Phase resolved spectroscopy of the Crab with XMM-Newton

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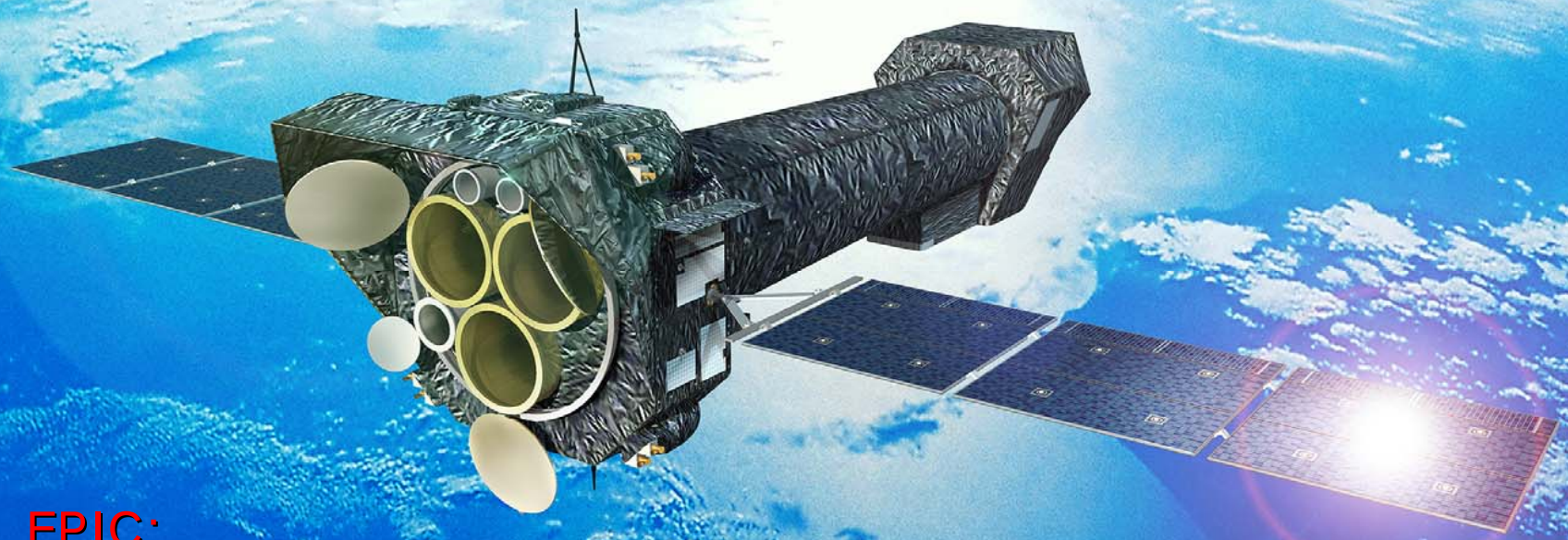
menu

- XMM-Newton and the Crab
- Localisation of the pulsar
- Spectra
- Spatial variation of photon index
- Phase resolved spectroscopy

