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# High-redshift GRB afterglows

Munich, May 2012

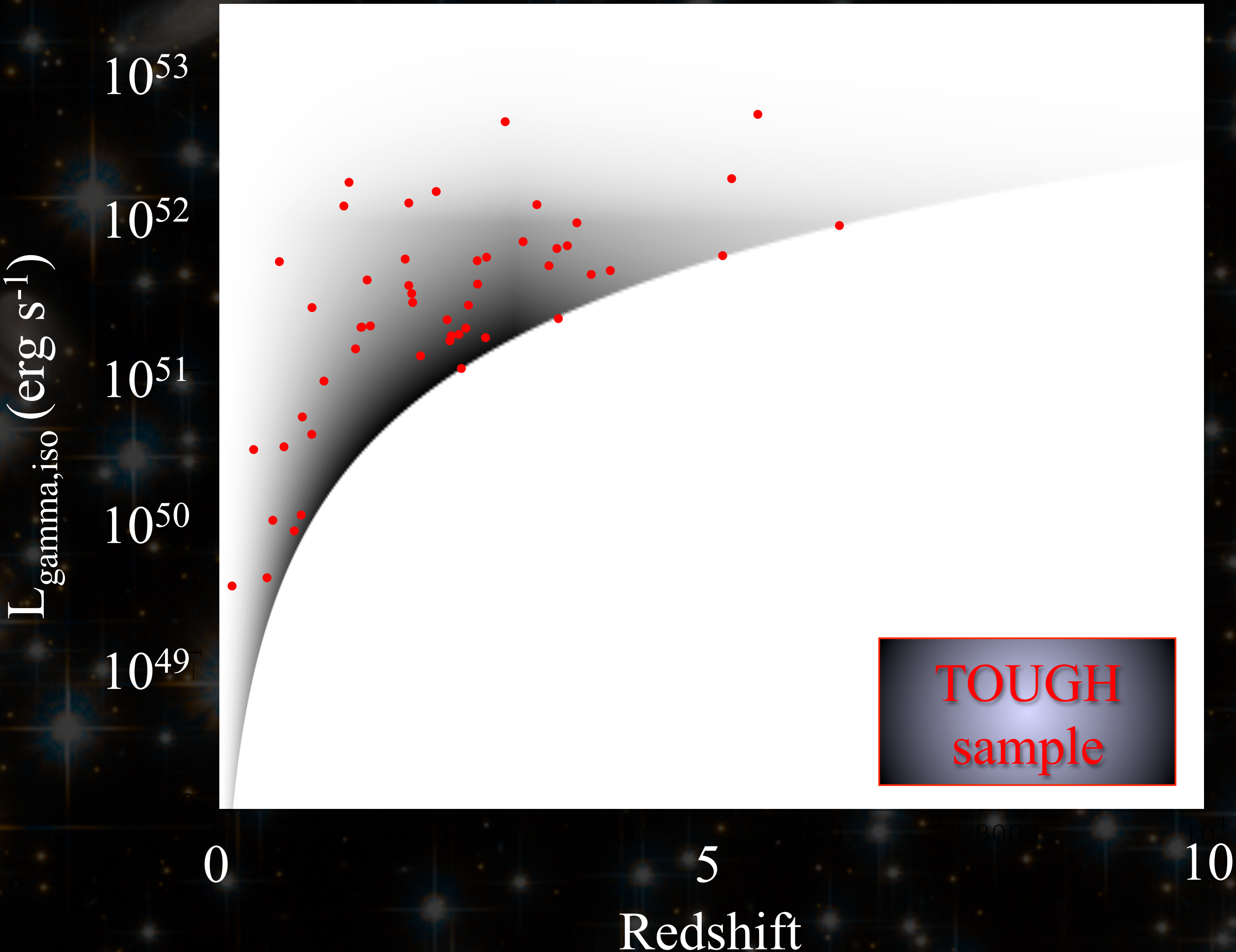
# Afterglows – finding them …

- Only intrinsically bright GRBs detected at high-z
- High-z GRB (optical/IR) afterglows will be absent in blue wavelengths and present in red, due to Ly-alpha break (IGM HI absorption)
- Unfortunately some other afterglows, particularly those on dusty sight-lines, also appear red in optical-IR colours.

# … and what they tell us

- Photometric and/or spectroscopic redshifts (Kruehler)
- Dust laws (Schady)
- Metallicity/molecular content/internal-velocities/conditions (Schady)
- HI columns (Schady, Watson)/escape-fractions
- Locations of star-forming galaxies (however faint!) and massive star formation (Kruehler, Elliot, Hjorth, Levesque, Perley,…)
- Possibly diagnostic of changing populations (e.g. pop III progenitor)

# Afterglows – finding them ...

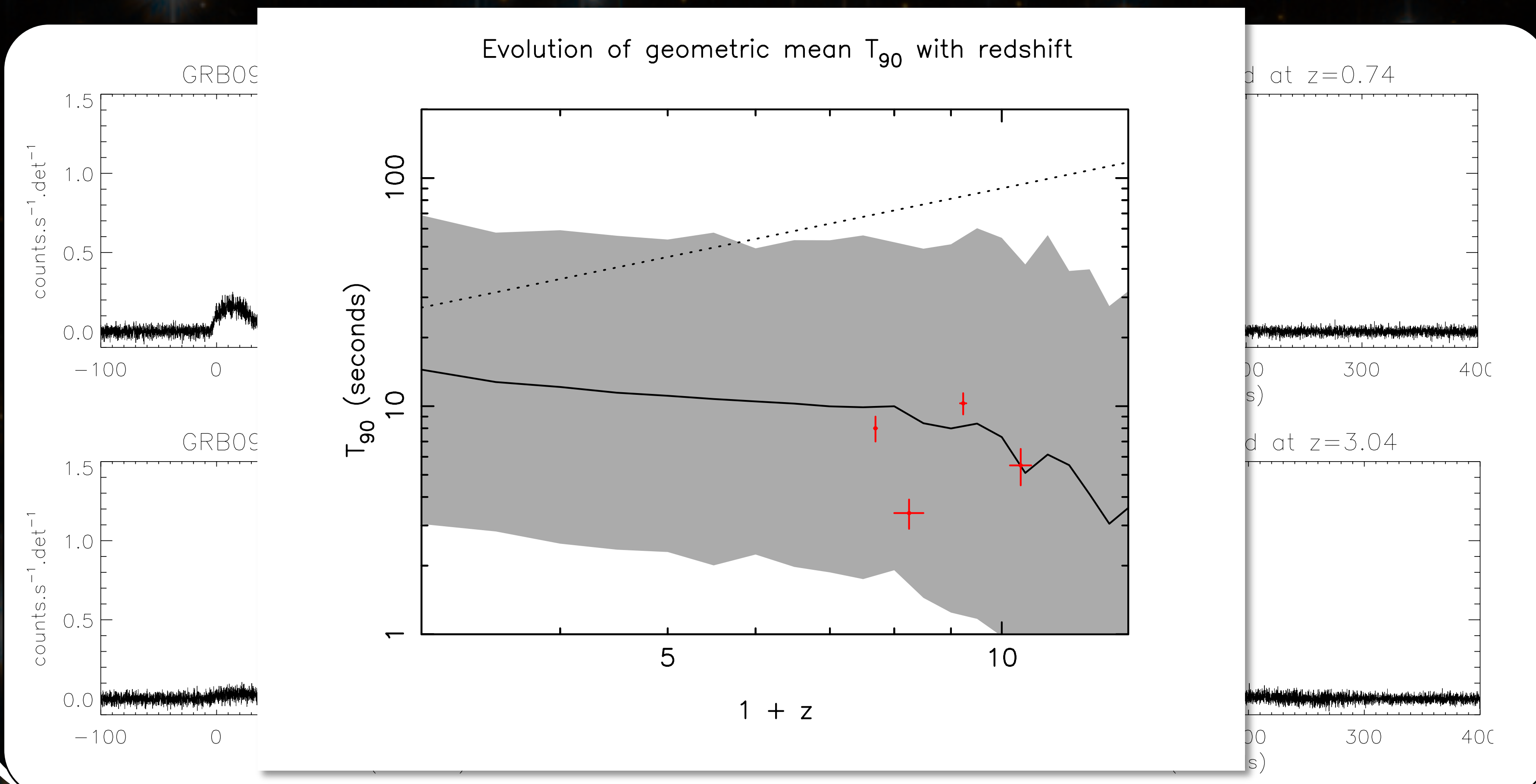


# Are high redshift bursts shorter duration?

PROVISIONAL

Generate simulated light curves in the 15-25 keV band at various redshifts above the true redshift.

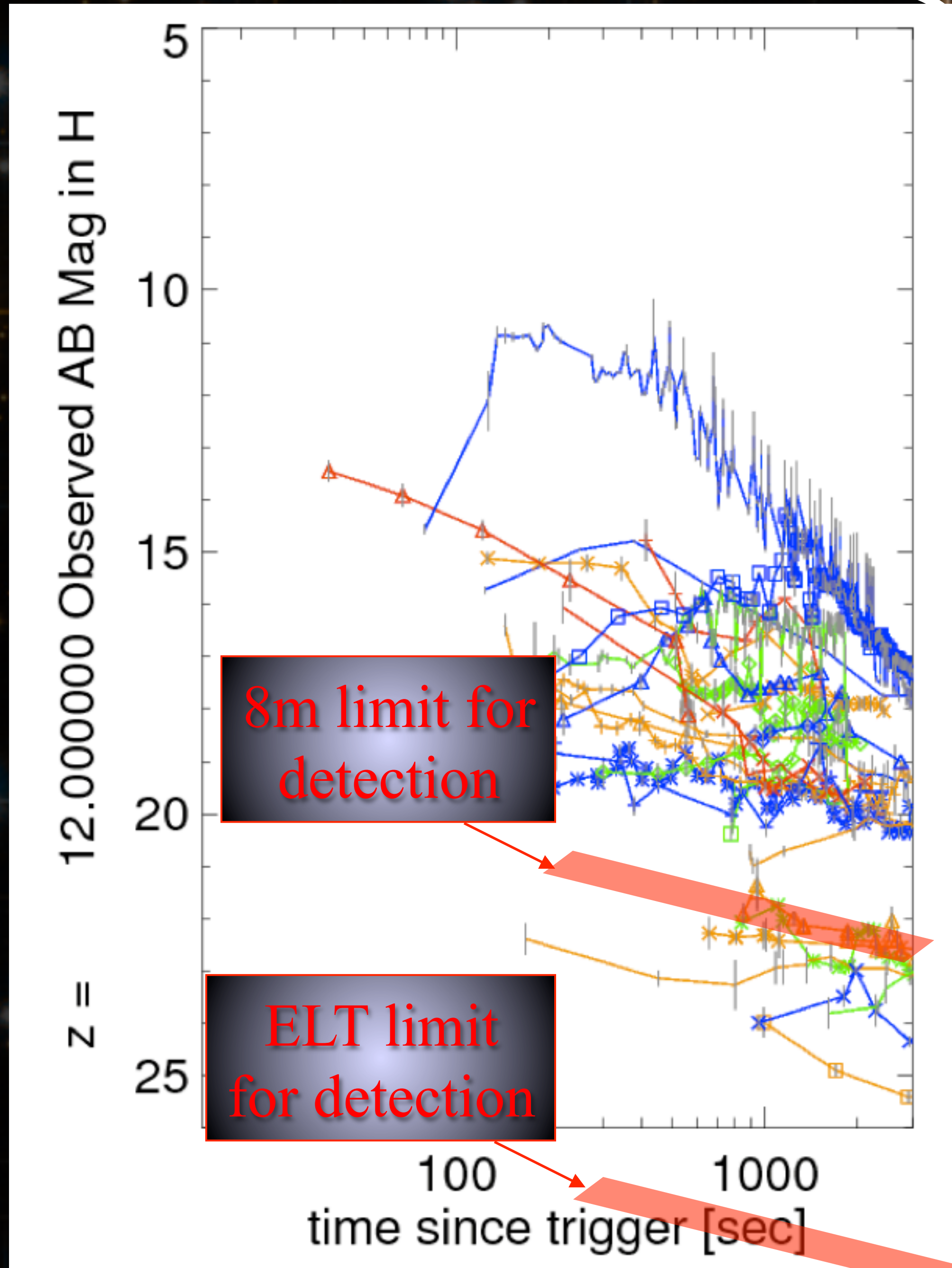
*Littlejohns et al., cf Kocevski 2012*



# Afterglows can be very bright!

Brighter afterglows easily detectable at very high redshifts. (in part because cosmological time dilation means we can get on target earlier in the rest frame)

*Figure from Grindley et al. 2010*



# Reionization epoch

The last major phase change in the universe.

