A TOUGH job: The host galaxies of long GRBs

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GRB hosts as a class of high-redshift galaxies

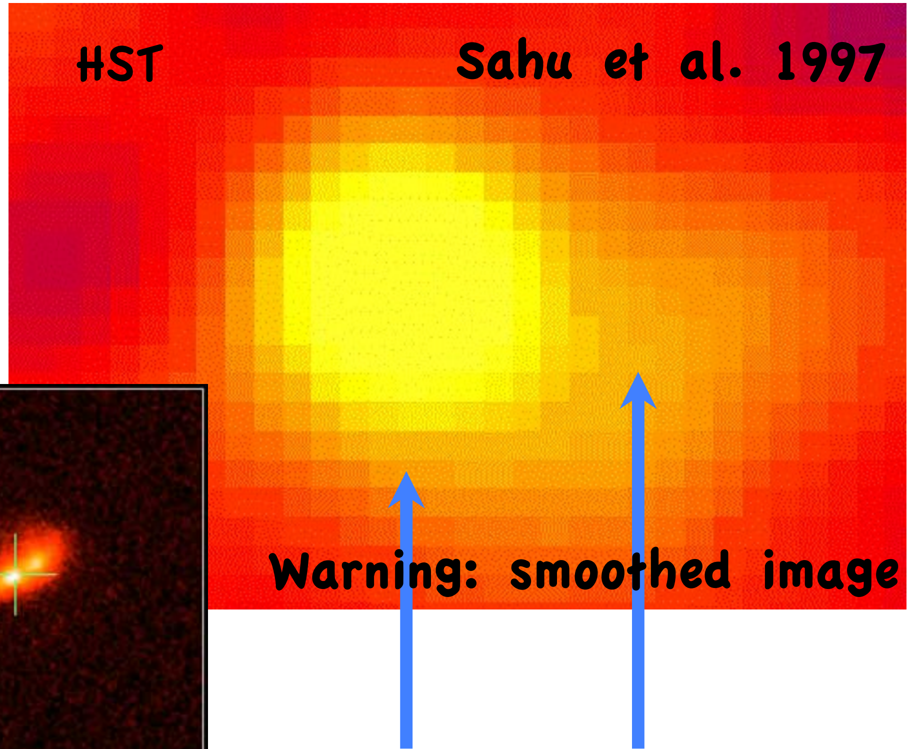
- GRBs follow ongoing star formation (SN/GRB connection)
- They are bright and detected at all redshifts
- They select galaxies independently of their flux
- Complementary study: emission and absorption

GRB hosts form a

population of high-redshift star-forming galaxies
treasure trove for high-z SFR studies

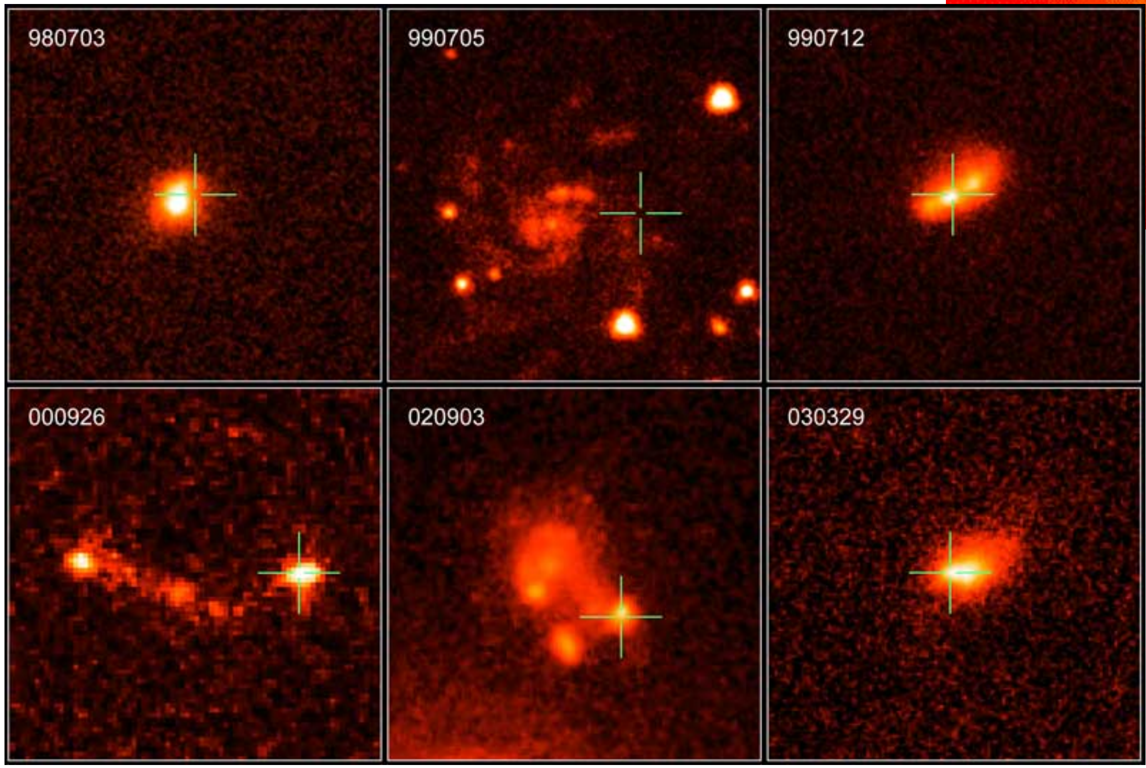
GRB hosts are ubiquitous

GRBs explode within
star-forming galaxies



Afterglow host

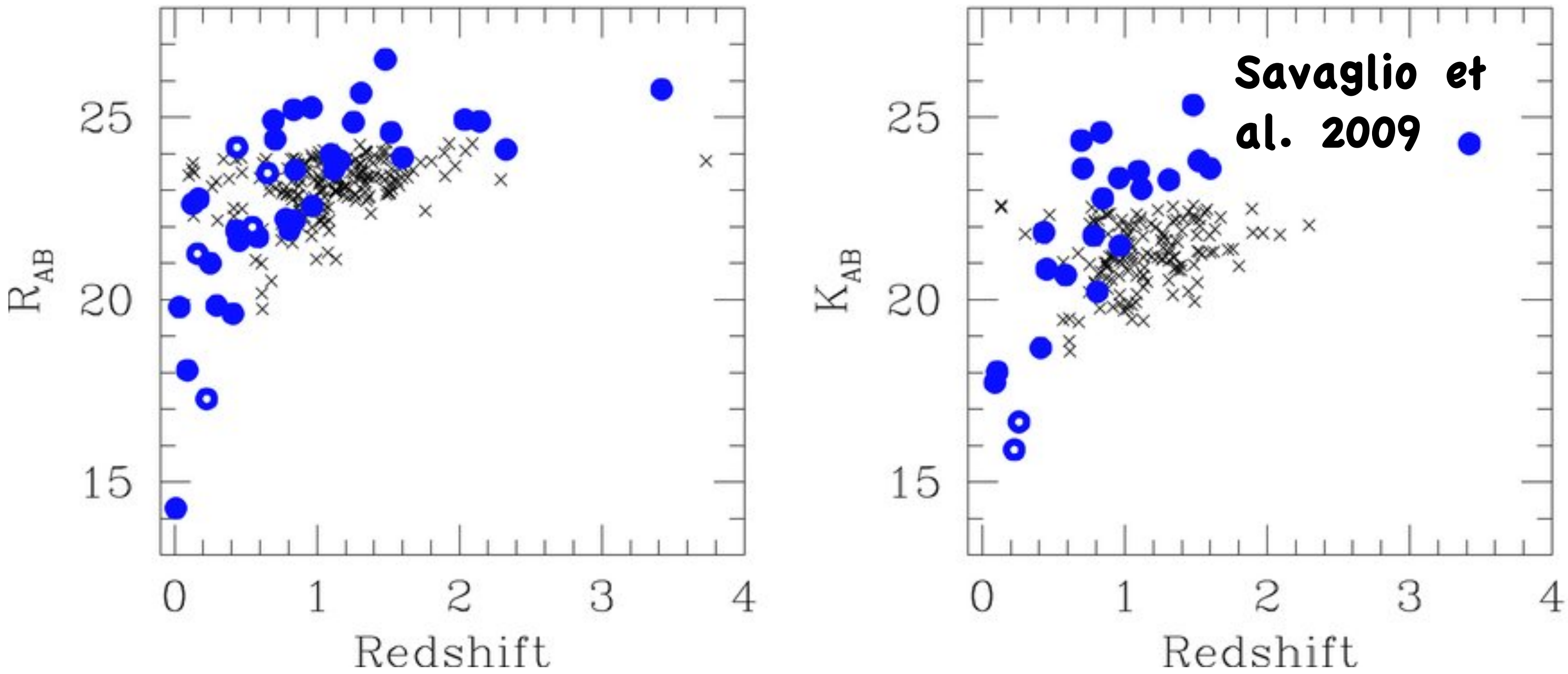
Fruchter et al. 2006



GRB hosts are
ubiquitous

Basic GRB host properties

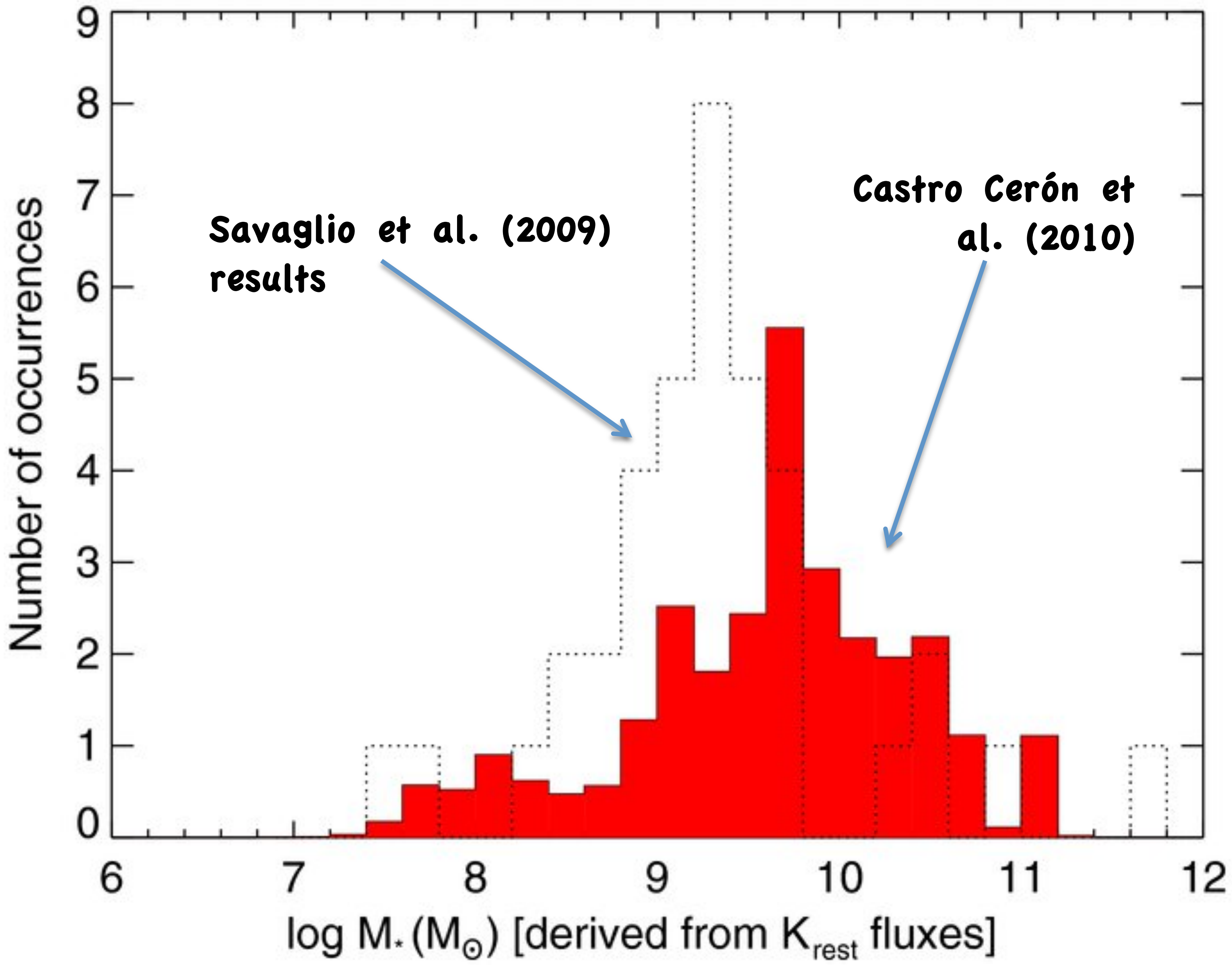
Several works have studied different host samples



See also Le Floc'h et al. 2003; Fruchter et al. 2006; Wainwright et al. 2007 etc.

