The Evolution of the Galaxy Merger Rate at z < 1

Jennifer Lotz - NOAO

+ AEGIS team

AEGIS

All-wavelength Extended Groth strip International Survey

Why study the galaxy merger rate?

transform star-forming disks (blue cloud)
→ 'dead' spheroids (red sequence)

trigger starbursts (IR-luminous galaxies,
Lyman break galaxies?)

fuel AGN + grow super-massive black holes

Want to be able to track
'galaxy merger rate' as a function of time,
mass, environment ...

Galaxy merger rate ==
number of galaxy mergers/ Gyr / unit volume

Direct measurement:

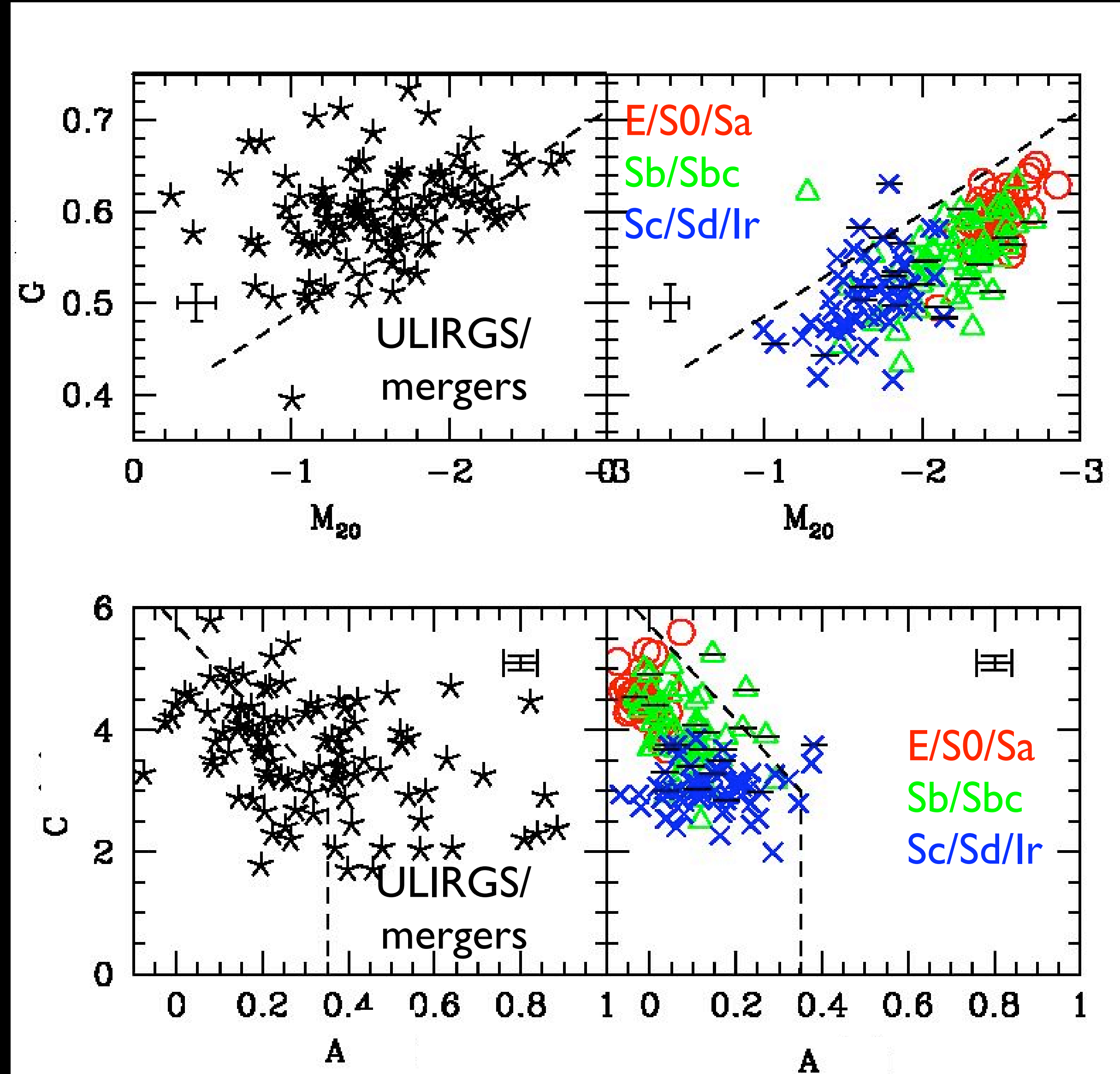
[1] identify galaxy mergers

- disturbed morphology
  - visual classifications
  - quantitative measurements (Gini/M20, Asymmetry)
- close pairs (dv < few 100 km/s
  dr < 30-50 kpc)

Quantitative Merger Classification

z=0
quantitative
morphologies
v.
visual
classifications

major-mergers
separate from
'normal galaxies'
in Gini-M20
and
Asymmetry



Lotz, Primack, & Madau 2004, Conselice 2004

Galaxy merger rate ==

number of galaxy mergers/ Gyr / unit volume

Direct measurement:

