CEMP - Sept 2019 - Geneva

Chemical evolution, chemical enrichment and the ionizing escape fraction from GRBs

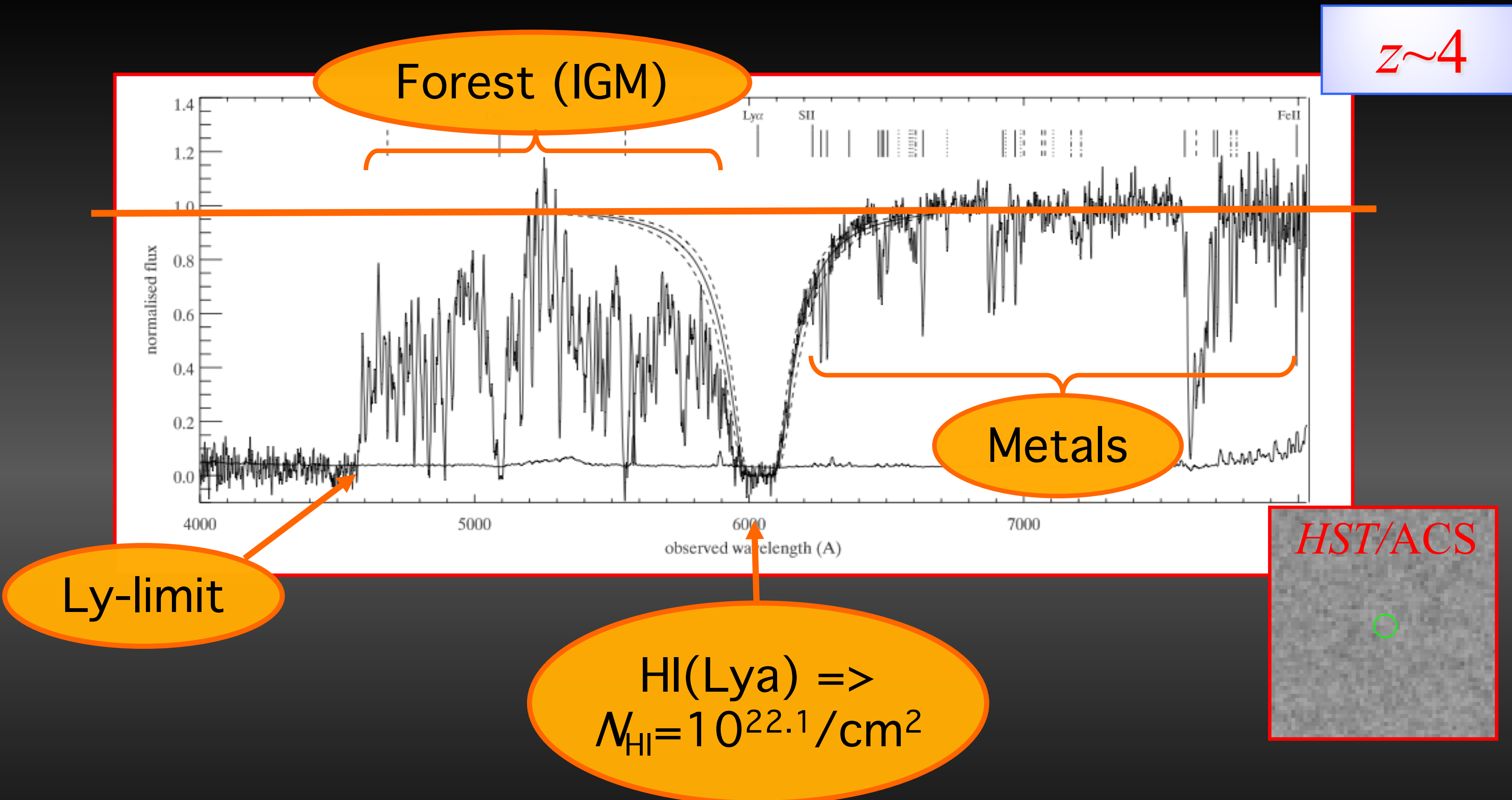
Nial Tanvir, University of Leicester

Topics

Several overlaps with interests of this meeting:

- Probes of ISM/IGM chemistry in/around distant galaxies.
- Probes of ionizing escape fraction from massive stars.
- Kilonovae (and collapsars) as sources of heavy r-process elements.

Typical GRB afterglow spectrum



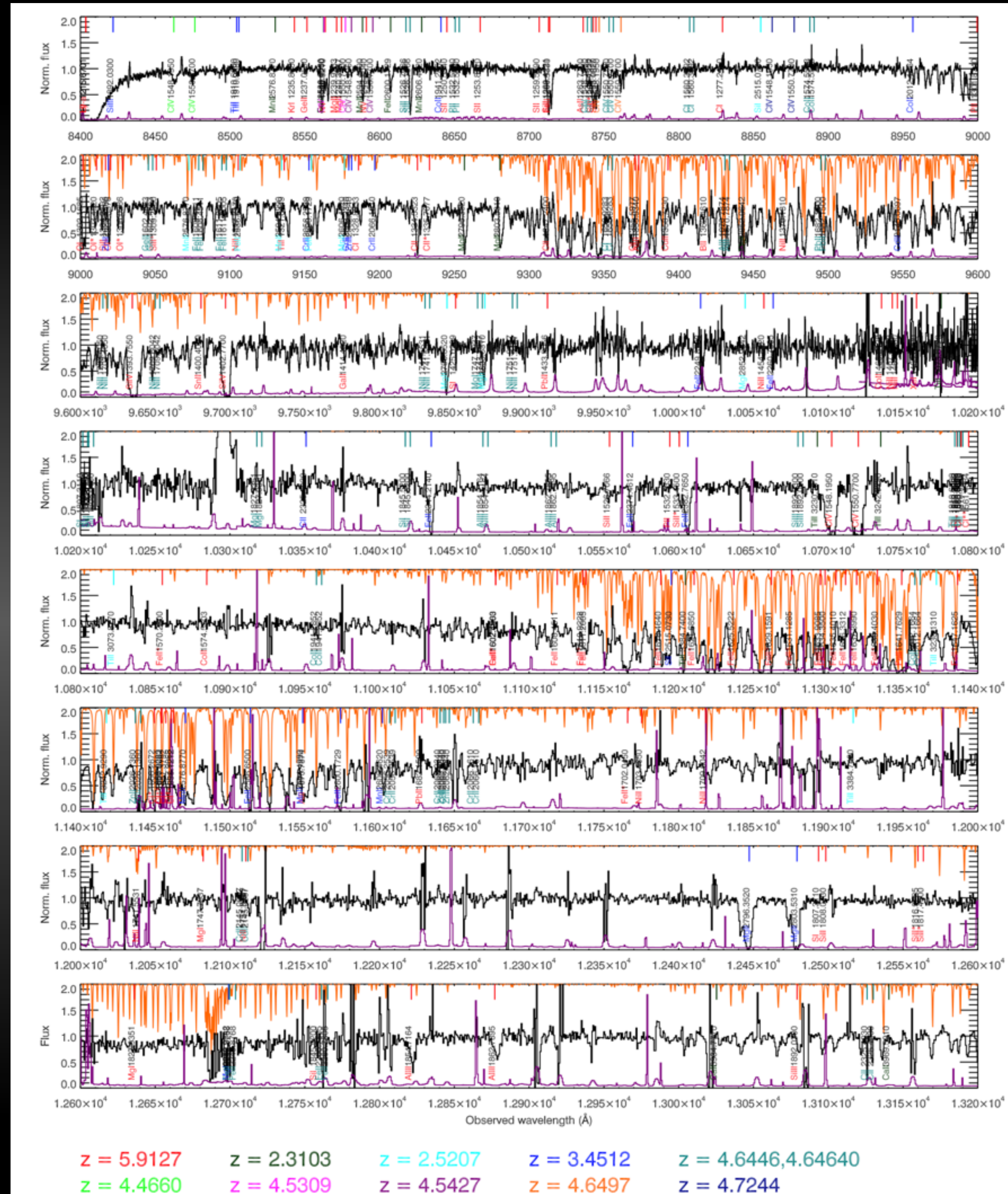
$$\tau_{LL} = 6.3\times10^{-18}\, N_{\rm HI} \approx 10^5$$

Cosmic chemical evolution

Bright afterglows provide high-S/N spectra enabling detailed study of abundances in host and intervening absorbers.

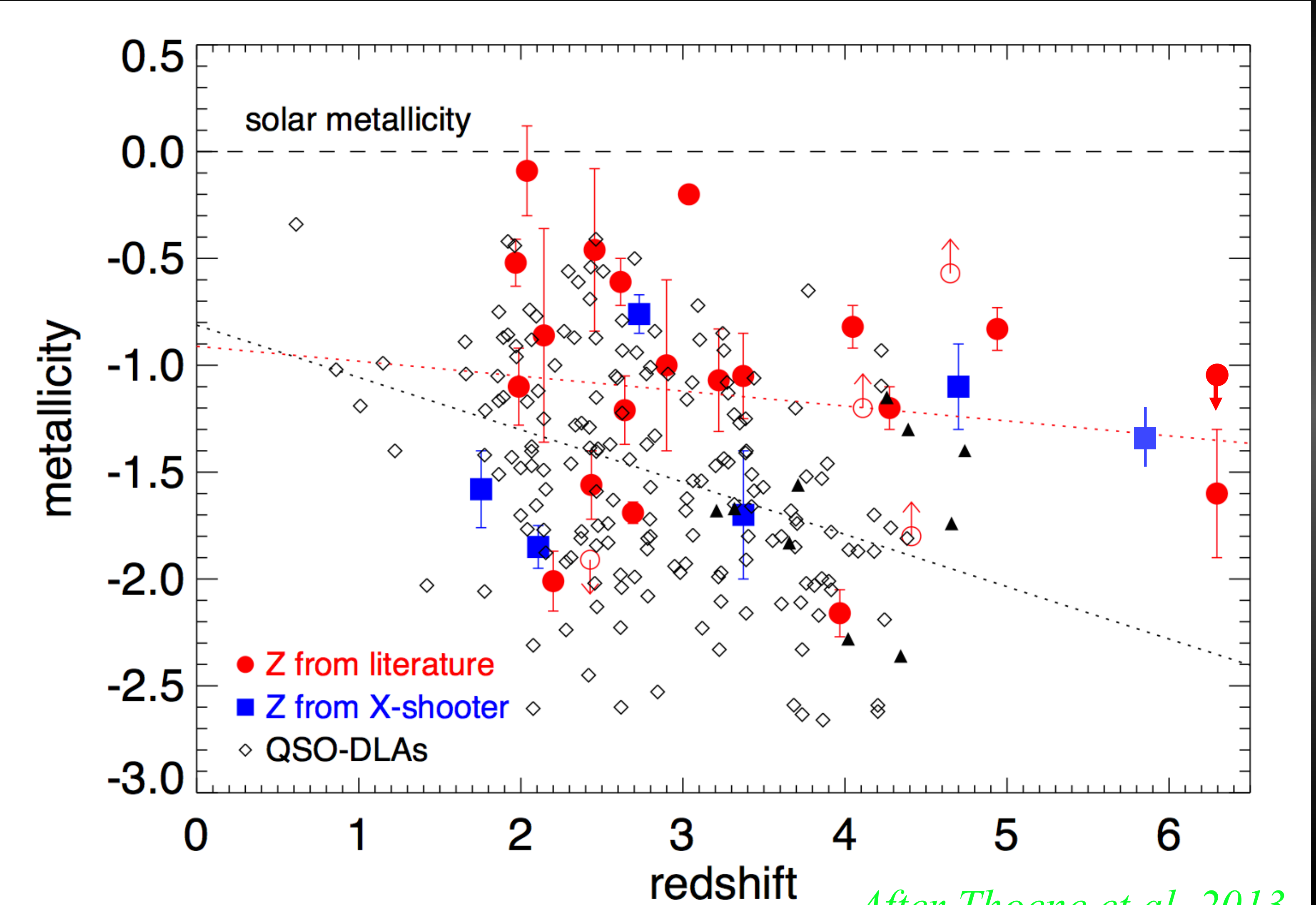
e.g. GRB 130606A at z=5.91; VLT/ X-Shooter spectrum gives Z ~ 0.05 $Z_{\odot}$.

