Synergies between Herschel and ALMA for the study of the high redshift universe

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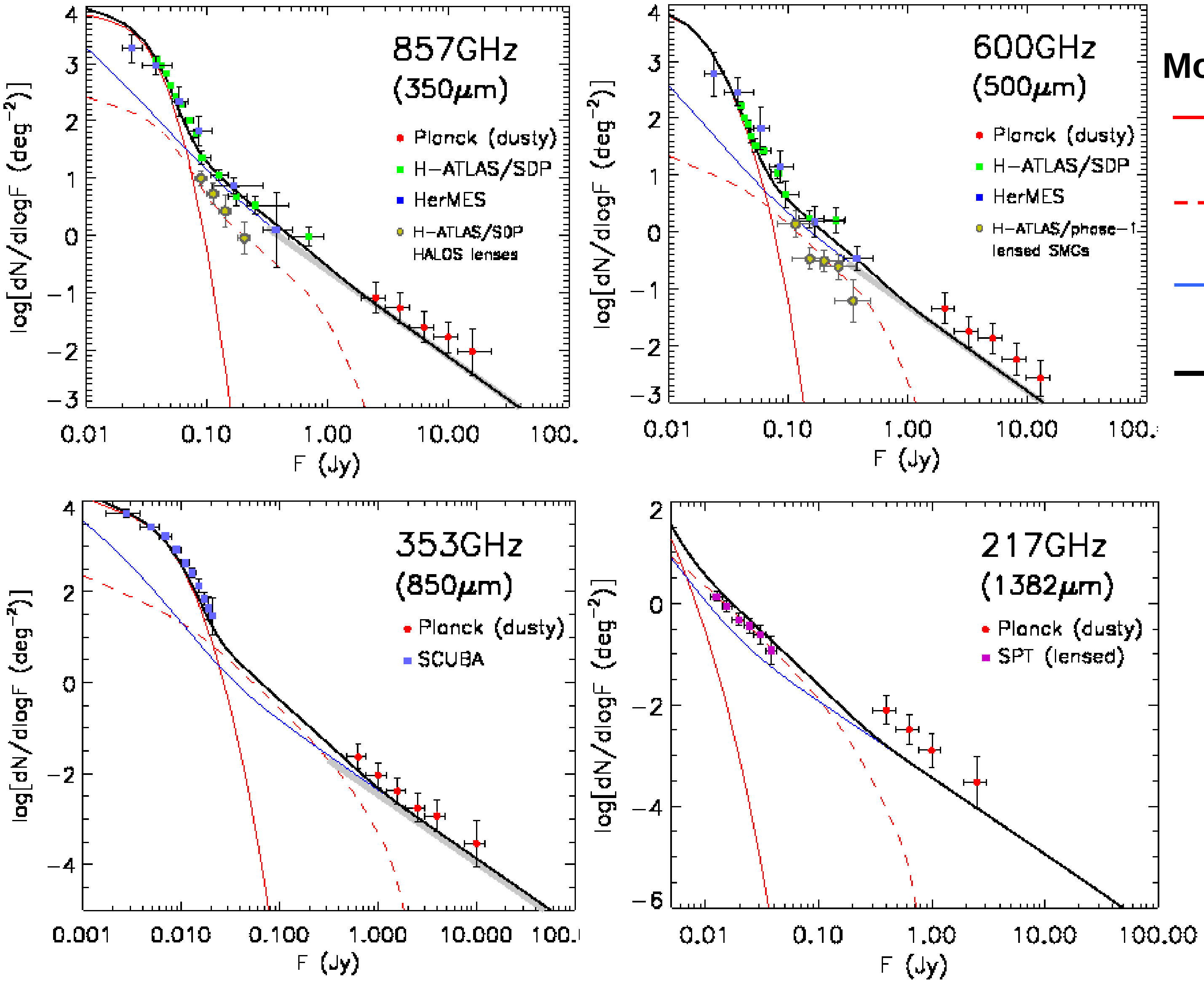
thanks to: Andrea Lapi, Mattia Negrello, Joaquin González-Nuevo, Luigi Danese

Something we learned from Herschel

Sub-mm/mm counts of **dusty galaxies**



Models

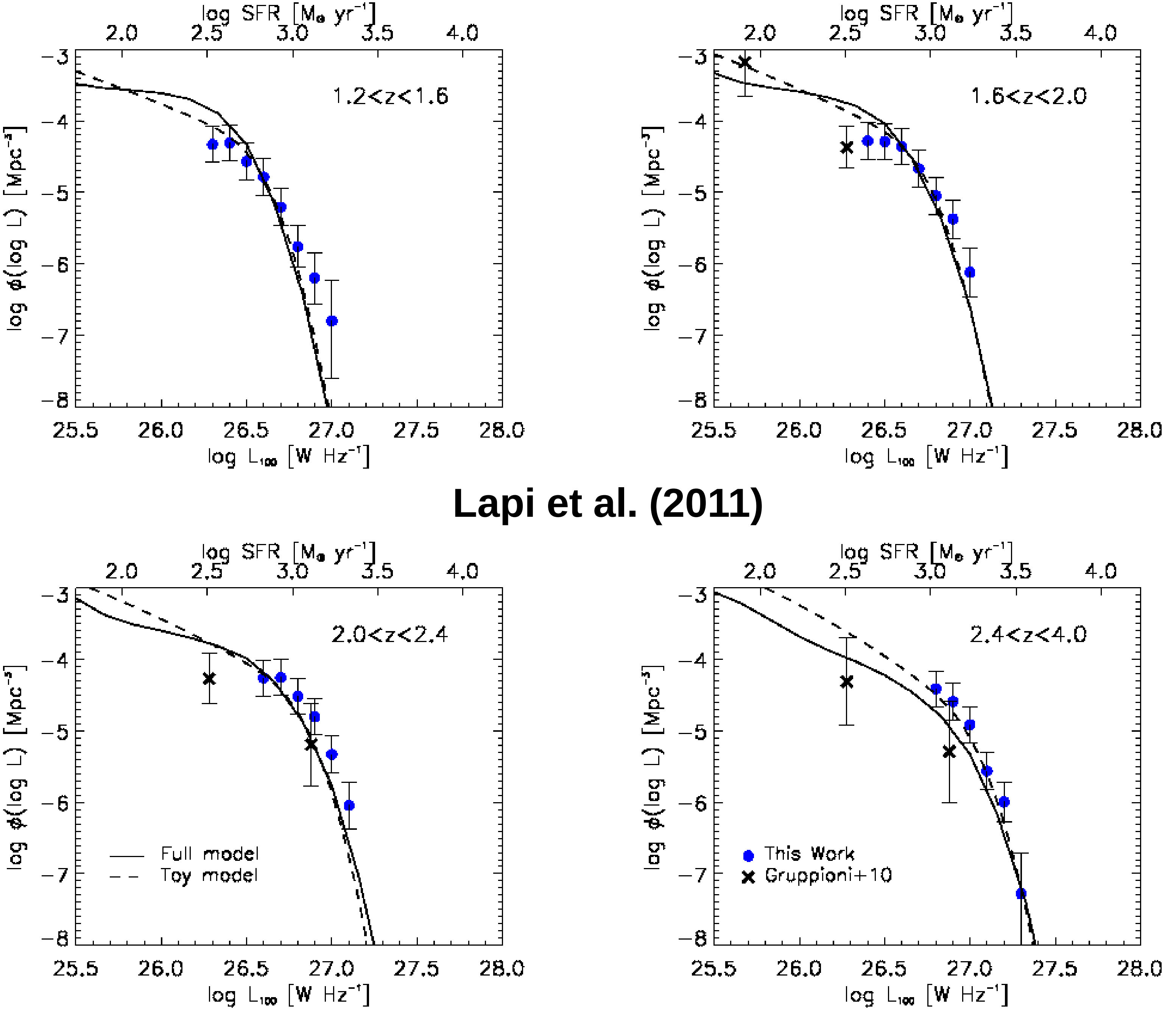
- un-lensed spheroids (Lapi et al. 2011)
- lensed spheroids (Negrello et al. 2007)
- late-type galaxies (Negrello et al. 2007)
- TOTAL

Courtesy of M. Negrello & A. Lapi

References:

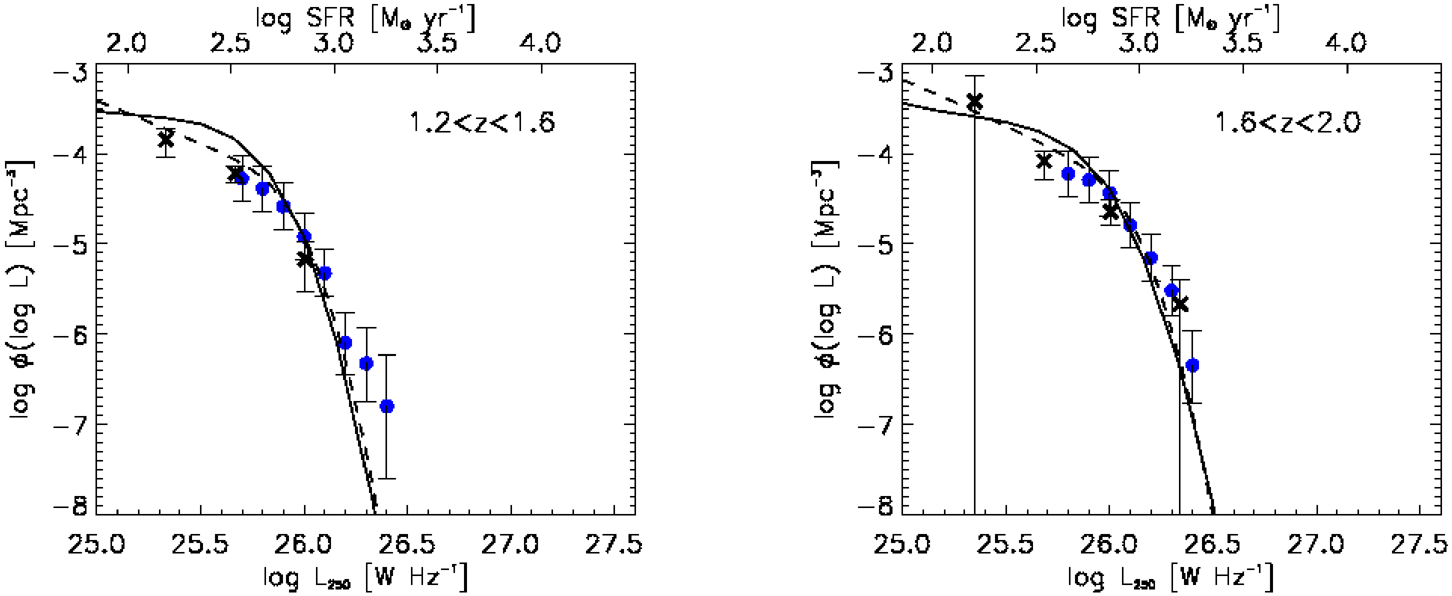
- **Planck Collaboration**
- **Serjeant & Harrison (2005)**
- **Clements et al. (2010)**
- **Oliver et al. (2010)**
- **Coppin et al. (2006)**
- **Vieira et al. (2010)**

