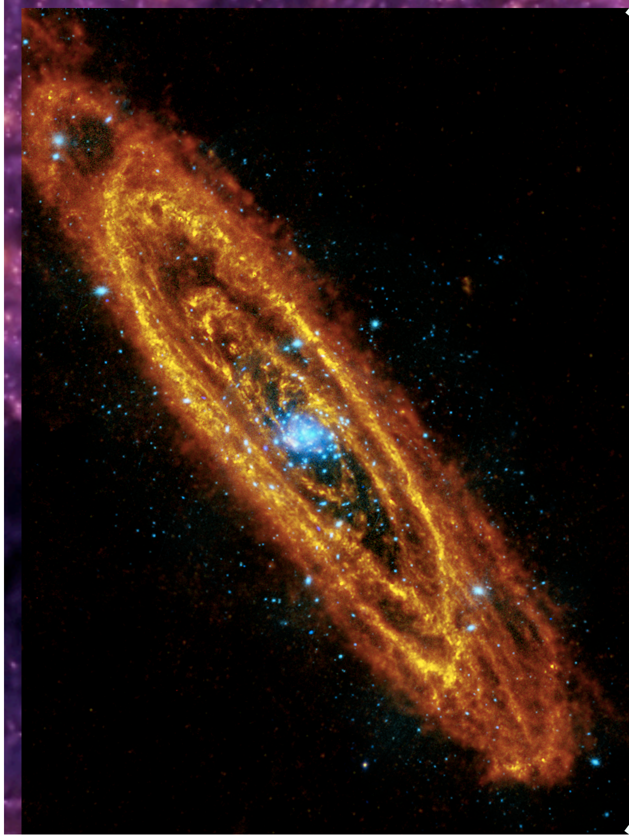
The SF^2 Project:

The impact of the Structure Formation process in the Star Formation process of the Universe

31.25 Mpc/h

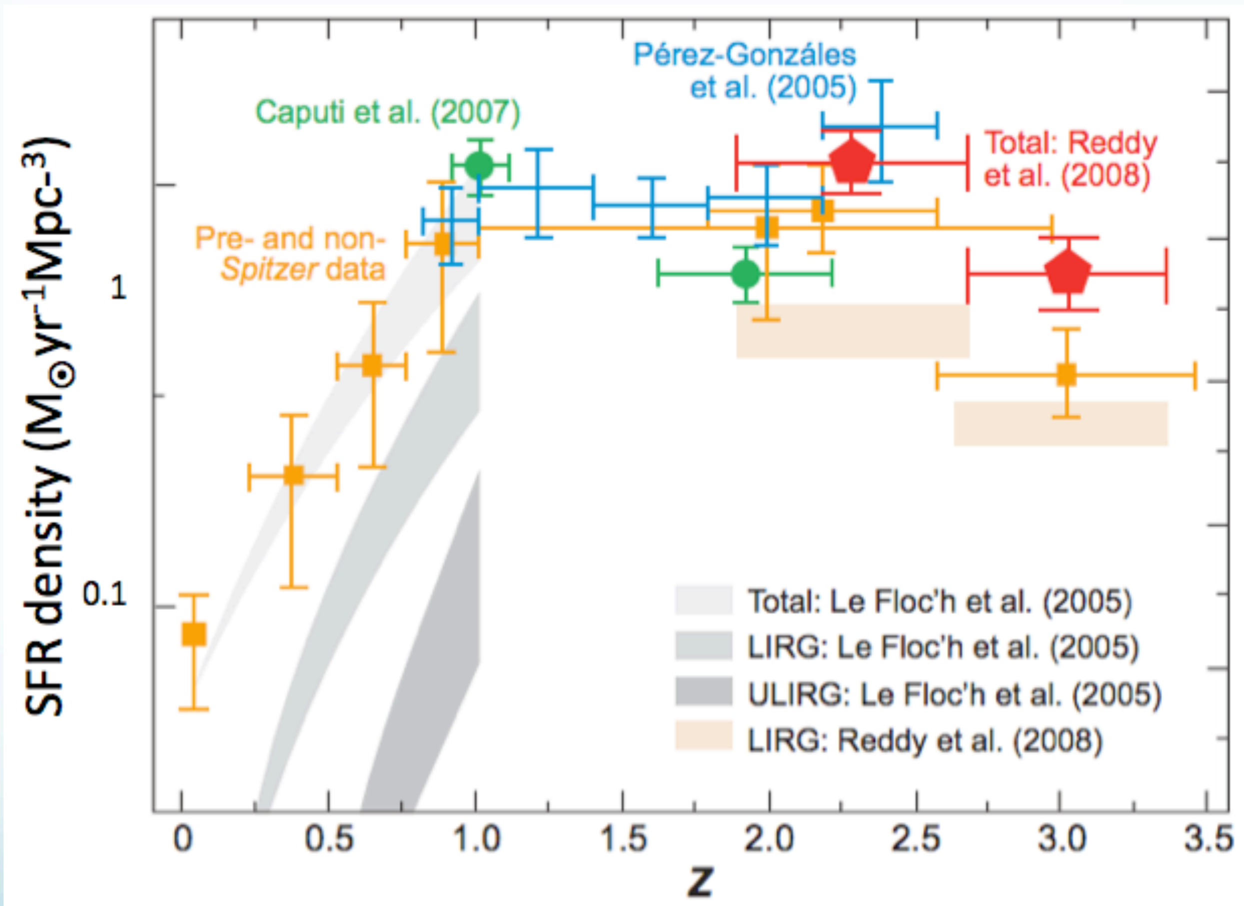


P. Popesso
(Excellence cluster Universe)
G. Erfanianfar, F. Ziparo, M.S. Mirkazemi, A. Biviano, A. Finoguenov, M. Salvato, A. Merloni

Outline

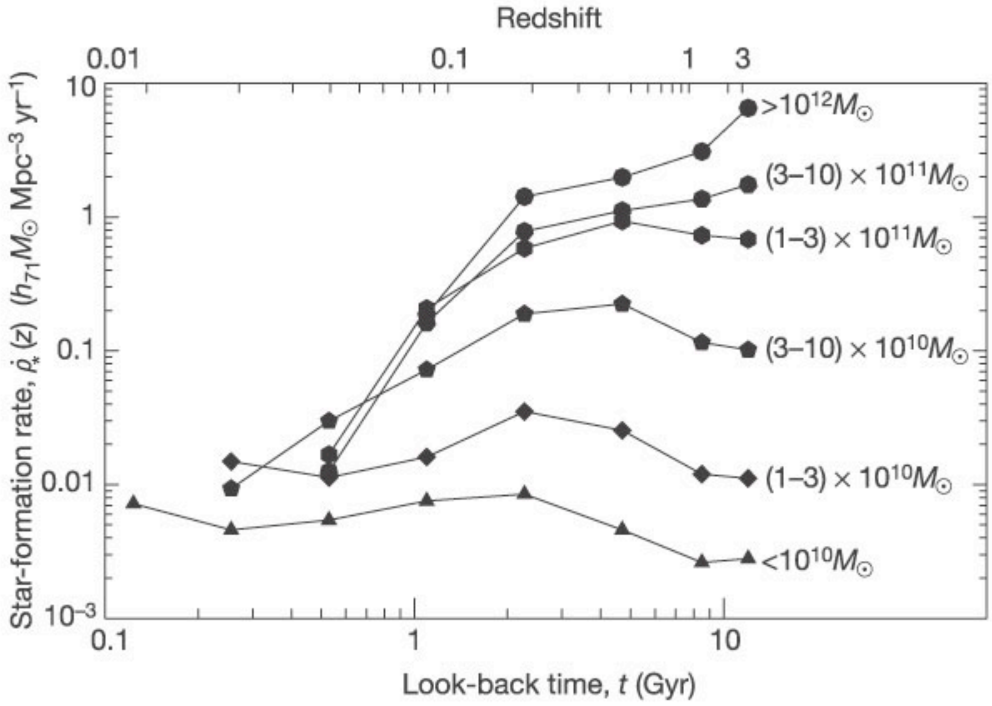
- **What?** →What is the Cosmic Star Formation History (CSFH) of the Universe
- **Why?** → Why the mainstream picture of galaxy formation (*AGN feedback driven*) seems to fail in reproducing the observational evidence and why we need and alternative (*environment driven*)
- **How?** The SF^2 Project and its multi-tiered survey strategy
  - *Evolution of Group IR LF*
  - *Location of group galaxies with respect to the MS*
  - *Cosmic star formation history per halo mass*

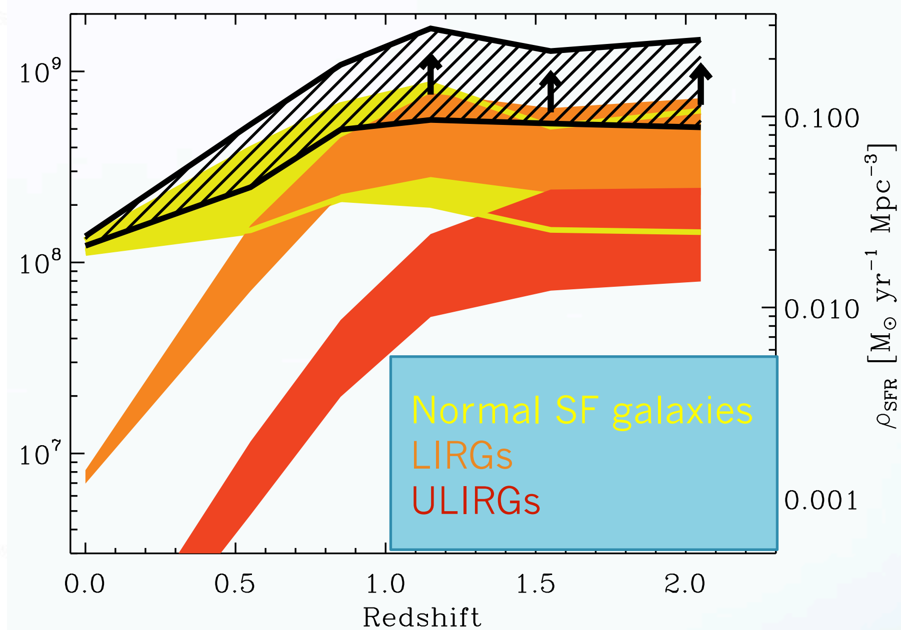
The Cosmic Star Formation History



Soifer et al. (2008)

The Cosmic Star Formation History

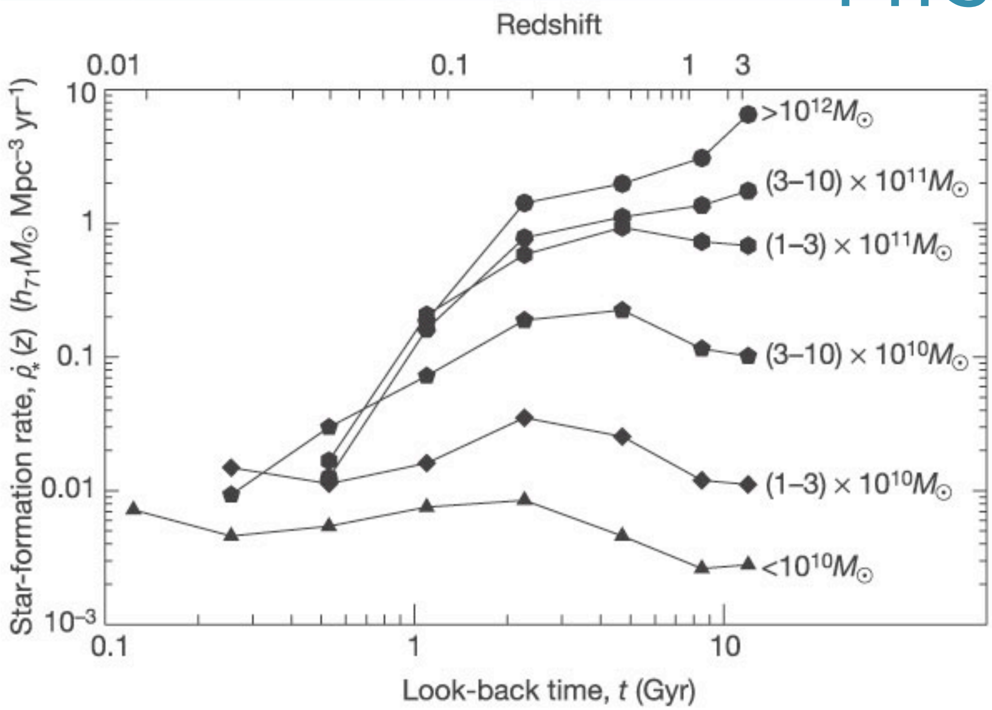


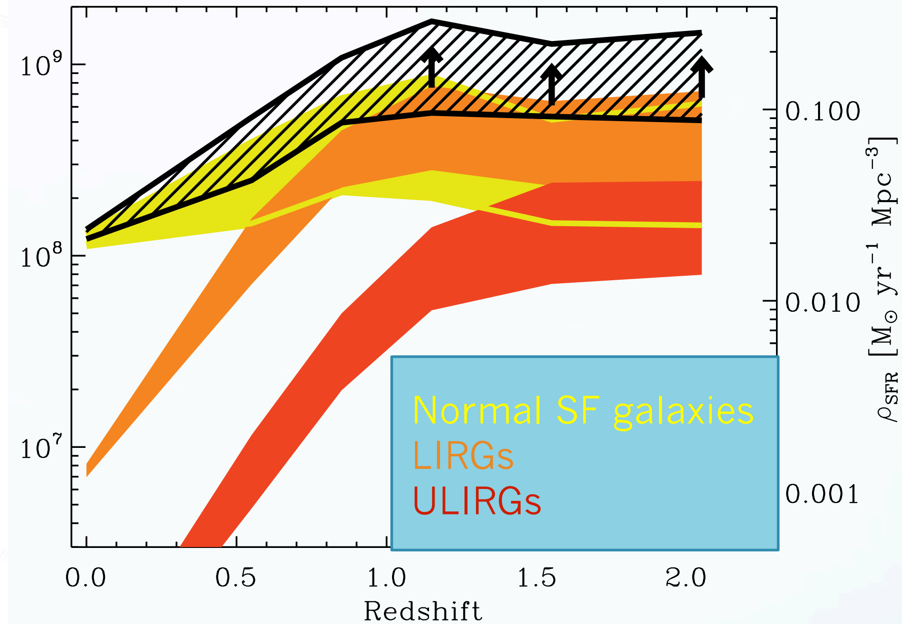


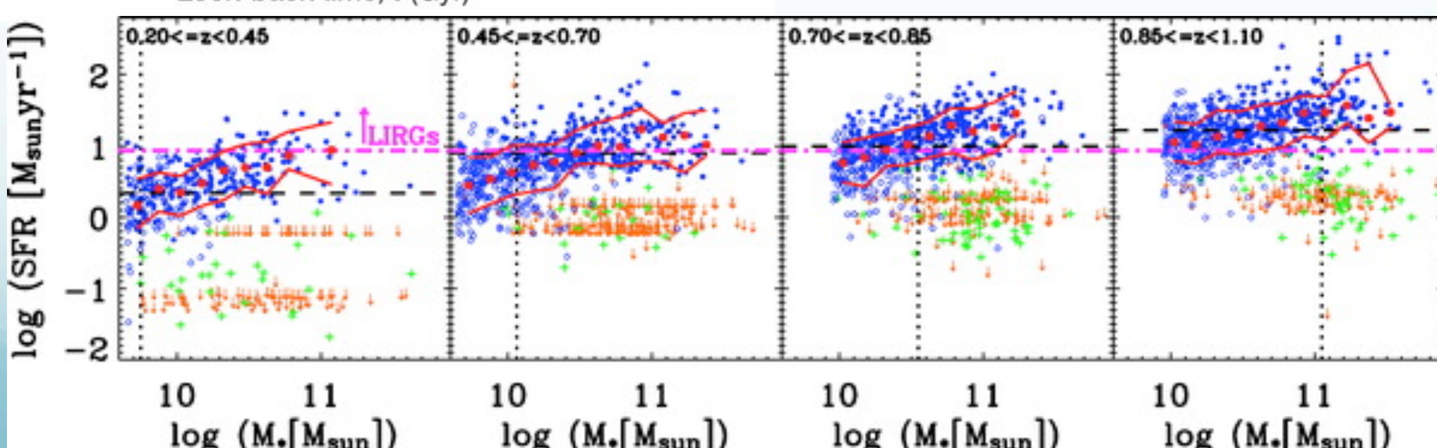
CSFH per galaxy stellar mass
Heavans et al. (2004)

CSFH per galaxy IR luminosity
Magnelli et al. (2013)