Hartoog +2015 (also Castro-Tirado +2013; Chornock +2013)



Cosmic chemical evolution

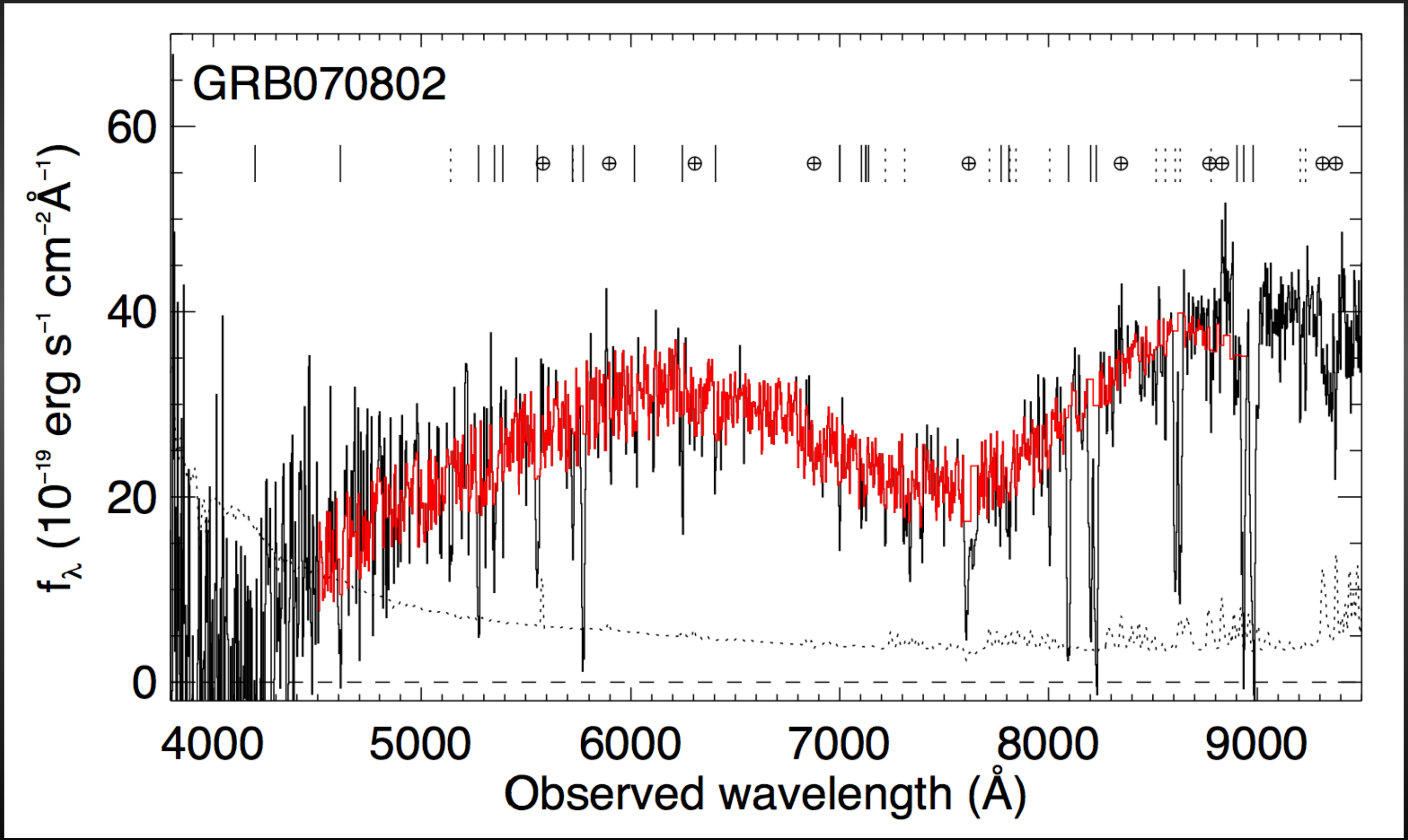
From hosts and afterglow spectroscopy, mostly low (at least ~sub-solar) metallicity.



After Thoene et al. 2013

Dust

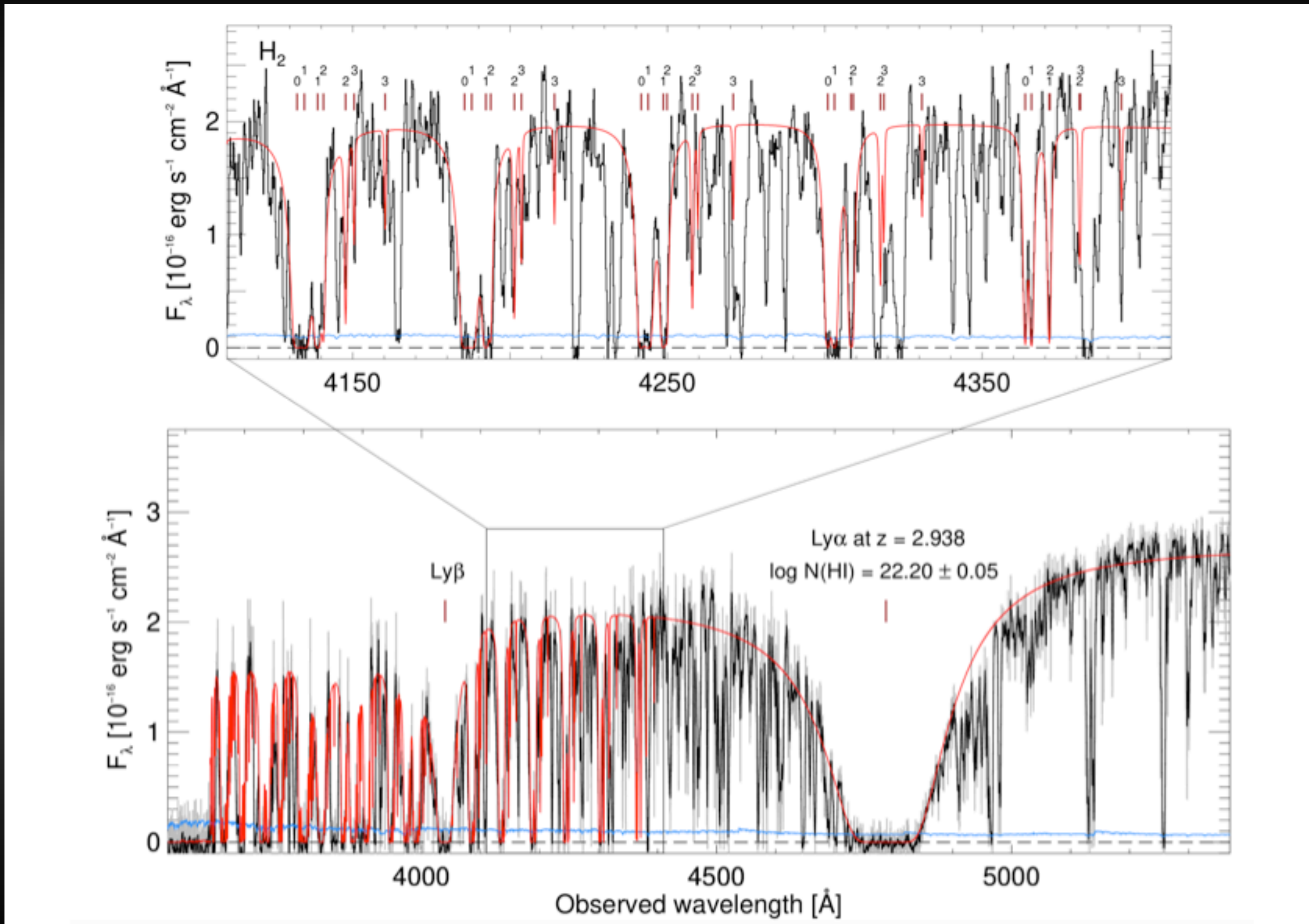
Dust extinction and dust laws: SMC often a reasonable match, but 2175A features sometimes seen, as are more exotic laws.