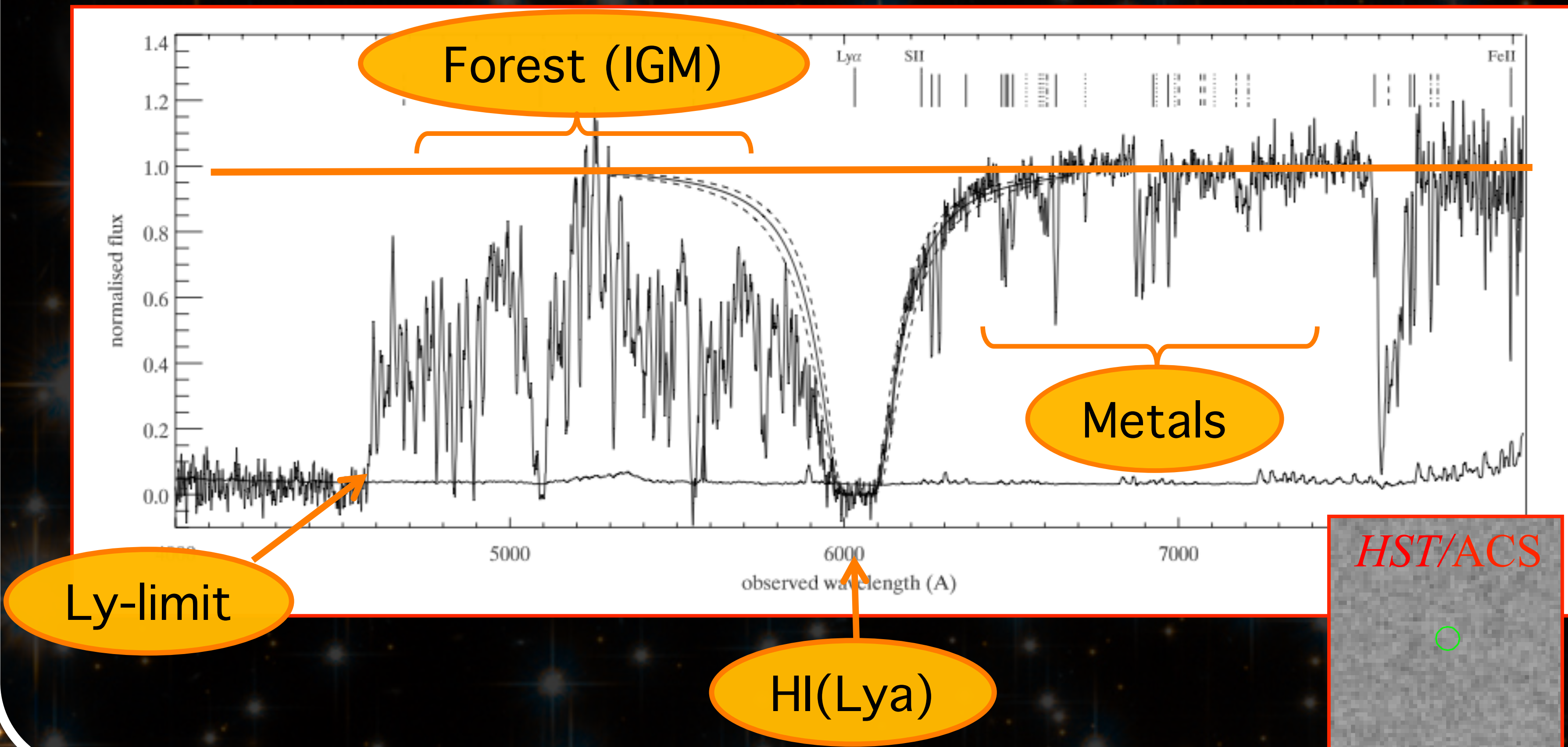
Tied to the formation of the first collapsed objects.

Very hard to study bec…
only the brightest so…
be seen directly - limi…
means limited informa…
and they were also rare
beyond z=7.

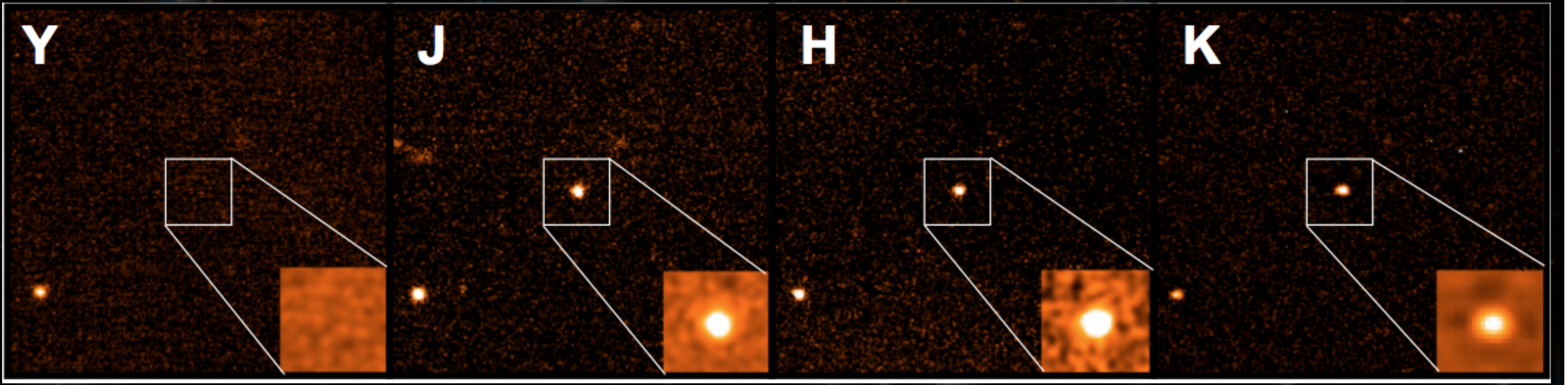

Key question not so much "when?" but "how?" – were the stars enough?

# Afterglow spectra contain much information (as we have already seen)

E.g. GRB 050730: faint host (R>28.5), but $z$=3.97, [Fe/H]=-2 and low dust, from afterglow spectrum (Chen et al. 2005; Starling et al. 2005).



# GRB 090423



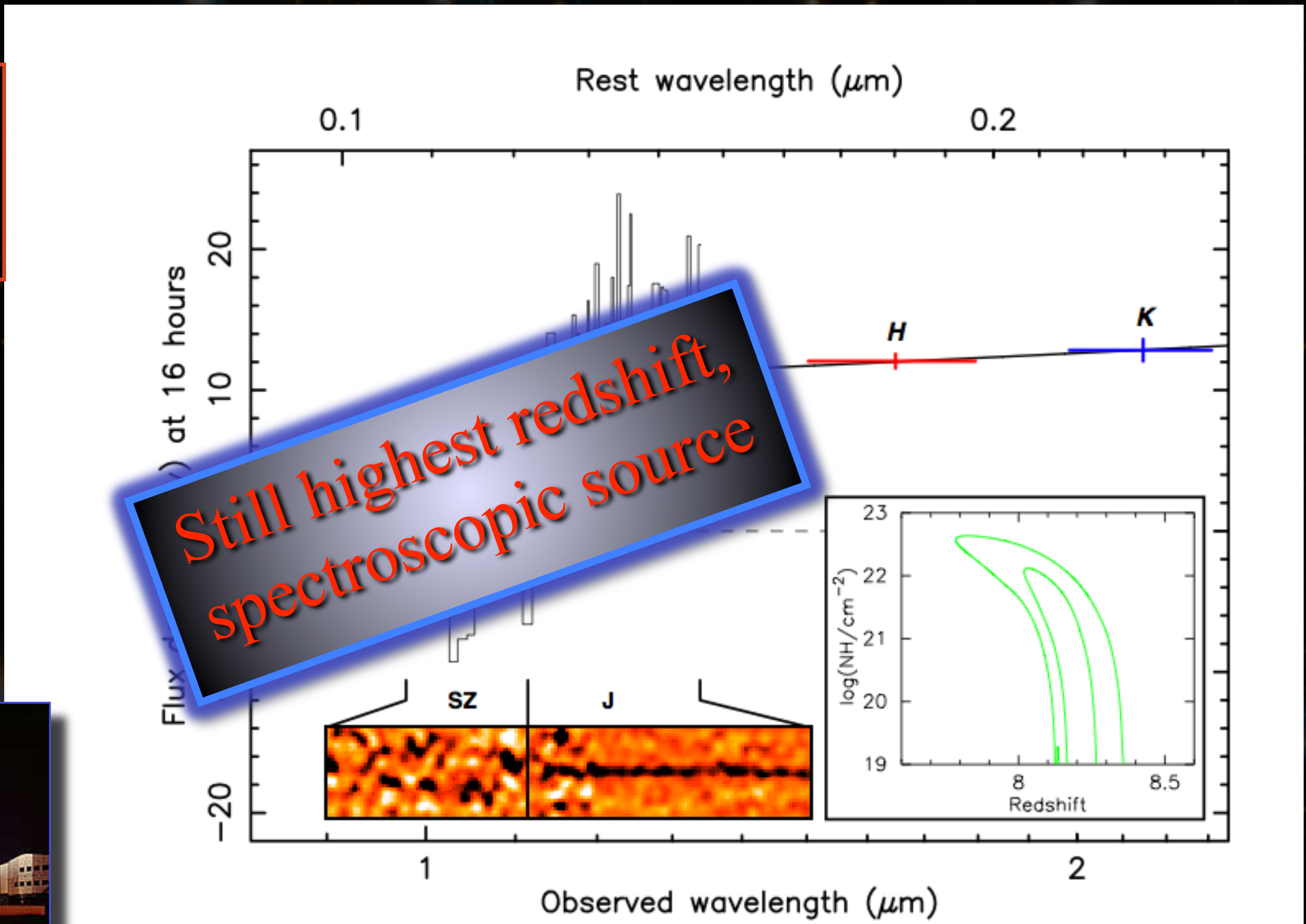

# GRB 090423

$z = 8.23 \pm 0.08$

Power law continuum ⇒ photo-z robust

Age of universe = 630Myr

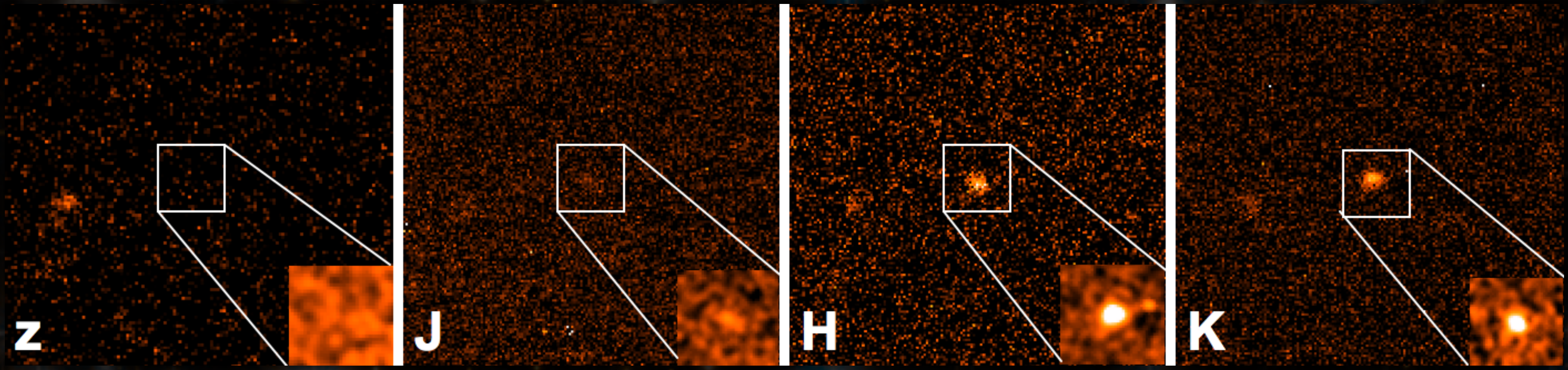
Still highest redshift, spectroscopic source




