Massive Galaxies and Their Activity at z~2-3

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Collaborators

- Tim Weinzirl: Weinzirl, Jogee, Conselice, and GNS team 2011, ApJ, 743
- I. Marinova, C. Conselice, R-R Chary, C. Papovich
- GOODS-NICMOS Survey (GNS) Team
- Theoretical Comparisons: P. Hopkins, T.J. Cox, A. Burkert, S. Khochfar, T. Naab, L. Oser

Sample of Massive Galaxies from GOODS-NICMOS Survey (GNS)

GNS = 180 orbits of HST NIC3/H-band imaging (PI: Conselice+2011) .

While ACS surveys trace rest-frame-UV light at z>1, GNS provides **rest-frame optical** images for massive galaxies at z=1-3. This is critical for studying galaxy structure

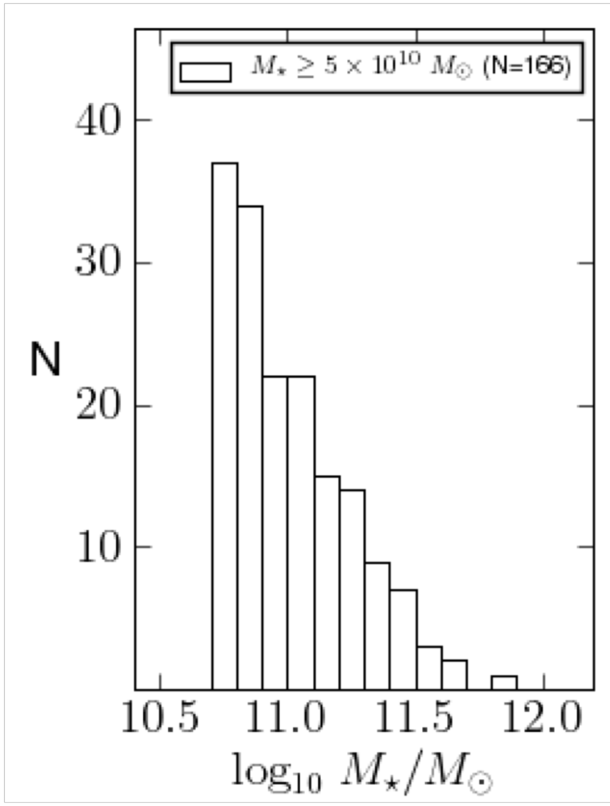
GNS has 60 deep (5σ limiting mag H = 28 AB) pointings chosen to include known massive galaxies at z=1.5-3 with a wide range of properties from old to star-forming

- Distant Red Galaxies (DRG; Papovich+06) : J-K>3 (Vega); old
- Extremely Red Objects (EROs; Yan+04) = red (old or dusty)
- BzK (Daddi+04): star-forming and evolved

GNS sample includes all galaxies in the area mapped, with a reliable M_* and photometric redshift (Conselice + 11) Complete at z~3 down to $M_*/M_0 \sim 3\times10^9$ (Mortlock+10),.

Final sample of massive galaxies ($M_*/M_0 >= 5\times10^{10}$) at z=1-3 galaxies is one of the largest samples at with deep high resolution (0.3") rest-frame optical imaging:

166 with $M_*/M_0 >= 5\times10^{10}$, 73 with $M_*/M_0 >= 1\times10^{11}$

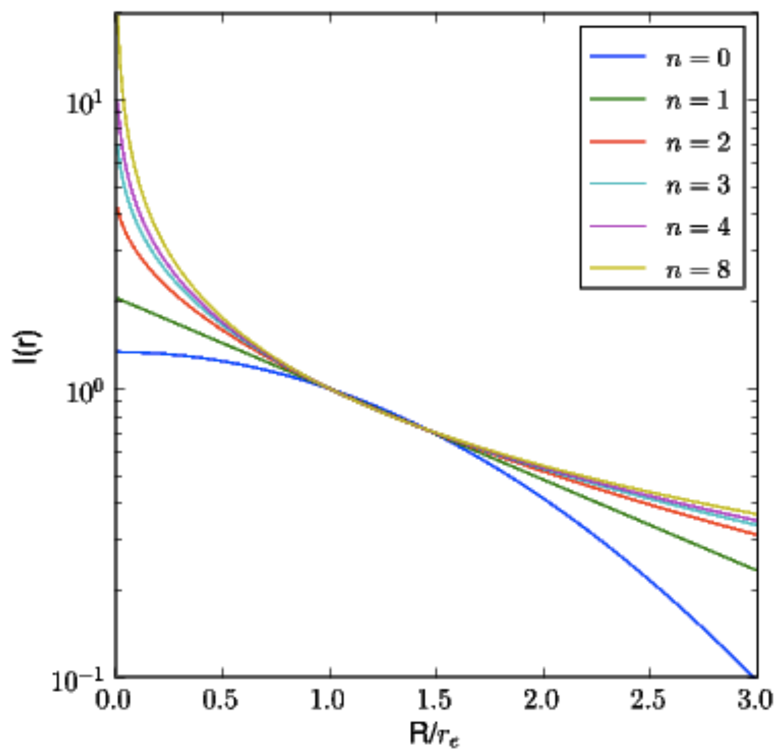


Structural Decomposition

Fit single-component Sersic models to rest-frame B (NIC3/H) images of massive z~2-3 galaxies after convolving with PSF (0.3")

$$I(r) = I_e \exp\left\{ -b\left[\left(\frac{R}{R_e}\right)^{1/n} - 1\right]\right\}$$

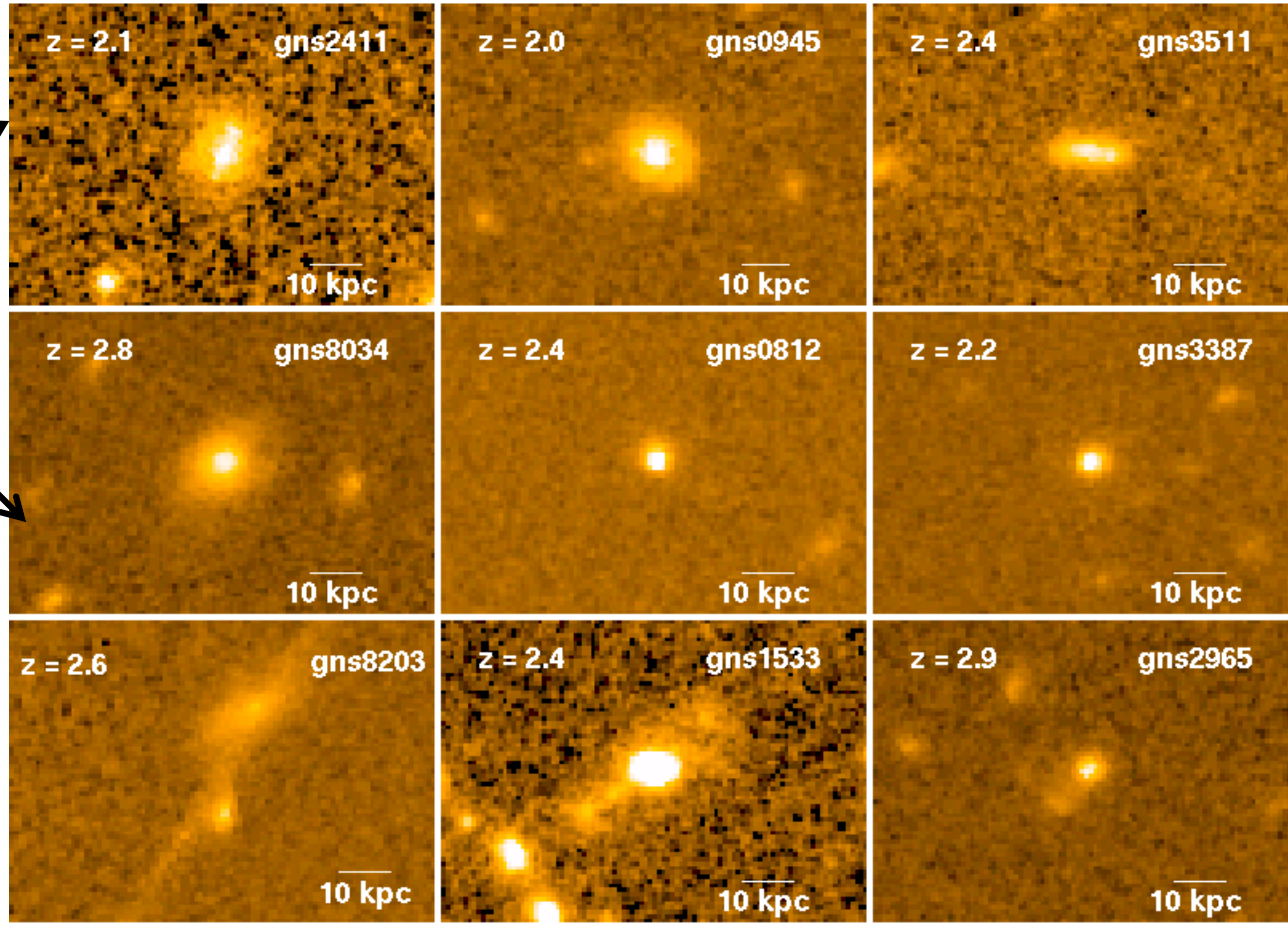
r_e = half-light radius
n =Sersic index



- n=1 for Exponential (pure disk)
- n=4 for de Vaucouleurs (classical bulge/E)