[1] identify galaxy mergers

- disturbed morphology
- close pairs

[2] estimate timescales for which merger can be identified

Merger Timescale:

time during which a merger can be identified

- poorly constrained

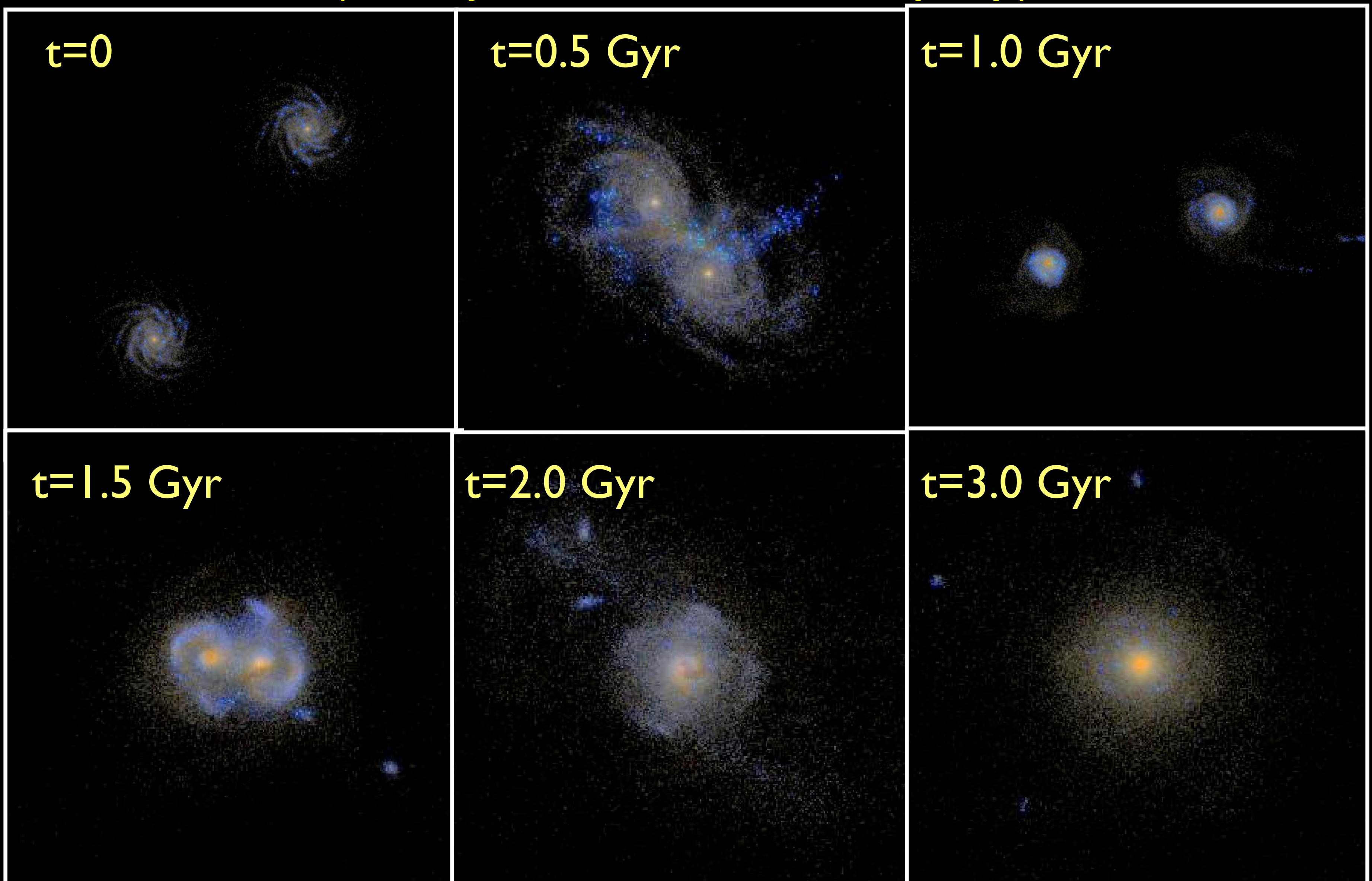
  (Conselice 2005, Iono, Yin, & Mihos 2004, Bell et al 2005)

- depends on merger conditions:
  gas fraction, orbital parameters,
  SFR/feedback, mass ratio

- depends on observations:
  wavelength, viewing angle, S/N, resolution

$\Longrightarrow$ calibrate with simulations!

Gas-rich equal mass mergers
GADGET2 + SUNRISE sims
(Lotz, Jonsson, Cox, et al prep)



