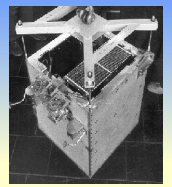
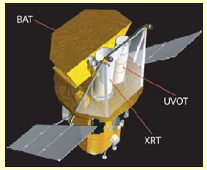
# Crab: the standard X-ray candle with all (modern) X-ray satellites

**M.G.F. Kirsch[a],**

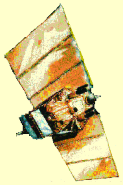
**U.G. Briel[b], D. Burrows[c], S. Campana[d], G. Cusumano[e], K. Ebisawa[f], M.J. Freyberg[b], M. Guainazzi[a], F. Haberl, K. Jahoda[g], J. Kaastra[n], P. Kretschmar[a], S. Larsson[h] , P. Lubinski[i], K. Mori[j], P. Plucinsky[k], A.M.T. Pollock[a], R. Rothschild[l], S. Sembay[m], J. Wilms[o], M. Yamamoto[j]**

[a]European Space Agency, [b]MPE, [c]Penn State University, [d]Osservatorio Astronomico di Brera, [e]IFCAI/CNR [f]Astro-E2 Guest Observer Facility, [g]NASA' s GSFC, [h]Stockholm Observatory, [i]CAMK, Warsaw; INTEGRAL Science Data Center, [j]University of Miyazaki [k]Harvard-Smithsonian Center for Astrophysics, Cambridge, [l]Center for Astrophysics & Space Sciences, University of California, , [m] Leicester University, [n]SRON, [o]University of Warwick

