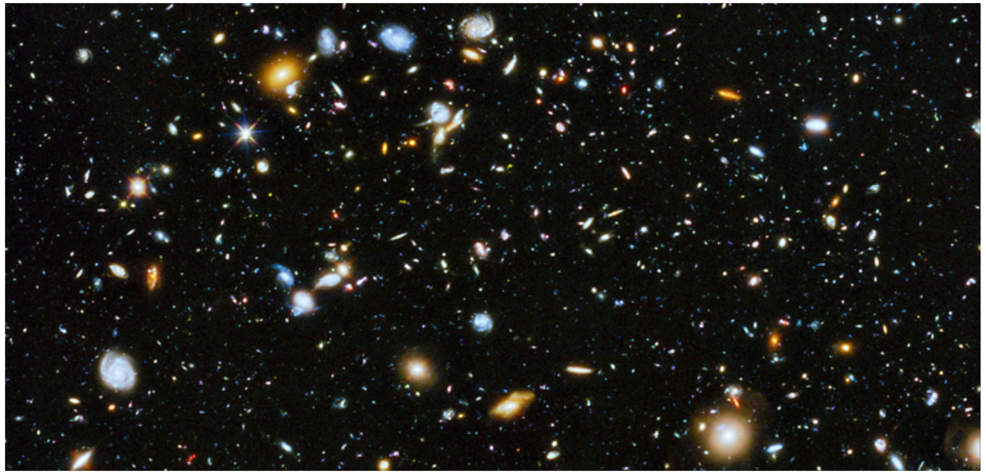
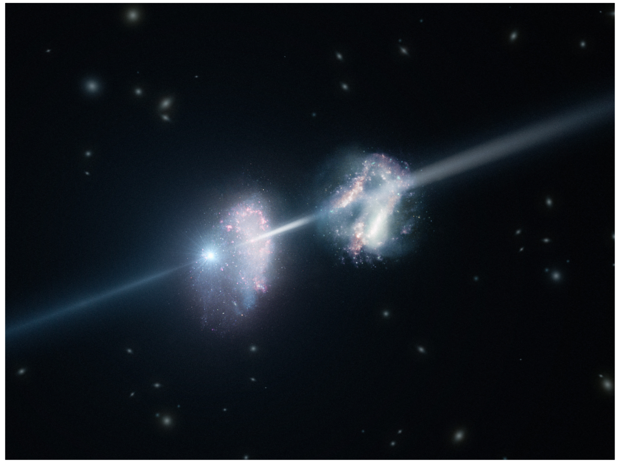
Routes to reionization (N. Tanvir)



Key question is, what reionized the universe? Ingredients:

- What was the timeline and topology of reionization?
- How much massive star formation was occurring?
- How much EUV did they produce?
- Did (somewhat lower mass) binaries contribute significantly?
- How much ionizing radiation escaped to the IGM?
- If not stars, then what?

