X-ray Eyes on the Universe's Brightest Explosions:

Probing the GRB Afterglow Emission Mechanism with Chandra

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Six Years of Science with Chandra
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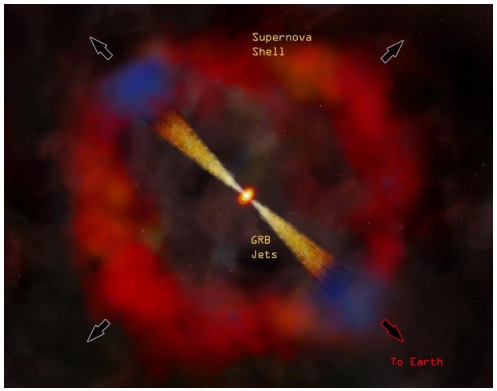

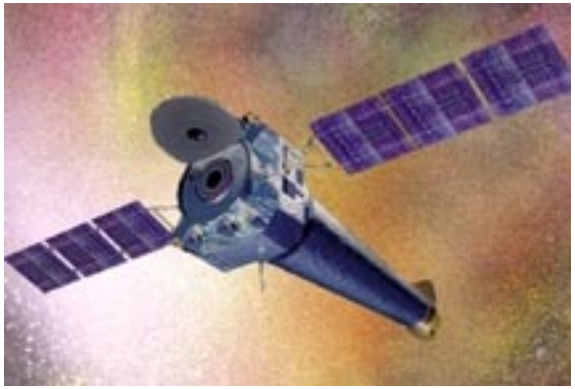

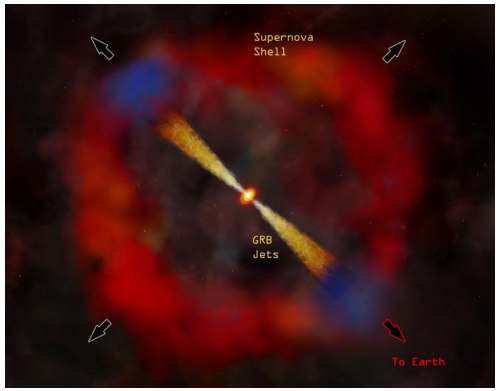

Collaborators

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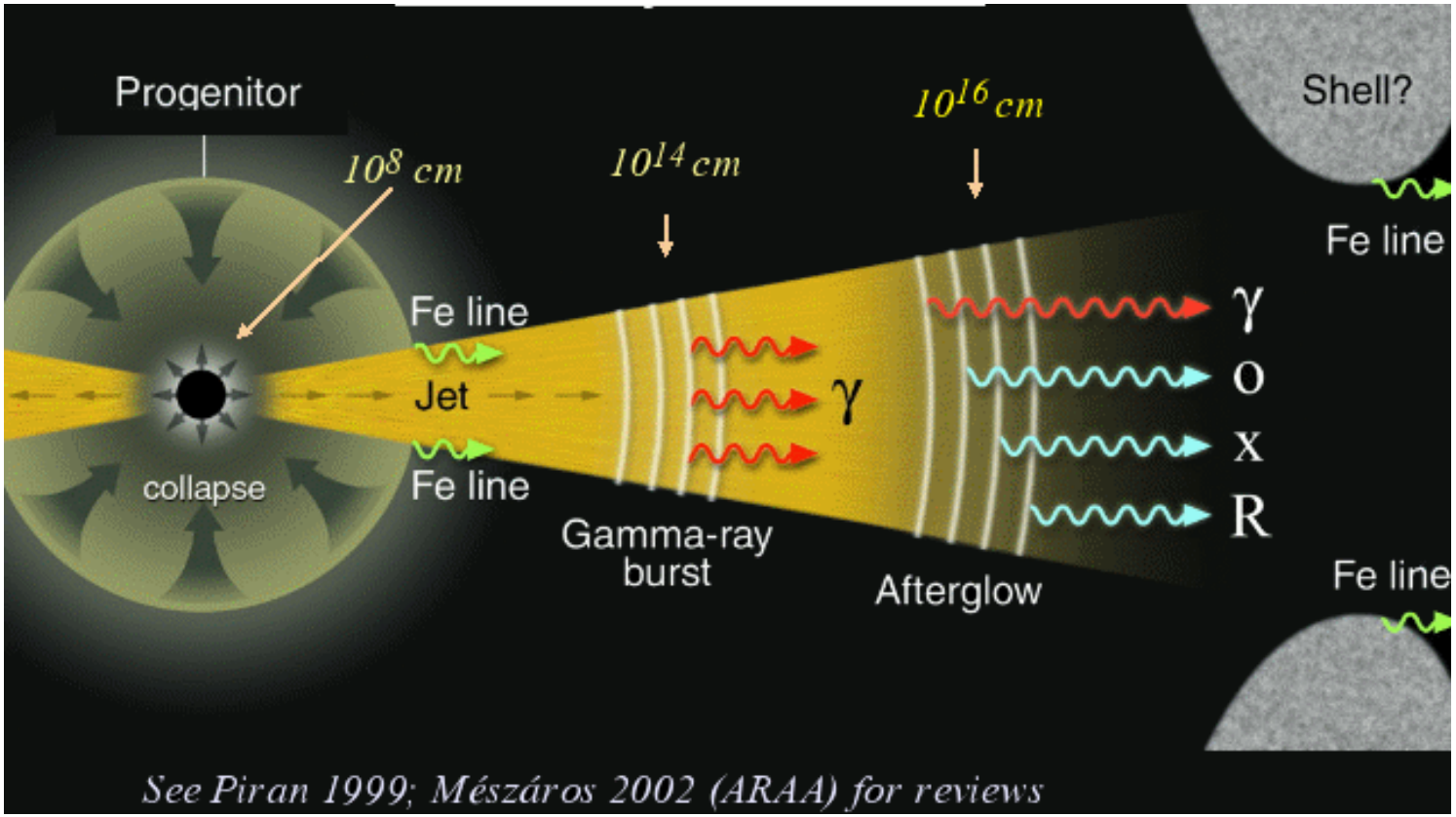
Outline

