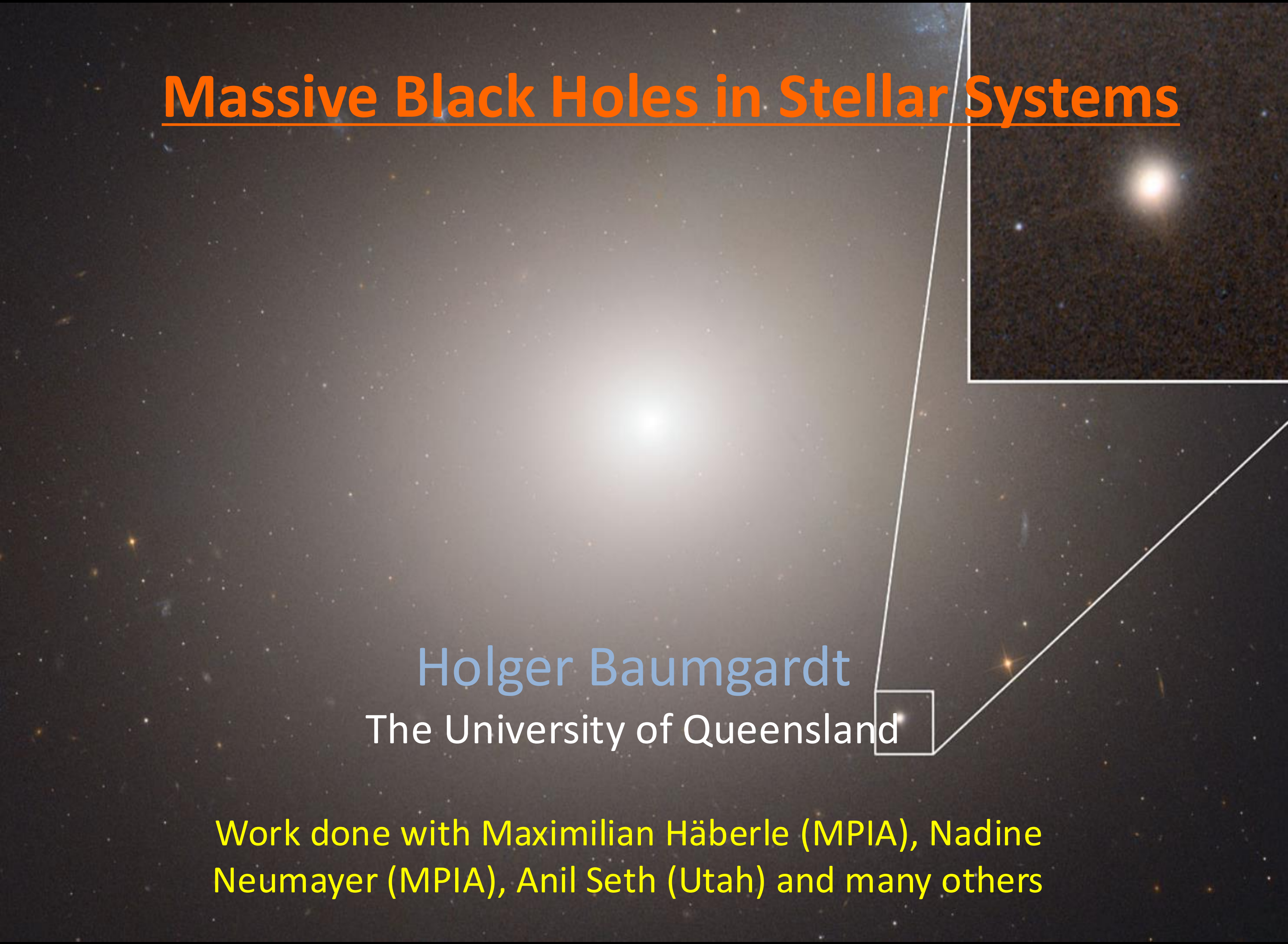
Massive Black Holes in Stellar Systems



Holger Baumgardt
The University of Queensland

Work done with Maximilian Häberle (MPIA), Nadine Neumayer (MPIA), Anil Seth (Utah) and many others

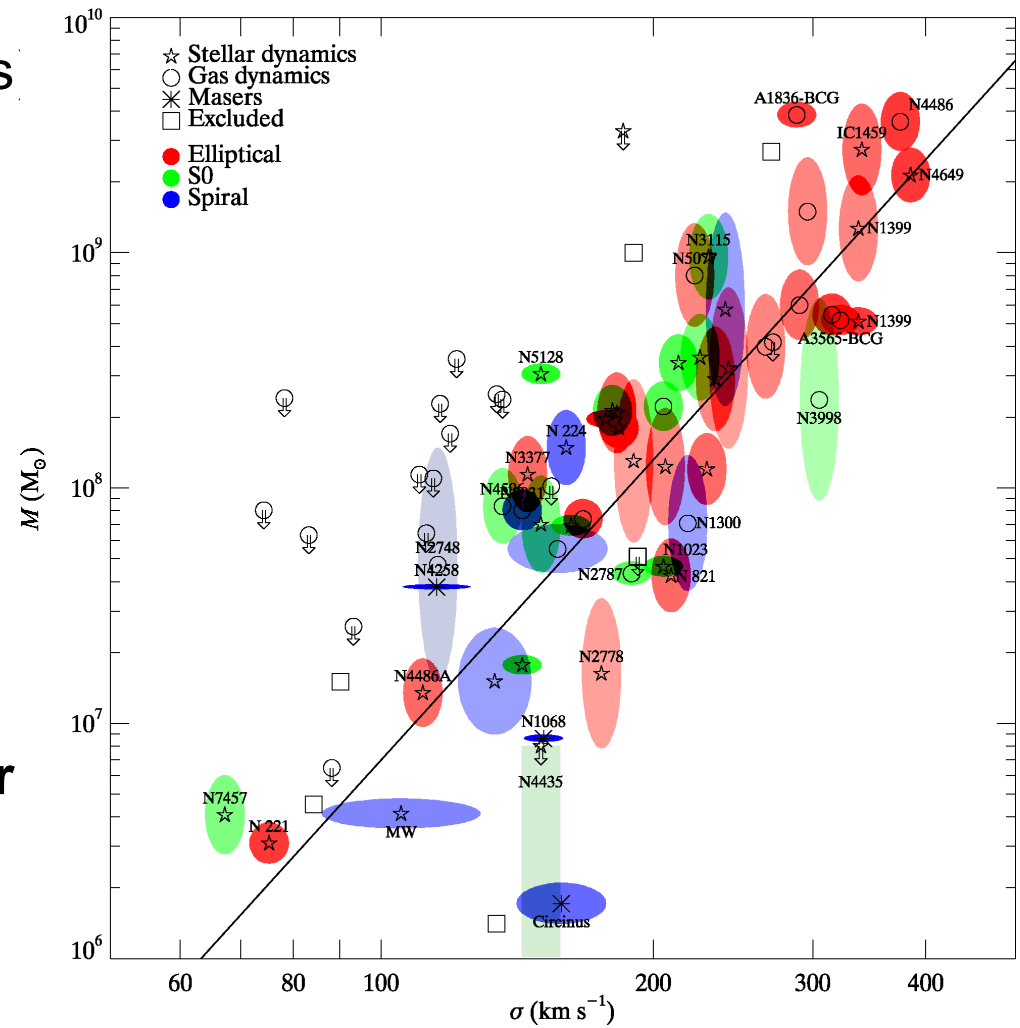
$M_\bullet$-σ relation for SMBHs

Supermassive black holes (SMBHs) in galaxies exhibit well known scaling relations.

However a number of unsolved questions still remain:

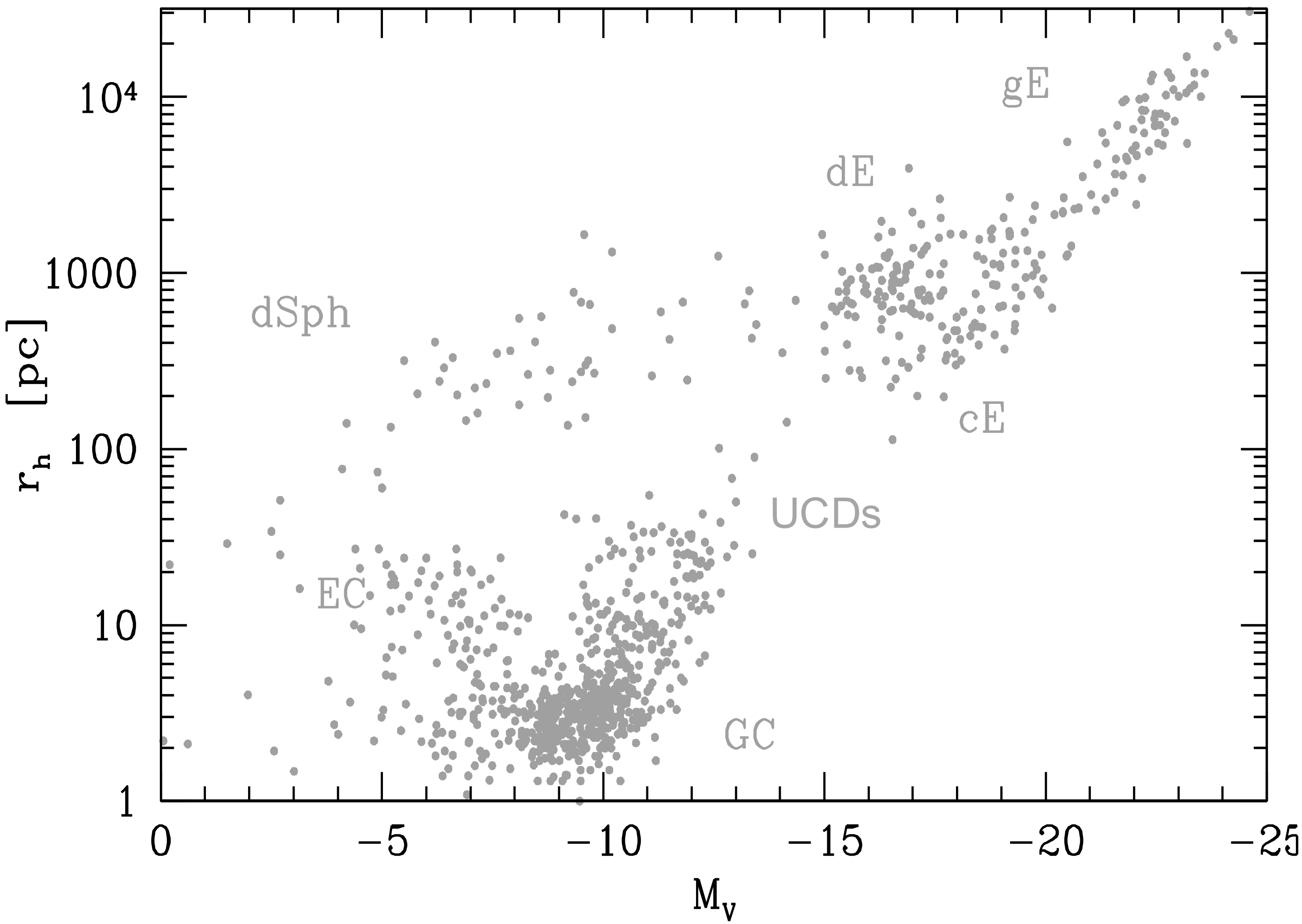
How were these relations established?

