Low-surface-brightness galaxies – a new frontier in galaxy evolution studies

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With: Garreth Martin and the Horizon-AGN team

The significance of LSB galaxies

- Wide surveys like SDSS become incomplete at $\mu_e > 23$ mag arcsec^{-2} **(e.g. Kniazev +04, Bakos +12, Williams +16)**

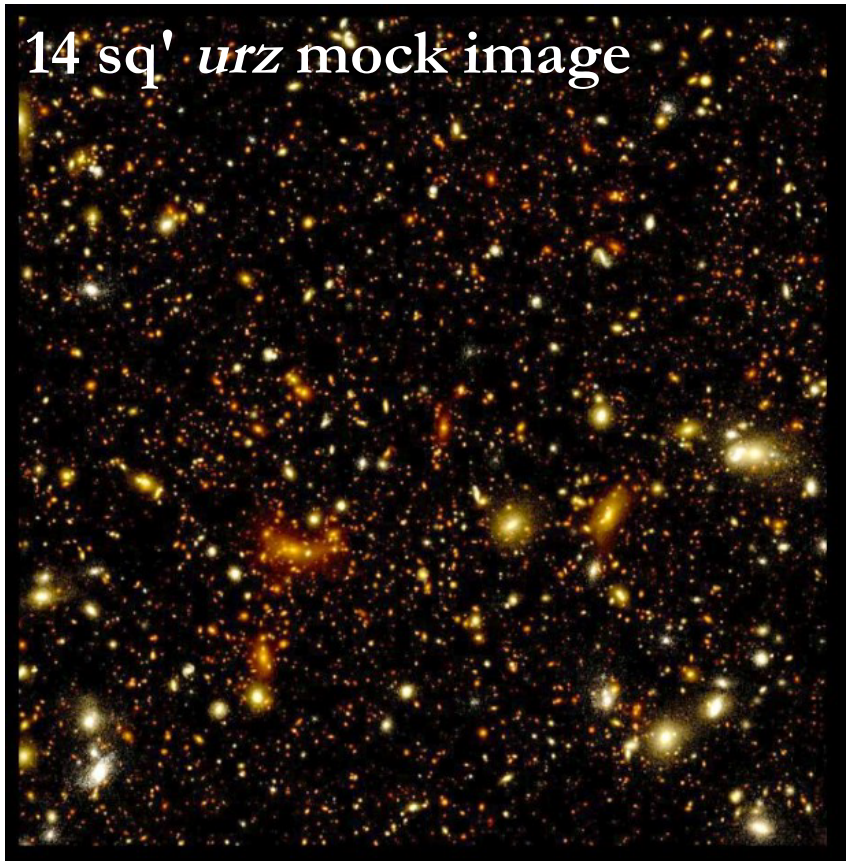
- **Galaxy evolution studies (obs and theory) are dominated by high-surface-brightness ($\mu_e < 23$ mag arcsec^{-2}) galaxies**

- New instruments and small, deep surveys are studying the LSB domain (e.g. **Kaviraj 14, van Dokkum+15, Koda +15,Venhola +17)**

- Sizeable LSB population exists below current detection limits – but how significant is it?

