Modeling GRB Host Galaxies

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Outline

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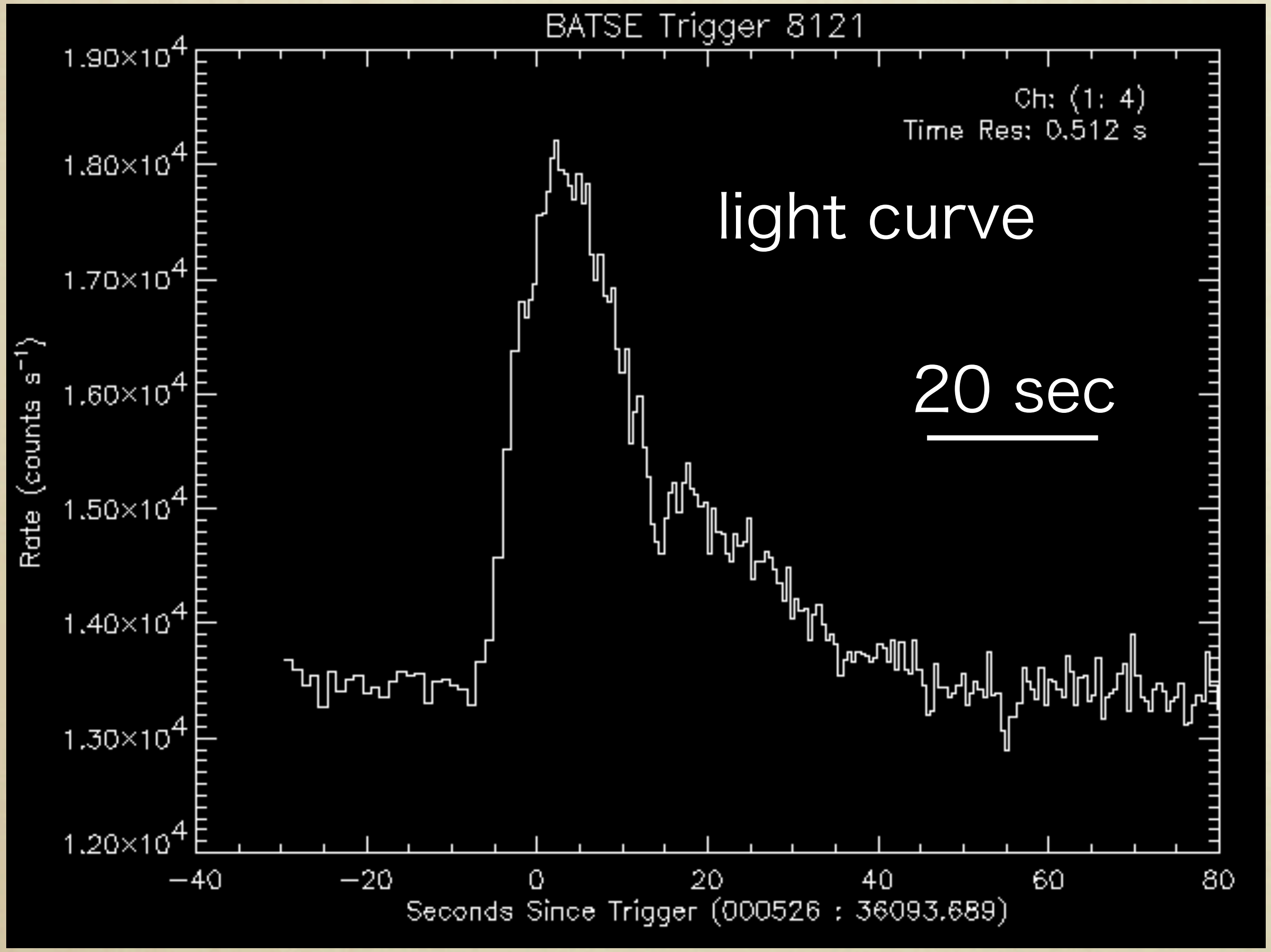
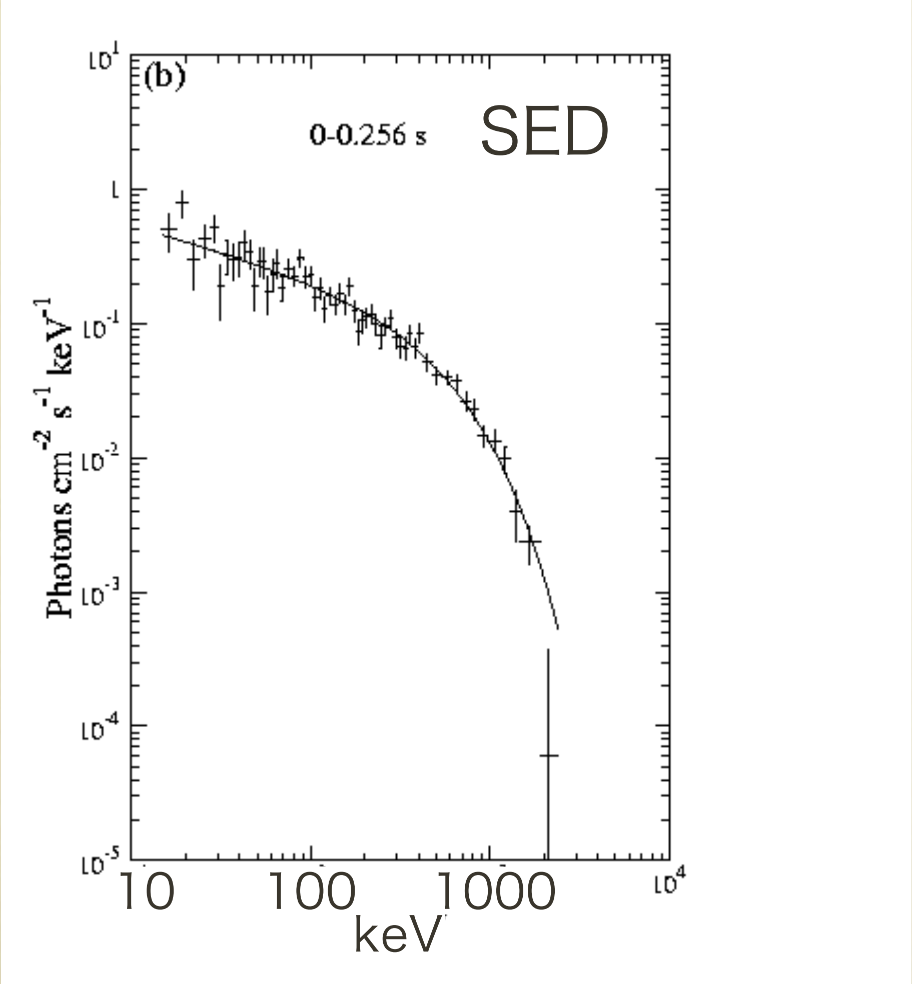
- Host Galaxies and the metallicity dependence of GRBs
  - Emission Line
  - Absorption Lines in Afterglow Spectra
  - Luminosity Function
  - Lyman-α emission
- Summary

Introduction

Gamma-Ray Burst (GRB)

- GRBs...
  - are short and intense pulse of ~ 100 keV gamma-rays.
    - duration of 0.1 - 100 second
  - are in cosmological distance.

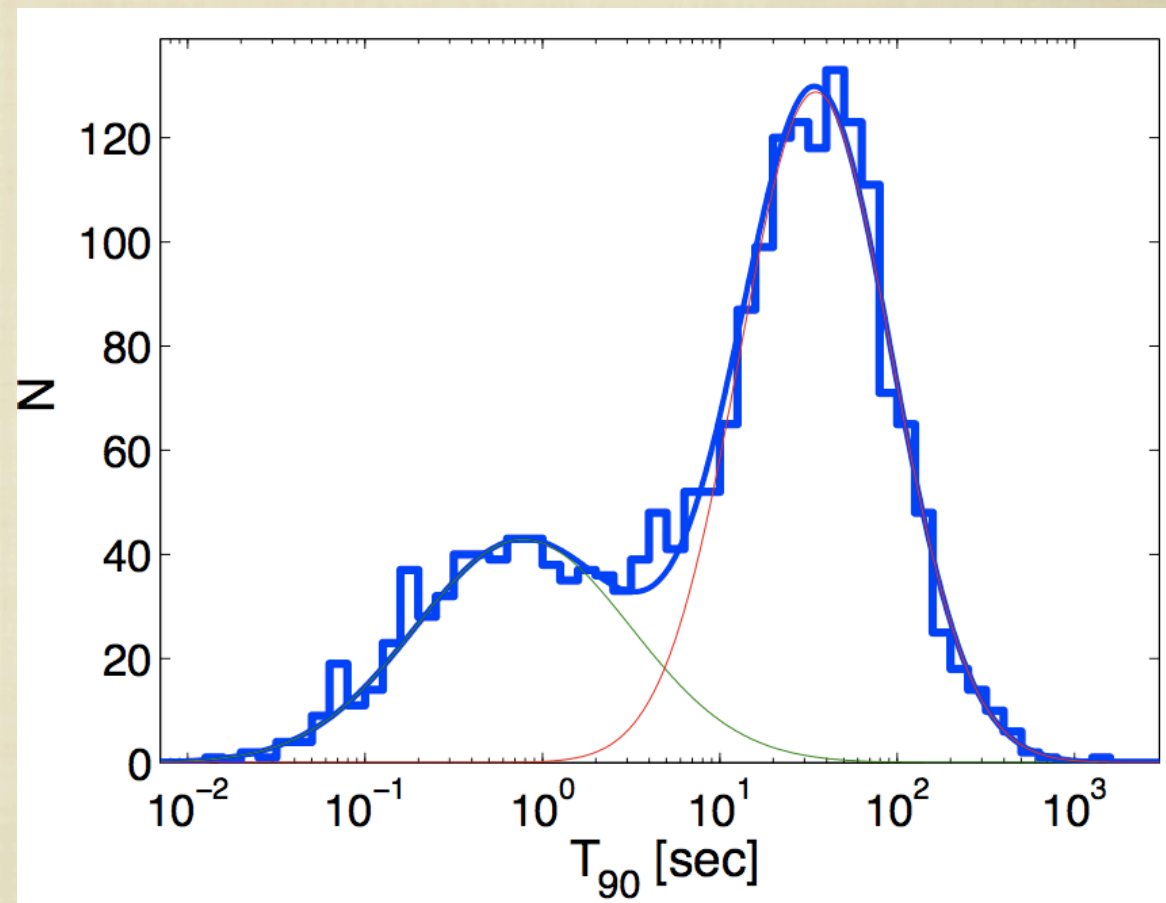




GRB 000526 (BATSE archive)