I. X-ray Afterglows Lines, Controversy, Resolution?

II. Uncovering the Short GRB Progenitors

...skipping... **optically dark GRBs, afterglow synchrotron modelling, late-time energy injection, X-ray Flash Observations, GRB remnants.**

The Anatomy of a GRB



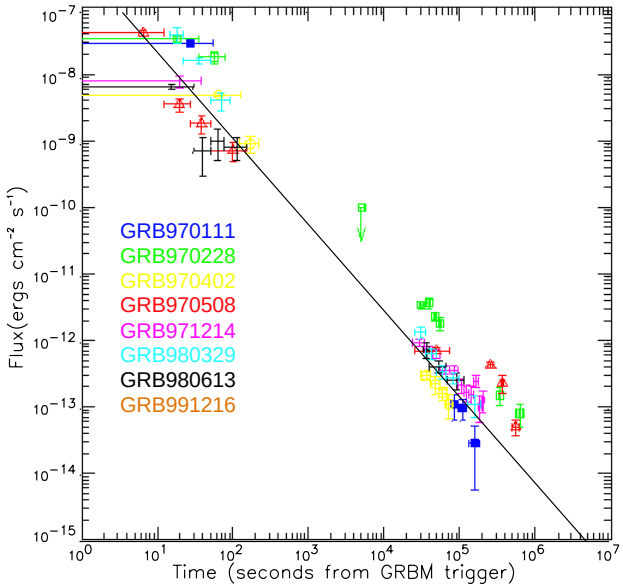
X-ray Bright Afterglows and Chandra

Beppo-SAX, 90% detection of X-ray afterglow.

Chandra provides arcsecond positions for "optically dark" GRBs, spectra, light curves.

Chandra has observed GRBs for 1.07 **Msec, since GRB 991216. 43 observations (6 gratings observations) of 28 fields.**

5-10 times better sensitivity, spatial resolution, and spectral resolution than Swift XRT.



Costa et al. (1999)

I. X-ray Line Emission, Observational Background

Emission lines have been claimed in the X-ray afterglow spectra for GRBs, taken from multiples missions.

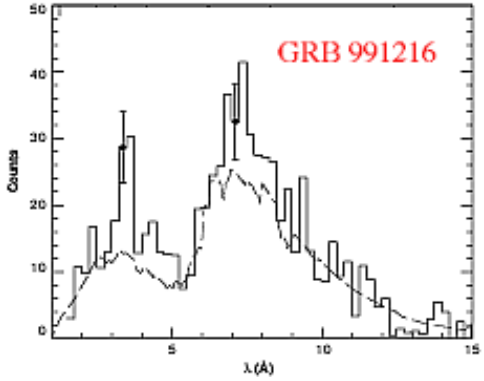
Claims of moderately low significance ($\sim 3\sigma$).

