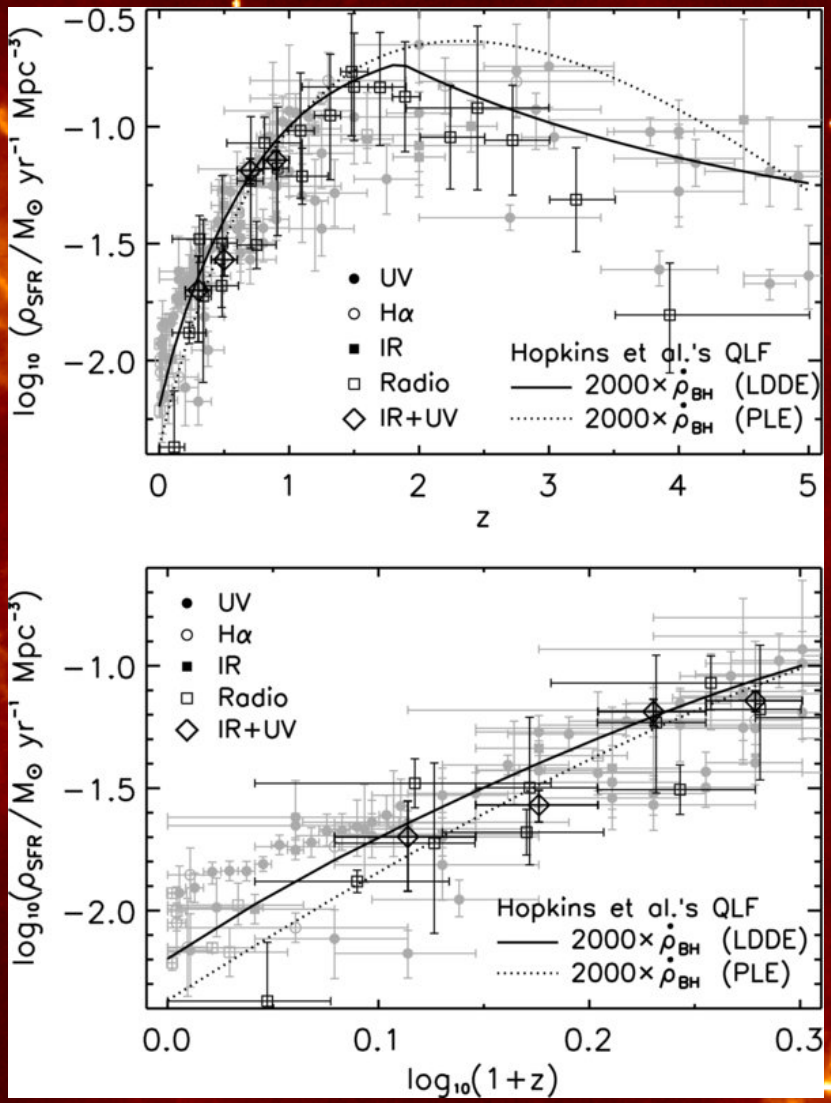
Clustering of Star-forming Galaxies and connections with AGN activity

MANUELA MAGLIOCCHETTI
IAPS-INAF

Collaborators: Herschel PEP team (D.Lutz, P.Popesso, D.Rosario et al.)
& A.Lapi, M.Negrello, G.De Zotti., G.Danese

Credits for image: Hi-GAL

Rationale: Why are star-forming galaxies important for AGN?



Remarkable similarity between cosmic history of star formation and black hole accretion.

Plot from Zeng et al. 2009.
BH accretion history from Hopkins+2007 AGN LF assuming ε =0.1 for radiation efficiency.
BH accretion curve shifted upwards by factor ~2000.

Intrinsic and very tight connection between star-forming phase of a galaxy and its AGN phase.