The significance of LSB galaxies

The Horizon-AGN simulation

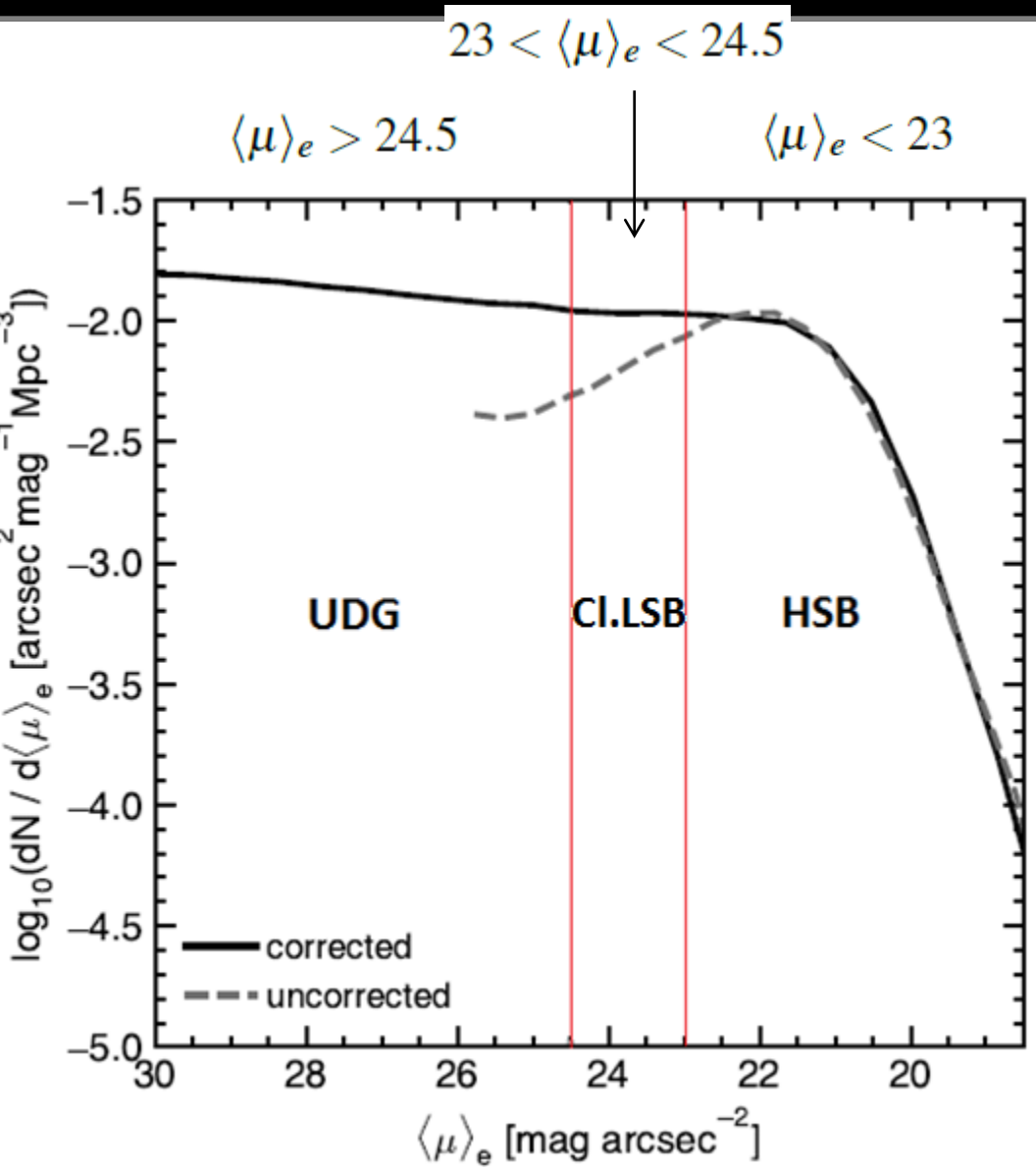


Kaviraj +17, MN, 467, 4739

- 100 Mpc box length, 1 kpc resolution, WMAP7 cosmology
- Good agreement with galaxy and BH properties at $z<6$ **(Dubois +14, +16, Volonteri +16, Kaviraj +17)**
