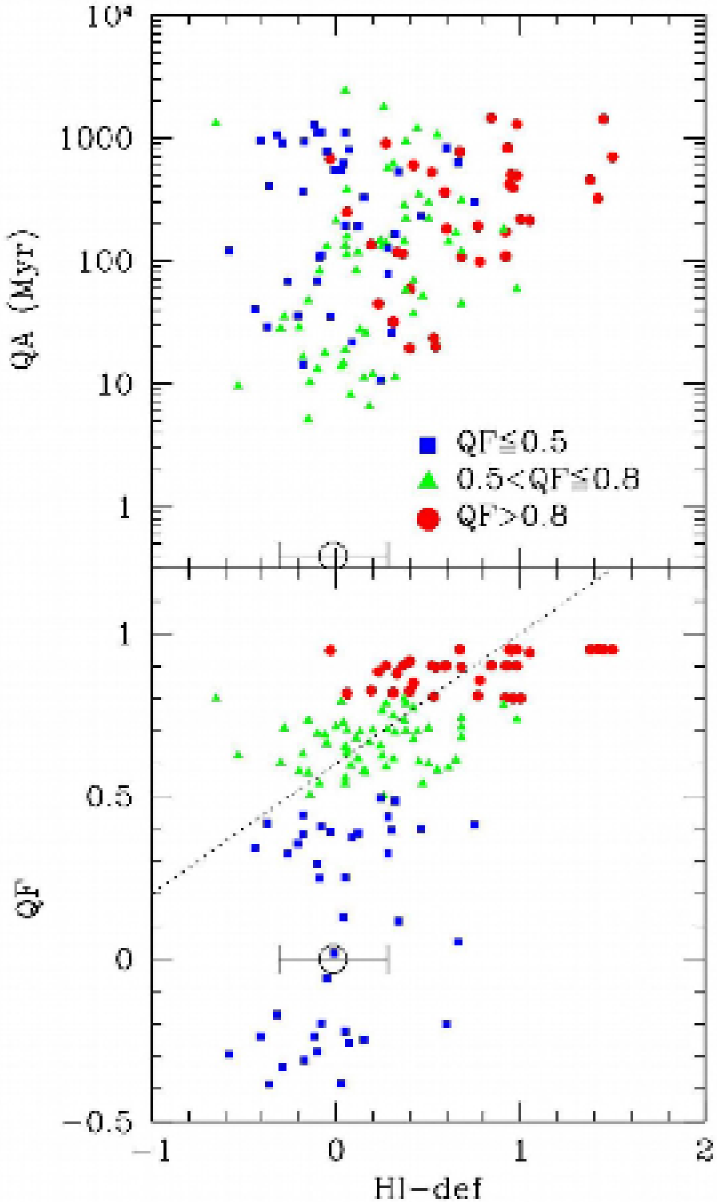
Star formation quenching in the Virgo cluster

- if only those galaxies where *QA* is securely determined (*QF*> 0.5) are considered. The activity of star formation has been reduced ~1 Gyr ago in the most HI-deficient objects of the sample (*HI−def* ≳ 0.8).
- The typical quenching age of the perturbed late-type galaxies is *QA* ≲ 300 Myr whenever the activity of star formation is reduced by 50% < *QF* ≤ 80% and *QA* ≲ 500 Myr for *QF* > 80%, while that of the quiescent early-type objects is *QA* ≃ 1–3 Gyr.
- The fraction of late-type galaxies with a star formation activity reduced by *QF* > 80% and with an HI-deficiency parameter *HI−def* > 0.4 drops by a factor of ~5 from the inner half virial radius of the Virgo cluster ($R/R_{vir} < 0.5$), where the hot diffuse X-ray emitting gas of the cluster is located, to the outer regions ($R/R_{vir} > 4$).



Boselli et al. (2016)

Cold Atomic and Molecular Hydrogen across Environments

Luca Cortese

The Tools in a Nutshell

Single-dish

Pros

- Large collecting areas
- Blind surveys (HI)
- Statistical studies

Cons

- No spatial resolution
- Aperture effects (CO)

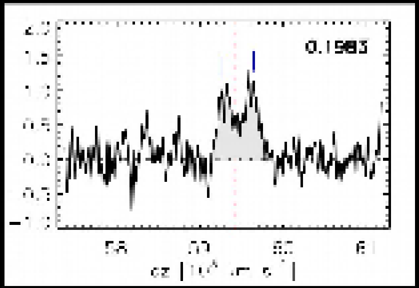
Interferometer (or mapping)

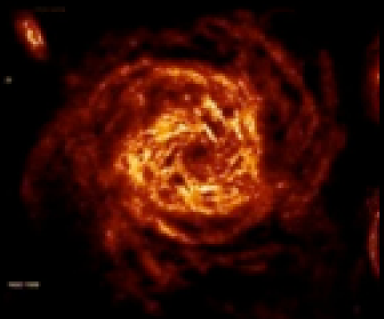
Pros

- 3D high-res maps
- Beyond Virgo, FoV ~ R_{vir}

Cons

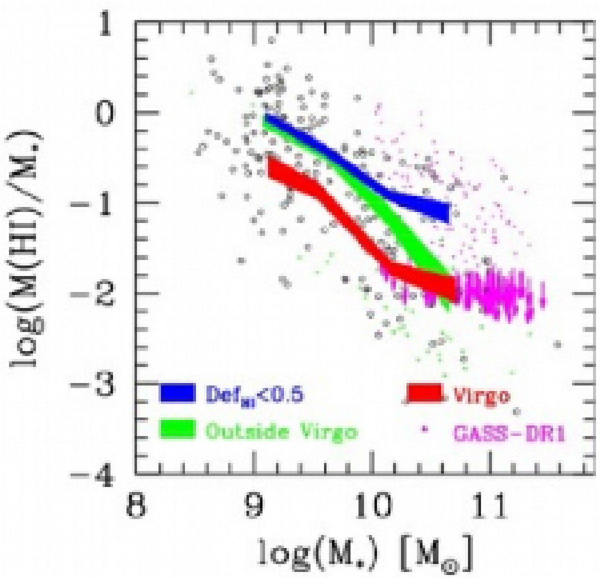
- Statistics still limited
- Harder to reach gas-poor regime





Two highly complementary approaches

The Virgo cluster (HI)



ALFALFA

(plus deeper Arecibo observations)

Whole cluster!

3 arcmin beam

10 km/s resolution

$M_{HI} \sim 10^8 M_{sun}$

(plus other resolved/mapped data

~60 spiral galaxies

~15-20 arcsec beam

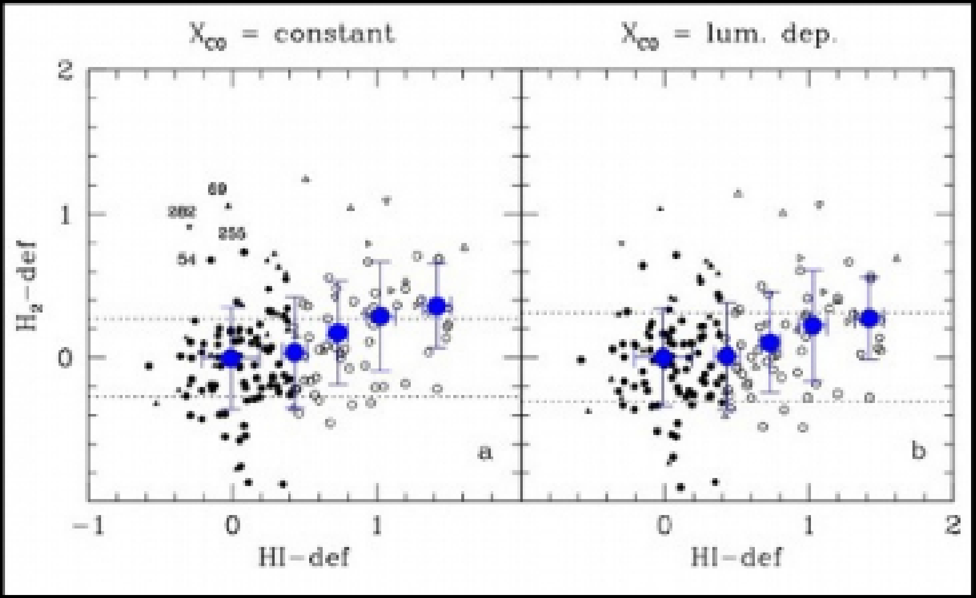
~20 km/s resolution

~3-5 10^{19} cm^{-2}

Giovanardi+ 1983; Helou+1984;Giovanelli & Haynes 1985; Hoffman+1987; Bottinelli+ 1990; Giovanelli+2005; Gavazzi +2008; Cortese+2011; Boselli+2014....

Warmels 1988 Cayatte 1990;Vollmer+2004;2006; Oosterloo & van Gorkom 2005; Chung+2010...

The Virgo cluster (H_2 or better CO)

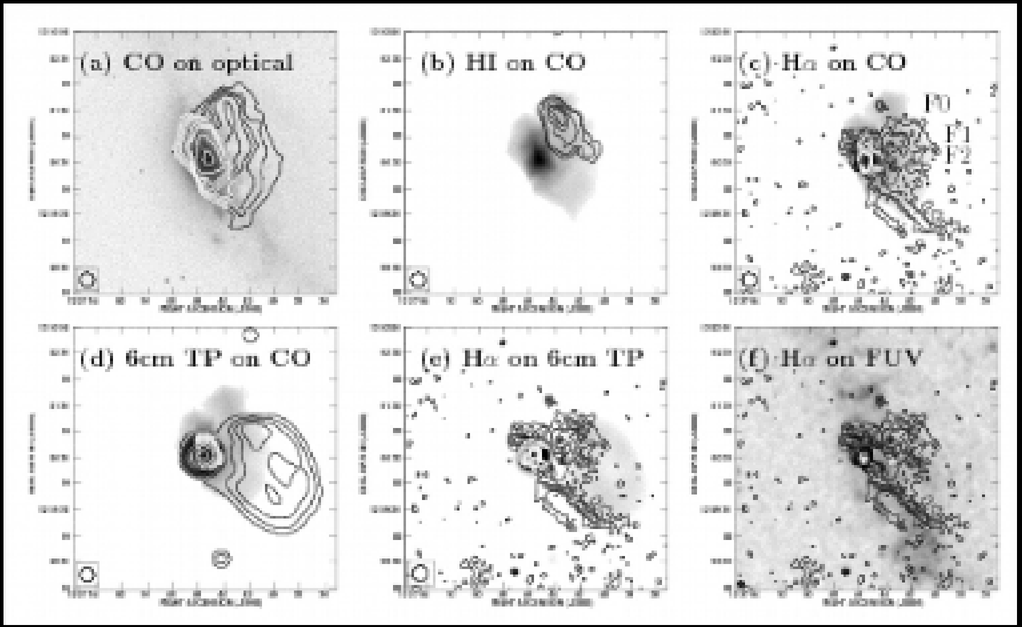


Nearly all spirals with $M^* > 10^9$ M_{sun}

(plus massive early-types)

20-55 arcsec beam (aperture effects!)
10 km/s resolution
$M_{H2} \sim 10^8$ M_{sun}

Sage+ 1989; Stark+1986; Young 1995; Boselli+2002,2014....

