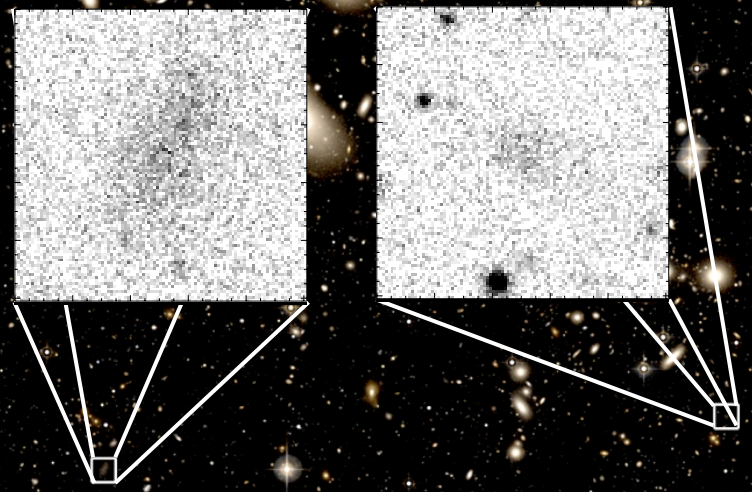
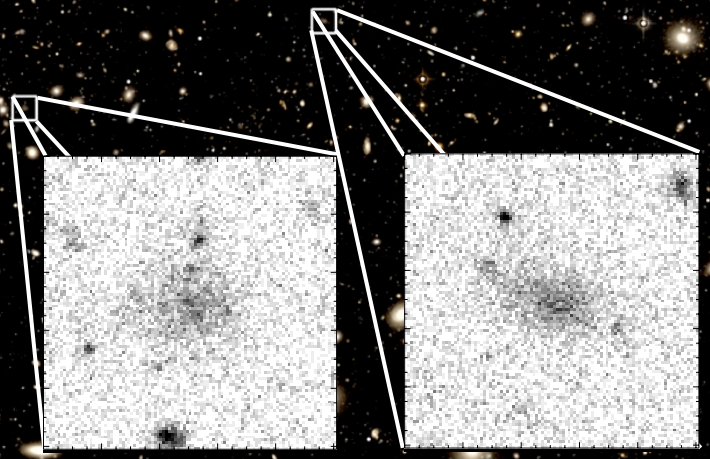
Towards Understanding the Origin and Evolution of Ultra-Diffuse Galaxies





Remco van der Burg
CEA Saclay, France

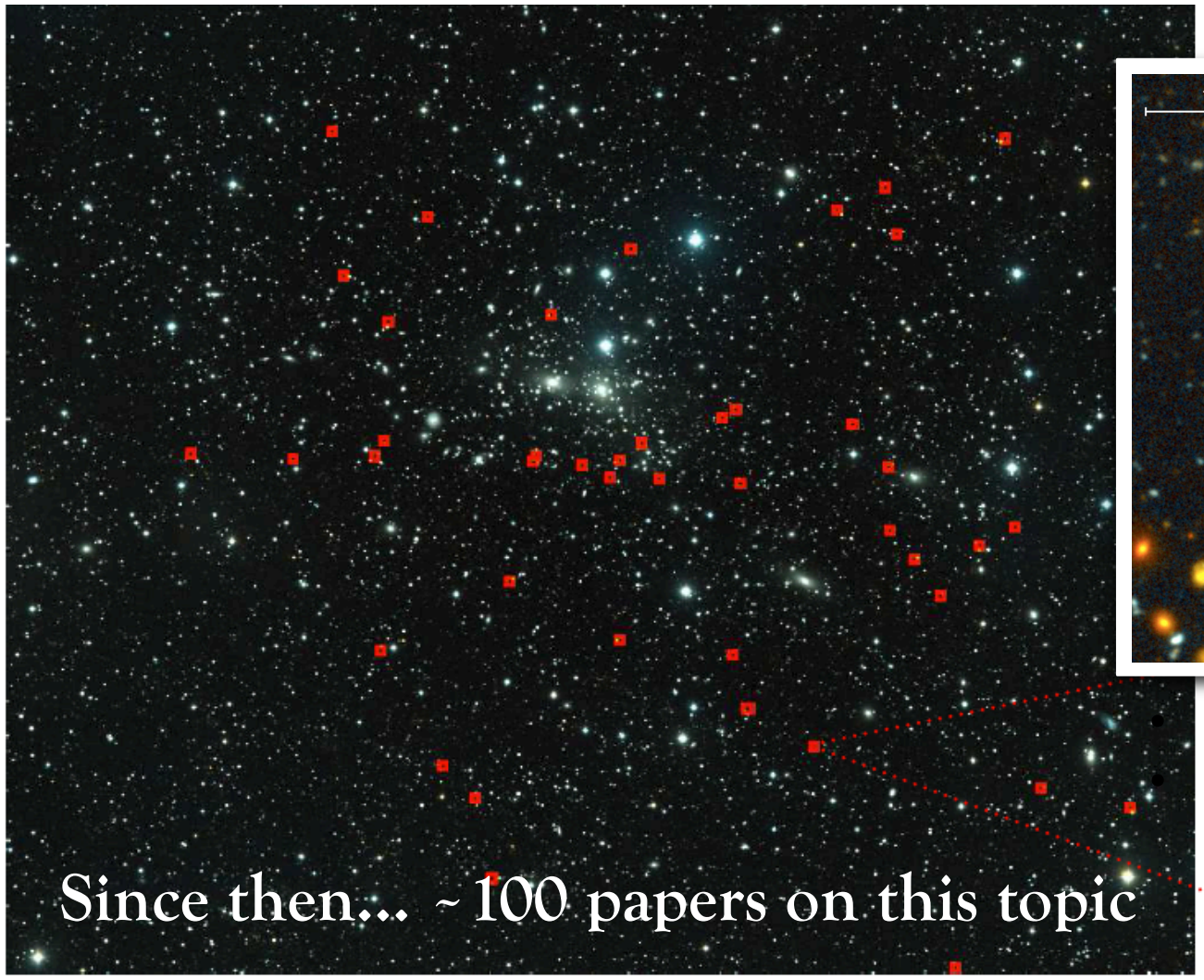
Cristóbal Sifón, Adam Muzzin, Henk Hoekstra,
KiDS & GAMA Collaborations

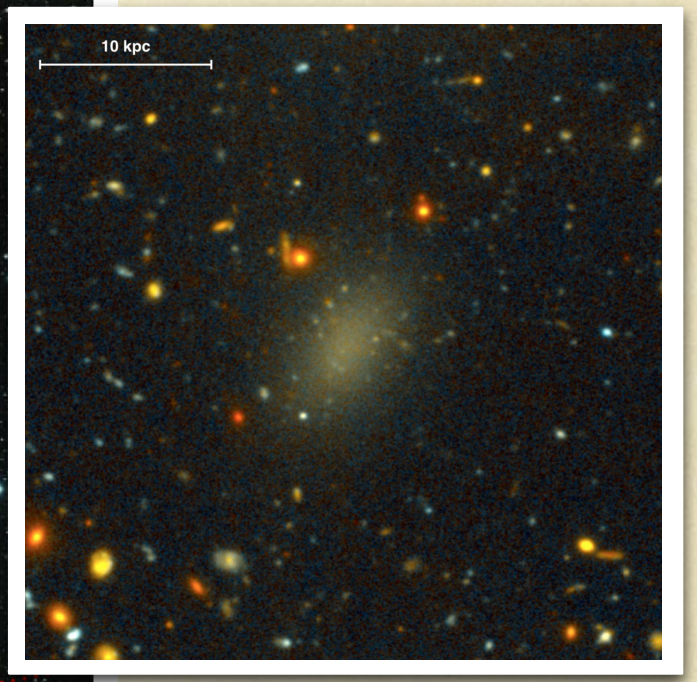
Abell 85, z=0.05

At the beginning of 2015...

