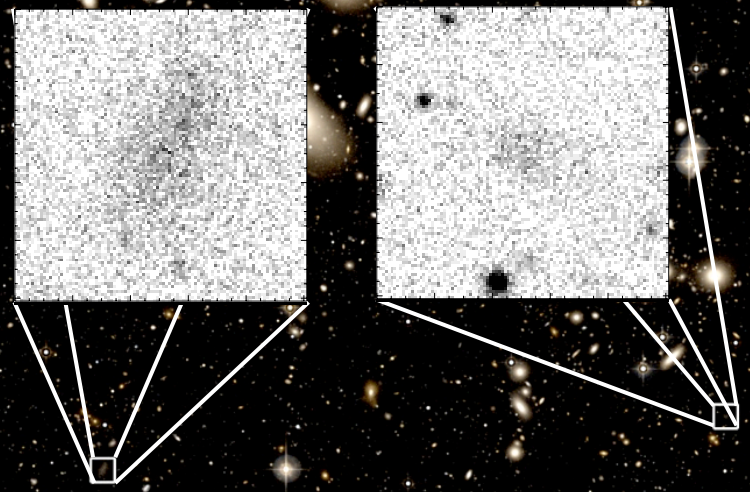
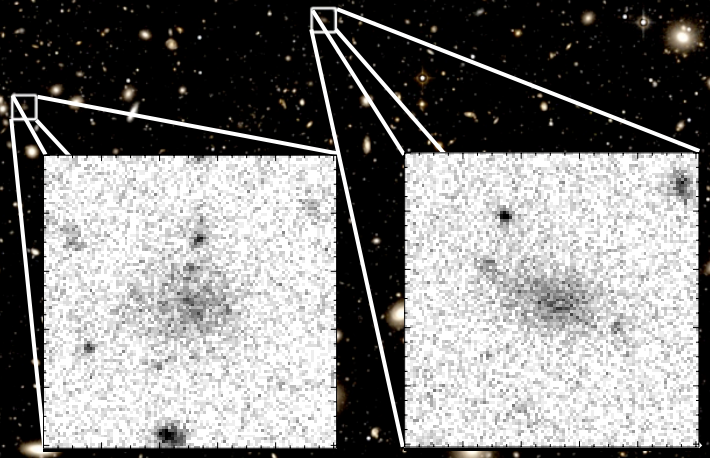
Towards Understanding the Origin and Evolution of Ultra-Diffuse Galaxies