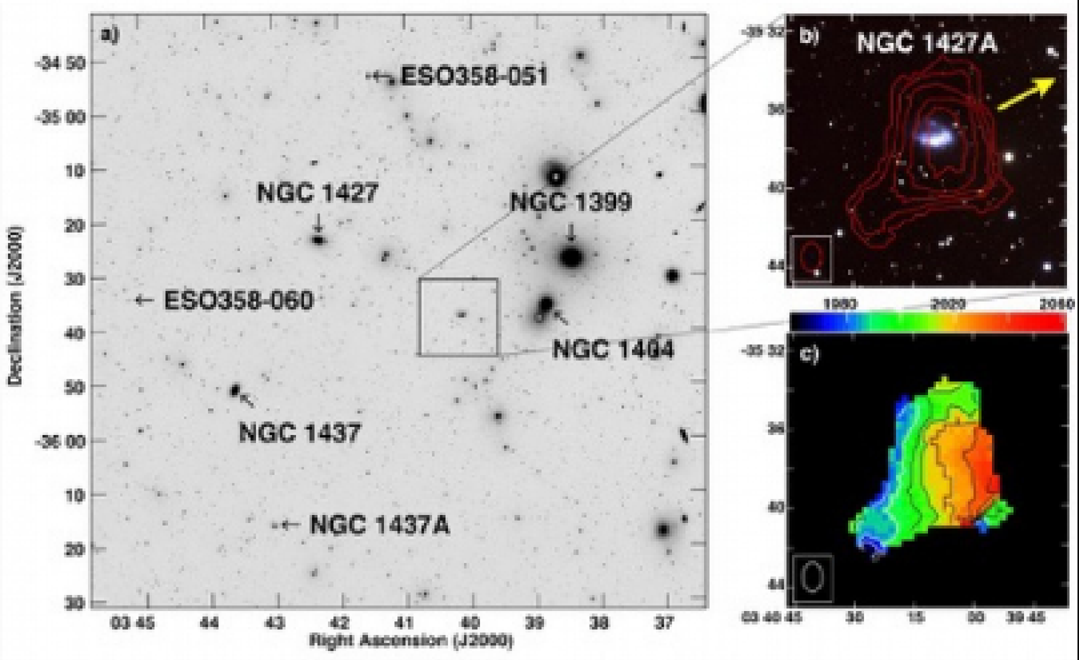


~20 galaxies (!)
~6-20 arcsec beam
~5-20 km/s resolution
~1 M_{sun} pc^{-2}

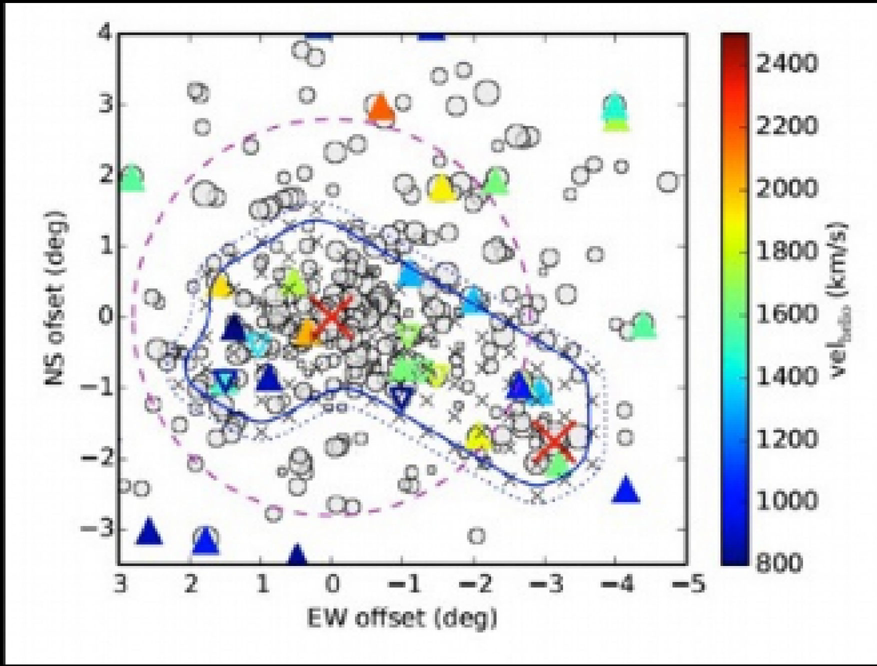
ALMA!

Helfer+ 2003; Vollmer+2005; Kuno+2007; Wilson+2009; Lee+2017...

The Fornax cluster (HI and CO)



Lee-Waddell+2017



Serra+2017 [MeerKAT]

HI: ATCA survey (13 deg^2, 1.2' beam, ~7km/s, 5x10^{19} cm^{-2})

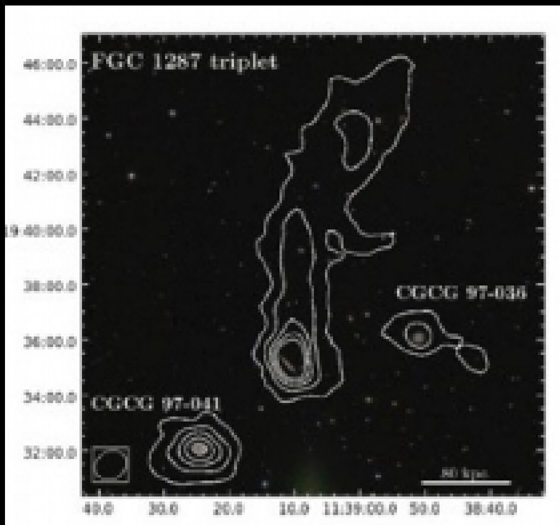
CO: ~10-20 galaxies [MOPRA/ALMA]

Horellou+1995; Lee-Waddell+2017; Smith++;Davis++...

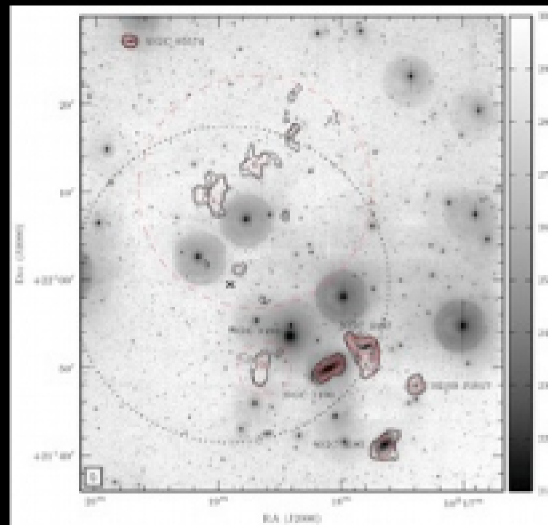
In Virgo, all data consistent with HI stripped fast and outside-in by hydro mechanisms with H_2 affected but in a less dramatic way (differential stripping)

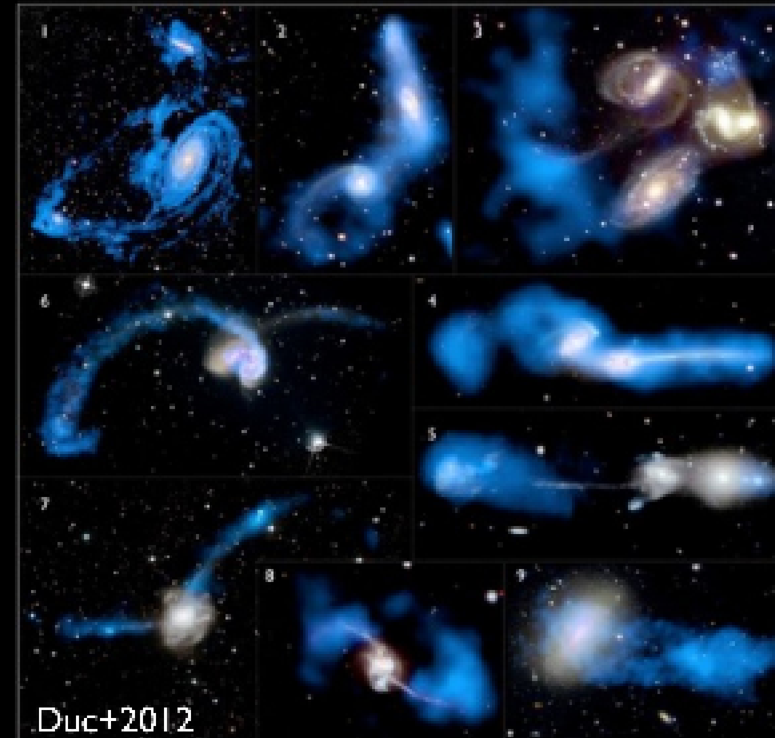
What about structures at “larger” distances (e.g., Coma)

