The Gamow Explorer

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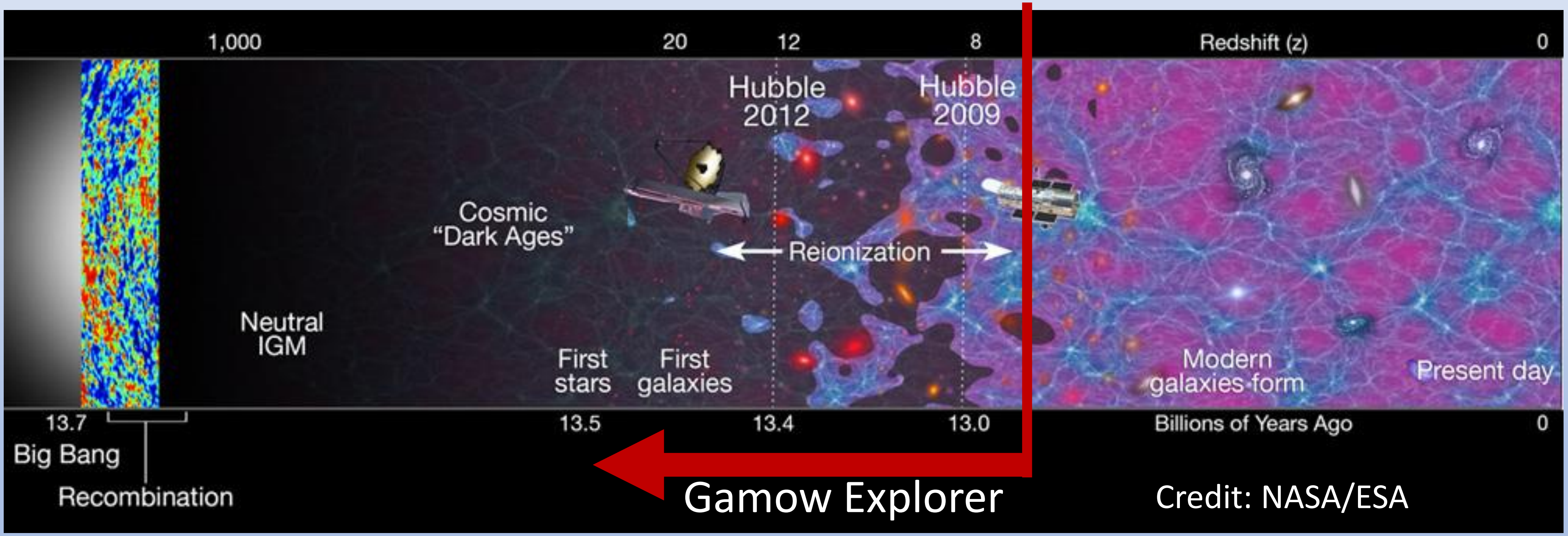
A proposal in preparation for the NASA 2021 MIDEX Announcement of Opportunity

Driving Science Goal

Use Gamma Ray Bursts to probe the high redshift (z > 6) Universe when the first stars were born, galaxies formed and Hydrogen was reionization



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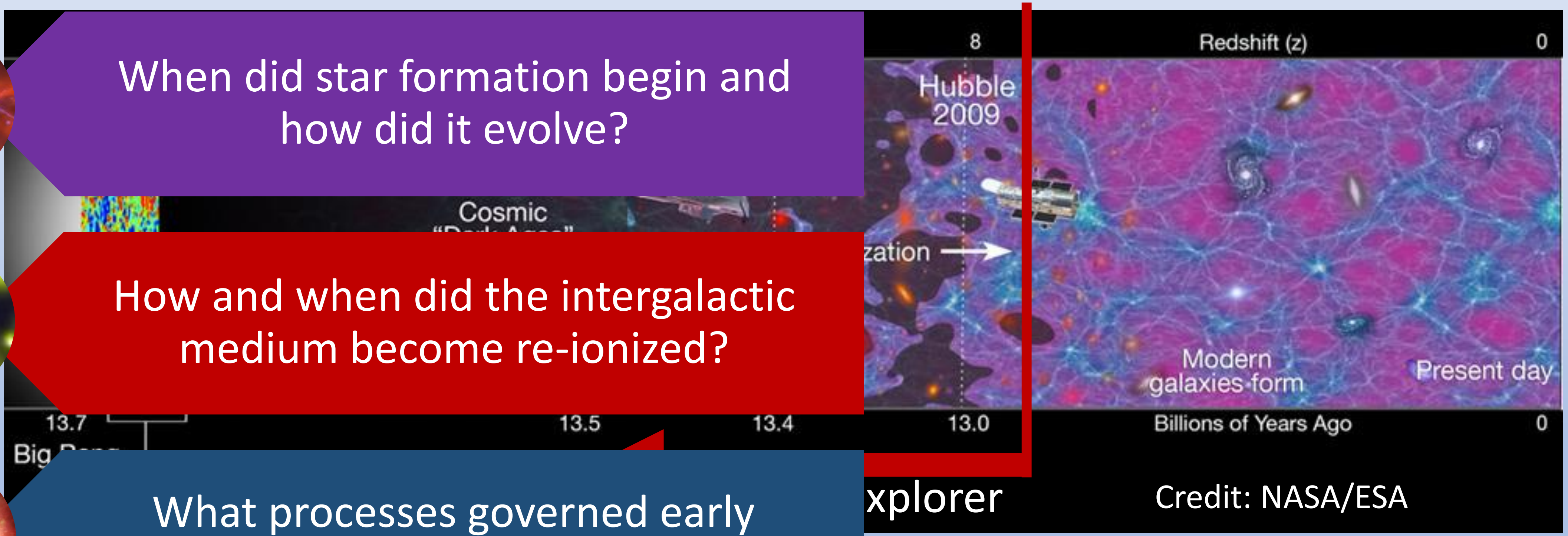
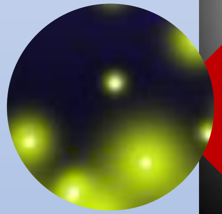
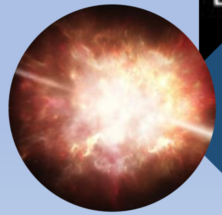


Credit: NASA/ESA

When did star formation begin and how did it evolve?



How and when did the intergalactic medium become re-ionized?



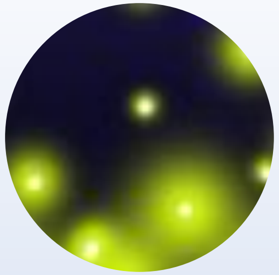
What processes governed early chemical enrichment?

Gamow

High redshift GRB alerts are needed for space and ground based telescopes to follow up

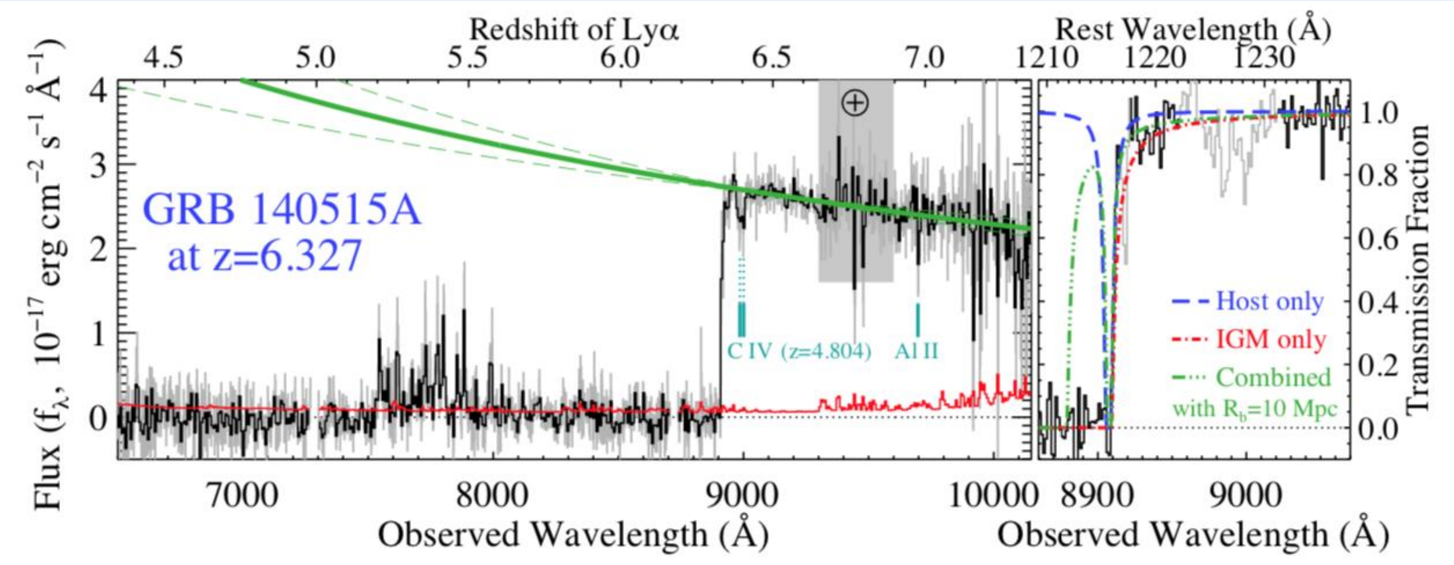
Gamow Explorer **will trigger within 30 minutes existing *8-m class* & the coming generation of *30-m class* ground based telescopes in Chile and Hawaii for high resolution spectroscopy**

