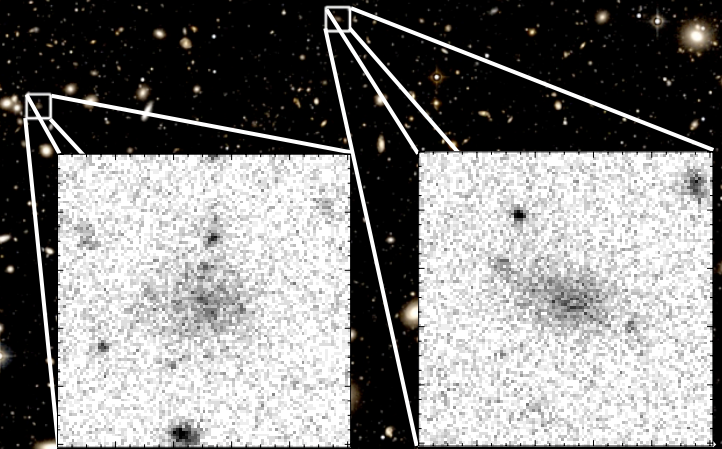
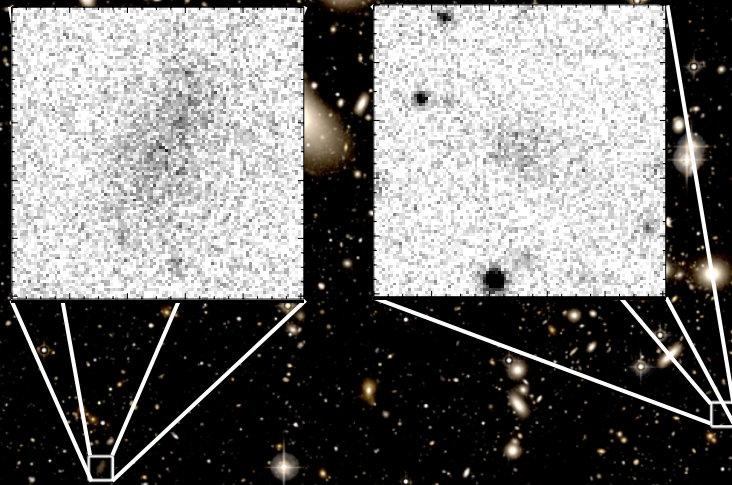


Towards Understanding the Origin and Evolution of **Ultra-Diffuse Galaxies**



Remco van der Burg
CEA Saclay, France

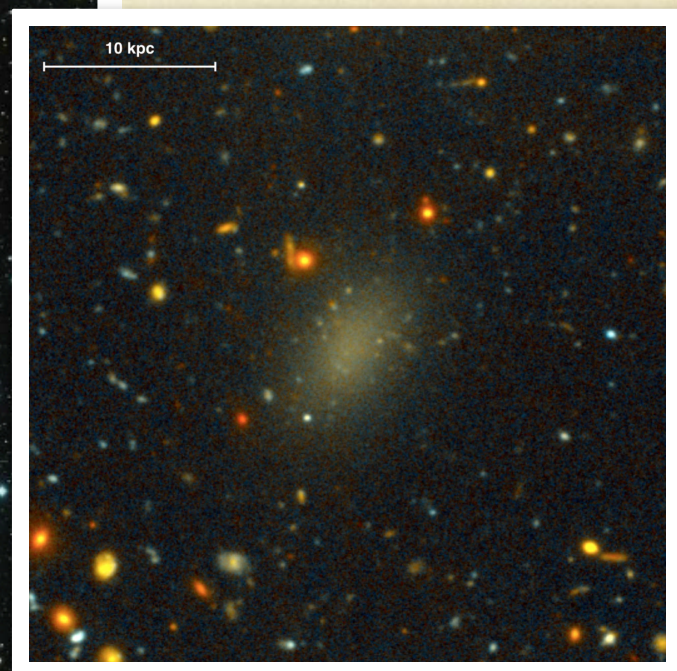
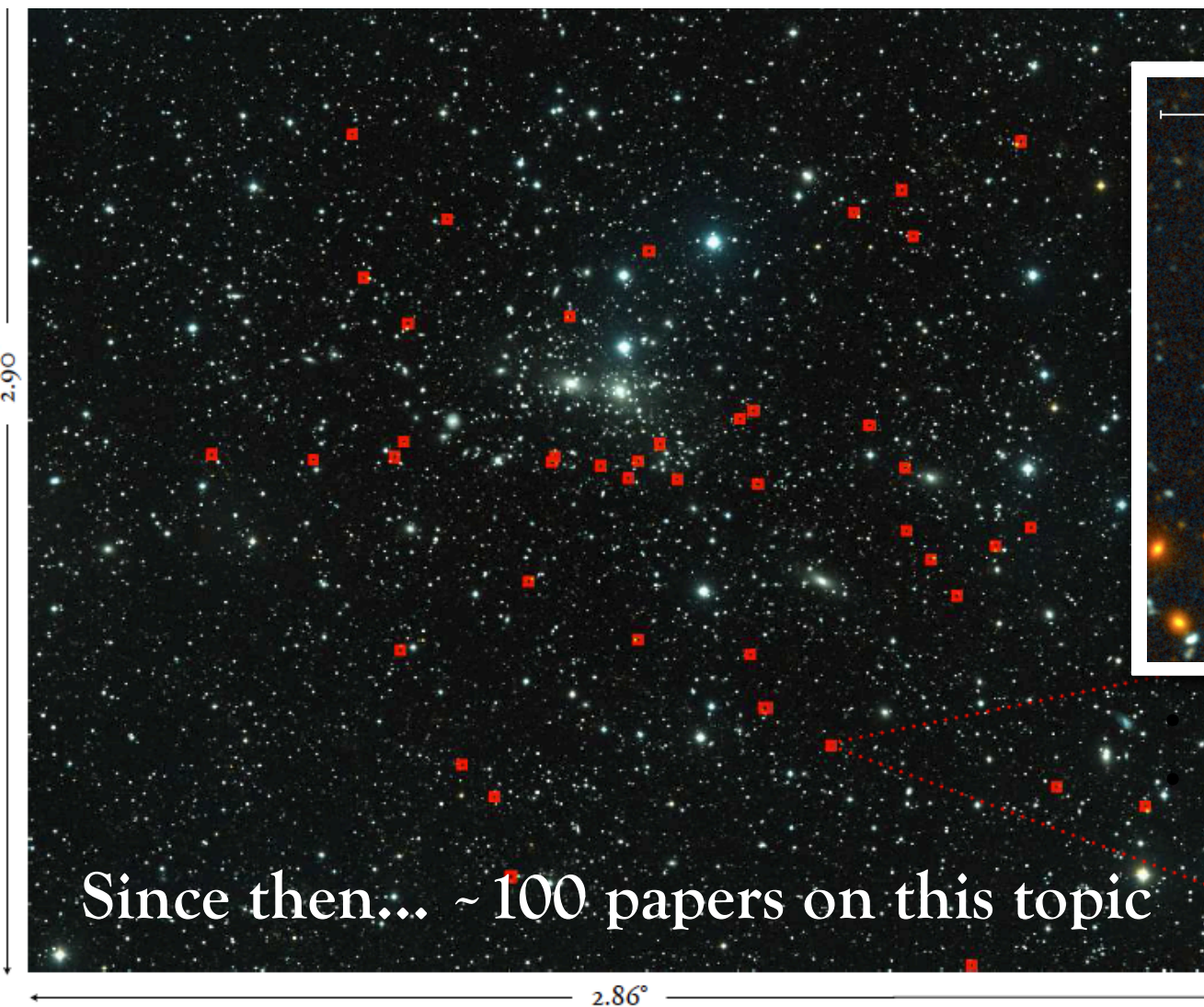
Cristóbal Sifón, Adam Muzzin, Henk Hoekstra,
KiDS & GAMA Collaborations

Abell 85, $z=0.05$

At the beginning of 2015...

