Emission Lines from X-ray Afterglows of Gamma-ray Bursts

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X-ray Observations of GRBs

- Why X-rays?
  - optical/UV emission lines typically confused from host galaxy emission
  - gamma-rays are also good, but current instruments typically lack the spectral capabilities
- Very difficult measurement
  - Requires fast response (t < 1 day) and long exposures (~1 day) for useful spectroscopy with current observatories

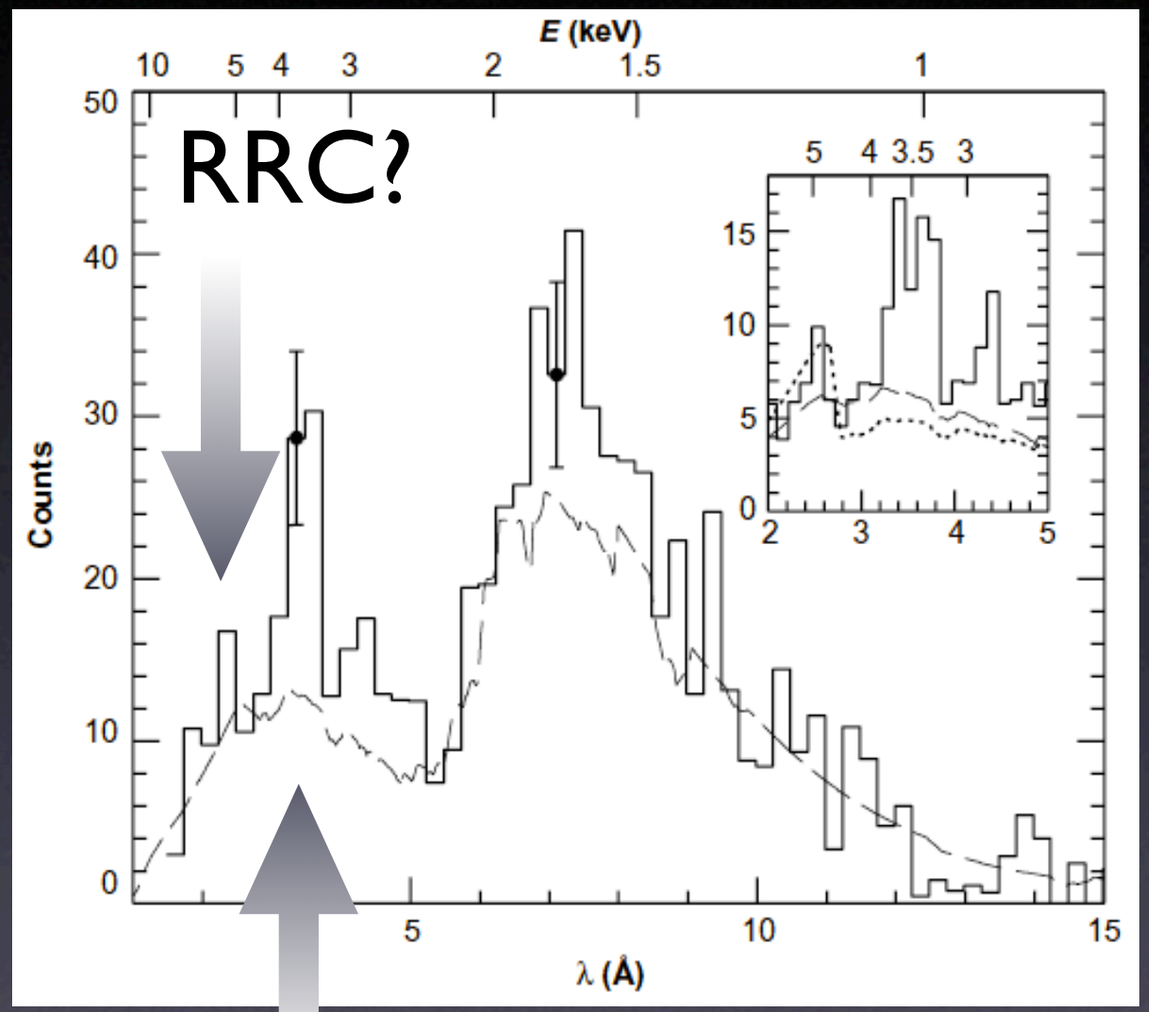
Production of discrete X-ray features during GRB afterglows

