Self-regulated evolution of spheroidal galaxies and AGNs

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MOST SUBMILLIMETER GALAXIES ARE MAJOR MERGERS

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Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

Mon. Not. R. Astron. Soc. **425**, 1320–1331 (2012) doi:10.1111/j.1365-2966.2012.21544.x

Gas-rich mergers and feedback are ubiquitous amongst starbursting radio galaxies, as revealed by the VLA, IRAM PdBI and *Herschel*

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Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRASL **429**, L40–L44 (2013) doi:10.1093/mnrasl/

The insignificance of major mergers in driving star formation at $z \simeq 2$

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Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY LETTERS

Mon. Not. R. Astron. Soc. **425**, L61–L65 (2012) doi:10.1111/j.1745-3933.2012.0130

Heavily obscured quasar host galaxies at $z \sim 2$ are discs, not major mergers★

Kevin Schawinski,[1,2]†‡ Brooke D. Simmons,[2,3] C. Megan Urry,[1,2,3] Ezequiel Treister[4] and Eilat Glikman[2,3]§

The Astrophysical Journal, 726:57 (14pp), 2011 January 10 doi:10.1088/0004-637X/726/2/5

THE BULK OF THE BLACK HOLE GROWTH SINCE $z \sim 1$ OCCURS IN A SECULAR UNIVERSE: NO MAJOR MERGER–AGN CONNECTION*

Mauricio Cisternas[1,20], Knud Jahnke[1], Katherine J. Inskip[1], Jeyhan Kartaltepe[2], Anton M. Koekemoer[3], Thorsten Lisker[4], Aday R. Robaina[1,5], Marco Scodeggio[6], Kartik Sheth[7,8], Jonathan R. Trump[9], René Andrae[1], Takamitsu Miyaji[10,11], Elisabeta Lusso[12], Marcella Brusa[13], Peter Capak[7], Nico Cappelluti[13], Francesca Civano[14], Olivier Ilbert[15], Chris D. Impey[9], Alexie Leauthaud[16], Simon J. Lilly[17], Mara Salvato[18], Nick Z. Scoville[7], and Yoshi Taniguchi[19]

Monthly Notices of the Royal Astronomical Society

Mon. Not. R. Astron. Soc. **423**, 1544–1555 (2012) doi:10.1111/j.1365-2966.2012.20975

The origin of discs and spheroids in simulated galaxies

Laura V. Sales,[1★] Julio F. Navarro,[2] Tom Theuns,[3,4] Joop Schaye,[5] Simon D. M. White,[1] Carlos S. Frenk,[3] Robert A. Crain[5] and Claudio Dalla Vecchia[6]

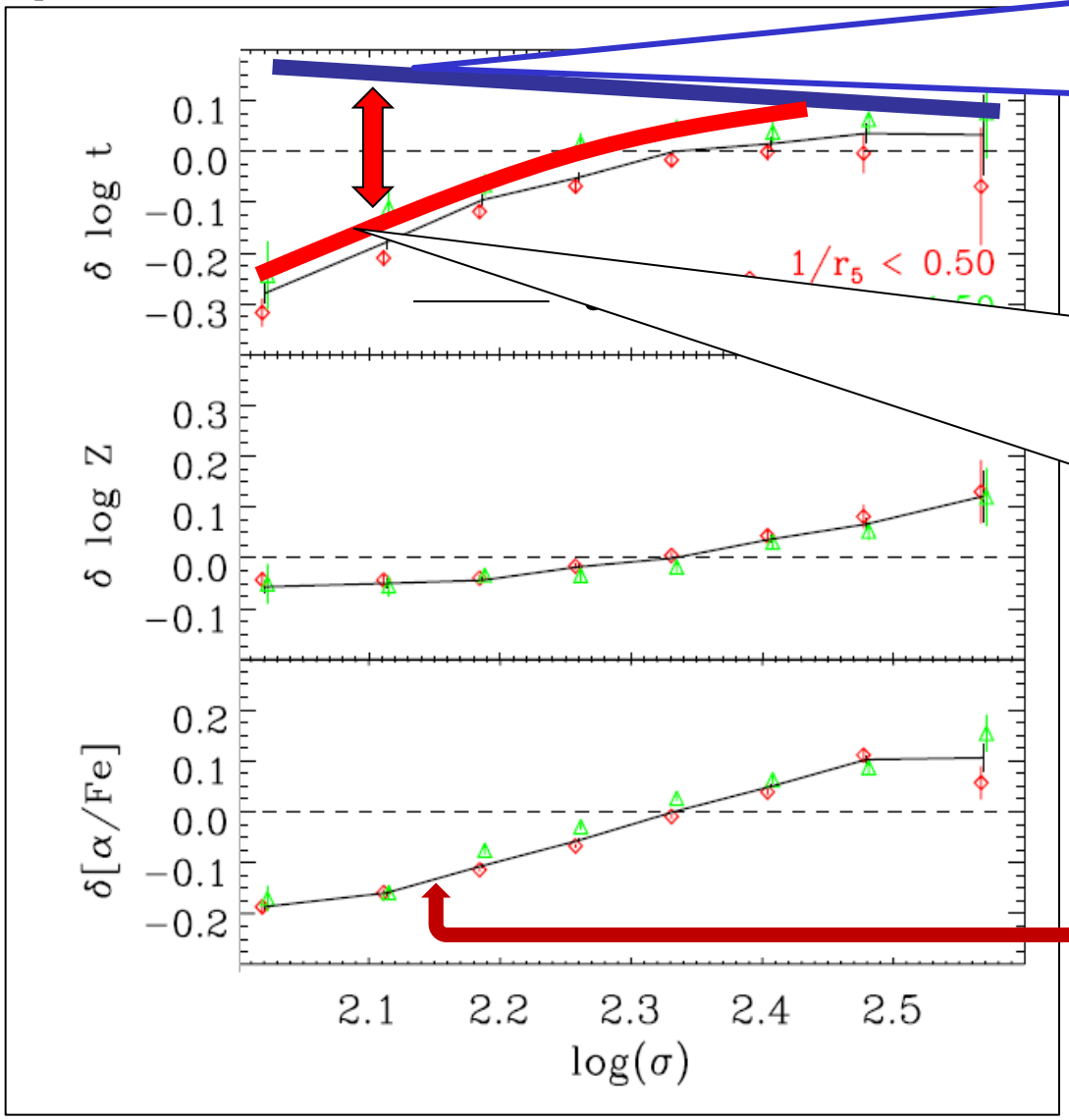
… mergers play a negligible role in the formation of spheroids, whose stars form primarily in situ.

Problems with merger-driven galaxy evolution - 1

- Early type galaxies are characterized by old and homogeneous stellar populations. Correlations tight enough to leave little room for random processes have been known for a long time (colour-luminosity; fundamental plane relations; dynamical mass - luminosity) and have been recently confirmed and strengthened with very large samples.
- Such correlations have been found to be insensitive to environment (Clemens et al. 2009; Nair et al. 2010) and to persist up to substantial redshifts.
- They appear to be driven only by self-regulation processes and intrinsic galaxy properties such as mass.

