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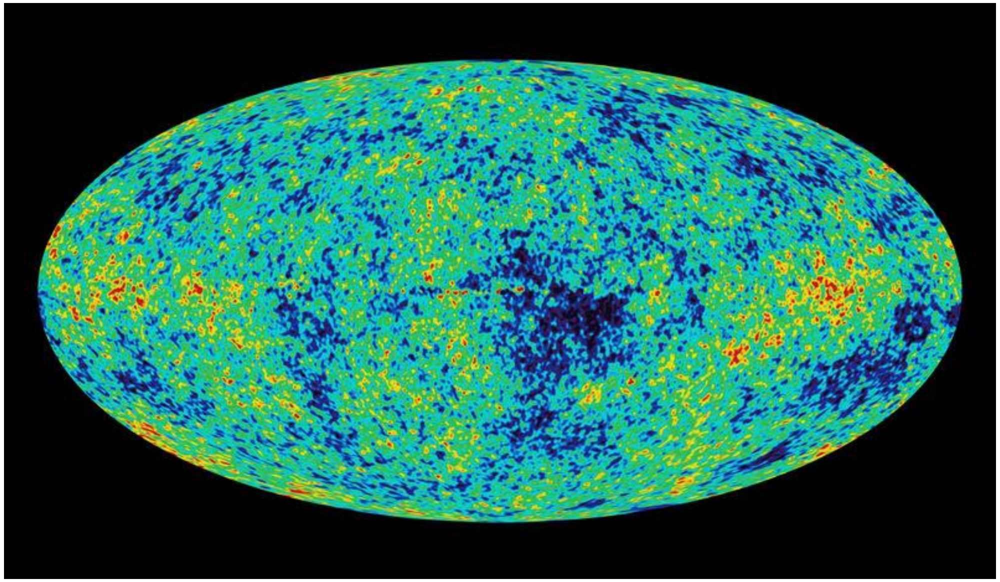
Probing the High Redshift Universe with GRBs

Overview

- Background
- Detecting GRBs at VHR
- Probing SF with GRB afterglow
- Finding SN at VHR
- Measuring the redshifts of VHR GRBs
- Tracing Metallicity
- Probing Large-Scale Structure
- Determining Epoch of Reionization
- Conclusion

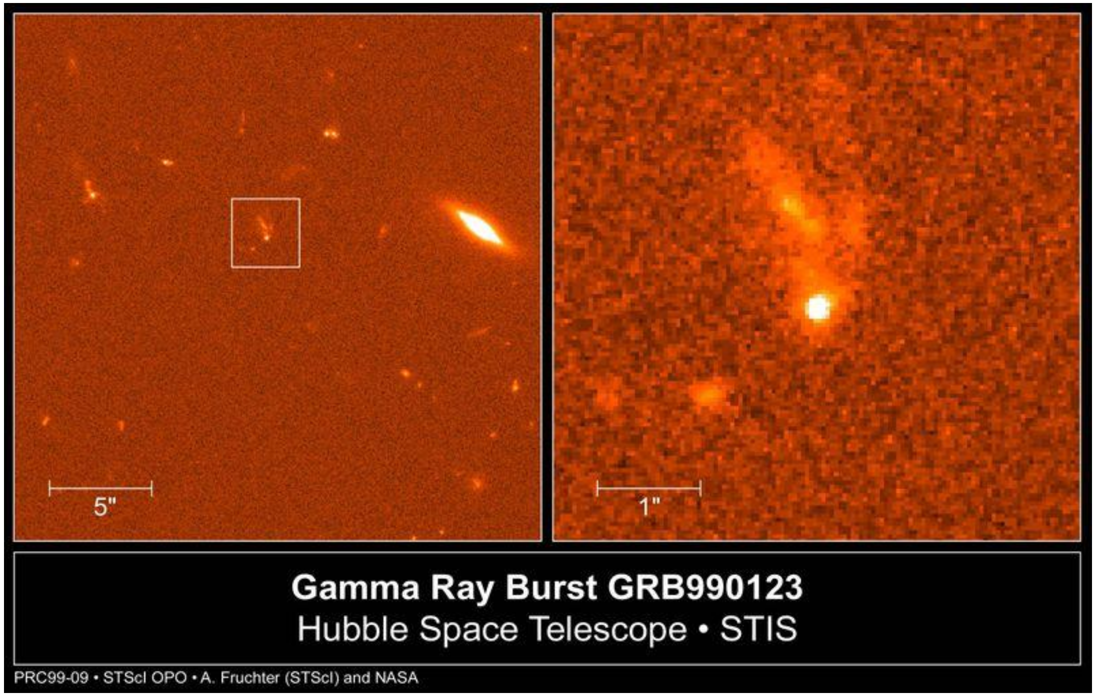
Constants

- Constants used are from WMAP1 results:
- Total matter density $\Omega_M = 0.3$
- Dark energy density $\Omega_\Lambda = 0.7$
- Hubble constant $H_0 = 65$ km s^{-1} Mpc^{-1}



Useful Acronyms

- GRB: Gamma-ray burst
- VHR: Very high redshift
- SFR: Star formation rate
- SNe: Supernova explosion
- BATSE: Burst and Transient Source Experiment on Compton Gamma Ray Observatory
- HETE - 2: High Energy Transient Explorer
- BeppoSAX: Italian-Dutch X-ray satellite



- Gamma-ray bursts (GRBs) are the most luminous events seen in the Universe
  - Bursts last from milliseconds to minutes
  - Followed by an afterglow at longer wavelengths
    - Likely caused by shocked gas encountering magnetic fields and give off synchrotron radiation

Background

- GRB found with BeppoSAX (1997)
  - Afterglow contains X-ray, Optical, Radio components
- Light of GRB host galaxy is detected and is very blue (1998)
  - Implies GRBs may be associated with SF Galaxies
- GRB might contain an SN component (1999)
  - GRBs associated with core-collapse SN