*NT et al. 2009, see also Salvaterra et al. 2009.*

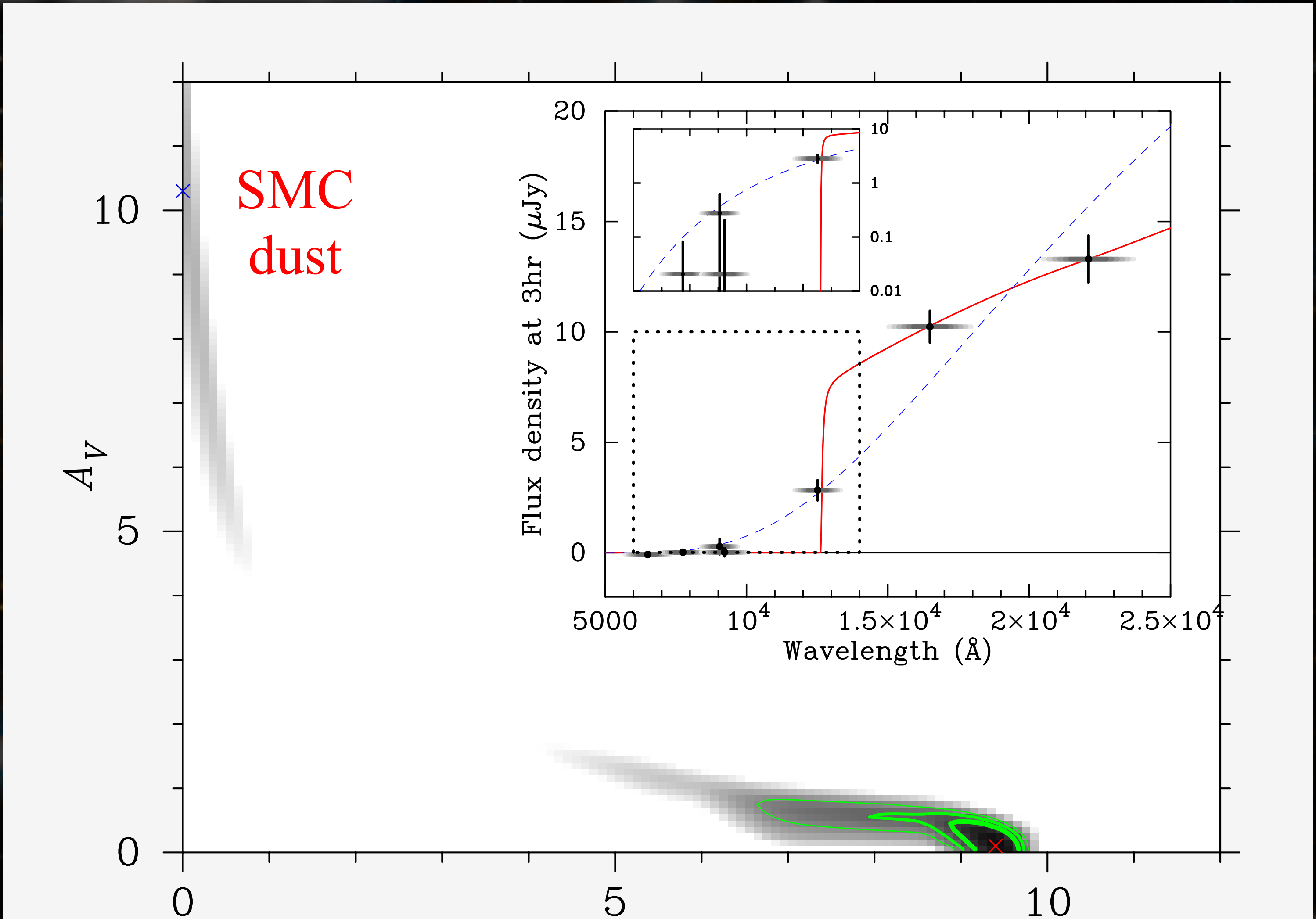
# GRB 090429B

Another high-redshift candidate (photo-z~9.4).




*Cucchiara et al. 2011*

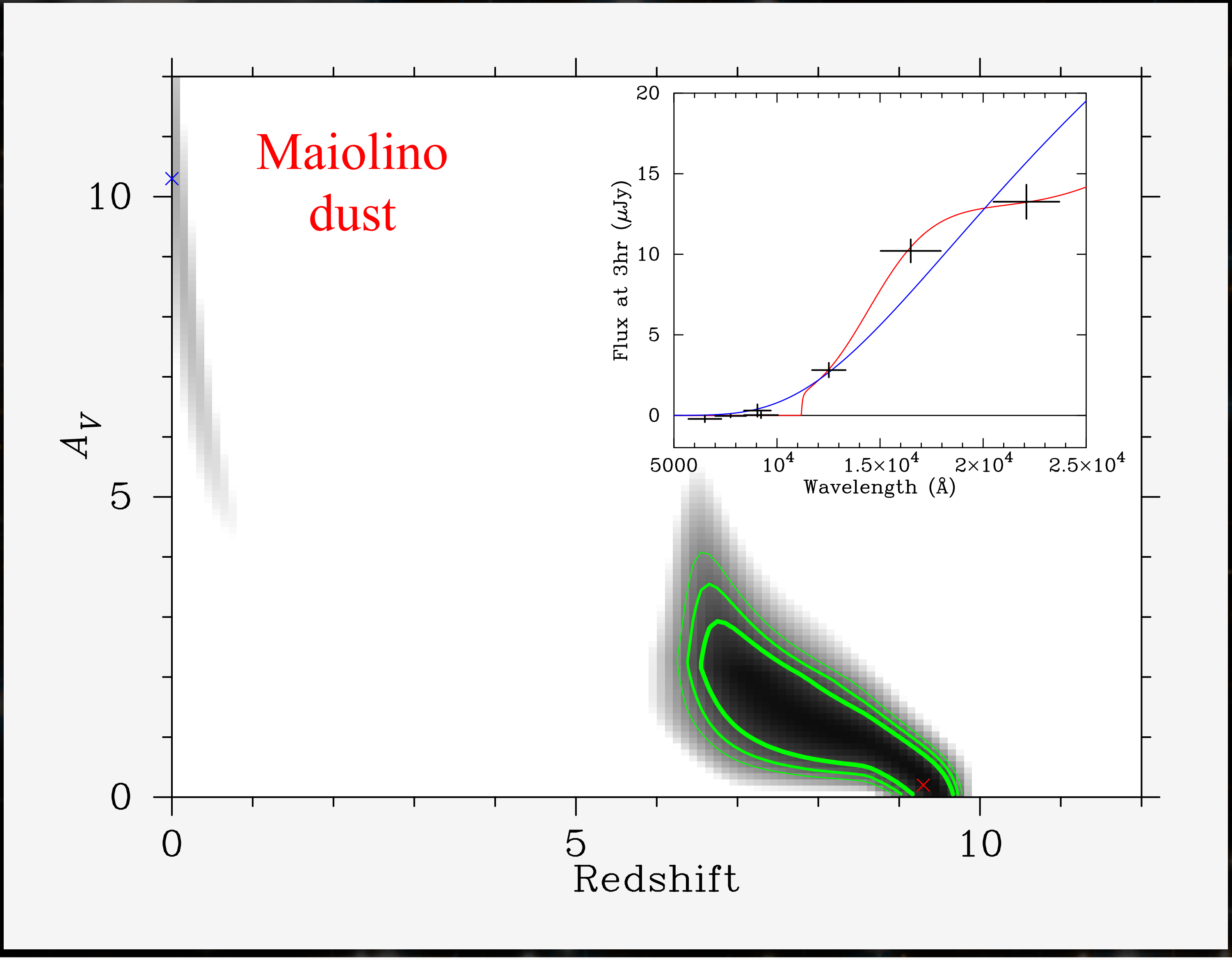
# GRB 090429B Another high-redshift candidate (photo-z~9.4).




Cucchiara et al. 2011

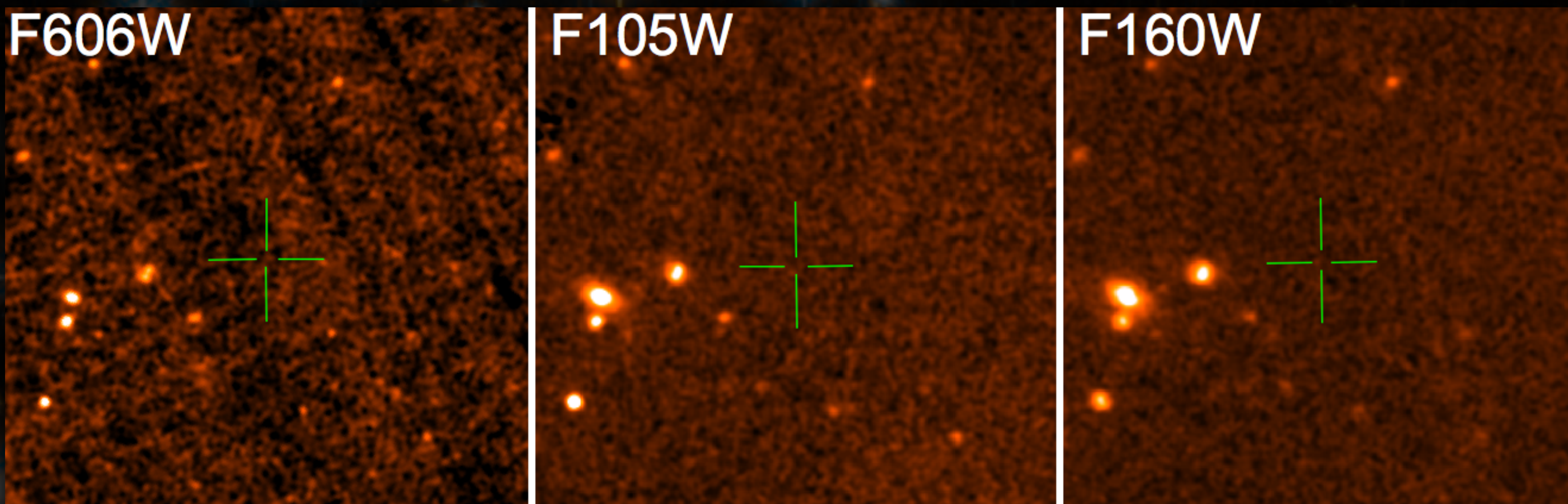
# GRB 090429B

Other dust laws allow somewhat wider range of z, but all high.



# GRB 090429B

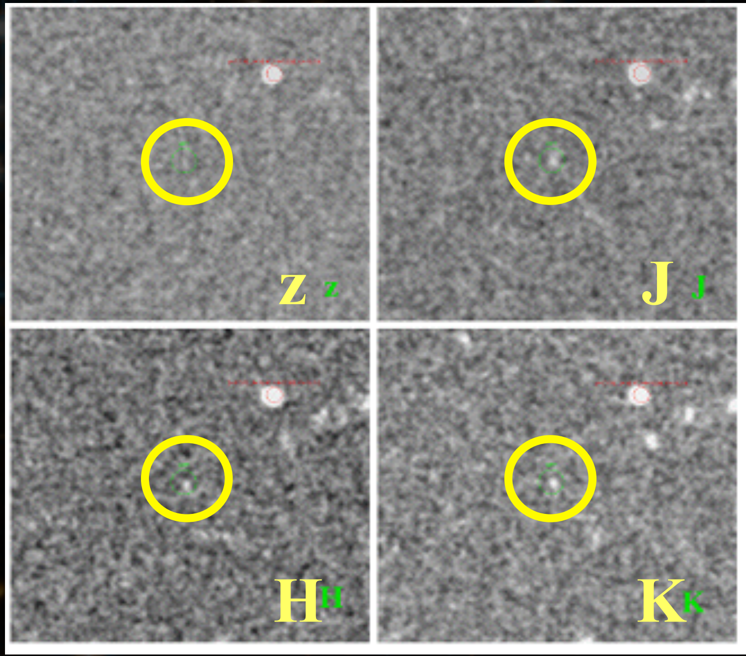
Other evidence...



# GRB 100905A

A burst with photo-z ~7. 5 ?

Courtesy of Myungshin Im




(Im et al. 2010, GCN Circ.11222)

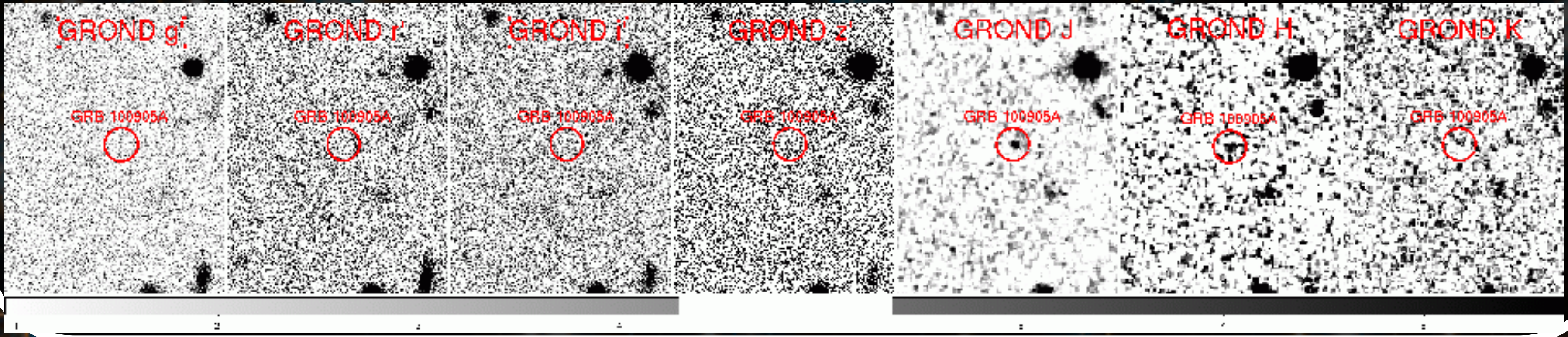
- BAT alert at 2010, Sept. 5

  $T_{90} = 3.4 \pm 0.5$ sec

- UKIRT follow-up, 14-26 min after the burst (z,J,K,H)

  → NIR afterglow (z-drop)

GROND (~17 hrs after BAT alert)