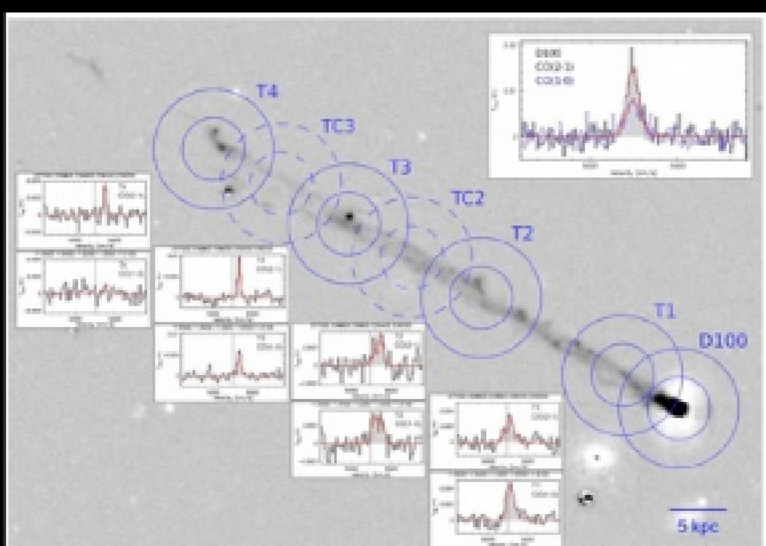
A plethora of `Rosetta Stone' cases



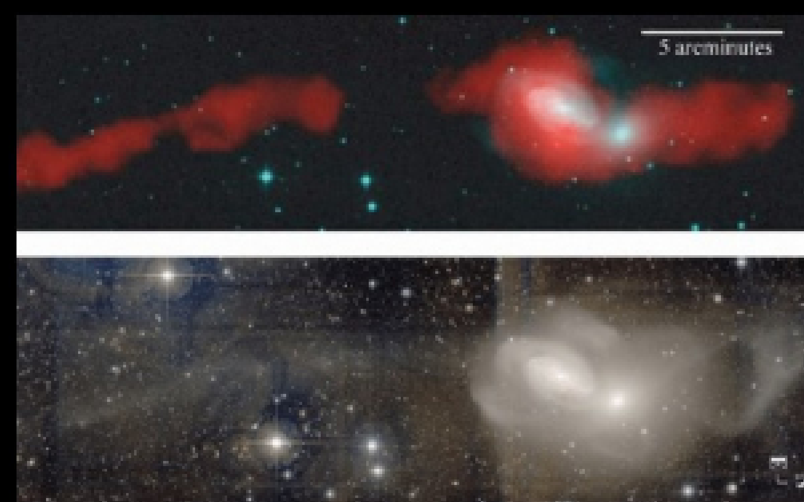
Scott+2012


Serra+2013


Duc+2012

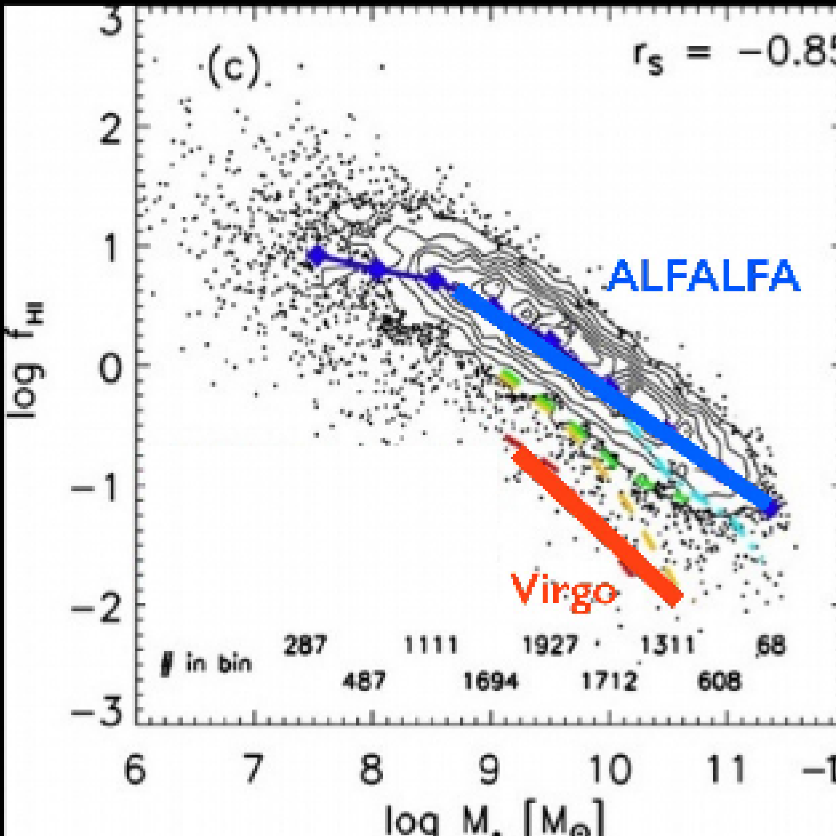


Jachym+2017

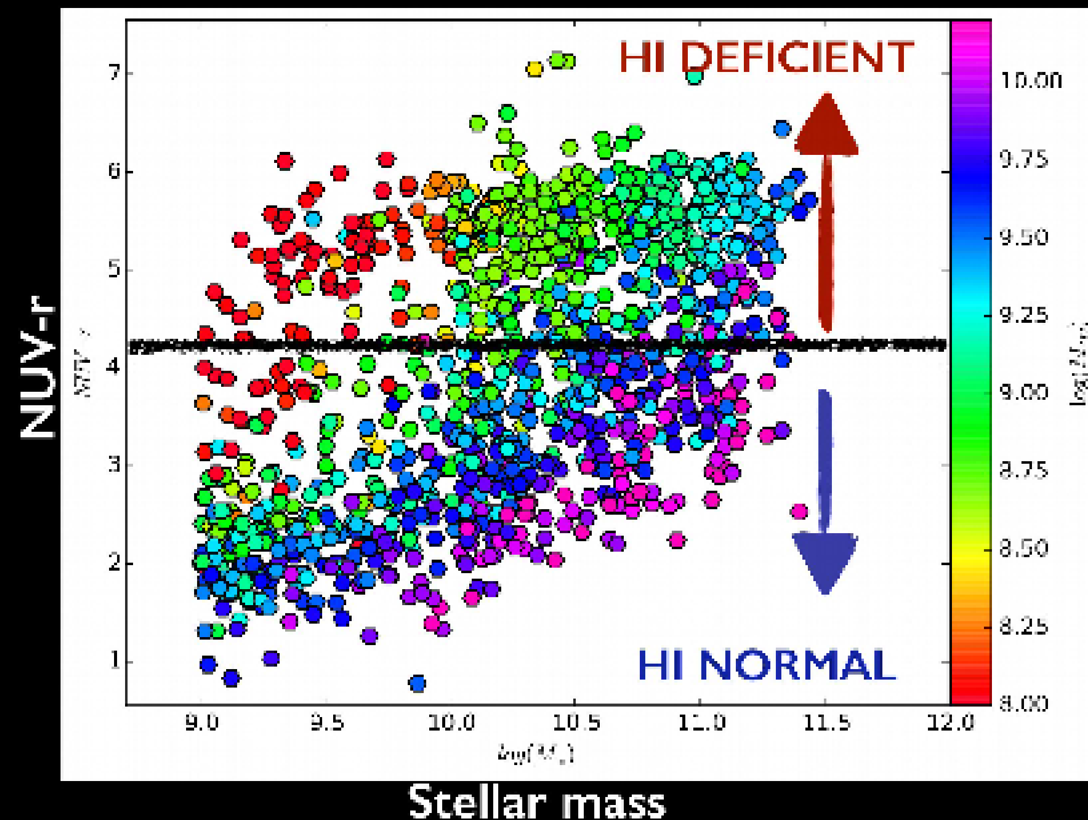


Appleton+2014

Still very hard to reach the gas-poor regime



Huang+2012

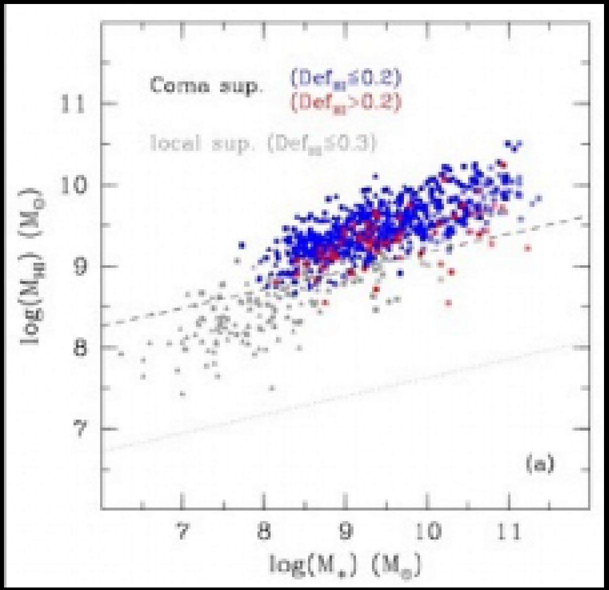


To keep detecting galaxies affected by the environment need to go well below 10^9 Msun