Detecting GRBs at VHRs

TABLE 1

PEAK PHOTON FLUXES AND ISOTROPIC LUMINOSITIES FOR GRBS WITH SECURE REDSHIFTS

GRB	Redshift	P (photons cm^{-2} s^{-1})[a]	L_P (photons s^{-1})[b]	Redshift Reference
970228	0.695	3.5	5.1×10^{57}	1
970508	0.835	1.2	2.5×10^{57}	2, 3
971214	3.418	2.3	6.4×10^{58}	4
980613	1.096	0.63	2.3×10^{57}	5
980703	0.967	2.6	7.4×10^{57}	6
990123	1.600	16.4	1.2×10^{59}	7
990510	1.619	8.16	6.2×10^{58}	8
990712[c]	0.430	...	...	9

Detecting GRBs at VHRs

(1) $$L_P = \int_{\nu_l}^{\nu_u} \frac{dL_P}{d\nu}\, d\nu$$

Peak photon number luminosity

(2) $$P = \int_{\nu_l}^{\nu_u} \frac{dP}{d\nu}\, d\nu$$

Peak photon number flux

(3) $$P = \frac{L_P}{4\pi D^2(z)(1+z)^\alpha}$$

(4) $$D(z) = c\int_0^z (1+z')\left|\frac{dt(z')}{dz'}\right| dz'$$

Comoving distance to the GRB

Detecting GRBs at VHRs

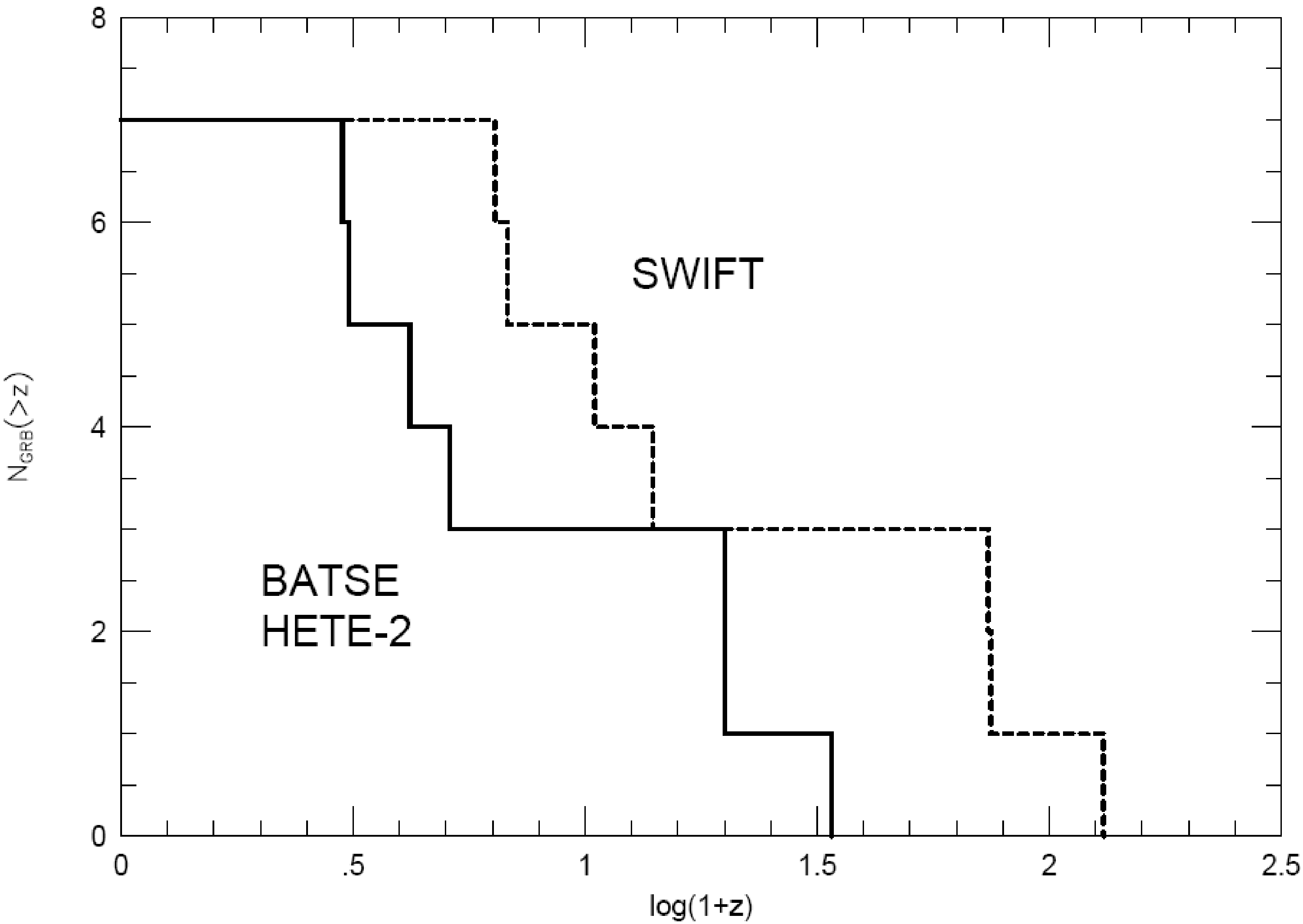
$$(5)\quad \frac{dt(z)}{dz} = -\left(\frac{c}{H_0}\right)\{(1+z)[\Omega_m(1+z)^3 + \Omega_\Lambda + (1-\Omega_m-\Omega_\Lambda)(1+z)^2]^{1/2}\}^{-1}$$

$$(6)\quad D(z) = \frac{c}{H_0}\int_0^z \frac{dz'}{\sqrt{\Omega_m(1+z')^3 + \Omega_\Lambda}}$$

