The Crab: the absorption model and consequences for absolute effective area calibration

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SRON

Using the Crab nebula as calibration source

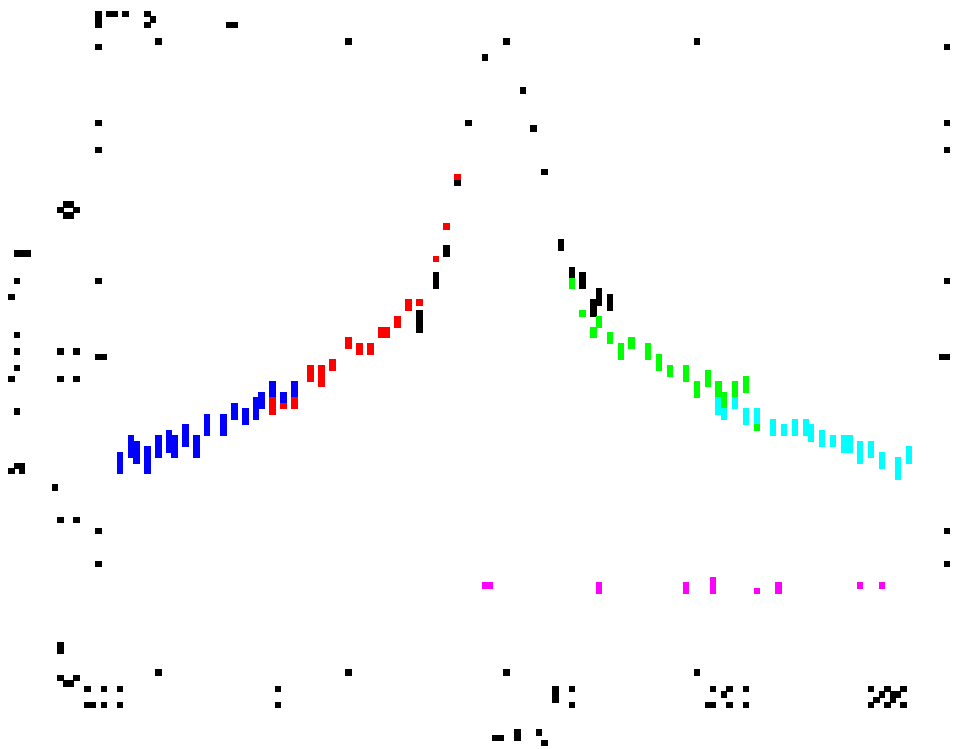
- Good calibration sources should obey:

1) Simple continuum
2) Known continuum
3) Constant in time
4) Point source
5) No dust scattering halo

Crab only obeys rule 1 and 3 partially, but except for White dwarf spectra there is nothing better

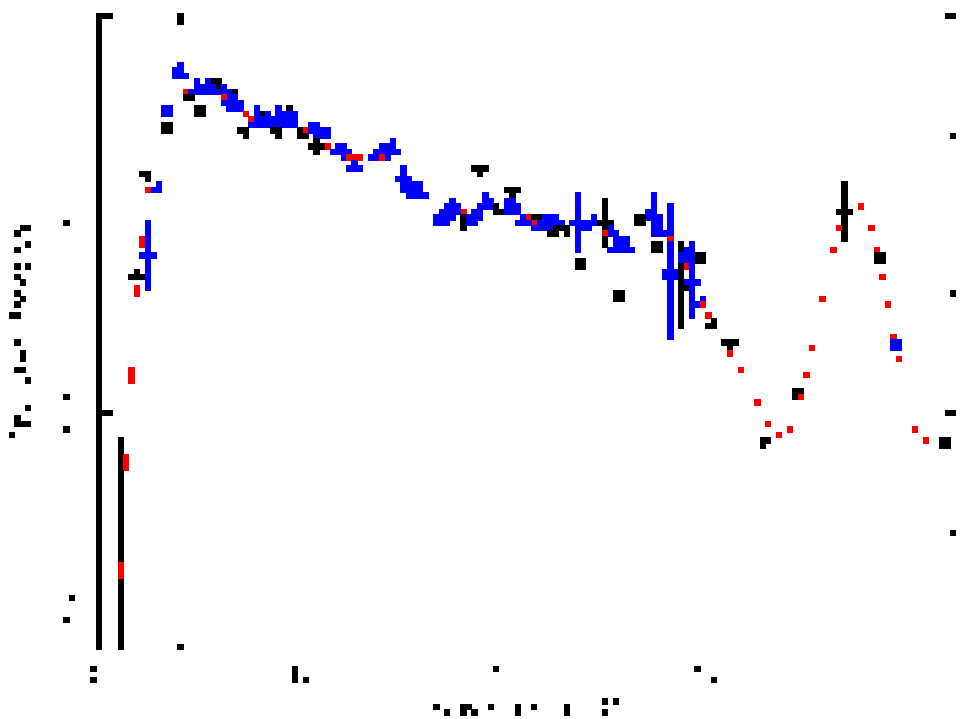
Extended emission

- Crab is extended: synchrotron nebula + dust scattering
- RGS detectors (5’ width) contain ~90 % of flux
- Fraction energy-dependent
- Determine using power law fits to tail spatial distribution



