Towards Understanding the Origin and Evolution of Ultra-Diffuse Galaxies

Abell 85, $z=0.05$

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At the beginning of 2015...

Forty-seven Milky Way-sized, extremely diffuse galaxies in the Coma Cluster

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Since then... ~ 100 papers on this topic
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:
  \[ r_{\text{eff}} > 1.5 \, \text{kpc} \]
  \[ <\mu(r,r_{\text{eff}}) > \approx 25 \, \text{mag arcsec}^{-2} \]

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

- 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
A&A, 590, 20
ArXiv:1602.00002
Selection based only on morphology

All on the red sequence -> old stellar populations

Median stellar mass $\approx 10^8 M_\odot$
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

Roughly follows dynamically old population in outskirts

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Radial distribution of UDGs

Total stellar-mass-weighted distribution of quiescent galaxies

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- 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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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
- No significant detection!
- \(2\sigma\) upper limit \(M_{200} < 10^{11.8} M_\odot\)

(Arxiv:1704.07847)
Does this relation extend down to groups? And individual galaxies?
(cf. Román & Trujillo 2017; Merritt+2016)
The UDG abundance from clusters to groups

- 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
The UDG abundance from clusters to groups

UDGs also in groups (cf. Román & Trujillo 2017; Merritt+2016)

Abundance scales steeply with mass
The UDG abundance from clusters to groups

Richness - mass relation shallower than 1:1

UDGs are relatively more common in more massive haloes

vdBurg+17 ArXiv:1706.02704
UDGs are relatively more common in more massive haloes

- 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≈1.4) and groups (n≈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)
  - 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 2 σ) that they are all “failed Milky Ways”
  - UDGs are relatively more common in more massive haloes
- Combination of different mechanisms to make UDGs?

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Sifón,vdB+17 (1704.07847)
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