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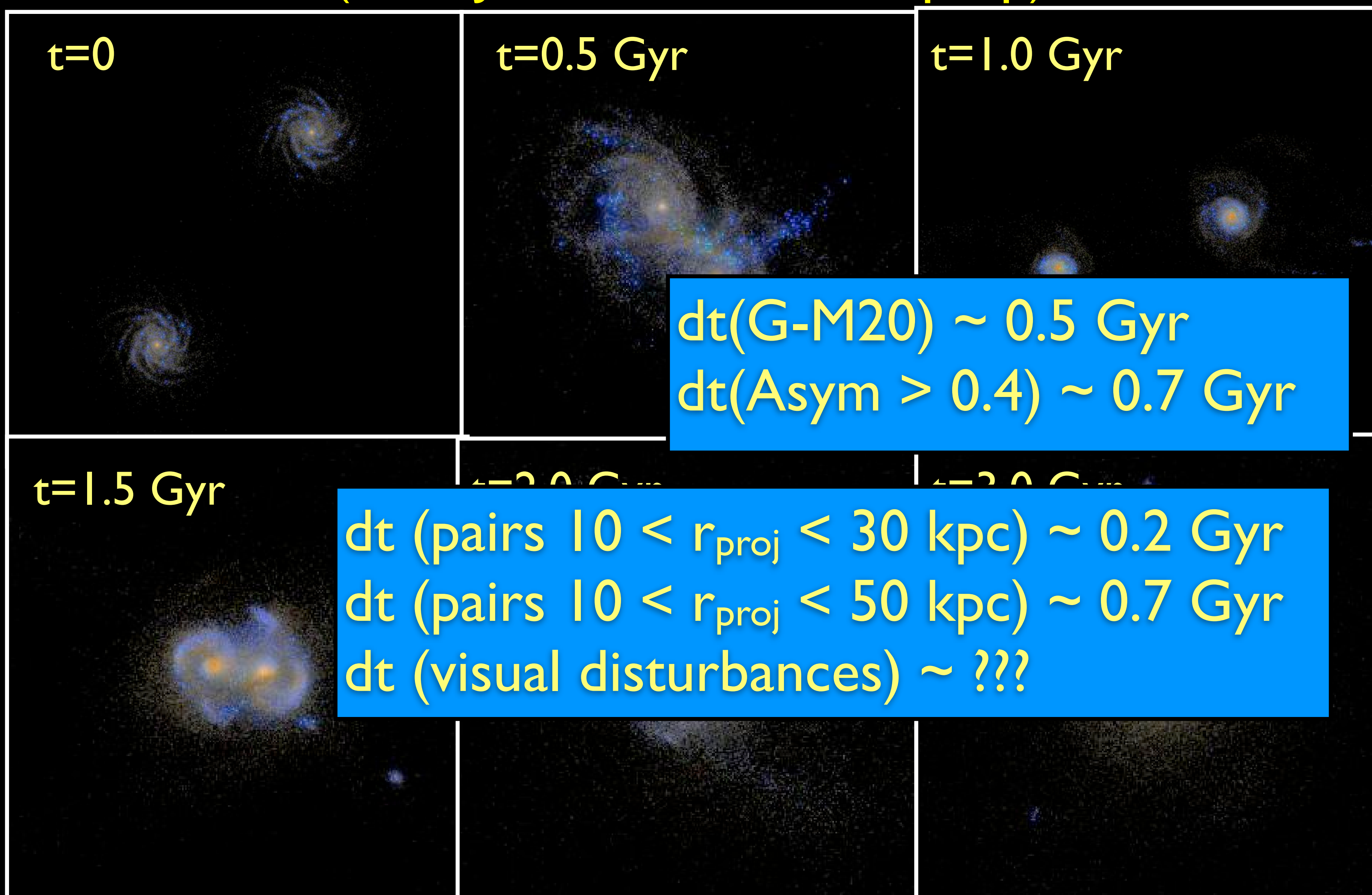


dt(G-M20) ~ 0.5 Gyr

dt(Asym > 0.4) ~ 0.7 Gyr

dt (pairs 10 < r_{proj} < 30 kpc) ~ 0.2 Gyr

dt (pairs 10 < r_{proj} < 50 kpc) ~ 0.7 Gyr

dt (visual disturbances) ~ ???

Morphologies at z >> 0

resolution: 1 kpc ~ 0.1 arcsec at $z \geq 1$

$\Rightarrow$ need HST or adaptive optics

surface-brightness / signal-to-noise:

quantitative measures dependent on S/N

visual classifications difficult

selection effects (miss low μ disks)

wavelength/ morphological k-correction:

UV morphologies more irregular

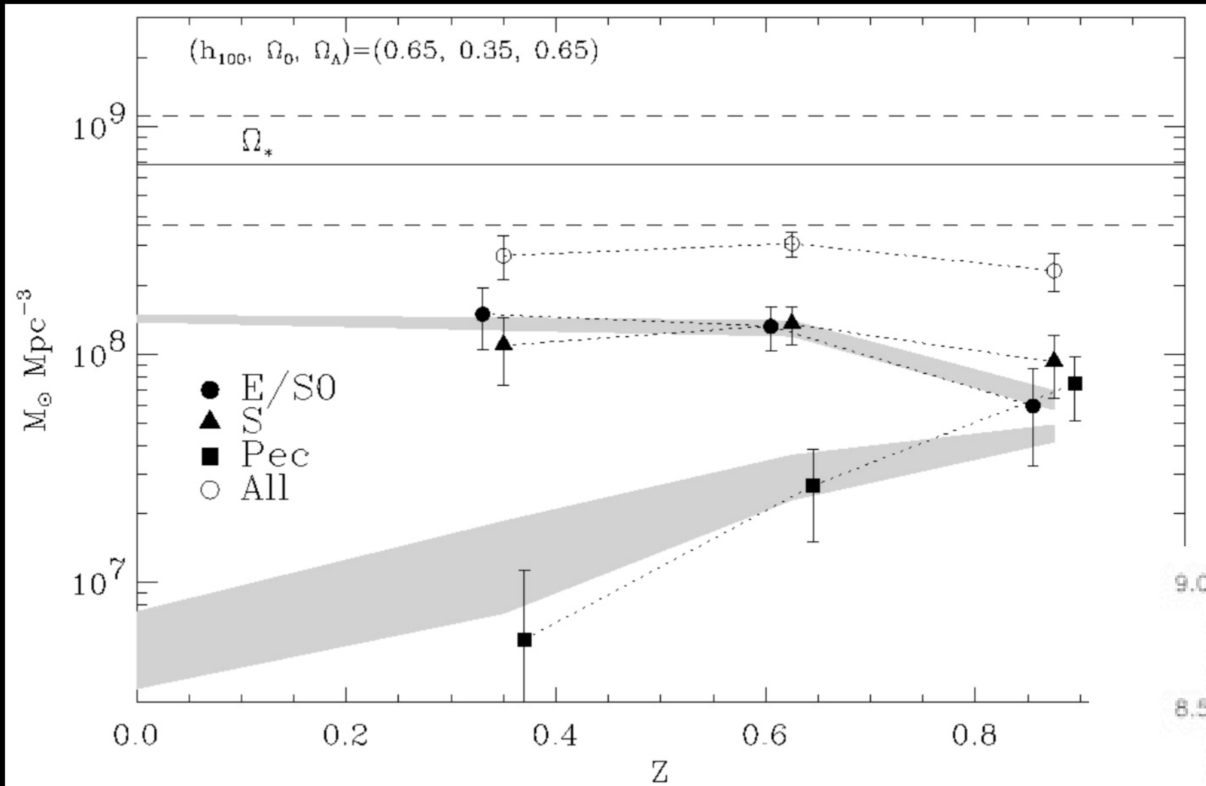
$\Rightarrow$ can't use single observed λ