How do the measured scaling relations continue towards lower galaxy masses?



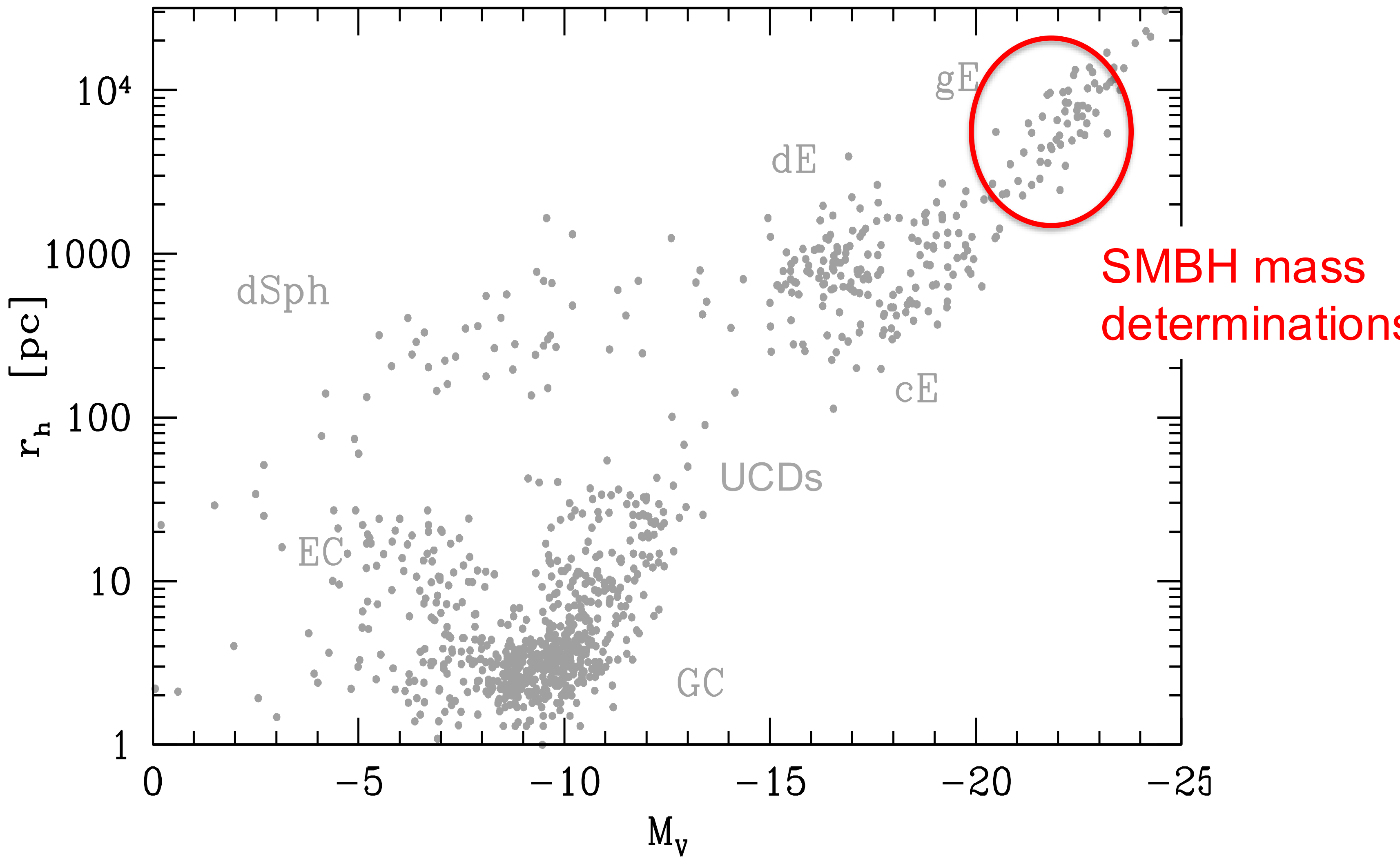
from Gültekin et al. (2009)

Mass vs. radius of stellar systems



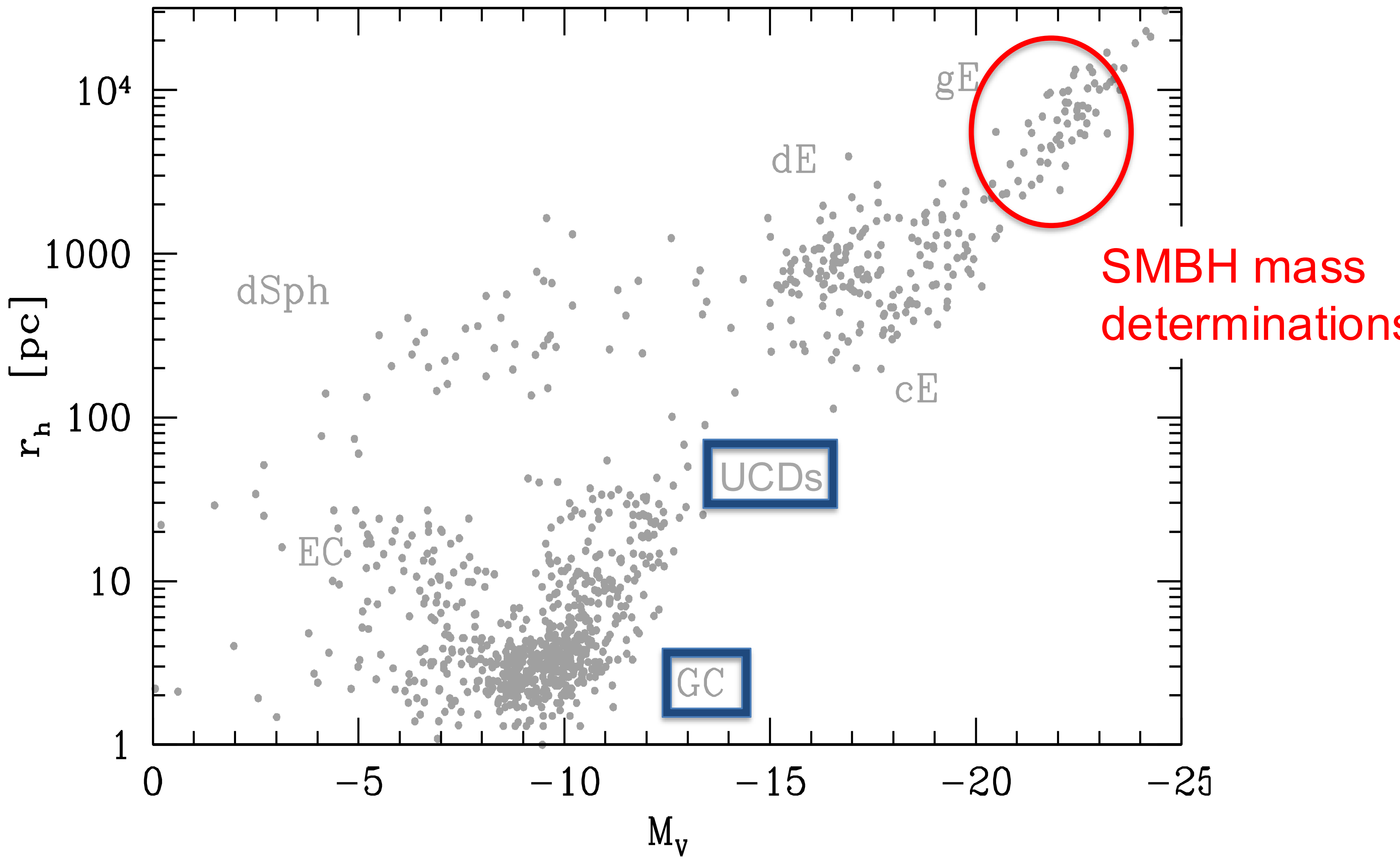
from Brodie et al. (2013)

Mass vs. radius of stellar systems



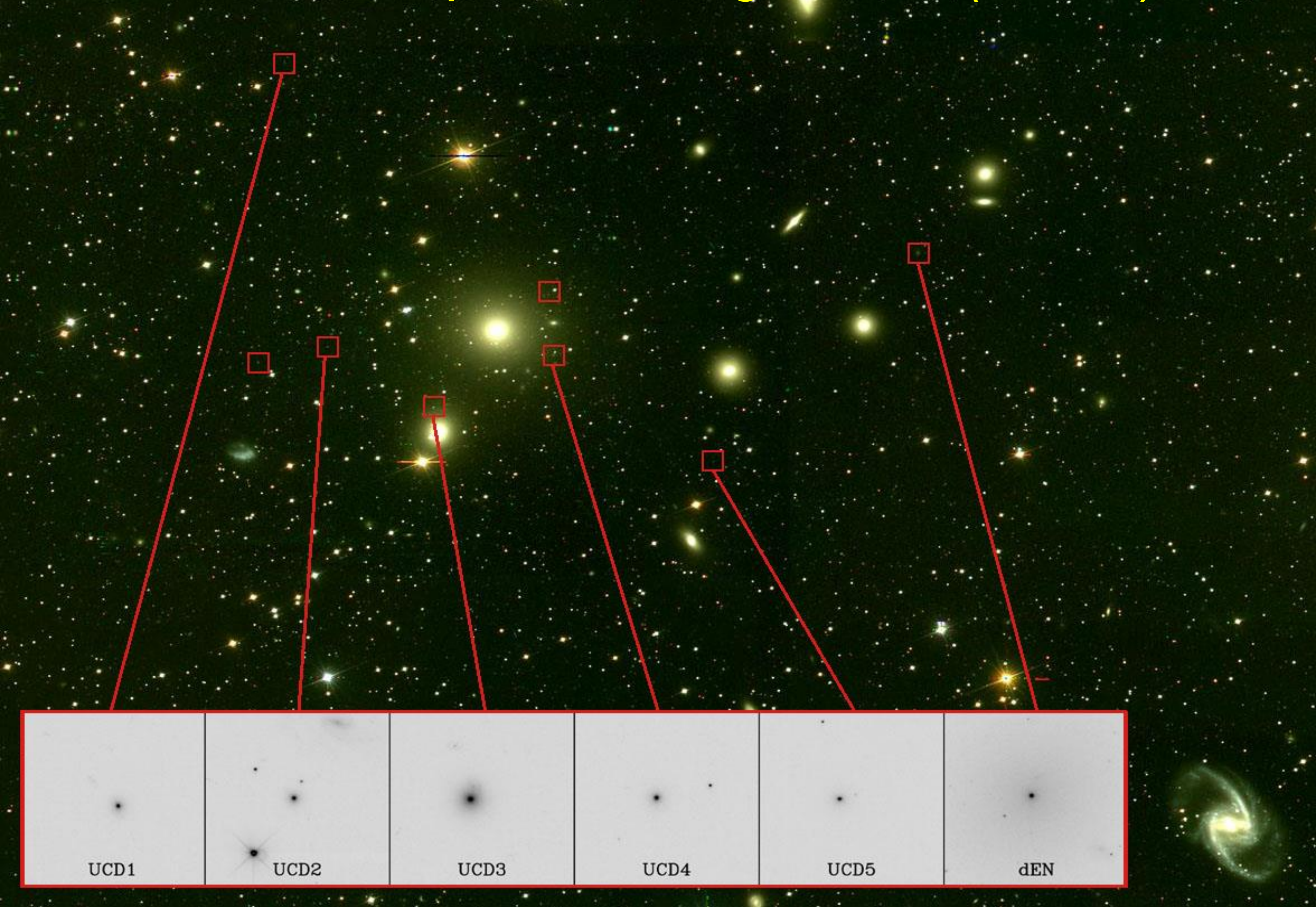
from Brodie et al. (2013)