Eliasdottir et al. 2009

Molecules

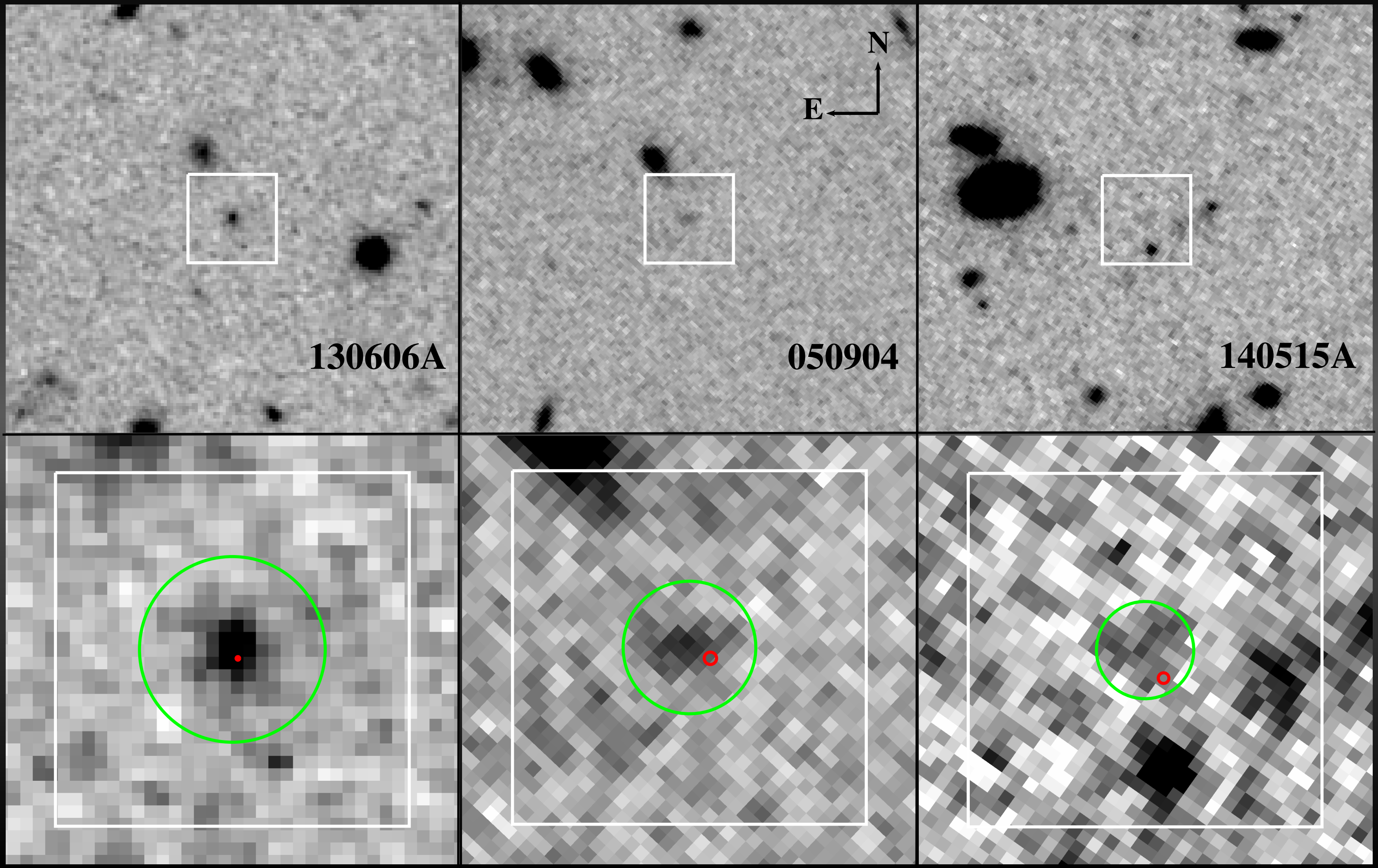
Directly detect H_2 in absorption.



Heintz et al. 2019

First GRB hosts at $z \sim 6$

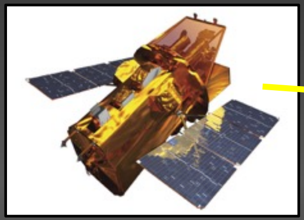
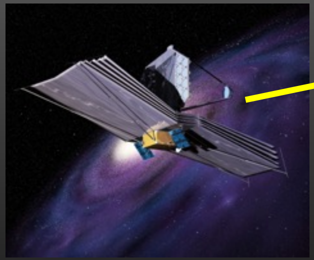
Majority of hosts at $z > 5$ undetected in deep HST observations.

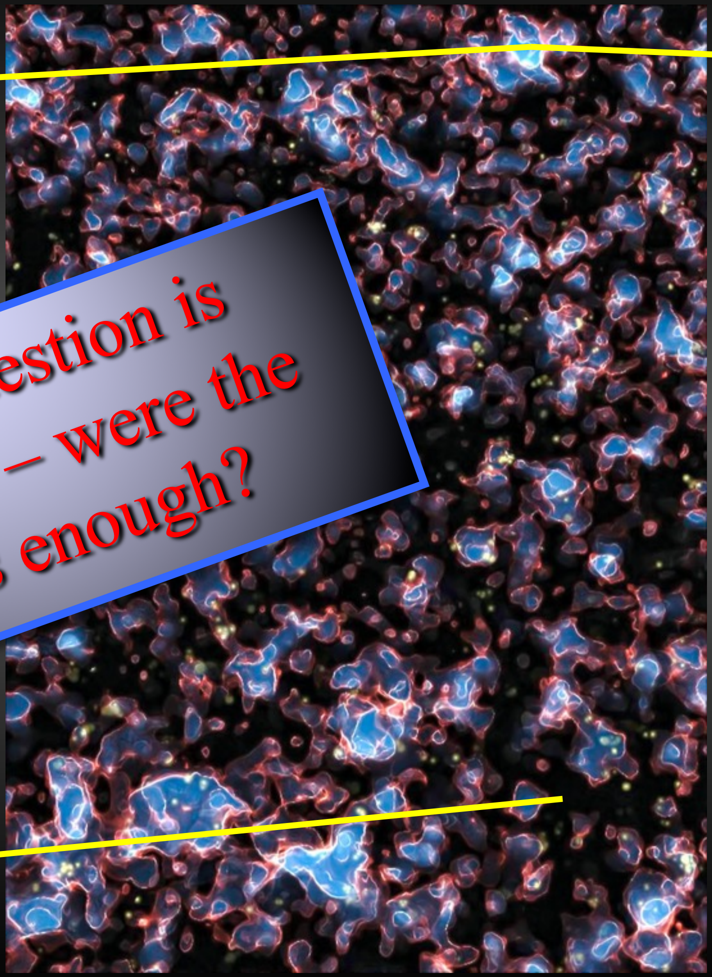


McGuire et al. 2016 ApJ

Probes of reionization

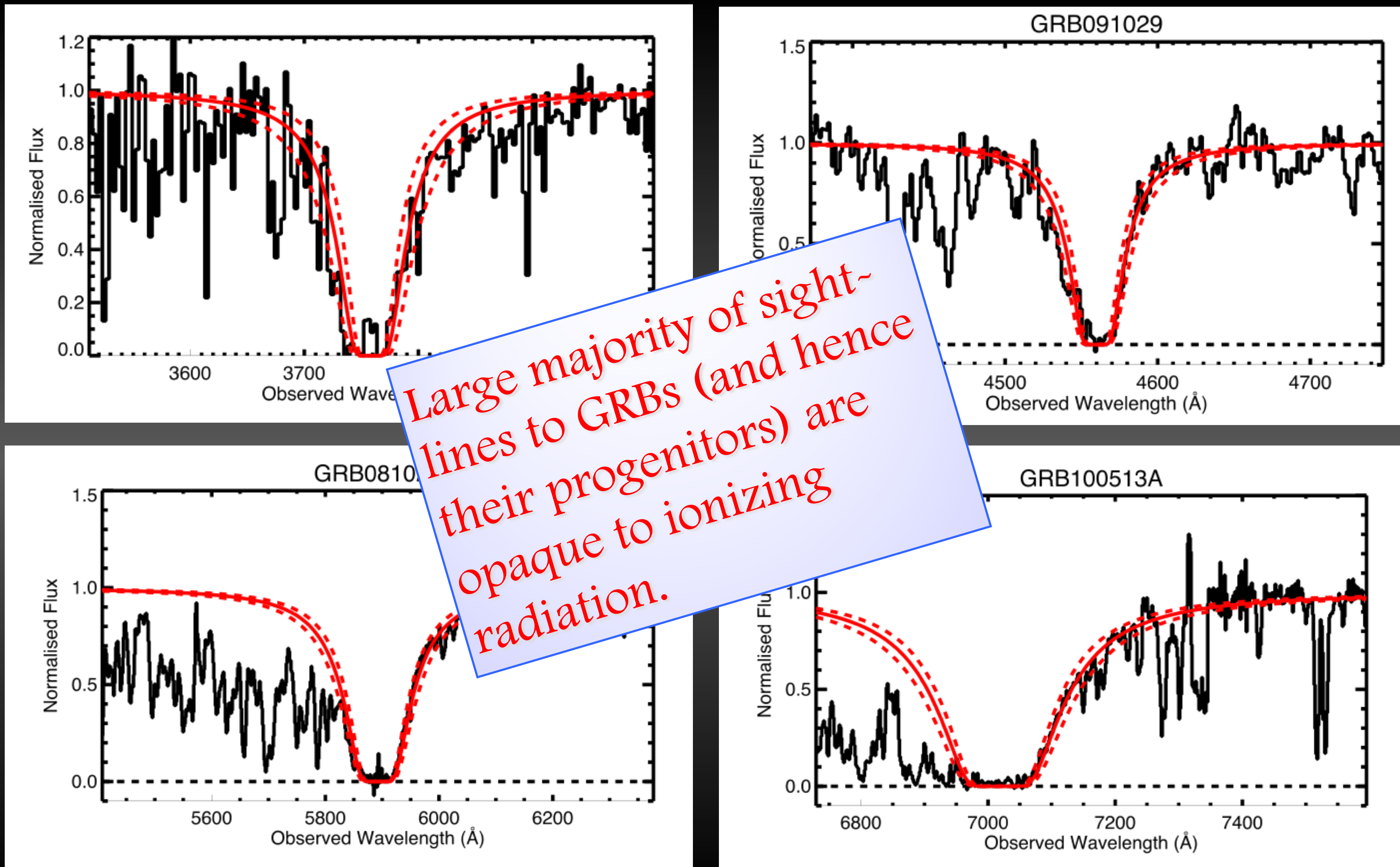
Reionization occurred around z~7-9 (but timeline and topology poorly constrained)



Key question is "how?" – were the stars enough?

