Linking stars, gas and the galactic environment using deep optical & HI surveys

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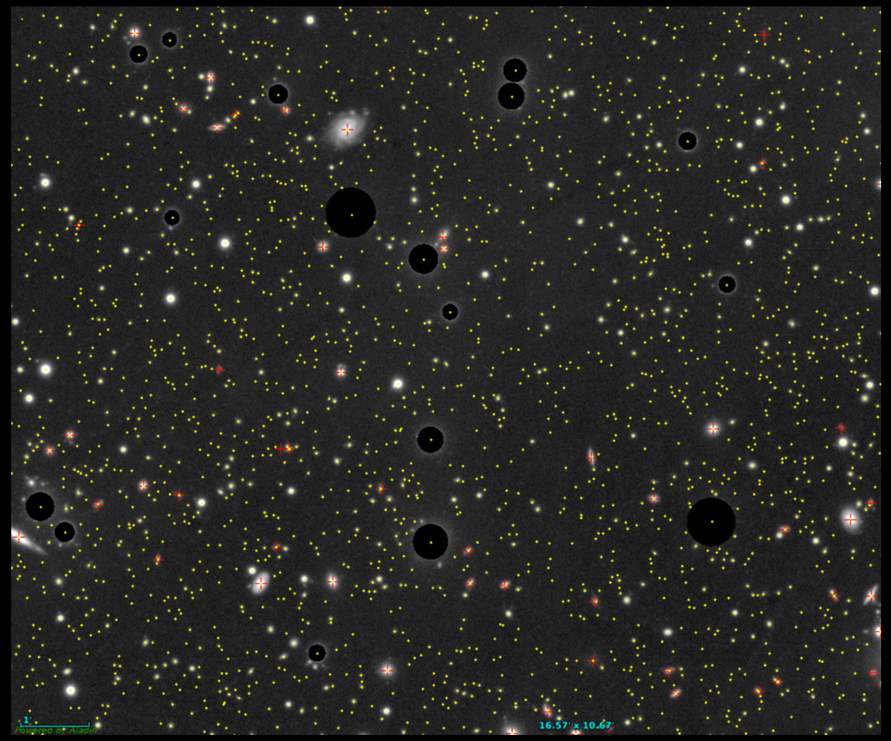
NASA Ames Research Center

10-11 SKA Day, Göteborg, Sweden

Galaxies are found in different environments

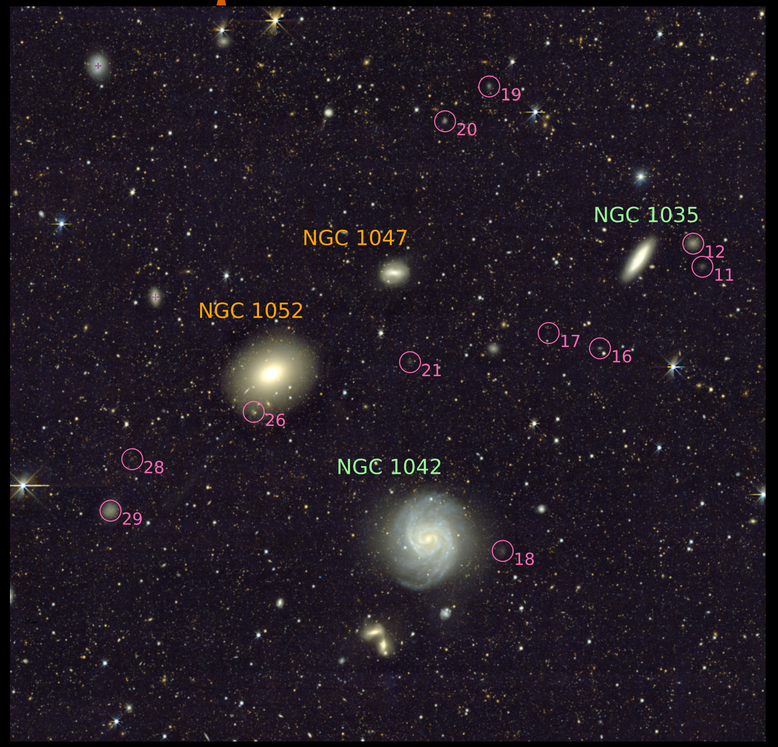
“morphology-density” relation

Cluster (thousands)



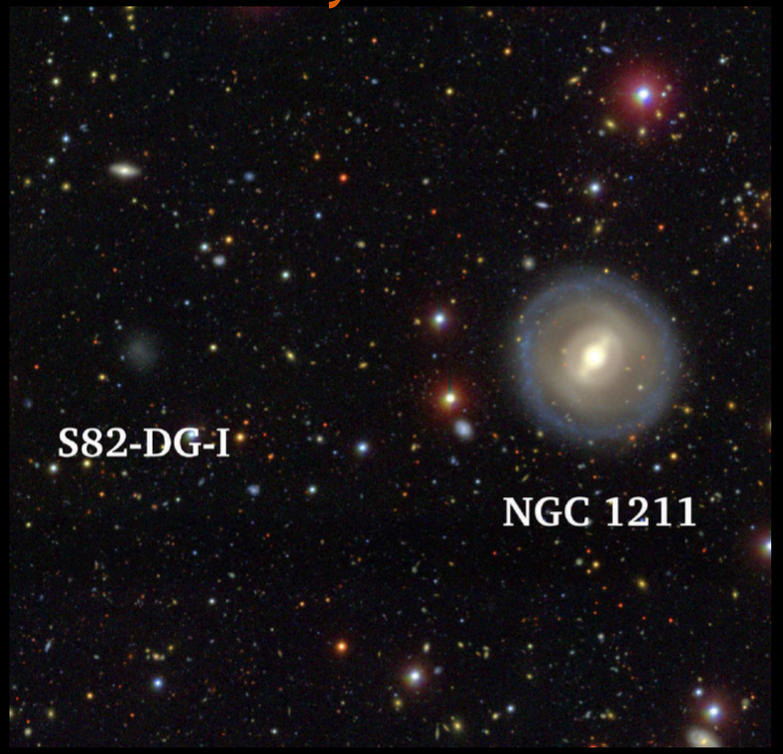
Fornax Cluster, FDS. Credit: Venhola et al. 2018

Groups (several tens)



NGC1052-1042 system, DeCALs

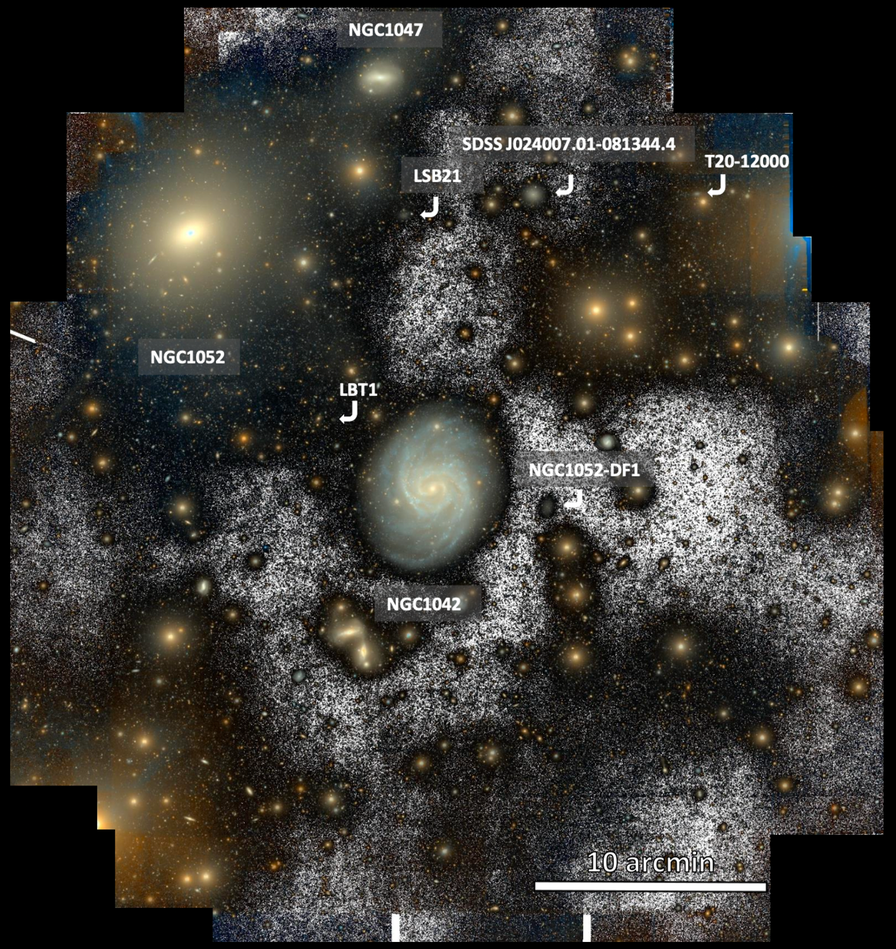
Nearly isolated



Stripe 82, Credit: Roman et al. 2019

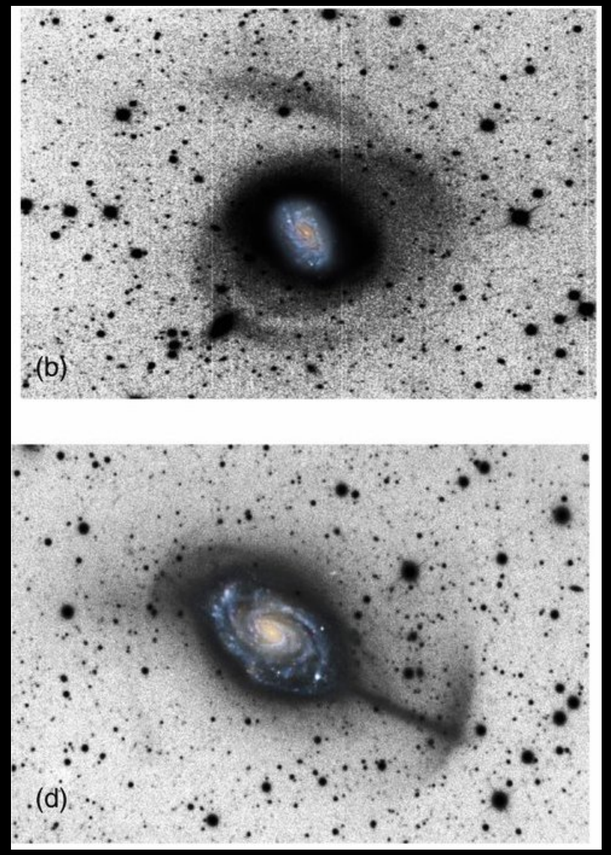
Observable signatures of physical processes