The Cosmic Star Formation History

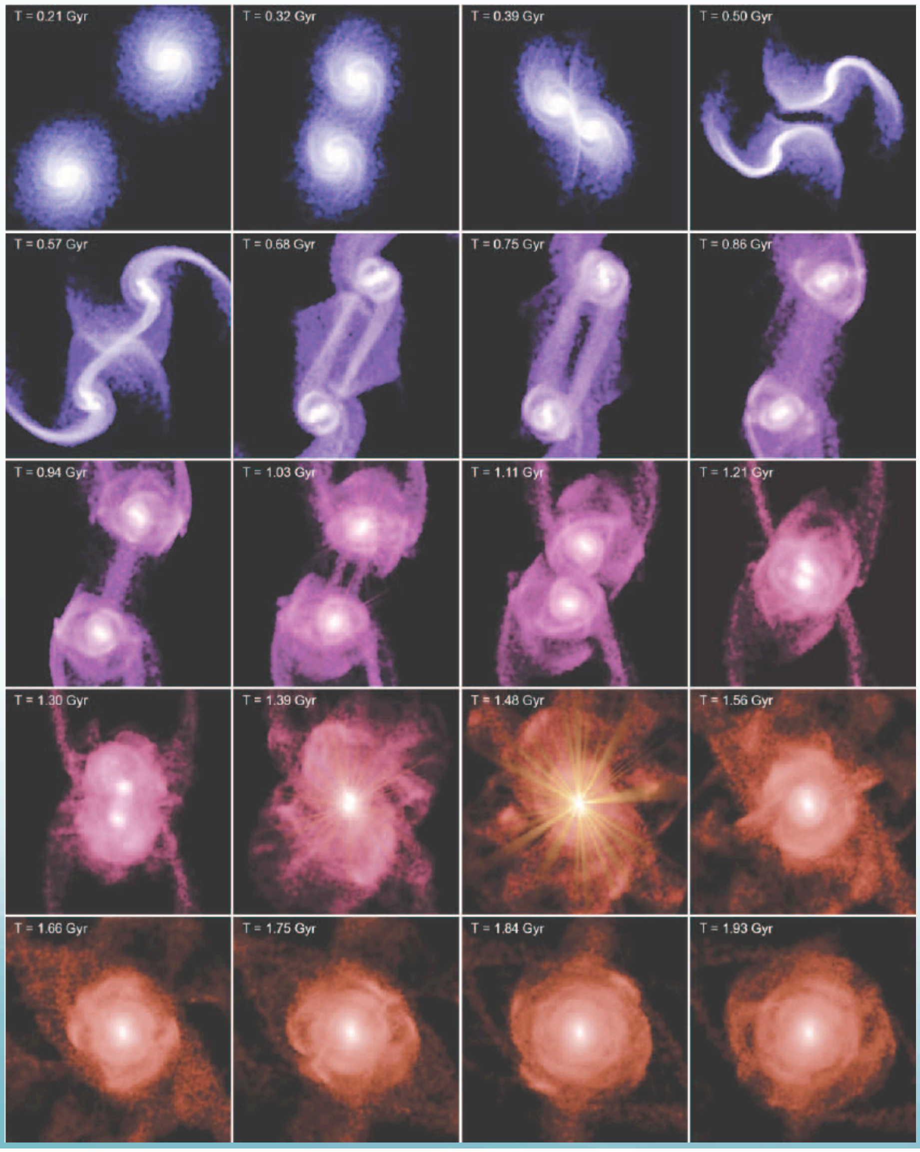






Noeske et al. (2007)

The mainstream picture:
evolution driven by AGN feedback



co-evolution of host galaxy and central black hole

•gas rich major merger

• gas inflow triggers BH accretion and host star formation activity

• dust/gas clouds obscure AGN

• AGN outflows sweeps away gas quenching accretions and star formation

Hernquist (1989)
Springel et al. (2005)
Hopkins et al. (2006)

The mainstream picture:
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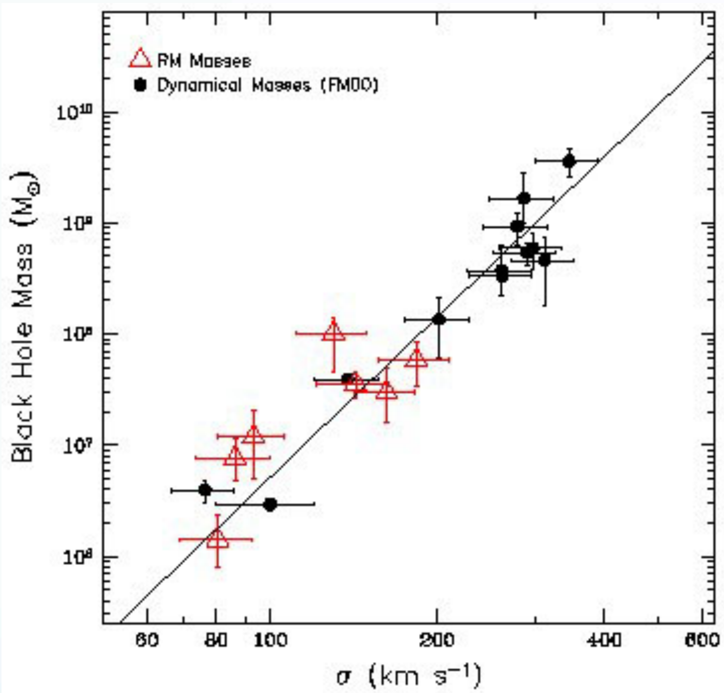
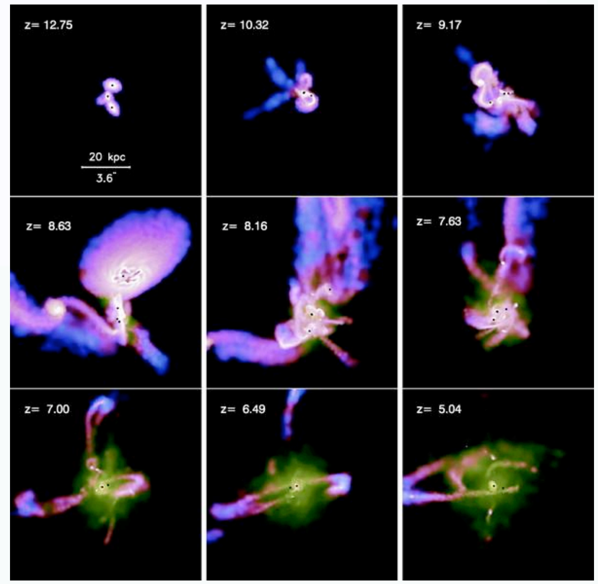
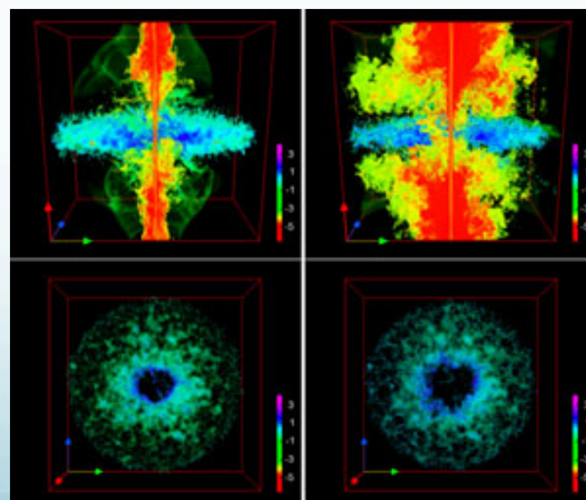


Ferrarese & Merritt (2000)



Quasar mode feedback: efficient at low mass scale (able to fix color bimodality)



Radio mode feedback: Efficient at high mass scale (able to fix defect of luminosity function)

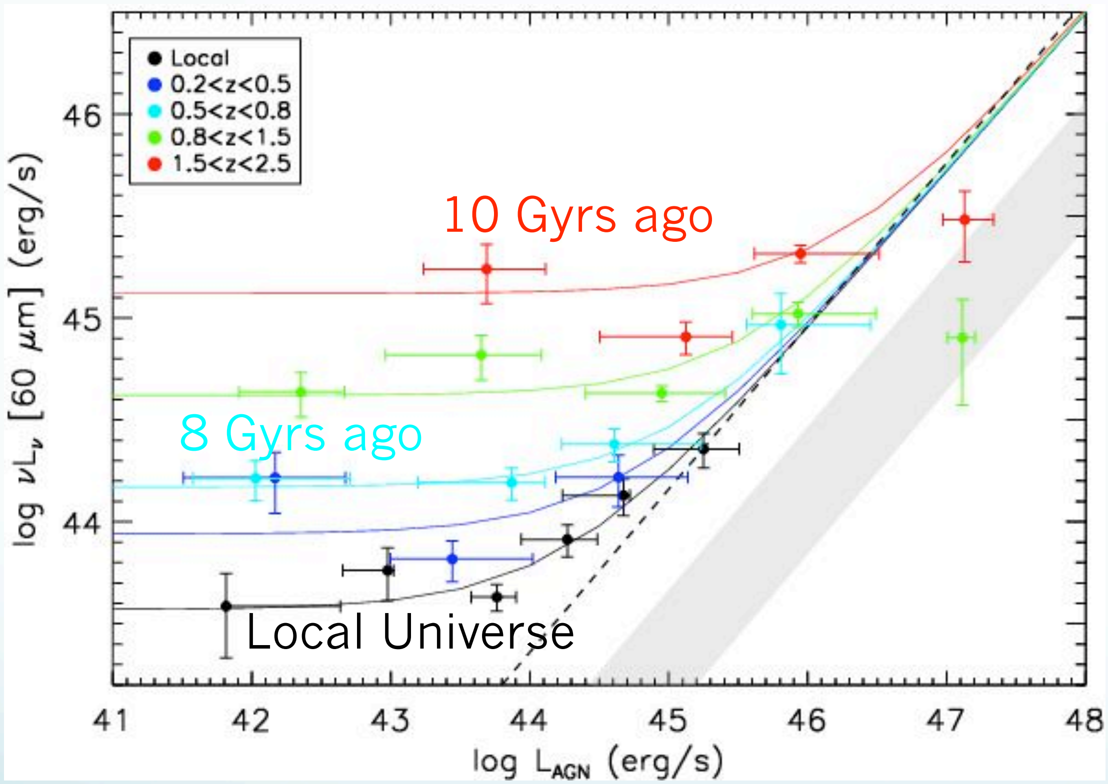
Hernquist (1989), Springel et al. (2005), Hopkins et al. (2006), Croton et al. (2006)

Why?

Questioning the paradigm

No observational evidence of AGN-host galaxy co-evolution

Host galaxy SF activity proxy



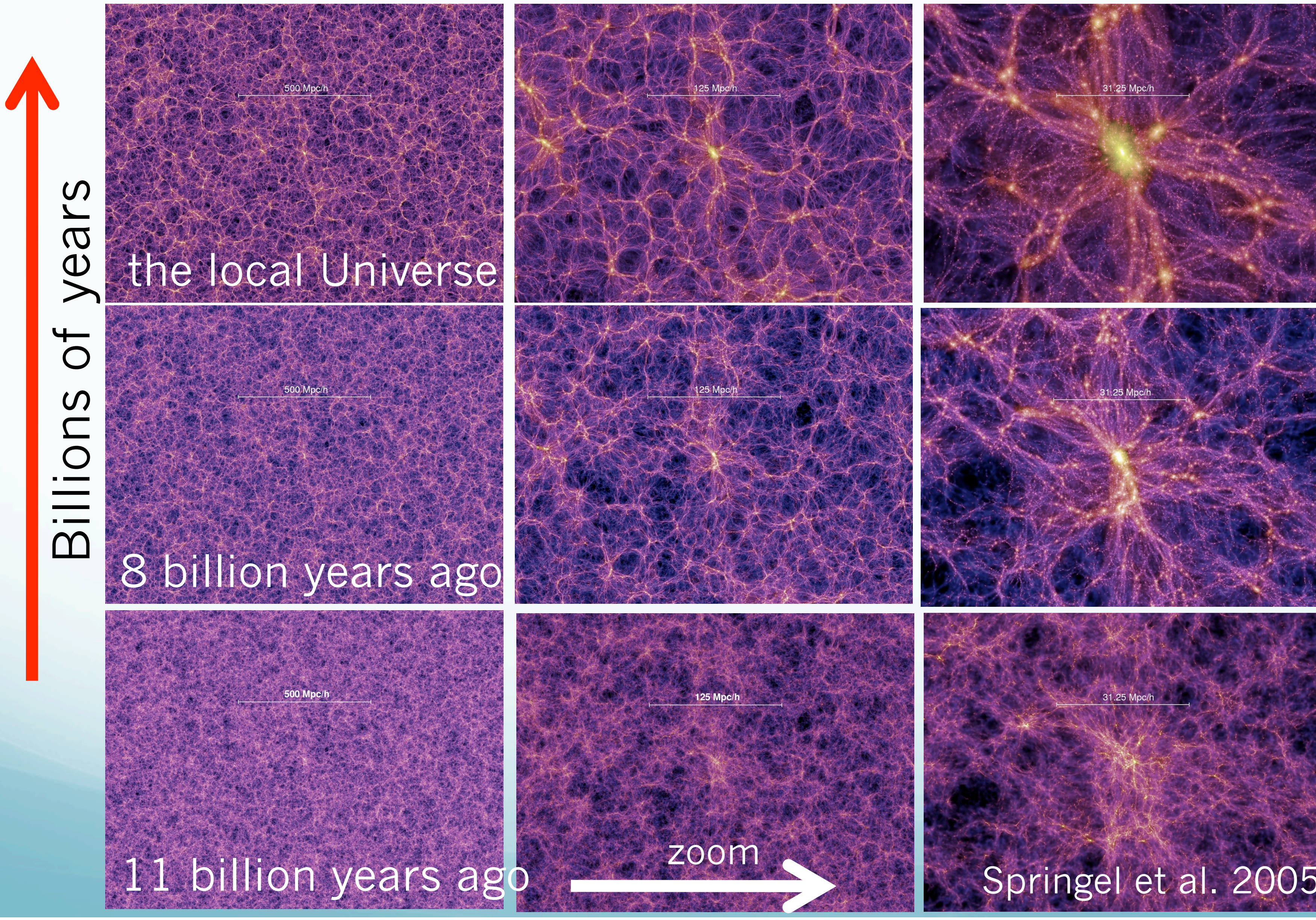
AGN accretion rate proxy

Rosario et al. (2012)

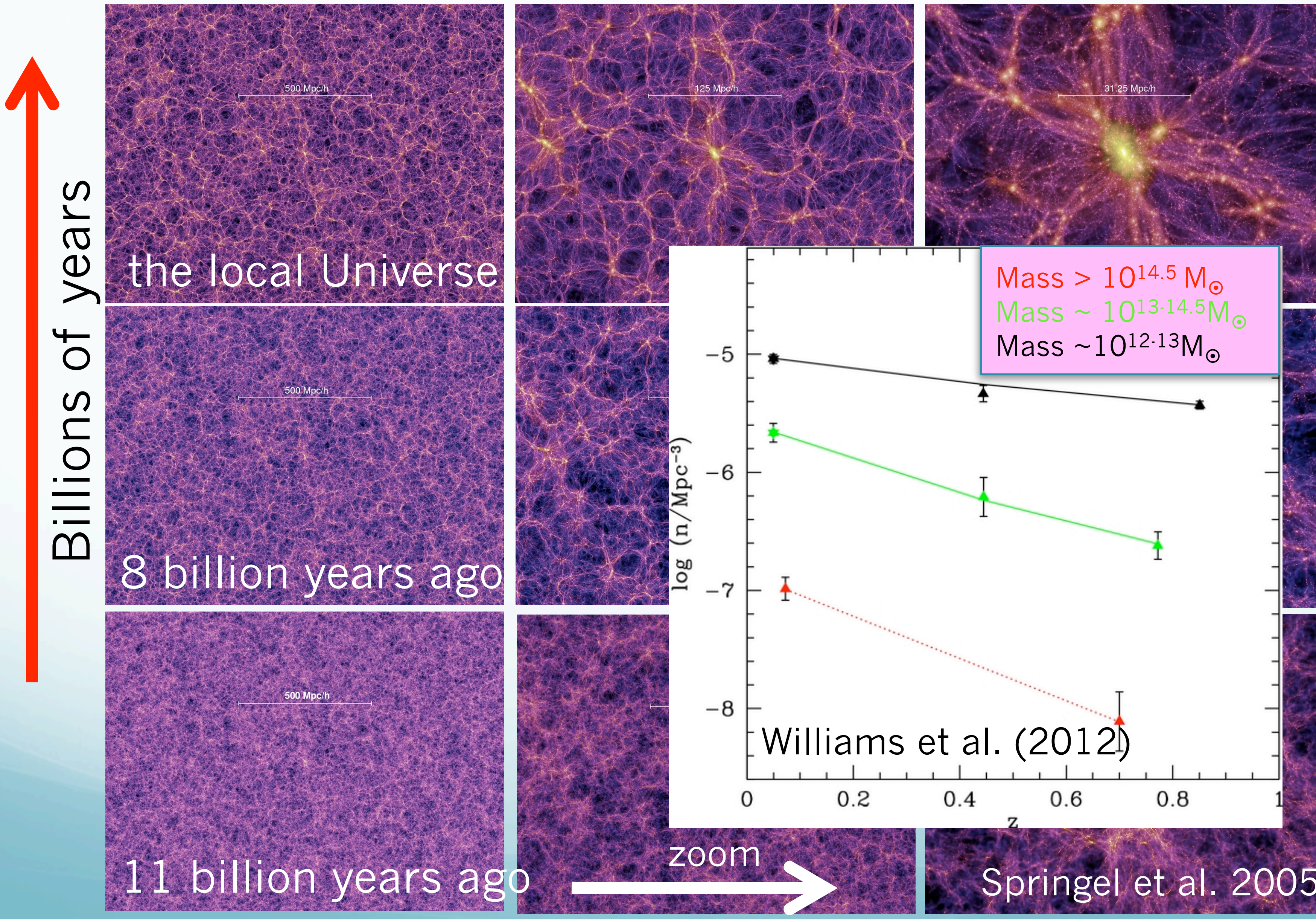
No “smoking gun” of AGN feedback.
Powerful outflows are observed only in few very peculiar objects (Sturm et al. 2011, Maiolino et al. 2012).

