CALIBRATION & THE CALDB

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Calibrate: To check, adjust, or determine by comparison with a standard

* with some material borrowed from Mike Nowak's CIAO/X-ray presentations.

What we want from X-ray observations:

$\vec{I}_\nu(\vec{x})$: Energy / sec / Hz / area / steradian

What we get from the instrument:

$C(h, \Delta p, \Delta t)$: *Counts* integrated over time bins, spatial pixels, in detector channels

All counts are not photons!

All photons don't make counts!

Pixels are not angles!

Channels are not Energy!

Calibration is what allows us to convert physical source models into a detector signal. For example consider spectroscopy:

$$C(h) \;=\; \int_0^\infty \sum_i R_i(h,E) A_i(E)\; S_i(E)\; dE\; dT \;+\; B(h)$$

DETECTED COUNTS

RESPONSE MATRIX

EFFECTIVE AREA

SOURCE SPECTRA

BACKGROUND COUNTS

CAN "OVERLAP"

(SEE J. DAVIS, 2001, APJ, 548, P. 1010)

Note: we don't go the other way, from detected signal to source model because the integral in general cannot be inverted uniquely! (See the other talks in this workshop on data analysis and statistics.)

$S(E)$: SPECTRAL ENERGY DISTRIBUTION, UNITS = PHOTONS/SEC/AREA/ENERGY

$A(E)$: EFFECTIVE AREA/ANCILLARY RESPONSE FUNCTION/ARF, UNITS = AREA/PHOTON

$R(h,E)$: RESPONSE FUNCTION/RMF, UNITLESS & SOMETIMES NORMALIZED - $\sum_h \int_0^E R(h,E)\ \delta(E-E_0)\ dE \ = \ 1$

dE, dT : PHOTON ENERGY, INTEGRATION TIME

$C(h), B(h)$: SOURCE & BACKGROUND COUNTS (EVENTS)

h : PULSE HEIGHT ANALYSIS (PHA) OR PULSE INVARIANT (PI) CHANNEL. DISCRETE!!!

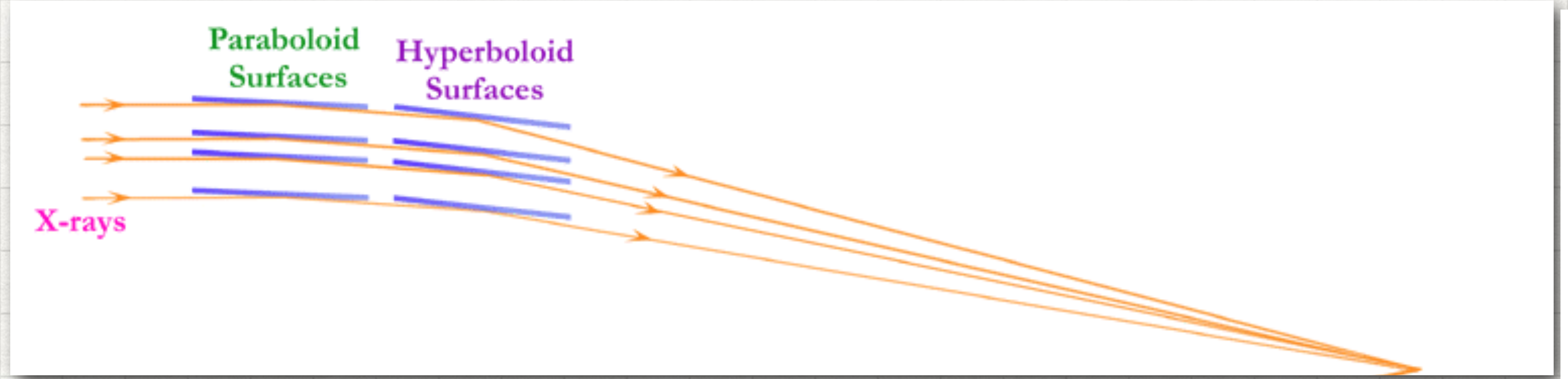
Most of the calibration here goes into *A* and *R*.

*A*R* is typically called "The Response".

Similar integrals (like convolutions) can be written for imaging observations.

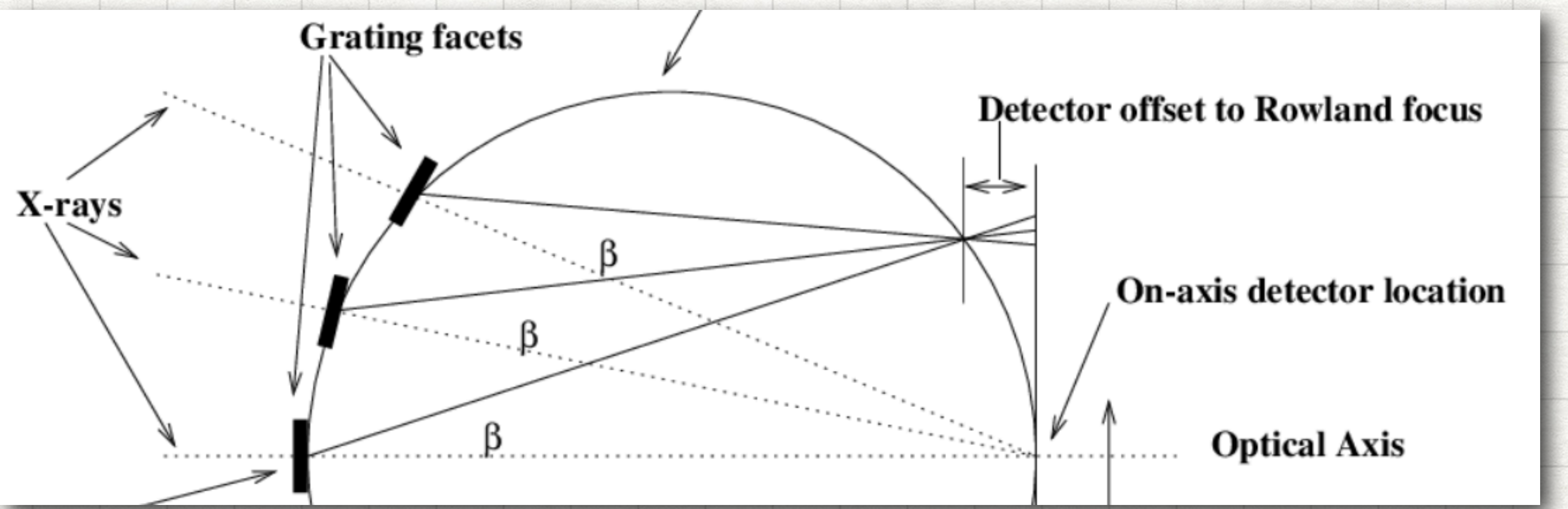
EFFECTIVE AREA ("ARF": AUXILIARY RESPONSE FILE) MAKEUP

Mirrors: X-rays enter at some angle…



… and some fraction exit, over a distribution of angles (Point Spread Function, "PSF"). Efficiency and PSF depend on energy and angles.

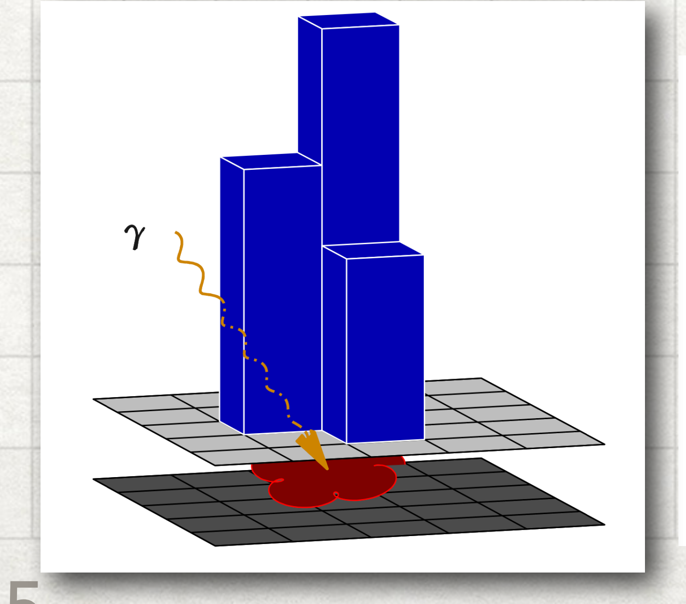
Gratings (optional):



Change the angle according to energy, with some efficiency (vs. order), and with some scatter (Line Spread Function, "LSF")