- X-ray spectroscopy
  - abundance estimates $\longrightarrow$ progenitor star
  - dynamics $\longrightarrow$ burst/circumstellar geometry
  - temperature, density $\longrightarrow$ model constraints

- A handful of high-resolution observations available with Chandra; some with reported emission line detections

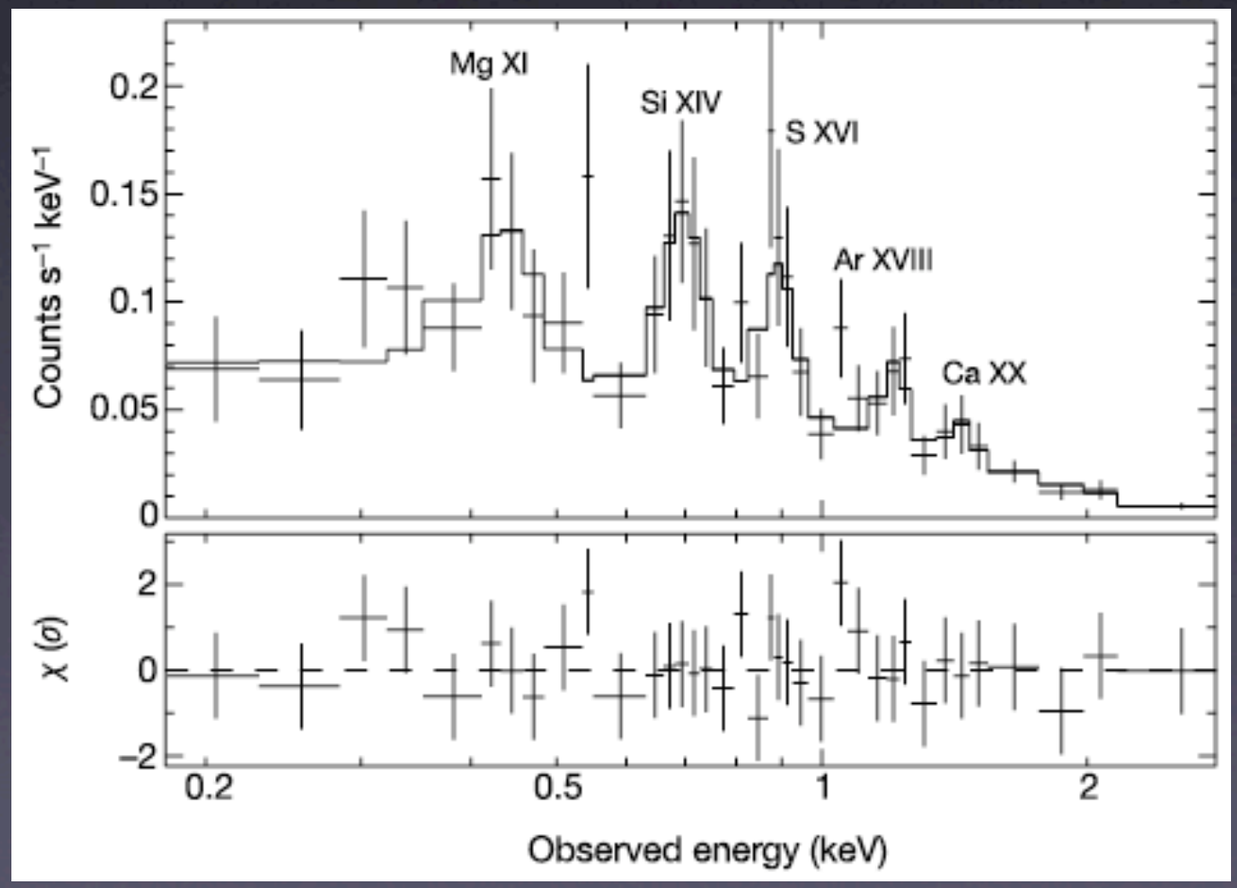
Observation of GRB991216

- Piro et al. (2000) reported the detection of an iron line (and possibly an associated recombination continuum) in the X-ray afterglow of GRB991216
  - first high-res grating observation of a GRB afterglow
- The claimed single-trial signficance of the line is 4.7σ (occurs only once in ~380,000 random trials at this particular energy).