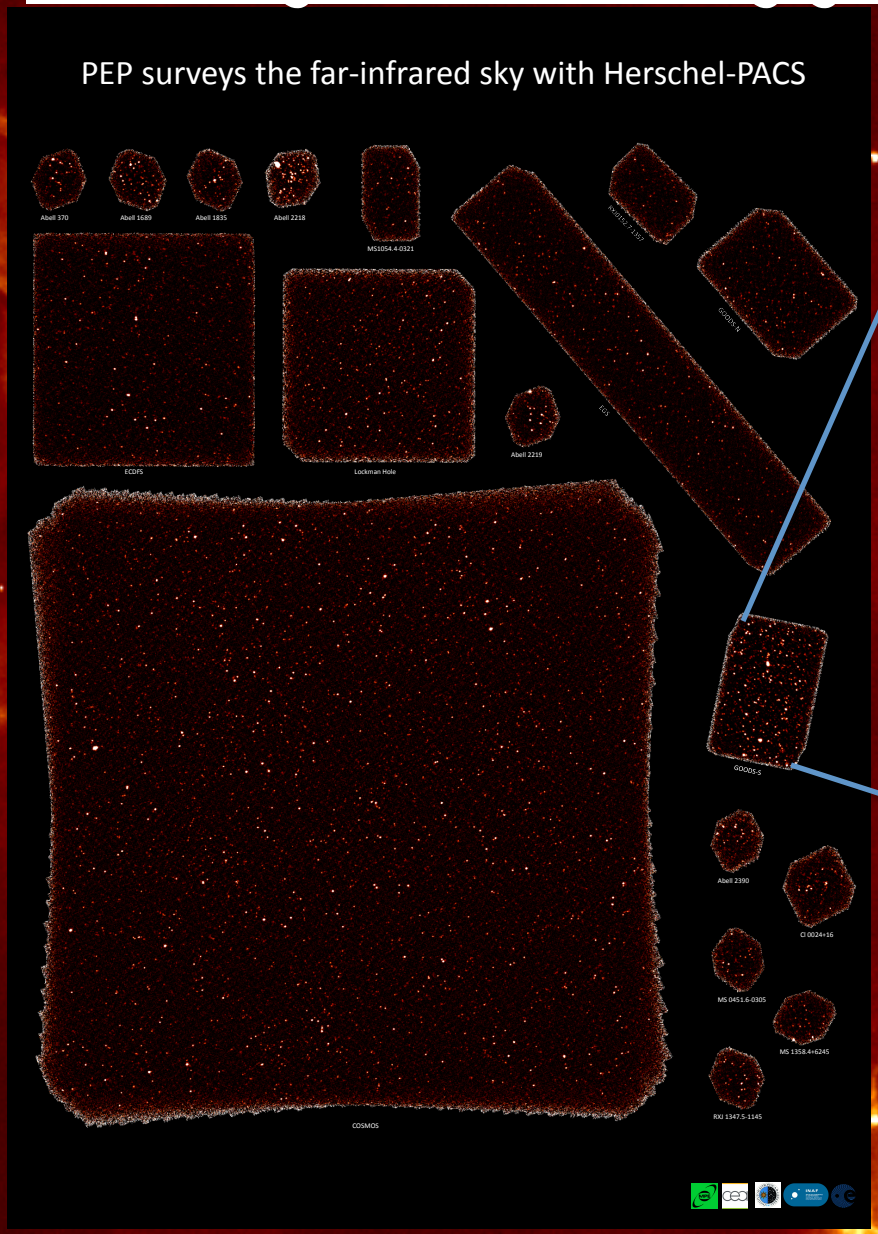
Outline

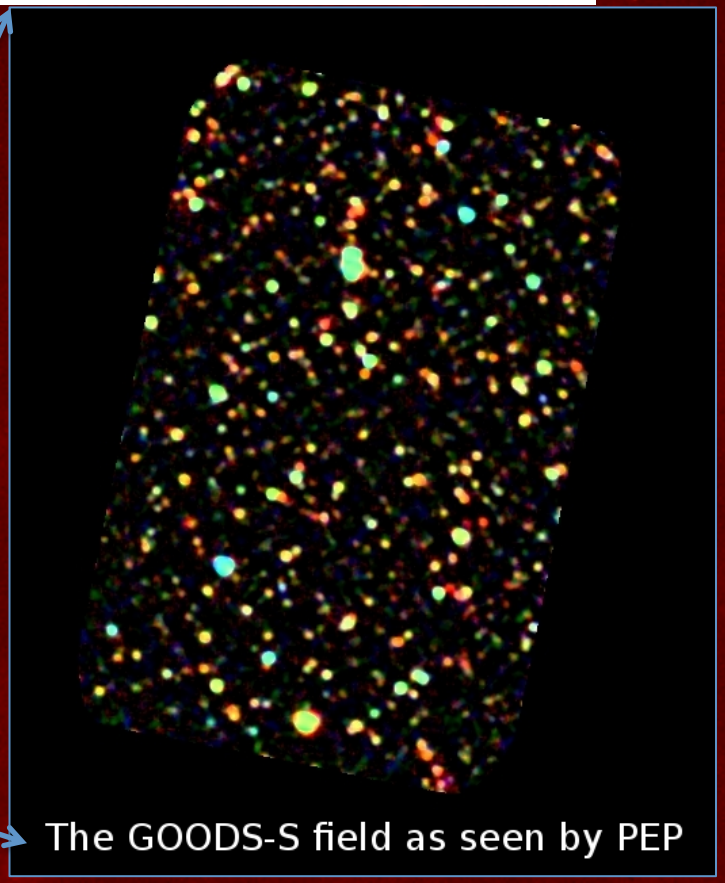
-Clustering of star-forming galaxies:
the Herschel/FIR view

-Clustering of star-forming galaxies:
the multi-wavelength view

- Possible scenarios for evolution into galaxies/AGN

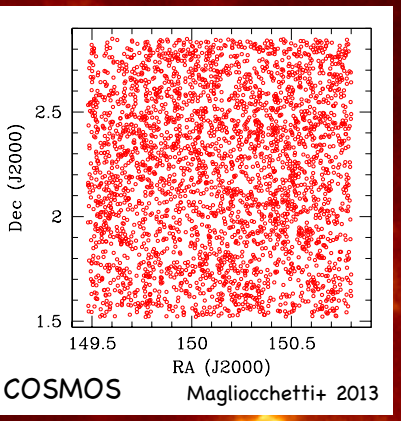
Clustering of star-forming galaxies: the Herschel view

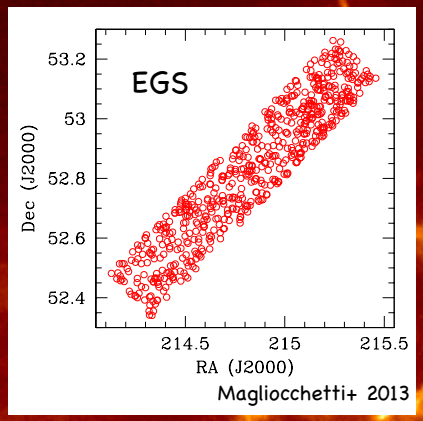




Concentrate on **COSMOS**, **EGS** and **GOODS-S** as either wide enough or deep enough to ensure statistically meaningful clustering measurements

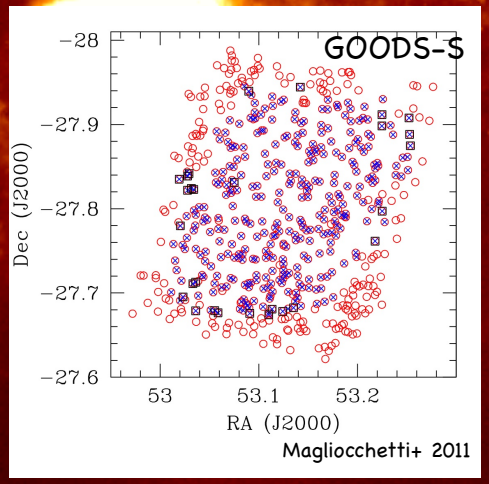
Clustering of star-forming galaxies with Herschel: characteristics of the fie

