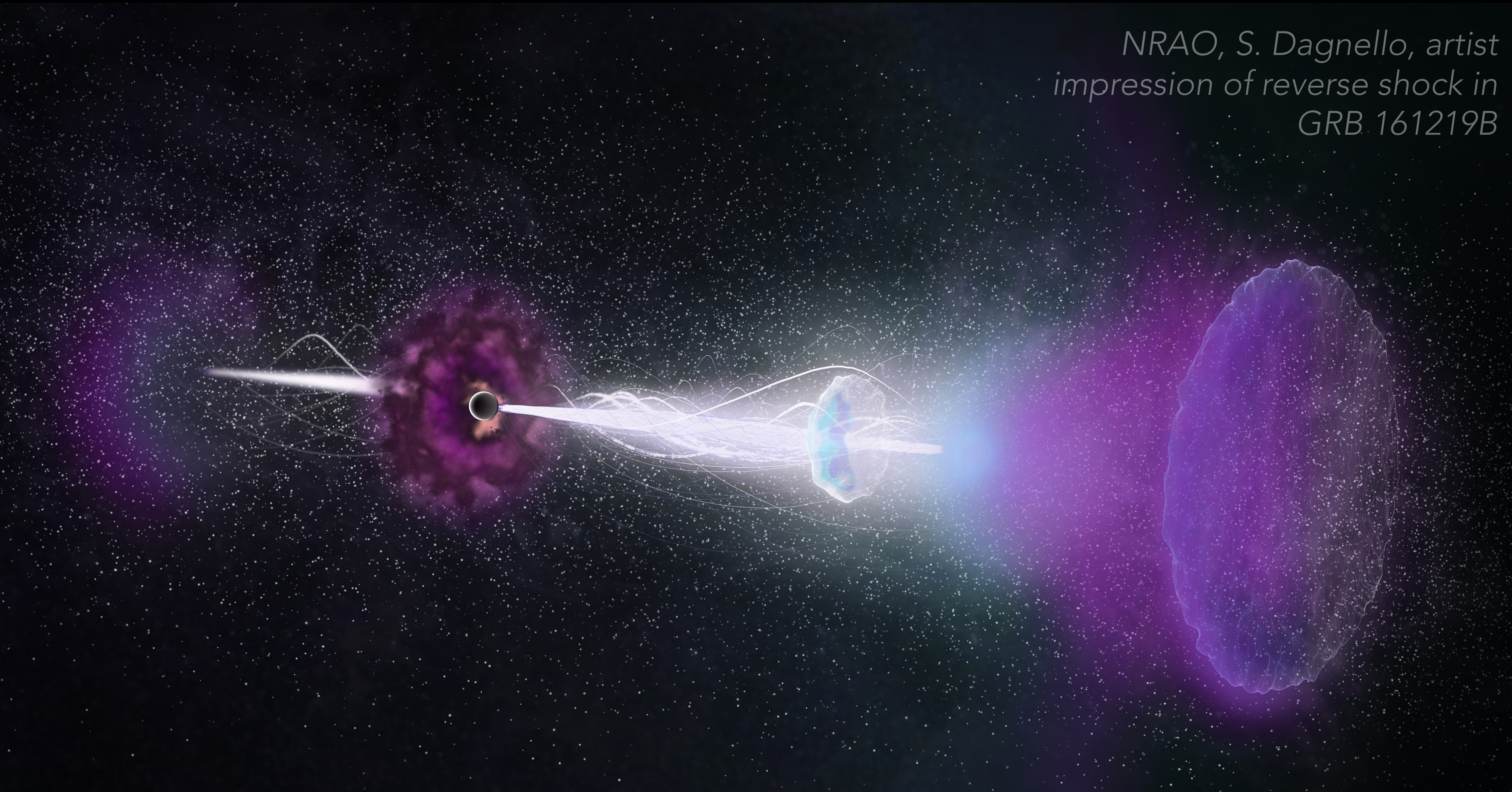
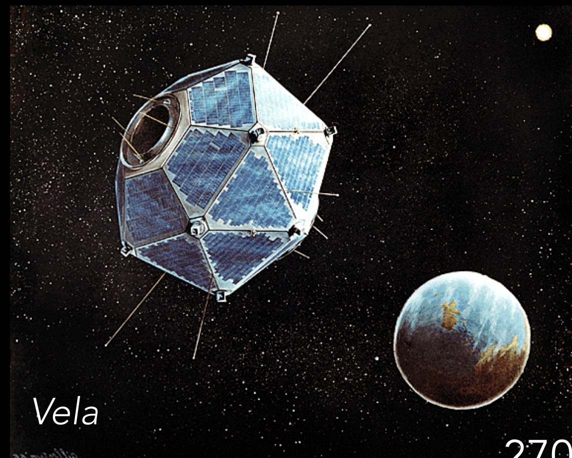
Gas and dust in the host galaxies of GRBs

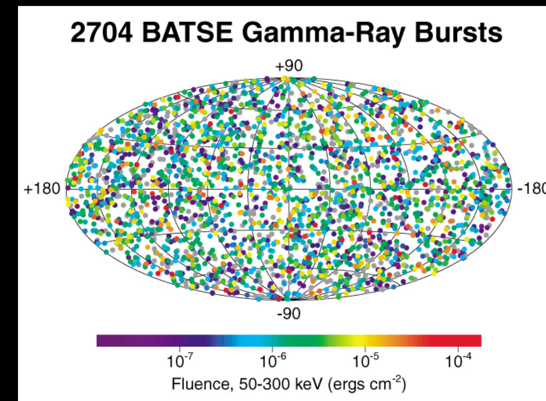


Leslie Hunt, INAF-Osservatorio Astrofisico di Arcetri, Firenze, Italy
Sylvio Klose, Thüringer Landessternwarte Tautenburg, Tautenberg, Germany
Michal Michalowski, Astronomical Observatory Institute, Poznań, Poland

Gamma-ray bursts (GRBs) discovered through deterrents of nuclear testing

first GRB discovered in 1967 by Vela during space monitoring of ground-based bomb testing (see Klebesadel + 1973)


Vela

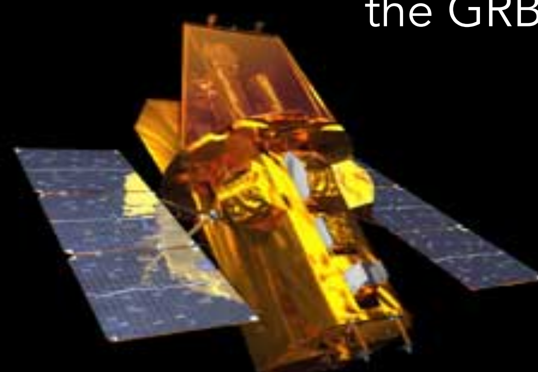


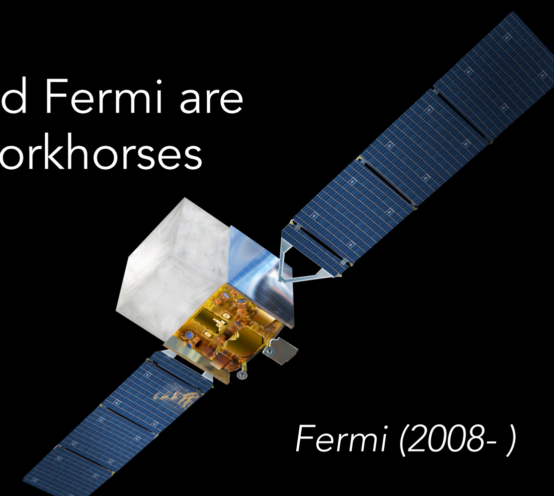
2704 GRBs found by Compton Gamma Ray Observatory-Burst And Transient Source Experiment (CGRO-BATSE) over its lifetime (1991-2000)

BeppoSAX (1993-2002) first localized GRB afterglows in 1997 (**970228, z=0.7; 970508 z=0.8), then** HETE-2 (2000-2006)

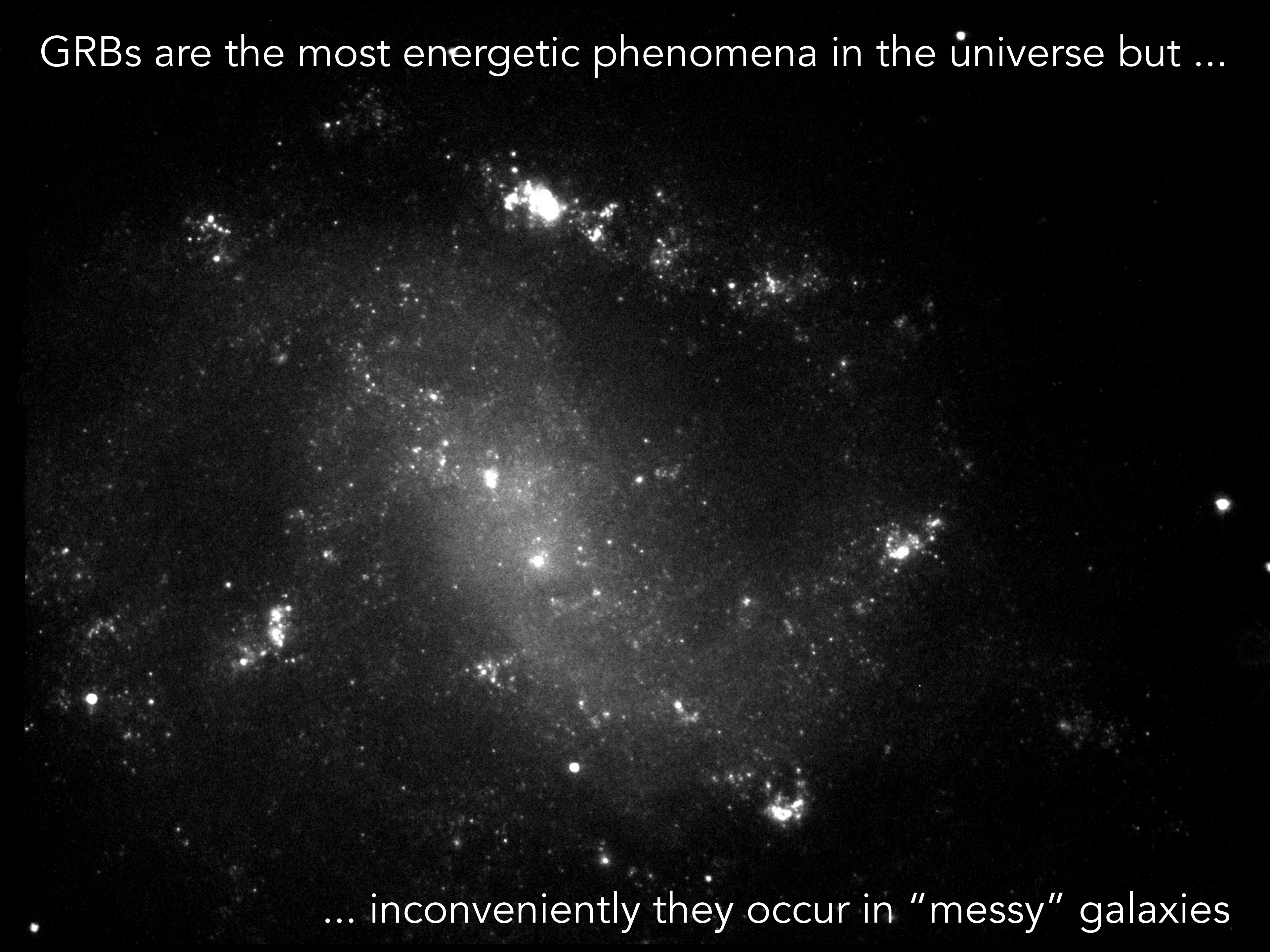
now Swift and Fermi are the GRB workhorses


BeppoSAX


Swift (2004-)


Fermi (2008-)

future THESEUS? (Amati+ 2018)

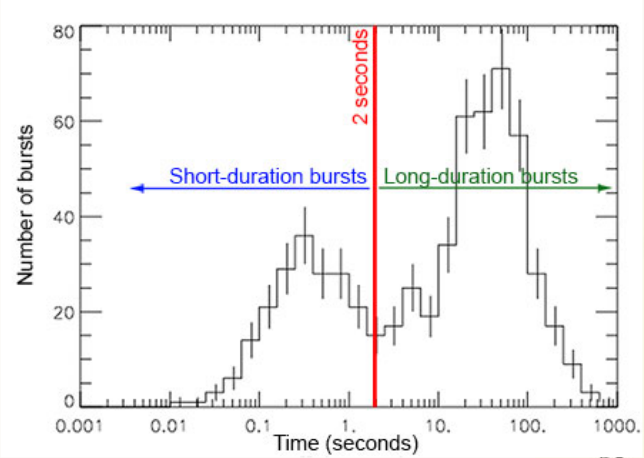

GRBs are the most energetic phenomena in the universe but ...
... inconveniently they occur in "messy" galaxies

... or in smoother, more regular galaxies ... but not in isolation!