- Effective mass limit of $\sim 10^8$ $M_\odot$ - can probe high-mass LSB galaxies

The significance of LSB galaxies

LSB galaxies dominate the local number density



The significance of LSB galaxies

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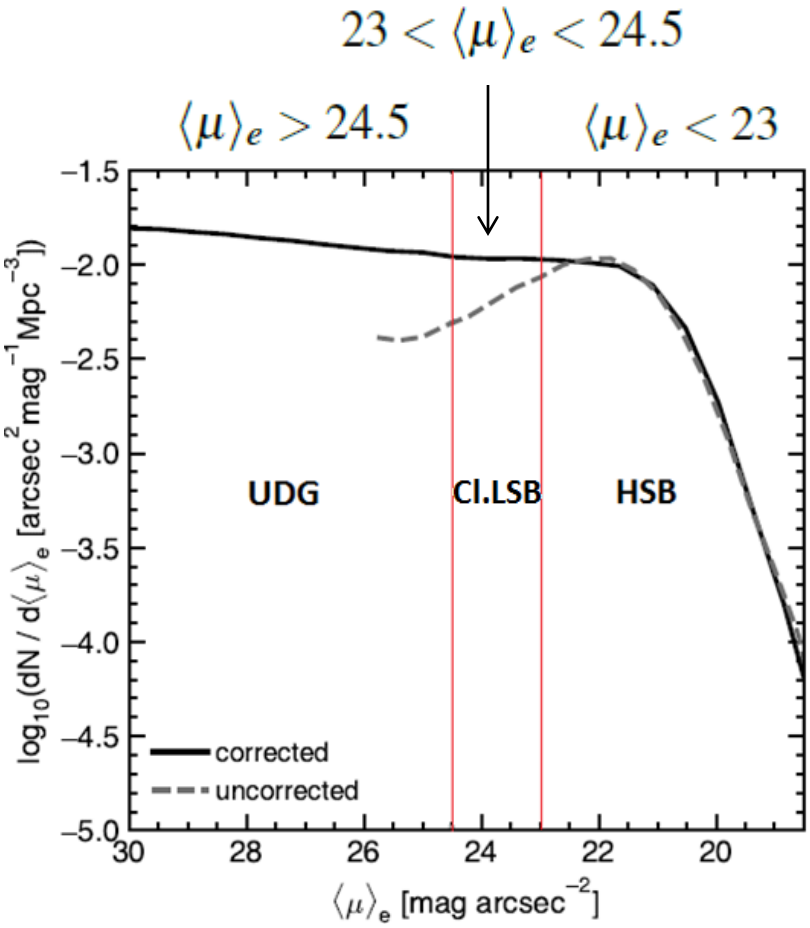
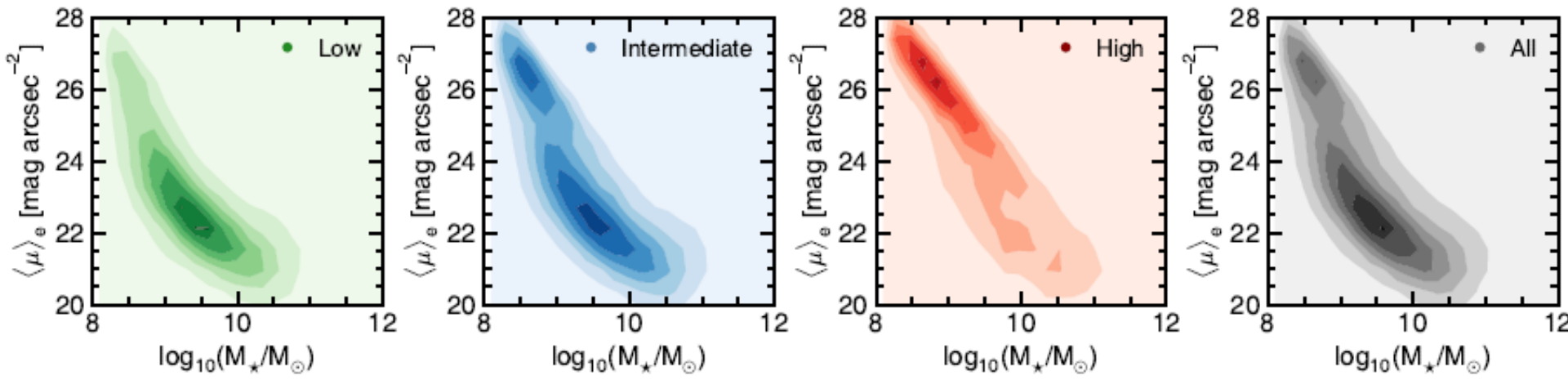