# GRB 100905A

GRB 100905A

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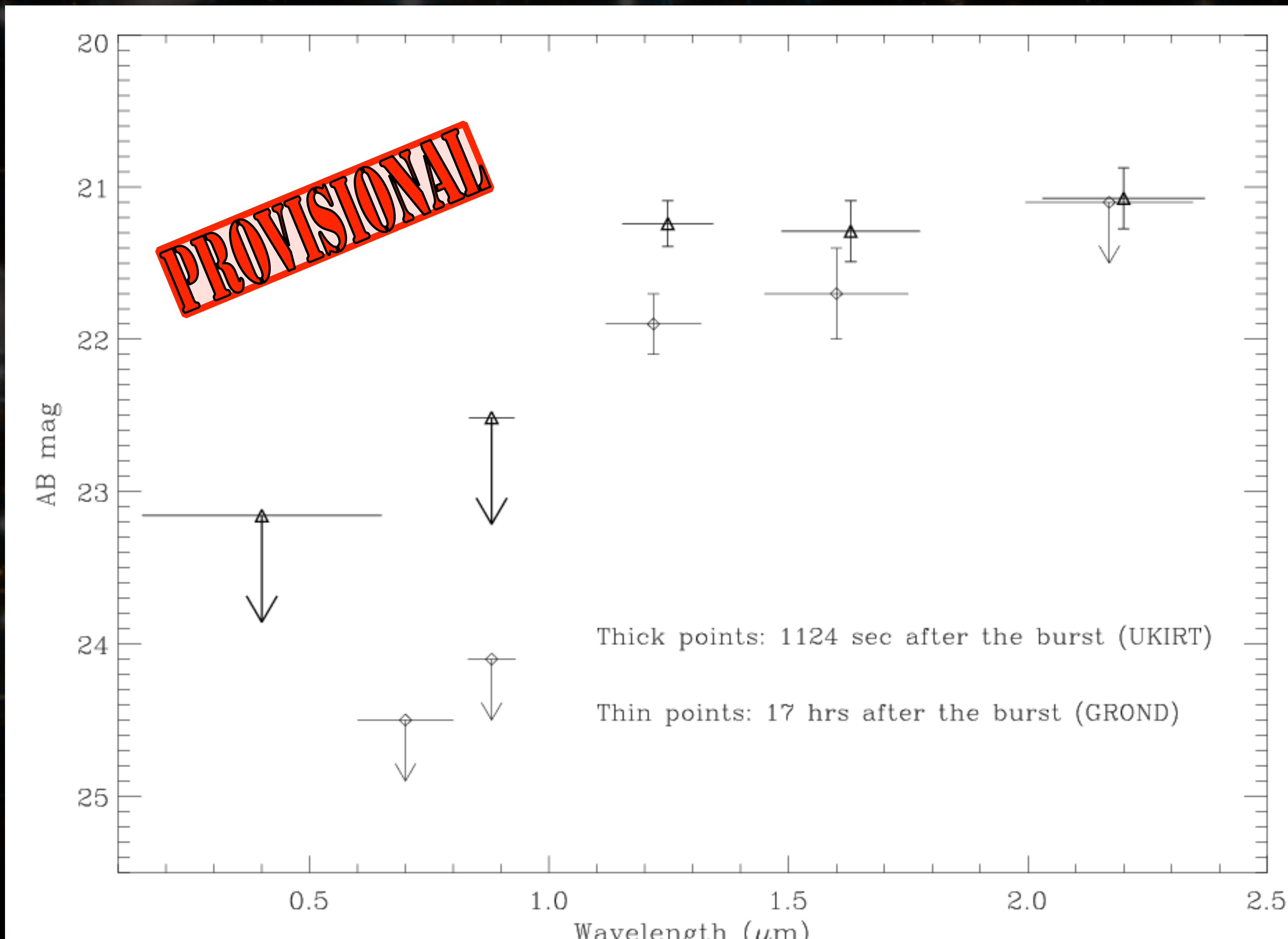

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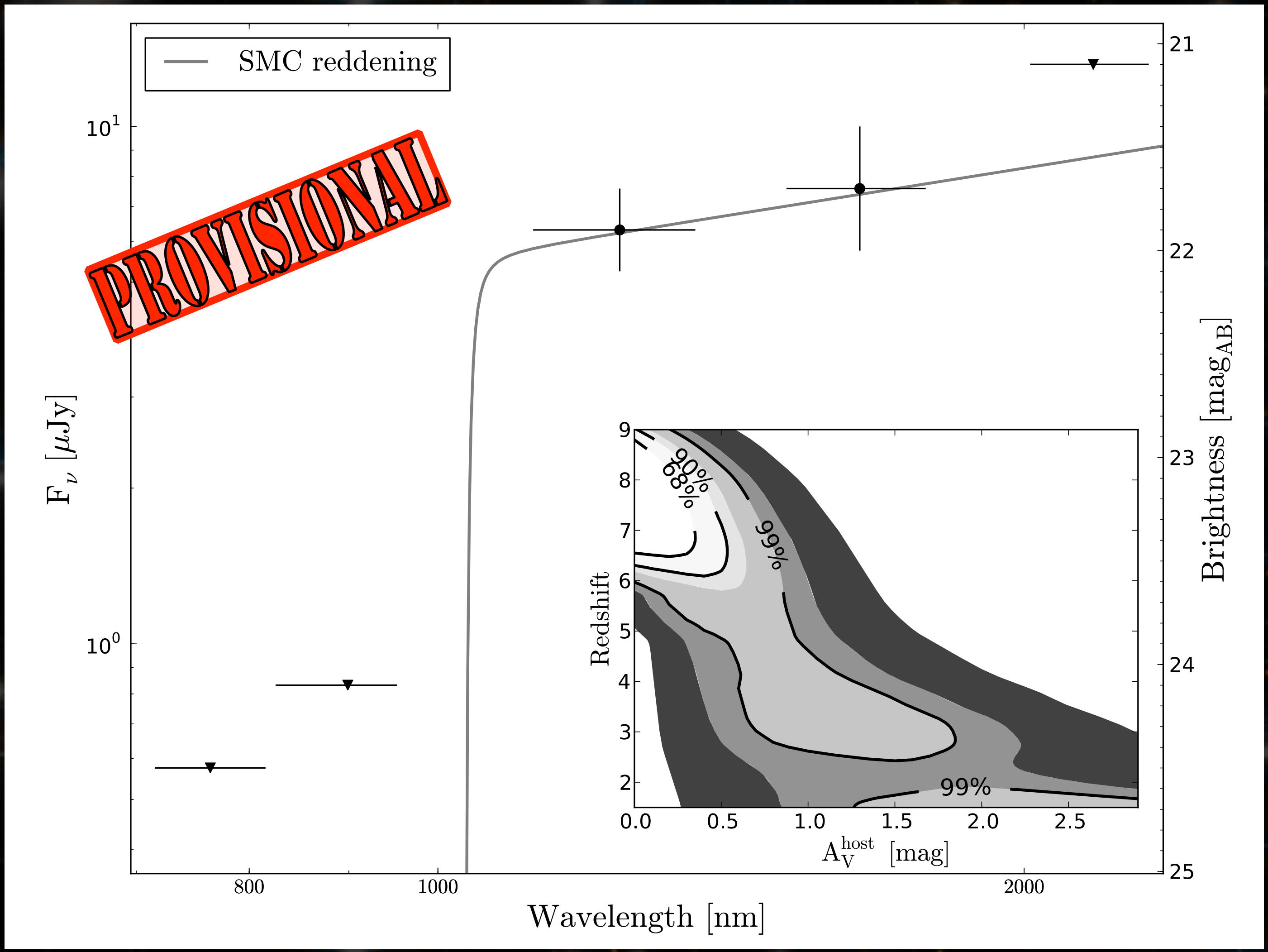
A burst with photo-z ~7. 5 ?

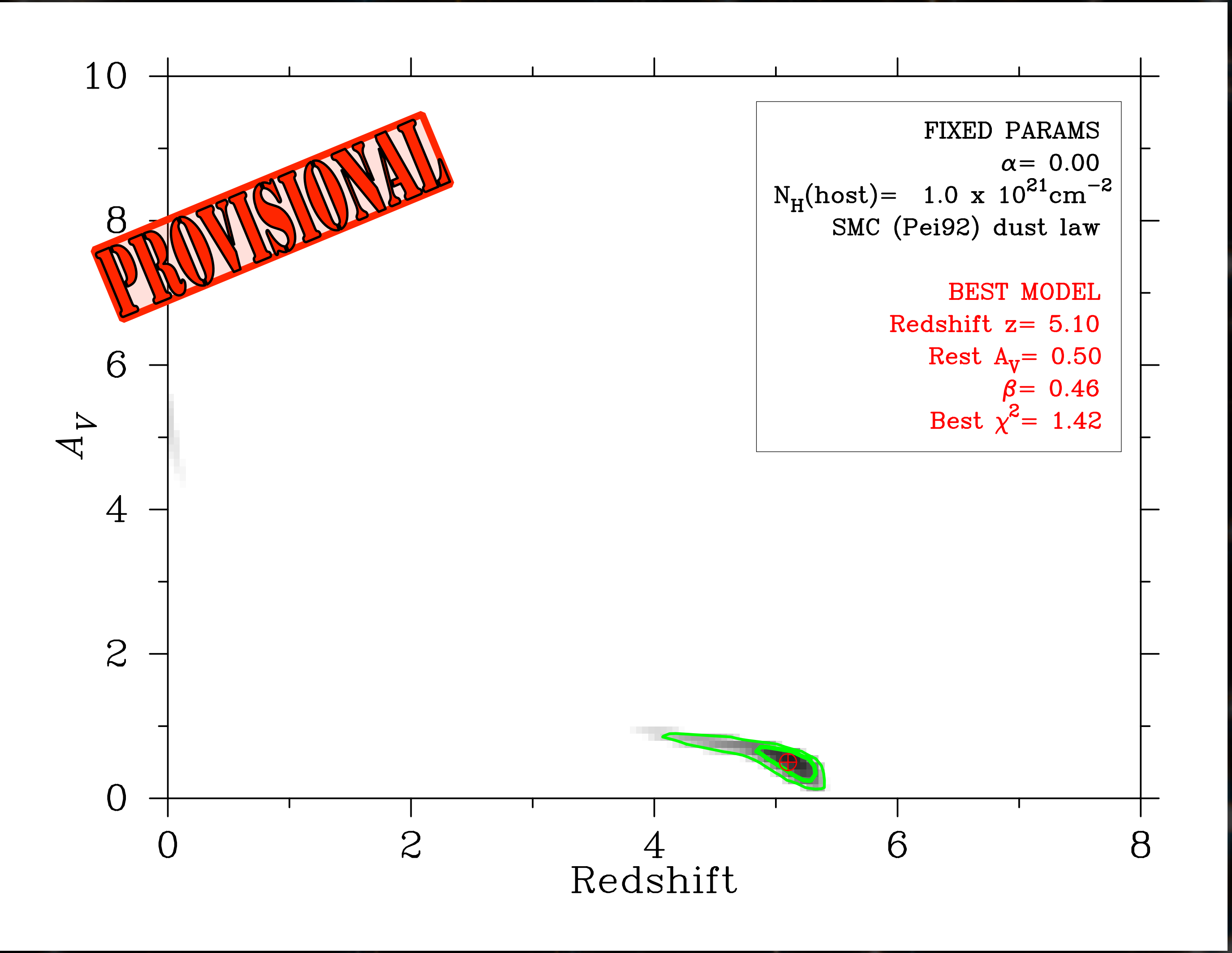
GRB 100905A



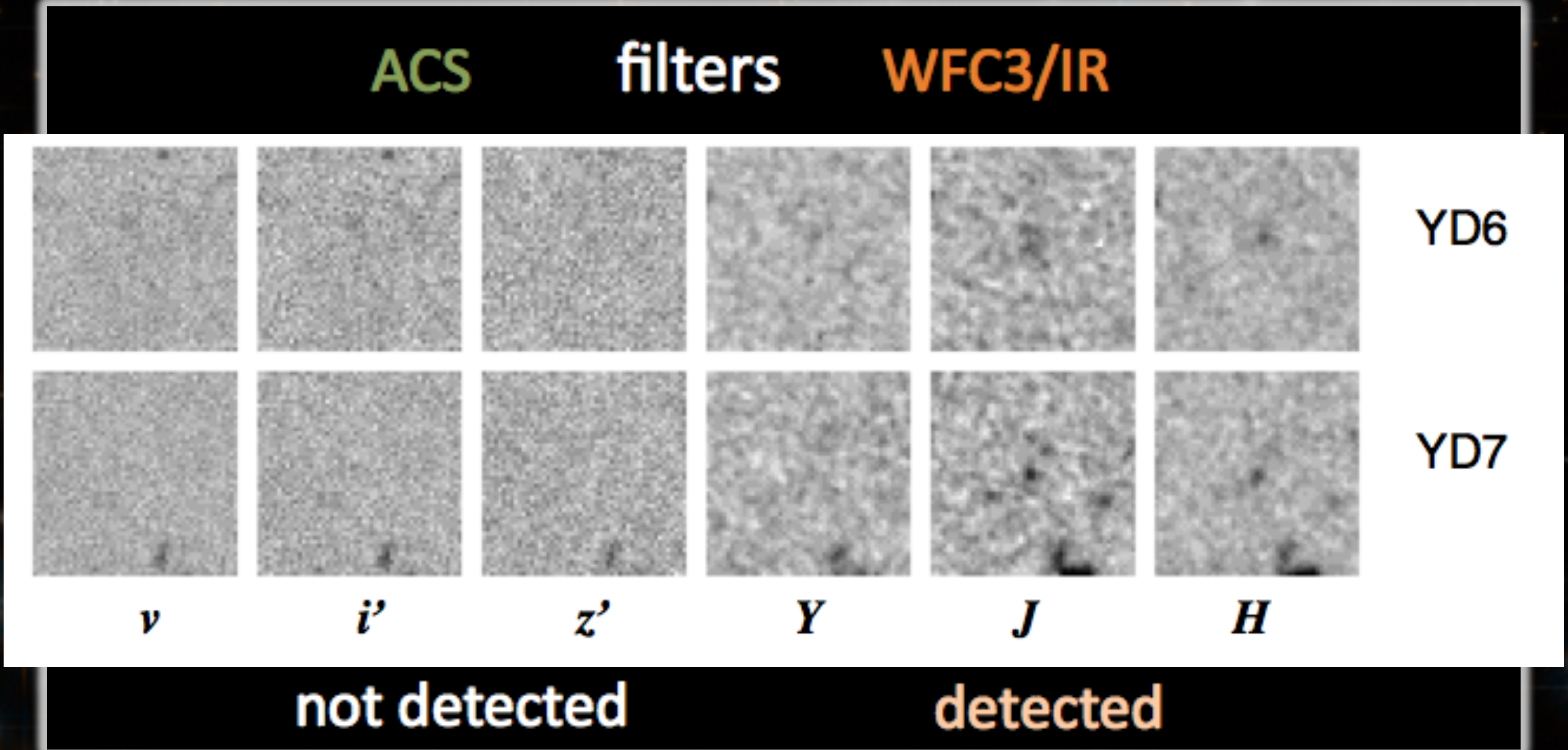

Courtesy of Thomas Kruehler/GROND

# GRB 080320

Another burst with photo-z ~ 5 ?