Long & Short GRBs

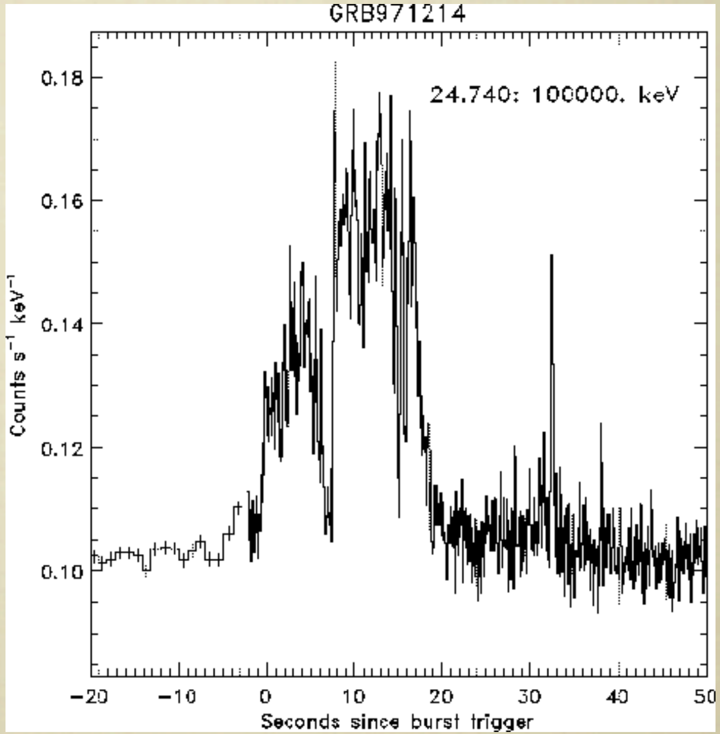
- GRBs can be divided into roughly two classes.
  - Long GRB: duration > 2 sec
    - $E_{iso} = 10^{52-54}$ erg
    - $E_{peak} = 10^{2.0}$ keV
  - Short GRB: duration < 2 sec
    - $E_{iso} = 10^{49-51}$ erg
    - $E_{peak} = 10^{2.5}$ keV



Horvath+ 2002

Origin of GRBs

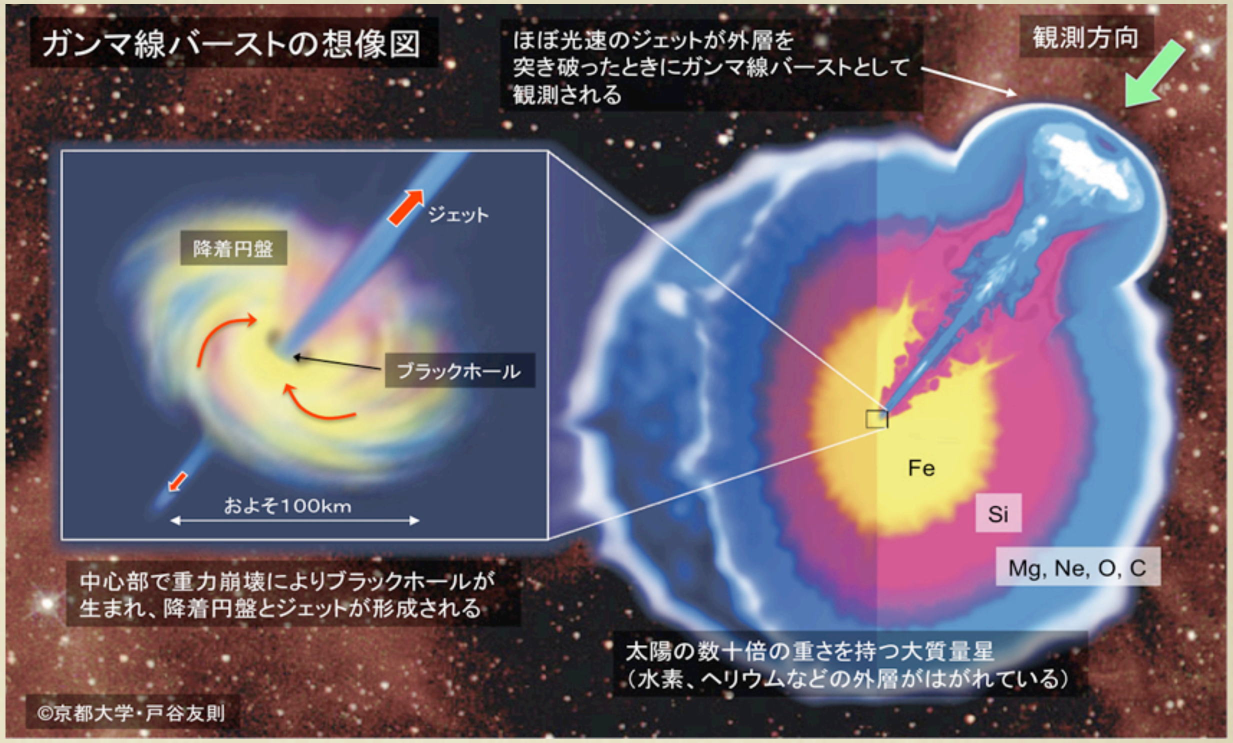
- Short time variability and large energy budget of GRBs suggest compact object involvement in GRB mechanism.
- two leading models
  - collapsar model
    - confirmed for some long GRBs
  - compact binary merger model
    - suggested for a few short GRBs



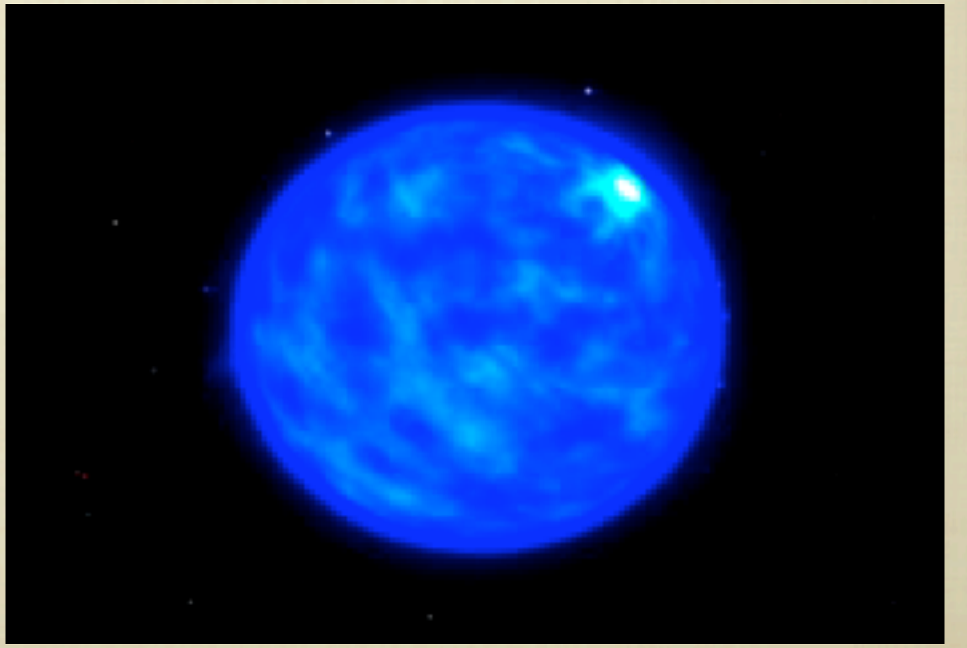
GRB 971214 (NASA website)

Collapsar Model

- Black hole (BH) and accretion disk are formed in core-collapse of massive star.
- Relativistic jet erupts.
- Shock accelerated particles in the jet emit gamma-rays (by synchrotron or inverse Compton).



Totani-san’s website



NASA website

Progenitor of Collapsars

- Not all CC SNe accompanies GRBs.
- A progenitor star of collapsar model GRB must...
  - be massive enough to produce BH.
  - lose its outer envelope so that the jet can get out of the star.
  - have central core with specific angular momentum sufficient enough to form accretion disk.

Model Study of Stellar Evolution

- rapidly rotating, low metallicity star
  (Yoon & Langer 2005, Woosley & Heger 2006)
  - rapid rotation
    - chemically homogeneous star
      - avoid super giant phase
      - whole star as a core
  - low metallicity
    - suppress stellar wind

required initial condition of the stars:

massive, rapidly rotating, low metallicity

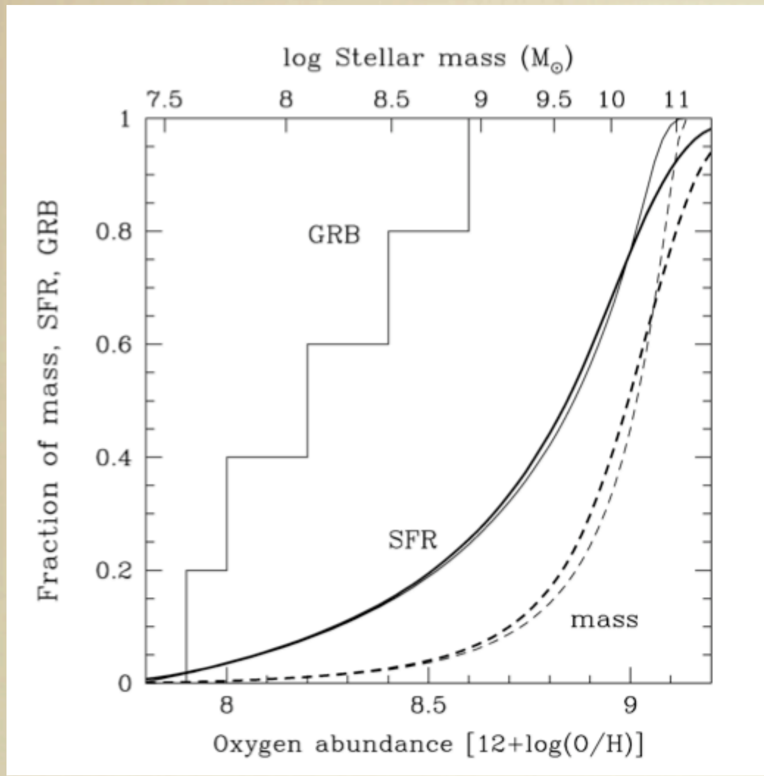
Host Galaxy and the metallicity dependence of GRBs