	f_{LSB}	f_{UDG}	N_{LSB}	N_{UDG}
Field	0.23 (0.09)	0.18 (0.77)	10760	5634
Group	0.21 (0.09)	0.27 (0.74)	12691	12119
Cluster	0.19 (0.07)	0.46 (0.83)	2310	4572

- LSBGs dominate local number density
- …and contribute ~20% of the mass and luminosity density
- **To fully understand galaxy evolution we need to understand the formation of LSBGs**

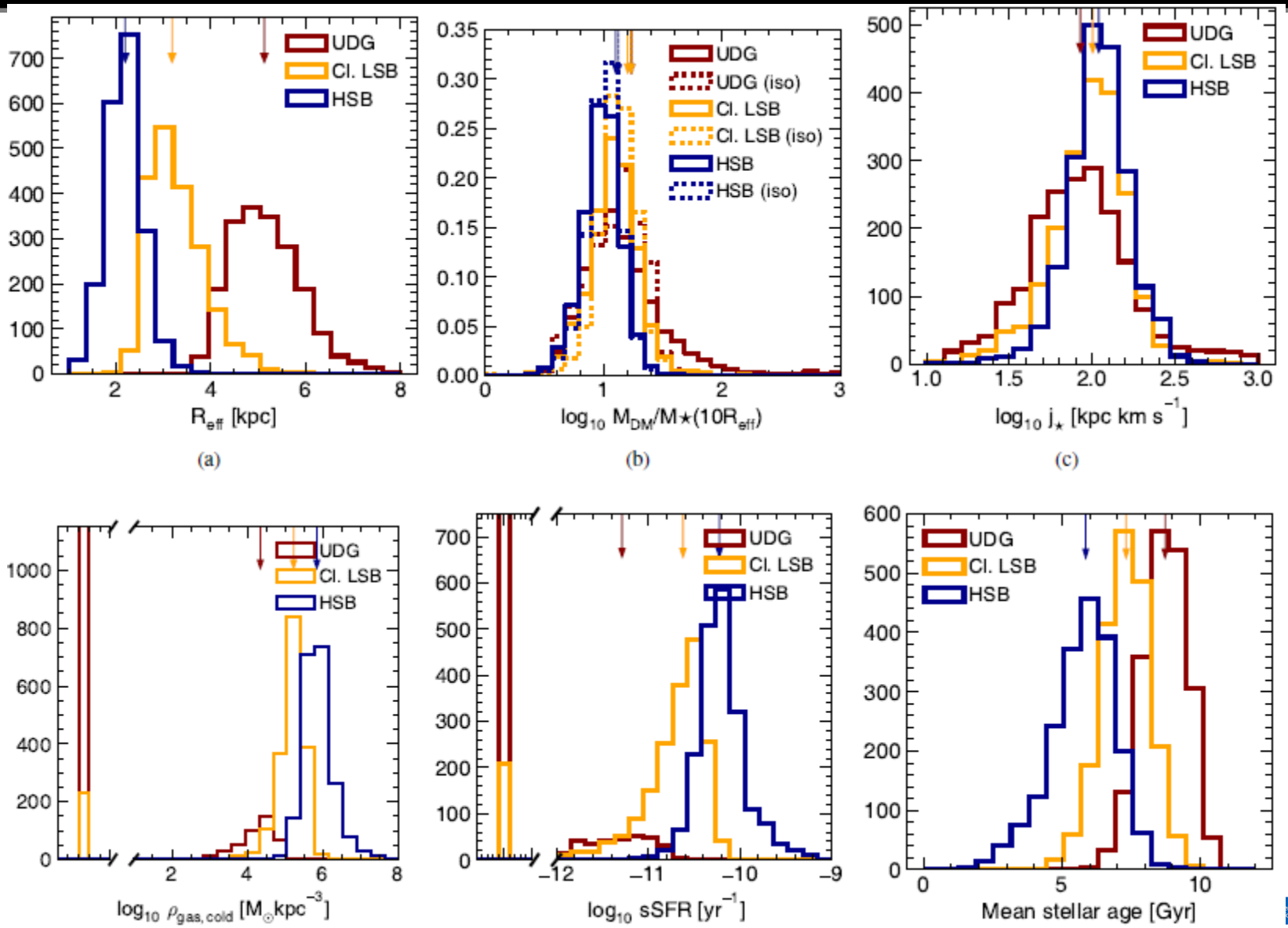
The significance of LSB galaxies

LSST is indispensable for LSB science

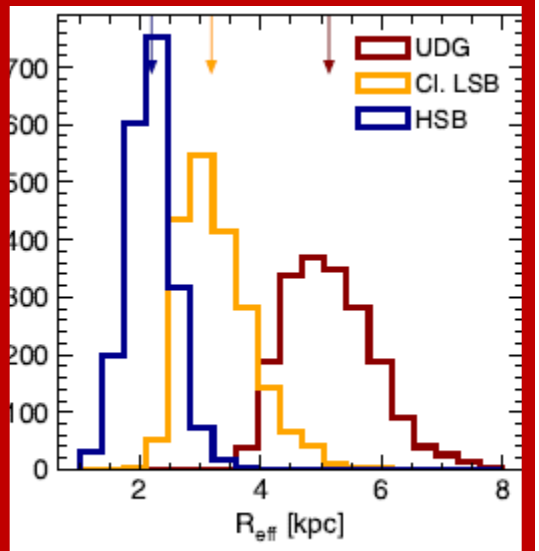


- More LSBGs at fixed stellar mass in denser environments
- But only ~10% of galaxies live in clusters
- More LSBGs in the field than in clusters (LSBGs are not a cluster phenomenon)
- **To study LSBGs we need a wide, deep survey (i.e. LSST!)**

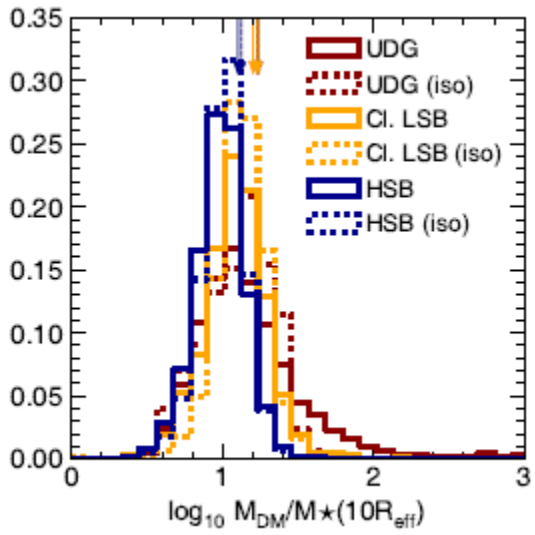
The properties of LSBGs at z=0



The properties of LSBGs at z=0



(a)