to trace morphology evolution

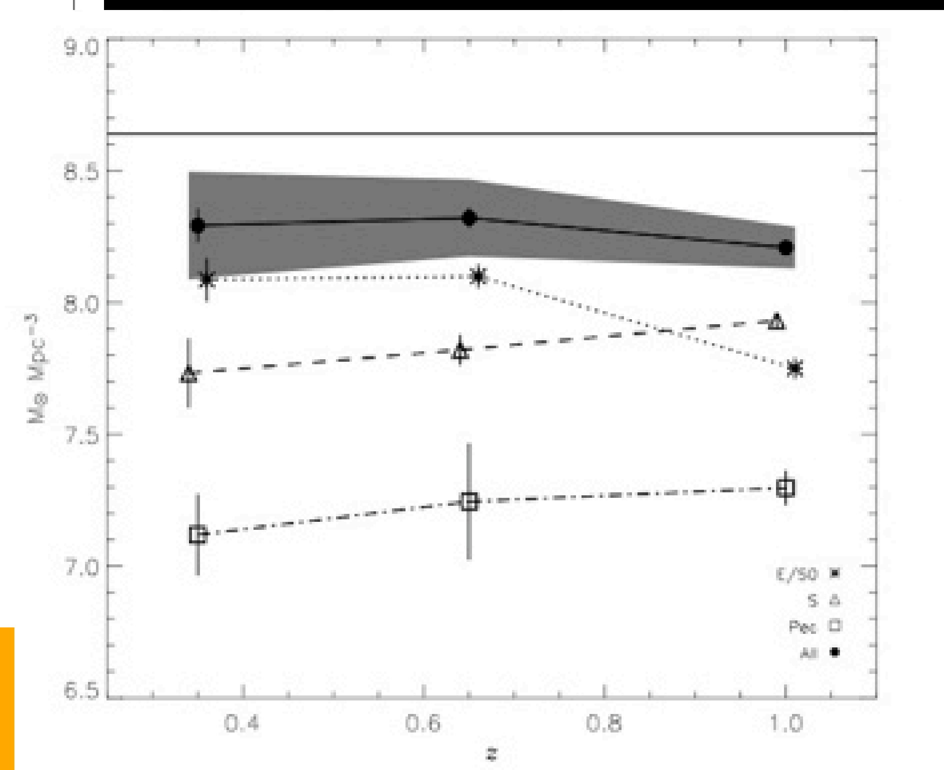
Morphology v. Wavelength

Andromeda Galaxy
GALEX

Andromeda Galaxy
Visible light image (John Gleason)



