SPIE 2008 :: Observatory Operations :: 7016-23 :: 16:20 Wednesday 25 June 2008

How to handle calibration uncertainties in high-energy astrophysics

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How to handle calibration uncertainties in high-energy astrophysics

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bottom line

there is now a way
to include calibration uncertainty
in astrophysical data analysis
in a flexible way
for any instrument, mission, or detector.

Part I
calibration uncertainty
in data analysis

Part II
practical issues of
storage, retrieval, flexibility

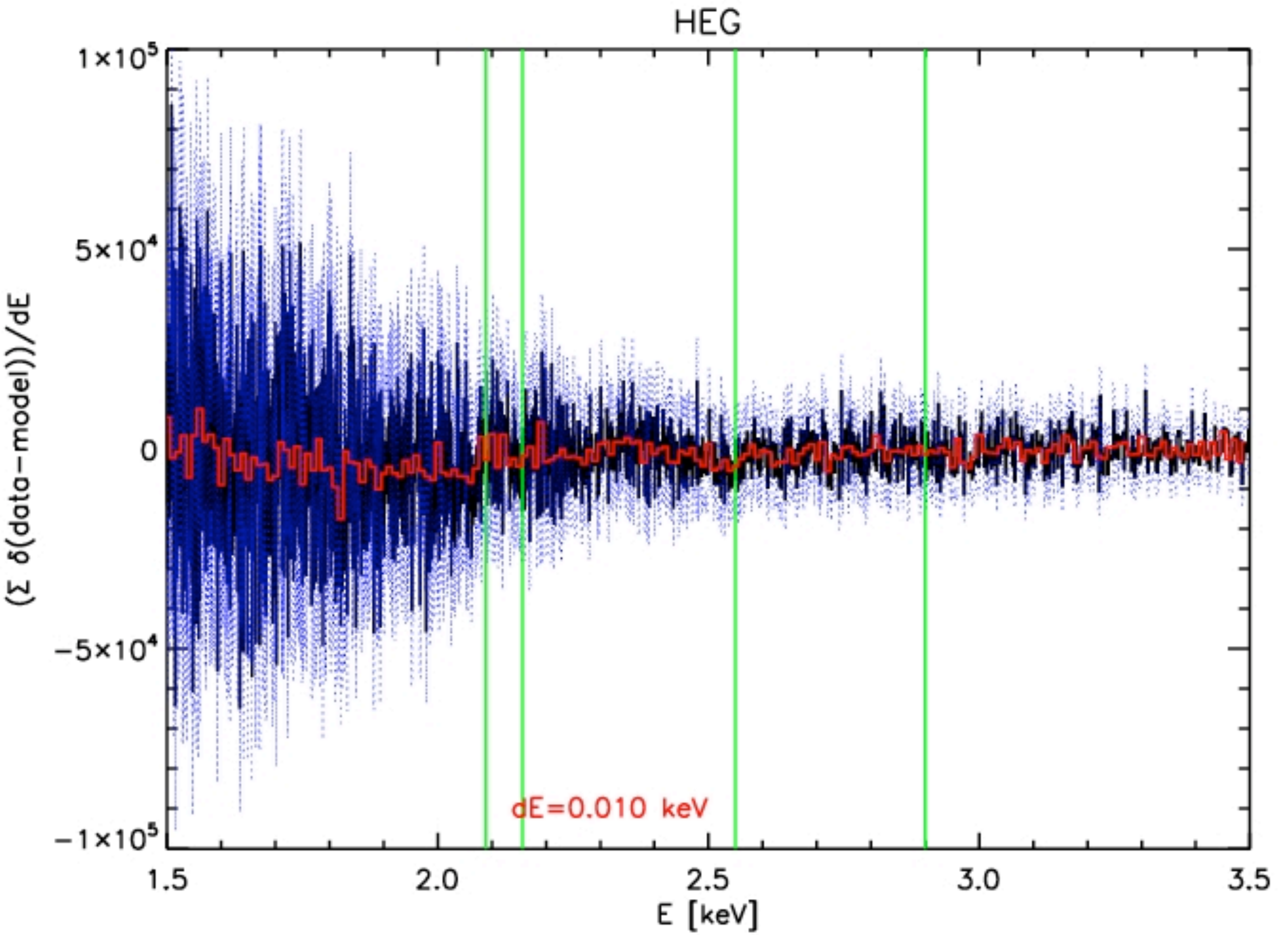
The three most important effects that affect data analysis

astrophysical model uncertainty

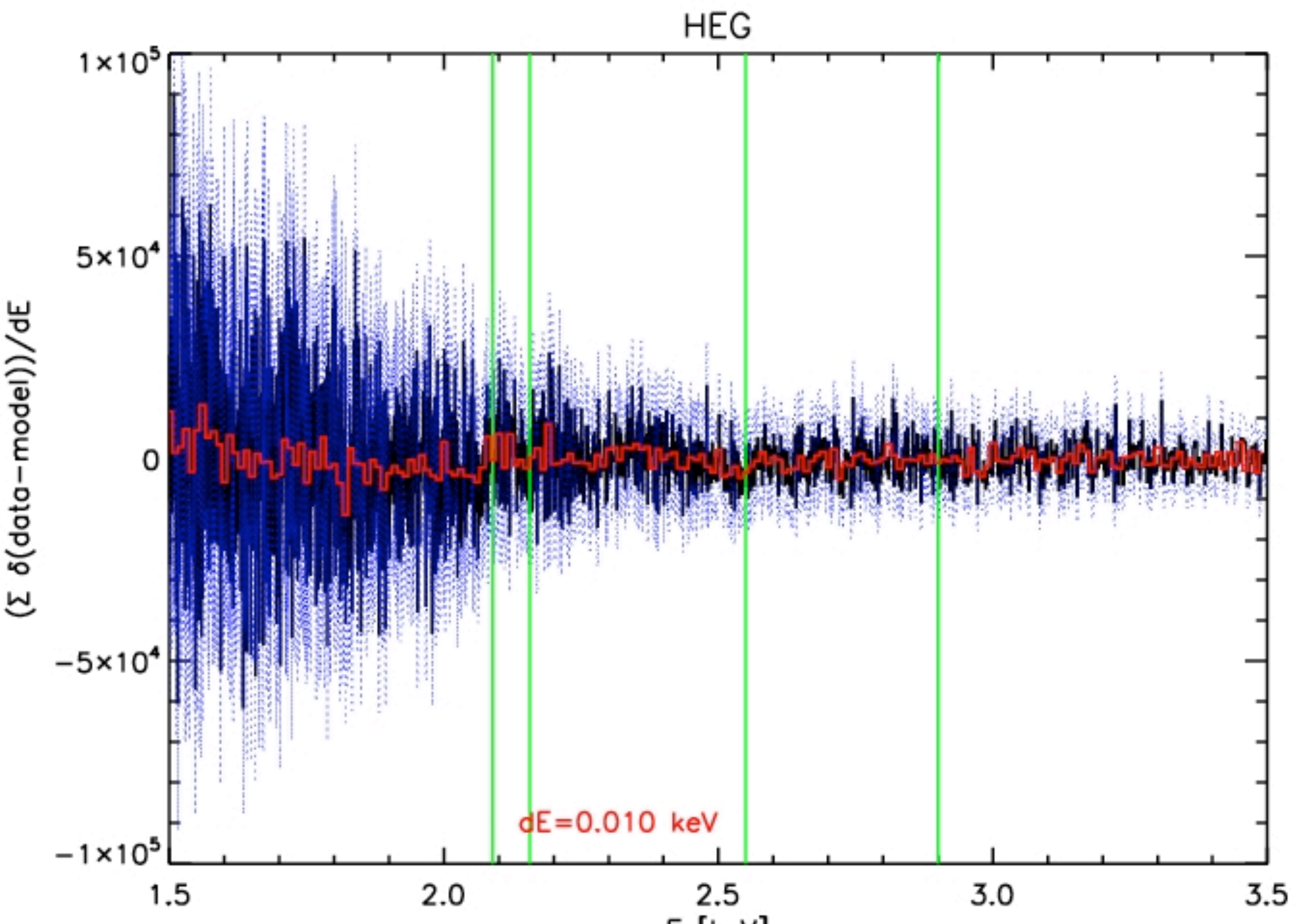
statistical uncertainty (measurement error)