Taking $\alpha = 1$

$$P = \frac{L_P}{4\pi D^2(z)(1+z)}$$

Detecting GRBs at VHRs



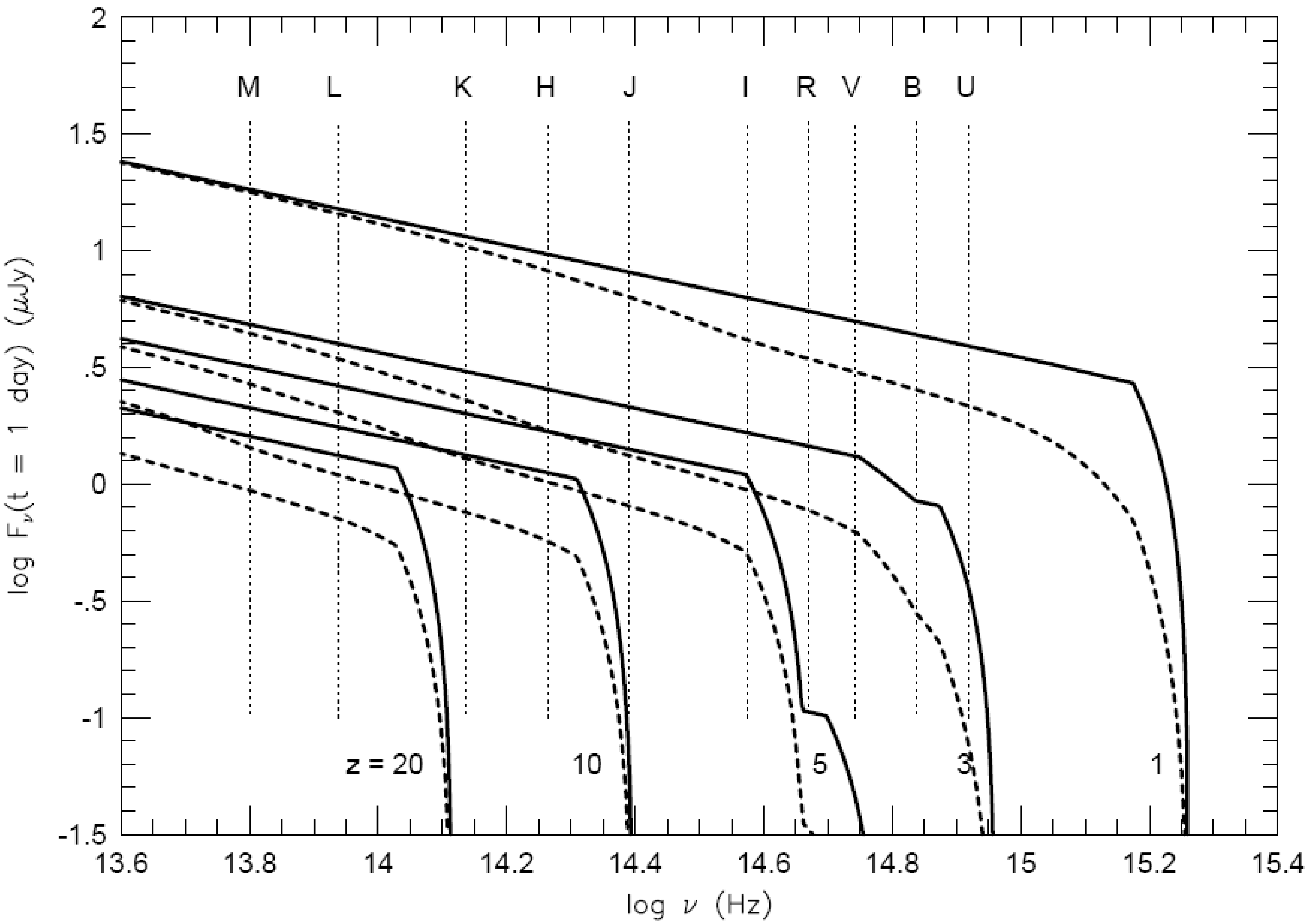
Detecting GRBs at VHRs

- Factors decreasing spectral energy flux:
  1. Distance away
  2. Redshift

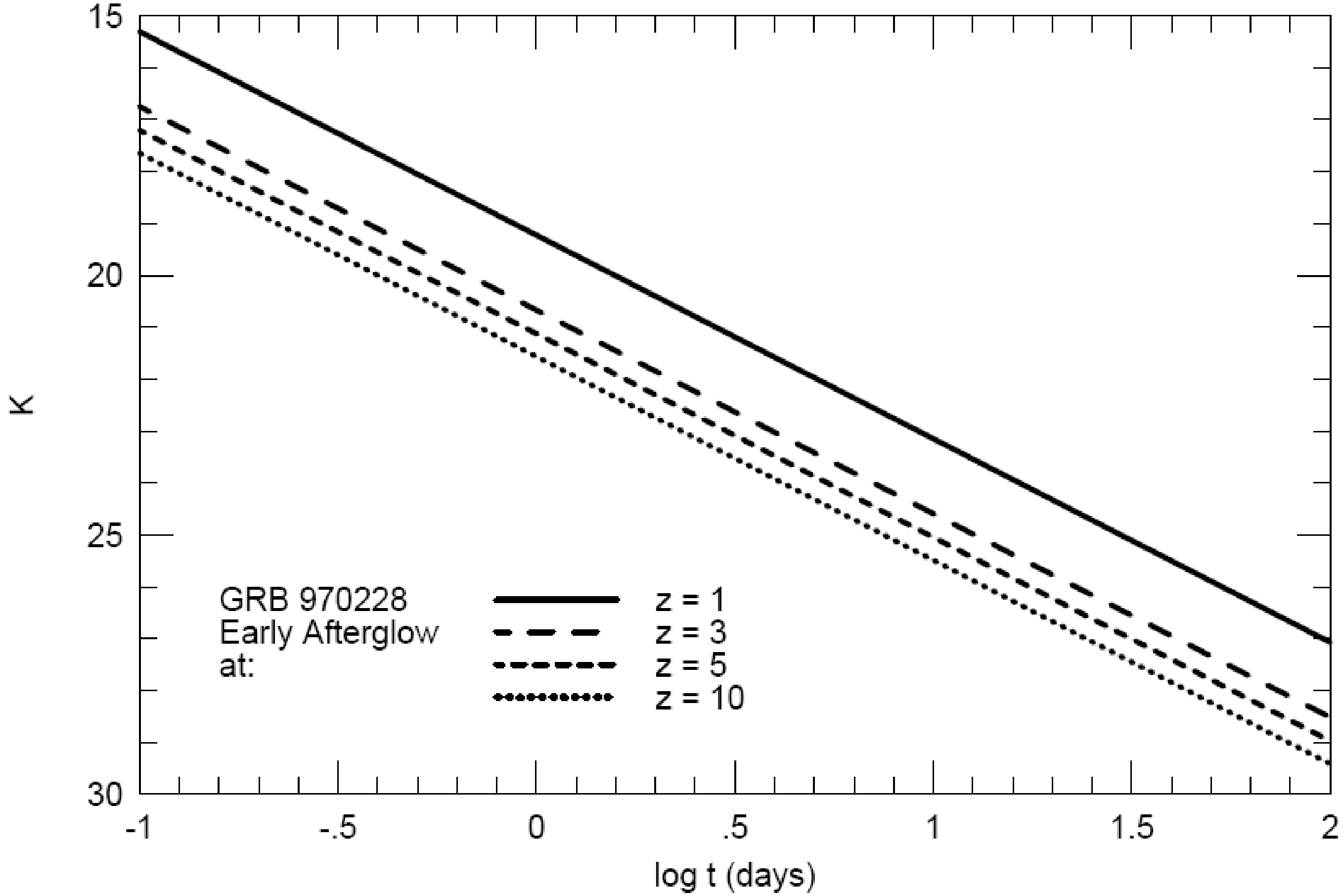
- Factor increasing spectral energy flux:
  1. Time dilation
     - Space between GRB and observer decreases and amount of energy released over an hour is received in less time