Methods to Study GRB environment

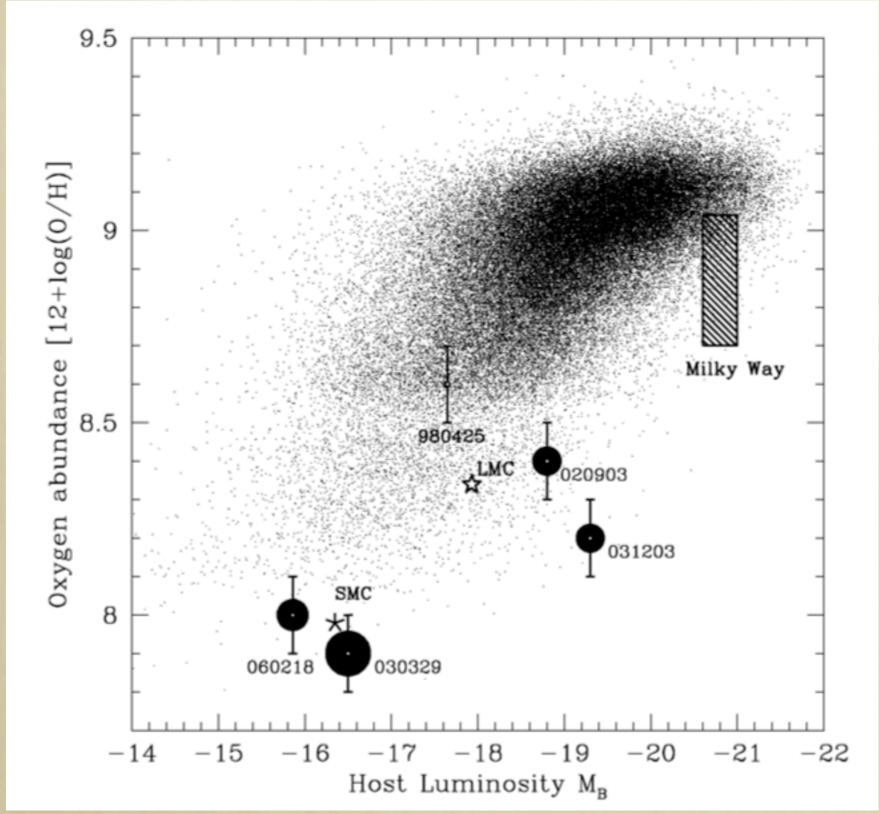
- Emission Line
- Absorption Line in Afterglow Spectra
- Luminosity Function
- Lyman-α emission

GRB Host Emission Line Measurement

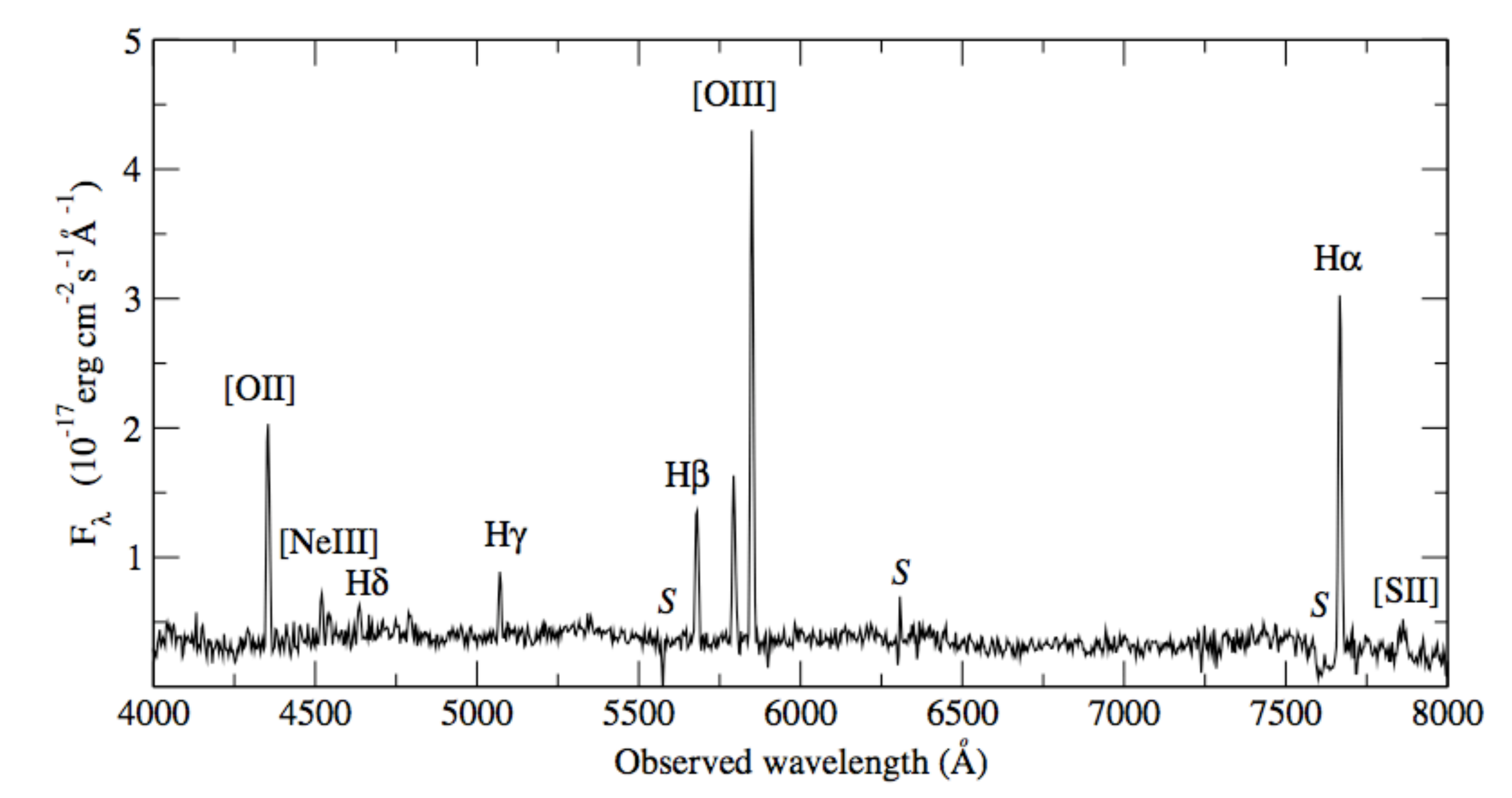
Metal Emission Lines



- Direct measurement of the host metallicity is available for low redshift (z < 1) GRBs.
- GRB hosts have lower metallicity than general star forming galaxies.



Stanek+ 2006



host spectrum of GRB 030329 (Gorosabel+ 2005)

Calibration

Table 9
GRB-Host Metallicities

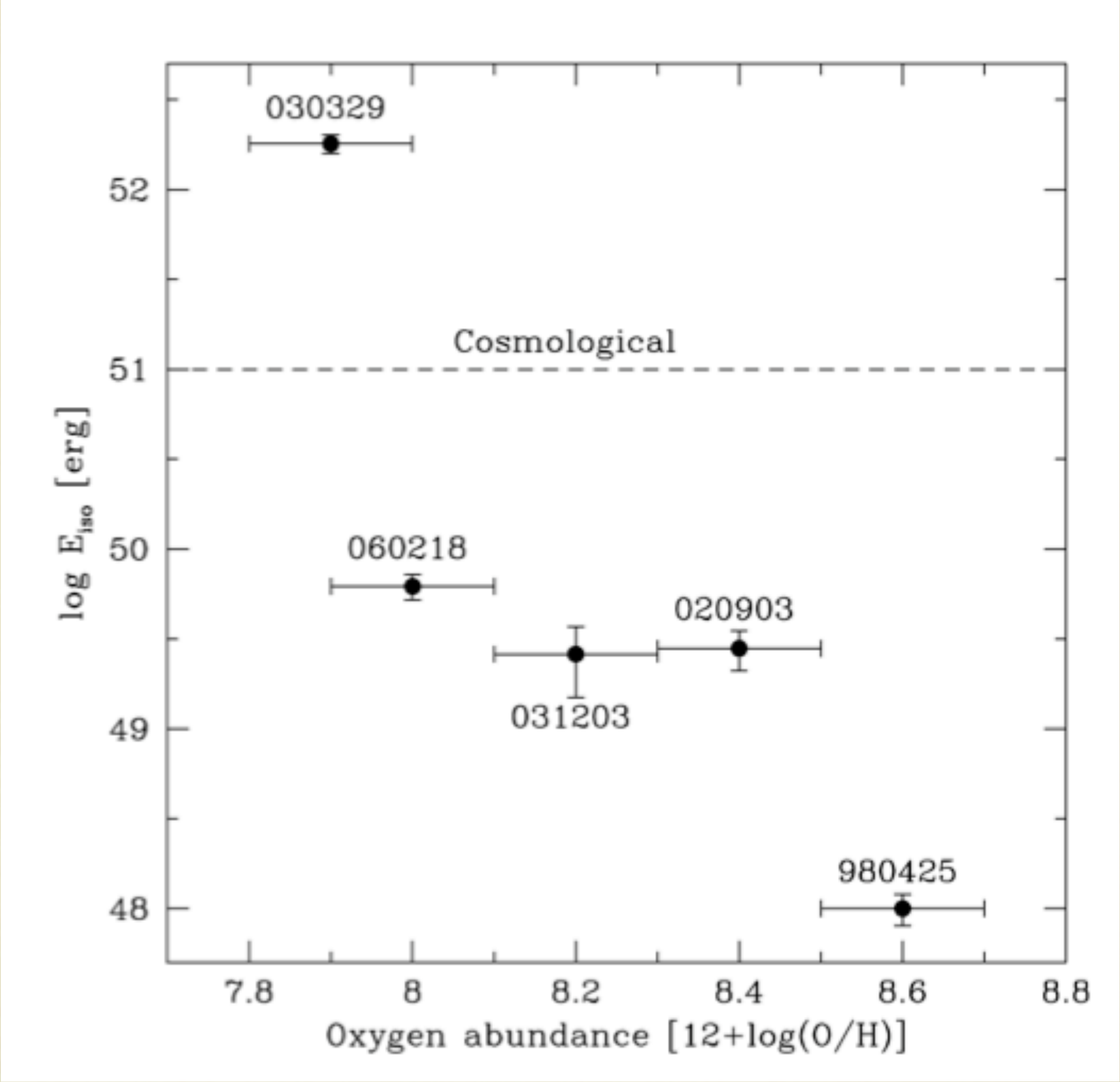
Savaglio+ 2009

GRB	log R_{23}	log O_{32}	12 + log(O/H)						log([N II]/[O II])	log([N II]/Hα)
			Lower KD02[a]	Upper KK04[b]	Lower N06[c]	O3N2[d]	T_e[e]	Adopted[f]		
980425	0.960	0.550	...	...	~8.1	8.1	8.16	8.16	−1.06	−1.21
980703	0.840	−0.529	...	8.14	7.6	...	...	7.6/8.14	...	...
990712	0.932	0.302	...	...	~8.1	<8.3	...	8.1	<−0.66	<−0.66
991208	0.330	0.491	...	8.73	<7.4	...	...	<7.4/8.73	...	...
010921	0.857	−0.064	...	8.15	8.0	...	...	8.0/8.15	...	...
011121	0.566	−0.429	7.50	8.64	...	...	...	7.50/8.64	...	...
020405	0.759	0.279	7.78	8.44	...	...	...	7.78/8.44	...	...
020903	0.957	0.508	...	...	~8.1	8.0	8.22	8.22	−1.55	−1.67
030329	0.820	0.430	7.97	8.33	...	<8.2	...	7.97	<−1.08	<−1.25
030528	0.935	0.179	...	...	~8.1	...	...	8.1	...	...
031203	0.965	1.067	8.25	...	...	8.1	8.02	8.02	−0.68	−1.27
050223	0.536	−0.135	...	8.66	7.5	...	...	7.5/8.66	...	...
050416	0.741	−0.029	7.97	8.44	...	...	...	7.97/8.44	...	...
051022	0.556	0.186	...	8.65	7.5	...	...	7.5/8.65	...	...
051221	0.614	−0.336	...	8.59	7.6	...	...	7.6/8.59	...	...
060218	0.927	0.396	...	...	~8.1	8.13	7.29[g]	8.13	−1.15	−1.22
060505	0.770	−0.292	...	8.37	7.8	8.44	...	8.44	−0.88	−0.75