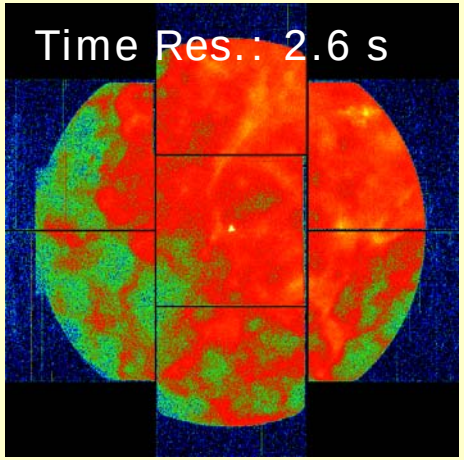
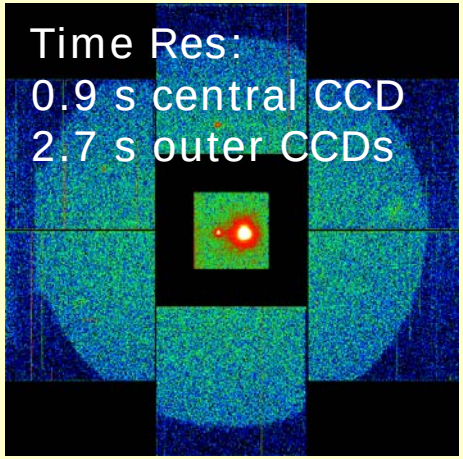
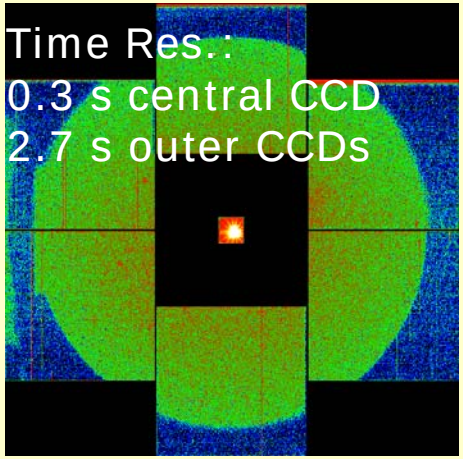
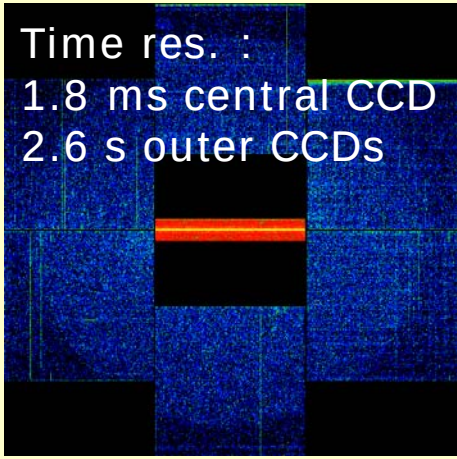
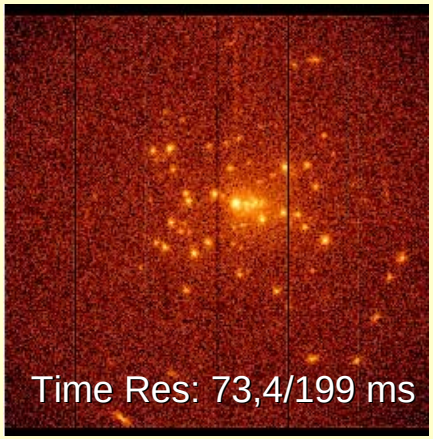
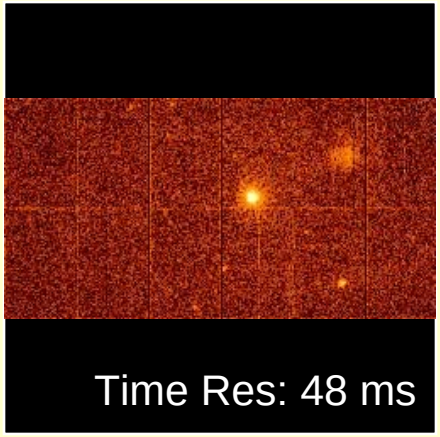
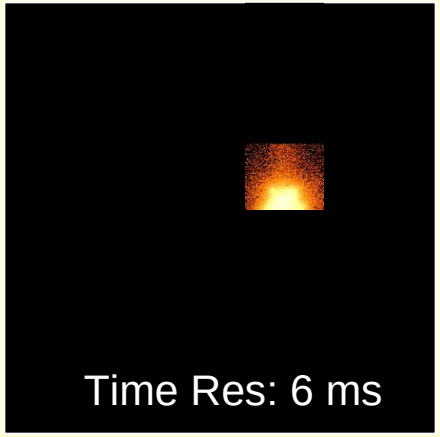
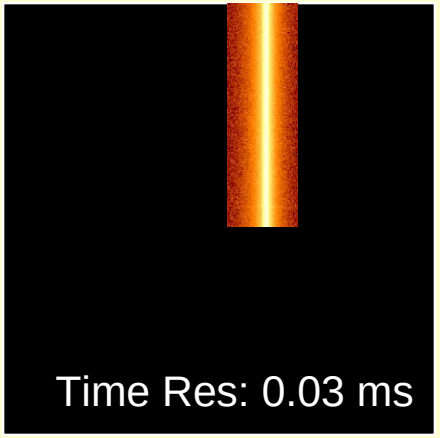
XMM-Newton

