JEREMY DRAKE, PETE RATZLAFF, VINAY KASHYAP
AND THE MC CALIBRATION UNCERTAINTIES TEAM

MONTE CARLO CONSTRAINTS ON INSTRUMENT CALIBRATION

11th IACHEC Meeting, Pune March 2016

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OUTLINE

- Brief review of our MC uncertainties method
- Using observations as MC calibration constraints: G21.5-0.6
- Using observations and MC methods for cross-calibration

MONTE CARLO APPROACH TO CALIBRATION UNCERTAINTIES

Highly correlated - analytical solutions difficult….

- Use brute-force Monte Carlo methods instead:
  - Simulate 100's-1000s of response functions that sample nominal response and its uncertainties
  - Repeat parameter estimation and examine distributions of "best-fit" parameters
  - Can be used to understand the true accuracy of flux measurements, parameter fits… and refine the calibration itself

CONTEXT WITH PYBLOCXS, STATISTICS APPROACHES

Finesse

Brute Force

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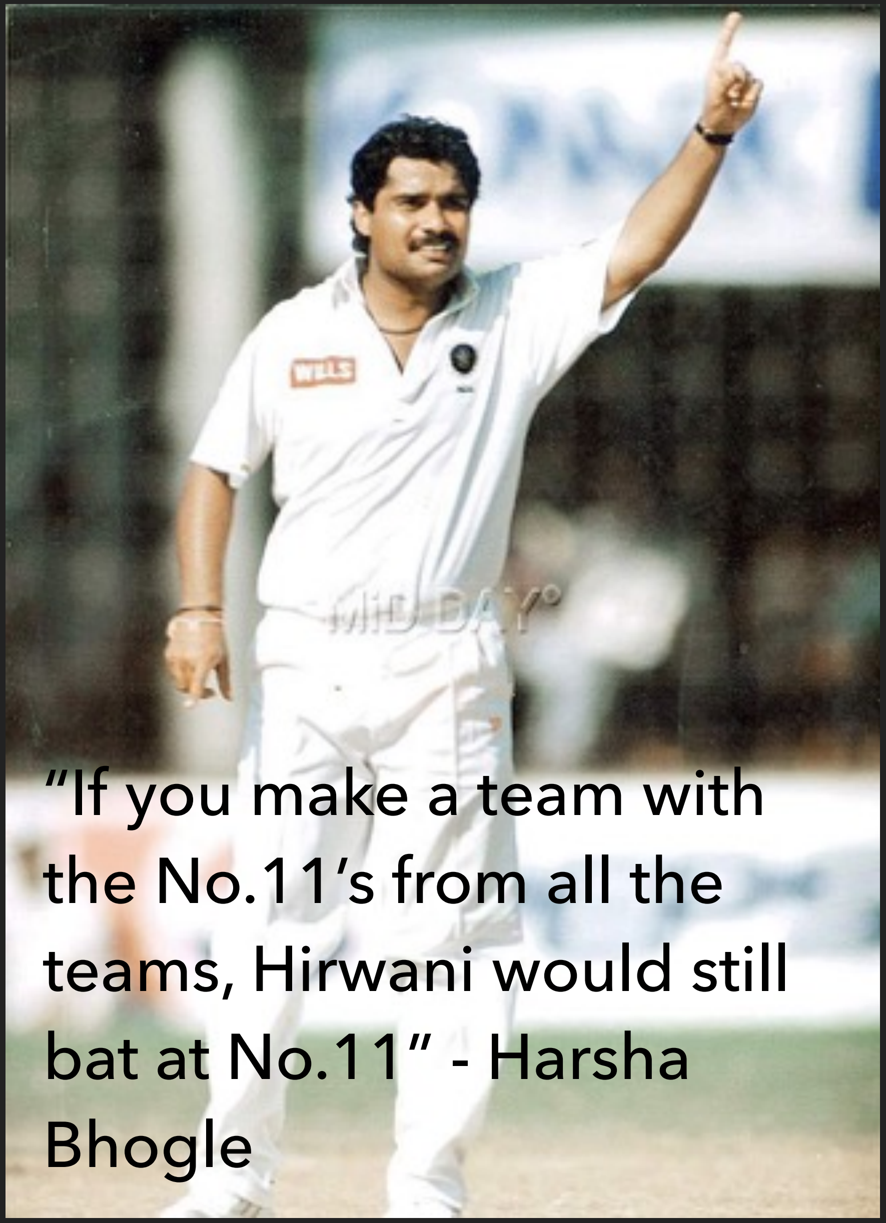
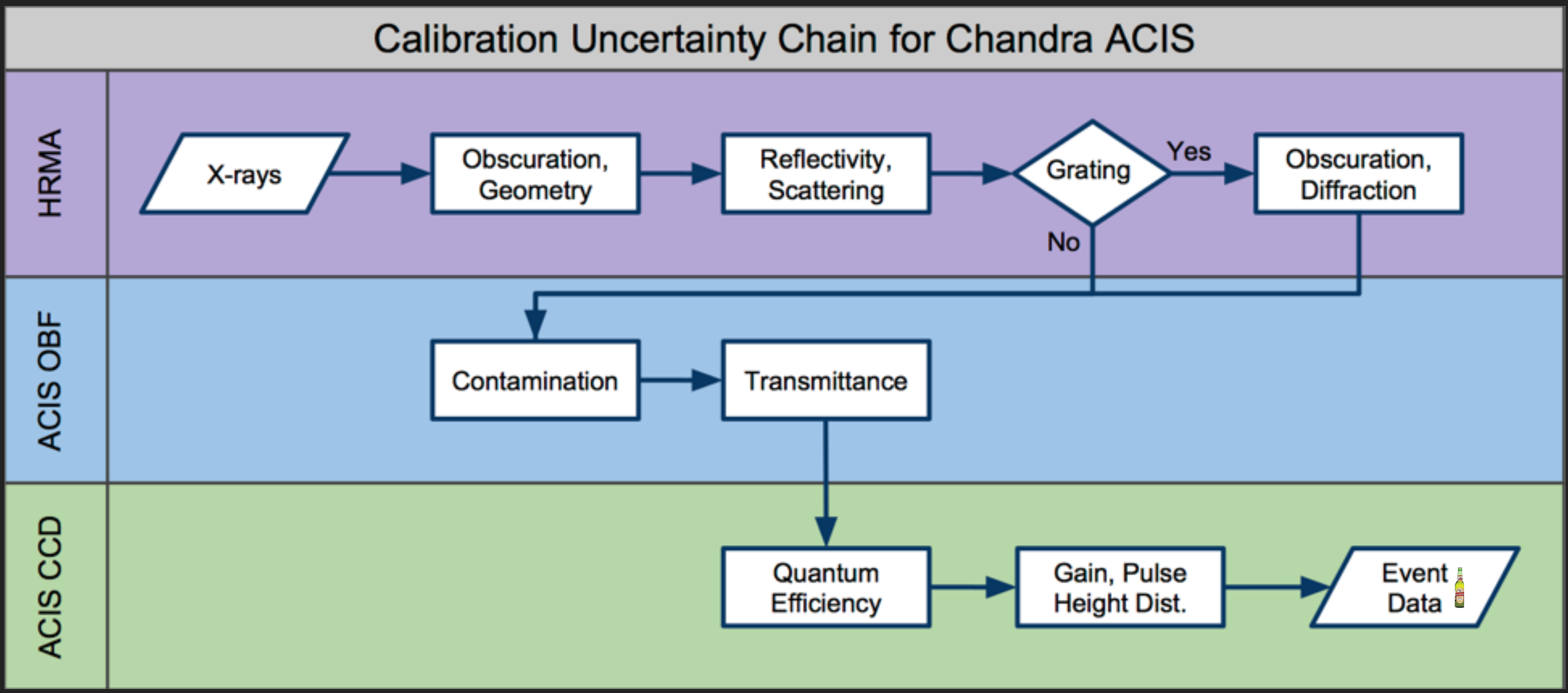
Finesse

Brute Force



TYPICAL UNCERTAINTY CHAIN: CHANDRA ACIS-S

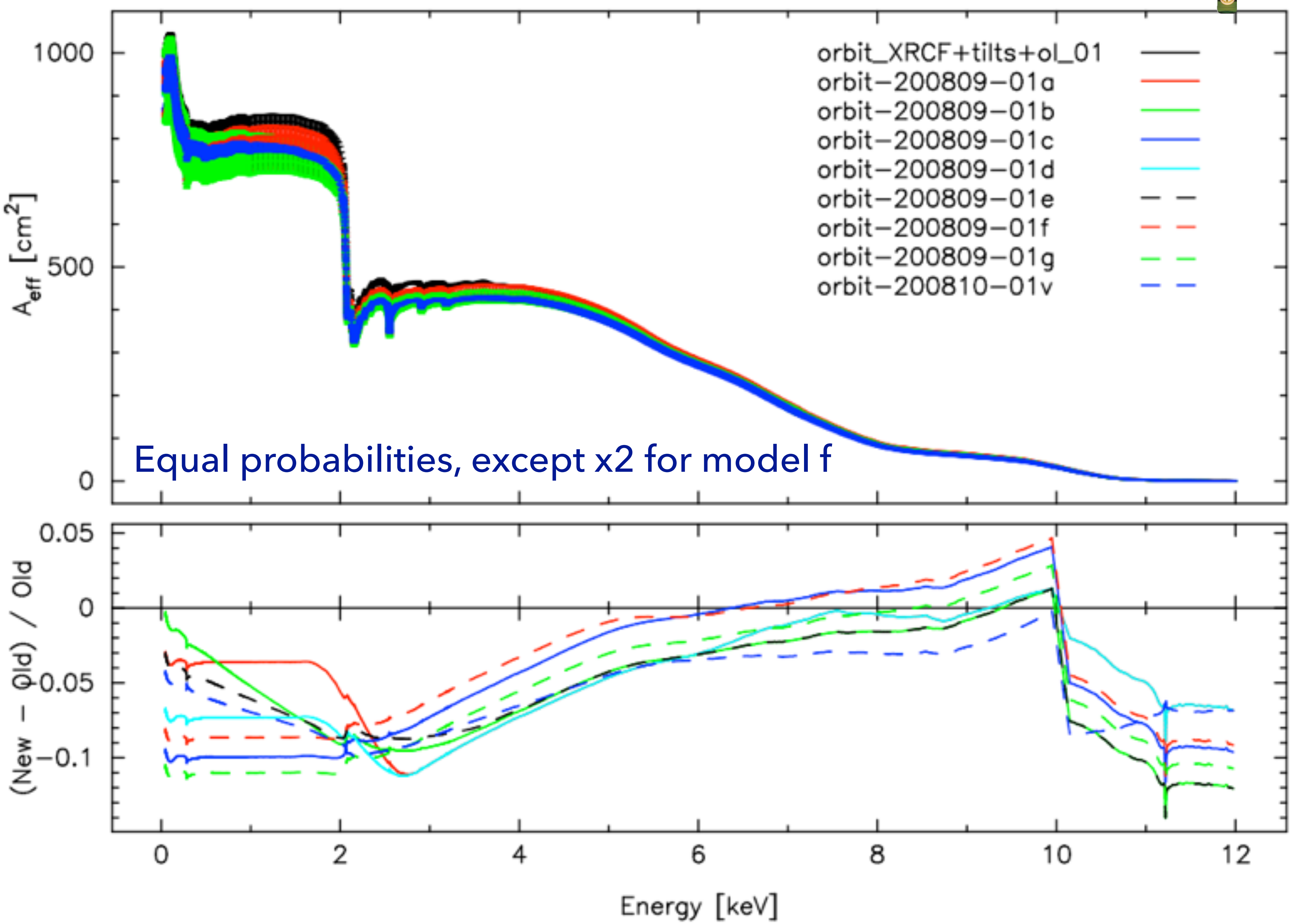


GENERATING MONTE CARLO EFFECTIVE AREAS

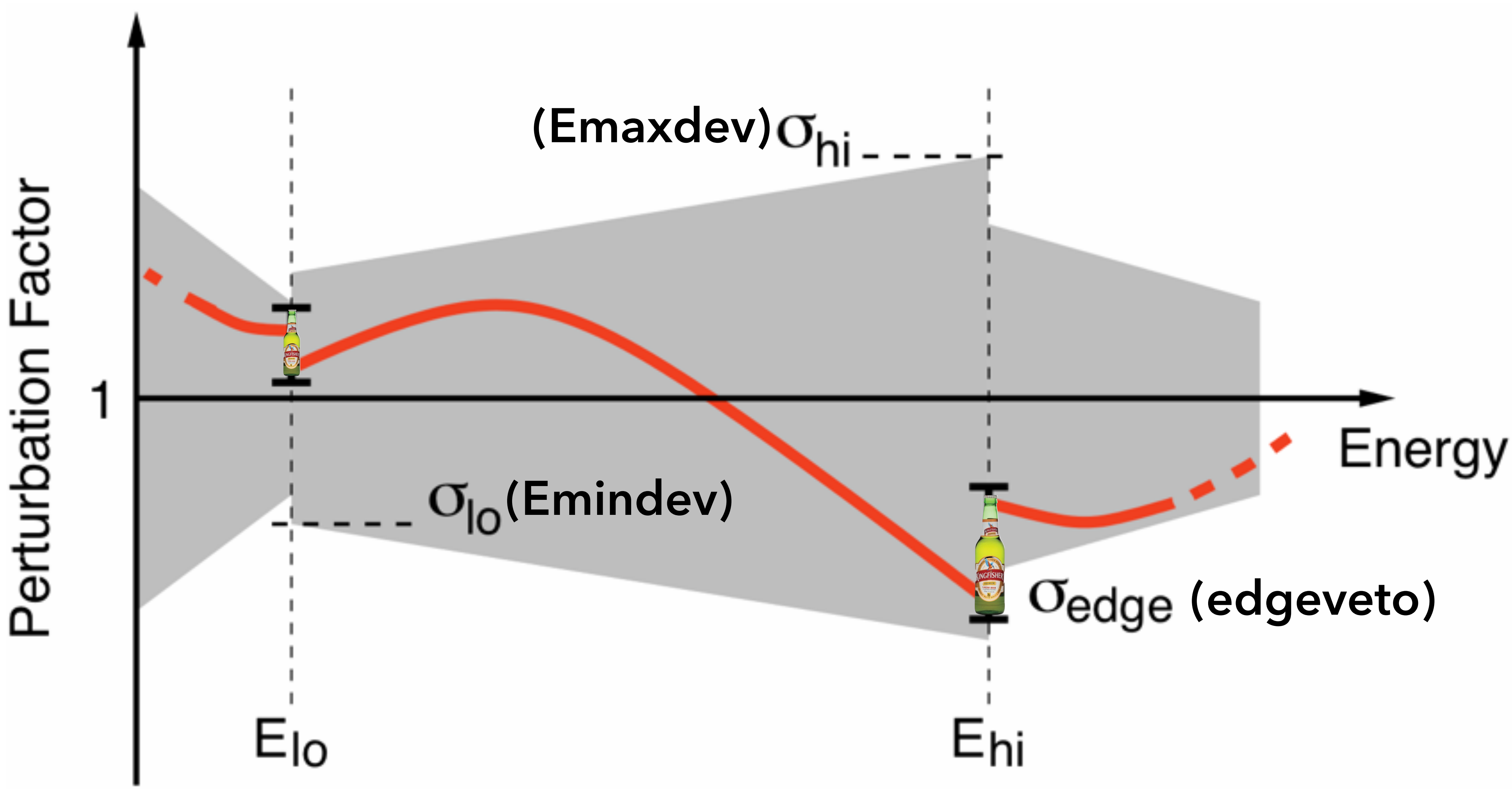
[Do MC RMFs too but not discussed today…]