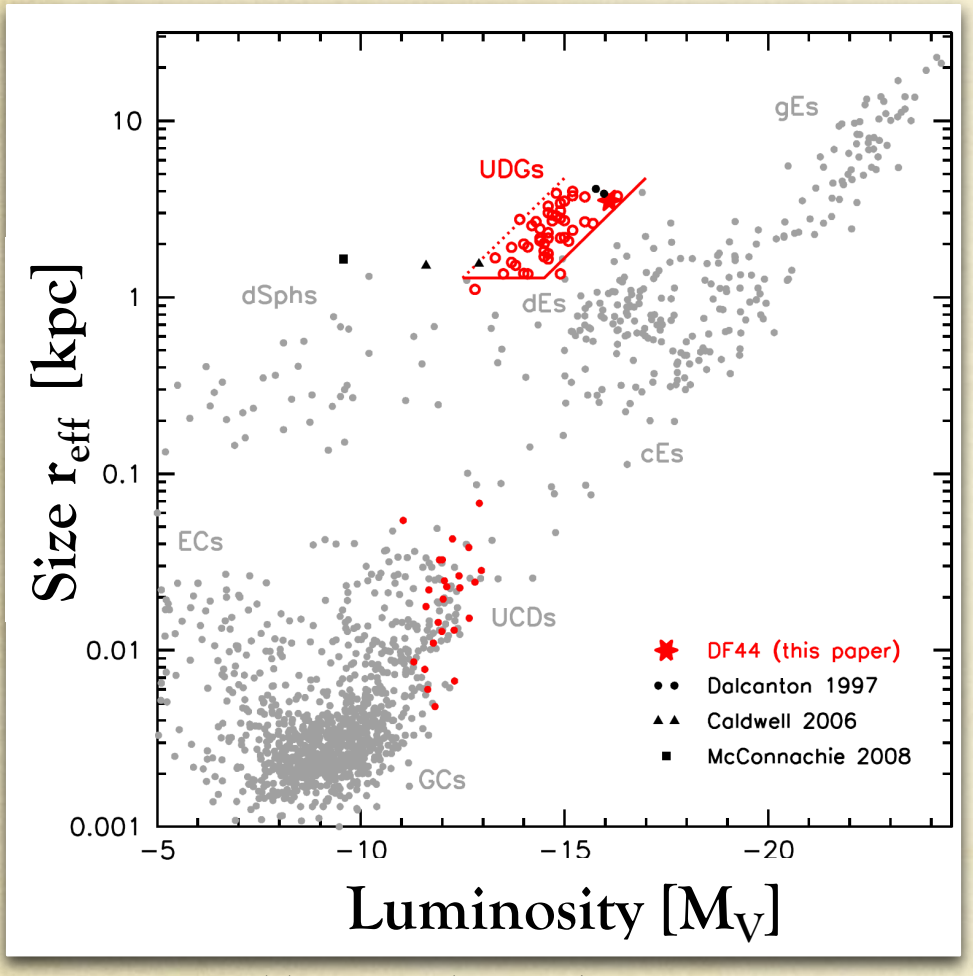


Remco van der Burg
ESO Garching

Cristóbal Sifón, Adam Muzzin, Henk Hoekstra,
Jérémy Fensch, Eric Emsellem
KiDS & GAMA Collaborations

Abell 85, z=0.05

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:

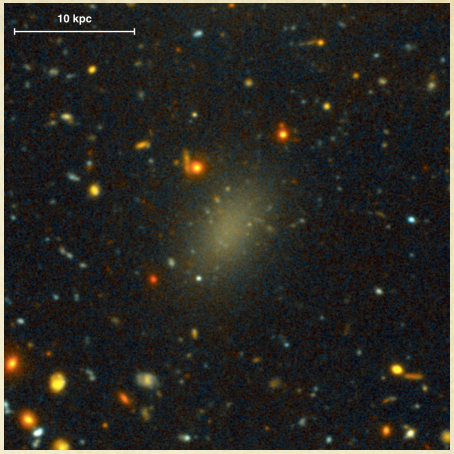
r_{eff}>1.5 kpc

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

How do these large variations in dwarf galaxy properties fit in our LCDM model of galaxy formation?

What do we know/ need to know?

- Abundant in galaxy clusters (e.g. van Dokkum+15, Mihos+15, vdBurg+16, Venhola+17)