Hosts are often underluminous especially in the NIR

GRB host masses



Very biased samples

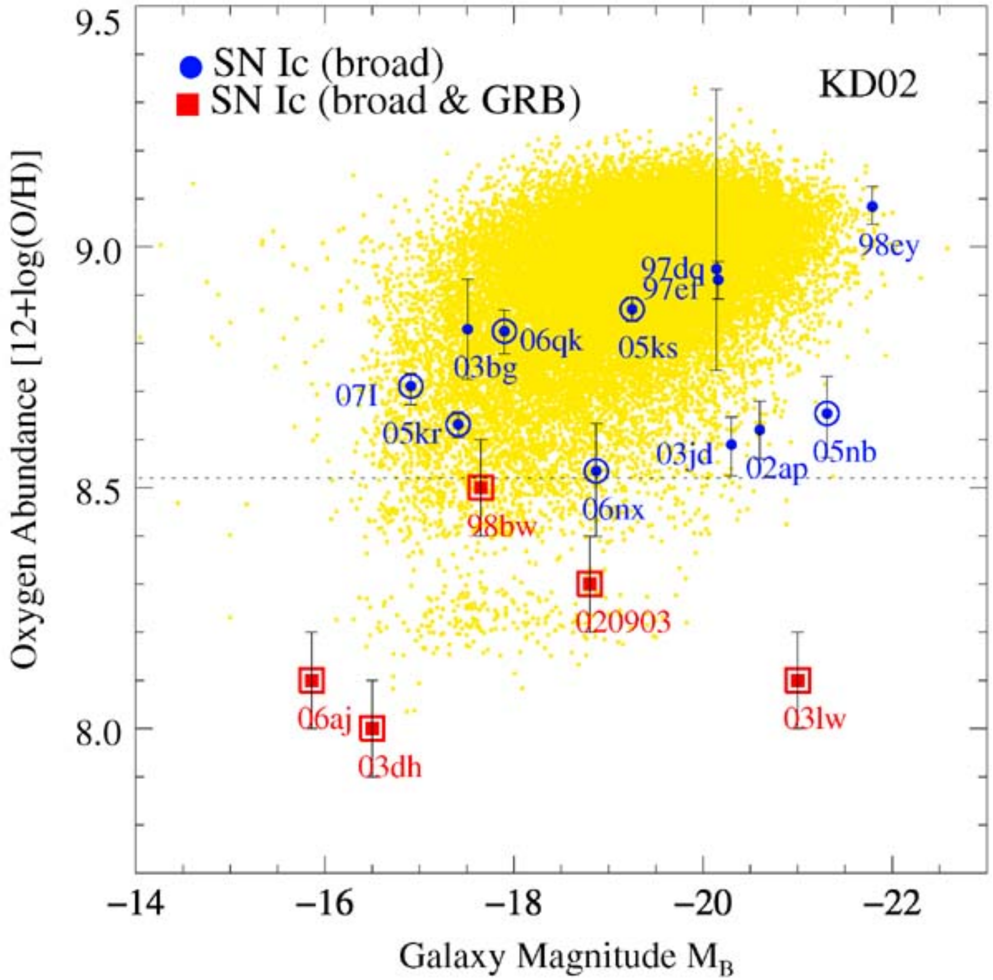
Spitzer legacy survey in progress to get ~100 host masses

See also Perley et al. 2013

GRB host metallicities

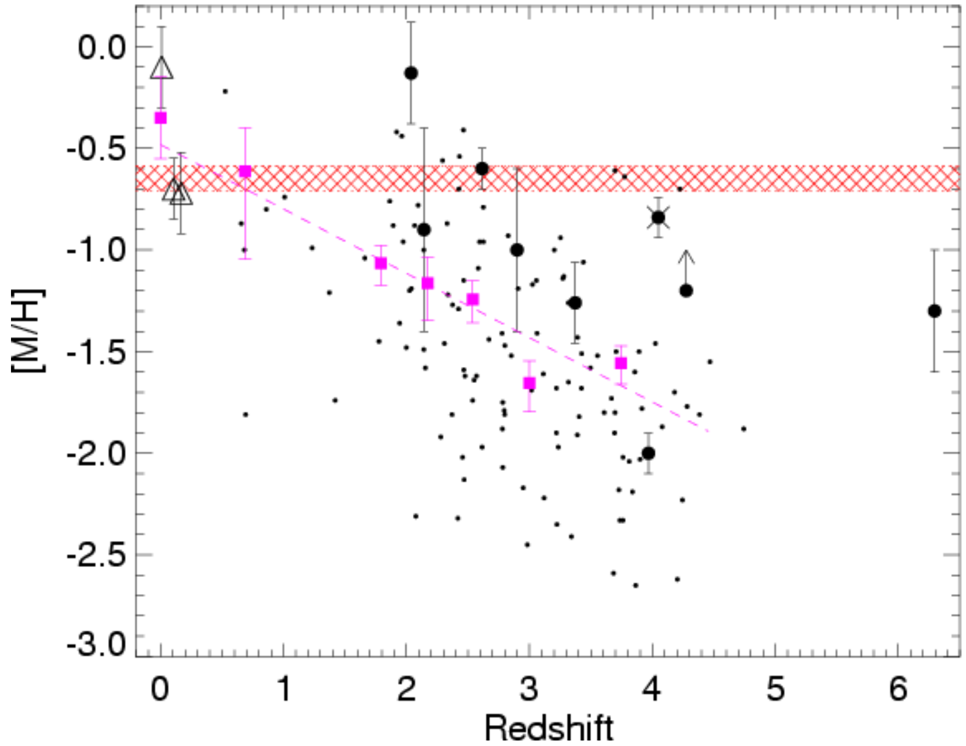
Low redshift, integrated, emission

e.g. Modjaz et al. (2008)



High redshift, los, absorption

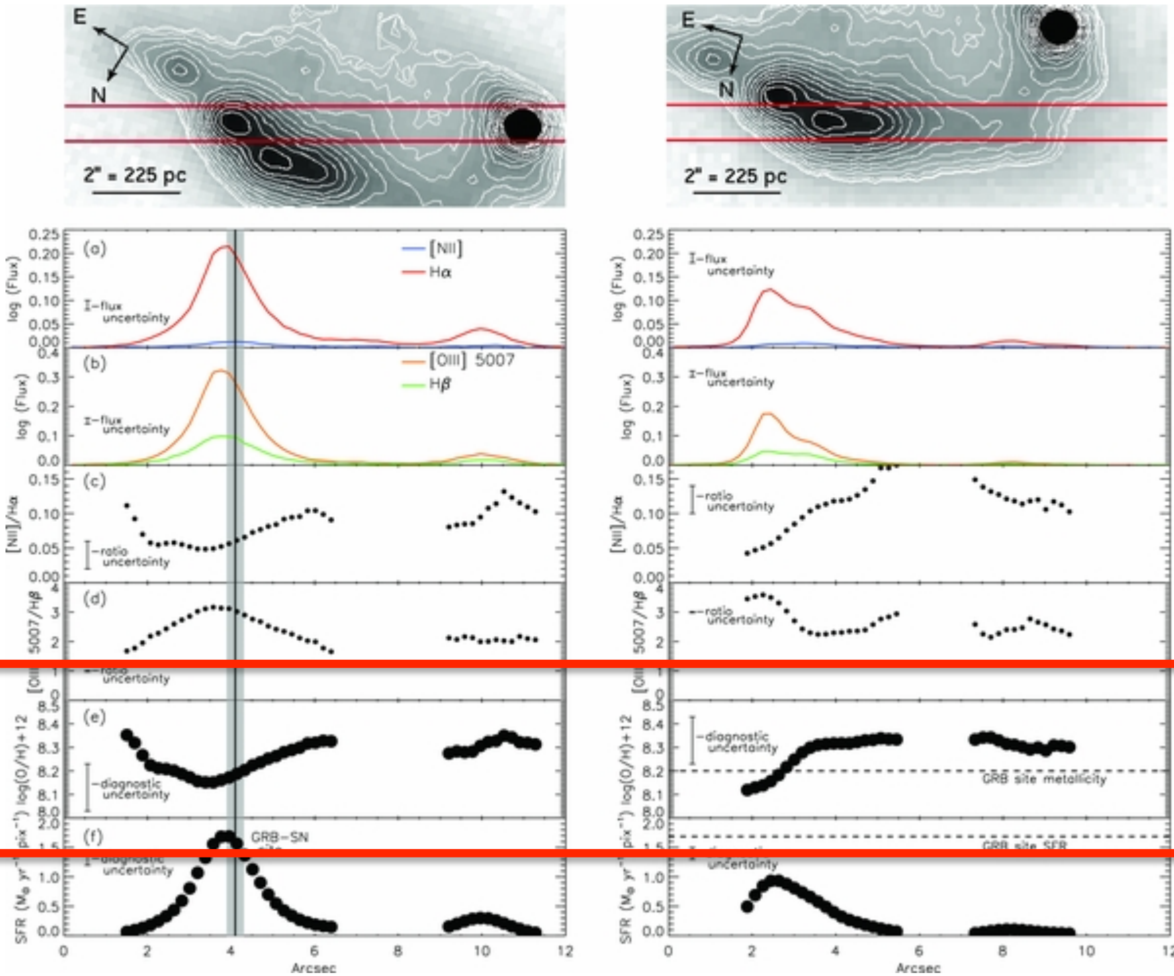
e.g. Fynbo et al. (2006)



See also Stanek et al. (2006), Levesque et al. (2010) John Graham's talk

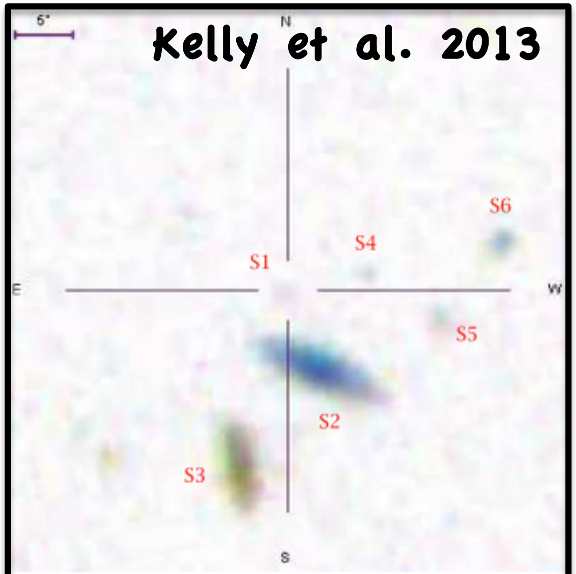
Gradients?

GRB 100316D @ z = 0.059



The GRB region has the lowest metallicity in the host system

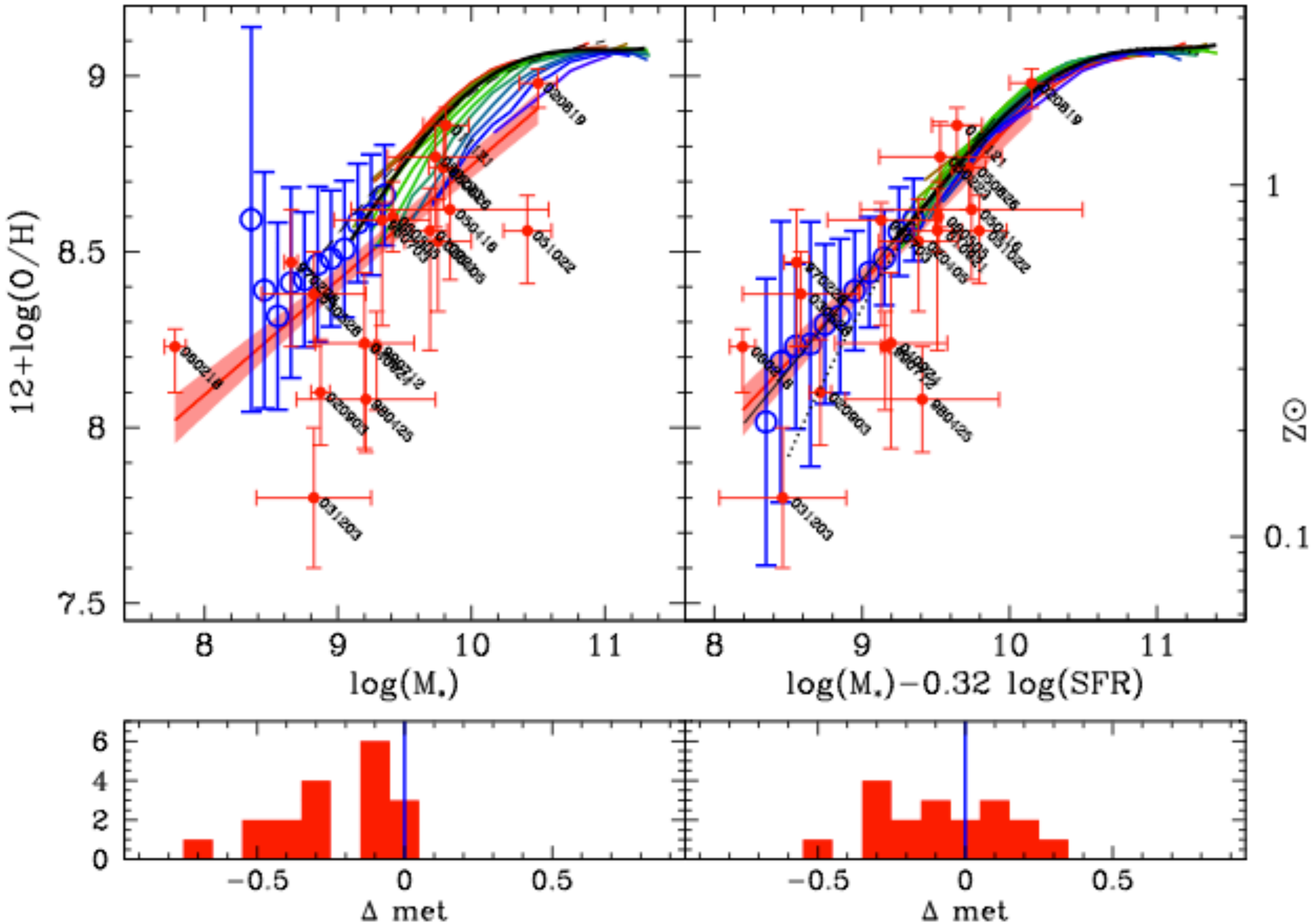
Kelly et al. 2013



GRB 130702A
z=0.145
Separation 19 kpc
2" @ z=2

Levesque et al. (2010)
See also Thöne et al., Christensen et al.

Fundamental metallicity relation



Mannucci et al. (2010, 2011), Lara-López et al. (2010)

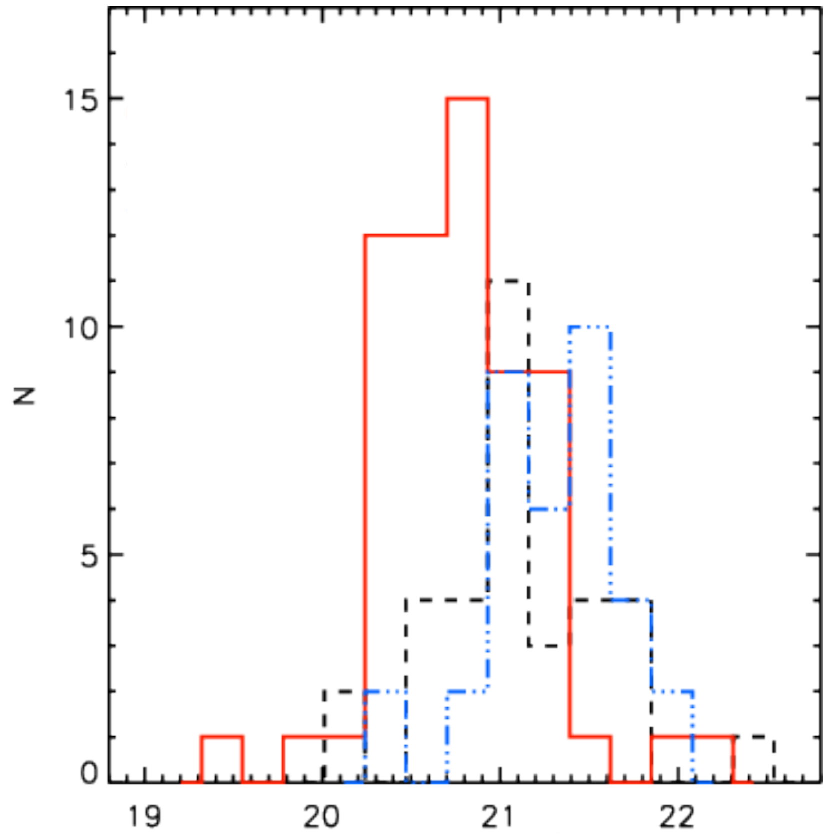
But see talks by: Sebastián Sánchez and John Graham and Susanna Vergani

The role of selection effects

We know preferentially optically detected GRBs and ~50% GRBs have no optical (and no *z*!)