Stellar & gas accretion/removal regulates how stars form in galaxies



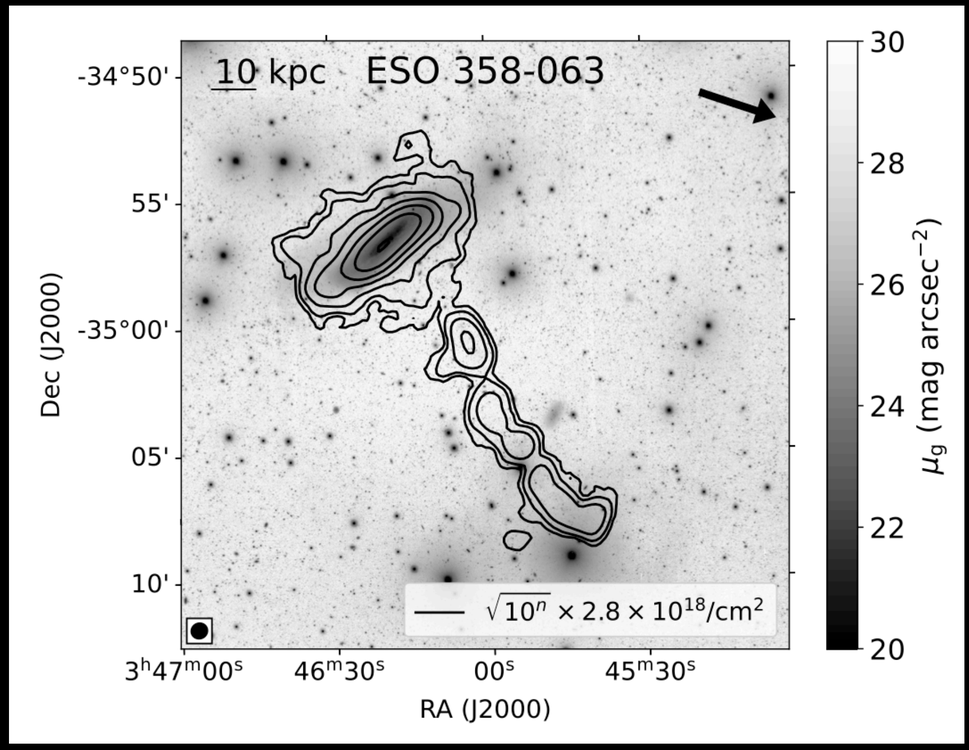
Galaxy- galaxy/group/cluster

LIGHTS Collaboration, Trujillo et al. 2021



satellite accretion

Credit: Martinez-Delgado et al. 2010

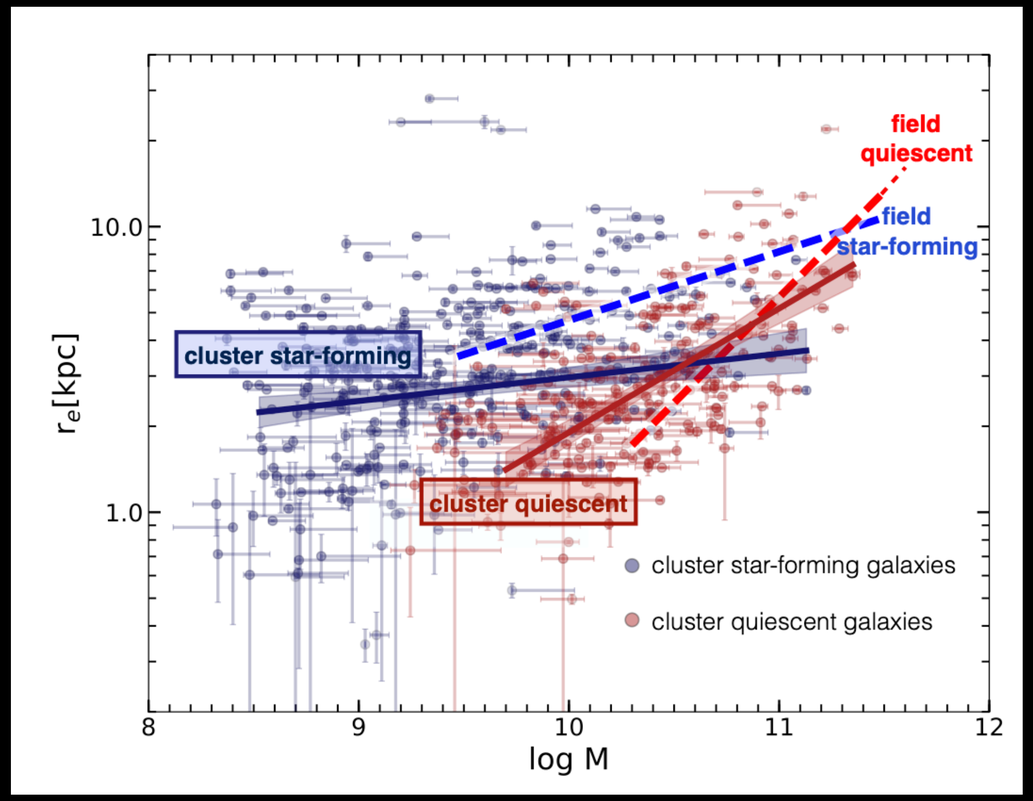


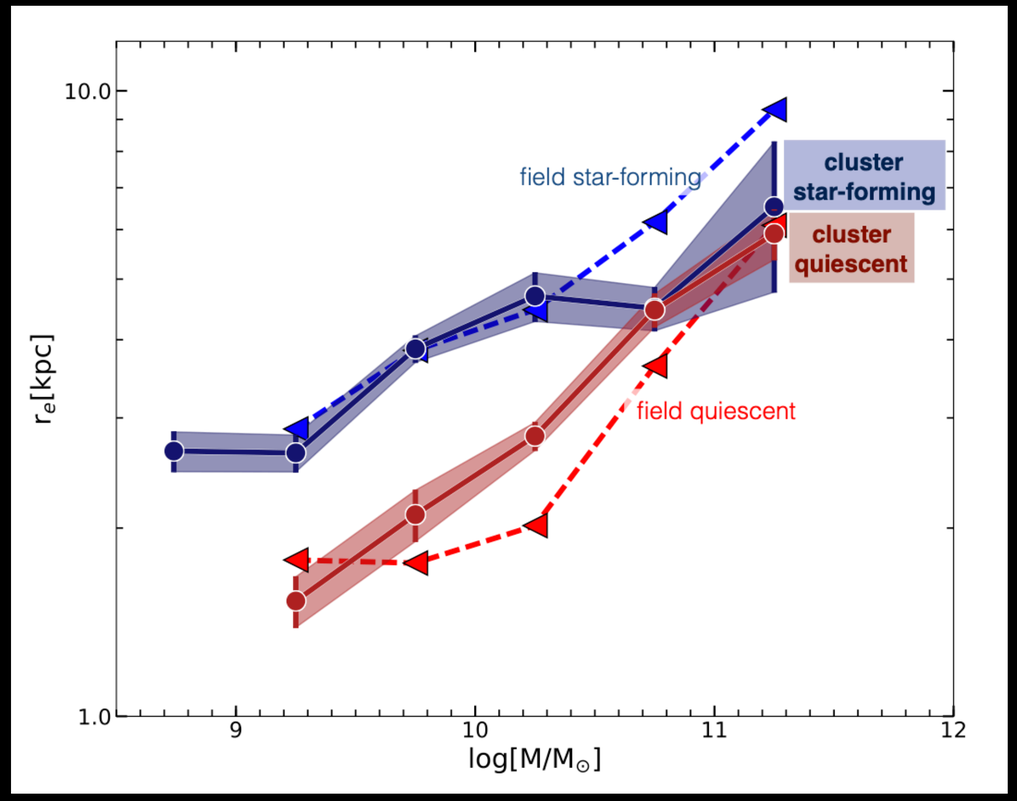
signs of ram pressure

MeerKAT Fornax Survey. Credit: Serra et al. 2023

Tracking how environmental processes affect galaxy growth

- Scaling relations A typical example is the effective radii (Re) of galaxies plotted as a function of stellar mass. E.g. from Kuchner et al. (2017):





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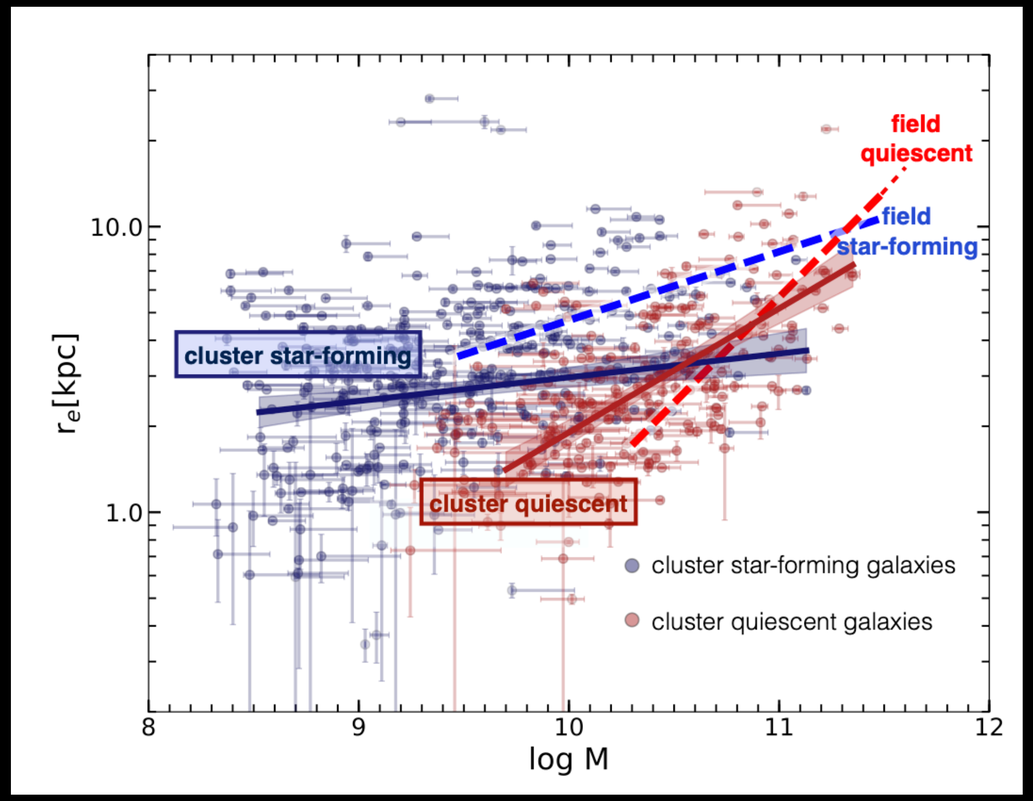
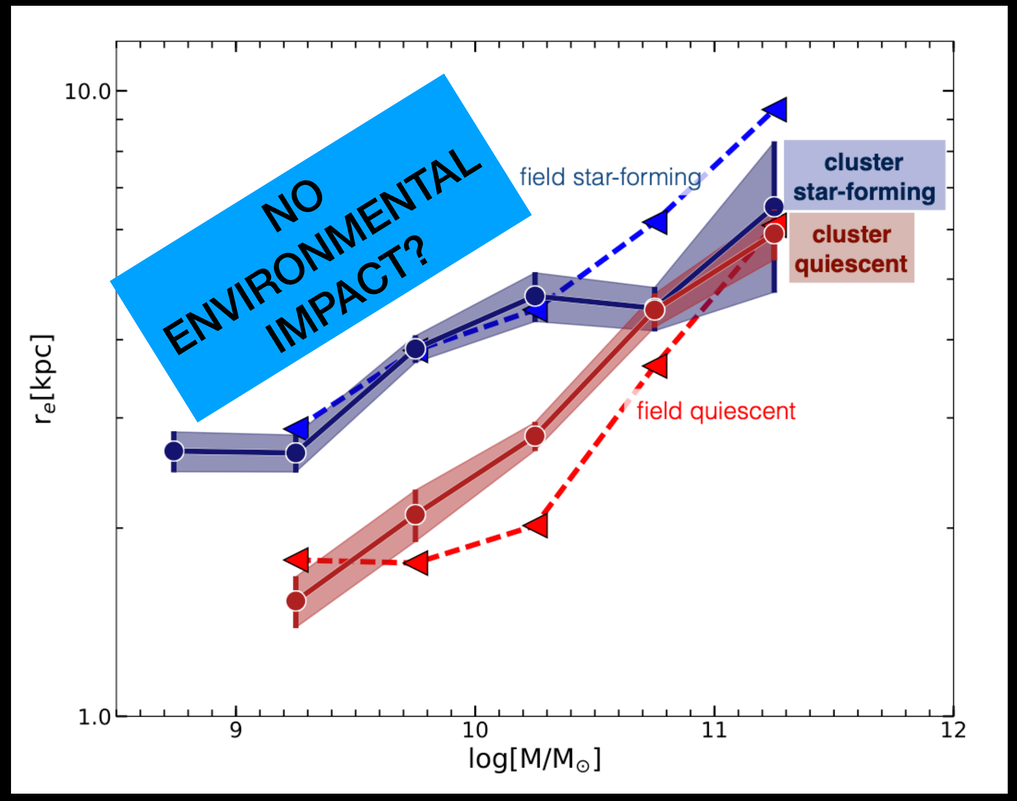
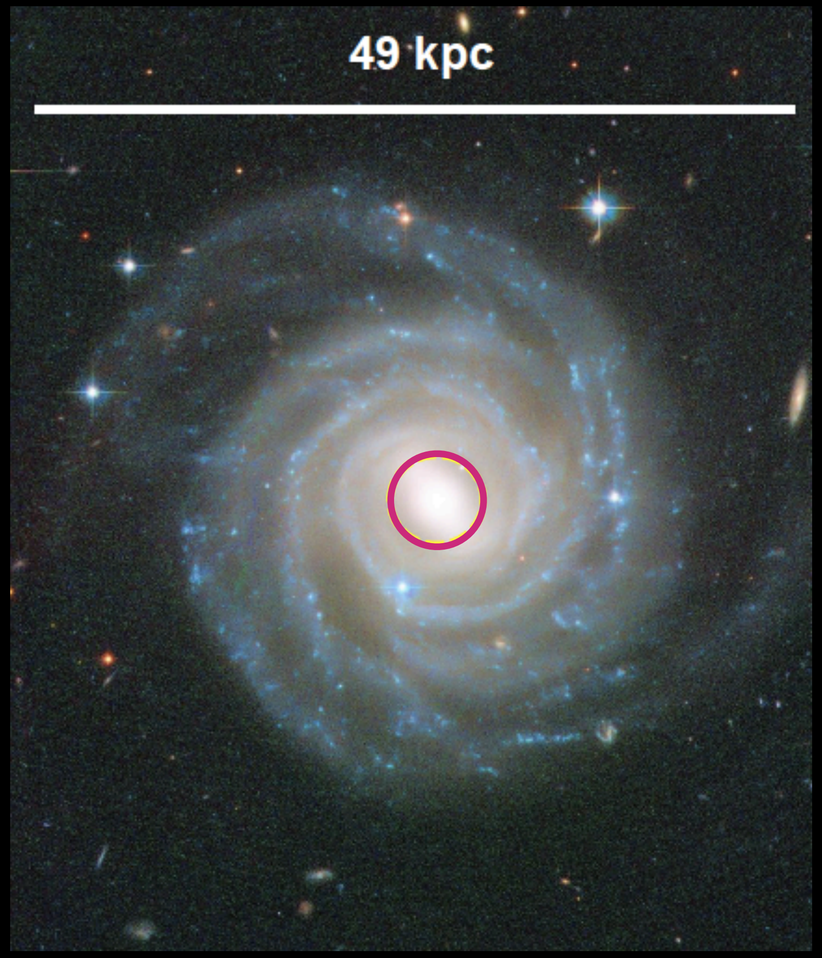


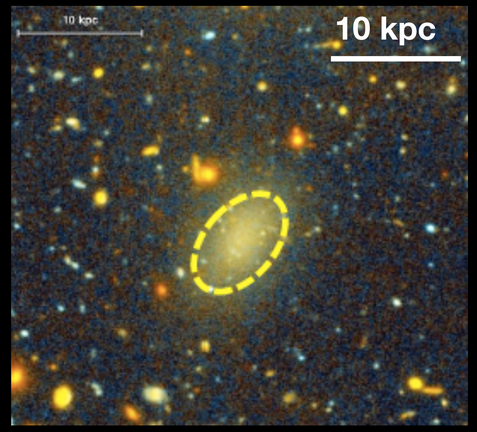


Definitions like Re may not enclose outer structure

See also Chamba, Trujillo & Knapen (2020) & Chamba (2020)