3 instruments: EPIC, RGS, OM

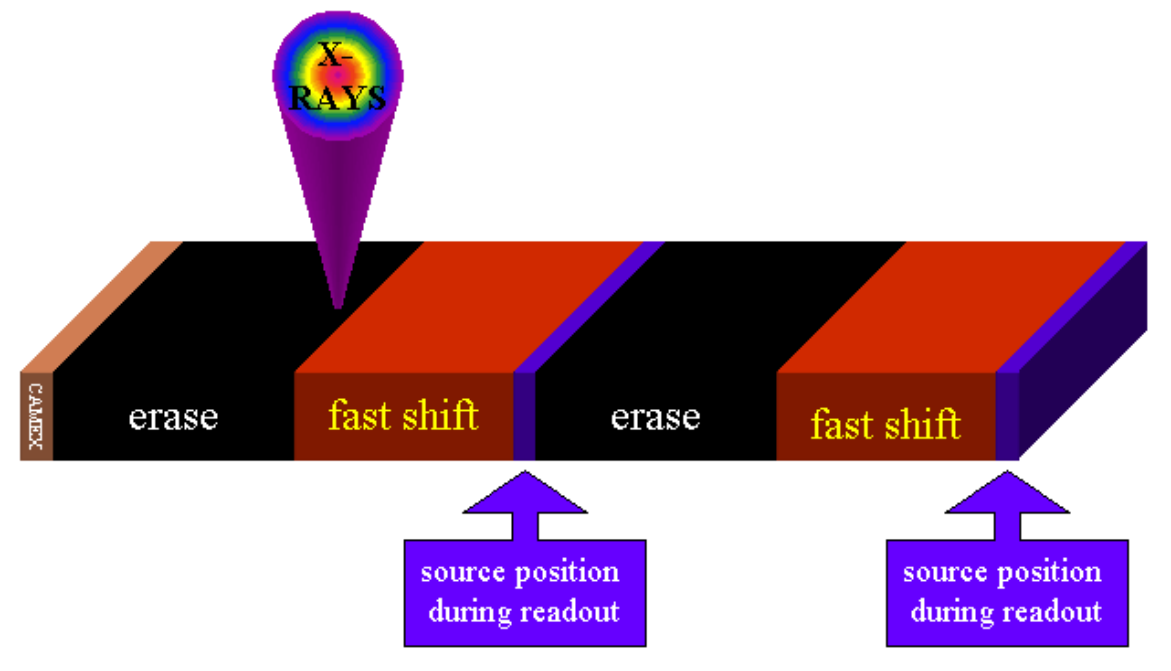


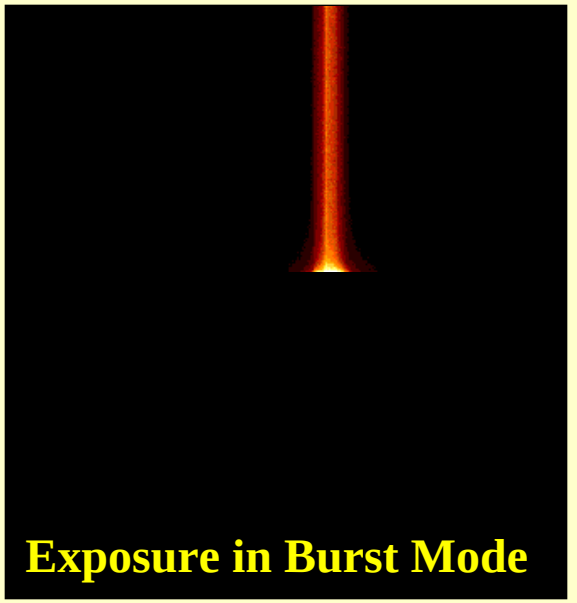
- EPIC:
  3 independent cameras (2 MOS & 1 PN),
  observing simultaneously the same field

EPIC operating modes

	Full Frame	Large Window	Small Window	Timing
MOS	 Time Res.: 2.6 s	 Time Res: 0.9 s central CCD 2.7 s outer CCDs	 Time Res.: 0.3 s central CCD 2.7 s outer CCDs	 Time res. : 1.8 ms central CCD 2.6 s outer CCDs
PN	 Time Res: 73,4/199 ms	 Time Res: 48 ms	 Time Res: 6 ms	 Time Res: 0.03 ms

EPIC-pn Burst Mode





- 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)**

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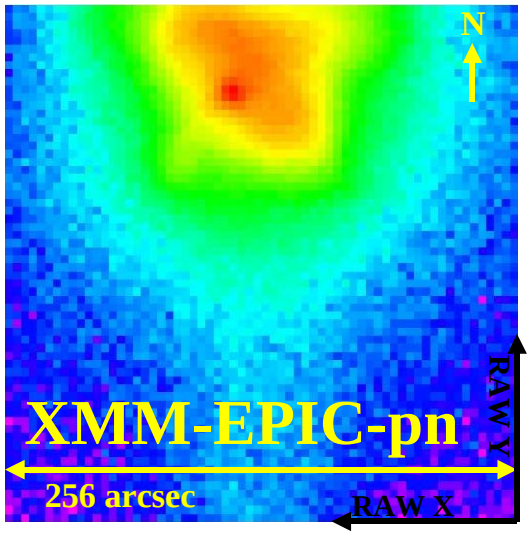
the Crab

- 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



observations

Obs ID	Revolution	Live Time [s]	Mode & Filter	Position Angle (α)
122330701	56	4327.7	Small W. Thick	269.58
135730701	234	298.1	Burst Thick	269.31
153750201	411	105.1	Burst Medium	267.34
153750301	411	181.7	Burst Medium	267.33
153750501	411	201.6	Burst Medium	267.33

← piled-up

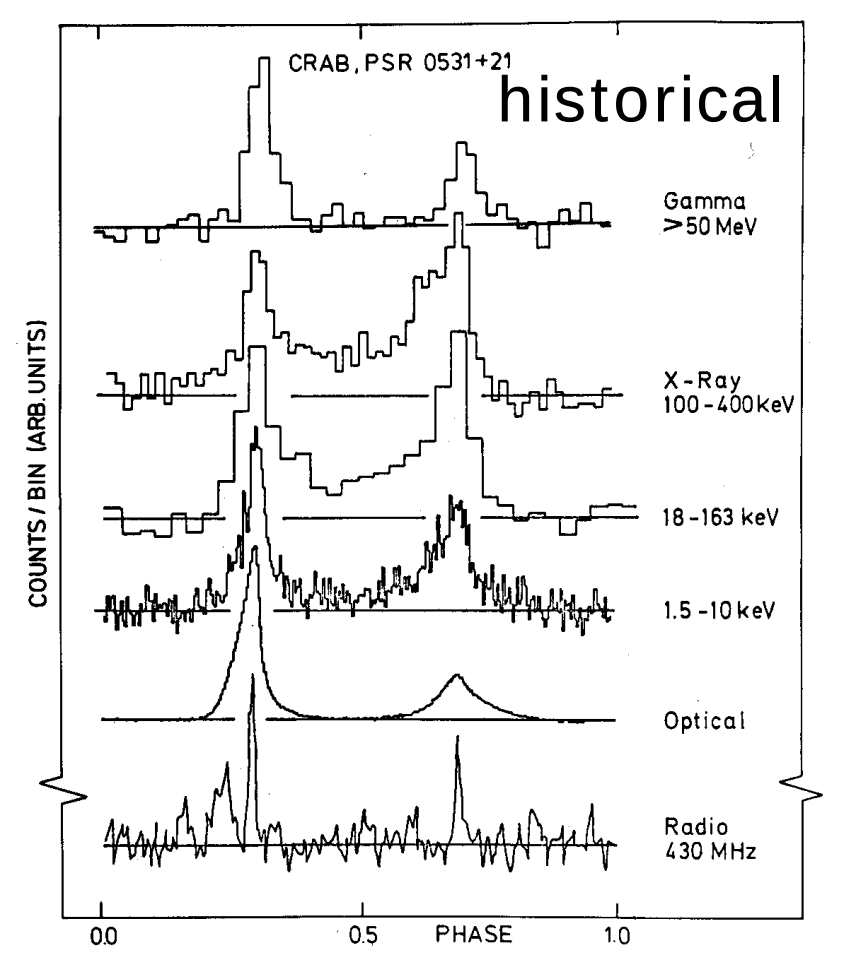
pile-up limit point source in SW
< 0.014 Crab

