WST workshop 10-12 March 2025

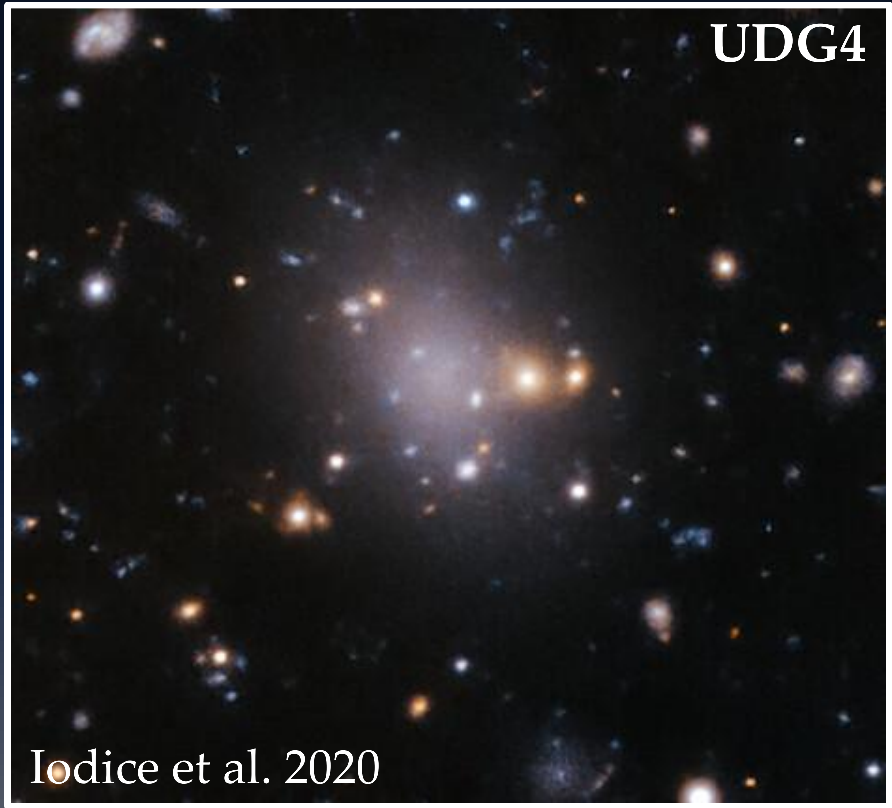
Probing the limits of spectroscopy in the low-surface brightness Universe with LEWIS

Chiara Buttitta

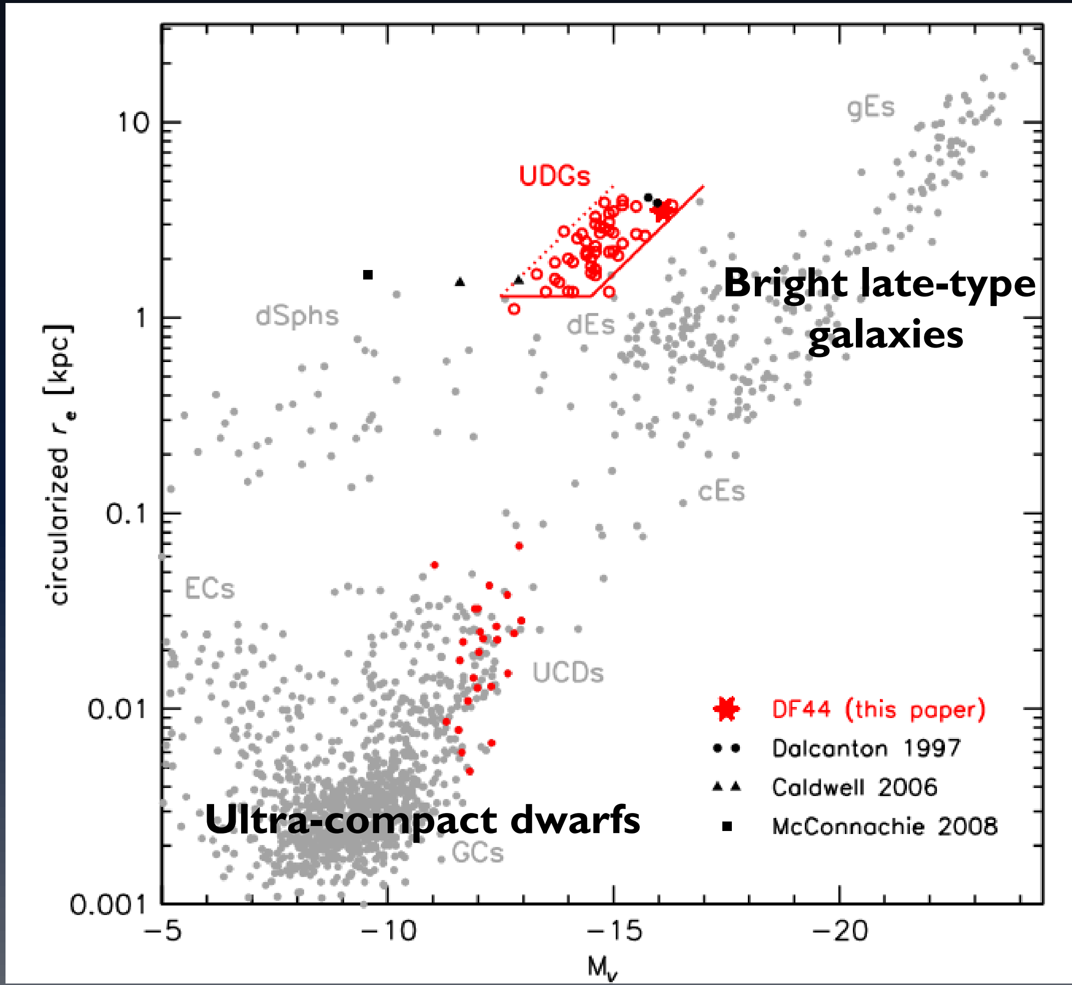
Postdoc at INAF - Capodimonte (Naples – IT)

Science case: ultra-diffuse galaxies

An **ultra-diffuse galaxy** (UDG) is empirically defined as a galaxy with a size comparable to that of the Milky-Way but a stellar mass 100-1000 times smaller



Considered as the extreme low surface brightness tail of the size-luminosity relation



van Dokkum et al. 2015

$\mu_0 \geq 24$ [mag/arcsec^2] and $R_{eff} \geq 1.5$ [kpc]

Science case: observations vs theoretical predictions

What we know today on UDGs?

Colour & spatial distribution:	Red UDGs located in dense environments (i.e. clusters of galaxies) Blue UDGs are found in low-density regions (groups & fields)
Globular clusters populations:	Wide range of properties (richer than dwarfs or dwarf-like)
Age & metallicity:	Old, metal-rich and quenched UDGs in dense environment Young, star-forming UDGs in low-density regions
Kinematics:	UDGs are dispersion-dominated systems HI-rich UDGs show hint of rotation
Dark Matter content:	Wide range of properties (DM-dominated, dwarf-like or DM free)

Science case: observations vs theoretical predictions

What we know today on UDGs?

Colour & spatial distribution:	Red UDGs located in dense environments (i.e. clusters of galaxies) Blue UDGs are found in low-density regions (groups & fields)
Globular clusters populations:	Wide range of properties (richer than dwarfs or dwarf-like)
Age & metallicity:	Old, metal-rich and quenched UDGs in dense environment Young, star-forming UDGs in low-density regions
Kinematics:	UDGs are dispersion-dominated systems HI-rich UDGs show hint of rotation
Dark Matter content:	Wide range of properties (DM-dominated, dwarf-like or DM free)

Different types of UDGs
=
Different formation channels

Science case: observations vs theoretical predictions

What we know today on UDGs?

