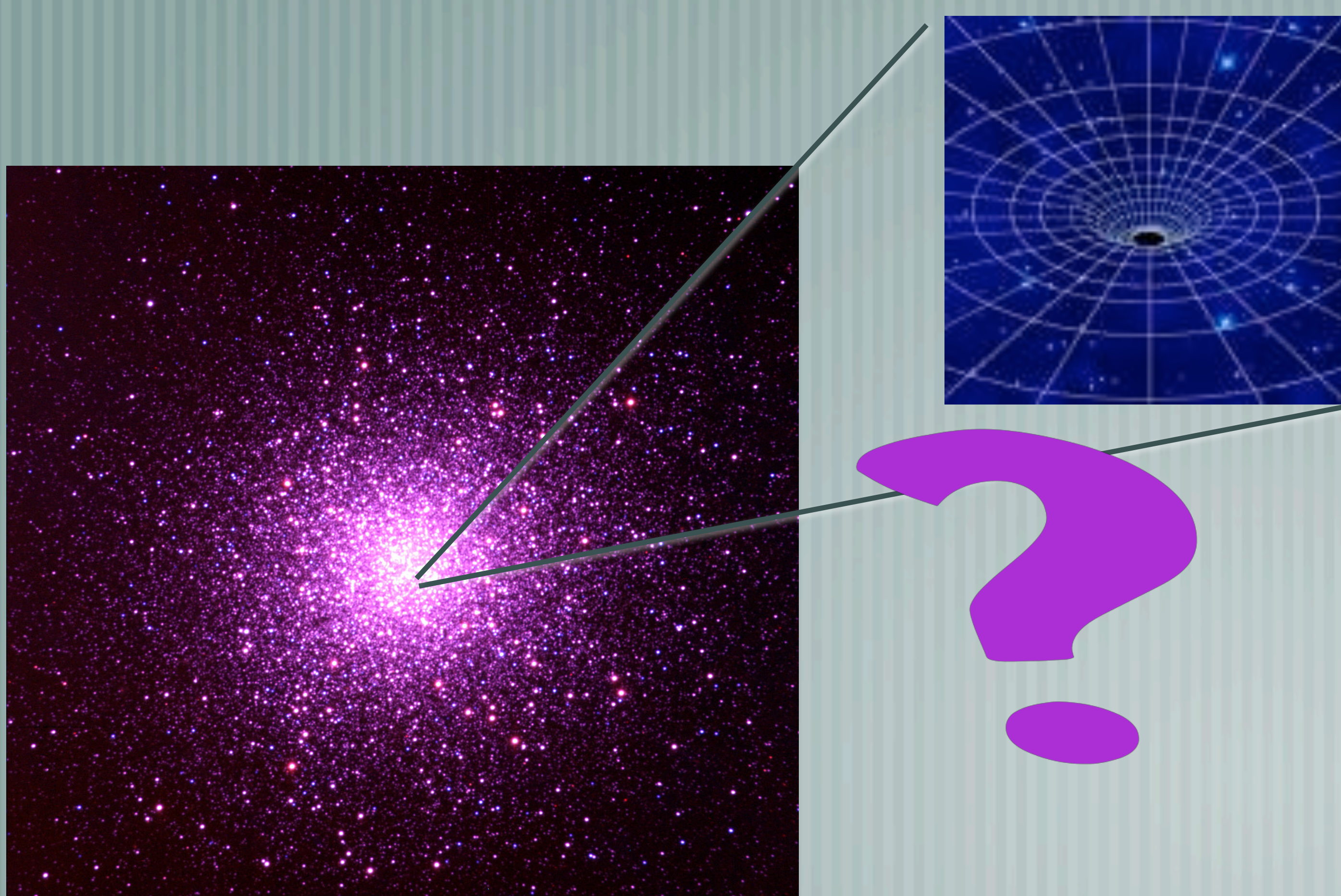
IMBH Fingerprints in Globular Clusters

(from stellar dynamics)



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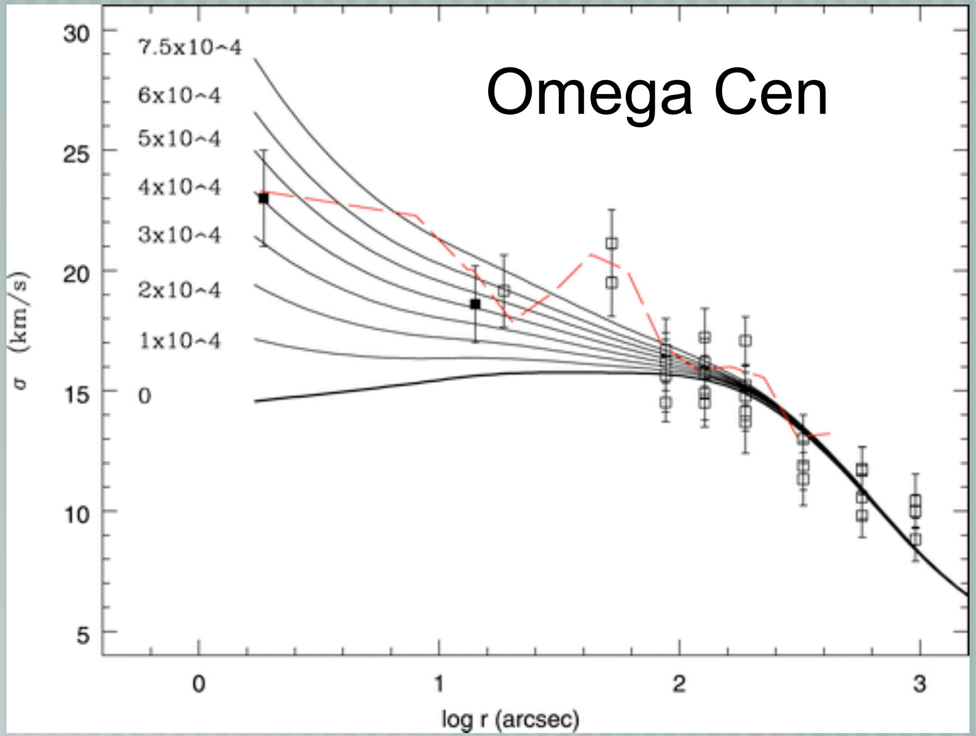
Intermediate Mass Black Holes

- Black holes of 10^2-10^5 Msun, missing link between stellar and supermassive BHs
- Have been predicted in different astrophysical scenarios:
  - Remnants of Population III stars (Heger et al. 2003)
  - Runaway collapse in young star clusters (Portegies-Zwart et al. 2004)
- Globular clusters may be the best place to look for them
- But unambiguous detection is hard to achieve

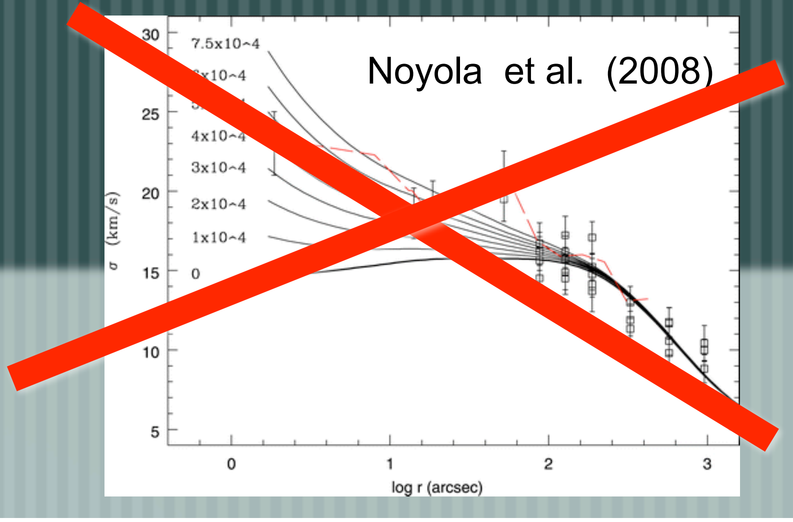
Searching for IMBHs in GCs

- Globular clusters have very little gas: x-ray/radio emission is faint
- Sphere of influence of the BH is small (a few arcsecs): Limited direct BH Influence
    - ~40000 Msun IMBH claimed in Omega Cen from Gemini IFU data + HST-WFPC2 imaging (Noyola et al. 2008)

