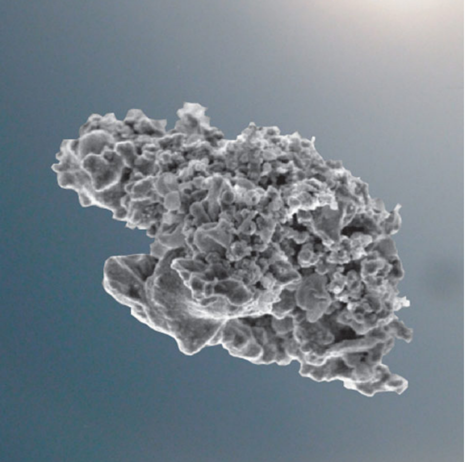
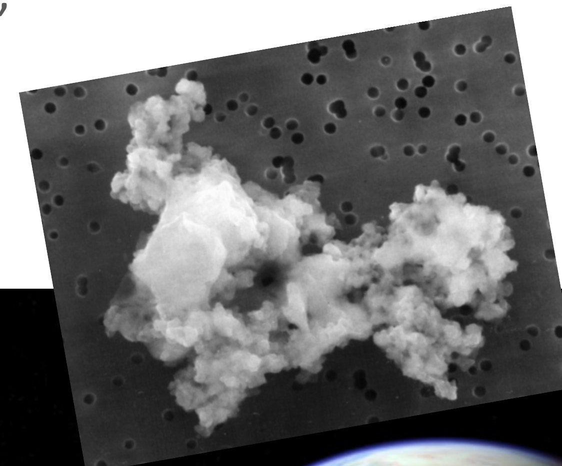
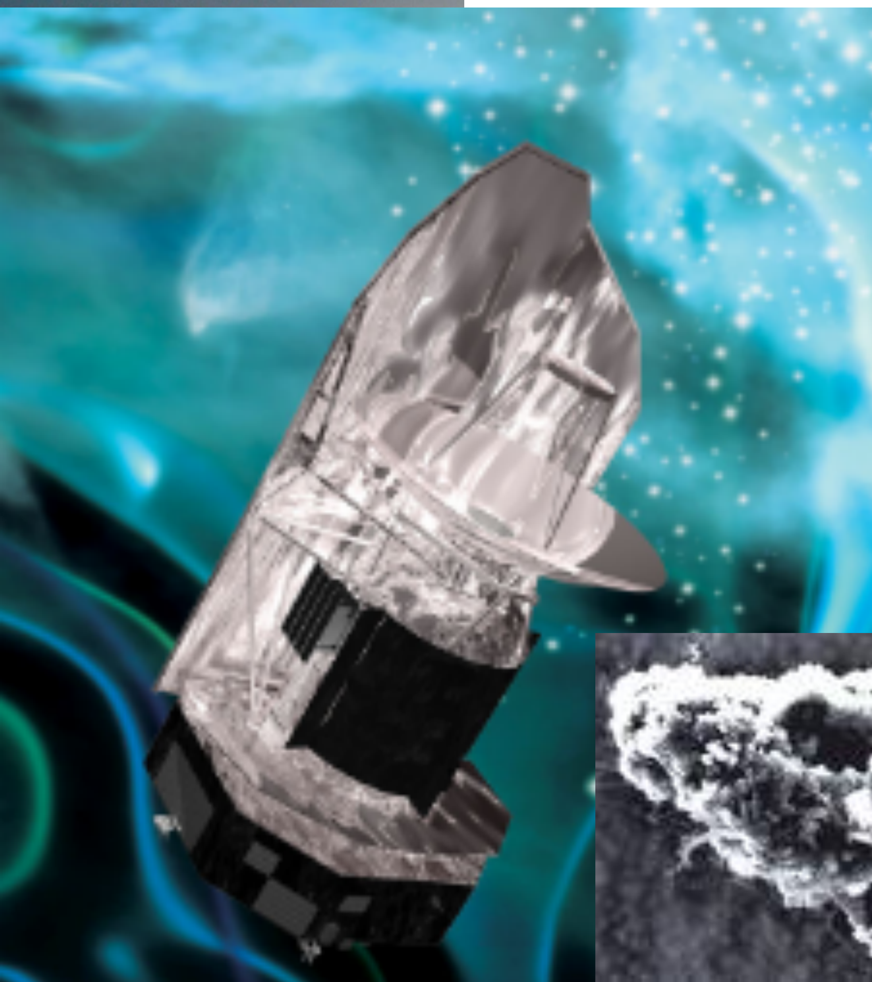


Demographics of the host galaxies of *long* GRBs

Leslie Hunt (INAF-Osservatorio di Arcetri),
E. Palazzi, S. Savaglio,
M. Michalowski,
J. Greiner et al.

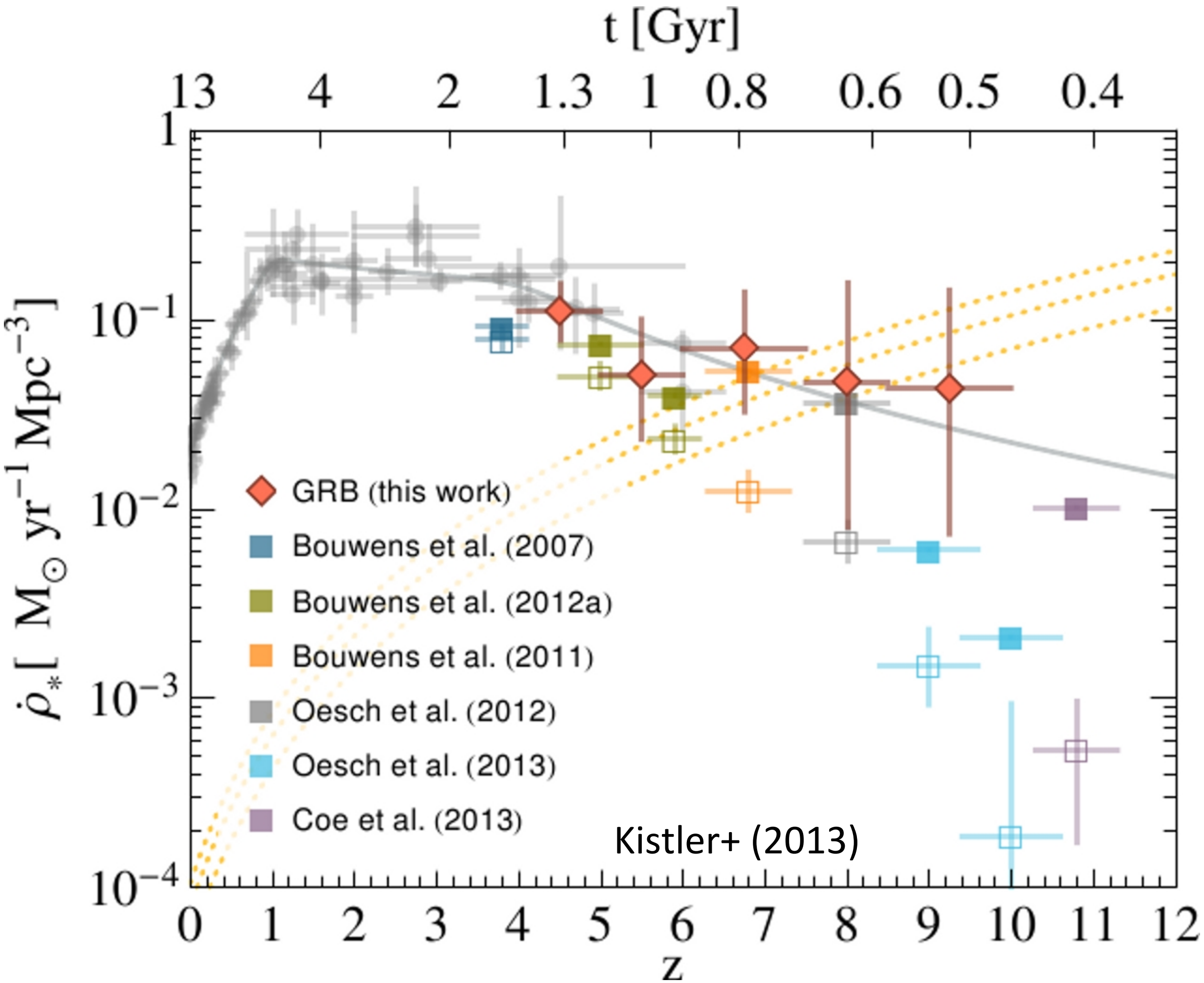




GRBs as probes of cosmic star-formation rate

GRBs probe the universe beyond the epoch of reionization and provide direct information on star formation when the universe was only a few 10^8 years old.

Thus to link the cosmic comoving star-formation rate (SFR) density with GRB rates is fundamental to understand cosmic reionization.



But it is not yet clear how this link changes with redshift: R(GRB) = constant • R(SFR)

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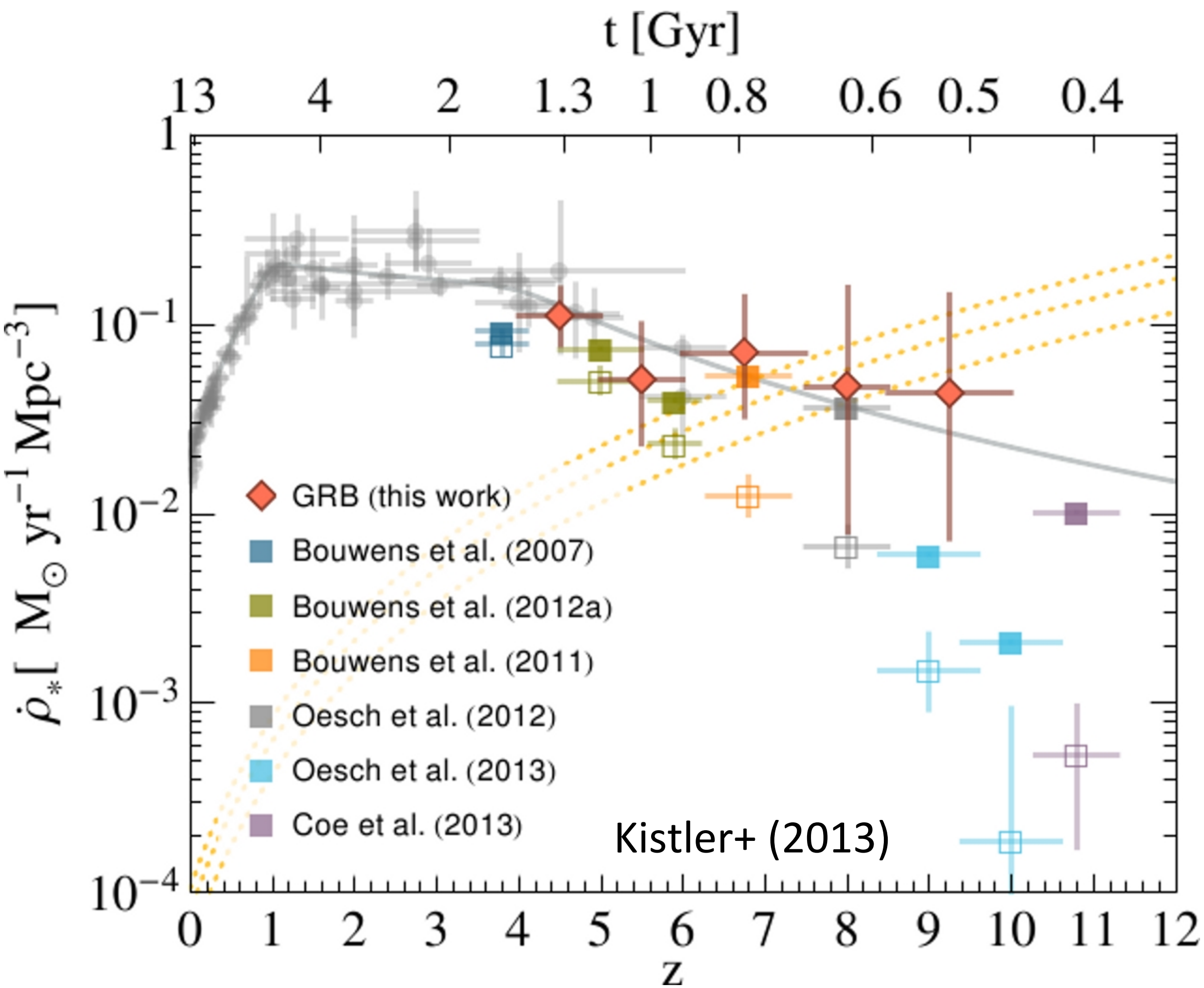

?

