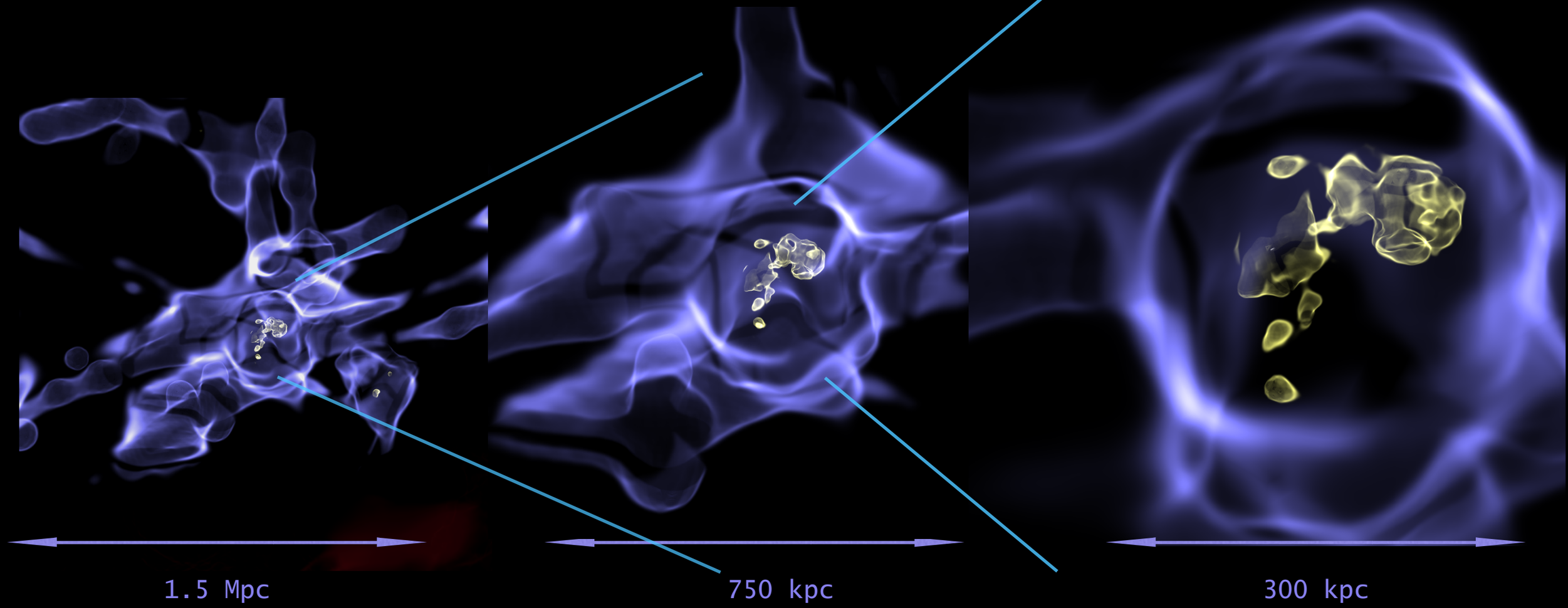
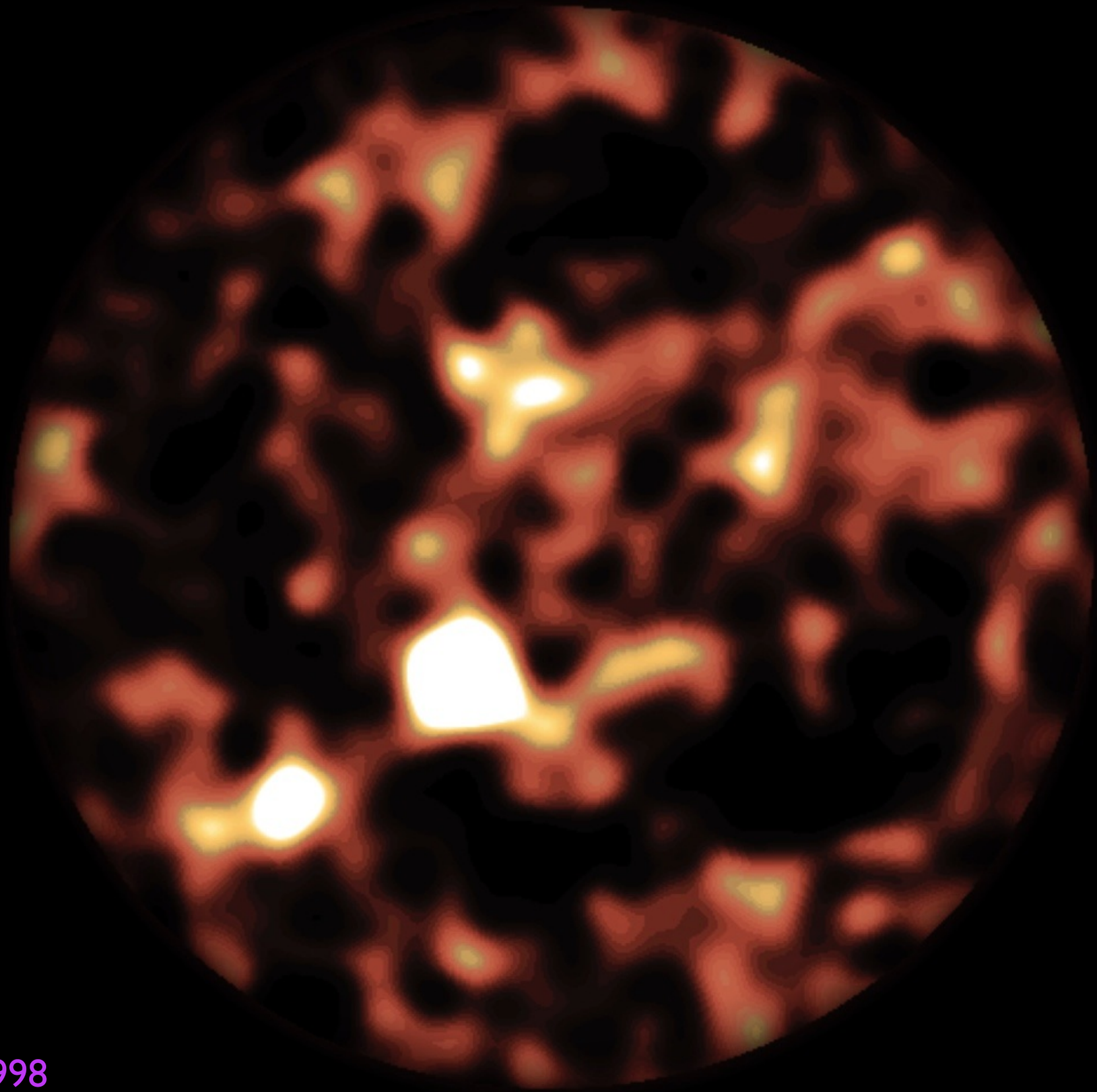
Forming the Brightest Galaxies in the Universe

Desika Narayanan
Haverford College



With Matt Turk, Mark Krumholz, Phil Hopkins

Lee Rosenthal: 143.47 (Monday)
David Ball: 251.14 (Tuesday)

