Modeling of individual globular clusters using direct N-body simulations

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Modeling of globular clusters

What we can observe:

Surface density profile
Velocity dispersion profile
……

What we want to know:

Total masses, Radii
IMBHs?
Formation/Evolution

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Modeling of globular clusters

Classical way to model GCs:

- Jeans equation
- Jeans theorem
- Schwarzschild orbital modeling

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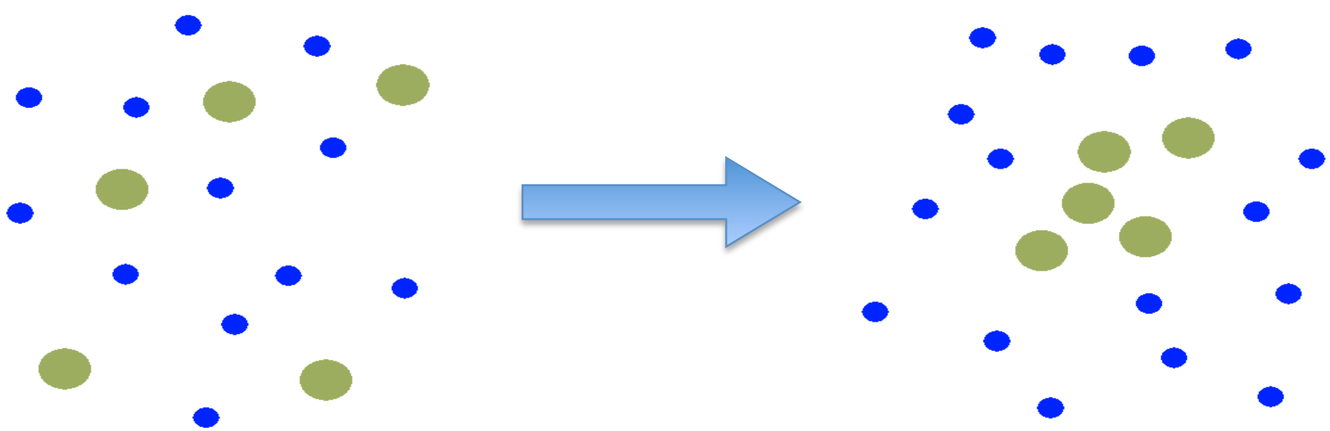
Classical way to model GCs:

- ❑ Jeans equation
- ❑ Jeans theorem
- ❑ Schwarzschild orbital modeling

Problem is mass segregation:



Modeling of globular clusters

Run a grid of N-body simulations and compare results with observed profiles to identify best-fitting model and infer cluster parameters and starting conditions.

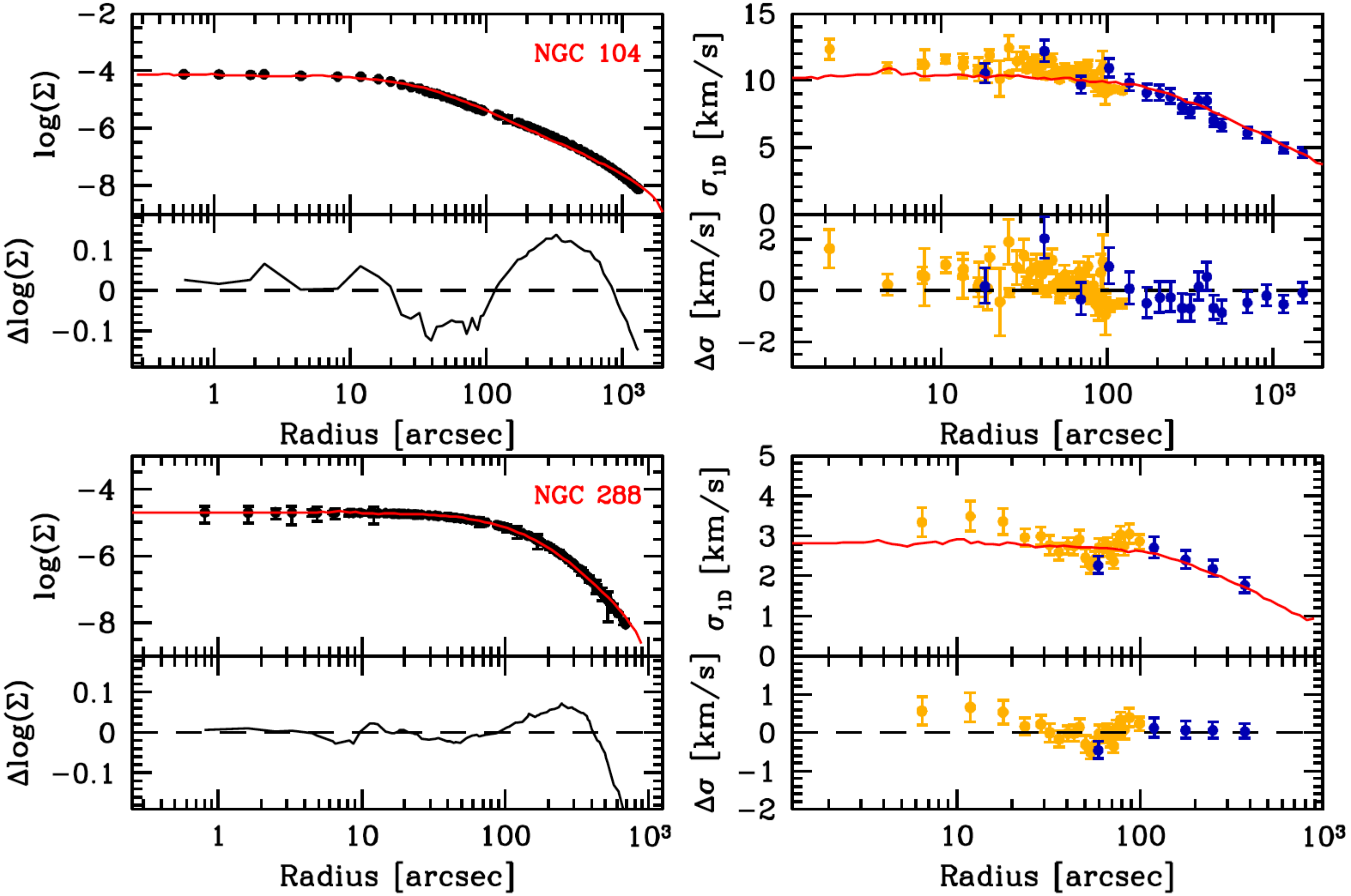
- ✓ Mass segregation fully taken into account
- ✓ Determine structural parameters, radii, densities
- ✓ Information on distribution of all stellar populations
- ✓ Understand how globular clusters formed and evolved