Dust can suppress optical emission, hence optically-based studies provide a biased view (e.g, against high metallicities)

Fynbo et al. 2009



Log metal column density

Example: N_H distribution

Red: with redshift
Blue: no afterglow

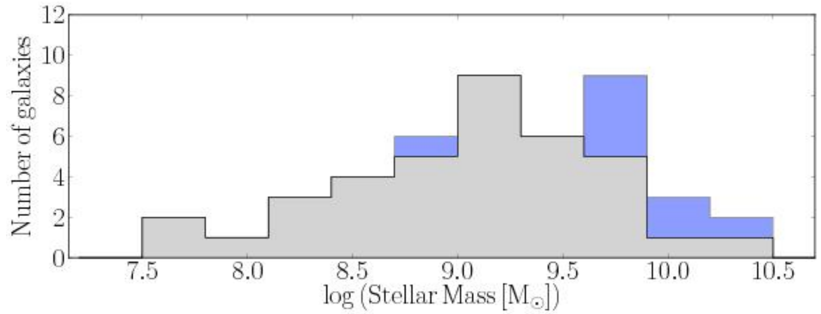
See also Melandri et al. 2012, Campana et al. 2012

Dark GRBs & evolved hosts

For dark GRBs we can find more evolved (older, more massive, enriched) systems

Prototypical example (Hunt et al. 2011; Svensson et al. 2012):
GRB 080207: SFR ~ 400 $M_\odot$ yr^{-1} $M \sim 10^{11}$ $M_\odot$ $A_V \sim 2$ mag

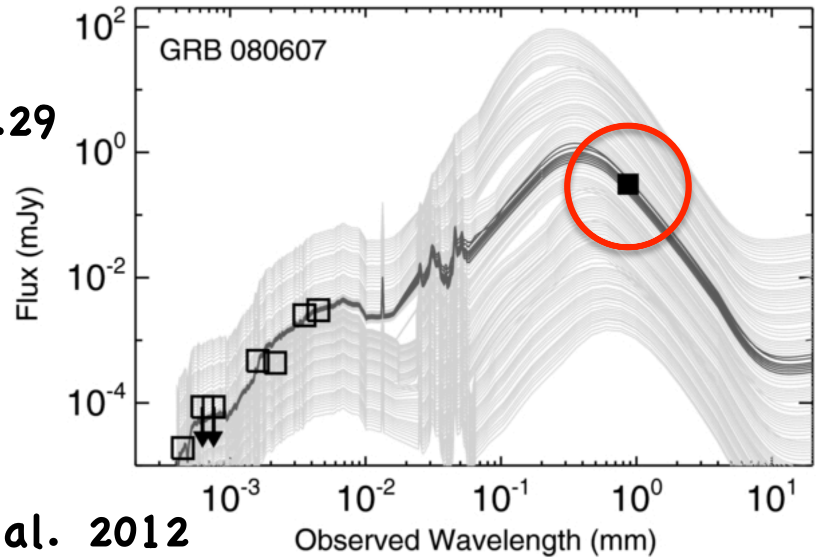
Krühler et al. (2011):
Dark GRB hosts from GROND sample:
redder, more luminous, more massive



ERO hosts: 020127, 030115, 080207, 120804A
(Levan et al.; Rossi et al.; Berger et al.)

Super-solar metallicity hosts
e.g. Savaglio et al. 2012, z=3.56, [Zn/H]=+0.29

First ALMA-detected GRB hosts
(GRB 080607 at z=3)
L_{IR} = a few x 10^{11} $L_\odot$
SFR ~ 50 $M_\odot$ yr^{-1}



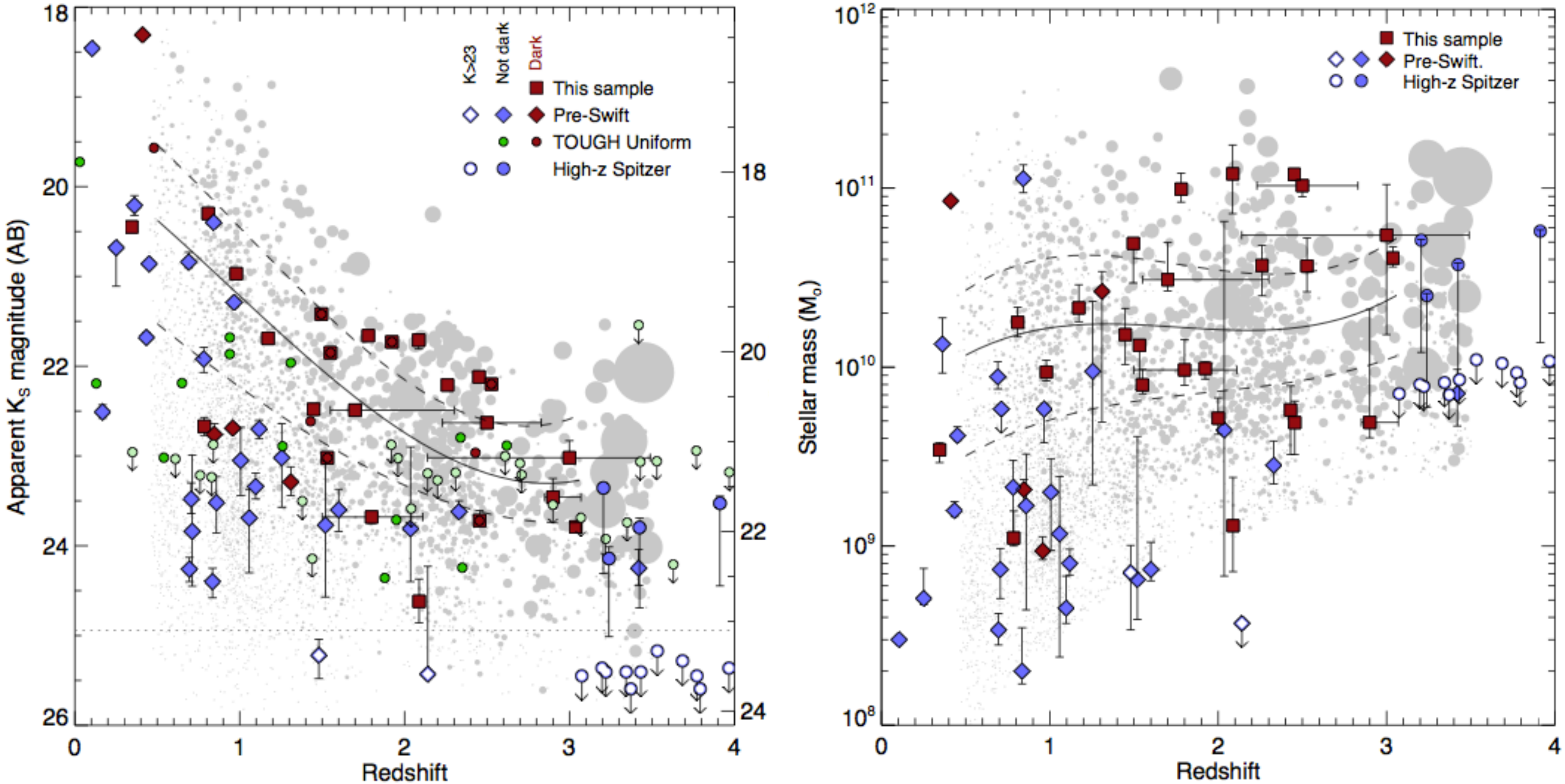
Wang et al. 2012

Dark GRB hosts

23 highly-obscured (A_V > 1 mag) GRBs, host studied including optical, NIR, MIR

Typical SFR and mass of GRB hosts is lower than of the typical SF galaxy

NON-DARK DARK field



Perley et al. 2013, Dan Perley's talk

The TOUGH program

X-ray selected sample of GRB host galaxies

The Optically Unbiased GRB Host (TOUGH) survey

We study the host galaxies where GRBs exploded with two aims:
- Retrieving the missing information for the GRBs (e.g., redshift)
- Study the galaxy properties per se

Study based on a VLT large program (PI Hjorth)
imaging + spectroscopy including X-shooter follow-up

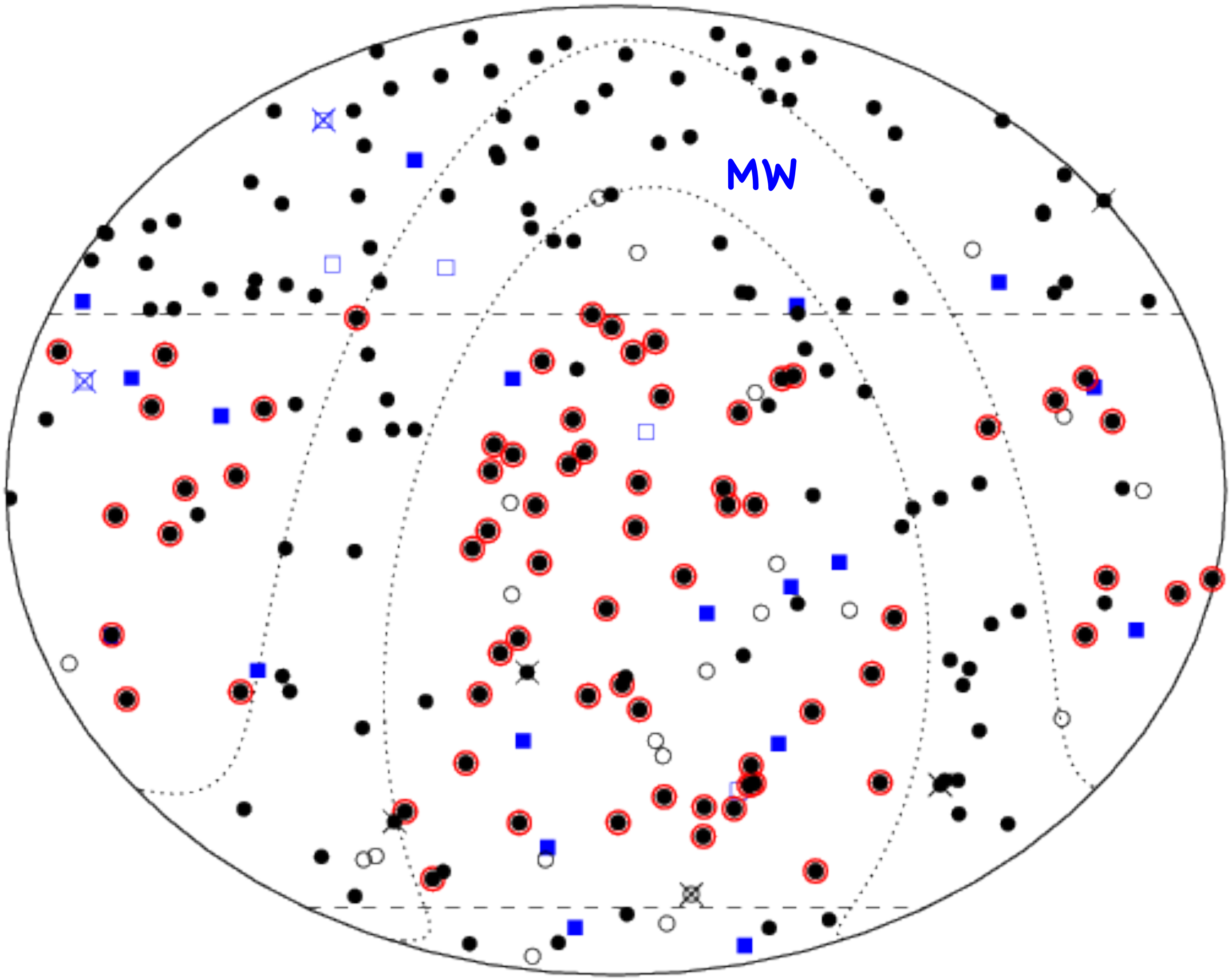
69 GRB host galaxies with $0.033 < z < 6.295$

6 core TOUGH papers + several in preparation

The TOUGH sample

TOUGH definition

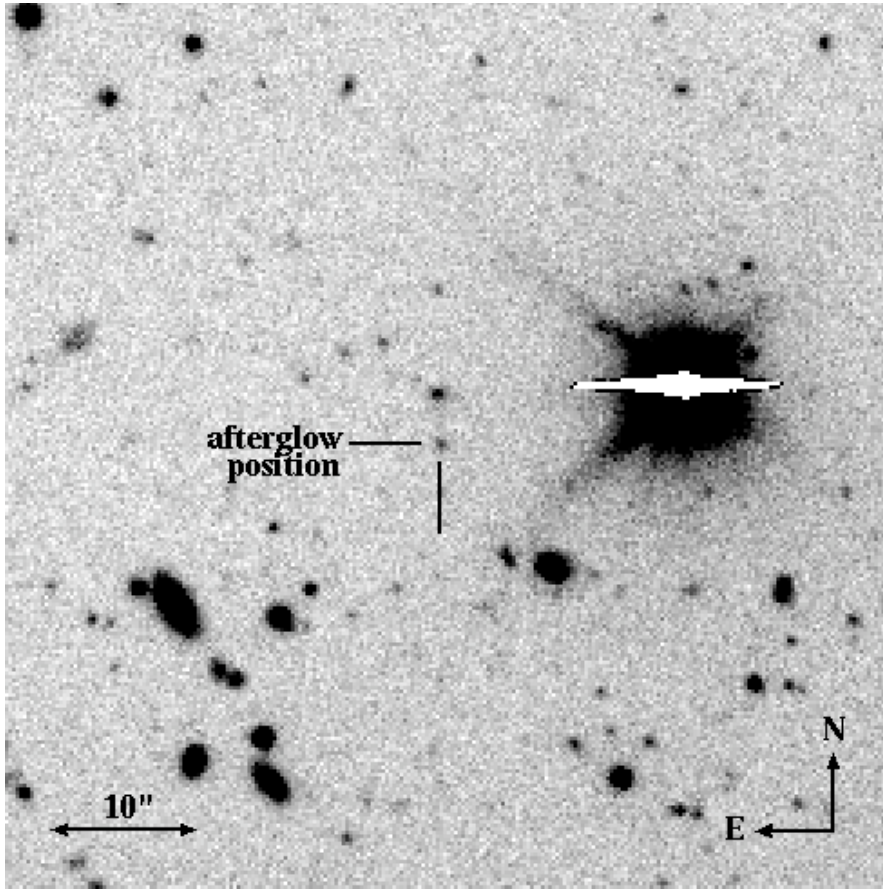
- A_V < 0.5 mag
- -70 < δ < 27
- Prompt XRT
- Long
- Triggered
- r_{XRT} < 2"