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

PIETER G. VAN DOKKUM[1], ROBERTO ABRAHAM[2], ALLISON MERRITT[1], JIELAI ZHANG[2], MARLA GEHA[1], AND CHARLIE CONROY[3]



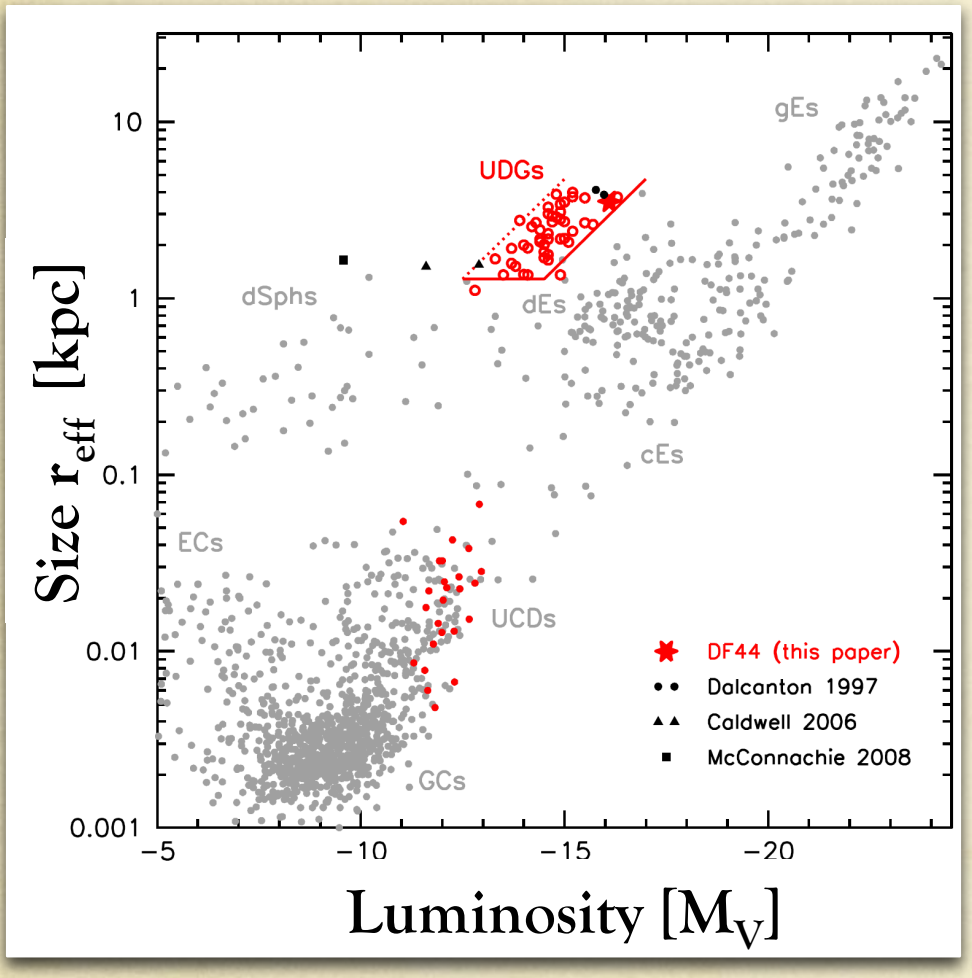


r_{eff}>1.5 kpc

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

Since then... ~100 papers on this topic

A long history of Low Surface-Brightness galaxies…



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

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

$r_{eff} > 1.5$ kpc

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

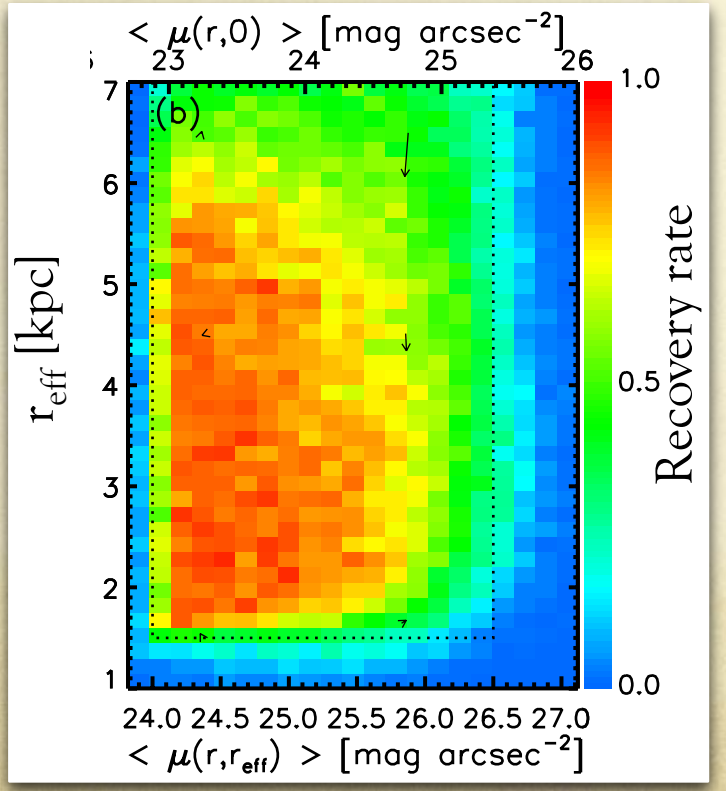
How can UDGs survive the harsh dynamical environment of galaxy clusters?

