IMBH Fingerprints in Globular Clusters

(from stellar dynamics)

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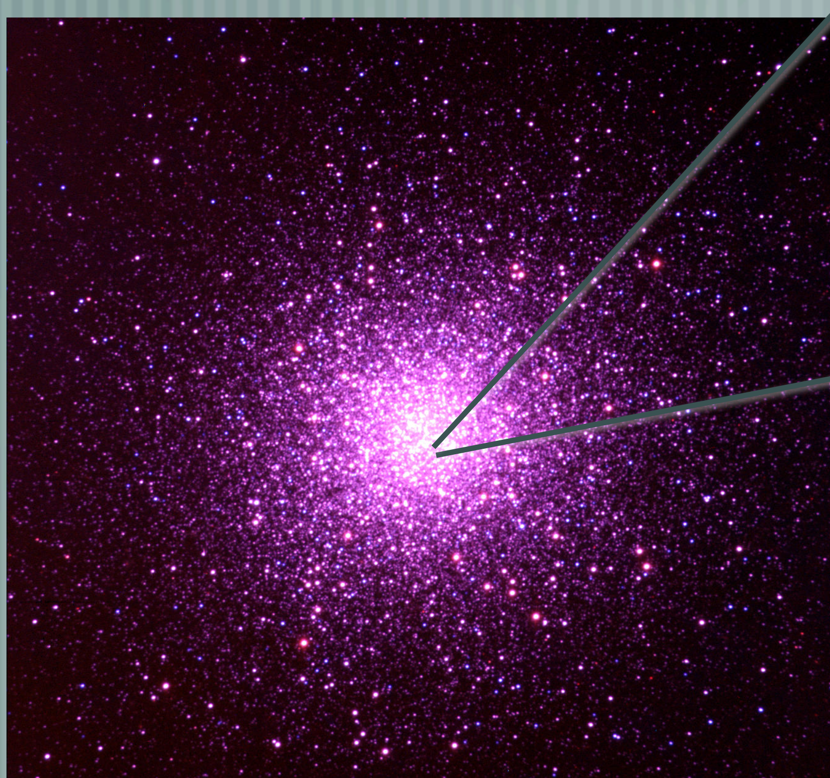
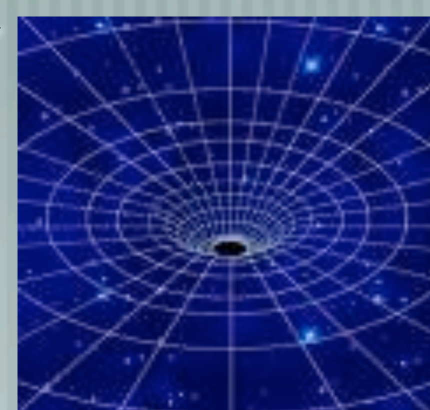




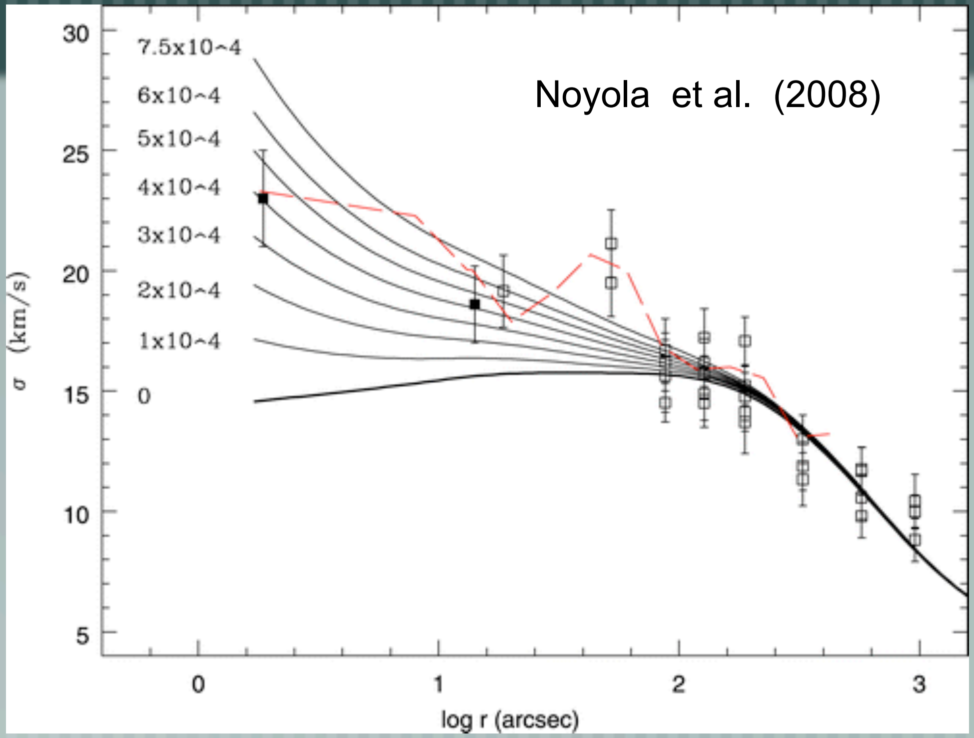
In collaboration with: Mario Pasquato, Giacomo Beccari, Enrico Vesperini, Roeland van der Marel, Mike Gill, Guido De Marchi, Massimo Stiavelli, Cole Miller, Douglas Hamilton, Douglas Heggie, Piet Hut, Shin Mineshige, Eliani Ardi

Intermediate Mass Black Holes

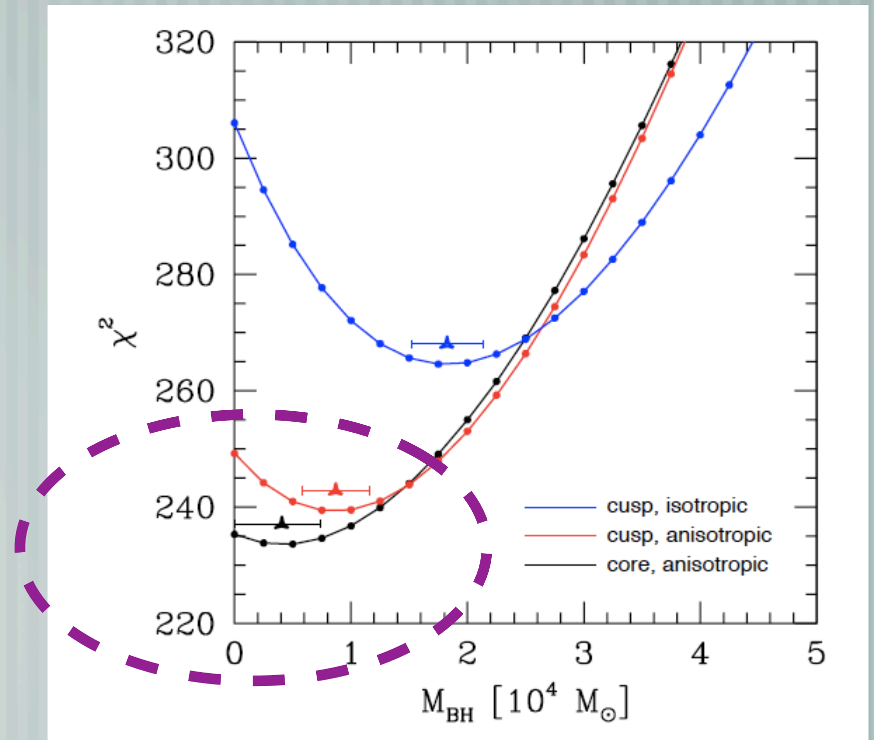
- Black holes of 10^2-10^5 Msun, missing link between stellar and supermassive BHs
- Have been predicted in different astrophysical scenarios:
  - Runaway collapse in young star clusters (Portegies-Zwart et al. 2004)
  - Remnants of Population III stars (Heger et al. 2003)
- Globular clusters may be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

Are there 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)
  - The claim disappears with proper motions kinematic from HST
    - New data set upper limit at 18000 Msun at 3σ confidence (van der Marel & Anderson 2010)



