Gamma-ray burst afterglows as probes of the ISM

Patricia Schady (MPE)

+ GROND and UVOT team
Probing the ISM of GRB Hosts

Probes young, star forming galaxies

Highly luminous synchrotron featureless spectra

Fruchter+06

Blustin+06

Synchrotron Spectrum

Flux Density (mJy)

Frequency (Hz)
Gas Absorption

GRB 060729

Schady+10

Prochaska+09

H₂

Lyα

Metal lines

NO,X
Dust Extinction
Location of Neutral Gas

GRB 060418

![Graphs and diagrams illustrating the location of neutral gas around GRB 060418.](image)
~30% of GRBs have spectroscopic redshift

~10% of GRBs at z>2, thus can detect Lyα absorption and measure N_{HI}

~90% of GRBs detected in X-rays

~60% of X-ray afterglows have soft X-ray absorption in excess of Galactic
Approximately 30% of GRBs have spectroscopic redshifts. About 10% of GRBs at $z > 2$ can detect $\text{Ly}\alpha$ absorption and measure $N_{\text{HI}}$. Approximately 90% of GRBs detected in X-rays and 60% of X-ray afterglows have soft X-ray absorption in excess of Galactic frequency ($\text{Hz}$) flux density ($\text{mJy}$). (Watson et al., 2007)
Watson+07

NHI (cm$^{-2}$)  XHI (cm$^{-2}$)

GRB host galaxies typically supersolar environments and/or X-ray observations probe larger column of gas than optical.

Savaglio+09

Optical vs. X-ray: Missing Gas Problem

$Z_{\odot} = 0.1$
$Z_{\odot} = 1.0$
$Z_{\odot} = 10$

Watson+07

$N_{HI} (cm^{-2})$

$N_{H,X} (cm^{-2})$

GRB-DLAs
QSO-DLAs

Solar

GRB hosts
$R_{21}$ lower
$T_e/O3N2/R_{21}$ lower

060070A
060526
060522
050908
050820A
050922C
050920
050505
050210
060714
060906
060730
060930
AO 0235+164
Crab
More natural to compare $N_{O,X}$ to metals

- Use weakly-ionised metal lines to trace neutral gas ($Zn\ II$, $S\ II$, $Si\ II$ or $Fe\ II$)
- Correct for dust-depletion
- Convert metal column densities to $N_H$ (assuming solar abundances):
  $N_{H,MII}$ versus $N_{H,X}$
Neutral vs. Ionised Gas

Neutral gas = Total gas

90% additional gas absorbing soft x-ray

$N_{H, ZnII}$
$N_{H, SiII}$
$N_{H, SII}$
$N_{H, FeII}$

Total Gas (Log $N_{H,X}$)
Neutral Gas (Log $N_{H,M}$)

Schady + 11
What is contribution to soft X-ray absorption from highly ionised gas?

- CIV, SiIV, NV and OVI may trace gas closer GRB (Fox+08, Prochaska+08)
Only <10% of gas highly ionised (i.e. IP~140eV)

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What is the Origin of the X-ray Excess?

- Ionised gas is in highly ionised state i.e. not seen in optical
  - Close to the GRB, within an ionised bubble
  - Within the halo of the host galaxy

- X-ray absorbed by intervening gas external to host galaxy
  - Intervening galaxies along line-of-sight (Campana+12)
  - A Warm Hot Intergalactic Medium within local Universe (Bahar+11)
  - Milky Way soft X-ray absorption is underestimated
Location of Extinguished Dust

Number of Afterglows

Greiner+11

Afterglows $A_V$ [mag]

GRB 070306 (Jaunsen et al. 2009)
GRB 080607 (Perley et al. 2009)

3.2      5.5

Schady+10

GRB 060729

Location of Extinguished Dust

Greiner+11

Number of Afterglows

Afterglows $A_V$ [mag]

GRB080607
(Perley et al. 2009)

GRB070306
(Jaunsen et al. 2009)

3.2 5.5
Metals-to-Dust ($N_{H,X}/A_V$)

![Graph showing the relationship between $N_{H,X}/A_V$ and $A_V$ with various markers indicating different studies and observations.](image)

- $A_V > 1$
- Greiner et al. (2011)
- Schady et al. (2010)
- Zafar et al. (2011)
- Perley et al. (2011)
- This work

- $[N_{H,X}/A_V]_{sol}$
- $2x[N_{H,X}/A_V]_{sol}$
- $3x[N_{H,X}/A_V]_{sol}$
Dust Extinction Curves

![Graph showing dust extinction curves with various GRBs and extinction values.](image)

- Low $A_V$ GRBs
- SMC
- LMC
- Milky Way
- GRB 070802
- GRB 080607

Schady+12

$A_V = 3.2$ (Elíasdóttir+09)

$A_V = 1.2$ (Perley+11)
Dust Depletion vs. Dust Extinction

GRB070802

[Fe/Zn] vs. $A_v$ (mag)

Schady+11
Conclusions

- Rich sample of GRB optical and X-ray afterglow spectra
  - Can probe ionisation state and relative abundances of host galaxy gas
  - Can probe $A_V$ distribution and dust extinction law across cosmic time

- Soft X-ray column densities typically an order of magnitude larger than neutral gas column densities
  - Majority of host gas along line-of-sight is in a super ionised state?
  - Soft X-rays absorbed by gas external to host; intervening galaxies, local WHIM, Milky Way?
  - Dust-to-metals ratio suggests soft X-rays absorbed within host

- Line-of-sight dust extinction properties ($A_V$, extinction curve) dependent on global host galaxy properties?
  - Older, more evolved galaxies have larger dust extinction and $A_V/N_{H,X}$, flatter extinction curves, more pronounced 2175Å bump