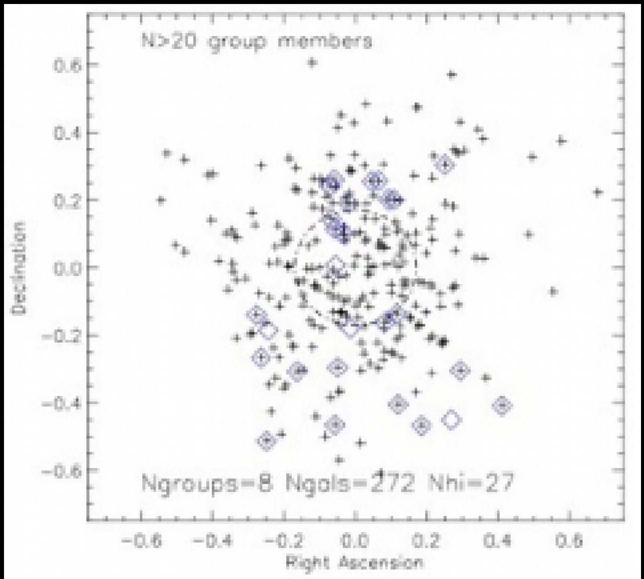
Very challenging above ~50 Mpc

Mostly limited to detection/non-detection dichotomy

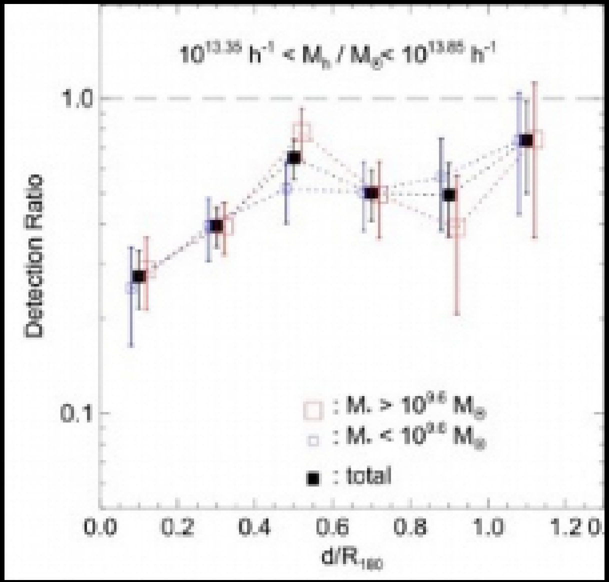
Gavazzi+2015

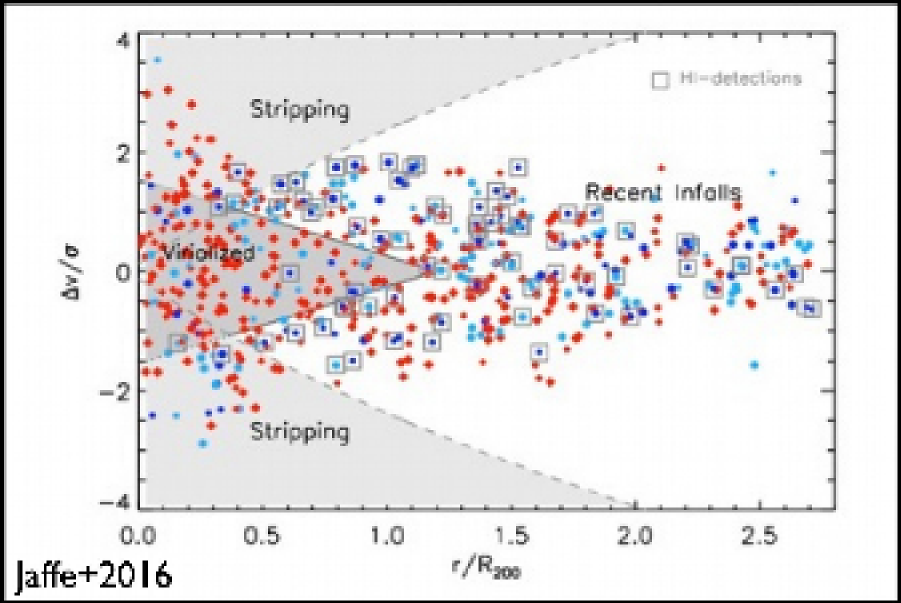


Hess & Wilcots 2013

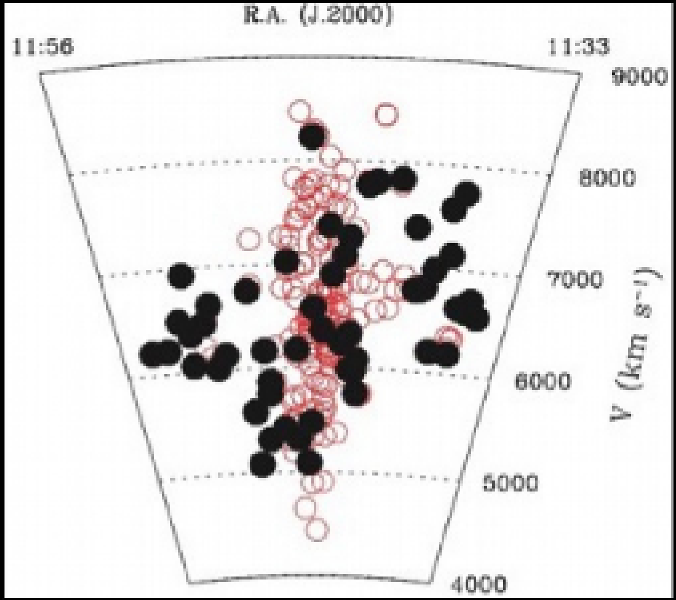


Yoon & Rosenberg 2017





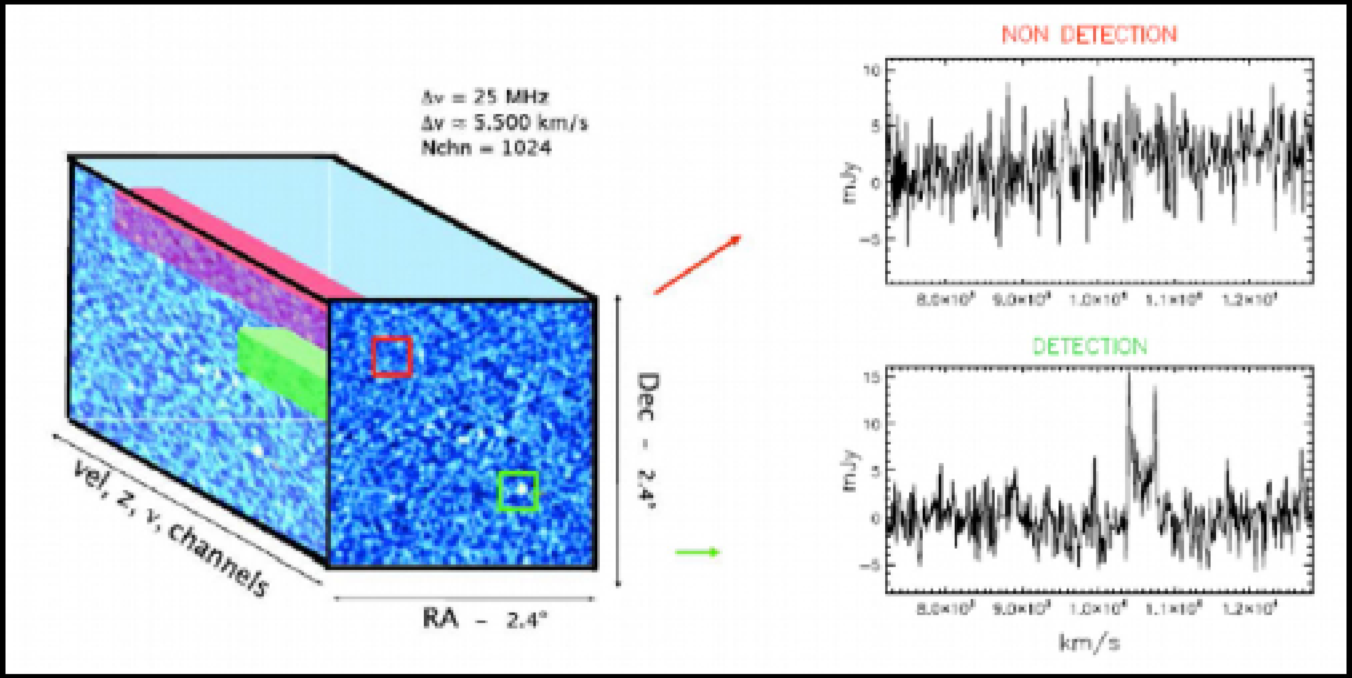
Jaffe+2016



LC+2008

A powerful solution for HI studies

The power of HI stacking (+stellar selected samples)



Fabello+ 2011

- extract HI spectra at known coords, z
- align in velocity, co-add & measure
- Get average HI content of a population

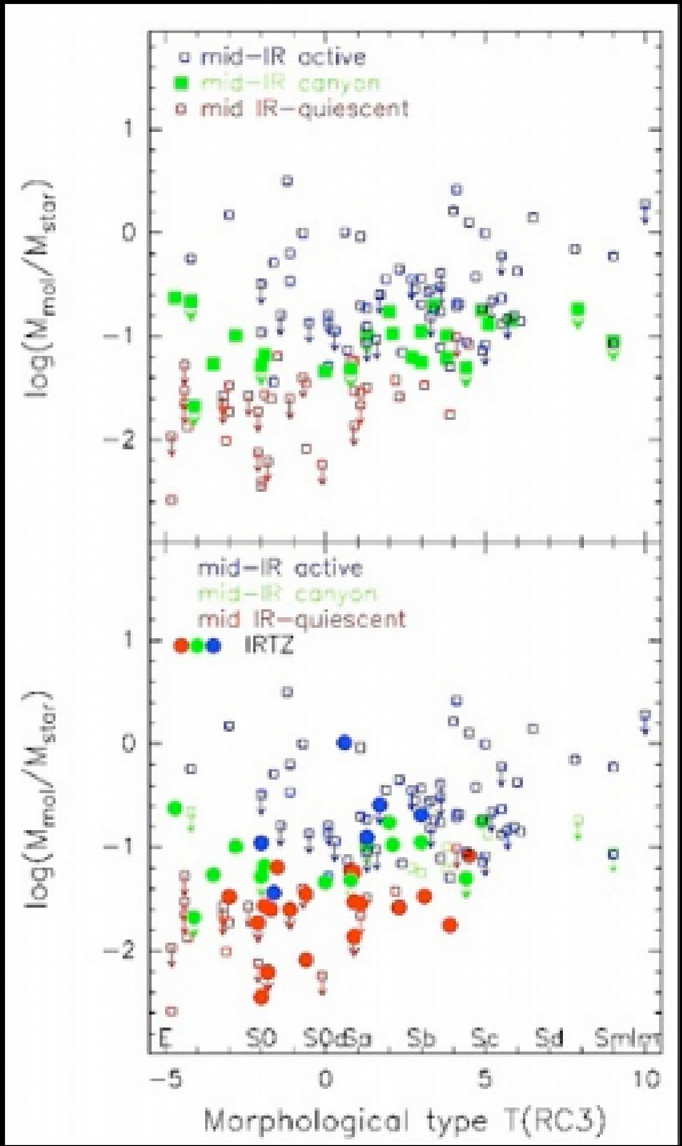
Thanks to optical spectroscopic surveys allow to reach very low gas-fraction limits!

Main limitation is confusion. Not always feasible for close pairs and clusters!
(but things will soon improve!)

See my "fast" talk tomorrow to more details on this!

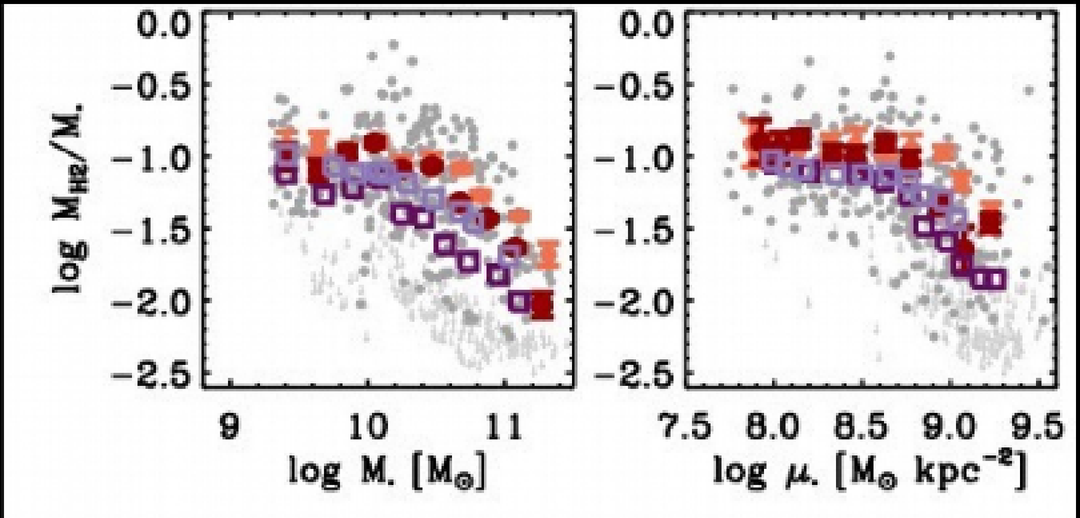
In CO situation even gloomier

Compact Groups



Lisenfeld+2017

Average galaxy in the local Universe



Saintonge+2018

Same story... but even without a CO-blind shallow survey!

ICRAR

Take-home messages

Virgo still a unique place to study effect of environment on ISM

Fornax quickly catching up

At larger (but still very nearby) distances difficult to step into gas-poor regime (still limited to main-sequence galaxies only!)