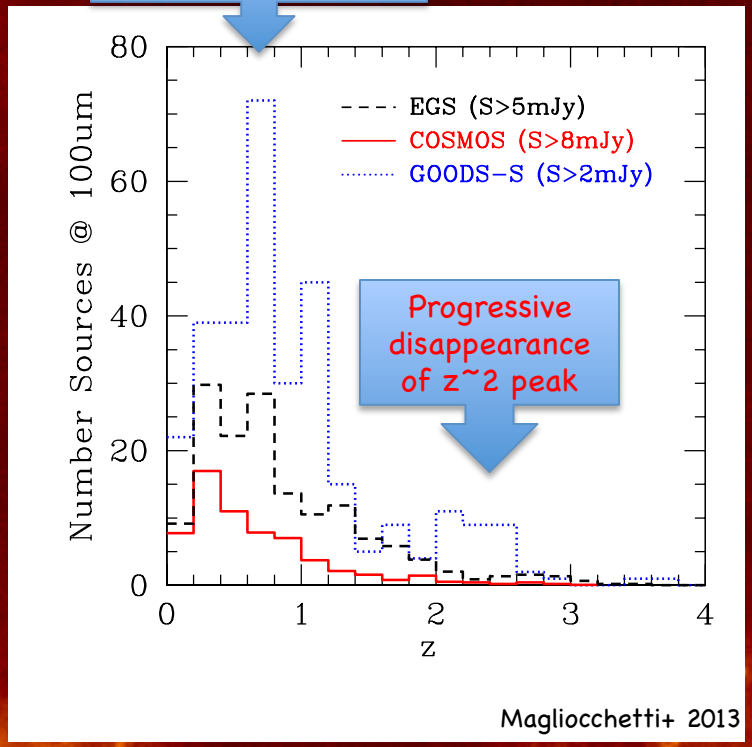




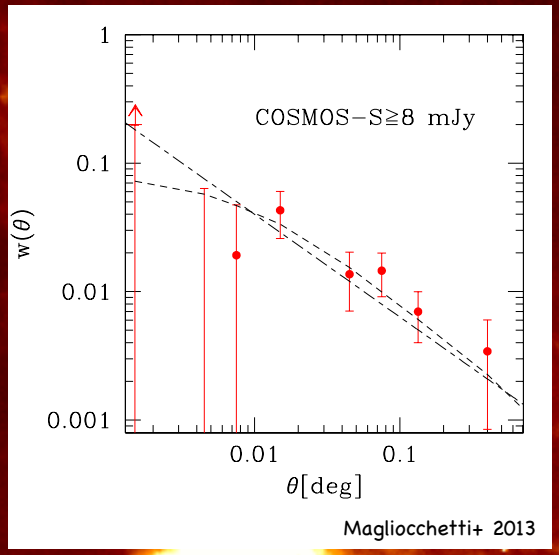
FLUX

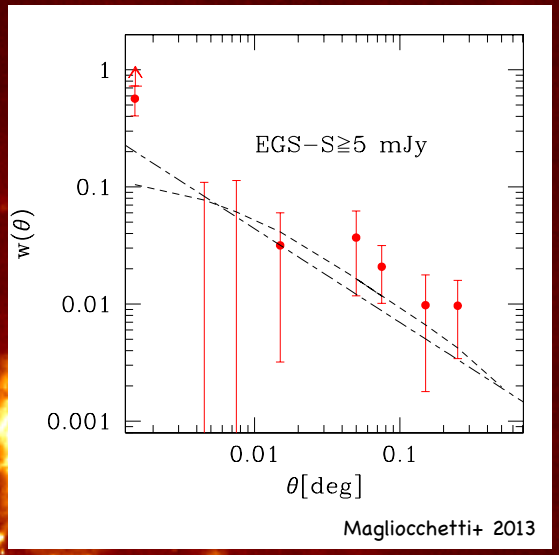
COSMOS: 80% completeness @100μm 8 mJy
EGS: 80% completeness @ 100μm 5 mJy
GOODS-S: 80% completeness @100μm 2 mJy

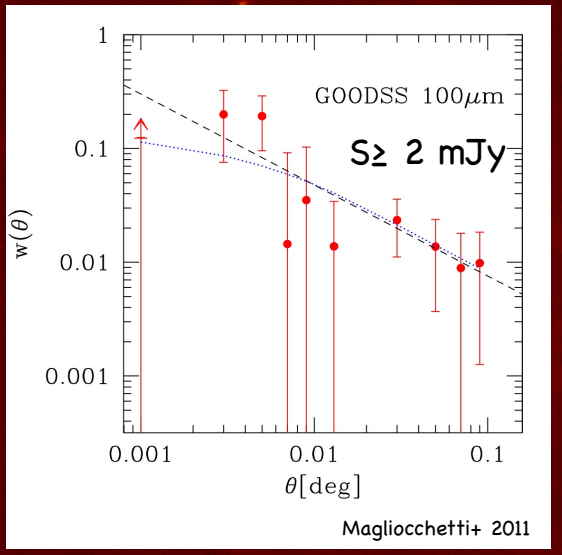




CLUSTERING PROPERTIES OF HERSCHEL-SELECTED GALAXIES I







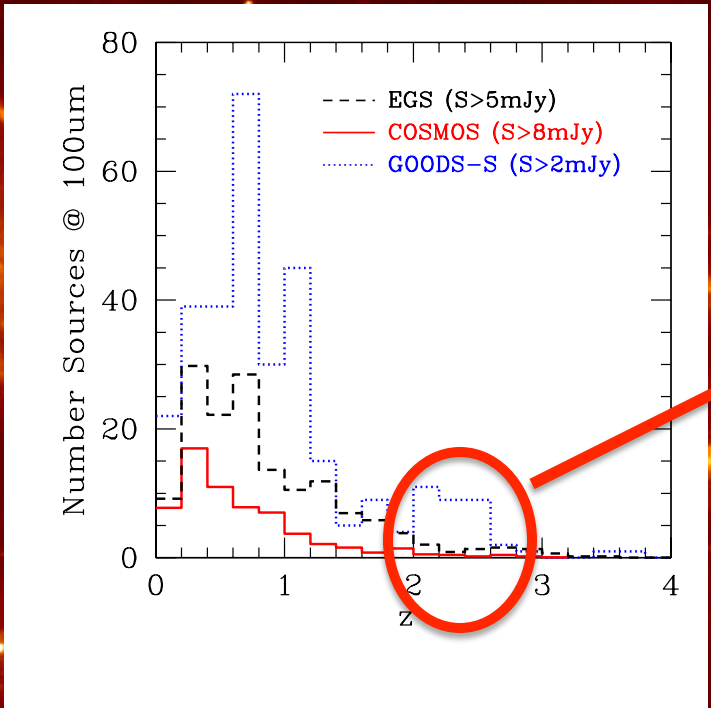
$S_{100\,\mu m}$>8 mJy
r_0~4.3 Mpc
M_{halo}>~$10^{11.6}$ M_{sun}