- ➢ Slow and need for scaling

Modeling ingredients

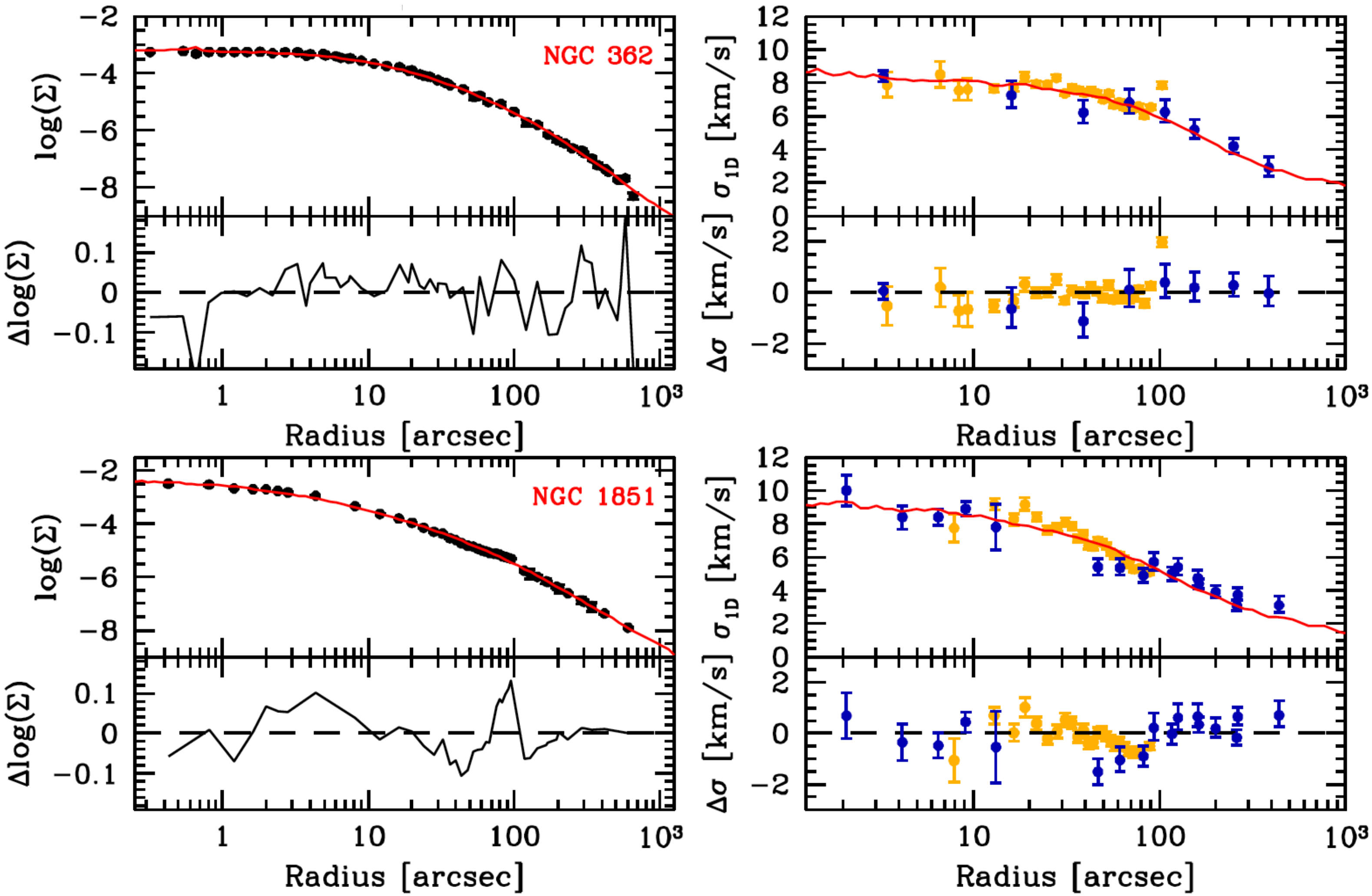
Surface brightness profiles:	Trager et al. (1995, ground-based) Noyola et al. (2007, HST) plus my own derivations for some clusters
Velocity dispersion profiles:	Radial velocities from literature plus Watkins et al. (2015, proper motions)
Stellar mass functions: (new project)	HST/ACS data from Sarajedini et al. (2007)
N-body simulations:	Grid of 900 N-body simulations of $N=10^5$ or $N = 2 \cdot 10^5$ star clusters of varying initial size, density profile, IMF, and IMBH fraction

Example fits of observed GC profiles



from Baumgardt (2017)

Example fits of observed GC profiles



58 clusters fitted so far !

from Baumgardt (2017)

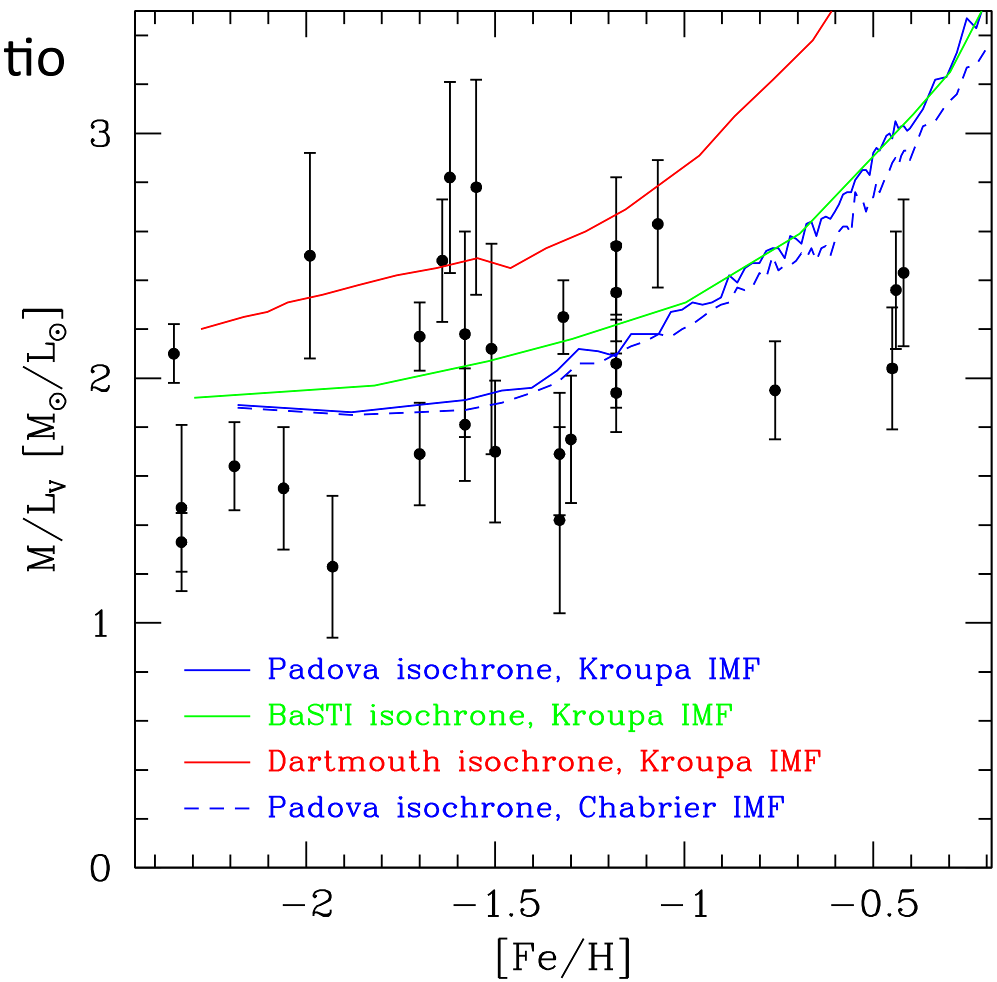
Results

Globular cluster mass-to-light ratios

Globular cluster mass-to-light ratios

Average globular cluster M/L ratio is $M/L_V \approx 2.0$ independent of metallicity.

High metallicity clusters show some evidence for M/L ratios below what one would expect for a Kroupa or Chabrier IMF.