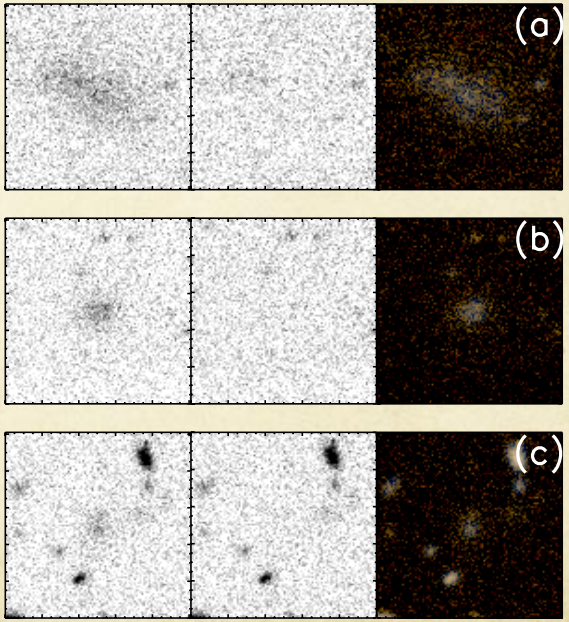
Models rely on quantitative observational constraints

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

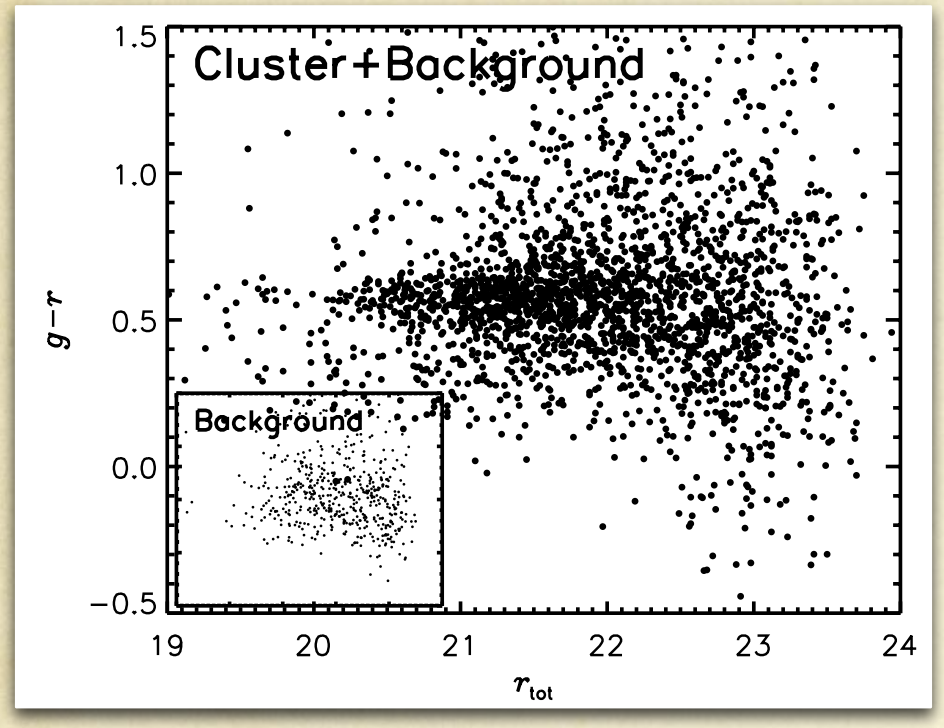


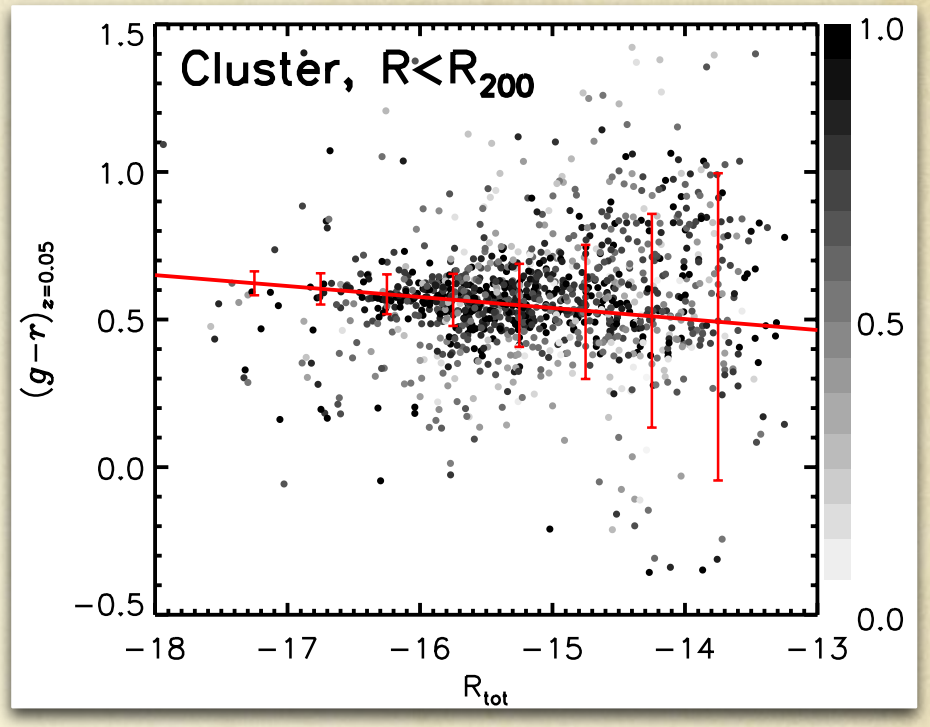


What are their physical properties?

vdBurg+16b

Colour-magnitude distribution



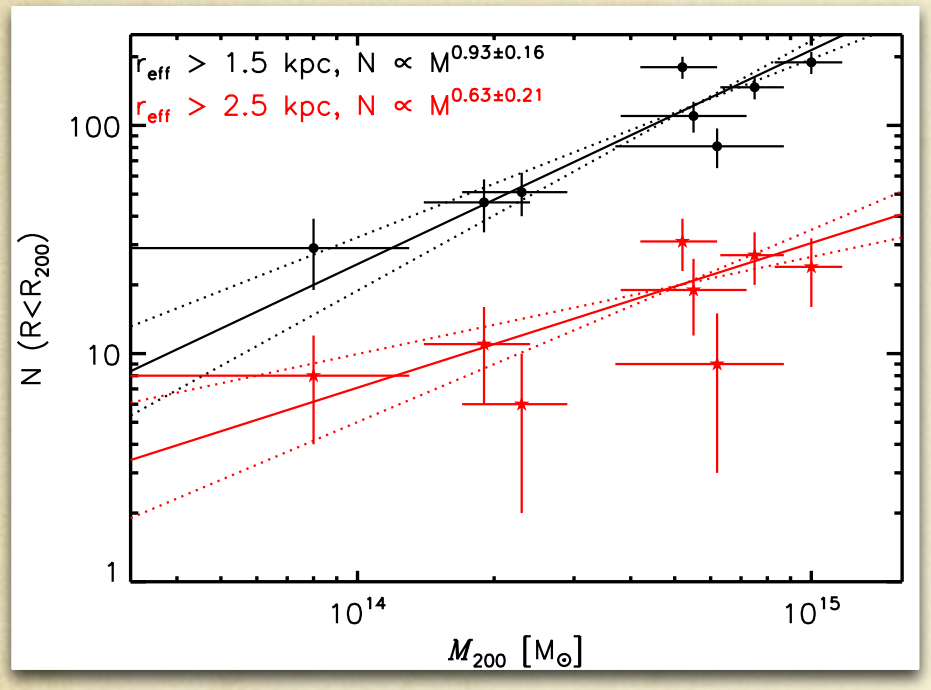


- Selection based only on morphology
- All on the red sequence -> old stellar populations
- Median stellar mass $\approx 10^8\,M_\odot$