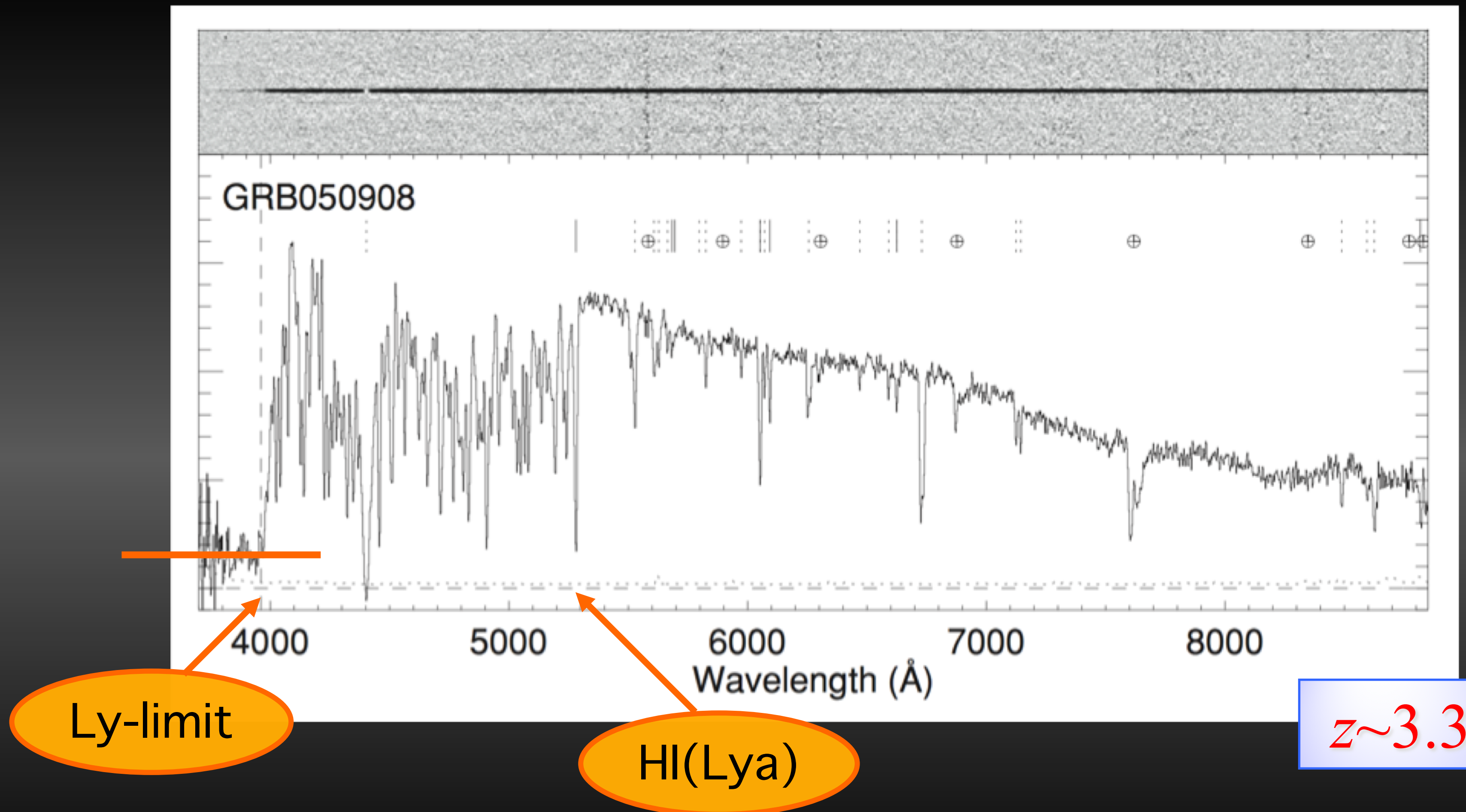
HI column density from Ly-a absorption in afterglow spectra



Large majority of sight-lines to GRBs (and hence their progenitors) are opaque to ionizing radiation.

Provides direct *upper limit* on escape fraction on each line of sight.

Rarely find low column sight-lines

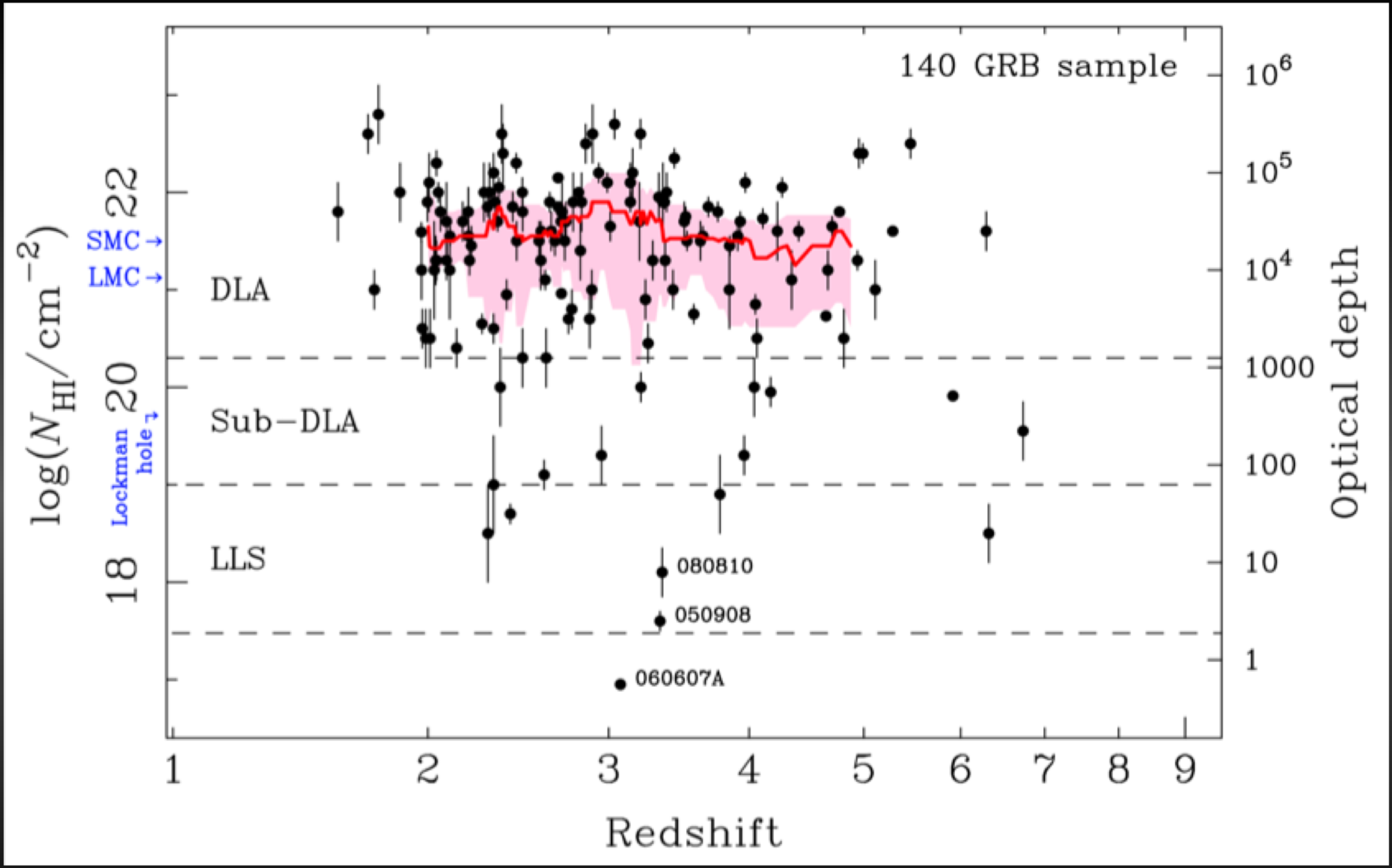


z~3.3

$$\tau_{LL} = 6.3\times10^{-18}\, N_{\rm HI} \approx 2.5$$

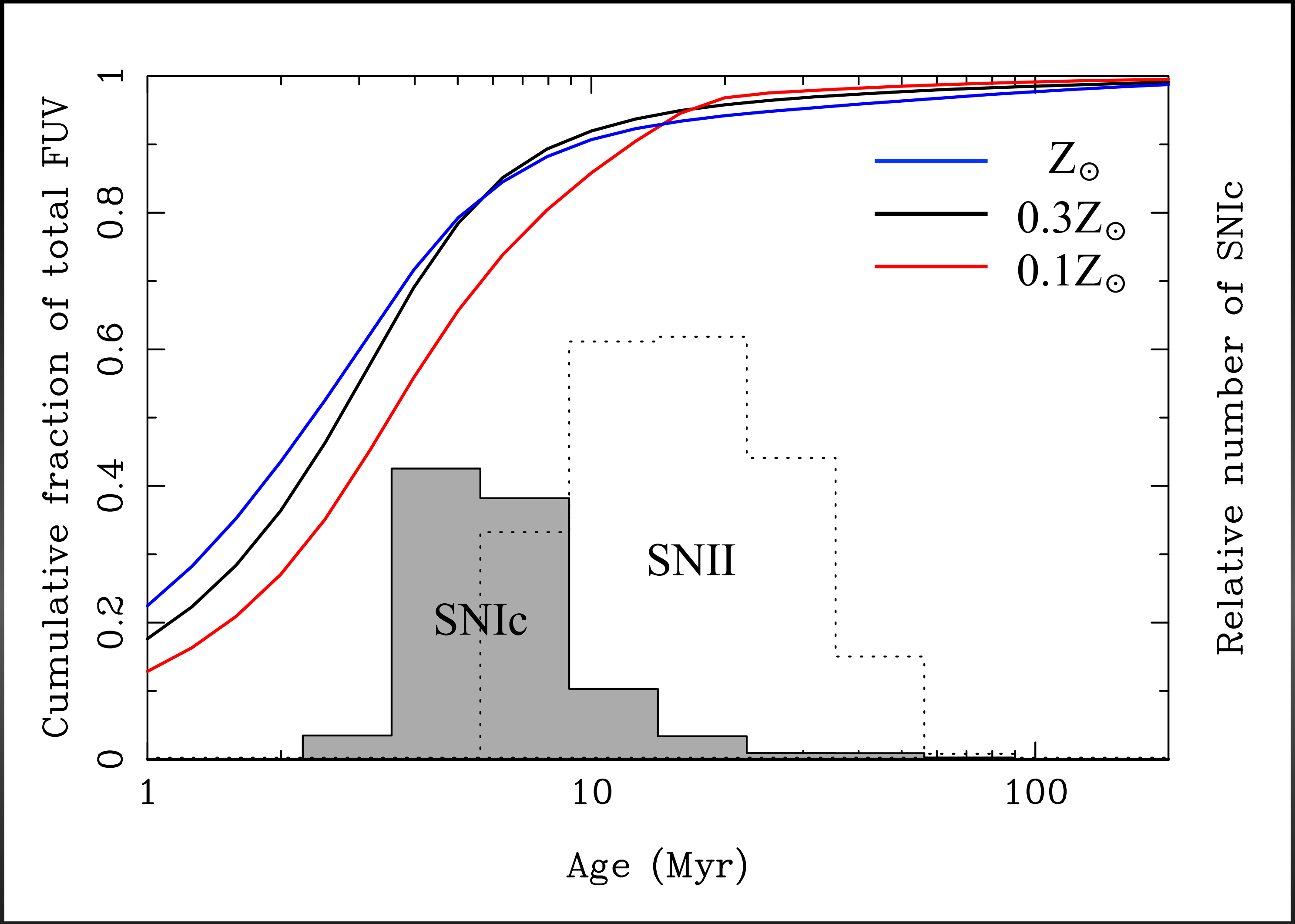
HI column density evolution

NT et al. (2019)