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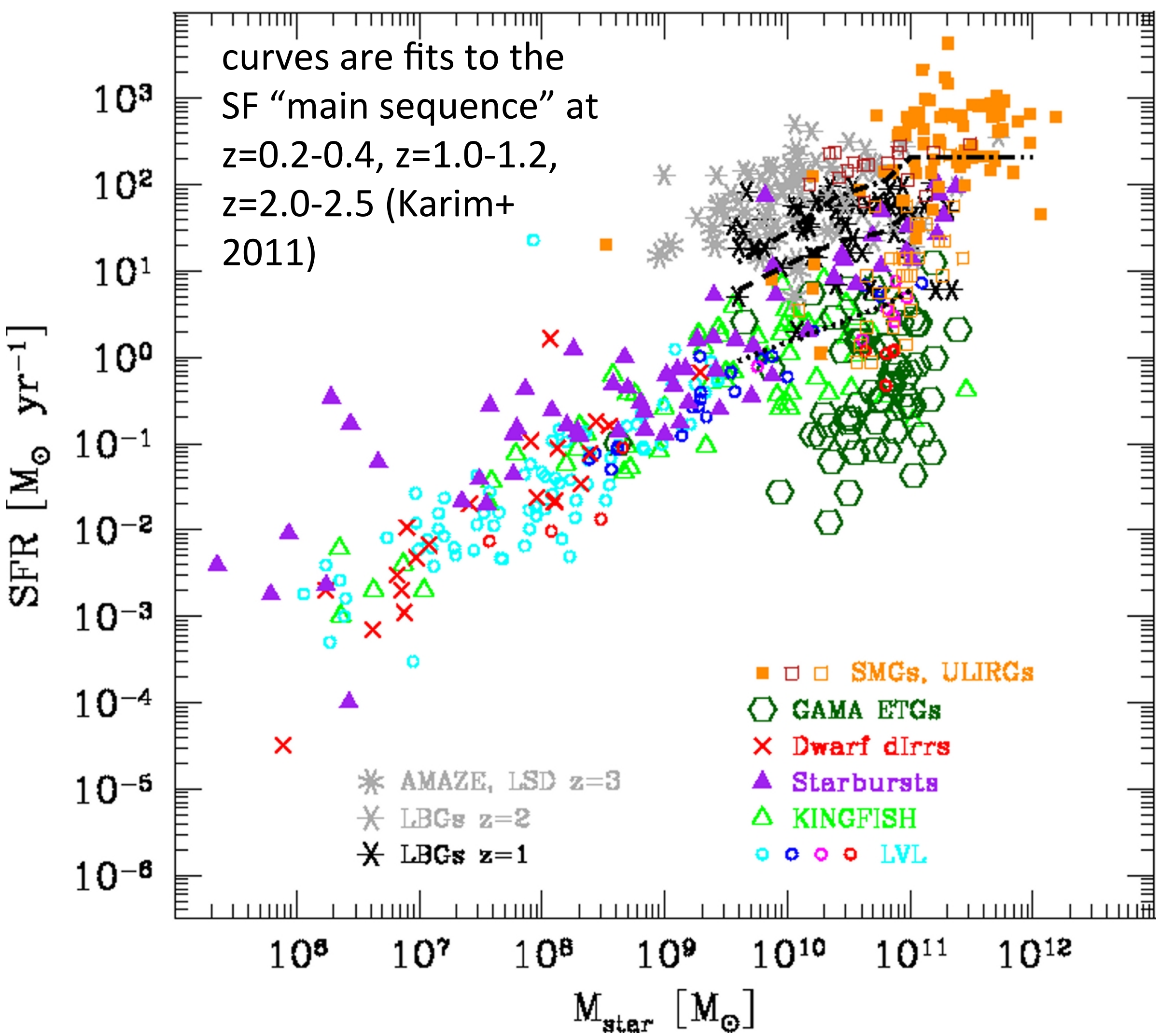
Why care about properties of GRB host galaxies?

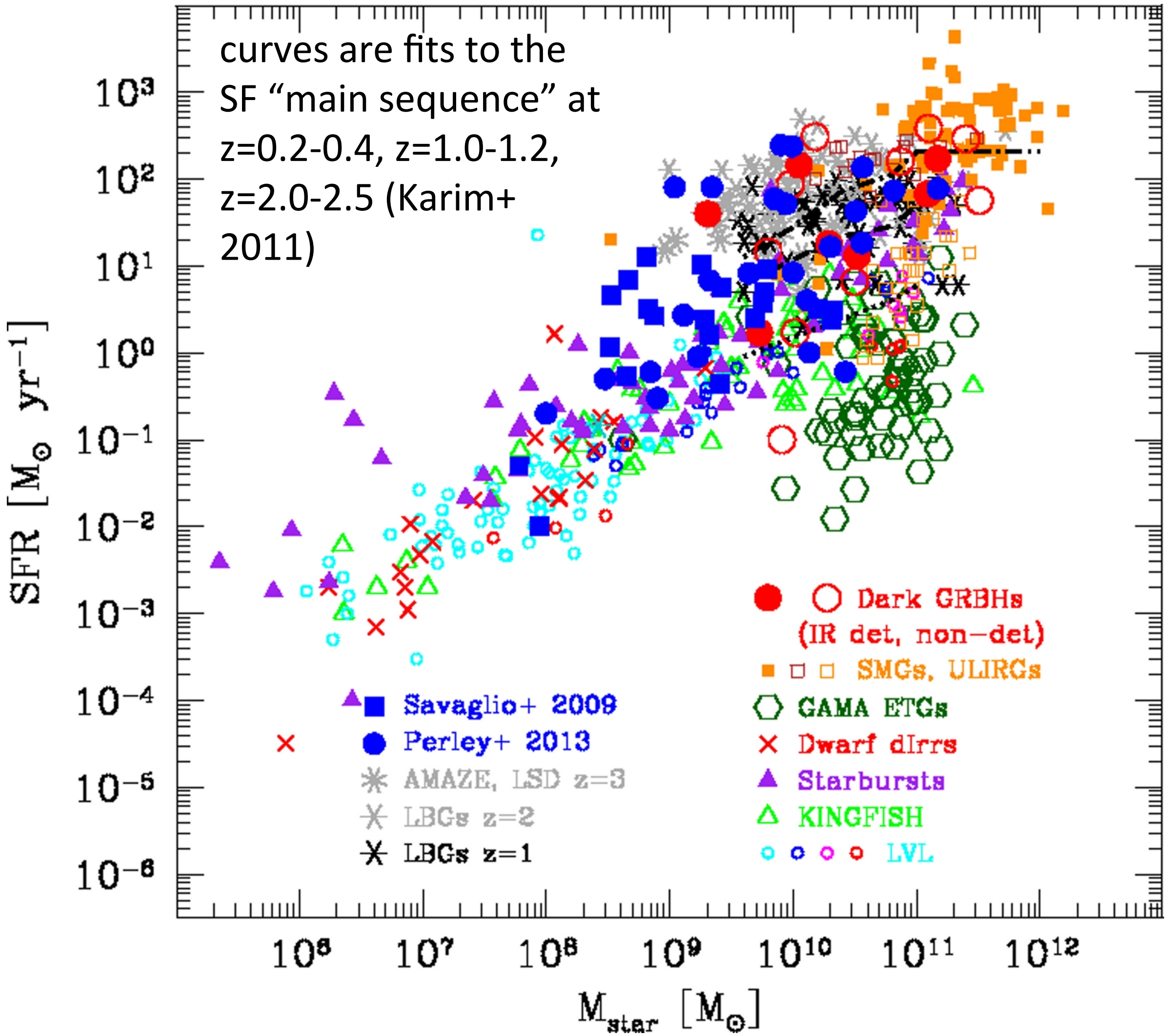


(adapted from Hunt+ 2012)

One approach to the question of tracing cosmic SFR to high redshift is to examine GRB host galaxies (GRBHs) and compare them with the galaxy populations that emerge from other kinds of surveys (e.g., local volume-limited, high-z color selected, ground-based K-band magnitude limited, sub-millimeter).

Stellar masses, SFRs, and dust masses

Why care about properties of GRB host galaxies?



(adapted from Hunt+ 2012, Hunt+ 2014)

One approach to the question of tracing cosmic SFR to high redshift is to examine GRB host galaxies (GRBHs) and compare them with the galaxy populations that emerge from other kinds of surveys (e.g., local volume-limited, high-z color selected, ground-based K-band magnitude limited, sub-millimeter).

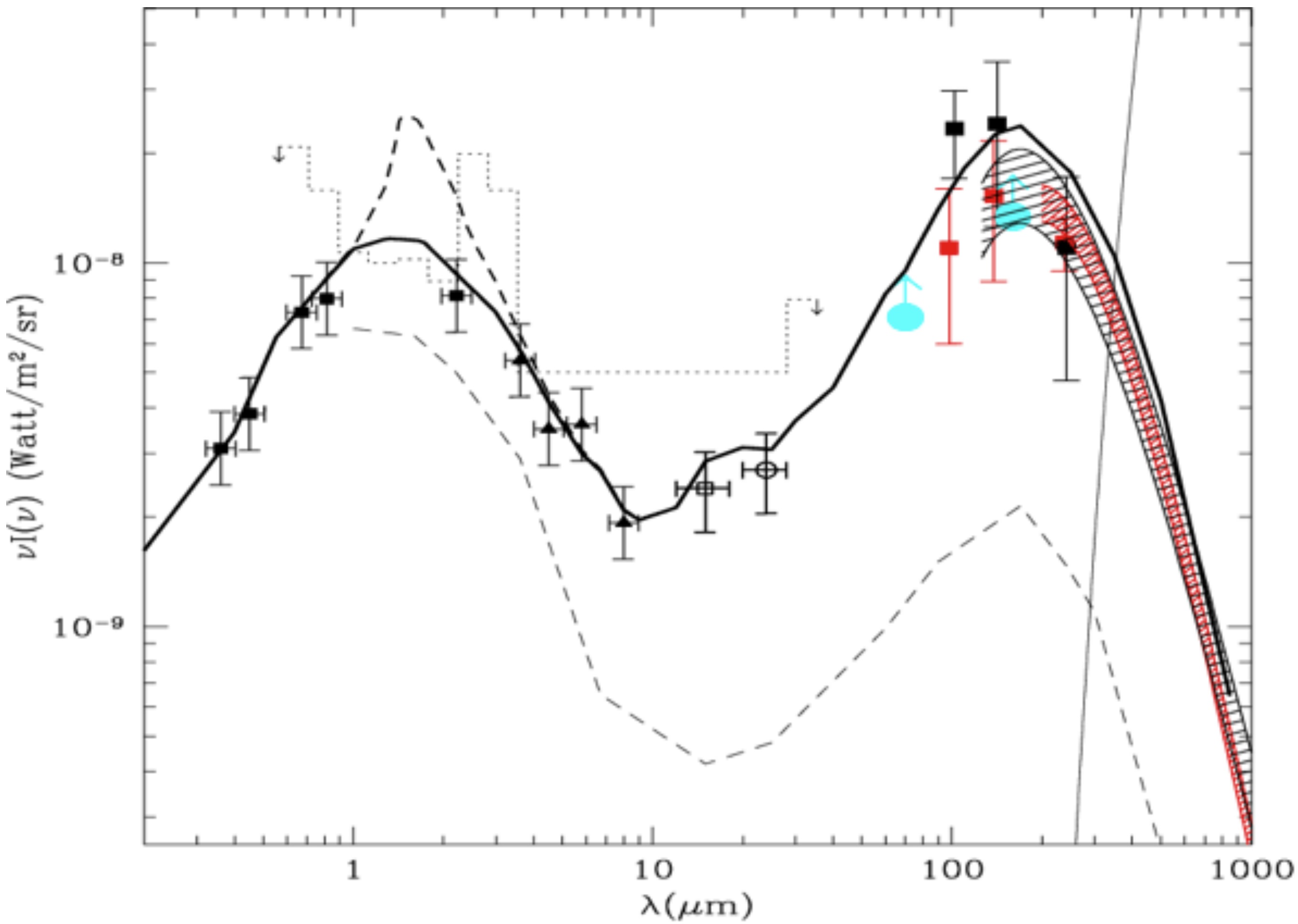
Stellar masses, SFRs, and dust masses

Why care about dust?