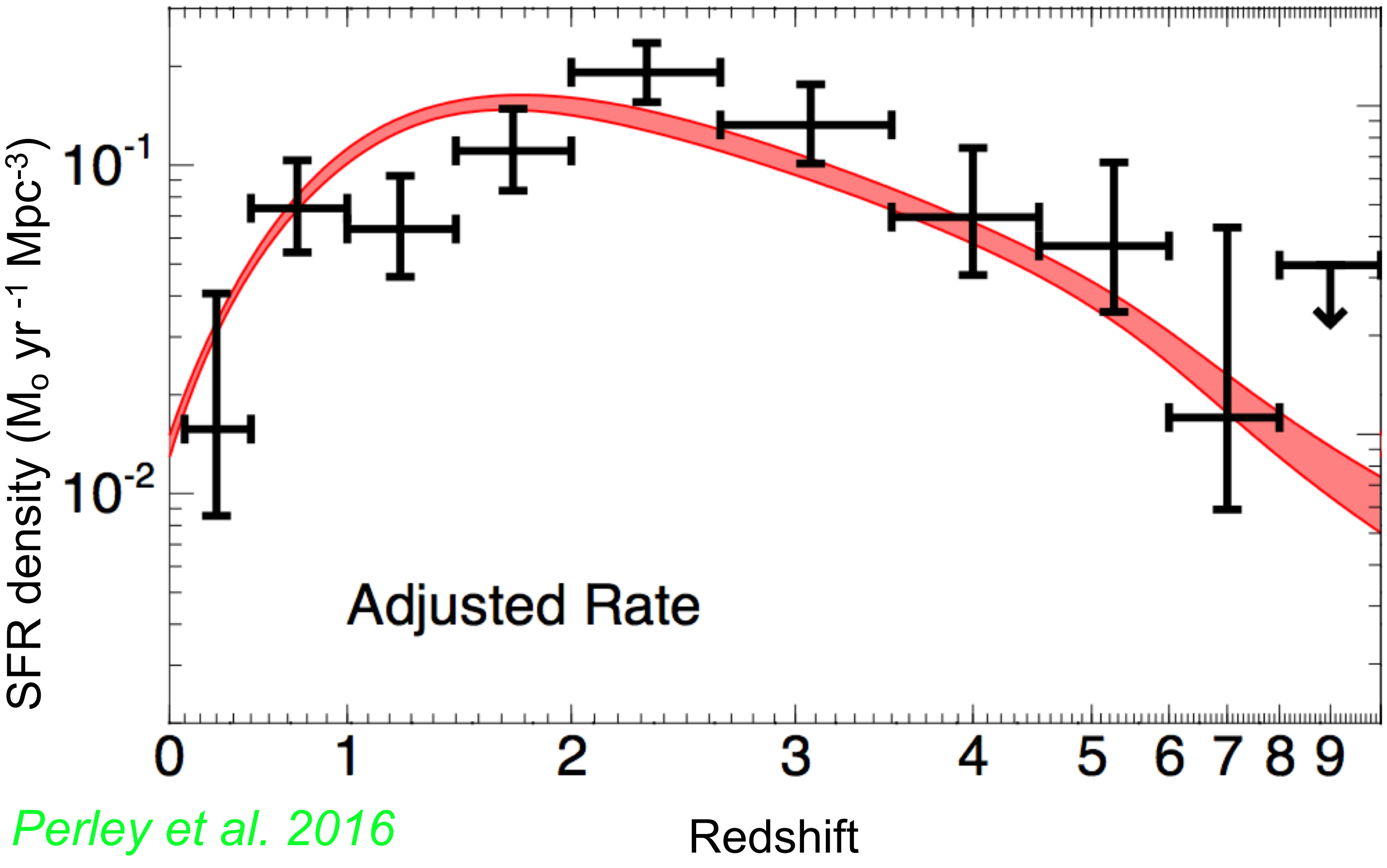
GRBs



- Global SFR
- Star forming galaxy populations
- Escape fraction
- Chemical enrichment (and implied SFR)
- Timeline and topology

Two routes to high-z SFRD

1. Count bursts in bins of redshift – scale luminosity function from lower redshifts (including corrections for evolutionary effects, particularly metallicity).



Perley et al. 2016

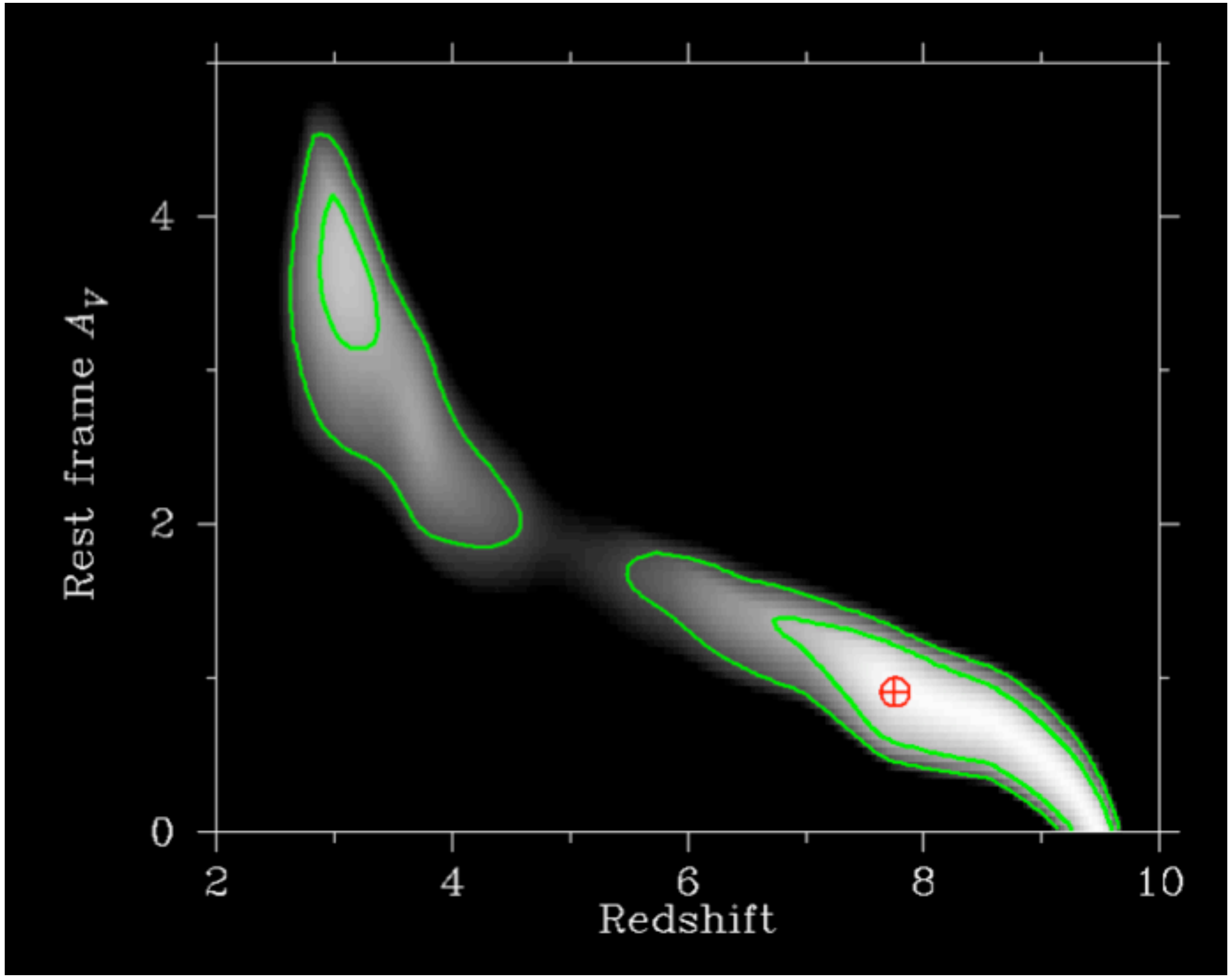
Note, still tension above/below z = 2; GRB rate continues to indicate higher SFR