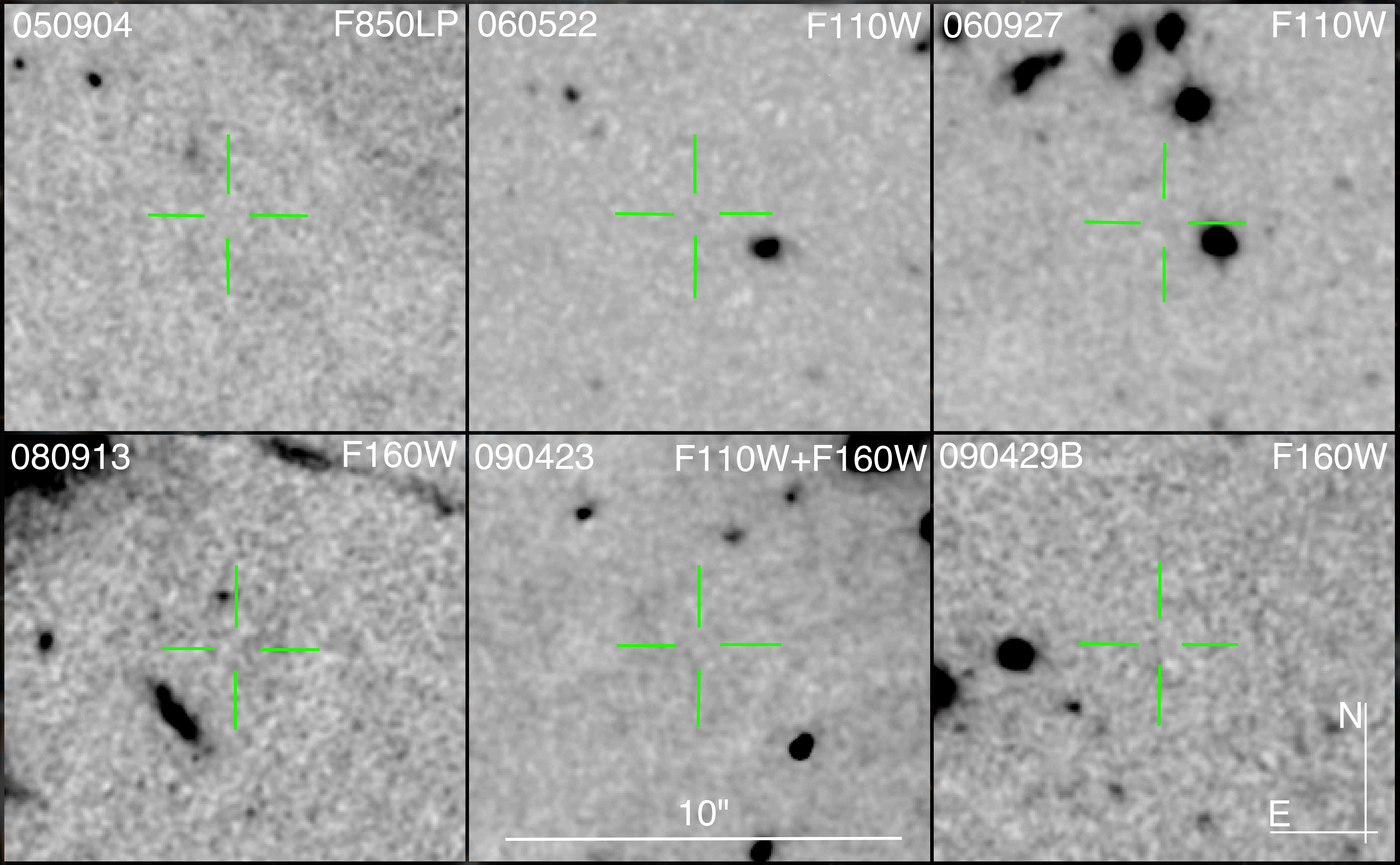


# Direct detection of stars and galaxies at z>7 is tough!




Bunker et al. 2010

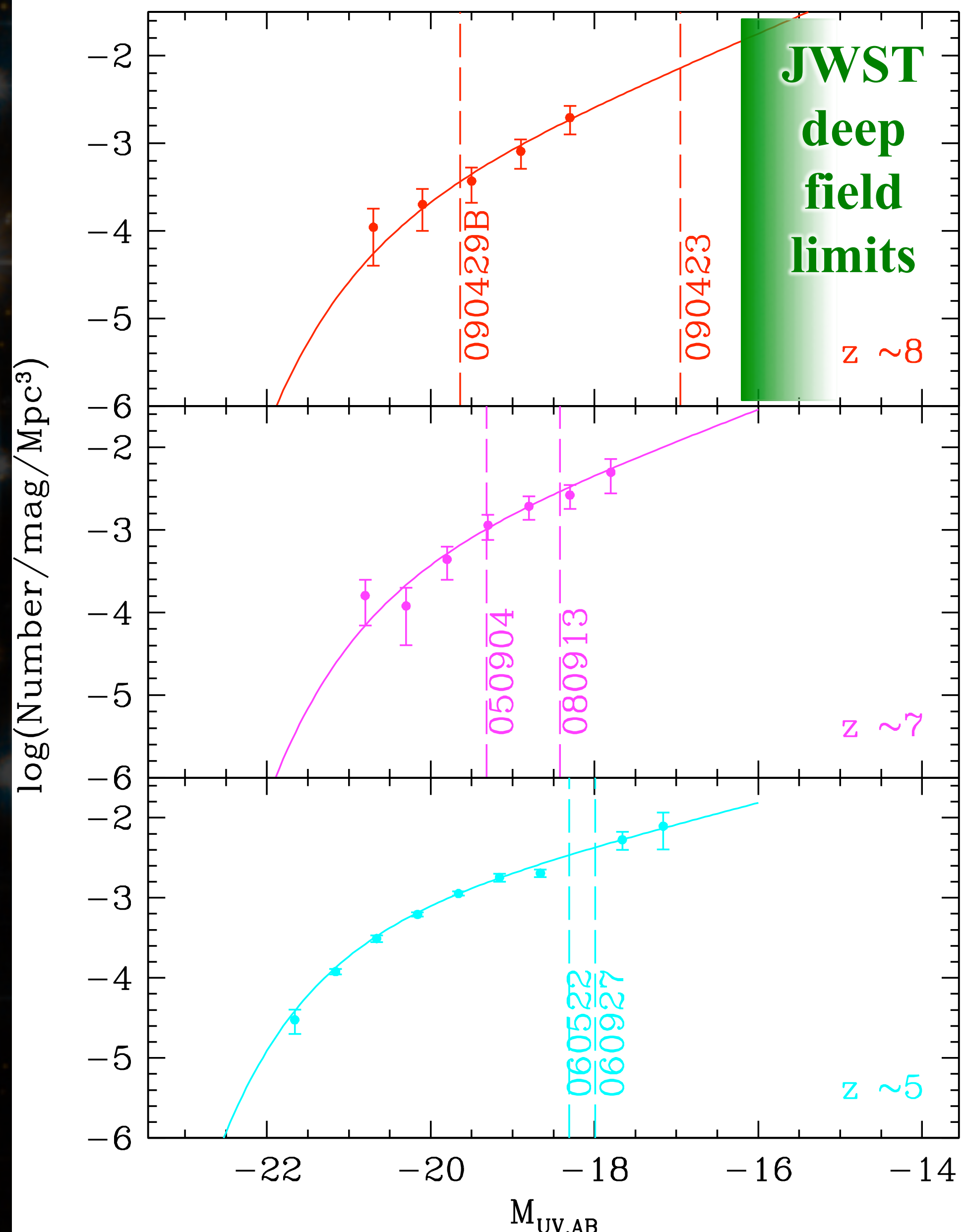
# Star formation location at high-z from GRBs




*Tanvir, Levan et al. ApJ in press*

Limits in some cases very deep since knowledge of position allows us to look for low-significance detections (and we don't need deep veto integrations).

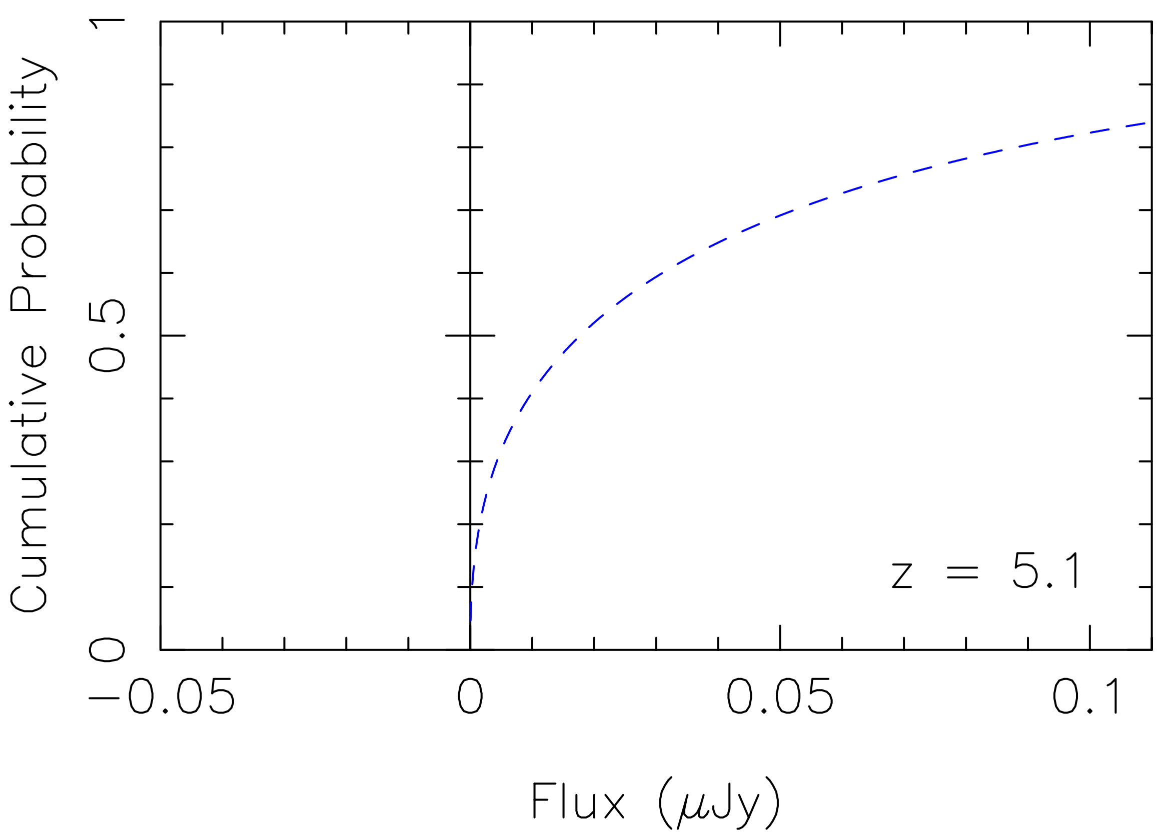
Even detection by *JWST* will be hard for the bulk of star-forming galaxies by $z$~10.



