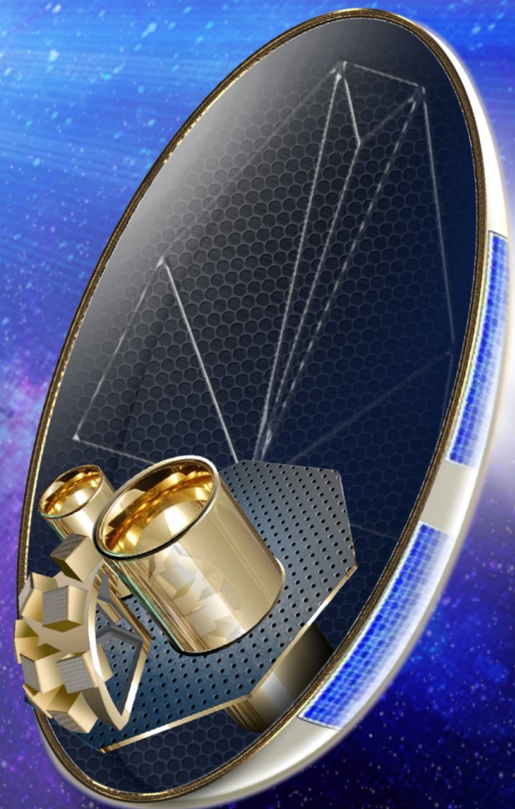
An Astrophysical Transients Observatory Probe for Cosmology



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on behalf of the ATO Probe Team*

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(*with acknowledgements to Antonino Cucchiara and Nial Tanvir)

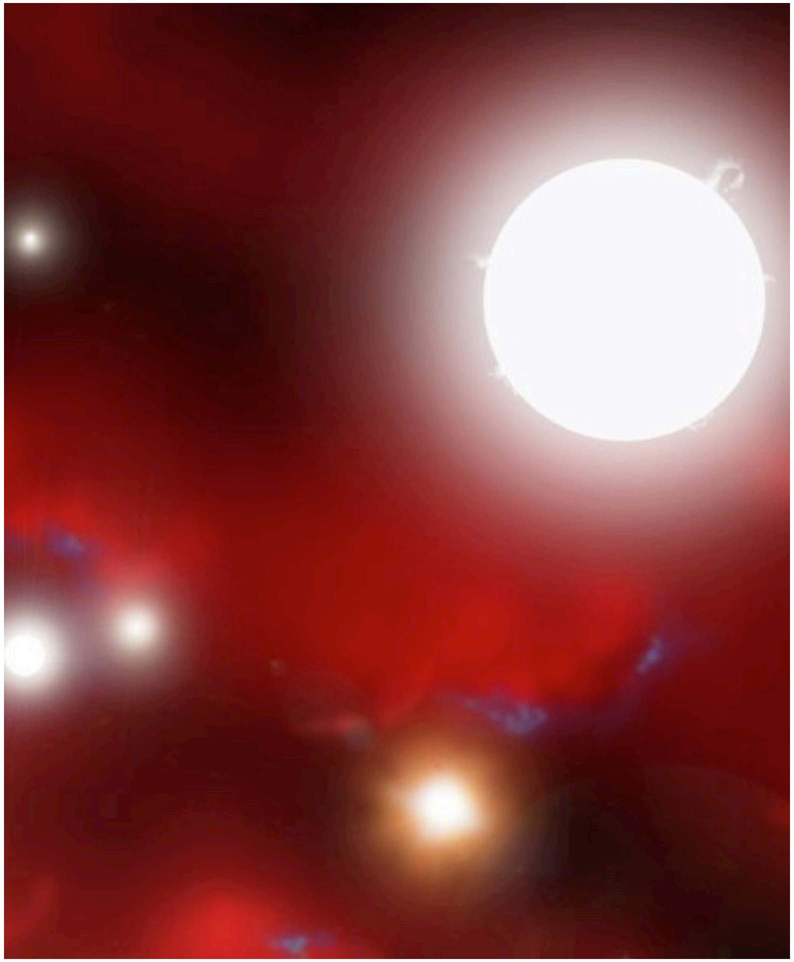
Probing the Early Universe

- Although massive stars are thought to be significant contributors to reionization [e.g. Alvarez et al. 2006, Ahn et al. 2012, Robertson et al. 2015], our understanding of them is limited.

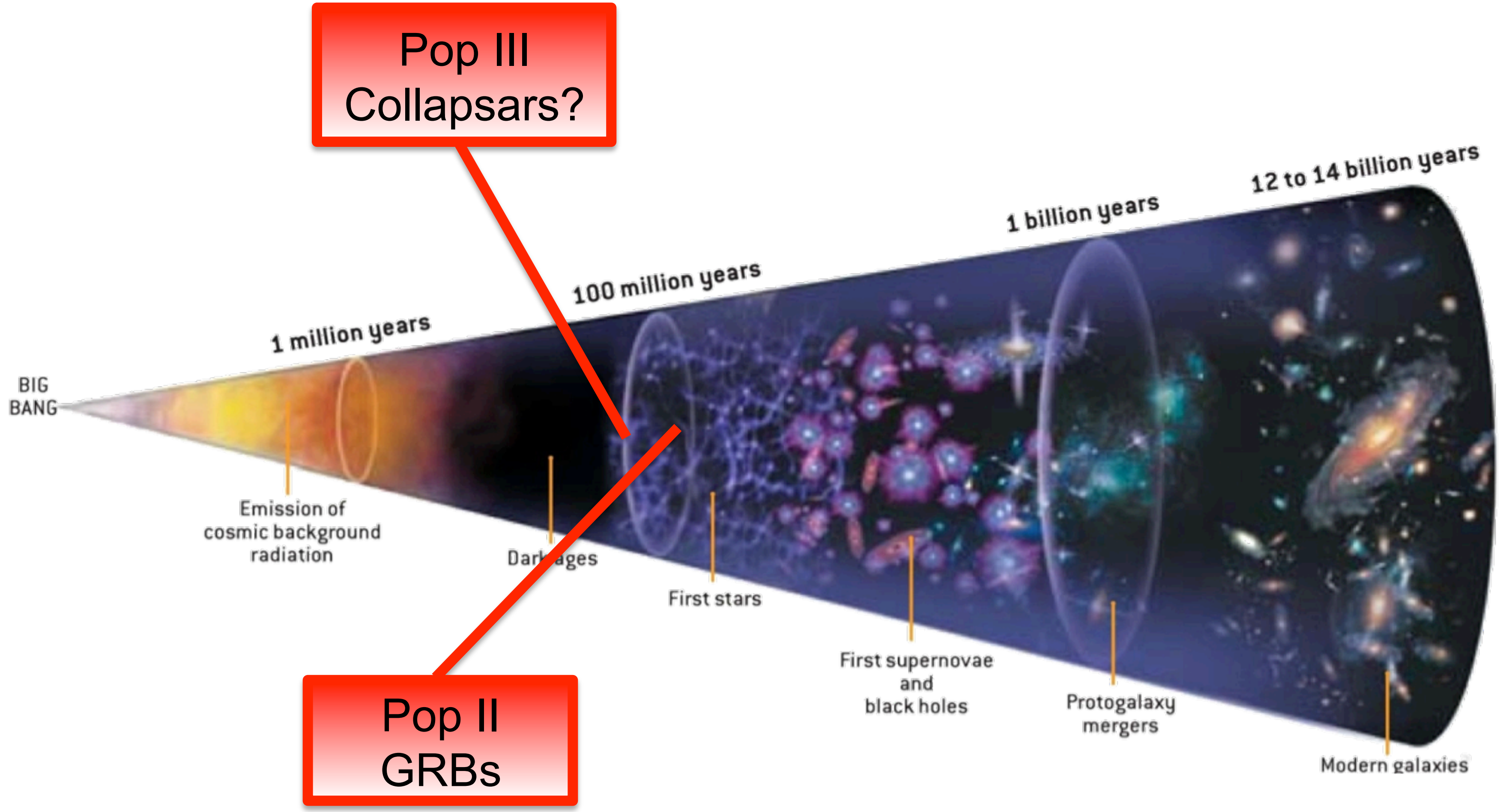
- Some key questions about massive stars include:
  - What environments do they reside and how does the environment change as a function of redshift?
  - How do they die?
  - When does star formation transition from zero-metallicity Pop III to Pop II dominated stars?
  - What is IMF for early Pop III and Pop II stars?