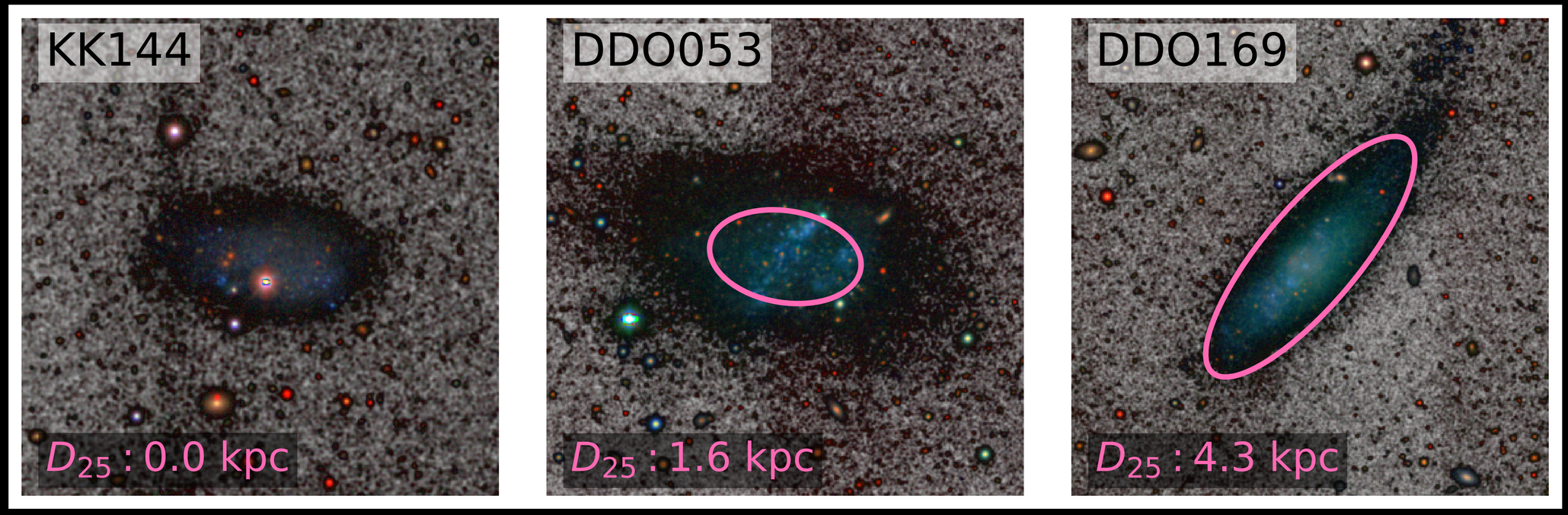
UGC 12158 (MW analogue)



DF44
van Dokkum et al. 2016

There are other size definitions BUT...

Field dwarf galaxies of similar stellar mass



Adapted from Chamba, Marcum, Saintonge et al. (2024)

Using the “edge of star formation” as a physically motivated size definition

‘*The outermost location where past or ongoing in situ star formation significantly drops due to the existence of a star formation threshold*’

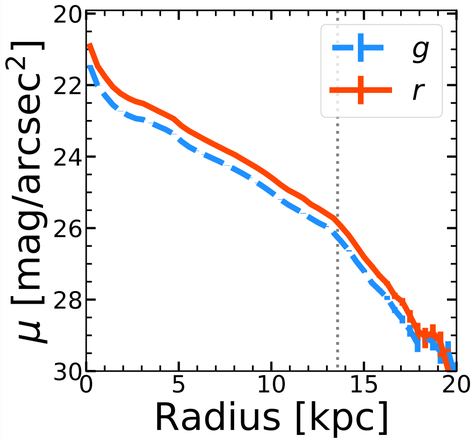
Compared to past size measures, a drop in star formation is a feature that we can anticipate to be sensitive to environmental influences because those processes can directly regulate star formation

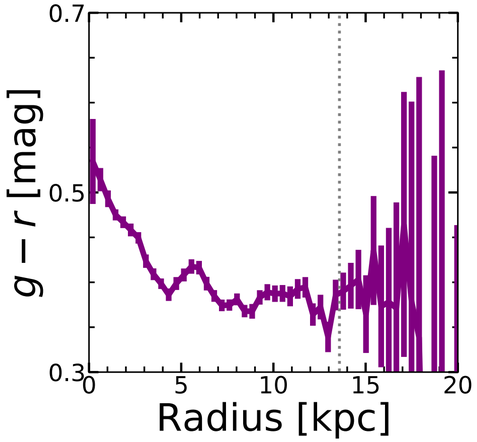
The truncation can be used as a *proxy* for the edge

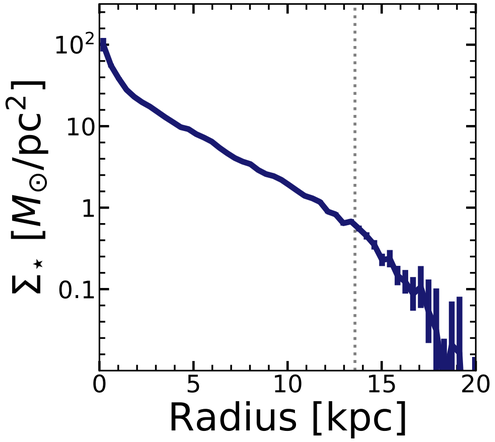
(see Trujillo, Chamba & Knapen 2020 & Chamba, Trujillo & Knapen 2022)