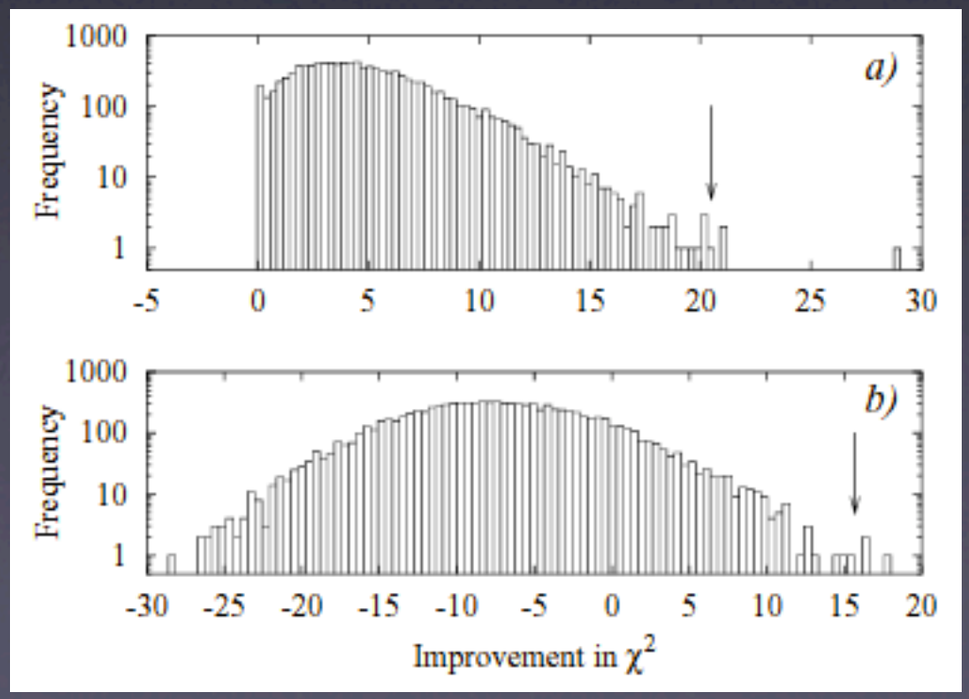
Soft X-ray Lines in GRB011211

- Reeves et al. (2002; 2003) have reported the detection of multiple emission lines from mid-Z elements (Mg, Si, S, Ar, and Ca) during the first ~5 ksec of an *XMM-Newton* observation of GRB011211
  - F-test : 99.7%
    - ~1/300 (3.0σ)
  - MC : 99.98%
    - ~1/5000 (3.7σ)



- The Monte Carlo method was elaborated in a later article (Reeves et al. 2003)
  - record the delta-chi-square that results from adding three gaussian lines to the continuum model
  - repeat for 10000 simulated spectra
  - count the number of simulations which result in an equal or larger delta-chi-square

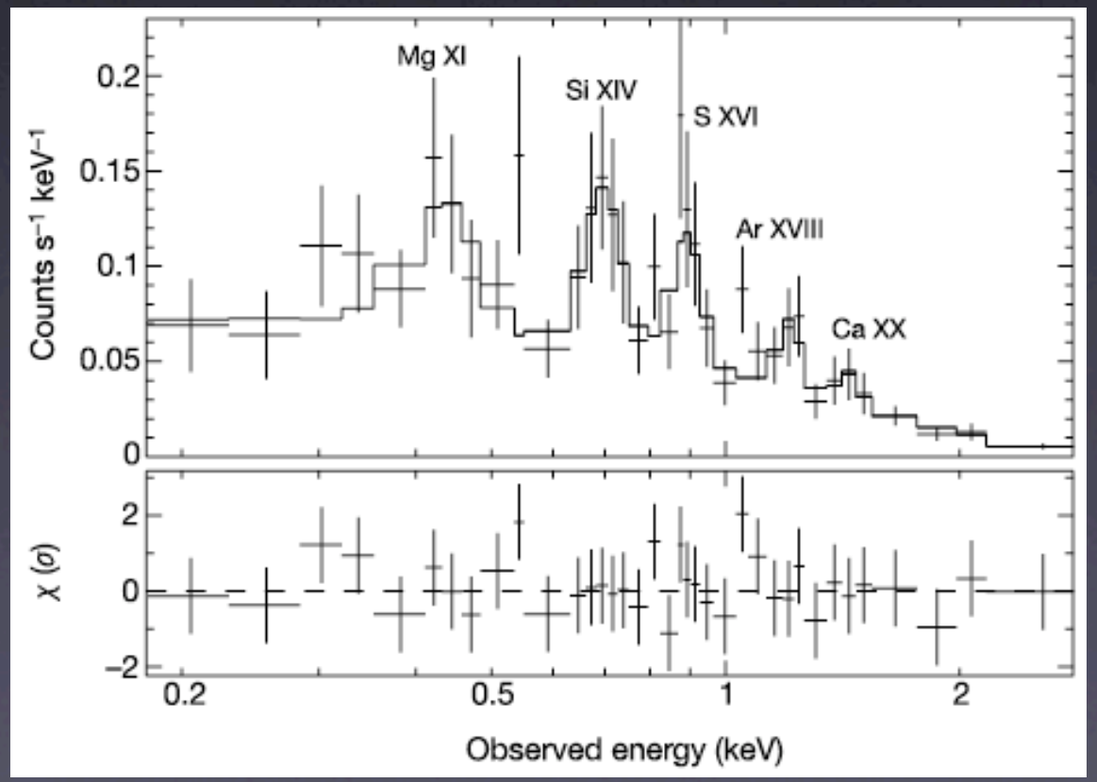
- Sounds like a reasonable procedure, but be careful!
  - automating the fit results in an underestimate of the $\Delta\chi^2$ (likely to find a local minimum; not a global minimum)