Using GRBs to Probe Early Stars

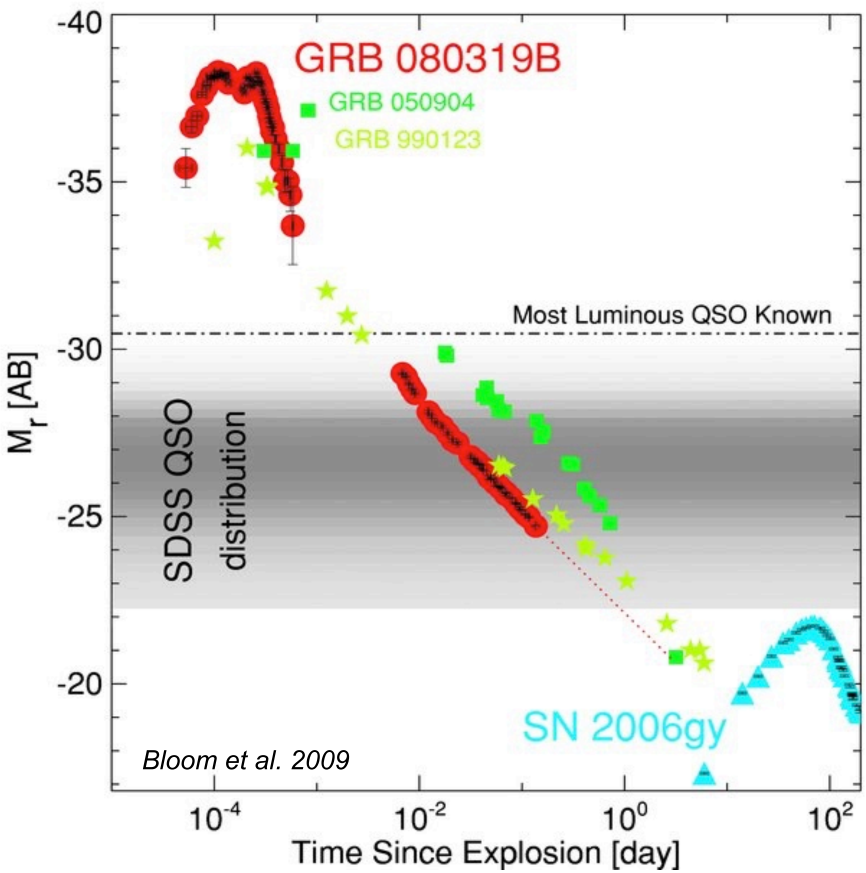
- GRBs may be the only way to observe these distant objects directly
  - JWST won't know where to look
  - Probability of finding one by chance extremely low
- Caveat: unclear that Pop III stars explode as GRBs
- If not, we will still see some of the earliest stars (Pop II)
  - GRB 090423 (z = 8.2)