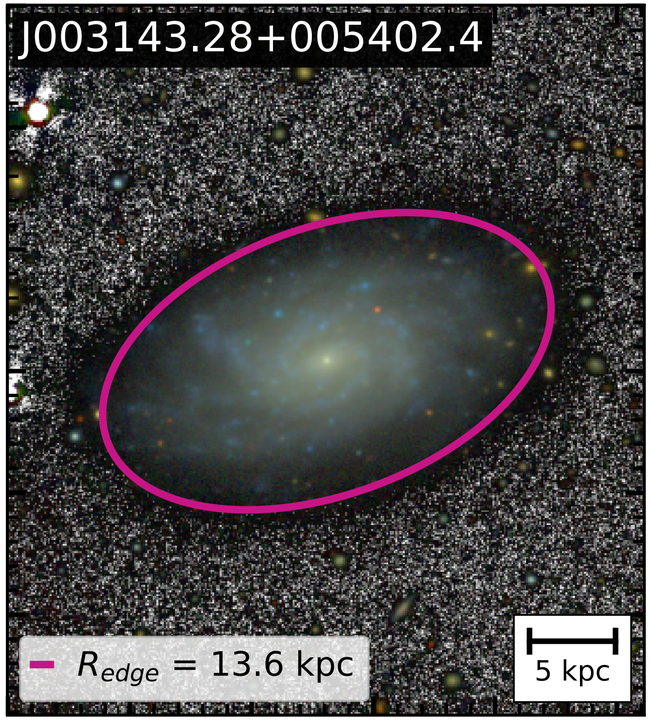
Finding the edge

From Chamba et al. (2022, Fig.1) - field disk galaxy

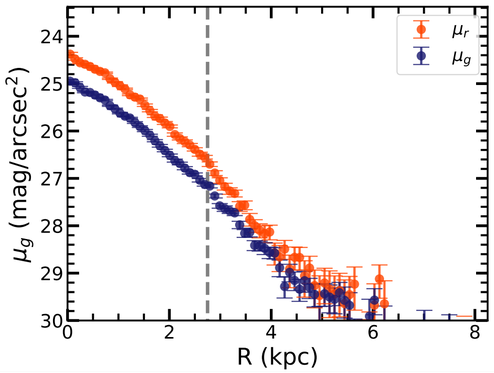


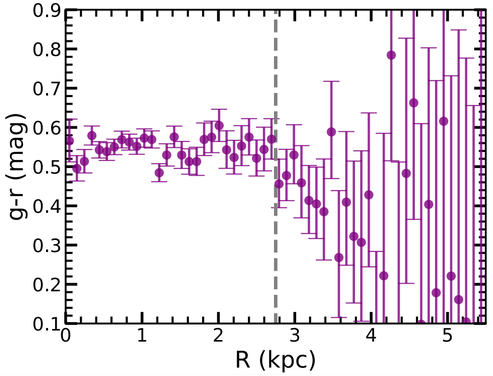


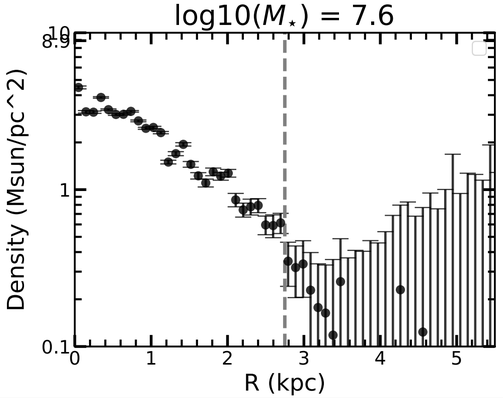


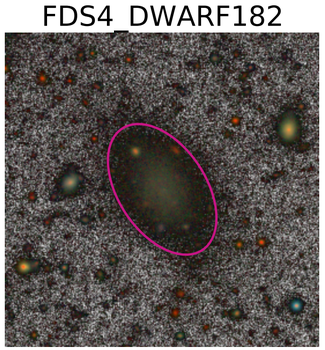


FDS Dwarf, Chamba, Hayes, et al. (2024) - cluster galaxy









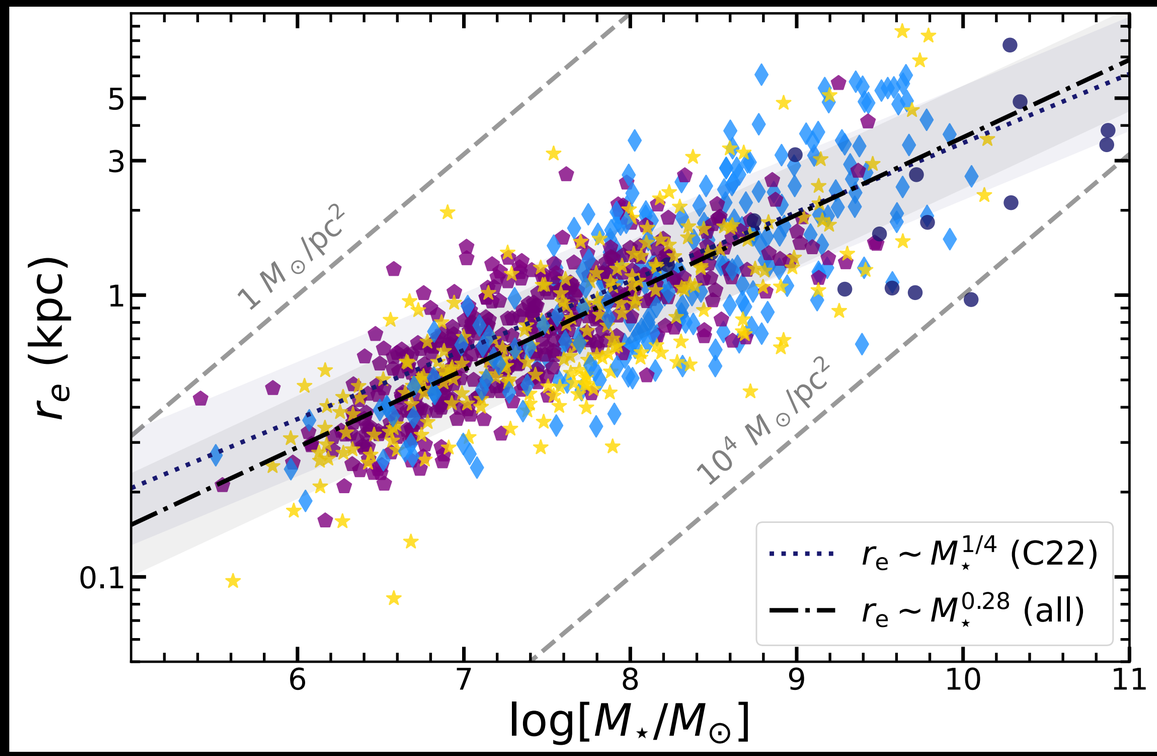
Data & Sample

See Chamba, Hayes, LSST-DESC (2024) for details

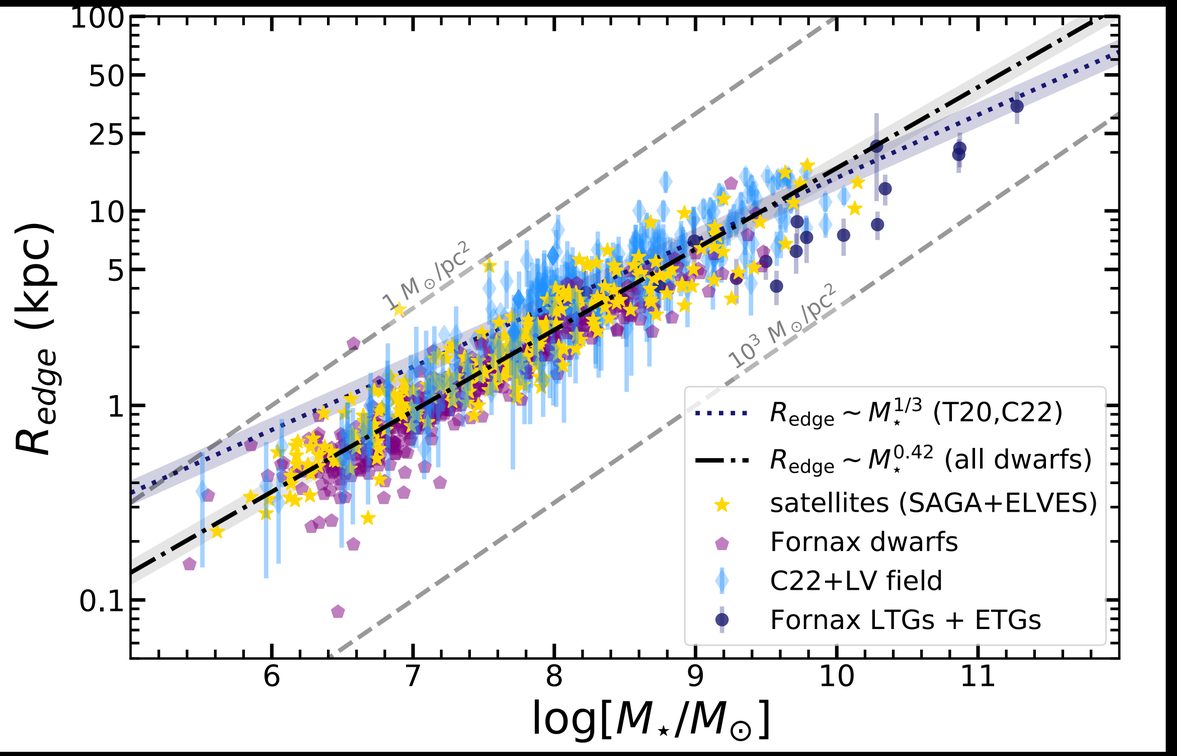
- Cluster galaxies - Fornax Cluster catalogue from FDS (Su et al. 2021) - 582 galaxies with stellar masses 10^{6}-10^{12} Msun
- Group/satellite galaxies - DECaLS imaging of 127 SAGA Stage II (Geha et al. 2017; Mao et al. 2021) and 179 ELVES (Carleston et al. 2021): 10^{6}-10^{10} Msun
- Field galaxies - deep Stripe 82 + DECaLS sample from Chamba et al. 2022 + Extended to lower masses with the Updated Nearby Galaxy Catalogue (Karachentsev et al. 2013): 10^{6}-10^{12} Msun. Cross matching with Yang et al. (2007) -> galaxies with masses < 10^{10} are in small groups or isolated environments
- After selection cuts to remove 'contaminated' galaxies (bright stars, overlapping neighbours, cirri, intra-cluster light) - 894 galaxies with <10^{10} Msun, 17 more massive, luminous galaxies

Comparing the sizes of field and Fornax cluster galaxies

Effective Radius-mass



Edge Radius-mass

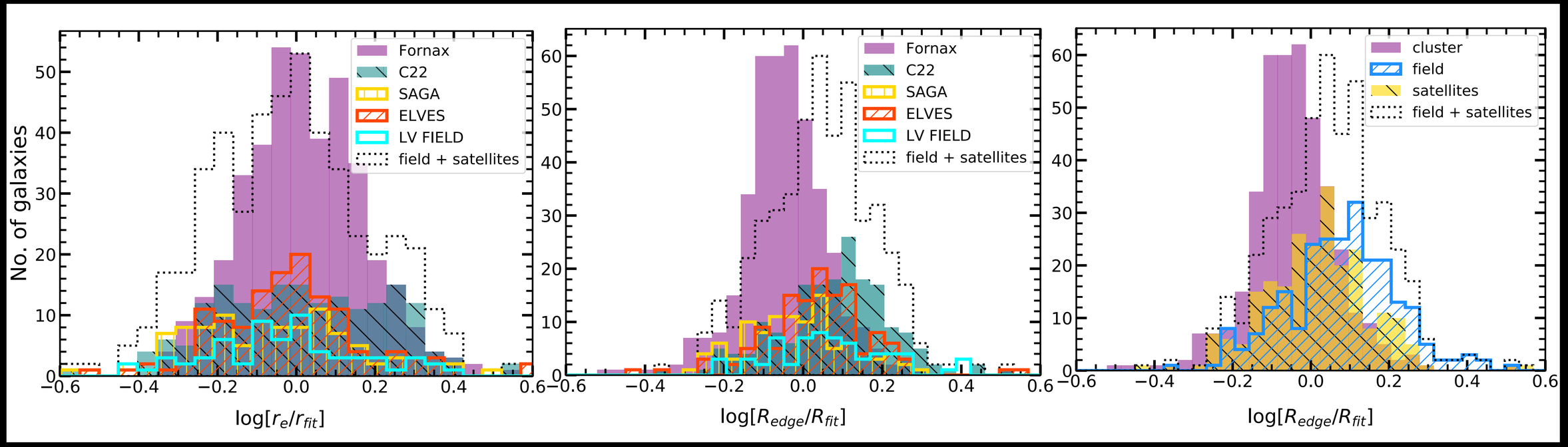


Chamba, Hayes, LSST-DESC (2024)

Fornax galaxies are ~ 50% smaller compared to the field sample

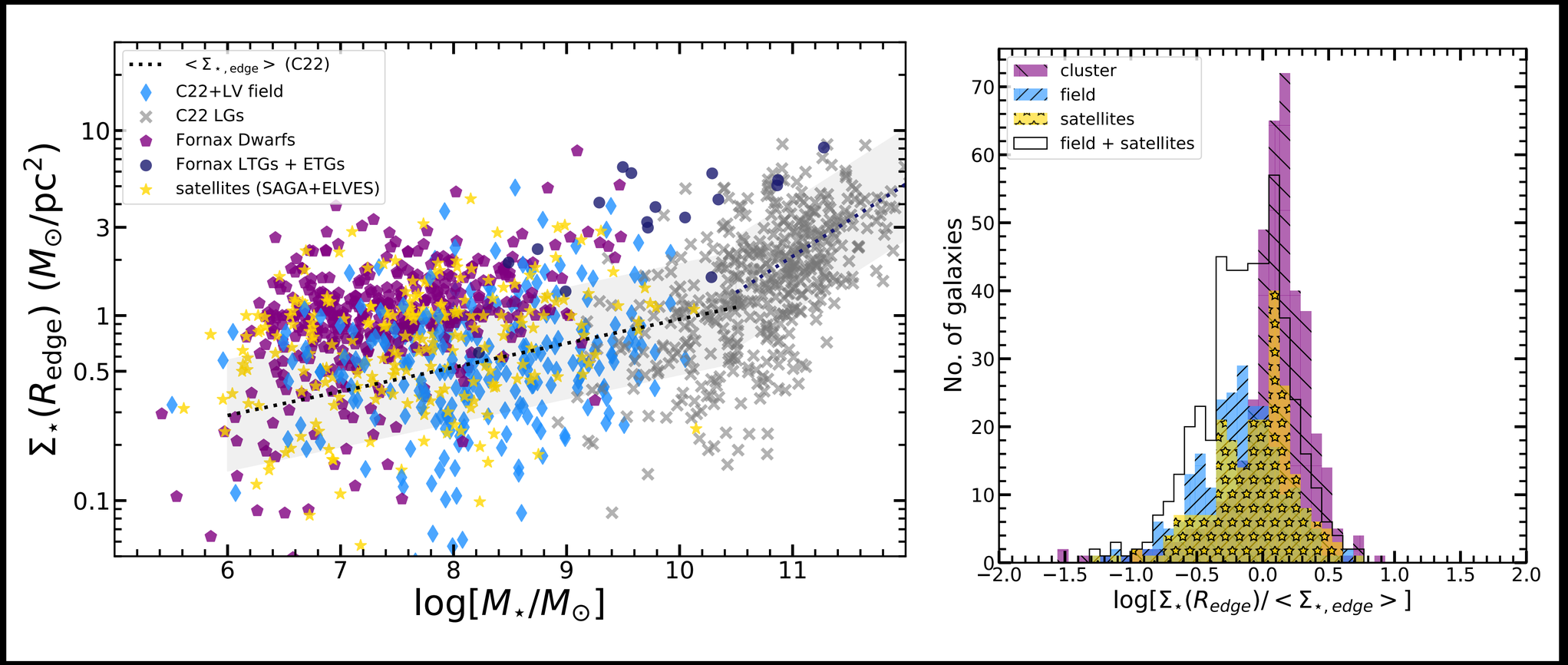
Effective Radius

Edge Radius



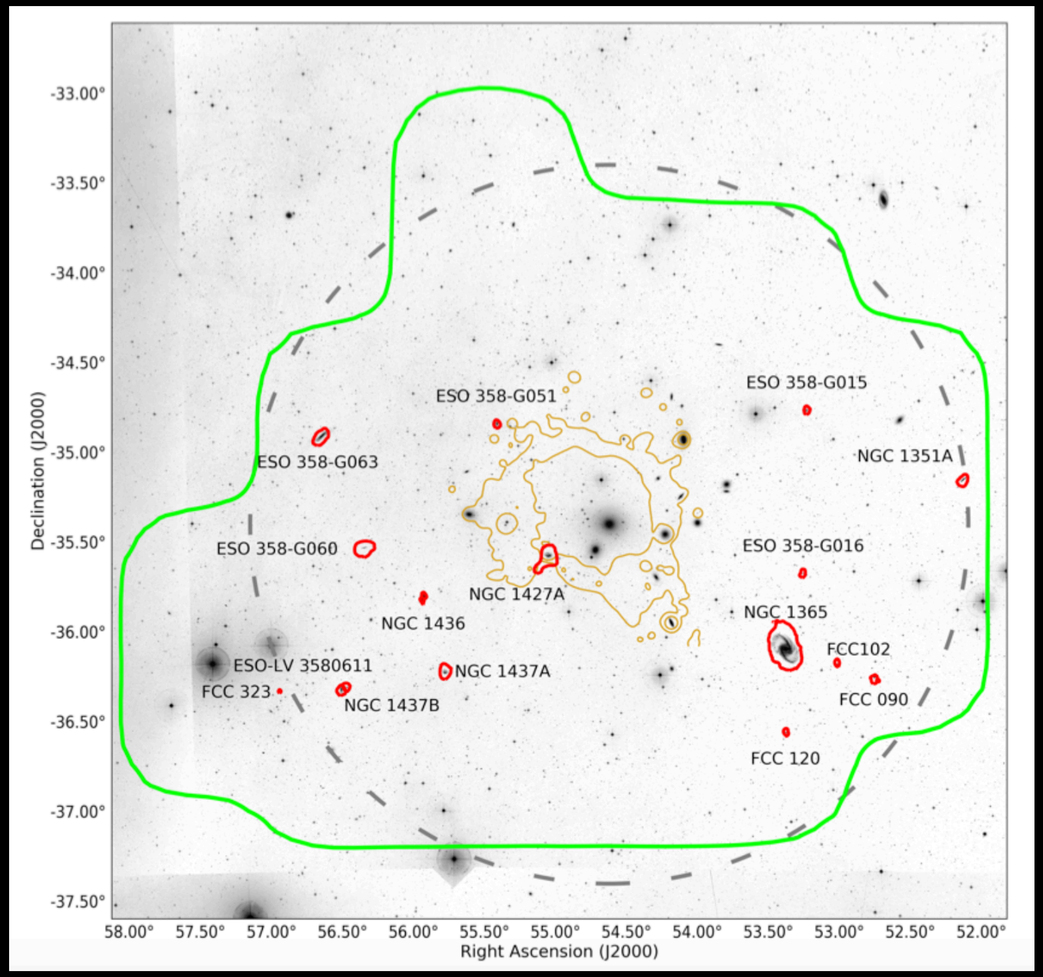
Chamba, Hayes, LSST-DESC (2024)