Rest-Frame Optical Structure of Massive Galaxies at z~2-3

Disky, flattened extended



Ultra-compact Re<2 kpc

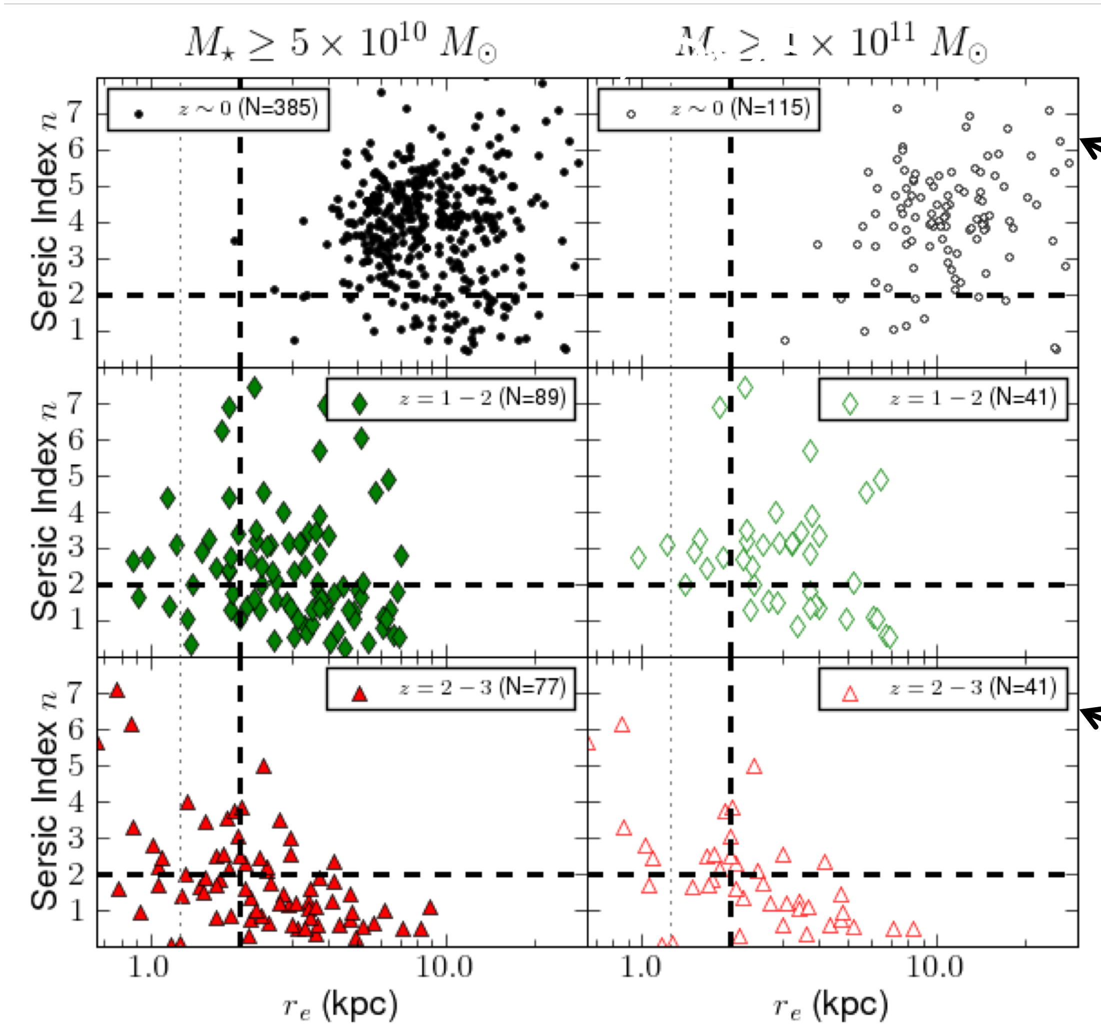
At z=2-3, among our 77 massive (M_*/M_0> = 5 x10^{10}) galaxies:

→ Most (65%) have extended (R_e>2 kpc), flattened/disky (n<2) morphologies

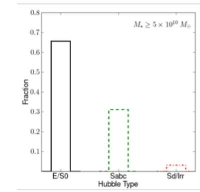
→ 40% are ultra-compact (Re<2 kpc)

→ A small fraction (<15 \%) have strong visible distortions

Rest-Frame Optical Structure of massive galaxies at z=2-3 vs z~0



(Weinzirl, Jogee,Conselice et al. 2011, ApJ, 743)



At z~0, most massive (M_*/M_0> = 5 x10^{10}) systems are E,/S0 followed by Sab : typically high (n, R_e), extended, host classical bulges/E or pseudobulges

At z~2-3, massive galaxies have very different structures of lower (n, r_e)

- 65% have n<2 disk morphologies at z=2-3 vs 20% at z~0.

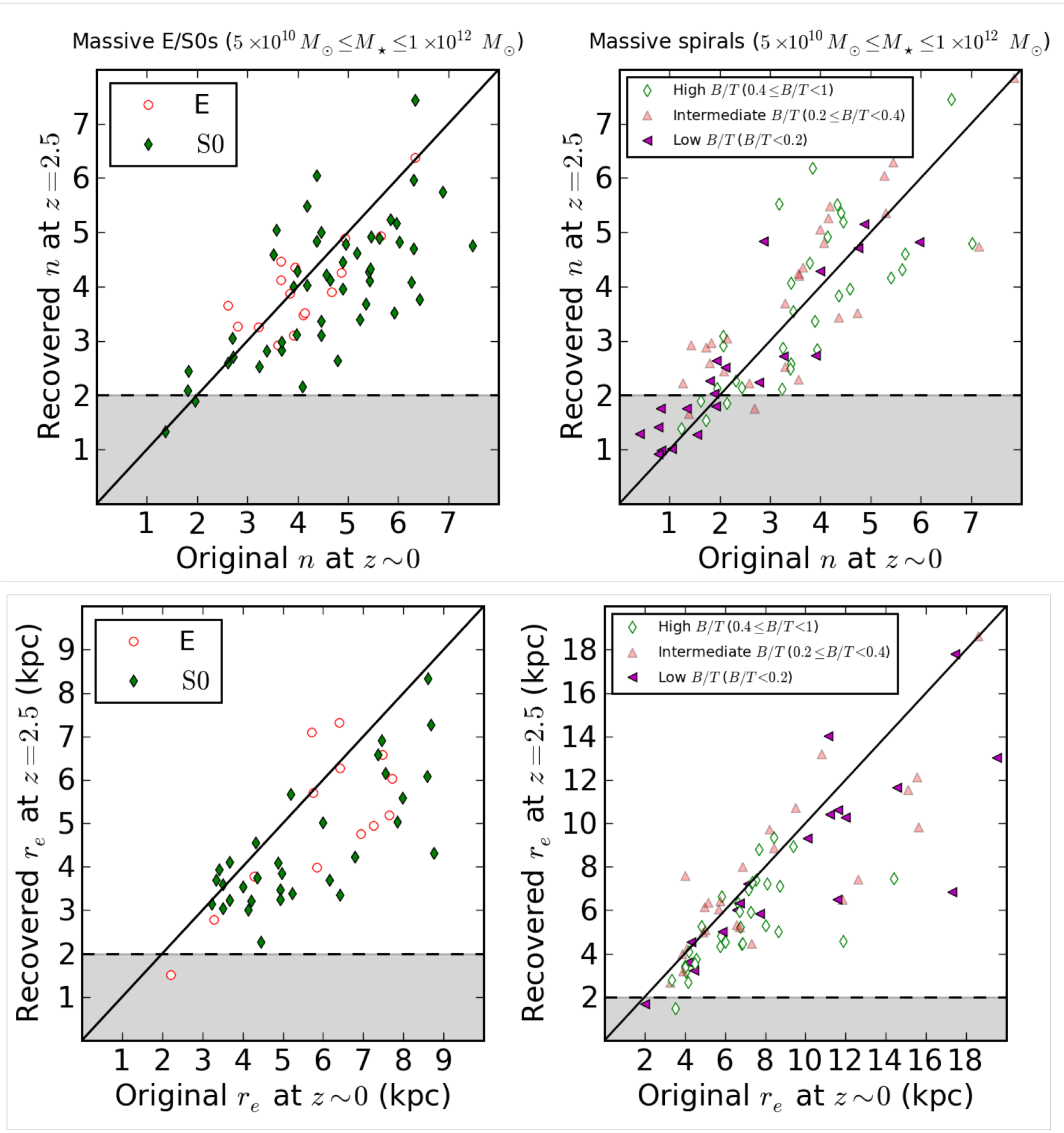
- 40% are ultra-compact (re<2 kpc) at z=2-3 vs <1% at z~0

Is the difference between massive galaxies at z~2-3 vs z~0 real

or

is it driven by redshift-dependent systematic effects (cosmological surface brightness dimming, loss of resolution) ?

Artificial redshifting of z~0 massive galaxies to z~2.5

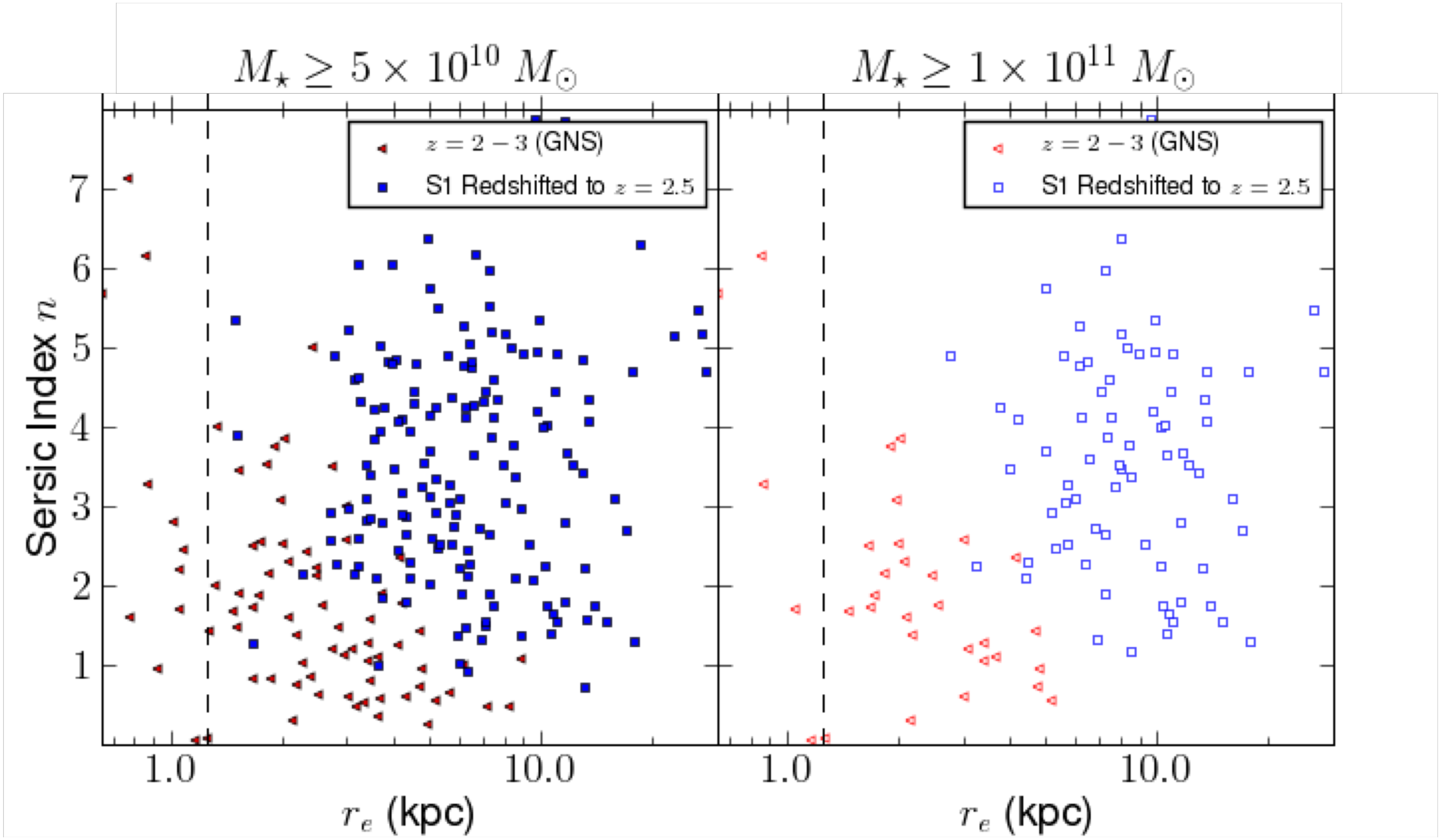


(Weinzirl, Jogee,Conselice et al. 2011, ApJ, 743)