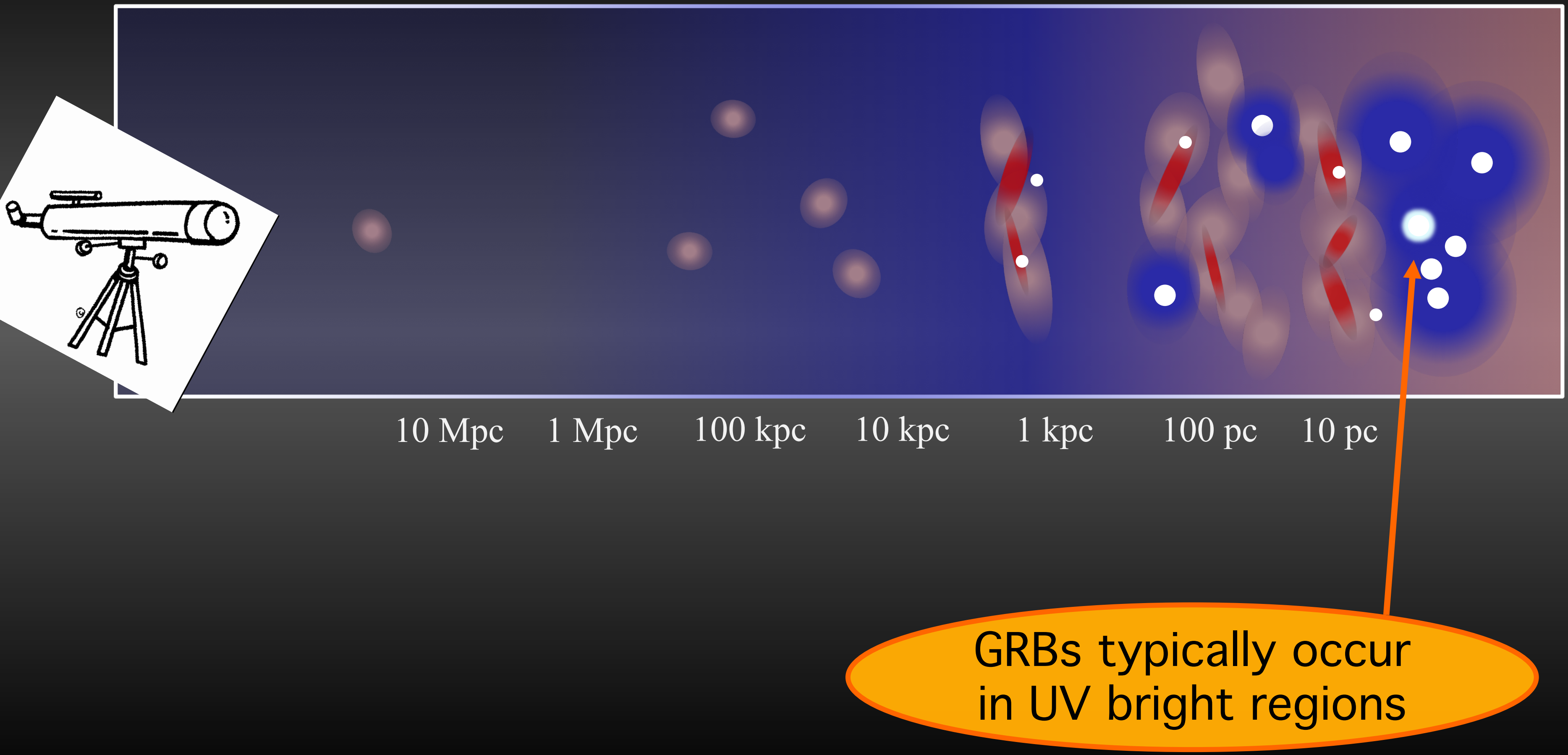
Reionization requires escape fraction >~10%

High column densities seen in optical spectra of most 2<z<5 GRBs suggest escape fractions for *these stellar pops* of <1.5 %.



Single burst stellar population synthesis, based on binary evolution BPASS-2 models (Stanway & Eldridge 2016) – most production is t <10 Myr, consistent with typical GRB progenitor lifetimes (and SNIc).

What we are measuring and what we are not



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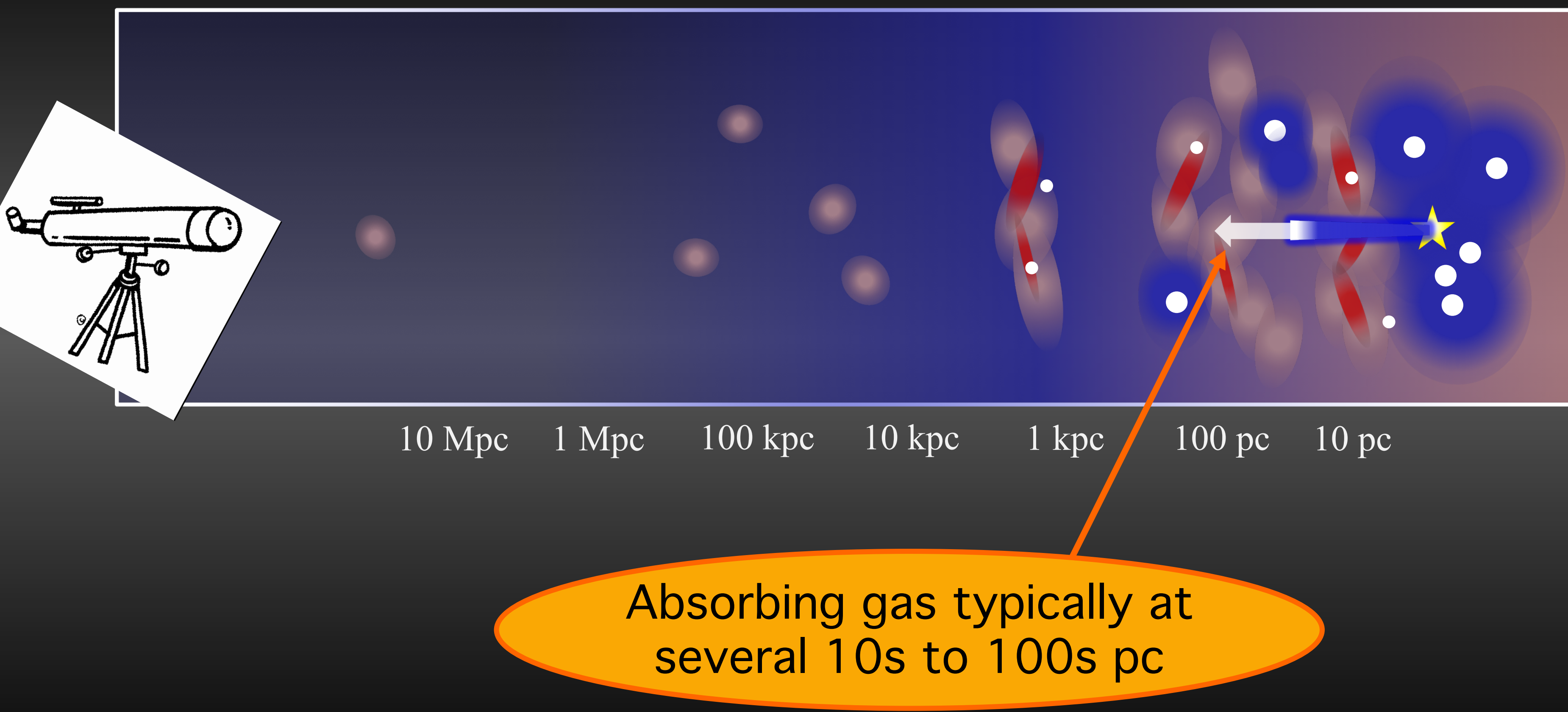
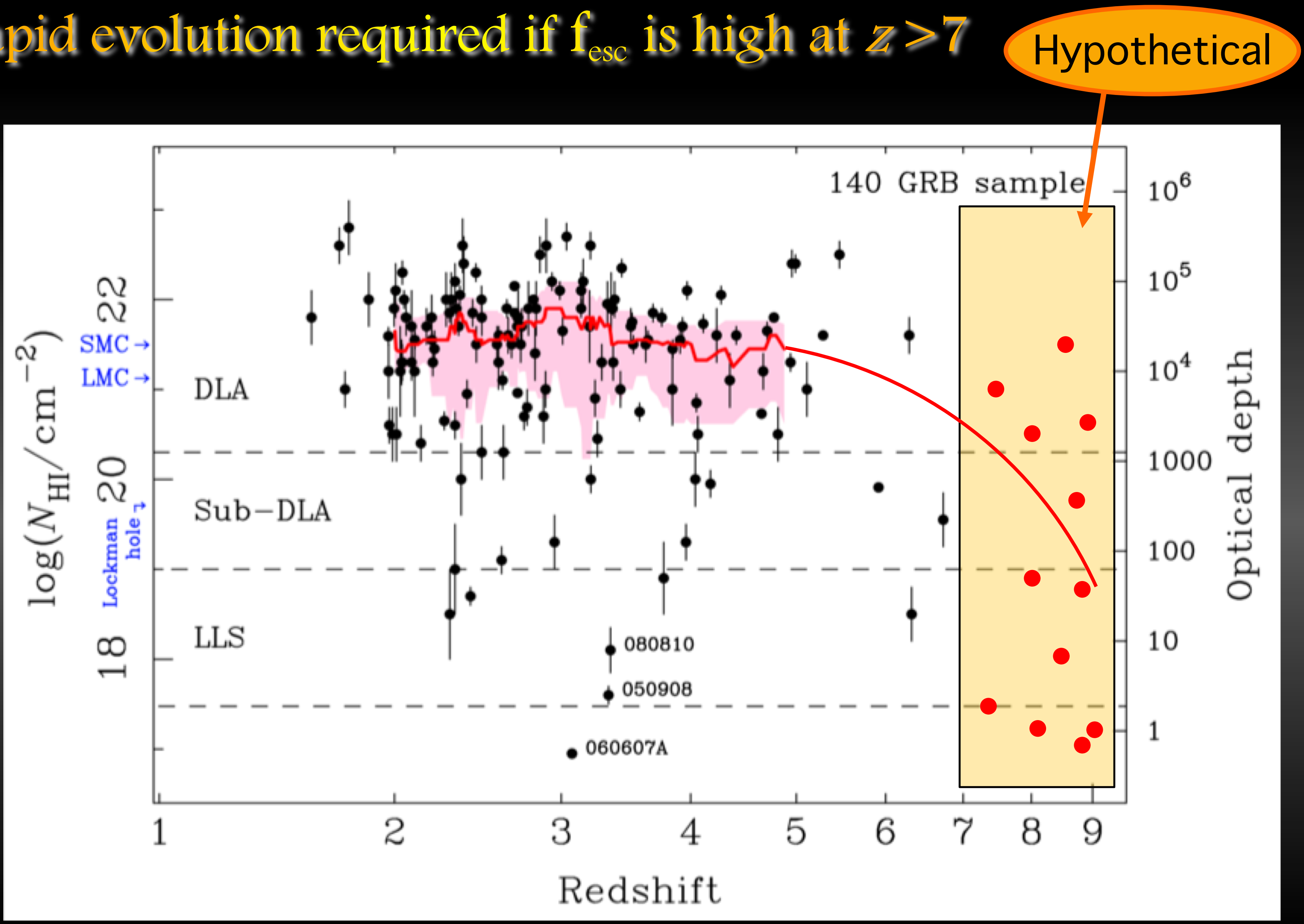
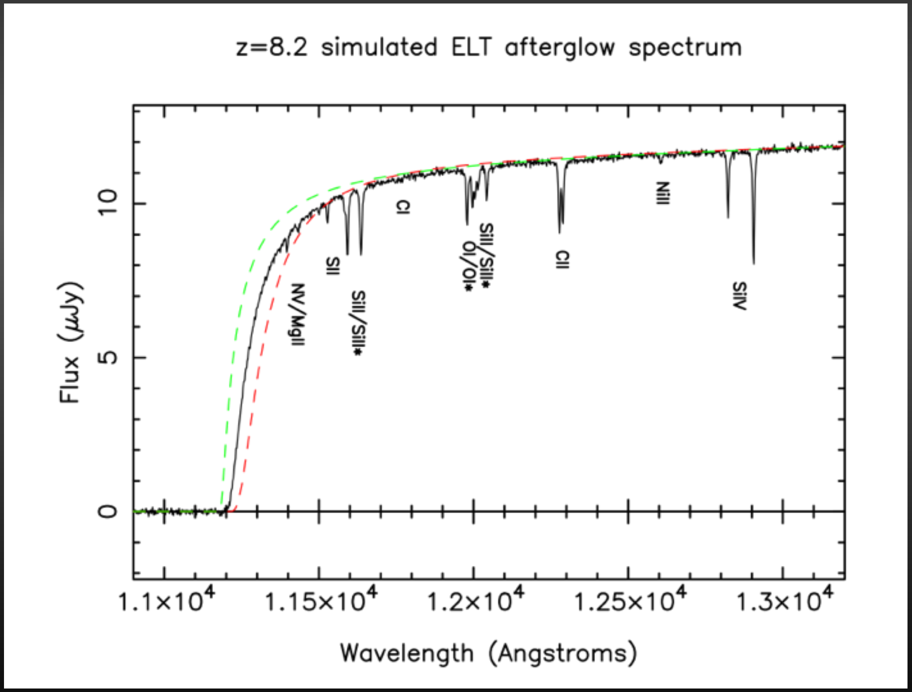