- Effects cancel → little or no decrease in flux

Detecting GRBs at VHRs



Detecting GRBs at VHRs



Detecting GRBs at VHRs

- Implications of light curve:
  - Detecting VHR GRBs require deep near-infrared observations
    - HETE-2 and Swift can do this
  - Deep optical observations needed to constrain the redshift
    - Looking for optical dropout

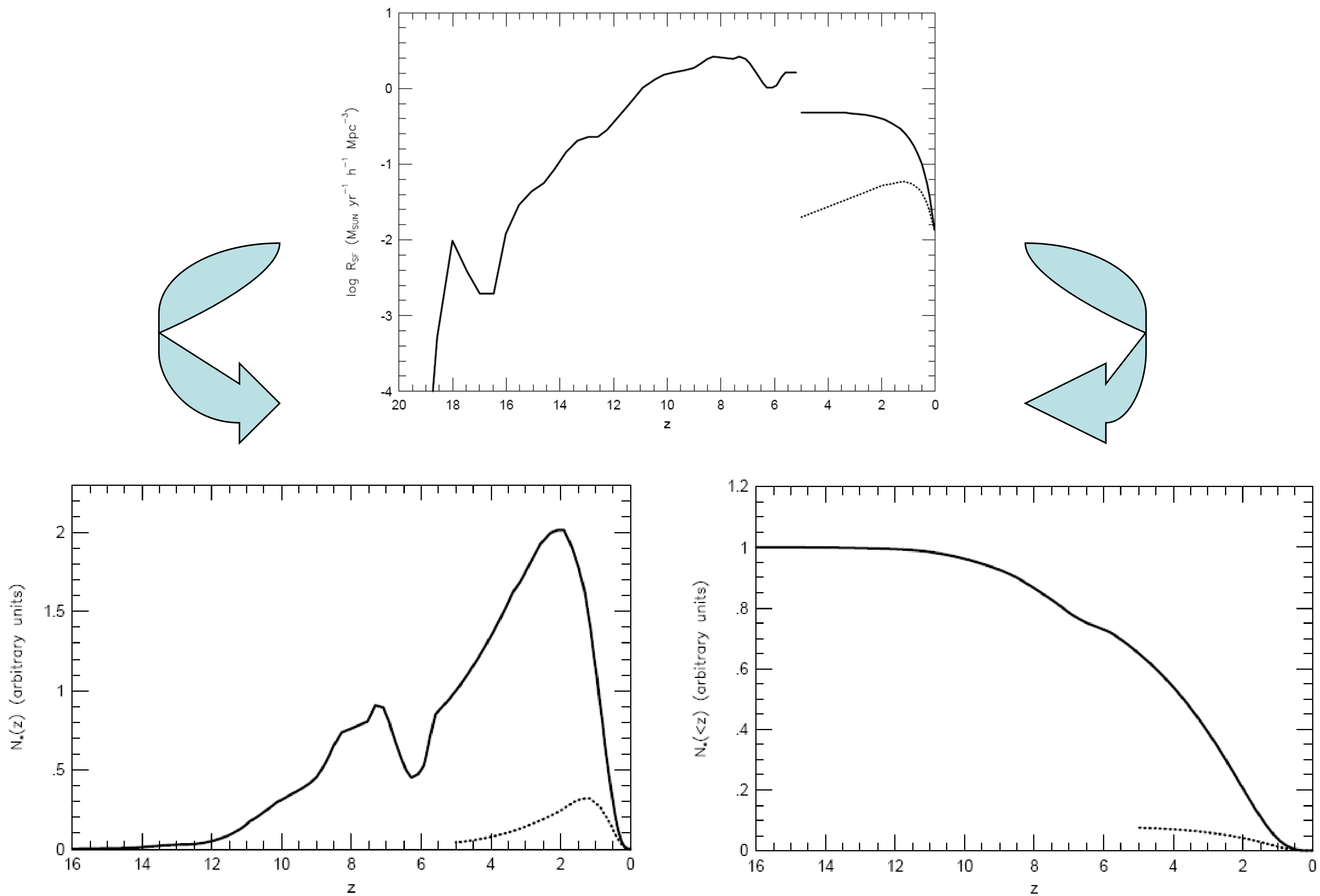
Probing Star Formation

- Collapsar model predicted GRBs caused by core-collapse SN
  - ≥40 M_solar as a main sequence star
  - Must be rapidly rotating to develop jets
  - Low Z so that jets can strip off H-envelope and reach surface

