Dark Cosmology Centre

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The X-ray afterglows of Gamma-Ray Bursts

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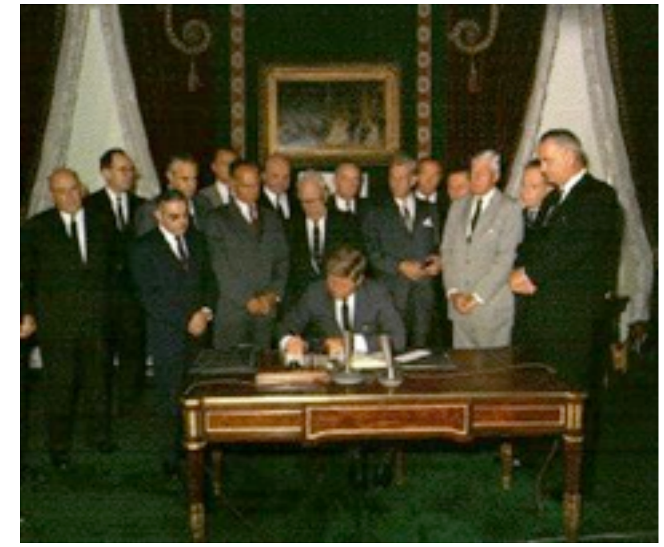
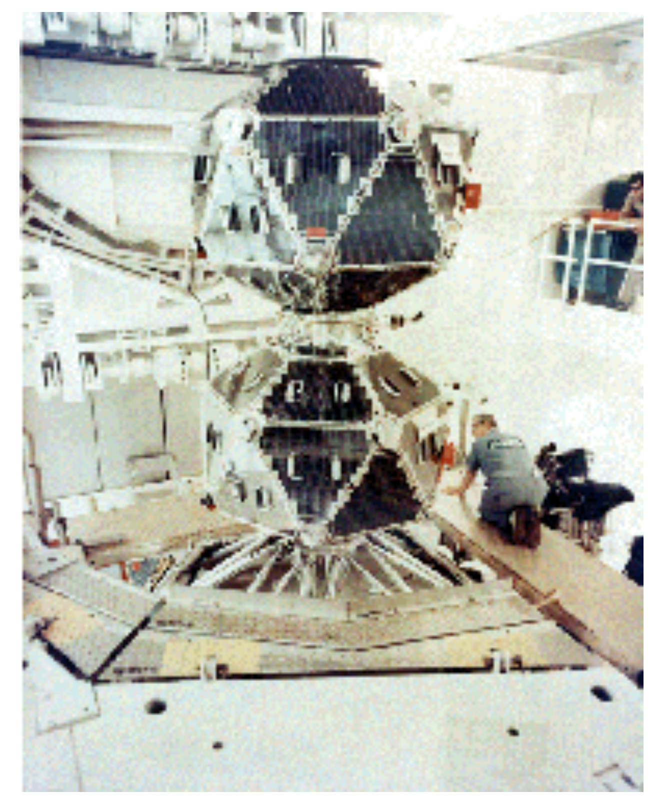
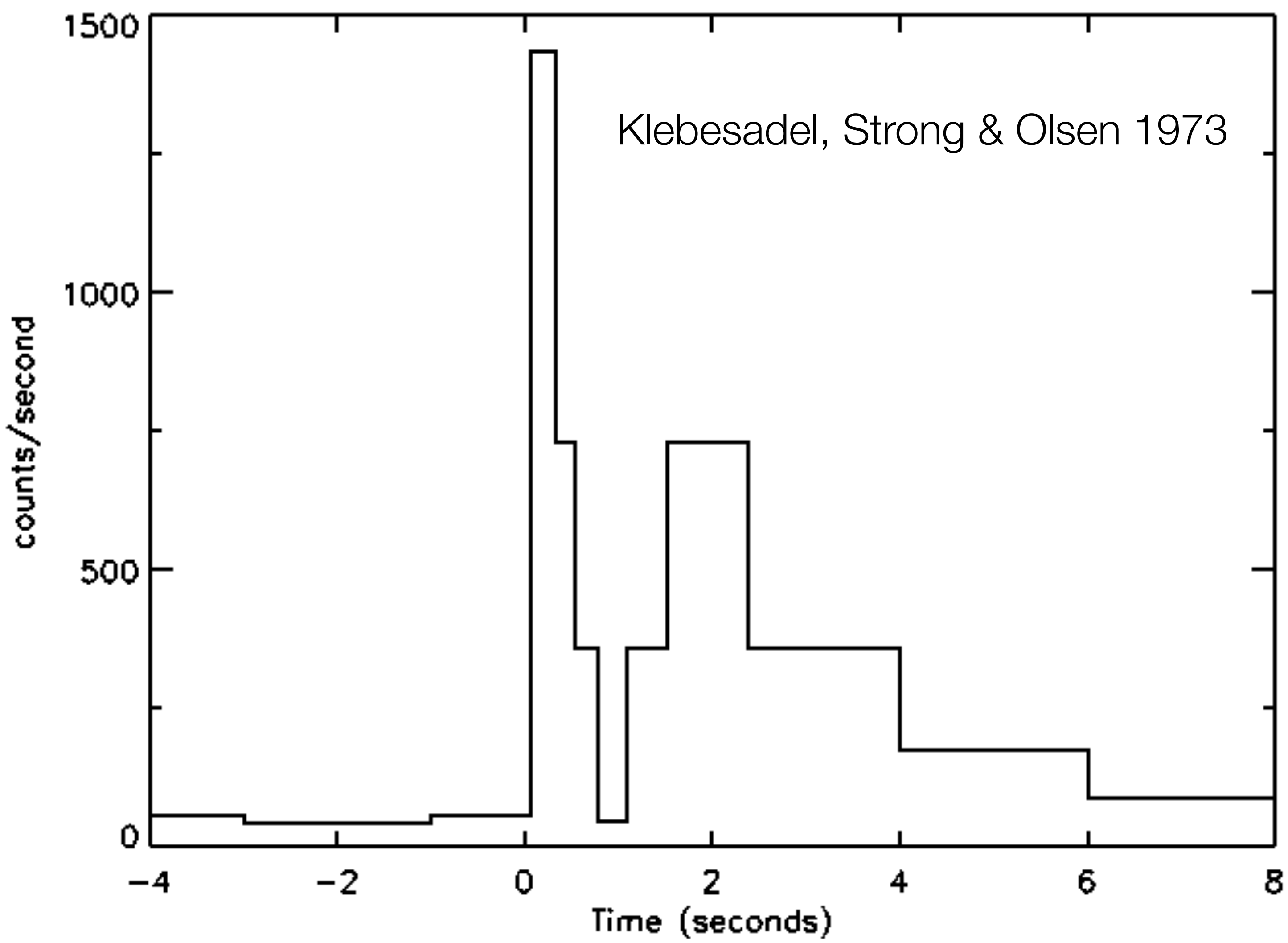
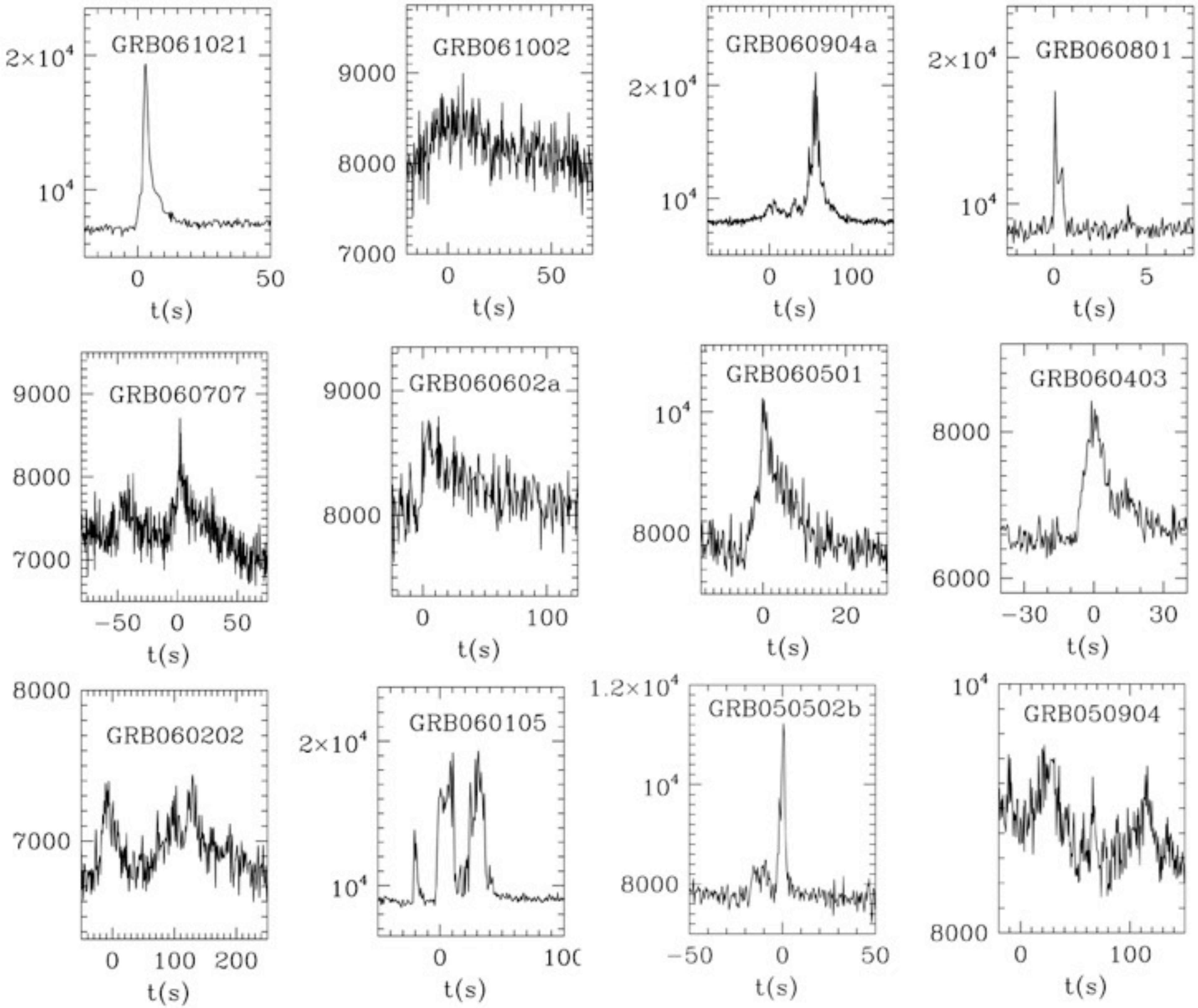
Gamma-Ray Bursts: A peace dividend

- GRB670702: The first known burst









Prompt Emission

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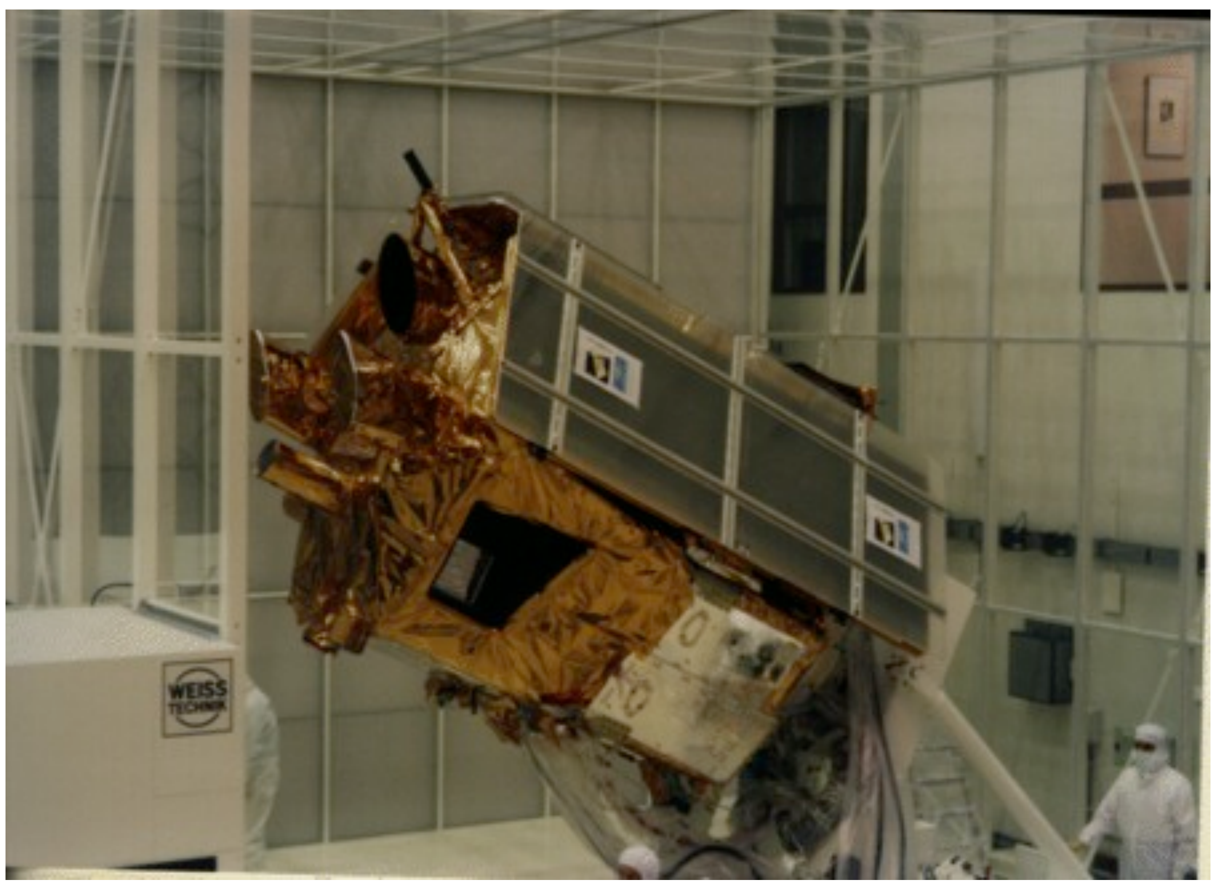
Major Observations in GRBs

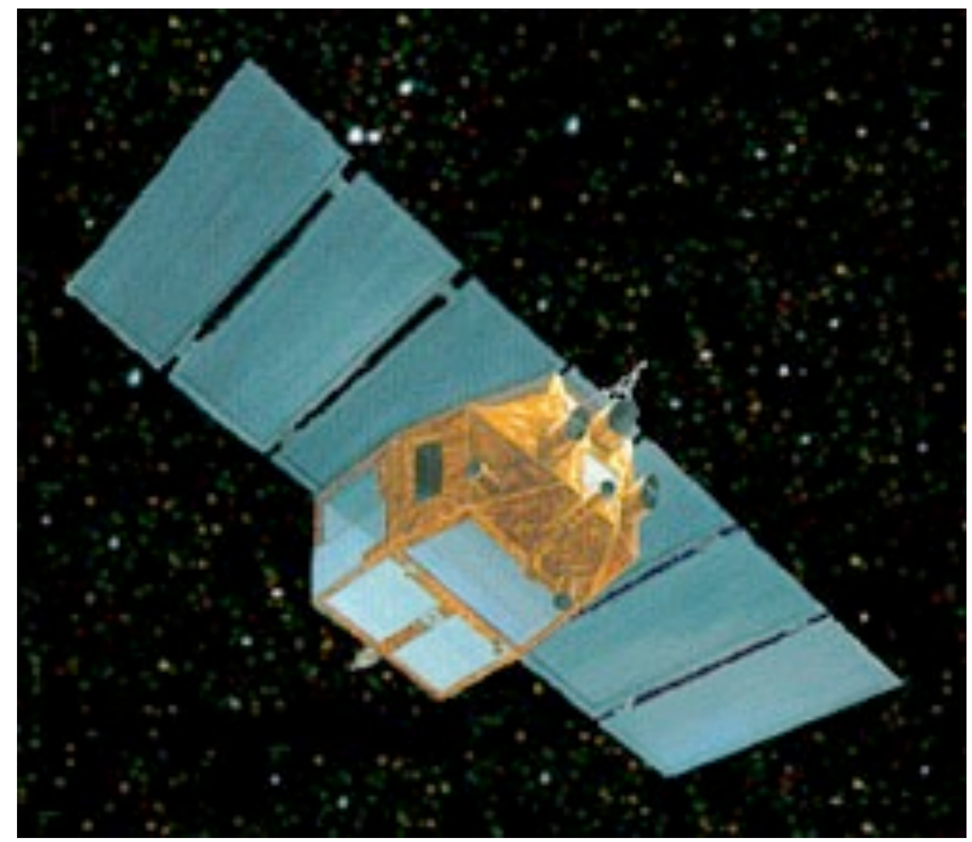
- 1973 — Discovery [Vela]
- 1984, 1993 — Long & short [Vela, CGRO-BATSE]
- 1992 — Isotropic & non-Euclidean distribs [BATSE]

- 1997 — Afterglows of long GRBs
- 1997 — Redshift of long GRBs
- 1998, 2003 — SN-GRB connection
- 2005 — Afterglows of short GRBs
- 2006 — SN-less GRBs
- 2009 — $z > 7$ GRB