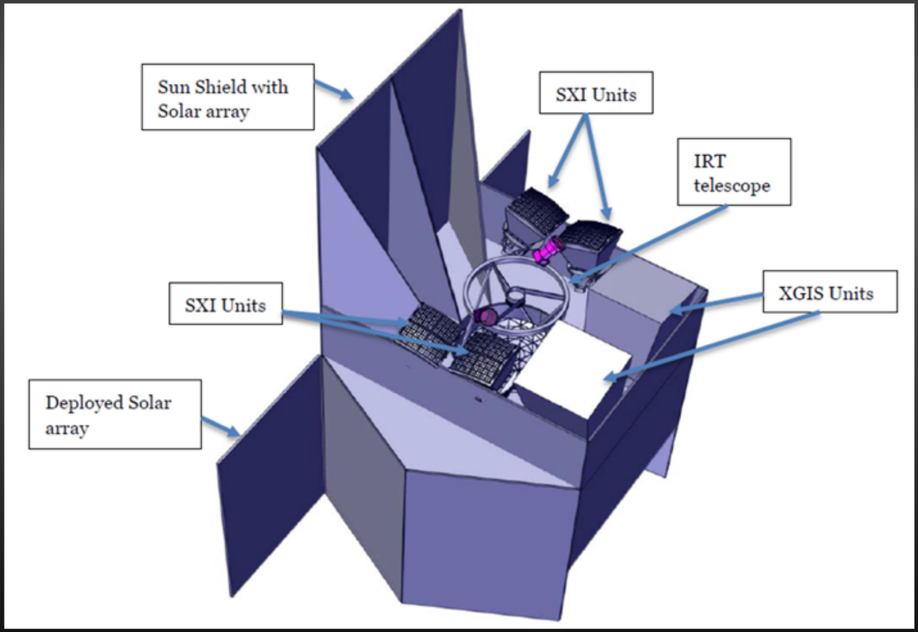
Rapid evolution required if f_{esc} is high at $z > 7$



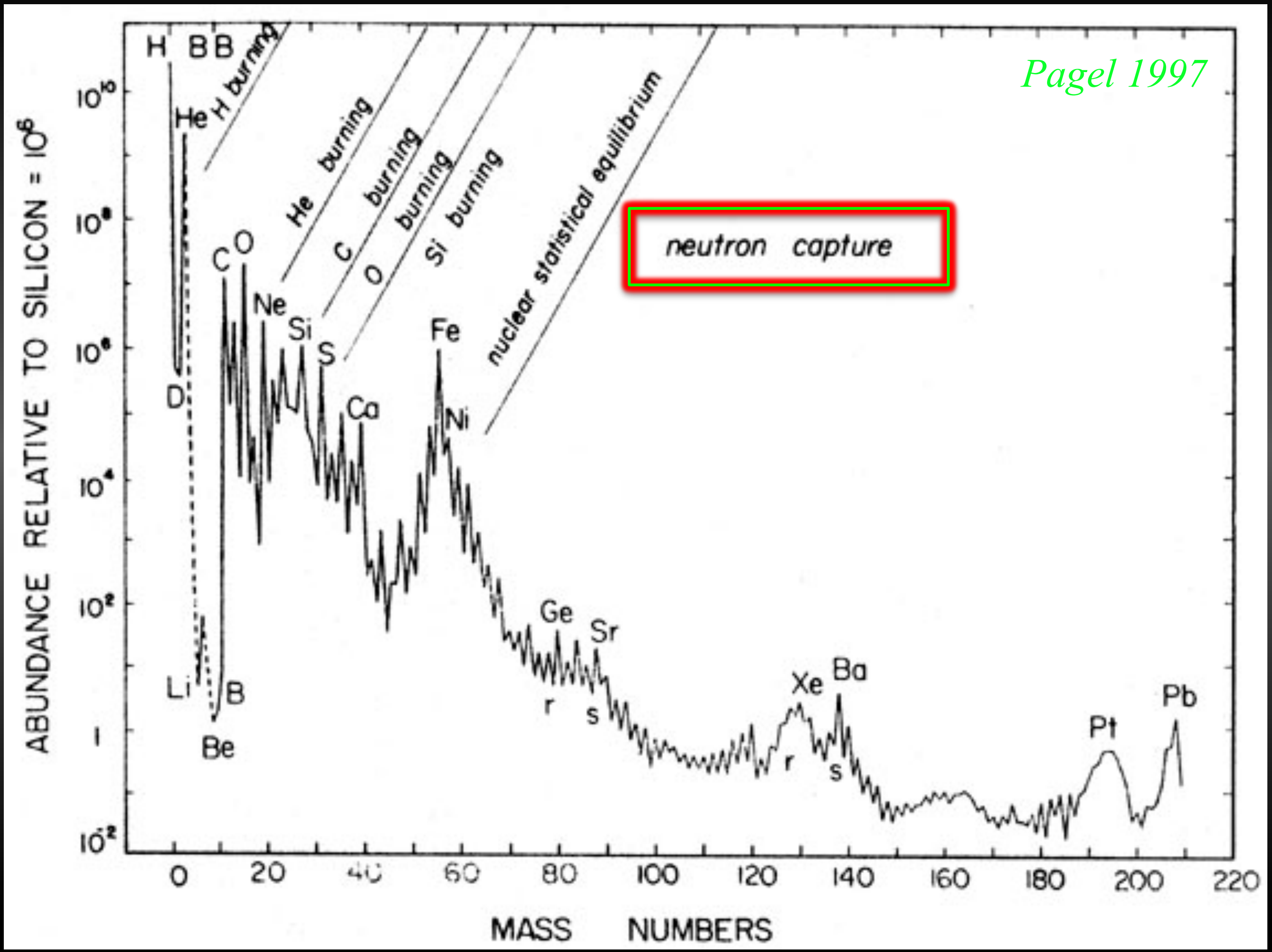
Future developments

- In future, benefit from powerful new spectroscopic facilities e.g. SCORPIO on Gemini, JWST, ELT, TMT, GMT, …
- Increased rate of discovery e.g. SVOM + Swift; THESEUS

