GRBs at z>6: an inside view of re-ionizing galaxies

Antonino “Nino” Cucchiara

Space Telescope Science Institute
NASA-GSFC

Jason Tumlinson (STScI)  Sylvain Veilleux (UMD)
Jeff Valenti (STScI)      Brad Cenko (NASA-GSFC)
Andrew Fruchter (STScI)  

THIRTY METER TELESCOPE
HUDF, Frontier Fields have open a new window in the exploration of re-ionization

Mainly bright galaxies have been observed….maybe too bright…

At the same time **Gamma-ray Bursts** have been identified at up to \( z=8 \), providing a new tool to identify high-z galaxy and test early epoch star formation.
The Universe before JWST

• After 25+ years of HST we are reaching the point of understand the nature galaxies at z>7

• Pushing the luminosity function at z~10

• Testing the SFR density models

Can we test the “behind the scene” actors of Star-formation/reionization?
Cosmological simulations allow us to model gas density and temperature of the Universe during re-ionization.

Pawlik et al. 2013
Fumagalli et al. 2011
Boylan-Kolchin et al. 2009

Furthermore re-ionization is likely a patchy process, making hard to identify the exact parameters due to line of sight to line of sight variation (Zahn+06, McQuinn+08).
Re-ionization from first principles

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Using LBGs and LAE we can place observational constraints on the neutral hydrogen fraction (Bouwens +15, Robertson+15, McGreer+15, Stark+15).
Gamma-ray Bursts (GRBs) 101

Short GRBs
GW
(cool stuff!!!)

Long GRBs
(also cool stuff!!)
GRB 090423 and GRB 090429B

- GRBs occur at $z > 7$
- At discovery they are BRIGHT!
- They are independent of the galaxy luminosity
- Pinpoint high-z “faint” galaxies
- They provide unique insights on star-formation during re-ionization

<table>
<thead>
<tr>
<th>$z$</th>
<th>Look-Back Time (Gyr)</th>
<th>GRB</th>
<th>Optical Brightness</th>
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<tbody>
<tr>
<td>9.4</td>
<td>13.1</td>
<td>090429B</td>
<td>K = 19</td>
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<tr>
<td>8.2</td>
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<td>K = 20</td>
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<td>~8</td>
<td>13.0</td>
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<tr>
<td>7.5</td>
<td>13.0</td>
<td>100905A</td>
<td>H ~ 19</td>
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<td>6.7</td>
<td>12.8</td>
<td>080813</td>
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<tr>
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Tanvir+09

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Oesch+16
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GRB 090423 and GRB 090429B

GRB 090429B: Cucchiara+11

z~9.4

KEY FACT

GRBs at z>7 stay bright for several days!!
NIRCAM/NIRSPEC will be able to obtain photo-z
High S/N spectra enable re-ionization studies

Chornock+13

GRB 050904 (z=6), Totani+05

Chornock+14
High S/N spectra enable re-ionization studies

Fitting the red wing of the afterglow spectra allows to measure fundamental parameters of re-ionization. But requires good data (AKA high S/N spectra).
GRBs afterglow enable to answers some key questions?

• What is the metallicity of a galaxy at $z>8$?
• What is the reservoir of HI in these primordial objects?
• Can we constrain the neutral hydrogen fraction?
• Can we constrain the size of the primordial ionized regions?
The perfect recipe (Cucchiara in prep.)

We model a GRB afterglow spectrum including:

• Simple GRB continuum (the beauty of the beast)
• Absorption lines (host+intervening) at $0.01 < \frac{Z}{Z_{\odot}} < 1.0$
• $\log(\text{HI}) > 17 \text{ cm}^{-2}$
• $0.01 < x_{\text{HI}} < 1.0$
• A grid of IGM bubble size $R_b$: 1, 10, 60 Mpc

We simulated the following instruments:

JWST+NIRSPEC (not-official tool)
TMT+IRIS (official)
WFIRST-GRISM
DCT+RIMAS (OH lines suppression)
JWST-NIRSPEC

$z=8.2$

$J_{\text{mag}}=22$ (S/N=10 with $T_{\text{exp}}=900\text{s}$)

G140H ($R\sim2700$

Pixel scale: 2 Å/pix

$Z/Z_{\text{sun}} = 0.1$
Determine the ISM metallicity of z>8 galaxies

At \( Z/Z_{\text{sun}} = 0.1 \), G140H = 900s, S/N 10 (\( J_{\text{mag}} = 22 \))

\[ \log(\text{HI}) = 19.5 \]

\[ \log(\text{HI}) = 20.5 \]

\[ \log(\text{HI}) = 21.5 \]
The future, JWST+NIRSPEC

At $Z/Z_{\text{sun}} = 0.01$, $G140H = 900s$, $S/N$ 10 ($I_{\text{mag}}=22$)

log(HI) = 19.5

log(HI) = 20.5

log(HI) = 21.5
Effect of pure HI column on the red wing

$X_{HI} = 50\%, \ R_b = 10 \text{ Mpc}$

Effect of $X_{HI}$ on the red wing

$\log(HI) = 19, \ R_b = 10 \text{ Mpc}$

Effect of $R_b$ on the red wing

$\log(HI) = 19, \ X_{HI} = 50\%$
Re-ionization (preliminary)

TMT+IRIS (R~4000) spectrum of GRB130606A shifted at z=8.2 (HI=19.9)

JWST+NIRSPEC (R~2700) simulated spectrum of a at z=8.2, with HII size 10Mpc, HI=19.5 \( x_{\text{HI}}=0.01 \)

Work to do

- Understand the error budgets (instrumental)
- Including sky transmission (IRIS)
- Perform observing strategies (slew response time for JWST)
- How many GRBs do we need to be sure we can constrain IGM
Conclusions

In the era of JWST and beyond (TMT, GMT, E-ELT) we will be able to move from stars to gas (ISM, IGM)

• GRBs a unique addition to the exploration of re-ionization

• Absorption lines analysis (OI, SII, FeII) will probe the ISM of primordial star-forming regions (ionizing bubble around first galaxies)

• High S/N spectra will help constraining the key ingredients of re-ionization ($x_{HI}$, HI, HII regions size).

• Rapid follow-up of z>8 GRBs is critical: combining space triggers (Gamma-ray) with ground based facilities (1-4m telescopes) + JWST/30m telescopes (spectroscopy)….promise 1-10 z>8 GRBs!!
2017-2023: Exploring the re-ionizing Universe

Direct access

Collaborators