Build-up of stellar halos

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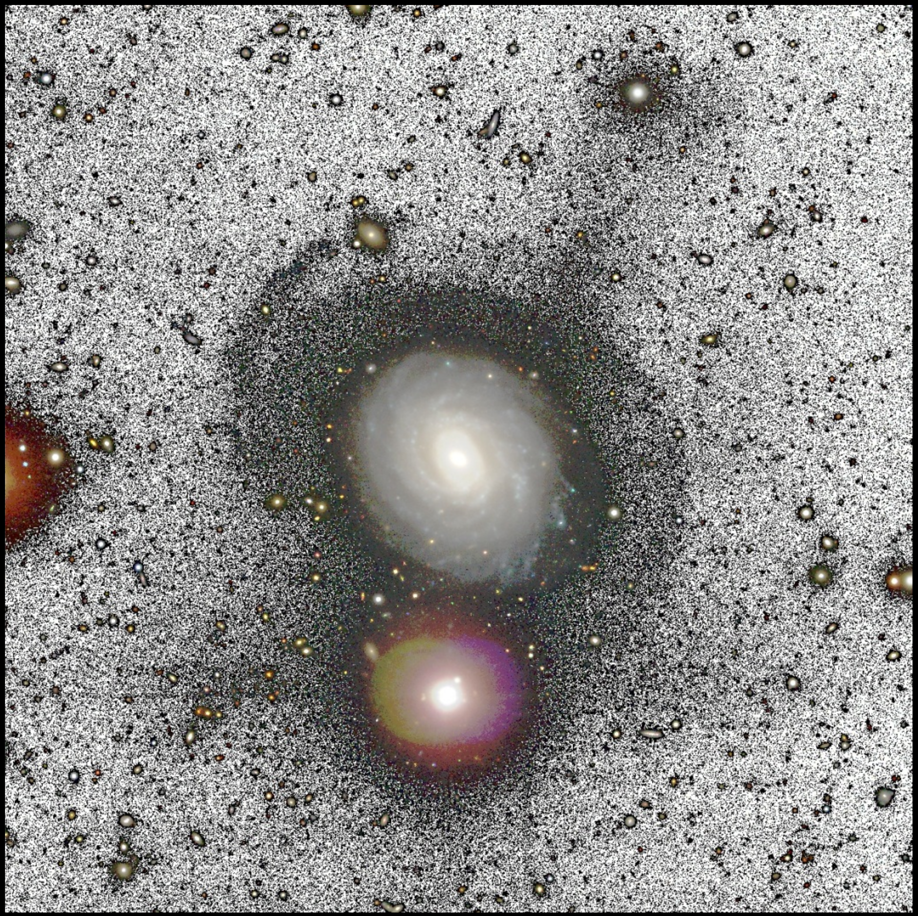
www.iac.es/project/traces

The two modes of stellar halo formation



NGC7716 as seen by SDSS Stripe82; Bakos & Trujillo (2012)

Two flavours:

In-situ

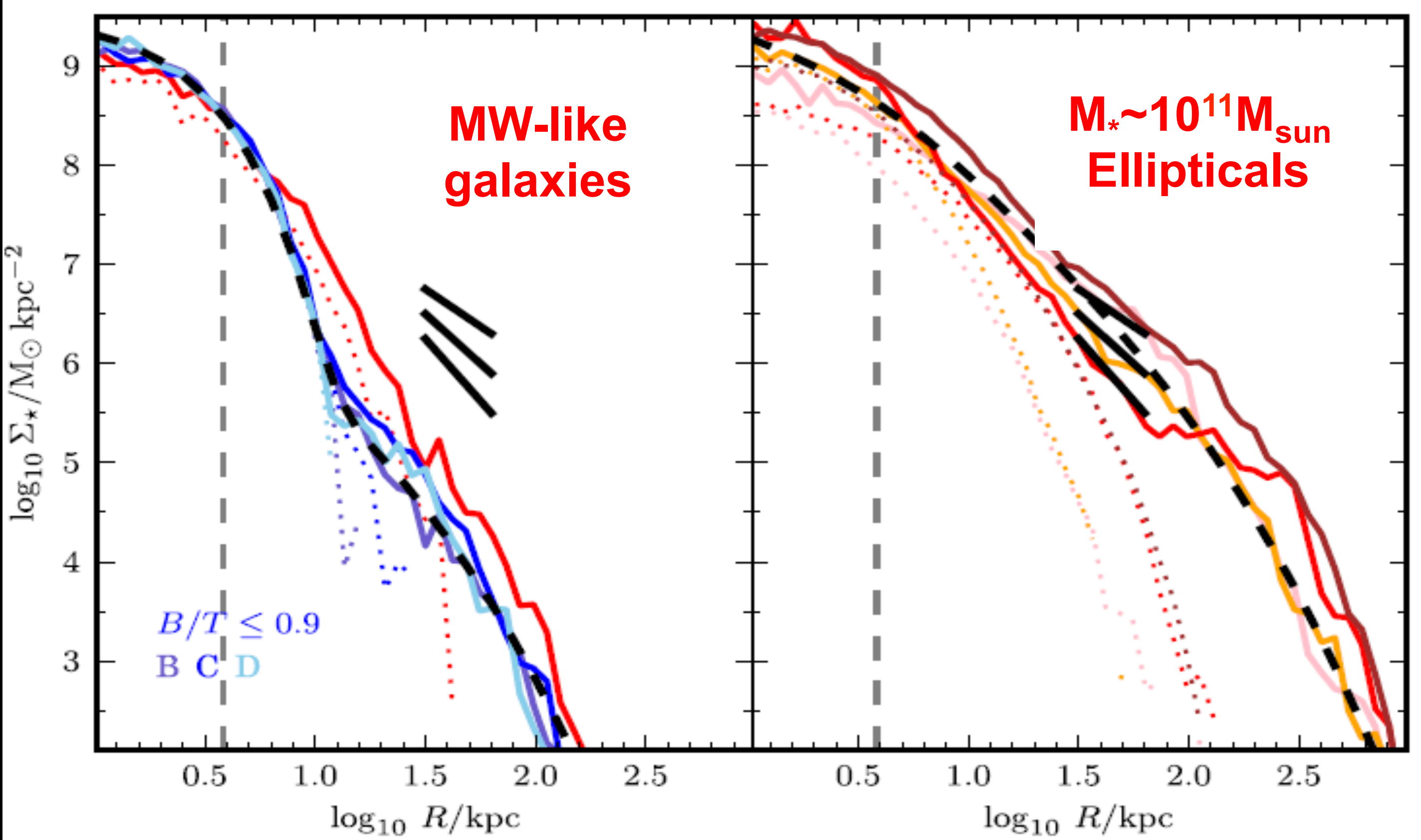
Stars form by accreted gas or by disc heating (e.g. Zolotov+09; McCarthy+12; Tissera+14)

Ex-situ

Accreted satellites completely or partially disrupted (e.g. Bullock & Johnston 05; Johnston+08; Cooper+10; Font+11; Tissera+12; Cooper+13; Pillepich+14)

The different distributions of the accreted stars

Cooper et al. (2013)



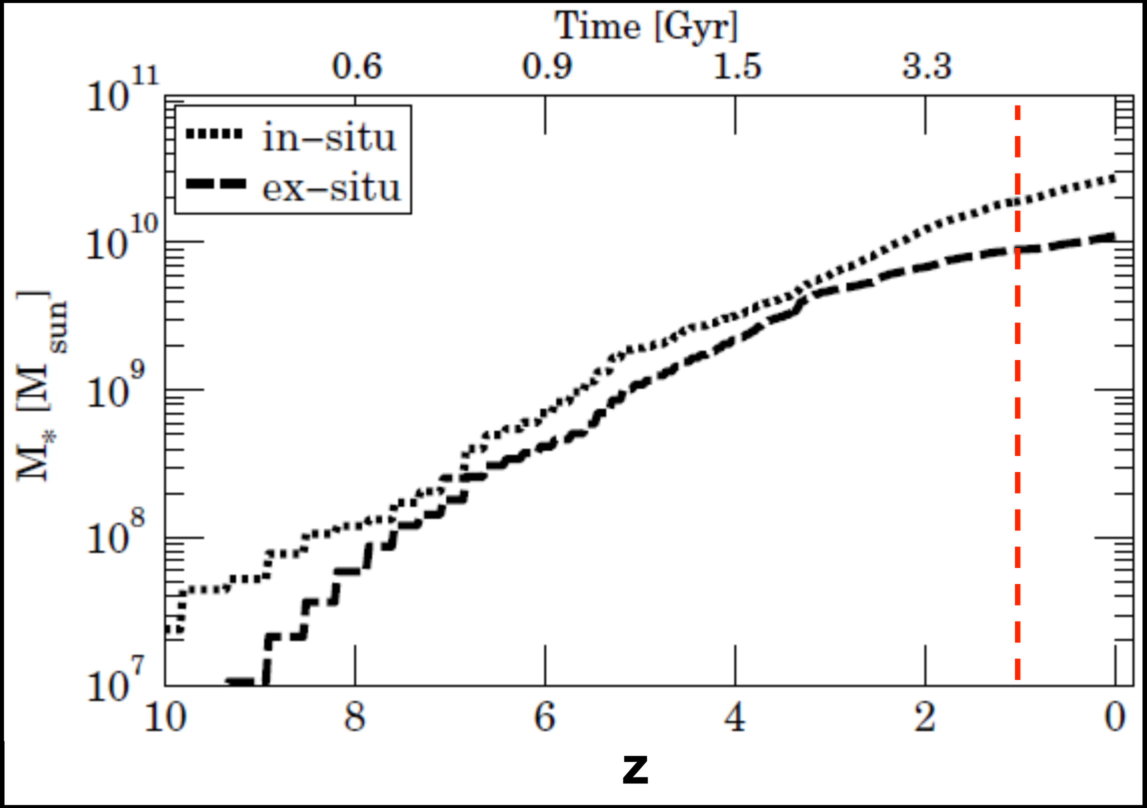
Two different accretion distributions depending on the morphology:

a) A break at μ_V~28.5 mag/arcsec^2 in MW-like galaxies (see also Abadi+06)

b) No obvious feature in early-type morphologies

The stellar halo evolution with cosmic time: MW-like galaxies

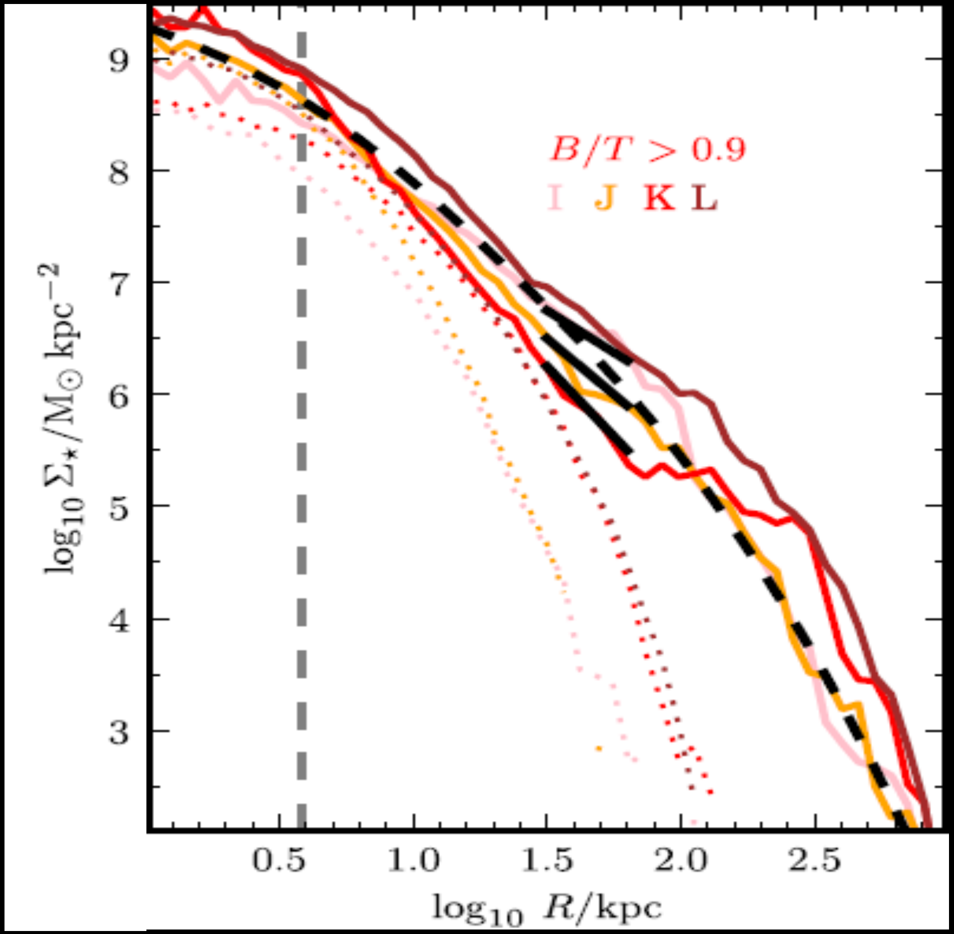
Pillepich et al. 2015



Since z~1, stellar halos of MW-like galaxies are expected to evolve very little (see also Sales et al. 2007, Cooper et al. 2010 and Font et al. 2011)

The stellar halo evolution with cosmic time: massive ($M_* > 10^{11}$ M_{sun}) elliptical galaxies

Cooper et al. (2013)



A continuous accretion of stars along the radial distribution; particularly more enhanced in the outermost regions

How to confront the theory with the observations?

Direct method:

- measuring the stellar halo properties at different z

a) For MW-like galaxies we use the break in the surface brightness to identify the emergence of the stellar halo

b) For massive elliptical galaxies there is not an obvious feature; We measure the amount of mass at R>10 kpc

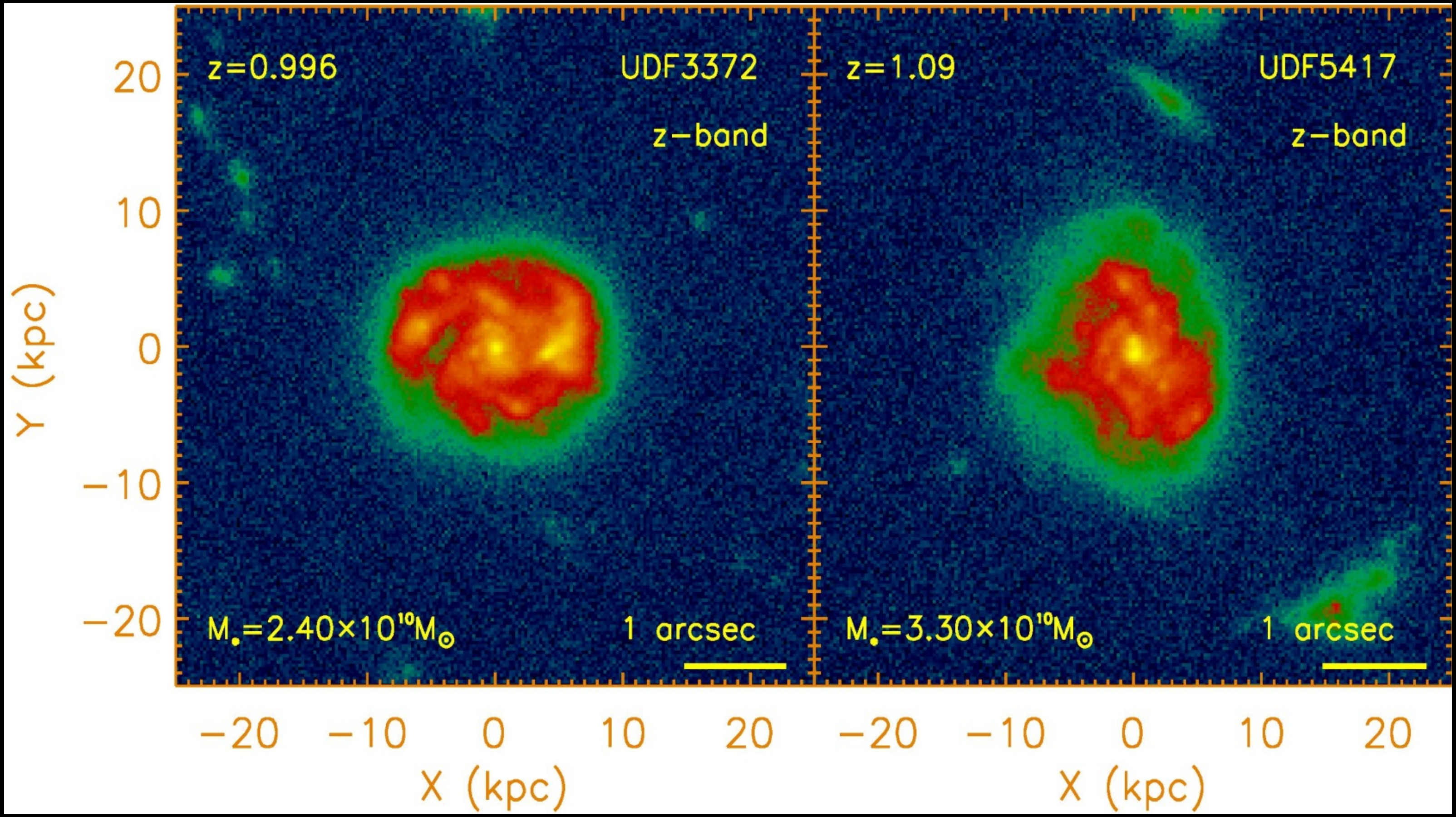
Indirect method:

- measuring the amount of stellar mass enclosed in satellites around the galaxies at different epochs