See also Mullaney et al. (2012), Bongiorno et al. (2012), Rovilos et al. (2012)

The Structure Formation Process

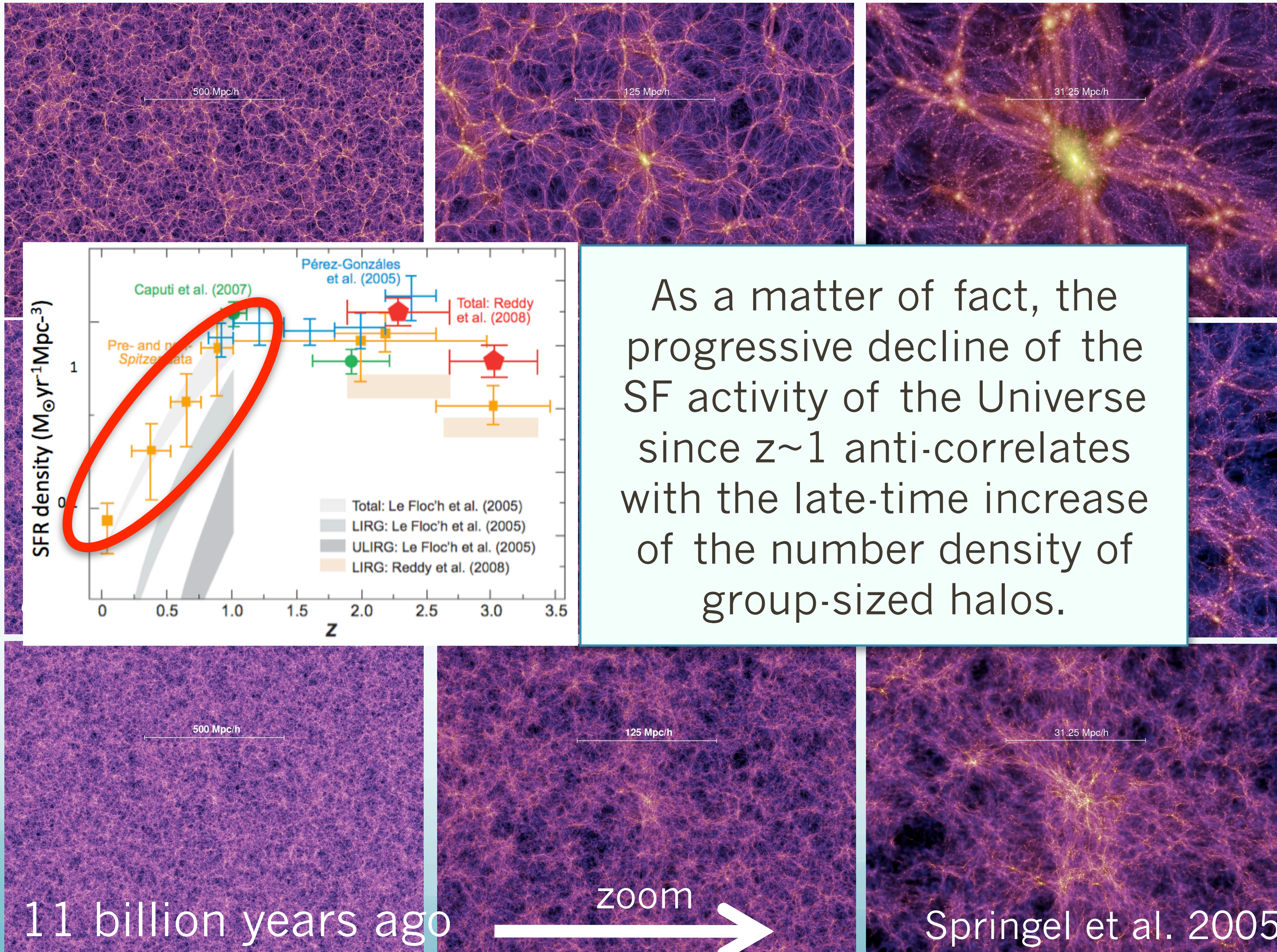


The Structure Formation Process



Why?

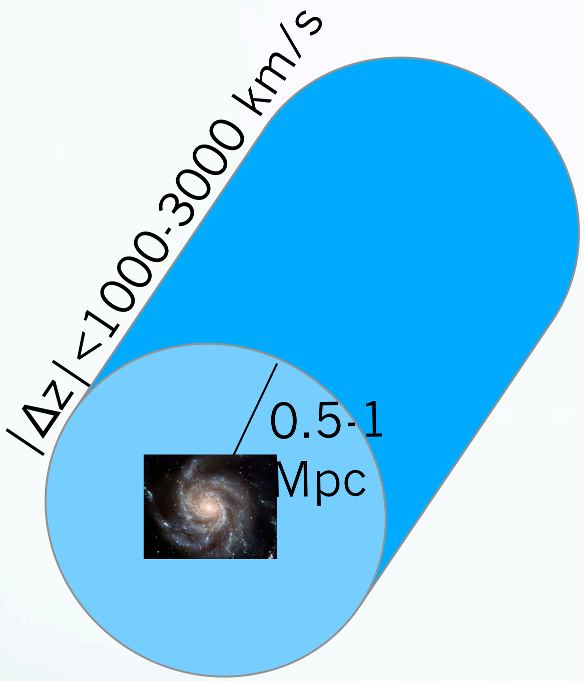
The Structure Formation Process



As a matter of fact, the progressive decline of the SF activity of the Universe since z~1 anti-correlates with the late-time increase of the number density of group-sized halos.

How to define the environment

- Galaxy number density field ≈ matter density field?



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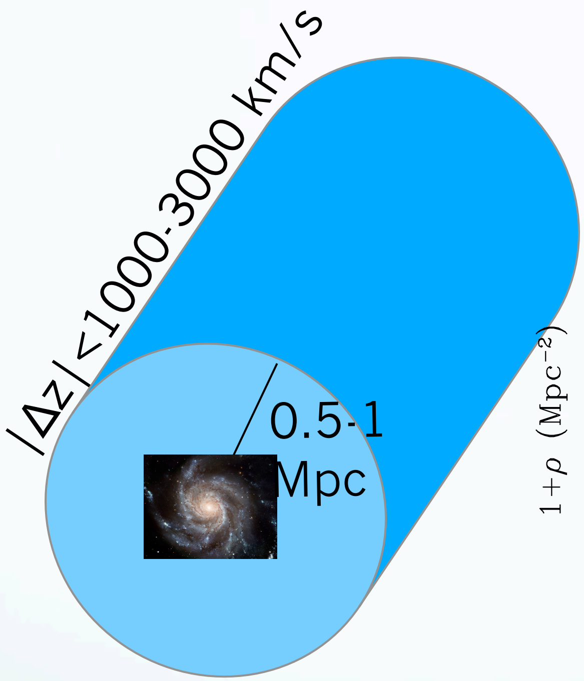
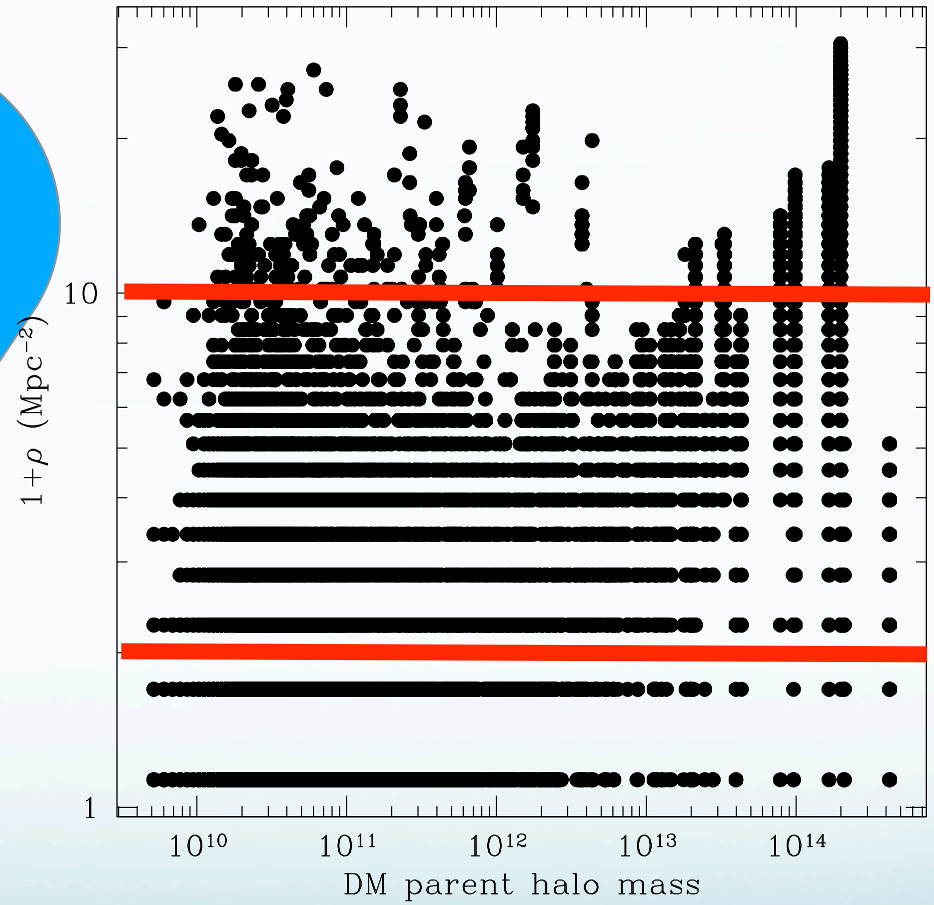




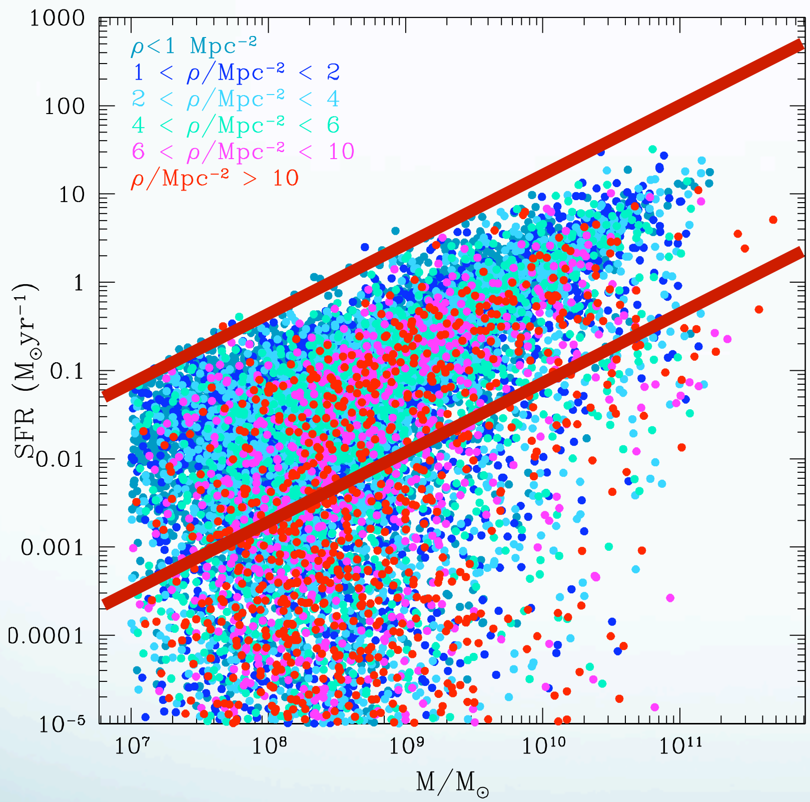
Contamination by galaxies in low mass halos ($M_{halo}< 10^{12}$ $M_\odot$) ~40%

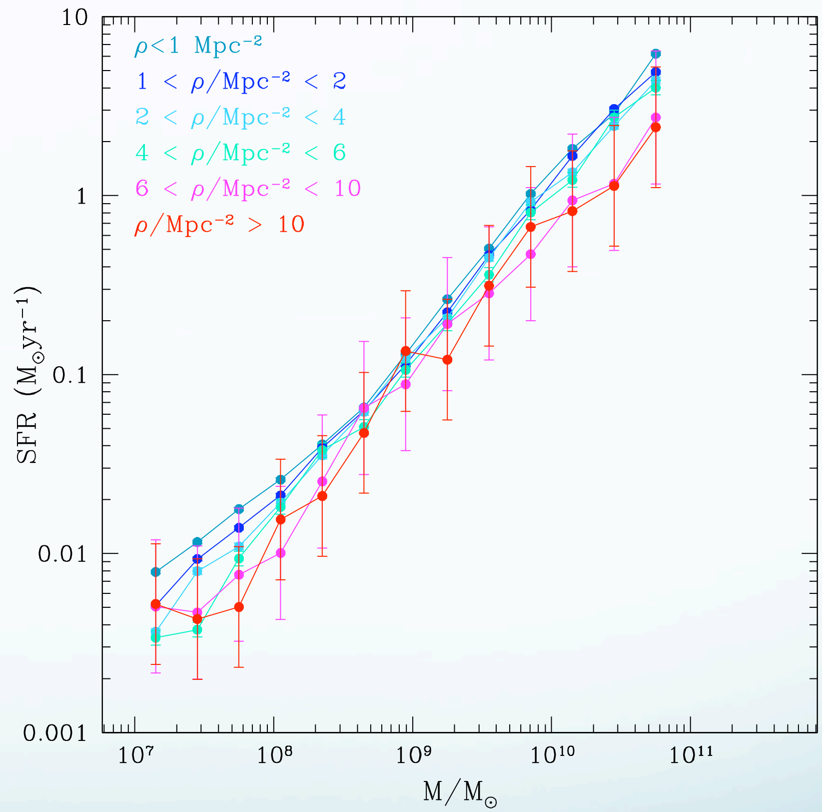
Contamination by galaxies in low mass halos ($M_{halo}< 10^{12}$ $M_\odot$) 64%

