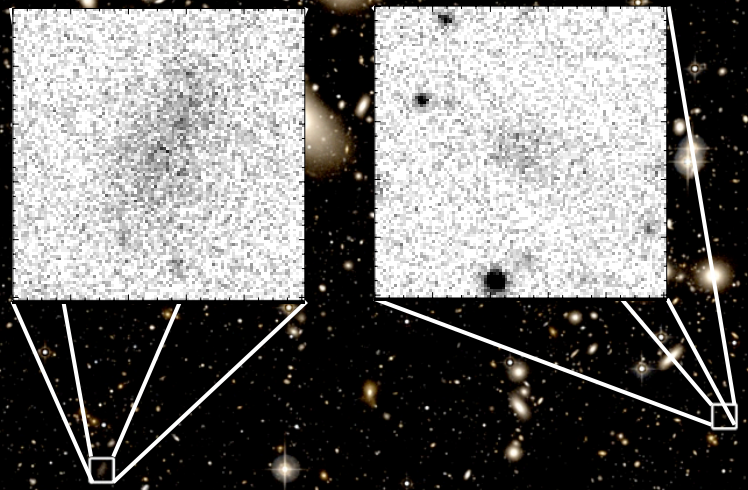
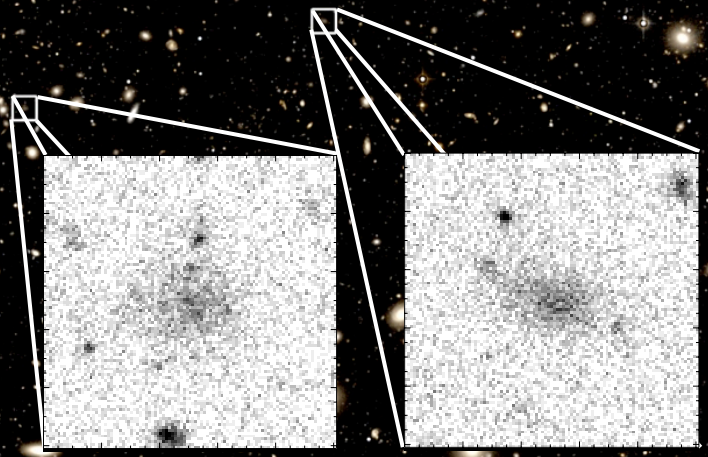
The abundance and radial distribution of ultra-diffuse galaxies in nearby galaxy clusters





Remco van der Burg
CEA Saclay, France

A&A, 590, 20 (ArXiv:1602.00002)

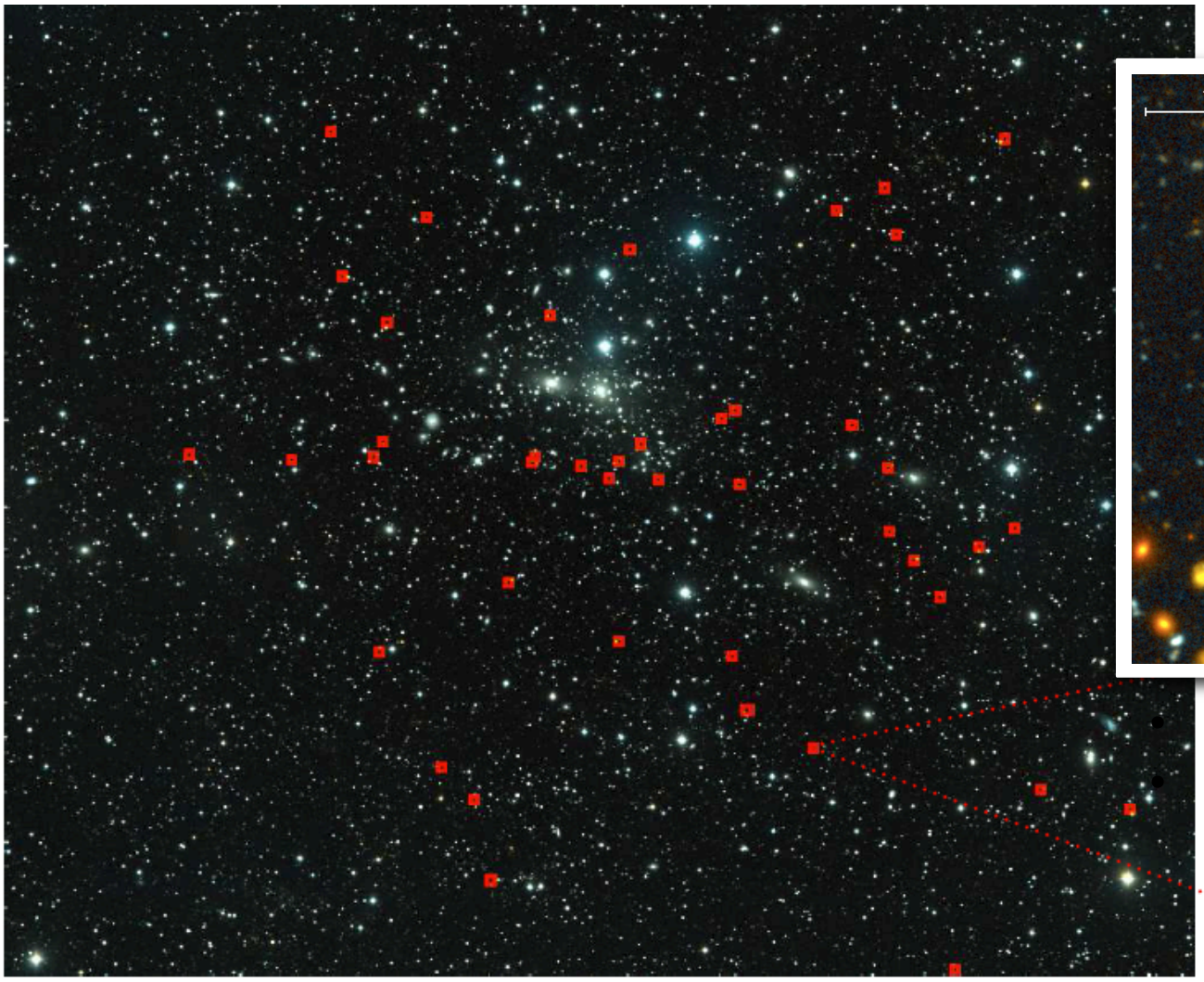
Adam Muzzin, Henk Hoekstra, Cristóbal Sífon