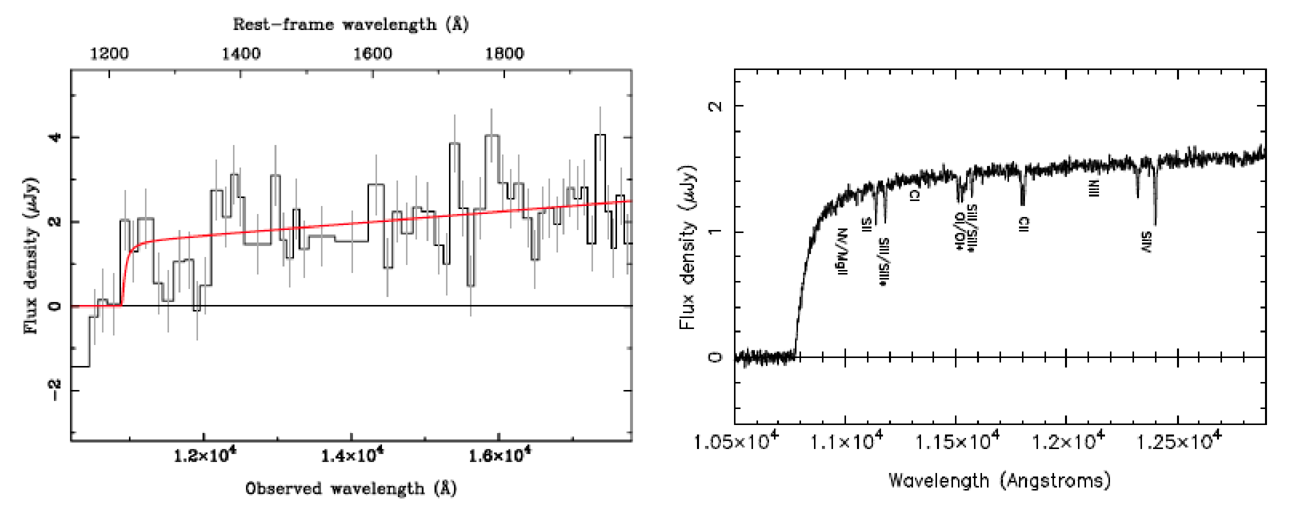
Gamow Explorer **will enable detailed follow up observations by JWST within 2 days for the highest redshift events, and later observations to identify the host galaxies when the afterglow has faded**



LGRBs as probes of the host Galaxy and Intergalactic Medium

Gemini spectrum of GRB 140515A at z = 6.3 taken 2.5hr after the burst from Chornock et al (2018)

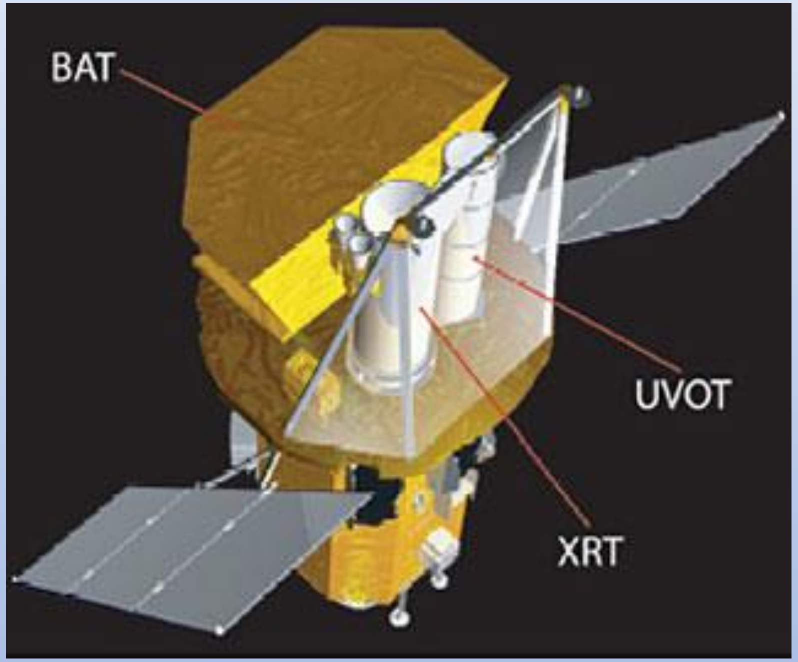




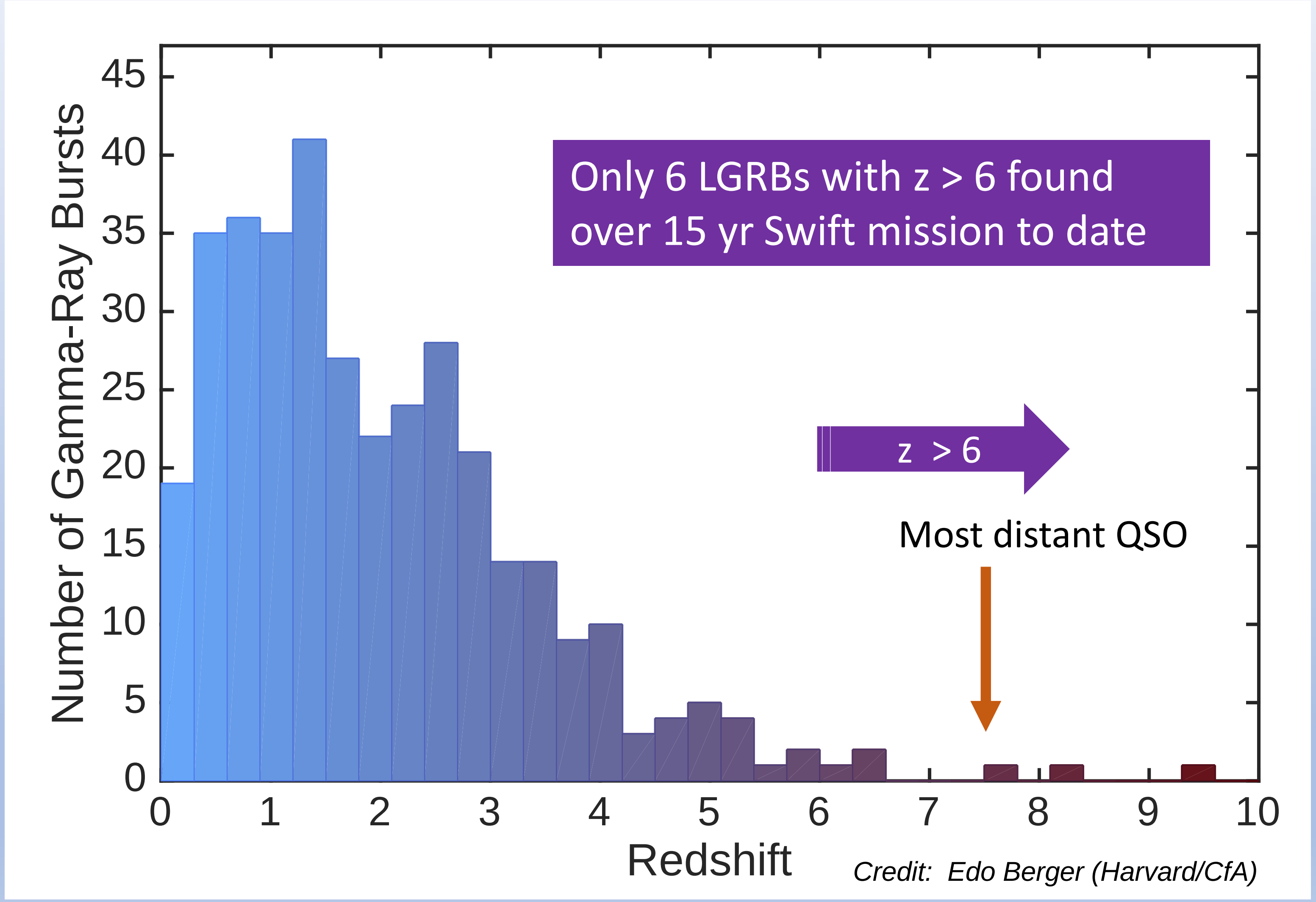
GRB 120923A afterglow from the VLT compared to a simulated ELT spectrum by Tanvir (2018) with the detection of metal lines and determination of the HI column from the Ly-alpha damping wing

