THE IMPORTANCE OF GALAXY SIZES

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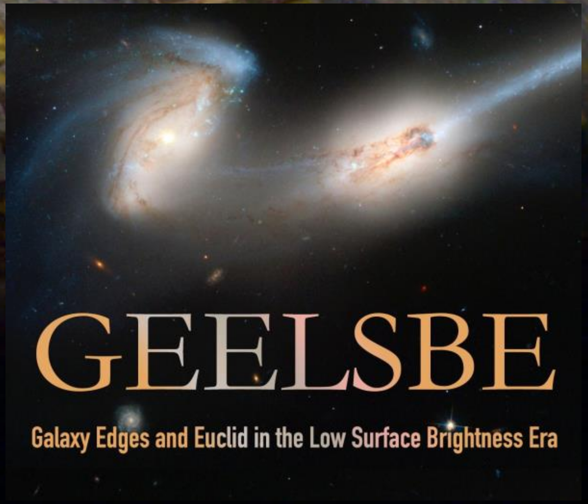



Radio
Microwave
Infrared
UV
X-Ray
Gamma Ray
Radio
60,000 nm
600 K
Infrared
1200-800 nm (10-3.6 um)
4,500 K
Optical
450-750 nm
6,000 K
Ultraviolet
400-200 nm
10,000 K
X-ray
100-10 nm
10,000,000 K
Multiwavelength Whirlpool Galaxy
COLD GAS: Radio waves reveal regions of gas cool enough for CO_2 molecules to exist.
COOL STARS: Infrared shows smaller cool red stars that make up most of the galaxy.
SOLAR STARS: Optical light comes from stars around the size of the Sun.
HOT STARS: Ultraviolet shows the larger hot blue stars that are less frequent in galaxies.
HOT GAS: X-rays are emitted from the hottest regions of gas where atoms are ionized.
COOL LOW ENERGY RADIATION
VISIBLE LIGHT
HOT HIGH ENERGY RADIATION

Stephan's Quintet and NGC7331 Deer Lick Group

SDSS

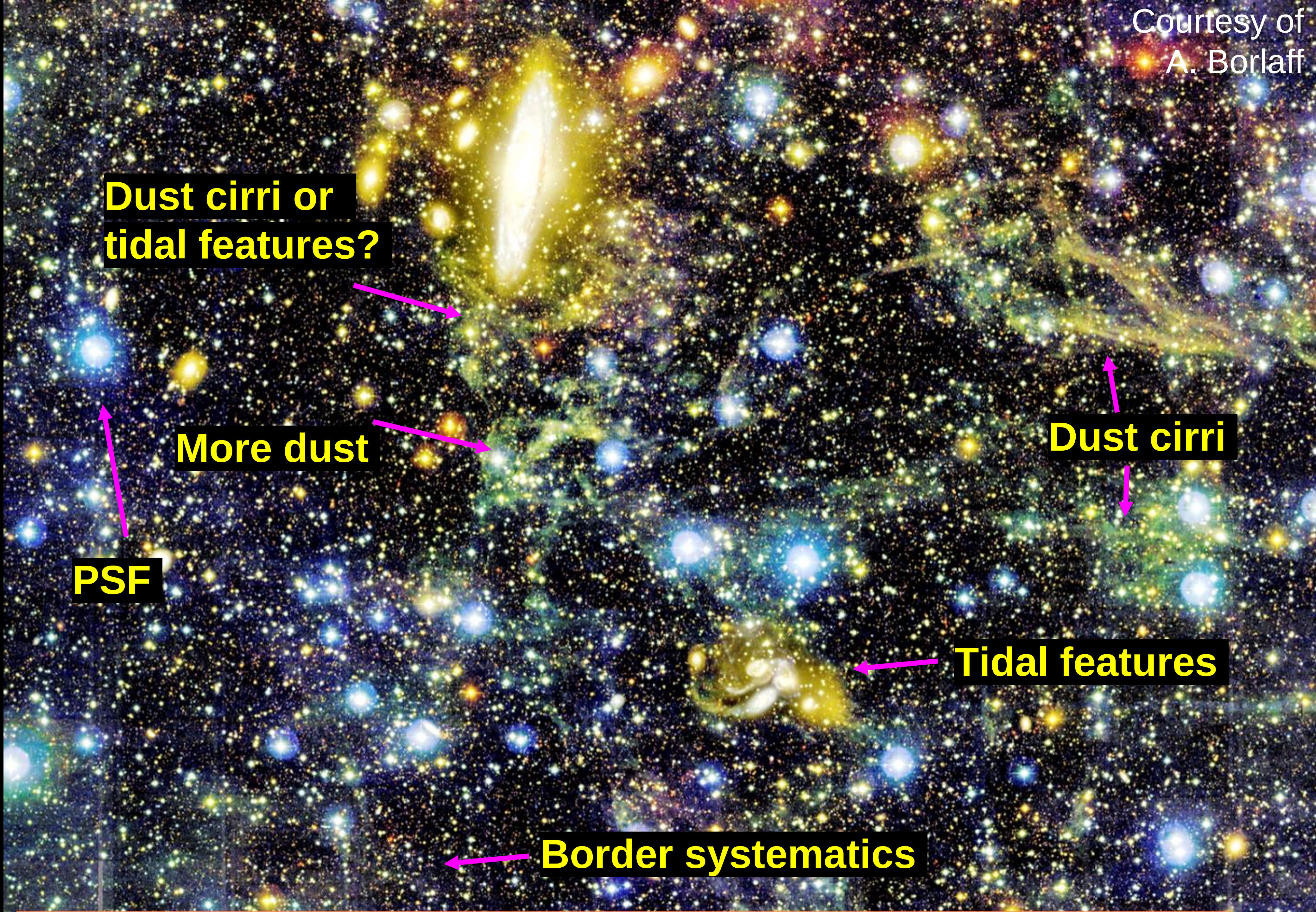
Surface brightness magnitude limit (g-band) 26.5 mag arcsec^{-2}

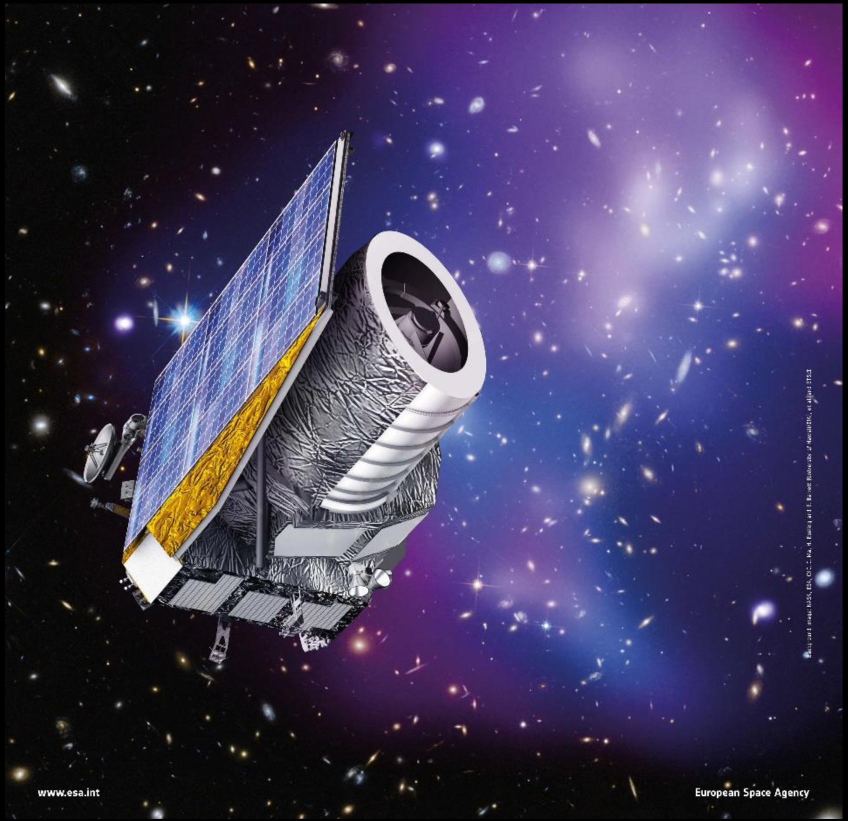
Courtesy of A. Borlaff

Stephan's Quintet and NGC7331 Deer Lick Group (CFHT)

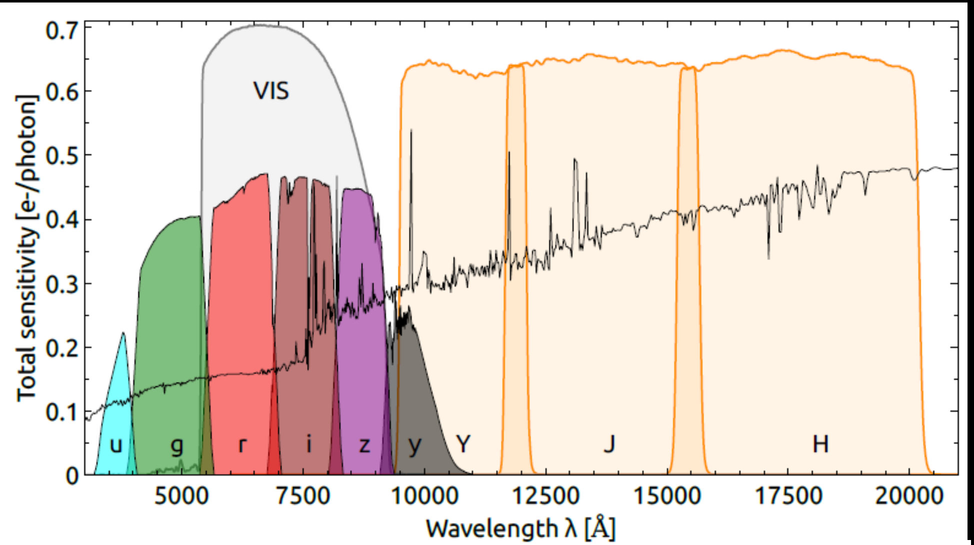
Duc, Cuillandre & Renaud (2018)

Surface brightness magnitude limit (u, g, r bands) 29.0, 28.6, and 27.6 mag arcsec^{-2}





EUCLID IN A NUTSHELL



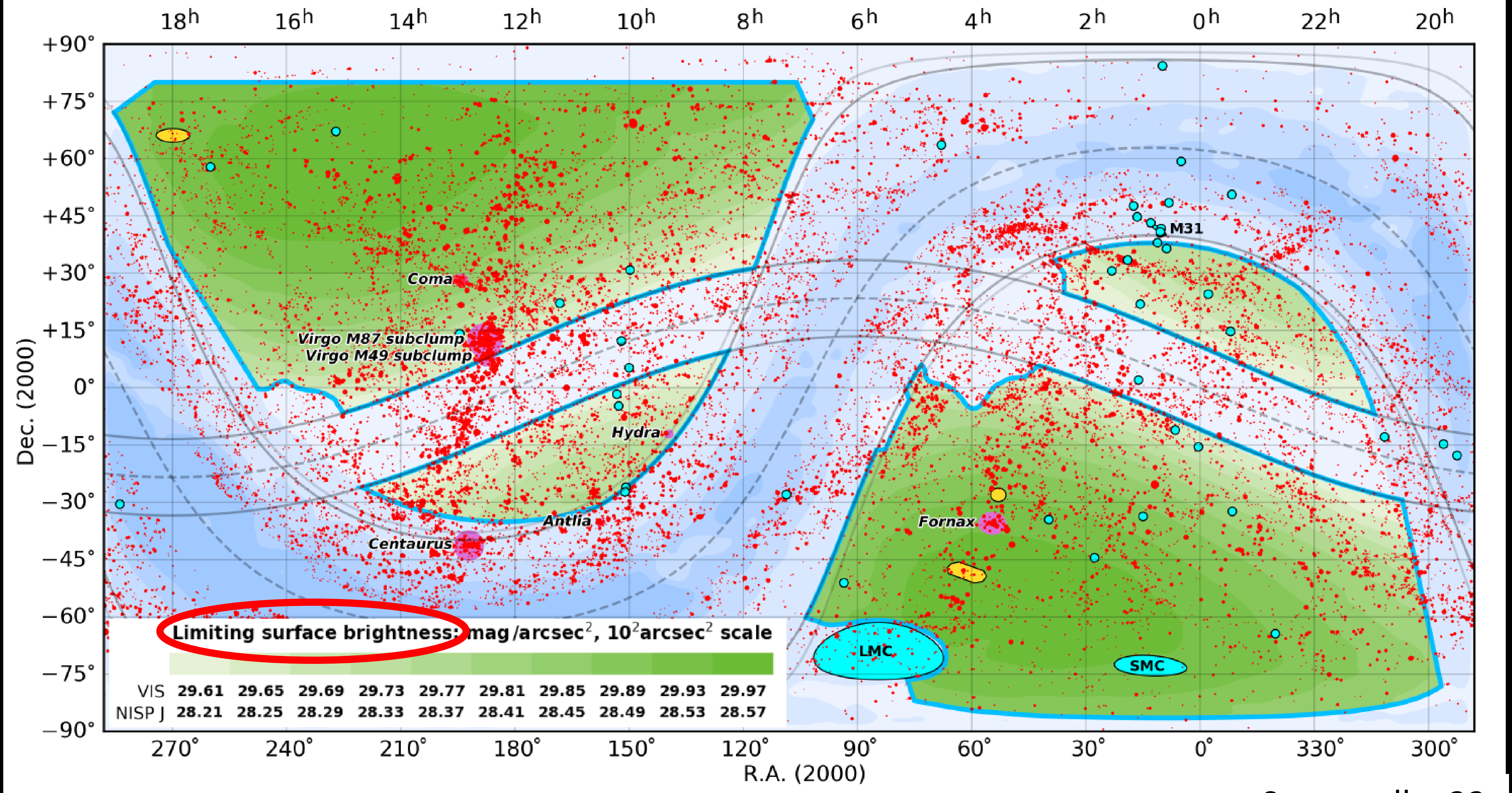
Scaramella+22

Instrument characteristics Visual imager (VIS)	
Field-of-view	0.787 deg × 0.709 deg
Capability	Visual imaging
Wavelength range	550 - 900 nm
Sensitivity	25 mag 10σ extended source
Detector Technology	36 arrays 4k × 4k CCD
Pixel Size **Spectral resolution**	0.1 arcsec