Mass vs. radius of stellar systems



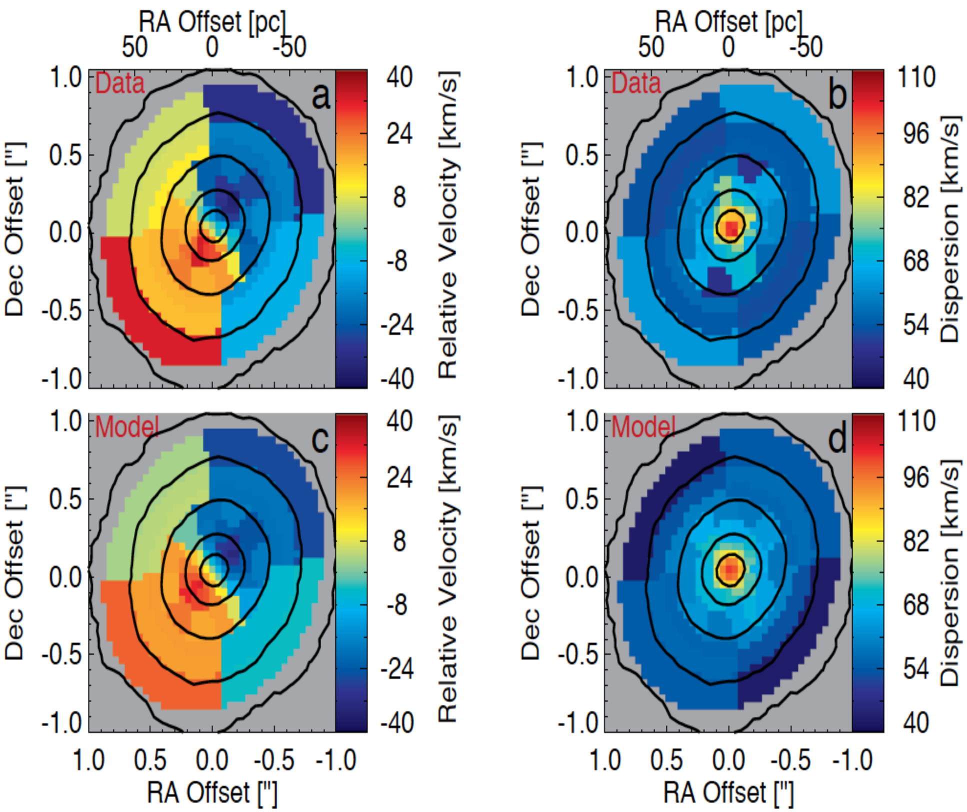
from Brodie et al. (2013)

Ultra-compact dwarf galaxies (UCDs)

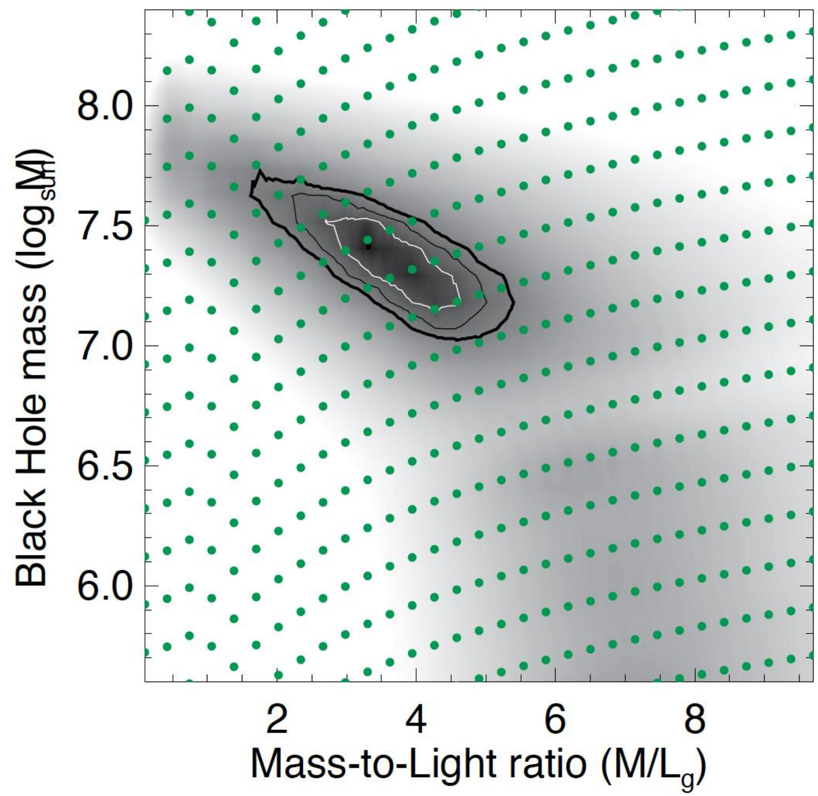


M60-UCD1

Kinematic data



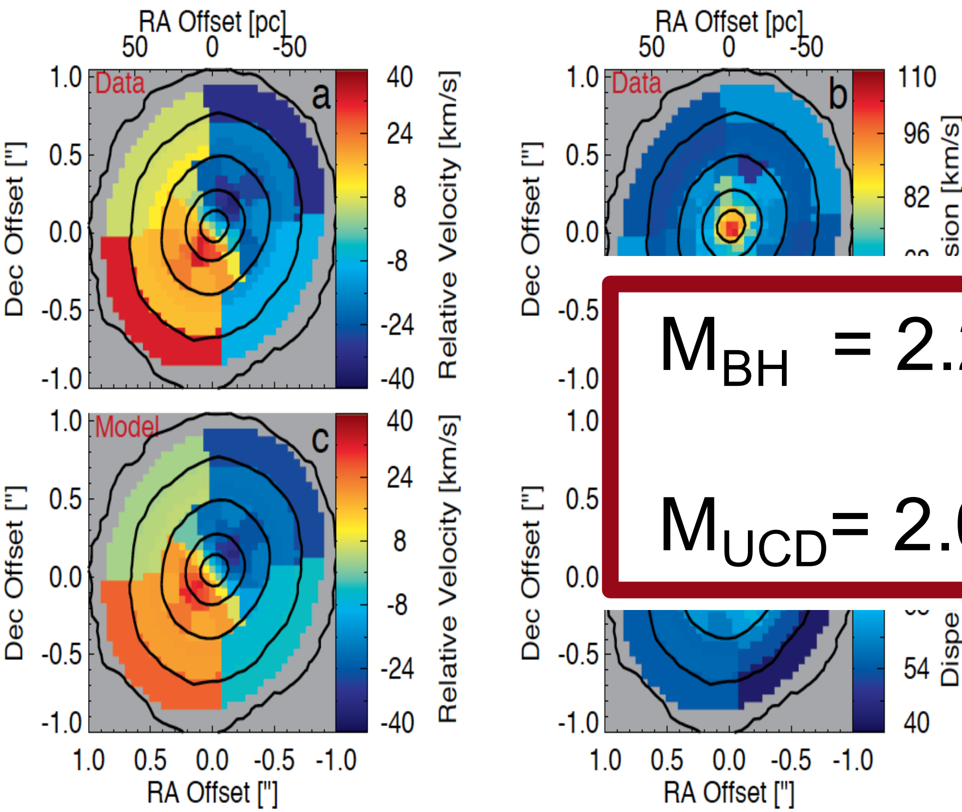
BH constraints



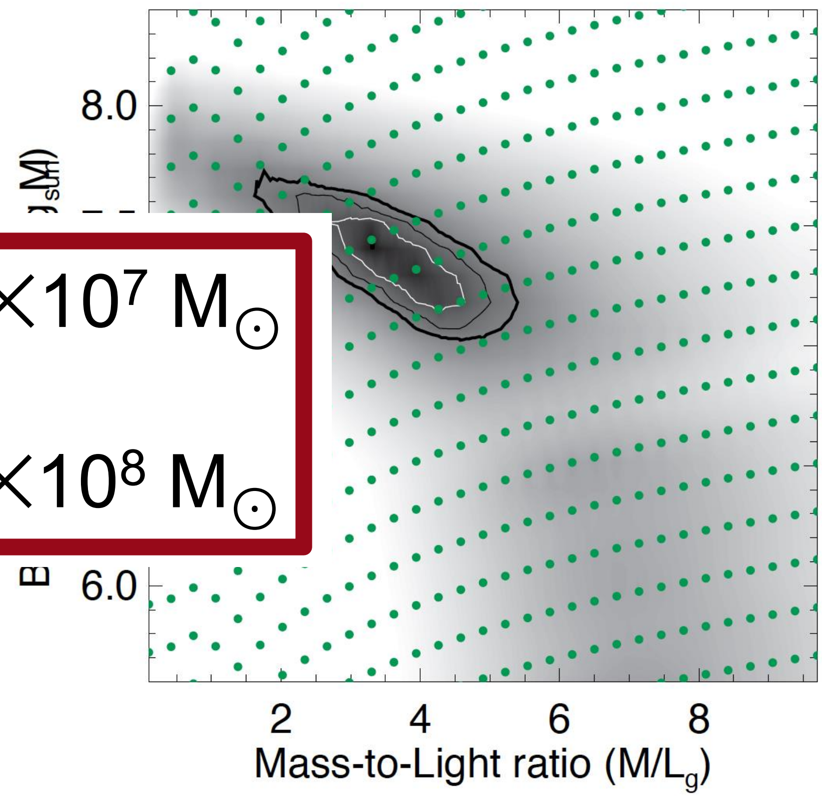
from Seth et al. (2014)

