The Stellar Mass of Submillimeter-Selected Galaxies and Constraints On Their Evolution

Laura Hainline

University of Maryland

In Collaboration With: Andrew Blain(Caltech), Ian Smail (Durham), Rob Ivison (Edinburgh), Scott Chapman (Cambridge), Mark Swinbank (Durham)

Galaxy Masses 2009

19 June 2009

Puzzle: Old Stars in Massive Galaxies

Observations challenge predictions of CDM galaxy formation scenarios:

- Most massive galaxies: Little to no SF activity since $z \sim 1$ (e.g., Fontana et al. 2004; Cimatti et al. 2006; Pérez-González et al. 2008)

- High-z: Massive, red galaxies at $z \sim 1$-2 indicate massive galaxies formed early in Universe (e.g., Franx et al. 2003)

  ⇒ "Red and Dead" galaxies: massive, passive galaxies already at $z \sim 1$-2? (e.g., Cimatti et al 2004)

How/When did these galaxies form?

One way to get a massive, passive galaxy at $z \sim 1.5$:
Massive $z \sim 2$ starburst!

SMGs: Massive Spheroids in Formation?

Dusty, luminous galaxies found by SCUBA seem consistent with quick formation of massive galaxies at high z:

- $L_{FIR} > 10^{12}\ L_{\odot}$ requires high SFR ($\sim 10^3\ M_{\odot}$/yr) (or efficient accretion onto an active nucleus)
- Molecular gas-rich = plenty of fuel for SF (e.g., Greve et al. 2005)
- Suggested as the (monolithic?) formation epoch of the (most) massive spheroids/ellipticals (e.g., Lilly et al. 1999)

Key Questions:

(1) What is the stellar mass of SMGs at $z \sim 2$? (see also Borys et al. 2005, Dye et al. 2008)

(2) How much stellar mass is assembled in the ultraluminous SB phase?

(3) How do SMGs fit in with the zoo of high-z galaxies we observe?

New Constraints on SMG Mass

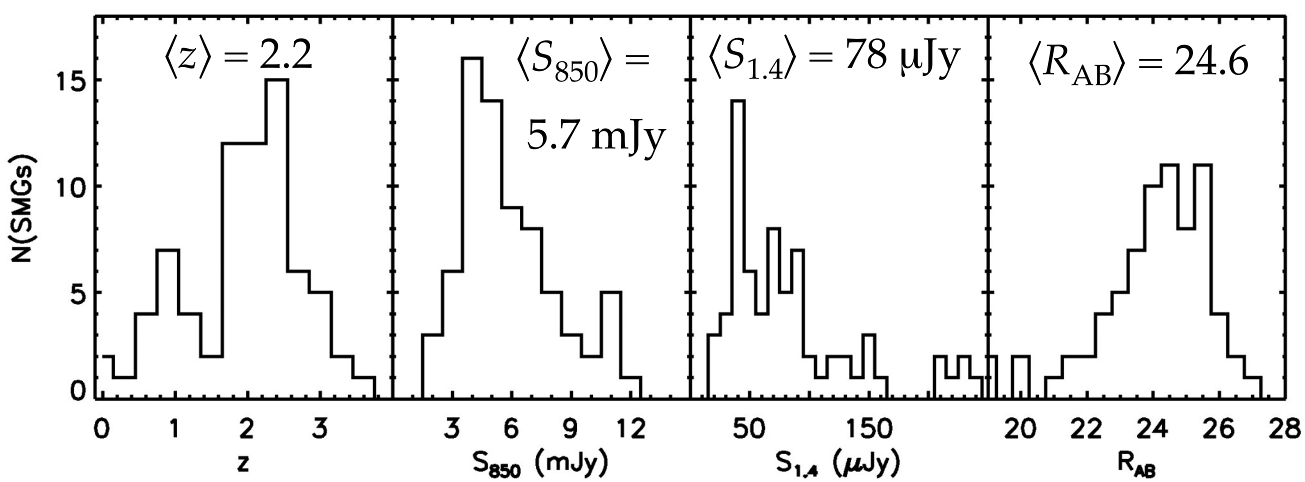
$M_\star$ from Optical-IRAC imaging of Chapman (2005) Sample