  - Tidally disturbed/heated "normal" dwarf galaxies?
  - Massive halo "failed" to form proper galaxy?
- Also in groups and some in isolation (e.g. Merrit+16, Roman&Trujillo 17)
  - Where do they originate from?



- Some are tidally disrupted, but most appear "smooth" (e.g. Burkert+17, Bennet+18)
  - Also smooth when measured to lower surface-brightness limit?
- How have they formed?
  - External processes or internal to a galaxy?
  - Most models suggest internal processes

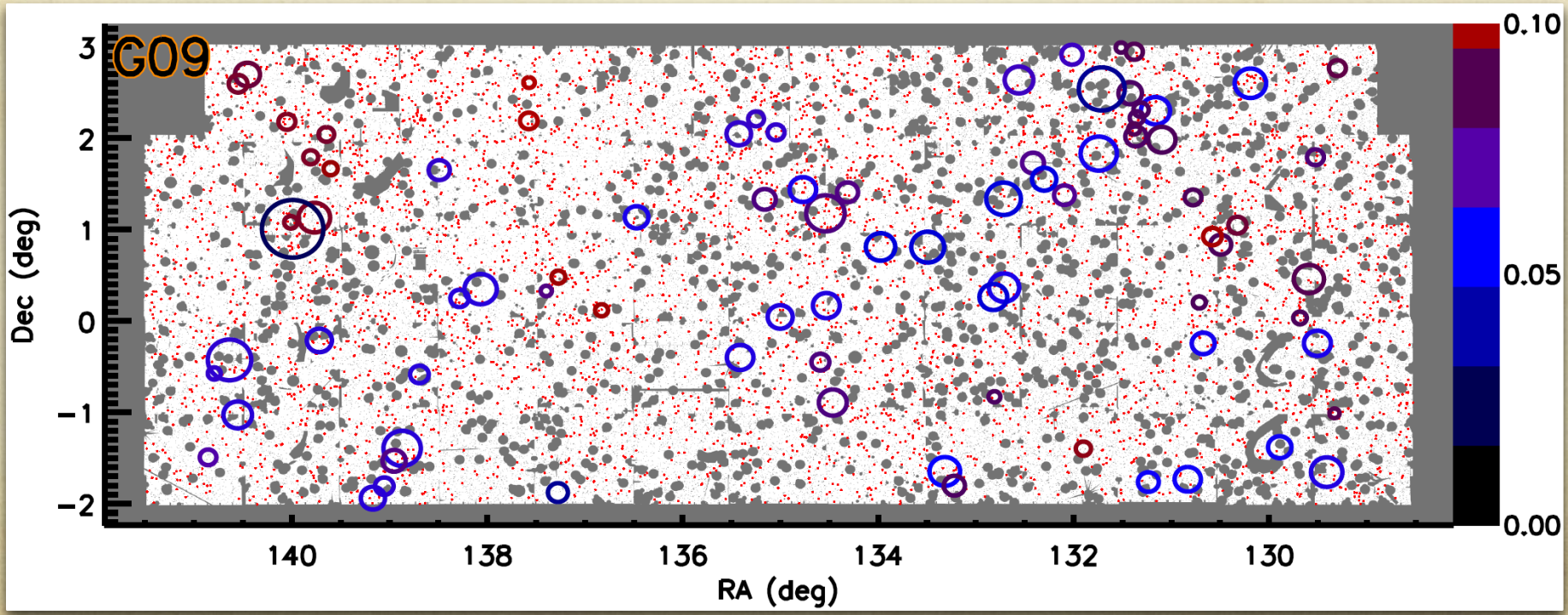
(e.g. Amorisco & Loeb 2016, Di Cintio+17, Chan+18, Carleton+18)