100 µm luminosity functions

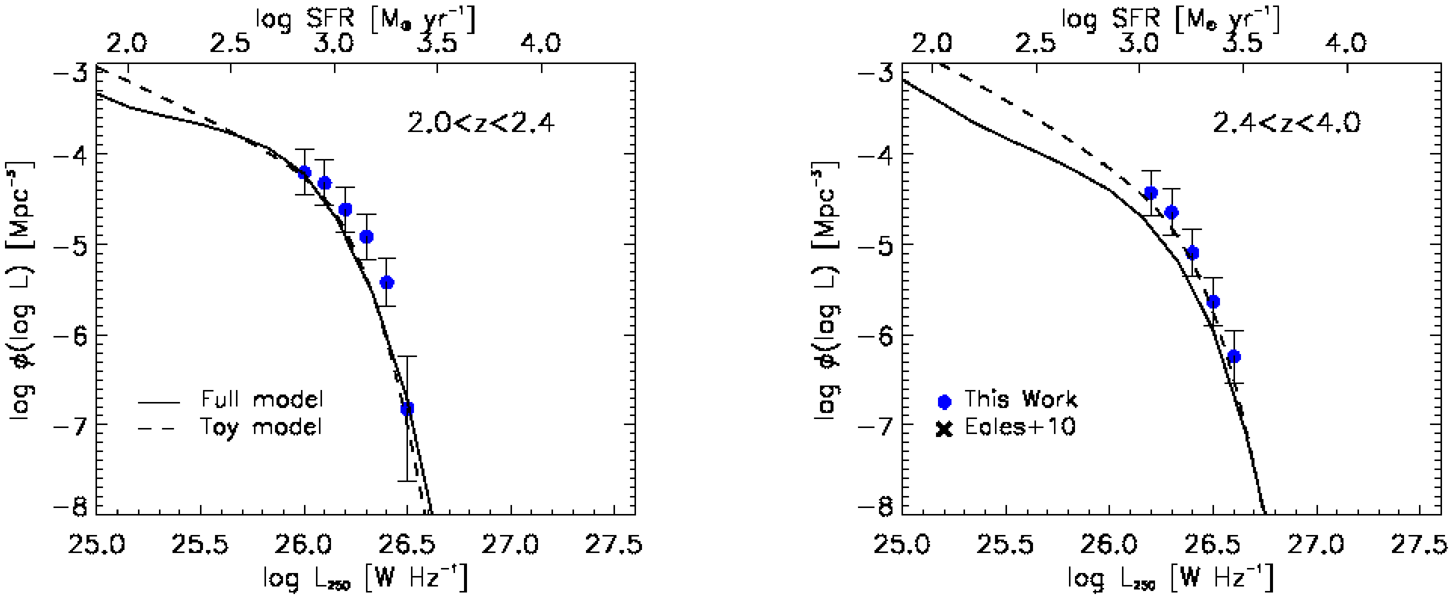


Lapi et al. (2011)

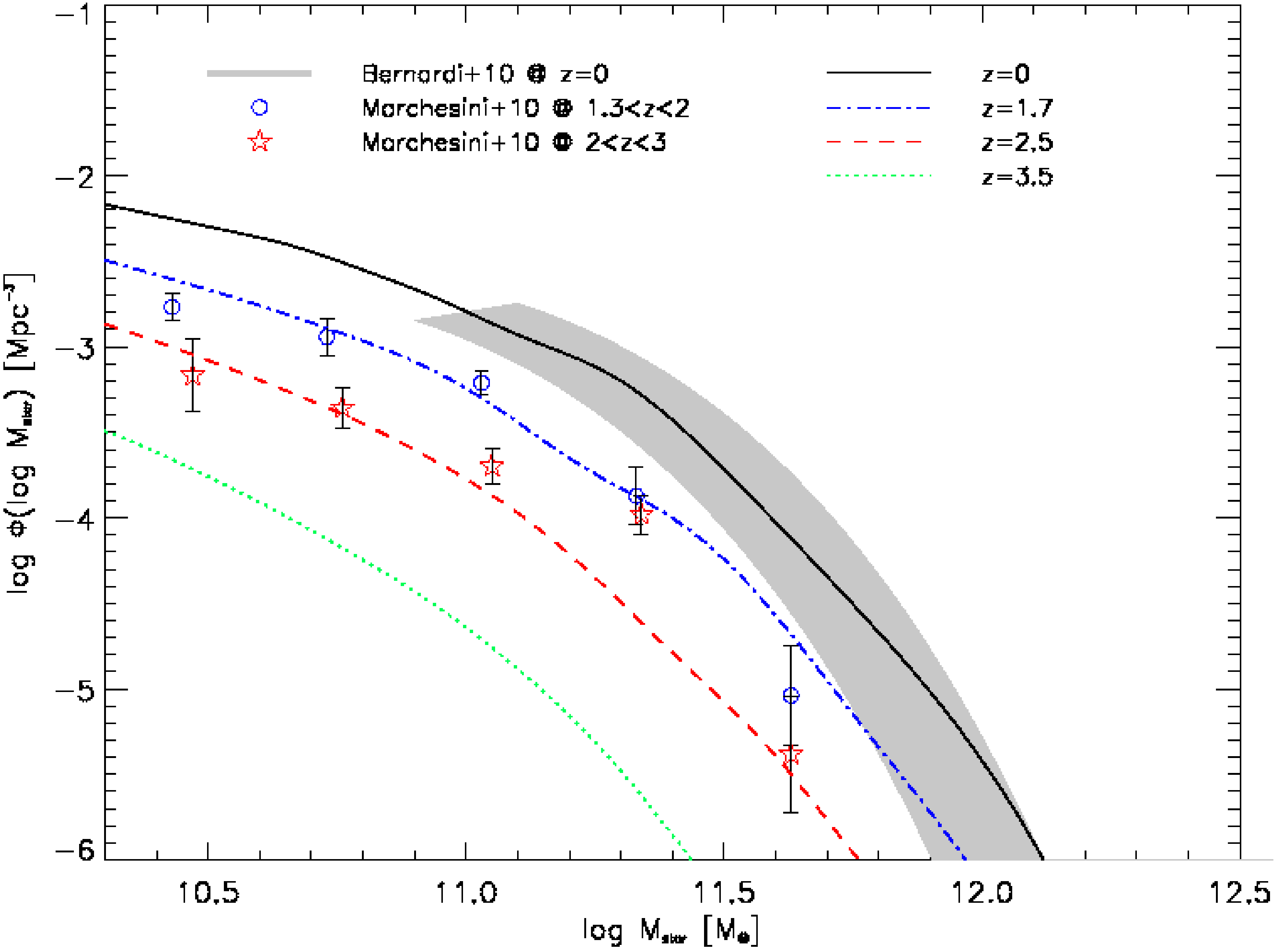
250 µm luminosity functions



Lapi et al. (2011)



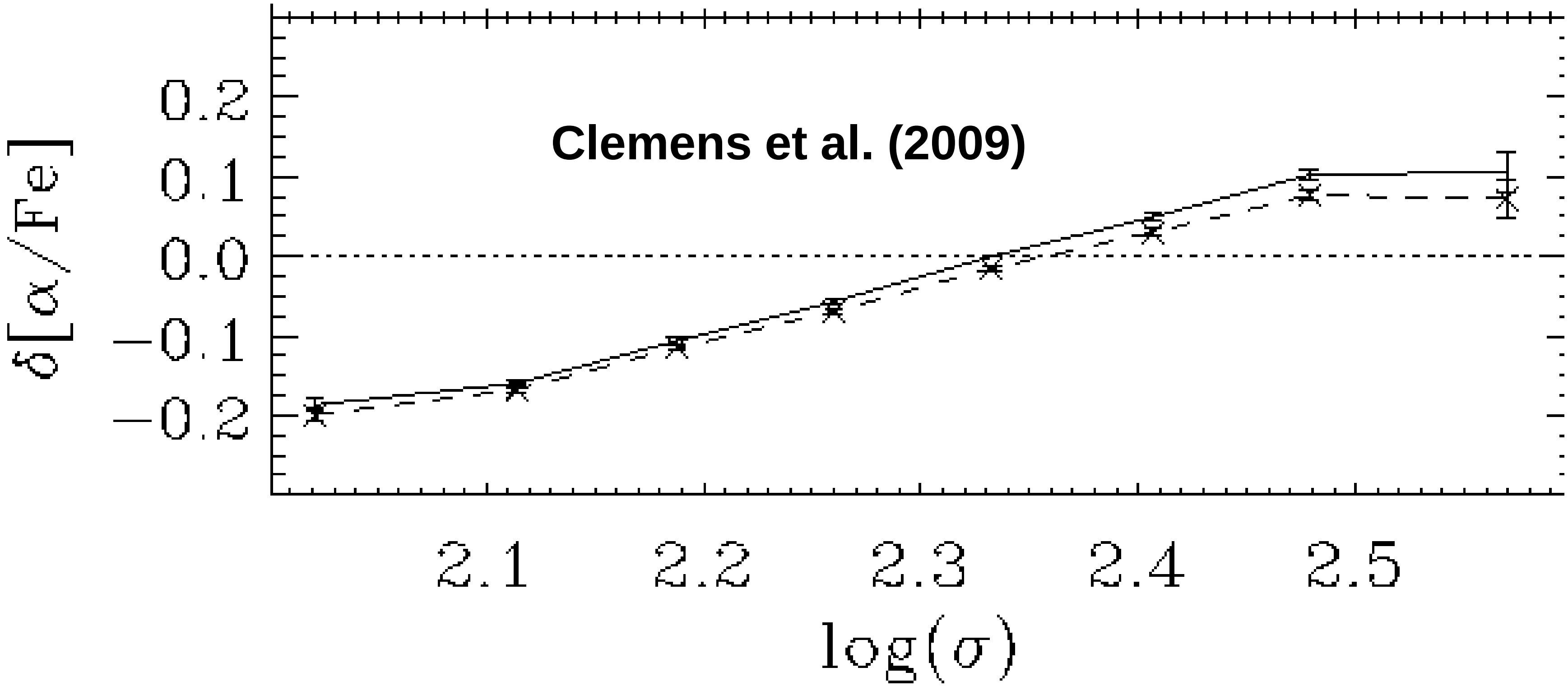
Stellar mass function (Lapi et al. 2011)



From the SFR function to the stellar mass function

- The stellar mass function of massive galaxies mirrors the SFR function for a typical duration of the star-formation phase ~ 0.7 Gyr, with a trend towards shorter durations for more massive galaxies
- SF timescale consistent with that expected for quenching by AGN feedback if a small fraction (~5%) of the Eddington luminosity is tranferred to the ISM (Lapi et al. 2006). The same fraction of L_{Edd} can account for the ‘entropy plateau’ of the ICM (Platania et al. 2002; Lapi et al. 2005)