Two routes to high-z SFRD

Health warning: dusty afterglows at lower-z can masquerade as high-z using photometric redshifts

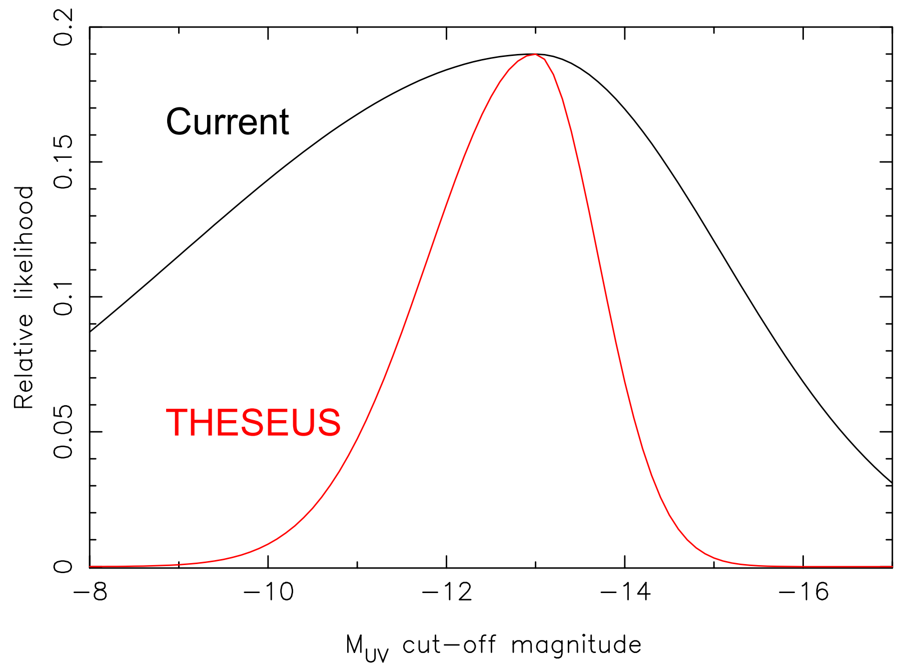
May rely more on ground spectroscopy for confirmation and refinement (although absence/presence of a low-z potential host in e.g. LSST imaging will clarify some cases).

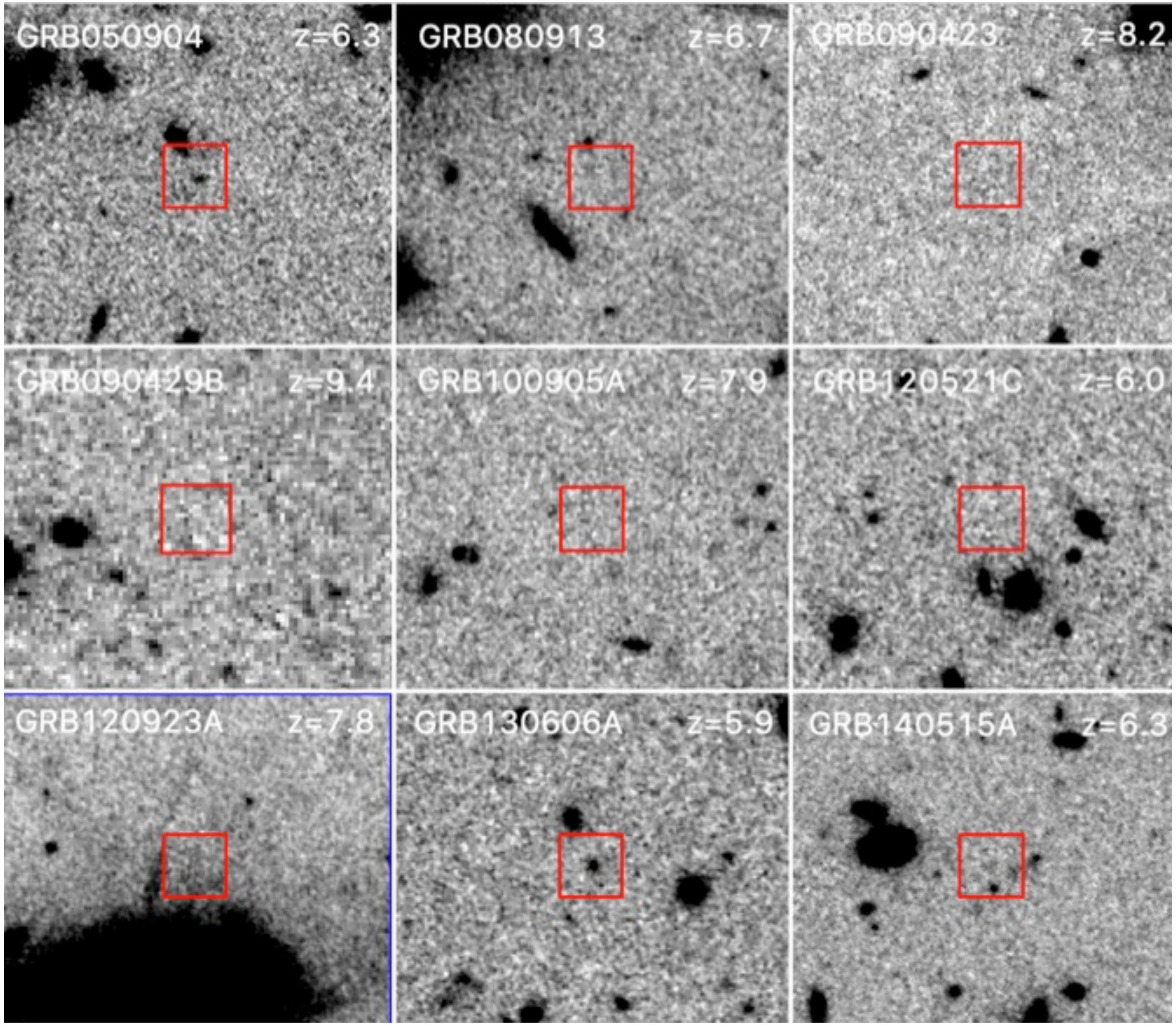
e.g. GRB 090429B without K-band data-point (z ~ 9.4 with K-band)