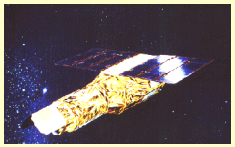





- The Crab
- XMM-observations of the Crab
- Comparison with other observatories



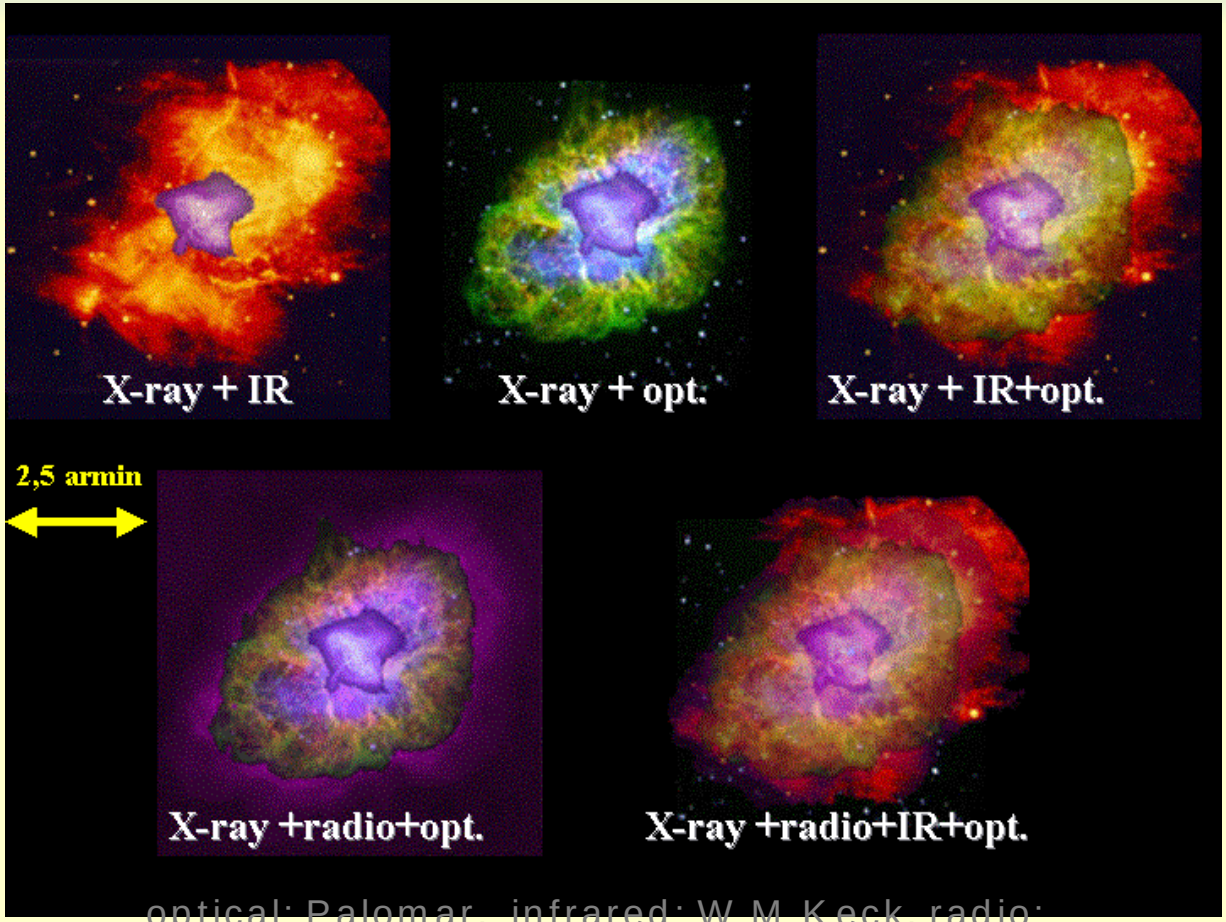
- The need for X-ray standards



Marcus Kirsch, XMM-Newton
European Space Astronomy Center

# the Crab

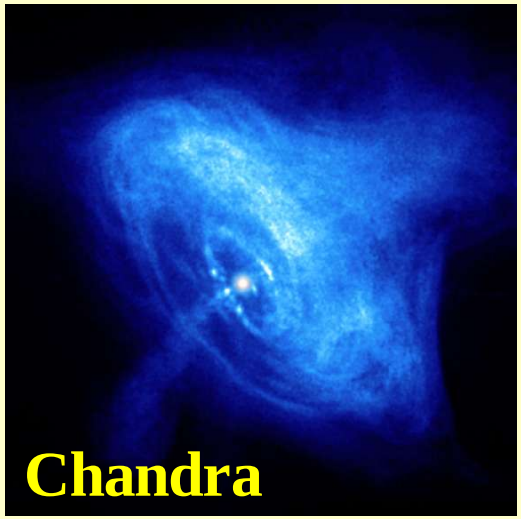
- Age: 900 years
- Distance: 2200 pc
- RA: 05 34 31.97
- DEC: +22 00 52.1
- L: $5*10^{38}$ erg/sec
- Lx: $4.9*10^{37}$ erg/sec
- P: 33.1 ms
- Pdot: 36 ns/d

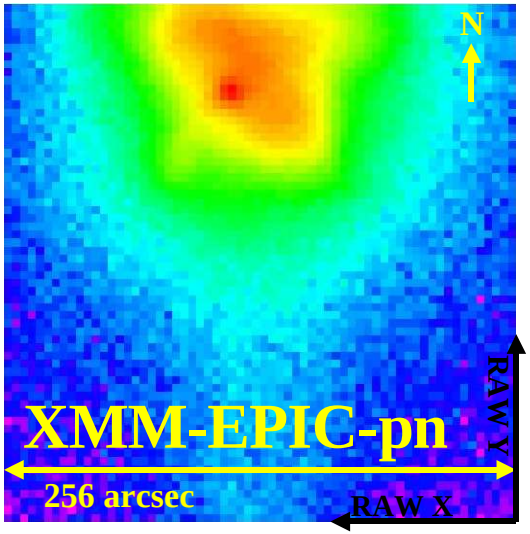



optical: Palomar, infrared: W M Keck, radio: VLA/NRAO:

# the Crab in X-ray

- 1963 Gurskey discovered x-ray source in Taurus region
- 1964 Bowyer located that source in the Crab region with an error box of 2˚x 2˚
- High energy Crab is smaller than low energy Crab (Staubert 75)
- Lx: 4.9 *$10^{37}$ erg/sec
- P: 33.1 ms
- Pdot: 36 ns/d
- Used as calibration source for balloon, rocket satellite born X-ray detectors