Soft X-rays – the key to GRBs

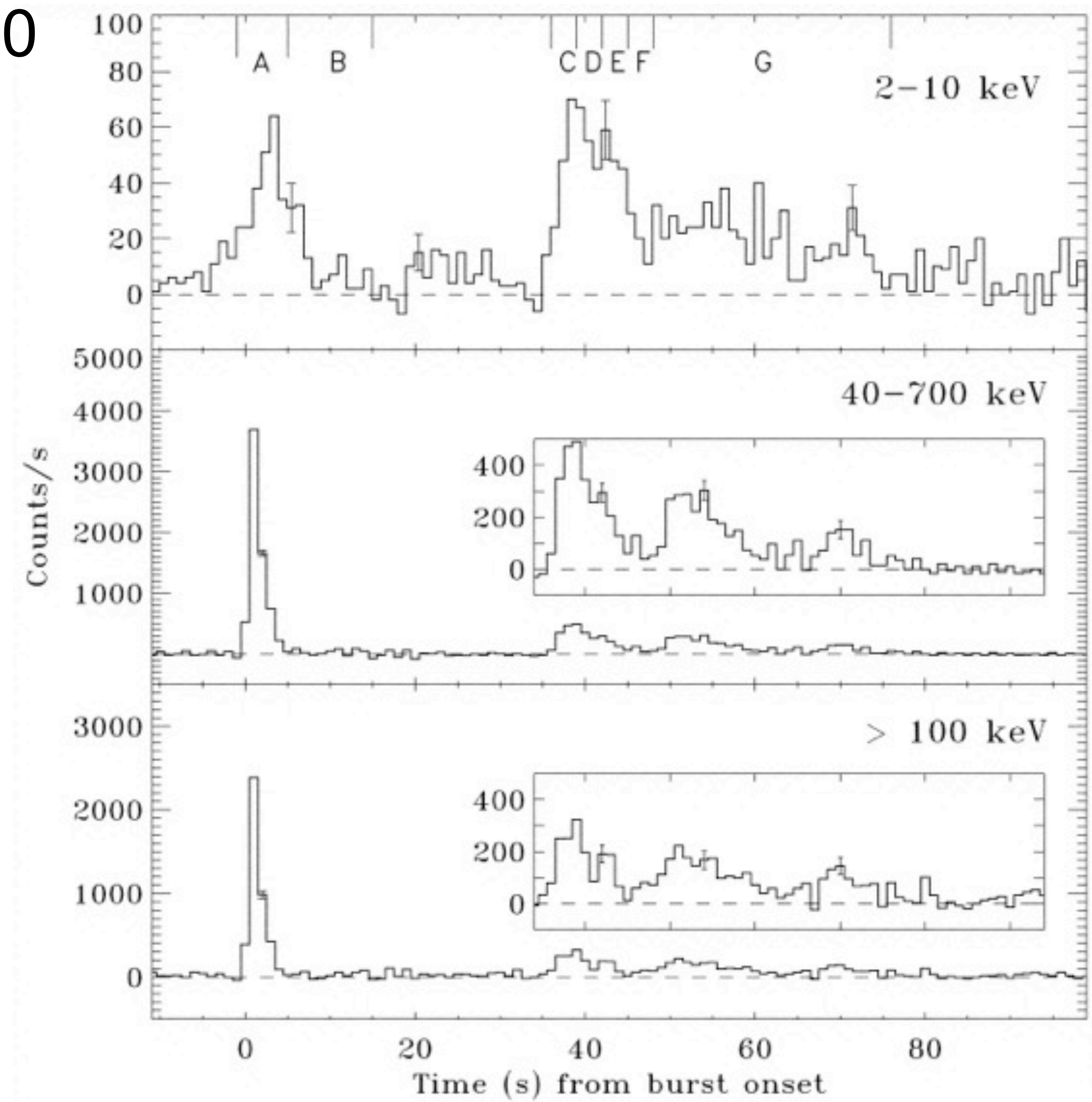
The BeppoSax Years: 1996–2002



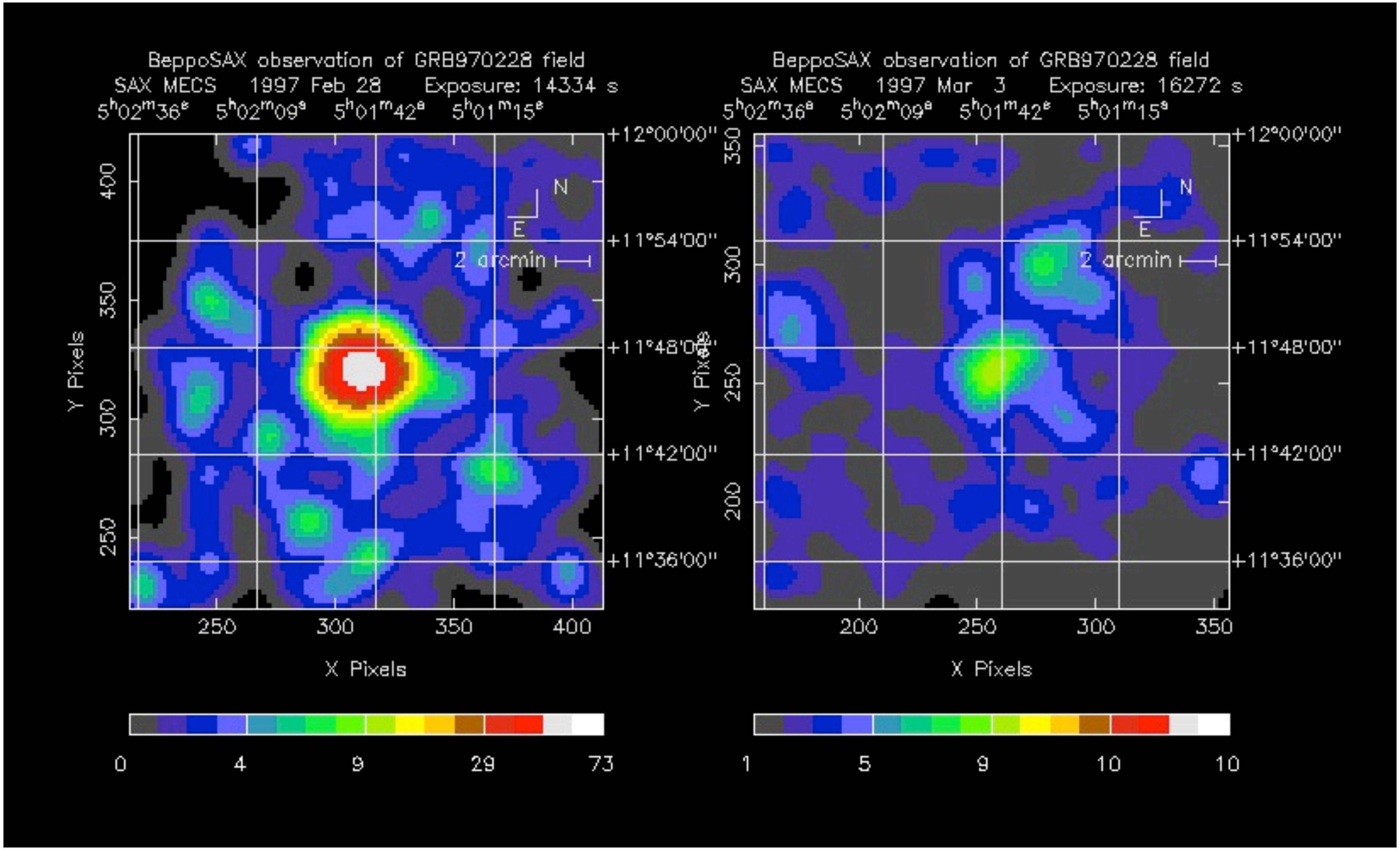


GRB970228: breakthrough

February 28.123620



GRB970228: X-ray afterglow



Costa et al. 1997

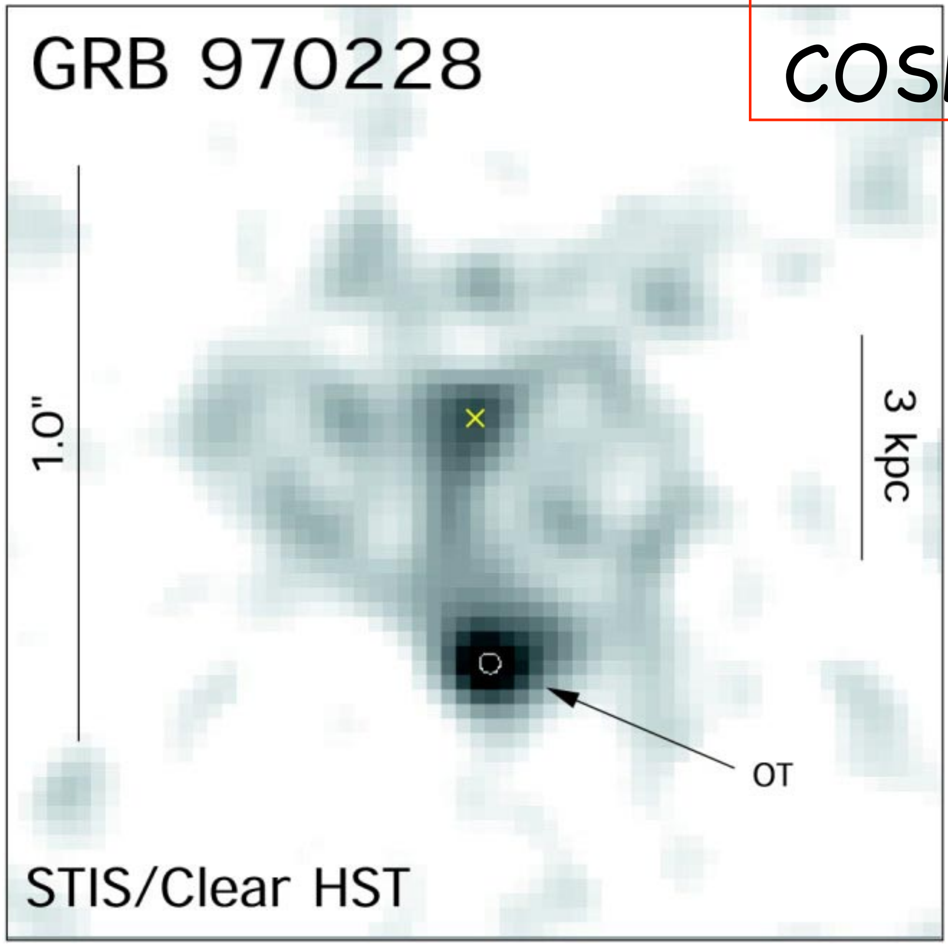
First Redshift

- GRB 970228: first redshift -> cosmological
- Accurate localisation of the GRB vital
- X-ray afterglow allows this

Host galaxy (z=0.695, d=4.2 Gpc)

↓

COSMOLOGICAL!

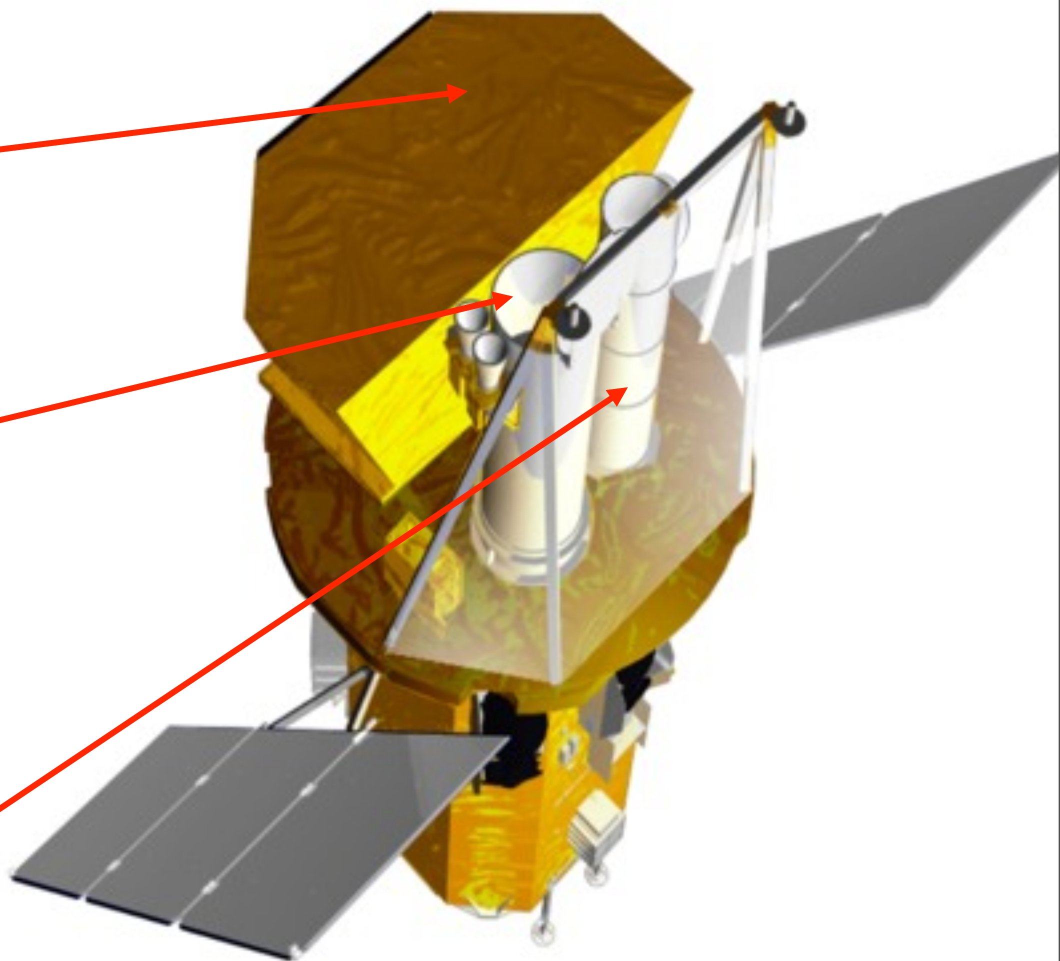


Bloom et al. 2001

OT: Van Paradis et al. 1997

Swift launched in 2004

- Burst Alert Telescope (BAT)
  - Most sensitive gamma-ray imager ever
- X-Ray Telescope (XRT)
  - Arcsecond GRB positions
  - CCD spectroscopy
- UV/Optical Telescope (UVOT)
  - Sub-arcsecond imaging; Finding chart
  - 18^{th} mag sensitivity (100 sec) <u>bluewards of the V-band</u>



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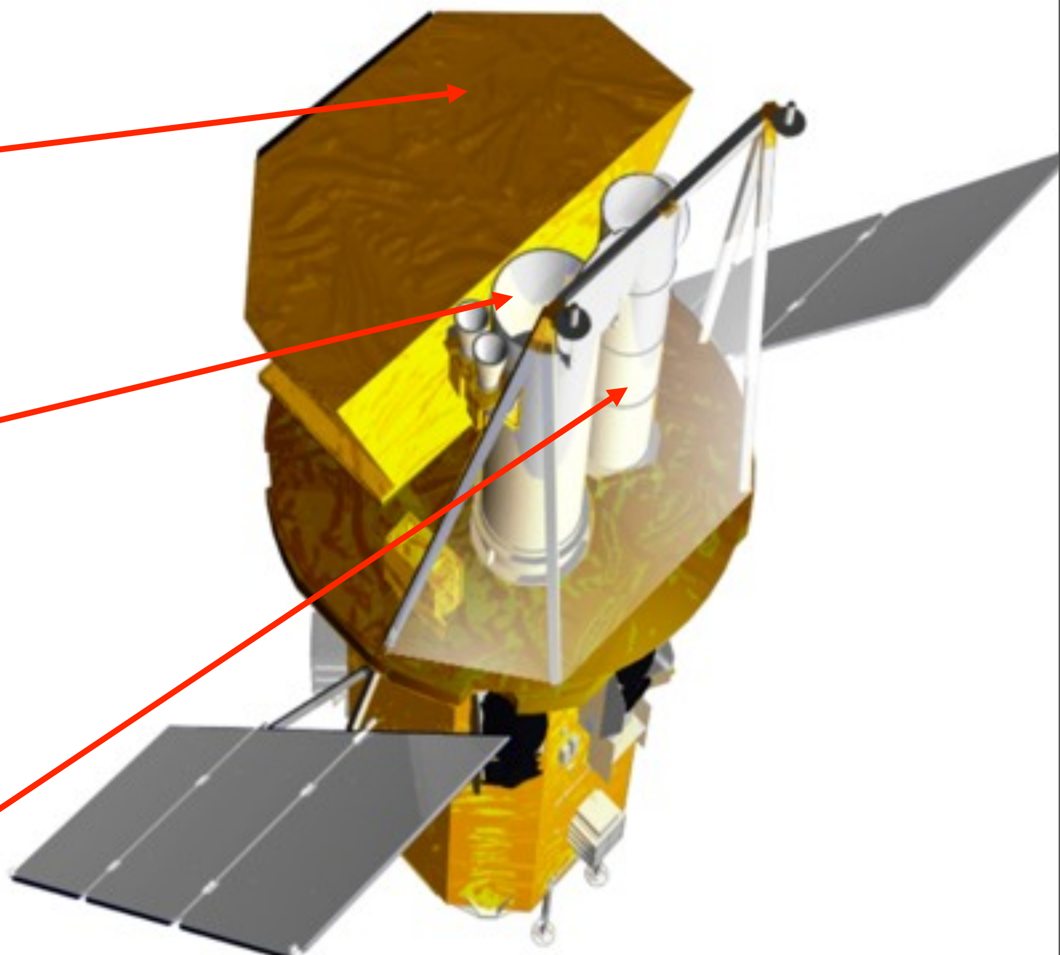

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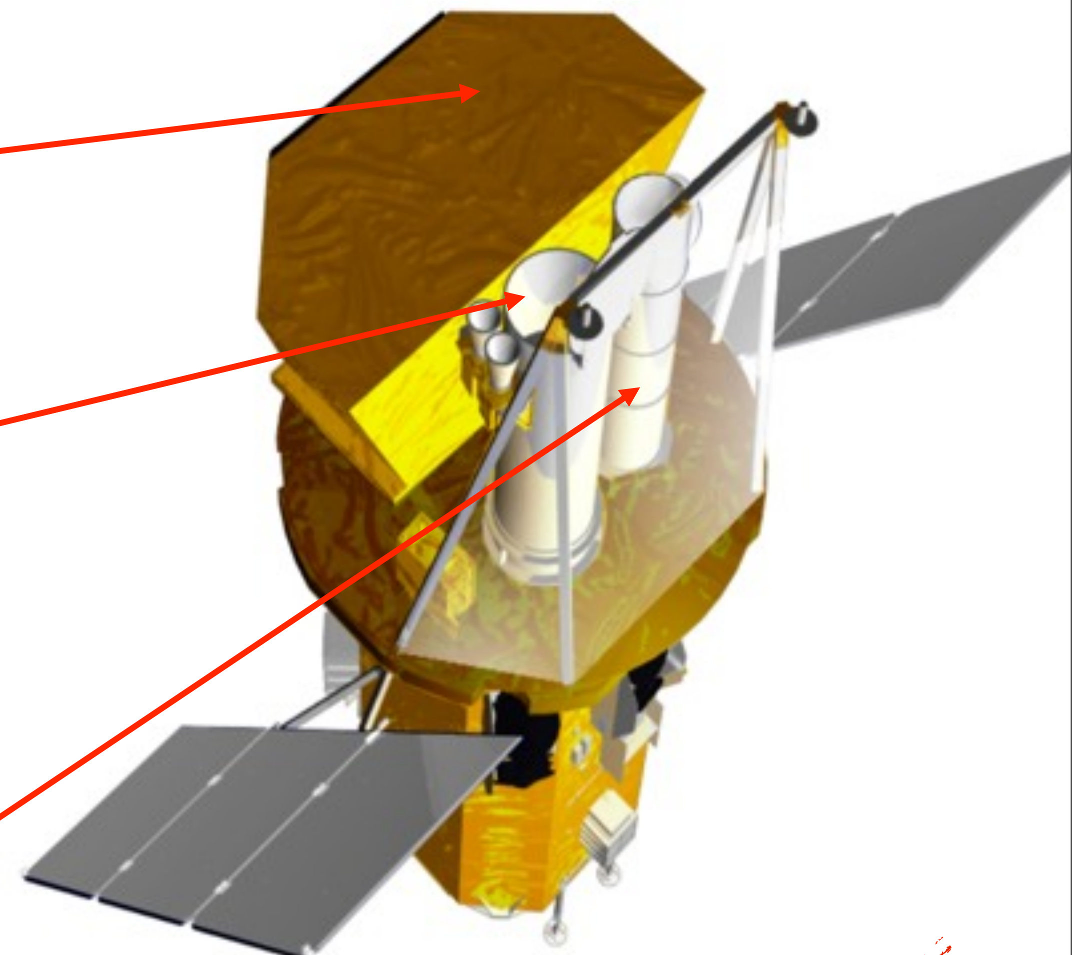
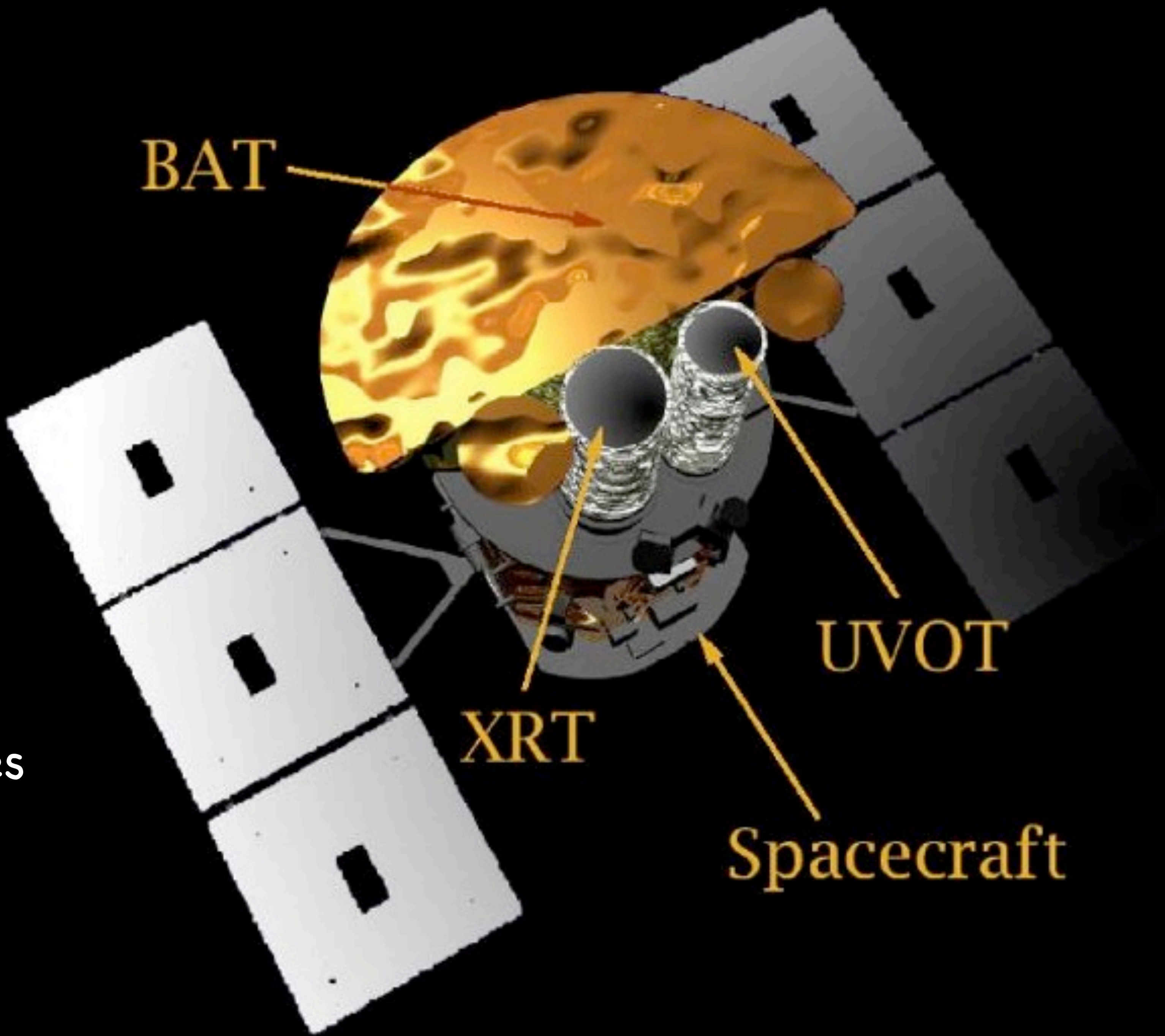