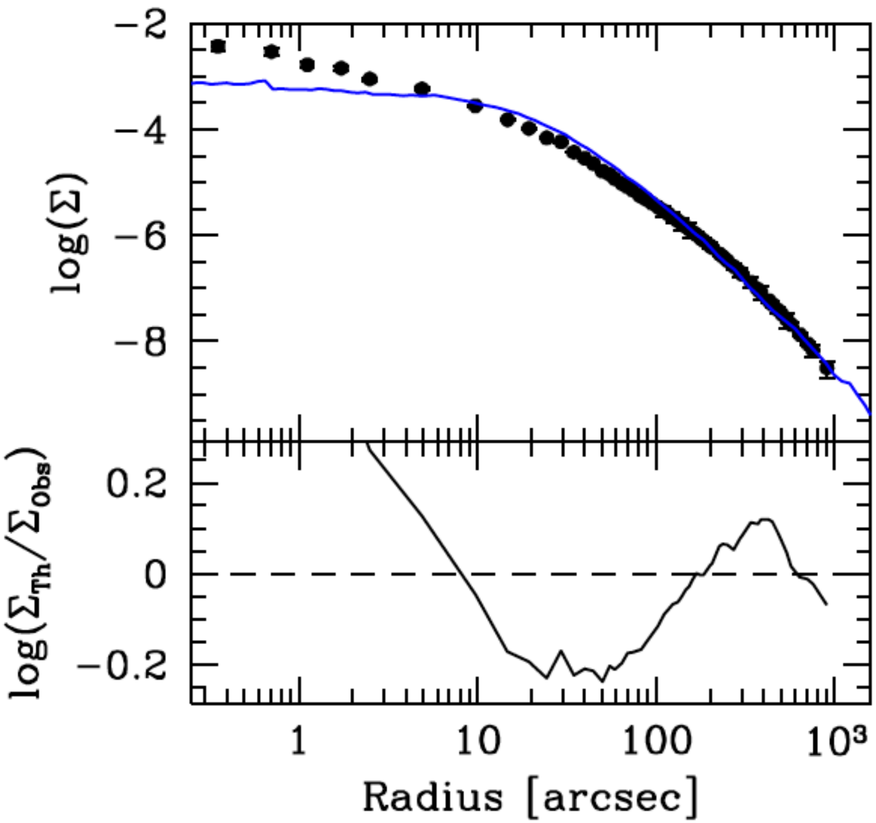


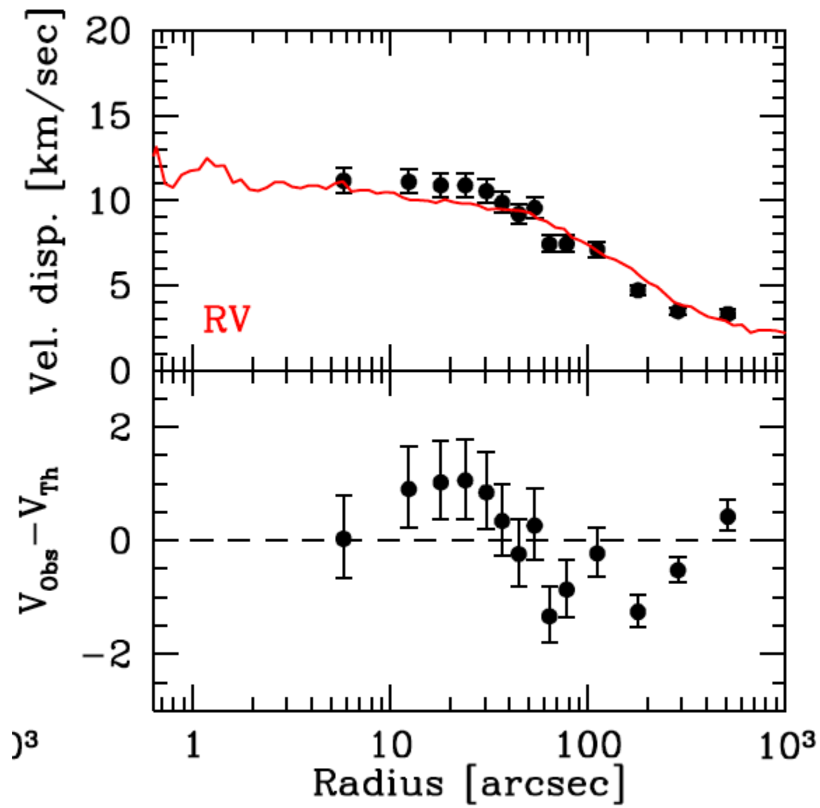
from Baumgardt (2017)

Results

Intermediate-mass black holes

In about 20% of all clusters the presence of an IMBH can be immediately excluded, e.g. M15:

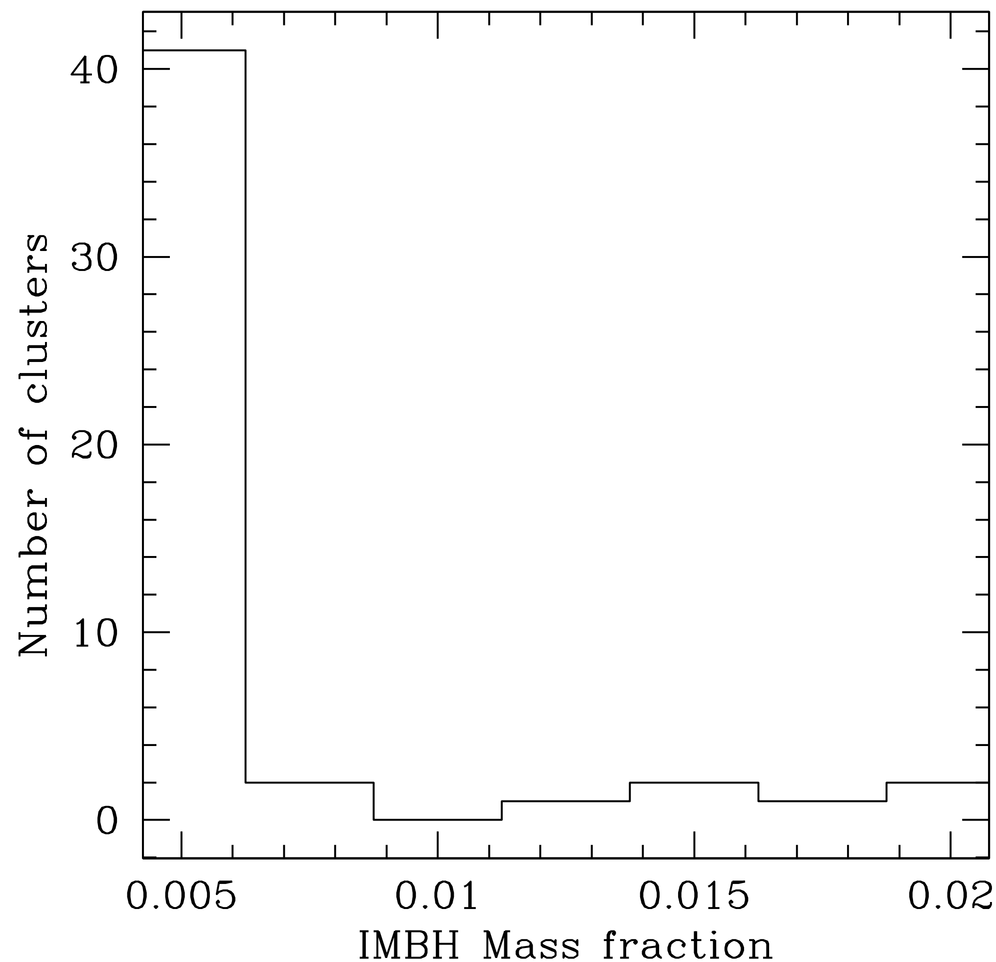




Reason: Clusters with IMBHs have weak cusps in their centers $\Sigma(r) \sim r^{-0.25}$ (Baumgardt et al. 2005) while observed profile is totally different.