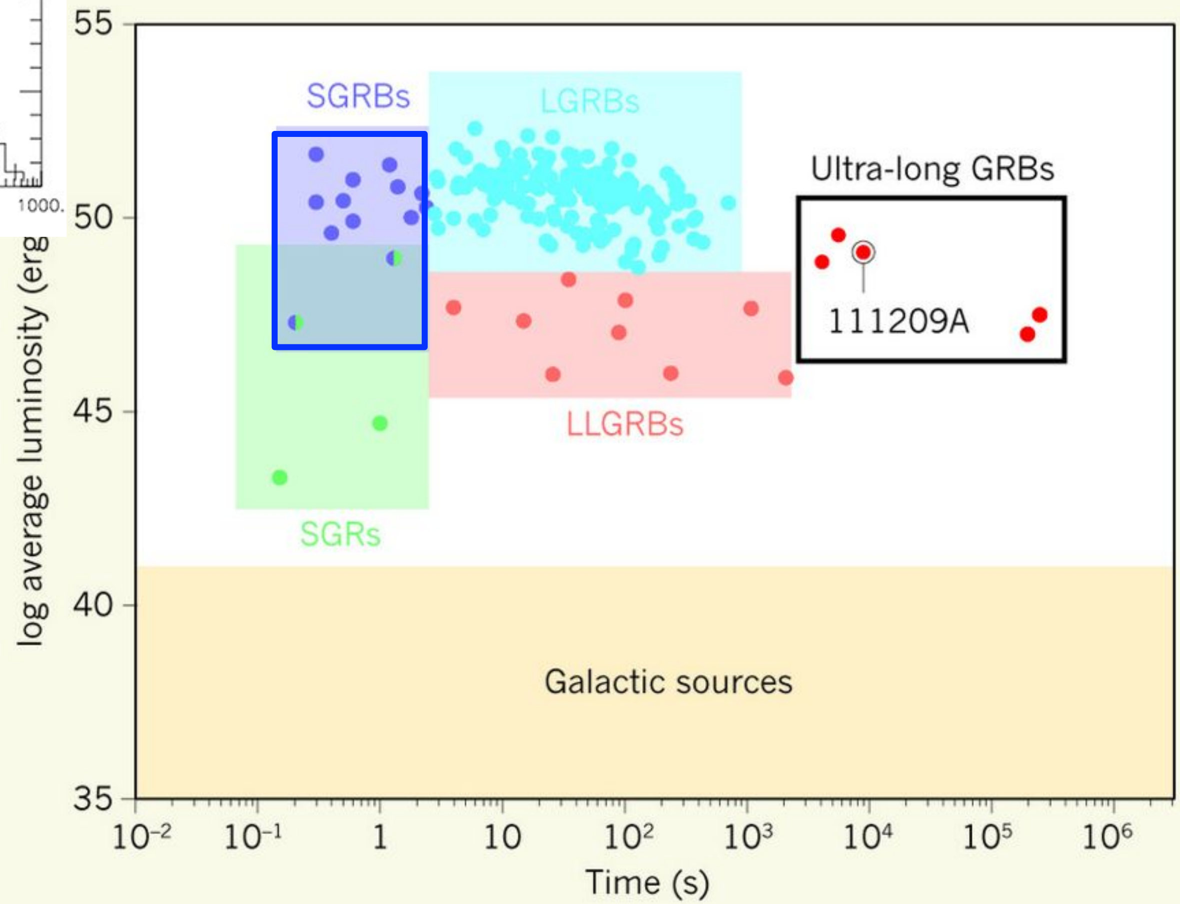
host galaxy properties are important for understanding the nature of GRB progenitors and selection bias

but also for "shedding light" on distant galaxy populations in the early Universe

the zoo of GRBs: short GRBs

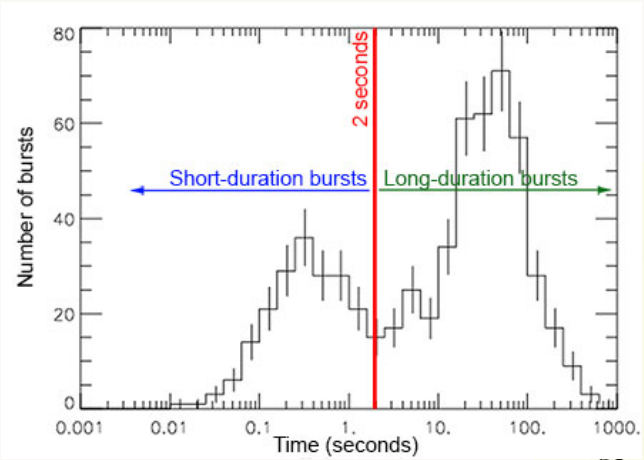


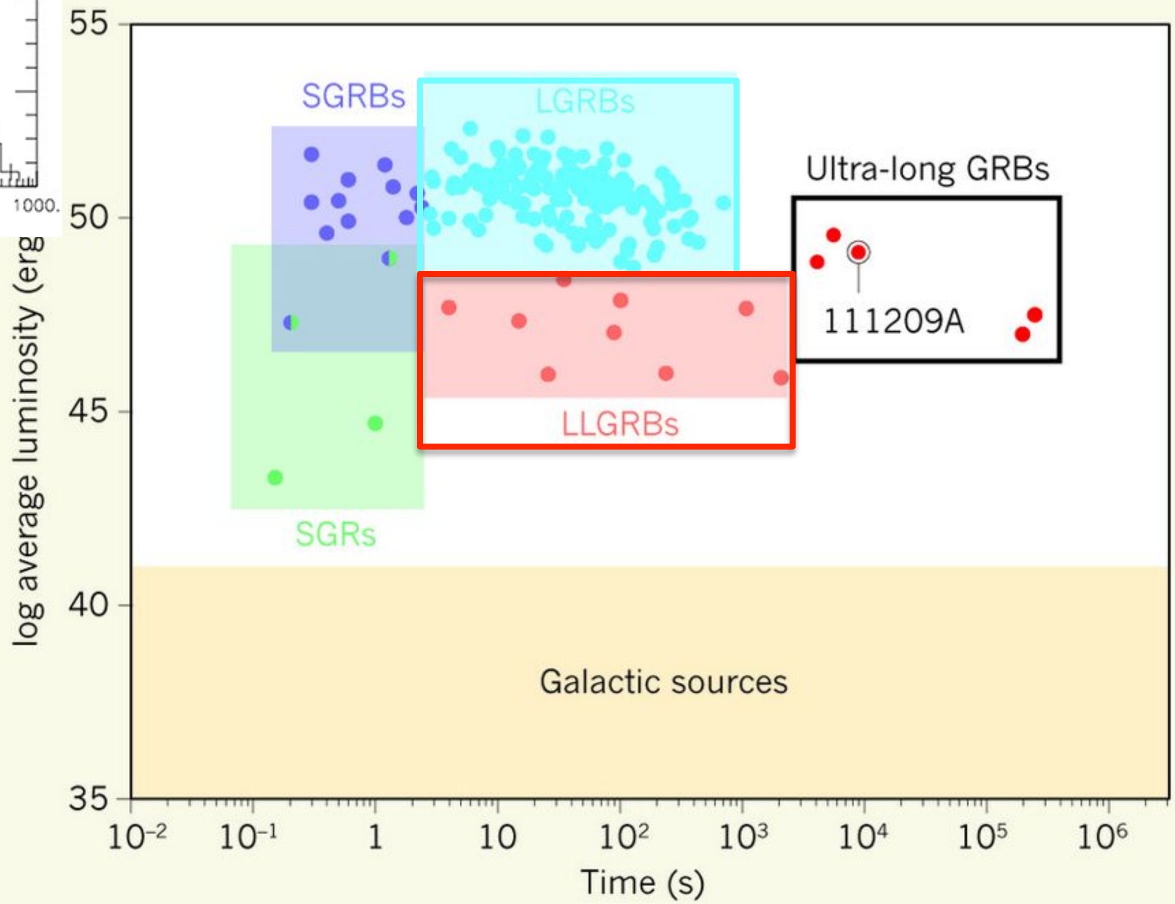
short GRBs (SGRBs) comprise ≈ 30% of GRBs, and are thought to be produced by neutron star-neutron star mergers (e.g., GRB 170817A)



taken from Smartt (2015)

the zoo of GRBs: long GRBs

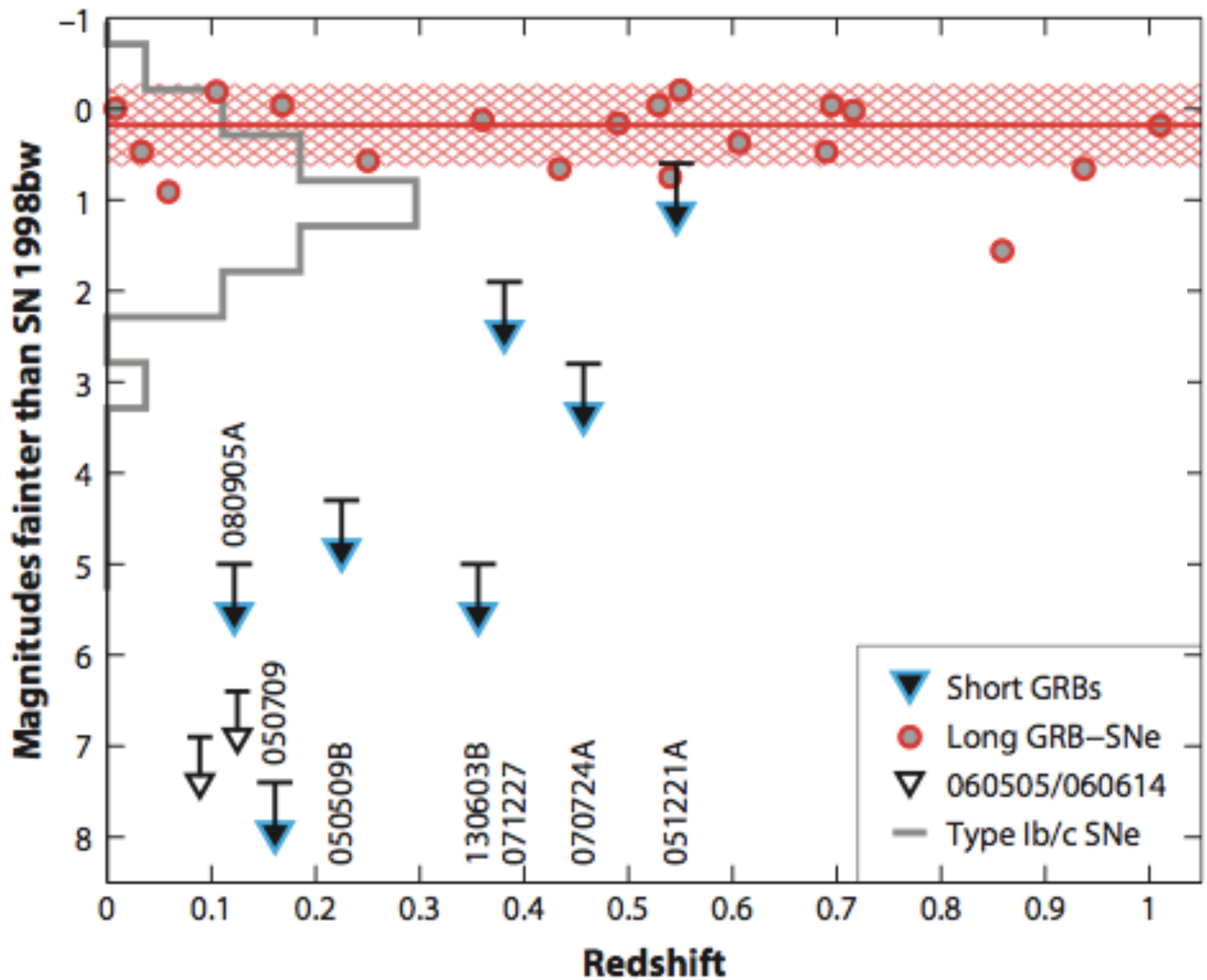




long GRBs (LGRBs) are majority of GRBs, thought to result from collapse of a rotating massive star followed by the formation of a black hole, and subsequent relativistic jets (collapsar, e.g., MacFadyen & Woosley 1999, Woosley & Bloom 2006, ...)