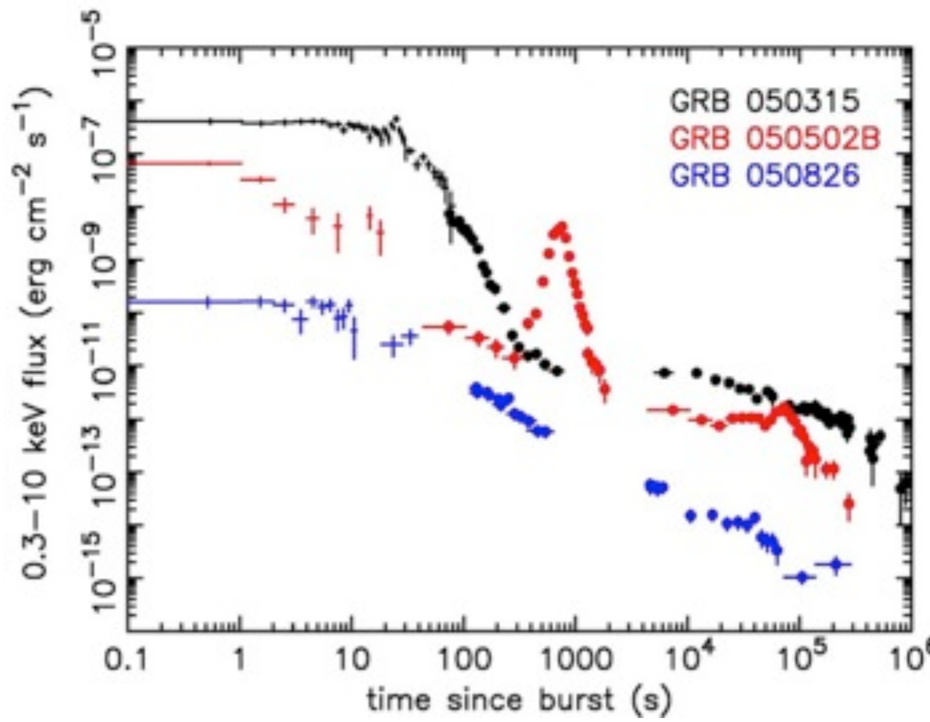
The Swift Revolution

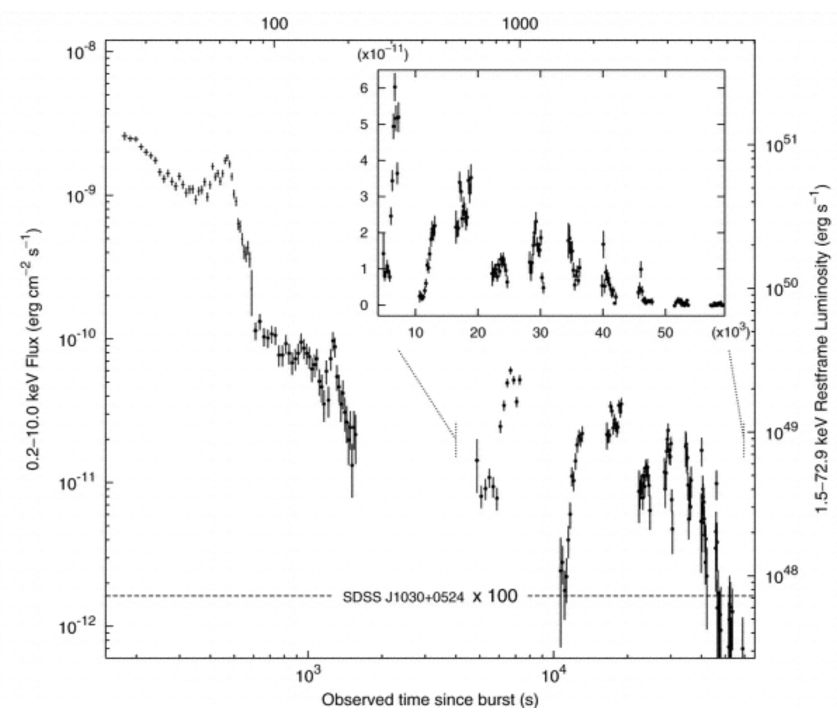
- Detections (1 per week)
- Far more precise positions
  BAT: 1-3 arcmin / 100%
  XRT: 2-6 arcsec / >90%
  UVOT: <1 arcsec / 30%
- Very rapid positions(few sec after the bursts)
- Detailed, early X-ray lightcurves



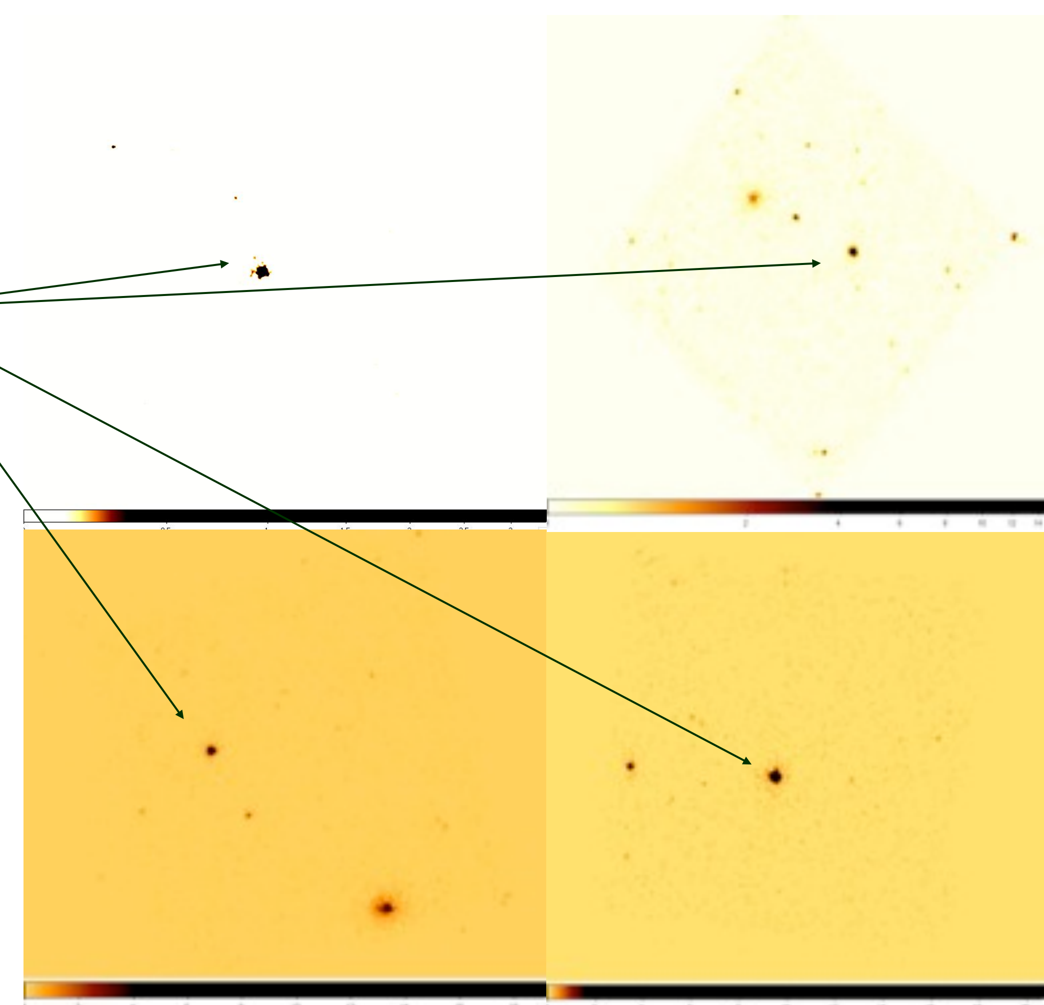
Most X-ray afterglows are the brightest sources in more than a square degree of sky -- very easy to find in the first hours

More luminous than some of the brightest AGN





X-ray Afterglows



X-ray

entre

At first GRBs were found at z~1.

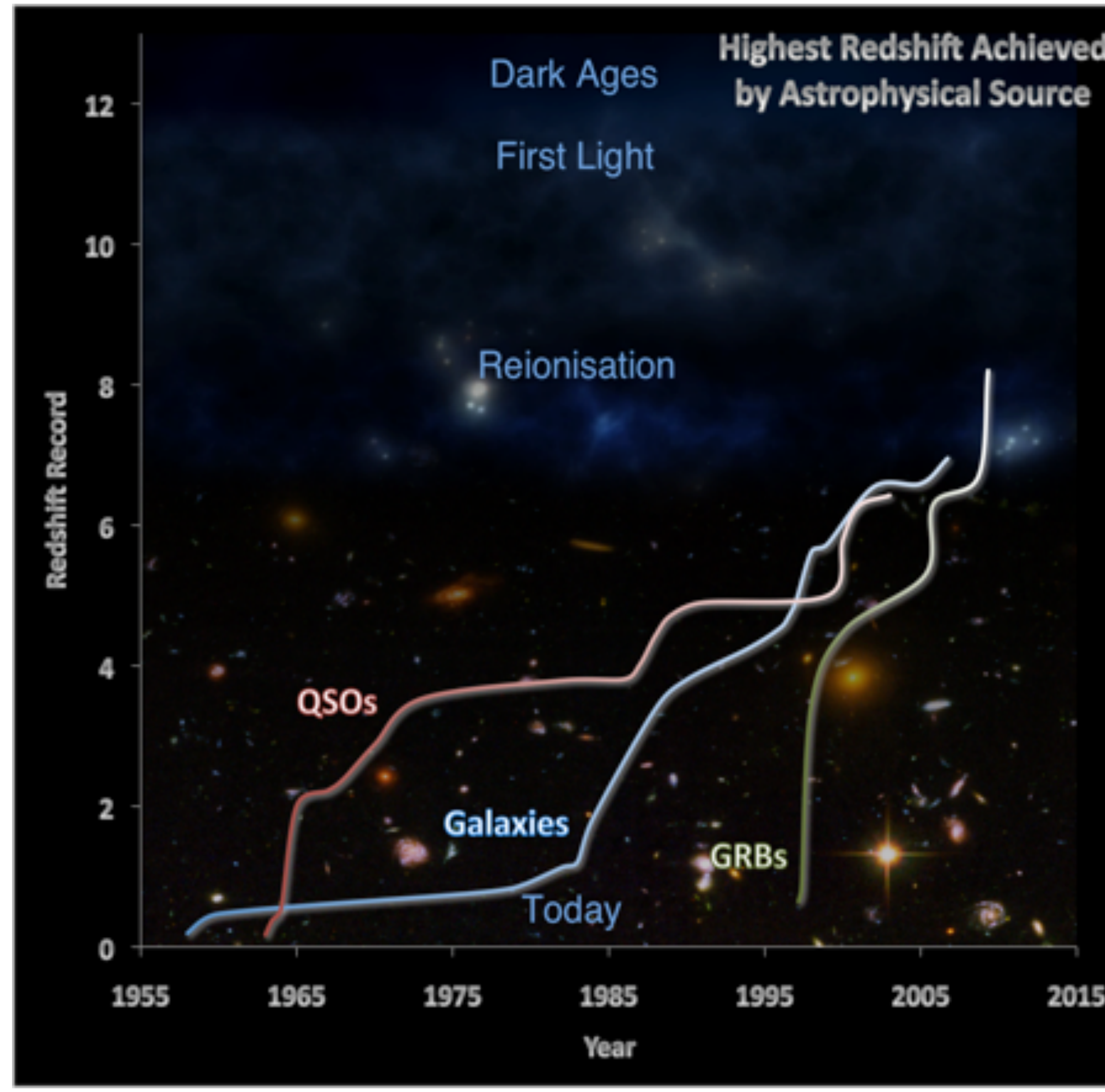
The mean redshift of Swift GRBs is now ~2.2 for a fairly unbiased sample

Most distant source known

GRB Redshift Record Holders

- $z = 6.3$ (GRB 050904, Kawai et al. 2005)
- $z = 6.7$ (GRB 080913, Greiner et al. 2009)
- $z = 8.3$ (GRB 090423, Tanvir et al. 2009)

Most distant galaxy, $z = 7.5$



Redshifts

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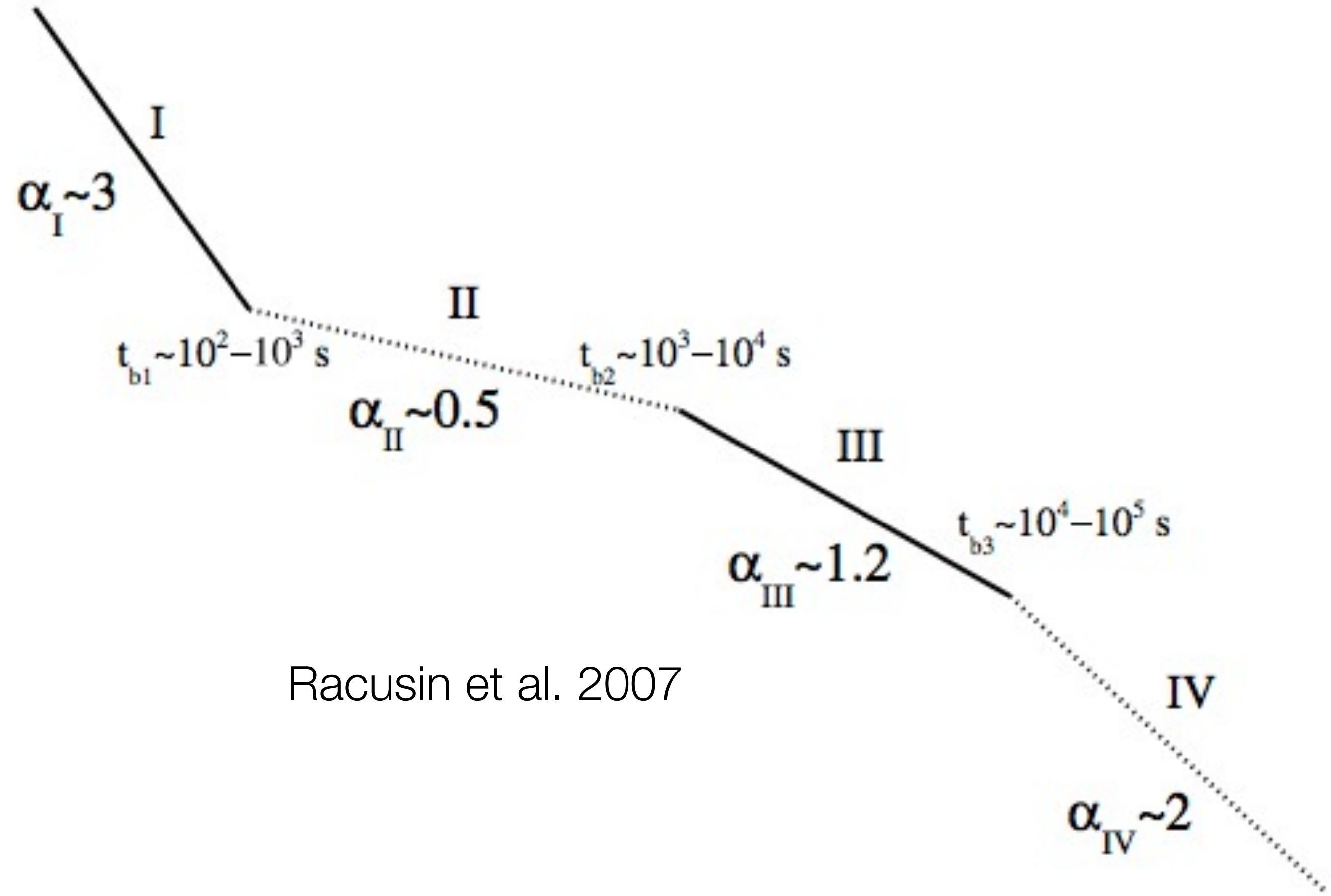
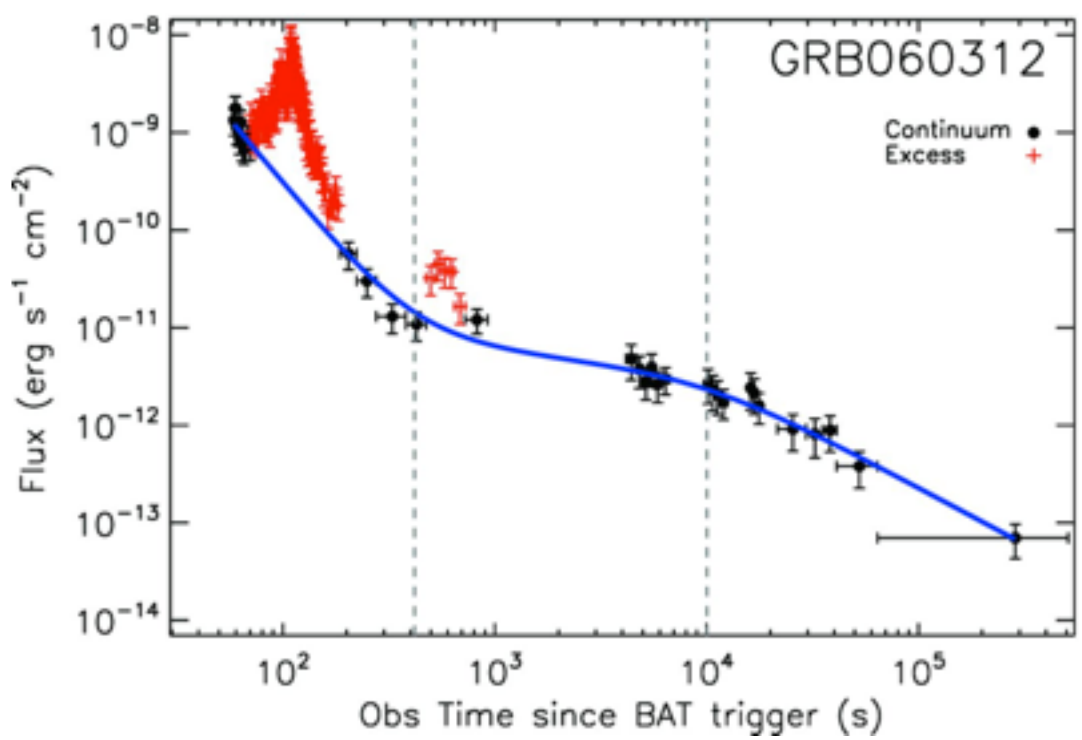
The afterglows: lightcurve properties