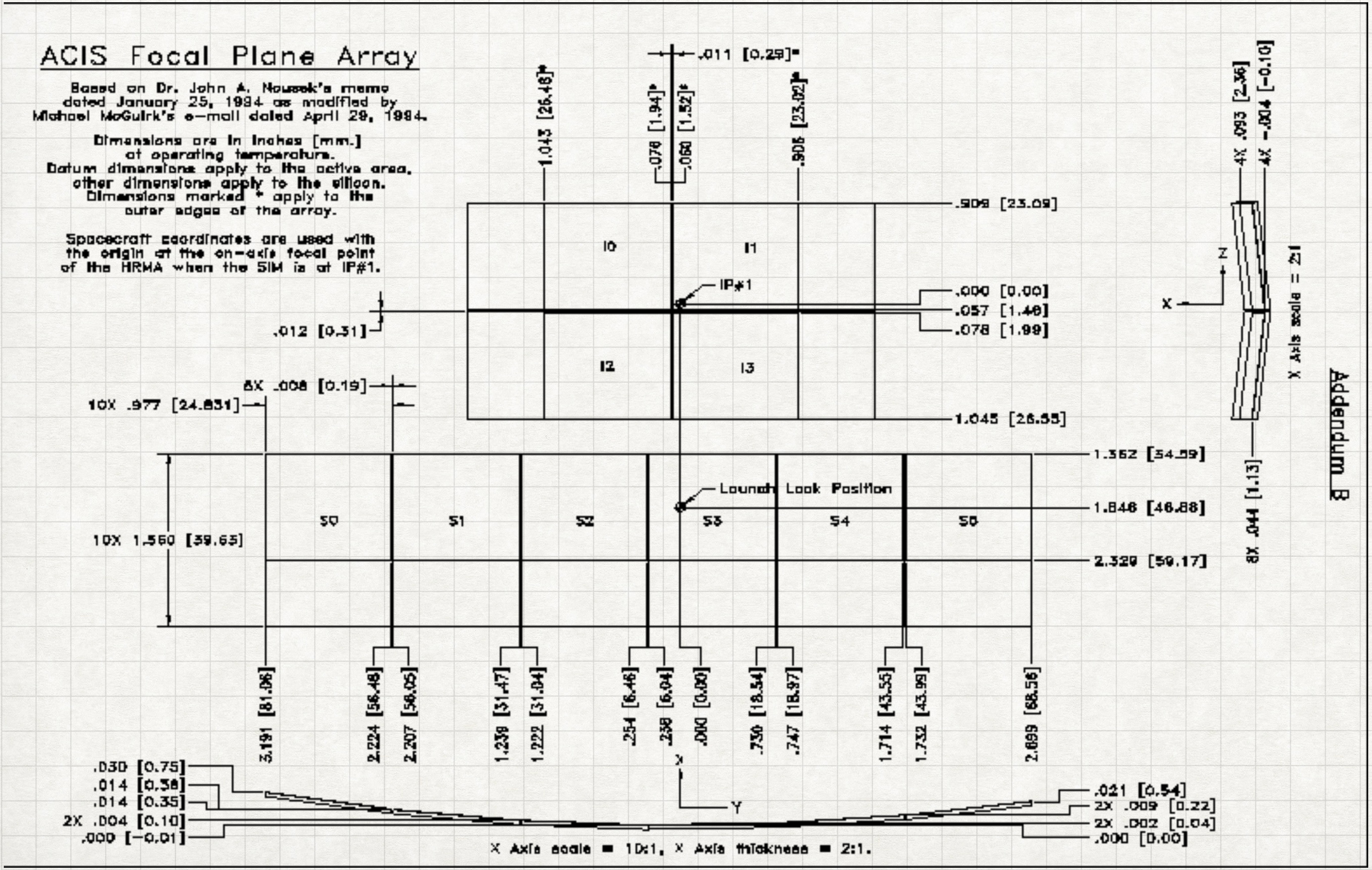
Filters: block optical light, but also have X-ray transmission dependent on energy.

Detectors:



Detect photons with some efficiency vs energy (Quantum Efficiency, "QE"), but also detectors also interact with photons, and have "fuzzy" pixels. For CCDs, there is a "charge cloud" distributed over several pixels.

METROLOGY: WHERE EVERYTHING IS…



We need to accurately know the positions of all components so we can convert an event from a local detector coordinate to a focal plane 3D coordinate (relative to the mirror node), to an angle on the projected sky.

A SIMPLIFIED EFFECTIVE AREA EXAMPLE:

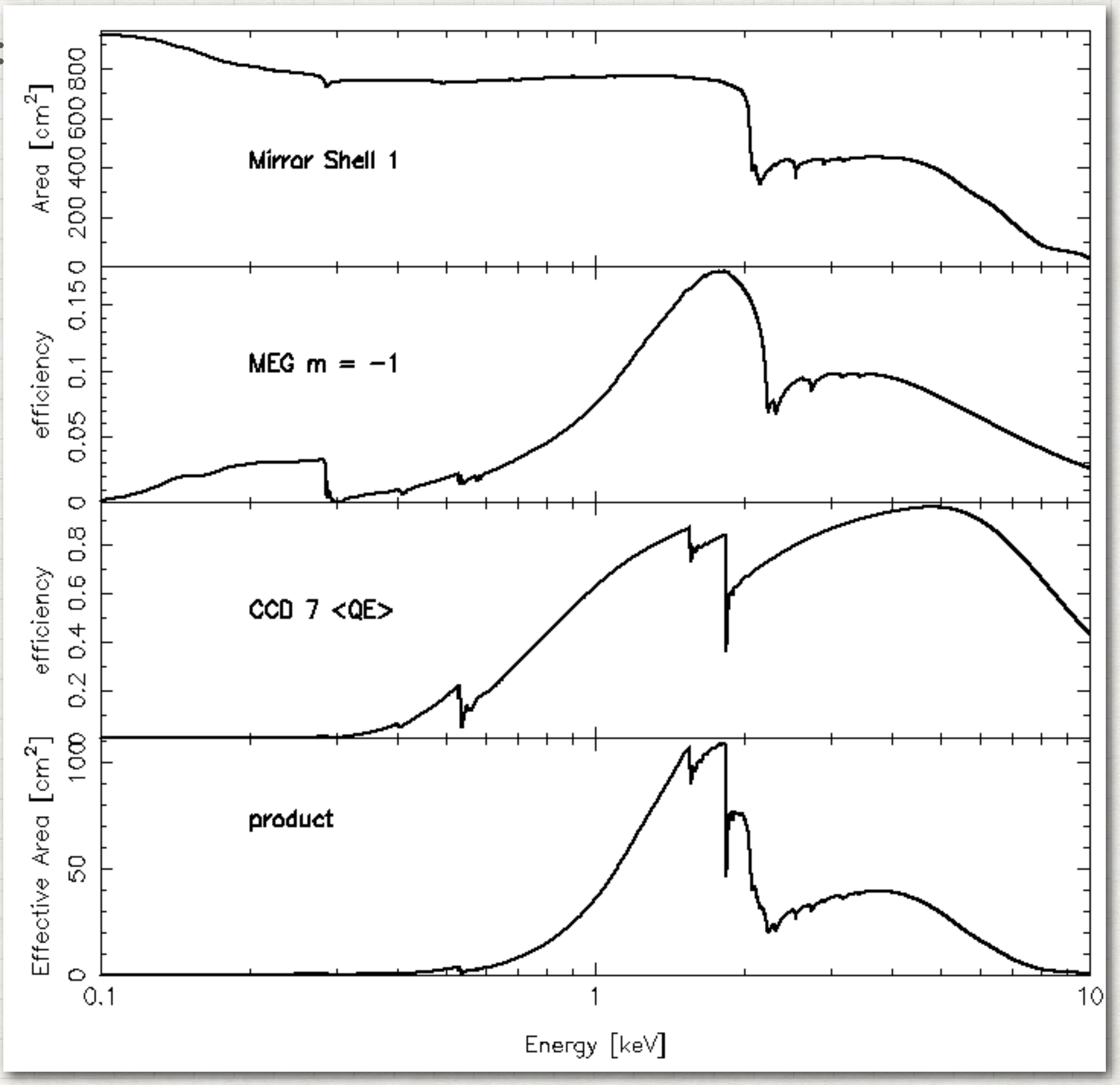
Mirror shell 1 area

× MEG Grating order -1 efficiency

× ACIS CCD 7 QE

= Effective Area [cm^2 count/photon]

(Remember, all photons are not events, and not all events are photons.)