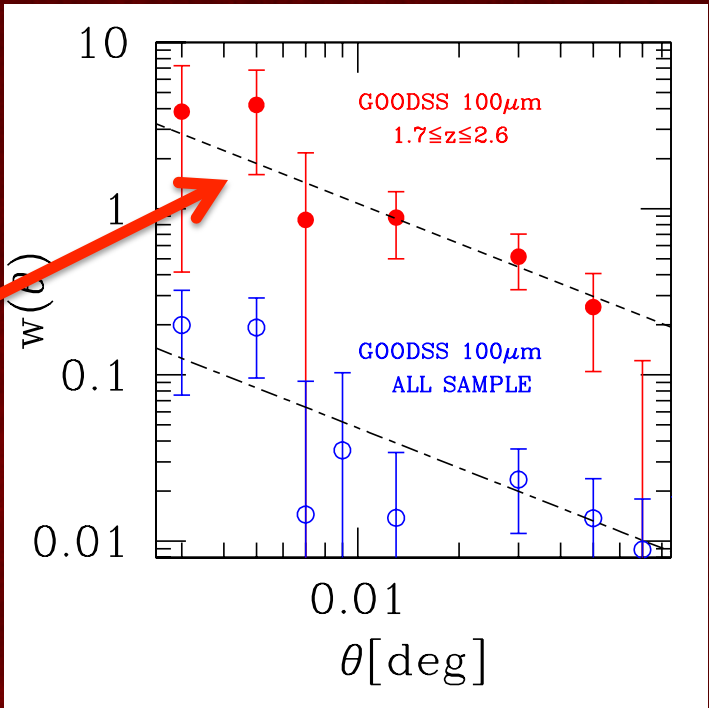
$S_{100\,\mu m}$>5 mJy
r_0~5.8 Mpc
M_{halo}>~$10^{12.4}$ M_{sun}

$S_{100\,\mu m}$>2 mJy
r_0~6.3 Mpc
M_{halo}>~$10^{12.5}$ M_{sun}

r_0 and M_{halo} increase for decreasing fluxes

THE CLUSTERING PROPERTIES OF HERSCHEL-SELECTED GALAXIES II



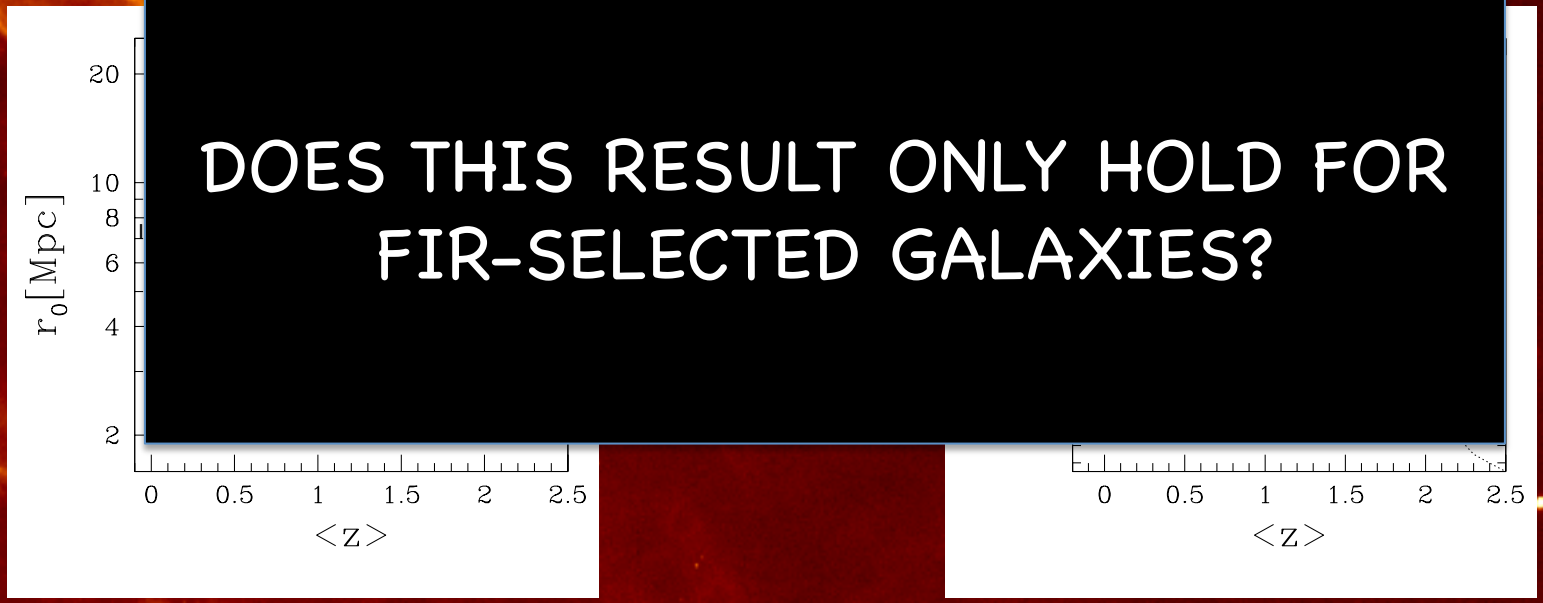


Galaxies at z~2 are 10 times more strongly clustered than the whole GOODS-S (and also COSMOS and EGS) sample

MALMQUIST BIAS (i.e. luminosity dependent) EFFECT?

