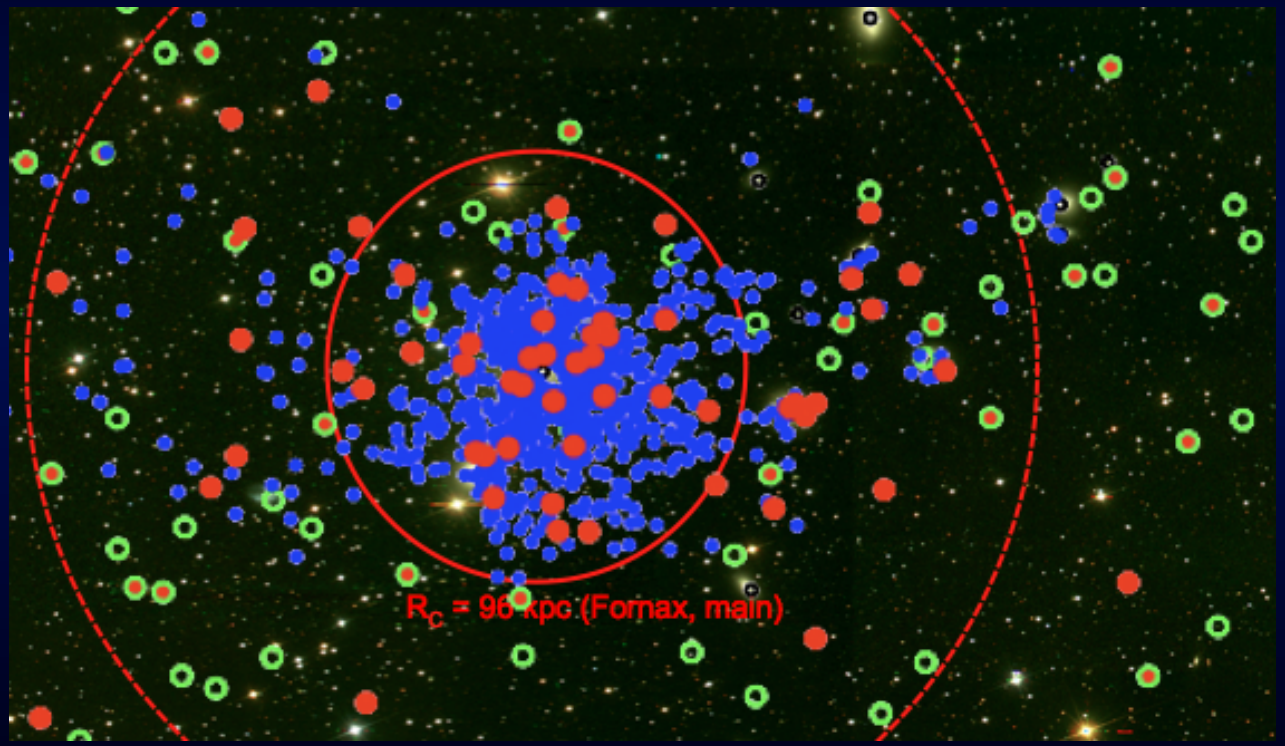
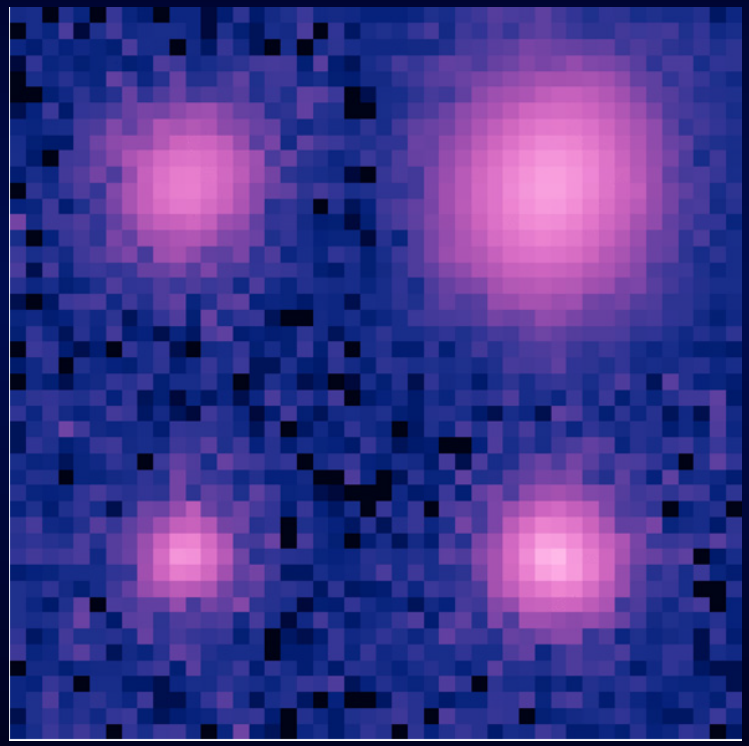
Ultra-compact dwarf galaxies: observational constraints on their origin

Michael Hilker

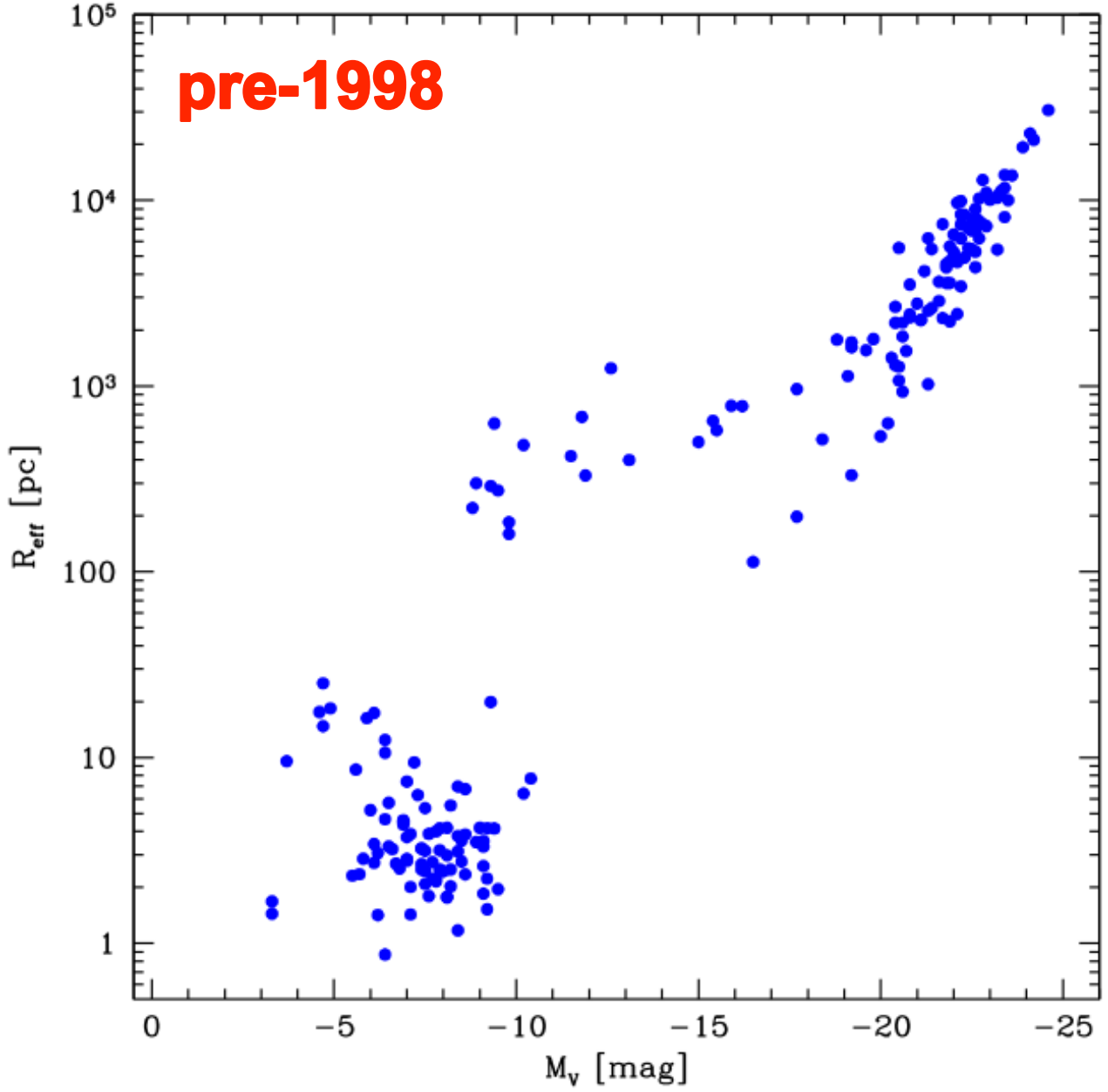




Where do we find UCDs? Have we found all UCDs? What actually are UCDs?

The (undefined) definition of UCDs

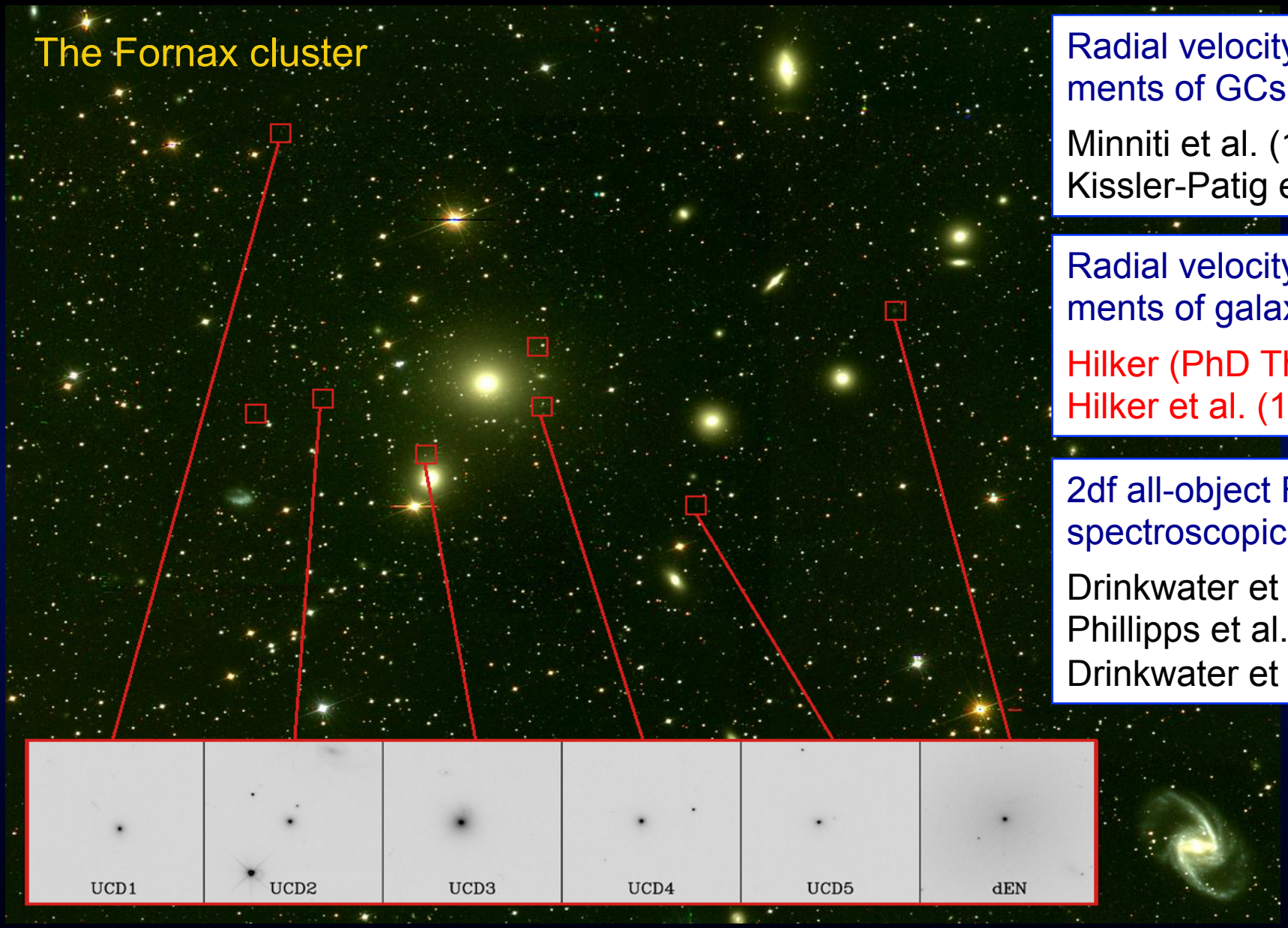
Early-type stellar systems in the luminosity-size plane



adapted from Misgeld & Hilker (2011)

mainly based on
Bender et al. (1993)
Mateo (1998)
Harris (1998)