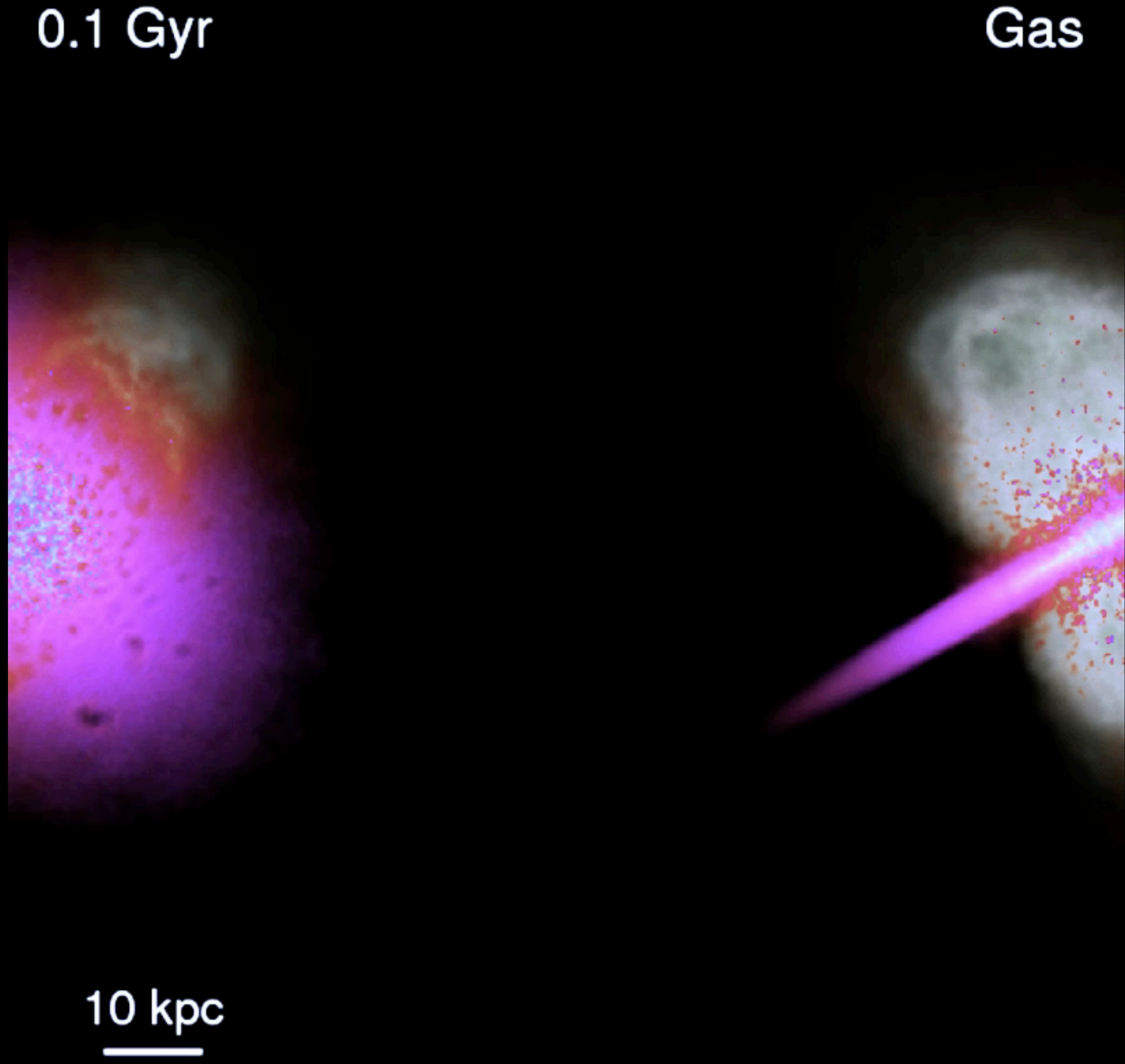


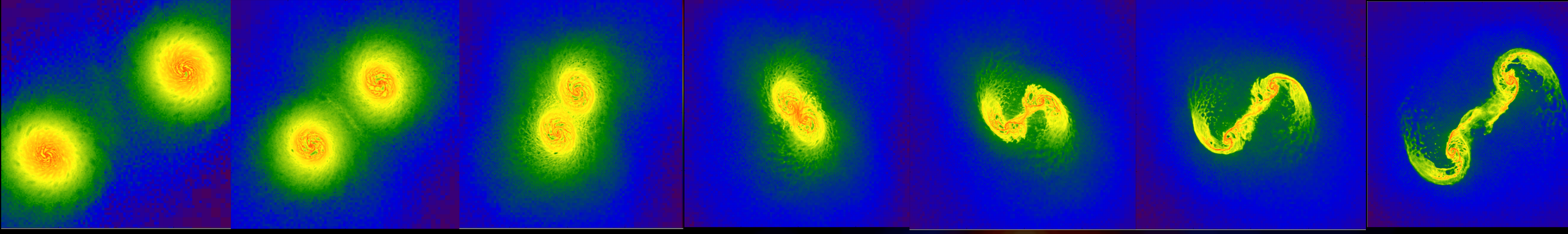
Barger et al. 1998
Hughes et al. 1998

the freakish nature of submillimeter galaxies

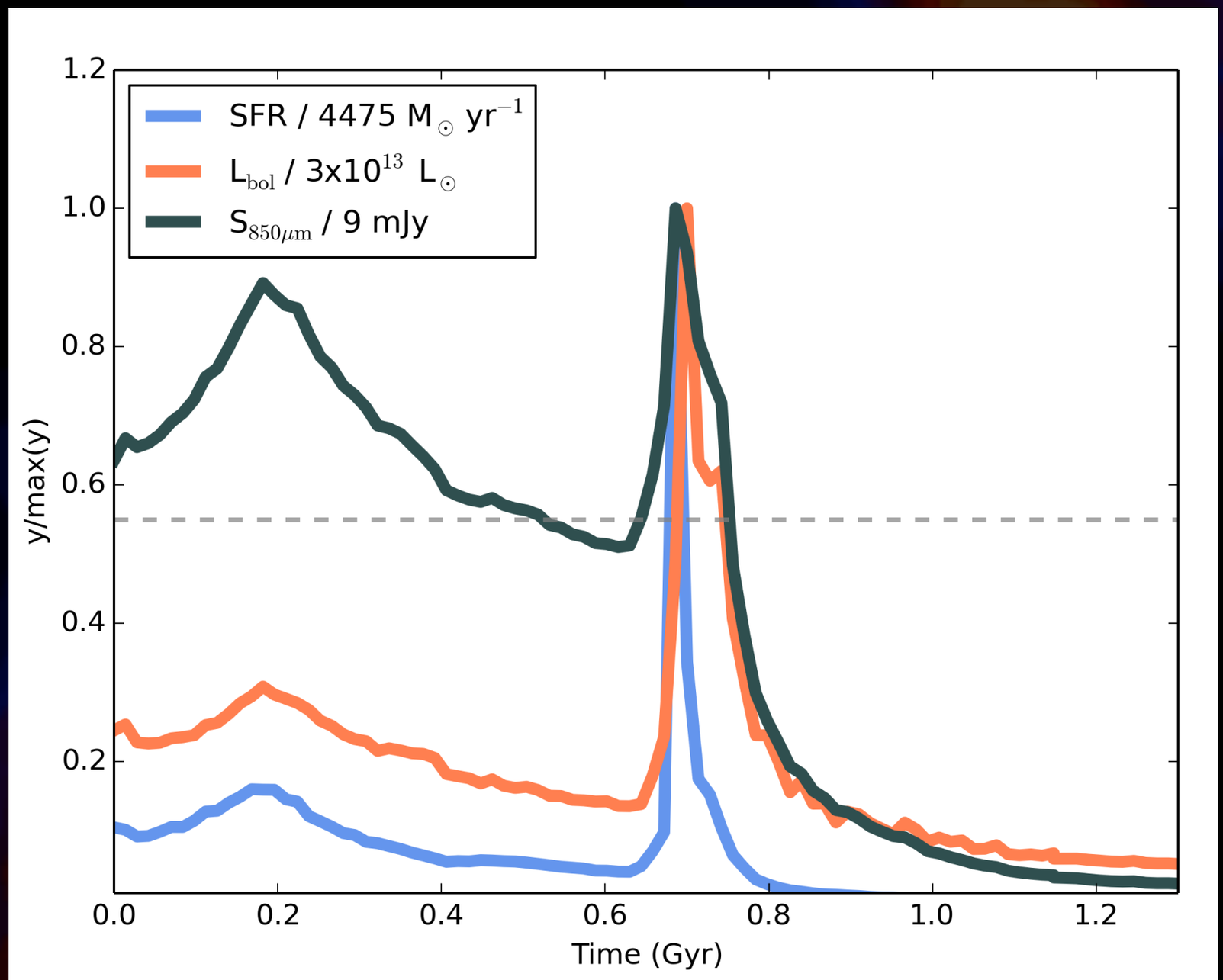
	submillimeter galaxies (SMGs)	the milky way
L	10	2x10
M	10	3x10
SFR	>1000 M	2-3 M
M	few x 10	10

SMGs: Major Mergers at High-Redshift?





The Evolution of a Galaxy Merger



Narayanan, Hayward et al. (2010)
Narayanan, Dey et al. (2010)
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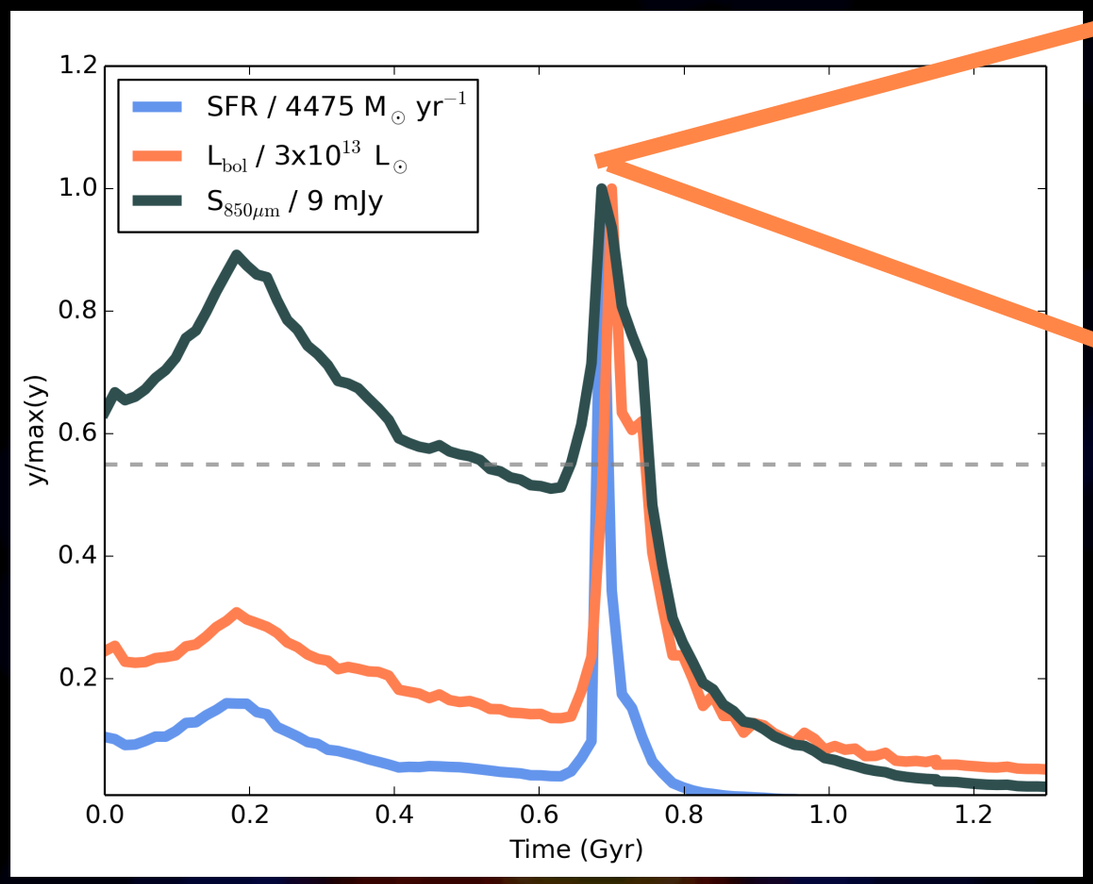

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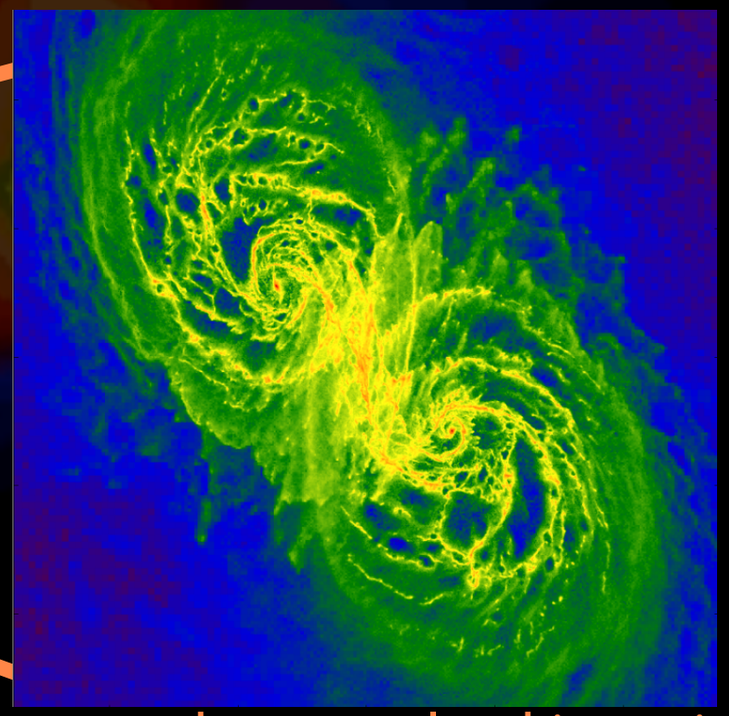
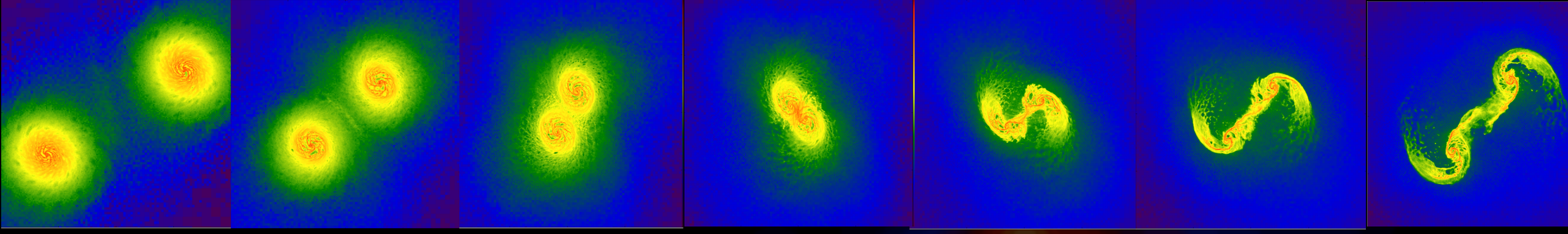


Galactic Pressure destroys cloud integrity, and results in ~uniform volume filling factor (huge columns of obscuration)



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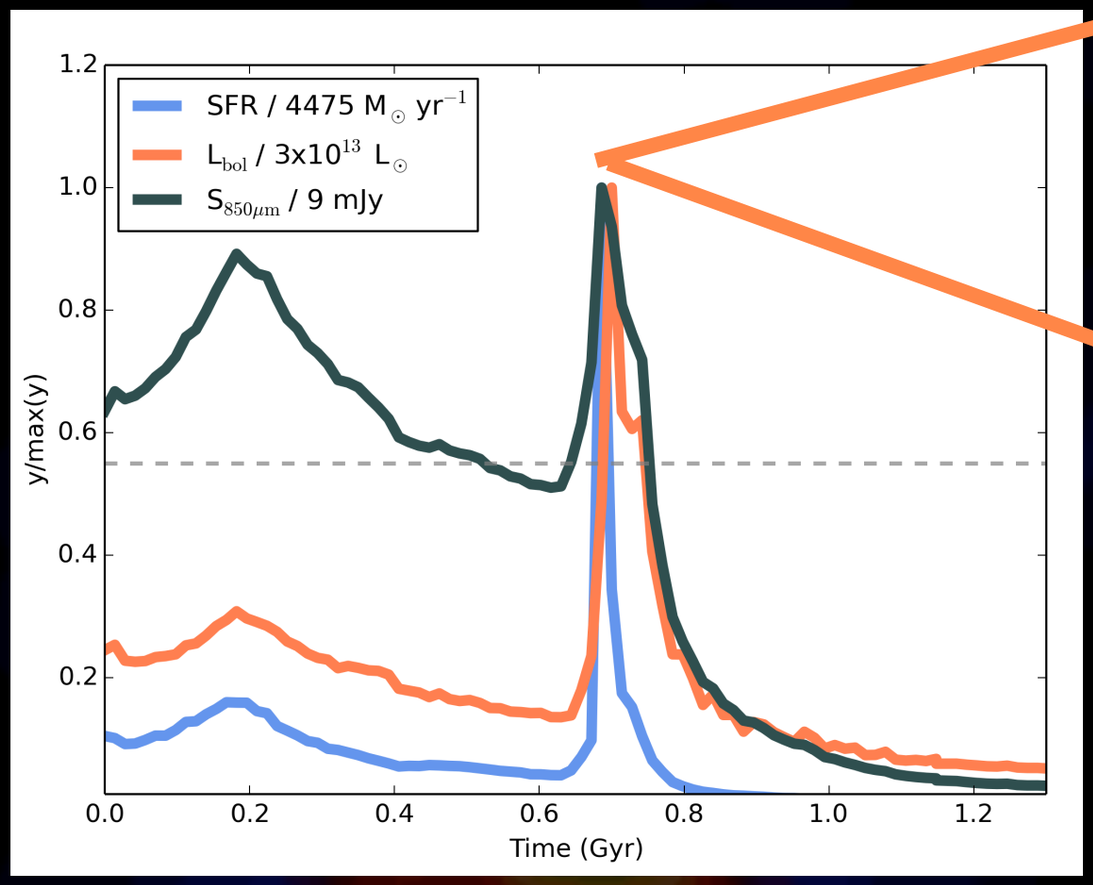