Artificial redshifting of z~0 massive E/S0, and intermediate B/T spirals out to z~2.5 **does not move them into the shaded grey area** where most the observed z~2.5 ultra-compact (Re<2kpc) and n<2 sysyems lie

→ Difference in rest-frame optical structure between z=2~3 and z~0 is real

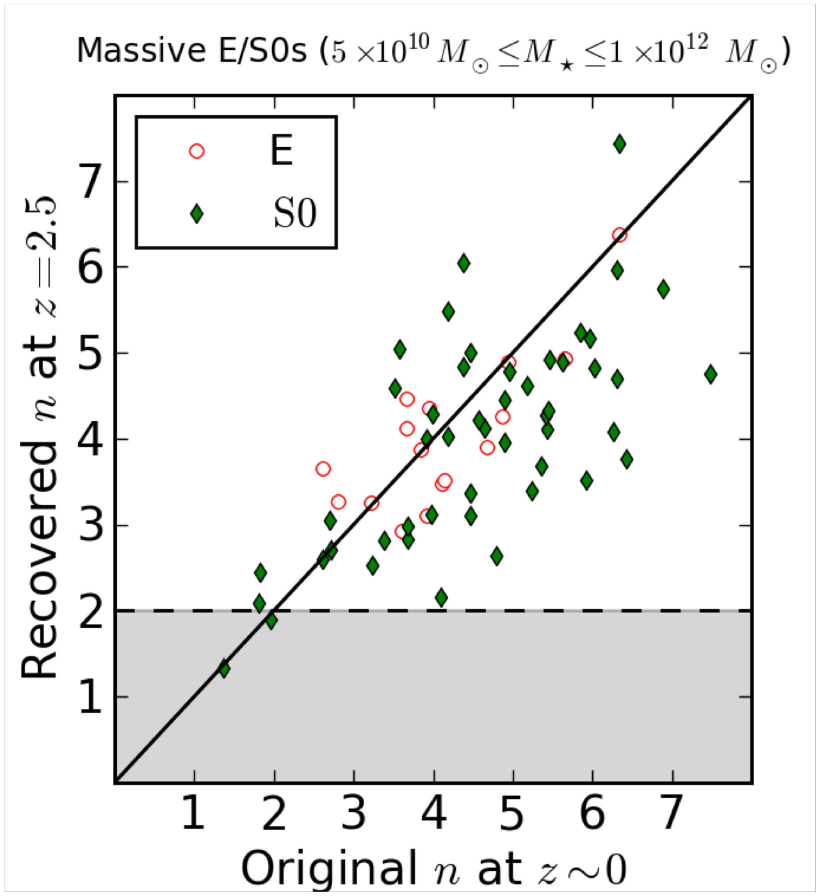
Artificial redshifting of z~0 massive galaxies to z~2.5



(Weinzirl, Jogee,Conselice et al. 2011, ApJ, 743)

Can we assume that massive galaxies with (large R_e, low $n<2$) at $z\sim2-3$ represent disk-dominated systems rather than classical Ellipticals?

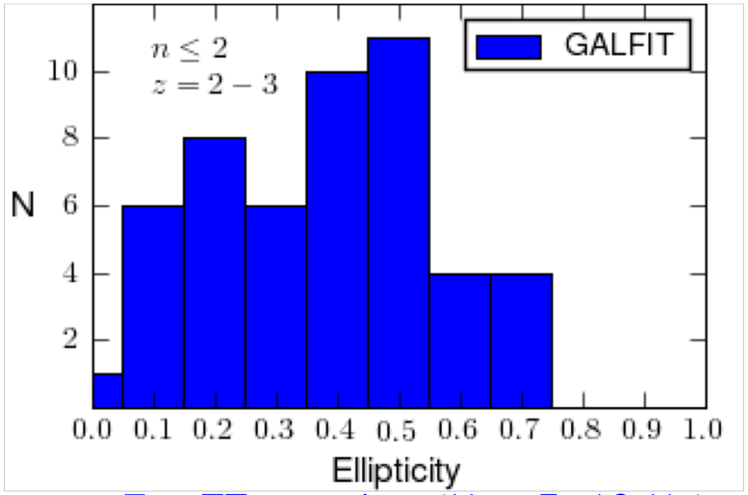
1) Could these massive galaxies at z~2-3 with n<2 be classical n~4 Ellipticals whose outer halo has been cosmologically dimmed out? Artificial redshifting suggests no.

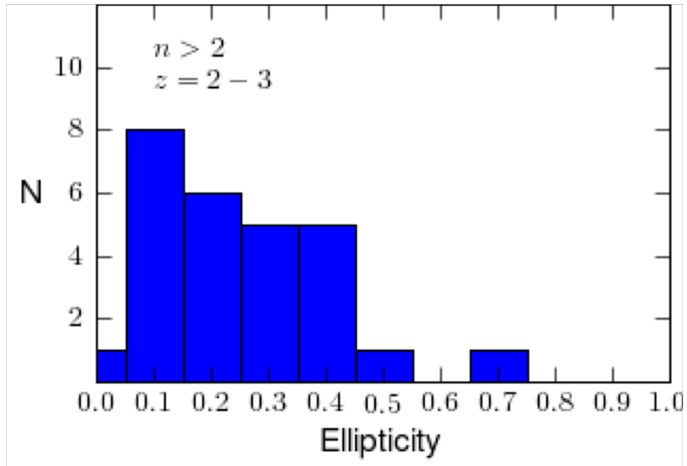


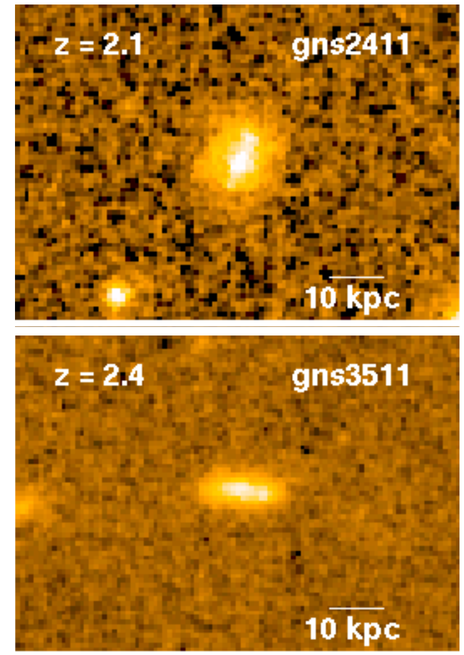
2)Very Deep (H~28 mag arcsec^{-2})WFC3 image of 1 compact galaxy reveals no outer low SB halo (Szomoru+2010)

3) For extended massive galaxies where bulge+disk decomposition is possible, B/T<0.5 and bulges are mainly pseudobulges with n<2

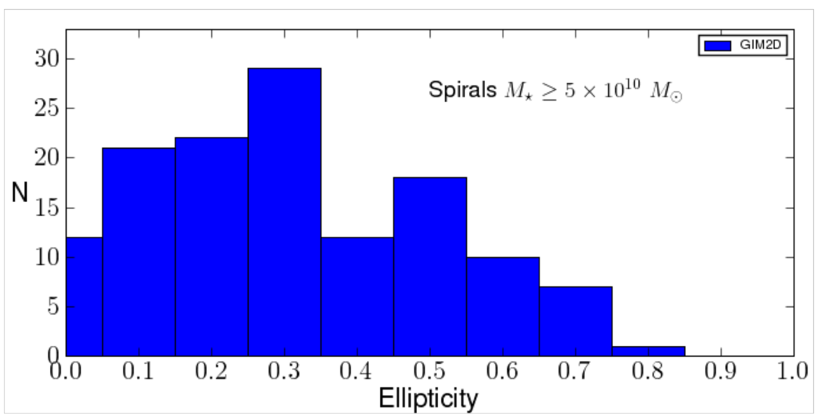
4) Distribution of projected ellipticity for massive galaxies with n<2 is more similar to that of massive spirals than Es (also van der Wel+2011 for 14 galaxies)