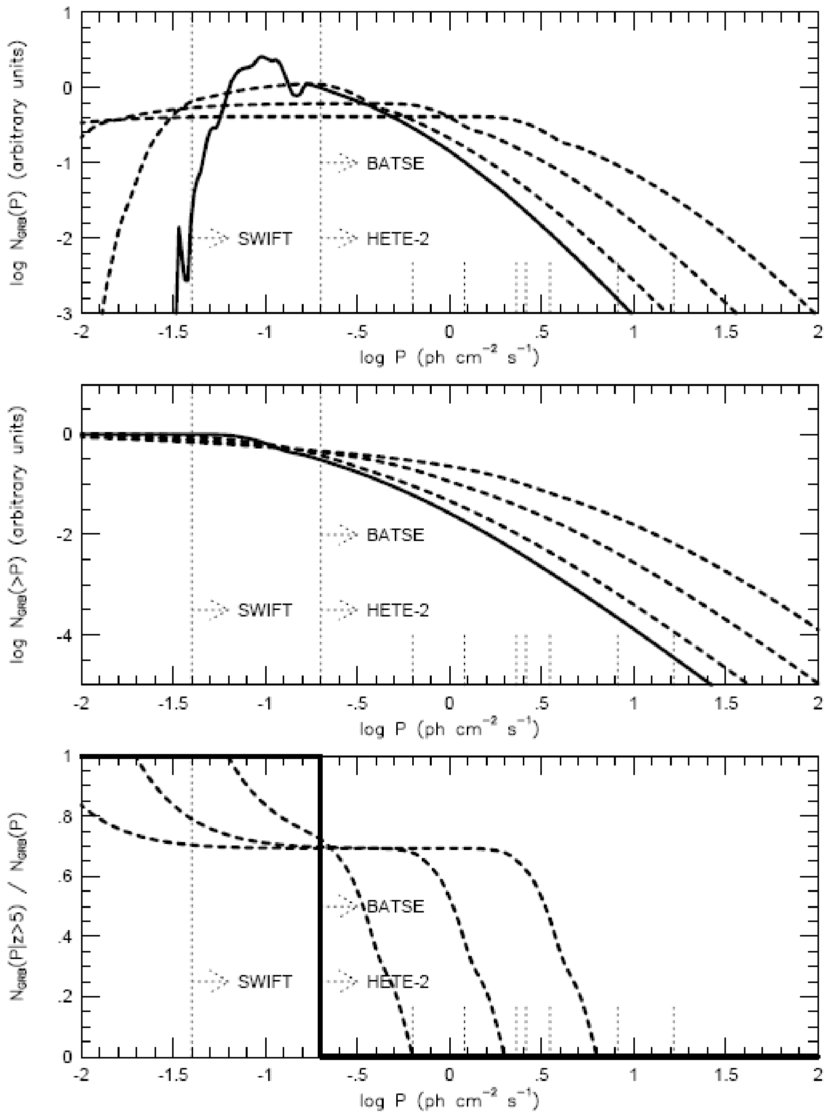
Probing Star Formation

- Recall that in 1999, a SN component was detected in GRB afterglow
  - Suggests that GRBs are related to the deaths of massive stars
  - If GRBs related to collapse of massive stars then GRB rate proportional to SFR
  - Should occur out to z ~ 10-20 → Probe VHR star formation

Probing Star Formation

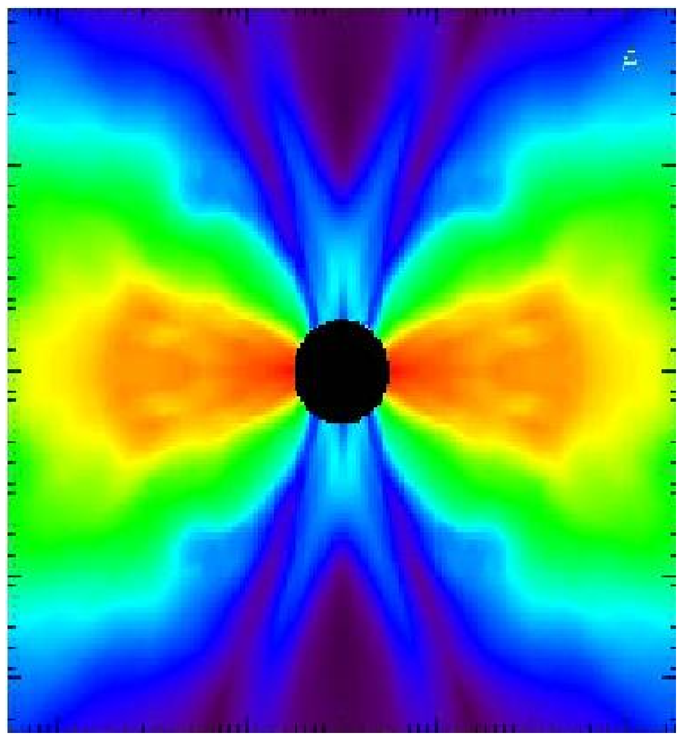


Probing Star Formation

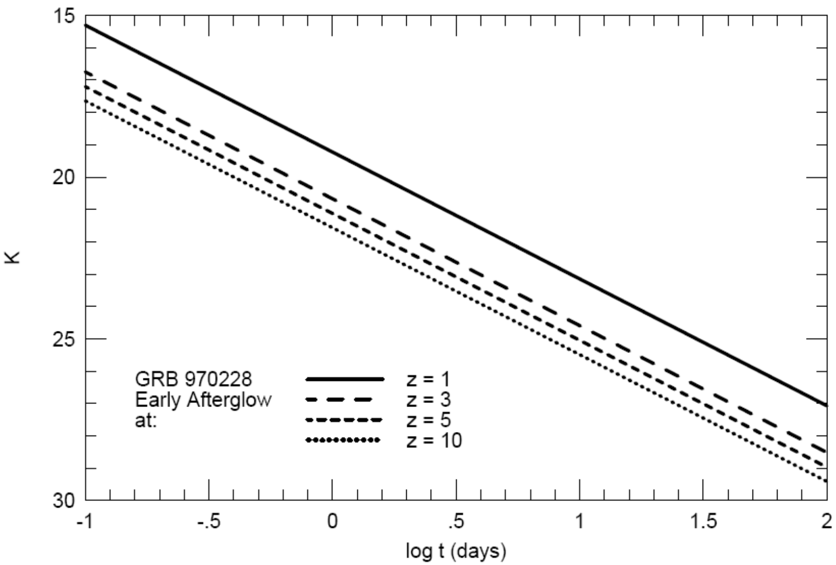


Finding SN at VHR

- GRBs are likely caused by core-collapse SN
  - Therefore we should be able detect SN component if we know what to look for and when to look for it