Redshift Distribution of LGRBs - 2019

Neil Gehrels Swift Observatory launched Nov 20, 2004



Only ~30% of Swift GRBs have a determined redshift

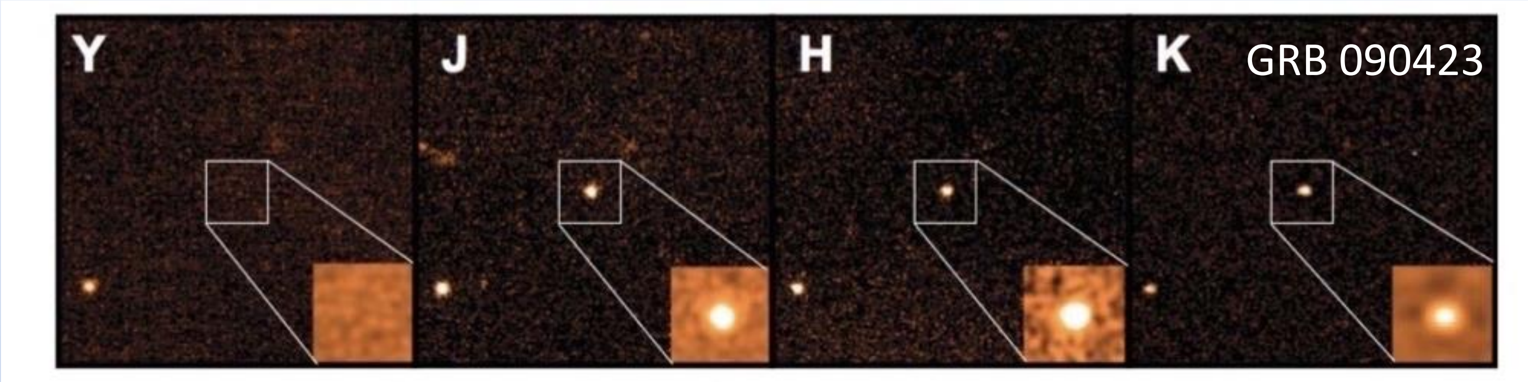


Concept of Gamow Explorer Operations

Event	Time after GRB Trigger
GRB Detection	0
Arc min position determination	~10s
Slew IR Telescope to GRB position	~60s
IR arc sec position Photo-z measurement	<1000s
R ~ 20 Prism Spectrum	~6000s

Gamow Explorer is a Next Generation *Swift* with XRT and UVOT replaced with a Photo-z IR Telescope (PIRT)

Gamow Onboard Photo-z Redshift Determination



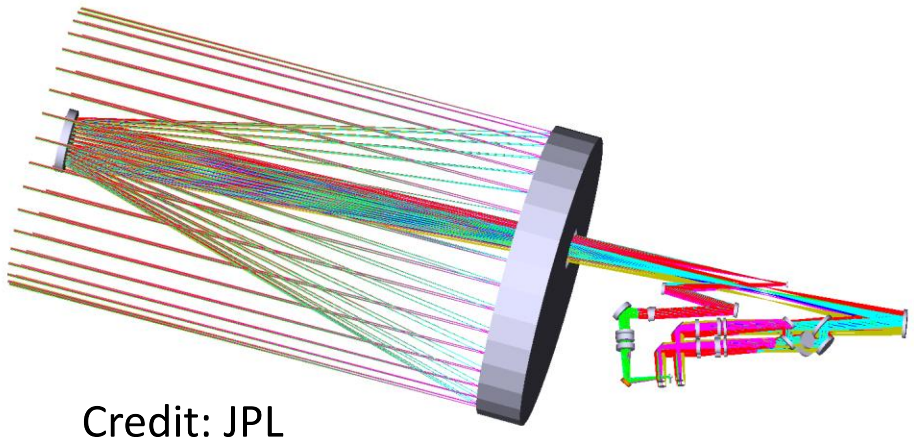
- Hydrogen Lyman-alpha absorption by neutral H from the host galaxy and local IGM creates a sharp blue-ward dropout which for redshifts 6 to 20 is in the 0.6 to 2.5 micron IR band
- Swift has detected a few high-z GRBs, many identified using this technique with ground based telescopes e.g. GRB 090423 at z ~ 8.2 (Tanvir et al 2009)
- Provides a simple method to identify z > 6 GRBs, which can be implemented onboard a spacecraft to autonomously broadcast high-z redshift alerts, along with the GRB time and celestial position

Photo-z Infra-Red Telescope (PIRT)

Obtain 1 arc sec location with 40 cm Aluminum TMA Telescope cooled to 200K to reach 5 micro-Jy in 500s

Four channels using dichroic mirrors onto a single focal plane detector with 10 arc min field of view

Slit prism spectrometer with R ~ 20 for follow up spectrum to confirm Lyman break and redshift



Credit: JPL

Focal plane: Flight qualified spare JWST NIRCam detector and focal plane assembly

2048x2048 pixels, 0.6 to 2.5 micron, cooled to 80-100K

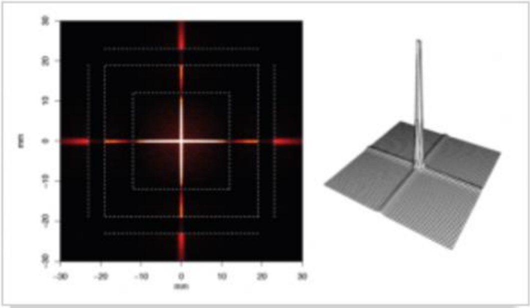
Heritage: Existing flight qualified hardware

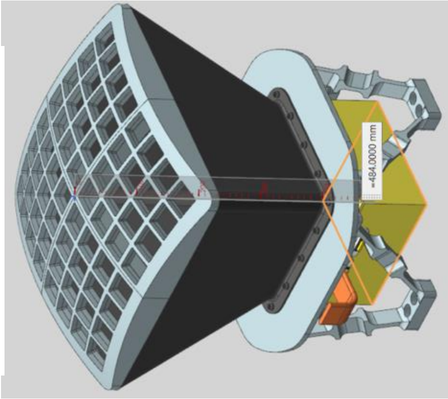
High redshift LGRB detection is optimal in the X-ray Band with two approaches under consideration

Lobster Eye X-ray Telescope (LEXT)

- Micro channel plates on a spherical frame
- 30 x 30 deg with 2 or 3 modules (0.5 to 0.75 sr)
- 0.5 to 5 keV
- 6.7 arc minute PSF, localization ~ 1 arc min

Cross shaped PSF



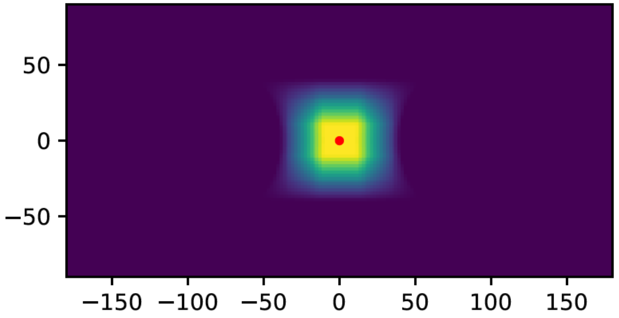


Paul O'Brien, Dick Willingale, Charly Feldman et al (University of Leicester)

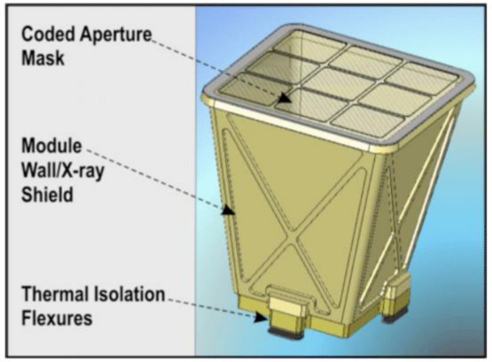
X-ray Coded Aperture Telescope (XCAT)

- FOV: ~20 x 20 deg fully coded
- Co-aligned 15-20 modules
- Open grasp 15.3 cm^2 sr per module
- 2 to 10 keV
- Localization of ~ 0.5 arc min.