Galaxy Formation

M.S. Clemens, A. Bressan, B. Nikolic, Rampazzo 09



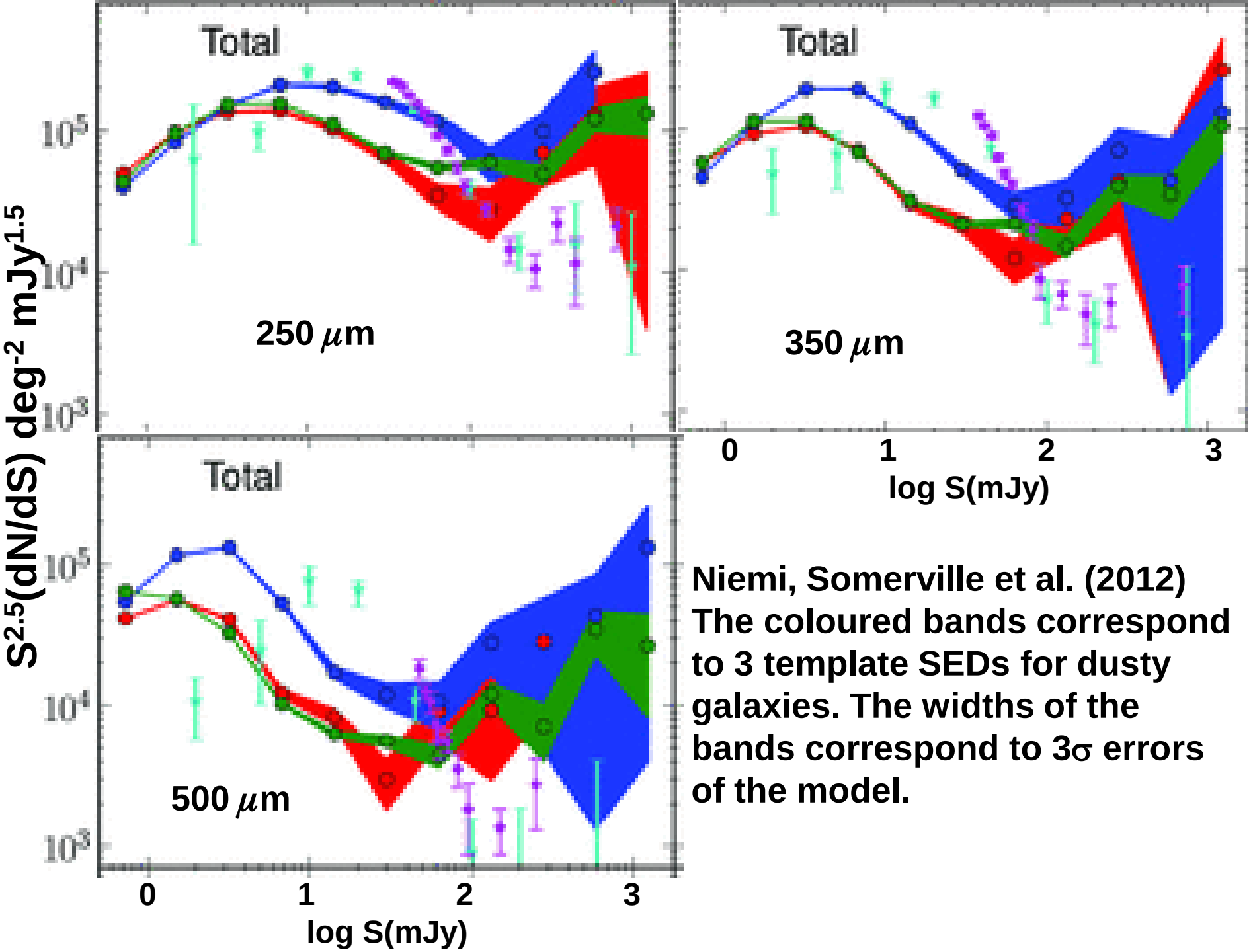
Evolution of DM Halos: smaller halos form first

The order of formation of visible galaxies is reversed: in smaller galaxies star formation proceeds slowly

lower [α/Fe] indicates longer duration

Problems with merger-driven galaxy evolution - 2

- **α-enhancement**: depending on the slope of the assumed IMF, the observed α/Fe element ratios require star formation timescales $\leq 10^9$ years (e.g. Matteucci 1994; Thomas et al. 1999). But in models of merger-driven galaxy formation, star formation in ellipticals typically does not truncate after 1 Gyr (Thomas & Kauffmann 1999; see however Arrigoni et al. 2010; Khochfar & Silk 2010).
- **Lifetime of Sub-Millimeter bright Galaxies:** *if a standard IMF is assumed* (sub-)mm counts imply that several percent of massive galaxies are forming stars at rates of thousands M_{sun}/yr at z= 2 – 3. This requires that this SFR is sustained for ~ 0.5-1 Gyr, much longer than the timescale of a merger-induced starburst.



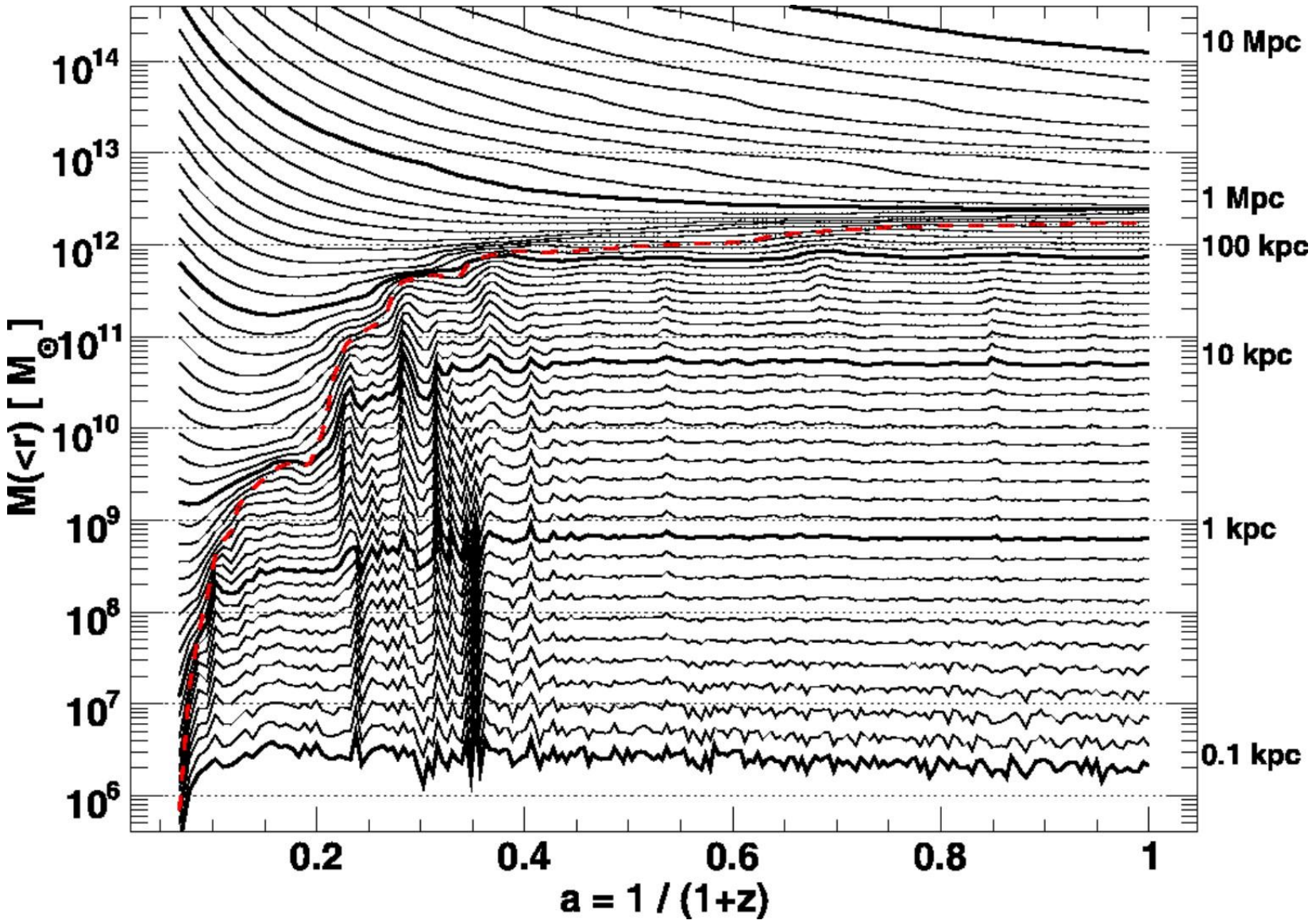
Niemi, Somerville et al. (2012)
The coloured bands correspond to 3 template SEDs for dusty galaxies. The widths of the bands correspond to 3σ errors of the model.

Self-regulated evolution - 1

- In the build-up of a galactic halo we can schematically identify two phases (Zhao et al. 2003):
  - a fast accretion phase (timescale « $H(z)^{-1}$) in which the potential well is created by major mergers, and that can define the formation epoch of the galaxy
  - a slow accretion (minor merger) phase in which mass is added in the outskirts of the halo, affecting only weakly the central region where the stellar component resides.