The Fornax cluster



Radial velocity measurements of GCs:

Minniti et al. (1998)
Kissler-Patig et al. (1999)

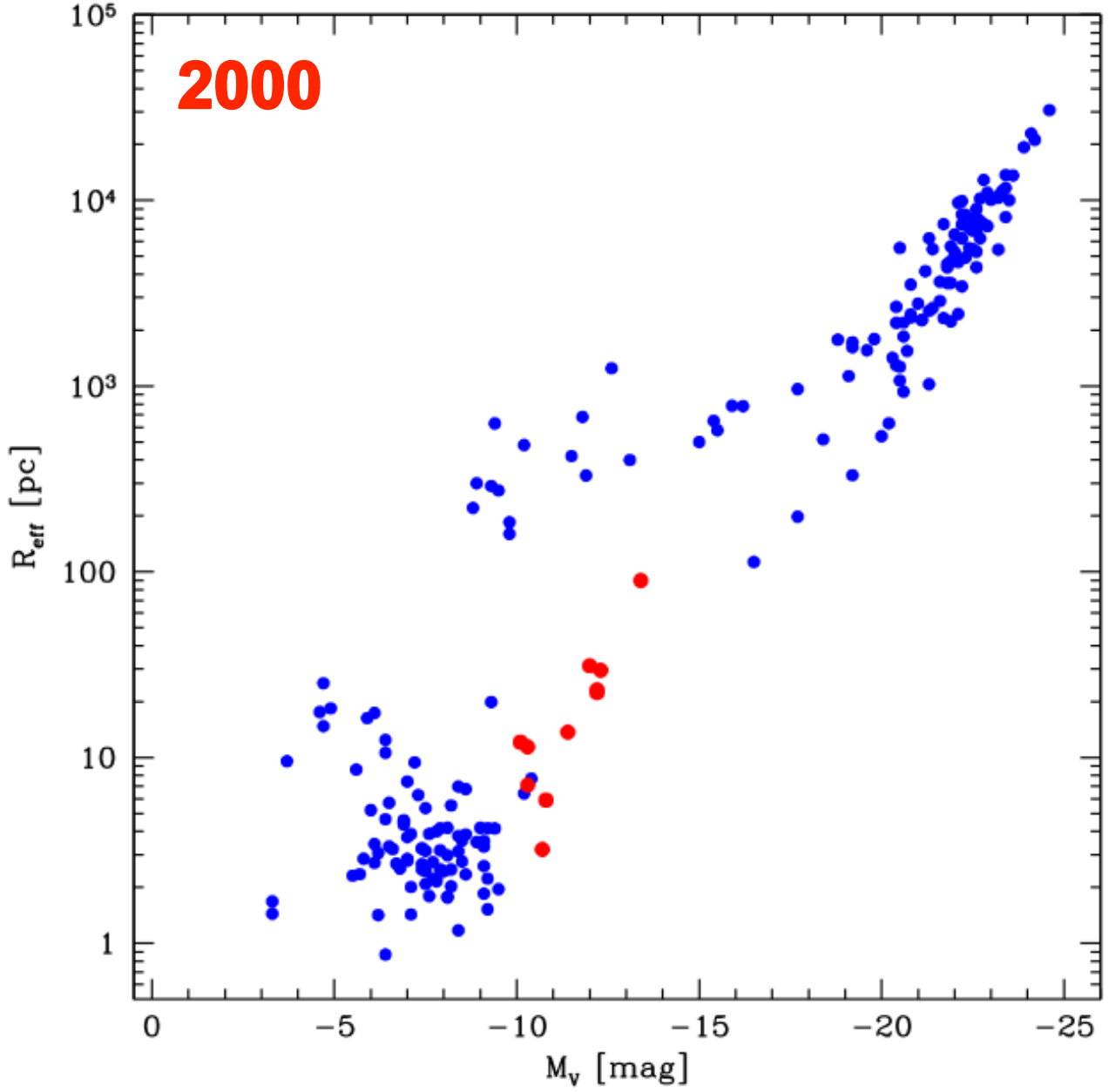
Radial velocity measurements of galaxies:

Hilker (PhD Thesis 1998)
Hilker et al. (1999)

2df all-object Fornax spectroscopic survey:

Drinkwater et al. (2000)
Phillipps et al. (2001)
Drinkwater et al. (2003)

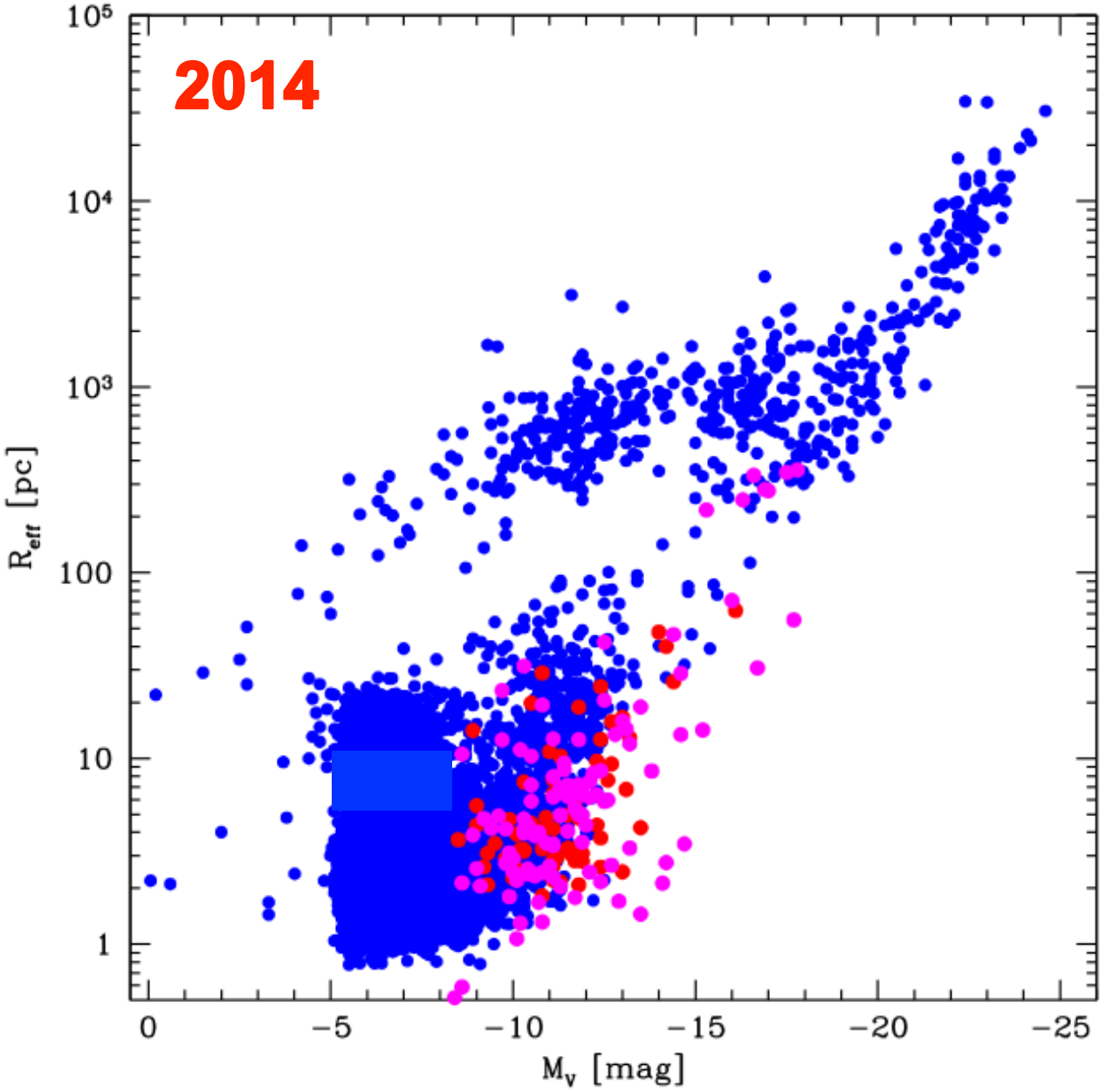
Early-type stellar systems in the luminosity-size plane



adapted from Misgeld & Hilker (2011)

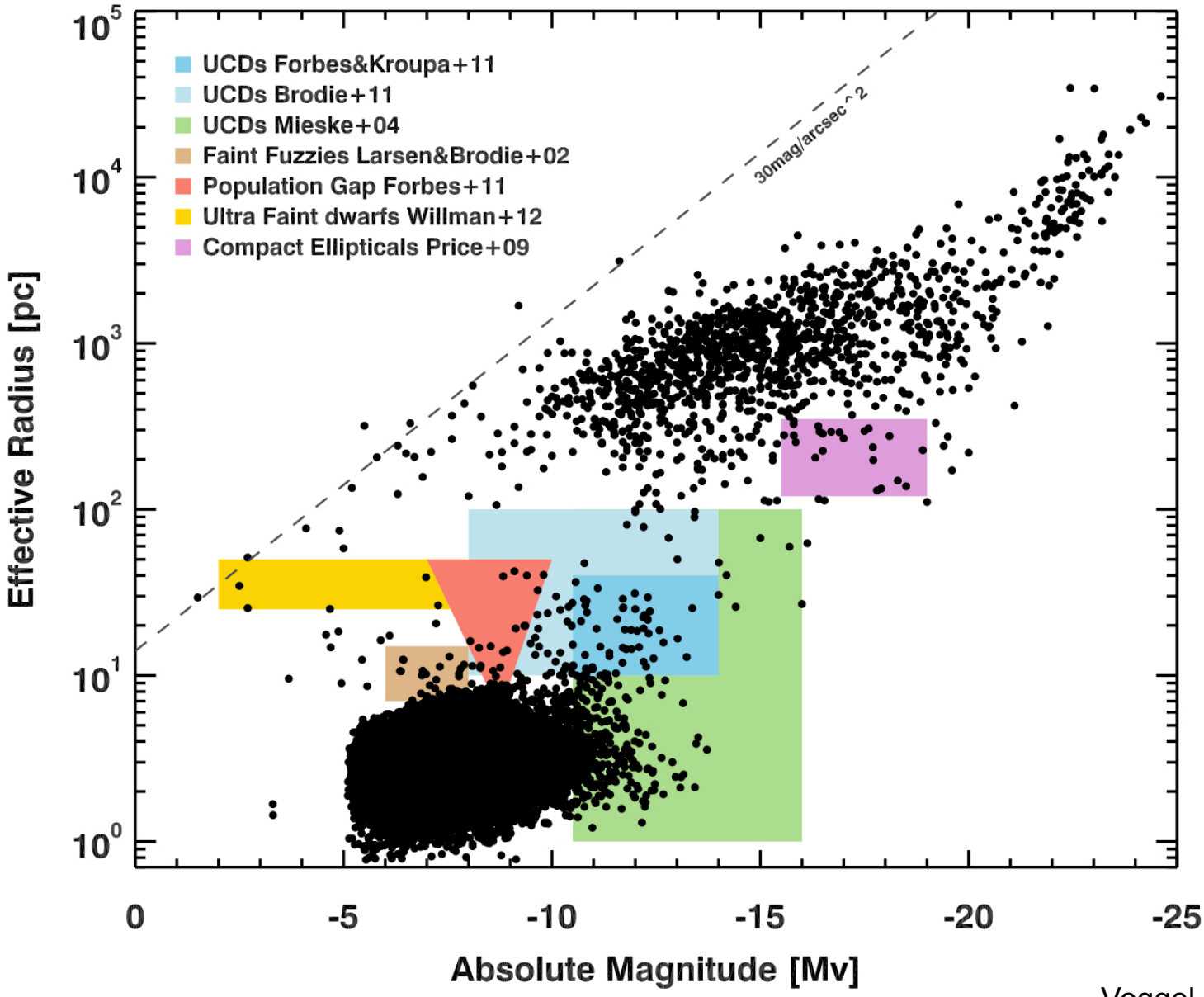
mainly based on
Bender et al. (1993)
Mateo (1998)
Harris (1998)
Holland et al. (1999)
Hilker et al. (1999)
Drinkwater et al. (2000)