REDISTRIBUTIONS (“RMF”: RESPONSE MATRIX FILE, AND “PSF: POINT SPREAD FUNCTION) MAKEUP

Efficiencies multiply. But *redistributions* are integrals.

CCDs redistribute one energy to a range of “Pulse Height Analyzer” (PHA) channels.

Mirrors redistribute one incident angle to a range of output angles.

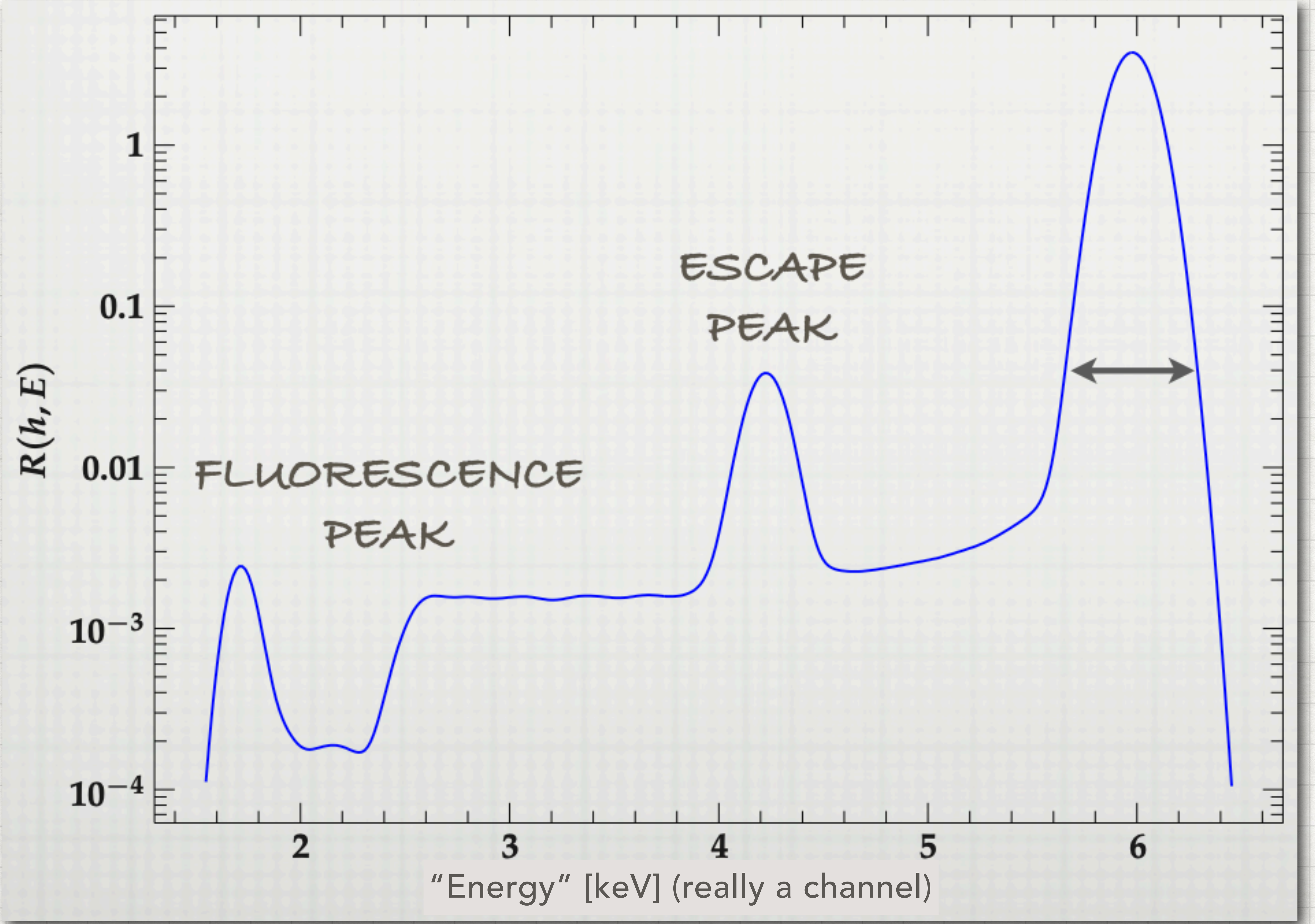
Gratings redistribute one incident energy to a range out output angles.

SCHEMATIC CCD REDISTRIBUTION ("RMF")

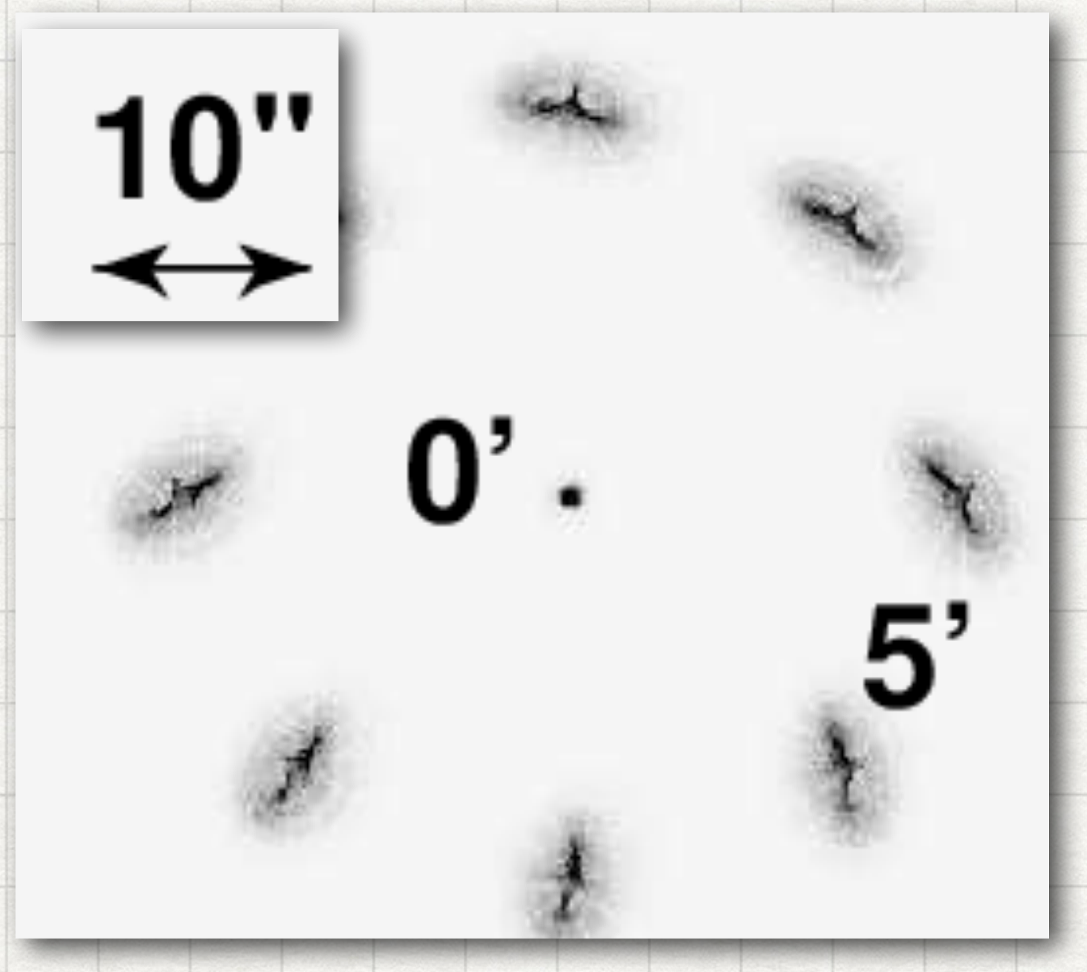
Input photons of energy of 6 keV results in a distribution of output "energies".

NOTE the output is really a *channel*, with a scaling which puts the main peak at an energy of the input photon. This function is called the "gain".

The escape & fluorescence peaks are due to photon-Si interactions.

