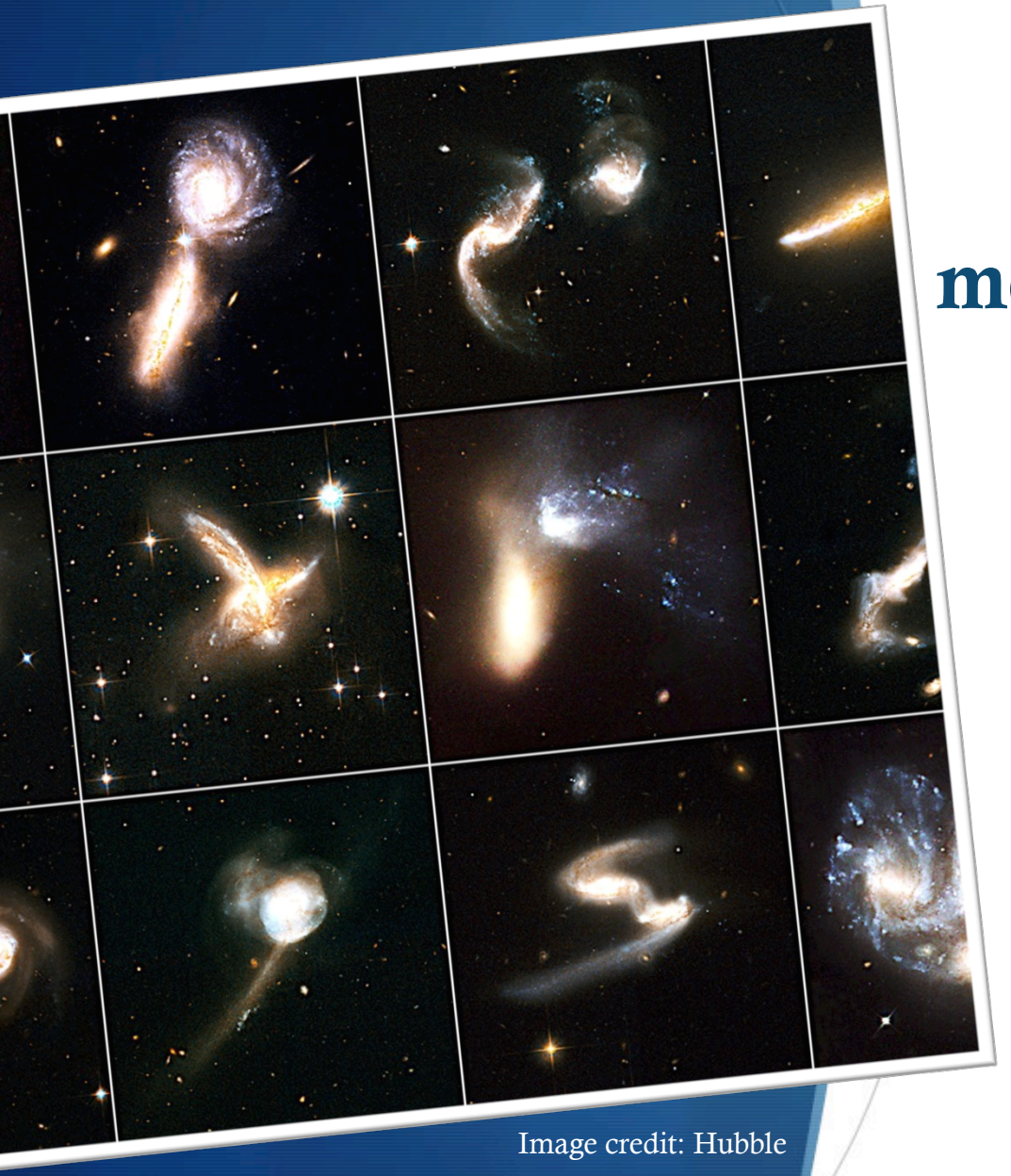


Image credit: Hubble

An emerging consensus on the merger rate of massive galaxies at z=0-3

Allison Man

European Southern Observatory, Garching HQ

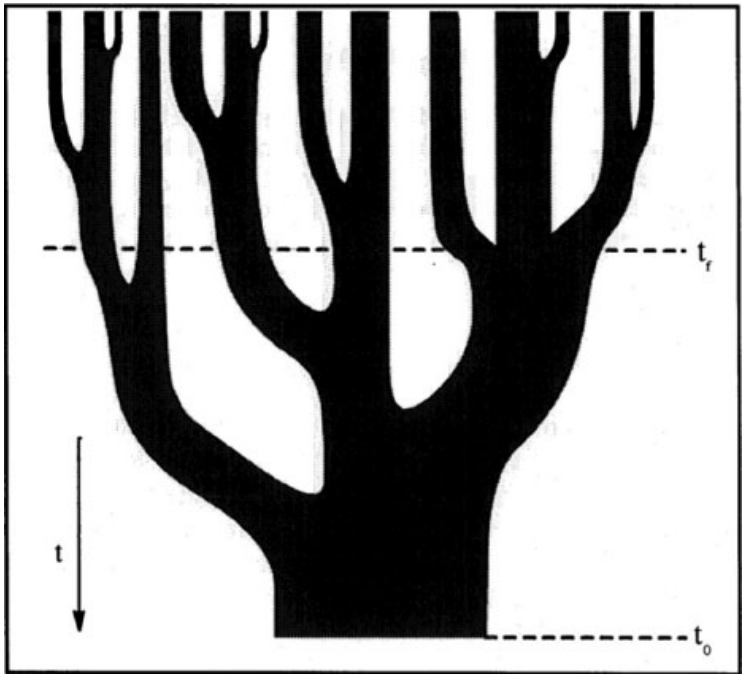
with Sune Toft & Andrew Zirm

Dark Cosmology Centre

Mergers…why should we care?