taken from Smartt (2015)

GRBs dichotomy: LGRBs and supernovae (SNe)

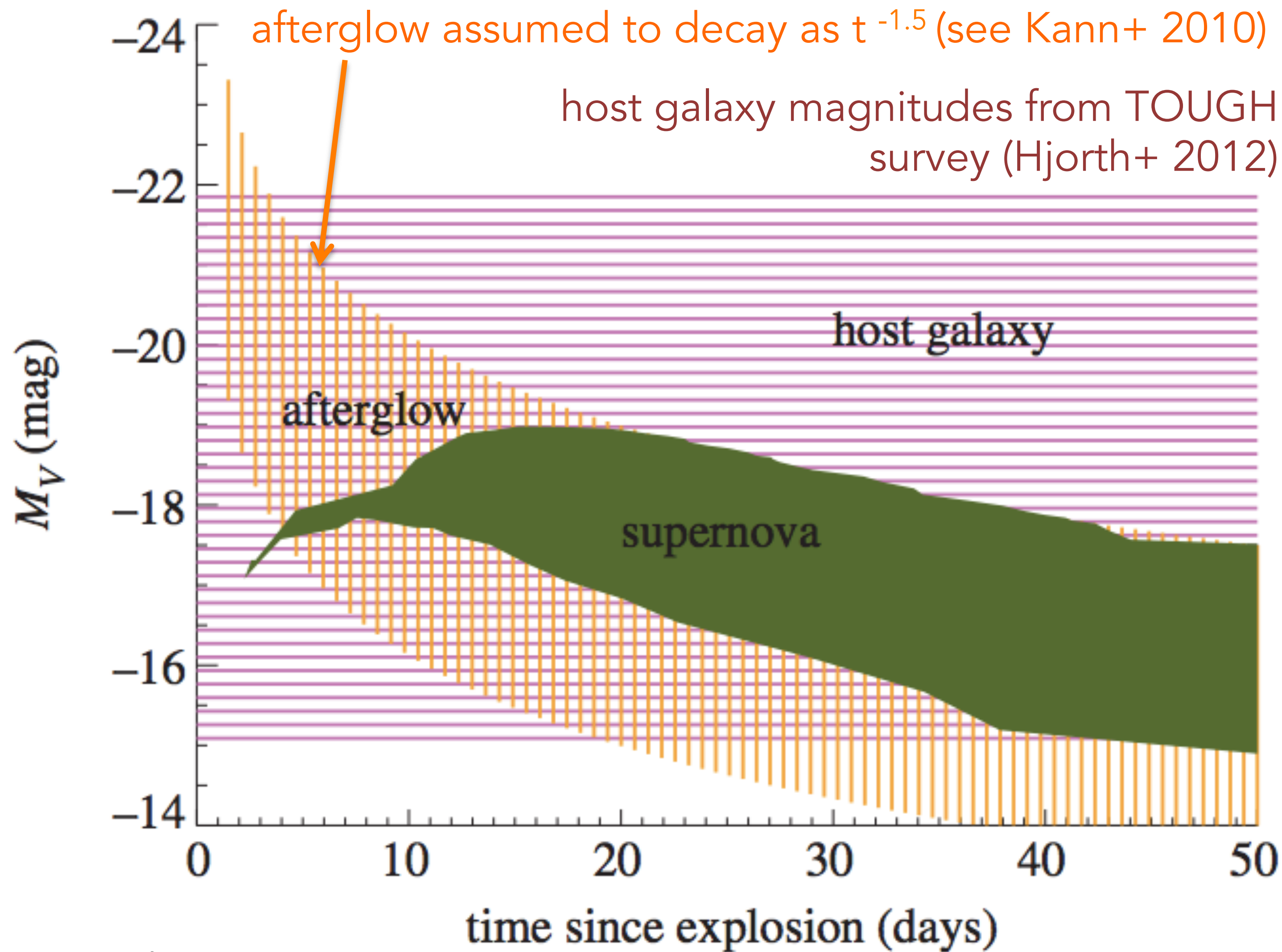


limits on SNe associated with short GRBs (filled triangles) relative to the peak absolute magnitude of the canonical long GRB-SN 1998bw (GRB 980425)

see also distribution of SN peak magnitudes for long GRBs (filled circles; hatched region marks the median and standard deviation for the population)

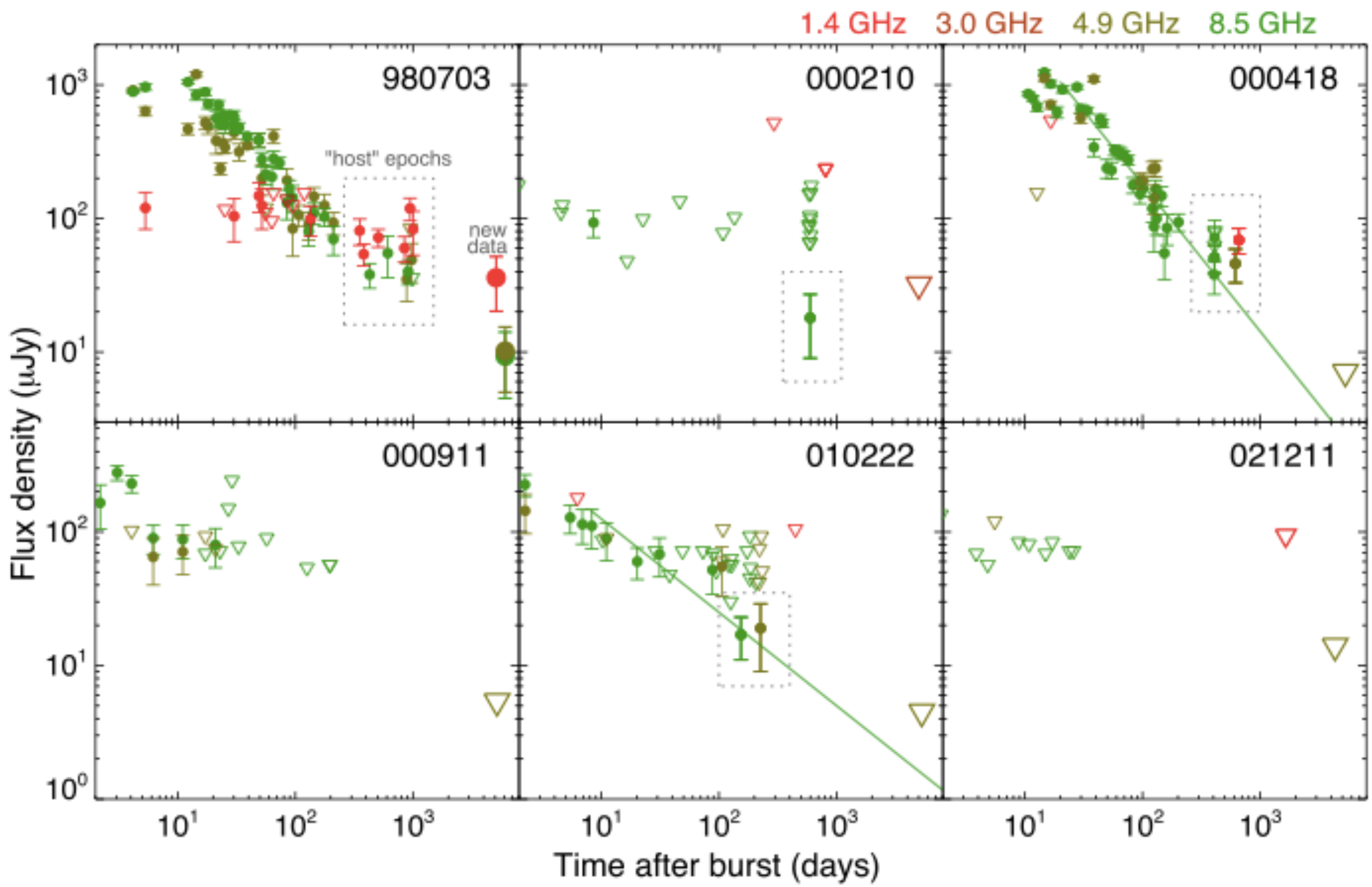
taken from Berger (2014)

challenge to separate afterglow and SN from host galaxy at late times (when SN onsets)



taken from Hjorth (2013)

GRB radio afterglows can be very persistent



pre-Swift GRBs with putative radio detections by Berger+ (2003) (shown in boxes) were shown to be long-lived radio afterglows with new JVLA observations by Perley+ (2017)

LGRB association with massive stars: do LGRBs track star-formation activity in an unbiased way over cosmic time?

answer needs unbiased GRB and host surveys

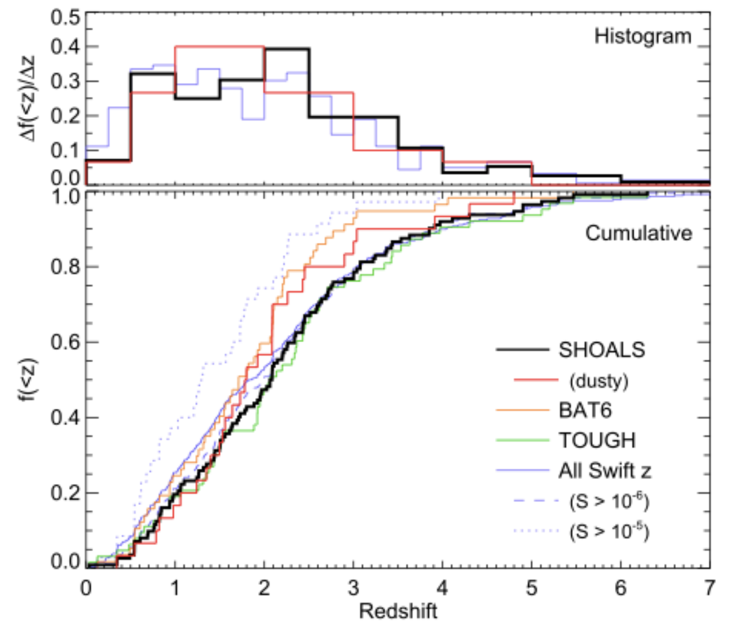
Salvaterra+ (2012): BAT6 (58 galaxies)