Finding SN at VHR



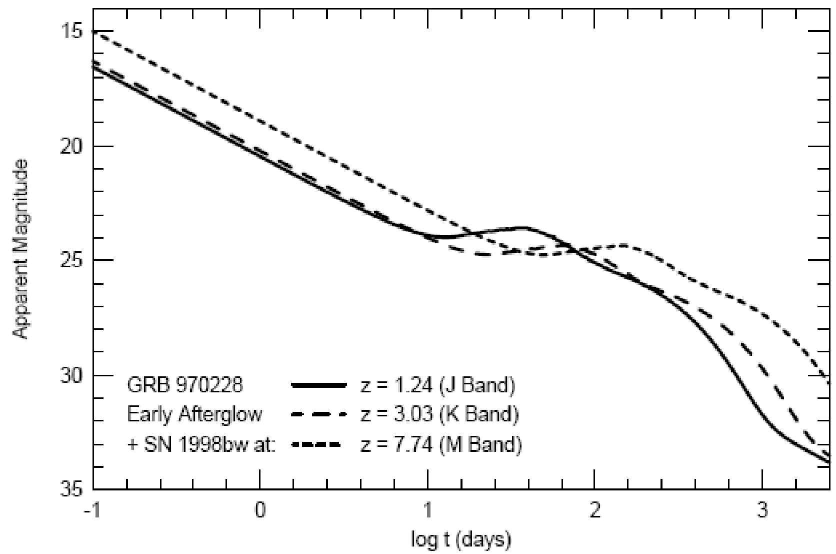
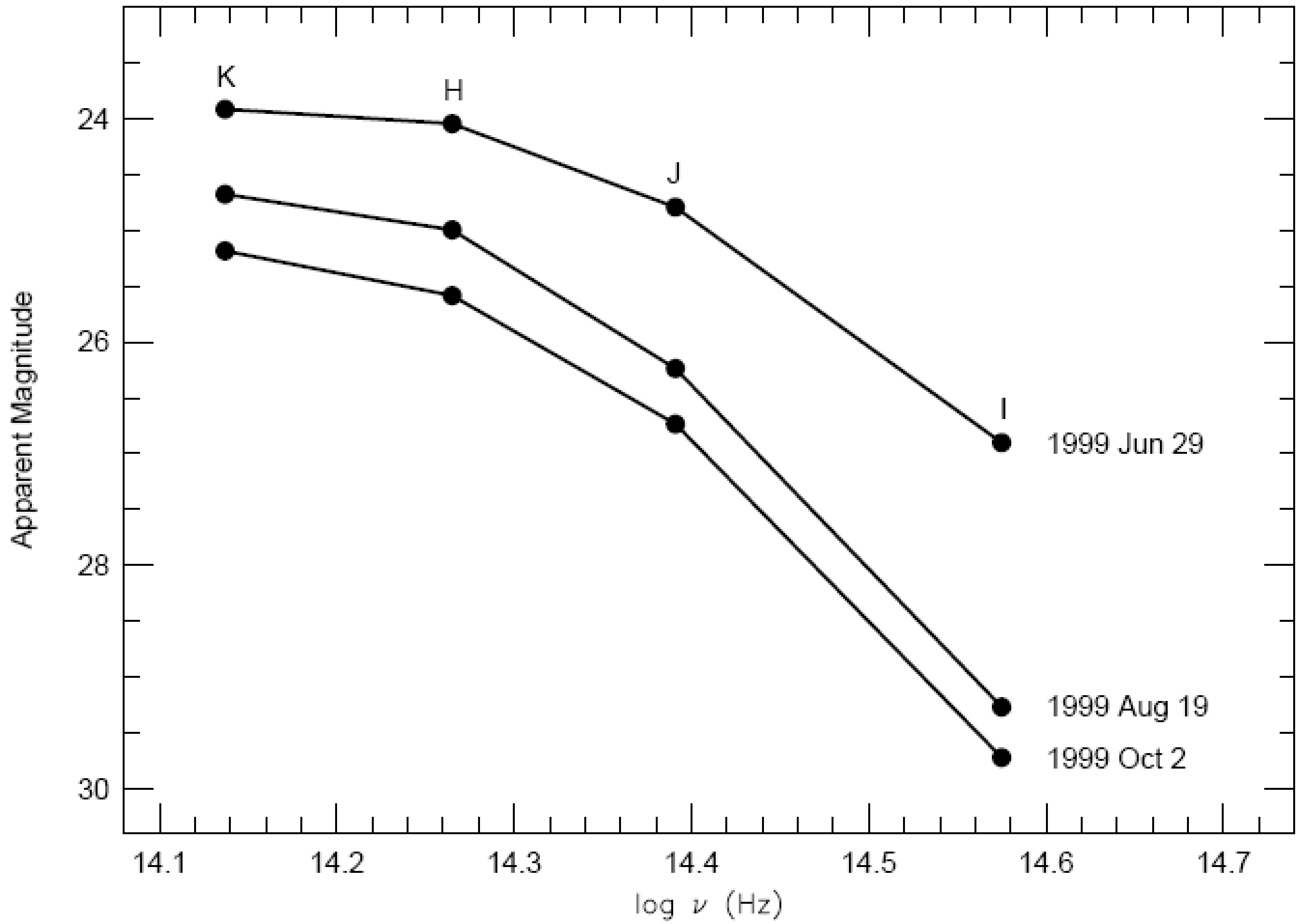


TABLE 2

BANDS, TIMES, AND MAGNITUDES AT WHICH A SN 1998bw-LIKE EVENT WOULD PEAK AT VARIOUS REDSHIFTS

Redshift	Band	Time (days)	Magnitude	Flux Density (μJy)
0.0 ……	*V*	17	…	…
0.2 ……	*R*	20	20.1	28
0.5 ……	*I*	25	22.0	3.9
1.2 ……	*J*	39	23.7	0.54
2.0 ……	*H*	52	24.1	0.22
3.0 ……	*K*	70	24.4	0.11
5.3 ……	*L*	110	24.5	0.045
7.7 ……	*M*	151	24.4	0.026