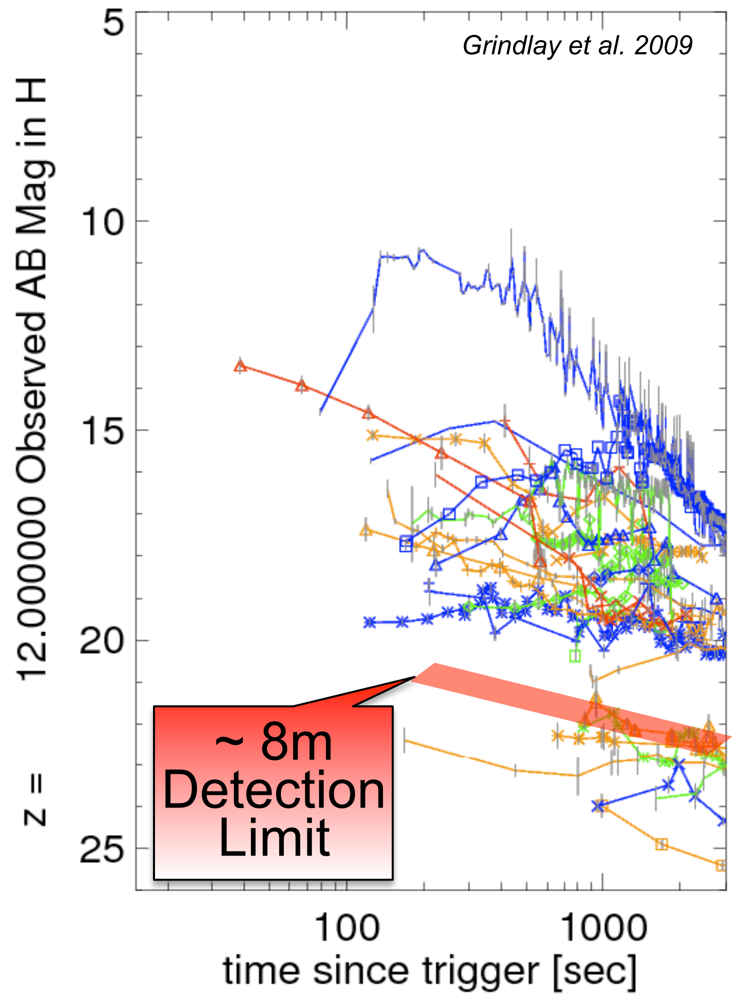


GRBs are in the Early Universe



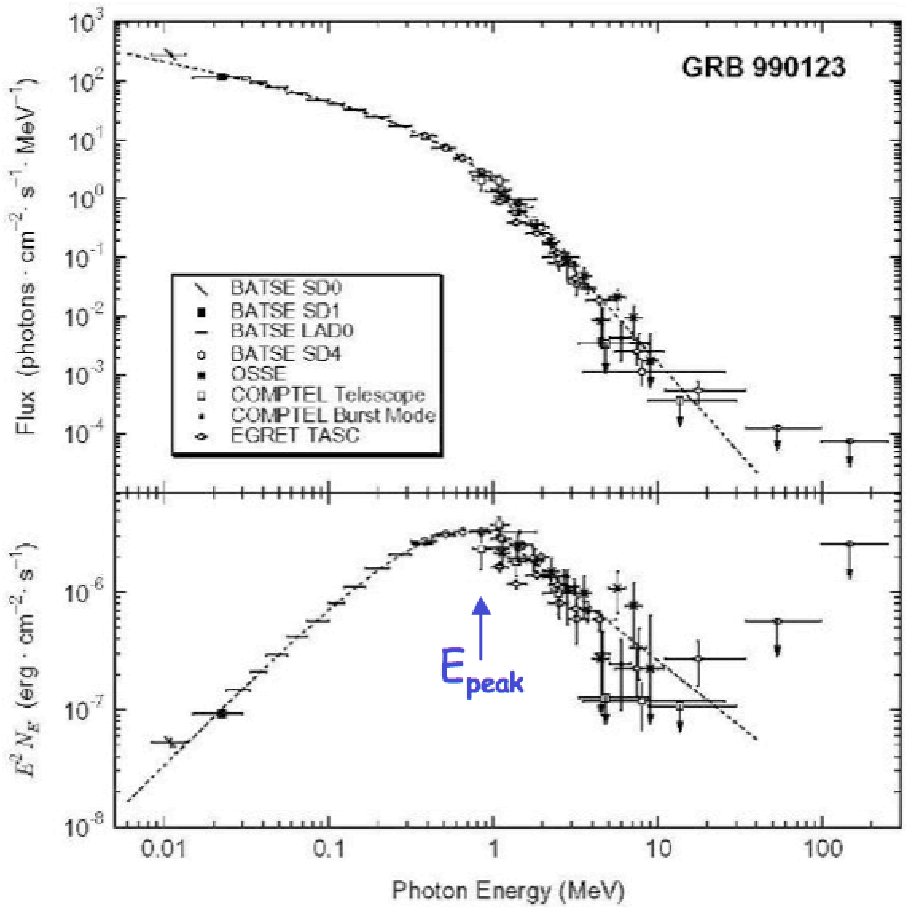
GRBs are Bright!



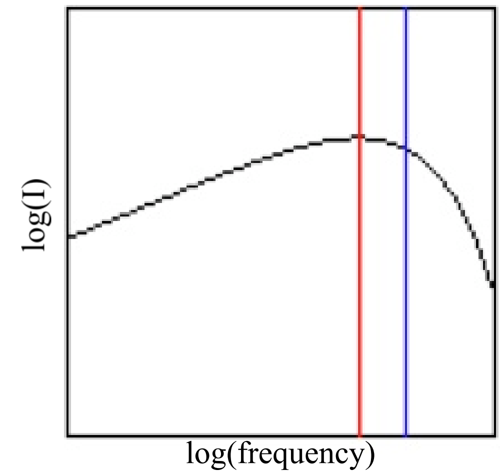


GRB Spectra Ideal for Probing

Non-thermal, smoothly joint broken power-law spectrum



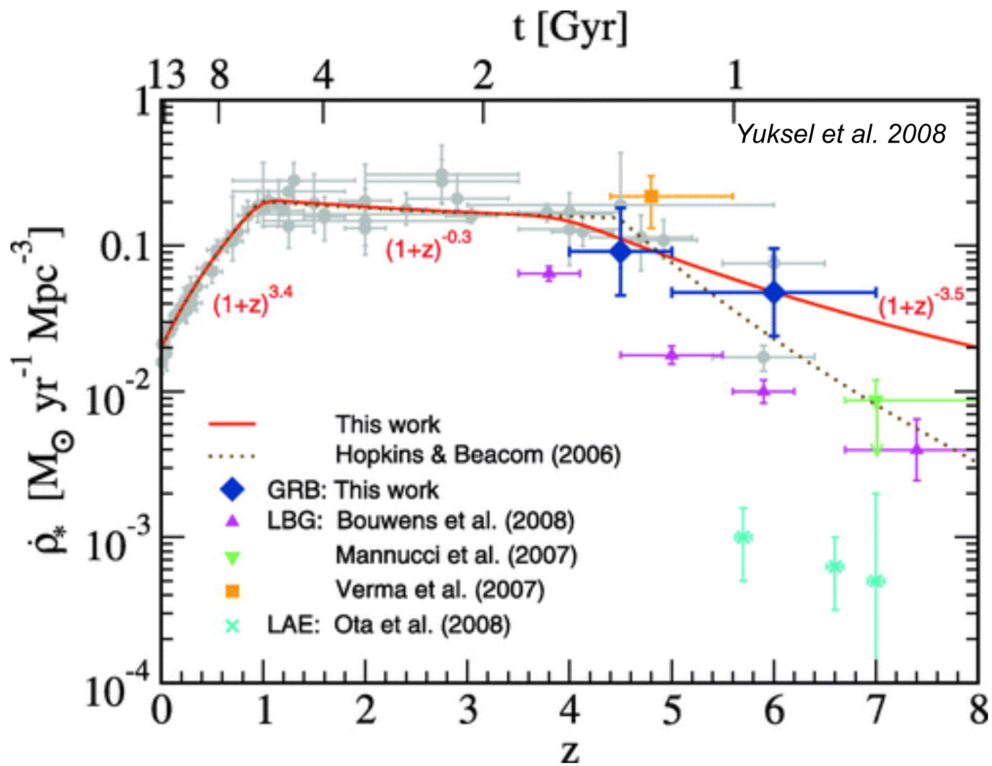
Briggs et al. 1999



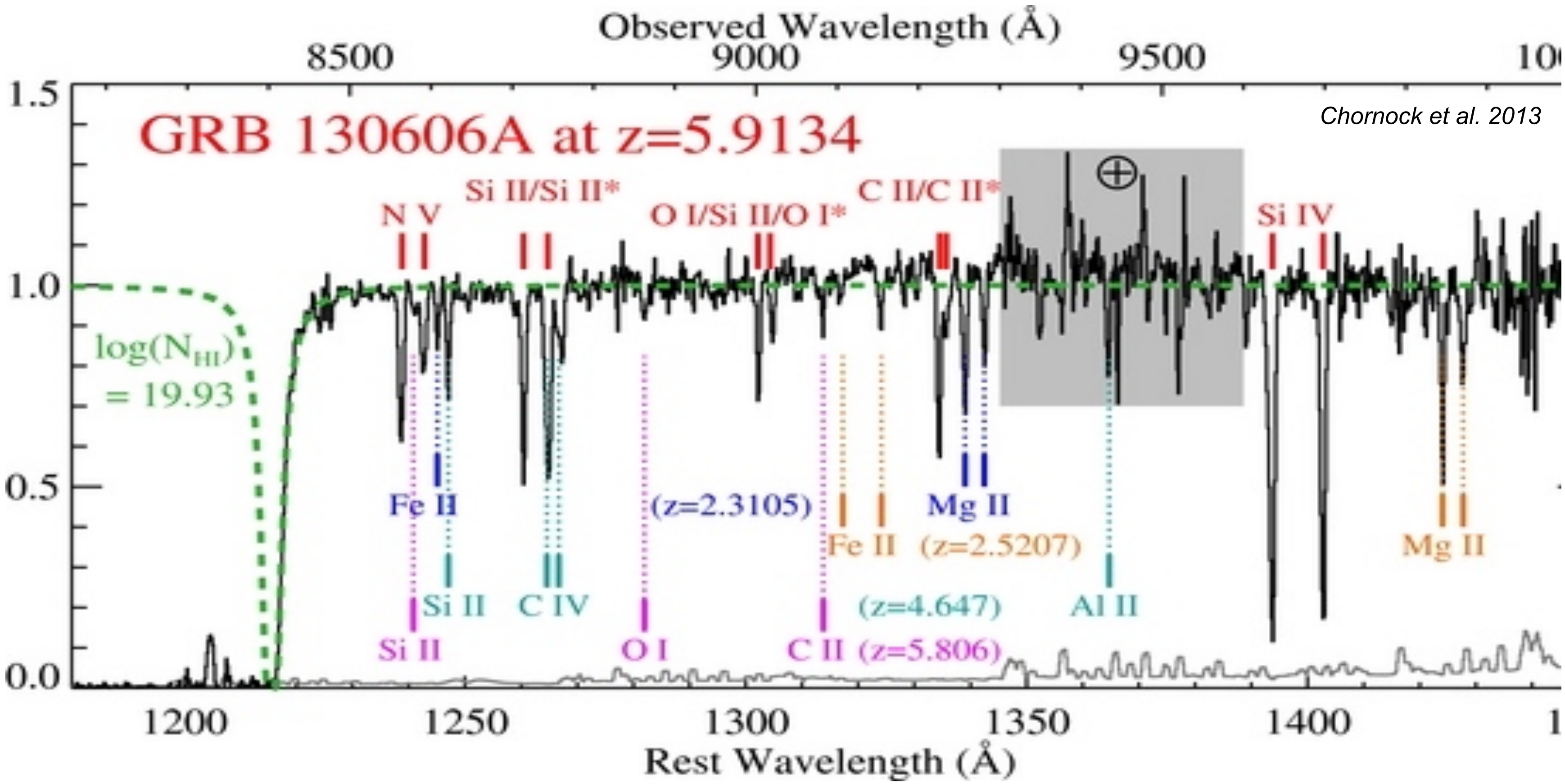
GRBs are not powered by a hot gas in equilibrium, but are powered by accelerated relativistic electrons not in thermal equilibrium.

