The Precision of Chandra

Including Calibration Uncertainties in (X-ray) Parameter Estimation Analyses

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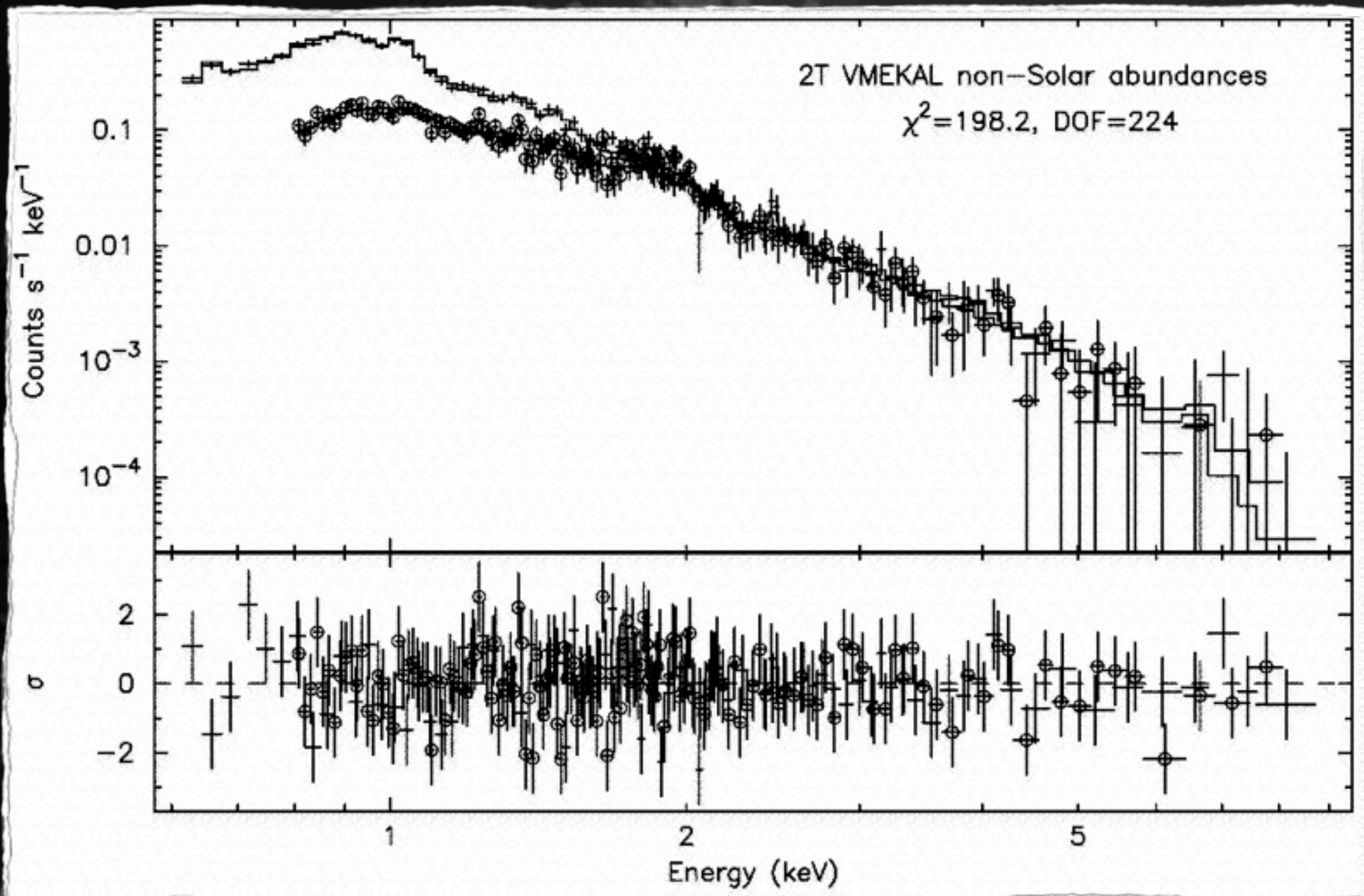
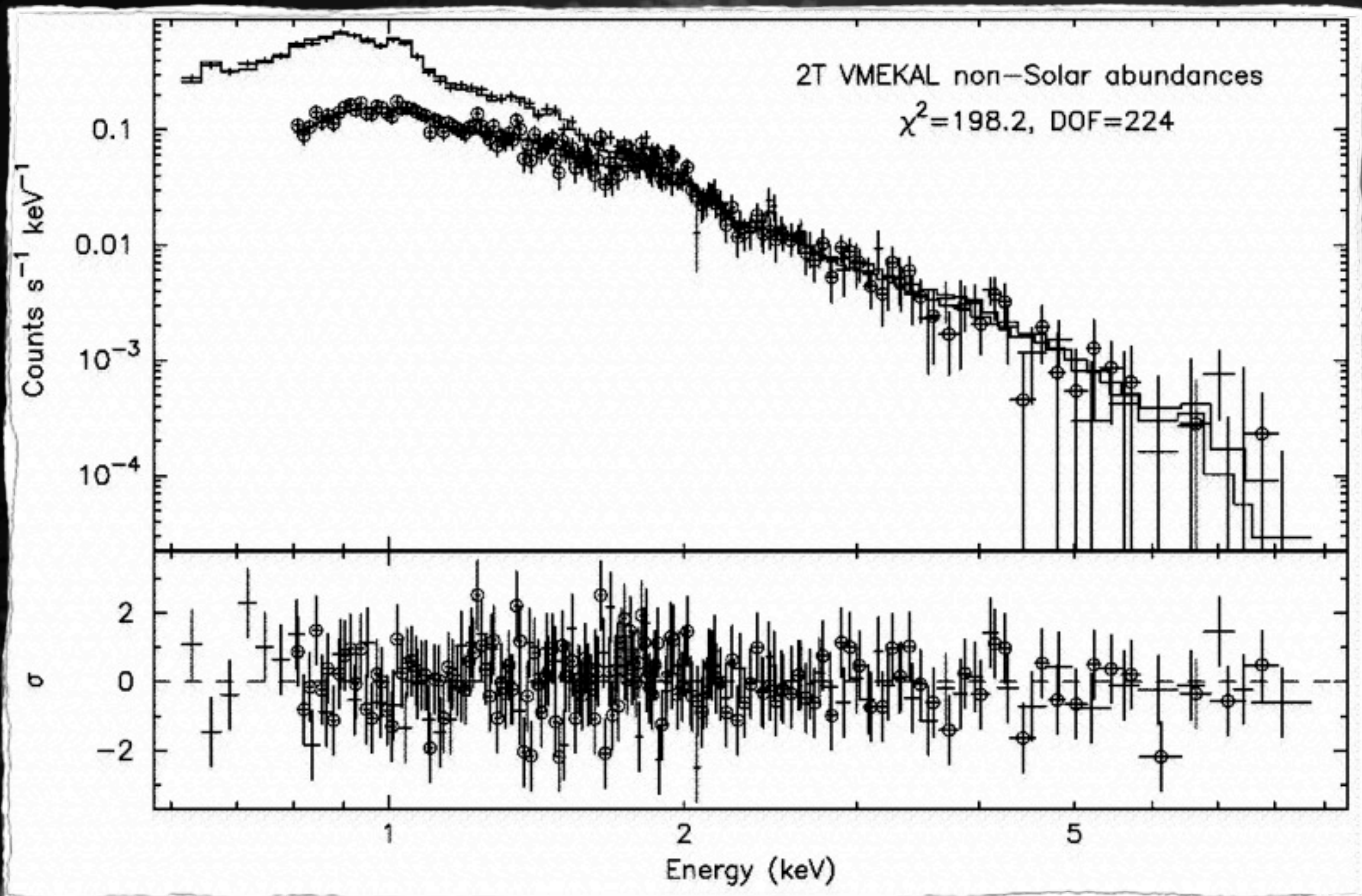
All the results presented at this meeting are wrong
Except for mine!