- 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*
- Combine the above into an ARF multiplicative perturbation

FOR HRMA WE ALSO USE RAY-TRACE MODEL AREAS



PERTURBATION FUNCTION



2014: Added "maxdiff" - the maximum difference allowed between min and max perturbation - controls curvature in function, prevents unrealistic deviations

PERTURBATION INPUT FILE

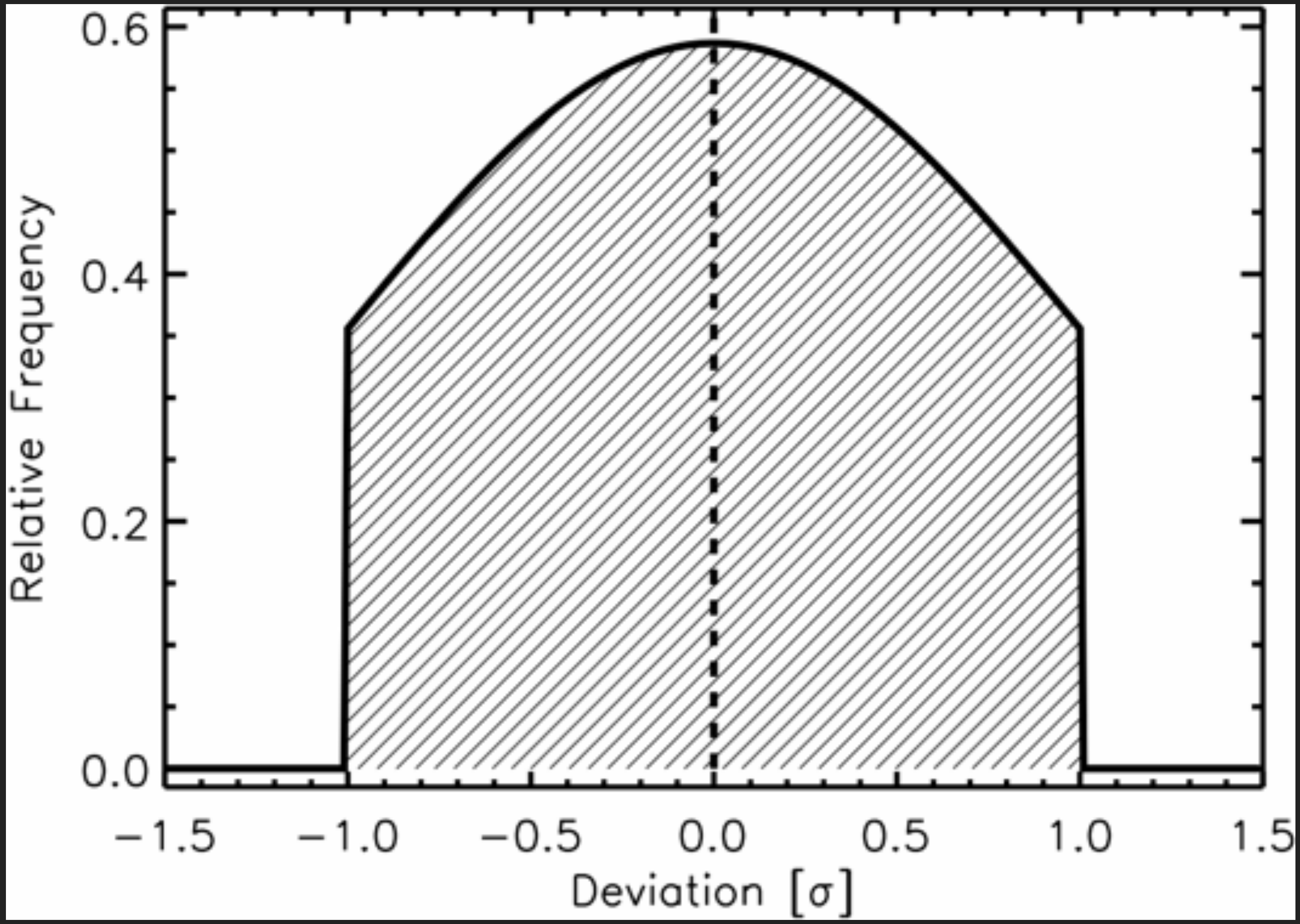
- Uncertainty data for each instrument subassembly (MM=multi-mirror, OBFM=optical blocking filter medium, etc)
- Each line refers to an energy range (in keV) bounded by instrument edges
- Format: Emin,Emindev,Emax,Emaxdev,Edge veto, maxdiff

MM
0.05 0.04 2.291 0.04 0.03 0.04
2.291 0.03 3.425 0.03 0.01 0.03
3.425 0.03 7.000 0.03 0.005 0.03
7.000 0.05 12.0 0.10 0.10
CONTAM
0.05 0.10 0.2838 0.02 0.02 0.10
0.283 … 0.02 0.02 0.02
0.409 … 0.02
0.53…
OBF…
0.05 … .15
0.297 0.06 … 0.06
0.540 0.02 1.567 0.02 0.02 0.02
1.567 0.02 12.0 0.02 0.02
EPICPN
0.05 0.20 0.132 0.10 0.11 0.20
0.132 0.15 0.539 0.05 0.03 0.15
0.539 0.04 1.827 0.04 0.03 0.04
1.827 0.04 12.0 0.03 0.04

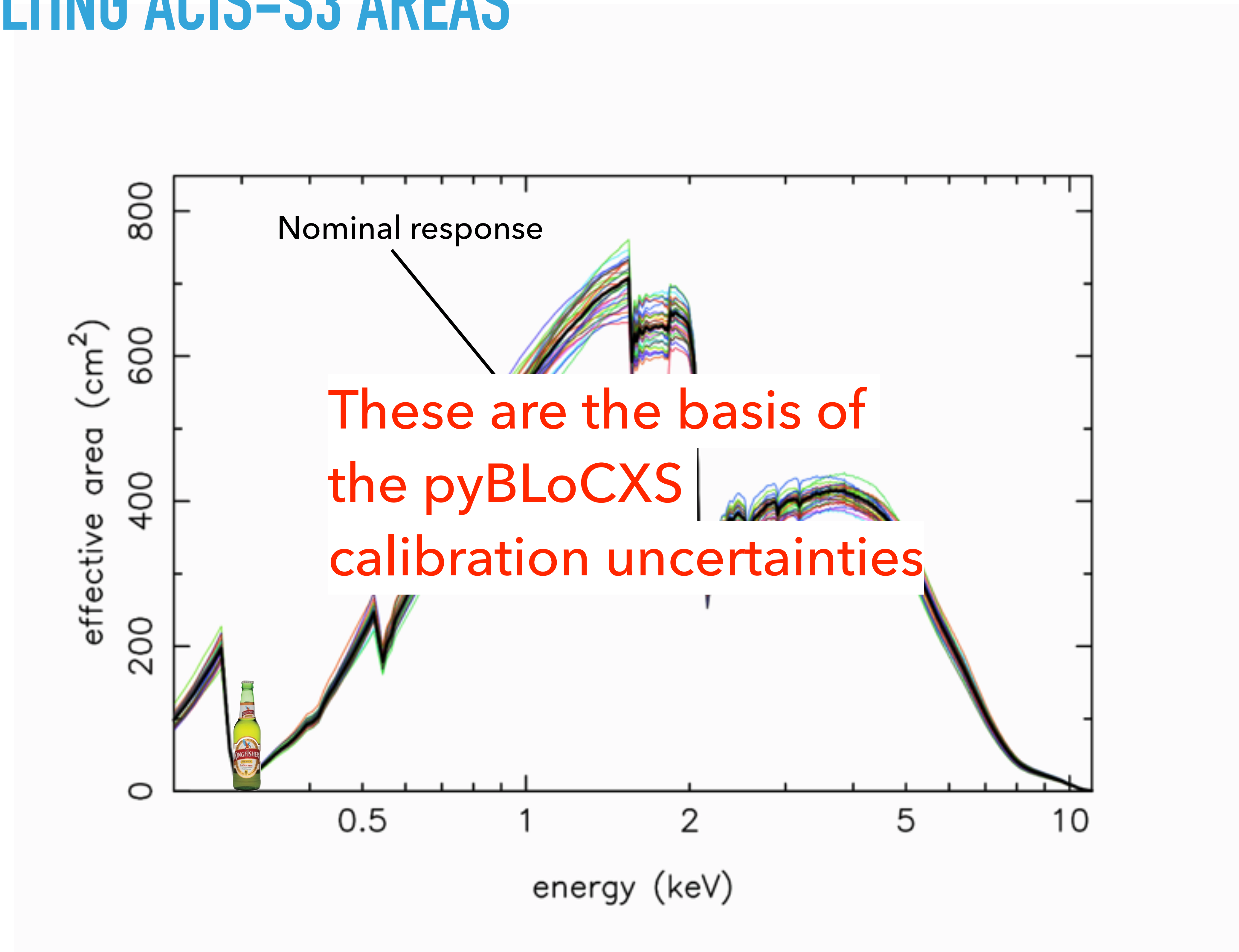
WE CAN PERFORM THE SAME (DIS)SERVICE FOR YOUR MISSIONS!

HOW ARE CALIBRATION UNCERTAINTIES DISTRIBUTED?

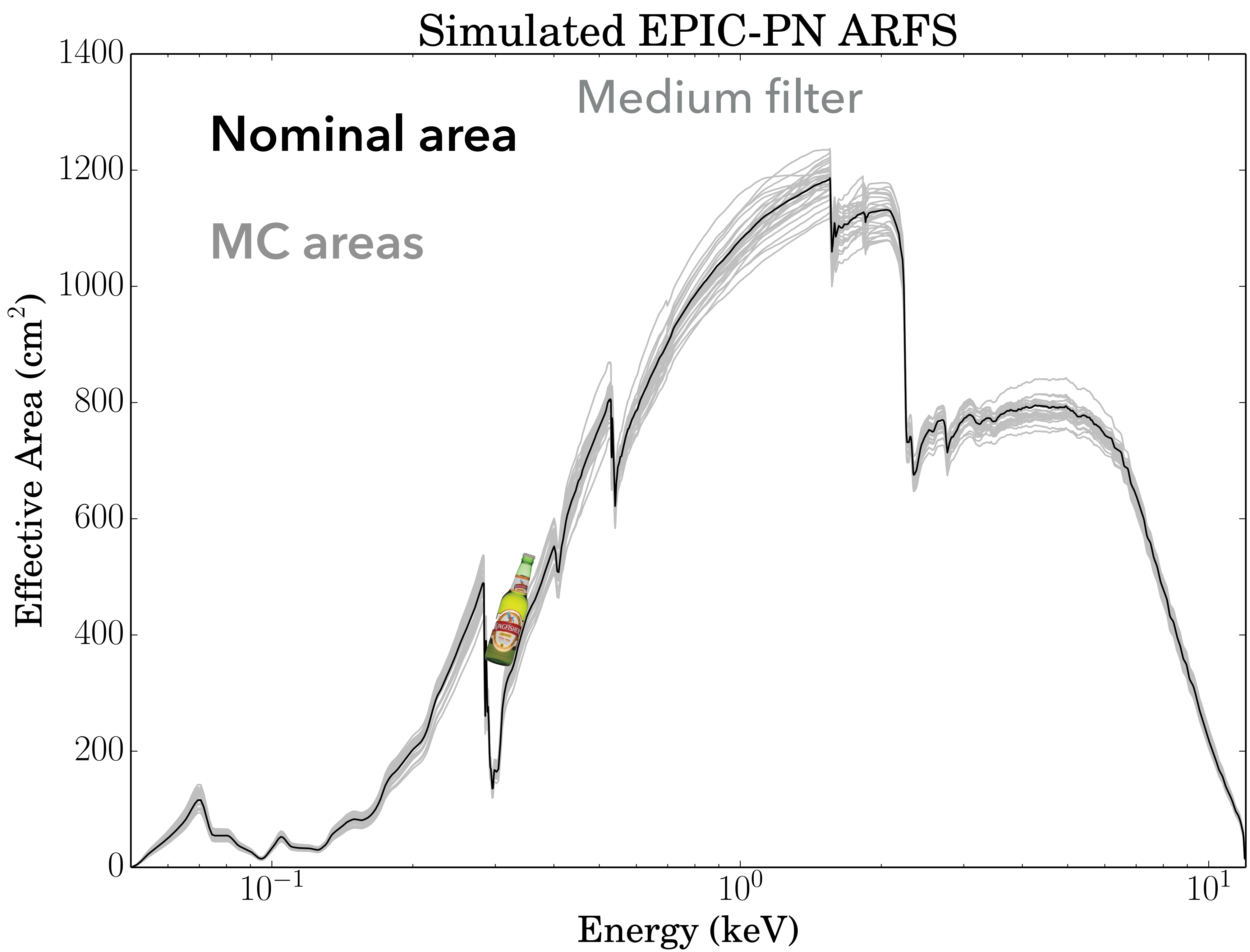
- Rigorous treatment requires knowledge of how uncertainties are distributed
  - Unknown!
- Assume a truncated normal distribution -1σ to +1σ
  - Peaked at preferred value
  - Includes gut feeling!