- Different calibration gives us different metallicity.
- Reliable method can be used only for z < 0.5 (currently 5 GRBs).

Low Luminousity Long GRB

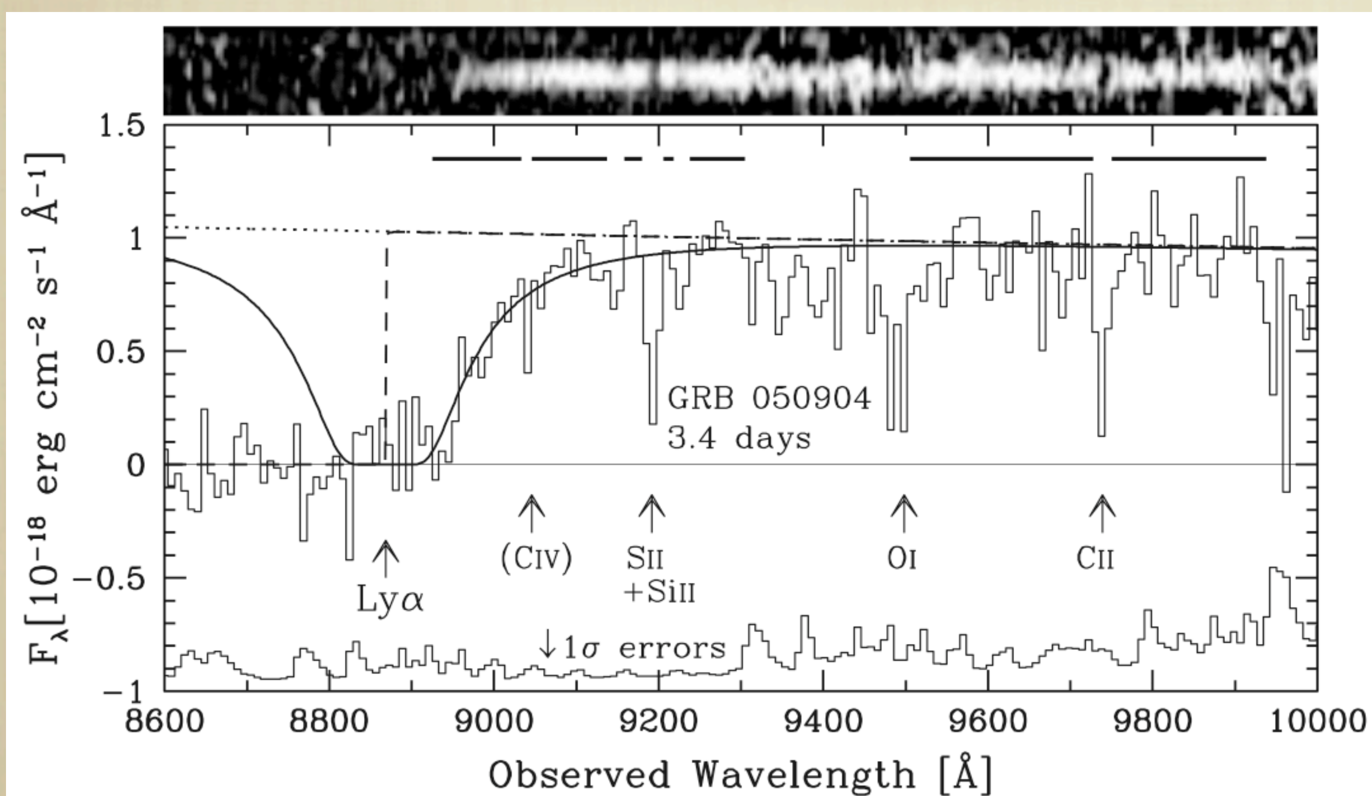
- Some low luminosity long GRBs (LLLGRB; $E_{iso} < 10^{50}$ erg) are found at $z < 0.3$.
- Rate of LLLGRBs can not be explained by mere extrapolation of long GRB luminosity function.
    - LLLGRBs may be different class to general long GRBs.



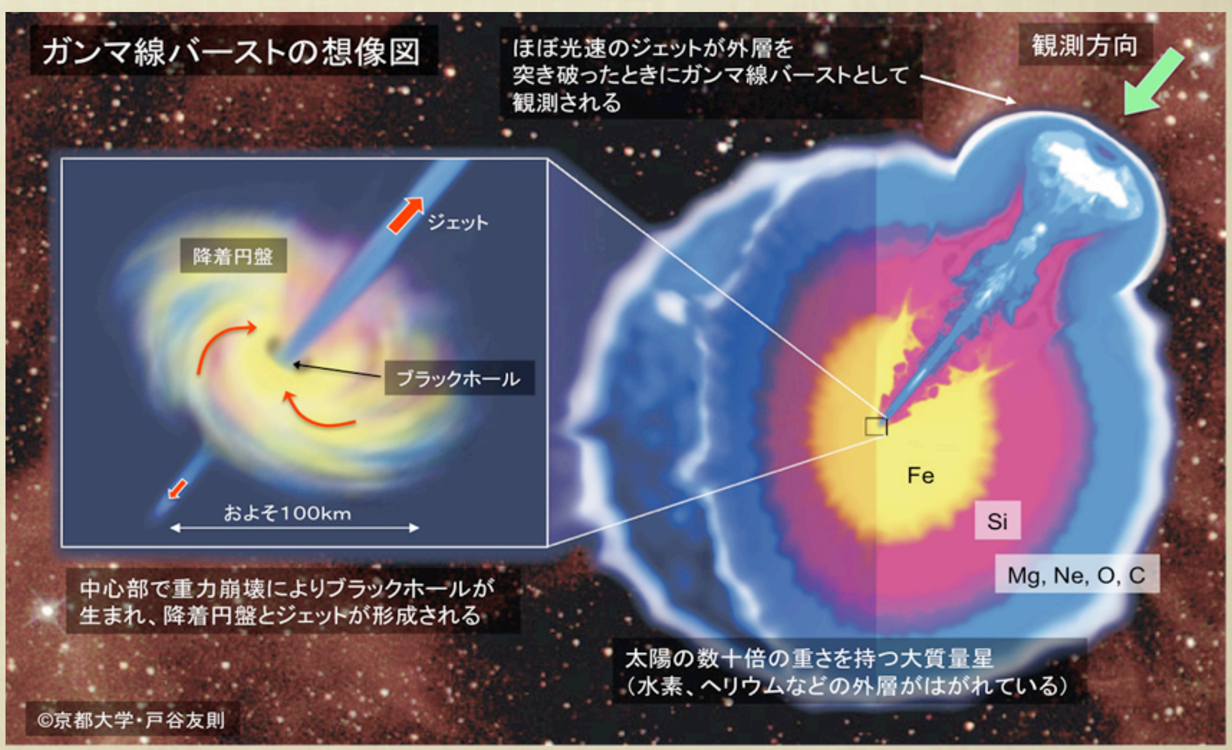
Absorption lines in GRB spectra

GRB Afterglow

- GRB afterglow is emission from front shock of the GRB jet.
- Absorption line system is seen in GRB afterglow in some case.



