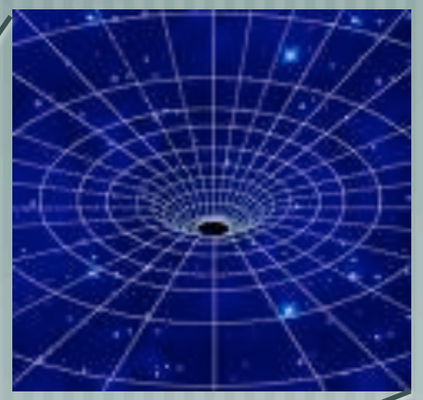
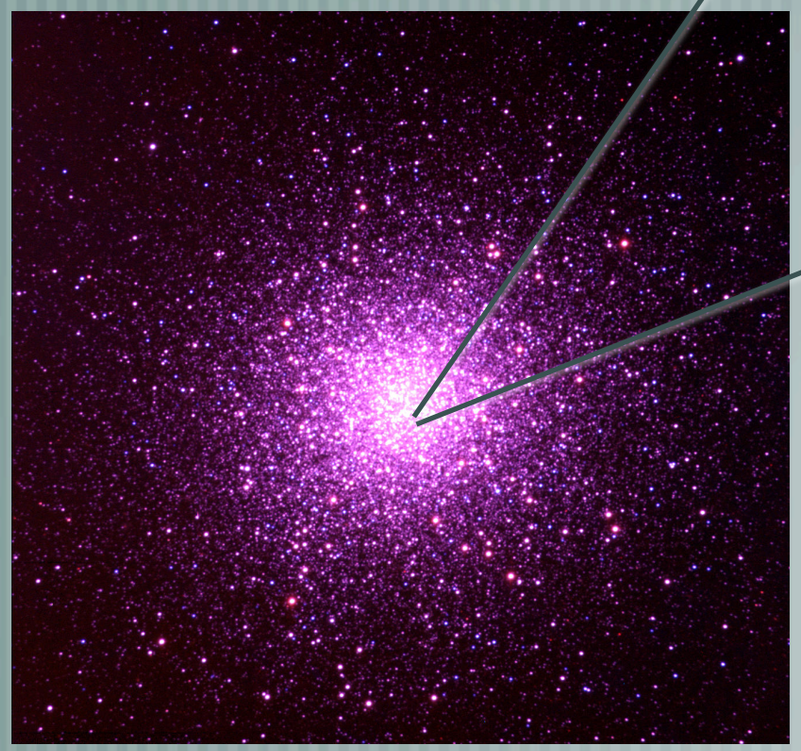
IMBH Fingerprints in Globular Clusters





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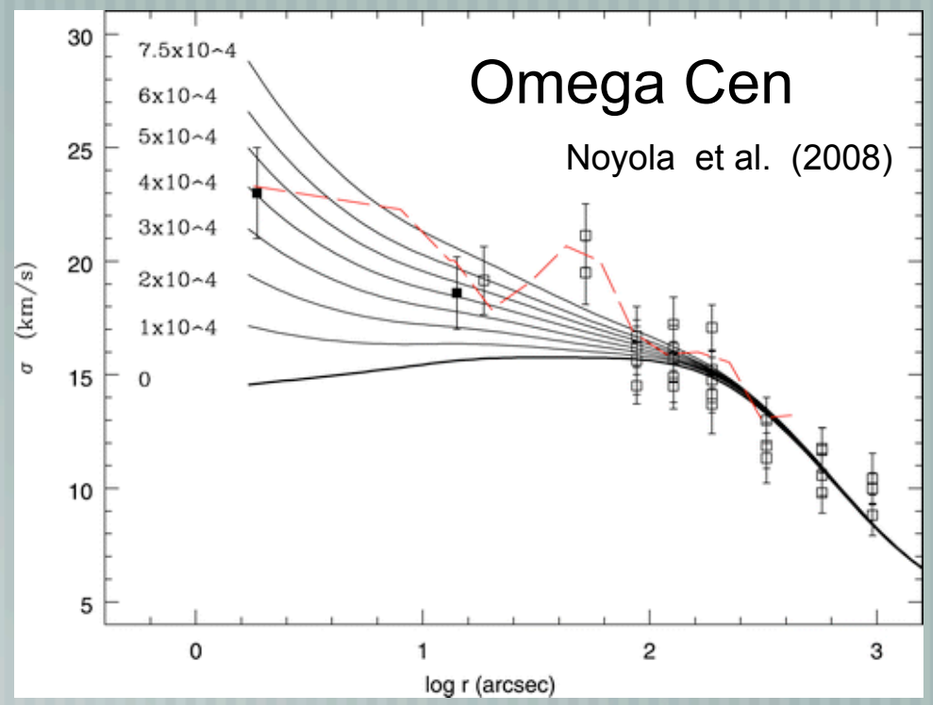
Intermediate Mass Black Holes

- Black Holes of 10^2-10^4 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 of Young Star Clusters (Portegies-Zwart et al. 2004)
- Globular Clusters seem the best place to look for them
- But unambiguous detection is still missing