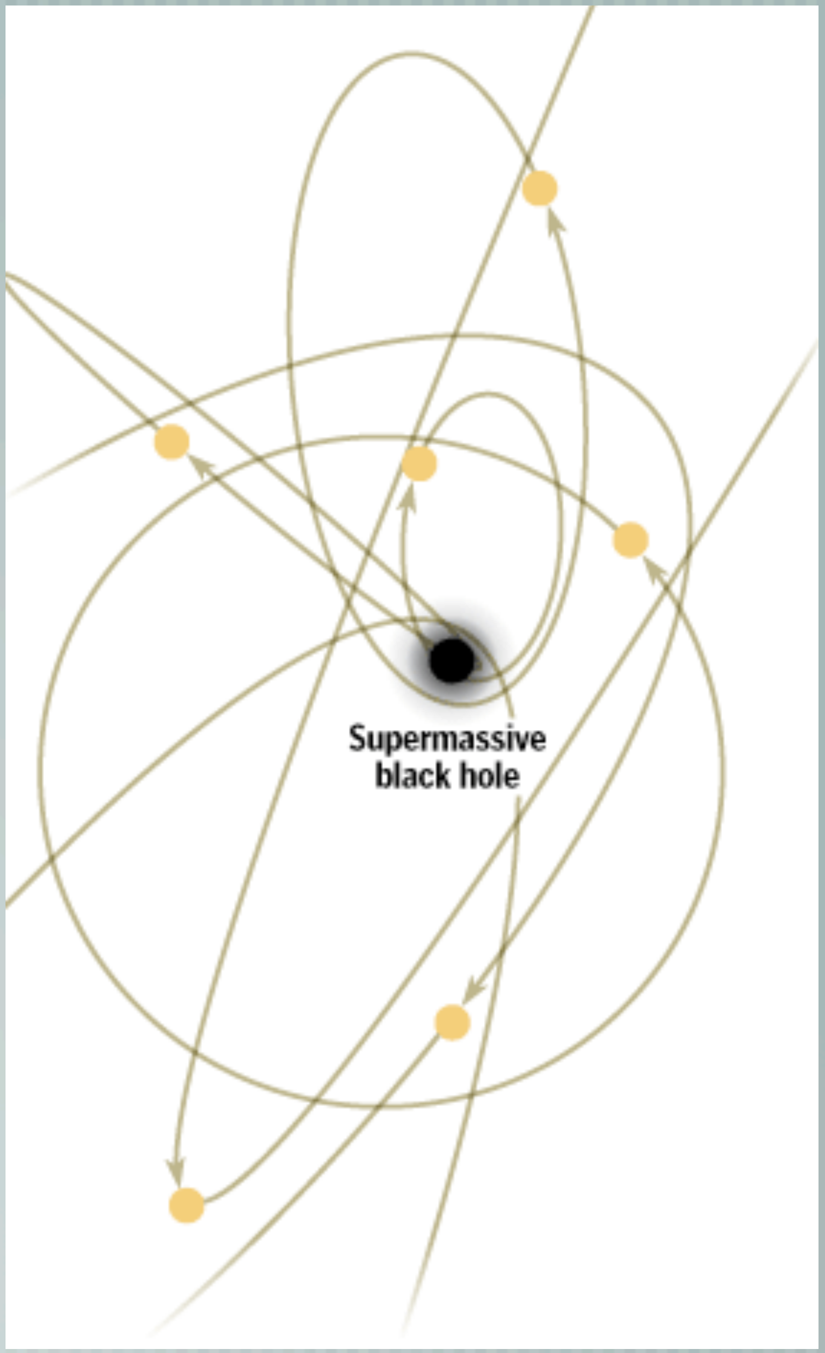
Omega Cen



van der Marel & Anderson (2010)

Searching for IMBHs in GCs

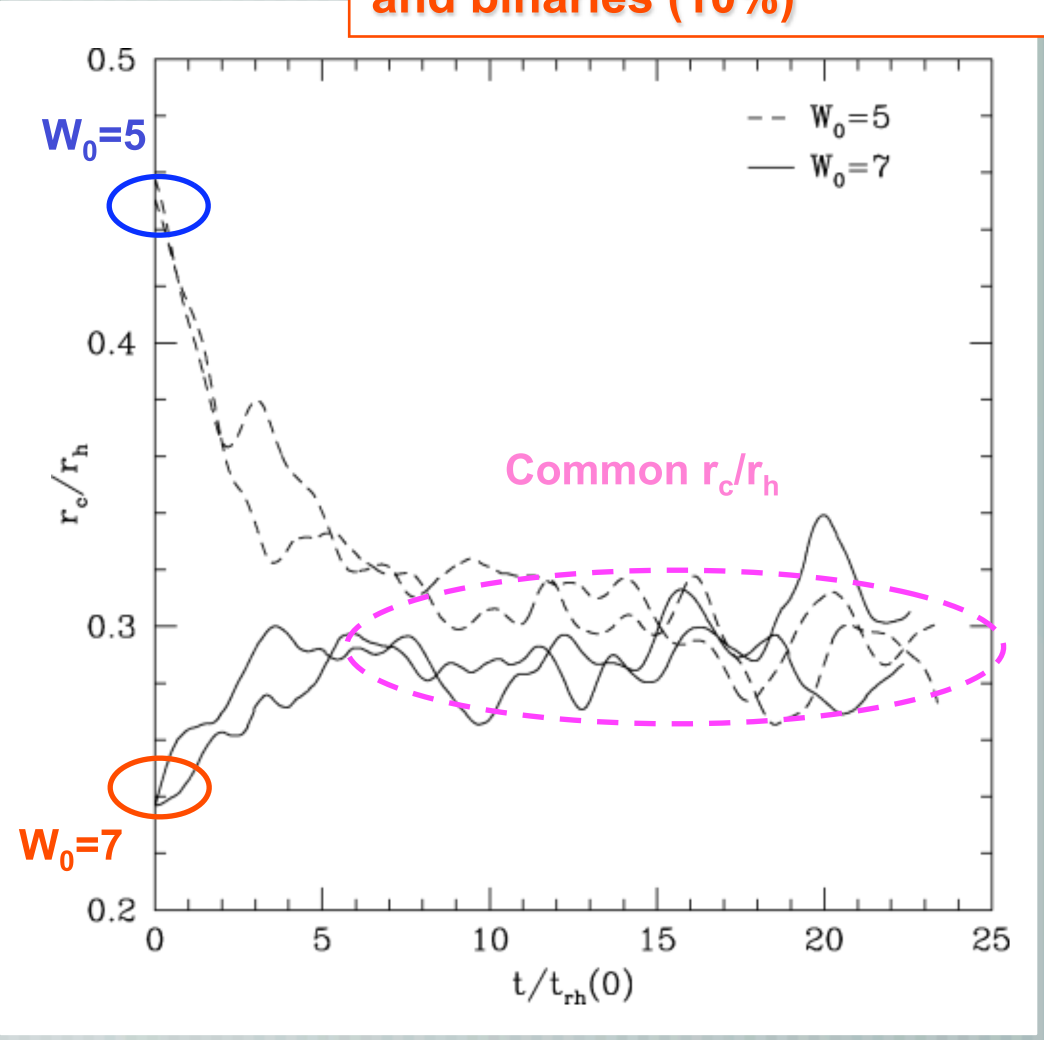
- Proper motion studies can provide the best evidence for IMBH based on dynamics but these are expensive
  - multiyear HST observations needed for GCs
- Are we focusing on the right GCs candidates?
  - Can we identify fingerprints for the IMBH presence?



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)

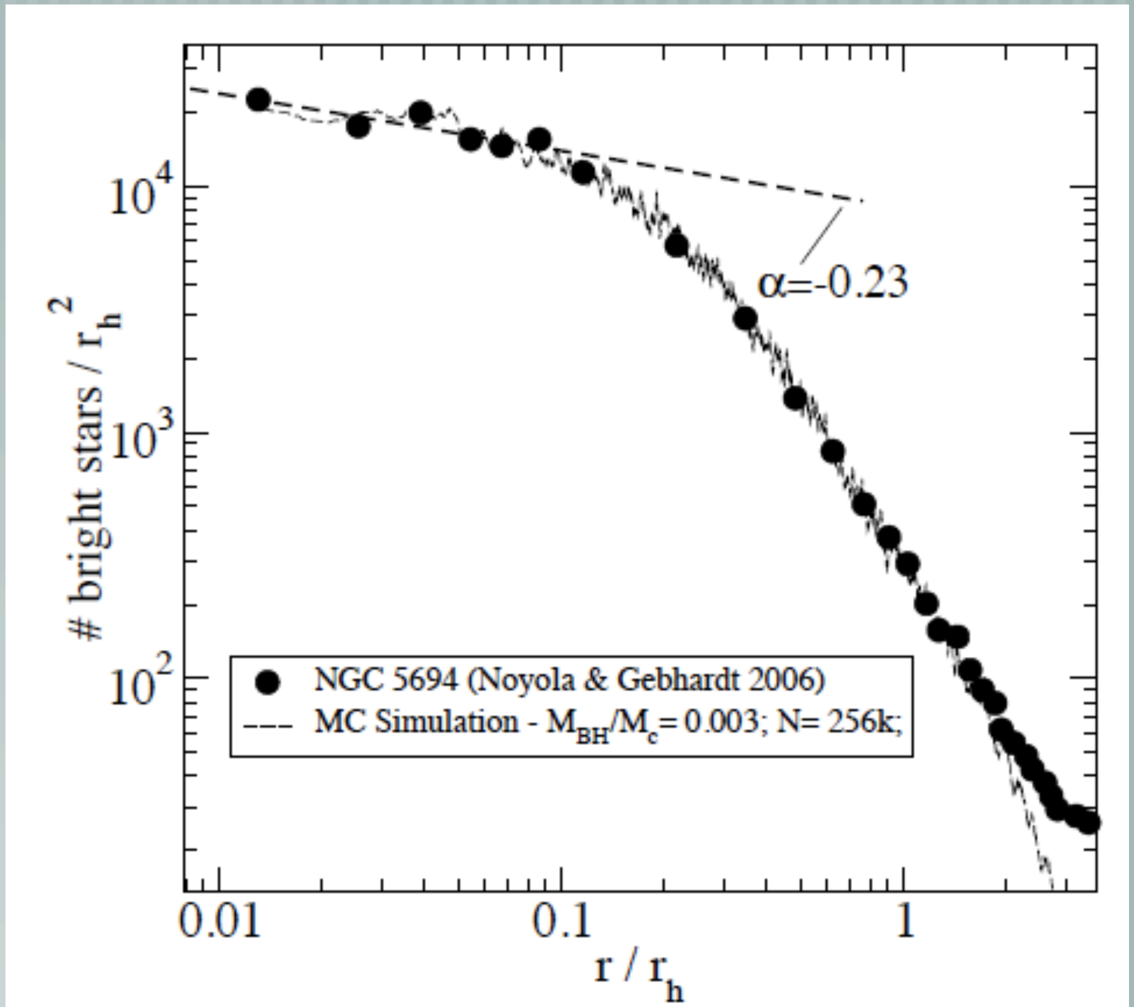
r_c/r_h with IMBH (m_{BH}/m_{tot}=0.014) and binaries (10%)