calibration uncertainty (systematic error) examples of calibration uncertainty

power-law residuals with current calibration



power-law residuals with 20Å contamination overlayer



general model of HEA data

$$M(E',\mathbf{p}',t) = \int dE\, d\mathbf{p}\; S(E,\mathbf{p},t;\theta)\, A(E,\mathbf{p}';\mathbf{p},t)\, R(E,E',\mathbf{p}';t)\, P(\mathbf{p},\mathbf{p}',E;t)$$

(E,p,t) : photon energy, location, arrival time

(E',p') : detector channel, chip location

S : astrophysical source model

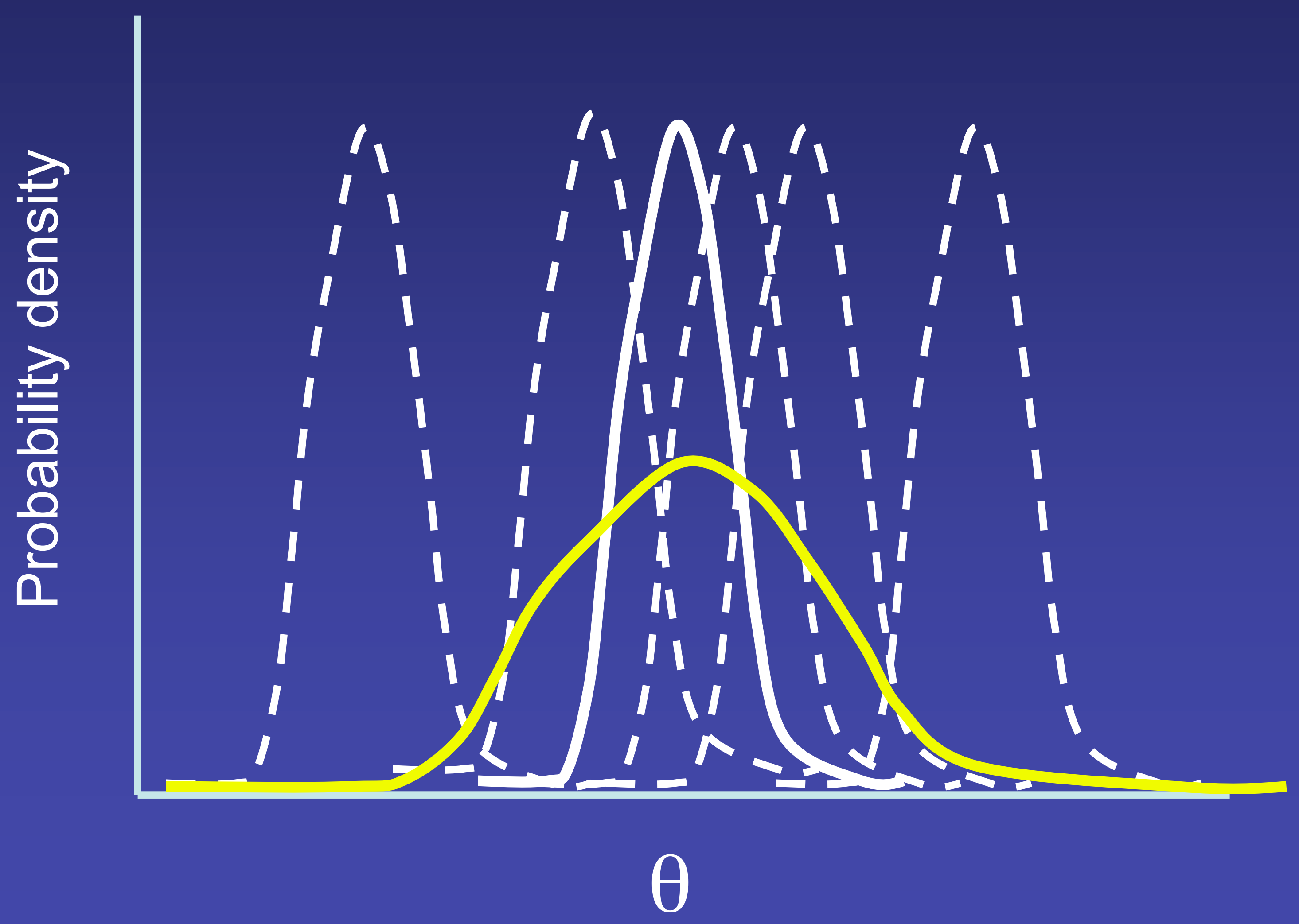
R : energy redistribution function (RMF)

P : position redistribution function (PSF)

A : effective area (ARF)