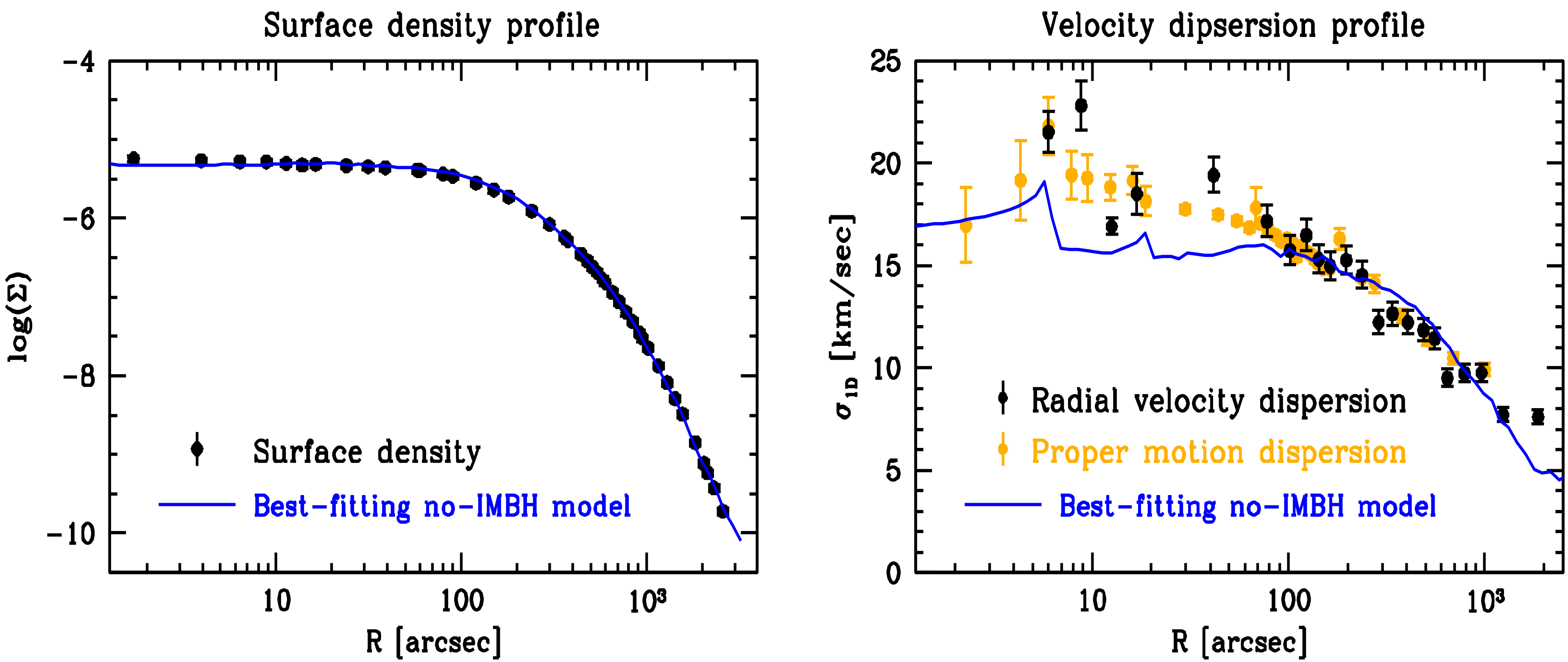
Best fitting IMBH mass fractions of all clusters. *Only models containing IMBHs with masses between 0.5% to 2% of the cluster mass are considered here.*

Almost all clusters prefer models with 0.5% IMBHs, i.e. those models which make the smallest difference to the no IMBH case.



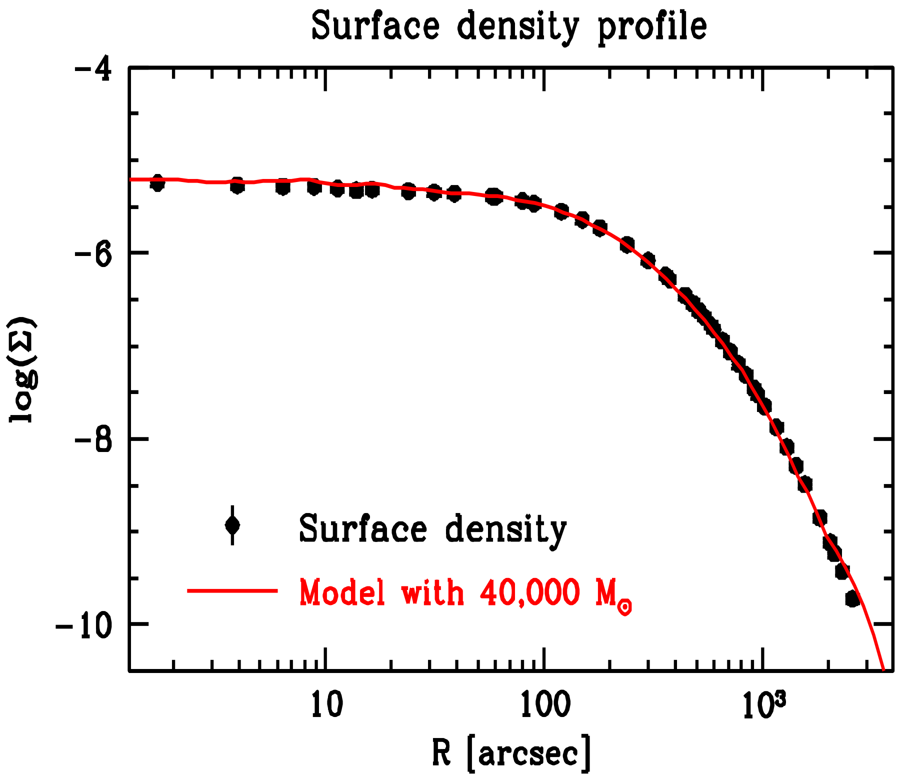
Overwhelming majority of GCs does not contain IMBHs !

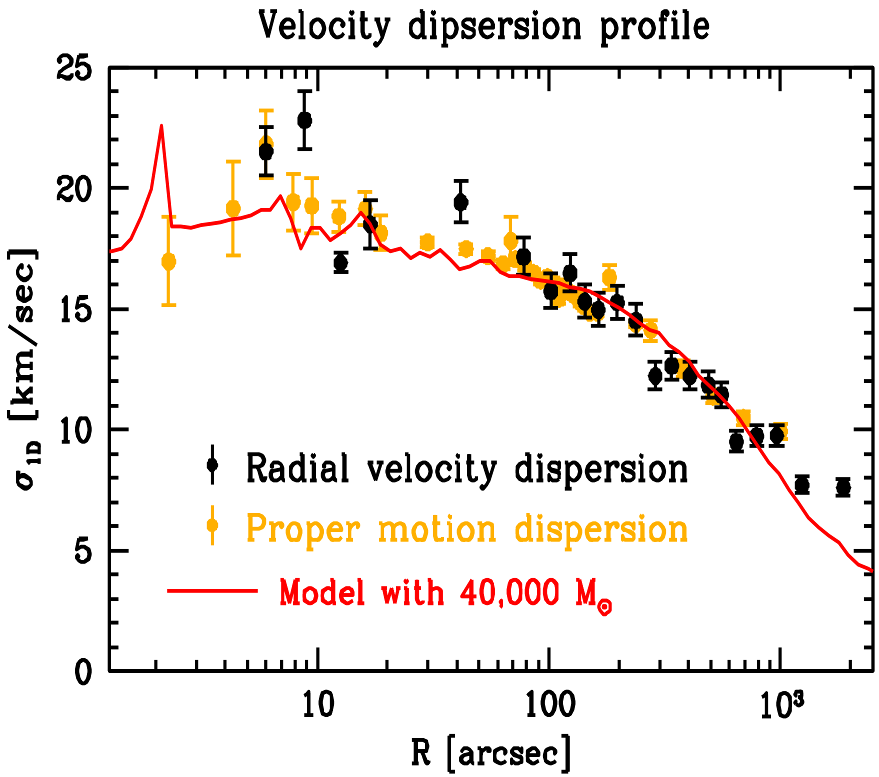
An IMBH in Omega Cen ?