Systematic studies in other environments and halo mass measurements essential to make progress

The UDG abundance from clusters to groups

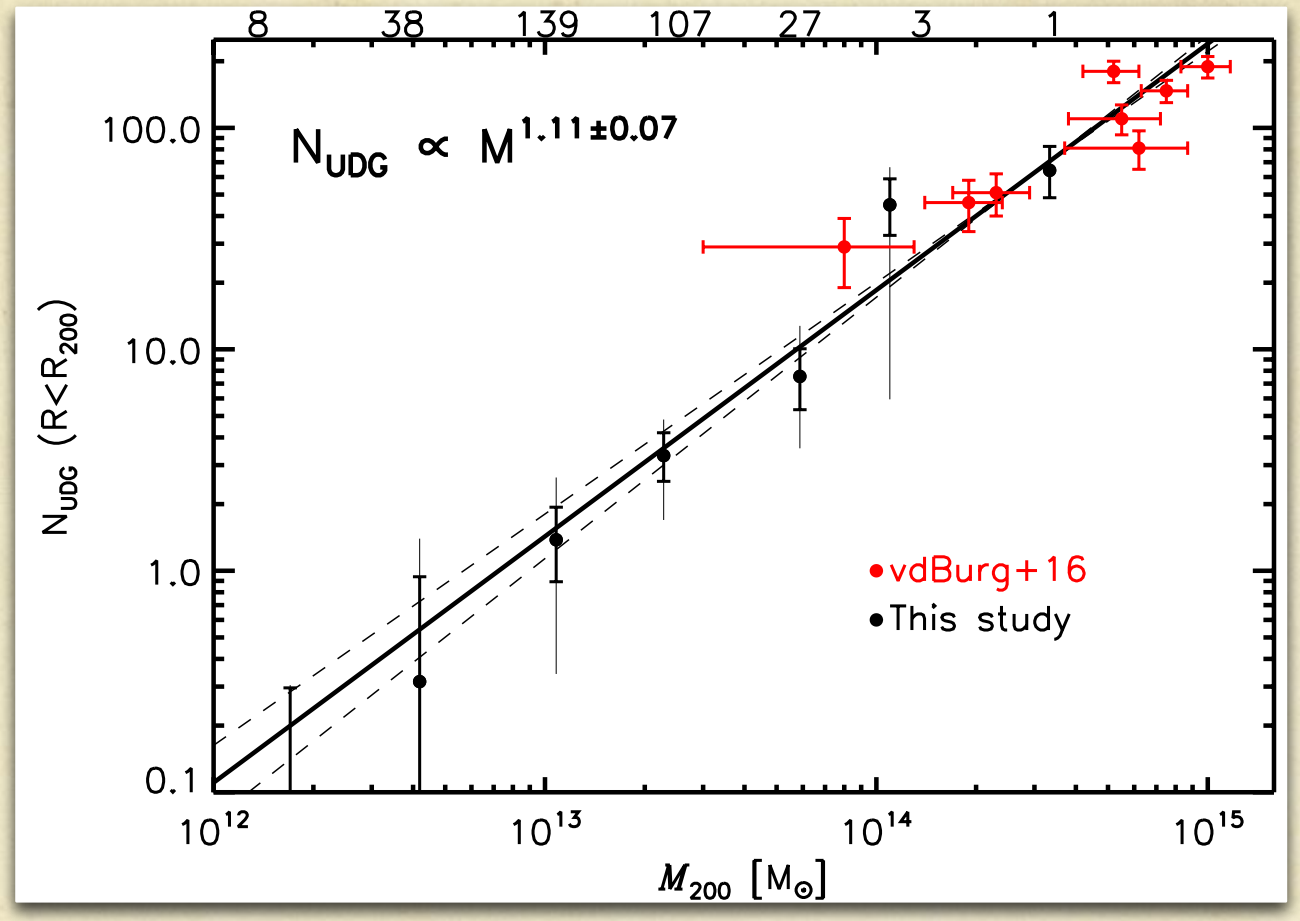
vdBurg+17
A&A, 607, 79

- Kilo-Degree Survey (KiDS)
  - Clean *r*-band imaging down to ~25.5 mag arcsec^{-2} over >1000 deg^2
- Galaxy And Mass Assembly (GAMA) spectroscopic survey (with AAT)
  - 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