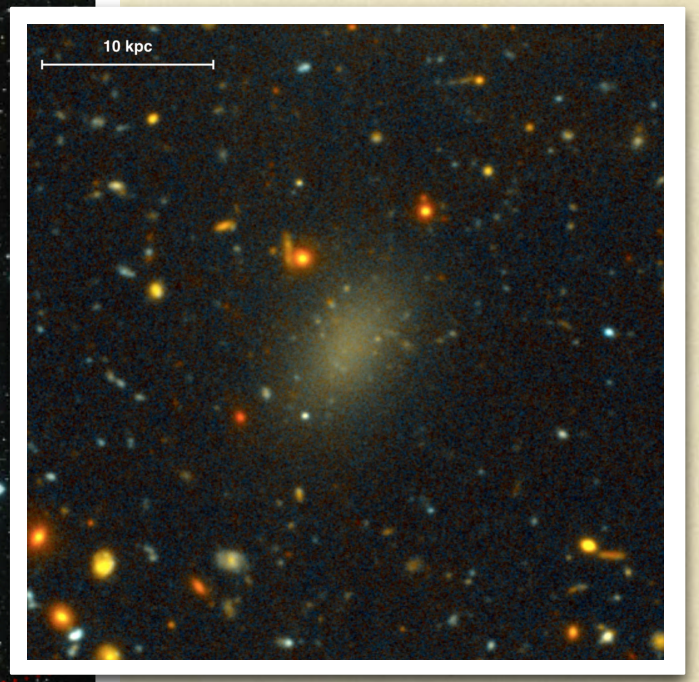
Abell 85, z=0.05

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}

In the following months:

SPECTROSCOPIC CONFIRMATION OF THE EXISTENCE OF LARGE, DIFFUSE GALAXIES IN THE COMA CLUSTER

Pieter G. van Dokkum[1], Aaron J. Romanowsky[2,3], Roberto Abraham[4], Jean P. Brodie[3], Charlie Conroy[5], Marla Geha[1], Allison Merritt[1], Alexa Villaume[3], and Jielai Zhang[4]

GALAXIES AT THE EXTREMES: ULTRA-DIFFUSE GALAXIES IN THE VIRGO CLUSTER

J. Christopher Mihos[1], Patrick R. Durrell[2], Laura Ferrarese[3], John J. Feldmeier[2], Patrick Côté[3], Eric W. Peng[4,5], Paul Harding[1], Chengze Liu[6,7], Stephen Gwyn[3], and Jean-Charles Cuillandre[8]

APPROXIMATELY A THOUSAND ULTRA DIFFUSE GALAXIES IN THE COMA CLUSTER

Jin Koda[1], Masafumi Yagi[2,3], Hitomi Yamanoi[2], Yutaka Komiyama[2,4]

UNVEILING A RICH SYSTEM OF FAINT DWARF GALAXIES IN THE NEXT GENERATION FORNAX SURVEY

Roberto P. Muñoz[1], Paul Eigenthaler[1], Thomas H. Puzia[1], Matthew A. Taylor[1,2], Yasna Ordenes-Briceño[1], Karla Alamo-Martínez[1], Karen X. Ribbeck[1], Simón Ángel[1], Massimo Capaccioli[3], Patrick Côté[4], Laura Ferrarese[4], Gaspar Galaz[1], Maren Hempel[1], Michael Hilker[5], Andrés Jordán[1], Ariane Lançon[6], Steffen Mieske[2], Maurizio Paolillo[7], Tom Richtler[8], Ruben Sánchez-Janssen[4], and Hongxin Zhang[1,9,10]

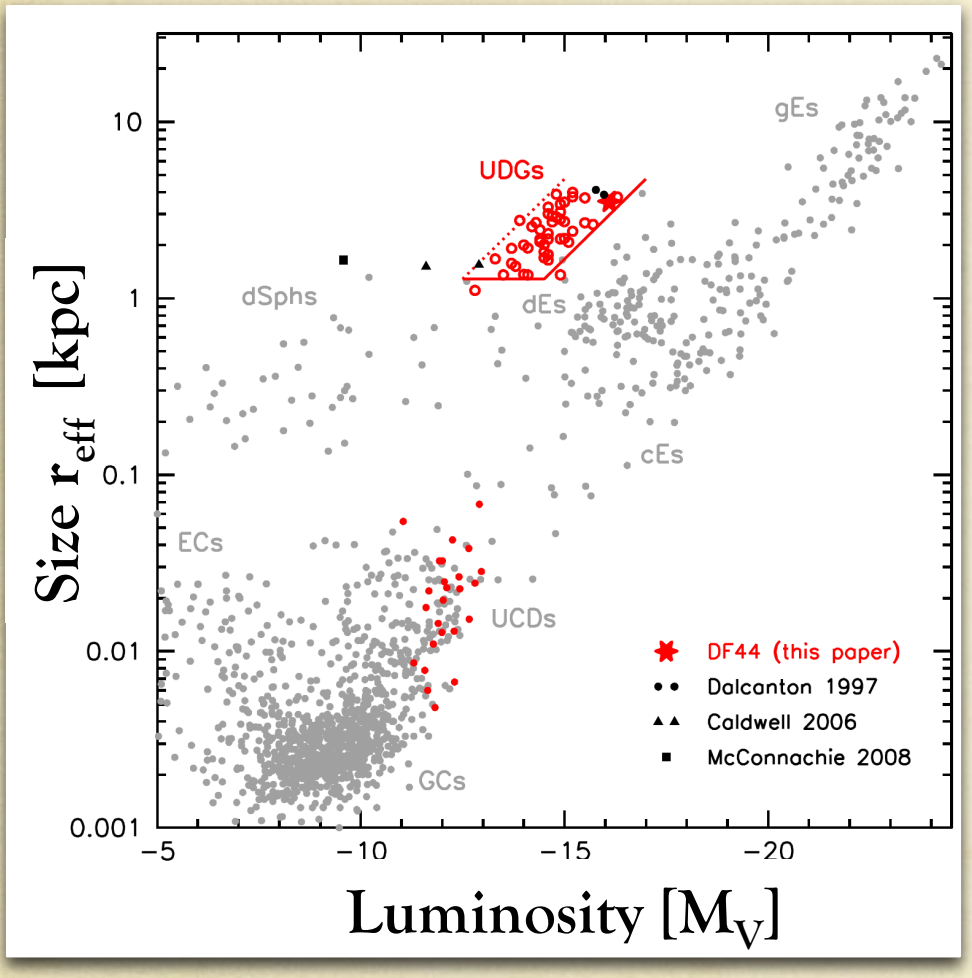
DISCOVERY OF AN ULTRA-DIFFUSE GALAXY IN THE PISCES-PERSEUS SUPERCLUSTER

David Martínez-Delgado[1,2], Ronald Läsker[2], Margarita Sharina[12], Elisa Toloba[5,13], Jürgen Fliri[3,15], Rachael Beaton[13], David Valls-Gabaud[4], Igor D. Karachentsev[12], Taylor S. Chonis[6], Eva K. Grebel[1], Duncan A. Forbes[10], Aaron J. Romanowsky[5,14], J. Gallego-Laborda[9], Karel Teuwen[8], M. A. Gómez-Flechoso[7], Jie Wang[17,11], Puragra Guhathakurta[5], Serafim Kaisin[12], Nhung Ho[16]

AN OVERMASSIVE DARK HALO AROUND AN ULTRA-DIFFUSE GALAXY IN THE VIRGO CLUSTER

Michael A. Beasley[1,2], Aaron J. Romanowsky[3,4], Vincenzo Pota[5], Ignacio Martin Navarro[1,2,4], David Martinez Delgado[6], Fabian Neyer[7], Aaron L. Deich[3]

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 observational constraints

- Only Coma cluster studied, and some examples in Virgo and Fornax

to perform a (mostly) objective selection with the aid of Sloan Digital Sky Survey (SDSS) and archival Canada France Hawaii Telescope (CFHT) data, as described in the next Sec-

sition. This step left 186 objects which were inspected by eye. Of these, 139 were rejected, with most turning out to be clumps of multiple objects fainter than the $i = 22.5$ limit.