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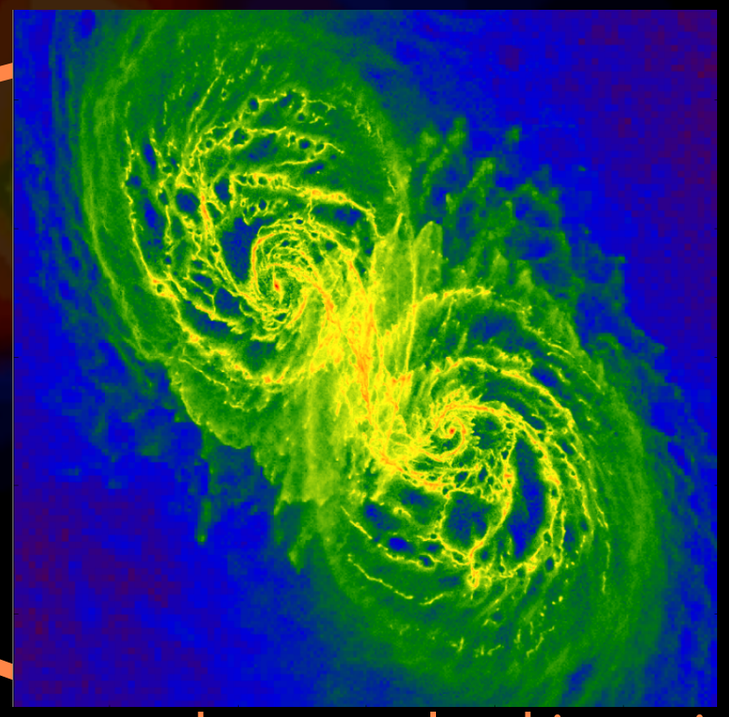
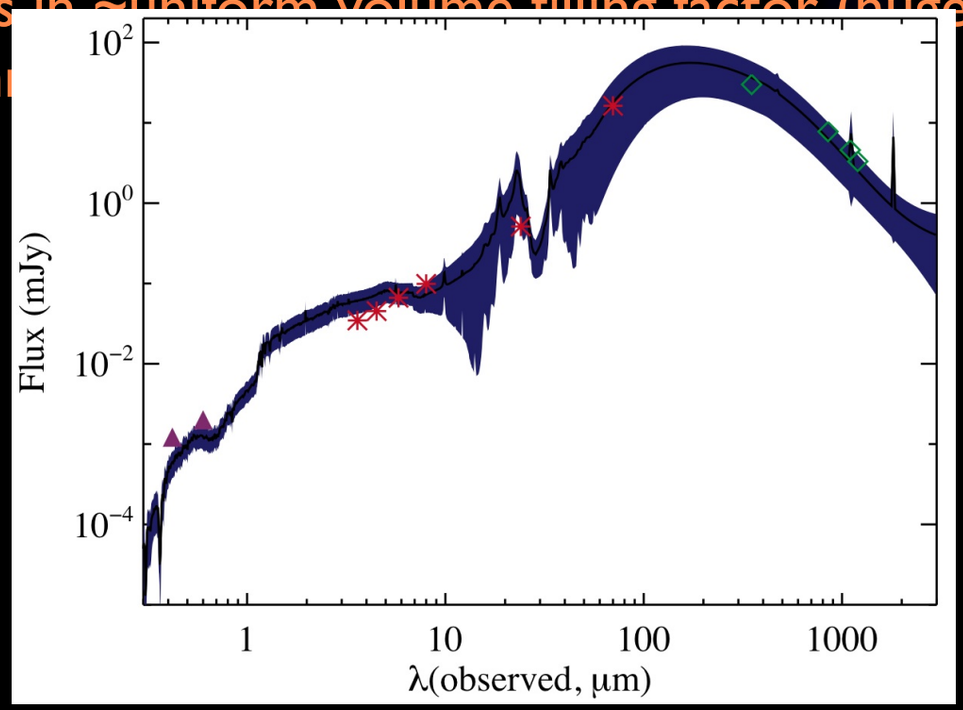


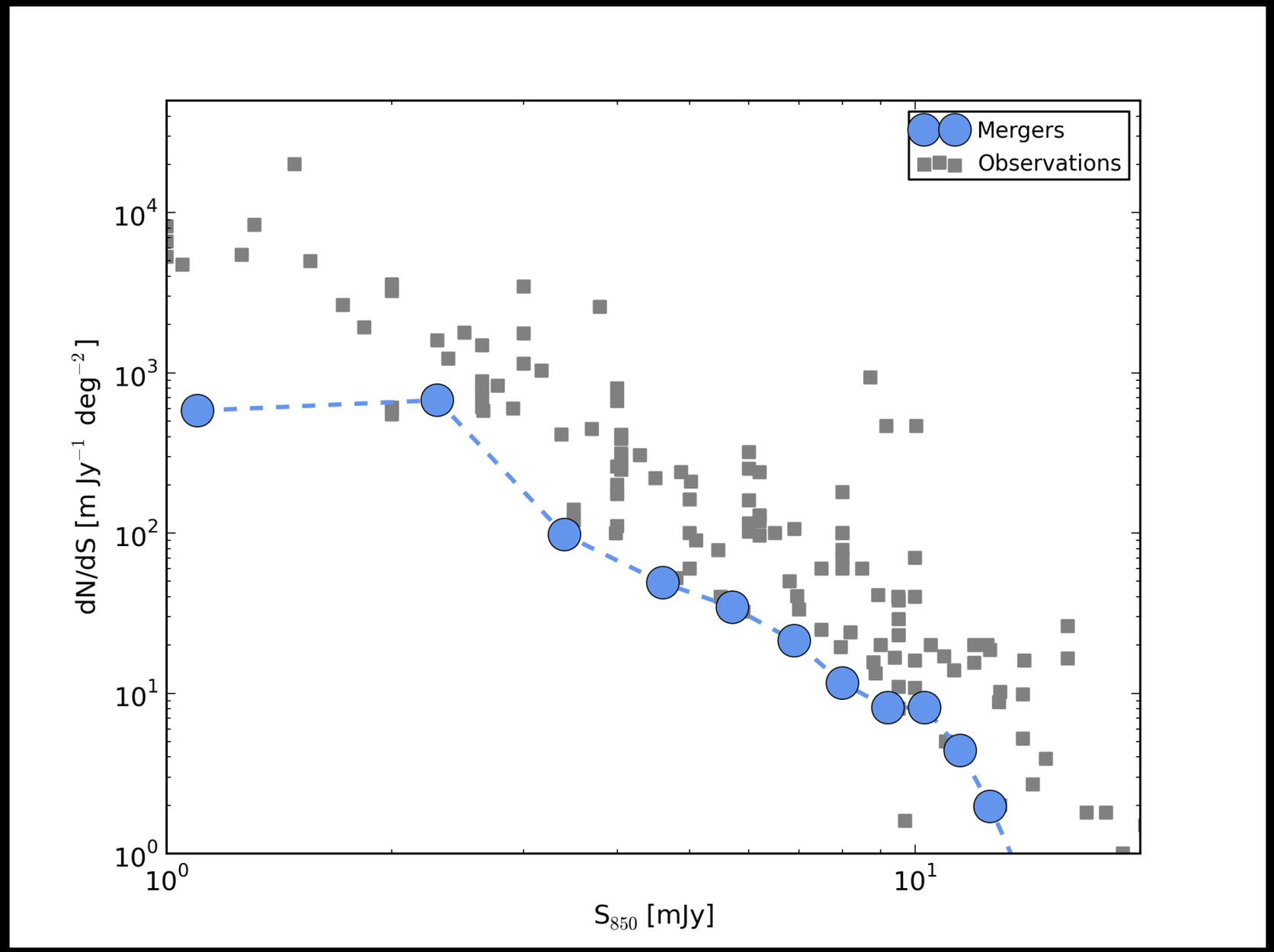
Galactic Pressure destroys cloud integrity, and results in ~uniform volume filling factor (huge column



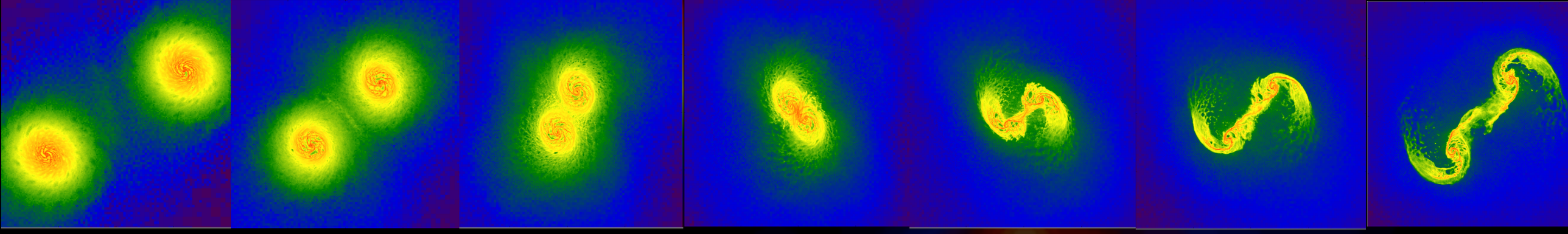
A thought experiment on SMGs: are they major mergers?

M_{halo} ~ 5x10^{12}-10^{13} $M_\odot$
M_* ~ 1-5x10^{11} $M_\odot$

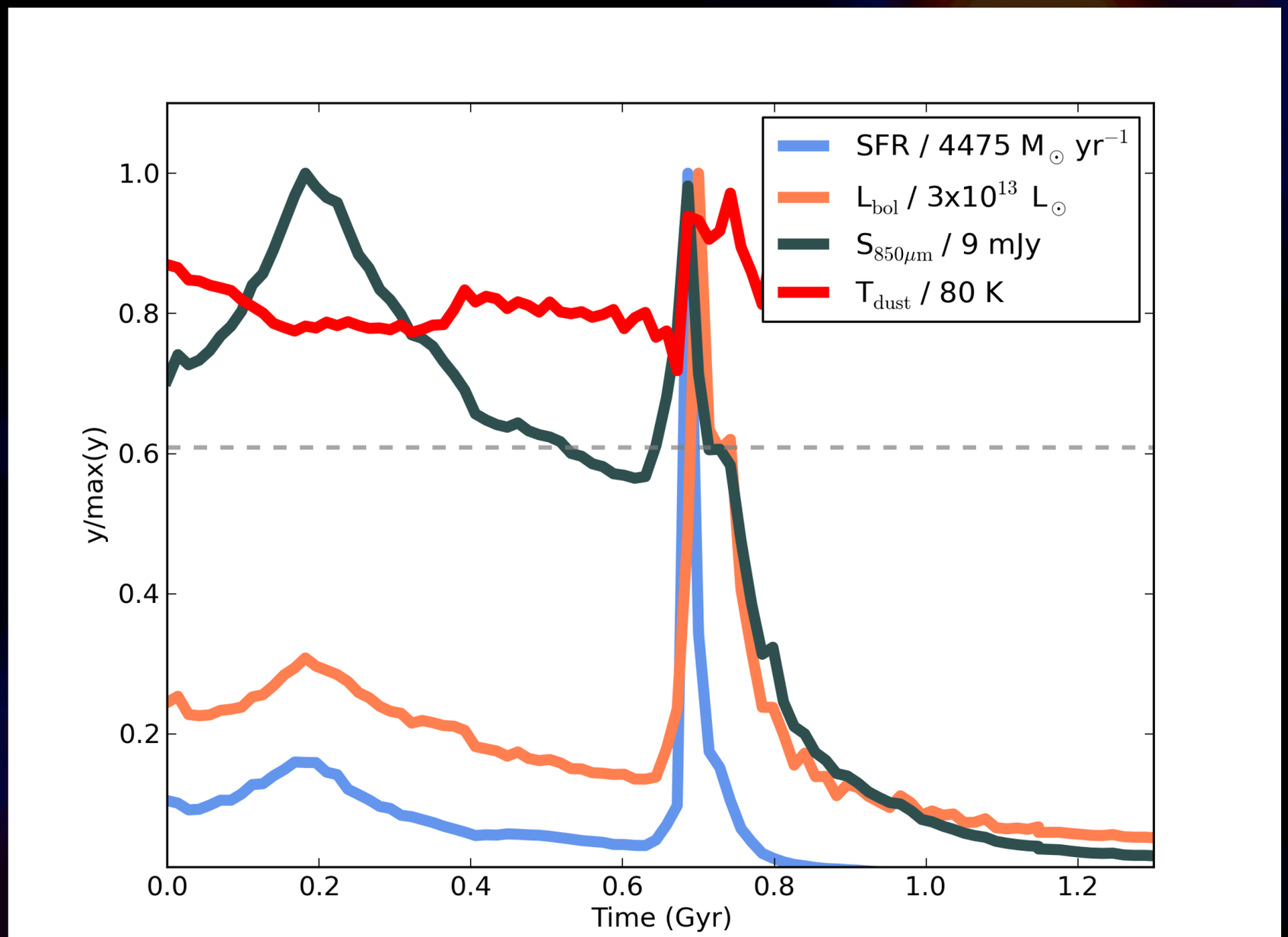
Merger rate ~1 per T_H at z~2
Space Density ~ 5x10^{-5} Mpc^{-3}
SFR_{burst}-M_{gal} relation
S_{850} ~ $SFR^{0.4}$



Hayward, Narayanan et al. (2013)



Starbursts are *inefficient* at forming SMGs



Narayanan, Hayward et al. (2010)
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Hayward, Keres, Jonsson, DN, Hernquist (2011)

Parsec Scale Cosmological Zoom Simulations

FIRE = Feedback in Realistic Environments

1. High Resolution (1-10 pc)
2. H1-H_2 phase tracking — KMT 2009
3. SF only in H_2: n_{thresh} > 100-1000 cm^{-3} — Shirley et al. 2003, Wu et al. 2005, Heiderman et al. 2010, Lada et al. 2010
4. Momentum Injection:

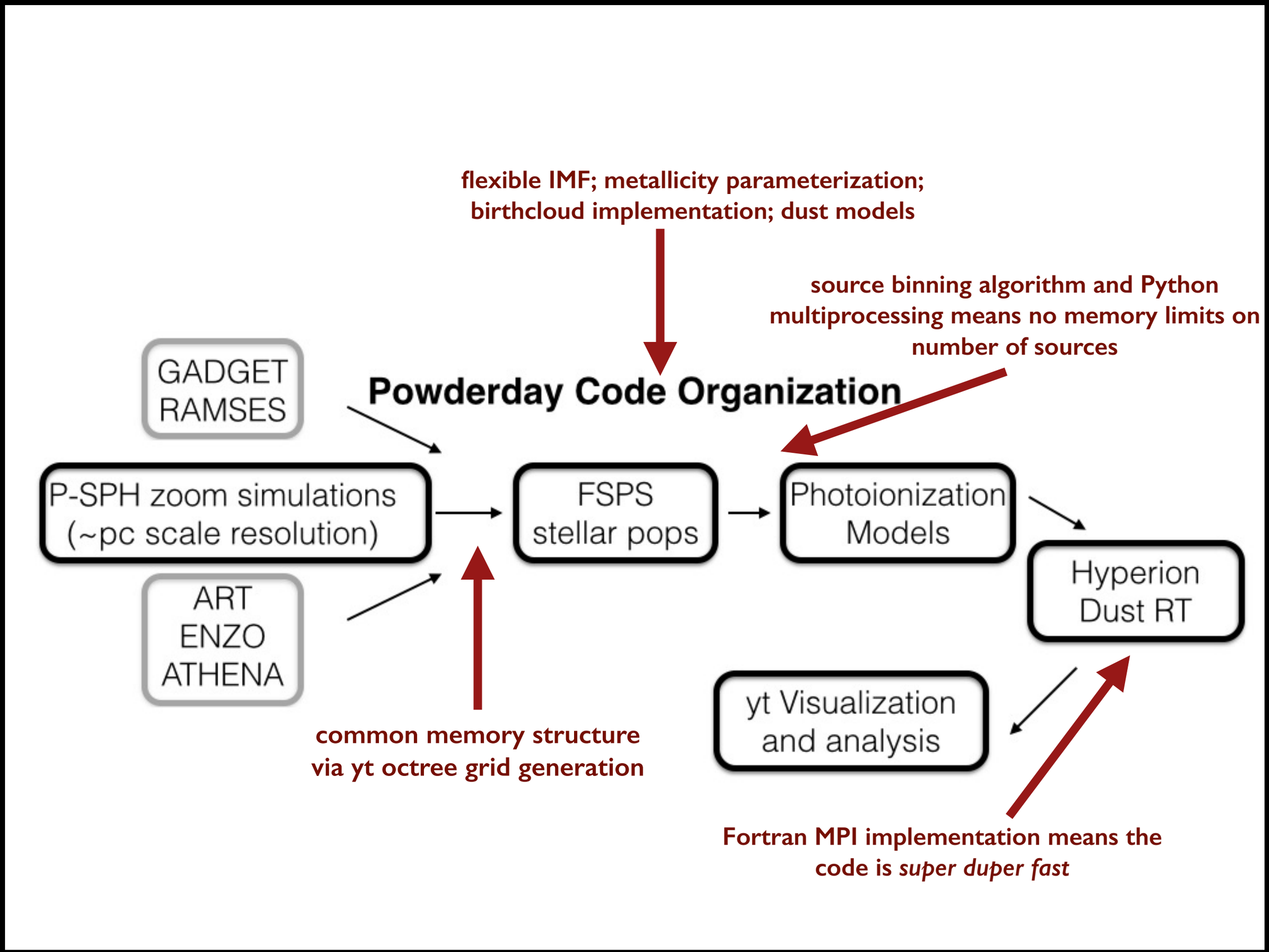
rad pressure: $$\frac{dP}{dt} \approx \frac{L}{c}(1+\tau_{IR})$$

SNe: $$\frac{dP}{dt} \approx \frac{dE_{SN}}{dt} v_{ejecta}^{-1}$$

Stellar Winds: $$\frac{dP}{dt} \approx \frac{dM}{dt} v_{wind}$$

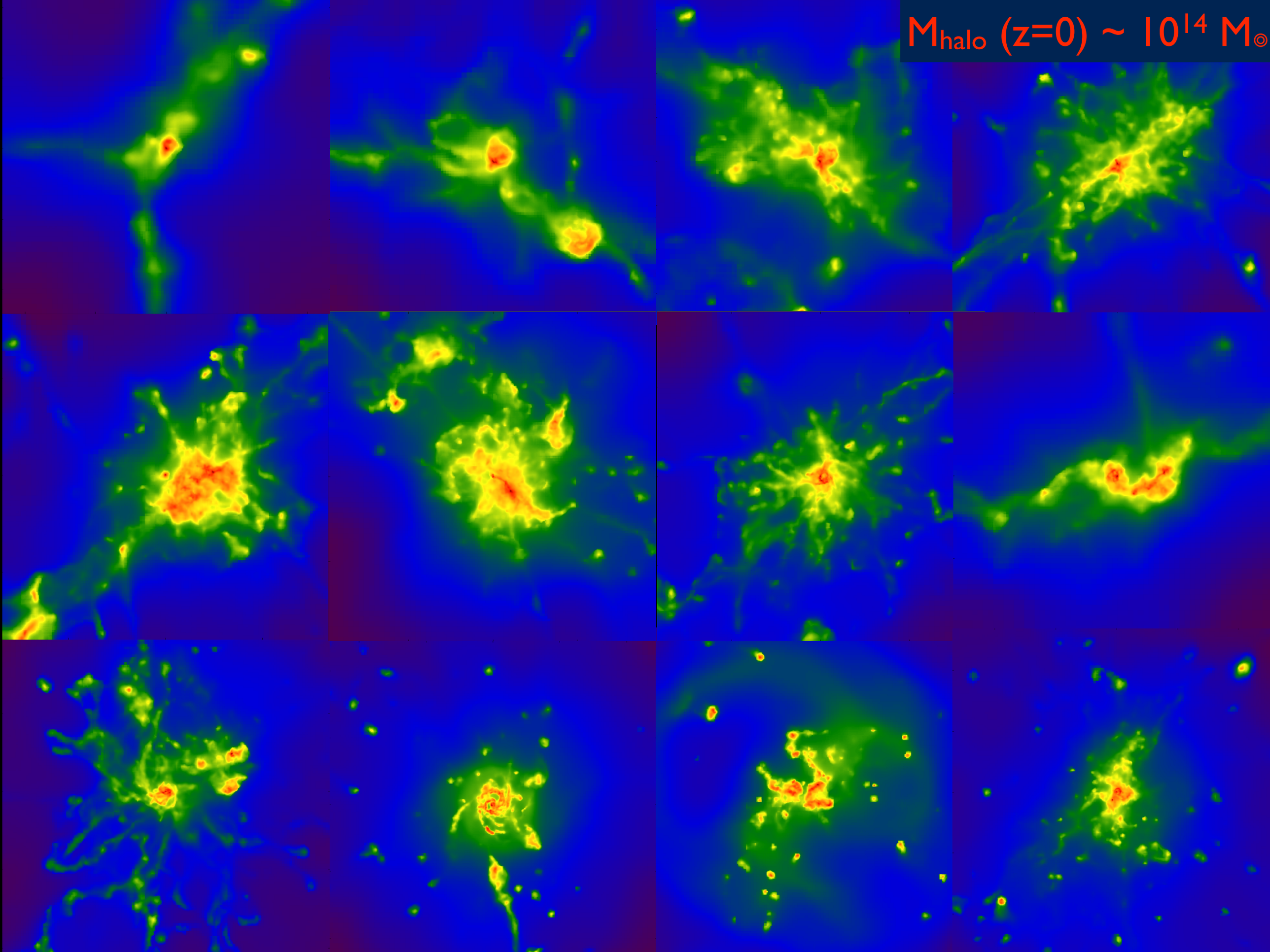
(with Phil Hopkins, Claude-Andre Faucher-Giguere, Robert Feldmann, Dusan Keres, Eliot Quataert)

Powderday: Extracting Broadband SEDs from Galaxy Sims since 2015



(with Matt Turk, Tom Robitaille & Robert Thompson)