Early-type stellar systems in the luminosity-size plane



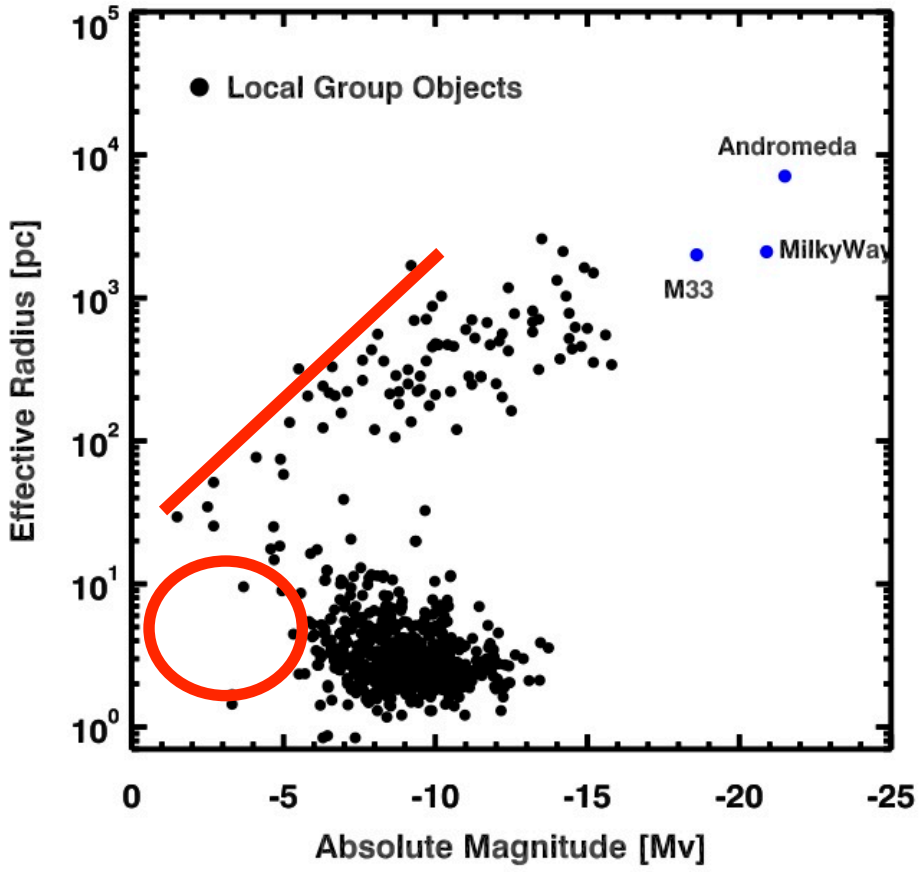
adapted from
Misgeld & Hilker (2011)
Brodie et al. (2011)
Brüns & Kroupa (2012),
plus nuclear star clusters from
Böker et al. (2004)
Rossa et al. (2006)
Cote et al. (2006)
Georgiev & Böker (2014)

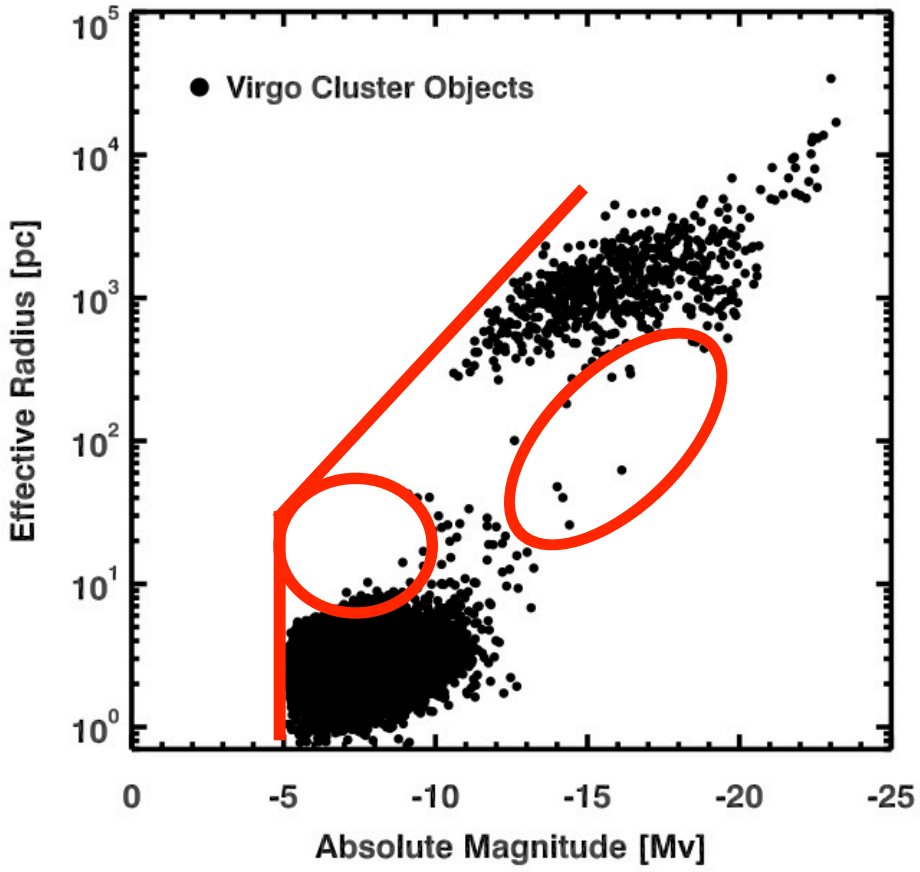
The (undefined) definition of UCDs?



Voggel, Hilker, et al. (in prep.)

Splitting the ‚everything plot' into different environments





Voggel, Hilker, et al. (in prep.)

What is the origin of UCDs?

UCD formation channels

There are two main lines of formation scenarios for UCDs:

1) UCDs are build up by star cluster formation processes

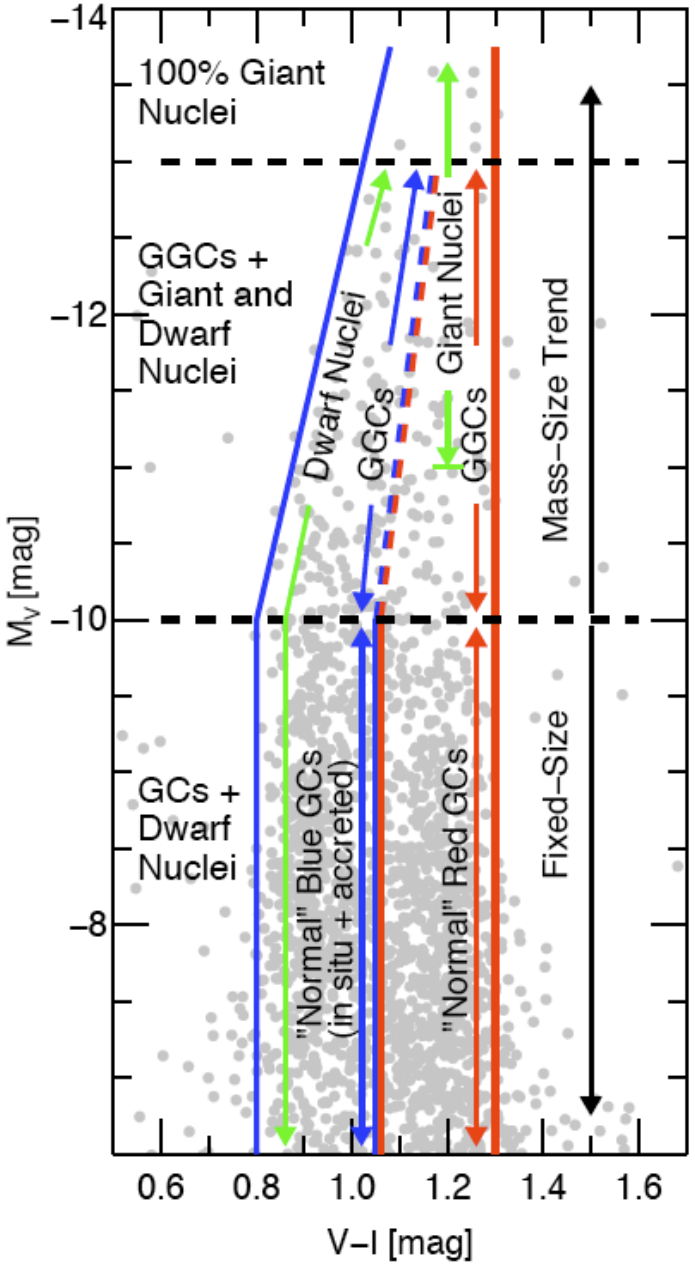
- they are the tip of the mass spectrum of a star cluster population
- formed in giant molecular clouds (maybe in clumps of high-z galaxies or in cooling flow filaments)
- or formed via the amalgamation of super star cluster complexes in merger induced star formation events

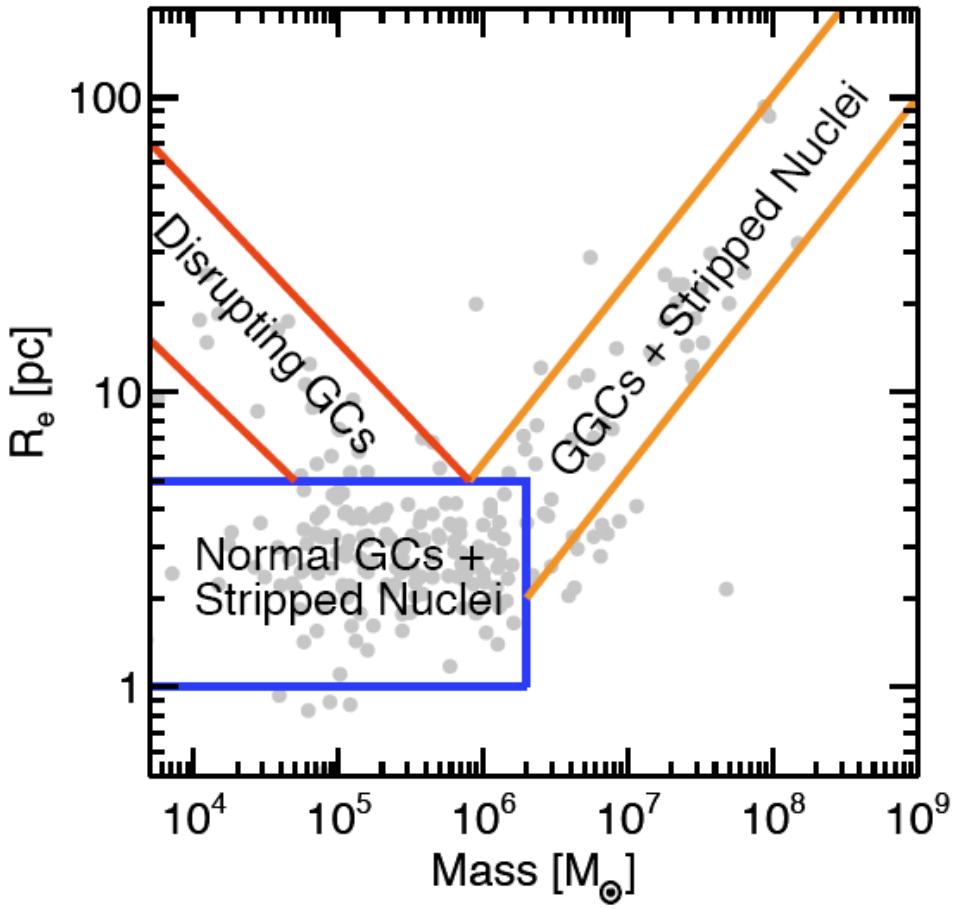
2) UCDs are remnants of disruptive galaxy evolution processes