Fornax galaxies are two times more dense at the location of the edge

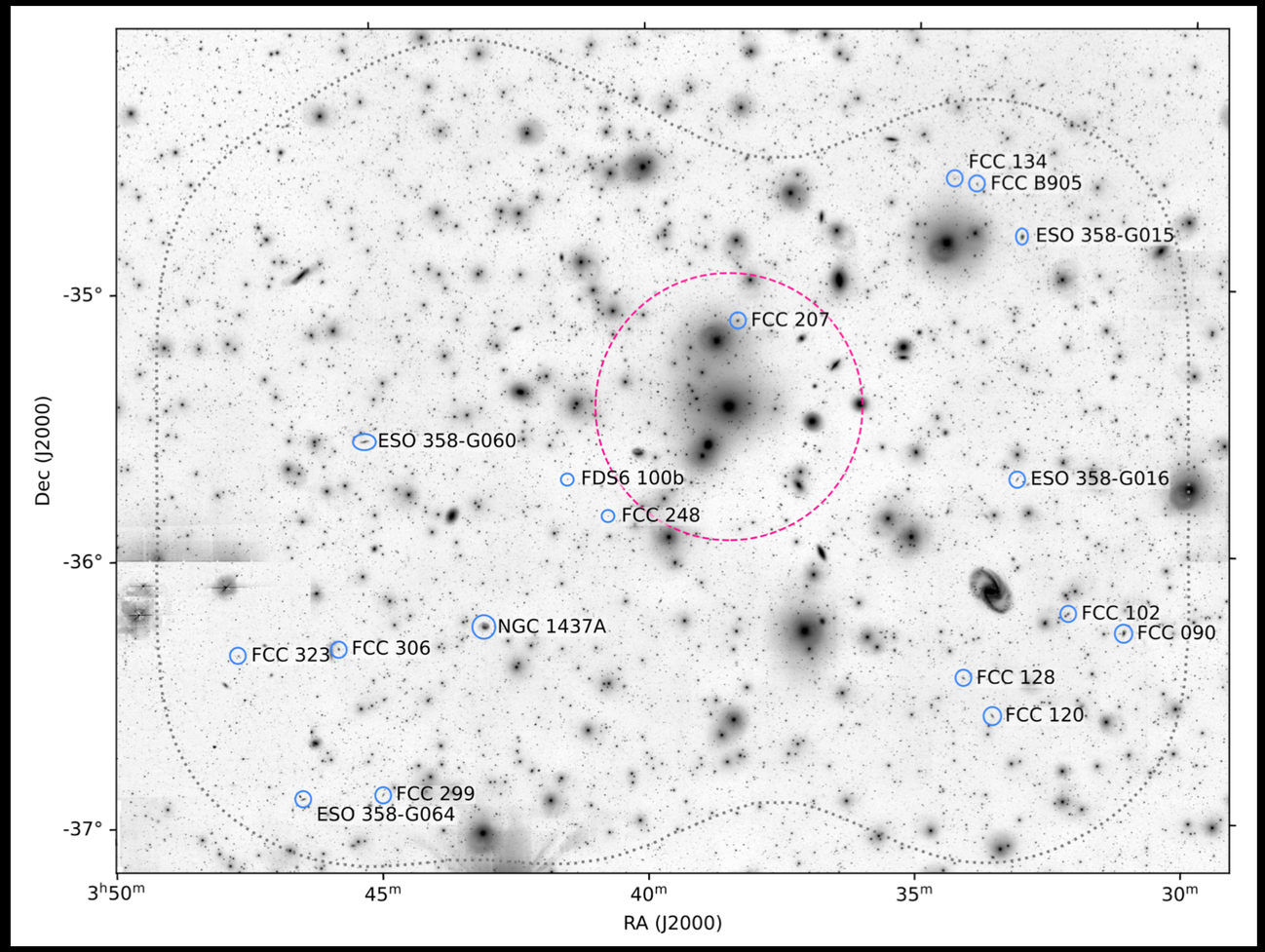


Chamba, Hayes, LSST-DESC (2024)

HI in Fornax has been rapidly removed



ATCA blind survey
(Loni et al. 2021)

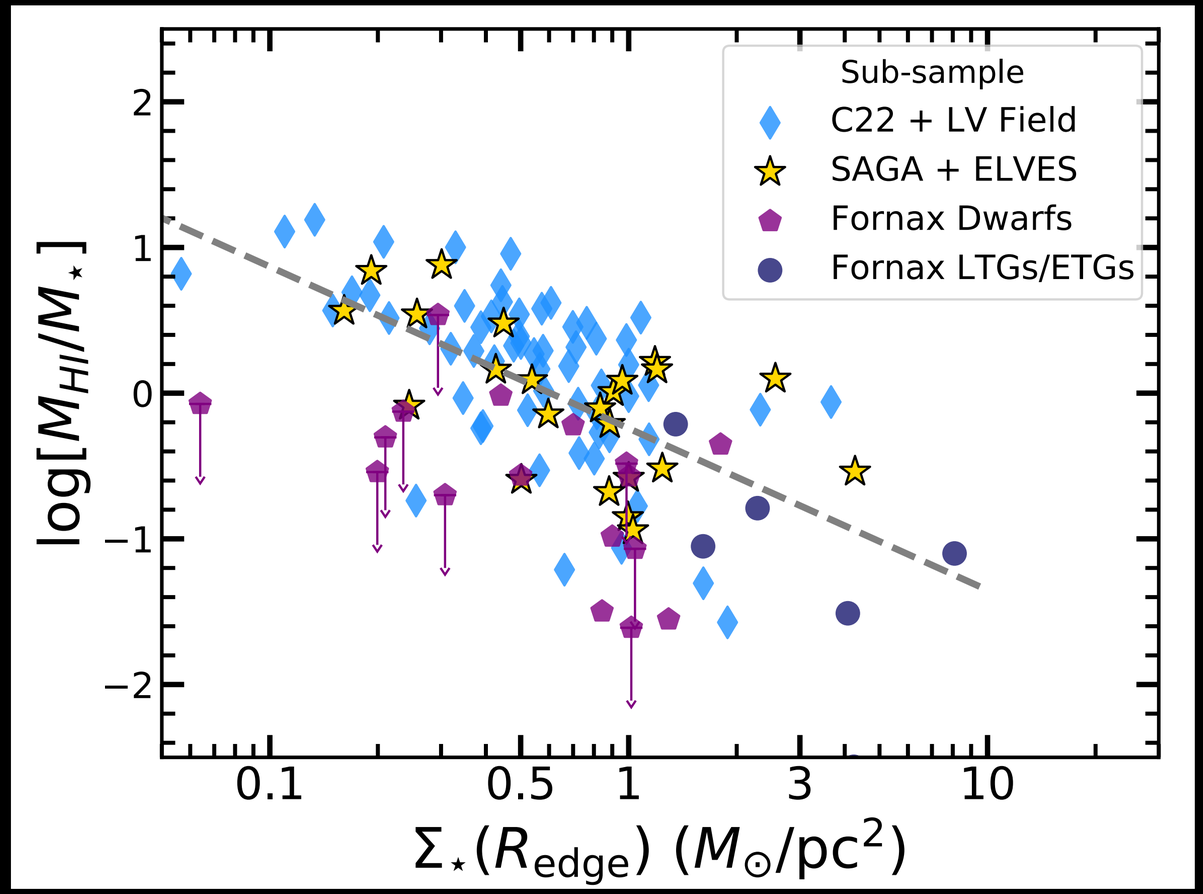


MeerKAT Fornax Survey
(Serra et al. 2023, Kleiner et al. 2023)

Cluster tides+Ram pressure takes it all?

Galaxies with lower HI fractions have higher density edges

HI masses compiled from the literature (Karachentsev et al. 2013, Durbala et al. 2020, Loni et al. 2021, Kleiner et al. 2023, Zhu & Putman 2023)



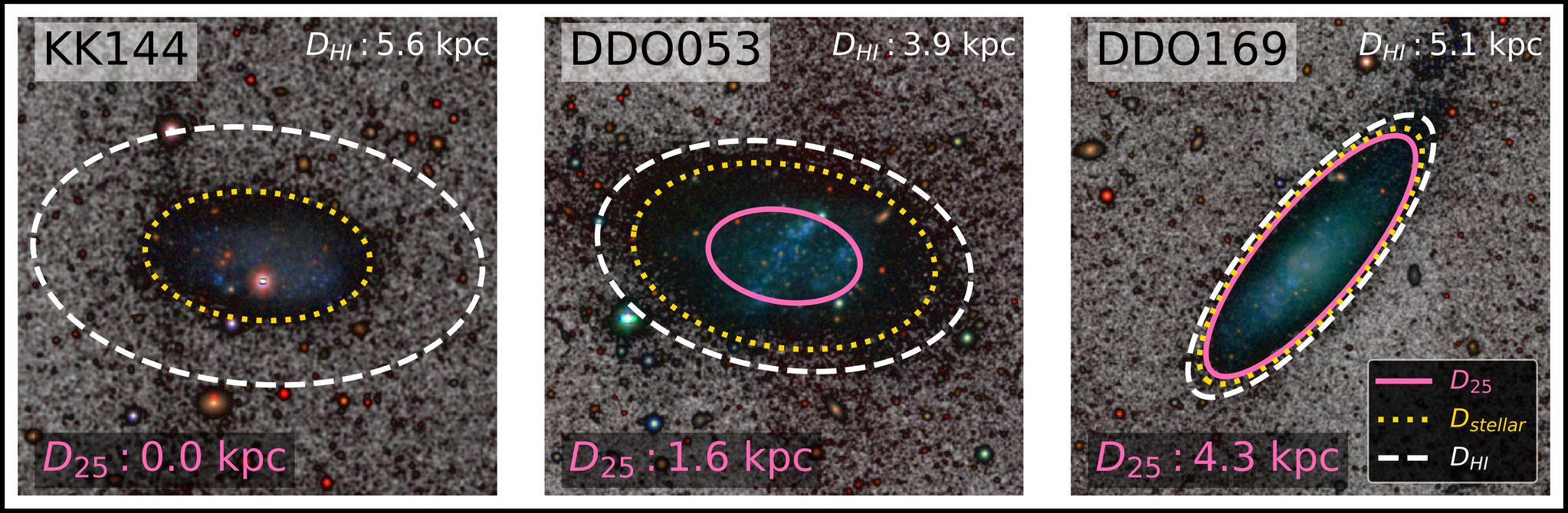
Chamba, Hayes, LSST-DESC (2024)

Comparing stellar and HI size relations

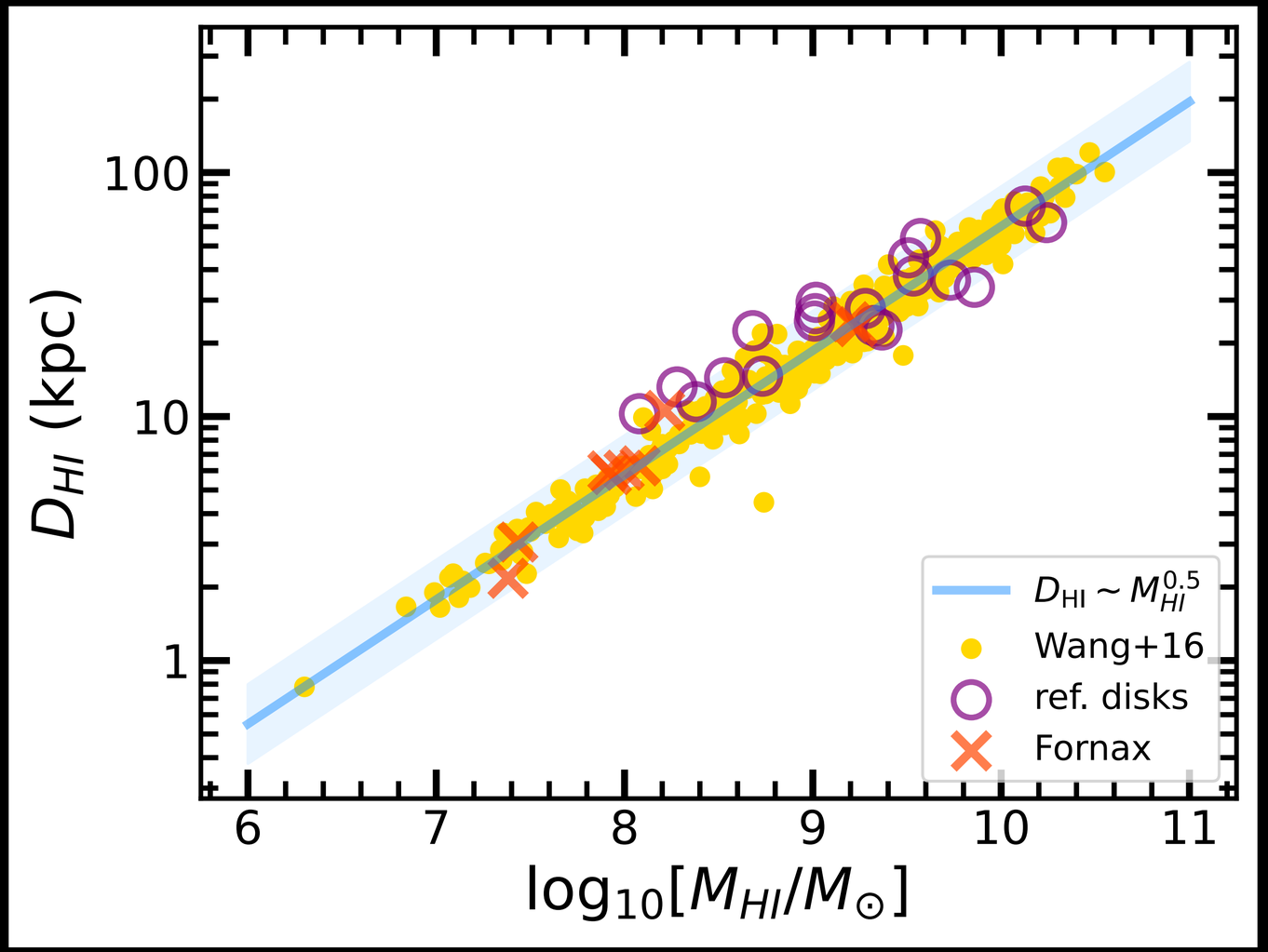
Chamba, Marcum, Saintonge et al. (2024)

$D_{stellar}$ = diameter defined at the location of stellar edges (optical, $2R_{edge}$)

D_{HI} = diameter where HI surface density is 1 Msun/pc ^{2} (HI)