Direct methods

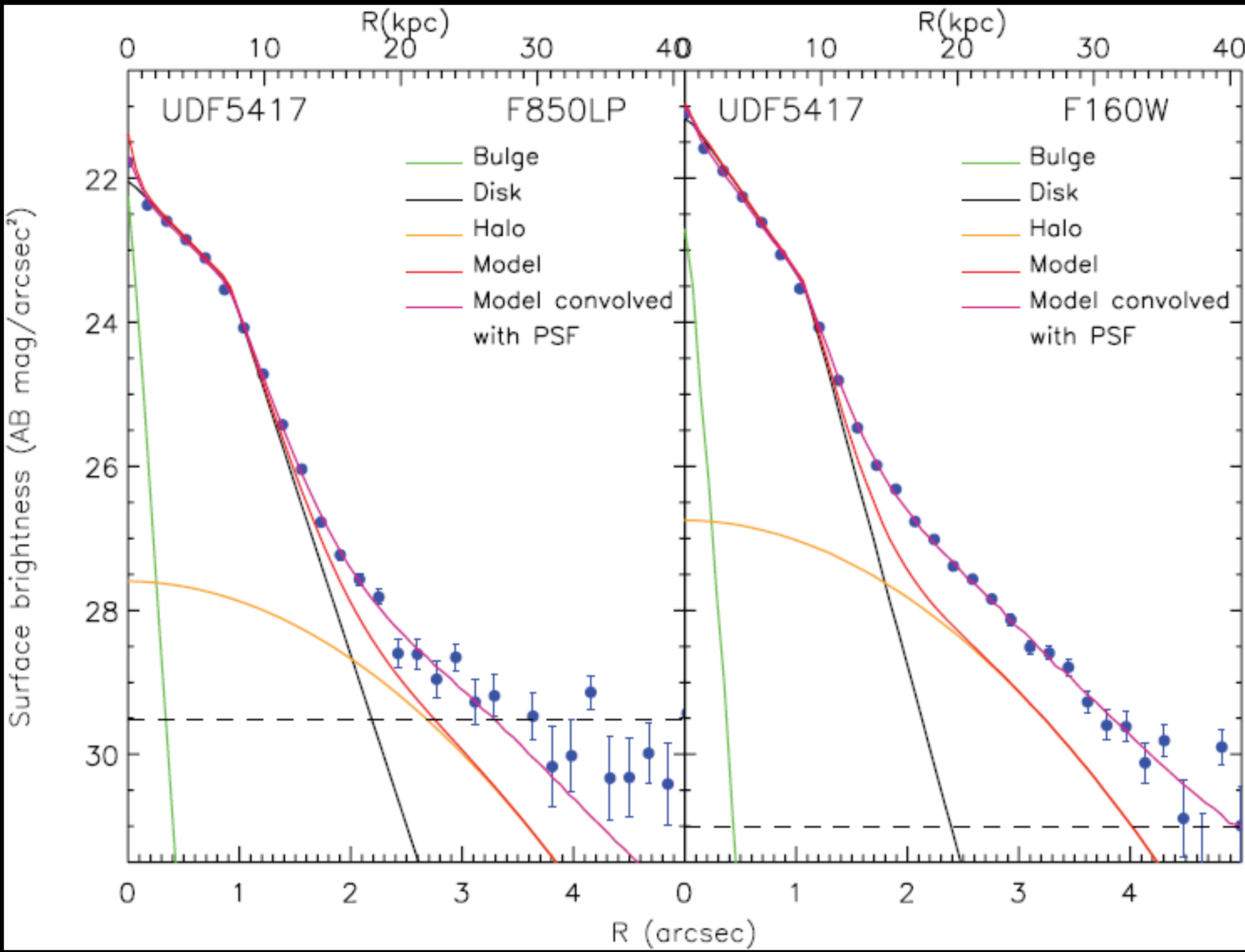
The build-up of stellar halos in MW-like galaxies

Trujillo & Bakos (2013)



2 MW-like progenitors galaxies (M_{star}~$3x10^{10}$ M_{sun}) at z~1 selected in the HUDF

The build-up of stellar halos in MW-like galaxies

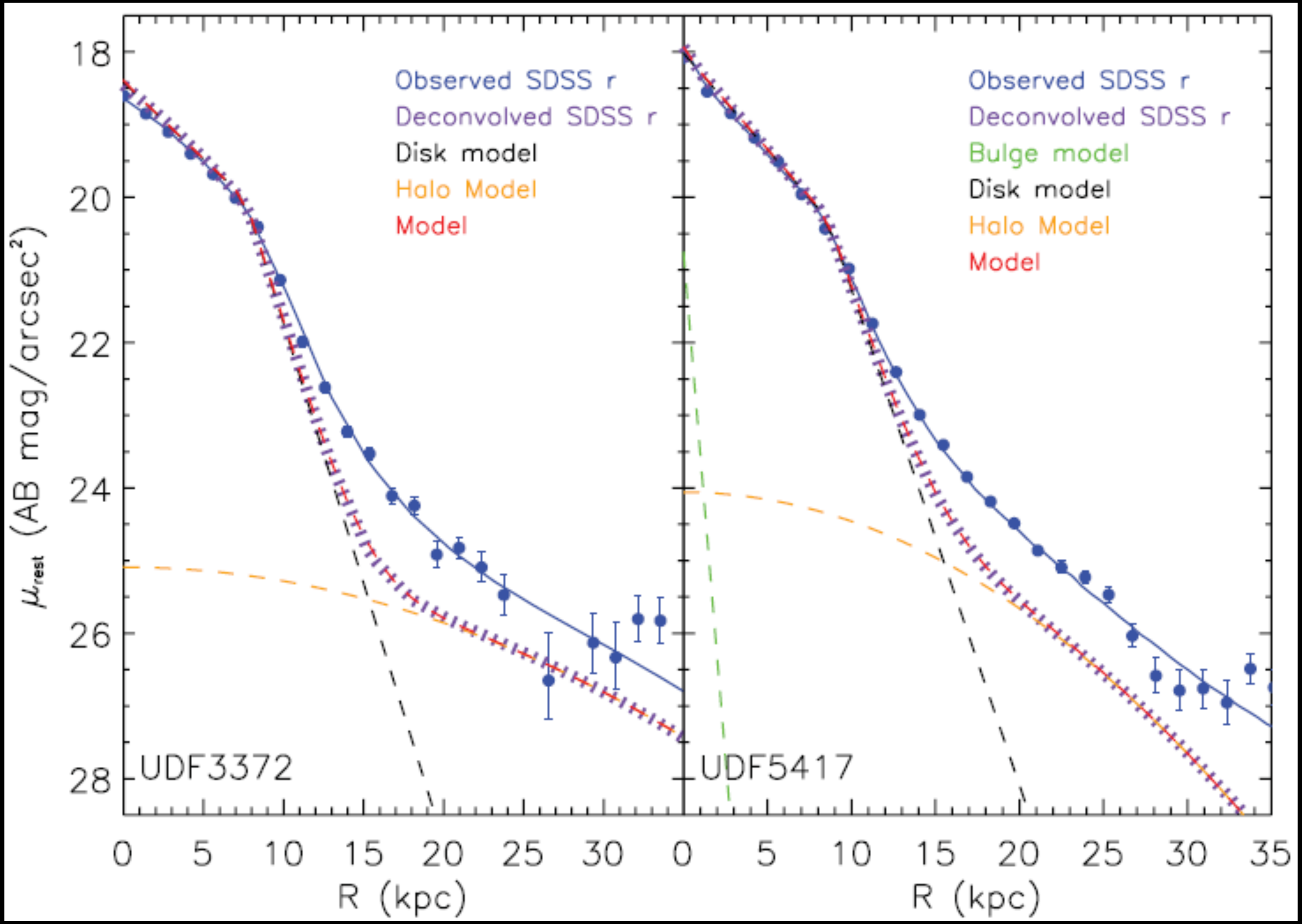


Bulge+Disk+Stellar Halo decomposition in each observed band:

F435W; F606W; F775W; F850LP; F105W; F125W; F160W

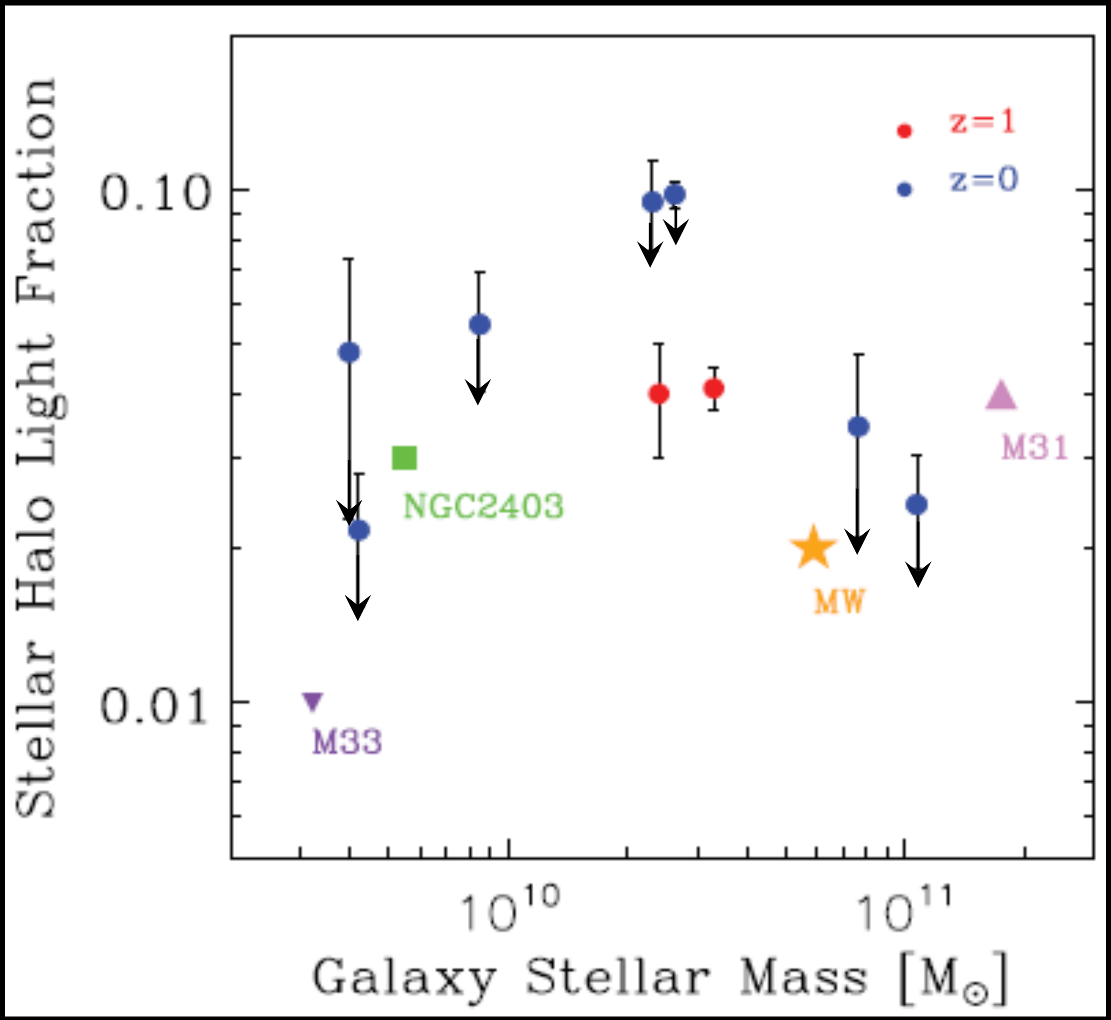
Trujillo & Bakos (2013)

The build-up of stellar halos in MW-like galaxies



Trujillo & Bakos (2013)

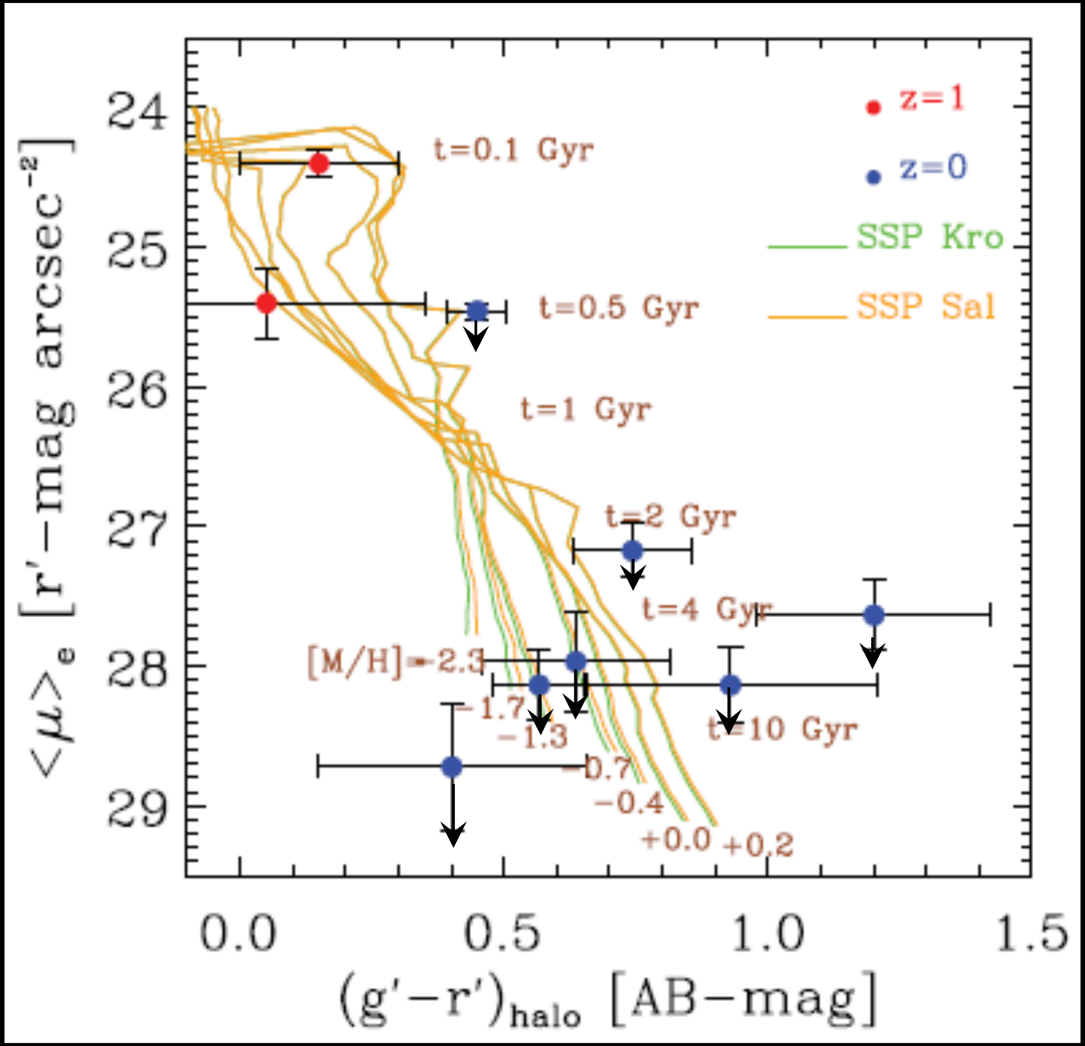
The build-up of stellar halos in MW-like galaxies



Trujillo & Bakos (2013)

Stellar Halo light fraction similar to present-day galaxies

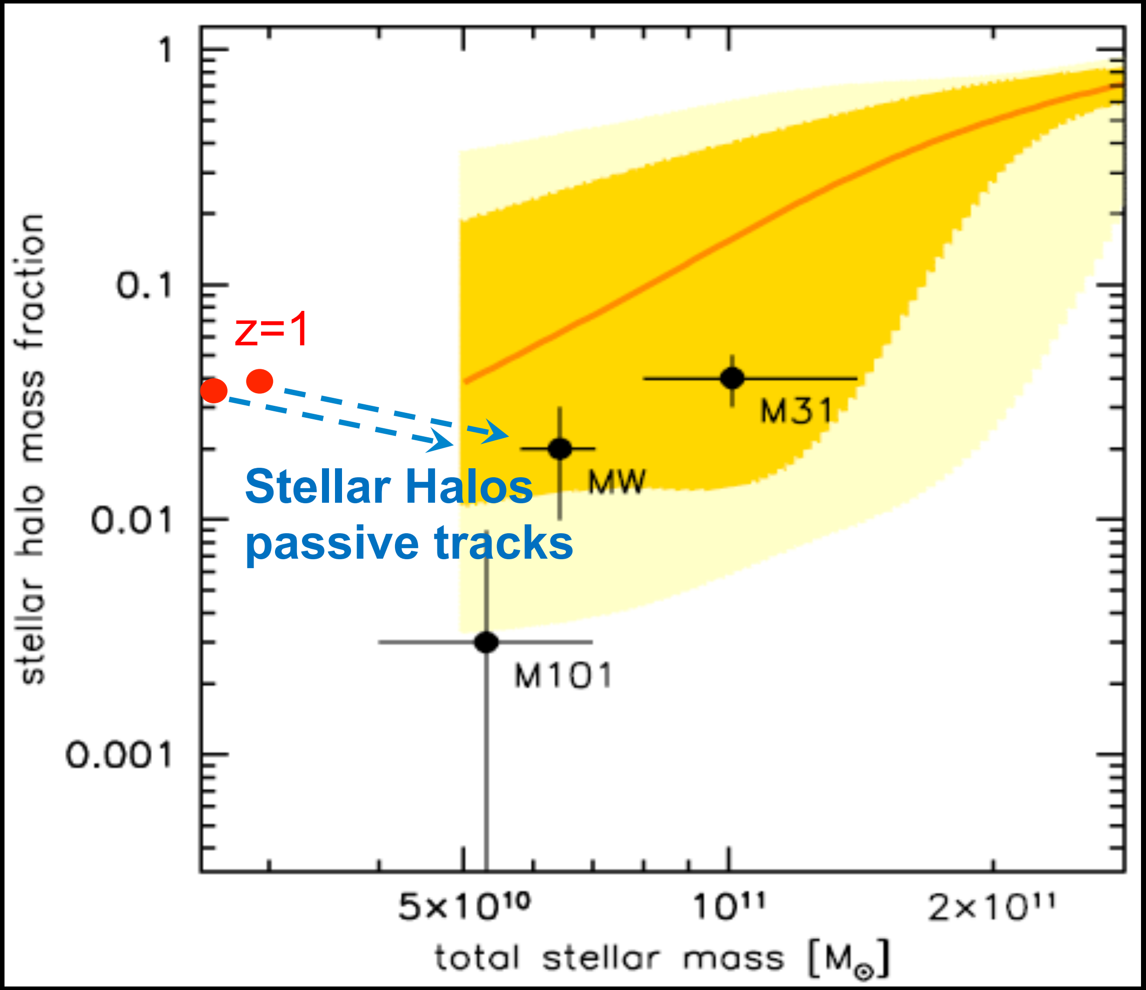
The build-up of stellar halos in MW-like galaxies



Passive evolution of the stellar populations of z=1 halos is compatible with today stellar halos properties

Trujillo & Bakos (2013)

The build-up of stellar halos in MW-like galaxies



Trujillo & Bakos (2013)

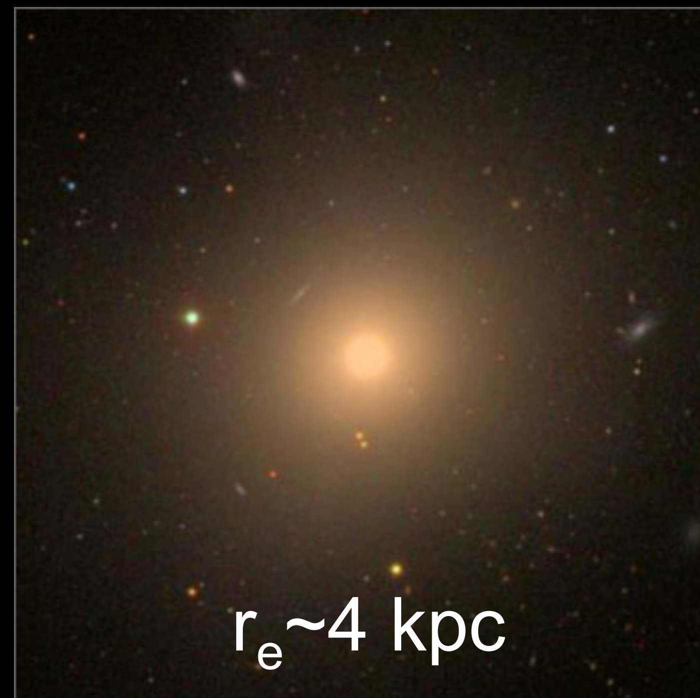
A passive track of the stellar halos of MW-like galaxies since z=1 is compatible with z=0 data