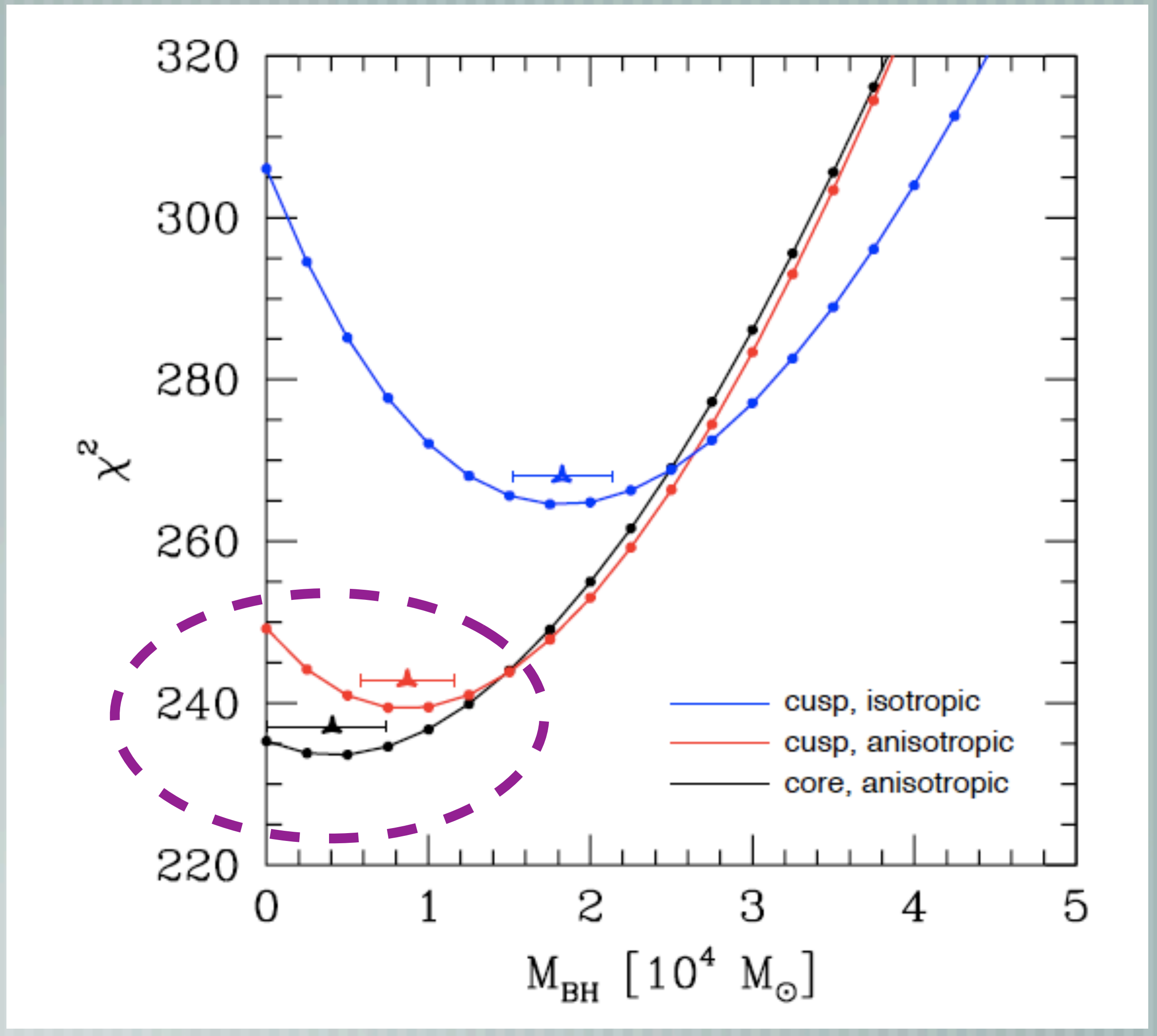


Noyola et al. (2008)

The case of Omega Cen



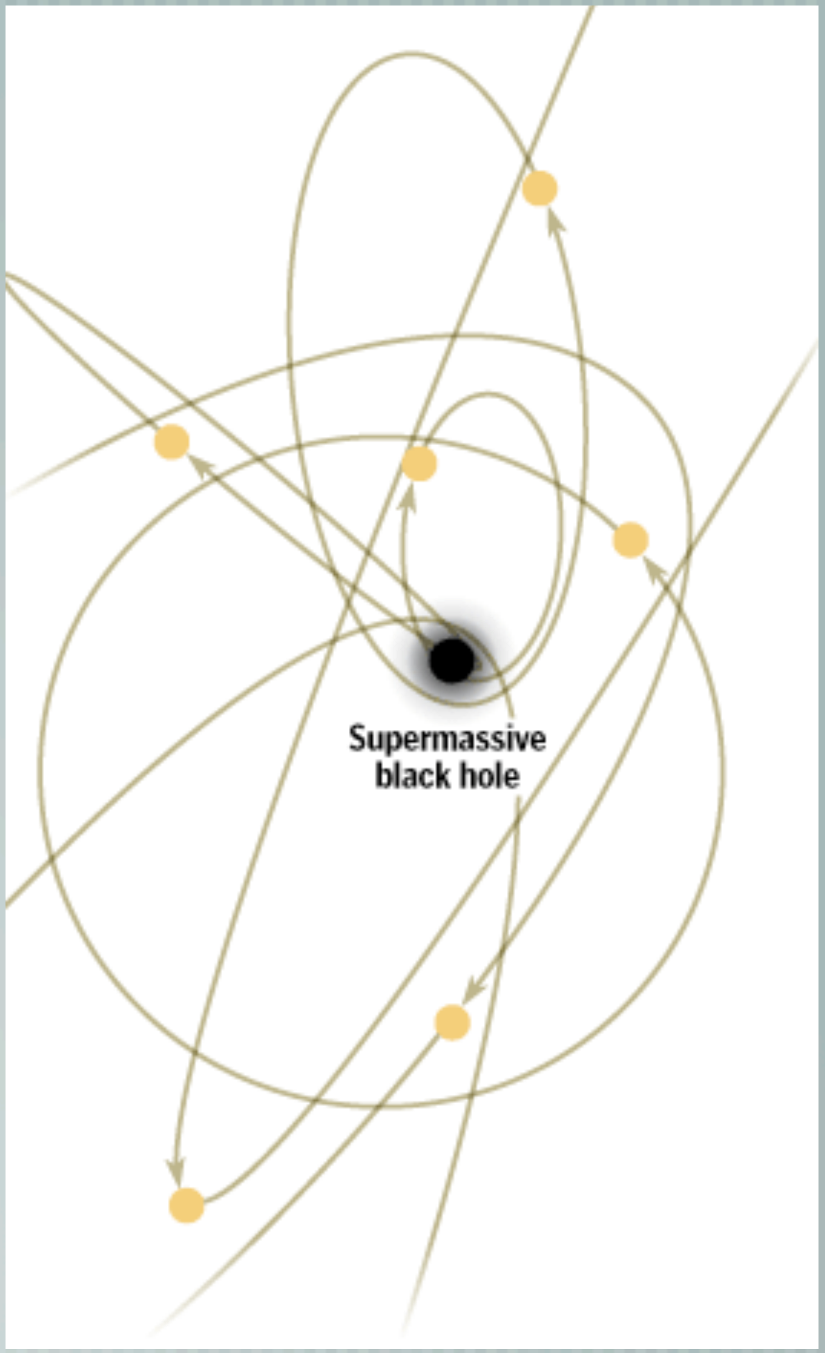
- But the claim disappears at higher resolution
- Kinematic measured from HST proper motions of individual stars
- New data set upper limit at 10000 Msun (van der Marel & Anderson 2010)



van der Marel & Anderson (2010)

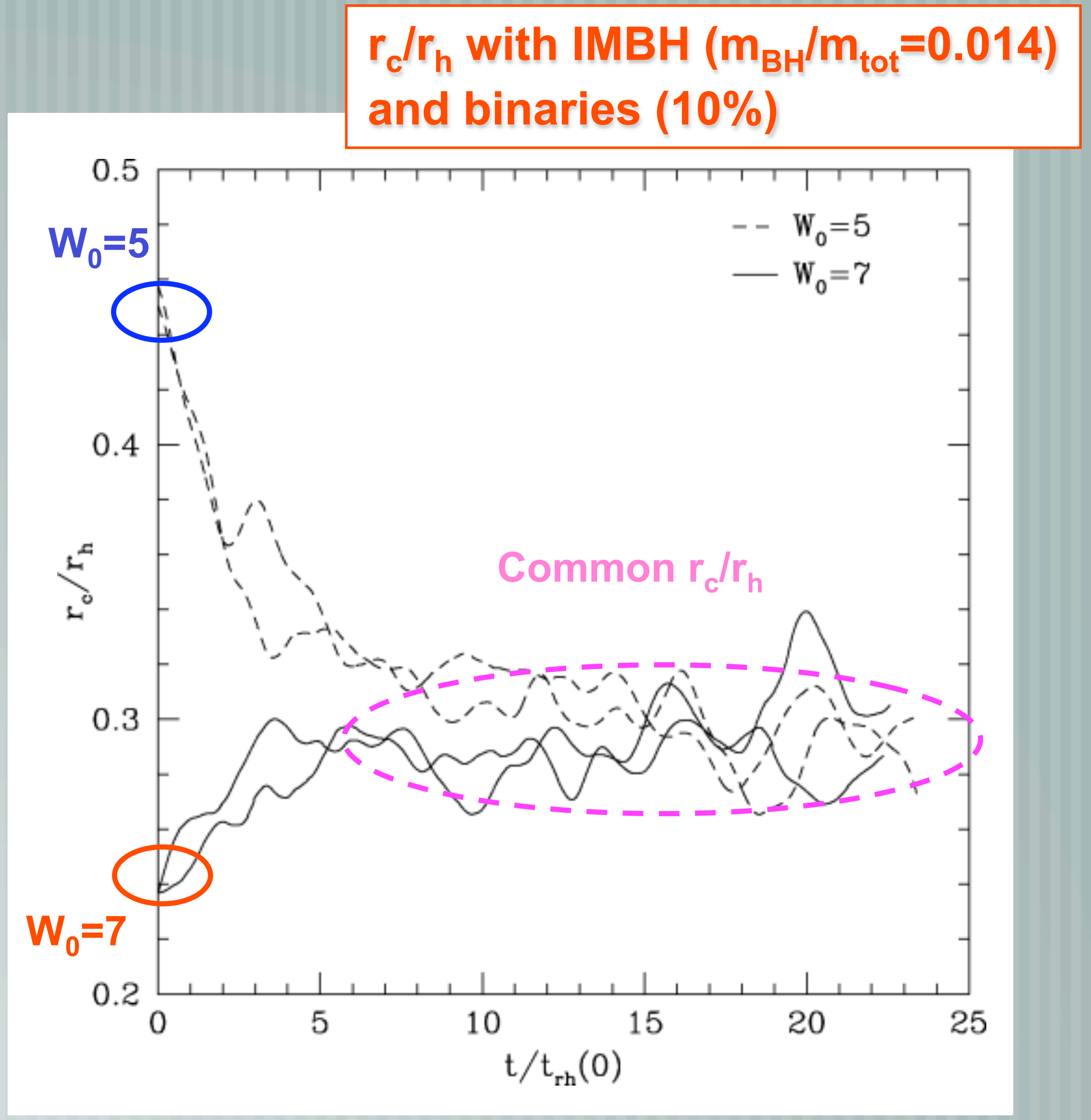
Searching for IMBHs in GCs

- Proper motion studies can provide the best evidence for IMBH based on dynamics but these are expensive
  - multiyear HST observations needed for GCs
- Are we focusing on the right GCs candidates?
  - Can we identify fingerprints for the IMBH presence?



