Looking for IMBHs in GCs: the mass-segregation method

53° congresso della Società Astronomica Italiana (SAIt)
Pisa 2009

Mario Pasquato

Mon May 4, 2009

in collaboration with

Michele Trenti, Guido de Marchi, Michael Gill,

Douglas P. Hamilton, Coleman M. Miller, Massimo Stiavelli, Roeland P. van der Marel

Black Hole mass spectrum

Loosely speaking, Black Holes are a prediction of GR.
Do we really observe them astrophysically?

Black holes come in different sizes:

- Stellar Mass Black Holes (up to $\approx 20\ M_\odot$) e.g. 2007 Nature, 449, 799
- Super Massive Black Holes ($10^6 - 10^9\ M_\odot$) e.g. 2002 Nature, 419, 694

for the existence of which there is convincing evidence, and

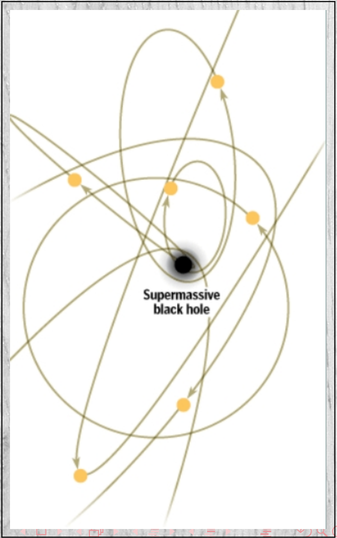
- Intermediate Mass Black Holes ($10^2 - 10^6\ M_\odot$)

for which a definitive detection is still missing.

Finding IMBHs? In globular clusters...

IMBHs (10^2-10^4 $M_\odot$) expected to lurk in GC cores but difficult to find:

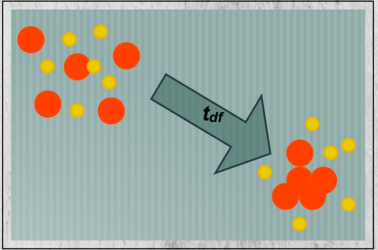
- Some claims based on dynamical modeling
  e.g. 2008 ApJ, 676, 1008
- Definitive detection requires proper motions of stars in GC center
- Multi-epoch effort needed, crowding issues
- The way to go: indirect tracers to narrow down candidate list



A promising indirect tracer

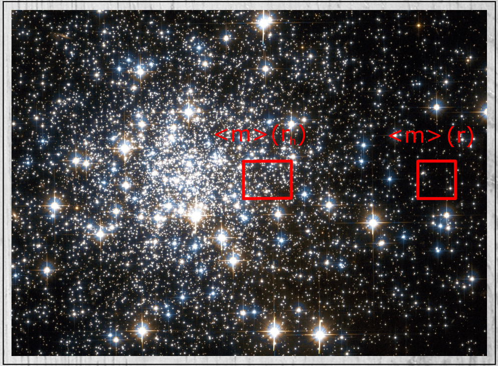
Mass segregation fingerprint:

- Massive stars segregate towards the center of a stellar system, lighter stars move outside and preferentially evaporate
- An IMBH quenches mass segregation (Baumgardt et al. 2004, Trenti et al. 2007, Gill et al. 2008)
- The effect can be measured in well relaxed GCs



Measuring mass segregation

- feasible with detailed star counts
- mass segregation → average mass $\langle m \rangle$ of MS stars higher in center wrt half-mass radius
- we measure $\langle m \rangle(r) - \langle m \rangle(r_h)$

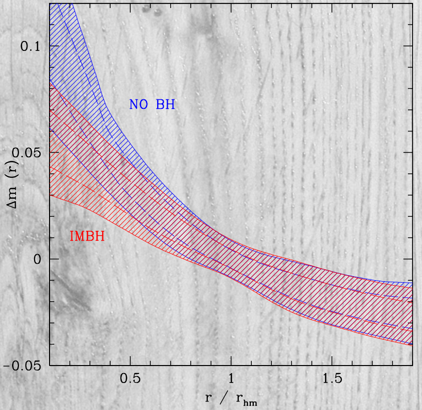


Pasquato, Trenti et al. 2009 ApJ, accepted (astro-ph/0904.3326v1)