Colour & spatial distribution: Red UDGs located in dense environments (i.e. clusters of galaxies)
Blue UDGs are found in low-density regions (groups & fields)

Globular clusters populations: Wide range of properties (richer than dwarfs or dwarf-like)

Age & metallicity: Old, metal-rich and quenched UDGs in dense environment
Young, star-forming UDGs in low-density regions

Kinematics: UDGs are dispersion-dominated systems
HI-rich UDGs show hint of rotation

Dark Matter content: Wide range of properties (DM-dominated, dwarf-like or DM free)

Different types of UDGs
=
Different formation channels

Failed galaxy scenario

Giant and bright galaxy which lost its gas supply and evolve into an UDG

?

Puffed-up scenario

Dwarf galaxy whose stellar distribution was stretched at larger radii

?

Science case: observations vs theoretical predictions

What we know today on UDGs?

Photometry: ~ 3000 UDGs

Colour & spatial distribution: Red UDGs located in dense environments (i.e. clusters of galaxies)
Blue UDGs are found in low-density regions (groups & fields)

Globular clusters populations: Wide range of properties (richer than dwarfs or dwarf-like)

Spectroscopy: ~ 50 UDGs, only 2 UDGs with IF

Age & metallicity: Old, metal-rich and quenched UDGs in dense environment
Young, star-forming UDGs in low-density regions

Kinematics: UDGs are dispersion-dominated systems
HI-rich UDGs show hint of rotation

Dark Matter content: Wide range of properties (DM-dominated, dwarf-like or DM free)

Failed galaxy scenario

Giant and bright galaxy which lost its gas supply and evolve into an UDG

?

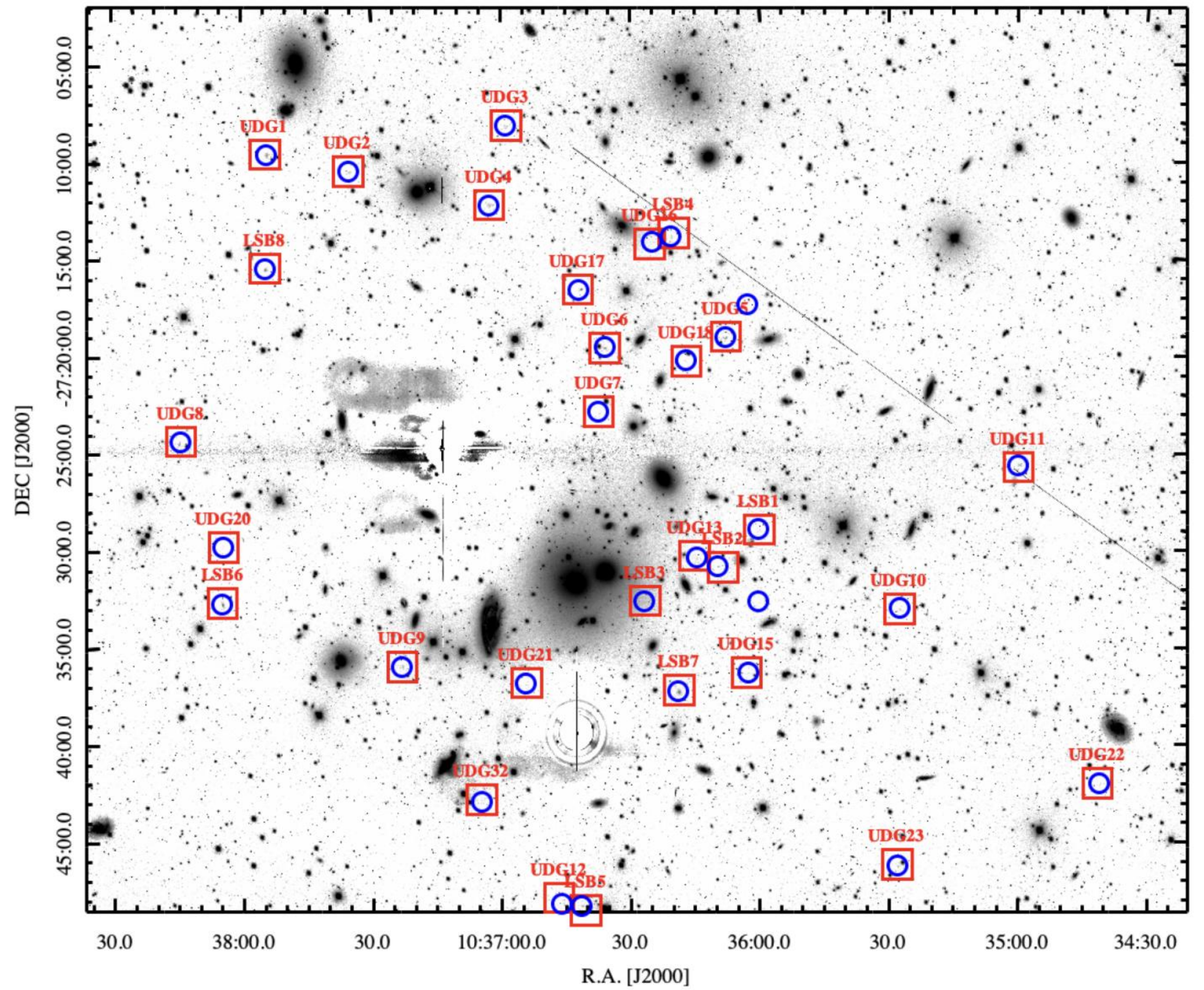
Puffed-up scenario

Dwarf galaxy whose stellar distribution was stretched at larger radii

?

The contribution of the LEWIS project in this field

Looking into the faint**E**st **WI**th mu**S**e (LEWIS)
On the nature of the ultra-diffuse galaxies in the Hydra I cluster



ESO Large Programme (P.I. E. Iodice)
MUSE@VLT 133.5 hours
(P108 - P110), 2021-2024

First homogenous spectrocopic survey of a complete sample of UDGs in Hydra I cluster