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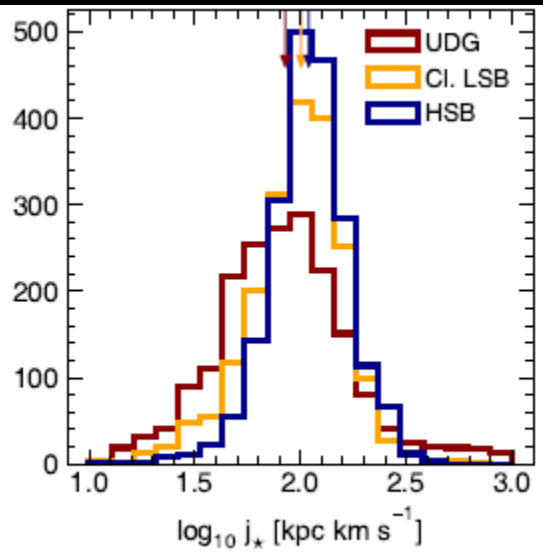
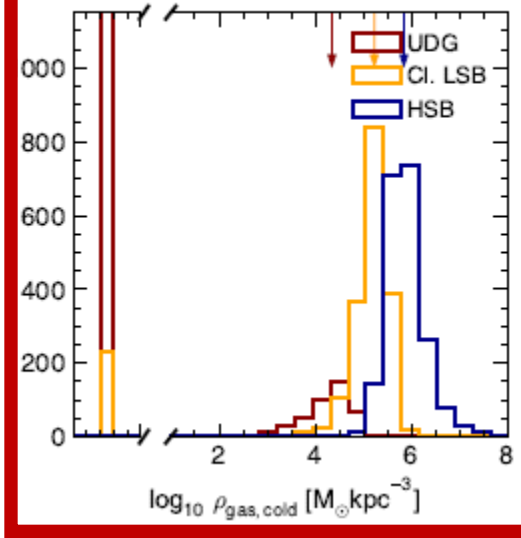
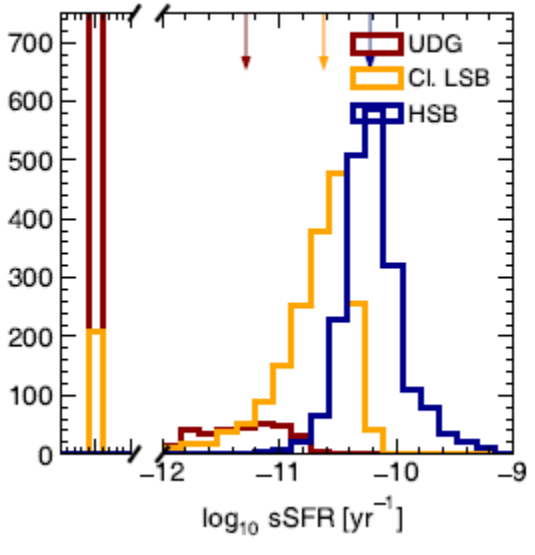
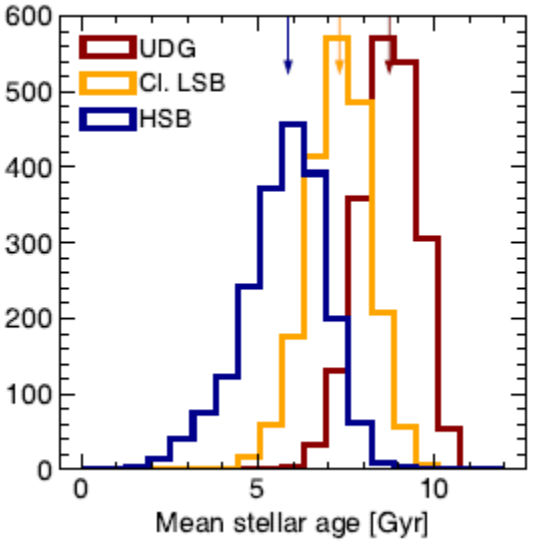


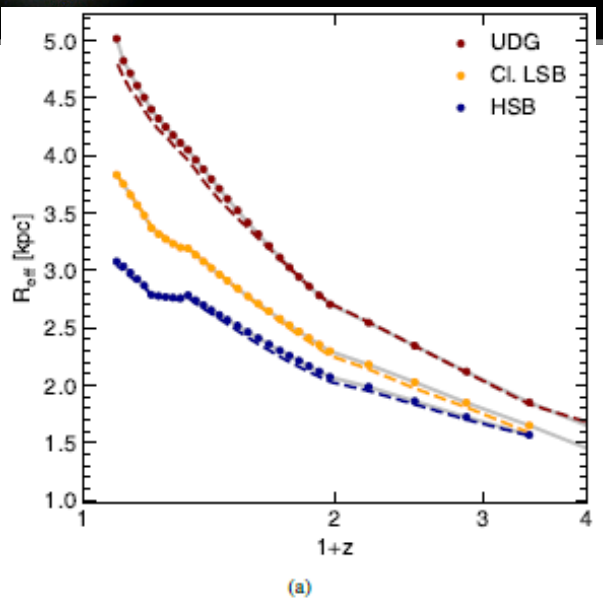
(c)