2T VMEKAL non-Solar abundances
χ^2=198.2, DOF=224
Counts s^{-1} keV^{-1}
0.1
0.01
10^{-3}
10^{-4}
σ
2
0
−2
1
2
5
Energy (keV)

Calibration uncertainties...



…and why we ignore them

- Problem: uncertainties are **correlated** in very complicated ways
- There are no easy statistical formulae to apply
- You might be able to make up some formalism, but….

E.g. where $\sigma_{i,j}$ represents relative uncertainty between channels i and j

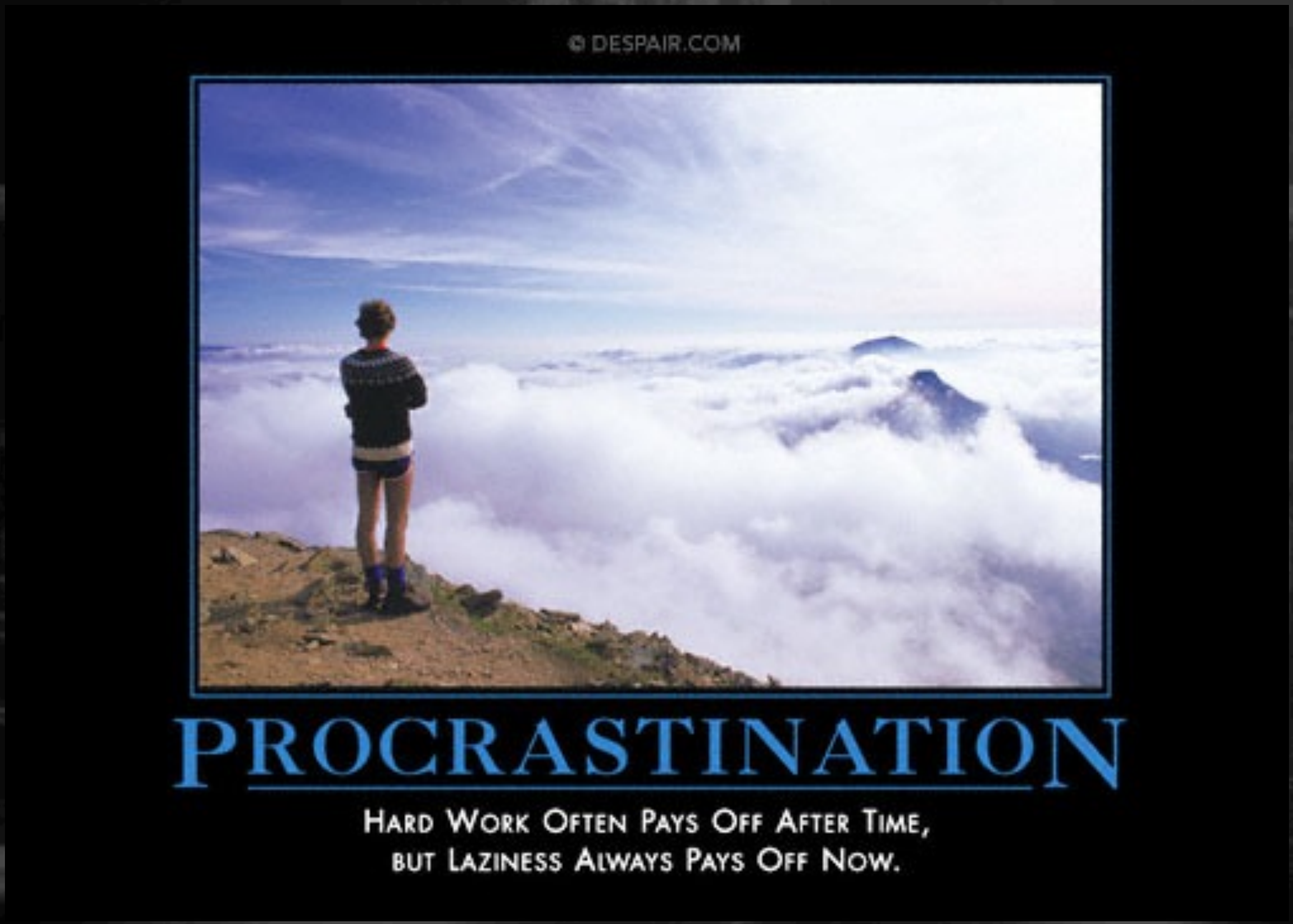
$$\begin{pmatrix} \sigma_{1,1} & \sigma_{2,1} & \cdots & \sigma_{n-1,1} & \sigma_{n,1} \\ \sigma_{1,2} & \sigma_{2,2} & & & \\ \vdots & & \ddots & & \vdots \\ \sigma_{1,n-1} & & & \sigma_{n-1,n-1} & \sigma_{n,n-1} \\ \sigma_{1,n} & & \cdots & \sigma_{n-1,n} & \sigma_{n,n} \end{pmatrix}$$

Statisticians on the correlated uncertainties

- "I haven't ever dealt with the problem of correlated uncertainties so I'm afraid can't be much help. Good luck!"
  - Keith Robinson (of Bevington & Robinson)

Monte Carlo Approach

Analytical solutions difficult....