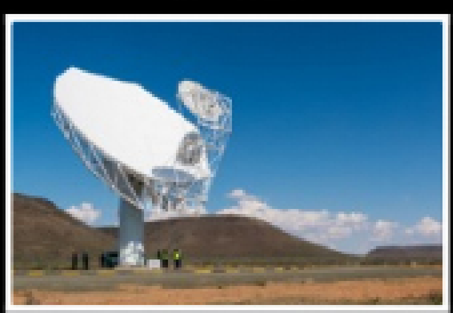
HI Stacking one current solution... otherwise probably have to wait end of deep SKA precursors surveys!

Missing large-area (deep or blind) CO surveys for groups/clusters

Future is promising... but significant progress in terms statistical studies will take time

ASKAP

MeerKAT

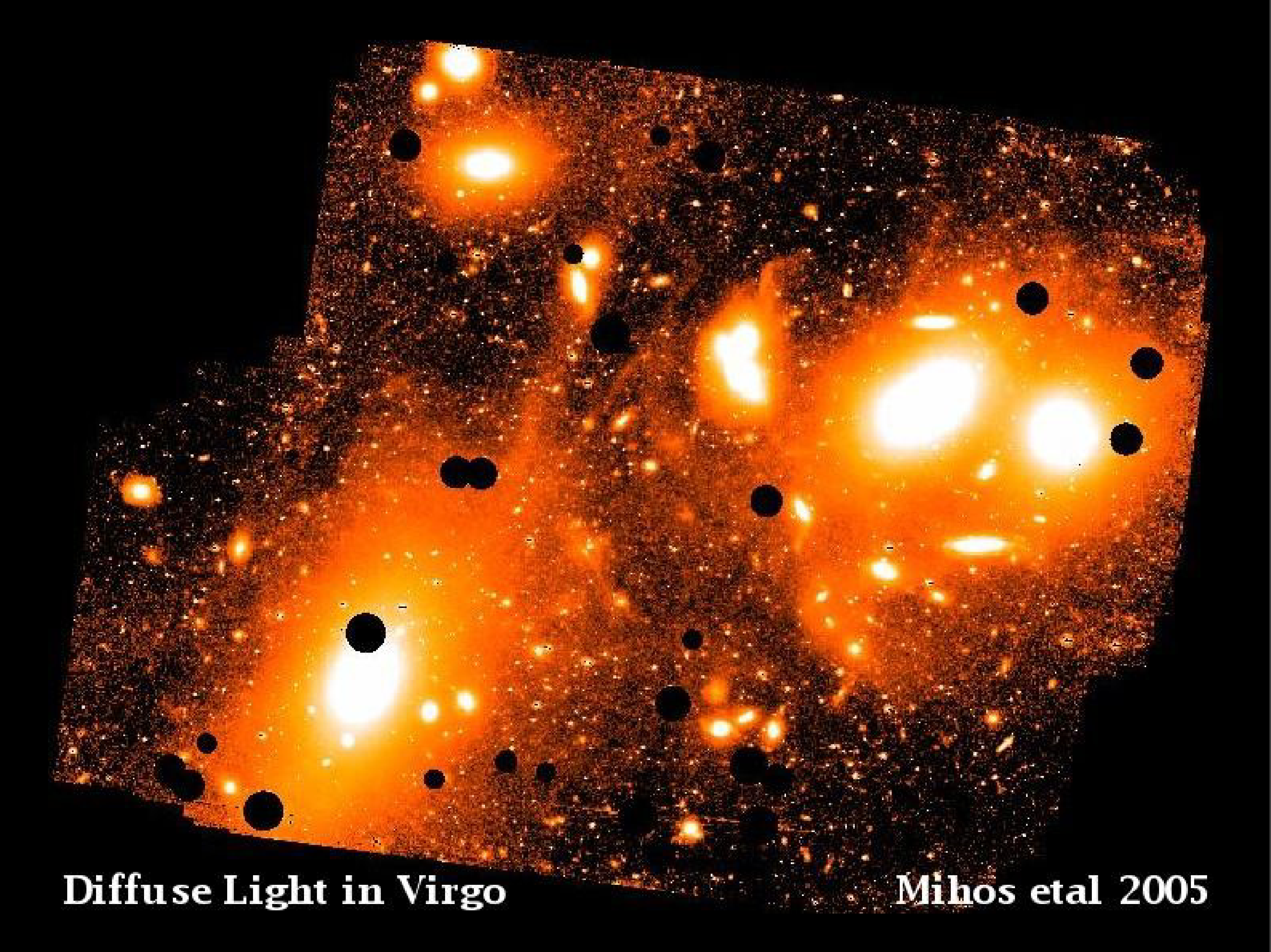


FAST

ALMA

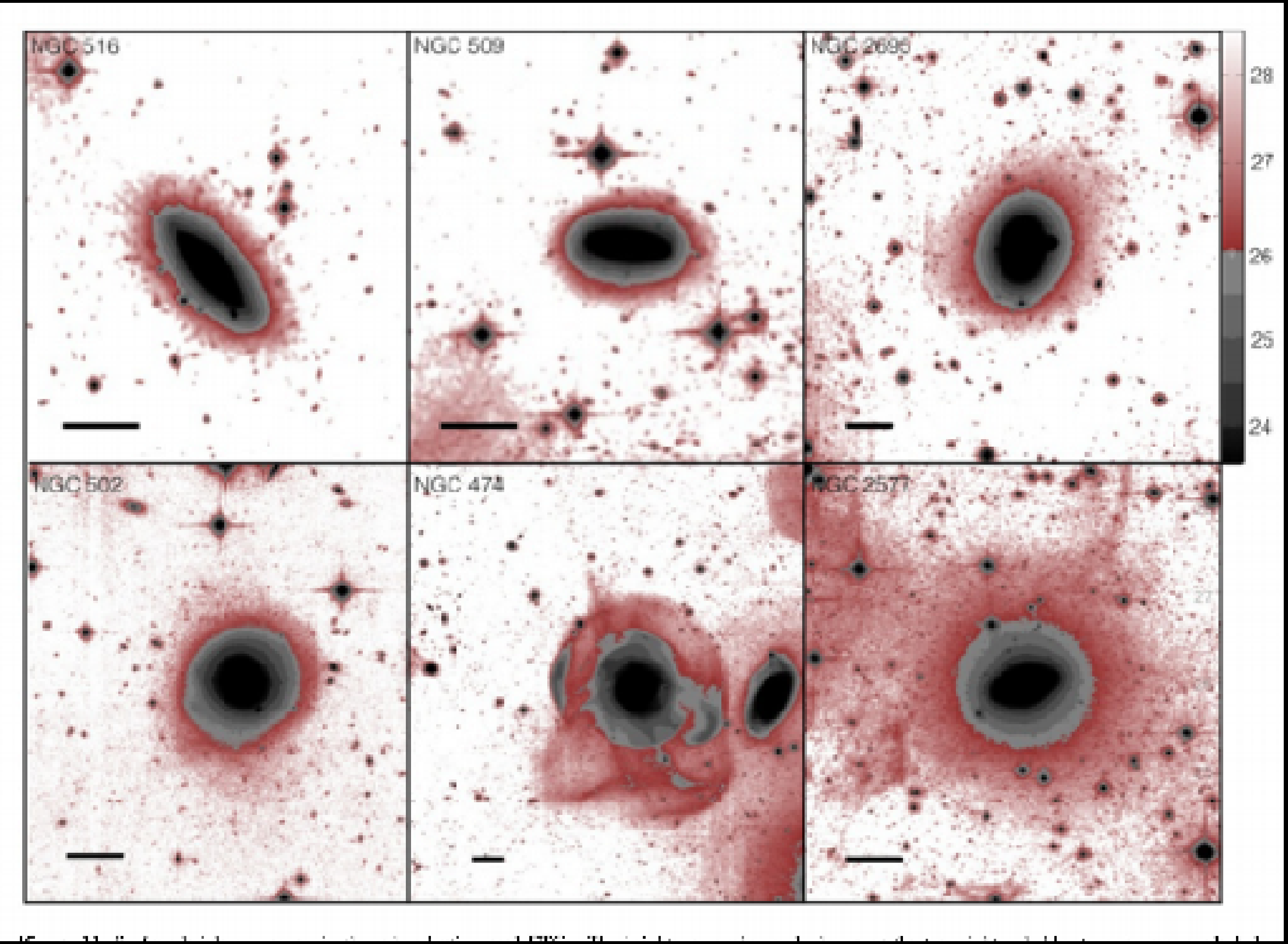
Galaxy Properties in the Nearby Universe showing the Effects of the Environment