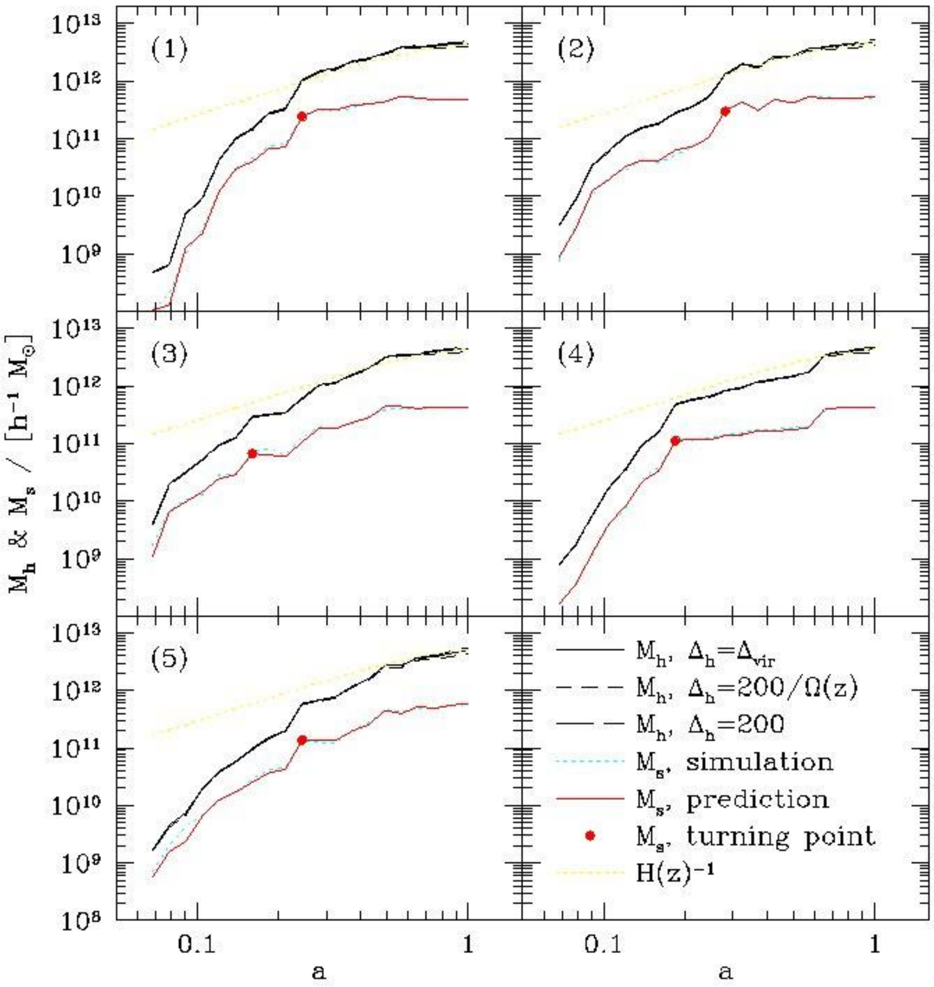
α-enhancement as a chronometer

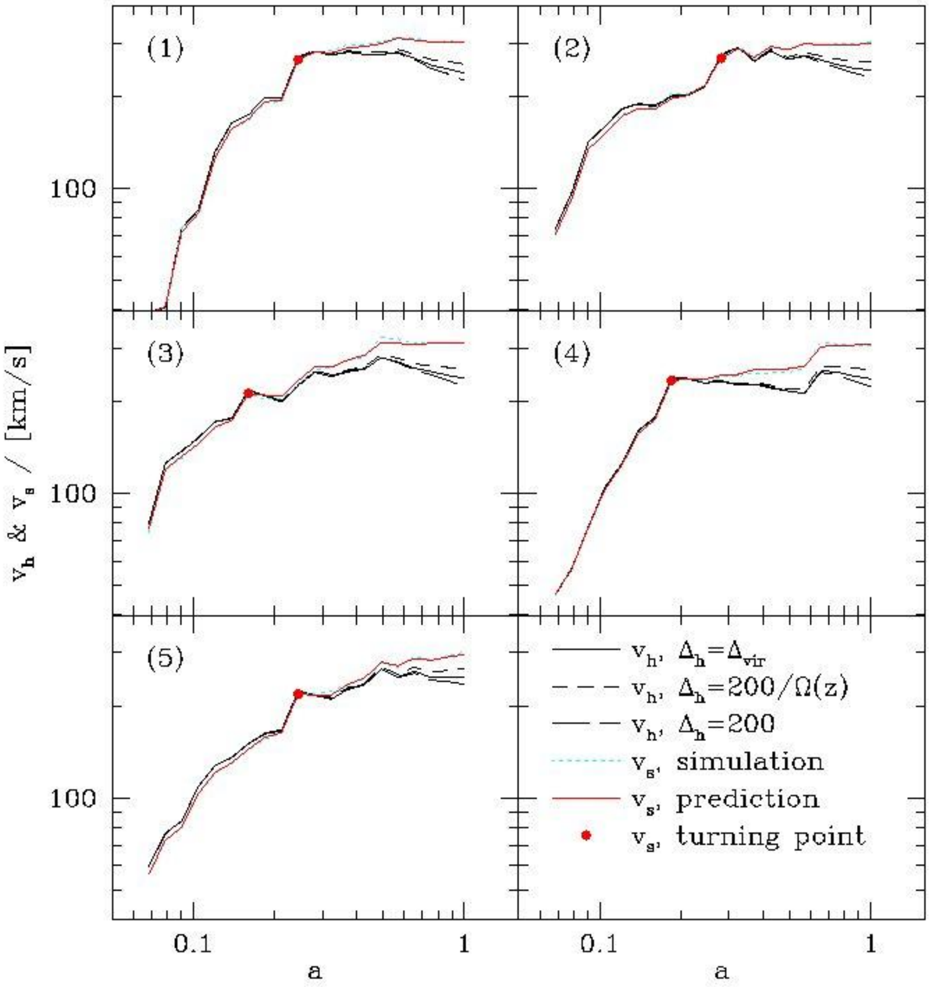


In massive early-type galaxies the star formation must have been stopped before the ISM could have been enriched in Fe by SN Ia (SFR duration < 1 Gyr). Not consistent with merger driven star formation implying a sequence of short (~0.1 Gyr) SF episodes, spanning altogether >> 1 Gyr.

Halo mass vs velocity evolution

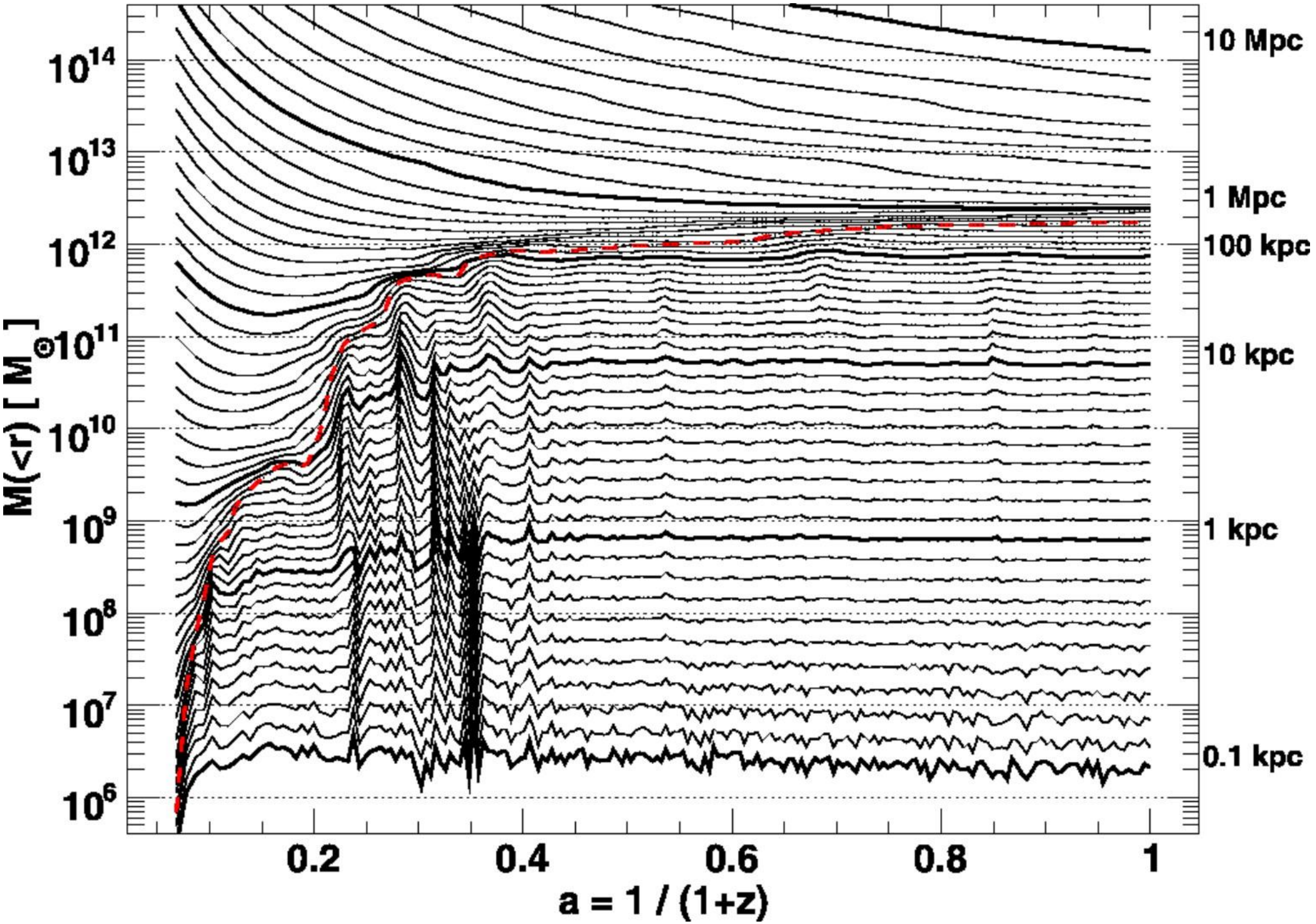
(Zhao et al. 2003)