THE CLUSTERING PROPERTIES OF FIR-SELECTED GALAXIES

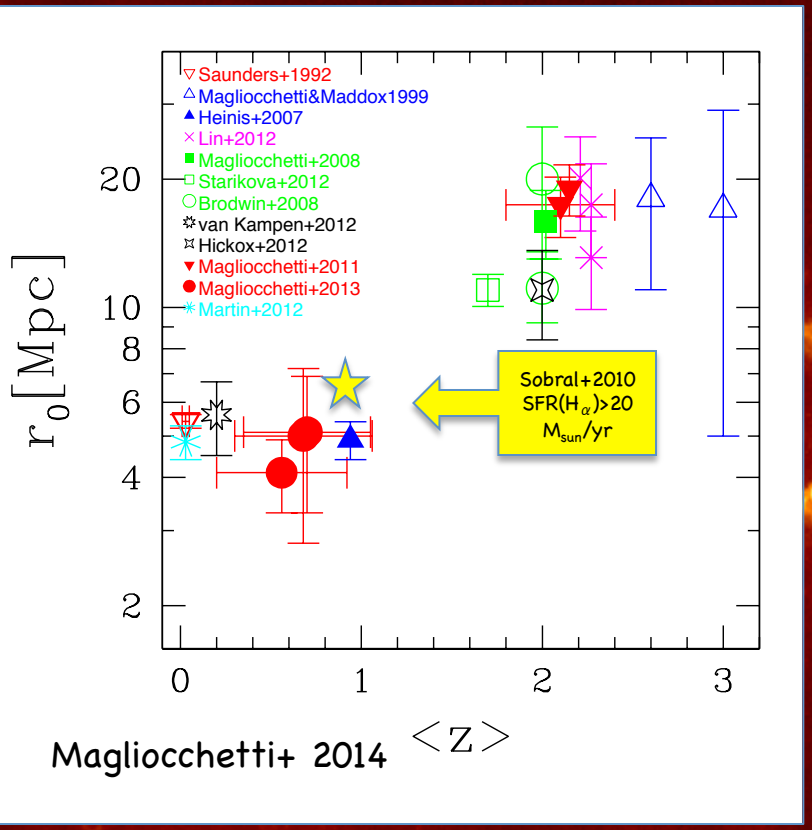
Consider clustering measurements of FIR sources selected at 60μm rest frame
All PEP galaxies with comparable SFR≥100 M_{sun}/yr → minimization of bias effects
Relevant quantities plotted as a function of median z of survey



DOES THIS RESULT ONLY HOLD FOR FIR-SELECTED GALAXIES?

DESPITE SIMILAR SELECTION CRITERIA SOURCES @ z~2 ARE A FACTOR 3 MORE CLUSTERED THAN LOCAL, z<1 COUNTERPARTS. REFLECTED IN EVOLUTION OF HALO MASS WHICH INCREASES FACTOR ~10^2 BETWEEN z~1 AND z~2

THE CLUSTERING PROPERTIES OF RAPIDLY STAR-FORMING SYSTEMS AT LOW AND HIGH Z



CONSIDER CLUSTERING MEASUREMENTS OF **ALL** SF GALAXIES AVAILABLE IN THE LITERATURE

Galaxies selected at all z only on the basis of their bolometric luminosity/SFR. Minimum 30 ≤SFR_{min}≤ a few 10^3 M_{sun}/yr.

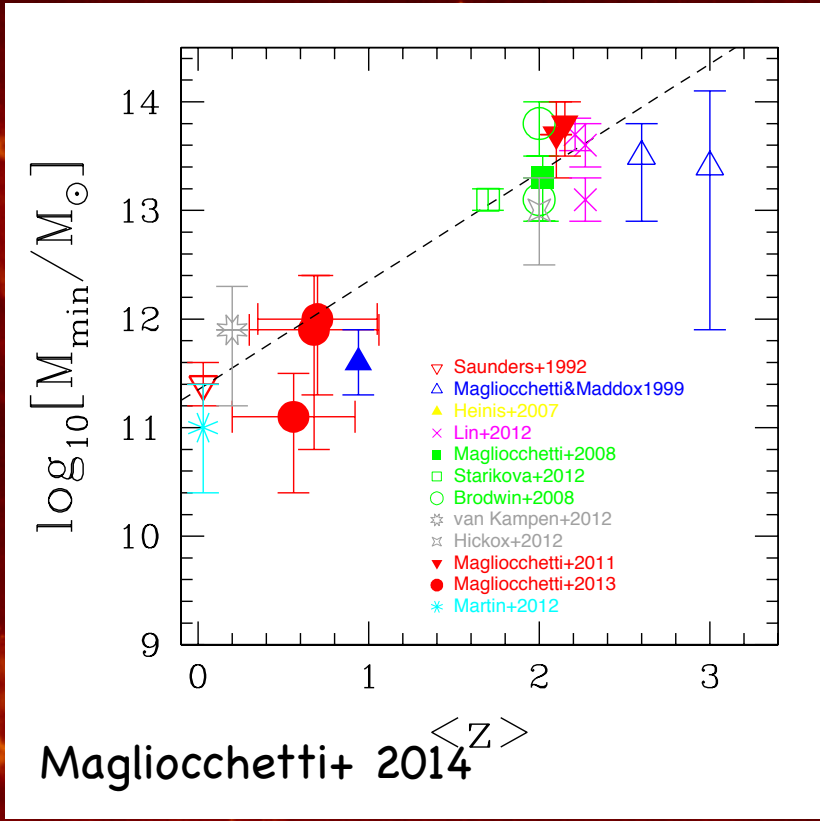
Data homogenized to correct for cosmology and γ dependence

Groups with same colour-coding selected at same rest-frame frequency

Blue: UV selection (SFR_{min} ~ a few 10^1 M_{sun}/yr)
Green: mid-IR selection (SFR_{min}~a few 10^3 M_{sun}/yr)
Magenta: BzK selection (SFR_{min}~[30-100] M_{sun}/yr)
Black: sub-mm selection (SFR_{min}~[60-900] M_{sun}/yr)

Irrespective of the selection technique and only very mildly depending on the SFR, clustering lengths of ALL very active star-forming galaxies present sharp increase from ~ 5 Mpc to ~15-20 Mpc (> factor 3) when moving from z≤1 to z≥2.