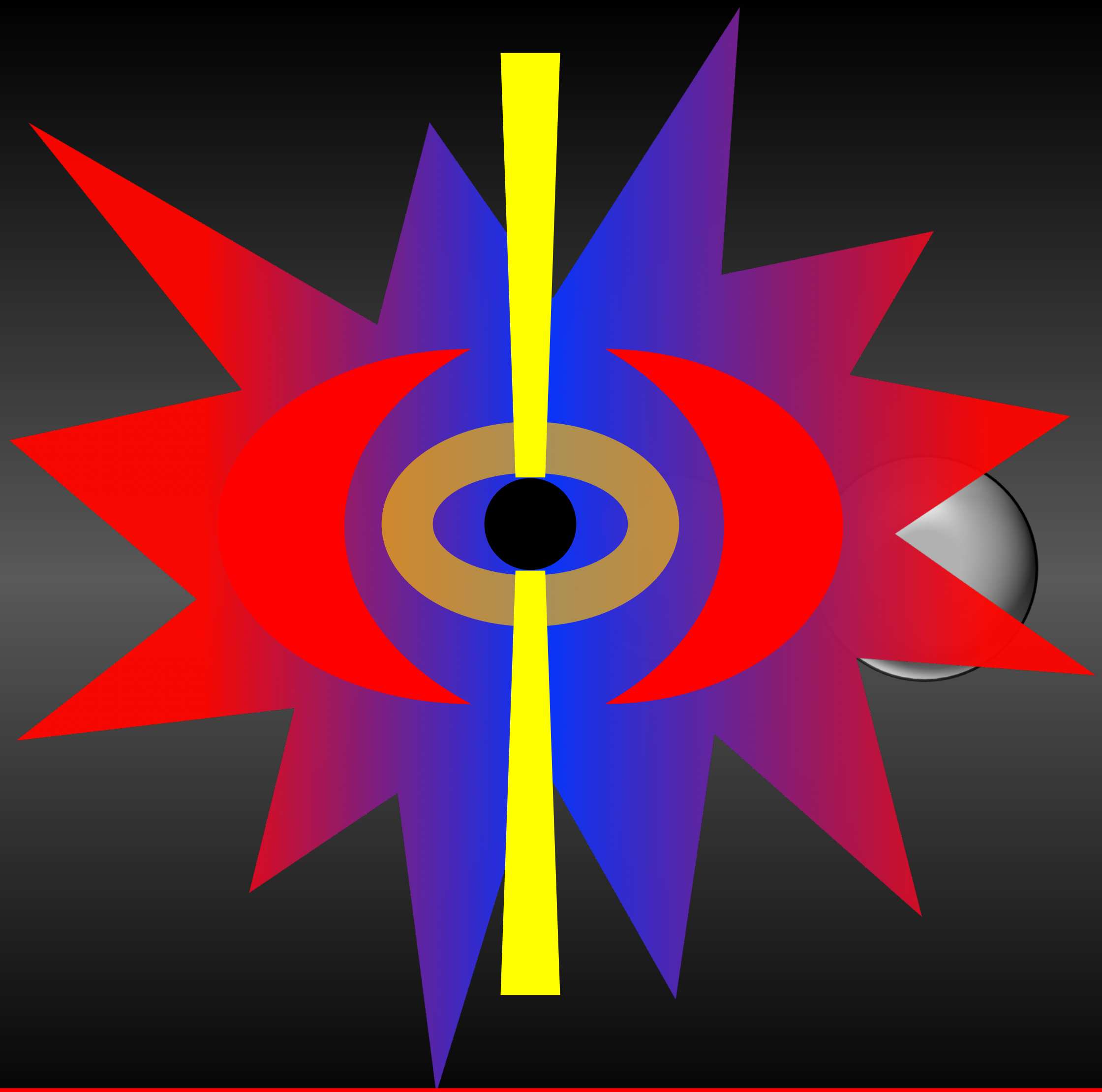




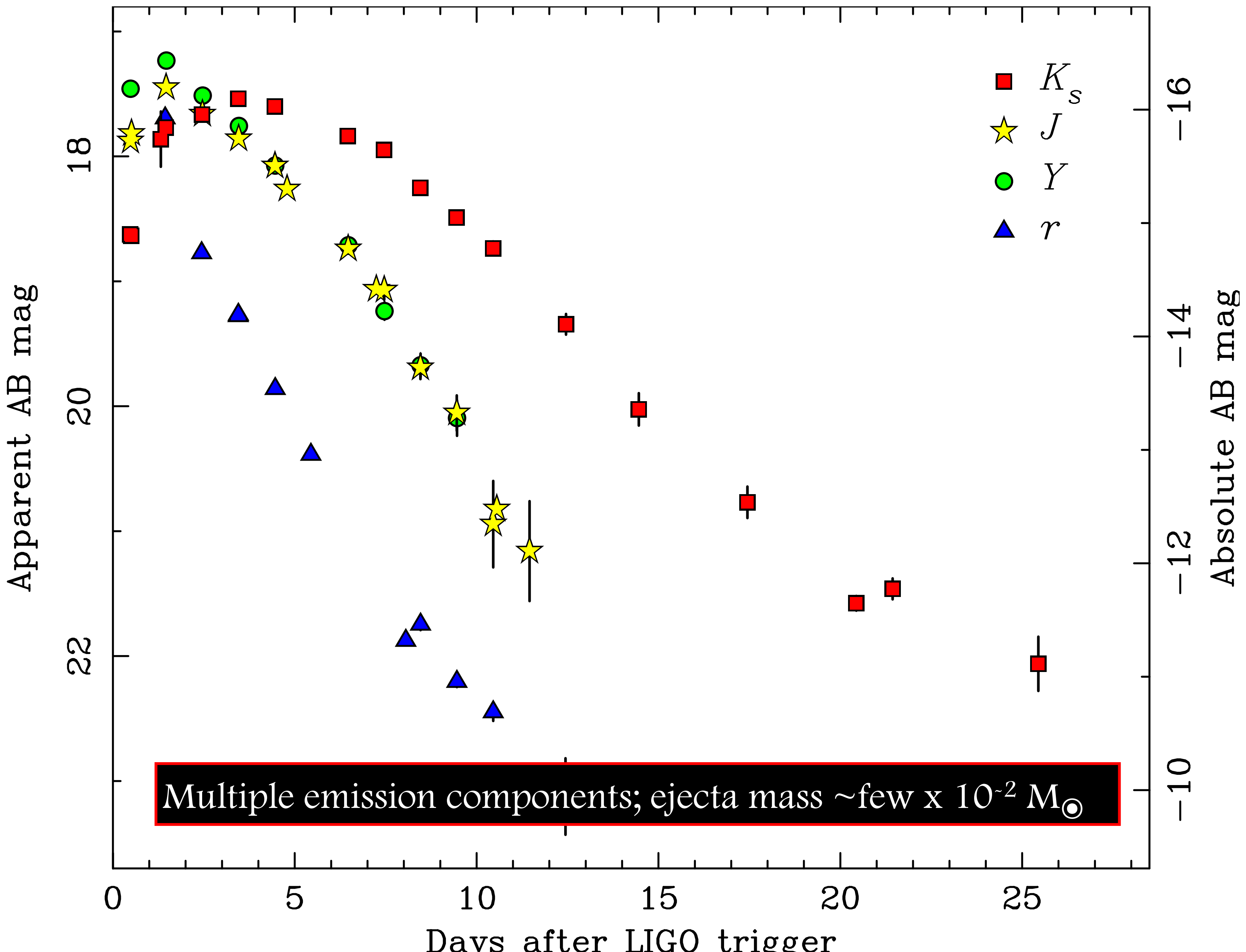
What about the r-process elements?



Ejection of neutron star material during CBC mergers

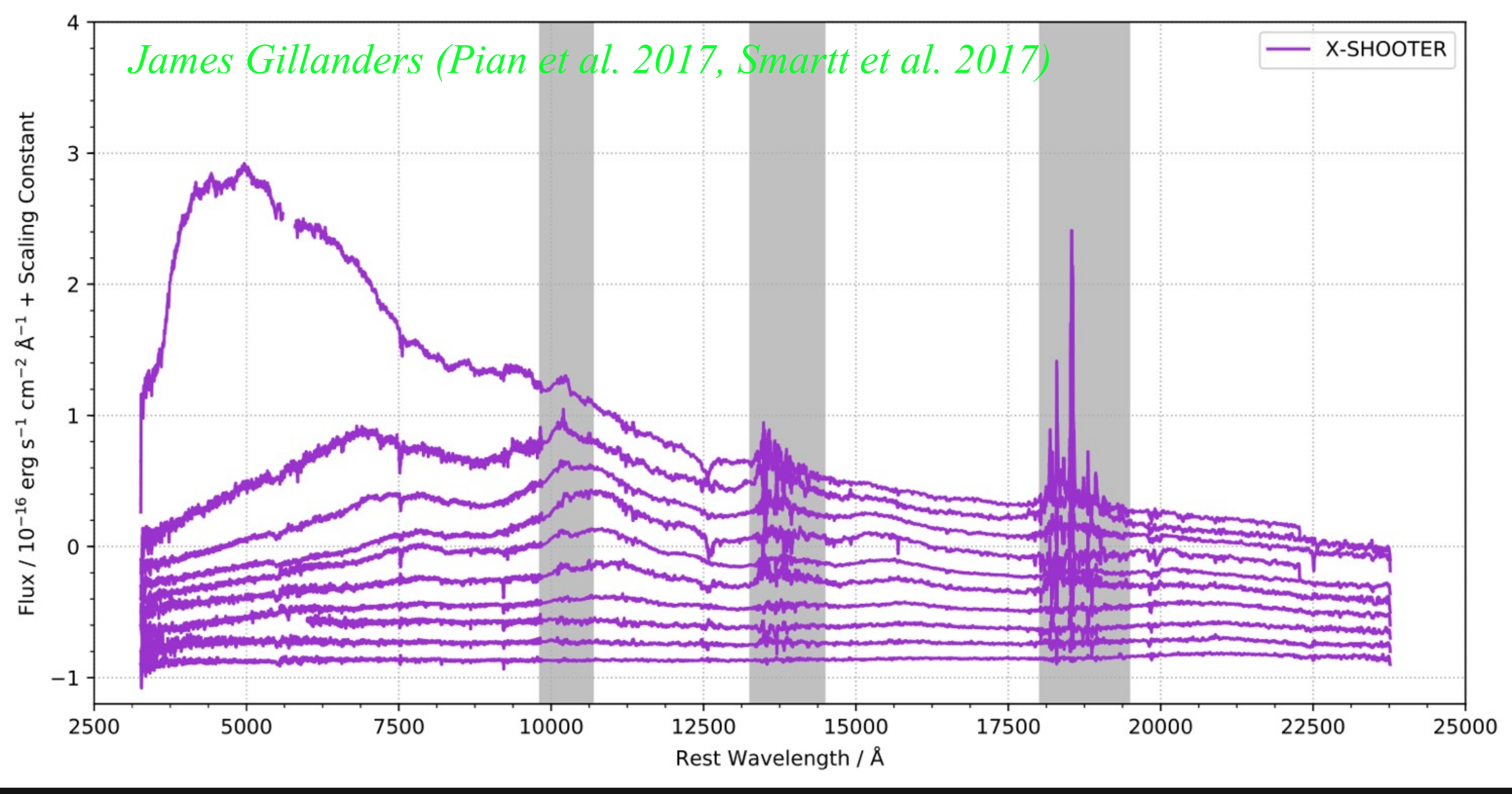


Long regarded as potiential r-process source (e.g. Lattimer & Schramm 1974).
Various components.