- UCDs were located in the centres of their host galaxies (nuclei)
- they followed the formation history of a nuclear star cluster
- they might be related to dark matter sub-structure

3) Exotic scenario: UCDs are recoiling 'runaway' SMBHs+stellar envelope originating from interactions of multiple SMBHs (Merritt 2009)

The origin of GCs and UCDs in the colour-magnitude plane and the mass-size plane





Norris & Kannappan (2011)

Observational parameters of UCDs

UCD observational studies (1)

There are two main lines of investigations to study the properties of UCDs and to decipher their origin:

1) **The ensemble properties of UCDs**
   in relation to globular cluster systems and dwarf galaxy populations in their respective environments

   - spatial distribution
   - mass spectrum
   - dynamics around host
   - metallicity (colour) distribution
   - size distribution
   - specific frequency

   We can learn about …

   … link of UCDs to their host
   … formation channel(s) of UCDs
   … galaxy and/or galaxy cluster formation and evolution

UCD observational studies (2)

2) The internal properties of UCDs

A. Unresolved point source:

- luminosity, colour → stellar mass
- global velocity dispersion → dynamical mass
- metallicity (Fe, [α/Fe] , …) + Balmer lines → age

B. Spatially resolved UCD:

- surface brightness profile
- colour/metallicity profile
- velocity dispersion profile, rotation

C. UCD resolved into single stars:

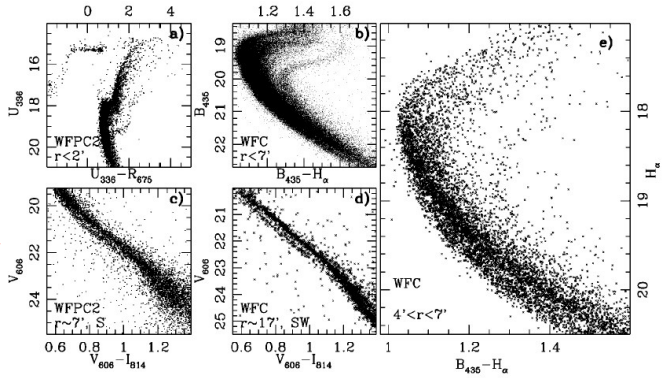
- CMD → multiple stellar populations

We can learn about …

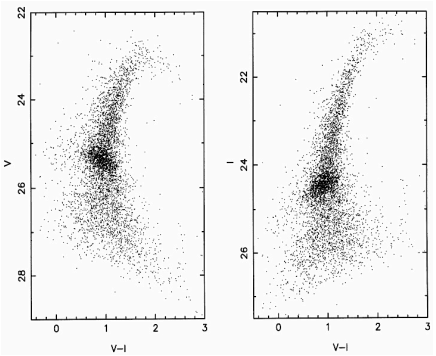
… formation history of individual UCDs

… distribution of seen and unseen matter in UCDs

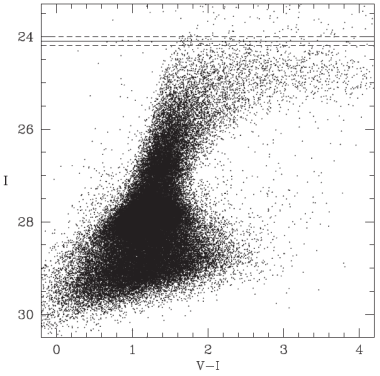
Most massive GC/UCD	Distance (kpc)	Half-light diameter
ω Centauri (Milky Way)	5.2	600”
	x148	
M31-G1 (Andromeda)	770	3.5”
	x5	
HCH99-18 (Cen A)	3800	1.5”
	x5	
UCD3 (Fornax)	19000	1.9”



Bedin et al. (2004)

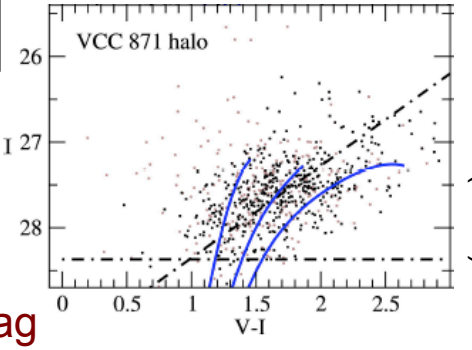


Meylan et al. (2001)



Rejkuba et al. (2005)

Cen A halo: RGB_{TIP}=24 mag



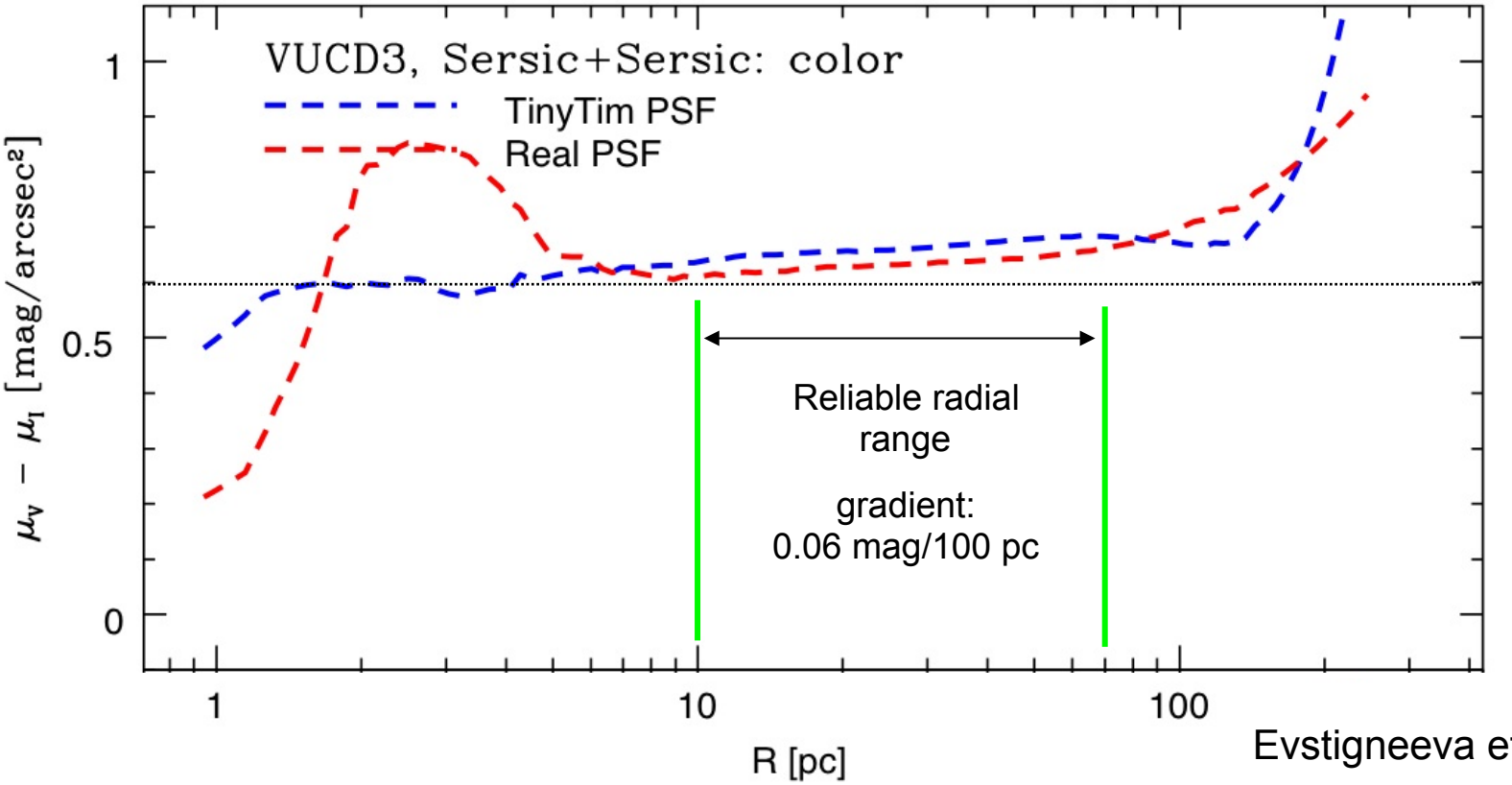
Caldwell (2006)

Virgo: RGB_{TIP}~27 mag
Fornax: RGB_{TIP}~27.5 mag

Multiple stellar populations in UCDs?

Motivation: ω Cen and G1 have complex stellar populations

Colour gradients within UCDs from HST photometry:



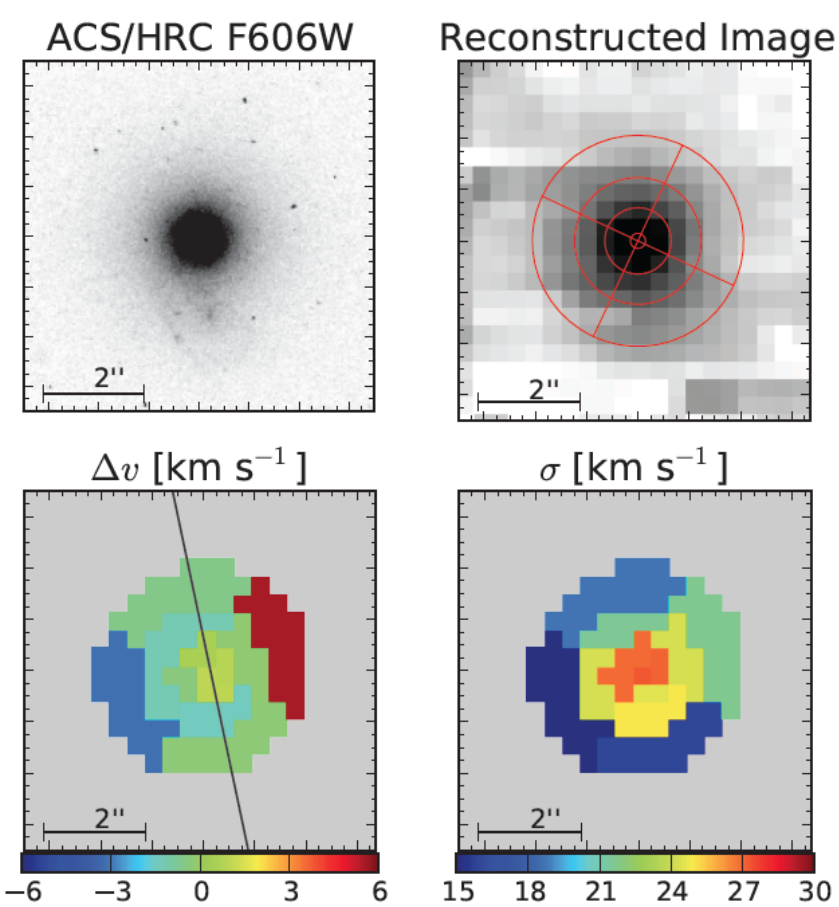
Evstigneeva et al. (2008)