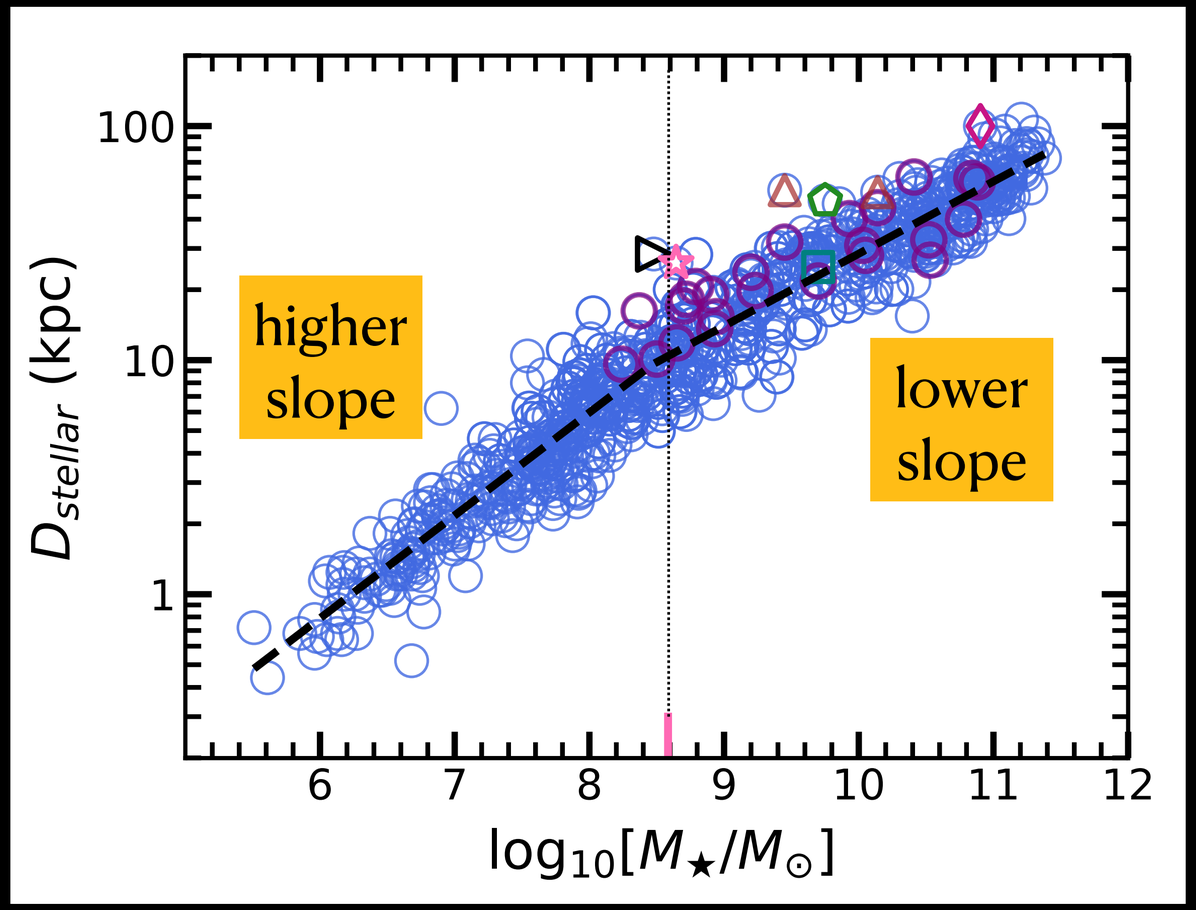


HI diameter relation is linear & has low scatter



Chamba, Marcum, Saintonge et al. (2024)

But the stellar edge relation is actually broken!

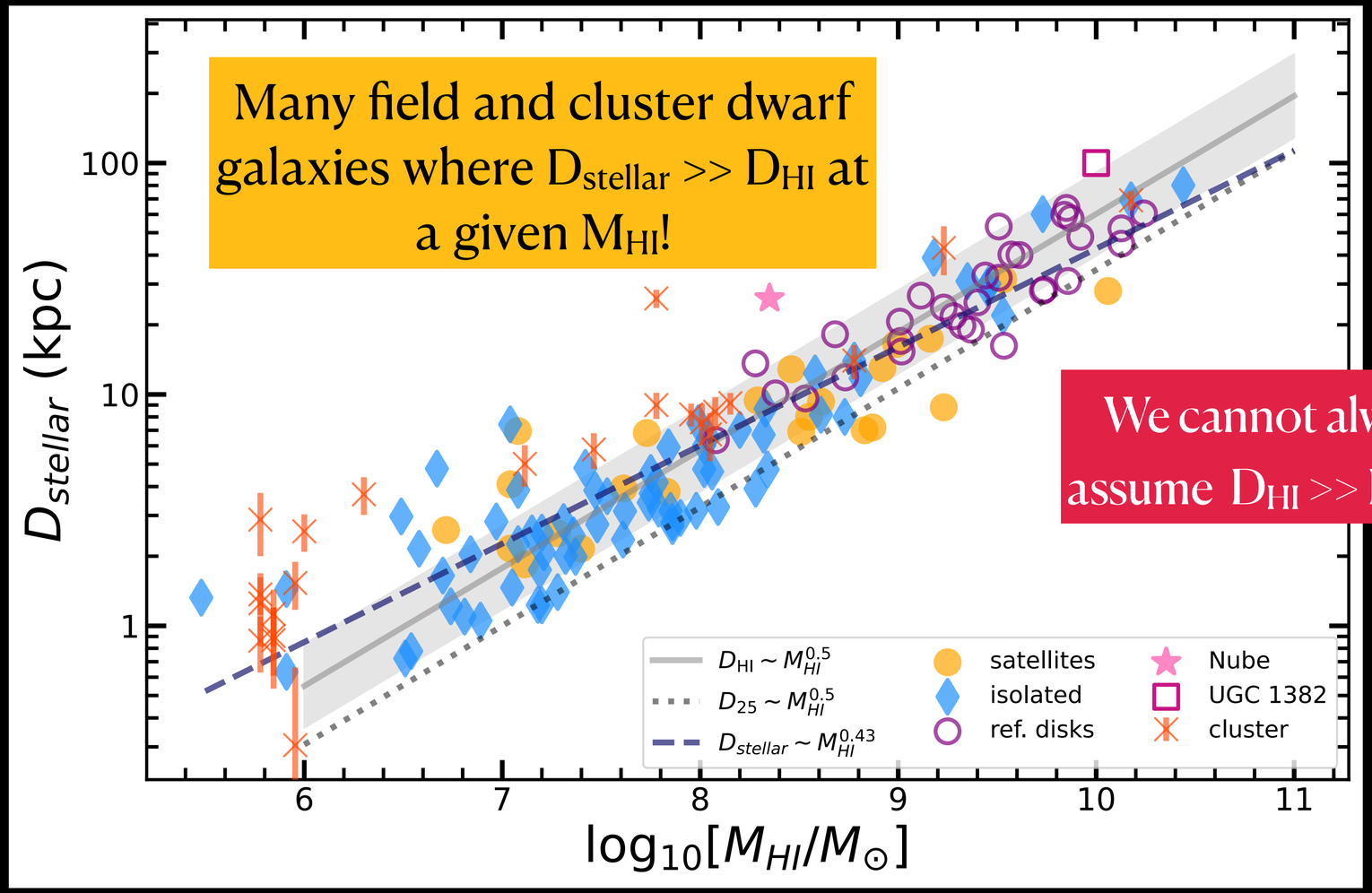


- Break M_{star} ~ 4 x 10^8 M_{sun}
- Compilation of truncations from the literature on disk galaxies (see Chamba, Marcum, Saintonge et al. 2024)

Total sample
$D_{stellar} \sim M_\star^{0.45}$ $(M_\star < m_{break})$
$D_{stellar} \sim M_\star^{0.32}$ $(M_\star \geq m_{break})$
van der Kruit+07
UGC 00180 (Trujillo+16)
Martinez-Lombilla+19
NGC 1042 (Trujillo+21)
UGC 7321 (Diaz-Garcia+22)
UGC 11859 (Ossa-Fuentes+23)
Nube (Montes+24)
UGC 1382

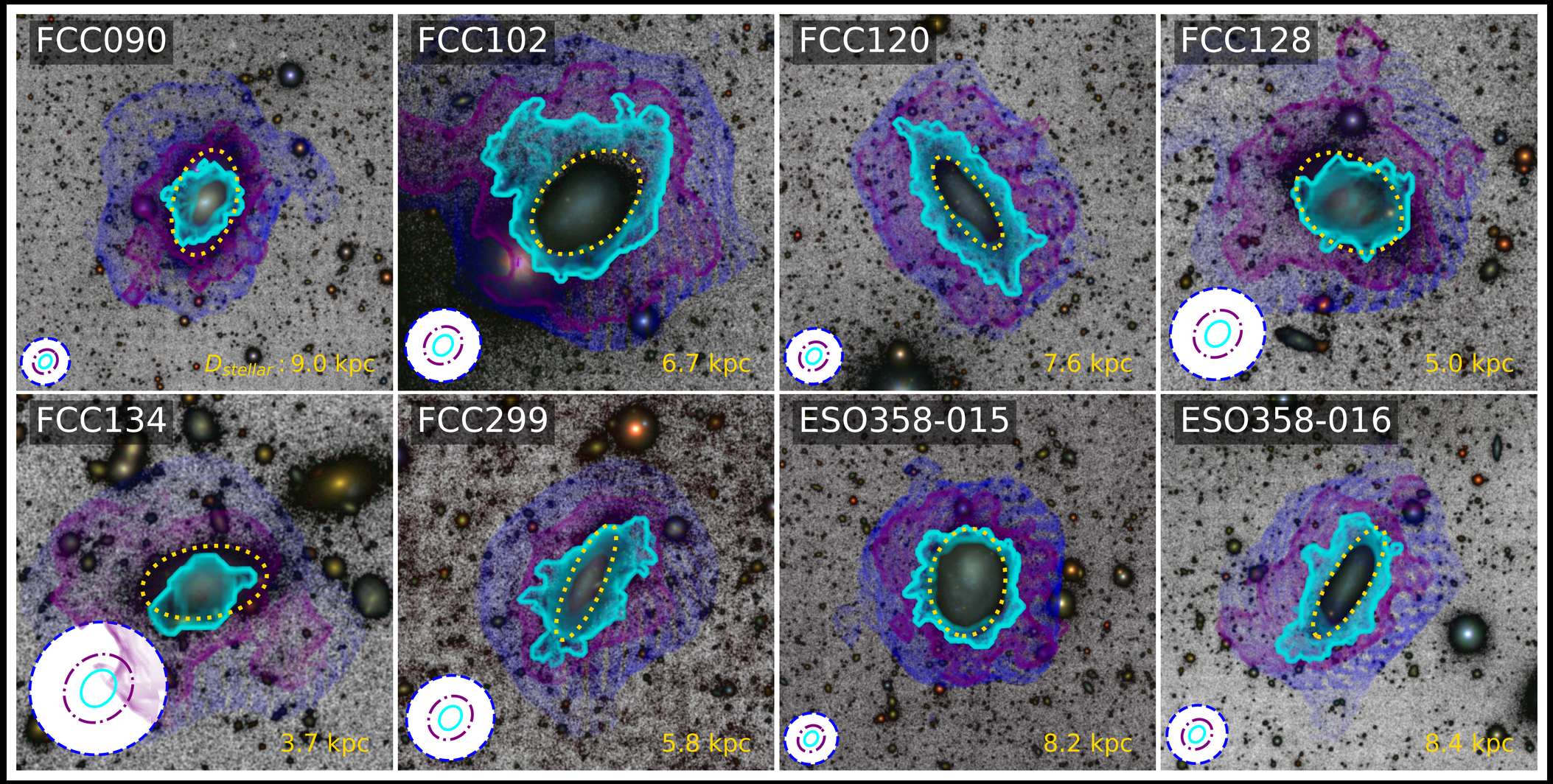
Chamba, Marcum, Saintonge et al. (2024)

To answer why: $D_{stellar}$ & D_{HI} as a function of M_{HI}



Chamba, Marcum, Saintonge et al. (2024)

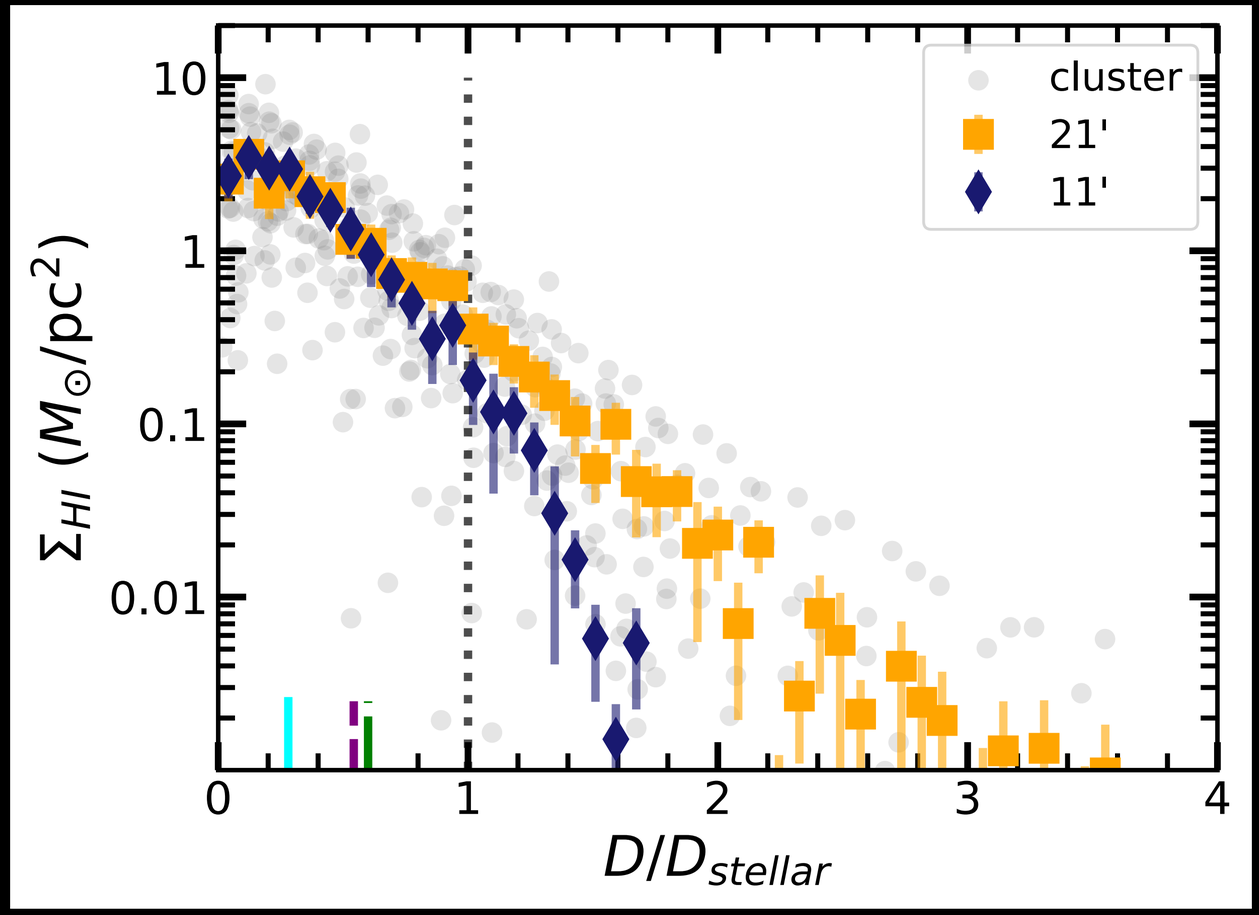
Fornax dwarfs have low density HI beyond D_{HI}