Most representative sample of SMGs with spectroscopic redshifts:

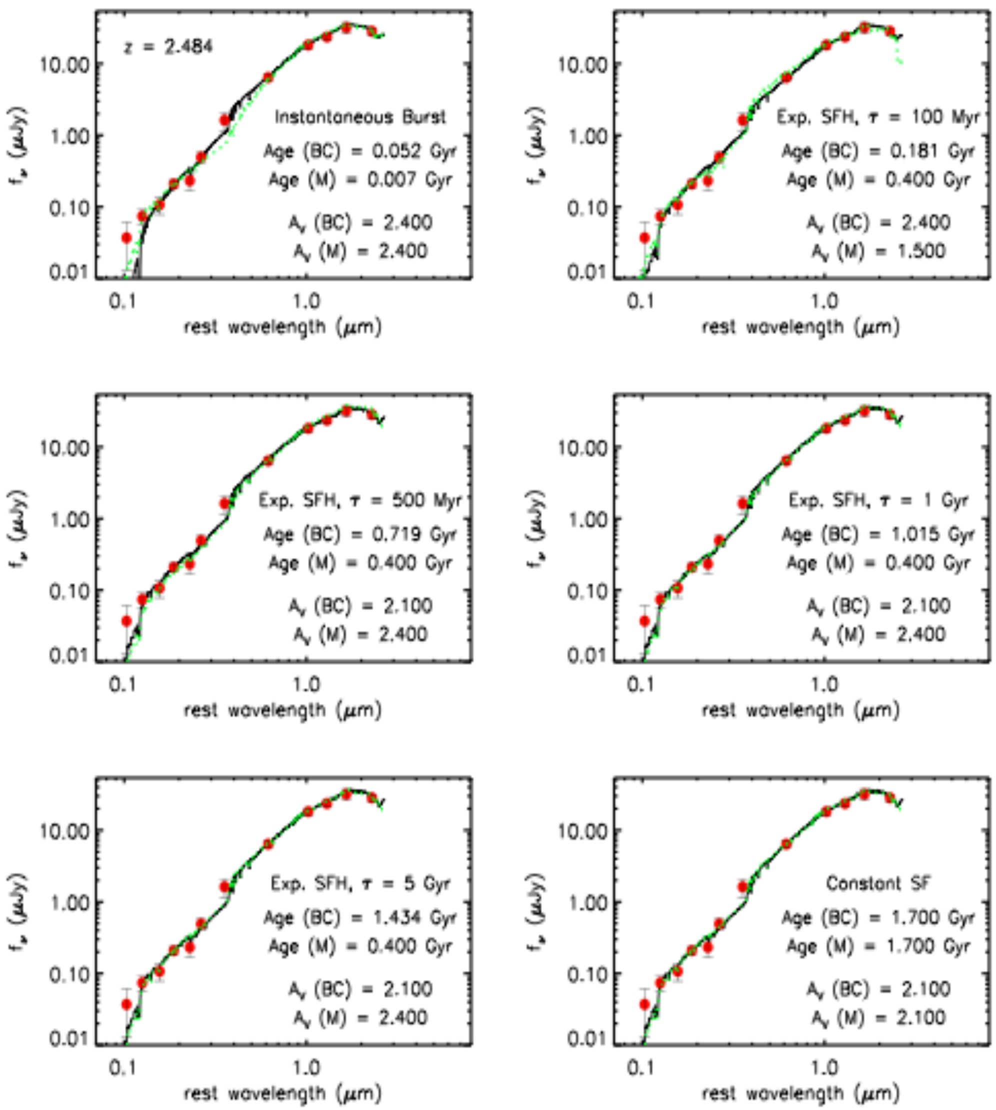
- 71 SMGs in 7 fields
- None are strongly lensed
- Radio detections used to obtain positions for optical spectroscopy
- 7 redshifts revised (within 20%) with mid-IR spectra

To derive $M_\star$:

- Fit Bruzual & Charlot (2003) and Maraston (2005) stellar pop models; use rest-frame H and M/L_H for $M_\star$
- Chabrier/Kroupa IMFs, $Z_\odot$, Calzetti (2000) extinction law
- Fit CSF, instantaneous burst, exponentially-declining SFHs



Constraining Star Formation History



Problem: All SFHs fit similarly well, but with very different ages!