A model without IMBH provides very bad fit to velocity dispersion profile. Not seen for other clusters. So something is very different with ω Cen!

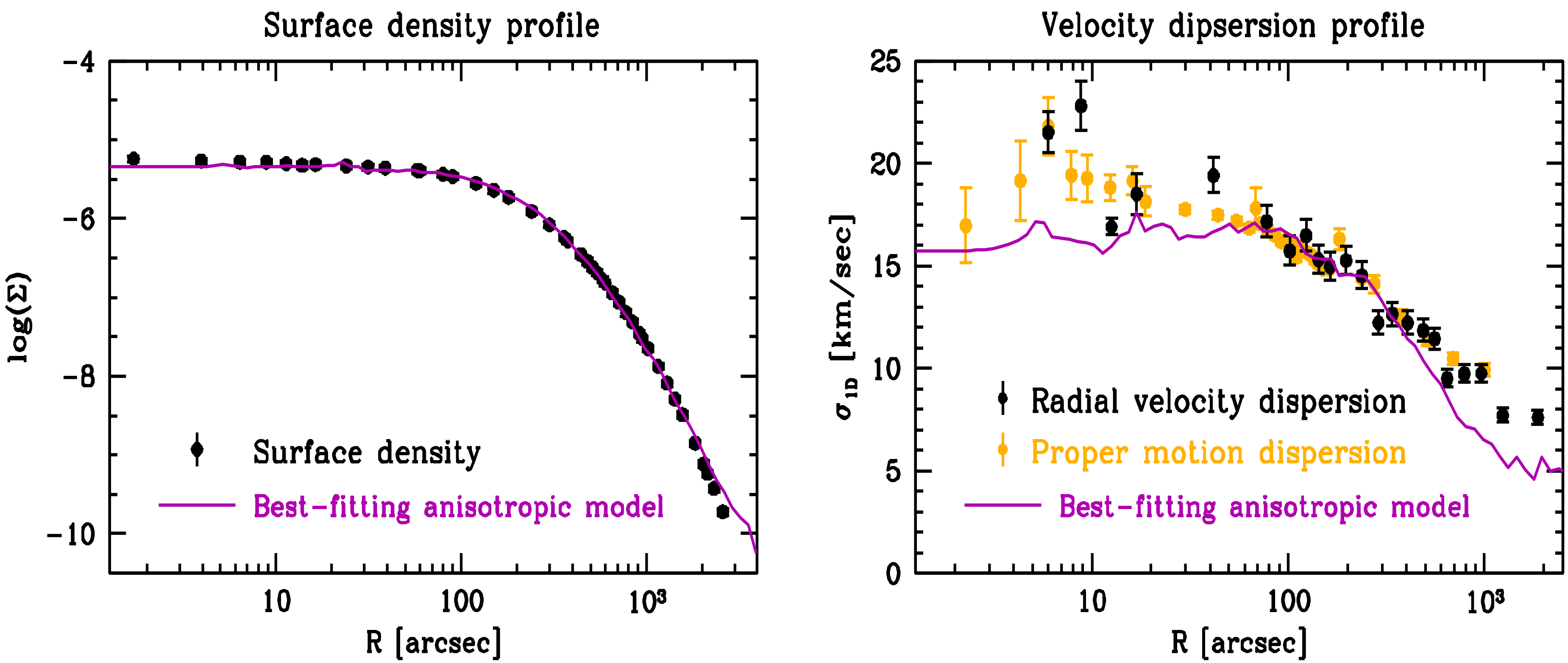
An IMBH in Omega Cen ?





The best fit is achieved for a model with an IMBH of about ~40,000 $M_{\odot}$.

An IMBH in Omega Cen ?



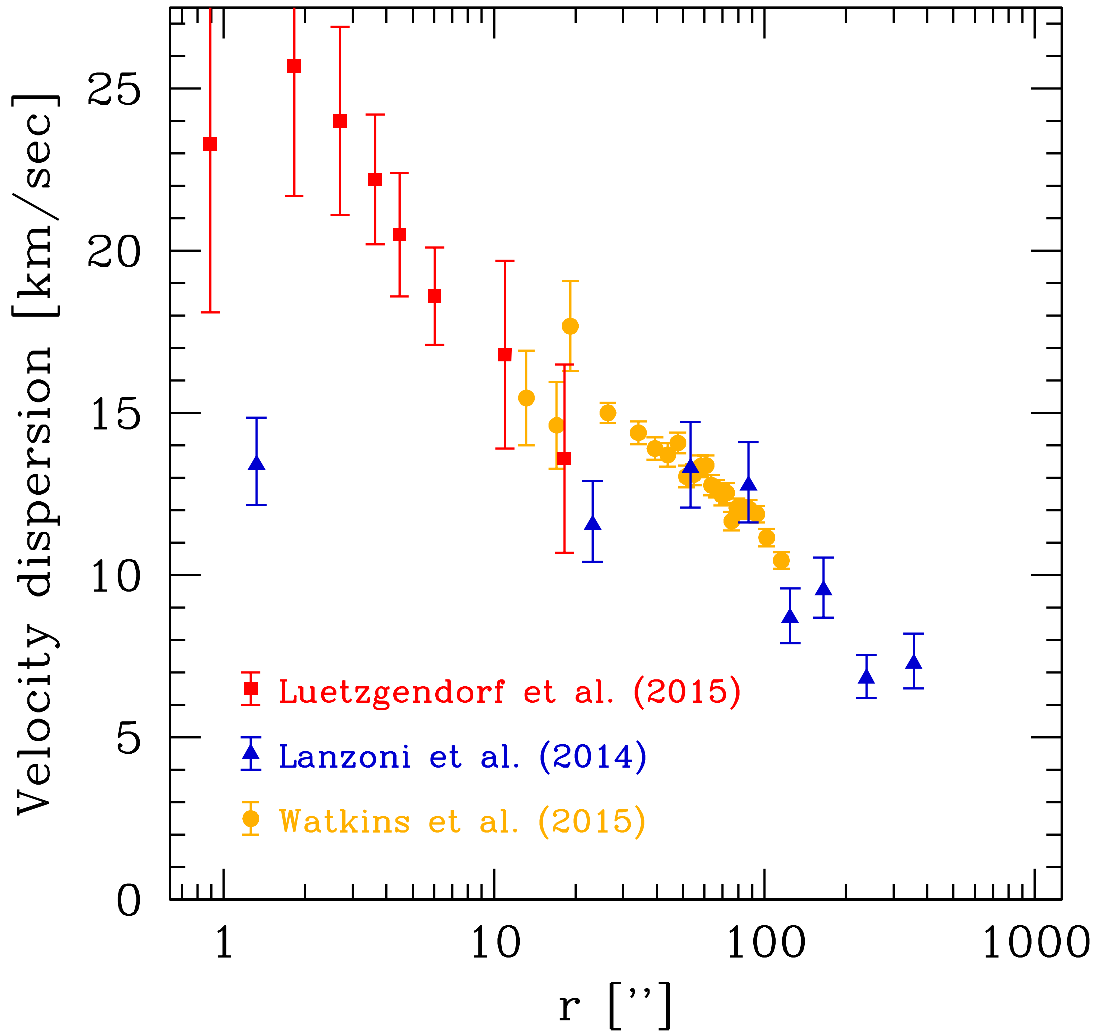
van der Marel & Anderson (2010) speculated that the difference is due to anisotropy. However N-body models starting from anisotropic velocity distributions do not provide a good fit.