- **live time in Burst only 3 %**
- **counting mode in 411**

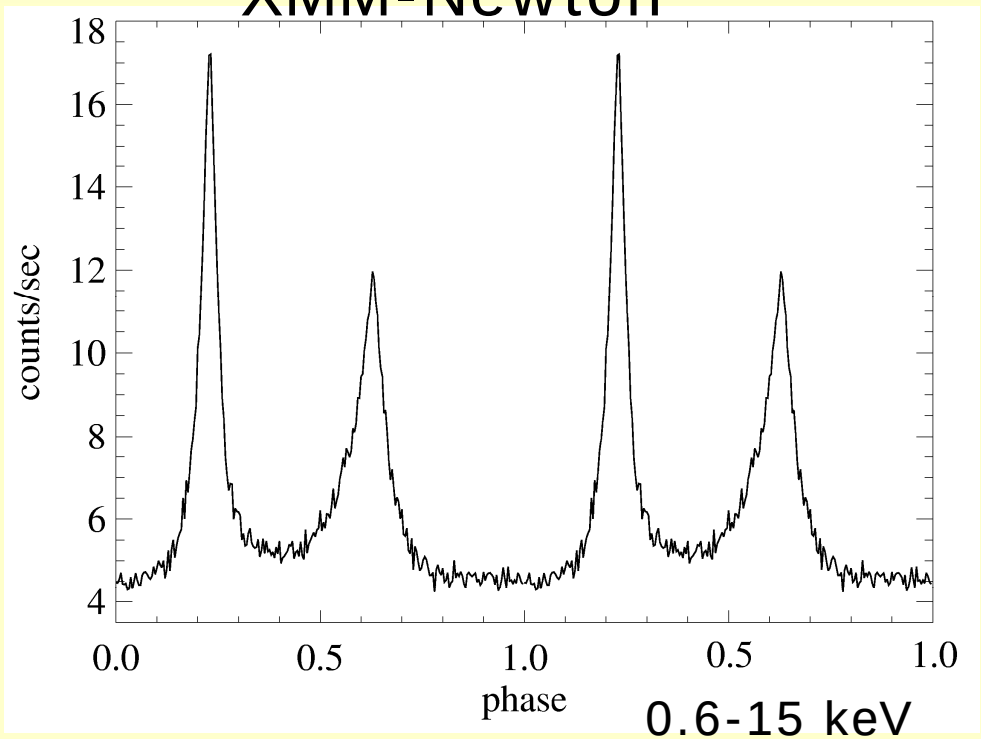
→ **800 sec**

merge 411 data and adjust to 238 data with phase shift for common analysis

the pulsar

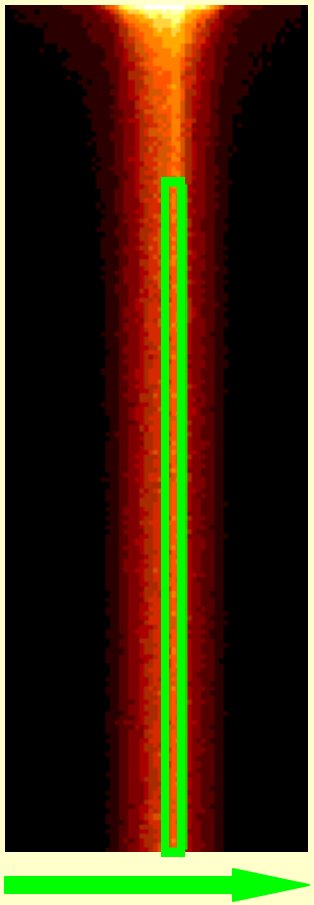


Exploring the X-ray Universe, P.A. Charlses & F.D. Seward, Courtesy of the plot: G. Bignami, CNR, Milan).