Mergers…why should we care?

- Hierarchical assembly = Backbone of LCDM



A merger tree, Lacey & Cole 1993

Mergers…why should we care?

- Hierarchical assembly = Backbone of LCDM
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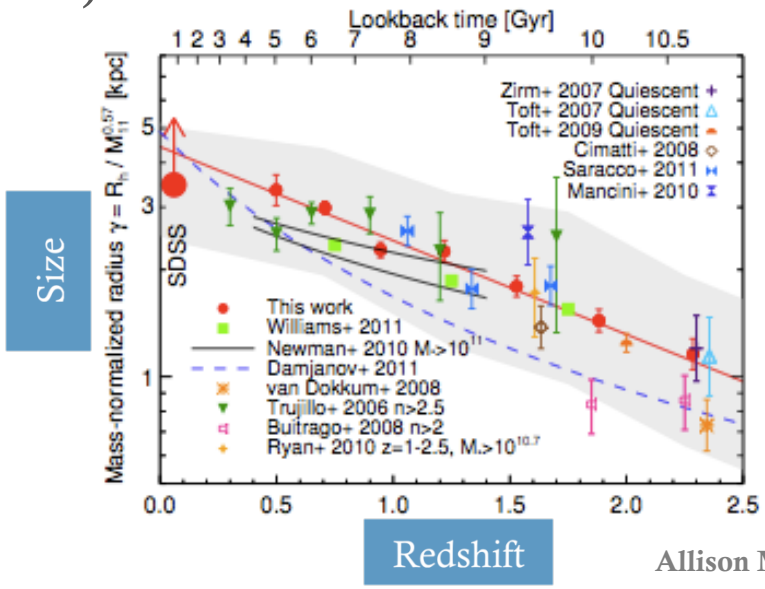
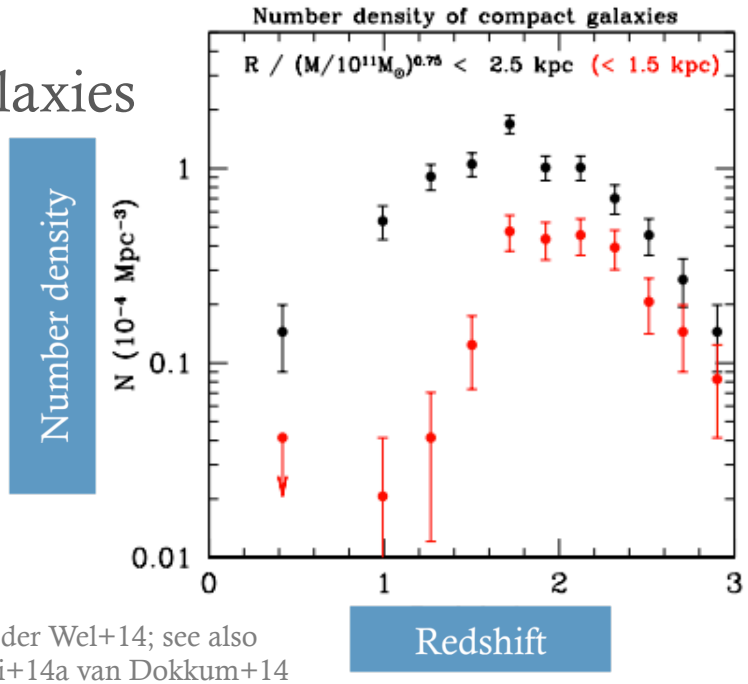


Newman+12;
see also Daddi+05, Trujillo+06,
Toft+07, Zirm+09, Franx+08,
van Dokkum+08…

Allison Man [ESO]

Mergers…why should we care?

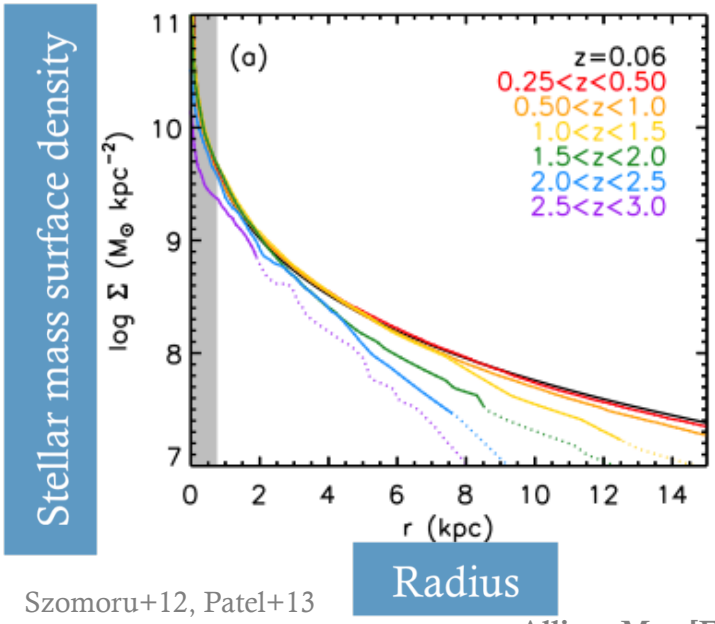
- Hierarchical assembly = Backbone of LCDM
- Post-mortem growth of quiescent galaxies
  - Puff up sizes (~half, Belli+15)
  - Destroy compact ones



van der Wel+14; see also Belli+14a van Dokkum+14

Mergers…why should we care?