The build-up of stellar halos in early-type galaxies

$M_{*} \geq 10^{11} M_{sun}$

z=0

z=2



$r_e \sim 1$ kpc

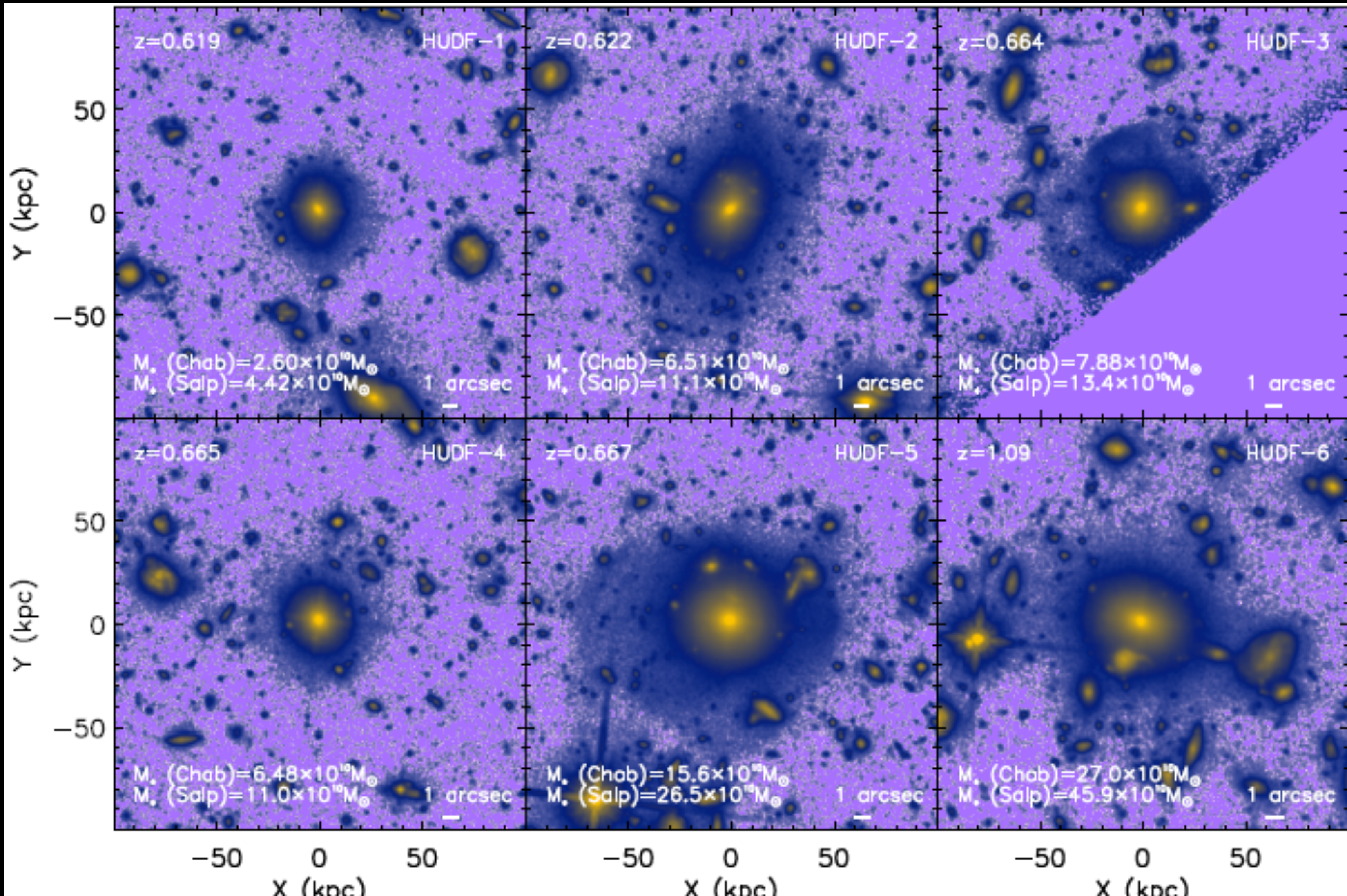
$r_e \sim 4$ kpc

At z~2 they were 4 times smaller!!!

Daddi et al. (2005), Trujillo et al. (2006)

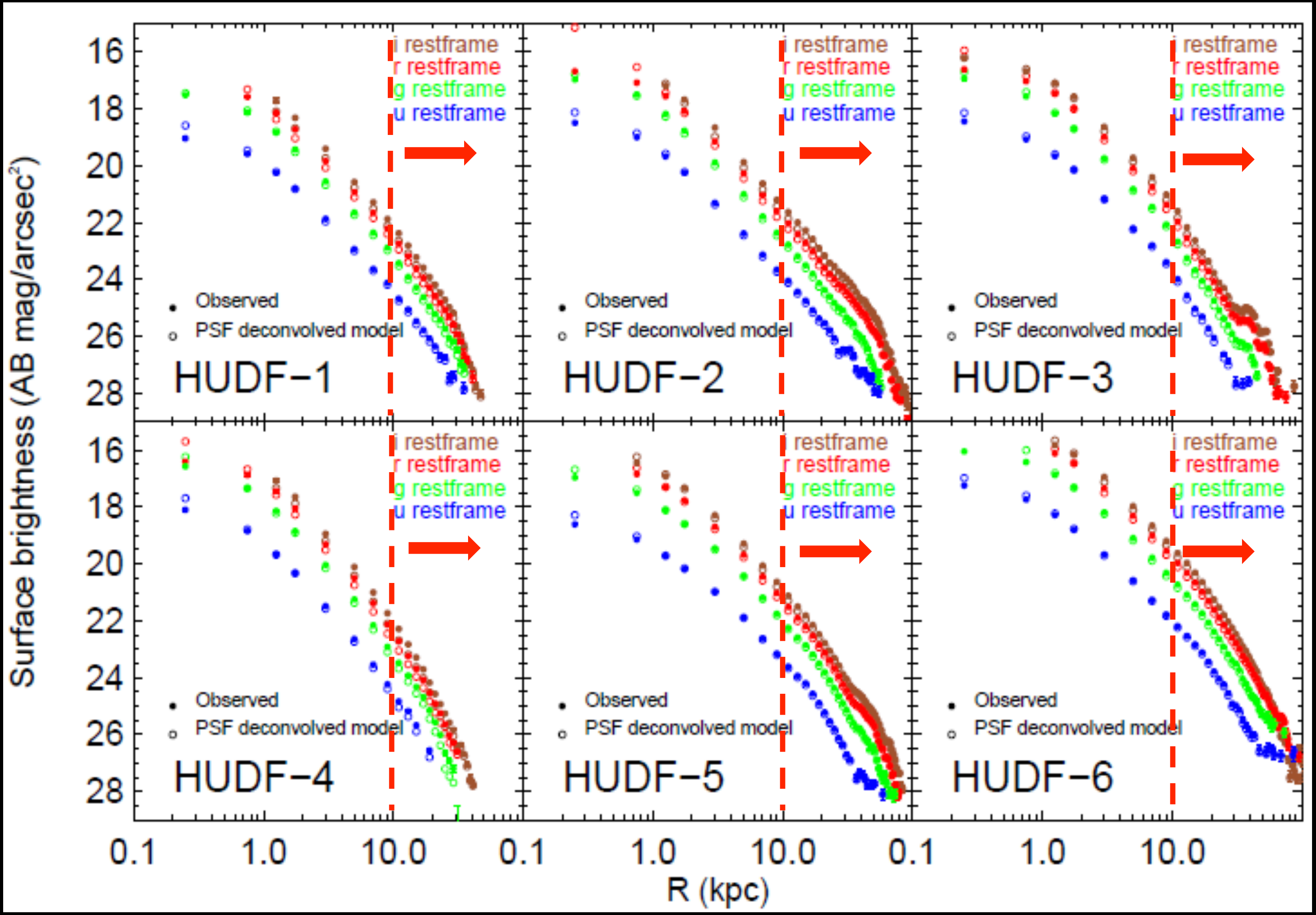
Halos of massive early-type galaxies at z~0.7

Buitrago et al (2015)



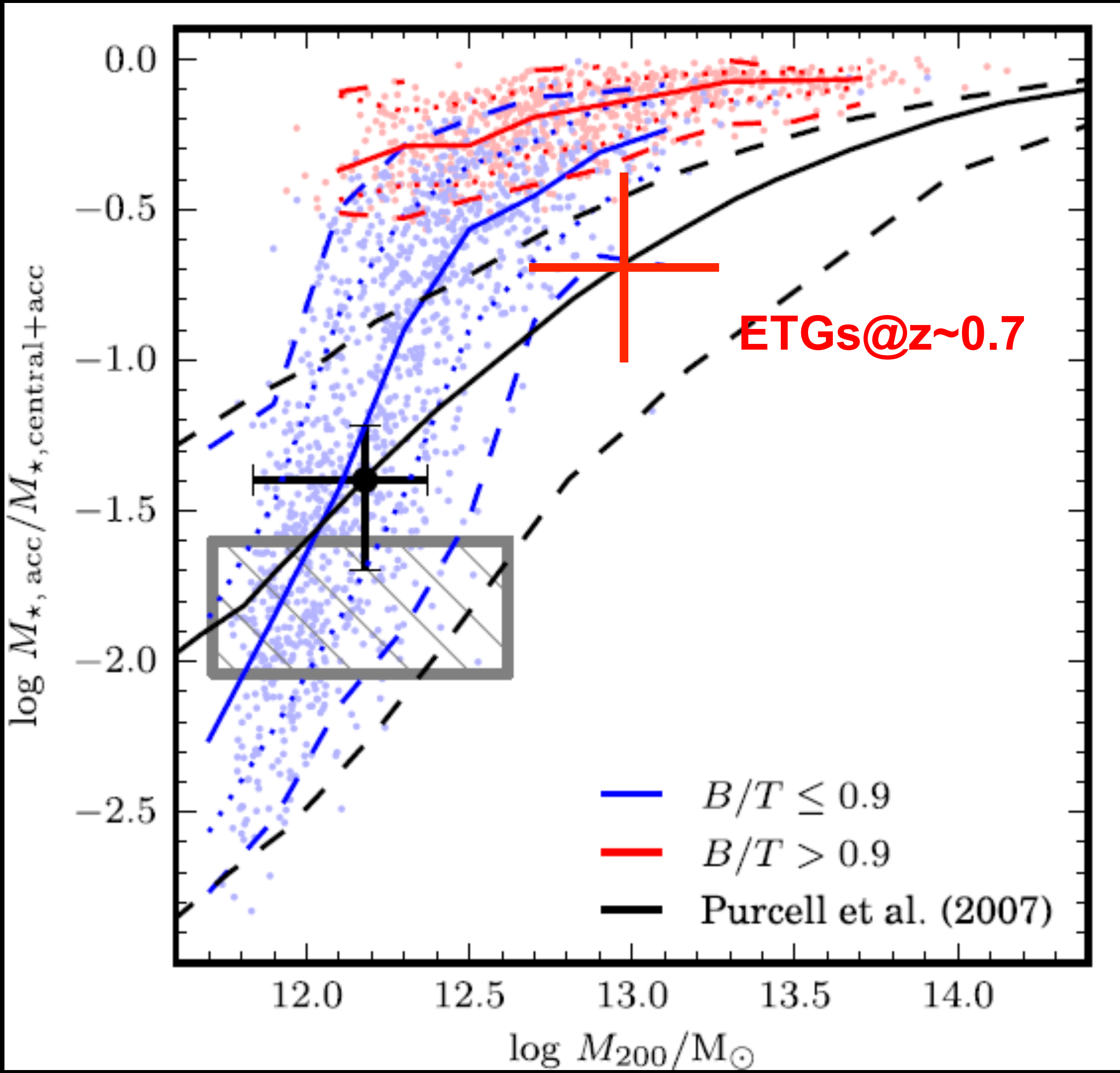
6 massive galaxies (M_{star}~10^{11} M_{sun}) at z~0.7 selected in the HUDF

Halos of massive early-type galaxies at z~0.7



Buitrago et al (2015)

Halos of massive early-type galaxies at z~0.7

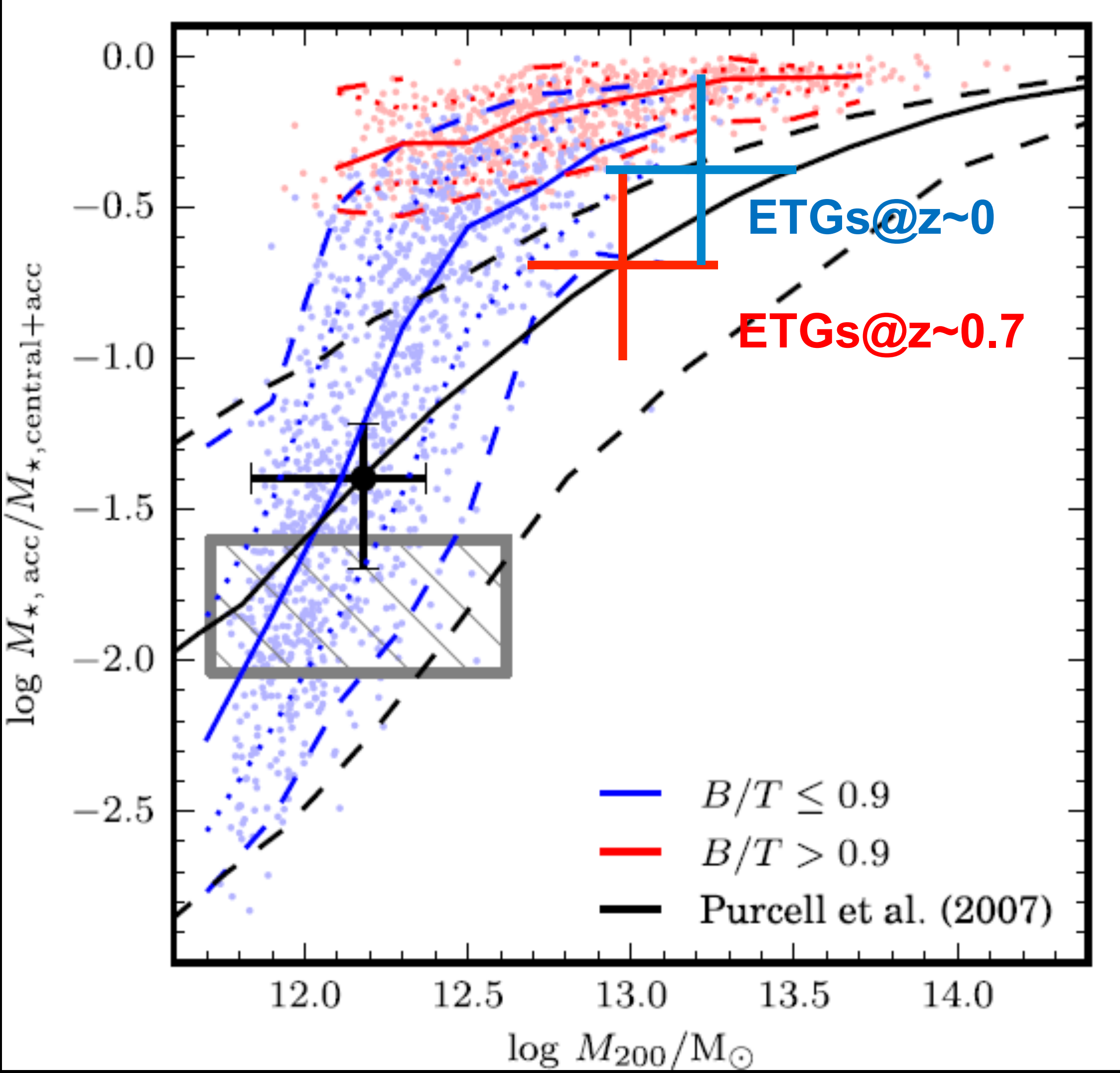


Cooper et al (2013); see also Purcell+07 and Pillepich+14

10-20% of stellar mass in ETGs at z~0.7 at R>10 kpc

Buitrago et al. (2015)

Halos of massive early-type galaxies at z~0.7



Cooper et al (2013); see also Purcell+07 and Pillepich+14

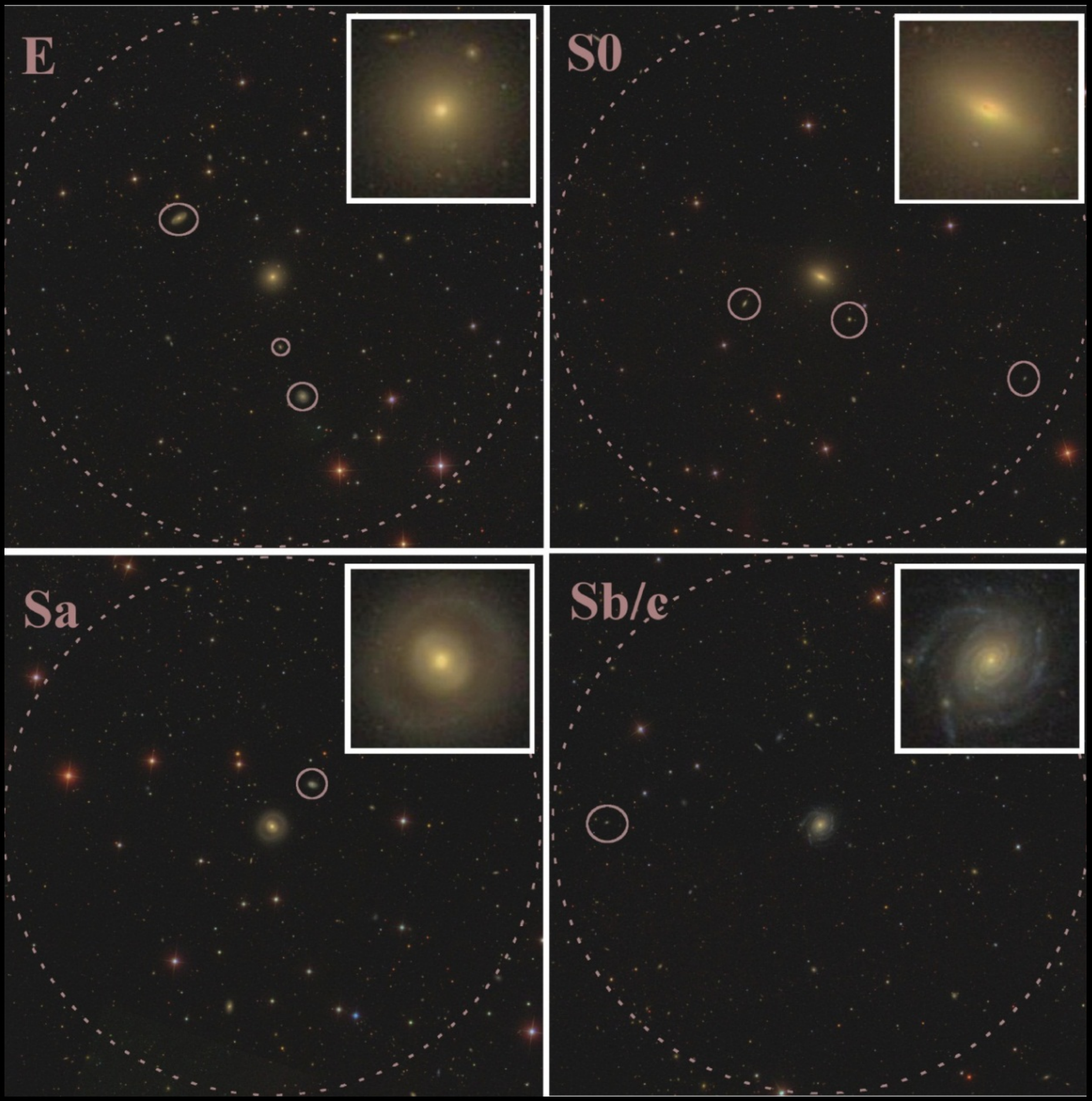
10-20% of stellar mass in ETGs at z~0.7 at R>10 kpc