- GRB X-ray emission has multiple phases
  Nousek et al. 2006, Zhang et al. 2006, O'Brien et al. 2007, Willingale et al. 2007, Granot et al. 2006,
  - Late Prompt
  - Steep decay (I)
  - Plateau (II)
  - Afterglow (III)
  - Post jet-break (IV)



Racusin et al. 2007



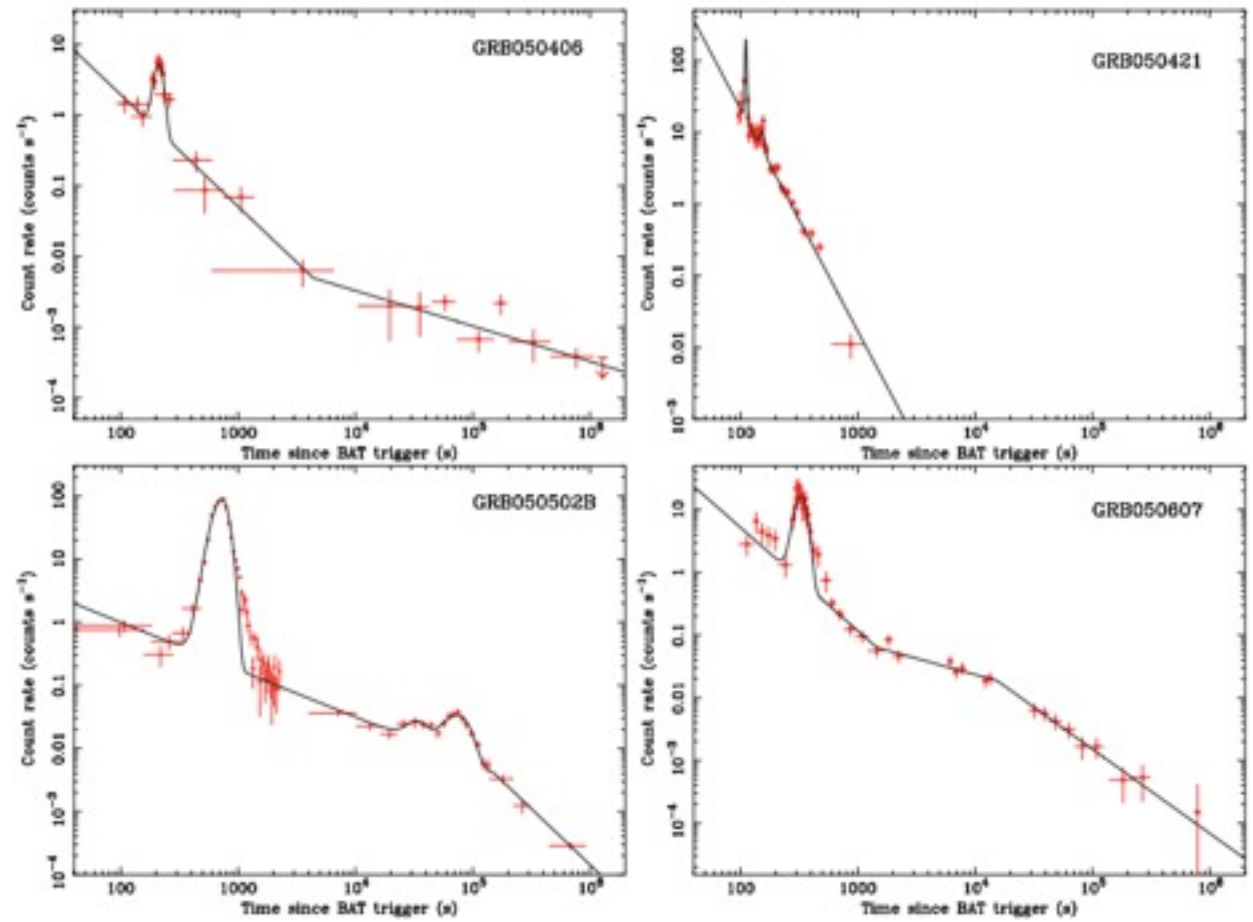
Margutti et al. 2013

X-ray flares

- Strong soft X-ray flares in pre-*Swift* data
  Piro et al. 2005, Watson et al. 2006

- Very common in *Swift*-XRT data
  Burrows et al. 2005, Falcone et al. 2007, Margutti et al. 2007, 2010, 2011, Chincarini et al. 2007, 2009, 2010, Morris 2008, Sweonson et al. 2010, Swenson & Roming 2014, and many more

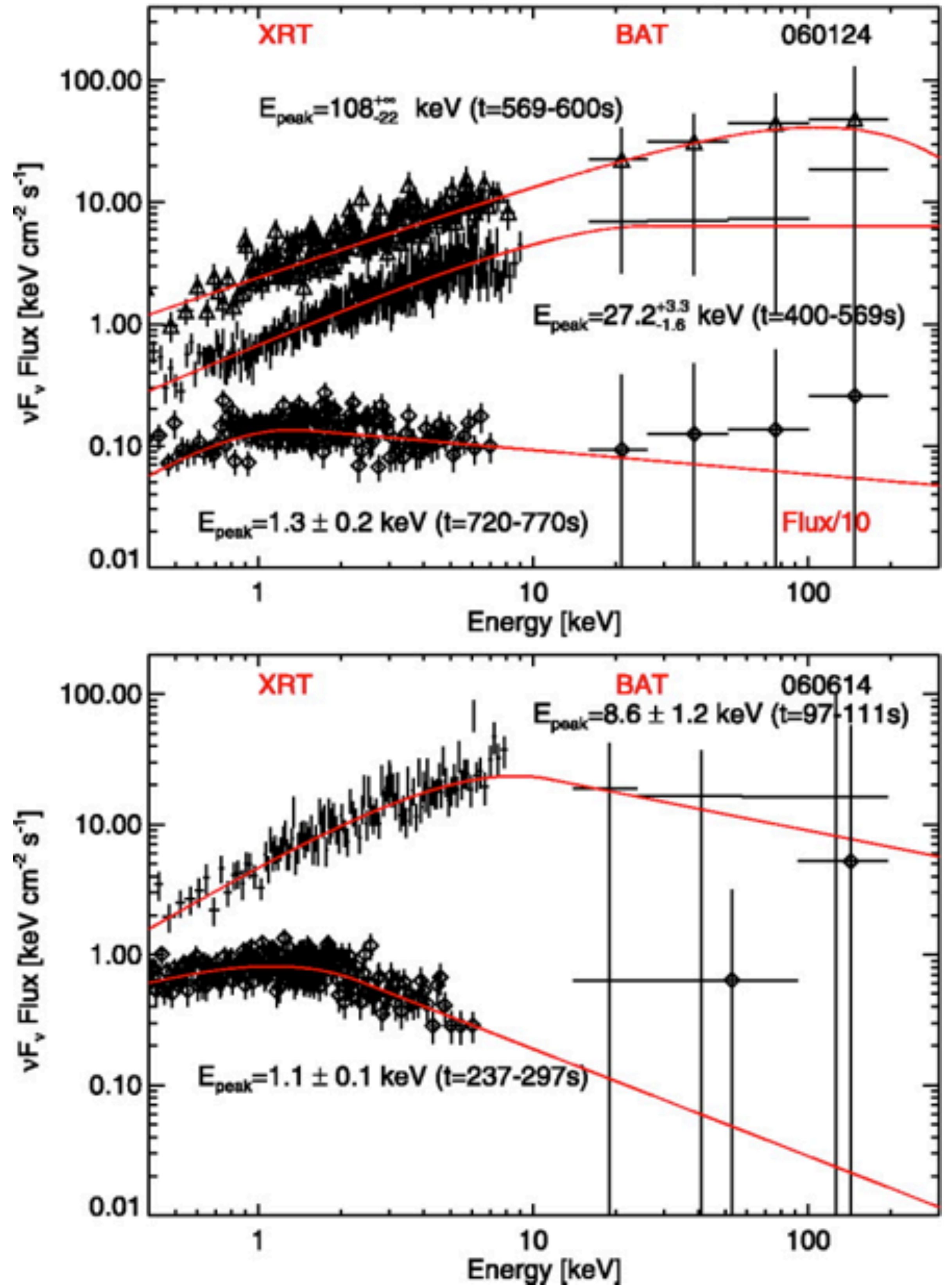
- Believed to be prompt phase-style peaks seen in soft X-rays. Origin in continuing accretion, late internal shocks, or some other
  Zhang et al. 2006, Butler & Kocevski 2007, Bernardini et al. 2012, Grupe et al. 2013, Stratta et al. 2013, Margutti et al. 2013 and many more



Chincarini et al. 2007

The afterglows: spectroscopic properties

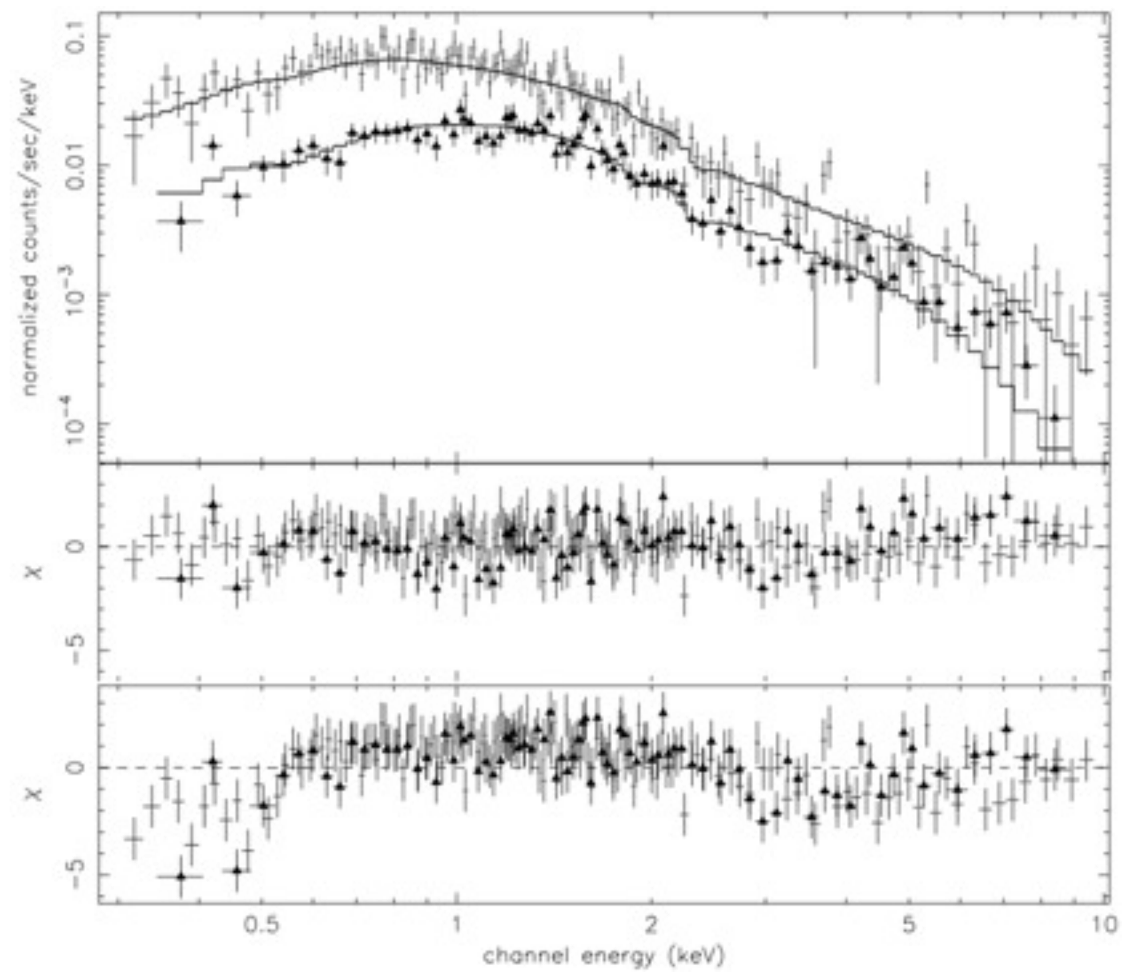
- Simple power-law – evolving
- Ubiquitous absorption
- Sometimes line emission?
- Sometimes quasi-thermal emission



Butler & Kocevski 2007

The nature of the absorption — Overview

- Downturn at low energies deviating from a power-law
- Very similar to photoelectric absorption observed in the galaxy
- Fit well by photoelectric absorption by metals at host redshift
- Values well above Galactic



Watson et al. 2002

Galama and Wijers 2001, in average.; Watson et al. 2002 single afterglow; Stratta+ 2004, de Pasquale+ 2006, Gendre+ 2006, Evans+ 2009, Campana+ 2006, 2010, 2012 samples

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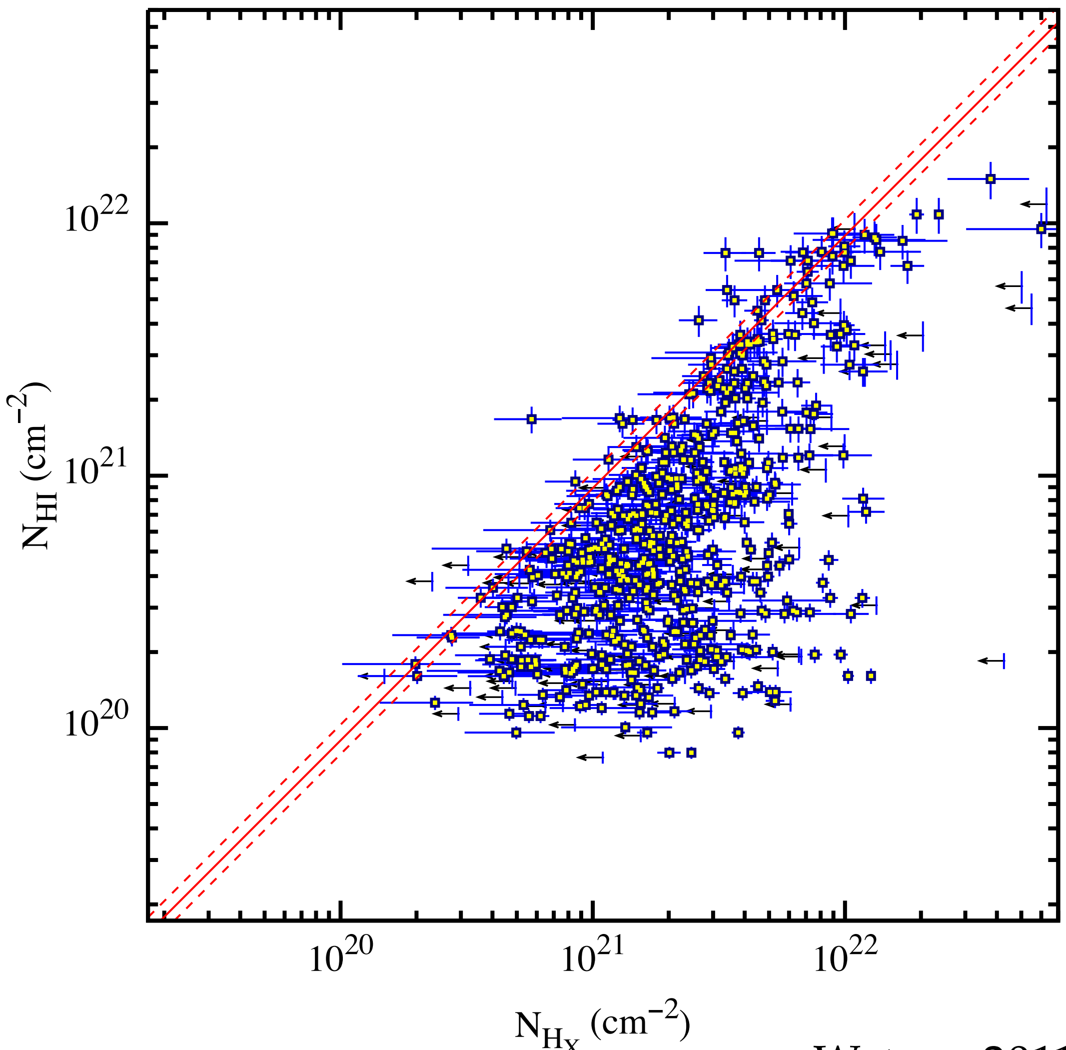

Watson 2011

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What causes the X-ray absorption?