Effective area over FOV



Detector Module (DM)



Abe Falcone (Penn State University), David Palmer (LANL)

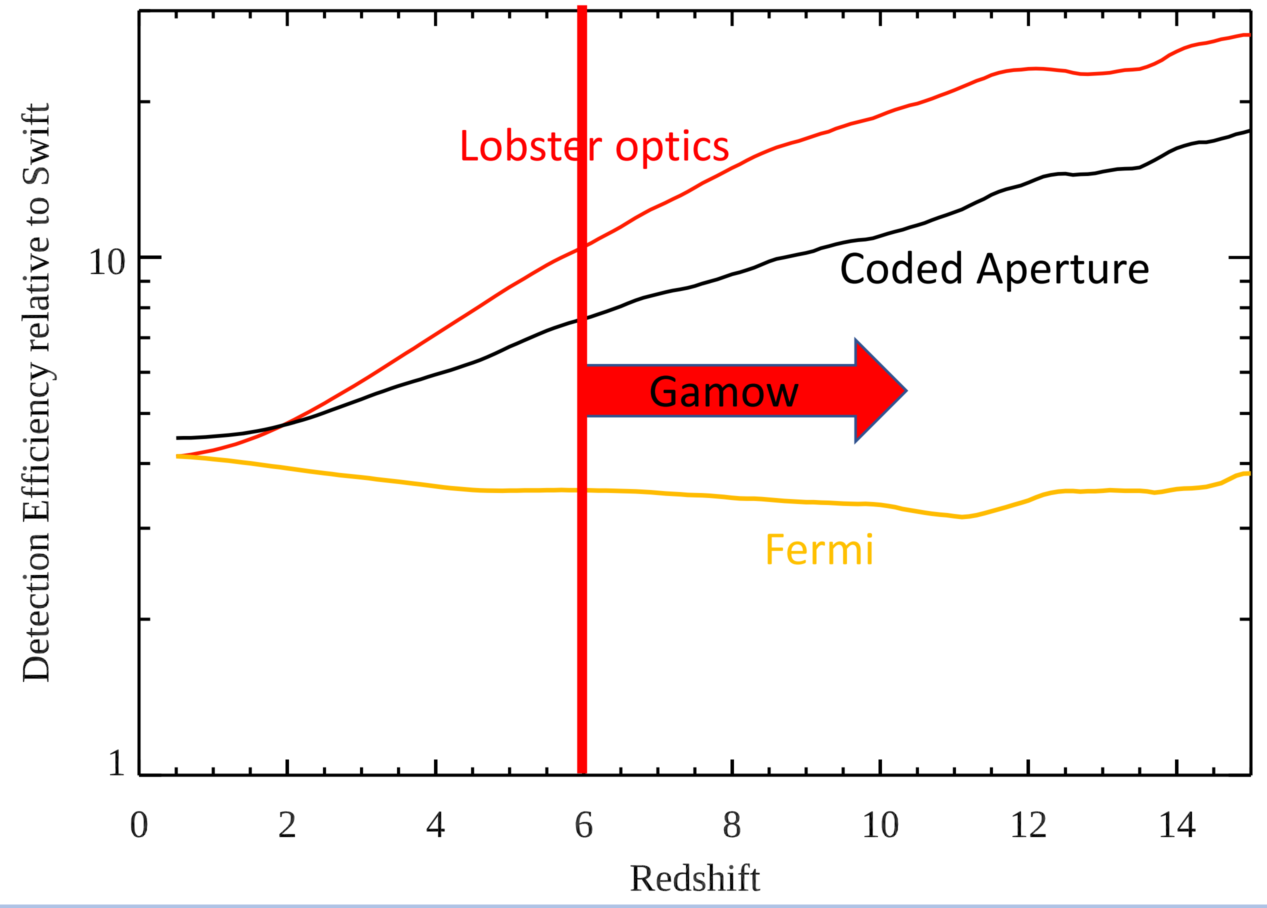
Order of magnitude increased efficiency relative to Swift

Requirement is at least 20 GRB detections with z > 6 over 2 year prime mission

Models predict approximately one z > 6 GRB a month or in two years 60 times more than Swift!

Optimization continuing

Red is LEXT, Black is XCAT, Yellow is Fermi



Credit: Giancarlo Ghirlanda

Time Domain Science

Tidal Disruption Event
Credit: NASA / CXC / M. Weiss.

Gamow Explorer will have unprecedented sensitivity to detect and/or respond to transients:

- Gravitational Wave events
- Tidal disruption events
- Stellar flares
- X-ray transients and bursts
- AGN variability
- Monitoring known sources

Community driven enhanced science program

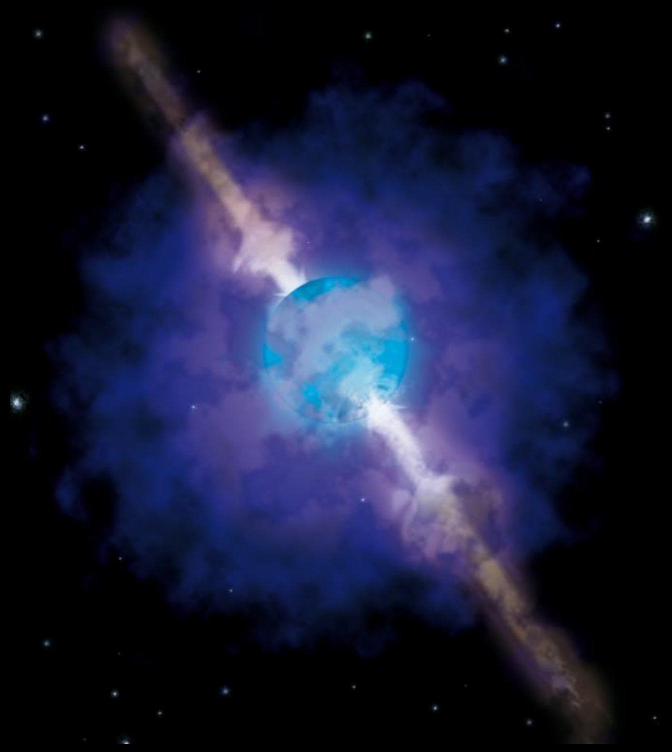
Take away messages

Gamow Explorer is a scientifically compelling GRB mission to address pressing scientific questions about the dawn of the modern Universe

Launched in 2028 will multiply the scientific return of JWST during its planned 10yr lifetime and the coming thirty meter telescopes

Like *Swift* the *Gamow Explorer* rapid response capabilities will be a key resource for multi-messenger astronomy

Low risk mission implementation utilizing flight spare JWST focal plane array, high heritage instruments and cost effective Sun-Sync or L2 orbit



Time Domain Astronomy in the High Redshift Universe

Conference at George Washington University

June 23 to 26, 2020

Purpose is to explore the required observational capabilities to study high redshift transients and how their multi-messenger studies can be used as probes of the formation of the modern Universe

https://tdahighz.columbian.gwu.edu

GW WASHINGTON, DC

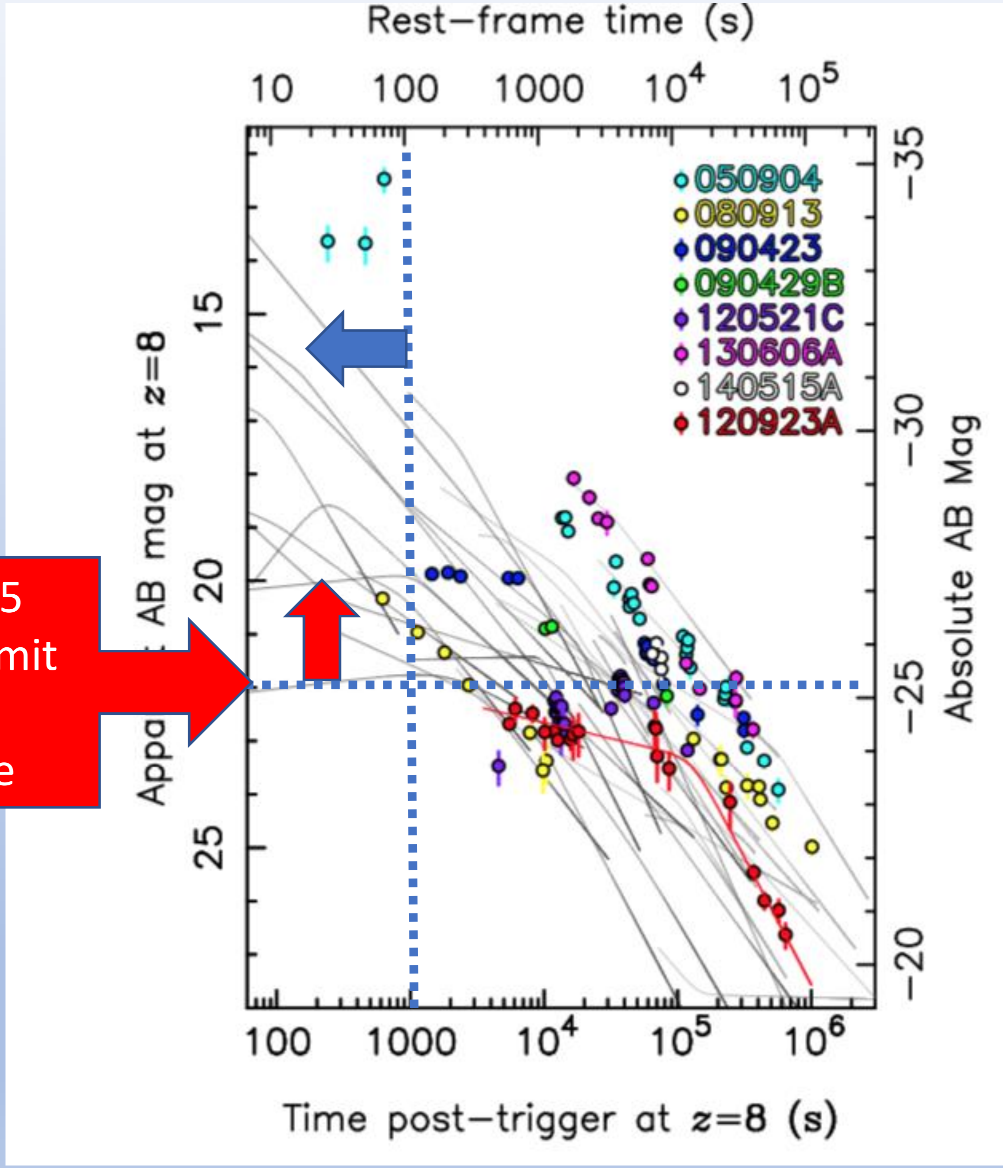
Setting the IR Requirements

Predicted IR afterglow light curves for GRBs observed at z > 6 and lines showing representative light curves transformed to redshift 8 (from Tanvir et al 2018)