Brinchmann & Ellis 2000
HST I-band only
visual classifications



Bundy, Ellis, Conselice 2005
HST GOODS (BViz)
visual classifications

including morphological k-corrections
gives much weaker evolution in peculiars

the Extended Groth Strip

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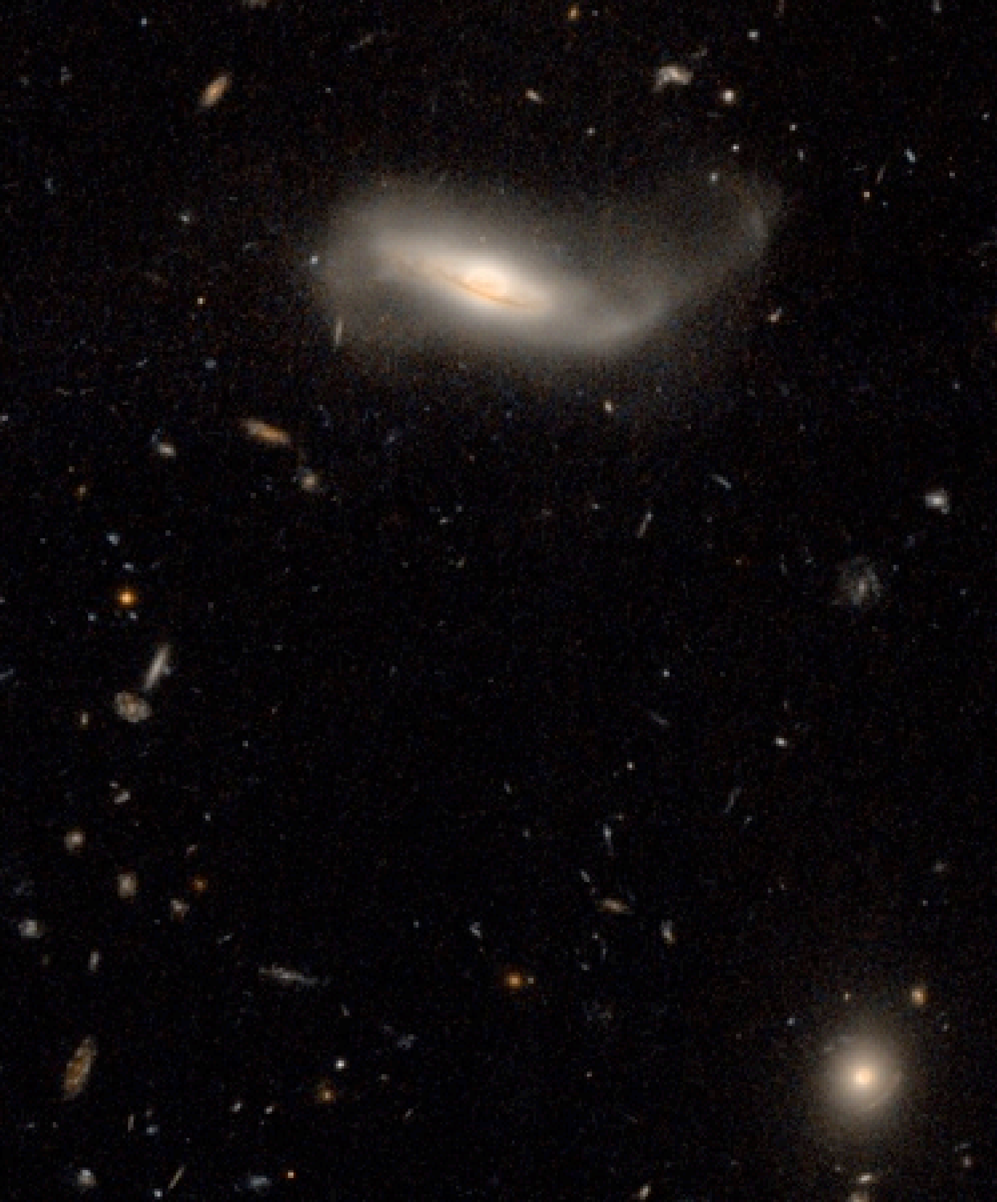


DEEP2: ~10,000 redshifts (PI Davis)
(~4000 redshifts in HST ACS field)

HST ACS: F606W, F814W
(PI Davis) ~710 sq. arcmins

Spitzer MIPS 24 micron data
(PI Rieke, Fazio)

Canada-France-Hawaii-Telescope
Legacy Survey ugriz
(⇒ photo-zs; O. Ilbert/VVDS)