M60-UCD1

Kinematic data



BH constraints

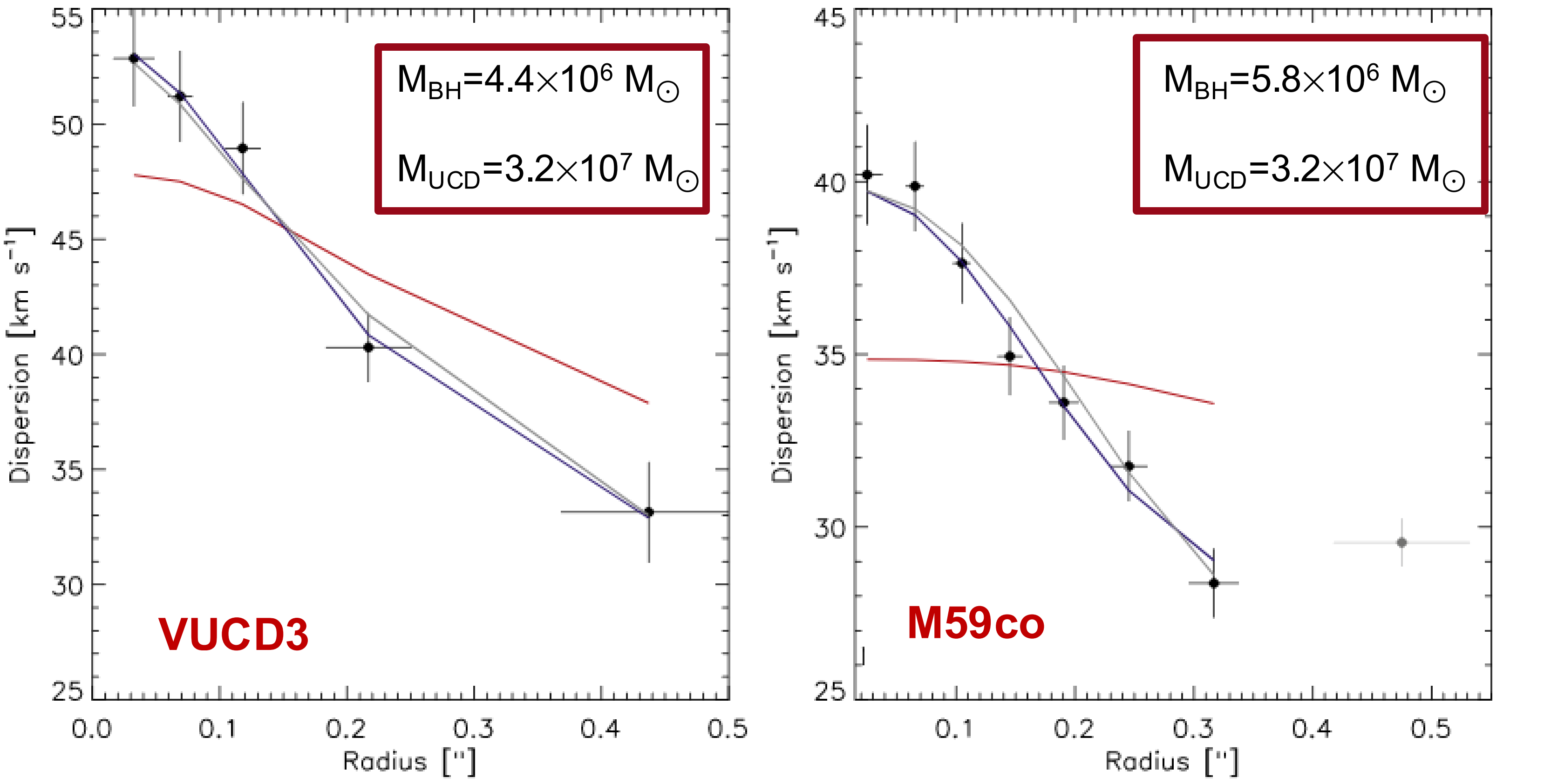


$$M_{BH} = 2.2 \times 10^{7}\ M_{\odot}$$

$$M_{UCD} = 2.0 \times 10^{8}\ M_{\odot}$$

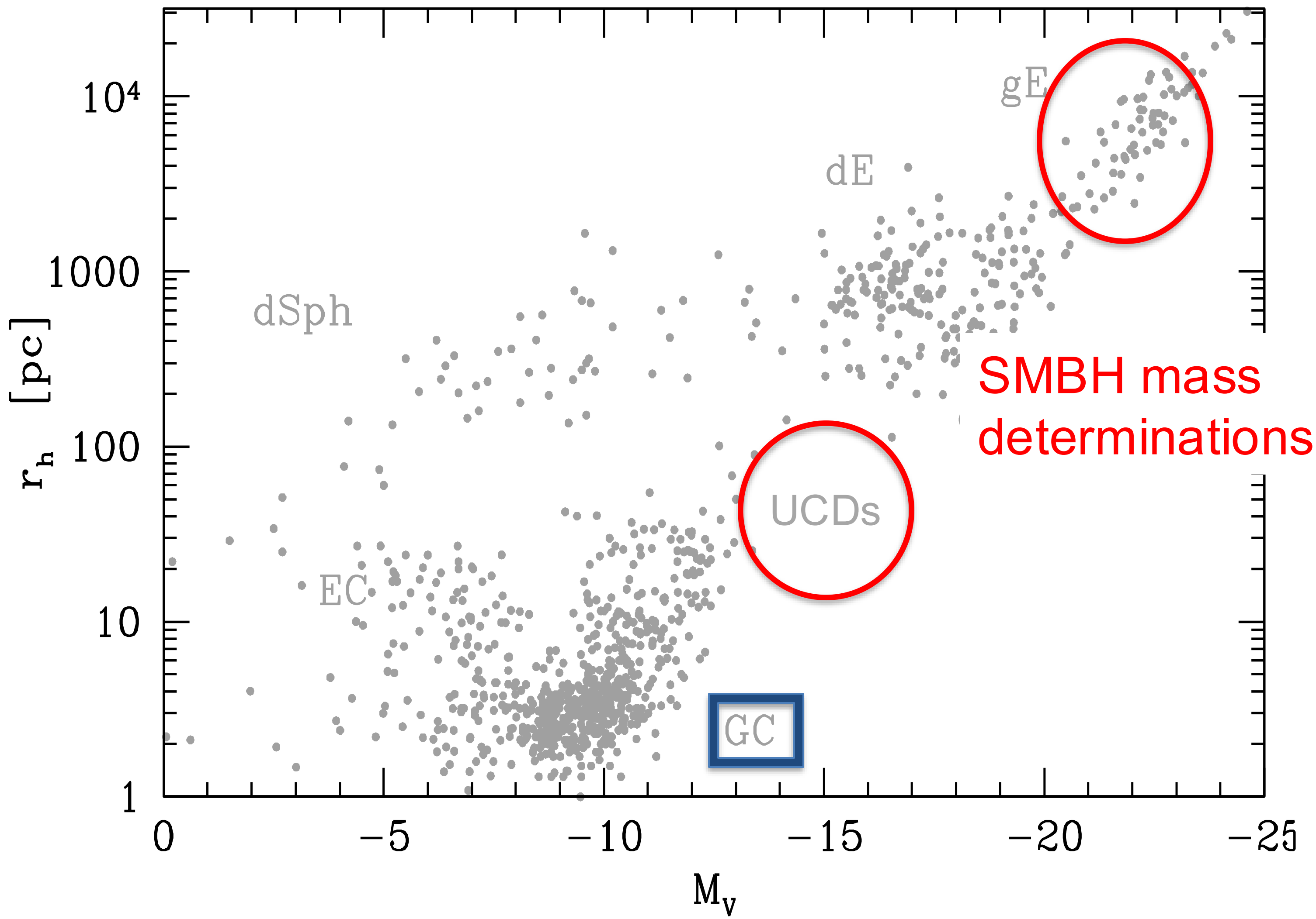
from Seth et al. (2014)

VCUD3 and M59co



from Ahn et al. (2017)

Mass vs. radius of stellar systems



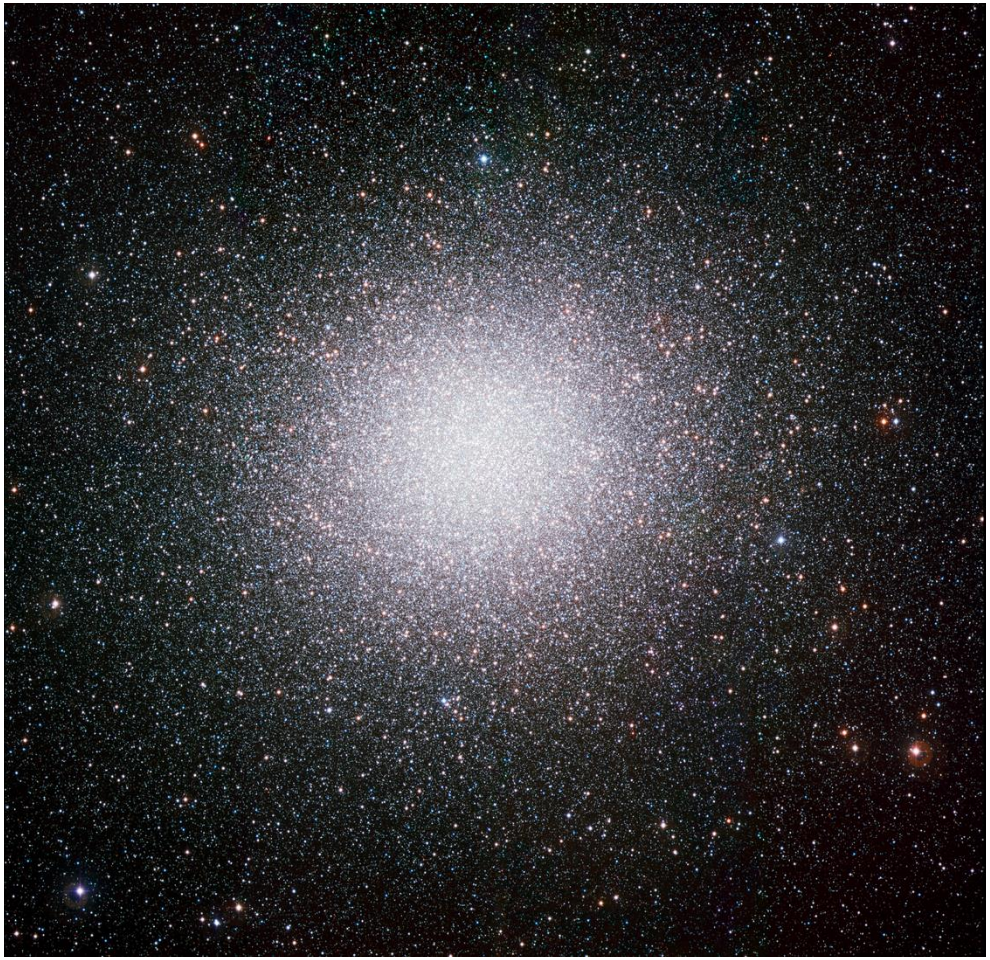
from Brodie et al. (2013)

A massive Black Hole in Omega Cen?