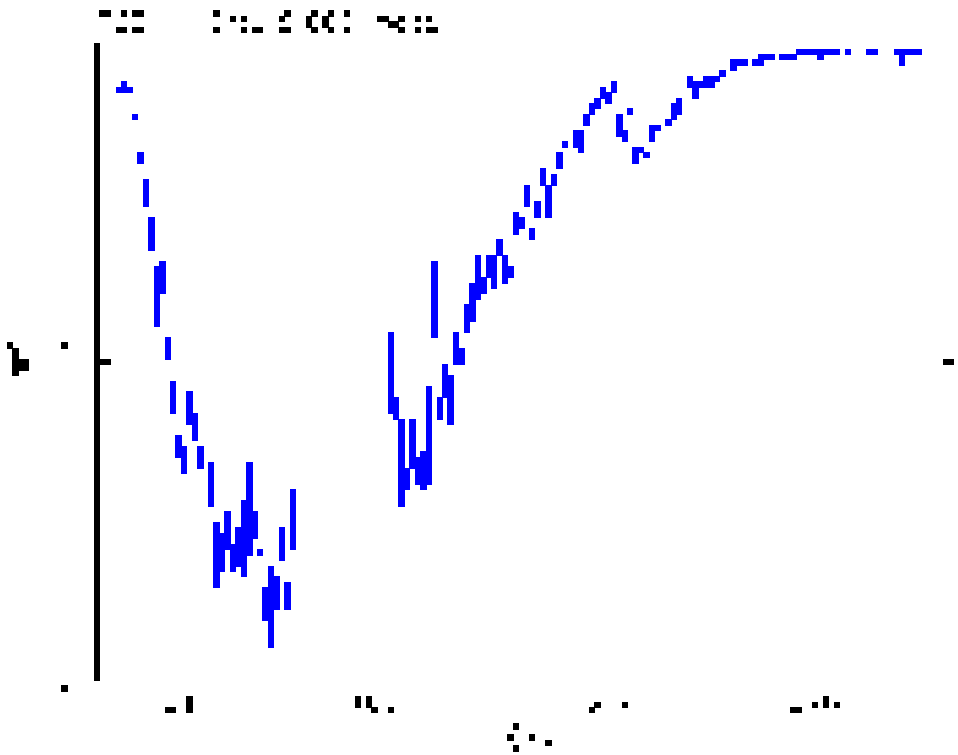
Enclosed fraction

- RGS1 and RGS2 slightly different (~2 % difference)
- Correction factor contains structures near dust scattering edges: Ne, Fe, O
- For λ>25 Å poorly determined (lower CR, higher BG, more scattering)