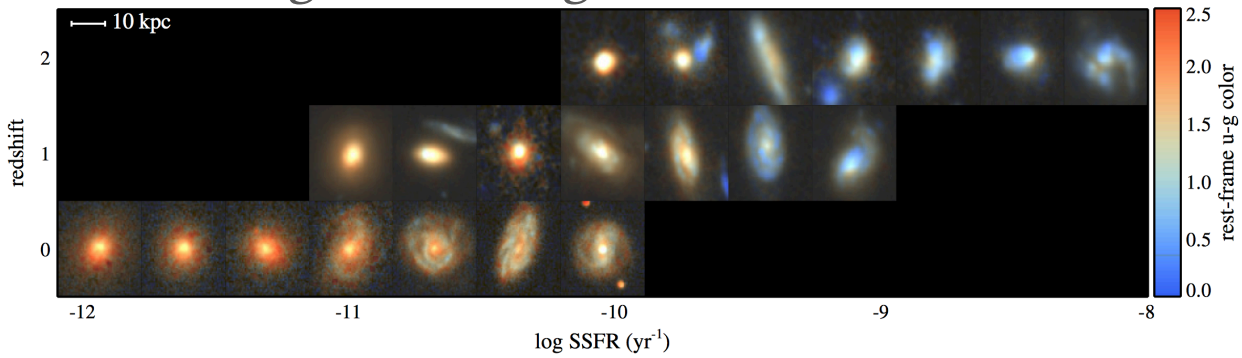
- Hierarchical assembly = Backbone of LCDM
- Post-mortem growth of quiescent galaxies
  - Puff up sizes (~half, Belli+15)
  - Destroy compact ones
  - Mass growth at outskirts



Szomoru+12, Patel+13

Mergers…why should we care?

- Hierarchical assembly = Backbone of LCDM
- Post-mortem growth of quiescent galaxies
  - Puff up sizes (~half, Belli+15)
  - Destroy compact ones
  - Mass growth at outskirts
  - Negative color gradient



Szomoru+11; see also van Dokkum+10, Guo+11, Gargiulo+12, Szomoru+13

Allison Man [ESO]

Mergers… how should we care?

- How often do massive galaxies merge?
- Is merging responsible for the evolution of any galaxy properties?

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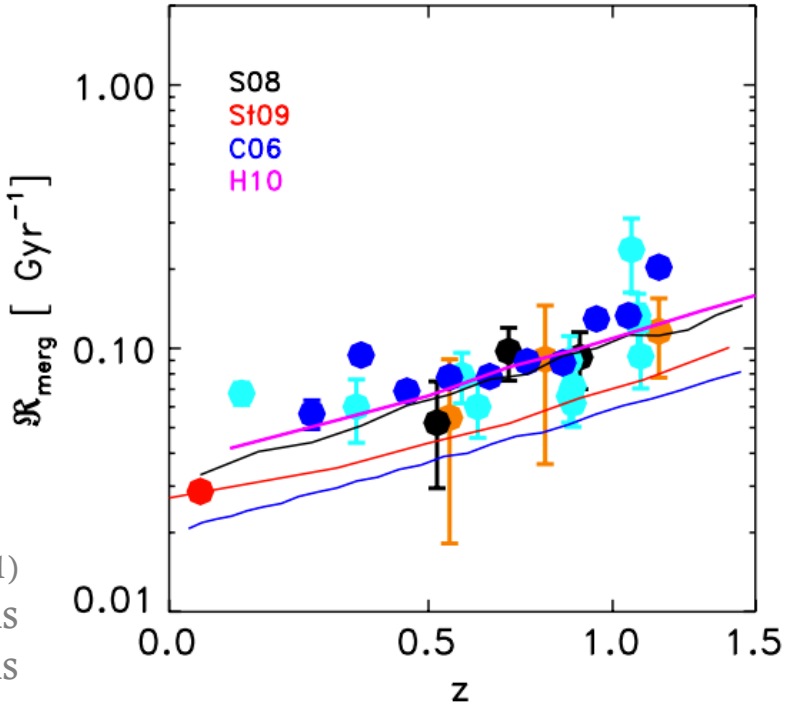
Consistent merger rates at z<1.5

- Consistent major merger rate between observations & theoretical predictions up to z=1.5

