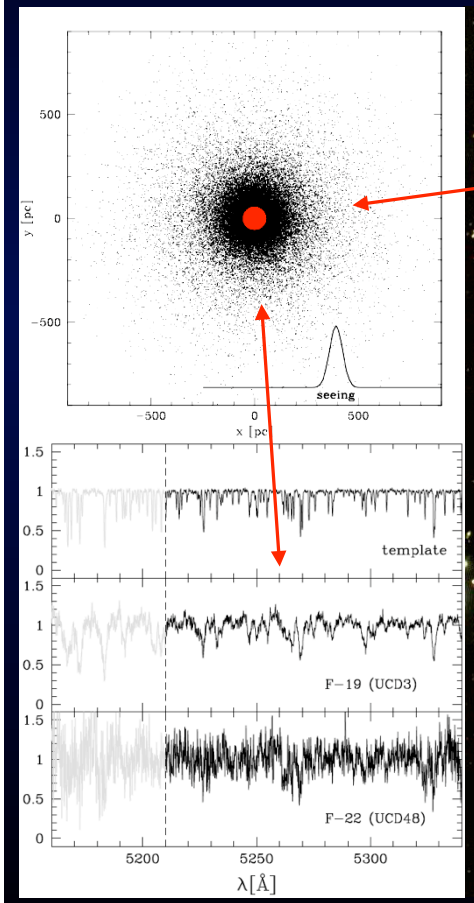
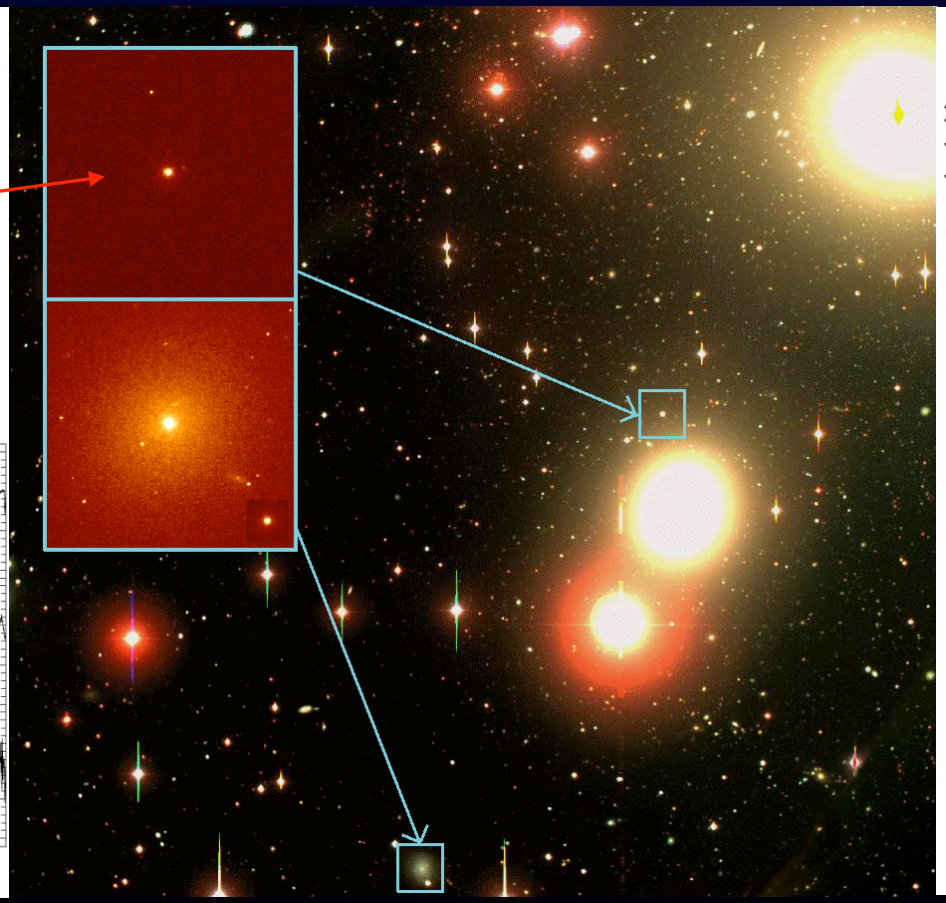
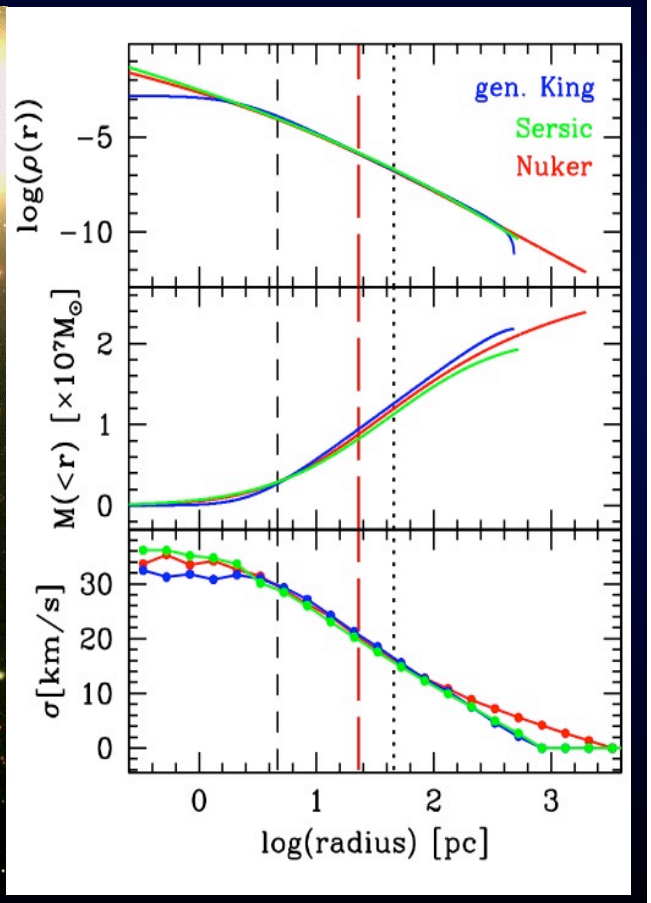
Internal dynamics of ultra-compact dwarf galaxies I

Michael Hilker (ESO/Garching)







Steffen Mieske, Matthias Frank, Holger Baumgardt, Ingo Misgeld, Igor Chilingarian

Characteristics of „Ultra-Compact Dwarf galaxies“ (UCDs)

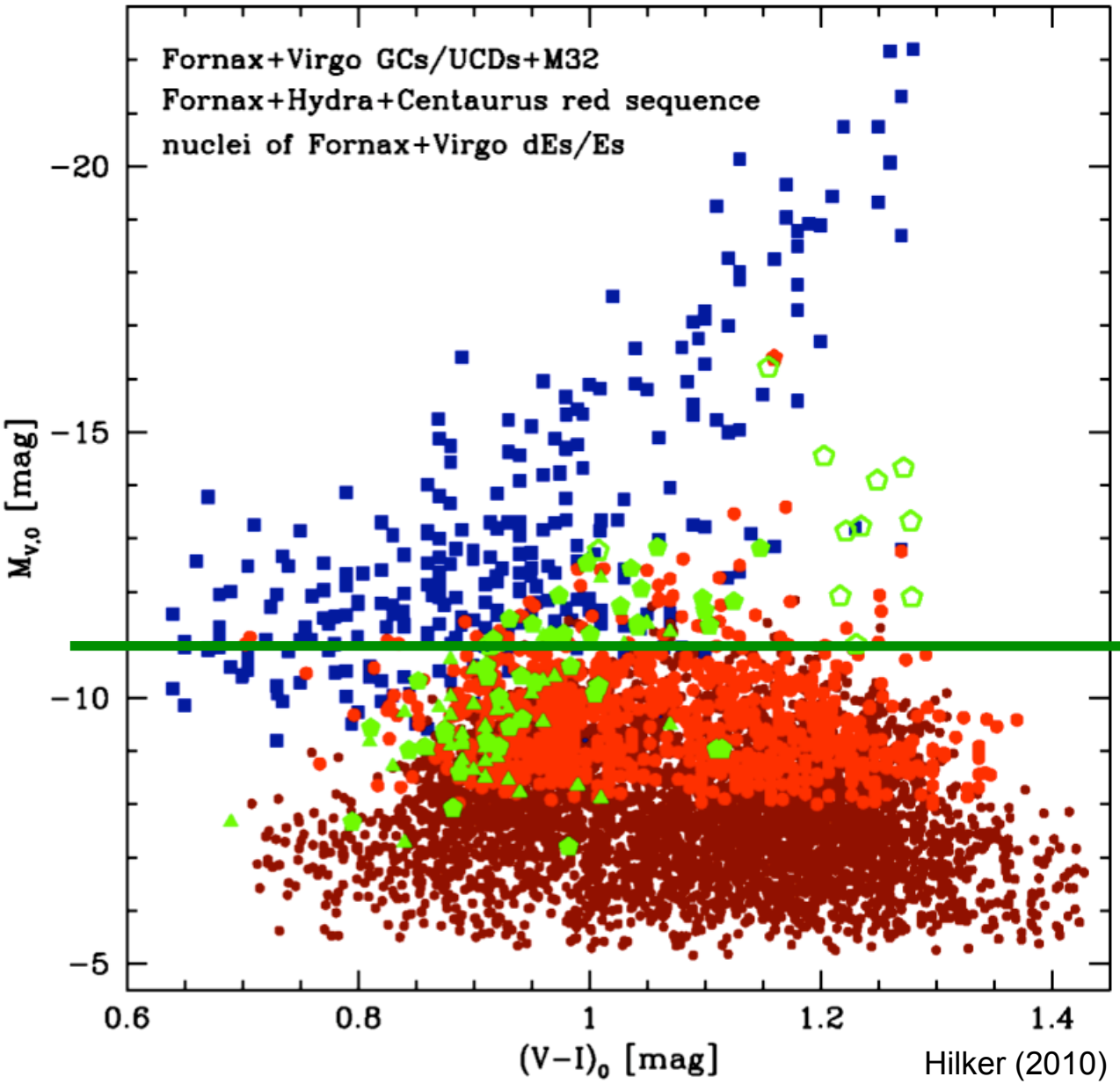
Dr. Michael Hilker (ESO, Garching)

Ultra-compact dwarf galaxies*

Luminosities:	**$-13.5<M_V<-11.0$**	(although ω Centauri (M_V=-10.4) might be a small UCD)
Half-light radii:	**$5<R_{h,p}<30$ pc**	(a few have LSB envelopes with $80<R_{eff}<120$ pc)
Velocity dispersion:	**$25<\sigma_0<45$ km/s**	(extrapolated from the observed velocity dispersion)
Mass range:	**$\geq 2 \times 10^6$-10^8 $M_\odot$**	(dynamical mass)
M/L_{dyn}:	**2-10**	(different from the expected M/L of canonical stellar populations)
Occurence:	**In cores of galaxy clusters or close to major galaxies (also in groups and field)**	

*First discoveries: Hilker et al. (1999), Drinkwater et al. (2000); name 'UCD': Phillipps et al. (2001)

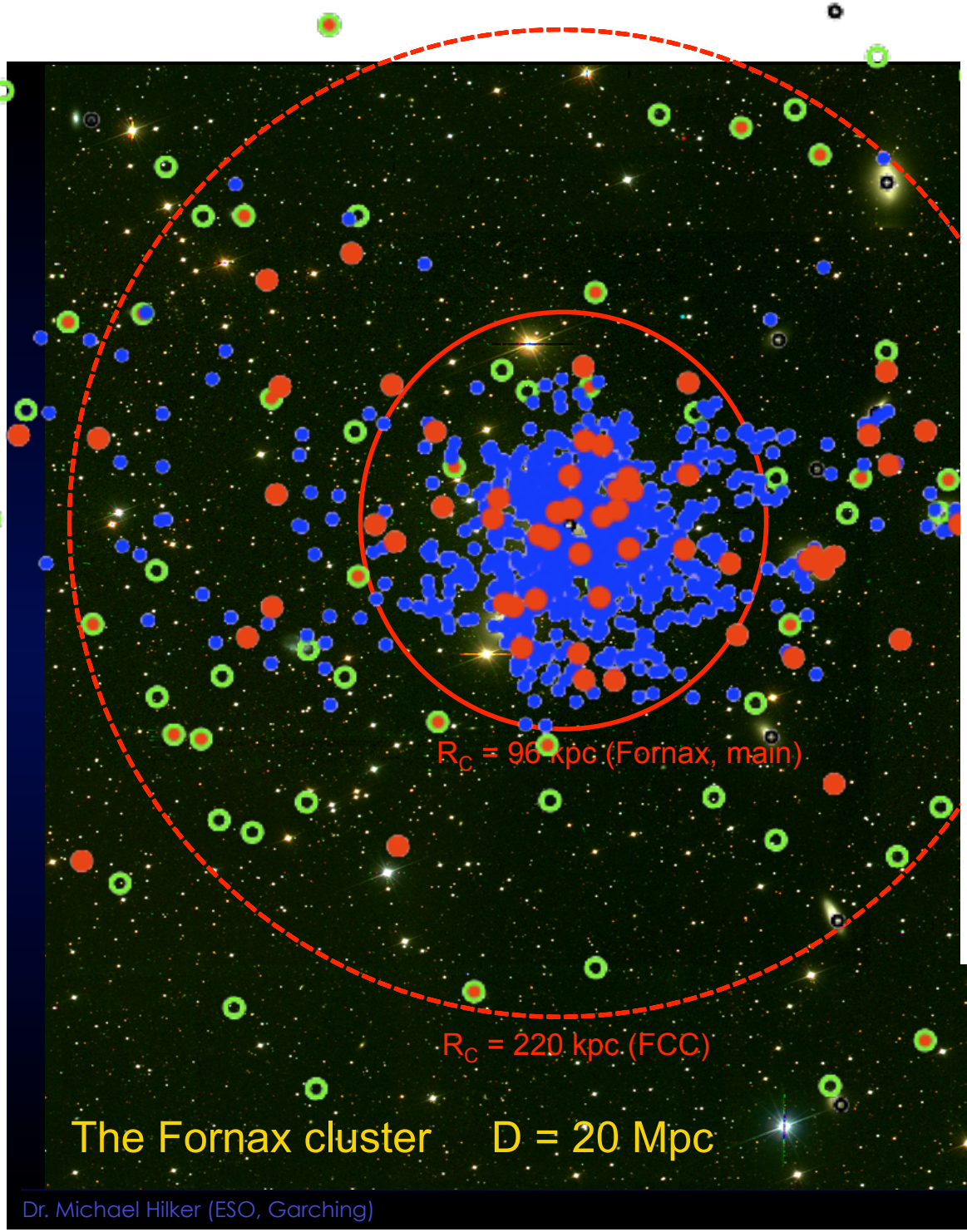
Colour-magnitude diagram of ‚hot' stellar systems in galaxy clusters

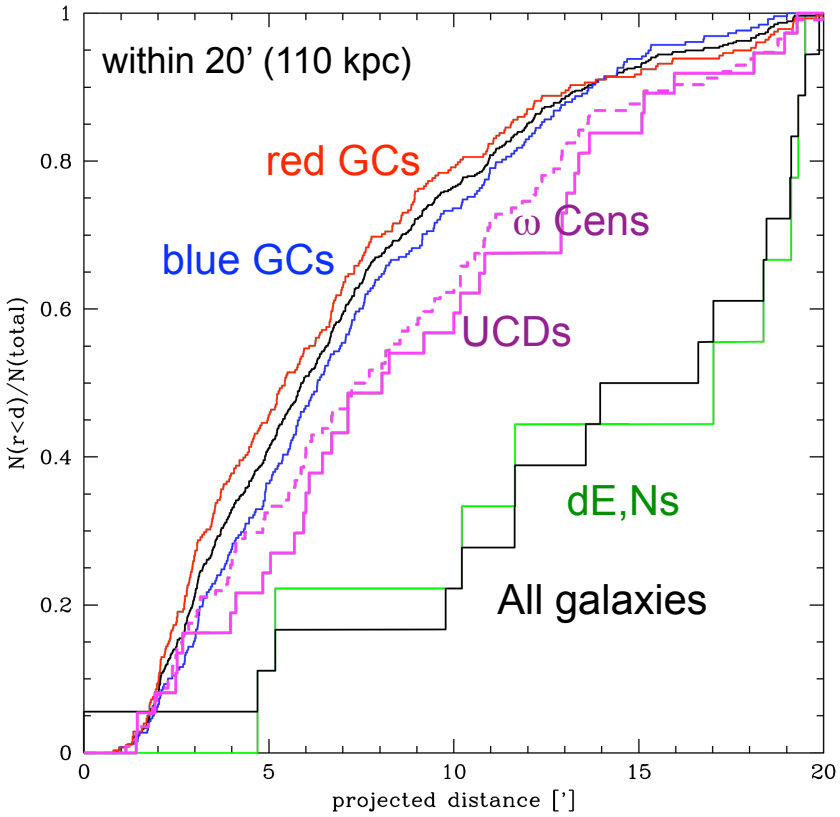


Hilker (2010)