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

Uncertainties in Photon Path

↓

HRMA: geometry, obscuration, reflectivity, scattering

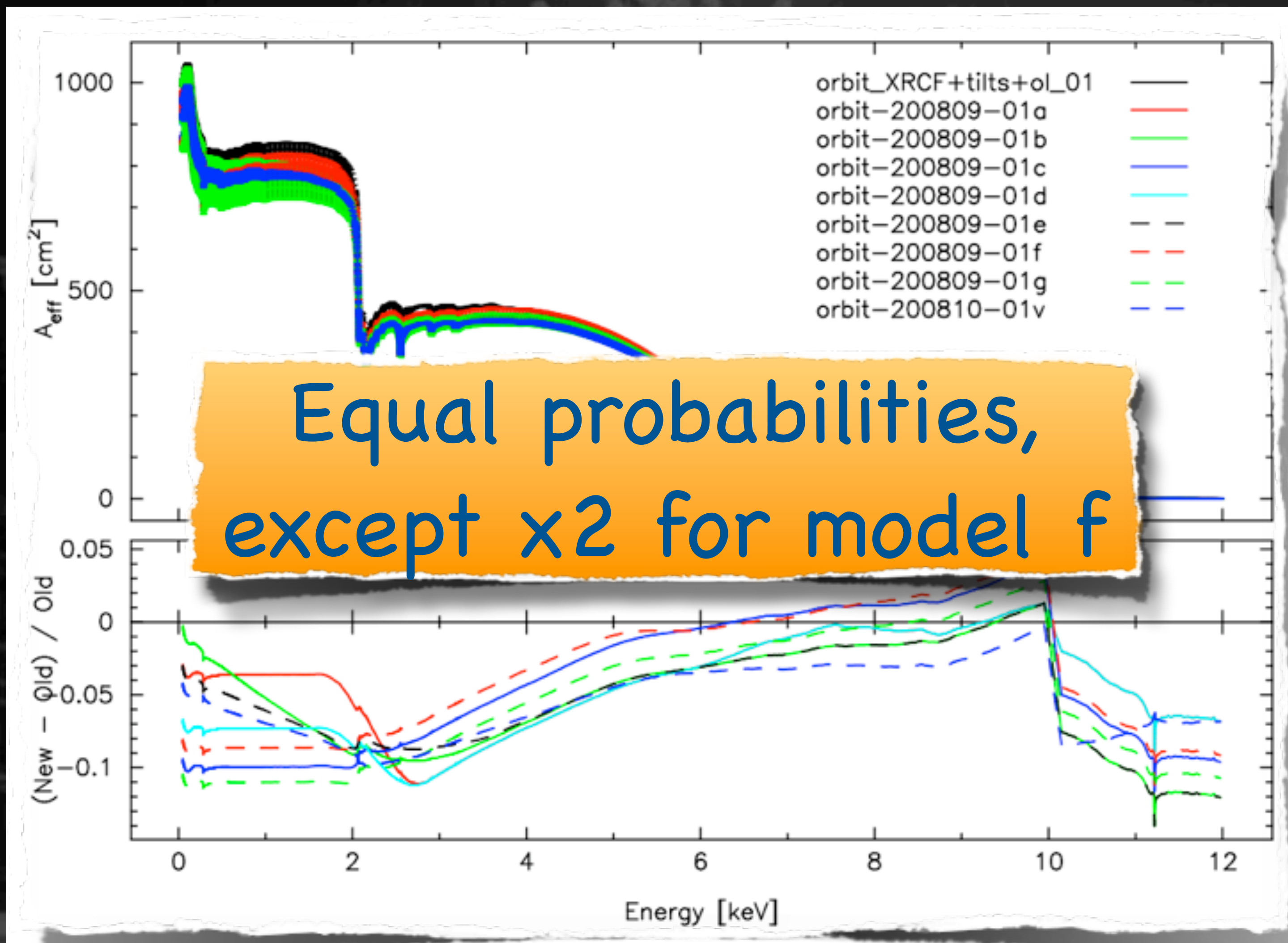
↓

ACIS OBF: transmittance, contamination

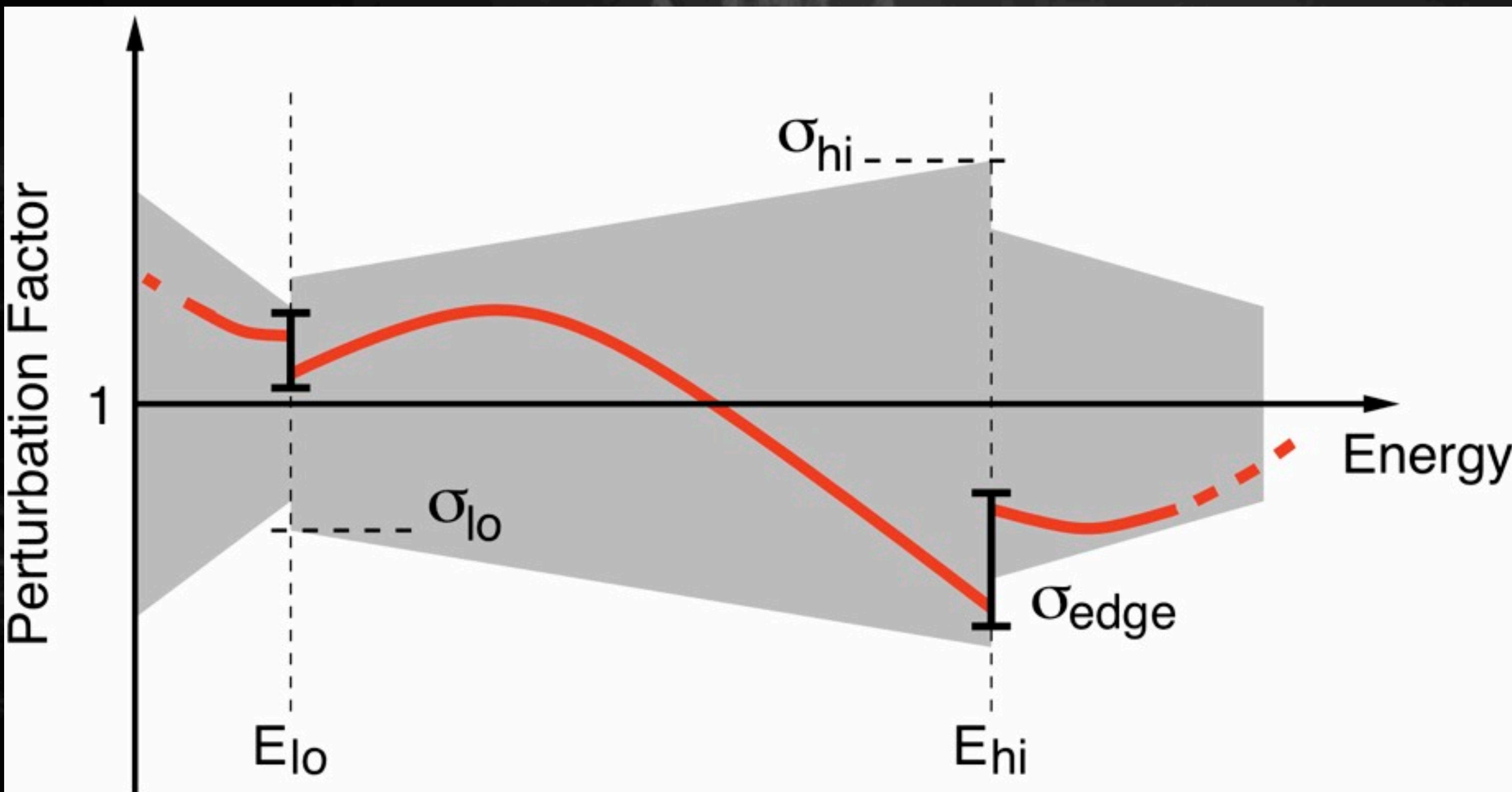
↓

ACIS QE: (CTI, dead time, cosmic rays, electronics…)
ACIS RMF: (gain distribution, escape peaks...)