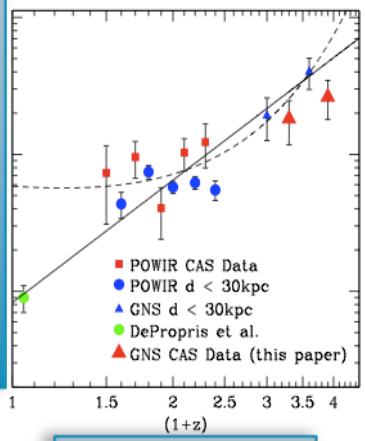


Major merger rate (Lotz+11)
••• Observations
--- Theoretical predictions

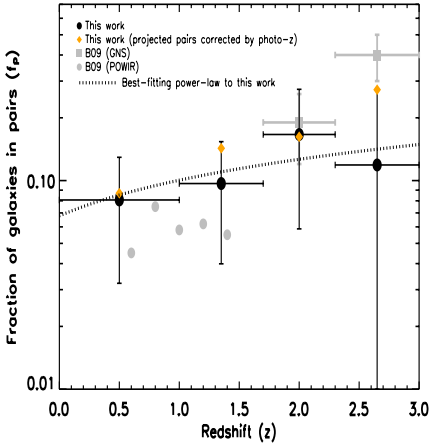
Discrepant merger fractions at z~2

Merger fraction

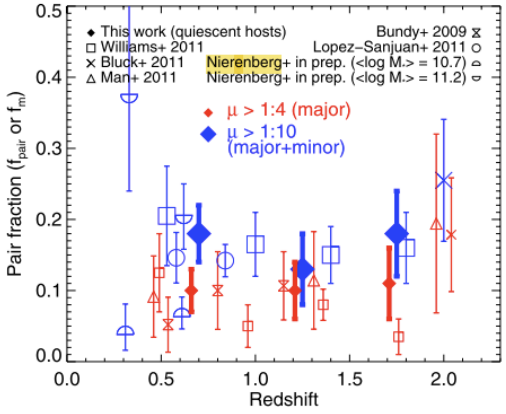
Bluck+09



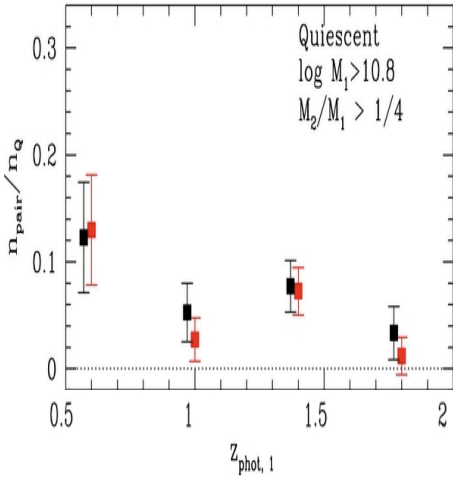
Man+12



Newman+12



Williams+11



Redshift

Increase strongly with z

No evolution with z

Decrease with z

Observed *H*-band flux ratio

Stellar mass ratio

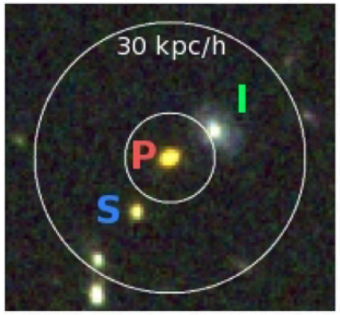
Galaxy merger rate – this work

- Mergers of massive galaxies of $M_\star > 10^{10.8} M_\odot$
  - Projected separations 10-30 kpc/h
  - Matching photo-z's

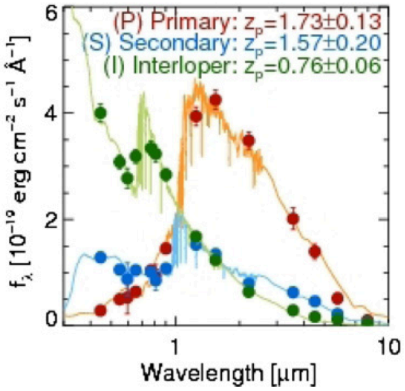
    $|z1-z2|/(z1+1) < 0.2$ (0.1) at $z>1$ ($z<1$)
  - **Stellar mass** or **H-band flux ratio** between 1 – 4 (major) or 4 – 10 (minor)

- Merger rate (# mergers / galaxy / unit time)

  = Merger fraction / timescale (Lotz + 2010)



Newman+12



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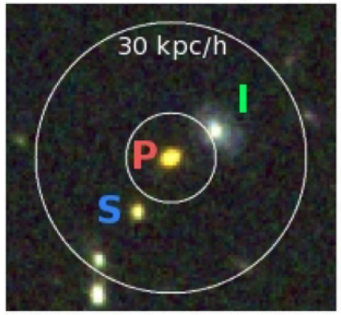
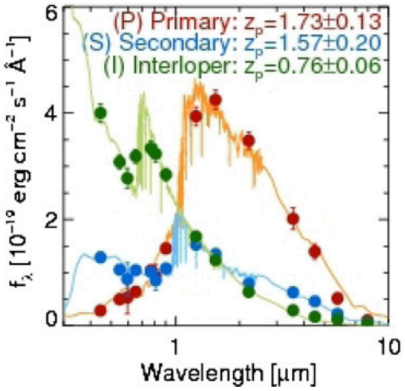