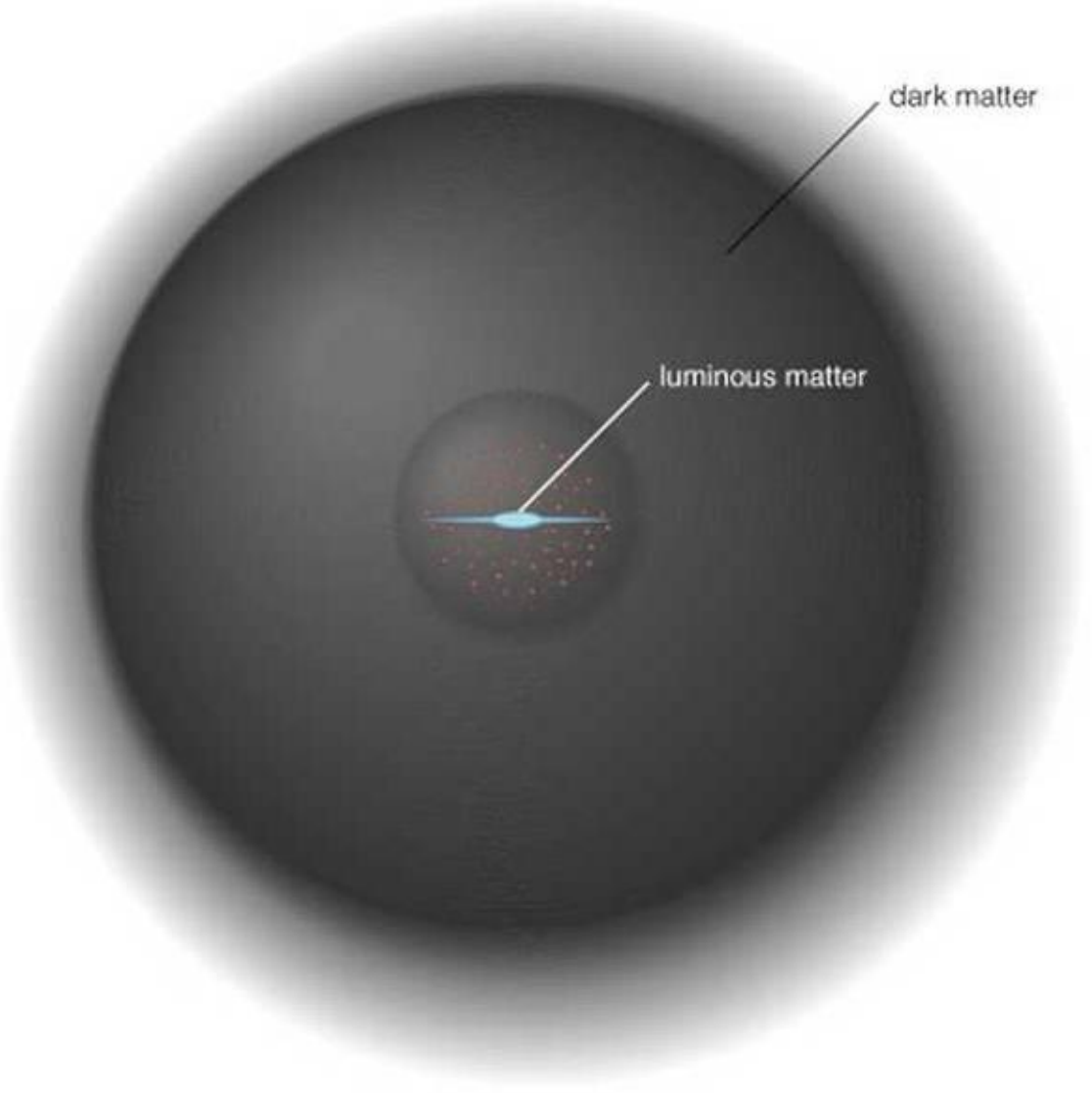
This second phase affects only marginally the stellar component, although occasionally major mergers occur, but they involve a minority of large galaxies.

Mass within size of visible galaxy



Diemand et al. (2007)

Size comparison: stars vs dark matter



The size of the halo is 20-30 times larger than the size of the stellar distribution. Thus the cross section of the visible galaxy is ~0.1% of that of the dark halo and collisions between substructure halos and the visible part of the galaxy occur quite infrequently.

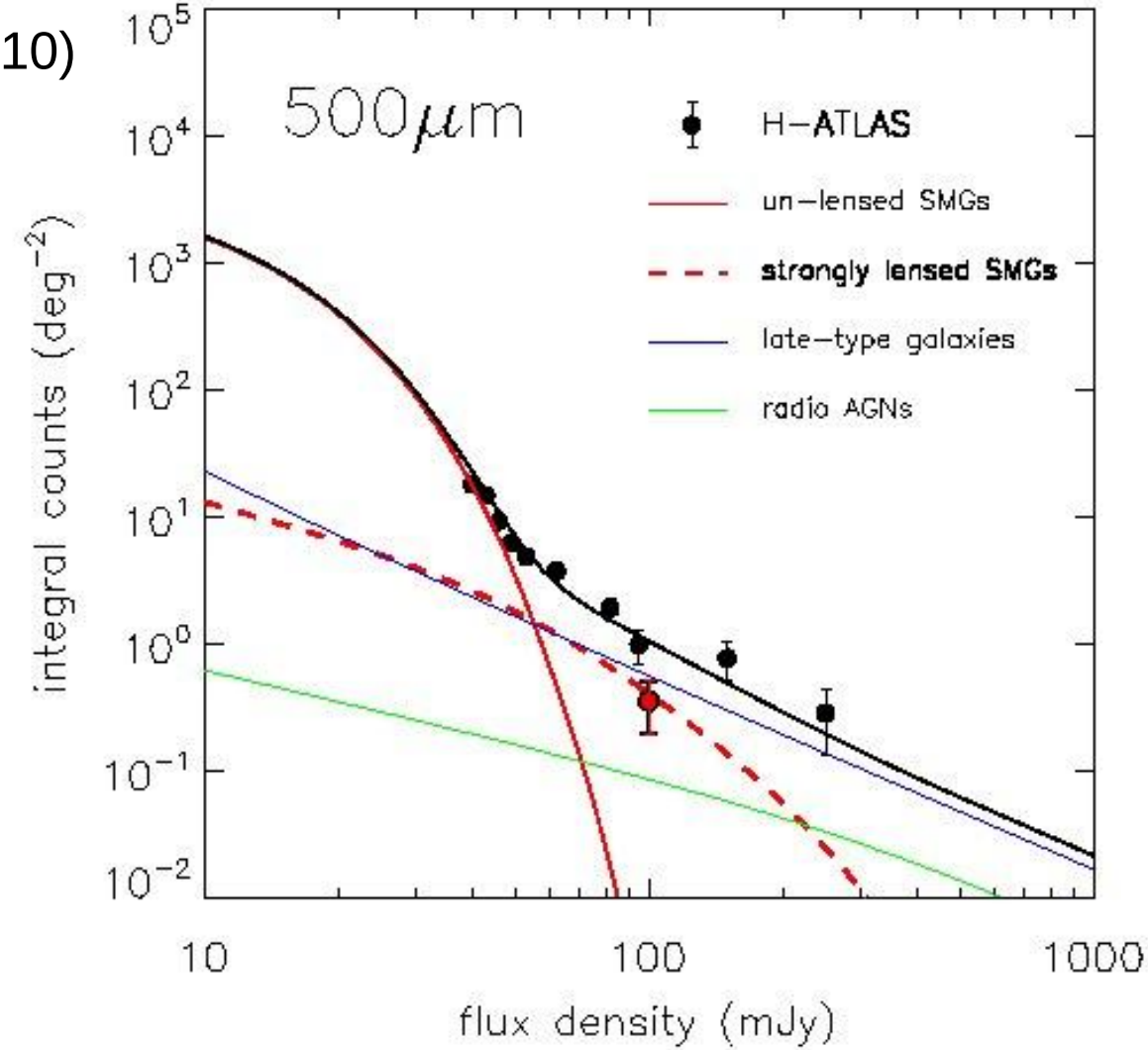
$$R_v \approx 170 * 4/(1+z_v) * (M_v/10^{13}\ M_{sun})^{1/3}\ \text{kpc}$$

Self-regulated evolution - 2

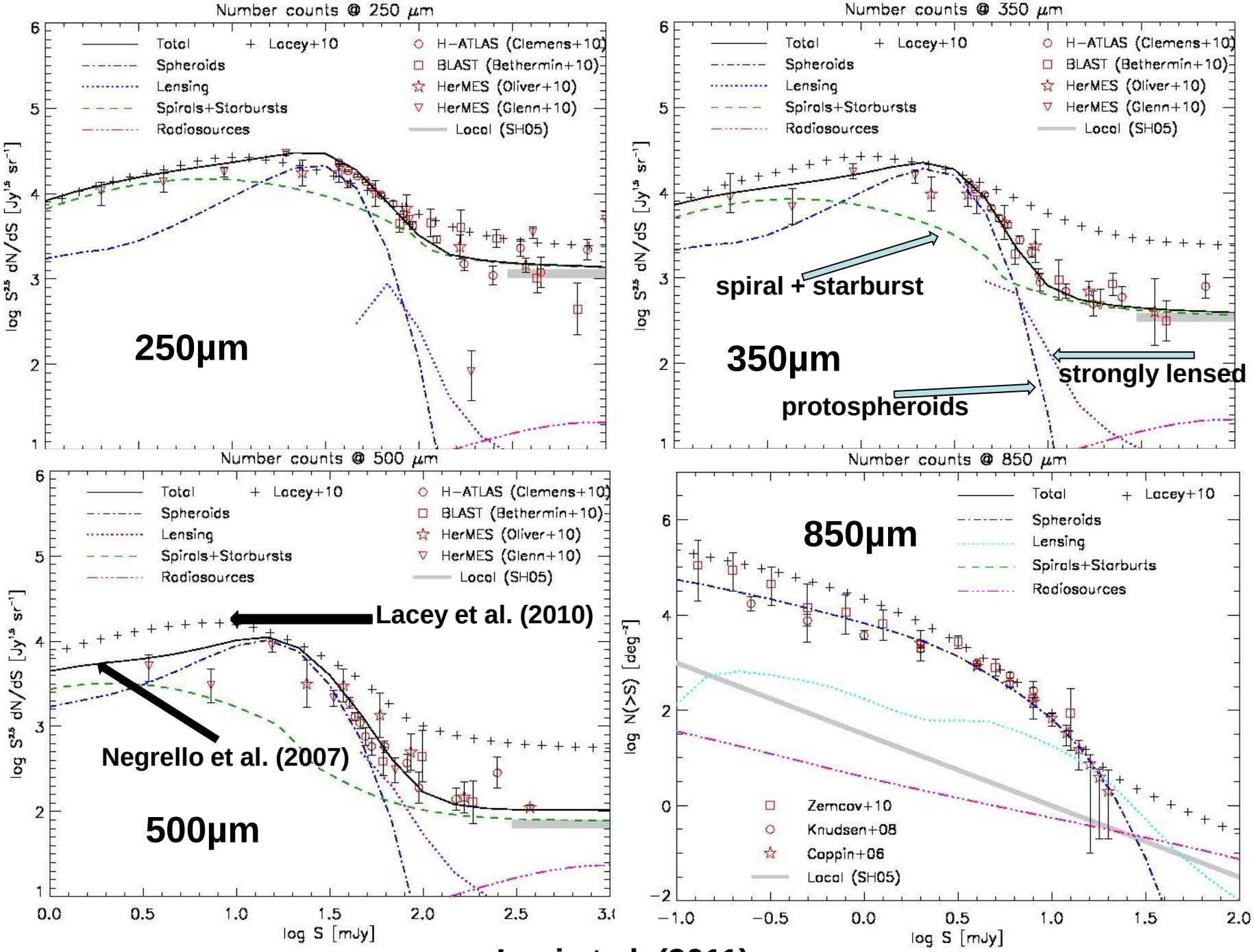
- Plenty of gas available: the total mass density in stars is Ω_{star}=0.0027±0.0005 (Fukugita & Peebles 2004), i.e. only 5.8%±1.1% of the initial baryonic mass density (Ω_b = 0.0456 ± 0.0016; Komatsu et al. 2010) is used to form stars. No need of inflows from outside. If they happen, probably add little.
- Enhanced SFR rate in most massive galaxies: very high (thousands M_{sun}/yr) SFRs for very massive high-z galaxies, without invoking non-standard (top-heavy) IMFs.
- Fast metal enrichment and therefore rapid increase of dust abundance.
- The two ingredients above allow to easily account for (sub)-mm counts and redshift distributions.