IS THAT AN EXPECTED EFFECT DUE TO INCREASE OF BIAS WITH Z AT CONSTANT MASS?



Magliocchetti+ 2014

Quick answer: NO!

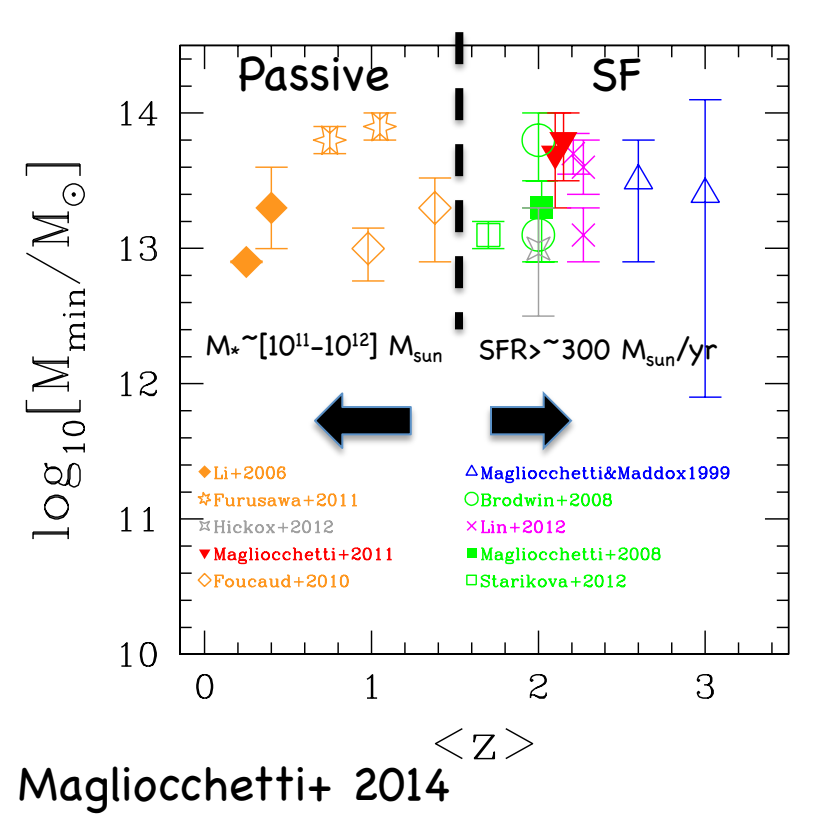
Halo masses also increase by about 2 orders of mag from ~$10^{11.5}$–10^{12} M_{sun} at $z \lesssim 1$ to $10^{13.5}$ M_{sun} and higher at $z \gtrsim 2$

As for r_0, very little spread amongst low-z group and high-z group (~independence of SFR)

GALAXIES WHICH ACTIVELY FORM STARS AT HIGH z ARE NOT THE SAME POPULATION WE OBSERVE IN THE MORE LOCAL UNIVERSE. VIGOROUS STAR FORMATION IN THE EARLY UNIVERSE IS HOSTED BY VERY MASSIVE STRUCTURES, WHILE FOR $z \lesssim 1$ A COMPARABLE ACTIVITY IS ENCOUNTERED IN MUCH SMALLER SYSTEMS → DOWNSING (M_{halo} propto z)

WHAT HAPPENS TO HIGH-z STAR-FORMING GALAXIES?

- Space densities of SF galaxies @ z~2 indicate the rapid star-forming phase is very common amongst massive galaxies (~ 1 out of 2).
- Estimate T_{SF}~1 Gyr (see also Granato+ 2004; Lapi+ 2006 model).
- Merging excluded as dominant trigger of rapid SF phase as either too low masses or too short T_{SF} (e.g. Baugh+ 2005: Narayanan+2009)



Magliocchetti+ 2014

For typical SFR~300 M_{sun}/yr at the end of phase galaxy with M_*~3 10^{11} M_{sun}
→ look for clustering properties of low-z passive galaxies with very high M_*

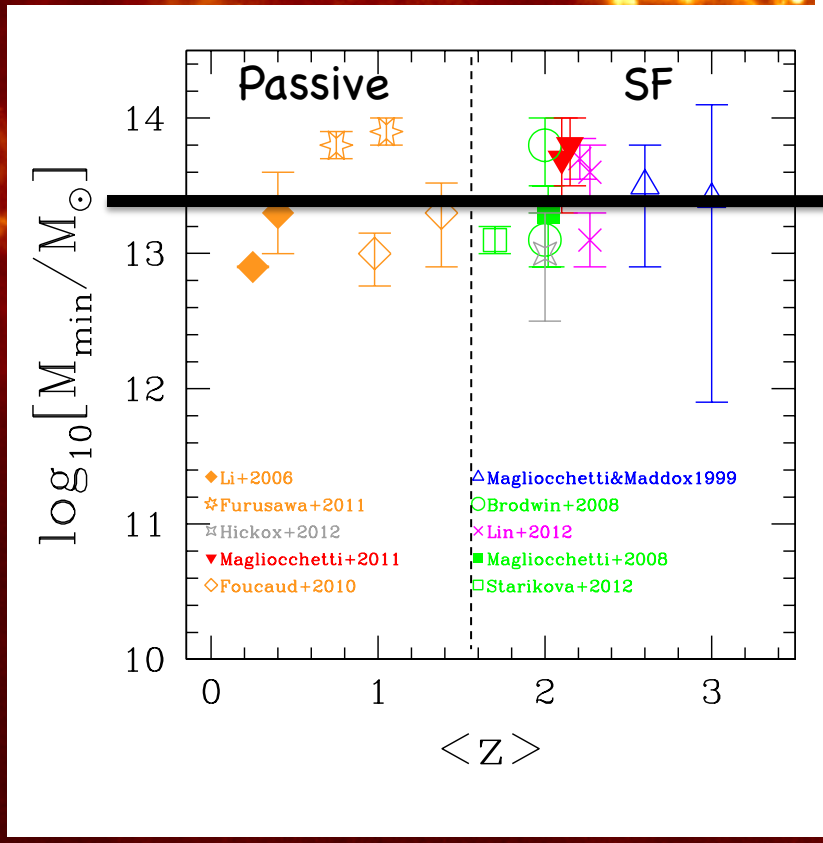
-High-z points: star-forming galaxies
-z≤1.5 points : early type galaxies with M_*~[10^{11}-10^{12}] M_{sun}