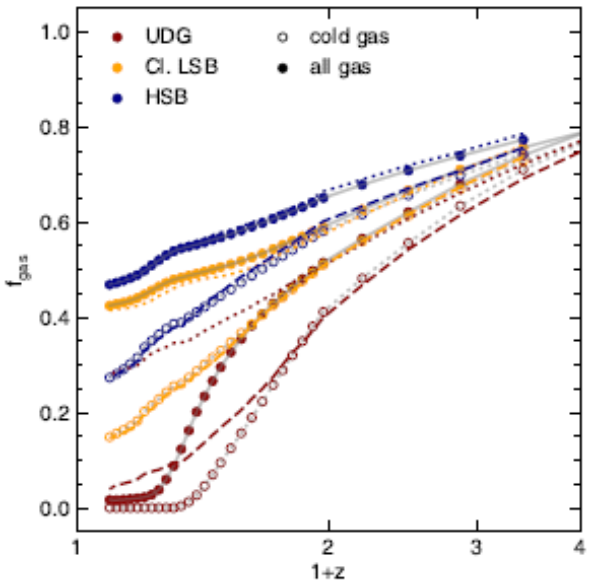






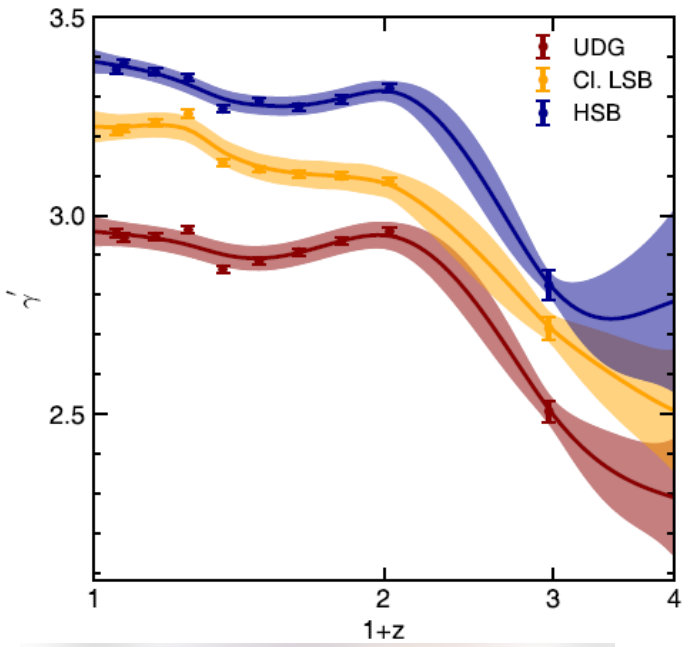
The redshift evolution of LSB progenitors





- Radii of LSBGs (esp. UDGs) increase faster than HSBs
- Radius change is smooth i.e. not the result of a single violent event
- UDGs undergo rapid gas loss at $z<1$ (isolated UDGs suffer less gas loss- no ram pressure stripping)

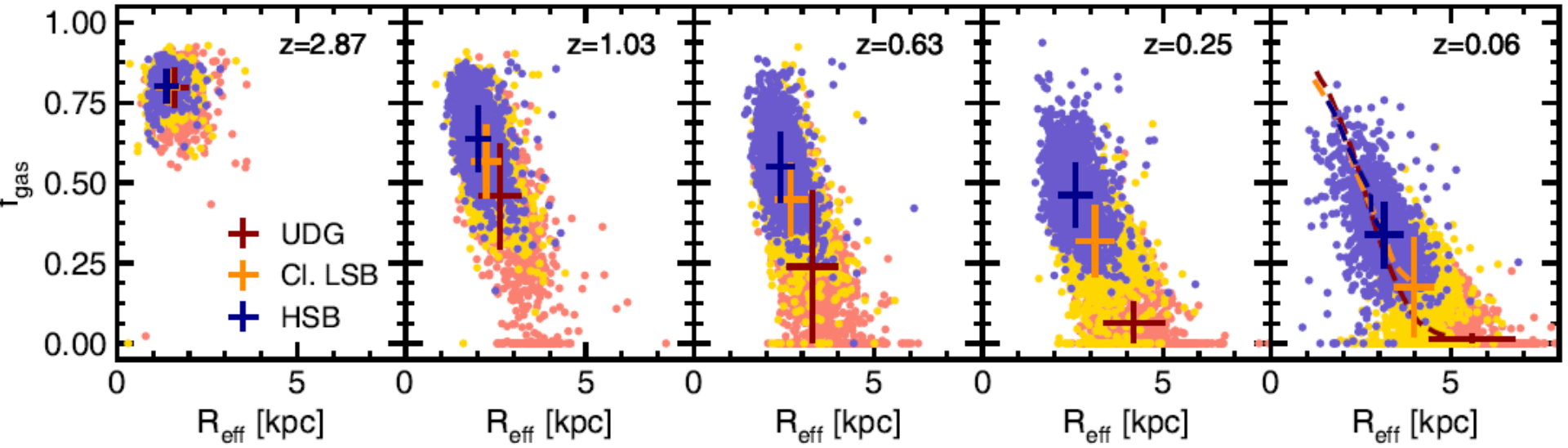
The redshift evolution of LSB progenitors



$$\gamma = -d\log(\rho)/d\log(r)$$

- Radii of LSBGs (esp. UDGs) increase faster than HSBs
- Radius change is smooth i.e. not the result of a single violent event
- UDGs undergo rapid gas loss at z<1 (isolated UDGs suffer less gas loss- no ram pressure stripping)
- Density slopes of UDGs are shallower (shallower potential wells)