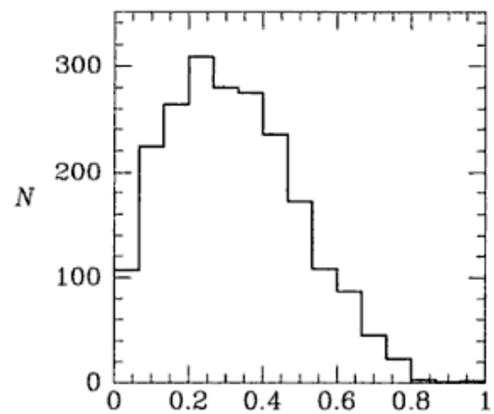




For 77 massive ($M_* >= 5e10\ M_o$) galaxies at z=2-3 in GNS

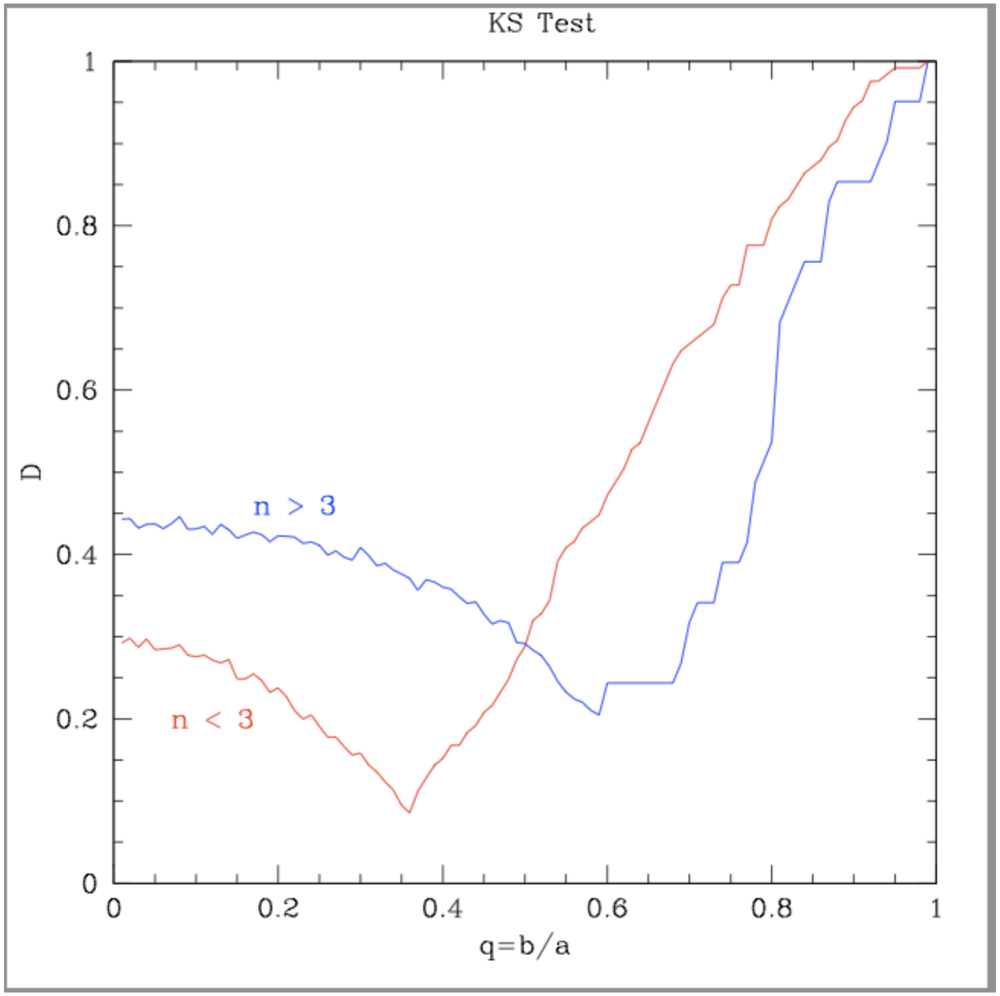


For z~0 massive ($M_* >= 5e10\ M_o$) spirals in MCG



For z~0 bright Es (Binney & Merrifield 2008)

5) Distribution of intrinsic ellipticity suggests n<2 systems are highly flattened unlike spheroids Es



1) Randomly incline oblate galaxies of intrinsic axial ratio b/a to generate F1(q1), CDF of projected axial ratios

2) D = max. separation D between F1(q1) and the CDF of observed axial ratios for n<3 or n>3 systems

For n<3 sample
b/a~0.35 or e~0.65
Highly flattened unlike Es
Possibly thick disks

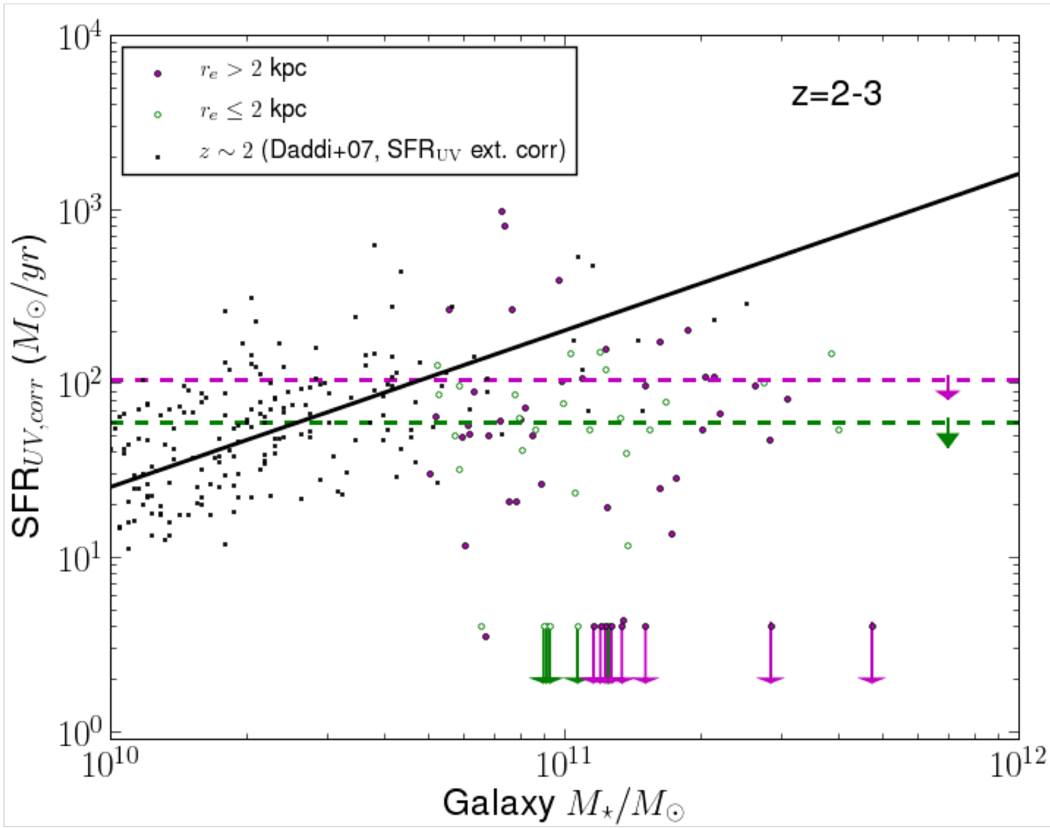
For n>3 sample
b/a~0.65 or e~0.35

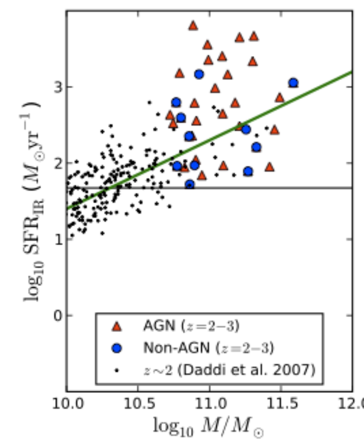
(Courtesy: A. Burkert)

Star Formation Rates in Massive Galaxies at z=2-3

SFR are estimated in two ways

1) From LIR (8-1000 μm) derived via SED fits to Spitzer 24 μm data. Overestimates SFR for AGN
2) From extinction-corrected rest-frame UV luminosity (Bauer+2011)





At z~2-3, SFR ranges from a few to several 100 M_o yr^{-1} (versus several M_o yr^{-1} at z~0)
The ultra-compact galaxies have the tail of lowest SFR or are undetected, while the extended disky systems have the highest SFRs

AGN in Massive Galaxies at z~2-3

- AGN identified mainly via X-ray properties (L_x,G), and some from IR power-law SEDs (Donely+08) , IR-to-optical excess (Fiore+08)

  At z~2-3, 40% (31/77) of massive galaxies host a AGN

- The 20 AGN with X-ray detection are low luminosity Seyfert-type systems

  L_x = few x 10^{42} to 10^{44} erg s^{-1}

  L_{bol} = few x 10^{43} to 10^{45} erg s^{-1} (for L_{bol} / L_x ~20; Vasudevan & Fabian 2009)

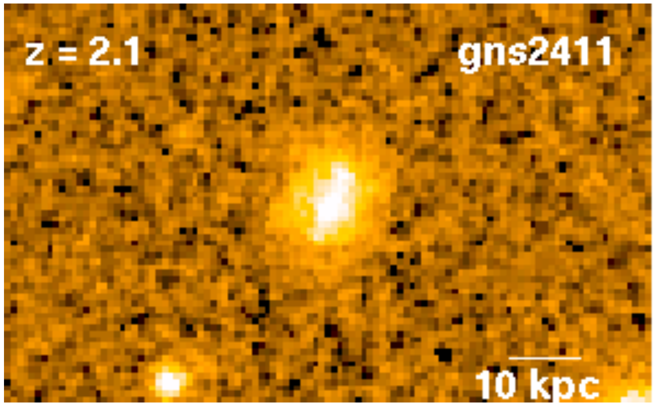
  Mass Accretion rate < 1 M_o yr^{-1} (for e=0.1)

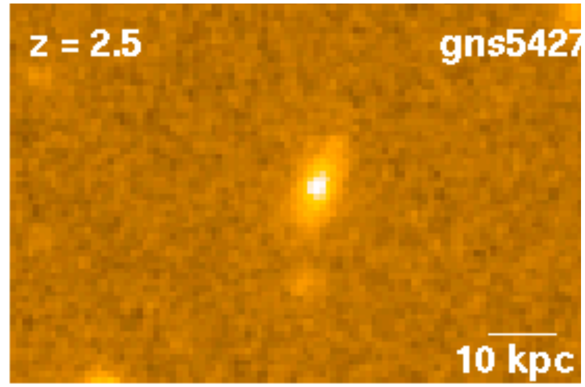
  (Complementary to high luminosity AGN --- Donley's talk]