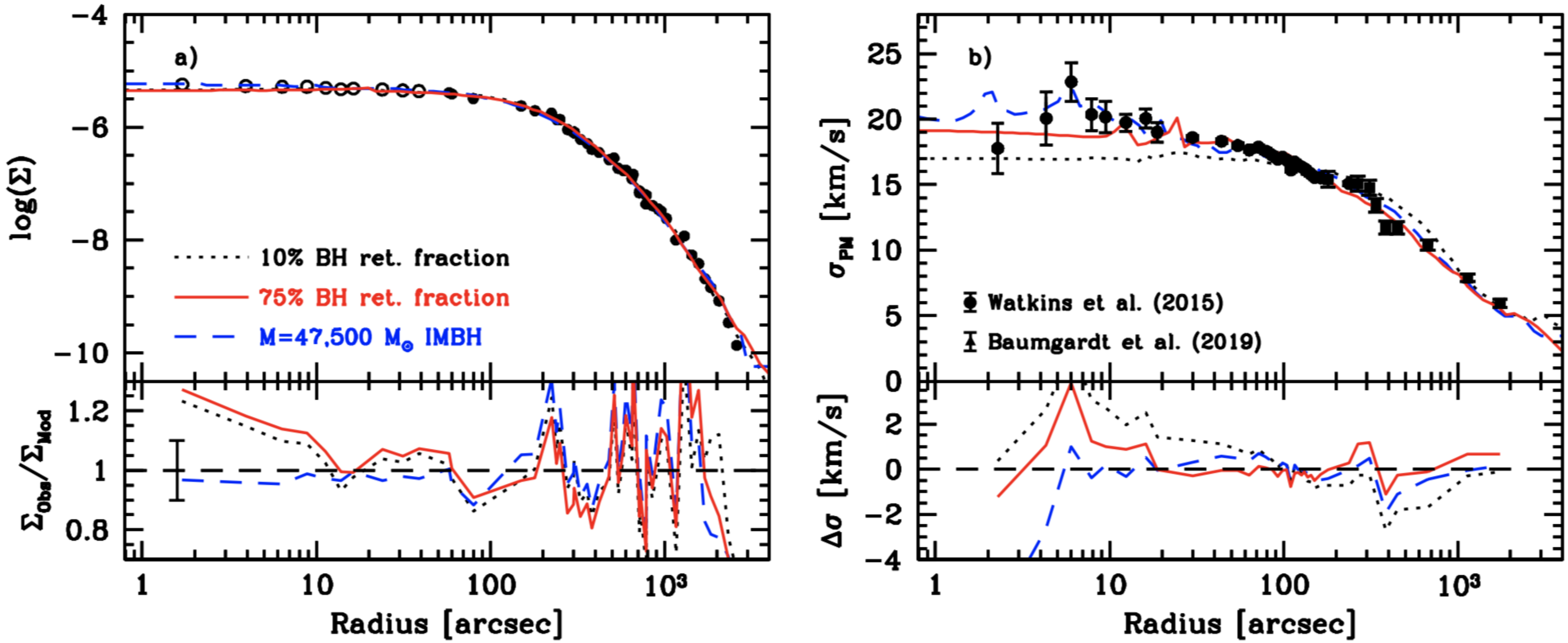
Most massive Milky Way GC: $M=3.5\ 10^6\ M_{\odot}$ (Baumgardt, Hilker & Sollima 2019)

Stars show evidence of both an age and a metallicity spread

Could be former nucleus of a dwarf galaxy formed from smaller fragments (Majewski et al. 1999, Sollima et al. 2006)



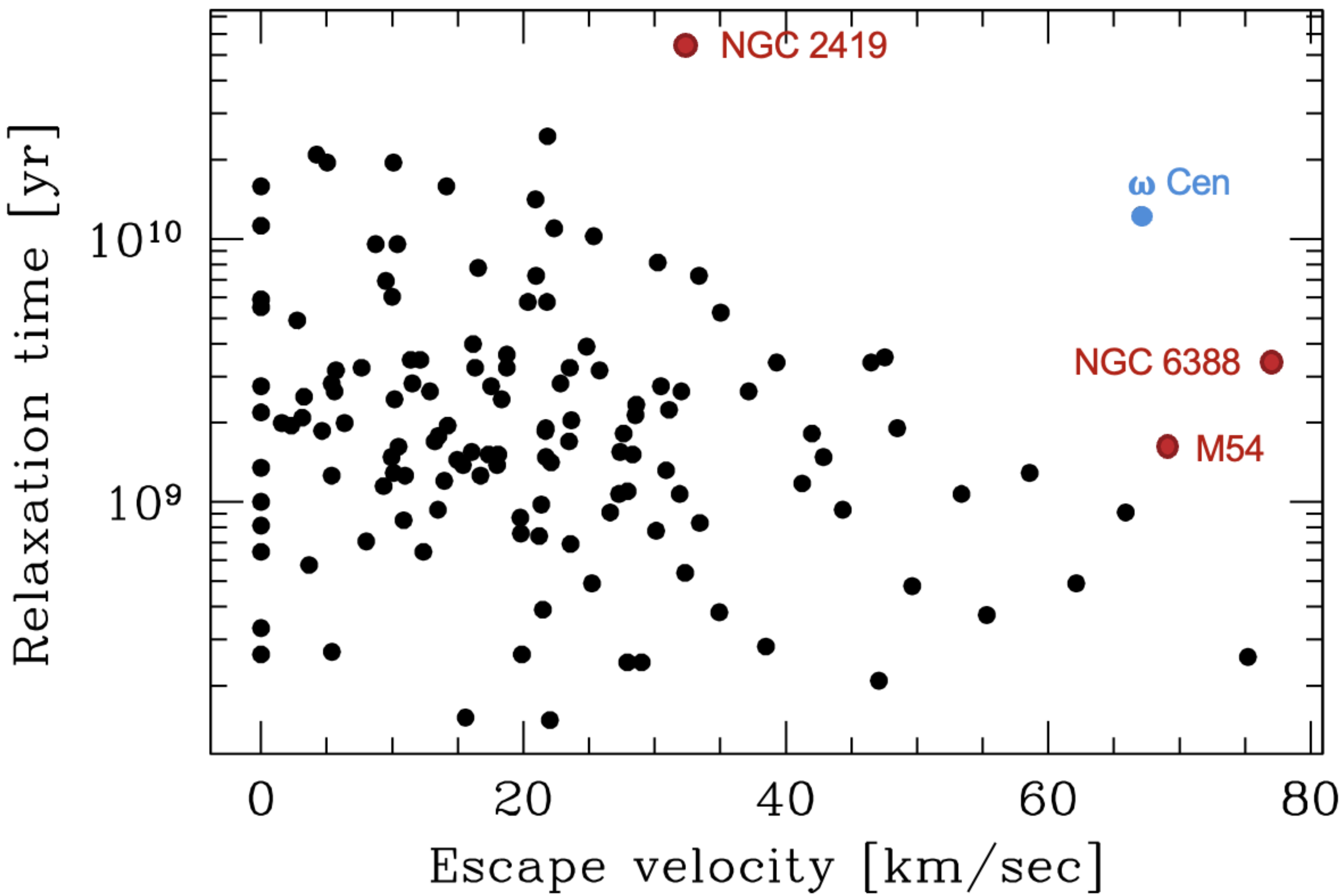
A massive Black Hole in Omega Cen?



from Baumgardt, Sollima et al. (2019)

A dense cluster of compact remnants could be an alternative to an IMBH (also found by van der Marel & Anderson 2010, Zocchi et al. 2019).

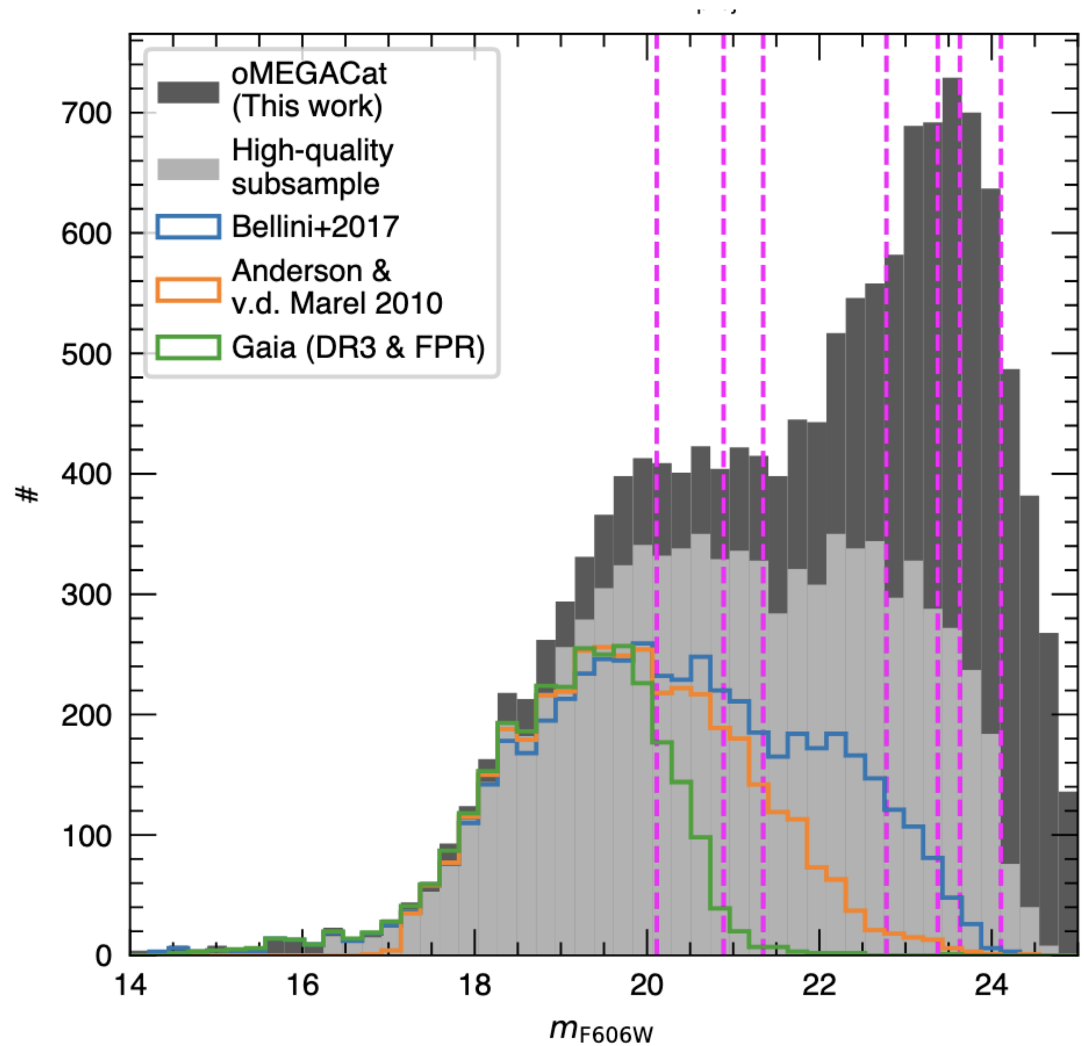
A massive Black Hole in Omega Cen?