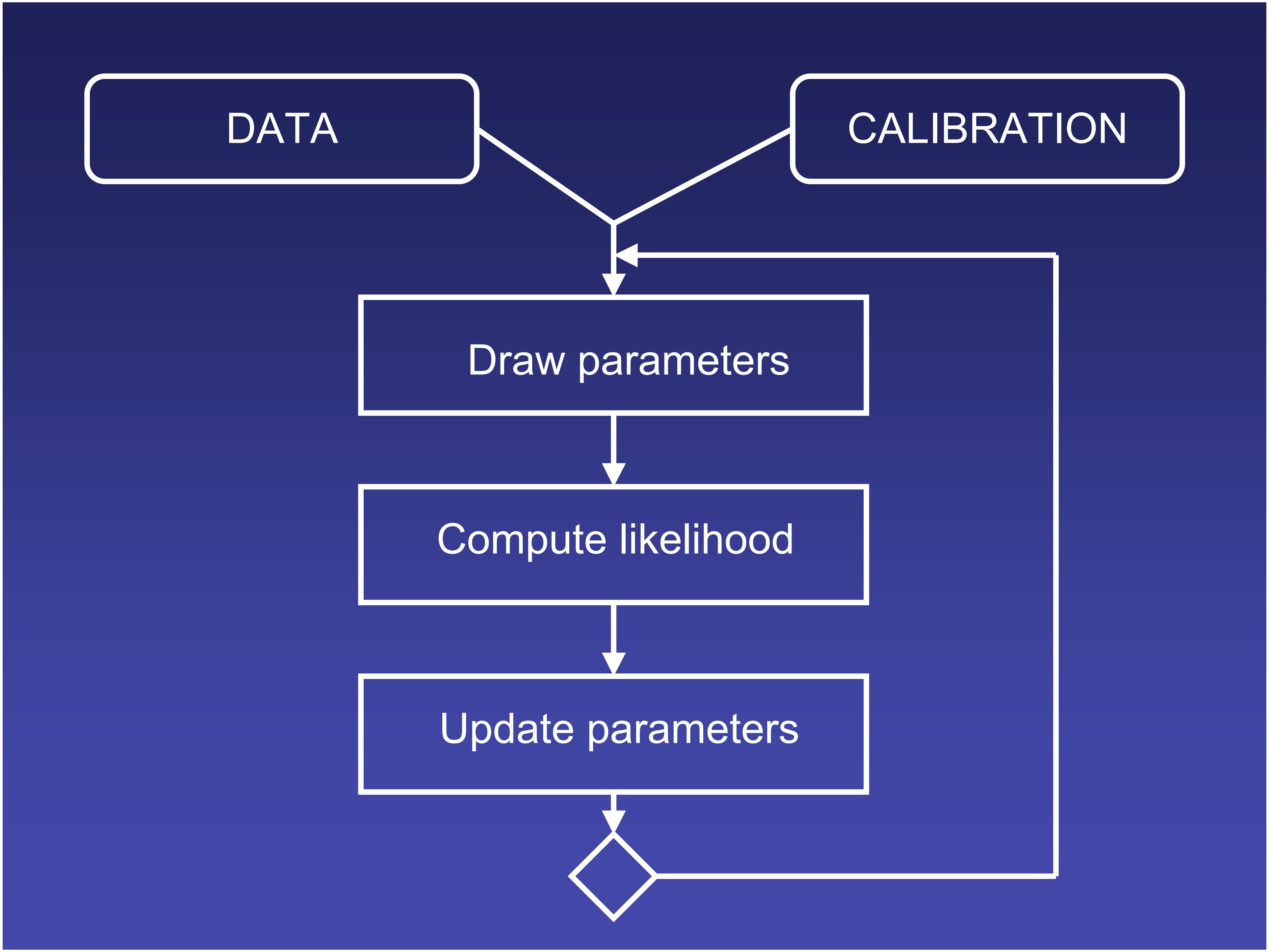
M : predicted model counts

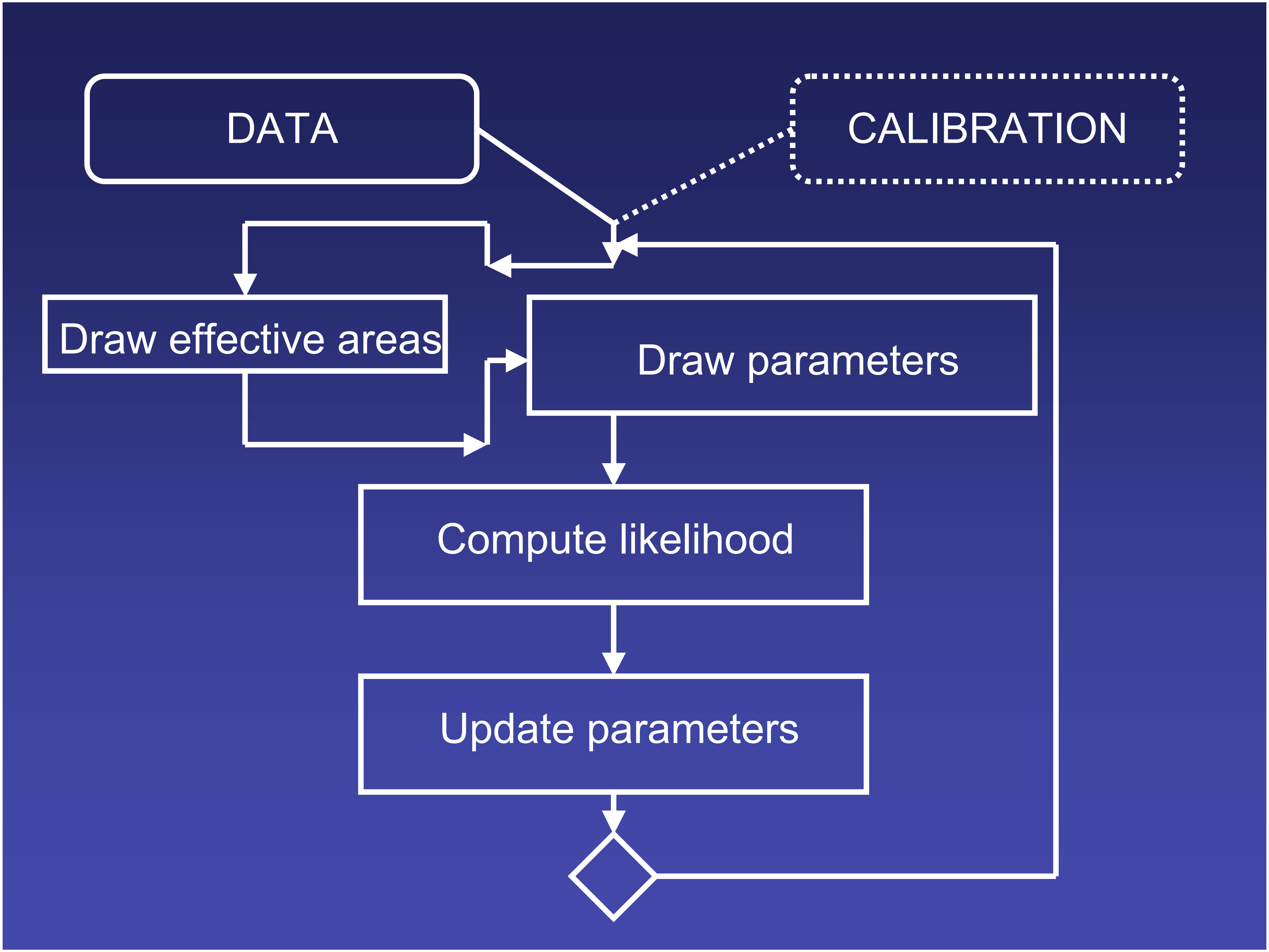