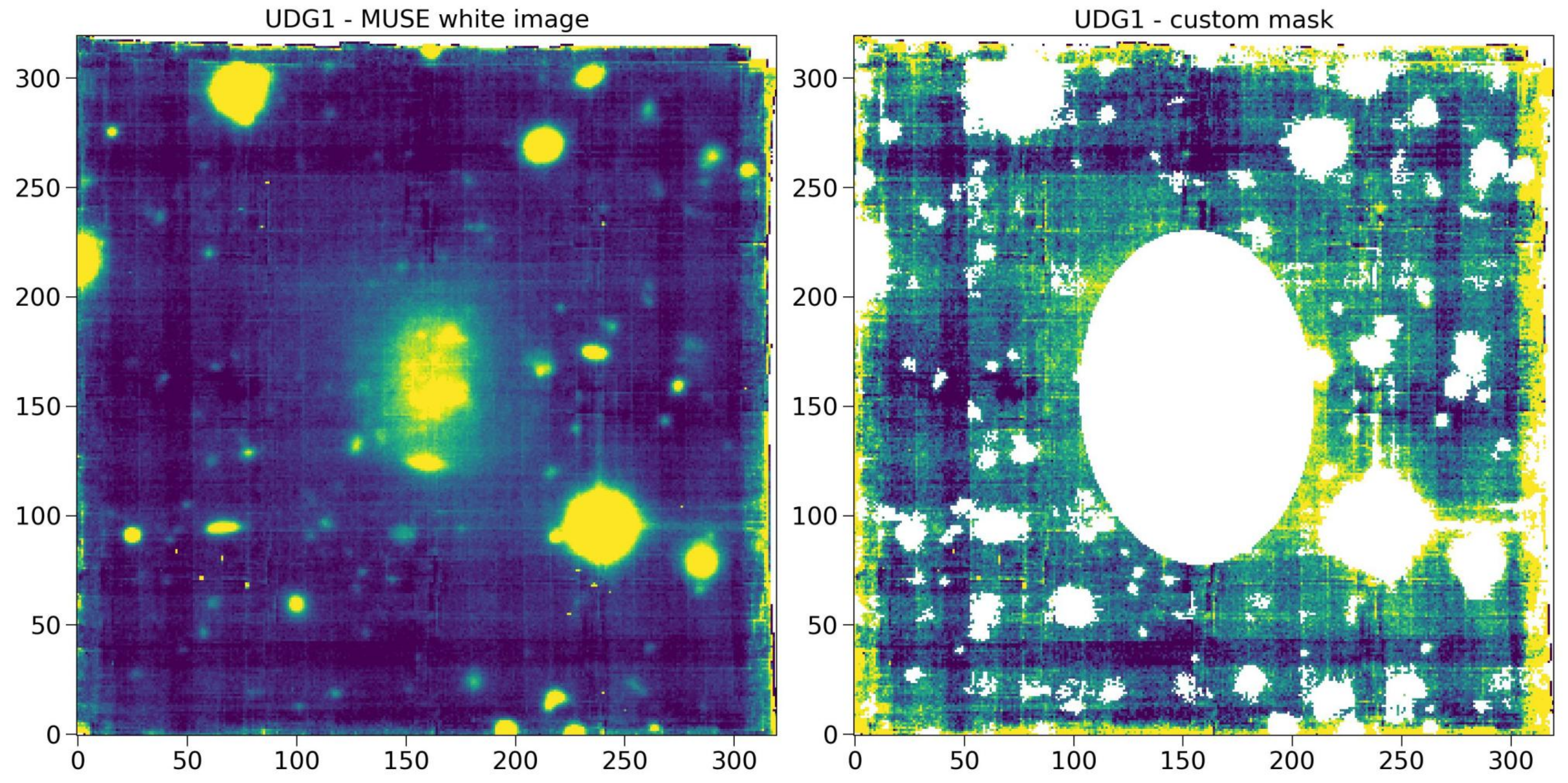
Project plan
Validate the cluster membership

- Stellar kinematics
- Stellar populations
- GCs properties

Challenges: what we learned with LEWIS

1: Luminosity of the target ~ sky level: Improve the sky background evaluation

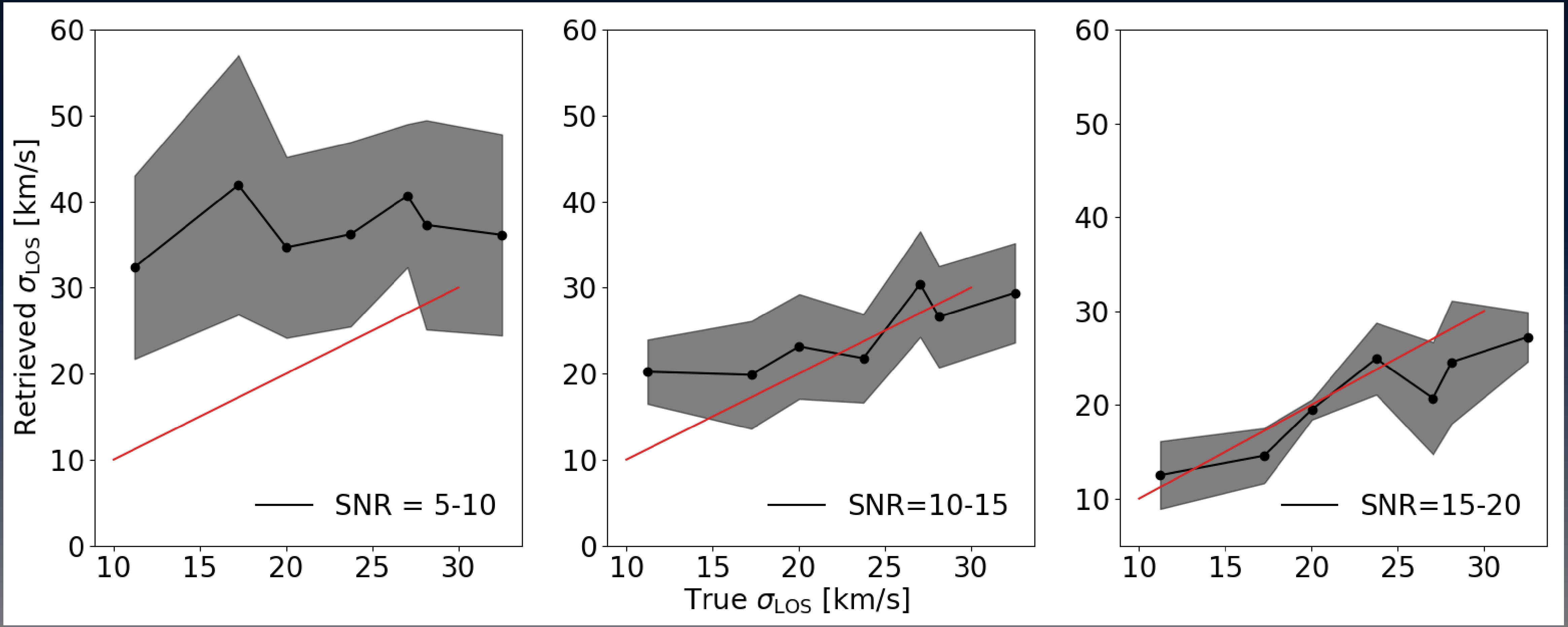
For each target, custom mask injected in the ESO Reflex workflow + ZAP algorithm



Challenges: what we learned with LEWIS

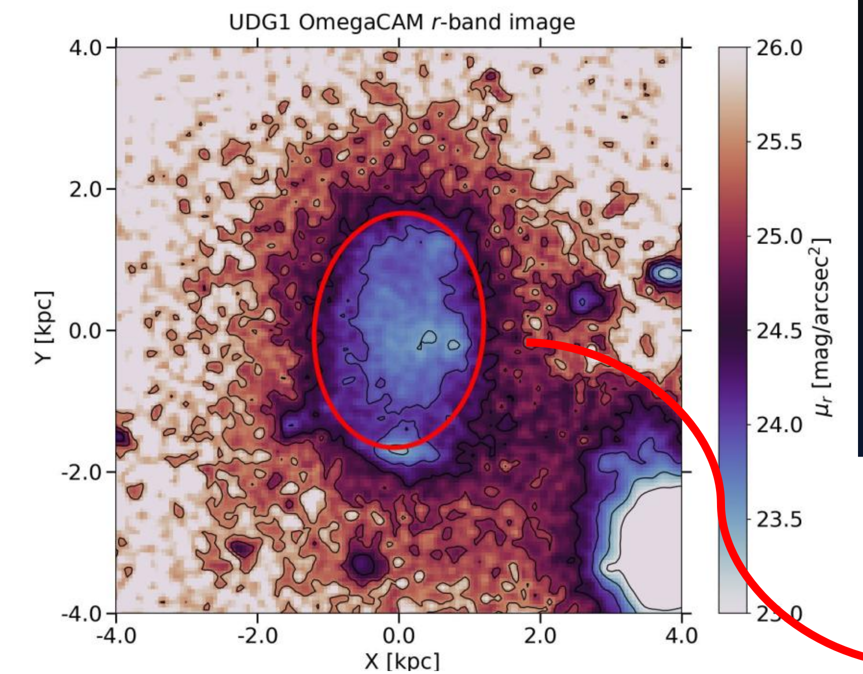
1: Luminosity of the target ~ sky level: Improve the sky background evaluation
2: High quality spectra (S/N > 15) to get an unbiased measure of $\boldsymbol{\sigma}_{\mathrm{eff}}$