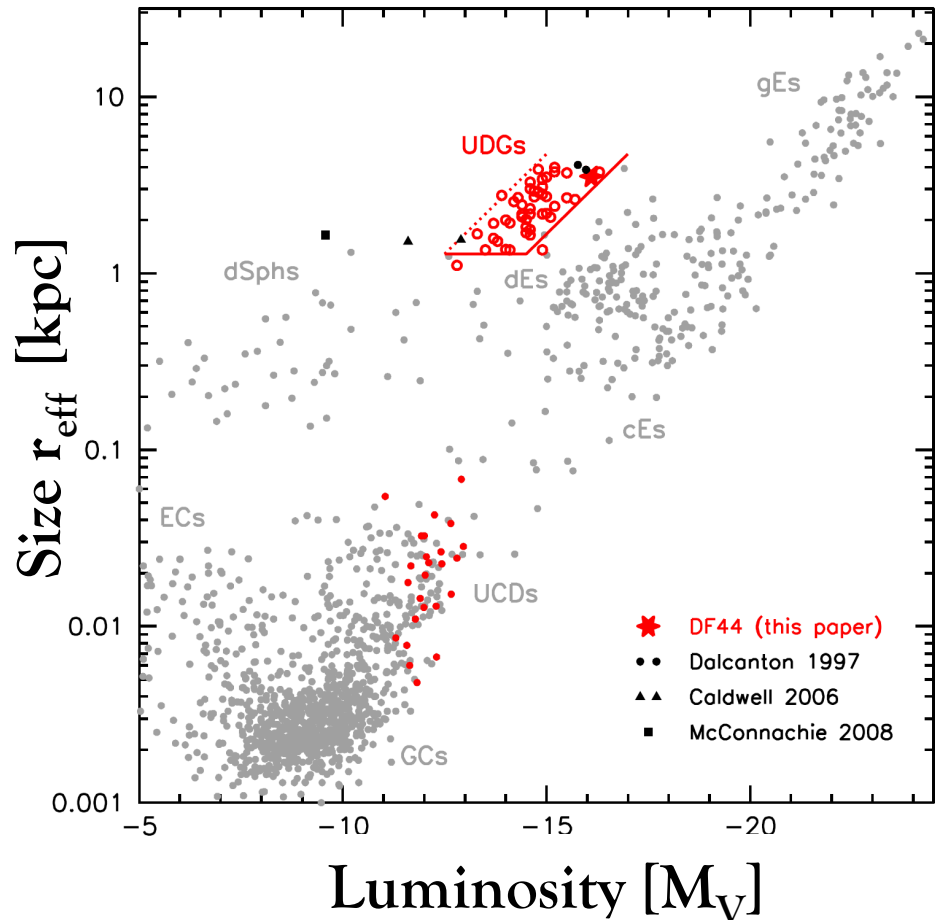
FORTY-SEVEN MILKY WAY-SIZED, EXTREMELY DIFFUSE GALAXIES IN THE COMA CLUSTER

PIETER G. VAN DOKKUM¹, ROBERTO ABRAHAM², ALLISON MERRITT¹, JIELAI ZHANG², MARLA GEHA¹, AND CHARLIE CONROY³



$$r_{\text{eff}} > 1.5 \text{ kpc}$$
$$\langle \mu(r, r_{\text{eff}}) \rangle \approx 25 \text{ mag arcsec}^{-2}$$

A long history of Low Surface-Brightness galaxies...



- LSBs have been known before (Impey+88, Bothun+91, Turner+93, Dalcanton+97, ...)
- Ultra-Diffuse Galaxies (UDGs) are extremes in the size-luminosity diagram:

$$r_{\text{eff}} > 1.5 \text{ kpc}$$

$$\langle \mu(r, r_{\text{eff}}) \rangle \approx 25 \text{ mag arcsec}^{-2}$$

How can UDGs survive the harsh dynamical environment of galaxy clusters?

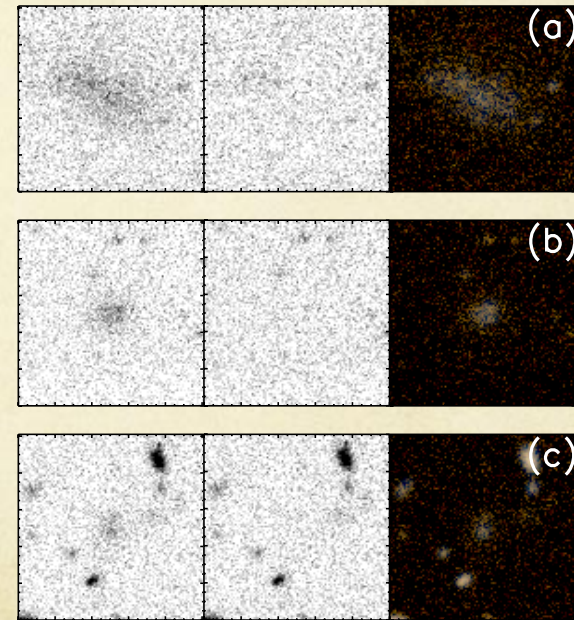
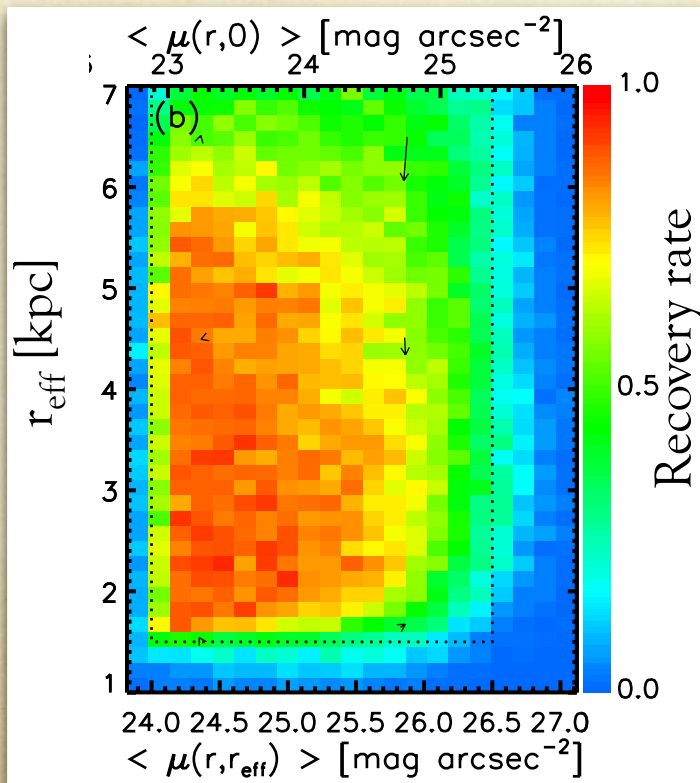
Models rely on quantitative observational constraints