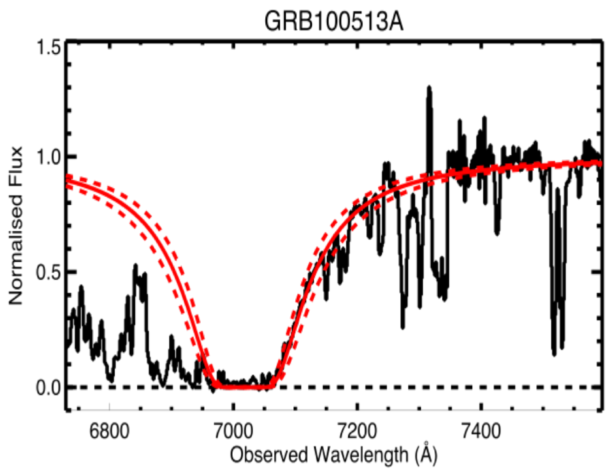
Two routes to high-z SFRD

2. Find ratio of “faint”-hosts to “bright”-hosts in the redshift range of interest, and hence extrapolate the star formation occurring in all galaxies, below the limits of even ELT.

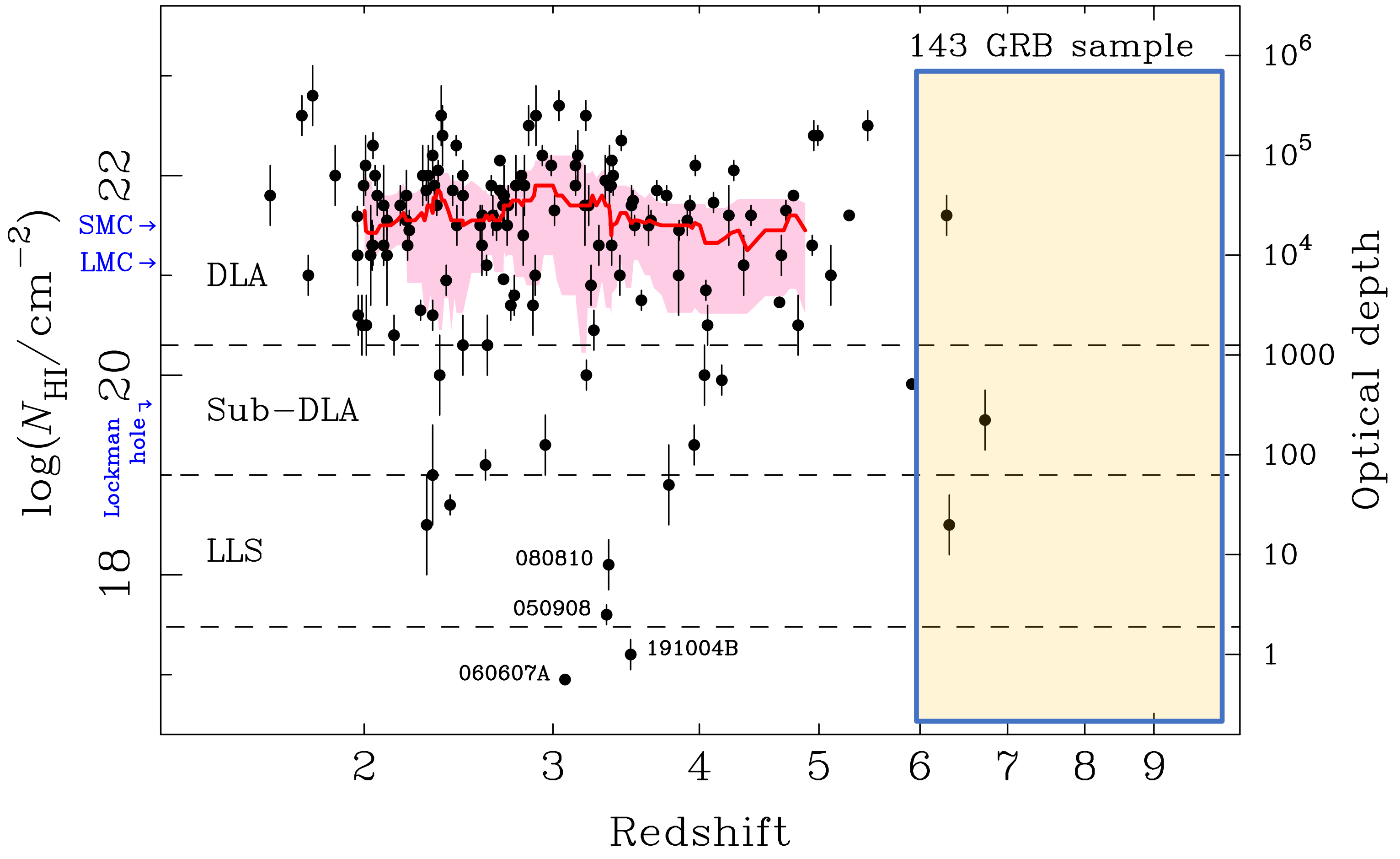




Reionization: constraining the EUV photon supply



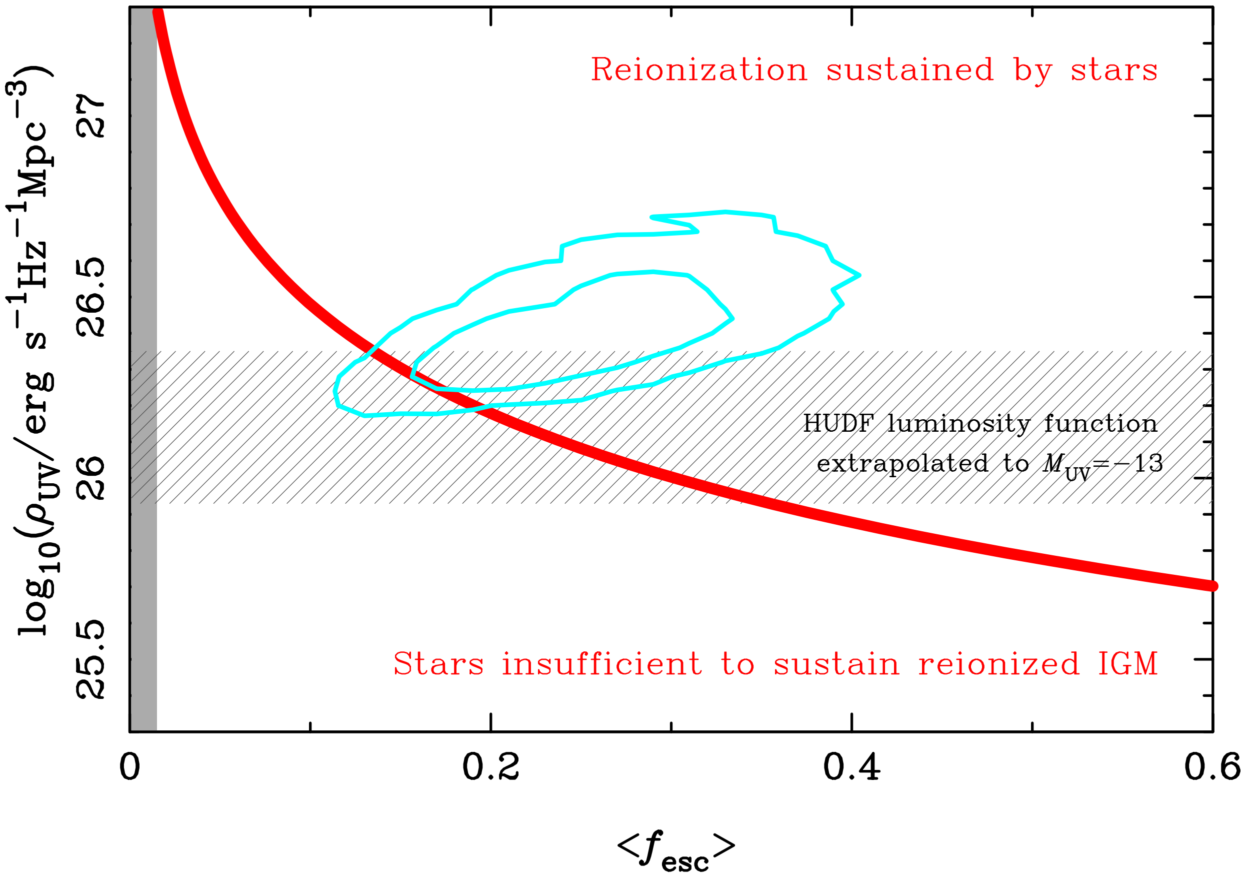
Observations of Ly-a absorption line in afterglow spectra provides robust measure of neutral H column, and hence opacity to ionizing photons.



High columns determined for most 2<z<5 GRBs gives strong upper limit to escape fractions for *these stellar pops* of <2 %, cf. ~10% required during reionization. Crucial to increase statistics at *z*>6.

Reionization: constraining the EUV photon supply

Combine SFR density with escape fraction constraints to assess viability of starlight bringing about and sustaining reionization.