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?

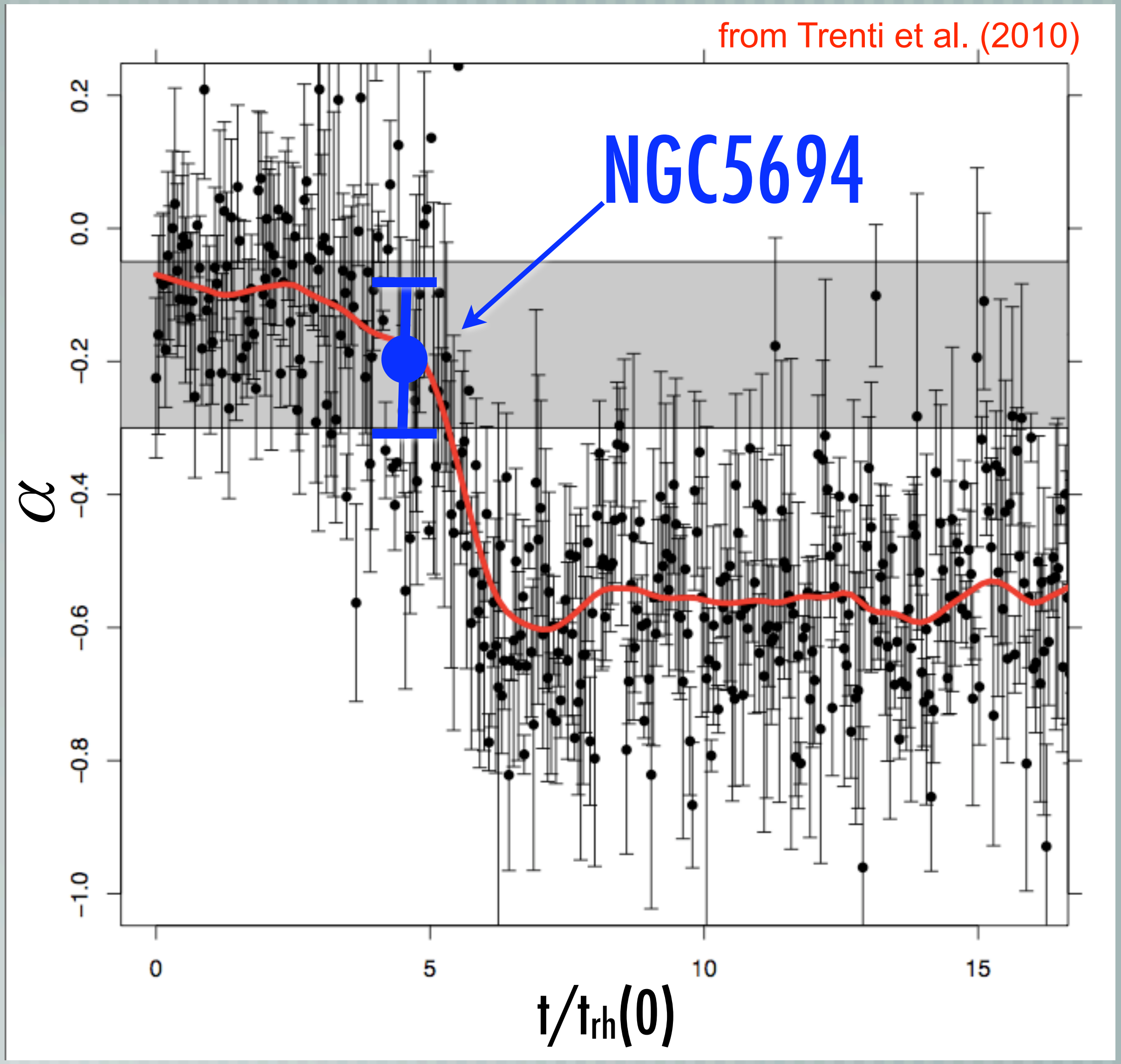


Umbreit et al. (2010)

IMBH fingerprint: shallow cusps

- But shallow cusps do not necessarily imply an IMBH:
  - always present before and around core collapse (Trenti et al. 2010, Vesperini & Trenti 2010)
  - NGC5694 likely undergoing core collapse: α~ -0.2 naturally expected
  - (large) observational errors and intrinsic scatter present

