Extremely compact massive quiescent galaxies at z~2.5

Sune Toft (ESO)

A correlation between size and star formation at z~2.5

Morphologies in the local Universe

Morphology scales with

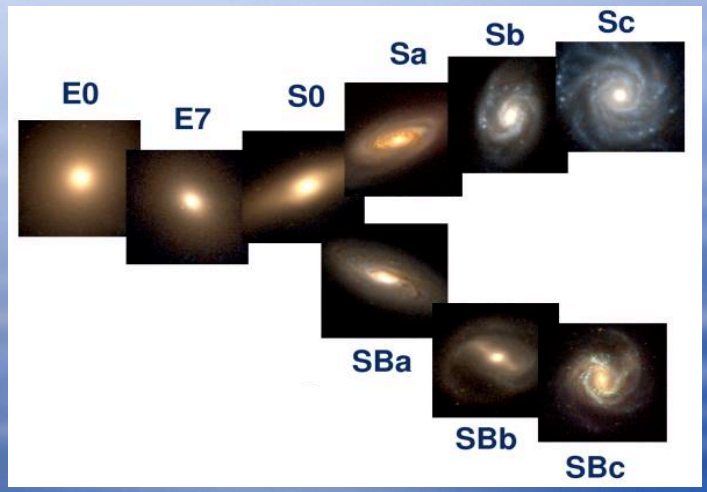
Density

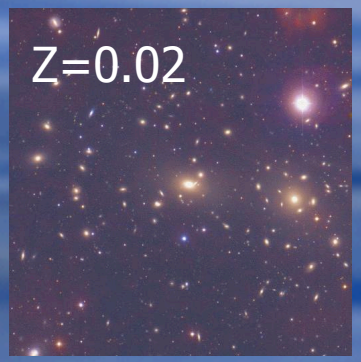
Star-formation

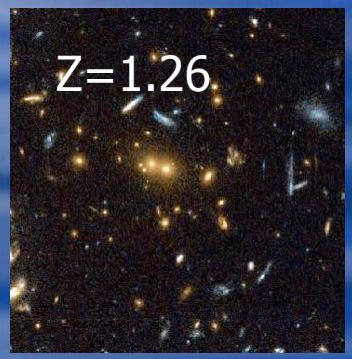
Age

Metallicity

Mass







Motivation:

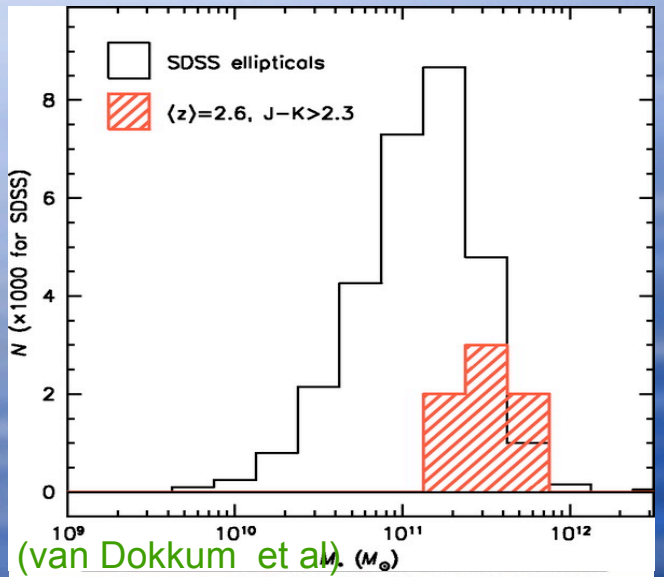
Push simultaneous studies of star formation and morphology to higher redshift

Properties of DRGs

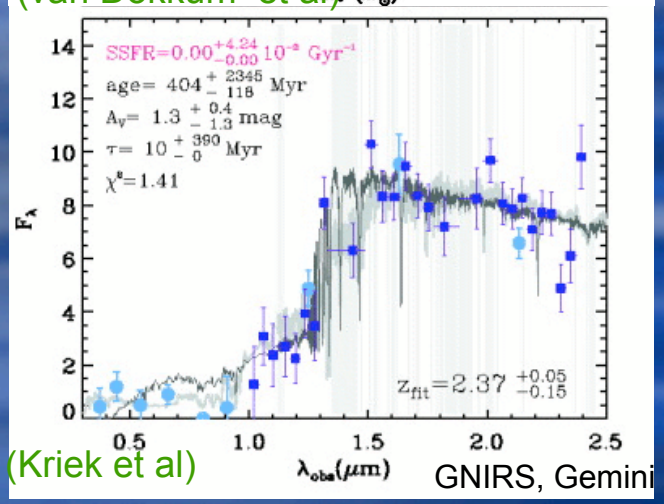
- J-K>2.3, <z>=2.5
- UV faint, evolved stellar pops
- Highly clustered
- <M>~ $2x10^{11}$ M_{sun}
- Dominate bright end of LF
- 35% quiescent, 65% star forming

Likely progenitors of elliptical galaxies

Blue galaxies (DBGs): J-K<2.3
Lower M, SFR, Av



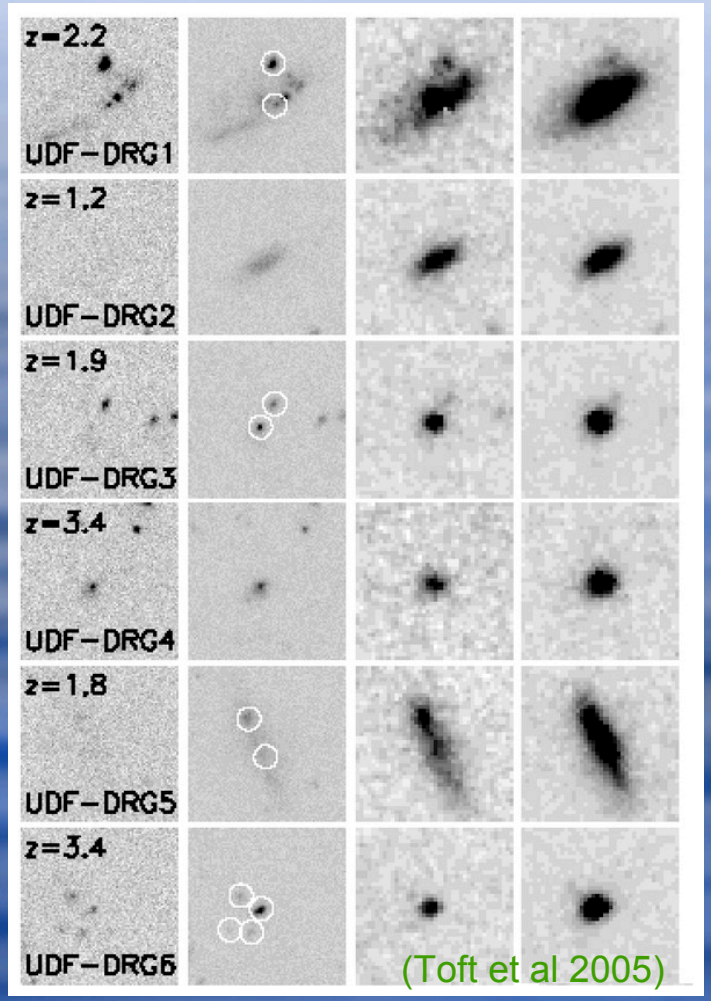
(van Dokkum et al)



(Kriek et al)

GNIRS, Gemini

UDF



(Toft et al 2005)

Data

- NICMOS (1.5h) + ACS (12h)
- 41 2<z<3.5 galaxies
- 27 DRGs (J-K>2.3) , 14 DBGs (J-K<2.3)
- FIRES MS1054-03 catalog:
- U-K band photometry + photo-z's
- IRAC imaging
- (3.6 hours in 3.6, 4.5, 5.8, 8.0 μm)
- MIPS imaging
- (1 hour at 24 μm)