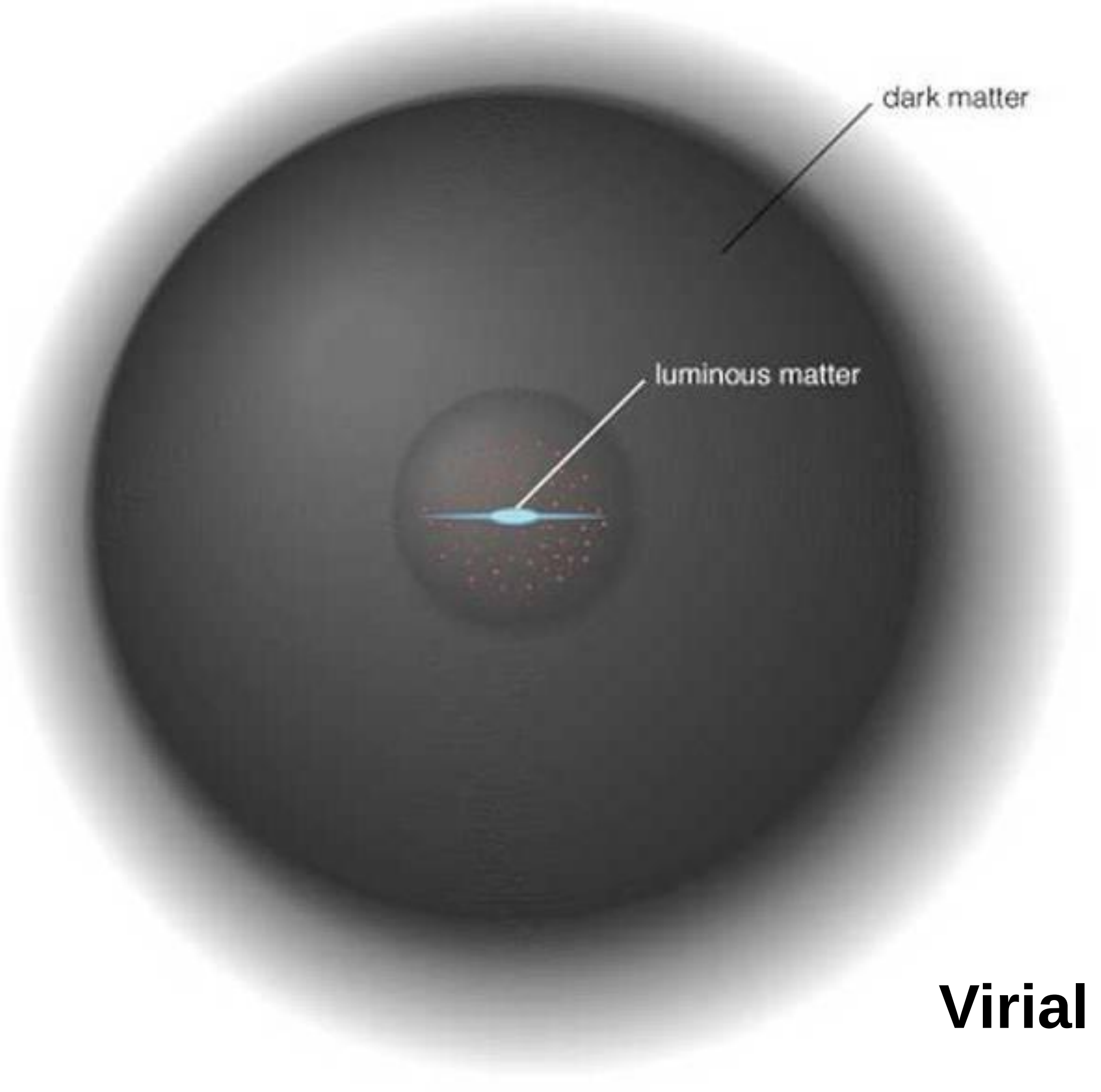
$a= (1+z)^{-1}$

Mass within size of visible galaxy



Diemand et al. (2007)

Size comparison: stars vs dark matter



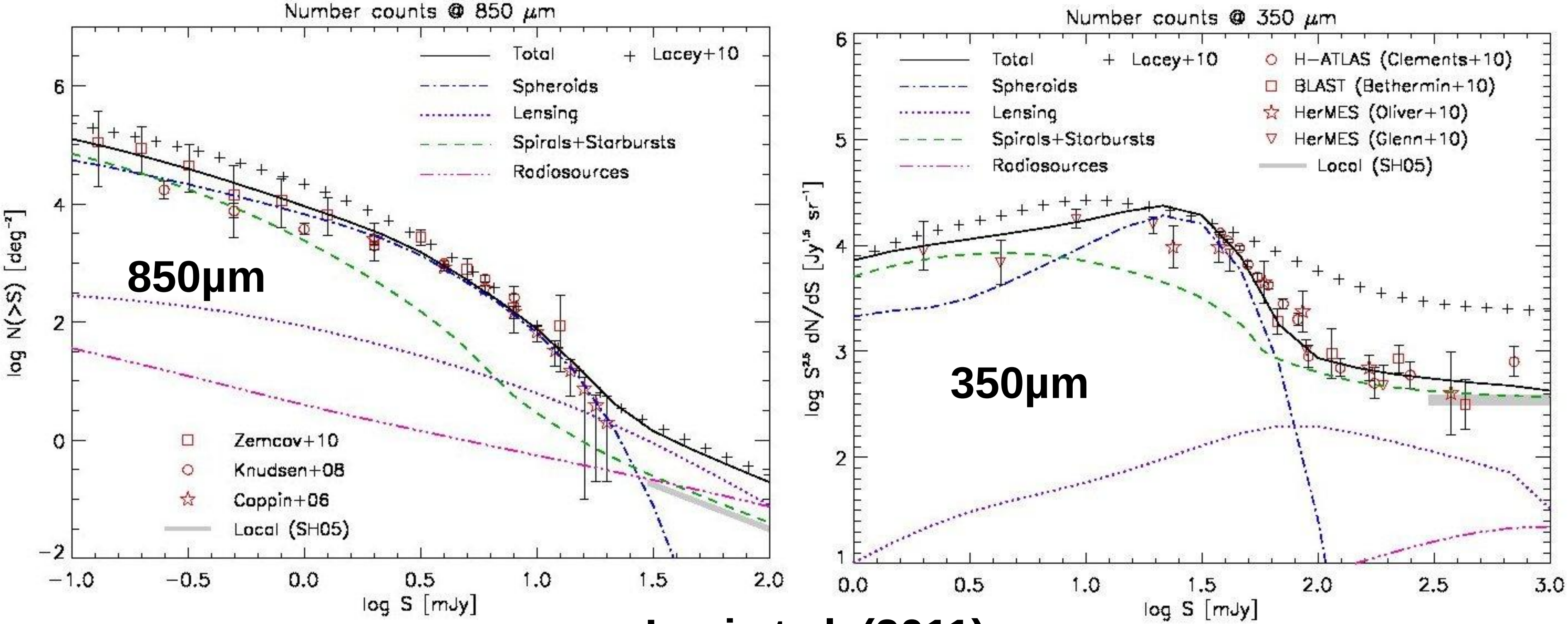
Effective radii of the most massive galaxies: ~ 10 kpc

Virial radius (dark matter):

$$R_v \approx 170 * 4/(1+z_v) * (M_v/10^{13}\, M_{sun})^{1/3} \text{ kpc}$$

Counter-check

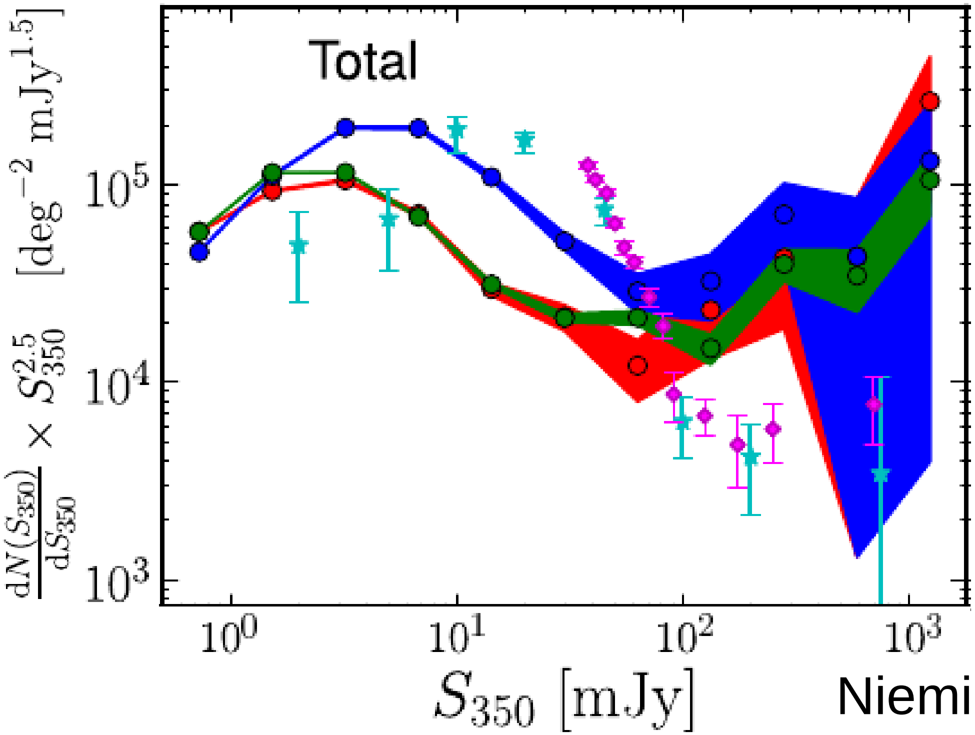
$\Phi(L_{FIR}) \sim N(M_h)\times\tau_{SFR}$: if τ_{SFR} is short need higher N i.e. smaller M_h and higher L_{FIR}/M_h → top-heavy IMF → problems with accounting for the stellar mass function, but also with sub-mm counts, even playing with dust properties.



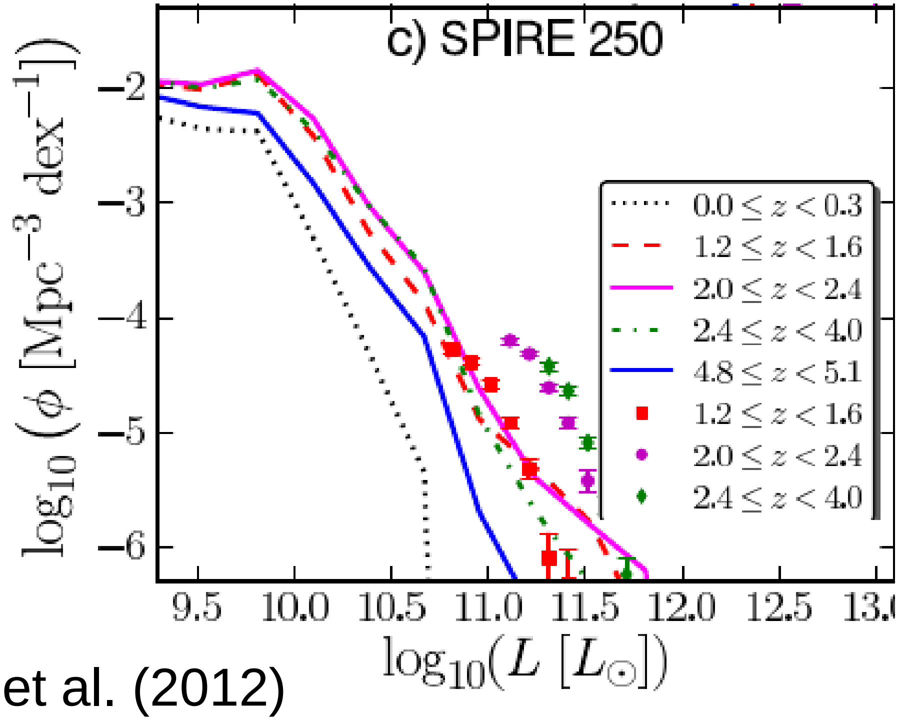
Lapi et al. (2011)