35% of stellar mass in ETGs at z~0 at R>10 kpc

Buitrago et al. (2015)

Indirect methods

The merging channel at z=0



Ruiz et al (2015)

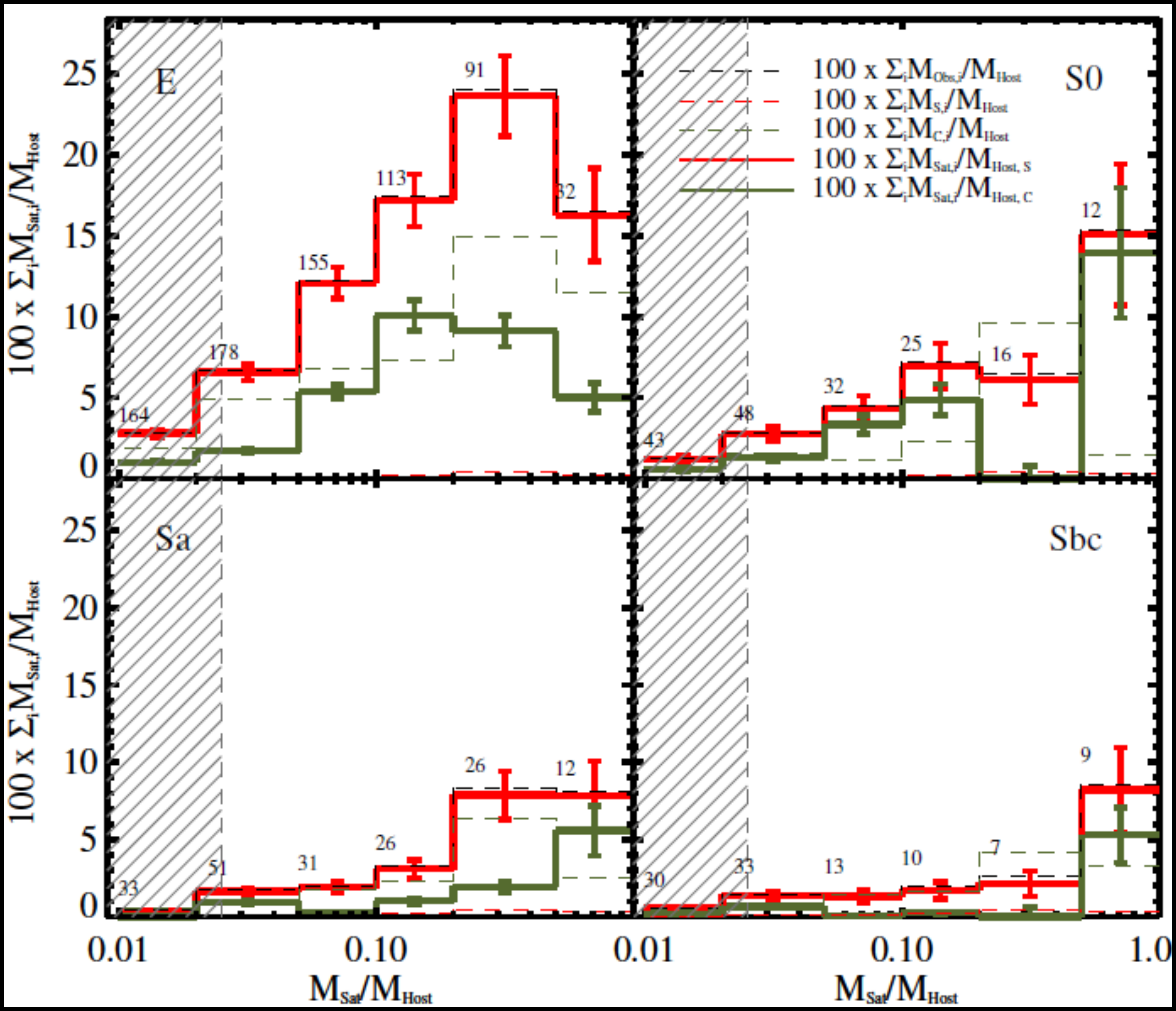
$M_{star} > 10^{11} M_{sun}$

Counting satellites within R=300 kpc down to a mass ratio 1:100

Exploring different morphologies:

E; S0; Sa; Sb/c

The merging channel at z=0

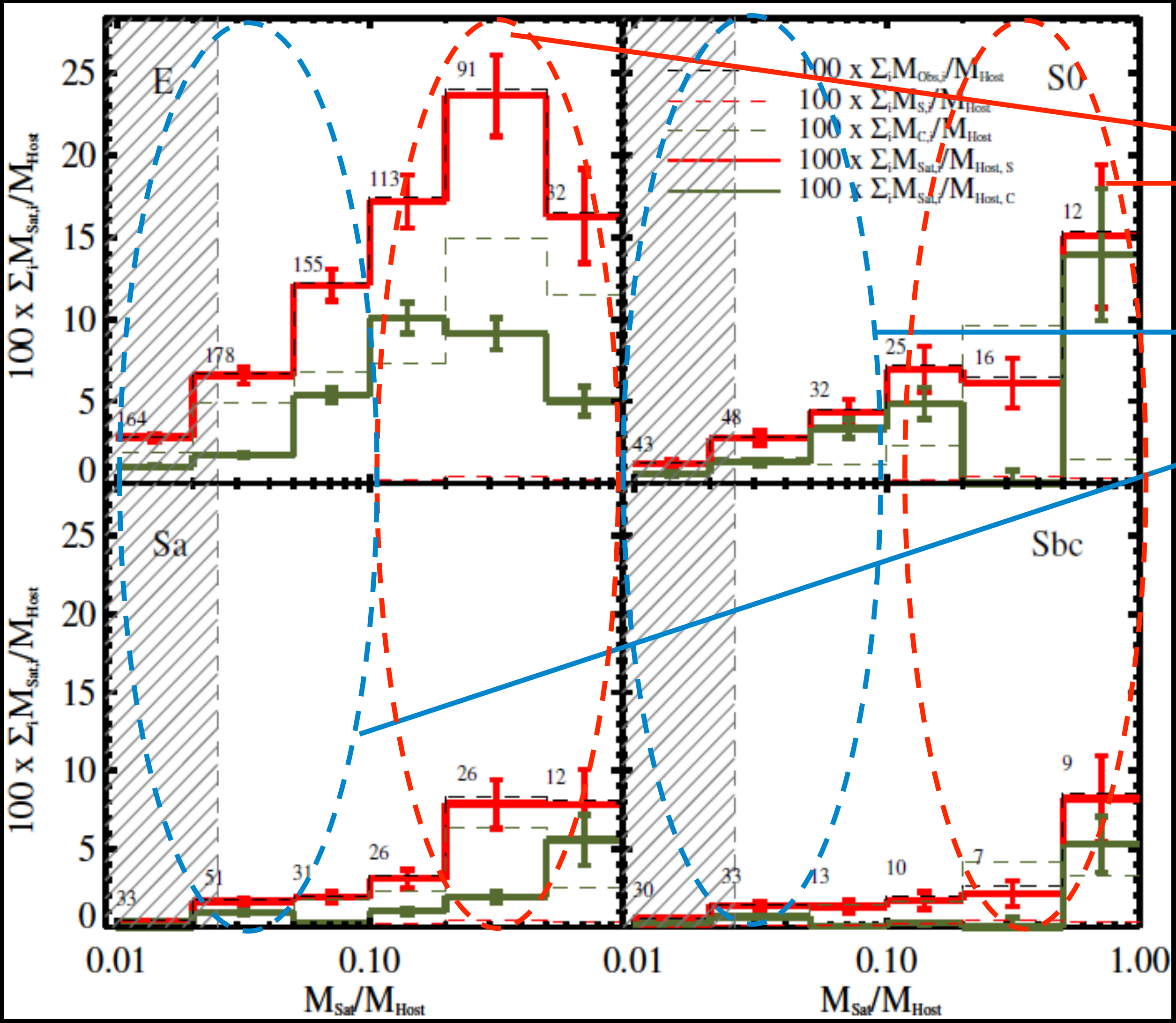


Ruiz et al (2015)

A dramatic increase of stellar mass enclosed in satellites from Sb/c -> E galaxies

In all cases, the merger channel is dominated by massive satellites

The merging channel at z=0



Contributors to the main galaxy growth

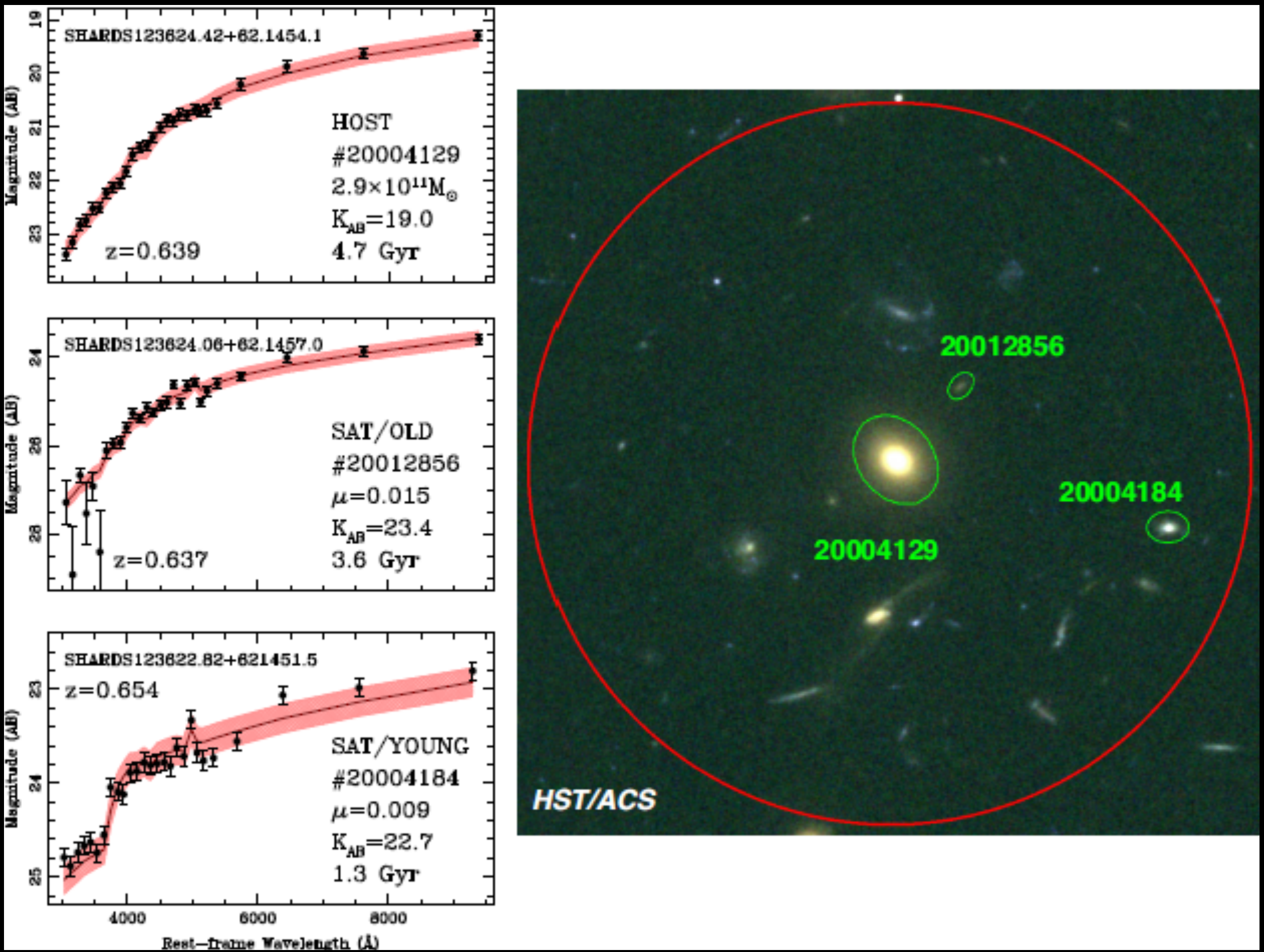
Contributors to the stellar halo growth

(Purcell et al. 2007; Cooper et al. 2013)

In all cases, satellites are more abundant around ellipticals

Ruiz et al (2015)

The merging channel since z~1



M_{star}>10^{11} M_{sun}

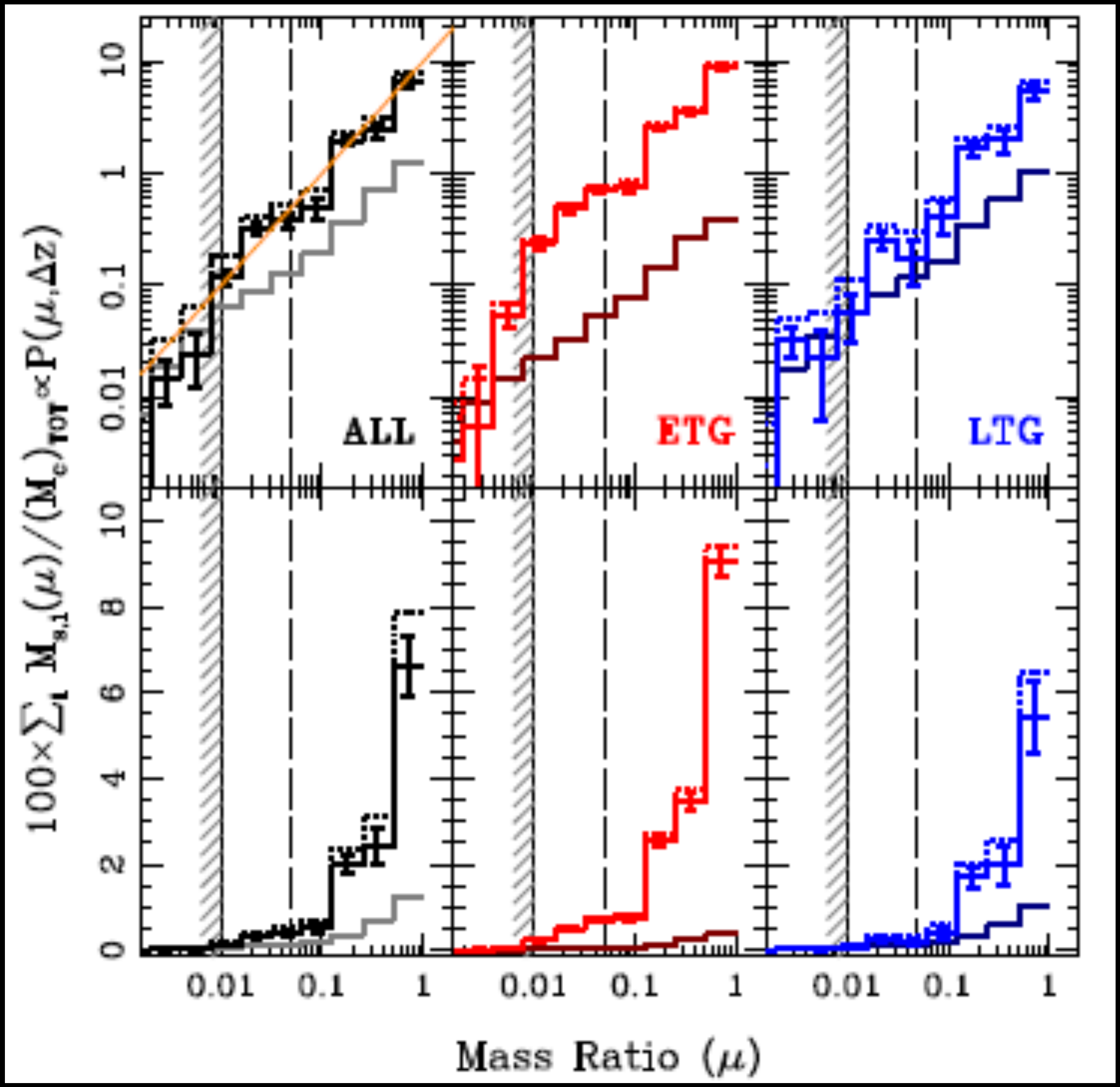
Counting satellites within R=100 kpc down to a mass ratio 1:100

Very high quality photo-z:

$\Delta z/(1+z)\sim 0.55\%$

Ferreras et al (2014); based on SHARDS (Perez-Gonzalez et al. 2013) data with GTC