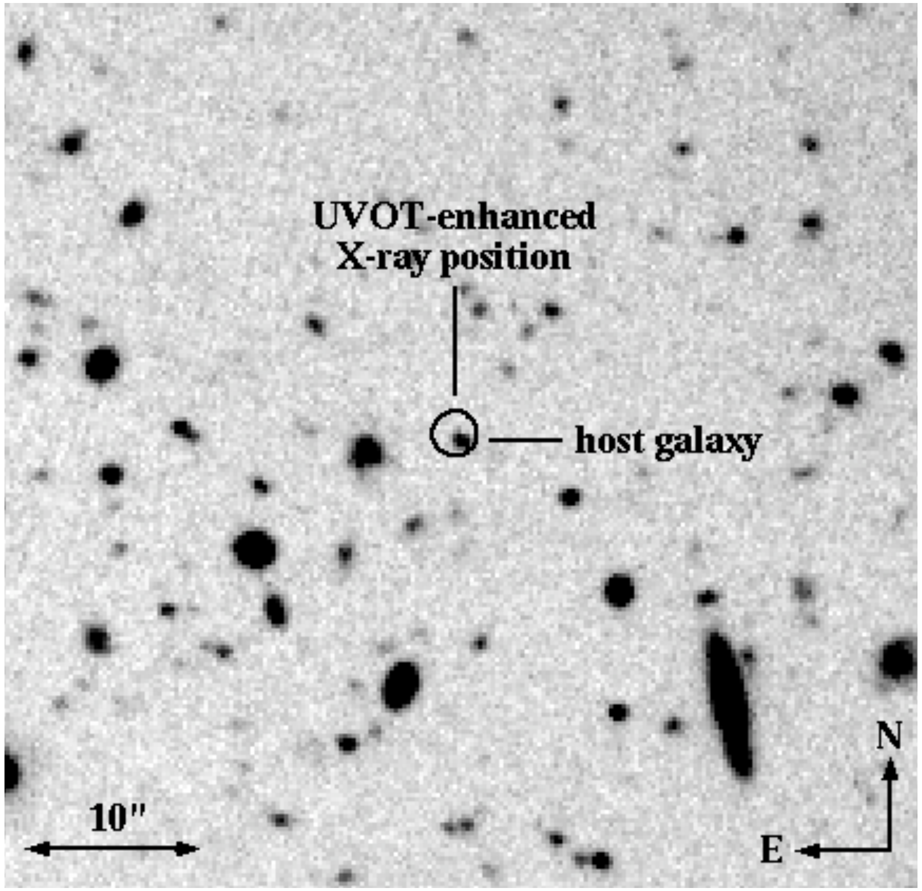
TOUGH = encircled

Finding hosts

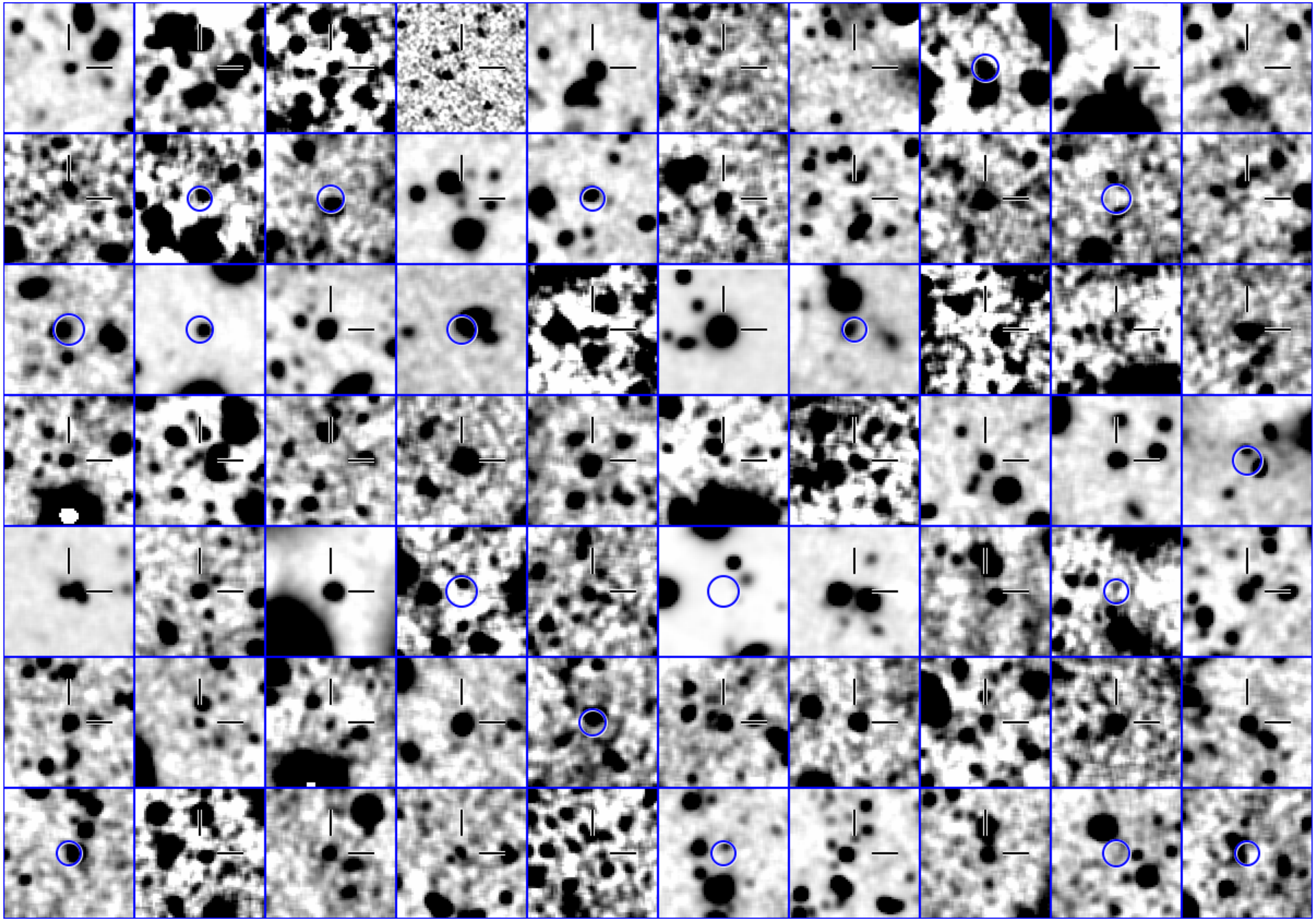
Optically bright GRB



Optically dark GRB (only X-ray pos)



Many of them



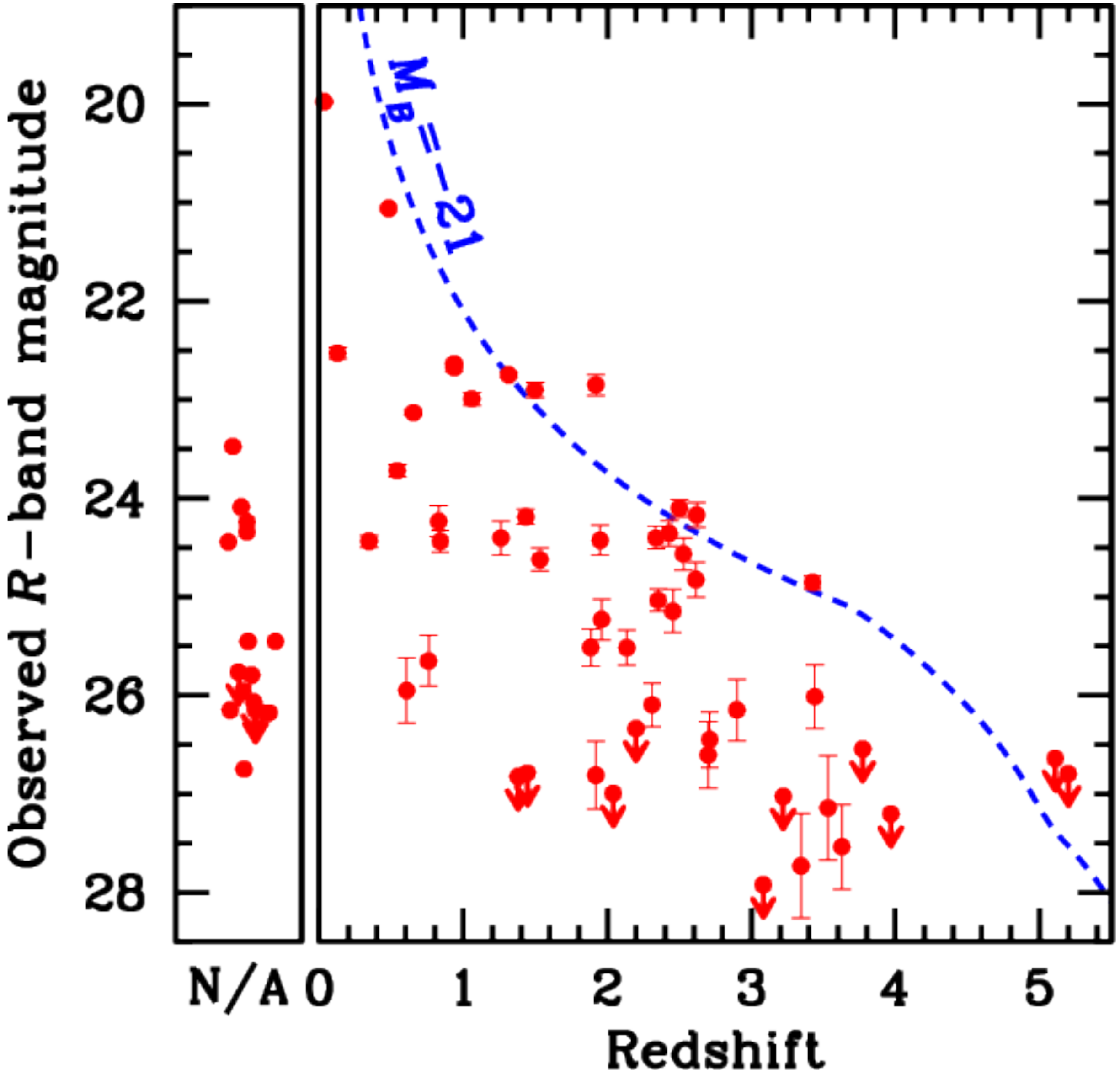
Detection rate

R-band detection:
55/69 = 80%

Detection at *z* > 3:
5/13 = 38%

Magnitudes: *R* = 20-27

K-band detection:
30/69 = 43%



Malesani et al. 2013
in preparation

Host luminosities

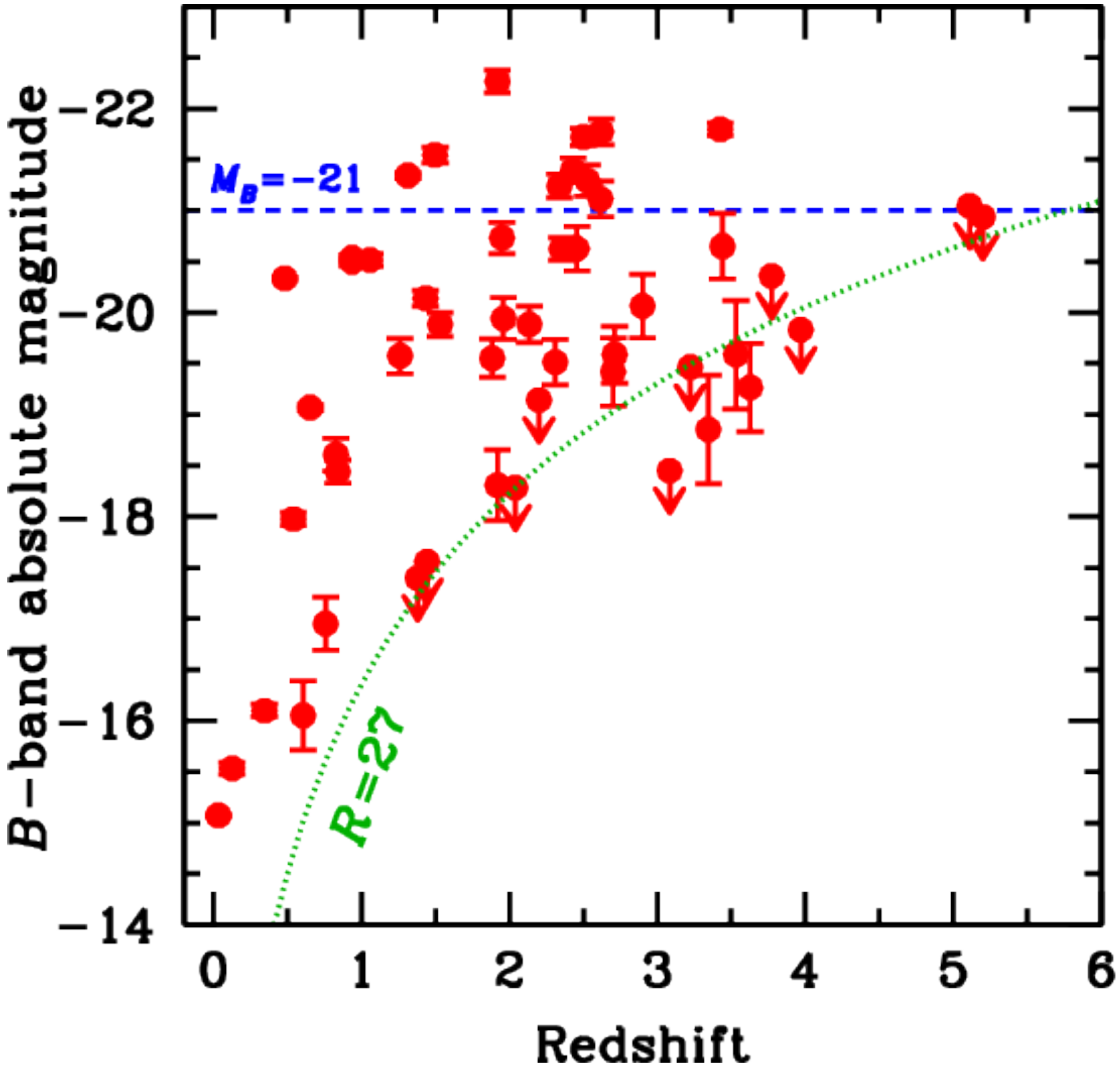
-15 > M_B > -22
0.01L^* < L < 2L^*

Some very faint galaxies:
GRBs only require 1 star!