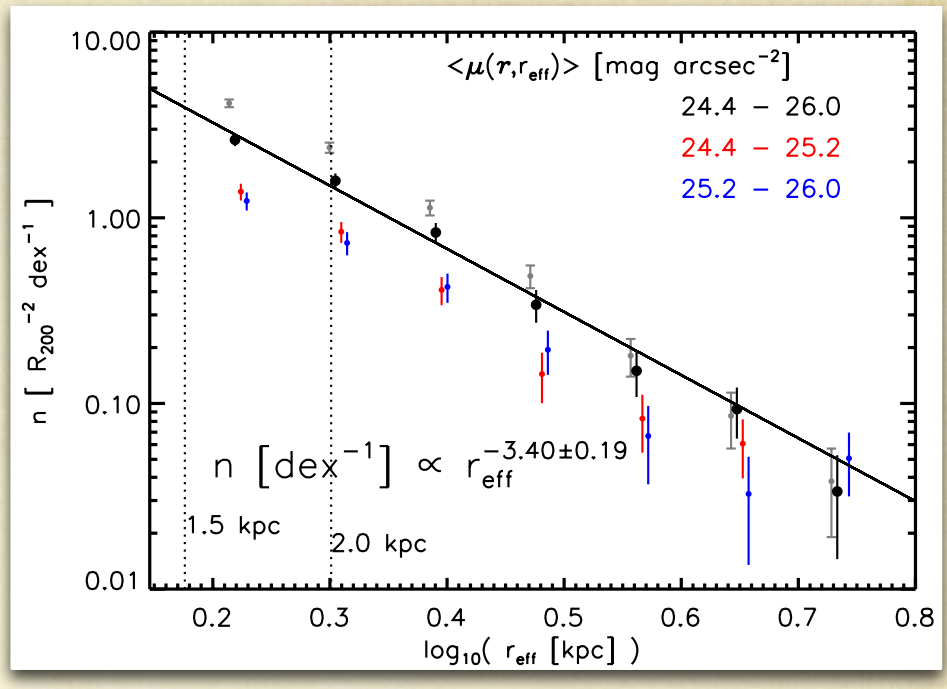
See also:
van Dokkum+15
Koda+15

vdBurg+16b

Abundance versus halo mass



Size distribution

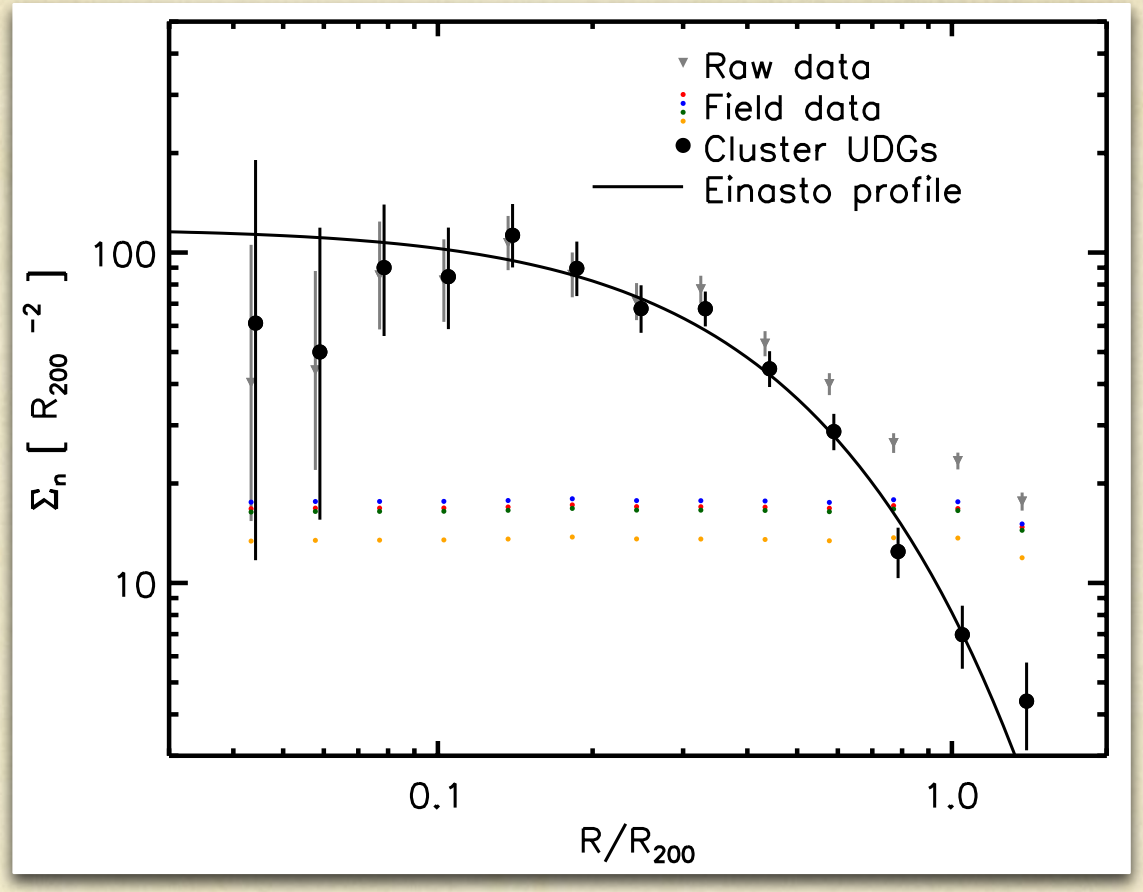


- Number of UDGs roughly scales linearly with halo mass

Mass measurements: Sifón+15

- Total stellar mass in UDGs ≈ 0.2% of total cluster stellar mass
- Steep size distribution -> largest UDGs very rare