→ Morphologies

SB-profiles

Sizes

→ SED fits

Mass, SFR

Dust, Age

→ LIR

SFR/AGN

Definitions

Distant Red Galaxies (DRGs): $J-K>2.3$, $2<z<3.5$

Distant Blue Galaxies (DBGs): $J-K<2.3$, $2<z<3.5$

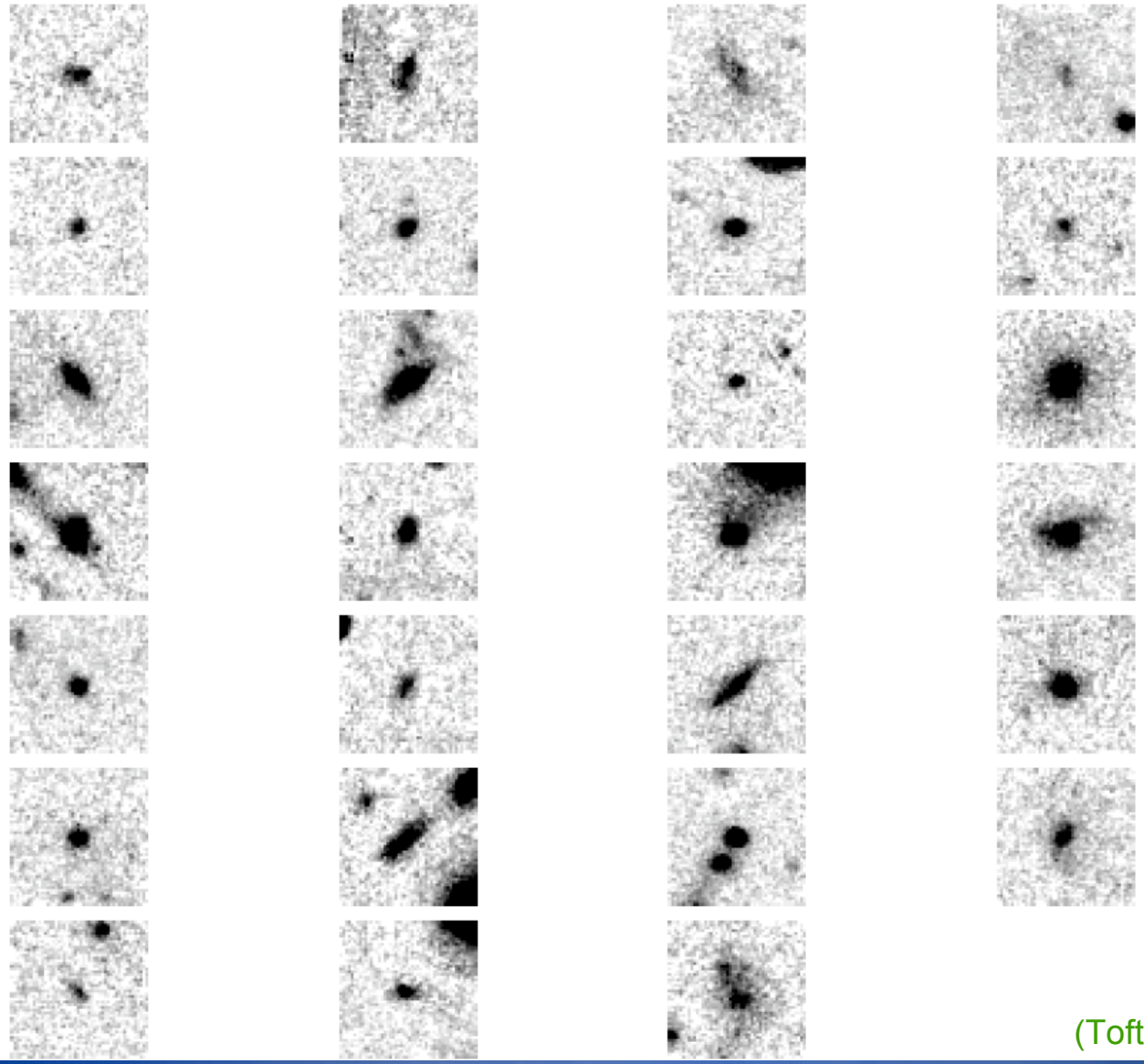
SFR: Star formation rate

sSFR = SFR/M*

Quiescent galaxy: low sSFR and dust content

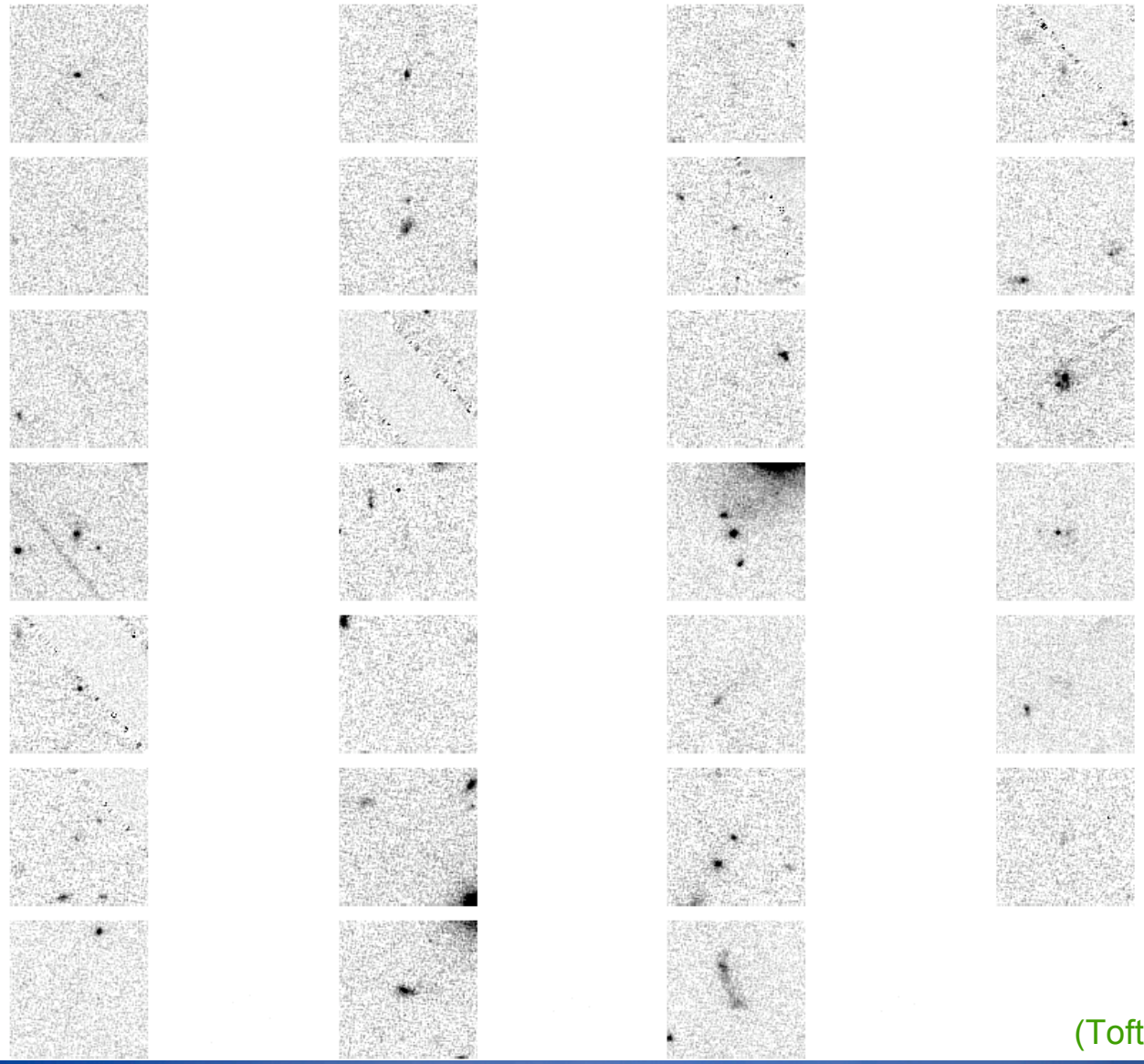
Star Forming galaxy: higher sSFR and dust content

J-K > 2.3, z > 2



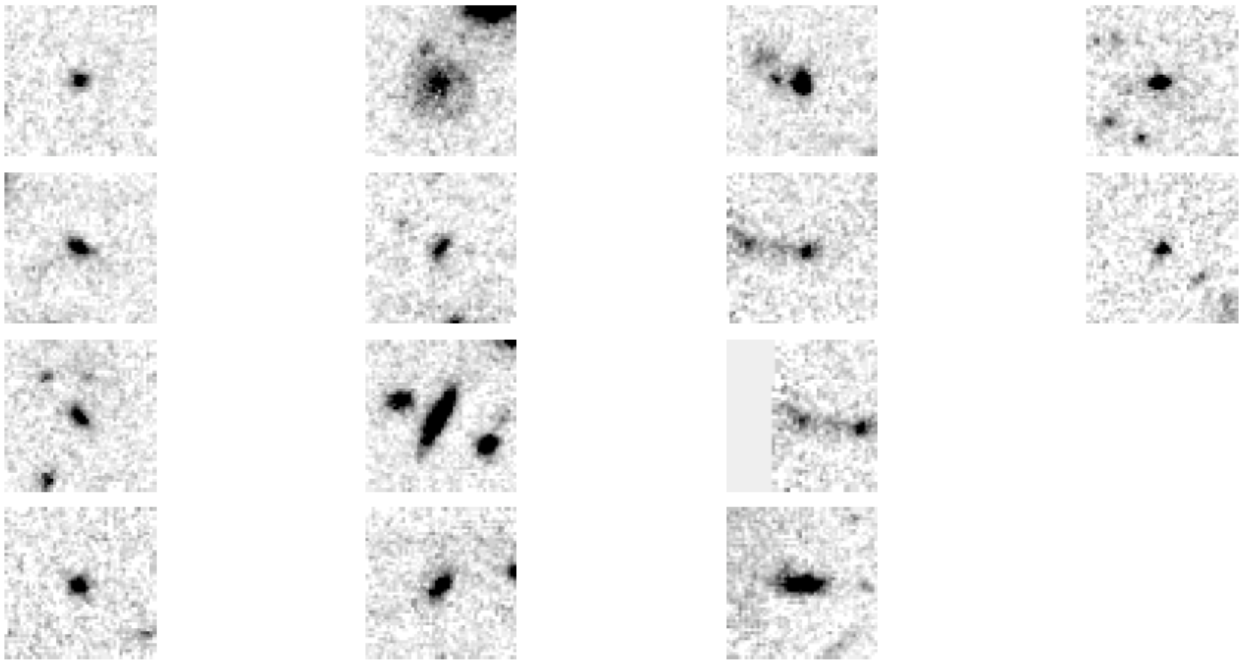
(Toft et al 2007)

J-K > 2.3, z > 2



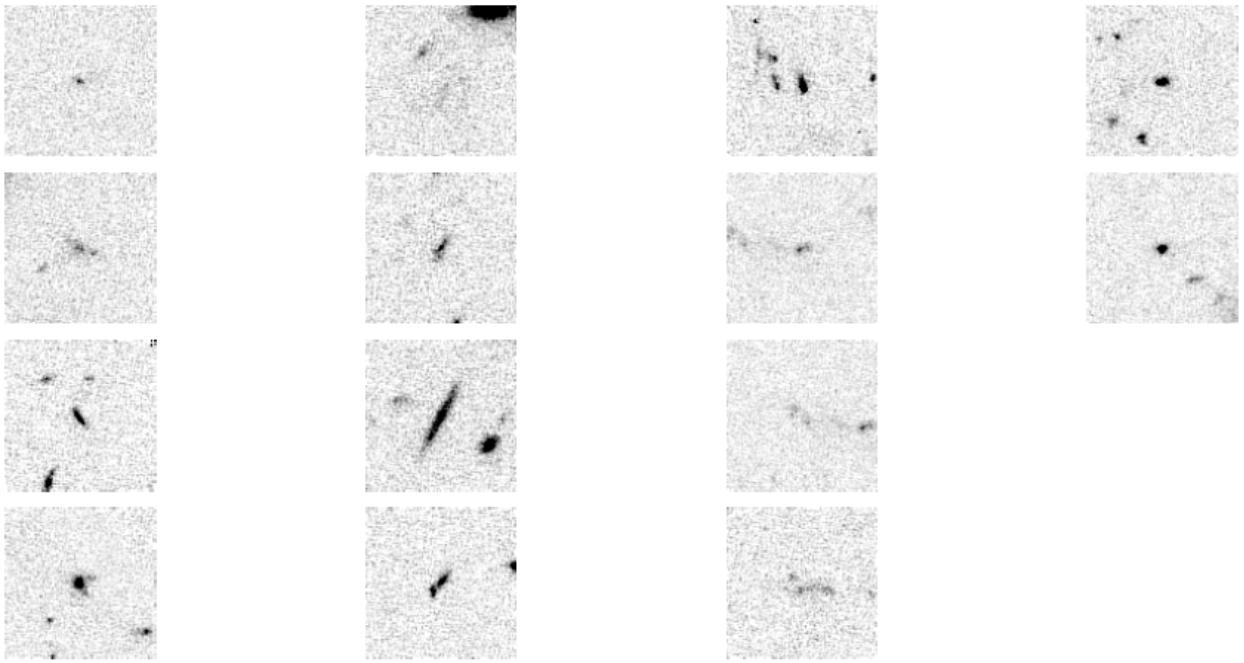
(Toft et al 2007)

J-K < 2.3, z > 2



(Toft et al 2007)

J-K < 2.3, z > 2



(Toft et al 2007)

2D surface brightness profiles

Sersic profile:

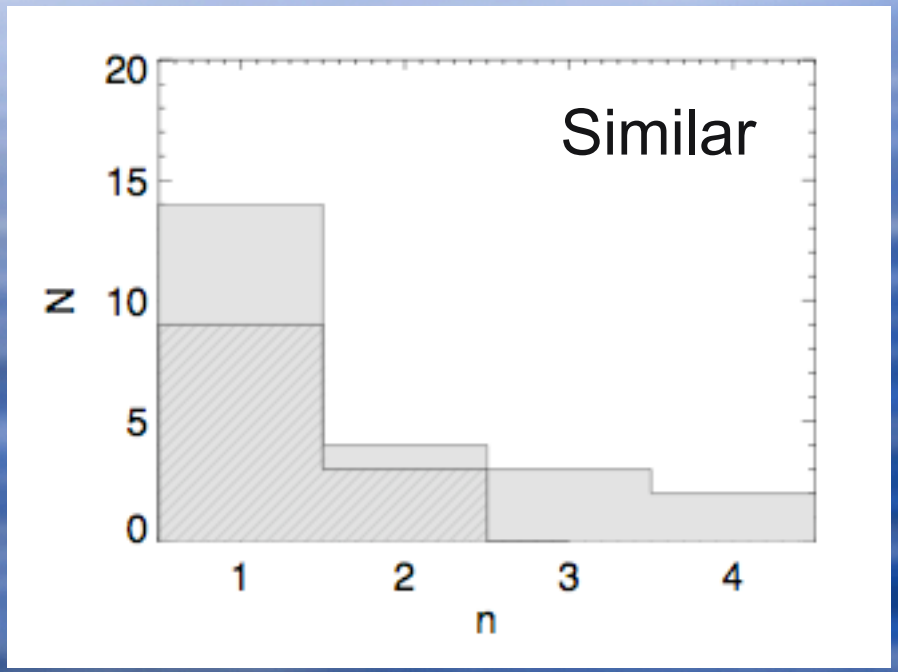
$$I(r) = I(0)\exp[b(r/re)^{1/n}]$$

n : Sersic index

re: effective radius

n=1,2: “Exponential disk”

n=3,4: “de Vaucouleurs”