Searching for IMBHs in GCs

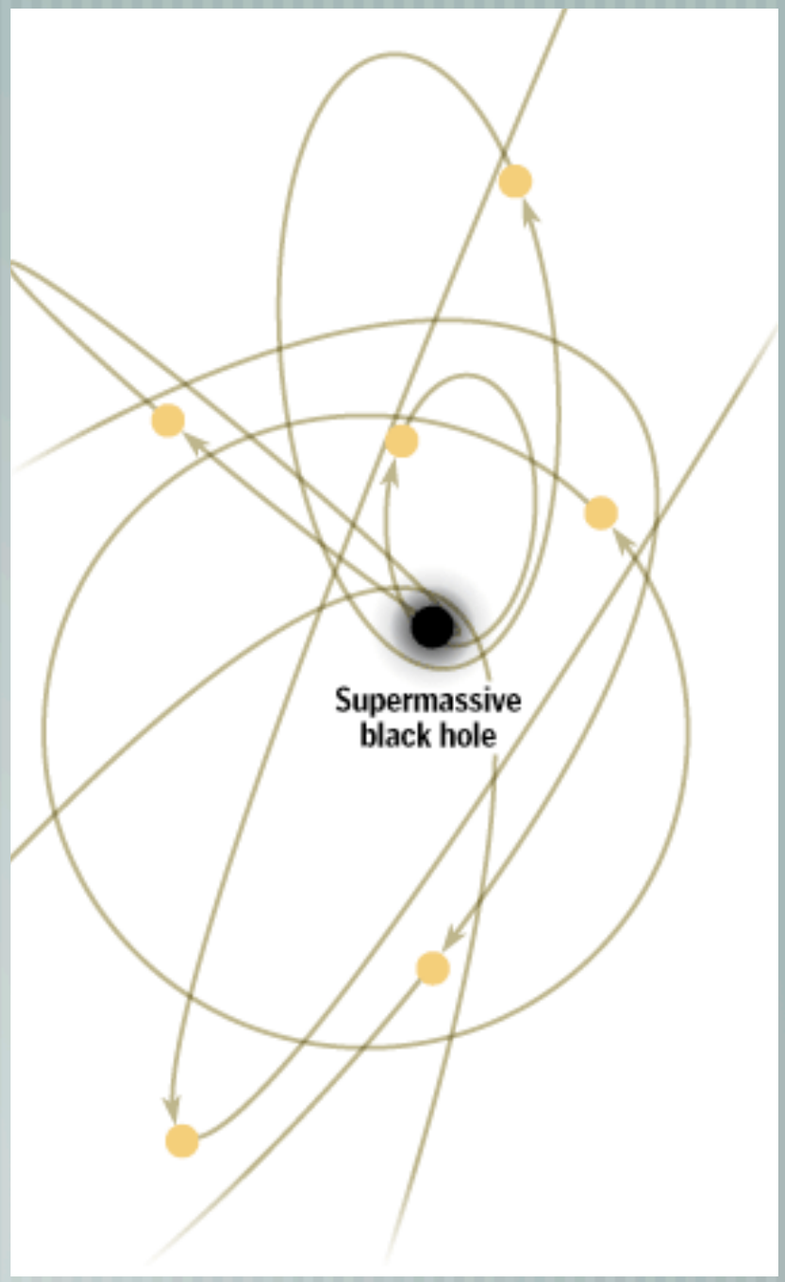
- Globular Clusters have very little gas
  - x-ray emission faint at best
- Sphere of influence of the BH is small (a few arcsecs): Limited Direct BH Influence



- Interpretation of surface brightness + velocity dispersion profiles is model dependent [e.g. through isotropic Jeans Equations]
  - Alternative Dynamic Models with NO BH can be constructed (e.g. Baumgardt et al. 2005)

Searching for IMBHs in GCs

- Proper motion studies can provide the best evidence for IMBH 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?

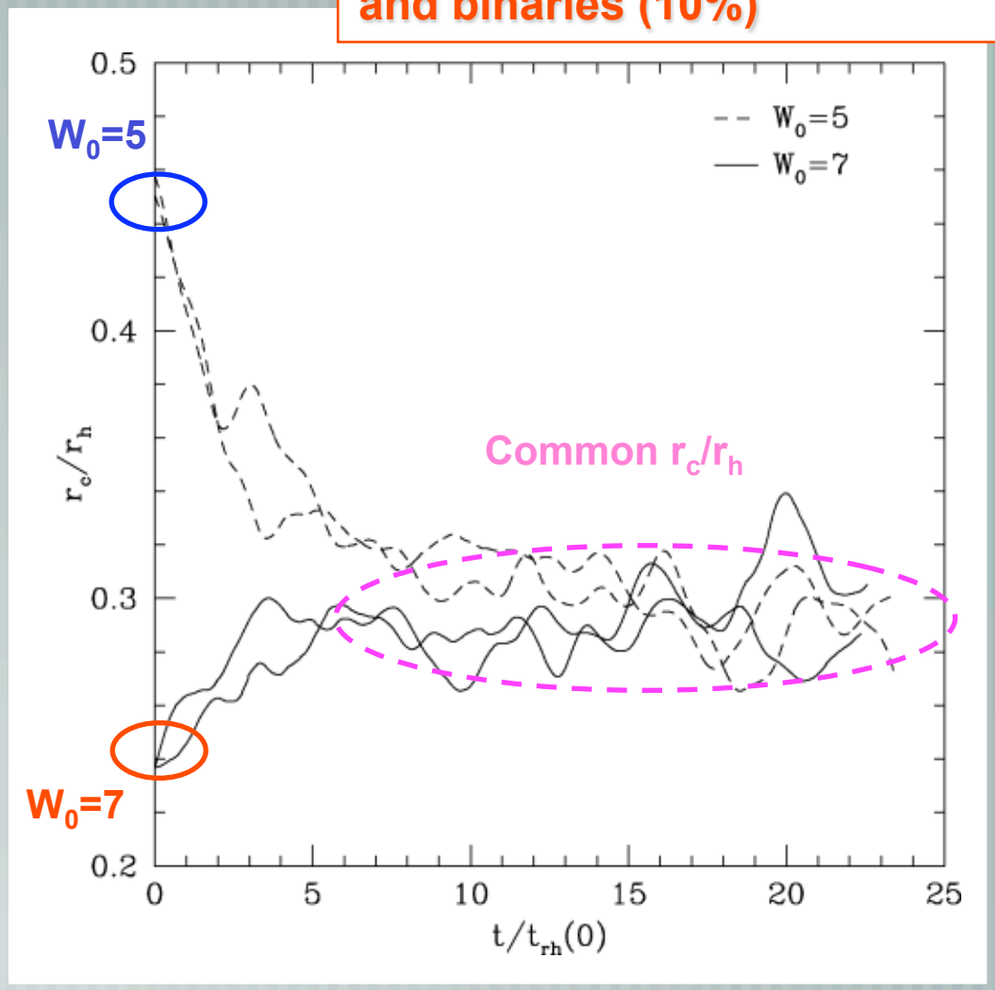


IMBH fingerprint: rc/rh

- 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 2007), WD kicks (Richer's talk), stellar collisions (Chatterjee et al. 2009),stellar BHs (Davies' Talk)