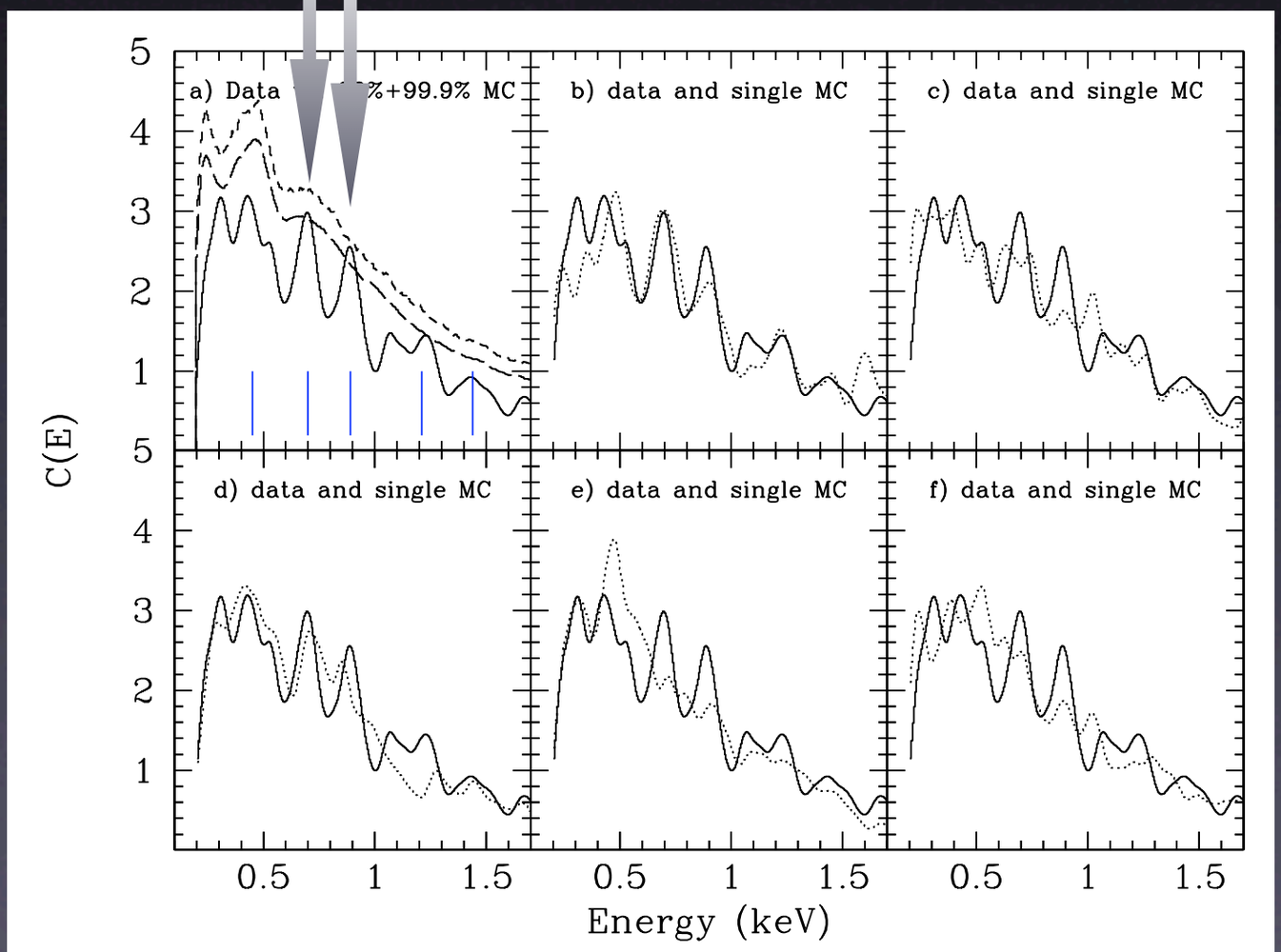
Reeves et al. (2003)