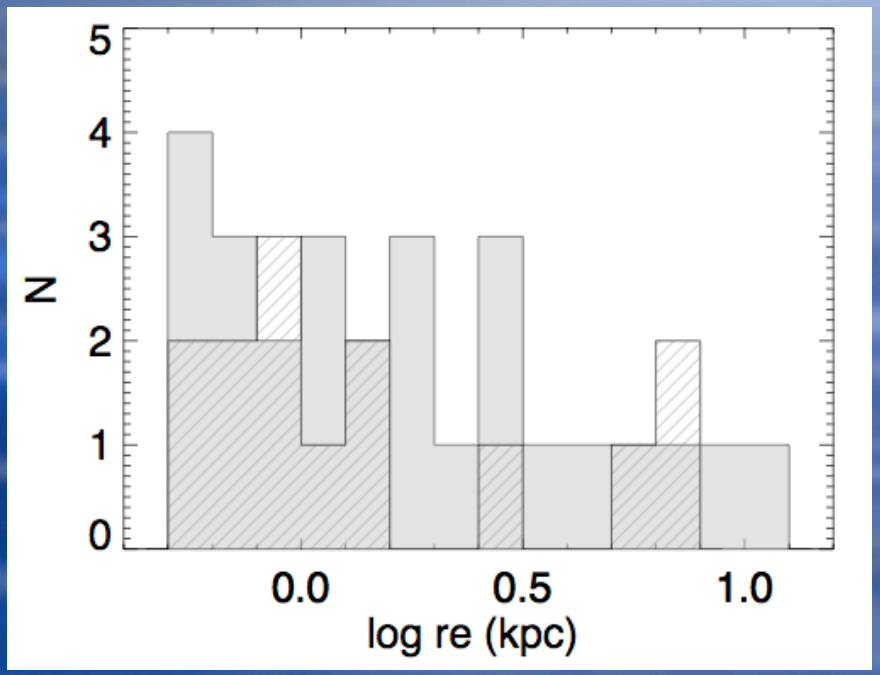


DRGs vs DBGs

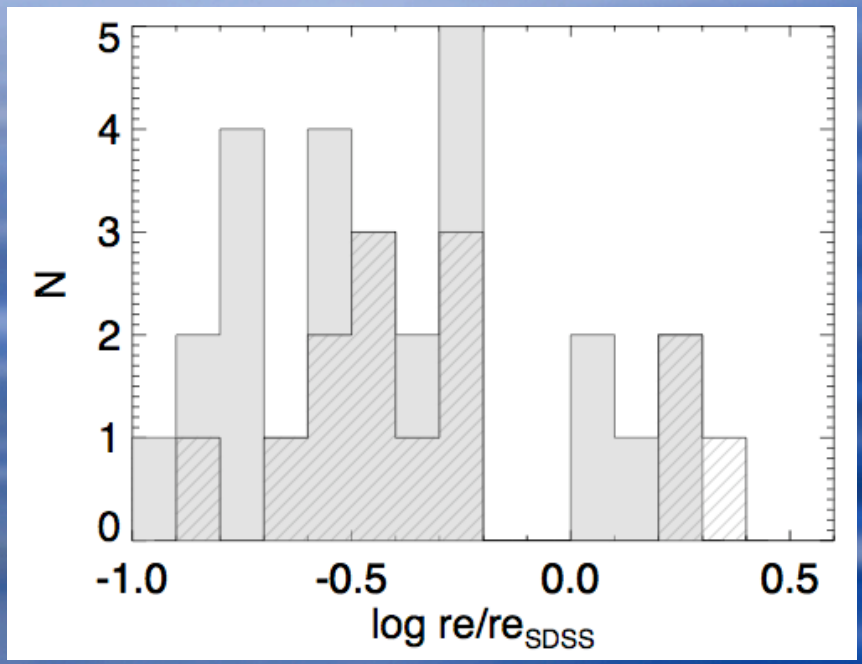
>80% Exponential disk like

Sizes: DRGs vs DBGs

Similar



Similar

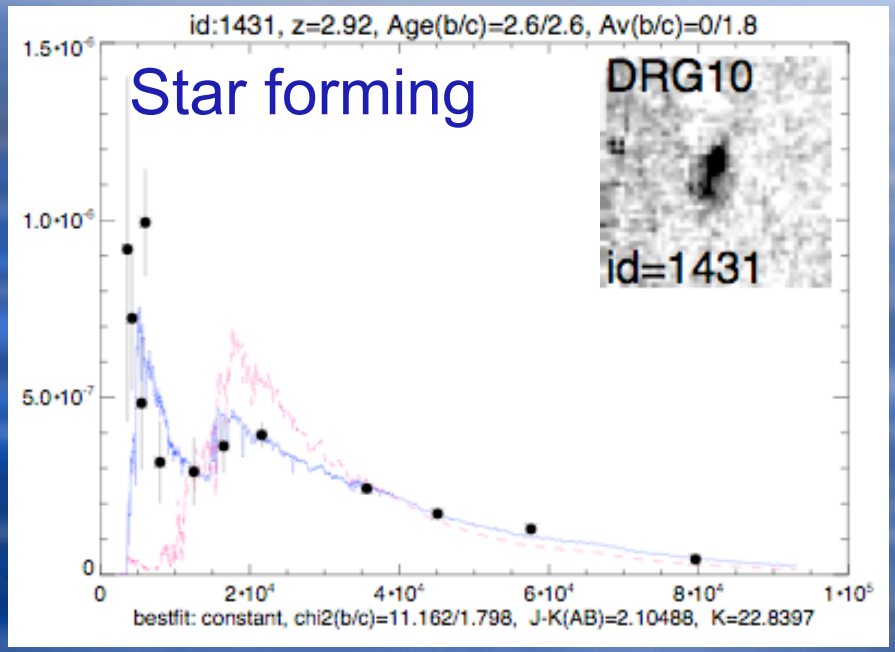


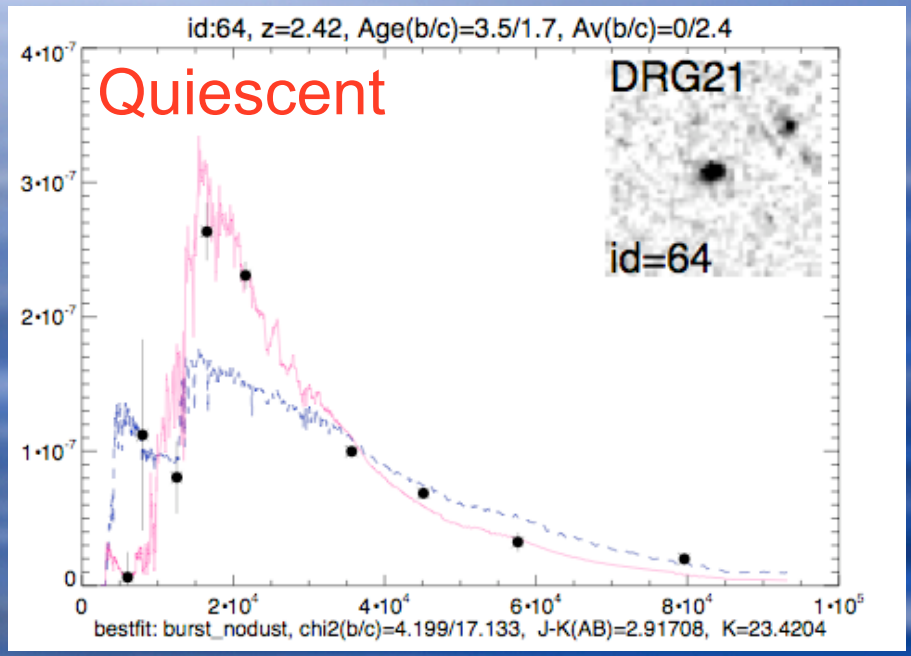
Normalized by SDSS Mass-re relation

Star forming vs Quiescent

67%

33%

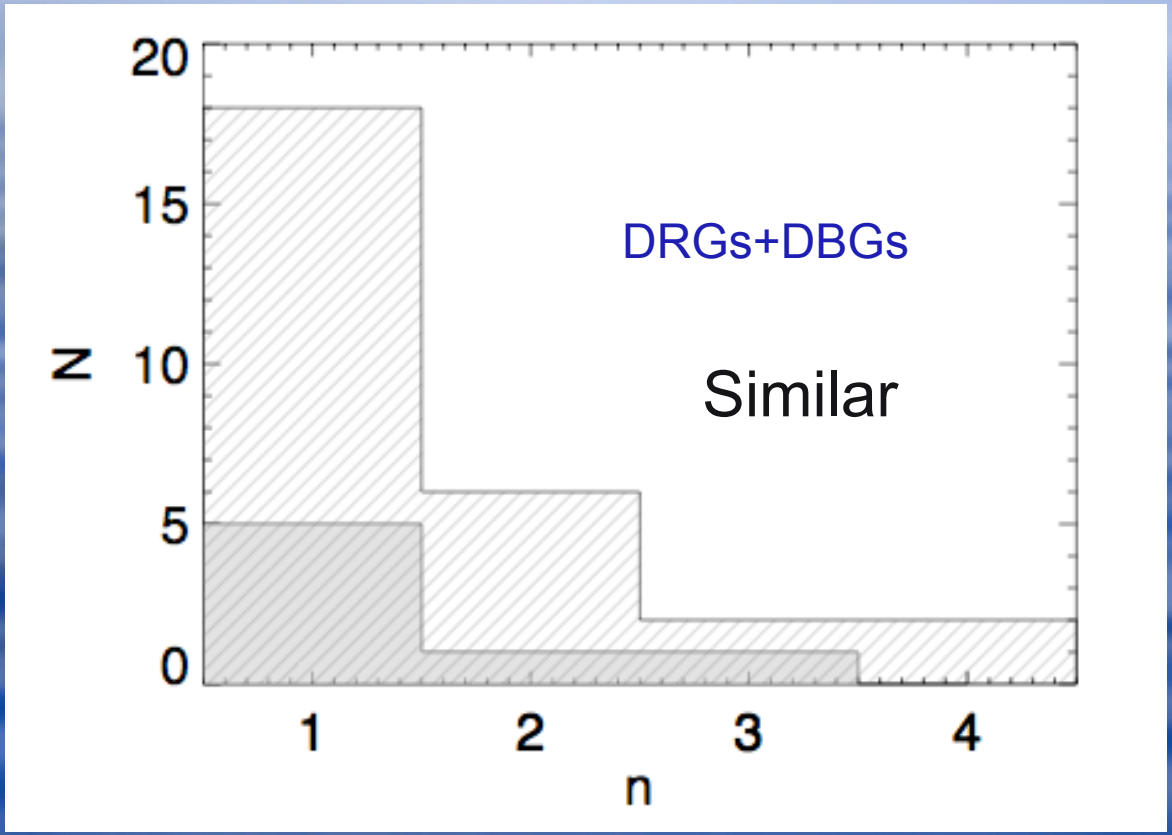




sSFR>0.01/Gyr

sSFR<0.01/Gyr

Star forming/Quiescent n-distributions

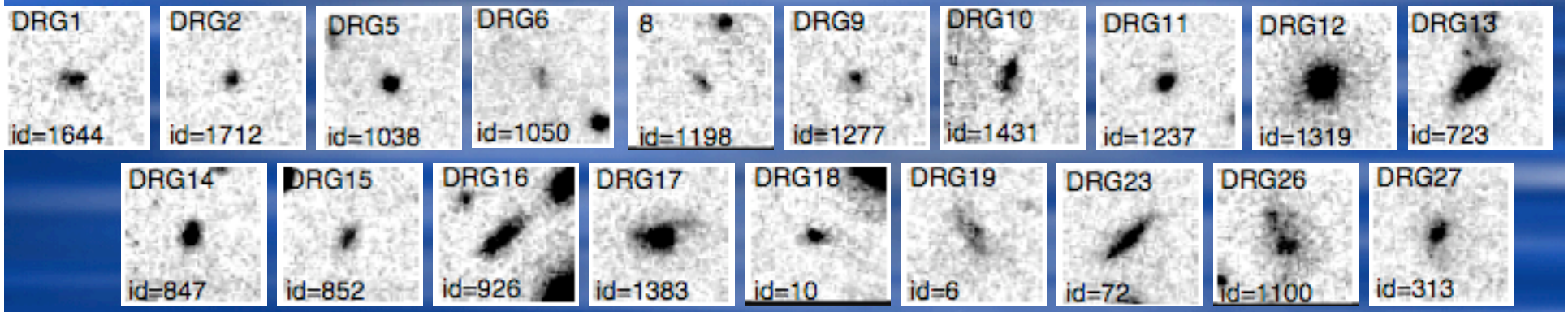


Star forming vs quiescent'