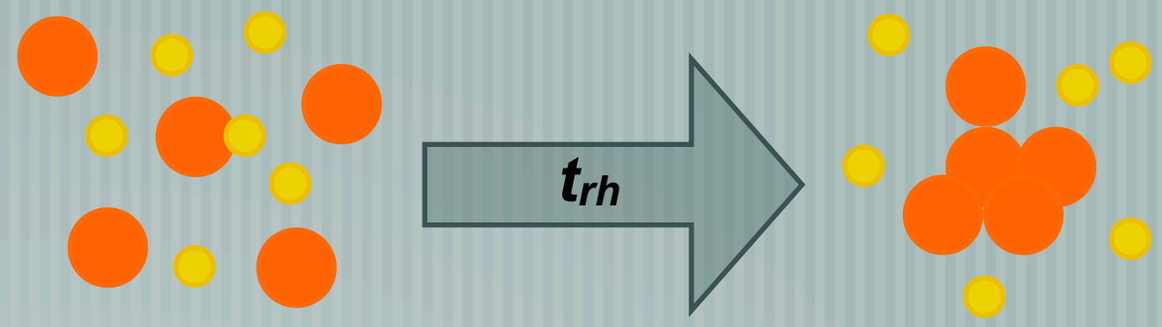
r_c/r_h with IMBH (m_{BH}/m_{tot}=0.014) and binaries (10%)



Trenti et al. (2007)

IMBH fingerprint: mass segregation

- In a GC the most massive stars segregate toward the center of the system (energy equipartition)

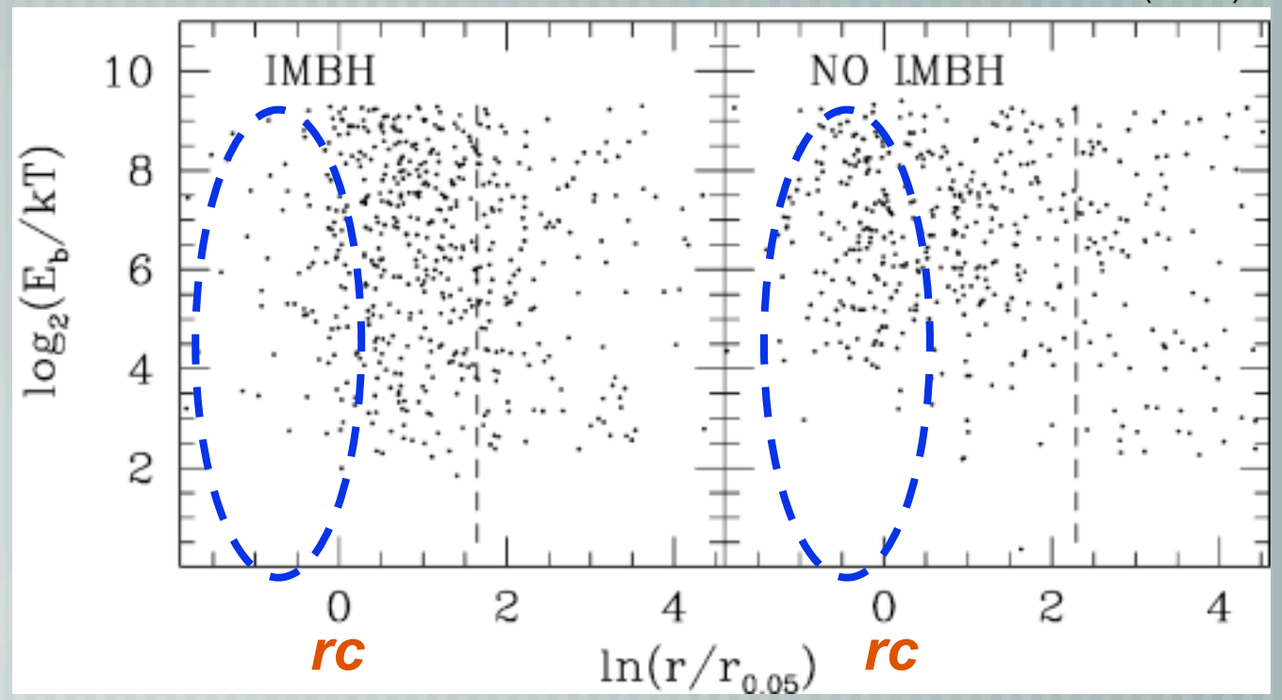


- Simulations with an IMBH have less mass segregation (Baumgardt et al. 2004, Trenti et al. 2007)

- Effect well beyond the BH sphere of influence!

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

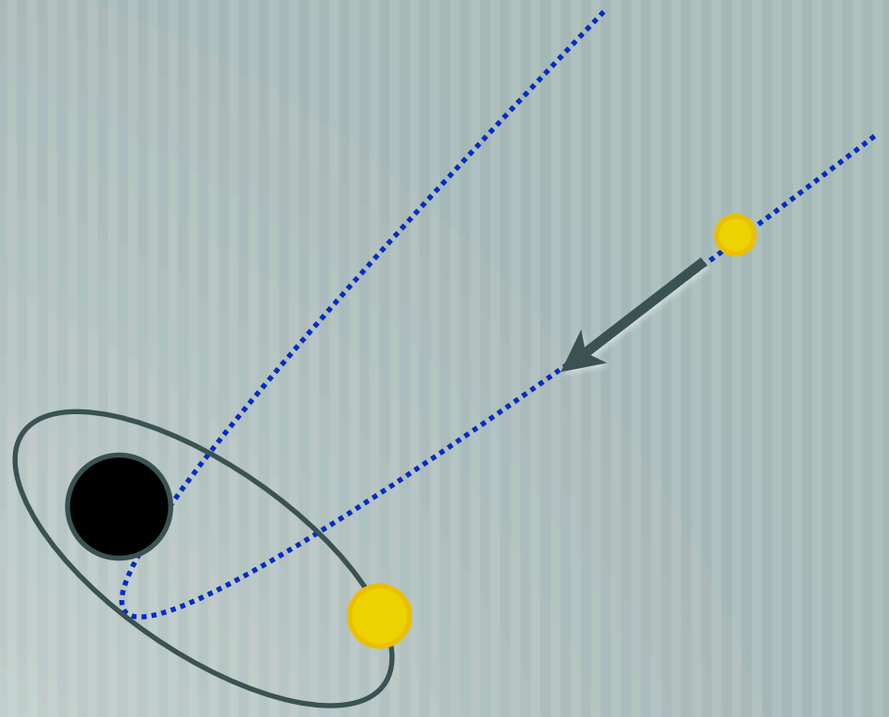
Trenti et al. (2007)