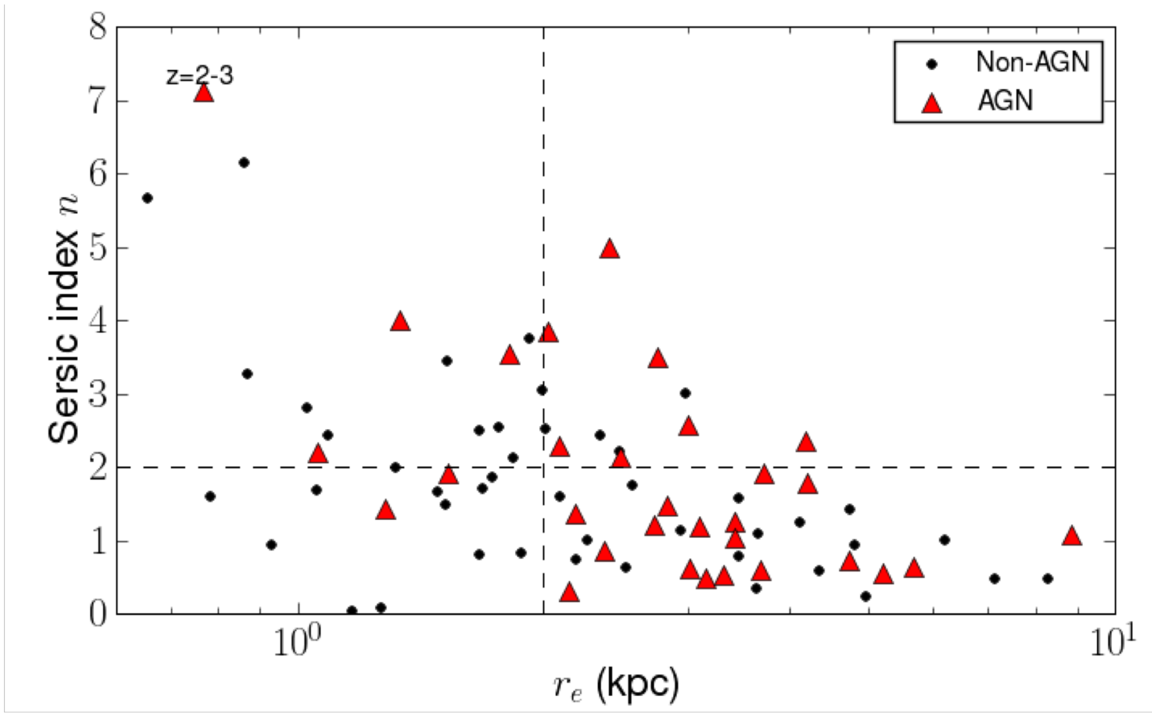
- Number density

Low Luminosity AGN at z~2-3:	2 x 10^{-4} Mpc^{-3}
SMG at z~2-3:	2 x 10^{-6} Mpc^{-3}
QSO at z~2-3:	~10^{-6} Mpc^{-3} ,
High-z radio galaxies	~few times 10^{-8} Mpc^-3

Morphology of (Low-Luminosity) AGN hosts at z=2-3



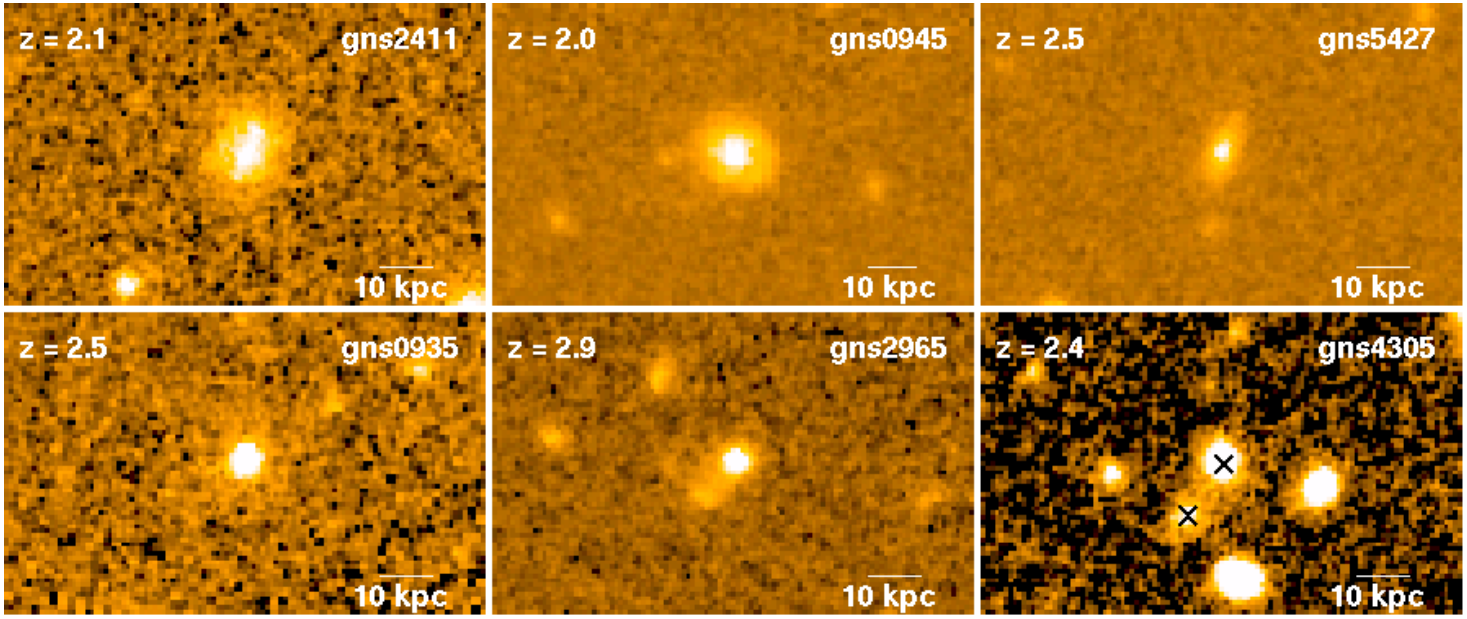




Most (65%) of AGN hosts are disky extended galaxies (just like the general population)

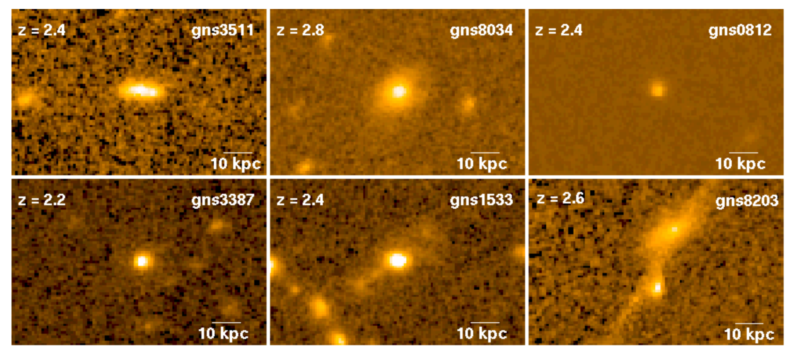
AGN hosts are ~3 times less likely than non-AGN to be ultra-compact (this is likely caused by the fact that many UC are undetected in SFR, gas starved and ‘dead’,)

Only a small fraction of AGN & Non-AGN show visibly strong distortions



AGN

Both AGN and non-AGN hosts have a comparably low fraction (<15%) of strong visible morphological distortions

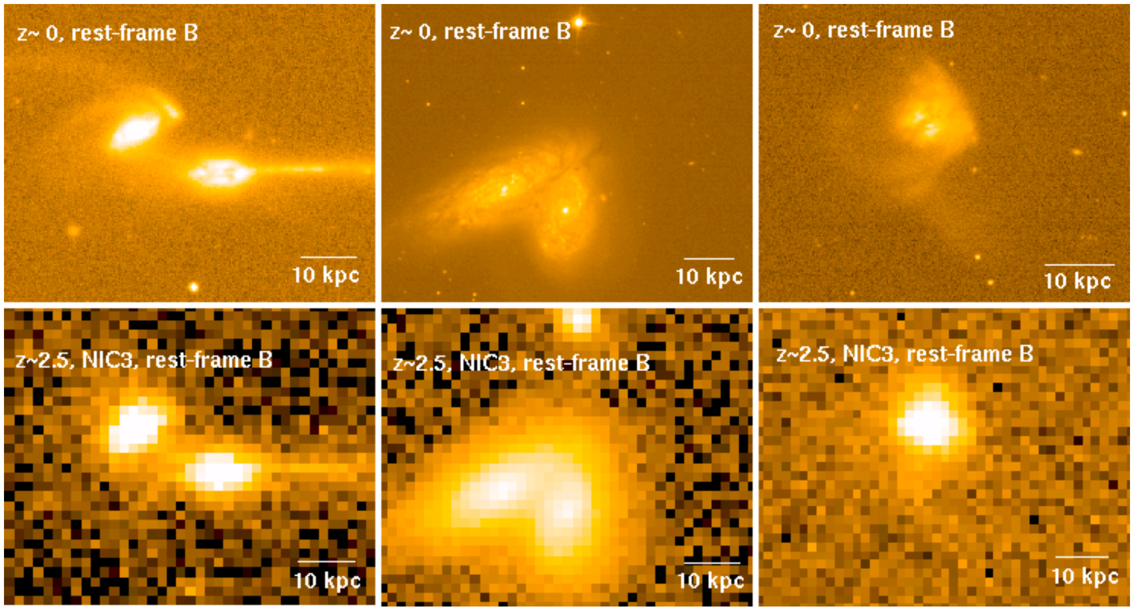


Non-AGN

However even best current datasets do not have resolution and sensitivity to detect late stages of major merger or minor mergers

Can we detect major & minor mergers with deep NIC3 data?

Artificially redshift rest-frame B light of mergers from z=0 to z=2.5 and re-observe with NIC3/F160W to depth of GNS survey.