The merging channel since z~1



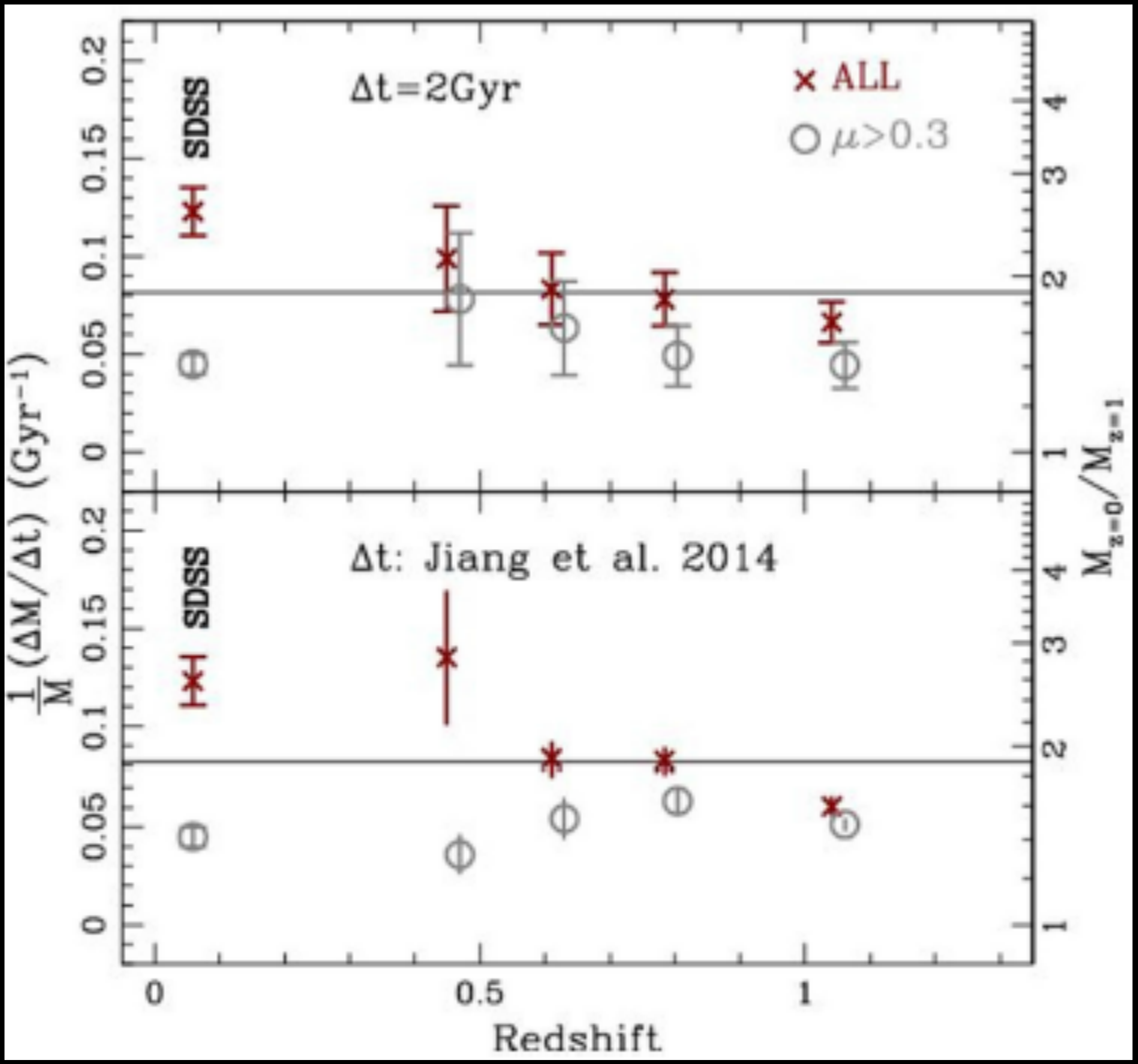
Ferreras et al (2014)

Similar to z=0:

Merging channel more enhanced for ETGs

Mass accretion dominated by massive satellites

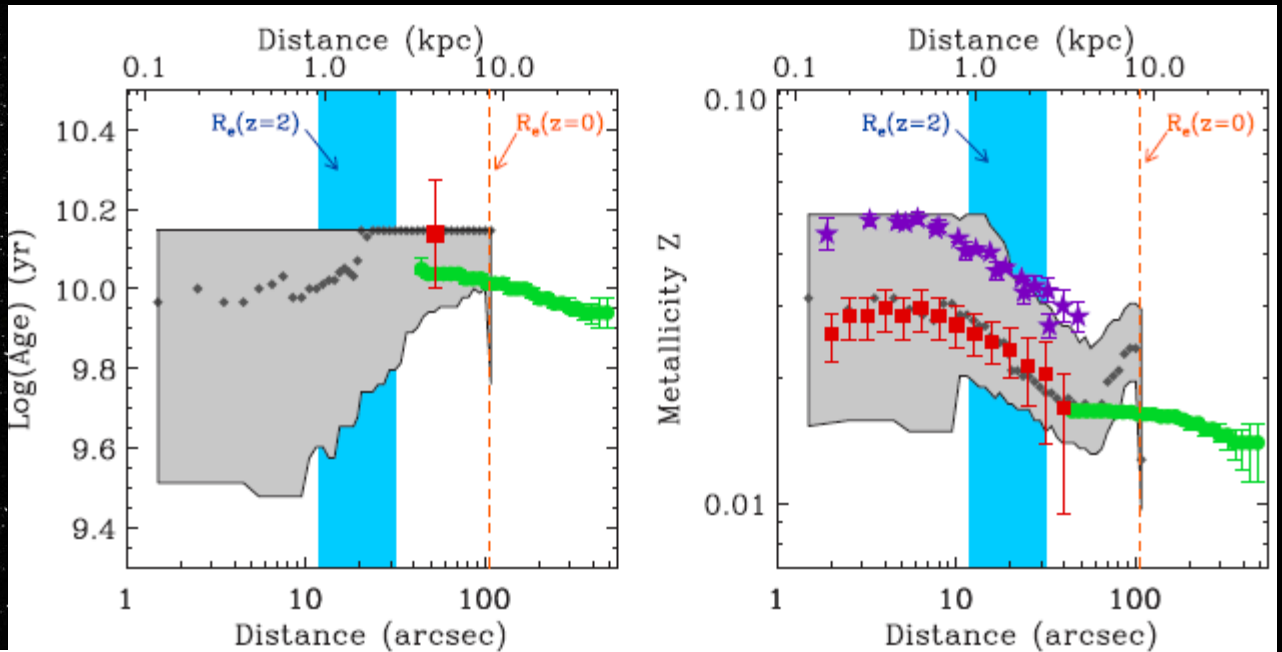
The merging channel since z~1



Ferreras et al (2014)

~8% mass increase per Gyr due to satellite infall in massive galaxies

Imprints on the stellar halos of the merging channel at z=0



Montes et al (2014)

Increasing number of papers exploring the stellar population properties in the outermost regions of massive elliptical galaxies

See also Coccato+10; Roediger+11; Greene+12; La Barbera+12

Summary

Observational constraints from:

Direct method (using HUDF):

- Stellar halos of MW-like galaxies at z~1 seem to be already in place at that epoch
- There is evidence for on-going major satellite accretion in massive ellipticals since z~1

Indirect method:

- A significant different channel of accretion depending on the galaxy morphology
- Low mass satellites (contributors to the stellar halo) are also more abundant in elliptical galaxies

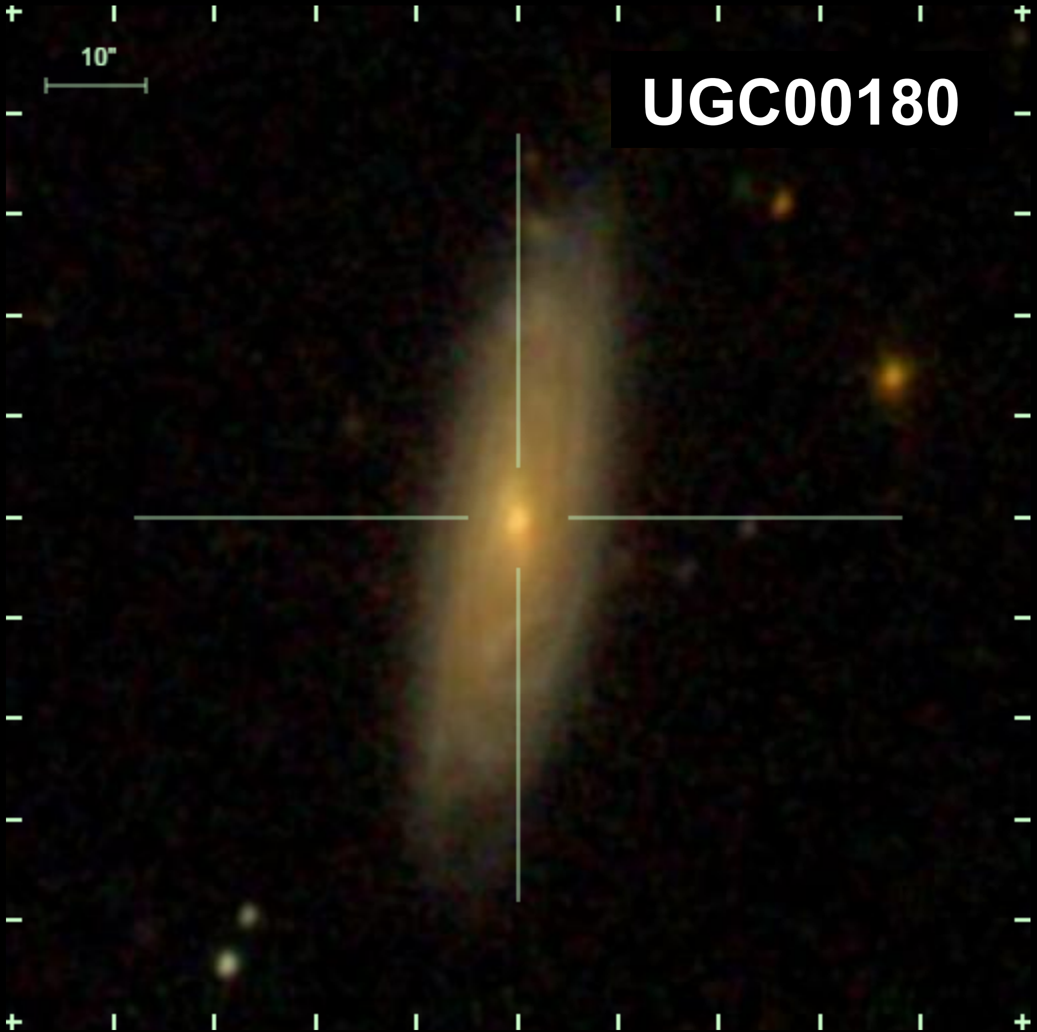
Bonus: GTC ultra-deep imaging

What is the limiting surface brightness that present-day largest telescopes can provide?

10.4m GTC telescope at the ORM

Trujillo & Fliri (2015)

Bonus: GTC ultra-deep imaging



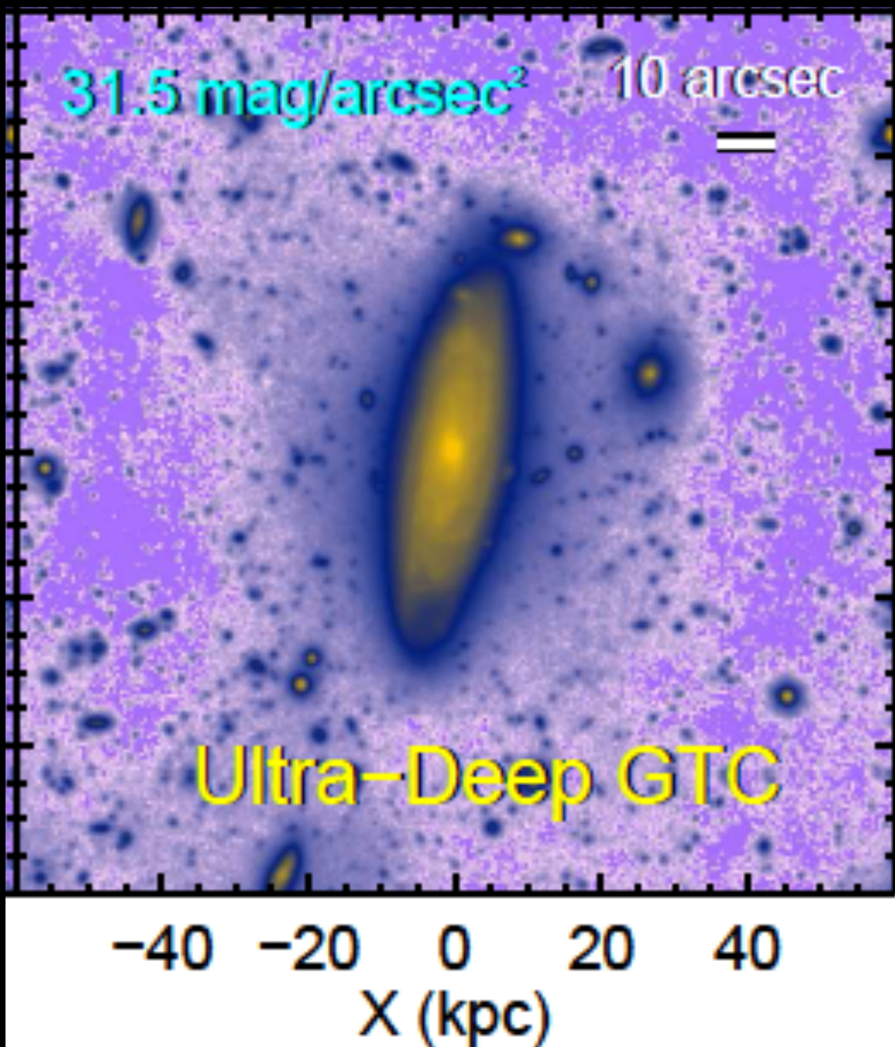
Trujillo & Fliri (2015)

Pilot Project with GTC

8 hours on source!!

- Dist=150 Mpc
- r-band
- g-r~0.9
- M_B=-21.8 mag
- V_{rot}=270 km/s
- Sab galaxy
- Similar to M31

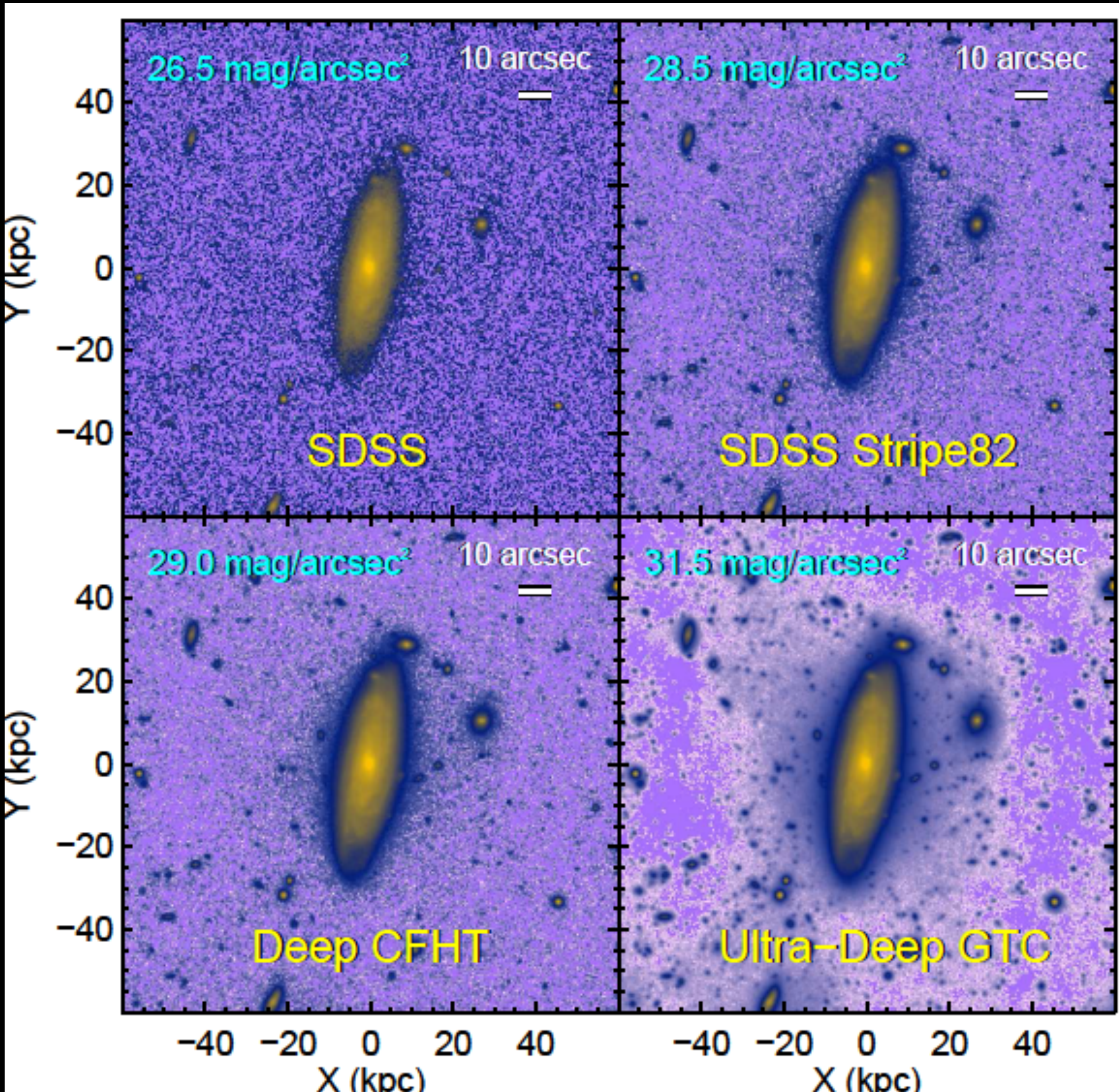
Bonus: GTC ultra-deep imaging



Trujillo & Fliri (2015)

31.5 mag/arcsec^2
10x10 arcsec^2 boxes
are detected at 3σ

Bonus: GTC ultra-deep imaging

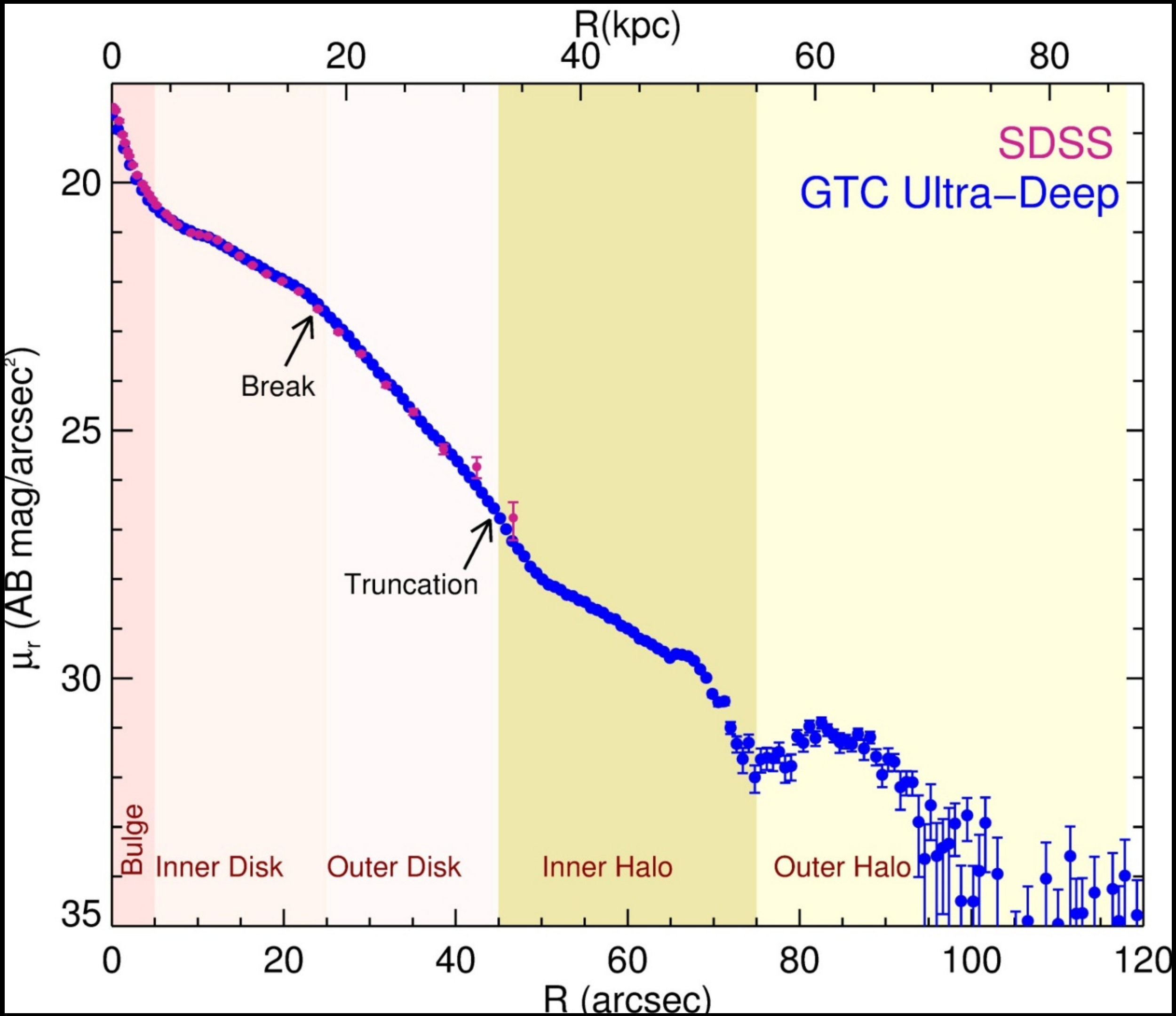


Comparison with present-day surveys

2-2.5 mag deeper than current deep observations

Trujillo & Fliri (2015)