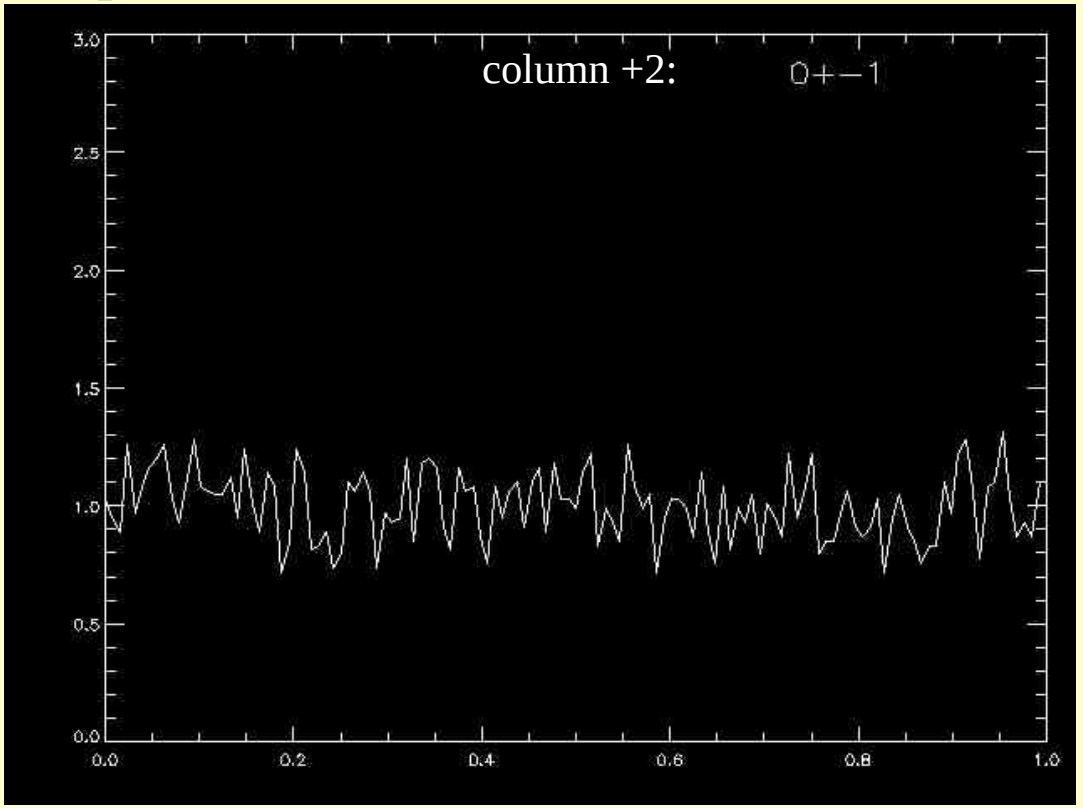


P=33.5341004590 +/- 1.7 10^{-9} ms
(Epoch 52340.6825136183 (MJD)
Relat. time error with EPIC-pn < some 10^{-9}

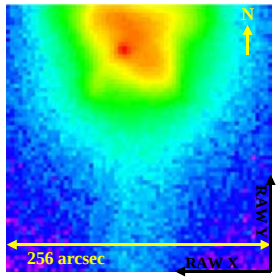
localization of pulsar -1

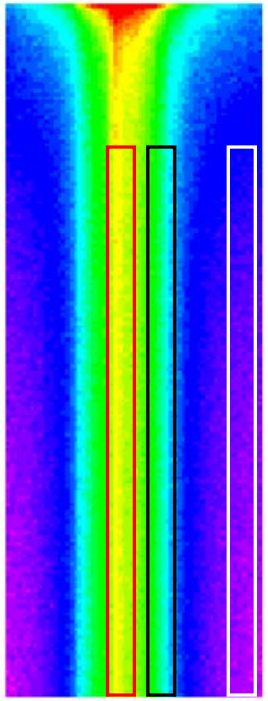


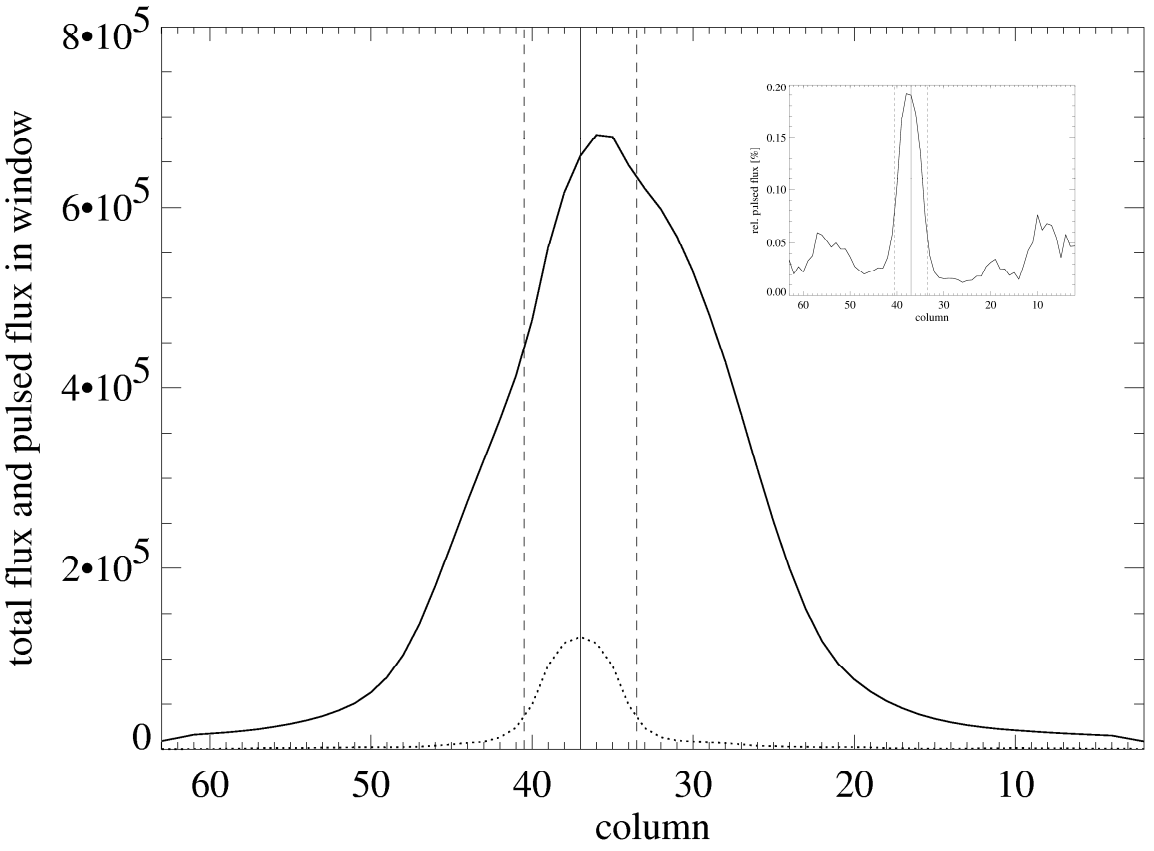
- localization of pulsar:
  running window in x direction and folding
  shows: pulsar is located in column 37± 3