UCDs are a continuation of the blue and red GC sequences

Defining UCDs by a luminosity cut seems quite arbitrary

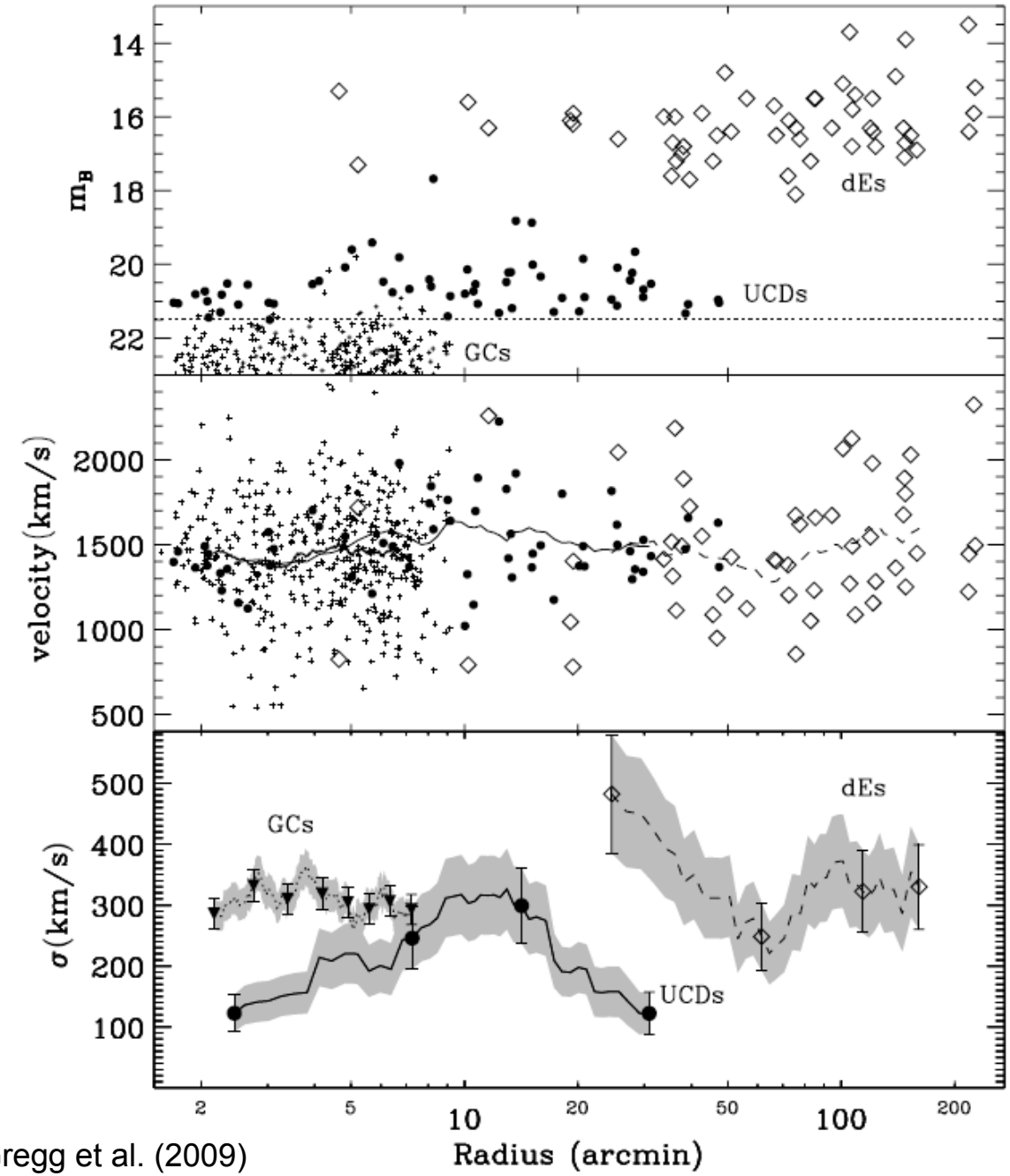




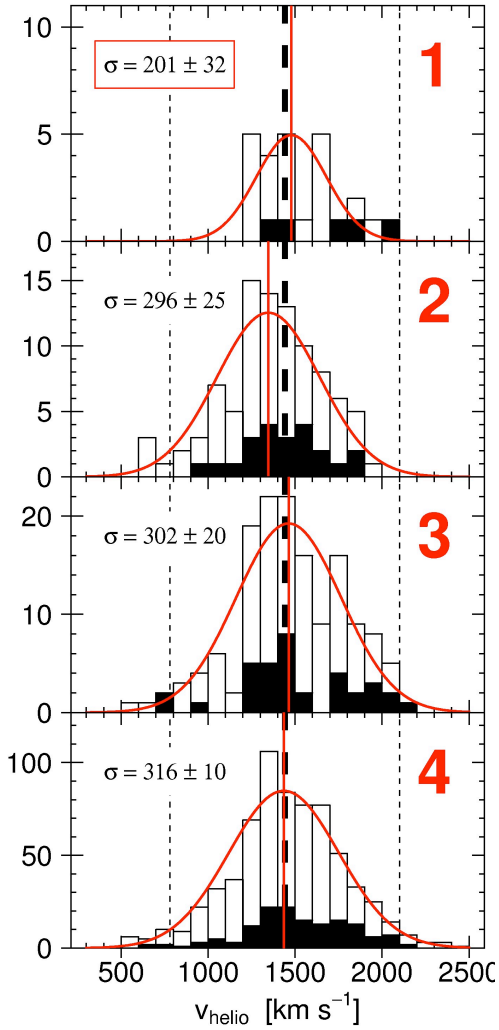
red GCs < blue GCs < ωCens < UCDs < dE,Ns < dEs < all galaxies

Hilker (2010)

The kinematics of dEs, UCDs and GCs in the Fornax cluster



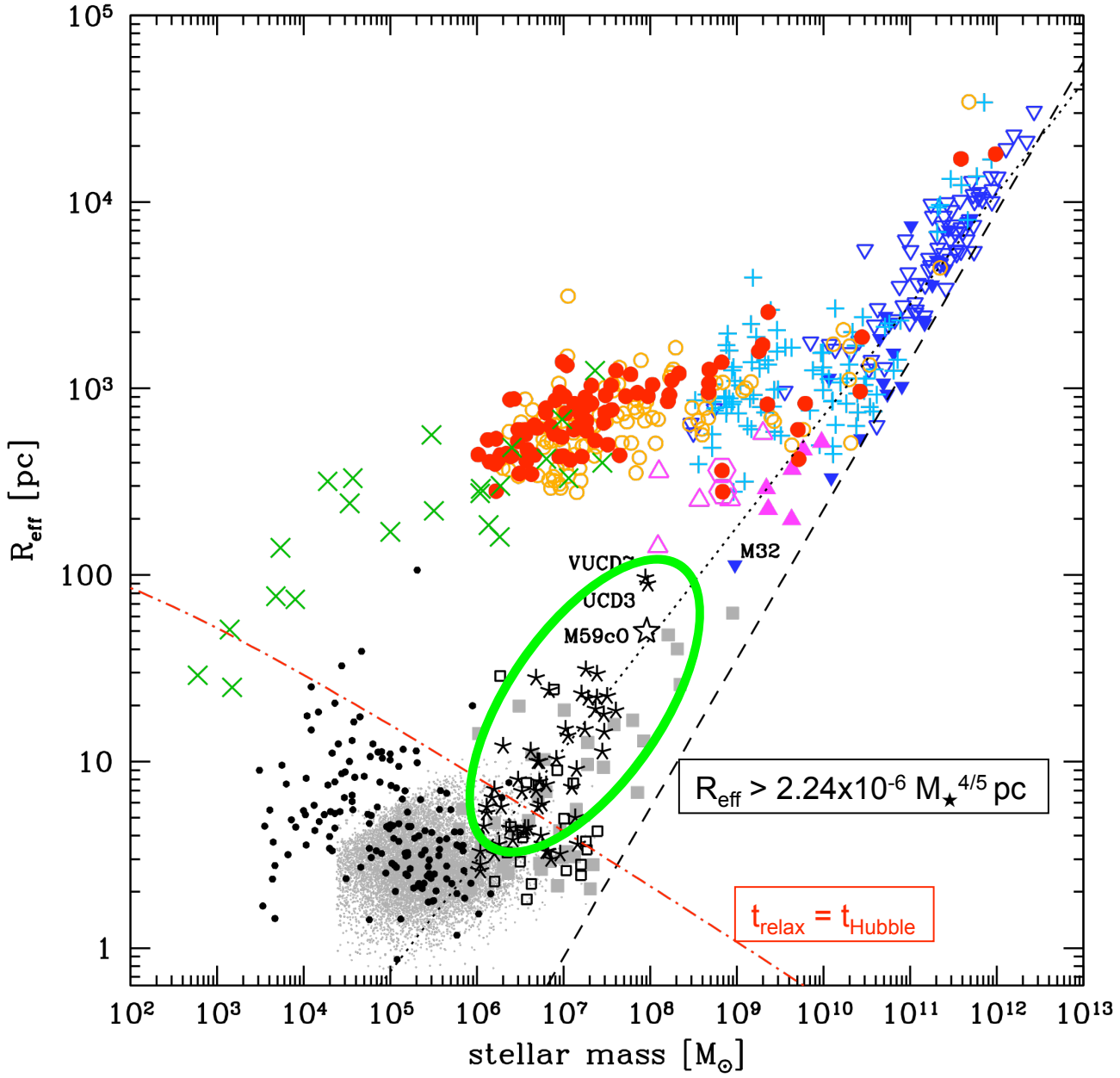
Gregg et al. (2009)



M_V<-11

Schuberth et al. (2011, in prep.)

Stellar mass-size relation of ‚hot' stellar systems



UCDs follow a mass-size relation!

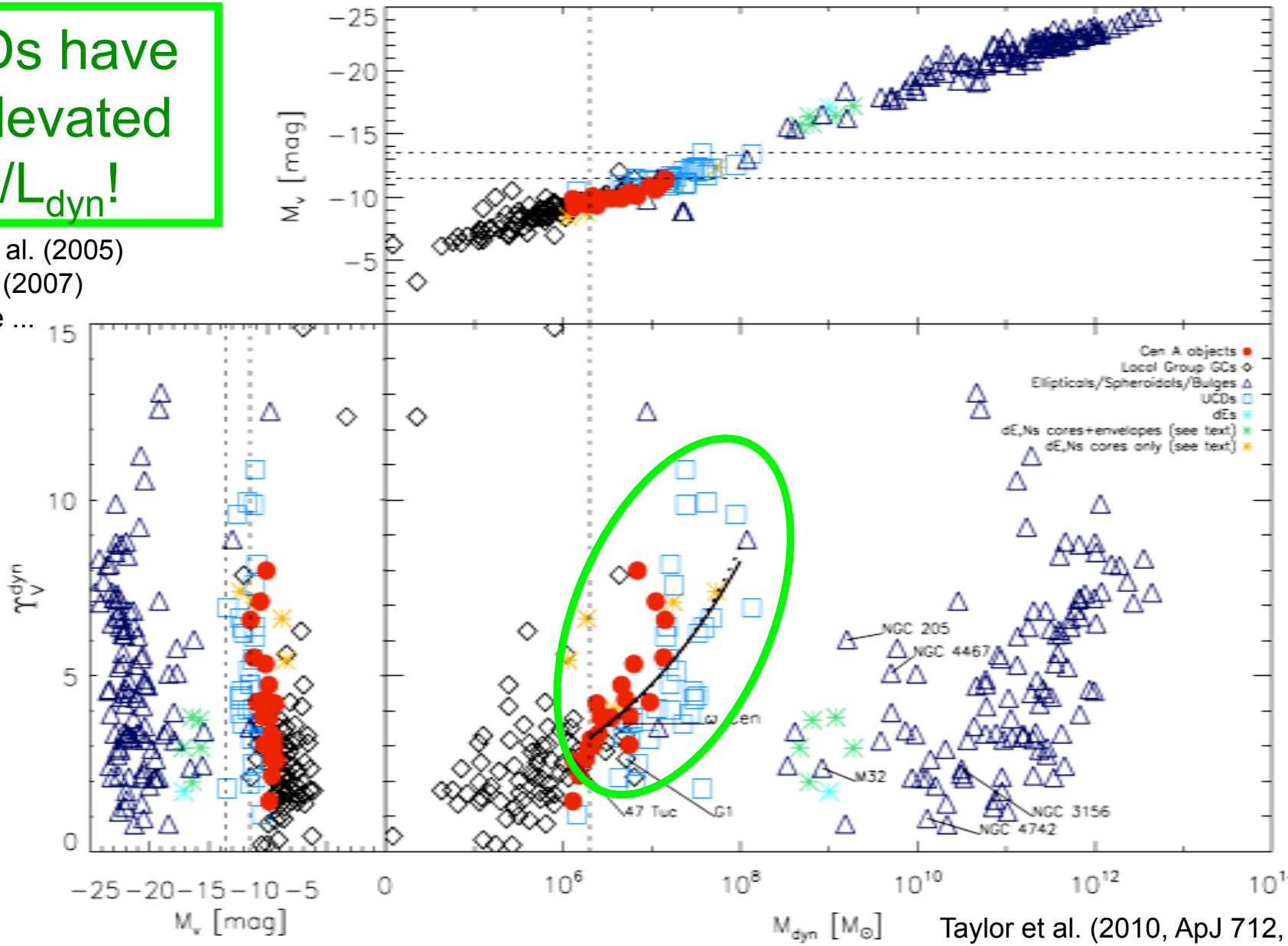
Hasegan et al. (2005)
Mieske et al. (2006)
Dabringhausen et al. (2008)
... and many more ...