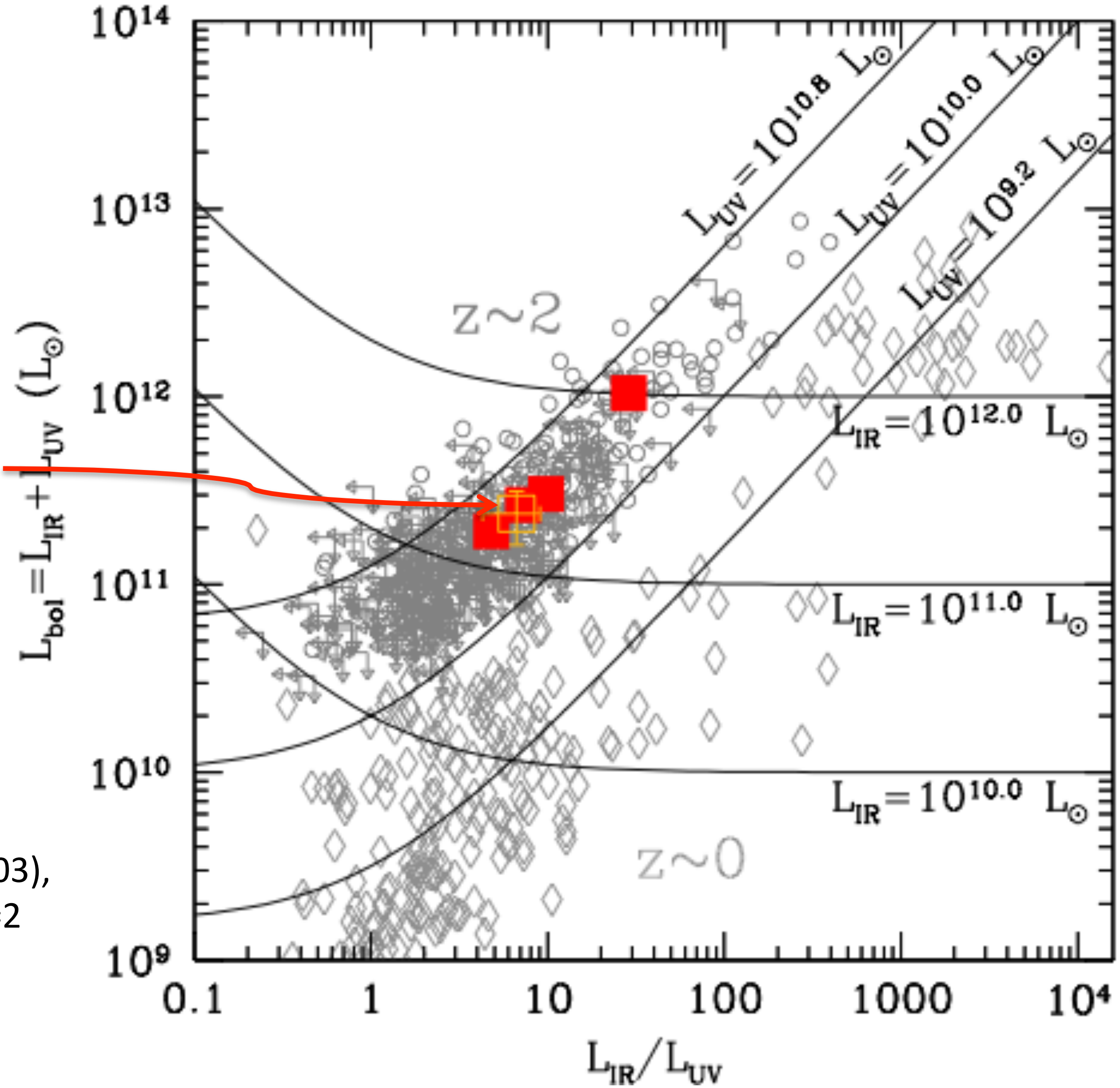
Much of the universe is obscured by dust

IRAS, ISO, SCUBA, COBE, Spitzer, Herschel, Planck have convincingly shown that half the photons and most of the energy in the universe come from infrared (IR) photons…

Cosmic extragalactic IR background as measured by COBE and optical from ultradeep HST fields, taken from Franceschini + (2008): unresolved infrared-bright galaxies



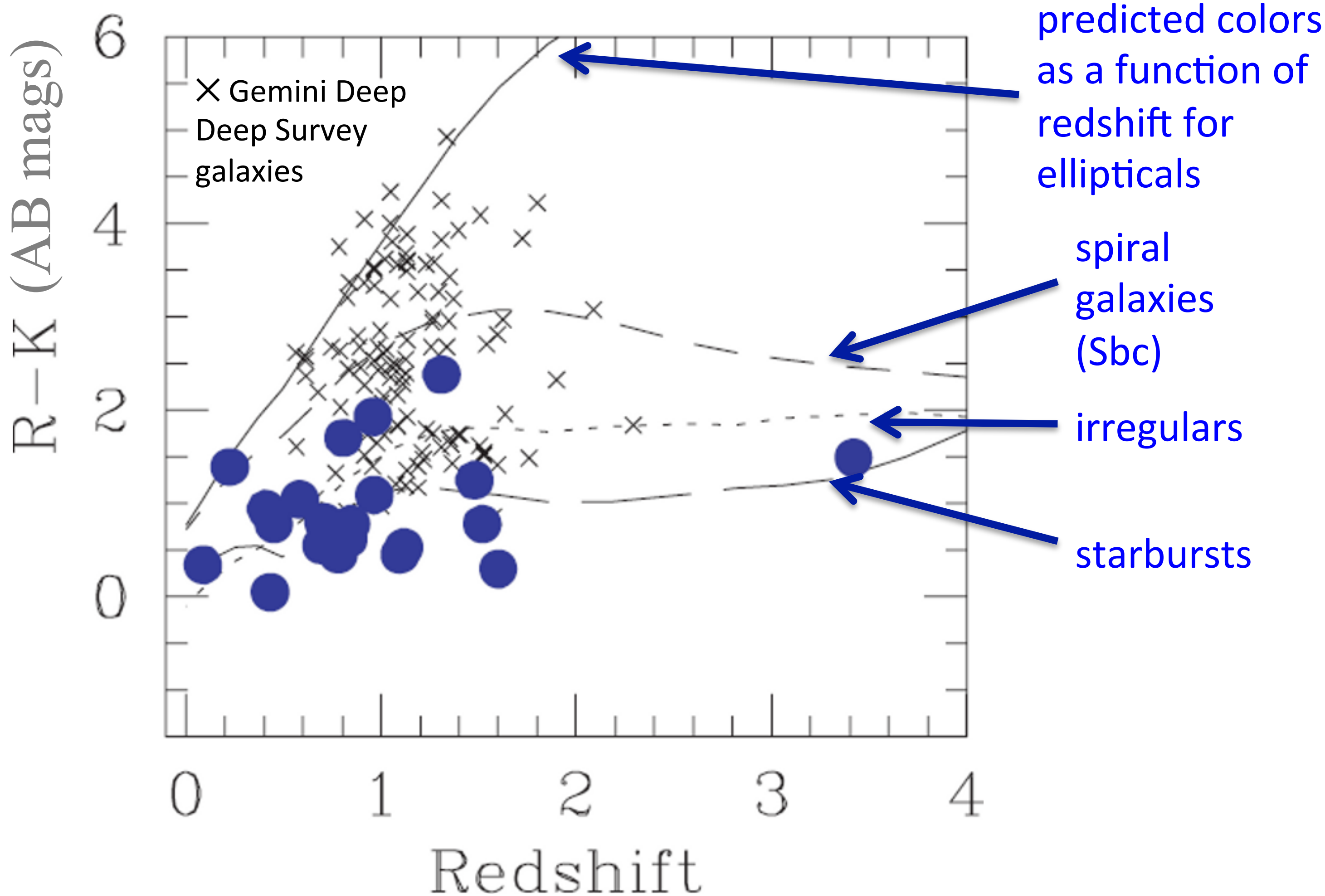
… and the most luminous galaxies in the universe are also the most obscured. Typical L*galaxies at z ~ 2 have 80% of their SF obscured by dust (Reddy+ 2006, 2012)



z=0 (diamonds) from Bell+ (2003), Huang+ (2009); UV-selected z=2 (circles) from Reddy+ (2010); stacked IR data (squares) from Reddy+ (2012)

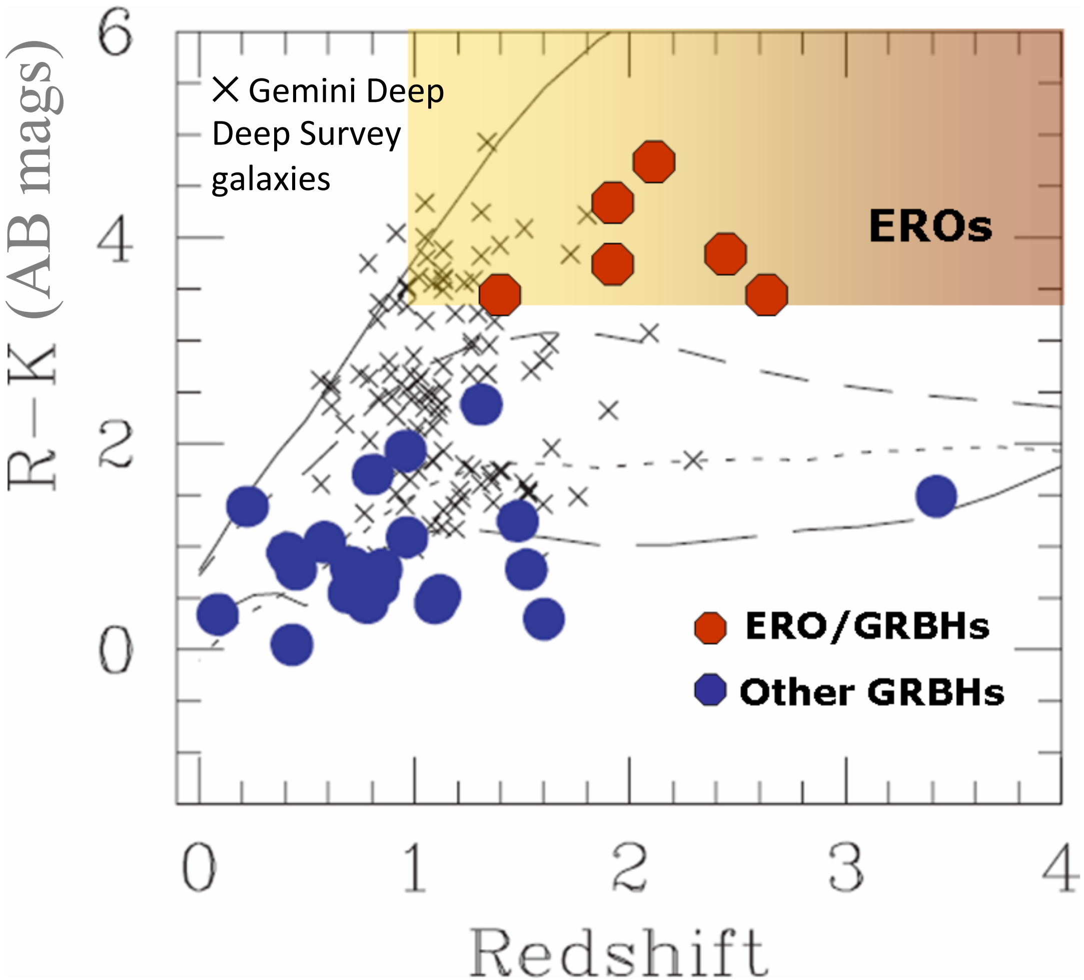
What kinds of galaxies host GRBs?