An IMBH in NGC 6388 ?

IFU observations show a strong rise in the central velocity dispersion profile of NGC 6388.

This rise could point to an IMBH with M=20,000 $M_\odot$ (Luetzgendorf et al. 2015).

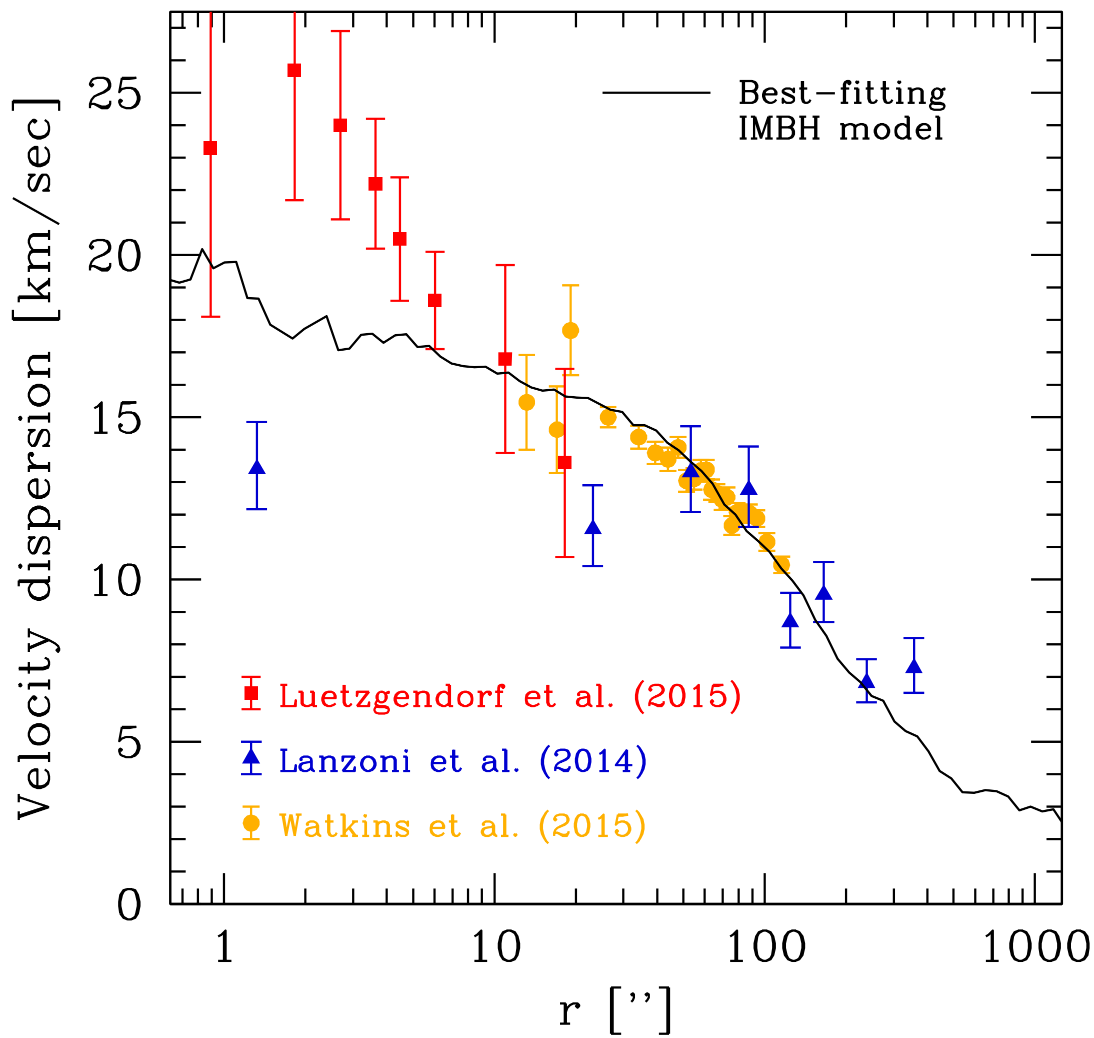
However this rise is not seen in individual radial velocities.



An IMBH in NGC 6388 ?

IFU observations show a rise that is above what the best-fitting IMBH model produces.

IFU observations might be influenced by a few bright stars which increase the measured velocity dispersion.

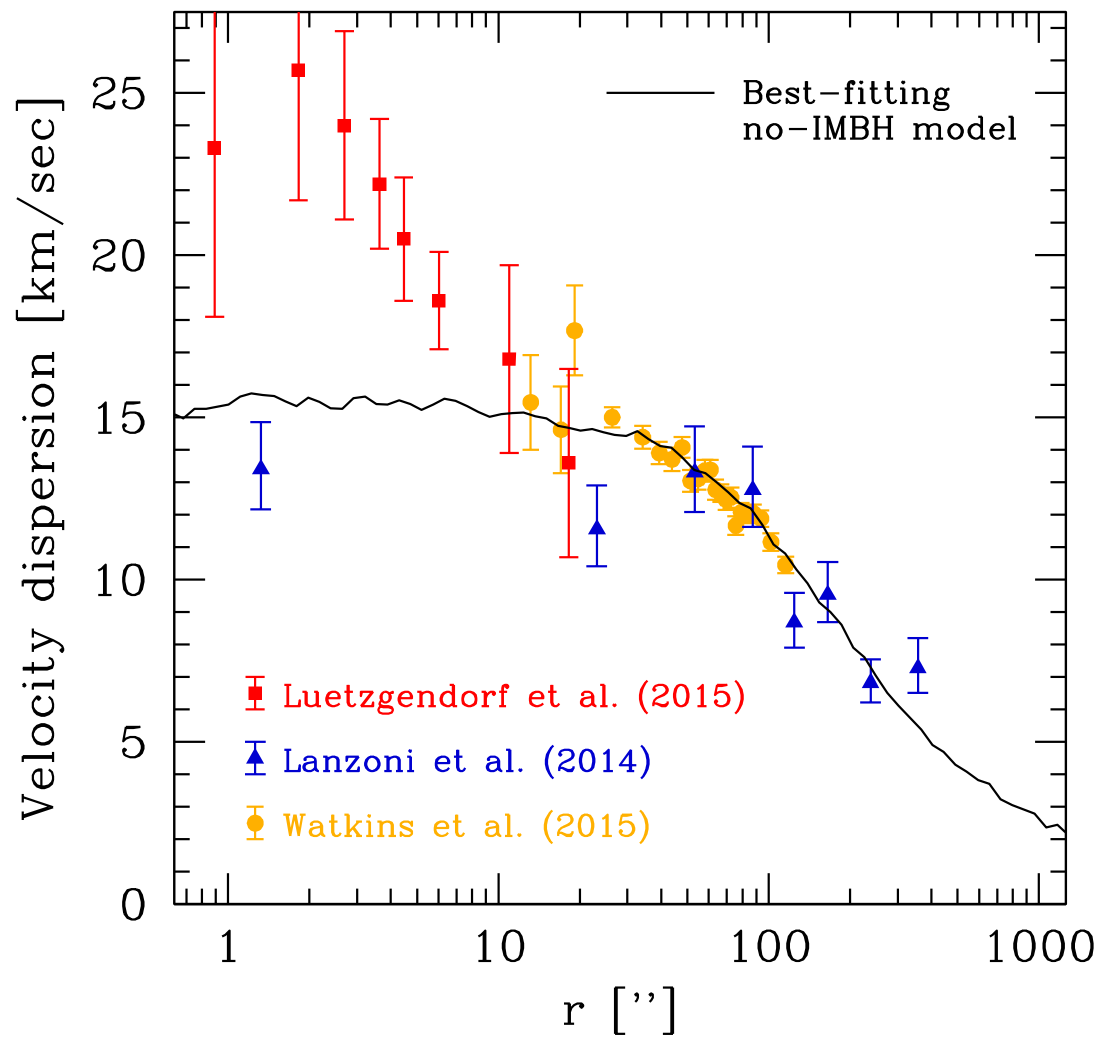


An IMBH in NGC 6388 ?