PSF~0.18 arcsec

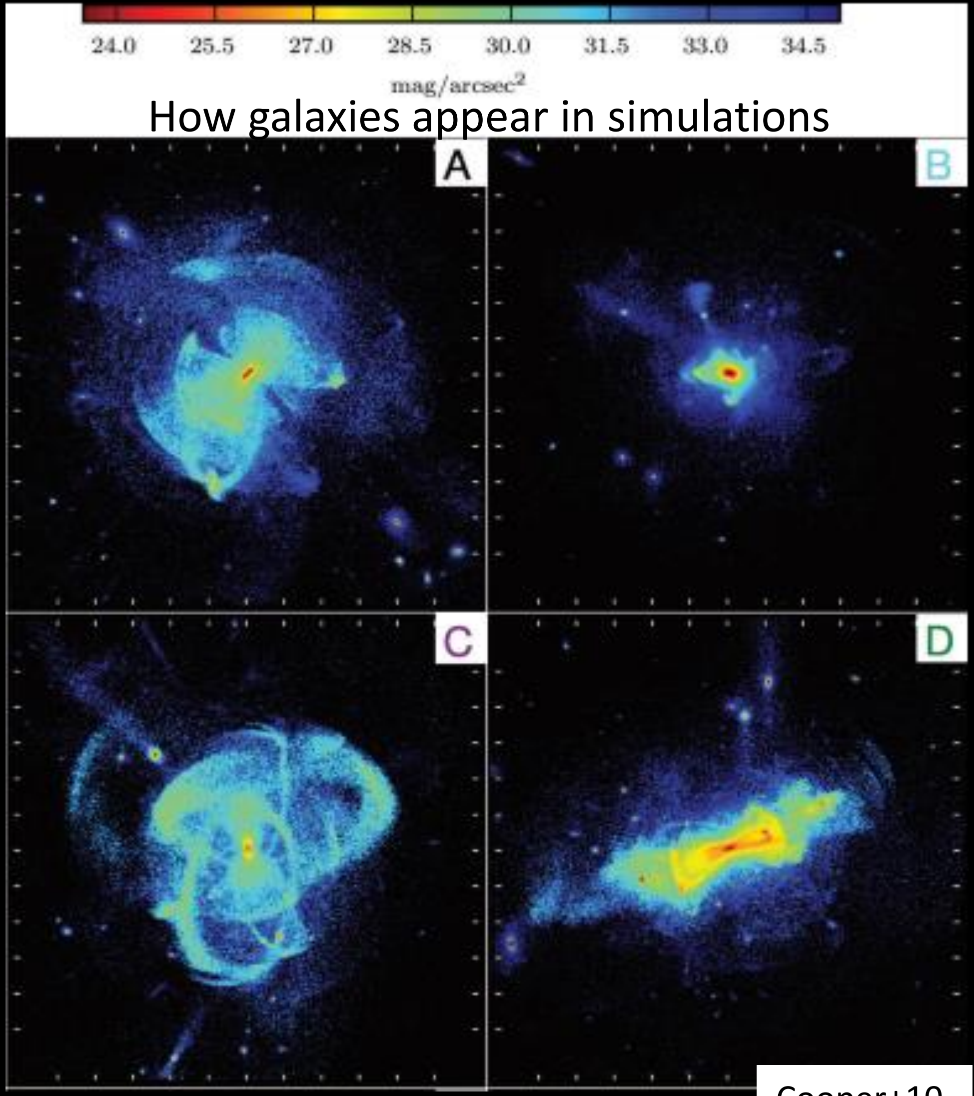
Instrument characteristics Near-infrared spectrometer and photometer (NISP)				
Field-of-view	0.763 deg × 0.722 deg			
Capability	Near-infrared imaging photometry			Near-infrared spectroscopy
Wavelength range	Y (920 - 1146 nm)	J (1146 - 1372 nm)	H (1372 - 2000 nm)	1100 - 2000 nm
Sensitivity	24 mag 5σ point source	24 mag 5σ point source	24 mag 5σ point source	3×10^{-16} erg cm^{-2} s^{-1} 3.5σ unresolved line flux
Detector Technology	16 arrays 2k × 2k near-infrared sensitive HgCdTe detectors			
Pixel Size **Spectral resolution**	0.3 arcsec			0.3 arcsec R=250

PSF~0.3 arcsec

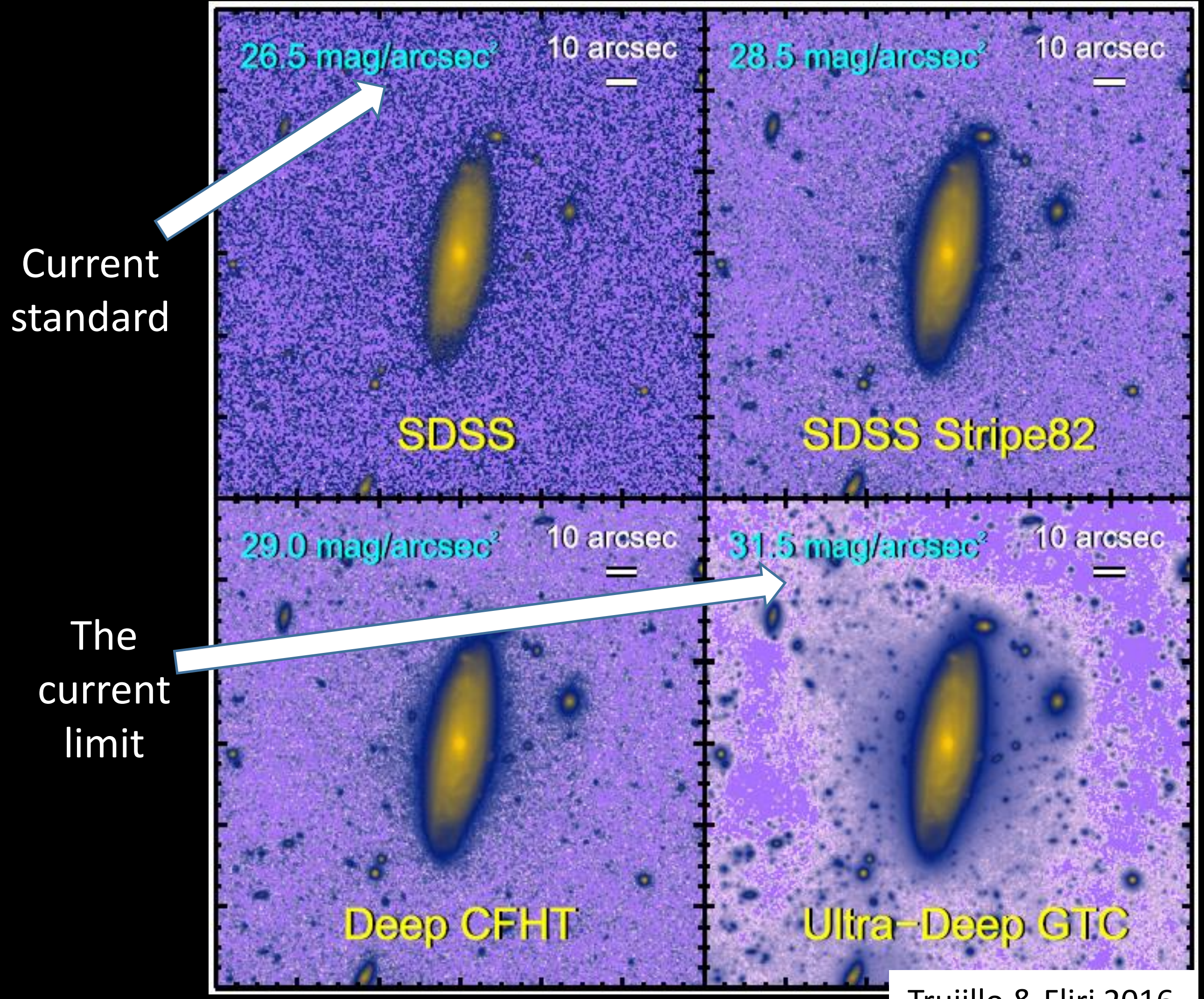


Scaramella+22

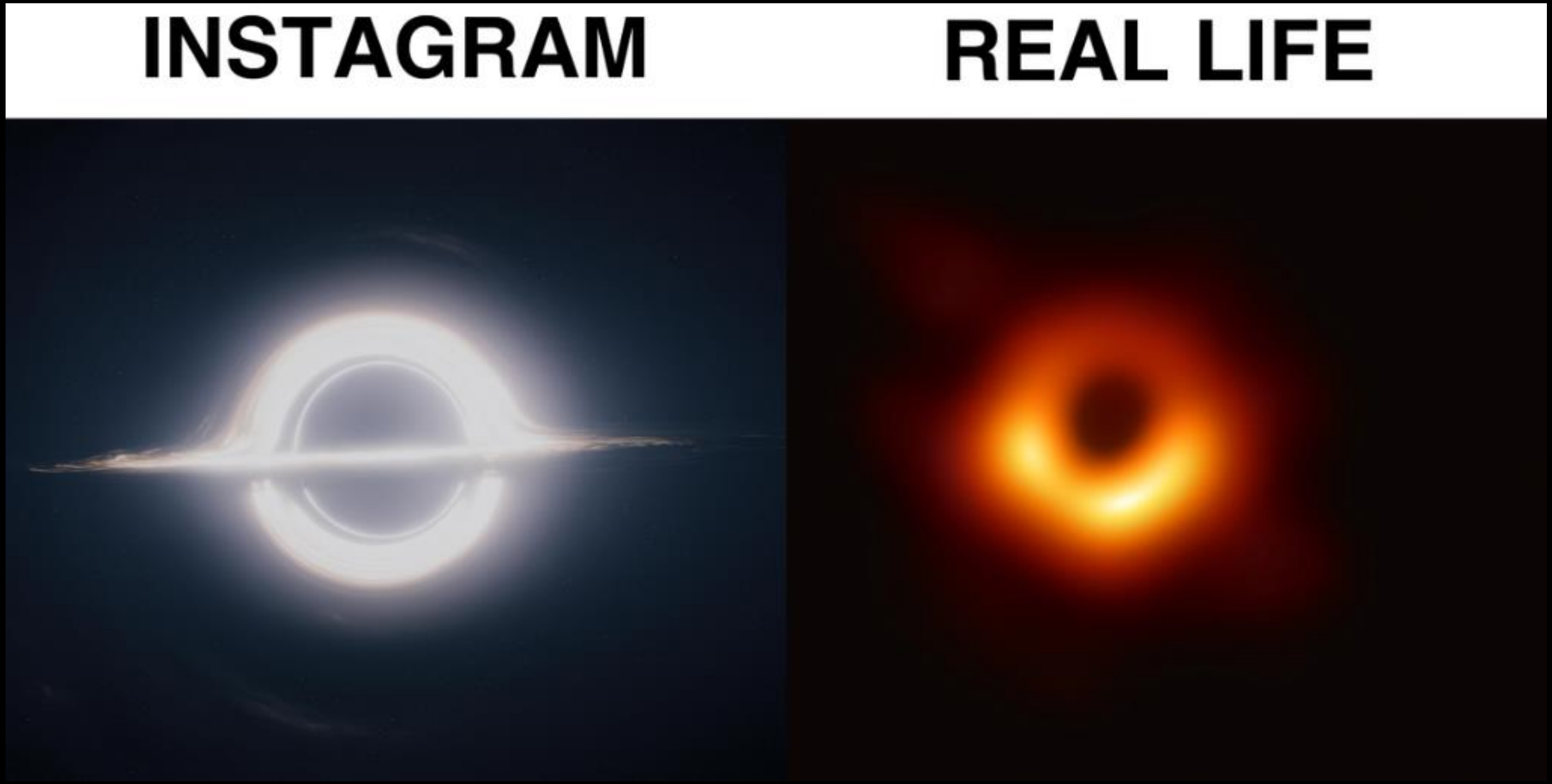
One of the most important direct observables of galaxies is their size… but how can you define the size of a fuzzy object?