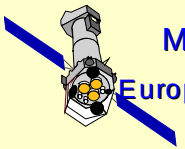


# Toor and Seward 1974

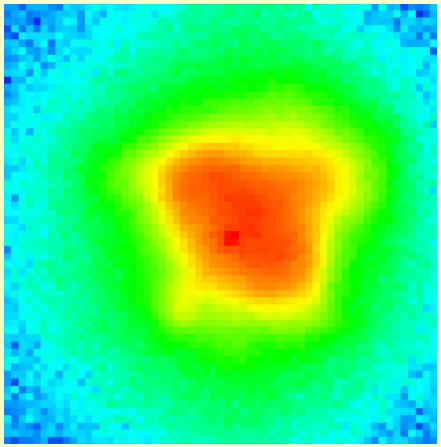
- Crab can be interpreted as a constant intensity source
- simple power law spectrum
- Used various observations with balloon, rocket and satellite born proportional Geiger and scintillation counters in energy ranges from 0.2-500 keV
- joint fit to past data: power law $\alpha=1.08\pm0.05$ and $N=9.5$ photons/keVcm$^2$s at 1 keV
- best spectral shape between 2-50 keV measured from their own experiment: a power law $\alpha=1.1\pm0.03$ and $N=9.7\pm1.0$ photons/keVcm$^2$s at 1 keV

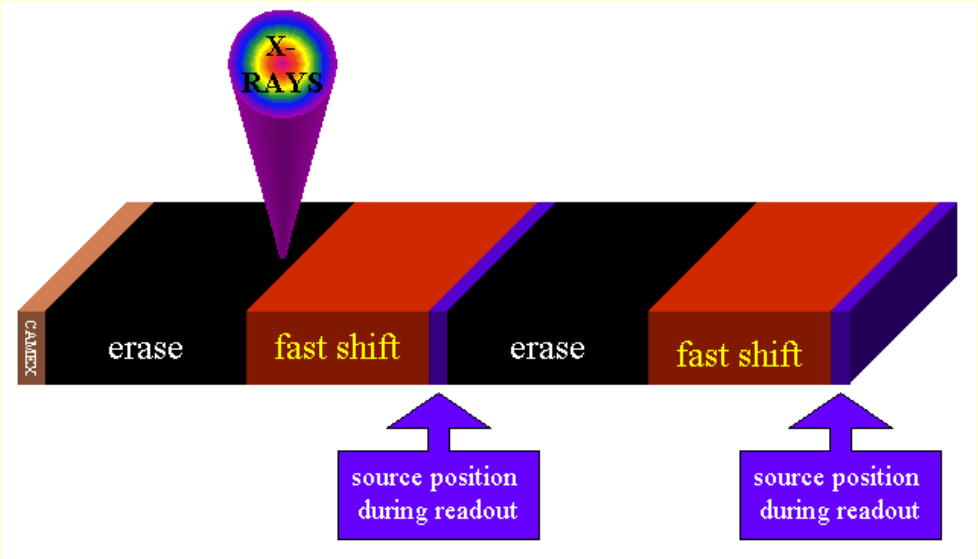
- Note: modern XSPEC notation: $\Gamma=\alpha+1$



# EPIC-pn observation

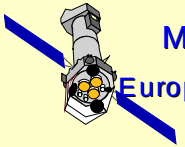
- Re-pointed such that the full nebula fell on the active CCD areas (checked in SW-mode)
- Observe in Burst mode:
  - fast transfer of pixels under PSF
  - time resolution: **7 µs**
  - life time only 3 %
  - Max. count rate (flux) point source [$s^{-1}$] ([mCrab]) : **60000 (6300)**