IMBH fingerprint: core/half-mass radius

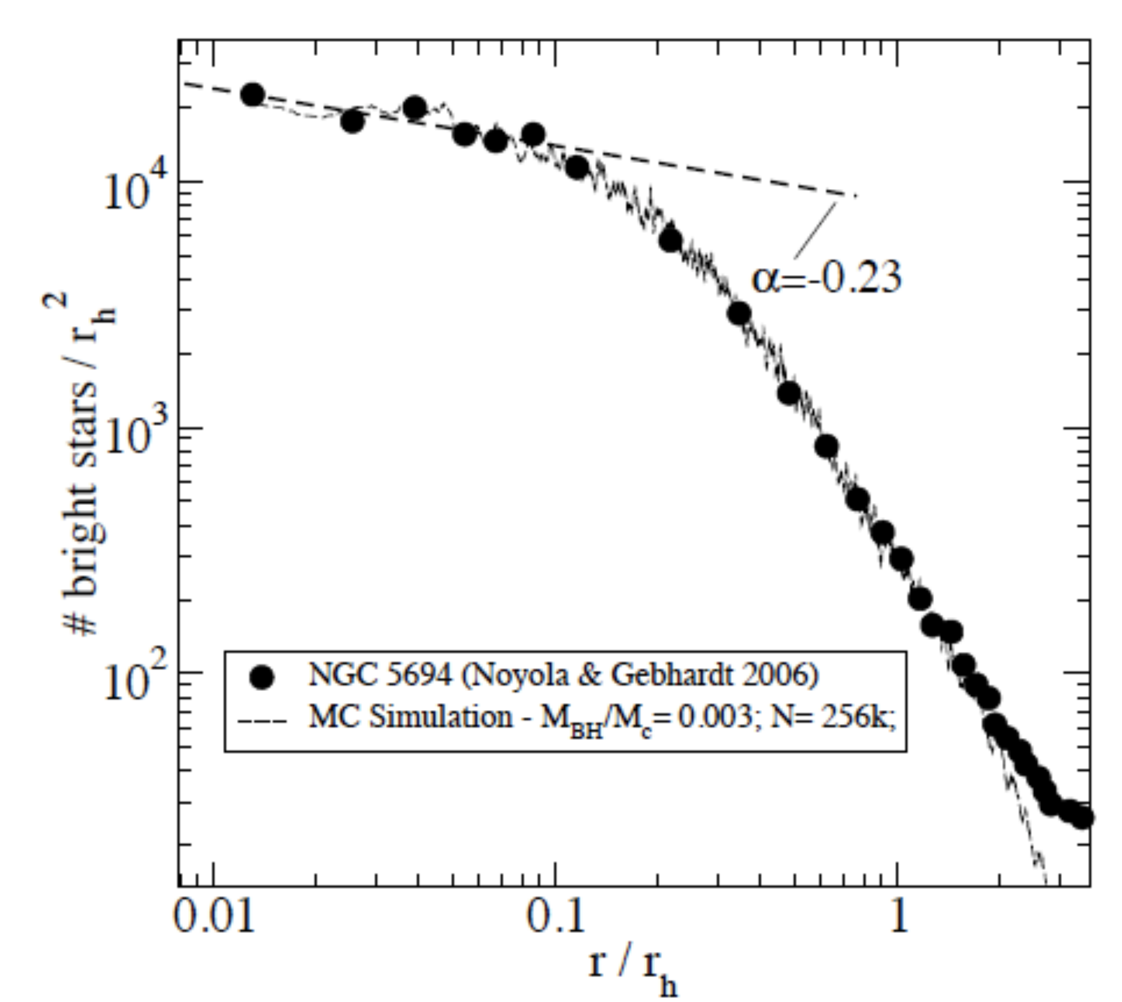
- Efficient IMBH heating leads to
  - Universal large rc/rh after a few relaxation times
- But... there are other (equally) efficient heating sources
  - Stellar evolution (Hurley 07), WD kicks (Fregeau et al. 09), Stellar collisions (Chatterjee et al.09), Stellar BHs (Mackey et al. 08)



Trenti et al. (2007)

IMBH fingerprint: shallow cusps

- Shallow cusps in surface brightness profile proposed as IMBH fingerprint: $\mu \sim R^{-0.2}$ (Baumgardt et al. 2004, Trenti et al. 2007, Miocchi 2007, Umbreit et al. 2010)
- Shallow cusps are observed from HST data (Noyola & Gebhardt 2006)
- Is this a unique sign associated to an IMBH?

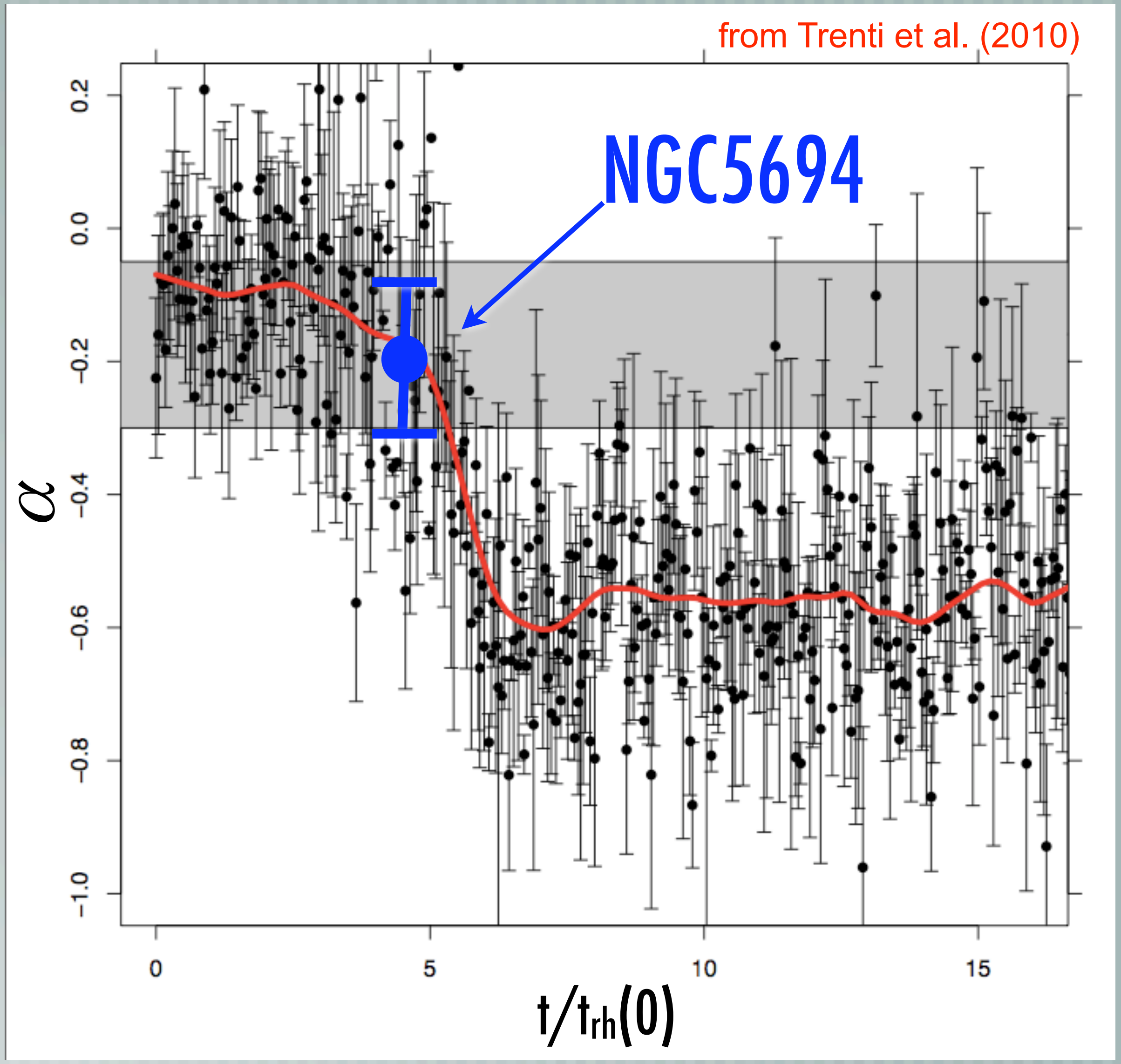


Umbreit et al. (2010)

IMBH fingerprint: shallow cusps

- But shallow cusps do not necessarily imply an IMBH:
  - always present during and after core collapse (Trenti et al. 2010, Vesperini & Trenti 2010)
  - NGC5694 likely undergoing core collapse: $\alpha \sim -0.2$ naturally expected
  - (large) observational errors and intrinsic scatter present

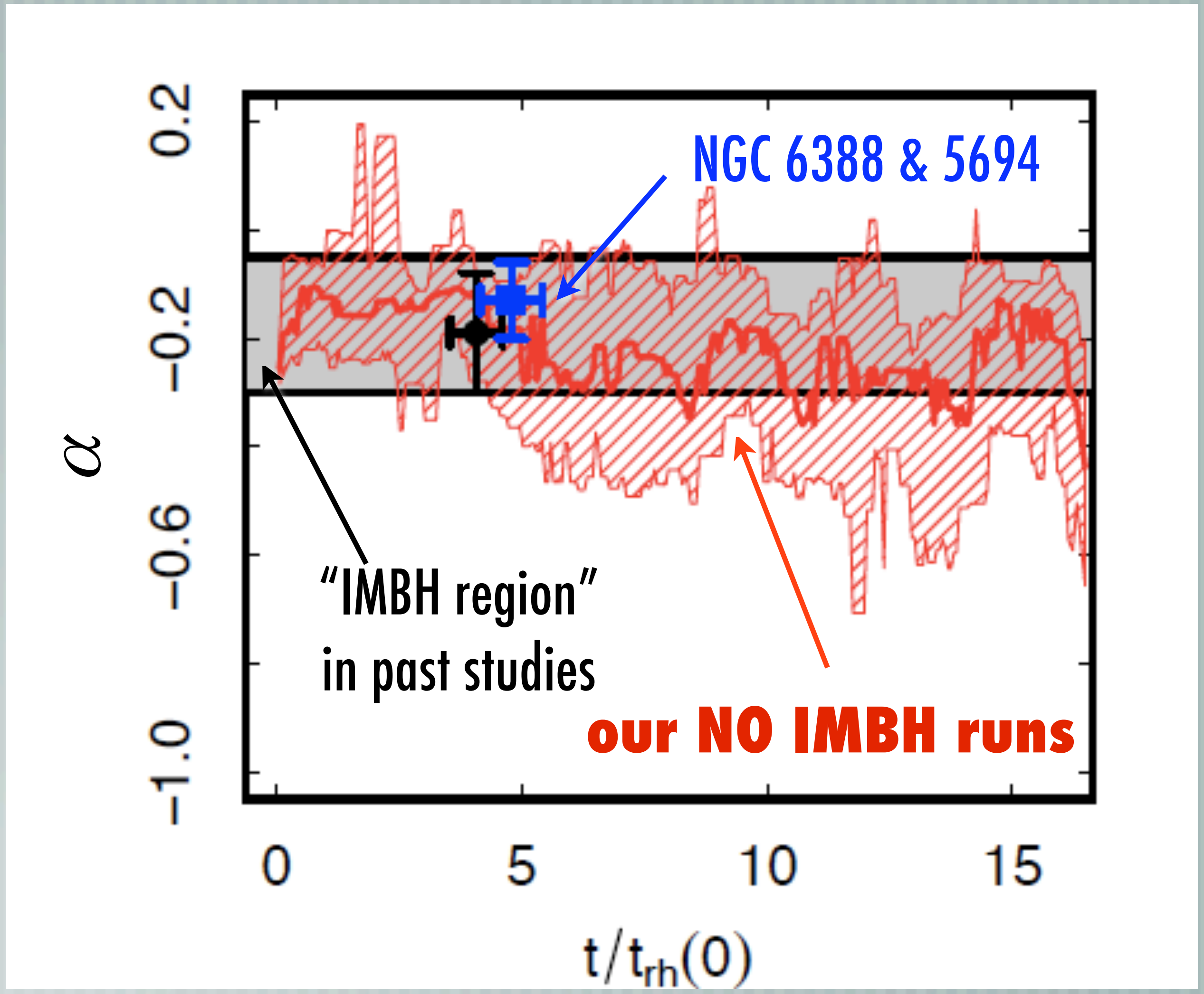
Direct N-body run, N=64k, no IMBH



IMBH fingerprint: shallow cusps II

- In addition:
  - Shallow cusps always present if a few percent binaries are present (Vesperini & Trenti 2010)
- **Shallow cusps are NOT reliable tracers of IMBH presence**
- See poster by Cseh for IMBH limits in NGC 6388