+ Chandra, GALEX, Palomar K,
Spitzer IRAC, VLA

Evolution in Morphologies+ Merger Fraction in EGS

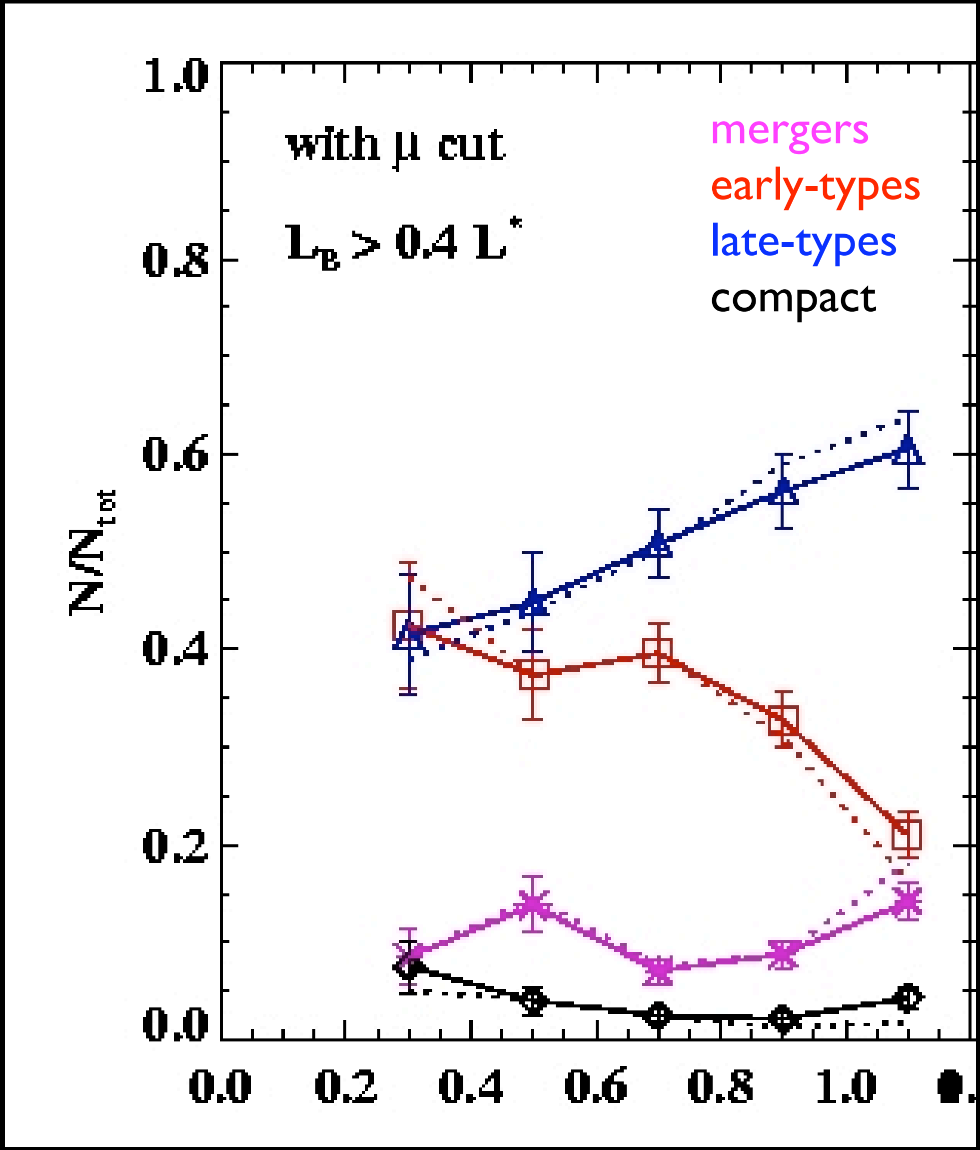
$L_B > 0.4\ L^*$ sample: 343/2783

G-M20 mergers:
~ constant at ~10%

Early-types:
increase at z <1.2

Late-types:
decrease at z <1.2

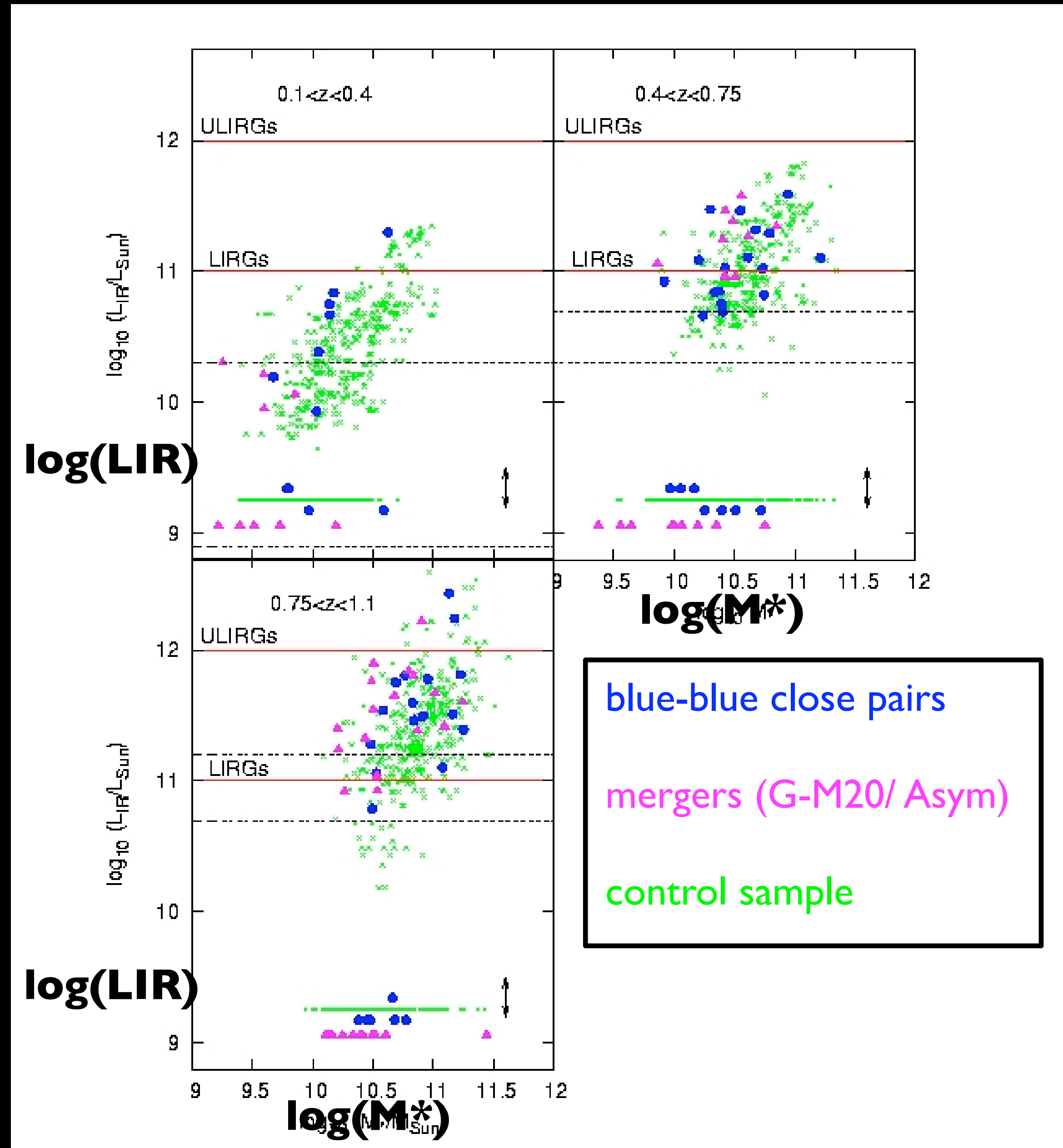
Lotz et al. 2006 astro-ph/0602088



Morphologies & Star-Formation

at 0.2 < z < 1.2
most IR-luminous galaxies are disks
(Bell et al 2005, Melborne et al 2005, Lotz et al 2006)