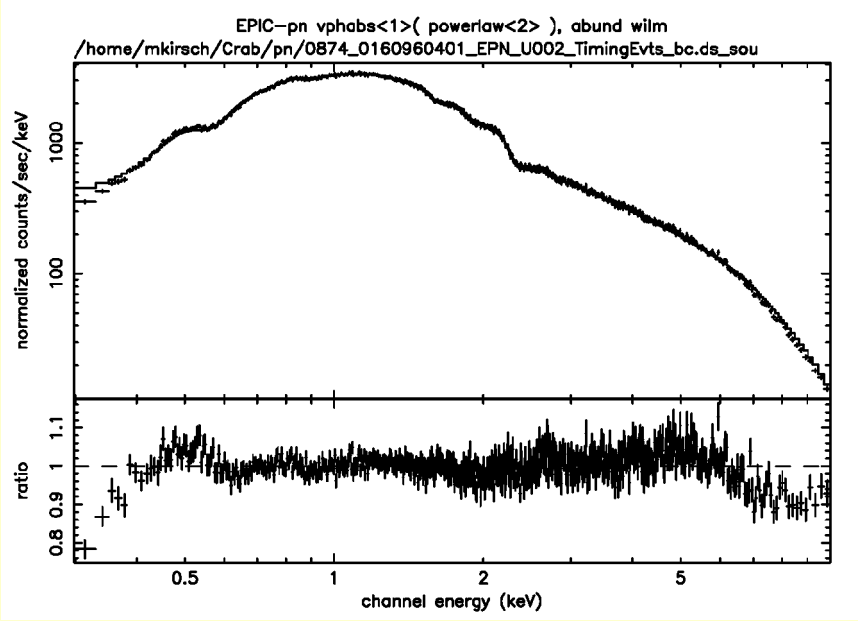
# Best fit model

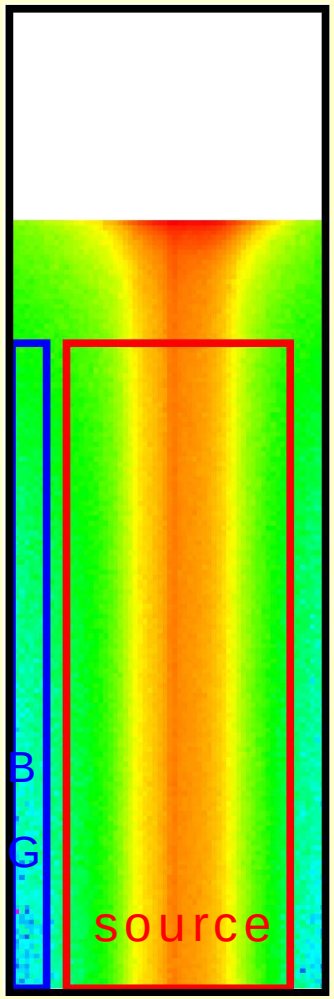
- simple absorbed power law
- question on the correct absorption model
- Based on an updated compilation of UV and optically derived abundances, *Wilms et al.* proposed new abundances with regards to the default XSPEC abundances of Anders and Grevesse
- For the Crab direction under-abundances in oxygen, neon and iron has been claimed by Willingale and Weisskopf .
- ***(v)phabs*powerlaw*** **using abundances of Wilms et al. and cross-sections of Balucinska-Church & McCammon or Verner et al.**
- Observations in the gamma-ray range typically indicate a steeper spectral shape but there is no general agreement on the best overall spectral model or the nature of the steepening



# Spectral EPIC-pn results

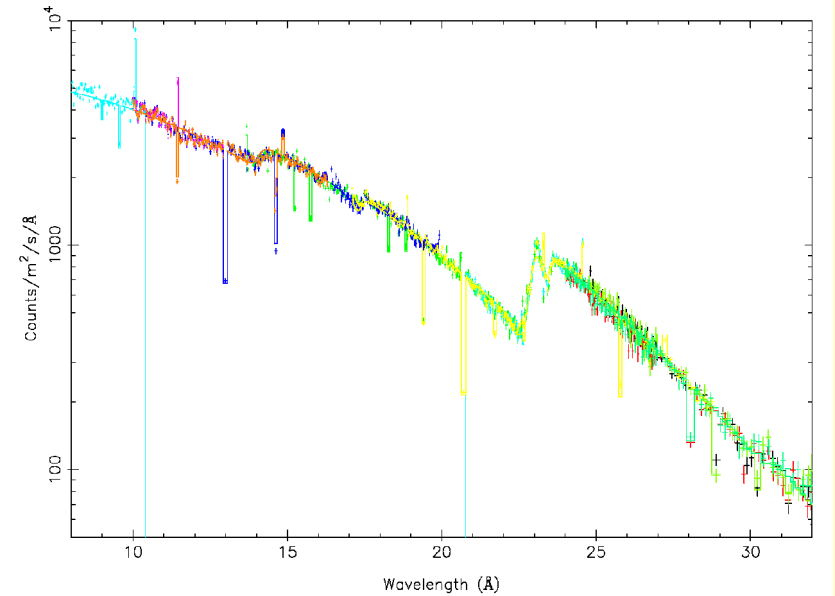
- $\Gamma$=2.118±0.005 N=8.56±0.05 $N_H$ = (4.04±0.03)·$10^{21}$ $cm^{-2}$
- variable abundances
  - O: 0.93±0.02,
  - Ne: 0.86±0.09
  - Fe: 0.76±0.08