Cooper+10



Trujillo & Fliri 2016



Place here you favourite galaxy

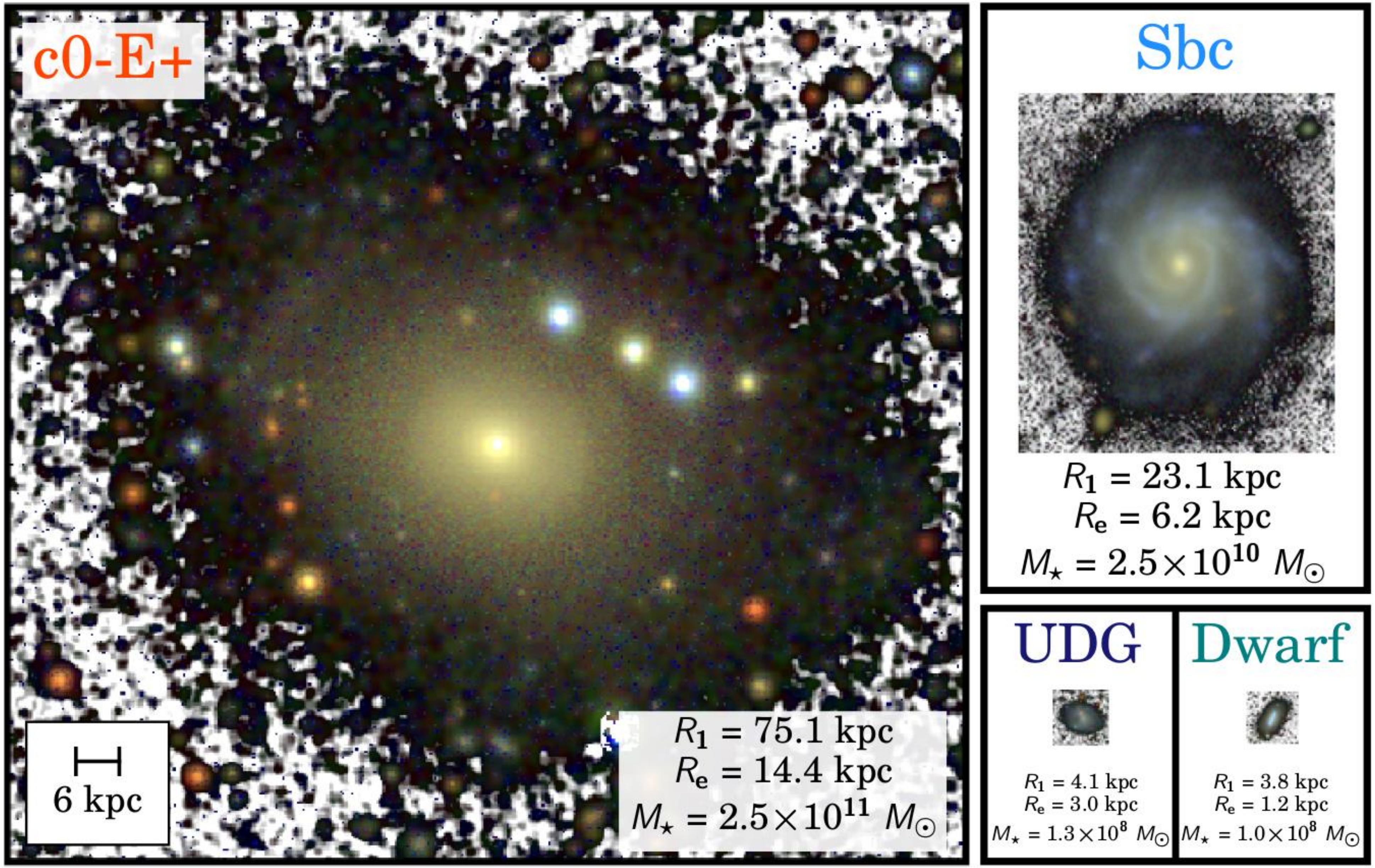
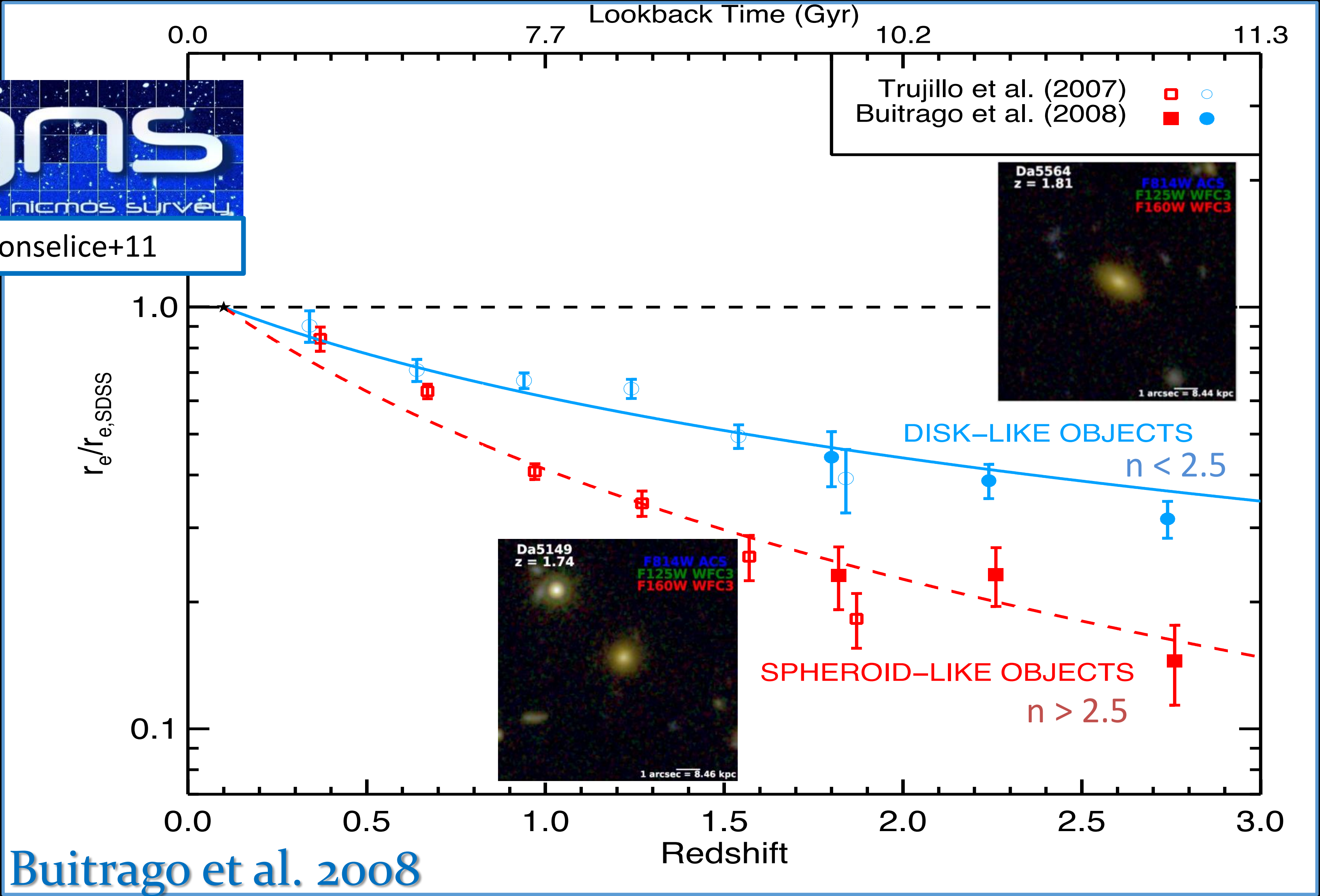


Figure 2: Representative galaxies shown to the same scale using images of the same depth ($\mu_{g,lim}$ $= 29.2\,\mathrm{mag/arcsec^2}$ $(3\sigma; 10\times10\,\mathrm{arcsec^2})$). *Credit:* *Chamba et al.* (*2020*).

THIS HISTORY STARTS WITH THE SIZE EVOLUTION OF THE MOST MASSIVE GALAXIES OF THE UNIVERSE…

goods nicmos survey

Conselice+11



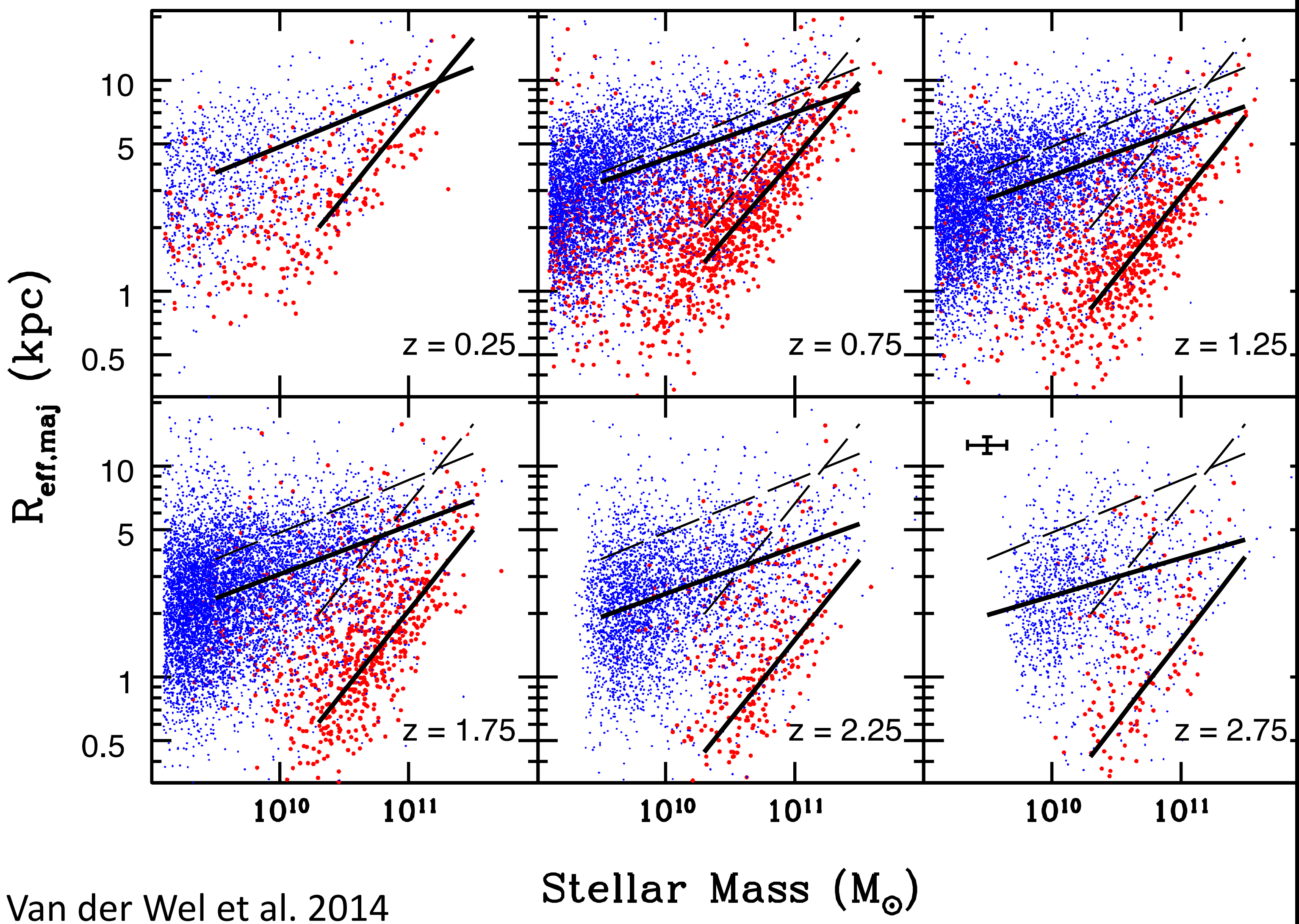
Buitrago et al. 2008

$M_* > 10^{11}\ M_\odot$
The so-called "red nuggets"

On average 3-5 times smaller than their local counterparts!