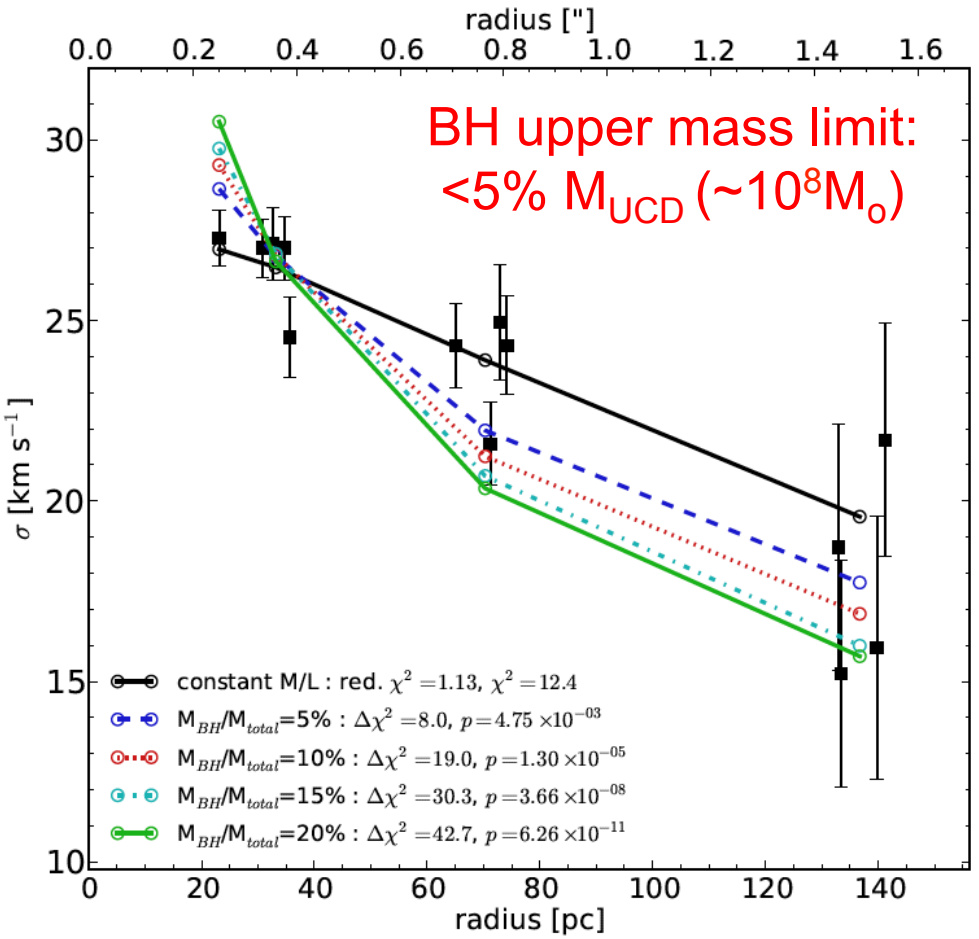
Positive colour gradient (getting redder outside) found in several of the most massive Fornax and Virgo UCDs.

Unseen mass (IMBHs/DM) in UCDs?

Motivation: high dynamical M/L ratios of massive UCDs

VLT FLAMES/ARGUS IFU observations of UCD3 in Fornax:



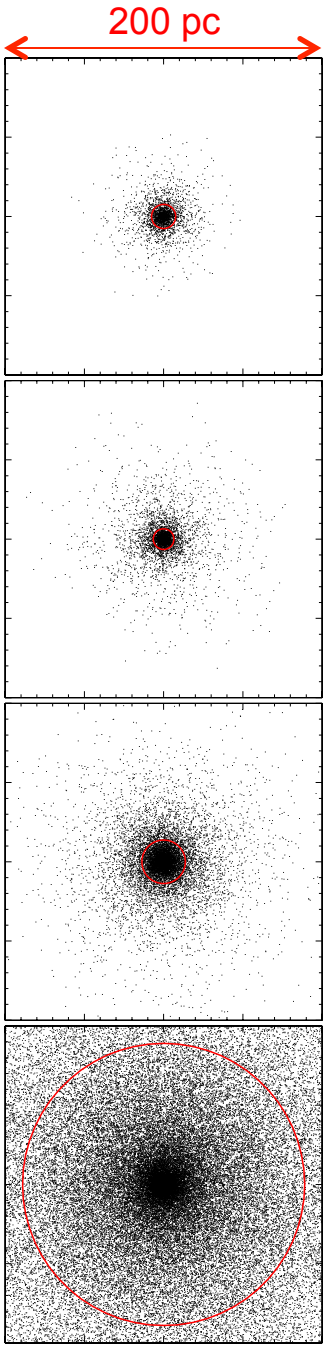


Frank, Hilker, Mieske et al. (2011)

Result for UCD3: mass follows light!

The most massive UCD in its environment

Most massive GC/UCD	Host galaxy	Mass (M_o)
ω Centauri	Milky Way	2.5×10^6
		x2
M31-G1	Andromeda	5.0×10^6
		x3
HCH99-18	Cen A	14.2×10^6
		x7
UCD3	NGC 1399	93.5×10^6



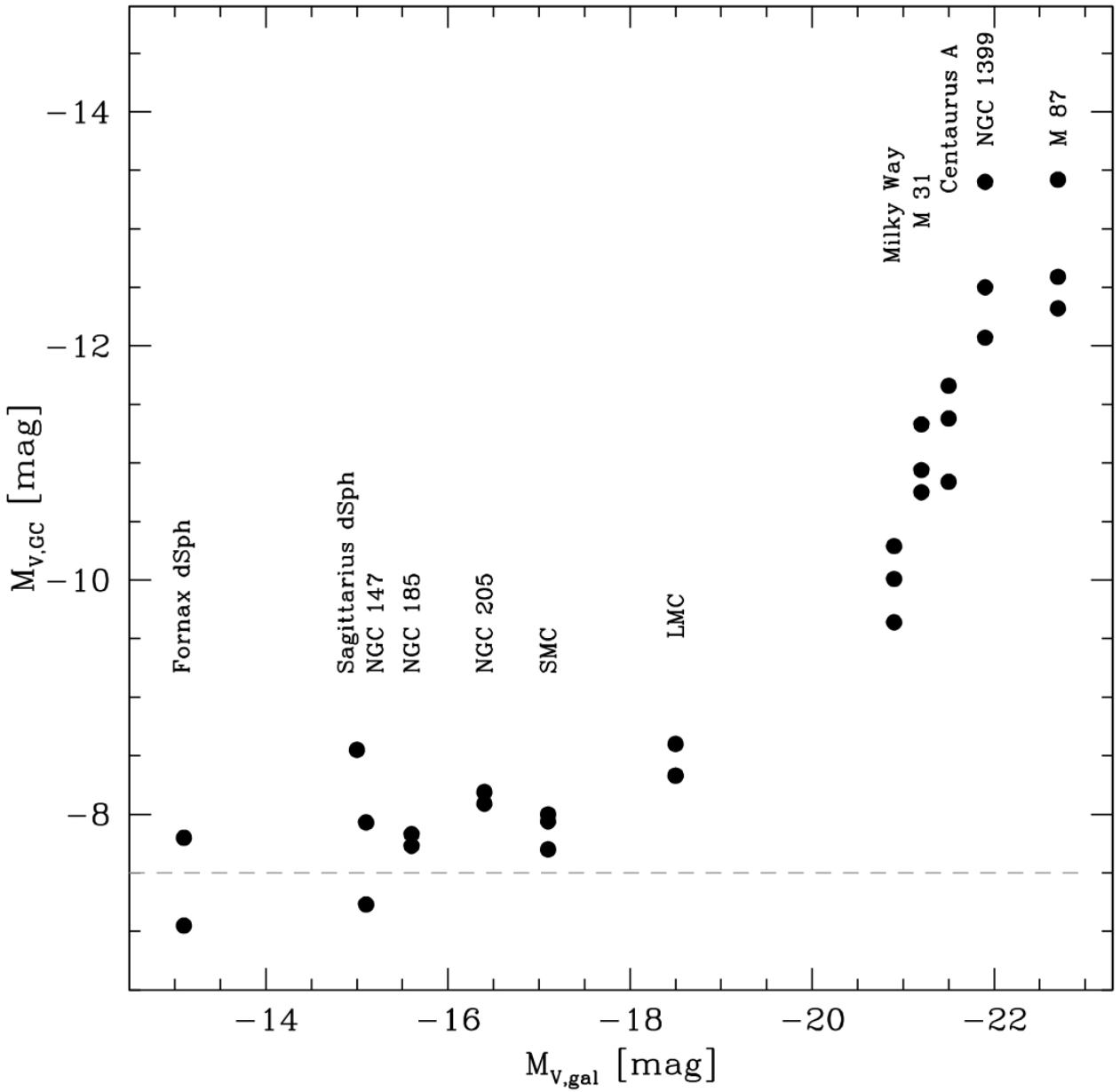
R_h=7.6 pc

R_h=6.5 pc

R_h=13.7 pc

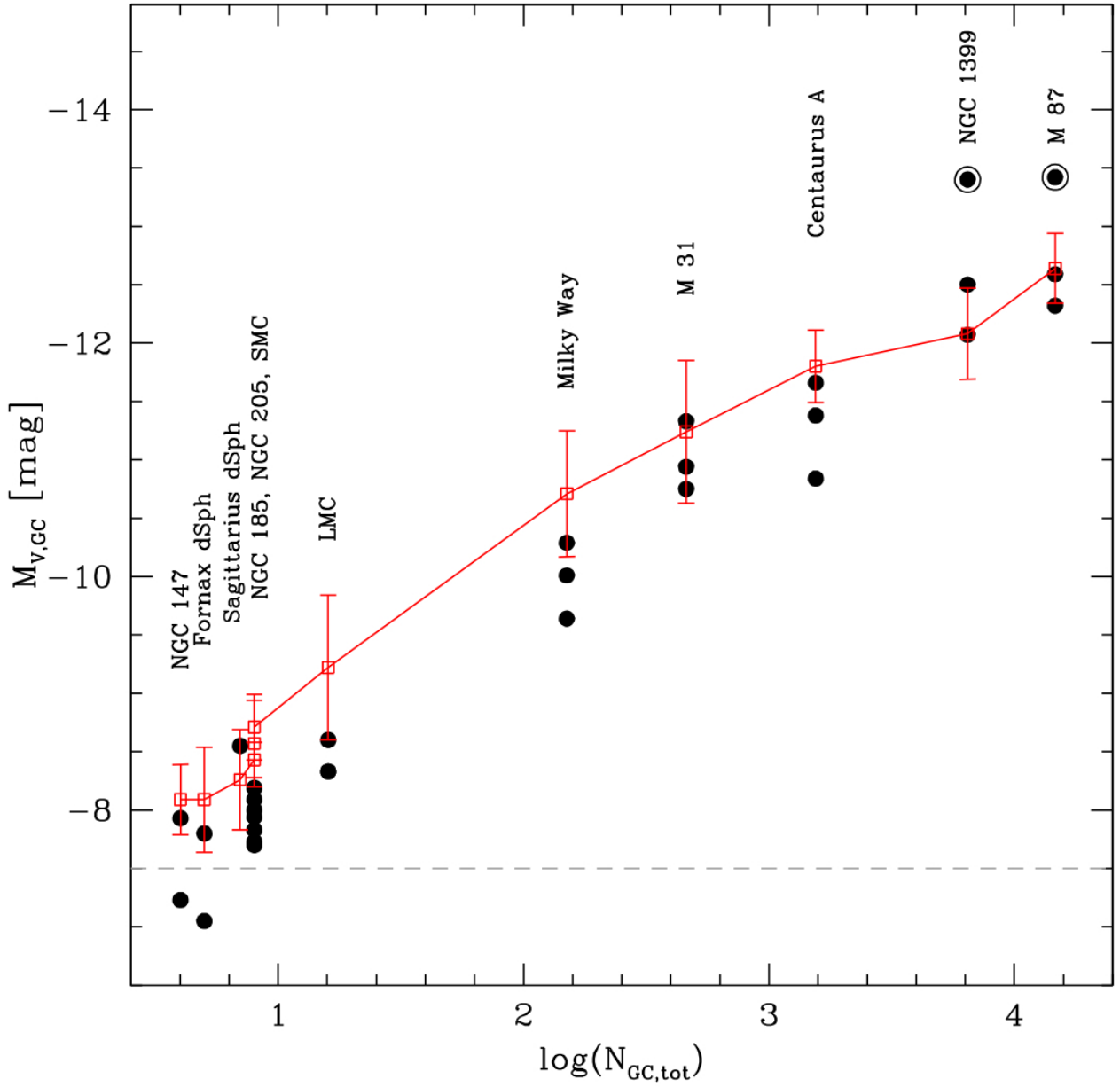
R_h=89.5 pc

The 2-3 most luminous GCs vs. host galaxy luminosity



Hilker (2009)