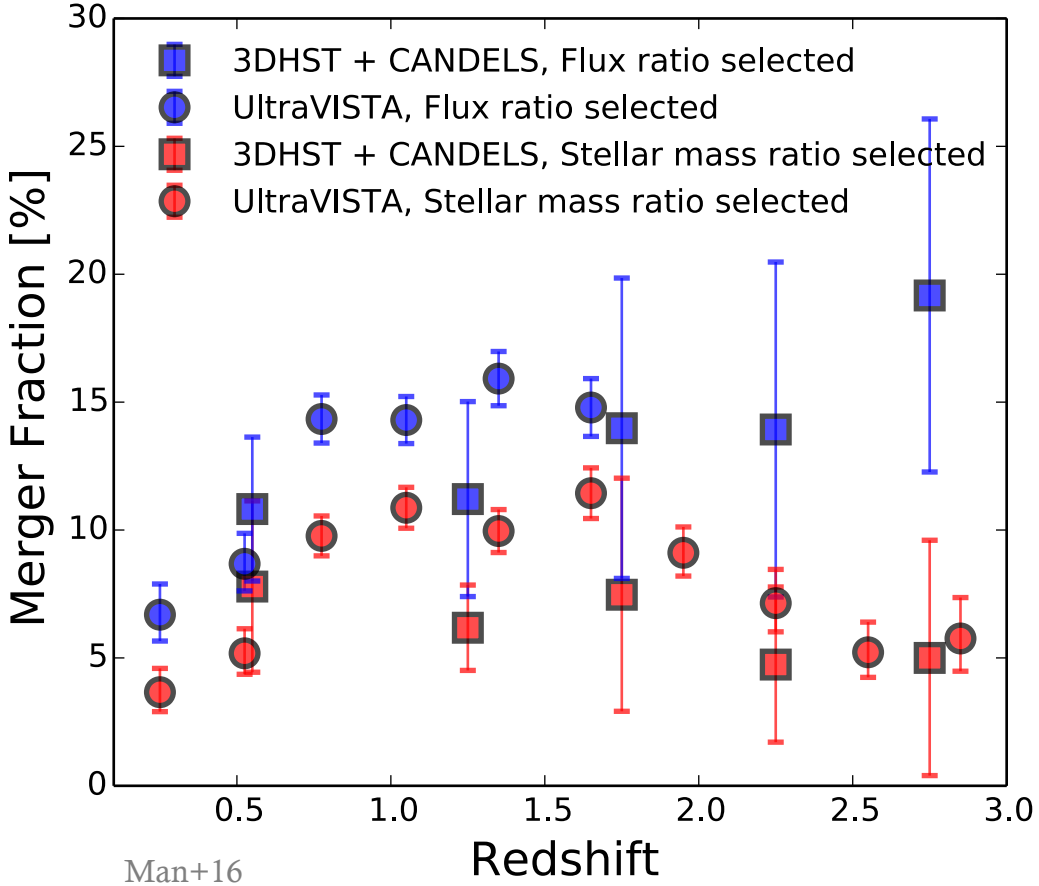
Newman+12



Survey	Ref	Area [deg^2]	Depth (5 σ)	FWHM
UltraVISTA / COSMOS	Muzzin+13	1.62	K=23.8	0.75"
CANDELS	Skelton+14	0.25	H=26.9	0.18"

Largest $M_\star$-complete sample of photometrically selected mergers at z>1

Major merger fraction – results



Man+16

- Observed H-band flux ratio
  - ➔ increasing trend
  - ➔ higher on average
- Stellar mass ratio
  - ➔ diminishing trend

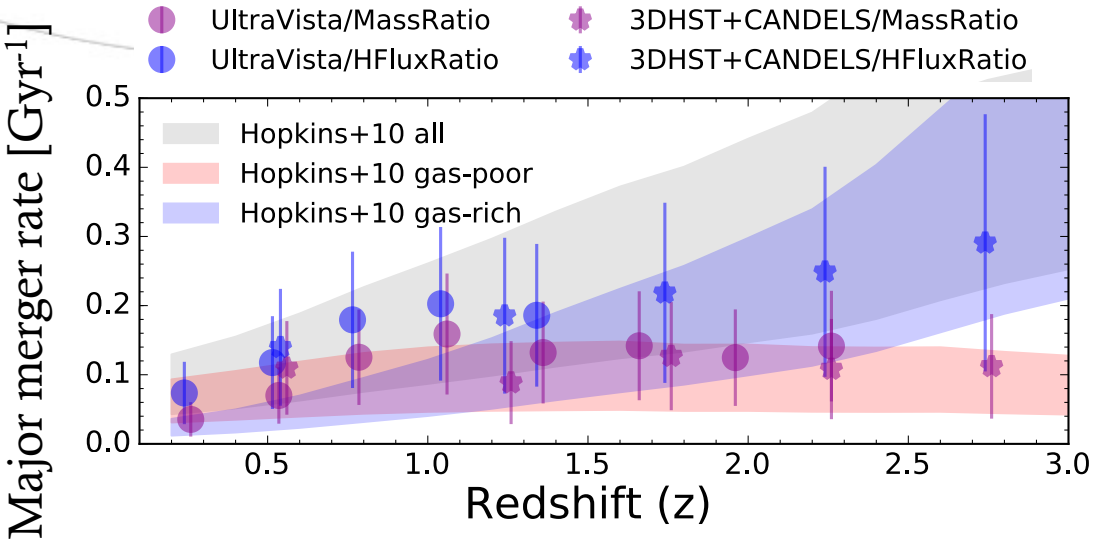
Stellar mass ratio vs Flux ratio

- What are the major *flux ratio* mergers at z=2-2.5?
  - ~ 19% major *stellar mass* ratio
  - ~ 19% minor *stellar mass* ratio
  - ~ 61% very minor (< 1:10) *stellar mass* ratio
- Observed *H*-band corresponds to bluer rest-frame wavelength at higher z
  - More sensitive to SF (hence gas mass) than stellar mass

z=2.3
Flux ratio = 3.6 (major)
Stellar mass ratio = 8.3 (minor)

HST/WFC3 H_{160} 12"x12"

