MONTE CARLO CALIBRATION UNCERTAINTIES: XMM-NEWTON EPIC-PN

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MC APPROACH

• Adopt same approach as for Chandra, realized in XSPEC MC and PyBLoCXS methods

• Currently just including inter-edge “perturbation function” method - see Appendix

• Input uncertainties currently pure JJD guesswork - can work with XMM team to include improved guesses, and any instrument numerical/analytical model info available

• In this example we use the “Medium” EPIC-pn filter
**INPUT FILE**

- File consists of uncertainty data for each instrument subassembly (MM=multi-mirror, OBFM=optical blocking filter medium, etc)

- Each line refers to an energy range (in keV) bounded by instrument edges

- Format: Emin, Emindev, Emax, Emaxdev, Edgeveto, maxdiff (see Appendix for details)

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EXERCISE: LIMITING ACCURACY OF EPIC-PN

- Same approach as previously applied to Chandra ACIS-S:
  - Simulate spectrum ("fakeit")
  - Fit using different effective area realisations a lot of (e.g. 1000) times
    - Sherpa driven by Python
    - Models: blackbody, MEKAL, power-law; all with ISM absorption
  - Compare with fits to 1000 different "fakeits" using nominal area to probe uncertainties from only counting statistics
FITTED PARAMETER DISTRIBUTIONS

Absorbed Power Law: $\alpha=1.5$, $n_H=10^{21}$

Different spectrum realisations
Different area realisations

$1 \times 10^5$ counts

$N_H$ ($10^{22}$ atoms cm$^{-2}$)  $\alpha$  norm
10^3 counts: Poisson noise dominates calibration uncertainties
FITTED PARAMETER DISTRIBUTIONS

- $10^5$ counts: **calibration uncertainties** dominate Poisson noise
XMM EPIC-PN PRECISION

Absorbed Powerlaw, $N_H=0.1 \times 10^{22}$, $\alpha=1.5$

Different spectrum realisations
Different area realisations
SUMMARY

- A fairly simple MC analysis using JJD-invented uncertainties for XMM-Newton EPIC-pn finds that the limiting precision is reached for about 10,000 counts; ie increasing exposure time to get more counts does not help the accuracy of the fit.

- Analysis can be repeated for “real” uncertainty data.
APPENDIX: NOTES ON METHODOLOGY
MONTE CARLO APPROACH

Analytical solutions difficult....

- Moore’s law: since initial thoughts and ideas, computer power sufficiently advanced to allow brute-force Monte Carlo methods:
  - Simulate 100’s-1000s of response functions that sample nominal response and its uncertainties
  - Repeat parameter estimation and examine distributions of “best-fit” parameters
METHOD APPLIED TO ACIS-S3

• Parameterised instrument models where available; vary parameters, re-compute response, eg:
  • Mirror trial models
  • CCD QE, contamination, RMF models
• Use a “perturbation function” – a perturbation vs E by which to change subassembly responses between edges
METHOD APPLIED TO ACIS-S3

Uncertainties in Photon Path

- HRMA: geometry, obscuration, reflectivity, scattering
- ACIS OBF: transmittance, contamination
- ACIS QE: (CTI, dead time, cosmic rays, electronics...)
- ACIS RMF: (gain distribution, escape peaks...)
METHOD APPLIED TO EPIC-PN

Uncertainties in Photon Path

- MM: perturbation function for reflectivity, obscuration etc
- OBF: perturbation function for transmittance, contamination
- EPIC QE: perturbation functions
- RMF: not yet included
2014: Added “maxdiff” - the maximum difference allowed between nominal (=1) and perturbed area.
- controls curvature in function, prevents unrealistic deviations
FOR HRMA WE ALSO USE RAY-TRACE MODEL AREAS

Equal probabilities, except x2 for model f
HOW ARE CALIBRATION UNCERTAINTIES DISTRIBUTED?

• Rigorous treatment requires knowledge of how uncertainties are distributed
  • Unknown!

• Assume a truncated normal distribution $-1\sigma$ to $+1\sigma$
  • Peaked at preferred value

• Includes gut feeling!
RESULTING ACIS-S3 AREAS

![Graph showing effective area vs energy](image)

- Nominal response

- Effective area (cm²)
- Energy (keV)