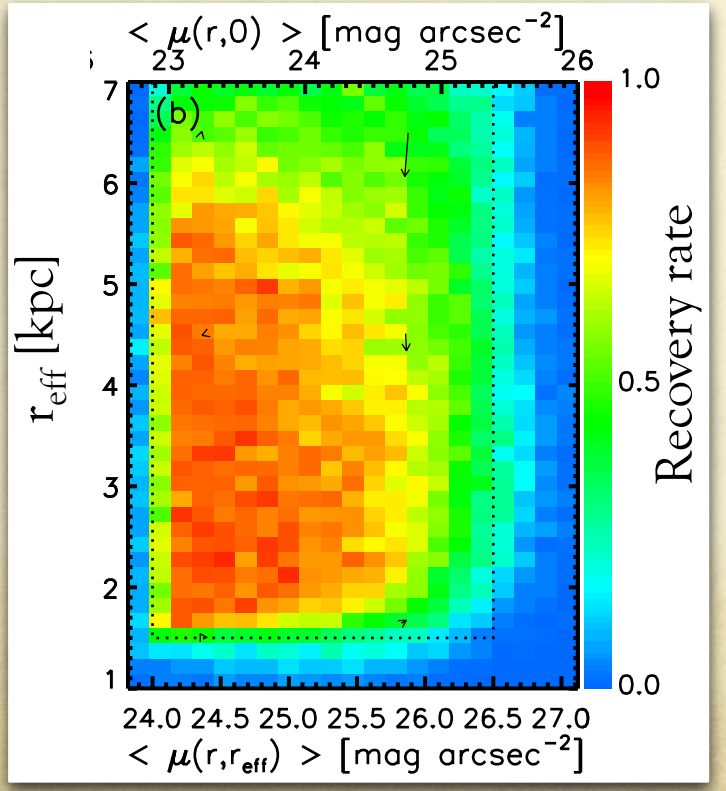
artifacts at image edges, and optical ghosts. To minimize human error, the four authors separately went through all postage stamp images. After this step and removal of duplications based on their coordinates, 854 UDG candidates were left on which at least three of us agreed. The

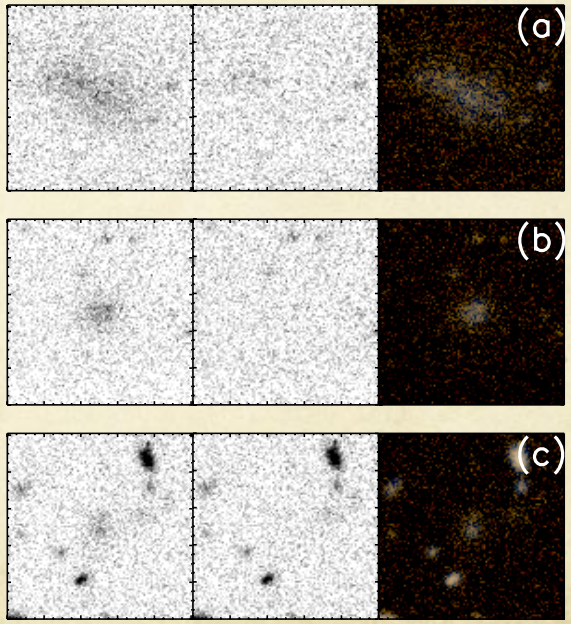
- Early studies not systematic, nor objective/reproducible

A systematic study of UDGs in 8 low-z clusters

vdBurg+16b

- 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

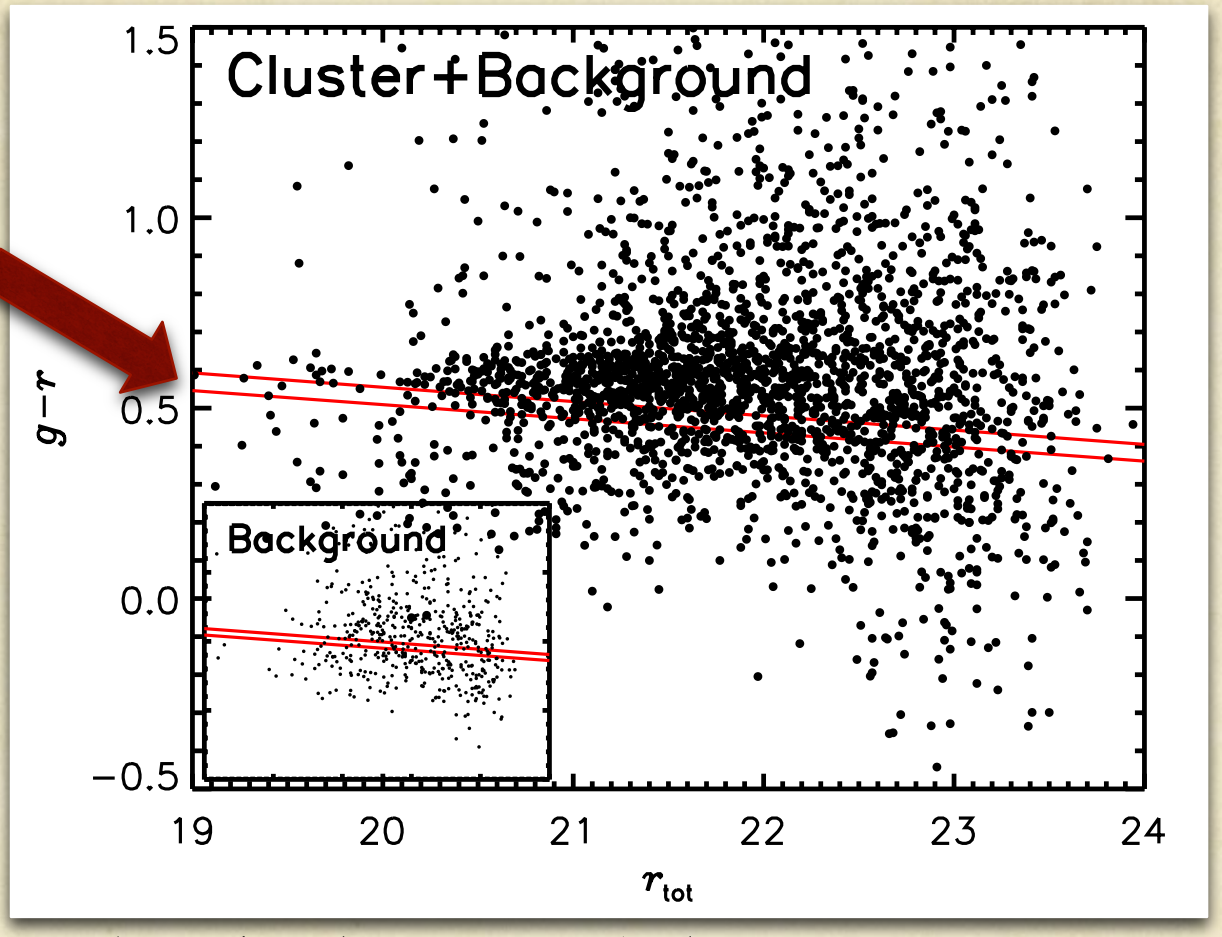




What are their physical properties?