- only Swift LGRB detections
- low Galactic foreground extinction
- large GRB sun distance (for optimized followups)
- declinations accessible to VLT, good X-ray positions
- bright in peak flux Swift 50-150 keV BAT band

Hjorth+ (2012): The Optically Unbiased GRB Host survey ((TOUGH, 69 galaxies)

- only Swift LGRB detections
- X-ray afterglow detected
- low Galactic foreground extinction
- large GRB sun distance
- no foreground objects
- declinations good for VLT, good X-ray positions

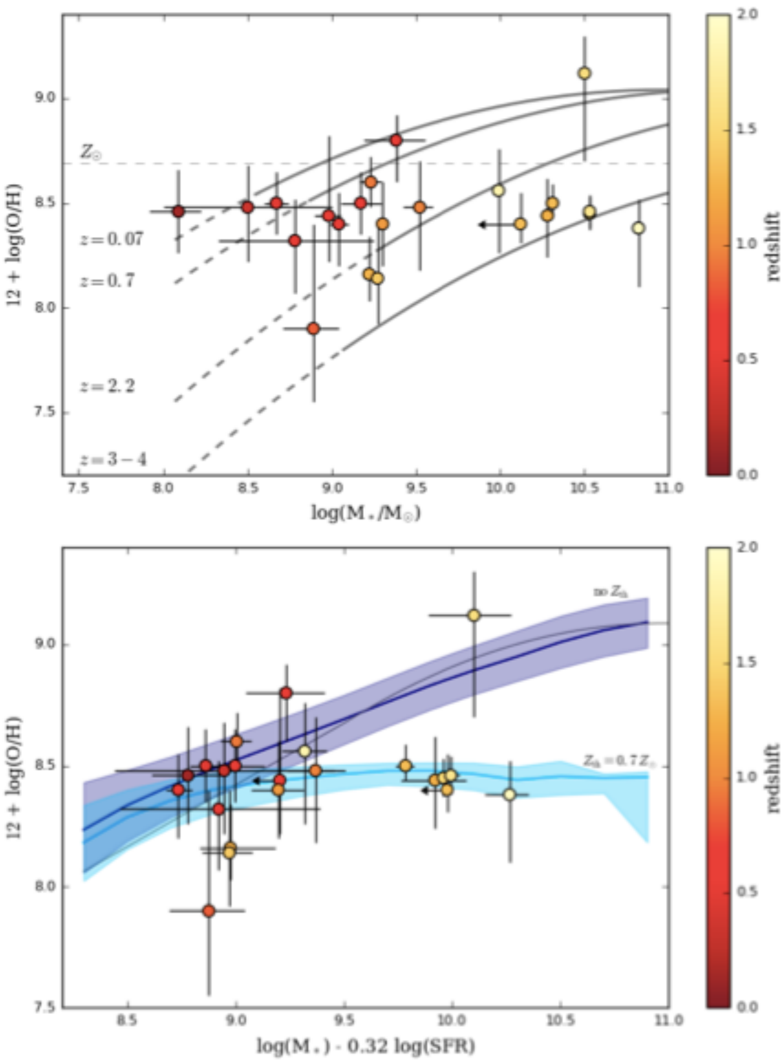
redshift distribution comparison from Perley+ (2016)



Perley+ (2016): Swift GRB Host Galaxy Legacy Survey (SHOALS, 119 galaxies)

- only Swift LGRB detections, prompt XRT localization
- low Galactic foreground extinction, no foreground objects
- bright in fluence Swift 50-150 keV BAT band

slight observed progenitor metallicity bias



stellar mass Mstar vs. metallicity relation for BAT6 GRB hosts with VLT-derived nebular O/H z< 2 (color coded with redshift, z)

for a given Mstar clear trend with decreasing O/H with increasing z

lower panel shows (blue region, grey line) predictions of the "Fundamental Metallicity Relation" (Mannucci+ 2010, 2011, Campisi+ 2011)

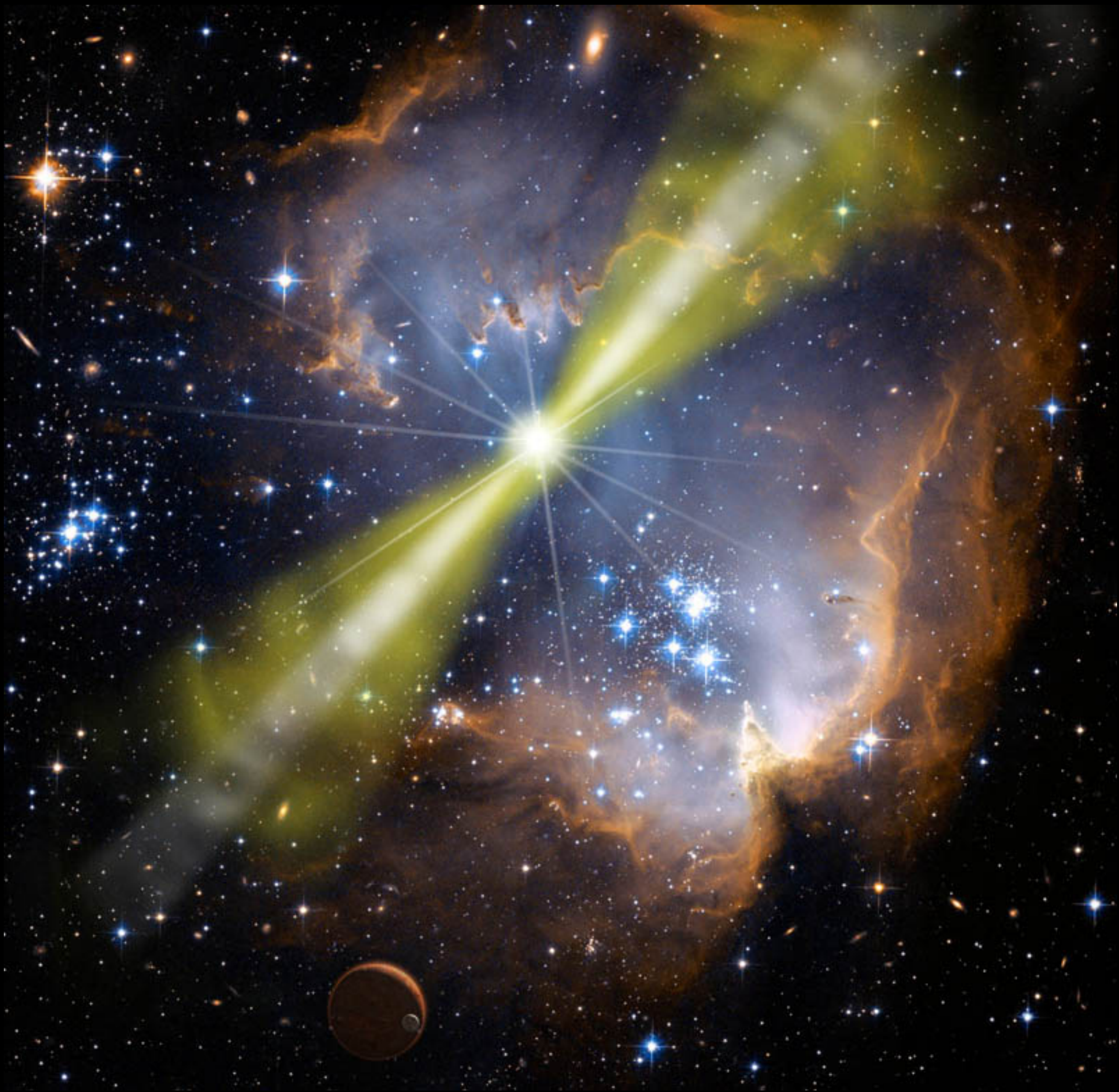
cyan region shows models taking into account a suppression of GRBs above (best-fit) metallicity threshold $Z/Z_{\odot}>0.73$

Vergani+ (2017) BAT6 hosts

see also Kocevski & West 2009, 2011, Graham & Fruchter 2013, Boissier+ 2013, Trenti+ 2013, 2015, Vergani+ 2015, Japelj+ 2016, Palmerio+ 2019

why would we expect a metallicity bias?

NASA/Swift artist impression of naked-eye GRB080319B



rotating single-star progenitors would not form a GRB unless sufficient angular momentum (necessary to launch collapsar jets). Aided by metallicity dependence of massive stellar winds but the metallicity thresholds are expected to be lower ≈ 0.1 $Z/Z_{\odot}$ (Woosley 1993, MacFadyen & Woosley 1999, Woosley & Bloom 2006)

possibly binary metallicity-independent channels could overcome, at least partially, the metallicity aversion (see e.g., Trenti+ 2013, 2015) and raise the threshold metallicity

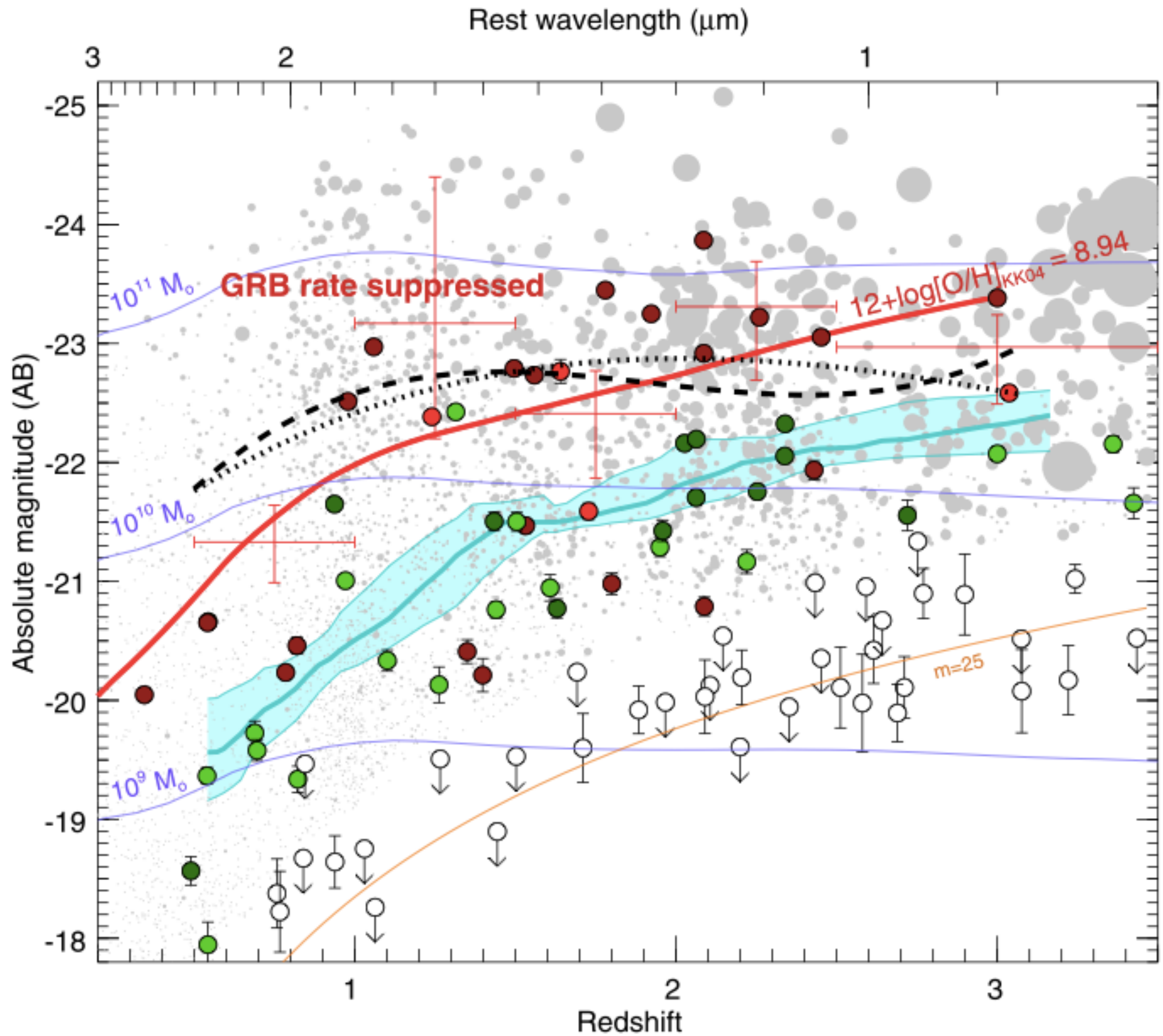
metallicity bias also perceived as mass bias