- ✓ Cosmological redshift makes them longer
- ✗ Cosmological dimming makes them fainter

To detect IR afterglow requires sensitivity of Apparent AB Mag ~22 (5 micro Jy) within 1000s of GRB trigger

Gamow 5 sigma Limit in 500s exposure



Gamow Explorer GRB rate per year vs. redshift

Thanks to Giancarlo Ghirlanda (INAF-Brera)

Credit: Giancarlo Ghirlanda

Requirement is at least 20 GRBs with z > 6 over 2 year prime mission

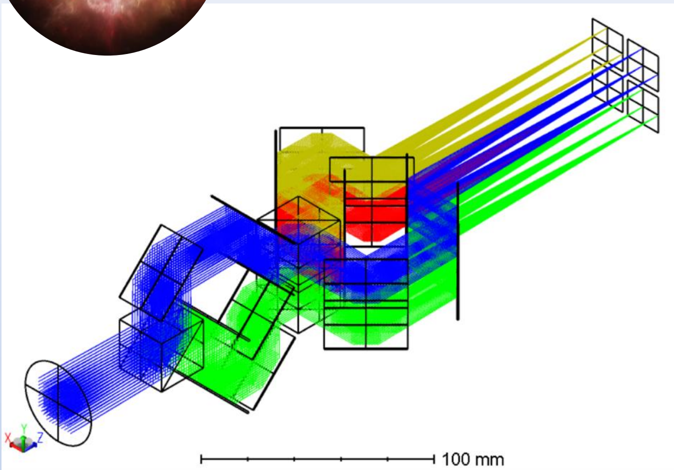
Models predict approximately one z > 6 GRB a month or in two years 60 times more than Swift!

Redshift	Lobster Optics Predicted LGRB yr^{-1}	Coded Aperture Predicted LGRB yr^{-1}
z > 0	314	345
z > 5	26	19
z > 6	15 (9-26)	11 (6-19)
z > 7	10	7
z > 10	3	2

High efficiency L2 Orbit assumed

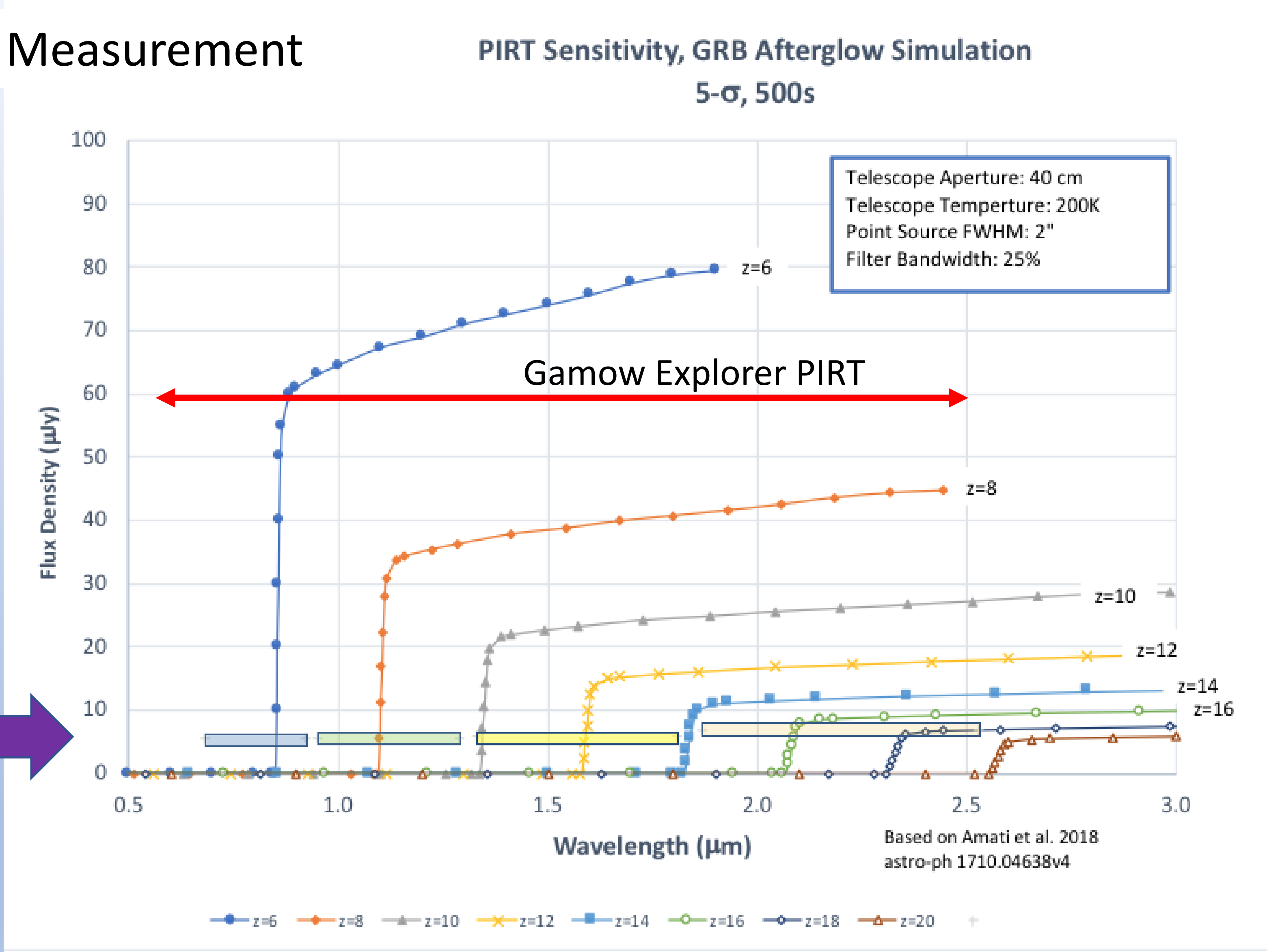
Both approaches meet the requirement
Optimization continuing for JWST and ELT follow-up (L2 vs. Sun-Sync Orbit)

Photo-z Redshift Measurement



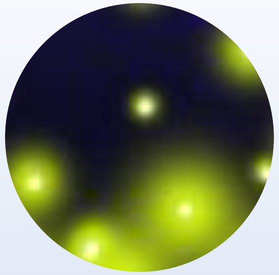
Credit: Ball Aerospace, Erick Young USRA

Gamow will autonomously identify GRBs with a redshift from 6 to 18 with sensitivity to 5 micro-Jy or Mag AB of ~22



Credit Erick Young

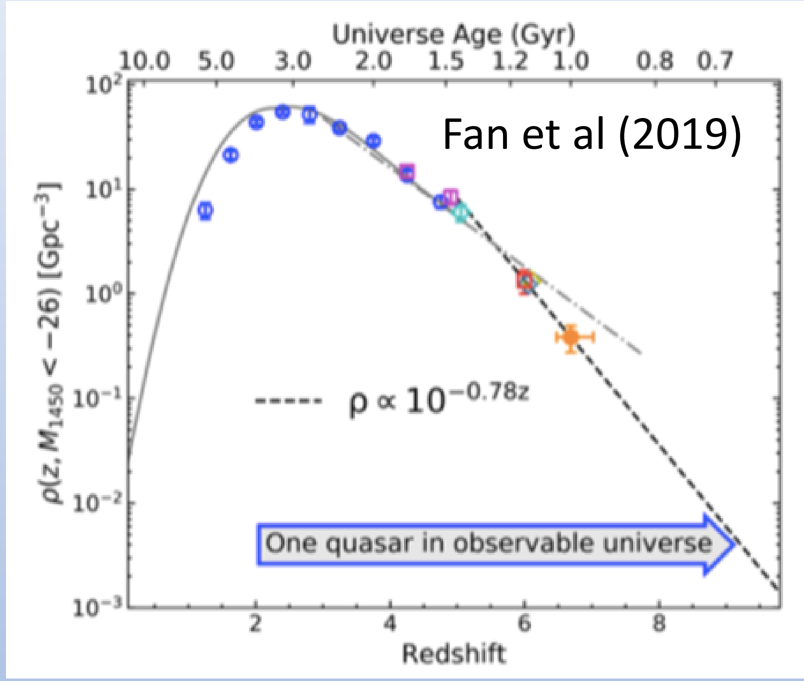
Gamow



GRBs verses QSOs as probes of the Intergalactic Medium during the period of reionization