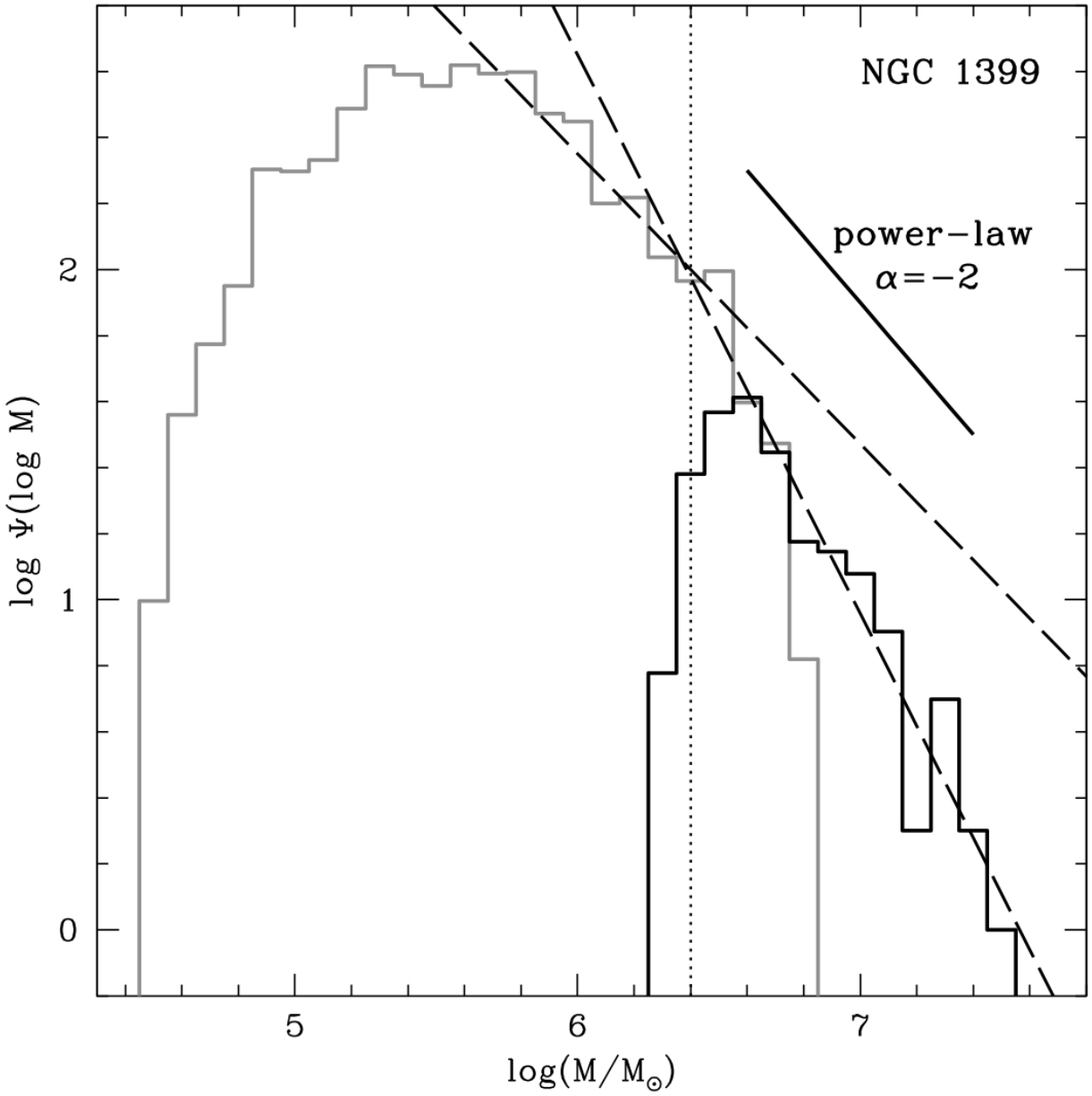
The 2-3 most luminous GCs vs. total number of GCs



Monte-Carlo simulation of most luminous GC drawn from a Gaussian GC luminosity function

Hilker (2009)

Mass function of GCs and UCDs in Fornax



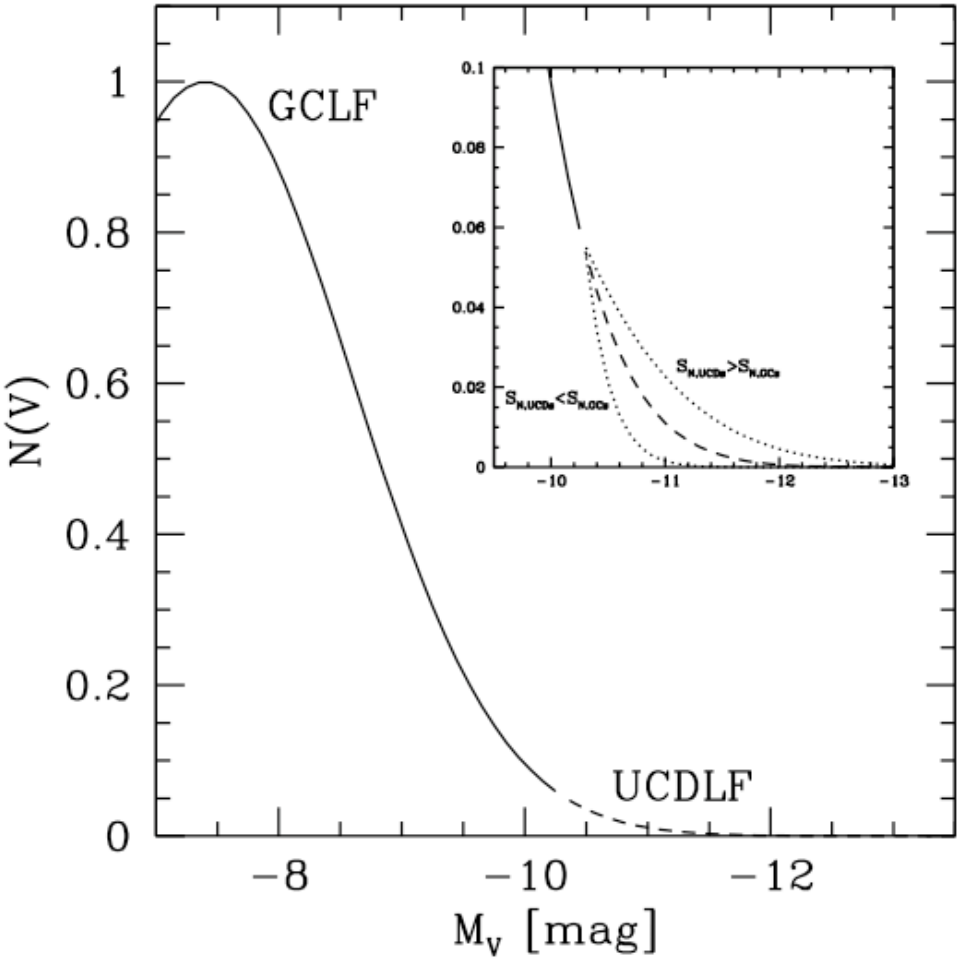
power-law slopes:

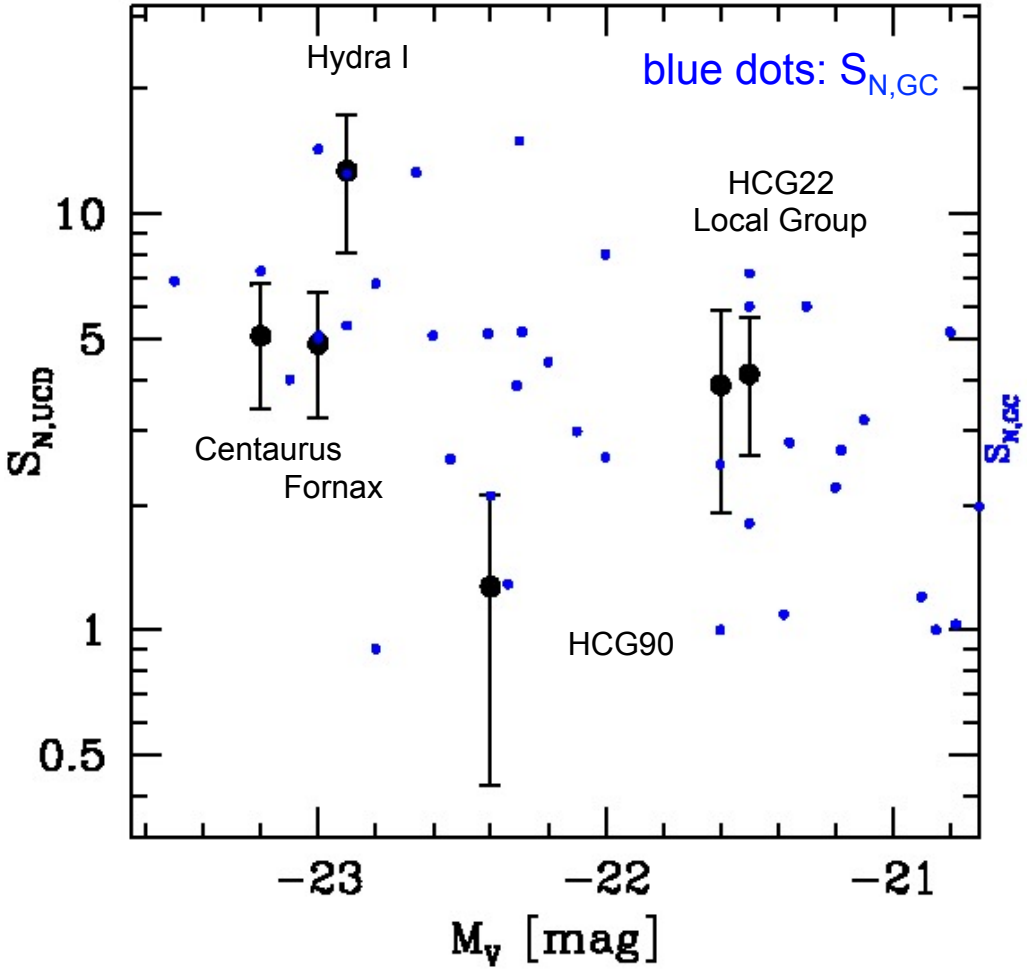
α = -1.9

α = -2.7

Hilker (2009)