# Is non-detection of high-z hosts expected?

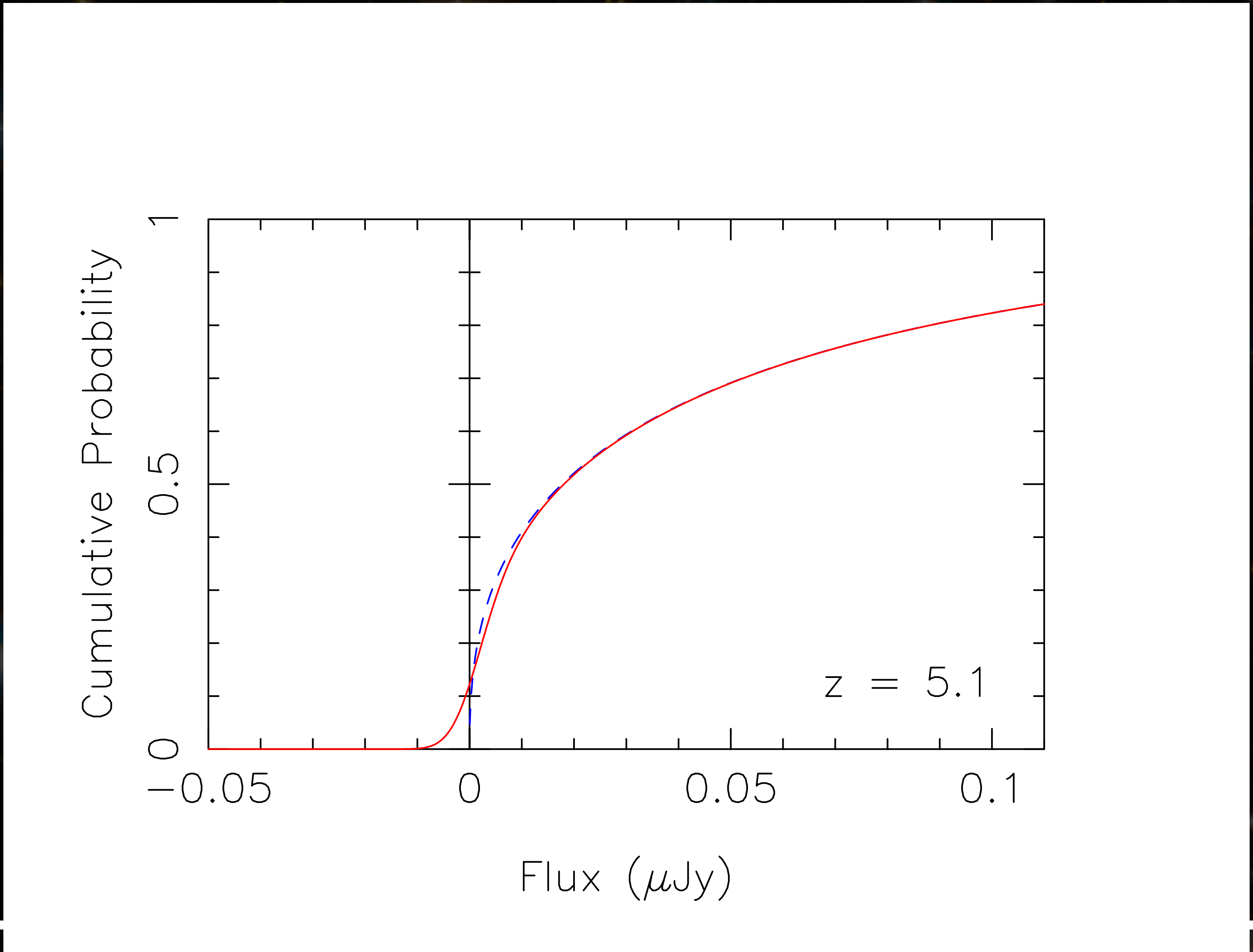
Assume GRB rate is proportional to the UV luminosity of a galaxy (implicitly this assumes no/little dust).

Construct luminosity-weighted luminosity function of all galaxies, which then provides a probability distribution of host luminosities (integrate to give cumulative plot shown).



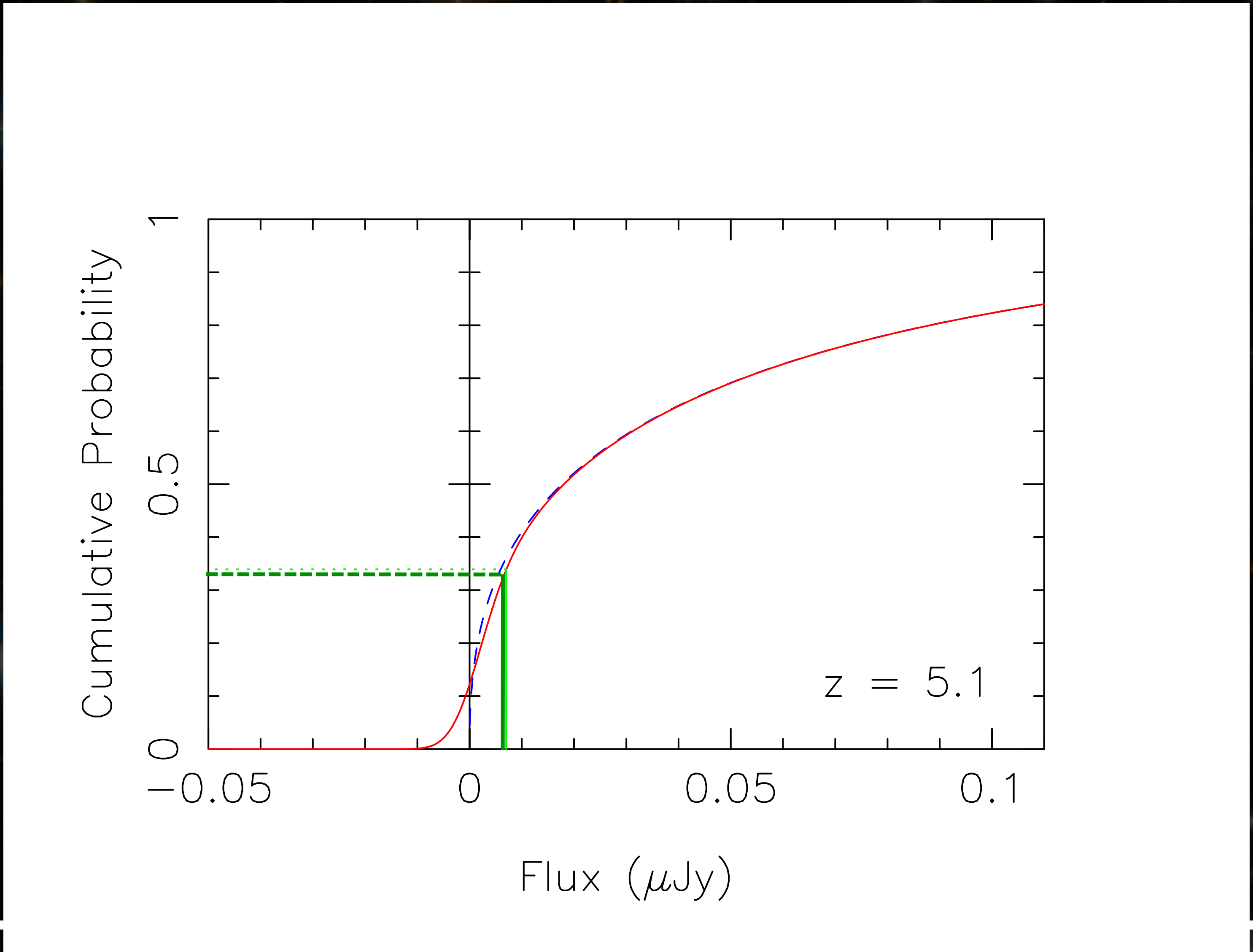
# Is non-detection of high-z hosts expected?

Convolve this with observational error distribution for flux measurement.

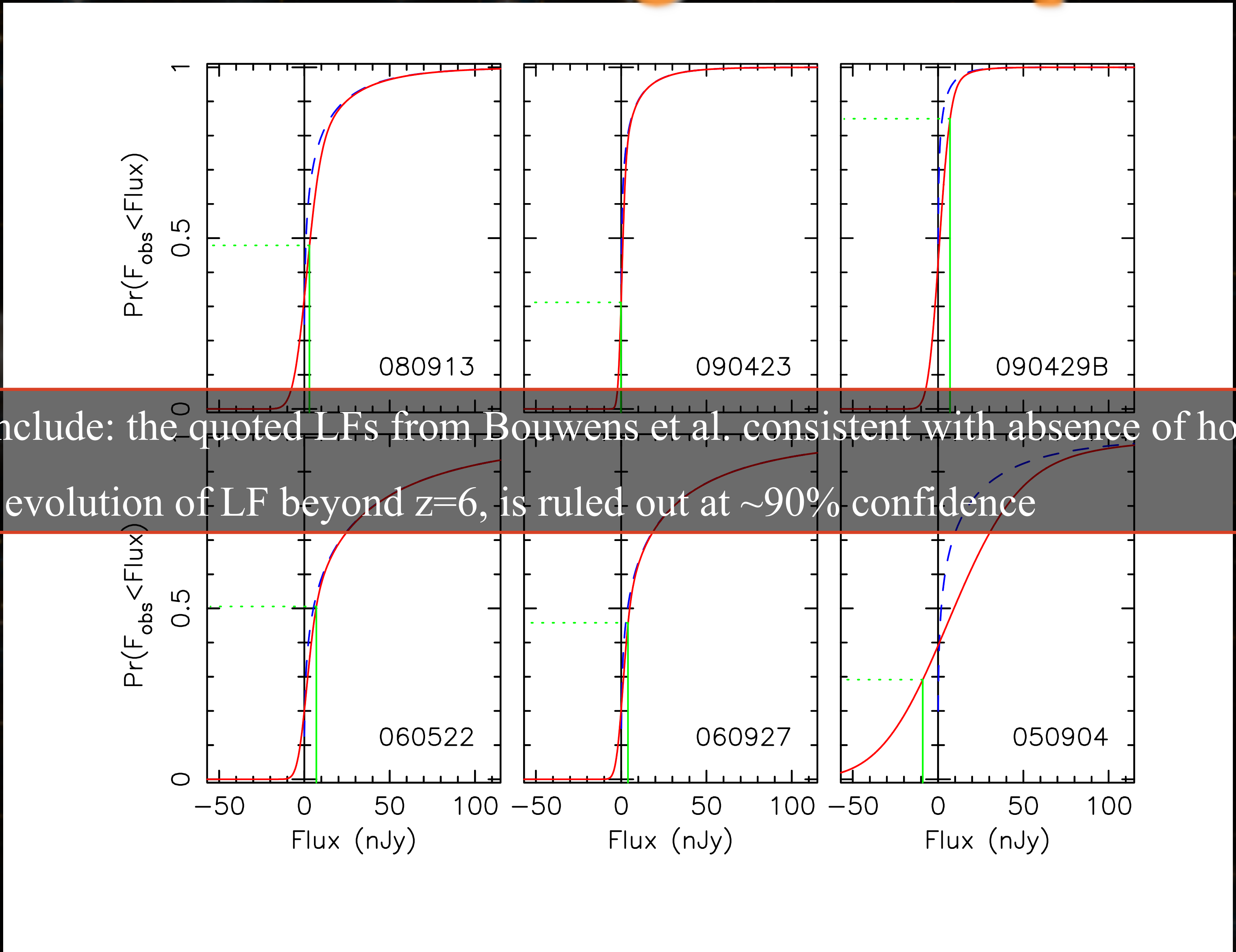


# Is non-detection of high-z hosts expected?

Compare to observed flux measured at site of GRB (assumes GRB "marks the spot")



# Is non-detection of high-z hosts expected?

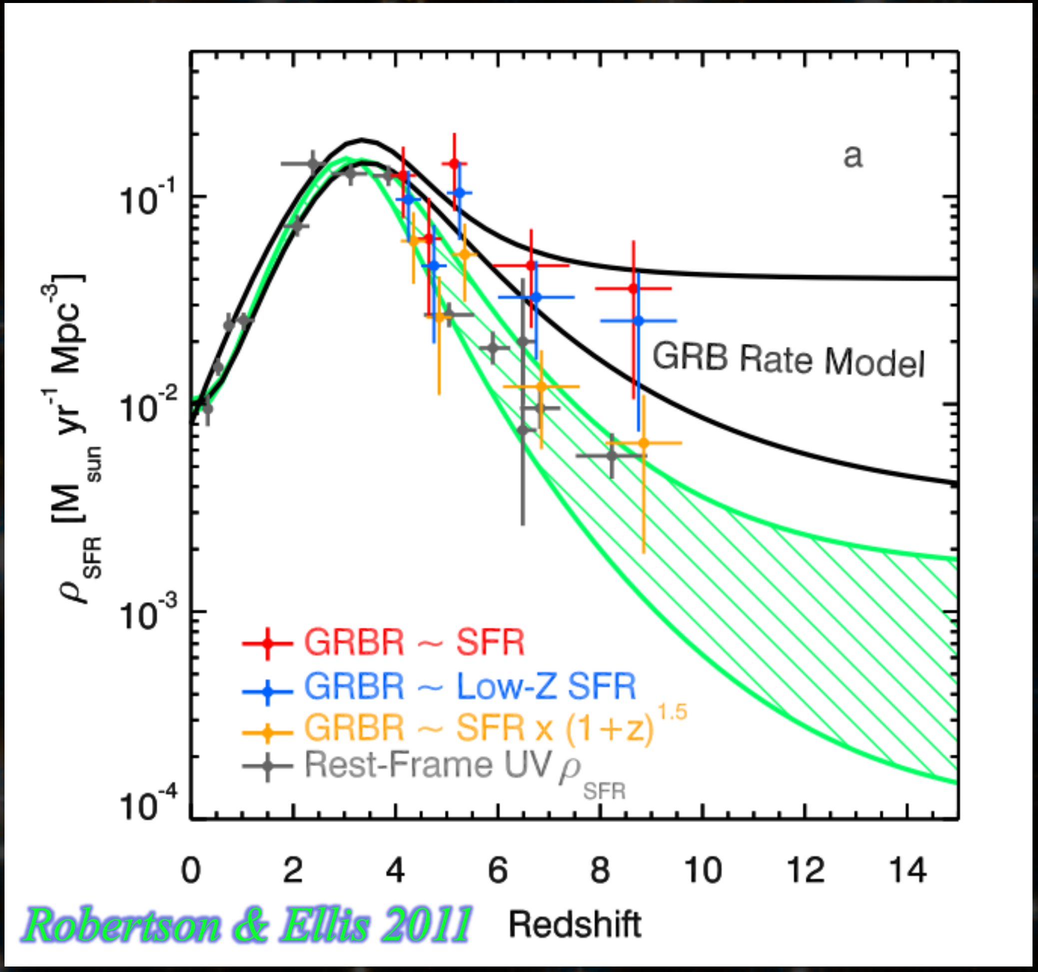



Conclude: the quoted LFs from Bouwens et al. consistent with absence of hosts.