RESULTING ACIS-S3 AREAS



XMM-NEWTON SAMPLE AREAS



EXERCISE: LIMITING ACCURACY OF X-RAY TELESCOPES

- Method applied to Chandra ACIS-S, XMM EPIC-pn, NuSTAR (see Kristin's talk):
  - Simulate spectrum ("fakeit")
  - Fit using *different effective area realisations* a lot of (e.g. 1000) times
    - XSPEC driven by Perl (Sherpa driven by Python soon…)
    - 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

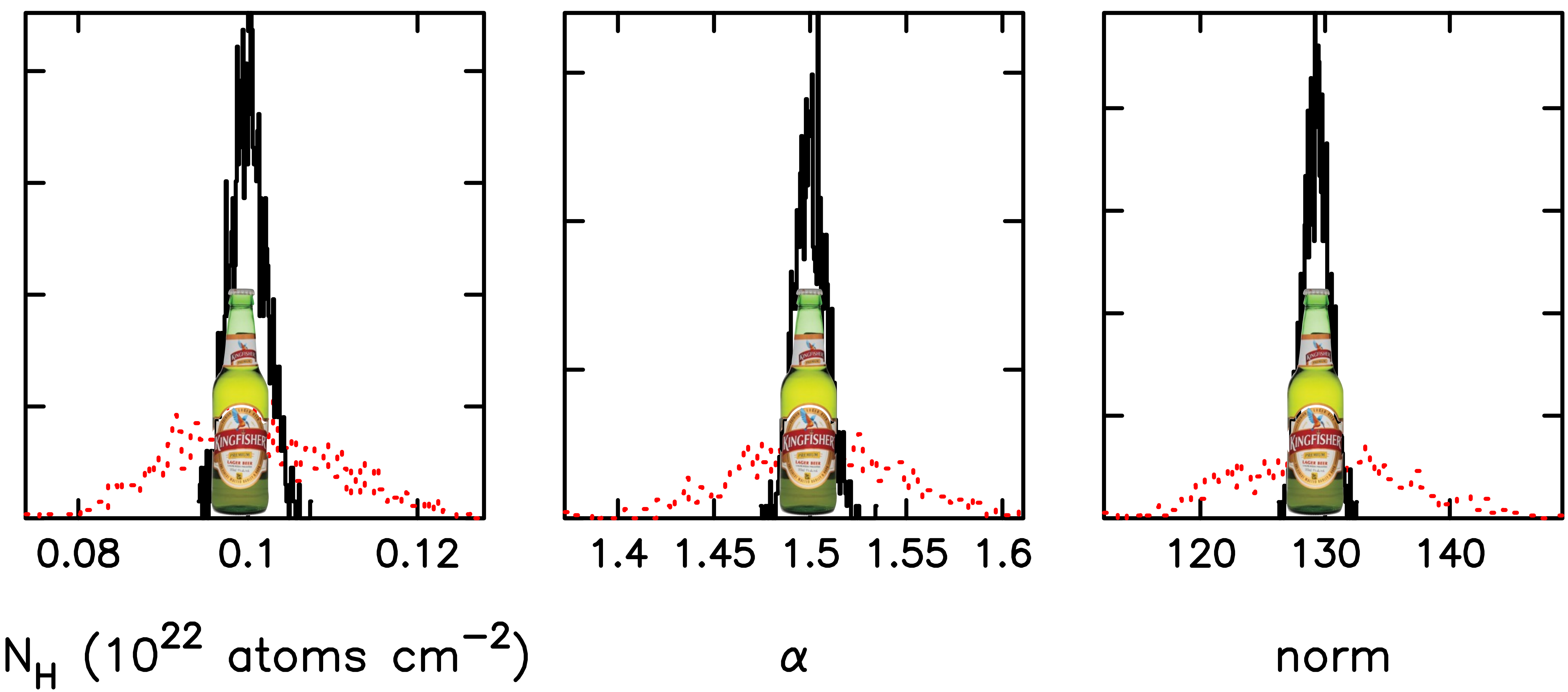
EXAMPLE FITTED PARAMETER DISTRIBUTIONS: EPIC-PN

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

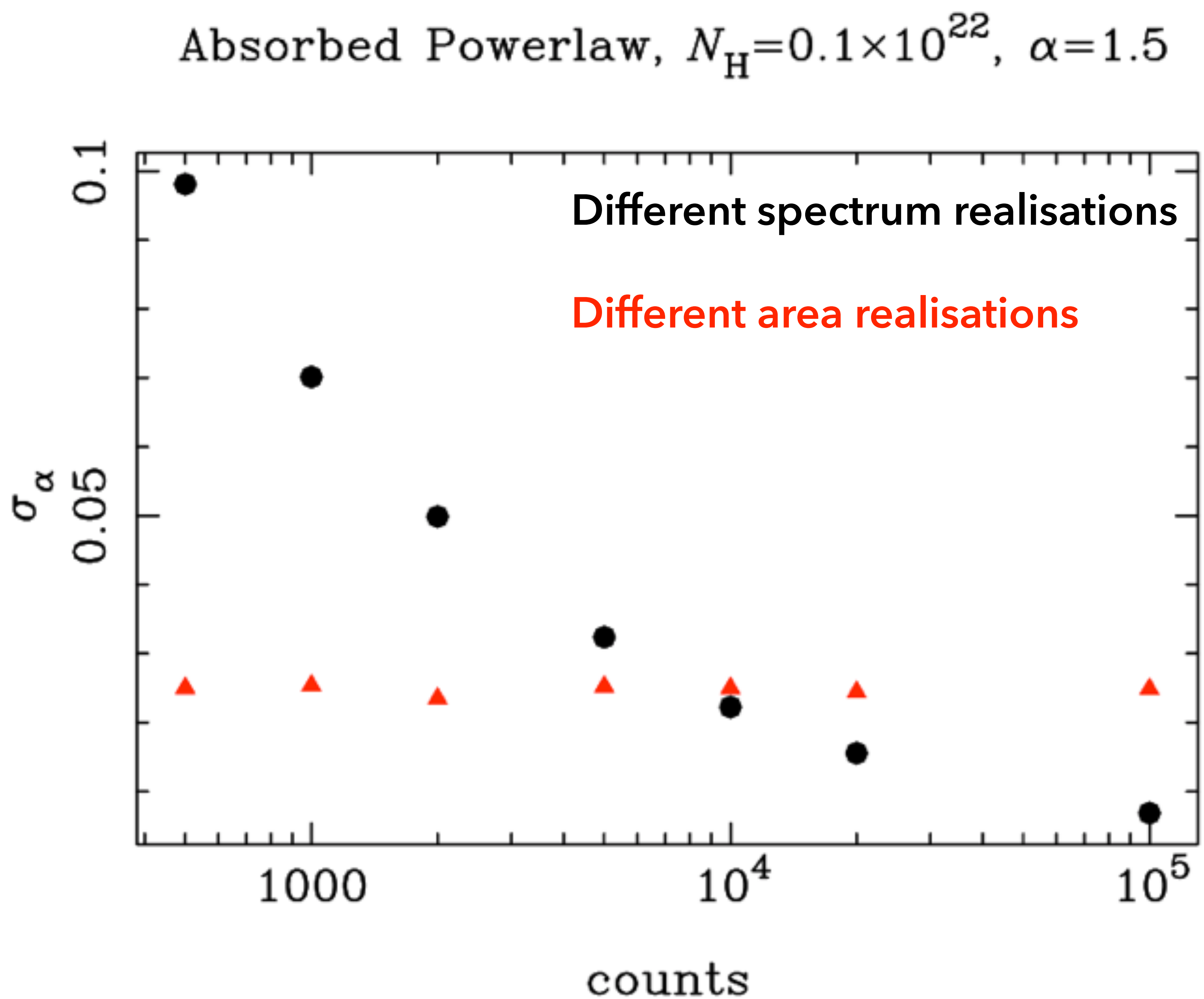
Different spectrum realisations

Different area realisations

1×10^5 counts



XMM EPIC-PN LIMITING PRECISION



LIMITING PRECISION SUMMARY

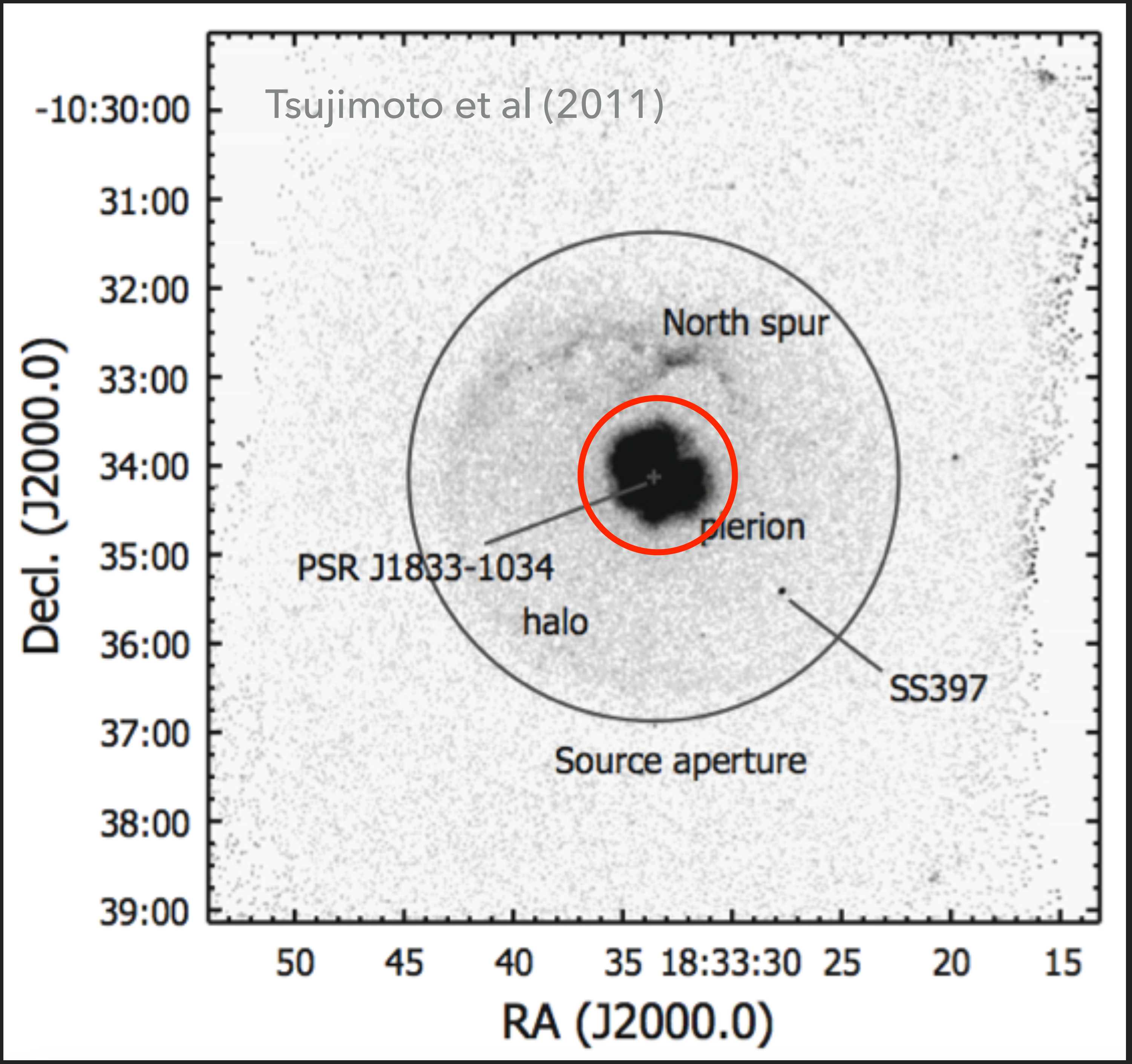
- MC analysis using best guess effective area uncertainties finds that the limiting precisions of Chandra and XMM-Newton are reached for about 10,000 counts; ie increasing exposure time to get more counts does not help the accuracy of the fit
- BUT:
    - based only “best guess” uncertainties at subassembly level
    - how to make sure we do not end up with areas *too deviant and to improve uncertainty estimates*?

HOW DO WE IMPROVE UNDERSTANDING OF THE TRUE UNCERTAINTIES?