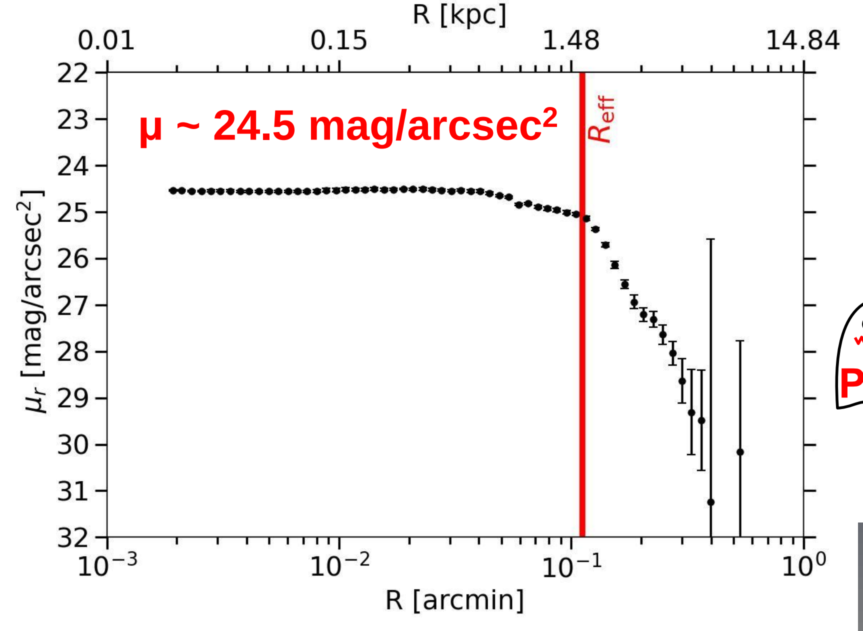
Monte Carlo simulations on a mock UDG-like spectrum at different S/N and different **σ** kernel