van Dokkum et al. 2015b,
after Brodie et al. 2011

A systematic study of UDGs in 8 low- z clusters

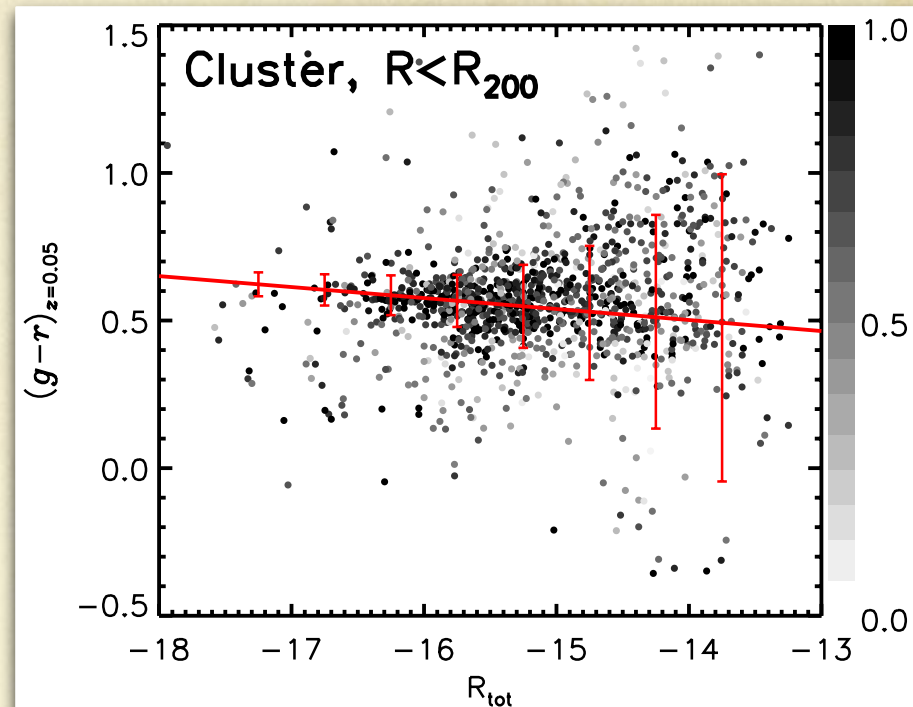
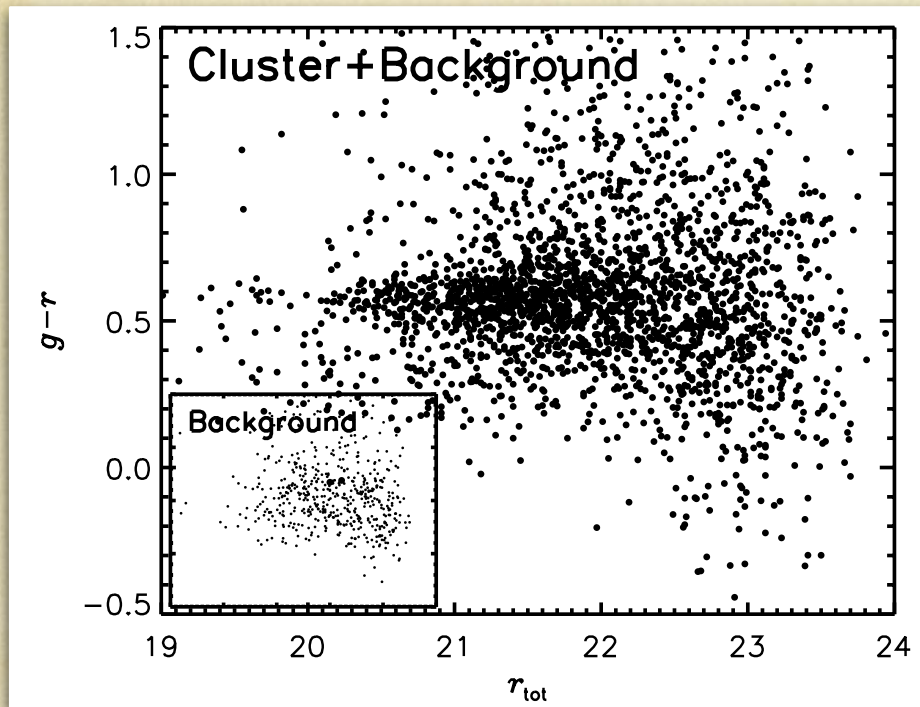
vdBurg+16b
A&A, 590, 20
ArXiv:1602.00002

- Image simulations to quantify completeness
- Tightened selection criteria (SExtractor & GALFIT) to keep purity high
- Estimate background statistically using “empty” fields
- 2500 selected in 8 clusters, 600 selected in 4 reference fields



What are their physical properties?