- Photoelectric absorption
- Inner shells of metals dominate
- He, C, O, Fe, Si, S etc.
- Relatively insensitive to ionisation state or phase (i.e. in normal situations, X-rays see almost all metals)
- Use column density in hydrogen as a useful proxy, but actually, insensitive to hydrogen

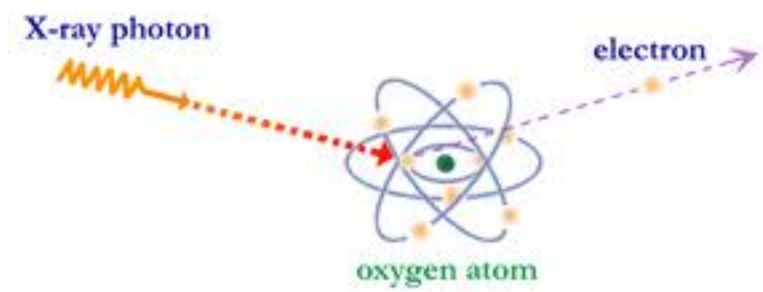
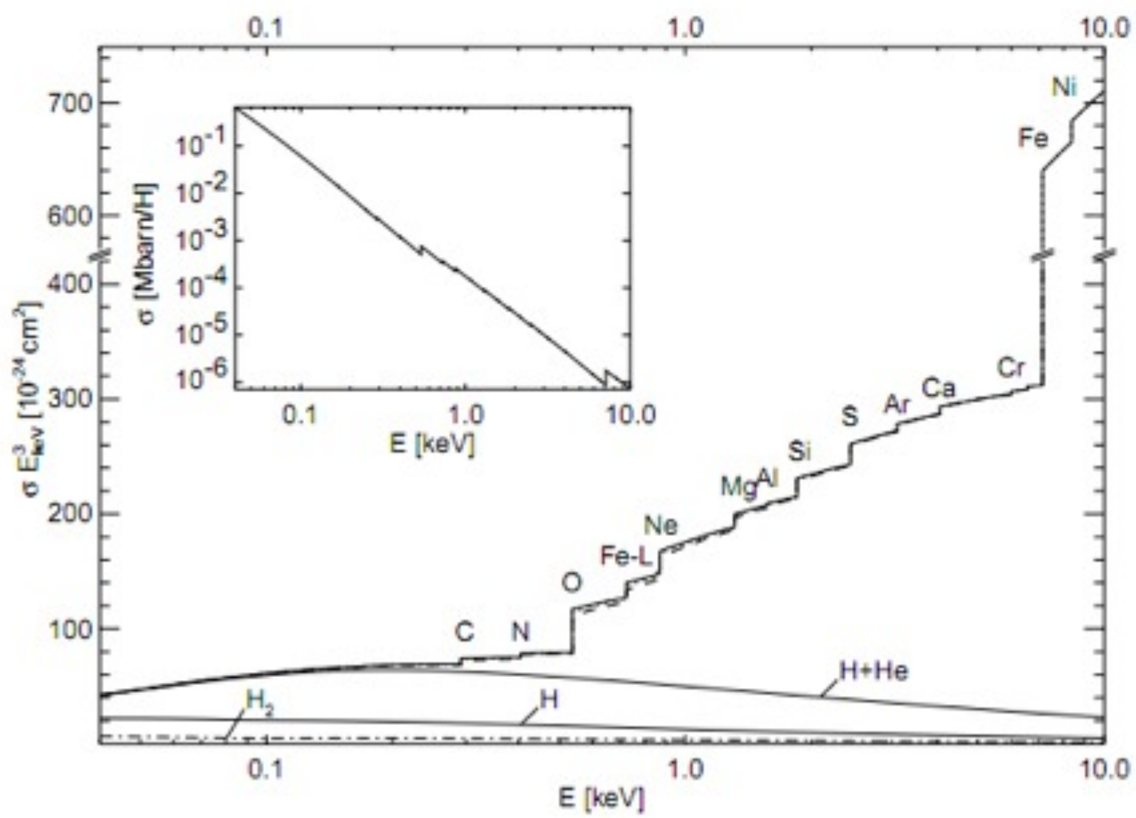


PHOTO-ELECTRIC ABSORPTION



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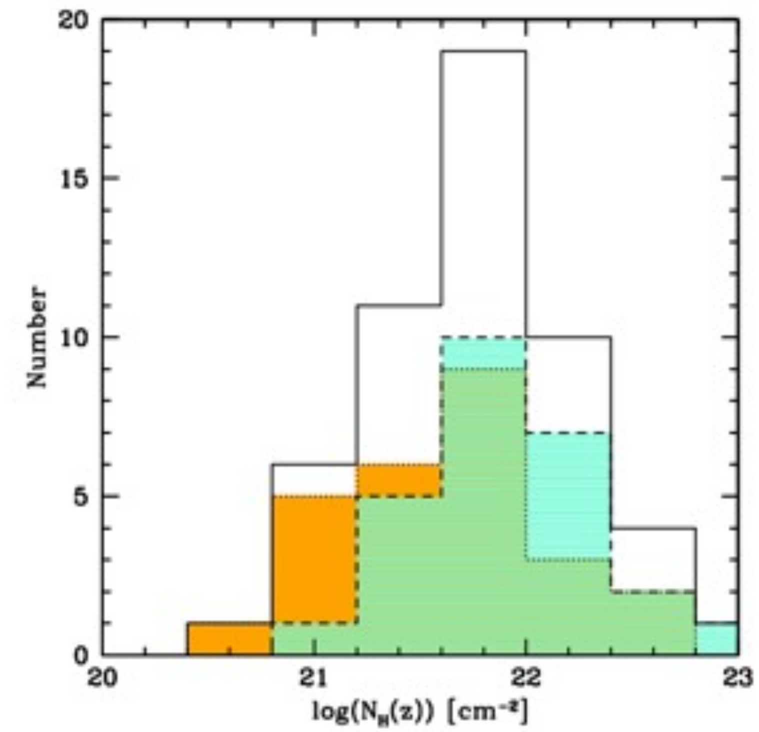
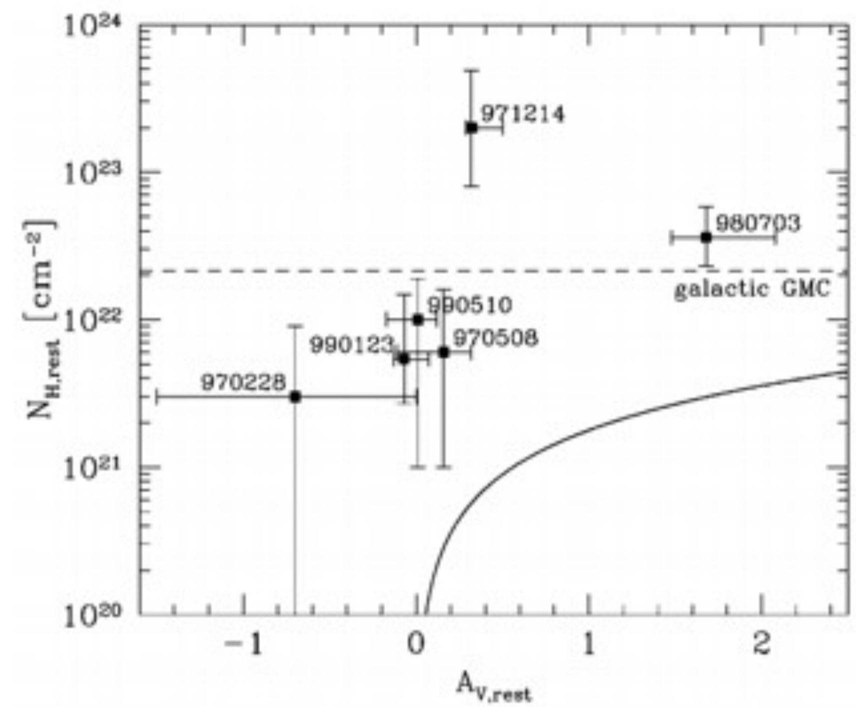
X-ray absorption — Problems

- Large X-ray absorption in many GRBs
- Not a variation of the Galactic column density
- Not a calibration effect
- Not generally due to intrinsic curvature of the spectrum
- At high-z column of metals must be very large
- Where is the corresponding dust?



Campana et al. 2012



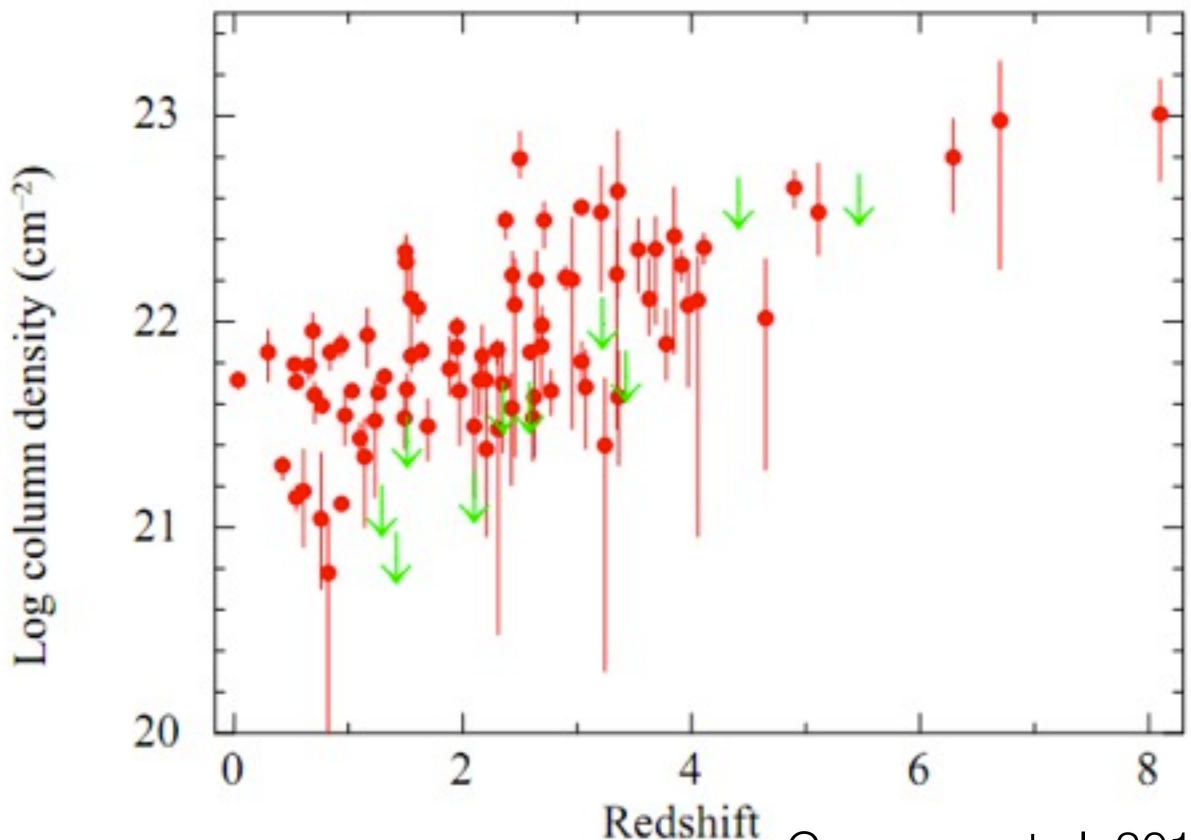
Galama & Wijers 2001

Other oddities:
The redshift distribution

- Oddity—X-ray absorption rises with redshift. Why?

- Expect detectability threshold to rise with redshift [$N_{H_X}(z) \approx (1+z)^{2.5} N_{H_X}(0)$]

- But missing low redshift, high absorption GRBs



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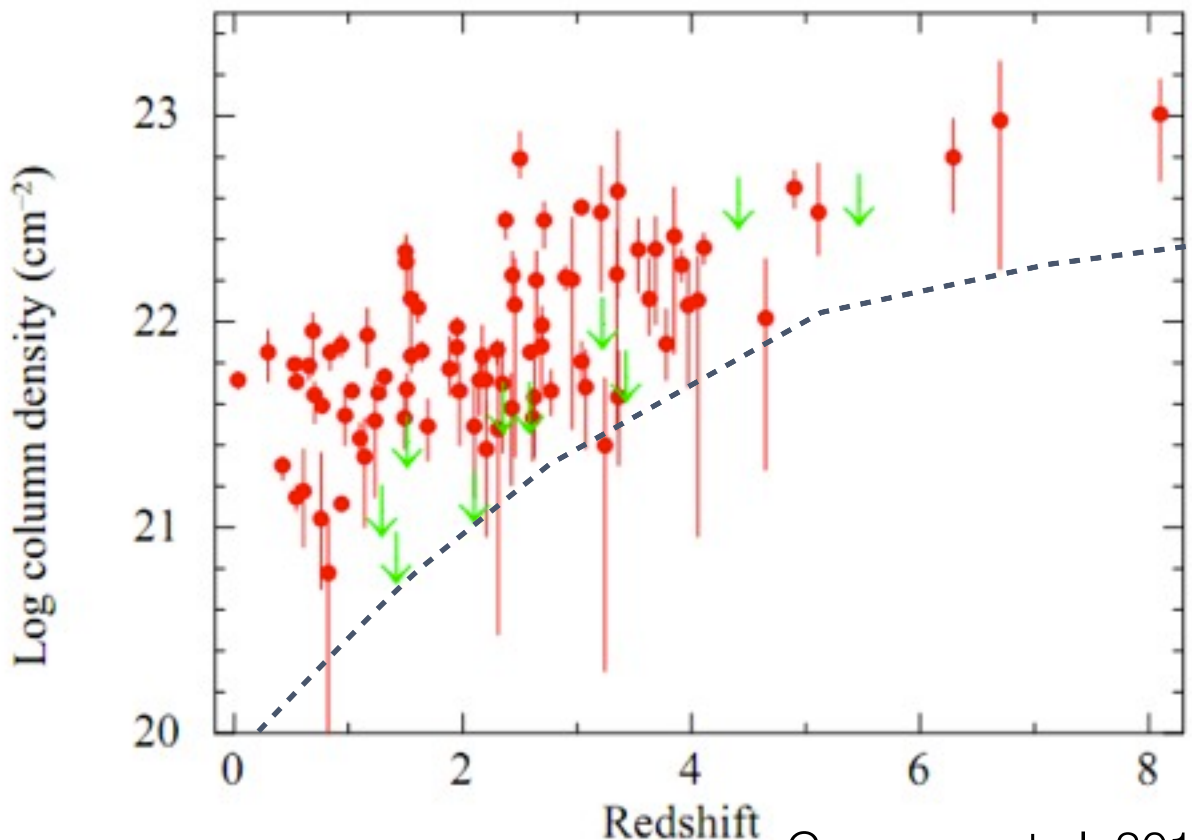

Campana et al. 2010

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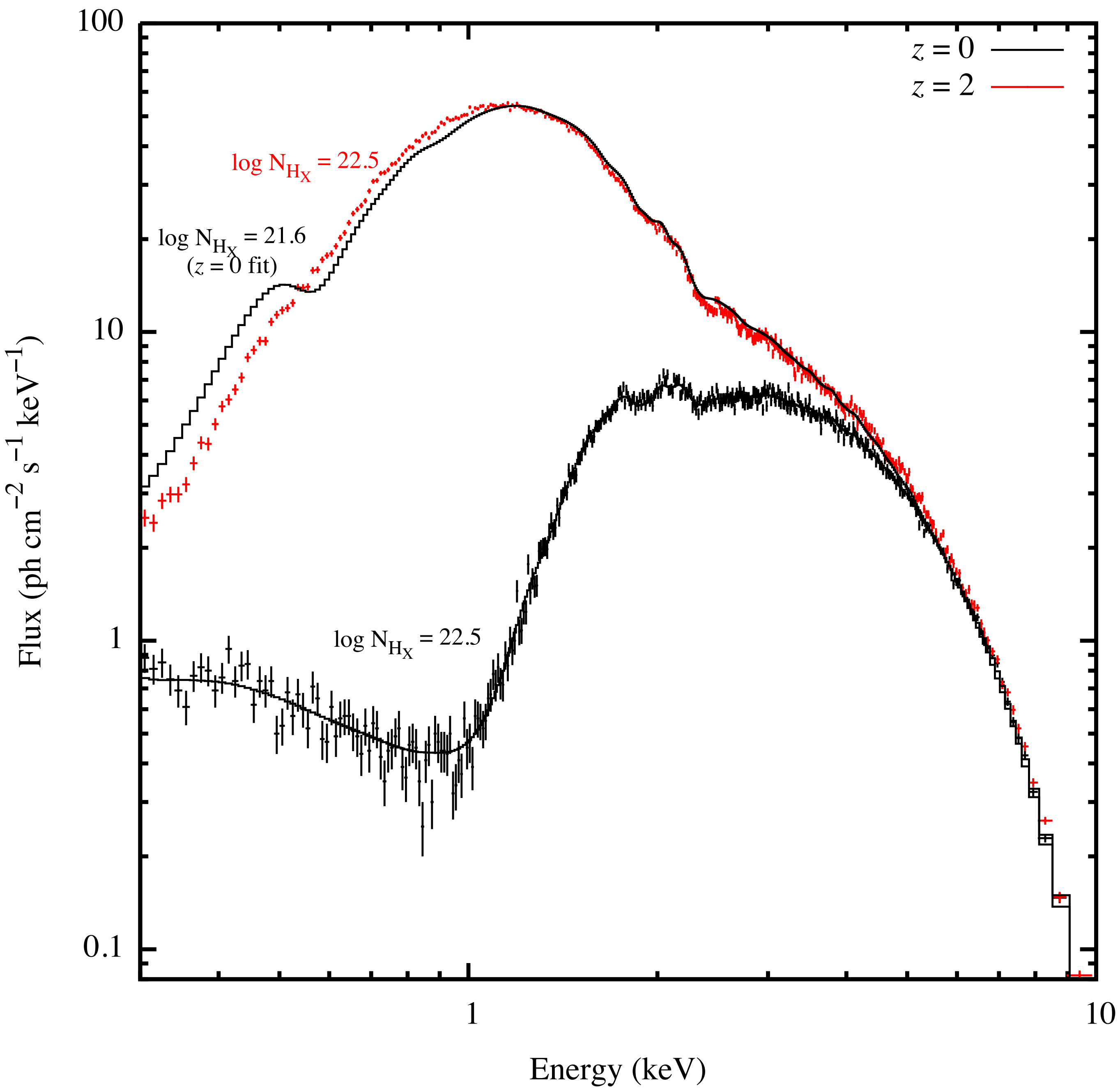
Redshift dependence

- Little redshift information in low-res X-ray spectra
- Get redshifts from optical
- But! Inferred absorption strongly redshift dependent:
- $N_{H_X}(z) \approx (1+z)^{2.5} N_{H_X}(0)$



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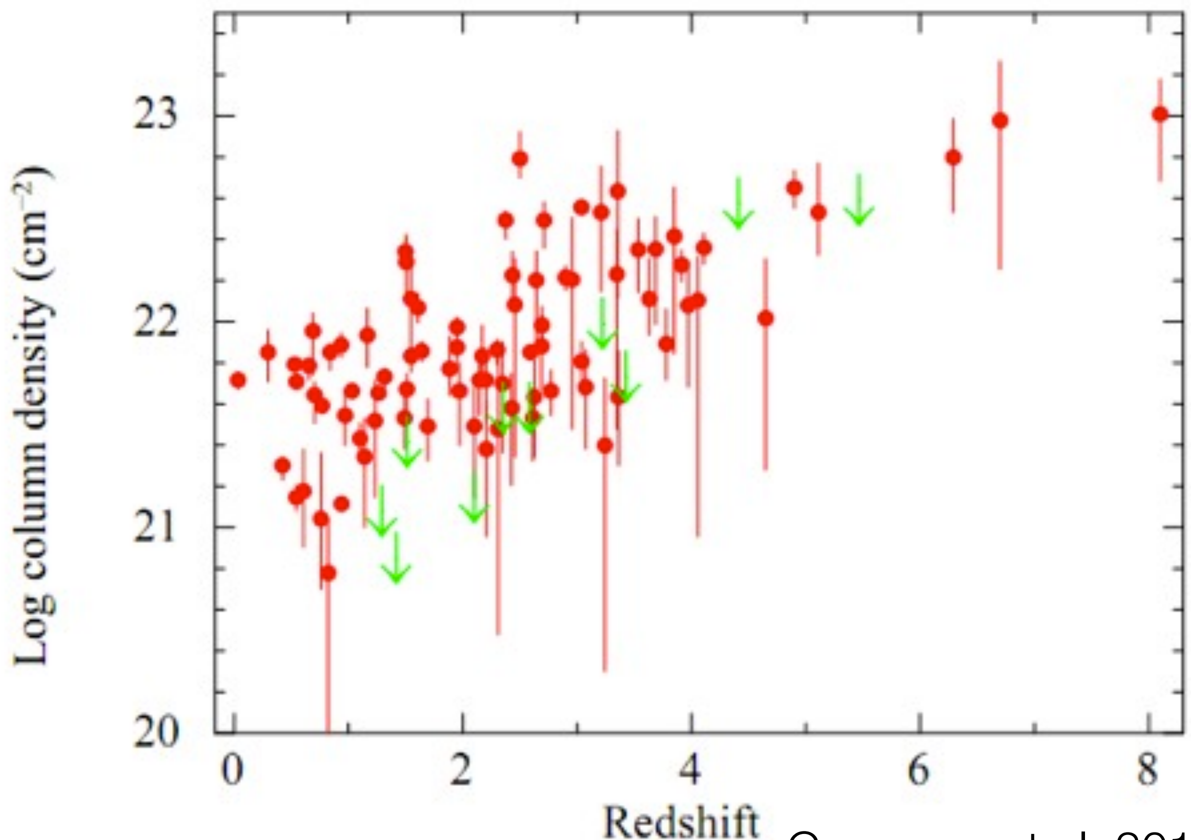