- Rutledge & Sako (2002): MC simulations to estimate multi-trial significances (i.e., chances of seeing fluctuations at an arbitrary energy)
- matched-filter approach

seen in ~20% of the simulations
$\sim 1.3\sigma$!



Reeves et al. (2003)



Rutledge & Sako (2002)

The Case for GRB991216

$\sim 2.8\sigma$ single-trial

seen in ~40% of simulations

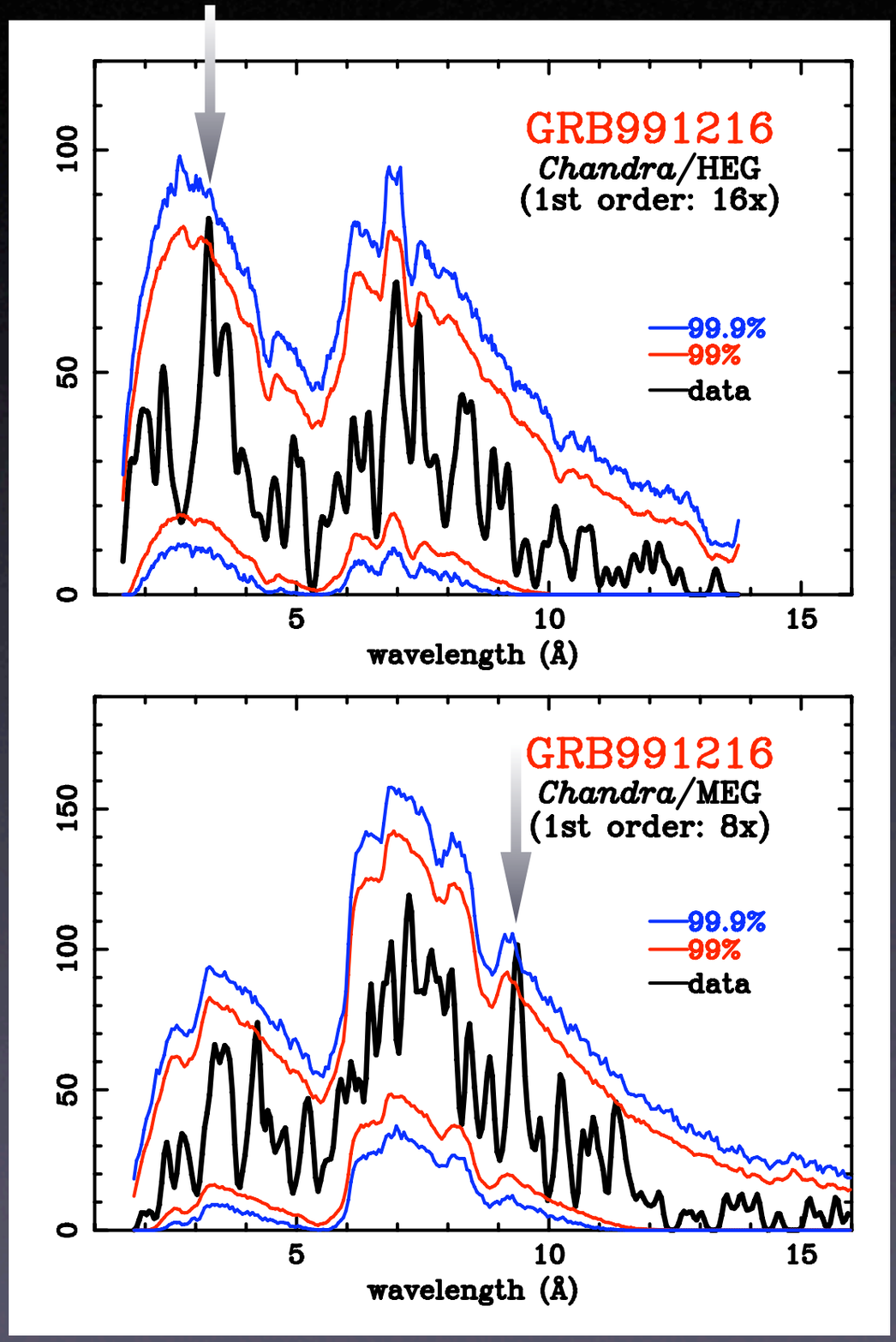
$\sim 0.8\sigma$ multi-trial

- Re-analysis
  - continuum adopted by Piro et al. (2002) is probably not reliable; the true single-trial probability is lower