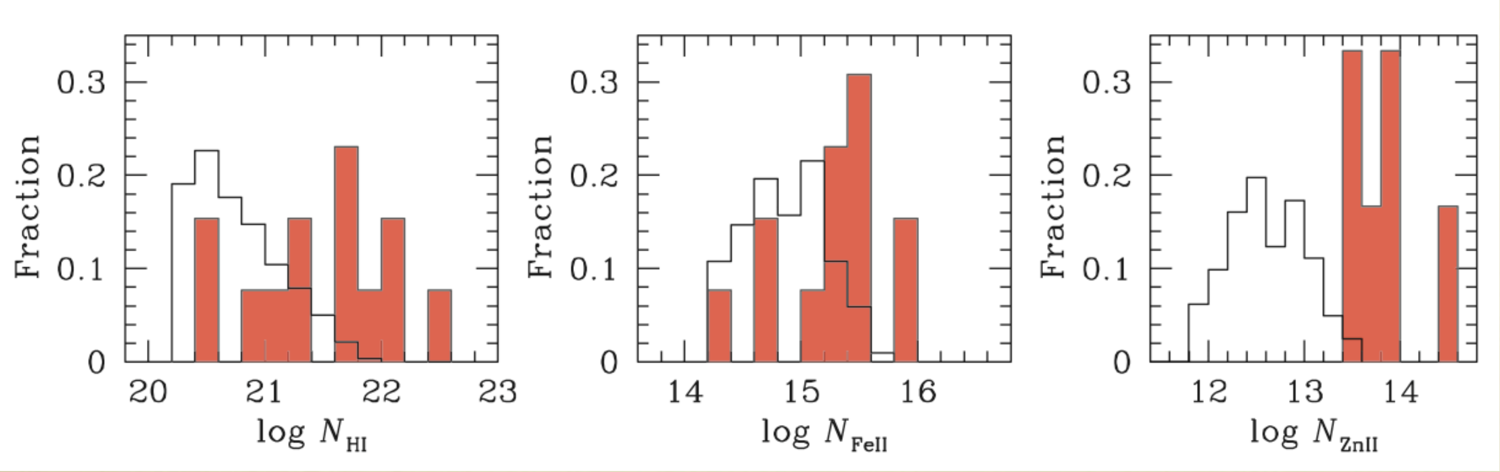
Totani+ 2006



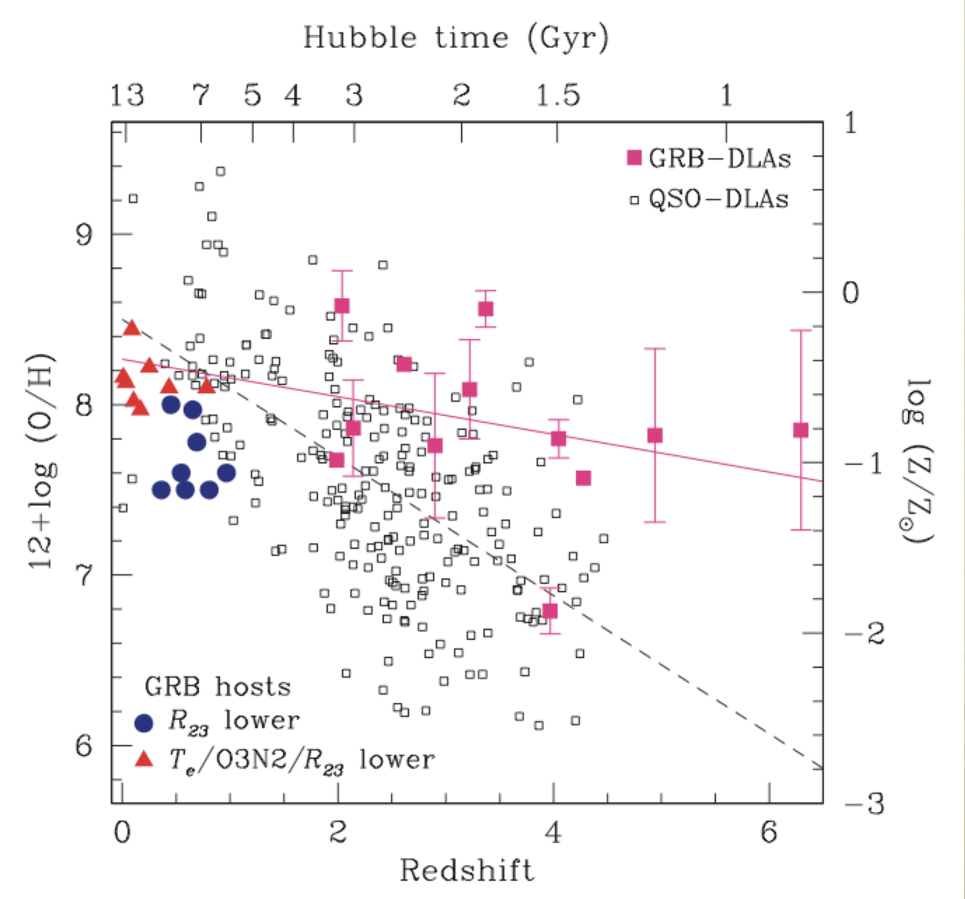
Totani-san’s website

GRB-DLA & QSO-DLA

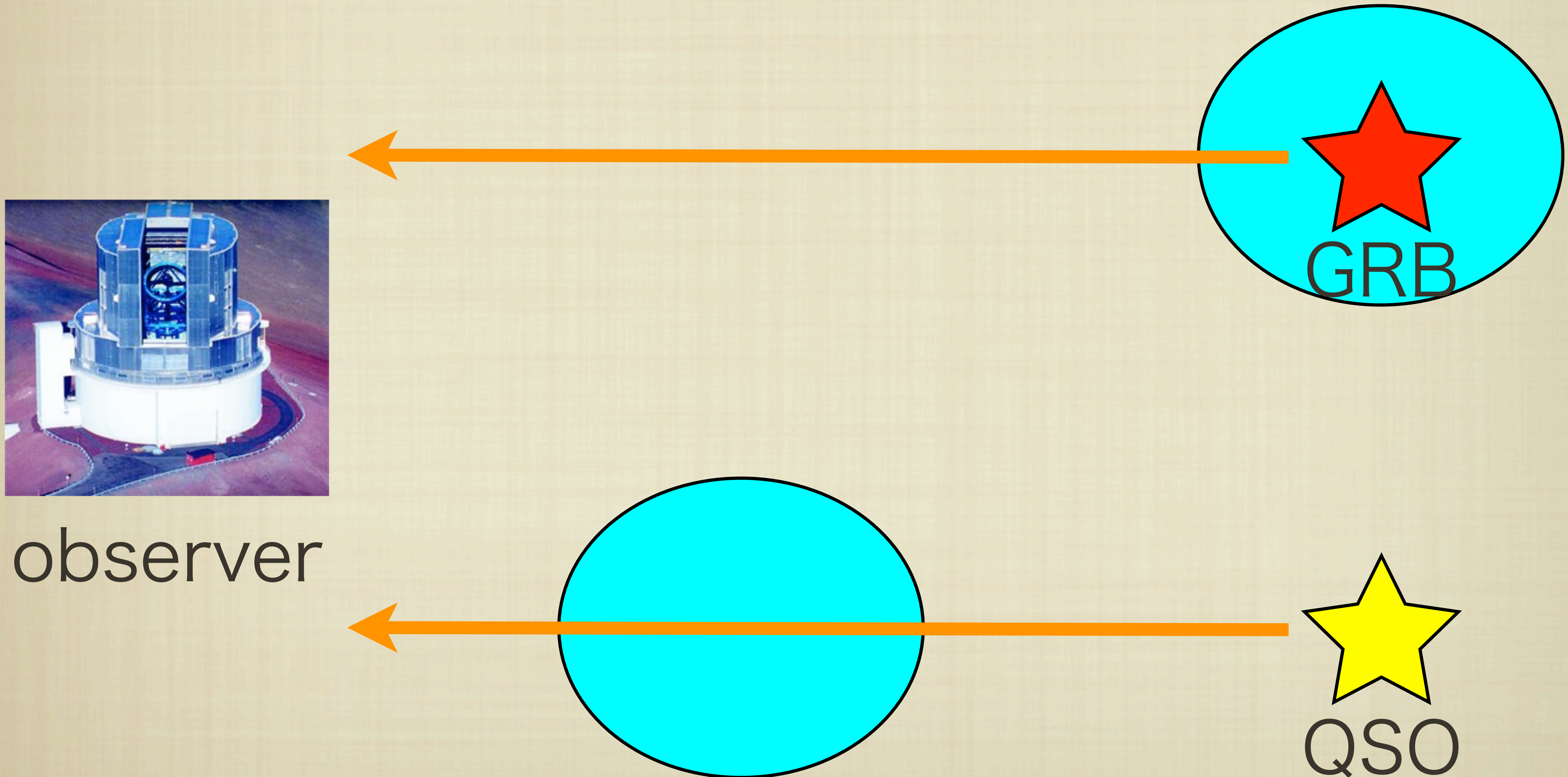
- GRB-DLA is often compared to QSO-DLA
  - GRB-DLAs are typically metal-rich.
- GRB-DLA and QSO-DLA are completely different object.



Savaglio 2008



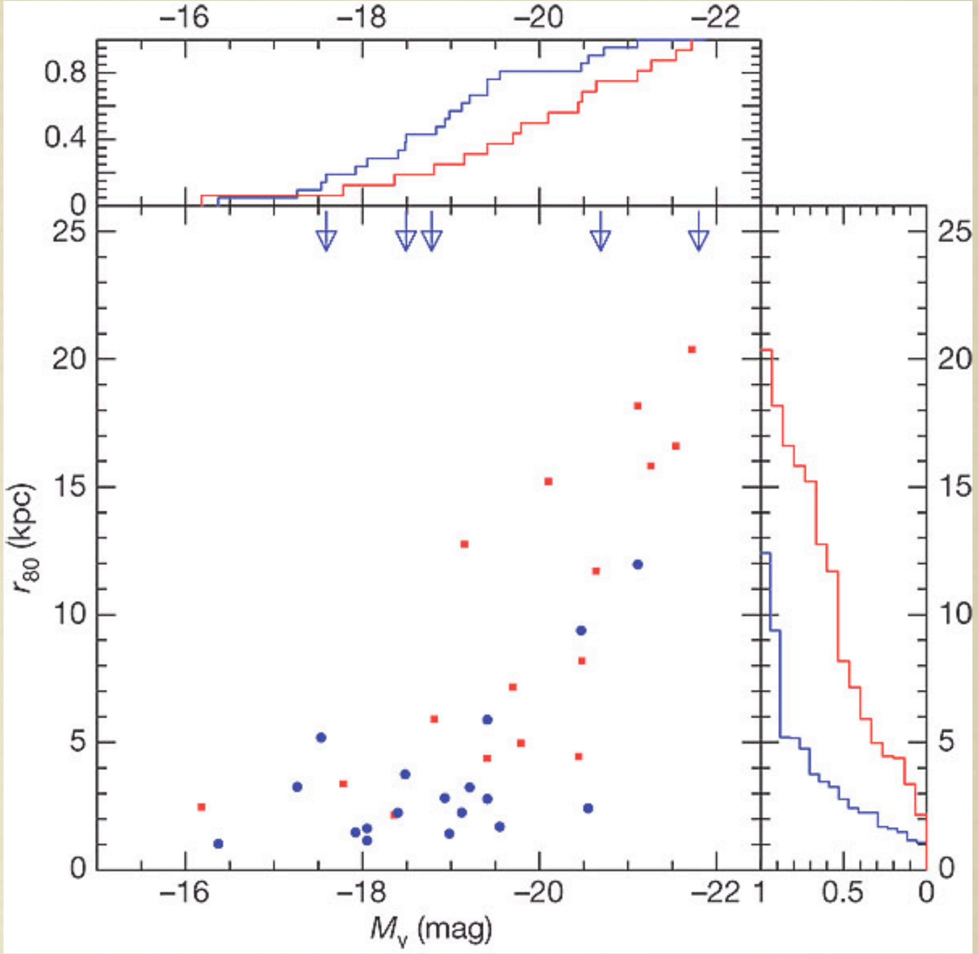
GRB-DLA & QSO-DLA



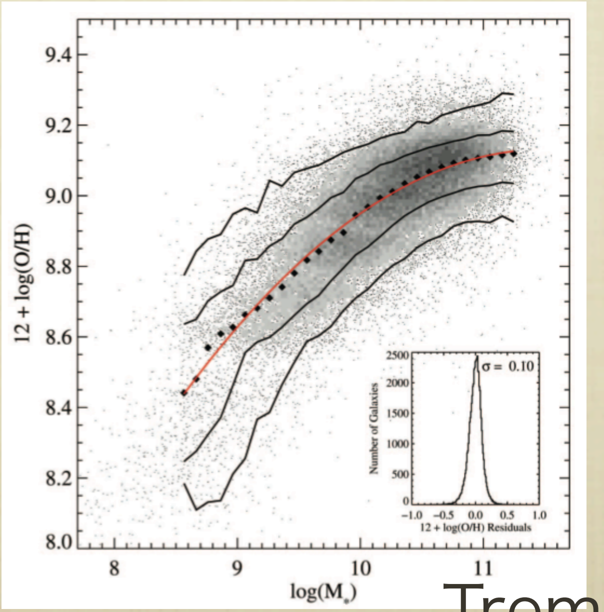
GRB Host Galaxy Luminosity Function

Observed Luminosity Function

- Fruchter+ 2006
  - comparison of host galaxies of long GRBs and CC SNe
  - GRB hosts are fainter and smaller (in size) than CC SN Hosts.
- Generally, galaxies with larger stellar mass have larger metallicity.