Misgeld & Hilker (2011, MNRAS)

Dynamical mass-to-light ratio vs. mass/luminosity

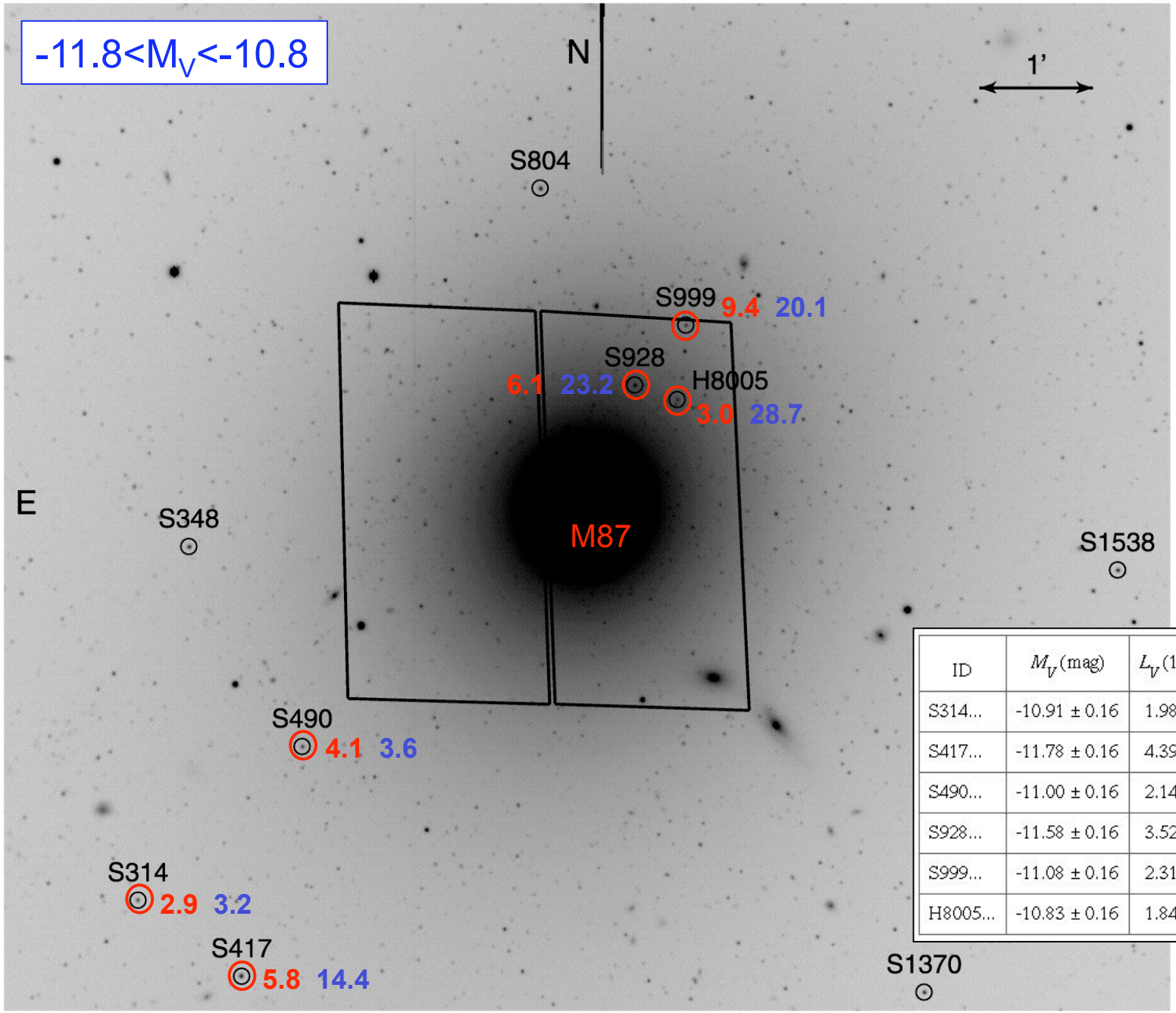
UCDs have an elevated M/L_{dyn}!

Hasegan et al. (2005)
Hilker et al. (2007)
... and more ...



Taylor et al. (2010, ApJ 712, 1191)

The ACS Virgo cluster survey



Dwarf-Globular Transition Objects (DGTOs)

V-band image (KPNO 4m) ACS footprint

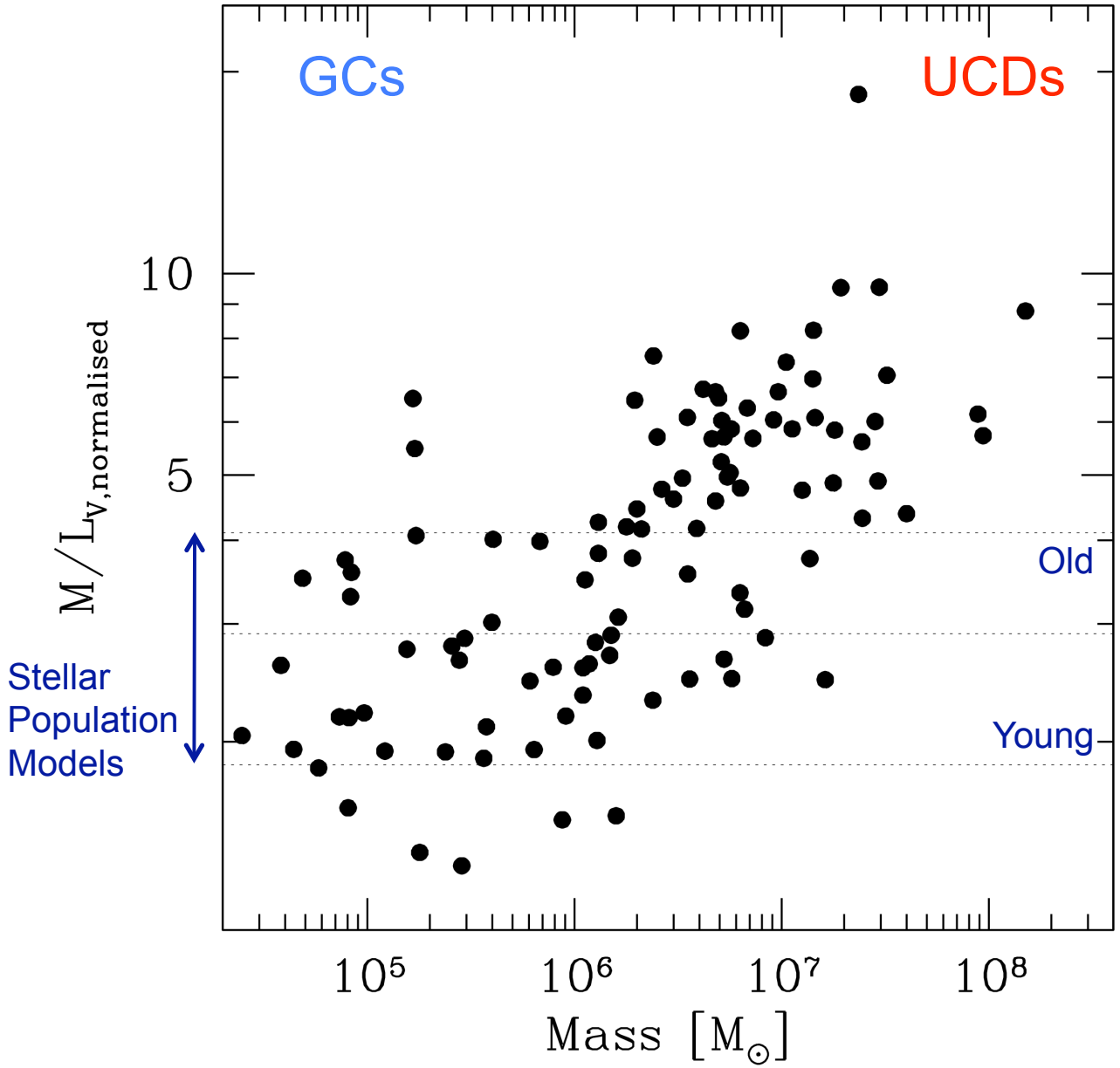
mass-to-light ratio M/L_V

half-mass radius r_h

ID	M_V (mag)	L_V ($10^6 L_{V,\odot}$)	M_k ($10^7 M_\odot$)	M_k/L_V ($M_\odot/L_{V,\odot}$)
S314...	-10.91 ± 0.16	1.98 ± 0.30	0.58 ± 0.10	2.94 ± 0.68
S417...	-11.78 ± 0.16	4.39 ± 0.66	2.56 ± 0.46	5.83 ± 1.36
S490...	-11.00 ± 0.16	2.14 ± 0.32	0.87 ± 0.21	4.06 ± 0.15
S928...	-11.58 ± 0.16	3.52 ± 0.53	2.13 ± 0.29	6.06 ± 1.23
S999...	-11.08 ± 0.16	2.31 ± 0.34	2.16 ± 0.29	9.36 ± 1.87
H8005...	-10.83 ± 0.16	1.84 ± 0.28	0.55 ± 0.23	2.98 ± 1.35

Hasegan et al. 2005 (ApJ 627, 203)

The M/L_{dyn} values of UCDs cannot be explained by SSP models



- Dark matter?

  Baumgardt & Mieske (2008)
  Goerdt et al. (2008)

- An unusual IMF?

  (either top- or bottom-heavy)

  Dabringhausen et al. (2008, 2009)

- Imperfect SSP models?

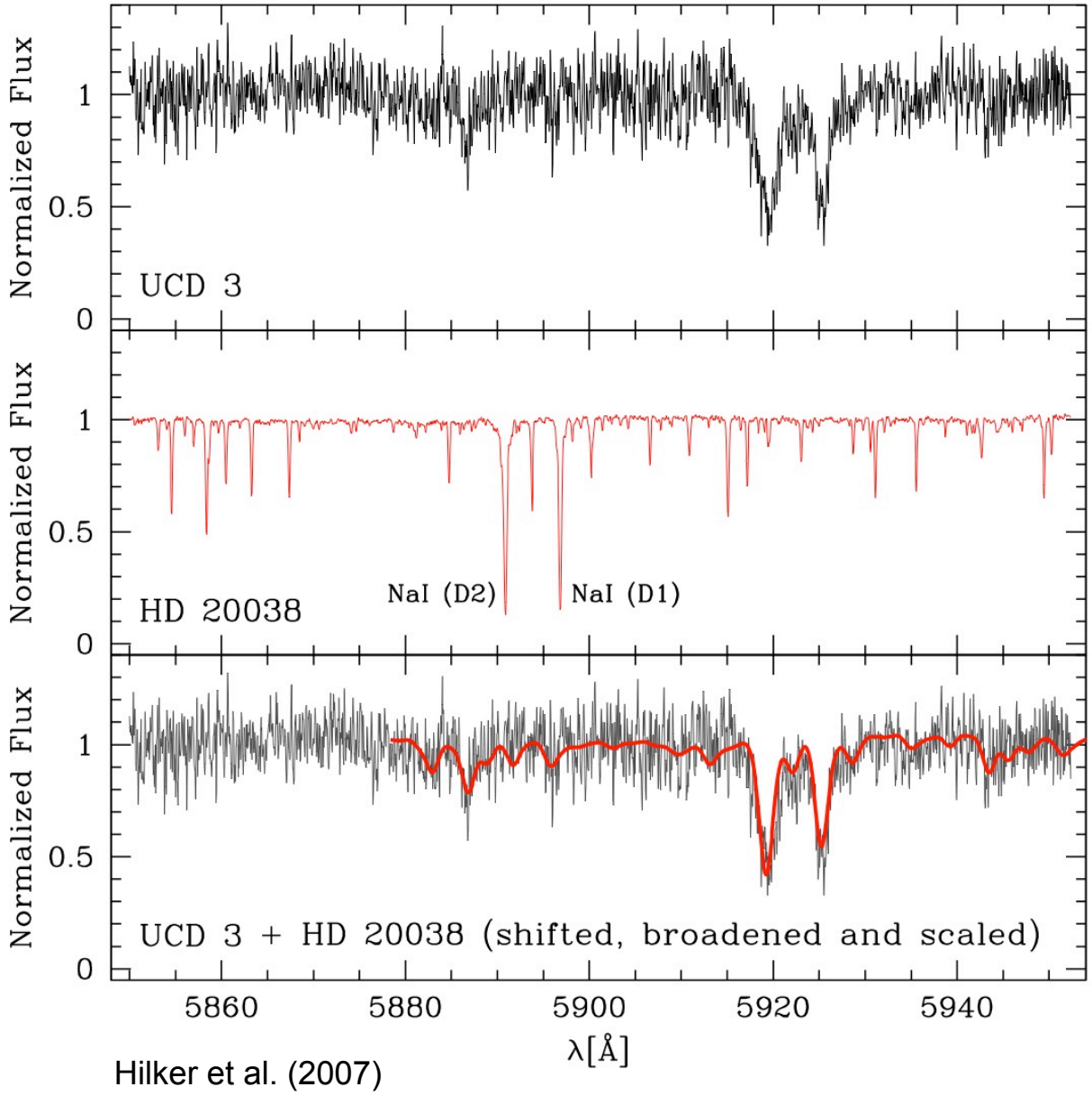
  (not taking dynamical evolution correctly into account)

  Kruijssen & Mieske (2009)

Mieske et al. (2008, A&A 487, 921),
see also: Dabringhausen et al. (2008, MNRAS 386, 864)

Global velocity dispersions and dynamical masses – some cautionary tales

Measurement of the velocity dispersion of UCDs



Hilker et al. (2007)

High resolution spectrum of the UCD

+

Spectra of standard stars (instrumental resolution) ~ a few km/s

→ Matching of both by a fitting method

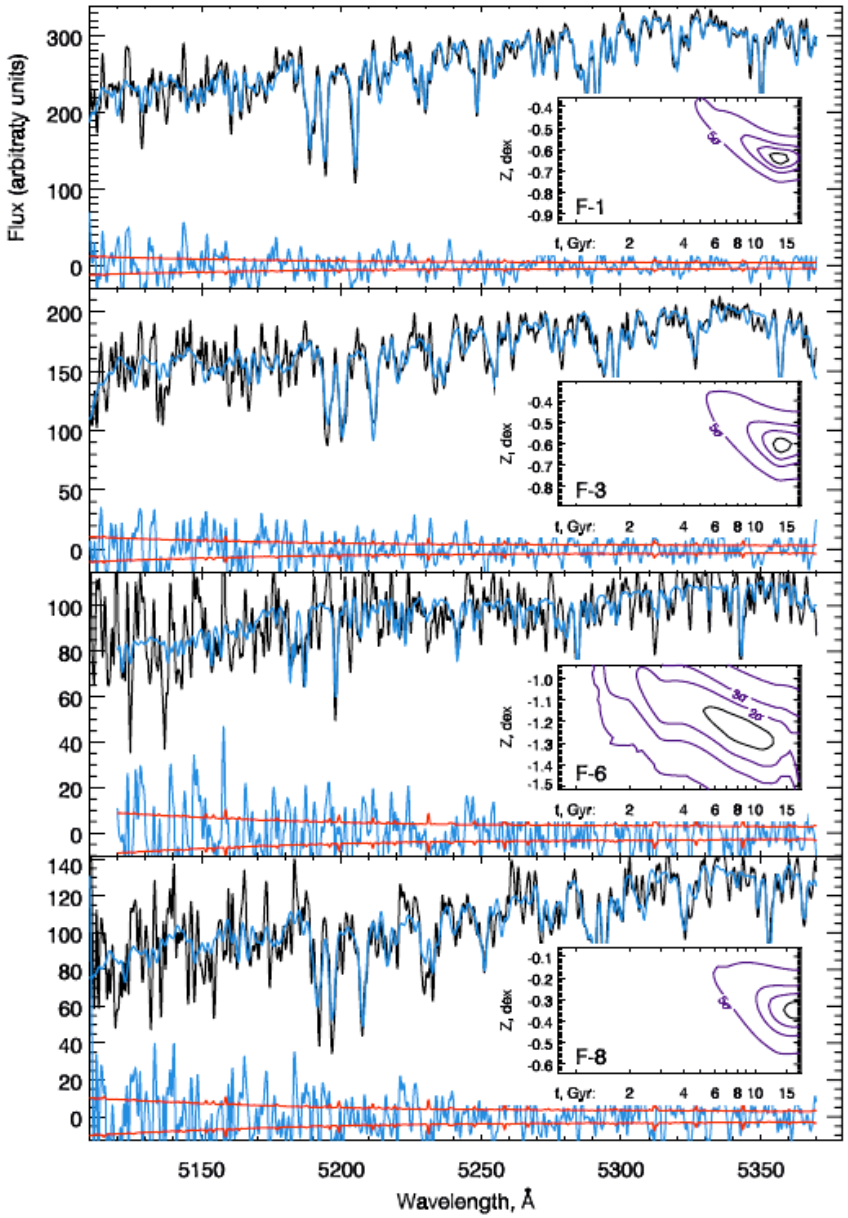
Uncertainties:

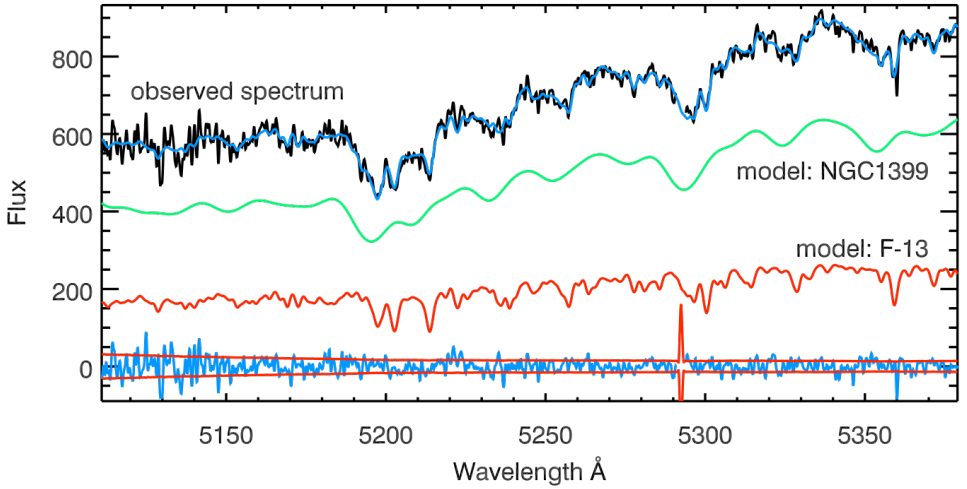
- different fitting methods
- different wavelength regions

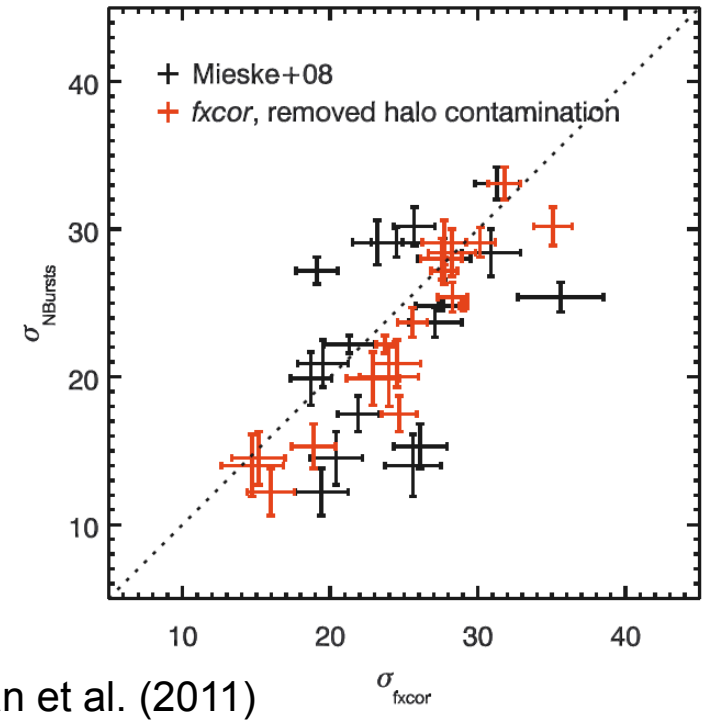
give different results!

Velocity dispersion of stars whose light got into the spectrograph!

Full spectral fitting of UCD spectra and background subtraction

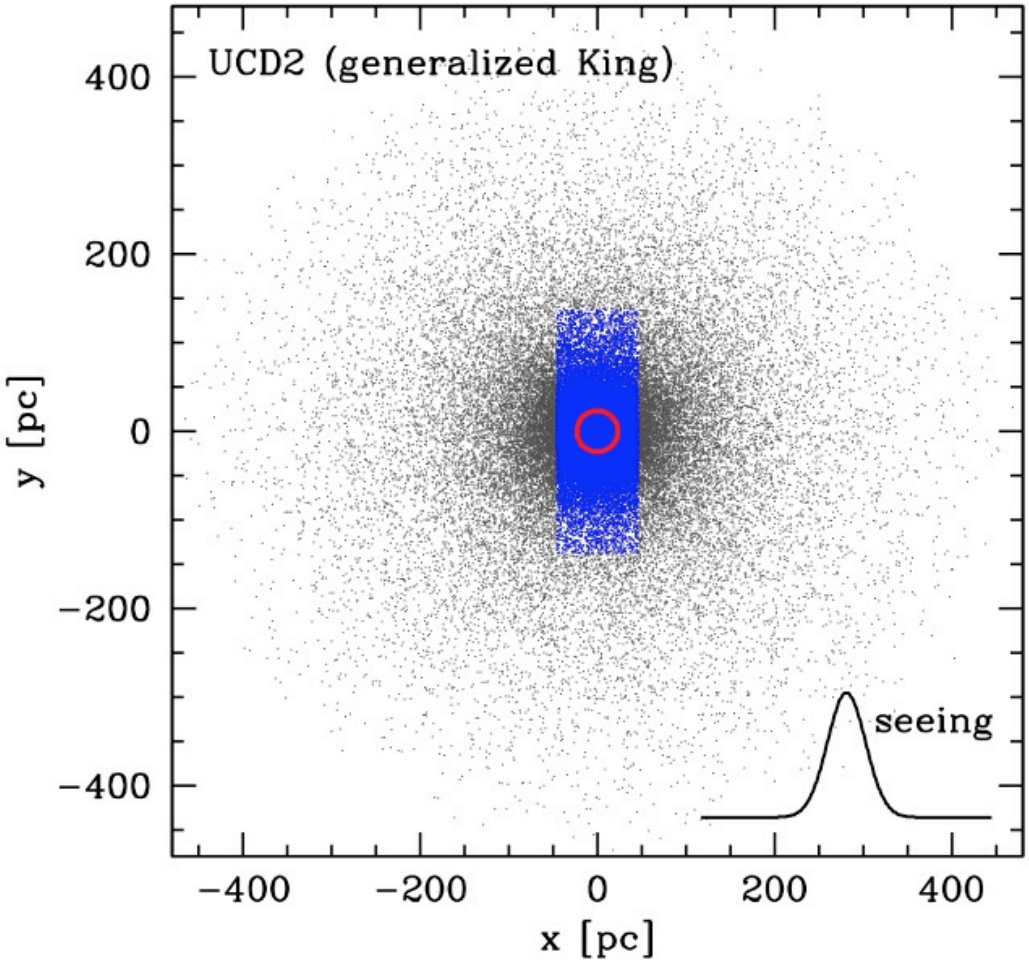


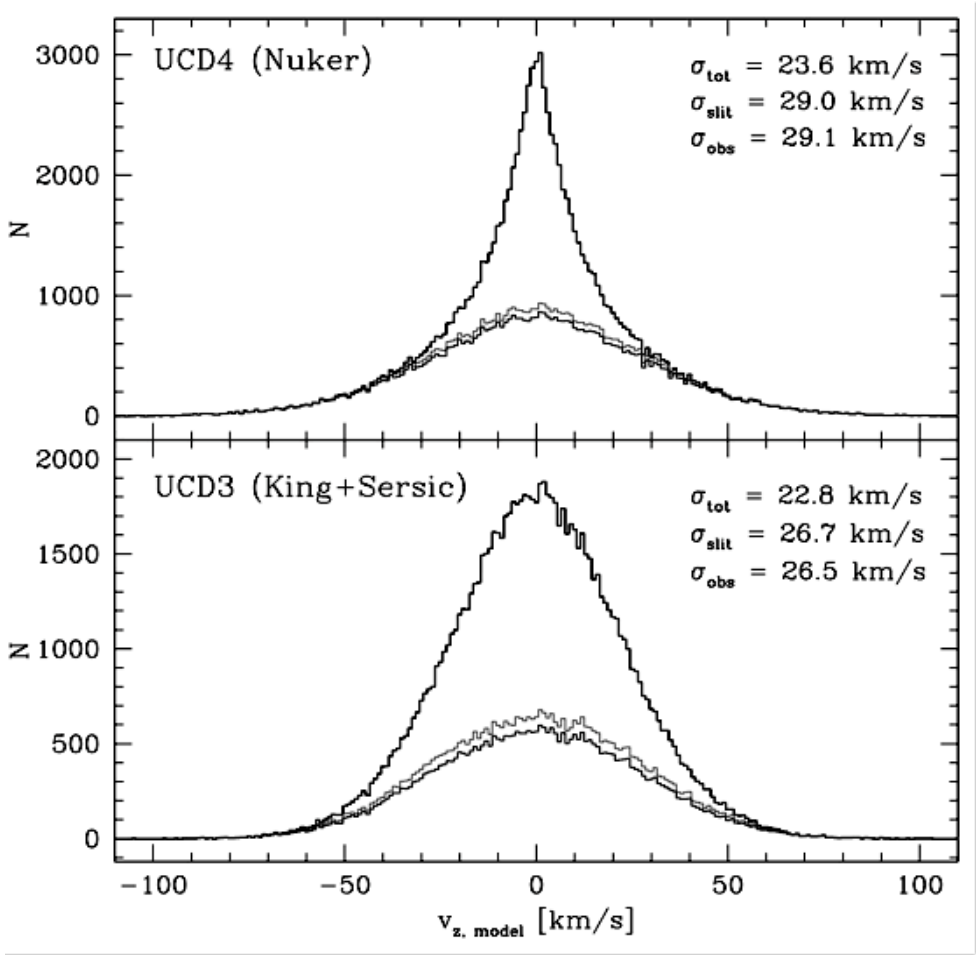




Chilingarian et al. (2011)

From observed velocity dispersions to dynamical masses

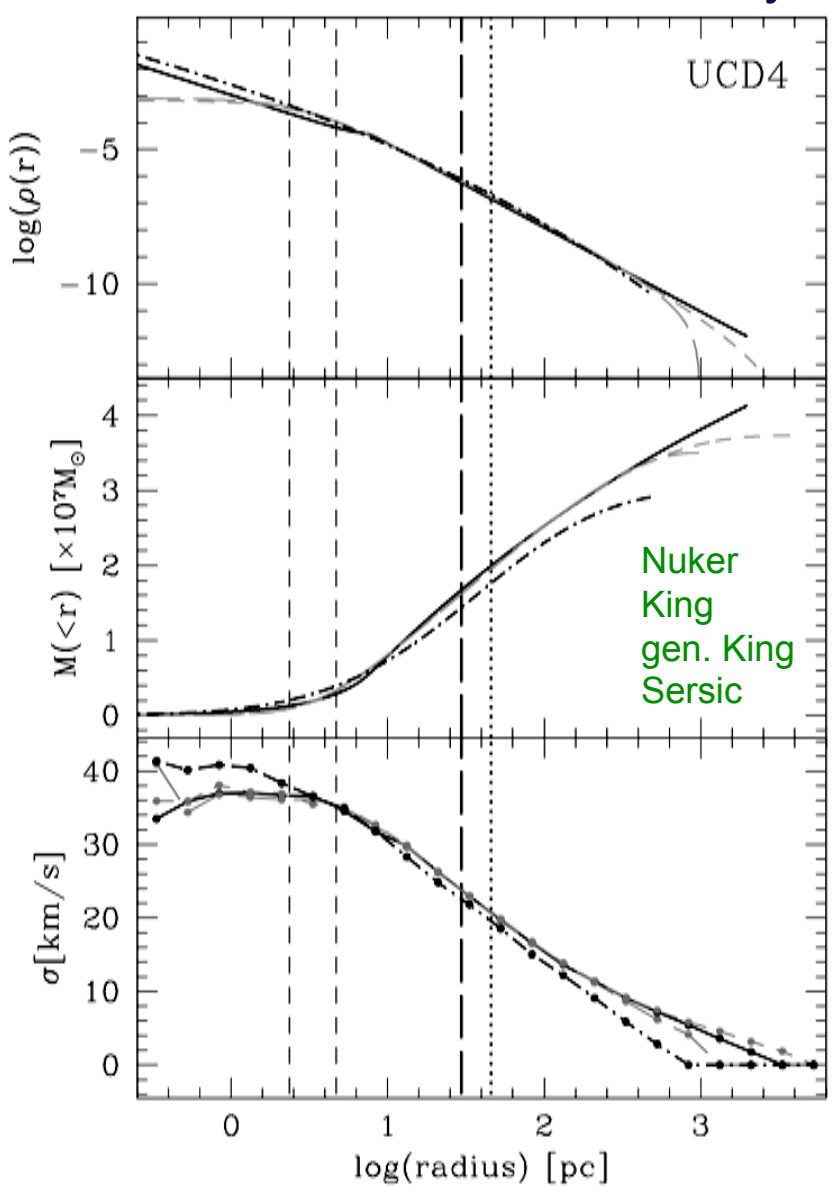


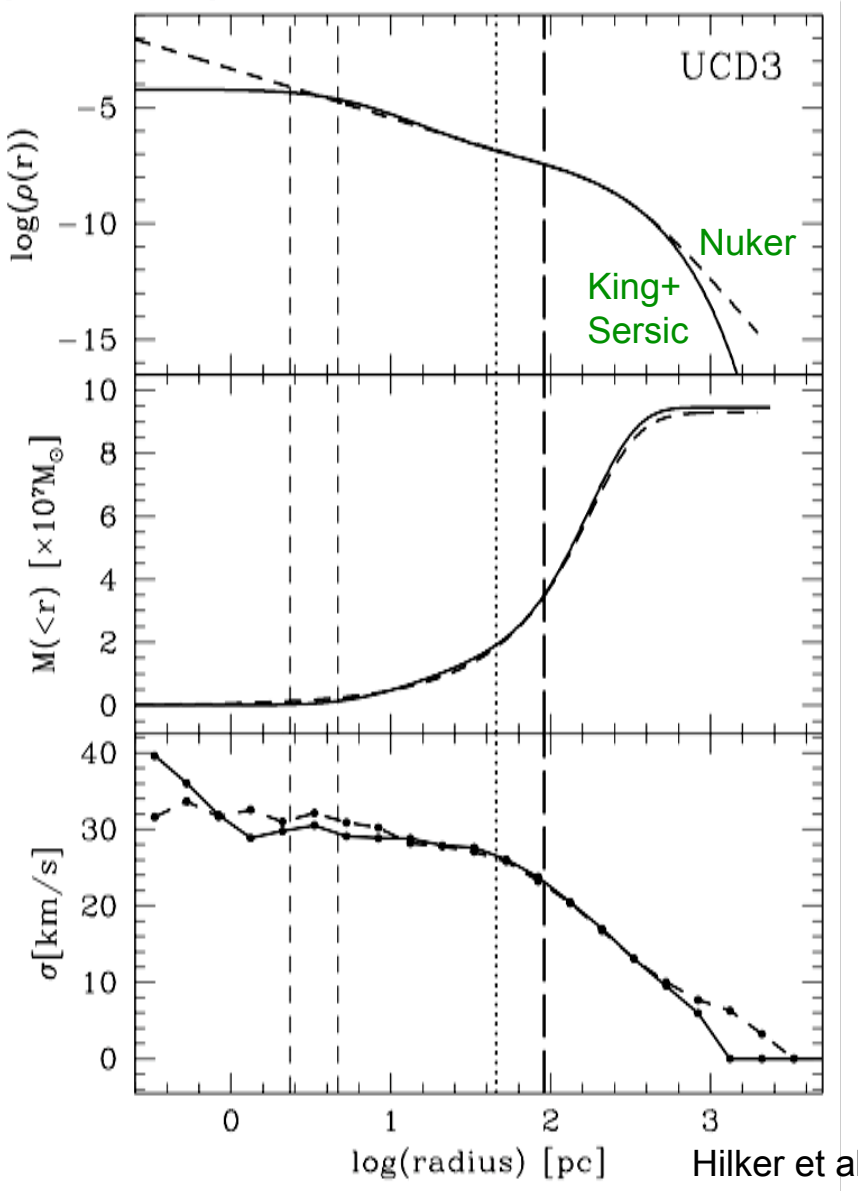


Hilker et al. (2007)

`Stars‘ distributed according to de-projected surface brightness profiles from HST imaging

Examples for modelled 3-dim density profiles, cumulative mass distributions and velocity dispersion profiles for two UCDs