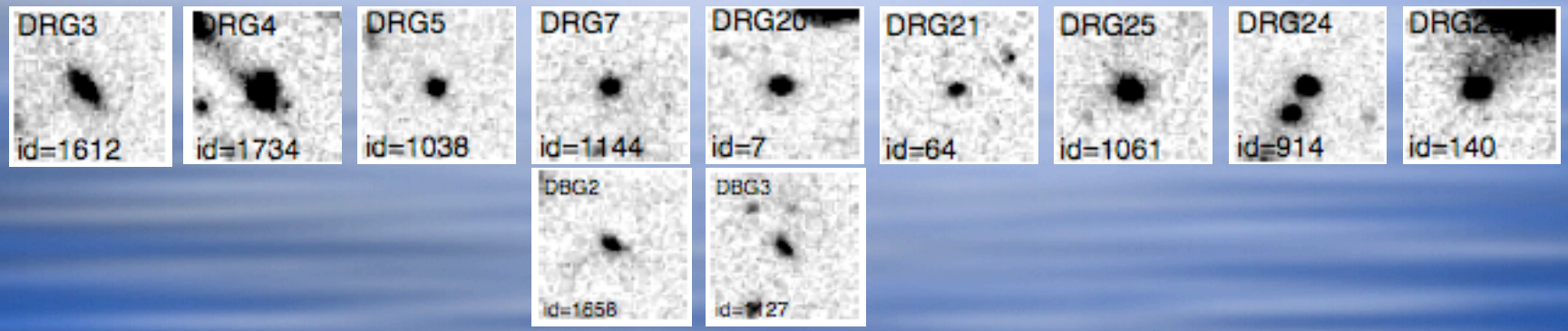
Star forming vs Quiescent DRGs

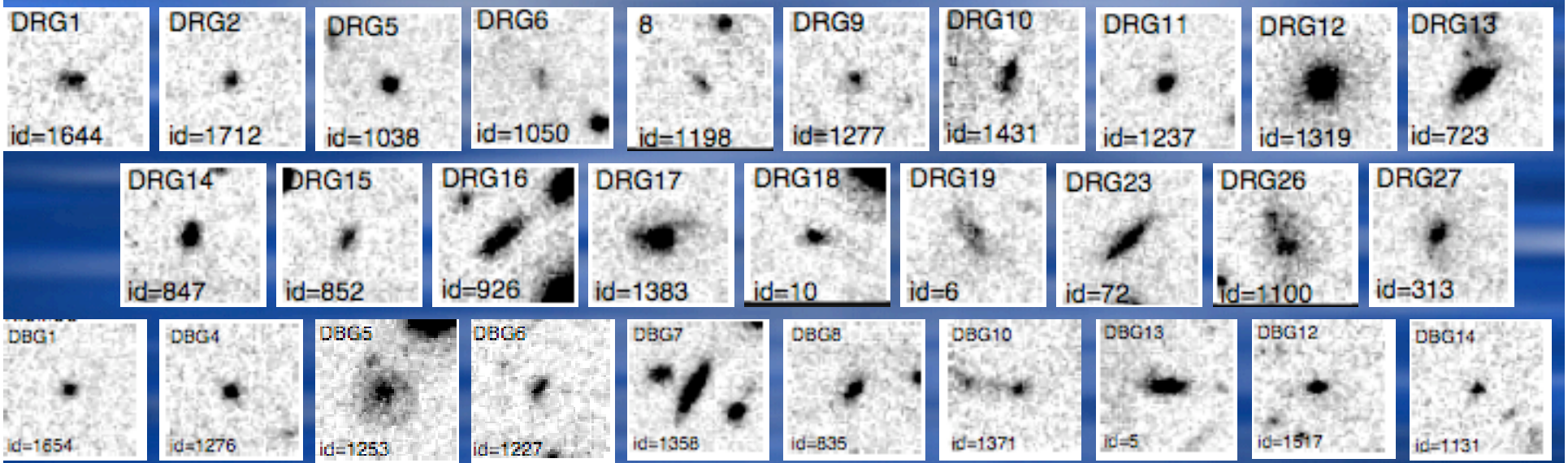
Quiescent - All compact and small

Star forming - Range of morphologies and sizes



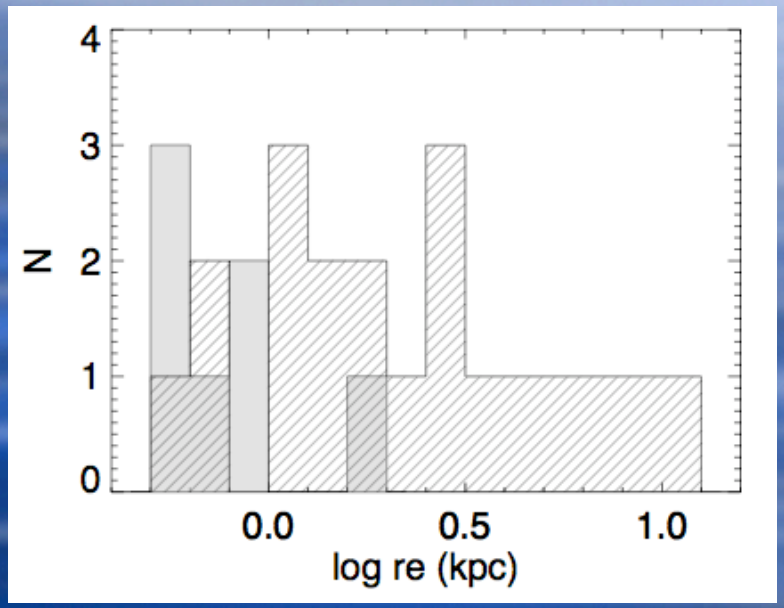
Star forming vs Quiescent DRGs+DBGs



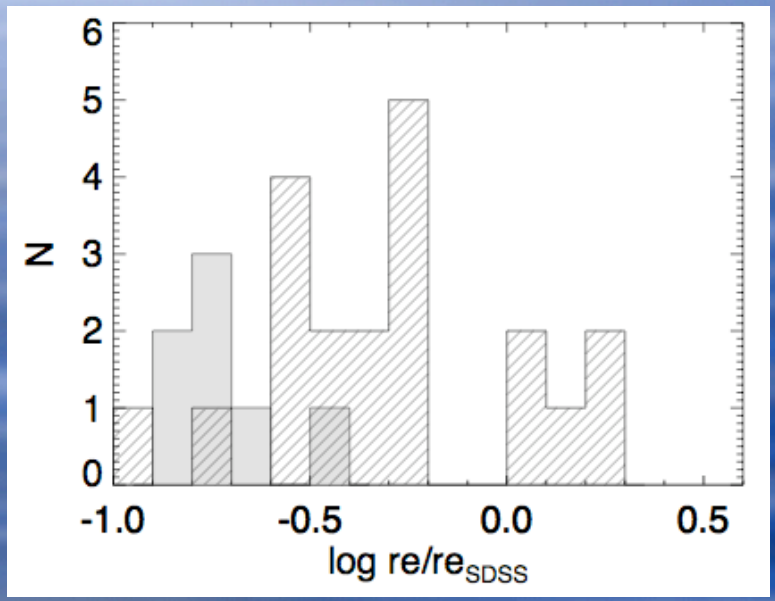


Sizes Star forming vs Quiescent

Different



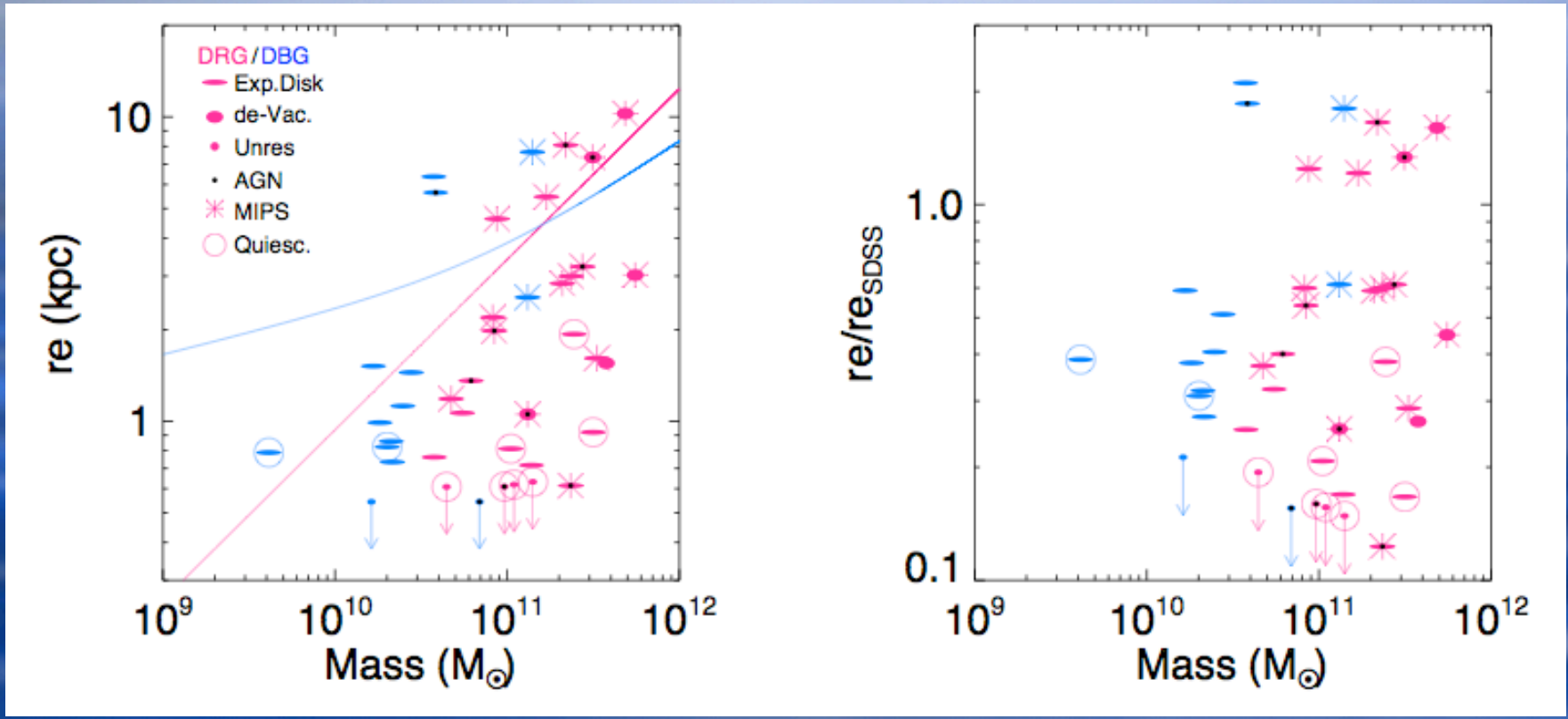
Different



Normalized by SDSS Mass-size relation

Quiescent galaxies are smaller than star forming galaxies

Mass-Size relation

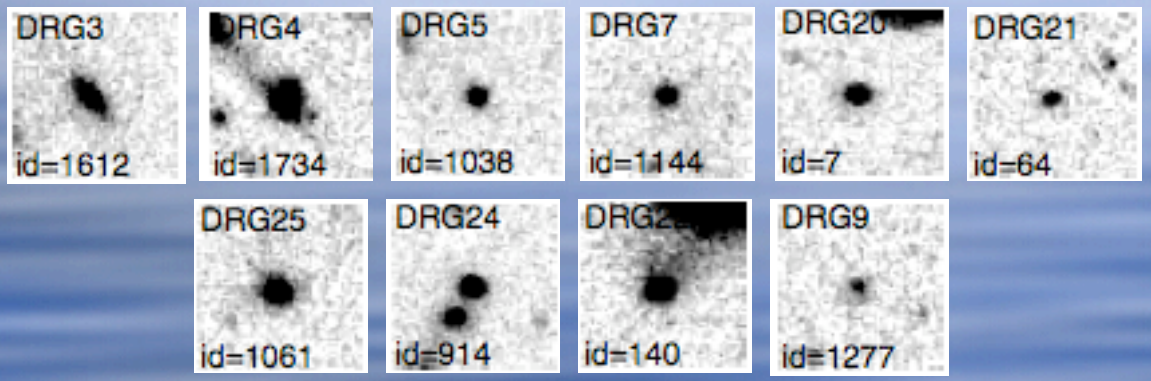


Normalized by SDSS relation

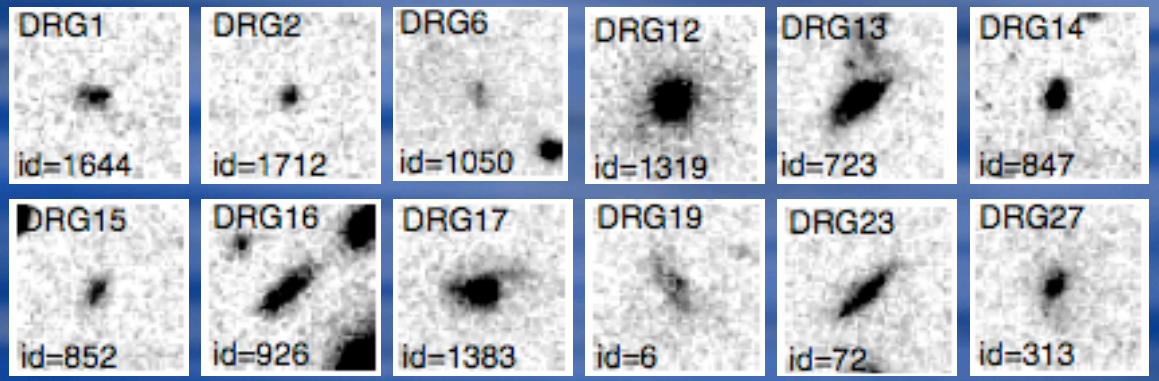
(Toft et al 2007)

2<z<2.5 MIPS DRGs