effect on model parameter uncertainty



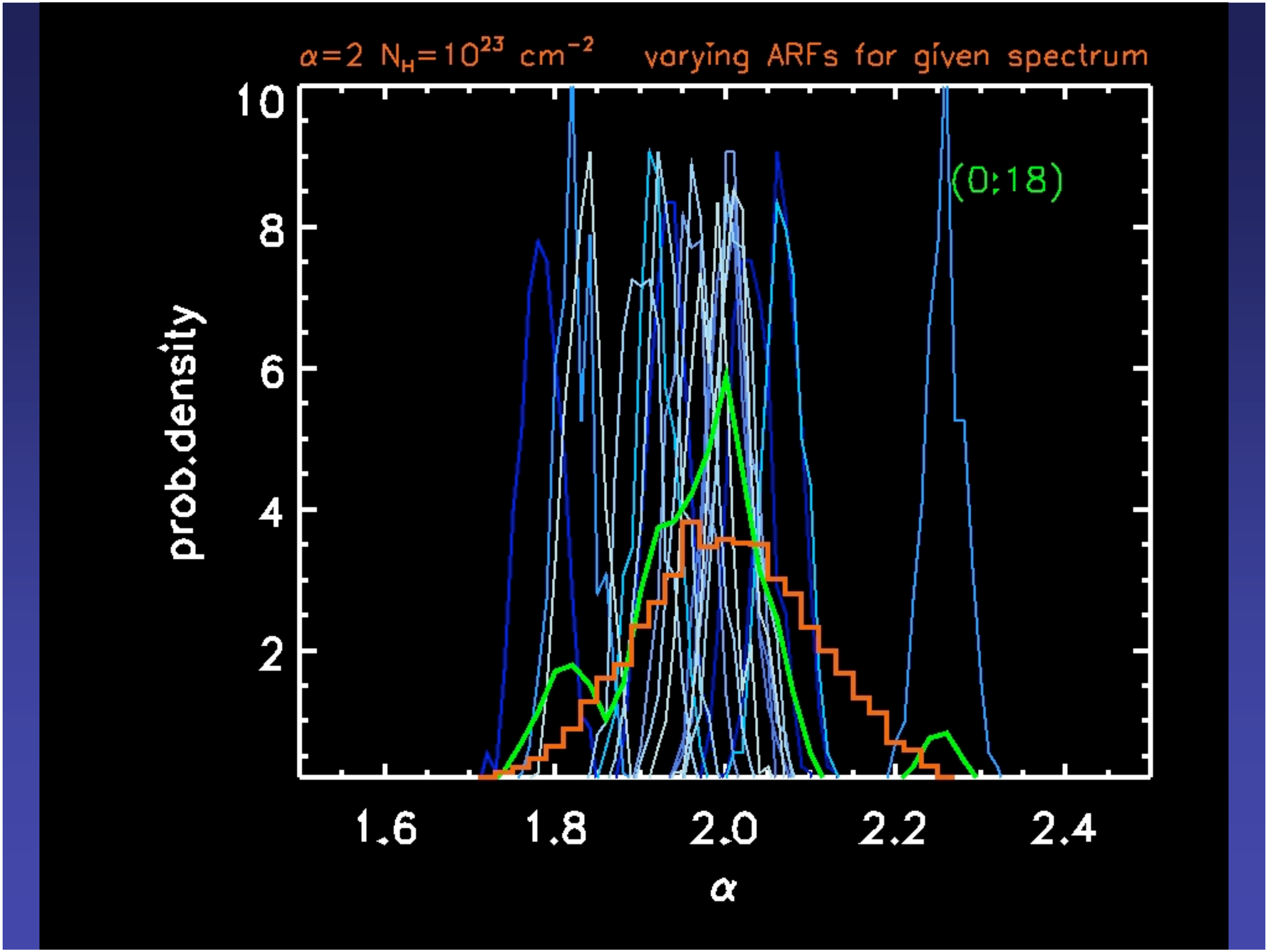
but how exactly?