Herschel/SPIRE 500µm counts

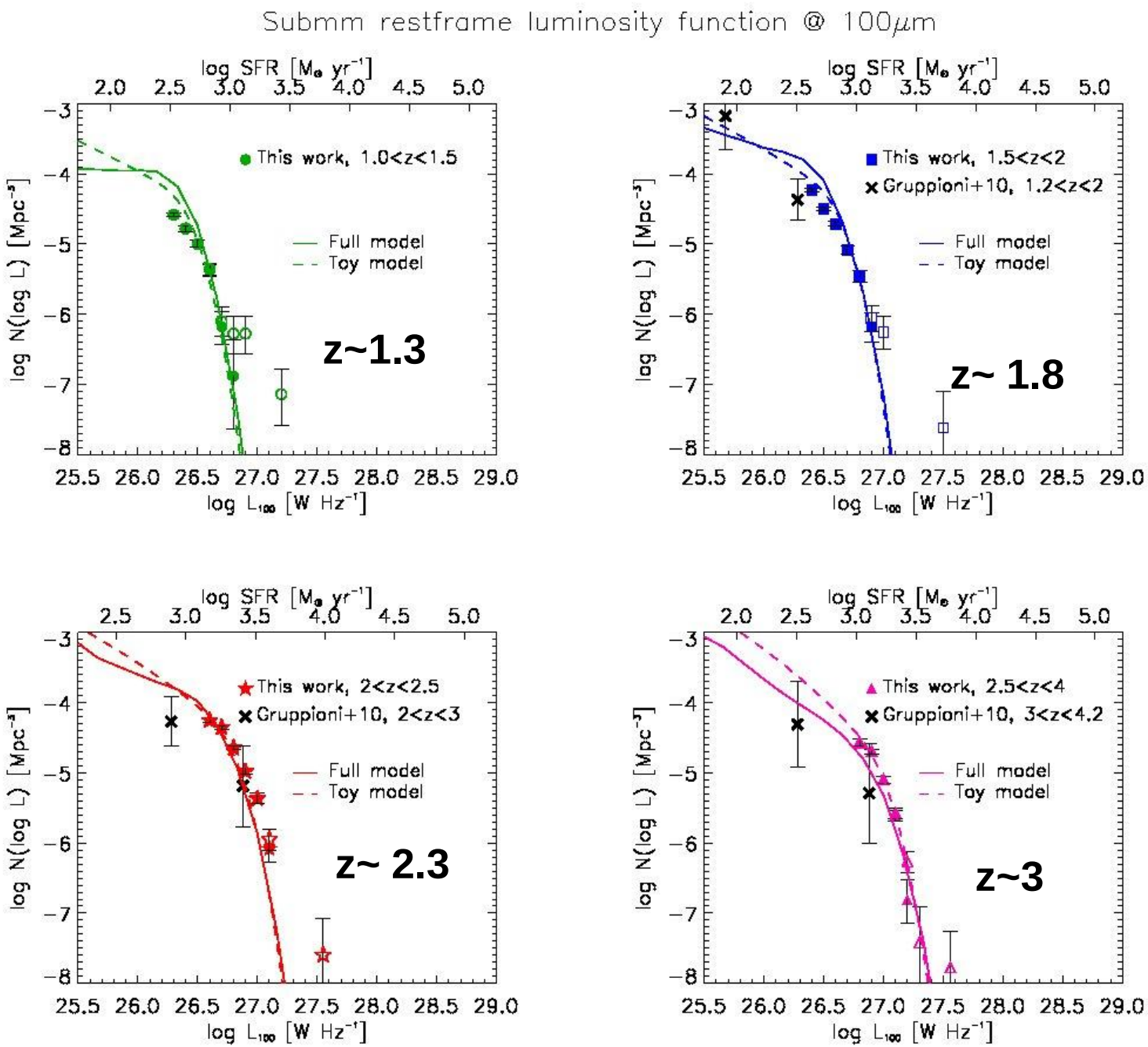
Negrello et al. (2010)



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).



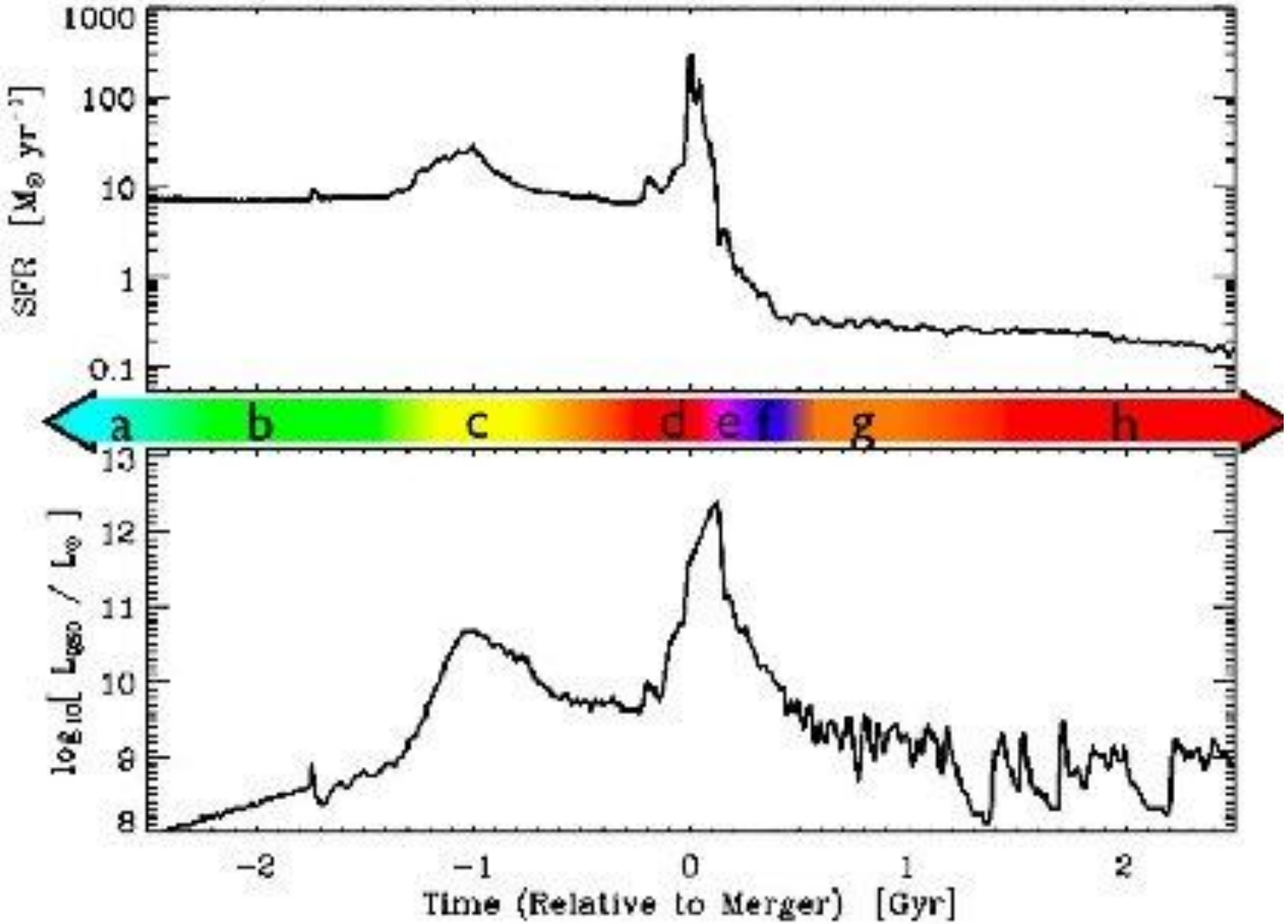
Lapi et al. (2011)