SHOALS (Perley+ 2016a, 2016b)

only complete part shown in plot, compared to the MODS survey (Kajisawa+ 2011) with similar limiting magnitudes (IRAC vs. Ks)

mass comparison weighted by SFR since GRB host populations are SFR weighted

note lack of high Mstar GRB hosts relative to comparison sample

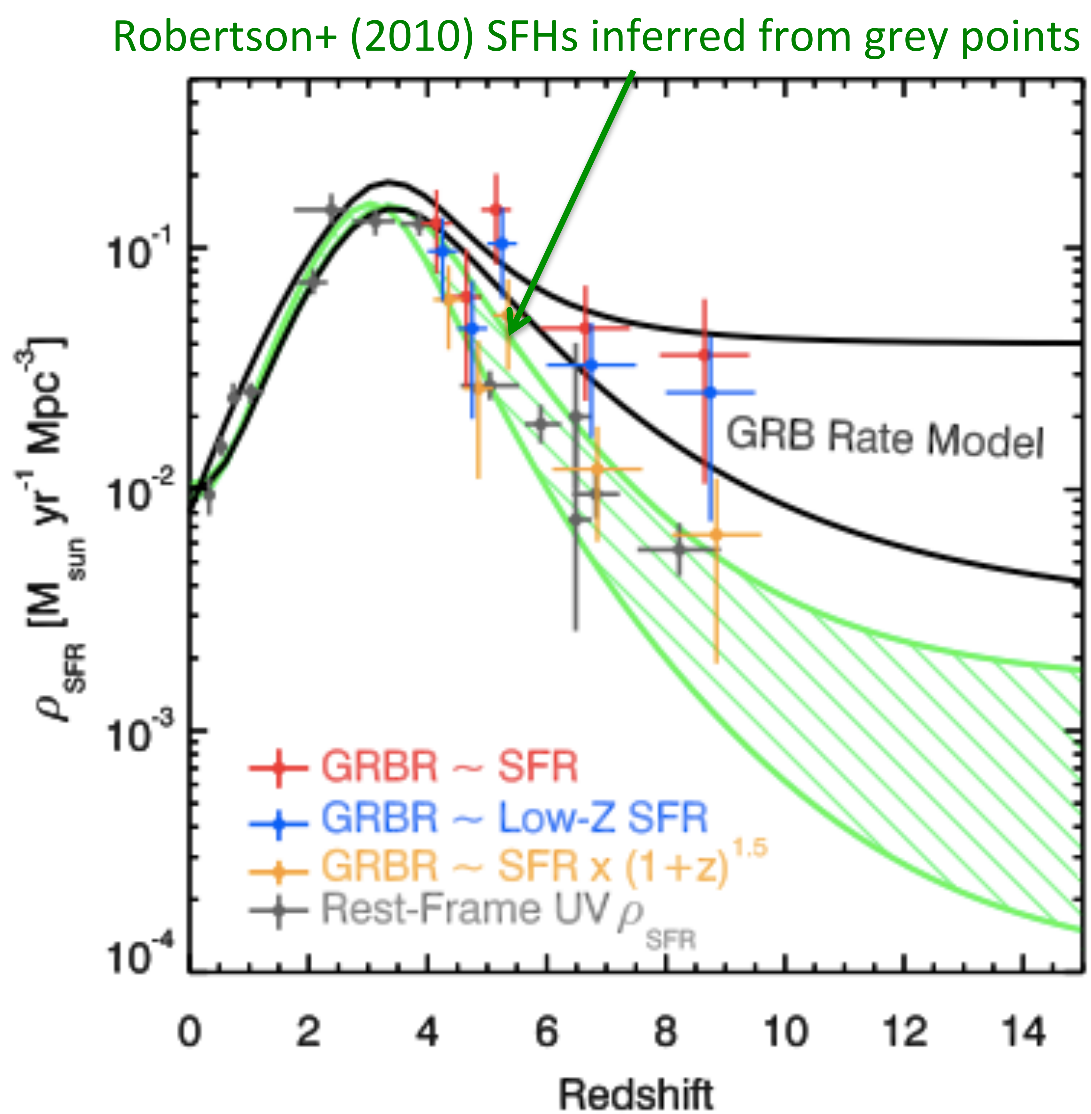


Perley+ (2016a, b)

but GRBs can trace cosmic SFR density...

using 112 GRBs above a fixed luminosity limit, and taking into account various restrictions on GRB rates (GRBR) including a metallicity restriction

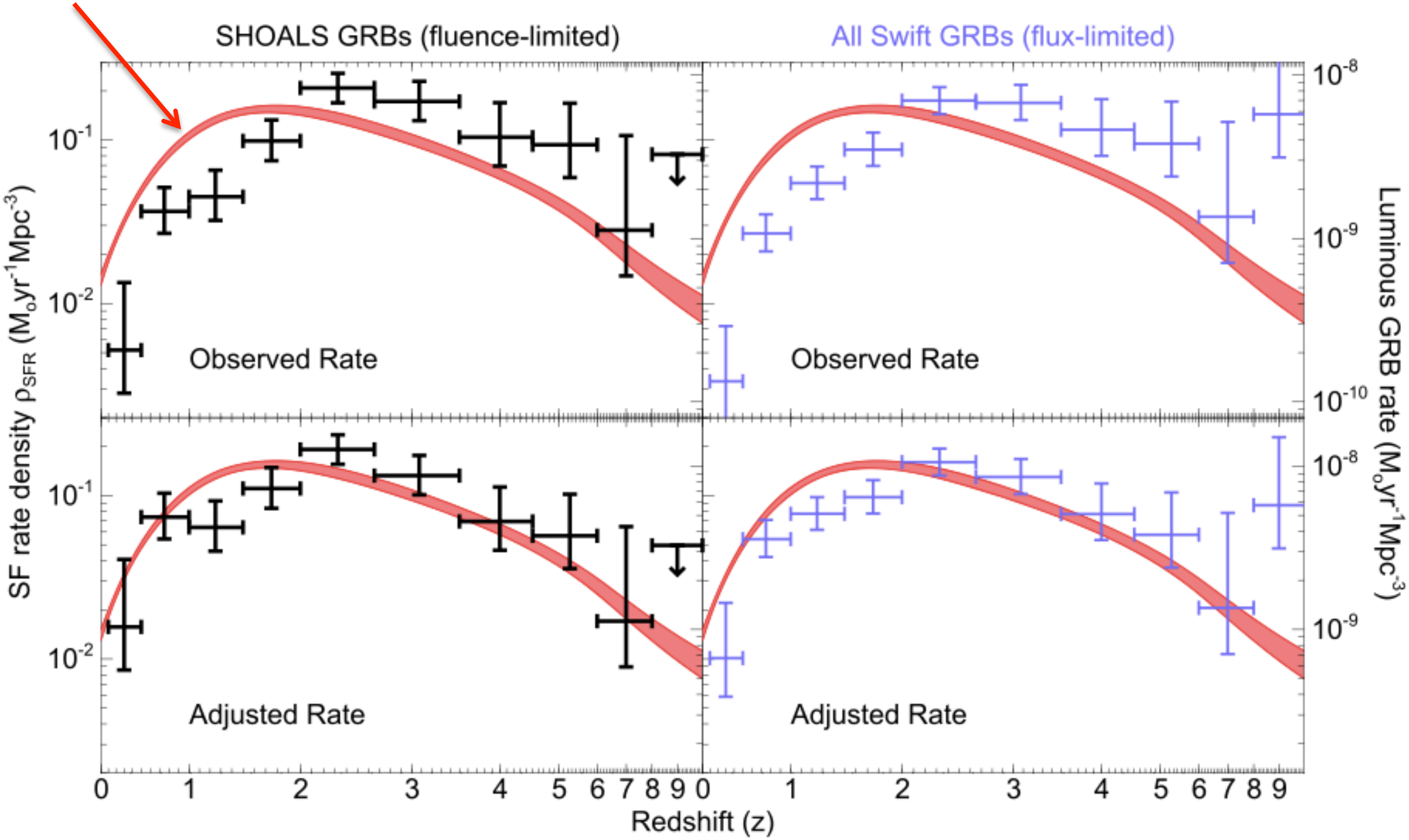
conclusions are that (in agreement with later work) only a modest metallicity threshold is required



Robertson & Ellis (2012)

...and GRBs do trace cosmic SFR density

Madau & Dickinson (2014)

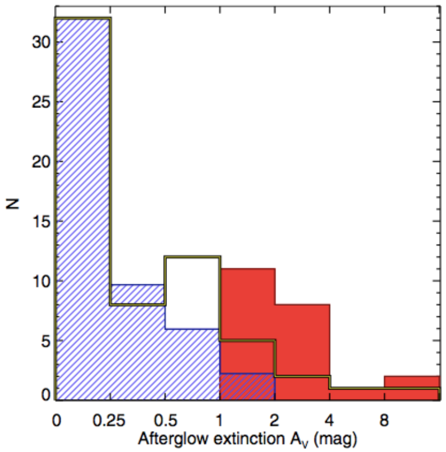


GRB cosmic rate density compared to SFR (Perley+ 2016b)

lower panel shows GRB rates **corrected based on the observed tendency for GRBs to avoid luminous (massive) galaxies at low z**

interstellar medium of GRB hosts (GRBHs): dust

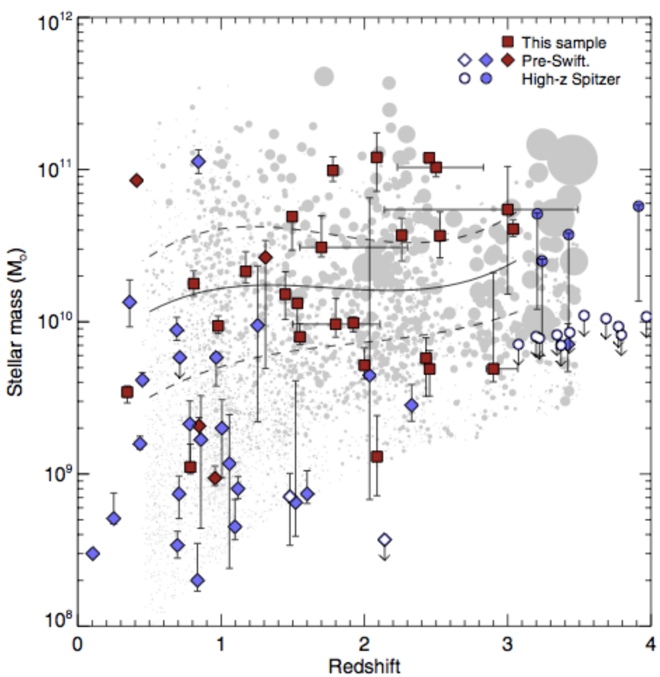
“dark” GRBs: why do we care about dust?