MCMC

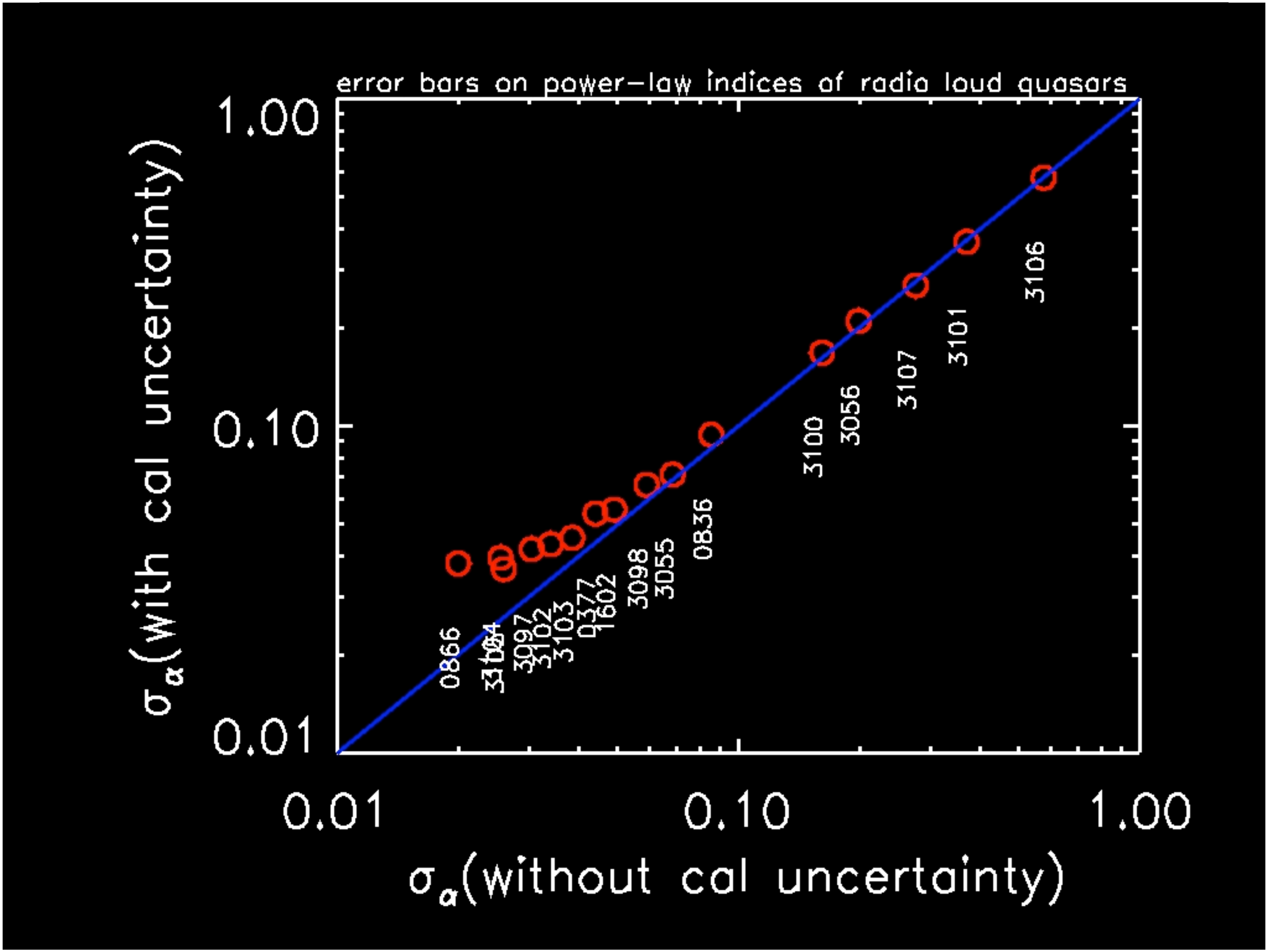

DATA
CALIBRATION
Draw parameters
Compute likelihood
Update parameters



DATA
CALIBRATION
Draw effective areas
Draw parameters
Compute likelihood
Update parameters

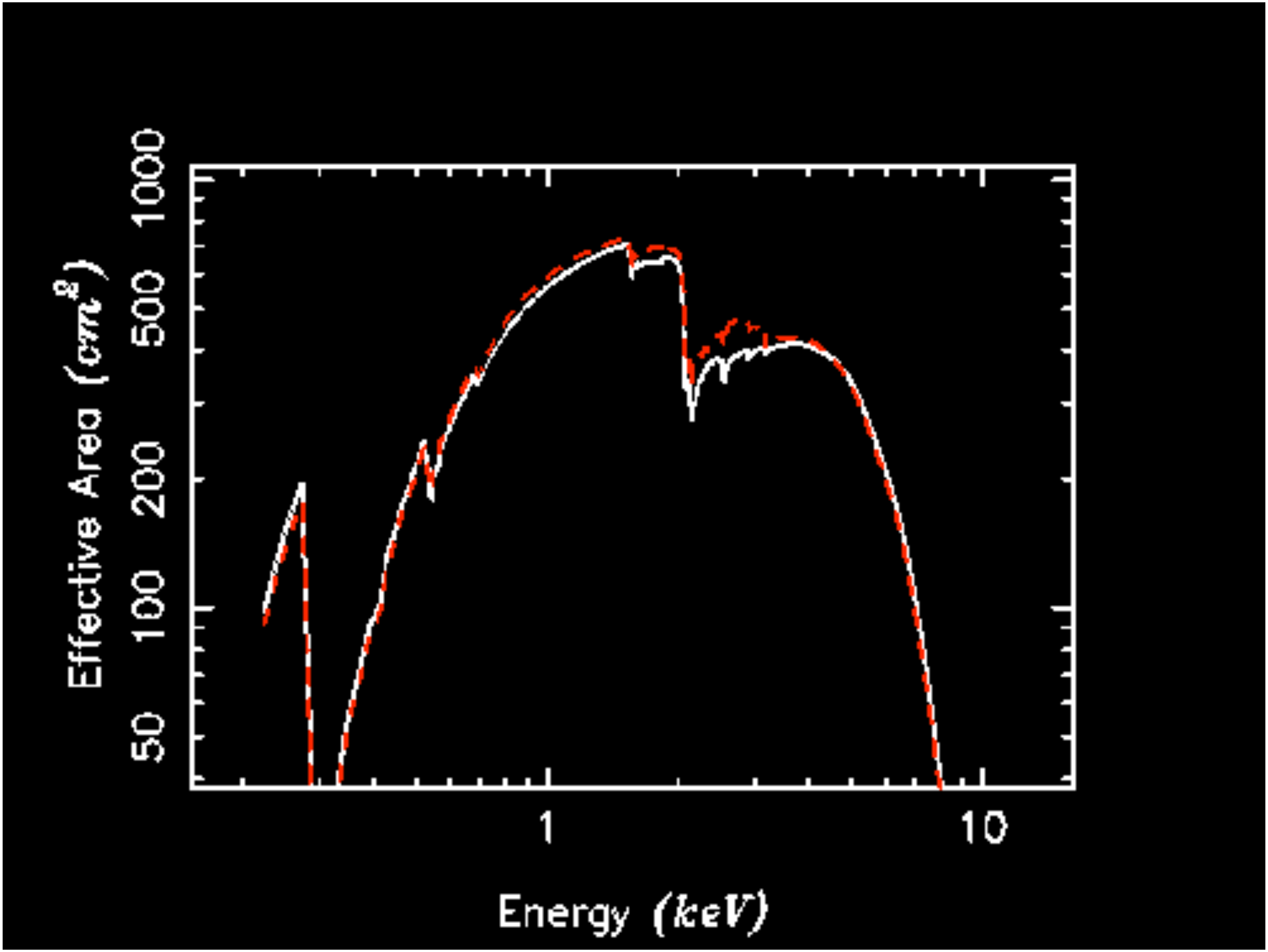


α=2 N_H=10^23 cm^-2 varying ARFs for given spectrum
(0;18)
prob.density
10
8
6
4
2
1.6
1.8
2.0
2.2
2.4
α