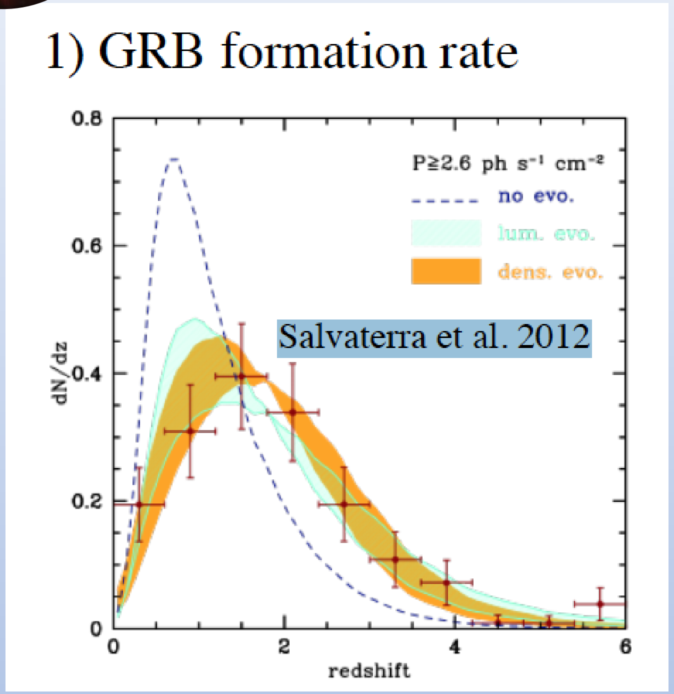
The Quasar population drops off rapidly at z > 7 and the absorption spectra are complicated by material surrounding the nucleus

GRBs track the star formation rate and occur in typical star forming regions and are excellent independent IGM/ISM probes because they have clean power law continuum

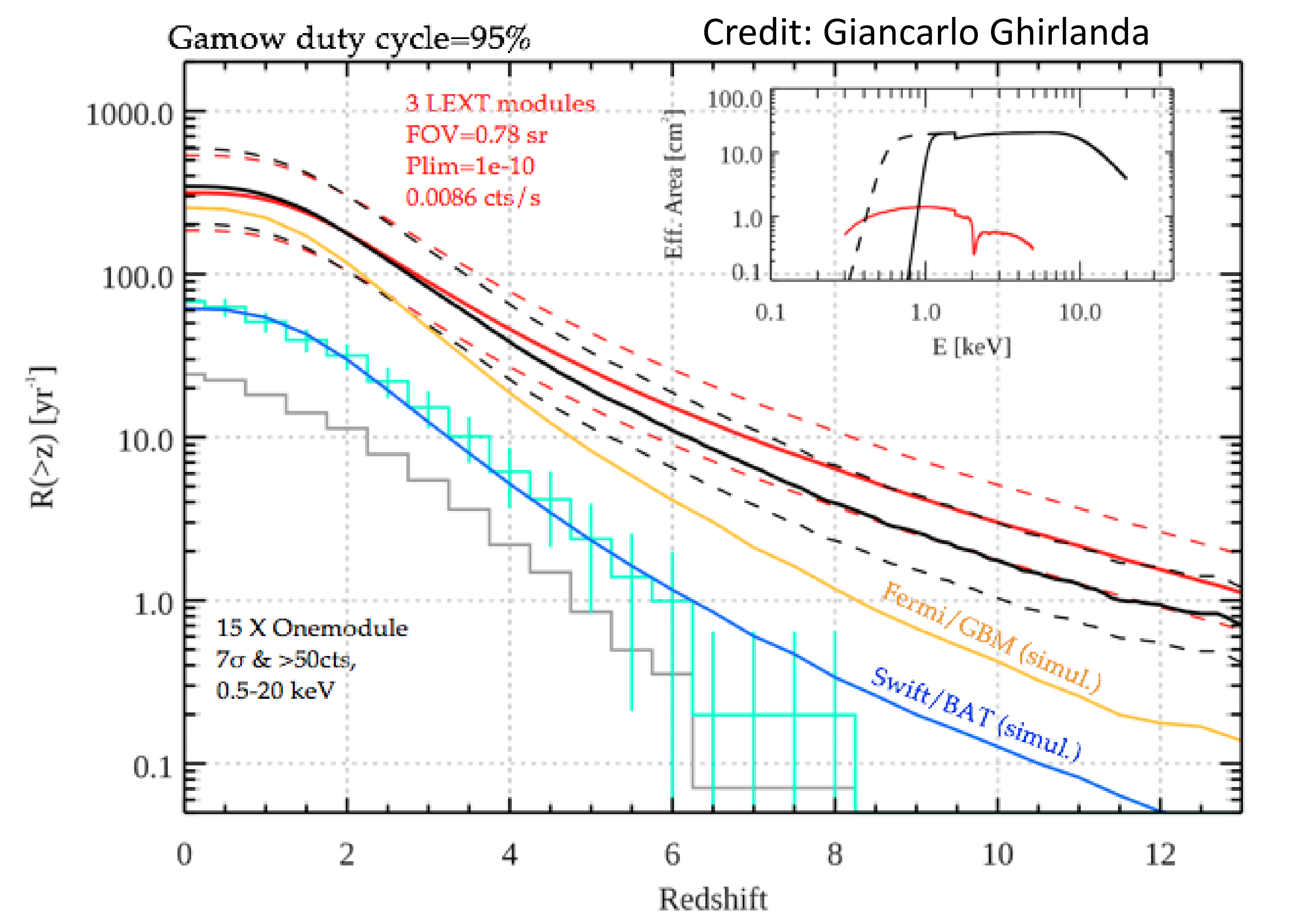


A GRB afterglow spectrum without prominent host absorption will allow detection or limits on the presence of diffuse neutral gas in the IGM (McQuinn et al 2008)

Detection rate for Gamow (XCAT, LEXT) verses Fermi and Swift



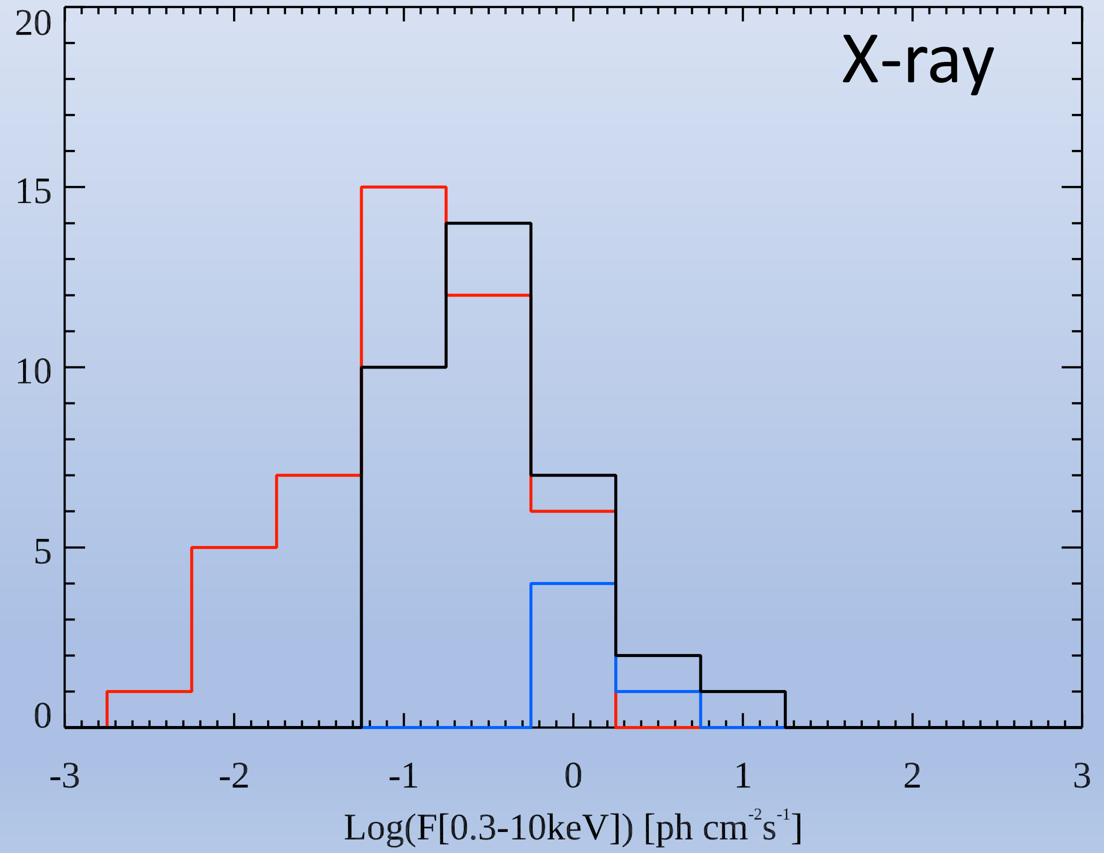
GRBs show density and/or luminosity evolution with redshift, GRB rate predictions at z > 6 depend on extrapolating uncertainties in those predictions