No evolution of LF beyond z=6, is ruled out at ~90% confidence

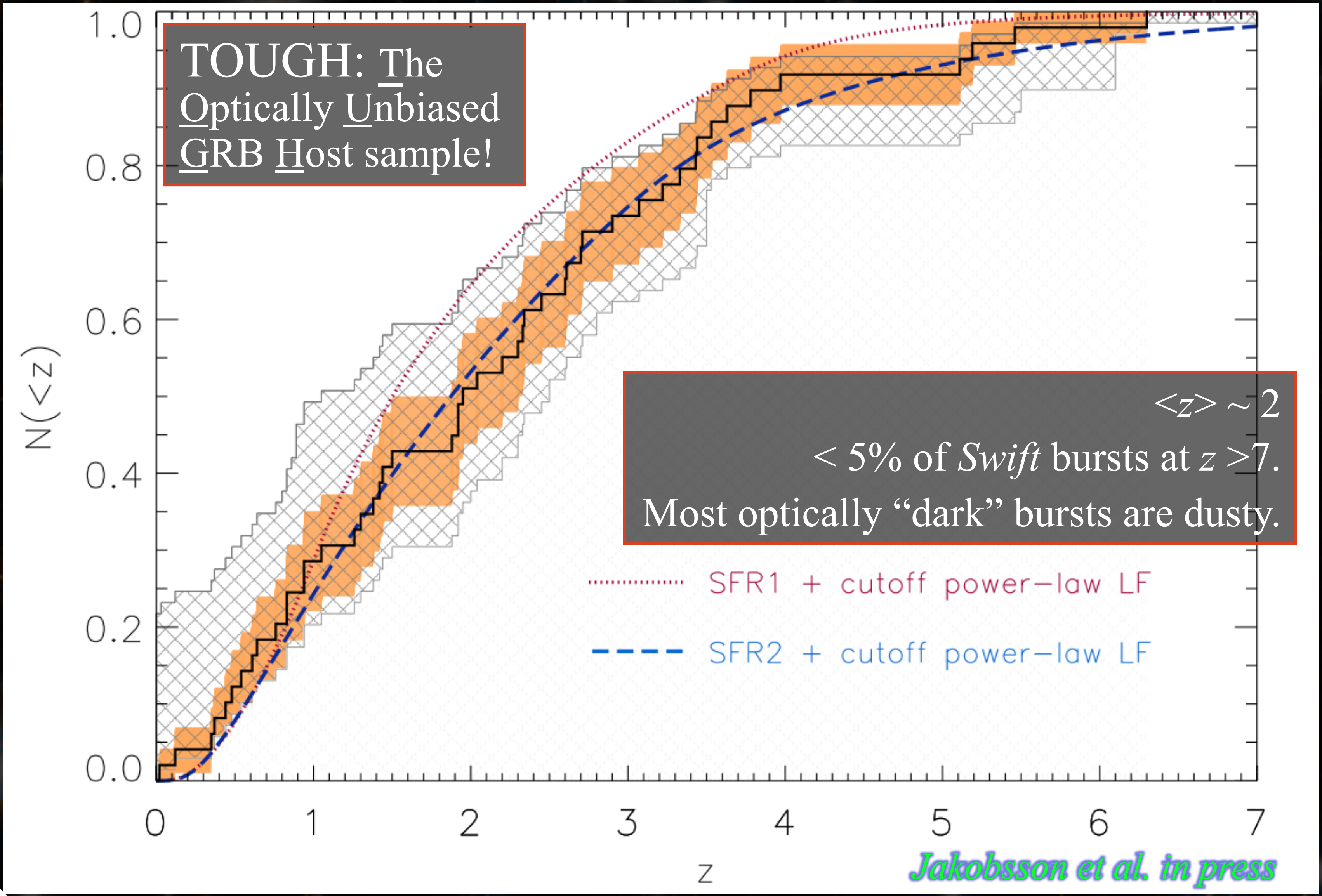
# Star formation history from GRBs

Appear to be too many GRBs at high redshift compared to conventional star formation history predictions.

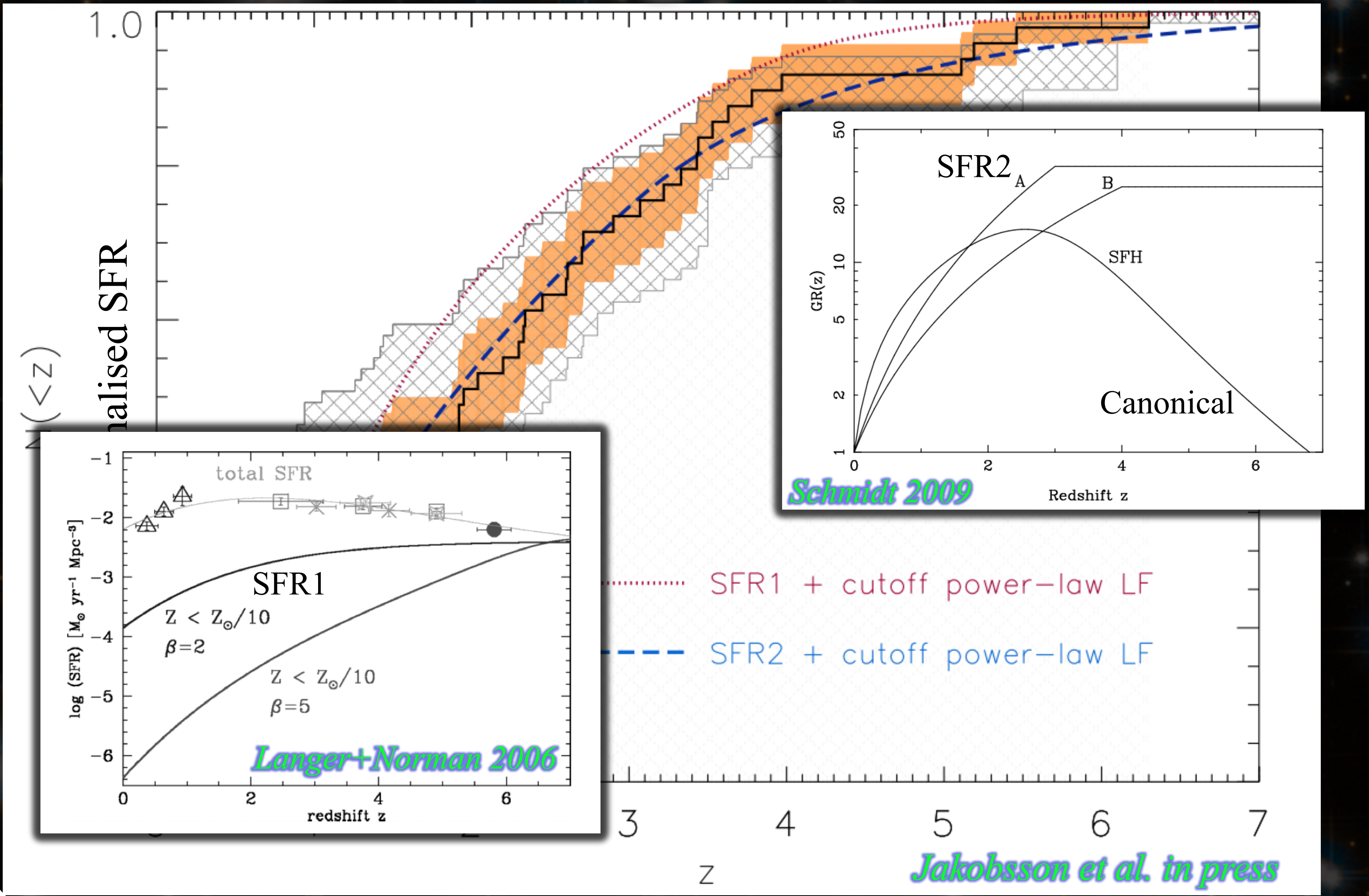



But, must worry about metallicity effects and also incompleteness of GRB redshift measurements.

# Star formation history from GRBs



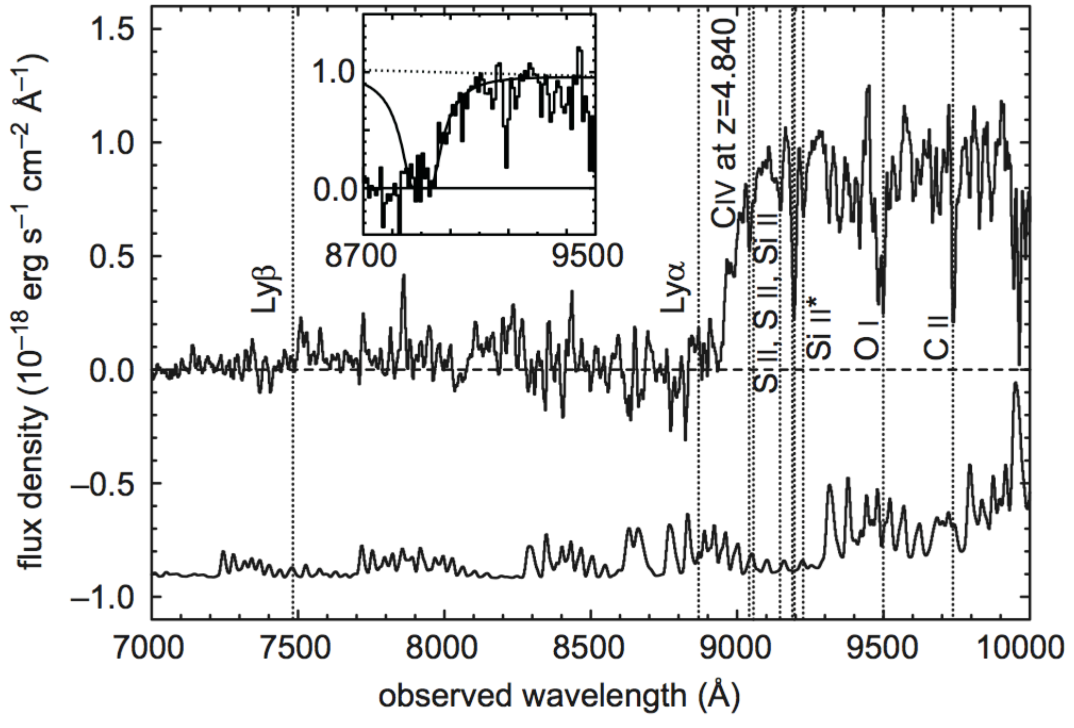
# Star formation history from GRBs



# Back to what we could learn from spectroscopy of high-z afterglows

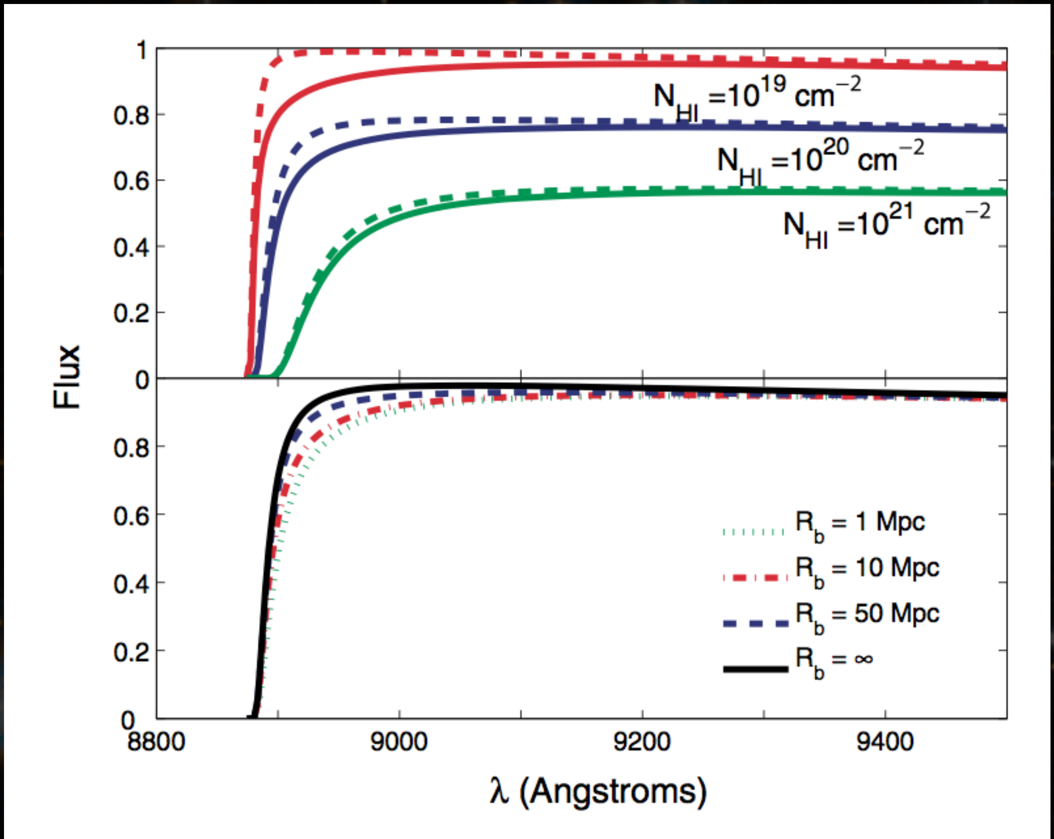
Evolution of metallicity, dust, escape fraction, IGM neutral fraction…

GRB 050904, Kawai et al. 2006



# GRBs: powerful probes of IGM during reionization

Red damping wing of Ly-alpha measures IGM neutral fraction.