Pre-Swift studies suggested that GRBHs are blue and sub-luminous



Sokolov+ 2001, Le Floc'h+ 2003, Le Floc'h+ 2006, Savaglio+2009, Svensson+ 2010

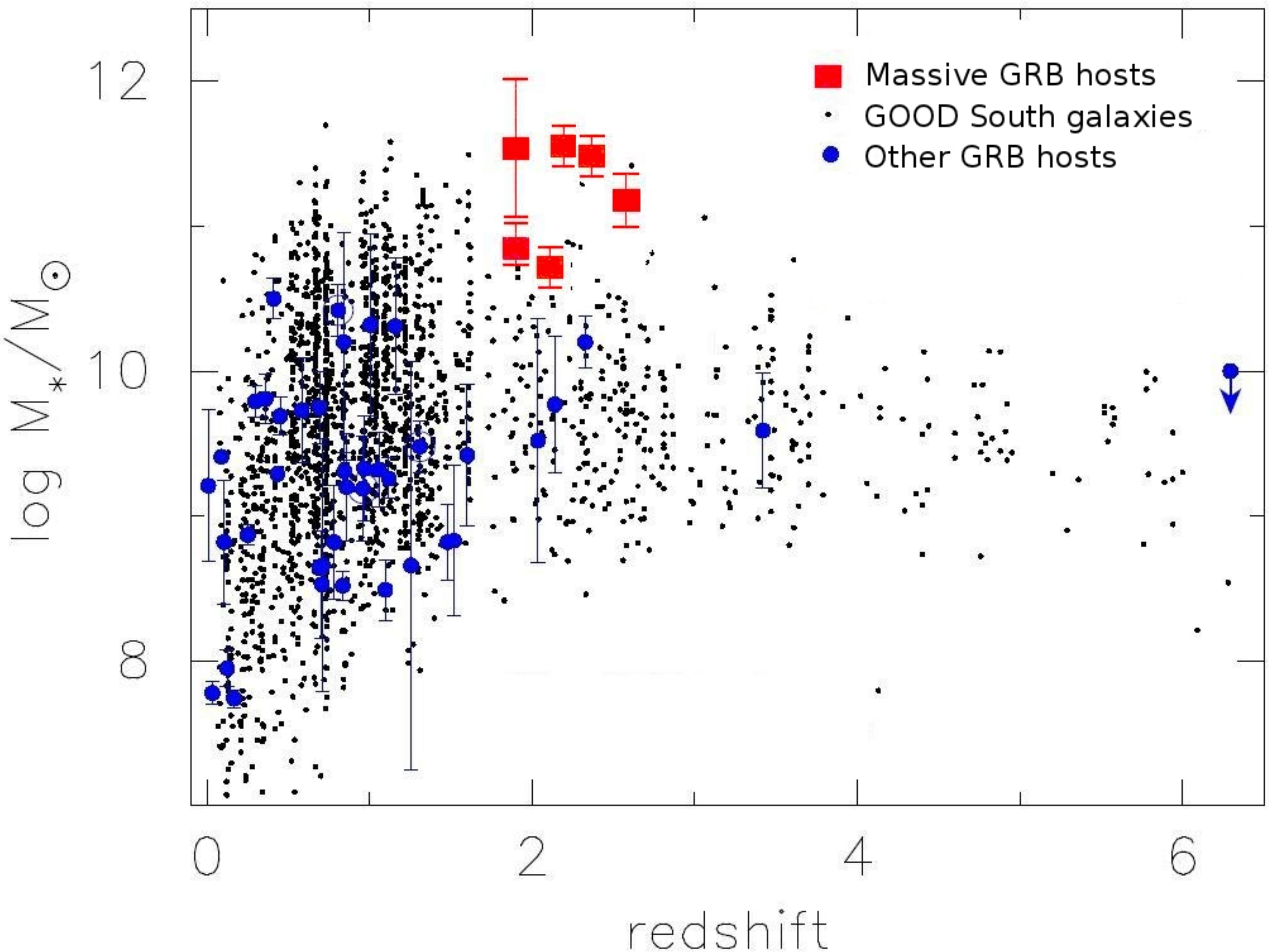
Pre-Swift studies suggested that GRBHs are blue and sub-luminous



but some recently discovered hosts can be Extremely Red Objects

(Rossi+ 2014, in prep.)

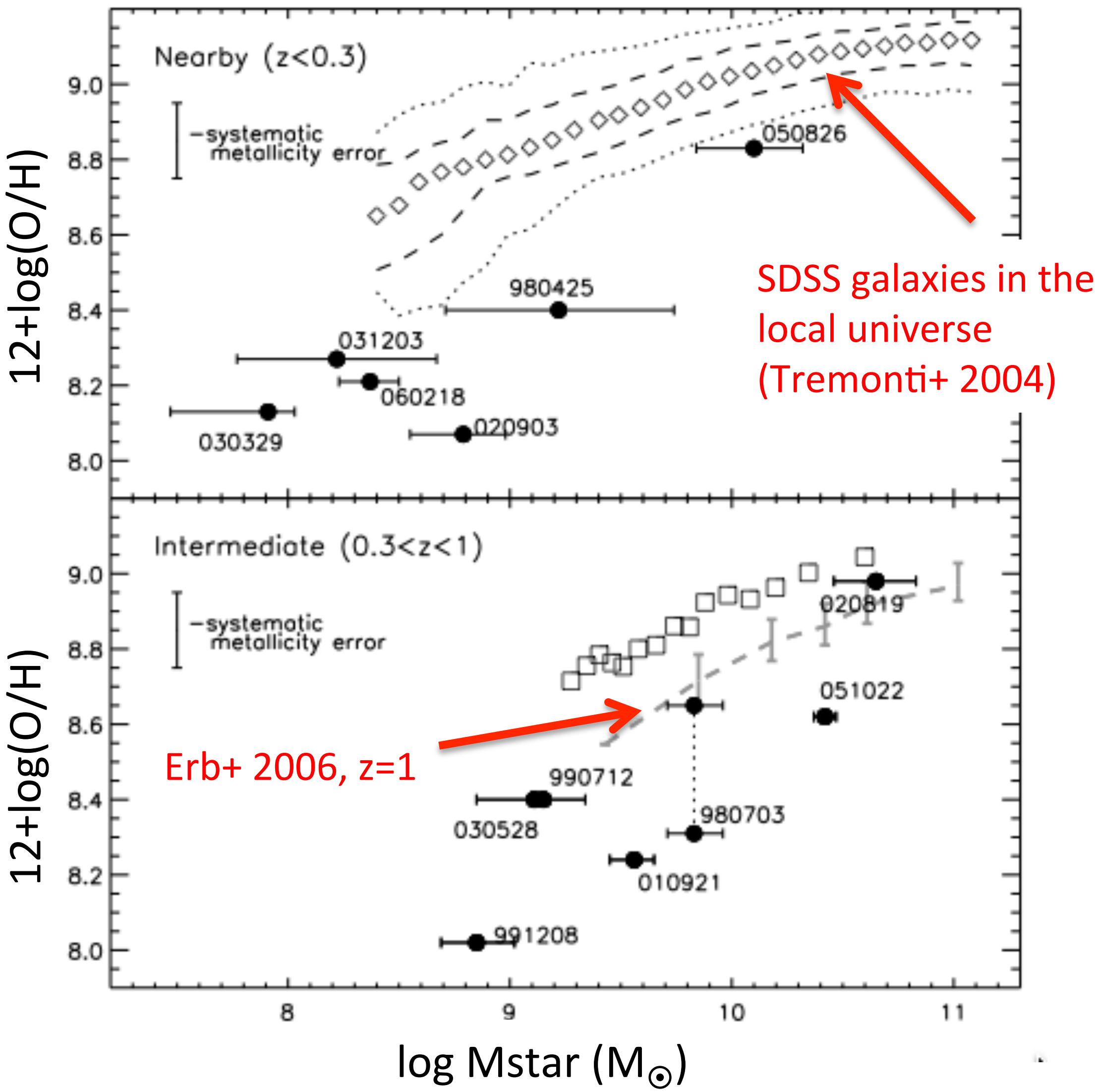
... and such hosts can also be quite massive



The host galaxy population of long GRBs is more diverse than previously thought, especially at z>1.

(updated from Hunt+ 2011)

Many GRBHs are also metal poor



(taken from Levesque+ 2010)

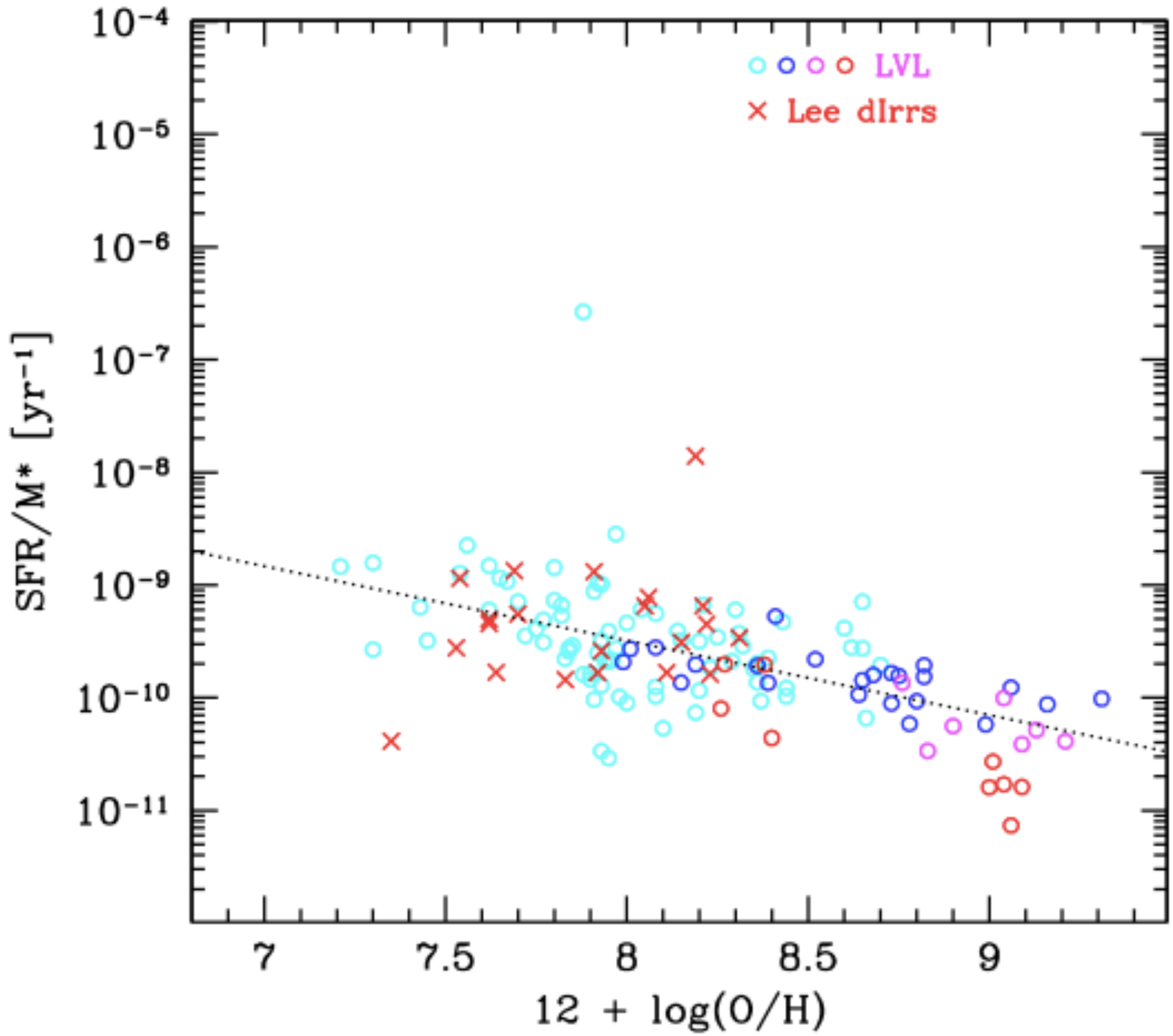
Because GRB progenitors are expected on theoretical grounds to be metal poor, this is not unexpected.

Star-forming galaxies show a well-defined trend with stellar mass (Mstar) and oxygen abundance (measured from emission lines, e.g., 53,000 galaxies from Tremonti+ 2004): the mass-metallicity relation

However, for a given stellar mass, GRBHs fall well below this trend (Levesque + 2010).