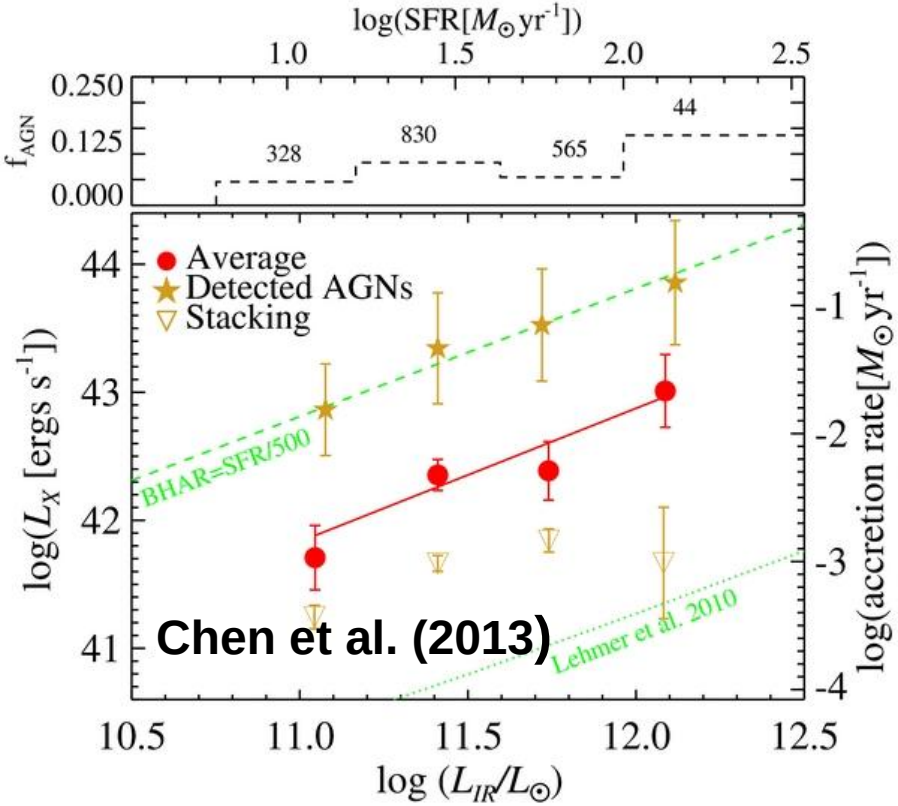
100μm Luminosity Function at different redshifts (Lapi et al. 2011)

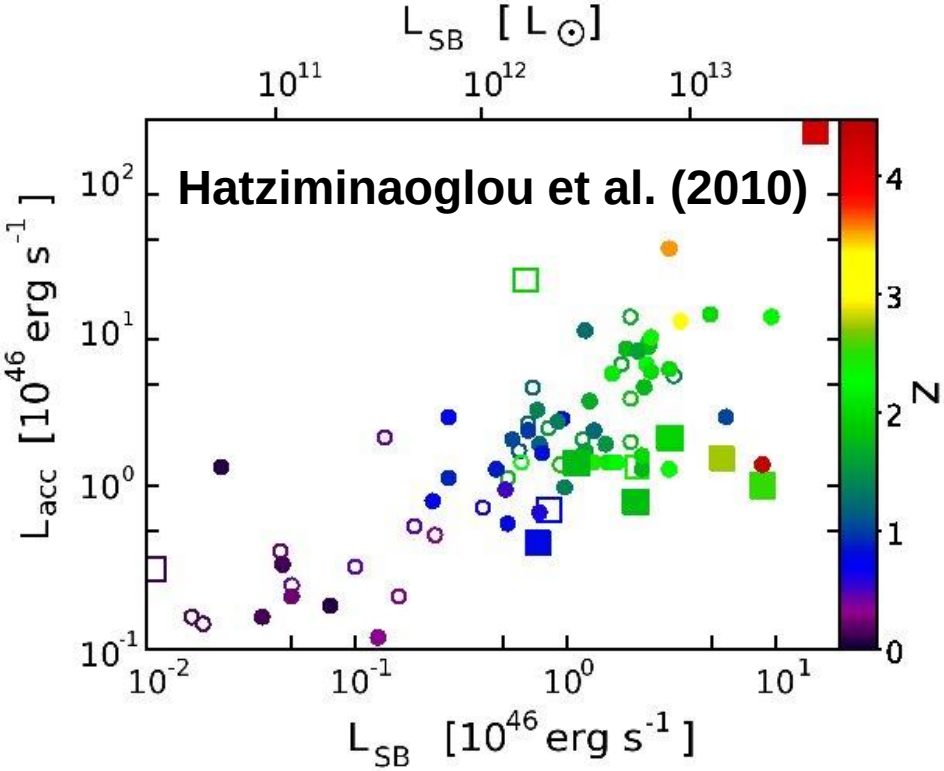
AGN evolution

Merger-driven evolution (Hopkins et al. 2008)



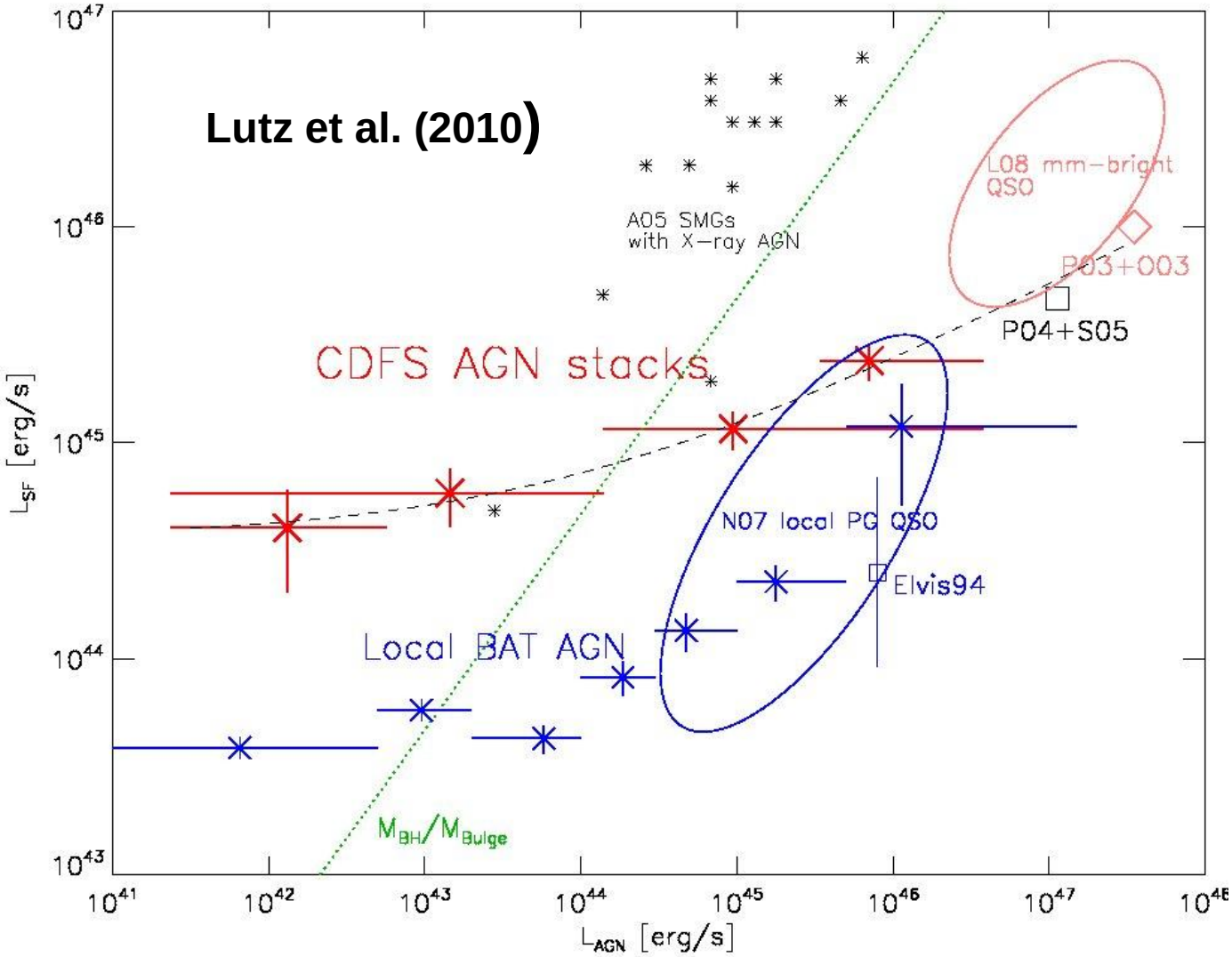
Light curve with multiple peaks and SFR well correlated with L_{QSO}