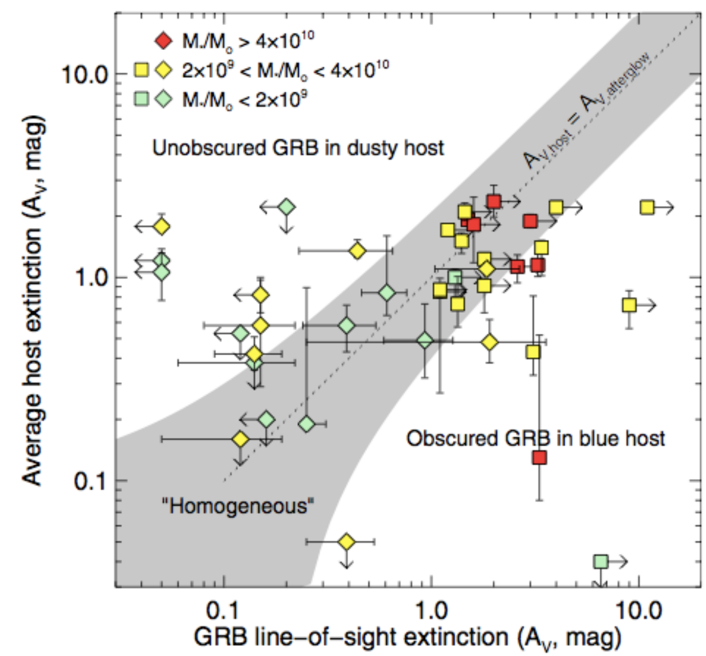
25-40% GRBs have very faint undetectable optical (or near-infrared) afterglows (Fynbo+ 2009, Greiner+ 2011)

formerly measured against fireball model predictions for X-ray flux (β_{ox})

dust extinction is one reason that afterglows are “dark”, others include intrinsic faintness and/or high redshift

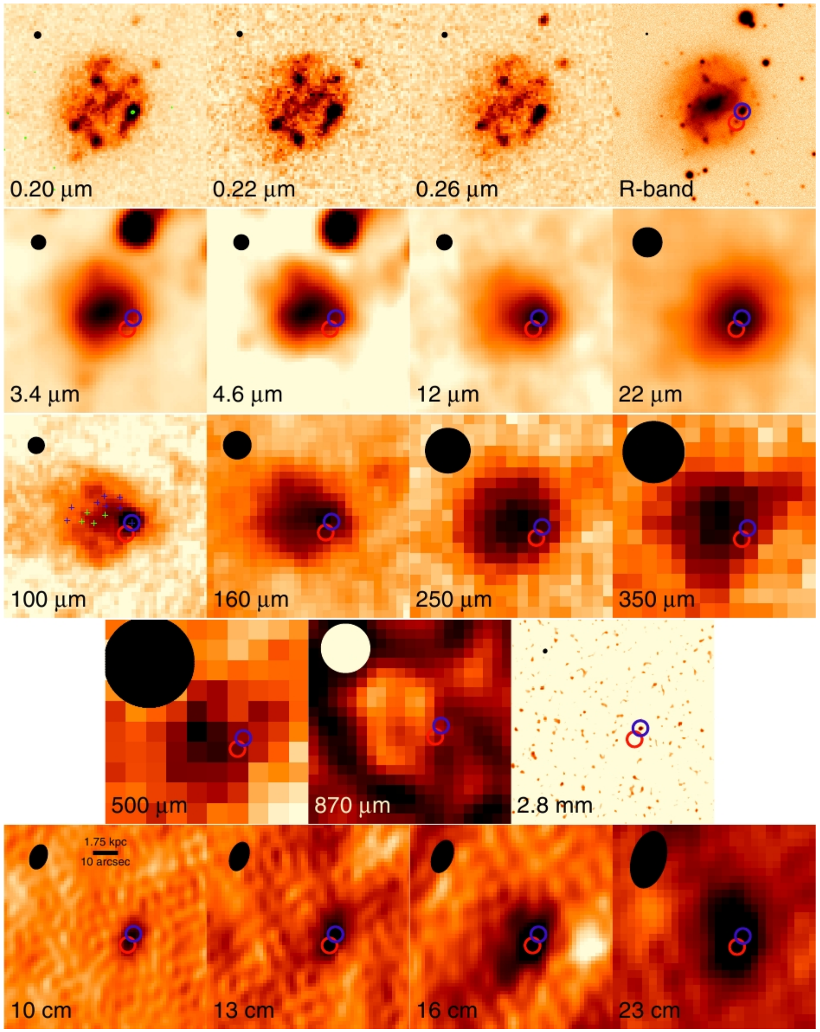


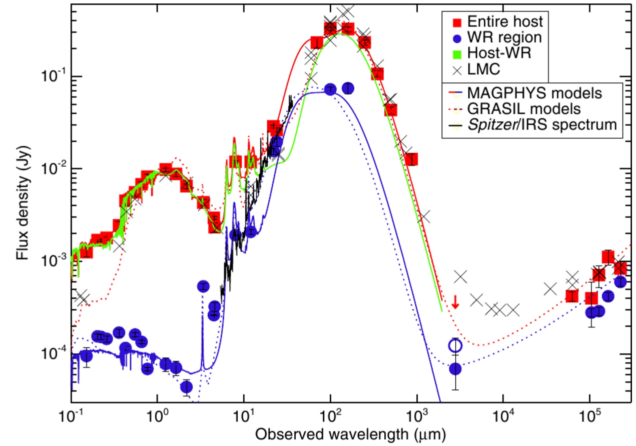
but dust-obscured galaxies tend to be more massive at all redshifts, and obscuration seems to be governed by mass



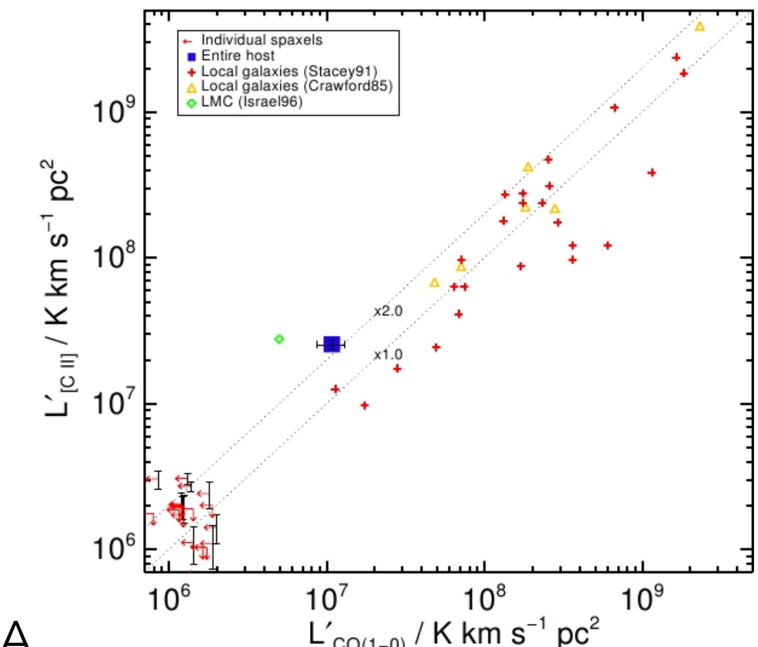
(Perley+ 2013)

the nearest GRBH with *Herschel*, GRB980425



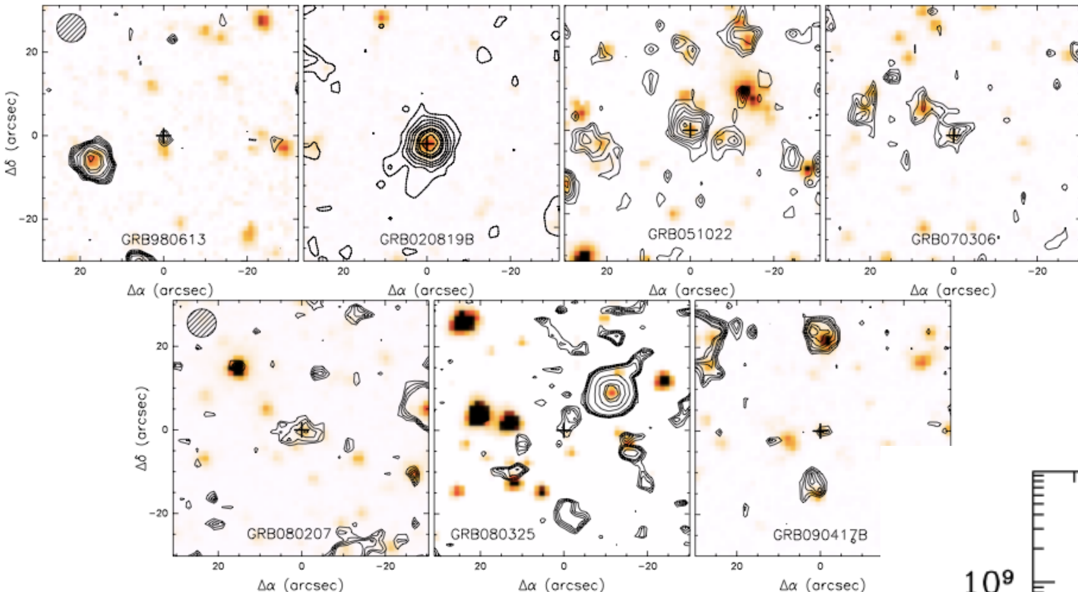


at z=0.00825, GRB980425 (and SN1998bw) in barred spiral galaxy ESO 184-G82 is the closest known LGRB



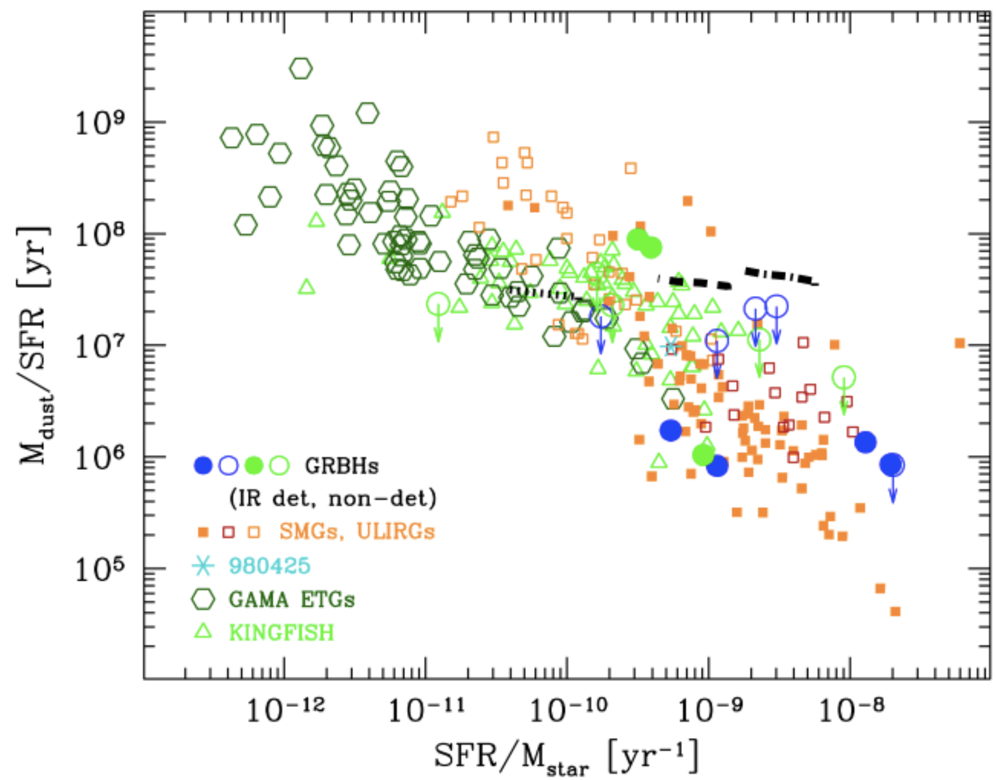
detected with Herschel (in 5 bands), APEX, ALMA, ATCA: complete SED and [CII] at 158µm with PACS