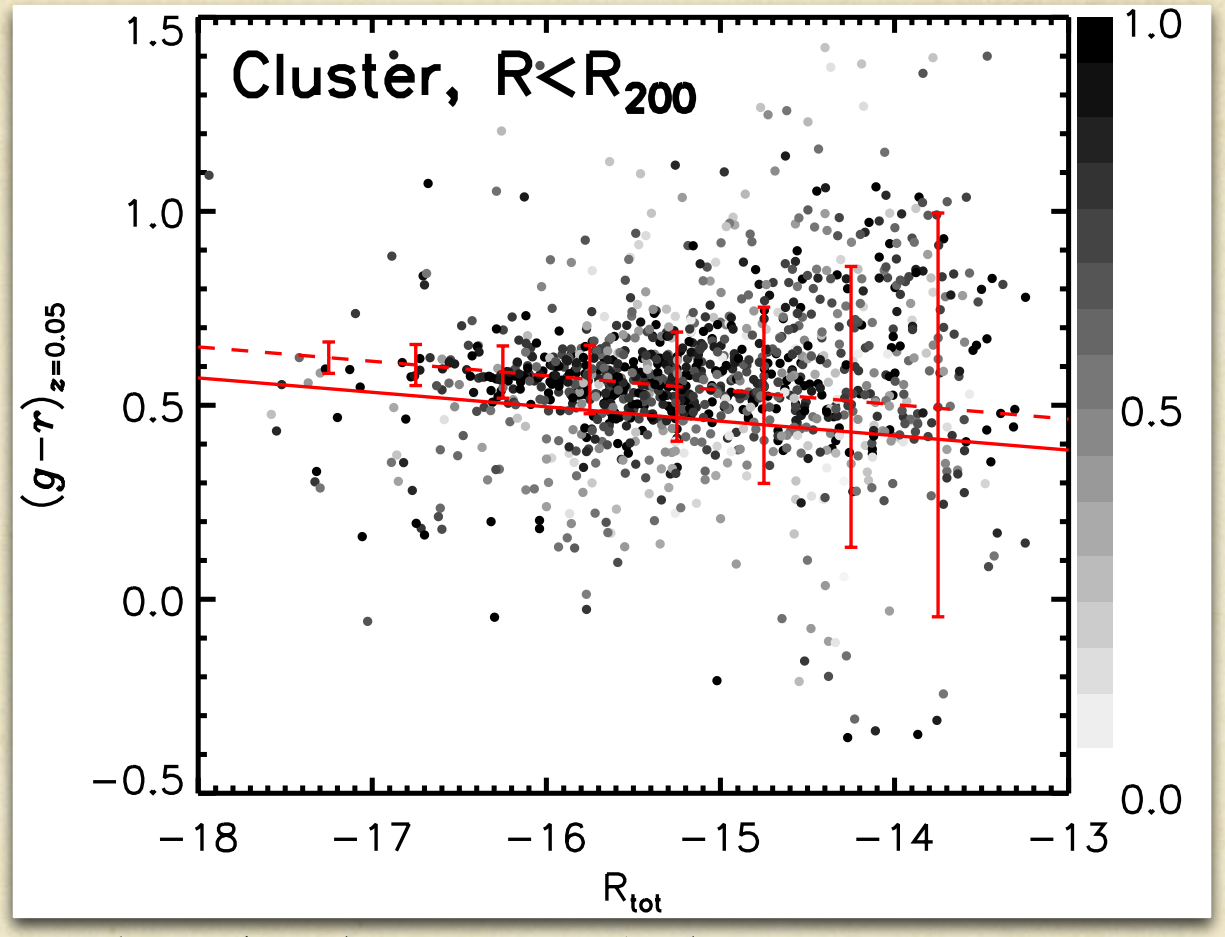
Colour-magnitude distribution

vdBurg+15



- Selection based only on morphology
- All on the red sequence

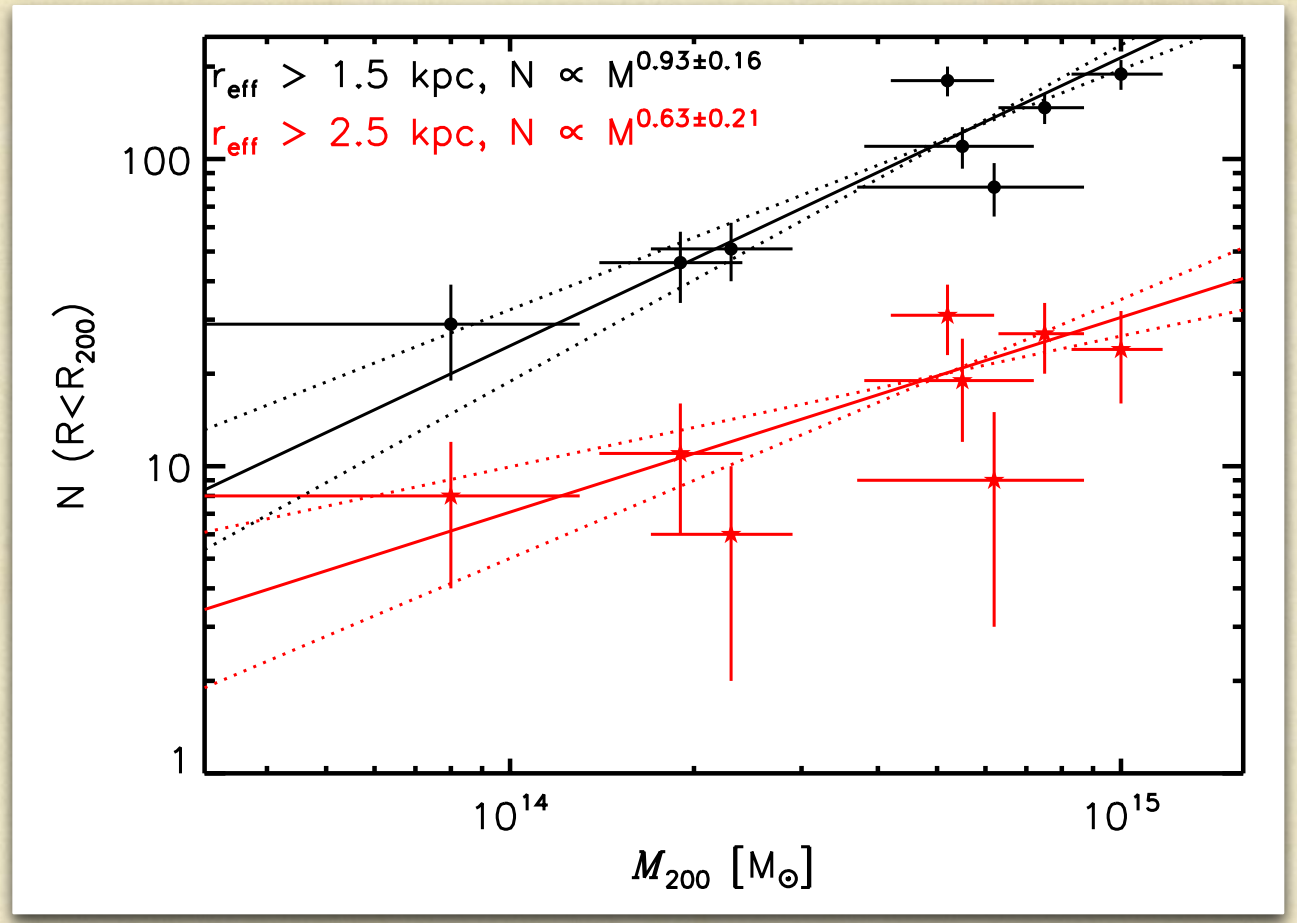
Colour-magnitude distribution



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

See also:
van Dokkum+15
Koda+15