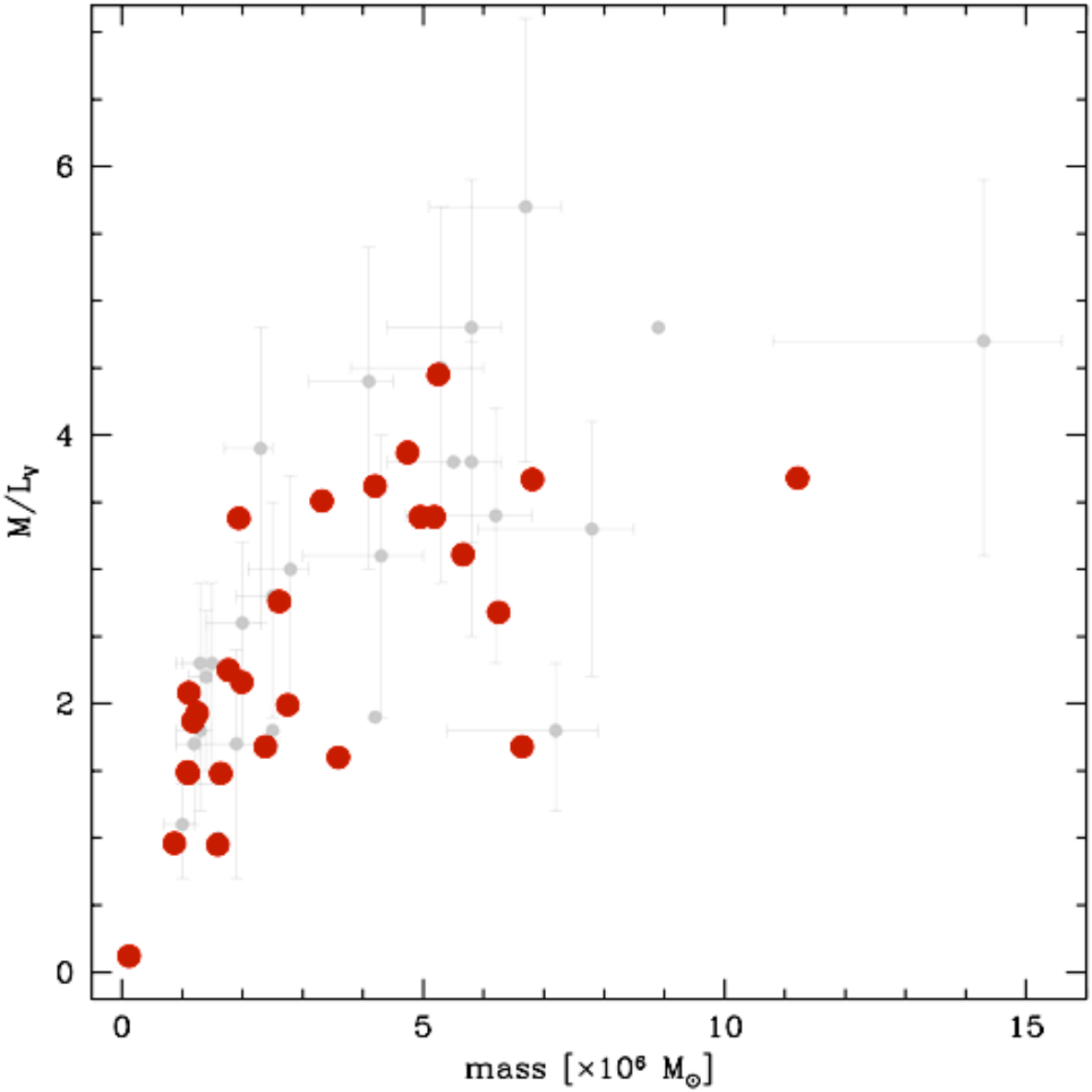




Hilker et al. (2007)

Masses and M/L values from the virial mass estimator

(without corrections)

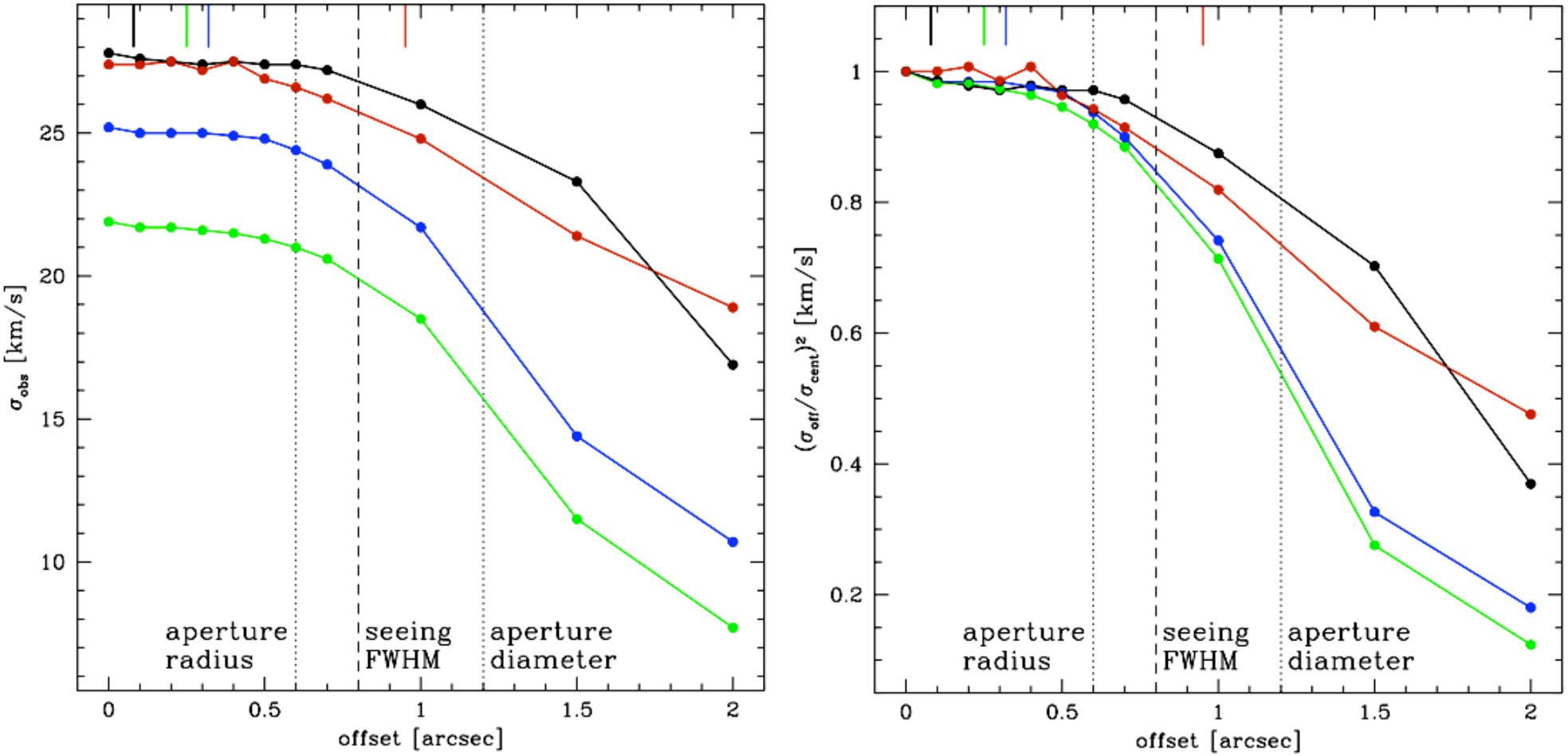


vs.

Masses and M/L values from the mass modelling

up to 30% lower than values from virial mass estimator applied to observed velocity dispersion

What if the object is not centred in the slit/aperture?

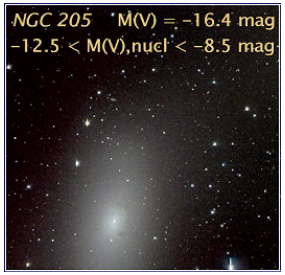


Dynamical masses would be underestimated if not corrected for

The top 4 formation scenarios for UCDs

"Remnant nuclei of disrupted galaxies" - NCs

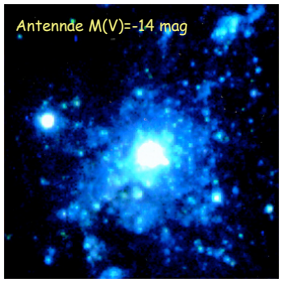
(Bekki et al. 2001, 2003, Bassino et al. 1994, Zinnecker et al. 1988)



vs.

"Merged supercluster complexes" - MSCs

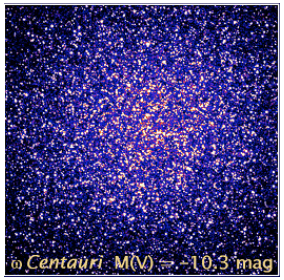
(Fellhauer & Kroupa 2002, 2005, Kroupa 1998)



vs.

"Most massive globular clusters" - GGCs

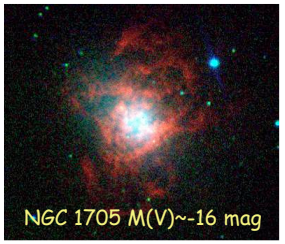
(Mieske et al. 2002, 2004, Norris & Kannappan 2011)



vs.

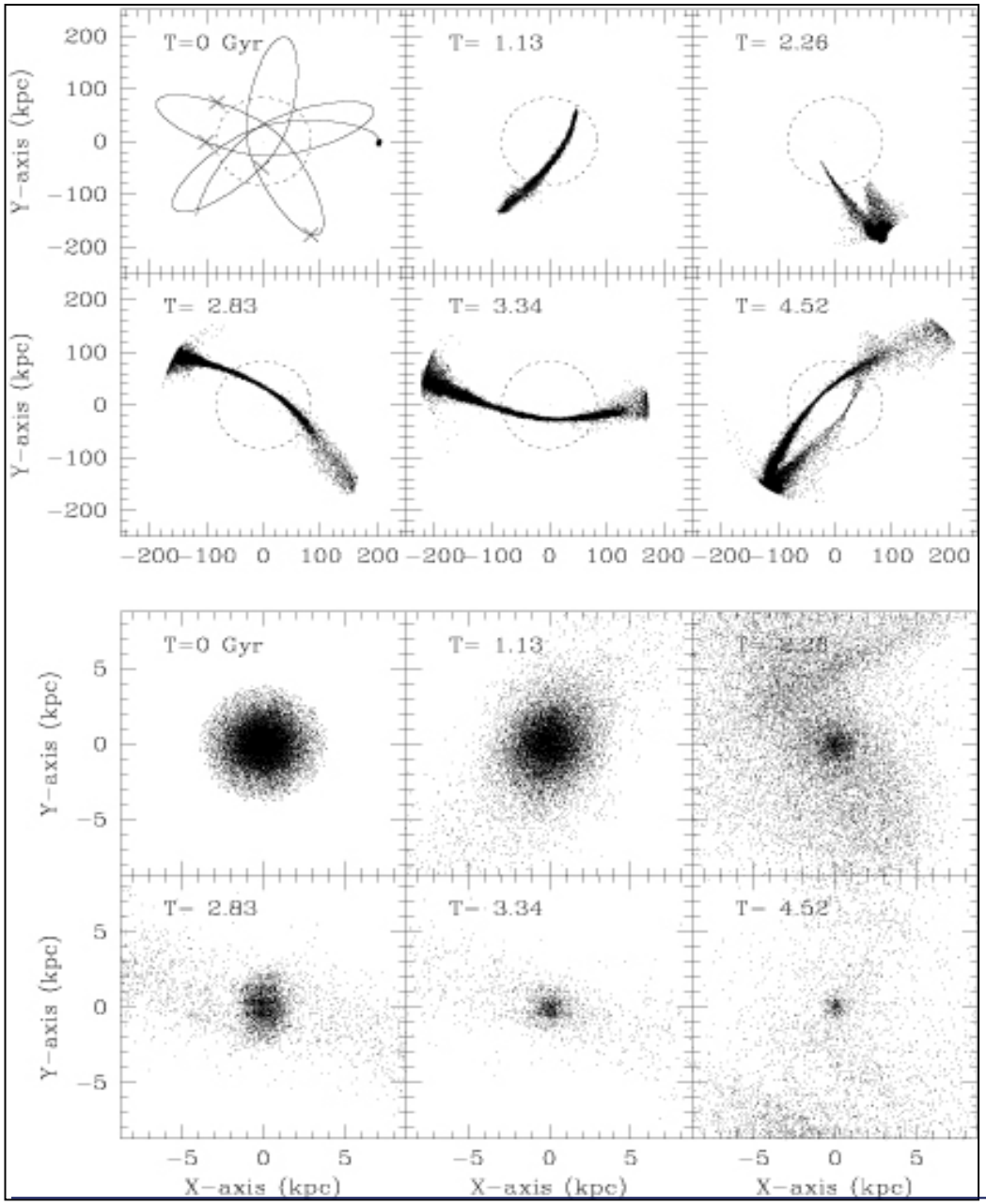
"Genuine compact dwarf galaxies" - BCDs

(Phillipps et al. 2001, Drinkwater et al. 2004, Richtler et al. 2005)