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



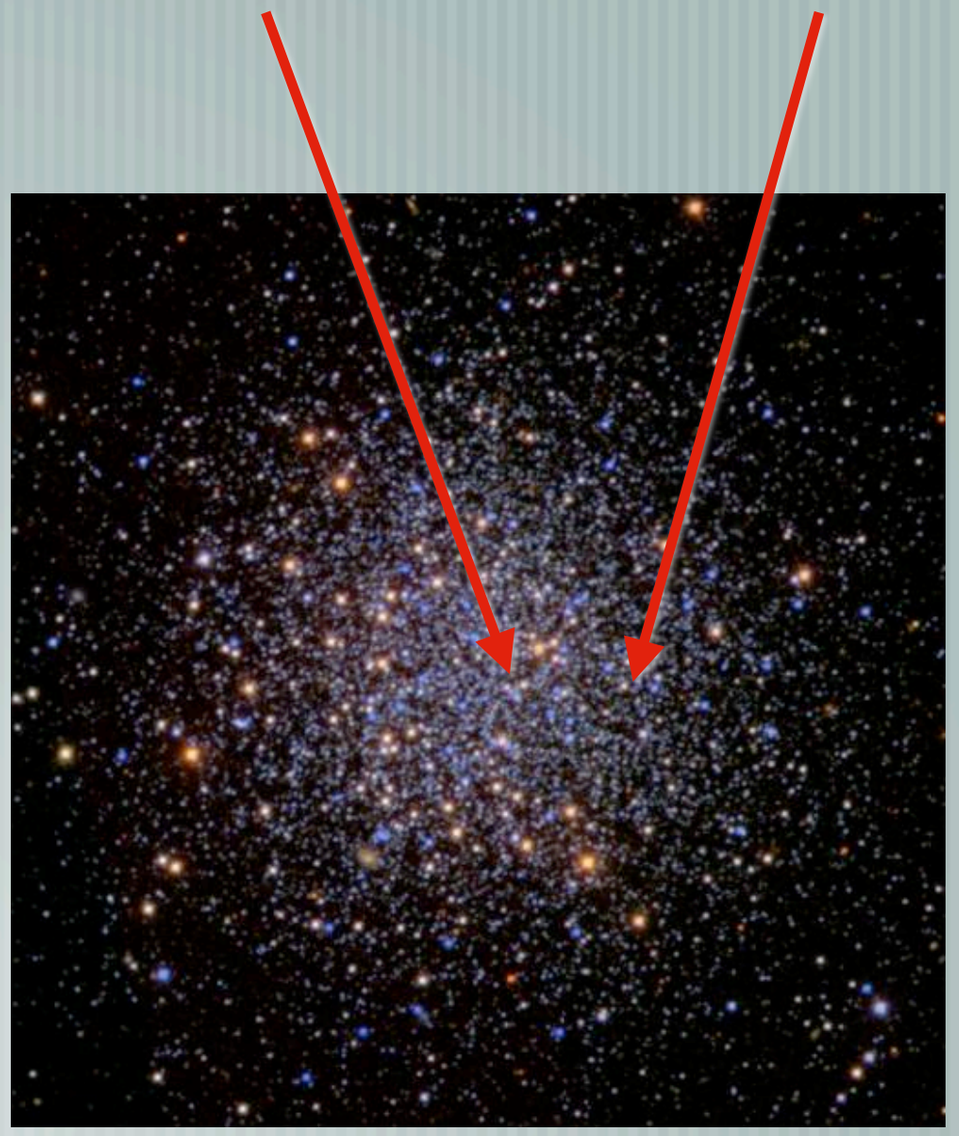
Our Modeling

- Direct N-body simulations with Aarseth's NBODY6:
  - NO softening
  - Exact treatment of all strong interactions including with the BH
    - Up to N=32768
- 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