Determining Massive SFR with GRBs

- Most star formation at z>10 is in galaxies fainter than 1nJy
  - This is fainter that what the JWST can see
- GRBs select high-z galaxies independent of host galaxy luminosity



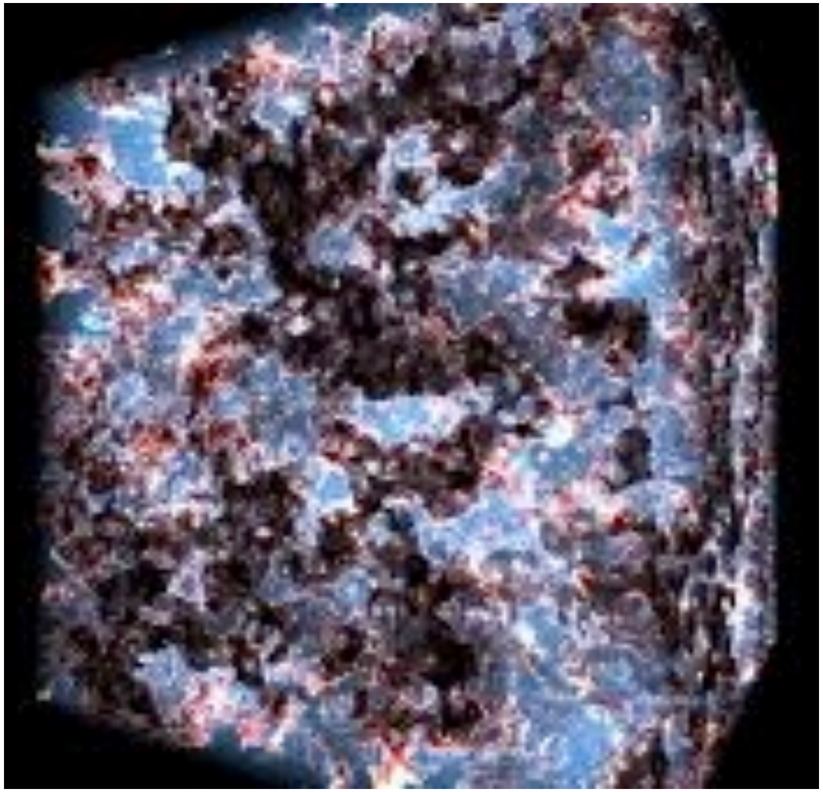
Determining Environments with GRBs



Afterglow spectroscopy provides z, HI column density of host, chemical abundances, dust, & info on intervening systems.

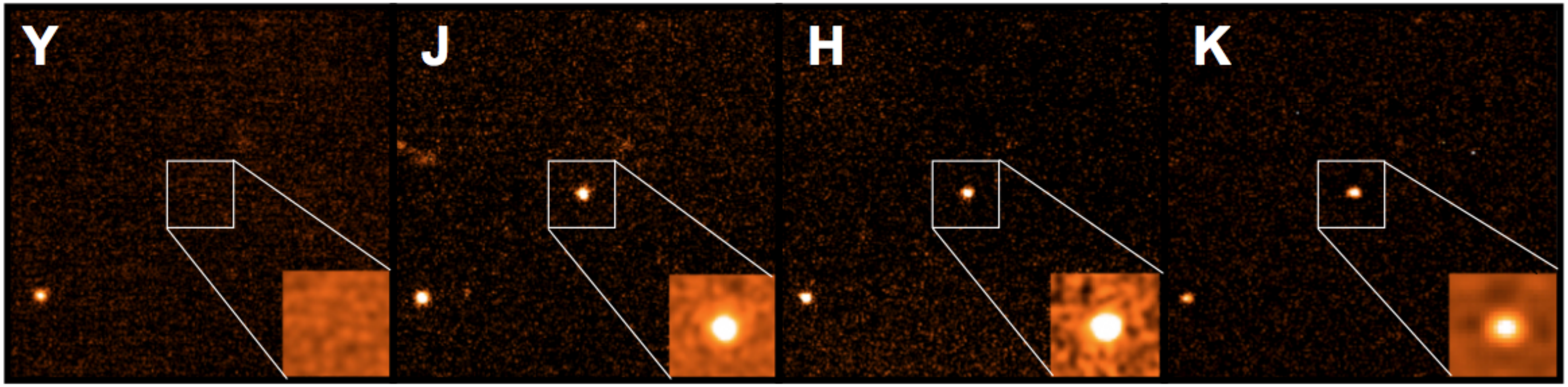
Probing Reionization with GRBs

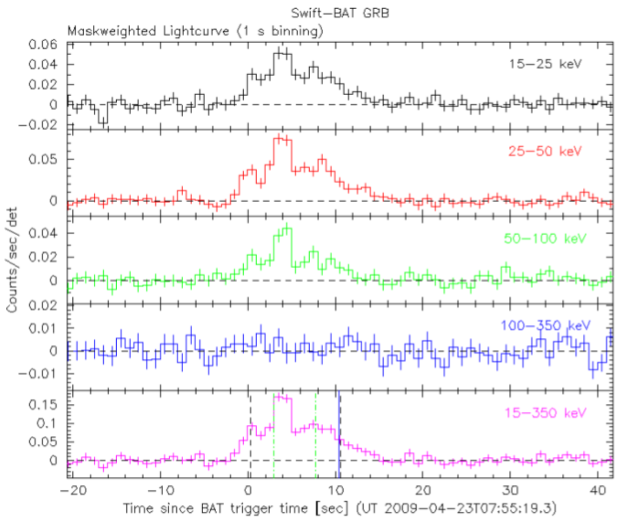
- Multiple GRB Sight Lines Addresses:
  - When reionization began
  - When it ended
  - Is it consistent with other sources?
    - If not, why?
  - Is it smooth or patchy?