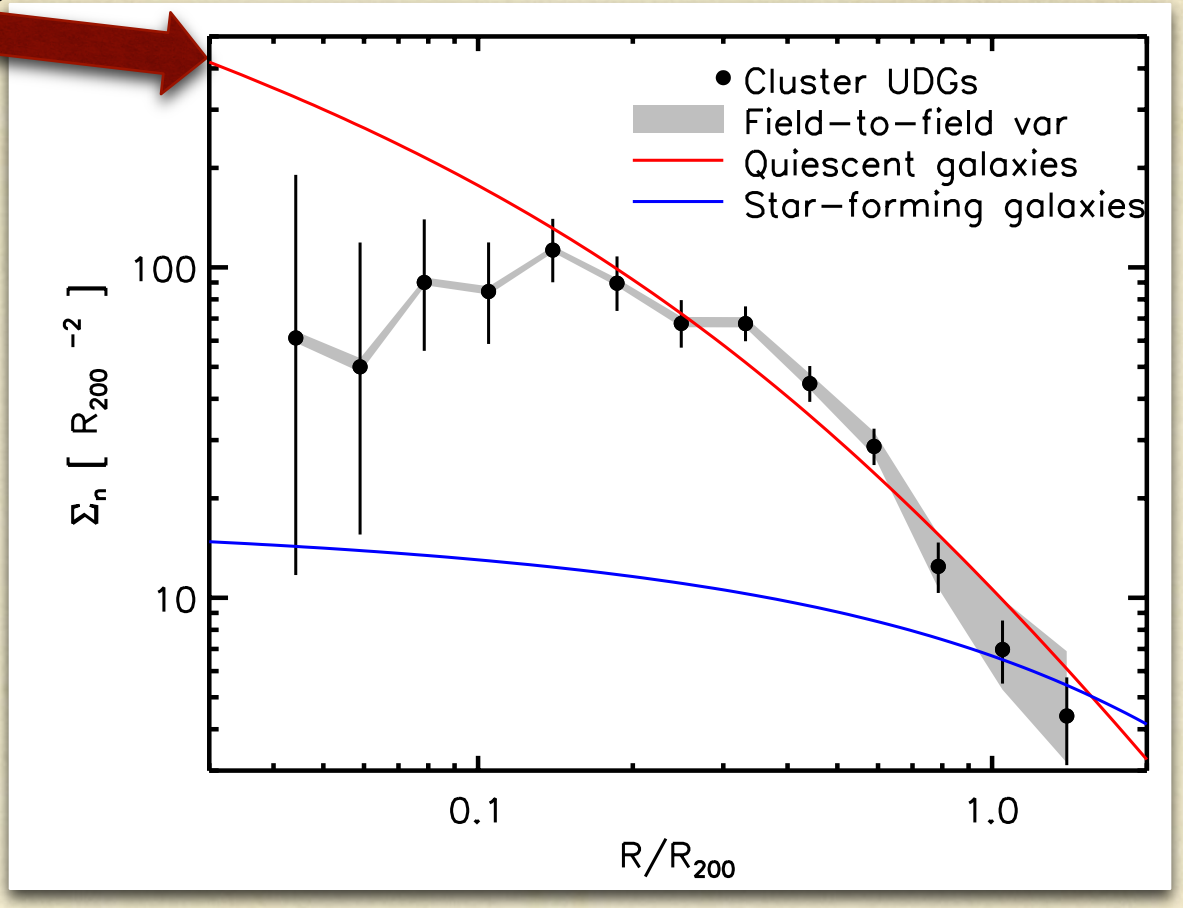
Radial distribution of UDGs



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

Radial distribution of UDGs

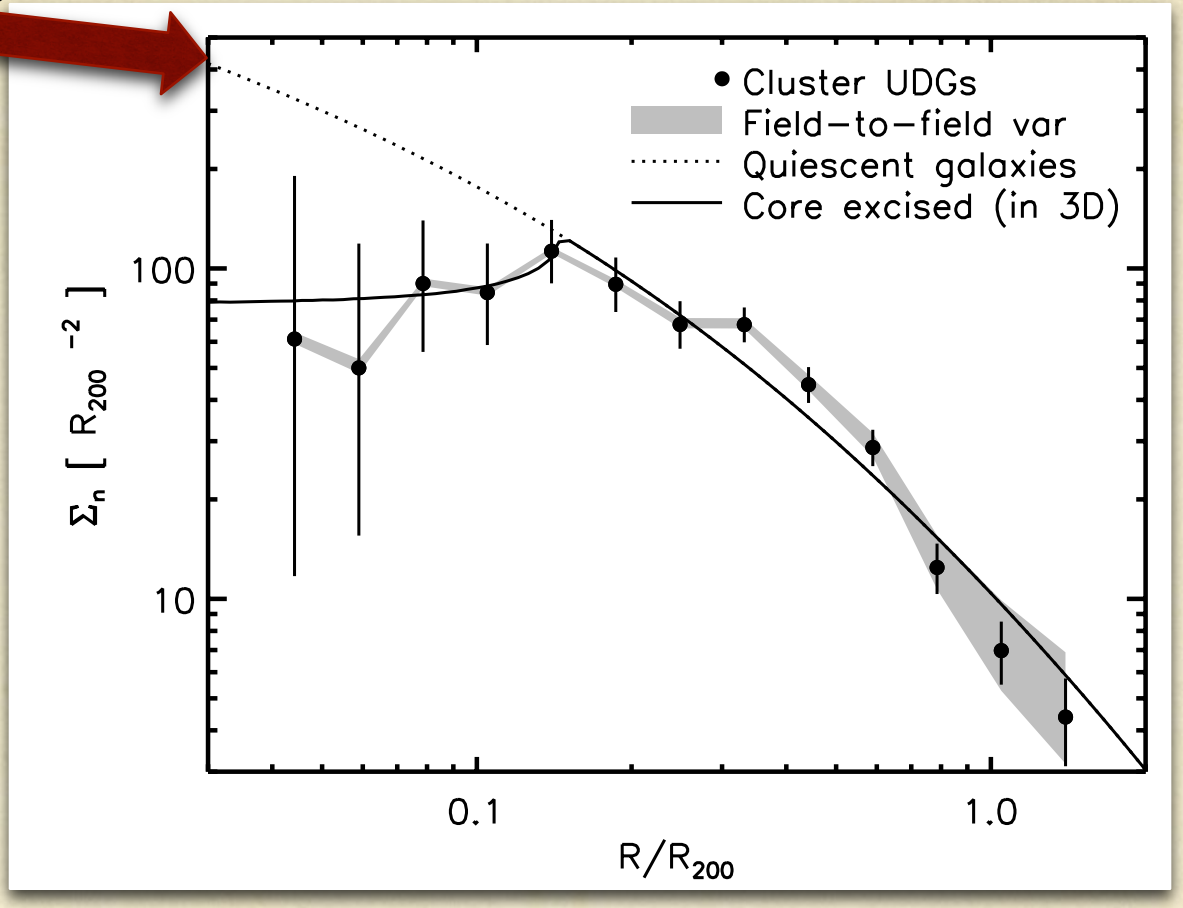
Total stellar-mass-weighted distribution of quiescent galaxies vdBurg+15