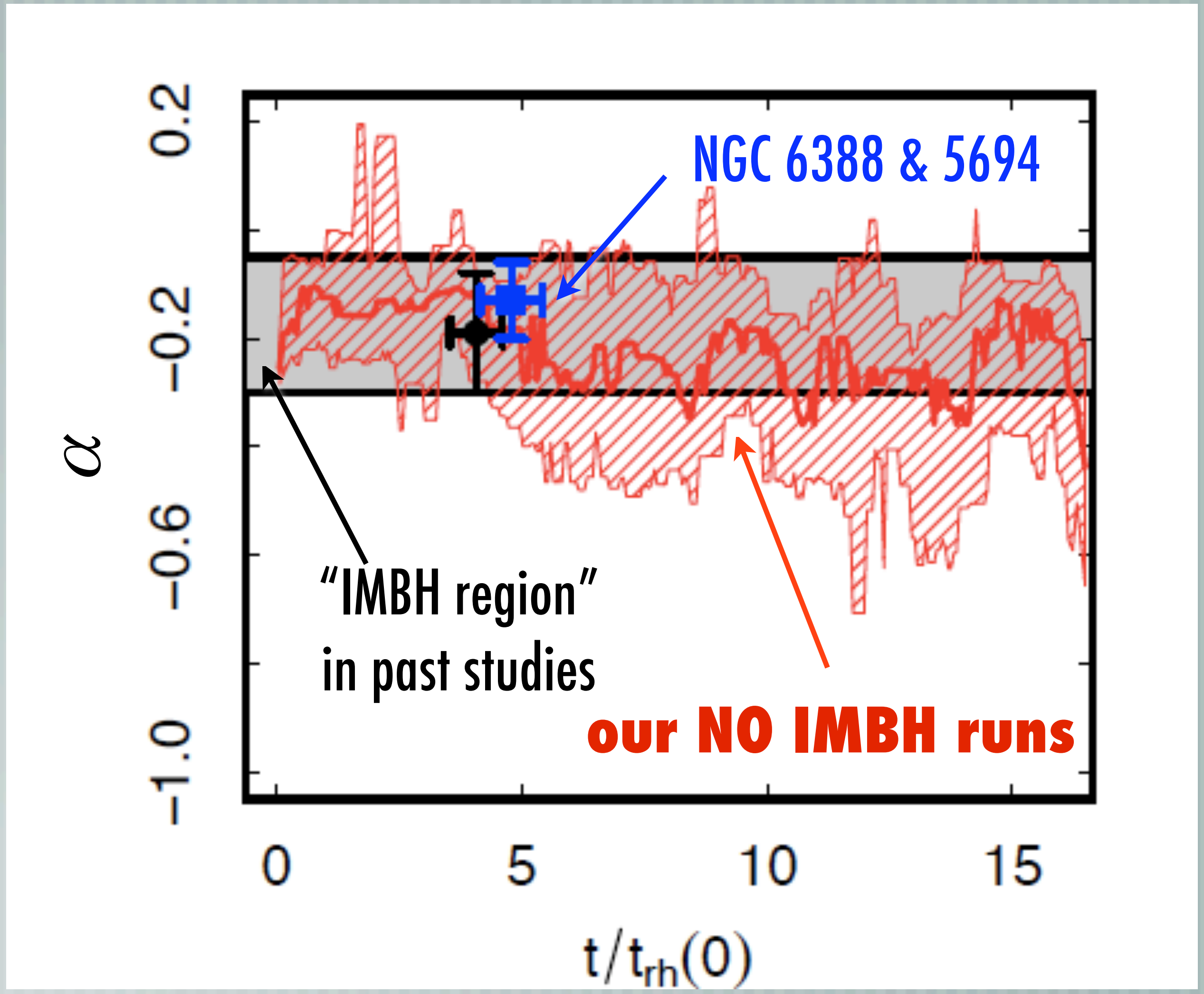
Direct N-body run, N=64k, no IMBH



IMBH fingerprint: shallow cusps II

Direct N-body run
no IMBH, 5% binaries

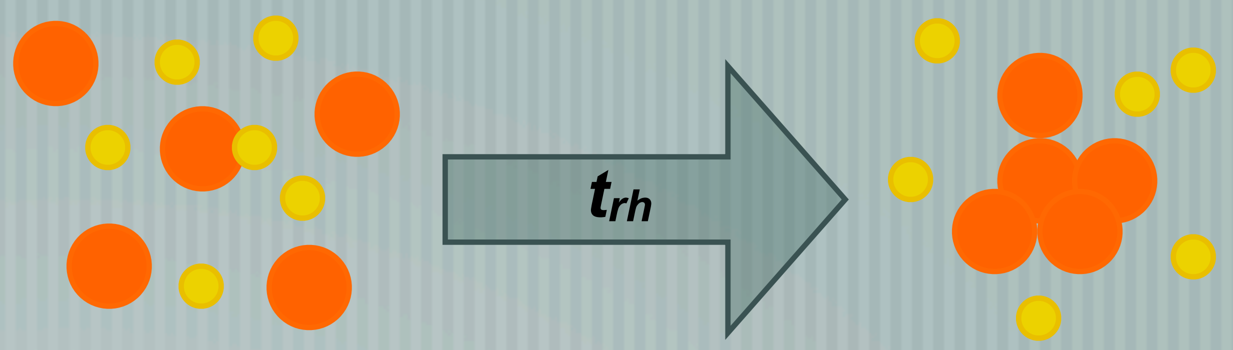
- In addition:
  - Shallow cusps always present if a few percent binaries are present
    (Vesperini & Trenti 2010)
- **Shallow cusps are NOT reliable tracers of IMBH presence**



Vesperini & Trenti, submitted

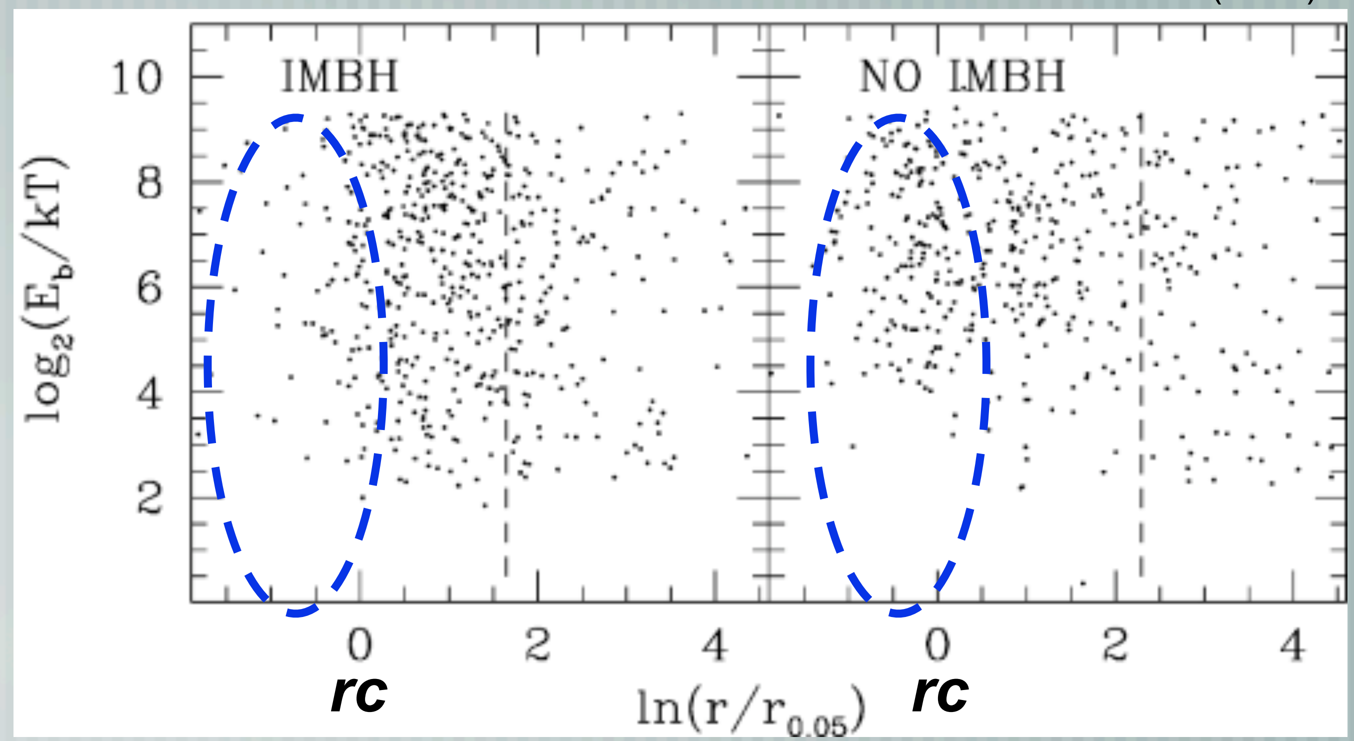
IMBH fingerprint: mass segregation

- 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 @ $t=10t_{rh}$

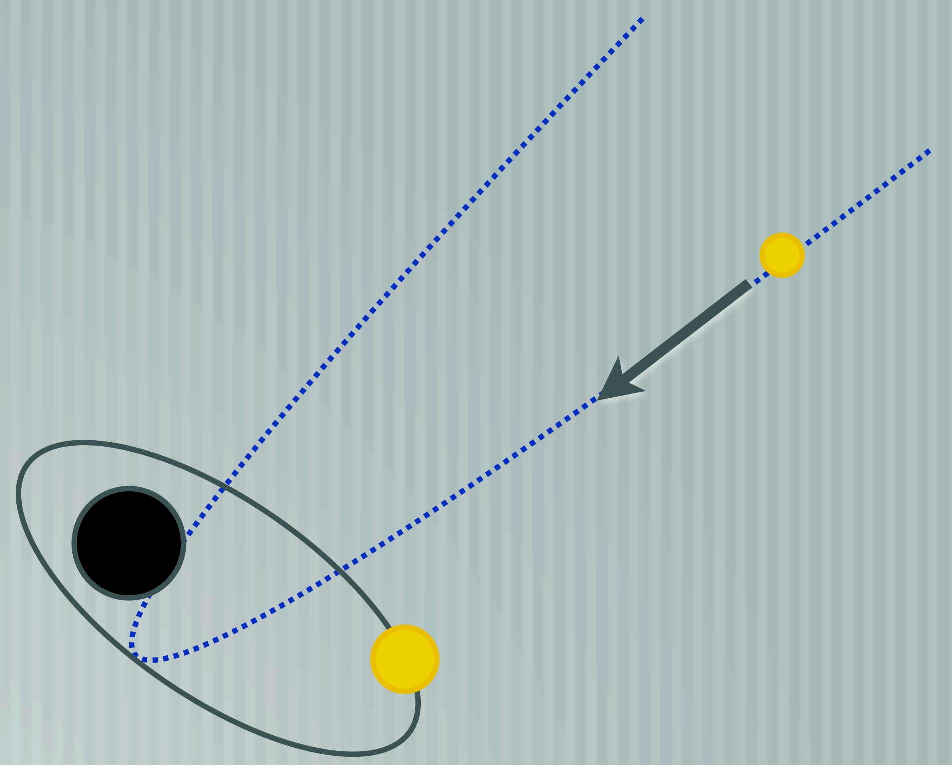
Trenti et al. (2007)