Reynier Peletier


Diffuse Light in Virgo
Mihos etal 2005

Duc et al. (2015, CFHT) – deep imaging of the ATLAS3D sample, E+S0

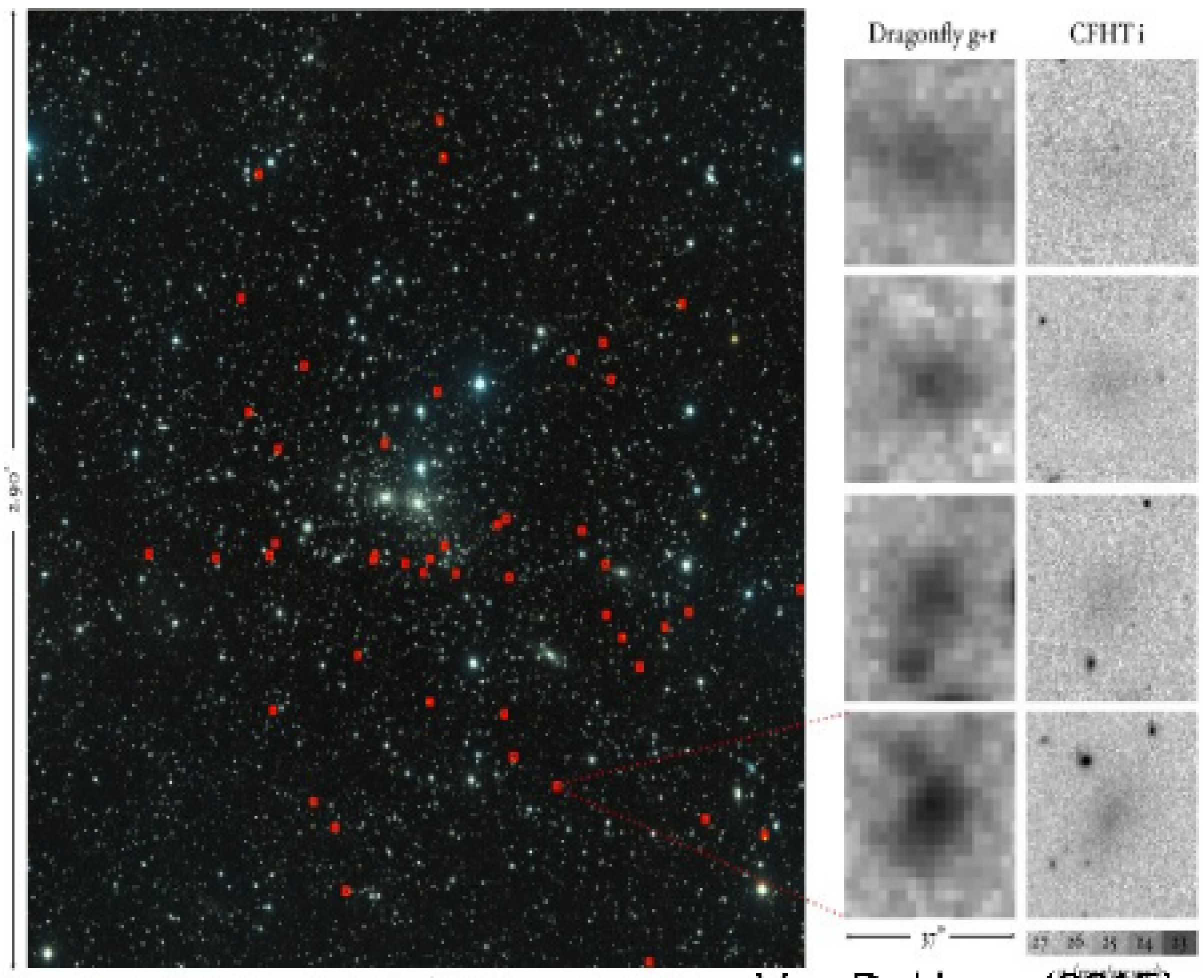
Field Galaxies



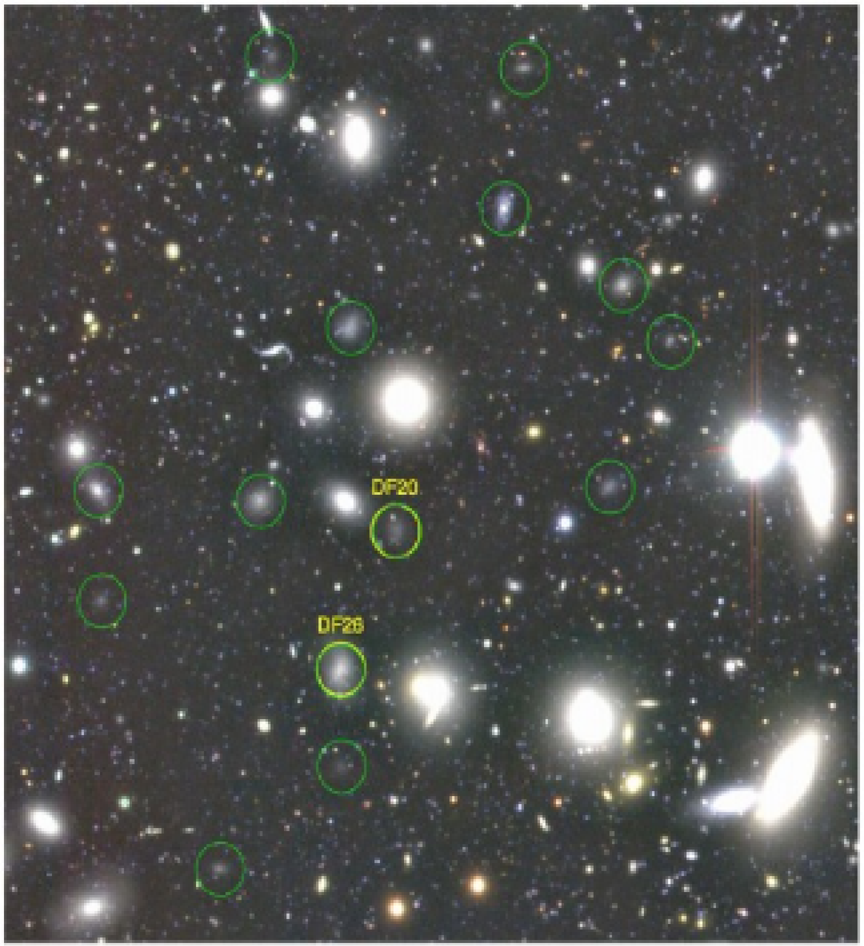
With deep photometry often low SB light is seen around massive galaxies

Ultra Diffuse Galaxies

- Van Dokkum et al. (2015a) reported of finding 47 large (R_e>1.5kpc) LSB galaxies ($\mu_{0,g}$>24mag arcsec^{-2}) from Coma
- These objects (and ~300 similar objects) were confirmed by Yagi+, 2016.
- Similar, even larger objects were then found also in Virgo (Mihos+2016).
- Shortly after, similar galaxies were found in groups (Merrit+,2016,Trujillo+, 2017) and low density environments (Martinez-Delgado et al. 2016) and field (Bellazini+, 2017).



Van Dokkum (2015)



Koda et al. (2015)

LSB galaxies in clusters

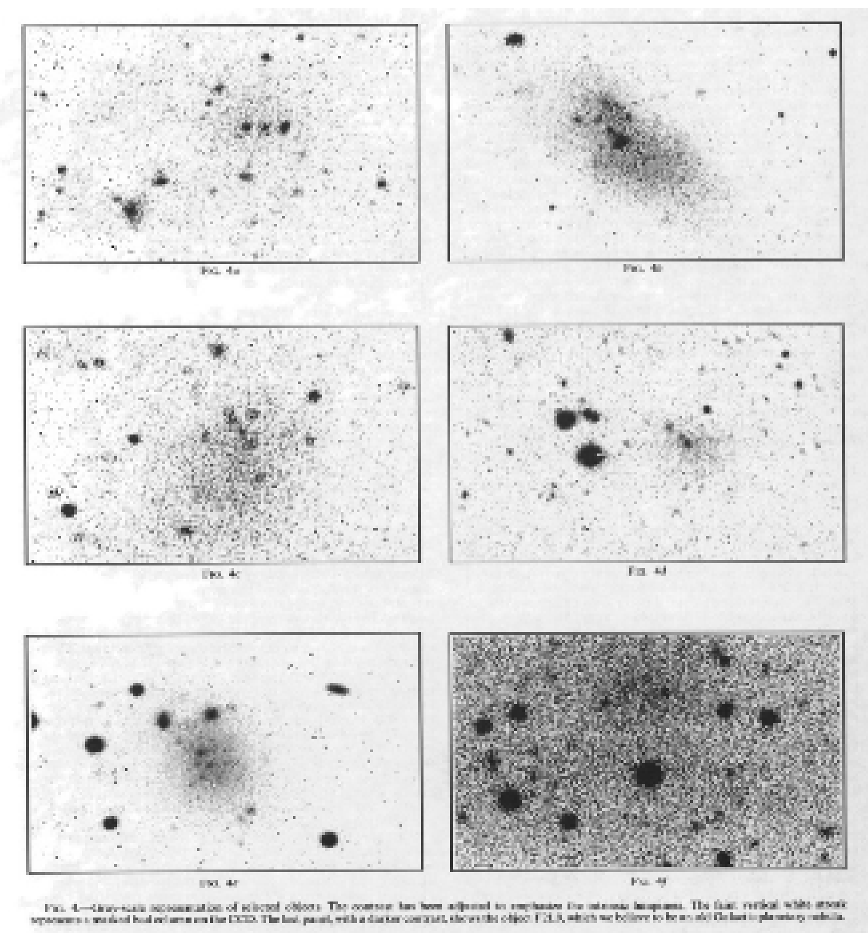
Many disruptive processes (ram pressure stripping, harassment, tidal interactions) take place in galaxy clusters

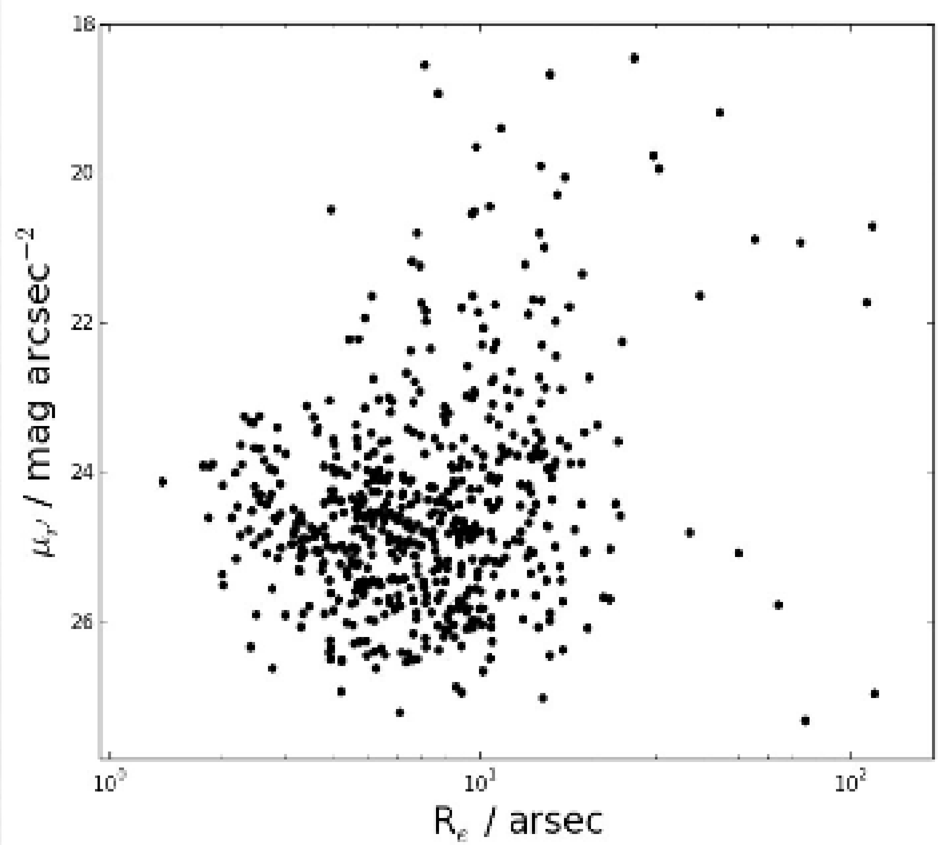
--> LSB galaxies in clusters should have high High Mass-to-light ratios (Bothun+,1991)

- Davies+, 1988: there is no size-SFB relation in the Fornax cluster i.e. the galaxies do not become smaller with decreasing SFB (confirmed for even lower SFB limit by Bothun+,1991).

  —>The dwarf LSB galaxies form the bulk of the population at the low luminosity end of the luminosity function.