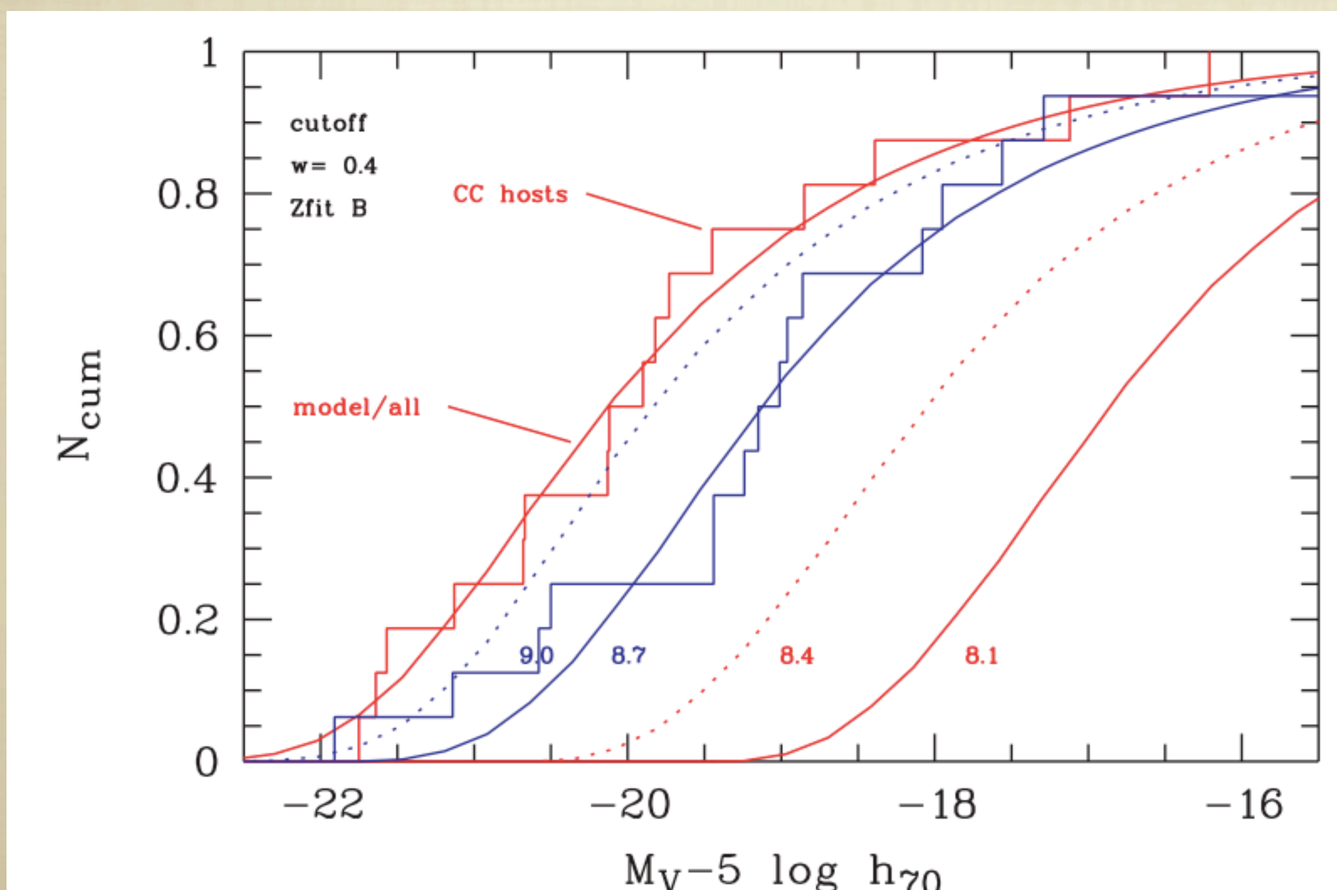
Fruchter+ 2006

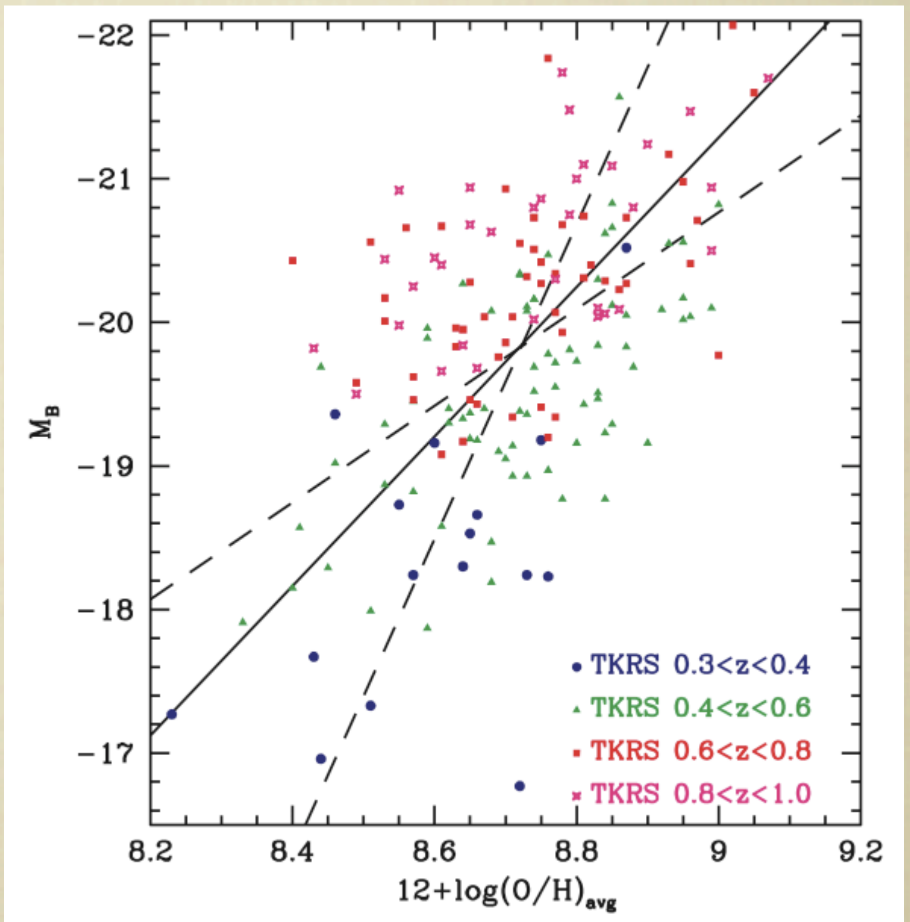


Tremonti+ 2006

Observation Based Study

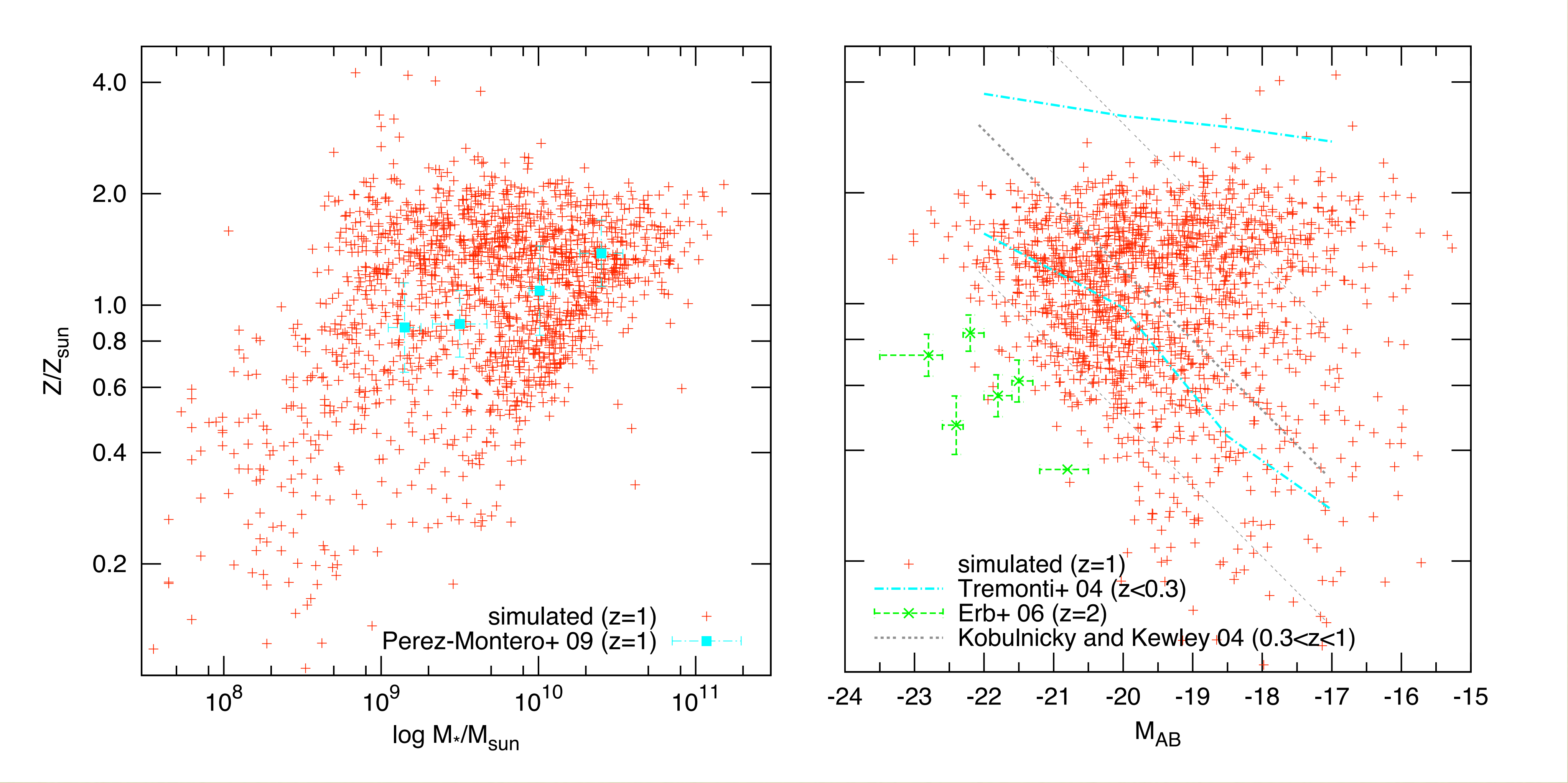
- Wolf & Podsiadlowski 2007
  - reproduce observation of Fruchter+ using luminosity function (LF), L-SFR relation & L-Z relation of survey galaxies.