But metallicity correlates with star-formation rate

Locally, galaxies are correlated with star-formation rate (SFR) and more importantly with specific SFR (sSFR = SFR divided by stellar mass)

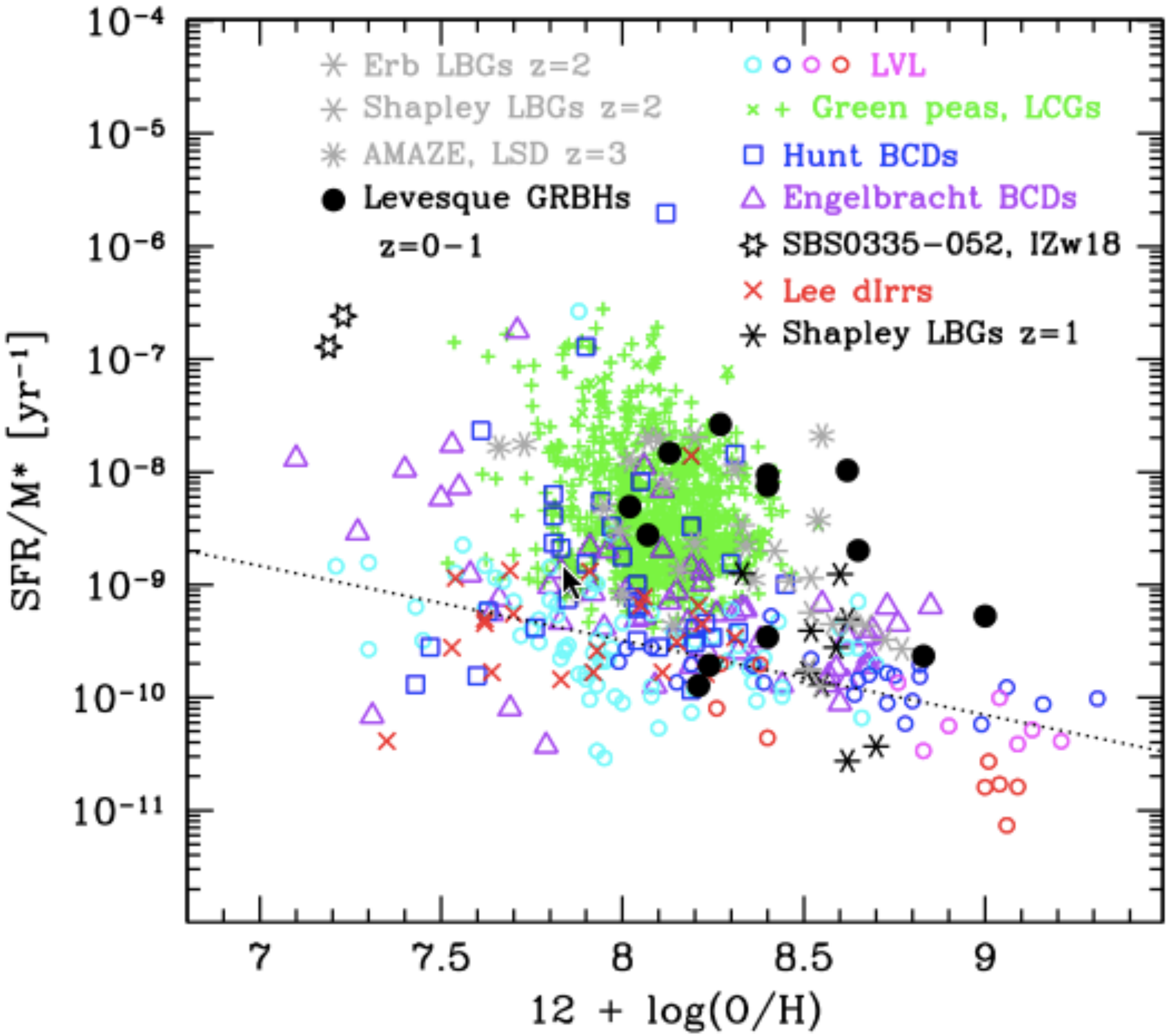


(adapted from Hunt+ 2012)

But metallicity correlates with star-formation rate

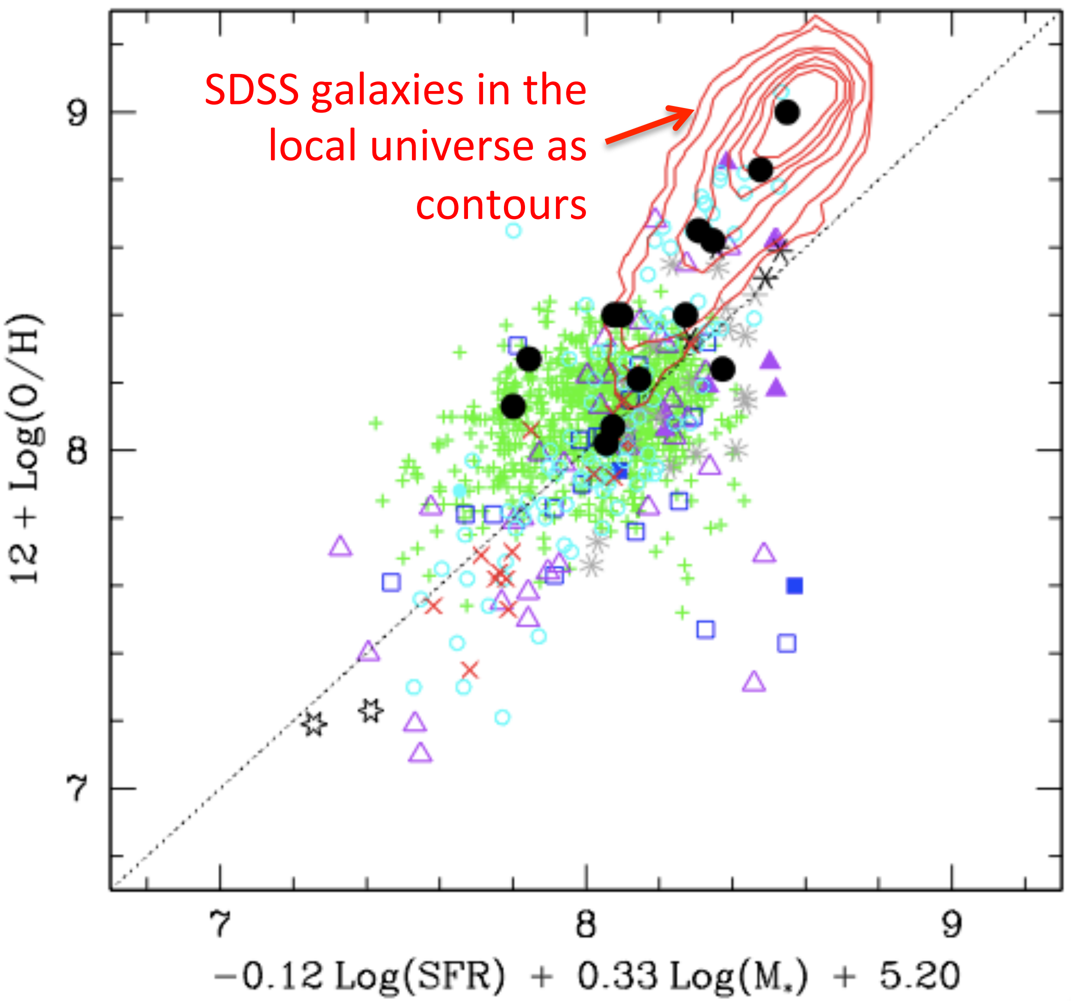
Locally, galaxies are correlated with star-formation rate (SFR) and more importantly with specific SFR (sSFR = SFR divided by stellar mass)

But starbursts (those with high sSFR) show a larger deviation from this main trend, including the GRBHs analyzed by Levesque + (2010) shown as filled circles.



(adapted from Hunt+ 2012)

Metallicity, stellar mass, and SFR are correlated in GRBHs in the same way as in normal star-forming galaxies



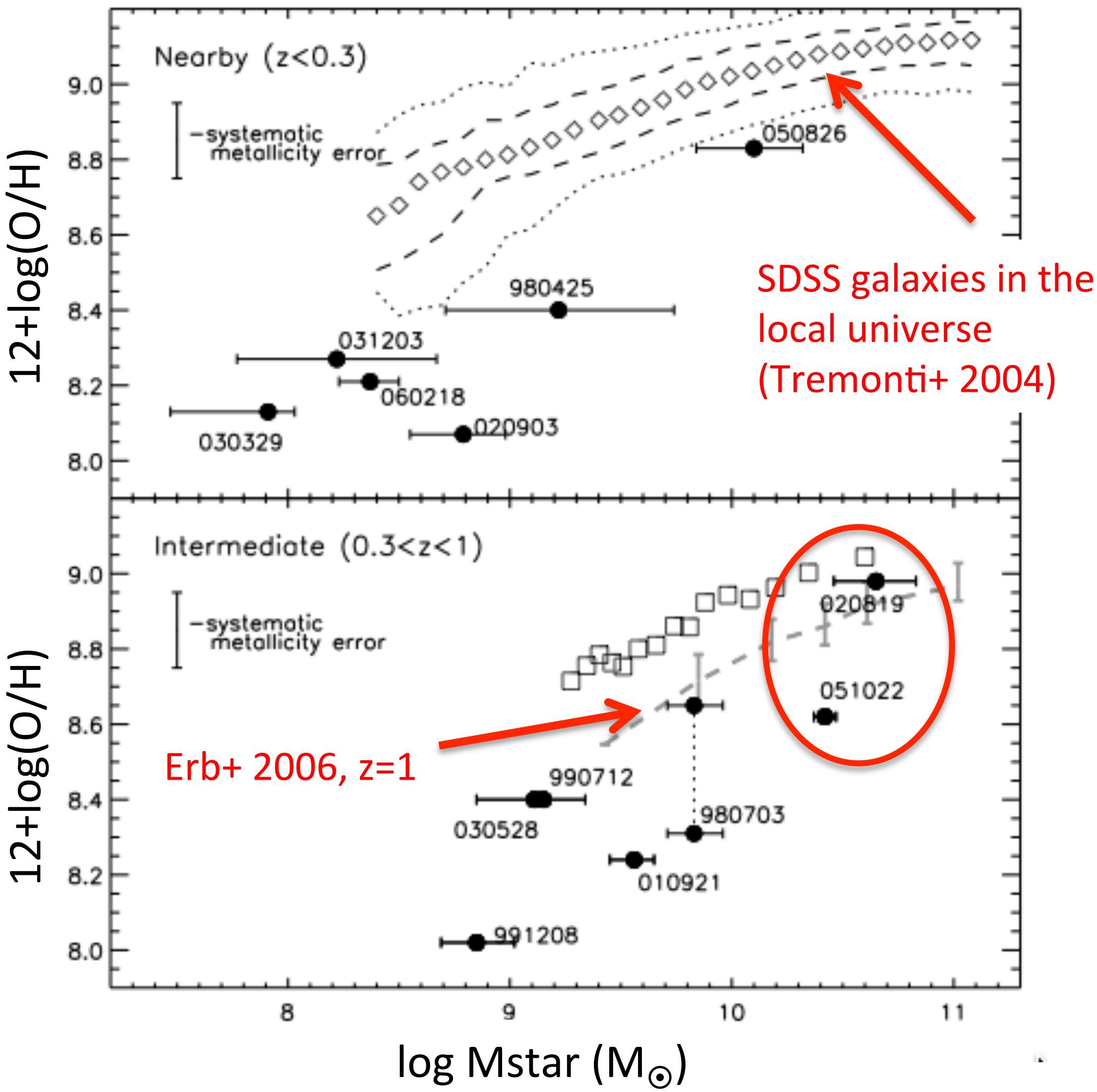
(adapted from Hunt+ 2012)

Here the same galaxies as in the previous plot are shown in the O/H-SFR-Mstar projection that minimizes the spread in metallicity:

the so-called "fundamental metallicity relation" (Mannucci+ 2010), formulated at low metallicity by Hunt+ (2012) as a "fundamental plane" (see also Mannucci+ 2011).

Now focus on the diversity, in particular massive GRBHs which are identified almost exclusively from dark GRBs

Some GRBHs are also metal poor



(taken from Levesque+ 2010)

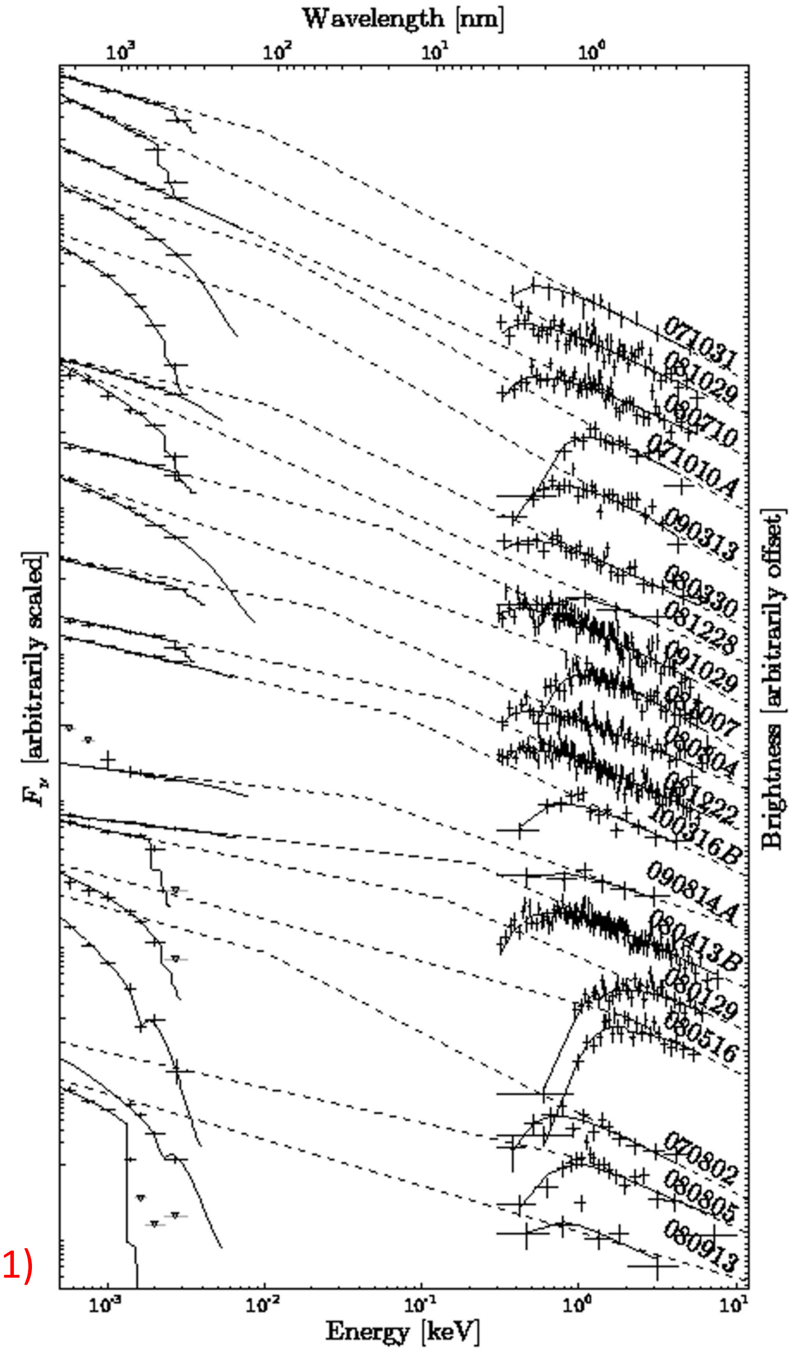
The two most massive galaxies in Levesque+ (2010) host dark GRBs.