MeerKAT Fornax Survey (Serra et al. 2023)
Fornax Deep Survey (Peletier et al. 2020)

Chamba, Marcum, Saintonge et al. (2024)

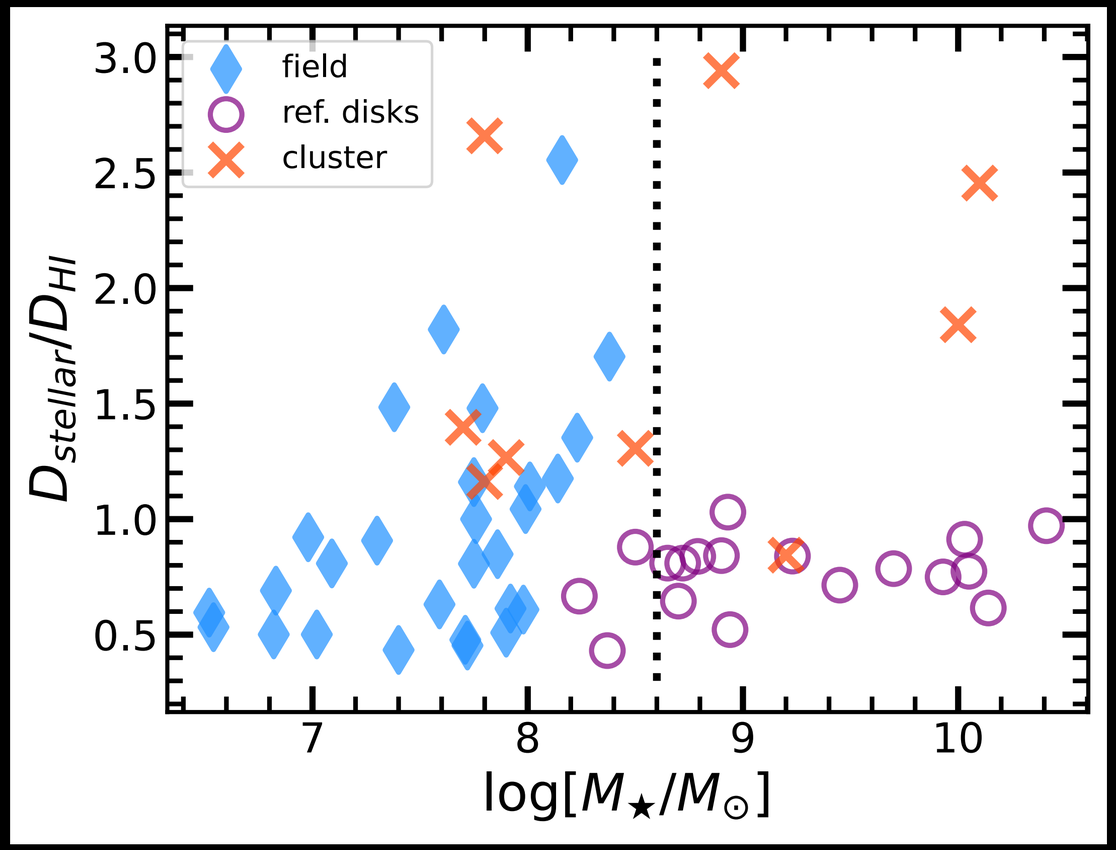
Environmental quenching has *lowered* the HI surface density at the location of the stellar edge



Chamba, Marcum, Saintonge et al. (2024)

$D_{stellar}$ >> D_{HI} for field galaxies is evidence for how *stellar feedback* regulates size

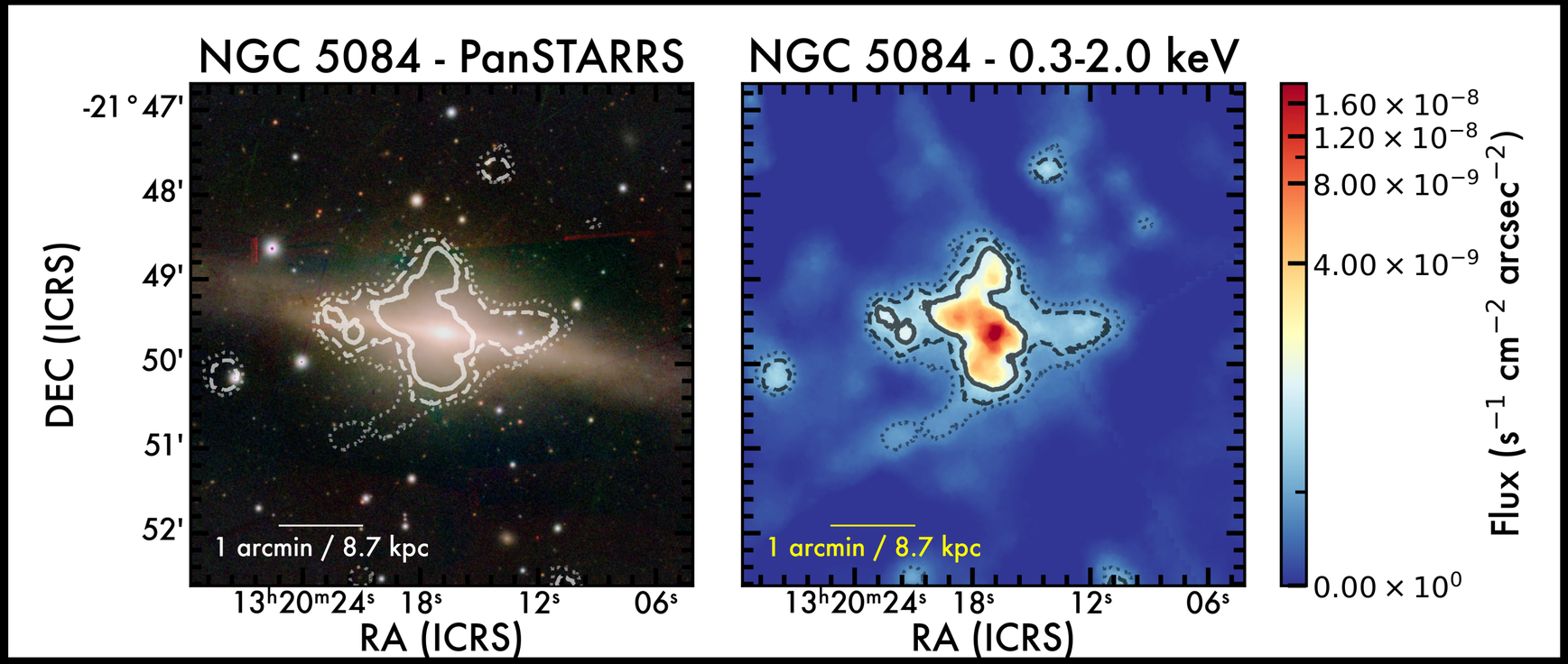
- Stellar feedback causes outflows of gas which can then cool and fall back into the center of the galaxy, inducing star formation.
- Gaseous outflows may also lower the gravitational potential significantly. Therefore, the feedback process could change both the HI and optical sizes
- The break location is within the stellar mass range where the influence of feedback is expected to be more prominent (e.g. El-Badry et al. 2016)



See Discussion in Chamba, Marcum, Saintonge et al. (2024)

Ongoing work at Ames: Analyzing hot gas using X-ray imaging from the Chandra Space Telescope

Borlaff, Marcum, Temi et al. (2024 a, b). New discovery of cross-shaped X-ray emission in a disk galaxy using SAUNAS (Soft-band Amplification of Ultra Noisy Astronomical Signal)



Conclusions

Need multi-wavelength analysis to understand the origin of scaling relations

- Chamba, Hayes & LSST-DESC (2024)

  The impact of environment on size: Fornax cluster galaxies are ~50% smaller and denser at the location of the edge compared to field galaxies of similar stellar mass

- Chamba, Marcum, Saintonge et al. (2024)

  The stellar edge - mass relation is broken. The sizes of low mass dwarf galaxies where $M_{star} < 4 \times 10^8 M_{sun}$ are more impacted by *stellar feedback* & *environmental quenching*

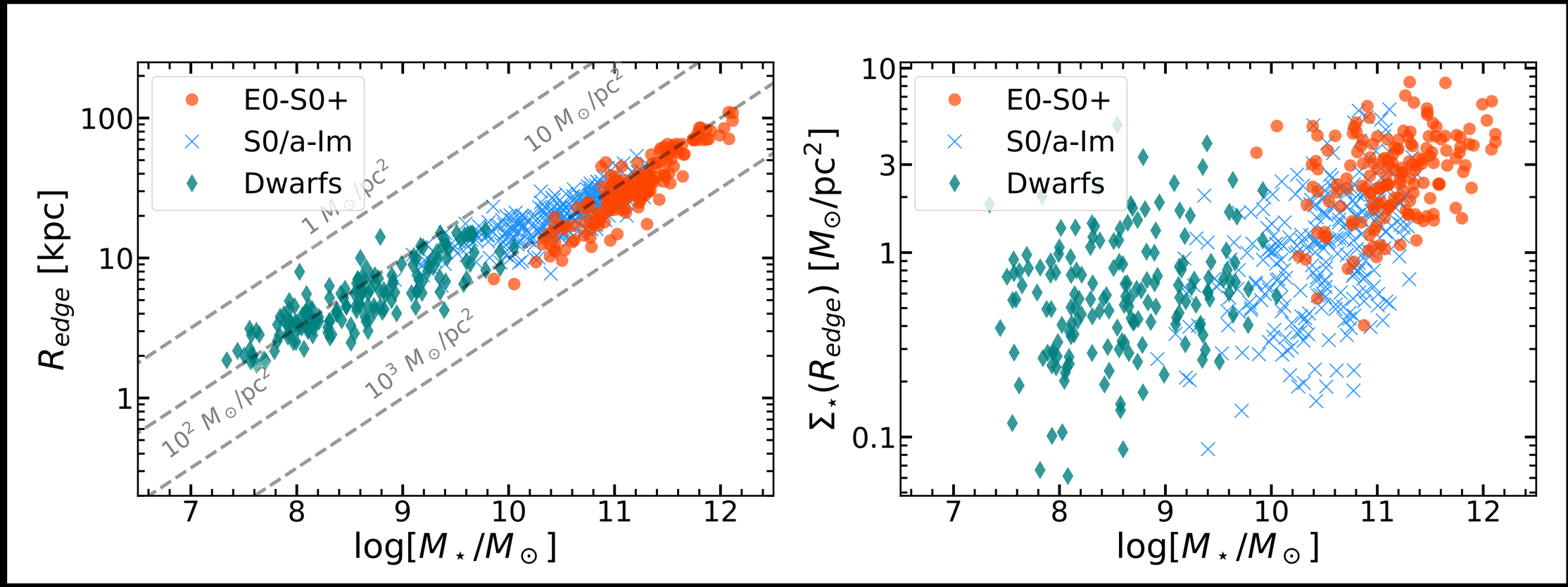
- SKA will provide homogenous deep data for field galaxies and allow us to study the scaling relations of the fainter, HI-poor systems

- Stay tuned for future work combining HI and X-ray imaging!

