The halo mass: a key ingredient to understand galaxy evolution

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Introduction

Cosmic Star Formation Rate Density
SFRD(z) ↑↑ with z up to z~1, and does not decrease before z~2-3 *(e.g. Madau+98, Reddy+08)*

SFRD is mostly from LIRGs at high-z, but not at low-z *(e.g. Le Floc'h+05)*

Group number density ↑ with time,
→ more and more galaxies experience the group environment, that is, more galaxies become satellites of more massive halos.

Is the cosmic SFRD(z) ↓ related to this?

Let's measure the contribution of halos of different mass to SFRD(z)

Two ingredients needed: 1) IR luminosity functions (LFs)
2) Halo masses, M_{halo}

The Dataset

Chandra & XMM **X-ray** selected groups with L_X
(Finoguenov+15)

COSMOS Spitzer @ 24 μm *(Le Floc'h+09, Sanders+07)*
Herschel PEP PACS @ 100 160 μm *(Lutz+11, Magnelli+13)*

CDFN, ECDFS, GOODS: Spitzer 24 μm Fidel Pgm *(Magnelli+09)*
Combined PACS PEP *(Lutz+11)*
& GOODS-Herschel *(Elbaz+11)*
@ 70, 100, 160 μm *(Magnelli+13)*

IR sources associated with **optical** *(Capak+07, Cardamone+10,*
Berta+10 for COSMOS, CDFS, CDFN) via Max Lik

Redshifts for COSMOS (SDSS or zCOSMOS via VLT/VIMOS, *Lilly+07;*
Keck/DEIMOS, *Scoville+*; Magellan/IMACS, *Trump+07*;
MMT, *Prescott+06*); CDFS (*Cardamone+10, Silverman+10,*
ACES: *Cooper+12*, GMASS: *Cimatti+08*); CDFN (*Barger+08*)

The Sample

38 X-ray selected groups at $0<z\leq1.05$
(Finoguenov+15)

+ the group of *Kurk+08* at $z=1.6$
+ stack of GAMA low-z optically selected groups *(Robotham+11)* made by *Guo+14*
+ 9 clusters from *Popesso+12*
+ Coma cluster of *Bai+06*
+ 3 stacks of LoCuSS clusters by *Haines+13*

Spectroscopic **completeness** $\geq$60% down to 0.06 mJy @ 24 μm

Cluster **membership** from projected phase-space distribution (l.o.s. velocities vs. clustercentric distances) using *CLEAN* algorithm (*Mamon+13*)

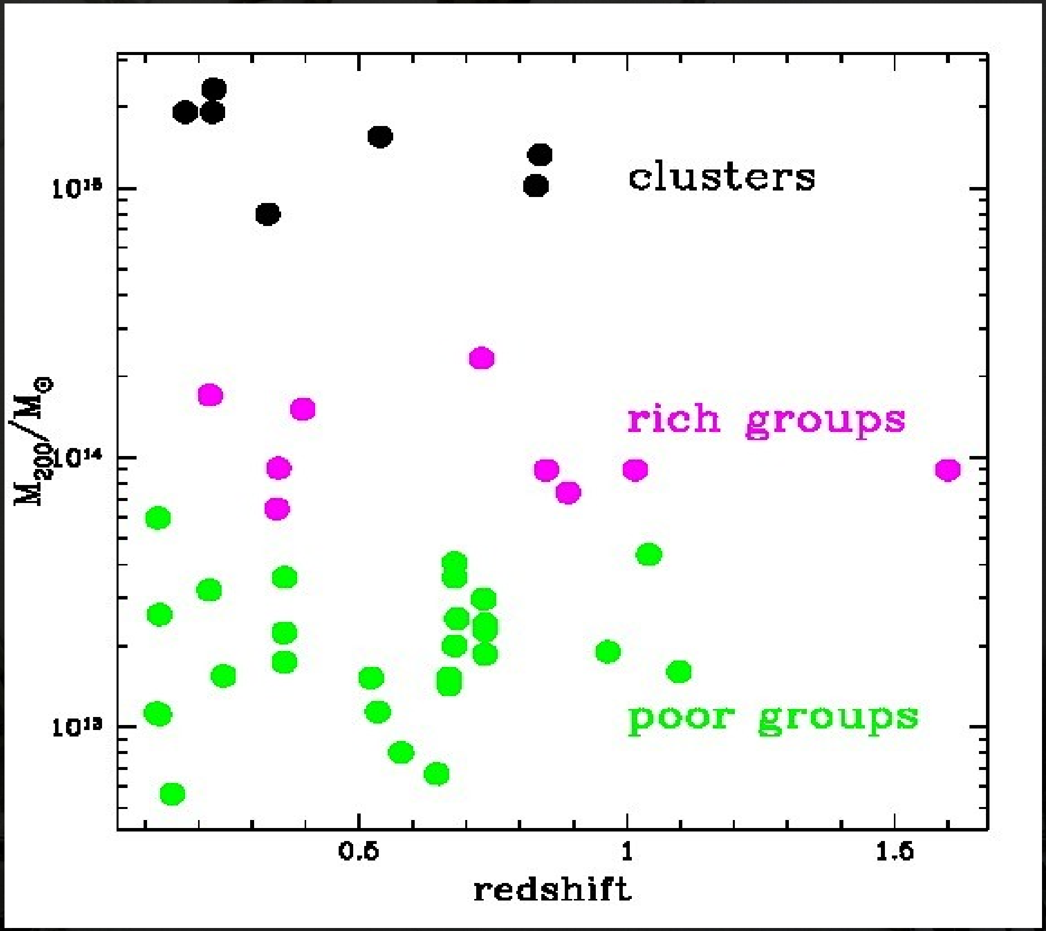
The group and clusters masses

Derived from L_X via scaling relation *(Leauthaud+10)*, or – for the most distant group - from its velocity dispersion, via a scaling relation *(Mamon+13)*, or taken from the literature

We define three samples:

- **clusters**
- **rich groups**
- **poor groups**

separated by M_{halo}



The galaxy IR luminosities

Derived from **SED fitting** of the main sequence
and starburst templates of *Elbaz+11* to
PACS (70, 100, 160 μm) and MIPS (24 μm) fluxes.

If only MIPS available, adopt the main sequence template.

Integrate over the 8-1000 μm spectral range of the template.

SFR from L_{IR} via *Kennicutt's (1998)* relation

The IR luminosity functions (LFs)