A massive Black Hole in Omega Cen?

Nitschai et al. (2023) and Häberle et al. (2025) published MUSE based radial velocities and HST based proper motions for 1.5 Million stars in the centre of Omega Cen.

This data set presents a significant improvement over existing data making it possible to again investigate the question of an IMBH.



N-body simulations of Omega Cen

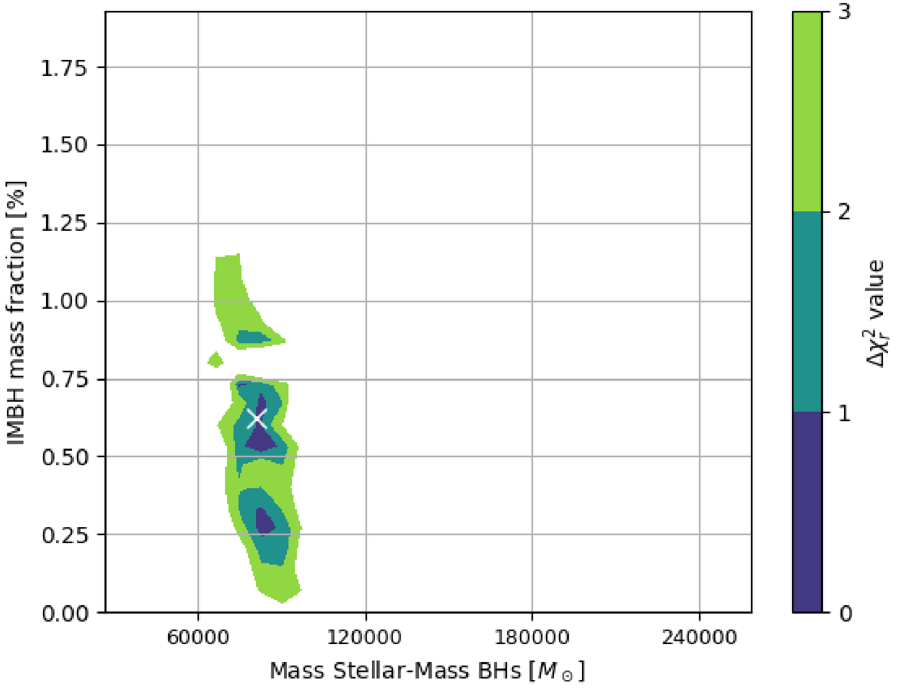
New grid of N-body simulations varying:

- Density profile (King 1962 models with varying concentrations c)
- IMBH mass fraction (0% IMBH to 2% IMBH in steps of 0.5%)
- BH retention rate between 0% to 100% in steps of 10%
- Two prescriptions for stellar-mass BH kicks: Either mass dependent kick velocities following Banerjee et al. (2020) or mass independent)

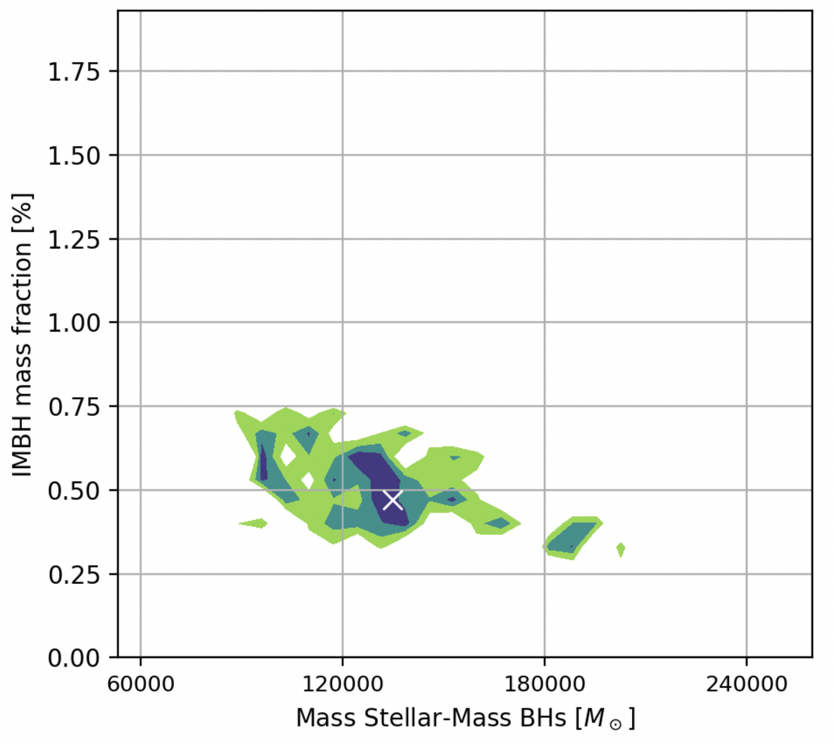
Simulations are run with 2×10^5 stars and are scaled to Omega Cen (Baumgardt 2017).

N-body simulations of Omega Cen

Mass dependent BH kicks



Mass independent BH kicks



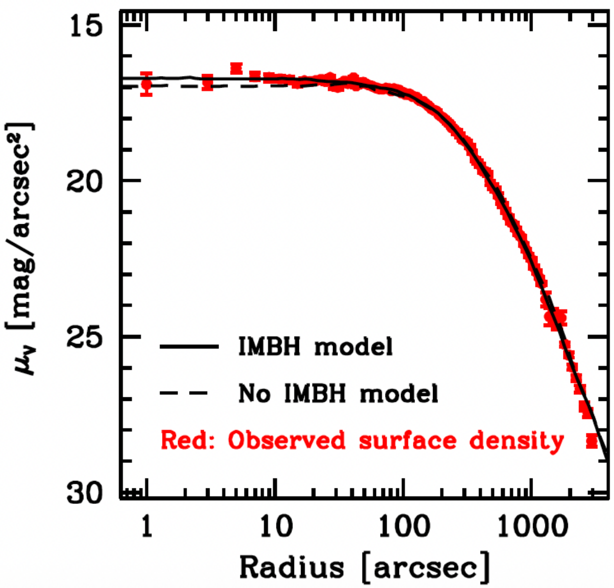
N-body simulations of Omega Cen

Best-fitting solution: $M_{Clus} = 3.1 \times 10^6 \, M_\odot$

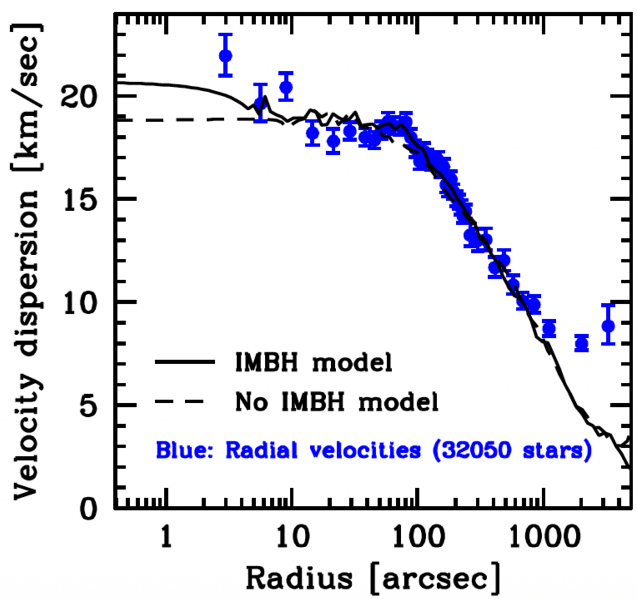
$M_{IMBH} = 1.5 \times 10^4 \, M_\odot$ (0.47% of cluster mass)

$M_{BH} = 1.3 \times 10^5 \, M_\odot$ (3.5% of cluster mass)