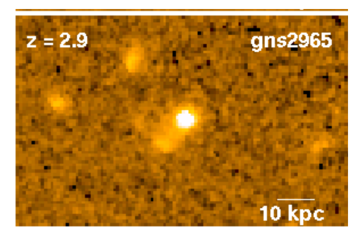


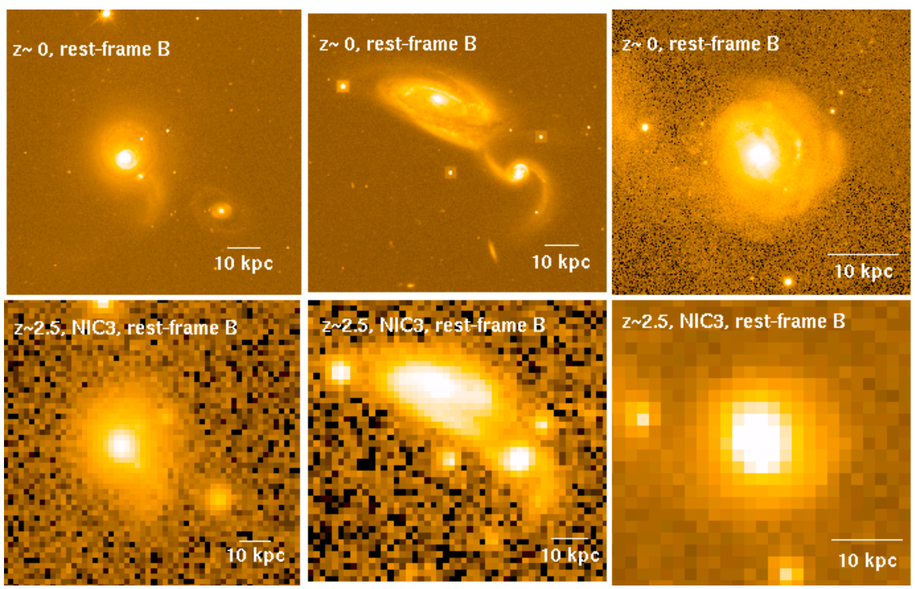
Major mergers

z=0, rest-frame B

↓

z=2.5, rest-frame B (NIC3/F160W)





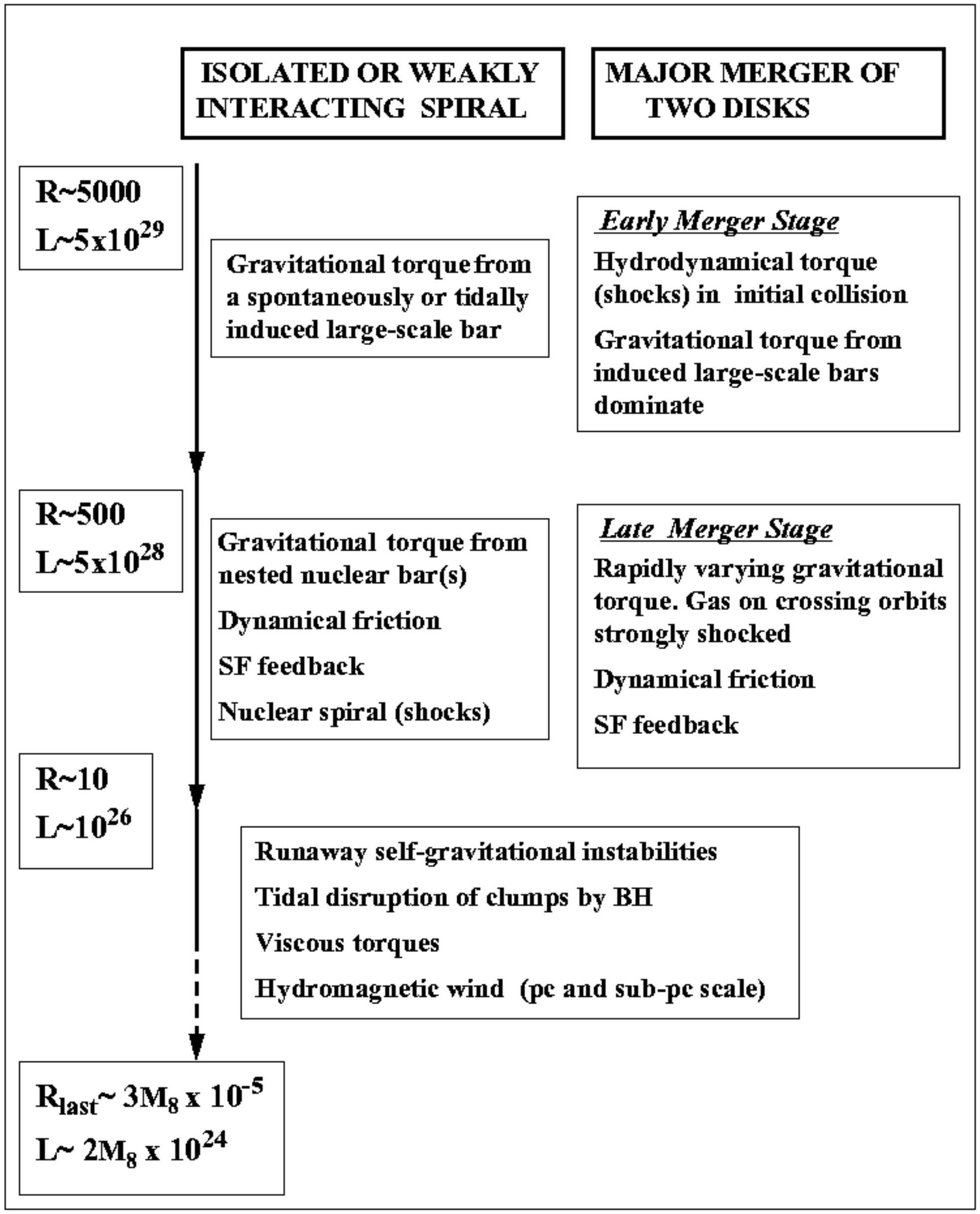
Minor mergers

z=0, rest-frame B

↓

z=2.5, rest-frame B (NIC3/F160W)

Why are large-scale properties of AGN and non-AGN at z~2-3 similar?



In order to feed gas from tens of kpc down to an AGN, transport mechanisms on different scales must remove over 99% of its angular momentum

The AGN at z~2-3 have low estimated gas accretion rate dM/dt <= $1 M_o$ yr^{-1}. The implied accreted gas mass (< 10^8 Mo) over a duty cycle is *much less than the typical gas content in inner kpc of most massive galaxies (except in some gas-starved ultra-compact galaxies).*

Thus. the AGN activity can be triggered by circumnuclear gas transport mechansims (e.g., dynamical friction on clumps, nuclear bars, shocks)

Large-scale transport or fueling mechanisms (e.g, mergers, large-scale bars) are not necessary conditions to fuel the AGN (but can grow the galaxy as a whole

(Jogee 2006, Ch6, AGN Physics on All Scales; astro-ph/0408383)

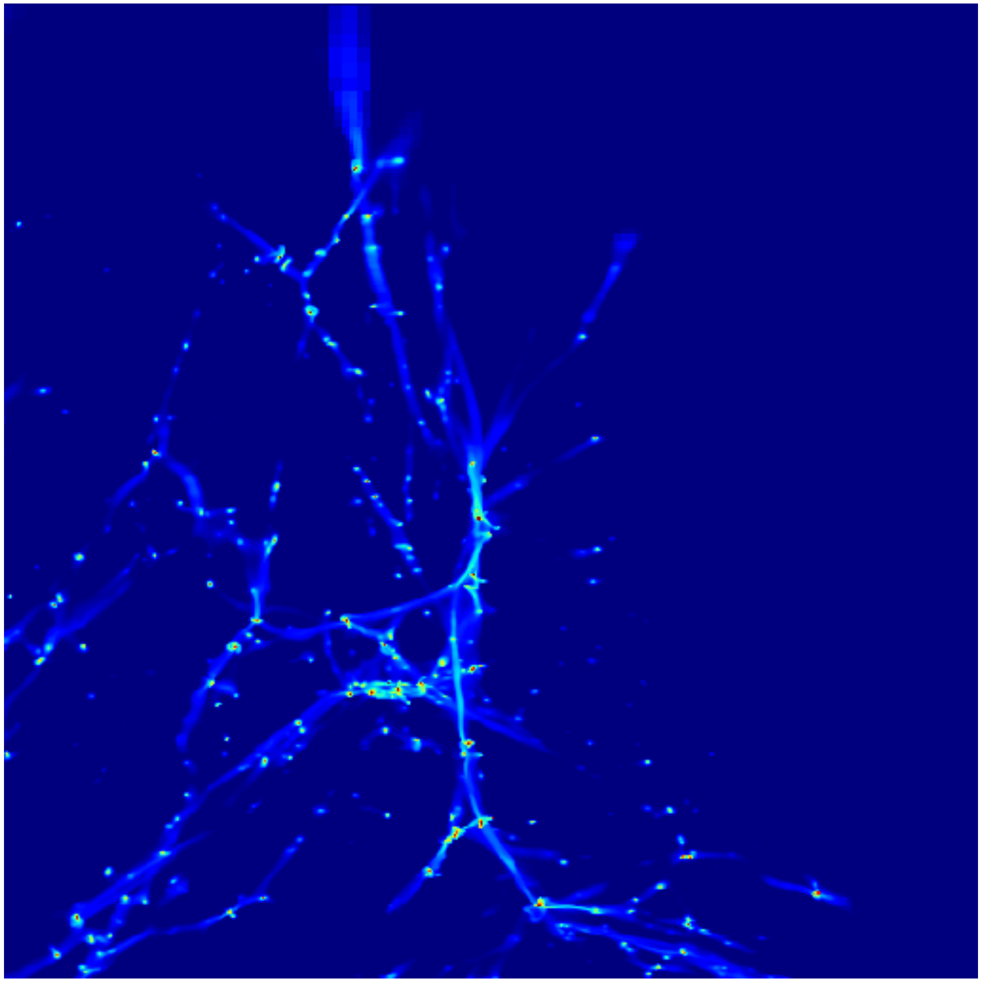
How did the massive galaxies at z~2 form ?