The redshift evolution of LSB progenitors

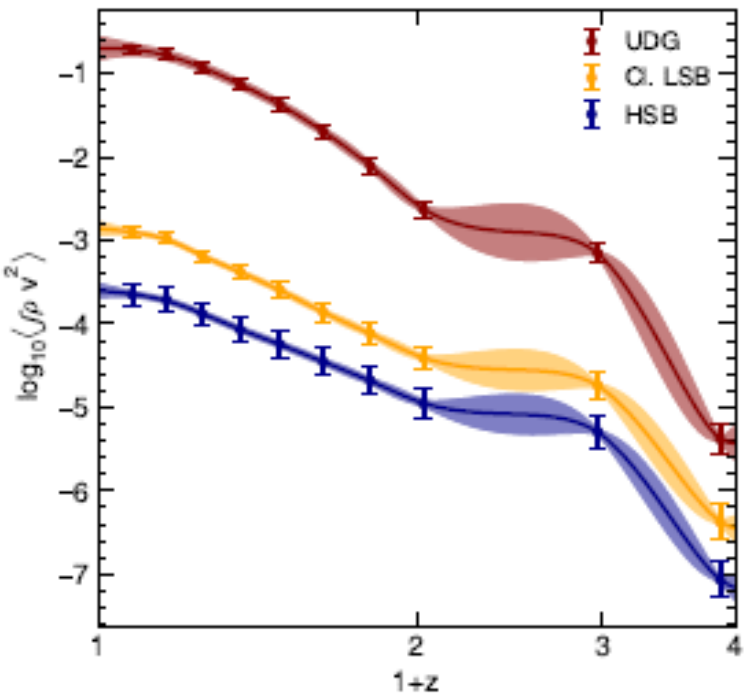


- The progenitors of HSB and LSB galaxies are similar at high redshift

- They diverge at later epochs – why?

How do LSBGs form?

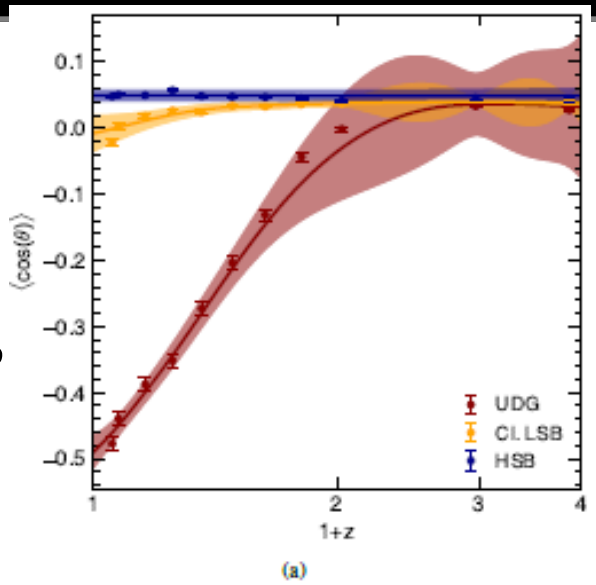
Ram pressure stripping

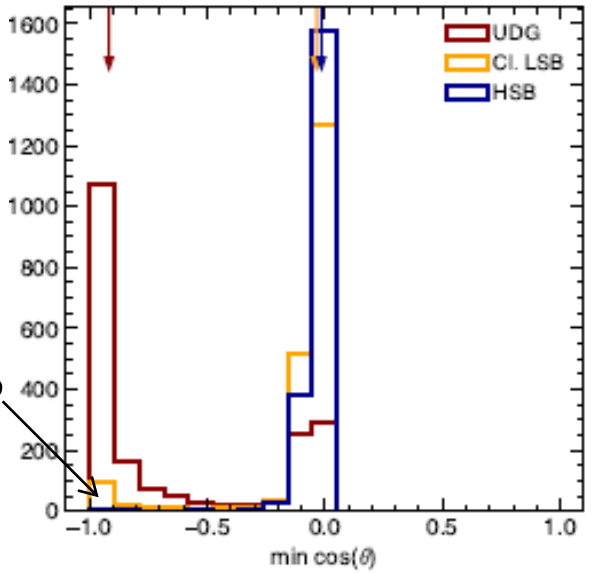


- UDGs suffer significantly higher ram pressure stripping

How do LSBGs form?