# Spectral RGS results

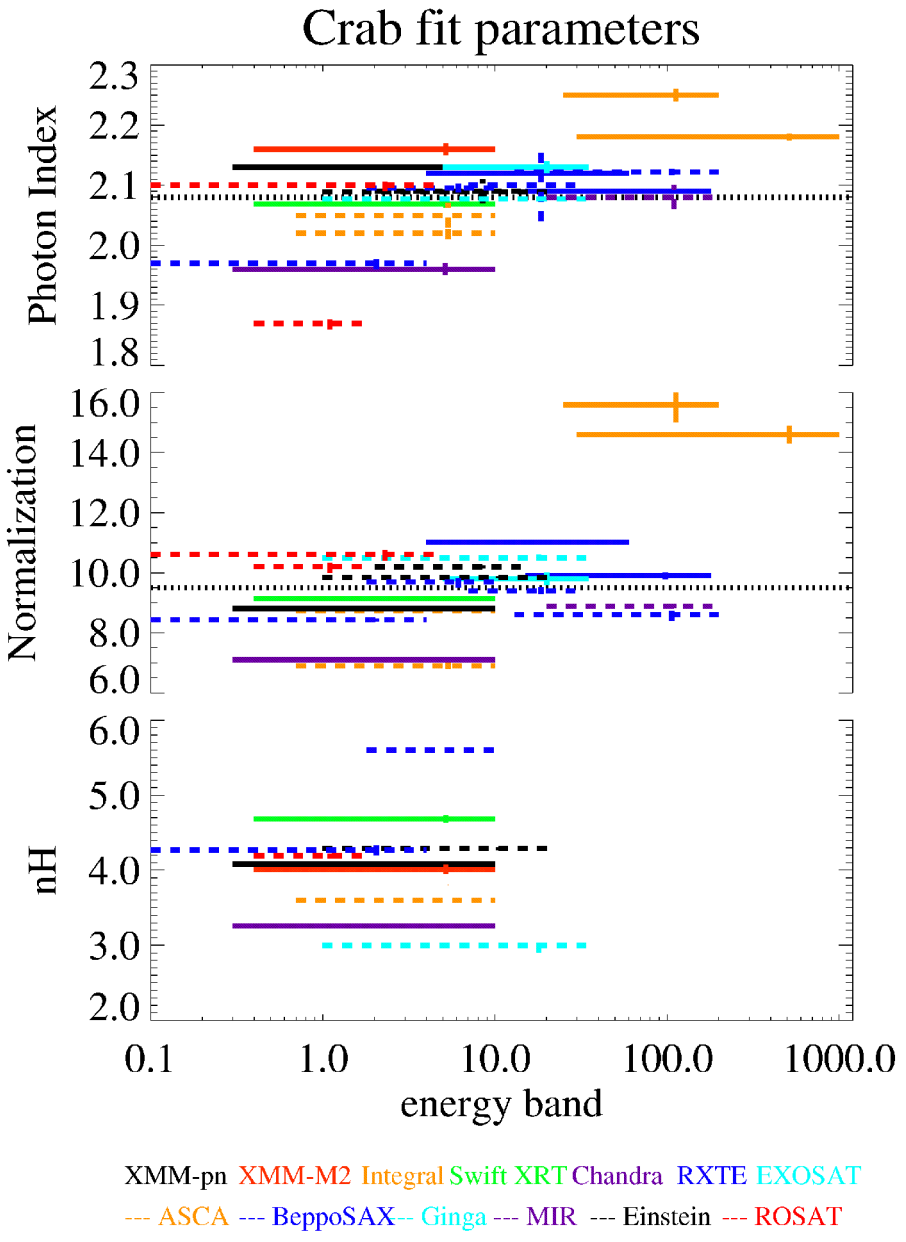
- high spectral resolution → depths of the absorption edges due to interstellar gas can be measured much better with the RGS than with any other instruments
- accurate column densities of individual elements
- Caution: nebula has a significant dust-scattering halo which may scatter a wavelength-dependent fraction outside the RGS aperture → serious at the longest wavelengths
- spectrum was extracted from data in which only 3 CCDs were used in order to avoid pile-up
- Solar Abundances:
  - H: 1 (=$37.7 \pm 0.04 \cdot 10^{21} cm^{-2}$)
  - C: 0
  - N: $1.04 \pm 0.13$
  - O: $0.93 \pm 0.007$,
  - Ne: $2.51 \pm 0.04$
  - Fe: $0.456 \pm 0.019$
- C not real but probably a consequence of dust scattering
- strong over-abundance of Ne and the under-abundance of iron may be signatures that line of sight contains significant amounts of dust