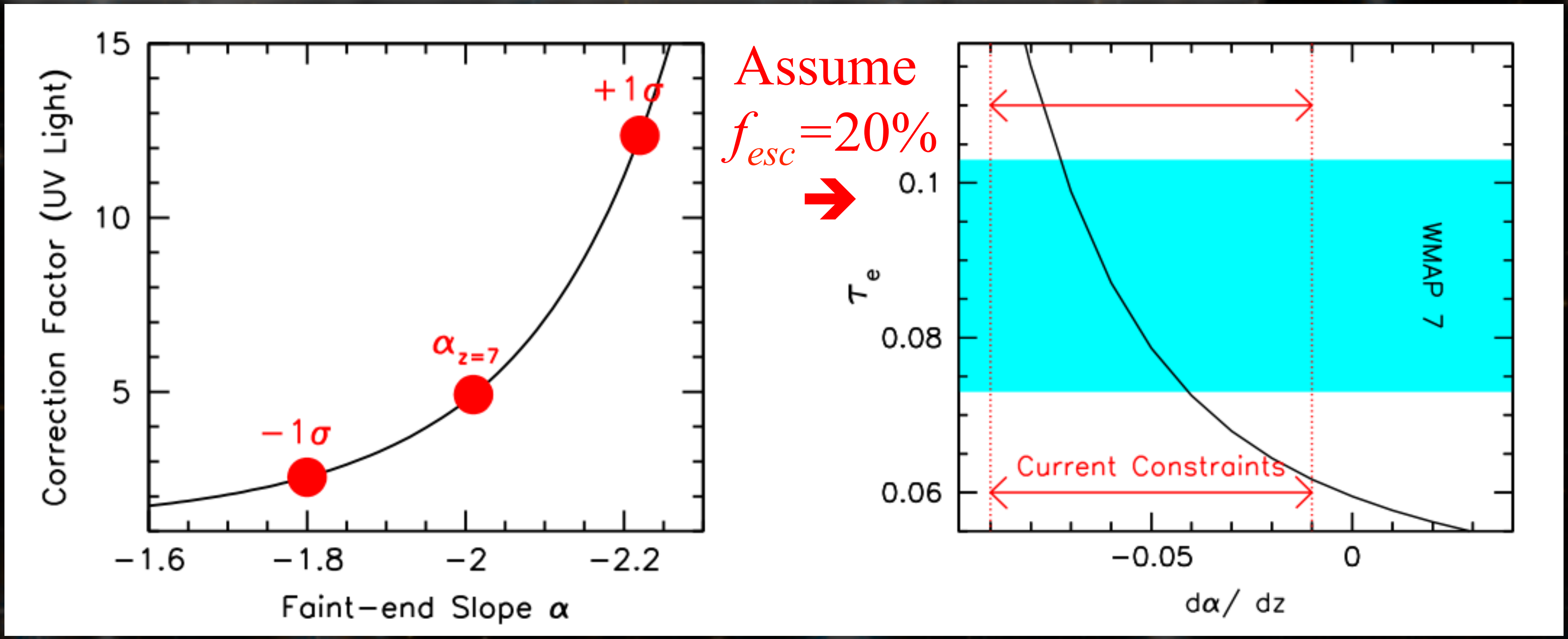

In practice very good S/N required to disentangle host absorption and effects of local ionized bubble.

Also many sight-lines required to map environment-dependent progress of reionization.

If you can disentangle contributions, then also can get host NH and metallicity.

*McQuinn et al. 2008 (Barkana & Loeb 2004) also Totani et al. 2006*

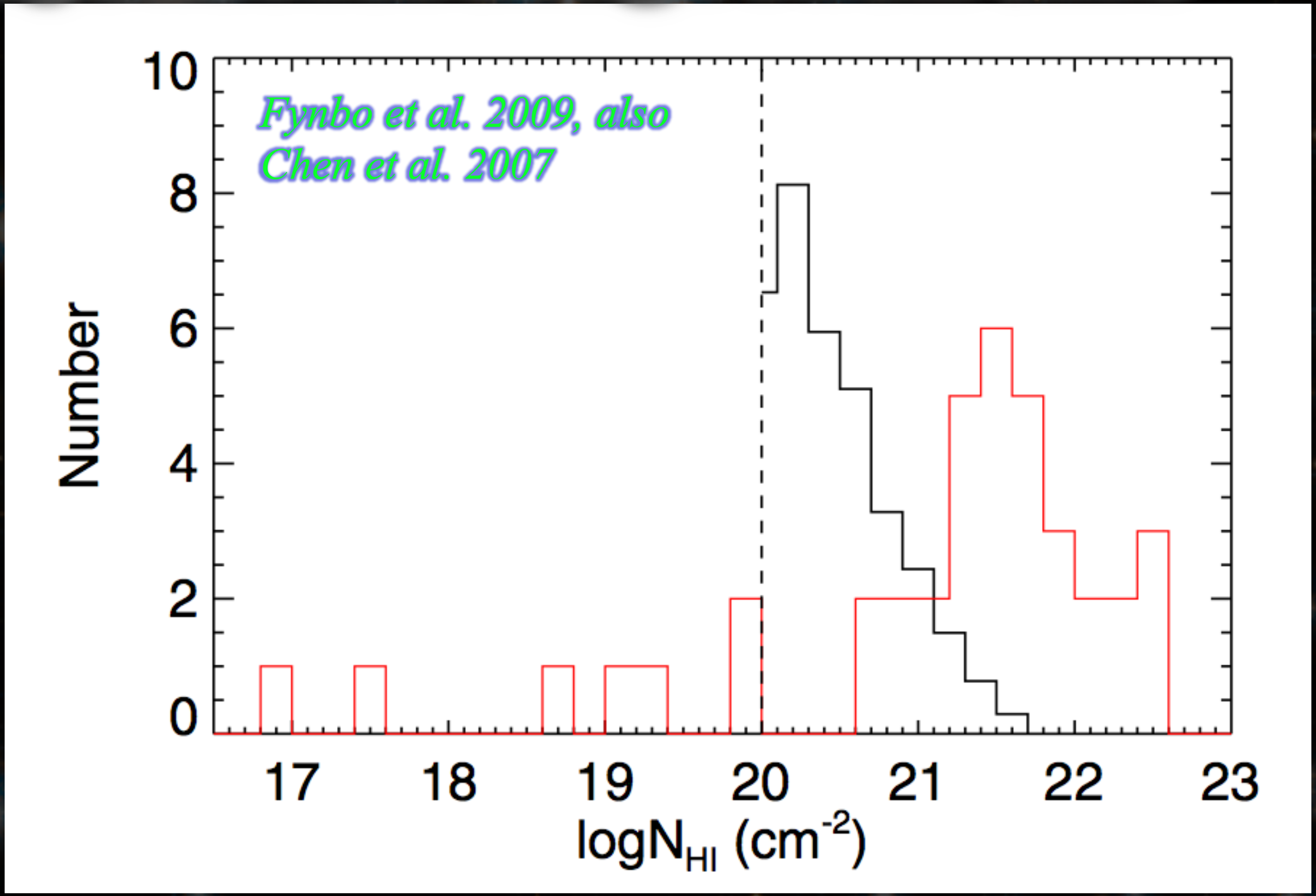
# Could stars have reionized the universe?



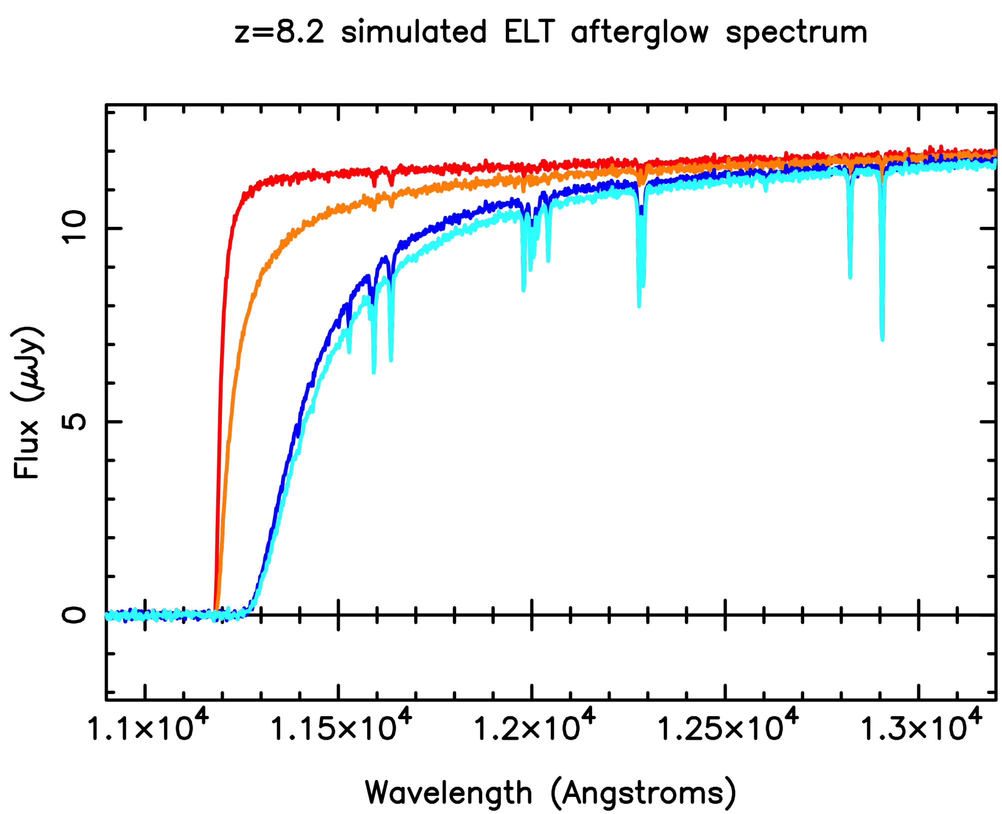

other uncertainties too: is Schechter function appropriate? Is there dust not accounted for? What is the Lyman continuum escape fraction at high redshift? Cosmic variance?

*Bouwens et al. 2011*

# Escape fraction at high-z from GRBs




High column densities seen in optical spectra of most 2<z<4 GRBs suggest escape fraction <few %


| Log(NH) (host) | NF (IGM) |
|---|---|
| 20 | 0 |
| 20 | 0.8 |
| 22 | 0 |
| 22 | 0.8 |

Little gas in host ⟹ good characterization of IGM.

Much gas in host ⟹ superb metallicity determinations.

Simulated GRB090423 spectrum taken by ELT rather than VLT (remember this was a faint afterglow!)

# Conclusions

- All the difficult things to measure through faint galaxy surveys can be accessed via high-z GRBs: faint-end slope of the LF, abundance determinations, dust laws, escape fractions, global star formation rate.

- Current results consistent with the bulk of z>6 star formation occurring in very faint galaxies below HST detection thresholds, but the GRB rate also suggests a significantly enhanced global star formation rate at high-z (but could be a manifestation of, e.g. metallicity dependence, changes in the stellar IMF).

- A steep faint-end slope of the galaxy luminosity function would help explain reionization as being largely due to star light, but high column densities in the hosts of GRBs argue for a low escape fraction of ionizing photons, so the predicament could still return.

- Although we have begun to exploit this potential, we need to plan for the *JWST* and 30-m class telescopes for much greater returns.