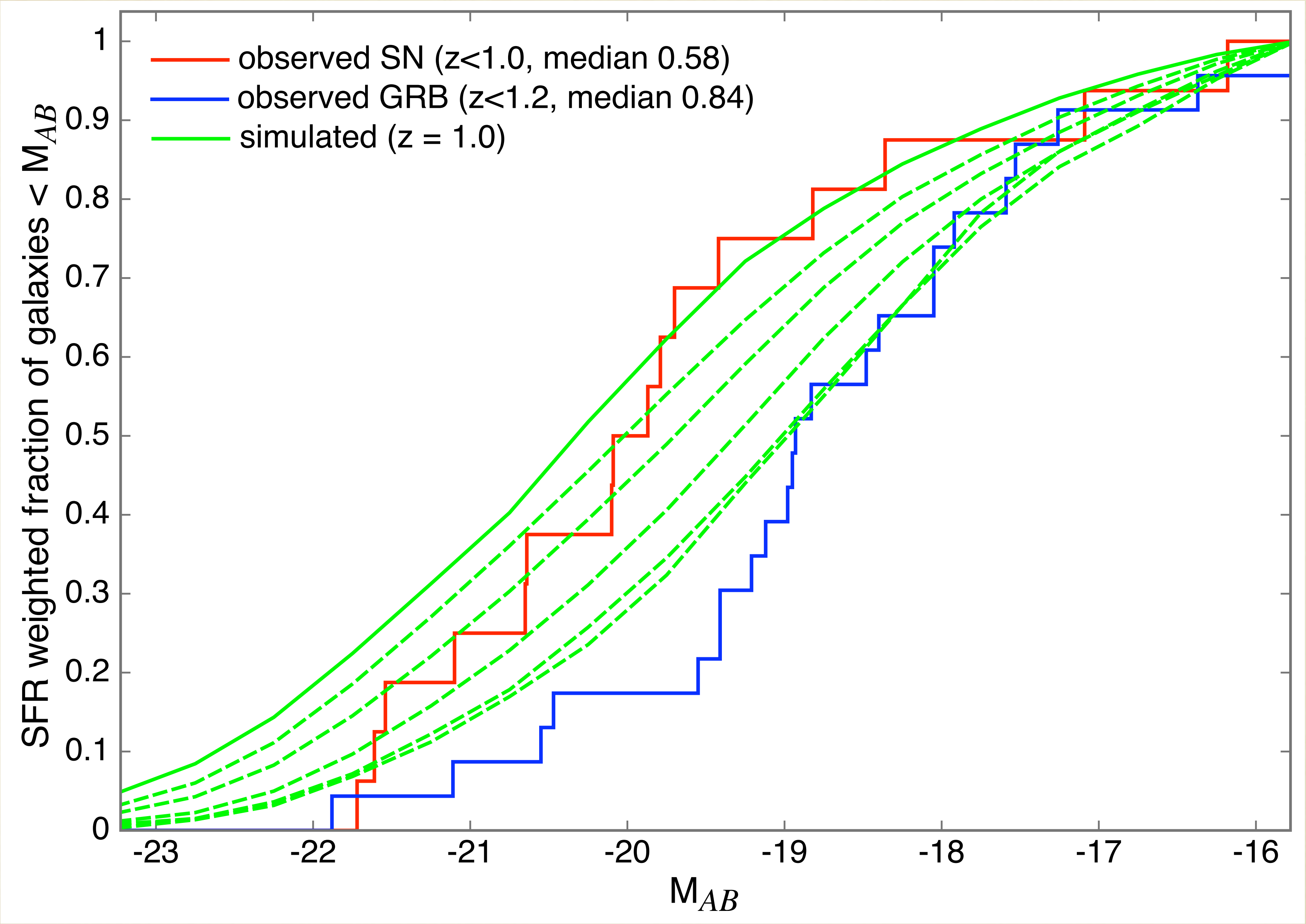
Cosmological Simulation

- Niino et al. (in progress)
  - use cosmological simulation to reproduce observation.



LF of Simulated GRB hosts

- preliminary result



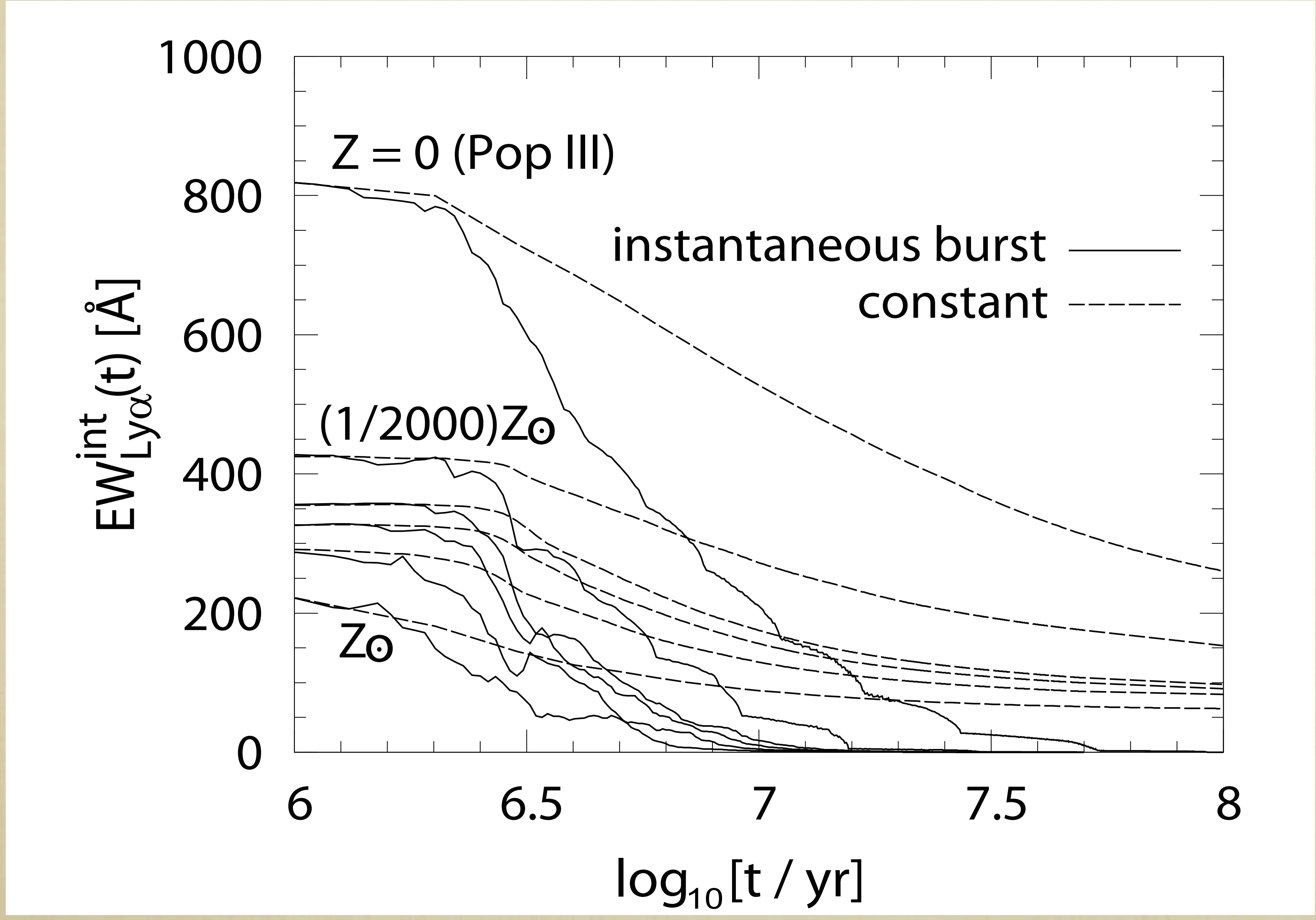
simulated metallicity threshold:

$1.0Z_{sun}$, $0.5Z_{sun}$, $0.1Z_{sun}$, $0.01Z_{sun}$, $10^{-3}Z_{sun}$

Lyman-α Emission of GRB Host Galaxies

Lyman-α Emission

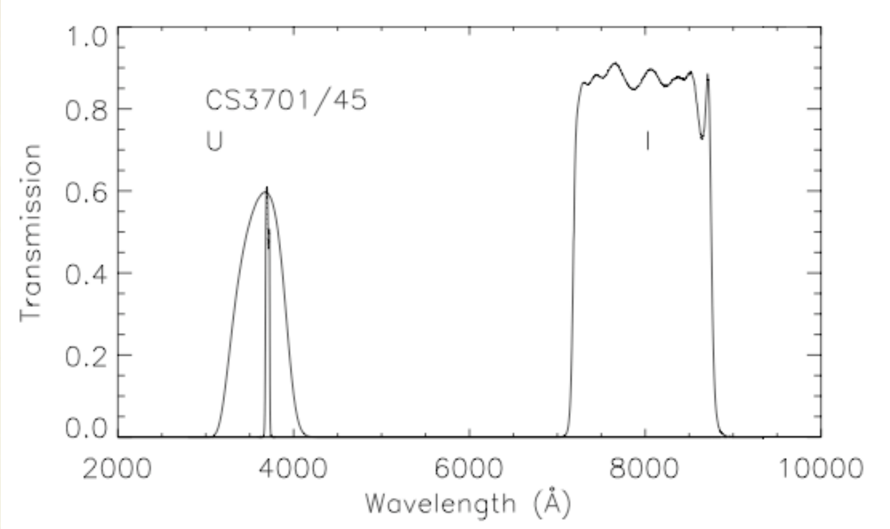
- recombination line of hydrogen
  - Low metallicity star emits more ionizing flux.