M_{halo} (z=0) ~ 10^{14} $M_{\odot}$



M_{halo} (z=0) ~ 10^{14} $M_\odot$

z~6; SFR~50-200 $M_\odot$/yr

z~6; SFR~50-200 $M_\odot$/yr

z~3; SFR~500-1000 $M_\odot$/yr

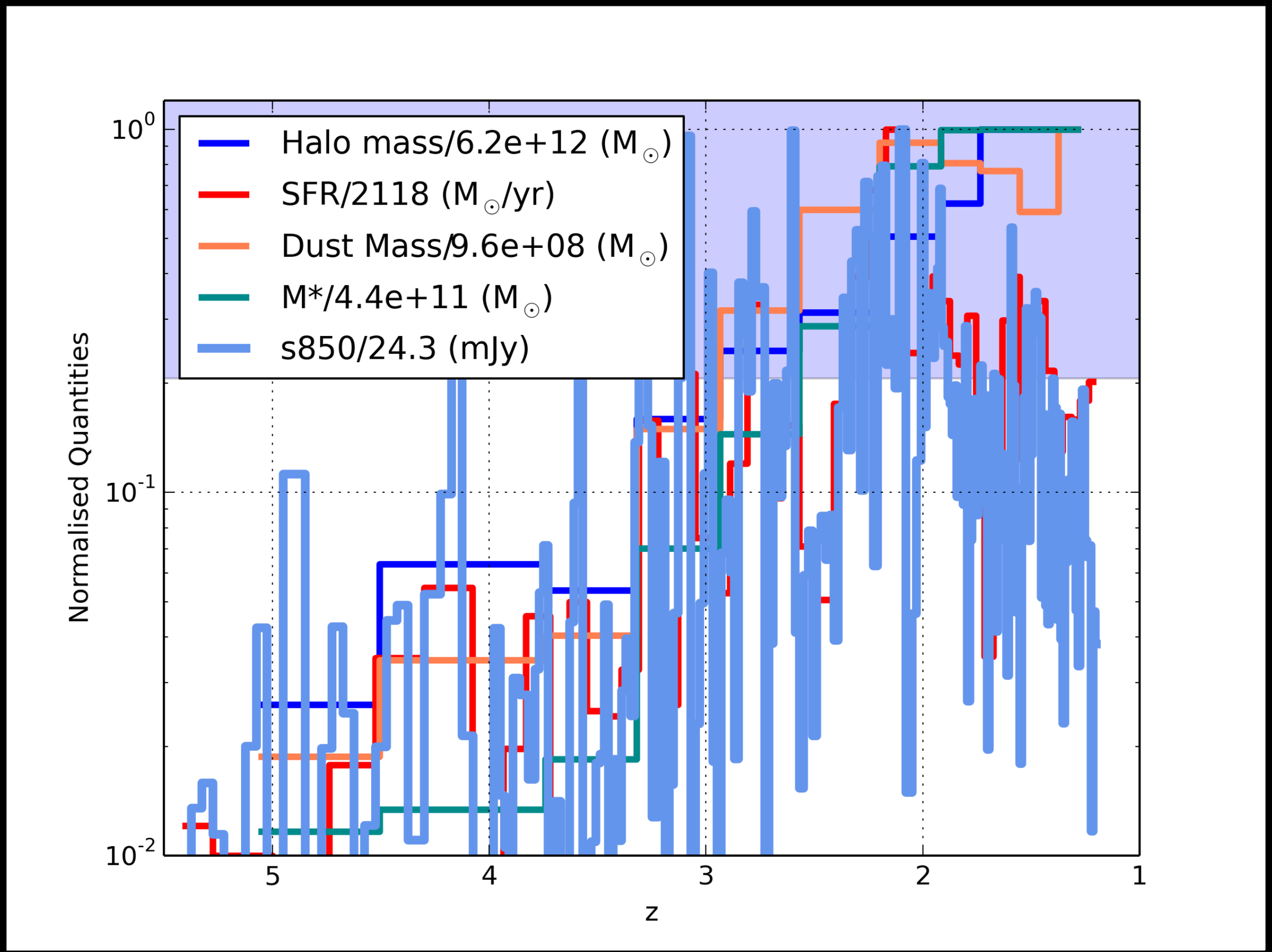
z~6; SFR~50-200 M⊙/yr

z~1.5; SFR~500 M⊙/yr

z~1-3

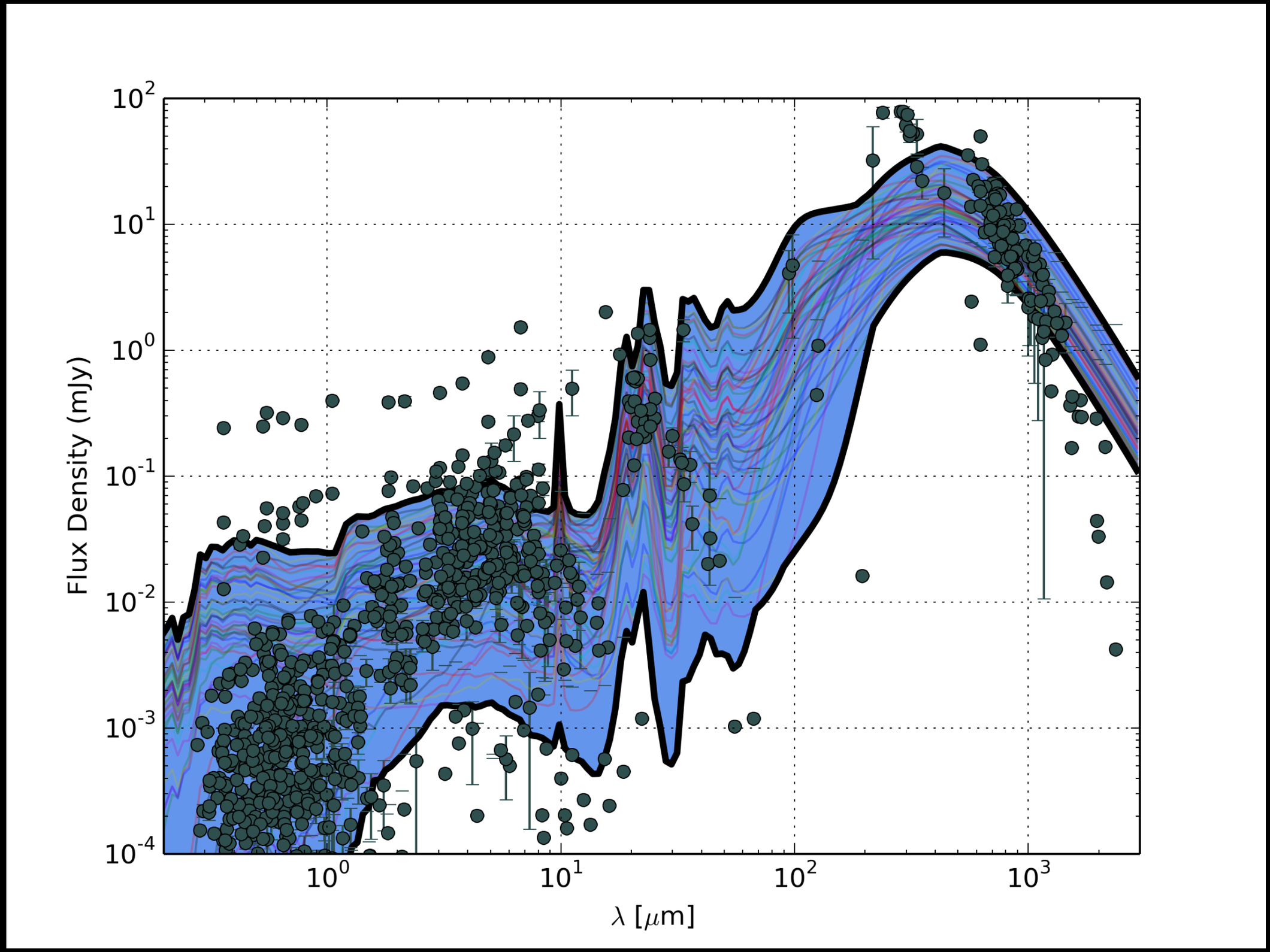
z~1.5; SFR~500 M$_\odot$/yr

Submillimeter Galaxies are Massive Galaxies in the process of assembly (rather than a short-lived, unique phase)



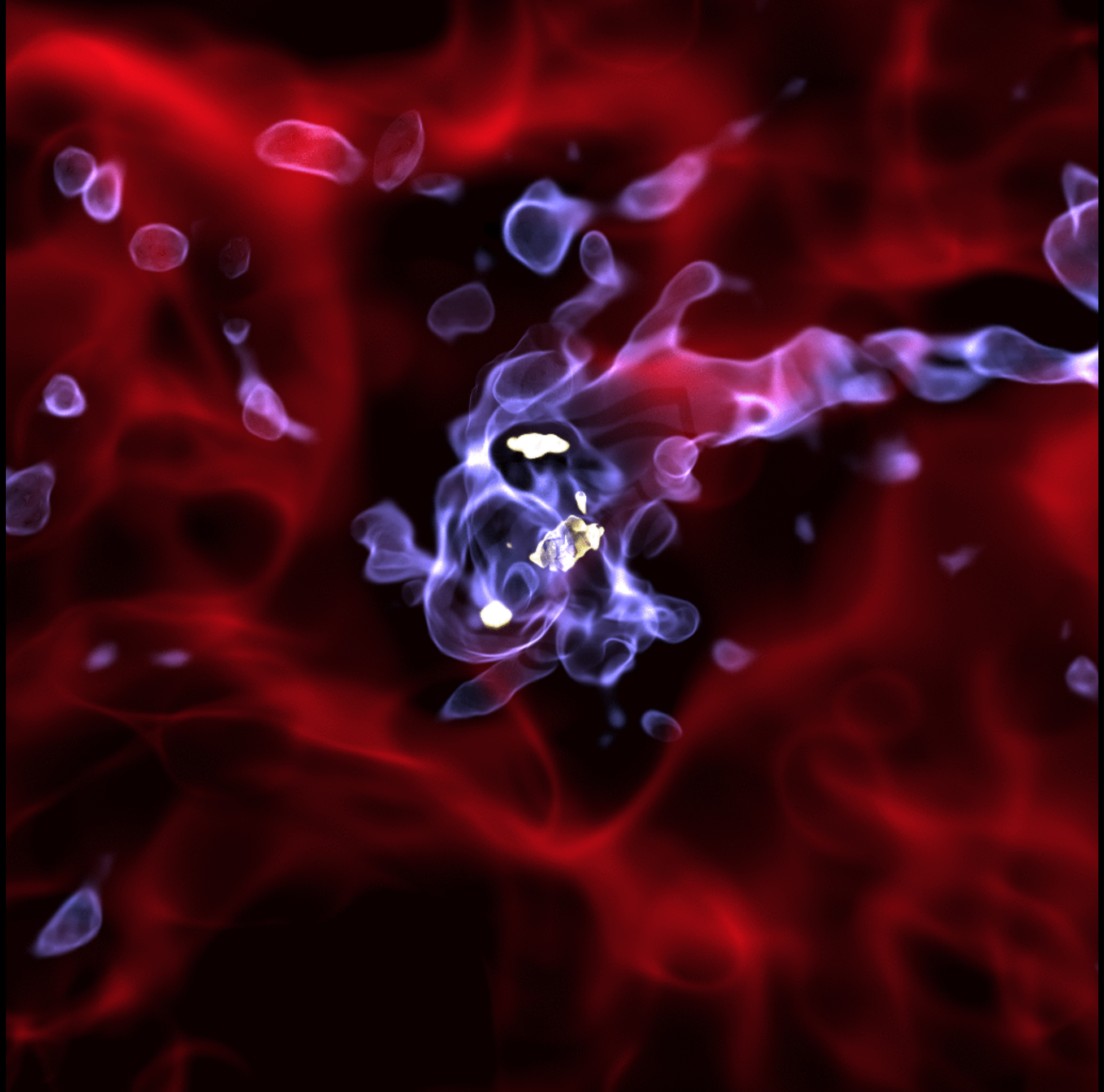
Narayanan, Turk, Hopkins et al. 2014

Comparison to Observations: SED

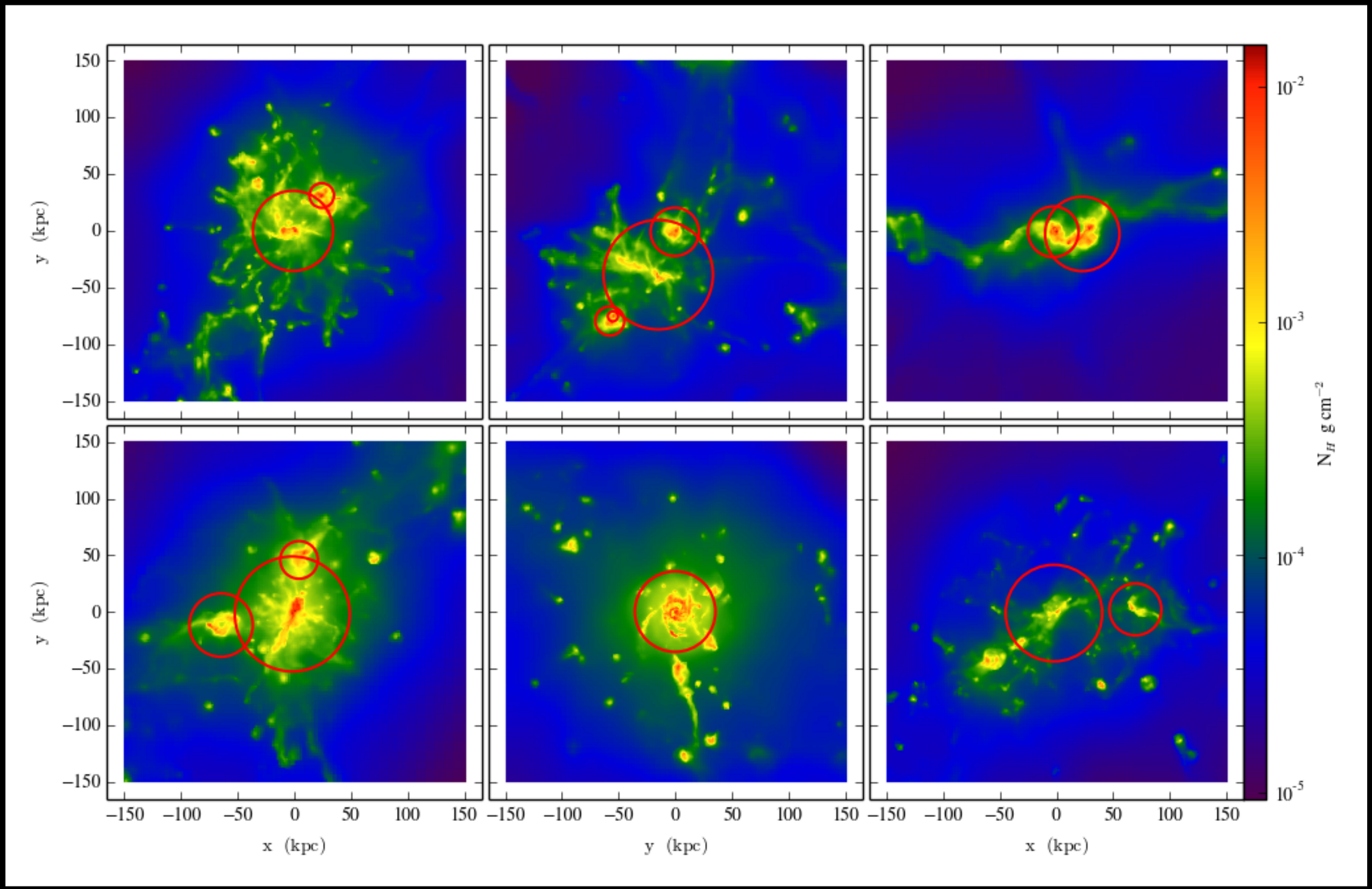


data compiled by Michal Michalowski

Narayanan, Turk, Hopkins et al. 2014



Subhalos in SMGs: SMGs are usually not a single galaxy



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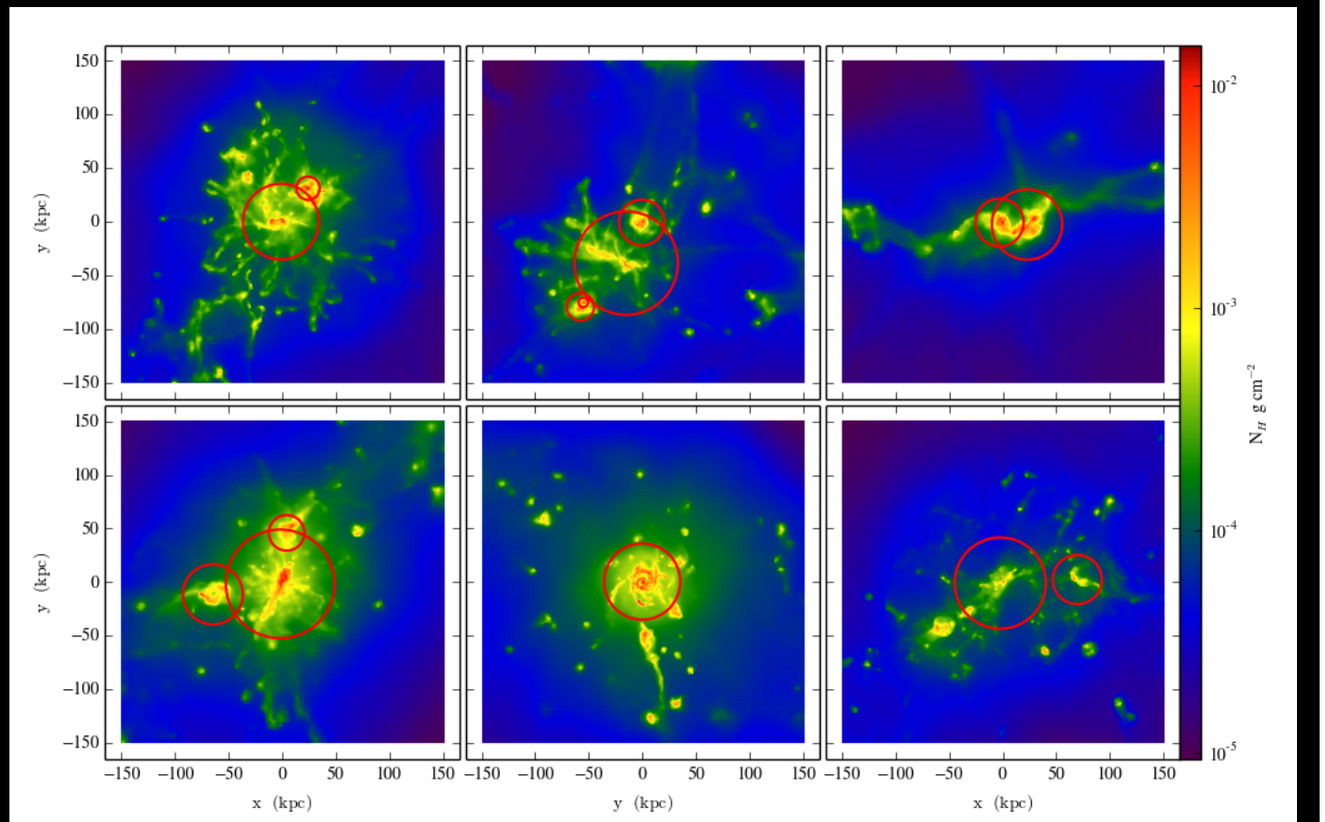