Mass-segregation: simulations

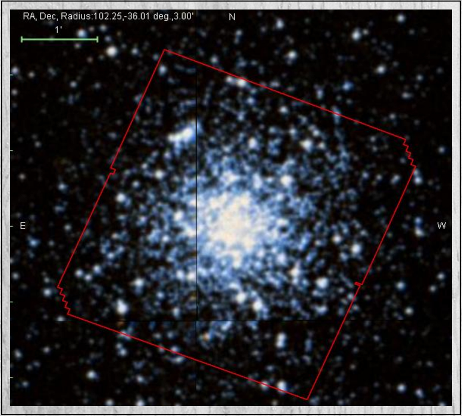
Pasquato et al. 2009 ApJ, accepted (astro-ph/0904.3326v1)

- Direct N-body, 16k to 32k particles, no softening, galactic tidal interaction
- IMBH with $M \approx 0.01 M_{GC}$ in half of the simulations
- Broad array of initial conditions:
  - Different IMFs (Miller & Scalo, Salpeter)
  - Different primordial binary fractions
- a differential measurement, robust against IMF change
- 2σ shaded areas at relaxation



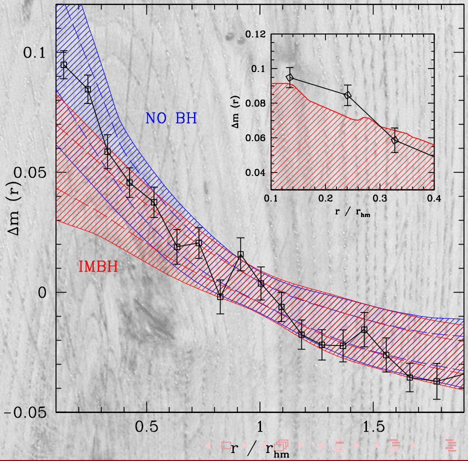
Mass-segregation: observations

- NGC 2298 chosen for deep ACS photometric data
- Small size, almost 1:1 star-to-simulated particle ratio
- HST/ACS field contains $\approx 2r_h$
- Data reduction (de Marchi & Pulone 2007) gives detailed star counts
- 0.2 $M_\odot$ stars still have 50% completeness in the core
- Low background contamination
- Is relaxed: $t_h < 1$ Gyr



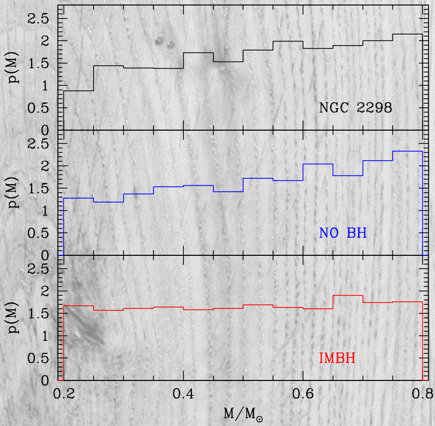
Comparing simulations to observations

- Only projected simulation data is used
- Finite FOV effects are imposed when ”observing” simulations
- NGC 2298 data overlap with NO IMBH confidence area
- 3σ upper limit on IMBH mass is 300 $M_{\odot}$

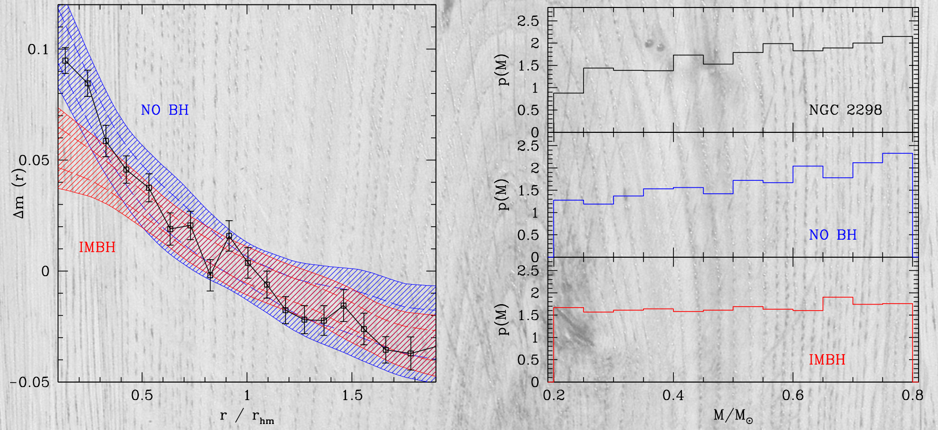


Predicting the mass segregation profile

- present day global MF of NGC 2298 has a distinctive shape due to tidal stripping
- our simulations without an IMBH and with Miller & Scalo IMF match it well when $\approx$ 70% of initial mass stripped
- they must accurately predict NGC 2298 mass segregation profile