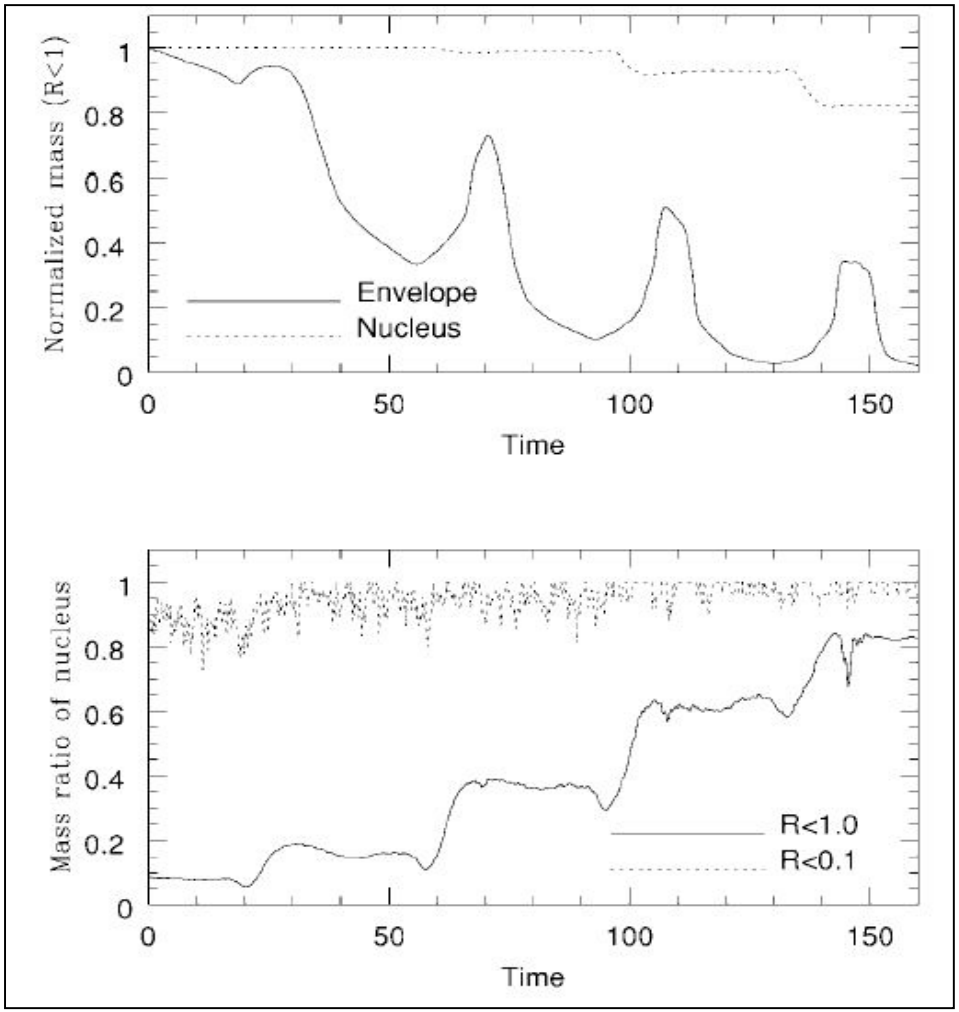


Simulation of UCD formation from the disruption of dwarf galaxies

orbit

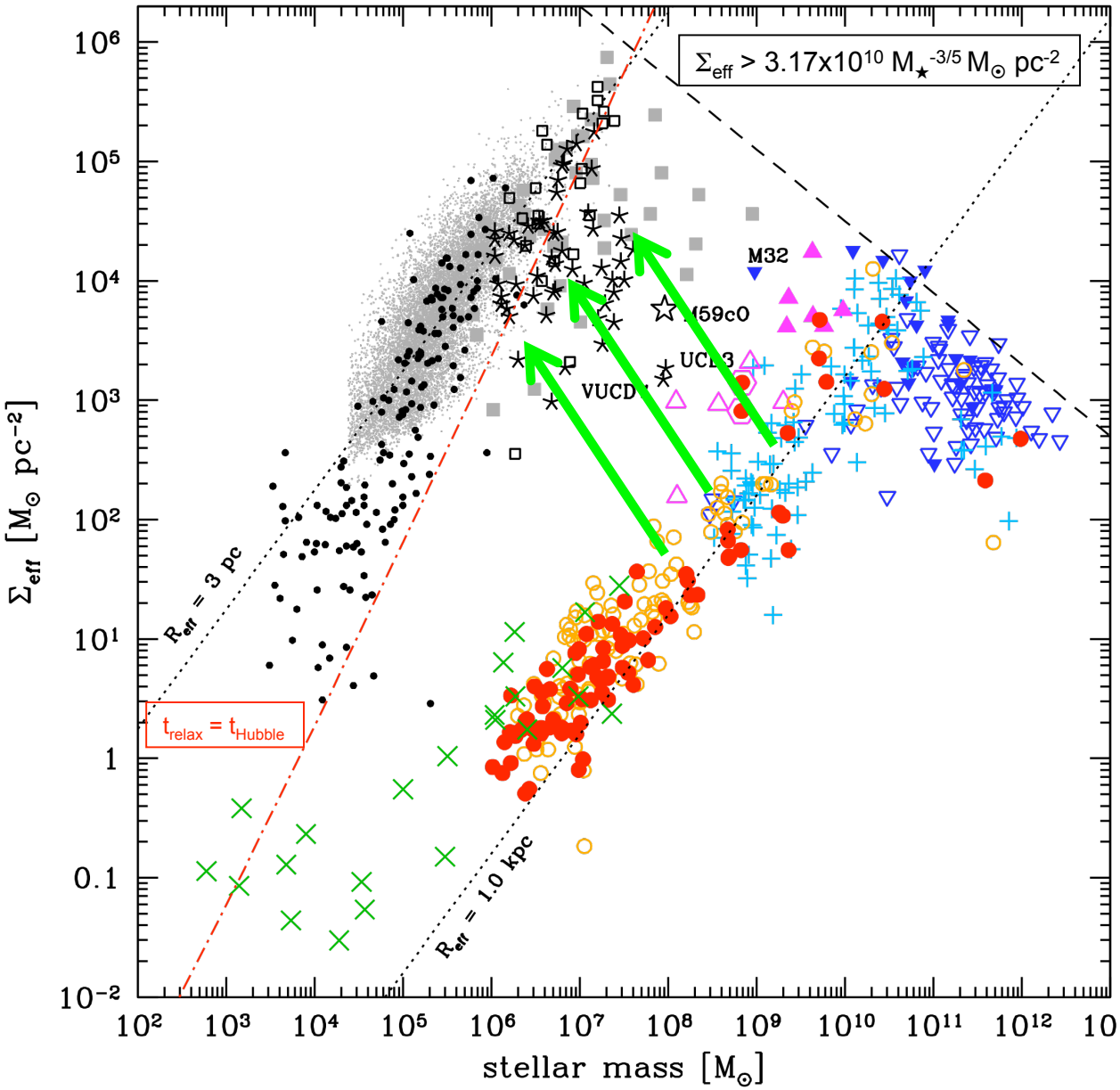


nucleus mass and mass loss



Bekki et al. (2001, 2003)

Surface density-mass relation of hot stellar systems

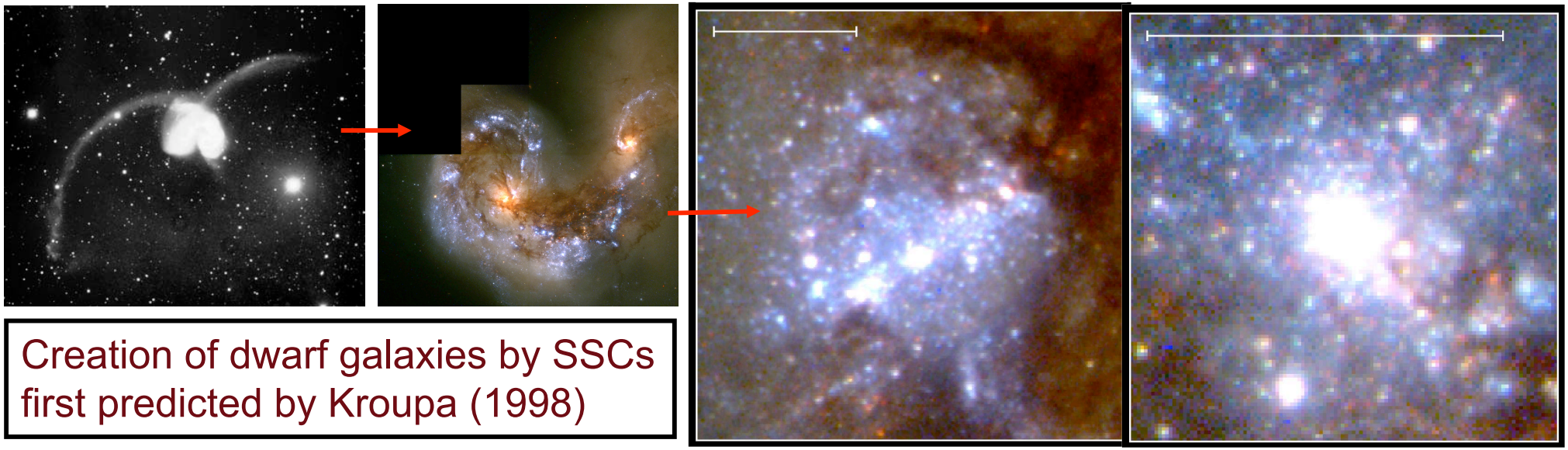


In terms of galaxies, UCDs are `ultra-compact'.

In terms of star clusters, UCDs are rather diffuse.

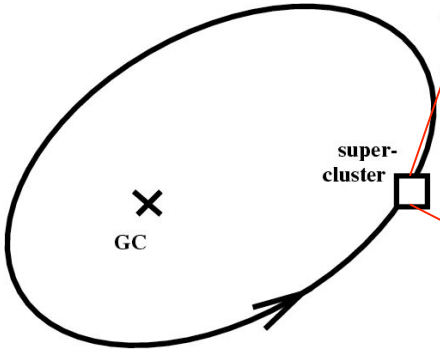
Misgeld & Hilker (2011, MNRAS)

Formation of UCDs by the amalgation of stellar superclusters (SSCs)

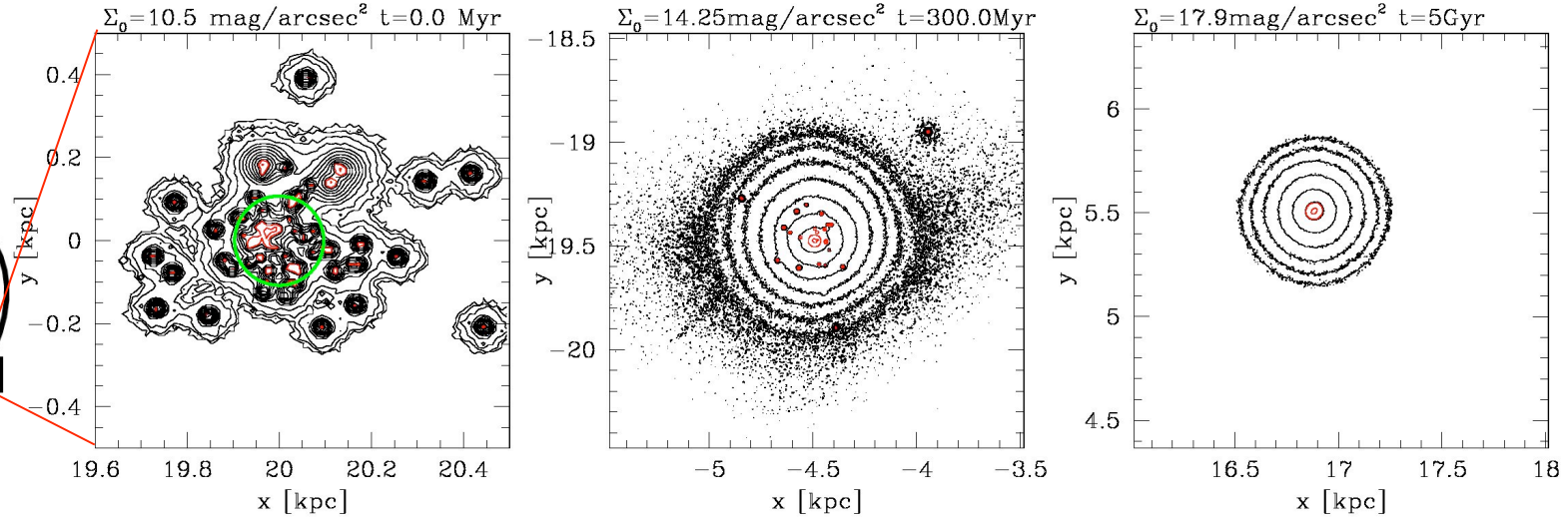


Creation of dwarf galaxies by SSCs first predicted by Kroupa (1998)

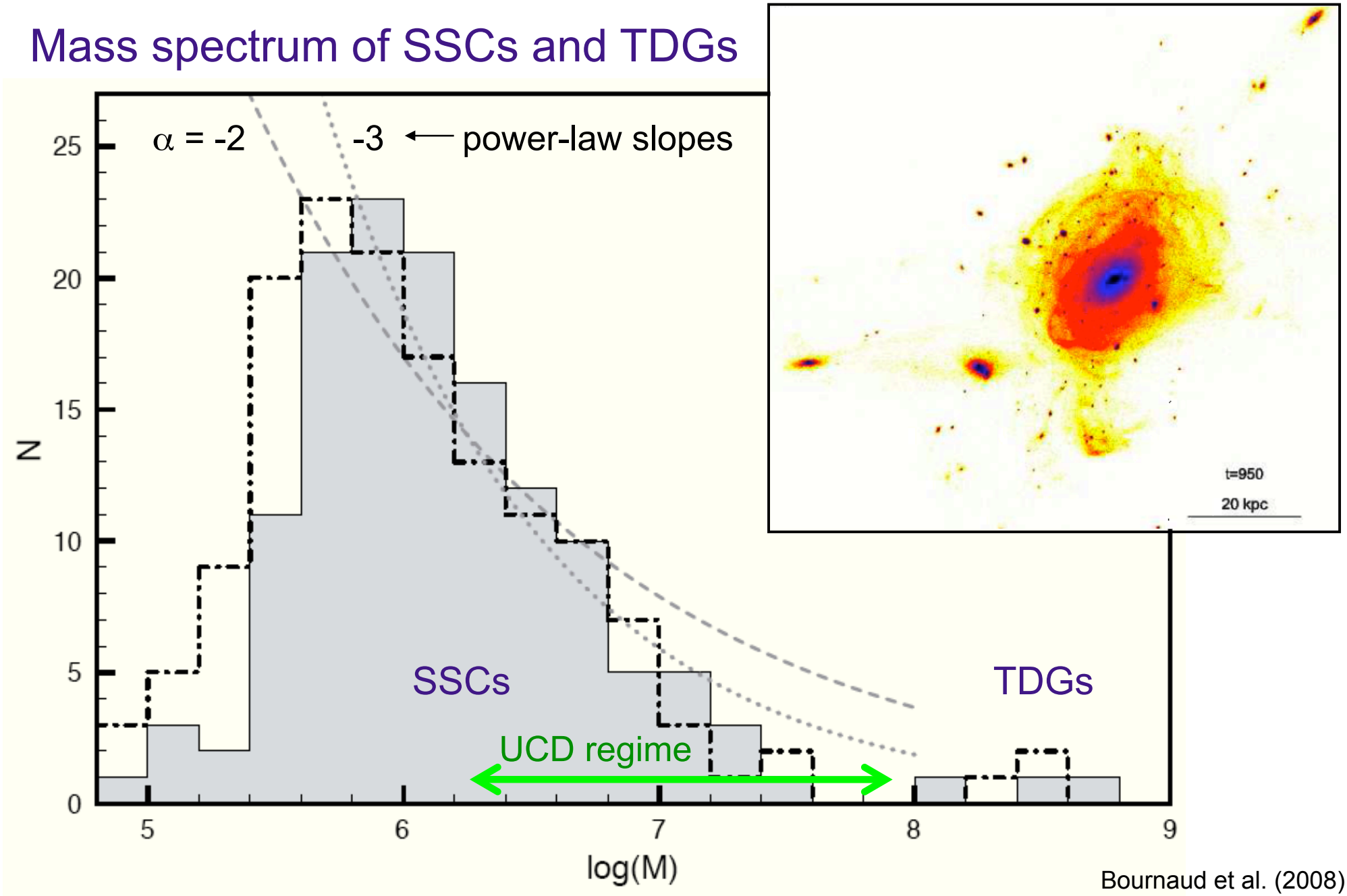
Setup of models: super-cluster orbits in an analytic galactic potential on an eccentric orbit (SUPERBOX)



Fellhauer & Kroupa (2002, 2005)