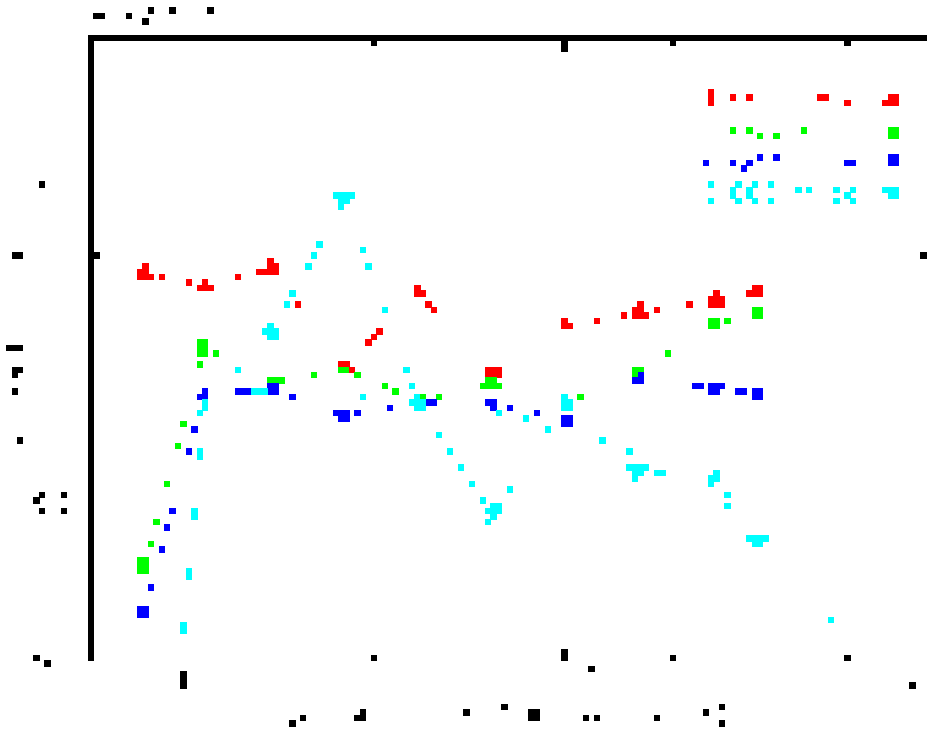
Pile-up

- In full CCD mode, Crab shows pile-up up to 8 %
- Use observations at 1, 2, 4 and 8 CCD mode to set-up model of pileup
- Single CCD mode (0.574 s) < 1% pile-up but taken into account as arf correction for 1st order
- Plot shows arf-correction for 8 CCD mode



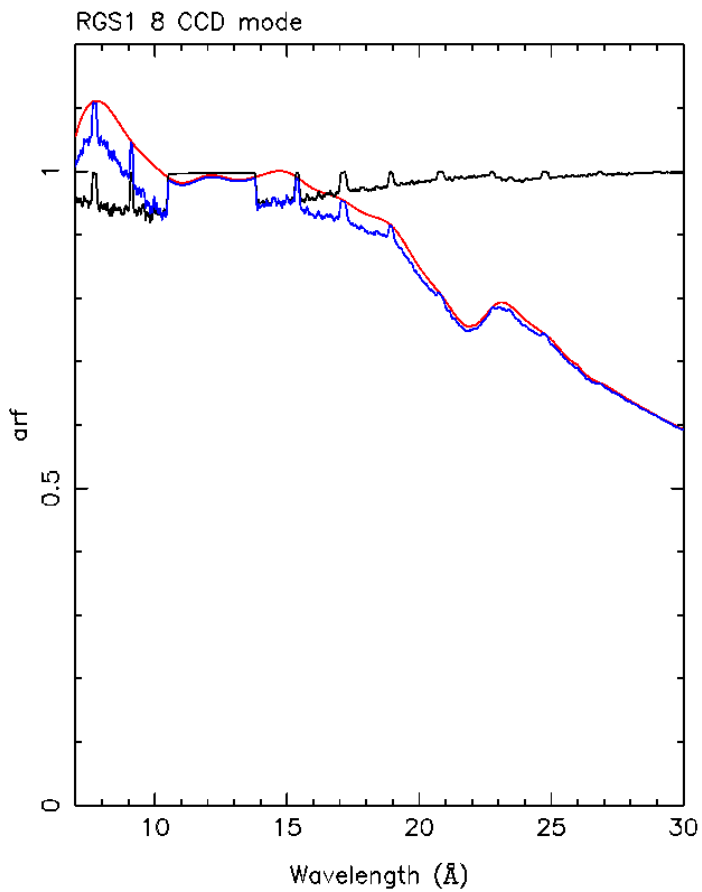
Pile-up model

- Pile-up depends on intensity at a given pixel
- Possible to determine empirically correction factor