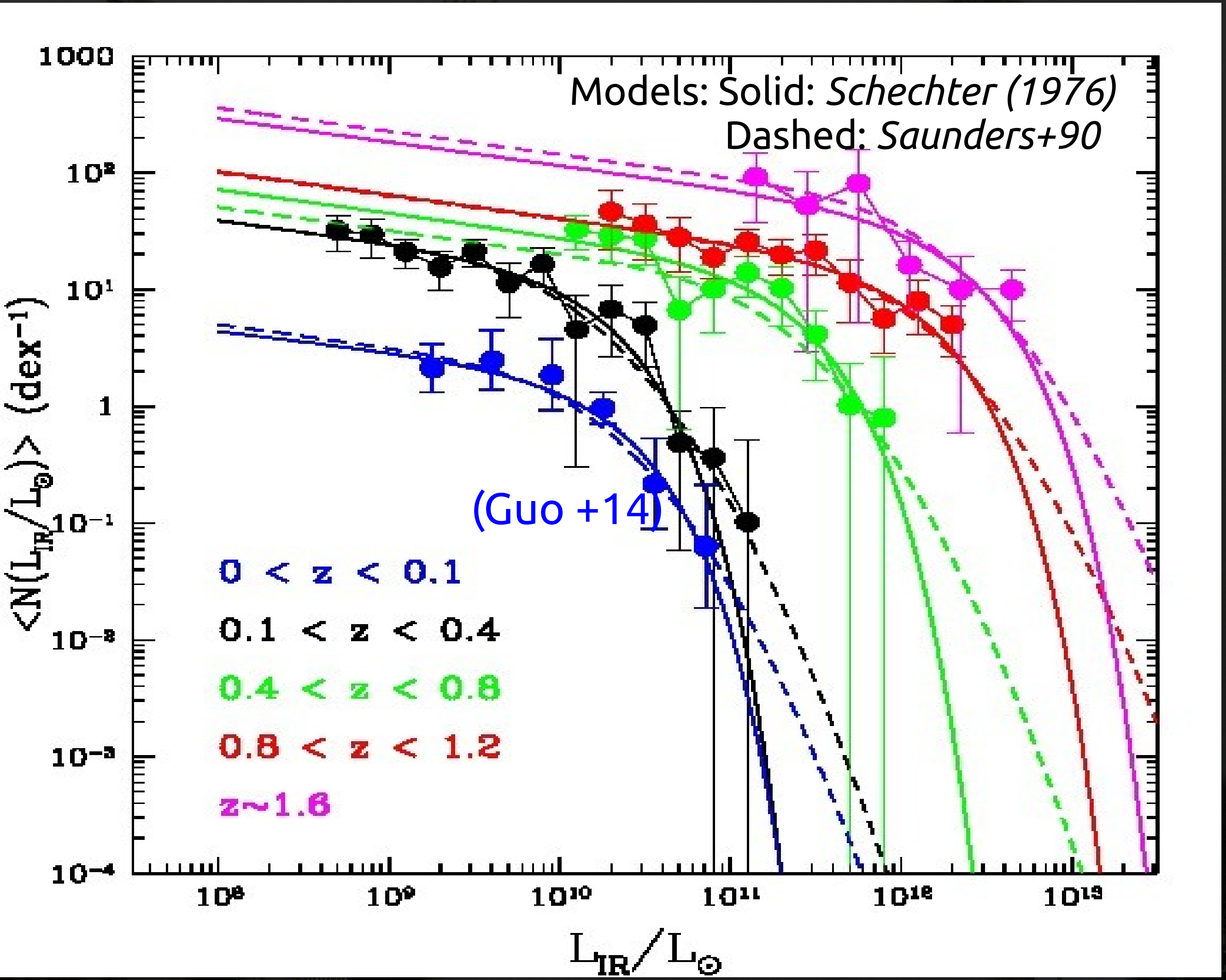
Composite per redshift bin
using *Colless' (1989)* method for groups.
Taken from the literature for clusters and the global population.

The group IR LFs vs. z

Both L_{IR}* and the LF normalization increase with z

star-formation is **more common** and **more intense** among higher-z group galaxies

(also seen in the field, e.g. Magnelli+09, Gruppioni+13)



The group vs. global IR LFs

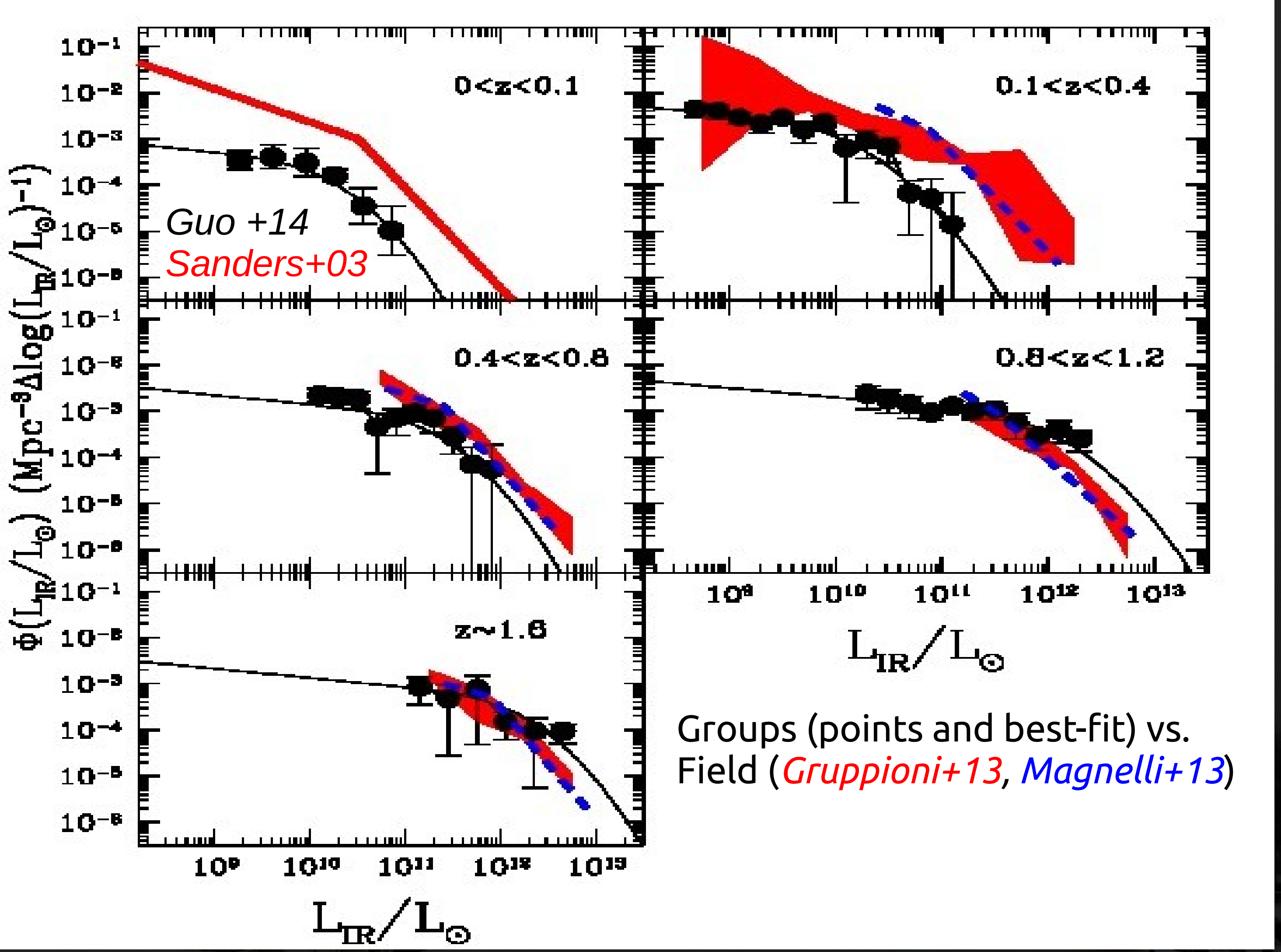
Number density
DM halos with
group-like masses
+
group IR LF
⇩
group IR LF per unit volume

Cmp to global IR LF:

@ z~1:

➔group <SFR> > global <SFR>

➔large fraction of SF gal.s in groups

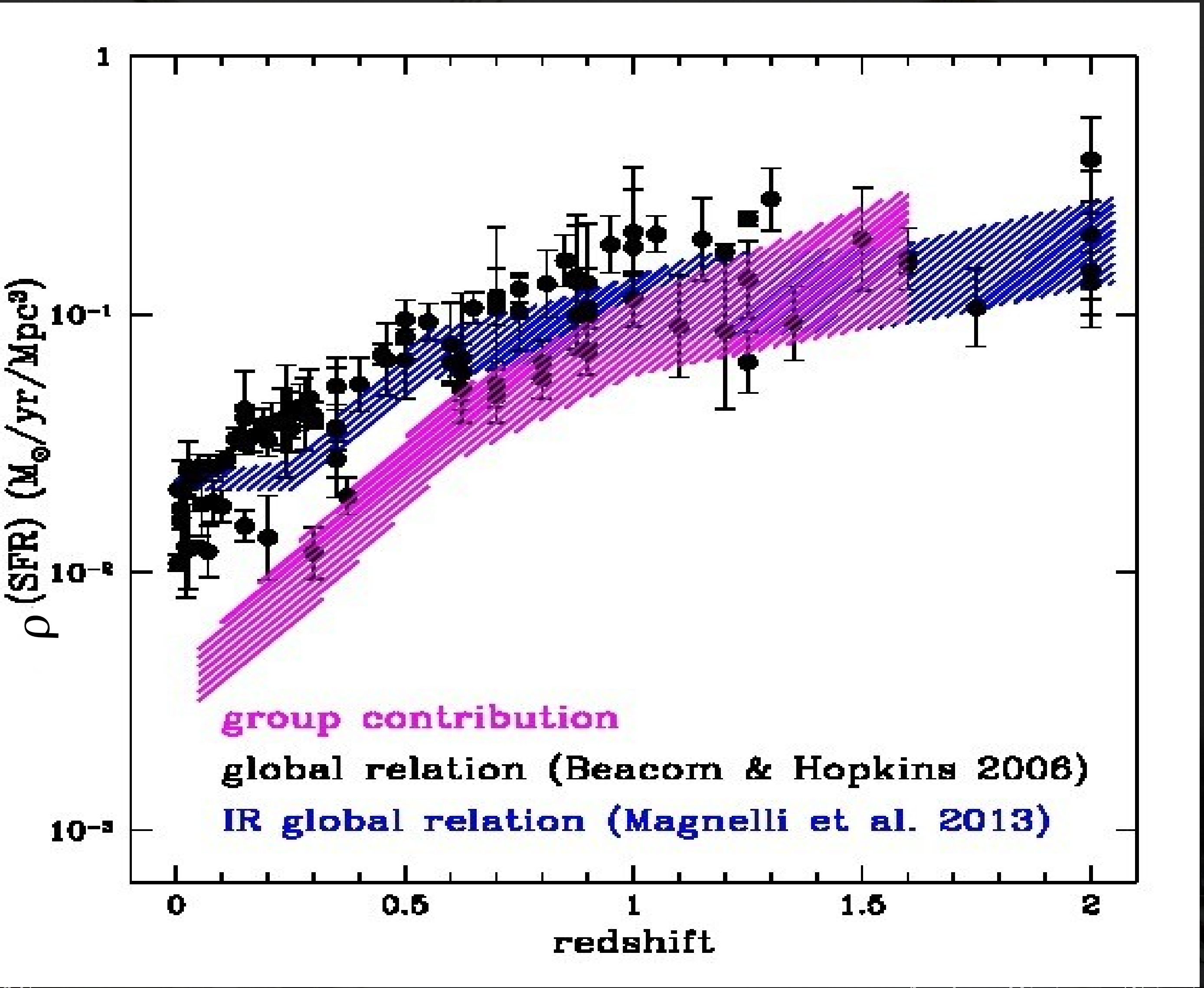


Groups (points and best-fit) vs. Field (*Gruppioni+13*, *Magnelli+13*)

Comoving IR luminosity (⇔SFR) density vs. z: the contribution by group galaxies

Integrate the IR LF to estimate the comoving IR luminosity (hence SFR) density

Strong contribution of group galaxies to the cosmic SFR density at z⩾1

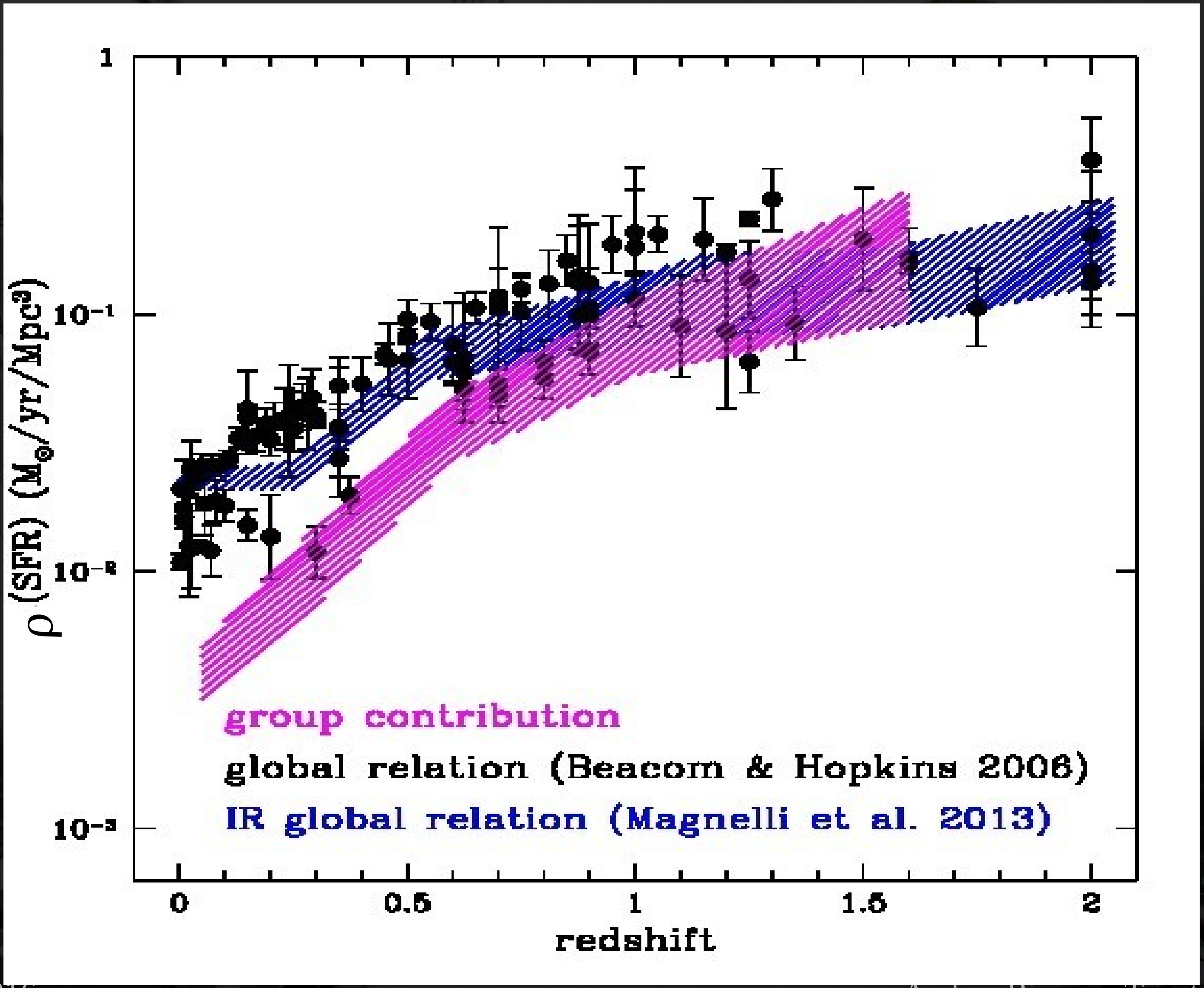


Comoving IR luminosity (⇔SFR) density vs. z: the contribution by group galaxies

Integrate the IR LF to estimate the comoving IR luminosity (hence SFR) density

Strong contribution of group galaxies to the cosmic SFR density at $z \gtrsim 1$

This occurs mainly through **(U)LIRGs**.



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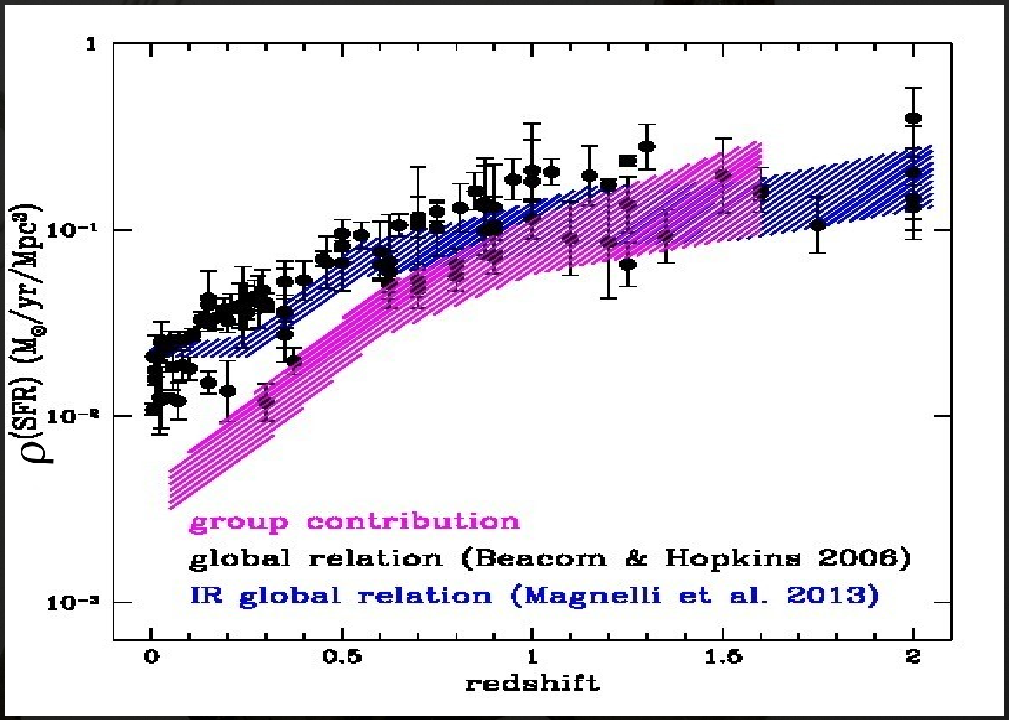