< 3σ MIPS 24μm detection

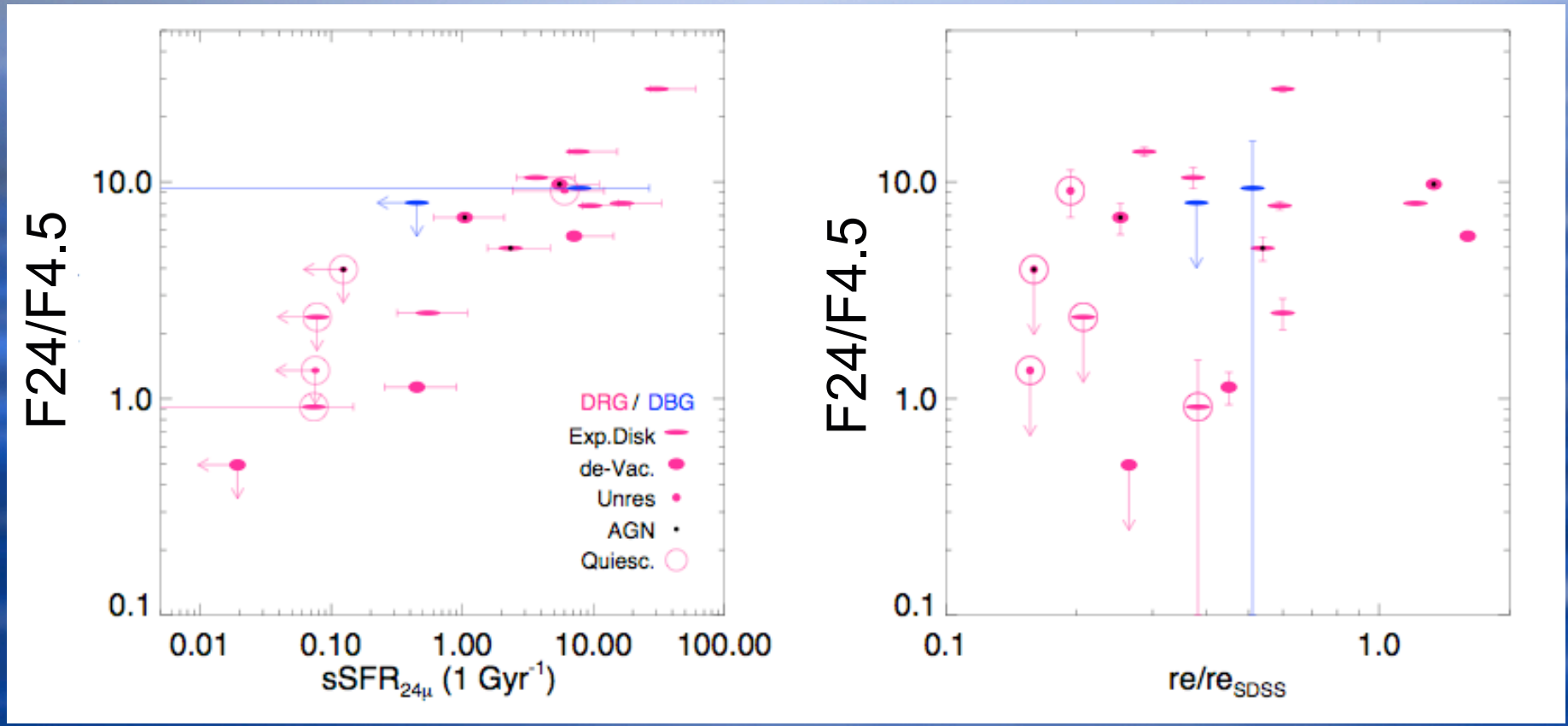


> 3σ MIPS 24μm detection



MIPS 24 μm

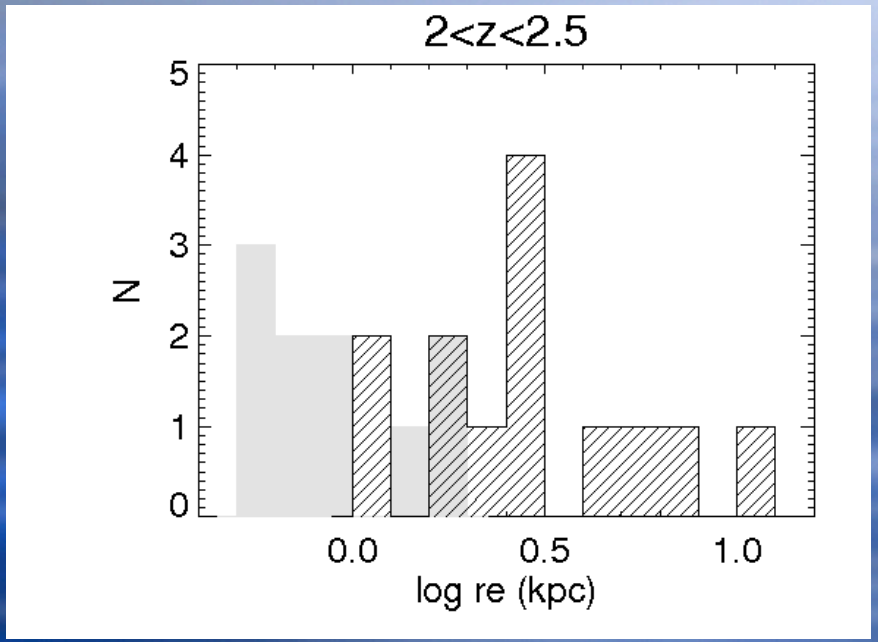
2<z<2.5

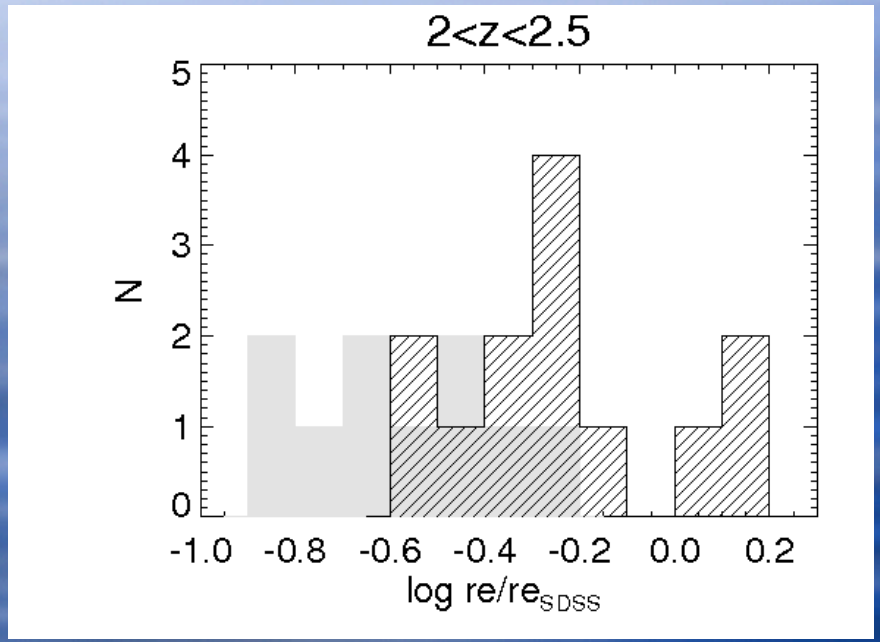


Quiescent galaxies are small, and do not host AGN

(Toft et al 2007)

MIPS 24μm detections





Normalized by SDSS Mass-size relation

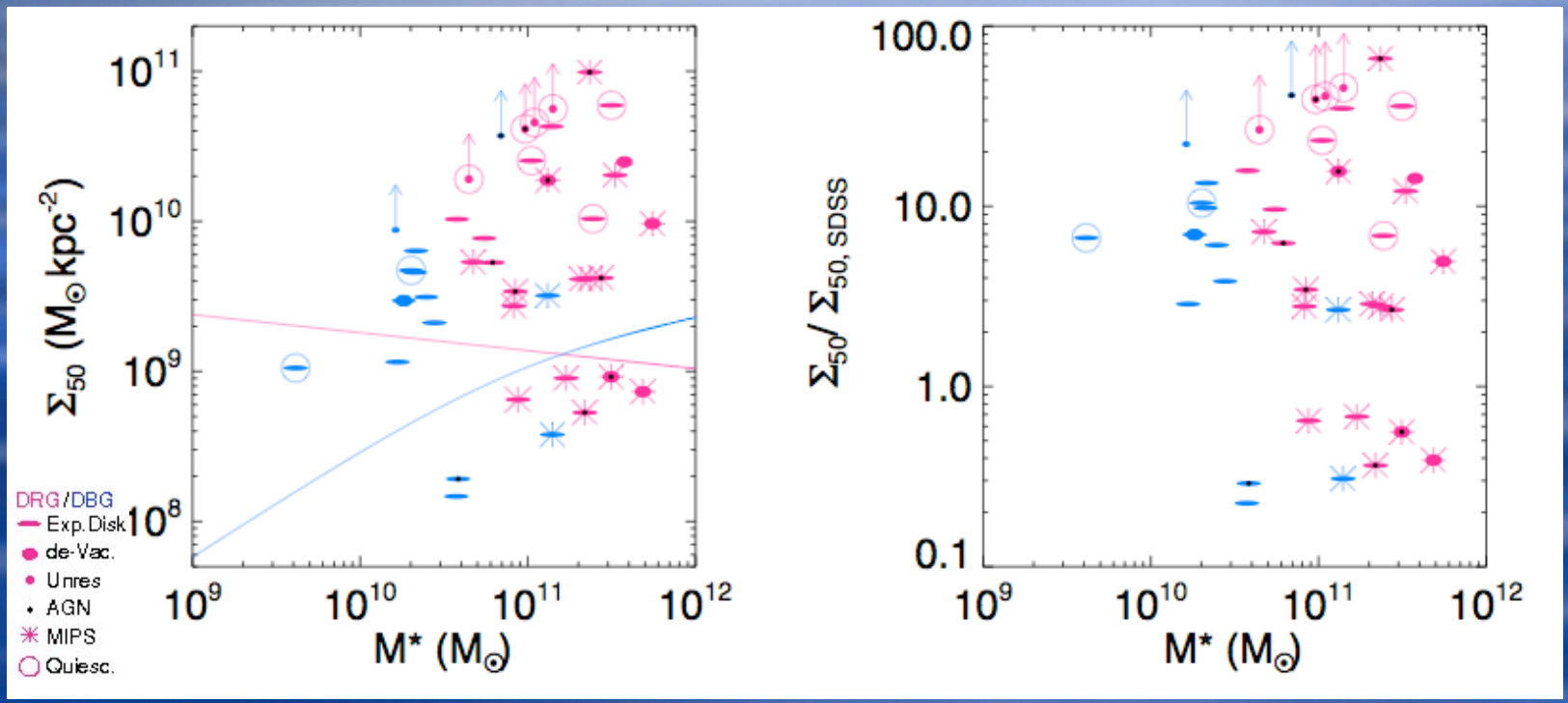
(MIPS 24μm not sensitive to PAH features beyond z>2.5)

Mass-size summary

- Star forming DRGs and DBGs consistent with spanning the same M-re relation.
- Median size of star forming galaxies a factor of 2 smaller than in SDSS (at a given M)
- Median size of quiescent galaxies a factor of 6 smaller than in SDSS.