Contamination by galaxies in high mass halos ($M_{halo}>$ 10^{13} $M_\odot$) ~4%

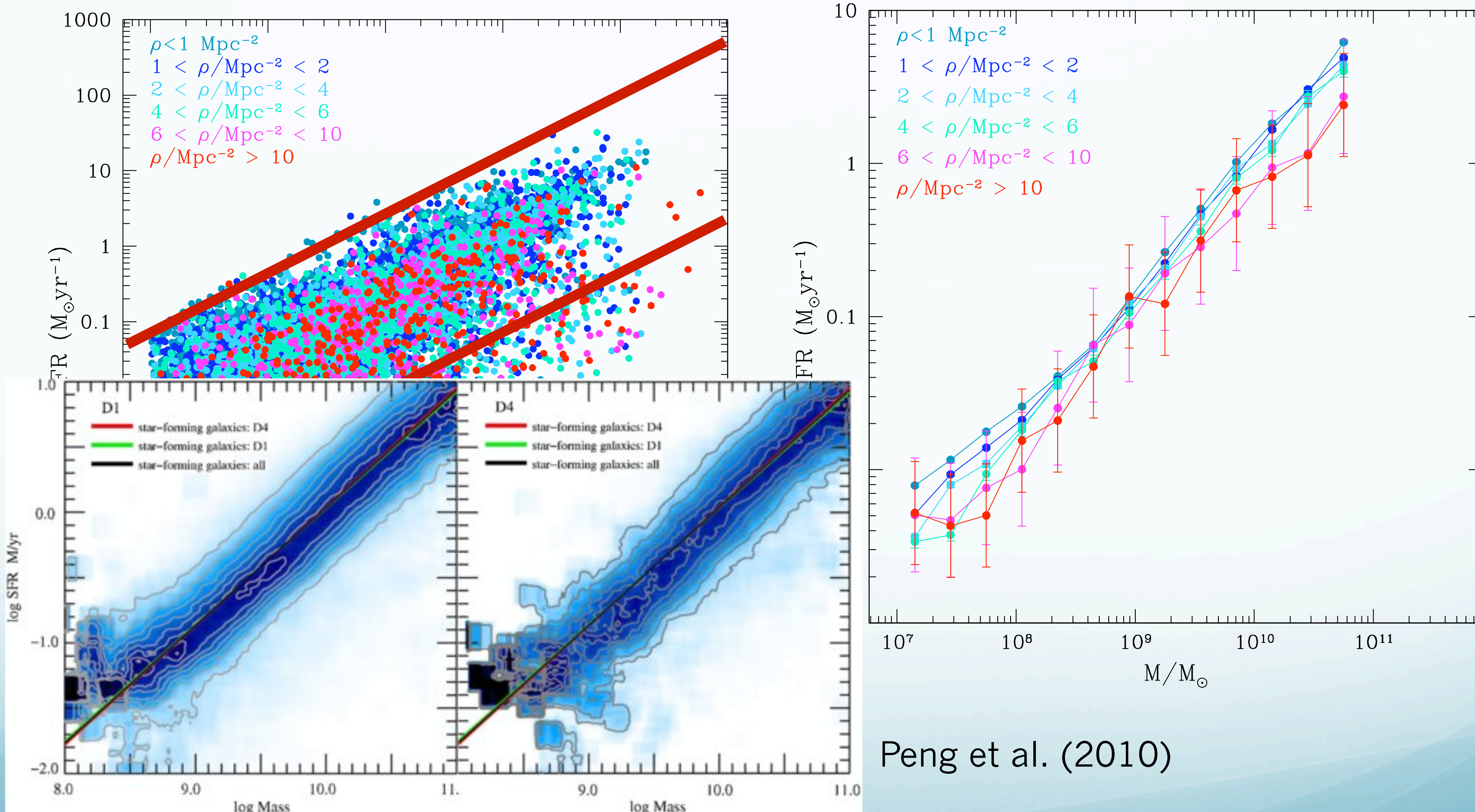
Millennium Simulation (Springel et al. 2005)

Density field vs. halo mass in the Millennium simulation



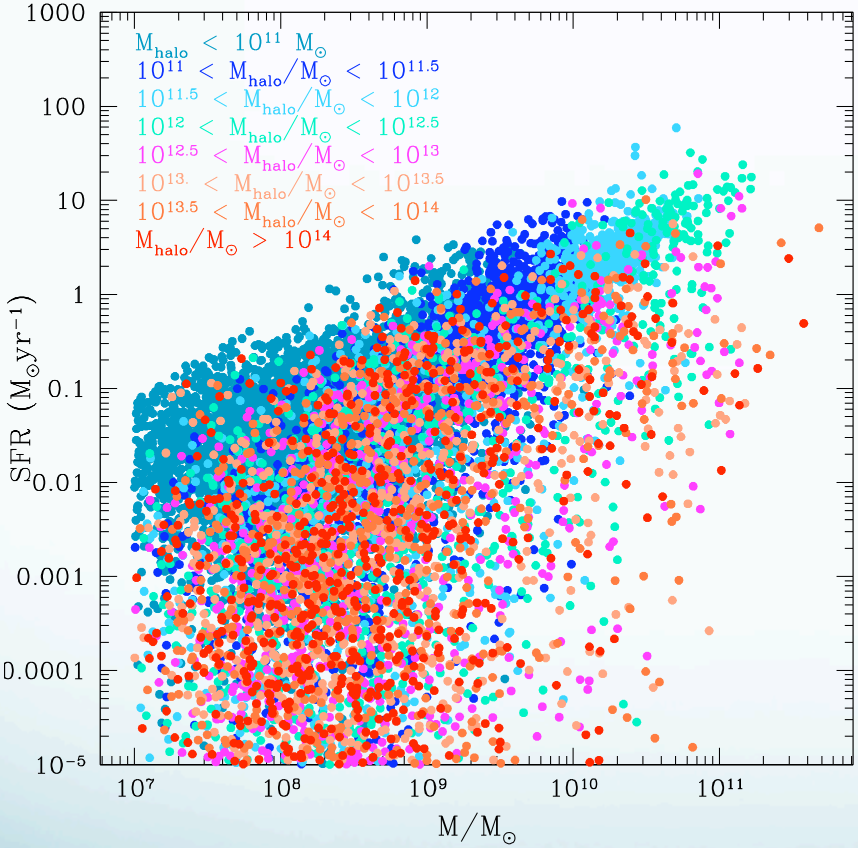


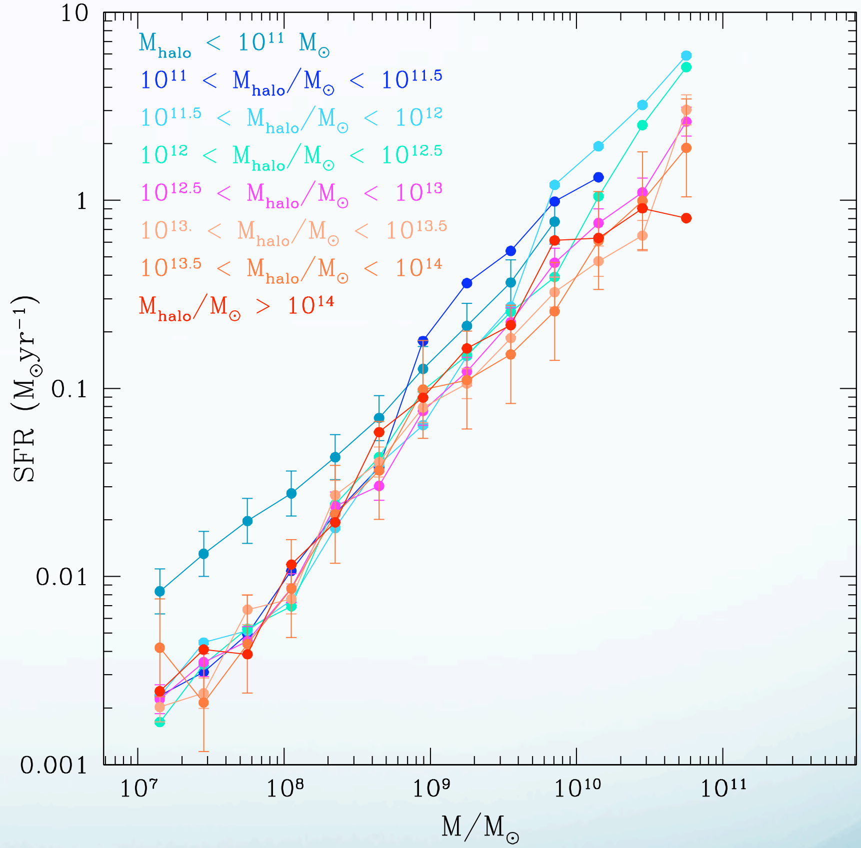
Density field vs. halo mass in the Millennium simulation



Peng et al. (2010)

Density field vs. halo mass in the Millennium simulation





Popesso, Erfanianfar, Biviano et al. in prep.

The dataset

- **X-ray data** for selecting group and cluster sample
- **Far-infrared data** for retrieving accurate estimate of SFR
- **Spectroscopic data** for group and cluster membership

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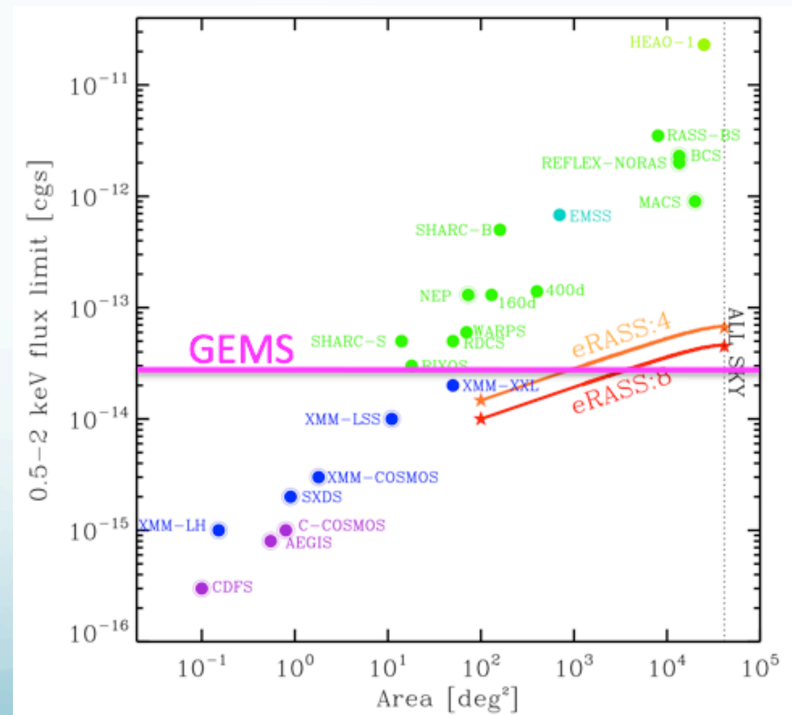
The Deepest X-ray Surveys:
CDFN, CDFS, COSMOS, AEGIS

The Deepest Legacy Spitzer
And Herschel surveys:
FIDEL, S-COSMOS, PEP,
GOODS-Herschel
and Herschel-CANDELS
surveys of major blank fields

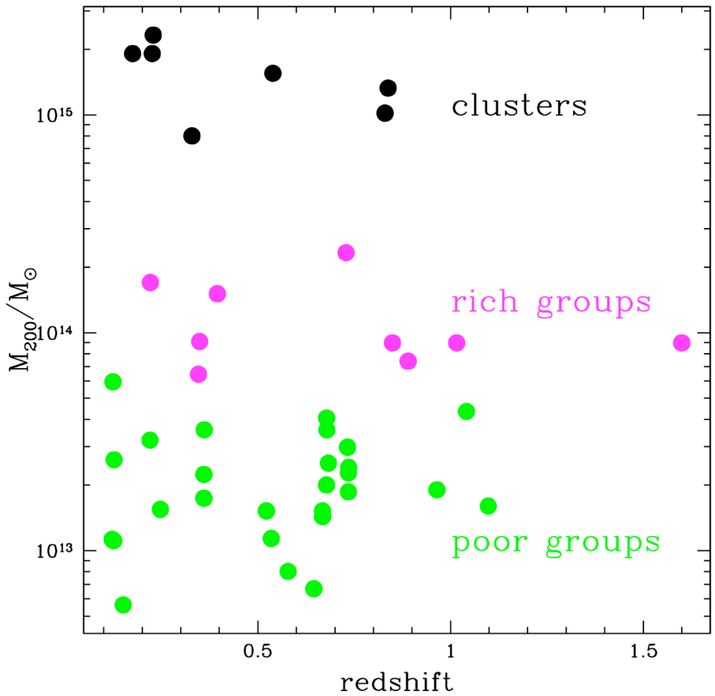


The dataset

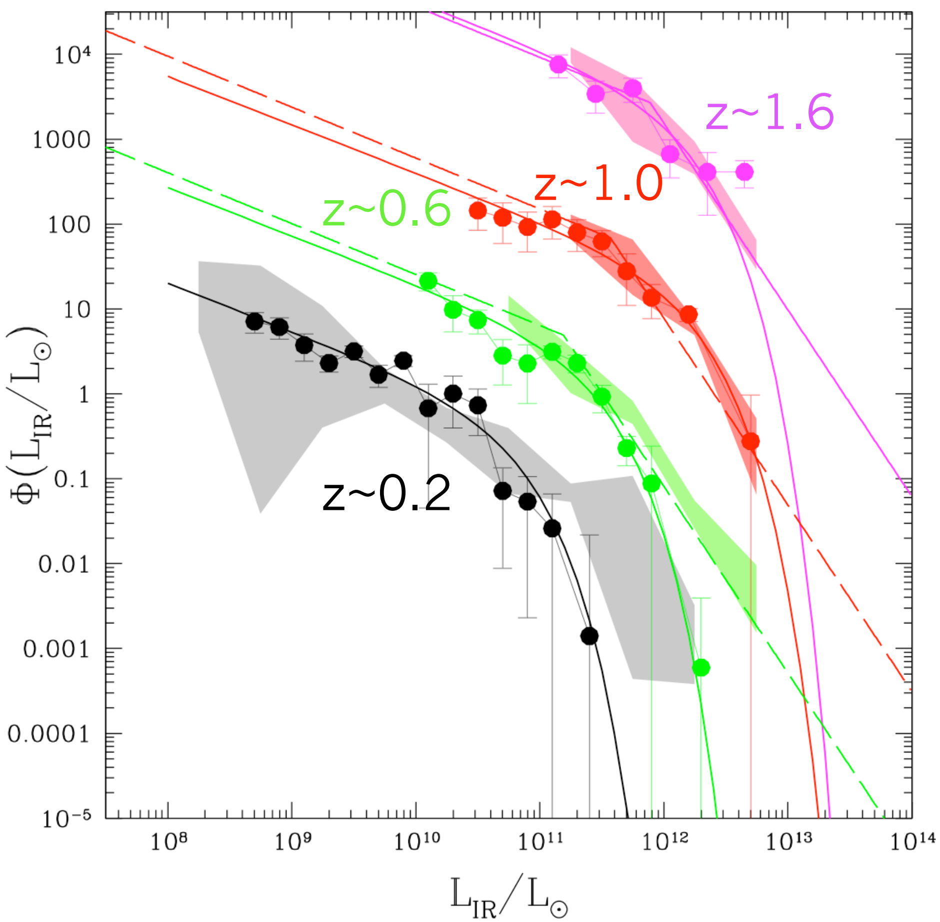
- **X-ray data** for selecting group and cluster sample
- **Far-infrared data** for retrieving accurate estimate of SFR
- **Spectroscopic data** for group and cluster membership

•**<u>35 groups</u>** at 0.1< z <1.6 (M_{200}~ 2×10^{13} $M_{\odot}$) observed with Herschel PACS at 100 and 160 μm

•**<u>8 clusters</u>** at 0.1< z < 0.8 (M_{200}~ 5×10^{14} $M_{\odot}$)



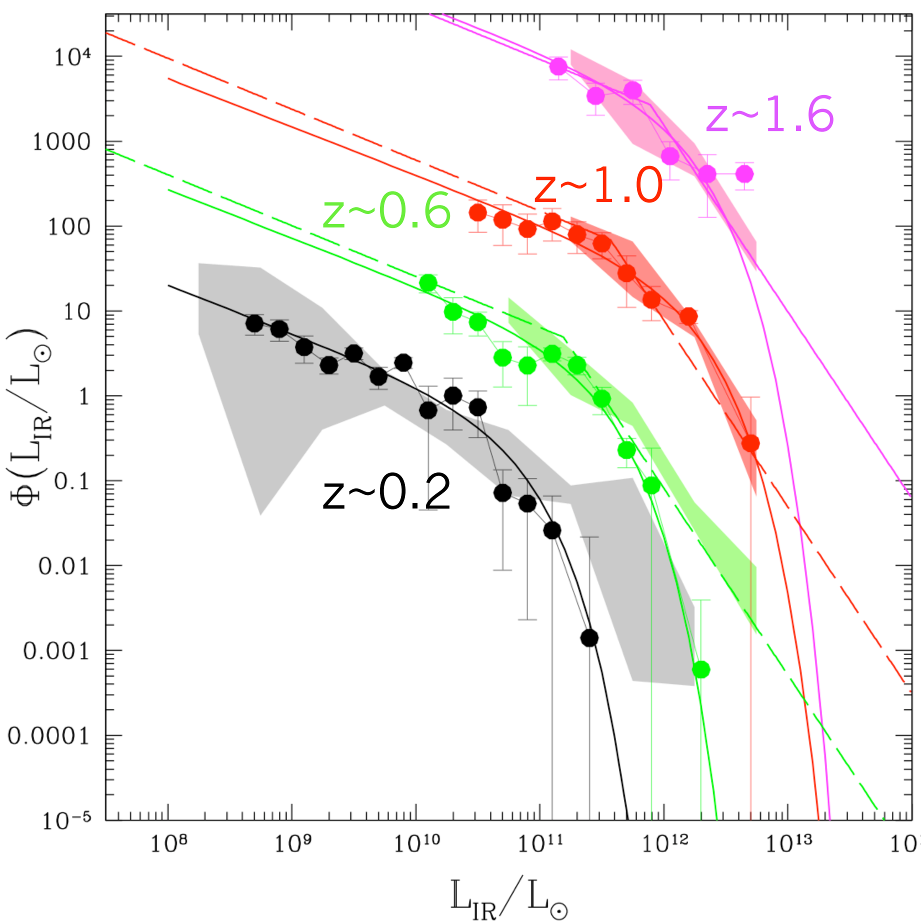
The Galaxy Group IR Luminosity Function

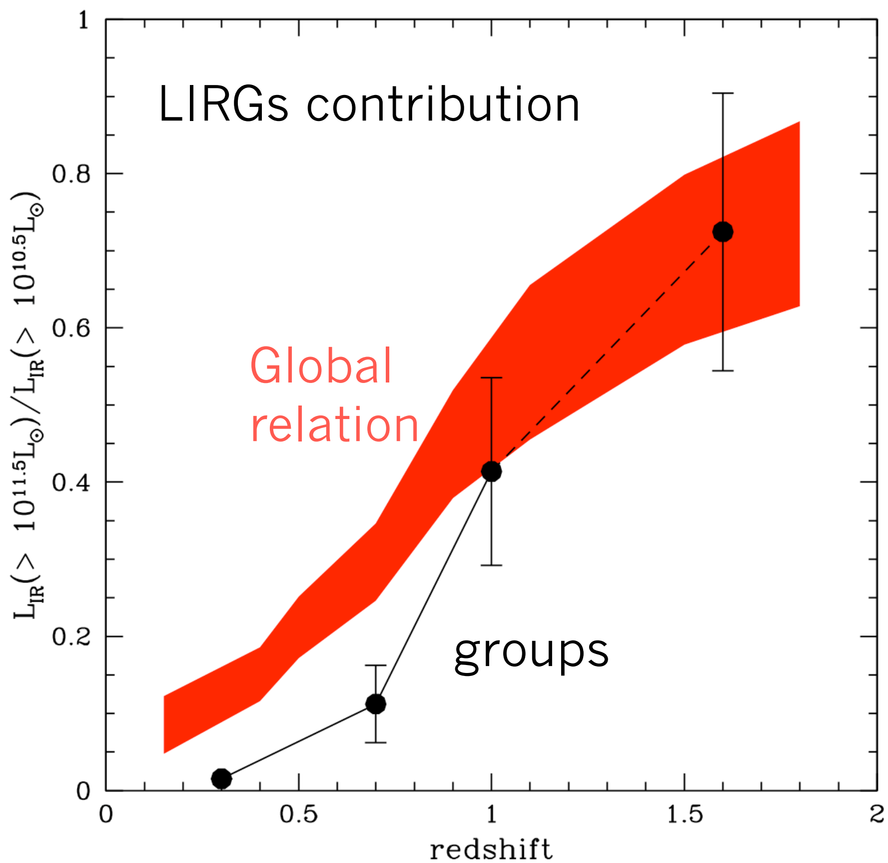


Popesso, Biviano, Finoguenov et al. (2013)