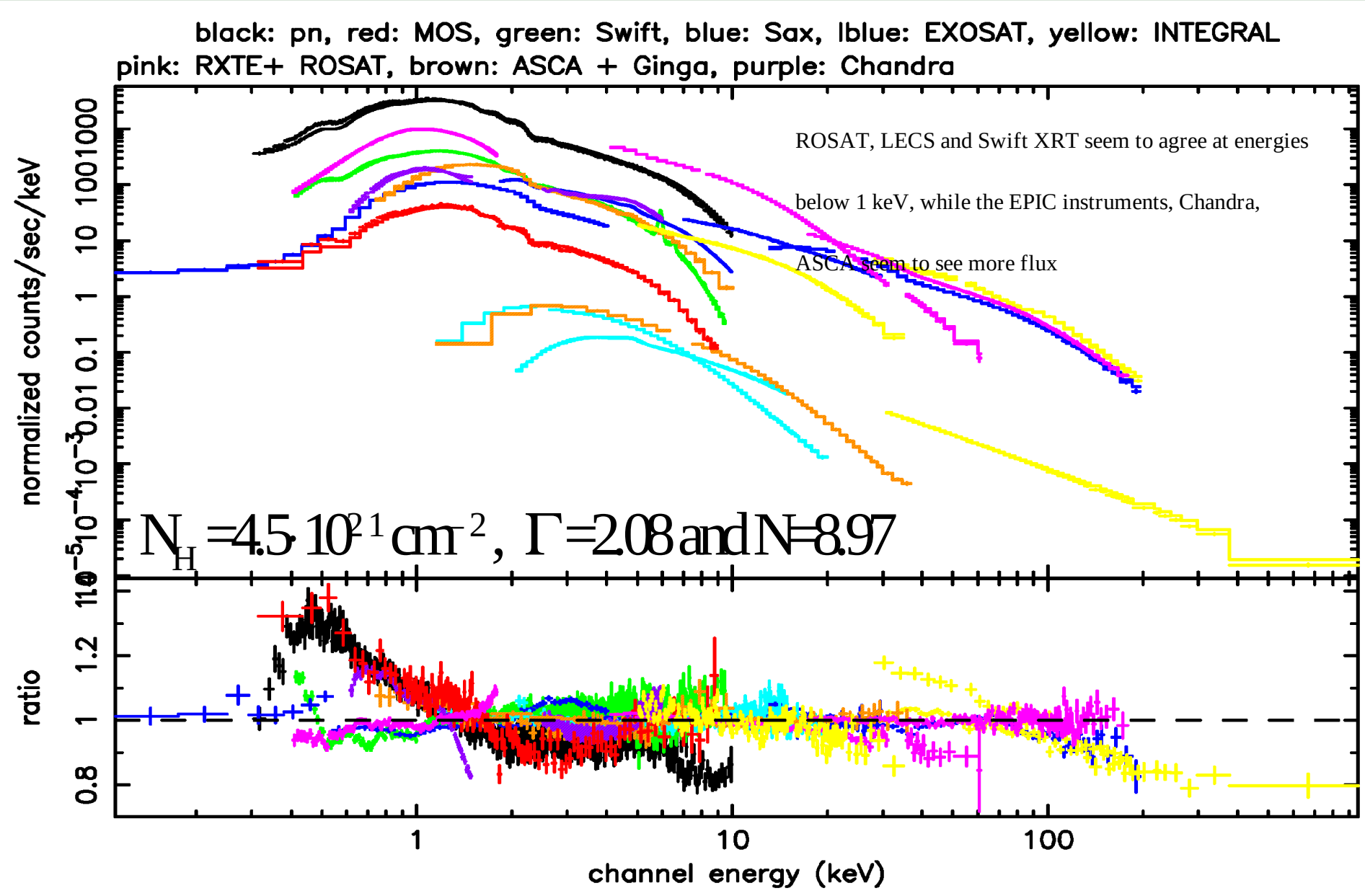
# Individual fits

- Model: *phabs*powerlaw* (abundances of Wilms et al. and cross-sections of Verner et al.)
- No systematic errors
- parameters for $N_H$ differ in absolute terms from previous values since we use a different absorption model and not the obsolete *wabs* model
- comparison of the 1 keV flux can be misleading for the high energy instruments since tiny differences in the power-law index are hugely magnified
- work is underway to determine the "best-fit flux" in several bands and to compare the flux for each instrument in the appropriate band to the "best-fit flux" in that band
- EPIC suggests a lower $N_H$ than BeppoSAX, Swift, EXOSAT, however those have been calibrated to the Crab
- ASCA, Ginga, Chandra $N_H$ is lower then EPIC (Chanra has pile-up problems)

- EPIC with their immense throughput can refine possibly the $N_H$ value of the Crab.



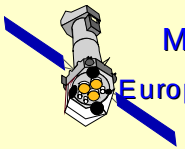
# Joint fit


black: pn, red: MOS, green: Swift, blue: Sax, lblue: EXOSAT, yellow: INTEGRAL
pink: RXTE+ ROSAT, brown: ASCA + Ginga, purple: Chandra
ROSAT, LECS and Swift XRT seem to agree at energies
below 1 keV, while the EPIC instruments, Chandra,
ASCA seem to see more flux
$N_H = 4.5 \cdot 10^{21}\ cm^{-2}$, $\Gamma = 2.08$ and $N = 8.97$
normalized counts/sec/keV
ratio
channel energy (keV)

# Conclusion

- Most of the instruments that have their main sensitivity range above 2 keV cannot be used efficiently to constrain the absorption towards the Crab and have been calibrated to fit canonical Crab parameters.
- XMM-Newton may revise the X-ray absorption of the Crab, given EPIC' s very high effective area in the low-energy regime.
- Photon index and normalization provided by EPIC agree within the errors of the Toor and Seward values taking also into account the systematic errors of EPIC on the photon index (0.05).
- Further work needs to be carried out to combine the RGS results of the under-abundances with the EPIC results.
- XMM-Newton may soon provide the best calibrated spectrum of the Crab. The current discrepancy between EPIC-pn and MOS in photon index is comparable to the scatter among all instruments.