dust emission in GRBH hosts with *Herschel*



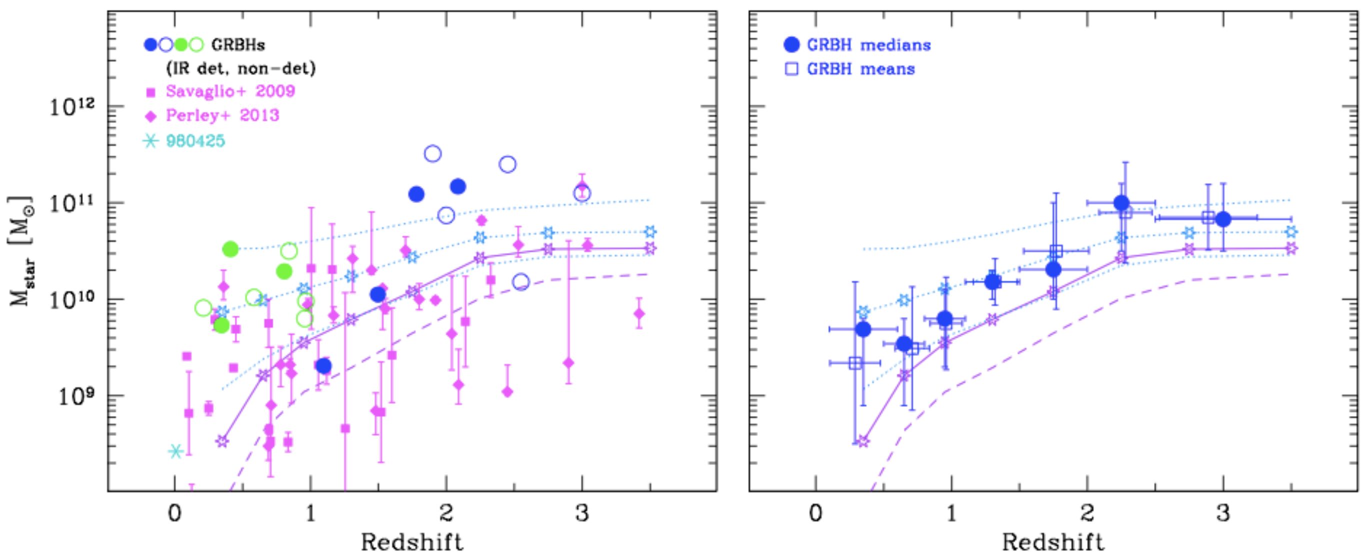
Herschel (PACS) detected 7 of 17 GRB hosts observed (and 1 was the spiral galaxy misinterpreted as the host of GRB020819B, see Perley+ 2017a)

dust mass ratios with SFR consistent with "normal" star-forming galaxies at similar redshifts (see da Cunha+ 2010)



(*Hunt+ 2014*)

these GRBH hosts are massive, consistent with COSMOS populations



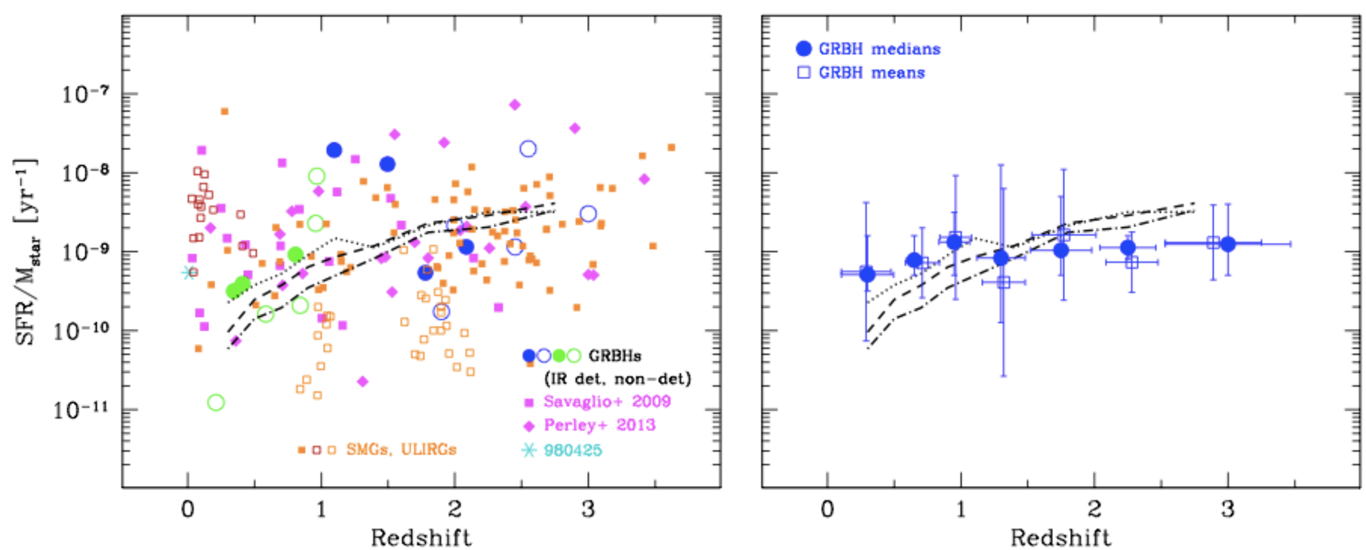
median stellar masses vs redshift: COSMOS (Ilbert+ 2013) purple stars, weighted by SFR blue stars

GRB hosts as blue dots for z>1 or green dots for z≤1

(Hunt+ 2014)

but *Herschel* sample 80% dark bursts, so possibly selection effect

high specific SFR (SFR/Mstar) for z<1, but lower than COSMOS populations for z>1

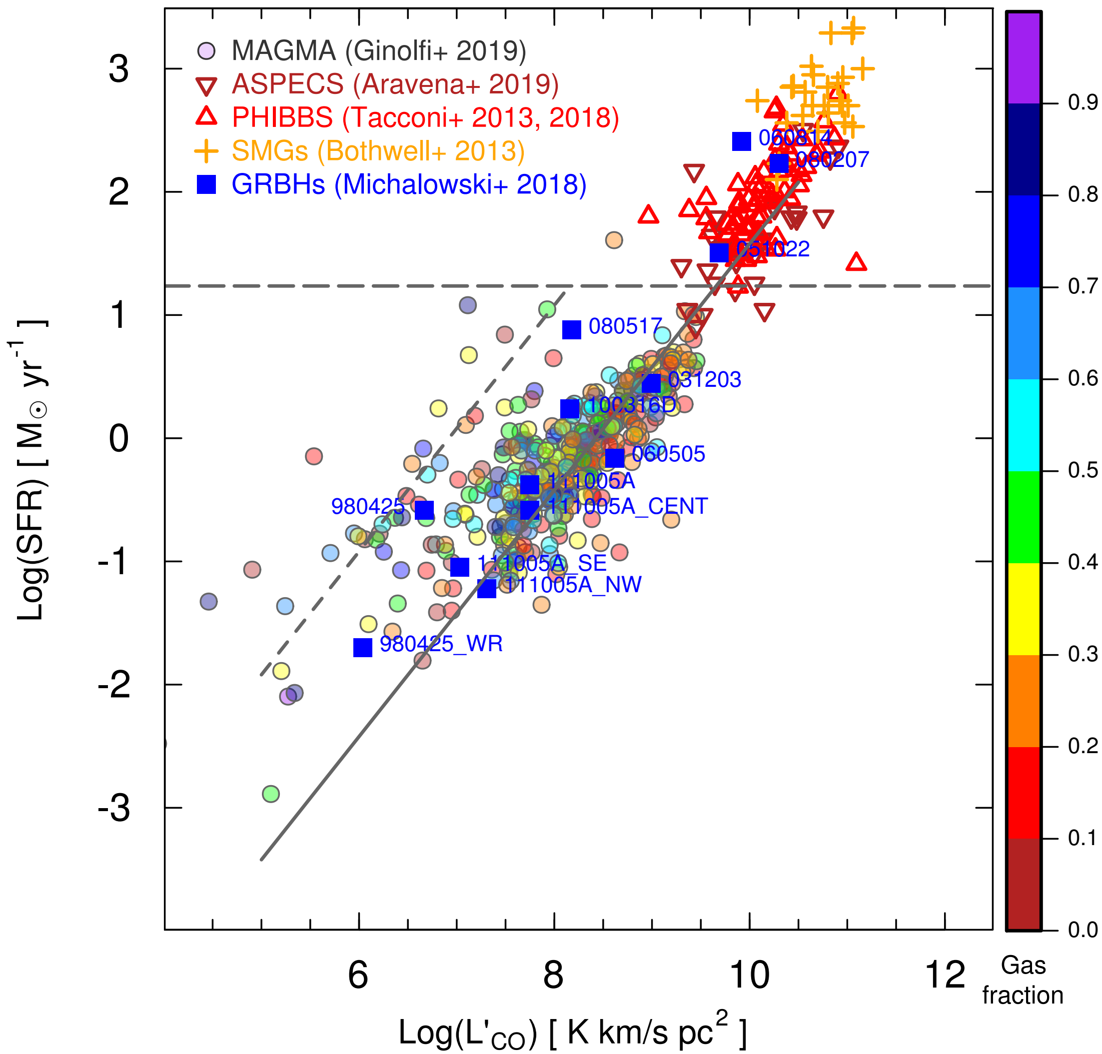


interstellar medium of GRBHs:
cool gas

measure molecular gas of GRBHs with APEX

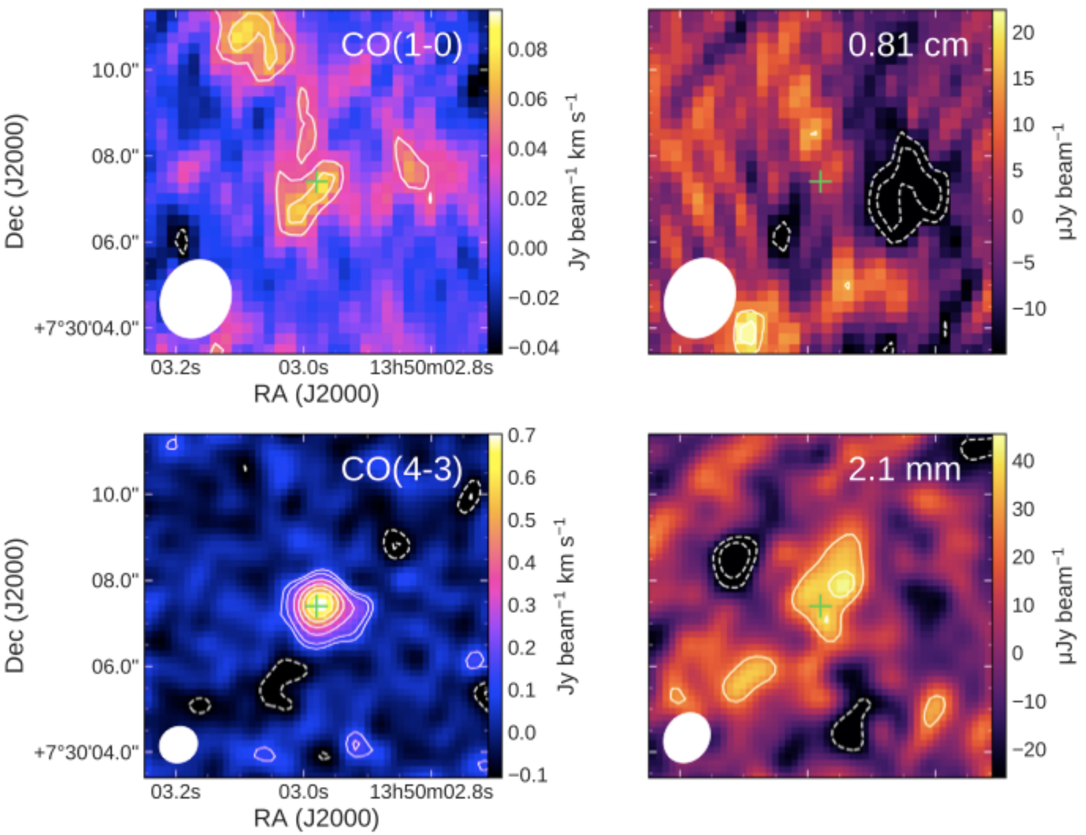
CO(1-0) luminosity vs SFR of GRBHs is typical of "normal" field galaxies in the new z ≈ 0 compilation (Metallicity and Gas for Mass Assembly, MAGMA) by Ginolfi+ (2019) with 390 galaxies having HI and CO detections

the two regressions correspond to Gao & Solomon (2004) for star-forming galaxies and ultra-luminous infrared galaxies (ULIRGs) and the leftmost one from Hunt+ (2014) for metal-poor dwarf galaxies ($Z \leq$ 0.2-0.3 $Z_\odot$)