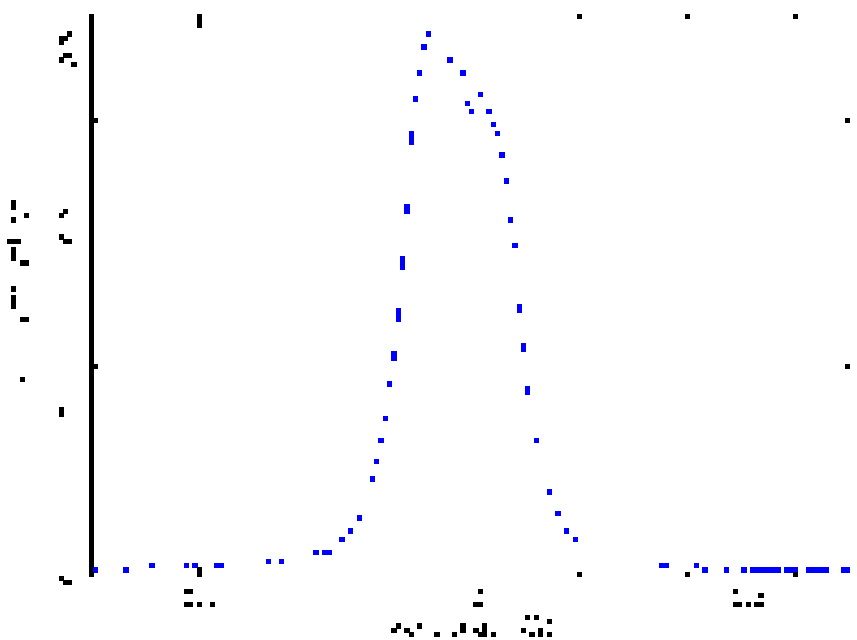
Production of Crab arf

- Use polynomial correction based on blazar PL fits 10-25 Å
- Correct for time-dependent C-contamination
- Correct for cross-disp loss
- Include pile-up correction
- Correct for 98 % PI selection



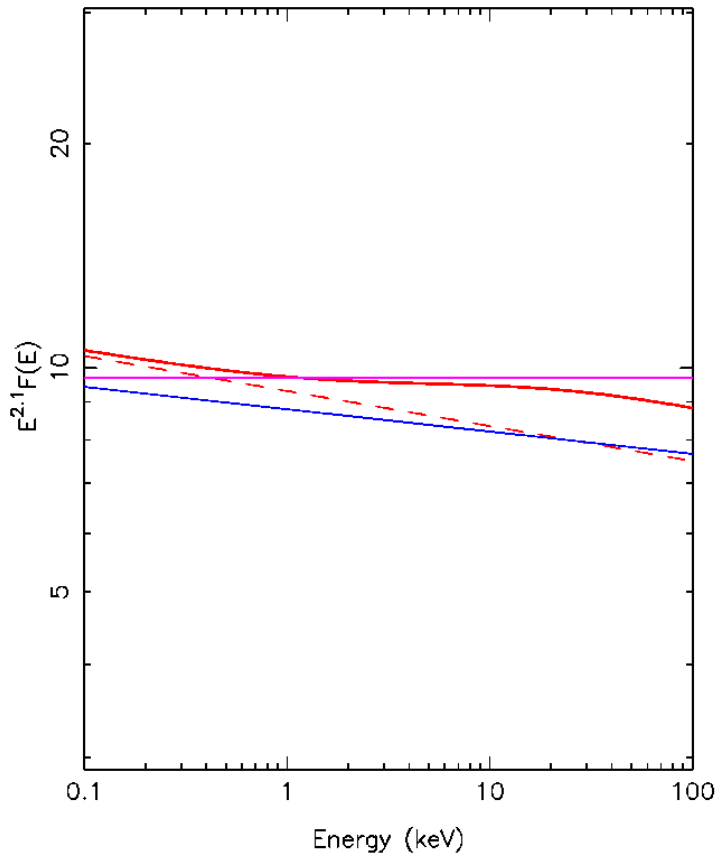
Spectral fitting

- Spatial profile in dispersion direction ~0.2 Å FWHM
- Determined from MOS image