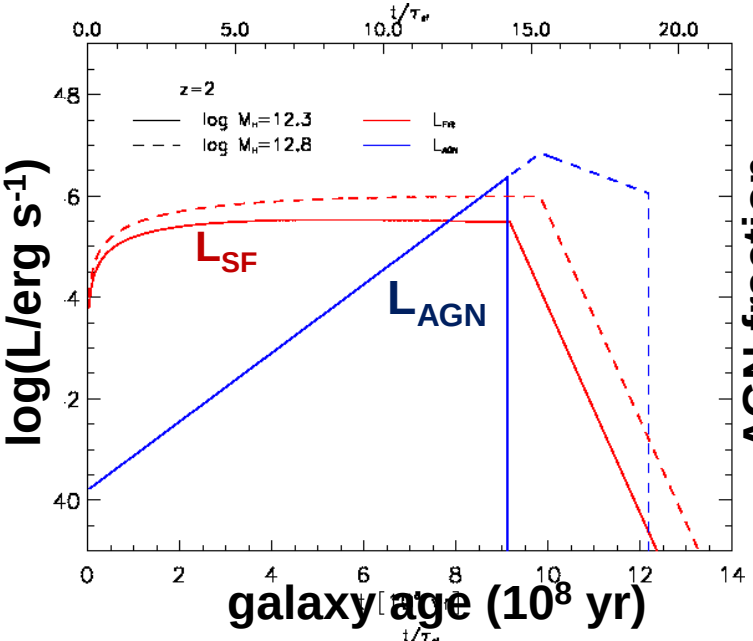


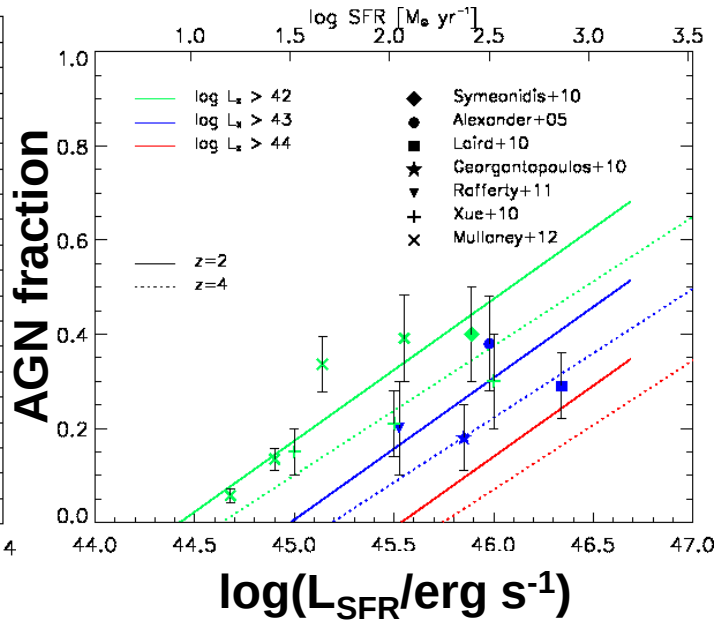
Approximate proportionality between SFR and accretion rate found for far-IR selected galaxies in the redshift range $0.25 < z < 0.8$ (left panel). The correlation weakens as we move to slightly higher redshifts and disappears at $z \geq 2$ (right panel).