∴ Cannot constrain ages and SFH.

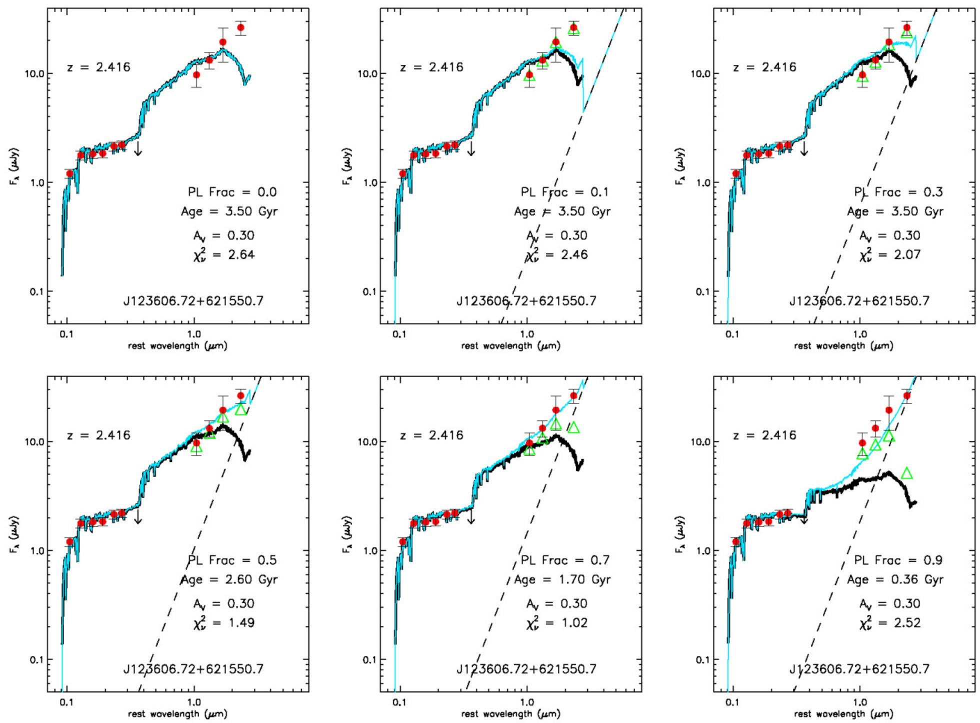
Solutions:

(Note: $L_H/M_\star$ variation small between SFHs for Age>100 Myr [factor of 2])

1. Use a single $M_\star/L_H$ value ($M_\star/L_H$ @ average sample age)
2. Average $M_\star$ from Instantaneous Burst and CSF models

AGN Contribution in Near-IR?