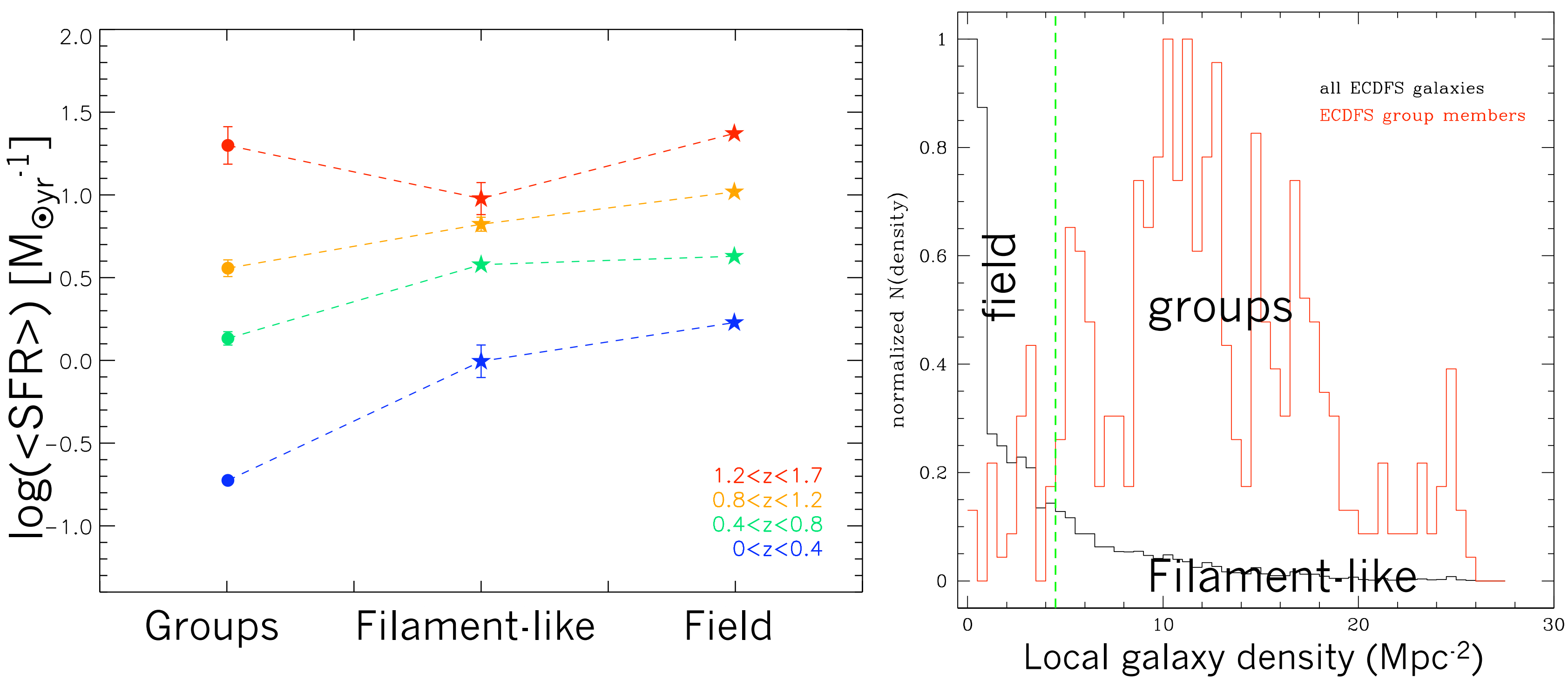
- Composite Group LF obtained through modified Colless (1989) method
- IR LF based on group galaxies spectroscopically confirmed
- shaded region: Global IR LF of Gruppioni et al (2013)
- dashed lines: Global IR LF of Magnelli et al. (2013)

The Galaxy Group IR Luminosity Function



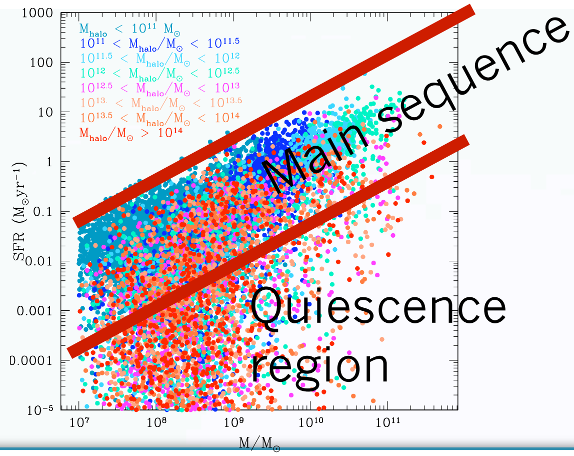


SFR-density relation:
a dynamical approach

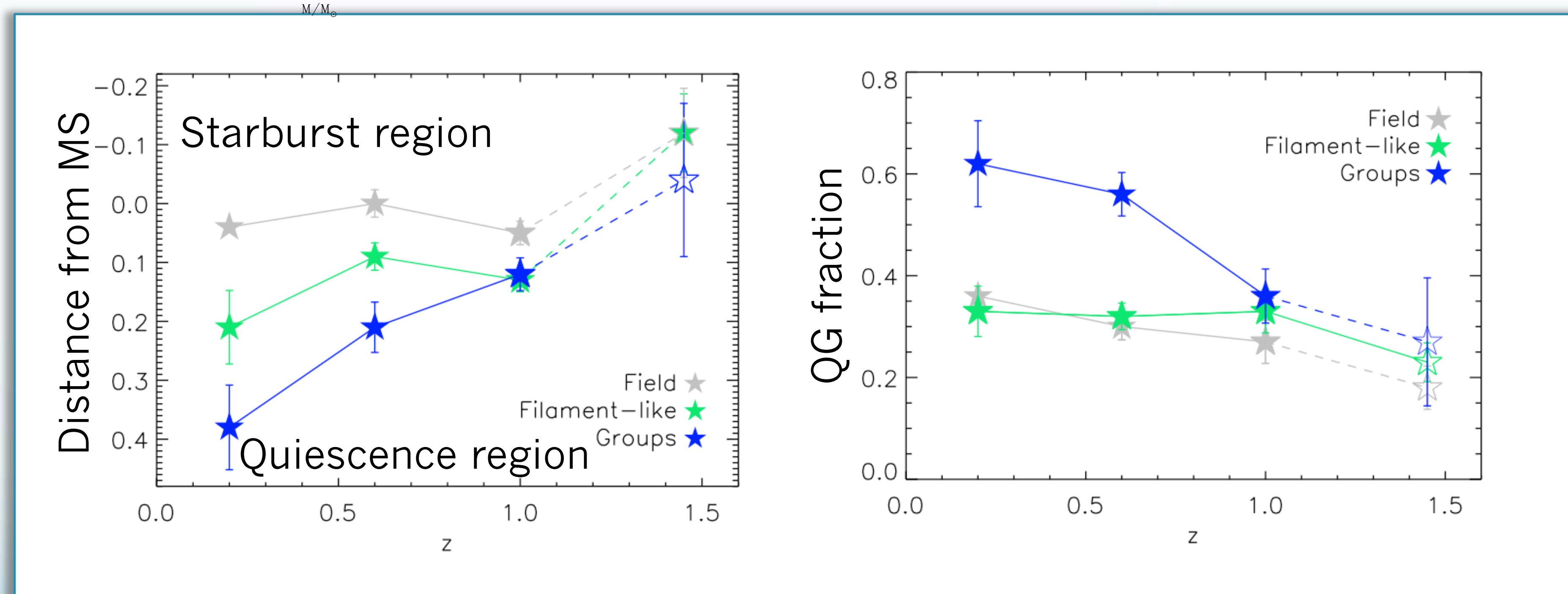


Environment defined via dynamical properties rather than density

Ziparo, Popesso, Biviano et al. (2013)



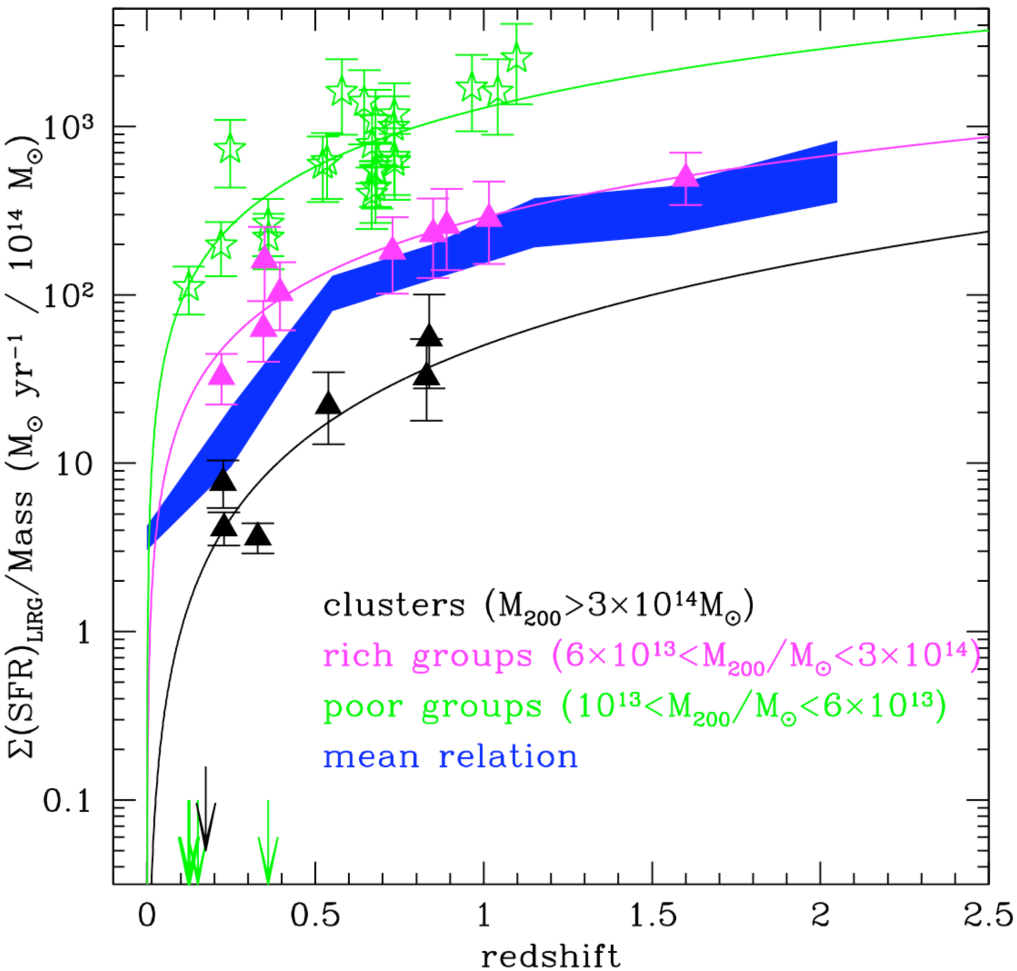
Halo mass dependence of SF quenching in the data



- We observe quenching of SF in group galaxies with respect to galaxies at the same density but in unbound structures (filament)
- Quenching is not density dependent but DM halo dependent

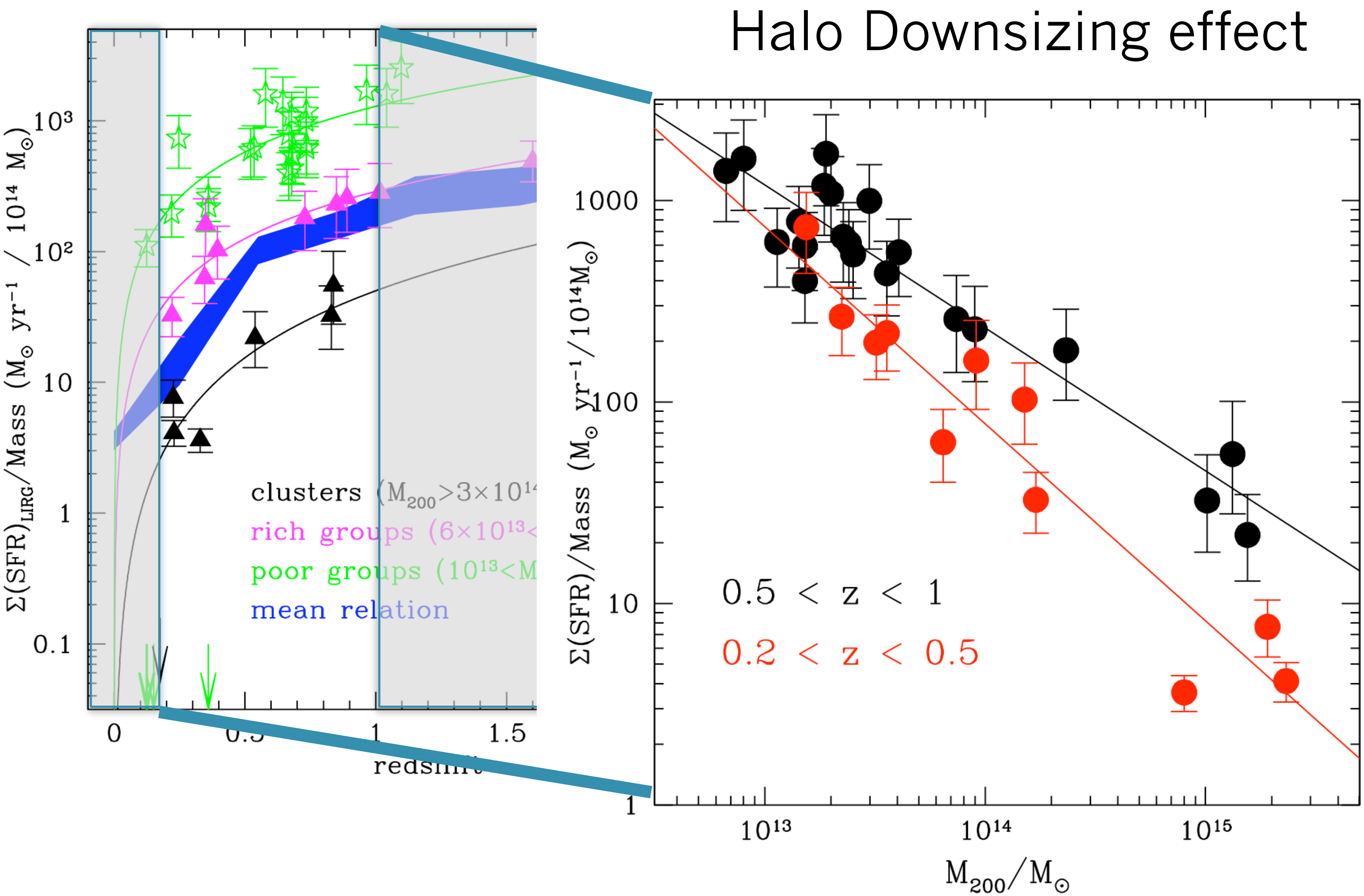
Ziparo, Popesso, Biviano et al. (2013)