Cimatti+08, Cava+10, Van Dokkum+2010, Bruce+2012, Viero+12, Mancini+15, …

THIS IS HOW THE MASS-SIZE RELATION LOOKS FOR HIGH REDSHIFT GALAXIES



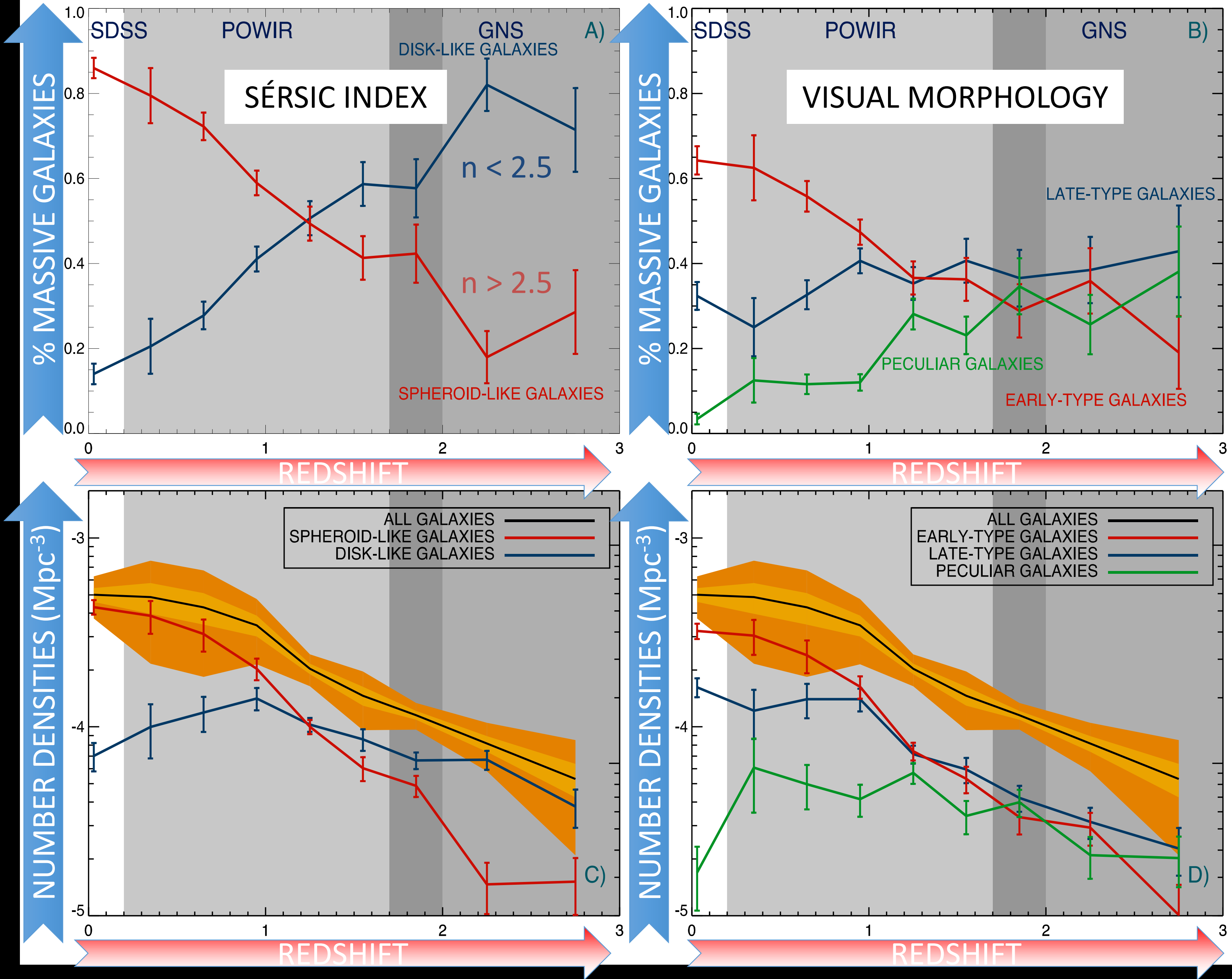
Van der Wel et al. 2014

- More massive galaxies have larger sizes at a given redshift

- The evolution is different for late- and early-types

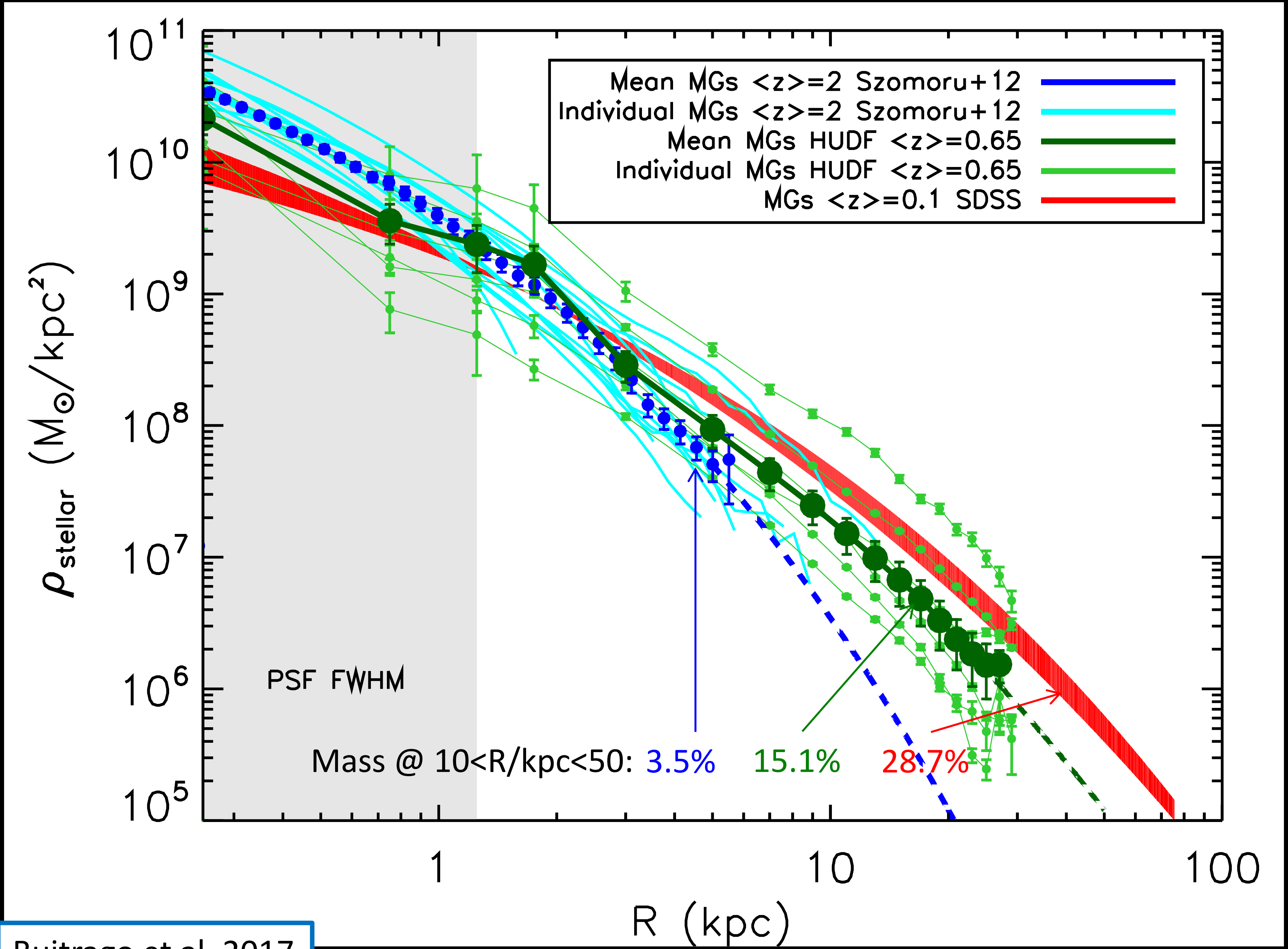
- More massive galaxies underwent an accelerated evolution in comparison with lower mass objects

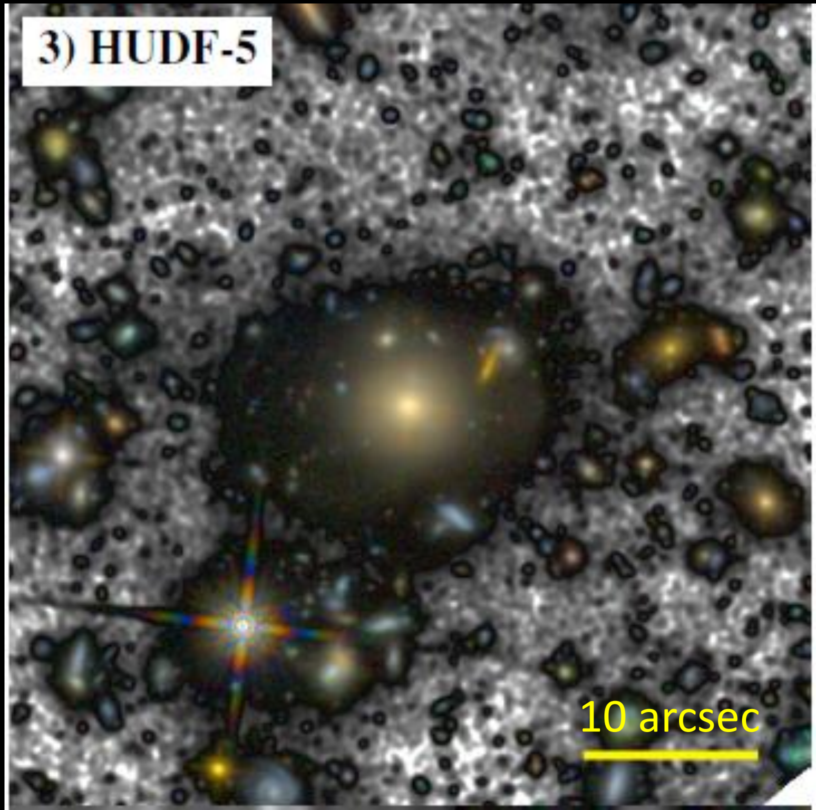
MORPHOLOGICAL EVOLUTION



Buitrago et al. 2013 (See the spectroscopic confirmation in Buitrago et al. 2014)

EVOLUTION OF MASS PROFILES OF MASSIVE GALAXIES

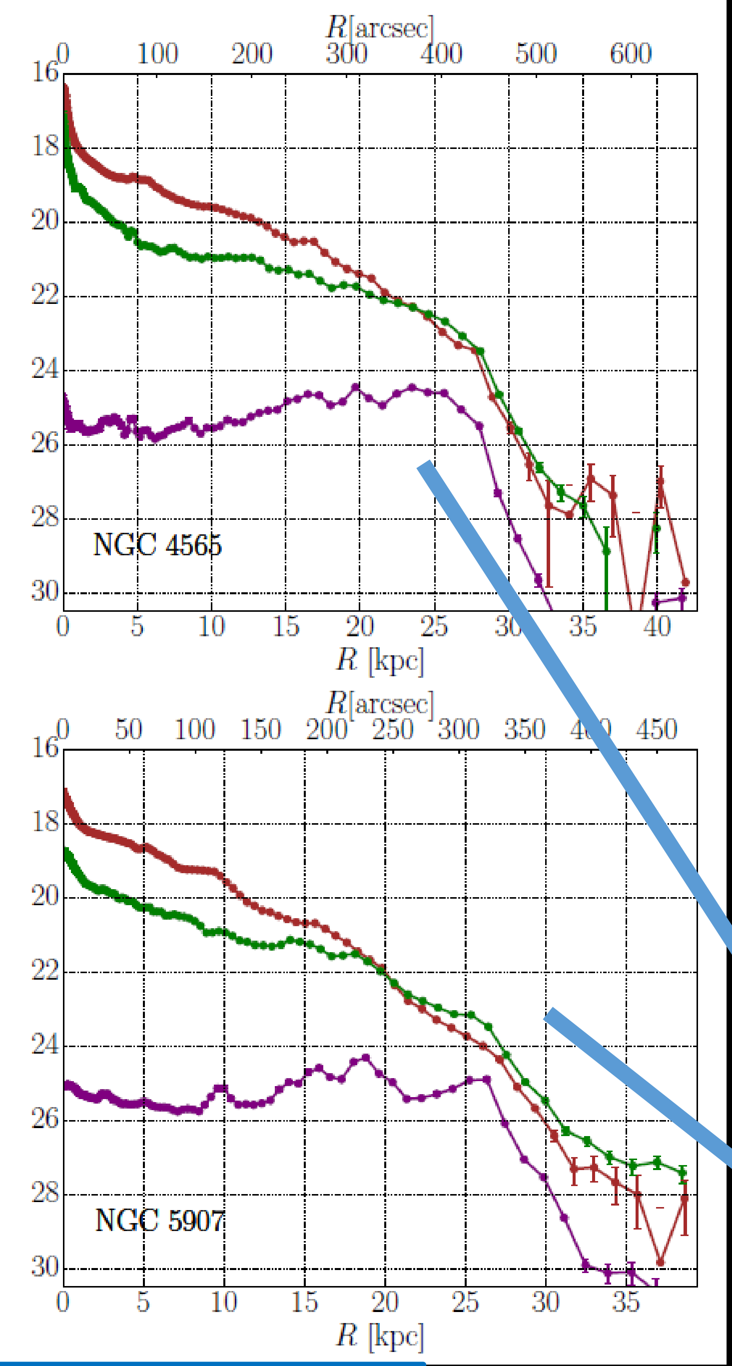




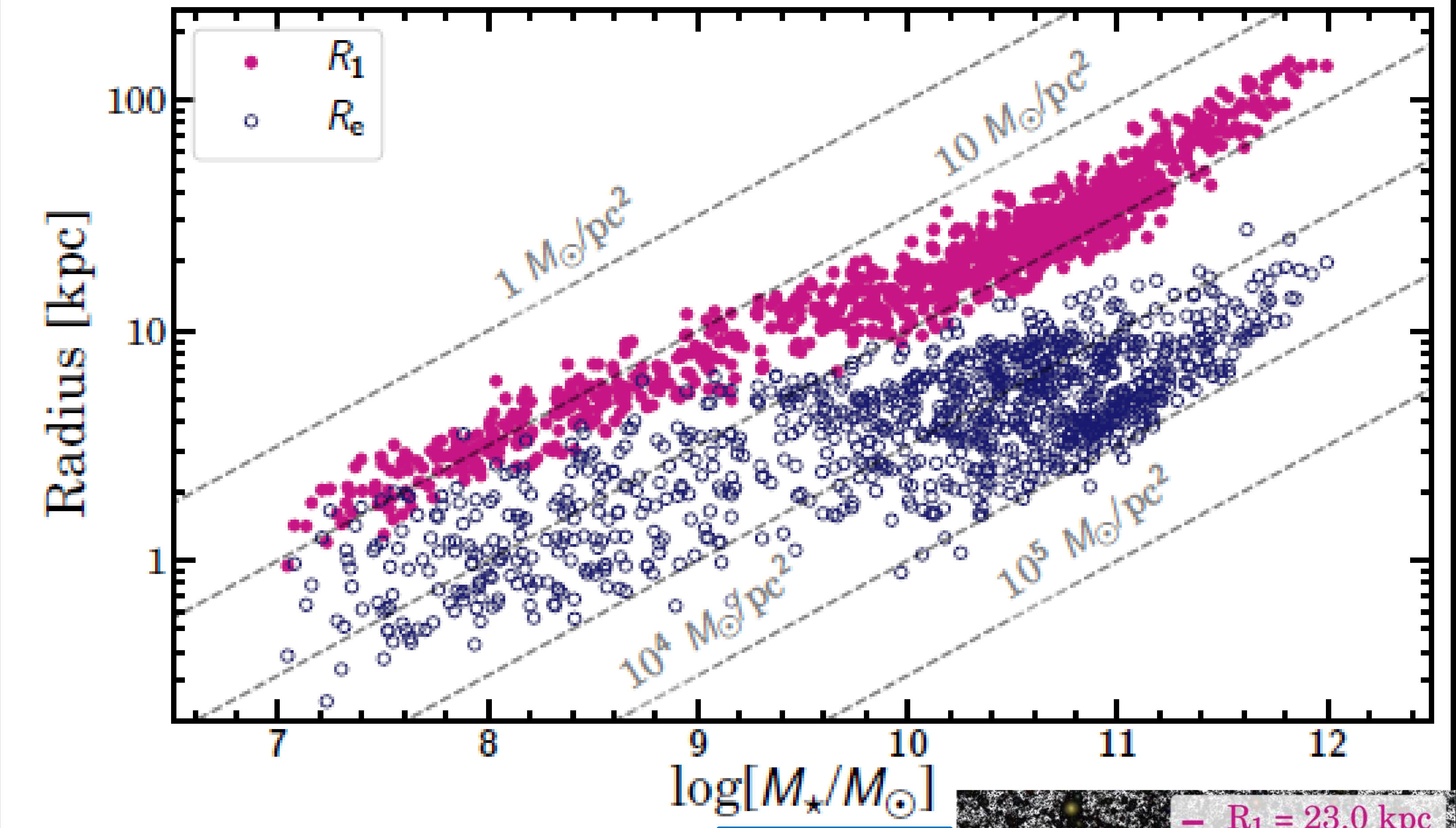
Buitrago et al. 2017

OUR IDEA

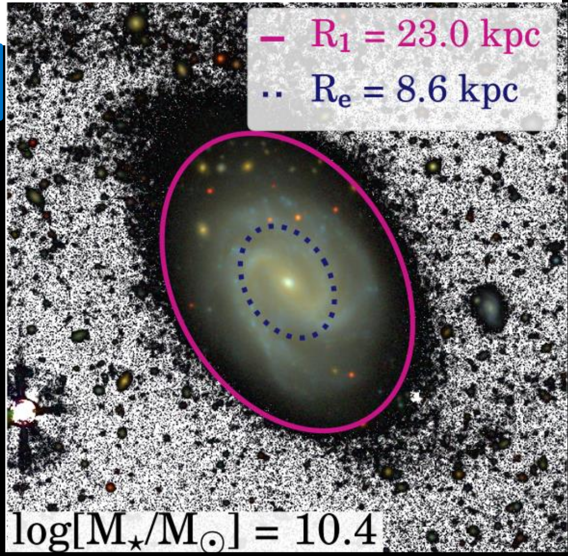
Determine the farthest radial location where the gas has been efficiently able to collapse and transform into stars



