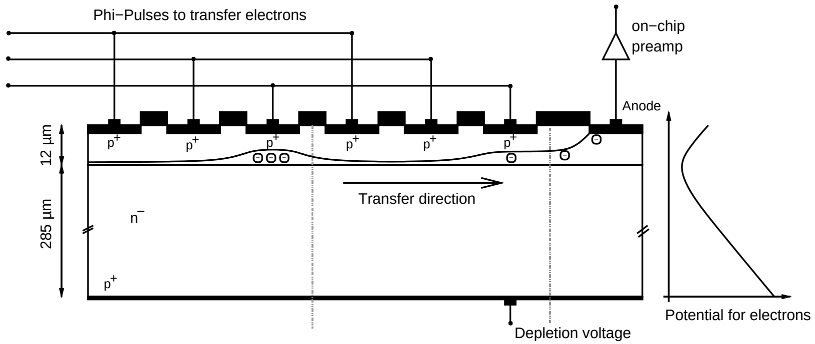
Backside Illuminated CCDs

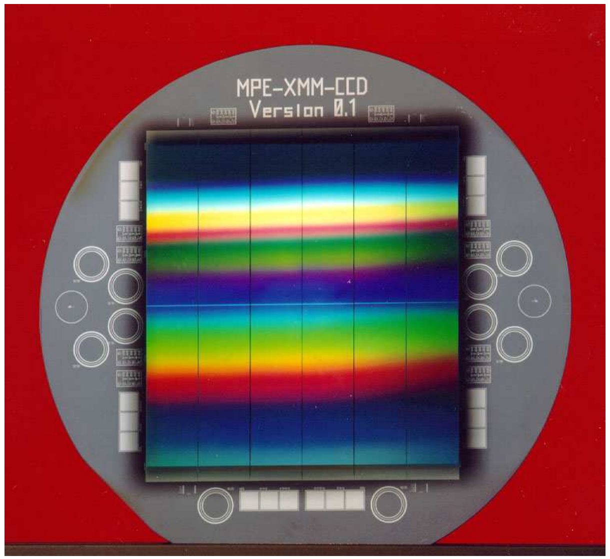


Schematic structure of the *XMM-Newton* EPIC pn CCD.

Problem: Infalling structure has to pass *through* structure on CCD surface $\Longrightarrow$ loss of low energy response, also danger through destruction of CCD structure by cosmic rays. . .

Solution: Irradiate the back side of the chip. Deplete whole CCD-volume, transport electrons to pixels via adequate electric field (“backside illuminated CCDs”)

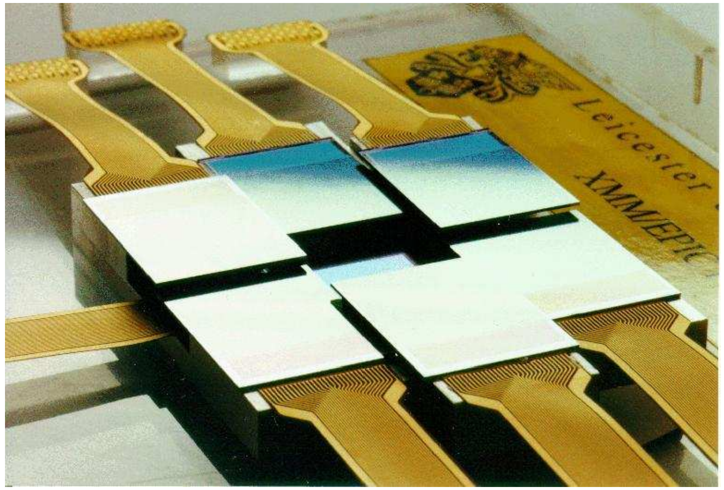
XMM-Newton: EPIC-pn CCD



XMM-Newton: Array of individual backside illuminated CCDs on one Silicon wafer $\Longrightarrow$ requires extreme care during production

at the time of production one of the most complex Silicon structures ever made (diameter: 65.5 mm)

XMM-Newton: EPIC-pn CCD



XMM-Newton (EPIC-MOS; Leicester): 7 single CCDs with 600×600 pixels, mounting is adapted to curved focal plane of the Wolter telescope.

Data Analysis

optical CCDs: mesure intensity $\Longrightarrow$ need *long* exposures

X-ray CCDs: measure individual photons $\Longrightarrow$ need fast readout

bright sources: several 1000 photons per second $\Longrightarrow$ readout in μs!

In X-rays: spectroscopy possible. Typical resolution reached today:

$$\frac{\Delta E}{E} = 2.355 \sqrt{\frac{3.65\,\text{eV} \cdot F}{E}} \tag{5.8}$$

with $F \sim 0.1 \Longrightarrow \sim 0.4\%$, so much better than gas detectors.