Total SFR per halo mass

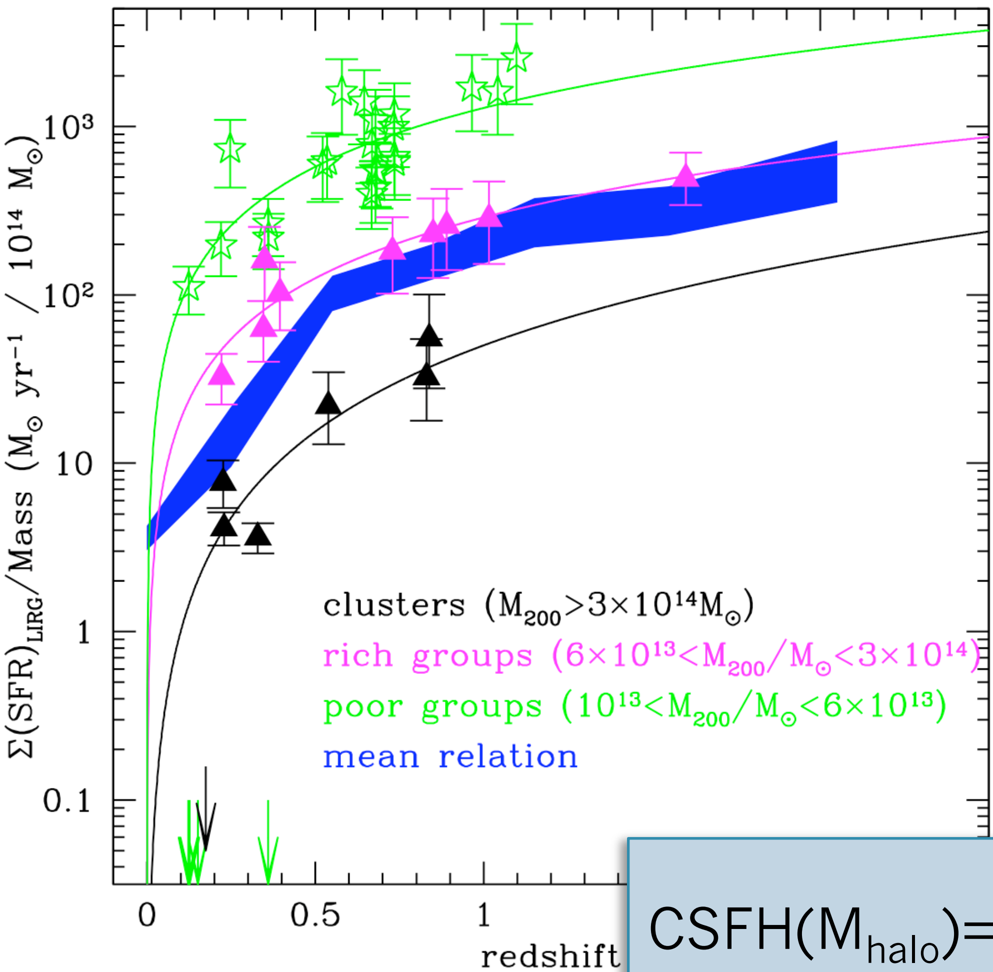


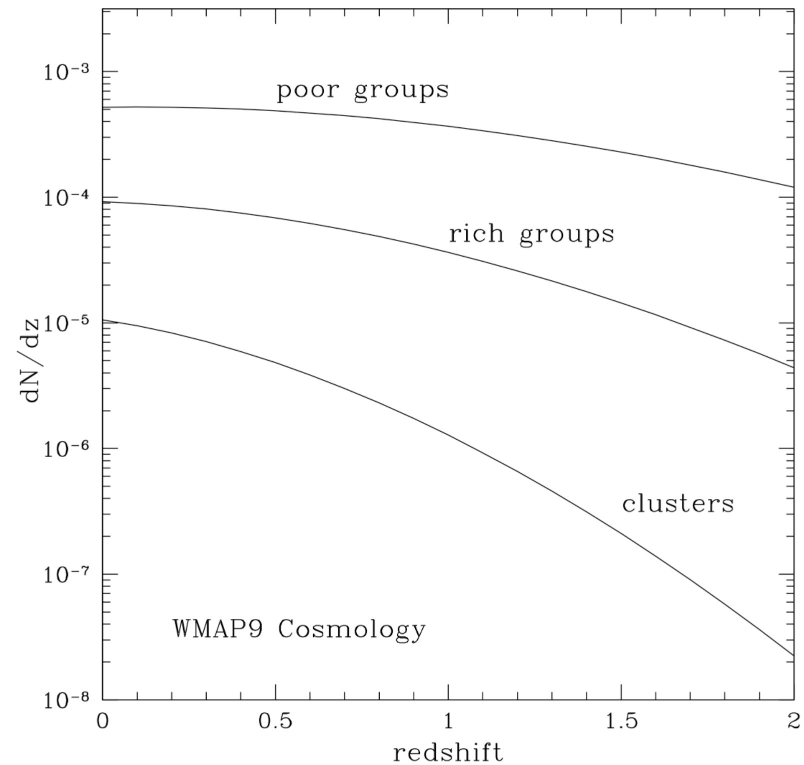
Popesso, Biviano, Finoguenov et al. (2013)

Total SFR per halo mass



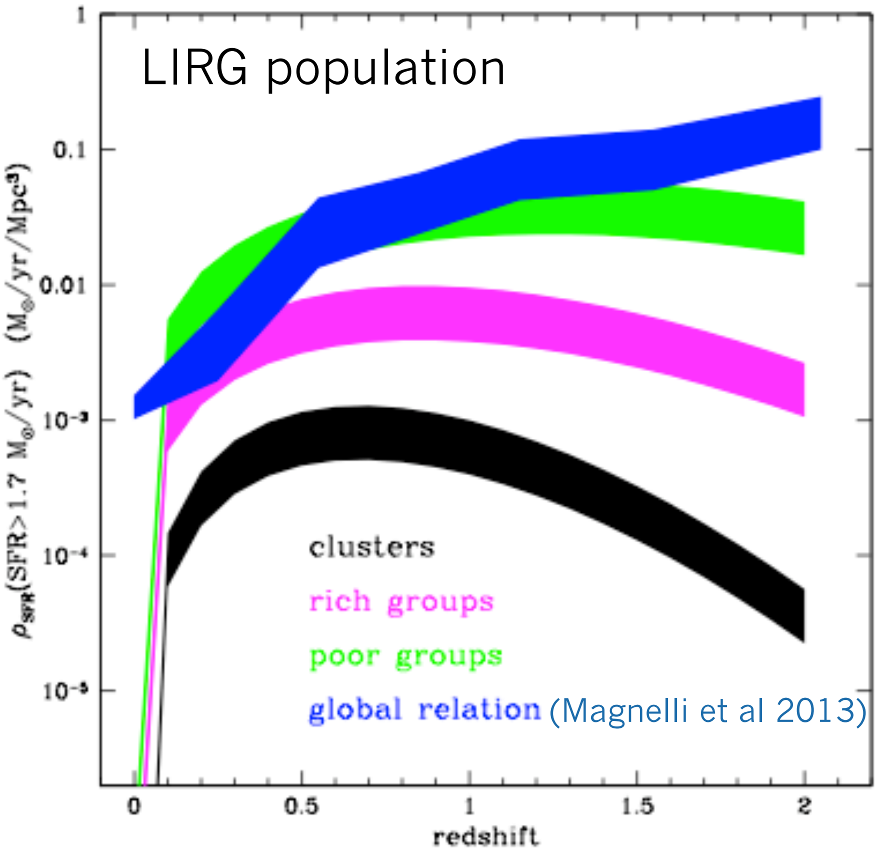
Total SFR per halo mass

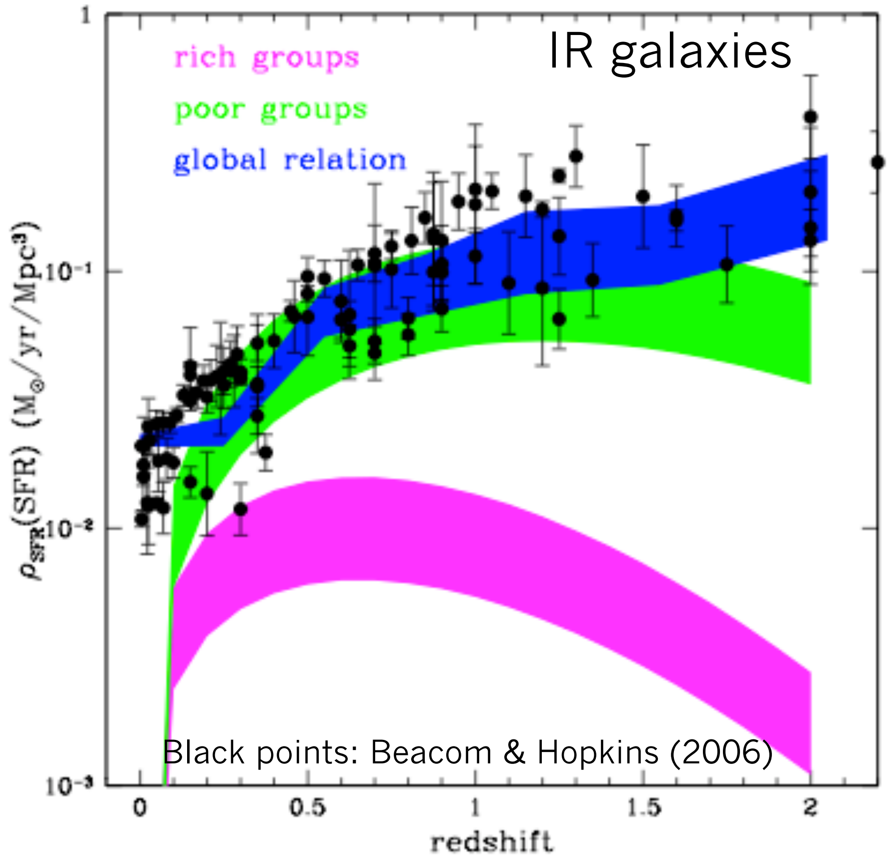




$$CSFH(M_{halo}) = \Sigma\,(SFR)/Mass * \langle M_{halo} \rangle * \rho_{halo}(z)$$

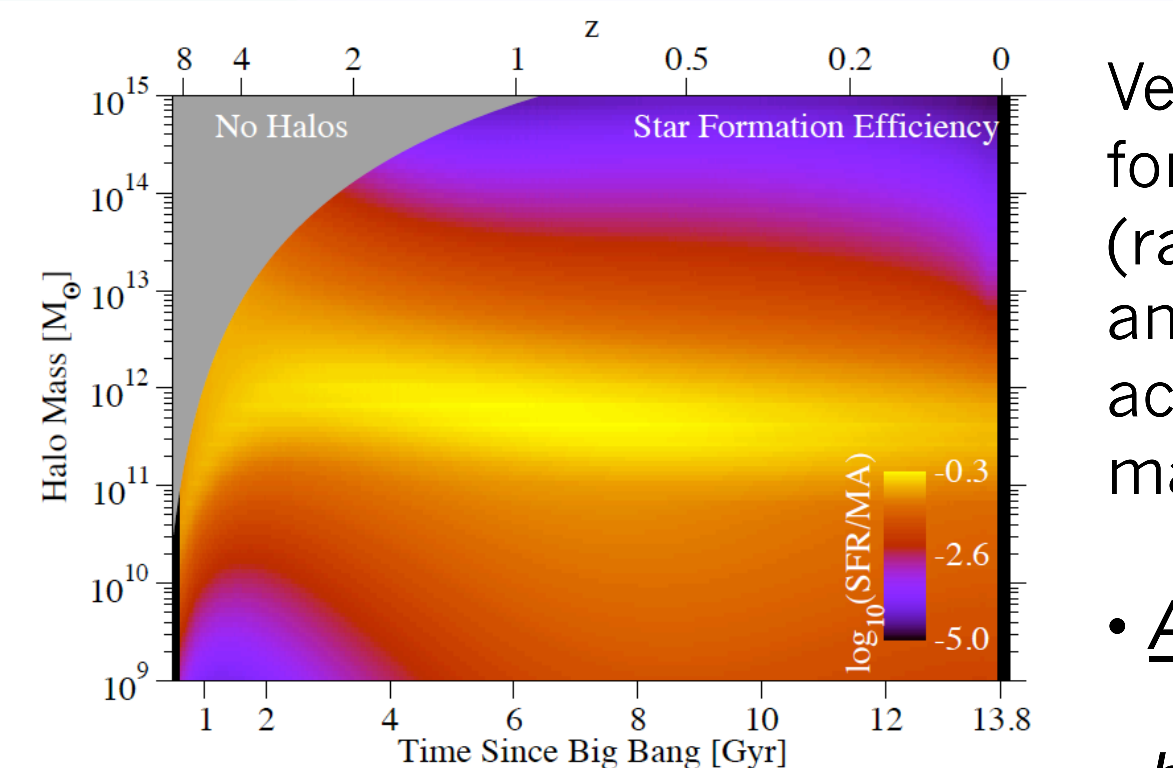
CSFH per halo mass





Popesso, Biviano, Finoguenov et al. (2013)

Two possible scenarios

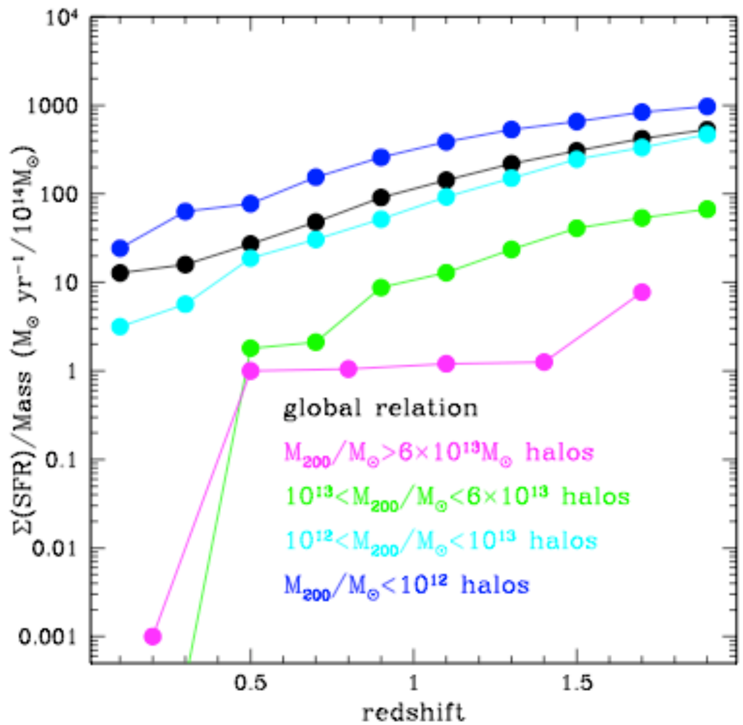


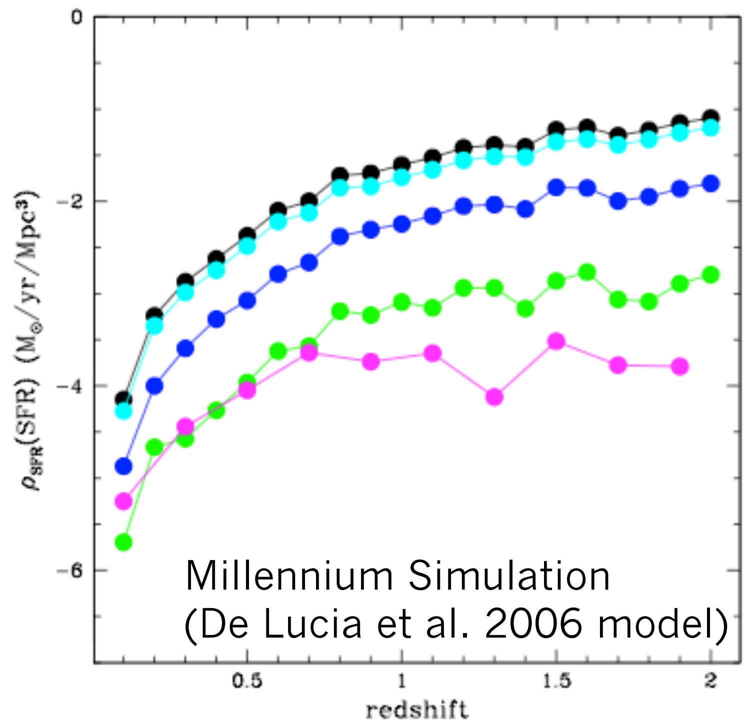
Behroozi et al. (2012)