Subject of debate at the last 2 annual GRB conferences.

(e.g., Rutledge & Sako 2002; Butler et al. 2003; Sako, Harrison, & Rutledge 2005)

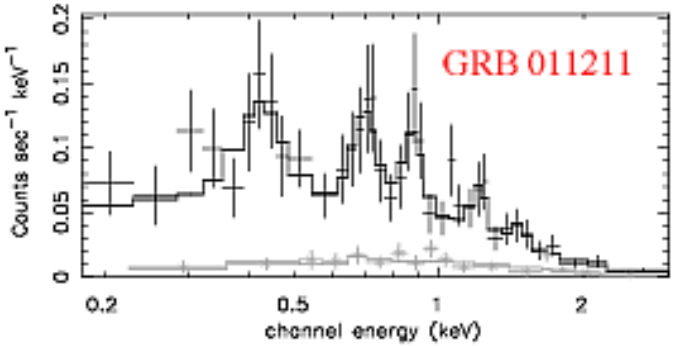
Fe-group (i.e Fe, Ni, or Co) lines

970508, 000214 (SAX), 970828 (ASCA), 991216 (Chandra)



low-Z (e.g. Mg, Si, S, Ar Ca) lines

011211, 030227, 040106 (XMM), 020813 (Chandra)



The X-ray Line Controversy, GRB 011211

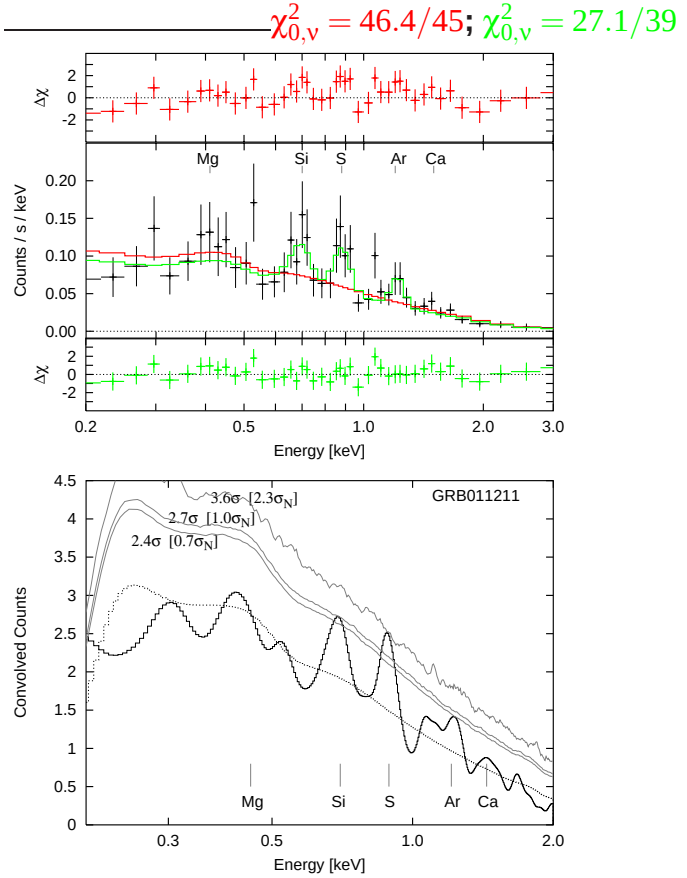
Set of low-Z emission lines claimed by *Reeves et al. (2002)* **in first 5 ksec of GRB011211 XMM Epic-PN spectrum. 0.1% significance.**

However, *Rutledge & Sako (2002)* **"Matched-Filter" approach finds ~ 10% significance.**

Criticisms:

1. Line associations not unique 2. Blind search necessary 3. Statistical methodology wrong.

Butler et al. (2005) **uncovered the root of the discrepancy (N_H parameter is important).**