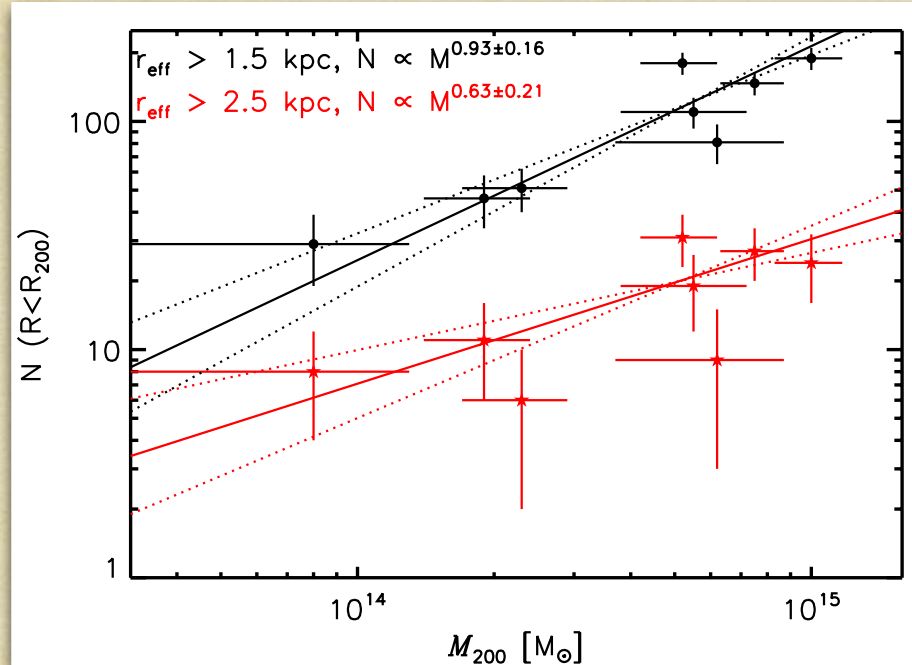
Colour-magnitude distribution



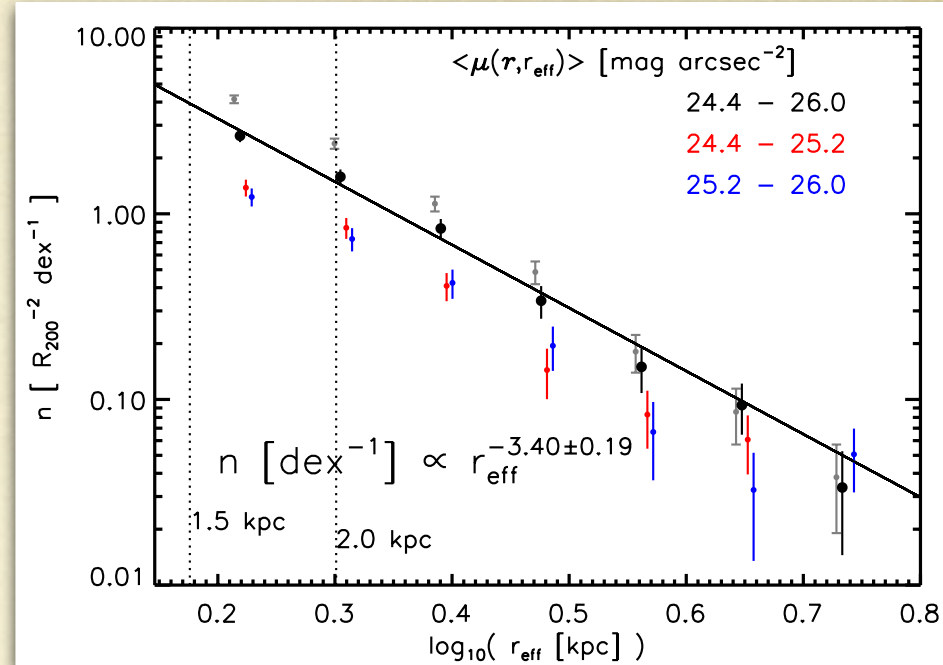
- Selection based only on morphology
- All on the red sequence \rightarrow old stellar populations
- Median stellar mass $\approx 10^8 M_{\odot}$

See also:
van Dokkum+15
Koda+15

Abundance versus halo mass

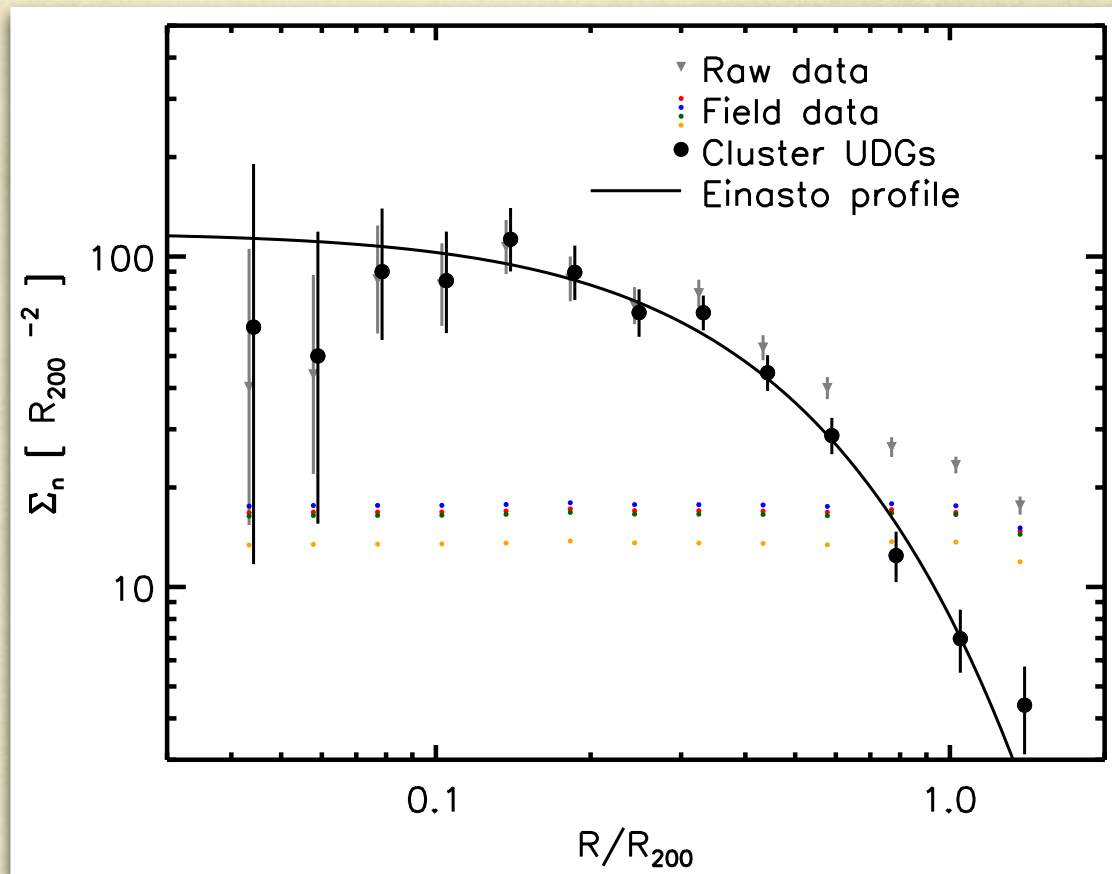


Size distribution



- Number of UDGs roughly scales linearly with halo mass
Mass measurements: Sifón+15
- Total stellar mass in UDGs $\approx 0.2\%$ of total cluster stellar mass
- Steep size distribution \rightarrow largest UDGs very rare