- Roughly follows dynamically old population in outskirts

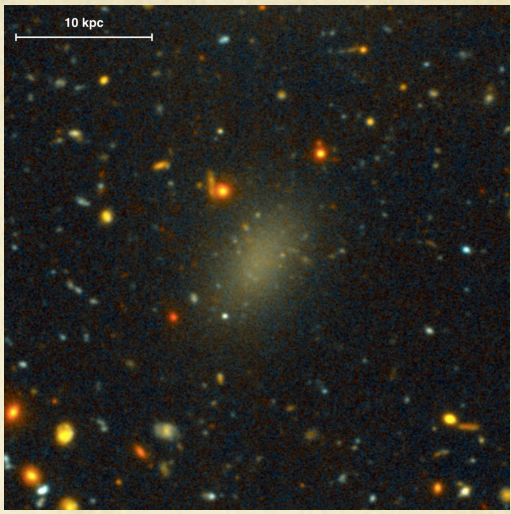
Radial distribution of UDGs

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

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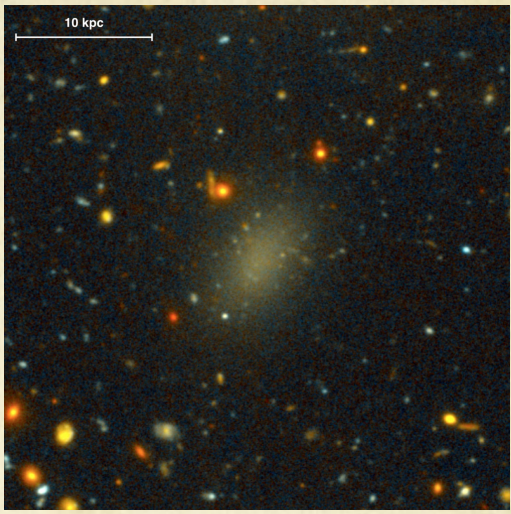

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Halo measurements and studies in other environments essential to make progress

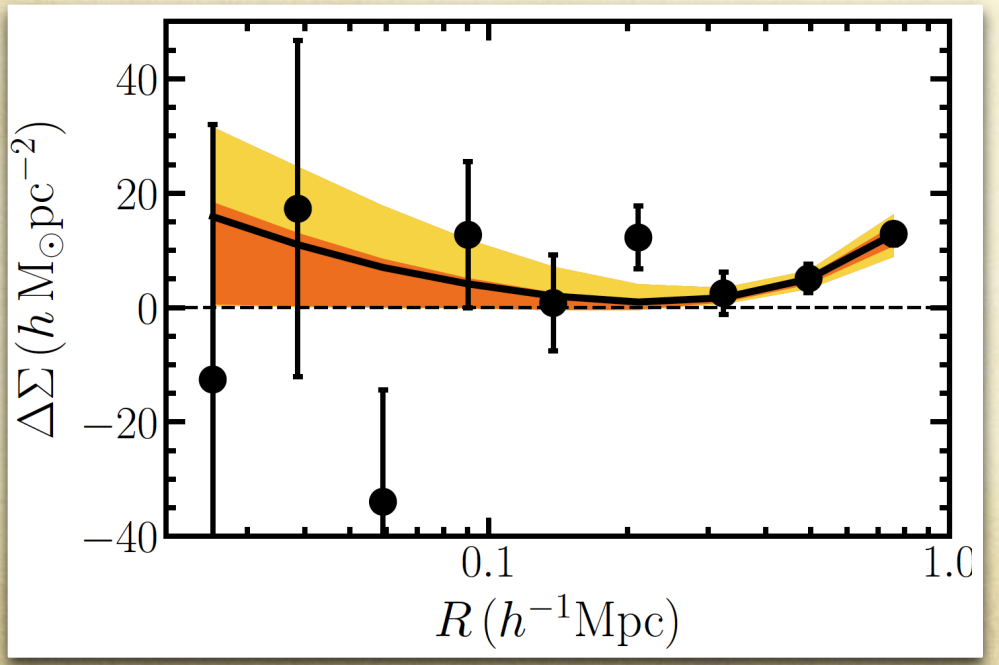
Measuring halo masses of UDGs

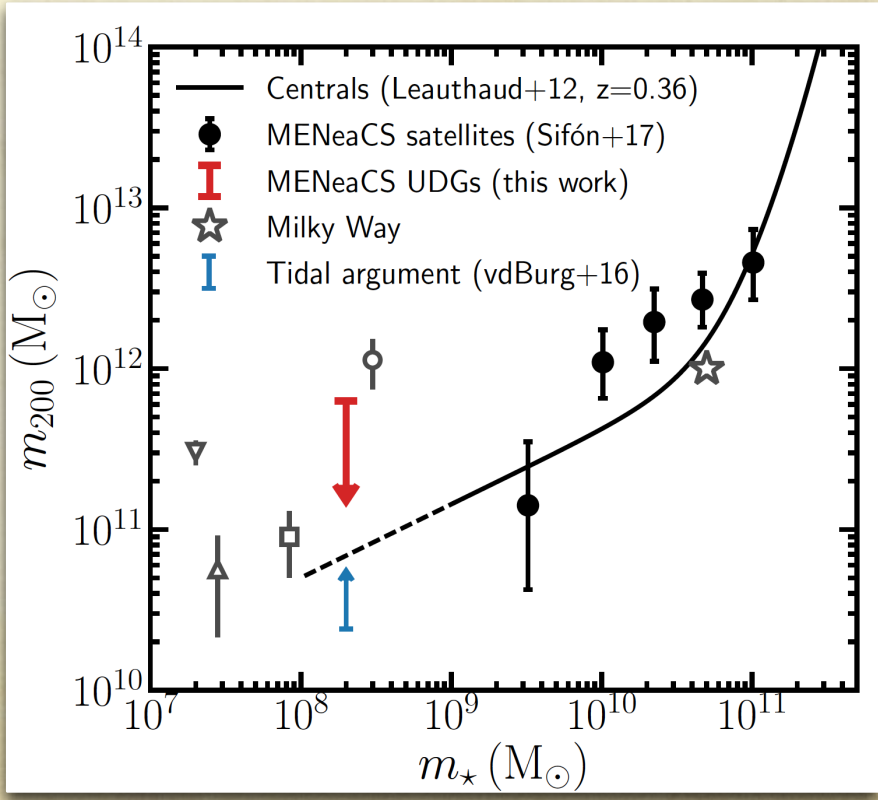
- Difficult (expensive!) to use methods that rely on stellar tracers of the potential (van Dokkum+16)
  - Using Globular Clusters may help (Beasley+16, Amorisco+16b)
- An alternative is to measure the masses of UDGs via weak gravitational lensing
  - CFHT data were taken with weak gravitational lensing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