  - multi-trial? The feature corresponds to Fe XXVI Lyα at z=1.02 (Vreeswijk et al. 1999); the highest-redshift optical absorption-line system.

$\sim 3.3\sigma$ single-trial

seen in ~15% of simulations

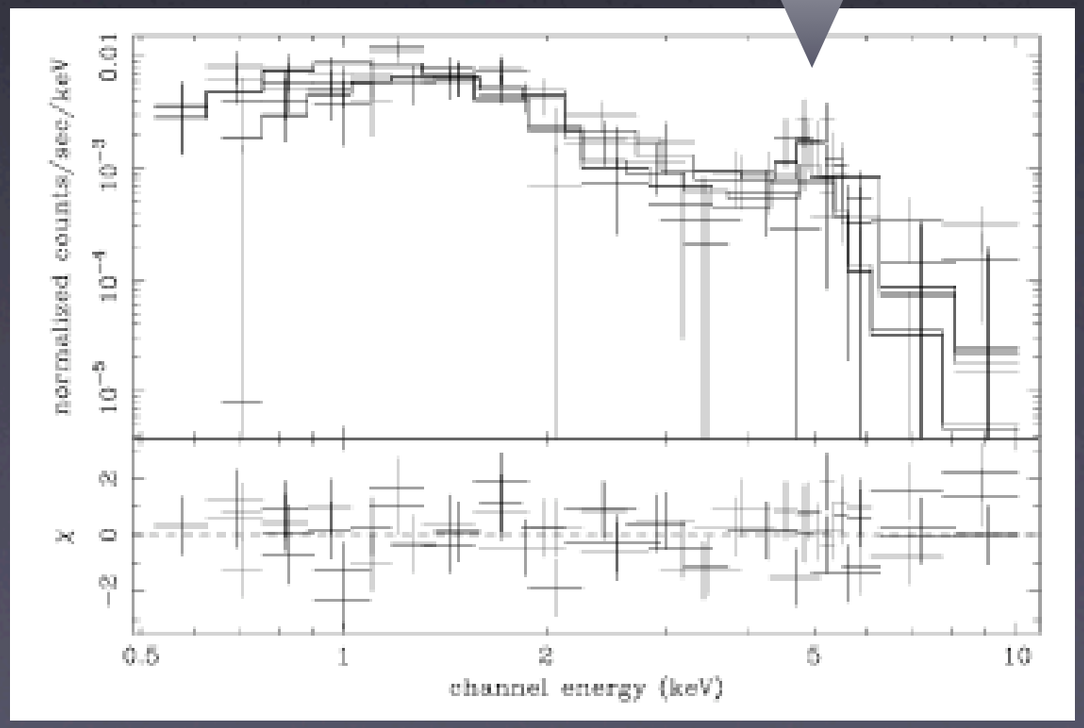
$\sim 1.4\sigma$ multi-trial



GRB970828

- ASCA spectrum originally publised by Yoshida et al. (1999) also shows a statistically significant feature
- F-test : 98.3% significance
  - ~17/1000 (2.4σ)

Fe line?