Dark bursts are those for which the optical afterglow is fainter than expected from X-ray emission (e.g., Jakobsson+ 2004, van der Horst+ 2009)

~25-40% of GRBs are dark (Fynbo+ 2009, Greiner+ 2011, Melandri+ 2012)

"Darkness" is due to

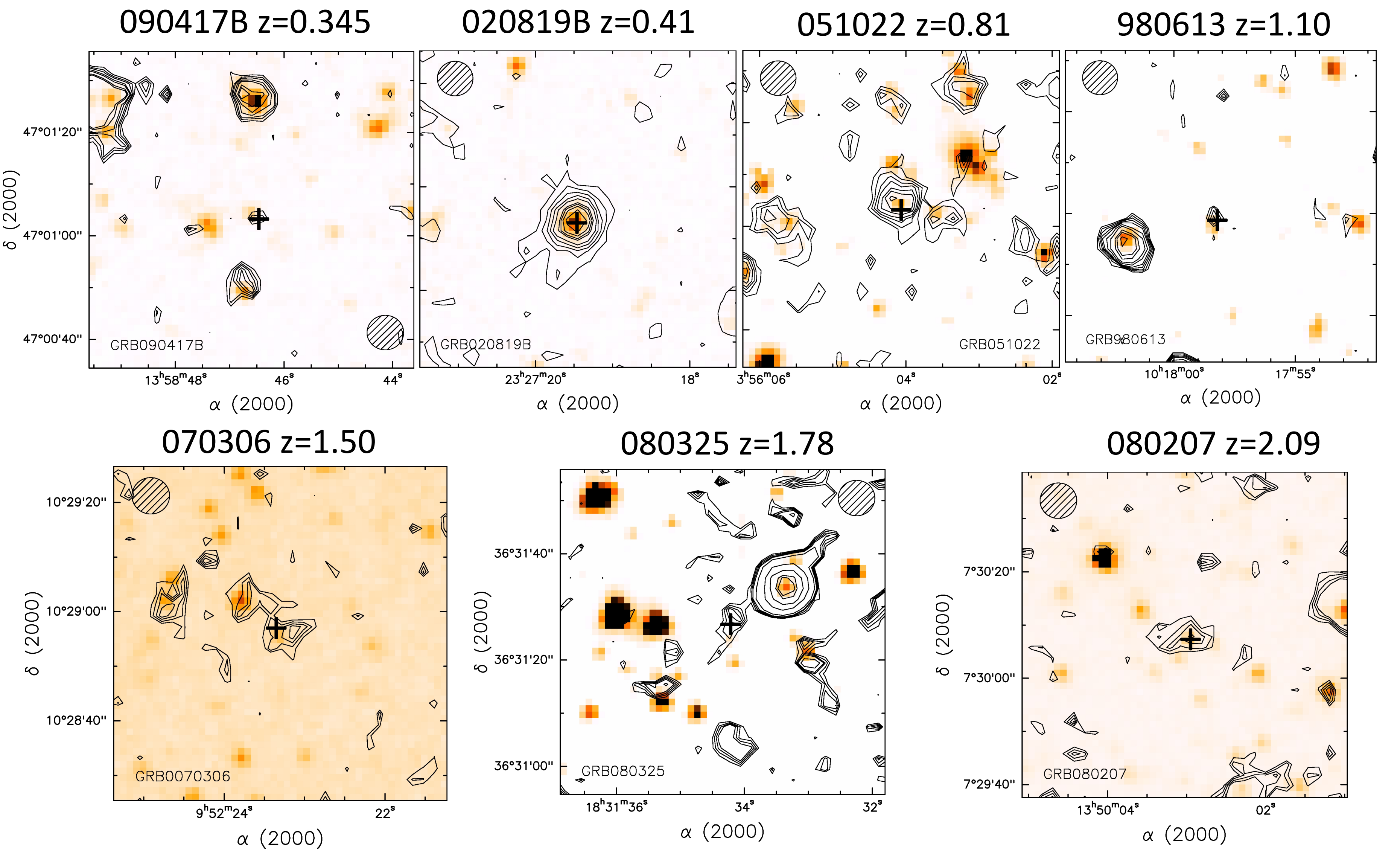
1) dust extinction in the galaxy or in the circumstellar environment of the GRB progenitor, or
2) faintness because of high redshift, or
3) both



(taken from Greiner+ 2011)

Because of the potential role of dust, we undertook an observing program with *Herschel* of (mostly) dark GRB hosts.

7 detections out of 17 GRBHs (not including 980425)



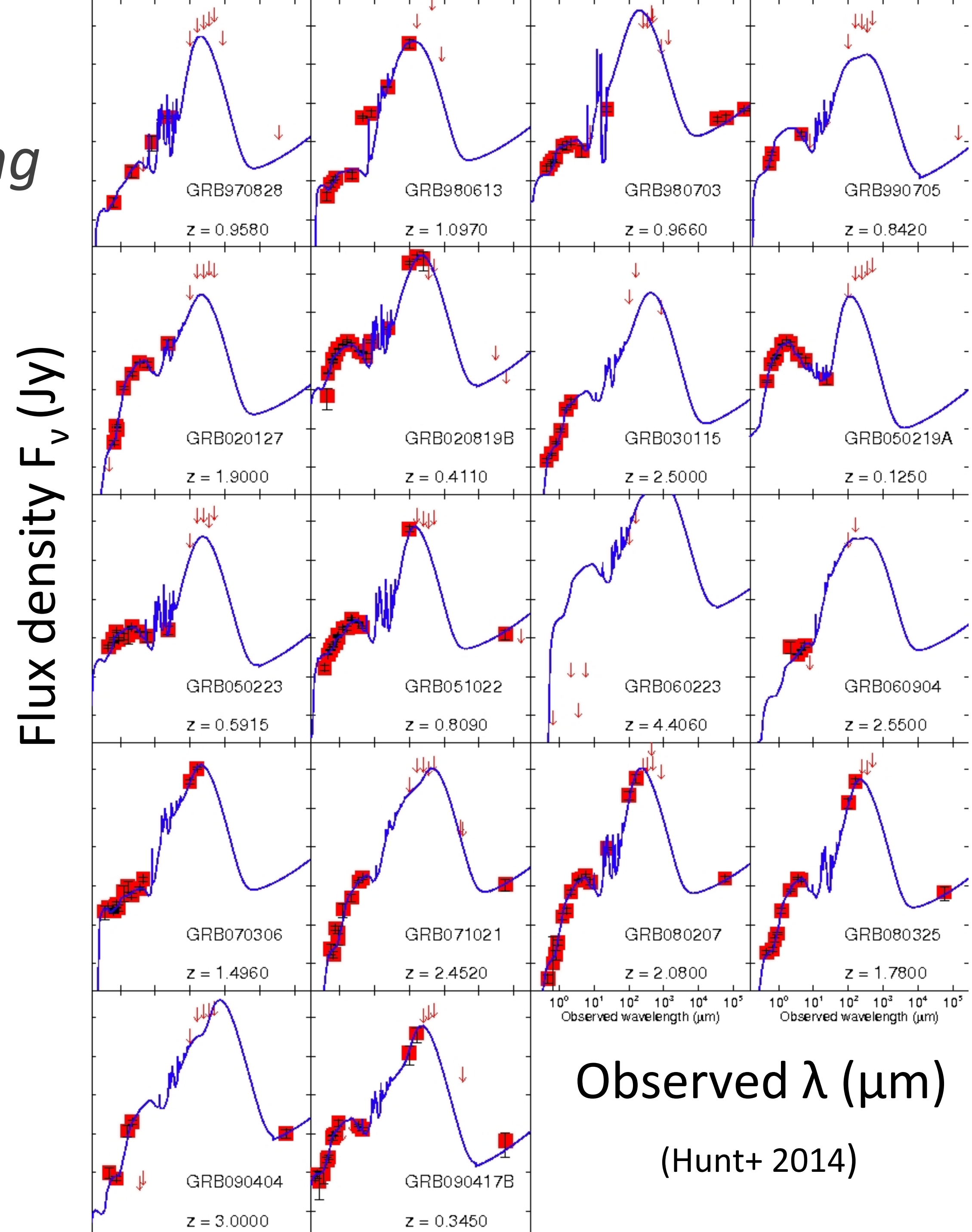
Herschel/PACS 100μm contours overlaid on IRAC 3.6μm

Spectral Energy Distribution (SED) fitting with GRASIL

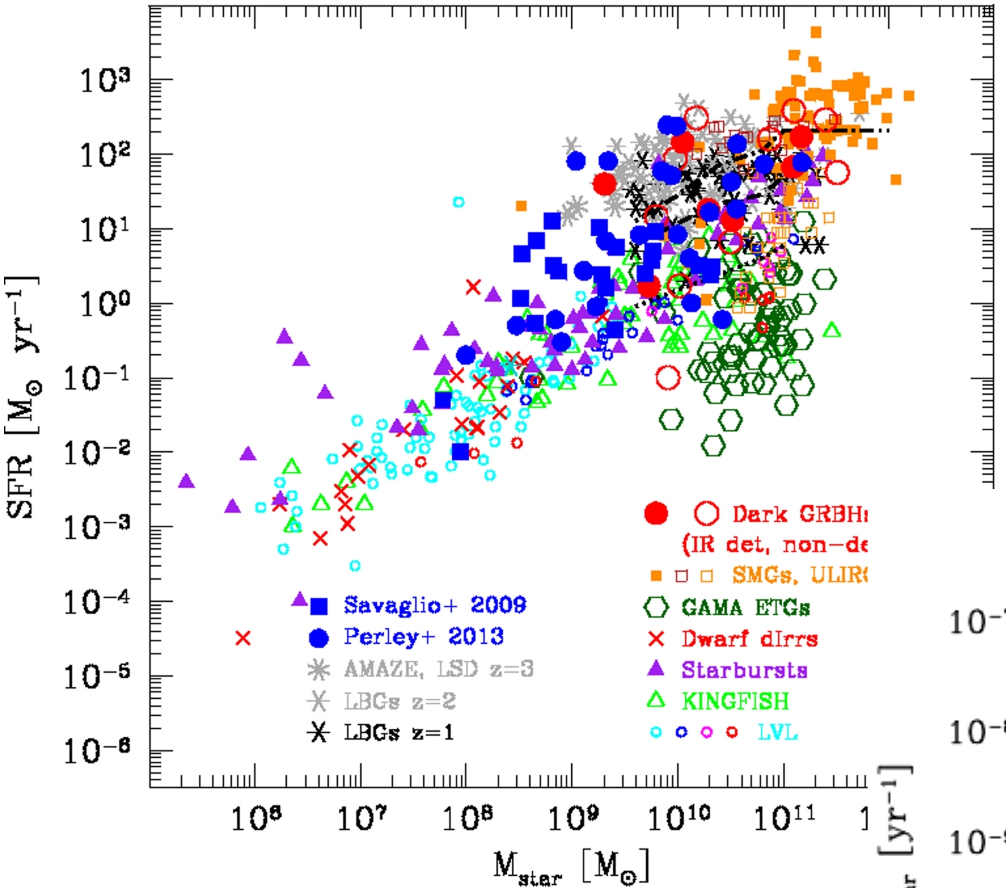
Data compiled from the literature (relying heavily on GHostS), and combined with *Spitzer* and our new *Herschel* photometry of (mostly) dark GRBHs:
detection rate for dark GRB hosts 43%, higher than 8-25% for optically bright GRBs.