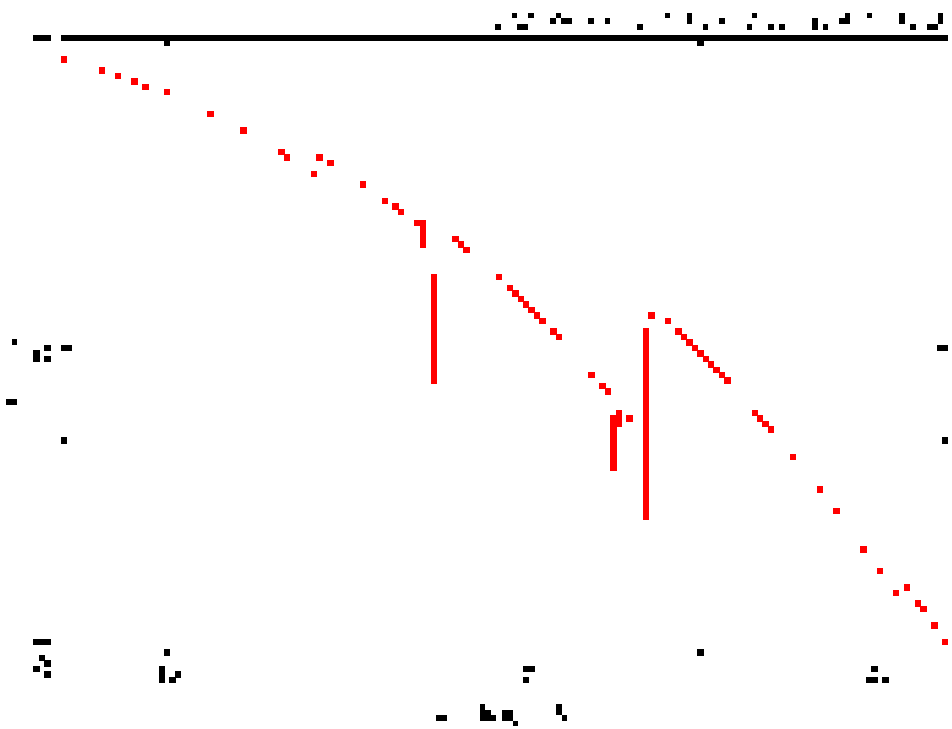
Unabsorbed continuum model

- Based on fits to Crab with BeppoSAX; separate pulsar (curved spectrum) + nebula (Powerlaw, Γ=2.147±0.002, Norm=9.31 (Kuiper et al.)
- Toor & Seward
- Kirsch et al. pn



Absorption model

- Model (“hot”) from SPEX (Verner et al. cross sections, plus lines)
- Abundances proto-solar (Lodders)
- Free abundance of H, N, O, Fe I & Fe II, Ne

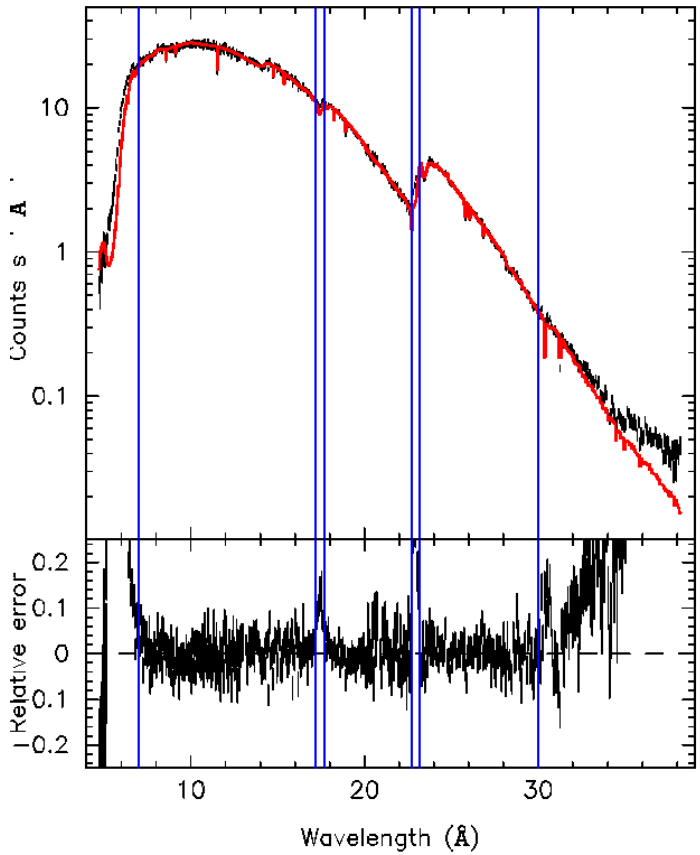


Spectral fit

- Fit first order, RGS1 & RGS2, 1CCD & 2CCD mode spectra simultaneously
- No free renorm for instruments, except:
- Multiply model by PL: $N\lambda^a$, N & a free, in order to allow for unknown absolute slope & norm of blazar spectra
- ➔ RGS absolute area
- Practice: determine PL by its (extrapolated) value @ 5 and 40 Å