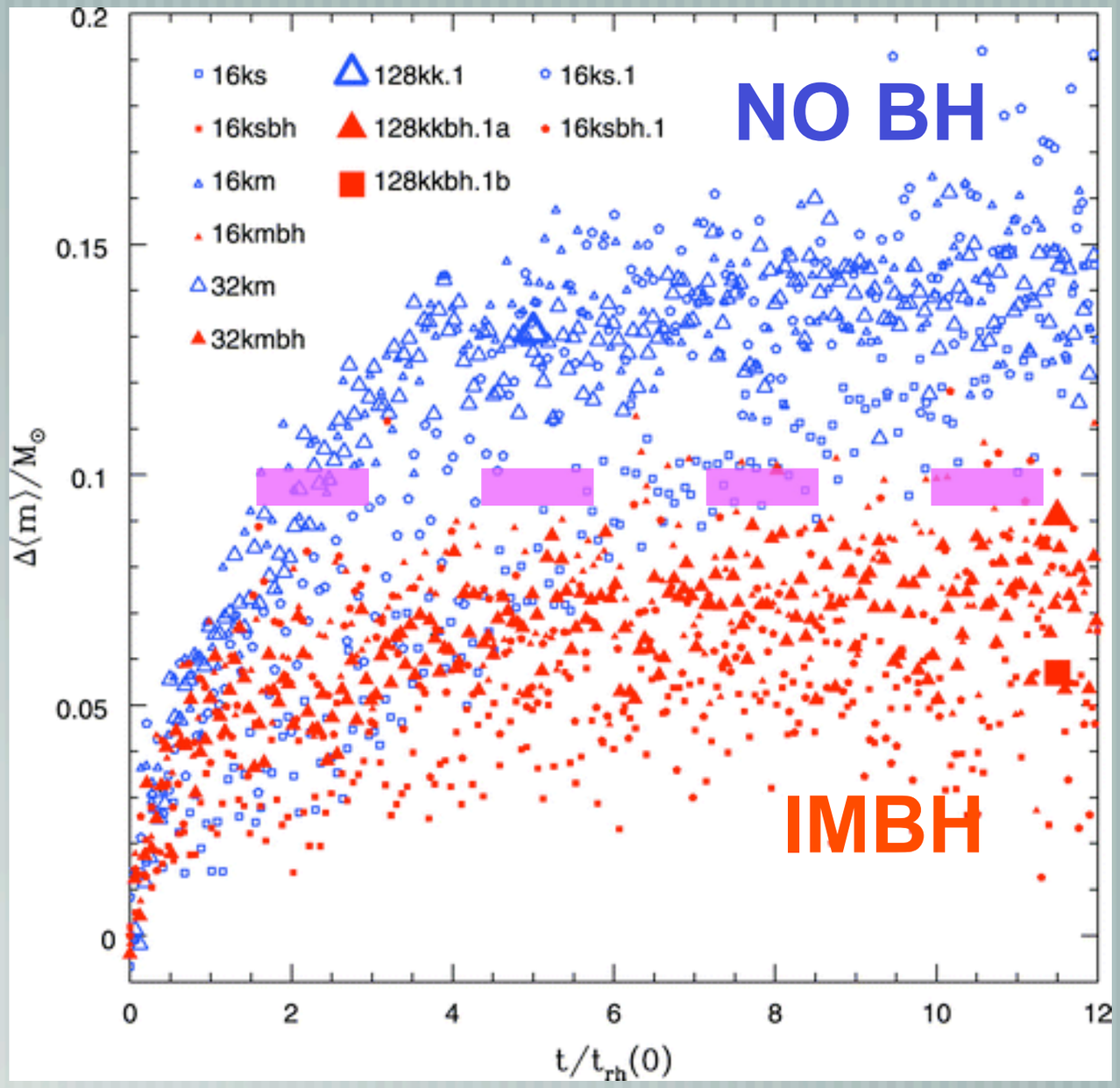
$$\Delta\langle m\rangle = \langle m(r = 0)\rangle - \langle m(r = rh)\rangle$$

- 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
- Mass not light based:
  - less sensitive to fluctuations due to small number of 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

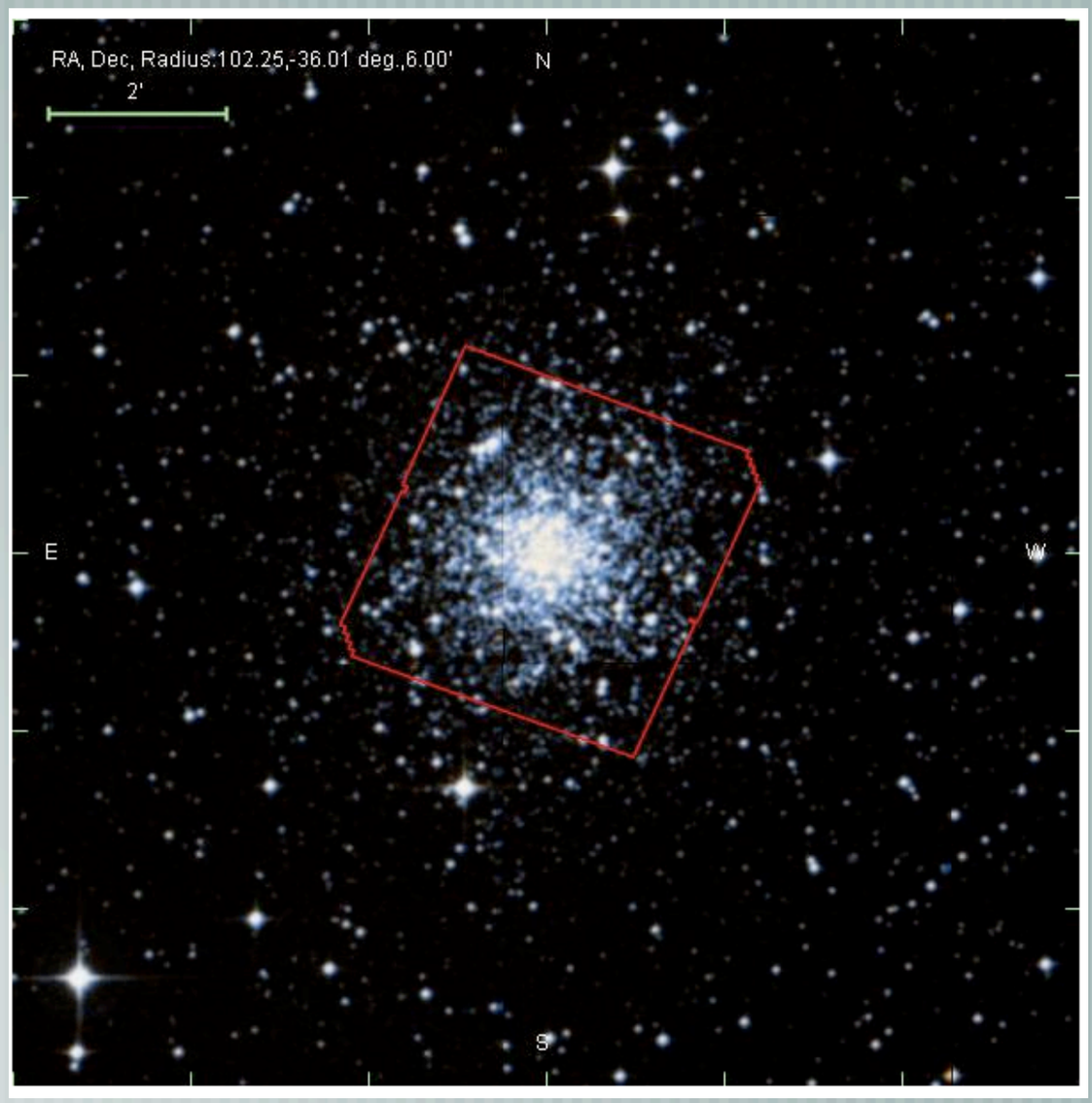


Gill, Trenti et al. (2008)