Brighter hosts @ z~2?
But: evolution at high z

Compared to previous work
(incomplete/biased samples)
also bright (~L*) objects

Absolute magnitudes

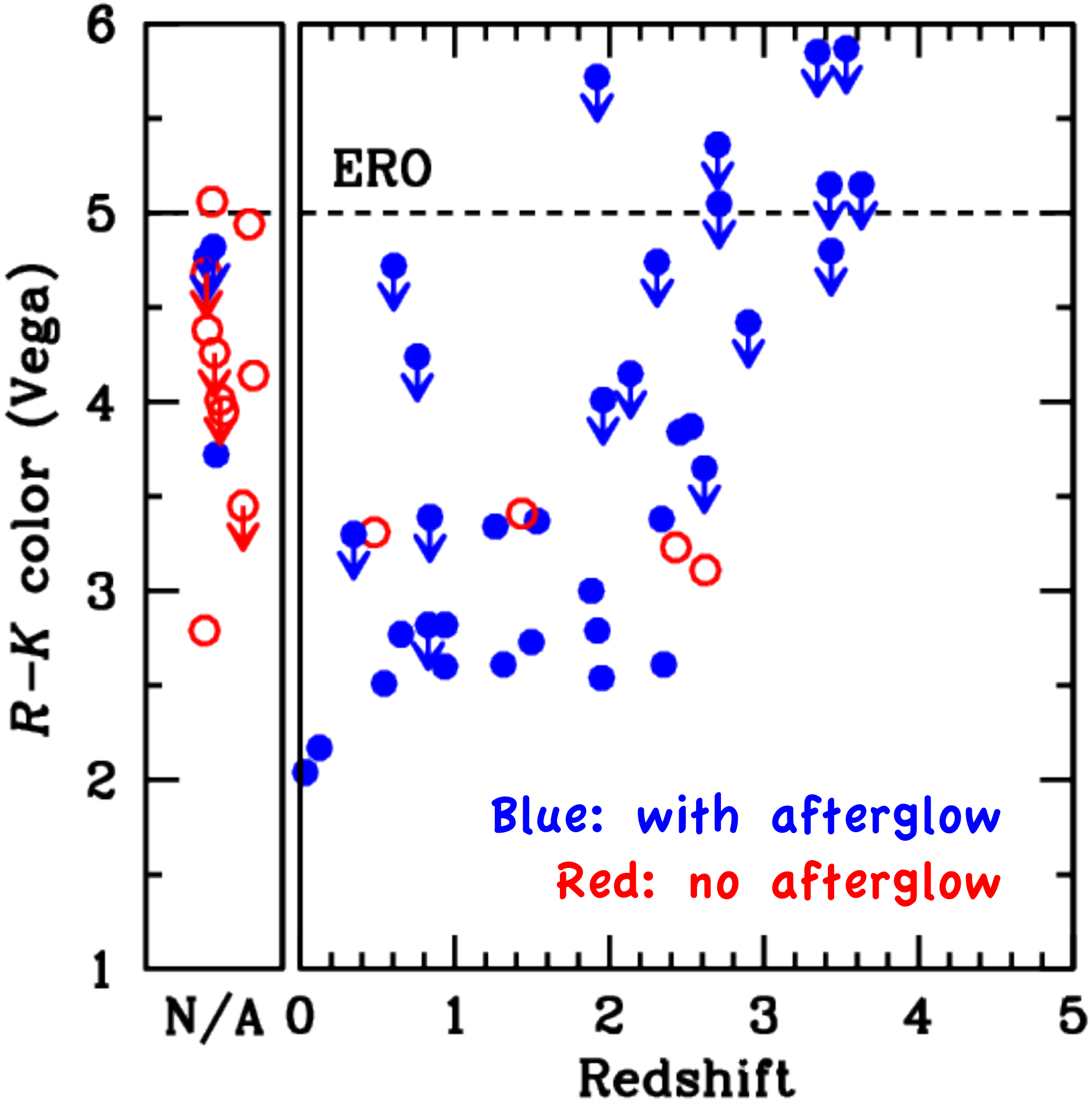


Host colors

GRB hosts are mostly blue
(star forming systems!)

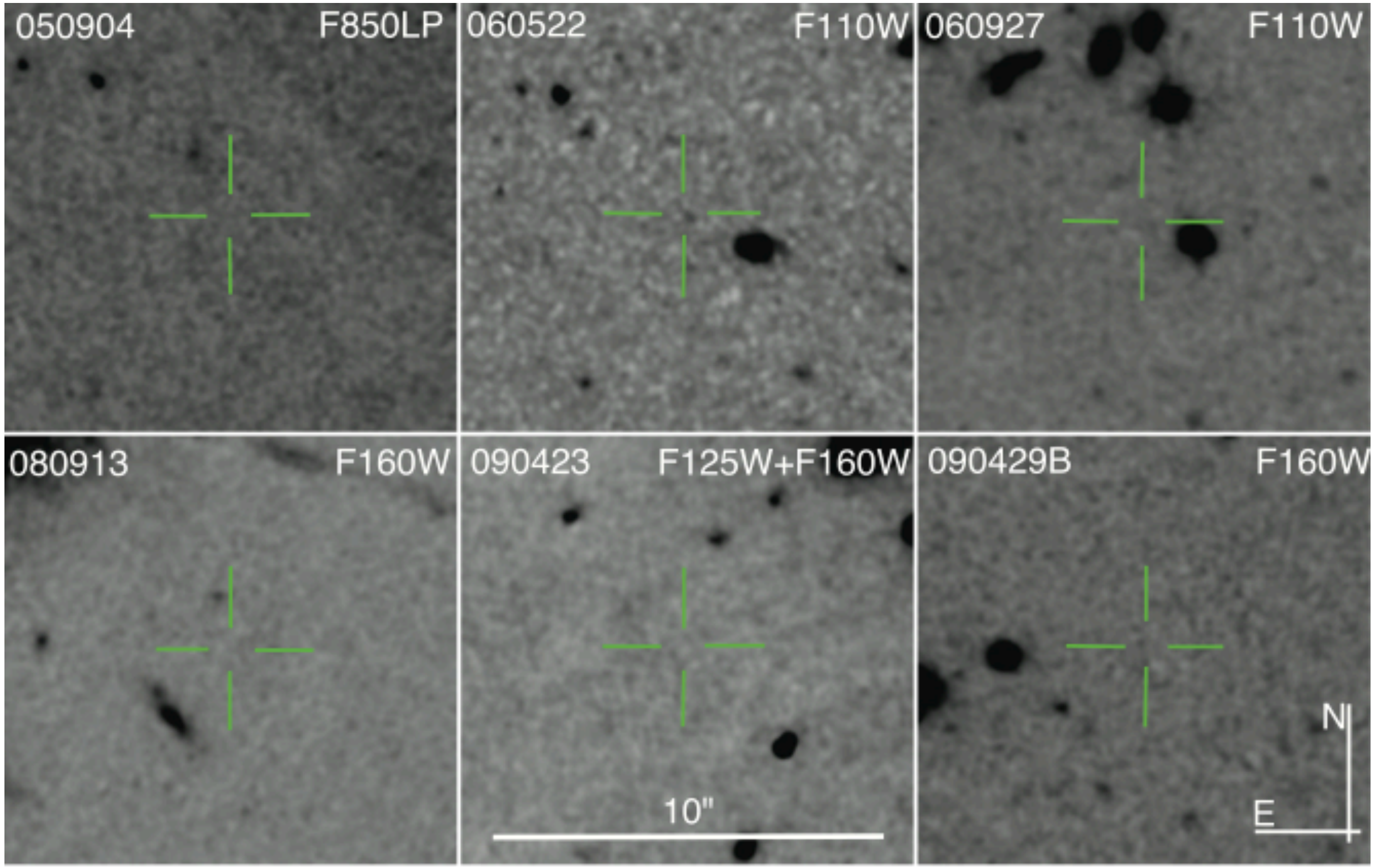
Dark GRBs: redder hosts
Two extremely red objects
(EROs)

R-K colors



High-redshift GRB hosts

Tanvir et al. (2012) have looked with deep HST images for $z > 5$ GRB hosts, and found none.



Inference on the faint-end slope of the galaxy luminosity function

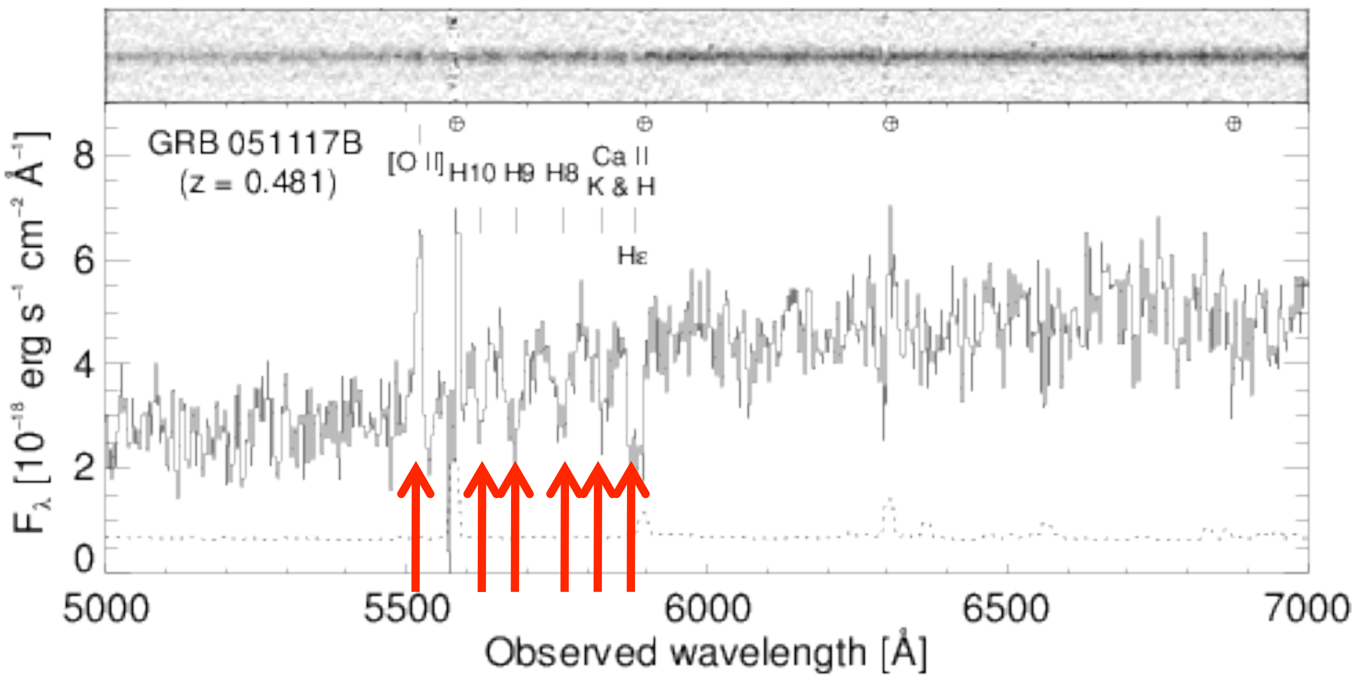
Trenti et al. (2012)

$M_{AB} > -15$ present at $z > 5$ at 95%

Redshift campaign (1)

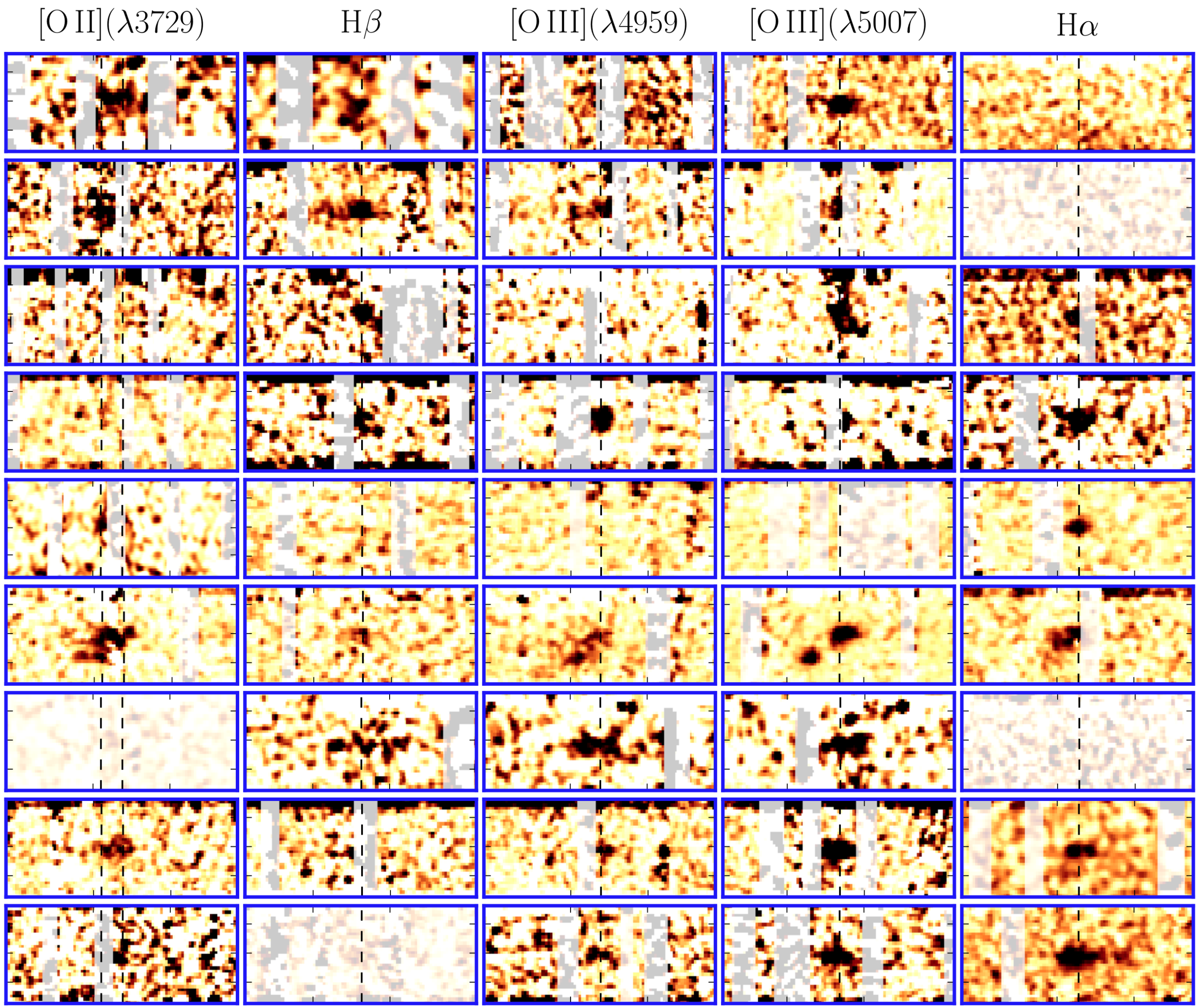
Goal to increase the redshift completeness,
Initially (before TOUGH): 55%

Spectroscopy of hosts with *R* < 25
Special credits to X-shooter (our "redshift-machine")



Jakobsson et al. (2012)

Redshift campaign (2)



Krühler et al. 2012 - arXiv:1205.4036

Redshift distribution (1)