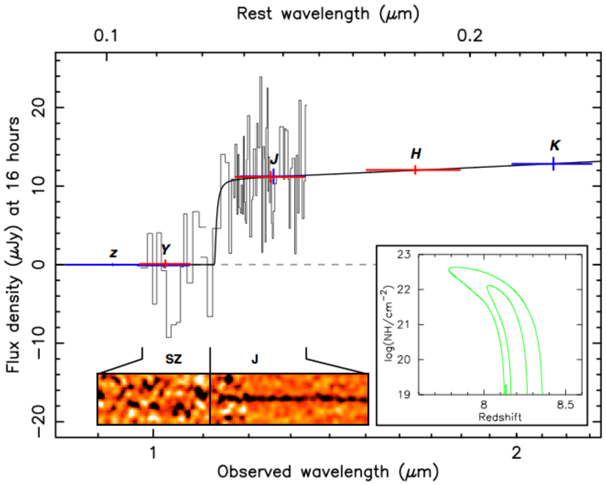
Is It a High-z GRB?

Tanvir et al. 2009

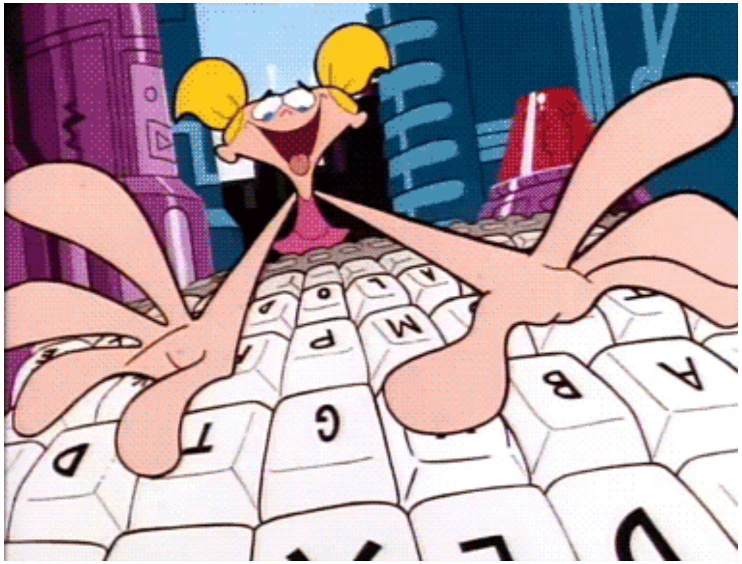




Current missions don't tell us anything about the redshift



Problem with No "*A Priori*" Redshifts



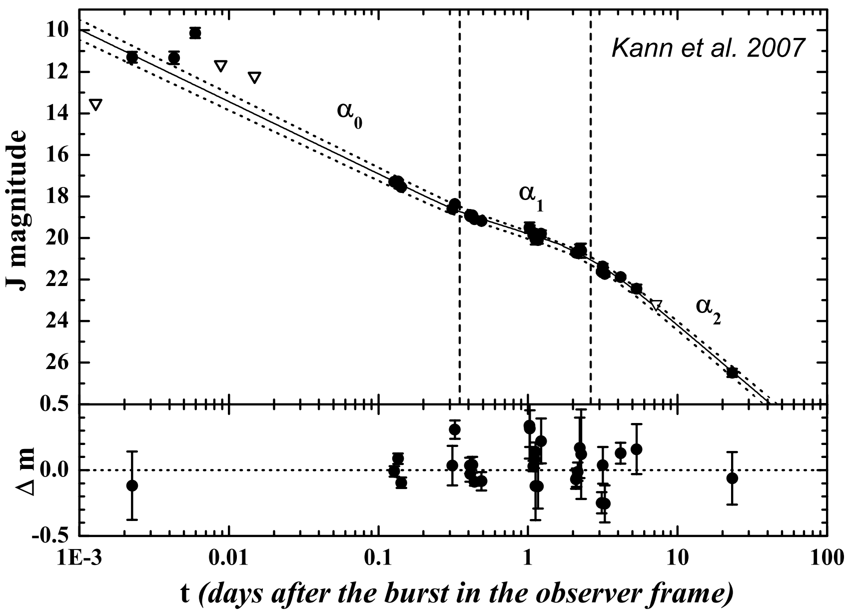
First few GRB alerts

100th GRB alert

You want to interrupt my telescope time?!?

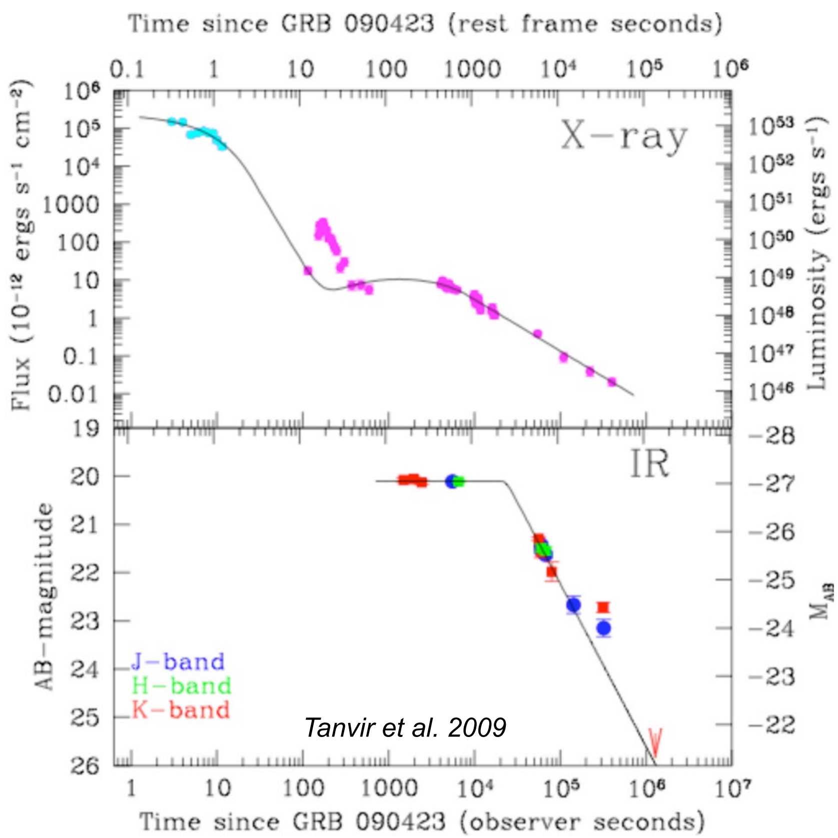
Problem with No *A Priori* Redshifts

GRB 050904



GRB	$t_{Photo-z}$	$t_{Spectra-z}$	*z*
050904	10 hrs	3.5 dys	6.3
080913	10 hrs	11 hrs	6.7
090423	7 hrs	24 hrs	8.2