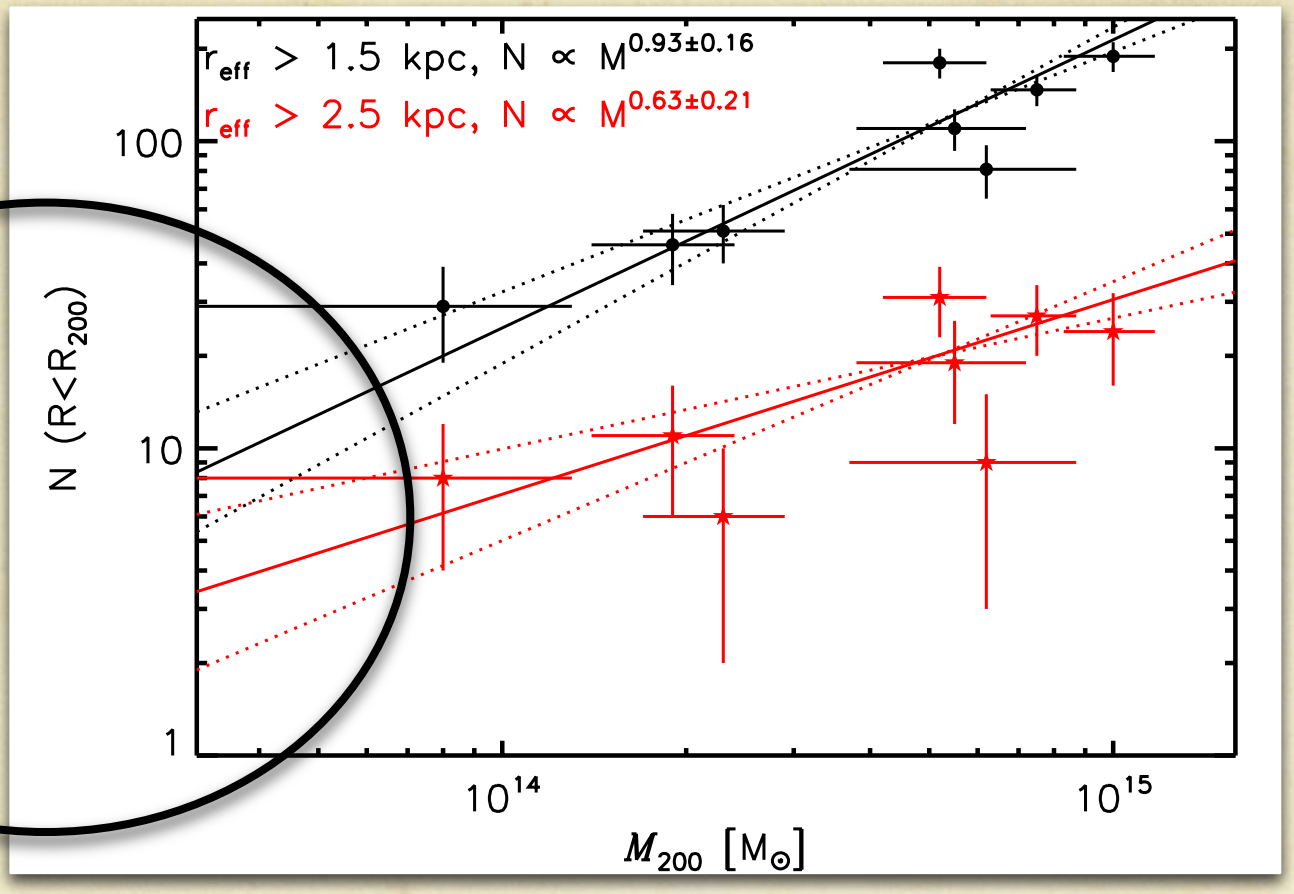
Cristóbal Sifón[1,2], Remco F. J. van der Burg[3], Henk Hoekstra[2], Adam Muzzin[4] and Ricardo Herbonnet[2]

- 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



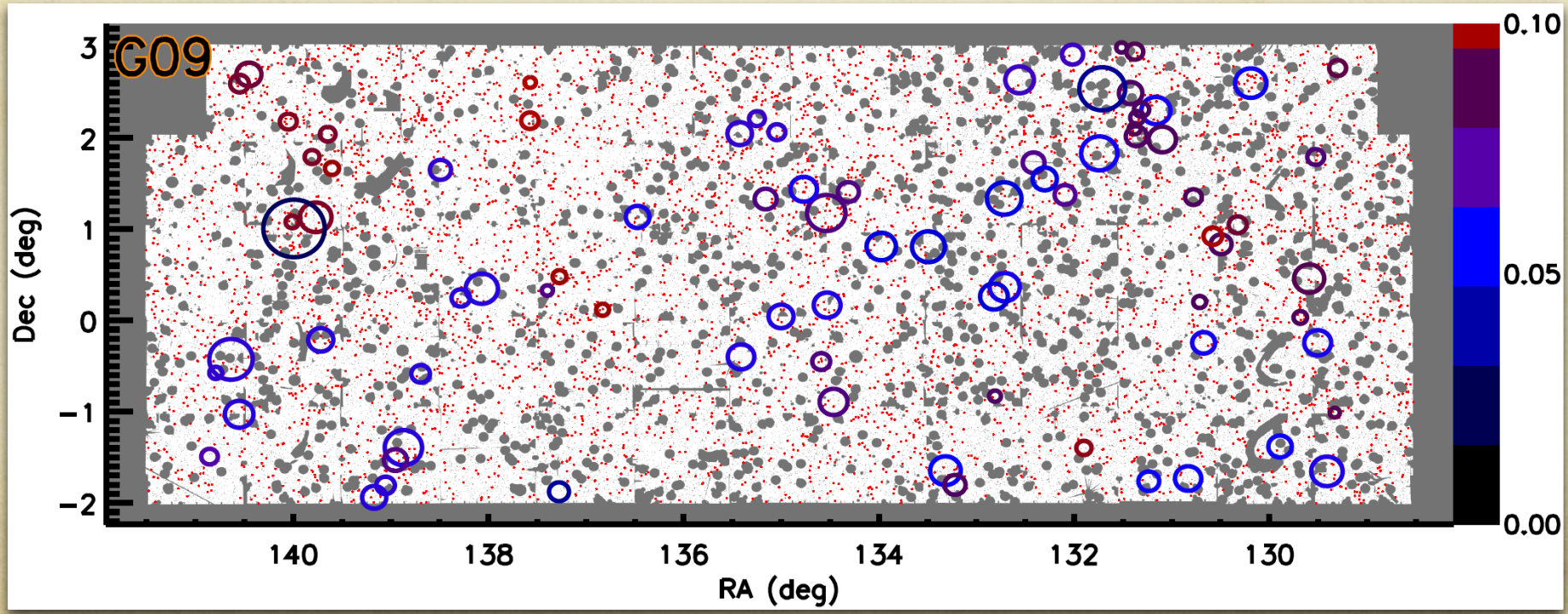
- Does this relation extend down to groups? And individual galaxies?

(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 deg^2
- Galaxy And Mass Assembly (GAMA) spectroscopic survey
  - 325 spectroscopic groups up to redshift 0.10 (three equatorial fields)
- 200 deg^2 overlap between GAMA and KiDS