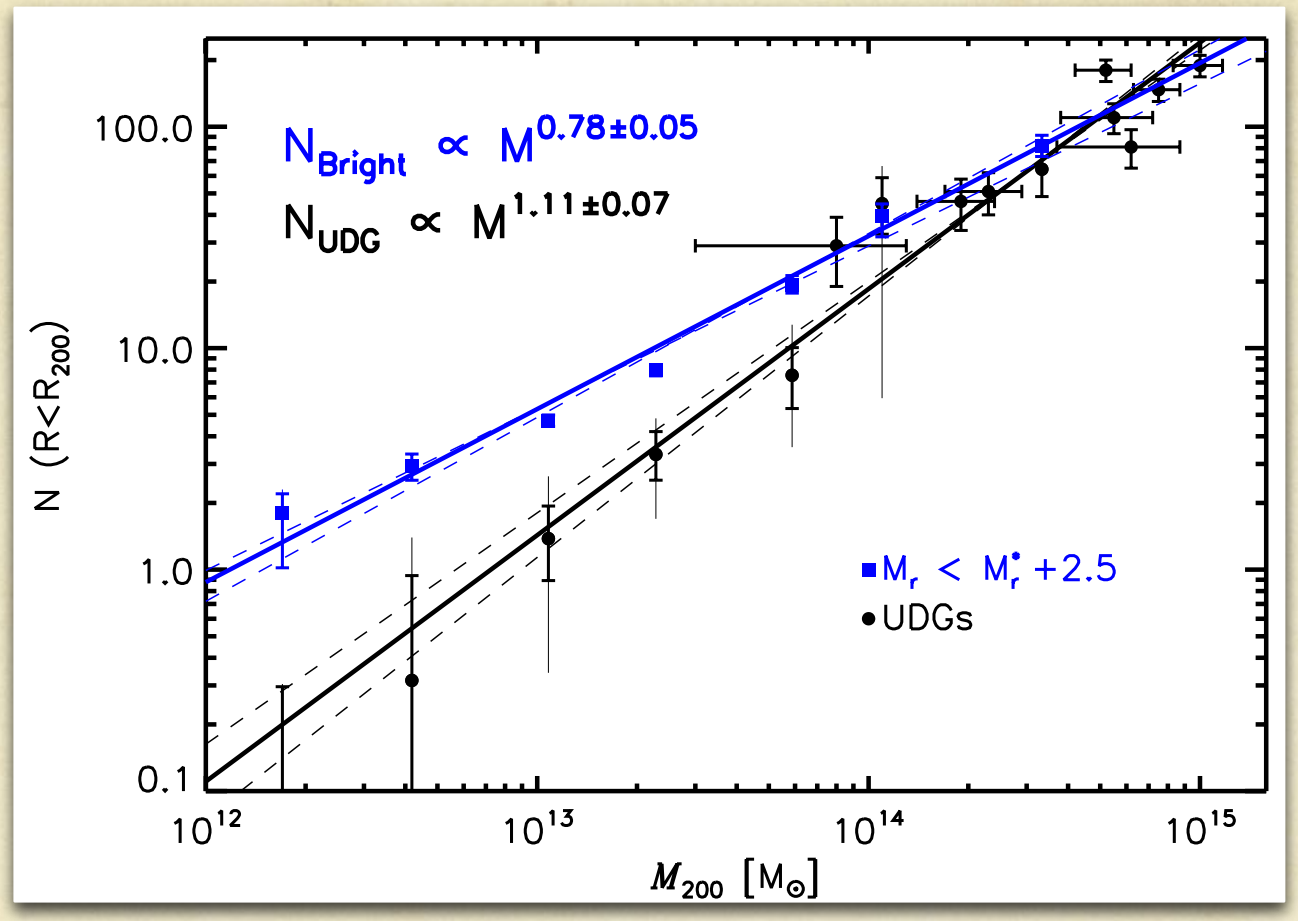
vdBurg+17
A&A, 607, 79



- UDGs also in groups (cf. Román & Trujillo 17; Merritt+16)
- Abundance scales steeply with mass

The UDG abundance from clusters to groups

vdBurg+17
A&A, 607, 79



- Bright galaxies "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
A&A, 607, 79

- 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, Beñados+10, Lan+16)
- Combination of UDGs formed in different ways?
  - Internal versus externally driven processes?

Measuring halo masses of UDGs

- Using Globular Clusters (Beasley+16, Amorisco+16, Toloba+18, Prole+19)
  - N_{GC} tight correlation with halo mass (Forbes+18)
    - But some UDGs seem to have very strange GC systems
  - Using Globular Clusters as dynamical tracers
- Use stellar tracers of the potential (MUSE@VLT, KCWI@Keck, MANARA@GTC)
  - Becoming more efficient with IFU spectrographs
- Measure masses of UDGs using weak gravitational lensing
  - 784 UDGs in 18 clusters
  - 2σ upper limit average $M_{200} < 10^{11.8}\,M_{\odot}$ (Sifón, vdBurg+18)

Direct mass measurements of UDGs

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], and Aaron L. Deich[3]

A HIGH STELLAR VELOCITY DISPERSION AND ~100 GLOBULAR CLUSTERS FOR THE ULTRA-DIFFUSE GALAXY DRAGONFLY 44

Pieter van Dokkum[1], Roberto Abraham[2], Jean Brodie[3], Charlie Conroy[4], Shany Danieli[1], Allison Merritt[1], Lamiya Mowla[1], Aaron Romanowsky[3,5], and Jielai Zhang[2]

GLOBULAR CLUSTERS INDICATE THAT ULTRA-DIFFUSE GALAXIES ARE DWARFS

Michael A. Beasley[1,2] and Ignacio Trujillo[1,2]

The globular cluster systems of 54 Coma ultra-diffuse galaxies: statistical constraints from *HST* data

We find no candidate for a GCS as rich as that of the Milky Way, our sample has GCSs typical of dwarf galaxies.

N C Amorisco ✉, A Monachesi, A Agnello, S D M White

A galaxy lacking dark matter

Pieter van Dokkum[1], Shany Danieli[1], Yotam Cohen[1], Allison Merritt[1,2], Aaron J. Romanowsky[3,4], Roberto Abraham[5], Jean Brodie[4], Charlie Conroy[6], Deborah Lokhorst[5], Lamiya Mowla[1], Ewan O'Sullivan[6] & Jielai Zhang[5]