The specific frequency of UCDs





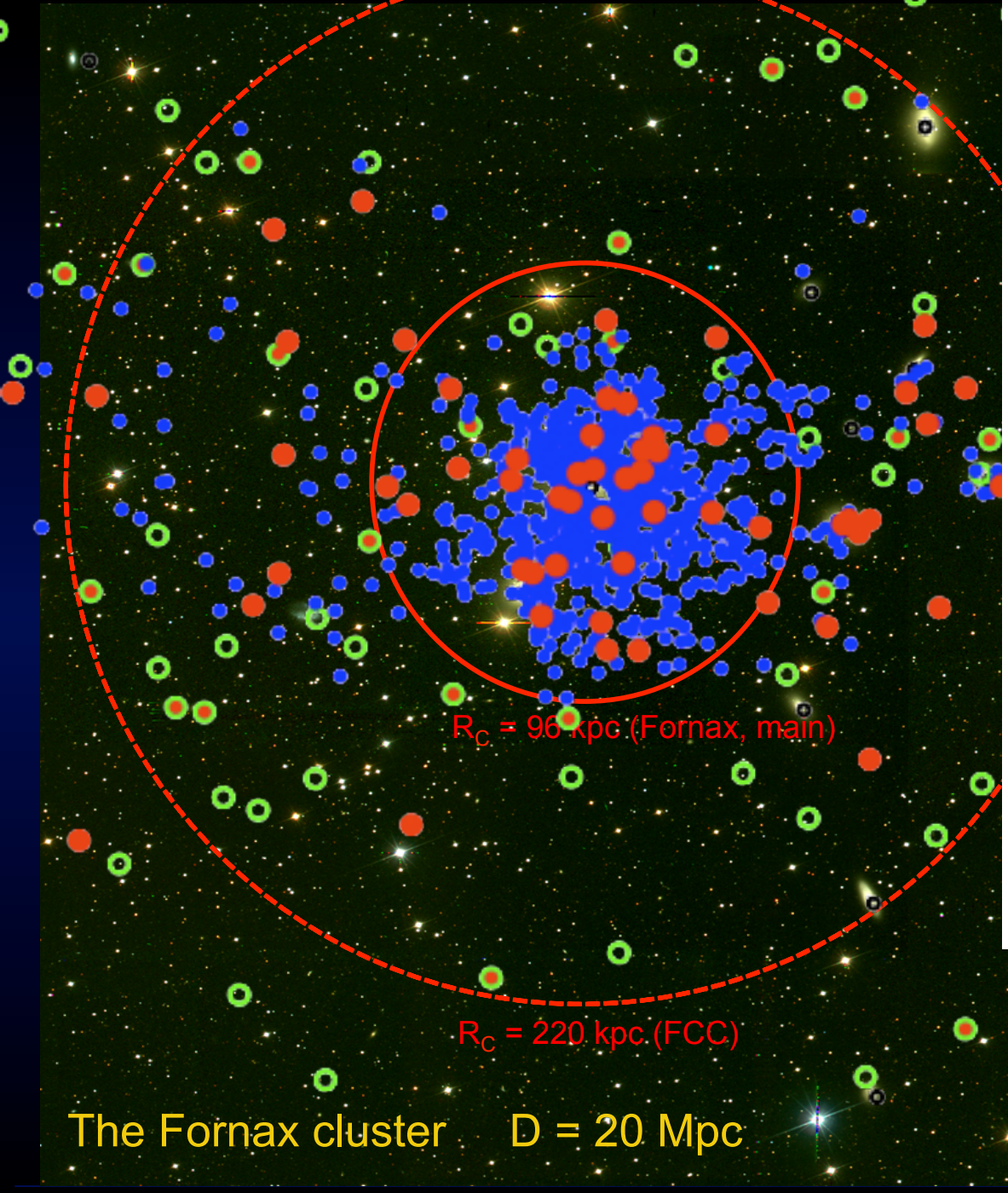
$$S_{N,UCD} = N_{UCD} \times 10^{\,0.4 \times (\,M(V,host) - M(V,0)\,)} \times c_w$$

accounts for lost galaxy luminosity-width of GCLF relation

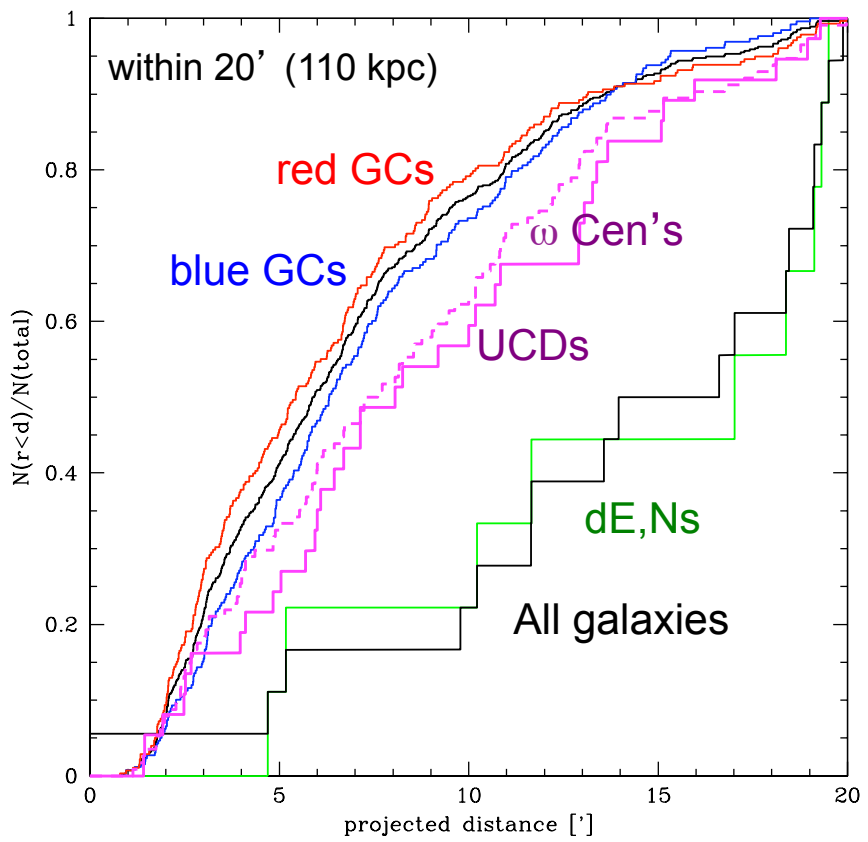
$S_{N,UCDs}$ follows $S_{N,GCs}$!!

Mieske, Hilker & Misgeld (2011)

Spatial distribution of UCDs



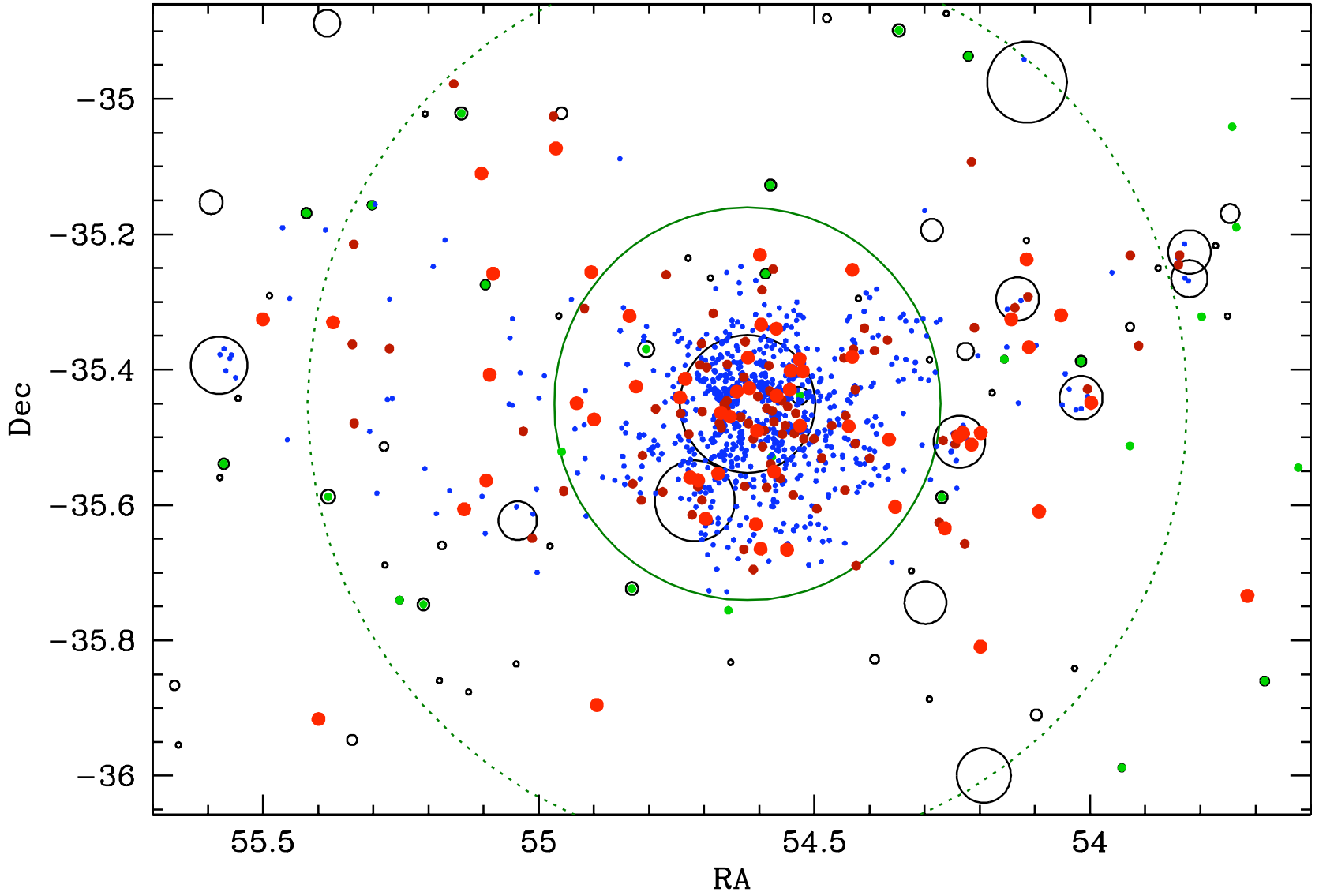
The Fornax cluster D = 20 Mpc



red GCs < blue GCs < ωCen's < UCDs < dE,Ns < dEs < all galaxies

Hilker (2010)

Distribution of confirmed UCDs/GCs and dEs in Fornax



M_V<-8.5

M_V<-10.4

M_V<-11.0

dE,Ns

UCDs/GCs:

Hilker et al. (1999, 2007)

Drinkwater et al. (2000, 2003)

Mieske et al. (2004, 2008)

Bergond et al. (2007)

Schuberth et al. (2008, 2010)

Richtler et al. (2004, 2008)