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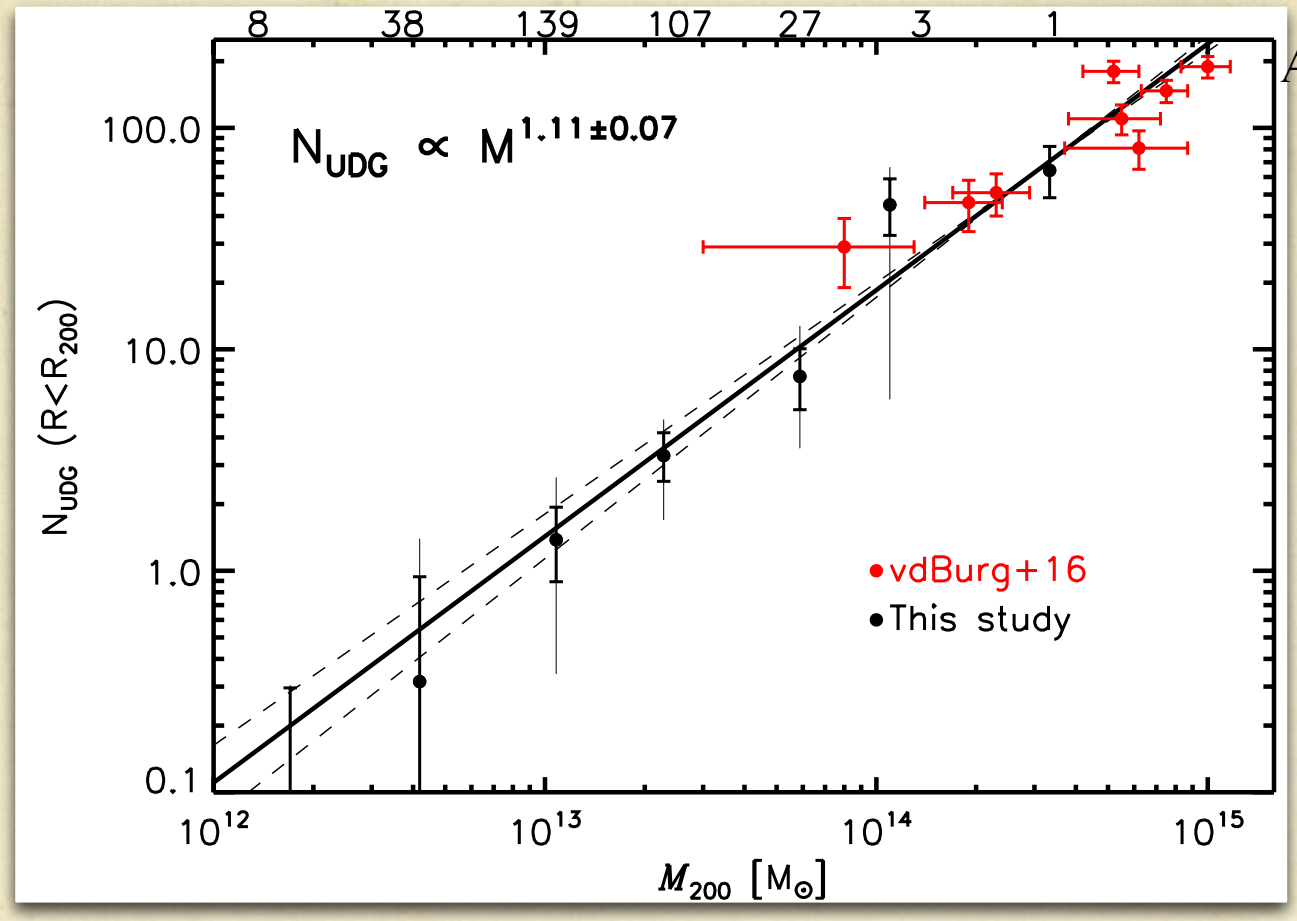
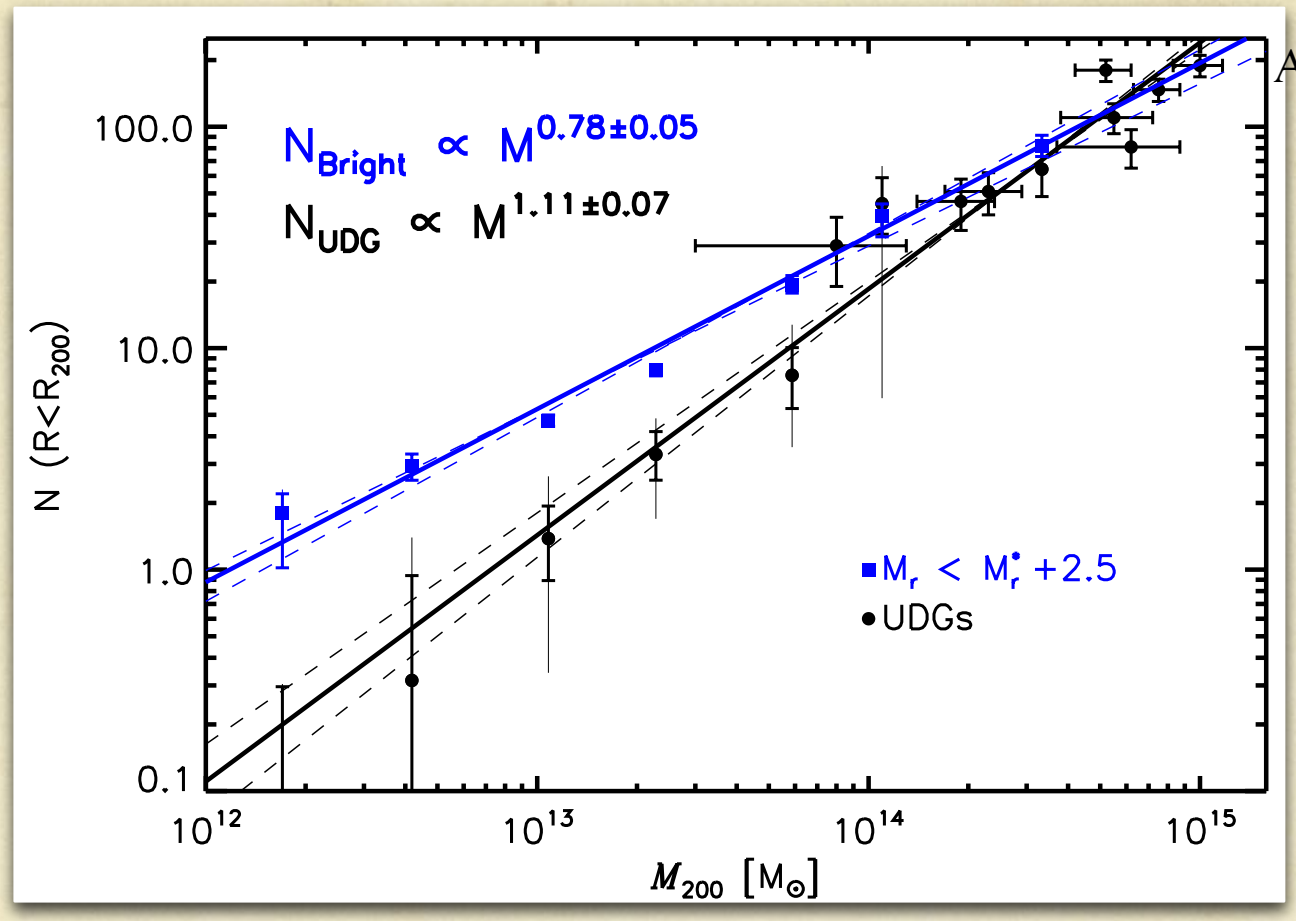


- UDGs also in groups (cf. Román & Trujillo 2017; Merritt+2016)
- Abundance scales steeply with mass

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

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- 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 vdBurg+16 (1602.00002)
  - Steep size distribution (largest UDGs rare)
  - 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?