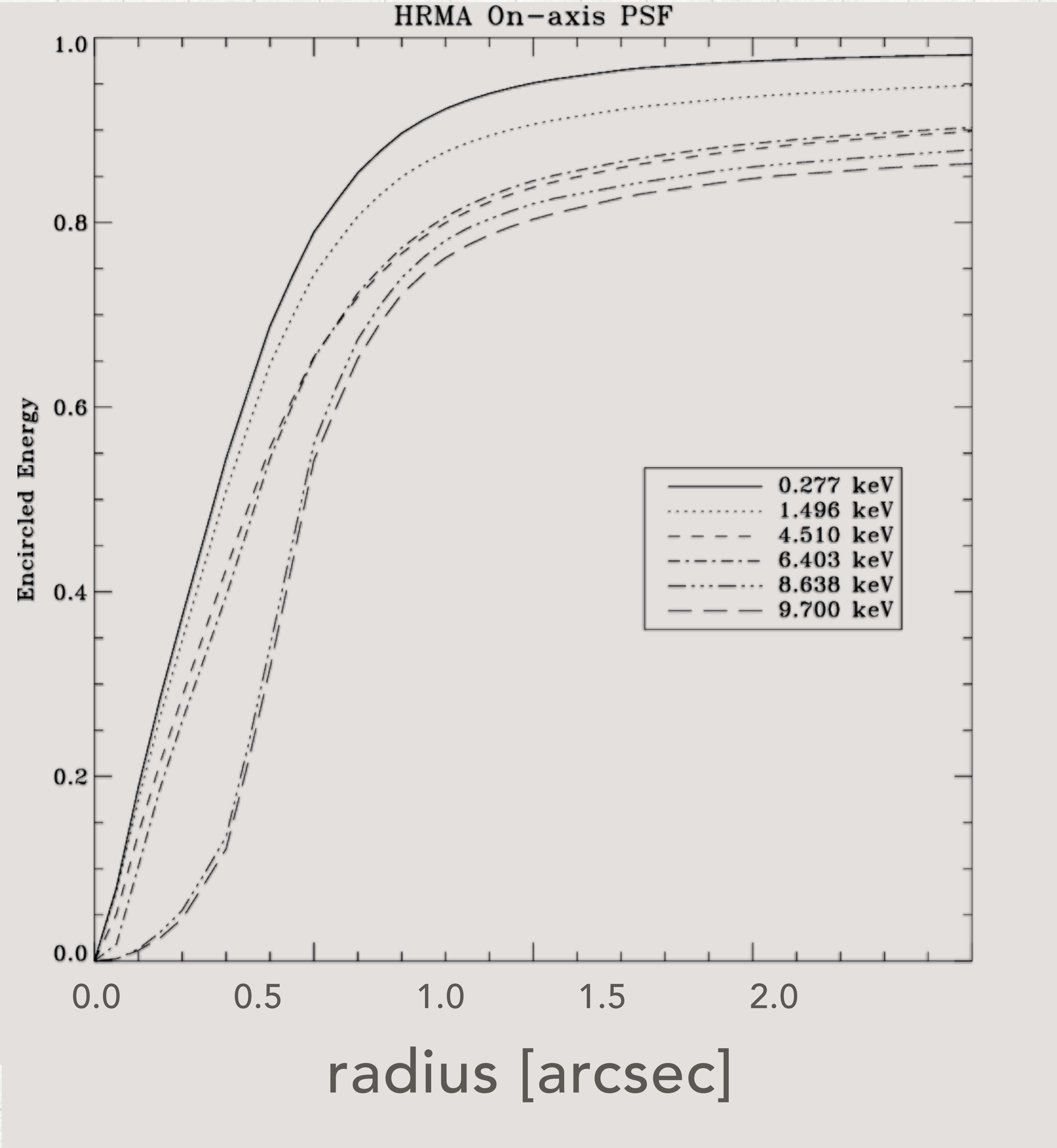


ANGULAR REDISTRIBUTIONS: IMAGING PSF

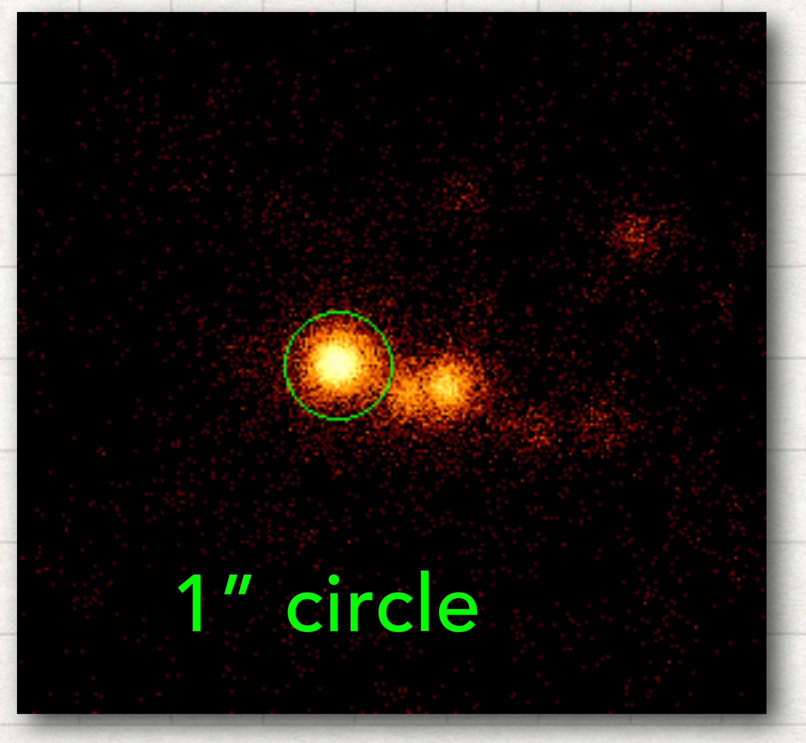


Simulated Mirror PSF vs. off-axis angle at 1.49 keV

On-axis enclosed energy fraction vs energy.

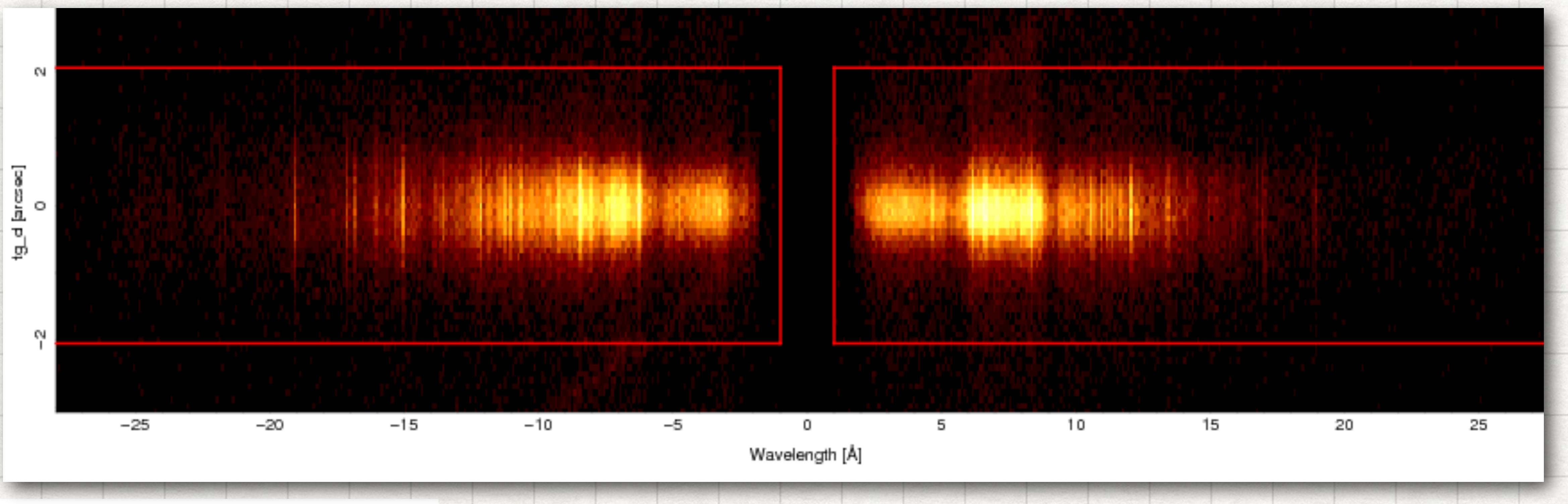


The source region size and position in the field determines your effective area function.