Galaxy merger rates – observed vs predicted



~ 1 major +
1 minor merger

Stellar mass ratio
Gas-poor merger rate ✔

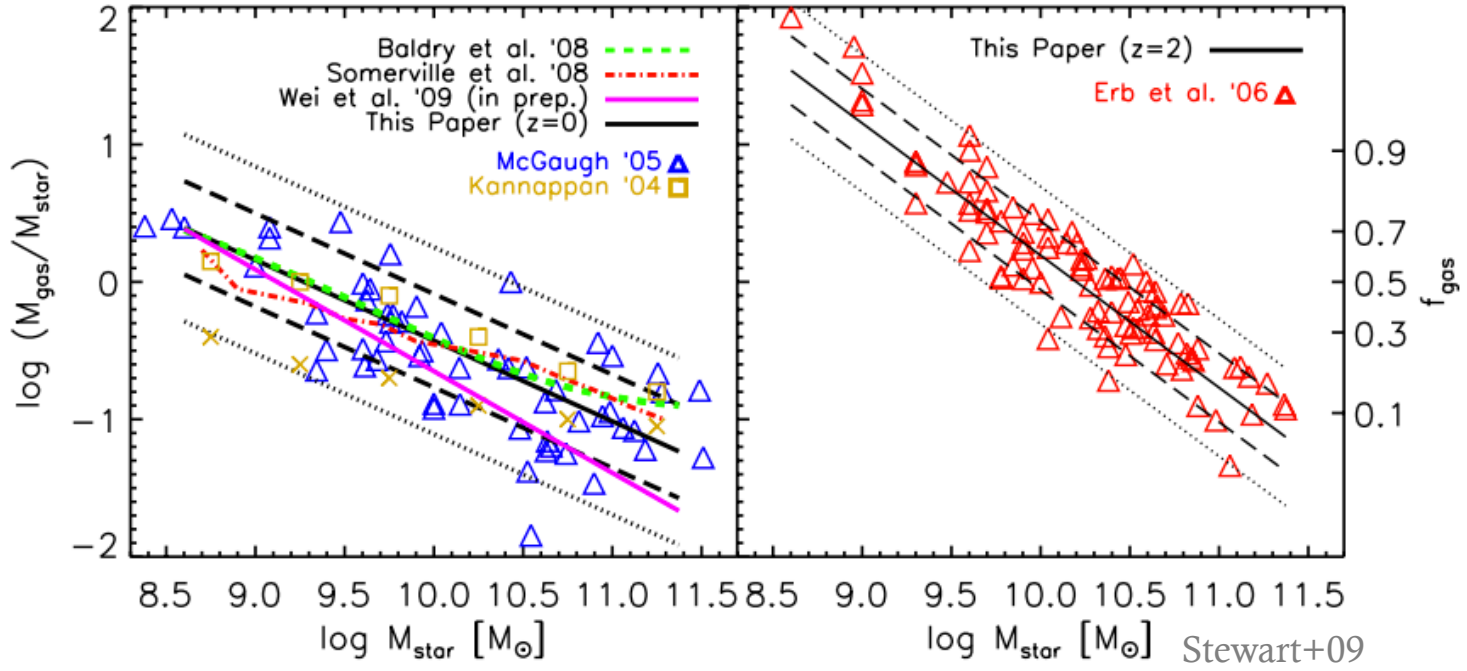
Obs. H-band flux ratio
can find some gas-rich mergers,
but is a problematic tracer of mass

If merging timescale shorter at higher-z, may find better match (Synder + in prep.)

Gas fraction f_{gas} ($M_\star$, z)

Gas fraction:

- Increases with redshift
- Decreases with stellar mass



Stewart+09

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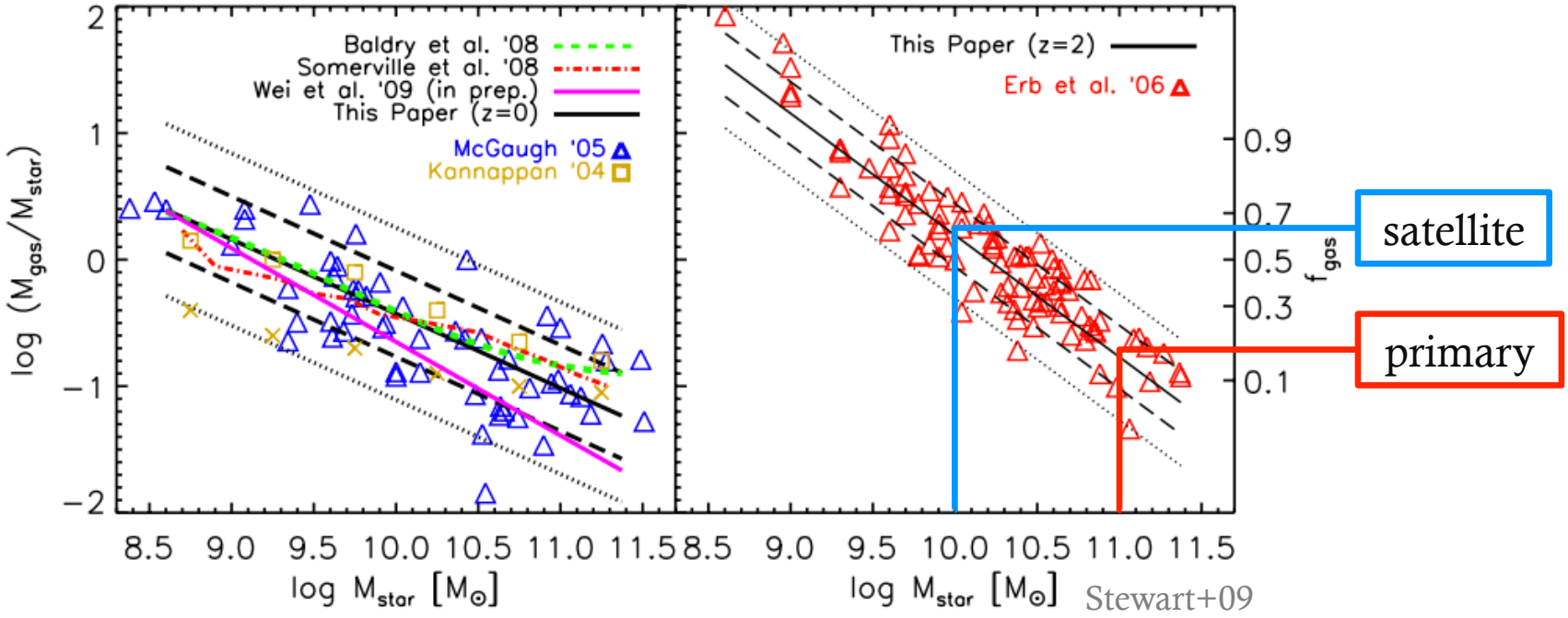