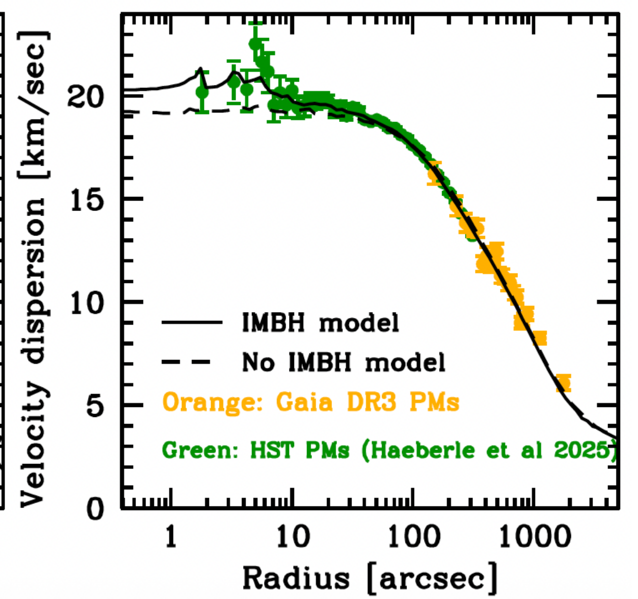
Surface density



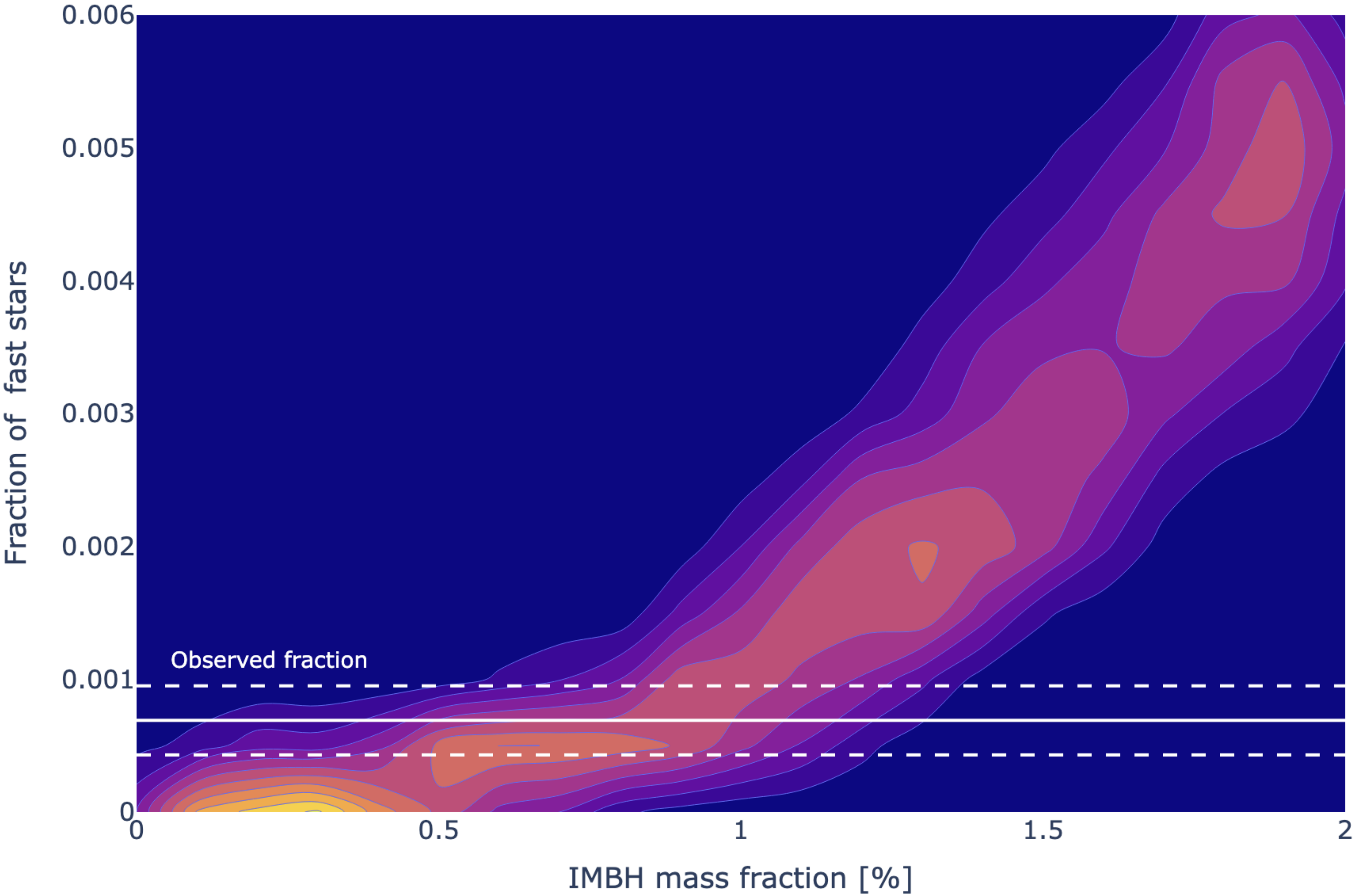
Radial velocities



Proper motions

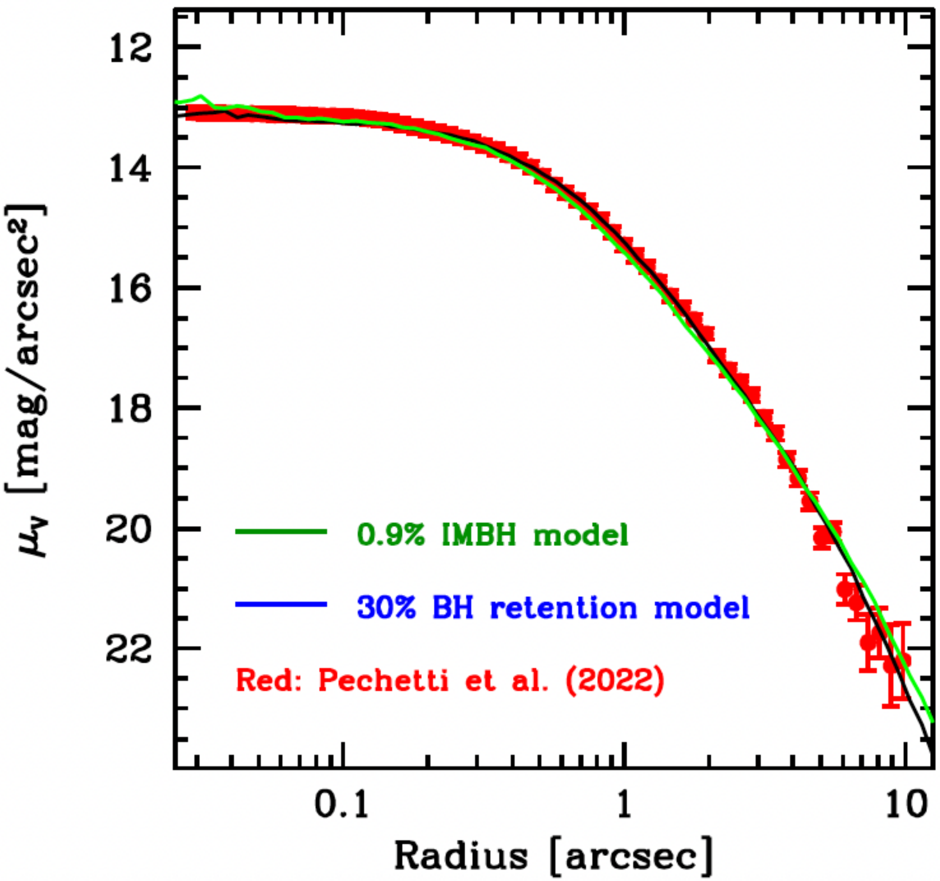


N-body simulations of Omega Cen

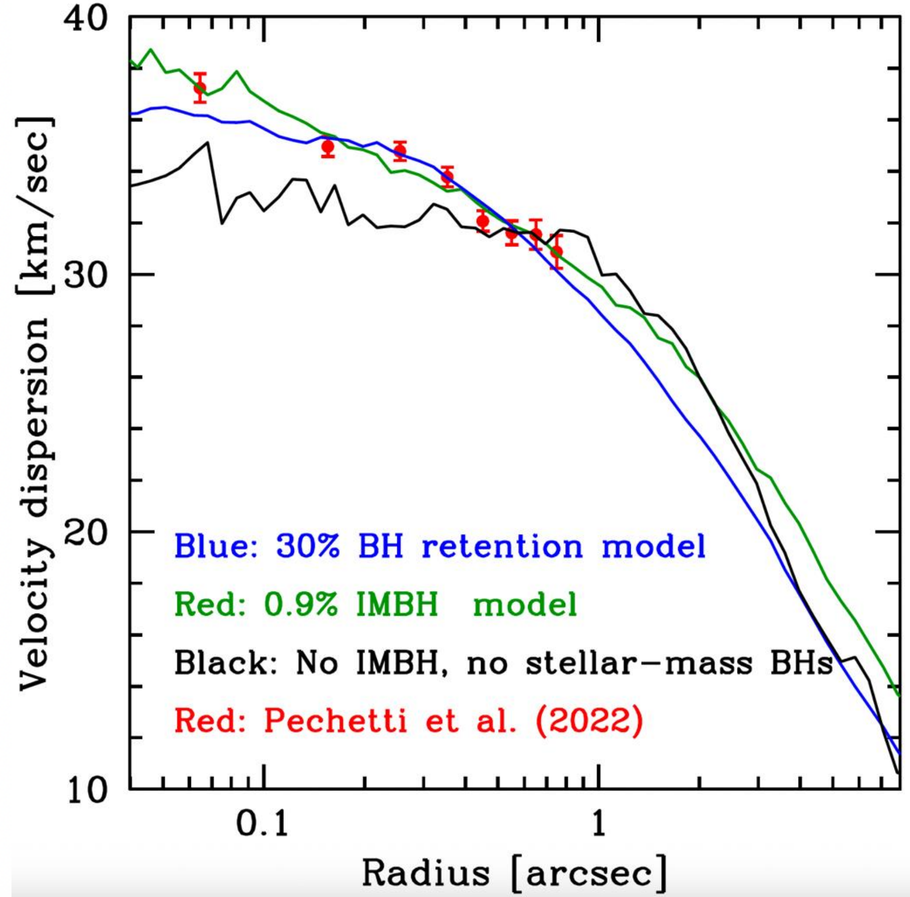


Other clusters: B023-G078

Surface density

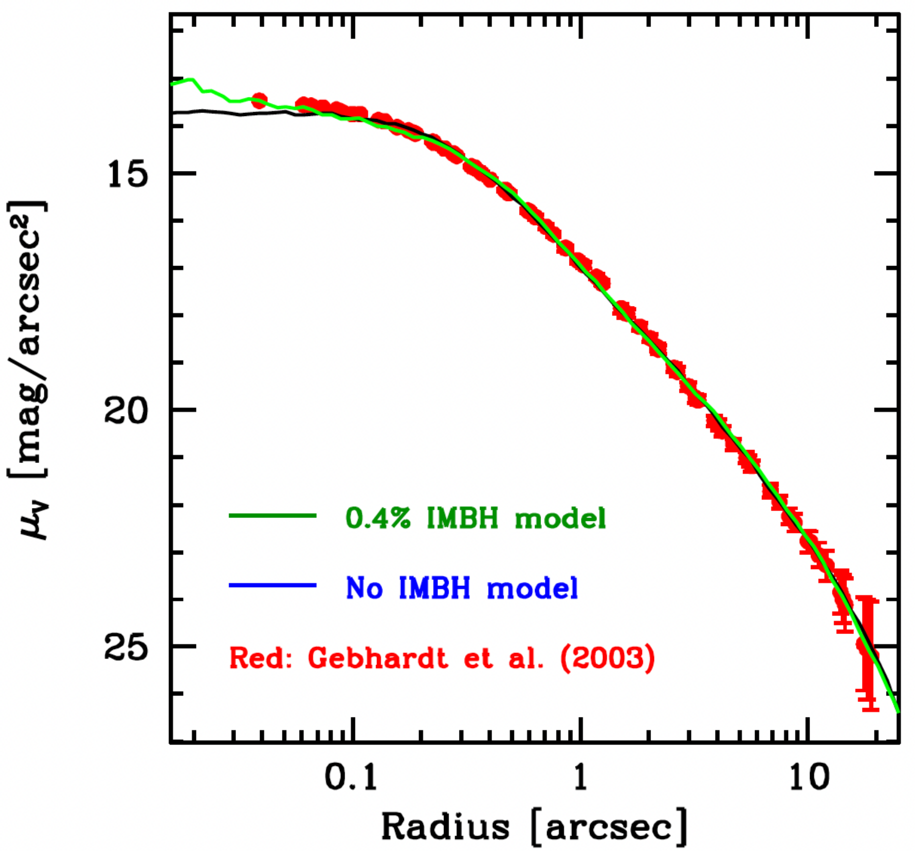


Velocity dispersion

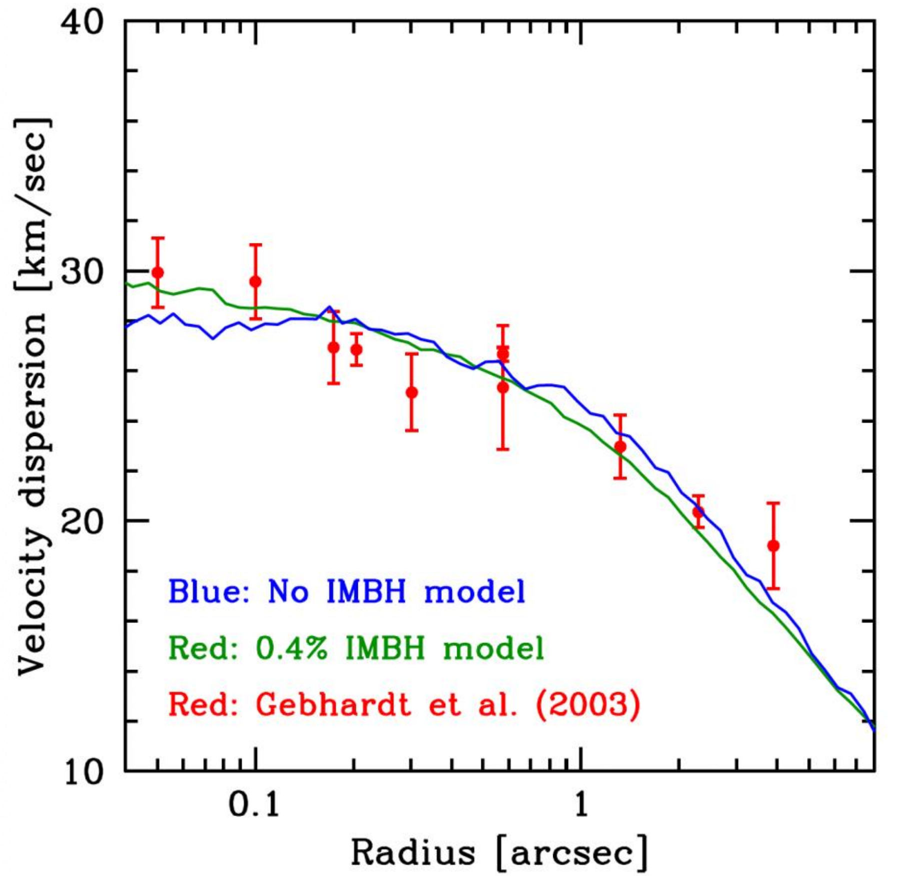


Other clusters: M31-G1

Surface density



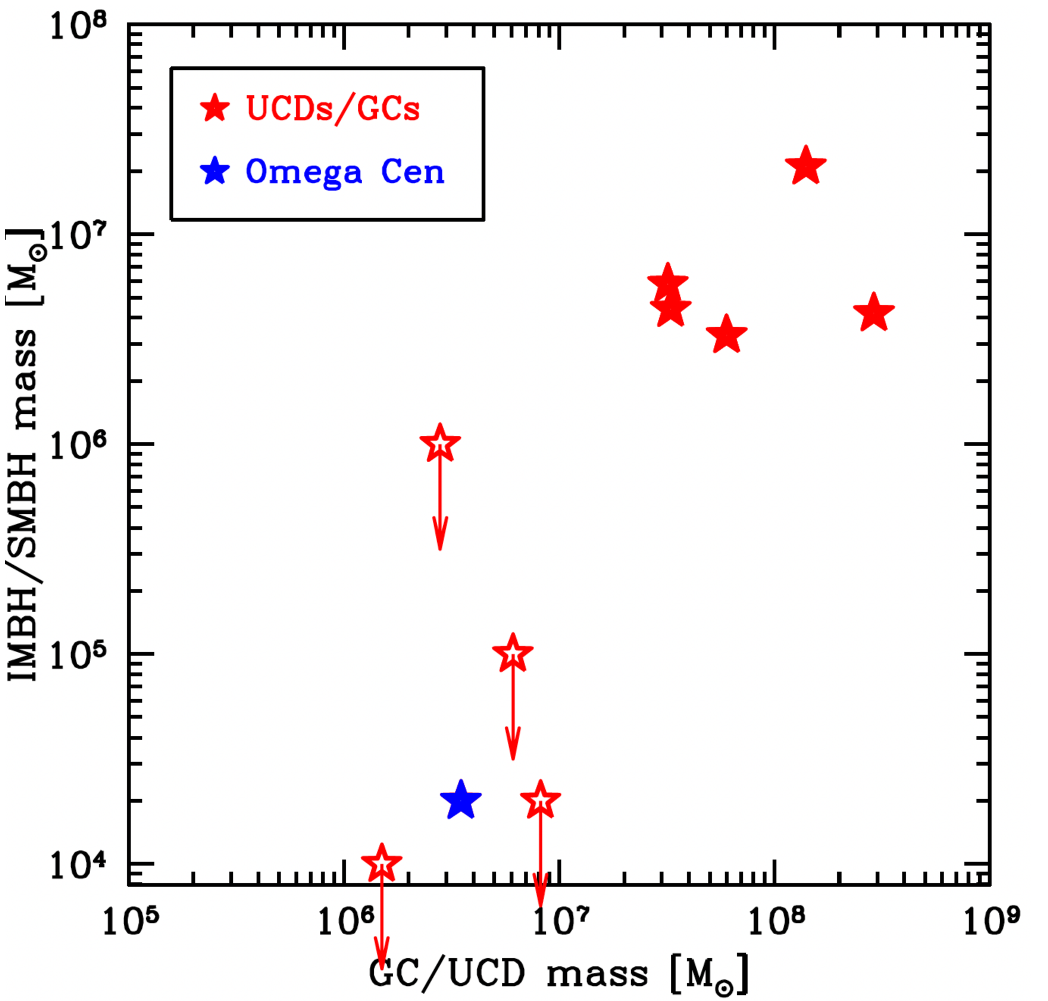