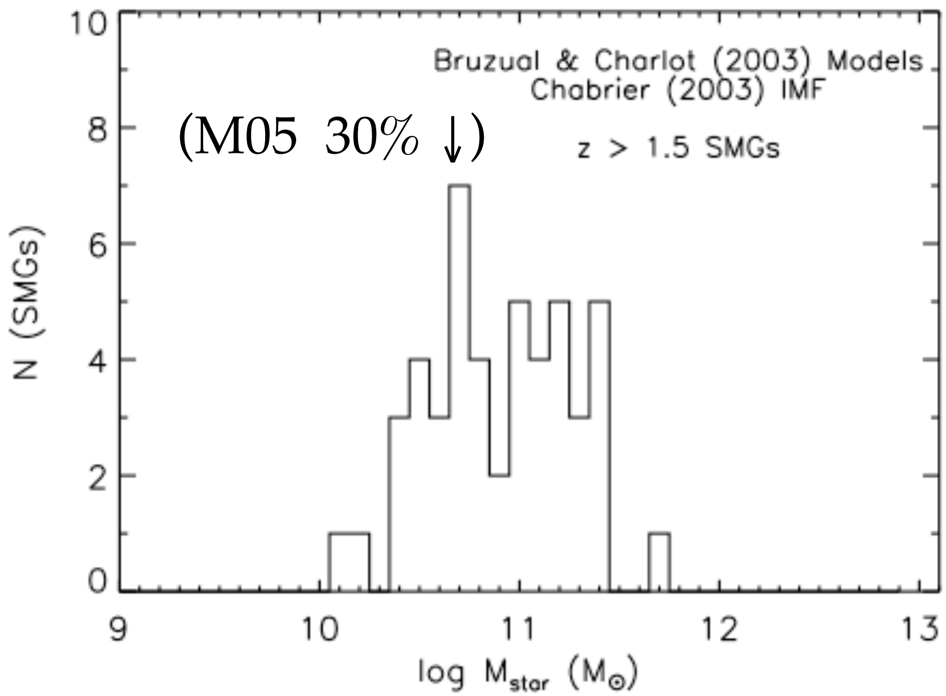
~20% of sample: SED shows red upturn

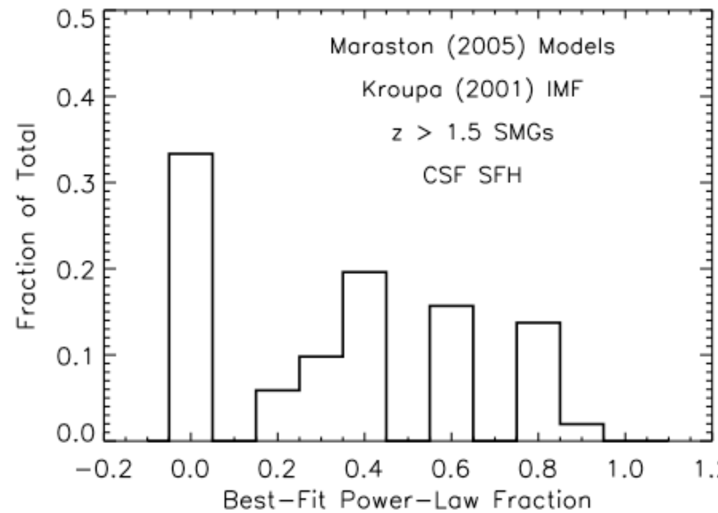


Removal process:

- Scale ν^{-2} / ν^{-3} PL to 8μm data point = "maximal" AGN contribution
- Iteratively subtract from photometry various % of maximal
- Fit stellar pop models to AGN- subtracted data
- Take best fit AGN fraction and PL index (gives luminosity of stars only)

Stellar Masses of SMGs from SED Fits





$\langle \text{AGN fraction} \rangle = 0.4$

For $z > 1.5$ SMGs:

$\langle M_\star \rangle = 9.0 \times 10^{10}\ M_\odot$ (BC03)

$\langle M_\star \rangle = 7.2 \times 10^{10}\ M_\odot$ (M05)

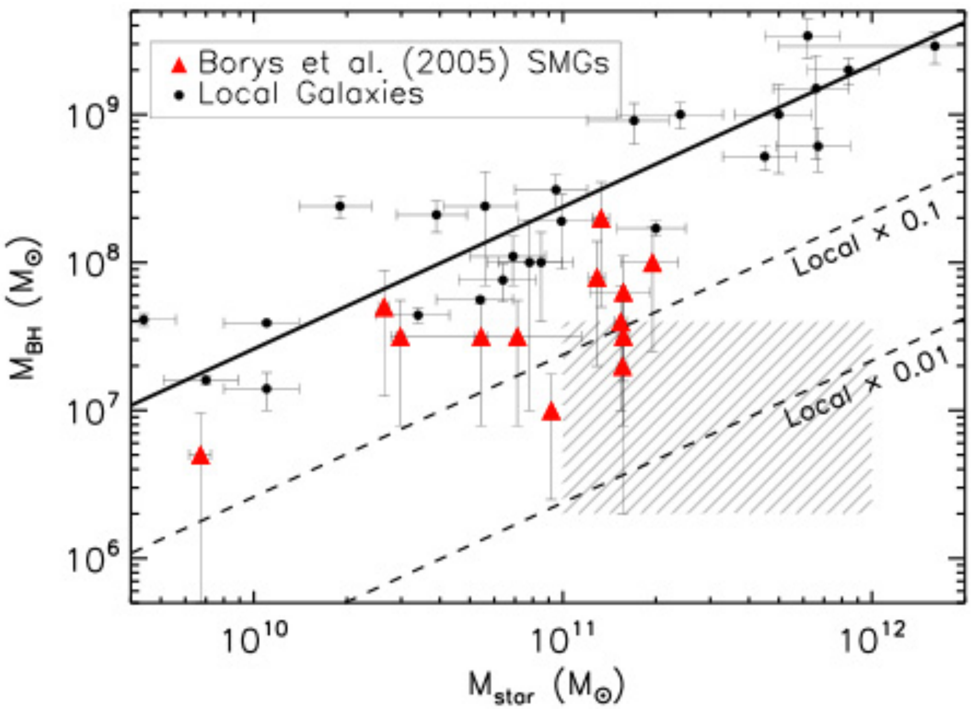
Note: For L^*, $M_\star \sim 1.4 \times 10^{11}\ M_\odot$