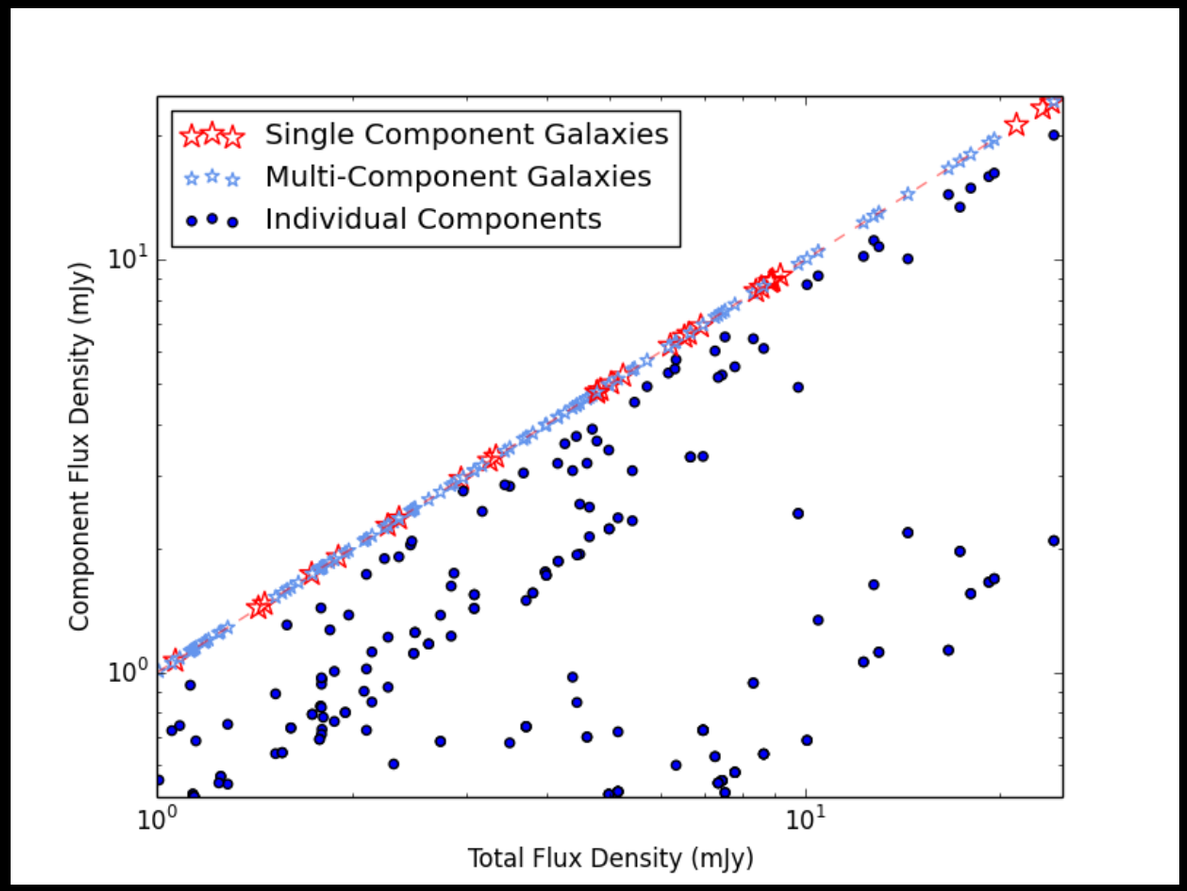

David Ball: 251.14 (Tuesday)

Narayanan, Turk, Hopkins et al. 2014

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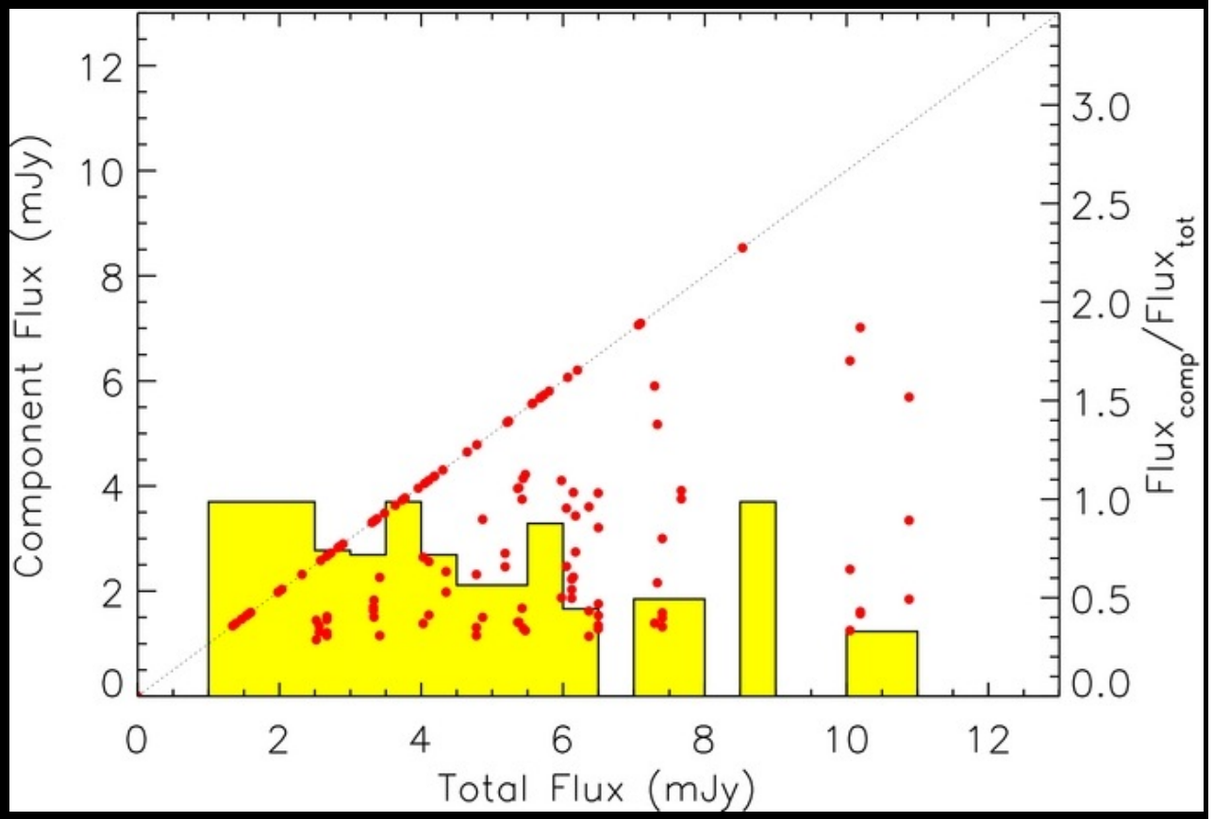
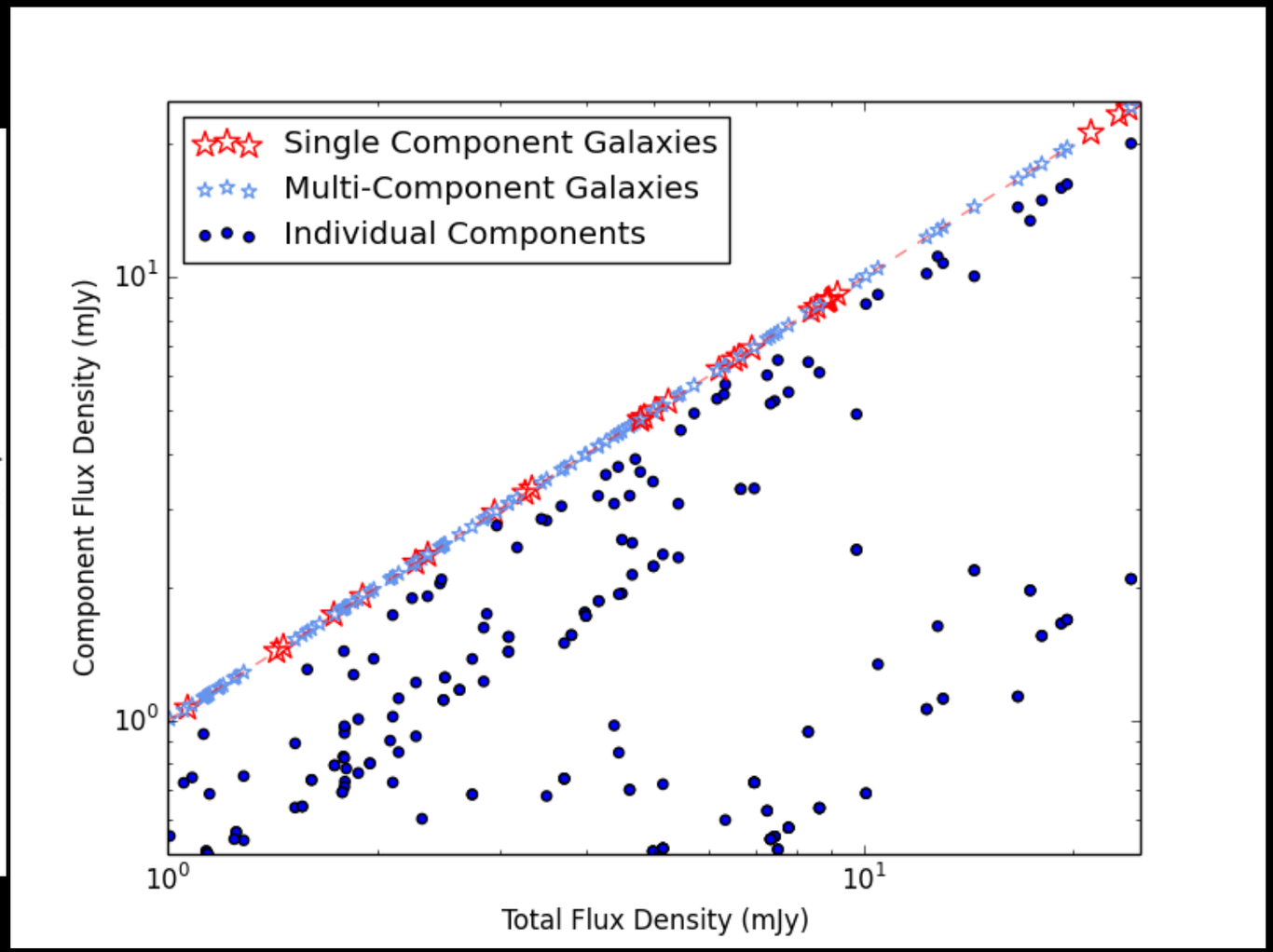


Hodge et al. 2012 (ALMA cycle 0)