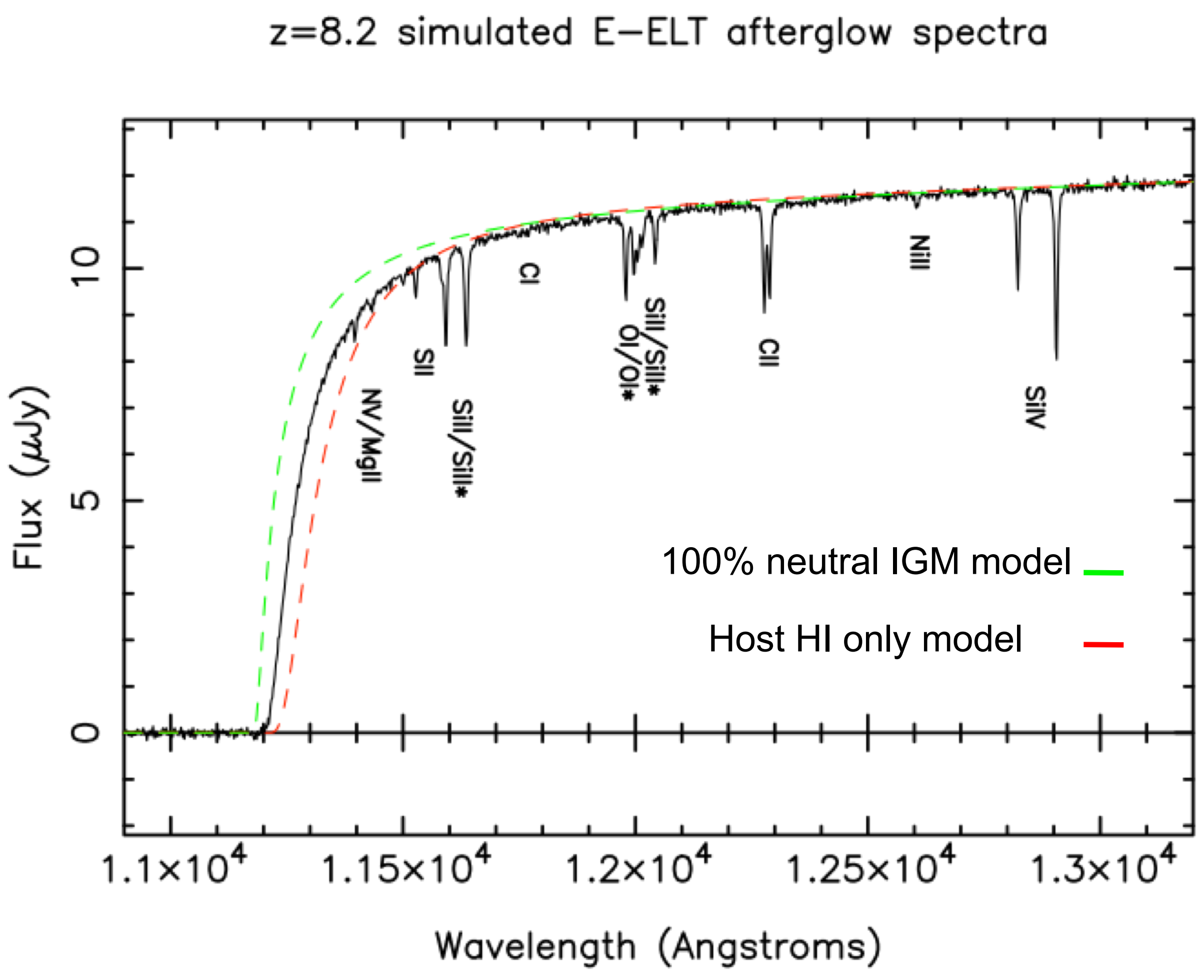


Simple simulation of constraints from 20 GRBs with ELT-class deep imaging for hosts and ELT-class spectra of afterglows. Comparable constraints on SFRD may come from GRB redshift distribution.