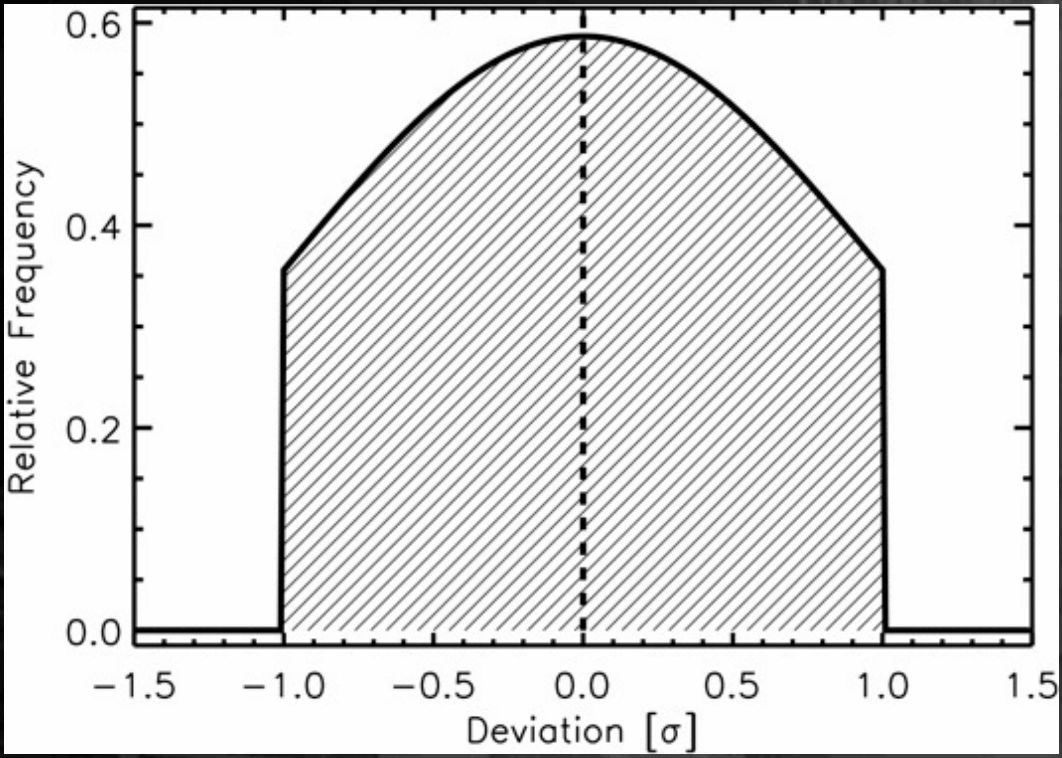
HRMA seed areas



Pertubation function

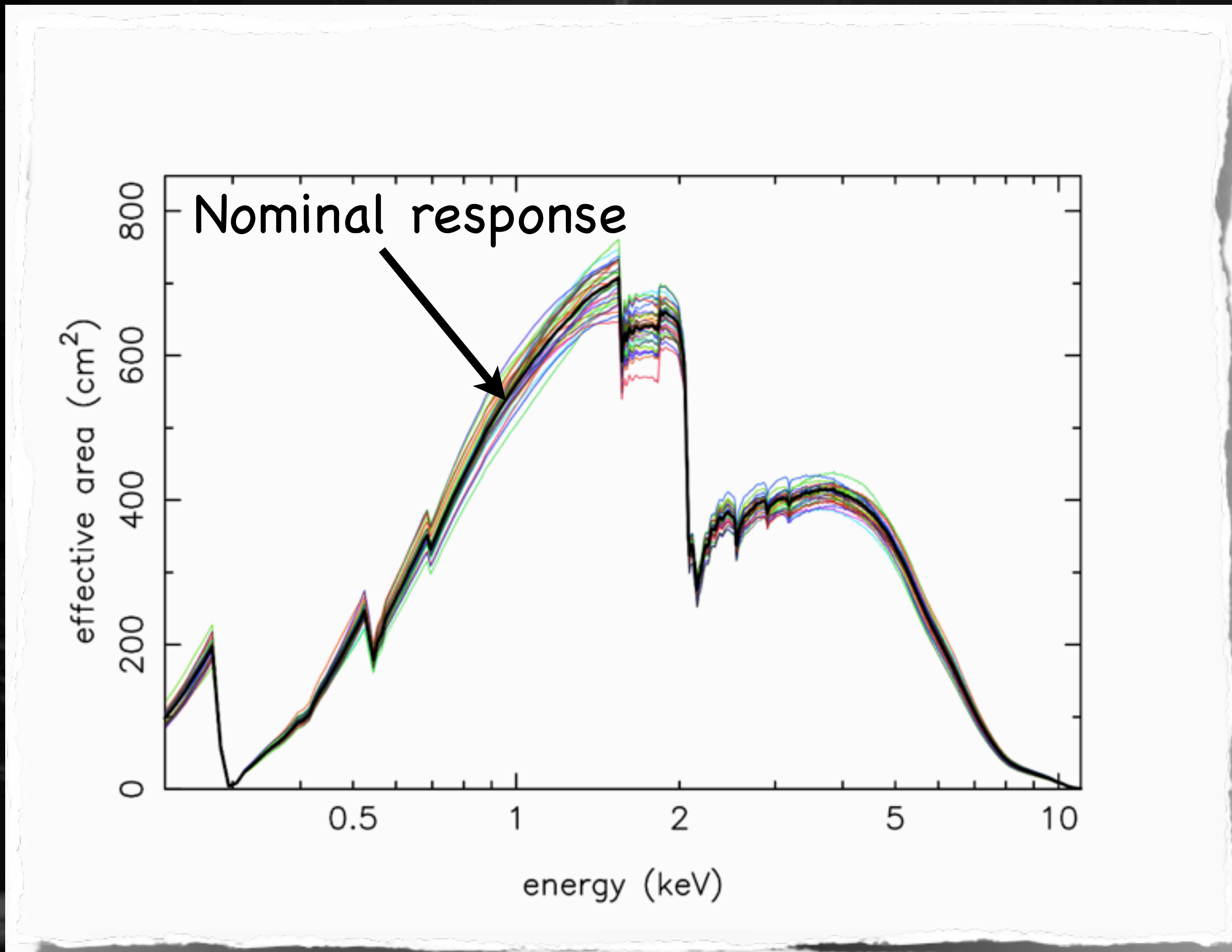


How are calibration uncertainties distributed?