Quenching of mass segregation

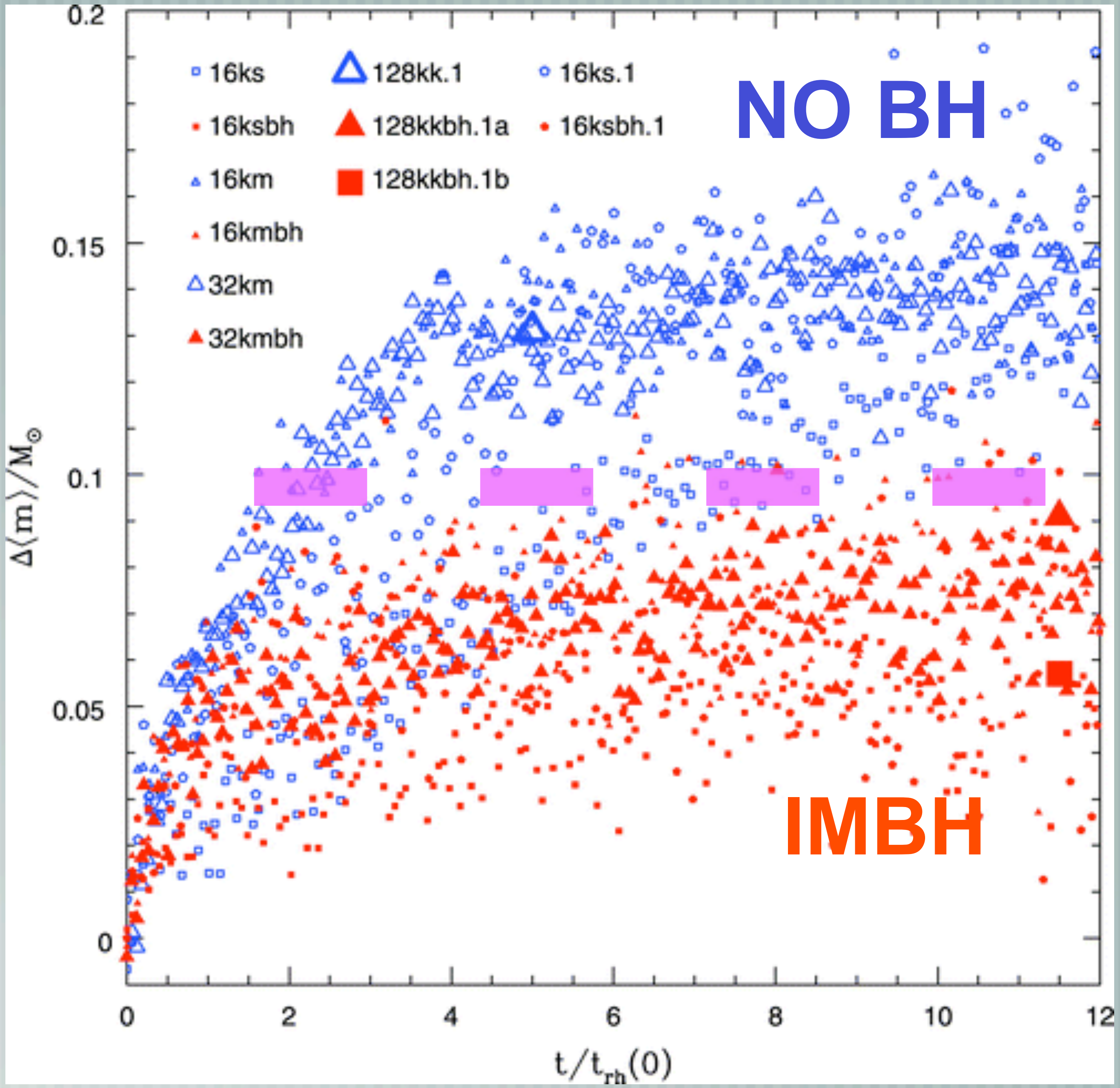
A Cartoon Picture

- 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



Mass Segregation Results: Simulations

- Direct N-body simulations with Aarseth's NBODY6
- Runs 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

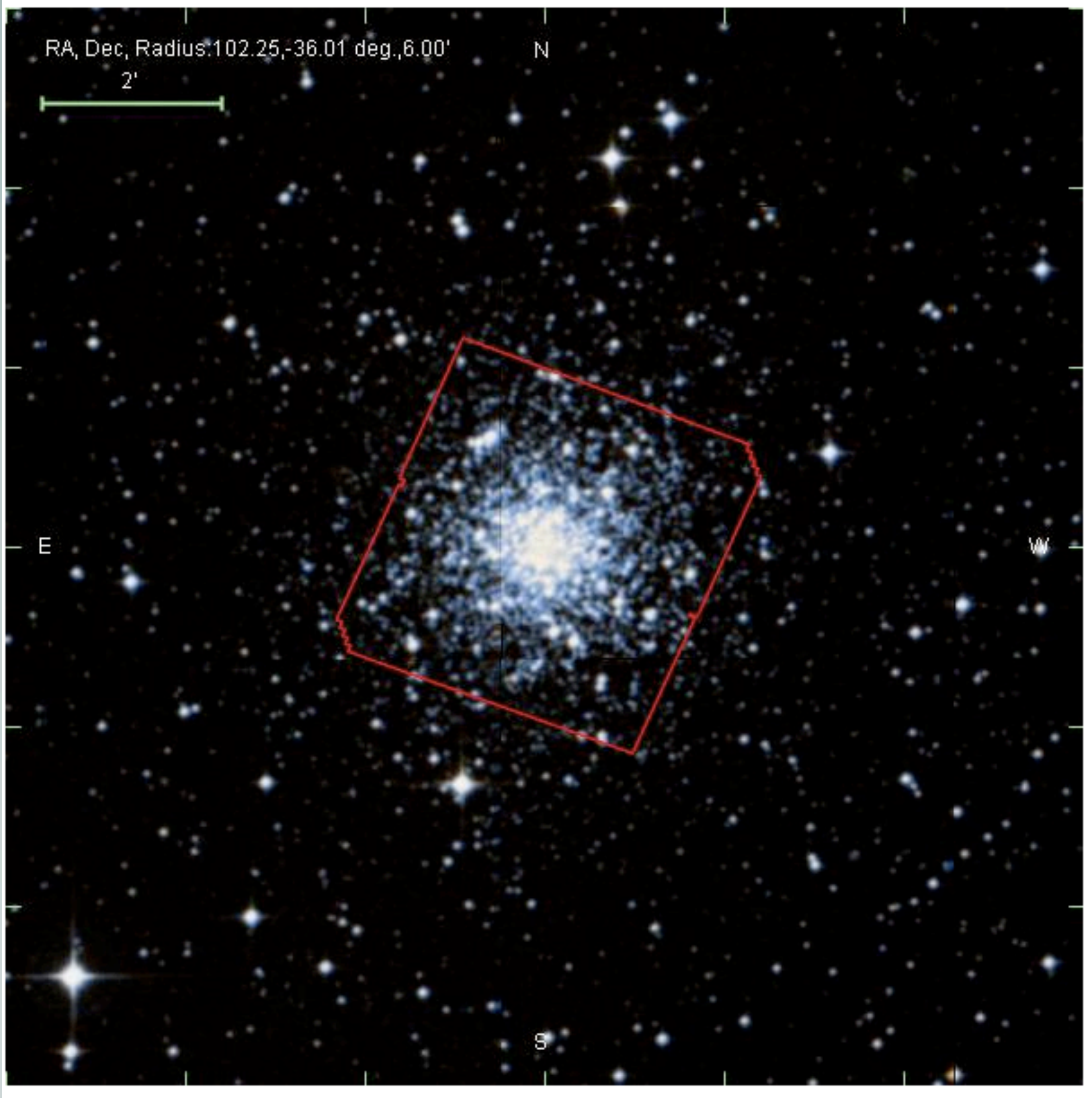


Gill, Trenti et al. (2008)