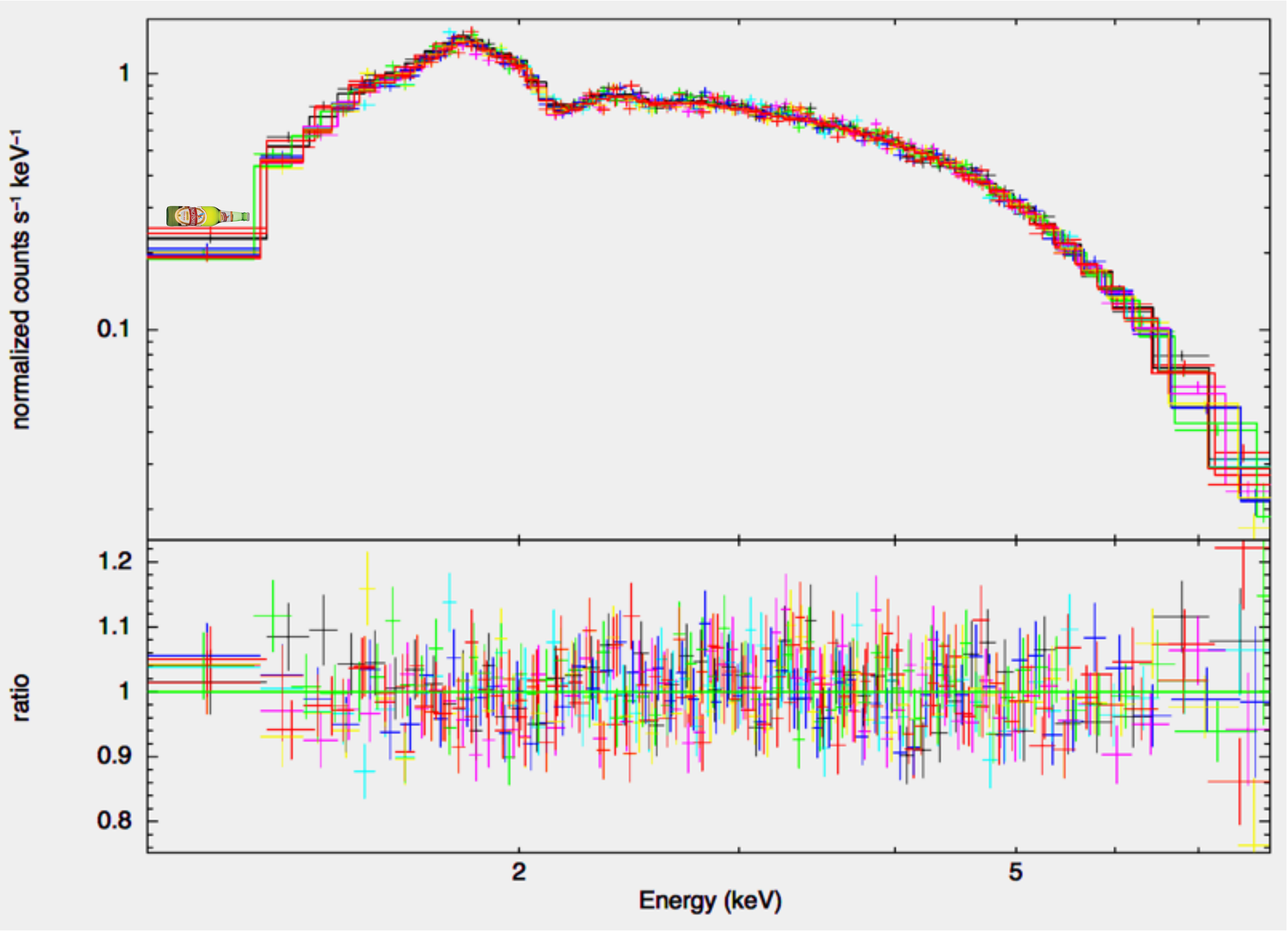
G21.5 –0.6

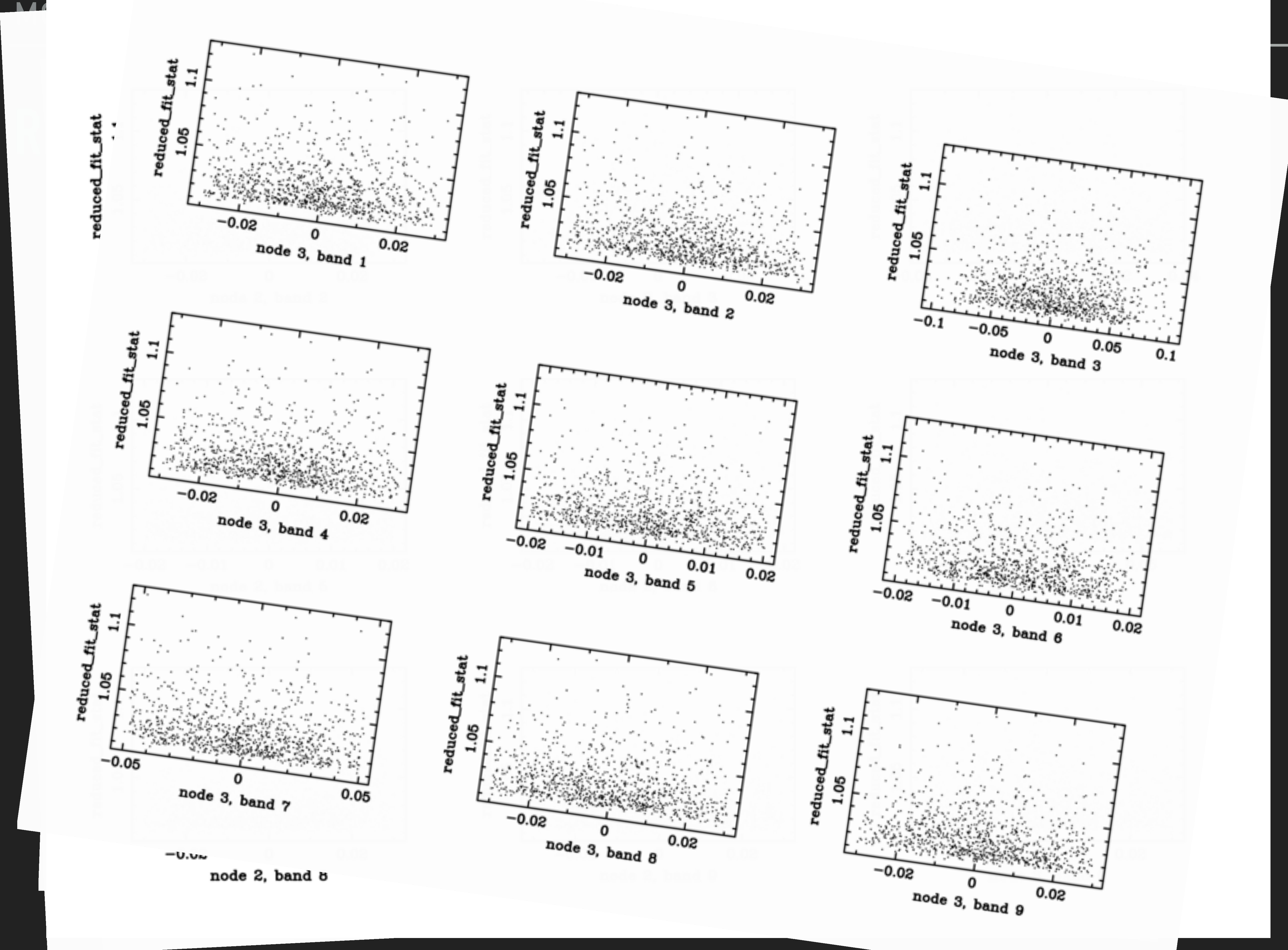
G21.5 -0.6

- Plerionic SNR
- Appears to have power-law spectrum
- Used as an IACHEC cross-calibration source (Tsujimoto et al 2011)
- High N_H - relatively insensitive to ACIS contamination model

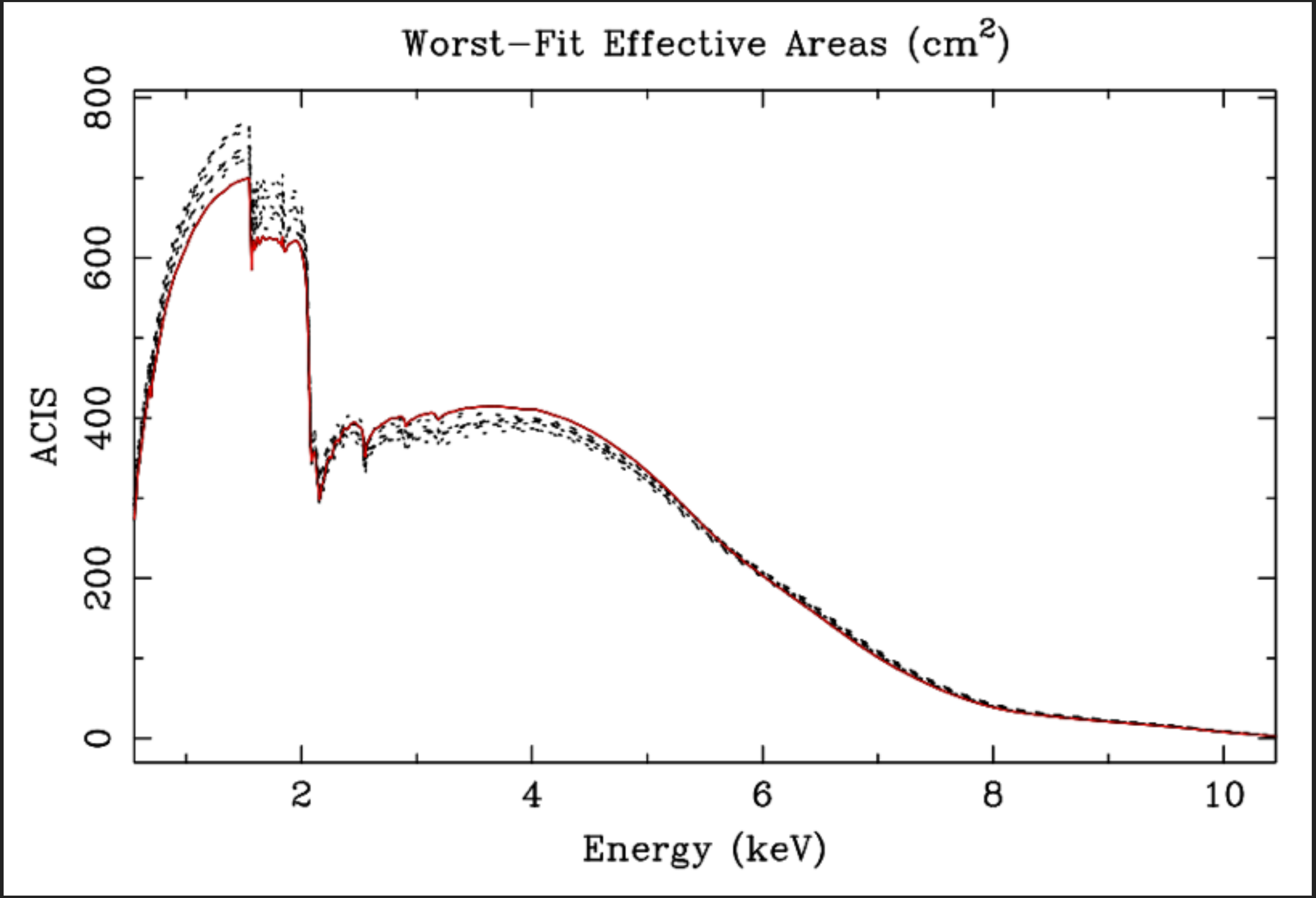


CHANDRA ACIS-S: SIMULTANEOUS FIT TO 8 OBSERVATIONS

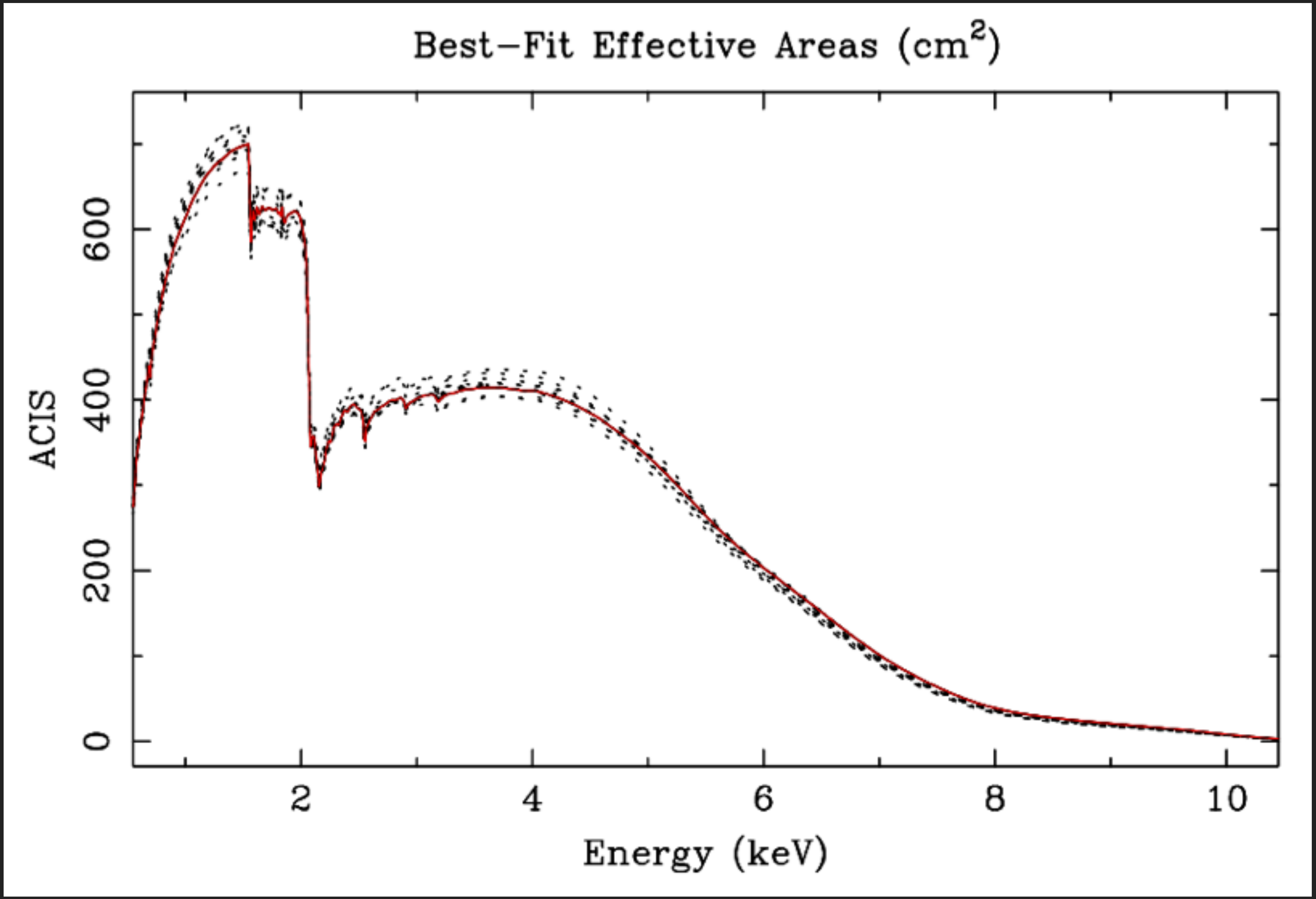



reduced_fit_stat
1.1
1.05
-0.02
0
0.02
node 3, band 1
node 3, band 2
-0.1
-0.05
0.05
0.1
node 3, band 3
node 3, band 4
-0.01
0.01
node 3, band 5
node 3, band 6
node 3, band 7
node 3, band 8
node 3, band 9
node 2, band 8