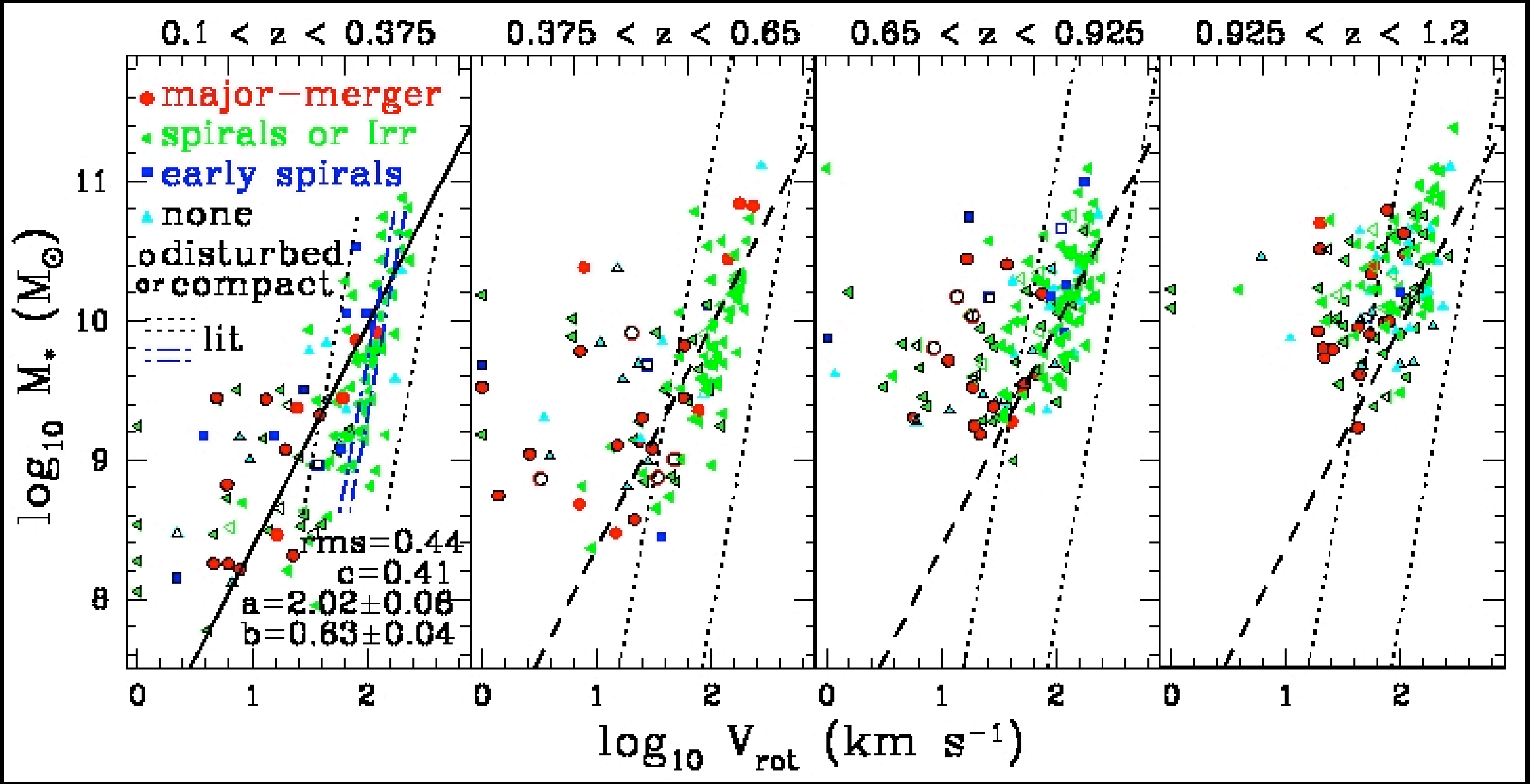
however,
G-M20 merger candidates + close pairs have higher L(IR) at given stellar mass
(Lin et al 2006 astro-ph/0607355)