Mass Segregation: A first application

NGC 2298

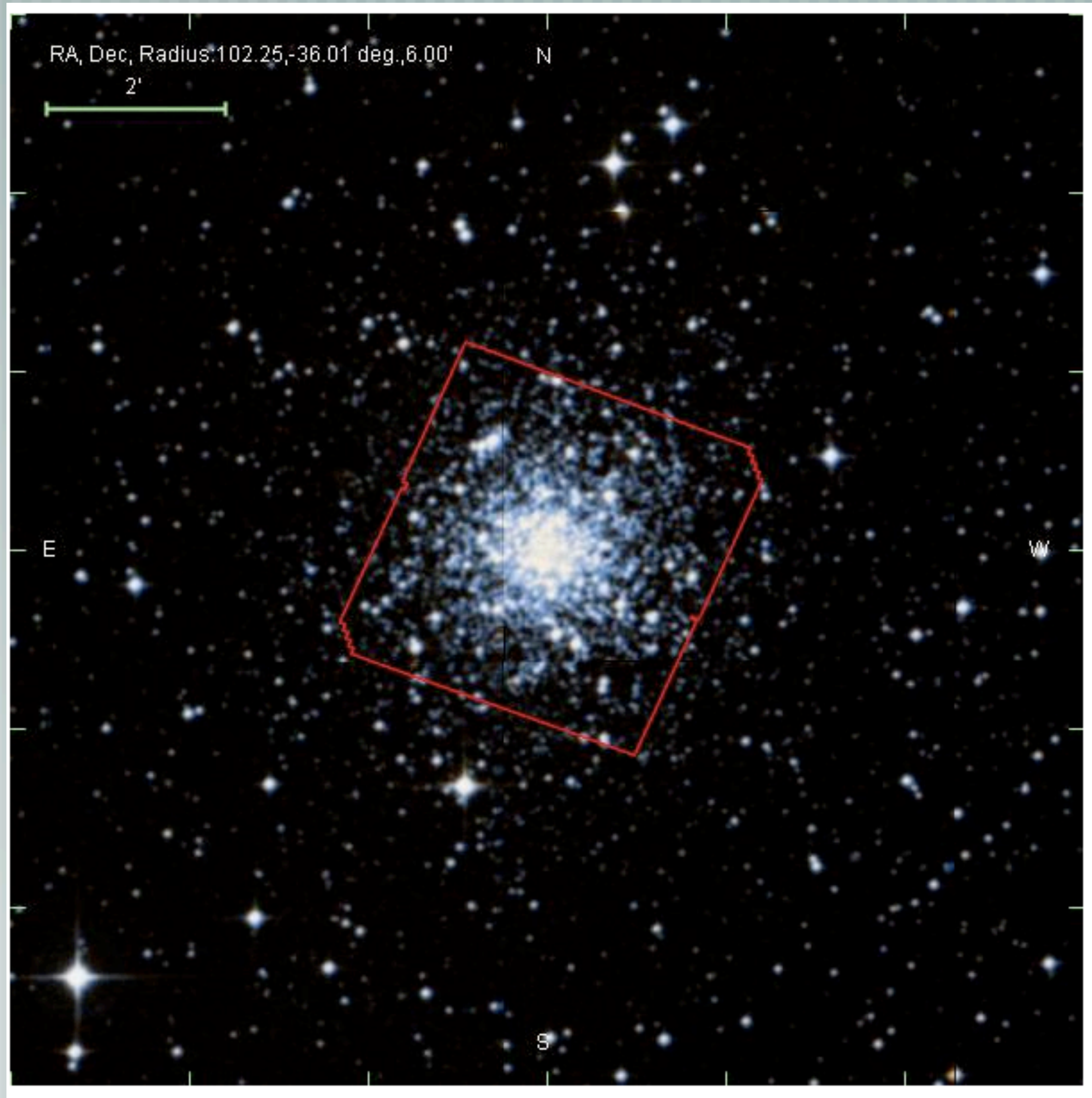
- Method restricted to well relaxed clusters (t_{rh}<1Gyr)
- Detailed star counts of main sequence stars are needed, with coverage to at least half-mass radius
- Data and simulations need to be treated self-consistently
    - e.g. completeness, FOV, measure of structural parameters



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

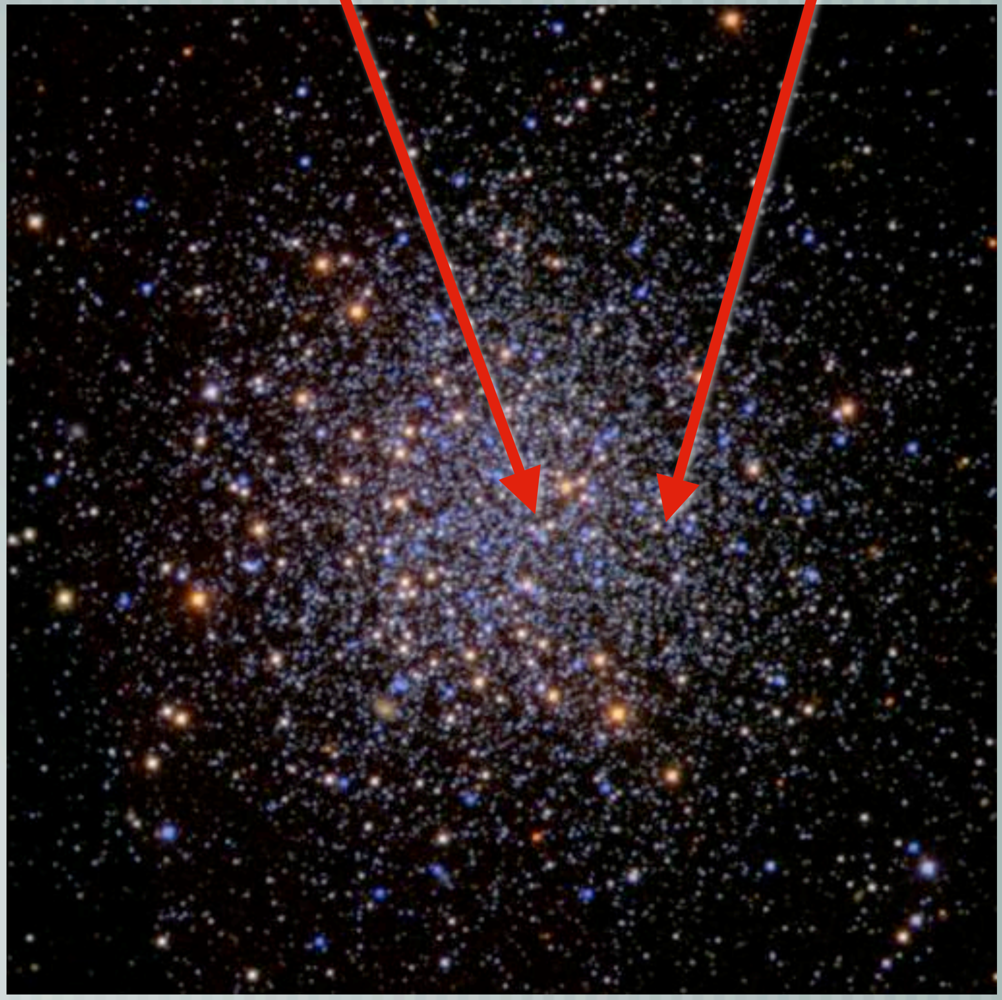
NGC 2298



Measuring Mass Segregation

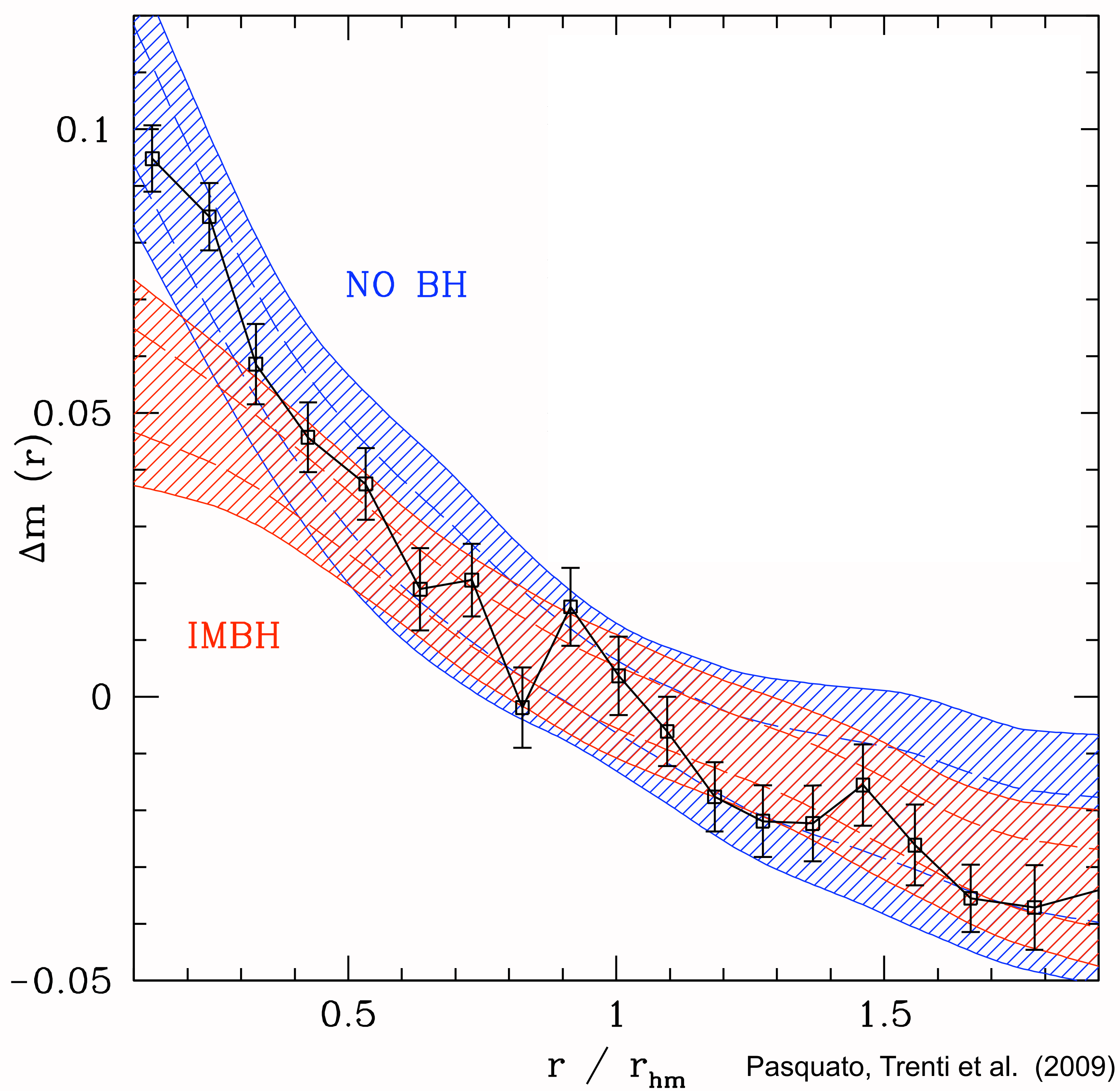
$$\Delta\langle m\rangle = \langle m(r = 0)\rangle - \langle m(r = rh)\rangle$$