SFR vs accretion rate

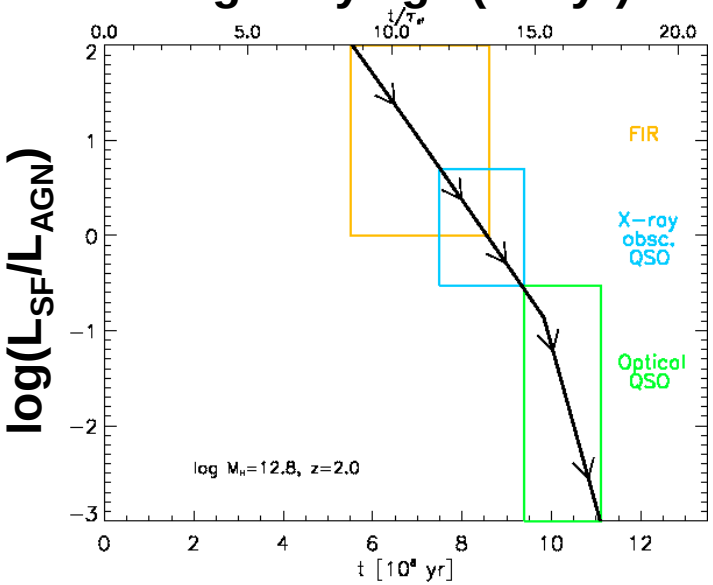


Galaxy-AGN co-evolution in the self-regulated model -1

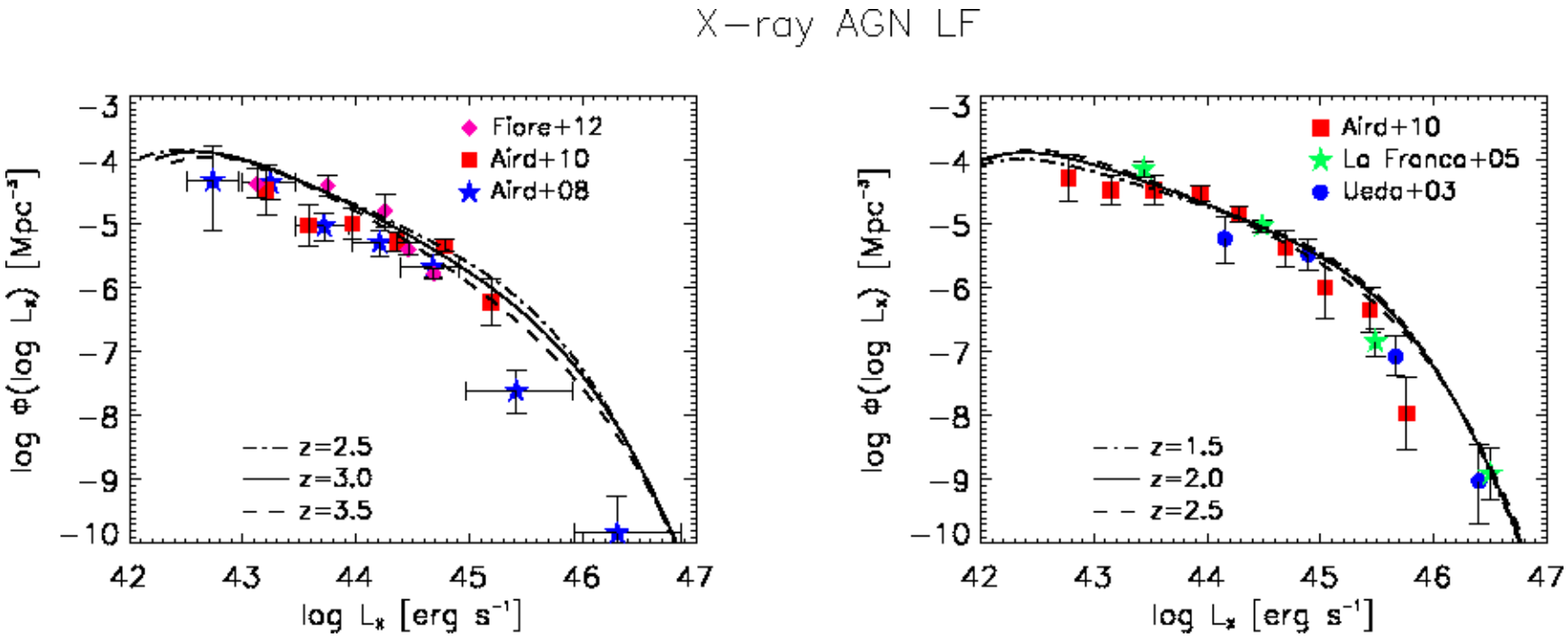




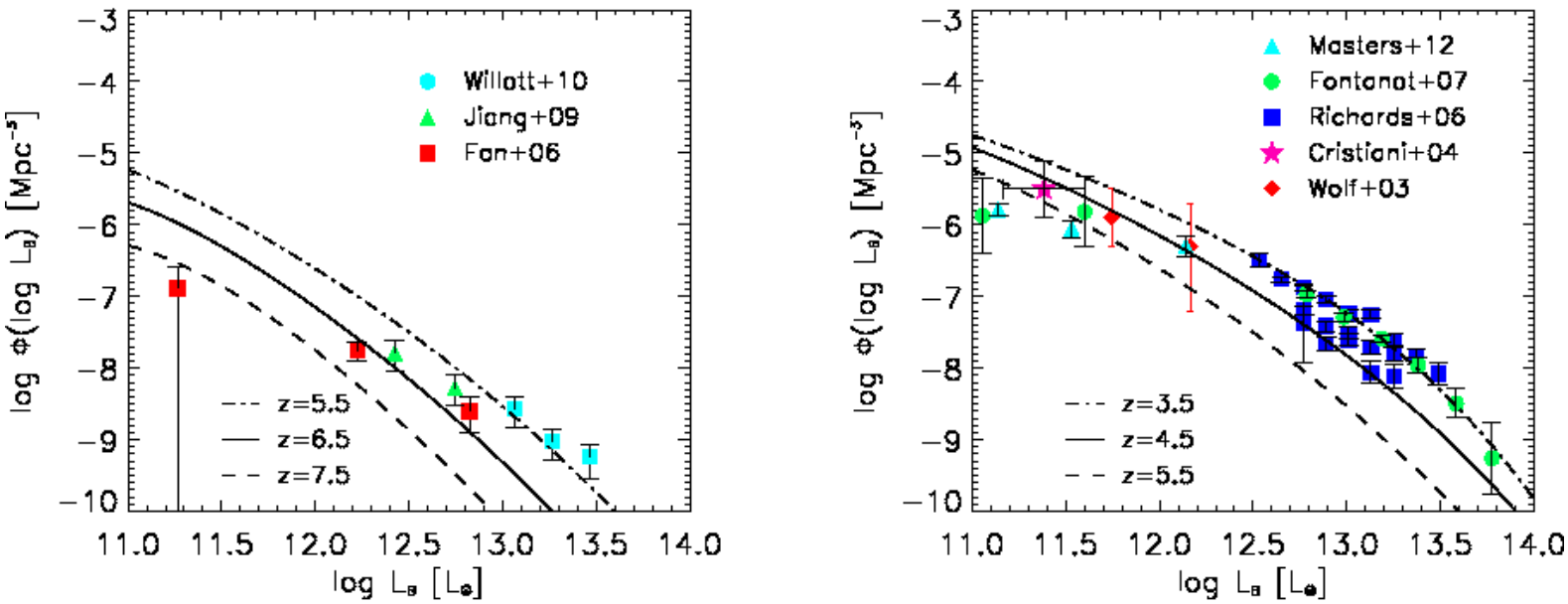
Comparison of the evolution of L_{AGN} and L_{SF} . Dust obscured evolution of L_{AGN} Eddington limited, hence independent of host galaxy properties. Sort of proportionality between L_{AGN} and L_{SF} when L_{AGN} around its maximum: fraction of X-ray detected AGNs in far-IR/sub-mm selected galaxies is higher for the far-IR brighter objects that have higher L_{AGN}/L_{SF} ratios. L_{SF}/L_{AGN} ratio strongly decreases afterwards in a way that depends on halo mass. From Lapi et al. (2013).