Groundbreaking results from LEWIS

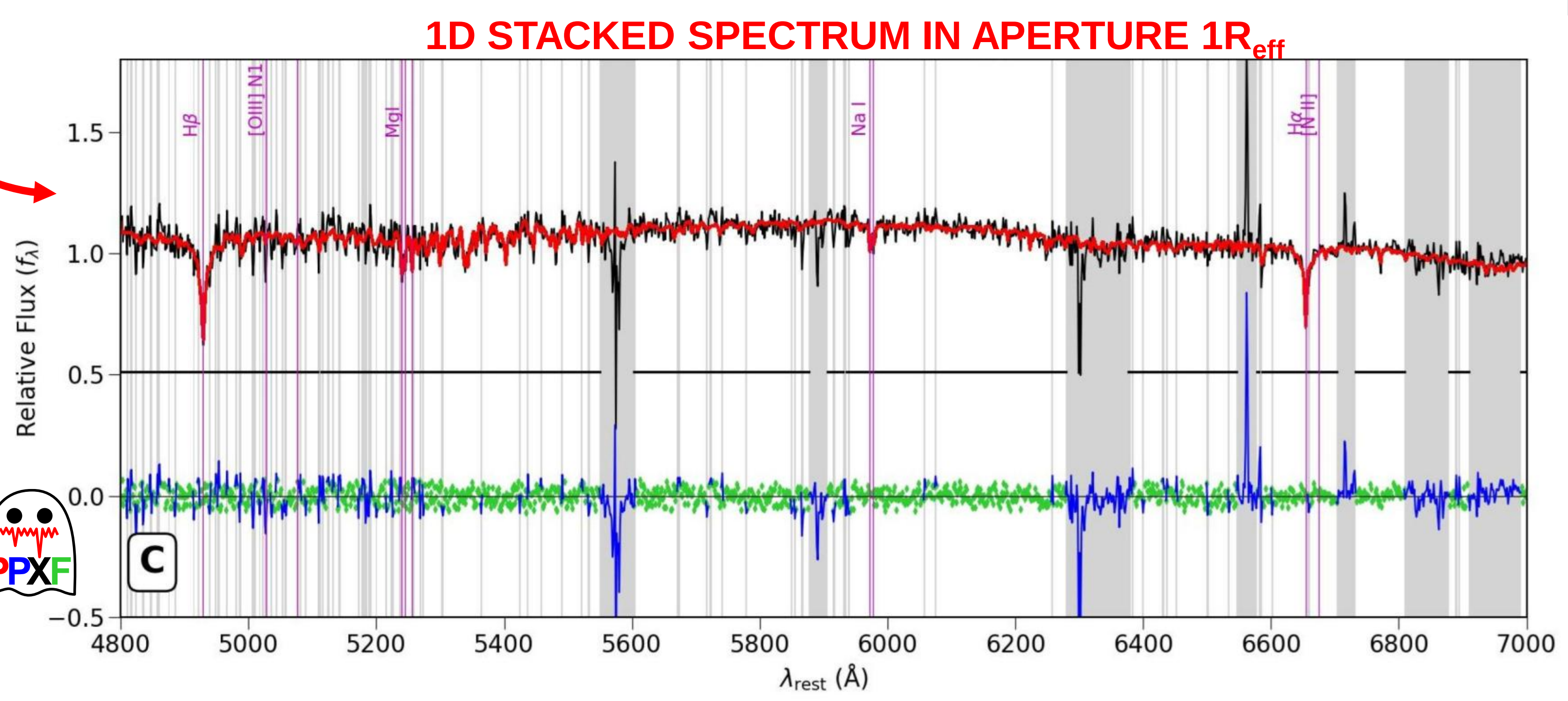
Stellar kinematics





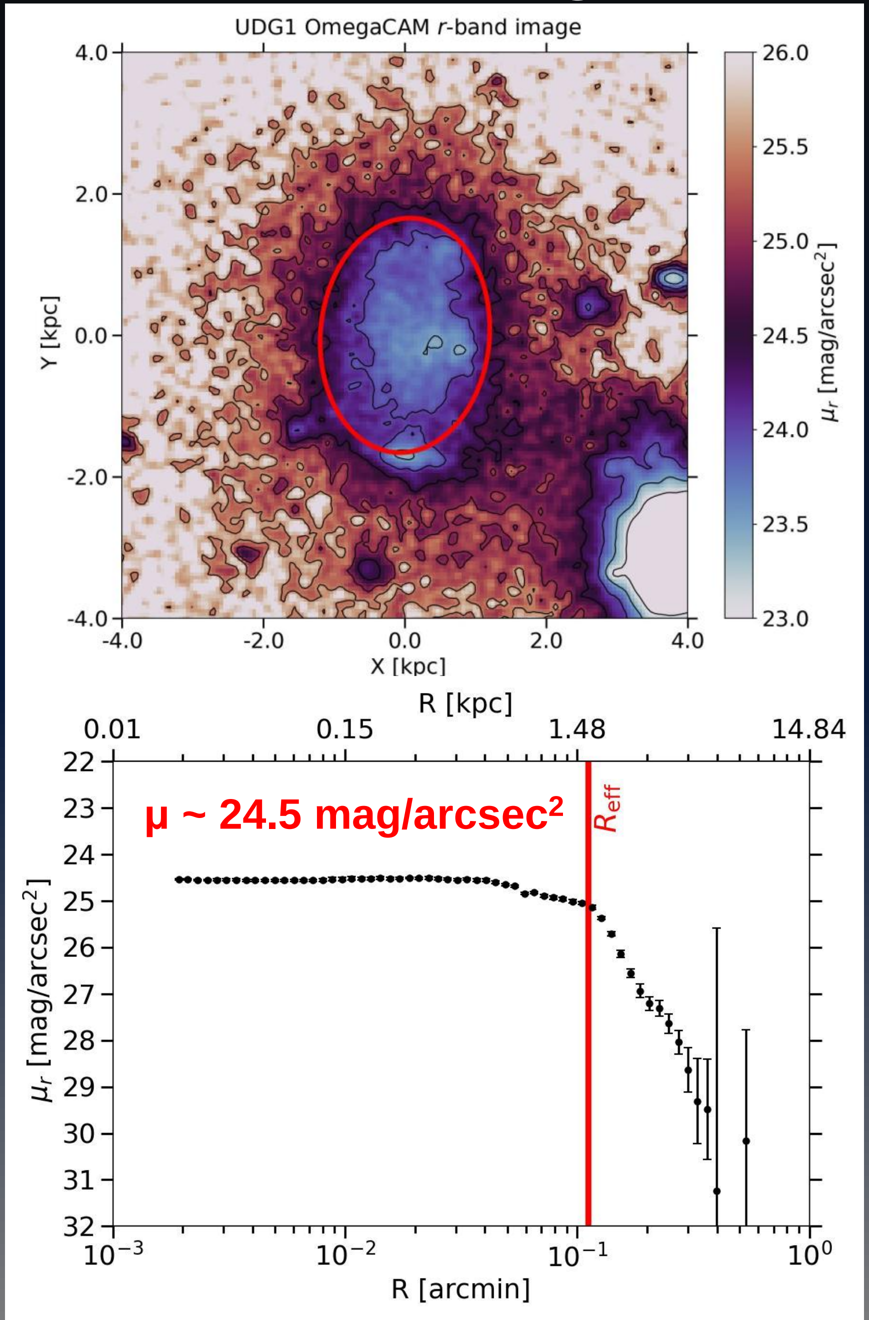
Results from LEWIS data:

UDGs have low values of $\boldsymbol{\sigma}_{eff}$ ~ 20-50 km/s and high DM content



Groundbreaking results from LEWIS

Stellar kinematics

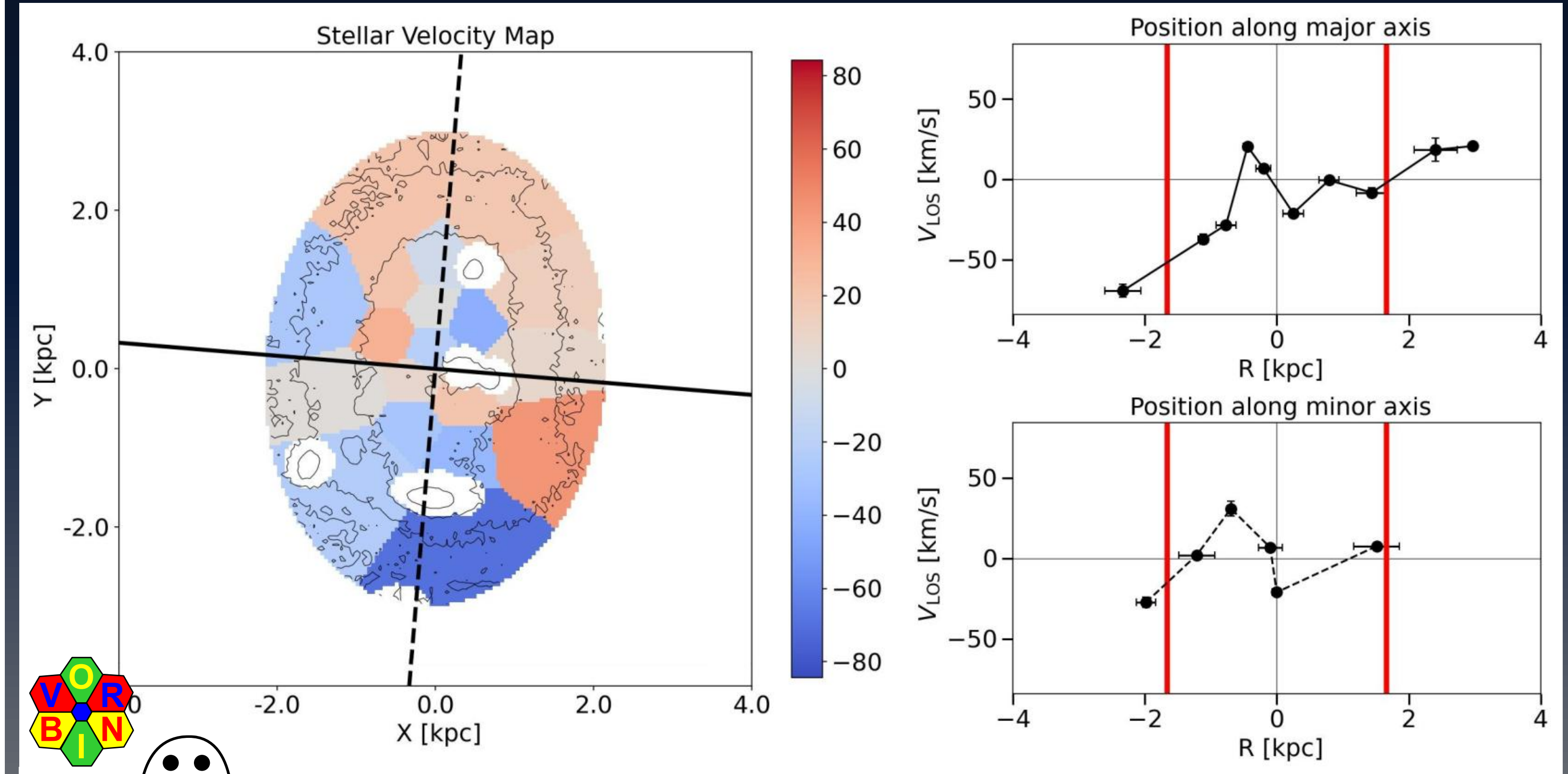


Results from LEWIS data:

UDGs have low values of $\boldsymbol{\sigma}_{\mathrm{eff}}$ ~ 20-50 km/s and high DM content