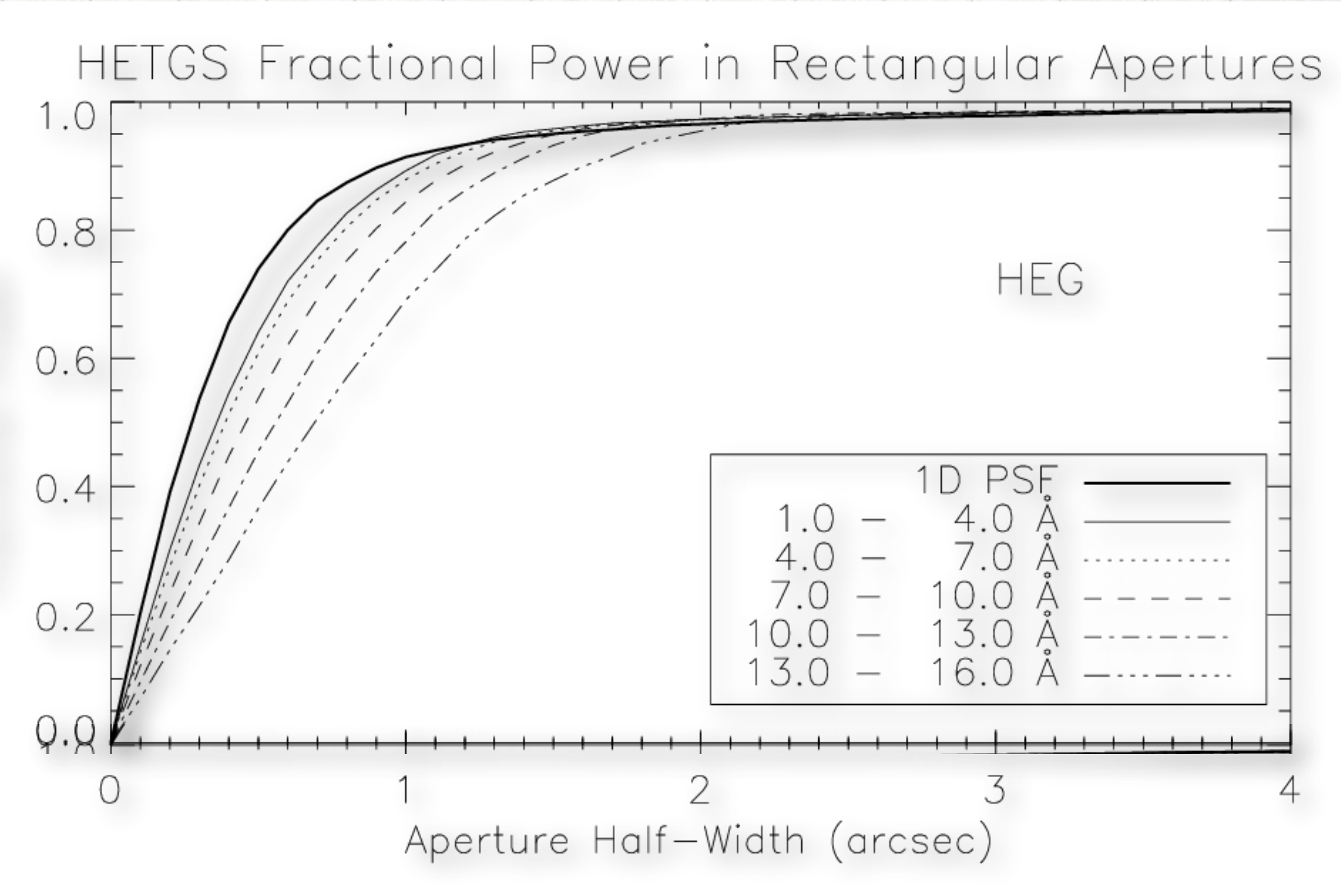


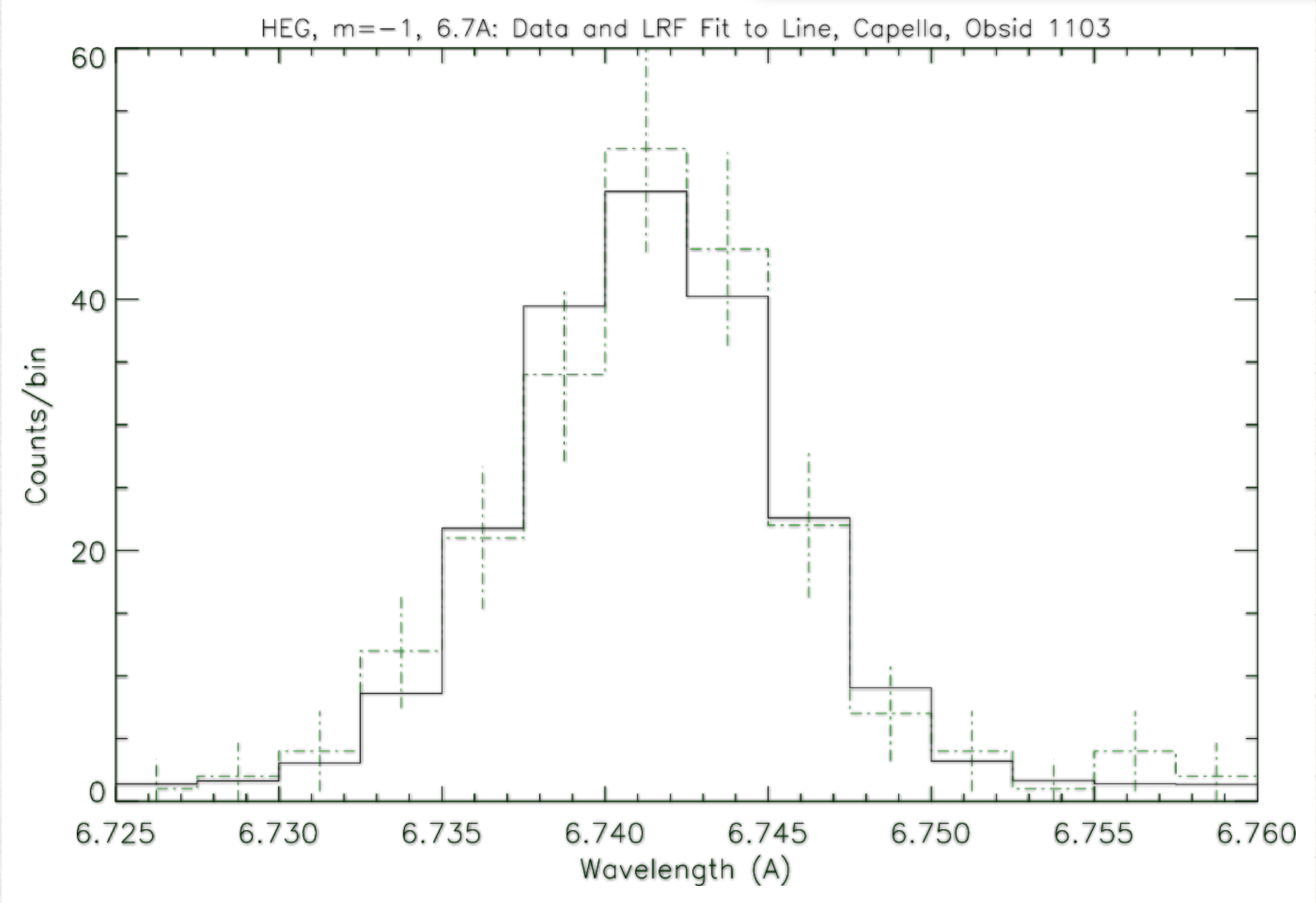
ANGULAR REDISTRIBUTIONS: GRATING PSF & LSF