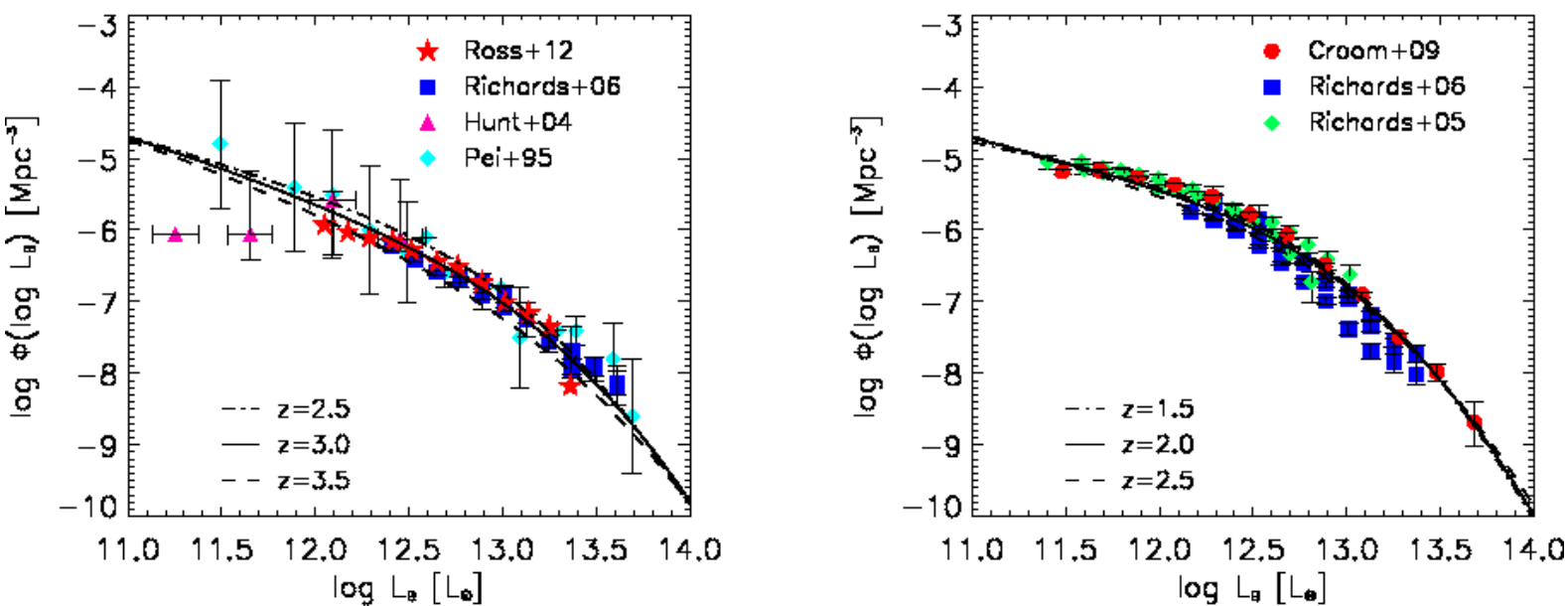


X-ray luminosity functions of AGNs

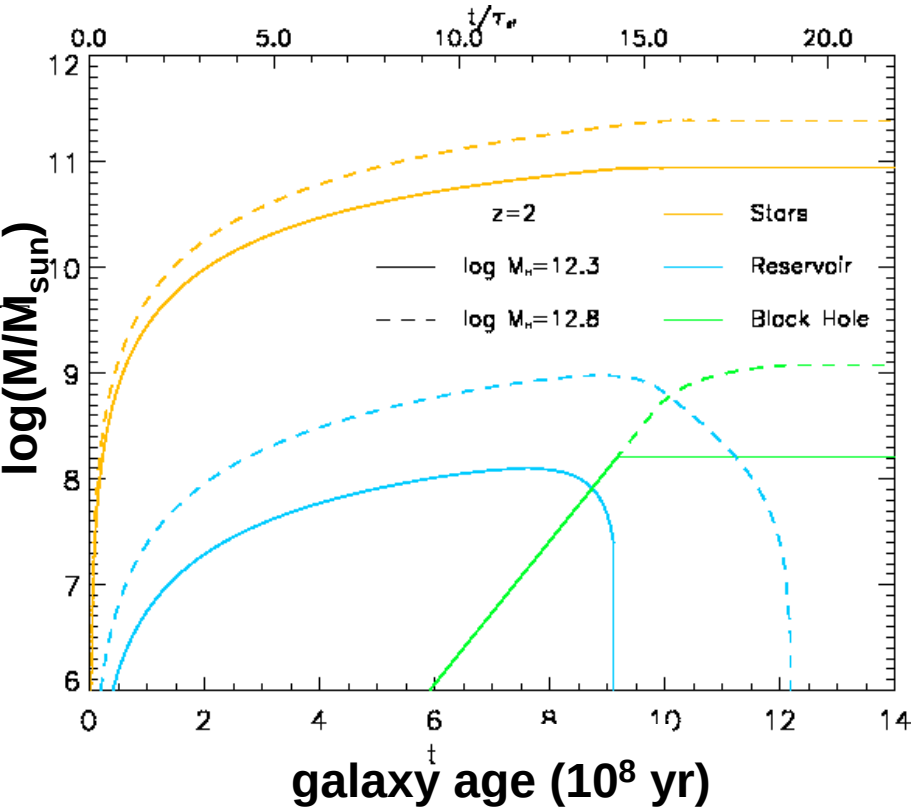


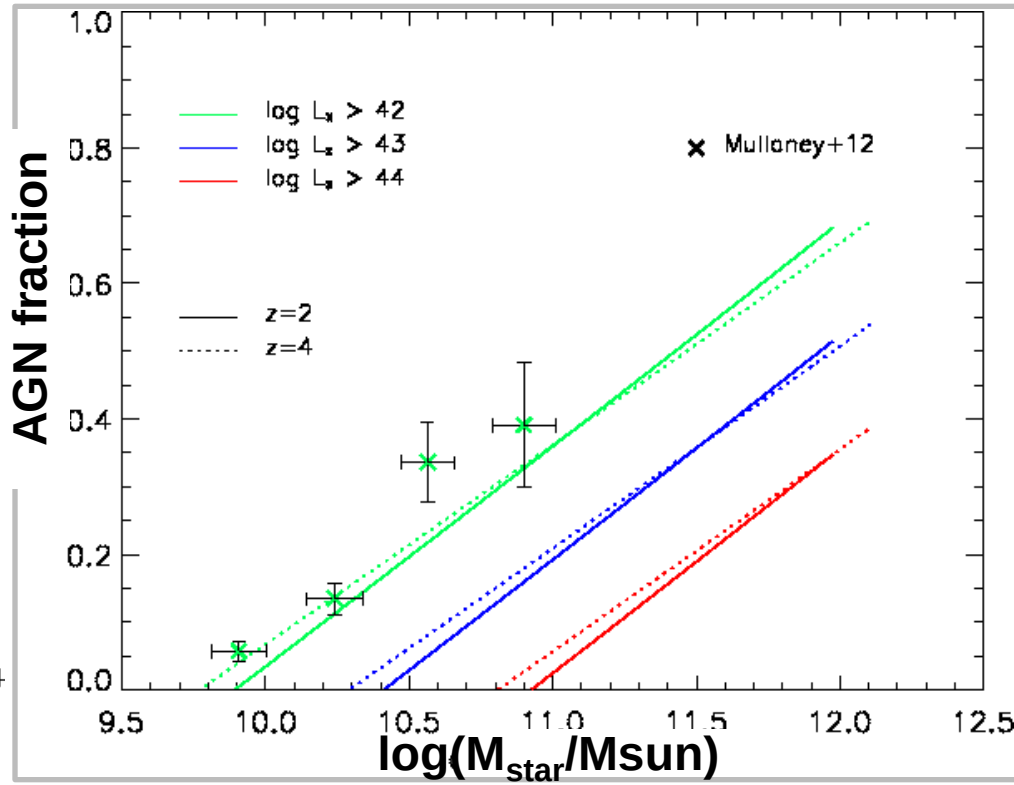
Optical luminosity functions of AGNs





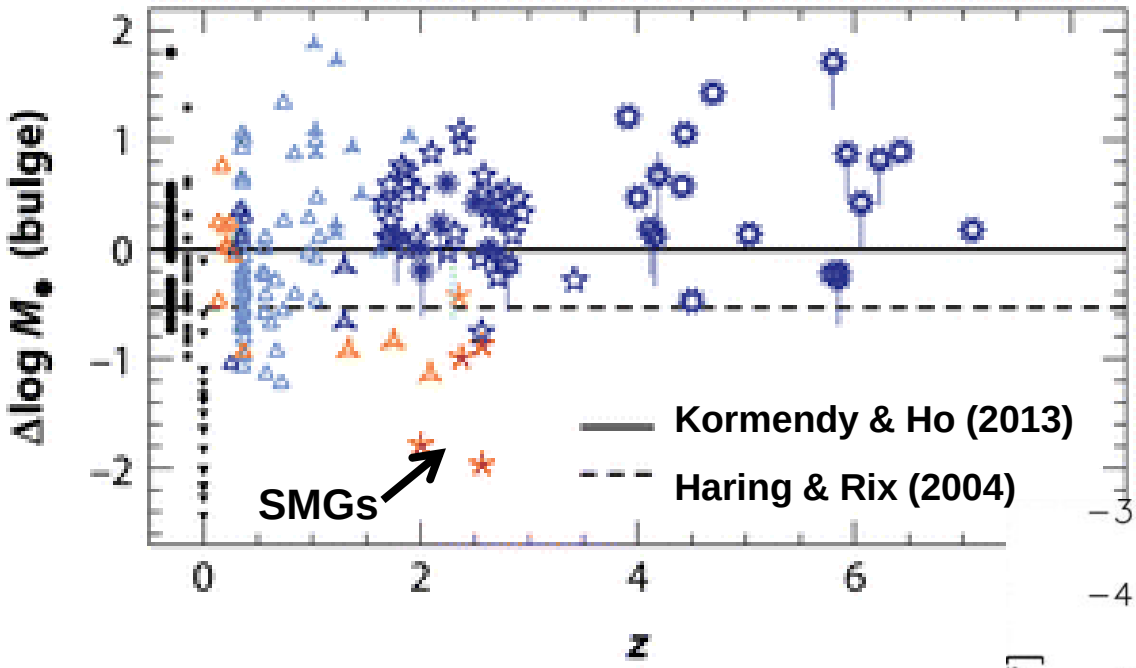
Galaxy-AGN co-evolution in the self-regulated model - 2





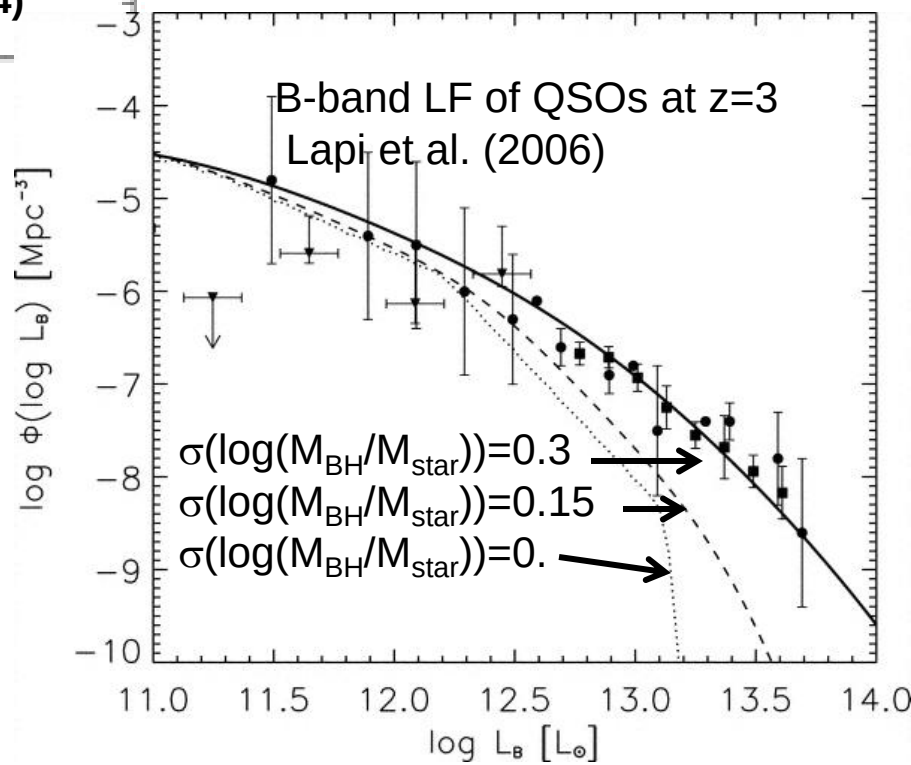
The BH mass growth follows, with some delay, the growth of stellar mass. Hence a higher AGN fraction is expected in star-forming galaxies with higher stellar mass. From Lapi et al. (2013).

Did BHs grow faster than their hosts formed stars or were assembled?



High-z BHs found to have M_{BH}/M_{star} ratios higher than local values. Sub-mm galaxies found to have lower ratios.

The distribution of M_{BH}/M_{star} ratios has a large scatter. The high-luminosity tail of the QSO LF is dominated by sources with the highest ratios. Only the brighest QSOs can be detected at high-z.



Summary - 1

- The “merger-driven galaxy evolution” paradigm faces serious difficulties. Several observational indications favour a scenario whereby star-formation and BH accretion in *proto-spheroidal galaxies* are *mostly* driven by self-regulated processes and intrinsic galaxy properties.
- The self-regulated evolutionary scenario provides a good fit to a broad variety of data on the evolution of both galaxies and AGNs. In particular:
  - It naturally reproduces the counts and the redshift-dependent luminosity functions of sub-mm selected galaxies, that are very hard to account for by alternative scenarios.
  - It was the only one capable of successfully predicting the sub-mm counts of strongly lensed galaxies.

Summary - 2

- This scenario also accounts for the population properties of high-z AGNs as well as for their relationships with the properties (halo mass, stellar mass, SFR) of host galaxies.
- Recent findings that high-z BHs have M_{BH}/M_{star} ratios higher than local values while sub-mm galaxies have lower ratios naturally fit in this framework;
  - During most of the sub-mm bright galaxy evolution phase the Eddington limited accretion rate is lower than the SFR
  - The final BH mass is determined by the mass of the reservoir whose ratio to M_{star} has a large variance. At high z AGNs with M_{BH}/M_{star} ratios in the high tail of the distribution are preferentially selected.