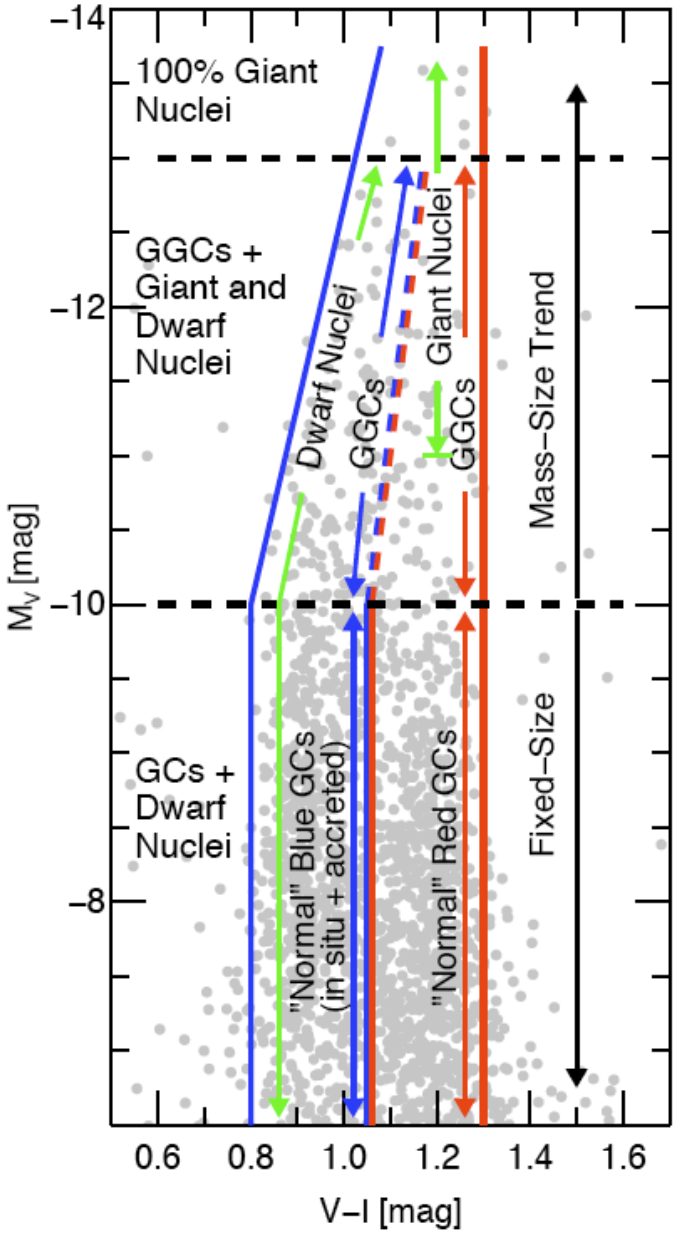


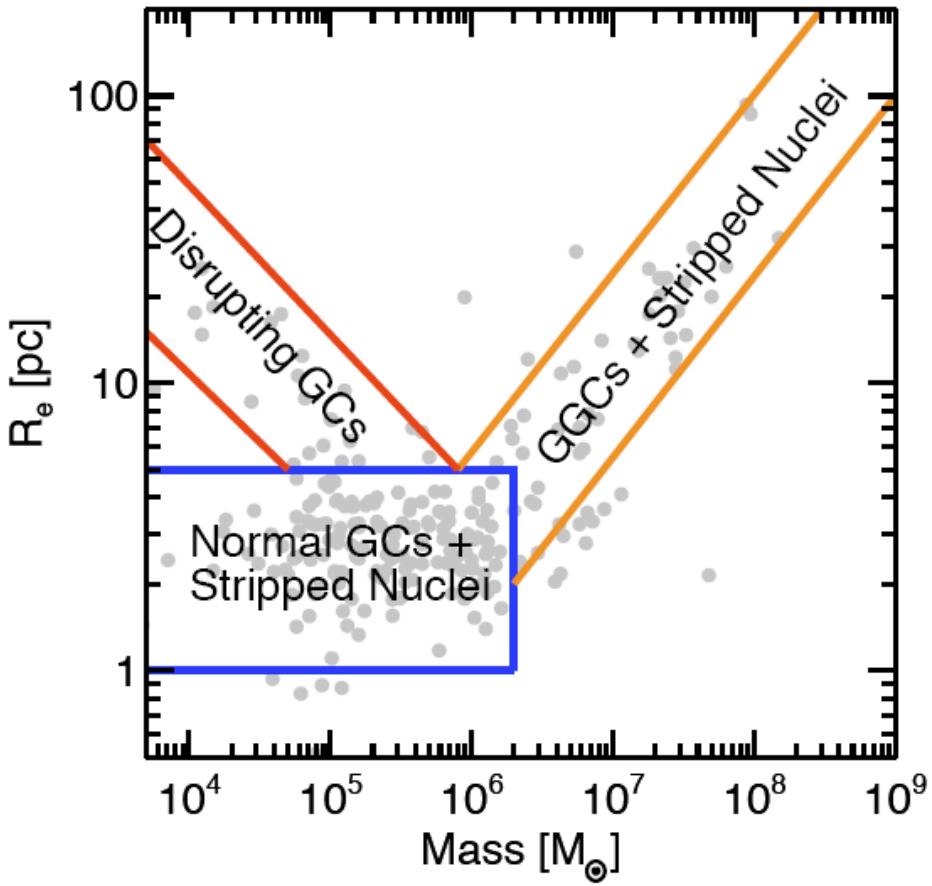
Mass spectrum of SSCs and TDGs



Bournaud et al. (2008)

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





Norris & Kannappan (2011)

Spatially resolved internal kinematics of UCDs

What can we learn from the internal dynamics of UCDs?

The shape of the spatially resolved velocity dispersion profile might support/disprove the one or other formation scenario.

Questions one might ask:

1) Is the velocity dispersion in the outskirts of UCDs influenced by dark matter?

2) Is the velocity dispersion in the centre of UCDs influenced by a massive black hole?

3) Are there signs for orbital anisotropy, rotation or tidal features?

1) Dark matter in UCDs – yes or no?

UCDs as NCs:

- Yes, if the remnant nuclei can 'focus' DM in their centers (Goerdt et al. 2008)
- No, if DM is stripped efficiently (Bekki et al. 2001, 2003)

UCDs as MSCs:

- No, super star cluster complexes in merging galaxies do not contain DM

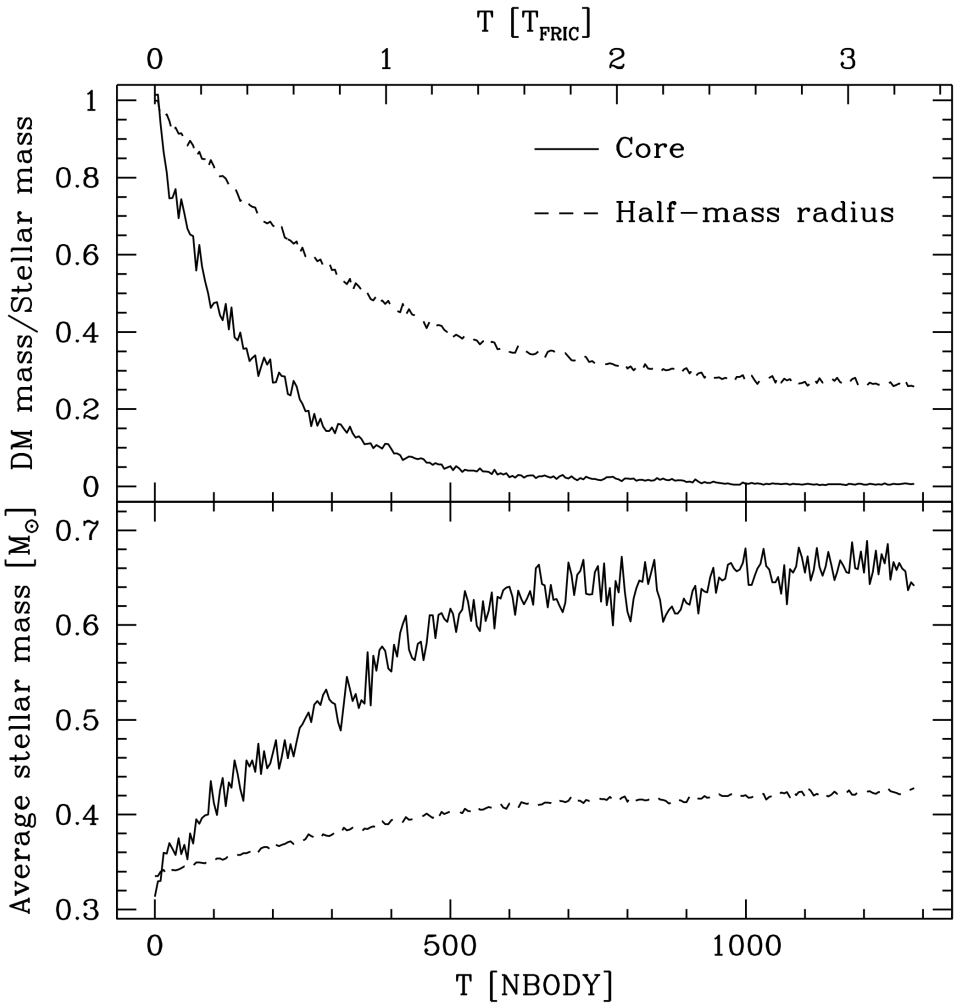
UCDs as GGCs

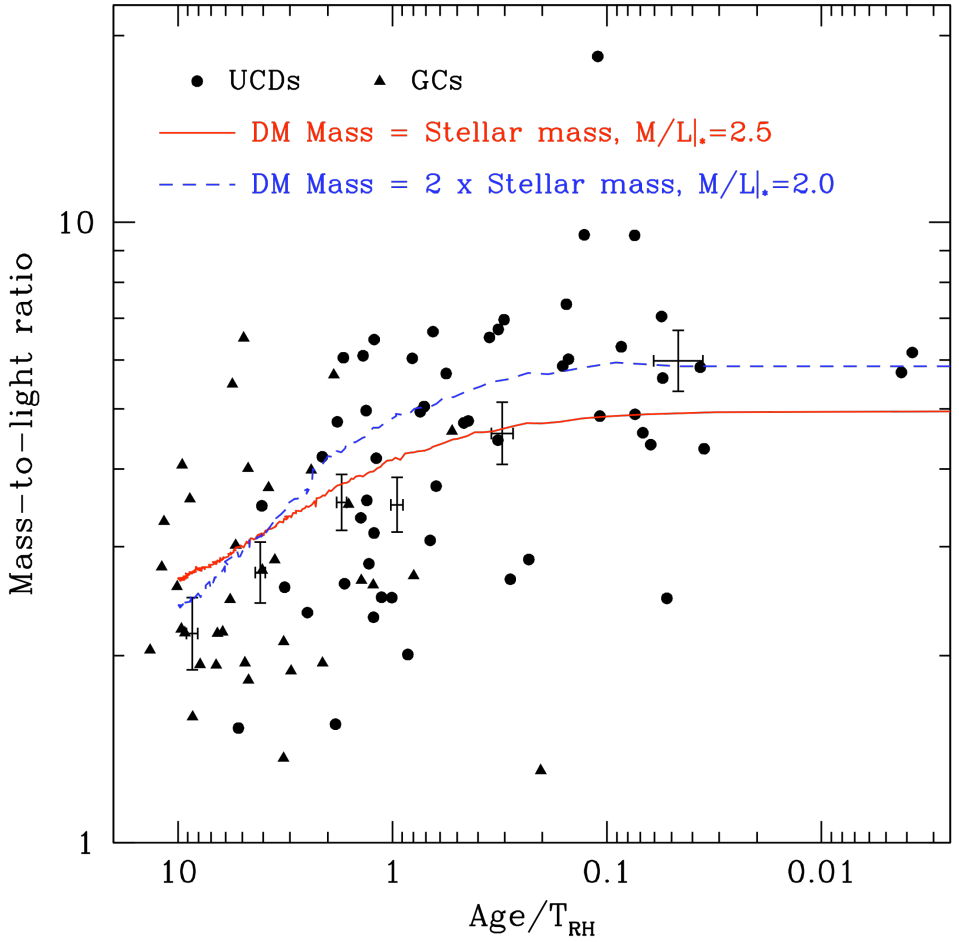
- Yes, if GCs formed in DM halos, the most massive GCs might retain some DM fraction (Baumgardt & Mieske 2008)
- No, so far no evidence for DM in GCs (see ω Cen, NGC 2419, …)

UCDs as BCDs

- Yes, per definition: UCDs formed in primordial DM density peaks, thus are cosmological sub-structures

DM dominated UCDs can retain DM after dynamical evolution





Baumgardt & Mieske (2008)

1) Massive black holes in UCDs – yes or no?

UCDs as NCs:

- Yes, SMBHs and NCs have been shown to co-exist (Graham & Spitler 2009)
- No, most galaxies with NCs do not seem to harbour a SMBH (Neumayer's talk)

UCDs as MSCs:

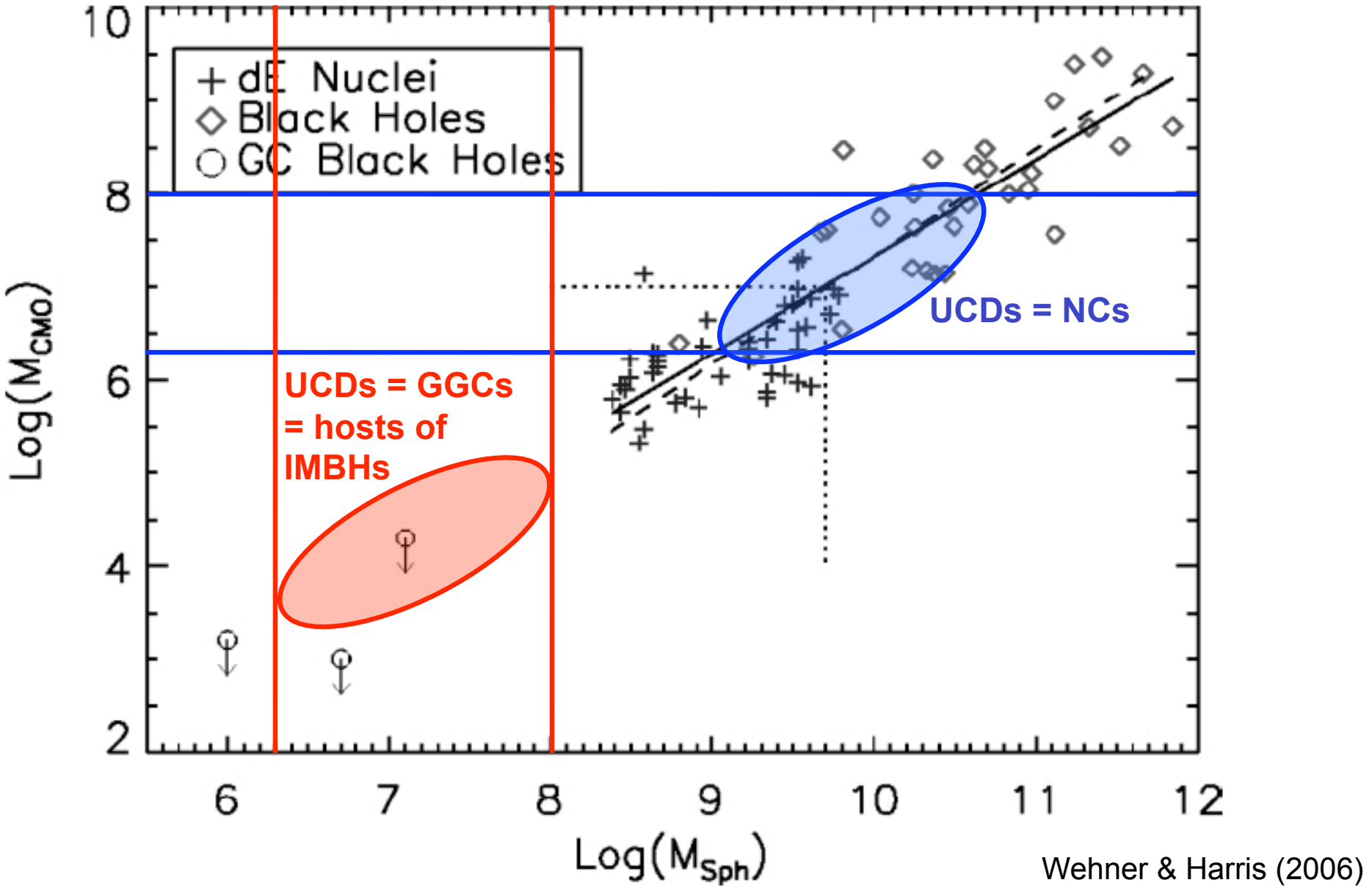
- No, young clusters do not possess IMBHs that could grow to a SMBH

UCDs as GGCs

- No, maybe some massive GCs harbour a IMBH but not a SMBH (Anderson, Noyola, Lützgendorf, Jalali)

UCDs as BCDs

- Yes, if 'bulge' formation is related to massive BH formation one would expect them in UCDs



Wehner & Harris (2006)

1) Anisotropy, rotation, tidal features in UCDs – yes or no?

UCDs as NCs:

- Yes, if NC formation works via disk accretion and/or multiple SF events (?), tidal features if stripped on eccentric orbits (Fellhauer & Kroupa 2006)
- No, if the memory of anisotropy or rotation is lost in stripped NCs (!?)