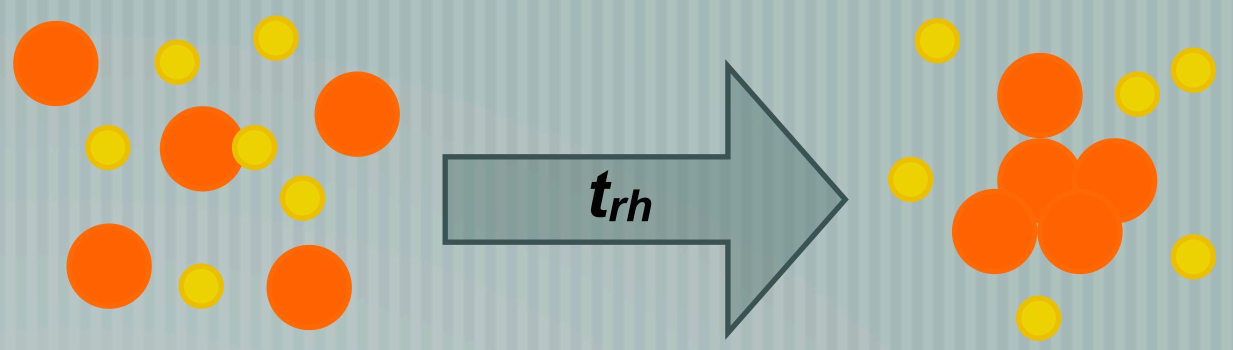
Direct N-body run, N=32k, **no IMBH**, 5% binaries



Vesperini & Trenti, submitted

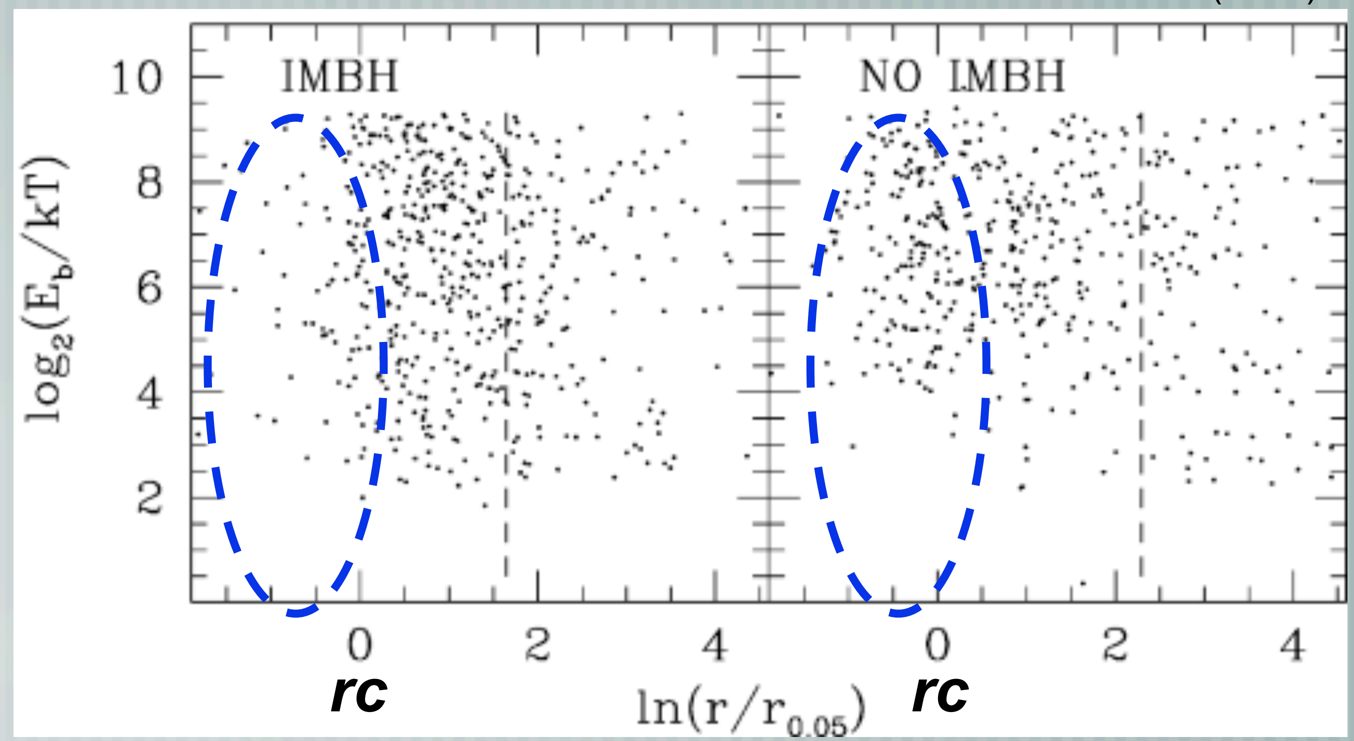
IMBH fingerprint: mass segregation

- In a GC the most massive stars segregate toward the center of the system (energy equipartition)
- Simulations with an IMBH have less mass segregation (Baumgardt et al. 2004, Trenti et al. 2007)
    - Effect well beyond the BH sphere of influence!



Spatial distribution of binaries @ $t=10t_{rh}$

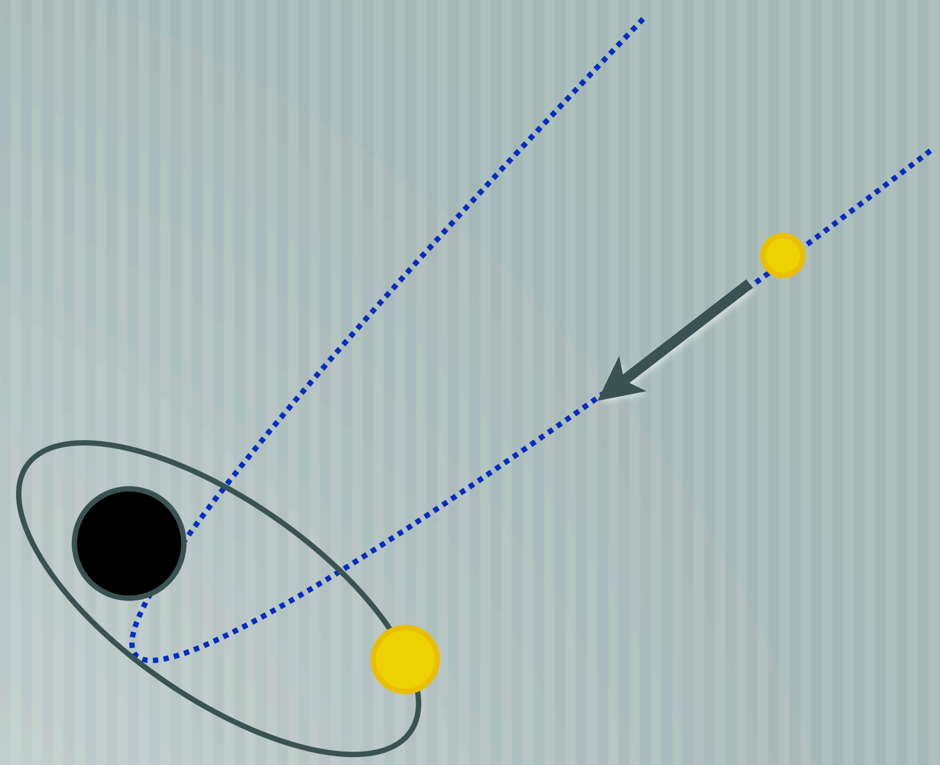
Trenti et al. (2007)



Quenching of mass segregation

A Cartoon Picture

- IMBH quickly gains at least one tightly bound massive star:
  - A super-scatter machine is born!
- Three body encounters with the BH scatter out incoming stars independently of their mass
  - No strong dependence on BH mass expected or seen in simulations when $m_{BH} >> m_{star}$
  - Random walk of the IMBH within the core: loss cone is constantly replenished, high rate of interactions over time