- 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



NGC2298: comparison with simulations

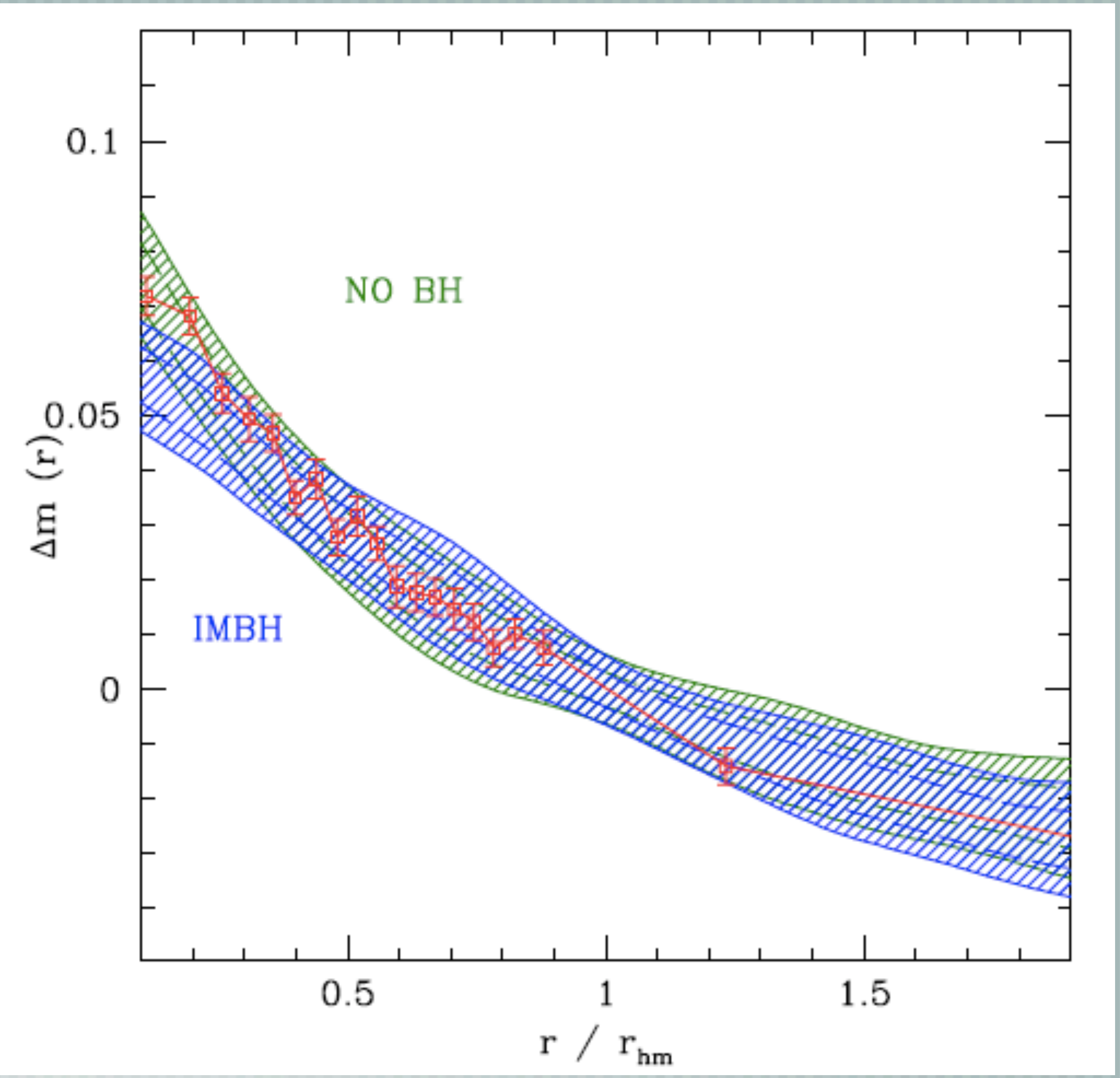
- Expected mass segregation profile constructed from N-body snapshots
- Excellent data-model match for runs without an IMBH!
- NGC2298 unlikely to host an IMBH: excessive mass segregation
(300 Msun excluded at 3σ CL)



Pasquato, Trenti et al. (2009)

Mass segregation: M10 (NGC 6254)

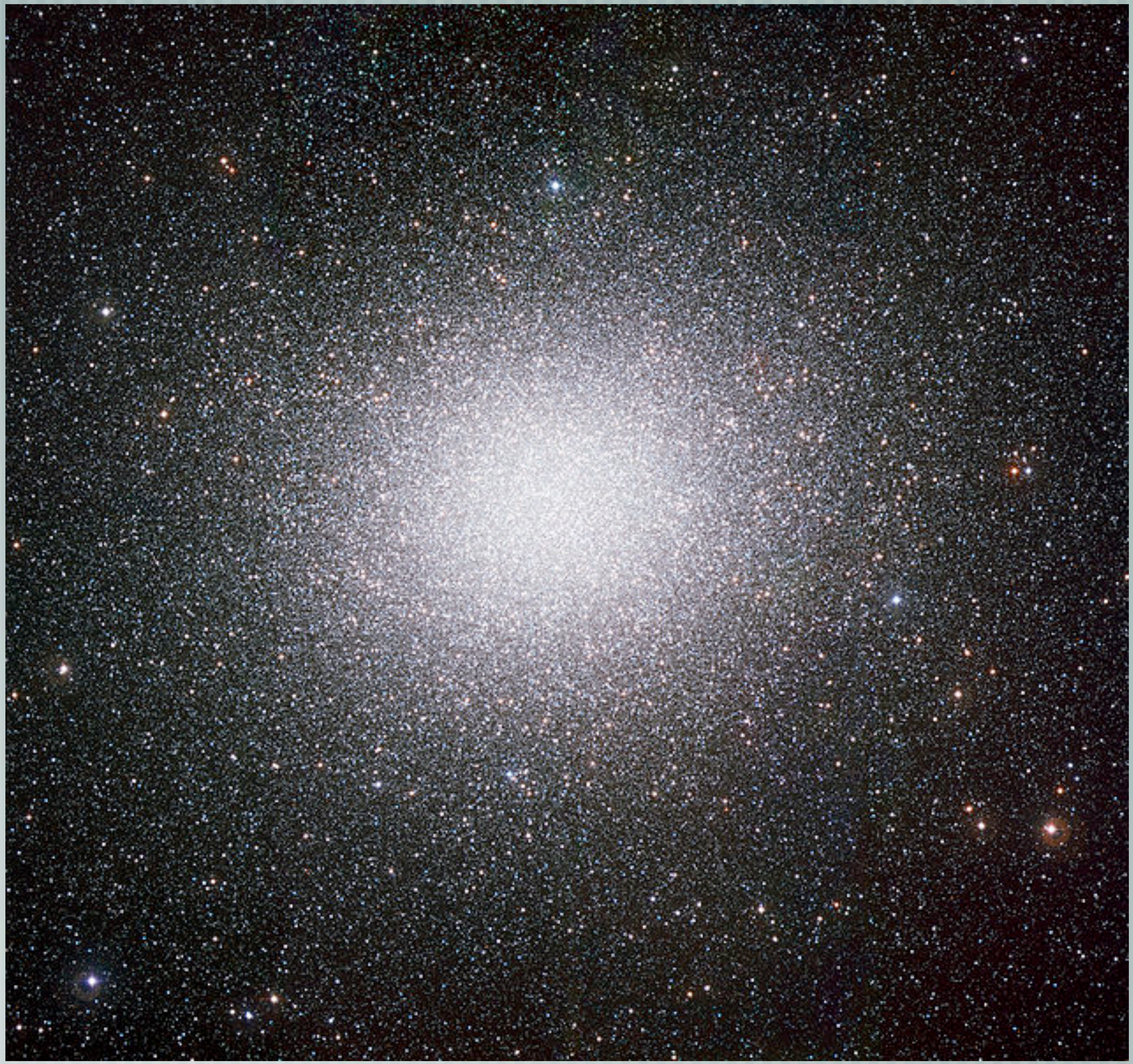
- Similar analysis also carried out for M10
- IMBH excluded at ~1.5σ confidence level
- More details from Giacomo later in the session



Beccari et al. (2010)

What about Omega Centauri?