- These galaxies have typically exponential or Sersic index n < 1 ('flat center') SFB-profiles, and many of them possess a nucleus.
- In clusters (Virgo:Sandage & Binggeli 1984,Coma:Davies+1988) these galaxies have smooth appearance (dE).

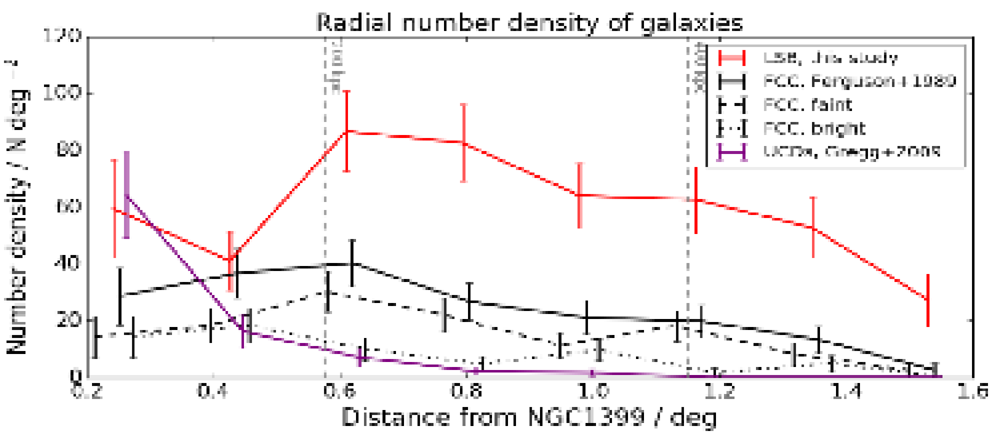


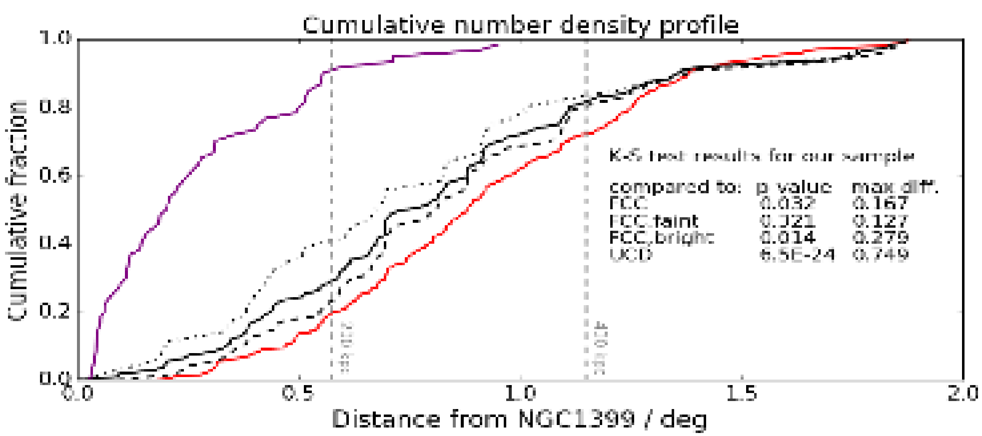


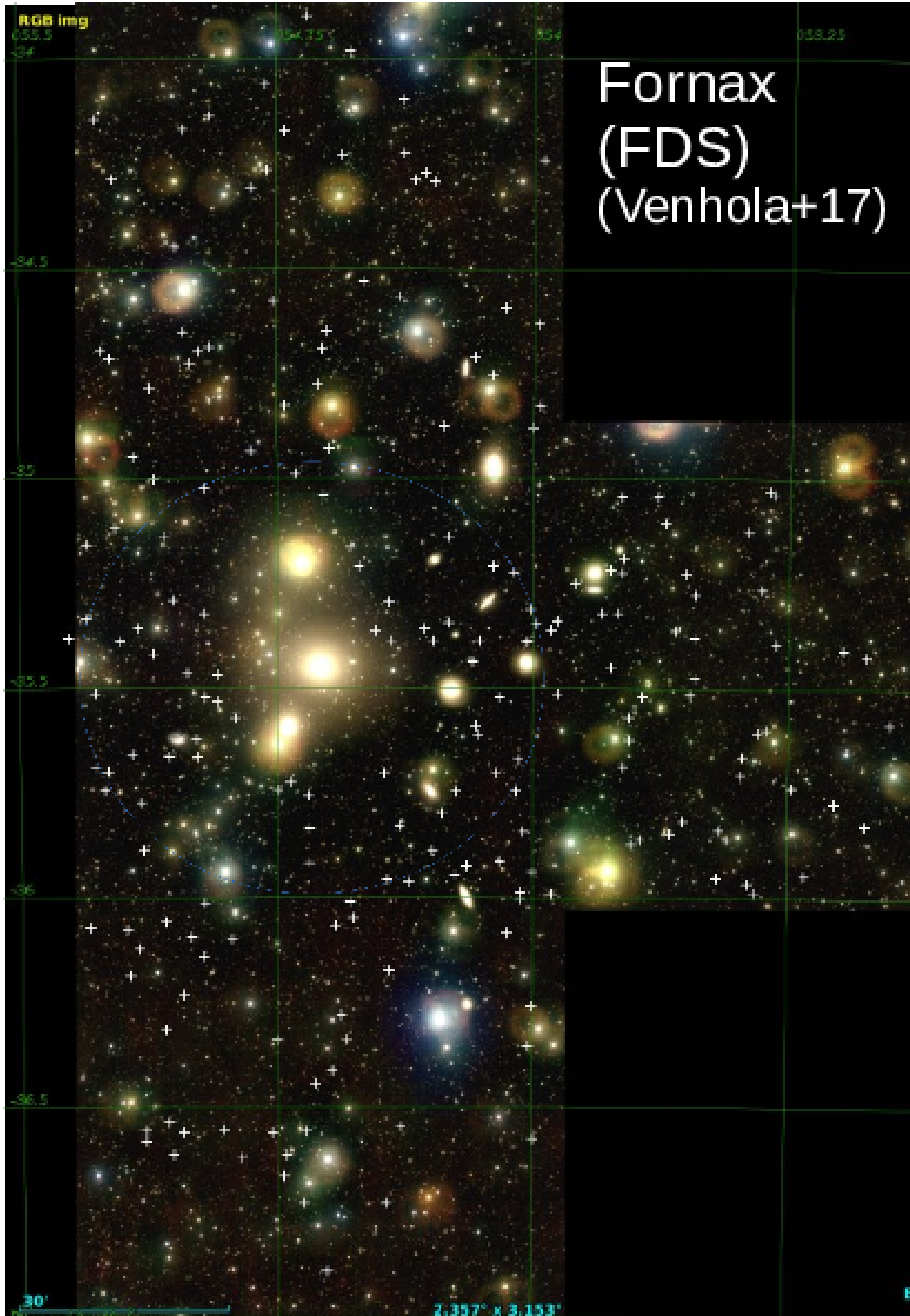
New FDS catalog

Radial distribution in the cluster

- Number density was measured in cluster centric bins and compared to FCC (Ferguson+, 1989) galaxies.
- The high surface brightness galaxies are deeper in the cluster potential than LSB
- Surface number density drops within the inner 200 kpc from the center, which can be resulting from the tidal disruption of galaxies in the cluster center.



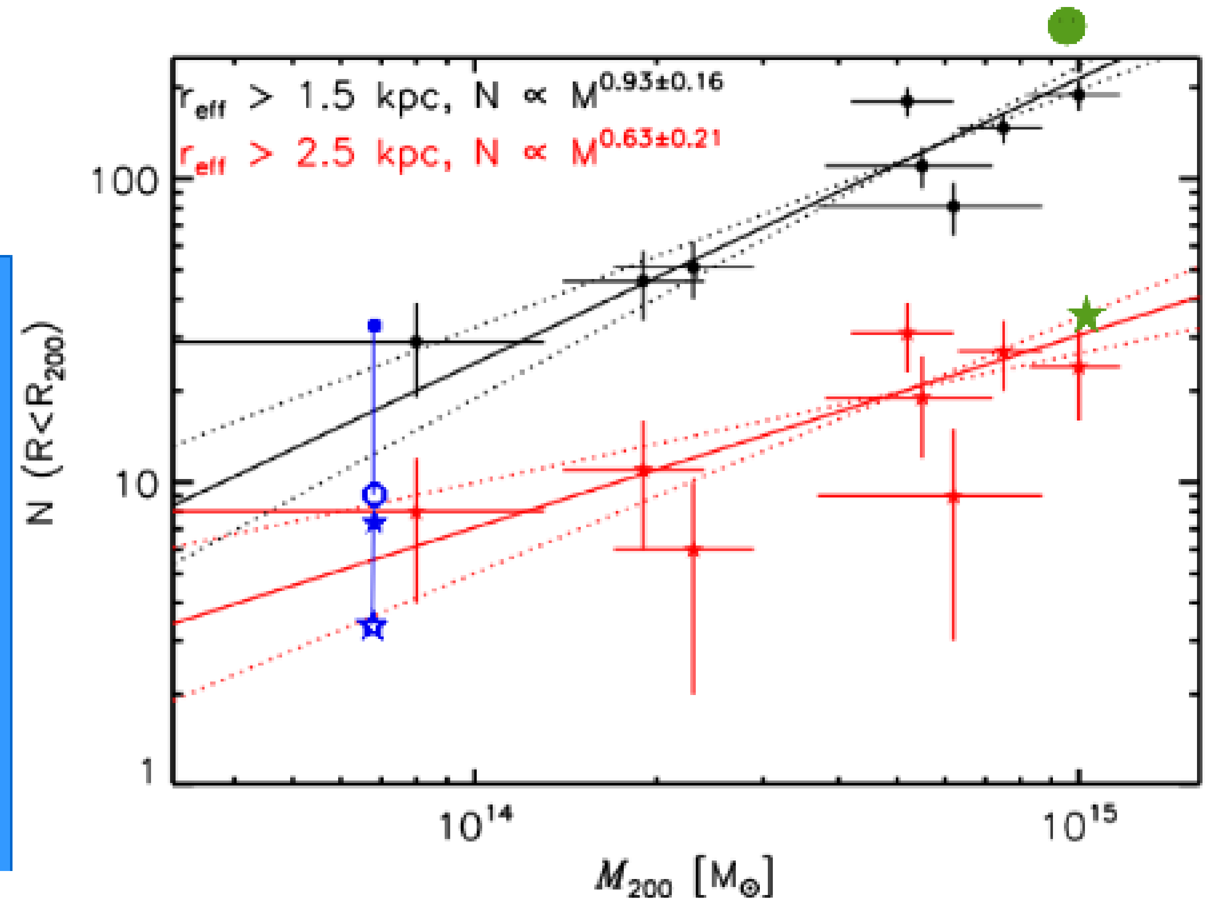




Number of UDGs

Fornax has a "normal" amount of UDGs compared to mid-z clusters
As does Coma.