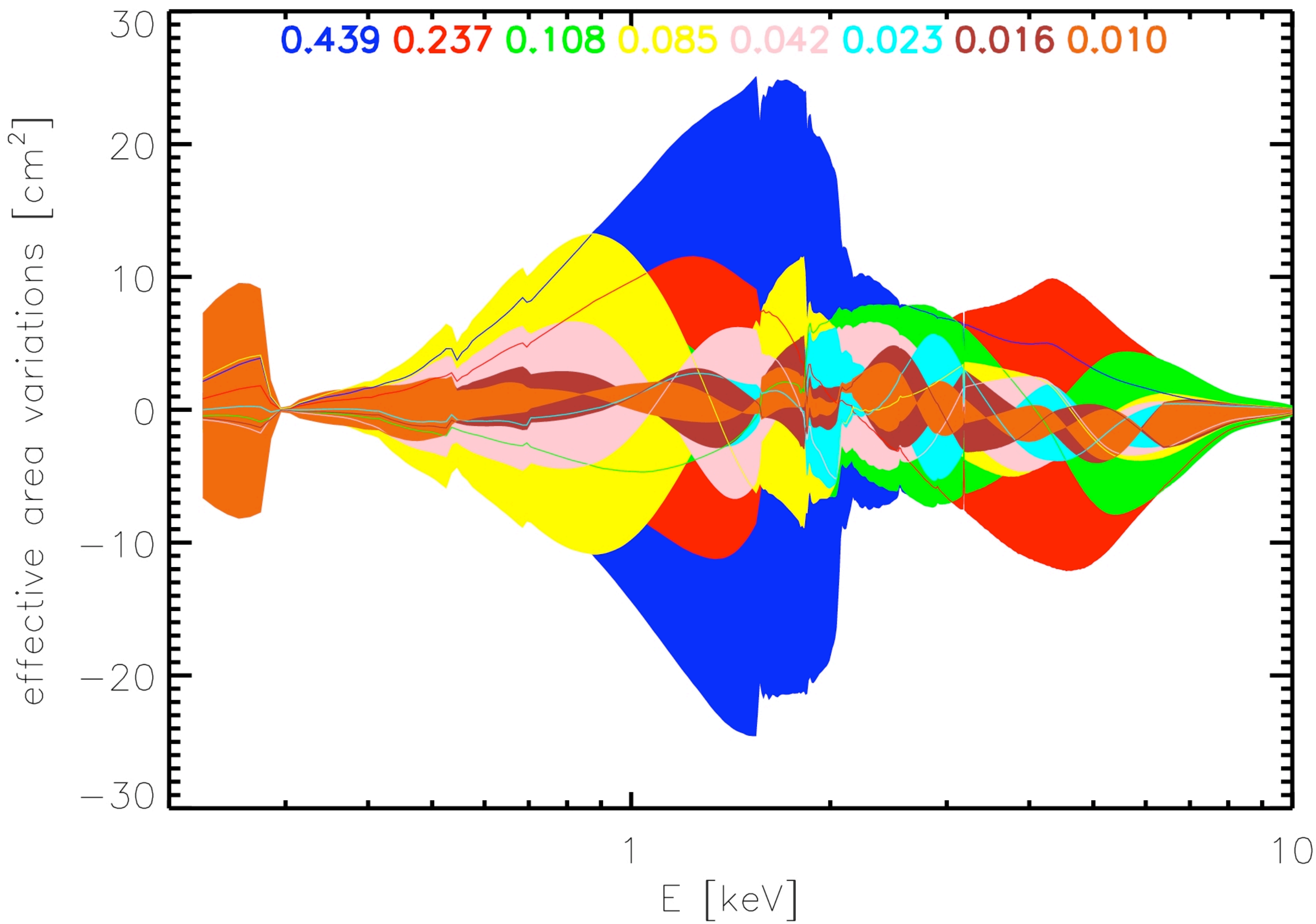
error bars on power-law indices of radio loud quasars
σα(with cal uncertainty)
σα(without cal uncertainty)
1.00
0.10
0.01
0866
3097
3102
3103
0377
1602
3098
3055
0836
3100
3056
3107
3101
3106

but where do the effective areas come from?



Effective Area (cm²)
1000
500
200
100
50
1
10
Energy (keV)

Principal Components



new nominal bias $\sim\mathcal{N}(0,1)$ eigenvalue eigenvector

$$\mathcal{A}'(E_j) = \mathcal{A}_0(E_j) + \overline{\delta\mathcal{A}(E_j)} + \sum_{k=1}^{N_{max}} r_k\, e_k\, \nu_k(E_j) + r_{(N_{max}+1)}\, \xi(E_j)$$

PCs

residual

A = A_0 + bias + components + residual

Part II
practical issues of
storage, retrieval, flexibility

$$A = A_0 + \text{bias} + \text{components} + \text{residual}$$

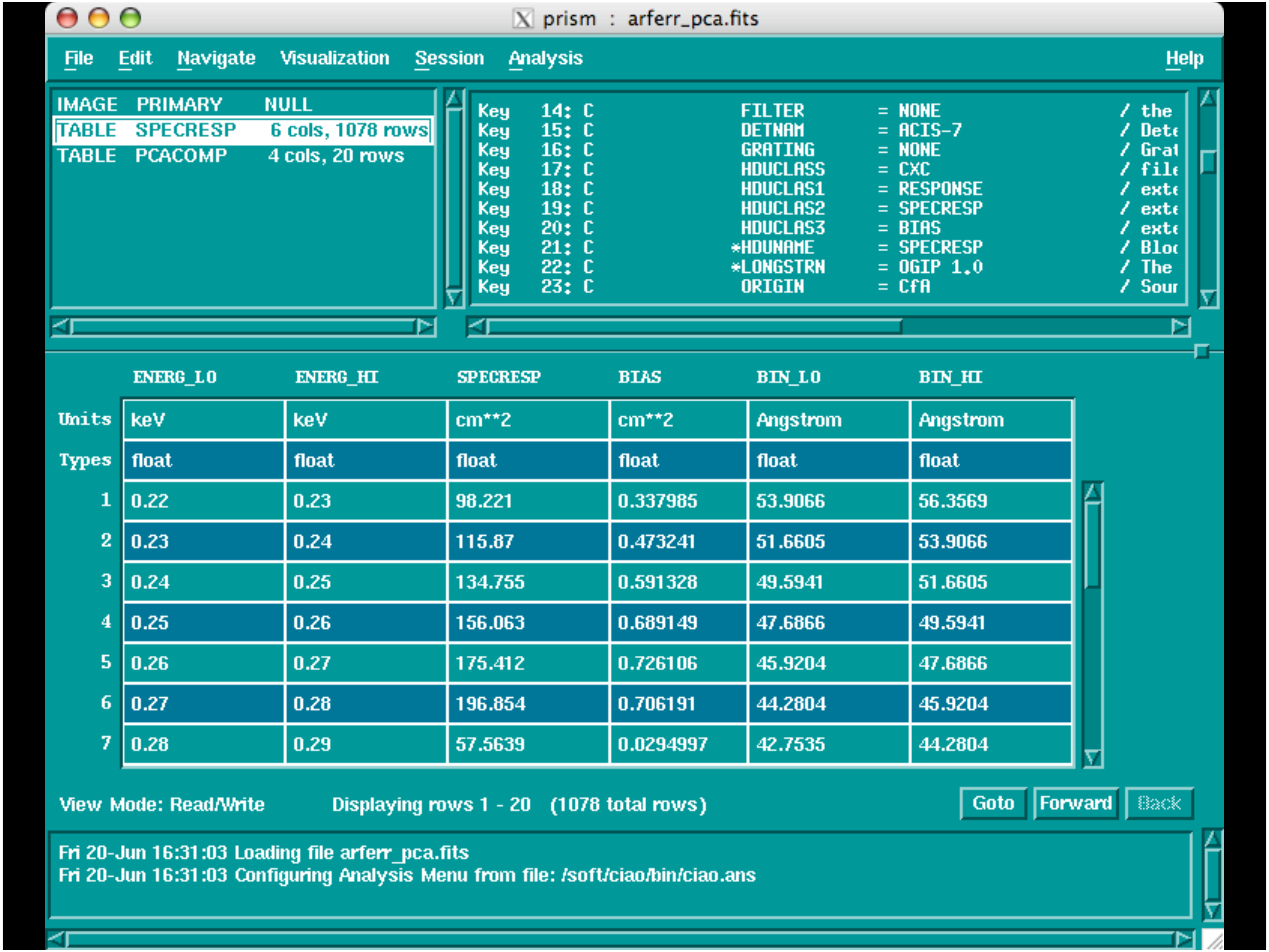
$$A = A_0 + \text{bias} + \text{components} + \text{residual}$$