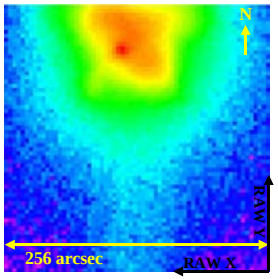
localization of pulsar -2







spectra



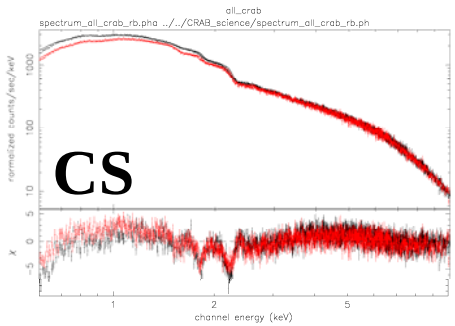
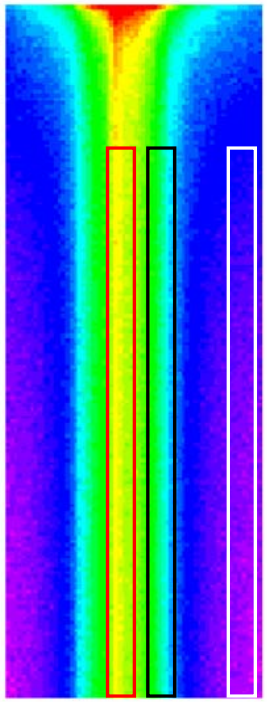
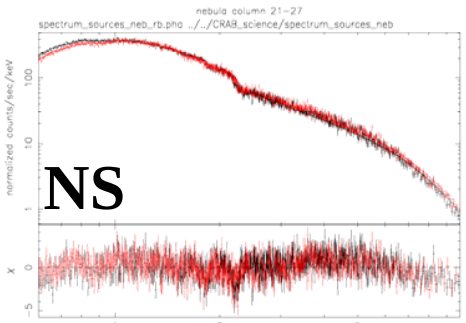


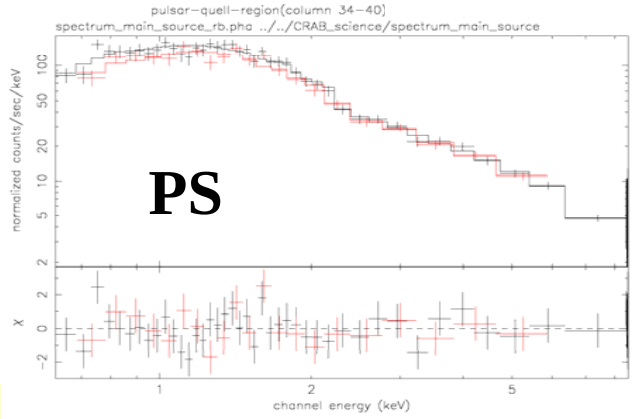
Table 2. Extracted spectra and extraction operations.

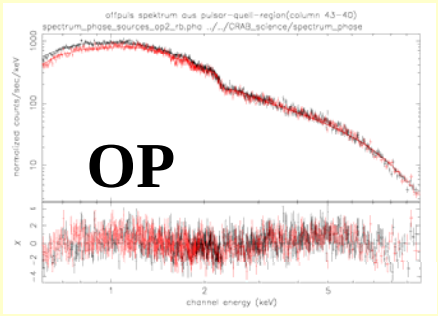
spec.	op.	N_H $10^{21}\,cm^{-2}$	PI	$\chi^2_{red}(dof)$
CS	C	2.65 ± 0.01	2.079 ± 0.004	2.54(3025)
PS	P-O2	2.88 ± 0.45	1.718 ± 0.080	0.88(72)
NS	N-B	2.81 ± 0.05	2.272 ± 0.012	1.38(1445)
OS	O2-B	2.68 ± 0.06	2.058 ± 0.015	1.30(1115)

CS: Crab spectrum, PS: Pulsar spec., NS: nebula spec., OP: OFF-puls spec.
C: all Crab (column 22–51), P: pulsar region (column 34–40), N: nebula region (column 21–27), B: background region (column 1–7), O1: OFF-pulse region (column 22–51), O2: OFF-puls region (column 34–40)