Abundance versus halo mass

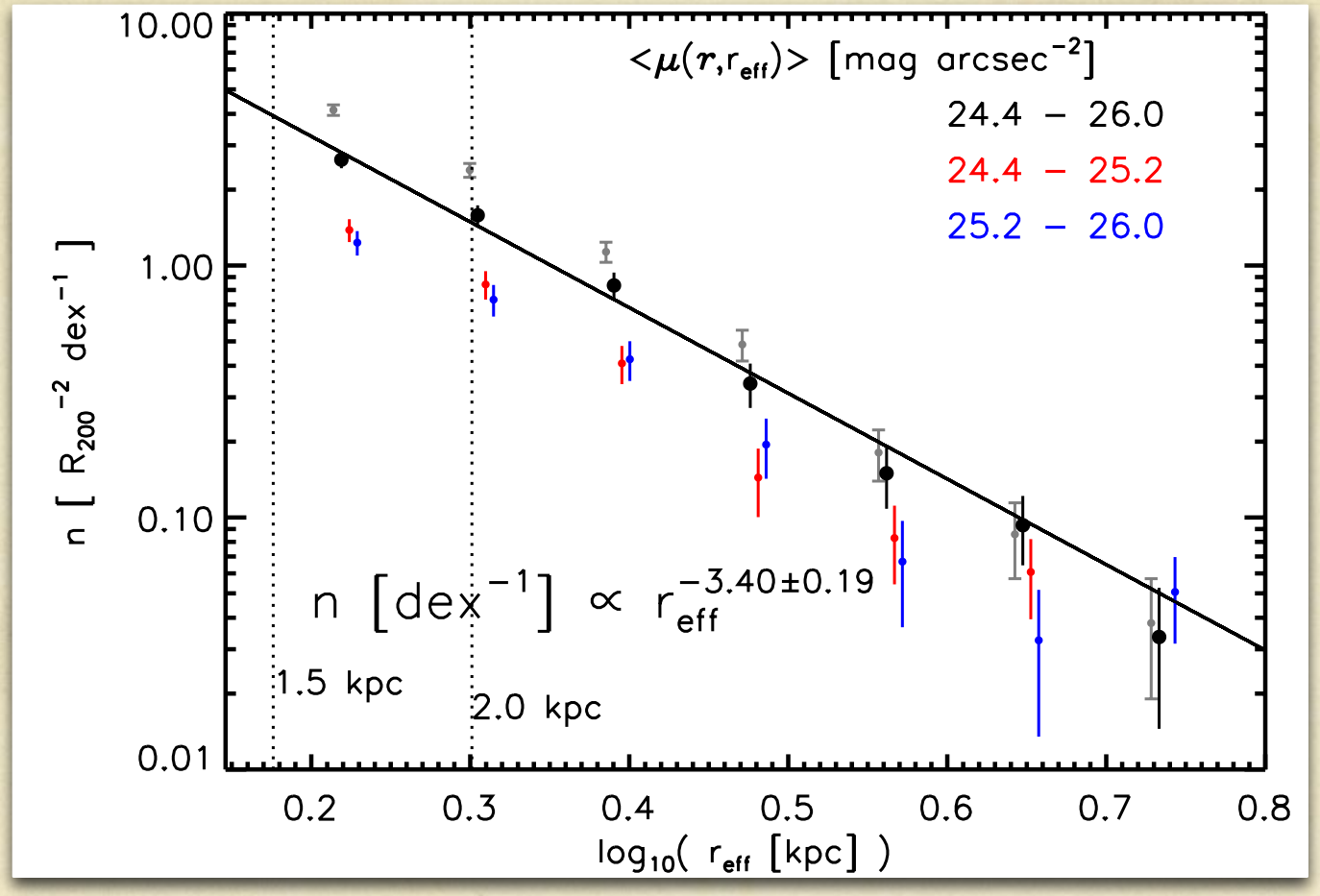


- Similar slope as mass-richness relation

Mass measurements: Sifón+15

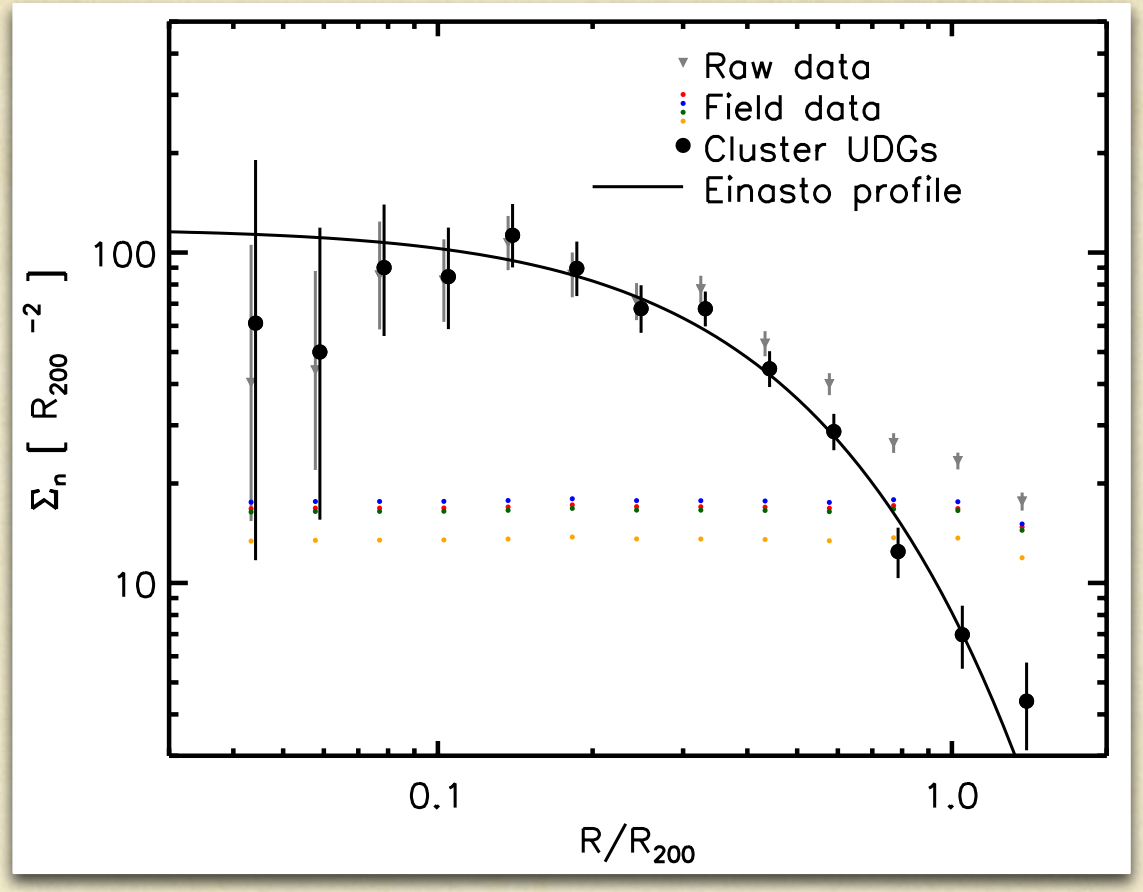
- Total stellar mass in UDGs ≈ 0.2% of total cluster stellar mass
- Steep size distribution -> largest UDGs very rare