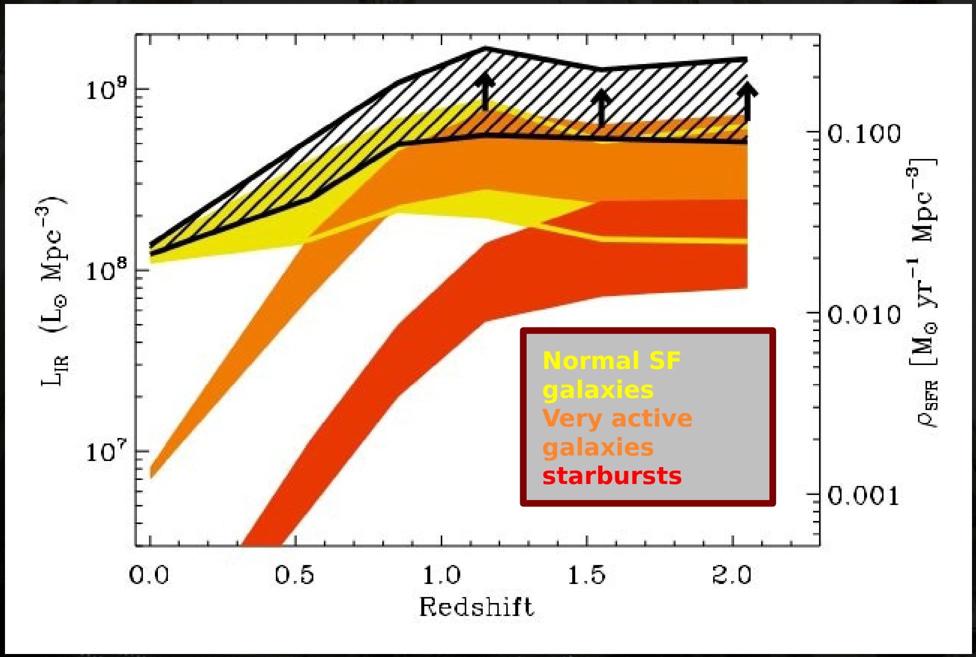

(U)LIRGs become the dominant contributors to the global SFR density at high-z *(Magnelli+11)*

Comoving IR luminosity (⇔SFR) density vs. z: the contribution by group galaxies

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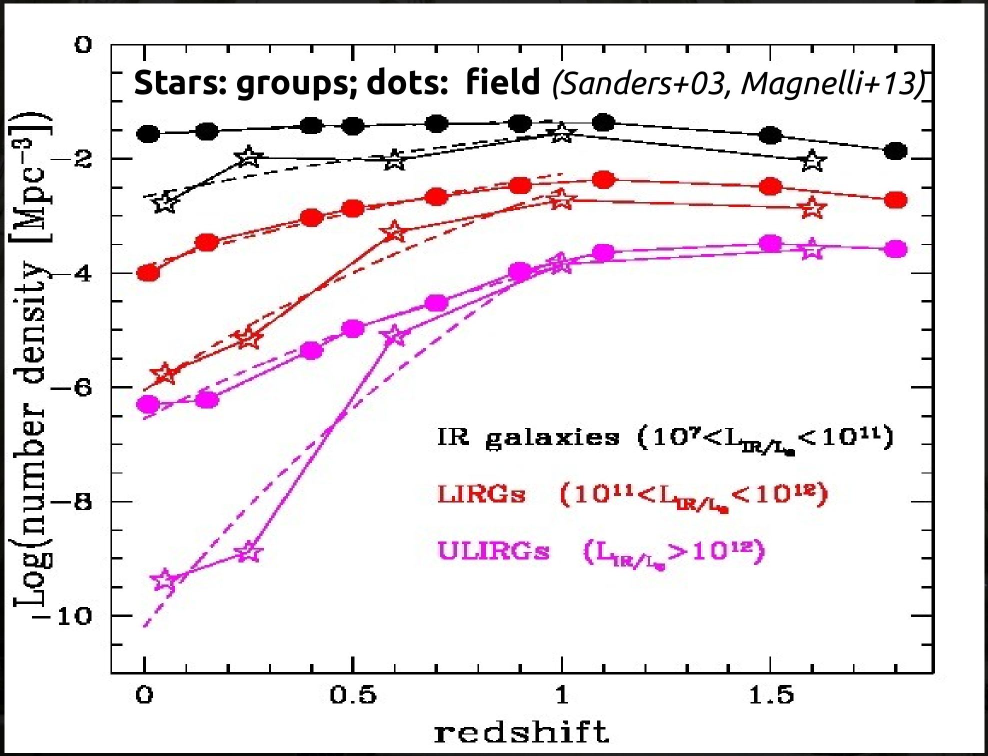
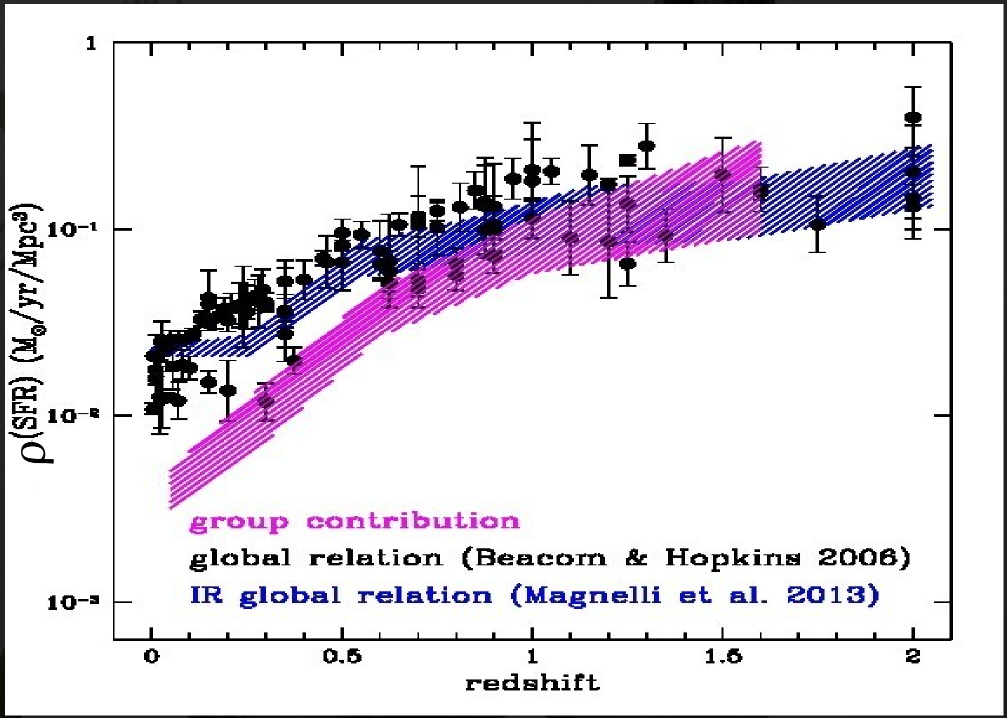
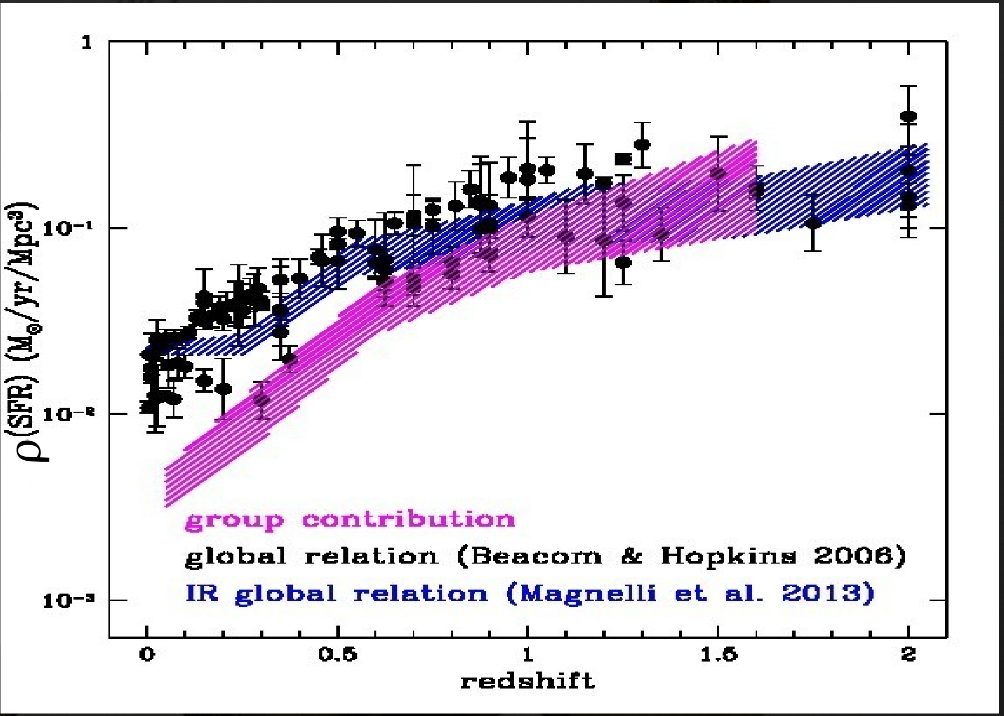