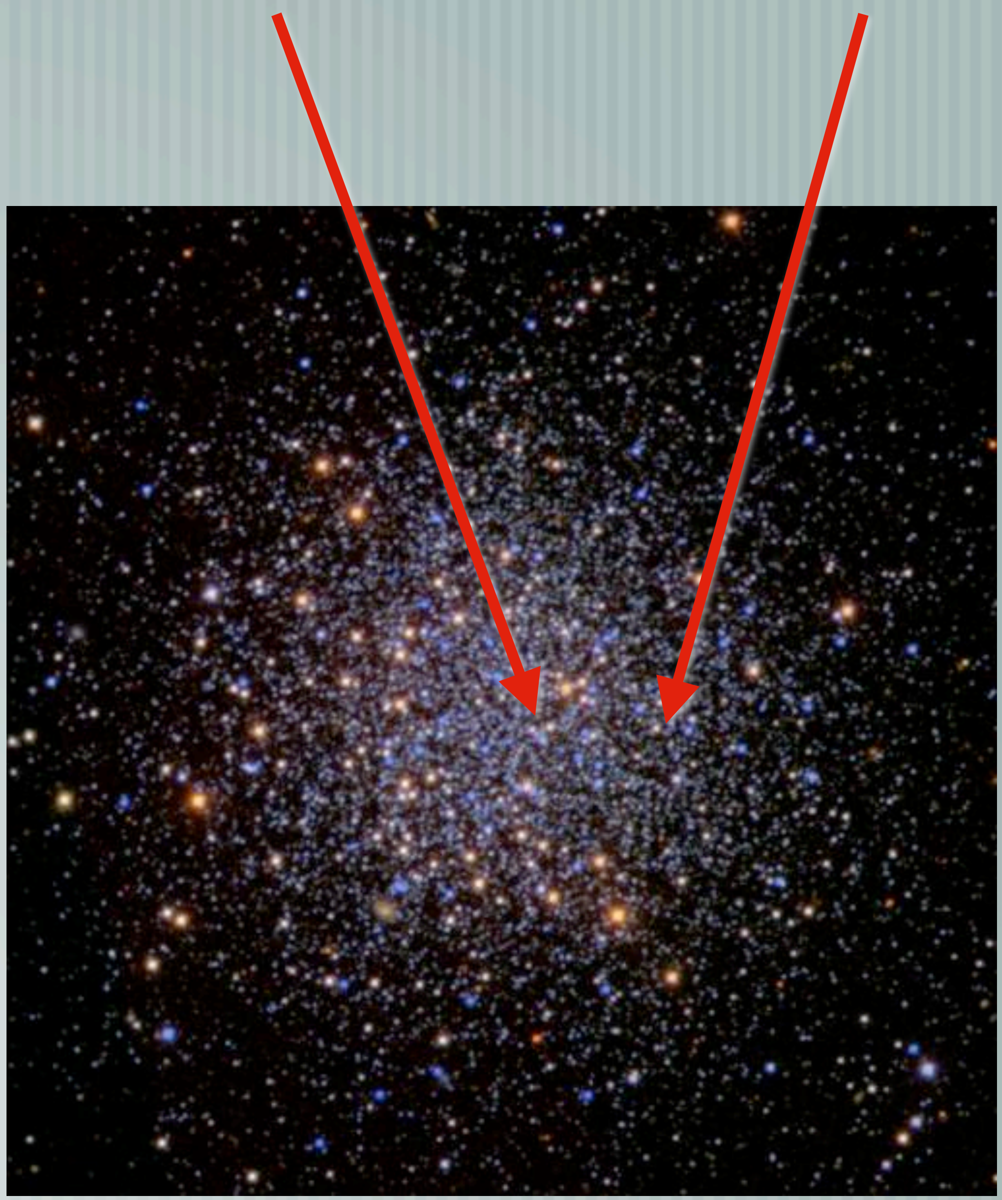
Our Modeling

- Direct N-body simulations with Aarseth's NBODY6:
  - NO softening
  - Exact treatment of all strong interactions including those with the BH
  - Up to N=65536 (Trenti et al. 2010)
- Grid of initial conditions
  - "Late Time" Mass function, Primordial Binary Fraction, Tidal Field, Concentration
- IMBH mass about 1% of total mass of the system
- Runs carried out until tidal dissolution (about 15 t_{rh})

Measuring Mass Segregation

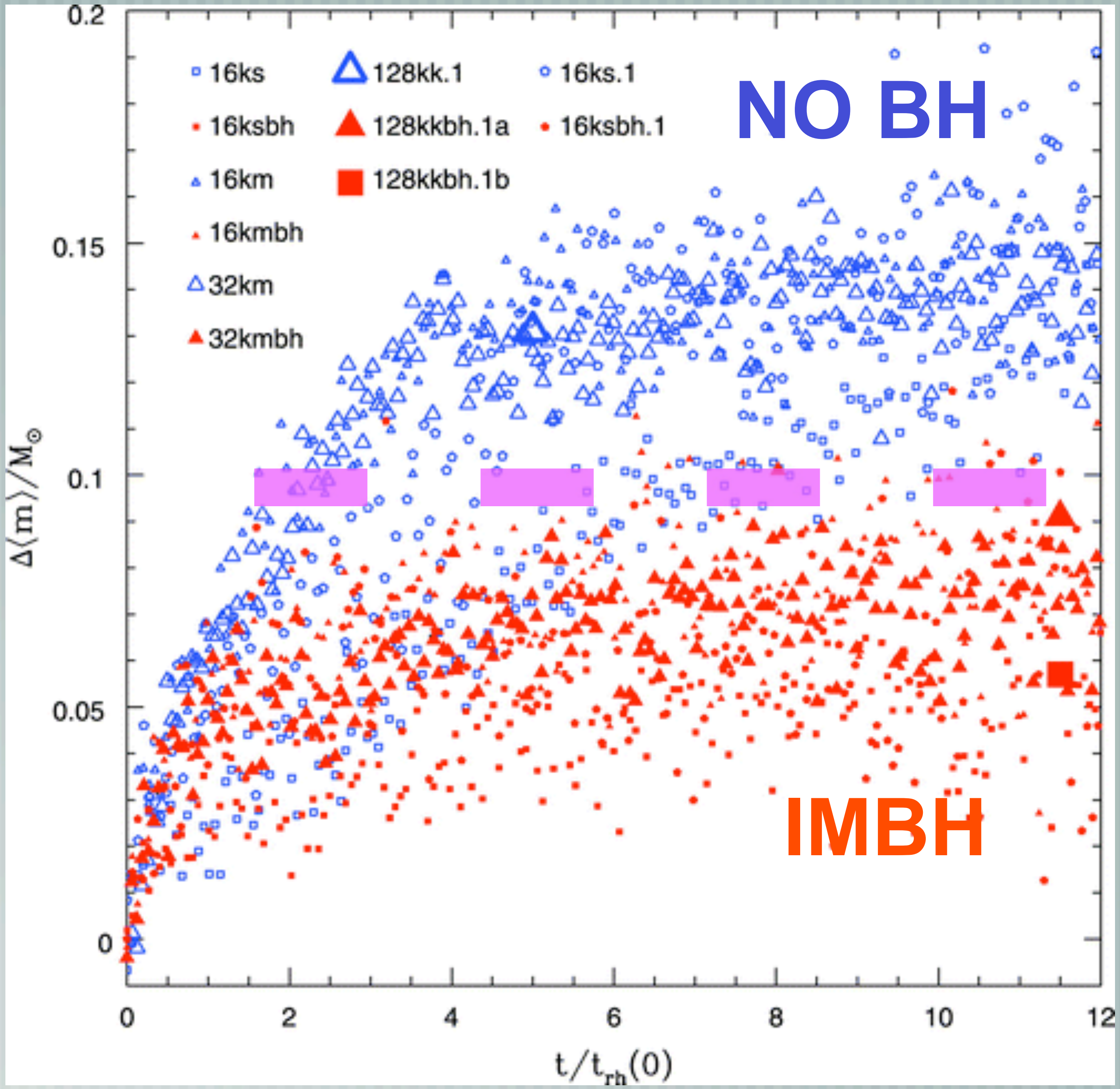
$$\Delta\langle m\rangle = \langle m(r = 0)\rangle - \langle m(r = rh)\rangle$$

- Mass segregation $\Delta\langle m\rangle$ is measured as the difference in average main sequence mass between the center and the half mass radius
- Differential measure:
  - Erases dependence on the IMF
- Based on star counts:
  - Less sensitive to fluctuations in light profile due to giant stars



Mass Segregation Results: Simulations

- Simulations start with no mass segregation
- After about 5 relaxation times equilibrium value of mass segregation is reached
- Good separation of runs with and without an IMBH

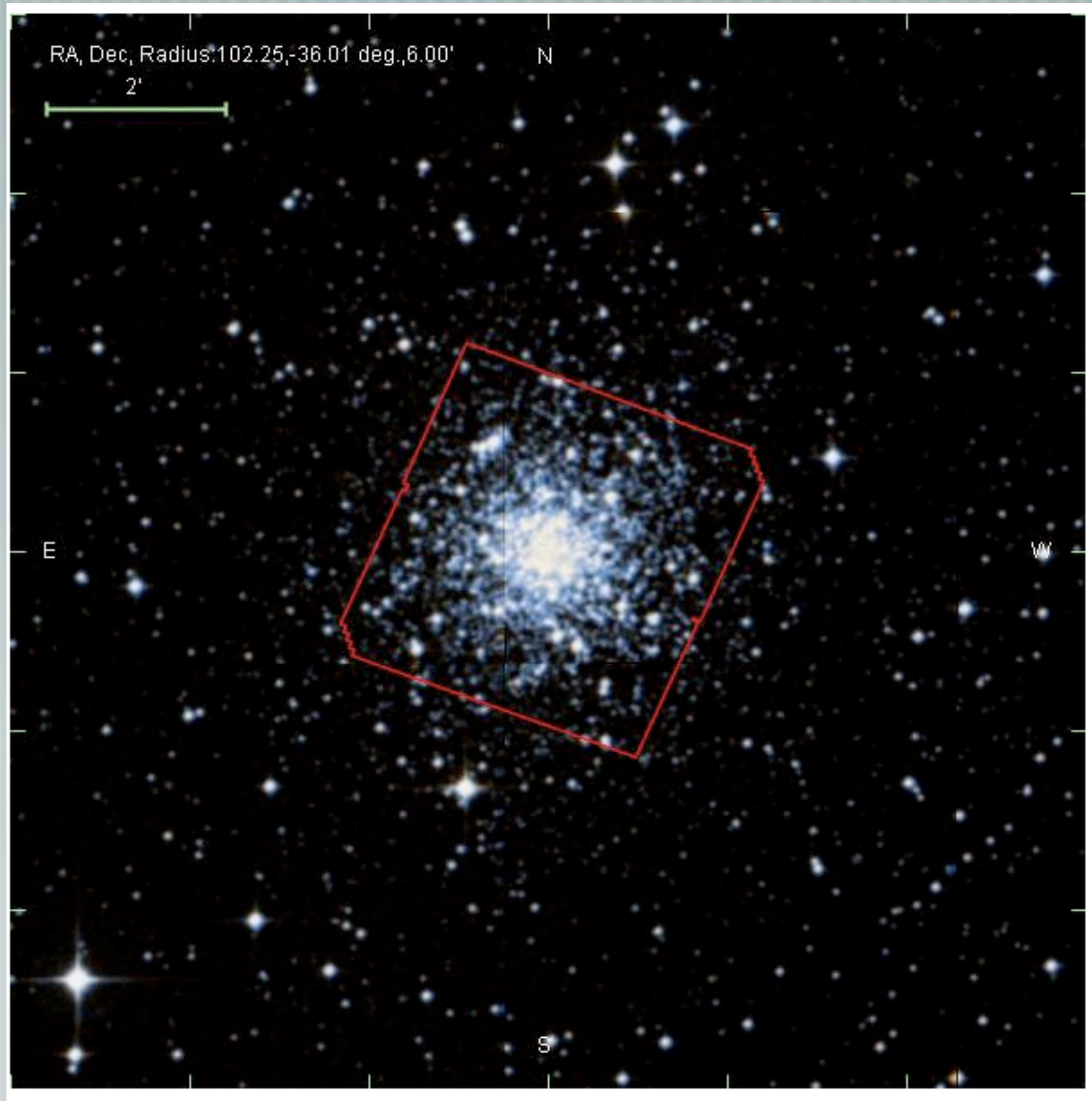


Gill, Trenti et al. (2008)