Martínez-Lombilla+19

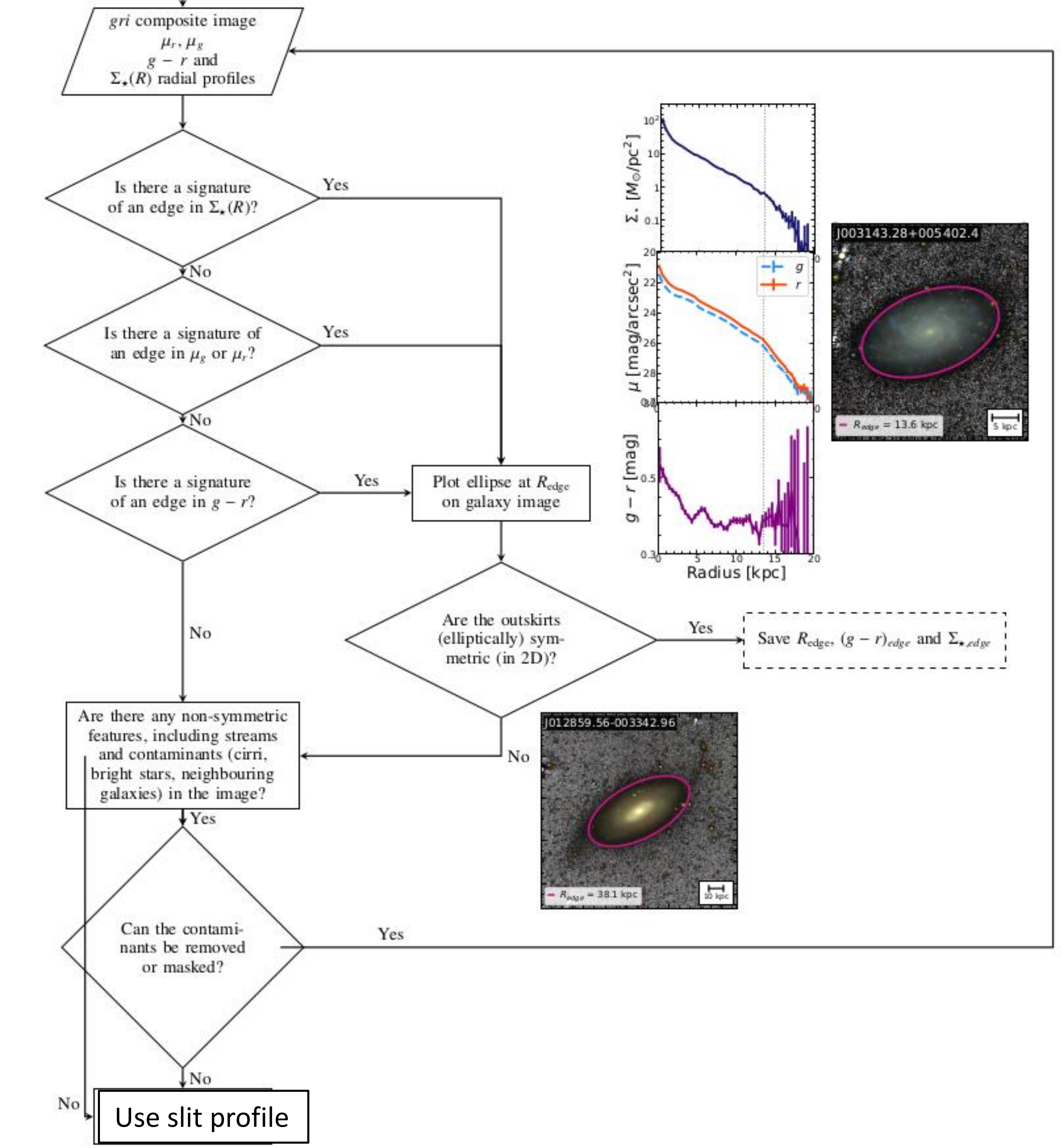


Trujillo+20

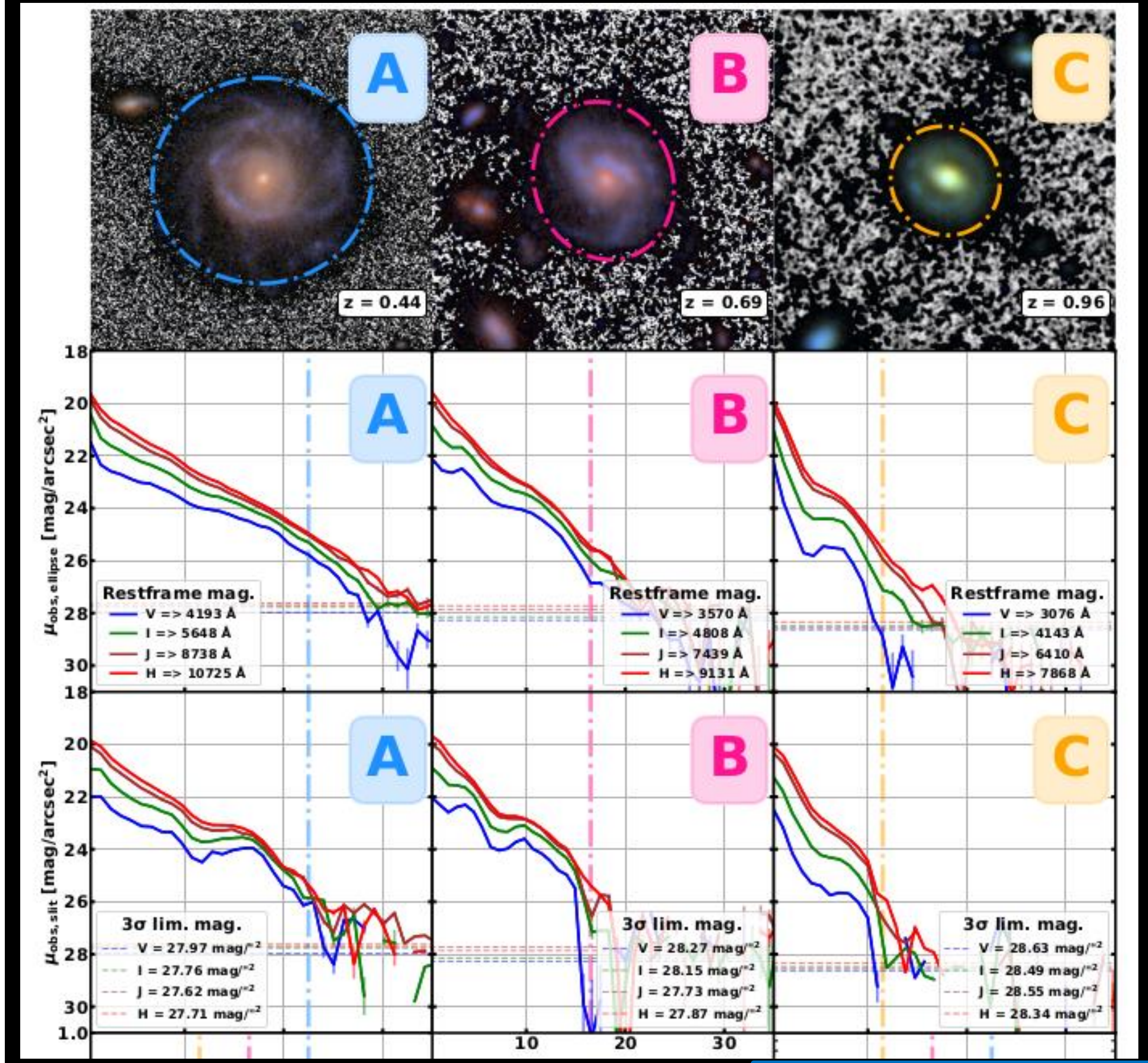


These are the so-called galaxy truncations (Van der Kruit 1979, Van der Kruit & Searle 1981a, b)

Chamba+22 – Low z

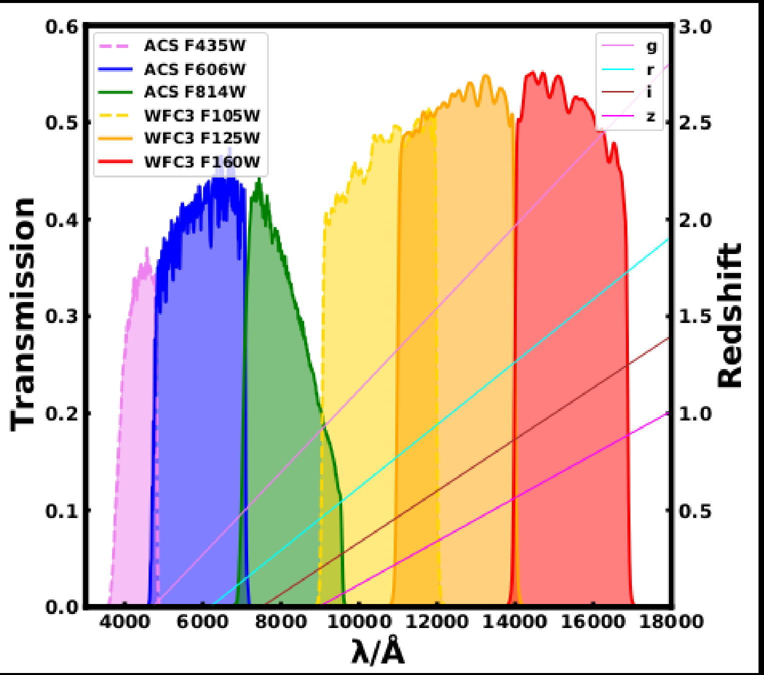


Use slit profile



Buitrago+23 – High z

ION CRITERIA

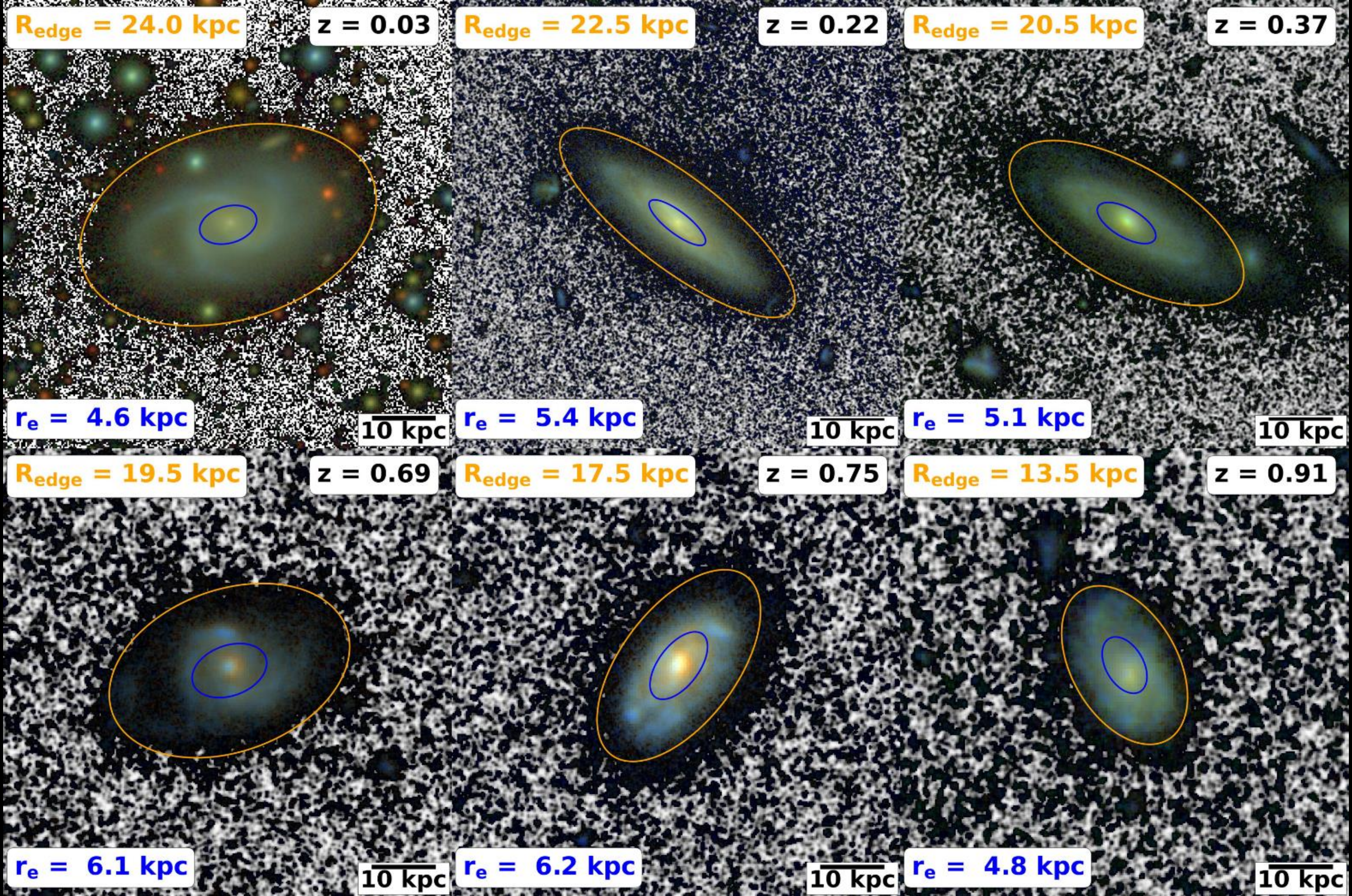


1052 galaxies among the 5 CANDELS fields

- Disk galaxies (as in Huertas-Company+15)
- -> Truncations might be more easily visible