Energy $\propto$ number N of initial photoelectrons $\Longrightarrow$ Energy resolution (Poisson statistics!):

$$\frac{\Delta E}{E} \propto \frac{\Delta N}{N} = \frac{N^{1/2}}{N} = \frac{1}{N^{1/2}} \propto E^{-1/2} \tag{5.9}$$

For both optical and X-rays: sensitivity close to 100%

Si-based CCDs are currently the best available imaging photon detectors for optical and X-ray applications.

Data Analysis

Finite resolution of X-ray detectors has major implications for X-ray data analysis.

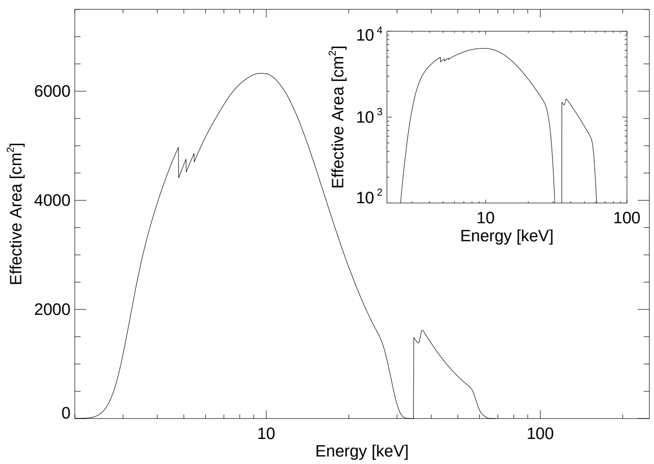
Mathematical description of the X-ray measurement process:

$$n_{\text{ph}}(c) = \int_0^\infty R(c, E) \cdot A(E) \cdot F(E)\, dE \tag{5.10}$$

where

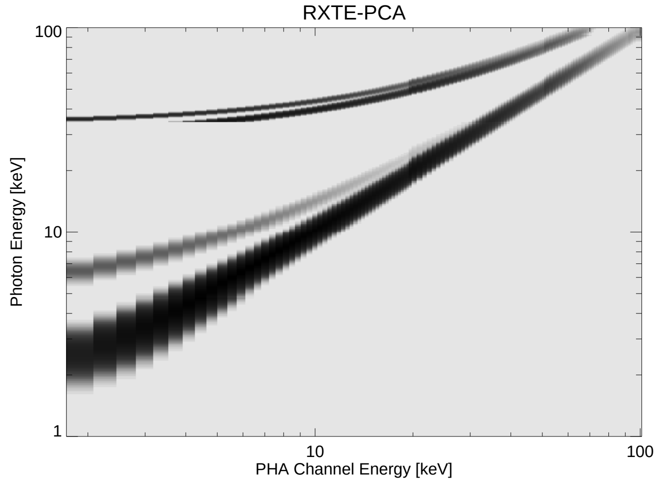
- $n_{\text{ph}}(c)$: source count rate in channel c (counts s^{-1}),
- $F(E)$: photon flux density (ph $cm^2\, s^{-1}\, keV^{-1}$),
- $A(E)$: effective area (units: cm^2),
- $R(c, E)$: detector response (probability to detect photon of energy E in channel c).

Data Analysis



Effective Area of the Rossi X-ray Timing Explorer's Proportional Counter Array (Xe gas detector).

Data Analysis



Response Matrix of the RXTE-PCA. Note the secondary peaks in the response caused by escaping Xe Kβ and Xe Lα photons.

Data Analysis

To analyze data: discretize Eq. (5.10):

$$S_{\text{ph}}(c) = \Delta T \sum_{i=0}^{n_{ch}} A(E_i) R(c, i) F(E_i) \Delta E_i \tag{5.11}$$

where $N_{\text{ph}}(c)$: total source counts in channel c, ΔT: exposure time (s), x$A(E_i)$: effective area in energy band i ("ancilliary response file", ARF), $R(c, i)$: response matrix (RMF), $F(E_i)$: source flux in band (E_i, E_{i+i}), ΔE_i: width of energy band.

Because of background $B(c)$ (counts), what is measured is

$$N_{\text{ph}}(c) = S_{\text{ph}}(c) + B(c) \tag{5.12}$$

So estimated source count rate is

$$\tilde{S}_{\text{ph}}(c) = N_{\text{ph}}(c) - B(c) \tag{5.13}$$

with uncertainty (Poisson!)

$$\sigma \tilde{S}_{\text{ph}}(c) = \sqrt{N_{\text{ph}}(c)^2 + B(c)^2} \tag{5.14}$$

Data Analysis

To get physics out of measurement, need to find $F(E_i)$.

Big problem: In general, Eq. (5.11) is *not invertible*.