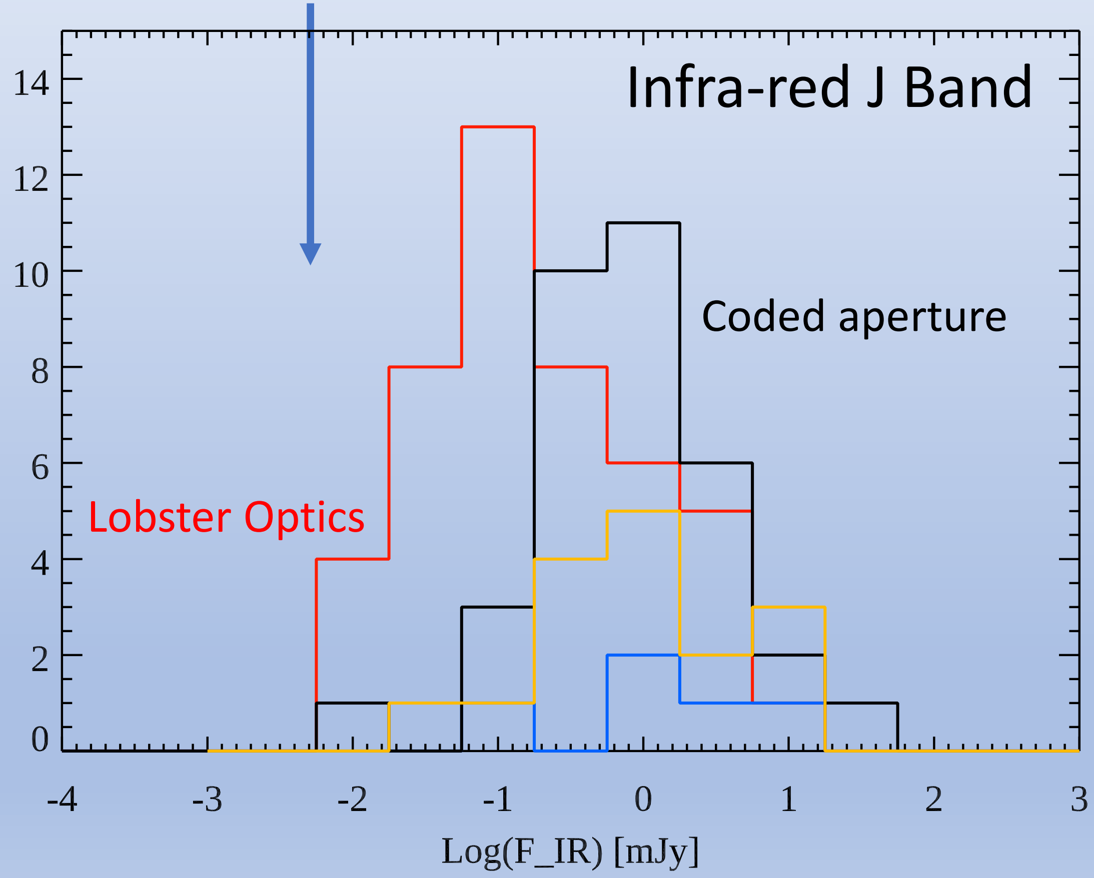
Predicted z > 6 X-ray and IR flux (600s after trigger) distributions

Credit: Giancarlo Ghirlanda

Red is LEXT, Black is XCAT15, Blue is Swift, Yellow is Fermi



Gamow IR flux limit 40 cm telescope



GRBs & Dust at High-z

Dust is known to be produced in

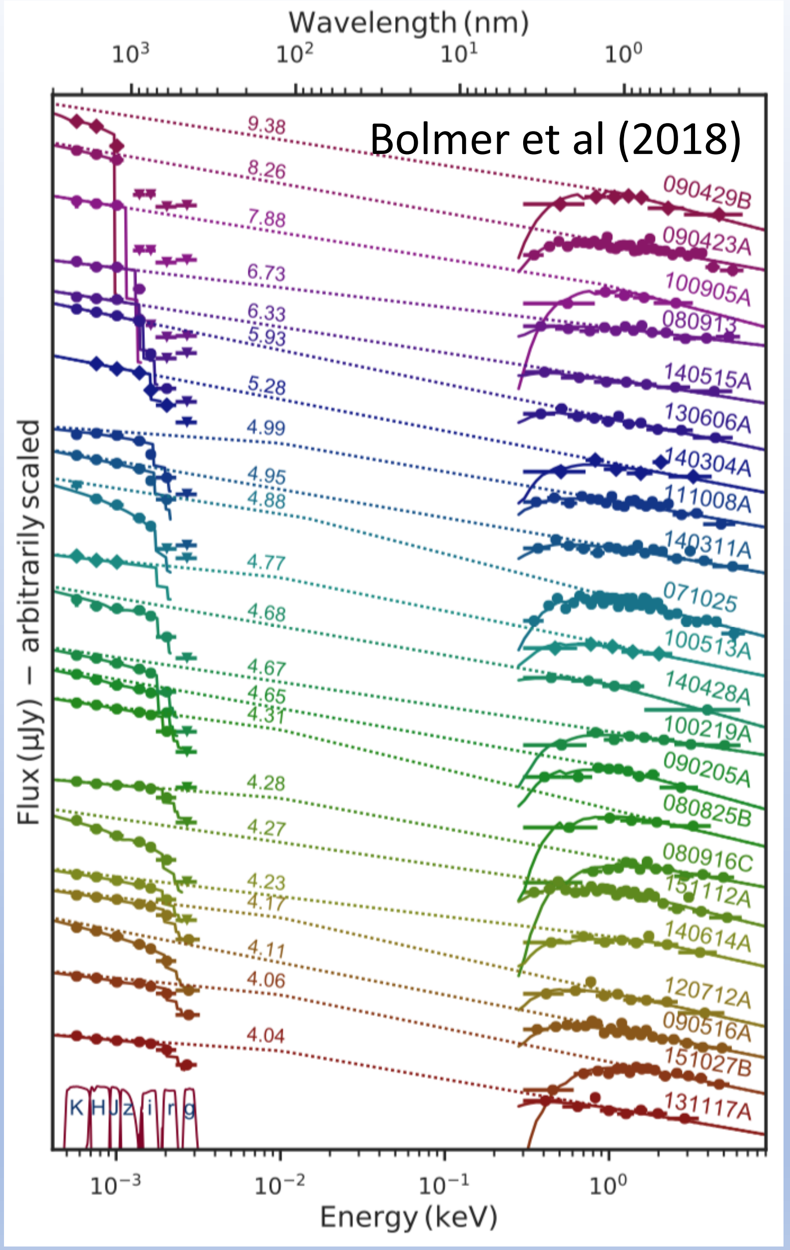
- the envelopes of asymptotic giant branch (AGB) stars,
- the expanded shells of supernova (SN) remnants, and
- in situ grain growth within the interstellar medium (ISM)

The efficiency of each of these dust formation mechanisms at different redshifts is poorly constrained

At high redshift AGB stars are unlikely to have been formed in sufficient numbers

Spectral energy distribution for 22 GRBs with increasing redshift from the bottom to top (Bolmer et al 2018)

GRB host galaxies at $4 < z < 6$ contain on average less dust than at $z \sim 2$ and for most cases can be modelled by a local extinction curve rather than a SN-like curve