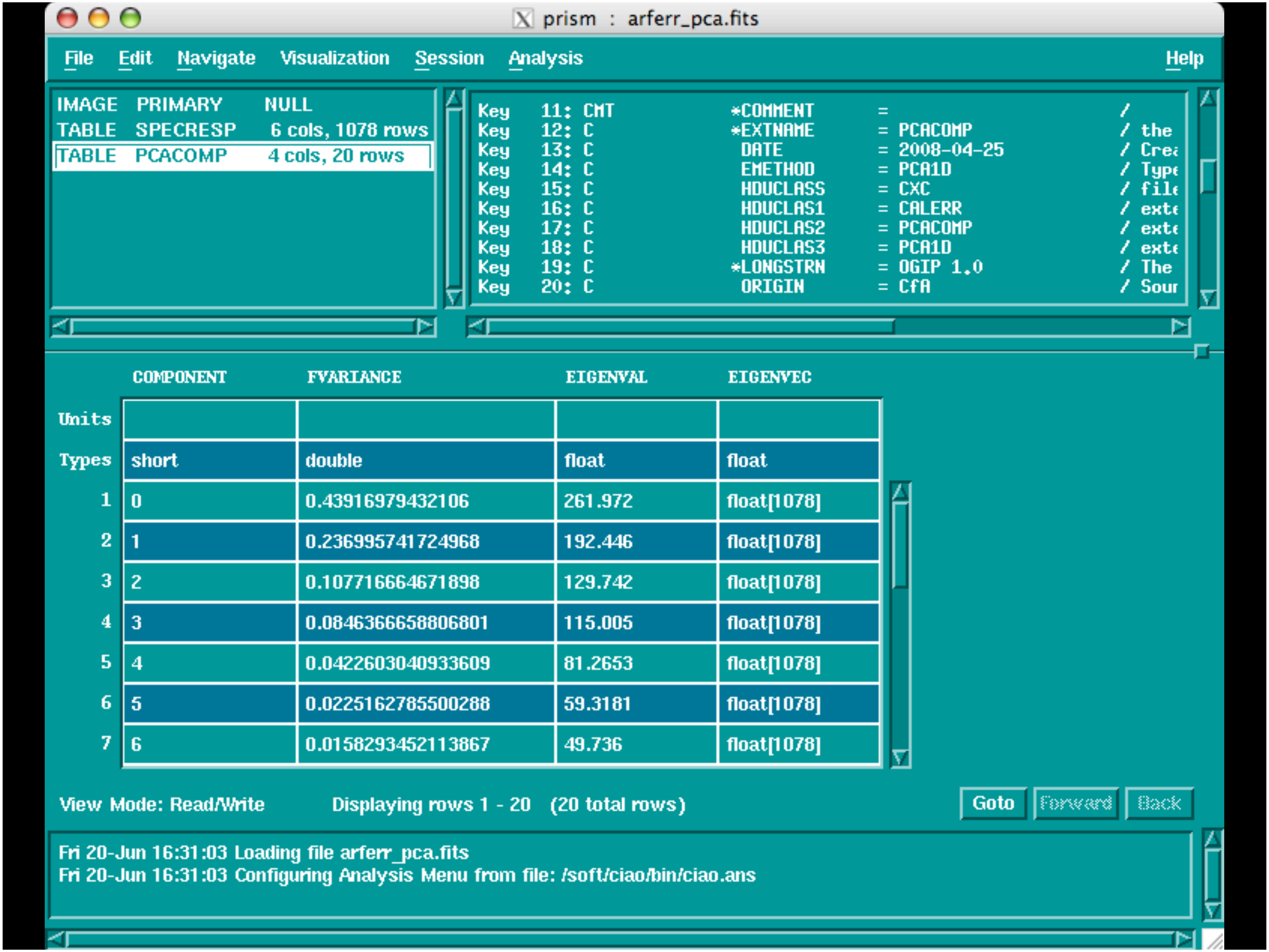
store in same format as A_0

e.g.,
SPECRESP

case specific secondary FITS extension

e.g.,
PCA1D
SIMS
POLY1D
PCPC
MULTISCALE


prism : arferr_pca.fits
File
Edit
Navigate
Visualization
Session
Analysis
Help
IMAGE PRIMARY NULL
TABLE SPECRESP 6 cols, 1078 rows
TABLE PCACOMP 4 cols, 20 rows
Key 14: C FILTER = NONE / the
Key 15: C DETNAM = ACIS-7 / Dete
Key 16: C GRATING = NONE / Grat
Key 17: C HDUCLASS = CXC / file
Key 18: C HDUCLAS1 = RESPONSE / exte
Key 19: C HDUCLAS2 = SPECRESP / exte
Key 20: C HDUCLAS3 = BIAS / exte
Key 21: C *HDUNAME = SPECRESP / Bloc
Key 22: C *LONGSTRN = OGIP 1.0 / The
Key 23: C ORIGIN = CfA / Sour
ENERG_LO ENERG_HI SPECRESP BIAS BIN_LO BIN_HI
Units keV keV cm**2 cm**2 Angstrom Angstrom
Types float float float float float float
1 0.22 0.23 98.221 0.337985 53.9066 56.3569
2 0.23 0.24 115.87 0.473241 51.6605 53.9066
3 0.24 0.25 134.755 0.591328 49.5941 51.6605
4 0.25 0.26 156.063 0.689149 47.6866 49.5941
5 0.26 0.27 175.412 0.726106 45.9204 47.6866
6 0.27 0.28 196.854 0.706191 44.2804 45.9204
7 0.28 0.29 57.5639 0.0294997 42.7535 44.2804
View Mode: Read/Write
Displaying rows 1 - 20 (1078 total rows)
Goto
Forward
Back
Fri 20-Jun 16:31:03 Loading file arferr_pca.fits
Fri 20-Jun 16:31:03 Configuring Analysis Menu from file: /soft/ciao/bin/ciao.ans