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

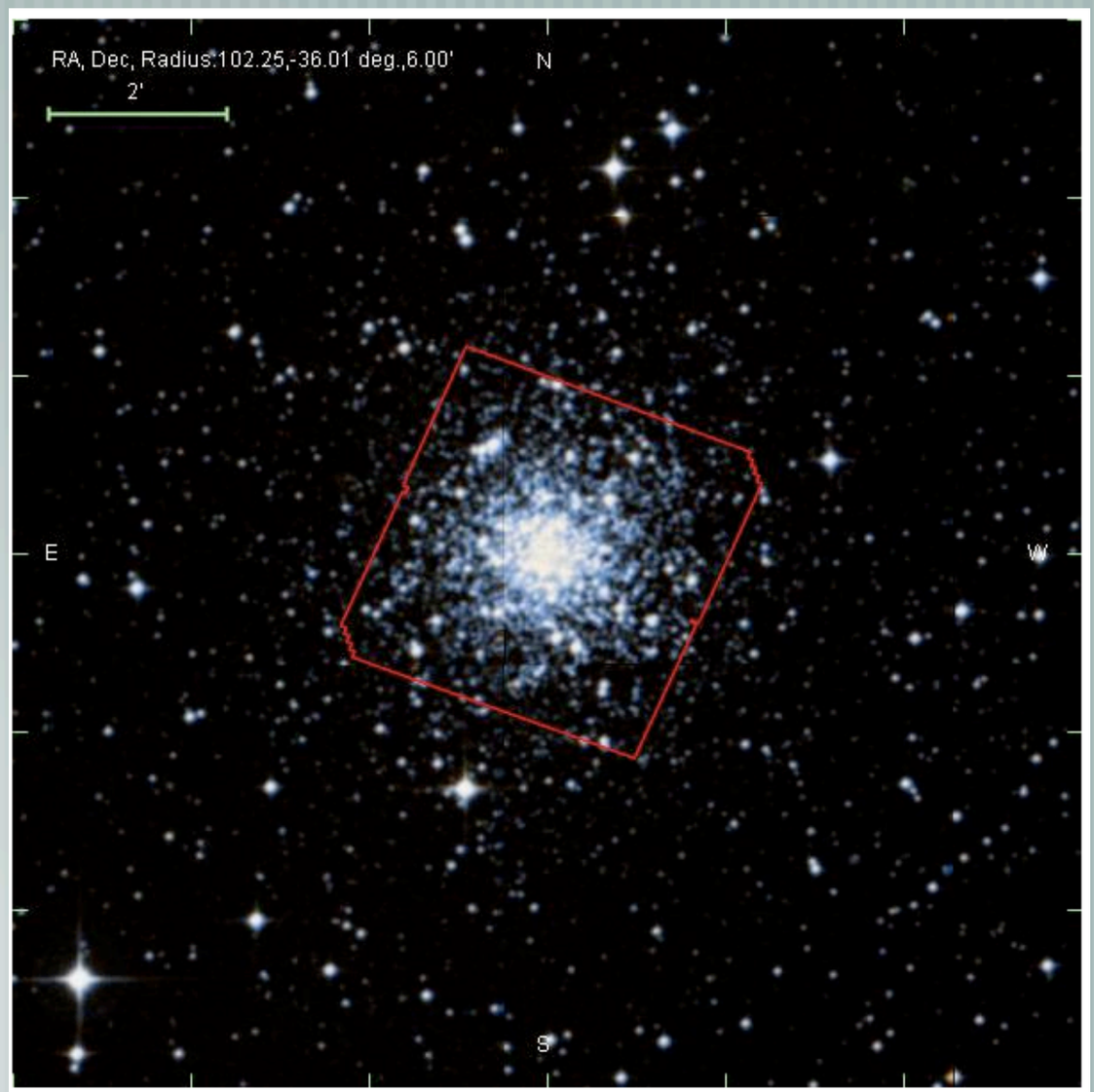
NGC 2298



NGC2298 dataset

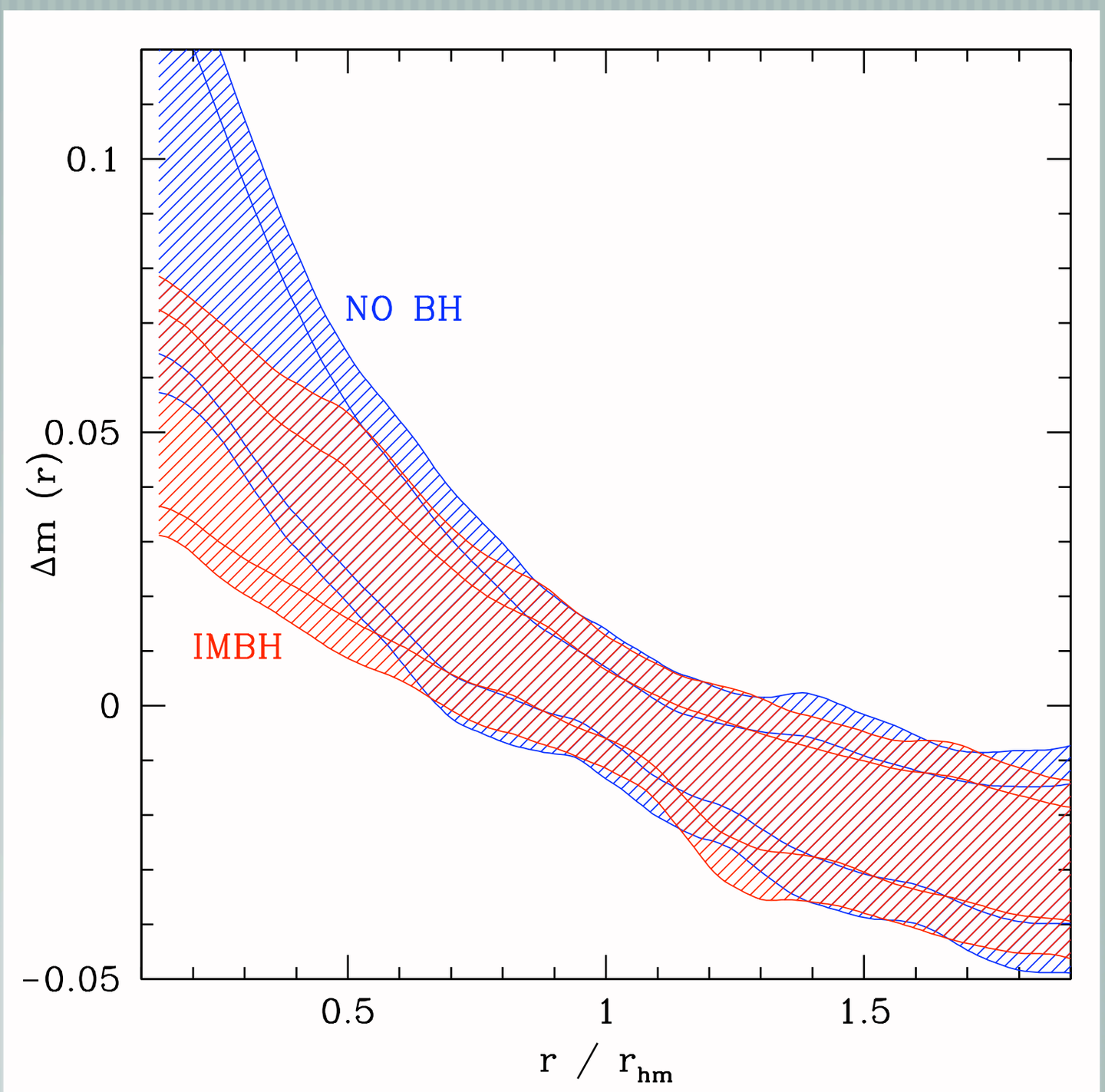
- Cluster properties
  - $t_{rh} = 10^{8.41}$ yr
  - rh = 49″
  - $M_{tot} = 3x10^4$ Msun
- Data Reduction: DeMarchi & Pulone (2007)