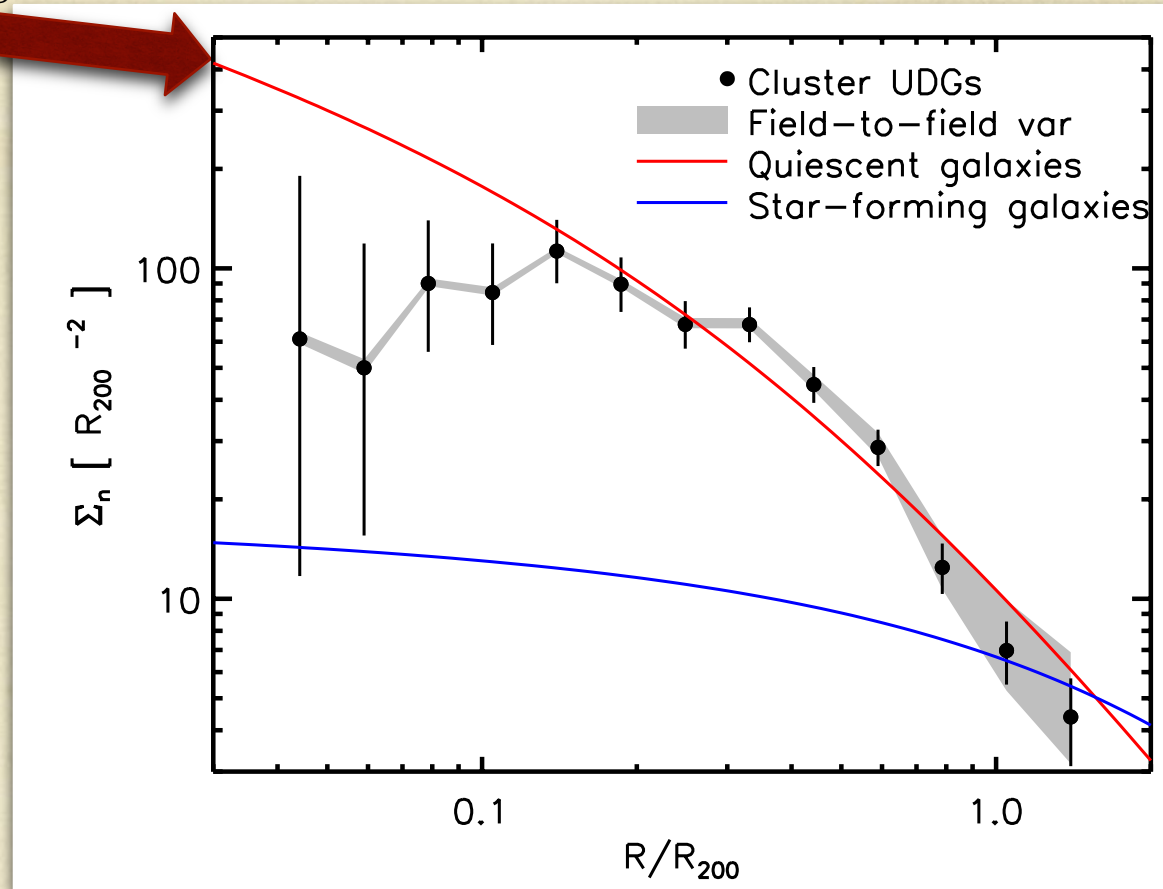
Radial distribution of UDGs



- Einasto parameters different from typical dark matter halo
- Where does this distribution originate from?

Radial distribution of UDGs

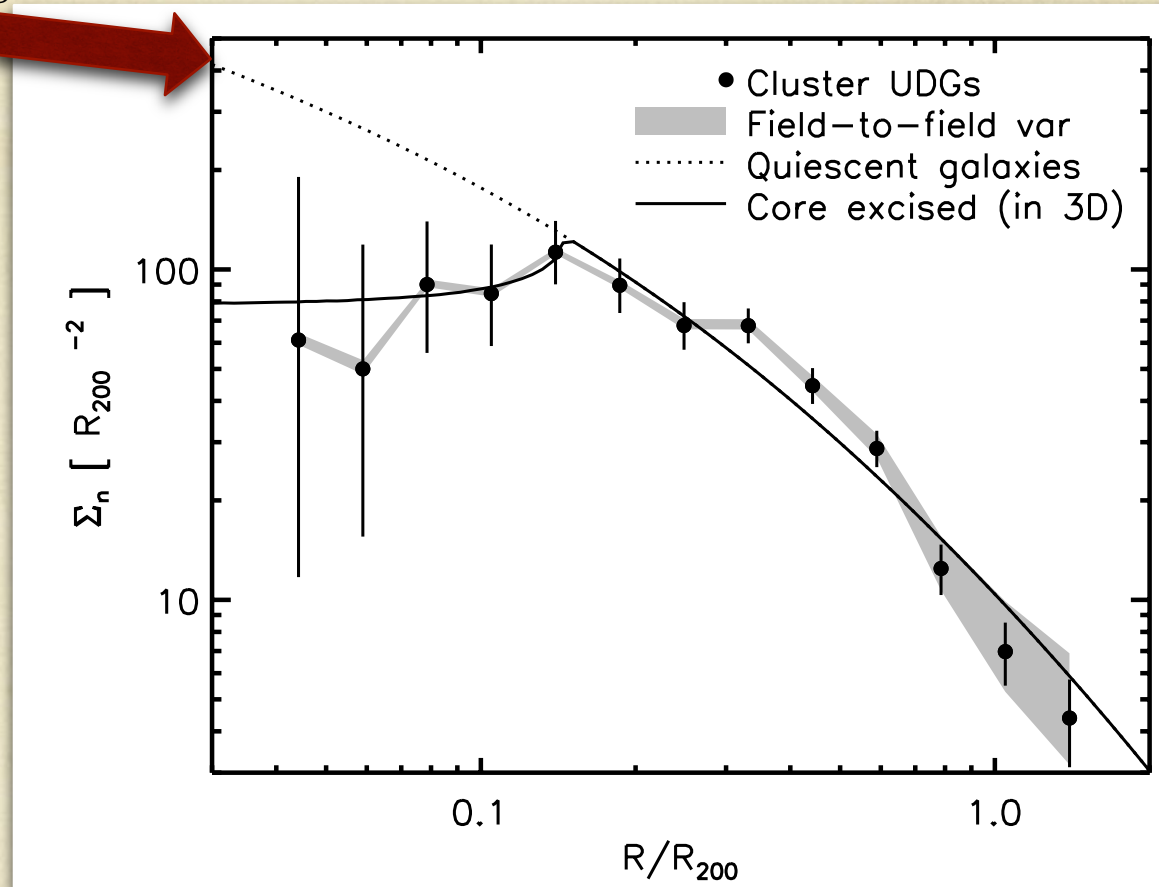
Total stellar-mass-weighted distribution
of quiescent galaxies
vdBurg+15



- Roughly follows dynamically old population in outskirts

Radial distribution of UDGs

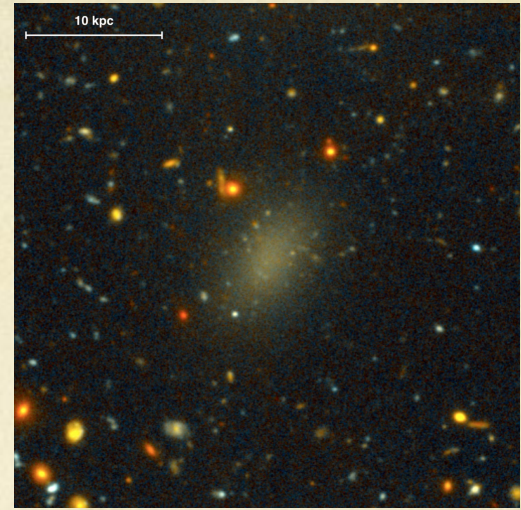
Total stellar-mass-weighted distribution
of quiescent galaxies
vdBurg+15



- They can exist down to 300kpc (3D radius, before projection)
- They have to be centrally dark-matter dominated
- Are they “failed Milky-Ways”? (van Dokkum+2015)

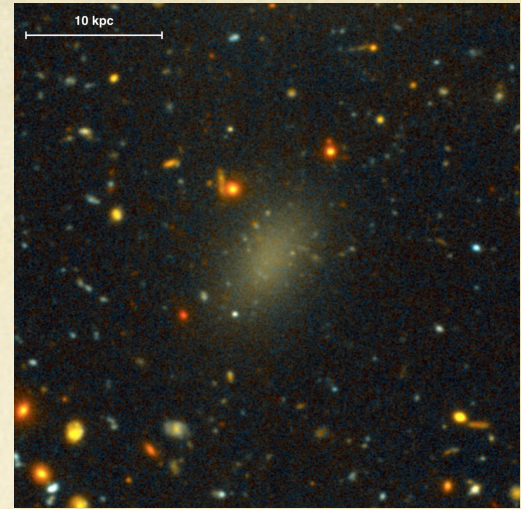
How to explain the UDG population?

- Tidal debris
 - Very unlikely given their smooth morphologies
- Tidally disturbed/heated “normal” dwarf galaxies
 - Unlikely given their extended radial distribution
- Failed Milky-Way type galaxies
 - Still unclear why some haloes would have “failed”
 - At least some UDGs have very high masses (MW-like) (van Dokkum+16)
- Internal processes responsible? e.g. Amorisco & Loeb 2016, Di Cintio+17



How to explain the UDG population?