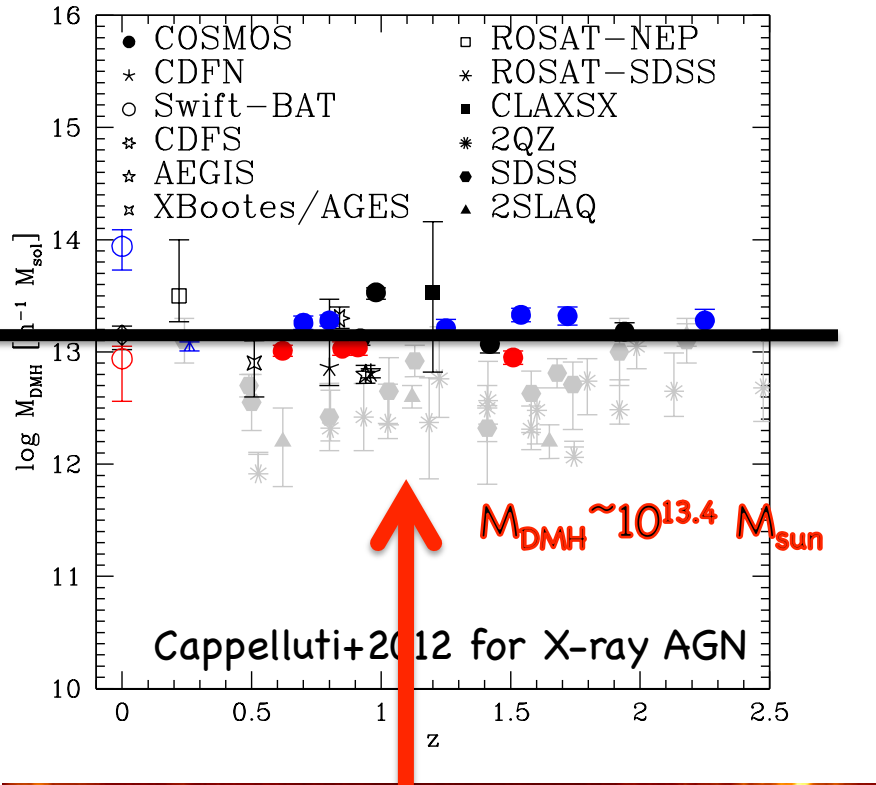
Halo masses ~[10^{13}-10^{14}] M_{sun} →
→perfect agreement with high-z values

WHERE DO AGN FIT IN THIS SCENARIO?

AGN vs Star-forming Galaxies: the X-ray band

Remarkable agreement between clustering properties of high-z SF-low-z passive galaxies and those of X-ray selected AGN.
High SFR SFG→ X-ray AGN → high M* passive?

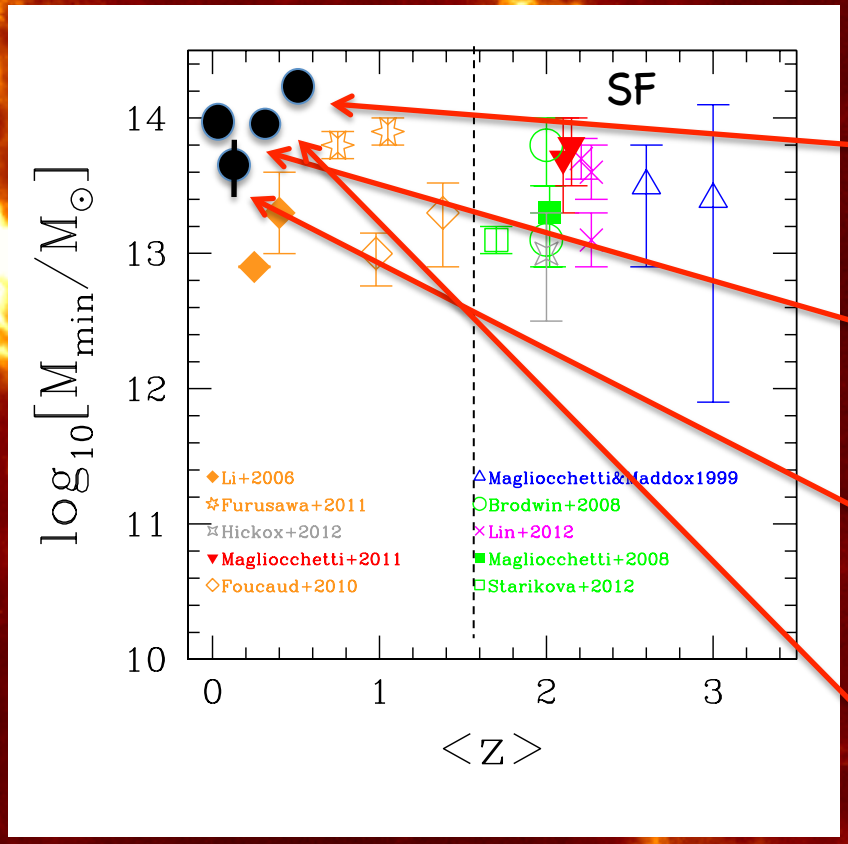




However, optically selected QSO are hosted by smaller structures…

AGN vs Star-forming Galaxies: the radio band

Clustering properties of relatively local radio galaxies still compatible (although on the high side) with those of intense SF galaxies at z>~1.5. High SFR SFG→ radio galaxies → group environment?