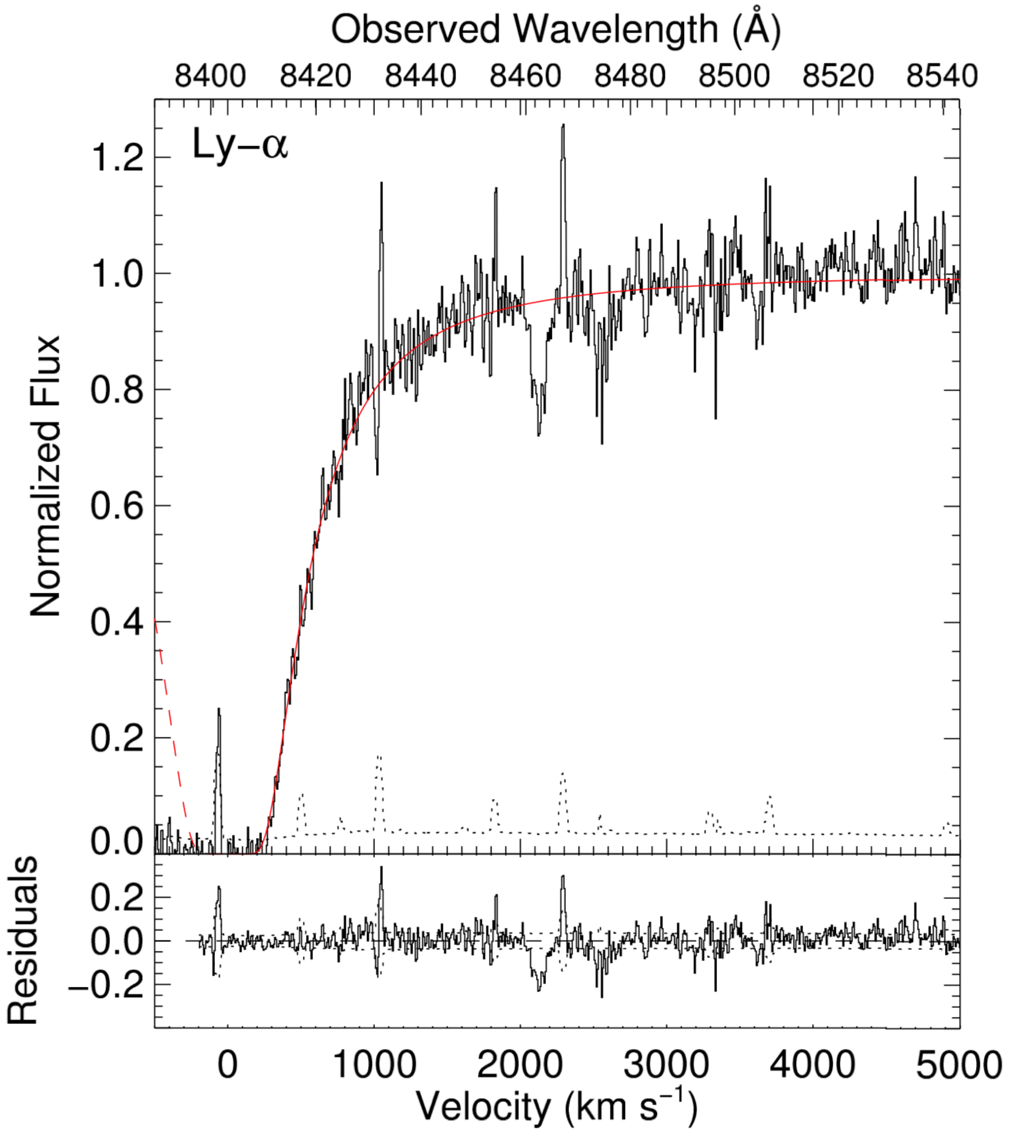
Reionization: constraining the demand

Classical route to measure IGM *neutral fraction* from GRBs, based on red damping wing of Ly-alpha absorption line in high-z sources *(Miralda-Escude 1998)*

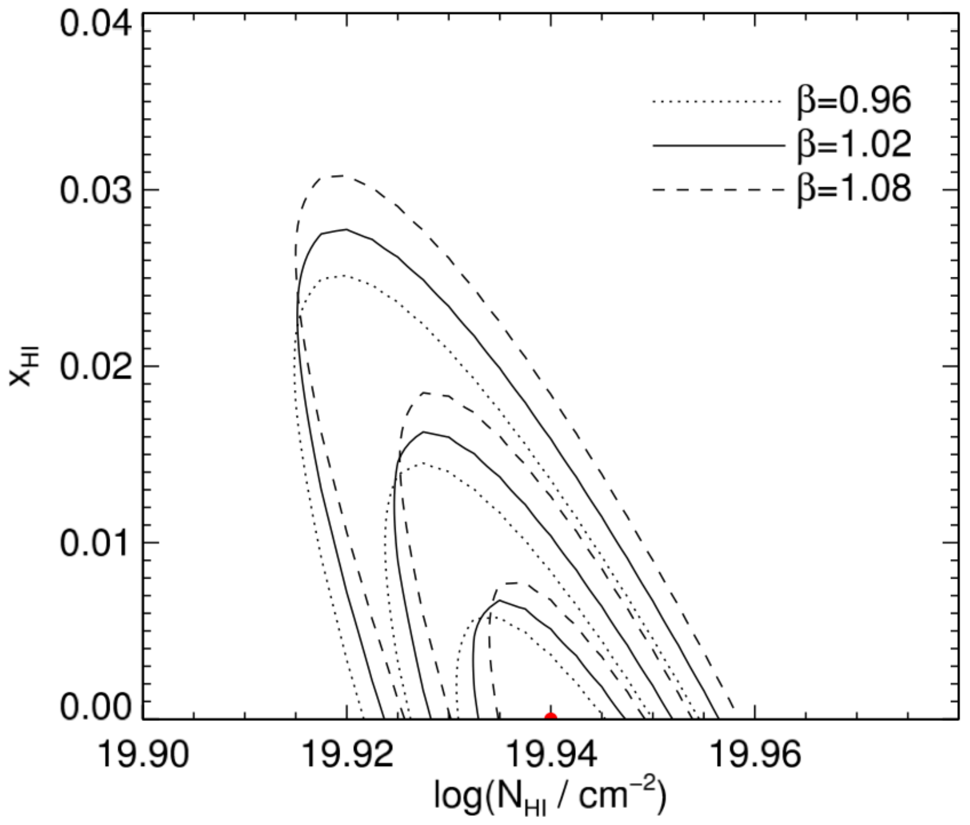
Barkana & Loeb 2003: decompose host and IGM contributions, with good S/N spectra and knowledge of systemic redshift.