- Tidal debris
 - Very unlikely given their smooth morphologies
- Tidally disturbed/heated “normal” dwarf galaxies
 - Unlikely given their extended radial distribution
- Failed Milky-Way type galaxies
 - Still unclear why some haloes would have “failed”
 - At least some UDGs have very high masses (MW-like) (van Dokkum+16)
- Internal processes responsible? e.g. Amorisco & Loeb 2016, Di Cintio+17



Halo measurements and studies in other environments essential to make progress

Measuring halo masses of UDGs

- Difficult (expensive!) to use methods that rely on stellar tracers of the potential (van Dokkum+16)
 - Using Globular Clusters may help (Beasley+16, Amorisco+16b)
- An alternative is to measure the masses of UDGs via weak gravitational lensing
 - CFHT data were taken with weak gravitational lensing in mind
 - Signal from Milky-Way type haloes should stand out

A first constraint on the average mass of ultra diffuse galaxies from weak gravitational lensing

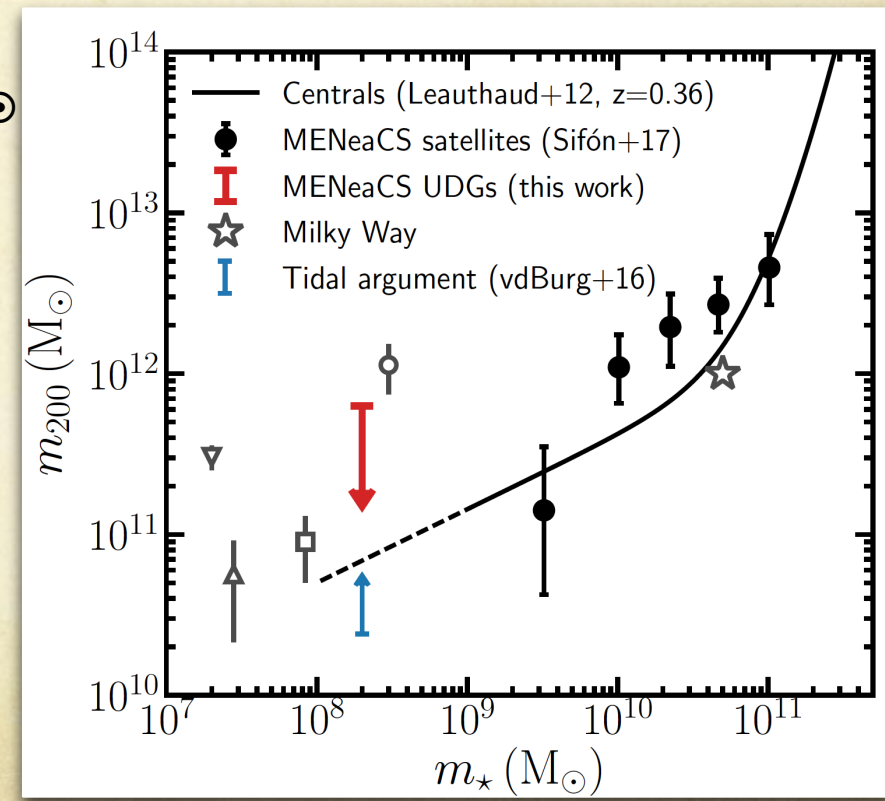
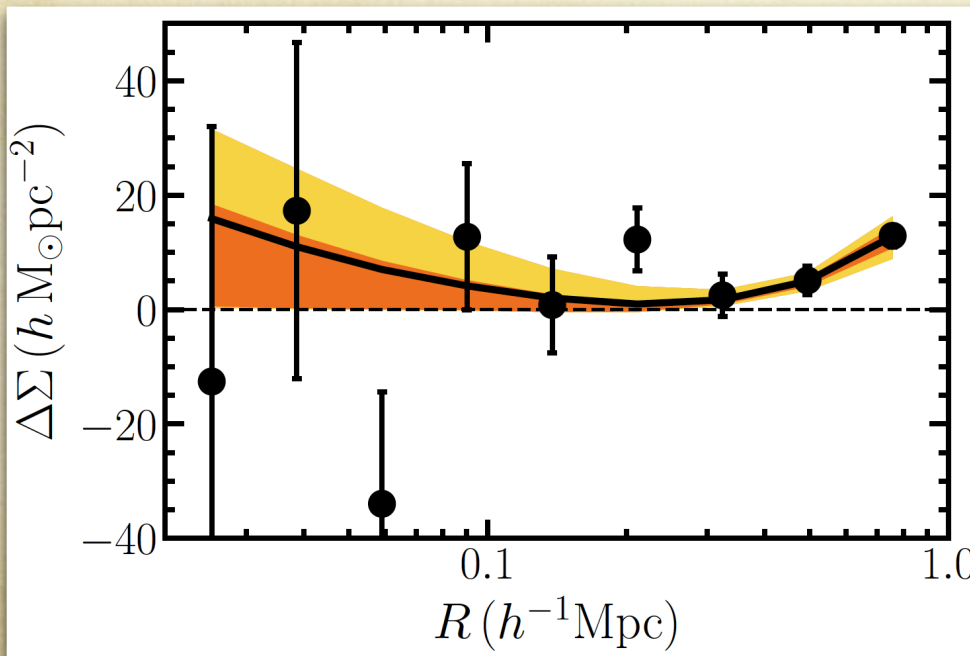
Cristóbal Sifón^{1,2}, Remco F. J. van der Burg³, Henk Hoekstra², Adam Muzzin⁴ and Ricardo Herbonnet²