in-dispersion

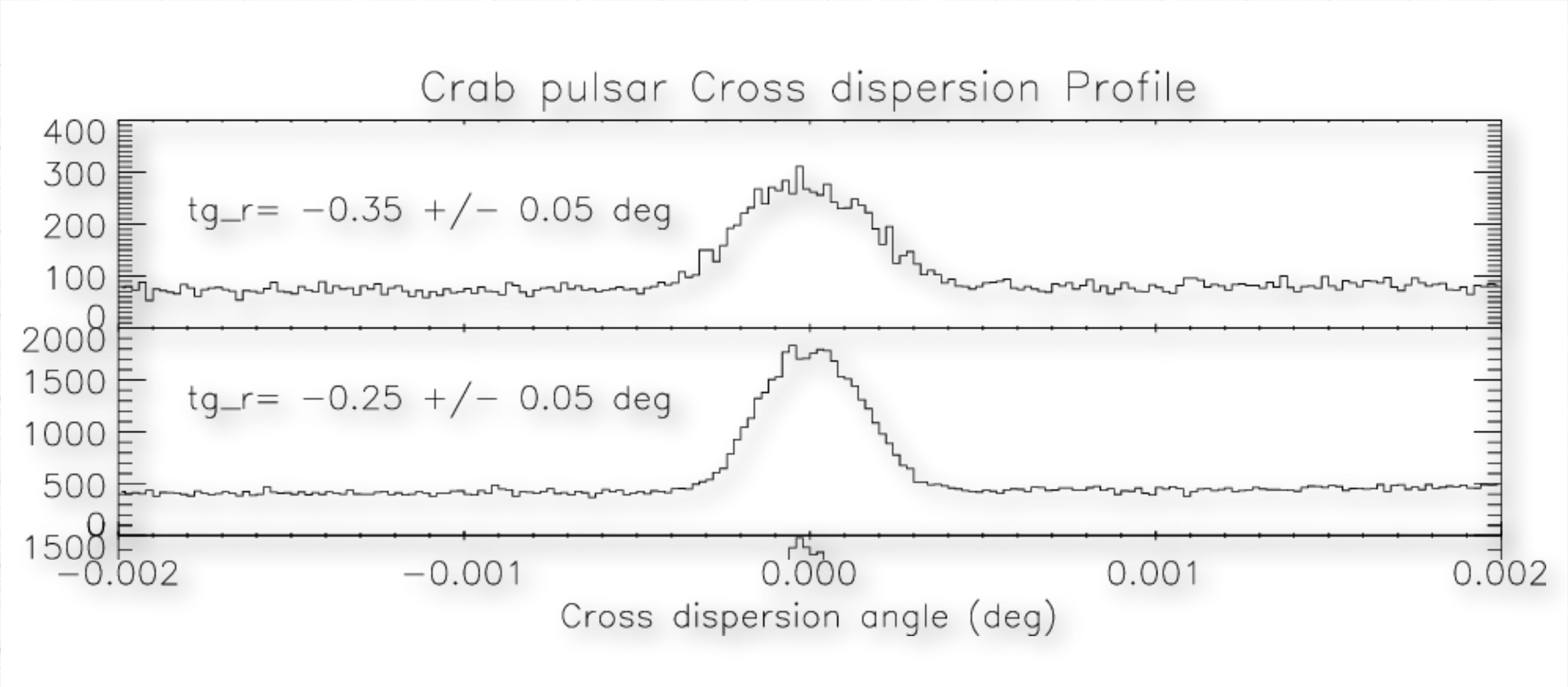


X-dispersion

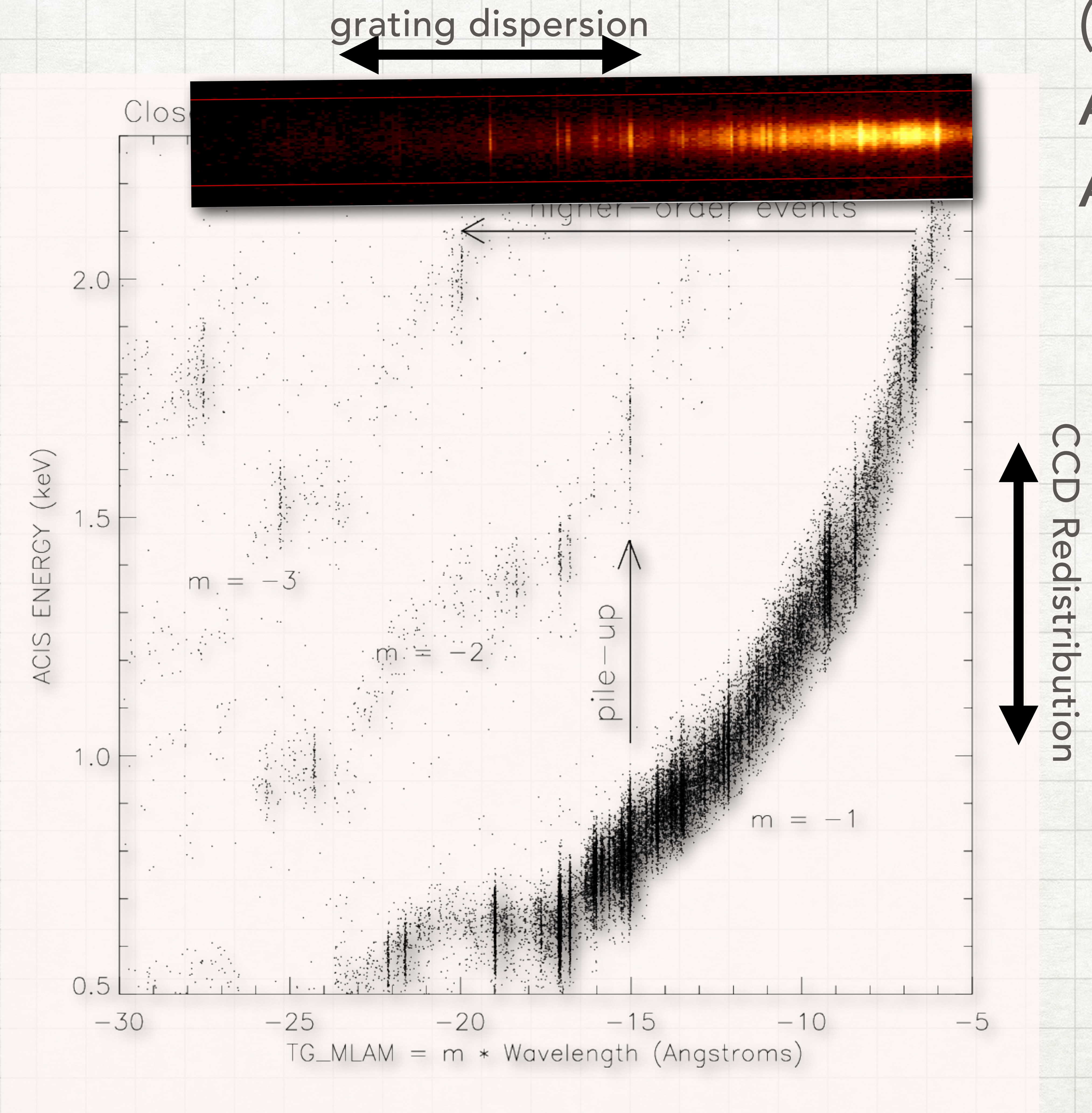




In-dispersion blur is the "Line Spread Function" due to both the imaging PSF and grating quality. Cross-dispersion is an imaging PSF (defocused). Both are included in the grating RMF.