GRB 130606A (poster child) Bright well-studied afterglow



Hartoog+2015



VLT spectrum Ly–a red wing well fit by host only (low column) absorption, and nearly fully ionised IGM.

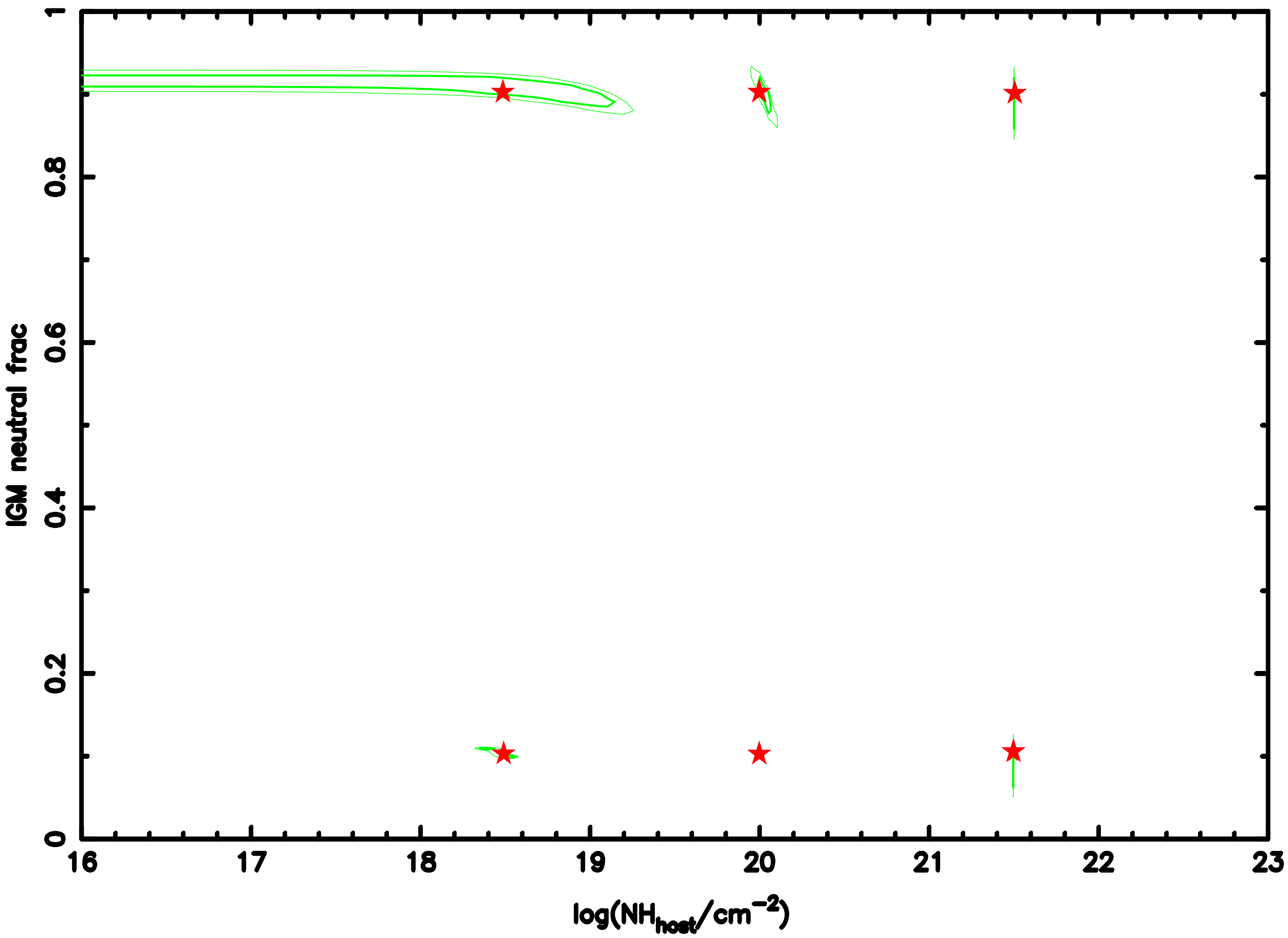
Decomposing

Decomposition generally works well with ELT depth spectra.

Many sight-lines -> track mean and variance of neutral fraction as function of redshift (complementary to SKA measures of 21cm signal).

Systematics may place limit e.g. *McQuinn et al. 2008:* effects of local ionized bubble add further complications, but small hosts may be the norm in EoR.

Simulation based on 120923A characteristics



Conclusions

- A sample of ~30 GRBs at high-z can provide unique constraints on star formation rate density in epoch of reionization, particularly accessing the faint end of the galaxy luminosity function beyond reach of JWST/ELT etc.

- Deep spectroscopy (esp. from 30 m class scopes) is key to much of the science, particularly the average ionising escape fraction and IGM neutral fraction - powerful new approach to time-line of reionization (but caveats).

- Need to build more realistic "end-to-end" simulations, starting with expected population of GRB discoveries, folding in likely/plausible follow-up, and hence predicting science results.