Back up

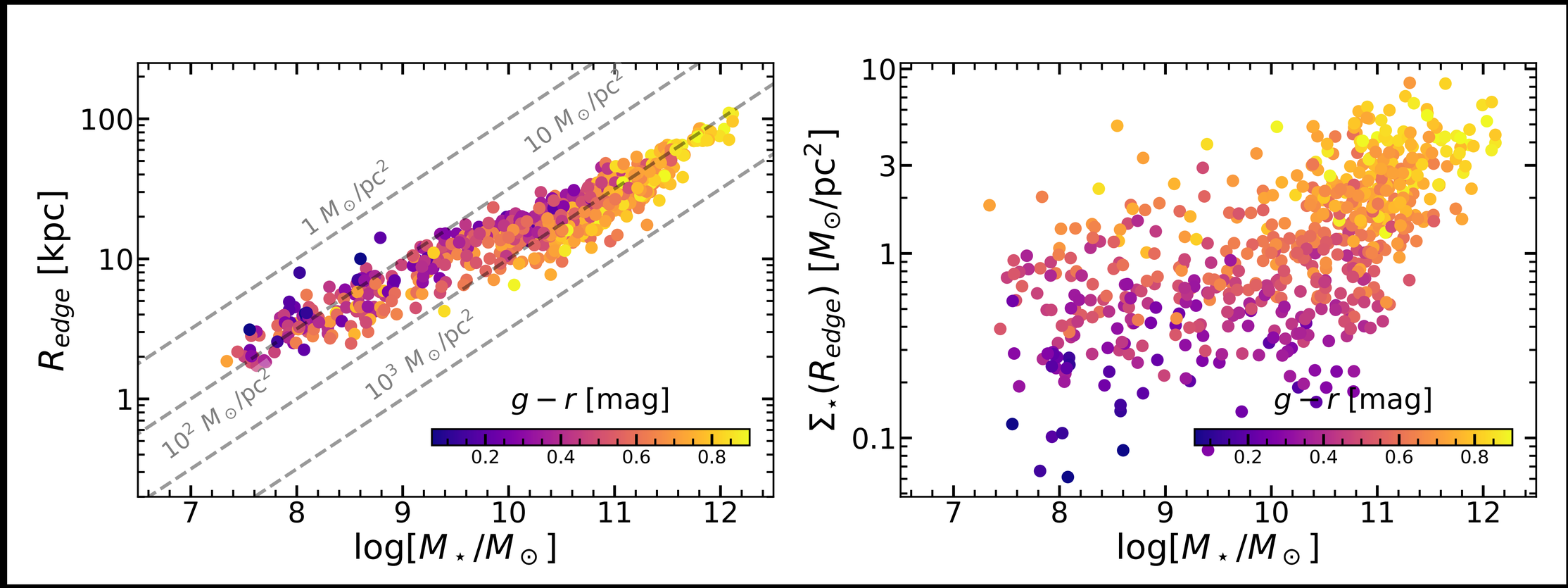
What are the edge properties in the field?

Scaling relations - Morphology (Chamba et al. 2022)



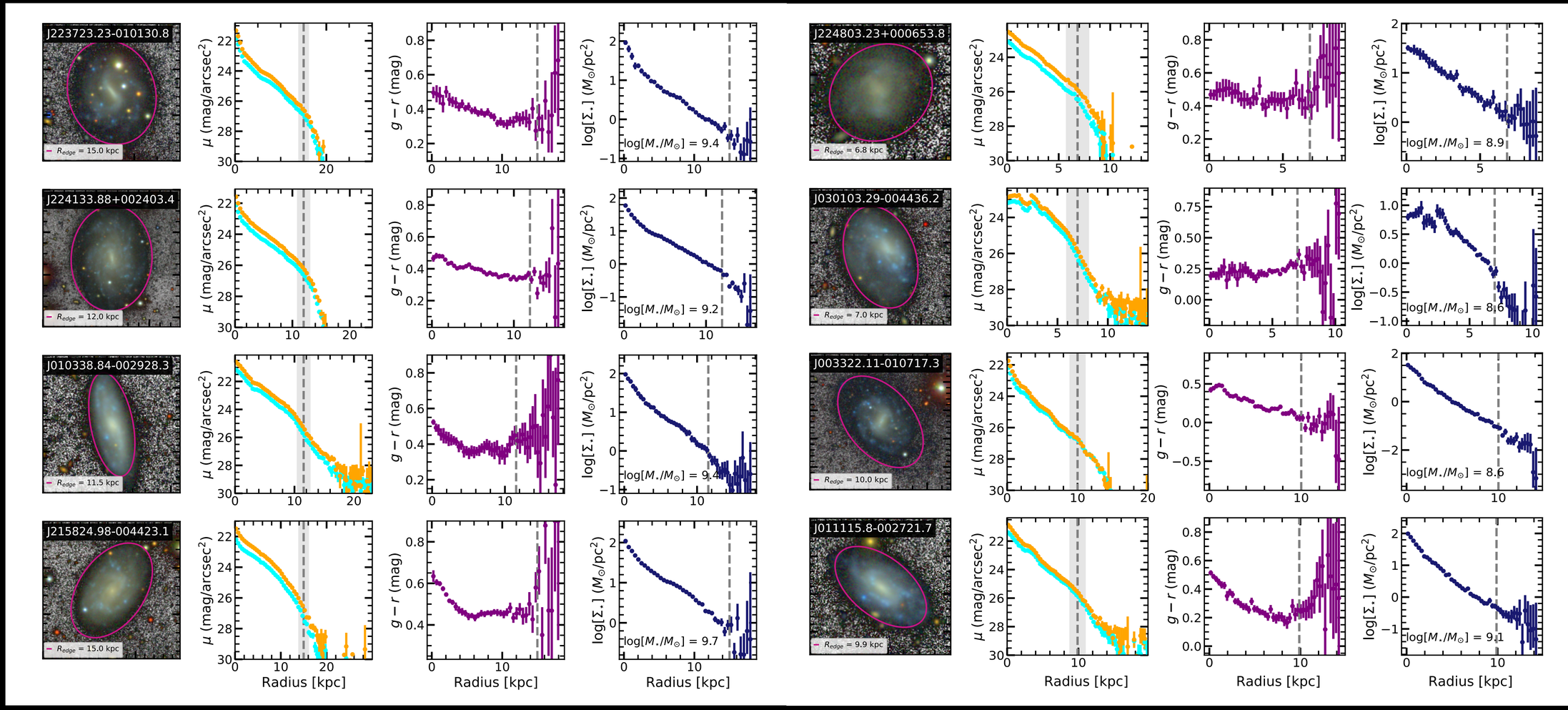
What are the edge properties in the field?

Scaling relations - Colour (Chamba et al. 2022)



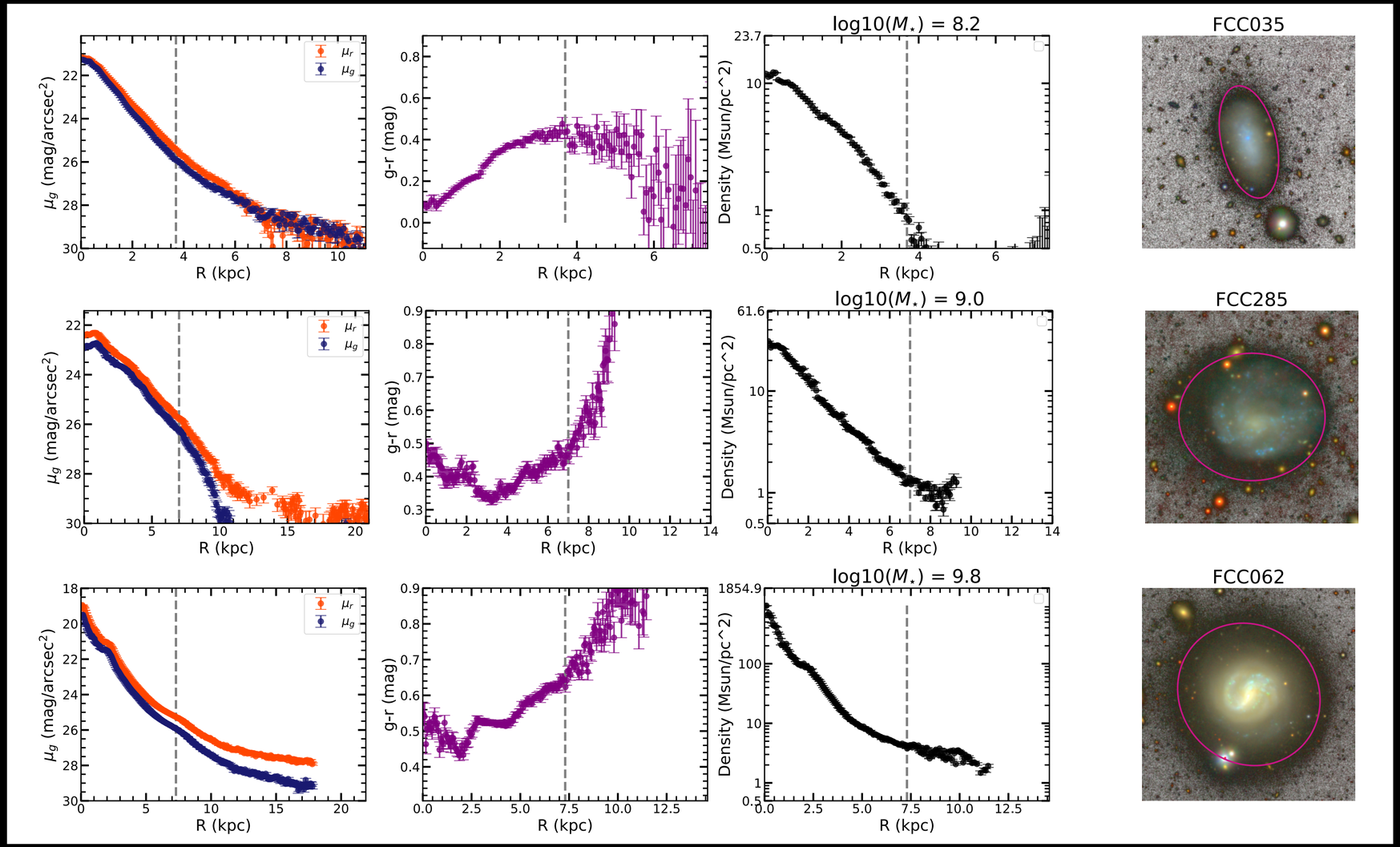
More examples

Field sample (Stripe 82)



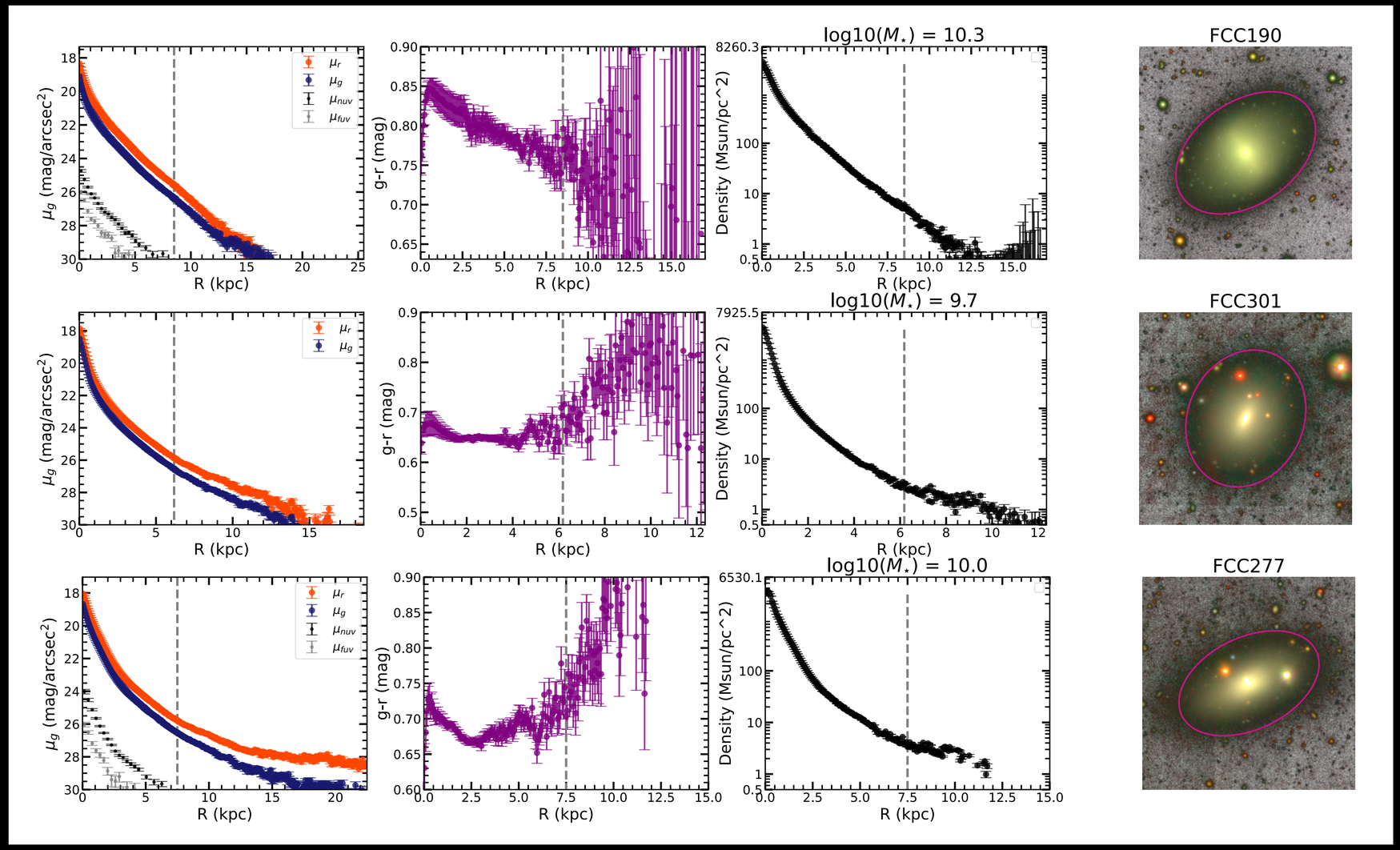
Examples

Fornax sample (FDS)



Examples

Fornax sample (FDS) - to compare with transition radius (Spavone et al. 2020)



HI-stellar mass relations