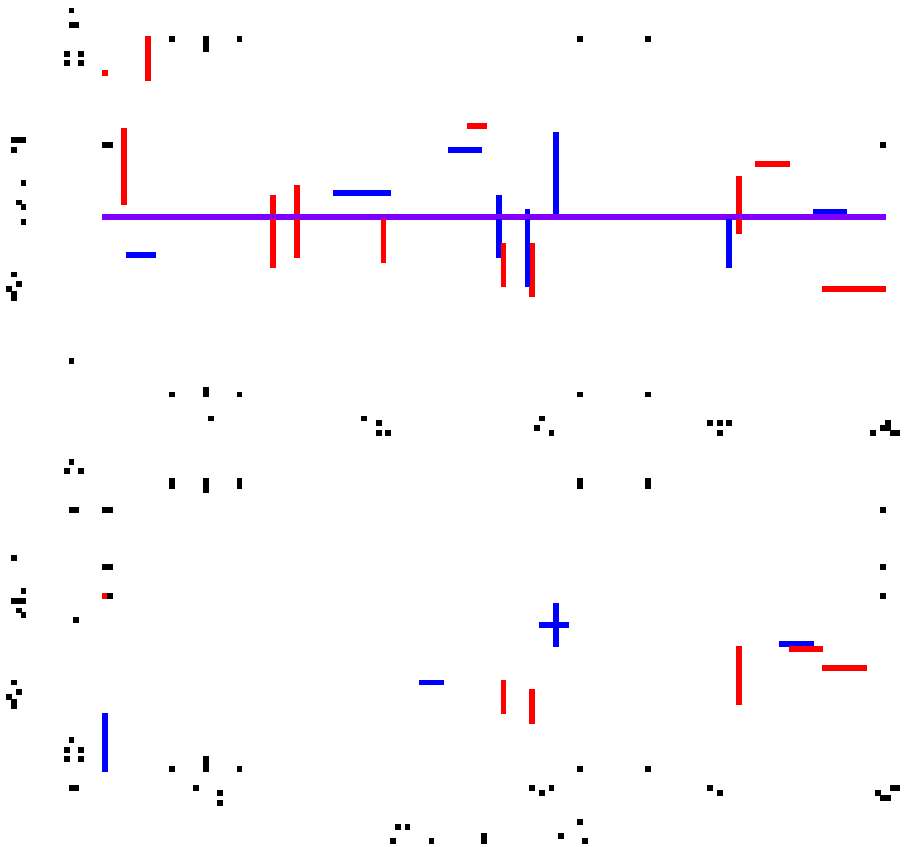
Results of fit

- Fit restricted to 7-30 Å
- Below 7 Å grating scattering
- Above 30 Å arf-correction uncertain @ loss off events at low PI (extended source, wider selections)
- Omit small region near O I and Fe I edge (arf poorly determined, narrow features)



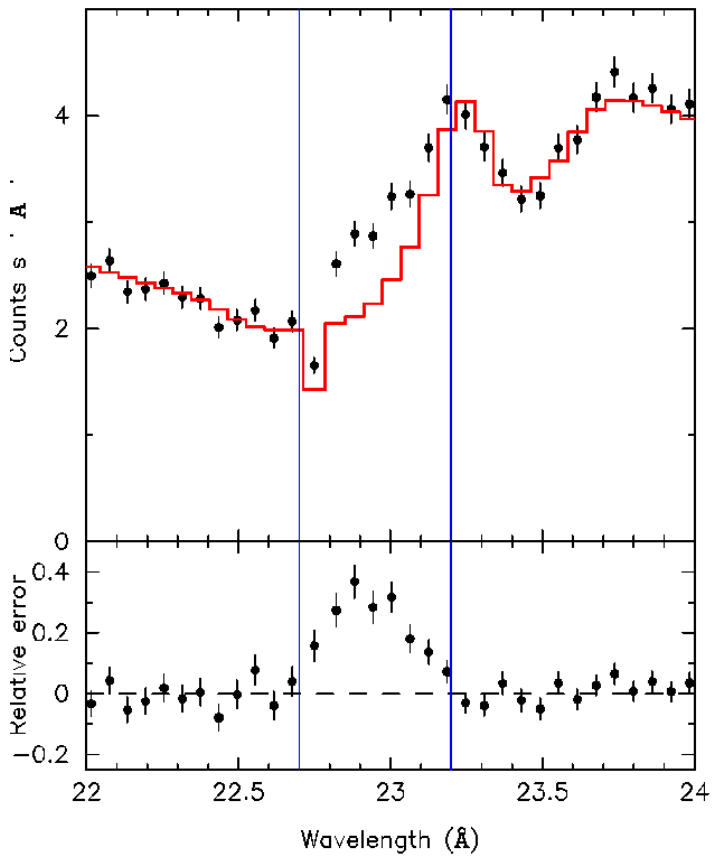
Rebinning: how good is the fit

- Fit good within 2 % systematic uncertainty
- RGS1 & RGS2
- 1CCD (upper) & 2CCD (lower) panel