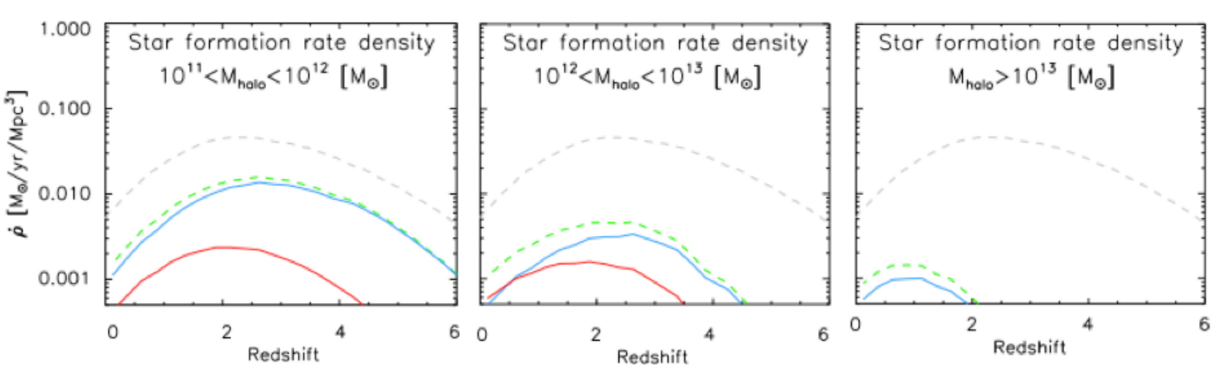
Very low star formation efficiency (ratio between SFR and baryonic accretion rate) in massive halos:

- ***AGN feedback***
- ***hot/cold accretion*** (Keres et al. 2005, Dekel & Birnboim 2006)

AGN feedback driven models



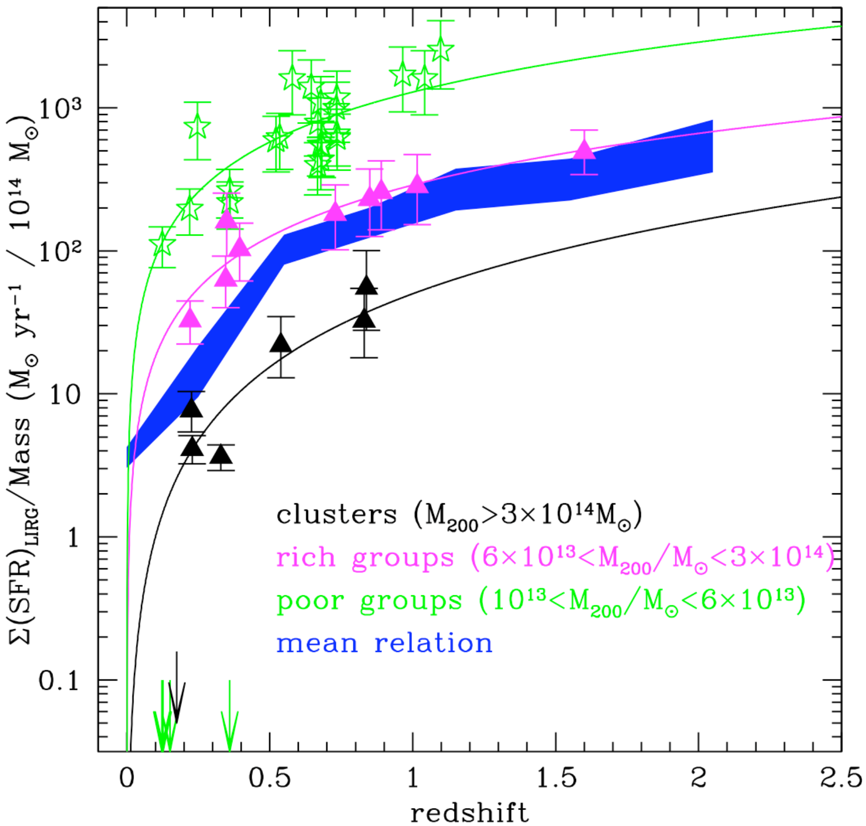




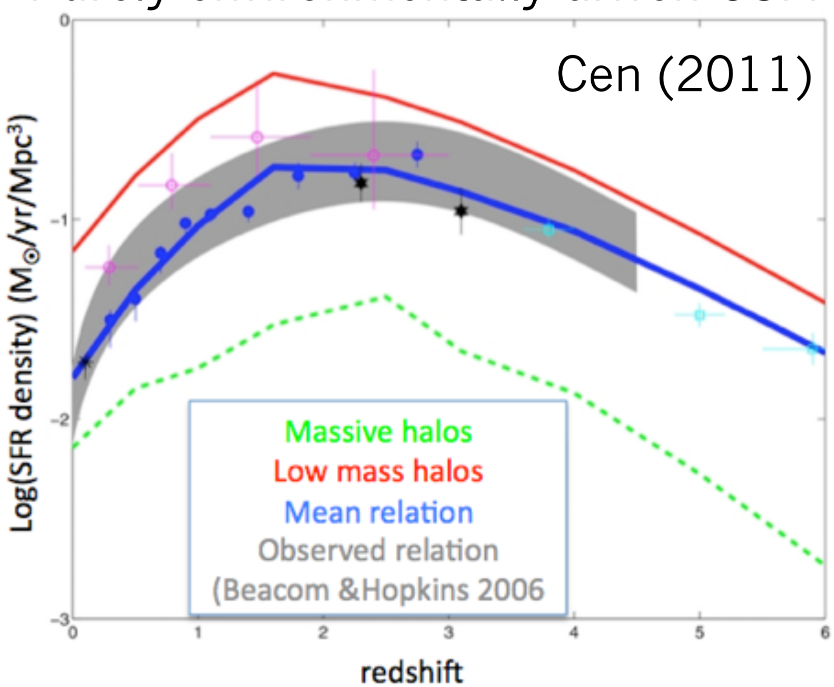
AGN over-quenching of group and cluster galaxies

Van der Voort (2011)

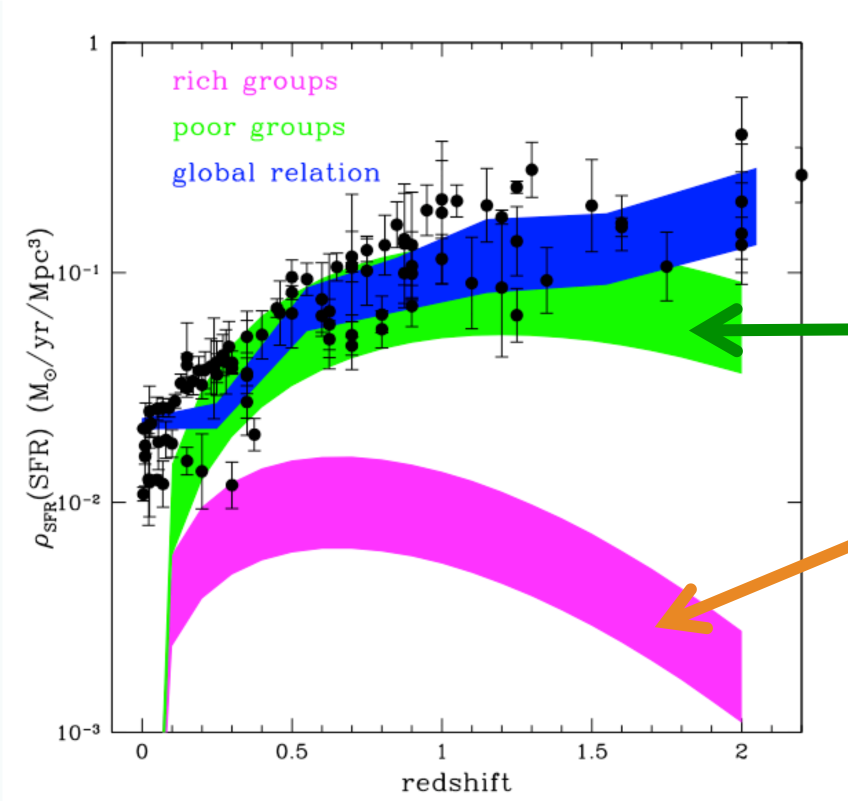
Environment driven models

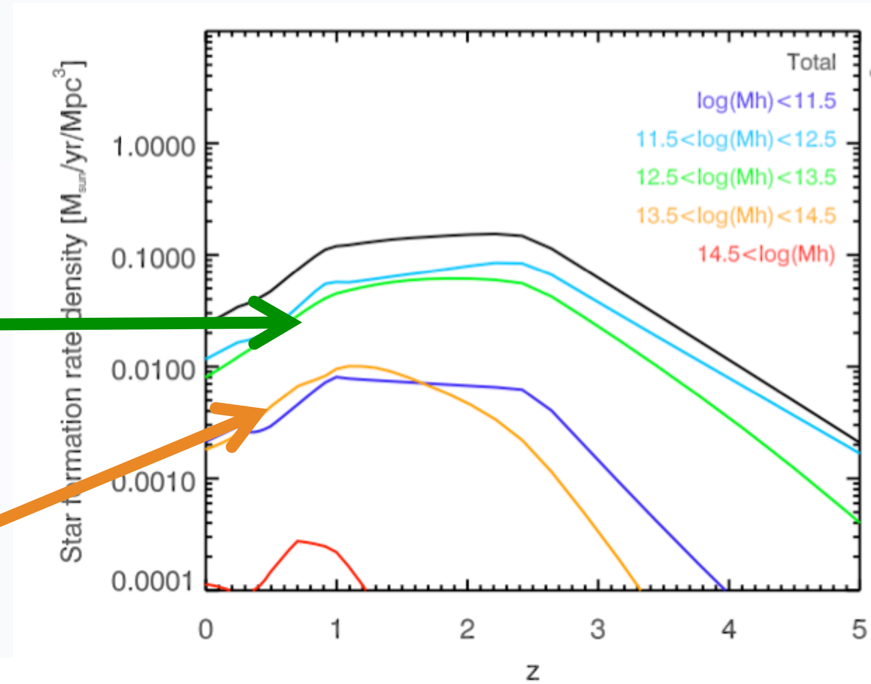


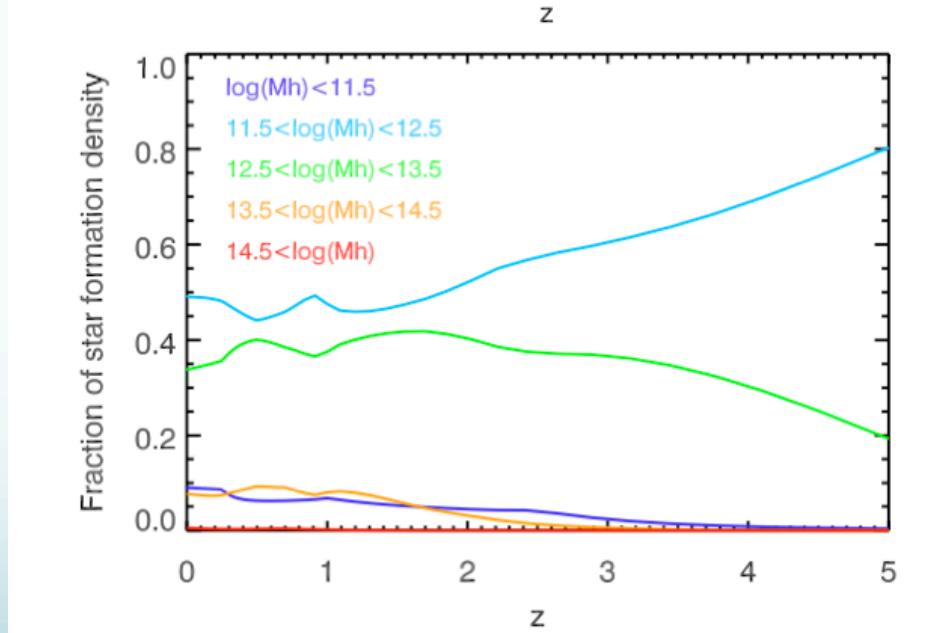
Purely environmentally driven CSFH



Hot accretion in massive halos leads to decrease in gas supply for galaxies entering group and cluster environment: *cold gas starvation → low star formation efficiency*







Empirical model of Bethermin et al. (2013, 2-SFM framework), which distinguishes between MS and SB galaxies and associates SF galaxies to host halo through abundance matching method.

How?

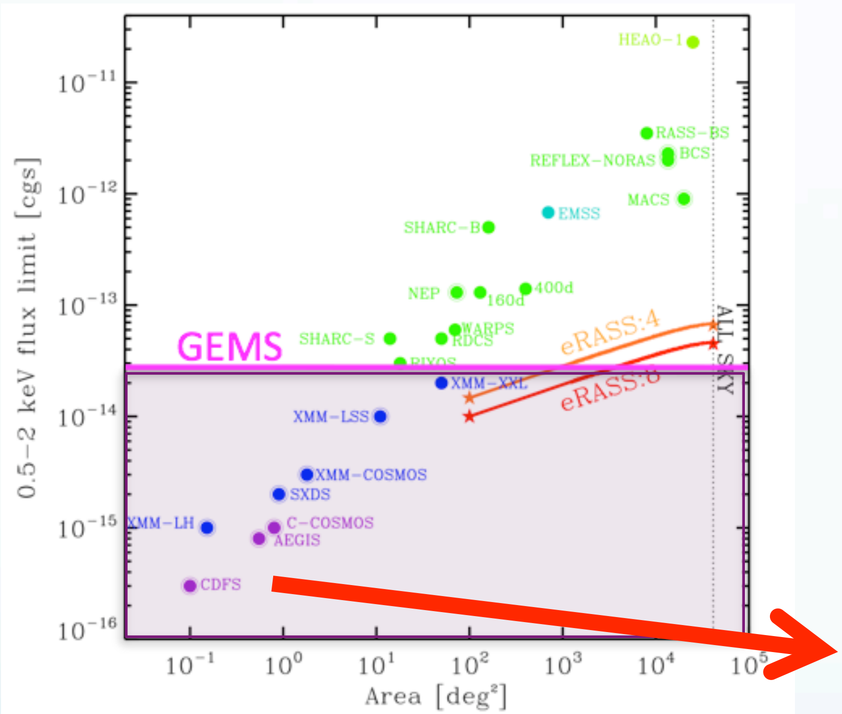
SF^2
A multi-tiered survey strategy

- *Requirement*:
  - the acquisition of a statistically significant number of galaxies, with measured star formation rate, in 3-4 bins of parent halo mass, ranging from $10^{12.5}$ (the dominating low mass groups) to $10^{15}M_{\odot}$ (the massive clusters), across the redshift range $0<z<1$.

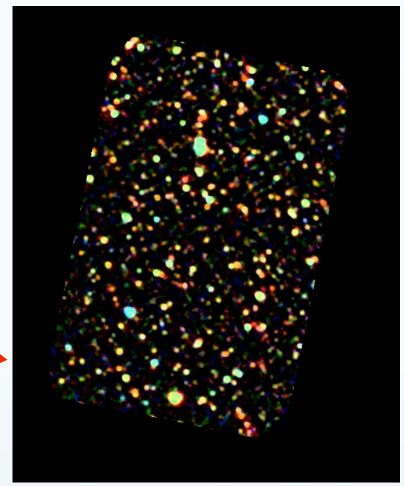
- *Three main ingredients needed:*
  - *Dark matter halo masses* →Deep X-ray survey over an extremely large area
  - *Accurate galaxy star formation rates* → *UV+IR* deep observations
  - *Secure identification of group and cluster membership* → highly complete spectroscopic coverage

How?

The first tier: Herschel+deep fields

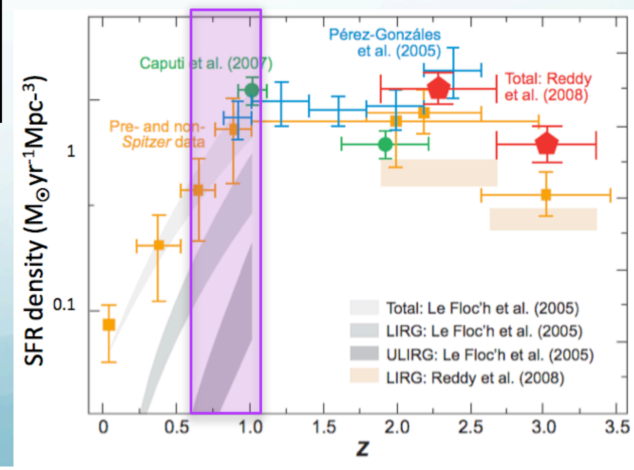


all the deep X-ray survey fields have Herschel coverage and deep spectroscopic coverage (e.g. Popesso et al. 2009, Lutz et al. 2010, Oliver et al. 2010).