Mass Segregation: A first application

- Search for IMBH fingerprint can be applied to well relaxed clusters (t_{rh}<1Gyr)
- Detailed Star Counts are needed, with coverage to at least half-mass radius
- Data and Simulations need to be treated self-consistently
  - e.g. completeness, FOV, measure of structural parameters

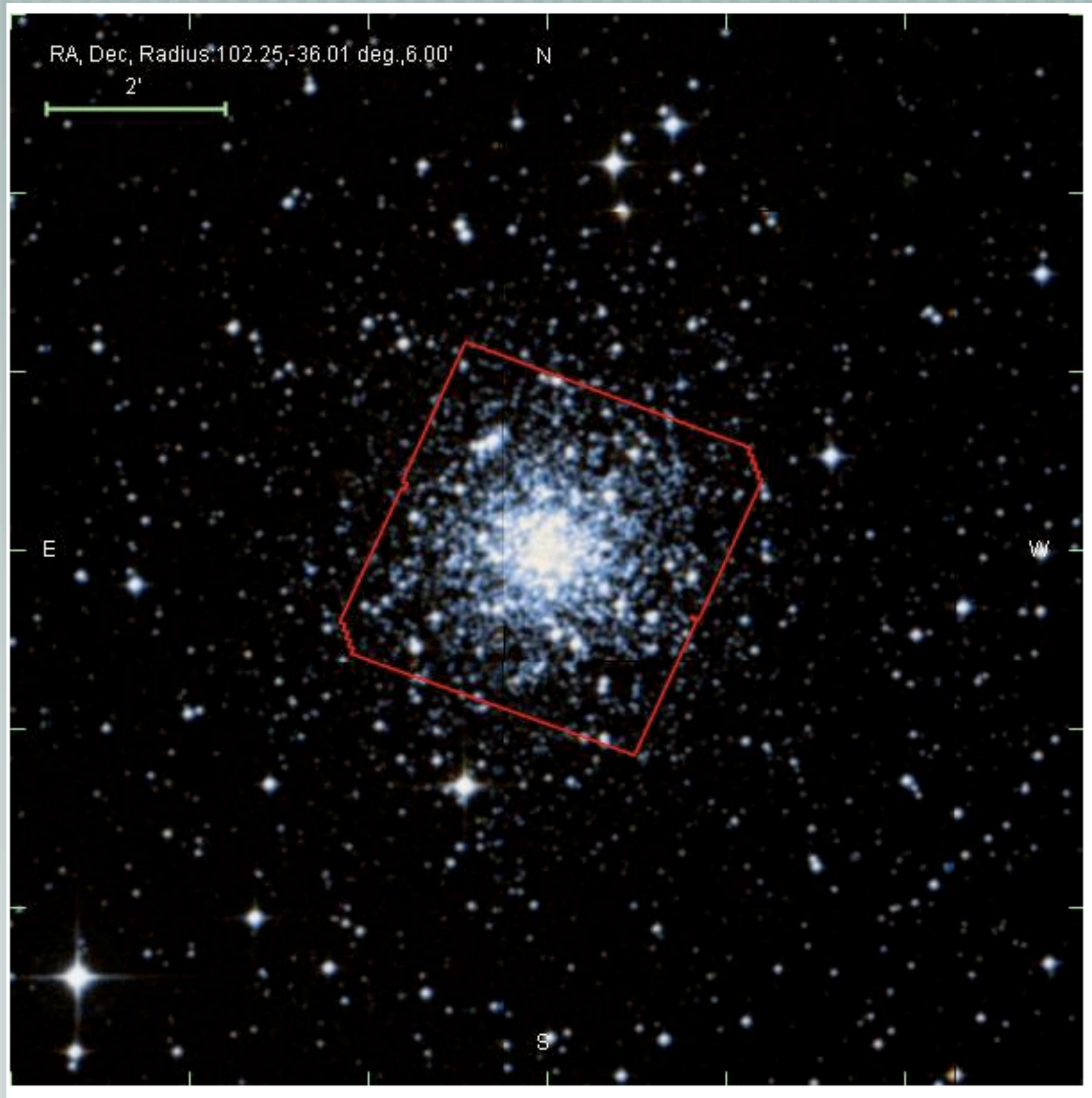
NGC 2298



NGC2298 dataset

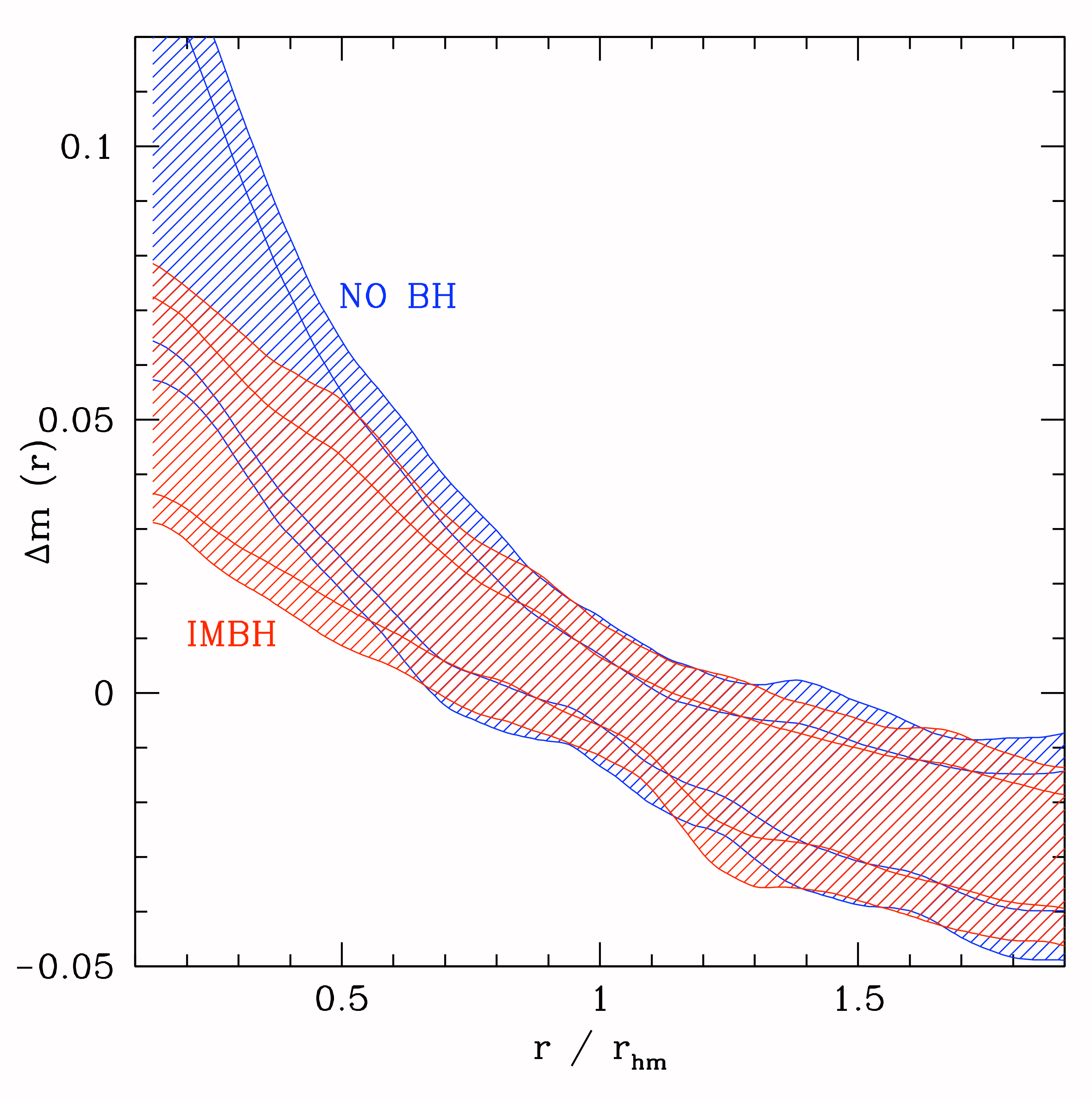
- Cluster properties
  - $t_{rh} = 10^{8.41}$ yr
  - rh = 49″
  - $M_{tot} = 3x10^4$ Msun
- Data Reduction: DeMarchi & Pulone (2007)
- HST-ACS WFC F606W & F814W
  - 10σ limit @ m_{606}=26.5, m_{814}=25.0
  - >50% completeness @ 0.2 Msun