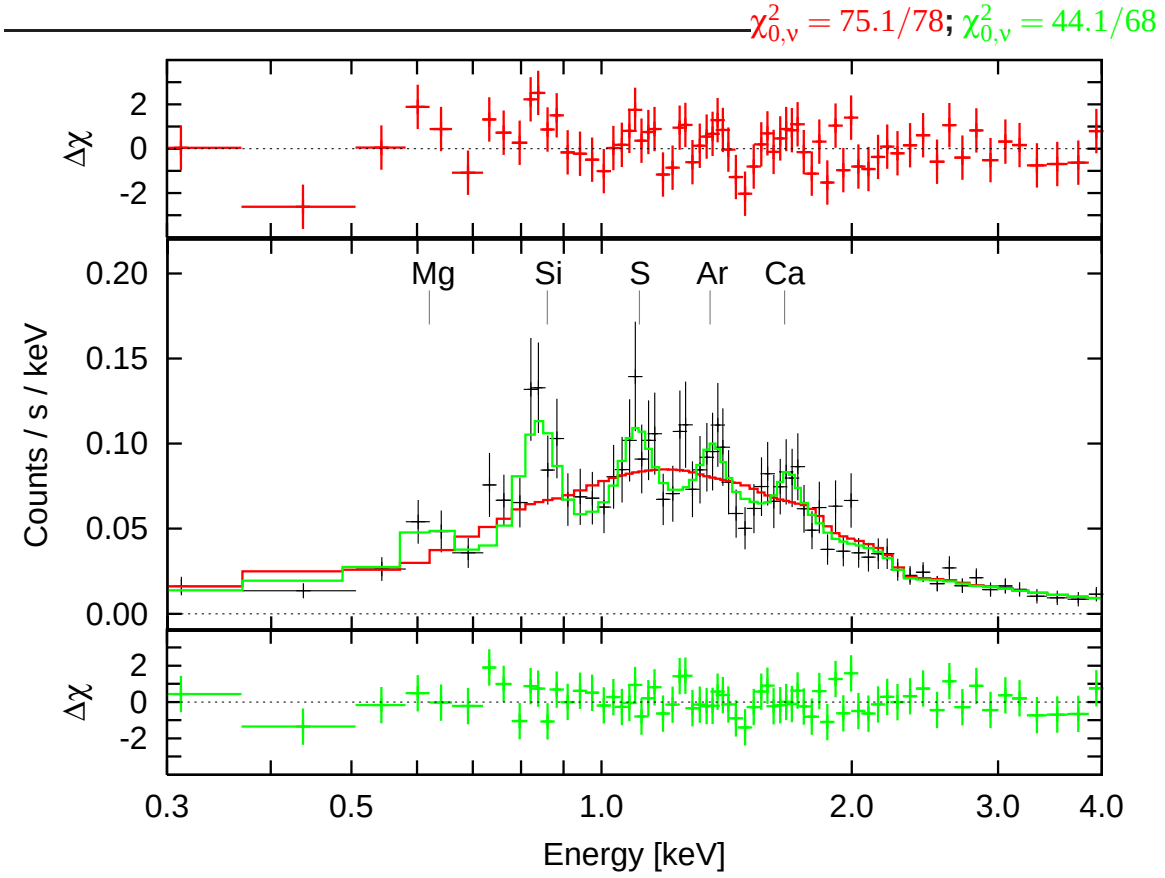


Claim of Low-Z Lines for GRB 030227

Set of low-Z emission lines claimed by *Watson et al. (2003)* **in last 10 ksec of GRB030227 XMM Epic-PN spectrum.**

Add 5 (unresolved) emission lines to the power-law fit: $\Delta\chi^2_0 = 31.0$**, for 10 additional degrees of freedom.**

That corresponds to 0.06% (3.4σ**) significance.**



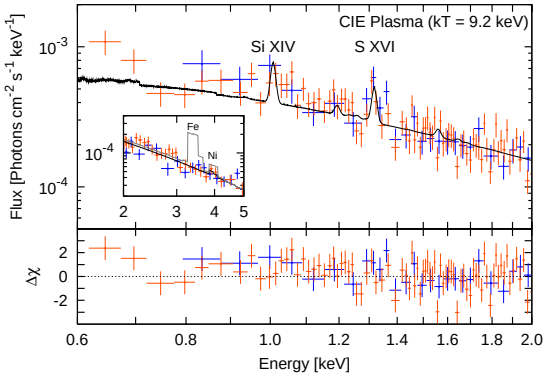
A Weak Detection in a Chandra Gratings Spectrum

Material (Si,S) characteristically produced during pre-supernova nucleosynthesis in massive stars. Blue-shift (0.1c) typical for inferred GRB-SN outflow velocities.