GRB 090423



The Solution

- Astrophysical Transients Observatory (ATO) Probe

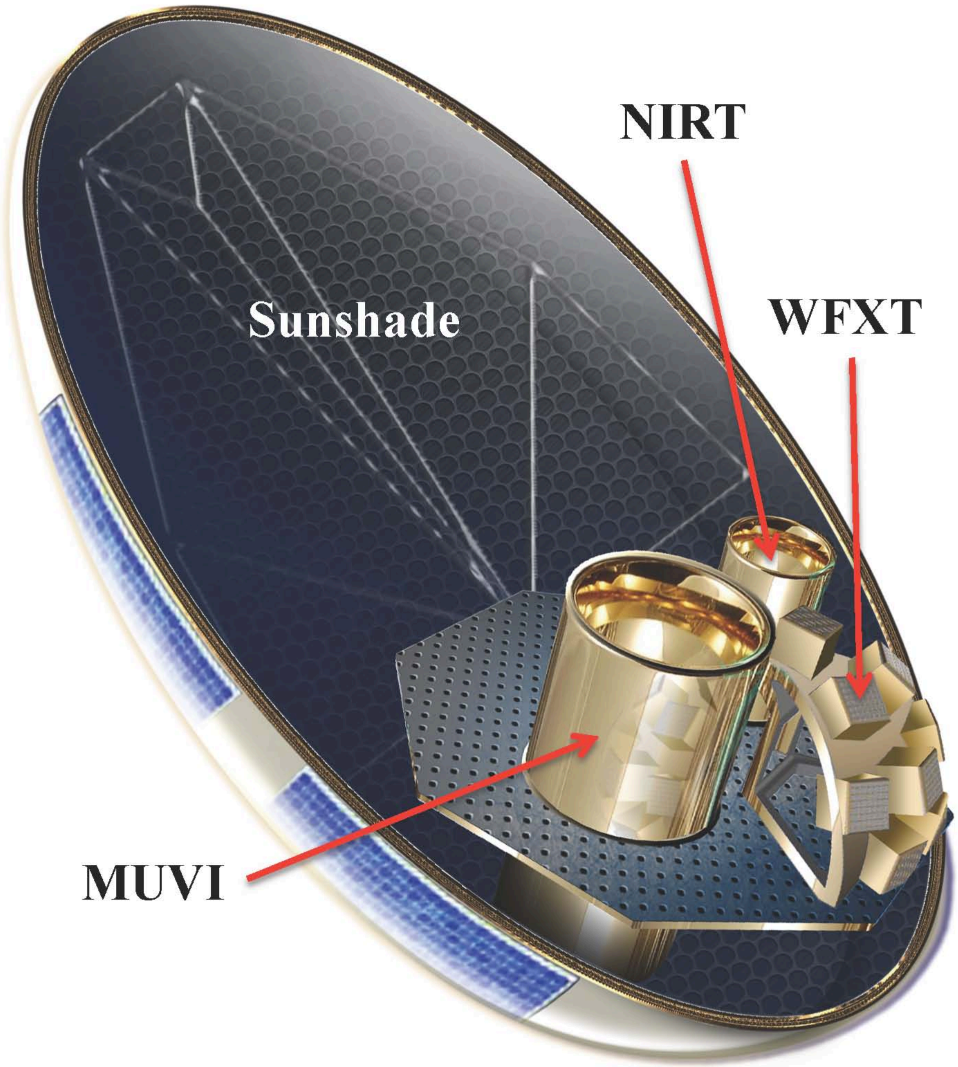
- Primary Goals
  - Characterize the highest redshift massive stars and their environments
  - Constrain the poorly understood explosion mechanism of massive stars

- Primary Objectives
  - Observe the first massive stars to explode as GRBs and probe their environments
  - Observe the shock breakout of core collapse SNe to measure the outer envelope parameters

Secondary Objectives

- Type Ia SNe Shock Breakouts & Interactions
  - 361 (X-ray) and 81 (UV) shock interactions
- EM Counterparts to GW Sources
- Tidal Disruption Events
  - Most luminous TDEs with relativistic jets detected out to z~4-6 [e.g. Fialkov & Loeb 2016]
    - Directly probe frequency of BHs in galaxies where quasars begin to become extremely rare
    - Use max TDE redshifts vs. pop III GRBs to infer growth of BHs from stellar mass seeds to supermassive systems
- Cataclysmic Variables
- Flaring from Exoplanet Host Stars
- Ionizing Radiation Escape from Star-forming Galaxies

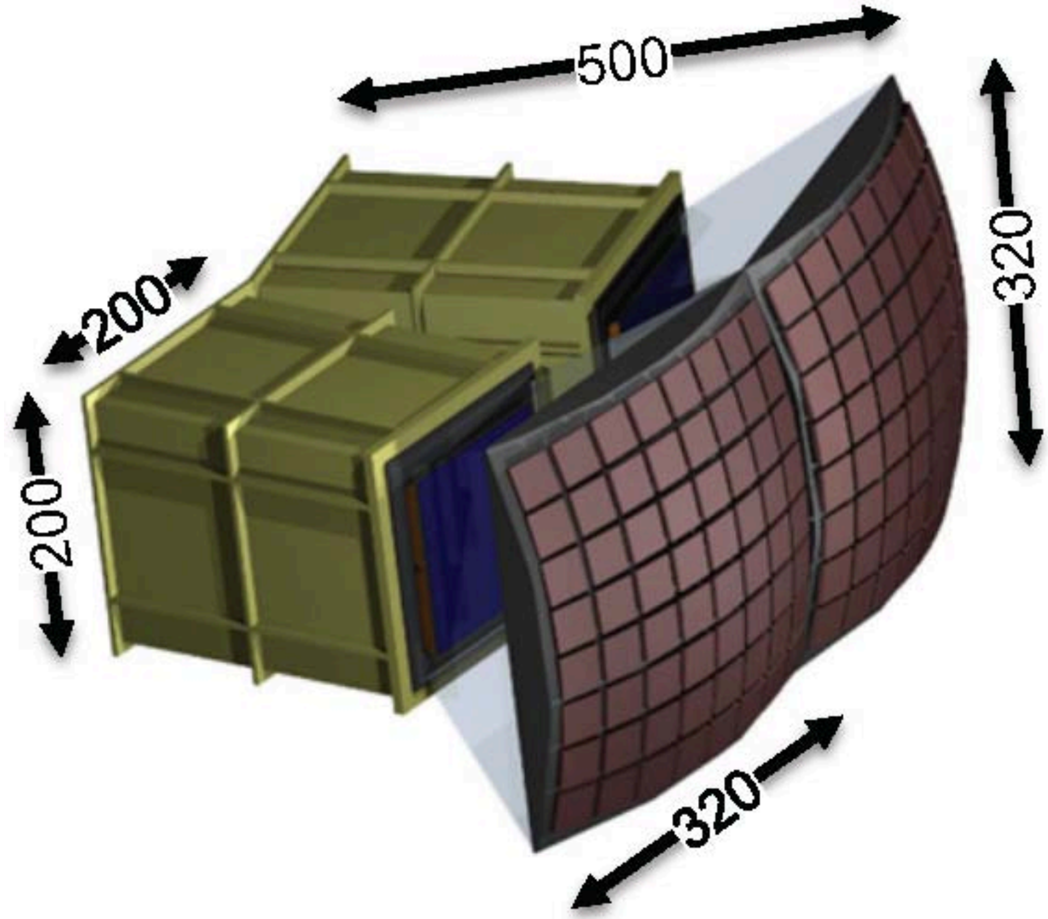
ATO Observatory



ATO observatory layout. The eight WFXT modules, NIRT, and MUVI are highlighted. The sunshade is also highlighted.