Ram pressure stripping

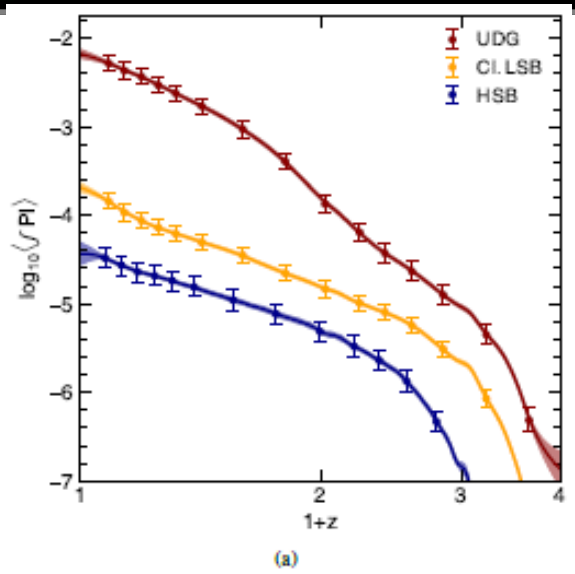


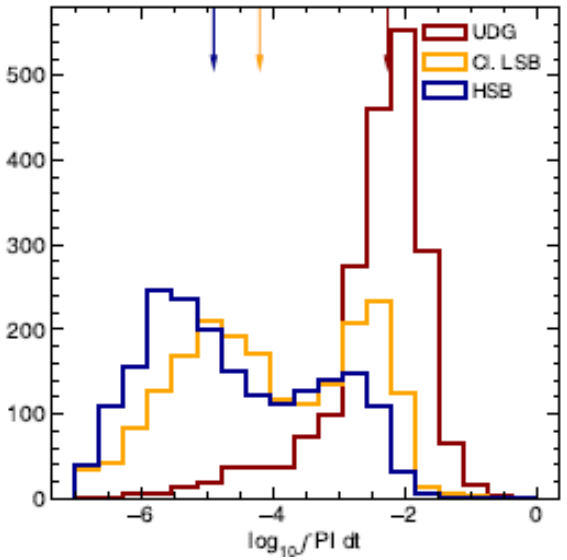


- UDGs suffer significantly higher ram pressure stripping
- Angle between gas velocity and stellar velocity in UDGs indicates strong RPS

How do LSBGs form?

Tidal perturbations



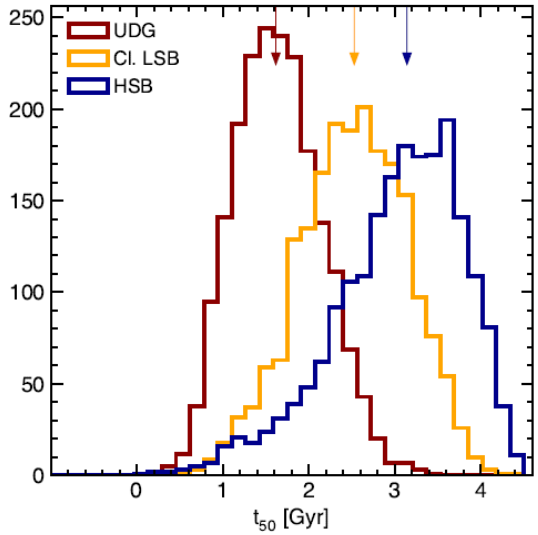


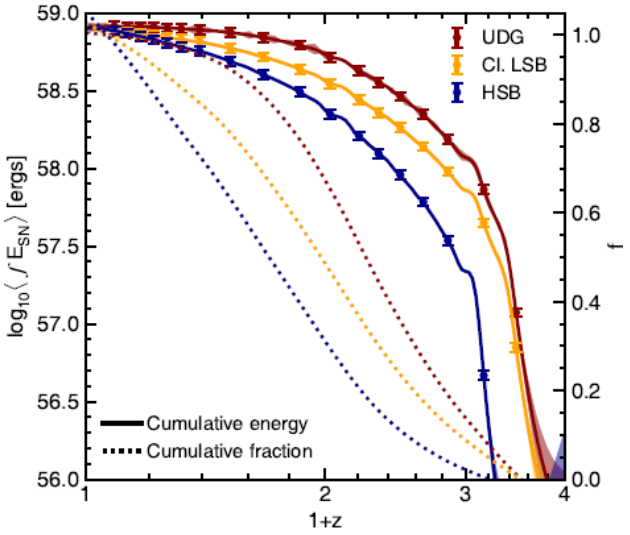
$$PI = \int_{t_0}^{t_1} \sum_i \left(\frac{M_i}{M_{gal}}\right)\left(\frac{R_{\rm eff}}{D_i}\right)^3 dt$$

- UDGs (and to a lesser extent Cl. LSBs) experience strong tidal perturbations
- Integrated perturbations over cosmic time in UDGs is 3 orders of magnitude higher than in HSBs
- Cold gas loss in isolated UDGs (no ram pressure stripping) caused by tidal heating of gas

How do LSBGs form?

Stellar feedback – a trigger for the creation of LSBGs





- Star formation in UDGs (and to a lesser extent Cl. LSBs) is more rapid and bursty
- Energy from SNe and stellar winds deposited more quickly (AGN feedback energy looks similar for different populations)
- Creates shallower potential wells **(e.g. Peirani +17)**
- …which are then more susceptible to processes like ram-pressure stripping and tidal perturbations

Summary

G. Martin, SK et al. in prep

- LSB galaxies outnumber HSB galaxies (for $M_* > 10^7\ M_\odot$, LSBGs account for 80%+ of galaxies) – **to understand galaxy evolution we need to understand LSBGs**

- LSB galaxies (UDGs in particular) are diffuse due to larger effective radii and low cold gas content (not due to higher spin or DM mass anomalies)

- Radii and gas fractions increase smoothly – LSBGs not formed in single violent events

- Formation trigger is more intense stellar feedback due to more bursty SFHs – creates shallower potential wells, more susceptible to ram pressure stripping and tidal perturbations

- Ram pressure stripping and tidal perturbations then gradually remove gas (in clusters) and tidally heat stars and gas to produce the LSBGs