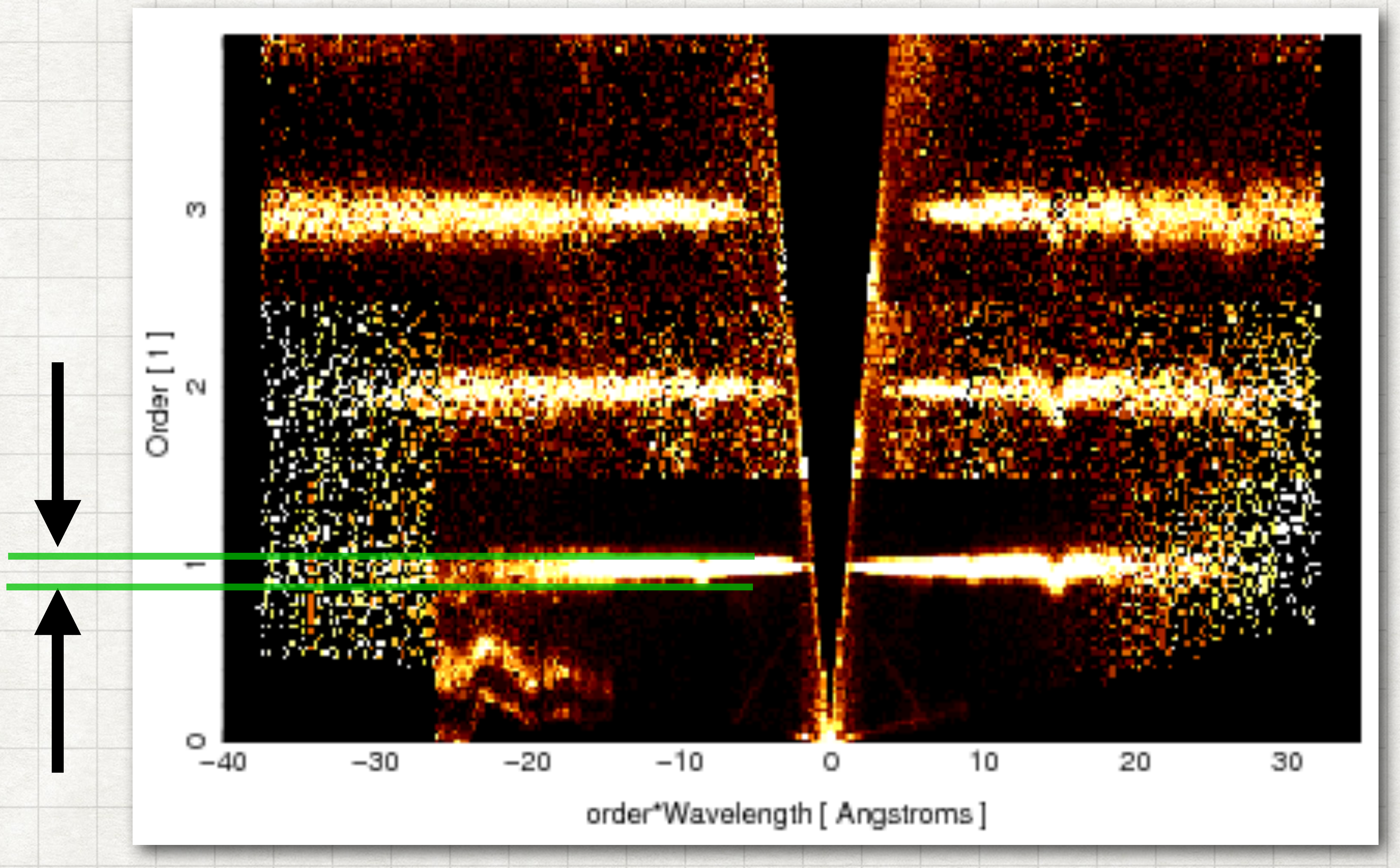


ENERGY REDISTRIBUTION: GRATING CASE*



Order-sorting (if using ACIS' CCDs): "native" view (left), and scaled to real-valued order (right). Aperture efficiency is encoded into the grating ARF.

Another extraction aperture and enclosed energy fraction to calibrate…

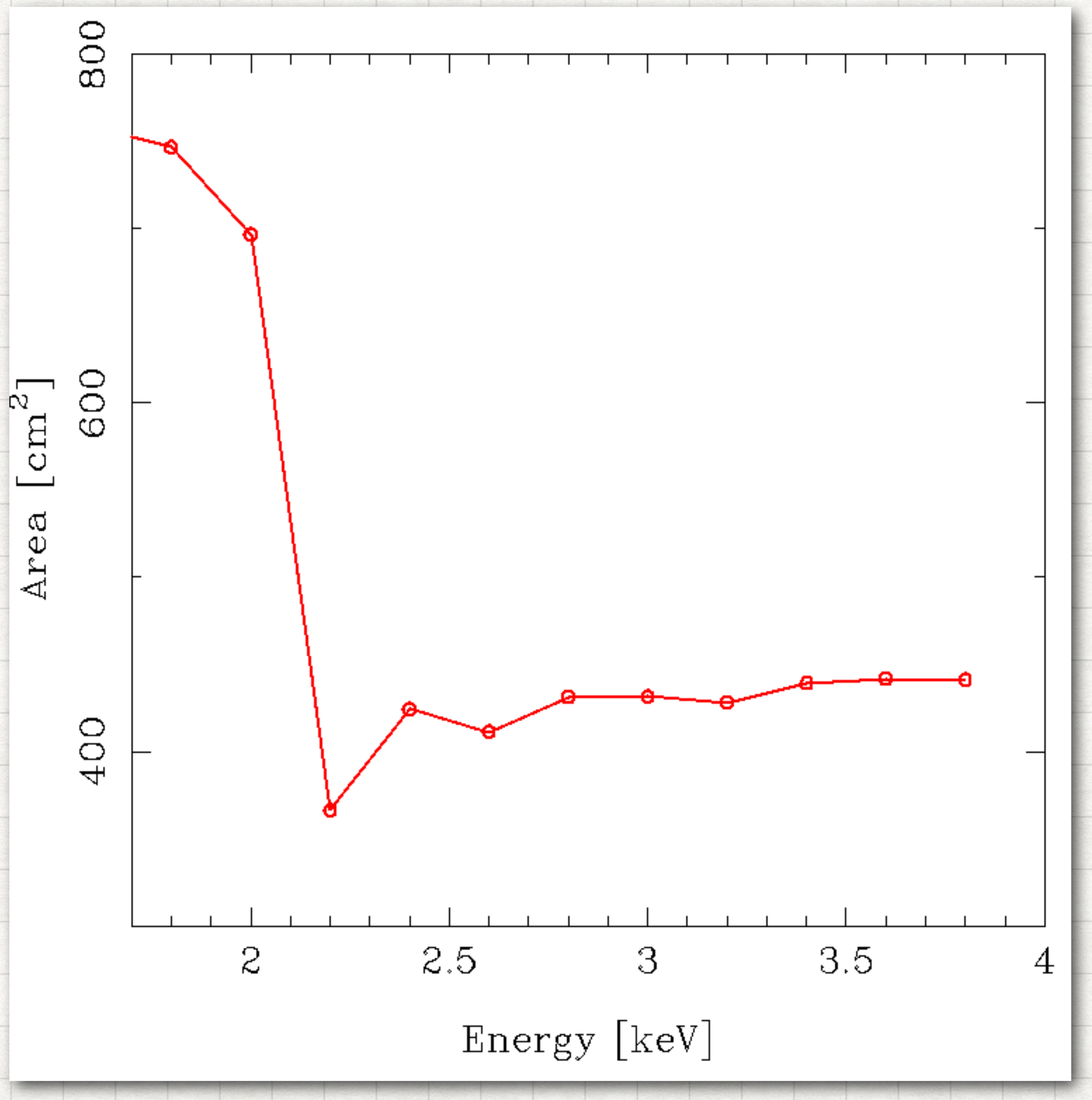


* See Guenther's grating data analysis talk for more details.

CALIBRATION IS *HARD*!

Suppose you only had time to make 10 measurements (or the X-ray calibration sources were limited to 10 energies). You could produce this empirical effective area:

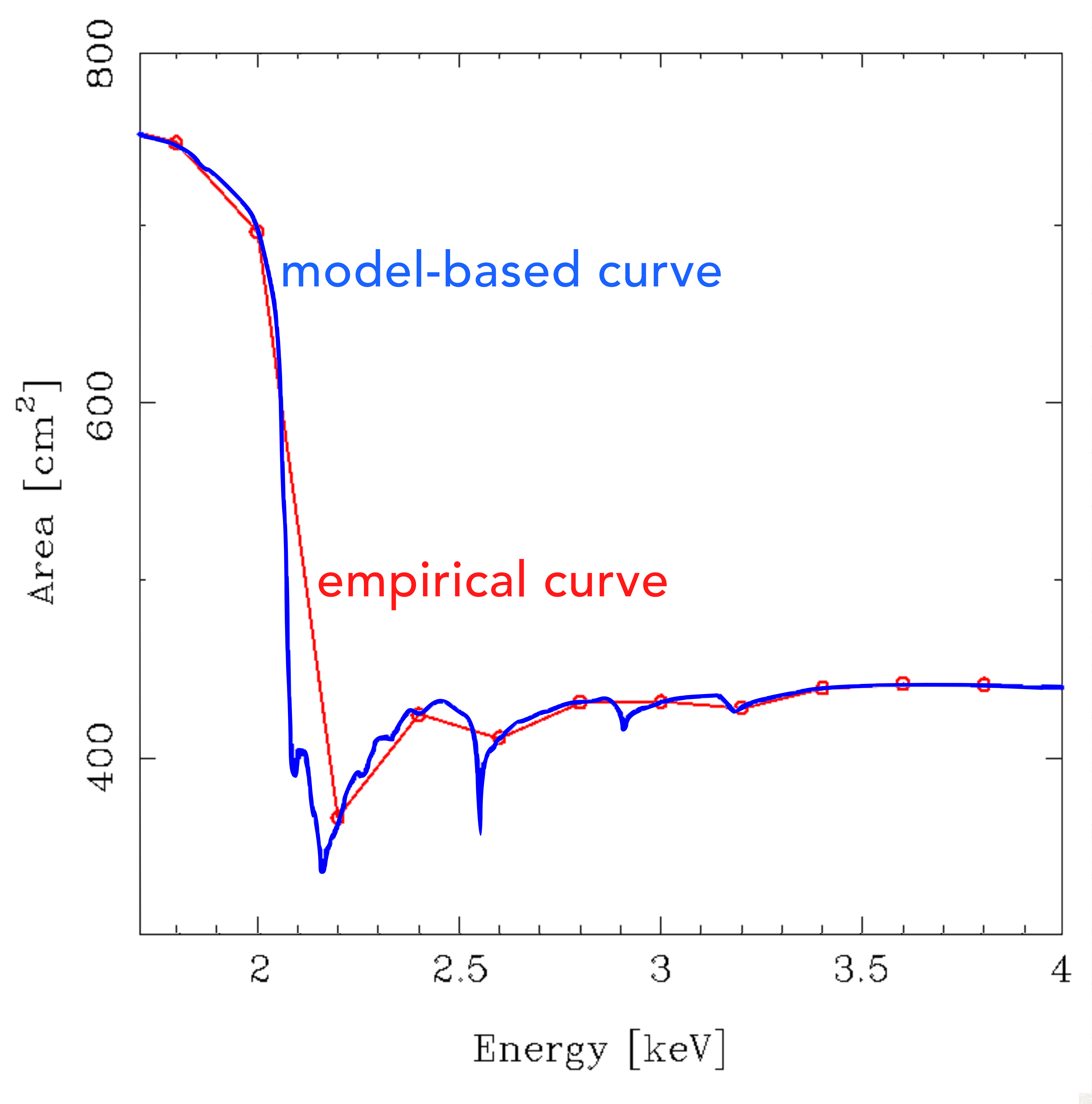
Are you done?