○ Stack of 784 UDGs in 18 clusters

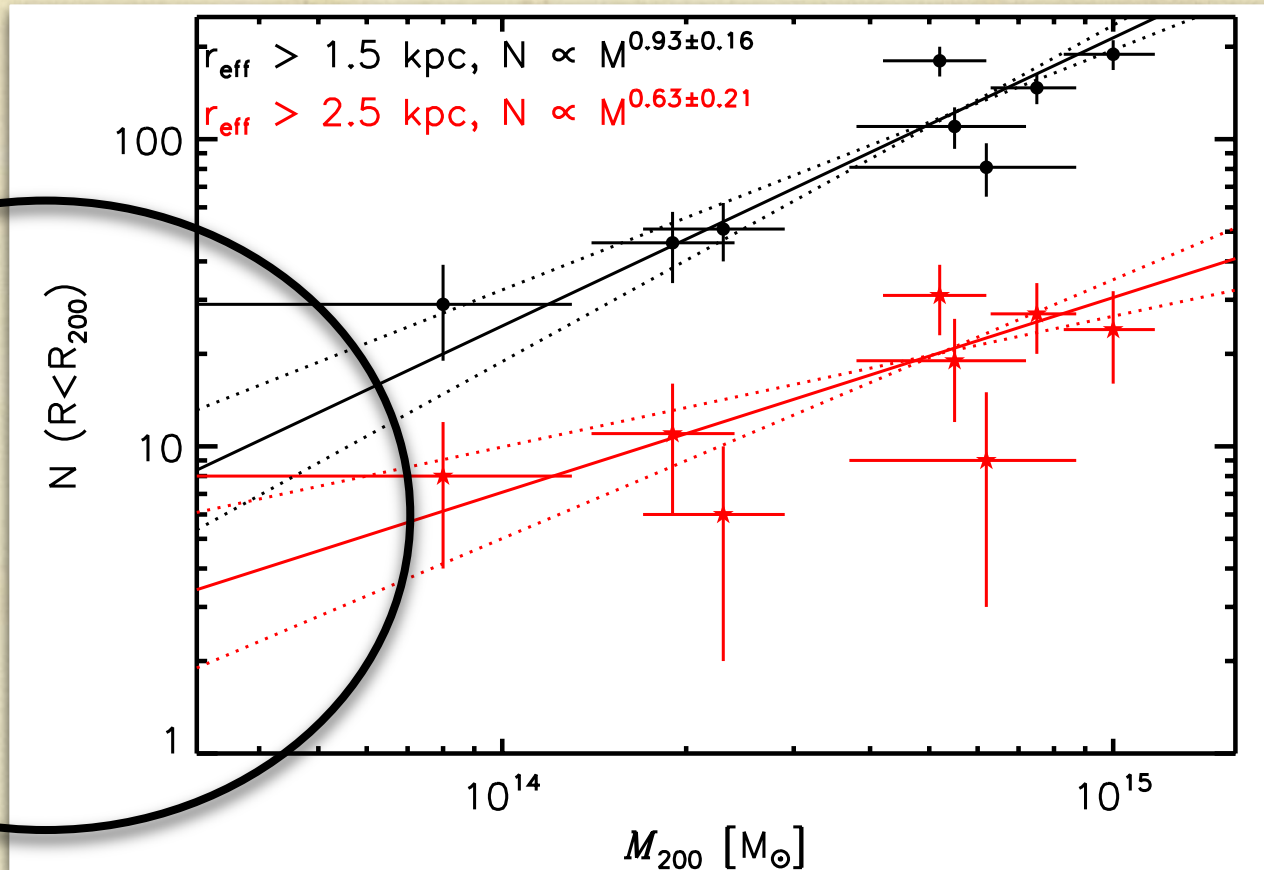
(ArXiv:1704.07847)

○ No significant detection!

○ 2σ upper limit $M_{200} < 10^{11.8} M_{\odot}$



Abundance versus halo mass



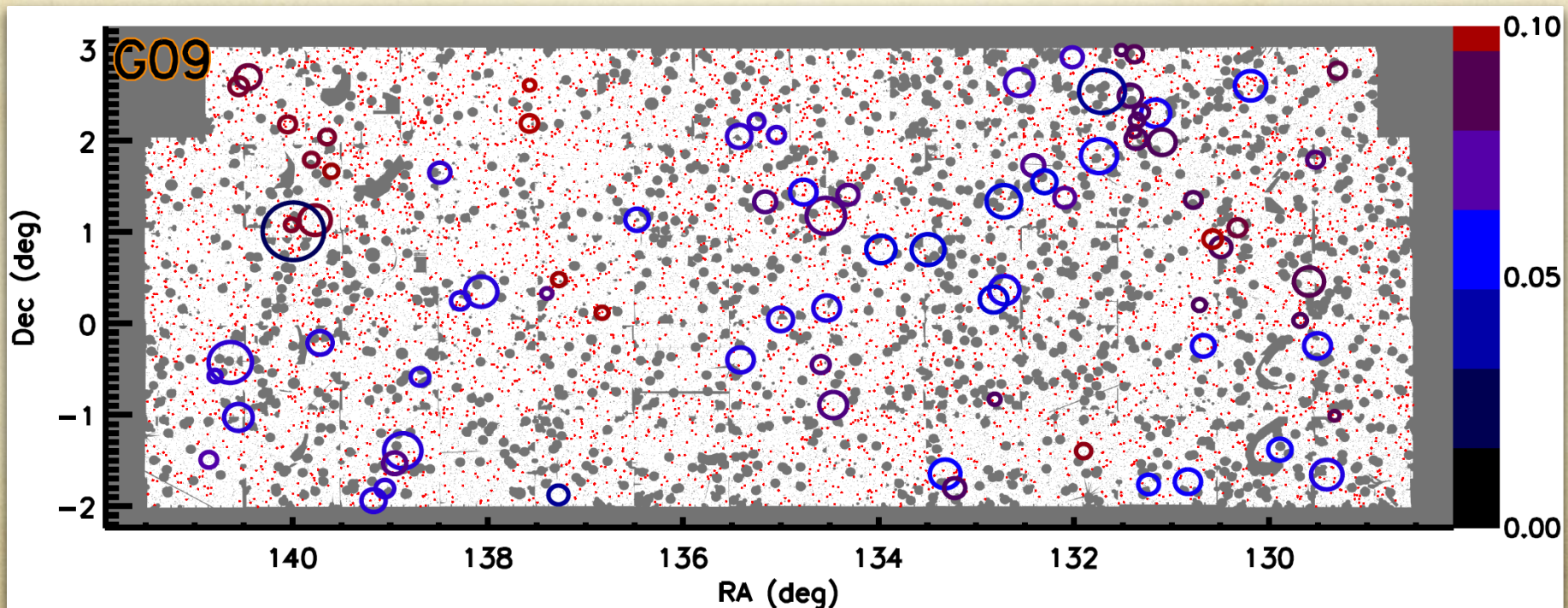
- Does this relation extend down to groups? And individual galaxies?
(cf. Román & Trujillo 2017; Merritt+2016)