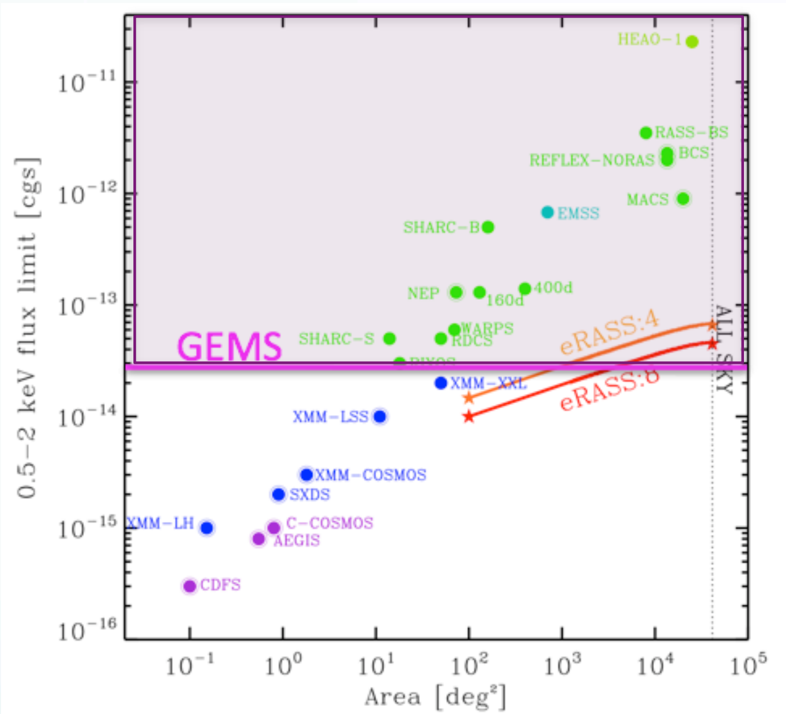
Herschel image of GOODS-S field

Deep X-ray selected groups and cluster catalog already available over all deep Xray fields (Popesso et al. 2012, Erfanianfar & Popesso in prep.)

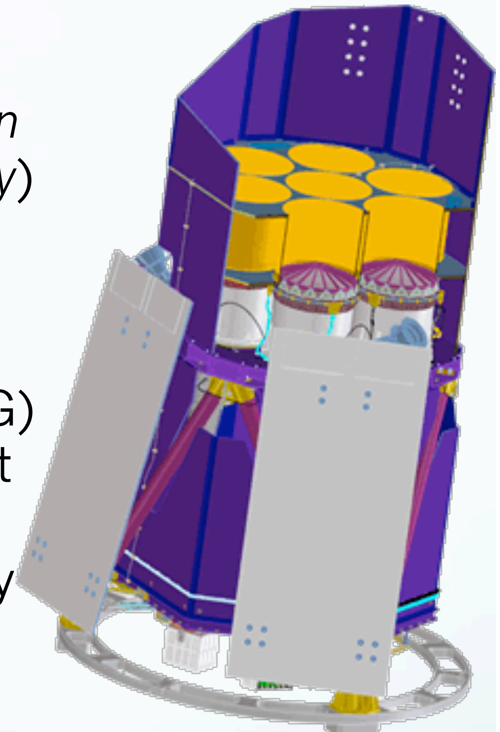


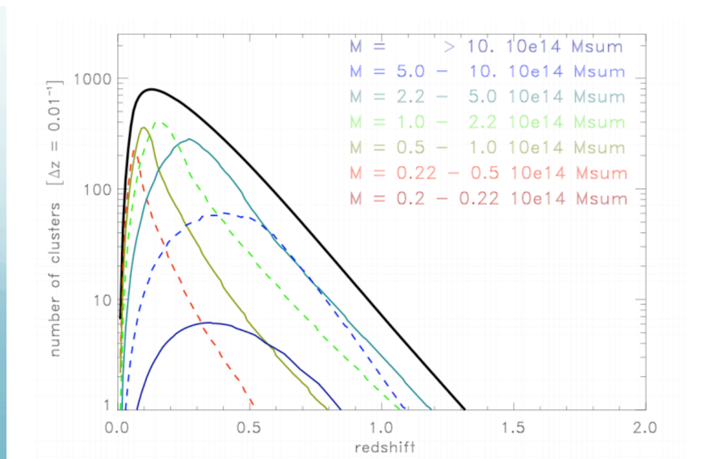
How?

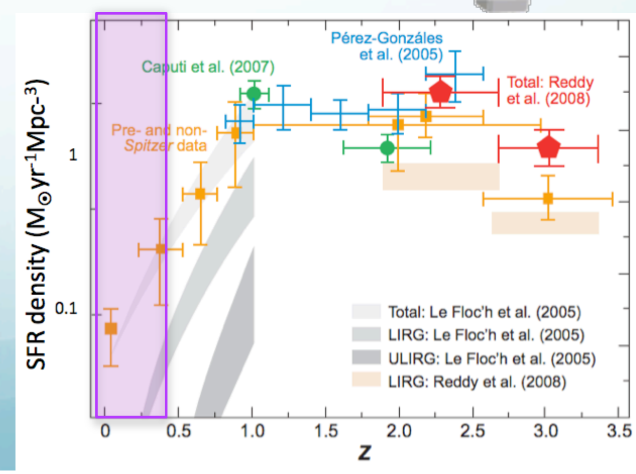
The second tier: Herschel+eROSITA



eROSITA (*extended ROentgen Survey with an Imaging Telescope Array*) will be launched on board of the X-ray Russian Spektrum-Roentgen-Gamma (SRG) mission in 2014, and it will perform a deep survey of the entire sky in the X-ray

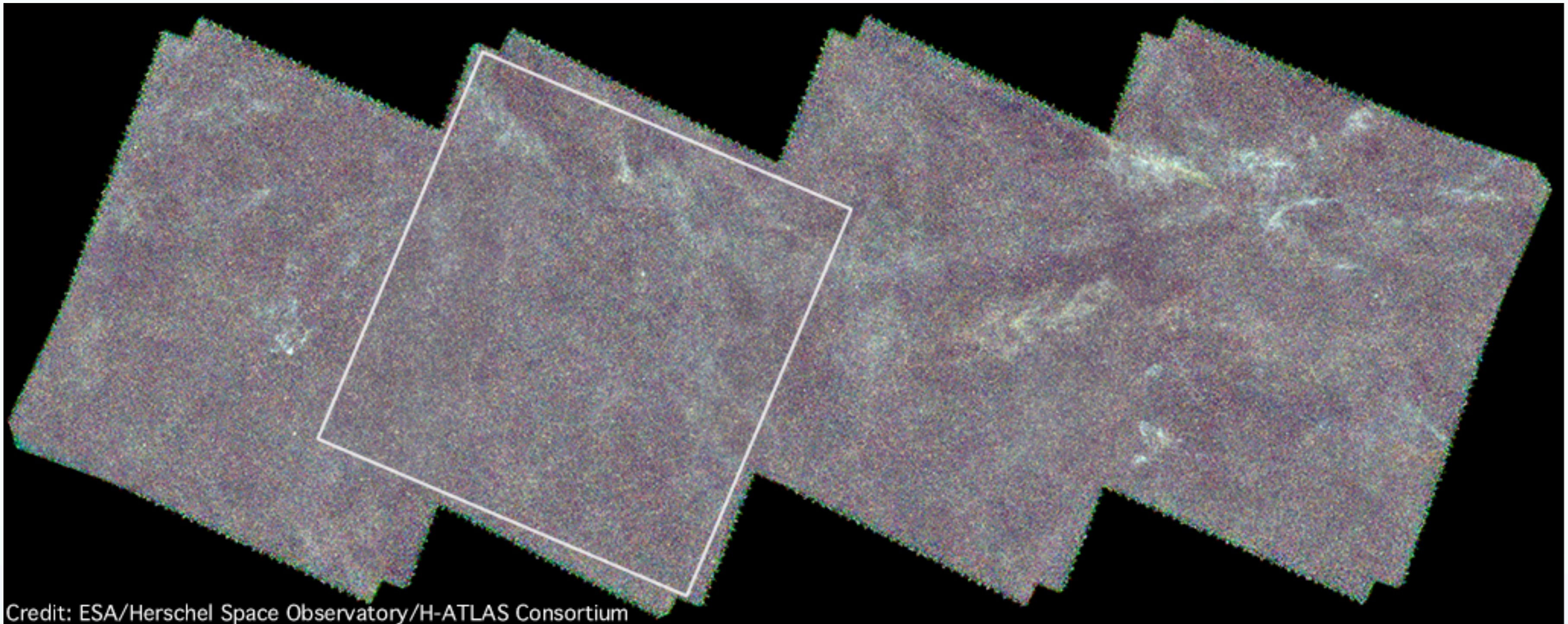






How?

The first tier: Herschel+eROSITA



Herschel -Atlas survey: far-infrared coverage of ~550 deg^2
Stripe 82 survey: Heschel coverage of ~250 deg^2
Galex All sky Survey for UV coverage

- Spectroscopic coverage from SDSS, 2dF, GAMA survey up to z~0.5
- this unique combination will allow us to amass ~100(50), 500(230) and 1500(2000) halos in the mass range $10^{12.5-13}$, 10^{13-14} and $10^{14-15} M_\odot$, respectively at $z<0.2$ ($0.2<z<0.5$).

Conclusions

- Galaxies in massive halos undergo a much faster evolution with respect to field galaxies:
  - The mean SF activity decreases faster since z~1 as confirmed by the evolution of the groups IR LF and the flattening of the SFR-density relation up to z~1-1.5
  - quenching of SF in group star forming galaxies (offset below the MS at z<~1) and a fast evolution of the galaxy type mix with respect to other environments
  - Anti-correlation between SF activity and halo mass present at any redshift; *halo downsizing effect*
  - Structures, in particular group-sized halos, play a central role in the evolution of the SF activity of the Universe since z~1

- Evolution is faster is halos of bigger mass consistent with model where SF activity is regulated by the gas starvation due to hot accretion rather than AGN feedback

The pre-Herschel global picture

- Bell et al. 2005 → no merger-driven decline of the SF activity in main sequence
- Connection between ULIRGs and AGN in local sample
- Hopkins et al. (2006), Croton et al. (2006)→ AGN feedback-driven evolution of SF activity in galaxies
- Daddi et al. (2007)→ all galaxies with 8 μm rest-frame excess at z~2 are Compton-tick AGN

The post-Herschel picture

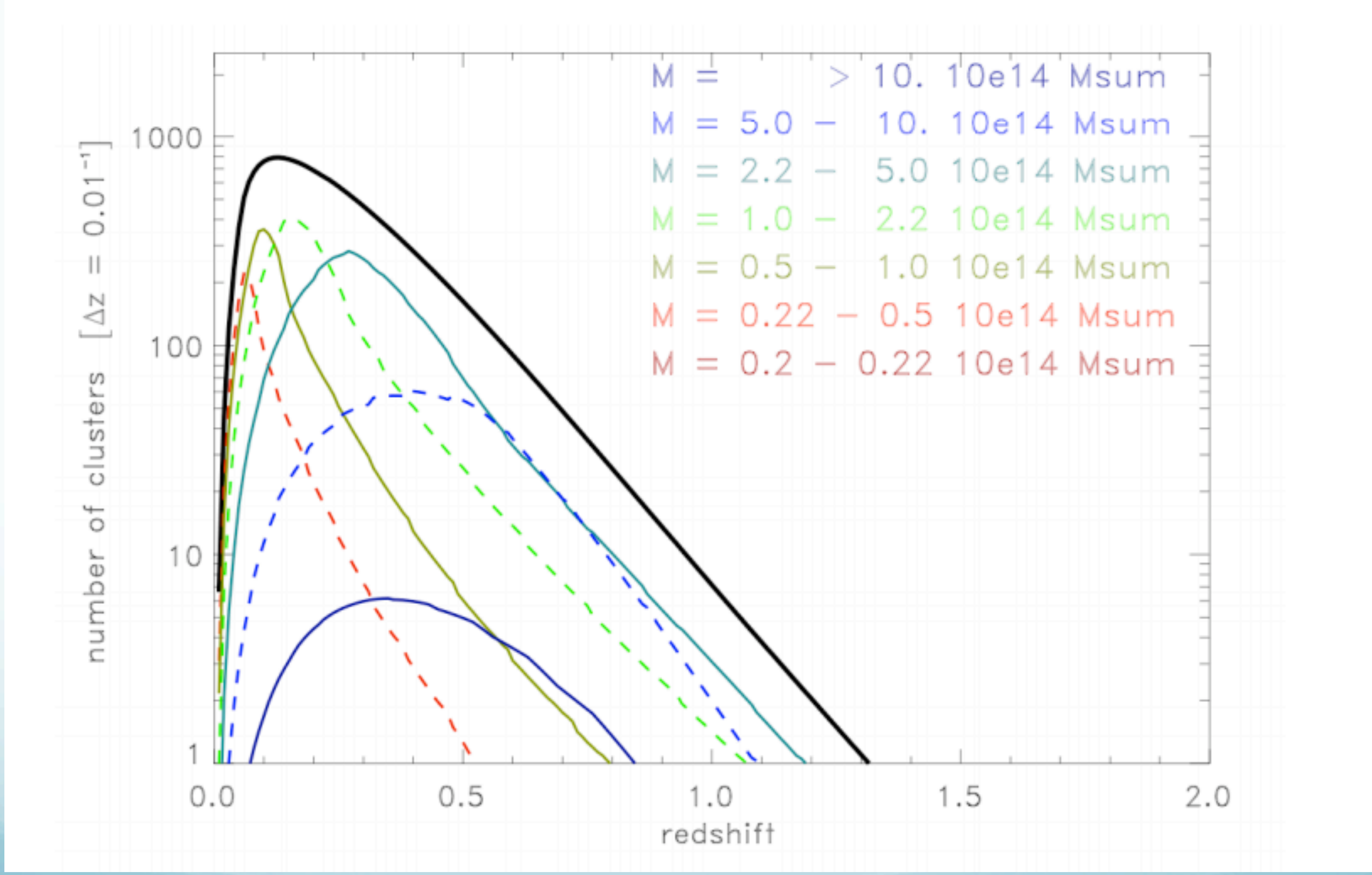
- High redshift ULIRGs are not generally AGNs but normal galaxies without sign of strong merger activity and AGN outflows
- galaxies with 8 μm rest-frame excess: different infrared SED (likely compact objects but no AGN, Elbaz et al. 2010, 2011)
- Off-sequence galaxies (mergers) in marginal percentage (15-20% contribution to the stellar mass assembly of the Universe, Rodighiero et al. 2011)
- No evidence for co-evolution between AGN and host galaxies (no quenching by AGN feedback, Rosario et al. 2012, Mullaney et al. 2012, Rovilos et al. 2012, Bongiorno et al. 2012)
- No "smoking gun" for existence of AGN feedback
- Structures, in particular group-sized halos, play a central role in the evolution of the SF activity of the Universe since z~1

The galaxy and their parent halo census in SF^2

Halo mass	X-ray data	Spectroscopic follow-up	SFR indicators	group catalog completion
$10^{12.5}$- 10^{13} $M_\odot$ at z < 0.2	- ~100 (150) groups from eRASS4(6)	SDSS DR9(10)	- UV+IR - Hα	eRASS4 2016 eRASS6 2017-2018
$10^{12.5}$- 10^{13} $M_\odot$ at 0.2 <z < 0.4	- ~70 (100) groups from eRASS4(6)	-GAMA -SPIDERS -eBOSS	- UV+IR -[OII]	eRASS4 2016 eRASS6 2017-2018
10^{13}- 10^{14} $M_\odot$ at z < 0.2	- ~150-500 groups from eRASS1:6	SDSS DR9(10)	- UV+IR -Hα	eRASS1 2015 eRASS6 2017-2018
10^{13}- 10^{14} $M_\odot$ at 0.2 <z < 0.4	- ~70-230 groups from eRASS1:6	-GAMA -SPIDERS -eBOSS	- UV+IR -[OII]	eRASS1 2015 eRASS6 2017-2018
$10^{12.5}$- 10^{14} $M_\odot$ at 0.4 <z <1.0	Deep X-ray survey: ~100 groups	Dedicated spectroscopic surveys	- UV+IR	Catalogs already in hand
10^{14}- 10^{15} $M_\odot$ at 0 < z < 1	- ~500-1000 @ z < 0.2 from eRASS1:6 - ~1000-2000 @ 0.2 < z< 0.4 from eRASS4:6 - ~50 @ z> 0.4 from eRASS4:6	-SDSS DR9(10) -GAMA -SPIDERS -eBOSS	- UV+IR (H-Atlas) -[OII]	eRASS1 2015 eRASS4 2016 eRASS6 2017-2018

The groups and cluster numbers, in the case of eROSITA, are based on dedicated simulations run by the eROSITA Consortium (Nicolas Clerc, private communication).

eROSITA cluster sample



The next step: the Euclid mission