$M_\star$ subject to uncertainties in:

- Metallicity (BC03: $Z\uparrow \Rightarrow M_\star\uparrow$)
- IMF (Salpeter $\Rightarrow M_\star$ higher by ×2)
- Contribution from AGN ($M_\star \downarrow$)
- PL Removal Procedure (Ages ↓; $M_\star \downarrow$)
- Extinction (?)

Implications for M_{BH} - $M_\star$ Relation for SMGs

New $M_\star$ estimates lower than Borys et al. (2005) by ×3

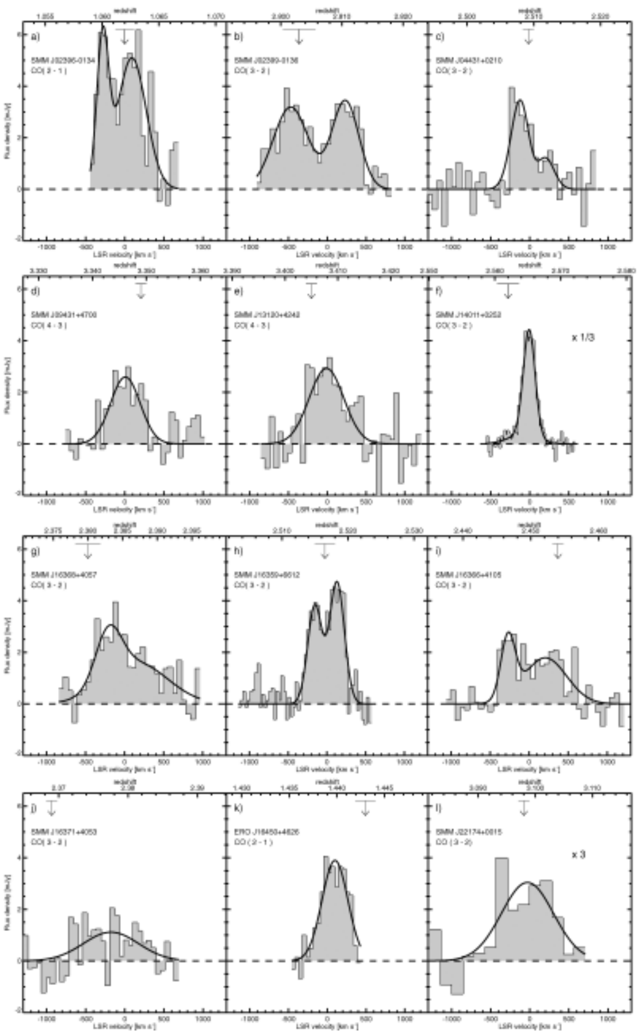


With new M_{BH}, $M_\star$ ⇒ SMGs closer to local relation (now ~ 5-10x below)

Note:

- AGN contamination of L_K not negligible
- Need independent checks on mass estimates

Independent Mass Estimates for SMGs



CO line profiles for SMGs from Greve et al. (2005)

SMGs unusual at high-z: can constrain M_{gas}, M_{dyn}, and $M_{\star}$ independently:

- Near-IR M_{dyn} from IFU: $M_{dyn} \sim 5.0 \times 10^{11}\ M_{\odot}$ (Swinbank et al. 2004, 2006)
- CO $J > 3$ observations (e.g., Greve et al. 2005; Tacconi et al. 2006, 2008):

$$M(H_2) = (3.0 \pm 1.6) \times 10^{10}\ M_{\odot}$$

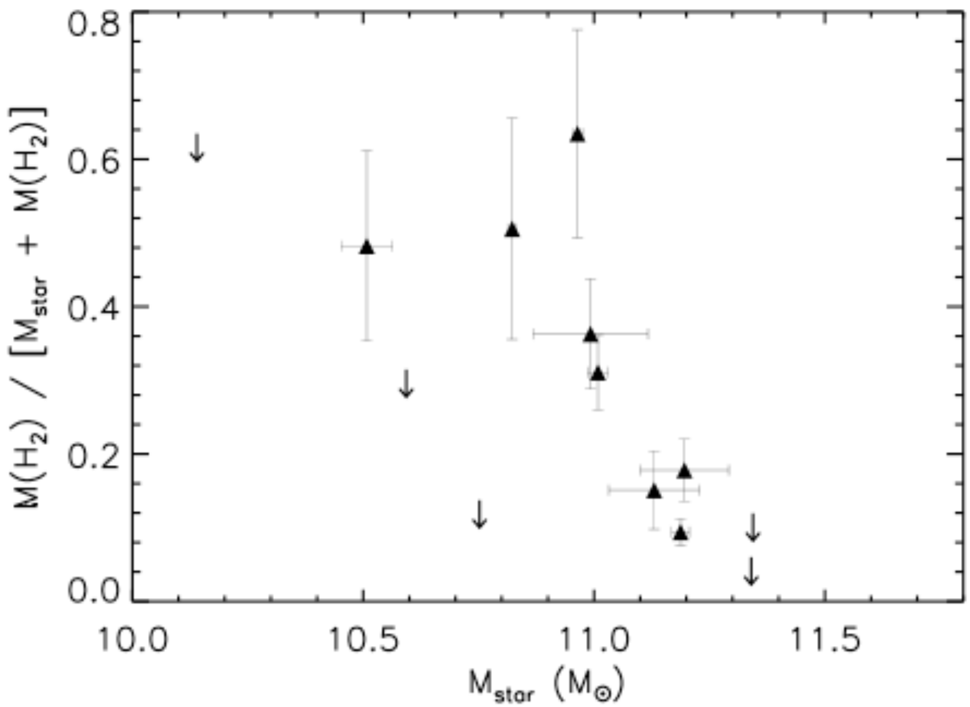
$$M_{dyn} > 1.2 \times 10^{11}\ M_{\odot}$$

If $\langle M(H_2) \rangle$ and $\langle M_{dyn} \rangle$ representative:

$$M_{gas} + M_{\star} \leq M_{dyn}\ \&$$

$$M_{baryon} \sim 1.0 - 1.3 \times 10^{11}\ M_{\odot}$$

Combining $M_\star$ & $M(H_2)$: Clues to Evolution



Compute gas fraction μ for 13 SMGs in sample with CO observations:

- μ(SMG) higher than local spirals, E's, ULIRGs (typical μ ~ 0.1, 10^{-4}, 0.16)
- μ declines as $M_\star$ increases ⇒ evolution?
- μ ⇒ $M_\star$(SMG) will not increase by more than ×2 in future

The Past and the Future of SF for SMGs

How much of $M_\star$ is formed in submm phase?

Avg time to form $M_\star$ at current SFR = 200 Myr (assume L_{IR} has 30% AGN) ⟷ SMG phase ~ 50-200 Myr (e.g., Smail et al. 2004, Greve et al. 2005, Tacconi et al. 2006/8)

$\Downarrow$

Significant fraction of $M_\star$ formed prior to submm phase.
(Not consistent with monolithic collapse)