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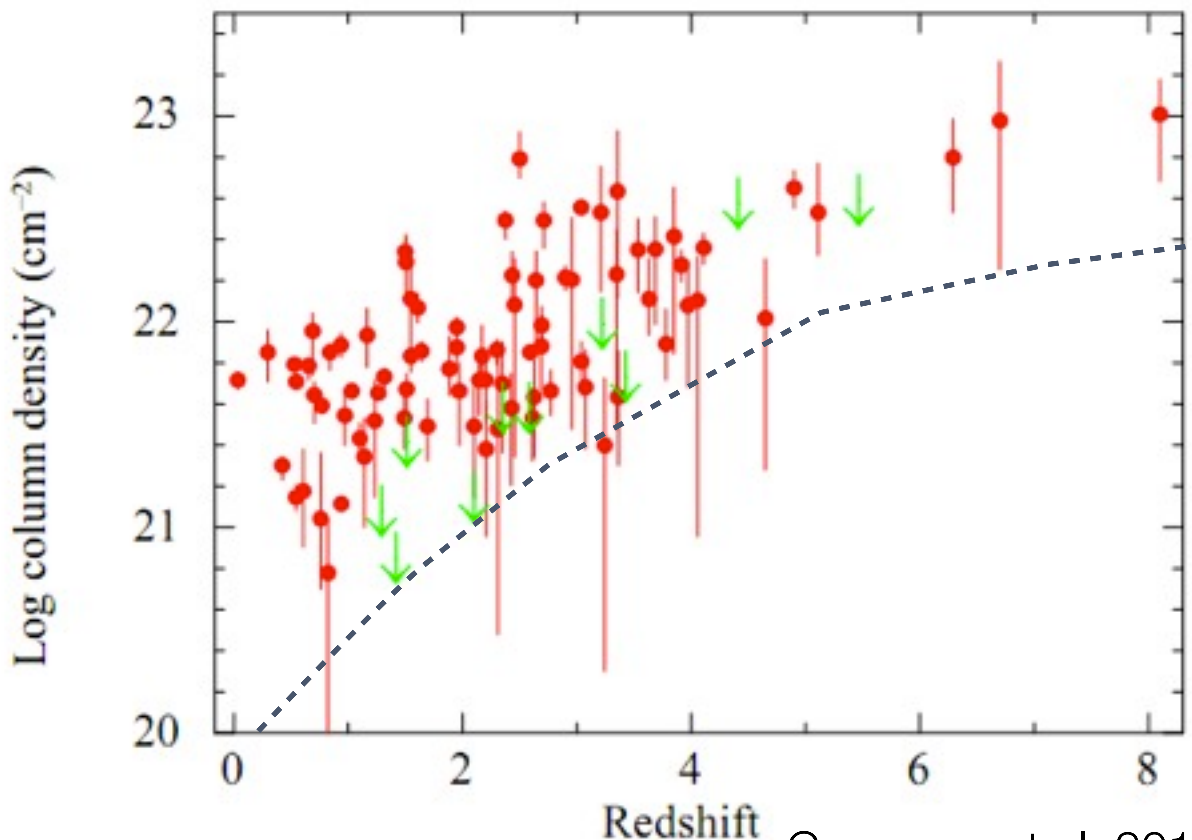

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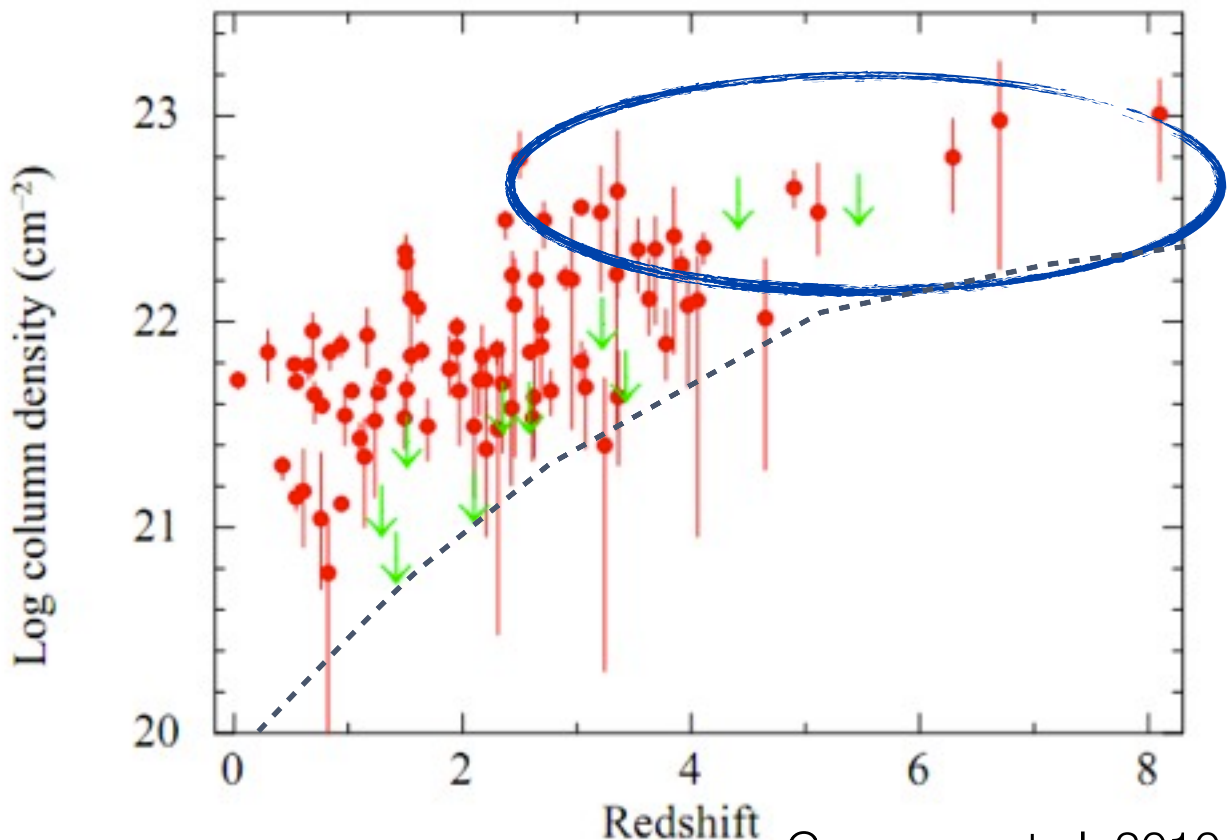

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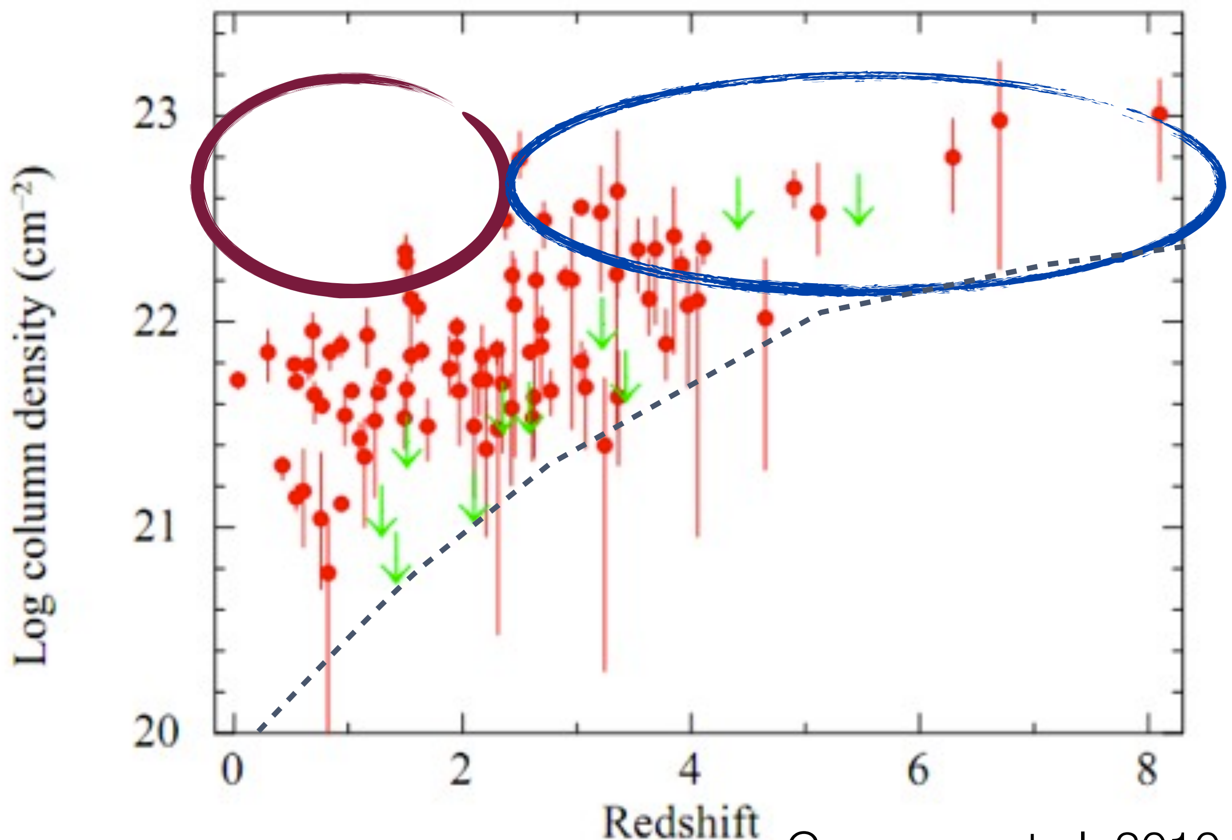

Campana et al. 2010

Solution: Dust bias

- X-rays unbiased by dust
- But redshifts from optical
- Bias obtaining redshifts

Watson & Jakobson 2012

See also Campana et al. 2012

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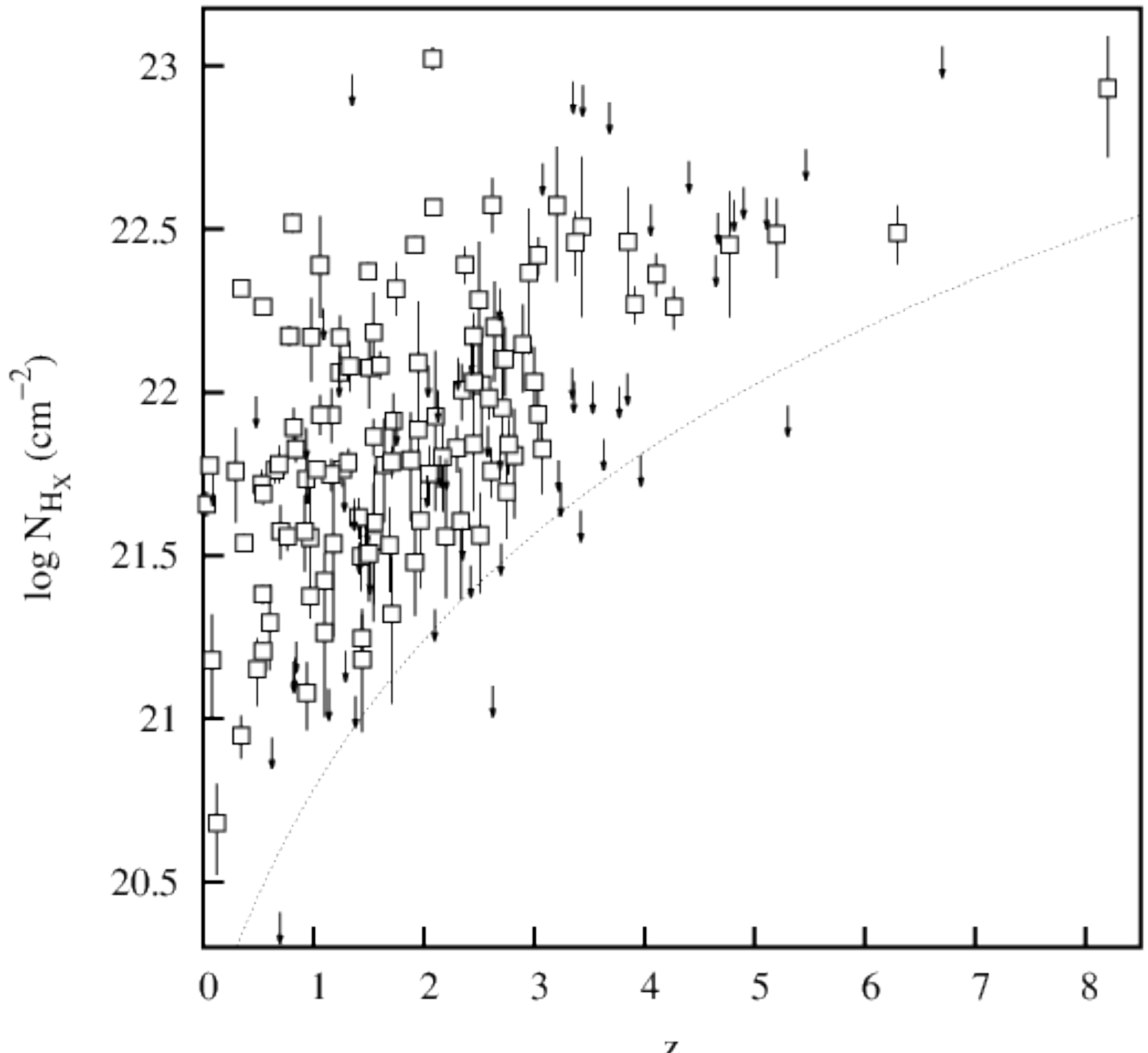

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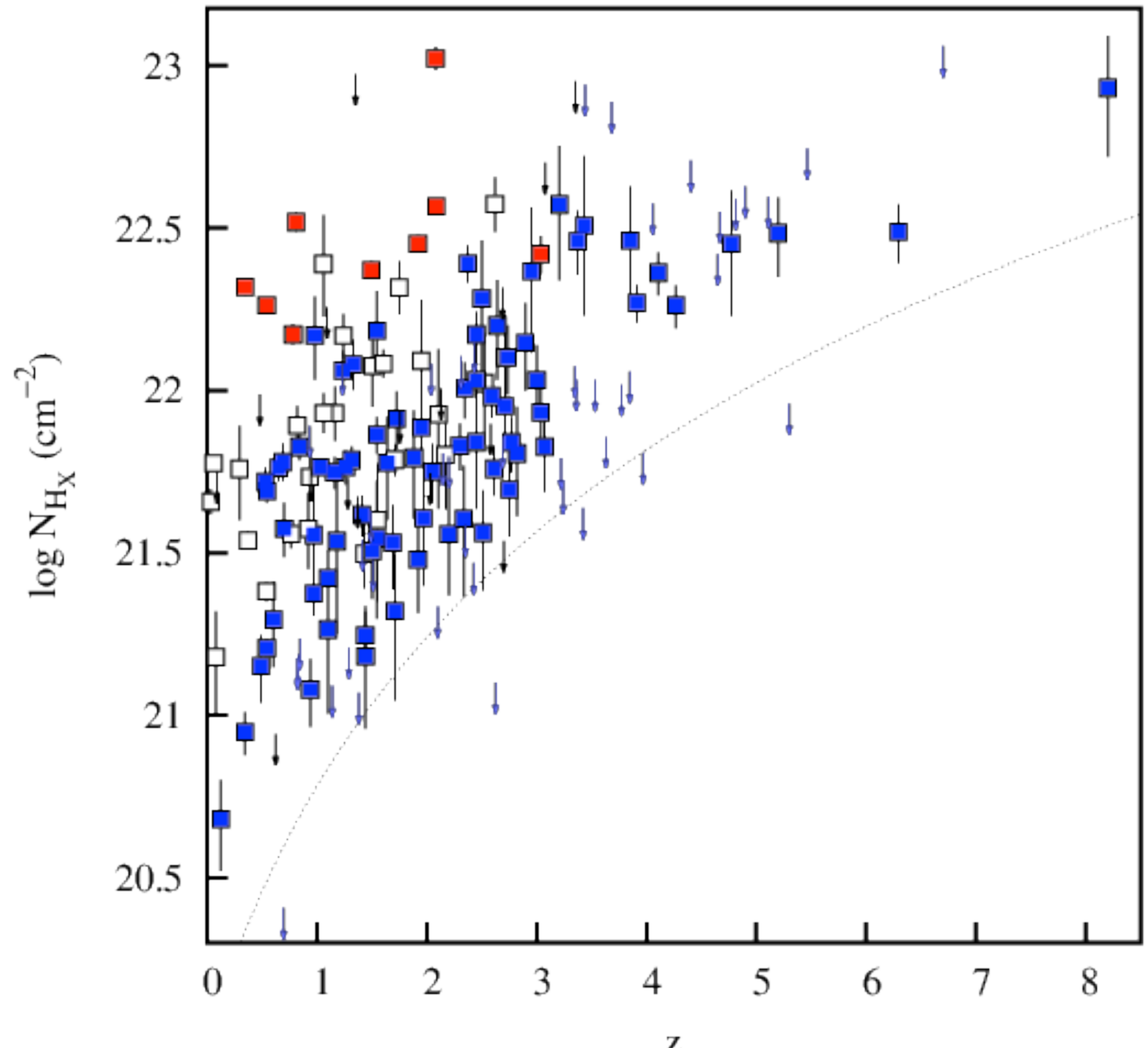

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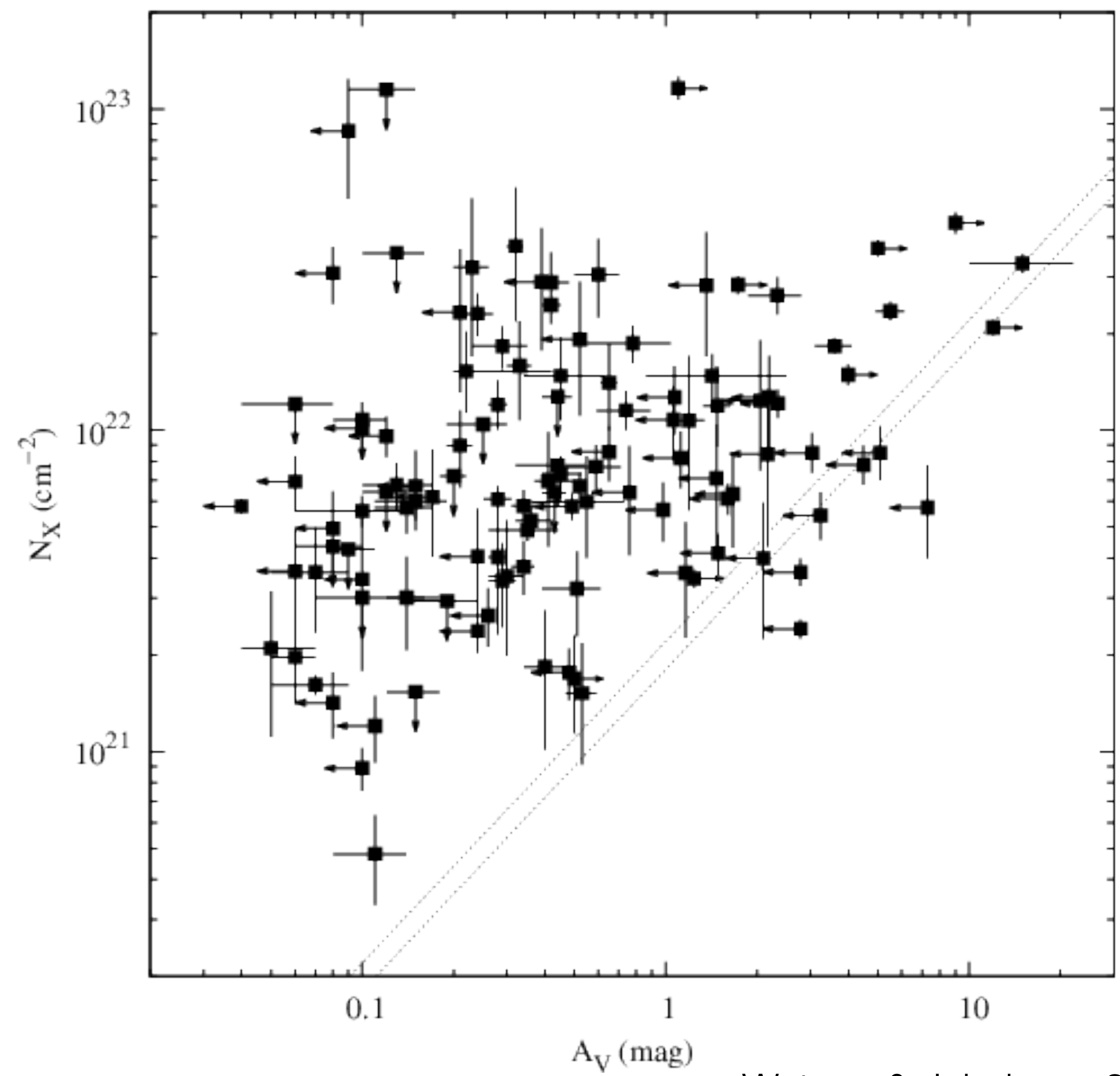
No N_{HX}-A_V correlation

- Evolving N_{HX}/A_V



Watson & Jakobson 2012

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N_{HX}-A_V correlation ?