Surface mass density

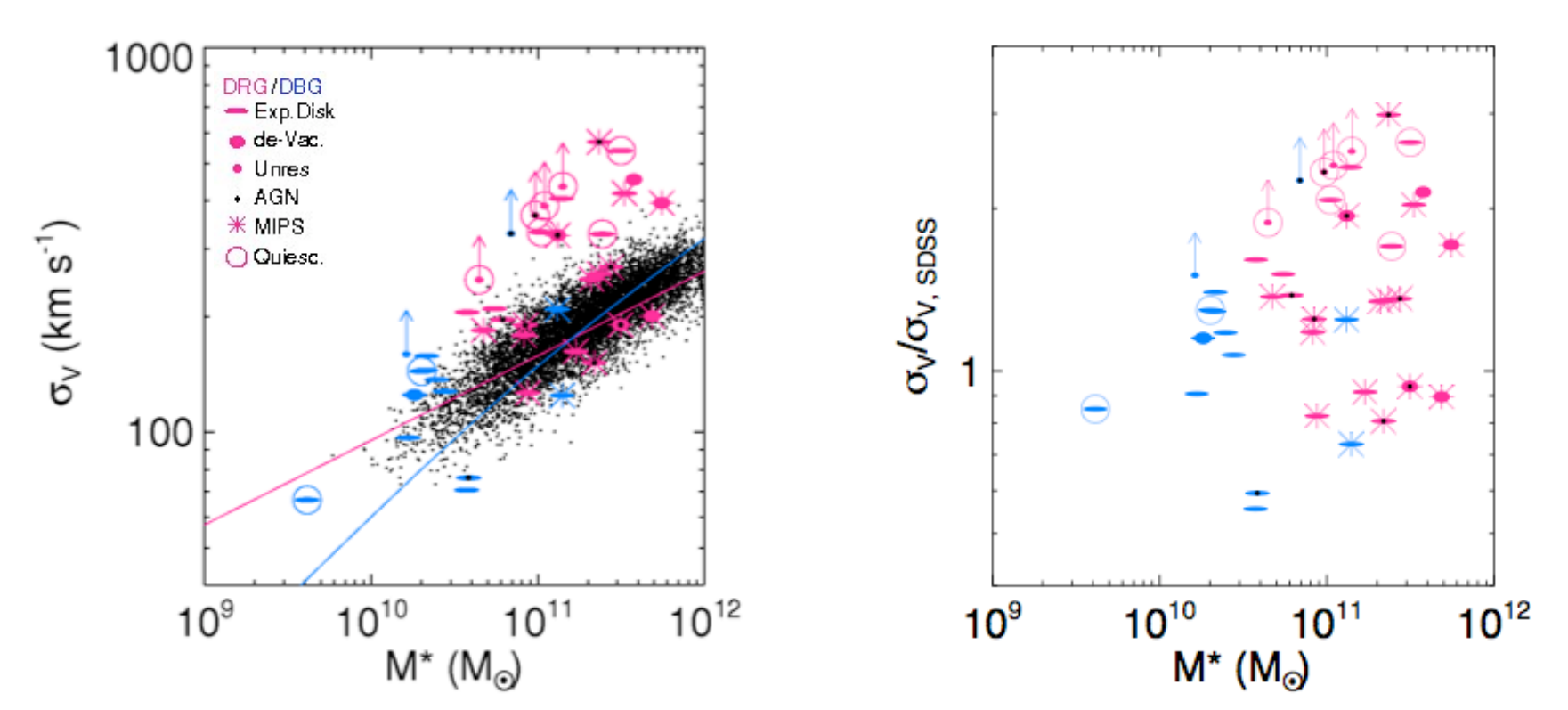
$$\sum_{50} = \frac{M/2}{\pi * re^2}$$



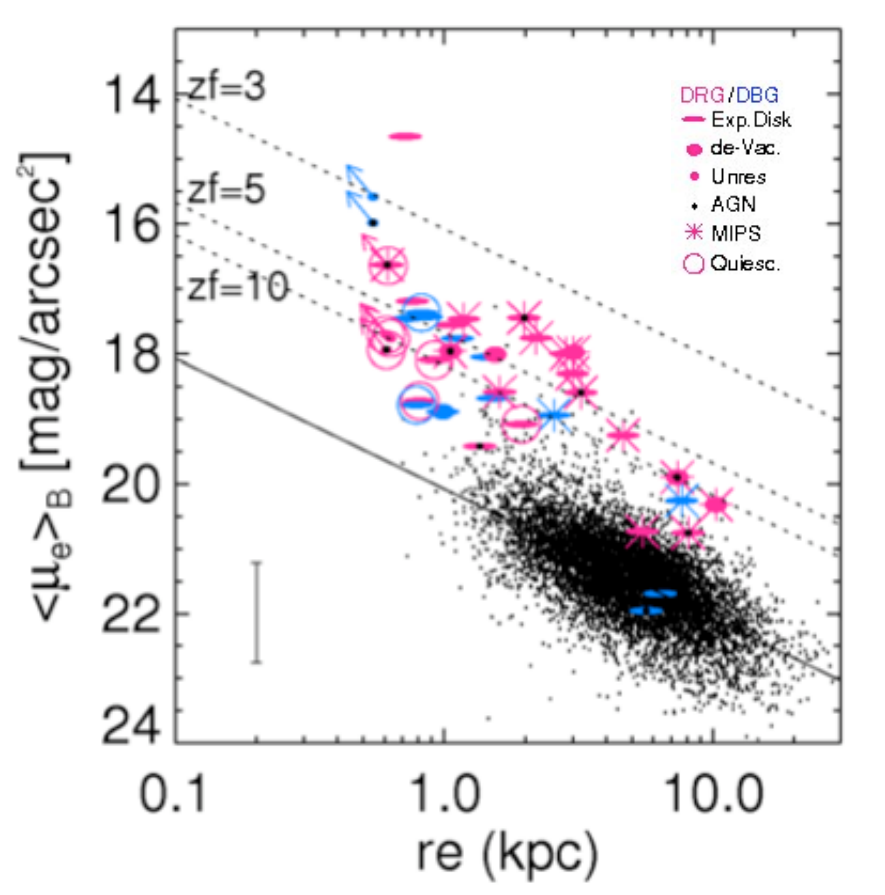
Normalized by SDSS relation

Velocity dispersion

$$\log(M) = 2\log(\sigma_V) + \log(re) + 6.07$$



Kormendy relation



$$\langle \mu_e \rangle_B = M_B + 5\log(r_e) + 2.5\log(2\pi)$$

Kormendy relation summary

- Full sample consistent with spanning same relation (despite large dust corrections).
- Galaxies too bright/small to passively evolve into local elliptical relation
- Merging needed

Summary

- Correlation between star formation activity and size at z=2.5
- Star forming galaxies are detected by MIPS, quiescent are not (i.e not dominated by AGN)
- Sersic n does not correlate with SFR or J-K: Majority of massive galaxies have exponential disk profiles.
- Actively star forming galaxies a factor of ~2 smaller than local galaxies of similar mass
- Quiescent galaxies a factor of ~5 smaller than local galaxies of similar mass

Models

Formation of quiescent galaxies

Early gas rich mergers ? (e.g. Khockfar & Silk 2006)

Evolution of quiescent galaxies

Need to “puff up” sizes, without adding too much mass or new star formation

Dry merging? (e.g. Boylan-Kolchin et al. 2006)

Evolution of star forming galaxies

Gravitational infall of gas? (e.g. Bouwens & Silk 2002, Sommerville et al 2006)

Models

Star forming galaxies

- Morphological properties not extreme: many bulge+disk systems which follow M-r, M- Σ, M-σ, r-μ relations
- Evolution: disks could grow by a factor of two by gravitational infall of gas, but that would probably produce too many massive disks at z=0
- Morphological transformation to early types, through merging and/or fading of disk components more likely

Models

Quiescent galaxies:

Formation

Gas rich mergers, lead to dense stellar cores. (e.g. Khockfar & Silk, 2006).

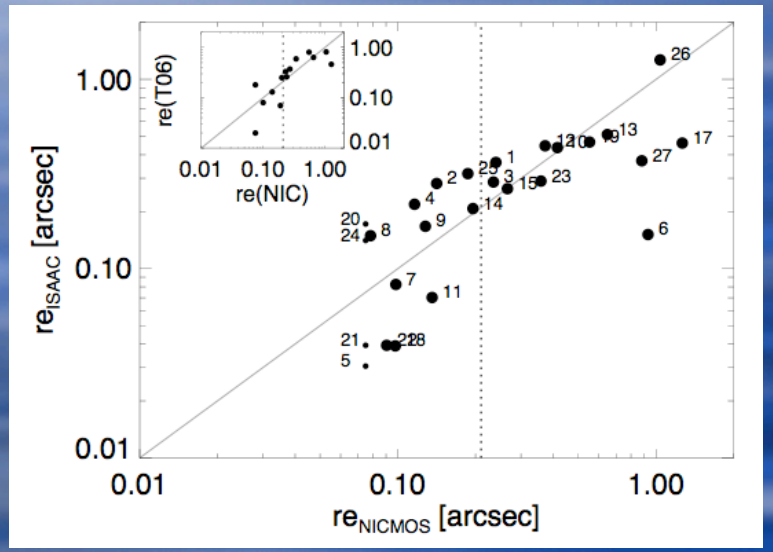
Evolution:

Dry merging lead to larger remnants with lower densities and velocity dispersions (e.g. Boylan-Kolchin et al, 2006)