Two kinematic classes: UDGs with and without rotation

Details on methods: Buttitta et al., 2025, A&A 694, 276



SB at the maximum kinematic extension μ ~ 25.5 mag/arcsec²

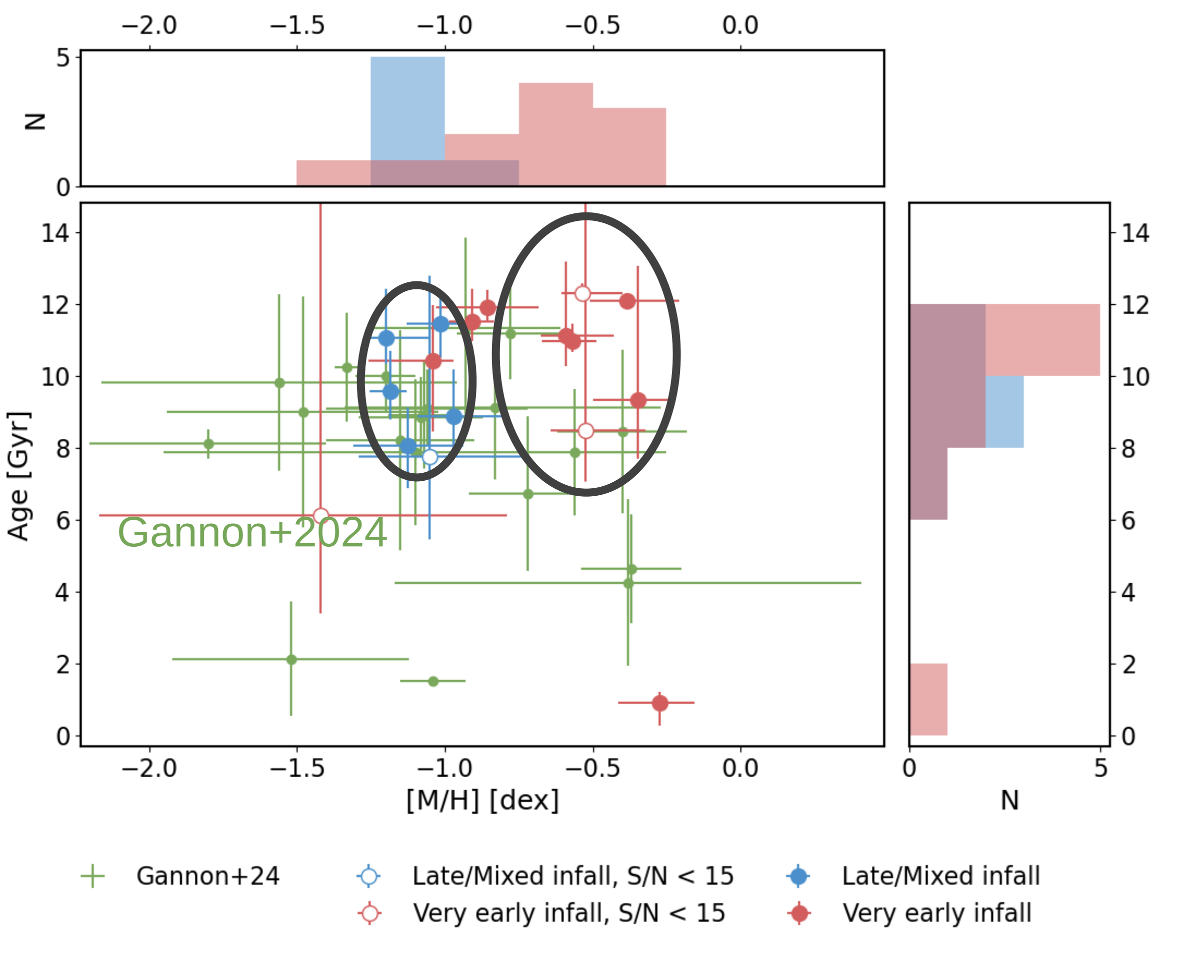
Groundbreaking results from LEWIS

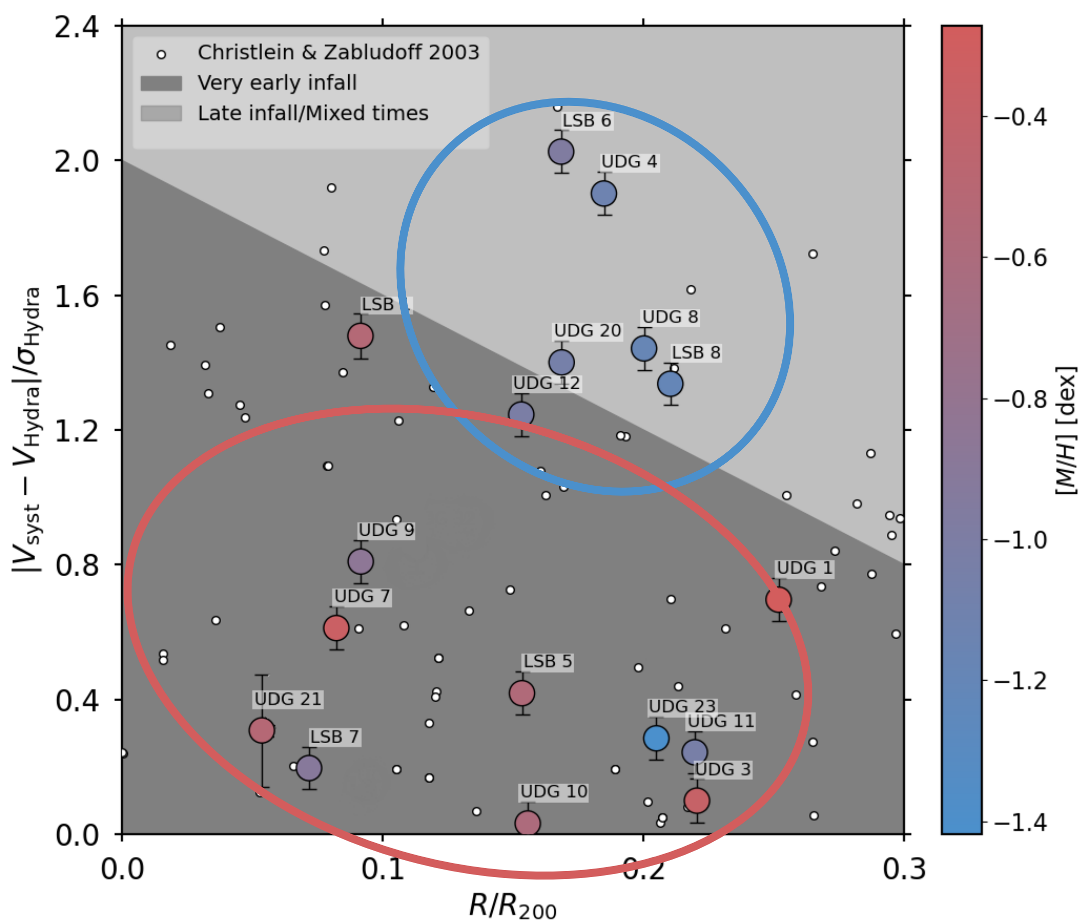
Stellar populations

Results from LEWIS data:
Bimodality in metallicity & SFHs
Metal-poor UDGs with long SFH are late infallers
Metal-rich UDGs with short SFH are early infallers
On going project: Doll et al., in preparation