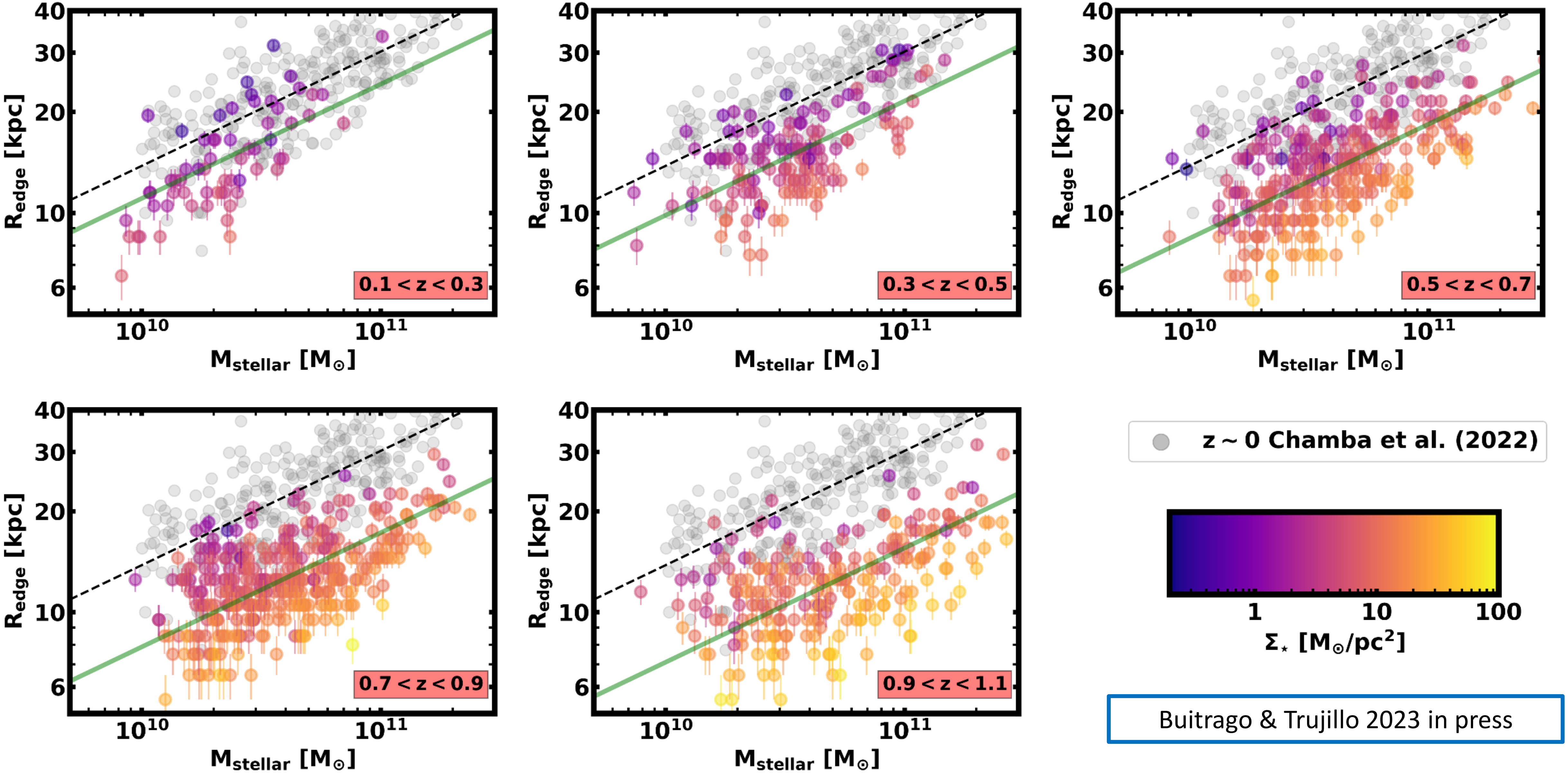
- Massive ($M_{stellar} > 10^{10}\ M_{\odot}$) and $z_{spec} < 1$
- -> Maximize S/N and not killed by cosmological dimming

- No observational artefacts or ongoing merging
- -> Truncations not erased



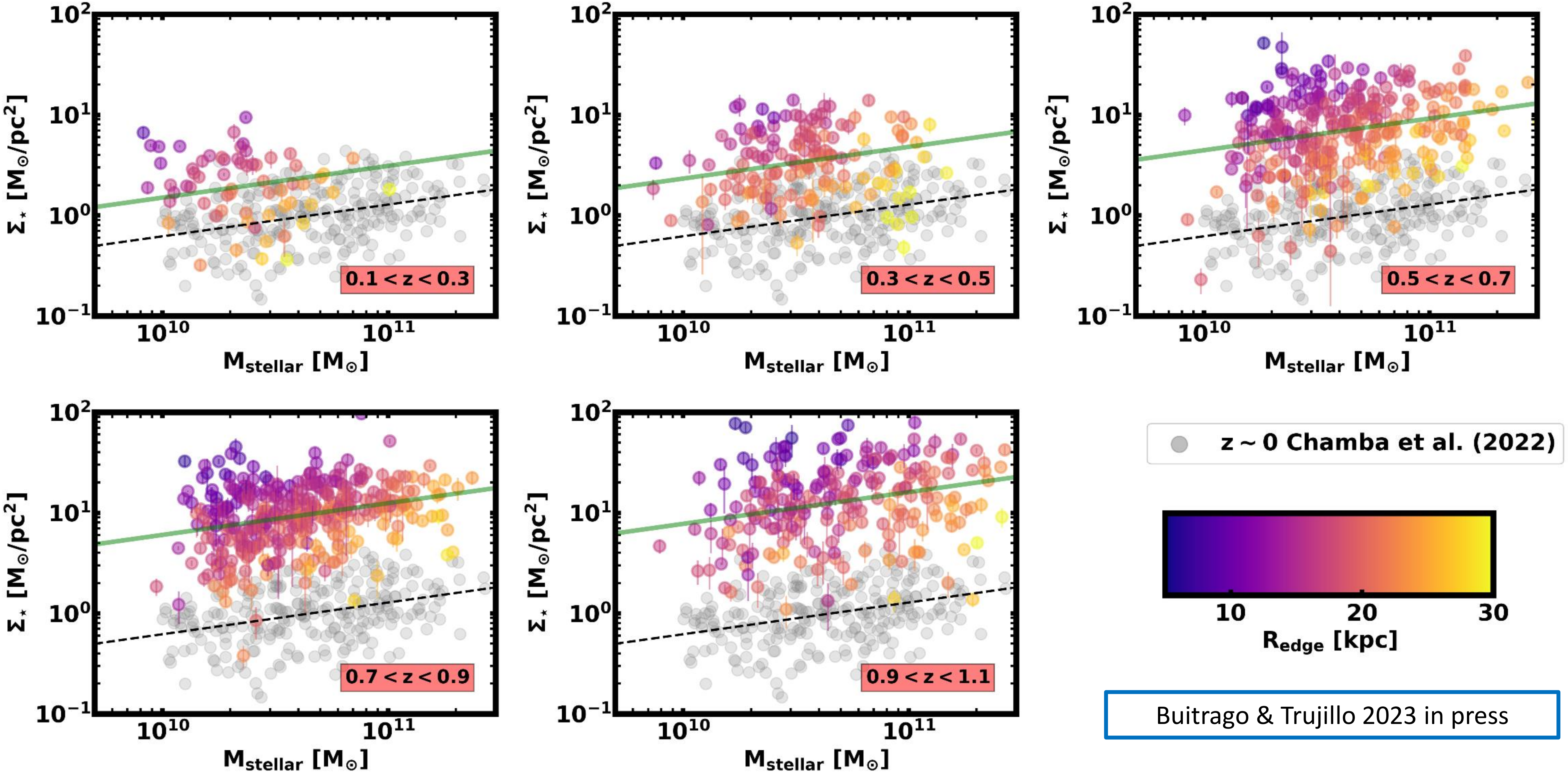
R_edge = 24.0 kpc
z = 0.03
r_e = 4.6 kpc
10 kpc
R_edge = 22.5 kpc
z = 0.22
r_e = 5.4 kpc
10 kpc
R_edge = 20.5 kpc
z = 0.37
r_e = 5.1 kpc
10 kpc
R_edge = 19.5 kpc
z = 0.69
r_e = 6.1 kpc
10 kpc
R_edge = 17.5 kpc
z = 0.75
r_e = 6.2 kpc
10 kpc
R_edge = 13.5 kpc
z = 0.91
r_e = 4.8 kpc
10 kpc

NEW SIZE-MASS RELATION

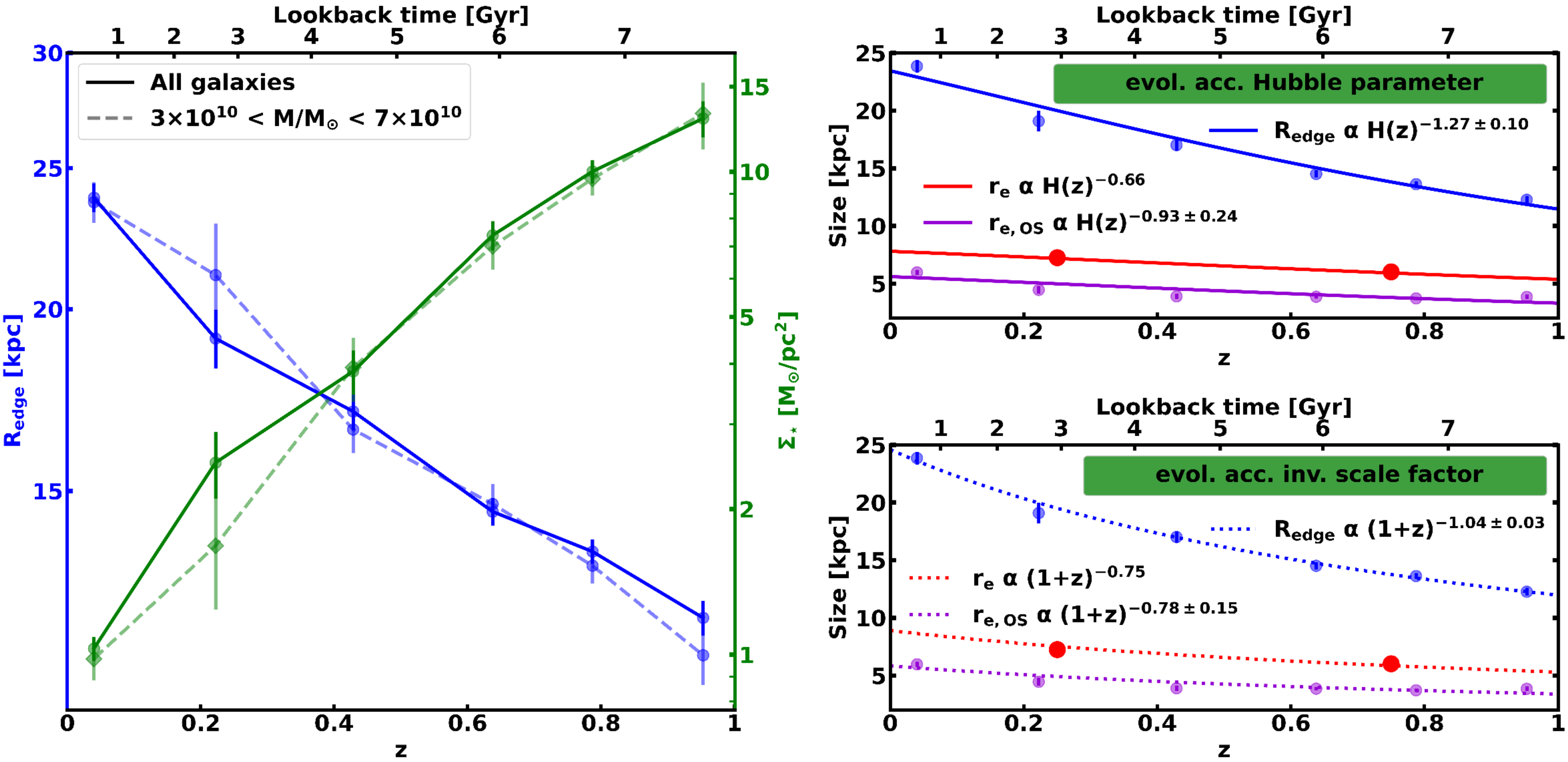


Buitrago & Trujillo 2023 in press

DENSITY-MASS RELATION



Buitrago & Trujillo 2023 in press

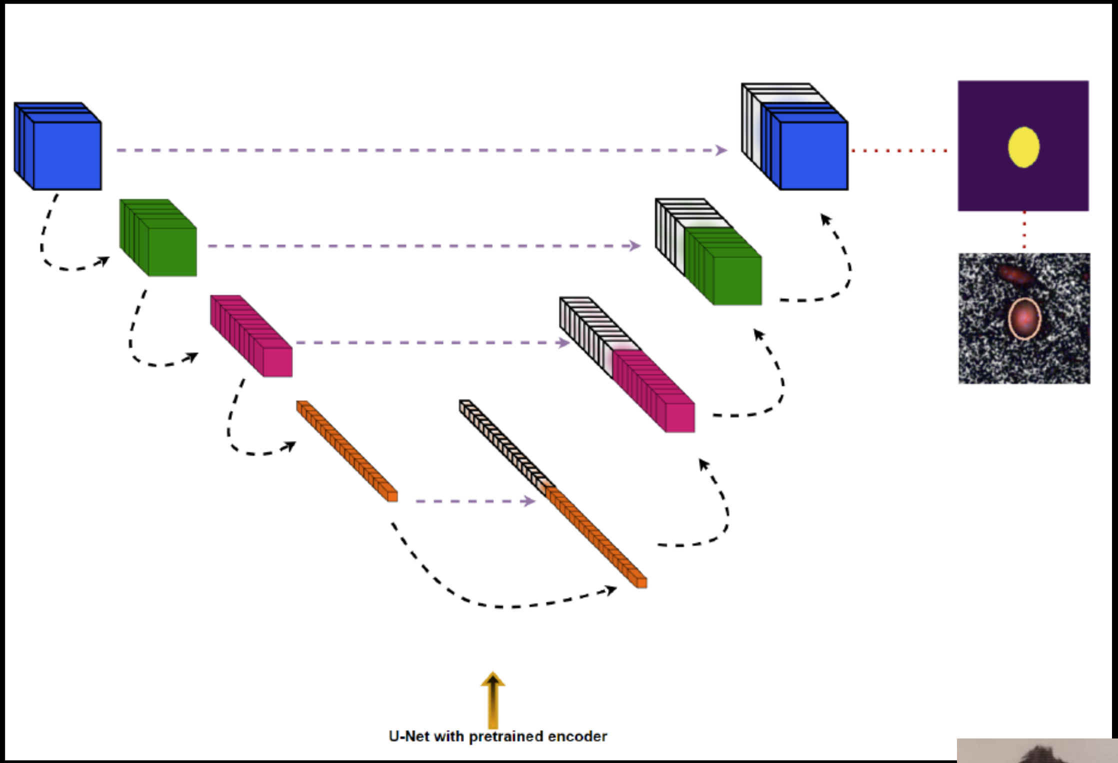


Buitrago & Trujillo 2023 in press

CAN WE RECOVER THESE FEATURES WITH ML?