Velocity dispersion



Summary

Several massive black holes found in M>10^7 $M_\odot$ UCDs.

Among lower-mass systems only one clear IMBH detection in Omega Cen so far.

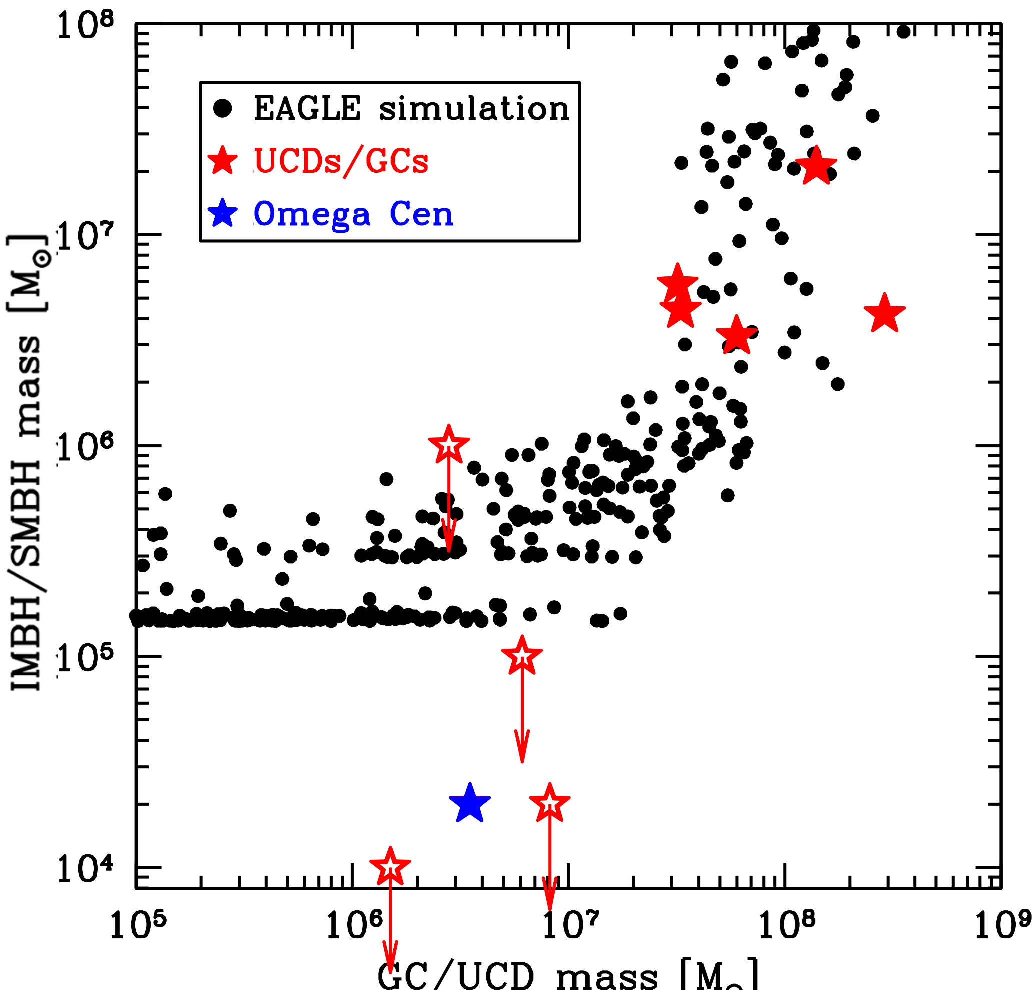


Summary

Several massive black holes found in M>10^7 $M_\odot$ UCDs.

Among lower-mass systems only one clear IMBH detection in Omega Cen so far.

SMBH masses are in agreement with cosmological simulations if 0.3% of galaxy mass is in nuclei which form UCDs.



see Mayes et al. (2024)