Size distribution



- Steep size distribution -> largest UDGs very rare

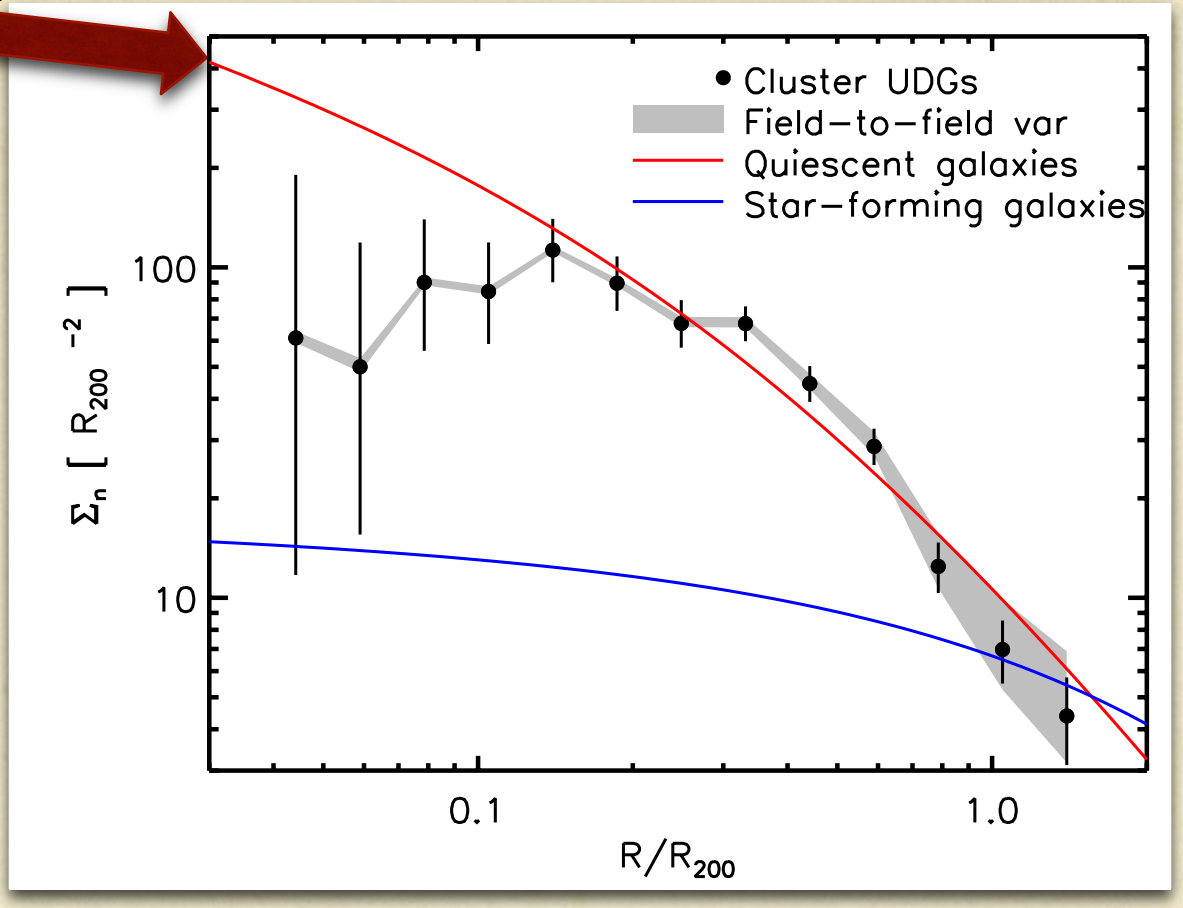
Radial distribution of UDGs



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

Radial distribution of UDGs

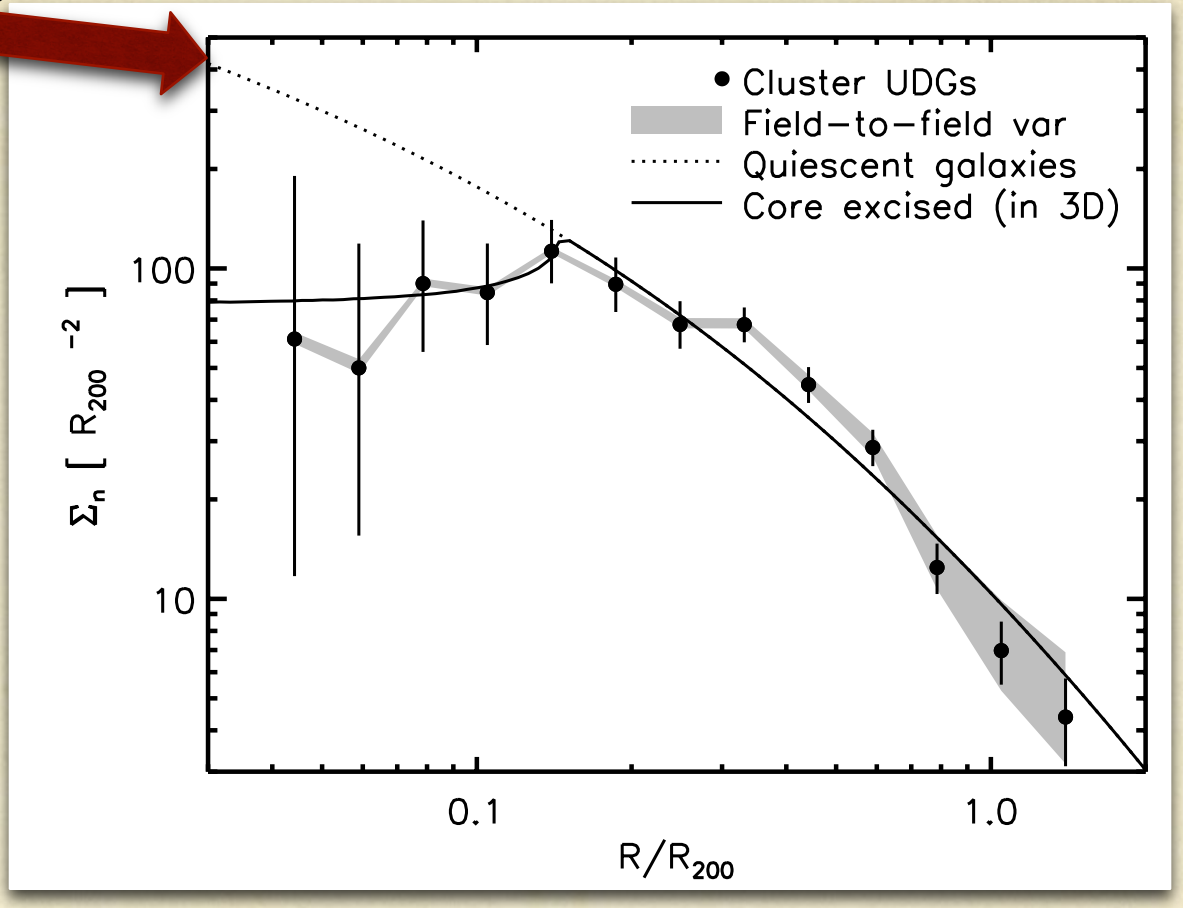
Total stellar-mass-weighted distribution of quiescent galaxies vdBurg+15