prism : arferr_pca.fits
File
Edit
Navigate
Visualization
Session
Analysis
Help
IMAGE PRIMARY NULL
TABLE SPECRESP 6 cols, 1078 rows
TABLE PCACOMP 4 cols, 20 rows
Key 11: CMT *COMMENT = /
Key 12: C *EXTNAME = PCACOMP / the
Key 13: C DATE = 2008-04-25 / Crea
Key 14: C EMETHOD = PCA1D / Type
Key 15: C HDUCLASS = CXC / file
Key 16: C HDUCLAS1 = CALERR / exte
Key 17: C HDUCLAS2 = PCACOMP / exte
Key 18: C HDUCLAS3 = PCA1D / exte
Key 19: C *LONGSTRN = OGIP 1.0 / The
Key 20: C ORIGIN = CfA / Sour
COMPONENT FVARIANCE EIGENVAL EIGENVEC
Units
Types short double float float
1 0 0.43916979432106 261.972 float[1078]
2 1 0.236995741724968 192.446 float[1078]
3 2 0.107716664671898 129.742 float[1078]
4 3 0.0846366658806801 115.005 float[1078]
5 4 0.0422603040933609 81.2653 float[1078]
6 5 0.0225162785500288 59.3181 float[1078]
7 6 0.0158293452113867 49.736 float[1078]
View Mode: Read/Write
Displaying rows 1 - 20 (20 total rows)
Goto
Forward
Back
Fri 20-Jun 16:31:03 Loading file arferr_pca.fits
Fri 20-Jun 16:31:03 Configuring Analysis Menu from file: /soft/ciao/bin/ciao.ans

what have we got so far?

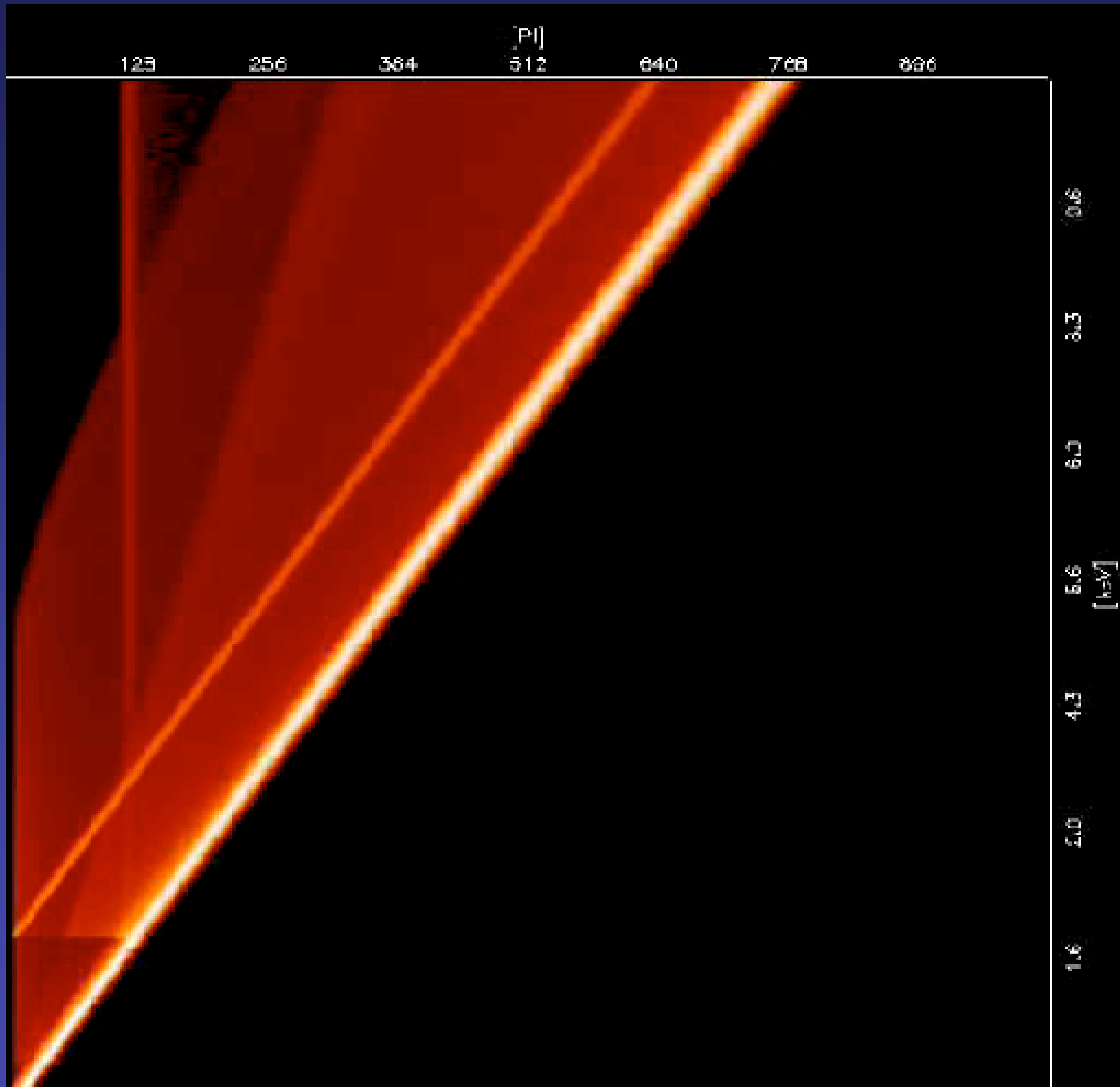
- ***realistic error bars***
- implemented in BLoCXS
- 500x speed up in analysis
- Sherpa on the way

- unified file format for use in XSPEC/Sherpa
- 100x drop in storage
- generalize to any instrument
- extendable to model lacunae
- roll your own

summary

there are a number of steps between a calibration scientist saying “the error on the effective area is X% at energy Y” to then have it fold into a spectral model fit and inflate the error bars on the parameters, and we believe that we have connected the dots.

uncertainty in energy response



one more thing..

what’s next?

unified file format implemented in XSPEC/Sherpa

other schemes of dimensionality reduction

RMFs: 2D PCA, within and between PCA

PSFs: multiscale residuals

The Three Poisson Model

$$
\text{Data}\left\{
\begin{array}{l}
n \sim \mathcal{P}\text{ois}(\epsilon\, s + b\,) \\
y \sim \mathcal{P}\text{ois}(t\, b\,)
\end{array}
\right.
$$

$$
z \sim \mathcal{P}\text{ois}(u\, \epsilon\,) \Big\}\ \text{Calibration}
$$