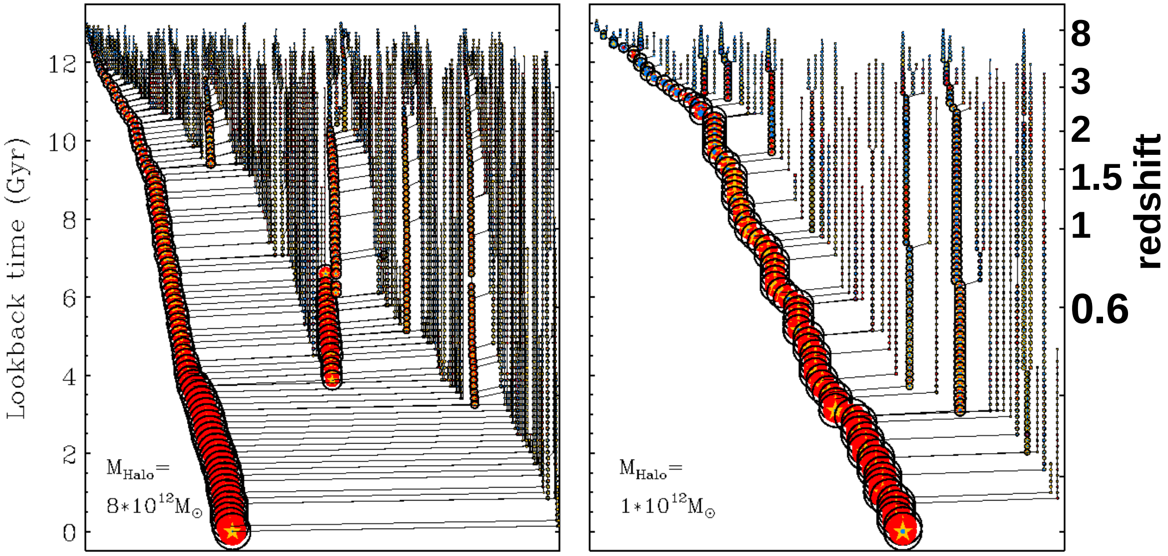
SAM with 2 SF modes (quiescent & starburst)

(Somerville et al. 2011)

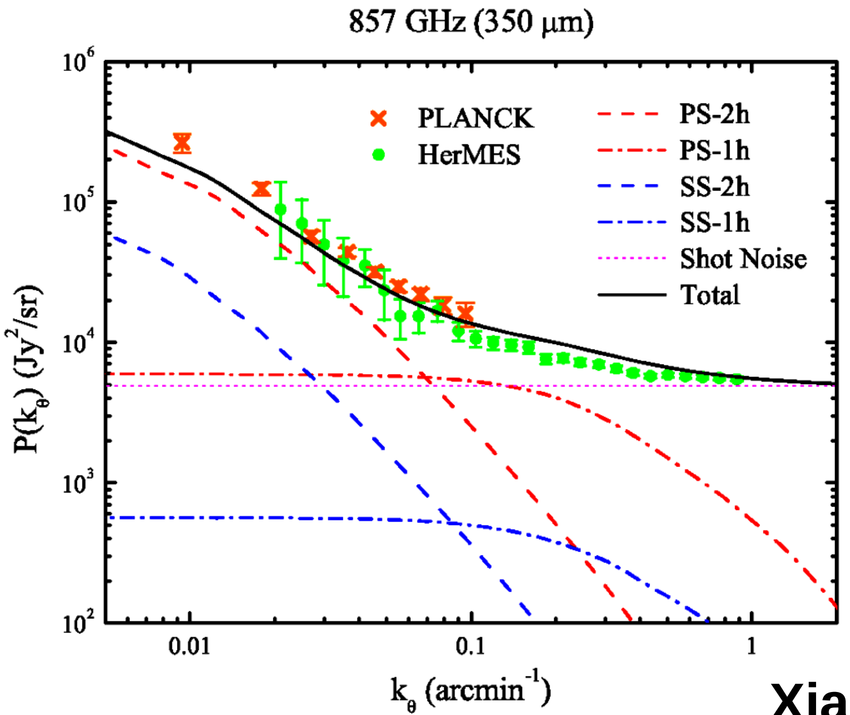


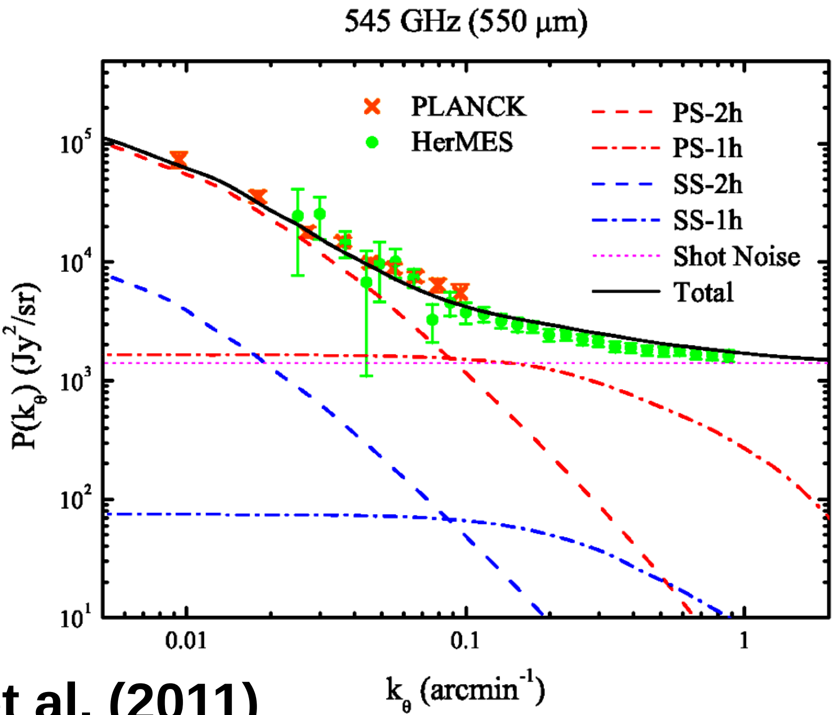
Niemi et al. (2012)



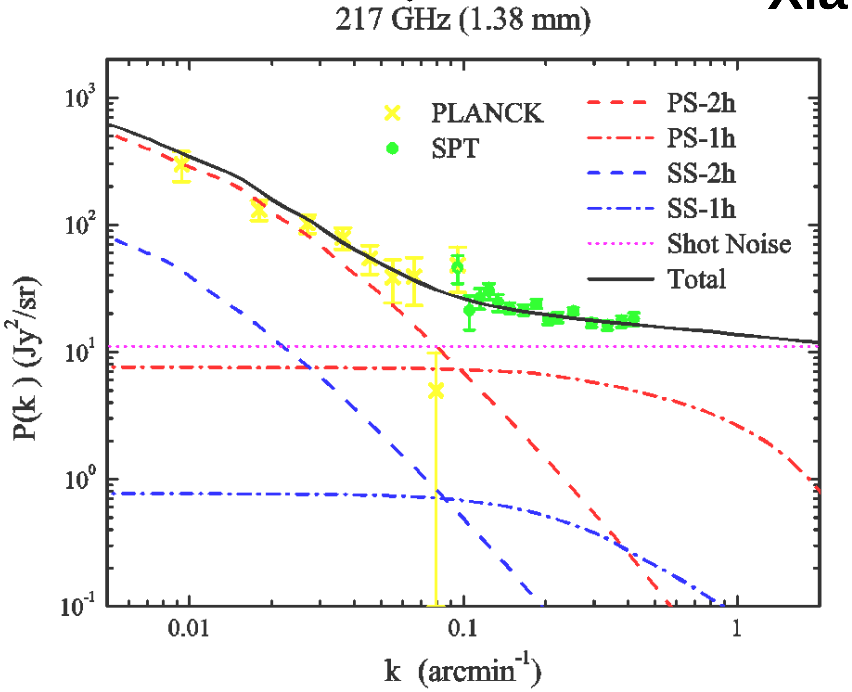


Hirschmann et al. (2012)



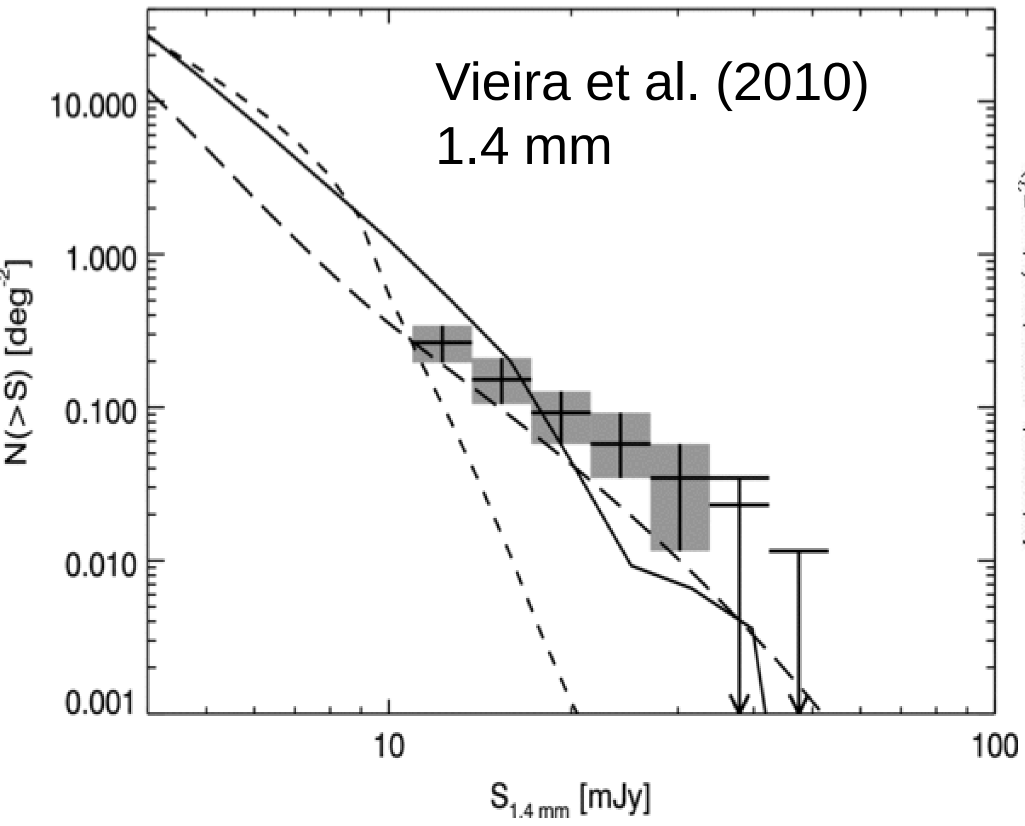


Xia et al. (2011)