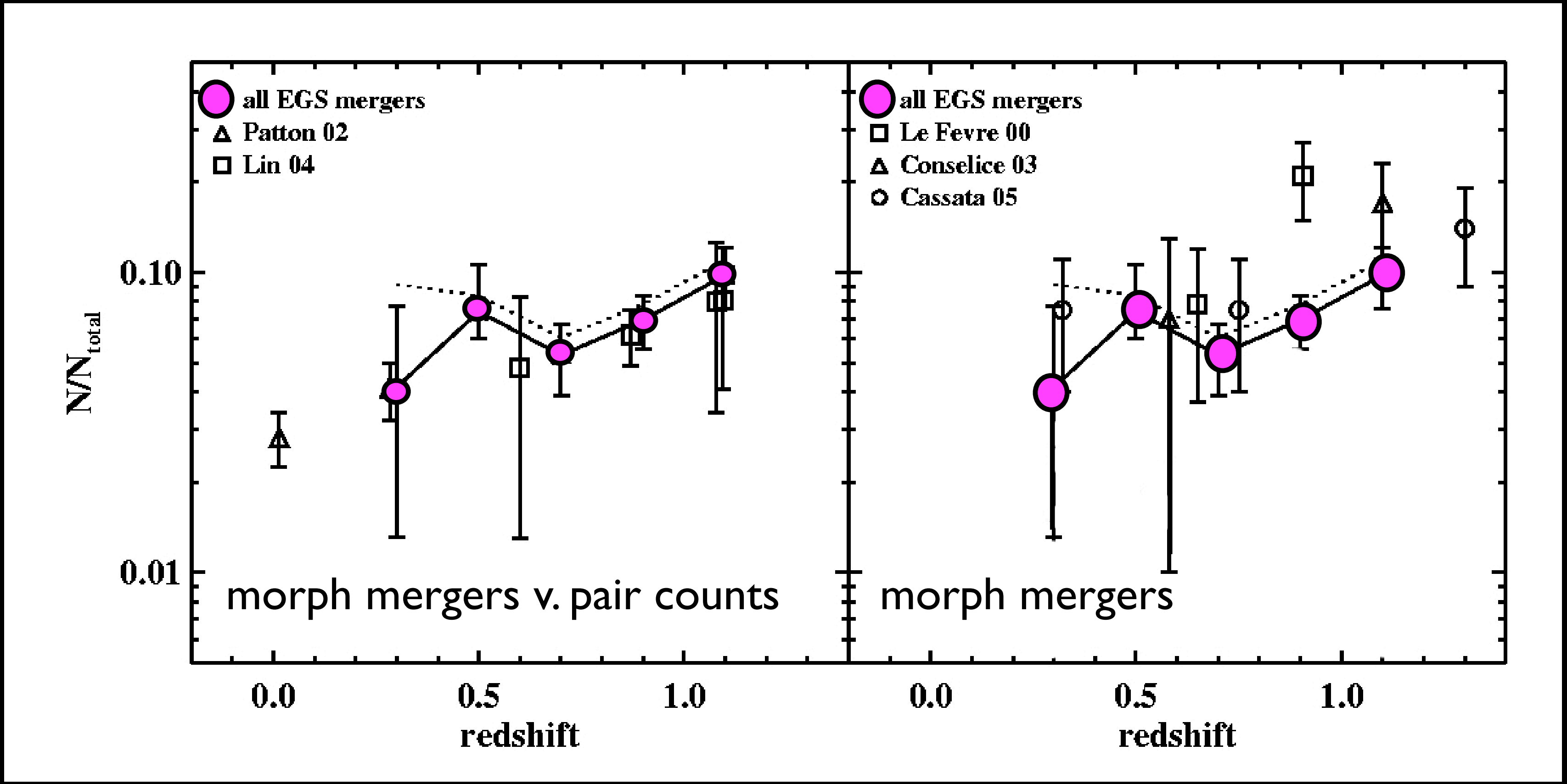
Morphologies & Kinematics

G-M20 mergers are kinematically disturbed

(see Kassin's talk; also Flores et al 2006, Weiner et al 2006, Kappannan & Barton et al 2004)



Evolution in Merger Fraction at z<1.2



$f_{merger} \sim (1+z)^m \Rightarrow m = 1.12 \pm 0.60$ (excludes ambiguous candidates)

$= 0.26 \pm 0.64$ (all G-M20 candidates)

(also Bundy et al 2004, 2005, de Propis et al 2005, Bell et al 2006, Ilbert et al 2006..)

Theory?

'distinct' dark matter halo merger rate ~ $(1+z)^3$
(Gottlöber et al 2001)

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but galaxy ⟷ dark matter halo correlation
is not straight-forward

more galaxies are 'sub-halos' at later times
+ fewer halos host galaxy pairs at early times
⇒

luminous galaxy merger rate/ close pair evolution ~ $(1+z)^{0.5-1}$
(Berrier et al. 2006)

Formation of Early-Types

Galaxy merger rate = n_{gal} f_{merger} / T_{merger}

f_{merger} (G-M20) ~ 10%, T_{merger} (G-M20) ~ 0.5 Gyr

⇒ ~1 major merger per L_B > 0.4 L* galaxy from z=1.1 to 0.3

⇒ many new E/S0/Sas *could* have formed in major-mergers

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But not all mergers transform blue disks into red spheroids (e.g. Springel & Hernquist 2005, Hammer et al 2005, dry mergers)

⇒ need to constrain mass function (Bundy et al 2005),

colors, + morphologies of merger progenitors

what about z>1 ?

z >3 Lyman break galaxies: 10-60% major mergers?

(Lotz et al 2005, Ravindranath et al 2006,
Cassata et al 2005, Conselice et al 2003)

high-z merger rate from morphology is difficult!

sample selection: UV-bright only

wavelength: rest-frame UV morphologies

Theory:

Collisional starbursts Somerville et al 2001

or

'Smooth' cold accretion Davé et al 2006

→LBG morphologies elongated (filamentary?)

Summary

- weak evolution in galaxy merger fraction at z < 1

  $f_{merger} \sim (1+z)^{0.2-1}$

  (from EGS, GOODS, DEEP2, Combo-17 using G-M20, Asym, visual morphs, kinematic pairs + angular correlation)

- normalization/ absolute merger rate uncertain, depends on relative timescales

  ~1 major merger per $L_B > 0.4\ L^*$ galaxy from z=1.1 to 0.3
  but may not all form red spheroids

- isolated dark matter halo merger rate ≠ galaxy merger rate

- G-M20 mergers: higher specific SFRs + disturbed kinematics

- galaxy merger rate at z >> 1 still unconstrained