When the actual bright galaxy (M_B<-16 mag) numbers of Fornax and Coma are compared the number of UDGs:
-> UDGs are more frequent in Fornax.
→ likely to be explained by different detection methods



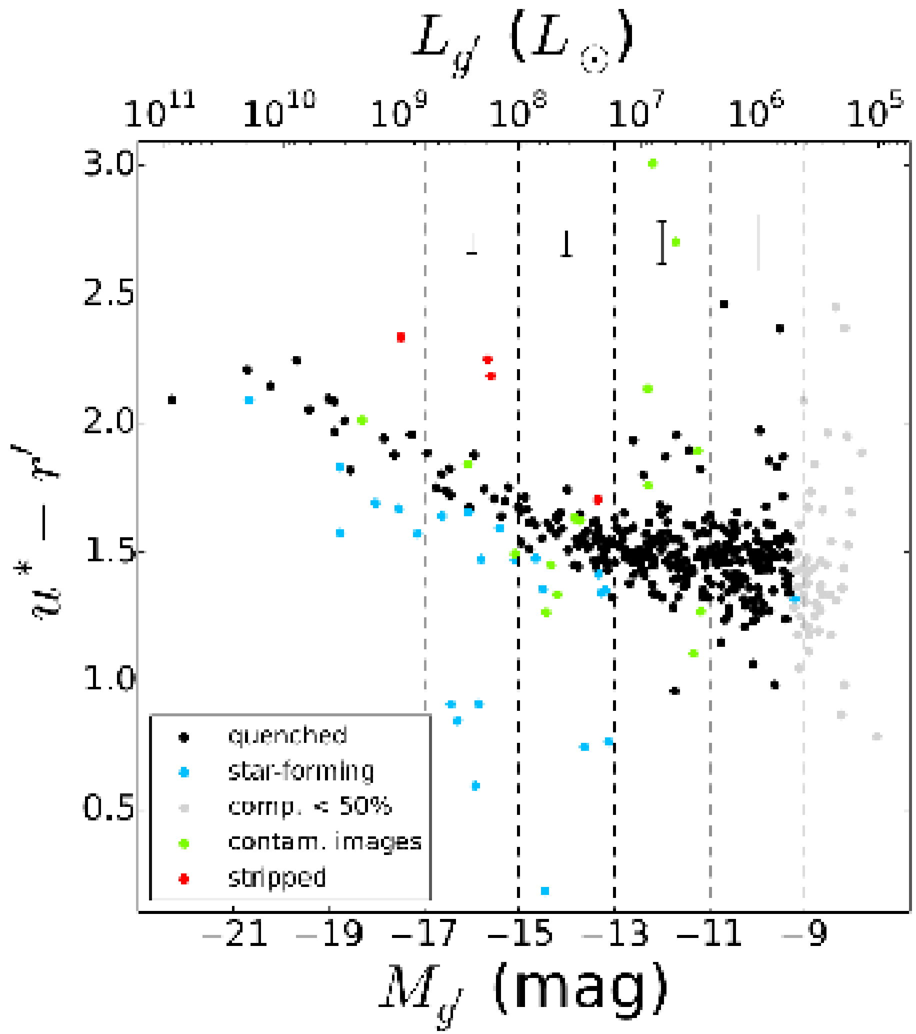
Van der Burgh+2016 relation for 0.044 <z< 0.063 clusters.

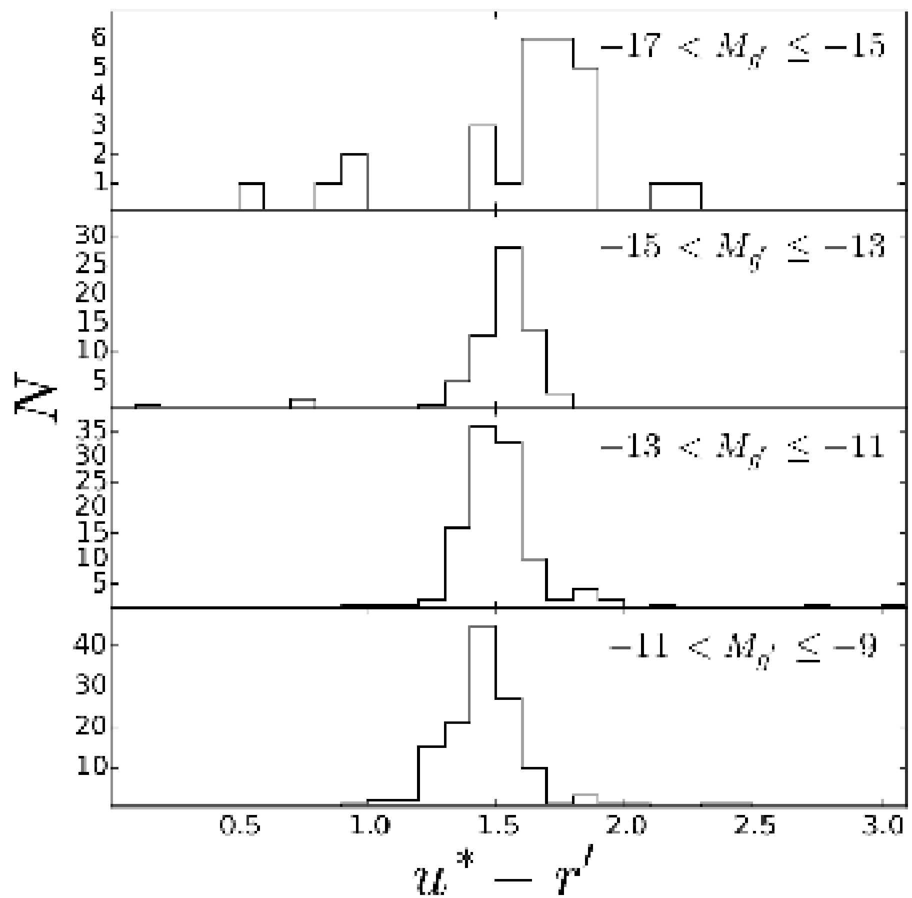
	Fornax (r=450kpc)	Fornax (r=0.7Mpc)	Coma (r=700kpc)	Coma (r=2.5Mpc)
UDGs	9±3	42±12	98	288
1.5 kpc < R_e < 3 kpc	5	22±8	91	267
R_e > 3 kpc	4	19±7	7	21
UDGs / Mpc^{-2}	25±8	-	64	-
Normalized frequency, $\frac{\nu_{UDG}}{\nu_{bright}}$	0.7±0.2	-	0.45±0.05	-

Venhola et al. 2017

Faint end of the color-magnitude relation

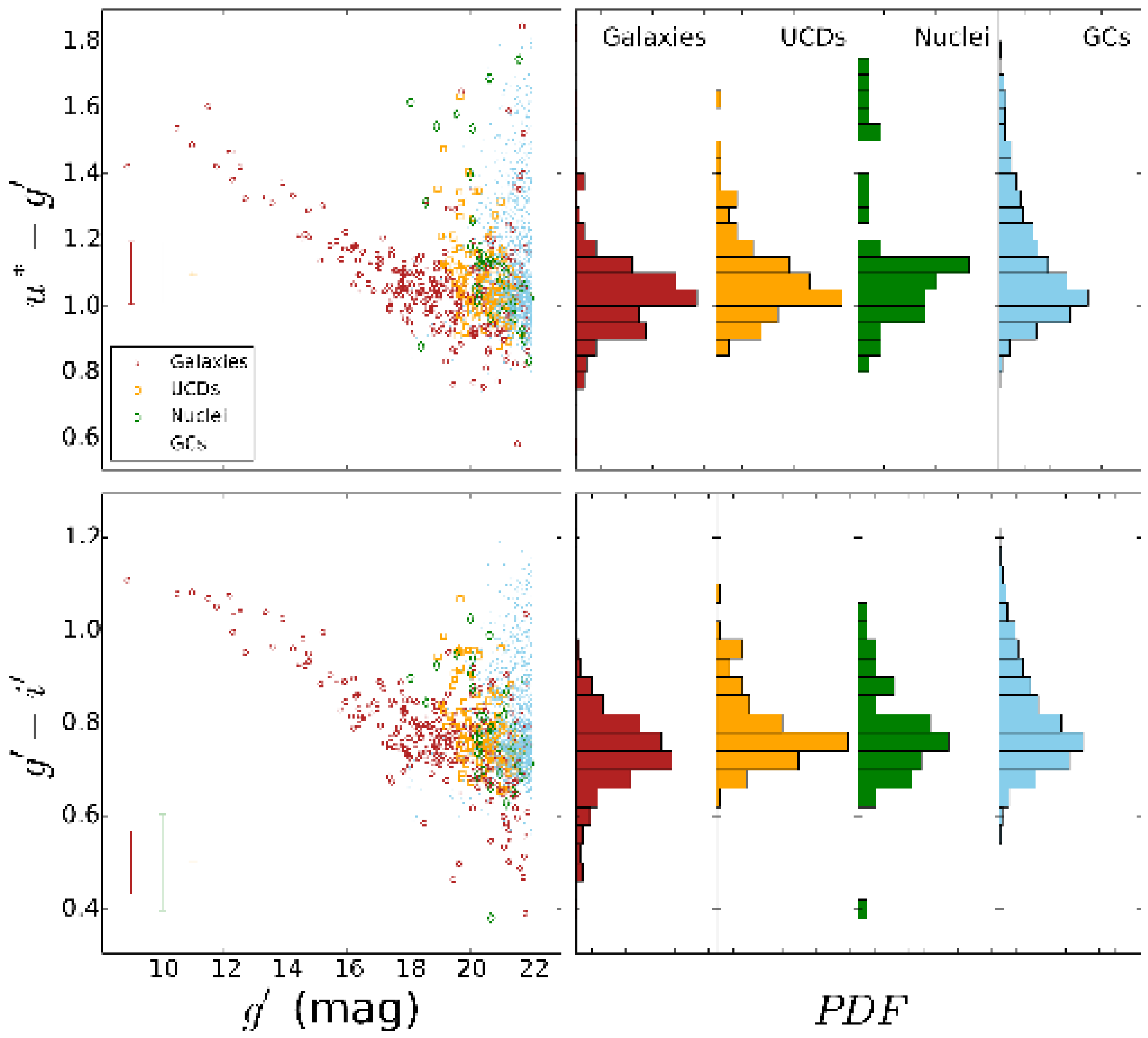
Central Region of Virgo Cluster





Flattening at the faint end.

Roediger et al. (2017)



Galaxies
UCDs
Nuclei
GCs
$u^* - g'$
$g' - i'$
g' (mag)
PDF