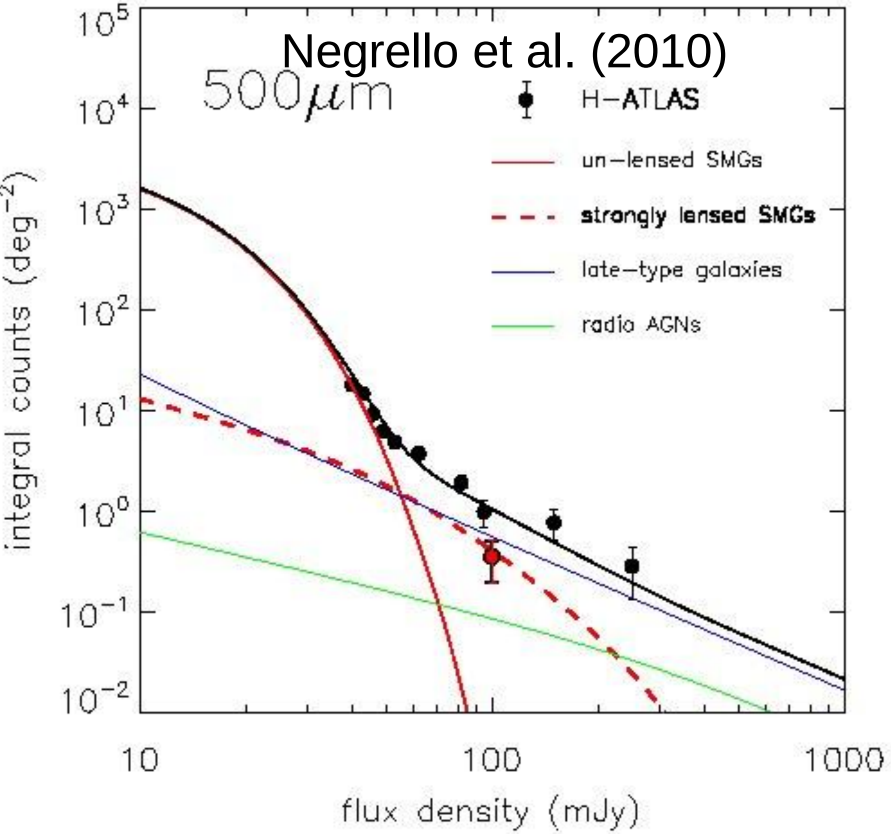
The effective halo mass can be estimated from clustering properties. From the Lapi et al. (2011) model: $M_{eff}=5\times10^{12}\ M_{sun}$ at z=2, consistent with independent estimates for most efficient star-formers. The merger-driven SF scenario implies substantially lower effective halo masses (Almeida et al. 2011; Kim et al. 2011).

Strong lensing



Vieira et al. (2010)
1.4 mm

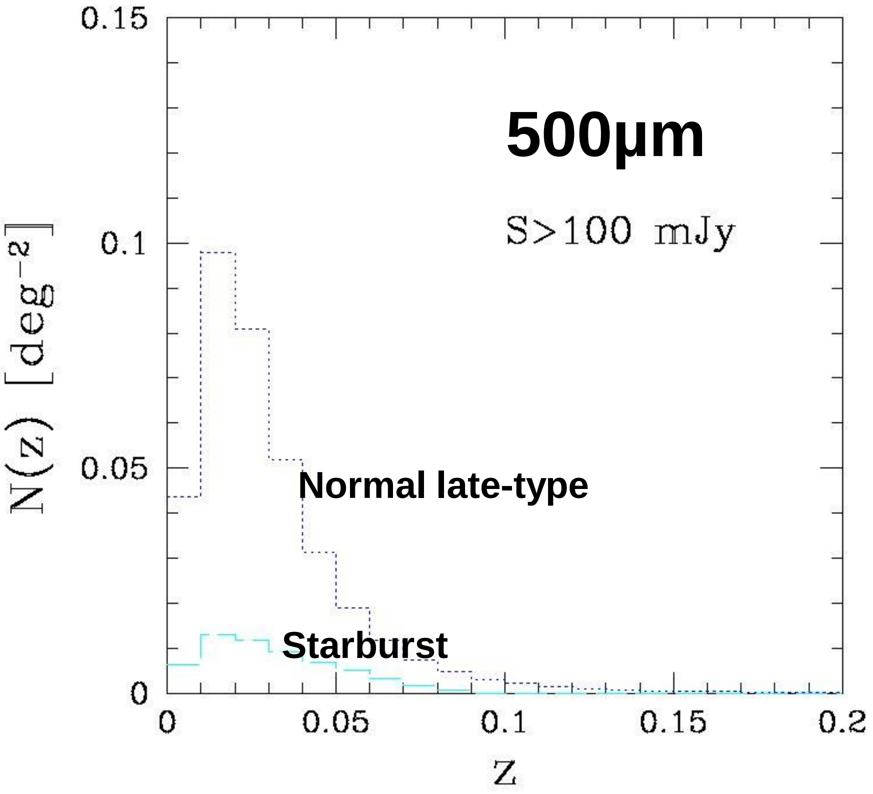
Comparison between counts of strongly lensed galaxies at 1.4 mm predicted by Negrello et al. (2007; long dashed line) with the counts of SPT galaxies without IRAS counterparts (hence presumably at high z). Predictions by Pearson & Khan (2009; solid) and Lagache et al. (2004; short dashes) also shown

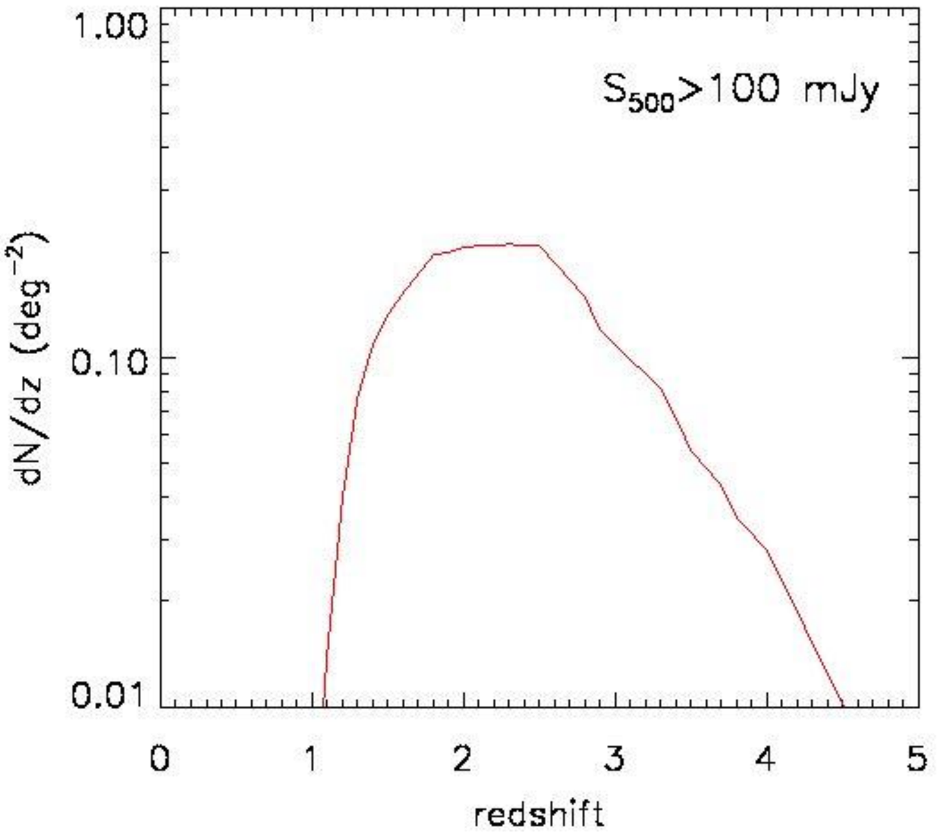


Negrello et al. (2010)

H-ATLAS counts from Clements et al. (2010); predictions by Negrello et al. (2007), based on model by Granato et al. (2004) and Lapi et al. (2006).