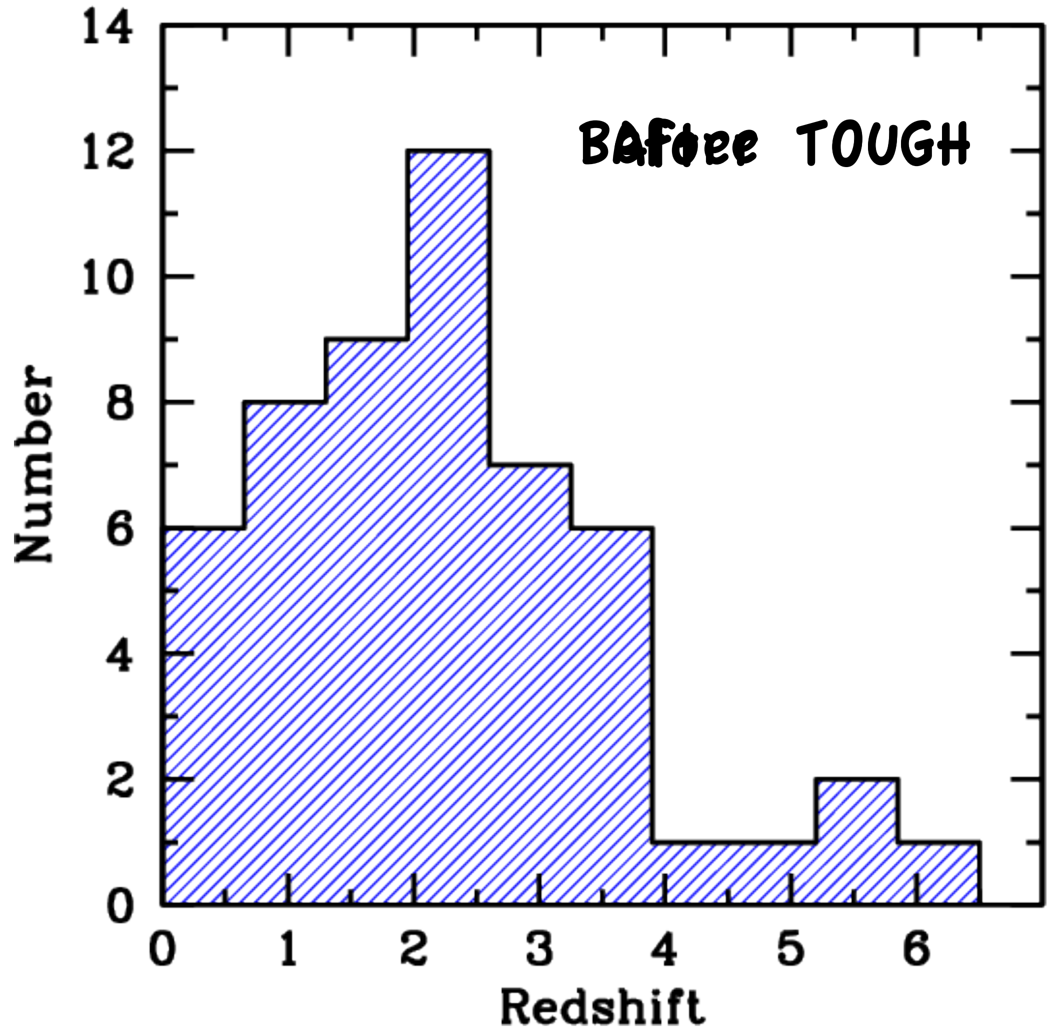
16 new redshifts

(3 fixed ones)

4 constrained ones

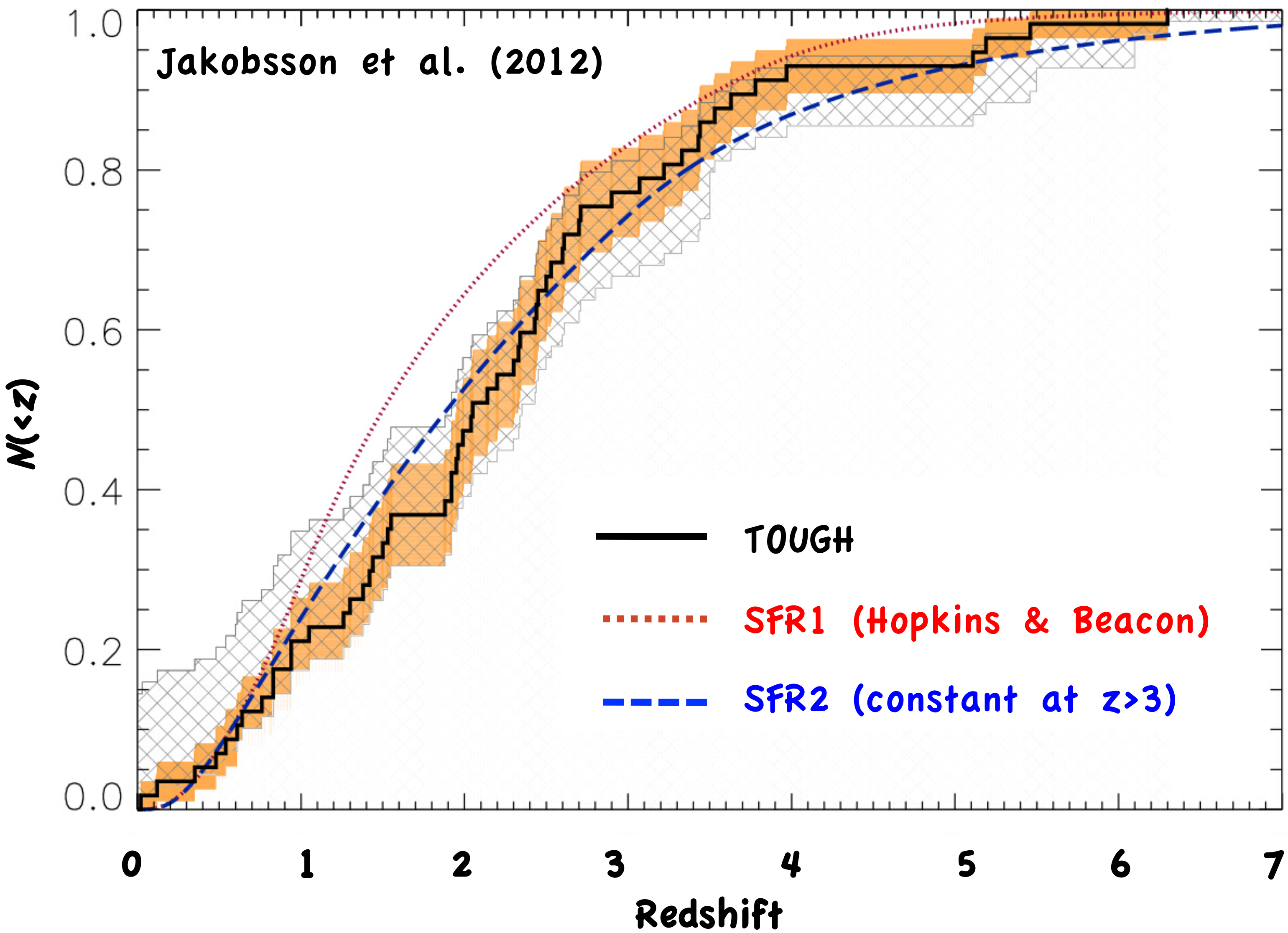
78% completeness

Median $\langle z \rangle$ = 2.23



Redshift distribution (2)

Goal: constrain the cosmic star formation rate



See also Robertson & Ellis; Salvaterra et al.; Wanderman & Piran; Elliott et al.; ...

Lyman α properties

Look for Lyα in emission for GRBs with $1.8 < z < 4.5$

Milvang-Jensen et al. 2012 ApJ, 756, 25

Radio properties

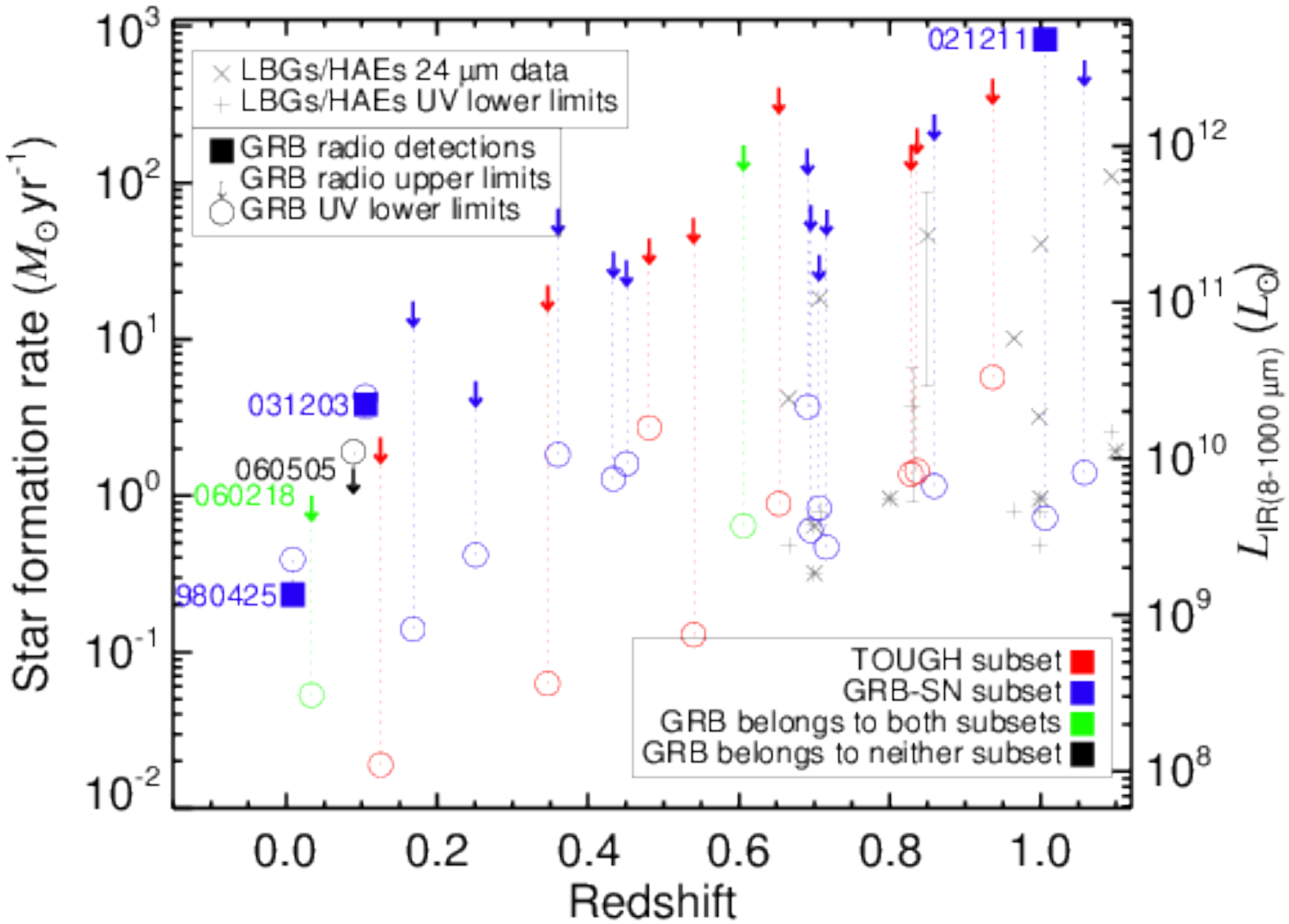
Radio survey of the TOUGH hosts at z < 1

12 systems

No host detected!

Constraints on obscured SFR

< 10-100 $M_\odot$ yr^{-1}



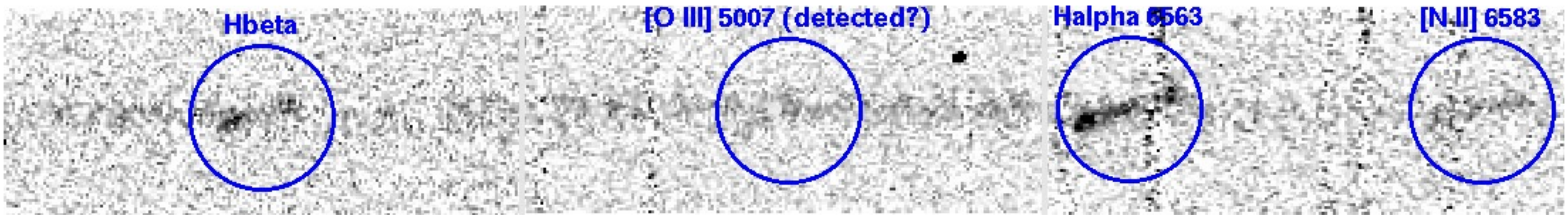
Michałowski et al. 2012 ApJ, 755, 85
See also Michał's talk

Metallicity project

Goal: investigate the role of metallicity in GRBs

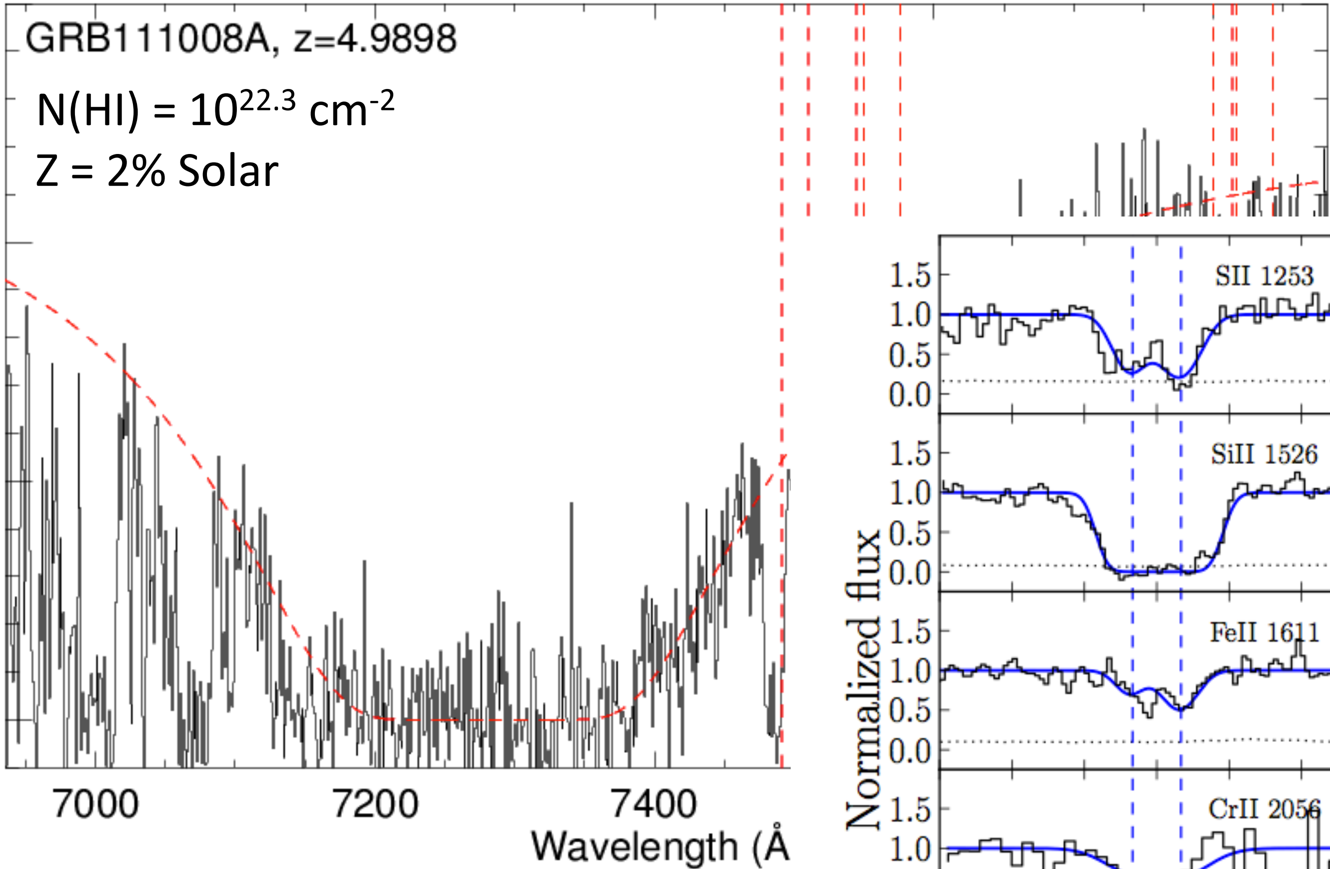
X-shooter campaign to measure metallicity of all the TOUGH GRB hosts at $z < 1$ - ongoing project