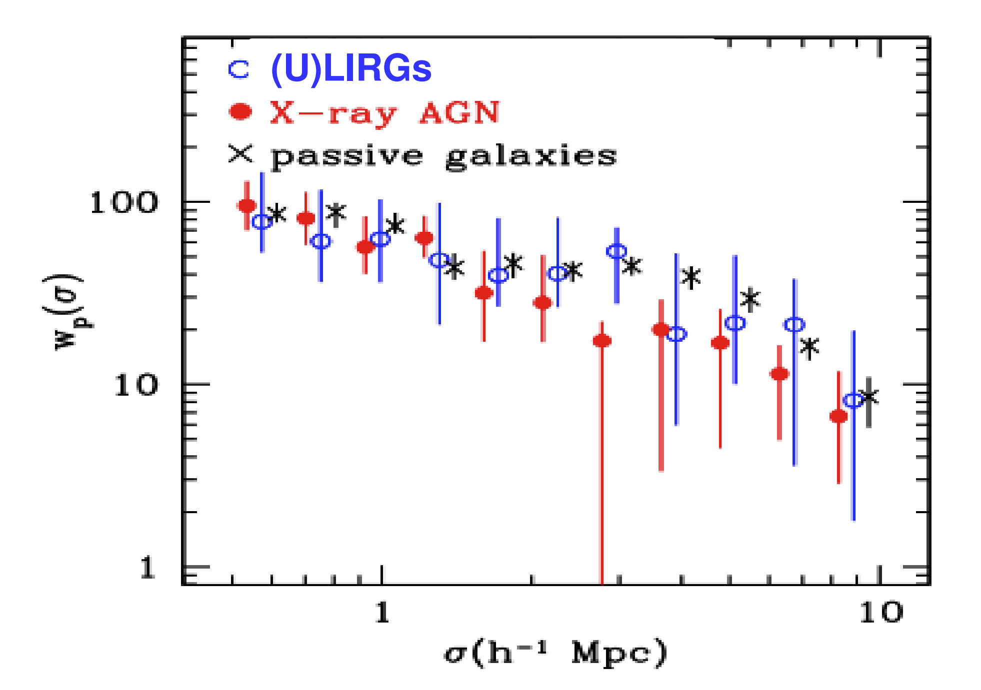


(U)LIRG number density ↑↑ with z; evolution is faster in groups than for the global average.
At z~1, 100% ULIRGs are in groups

Comoving IR luminosity (⇔SFR) density vs. z: the contribution by group galaxies

Strong contribution of group galaxies to the cosmic SFR density at z⩾1





Cross-correlation function of (U)LIRGs indicate they live in poor groups, $M_{halo} \approx 1.4 \times 10^{13}$ M⊙, at z≈1 *(Georgakakis+14)*

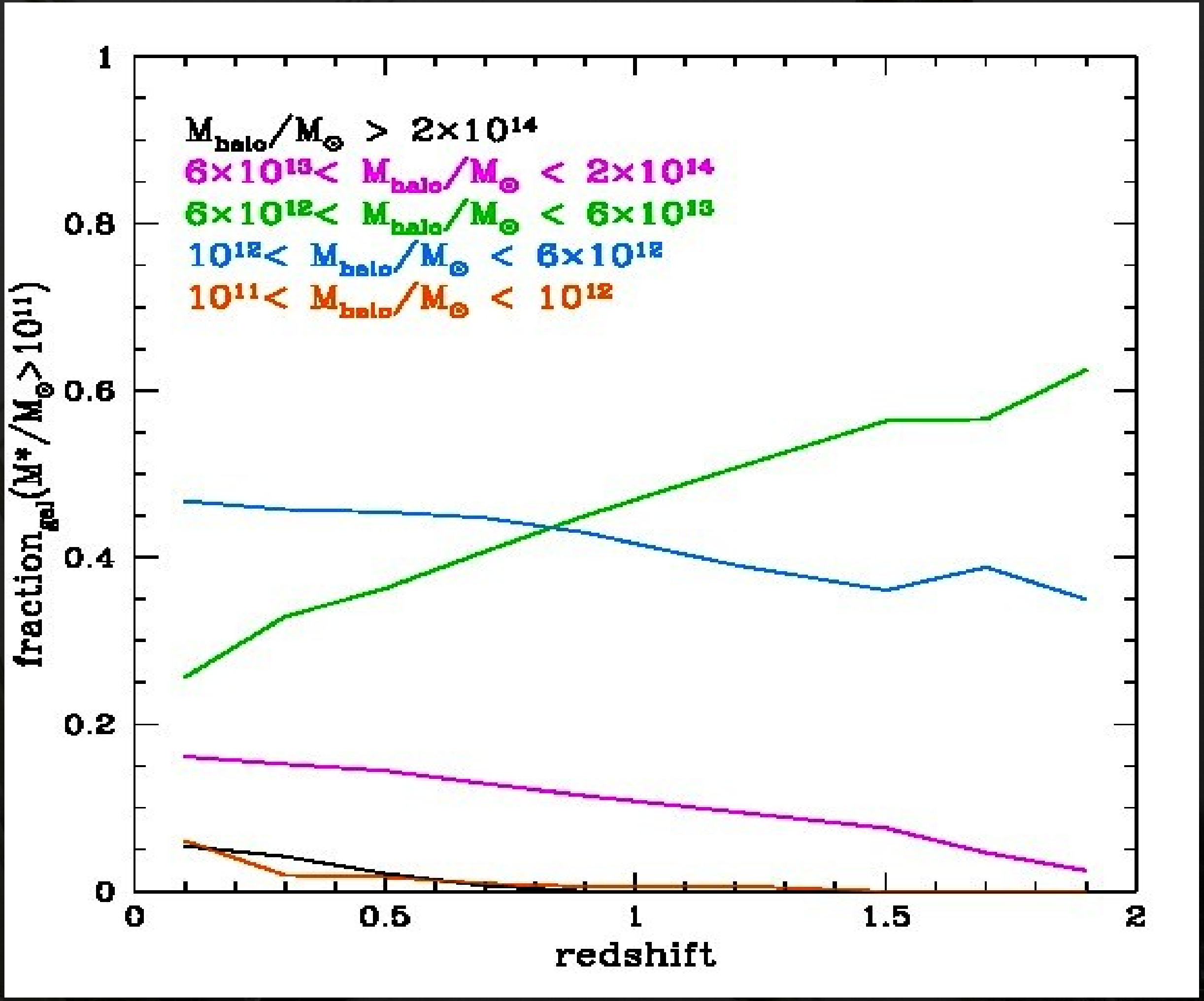
Galaxies of different stellar masses M_* in halos of different masses M_{halo}