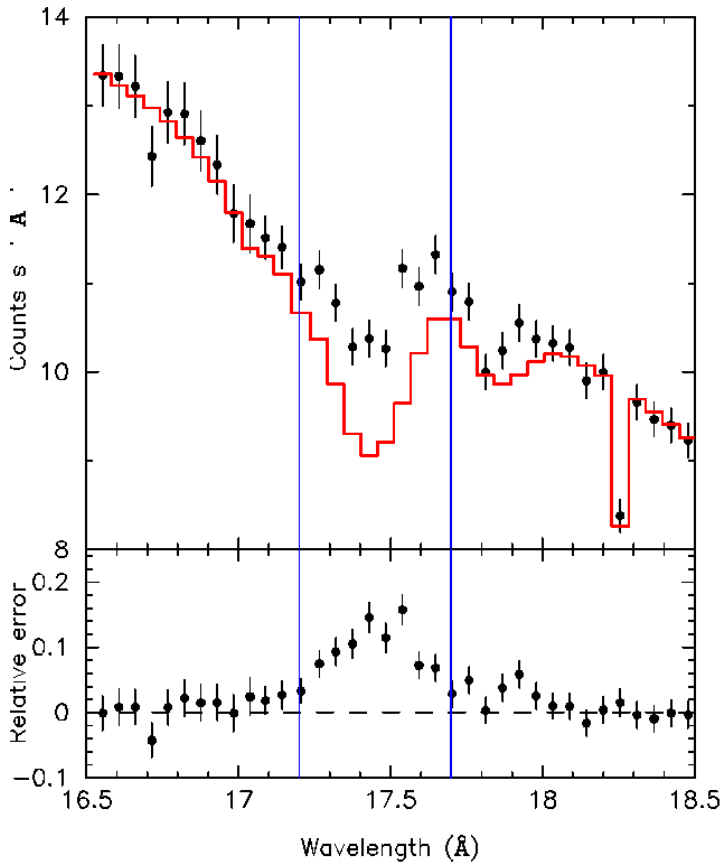


Residuals near O-edge

- Caused by λ-dependent dust scattering in cross-disp correction (can be determined within ~0.5 Å bins only, due to statistics)
- Is also smeared out by ~0.2 Å in disp
- Plus uncertainty in atomic physics O-edge (atomic & dust)

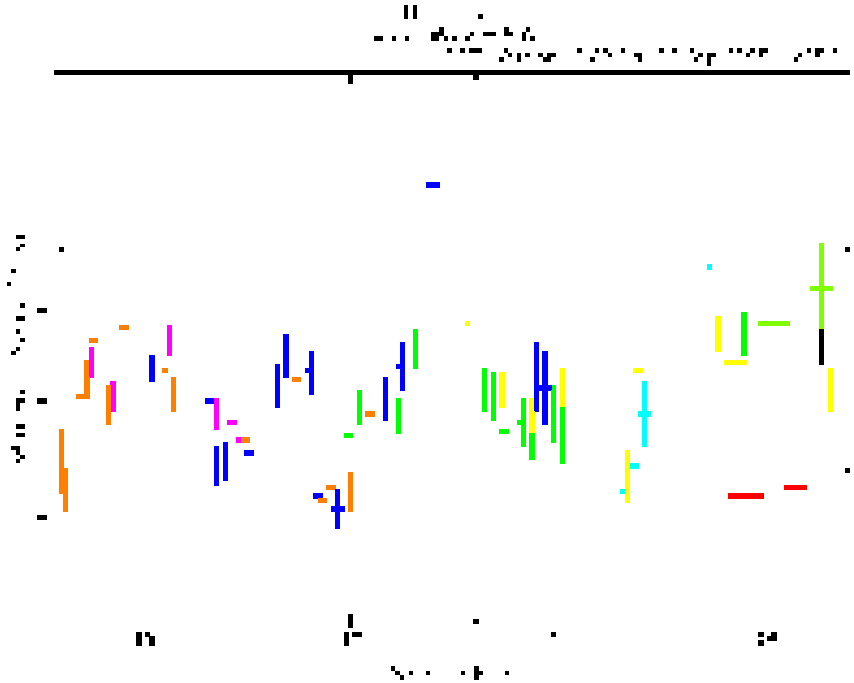


Residuals near Fe I 2p edges



Fun: old fits to RGS Crab spectrum (Escorial meeting)

- Improvement due to dedicated off-axis measurements in cross-disp direction last February