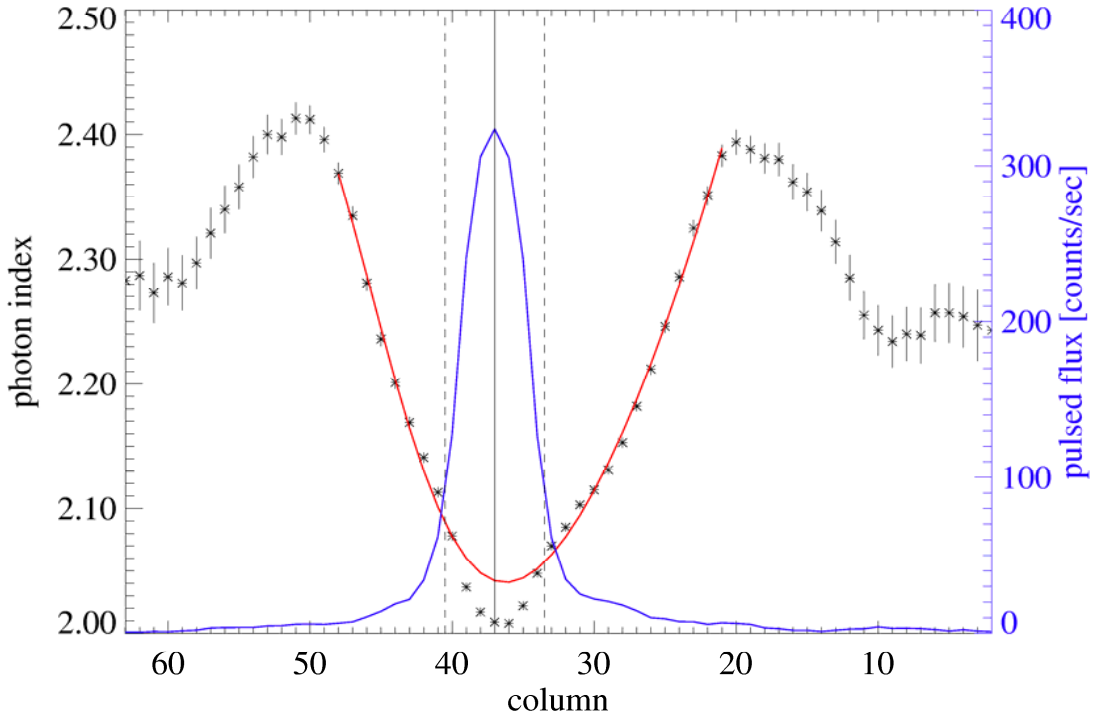






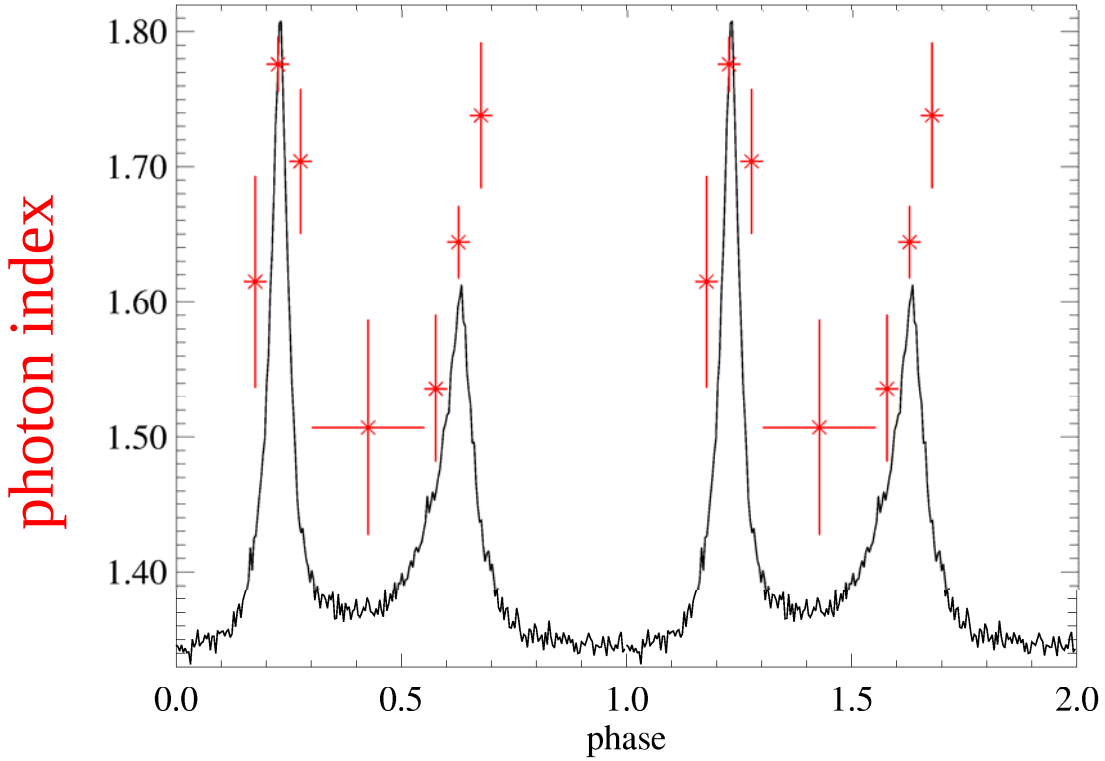


spatial variation of PI



- fit to data of 3 column wide window in X-direction absorbed powerlaw
- fix N_H to nebula value
- In pulsar region (columns 34-40), spectrum is the hardest
- also the highest pulse fraction was found in 34-40
- the spectrum of the background regions is the real X-ray background spectrum which is harder than the not background subtracted nebula spectrum.

phase resolved spectroscopy



- 7 phase intervals
- photon index with fixed N_H (OFF pulse value)
- bg: OFF-pulse region of columns 34-40 with phase 0.8-1.0 excluding events with RAWY>= 142

- change of the spectral index correlated with the pulse phase.
- second pulse shows a harder spectrum than the first
- intermediate pulse region again a harder spectrum than the two pulses.
- spectrum of the intermediate pulse region is harder than the spectrum of the main pulse by 0.3.
- spectrum of the second pulse is harder than the spectrum of the main pulse by 0.1.