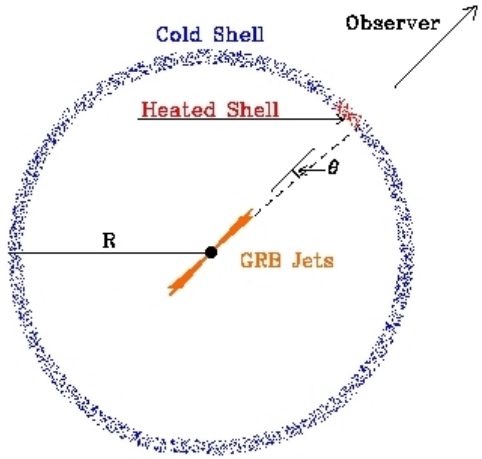
Narrow lines require $\theta_{\rm jet} \leq 40^{\circ}$.

Line duration ($t \geq 77$ ksec) then gives: $R = \frac{ct}{1+z}\frac{1}{1-cos(\theta_{\rm jet})} \geq 2 \times 10^{16}$ cm. (≥ 2 months between SN and GRB).

However, absence of Fe emission points toward $\xi = L_{\rm X}/nR^2 \sim 10 - 100$, nearby reprocessor model *(Lazzati, Ramirez-Ruiz, & Rees 2002)*.



Chandra HETGS Spectrum of GRB 020813, *Butler et al. (2004)*



Recent Upper Limits from Chandra, No Lines!

Gratings spectra for GRBs:

020405 (LETG 50 ksec),

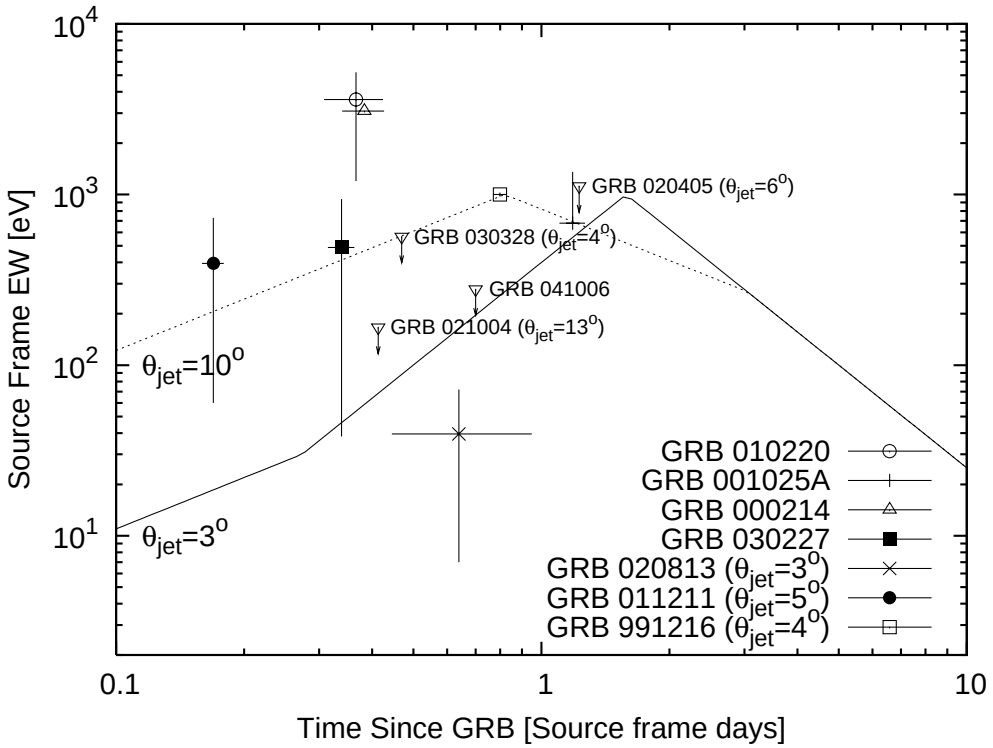
021004 (HETG 90 ksec),

030328 (LETG 90 ksec),

041006 (LETG 90 ksec).

The afterglow continuum must be weak enough not to over-power the emission, peak EW's at $t \sim 1$ day.

Butler et al. (2005)



Simple photo-ionization model from *Ballantyne & Ramirez-Ruiz (2001)*.

Are There Lines in the Swift XRT Data? *(e.g., Gou, Mészáros, & Kallman 2004)*

The Swift XRT data are accumulating!

First 7 months, 33 bright spectra (> 500 cts) in PC mode. (113 if time slice). Plus 30 (152) spectra in WT mode.