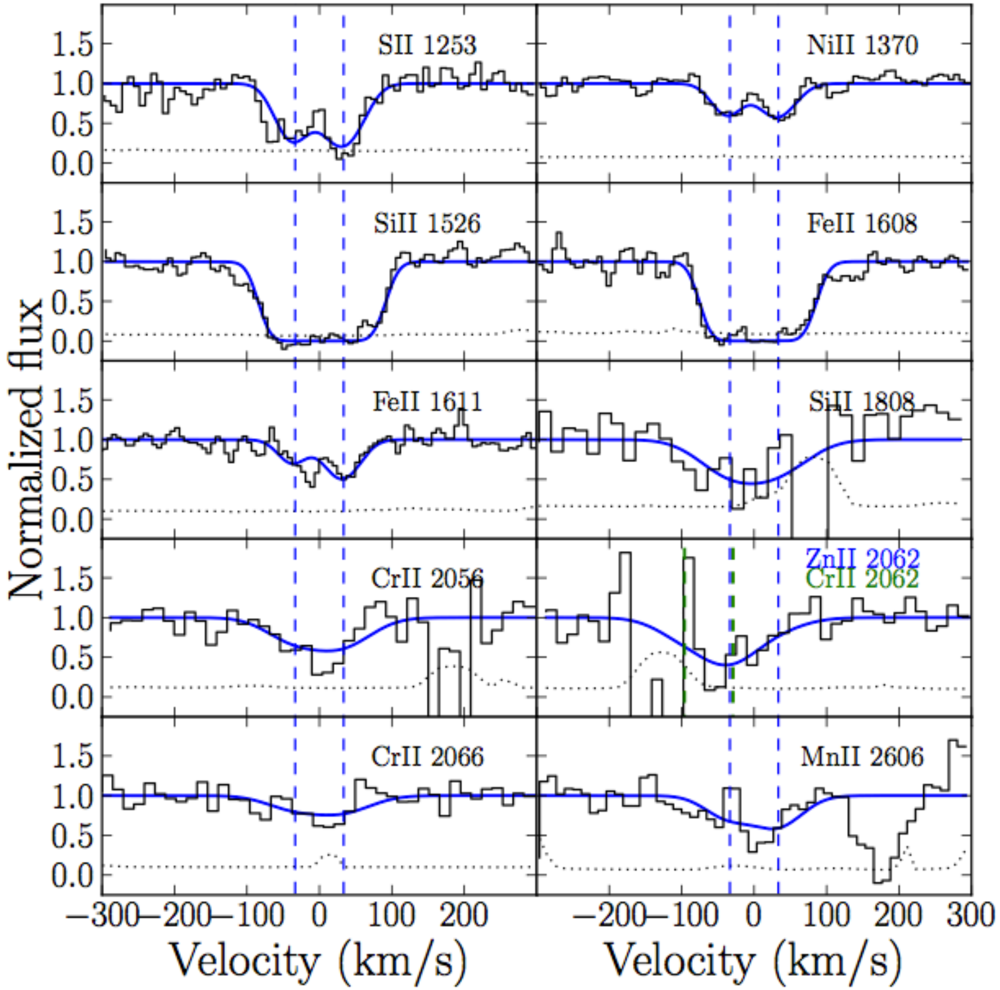
Work in progress



Example: GRB host with approximately Solar metallicity from [N II]

The other side of the story - afterglow spectroscopy



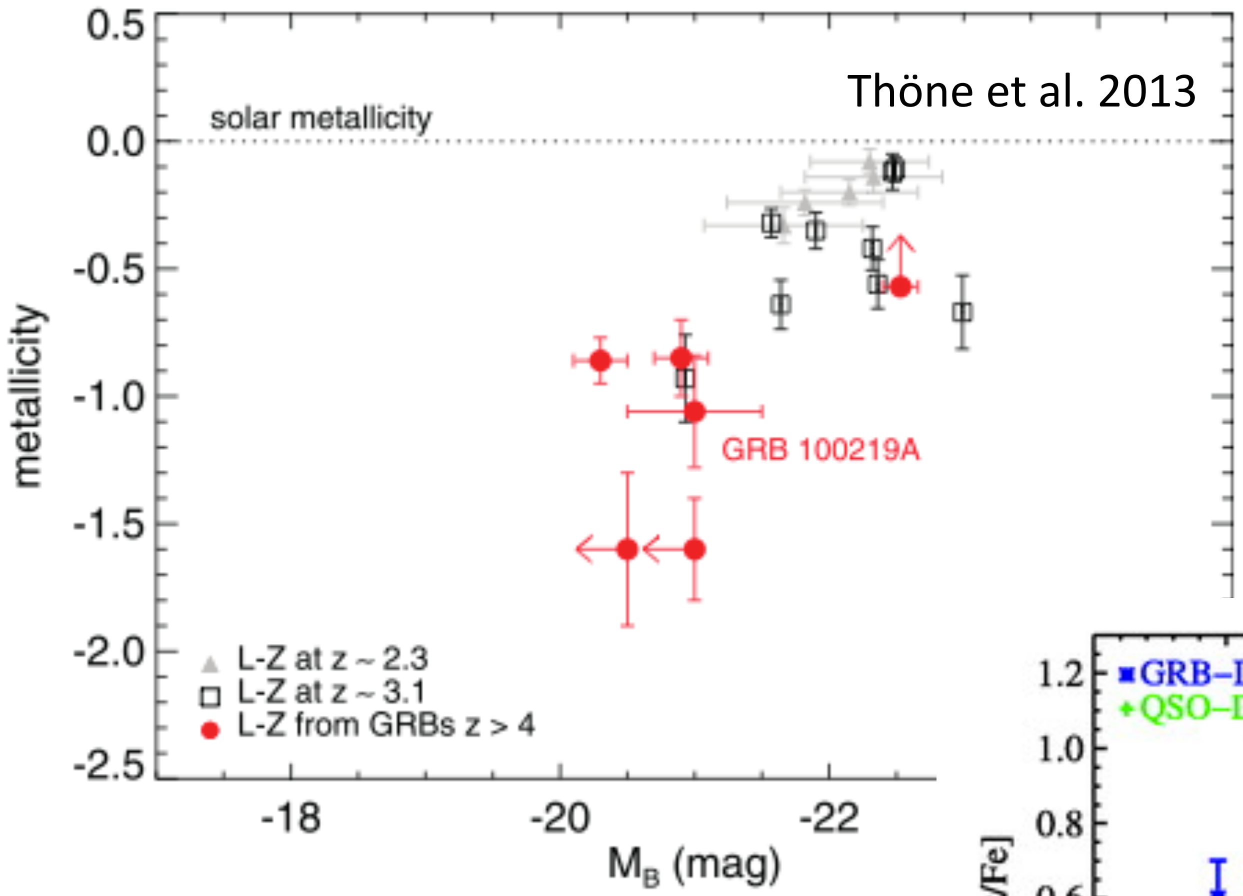


Sparre et al. 2013
Olga's talk

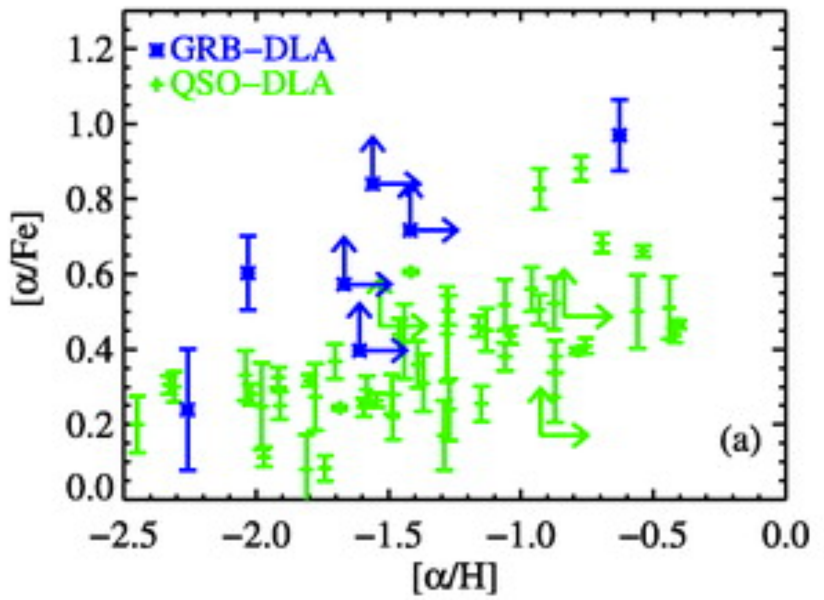
See also: Prochaska et al. 2007 - Rau et al. 2010 - D'Elia et al. 2011 Thöne et al. 2013 …

VLT / X-shooter contribution

Metallicity probes for faint high-z galaxies



Prochaska et al. 2007

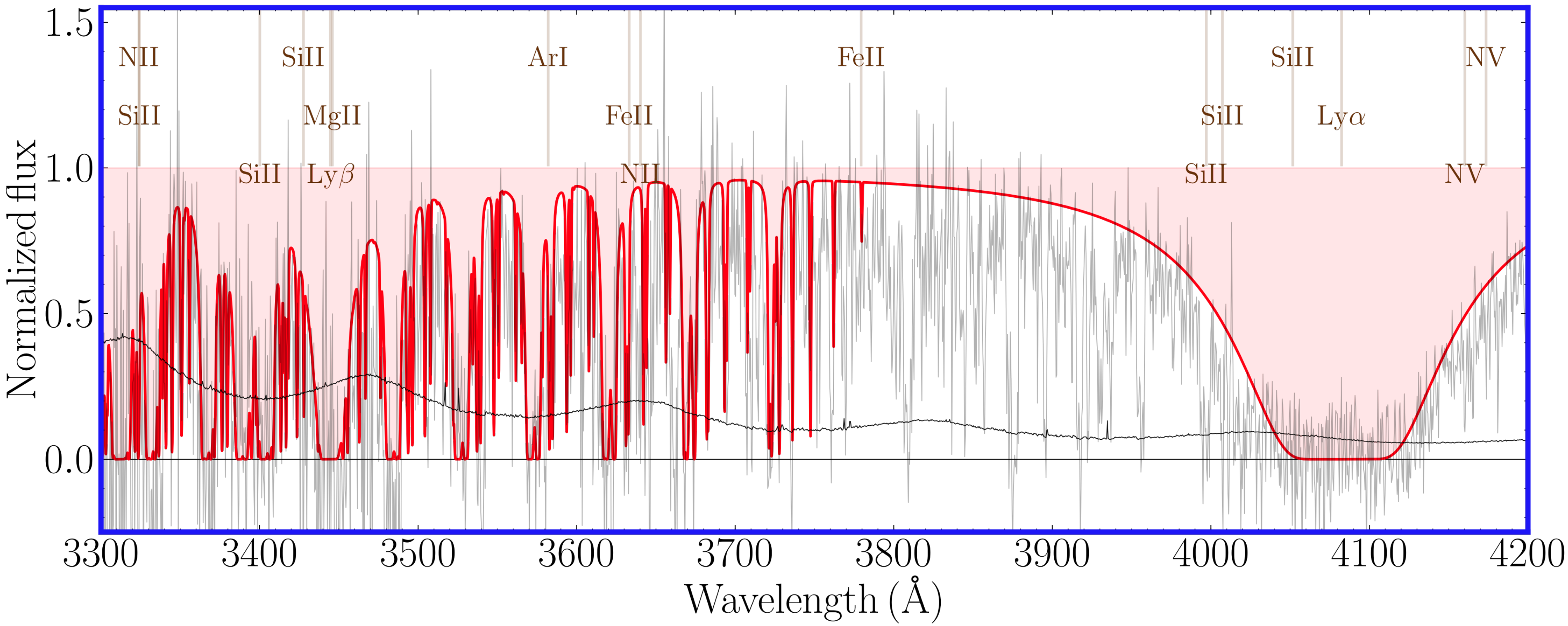


A case study - discovery of molecular Hydrogen

GRB 120815A at $z = 2.36$
Metallicity $\sim 0.1 Z_{\odot}$
Absorption $A_V = 0.15$ mag
Depletion [Zn/Fe] = 1
Column density $N(HI) = 10^{21.95}$ cm^{-2}