Best-fitting no IMBH model is above the radial velocity data in the centre.

Stellar radial velocities might suffer from blending.

Still unclear if there is an IMBH in NGC 6388 or not.



Results

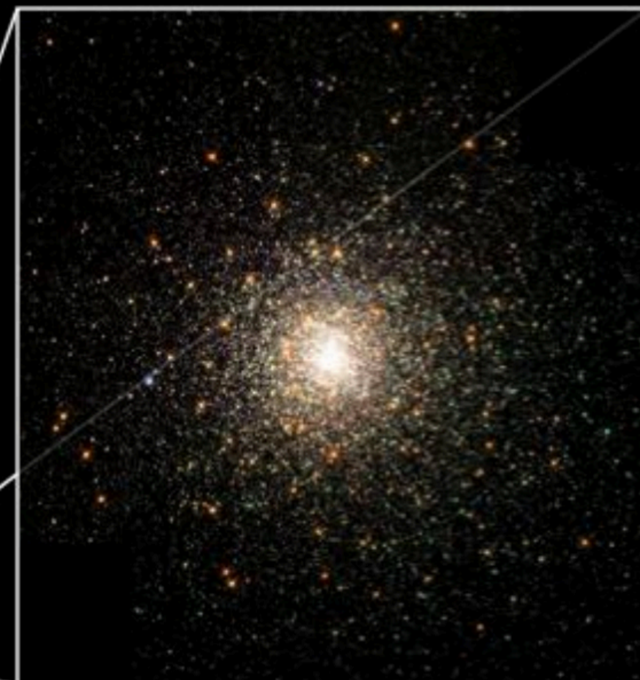
Stellar Mass Functions

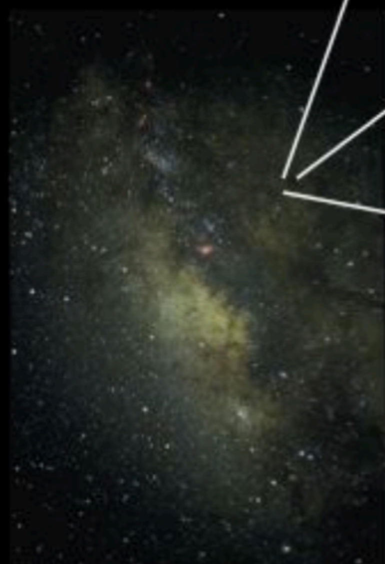
An ACS Survey of Galactic Globular Clusters

Project Description

Team Members

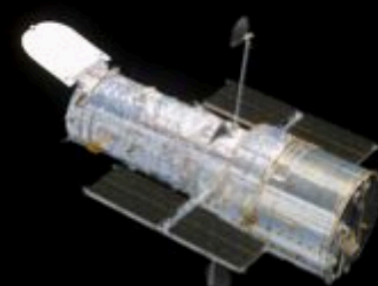
Program Clusters





Publications

Databases

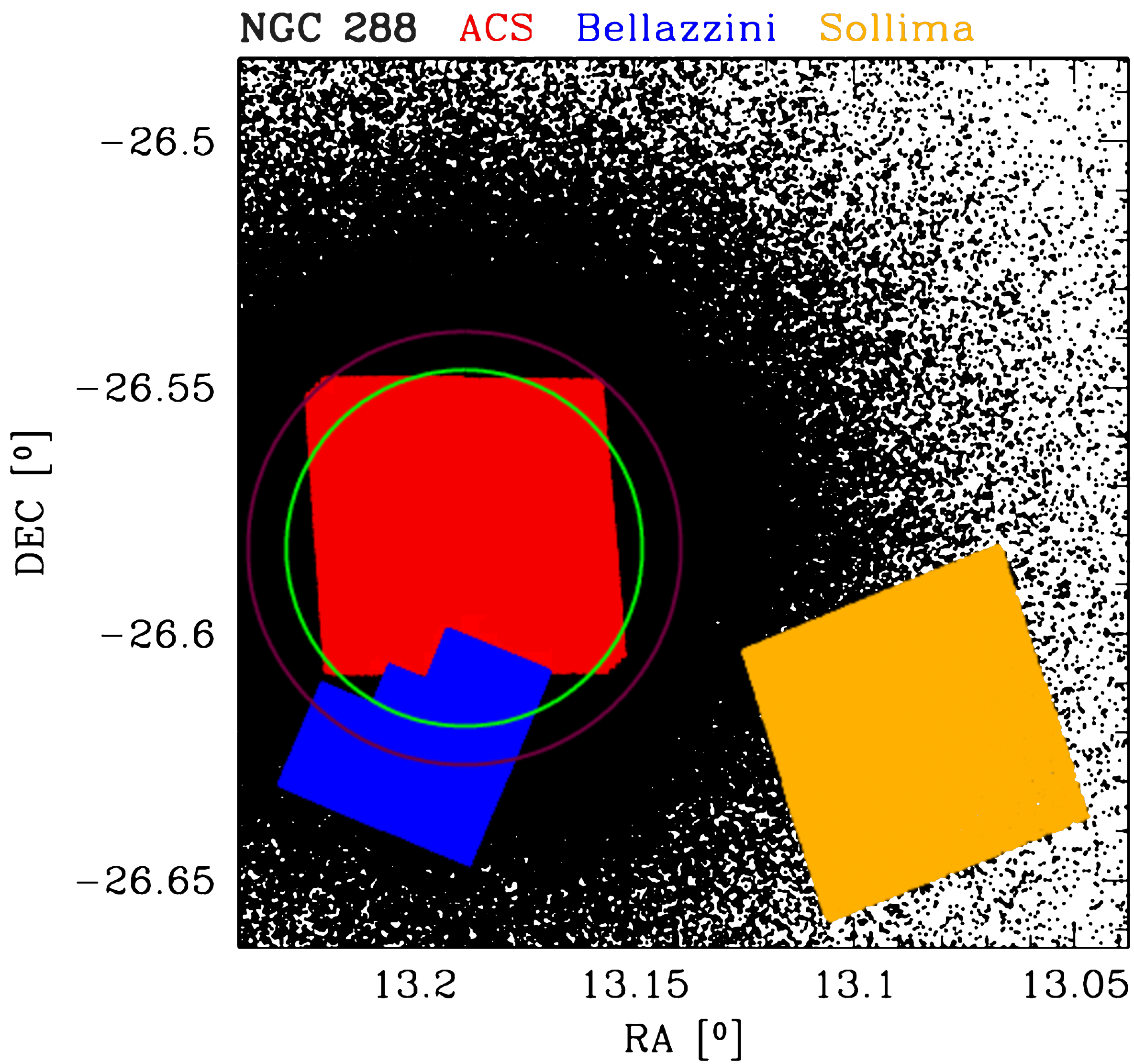


Stellar mass functions from HST/ACS data

We have analyzed the stellar mass functions of 46 star clusters that were part of the HST/ACS survey.

35 of these also have good velocity dispersion information.