Use *Guo+13*'s model to estimate the fraction of galaxies of different M_* in halos of various M_{halo}

The most massive galaxies are largely in groups at z>1

This **mass segregation** can partly account for the strong contribution of group galaxies to the cosmic SFRD at high z, via the SFR-M_* relation

Galaxies with $M_* \geq 10^{11}$

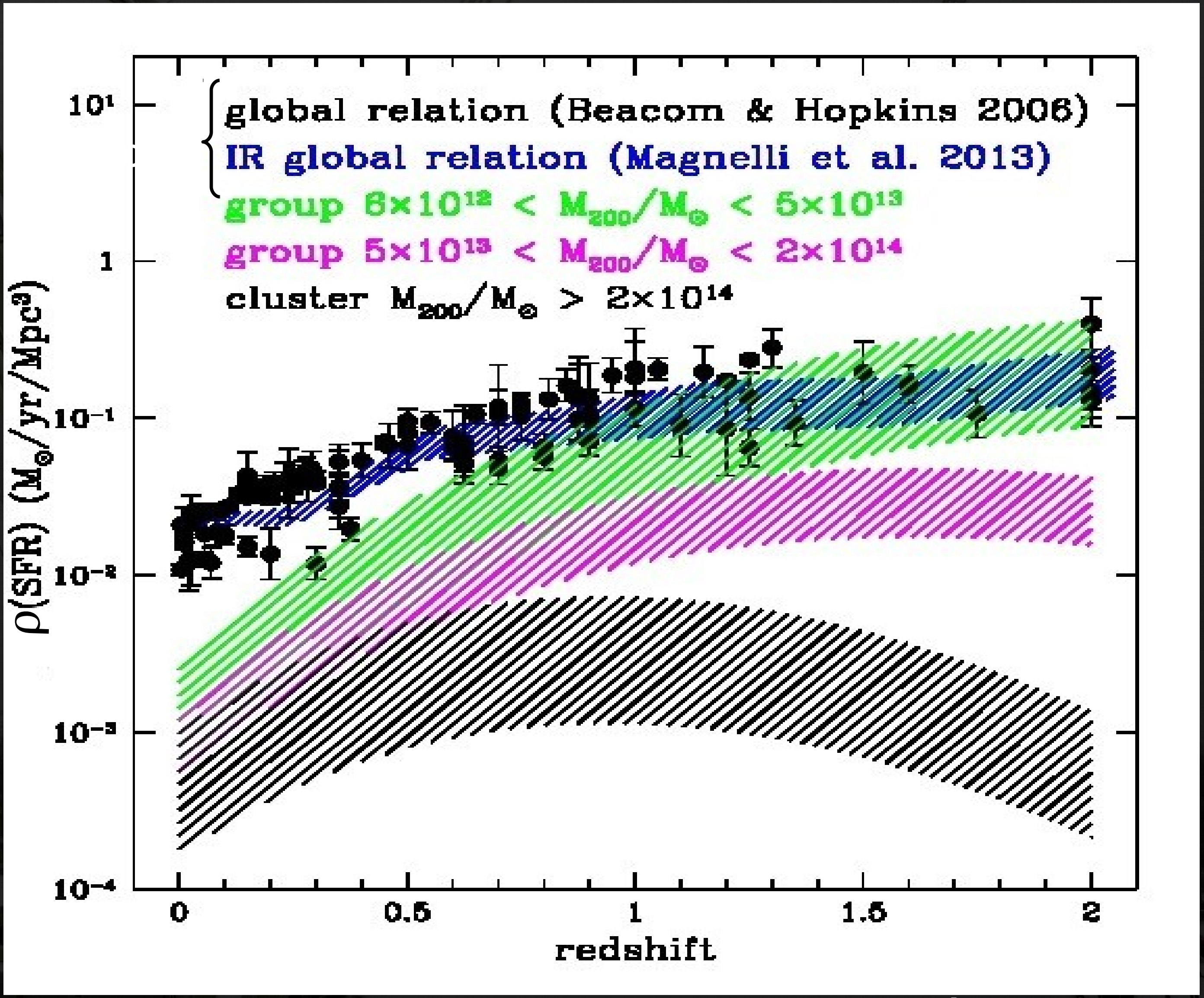


Cosmic SFR density as $f=f(z,M_{halo})$

Split the groups by mass, and consider also massive clusters

Low-mass groups make most of the cosmic SFR density at $z \geqslant 1$.

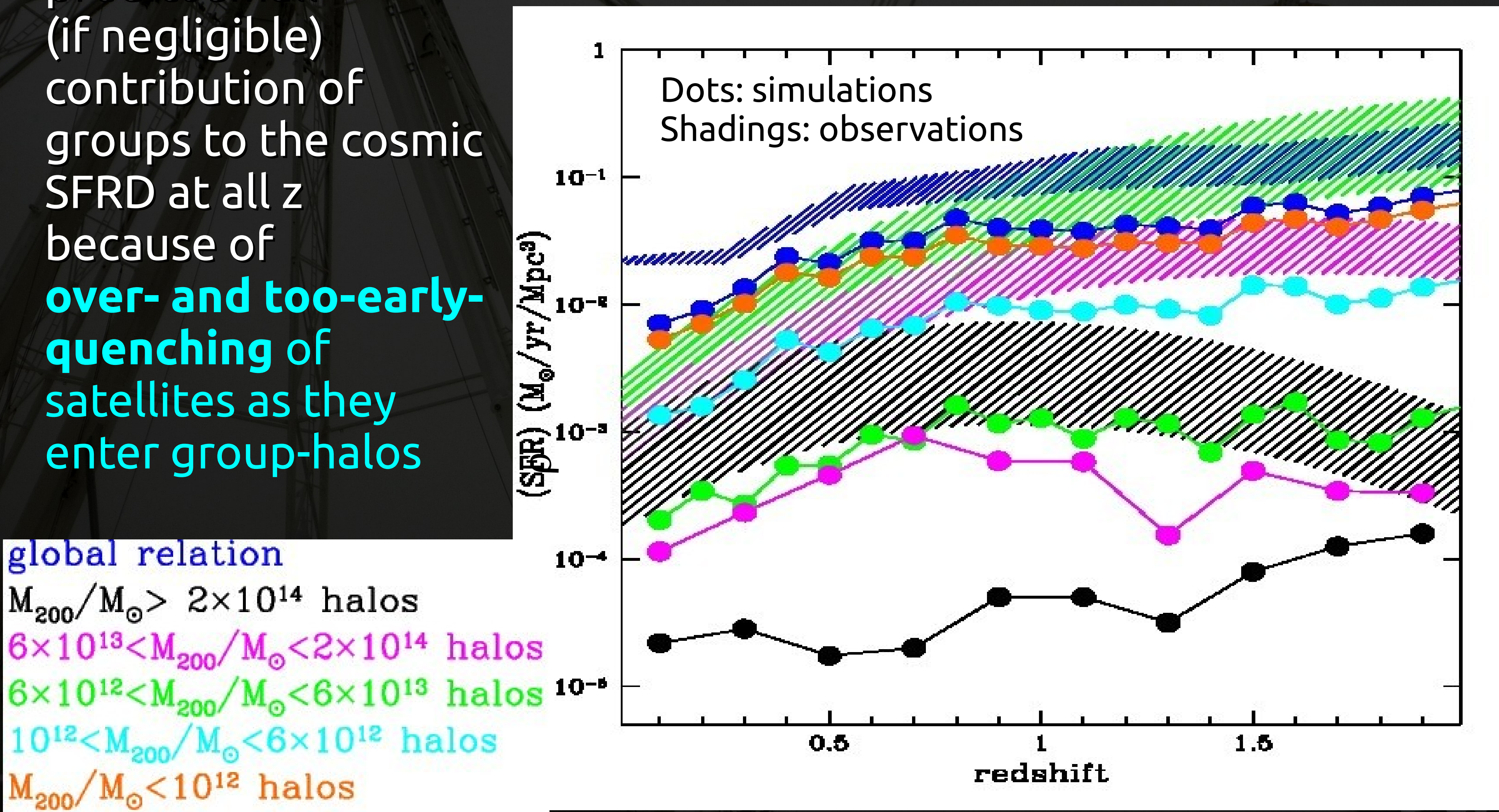
Massive groups and clusters contribute <10% and <1%, resp. *(low-SF and few)*