The UDG abundance from clusters to groups

vdBurg+17

ArXiv:1706.02704

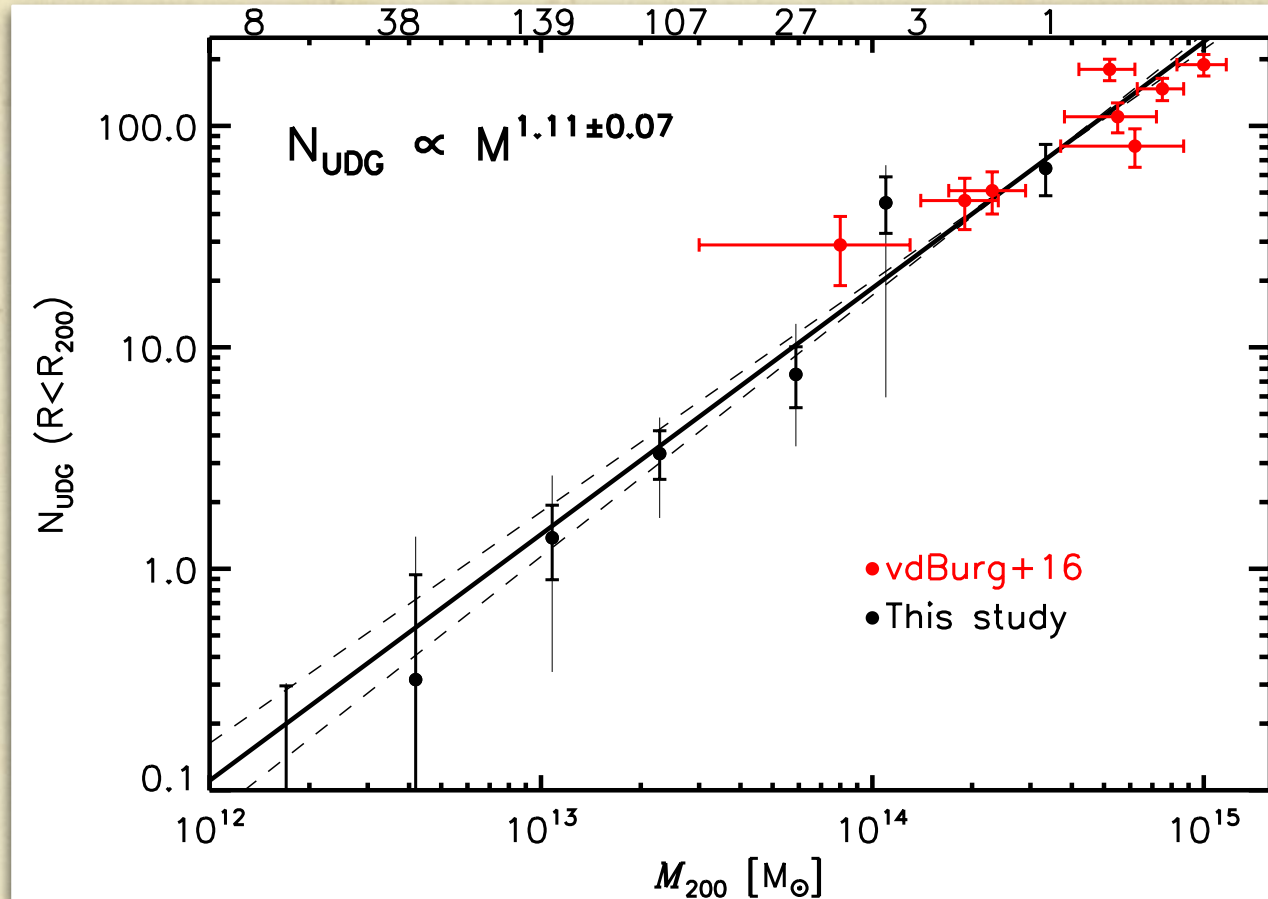
- Kilo-Degree Survey (KiDS)
- Clean r -band imaging down to 25 mag arcsec⁻² over 1500 deg²
- Galaxy And Mass Assembly (GAMA) spectroscopic survey
- 325 spectroscopic groups up to redshift 0.10 (three equatorial fields)
- 200 deg² overlap between GAMA and KiDS



The UDG abundance from clusters to groups

vdBurg+17

ArXiv:1706.02704

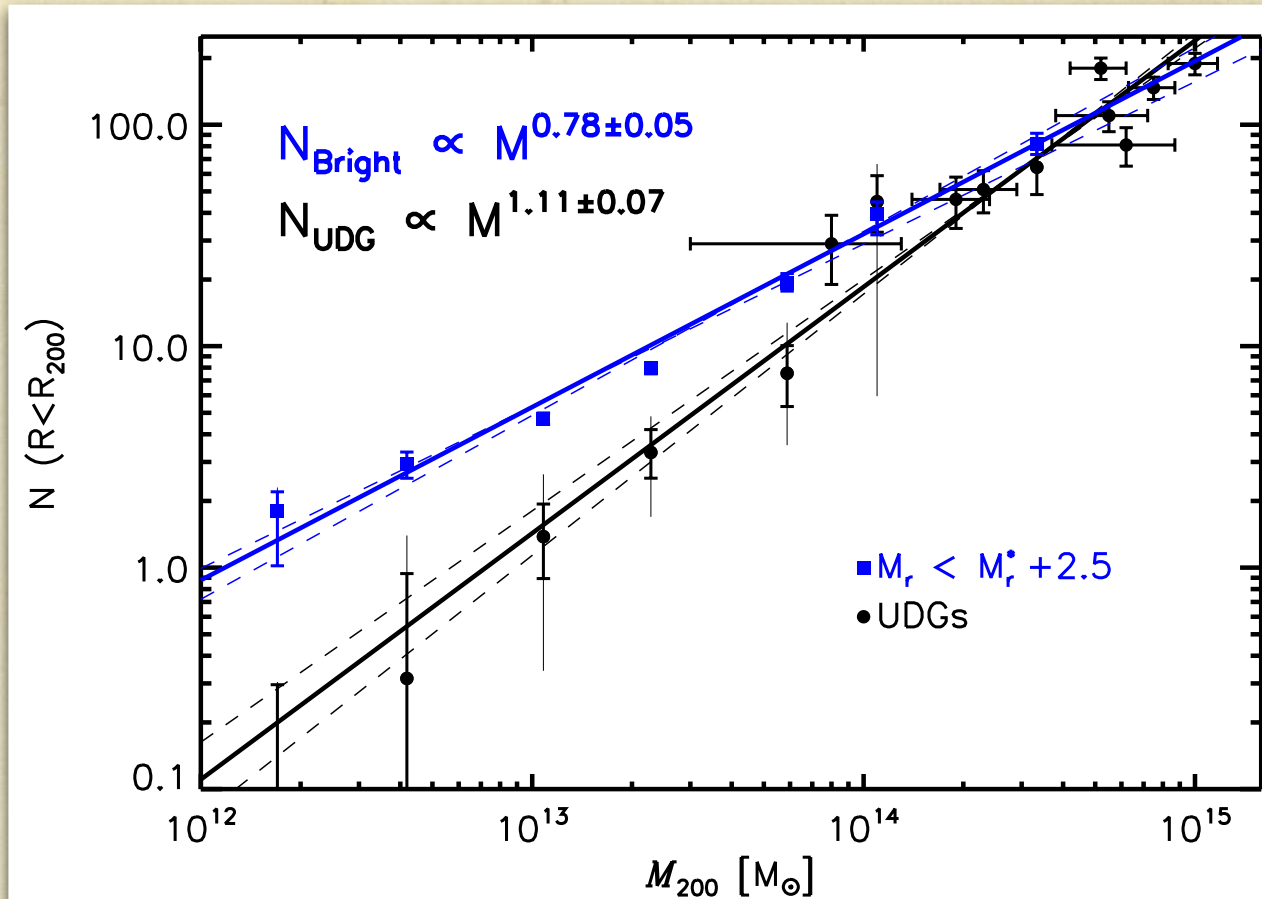


- UDGs also in groups (cf. Román & Trujillo 2017; Merritt+2016)
- Abundance scales steeply with mass

The UDG abundance from clusters to groups

vdBurg+17

ArXiv:1706.02704



- Richness –mass relation shallower than 1:1
- UDGs are relatively more common in more massive haloes

UDGs are relatively more common in more massive haloes

vdBurg+17
ArXiv:1706.02704

- Why? Not yet clear...
- Are they a fixed fraction of the general dwarf galaxy population?
 - Possible upturn of the luminosity function at the faint end (Popesso+05)
- UDG properties may depend on environment
 - Different Sérsic indices in clusters ($n \approx 1.4$) and groups ($n \approx 2.2$)
 - Combination of different formation mechanisms?

Summary

- Abundance of UDGs in groups and clusters not yet understood
- Constraints from a systematic study in 8 nearby clusters
 - Steep size distribution (largest UDGs rare) vdBurg+16 (1602.00002)
 - Colour-magnitude distributions (old stellar populations)
 - They follow dynamically old galaxies spatially, with central deficit
- To further test models, essential to measure halo masses, and estimate abundance in other environments
 - Weak lensing study rules out (at 2σ) that they are *all* “failed Milky Ways” Sifón,vdB+17 (1704.07847)
 - UDGs are relatively more common in more massive haloes vdBurg+17 (1706.02704)
- Combination of different mechanisms to make UDGs?