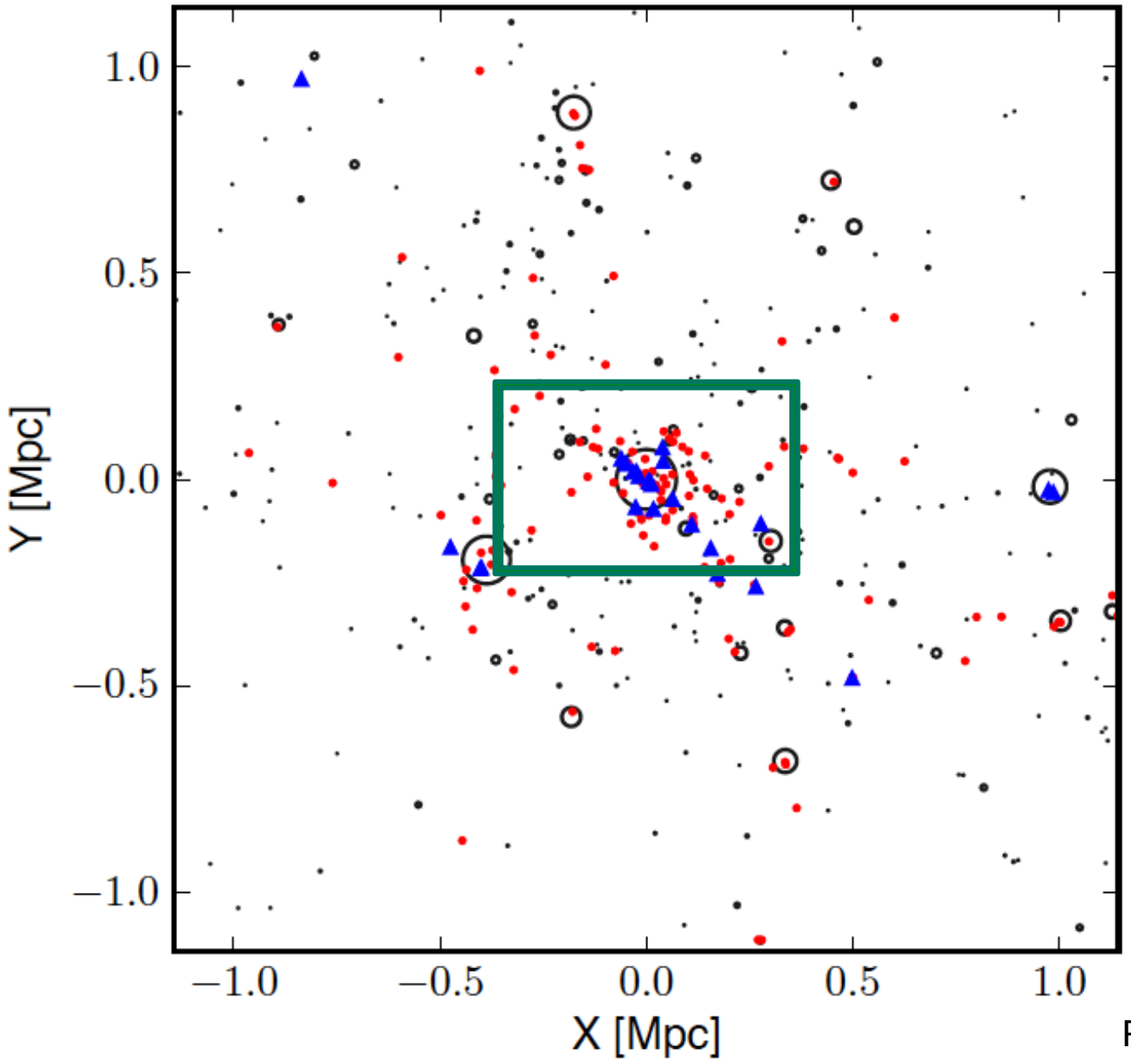
Kissler et al. (1999)

Firth et al. (2007, 2008)

Gregg et al. (2009)

Puzia, Hilker+ (2014, in prep.)

Distribution of stripped nuclei in simulations



$M>10^7\ M_o$

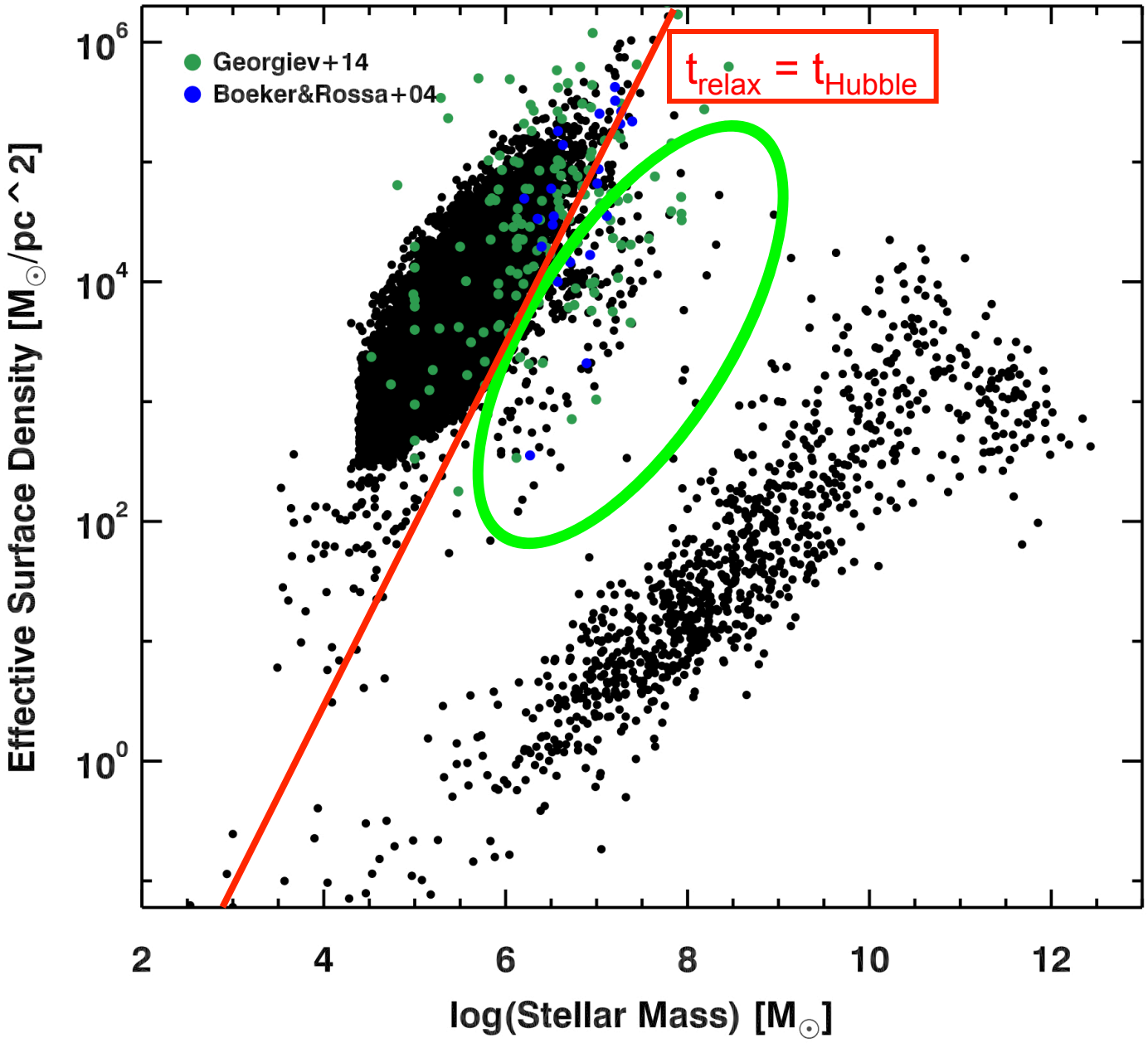
$3x10^5<M<10^7\ M_o$

Virgo-sized cluster

Pfeffer et al. (2014, subm.)

So, what are UCDs?

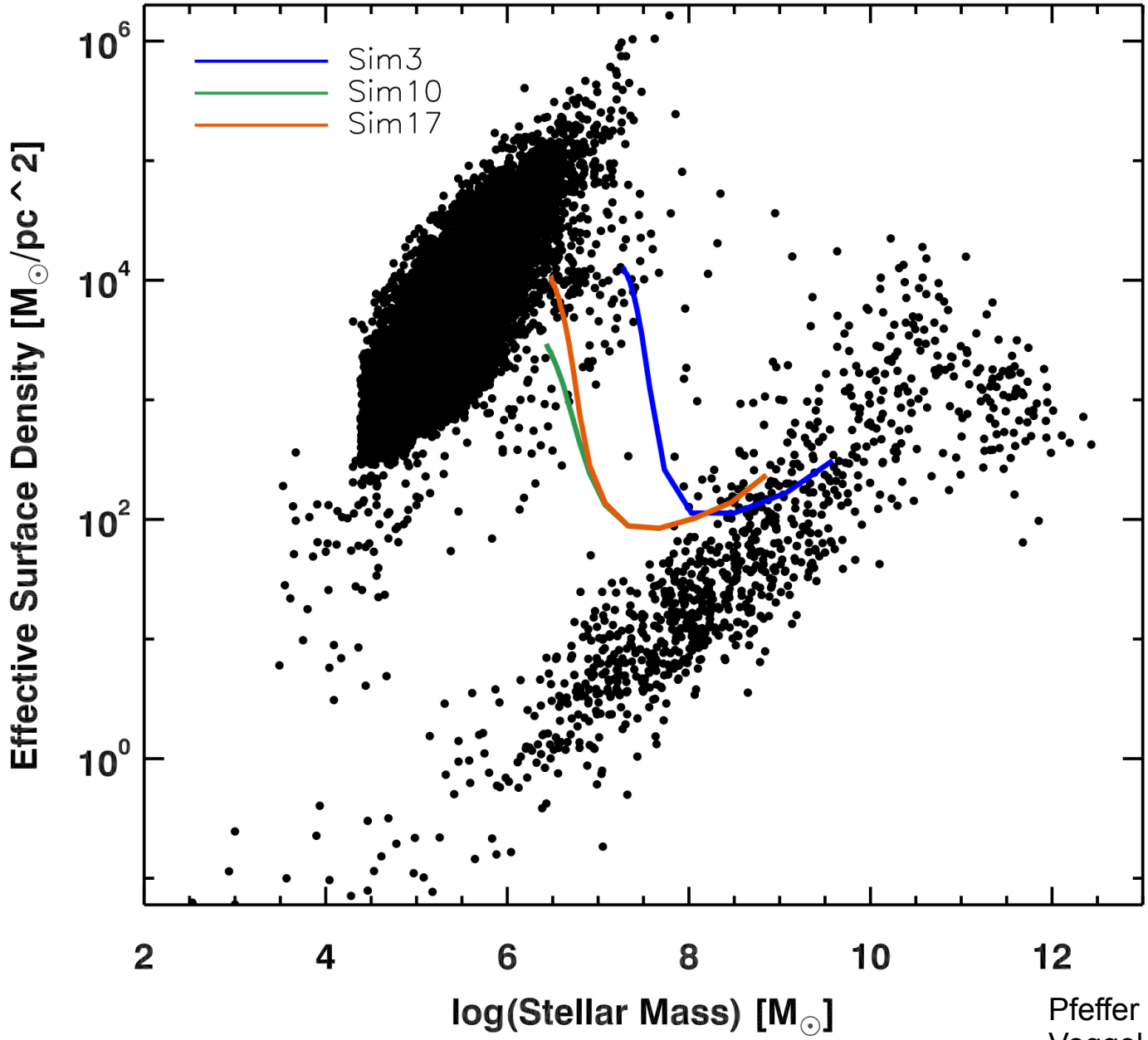
Surface density-mass relation of early-type stellar systems



In terms of galaxies, UCDs are `ultra-compact'.

In terms of star clusters, most UCDs are rather diffuse.

Voggel, Hilker, et al. (in prep.)



Pfeffer & Baumgardt (2013)
Voggel, Hilker, et al. (in prep.)

Summary

- `UCDs' are defined through an upper envelope in the mass-size relation and enhanced dynamical mass-to-light ratios – roughly occurring at >2x$10^6 M_\odot$
- `UCDs' share properties of nuclear star clusters, e.g. the mass-size relation, but also are the "tip of the iceberg" of rich globular cluster systems → they are mostly of `star cluster origin'
- UCDs are mostly concentrated around major galaxies but also are found in the intra-cluster space
- The specific frequency of UCDs follows that of GCs, i.e. a large UCD population is expected in rich globular cluster systems → the formation of UCDs is linked to that of GCs
- Still the studies of the UCD populations in nearby clusters suffer from incompleteness effects – more spectroscopic surveys!