- We need further, independent evidence for/against the IMBH presence

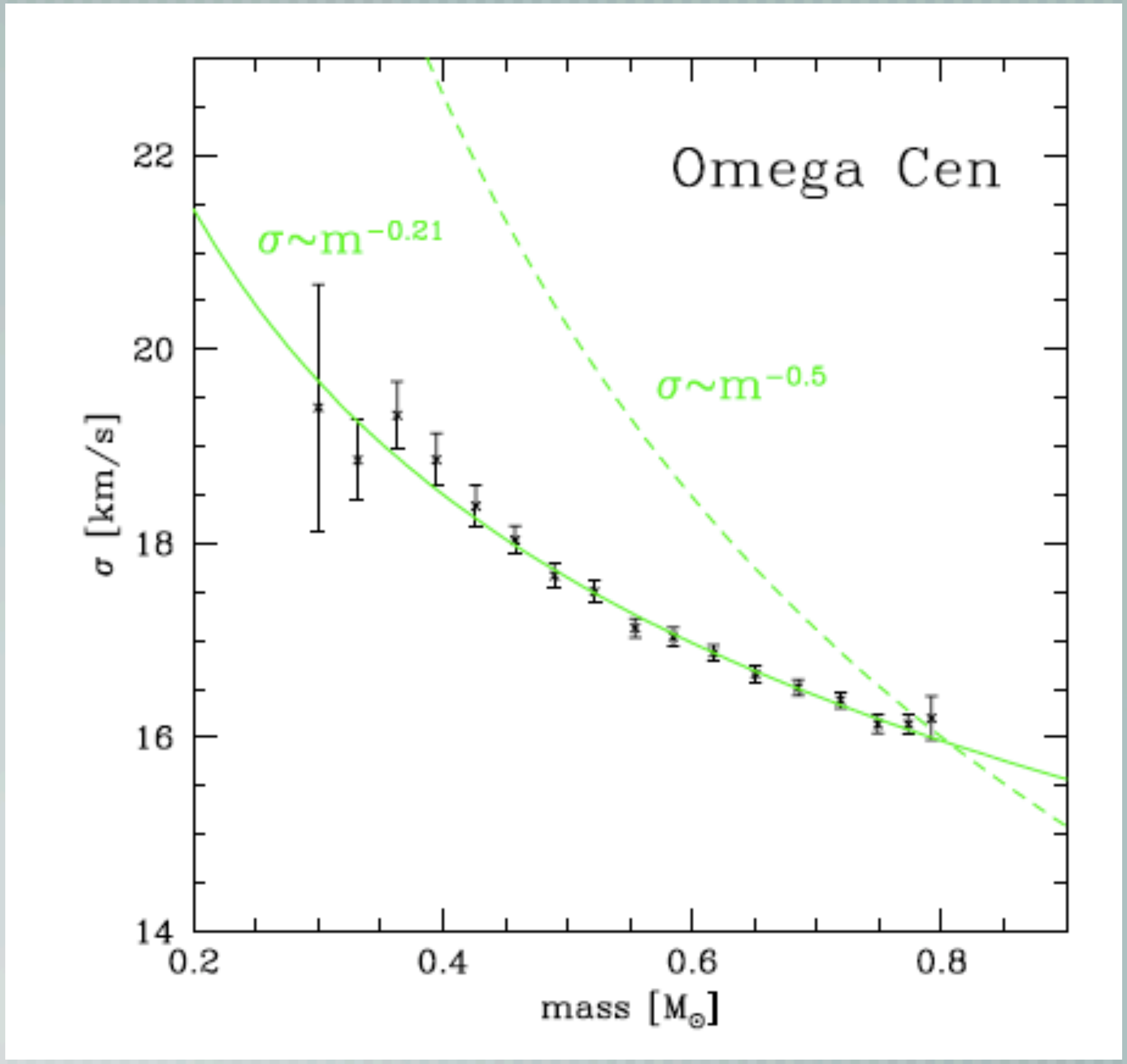


Credit ESO

Mass segregation analysis for Omega Cen

- Spatial mass segregation analysis cannot be applied because cluster is too massive
- But... mass-dependent kinematic at the center is available from proper motions
- Velocity dispersion versus star mass shows system not in equipartition
  - (Spitzer Instability)

Central velocity dispersion vs. star mass

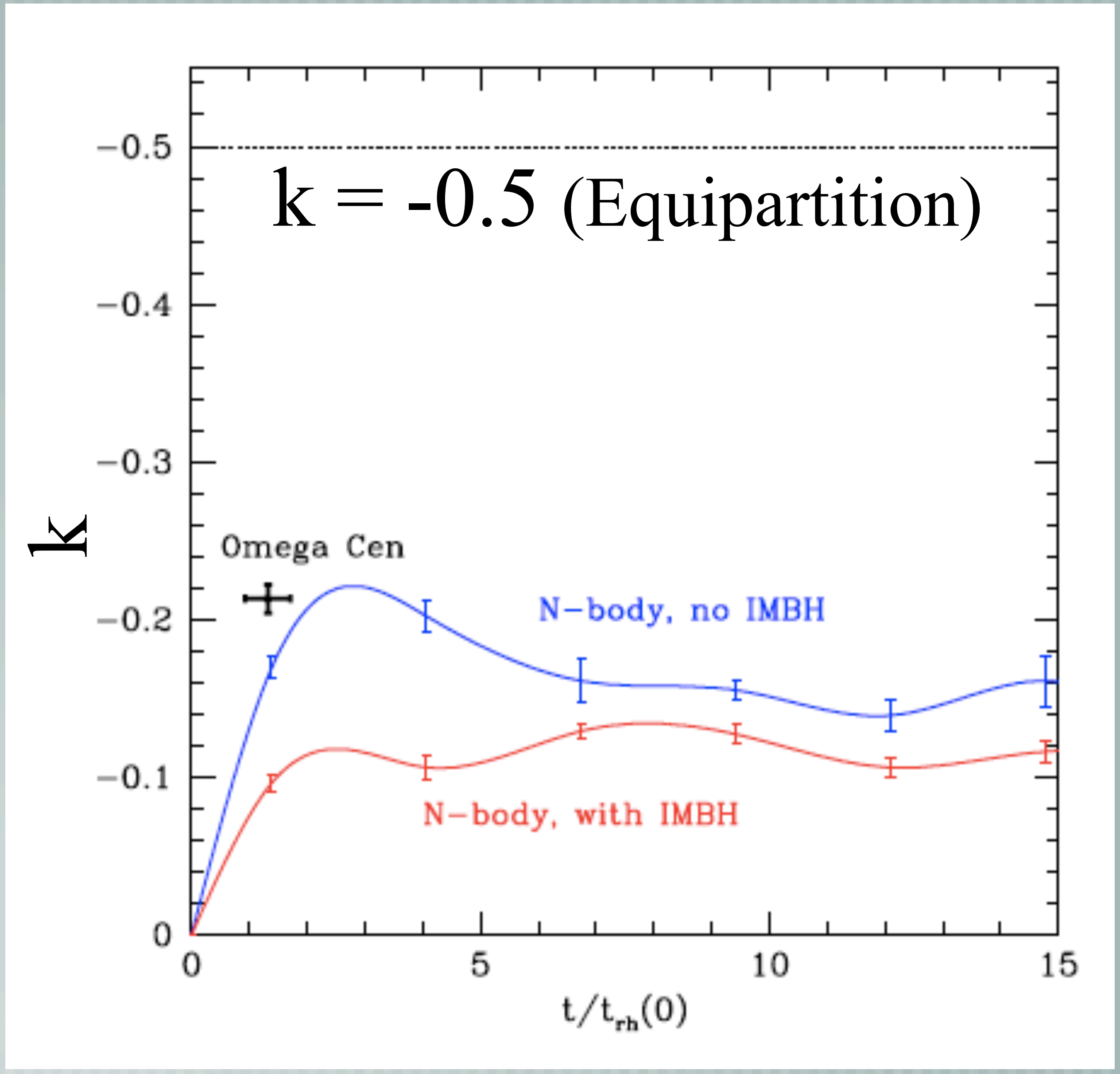


Trenti & van der Marel, in preparation

Mass segregation analysis for Omega Cen

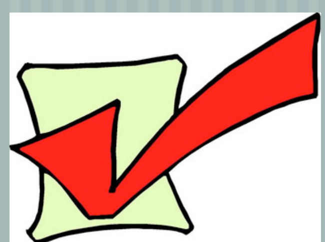
- Omega Cen is closer to energy equipartition than expectations from N-body simulations with a central IMBH
  - Simulations without IMBH provide better match
- Omega Cen appears indeed to lack a central IMBH

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

— Spatial mass segregation:
good for relaxed (small) globular clusters
(+ exciting prospects when 2D kinematics is available)

The future

- Larger sample of simulations
  - NBODY-6 OpenMP/GPU code on NCSA Lincoln cluster
    - soon upgraded with Fermi
  - Improved statistics, wider sampling of initial conditions, larger N (128K & 256K)
- Suitable HST data are available for other 6-8 clusters