UCDs as MSCs:

- Yes, in young MSCs some rotation/anisotropies might be detectable
- No, very rapid merging in a dissipative manner (violent relaxation)

UCDs as GGCs

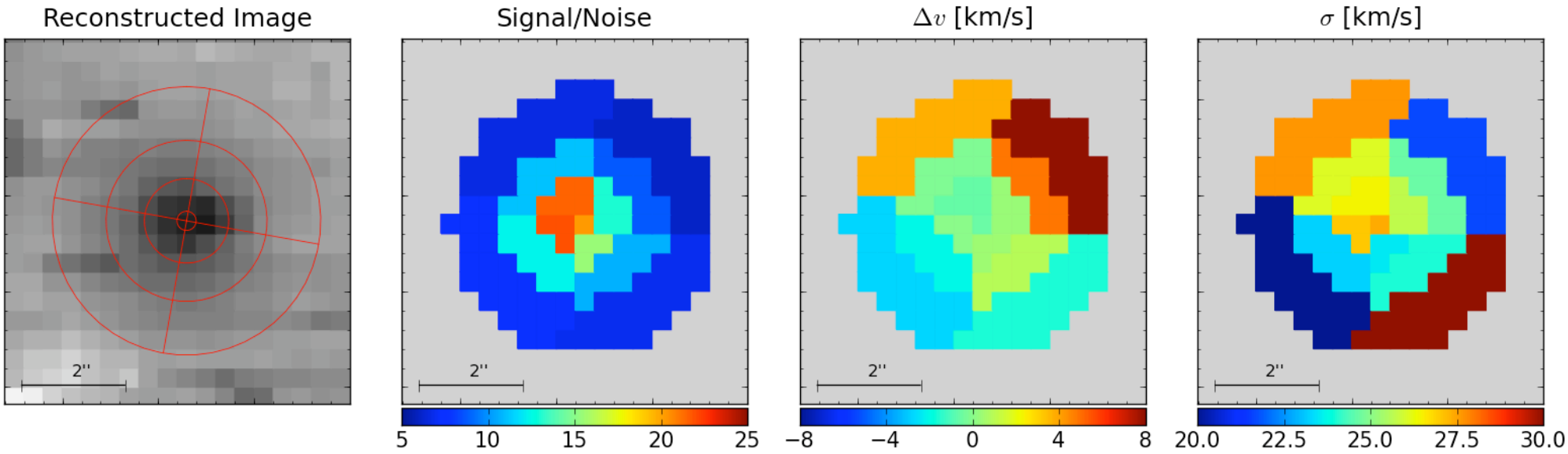
- No, so far not much evidence for anisotropy in Galactic GCs (except rotation in ω Cen which might be a NC-UCD)

UCDs as BCDs

- No, violent relaxation (spherical Es do not show rotation in general)

The first observational steps: IFU observations of UCDs

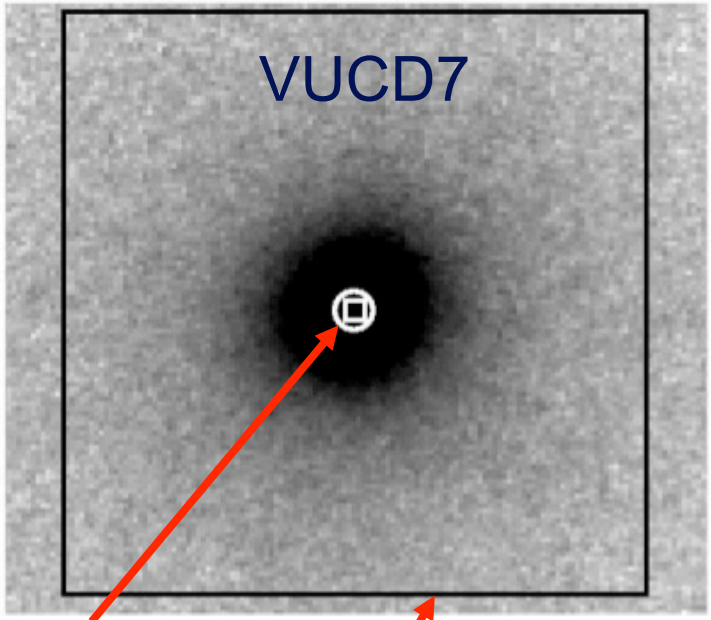
FLAMES/ARGUS observations of the most massive and extended UCD in the Virgo cluster

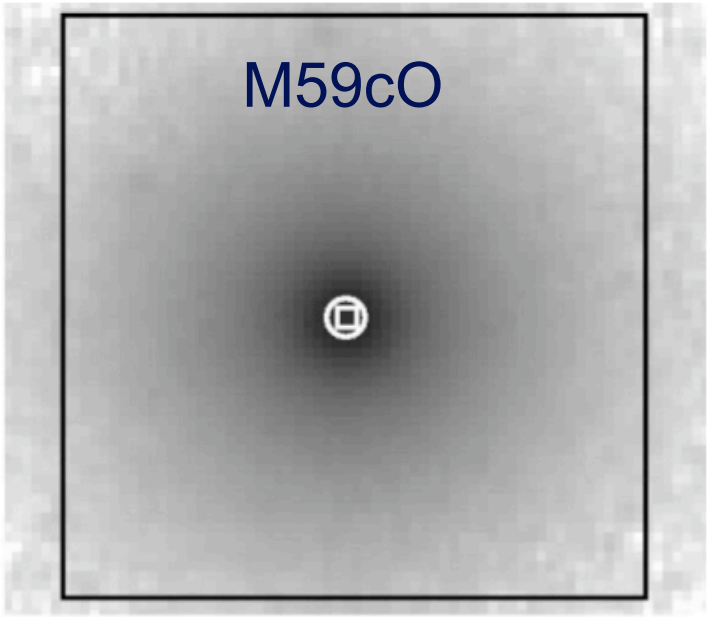


Frank et al. (2011, MNRASL, accepted last Monday)

Next talk!

Two massive UCDs in the Virgo cluster

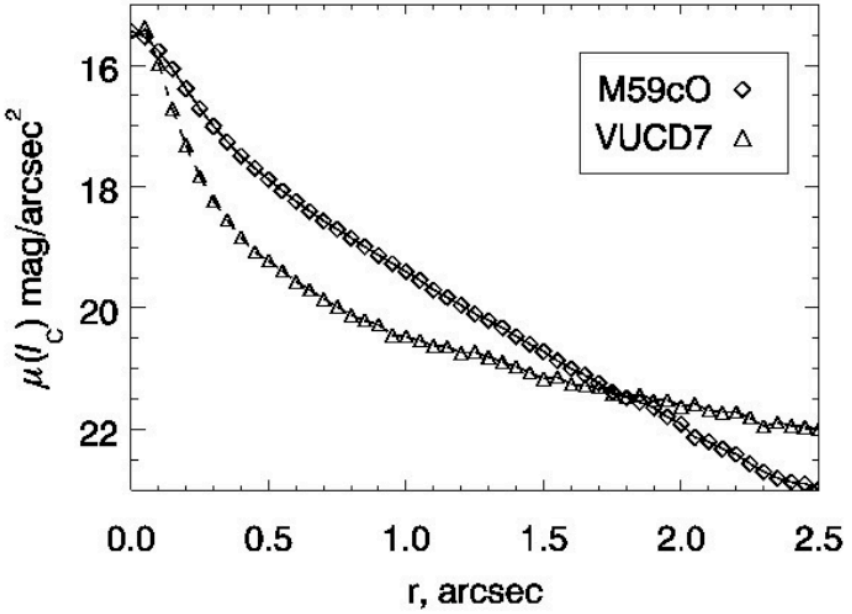




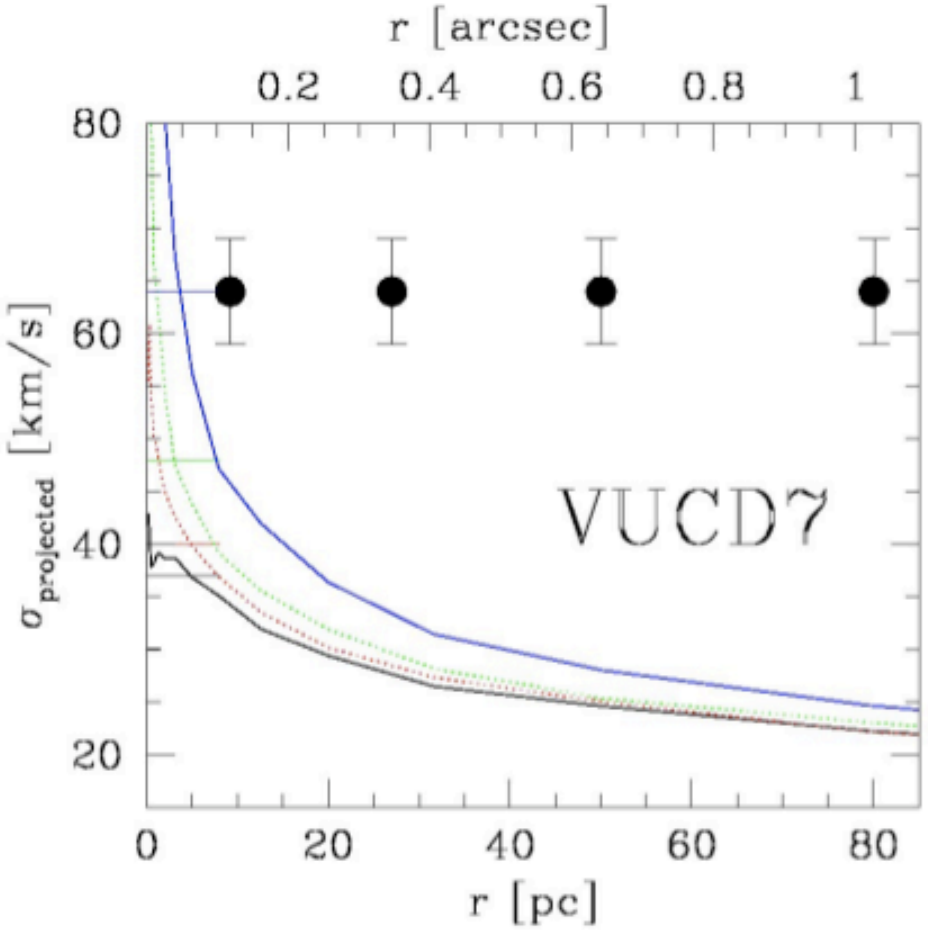
SINFONI pixel and
expected resolution

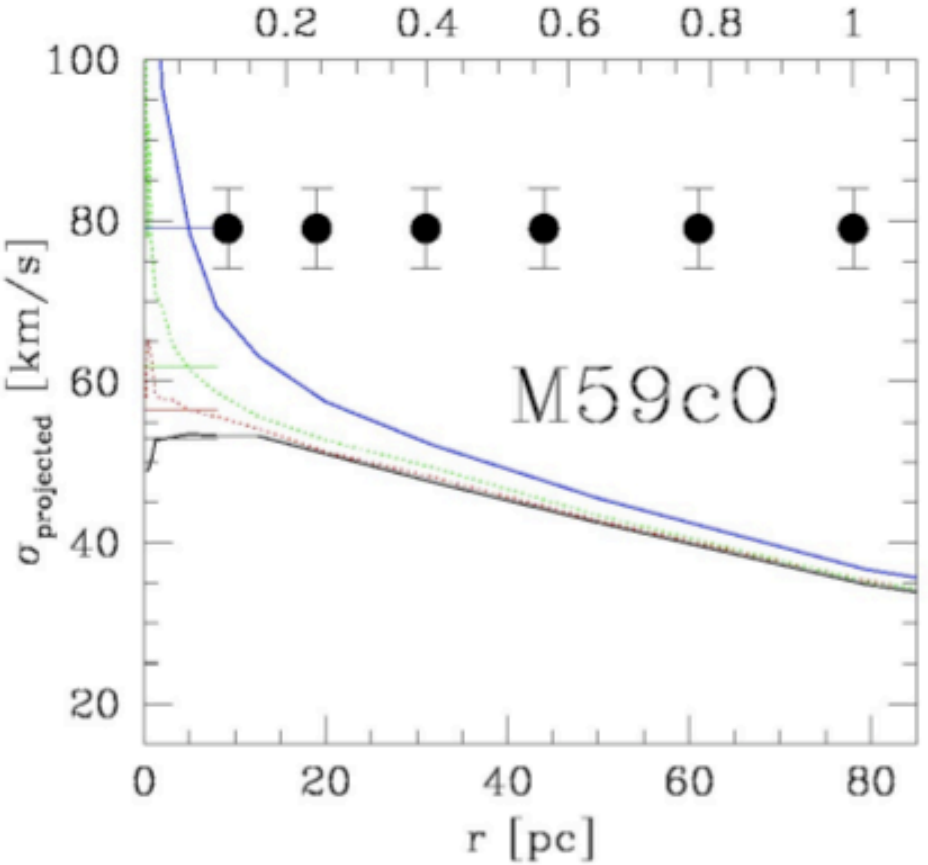
SINFONI 3“x3“ field-of-view

Surface brightness profiles



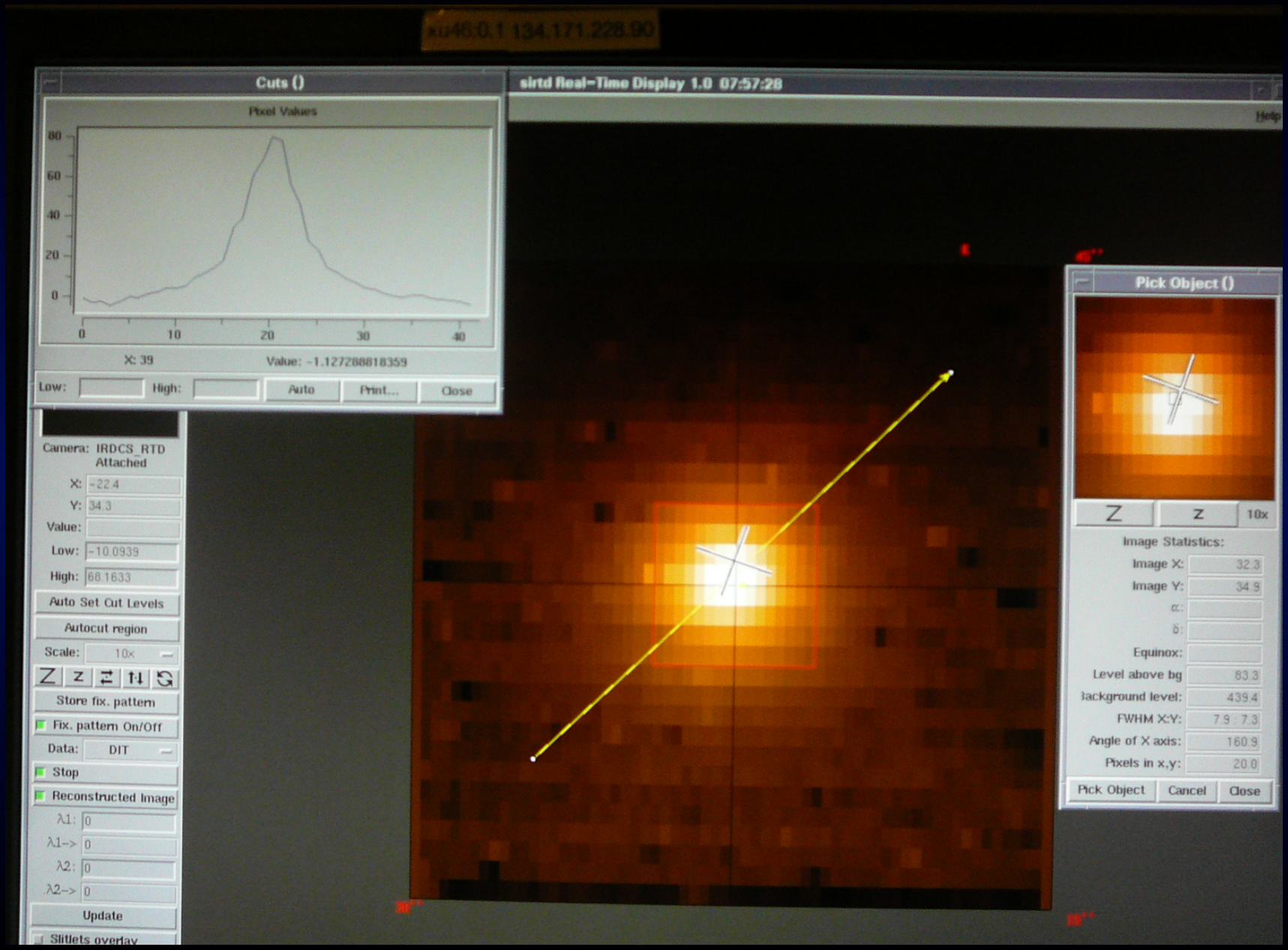
Simulated velocity dispersion profiles for different BH masses





From top to bottom: ratio of BH to total mass: 10%, 3%, 1%, no BH

First SINFONI observations of M59cO in March 2010



Summary

- `UCDs' are defined through their 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'
- Be careful with the correction of the observed velocity dispersions to total or central values for extended objects (r_{eff}~10-90pc) at distances of <20Mpc: the fraction of the light in the slit matters!!
- UCDs are mostly concentrated around major galaxies but also are found in the intra-cluster space, they do not follow the spatial distribution of nucleated dEs
- Resolving the internal kinematics of UCDs is very challenging, first attempts are underway