seen in 0.06% of the simulations

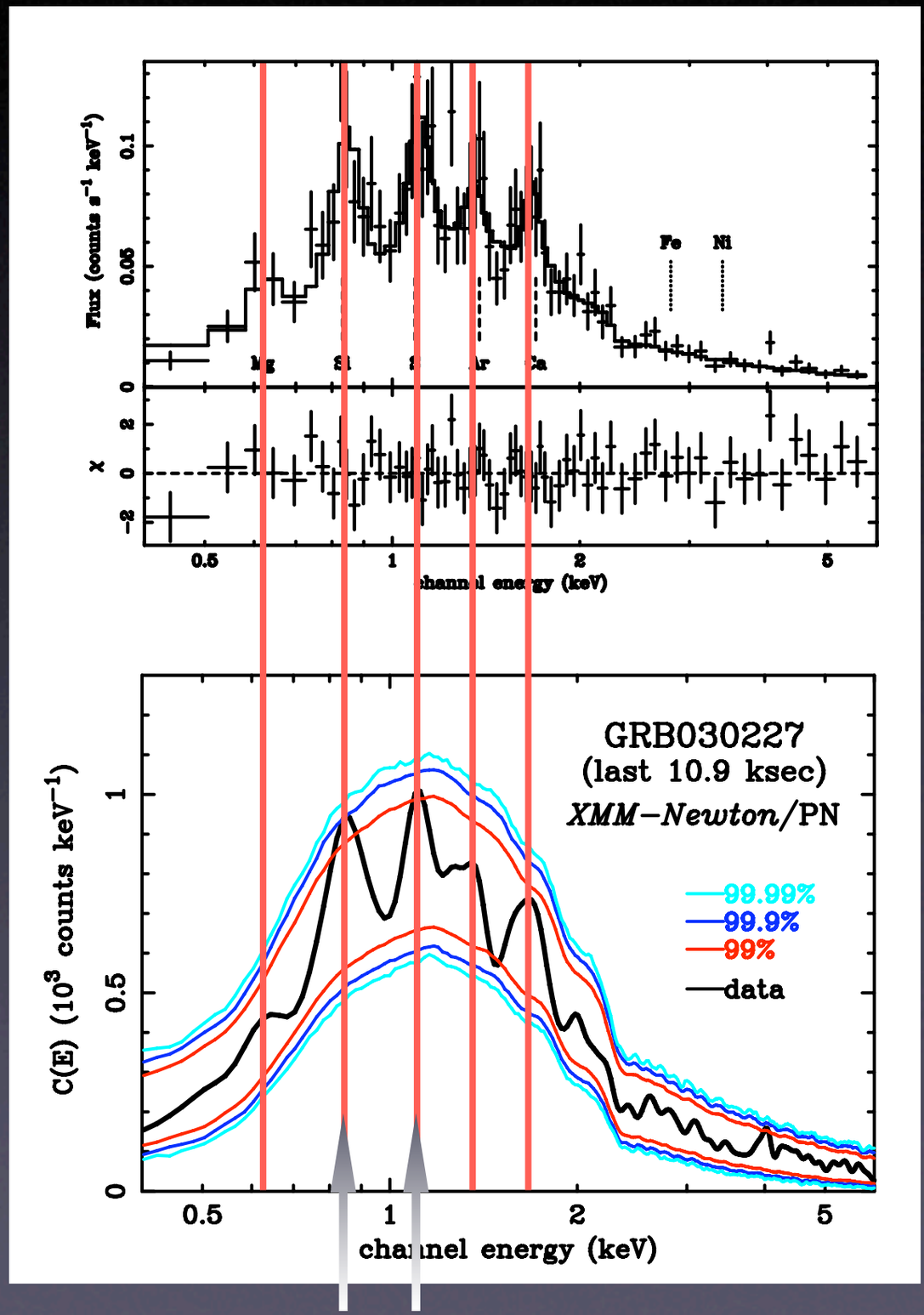
$\sim 3.4\sigma$ multi-trial

GRB030227

- Watson et al. (2003) see lines in the last 10.9 ksec of an *XMM-Newton* observation at a redshift of z=1.4 (no optical redshift measured)
  - the authors adopt a model in which "one expects to observe the Hydrogen-like emission lines Mg, Si, S and the Helikum-like lines of Ar and Ca at an arbitrary redshift"
- Claimed significance $4 \sim 5\sigma$

seen in ~15% of the simulations

$\sim 1.5\sigma$



Conclusions

- With the sole exception of the *ASCA* data of GRB970828, which is still very marginal, none show any convincing emission/absorption features
- Lines should be present at some level; how much depends on a lot of factors
- Localizations with *Swift* (April 2004) and future follow-up observations with *Chandra* and *XMM-Newton* will certainly resolve these issues