Bonus: GTC ultra-deep imaging

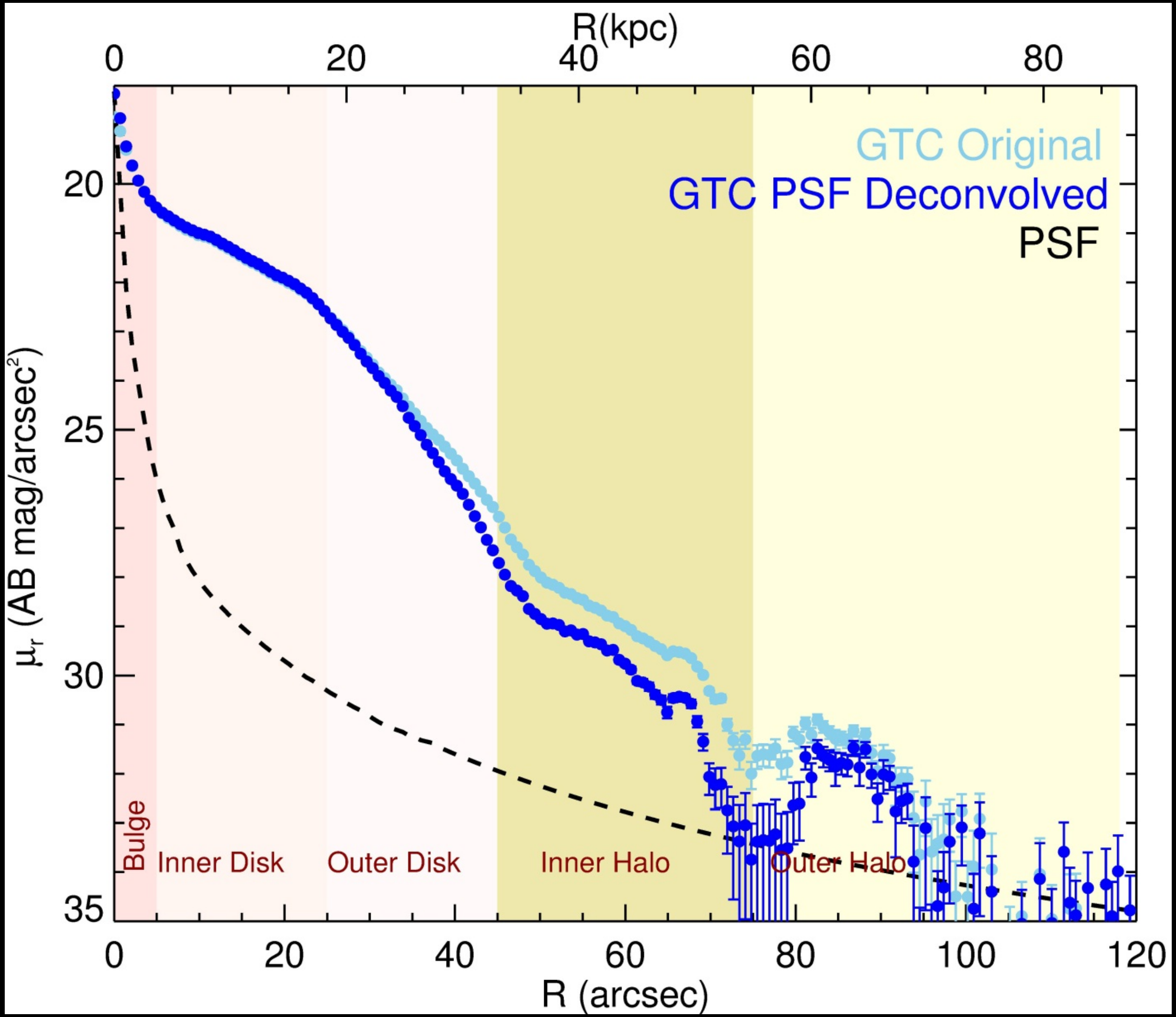


Trujillo & Fliri (2015)

Surface brightness profile of the galaxy explored over 15 magnitudes

Similar depth as star count techniques

Bonus: GTC ultra-deep imaging



The effect of the PSF

(see poster by Sandin)

Original

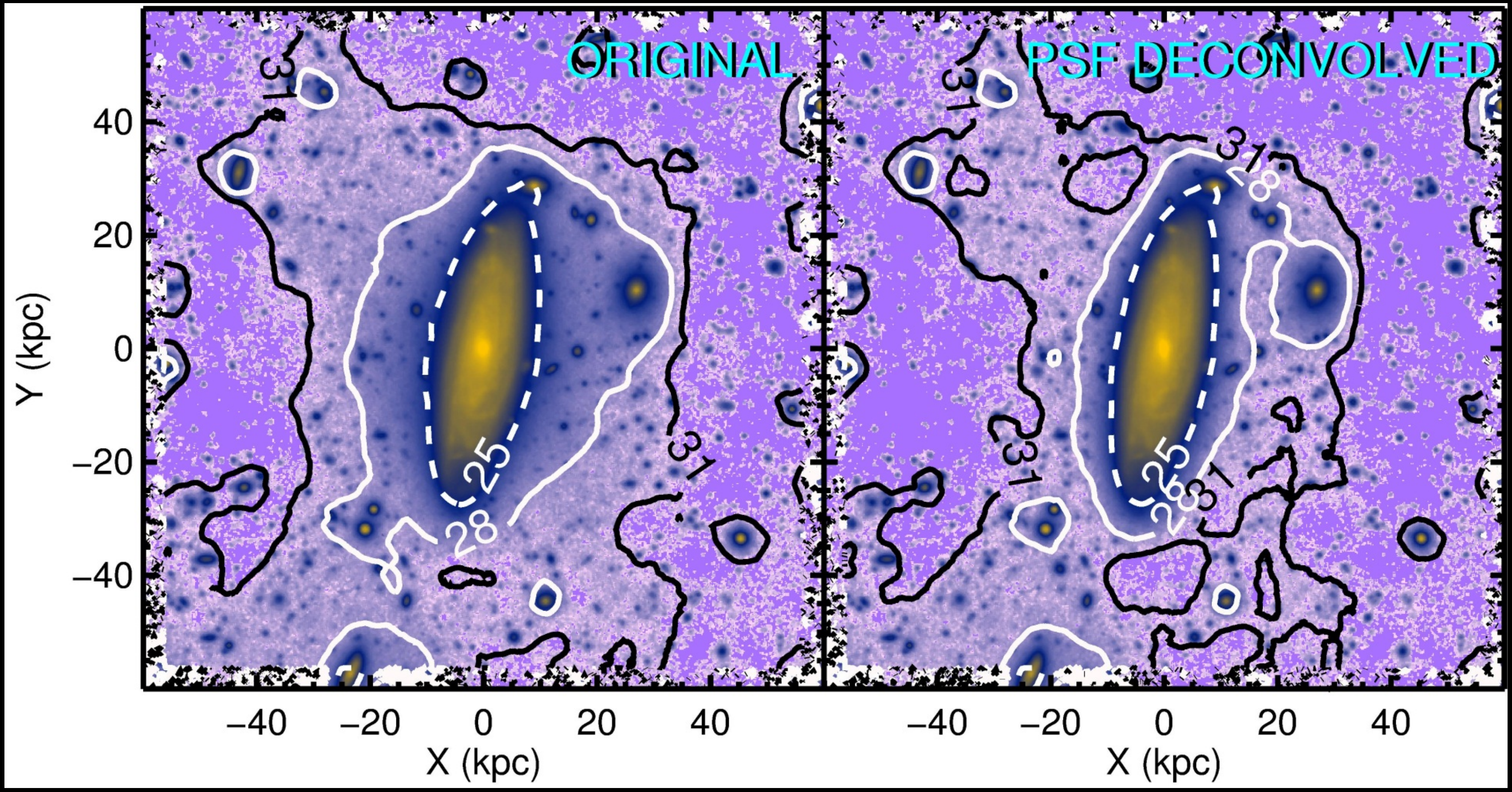
M_{SH}/M_T~0.028

PSF Deconvolved

M_{SH}/M_T~0.013

Trujillo & Fliri (2015)

Bonus: GTC ultra-deep imaging



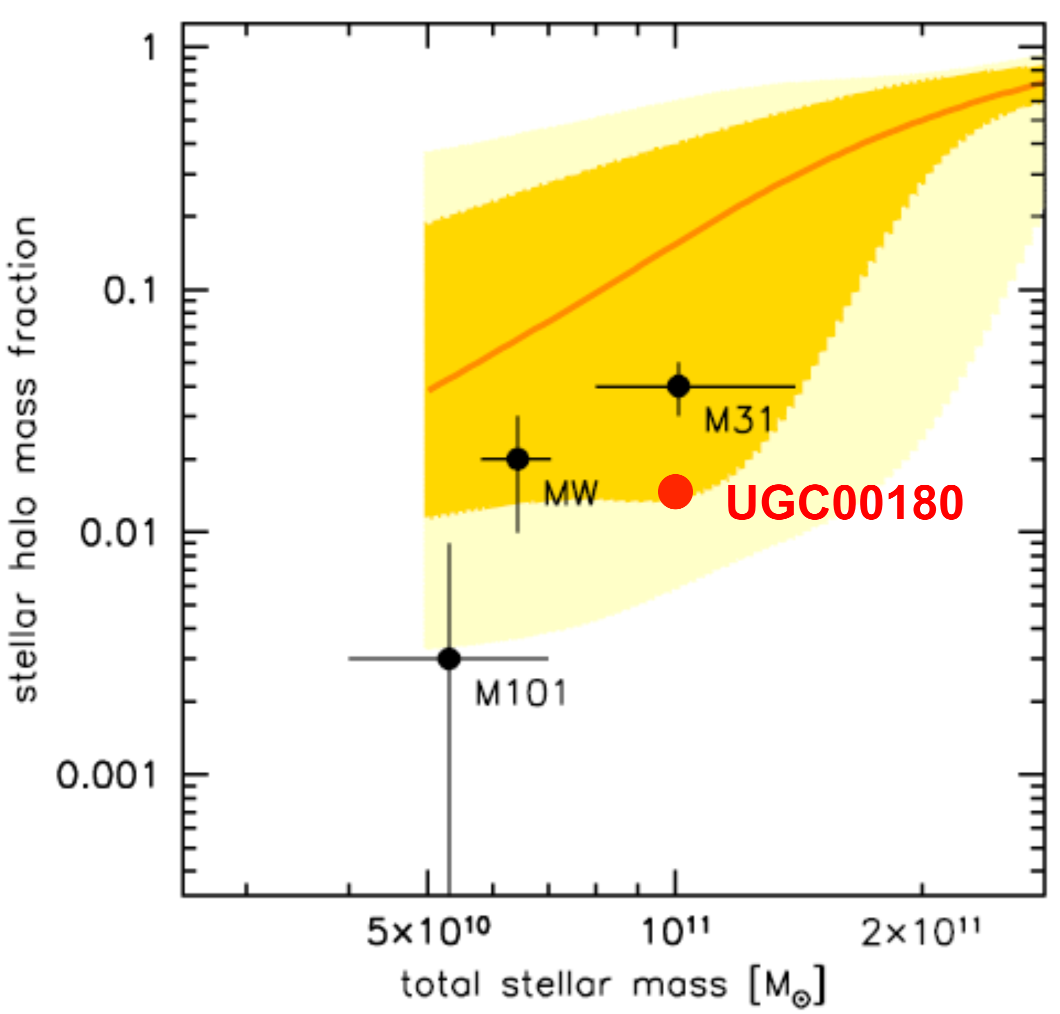
Trujillo & Fliri (2015)

The effect of the PSF

Original M_{SH}/M_T~0.028

PSF Deconvolved M_{SH}/M_T~0.013

Bonus: GTC ultra-deep imaging



Trujillo & Fliri (2015)

UGC00180 seems to have a poor stellar halo

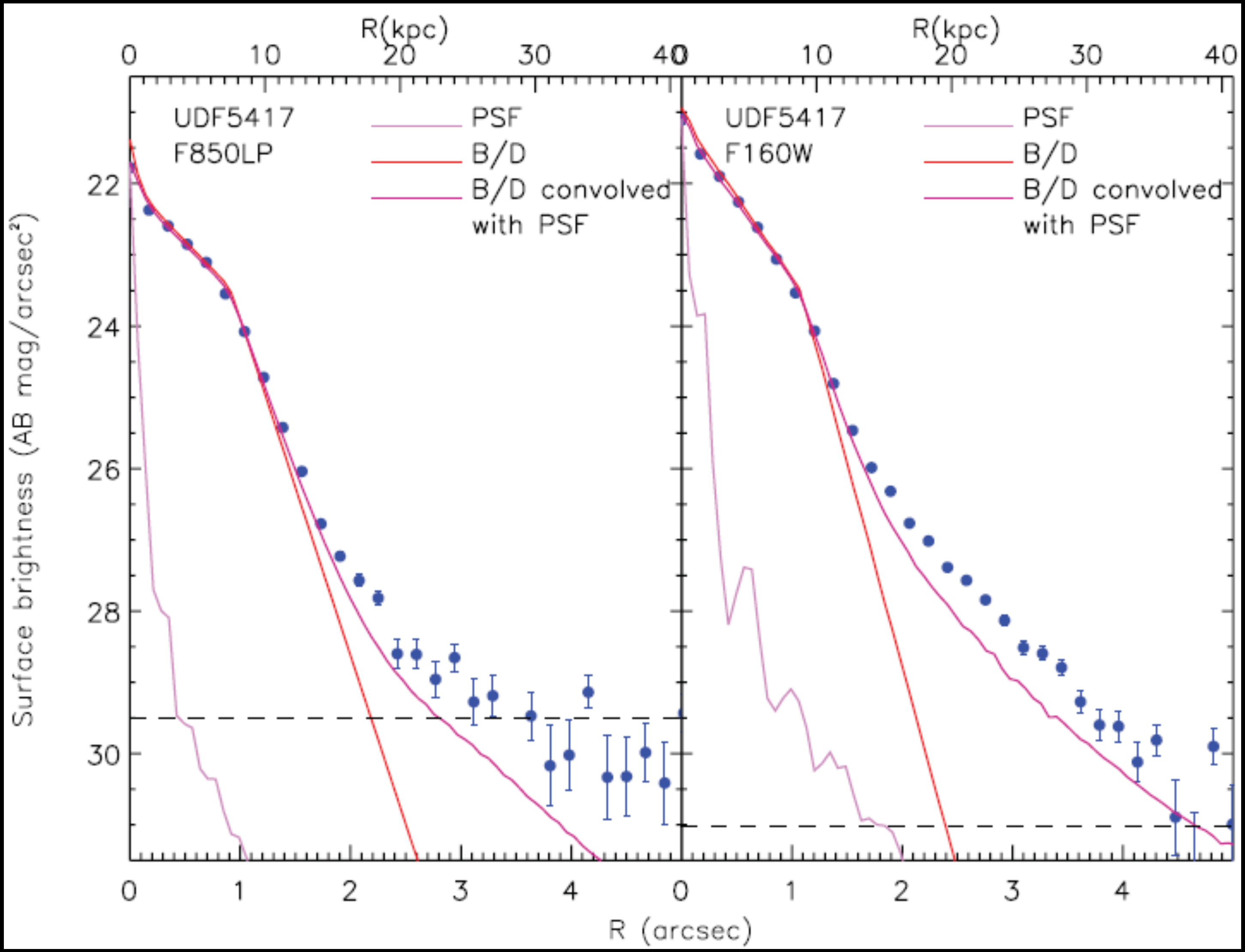
Are we witnessing a tension with the theoretical predictions?