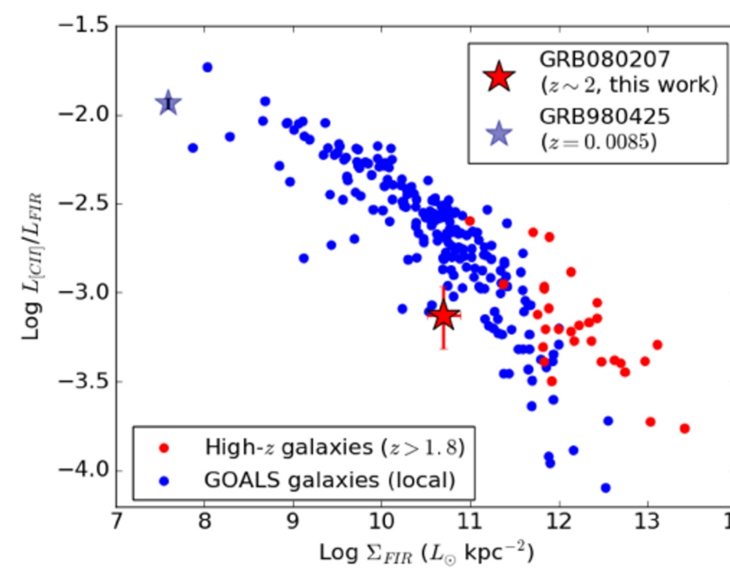


GRBH data from Michalowski+ (2018)

GRB080207: dark GRB with massive host at z ≈ 2



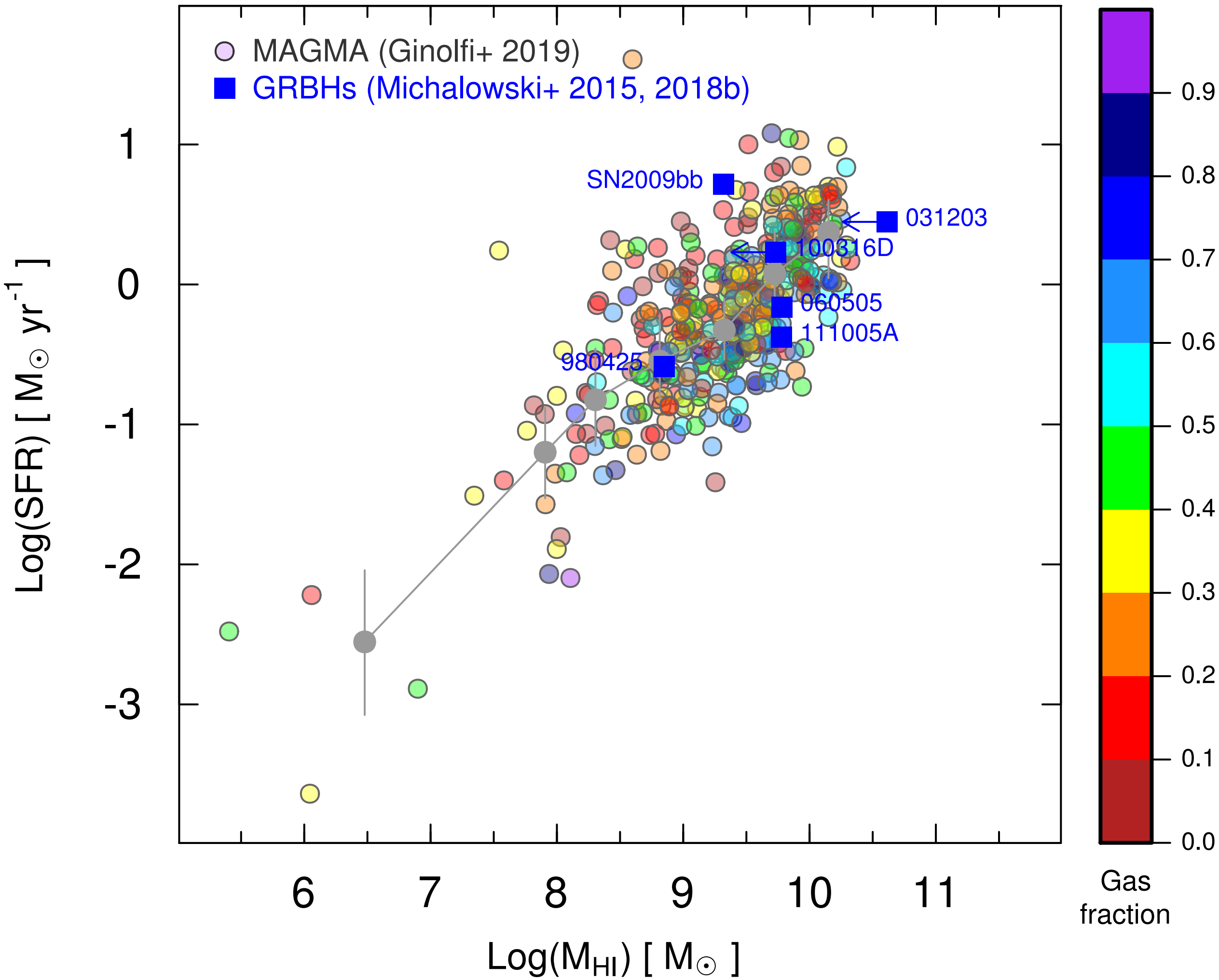
ALMA and VLA observations of CO(4-3) and CO(1-0) transitions suggests that disk kinematics, source size, molecular depletion times, gas fractions, gas-to-dust ratios are all similar to main-sequence galaxies at z ≈ 2



[CII] ratio with FIR of GRBH 080207 is one of the lowest ([CII] ("deficit") at similar redshifts, probably due to an excessively high volume density $n_H \approx 10^5 - 10^6$ cm^{-3}

(taken from Hatsukade+ 2019,Hashimoto+ 2019; see also Arabsalmani+ 2018, Svensson+ 2012, Hunt+ 2011)

measure atomic gas in GRBHs with JVLA, ATCA

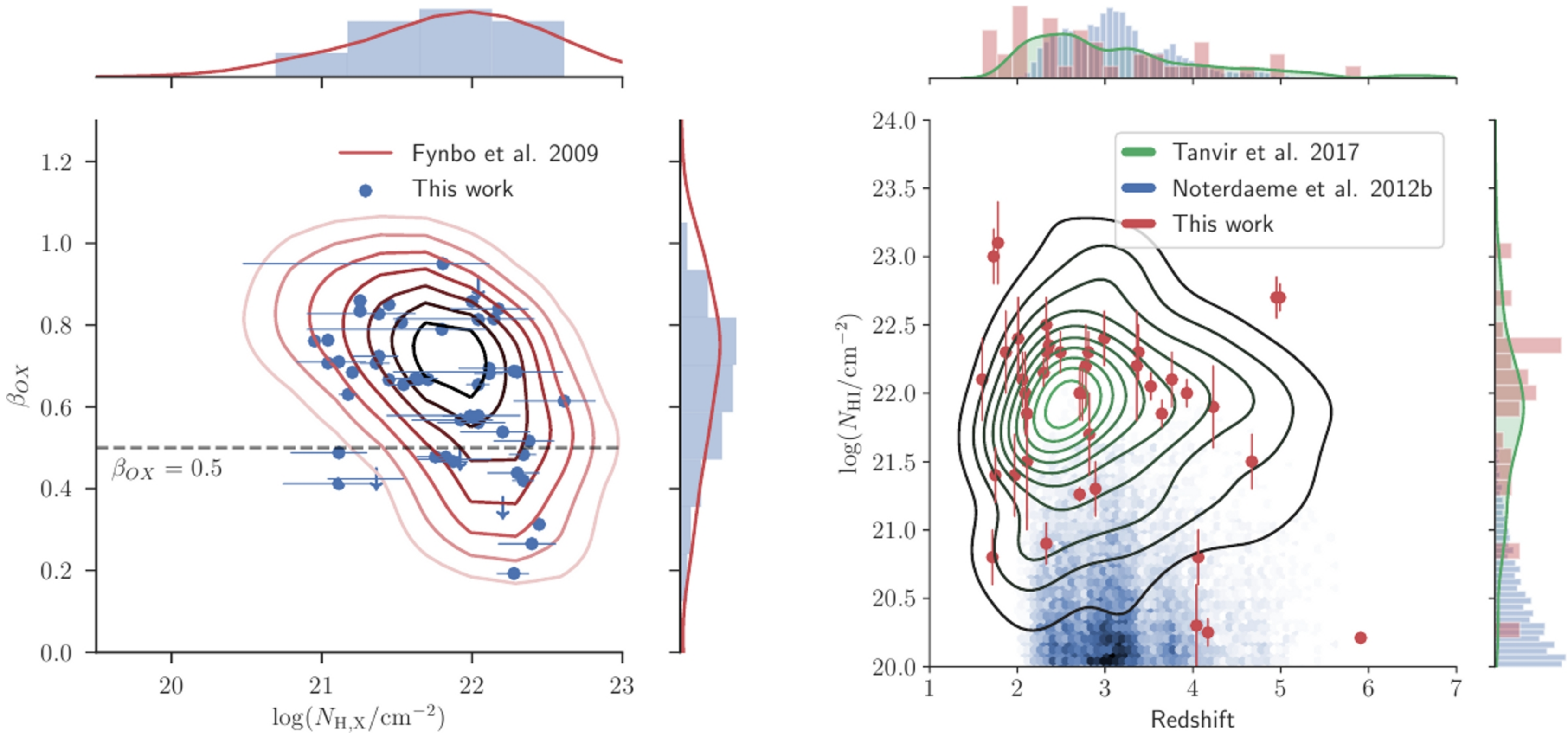


HI mass vs SFR of GRBHs is also consistent with "normal" field galaxies in MAGMA

not as clear a connection between HI mass and SFR, as with L_{CO} (and H_2 mass)

GRBH data from Michalowski+ (2015, 2018b)

GRBs physical properties from absorption lines in afterglows



HI column NHI larger for flatter β_{ox} and GRB afterglows effective at finding larger NHI

physical properties include dust extinction curves, dust-to-metals ratios, molecular content, ISM metallicities and temperatures, … (several 100s of references)

taken from XShooter GRB Legacy Sample (Selsing+ 2019)

lessons for multi-messenger astronomy

- ✓ transient events require prompt localization
- ✓ prompt multi-wavelength follow-up also fundamental for GRBs in order to identify afterglow, characterize its properties
- ✓ to generalize to host population properties, need to understand selection bias of transients with large "unbiased" samples (probably a metallicity aversion at work for GRBs at $z \leq 1$)
- ✓ beware of false associations, even though chance positional coincidence statistically "unlikely"
- ✓ important to interpret electromagnetic signatures also in the context of other tracers such as neutrinos and GWs