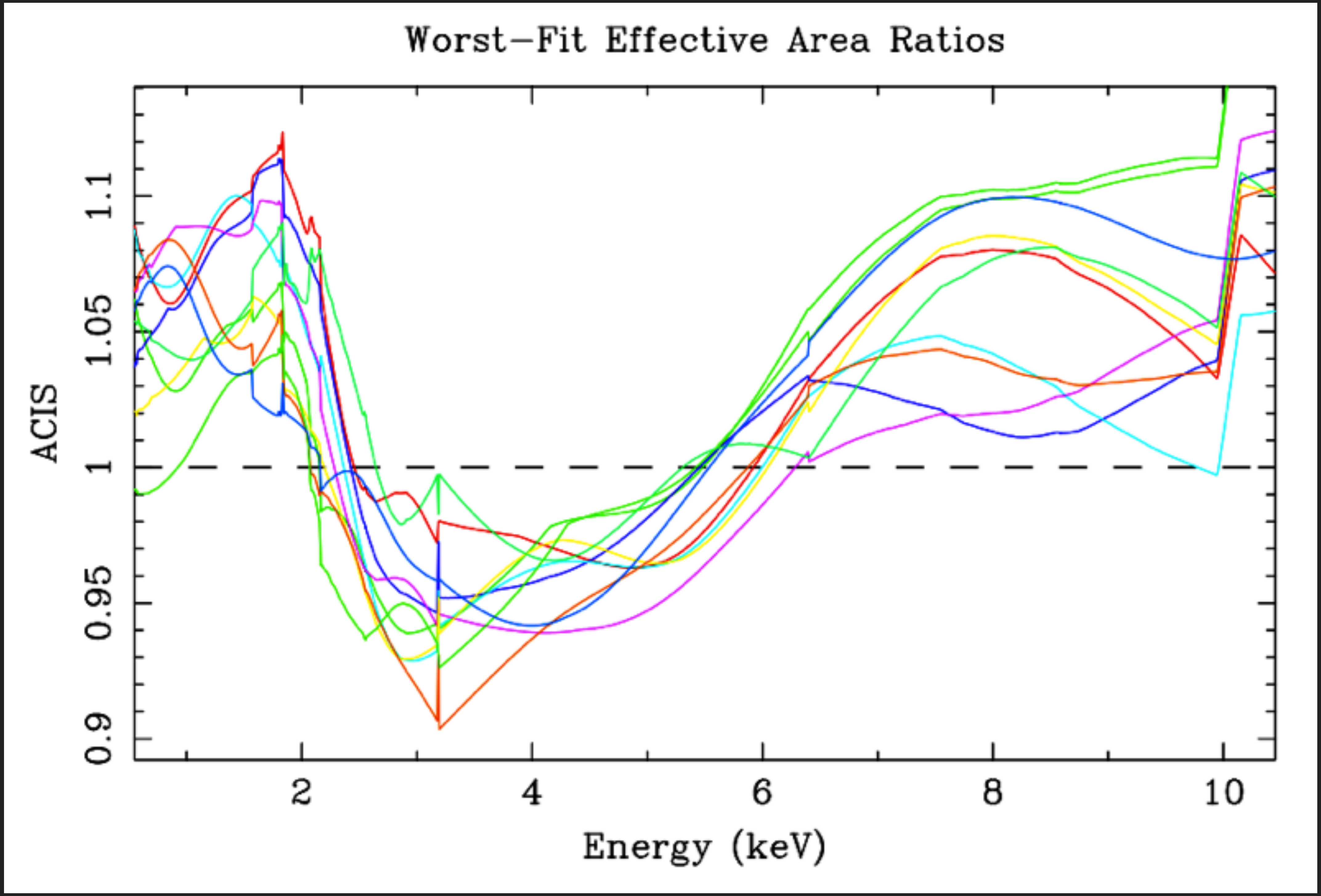
CONSTRAINTS ON “GOOD” AND “BAD” AREAS



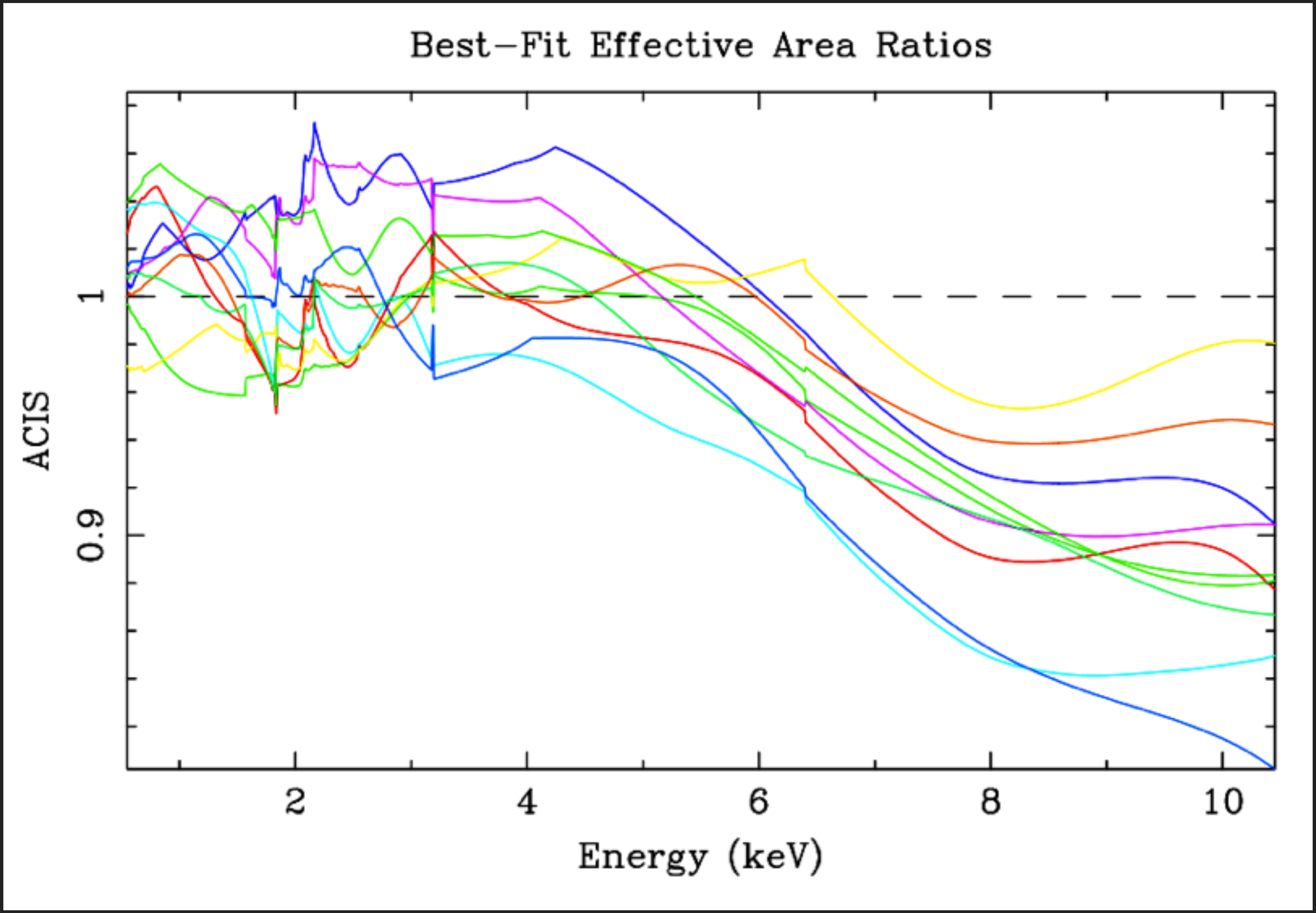
CONSTRAINTS ON "GOOD" AND "BAD" AREAS

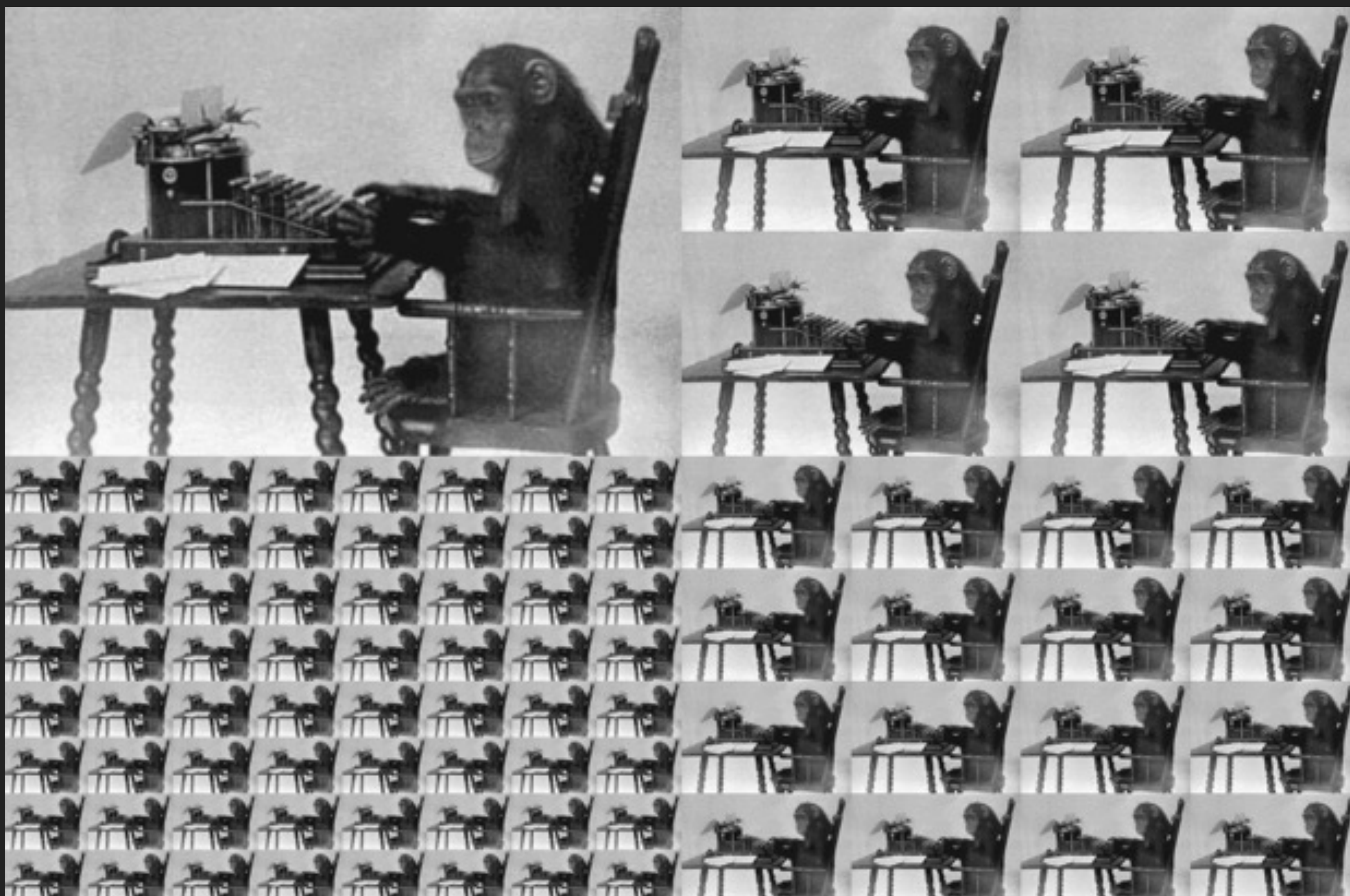


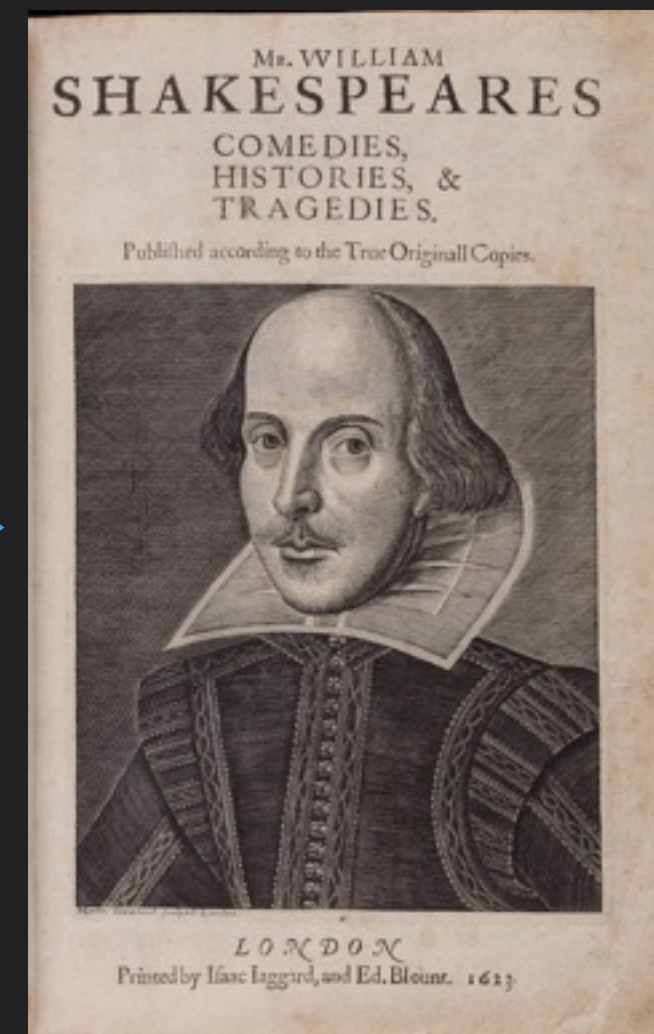
CONSTRAINTS ON “GOOD” AND “BAD” AREAS



CONSTRAINTS ON "GOOD" AND "BAD" AREAS



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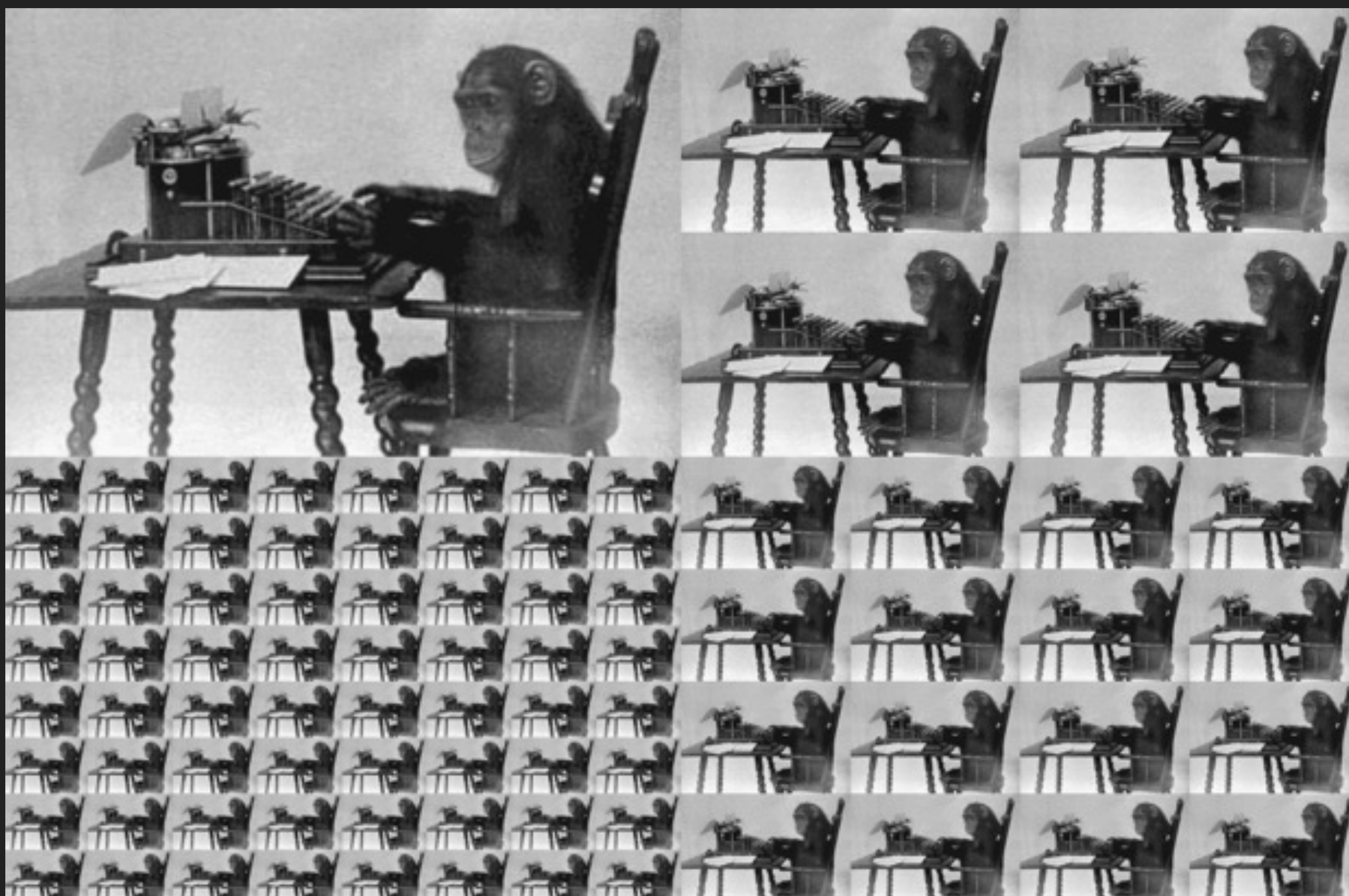
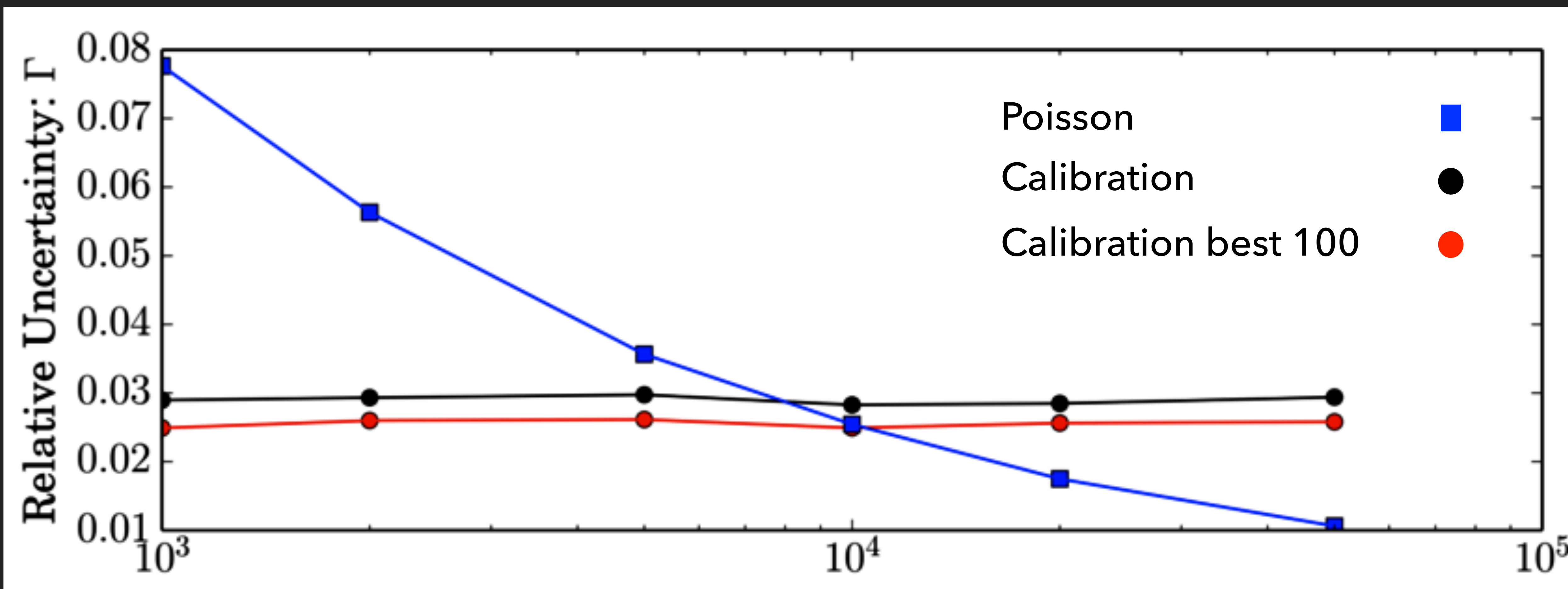


Calibration

REFINE TELESCOPE PRECISION ESTIMATES



To be submitted to the Astrophysical Journal
Preprint typeset using LaTeX style emulateapj v. 11/12/01

MONTE CARLO PROCESSES FOR INCLUDING TELESCOPE CALIBRATION UNCERTAINTIES IN PARAMETER ESTIMATION STUDIES

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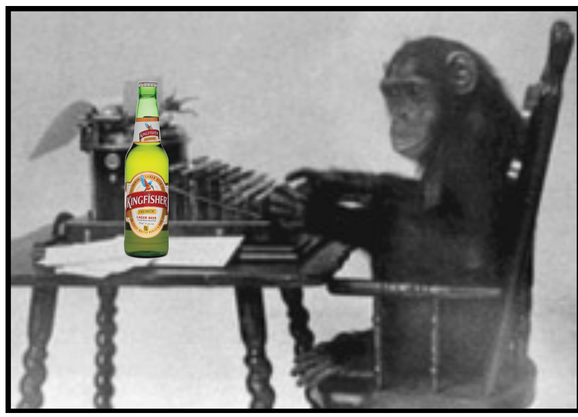

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To be submitted to the Astrophysical Journal

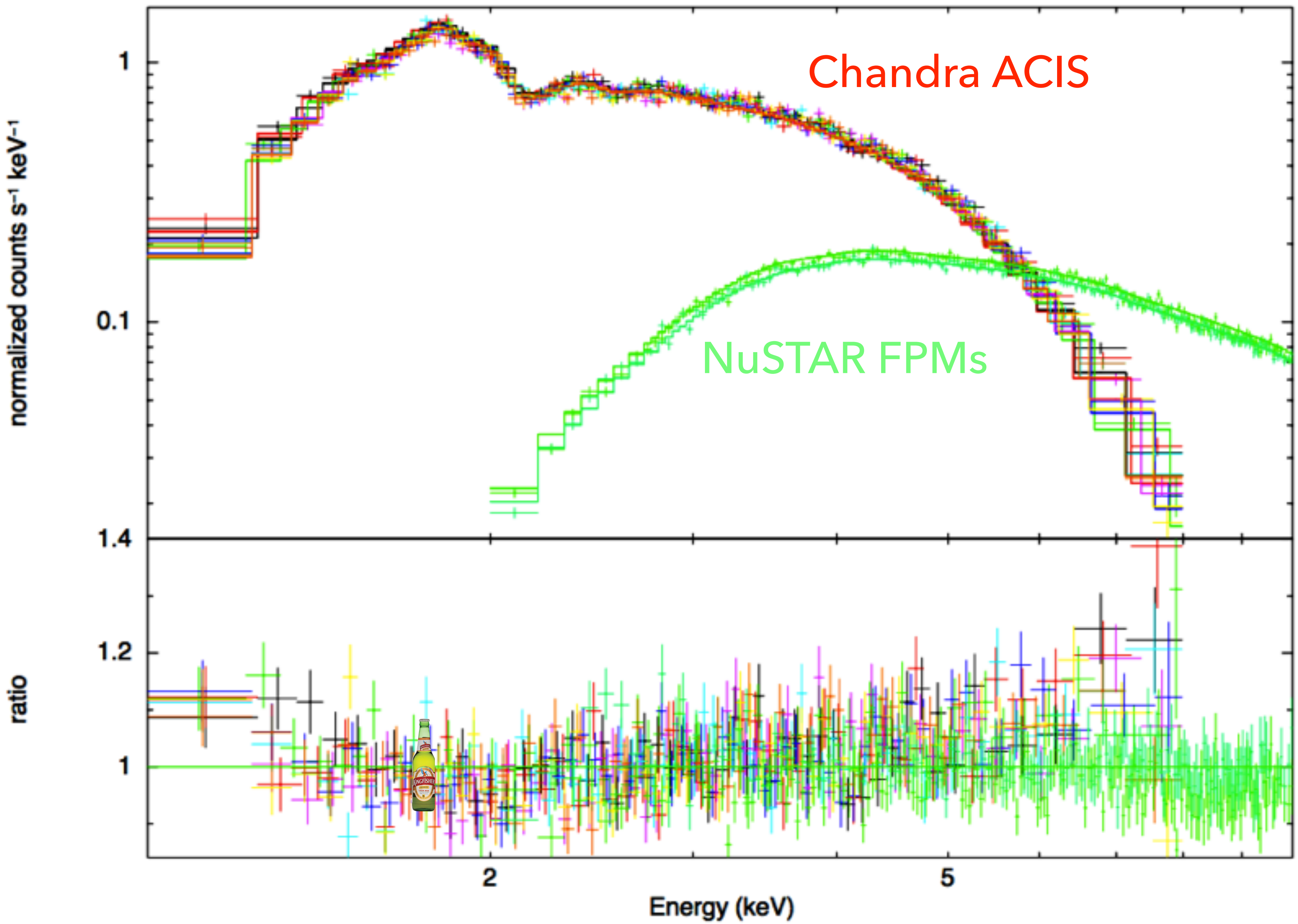
ABSTRACT

Telescope and instrument response uncertainties are almost universally ignored in current astrophysical data analysis. Yet modern X-ray observatories, such as Chandra and XMM-Newton, frequently acquire data for which photon counting statistics are not likely to be the dominant source of