- Resolving the pn-MOS discrepancy will provide a precise and accurate (and modern!) spectrum of the Crab with no assumptions about the spectrum built into the calibration. The modern spectrum will contain high-quality measurements of the absorption, in contrast to previous efforts.
- For energies above 30 keV the Crab is definitely difficult to use as calibration source. Since its spectrum is no longer a single power law no consensus obtains on the proper model of the spectrum which should be used for calibration tests. Different results may well be caused by the more complex character of these instruments which are generally difficult to calibrate and have a large intrinsic background that increases with energy

- Crab will be possibly too bright and too extended for future X-ray missions one may think about establishing a set of standard calibration sources for the X-ray regime



# The need for X-ray standards

- As much need in the X-ray domain for a set of objects to serve as photometric or spectrometric standards as at longer wavelengths
- The X-ray equivalents are much harder to define, not least because variability is a very common property of X-ray sources.
- Crab nebula has served as a reference which in common with other fainter SNRs is confidently expected to be constant, but may be to bright for future missions
- XMM-Newton has repeatedly observed a small set of objects that have been judged to serve as X-ray standards with the intention of both monitoring the evolution of instrument performance and providing straightforward comparisons with other instruments.
  see also talk M. Kirsch Tuesday 11:30
- strong need for a set of standard calibration sources for the X-ray regime  luxury situation of having 6 satellites (XMM-Newton, Chandra, RXTE, Swift, Integral, Astro-E2) in orbit that are having X-ray instruments as their payload for the coming years we strongly recommend to found an international calibration group that may steer the cross calibration efforts

**Splinter meeting for interested calibration people**

**Tuesday 2 August lunch break**