Herschel/SPIRE 500µm redshift distributions

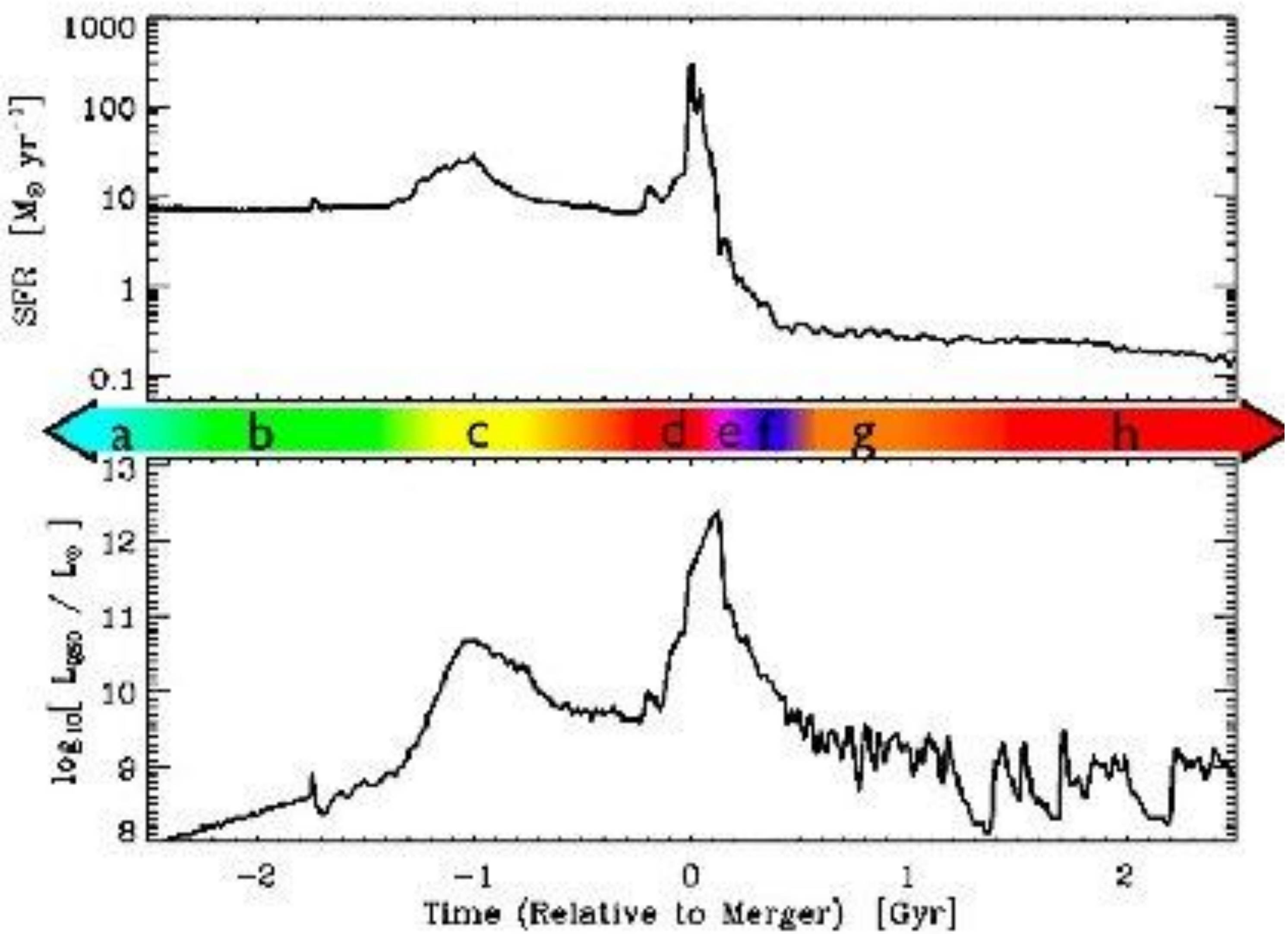




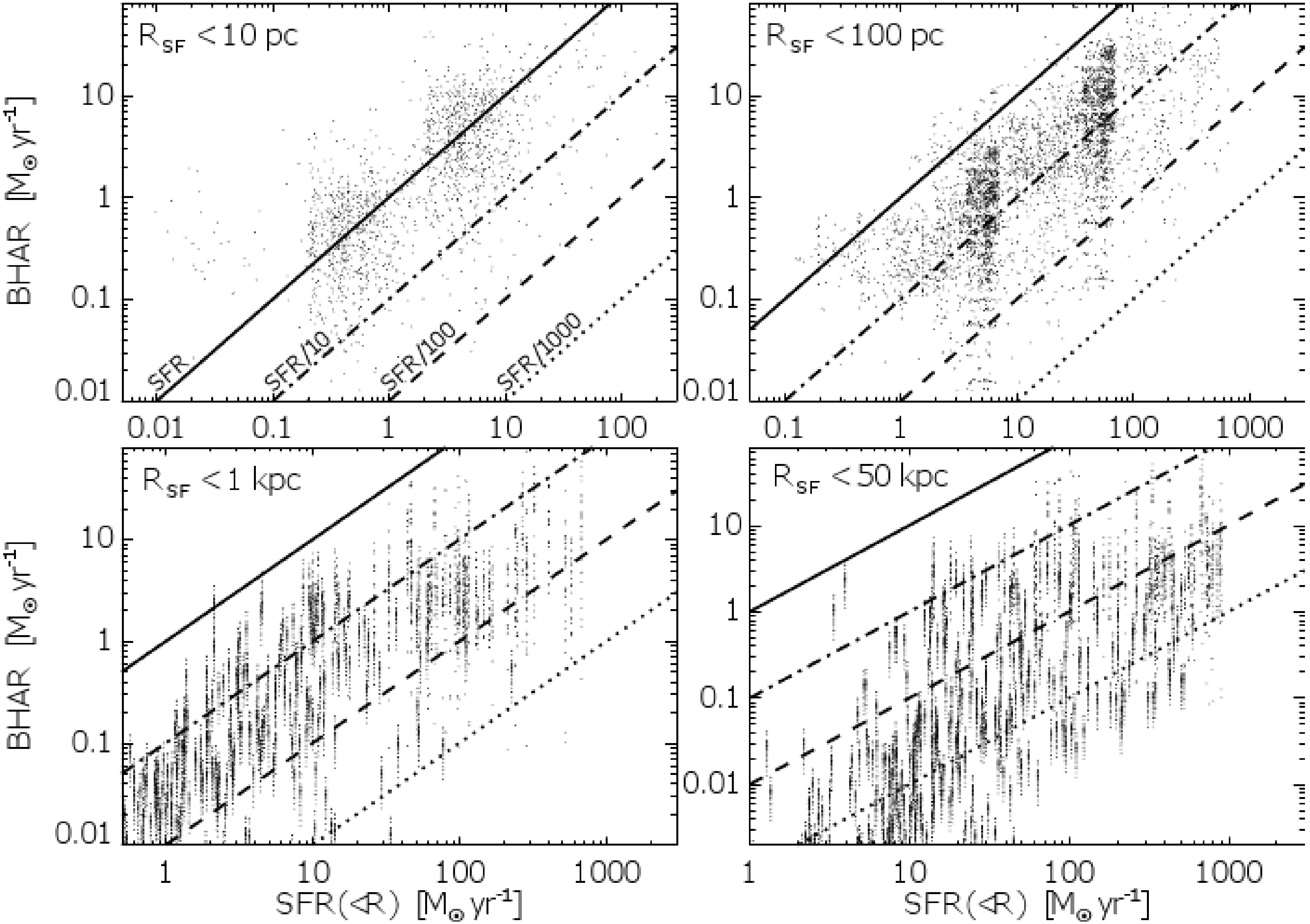
The H-ATLAS SDP catalog contains 10 sources (plus a Galactic dust cloud) with 500 µm flux density above 100mJy: 4 galaxies with spectroscopic redshifts in the range 0.01− 0.05, 1 blazar and 5 strongly lensed galaxies in the redshift range 1.6 − 3.1. The figures show the corresponding predictions by Negrello et al. (2007).

AGN evolution

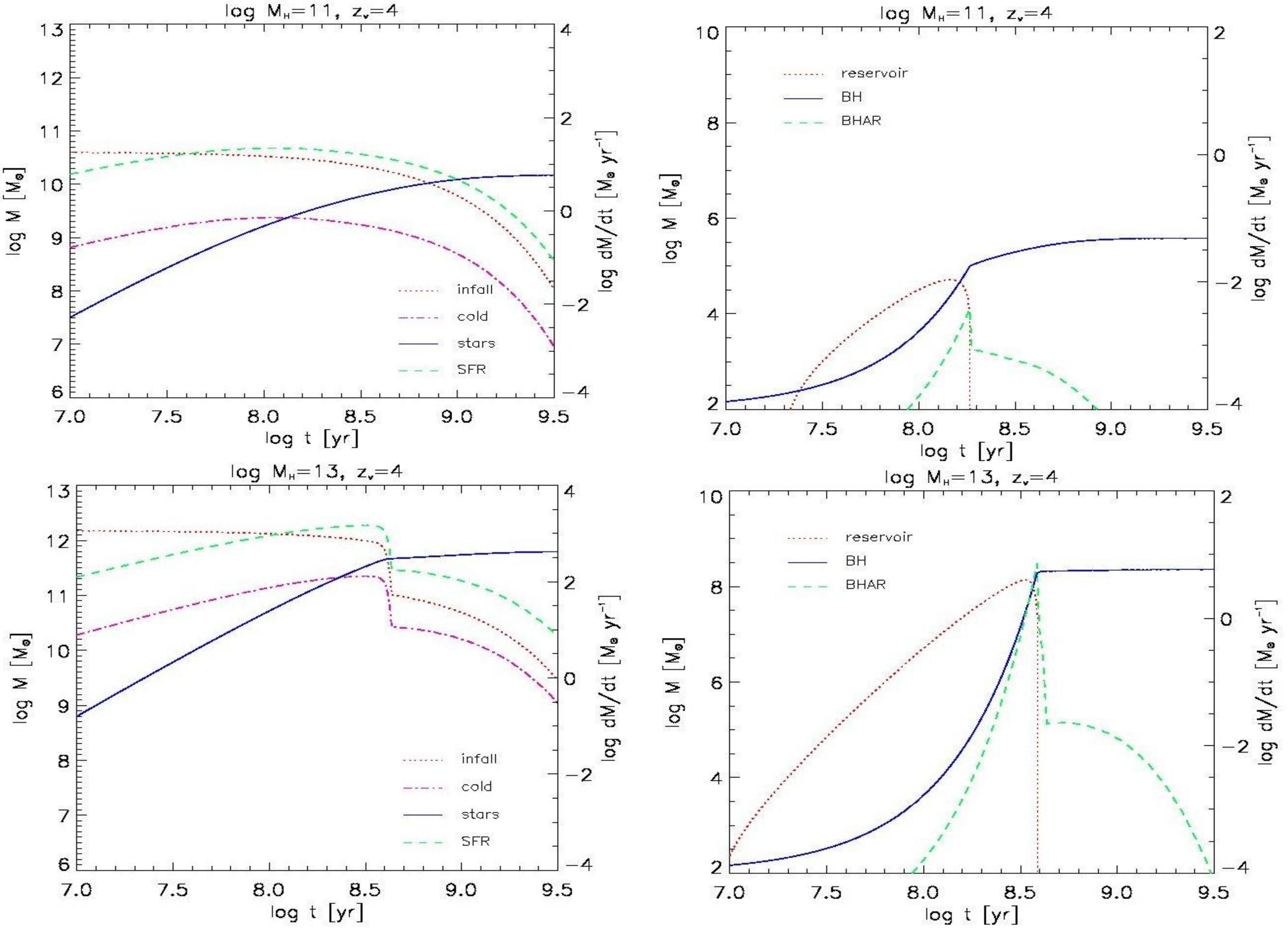
Merger-driven evolution (Hopkins et al. 2008)



Light curve with multiple peaks and SFR well correlated with L_{QSO}



Predicted relationship between the BH accretion rate (BHAR) and the star formation rate (SFR) inside a given radius for a merger +isolated bar-(un)stable disk scenario (Hopkins & Quataert 2010)

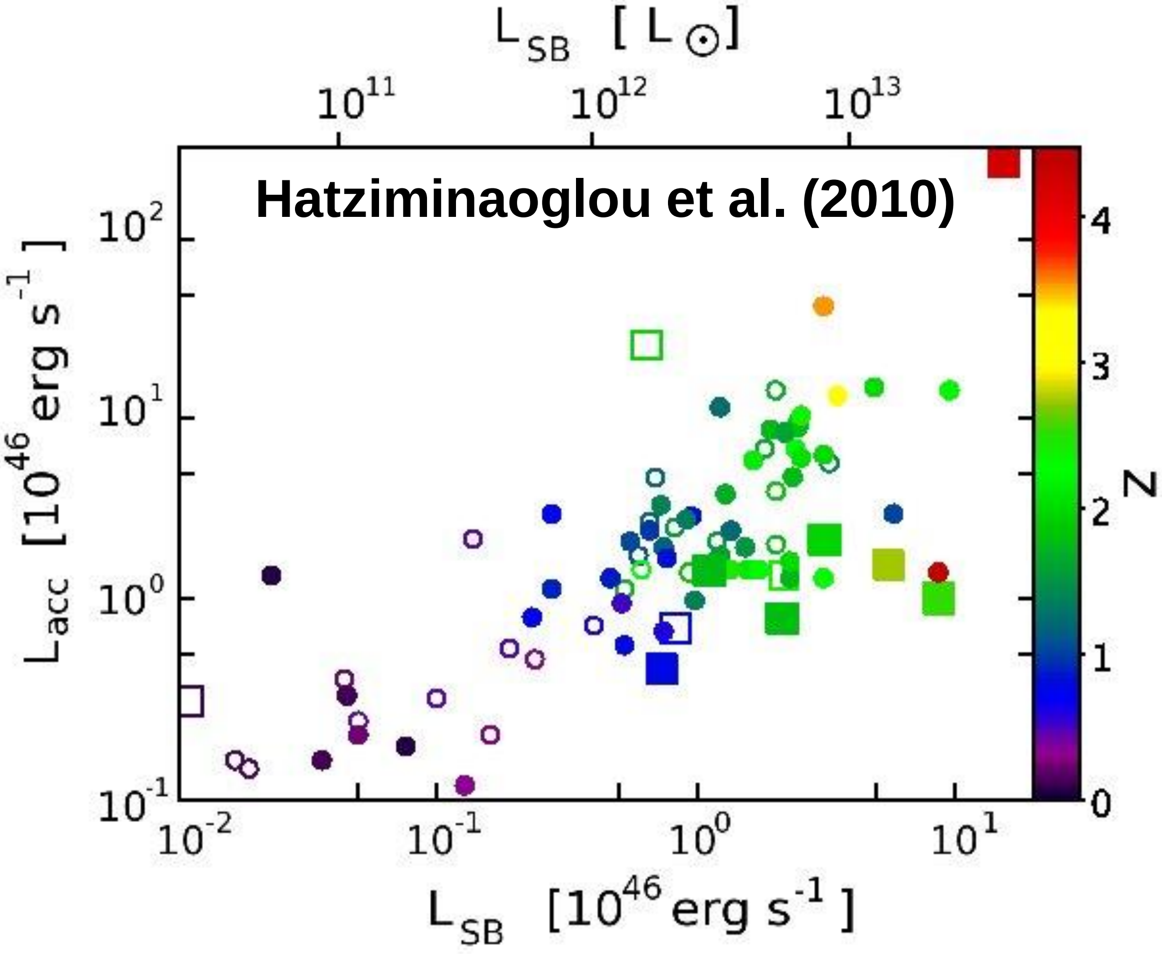


log M_H=11, z_v=4
log M [M_⊙]
log dM/dt [M_⊙ yr^-1]
log t [yr]
infall
cold
stars
SFR
reservoir
BH
BHAR
log M_H=13, z_v=4
7.0
7.5
8.0
8.5
9.0
9.5
6
7
8
9
10
11
12
13
2
4
-2
-4
0