Krühler et al. 2013

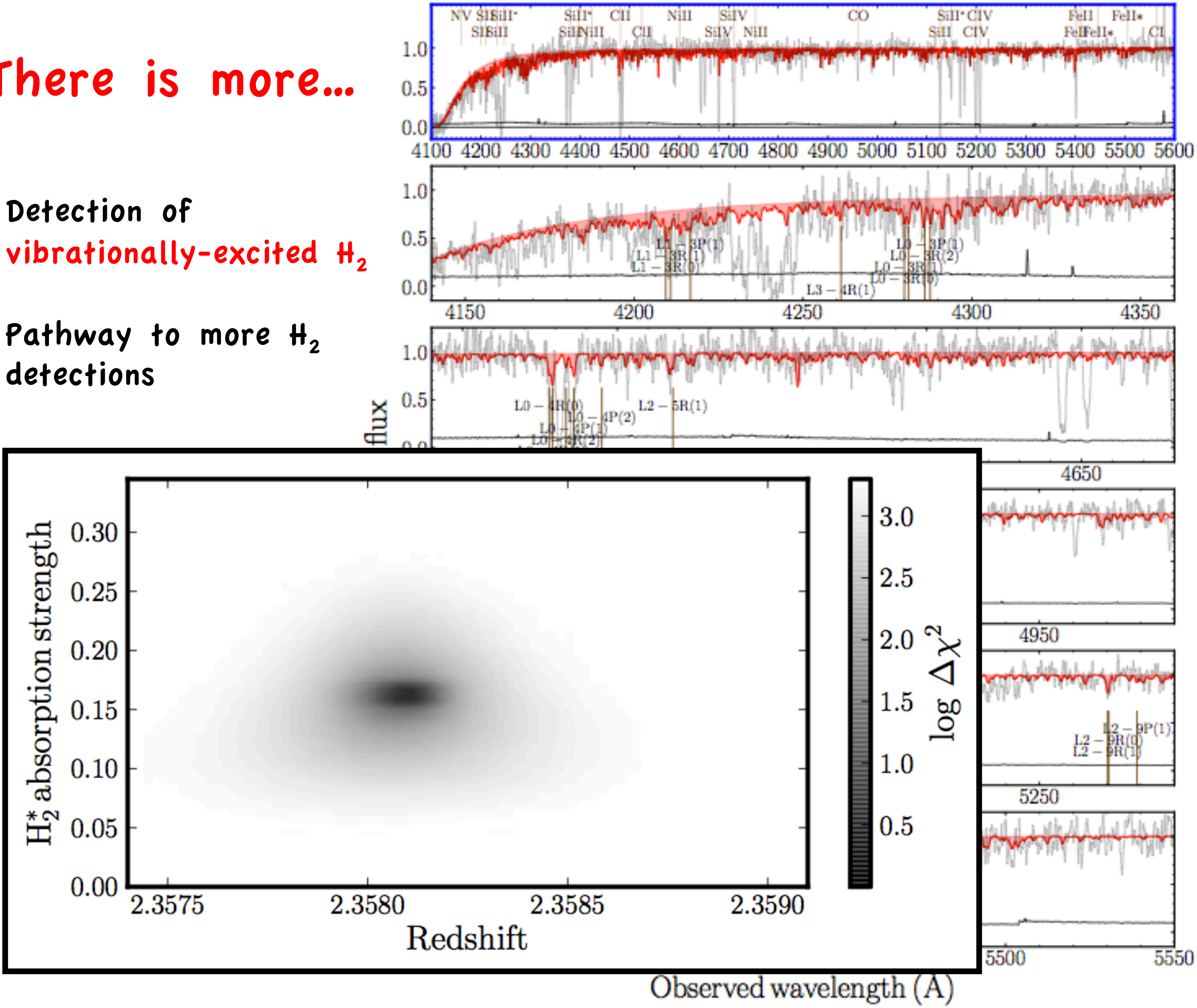
Detection of Lyman-Werner bands of molecular Hydrogen ($f = 10^{-1}$)



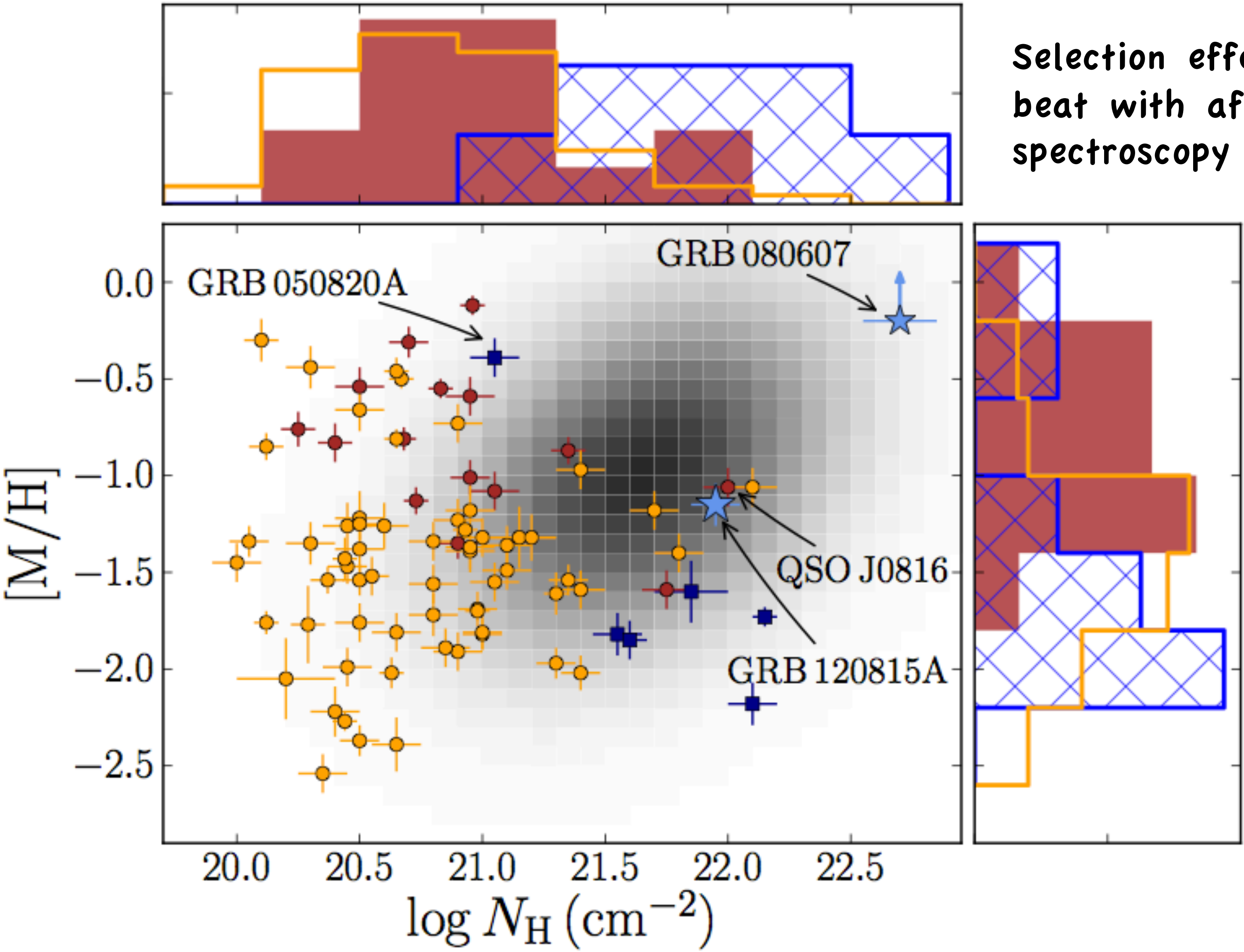
There is more…

Detection of vibrationally-excited H_2

Pathway to more H_2 detections



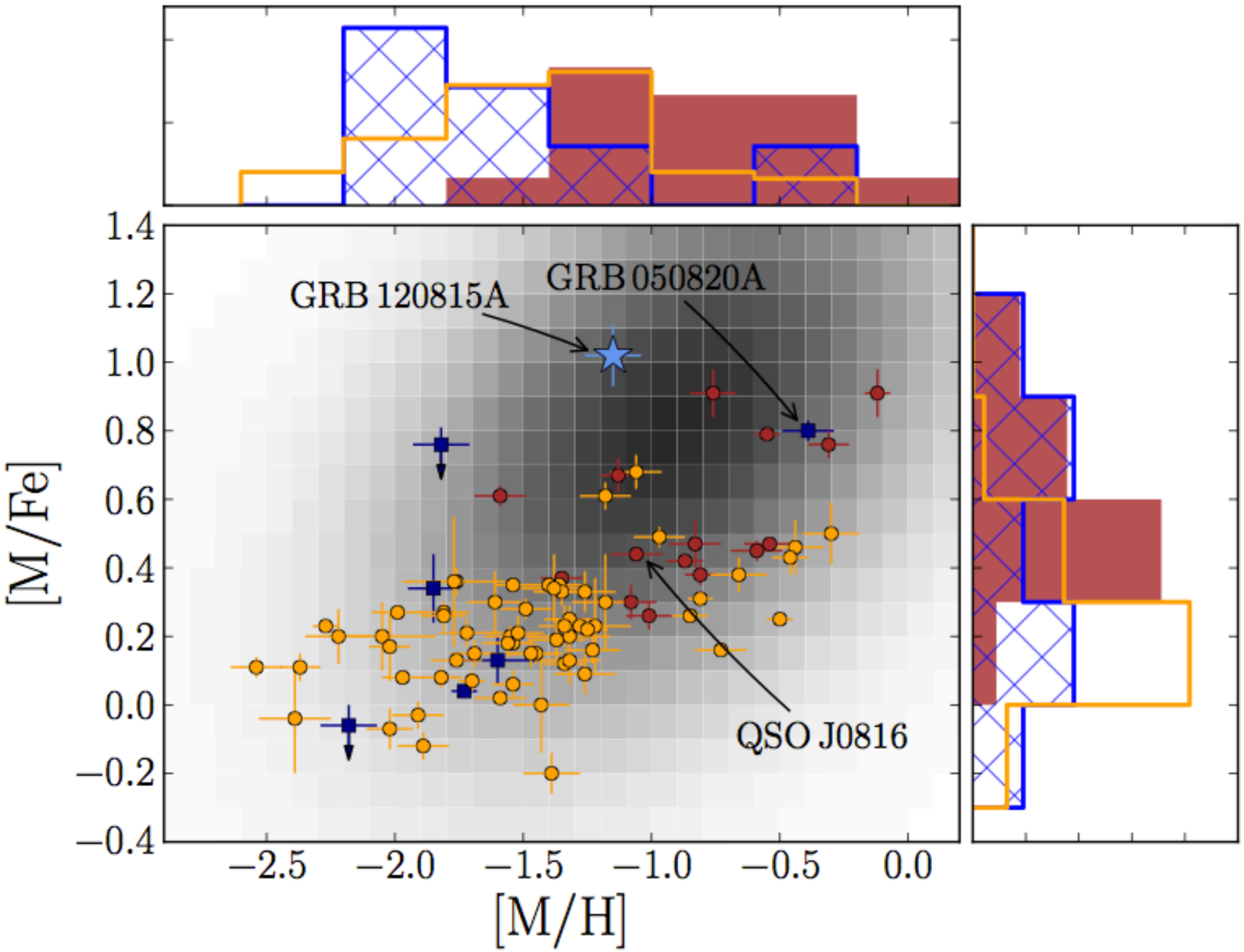
Opening the way to “normal afterglows”



Selection effects hard to beat with afterglow spectroscopy

Blue = GRBs
Gold= QSOs with H_2
Red = QSOs no H_2

Opening the way to "normal afterglows"



Blue = GRBs

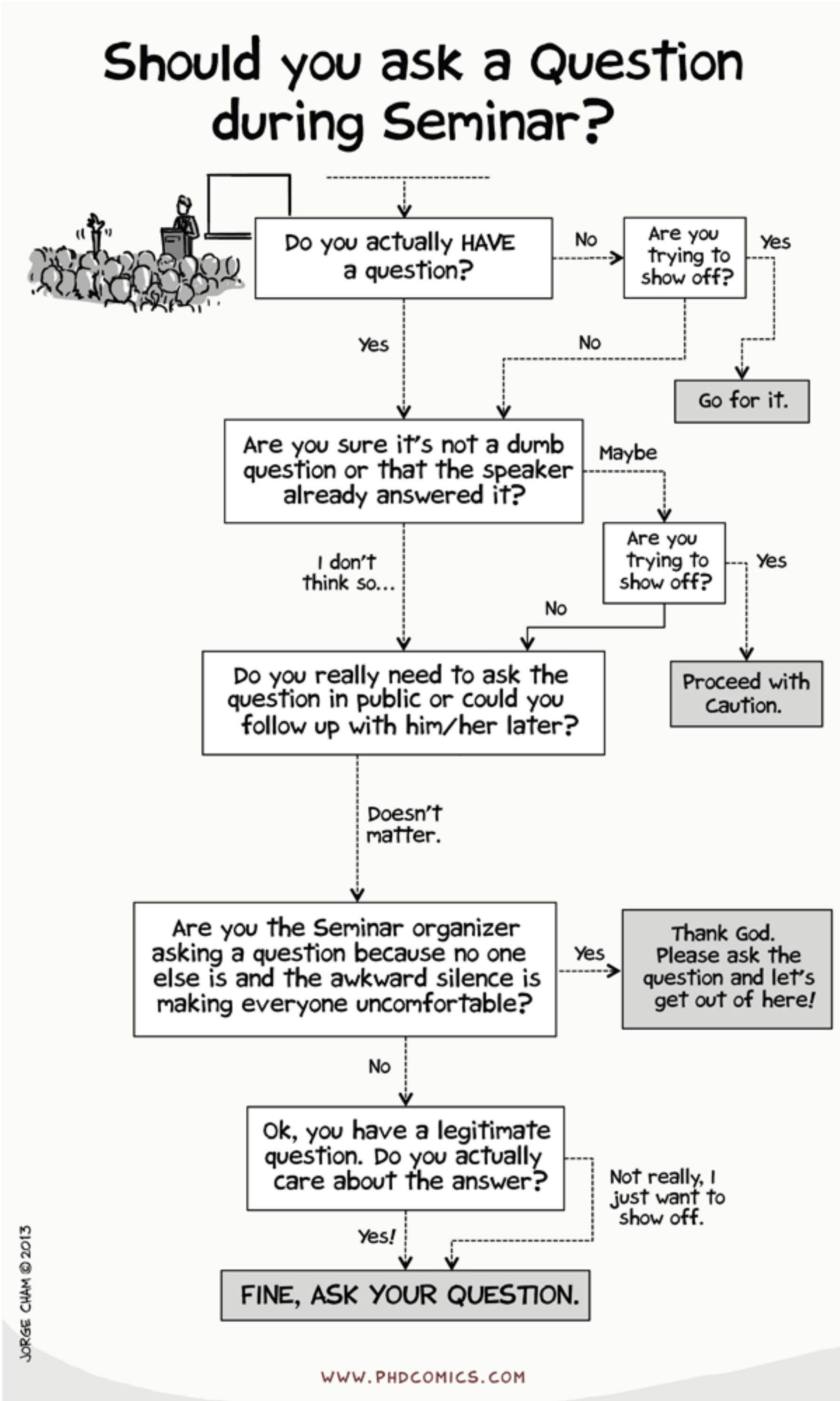
Gold= QSOs with H_2

Red = QSOs no H_2

Summary and outlook

- GRBs are promising tools to probe several aspects of the cosmic evolution.
- Necessary to base any inference on representative samples
- Evidence for preference for low metallicity still being amassed – need to draw quantitative constraints
- TOUGH and other surveys provide the starting point – a more detailed characterization of the hosts is needed
- Especially multi-band approach required (long wavelength)

Thank you!


Should you ask a Question during Seminar?
Do you actually HAVE a question?
No
Are you trying to show off?
Yes
Go for it.
No
Yes
Are you sure it's not a dumb question or that the speaker already answered it?
Maybe
Are you trying to show off?
Yes
Proceed with Caution.
No
I don't think so...
Do you really need to ask the question in public or could you follow up with him/her later?
Doesn't matter.
Are you the Seminar organizer asking a question because no one else is and the awkward silence is making everyone uncomfortable?
Yes
Thank God. Please ask the question and let's get out of here!
No
Ok, you have a legitimate question. Do you actually care about the answer?
Not really, I just want to show off.
Yes!
FINE, ASK YOUR QUESTION.
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