Join us for special session Sp16

The outskirts of galaxies: present status and future challenges

Deadline for abstract submission: 10 March 2015

The build-up of stellar halos in MW-like galaxies

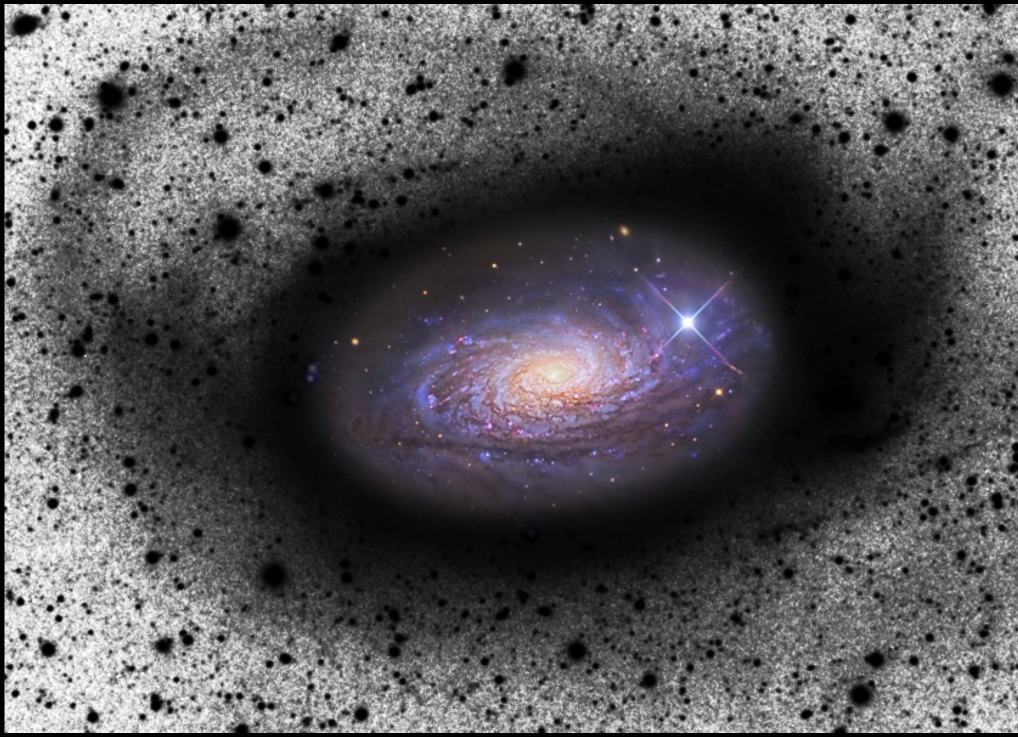


Trujillo & Bakos (2013)

The information hidden in the galaxy outskirts

Testing models of galaxy formation and evolution:

- Long dynamical and star formation time-scales
- Thick disks
- Stellar haloes
- On-going mergers
- Star formation thresholds
- Stellar radial migrations



M63 (NGC5033; Chonis et al. 2011)

Techniques to explore the outer regions

Resolved stellar populations:

Advantages: Detailed stellar populations analysis; Ultra deep surface brightness: ~32 mag/arcsec^2

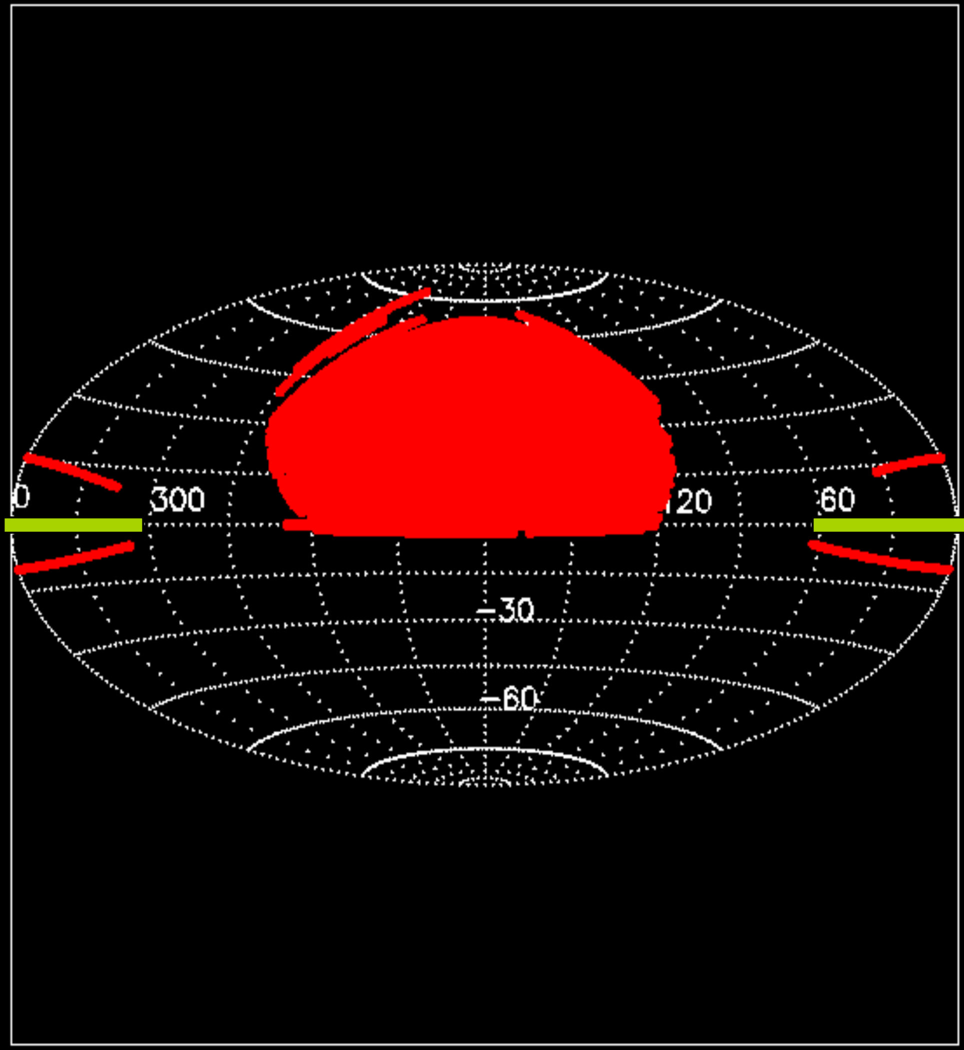
Disadvantages: Limited to nearby galaxies (≤5 Mpc)

Integrated photometry:

Advantages: Large collection of galaxies (≤100 Mpc): statistical analysis; deep surface brightness: ~30 mag/arcsec^2

Disadvantages: Limited stellar population analysis with broad-band photometry

SDSS Stripe 82: ultra-deep data



270 deg^2 area

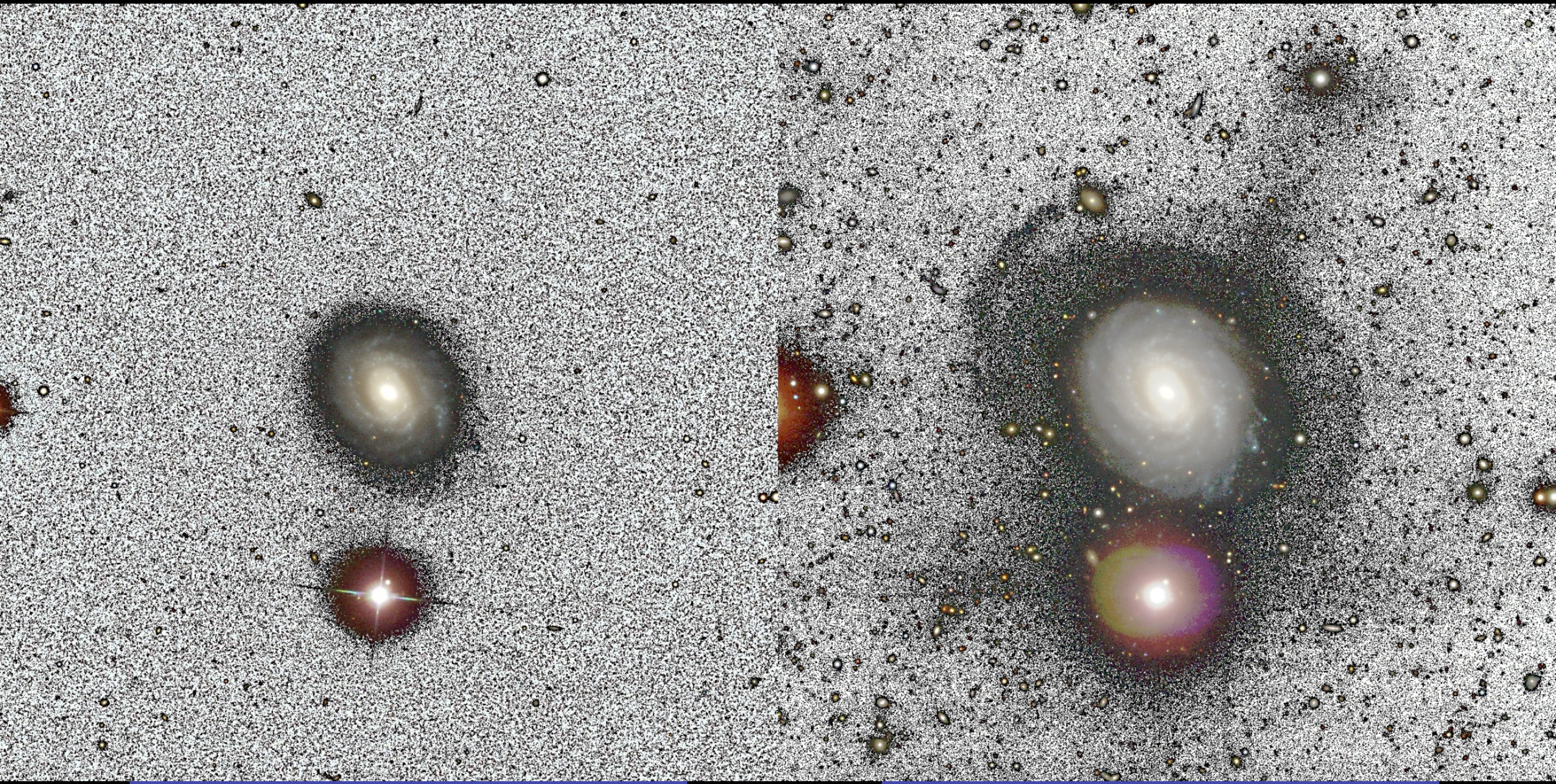
(-50 < RA < 59, -1.25 < DEC < 1.25)

2 mag deeper than regular SDSS

We can probe very faint structures in individual non Local Galaxies:

- NGC0450 (Sc; 24.4 Mpc; -19.8)
- NGC0941 (Sc; 21.9 Mpc; -19.1)
- NGC1068 (Sb; 15.3 Mpc; -21.5)
- NGC1087 (Sc; 20.7 Mpc; -20.7)
- NGC7716 (Sb; 36.5 Mpc; -20.3)
- UGC02081 (Sc; 36.5 Mpc; -18.5)
- UGC02311 (Sb; 102.8 Mpc; -21.5)

SDSS Stripe 82: ultra-deep data

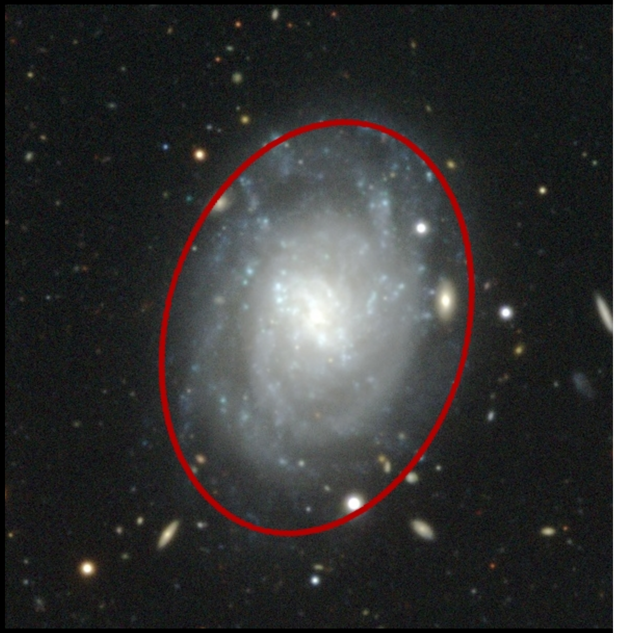


NGC7716; SDSS-DR7

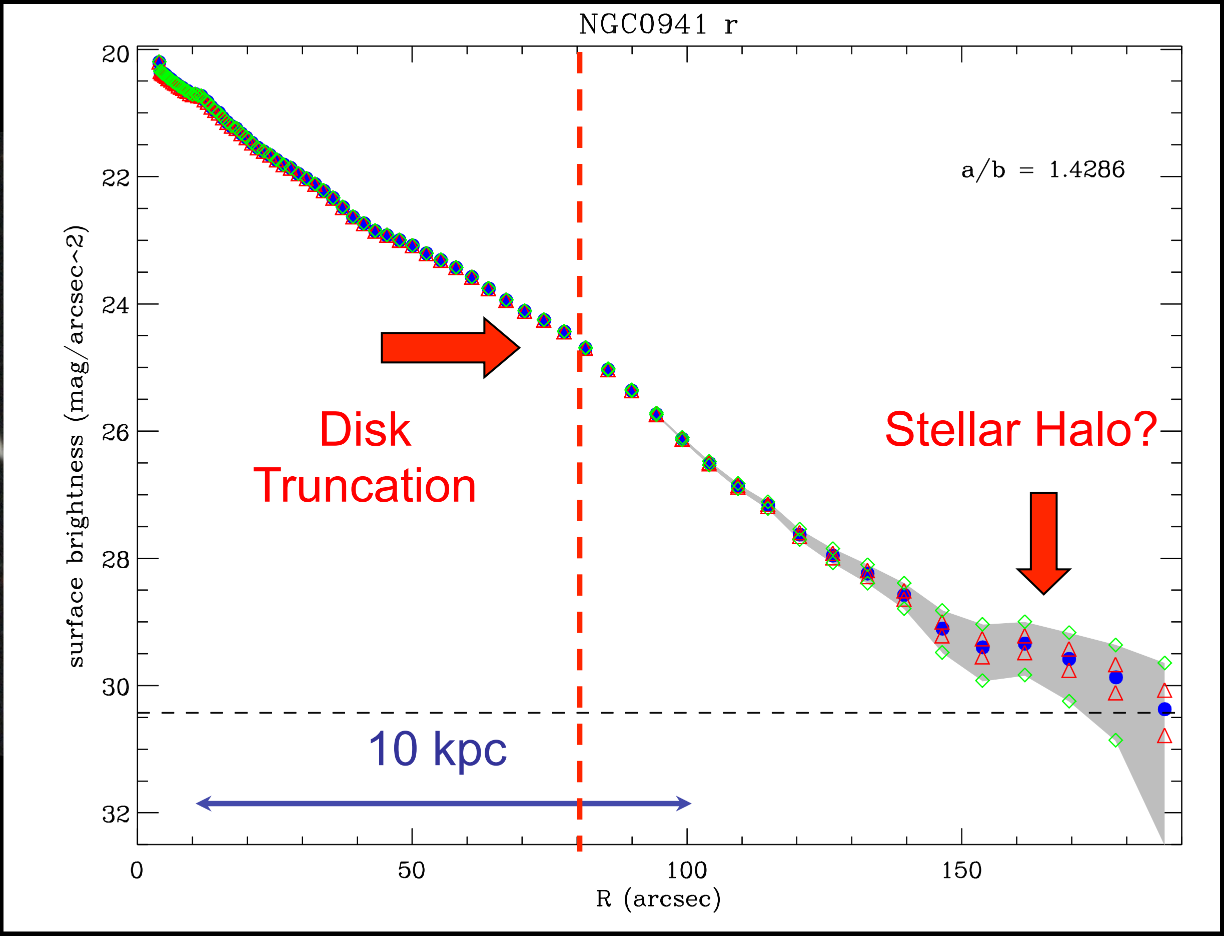
NGC7716; SDSS-Stripe82

Bakos & Trujillo (2011)

Excess of light at >28 mag/arcsec^2

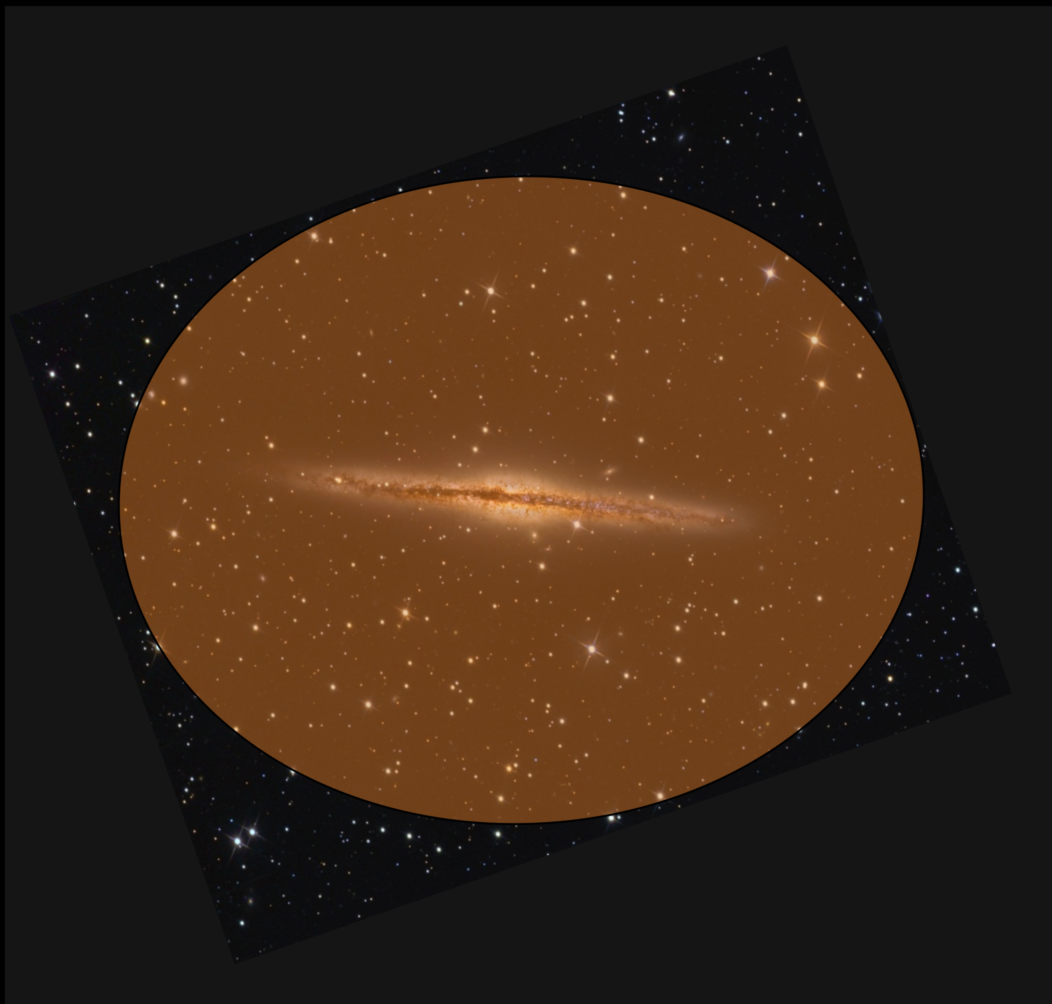


NGC0941; -19.1 mag



Bakos & Trujillo (2011)

Haloes around galaxies: Expected Properties

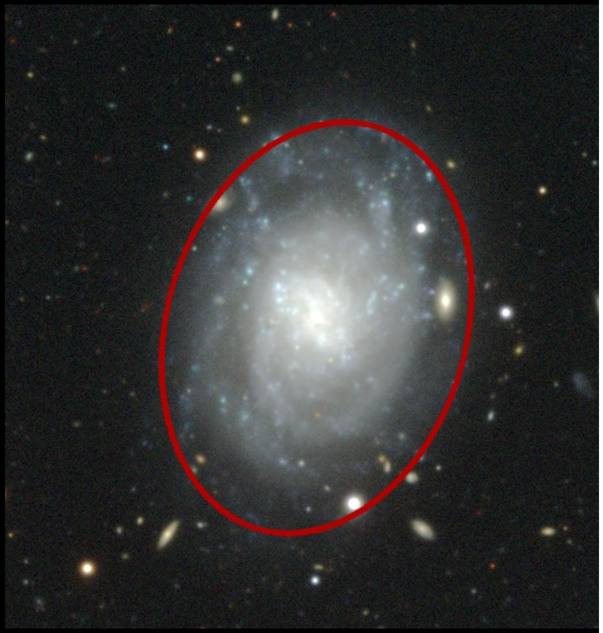


1. Very extended diffuse structure (~29 mag/arcsec^2)
2. Relic of the initial galaxy collapse
3. Interesting for measuring star formation efficiency in the early stages of galaxy formation.