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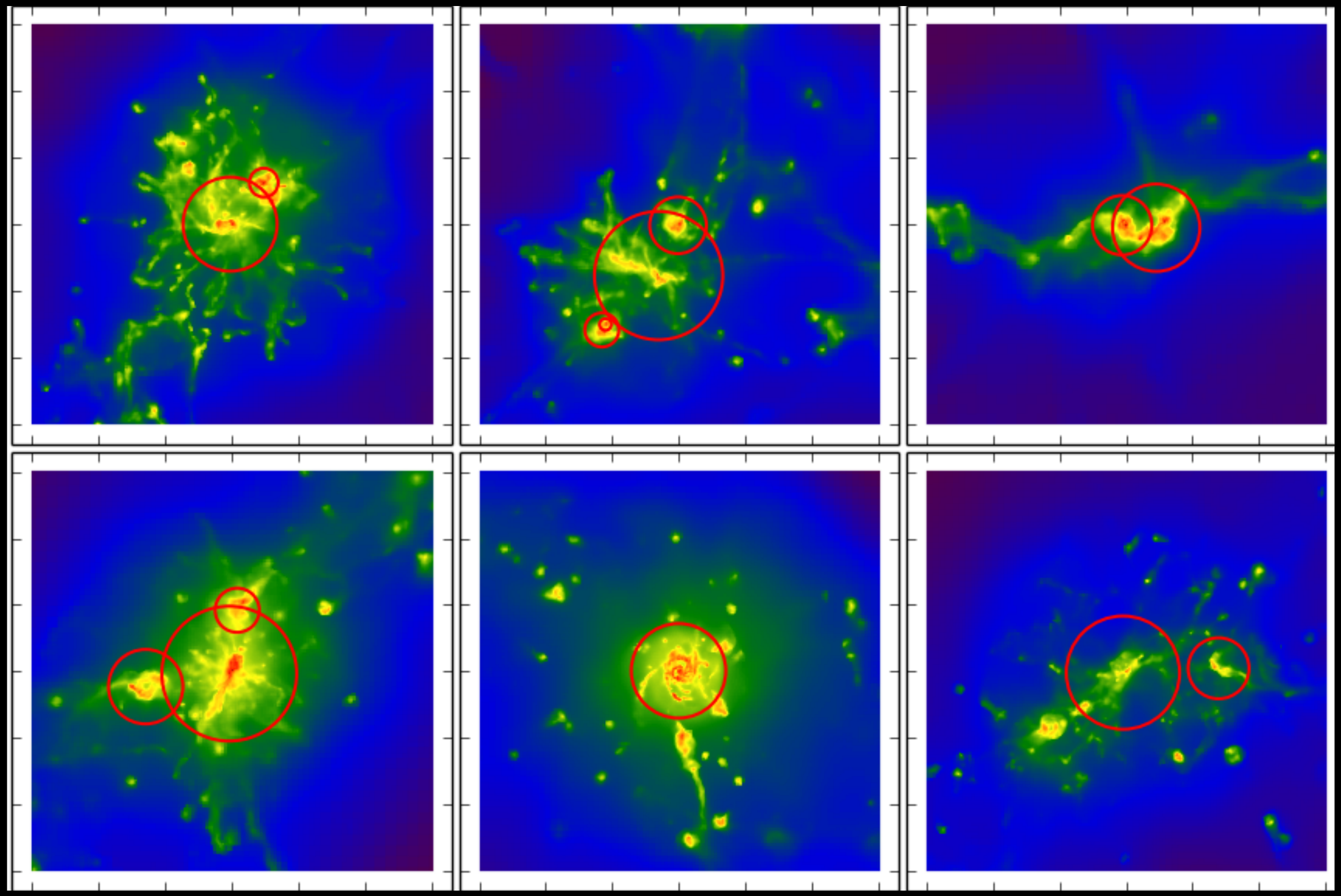
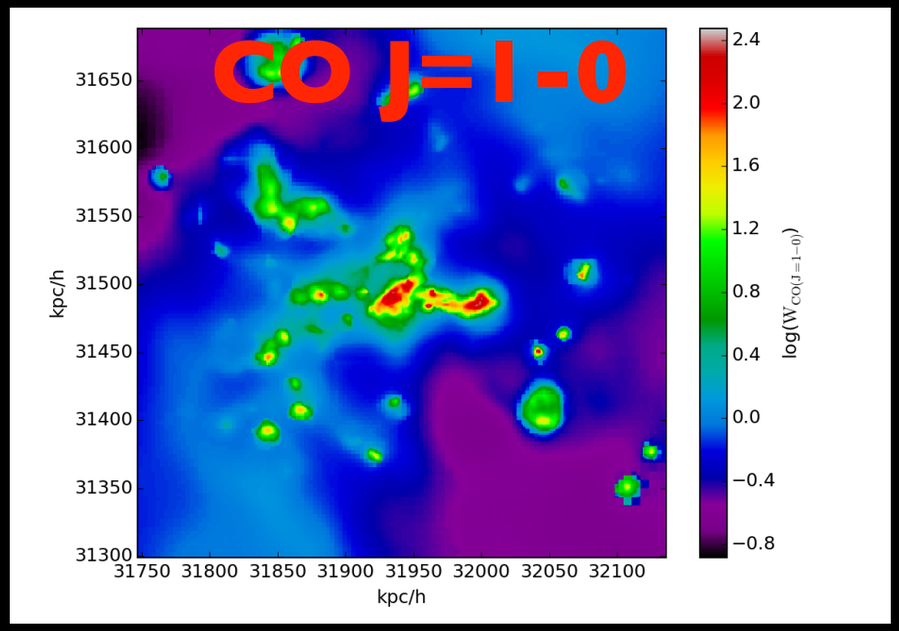
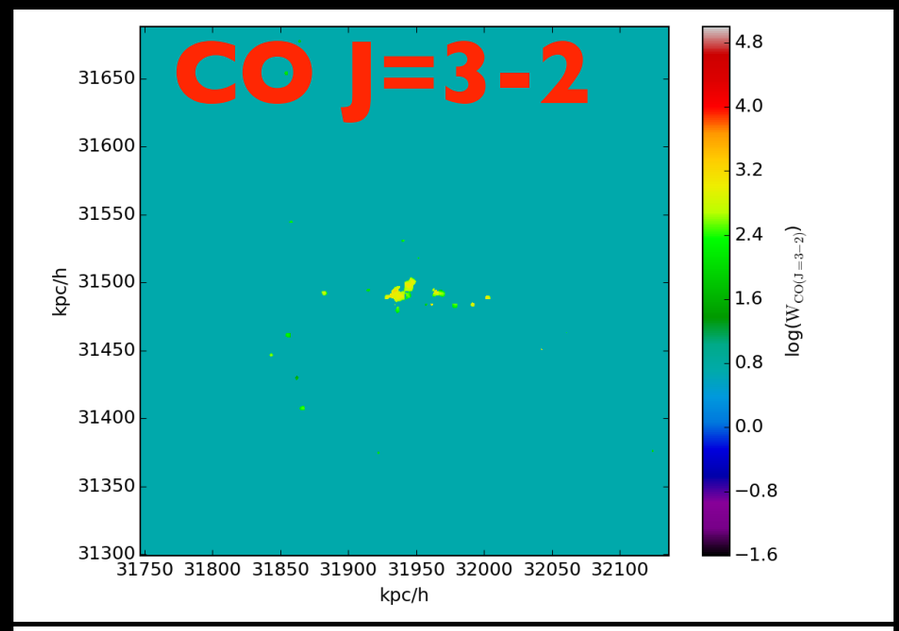
Narayanan, Turk, Hopkins et al. 2014

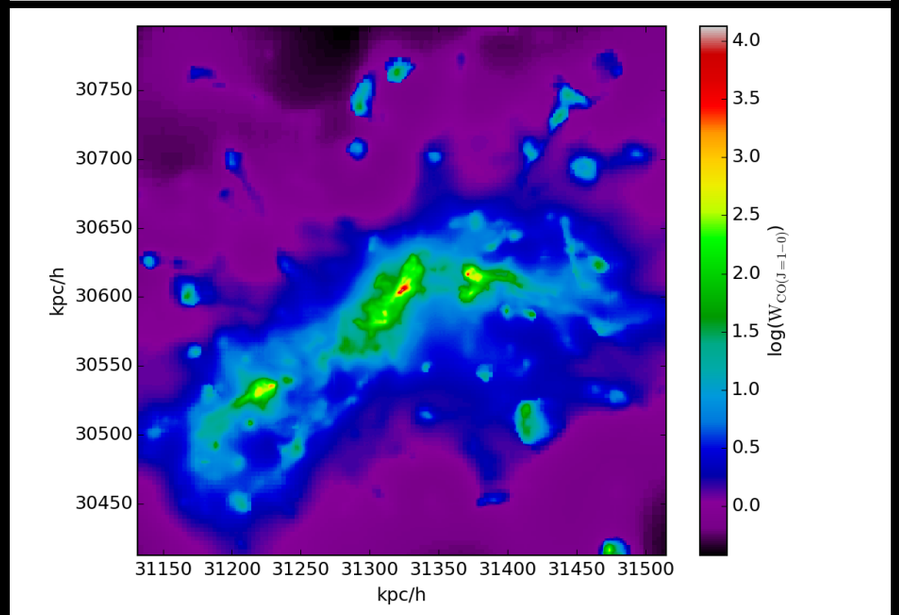
The NGVLA: Potential to Understand the gas Substructure of SMGs

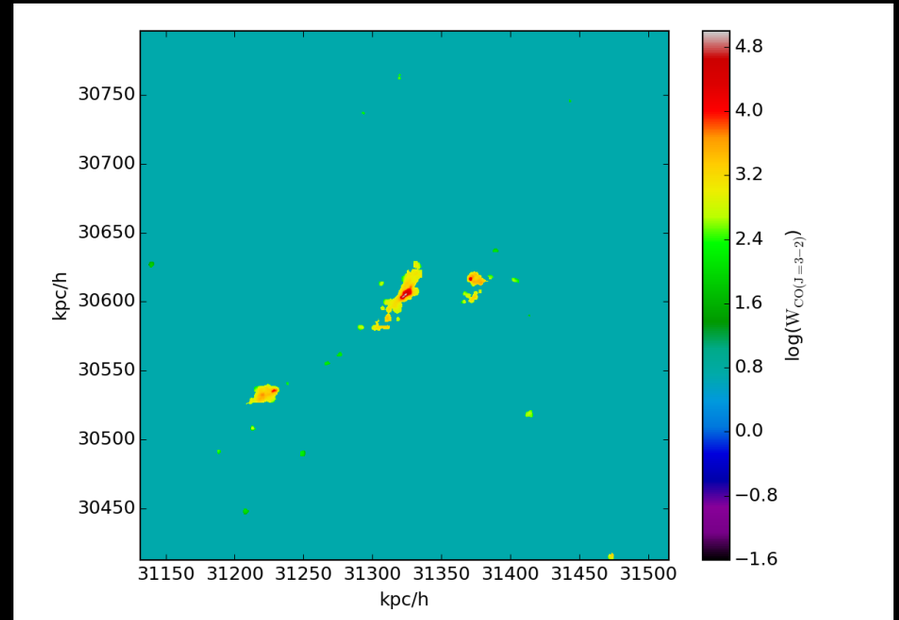


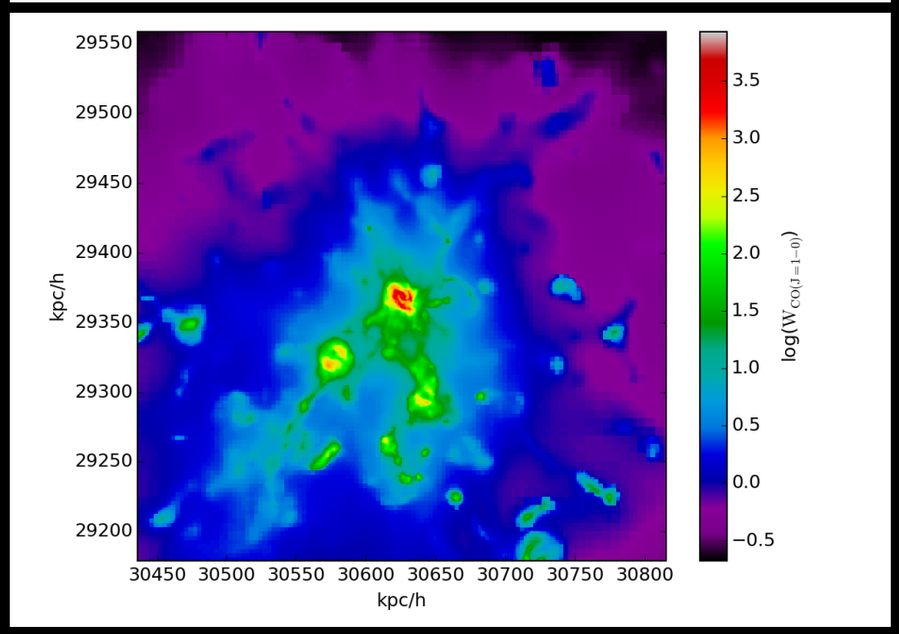
Narayanan, Krumholz, Ostriker & Hernquist (2011,2012)
Narayanan & Krumholz (2014)