- HST-ACS WFC F606W & F814W
  - 10σ limit @ m_{606}=26.5, m_{814}=25.0
  - >50%completeness @ 0.2 Msun

NGC 2298



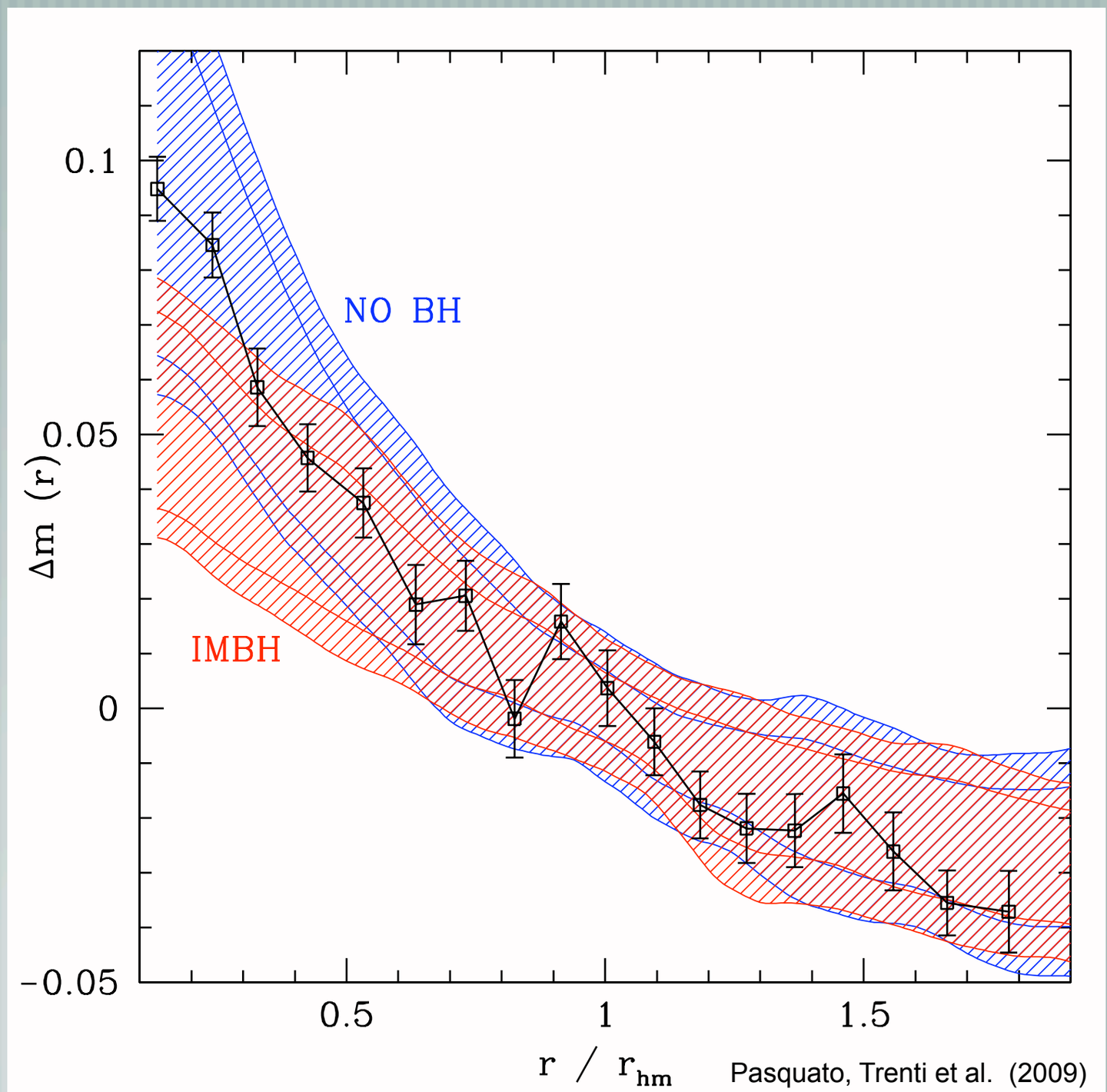
NGC2298: predictions from simulations

- Simulations analyzed between 6 and 8 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