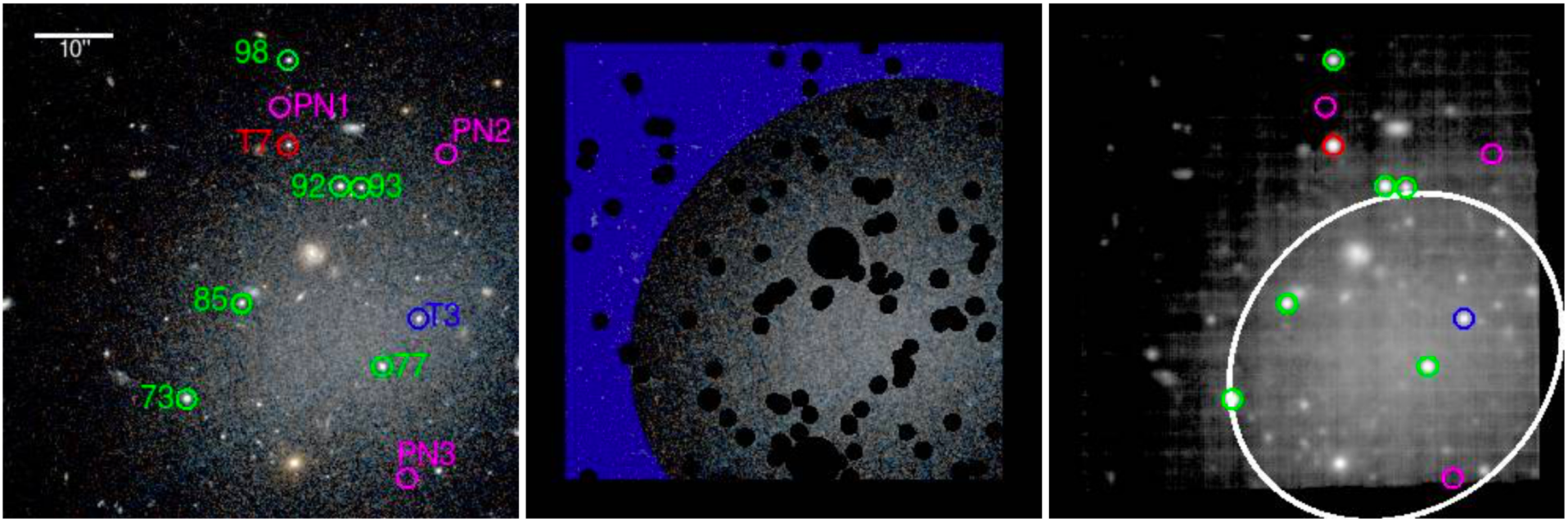
CURRENT VELOCITY DATA ON DWARF GALAXY NGC1052-DF2 DO NOT CONSTRAIN IT TO LACK DARK MATTER

Nicolas F. Martin[1,2], Michelle L. M. Collins[3], Nicolas Longeard[1], Erik Tollerud[4]

The ultra-diffuse galaxy NGC 1052-DF2 with MUSE: I. Kinematics of the stellar body⋆

ArXiv:1812.07345

Eric Emsellem[1,2], Remco F. J. van der Burg[1], Jérémy Fensch[1], Tereza Jerabkova[1,3,4], Anita