SEDs fit with GRASIL (Silva+ 1998) models as in Michalowski + (2008, 2009, 2010): M_{dust}, M*, SFR

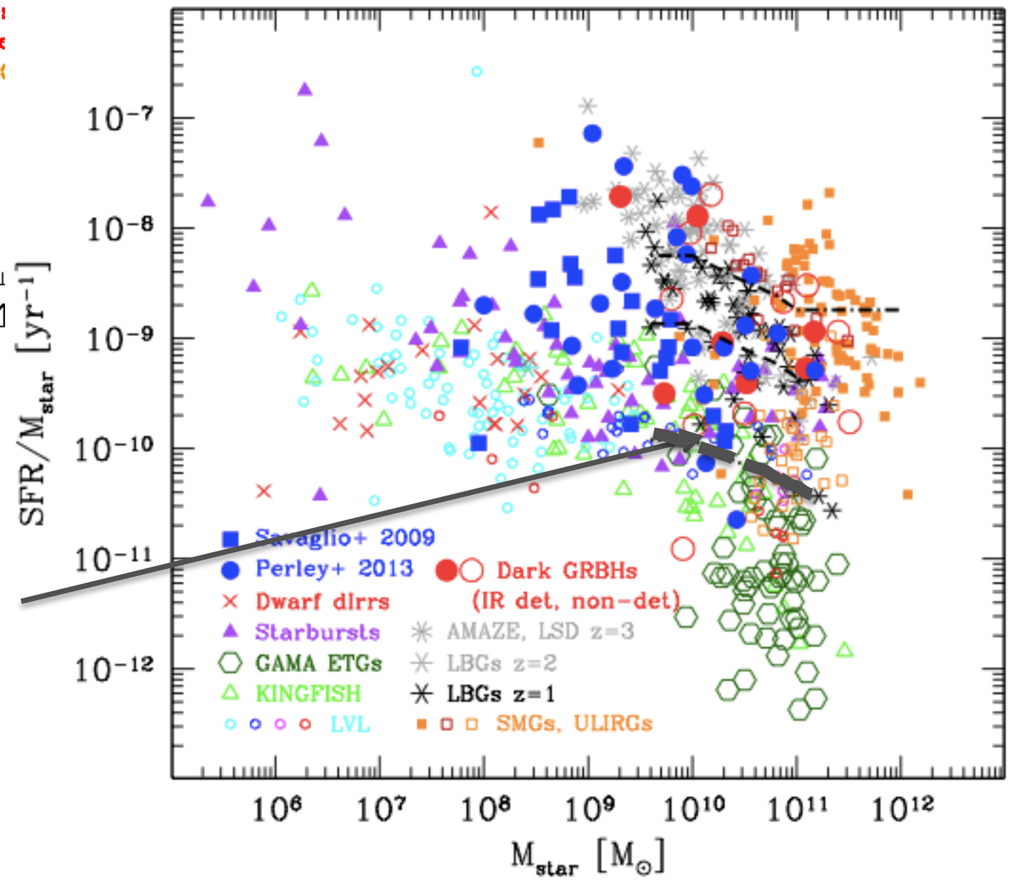
1.6μm bump in 11/18 hosts, and in 6/7 *Herschel* detections! Thus evolved stellar populations (not young, blue).



(Hunt+ 2014)



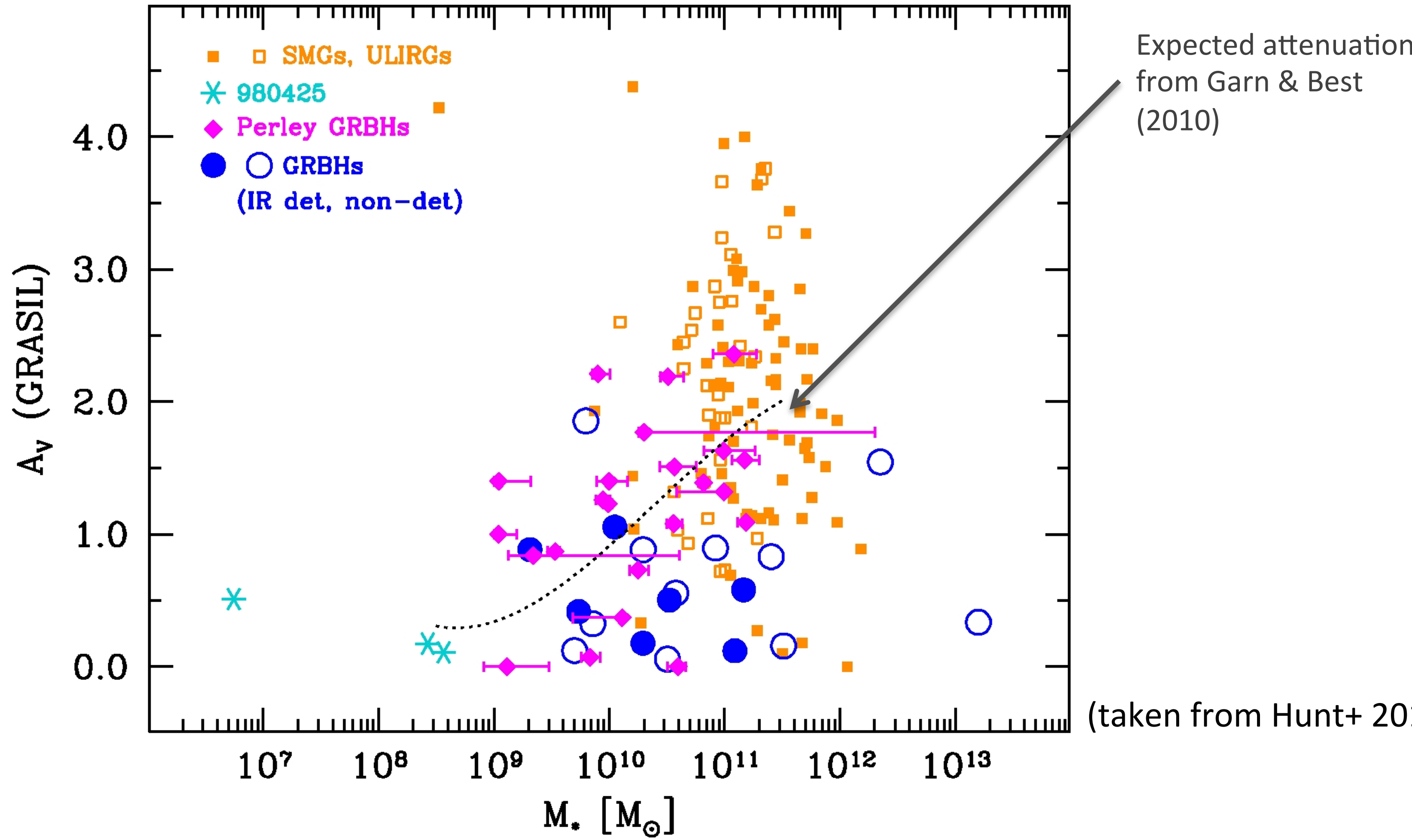
Star formation main sequence



Curves are taken from Karim+ (2011), from radio stacking of COSMOS galaxies, thus comparable with SFR(IR) from GRASIL. Lower curves correspond to z=0.3, middle to z=1.1, upper to z=2.3.

GRBHs SFRs look quite “normal” for their stellar mass but specific SFR is high!

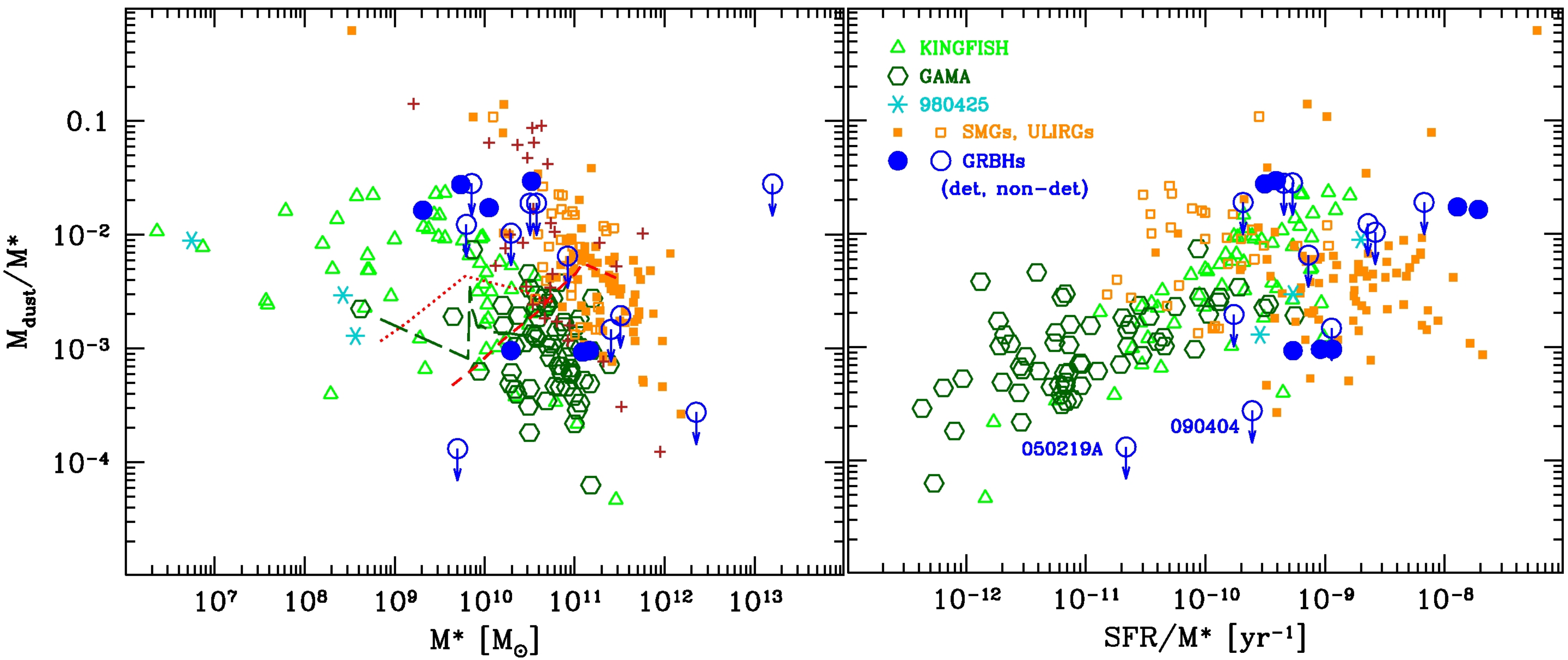
GRBH dust extinction compared with stellar mass



(taken from Hunt+ 2014)

GRBHs global extinctions fall short of the expected trend of attenuation with stellar mass. This result seems independent of IR detection. Is it the hosts or GRASIL? (which even for SMGs, ULIRGs gives low A_V in some cases).