Observed vs. simulated SFRD(z)

Most simulations predict small (if negligible) contribution of groups to the cosmic SFRD at all z because of **over- and too-early-quenching** of satellites as they enter group-halos

vs. *De Lucia+06* SAM (Millennium)



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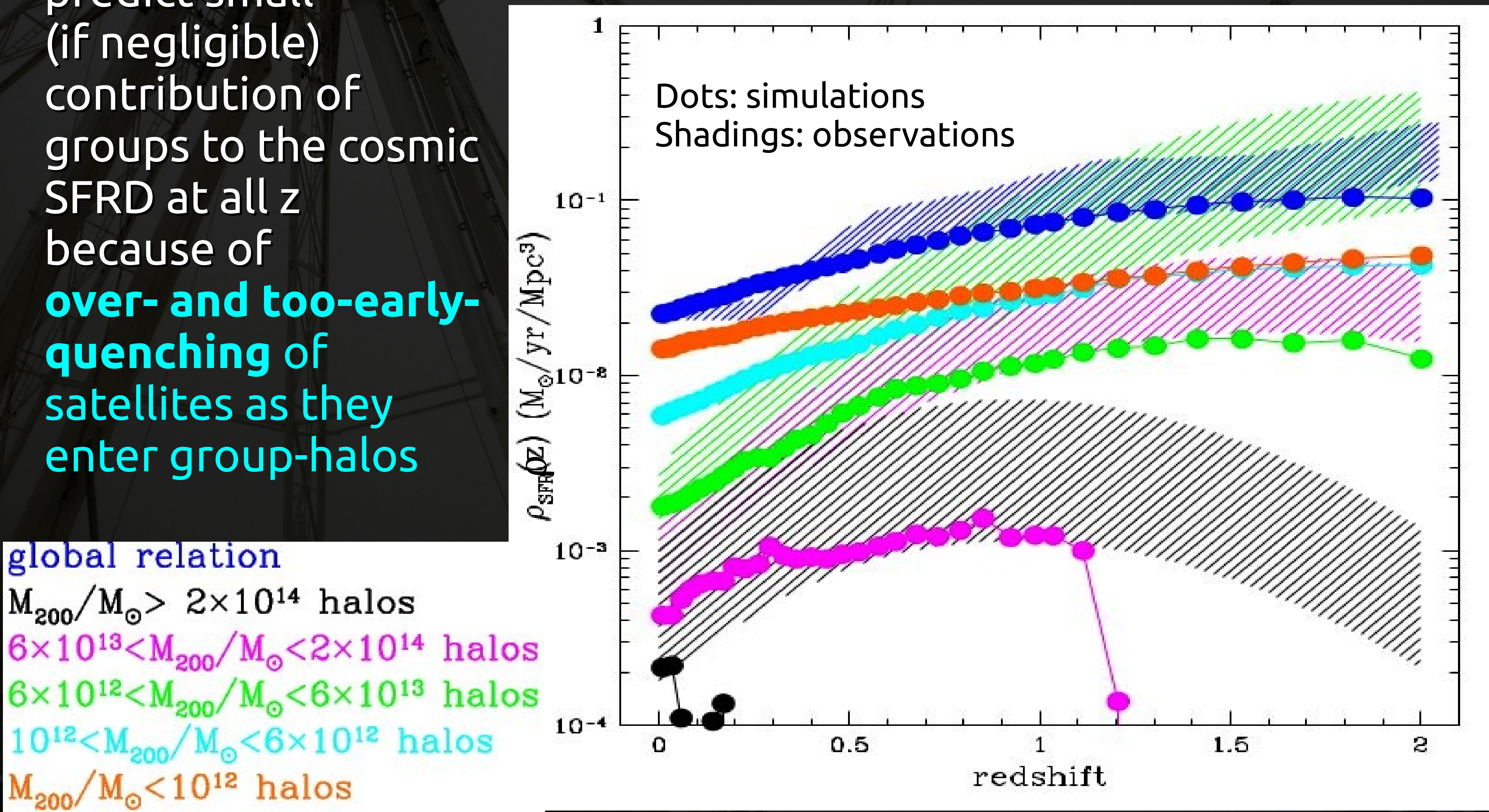
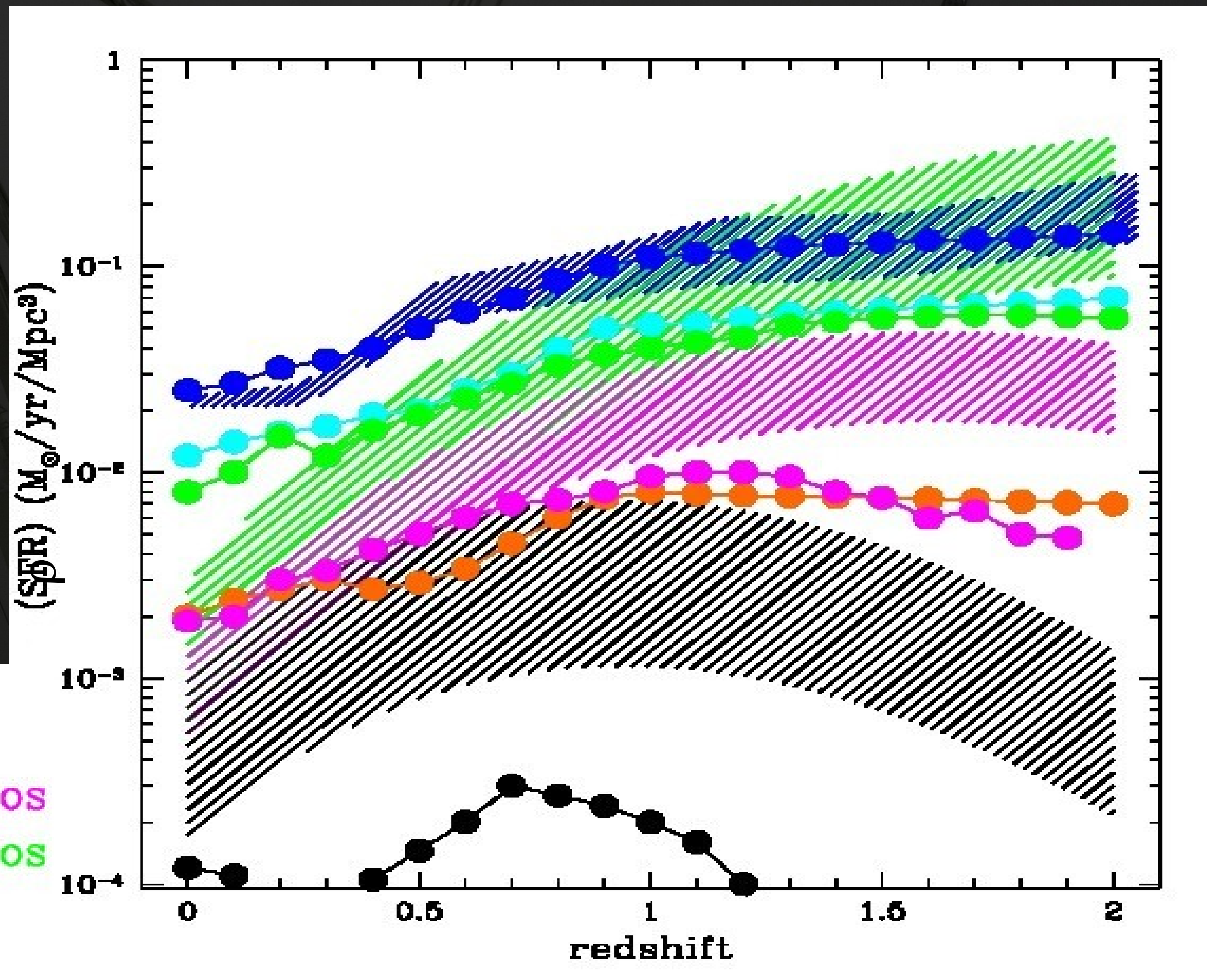
vs. *Genel+14* Hydro (Illustris)