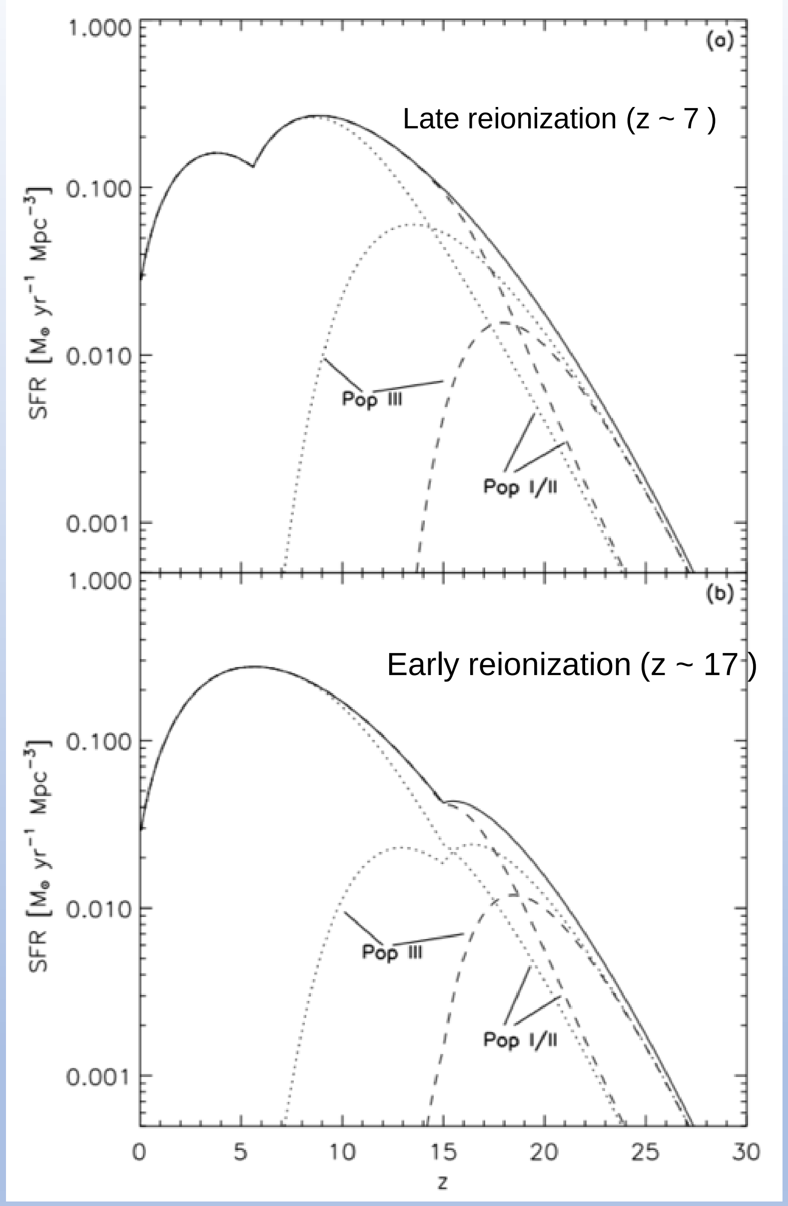
The First (Population III) Stars

Population III stars are expected to be prominent around redshifts z ~ 10-20, consisting of stars with mass 100-300 times the mass of the Sun

Models predict Pop III GRBs to be very energetic events, with total energies exceeding by orders of magnitude those expected in Pop II events

The detection of Pop III LGRBs might represent the most promising way to probe directly the nature of the first stars

Gamow Explorer observations with sensitivity out to redshift ~ 18 will search for Pop III GRB



Bromm and Loeb (2006)

LGRB as Tracers of Star Formation

Star Formation Rates (SFR) are typically determined by converting the Galaxy luminosity into a SFR

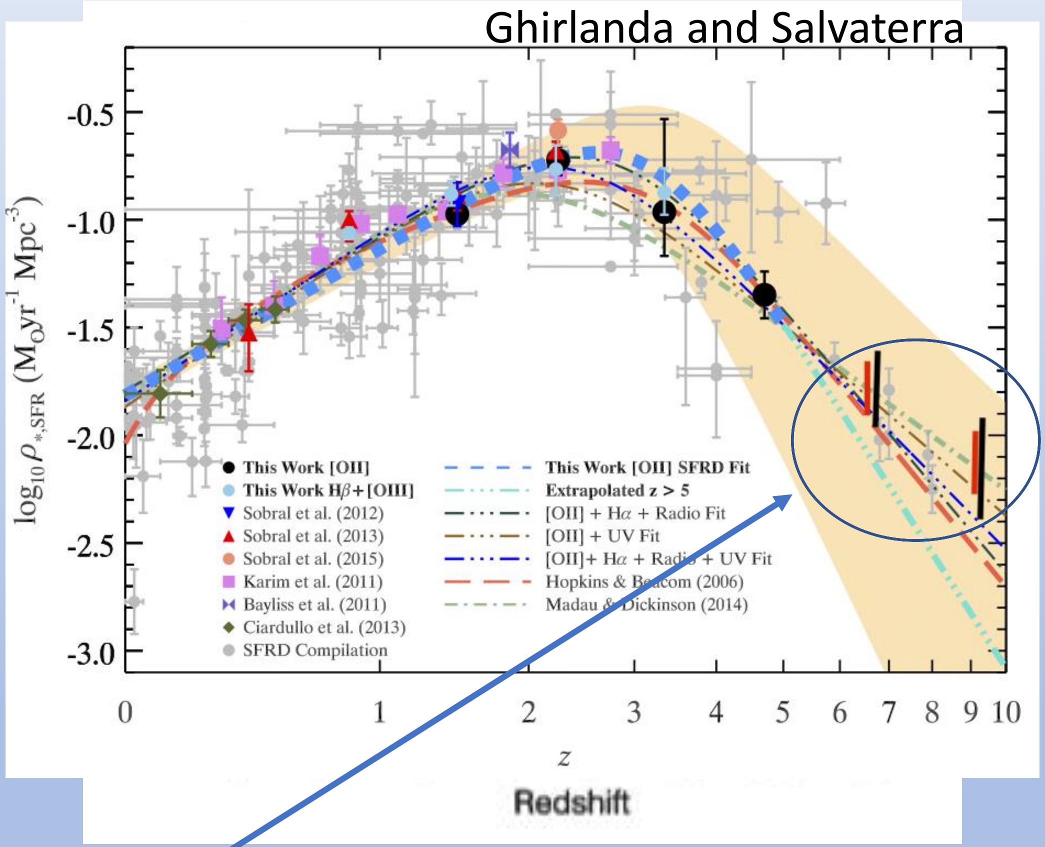
LGRBs are independent tracers of star formation

The LGRB rate at z > 4 declines more slowly than the SFR rate based on galaxy observations (Robertson & Ellis 2012)

Possibilities:

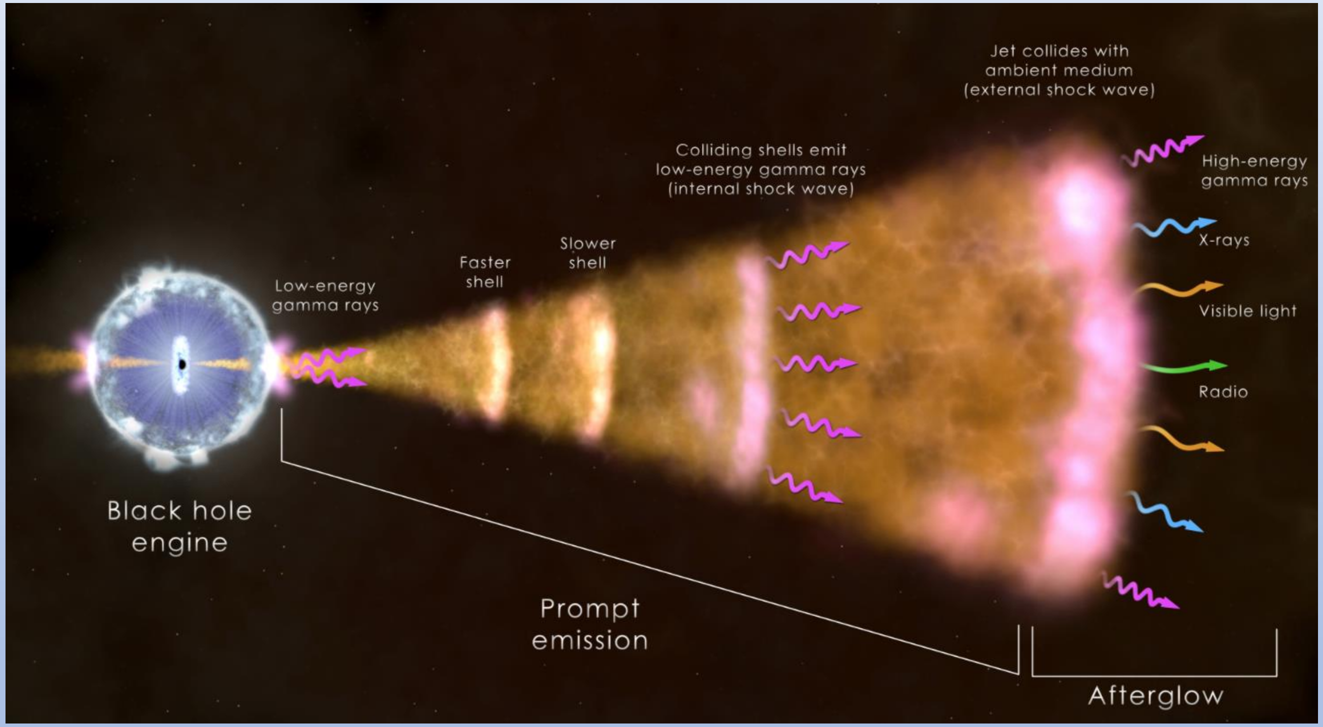
- the fraction of LGRB increases with redshift
- evolution in the luminosity of GRBs with redshift

We need to go beyond redshift 6 with a sample of GRBs



LGRB Observations by *Gamow Explorer* from redshift 6 to 10 will constrain the models

Long Gamma Ray Bursts



Long Gamma Ray Bursts (LGRBs) signal the formation of a black hole when a massive star explodes and the observer is viewing along the relativistic jet

- Most luminous events in the Universe (10^{54} erg/s)
- Can be used to determine star formation rates
- Possible way to directly detect Pop III stars when they supernova
- A bright beacon that can be used as backlights to probe the intervening material