Dust-to-stellar mass ratios for GRBHs



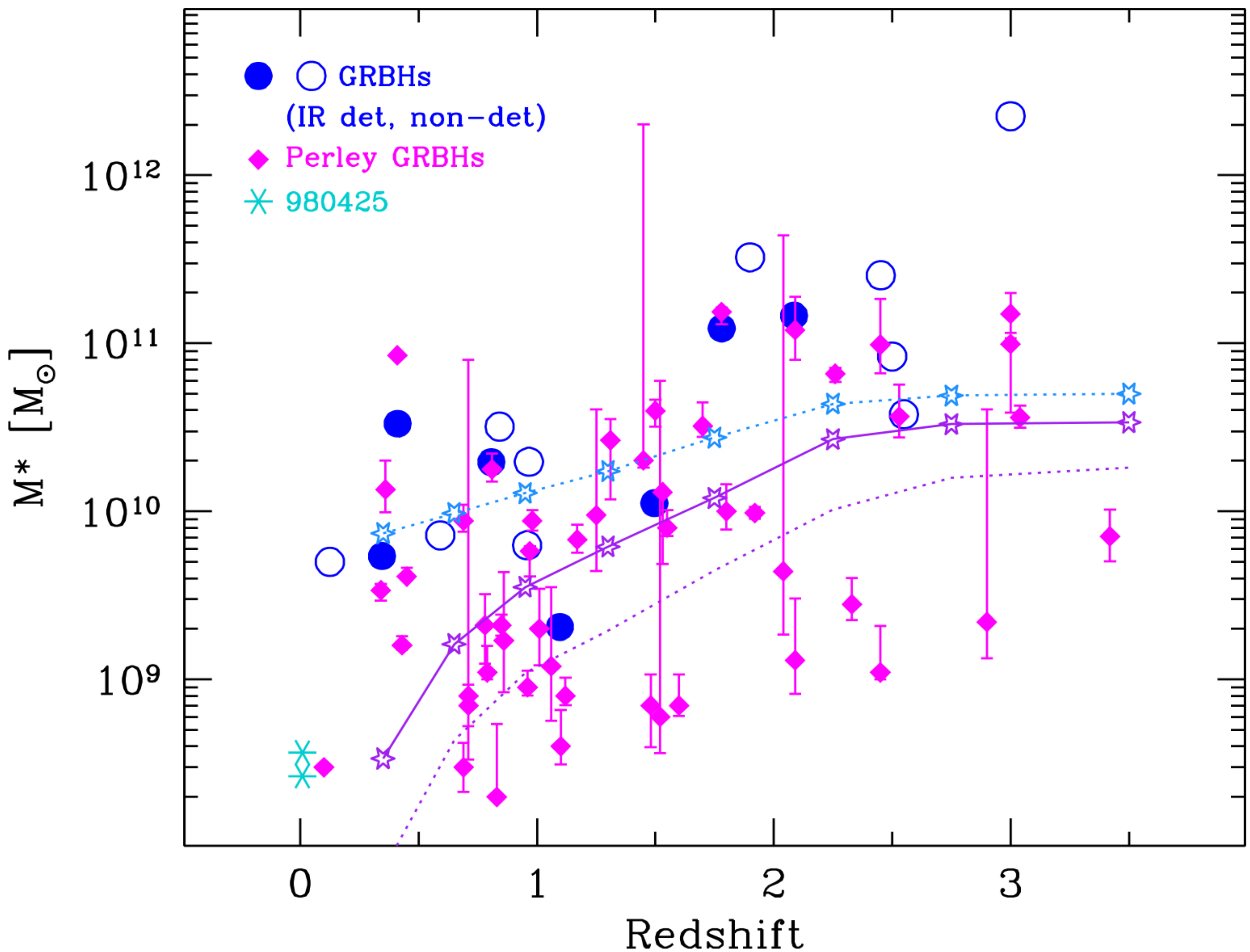
Da Cunha+ (2010) find strong correlation between Mdust/M*, but the GRBHs (and the SMGs from Michalowki+2010, ULIRGs from Lo Faro+2013, both with GRASIL SED fitting) turn over at specific SFR (sSFR) > 10^{-9} yr^{-1}.

Except for 2 upper limits, dust content of GRBHs is “normal”.

Are the stellar mass and SFRs of GRBHs representative of galaxy populations at all redshifts?

GRBH stellar masses vs. redshift

M* from fits of Schechter functions to COSMOS, UltraVISTA (220,000 galaxies, K_s<24: Ilbert+ 2010, 2013, Muzzin+2013): **median M* of star-forming galaxies, survey median M* star-forming galaxies weighted by SFR.** Mass lower limits dotted curve.



Analyze *Herschel* GRBH sample with Savaglio +2009, Perley +2013 to obtain a combined sample 66 hosts, 48% of which are dark

GRBs select galaxies which fall below even faint survey limits.

GRBH stellar masses vs. redshift

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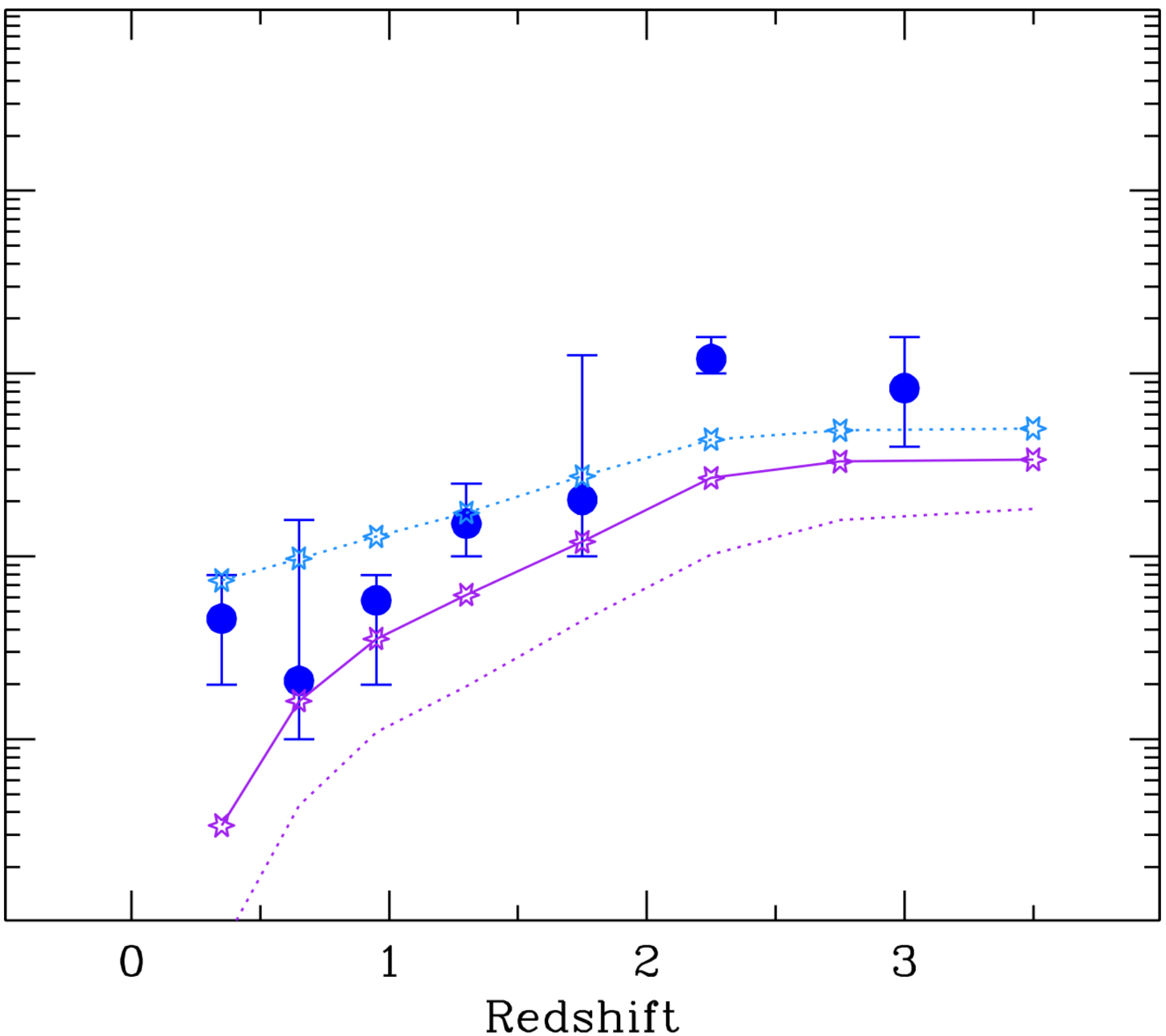
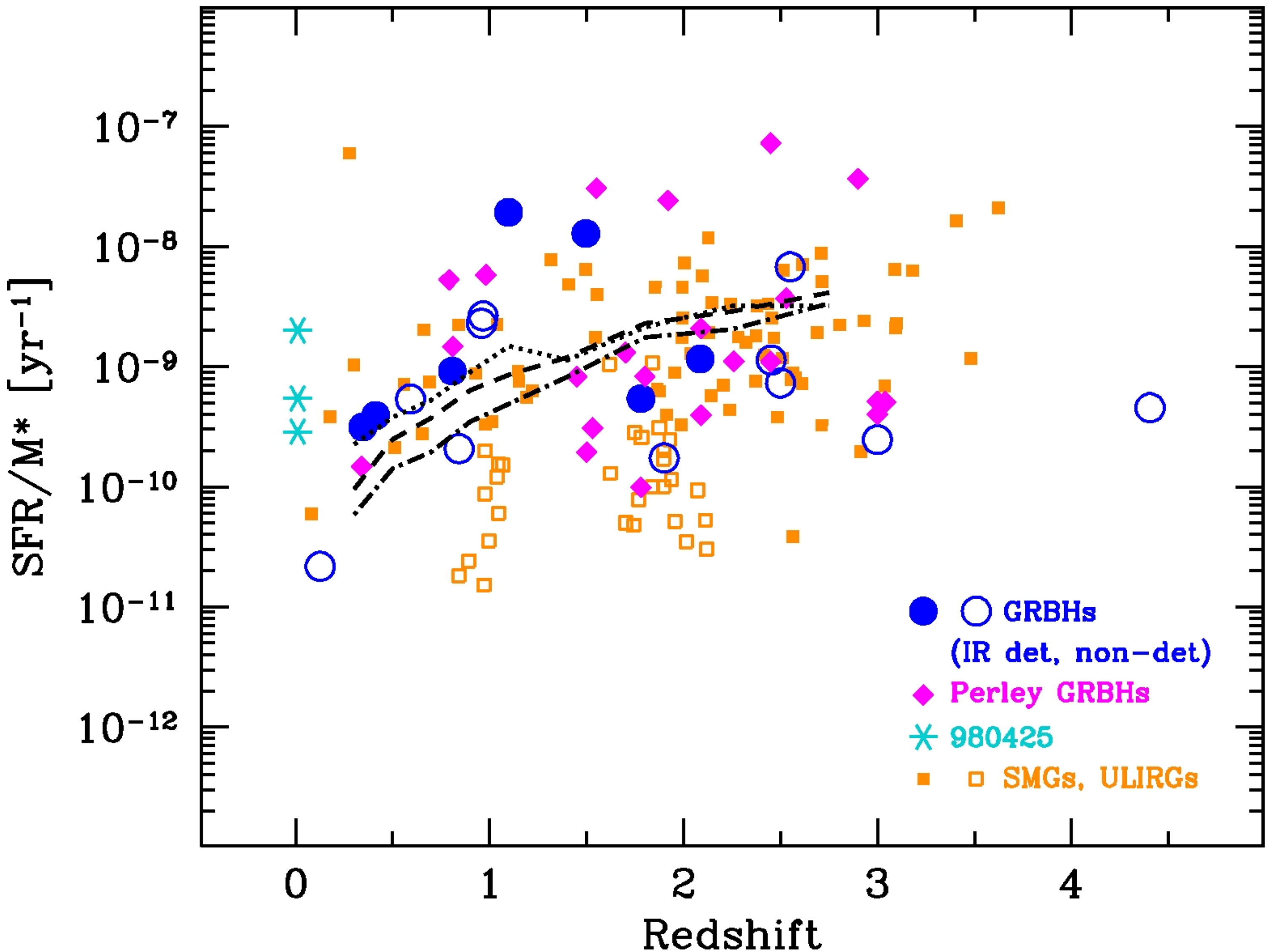


Blue circles show medians of 66 GRBHs of previous slide.

GRBH sSFRs vs. redshift

sSFR from Karim+ (2011) radio stacking of COSMOS galaxies (remember sSFR vs. Mstar).
Curves are for Mstar = dex(9.6) $M_\odot$, dex(10.4) $M_\odot$, dex(>11) $M_\odot$.



Conclusions…

At a given M*, and relative to local samples of galaxies, some hosts have high M_{dust}/M^*, while others do not, but small-number statistics. Generally, GRBH dust content is compatible with other galaxy populations.

M_{dust}/M^* not proxy for metallicity but rather for sSFR, at least for sSFR < 10^{-9} yr^{-1}. GRBHs are highly star forming, with high sSFRs, and have normal M* for their metallicity and sSFR. Compared to M* for star-forming galaxies, which tend to be less massive than quiescent populations, the stellar masses of GRBHs are consistent with statistical expectations, in particular at z>1 (cf. Perley+ 2013).

Nonetheless, GRBs can identify low-mass galaxies at high redshift which would not have been detected in magnitude-limited surveys. GRBHs, when dark GRBs are considered, are (apparently) unbiased reliable tracers of SFR up to z~3.

However, this point is still highly debated, especially for z<1 (see e.g., Perley+ 2013, Vergani+ 2014)! More samples are needed because of small-number statistics.