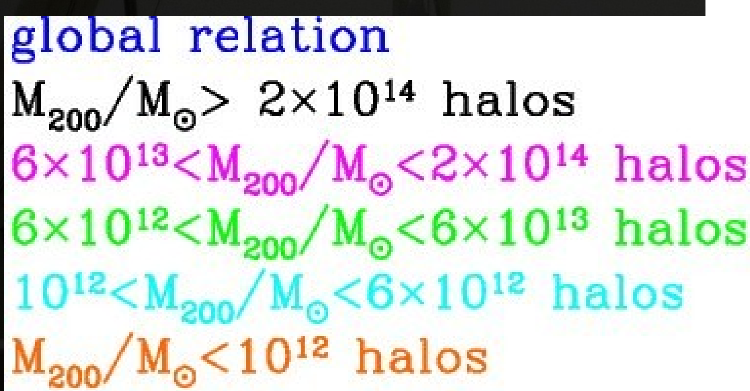


Observed vs. simulated SFRD(z)

Halo Abundance Matching model that fits IR observations (Cosmic IR Bkd, corr.funct. IR galaxies): adopting low-z environmental quenching fits the group <SFRD>. **Slow or delayed quenching** of satellites as they enter groups

vs. Bethermin+13
Halo Abundance Matching





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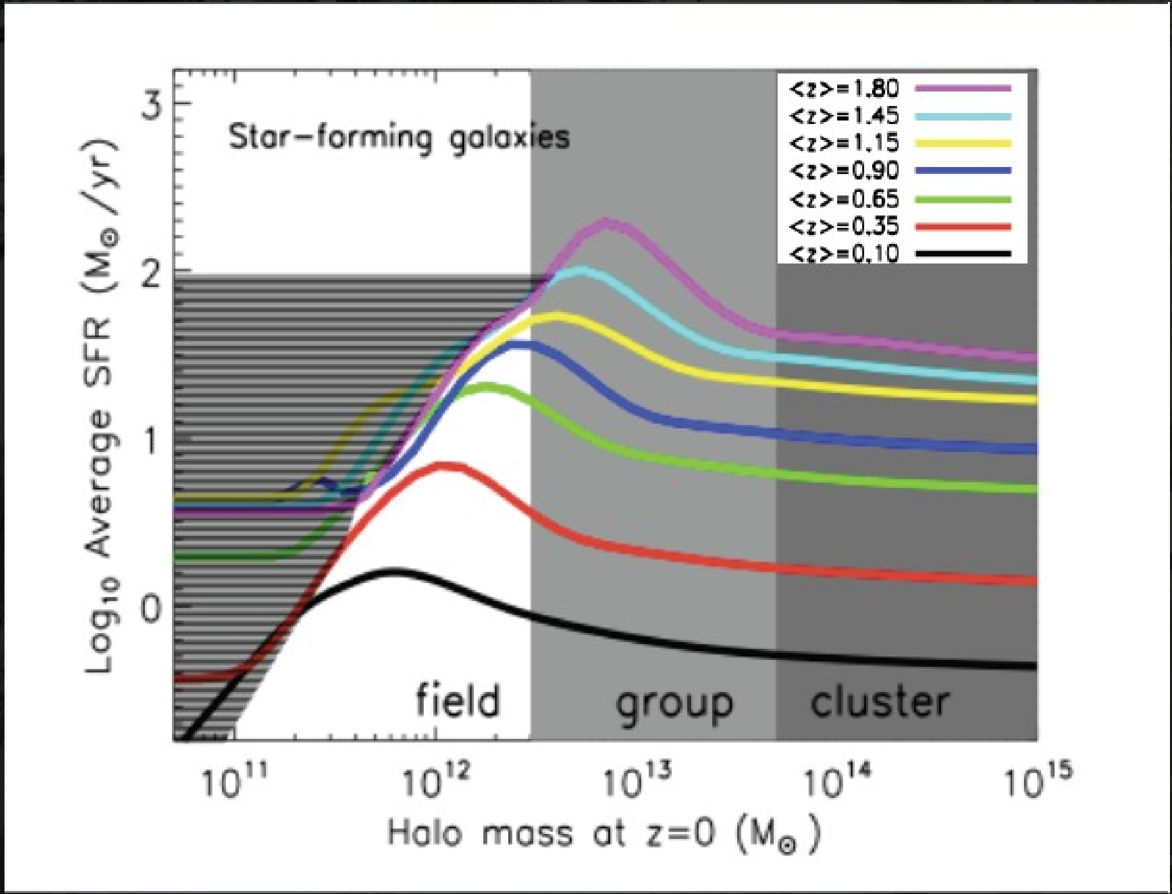

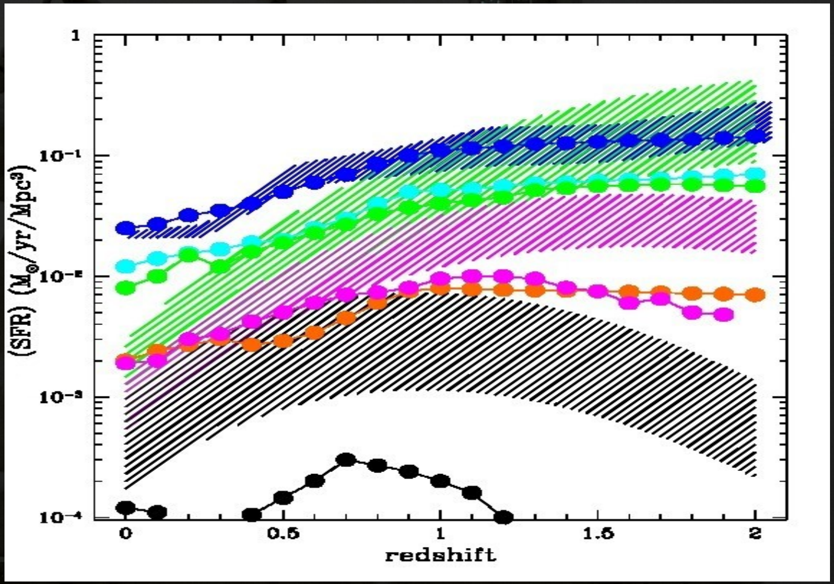

Halo Abundance Matching with Extended Halo Model (M_* and SFR related to M_{halo} based on Herschel data):

<SFR> peaks at higher M_{halo} with increasing z

(Wang+13)

Summary and conclusions

IR observations ⇒ galaxy SFR
X-ray observations ⇒ group masses
spectroscopic observations ⇒ group membership

- Differential evolution of IR LF of group/field galaxies: (U)LIRGs avoid groups at low-z, but prefer groups at $z \gtrsim 1$.
- SFRD(z) dominated by (low-mass) groups at $z \gtrsim 1$; partly due to mass segregation and SFR-M_* relation. Clusters contribute <1%: they are too rare.
- Cmp with models: rapid (<1 Gyr) quenching of SF upon accretion onto groups is ruled out.

Summary and conclusions

➔ **Bottom line:**

The evolution of a galaxy not only depends on its mass but also on the group where it evolves

Greystoke: The legend of Tarzan

Dawn of the planet of the Apes