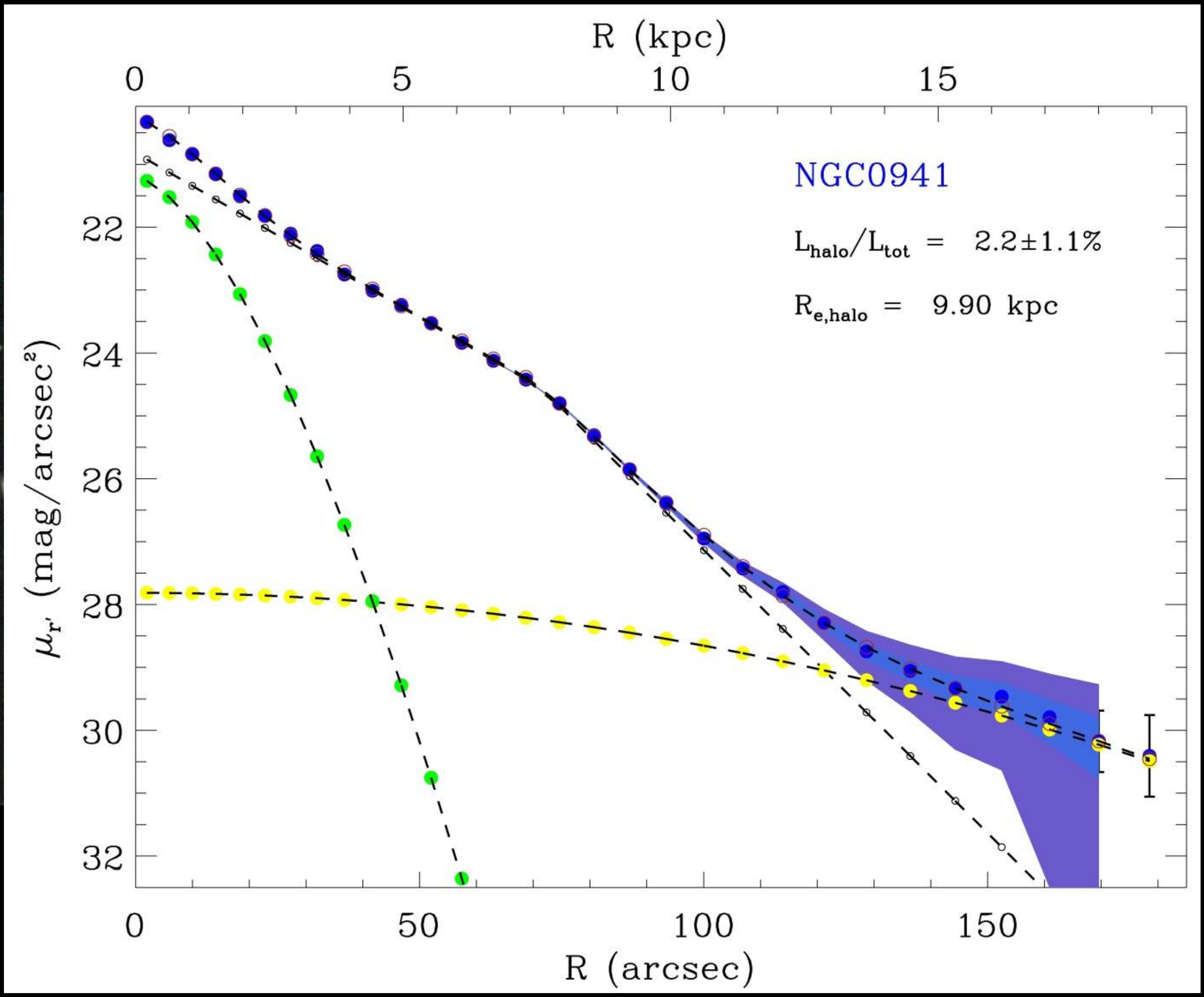
So far:

- Only explored in the MW and a few other nearby galaxies
- Stacking of many galaxies

NGC0941: an isolated galaxy case study

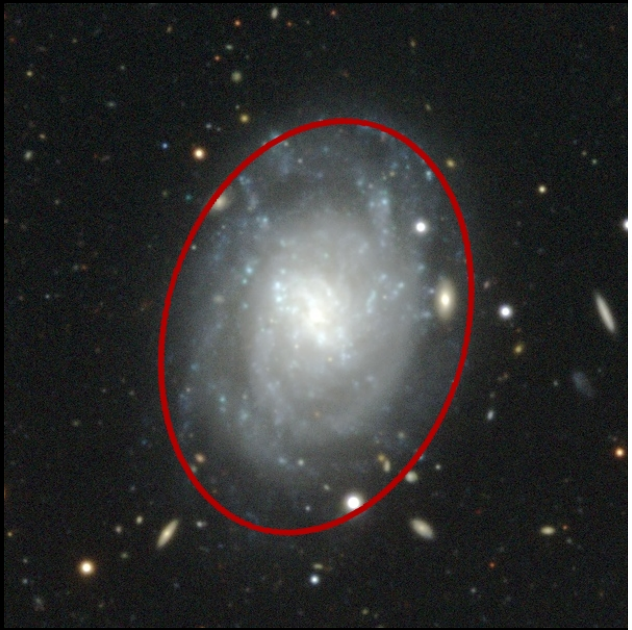


NGC0941; -19.1 mag

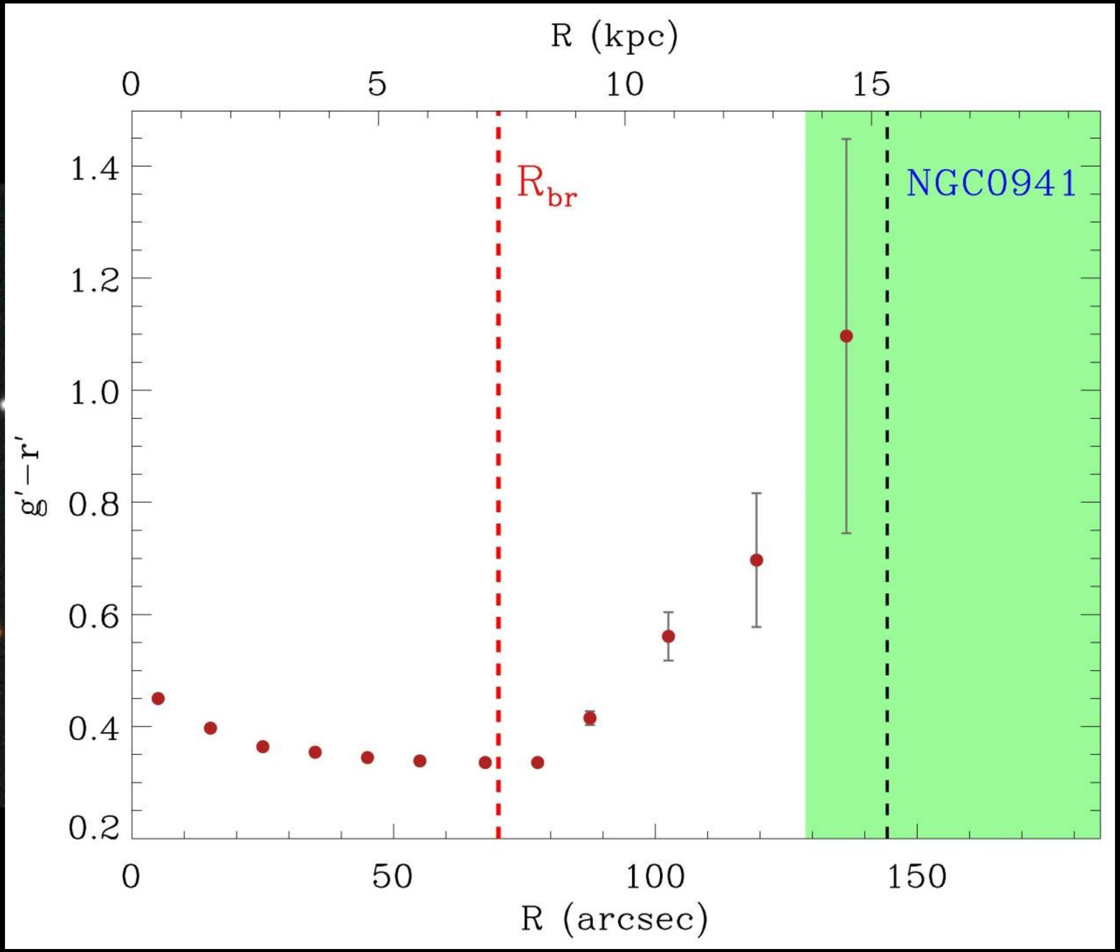


Bakos & Trujillo (2011)

NGC0941: an isolated galaxy case study



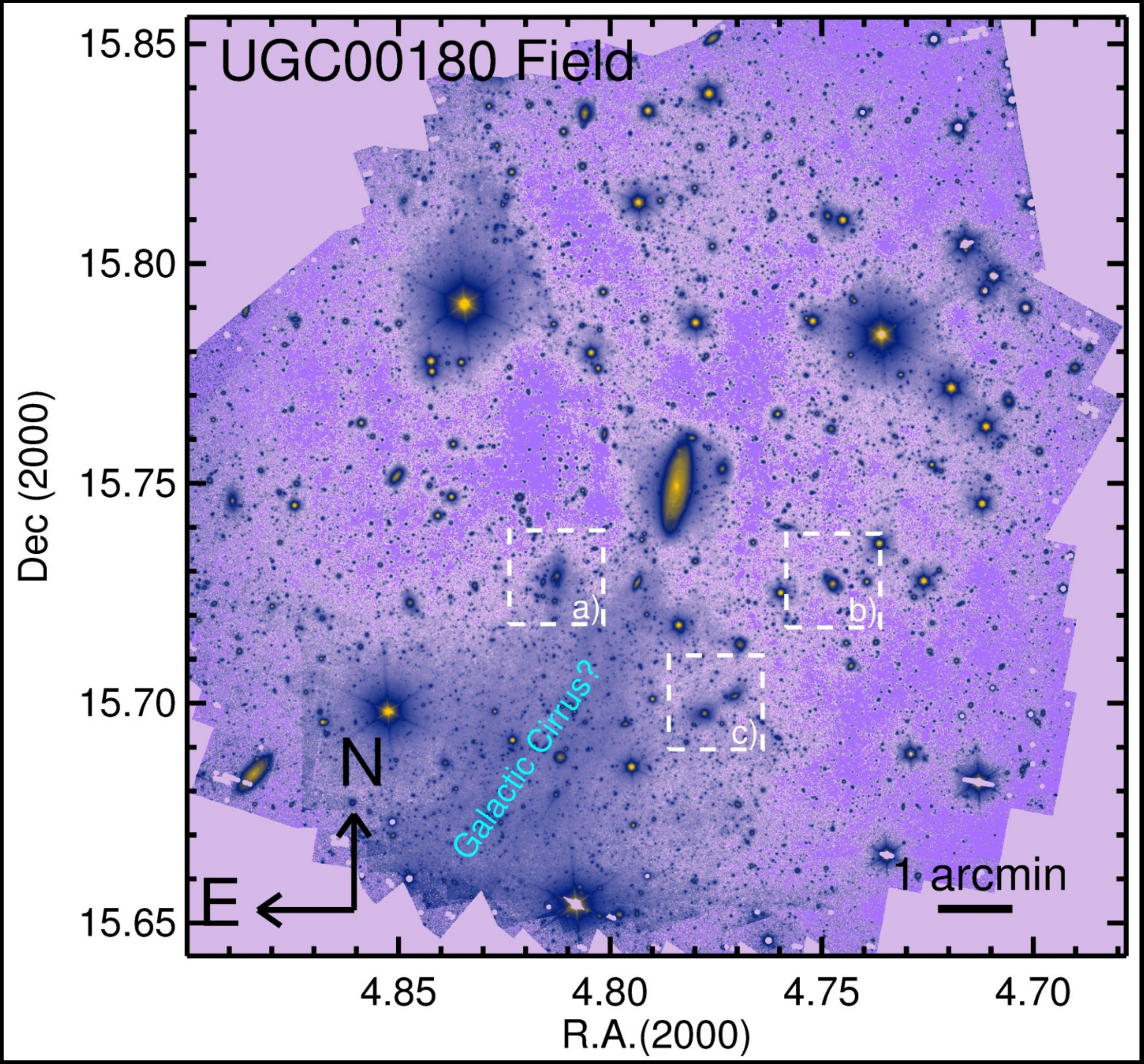
NGC0941; -19.1 mag



Bakos & Trujillo (2011)

Bonus: GTC ultra-deep imaging

Trujillo & Fliri (2015)



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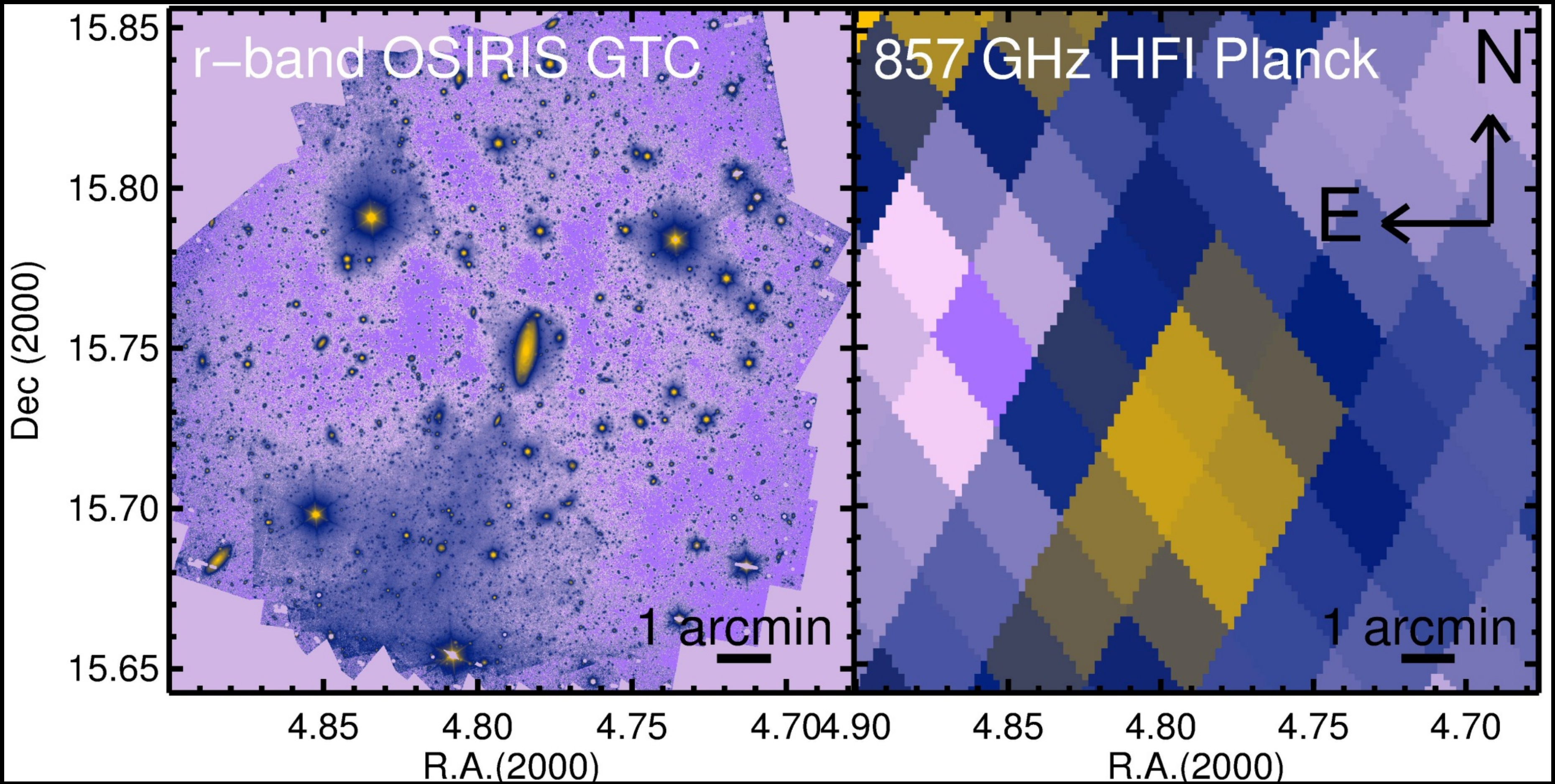

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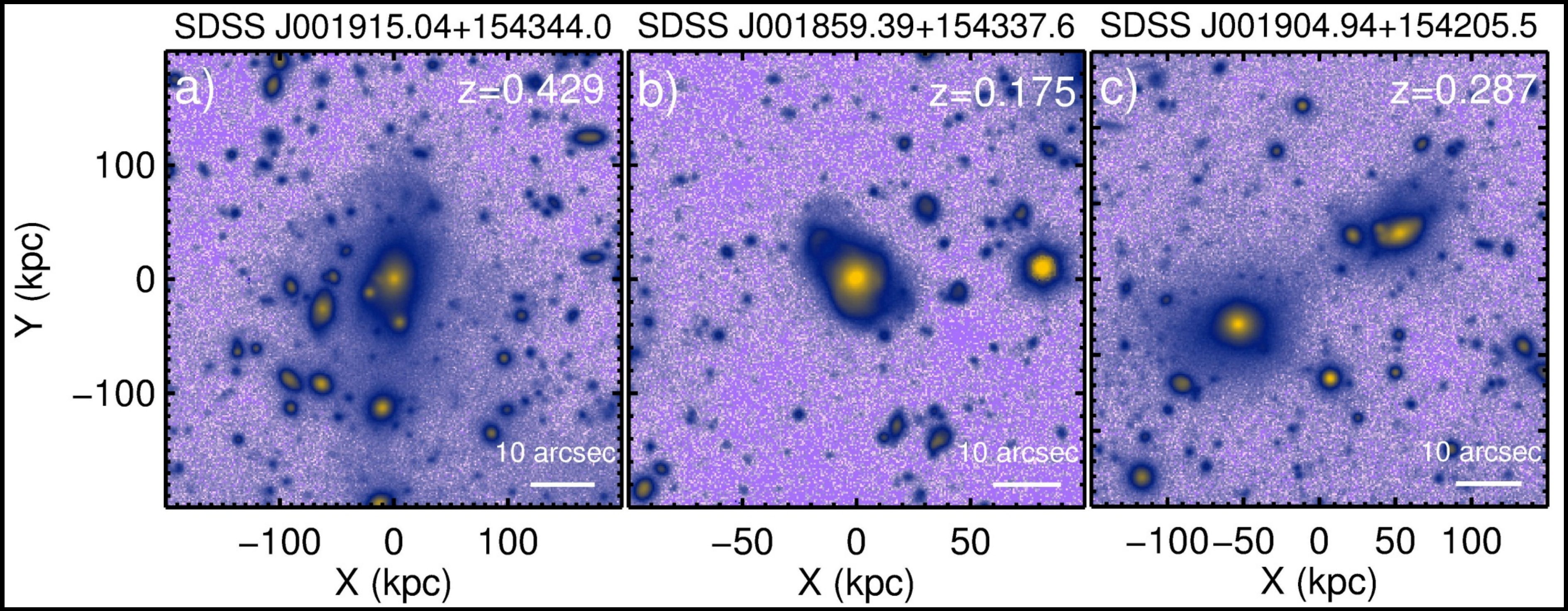

Trujillo & Fliri (2015)

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