Zanella[1], Adriano gnello[1,5], Michael Hilker[1], Oliver Mller[6], Marina Rejkuba[1], Pierre-Alain Duc[6], Patrick Durrell[7], Rebecca Haba Federico Lelli[1], Sungsoon Lim[9], Francine R. Marleau[8], Eric Peng[10,11], Rubén Sánchez-Janssen[12]



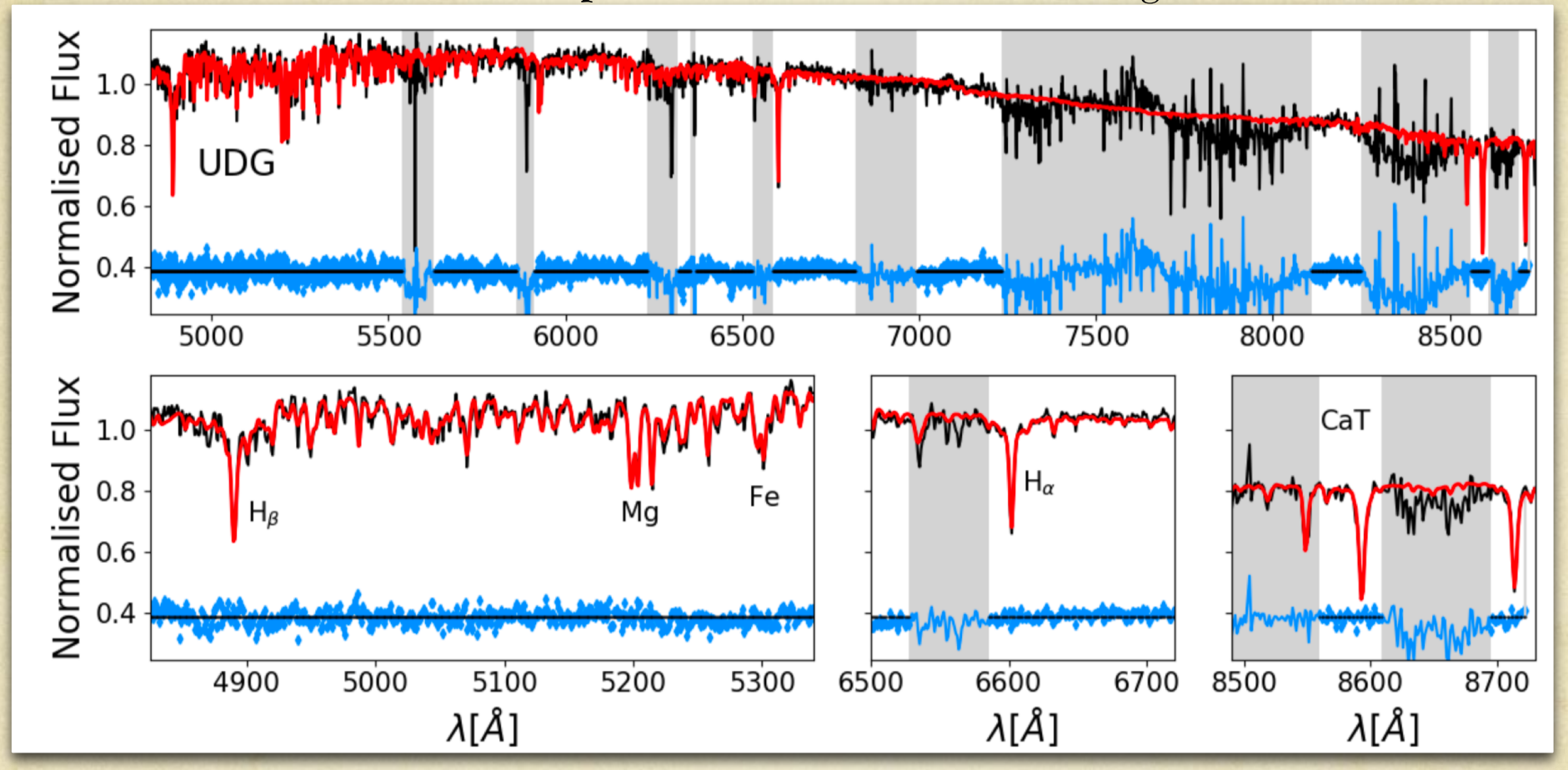
The ultra-diffuse galaxy NGC 1052-DF2 with MUSE: II. The population of DF2: stars, clusters and planetary nebulae⋆