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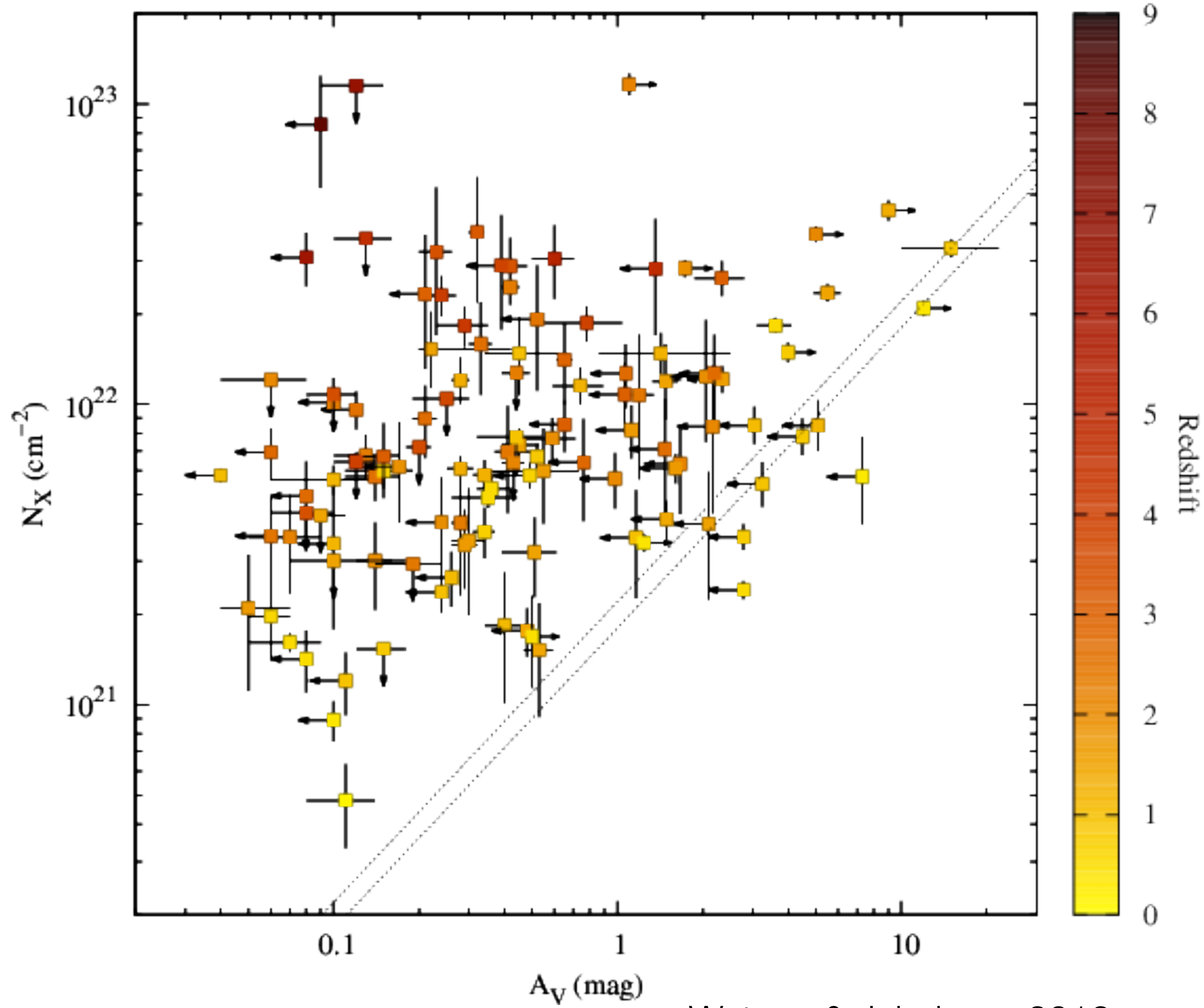

Watson & Jakobson 2012

Where does the absorption come from?

- Molecular cloud (Galama & Wijers 2001)

  No: Should see neutral hydrogen

- Intrinsic curvature (Butler et al. 2007)

  No: objects with strong slope change, constant absorption

- Underestimated Galactic (Starling et al. 2013)

  No: consistent with other surveys (dust, galactic sources)

- Intervening neutral absorbers (Campana et al. 2012, Wang et al. 2013)

  Not large enough. Metallicity decreases with redshift

- Warm/hot IGM (Behar et al. 2011)
- He in the HII region of GRB (Watson et al. 2013)

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  No absorption seen in high-z AGN
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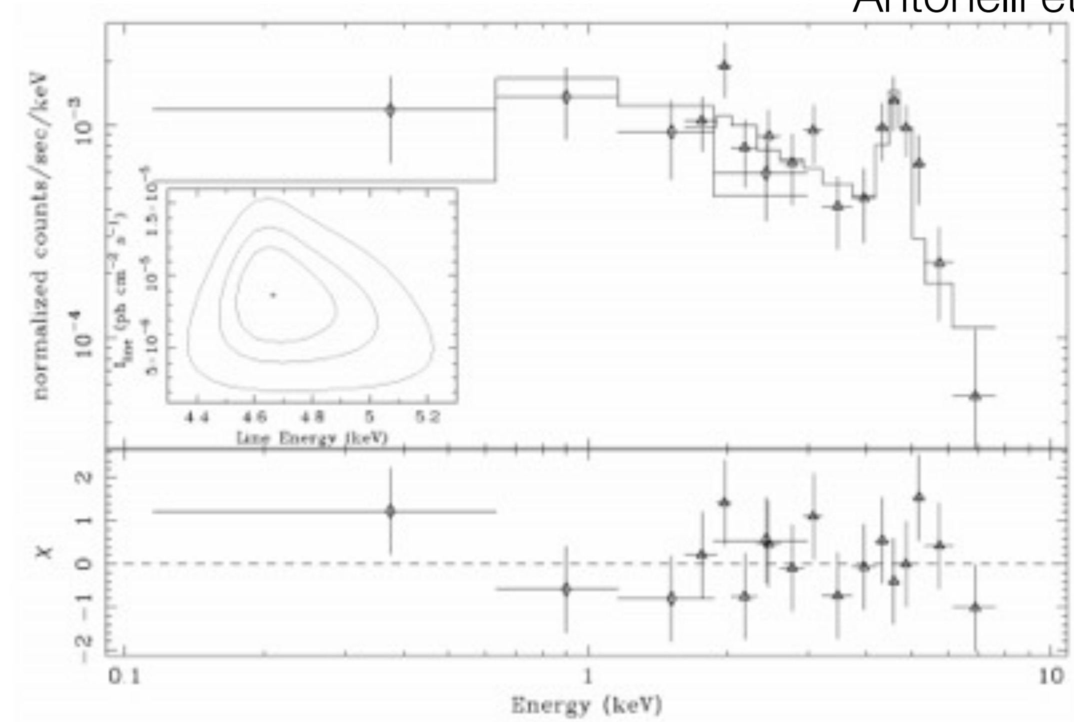
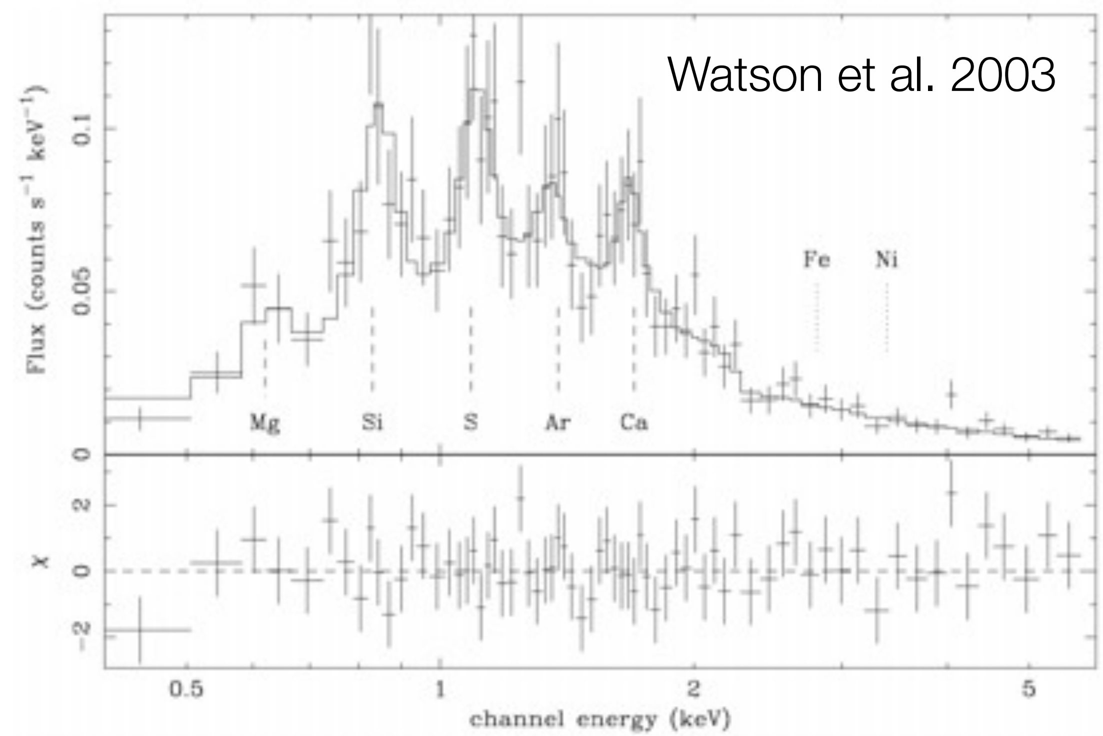
X-ray line emission

- Fe emission lines
  (Piro et al. 1999, Yoshida et al. 2001, Piro et al. 2000, Antonelli et al. 2000, Mereghetti et al. 2003)
- Ni?
  (Watson et al. 2002, Margutti et al. 2008)
- Lighter elements: Mg, Si, S, Ar, Ca
  (Reeves et al. 2003, Butler et al. 2003, Watson et al. 2003)
- No lines
  (Rutledge & Sako 2003, Sako et al, 2005, Hurkett et al. 2008, Giuliani & Mereghetti 2014)
- Explanation not clear. *Swift*-XRT shows no Fe lines with better sensitivity than BeppoSAX. Light element emission significance unclear

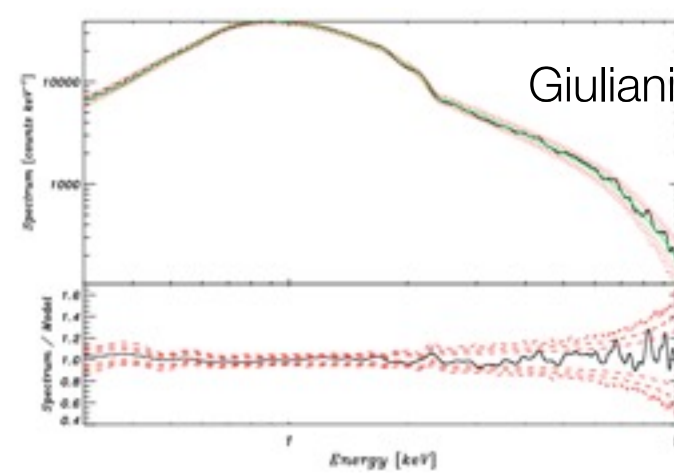
Antonelli et al. 2000



Watson et al. 2003

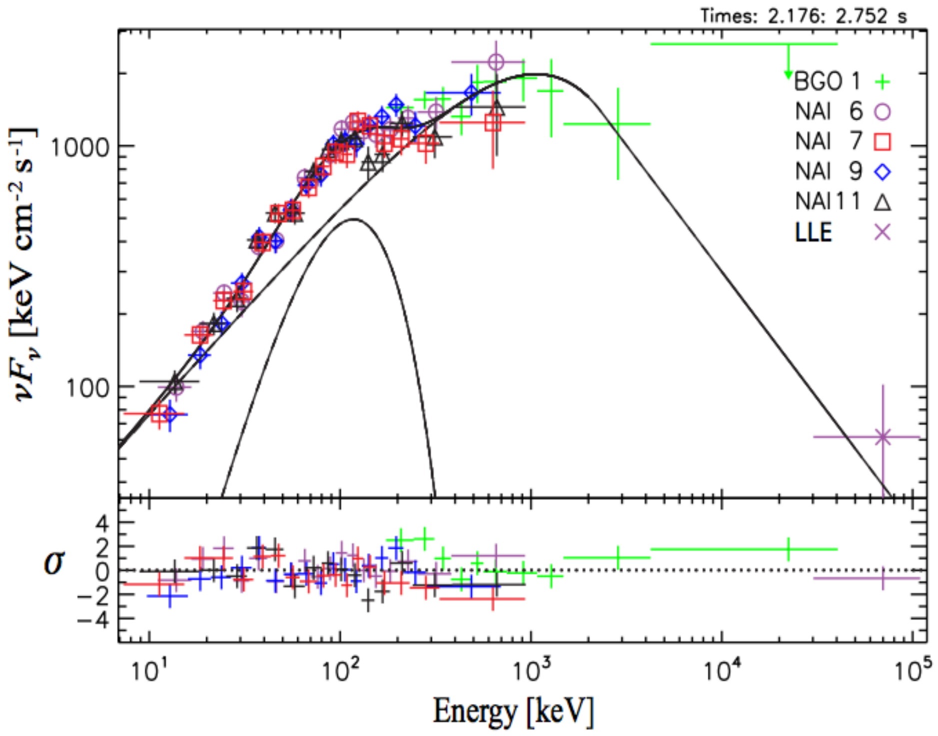


Giuliani & Mereghetti 2014

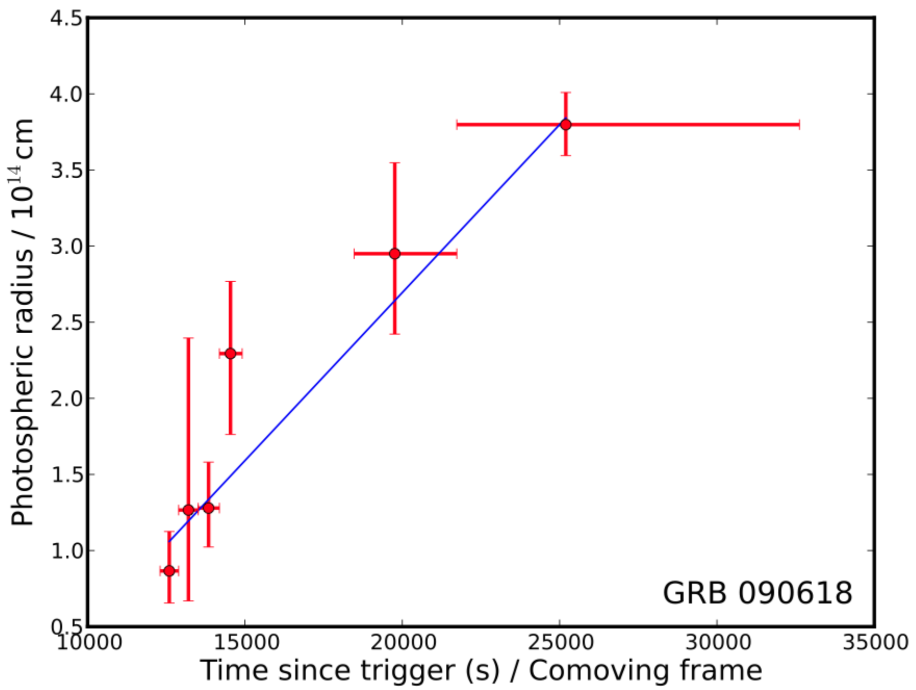


Quasi-thermal Emission

- Blackbody-like spectra found in a few X-ray afterglows (Campana et al. 2006)
- SN shock breakout? (Sparre & Starling 2012, Campana et al. 2006)
- Mostly too luminous, expansion velocities very high (Ghisellini et al. 2007, Page et al. 2011, Starling et al. 2012, Friis & Watson 2013)
- Blackbody(-like) spectra found in the gamma-ray prompt phase (e.g. Ryde 2005, Ryde & Pe'er 2009, Larsson et al. 2011)
- Photospheric emission from jet-head (Pe'er et al. 2007, Pe'er & Ryde 2011, Lazzati et al. 2013)
- Soft X-ray blackbodies better explained by photospheric emission—cooling of prompt-phase blackbodies (Friis & Watson 2013) — hot cocoon surrounding the jet head (Starling et al. 2012, Suzuki & Shigeyama 2013, Piro et al. 2014)



Iyyani et al. 2013



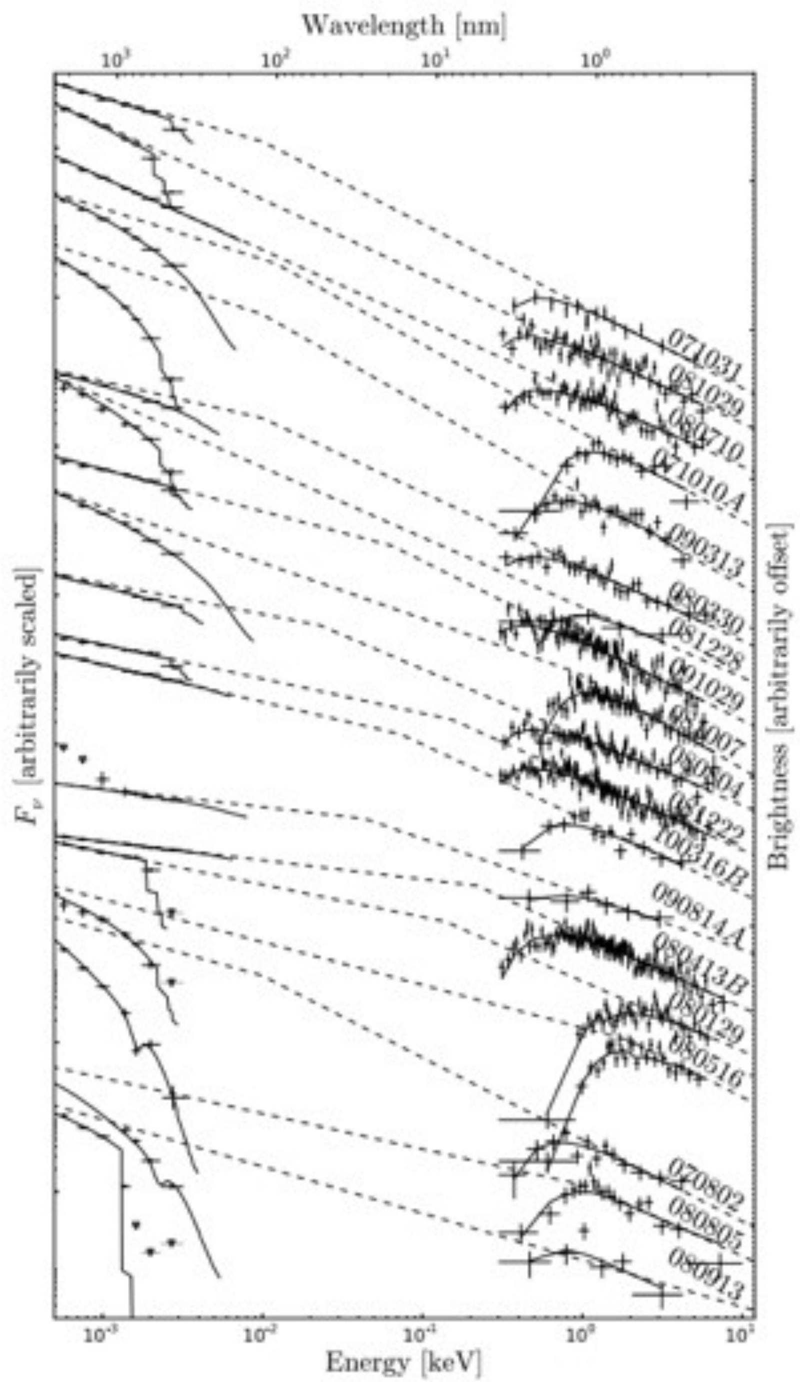
Friis & Watson 2013

Evolution of the photospheric radius for GRB 090618.