Lapi et al. 06

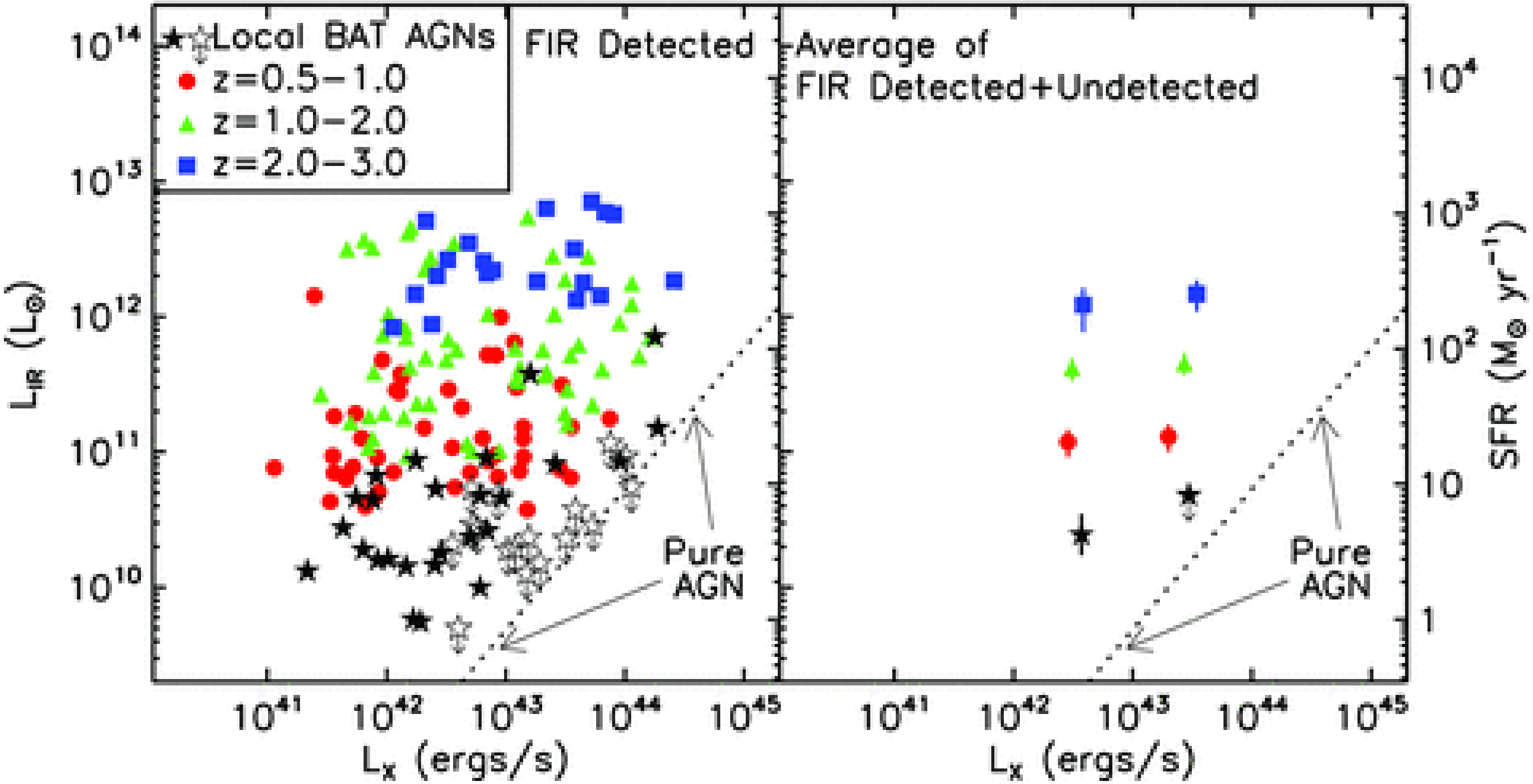
AGN luminosity vs SFR

We expect a correlation between SFR and AGN luminosity ***at high z*** because both are correlated with the halo mass, but not linear (because the AGN accretion rate is mostly Eddington limited, not determined by the SFR; the brightest AGN phase is associated to low SFR) and with a large dispersion. Bonfield et al. (2010) find $L_{FIR} \sim L_{QSO}^{0.32}$ (with some uncertain dependence on z) . Hatziminaoglou et al. (2010) find $L_{FIR} \sim L_{QSO}^{0.35}$ for objects at z > 2, with a large dispersion (see figure)



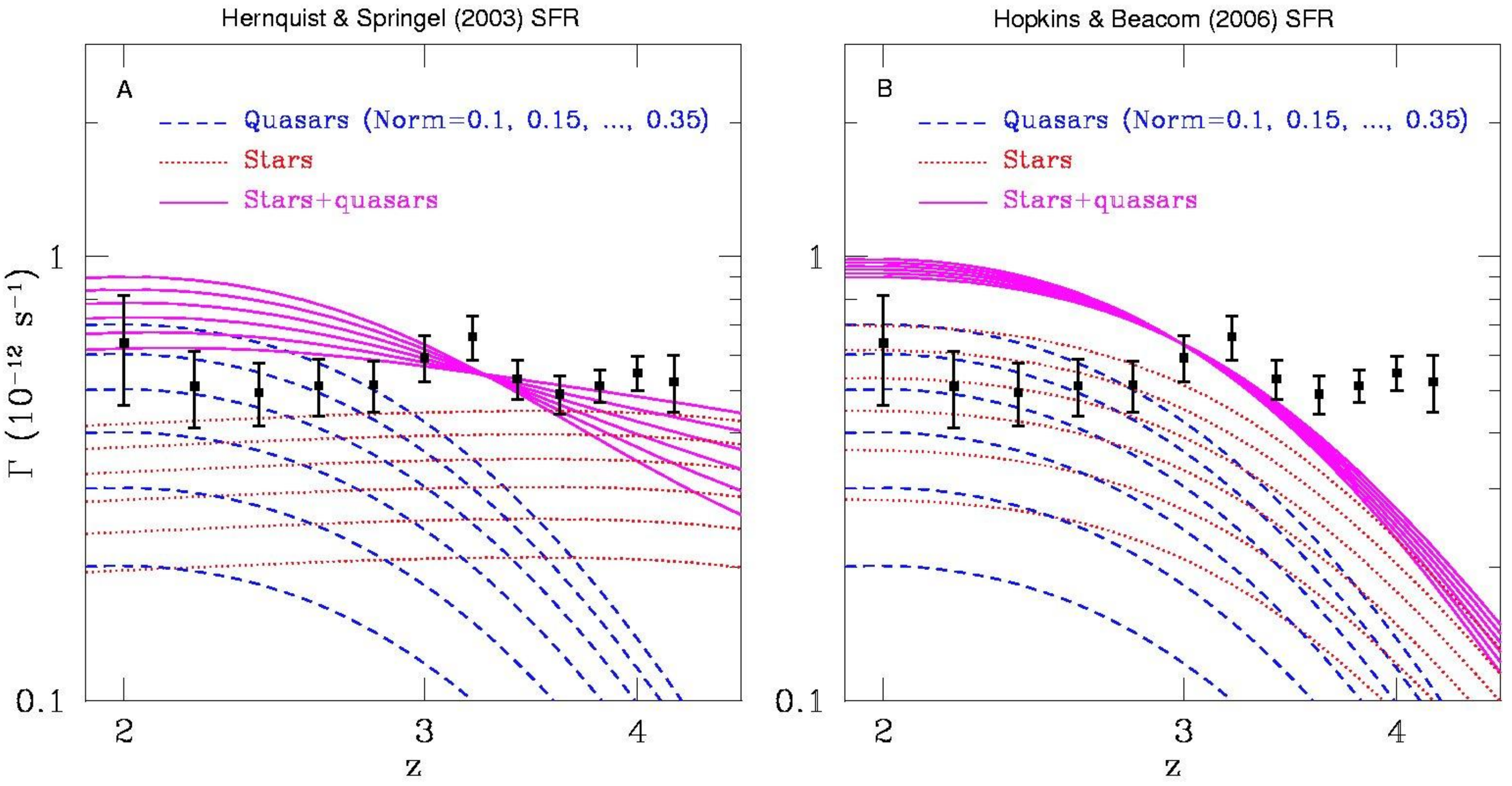
Known AGNs detected by Herschel/SPIRE in Hermes fields

Star-formation vs AGN activity



No correlation between far-IR luminosity (i.e. SFR) determined with Herschel/SPIRE observations (HerMES fields) and Lx (i.e. accretion luminosity) for X-ray selected moderate luminosity AGNs (Mullaney et al. 2011).

Sources of the ionizing background



Comparison of the ionization rate estimated, as a function of z, from τ_{eff} (data points) with the 2 estimated contributions from quasars and star-forming galaxies (Faucher-Giguère et al. 2008).

Conclusion - 1

- Sub-mm observations, particularly from Herschel surveys, are clarifying the reference scenario for the formation and early evolution of galaxies**.**
- The “merger-driven galaxy evolution paradigm” faces serious difficulties. Several observational indications seem to favour a scenario whereby star-formation and BH accretion are *mostly* driven by self-regulation processes and intrinsic galaxy properties.
- However, most evidences are *circumstantial*. ALMA will be crucial to provide *direct measurements* of the spatially resolved morphology and dynamics of high-z star-forming galaxies.

Conclusion - 2

In particular ALMA will provide direct answers to questions like:

- Are high-z SMGs really massive?
- How frequently are they associated to major mergers?
- Are they dynamically stable? Rotationally supported?
- Are they going to evolve into giant ellipticals?
- What is the relationship between SFR and nuclear activity?
- What drives the growth of black holes? What is the role of large-scale environment on the fueling of BHs? Is the gas flowing directly into the SMBH (via the accretion disc) or is it first piling in a reservoir?
- How does stellar and AGN feedback operate?
- Which are the properties of the different ISM phases in these galaxies?

Strongly lensed galaxies selected by Herschel surveys are obvious primary targets for these studies.