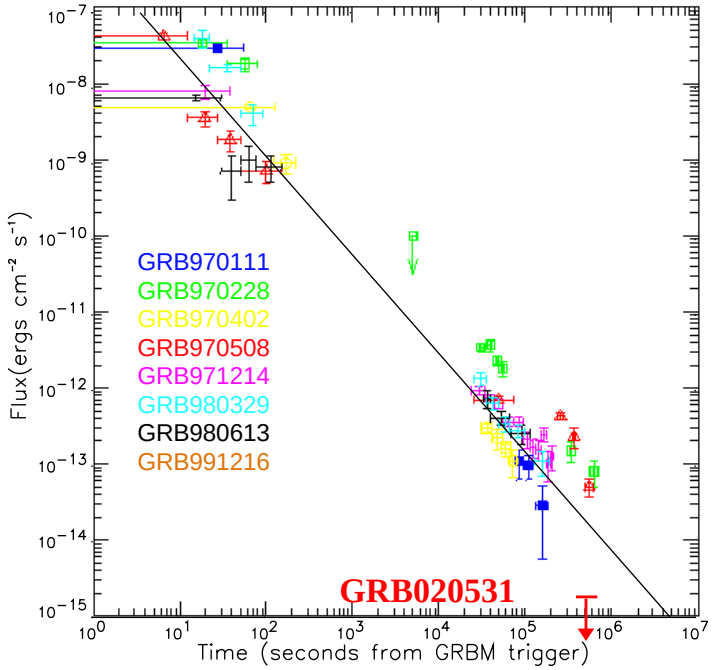
We are fitting these in a systematic (and autonomous) way, looking for lines. Nothing yet at $> 4\sigma$ significance.

II. Chasing Short GRBs Pre-Swift

Afterglow non-detections.

sGRB 020531 (HETE), 20 ksec (5 days) + 10 ksec (11 days). *(Butler et al. 2002)*

sGRB 021201 (IPN), 20 ksec (8 days) + 20 ksec (33 days). *(Hurley et al. 2001)*



sGRB afterglows must be 10-100 times fainter than for GRBs.

Enter Swift, The Short GRB Era

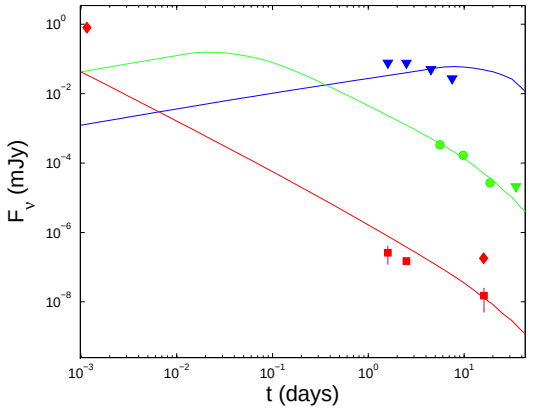
sGRB 050509b (Swift) , 50 ksec, (non-detection). *Elliptical Host Galaxy? (Burrows et al. 2005; Bloom et al. 2005)*

sGRB 050709 (HETE), 40 ksec (2.5 days) + 20 ksec (16 days). *Spiral Host Galaxy. (Fox et al. 2005)*

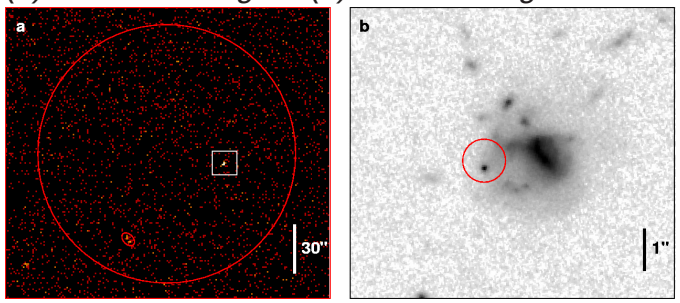
sGRB 050724 (Swift), 50 ksec. *Elliptical Host Galaxy. (Burrows et al. 2005; Berger et al. 2005)*

sGRBs appear to be associated with a variety of galaxy types, progenitor diversity.

sGRB 050709, (Fox et al. 2005)



(a) Chandra Image. (b) Hubble Image.



Conclusions

Chandra observations have enabled observations at longer wavelengths and have provided key insights.

Recent Observations show little evidence for X-ray lines.

Chandra is helping to close in on the progenitors of short GRBs.