Blue line shows fit that gives an expansion velocity at the speed of light.

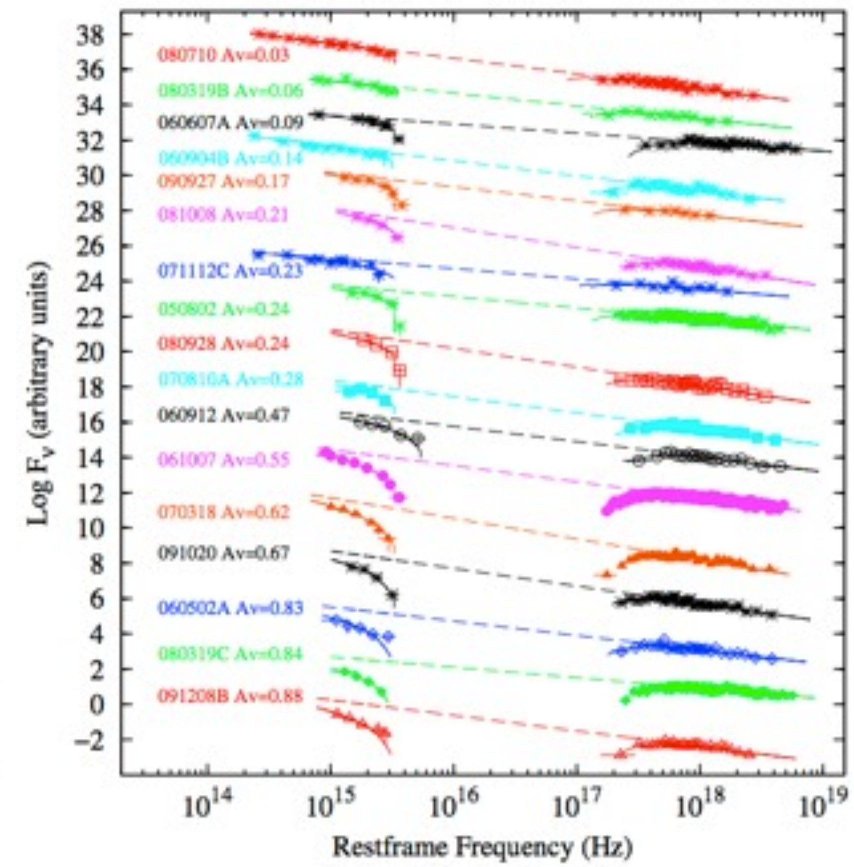
The spectral energy distributions

- Power-law or broken power-law fits work very well. No other features
- GRB afterglow spectra excellent for seeing features imprinted
- Especially excellent for broad features like dust extinction

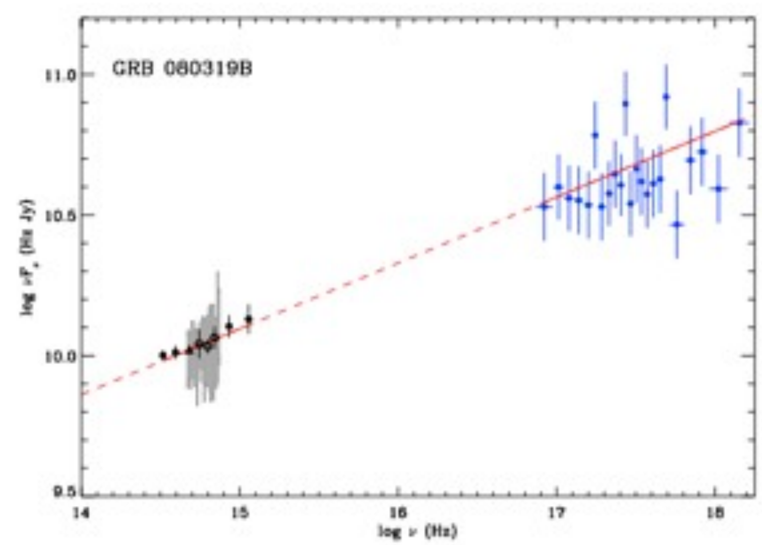


Greiner et al. 2011

Schady et al. 2012

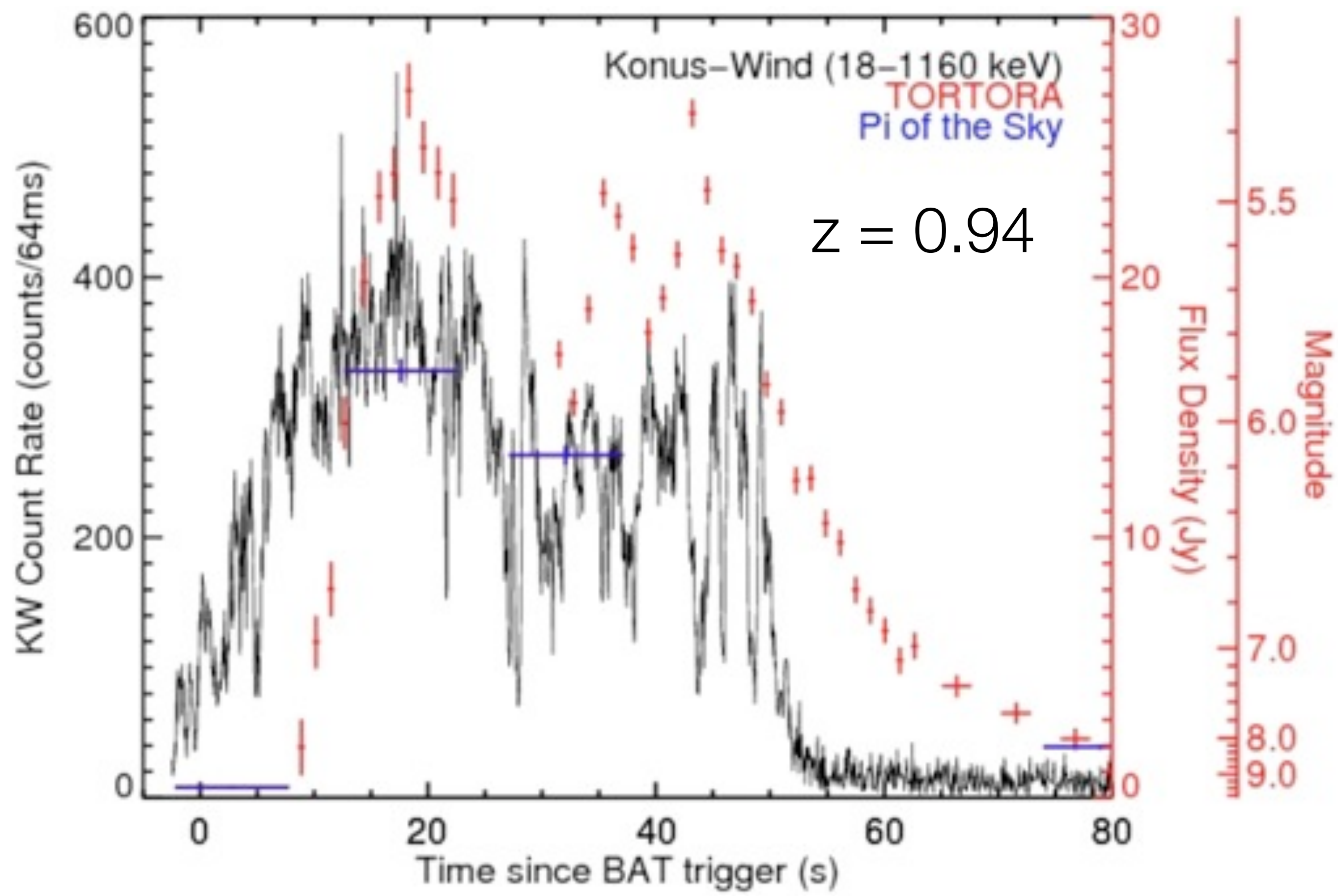


Zafar et al. 2011



Why are GRBs useful for dust?

- Advantages:
  - Luminous
  - Huge range of redshifts (<z>=2.1)
  - Very simple spectra
  - Occur in the hearts of star-forming galaxies



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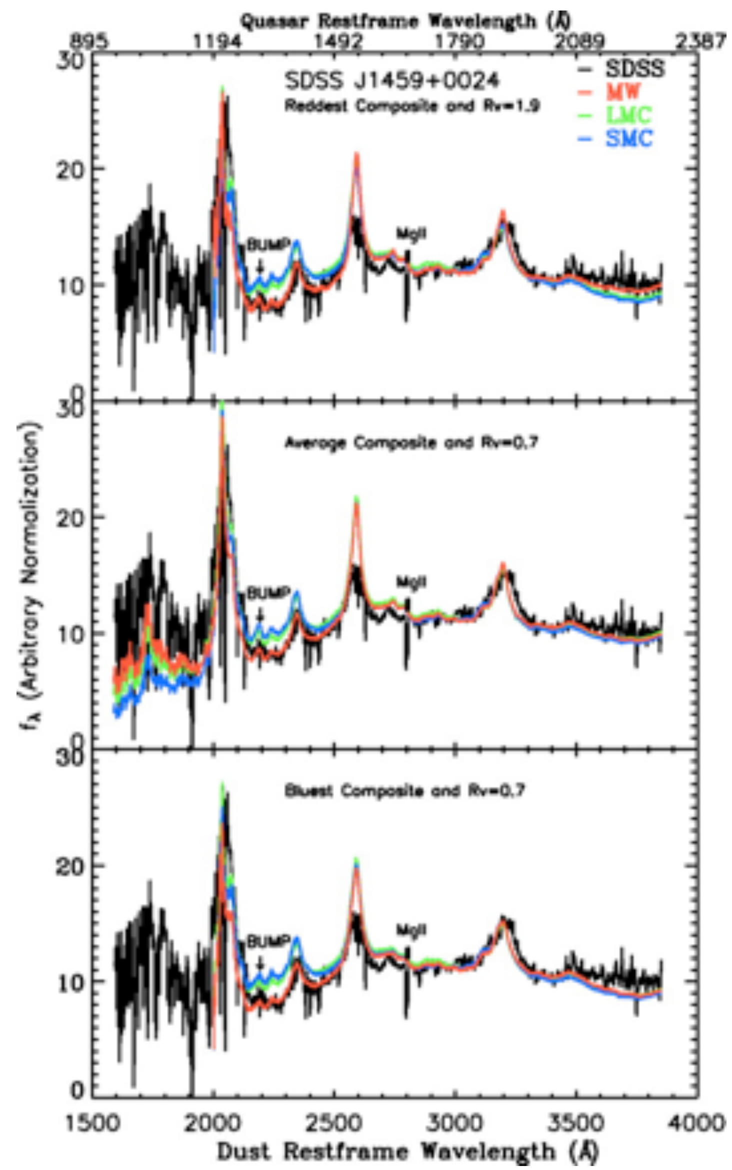

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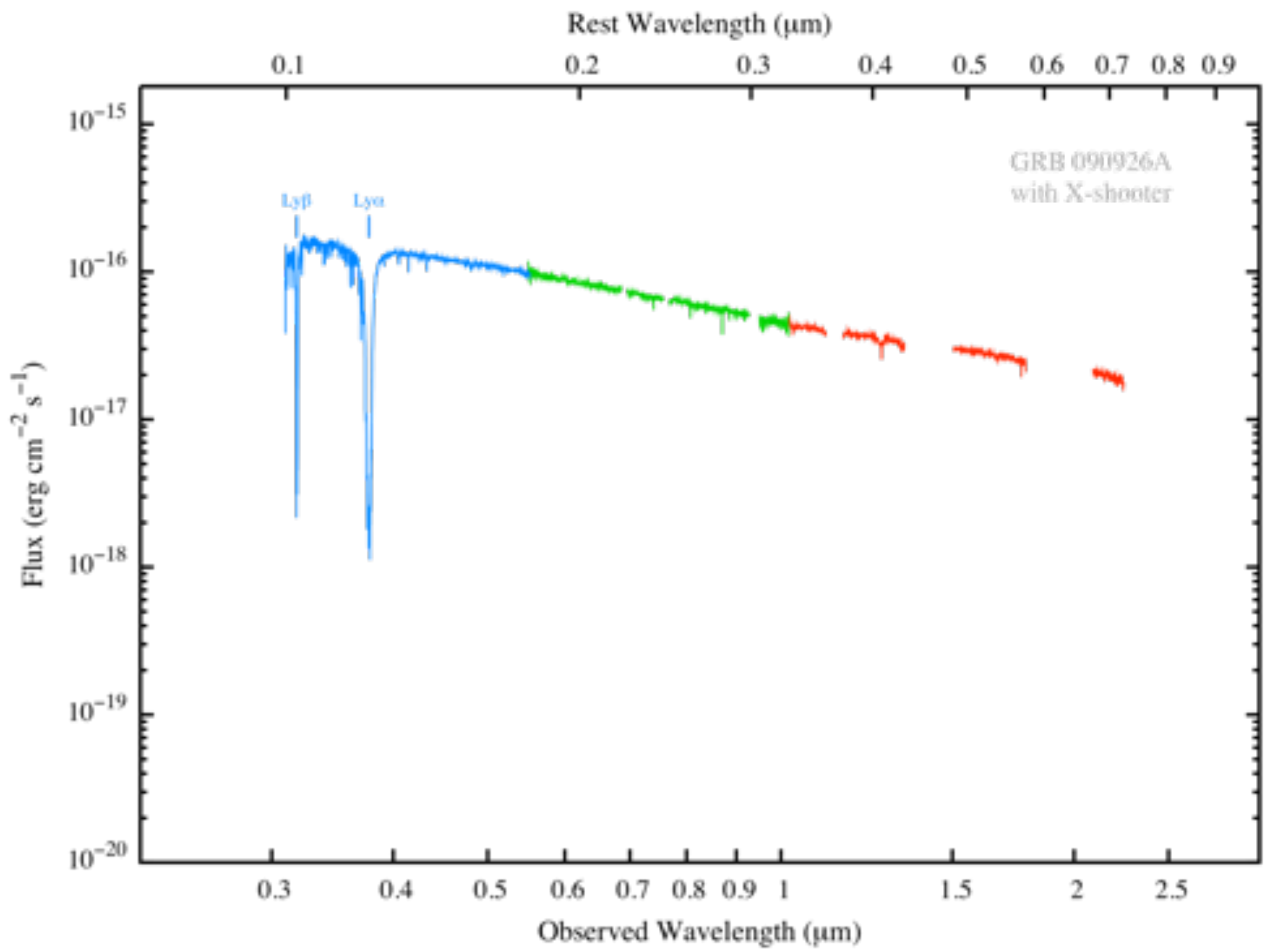
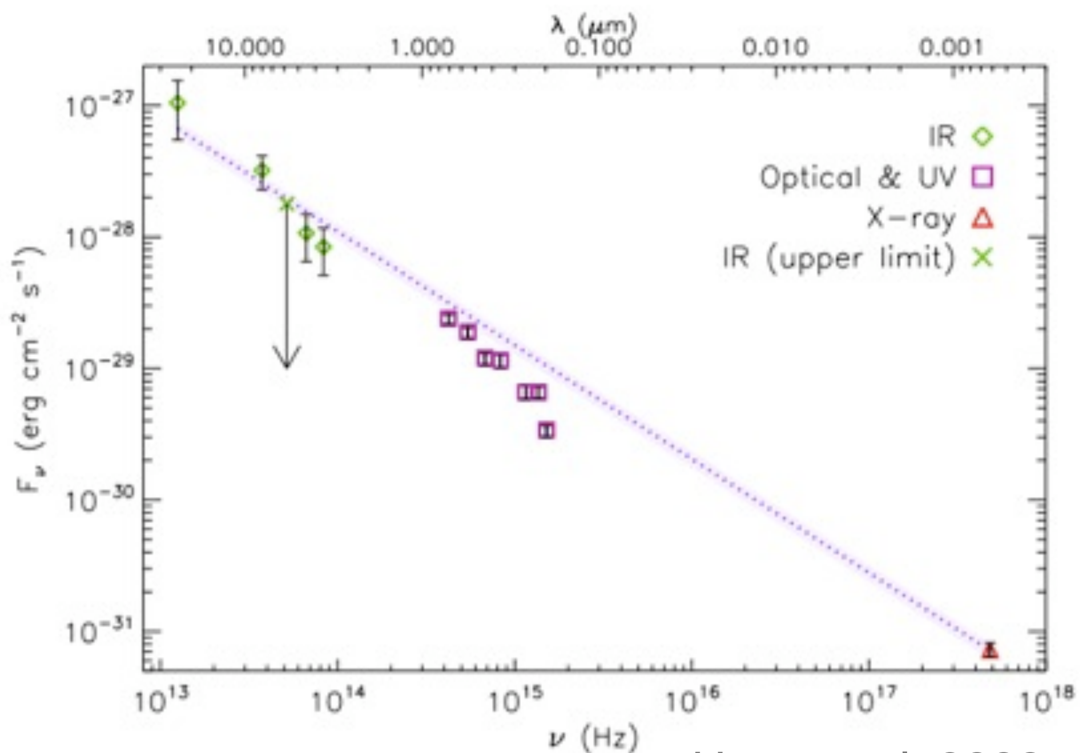


Extinction curves using GRBs

- Absolute extinction always difficult, often only use reddening
  (Galama & Wijers 2001, Kann et al. 2006, 2010, Schady et al. 2007)

- Use X-rays and IR to set absolute flux level (challenging)
  (Vreeswijk et al. 1999, Starling et al. 2005, Watson et al. 2006, Starling et al. 2007, Schady et al., 2010, 2012, Liang & Li 2010, Zafar et al. 2011, Starling et al. 2011, Covino et al. 2013 and many others)

- Observed K-band not always enough – but it helps!
  (Jaunsen et al. 2008, Heng et al. 2008, Greiner et al. 2011, Perley et al. 2011)



Heng et al. 2008

Dust properties from GRBs

- Absolute extinction curves can be determined
- NIR data helps a lot
- Currently the best way to get extinction curves outside the local group
- Sample sizes >40, with z = 0.1-4.5
- Mostly SMC-like with some 2175Å bumps
- Generally the bumps seen are smaller than MW or LMC