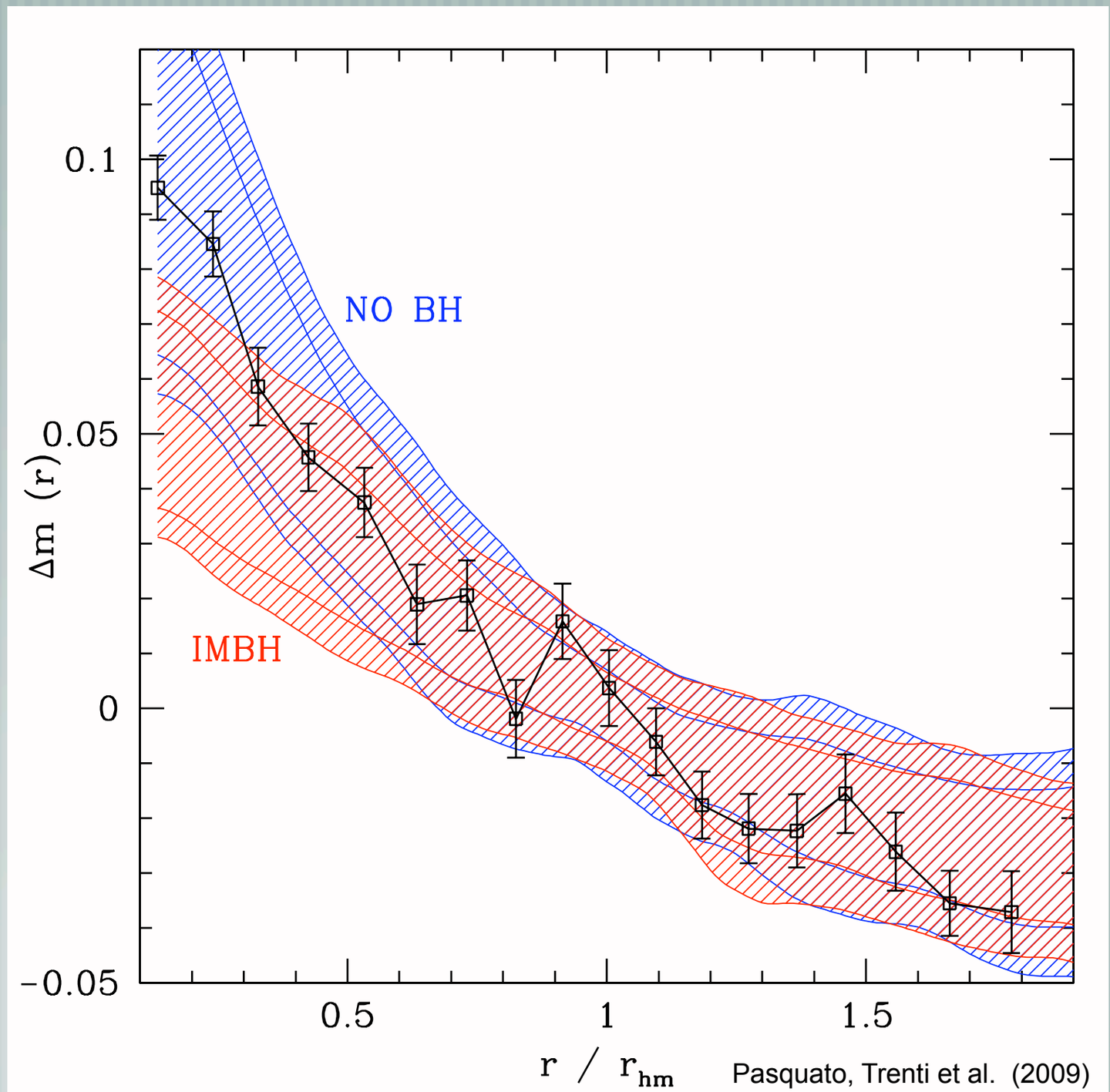
- Observed mass segregation profile is matched very well by simulations
- Cluster is too segregated to be likely to host an IMBH
- Formal limit from the inner two points: >300Msun BH excluded at 3σ CL
- but limiting factor is number of simulations (only 135 snapshots with IMBH)



Pasquato, Trenti et al. (2009)

NGC2298: Error budget

- Poisson errors have been estimated by bootstrap (100 synthetic catalogs)
- Possible systematic errors from determination of
  - Half mass radius. Even a +/- 4″ mis-determination only shifts by less than 1σ Poisson error
  - Center. We use mass, not light based measure, more stable: [0.4″ uncertainty at 1σ] Miscentering only increases BH rejection confidence level



Pasquato, Trenti et al. (2009)

The future

- Larger sample of simulations
  - NBODY-6 SSE/GPU code on NCSA Lincoln cluster
  - Improved statistics, wider sampling of initial conditions, larger N
- Suitable HST data are available in the archive for about 15 clusters

Summary

- IMBHs leave multiple fingerprints of their presence in *RELAXED* globular clusters
  - large rc/rh [unfortunately not unique]
  - *QUENCHING OF MASS SEGREGATION*
- Direct N-body simulations show a clear separation in the amount of mass segregation depending on IMBH presence
- Application to NGC 2298 validates the method
  - no evidence for BH found, limit $M_{bh} < 300$ Msun at 3σ
- Analysis of large sample of galactic globular clusters coming soon