Finding SN at VHR

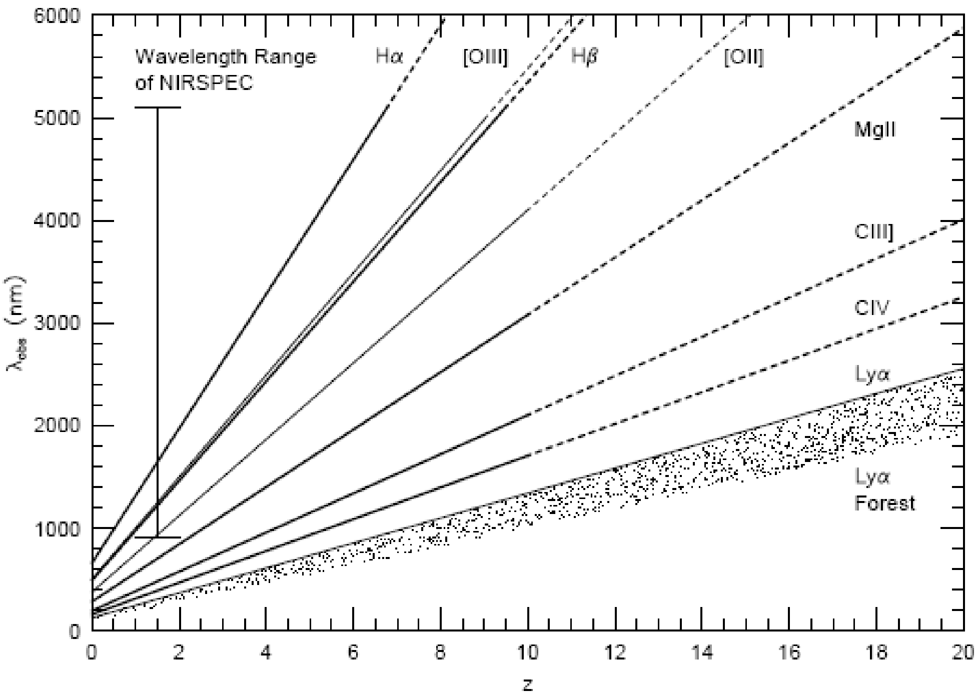


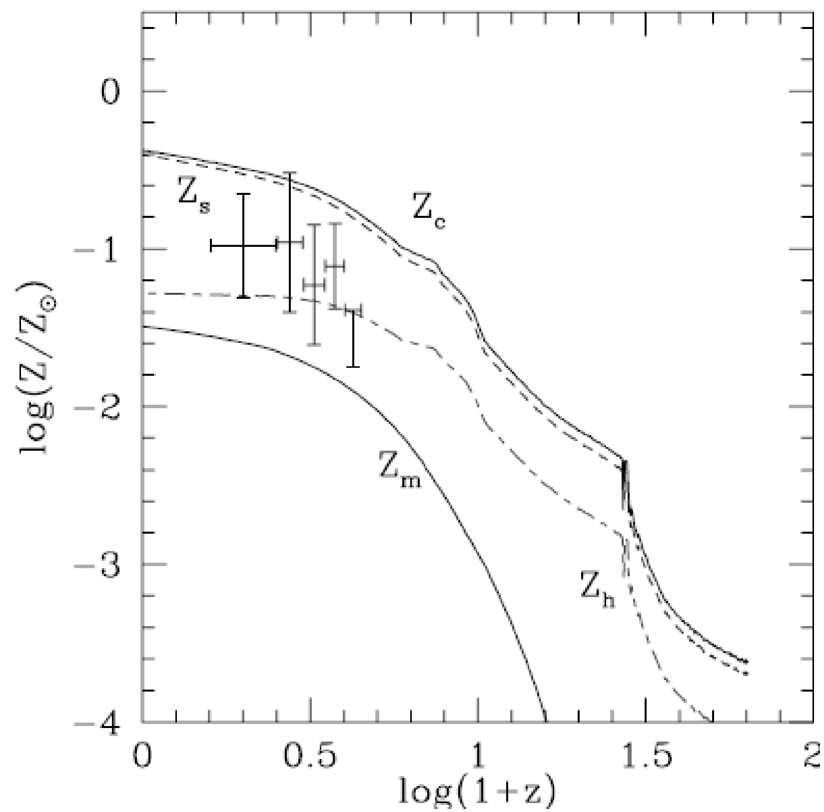
Measuring GRB Redshifts

- There 2 ways to measure the GRB redshift
  1. Taking spectrum of afterglow at early times
     - Lower-limit for measured redshift
  2. Taking spectrum of host galaxy
     - Not always easy to match host galaxy with GRB

- Both get harder to do at larger redshifts

Measuring GRB Redshifts



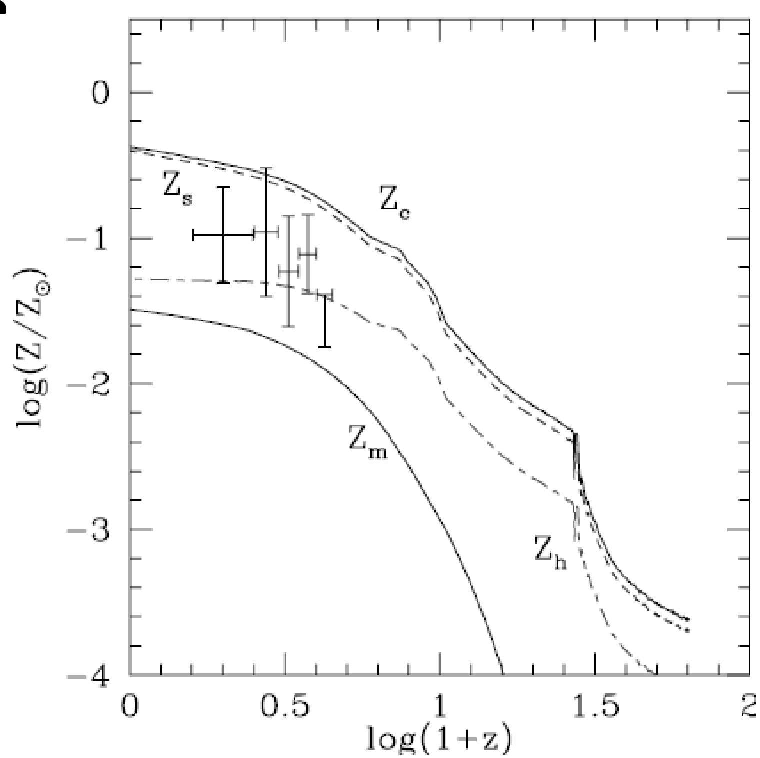


Measuring GRB Redshifts

- A possible third method:
  - Imagine a GRB at $z = 10$
    - Because of high redshift, the afterglow spectrum will be detectable in K-band
    - We will not detect signature in J-band due to drop-out from Lyα forest absorption
  - Therefore a ‘dark’ J-band switching on to ‘bright’ K-band is a signature of the GRB and can provide a good measure of the redshift