ArXiv:1812.07346

Jérémy Fensch[1⋆⋆], Remco F. J. van der Burg[1], Tereza Jeřábková[1,2,3], Eric Emsellem[1,4], Anita Zanella[1], Adriano Agnello[1,5], Michael Hilker[1], Oliver Müller[6], Marina Rejkuba[1], Pierre-Alain Duc[6], Patrick Durrell[7], Rebecca Habas[8], Sungsoon Lim[9], Francine R. Marleau[8], Eric Peng[10,11] and Rubén Sánchez Janssen[12]

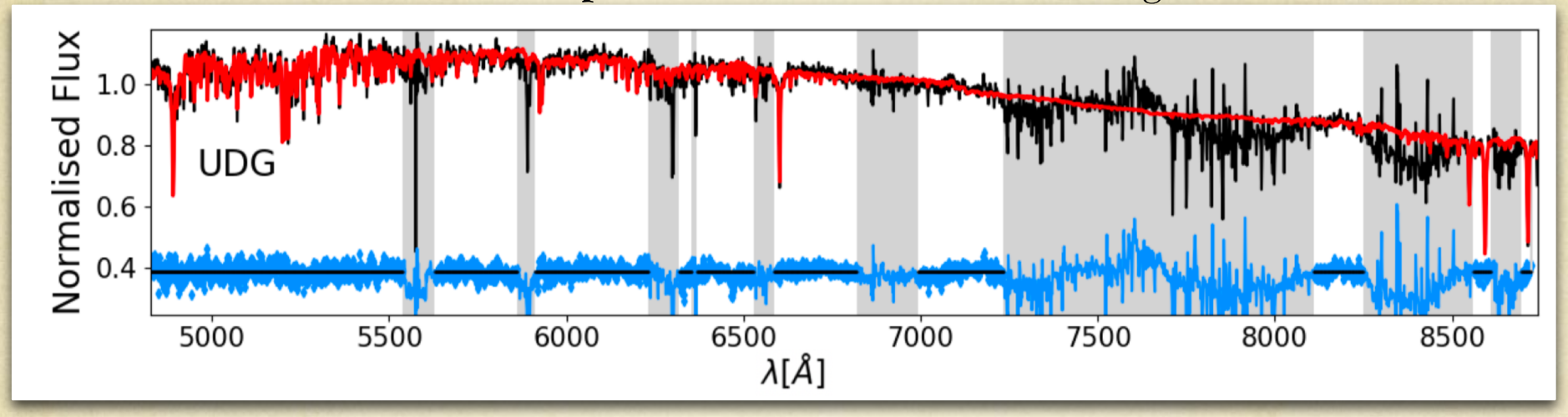
NGC 1052 – DF2 – Stellar body

VLT/MUSE spectrum: 5.1h on-source integration ArXiv:1812.07345



NGC 1052 – DF2 – Stellar body

VLT/MUSE spectrum: 5.1h on-source integration ArXiv:1812.07345

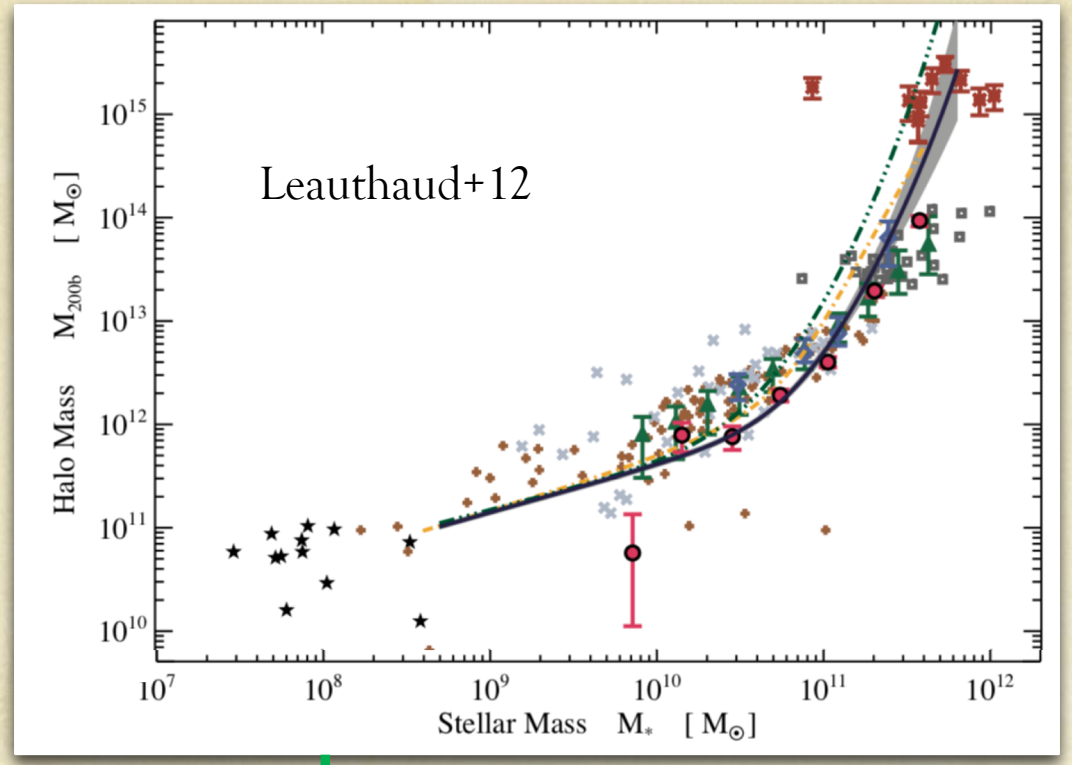


- Deep spectrum to constrain velocity dispersion of the stellar body and possible velocity trend
- Independent constraint using 15 tracers (instead of 10)
  - Velocities for 2 additional globular clusters, improved velocities for 5 others
  - Identification and velocity measurements of 3 Planetary Nebulae

$$\sigma_{\text{tracers}} = 10.6^{+3.9}_{-2.3}\ \text{km/s} \qquad \sigma_{\text{stars}} = 10.8^{+3.2}_{-4.0}\ \text{km/s}$$

NGC 1052 – DF2 – Stellar body

Emsellem,vdB+19
ArXiv:1812.07345



$M_{\mathrm{dyn}} \approx 2 - 4 \cdot 10^8\ \mathrm{M}\odot$

- Appears to indeed have a low total mass for its stellar mass
  (cf. Danieli+19 for complementary spectrum with Keck/KCWI)
- Large scatter in halo mass versus stellar mass in this regime
  - Other galaxy in the same group seems to have similar properties, but not yet measured σ_{stars} (van Dokkum+19)

Summary

- Formation and evolution of UDGs poorly understood
  - How do they fit in our current framework of galaxy formation?
  - Theoretical models and simulations make testable predictions
- A study combing KiDS with GAMA groups shows that UDGs are relatively more common in clusters than in groups vdBurg+17
- Weak lensing study rules out (at 2σ) that they are "failed massive galaxies" Sifón,vdBurg+18
  - Evidence for extreme individuals and thus large intrinsic scatter
- Both studies suggest combination of different mechanisms to form UDGs