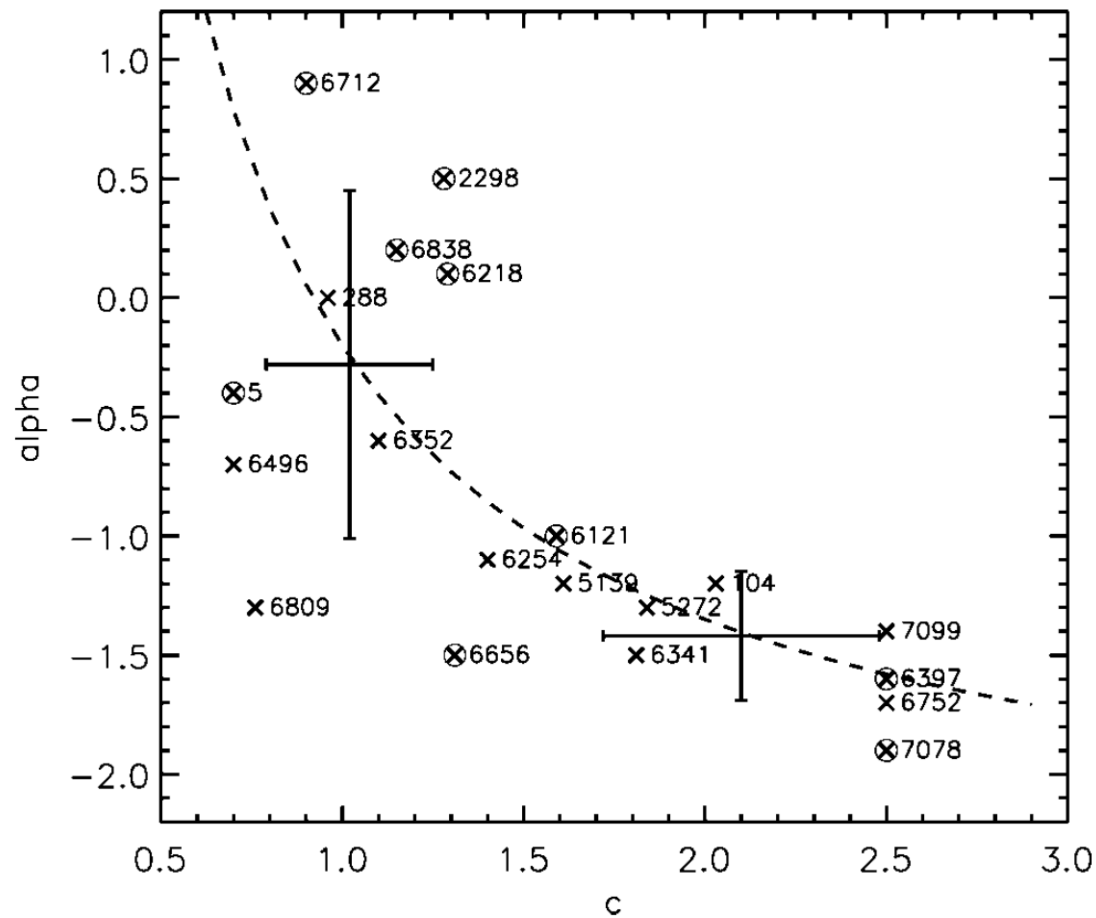
If available deep HST data from additional fields was added.



Correlation between MF slope and concentration ?

De Marchi et al. (2007) found an anti-correlation between cluster concentration and the global mass function slope.

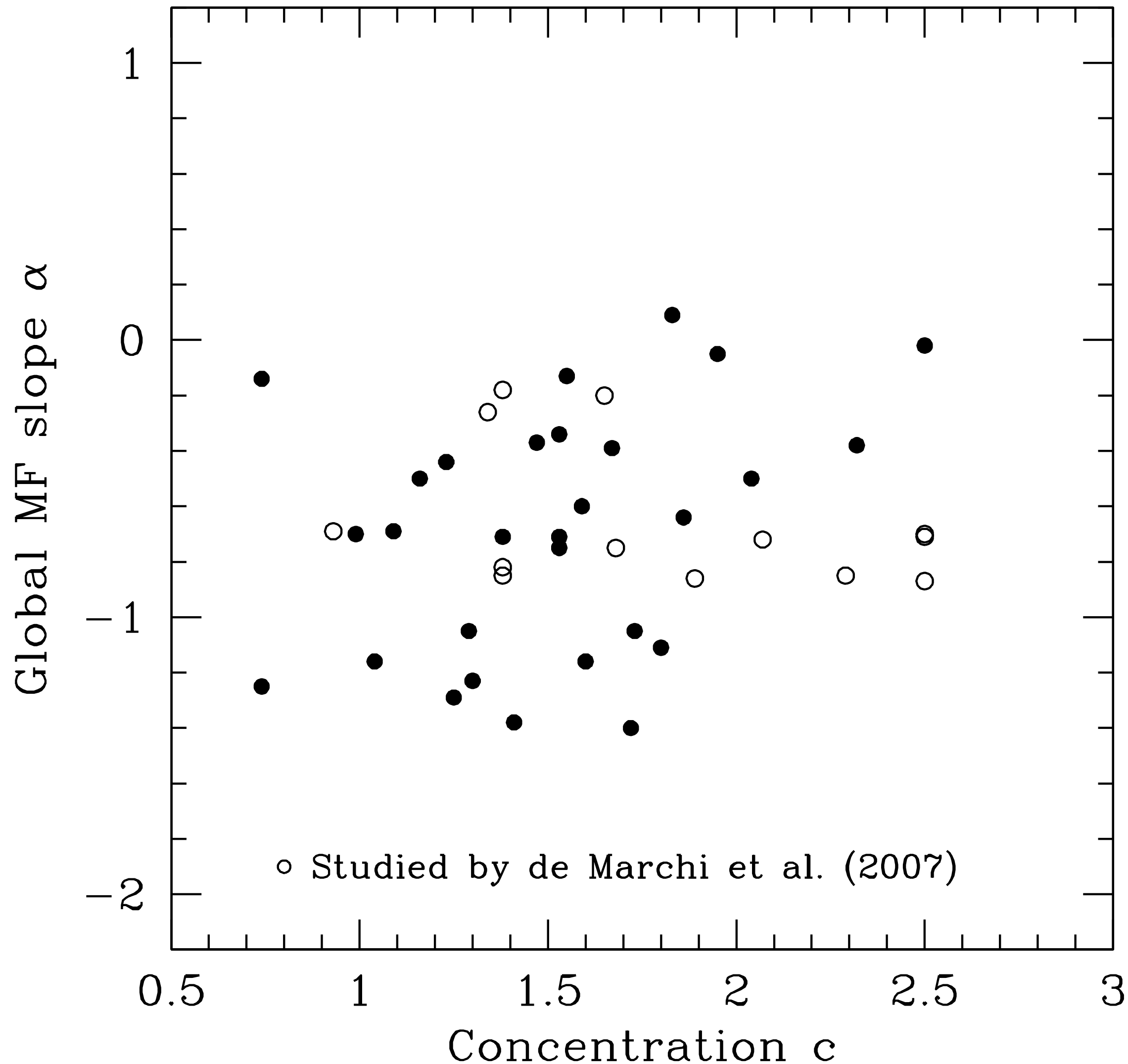
This correlation is surprising since theory would predict either no correlation or a positive correlation.



Correlation between MF slope and concentration ?

Our data does not confirm their results.

The cluster sample of de Marchi et al. (2007) probably suffered from low data quality and selection biases.



Conclusions

- The average M/L_V ratio of GCs is M/L_V=2, independent of metallicity. High-metallicity clusters might have slightly lower M/L ratios than predicted by canonical IMFs, which could be due to ongoing cluster dissolution or a different IMF.

- IMBHs of more than 1000 to 2000 $M_\odot$ are rare, out of 58 fitted GCs only one convincing case: The data for Omega Cen is compatible with a 40,000 $M_\odot$ IMBH.

- Stellar mass functions show that globular clusters follow a single evolutionary sequence driven by cluster dissolution. Majority of galactic globular clusters is dynamically highly evolved !