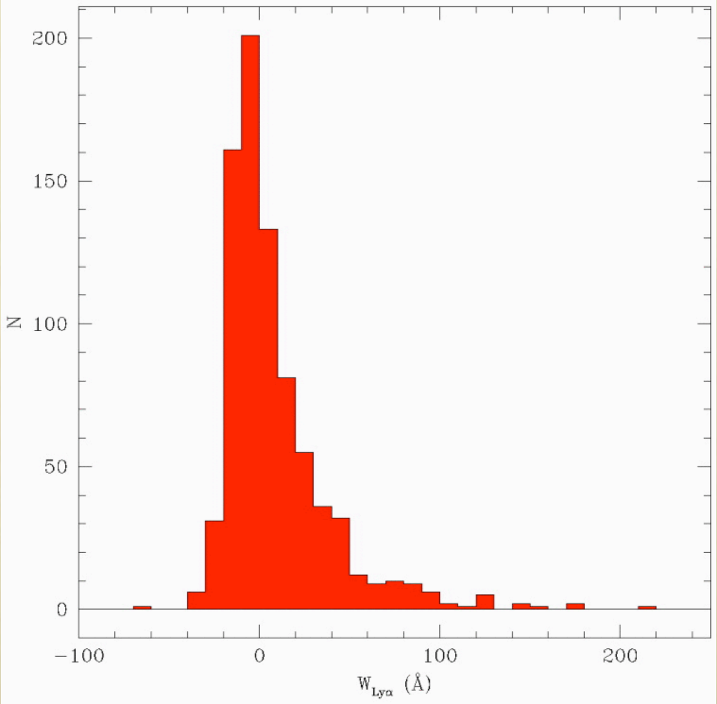
Kobayashi+ 2009
population synthesis code of Schearer 2003 is used.

Lyman alpha emission

- Almost all of GRB host galaxies with Lyα measurement have Lyα equivalent width (EW) > 10 Å. (only 7 galaxy)
  - Roughly 33% of Lyman break galaxies (LBGs) have such Lyα emission (Shapley + 2003).



host galaxy of GRB 000926
z = 2, LyA EW = 71 Å
(Fynbo+ 2002)



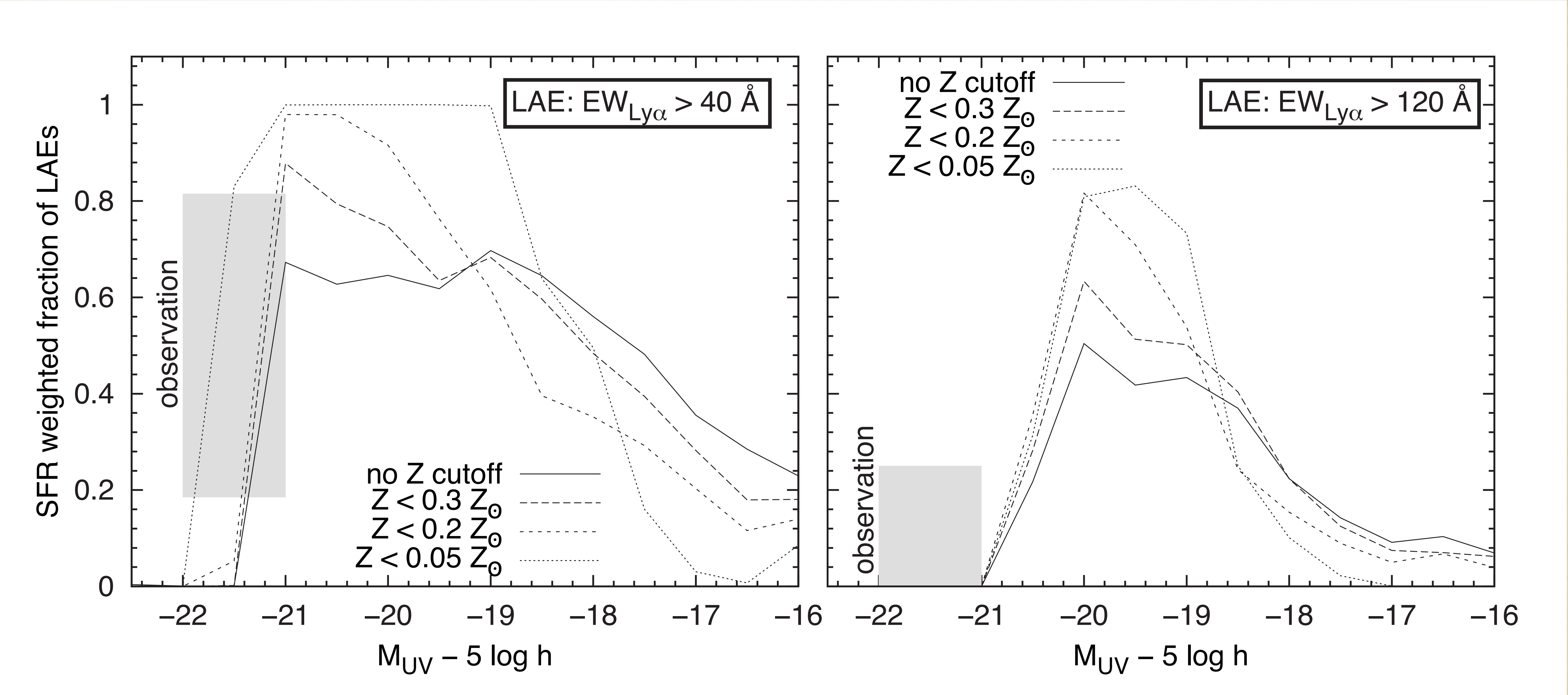
LyA EW distribution of LBGs (Shapley+ 2003)

Model of GRB Host Lyα Emission

- Niino, Totani & Kobayashi (2009) predict Lyα emission of GRB host galaxies using semi-analytic model (Mitaka model) of galaxy formation.
- Mitaka model provides us with mock numerical catalog of galaxies.
  - including SFR, metallicity, Lyα EW
  - in each galaxy:

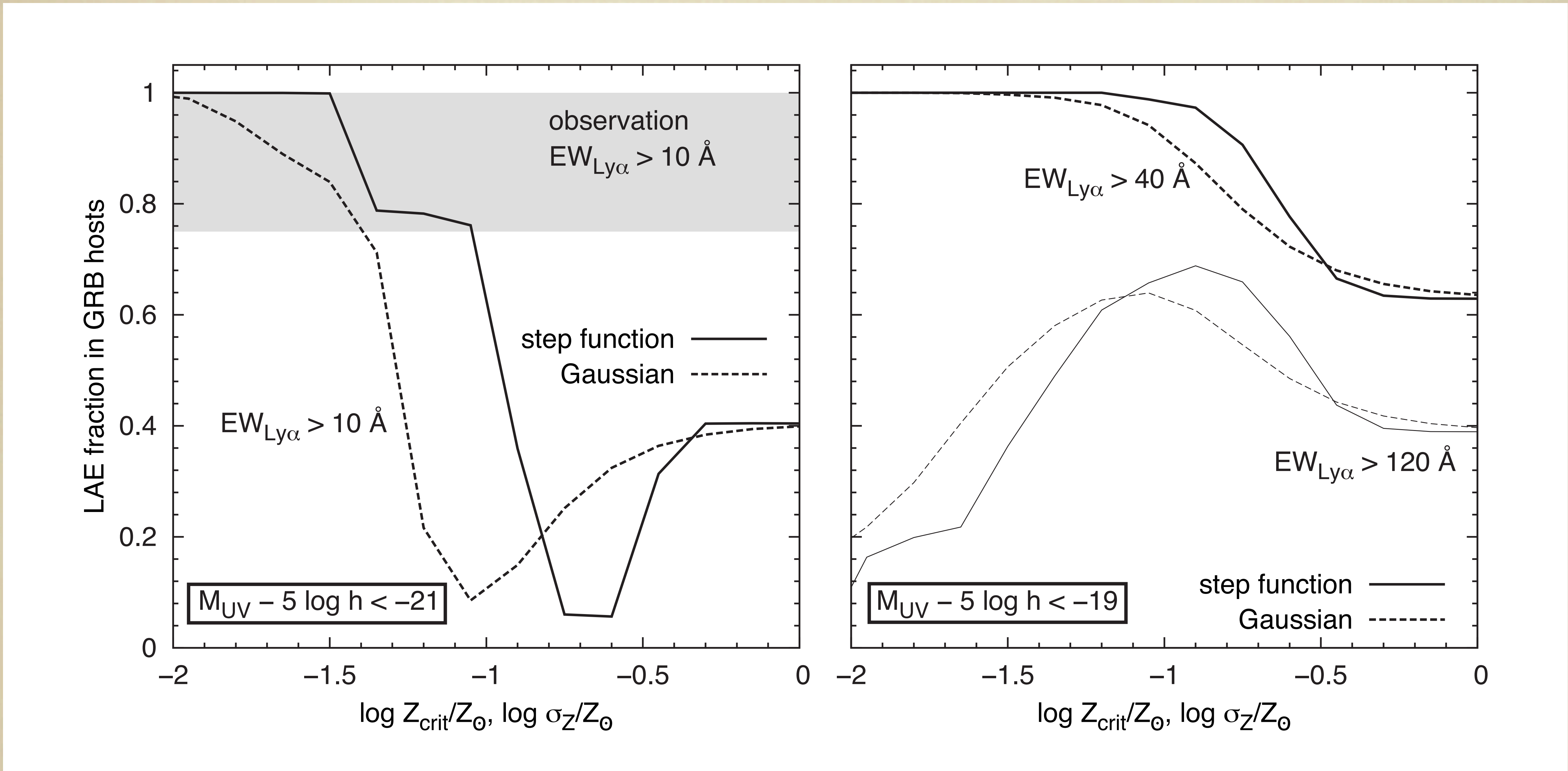
$$R_{\mathrm{GRB}} \propto \begin{cases} \mathrm{SFR}, & Z < Z_{\mathrm{crit}} \\ 0, & Z \geq Z_{\mathrm{crit}} \end{cases}$$

Lyman alpha emission



$$R_{\rm GRB} \propto \begin{cases} {\rm SFR}, & Z < Z_{\rm crit} \\ 0, & Z \geq Z_{\rm crit} \end{cases}$$

Lyman alpha emission



$$R_{\mathrm{GRB}} \propto \begin{cases} \mathrm{SFR}, & Z < Z_{\mathrm{crit}} \\ 0, & Z \geq Z_{\mathrm{crit}} \end{cases}$$

Summary

- Theoretical studies suggest that GRBs preferentially occur in low-metallicity environment.
- Though various method is used to test the metallicity dependence observationally, the dependence is not robustly confirmed.
  - Some method have potential to make robust conclusion with larger sample in future observation.