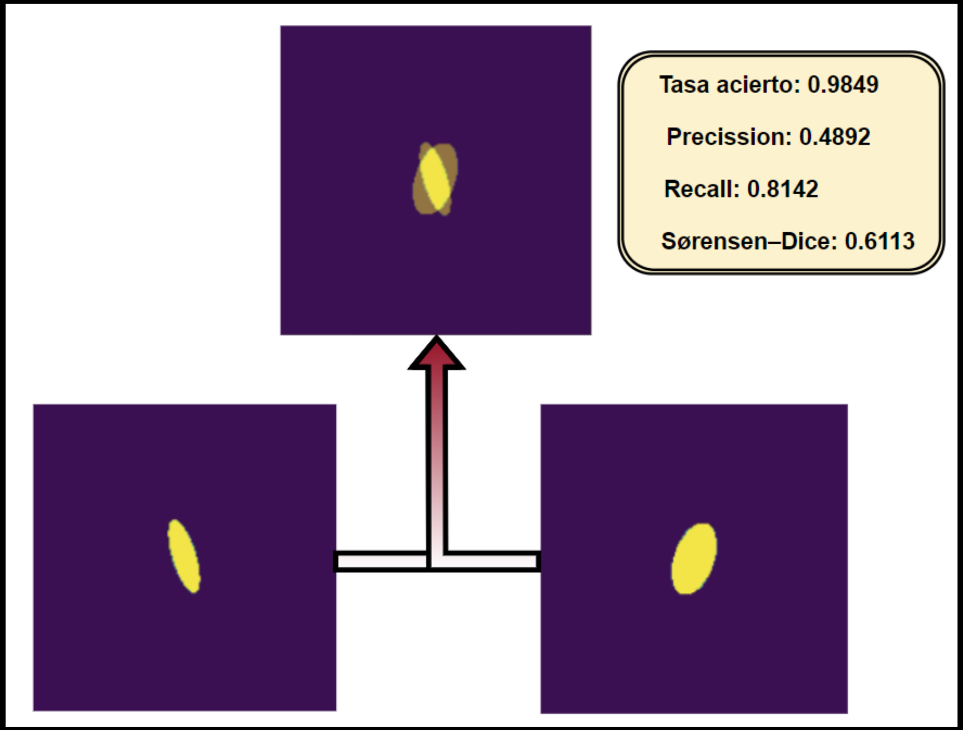
SPECIALLY FOR THE DELUGE OF DATA TO COME

- It's inherently a pattern-recognition problem
- State-of-the-art architectures: UNET+CNN (Resnet, EfficientNet, DenseNet) in PyTorch
- The metric that we are interested in is the Dice (=2·TP/2·TP+FP+FN, i.e. how many pixels right independently of the galaxy size)

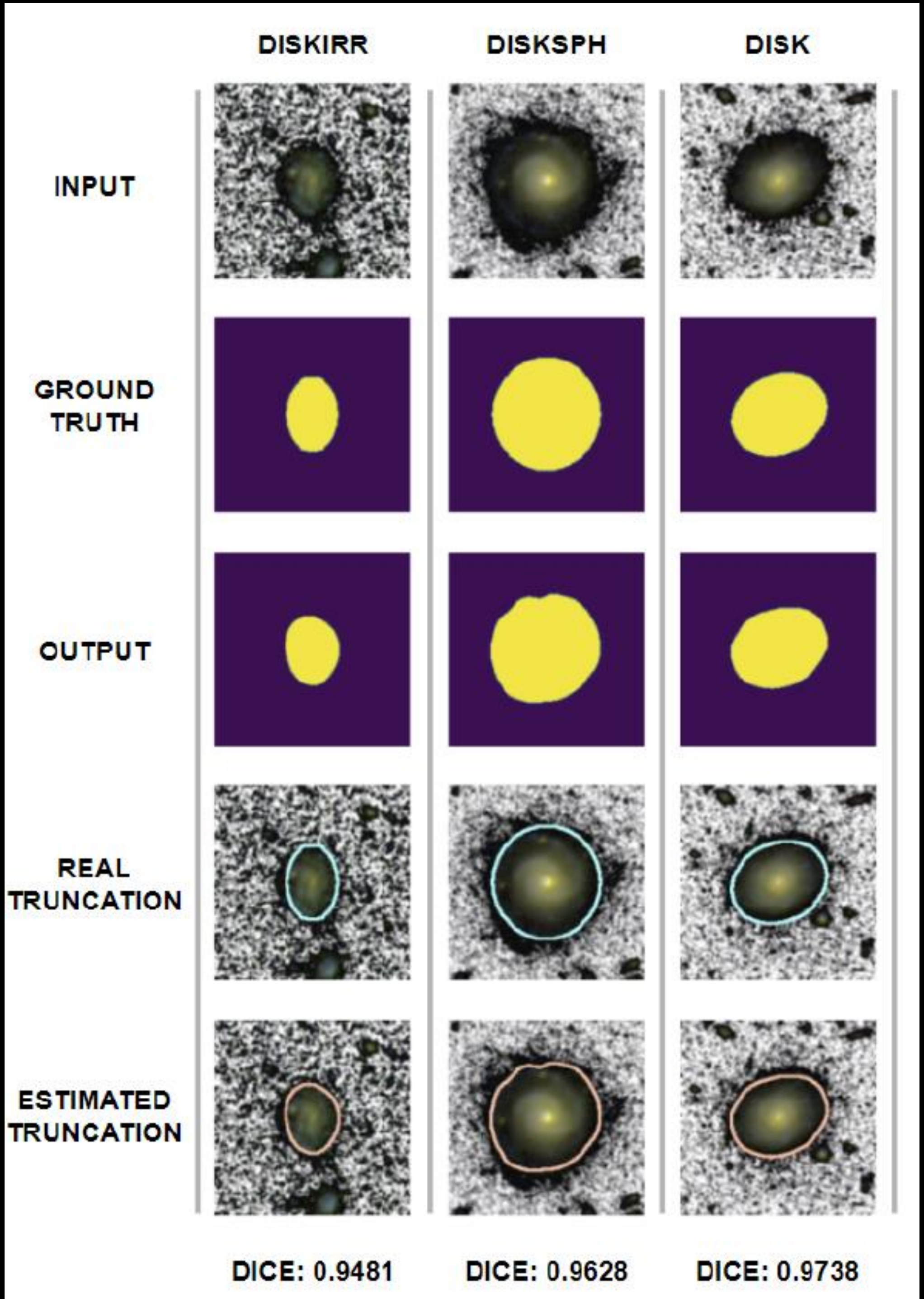


encoder - bottleneck - decoder

Fernández-Iglesias+23 in prep.



Fernández-Iglesias+23 in prep.

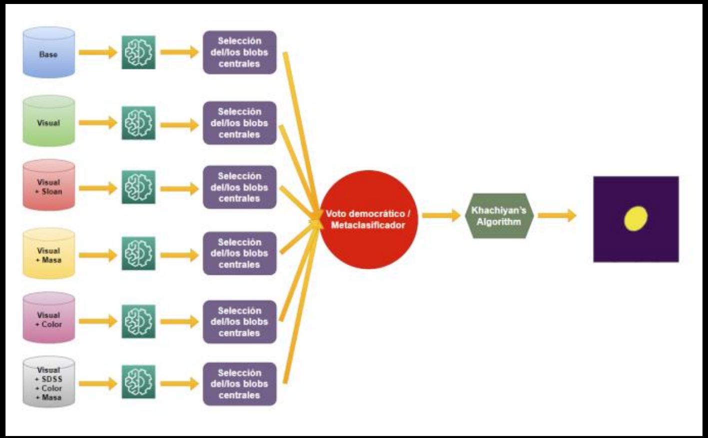


OUR ALGORITHM IN DETAIL

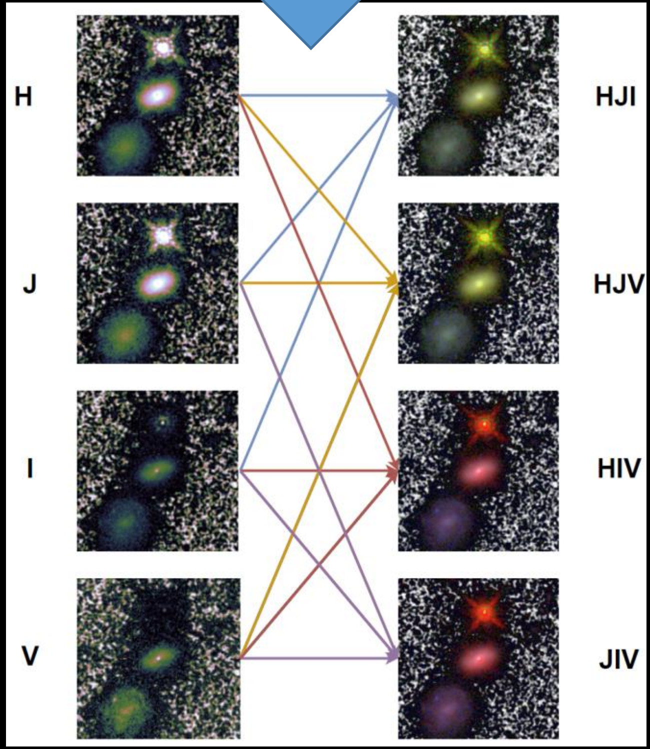
- Augmentations: standard (rotation, flip, gaussian noise) + “astronomic”

- 5 experiments: Base, Visual, Mass, Color, Sloan

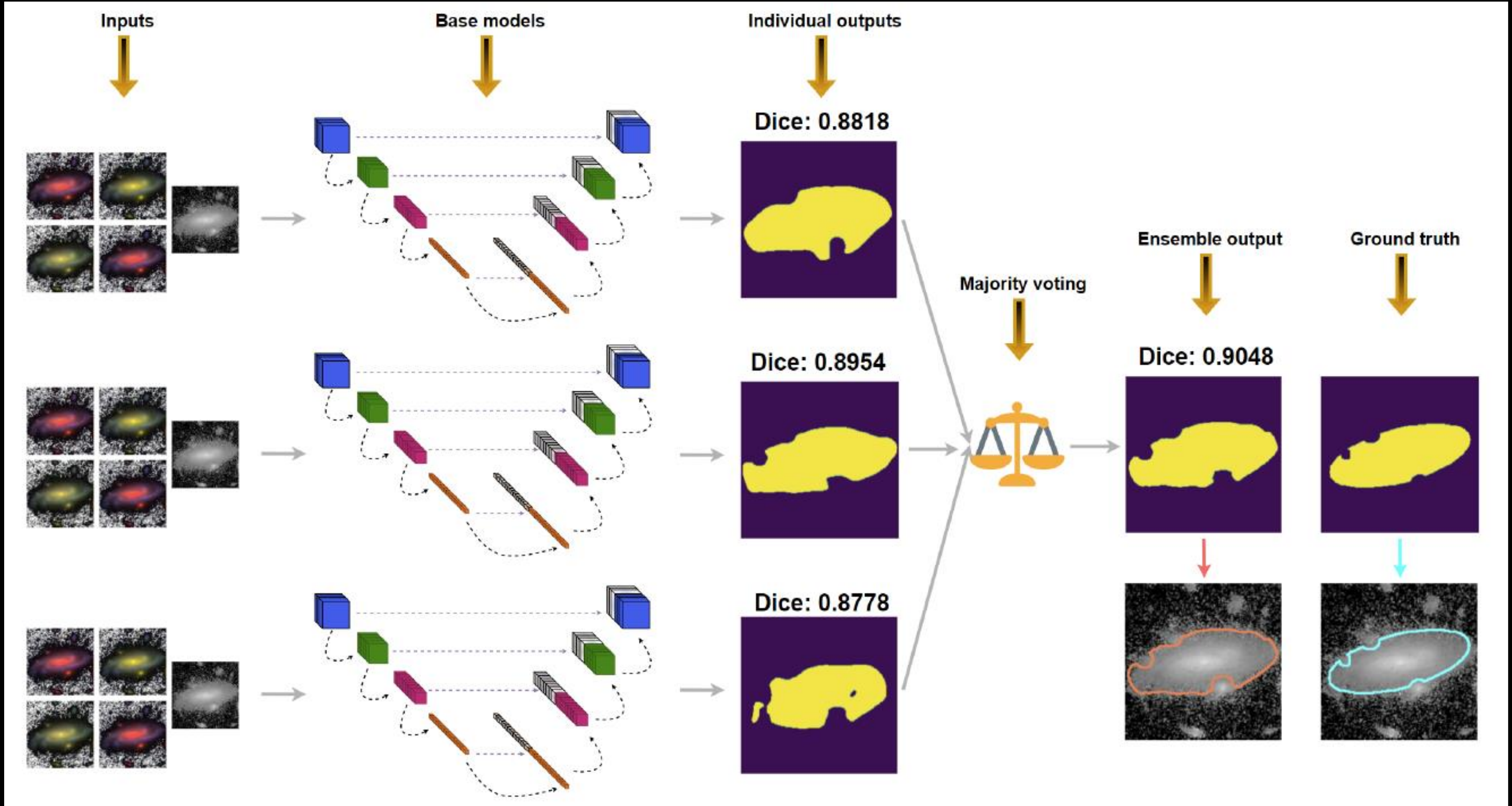
Encoder	Base	Visual	Mass	Color	Sloan
ResNet18	0.8849	0.8894	0.8949	0.8888	0.8876
ResNet50	0.8832	0.8911	0.8897	0.8943	0.8858
EfficientNetB1	0.8867	0.8884	0.8924	0.8819	0.8854
EfficientNetB2	0.8809	0.8805	0.8890	0.8886	0.8836
EfficientNetB6	0.8835	0.8856	0.8935	0.8845	0.8914
DenseNet161	0.8926	0.8893	0.8959	0.8869	0.8867
DenseNet201	0.8867	0.8969	0.8928	0.8830	0.8862