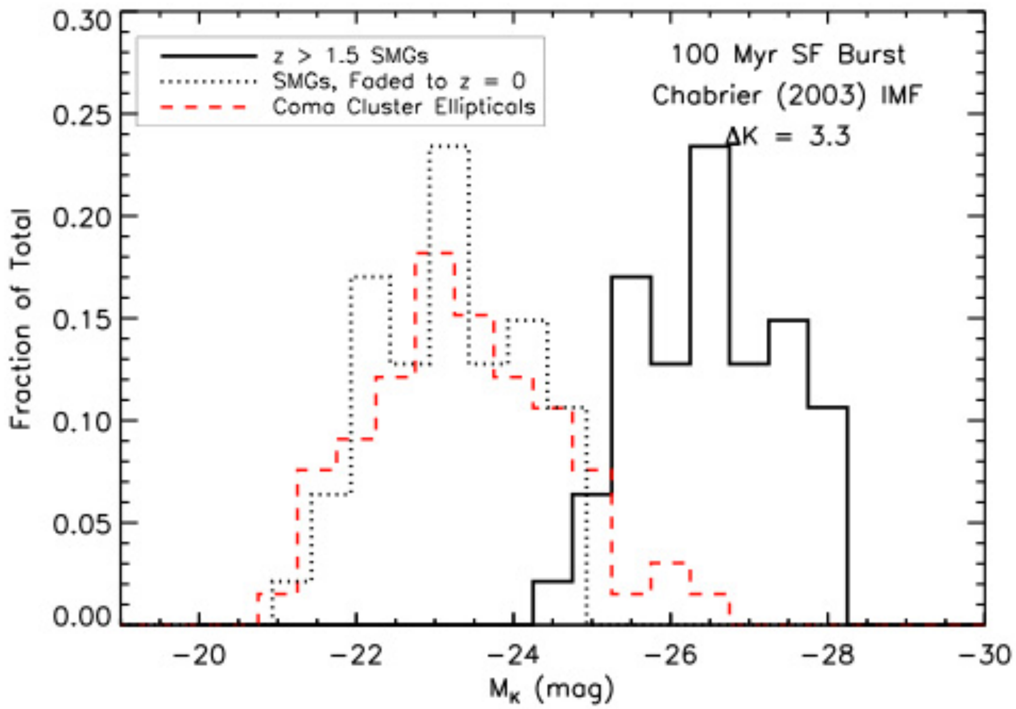
Will SMGs be giant ellipticals?

$M_\star$(gE) ~ $10^{12}\ M_\odot$ ⟷ M_{baryon}(SMG) ~ $10^{11}\ M_\odot$

$\Downarrow$

Not without future merger events…instead ~ L^* ellipticals

Descendants: Comparison to M_K for Local Ellipticals



Courtesy STSCI

- M_K(Faded SMGs) ~ M_K(E) in Coma Cluster *including* L^*
- 100 Myr Burst duration ⇒ space density of descendants ~ 4×10^{-4} Mpc^{-3}
- But ρ not high enough to account for all L^* ellipticals today!

- Use stellar M_K only for $z > 1.5$ SMGs
- Fade SMGs to 10 Gyr assuming passively-evolving BC03 model
- Model parameters: 100 Myr SF burst, obs @ 50 Myr, Chabrier IMF

SMGs not the only way to form an elliptical…

Comparison to Other High-z Galaxies: Stellar Luminosity and $M_\star$

SMGs: $\langle M_\star \rangle \sim 1 \times 10^{11}\, M_\odot$ & $\langle M_H \rangle \sim -26.0$

- LBGs and BX/BM: $\langle M_\star \rangle = 1 \times 10^{10}\, M_\odot$ & $\langle M_H \rangle = -23.7$
- HzRGs: $\langle M_\star \rangle = 2 \times 10^{11}\, M_\odot$ & $\langle M_H \rangle = -25.7$ (Seymour et al. 2007)
- DRGs: $M_\star \sim 1 \times 10^{11}\, M_\odot$ (e.g., Papovich et al. 2006) & $M_H \sim -24$

Options:

(1) SMGs/DRGs/HzRGs are all ~ equal mass (different stages/SFH/environment)

(2) Systematic effects ⇒ misleading results? (ages, SFH, stellar population models)

Time for a comprehensive, consistent study of stellar mass across high-z galaxy populations?

Conclusions

- Average $z \sim 2$ SMG has $M_\star = 0.7 - 1 \times 10^{11}\ M_\odot$
- Average SMG contains enough baryonic mass to form L^* elliptical
- Passively-evolved SMGs consistent with Coma ellipticals
- Significant fraction of SMG mass formed prior to SB phase
- AGN contribution not negligible for SMGs
- Gas fraction in SMGs declines with increasing stellar mass