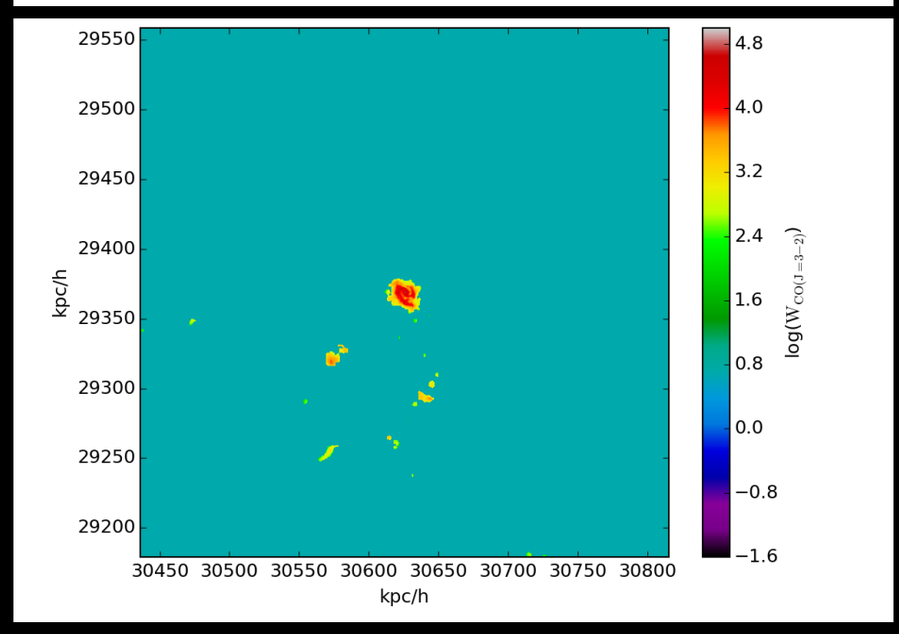




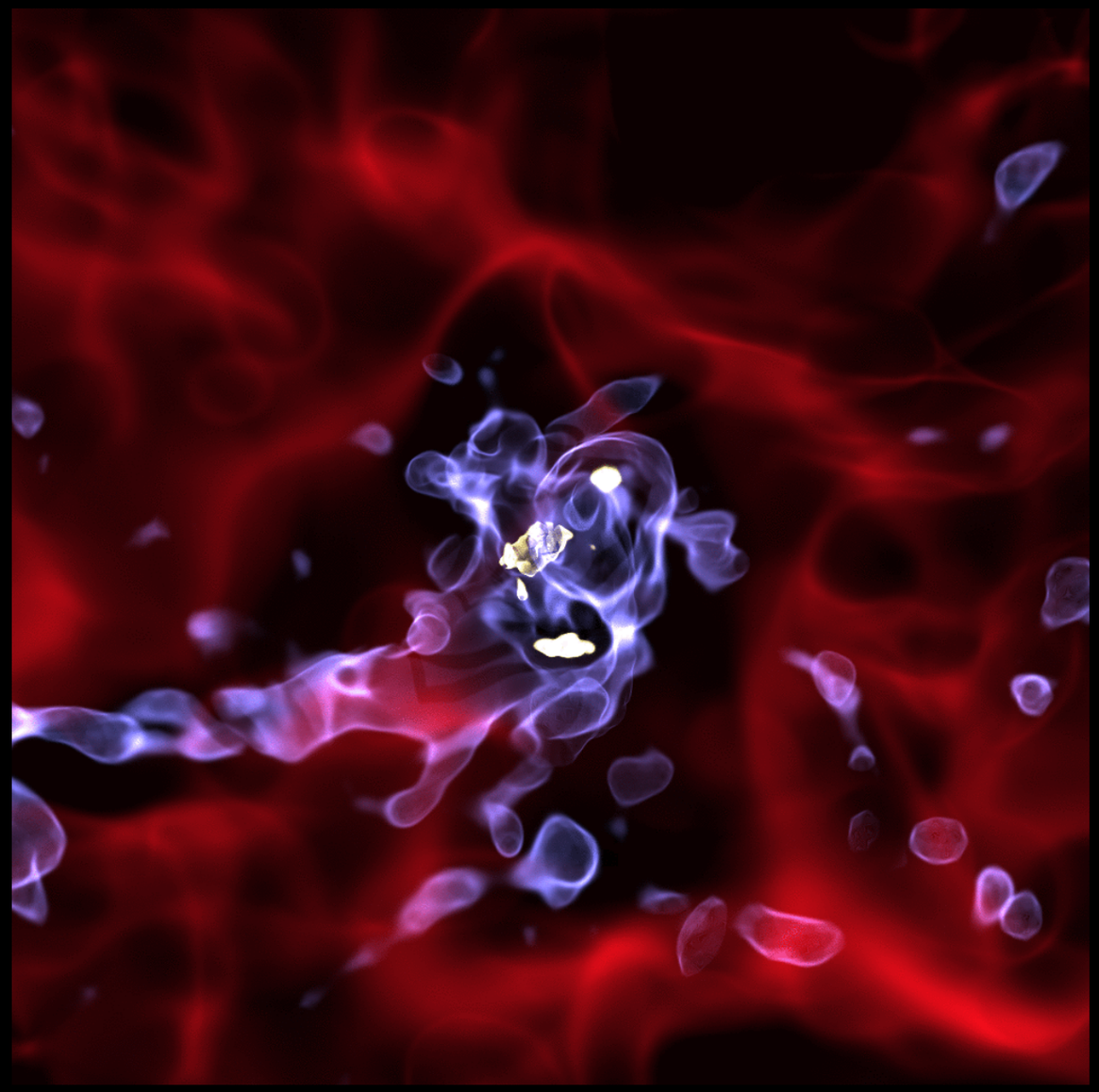






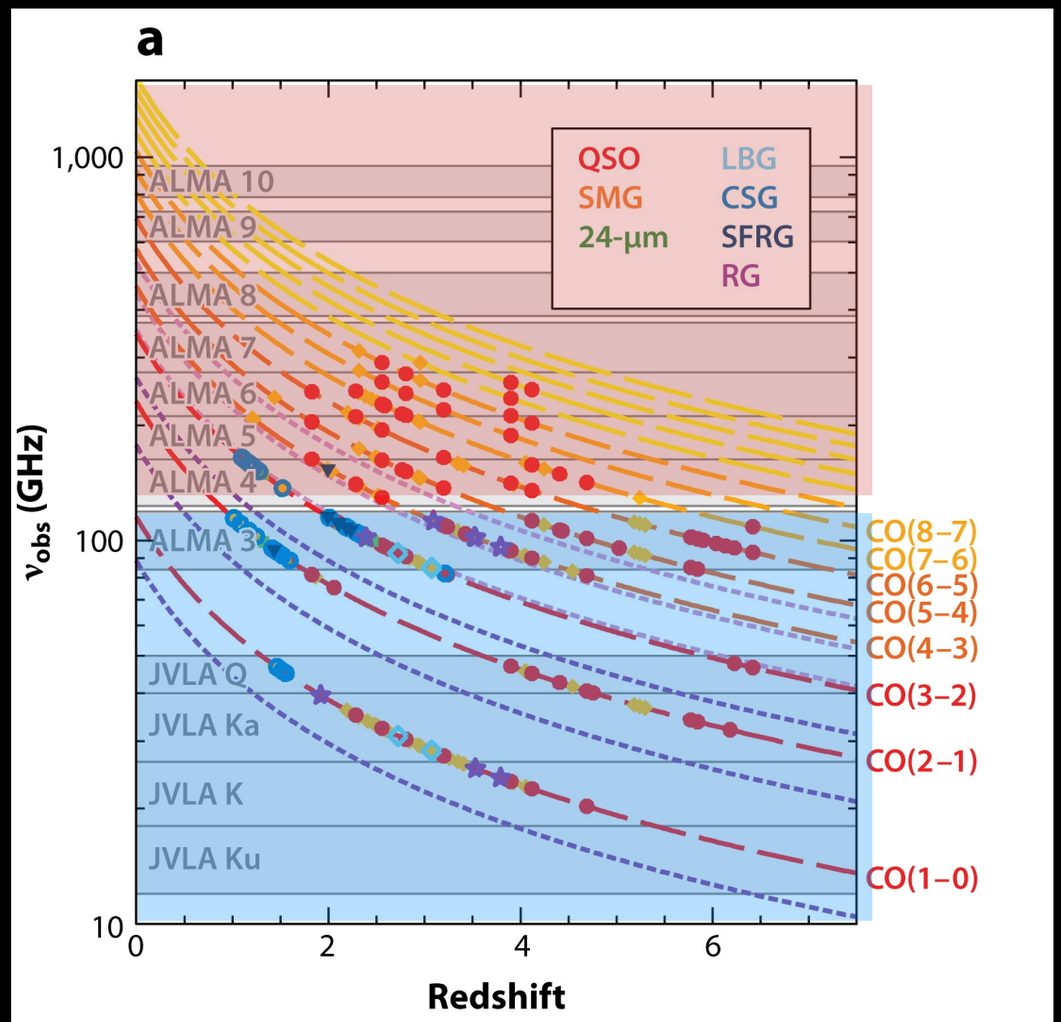


The NGVLA: Potential to Understand the Substructure of SMGs



ALMA

NGVLA



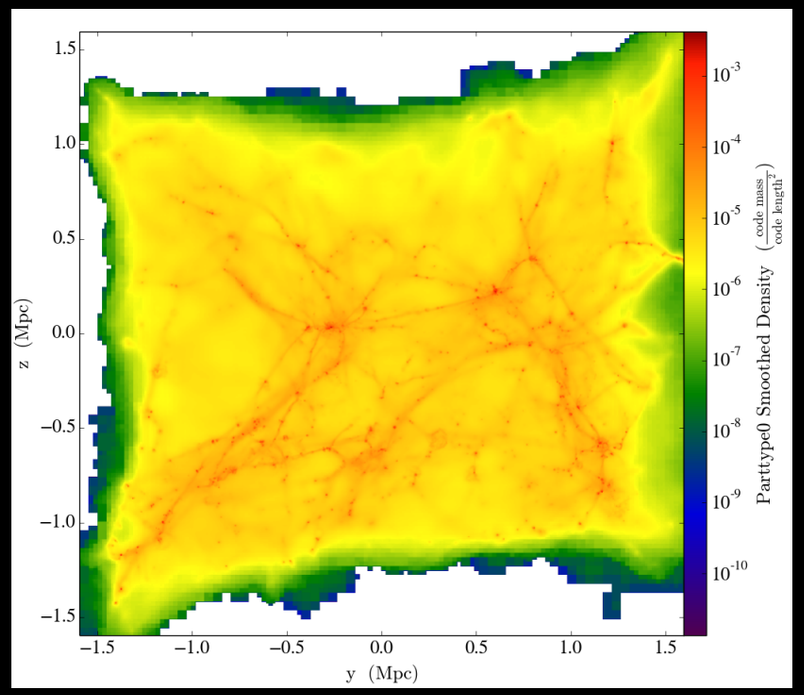
Carilli CL, Walter F. 2013.
Annu. Rev. Astron. Astrophys. 51:105–61

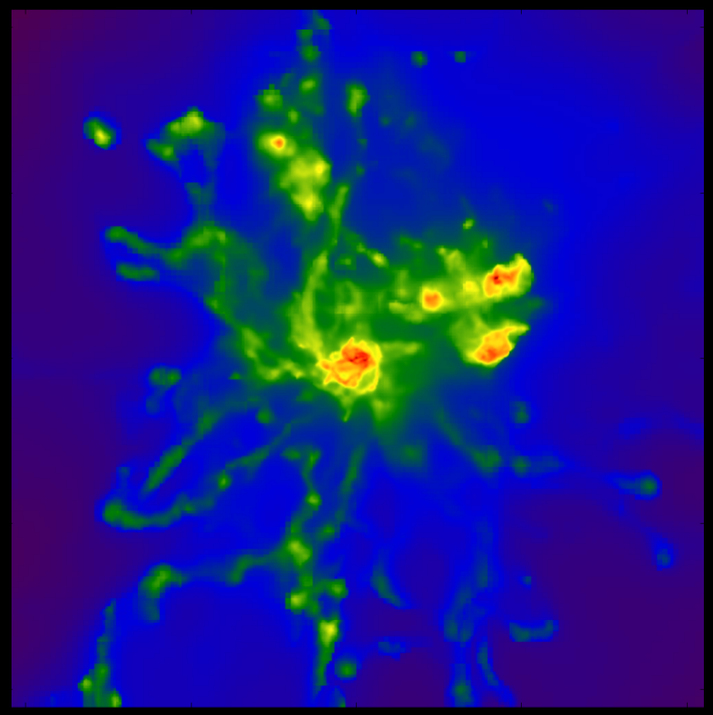
Summary:

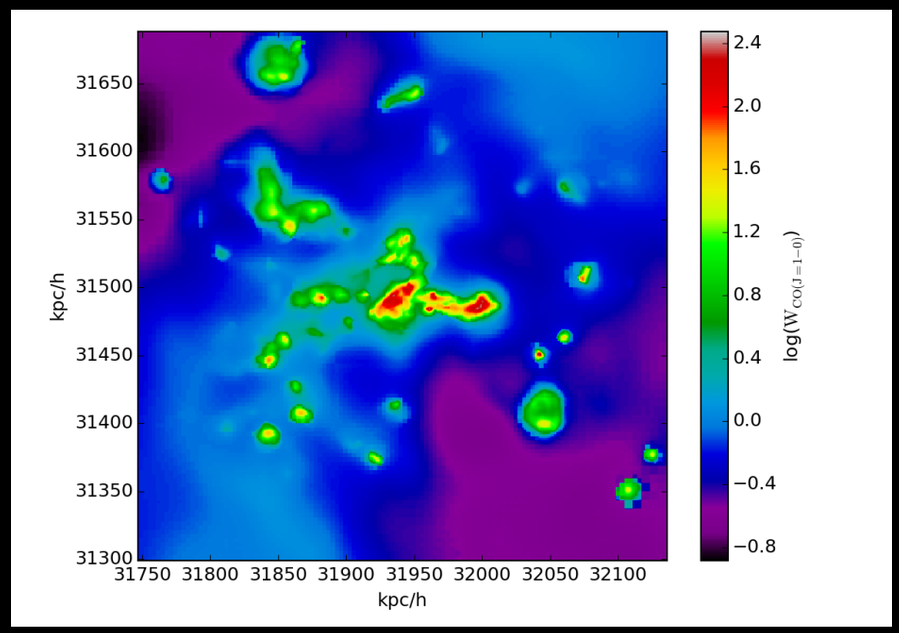
1. New cosmological zoom simulations for the formation of *high*-z dusty galaxies suggest that SMGs are *not* typically major mergers:

a. ALMA will only be able to get higher J lines at the z of interest, which misses most of the gas in subhalos.

b. Up to half of the molecular gas may be missed if only going for higher-J lines.







a. Stellar feedback at early times enables a large gas reservoir for star formation at late times (z~2-3).

b. They are massive halos being bombarded by numerous subhalos, and hence exhibit tons of substructure

2. The NGVLA is Critical for being able to measure molecular gas in substructure