Wake+2008 for $L_{1.4GHz}>10^{24}$ W/Hz 2SLAQ LRG sources (possibly biased high).

Peacock & Nicholson 1991 $S_{1.4GHz}>0.5$ Jy

Magliocchetti+ 2004 For FIRST/2dF AGN $S_{1.4GHz}>1$ mJy

Lindsay+ 2014 FIRST/GAMA $S_{1.4GHz}>1$ mJy

CONCLUSIONS

Star forming galaxies at high and low redshifts are two different populations.

Low-z (z<~1) intense star formation takes place in small galaxies (M_{DMH}~$10^{11.5}$ M_{sun}) over long timescales.
Only a fraction of virialized halos will host the SF event and such a fraction decreases for decreasing redshifts

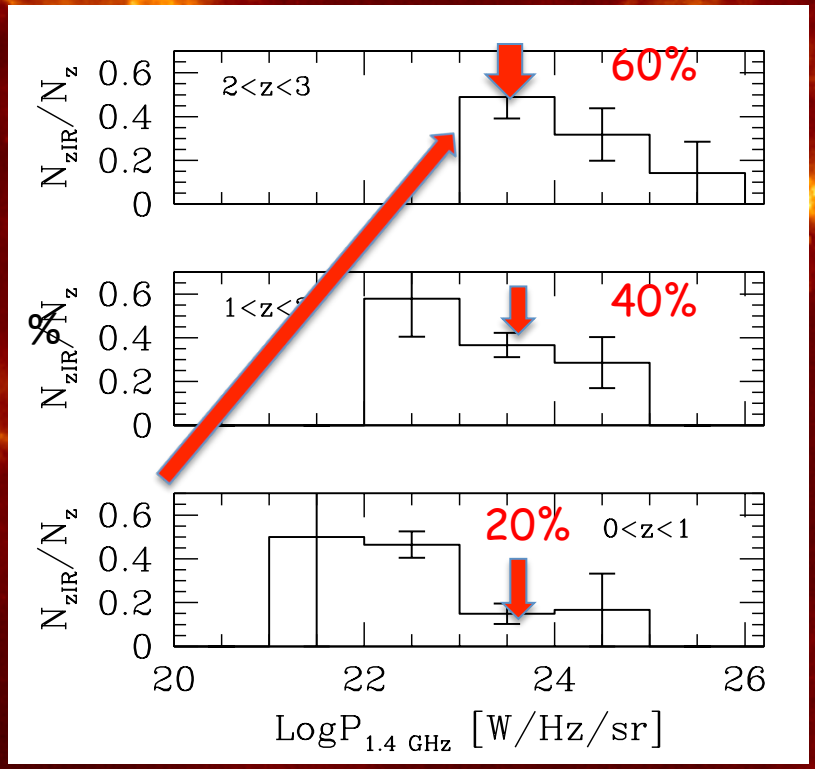
The same intense star formation activity (SFR>~ 30 M_{sun}/yr) at z>~1.5 takes place in very massive galaxies (M_{DMH}~$10^{13.5}$ M_{sun}) on relatively short timescales (T_{SF}~1 Gyr).
It is a very common event: about 1 out of 2 galaxies at z=2 is found in the rapid star forming stage.

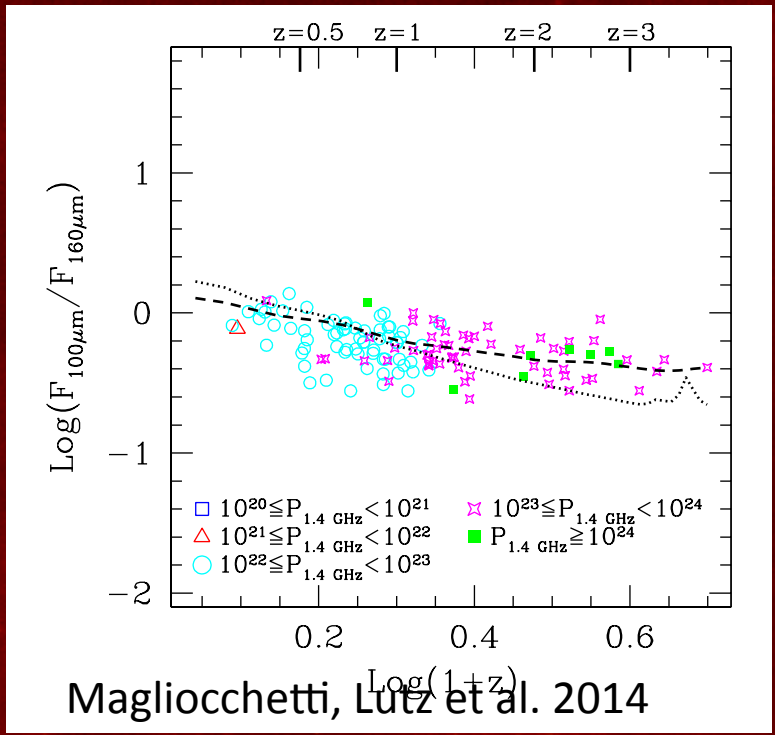
At z<~1.5-2 high SFR sources evolve in passive galaxies with M_*~10^{11}-10^{12} M_{sun}

Tantalizing resemblance between clustering properties of intense SF galaxies at z>~1.5 and of X-ray (and also possible radio) selected AGN at all z point towards evolutionary connection between these populations.

What about optically selected QSOs?

Completely off topic (but not quite): caution when associating radio sources to 'dead' ellipticals as strong function of z!





Magliocchetti, Lutz et al. 2014

Powerful radio sources are more likely to be FIR emitters at earlier epochs
FIR emission entirely due to star-forming processes