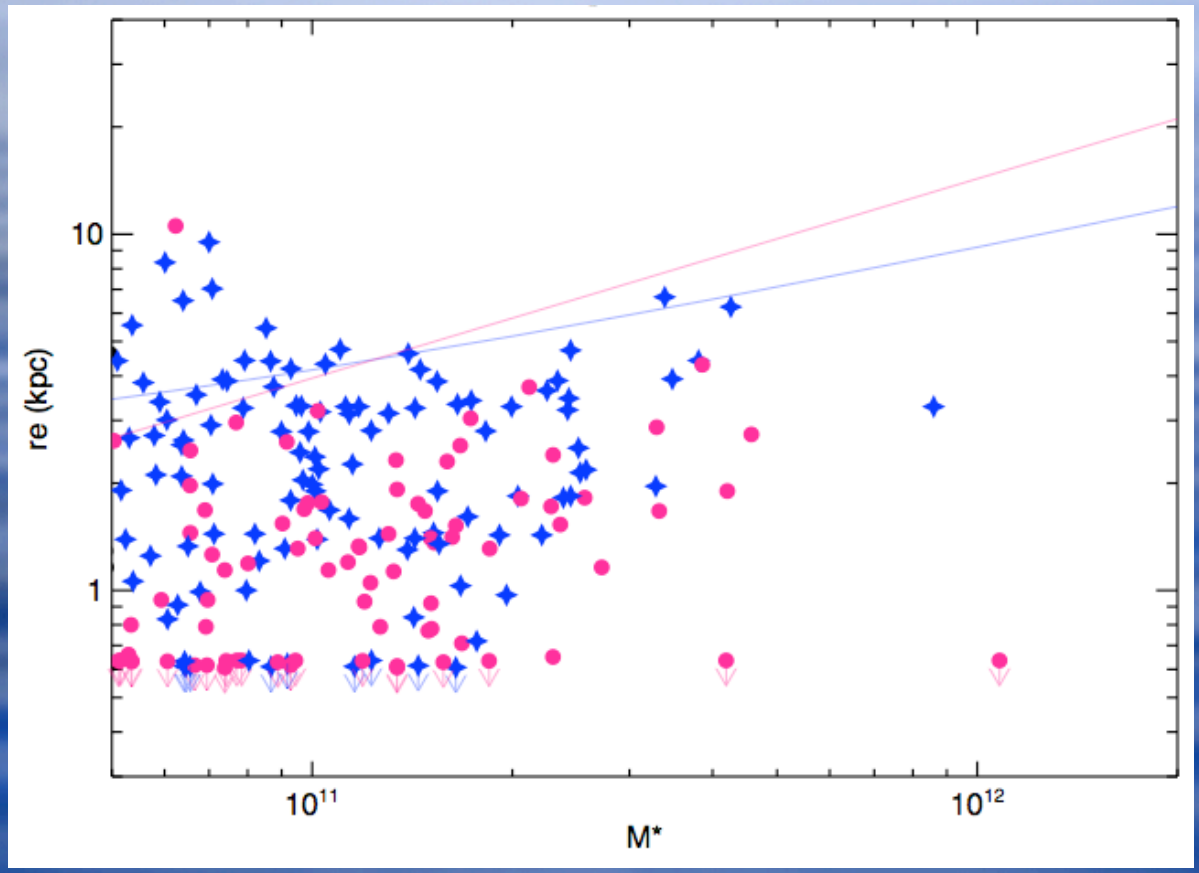
Next step:

The FIRES IRAC deep survey

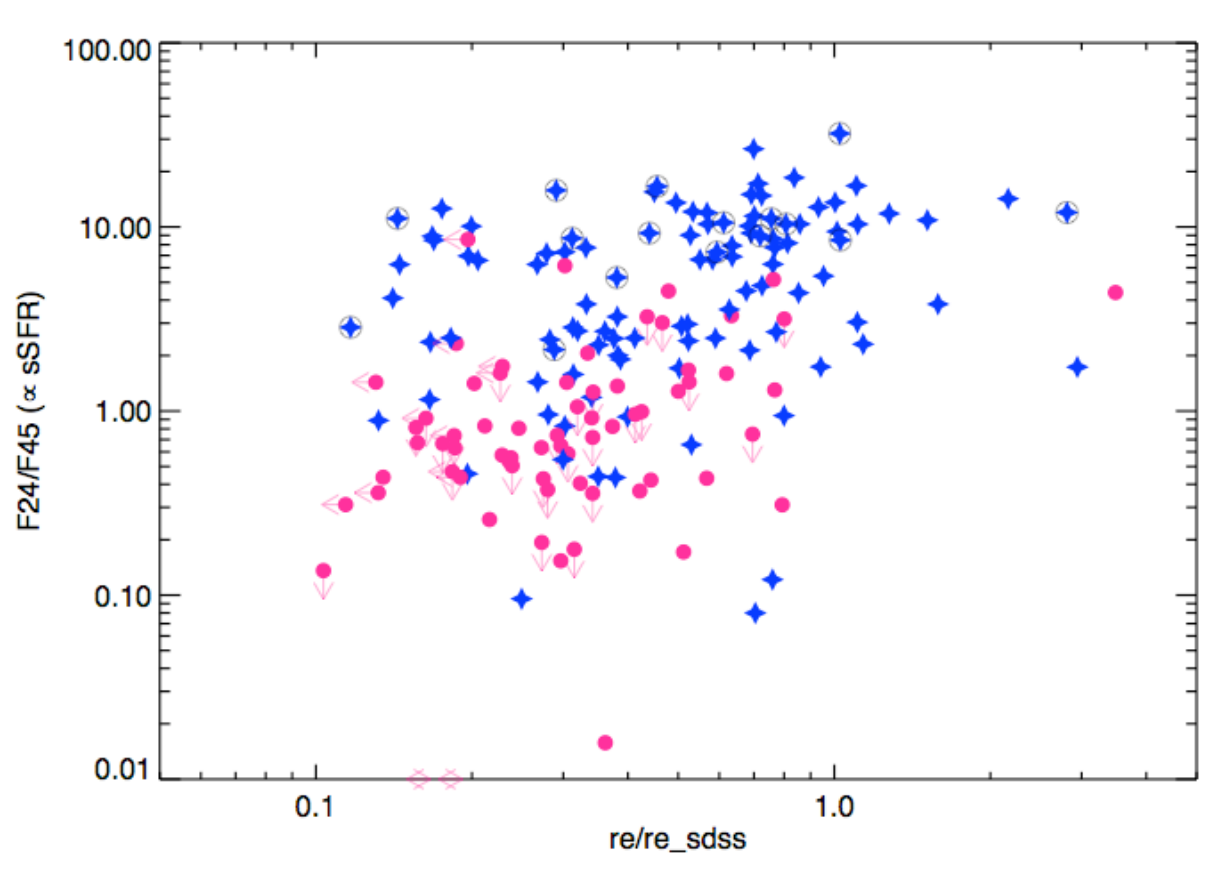
- 5 times larger area (MS1054, HDFS, CDFS) with deep U-K + Spitzer IRAC & MIPS
- 5 times larger mass selected ($M>5x10^{10}M_{\odot}$) sample of $1.5<z<2.5$ galaxies
- No NICMOS -> use ISAAC data to derive sizes



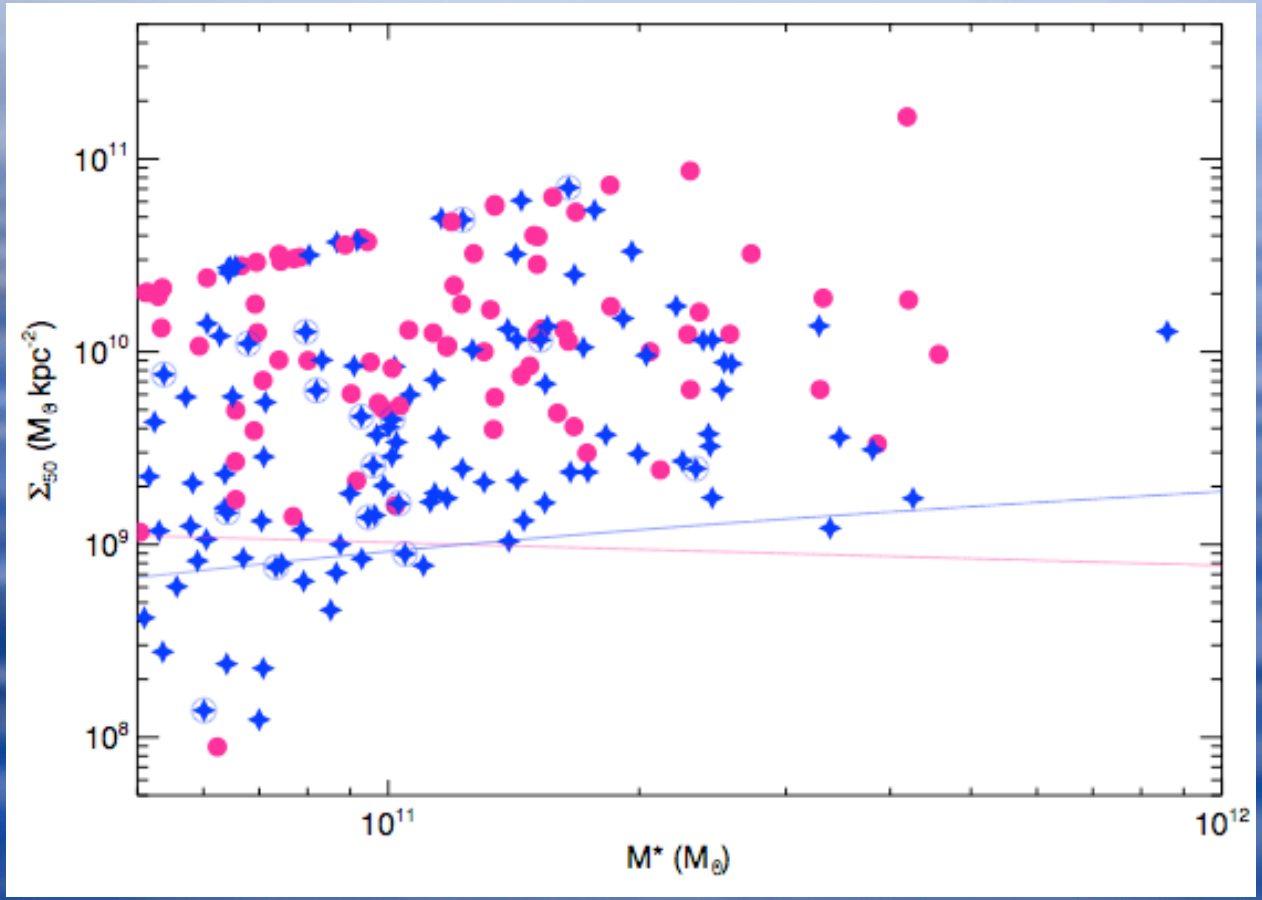
Mass-size



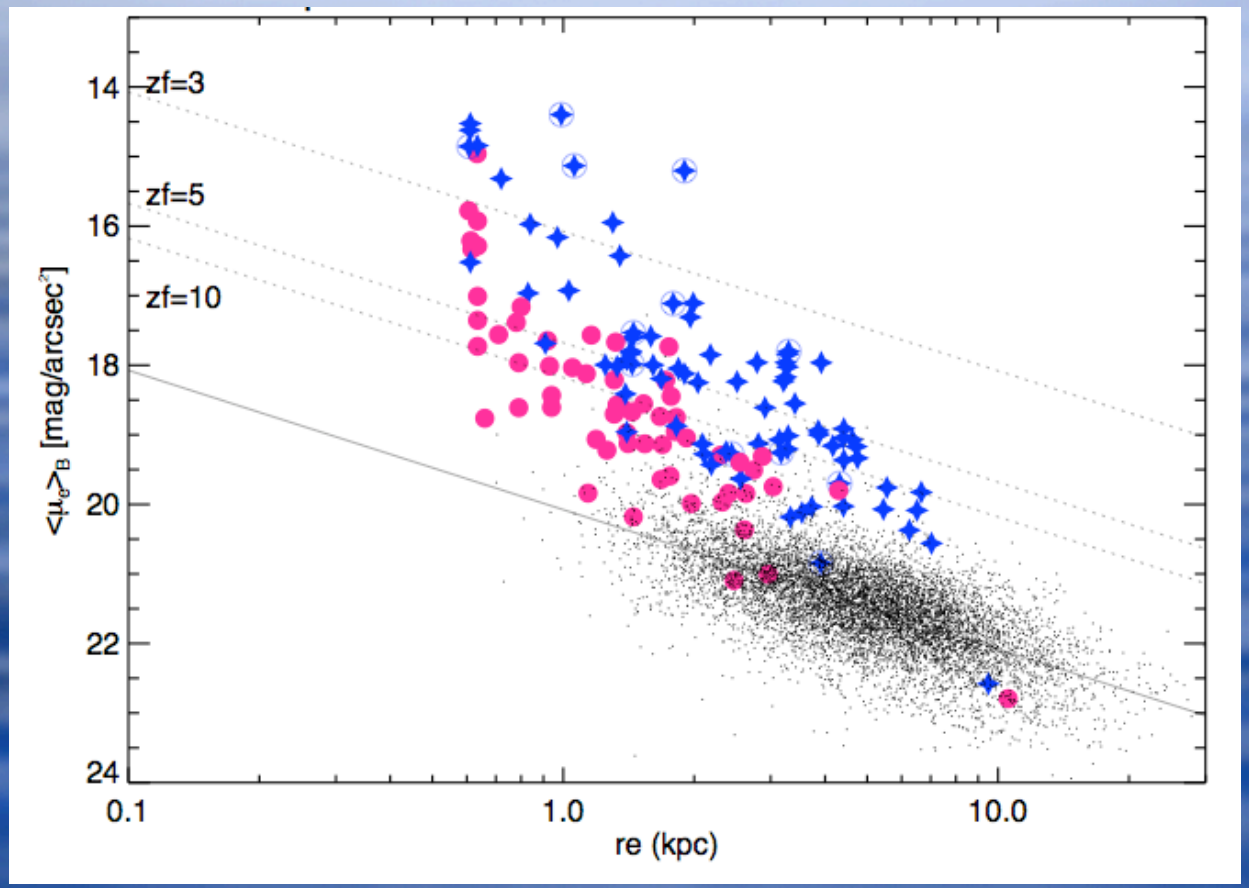
size - sSFR



Surface mass density



Kormendy relation




The end

Caveats

Mass uncertainties:

IMF (factor of ~2)
Stellar pop model (40%)
Photo-z (10%)

Size uncertainty:

Fitting: (15%)
Photo-z: (11%)

SED fits

Fit BC2003 models

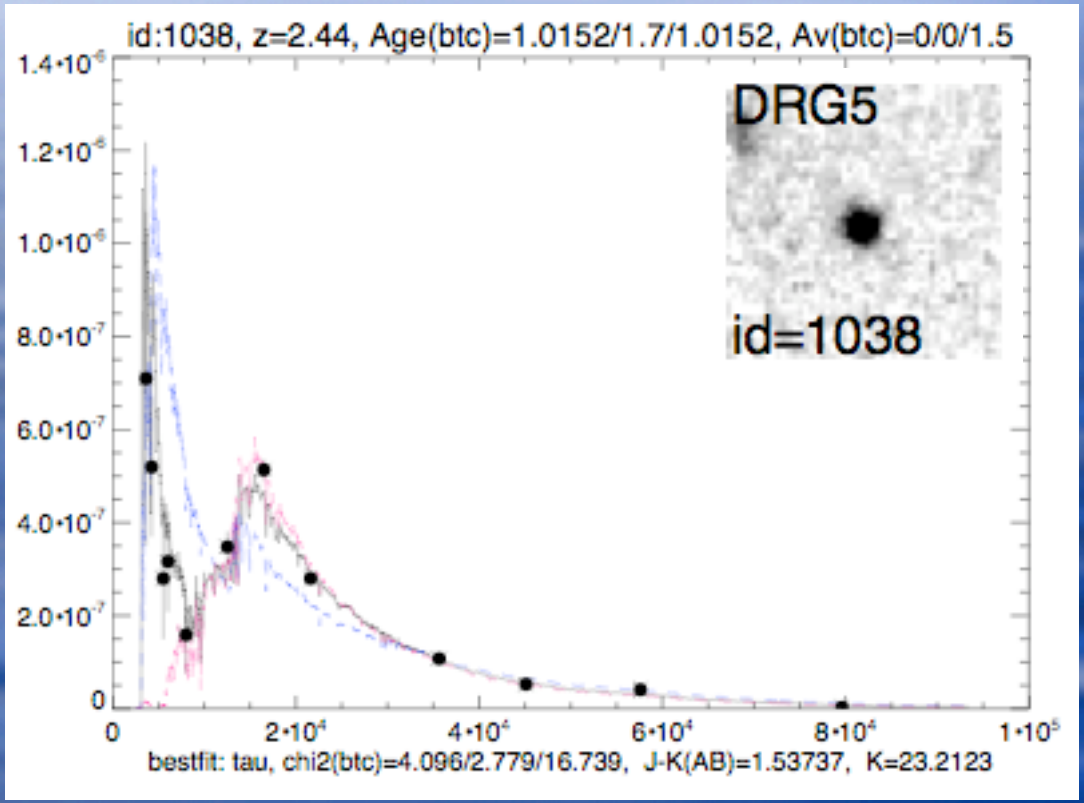
1: SSP no dust

2: Tau300+dust

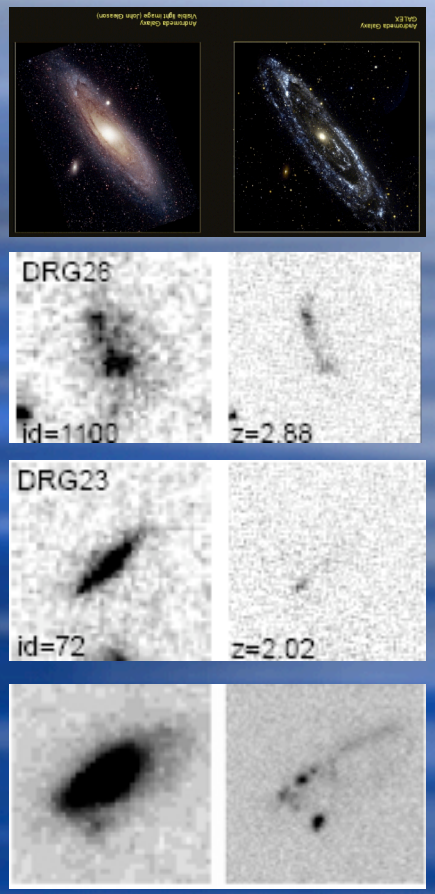
3: CSF+dust

↓

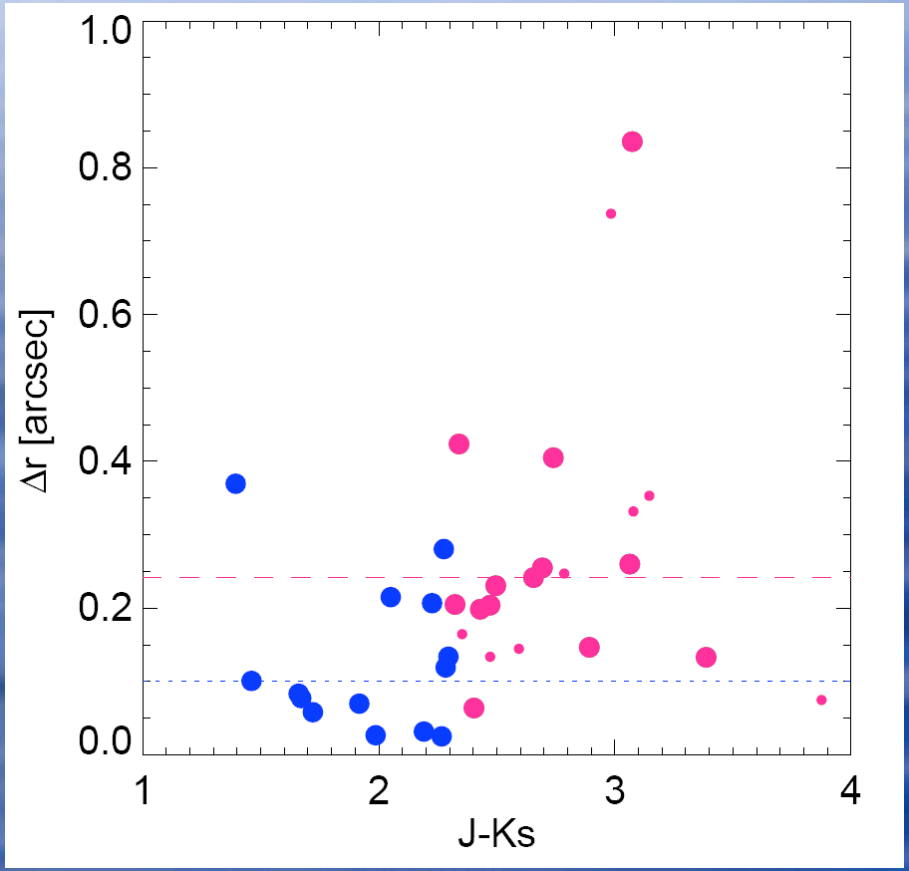
Mass, SFR,
Av, Age



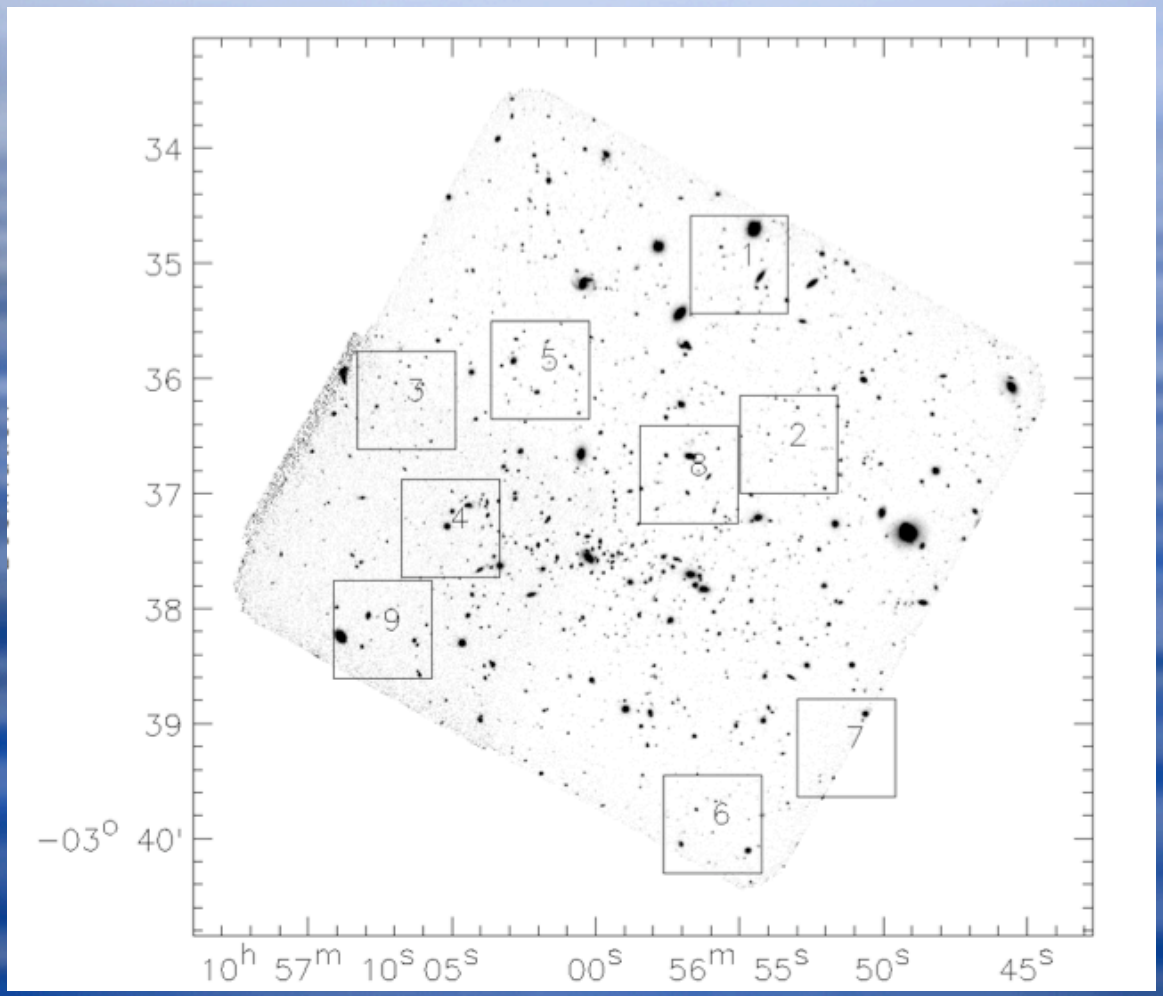
Morphological K correction



Shift of ACS centroid relative to NICMOS



Layout of NICMOS pointings



AGN

- X-ray detections
- IRAC colors
- SEDs
- MIPS