NGC 2298



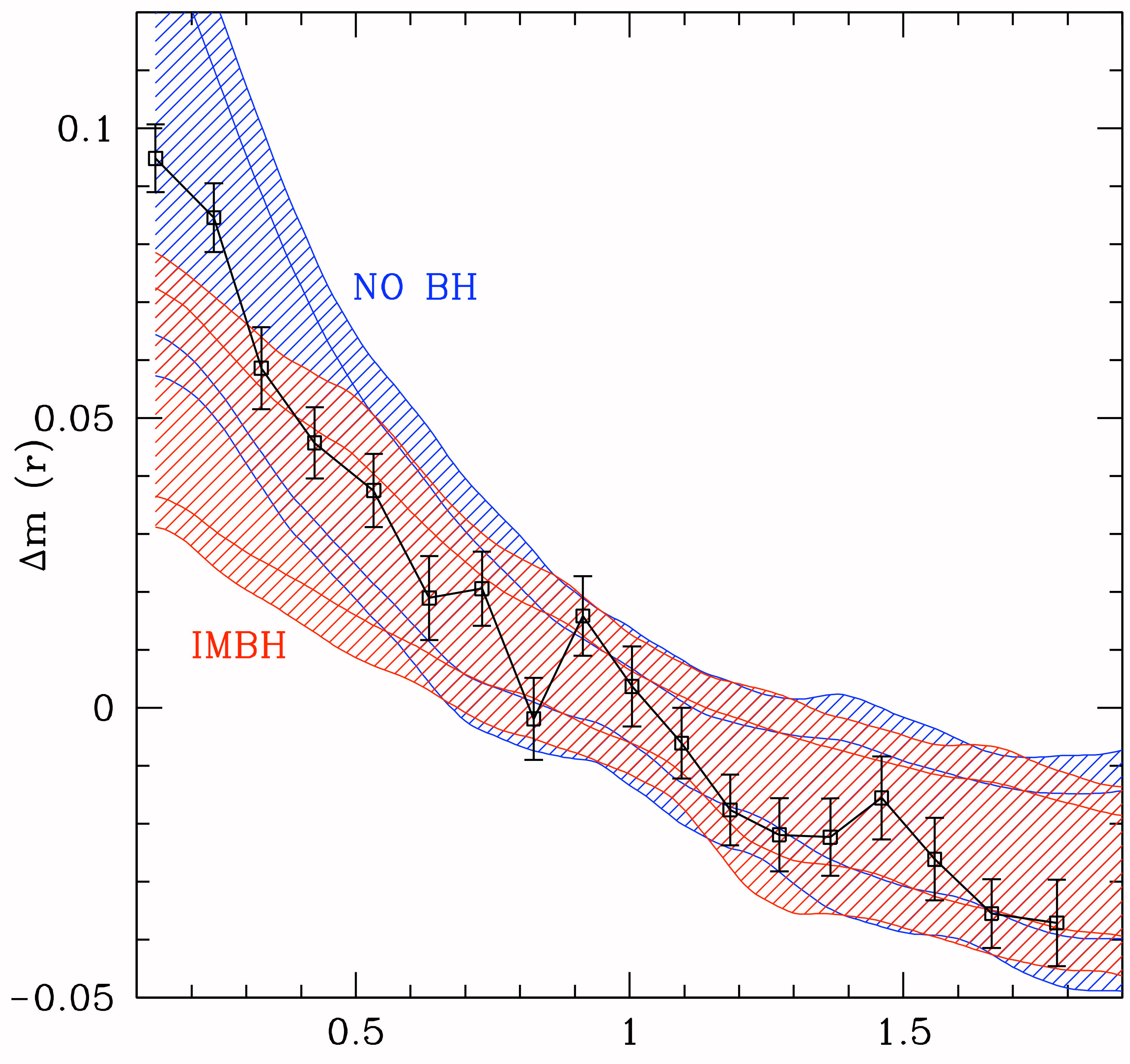
NGC2298: predictions from simulations

- Simulations analyzed between 7 and 9 t_{rh}
- Full radial mass segregation profile has been obtained
- Plot shows 1 and 2σ scatter of the simulated clusters
  - Sample of runs (270 snapshots), sample of random projections
  - Good separation IMBH vs NO BH in the center



NGC2298: comparison with simulations

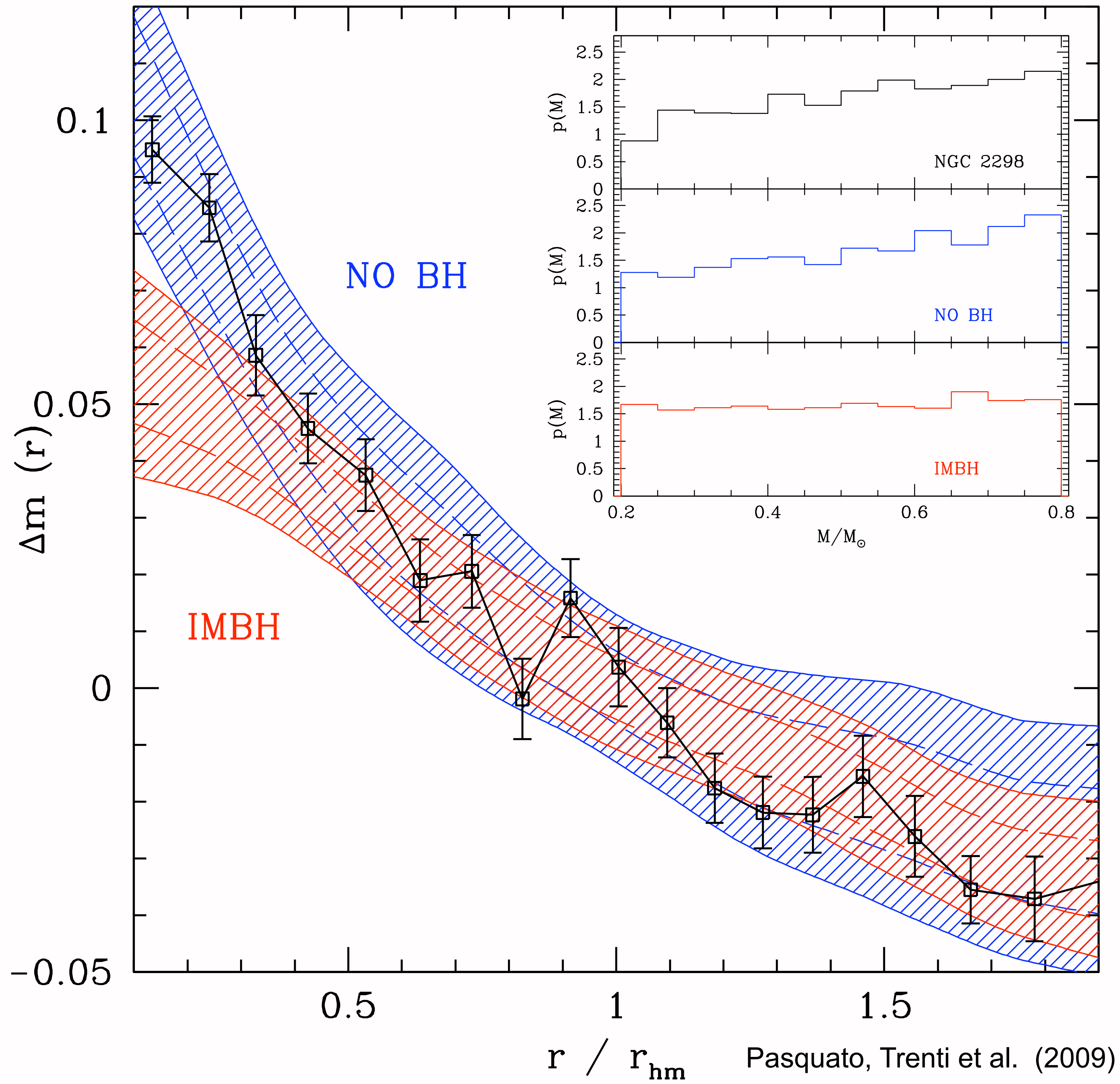
- Observed mass segregation profile is matched very well by simulations
- Cluster is too segregated to be likely to host an IMBH
- Formal limit from the inner two points: >300Msun BH excluded at 3σ CL



Pasquato, Trenti et al. (2009)

NGC2298: comparison with simulations

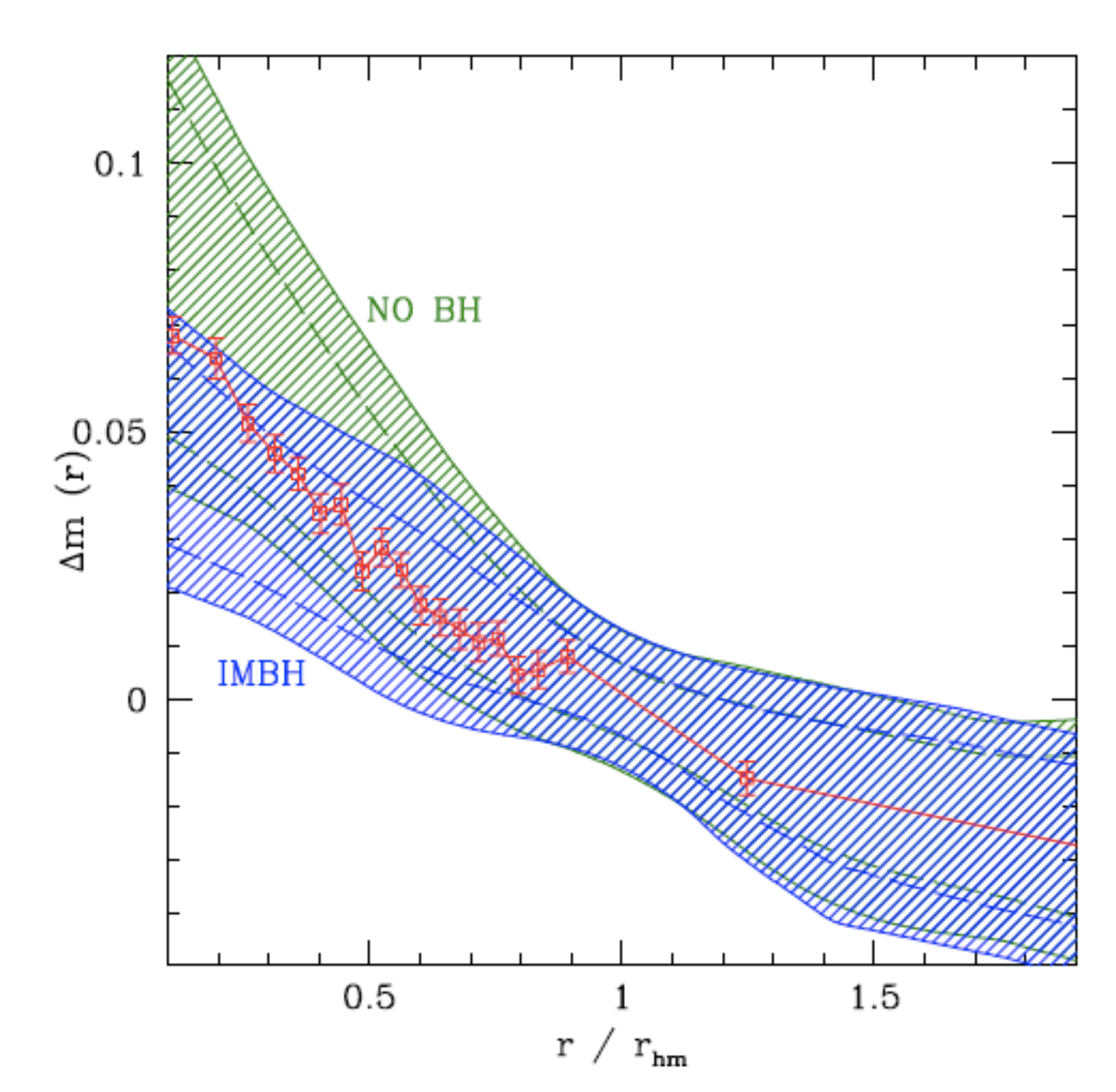
- NGC2298 has a peculiar mass function (very deficient in low mass stars)
- General analysis includes an ensemble of IMFs
- Restricting to a MF representative of 2298 yields more stringent prediction for $\Delta m(r)$
- Stronger IMBH rejection
- Excellent data-model match!