Most massive galaxies at z~2-3 have **high mass surface density and disky morphologies.** This implies they form through rapid gas-rich dissipative processes

1) Gas-rich (f_{gas}> 50%) major mergers builds disky remnants (Sersic n~2-3) rather than classical bulges/E (e.g., Robertson+06; Hopkins+09; Naab+09)

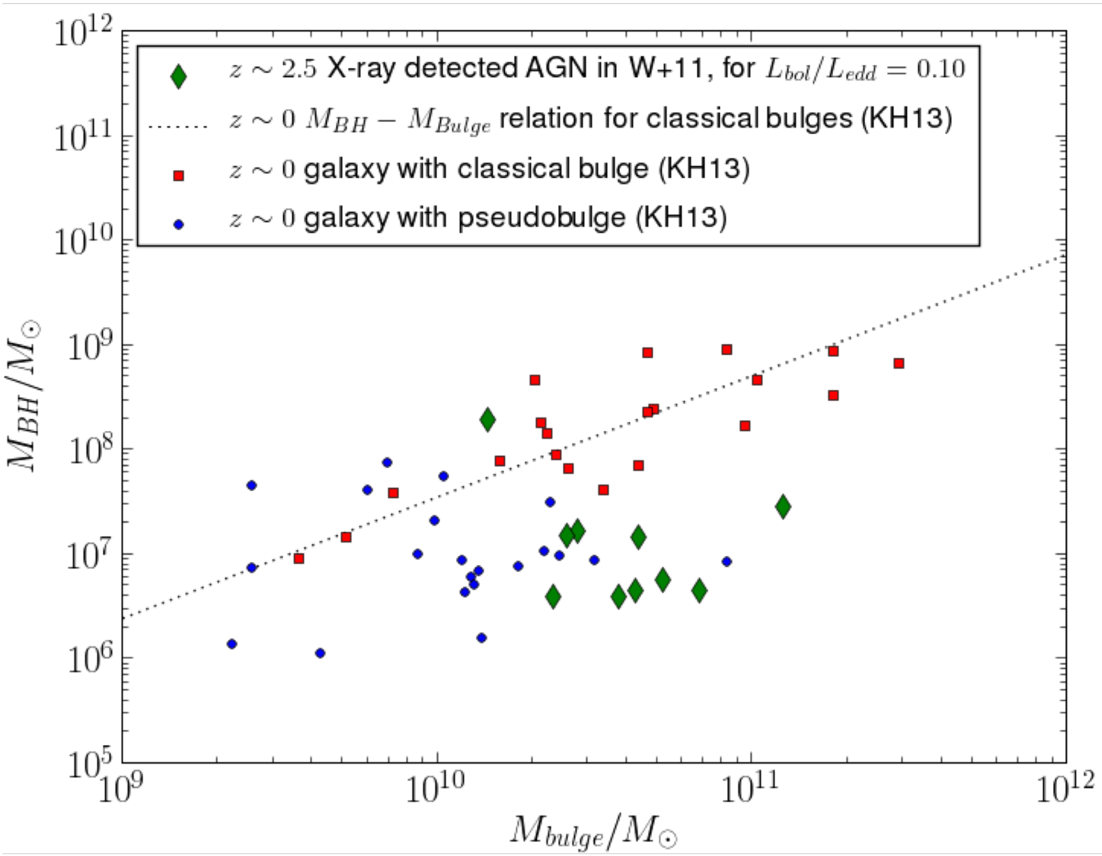
→ but hard to make 60% of galaxies disky

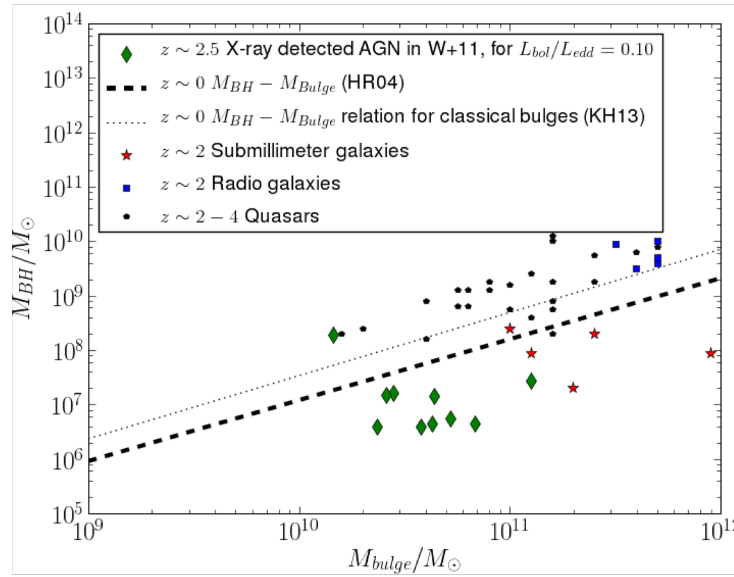
2) Cold accretion builds disks at z>2 (e.g., Keres+05; Khochfar & Silk 09; Dekel+09; Brooks+09; Oser+Naab+12; Burkert+10)



Courtesy: A. Dekel & R. Teyssier
(200 Mpc, z=5 to 2)

Relation between BH and Bulge Mass at z~2-3?



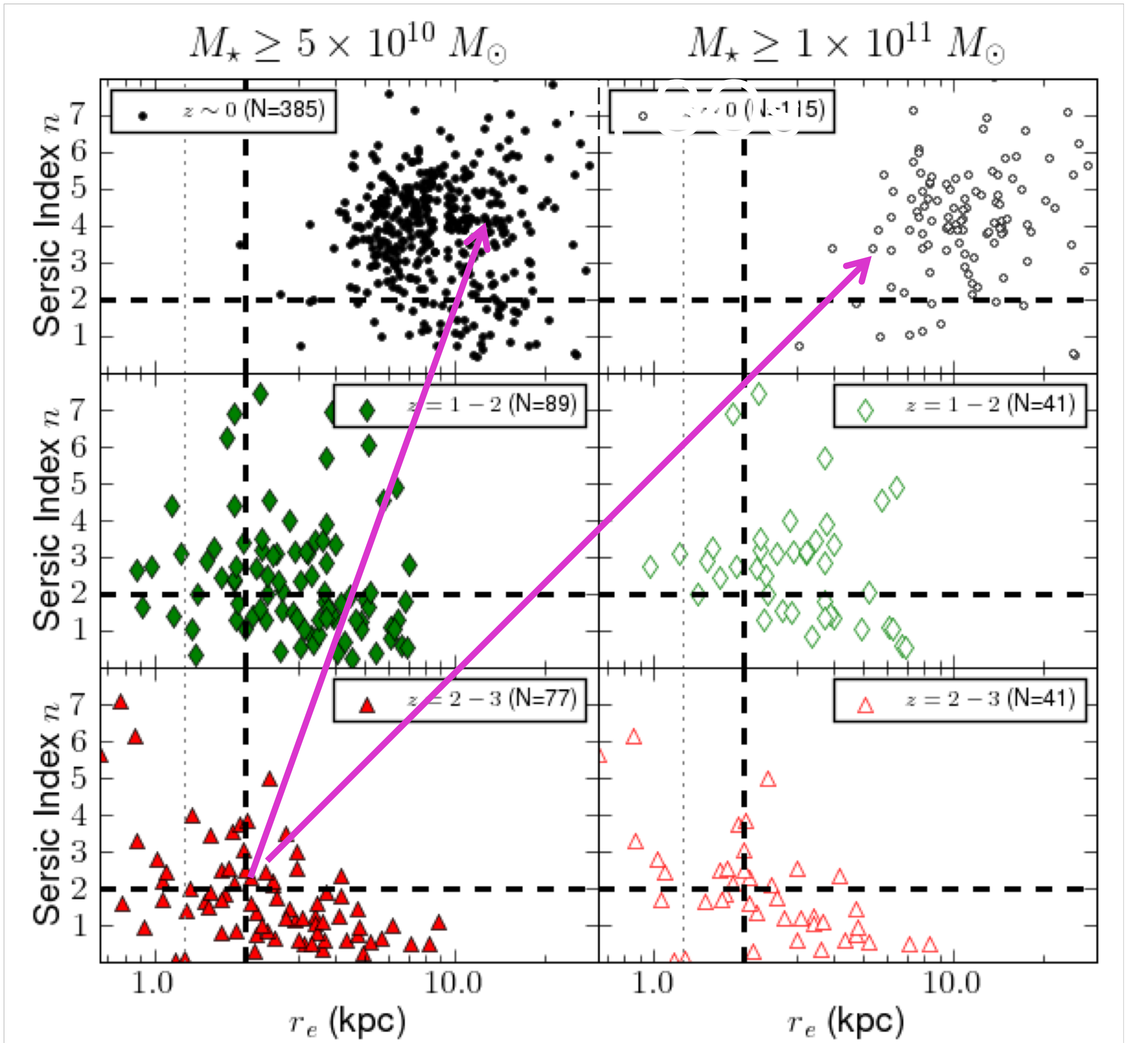


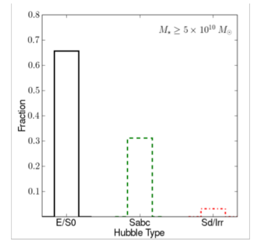
For a subset of AGN hosts (extended) at z~2-3, B+D decomposition is possible
We assume L_{bol}/L_{edd}=0.1 to get above ballpark plots (factors of several uncertainty)

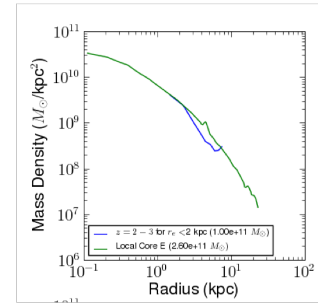
LHS plot: Low lum AGN at z~2-3 show no tight BH-bulge correlation. They are more similar to z~0 pseudobulges than z~0 classical bulges

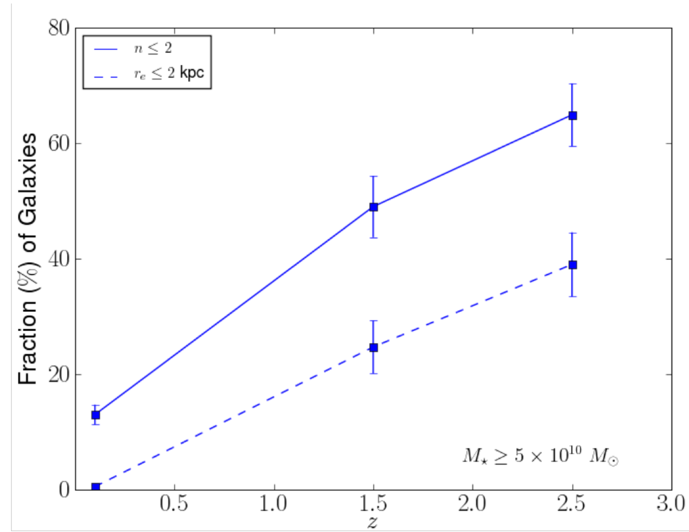
RHS plot: Low lum AGN at z~2-3 vs rarer z-2 luminous QS0s, Radio Galaxies from KH13

How will the massive galaxies (and their BH) evolve from z~2 toz~0?









Due to their already high mass, most massive ($M_*/M_0 >= 5 \times 10^{10}$) galaxies at z=2-3 can only evolve into E/S0 and Sabc by z~0.