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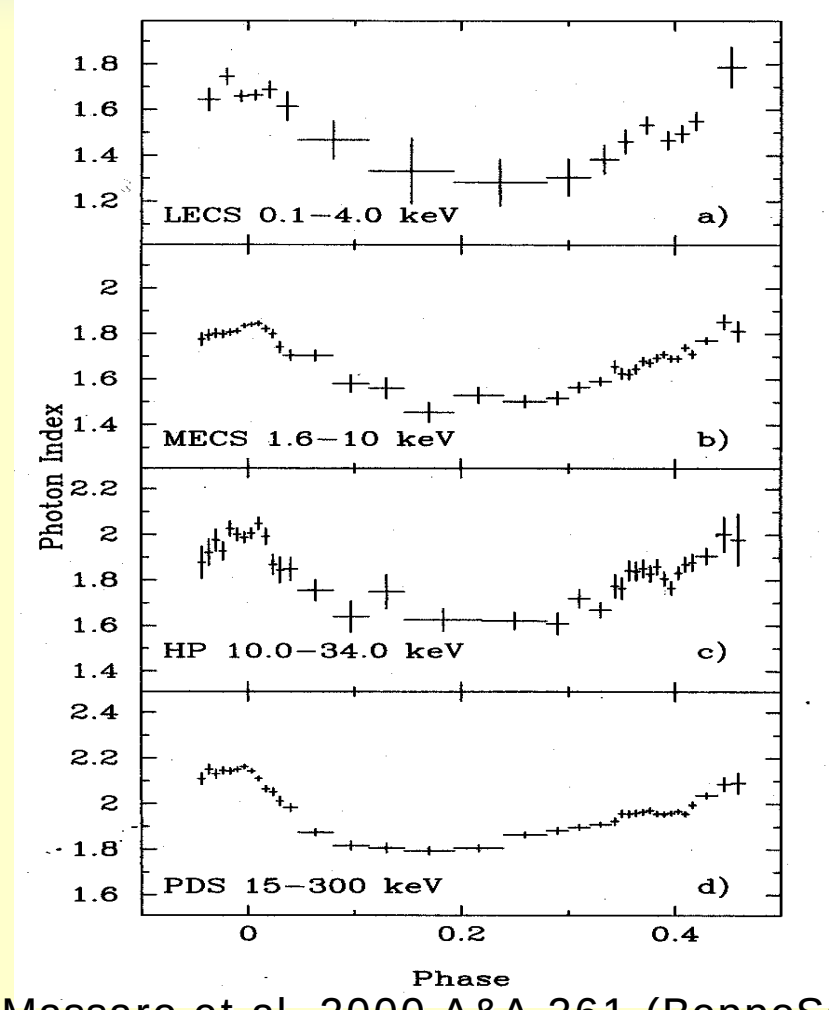
phase resolved spectroscopy

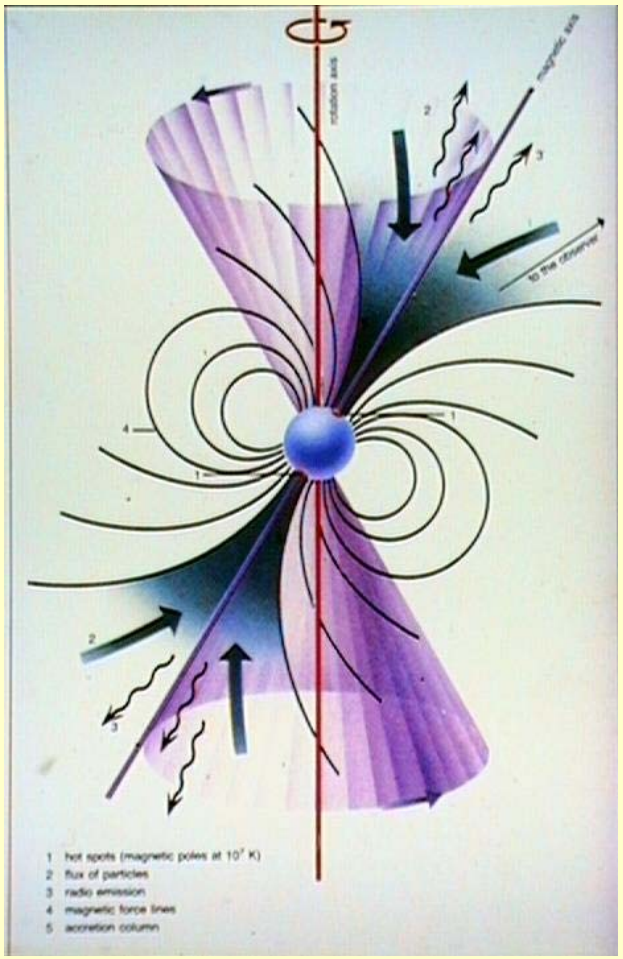


Massaro et al. 2000 A&A,361 (BeppoSax)

- qualitatively the same results as Massaro et al. 2000 A&A,361 (BeppoSax)
- and Pravdo et al. 1997ApJ,491 (RXTE)

theory

- Polar cap models Daugherty & Harding, 96 Sturner & Dermer, 96
- hollow-cone emission from a single magnetic pole
- two main peaks correspond to the crossing of the cone annulus by the line of sight.
- hardening of the spectrum in the inter-peak region, where one looks directly on the magnetic pole, is explained by pure curvature radiation
- in the outer rim, this curvature radiation is softened by the contribution of cascades producing a softer spectrum



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conclusion

- XMM-Newton results are qualitatively inline with former analyses of BeppoSax and RXTE data
- XMM-Newton is able to perform phase resolved spectroscopy with high time resolution even for the brightest sources like the Crab
- relative time accuracy of EPIC-pn: $\Delta P/P \approx 10^{-9}$
- **FYI: recently fixed absolute timing problem: absolute timing now ~ 300-600 μs**