- Roughly follows dynamically old population in outskirts

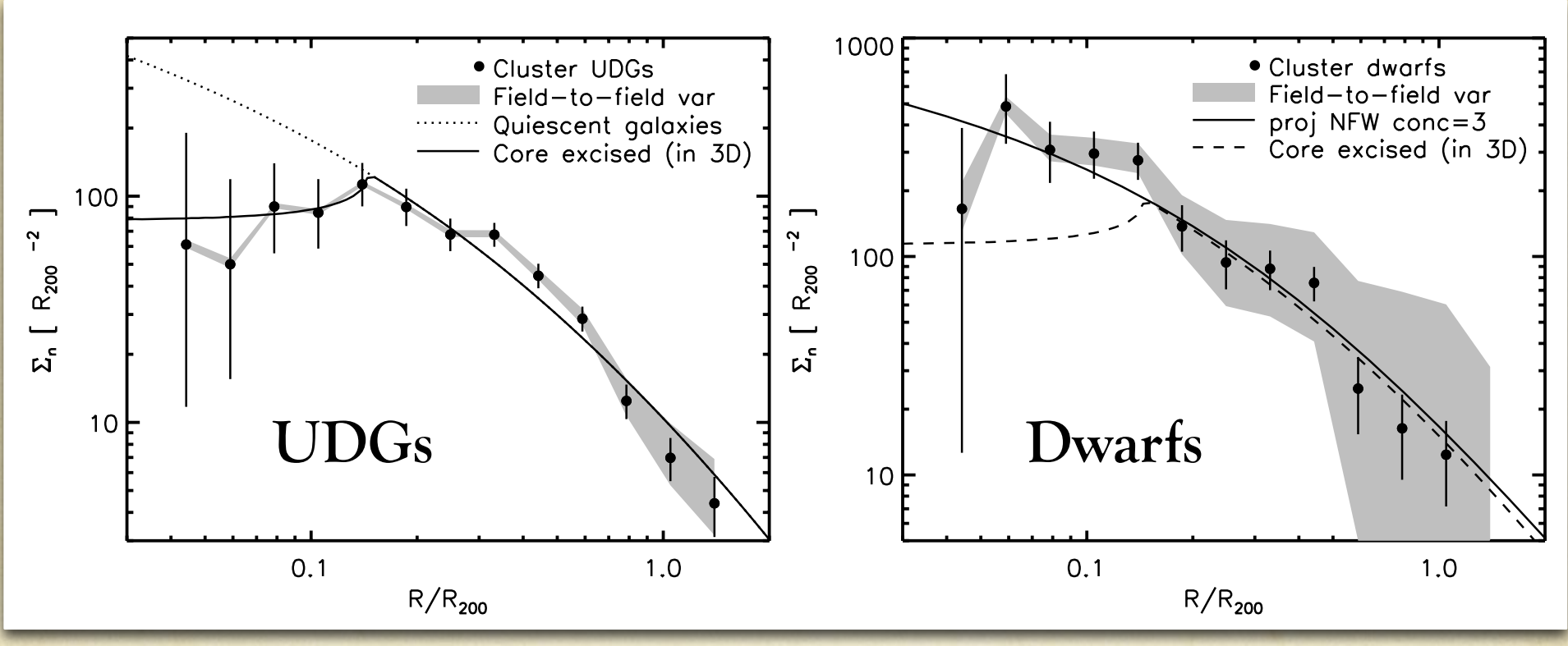
Radial distribution of UDGs

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)

Radial distribution of "normal" dwarfs



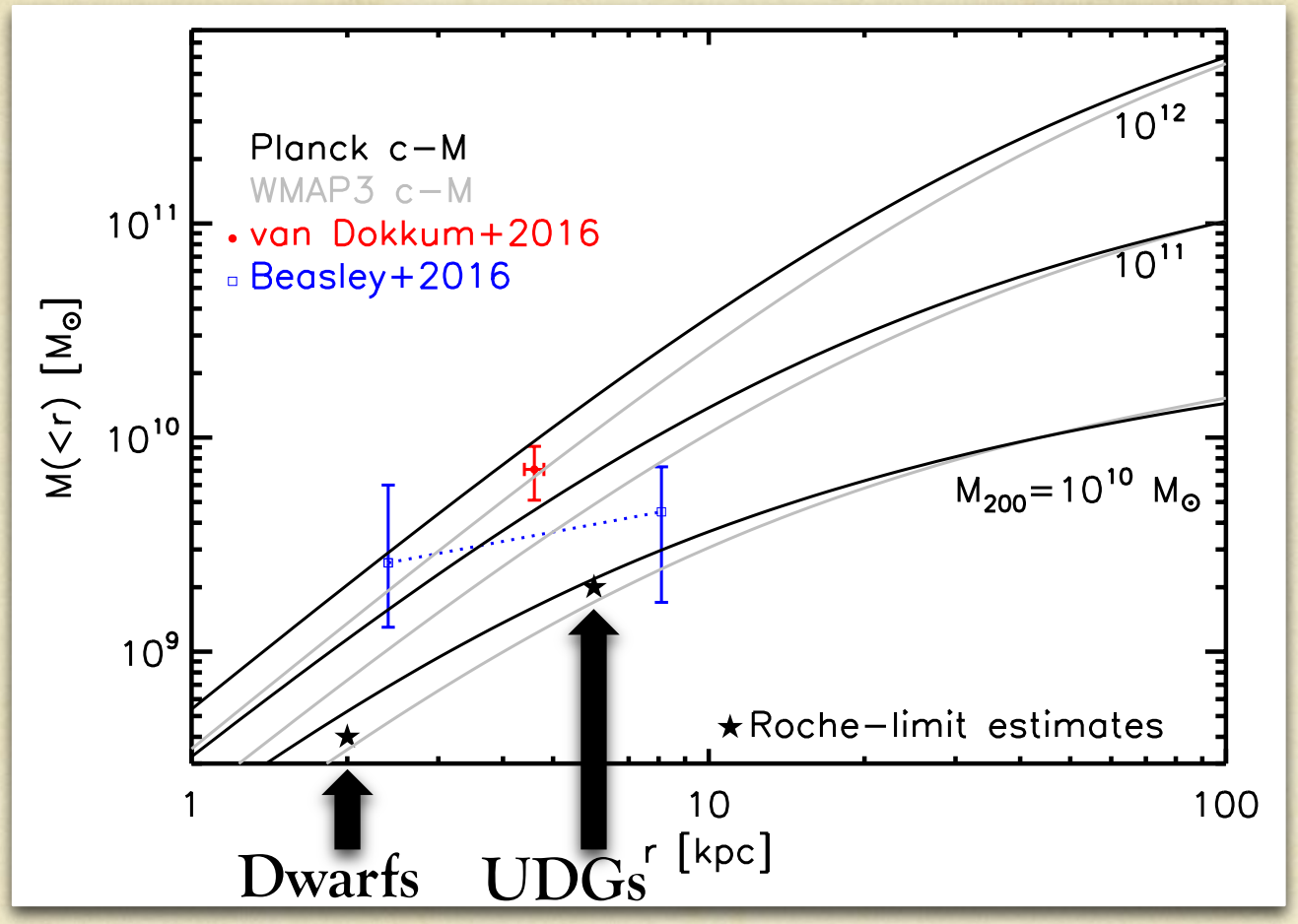
- "Normal" dwarfs with $0.5 < r_{eff}$ [kpc] < 1.0 and same luminosities as UDGs, exist down to ~100kpc from the cluster centre