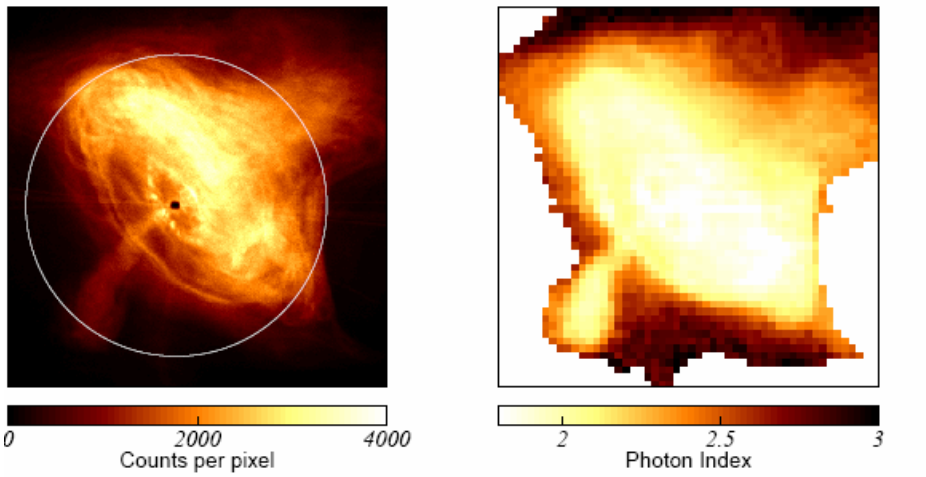
Derived abundances

- Best fit (brackets: predicted proto-solar value):
- $N_H = 3.14 \pm 0.02 \times 10^{21}$
- $N_N = 2.14 \pm 0.26 \times 10^{17}$ 2.49
- $N_O = 19.36 \pm 0.18 \times 10^{17}$ 18.07
- $N_{Ne} = 5.25 \pm 0.16 \times 10^{17}$ 2.80
- $N_{Mg} = 0.95 \pm 0.30 \times 10^{17}$ 1.31
- $N_{fe\ I} = 0.63 \pm 0.06 \times 10^{17}$ 1.09
- $N_{fe\ II} = 0.37 \pm 0.06 \times 10^{17}$ incl. Fe I
- O I / O II < 0.005
- Conclusion: proto-solar, except Ne 1.9 x solar

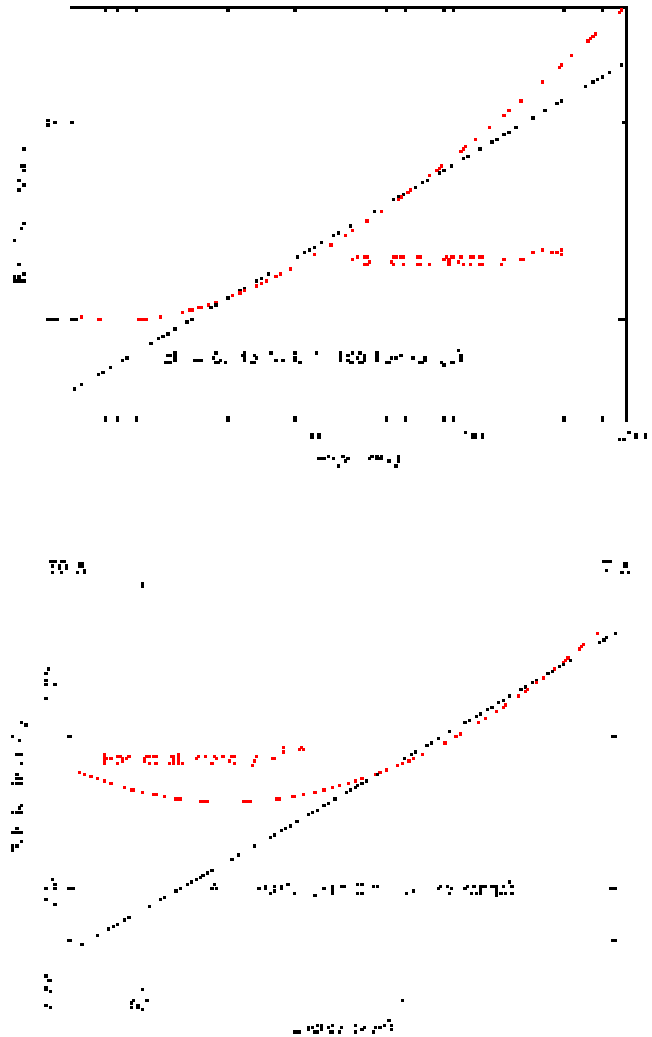
Fudge factor:

- $(0.946\pm0.012)/N\ (\lambda/10)^{-0.089\pm0.012}$
- Fudge @ 5 Å: 1.006±0.009
- Fudge @ 40 Å: 0.836±0.020
- However, true error at 40 Å may be 0.05, due to correlation with N_H (1CCD & 2 CCD mode give slightly different results, differ by 0.05 from the mean fit)
- Ultimate accuracy: using also WD spectra LETGS?

Caveat: curved continuum spectrum nebula?



Mori et al., Chandra imaging



Conclusions

- RGS observations allow for accurate model for depth ISM absorption edges towards Crab
- Needed for any observatory that uses Crab below 1 keV
- Some further fine-tuning may be needed (lowest E, bending continuum)