Goran Doll

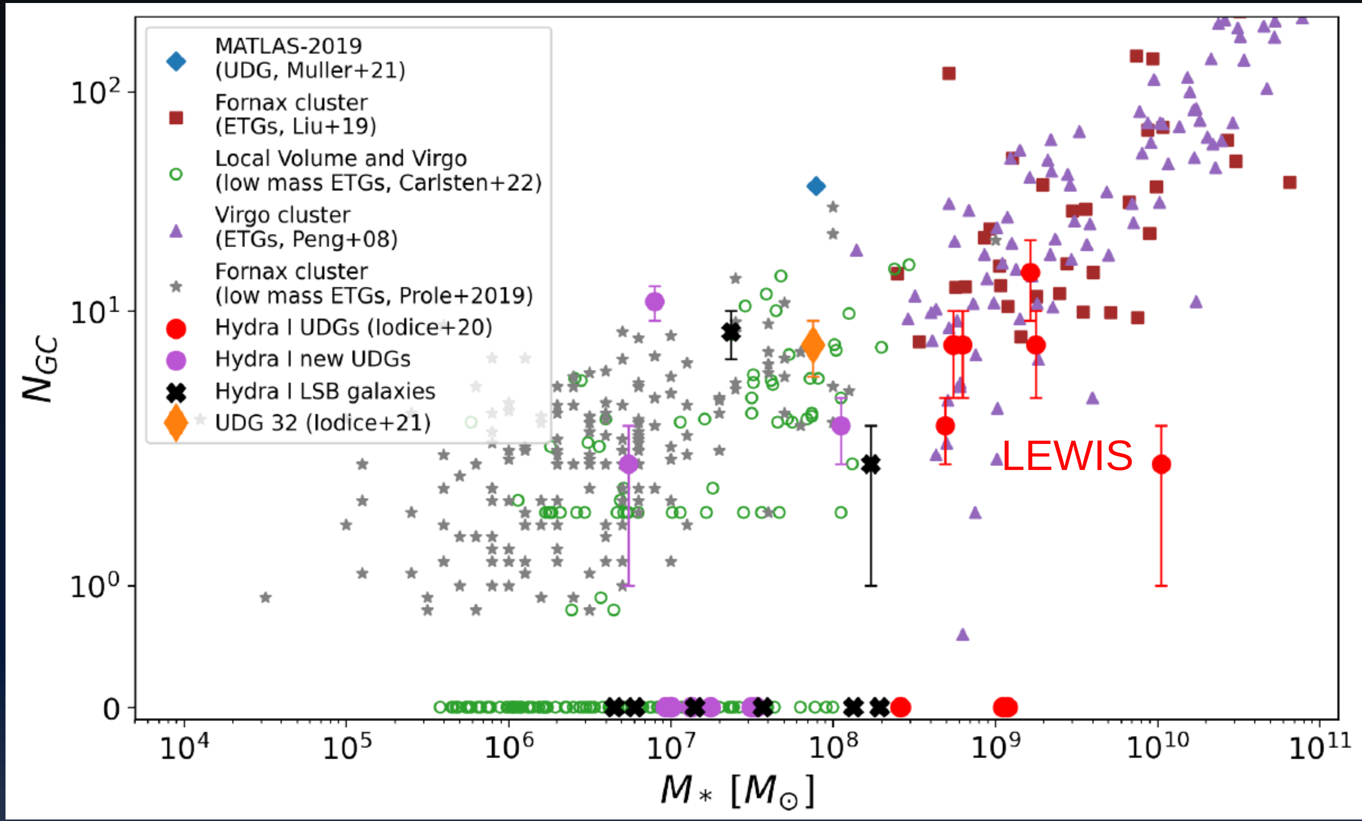
Average Age is 9.5±2.7 Gyr
Metal-rich group: -0.6±0.3 dex
Metal-poor group : -1.2±0.1 dex





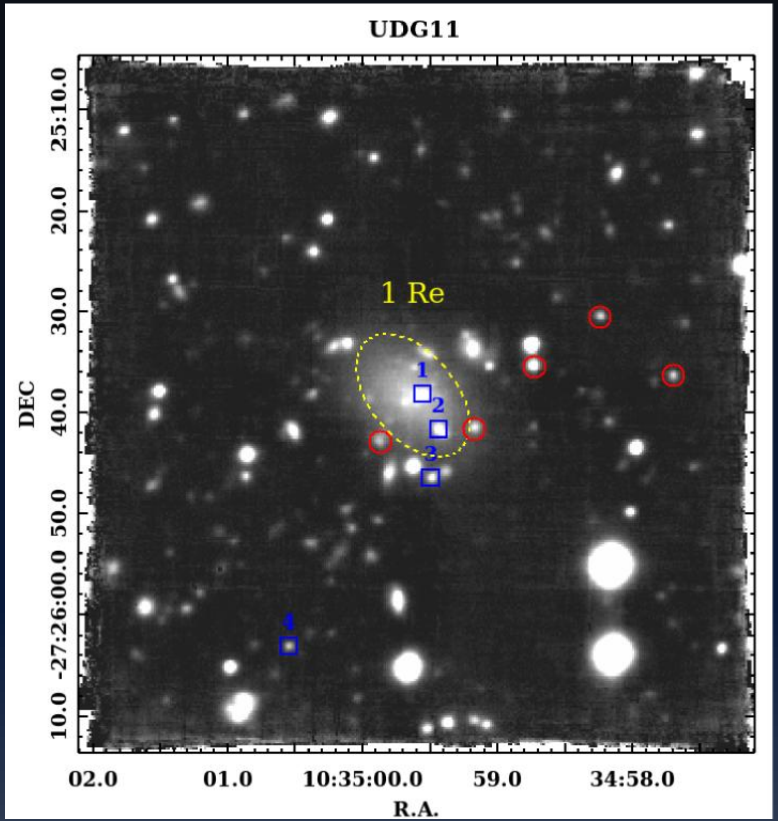
Groundbreaking results from LEWIS

GCs properties



Iodice et al. 2020, La Marca et al. 2022b

Iodice et al. 2023



Marco Mirabile

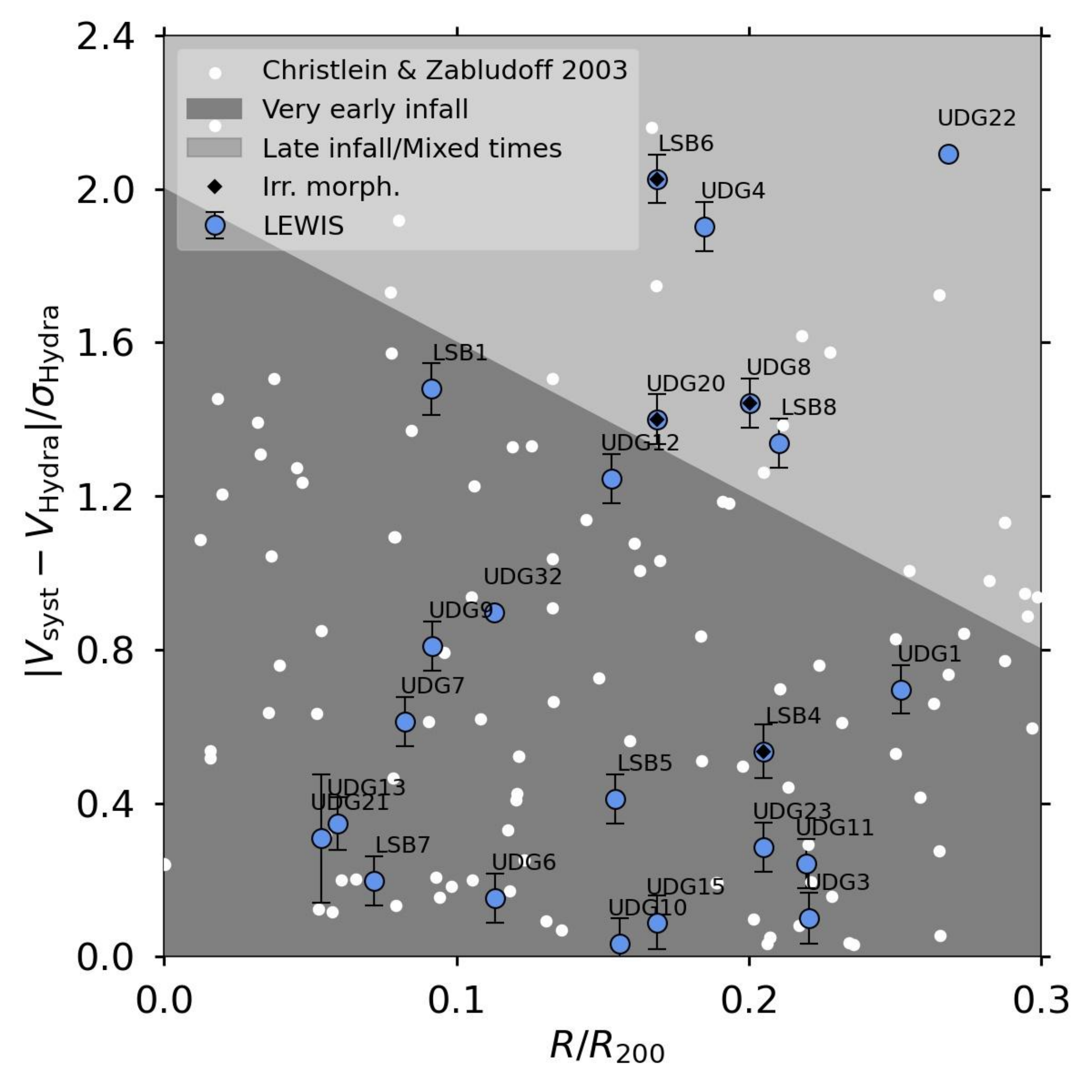
What we can do with LEWIS data:

- Confirm the membership of GCs
- Study & correlate the properties of GCs and host UDG
- Obtain a independent estimate of dark matter content

On going project (M.Mirabile et al. in preparation)

Fit (1)	λ range [Å] (2)	V_{sys} [km/s] (3)	$\langle\sigma\rangle_e$ [km/s] (4)	[M/H] [dex] (5)	Age [Gyr] (6)
1D	4800-9000	3507±3	20±8	−1.2±0.1	10±1
GC1	4800-9000	3503±12	–	−0.7±0.3	9±2

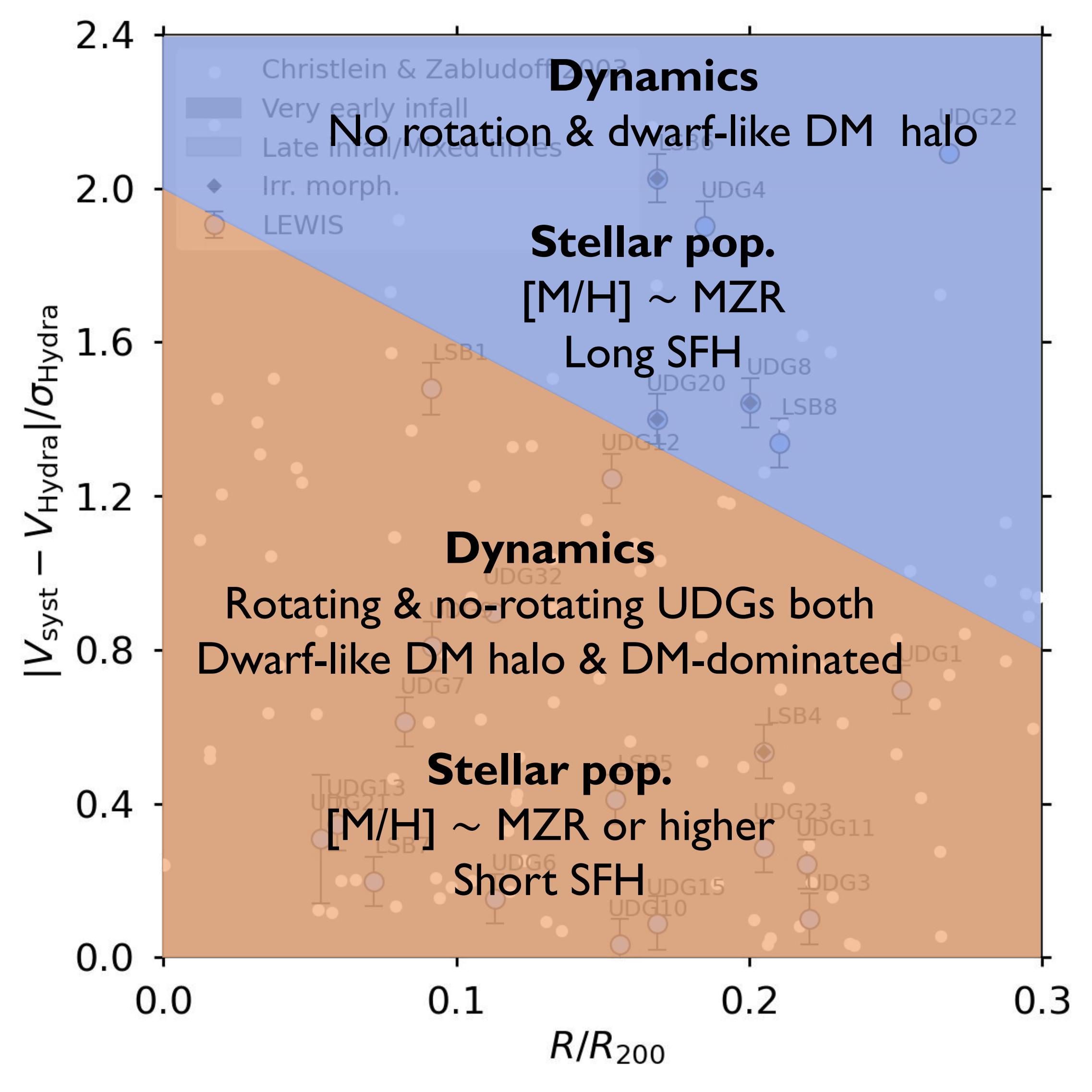
Summary of the main results & Future projects



The key parameters of UDGs:

Stellar kinematics & Stellar populations

Summary of the main results & Future projects



The key parameters of UDGs:

Stellar kinematics & Stellar populations

In the late infall region, a single population of UDGs

↓

Compatible with the Puffed-up scenario

In the early infall region, multiple populations of UDGs

↓

Different formation channels, the environment played a key role in the evolution

A new perspective with the WST telescope

Integral field spectroscopy is essential to derive the structural properties of UDGs!

Low values of velocity dispersion ($\boldsymbol{\sigma}_{eff}$ ~ 20-50 km/s) → high-spectral resolution!
Spatial information (velocity/metallicity gradients, GCs) → only achievable with IF!

the Wide-field Spectroscopic Telescope

Multi-object spectrograph (MOS)

- Spectral resolution: R~4000-40000 (σ ~ 30-3 km/s) in λ~ 3700-9700 Å

Integral-field spectrograph (IFS)

- Spectral resolution: R~3500 (σ ~ 35 km/s) in λ~ 3700-9700 Å

Additional material

Additional material: observations vs theoretical predictions

Failed galaxy scenario

Giant and bright galaxy which lost its gas supply and evolve into an UDG

?

Puffed-up scenario

Dwarf galaxy whose stellar distribution was stretched at larger radii

?

Iodice et al. 2023

Physical processes & predicted observational properties

Internal processes	
star-formation feedback (Di Cintio et al. 2017)	gas rich, dwarf-like DM halo
high-spin DM halo (Amorisco & Loeb 2016; Rong et al. 2017; Tremmel et al. 2019)	gas rich, dwarf-like DM halo
External mechanisms	
gravitational interactions & merging - ***collisional debris of a merger, i.e. TDG-like*** (Lelli et al. 2015; Duc et al. 2014; Ploeckinger et al. 2018) - ***ram-pressure stripped clumps*** (Poggianti et al. 2019)	blue, dust, moderate metallicity, SF, UV emission & gas rich, DM-free
gravitational interactions & merging - ***weak tidal interaction*** (Conselice 2018; Carleton et al. 2021; Bennet et al. 2018; Müller et al. 2019) - ***high-velocity galaxy collisions*** (Silk 2019; Shin et al. 2020; van Dokkum et al. 2022)	red, metal poor, gas free, DM free
interaction with the environment (Yozin & Bekki 2015; Tremmel et al. 2020)	gas poor dwarf-like DM halo
backsplash galaxies (Benavides et al. 2021)	quenched, isolated, gas poor, dwarf-like DM halo, near to a high density environment

Deep photometric data & Long-slit or IF spectroscopic data can help shed the light on the formation scenario