Note: calibration data have uncertainties, both statistical and systematic. A goal is to have statistical uncertainties 10x smaller than on typical good data. Systematic uncertainties are largely unknown (and hard to deal with in analysis).

CALIBRATION IS *HARD*!

Corollary: the 3 most important things about any observatory are calibration, *calibration*, & ***calibration***.



Calibration *must* be underpinned with physical models (reflectivity, diffraction efficiency, detector physics, transmission models).

You can't measure *everything*, so you have to model!

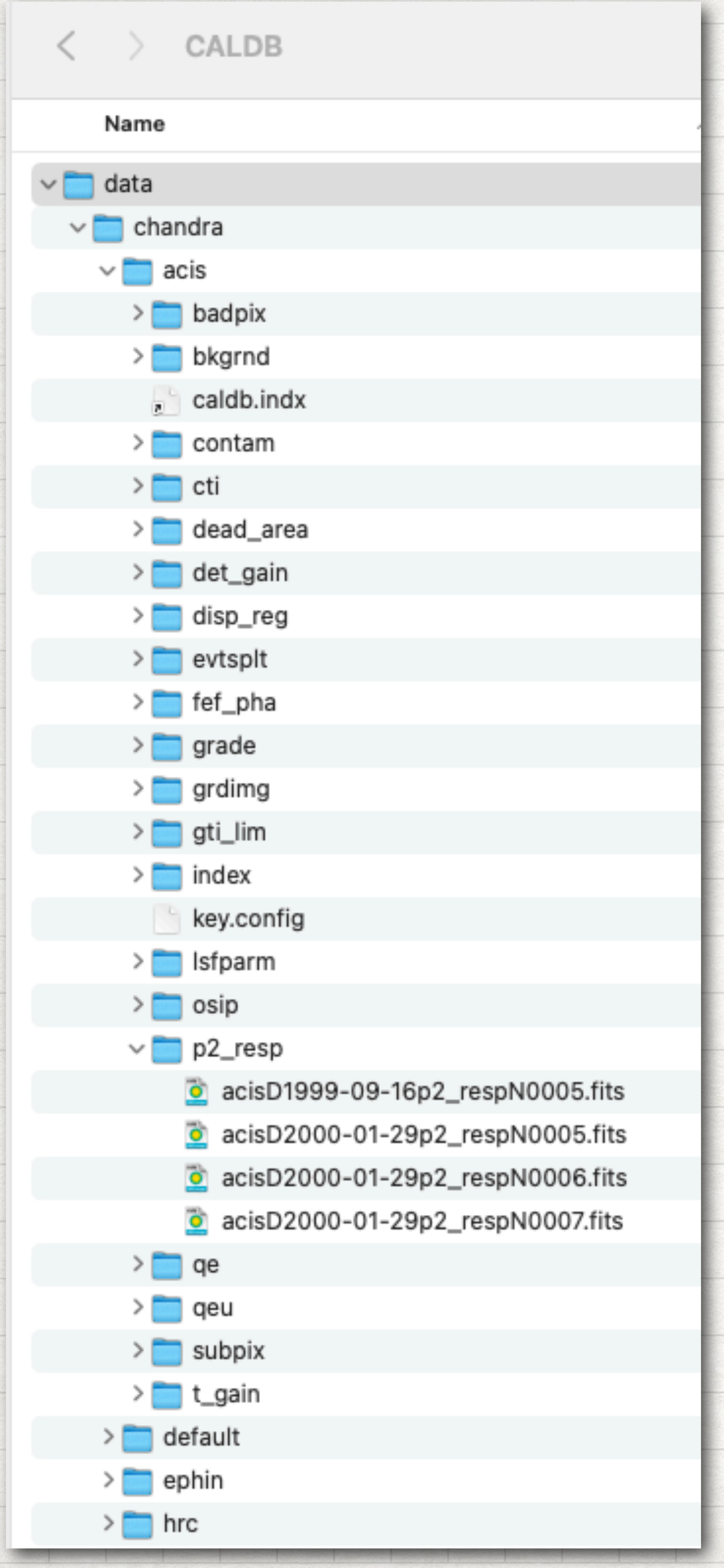
NO!

SOME PRACTICAL MATTERS

There are many calibration files. Some are used to process events (ACIS gain, CTI, T_GAIN), and some are used to *interpret* the events (mean QE, QE uniformity, CCD response, grating LSF parameters).

They can have many dependencies on observational conditions: (temperature, instrument mode, energy, angle) or analysis choices (event filters, region filters).

Hence, the *Calibration Database*, or CalDB



THE CALDB

The CALDB is a mission-dependent database of all calibration data in FITS format, grouped by instrument and type of file. There are about 800 FITS files in the Chandra CalDB (which includes multiple versions of some files vs. date of applicability; about 600 unique names).

Good news — you usually only need to know *one* thing: the default lookup in CIAO tools is given by the string “CALDB”! Everything else is done behind the scenes using CalDB indices and observational information from file headers.

CXC has worked very hard to separate calibration data from code. In principle, a CalDB can be updated independently of CIAO.

THE CALDB IN CIAO

Example for acis_process_events:

```
> plist acis_process_events | grep CALDB
    (gradefile = CALDB)           grade mapping file ( NONE | none | CALDB | <filename>)
(grade_image_file = CALDB)           grade image file for cti correcting graded mode ( NONE | none | CALDB | <filename>)
     (gainfile = CALDB)           acis gain file ( NONE | none | CALDB | <filename>)
   (threshfile = CALDB)           split threshold file ( NONE | none | CALDB | <filename>)
      (ctifile = CALDB)           acis CTI file ( NONE | none | CALDB | <filename>)
    (tgainfile = CALDB)           gain adjustment file ( NONE | none | CALDB | <filename>)
   (subpixfile = CALDB)           Name of input sub-pixel calibration file
```

If you have a customized (or brand new) calibration, you can put in an explicit name. The CIAO "ahelp" files will tell you what these file are for. The Calibration web pages will give details on their content (https://cxc.harvard.edu/cal/).

ARDLIB: A MID-LEVEL INTERFACE TO CALDB

ARD: Analysis Reference Data

```
ARDLIB is a software library that provides a mission independent interface to instrument-specific
calibration data. Tools such as `mkarf', `mkwarf', `mkinstmap', `mkgrmf', and `mkexpmap' use this library to
compute effective areas, detector efficiencies, and so on.

Currently the only mission supported by ARDLIB is Chandra. The following Chandra instruments are supported:


o) Mirrors: HRMA

o) Detectors: ACIS-[0-9], ACIS-I[0-3], ACIS-S[0-5], HRC-S[1-3], HRC-I

o) Gratings: HEG, MEG, LEG
```

The file, **`ardlib.par`**, controls what the response tools use per mirror shell, detector element, or grating type, for examples. Mainly useful for CXC for debugging (i.e., what if the detector QE were 1.0, ...). Or special use cases, like setting the time for contamination evaluation (without having to have a data file), or computing the exposure time on the sky (by setting mirror area to 1 and detector QE to 1).

See “ahelp ardlib” for details and specific examples.

RESOURCES

Proposers' Observatory Guide

<https://cxc.harvard.edu/proposer/POG/>

Chandra Instruments and Calibration

< https://cxc.harvard.edu/cal/>

The Chandra Calibration Database:

<https://cxc.harvard.edu/caldb/>