This evolution requires a rise in the size (R_e) by a factor of 3-5 and a rise in Sersic index n

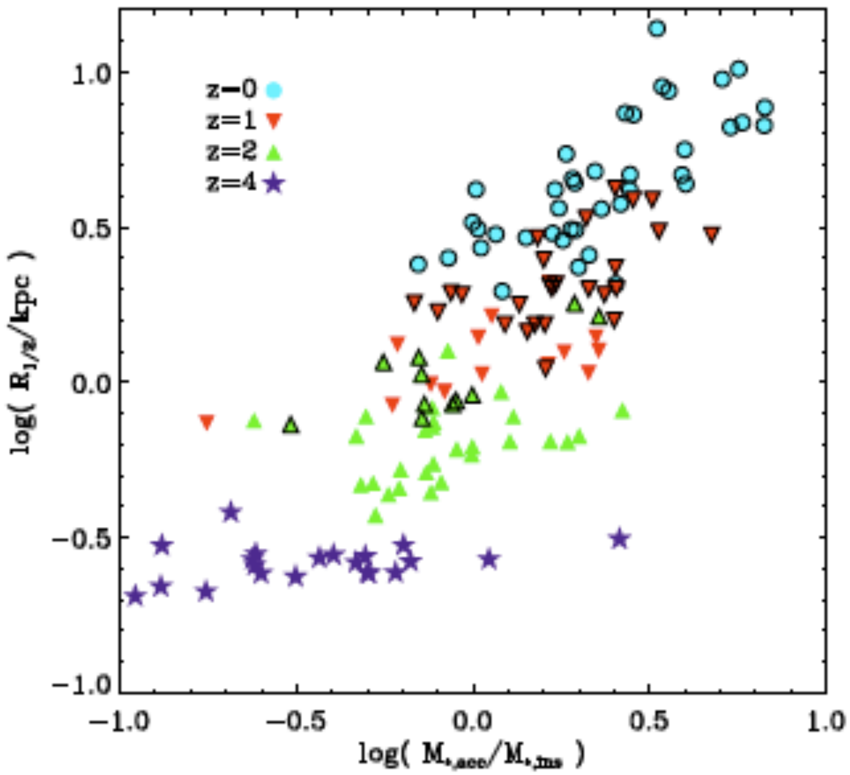
The observed mass density profile at z~2-3 suggest growth is needed in outer parts of galaxy

How will the massive galaxies (and their BH) evolve from z~2 to z~0?

Two main mechanisms to raise (size R_e and Sersic index n) from z~2.5 to z~0:

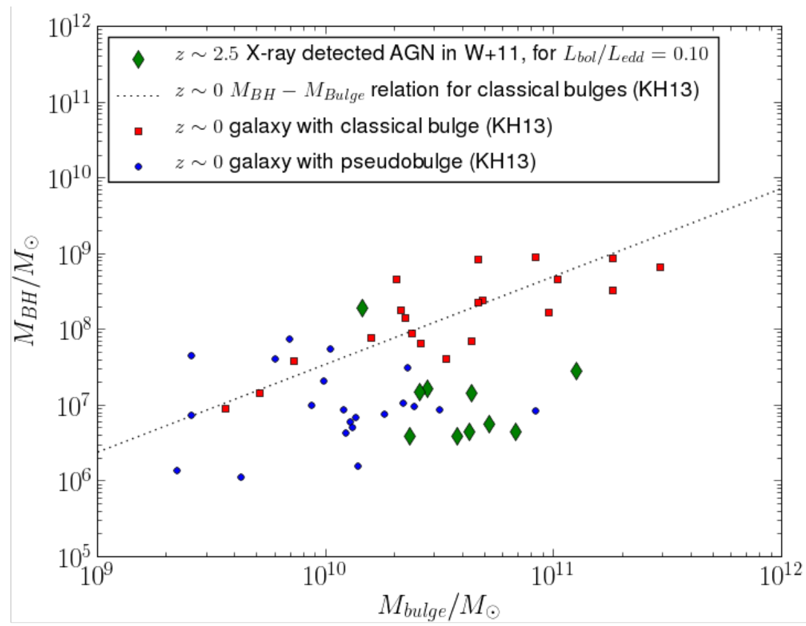
1) Moderately gas-poor major mergers: Convert disks into classical E/bulges with n~4

2) Minor mergers: Accreted stripped stars grows outer parts of galaxy **and raise size more effectively than major mergers** (Naab+09;Bezanson+09; Oser+12).



Fraction of accreted stars

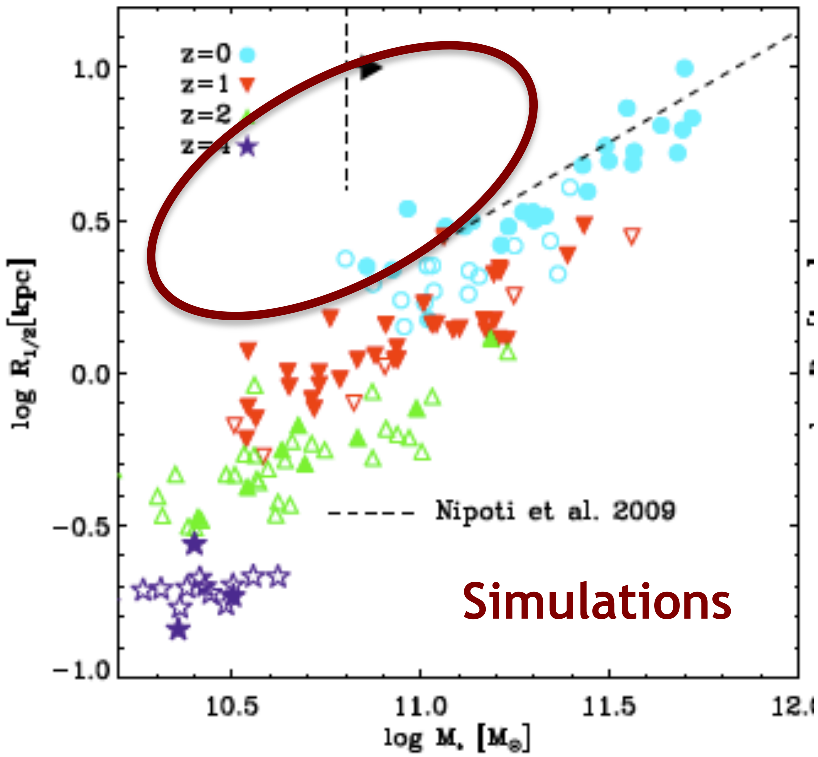
(Oser & Naab +12)



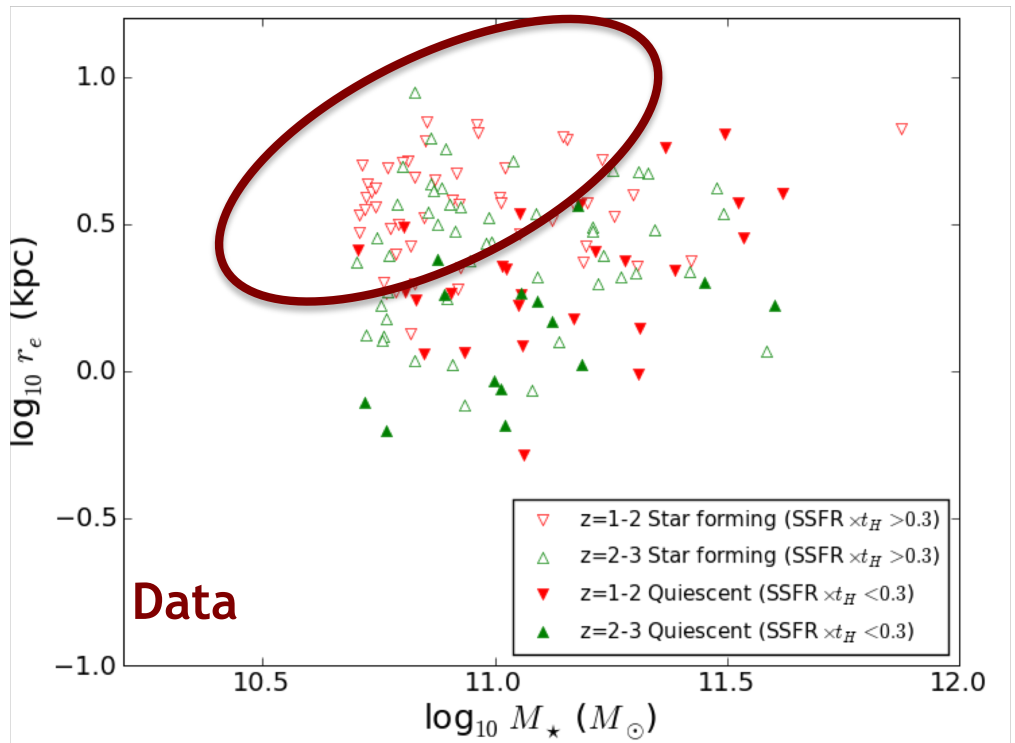
***Open QuestIon**: Can these minor mergers and major mergers correctly transform the overall galaxy structure from z~2.5 to z~0, while evolving the AGN in the BH-bulge plane such that some move closer to the z~0 BH-classical bulge relation?*

Simulations severely underproduce extended massive galaxies

Many cosmological simulations still strongly underproduce the fraction of massive extended (disky) galaxies at z~2-3 and over-produce compact galaxies e.g. Oser+12, Ceverino, Dekel et al in prep.)



Oser + Naab+12



Above: 40 high res. cosmological re-simulations of galaxies with $M_* = 5e10$ to $4e11$ M_o (Oser + Naab 2012). Include early phase at 2 <z<6 of rapid in-situ SF from gas accretion (cold streams + halo))

Summary:Massive Disks and their Activity at z~2-3

1) Massive galaxies (M_*/M_o>5x10^{10}) have different rest-frame optical structure at z~2-3 vs z~0:
- 40% are ultra-compact (R_e< 2 kpc) versus <1% at z~0
- 65% have flattened/disky (n < 2) morphologies versus only 20% at z~0

2) At z~2-3, 40% (31/77) of massive galaxies host an AGN .The 20 X-ray-detected AGN are low luminosity Seyfert-like (L_{bol}~ few x 10^{44}-10^{45} erg s^{-1}). Most AGN hosts are disky galaxies.

3) At z~2-3, AGN hosts are 3 x less likely than non-AGN to be ultra-compact (gas-starvation). Otherwise, AGN and non-AGN hosts show similar global properties: SFR, cold gas fraction and a low fraction (<15%) of strong visible morphological distortions.

Low-luminosity low gas accretion rate (<= 1M_o yr^{-1}) AGN in typical gas-rich circumnuclear region require circumnuclear gas transport mechansims (e.g., DF on clumps, nuclear bars) Large-scale trransport mechanisms (e.g, mergers, bars) are not necessary to fuel the AGN

4) For AGN at 2-3 where B+D decomposition is possible, if we assume L_{bol}/L_{edd}=0.1 AGN show no tight BH-bulge correlation and are similar to z~0 pseudobulges