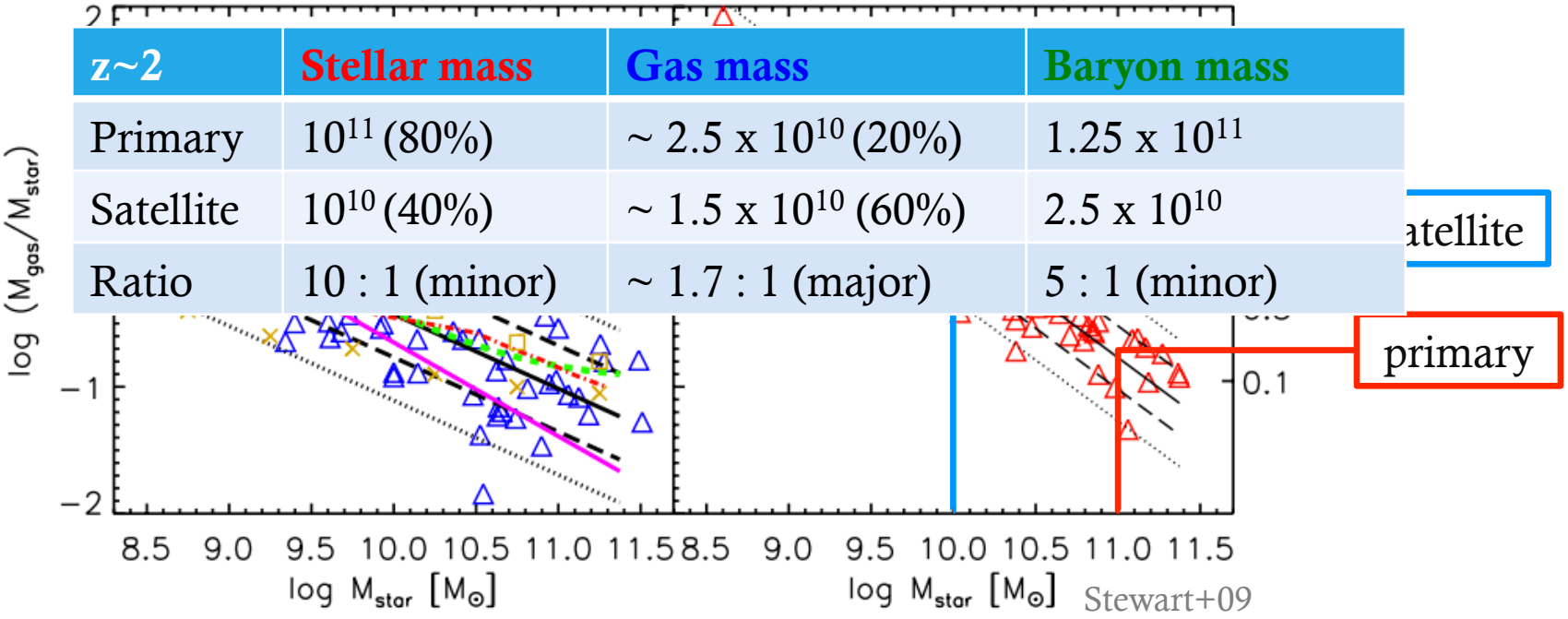
Stewart+09

Gas fraction f_{gas} (M_*, z)

Gas fraction:

- Increases with redshift
- Decreases with stellar mass

z~2	Stellar mass	Gas mass	Baryon mass
Primary	10^{11} (80%)	~ 2.5 x 10^{10} (20%)	1.25 x 10^{11}
Satellite	10^{10} (40%)	~ 1.5 x 10^{10} (60%)	2.5 x 10^{10}
Ratio	10 : 1 (minor)	~ 1.7 : 1 (major)	5 : 1 (minor)



The missing gas-rich mergers at z>2

If only stellar mass ratio is considered, we miss out on the gas-rich mergers at z>2 that have the right *baryon mass* ratio