Roche limit for UDGs and "normal" dwarfs

- A comparison of UDGs and more compact dwarfs with stellar masses of $10^8\,M_\odot$
- Given cluster mass interior to 100kpc, one needs $4\times10^8\,M_\odot$ within a tidal disruption radius of 2kpc for dwarfs
- Given cluster mass interior to 300kpc, one needs $2\times10^9\,M_\odot$ within a tidal disruption radius of 6kpc for UDGs

Two enclosed masses for 2 different populations

Roche limit for UDGs and "normal" dwarfs



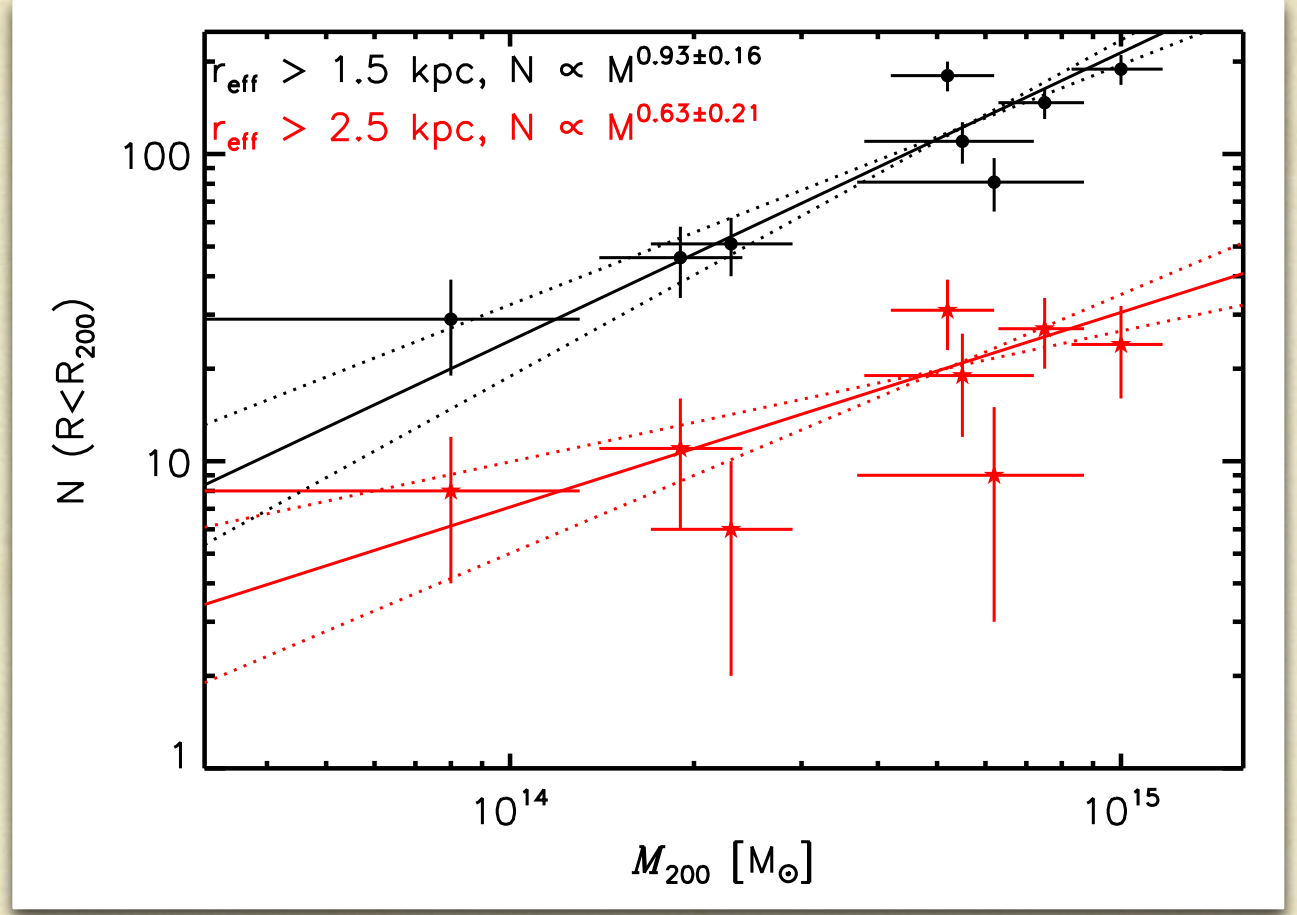
- Consistent with them having similar dark-matter haloes
- Dynamically-measured masses very high
  - May be there are different types of UDGs?

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 vdBurg+16
- Failed Milky-Way type galaxies
  - Still unclear why some haloes would have "failed"
- High-spin tail of the dwarf galaxy population Amorisco & Loeb 2016
  - May be explained by "standard model" of disk formation
- Episodes of gas outflows associated with star formation Di Cintio+17

Field studies and halo mass measurements essential to make progress

Field Studies



- Does this relation extend down to groups? And individual galaxies? (Román & Trujillo 2016; Merritt+2016)
- What would their properties be?

Measuring halo masses of UDGs

- Difficult to use methods that rely on stellar tracers of the potential
  - Even getting a redshift takes a long time
  - Perhaps using Globular Clusters is an (expensive) option for UDGs in low-z clusters (Beasley+16, Amorisco+16b)
- An alternative is to measure the coherent gravitational distortion of source galaxies behind the UDGs
  - CFHT data were taken with weak gravitational lensing in mind
  - Signal from failed Milky-Way type haloes should clearly stand out
  - Working on stacked lensing mass of UDGs

With Cristóbal Sífon, Henk Hoekstra, Adam Muzzin

Summary

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

- Abundance of UDGs in clusters surprising and not yet understood
- First constraints from a systematic study in 8 nearby clusters
  - UDGs abundant in each cluster, with abundance scaling with M_{200}
  - Steep size distribution (largest UDGs rare)
  - Colour-magnitude distributions (old stellar populations)
  - They follow dynamically old galaxies spatially, with central deficit
- Measurements already used to constrain theoretical models
- Several scenario's being considered
  - Essential to estimate field abundance and measure halo masses