Tracing Metallicity

- Comparing GRBs to Quasi-stellar objects:
  - QSOs probe low Z of Halos and IGM
  - GRBs probe higher Z of disks and SF regions



Tracing Metallicity

- Two other metallicity studies:
  - Determine contribution from different SNe by looking at relative abundances of metals
  - Determine whether [Fe/H] is a good chronometer at high redshift

- Probing metallicity at high redshifts requires extreme instrument sensitivity which is not doable any time soon

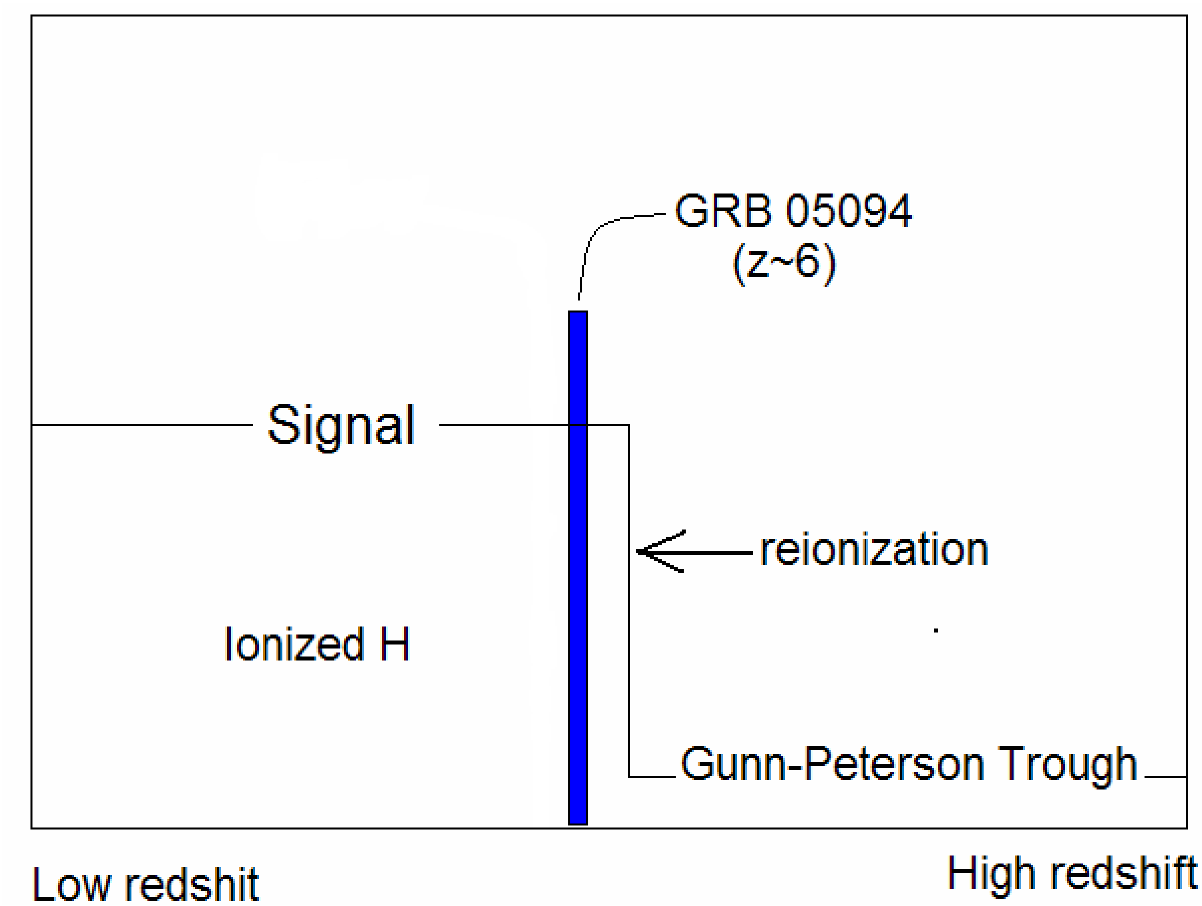
Probing Large-Scale Structure

- GRBs are useful because they are detectable at VHRs
  - But we would need a lot of recorded burst locations
- At such high redshifts there is not much large scale structuring yet (over-under densities much more modest at high z)

Probing Reionization

- Looking for signs of Gunn-Peterson Trough (GPT) in GRB spectra
  - GPT is the transition zone between where neutral H absorbs high flux of radiation and becomes ionized H
  - Location in redshift may point to mechanism of reionization

Probing Reionization



- Totani et al. paper put limit on reionization at z > 6 with GRB 05094 (2006)

Conclusion

- Background Findings:
  - GRB afterglow can be seen in x-ray, optical and radio
  - GRBs associated with SF
  - GRBs associated with core-collapse SNe

Conclusion

1. Detectability at VHR → have been detected out to z ~ 6.4 with Swift

3. Probing SF at VHR → can tell us where star forming regions are located and how active

5. Finding SN at VHR → has been confirmed at lower redshift and should work for high redshift

Conclusion

4. Measuring redshifts of GRB → looking for cut-off frequency method used to determine redshift of most distant GRB ever identified

5. Tracing metallicity → likely would take highly sensitive equipment and therefore not feasible

6. Tracing large-scale structure → need lots of recorded GRBs and not much out there to probe at high redshifts

Conclusion

7. Probing Reionization → seems to be a great method; have already changed constraints on reionization to $z>6$

Questions