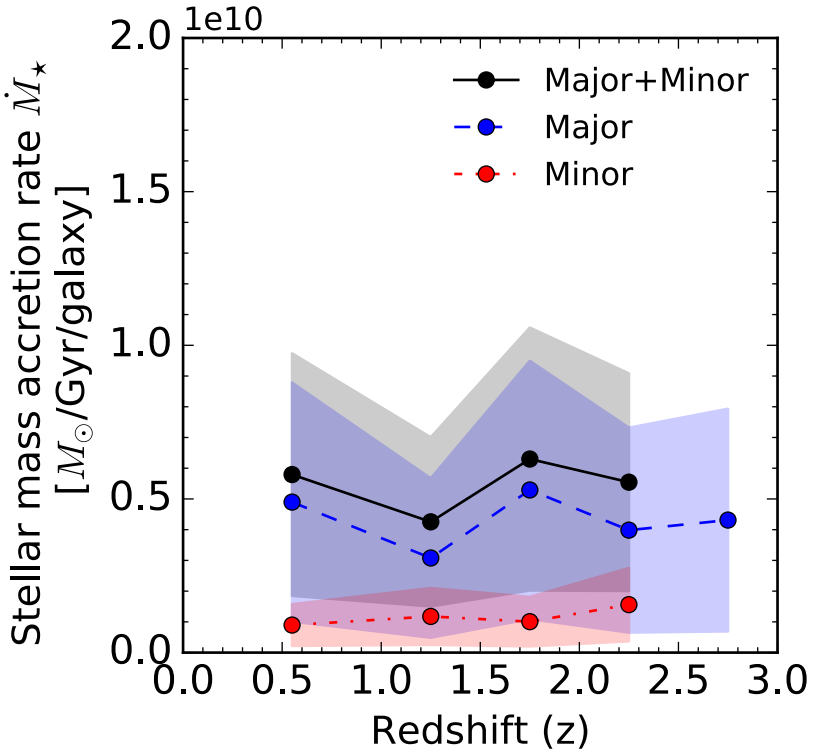
Stewart+09

Mergers… how should we care?

- How often do massive galaxies merge?
- Is merging responsible for the evolution of any galaxy properties?

Stellar mass accretion rate

- A massive galaxy doubles its stellar mass from z~3 to 0.3 by accreting stars via major & minor mergers



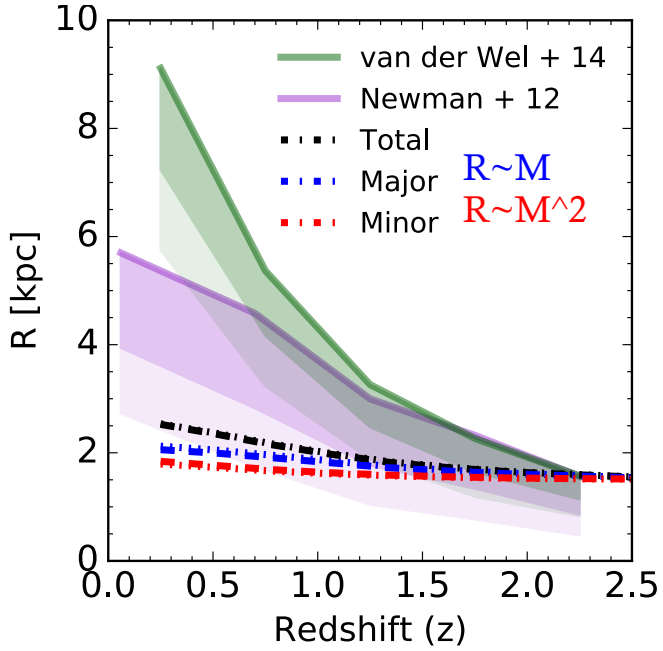
Size evolution of quiescent galaxies

- Average sizes of quiescent galaxies need to increase their sizes ~3-5 times
  (Newman+12, van der Wel+14)

Major + minor mergers can at most double the size from z~2.5 to 0

→ Need other mechanisms to explain the observed size evolution

Merger-driven size evolution models based on Naab+09; Hilz+13



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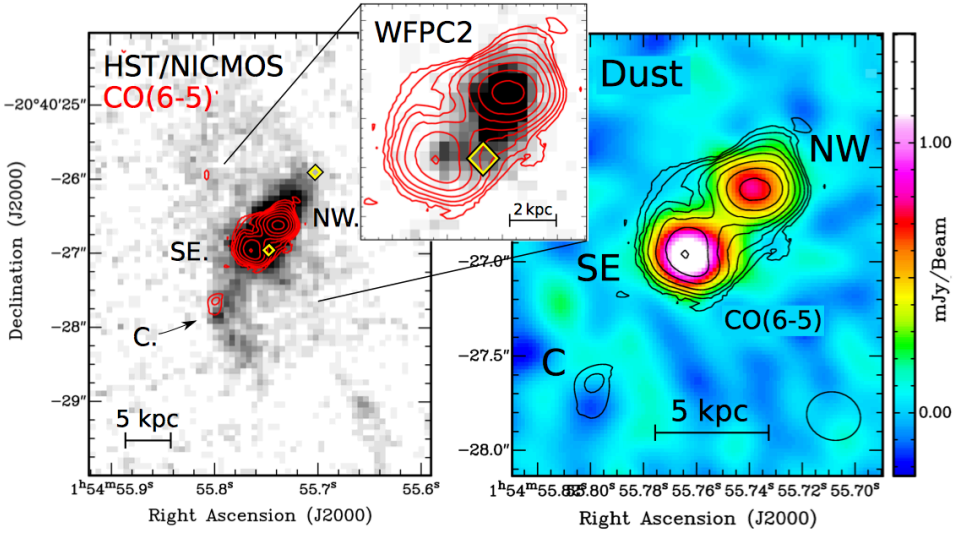
Stewart+09

Gas-rich mergers can:

↑ Merger contribution to cosmic SF budget

↓ Merger contribution to size evolution of quiescent galaxies (dissipation → more compact merger remnant)

ALMA can find the missing mergers



Dragonfly Galaxy: z~2 merger of massive galaxy (Emonts+15)

- CO (6-5) kinematics inconsistent with a single rotating structure
- Tidal debris on larger scale

Conclusions

- Discrepant merger fraction at z~2 across NIR observations: due to merger definition
  - Stellar mass ratio can find gas-poor mergers, but missing some gas-rich mergers at z>2
  - Observed *H*-band flux ratio can find some gas-rich mergers at z>2, but problematic tracer for mass
- Need molecular gas mass measurement for a complete understanding of merger role in galaxy evolution
  - Size growth
  - Stellar mass growth
  - Fueling SF & AGN