error. Including allowance for performance uncertainties is technically challenging in terms of both understanding and specifying the uncertainties themselves, and in employing them in data analysis. Here we describe Monte Carlo methods developed to include instrument performance uncertainties in typical model parameter estimation studies. These methods are used in combination with observations of the plerion supernova remnant G21.5-0.9 to refine the calibration uncertainties themselves and to estimate the limiting accuracy of *Chandra* for understanding typical X-ray source spectral model parameters. The present study indicates that, for ACIS-S3 observations, the limiting accuracy is reached for observations accruing $\sim 10^4$ counts. Future prospects for the type of method presented here are discussed, including cross-calibration between different X-ray telescopes using cosmic X-ray sources. The general ideas presented are not restricted to X-ray instruments and could be more widely applied to both space-based and ground-based astronomical instrumentation.

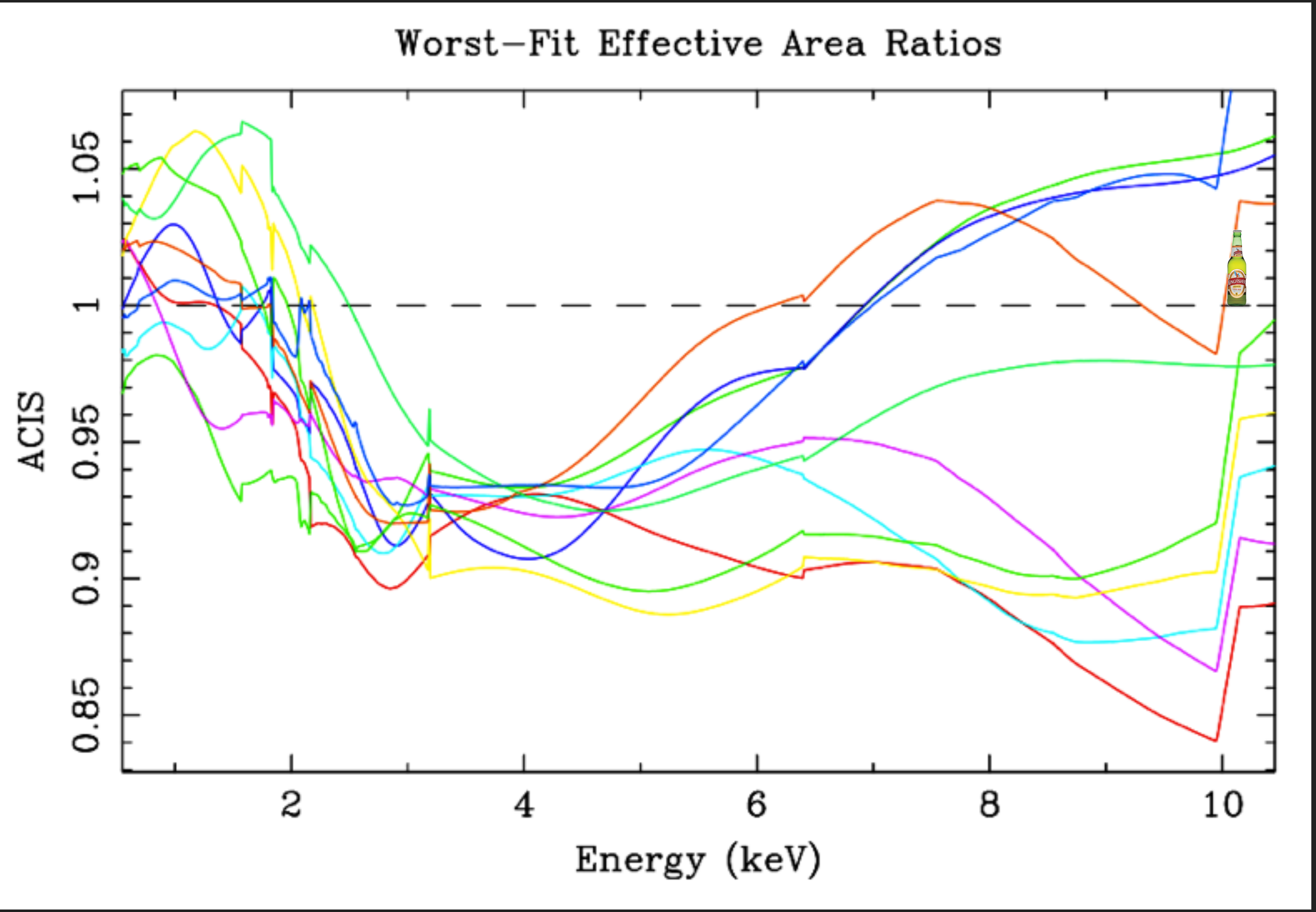
Subject headings: methods: data analysis — methods: statistical — standards — techniques: miscellaneous — X-rays: general

WHY STOP AT JUST CHANDRA?