Wide-Field X-ray Telescope (WFXT)

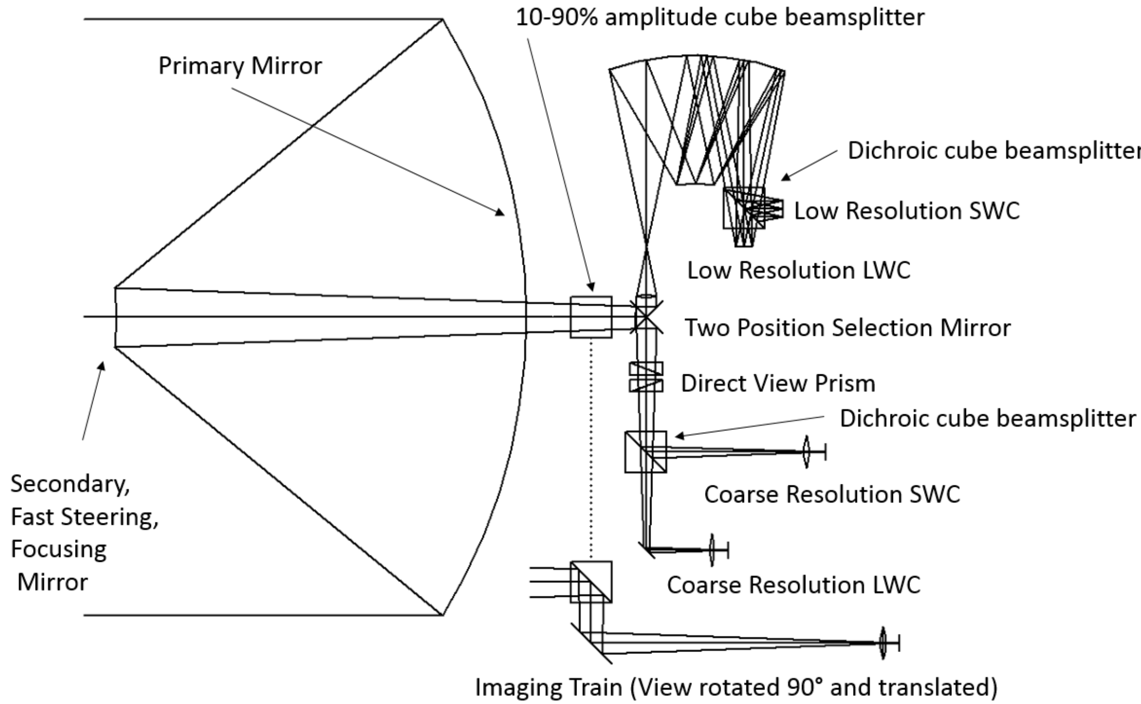
- *Energy band*
  - 0.3-5 keV
- *Telescope Type*
  - Lobster
- *Field-of-view*
  - 801 sq-deg
- *Positional accuracy*
  - 10-105 arcsec
- *Sensitivity*
  - 3.2×10^{-11} erg cm^{-2} s^{-1} (0.3-5 keV in 1500 s)



2 of 8 ATO-WFXT modules for localizing SBO events and high-z GRBs. The dimensions provided are in mm.

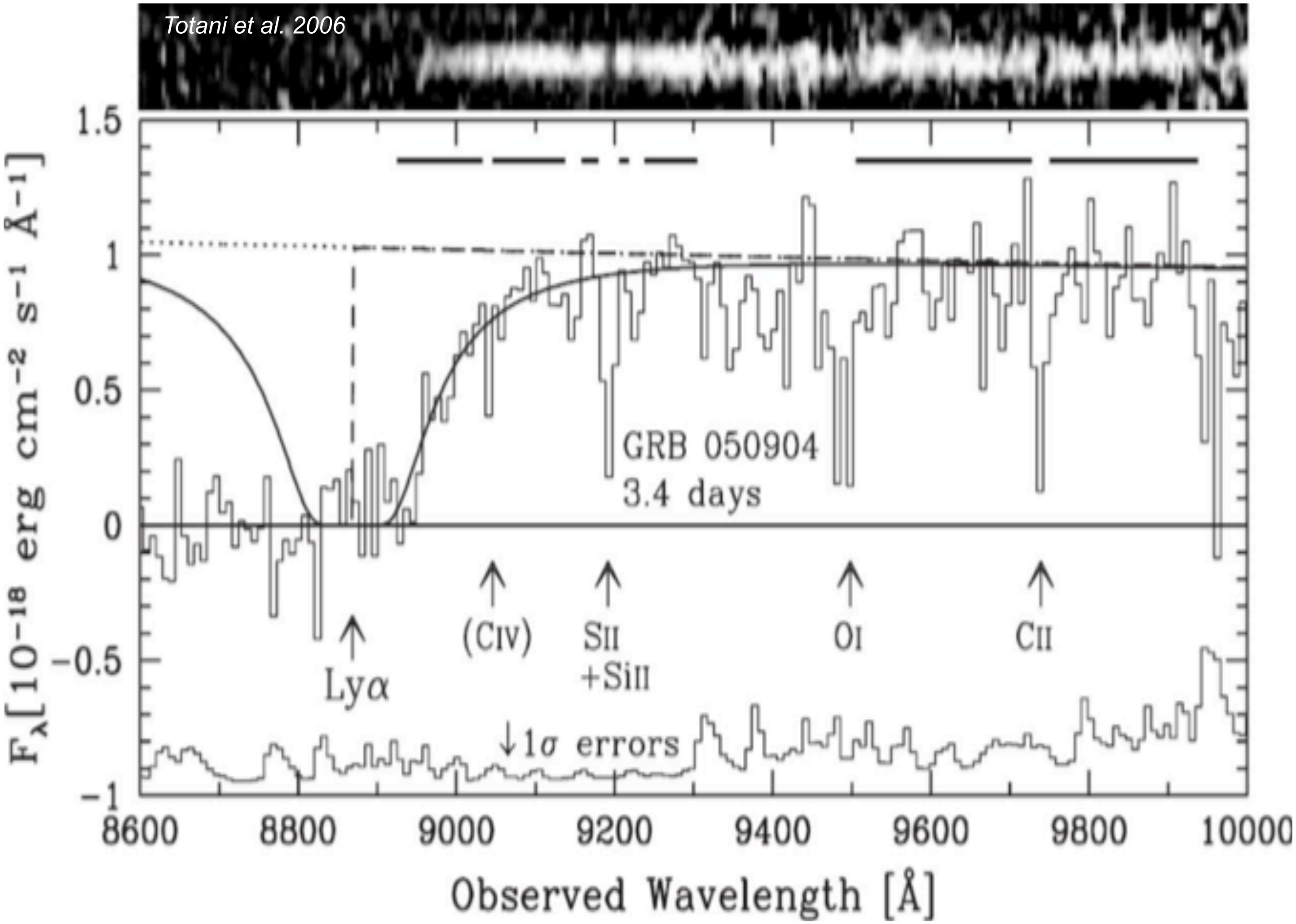
Near-IR Telescope (NIRT)

- *Wavelength*
  - 700-2000 nm
- *Telescope Type*
  - Ritchey-Chrétien
- *Aperture*
  - 55-cm
- *Field-of-view*
  - 1296 sq-arcmin
- *Angular accuracy*
  - <1 arcsec
- *Spectral resolution*
  - ~16 & ~1000



Optical layout of the NIRT showing the imaging (Direct; 0.7–2.0 μm), coarse resolution (R~16) short-wave (SWC; 0.7–1.35 μm) and long-wave (LWC; 1.35–2.0 μm) channels, and the R~1000 spectrograph. This design offers high throughput while providing arcsec-level imaging for GRB localization, rapid redshift determination, and spectroscopic follow-up.