Pasquato, Trenti et al. (2009)

Mass segregation: M10

- Similar analysis also carried out for M10
- IMBH excluded at ~1.5σ confidence level
- Most likely explanation of measured level of mass segregation is ~5% primordial binaries

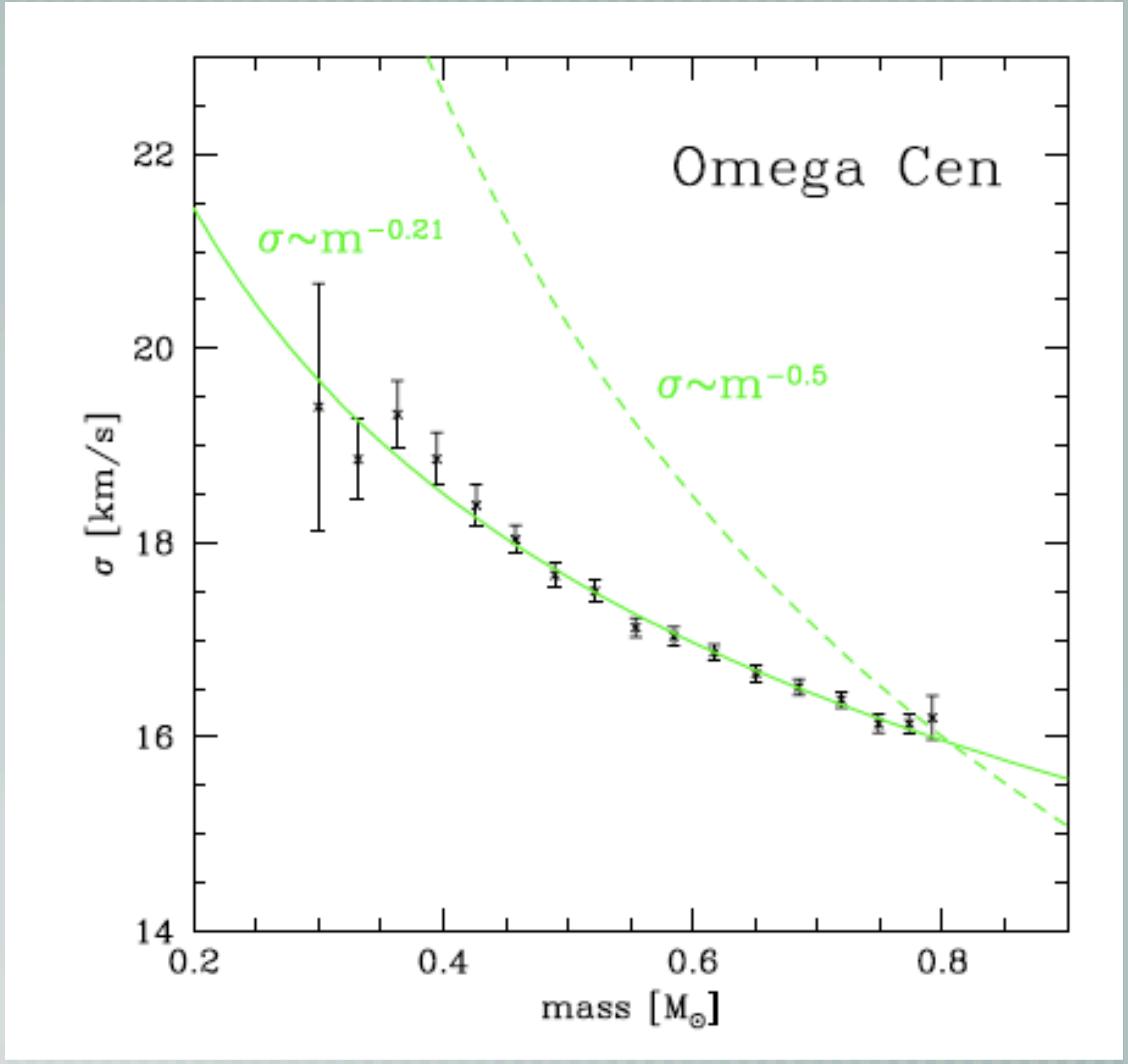


Beccari et al. (2010)

Mass segregation analysis for Omega Cen

- IMBH in Omega Cen debated in the community
- Spatial mass segregation analysis cannot be applied because relaxation time too long
- But... mass-dependent kinematic at the center is available from proper motions
- Velocity dispersion versus star mass shows system not in equipartition

Central velocity dispersion vs. star mass

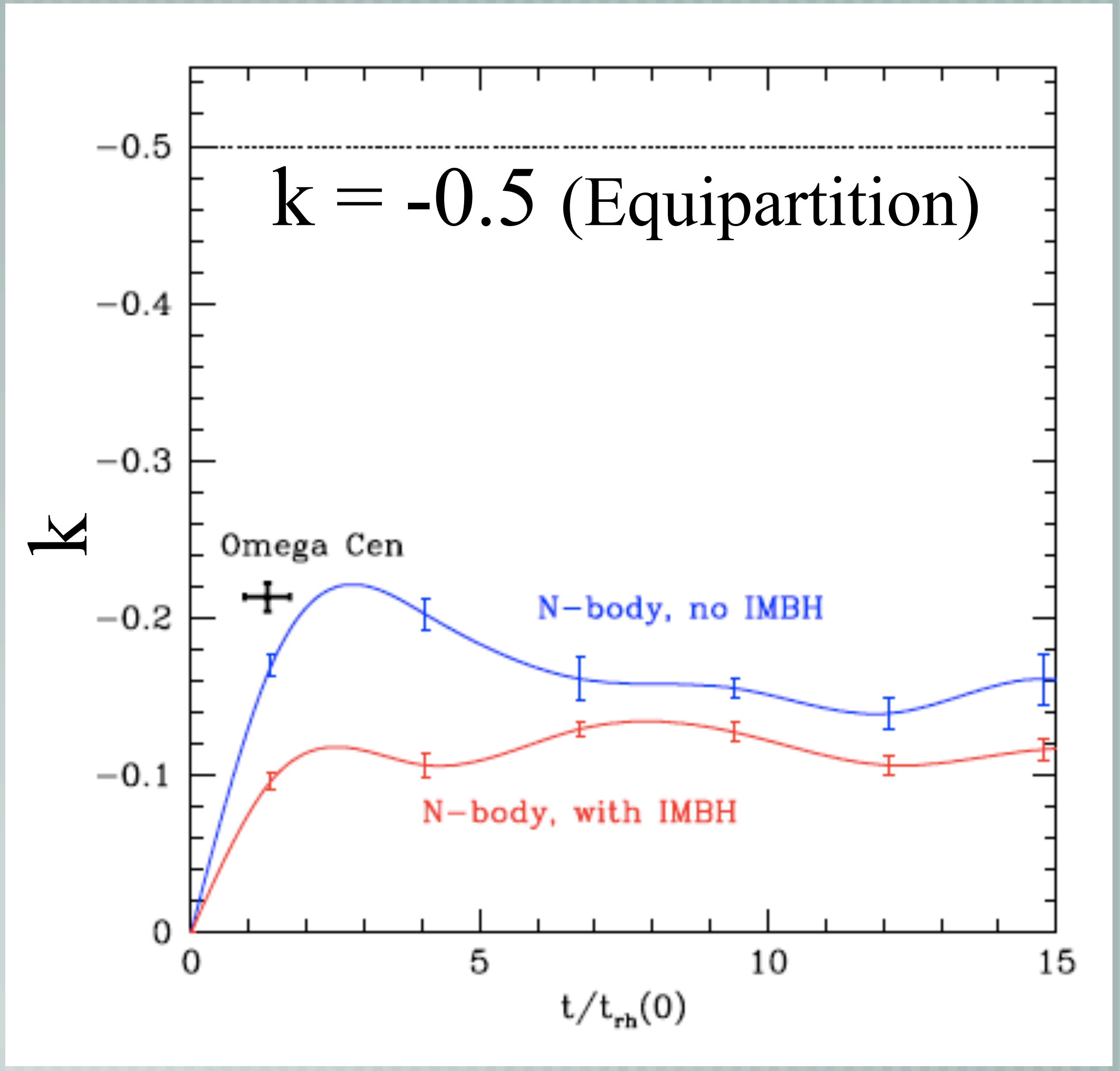


Trenti & van der Marel, in preparation

Mass segregation analysis for Omega Cen

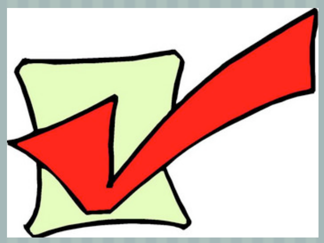
- Omega Cen is closer to energy equipartition than expectations from N-body simulations with a central IMBH
  - Simulations without IMBH provide better match
- But... there is a caveat to be explored: effects of primordial mass segregation

Time evolution for $\sigma \sim m^k$



Trenti & van der Marel, in preparation

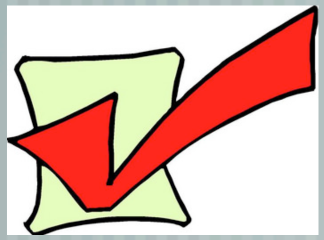
Summary: IMBH fingerprints (dynamics)



- Proper motions: best available
(but expensive in telescope time)

- Large rc/rh: necessary, not unique

- Shallow surface brightness cusps: not unique



- Mass segregation:
good for relaxed (small) globular clusters
(+ exciting prospects if 2D kinematics is available)