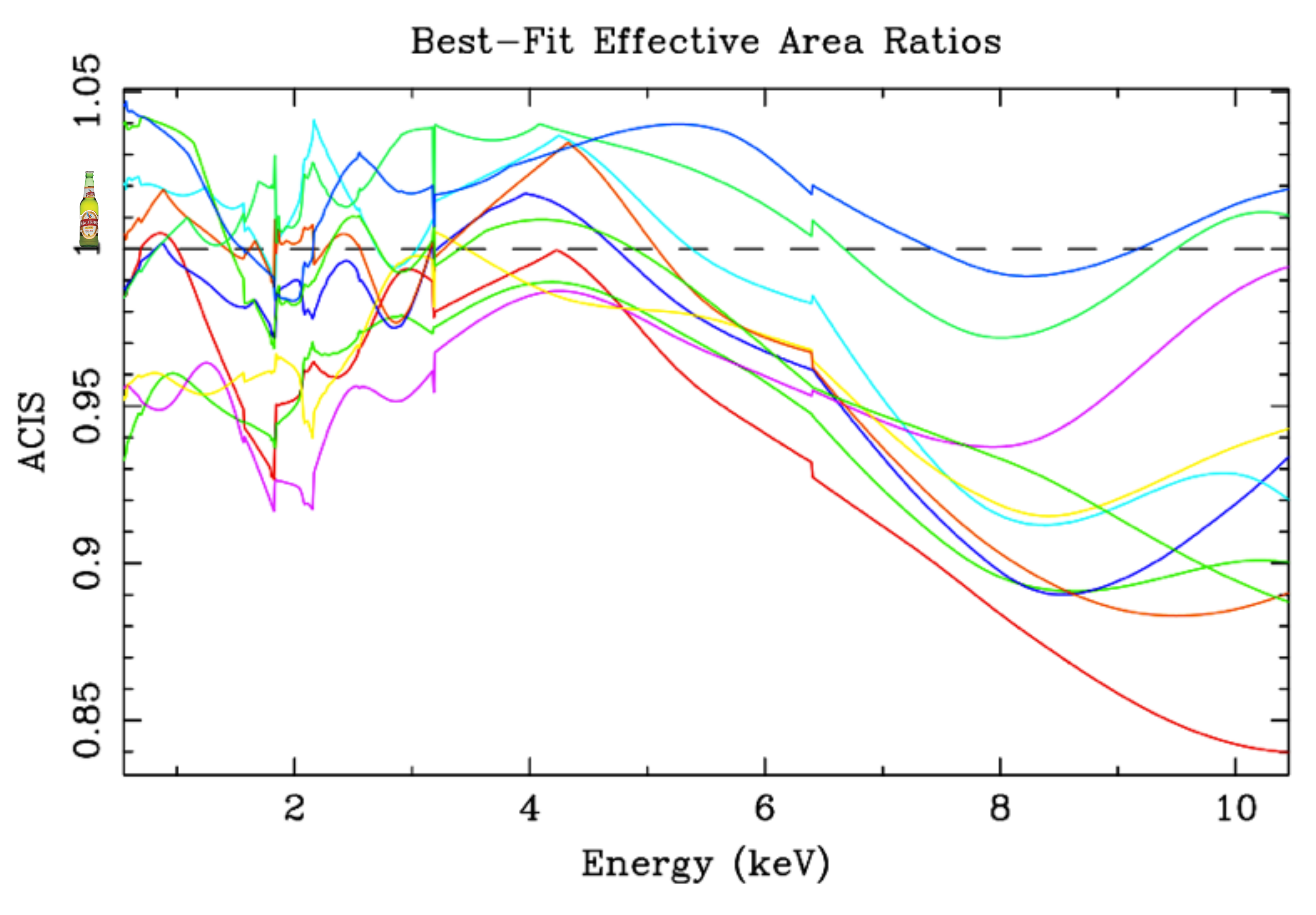
CHANDRA + NUSTAR: SIMULTANEOUS FIT



"BAD" AREA RATIOS: CHANDRA

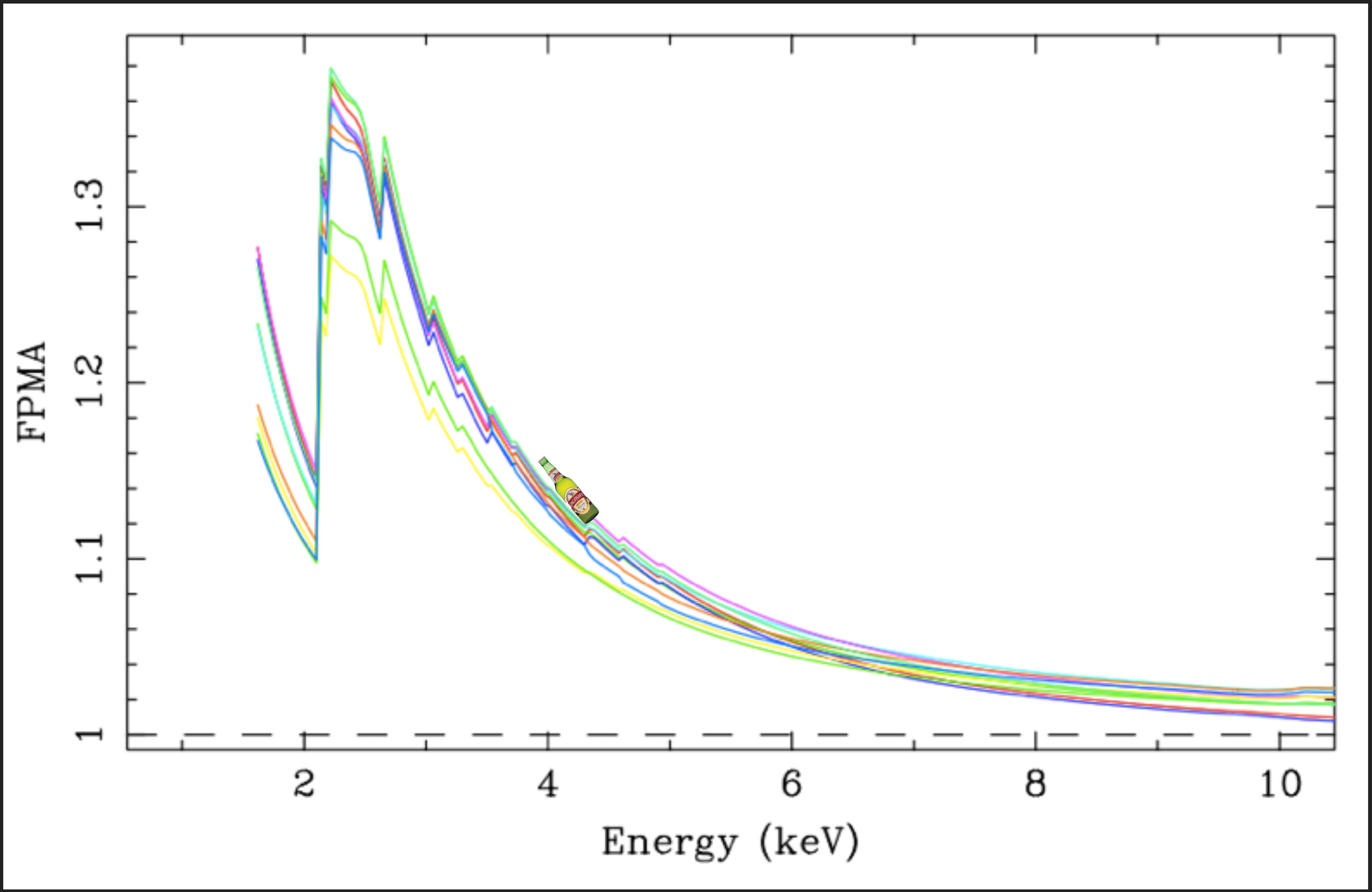


“GOOD” AREA RATIOS: CHANDRA

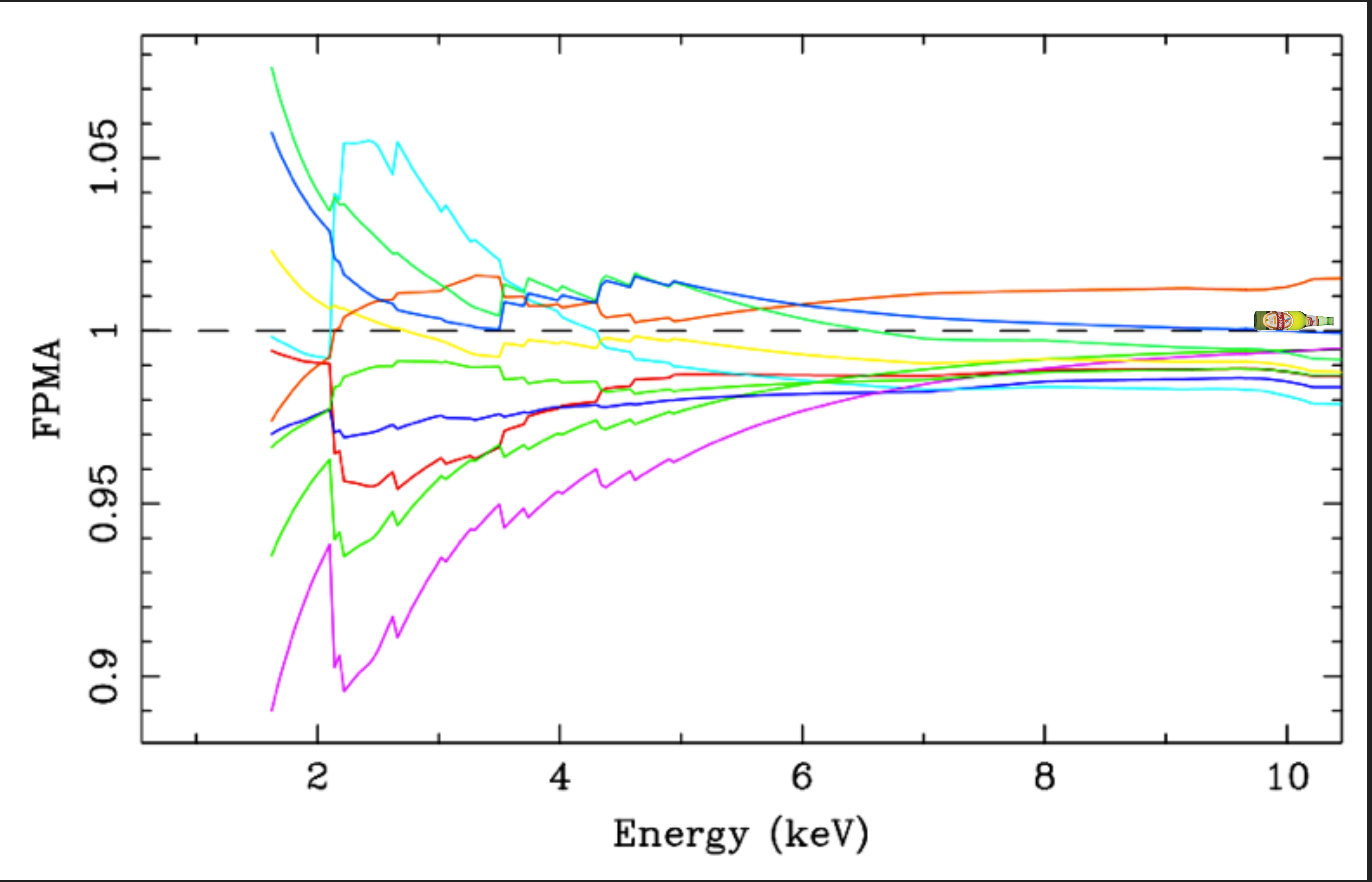


SEE KRISTIN'S TALK NEXT FOR DISCUSSION OF NUSTAR CALIBRATION UNCERTAINTIES…

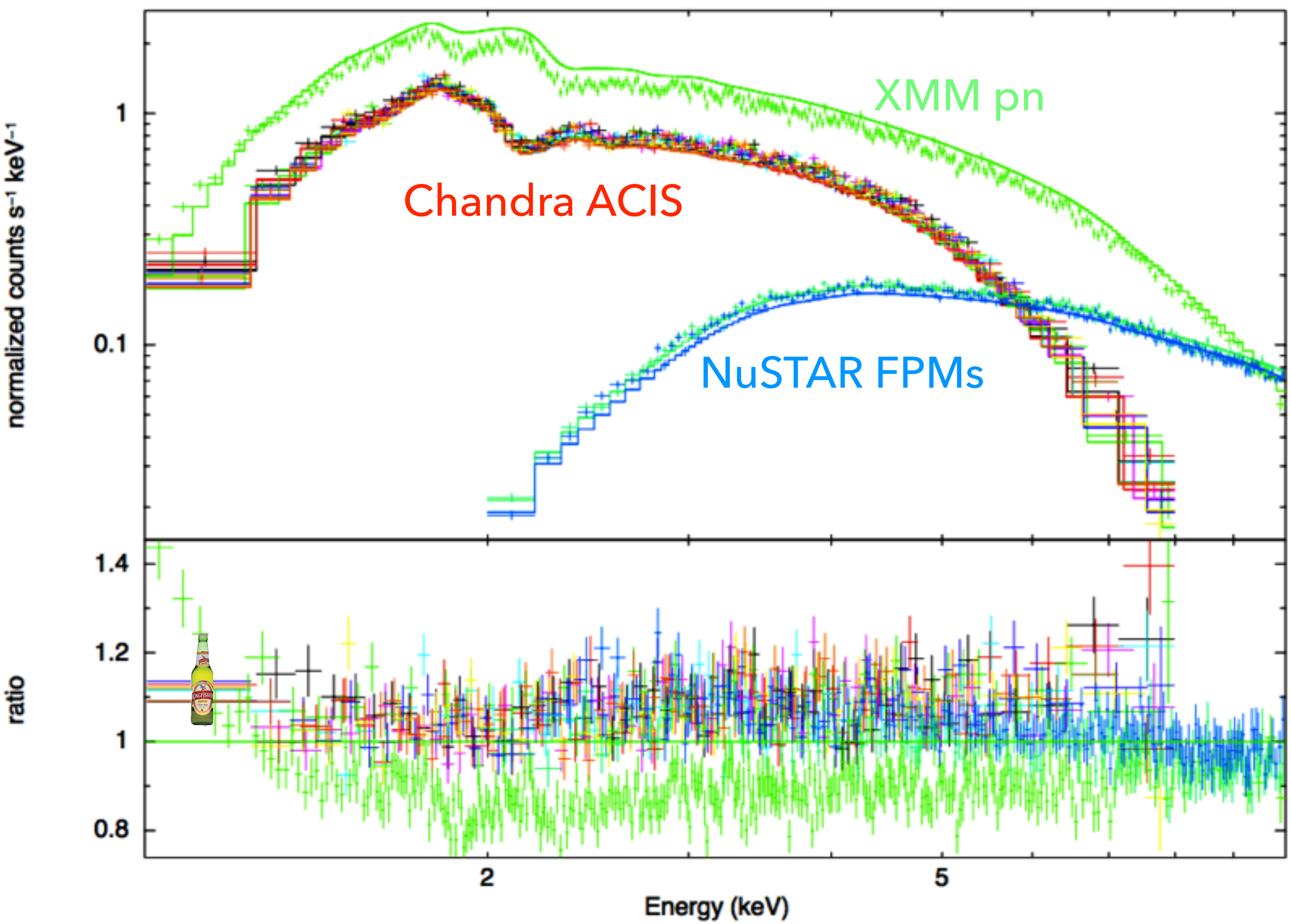
"BAD" AREA RATIOS: NUSTAR

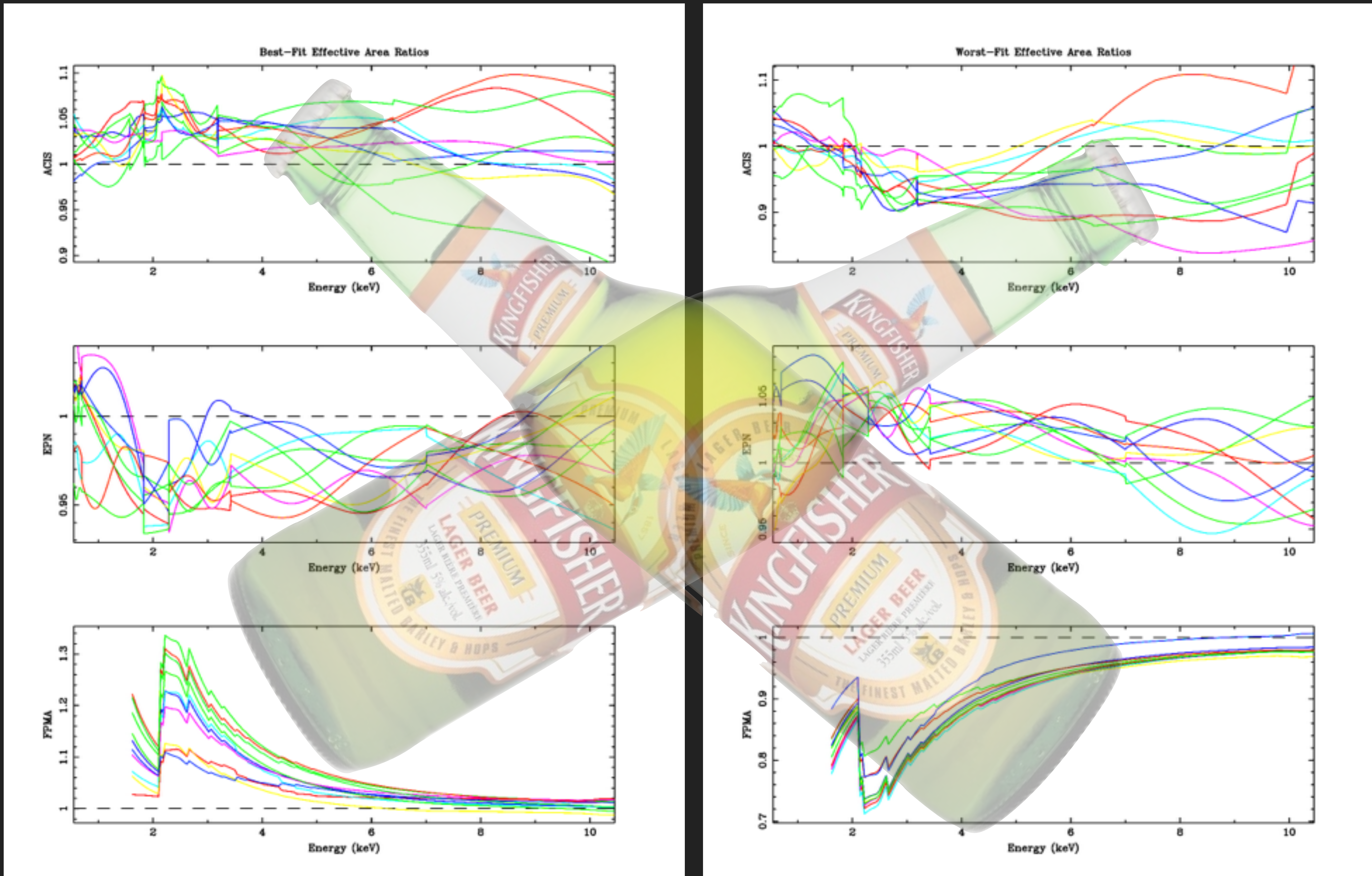


"GOOD" AREA RATIOS: NUSTAR



CHANDRA + NUSTAR + XMM: SIMULTANEOUS FIT

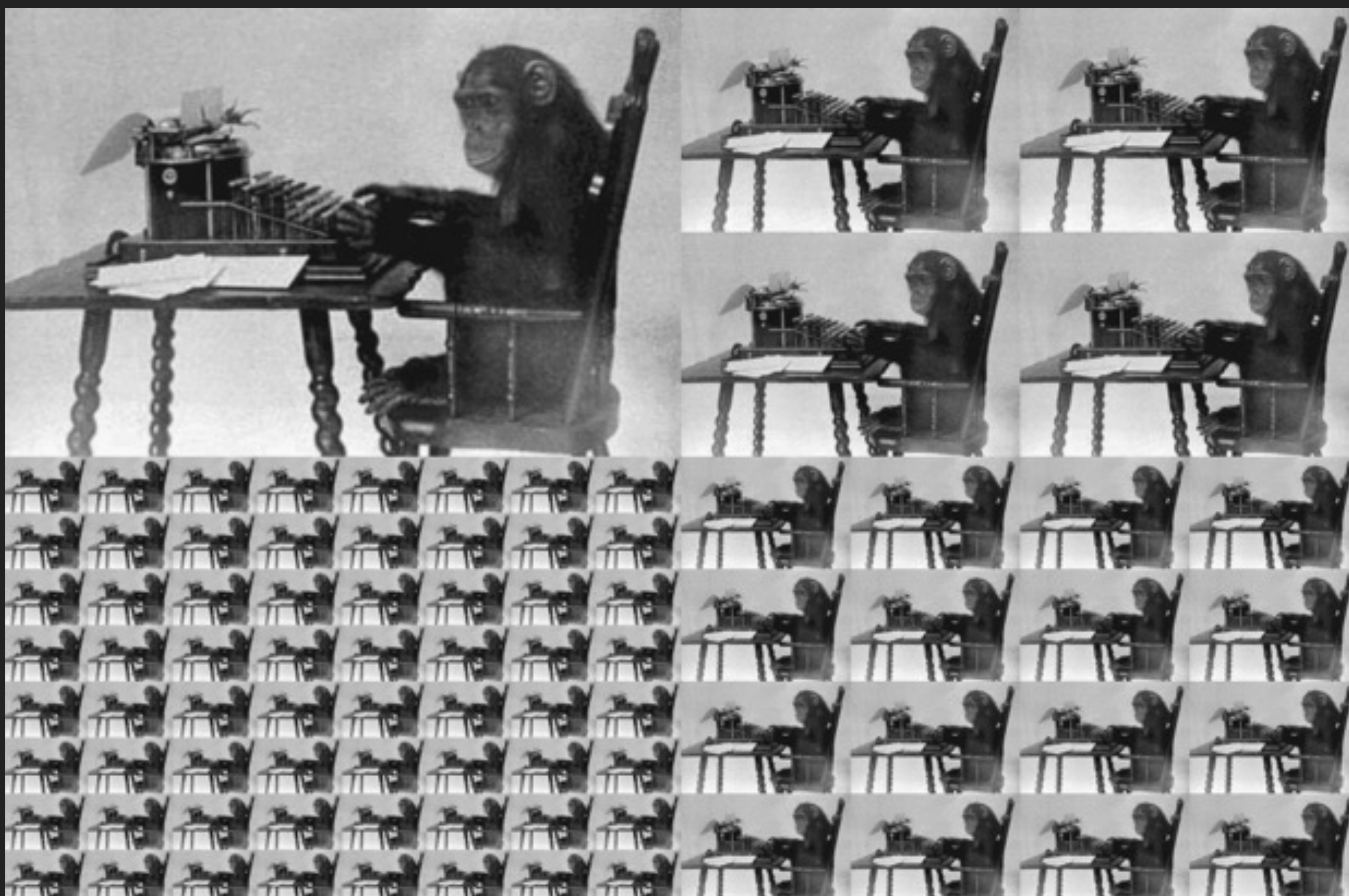




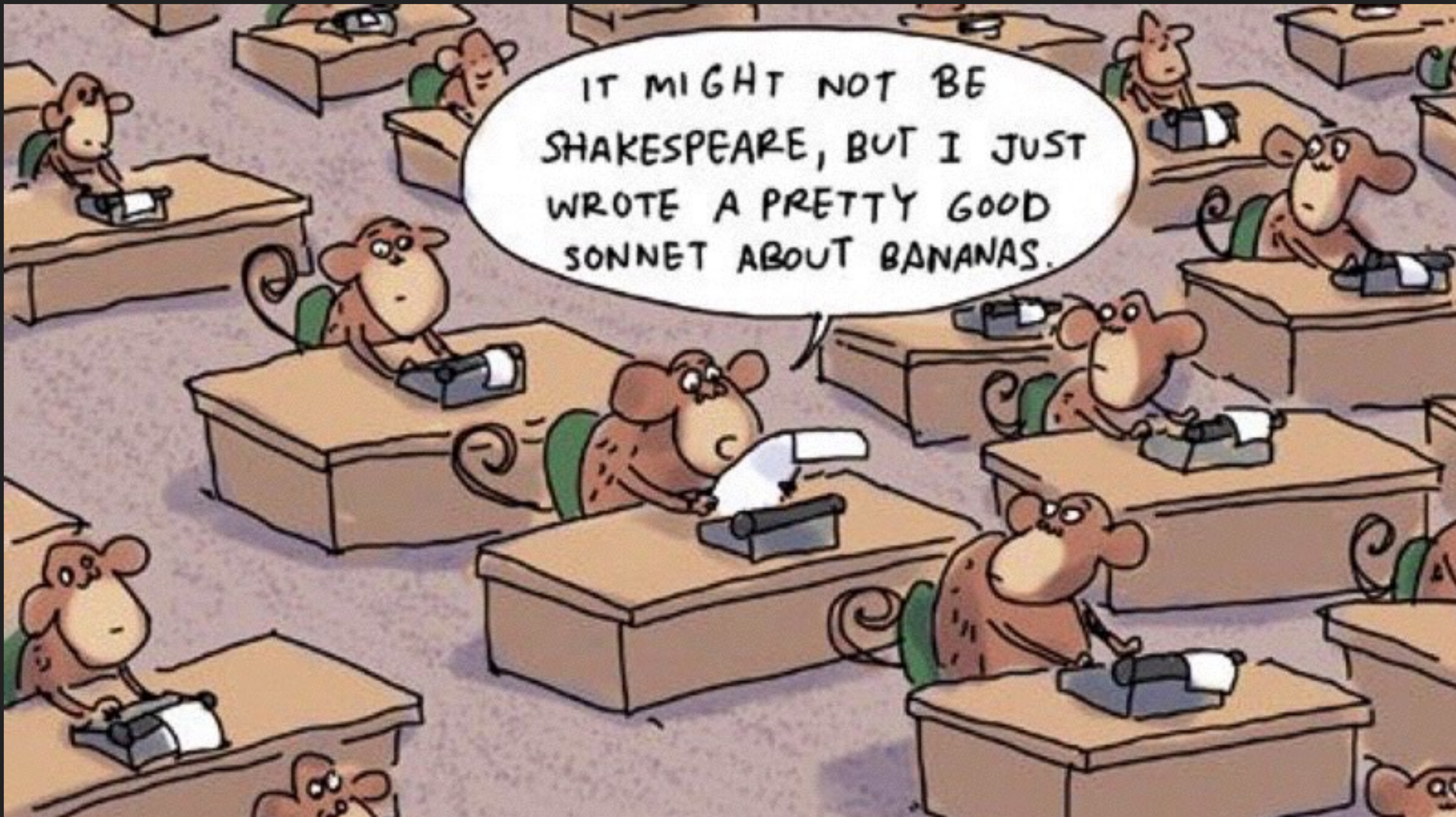
Best-Fit Effective Area Ratios
Worst-Fit Effective Area Ratios
ACIS
EPN
FPMA
Energy (keV)
KINGFISHER
PREMIUM
LAGER BEER

SUMMARY

- Application of MC effective areas to fitting of fiducial sources with assumptions about the spectral model provides a calibration discriminant
- Technique can be applied to multiple missions
- Technique can be applied to multiple and diverse sources (perturbation set is common to all)
- Needs refinements, e.g. balance between input spectra - “most counts wins”; improved input uncertainties…



Calibration


IT MIGHT NOT BE SHAKESPEARE, BUT I JUST WROTE A PRETTY GOOD SONNET ABOUT BANANAS.