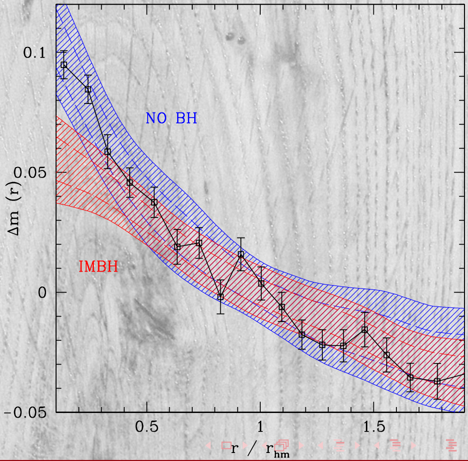


Predicting the mass segregation profile



Conclusions

- Quantitative match between observed mass-segregation profile of NGC 2298 and prediction from N-body simulations
- No IMBH in NGC 2298 (3σ upper limit at $300 M_{\odot}$)
- Method readily applicable to several GCs with HST archival data



Back-up slides

Back-up slides - NGC 2298

- RA: 6h 48m 59.2s, Dec: $-36^\circ\ 0'\ 19''$ Harris 2003
- Mass: $3.09 \cdot 10^4\ M_\odot$ McLaughlin & van der Marel 2005
- Half-light radius: $45.4''$ i.e. 2.35 pc McLaughlin & van der Marel 2005
- True distance modulus: 15.15 mag i.e. 12.6 kpc Harris 2003
- Reddening $E(B-V)$: 0.14 mag Harris 2003
- Half-light relaxation time: $2.57 \cdot 10^8$ yr McLaughlin & van der Marel 2005
- Concentration: 1.28 Harris 2003
- Ellipticity: 0.08 Harris 2003
- Metallicity $[Fe/H]$: -1.85 Harris 2003
- Distance from Galactic center: 15.7 kpc Harris 2003

Back-up slides - Our observations

Our data comes from De Marchi & Pulone (2007):

- ACS bands F606W and F814W used
- Size of field covered: $3.4' \cdot 3.4'$
- Completeness calculated in concentric annuli
- 50% completeness for 0.2 $M_\odot$ stars in the GC center
- Half-mass radius consistently computed from star counts
- Mass-luminosity relation used for MS stars from Baraffe et al. (1997) with $[Fe/H] = -1.85$
- $\approx 10^4$ MS stars in our sample

Back-up slides - Our simulations

Simulations from Gill et al. (2008) + an additional four runs:

- Direct N-Body code: NBODY6 Aarseth 2003, Trenti et al. 2007a
- 16k to 32k stars, simulated to 20 initial relaxation times (tidal dissolution)
- Simulations take days to months to run
- Instantaneous stellar evolution to 12 Gyr using Hurley et al. (2000) tracks
- Stellar mass black holes up to 10 $M_\odot$
- Primordial binary fraction either 0 or 10%, flat distribution in binding energy Heggie et al. 2006
- Miller & Scalo or Salpeter IMF used
- Control runs with invisible *brown dwarfs* (actually 0.1 to 0.2 $M_\odot$ stars)
- Initial conditions from a moderately concentrated $W_0 = 7.0$ King model, control runs with different concentrations

Back-up slides - Formation scenarios for IMBHs

Merging scenarios:

- Runaway merging of massive stars in dense young clusters Portegies Zwart et al. 2004
- Four-body interactions in dense GCs Miller & Hamilton 2002

Non-merging scenarios:

- Population III stars Madau & Rees 2001

The mechanism for forming IMBHs (if any such process ever takes place) is still debated.

Back-up slides - Half-mass relaxation time

The timescale over which two-body encounters between stars attain thermalization of the distribution function is named relaxation time.

In astrophysical units, the half-mass relaxation time is (Djorgovski 1993):

$$t_{rh} = \frac{8.9 \cdot 10^5 yr}{\log(0.4N)} \times \frac{1 M_\odot}{\langle m_* \rangle} \times \sqrt{\frac{M_{tot}}{1 M_\odot}} \times \frac{r_{hm}}{1 pc} \sqrt{\frac{r_{hm}}{1 pc}}$$

Back-up slides - Selected references

- Pasquato et al. 2009 ApJ, accepted (astro-ph/0904.3326v1)
- Gill et al. 2008 ApJ, 686, 303
- De Marchi & Pulone 2007 A&A, 467, 107