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

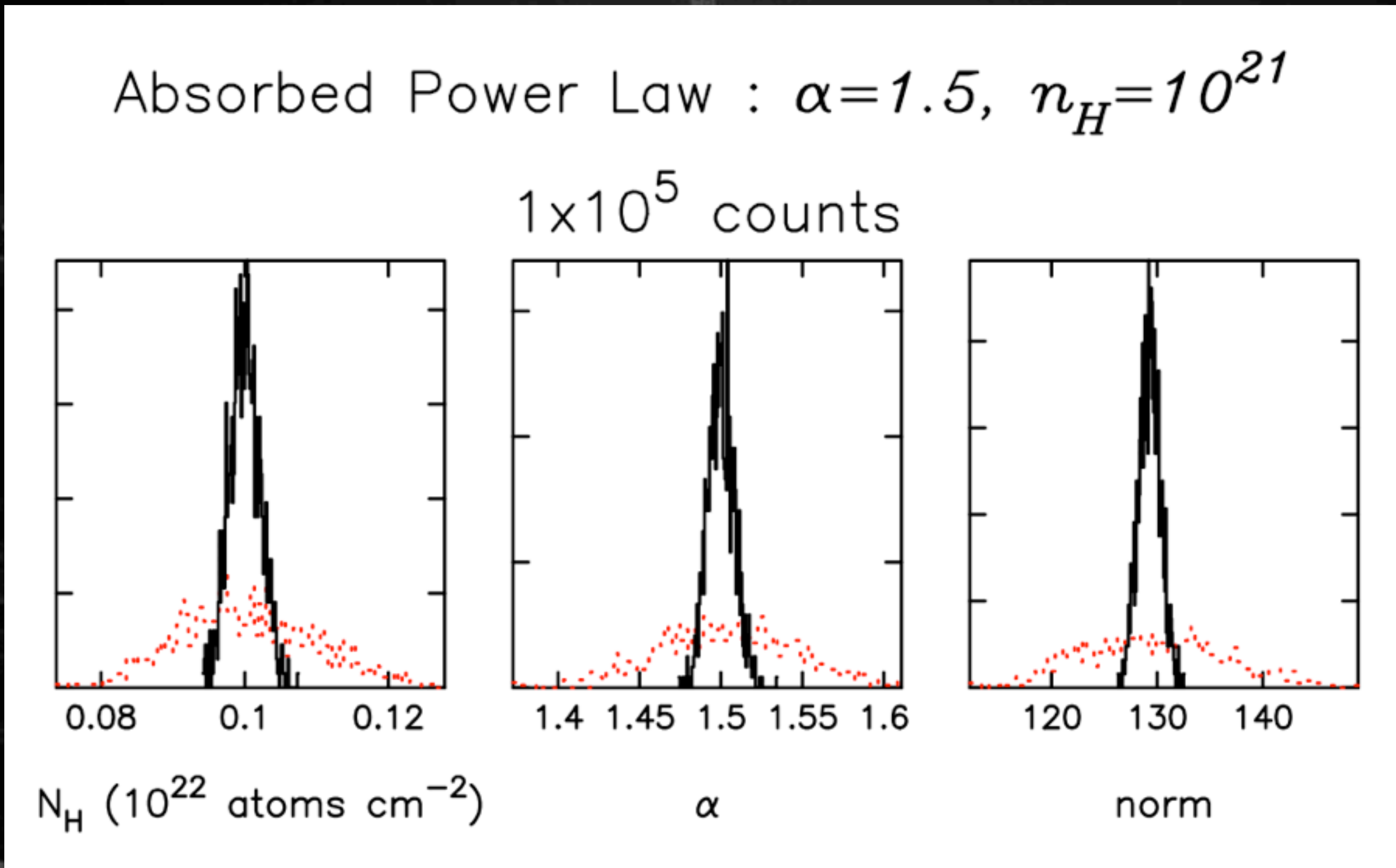
Resulting ACIS-S3 areas



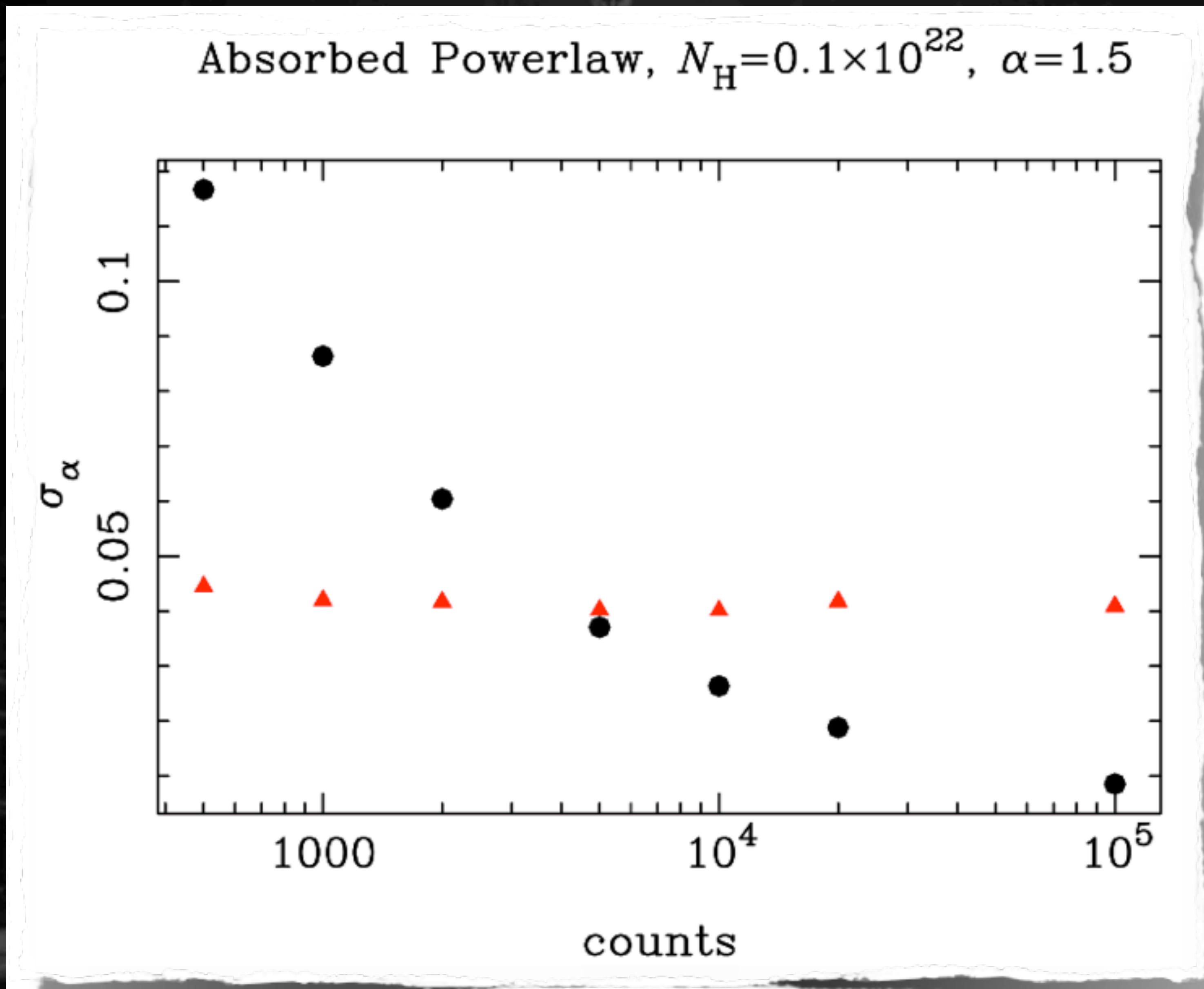
Limiting Accuracy of Chandra

- 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

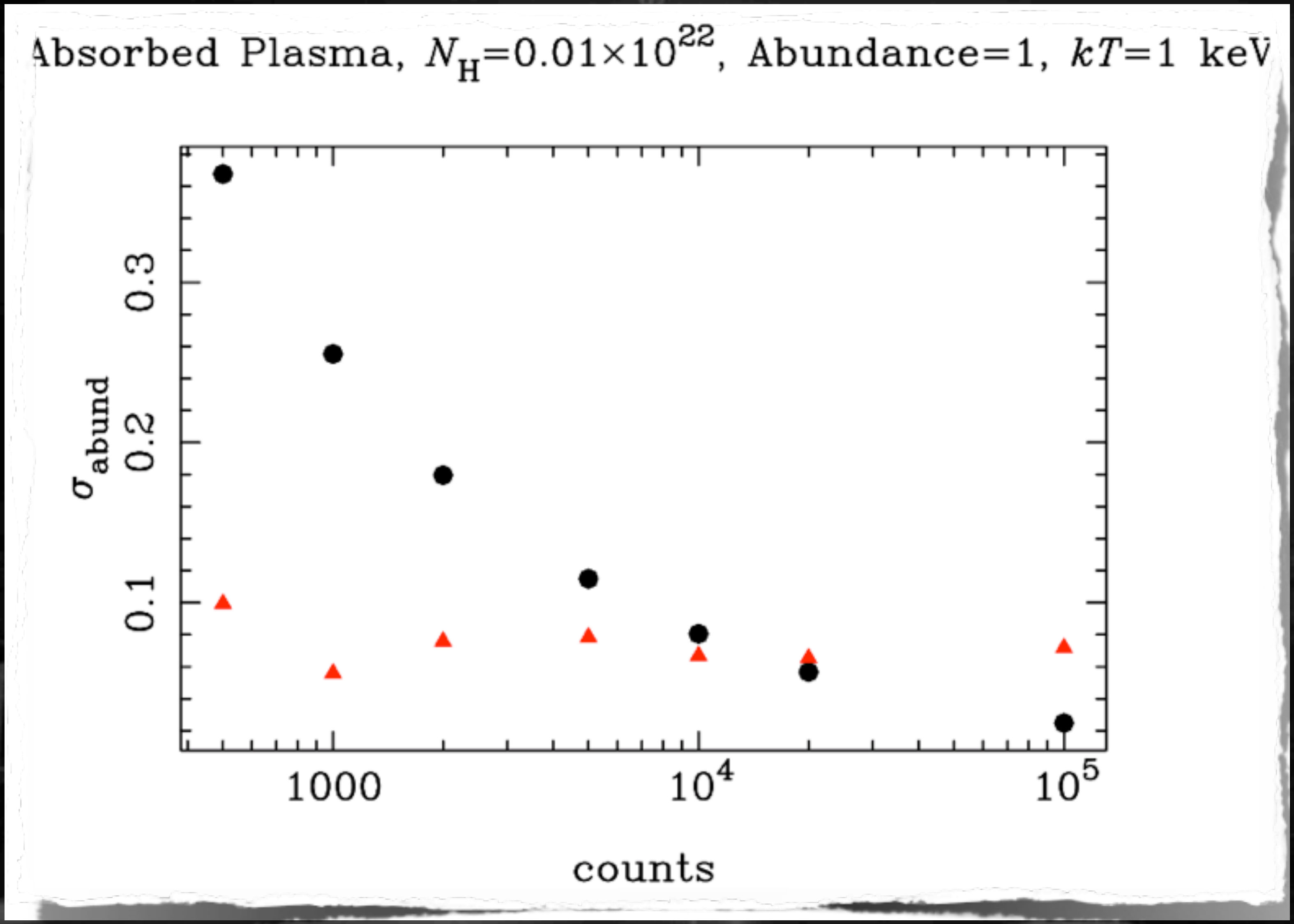
Poisson vs Calibration



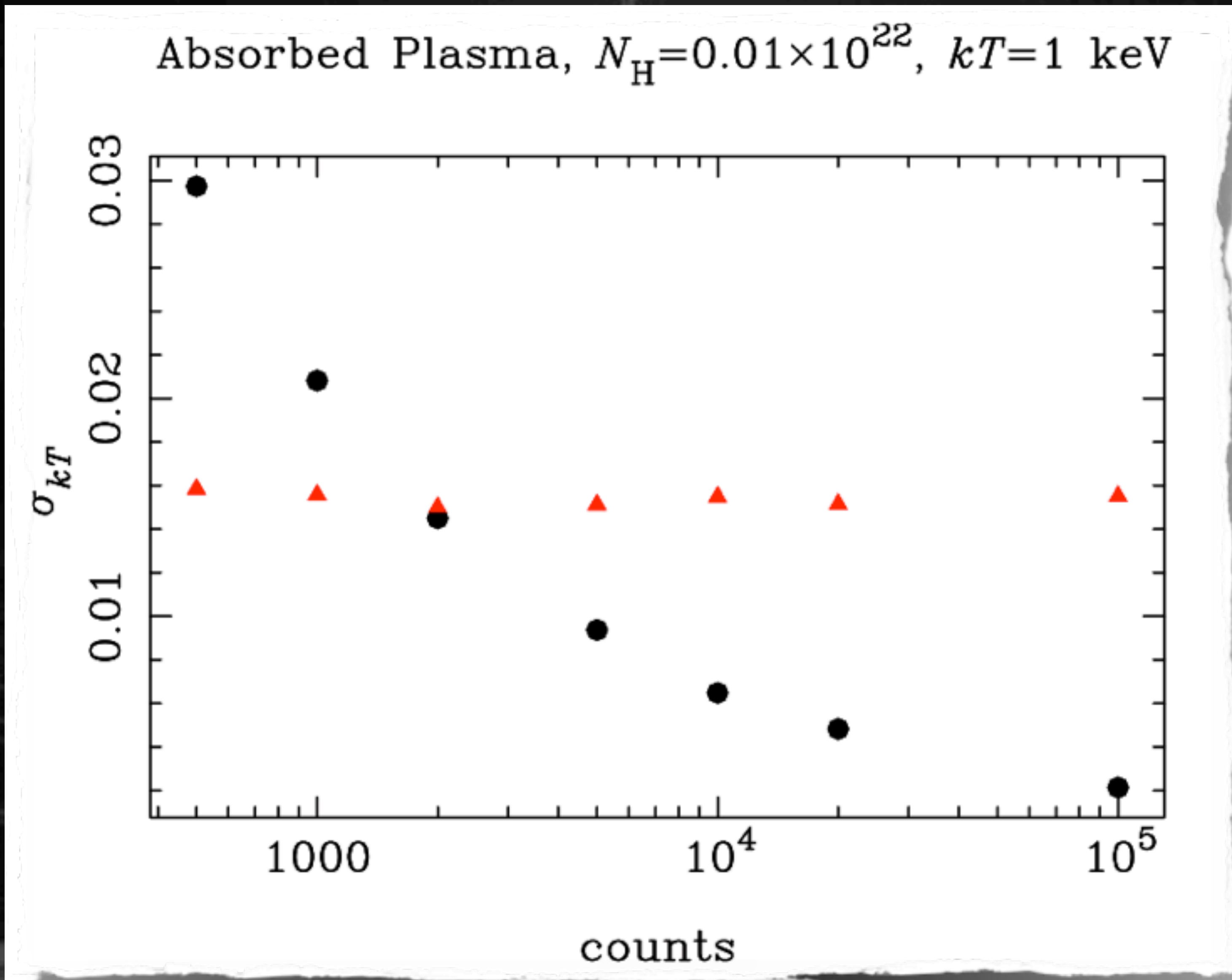
Poisson vs Calibration



Poisson vs Calibration



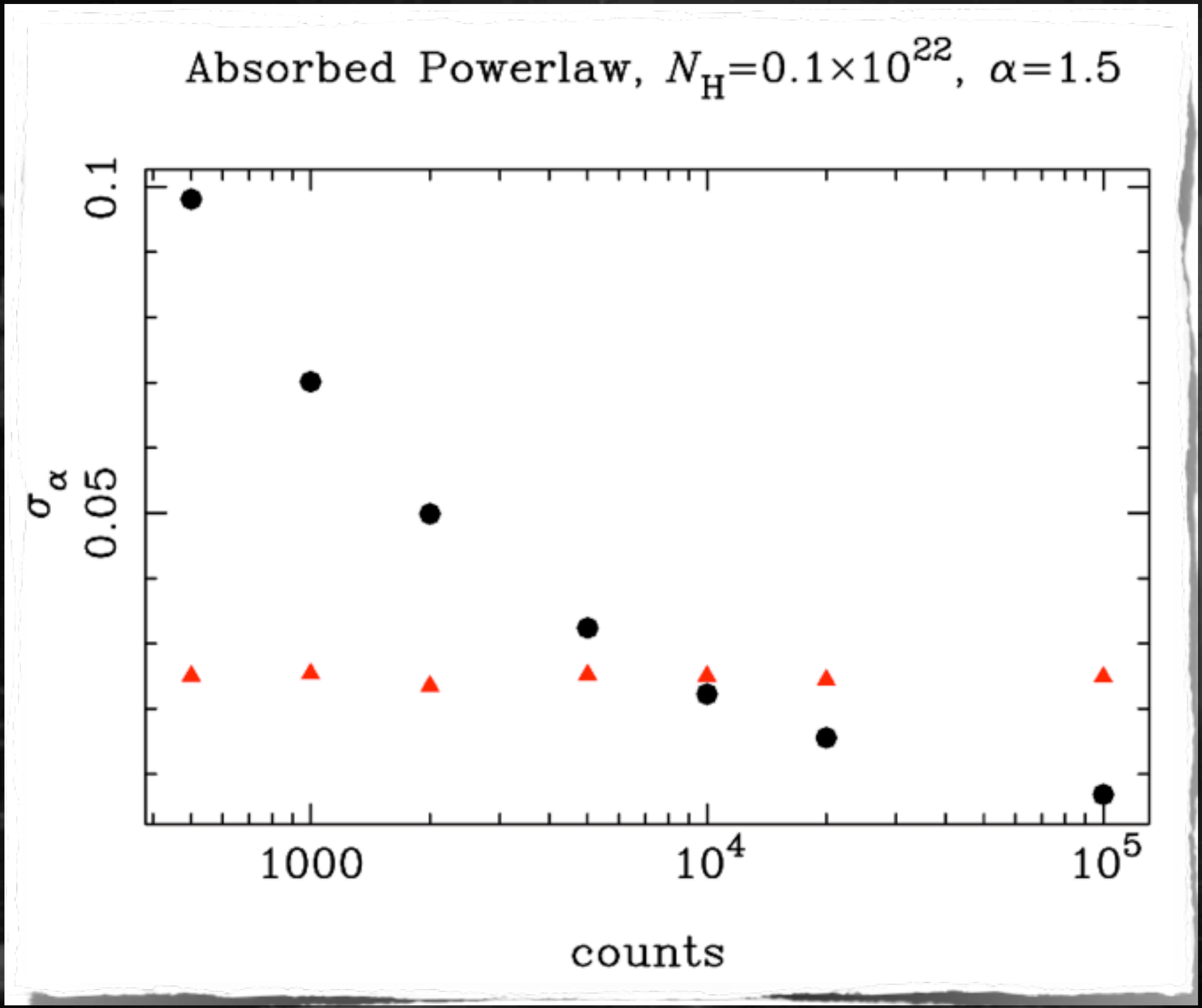
Poisson vs Calibration



XMM input file

```