$\Longrightarrow$ χ^2-minimization approach

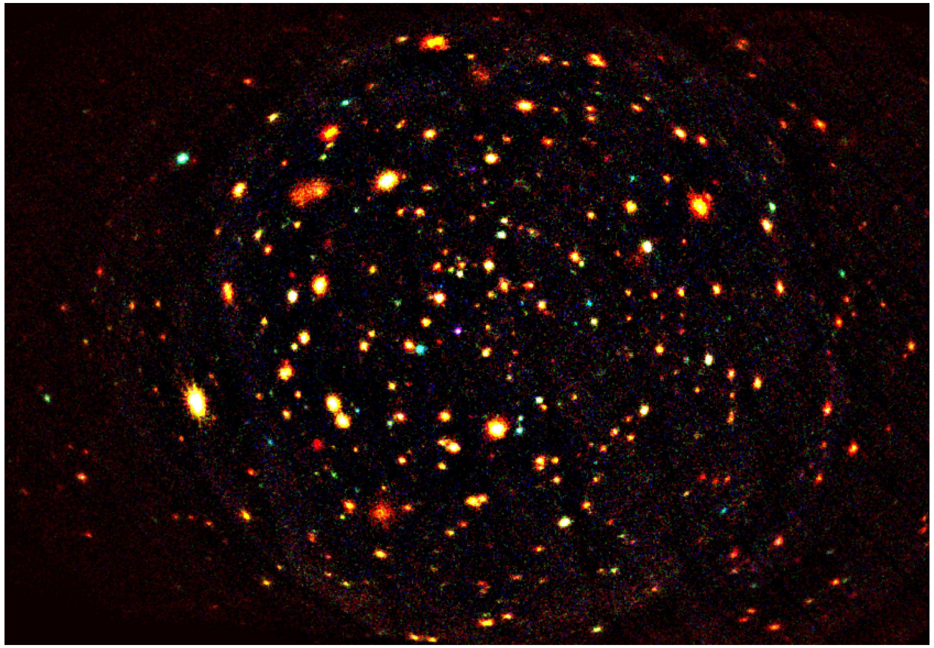
Use a model for the source spectrum, $F(E;\boldsymbol{x})$, where $\boldsymbol{x}$ vector of parameters (e.g., source flux, power law index, absorbing column,...), and calculate predicted model counts, $M(c;\boldsymbol{x})$, using Eq. 5.11).

Then form χ^2-sum:

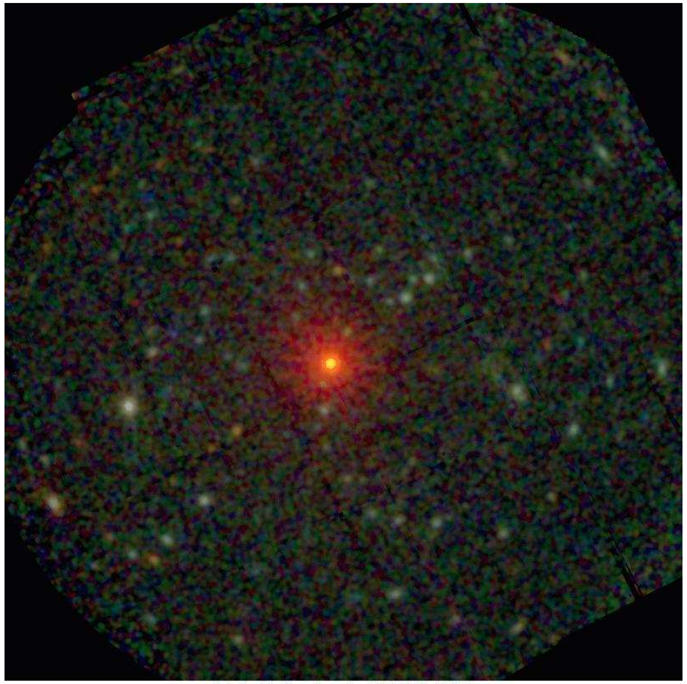
$$\chi^2(\boldsymbol{x}) = \sum_c \frac{\left(\tilde{S}_{\text{ph}}(c) - M(c;\boldsymbol{x})\right)^2}{\sigma\tilde{S}_{\text{ph}}(c)^2} \tag{5.15}$$

Then vary $\boldsymbol{x}$ until χ^2 is minimal and perform statistical test based on χ^2 whether model $F(E;\boldsymbol{x})$ describes data.

Programs used: `XSPEC`, `ISIS`



Lockman-Hole with *XMM-Newton*: The Universe is full of AGN!



The isolated neutron star RX J0720.4-3125

Image courtesy of F. Haberl

European Space Agency

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Aschenbach, B., 1985, Rep. Prog. Phys., 48, 579