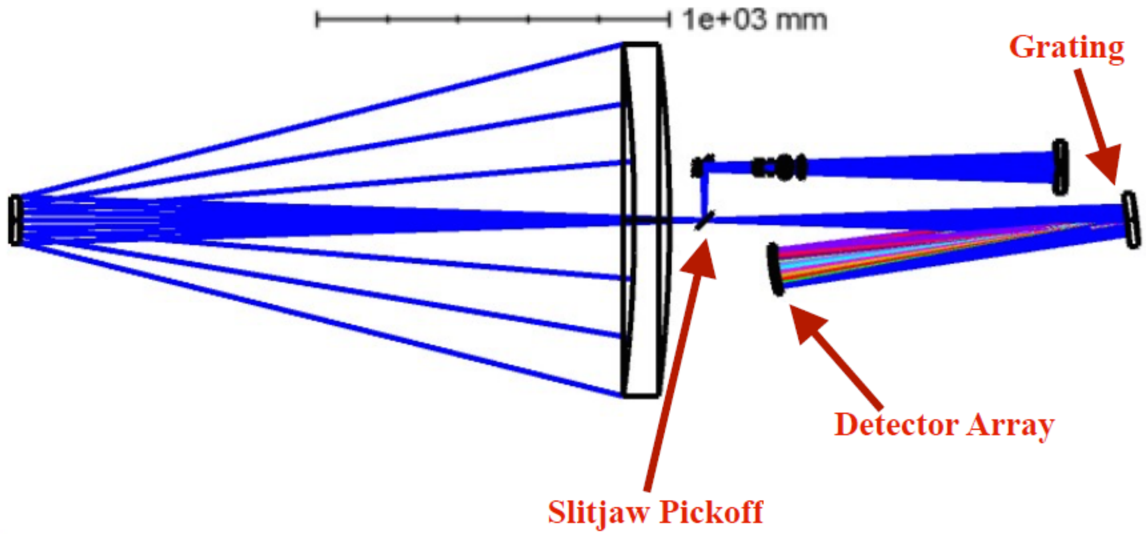
Probing Environments of High-z GRBs



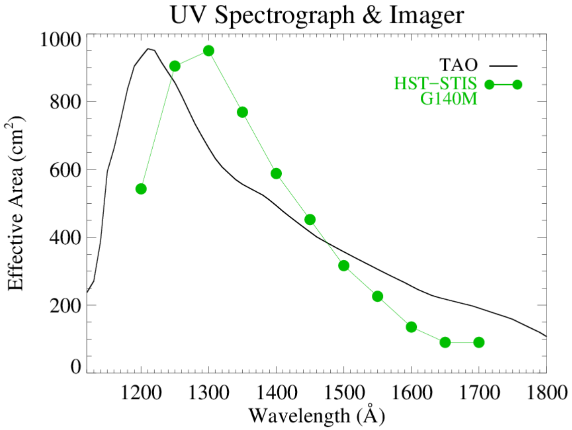
Afterglow spectrum (R~1000) of GRB 050904 (z=6.29) taken 3.4 days after the burst. ATO-NIRT spectra (0.7-2.0 μm) will yield host galaxy metal abundances out to the highest redshift, but at much earlier times when the afterglow is brightest. ATO will take us from our current status of 3 high-z bursts to ~200.

Multi-mode UV Instrument (MUVI)

- *Wavelength*
  - 115-350 nm
- *Telescope Type*
  - Ritchey-Chrétien
- *Aperture*
  - 1-m
- *Field-of-view*
  - 100 sq-arcmin
- *Angular accuracy*
  - ~1 arcsec
- *Spectral resolution*
  - ~3000

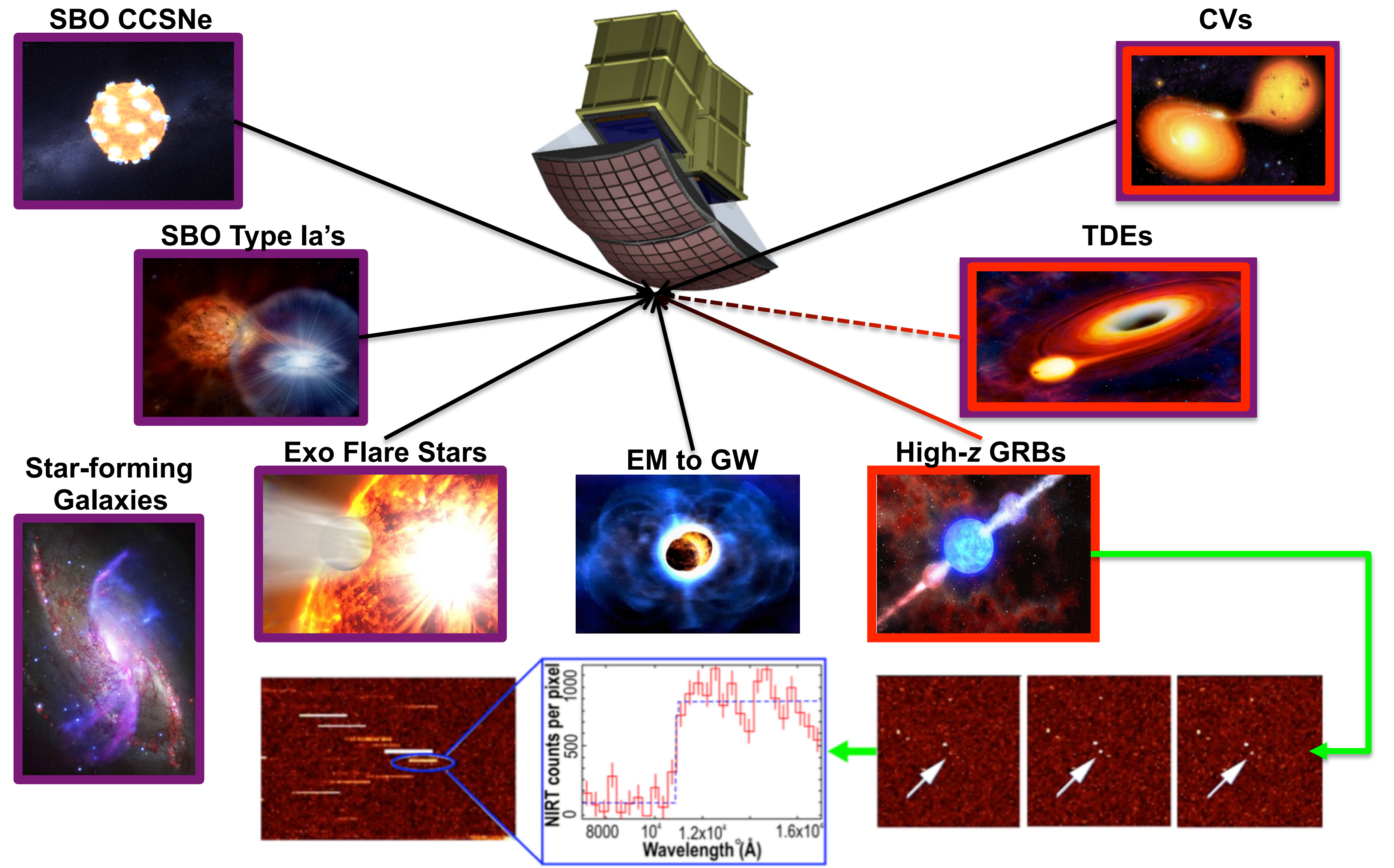


MUVI telescope, spectrograph, and imager design. This design offers high throughput while maintaining low-resolution spectroscopy and ~arcsecond-level imaging for SN localization, galactic characterization, and light curve follow-up.



MUVI FUV effective area. Through efficient design and modern componentry, the 1-m system provides comparable performance to the medium-resolution grating mode on HST-STIS (G140M). STIS has higher spectral resolution while MUVI has a factor of ~15 more spectral bandpass per exposure.

Performing the Investigation



ATO-NIRT images identify young, variable afterglows (upper 3 images), and objective prism exposures (lower images) yield redshifts via Ly-break at $z \geq 5$. Once high-z is ascertained R~1000 NIRT spectra are taken.