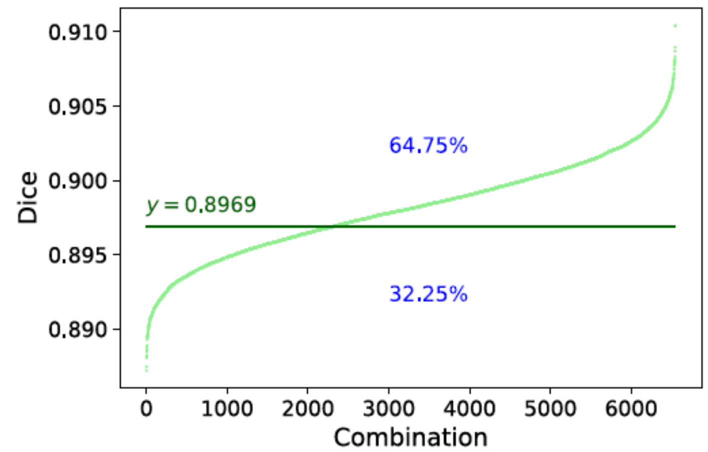


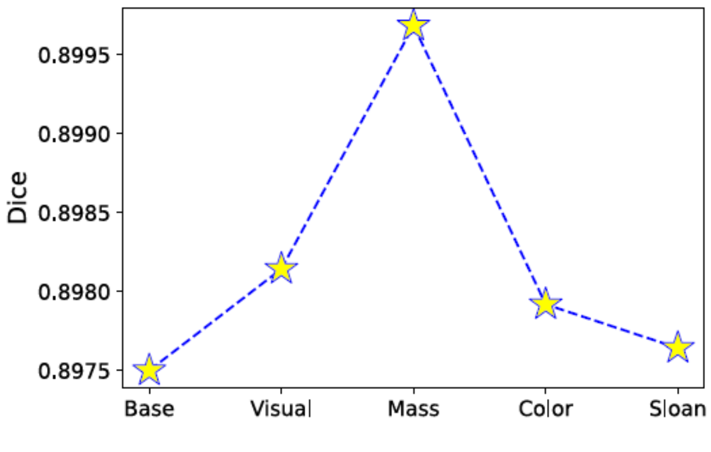
Vega-Ferrero+23 in prep.



Astronomic augmentations with observed profiles, but also with 2D images of SDSS equivalent images, colors and stellar masses

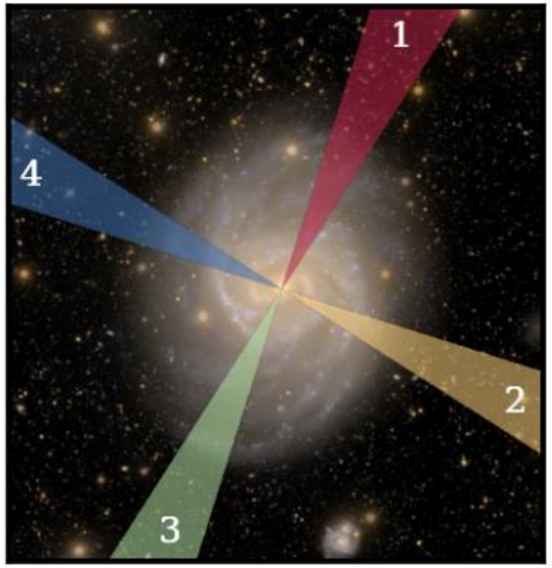


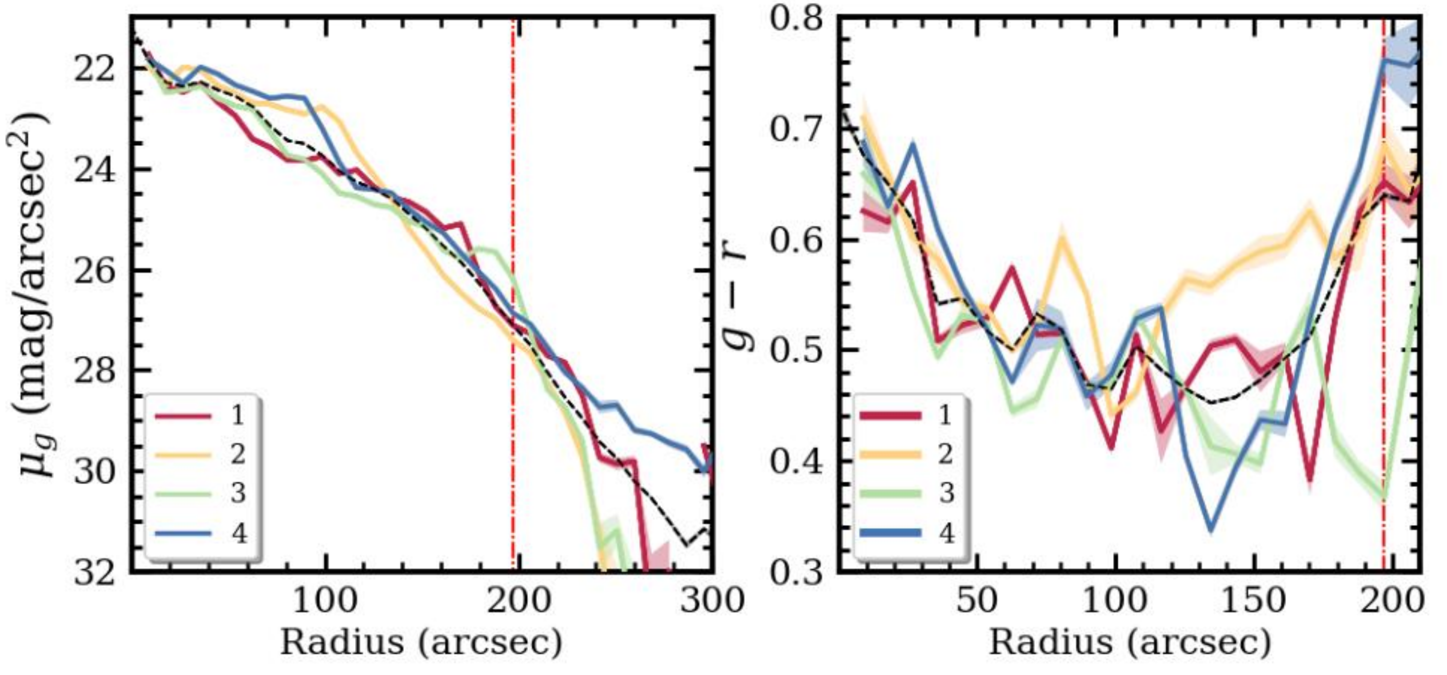




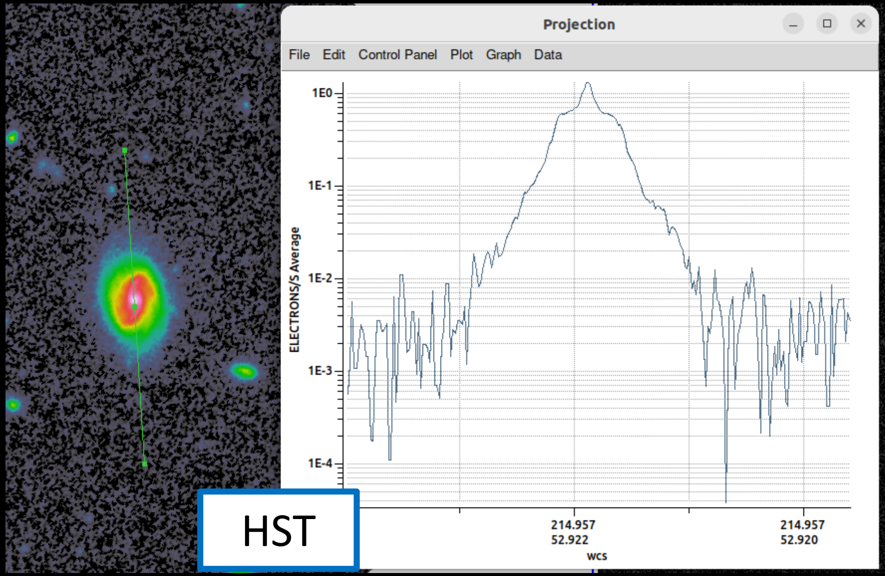
Fernández-Iglesias+23 in prep.

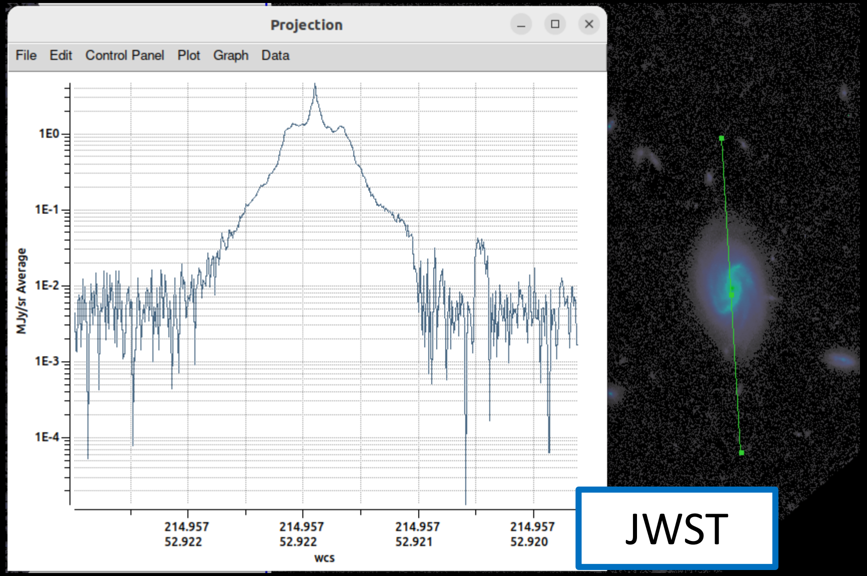
FUTURE





Understanding in detail the color profiles and the assymetries in the outer parts (Raji+23 in prep.)





JWST to dramatically improve our detections (77 galaxies in common with CEERS) and the possibility of breaking the z = 1 limit

And many more to come…

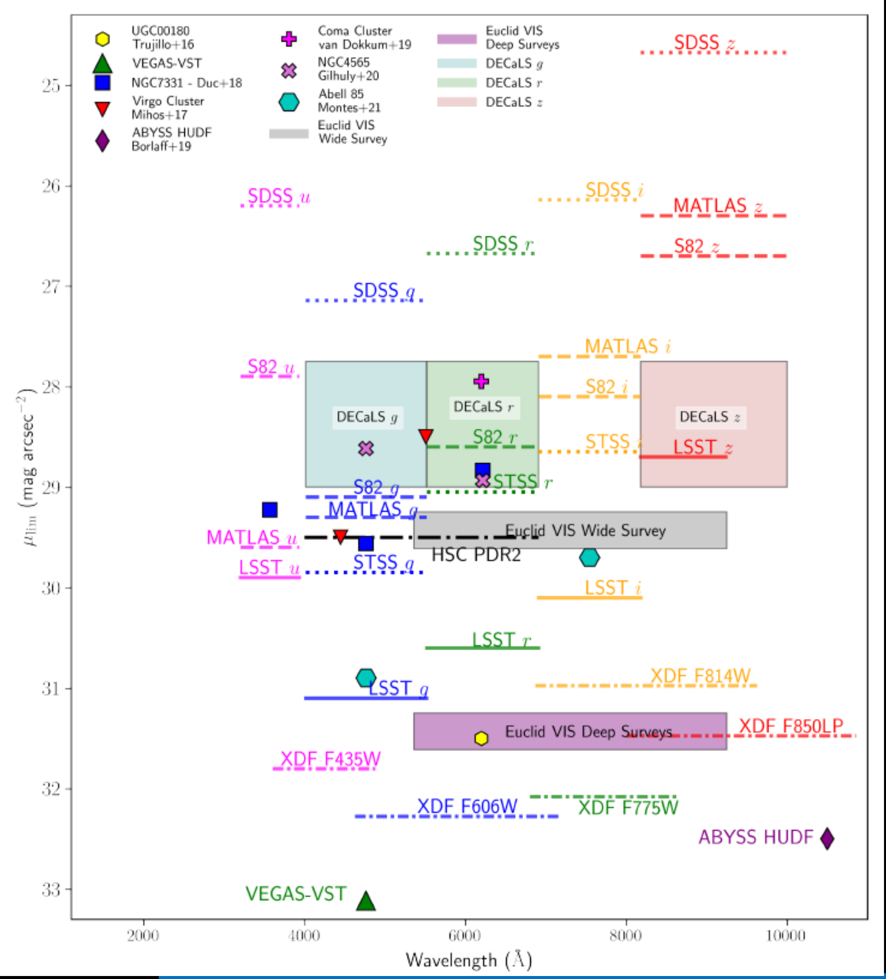
Development of Massive Elliptical Galaxies

SUMMARY

- Low Surface Brightness will be a game changer for galaxy evolution studies. It's not only about faint dwarfs, but also for luminous galaxies; we can finally obtain physically-motivated galaxy sizes (real edges!)

- MW-like galaxies decrease their sizes by a factor of 2 at z = 1 –following an evolution $\alpha(1+z)^{-1}$, faster than r_e– while at the same time their mass density at the truncation position increases by over an order of magnitude

Buitrago & Trujillo (2023) in press



Borlaff+22 (Euclid Consortium XVI)

- Machine Learning seems to replicate well (Dice > 0.9) the truncations' detections. It is time to enlarge our samples, ascertain spacially whether they are always present or not, and understand in detail the origin of these edges

Fernández+23 in prep. (almost over)
Raji+23 in prep.
Vega-Ferrero+23 in prep.

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