K_s
J
Y
r
18
20
22
−16
−14
−12
−10
0
5
10
15
20
25
Apparent AB mag
Absolute AB mag
Days after LIGO trigger
Multiple emission components; ejecta mass ~few x 10^{-2} $M_\odot$

R-process nucleosynthesis from compact binary mergers



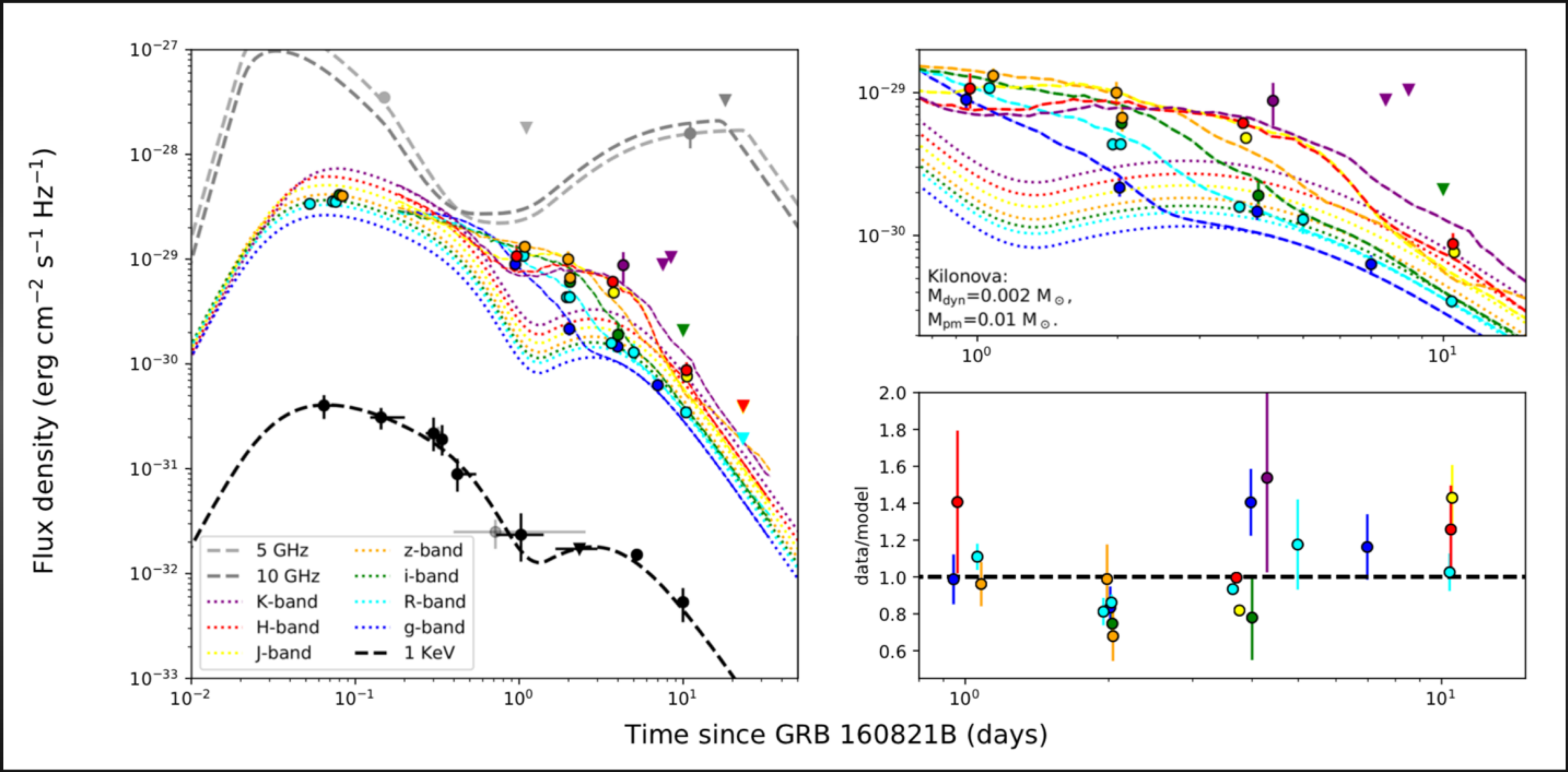
Recall Hansen talk this morning – likely some of these features explained by SrII (Watson et al. in press).

Third LIGO/Virgo science run

- Began April 2019; will run (with a break) to mid-2020.
- Several (~5) events with high chance of containing a neutron star component, plus many (~20) new BBH – all more distant than GW170817.
- Consistent with $z = 0$ rate of events "with ejecta" of ~few x 100 /Gpc^3/yr (only a small fraction of detected events are likely to be accompanied by prompt gamma-ray emission).
- Only one of these with a "small" error region (S190814bv, error region ~25sq-deg, distance~250 Mpc), thought to be a NSBH system, but so far no good candidate KN.

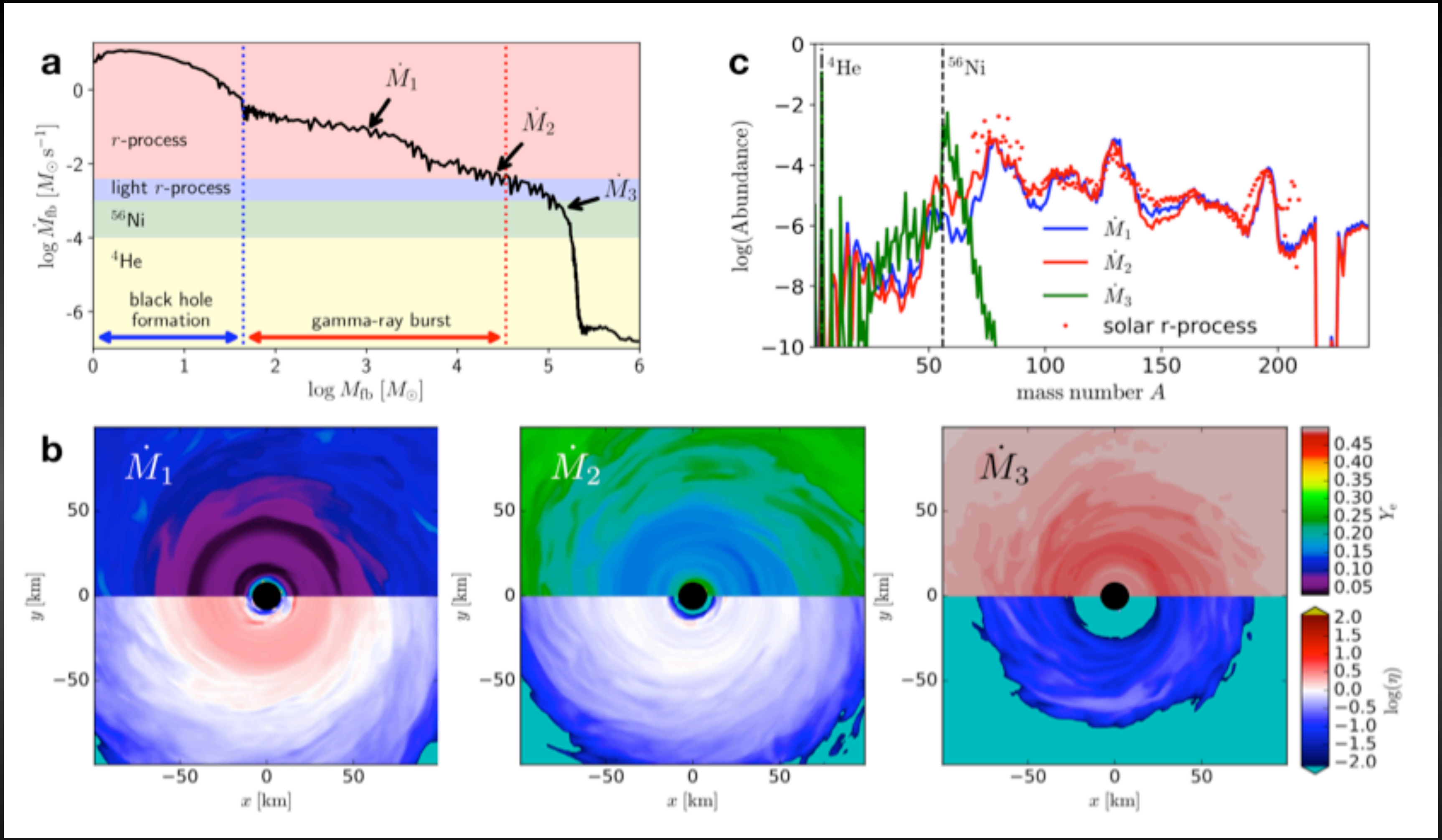
Diversity: continued explorations of SGRB-KN

Lamb et al. 2019 (also Troja et al. 2019)



SGRB 160821B: In this case, fainter KN suggests lower ejecta mass ~10^{-2} $M_\odot$

R-process nucleosynthesis from collapsars



Siegel, Barnes & Metzger 2019

Potentially substantial (dominant?) contribution to total budget, especially at early times in universe. (See also Fujimoto et al. 2007 for r-process in jets).

Conclusions

- GRB spectroscopy provides unique window on ISM/IGM in high redshift universe – abundances, ionization state, dust, molecules etc.
- Problem to reconcile the observed low escape fraction of ionizing radiation (~0.5%) from $z<6$ GRB *locations* with the requirement to reionize the intergalactic medium (~10%). ie. seems to require rapid evolution in galaxy population to $z\sim8$.
- New spectroscopic facilities will provide much better constraints in future, providing we keep/extend GRB localisation capability. Ideally would like samples of several tens of GRBs at $z>6$ to check for evolution in HI column distribution.
- Neutron star (and NS/BH) mergers now considered likely source of substantial heavy (and light) r-process enrichment. The budget, though remains challenging – calculating yields, and rates over cosmic history.
- More NS GW events being found, but we were lucky with GW170817!
- Collapsars accretion disk outflows may also provide a substantial contribution to heavy r-process nucleosynthesis.