# Each range emin,emindev,emax,emaxdev,edgeveto energies in keV
# Designed for XMM-Newton 21/06/11
# XMM mirrors are gold-plated, so differet mirror edge energies
MM 0.05,0.04,2.291,0.04,0.03
2.291,0.03,3.425,0.03,0.01
3.425,0.03,7.000,0.03,0.005
7.000,0.05,12.0,0.10
CONTAM 0.05,0.10,0.2838,0.02,0.02
0.2838,0.02,0.4099,0.02,0.02
0.4099,0.02,0.532,0.02,0.01
0.532,0.02,0.6967,0.02
OBFTN 0.05,0.15,0.297,0.07,0.03
0.297,0.05,0.540,0.03,0.02
0.540,0.02,1.567,0.02,0.02
1.567,0.02,12.0,0.02
OBFM 0.05,0.15,0.297,0.07,0.04
0.297,0.06,0.540,0.03,0.02
0.540,0.02,1.567,0.02,0.02
1.567,0.02,12.0,0.02
OBFTK 0.05,0.15,0.297,0.07,0.05
0.297,0.07,0.540,0.03,0.02
0.540,0.02,1.567,0.02,0.02
1.567,0.02,12.0,0.02
EPICPN 0.05,0.20,0.132,0.10,0.11
0.132,0.15,0.539,0.05,0.03
0.539,0.04,1.827,0.04,0.03
1.827,0.04,12.0,0.03
EPICMOS 0.05,0.30,0.132,0.20,0.11
0.132,0.15,0.539,0.07,0.04
0.539,0.05,1.827,0.05,0.04
1.827,0.05,12.0,0.04
```

XMM Precision



Code release

- Full Sherpa/Python release in October
  - More limited Perl-XSPEC b-release available at

    http://hea-www.harvard.edu/~rpete/mccal
- Sherpa/pyBLoCXS available shortly (Lee et al, 2011, ApJ, 731, 126)
  - jdrake@cfa.harvard.edu

Future

- Calibration uncertainties can now be routinely included in X-ray model fitting
- Addition of other Chandra instruments (+XMM-Newton....)
- Method completely general: can be done for any mission/instrument
  - eg perturbation function approach can be implemented for Suzaku, Swift, eROSITA, ASTRO-H... ``tomorrow"