X-ray Pulse Height Spectroscopy

- The expected channel distribution of detected counts $M(E', \hat{p}', t)$ is:

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

$S(E, \hat{p}, t)$ is the physical model that describes the physical energy spectrum, spatial morphology, and temporal variability of the source

$R(E'; E, \hat{p}, t)$ is the redistribution matrix (recorded in the RMF) that defines the probability that a photon with actual energy E, location $\hat{p}$, and arrival time t will be observed with apparent energy E' and location $\hat{p}'$

$A(E, \hat{p}', t)$ is the instrumental effective area (recorded in the ARF)

$P(\hat{p}'; E, \hat{p}, t)$ is the photon spatial dispersion transfer function (the instrumental PSF)

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X-ray Pulse Height Spectroscopy

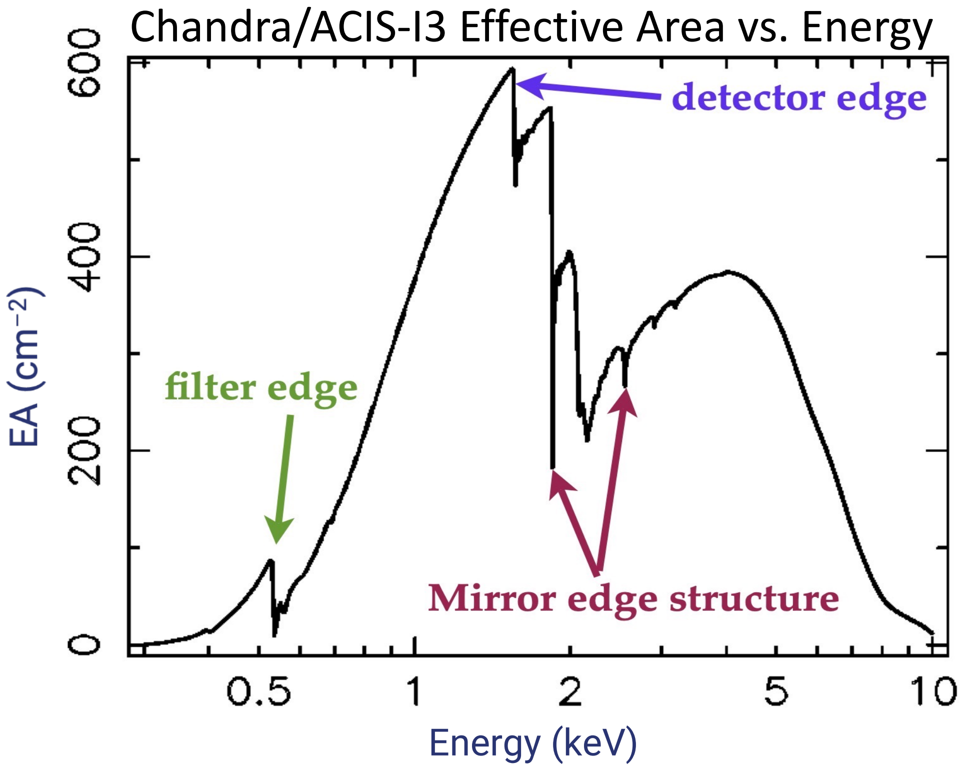
- For *Chandra*, we typically integrate over the exposure, assume the source position and shape are known, and that photons from the entire region of the source are extracted
- This removes the dependencies on t, $\hat{p}$, and $P(\hat{p}'; E, \hat{p}, t)$, simplifying the integral to

$$M(E') = \int dE \, R(E'; E) \, A(E) \, S(E)$$

  which depends on the physical source spectrum, RMF, and ARF

- Generally, this transformation is not easily invertible so forward fitting is used to *propose* a model for S, fold the model through the responses, and optimize the parameters of S by comparing with the observed channel counts distribution

Ancillary Response File



- Includes geometric collecting area × (energy-dependent) efficiencies of optics, gratings, detector
- Depends on extraction region on the detector because of vignetting and detector non-uniformities
- *Chandra* dithers on the sky so a source samples different regions of the detector and the aspect solution (position vs. time) is needed to calculate the average ARF for a source
- Units of cm^2 counts/photon
- Uses HEASARC OGIP-standard ARF FITS file format

Figures in this presentation from CXC guide "An X-ray Data Primer — What I Wish I Knew when Starting X-Ray Astronomy"

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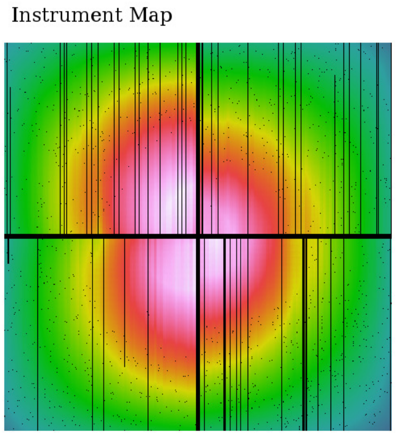
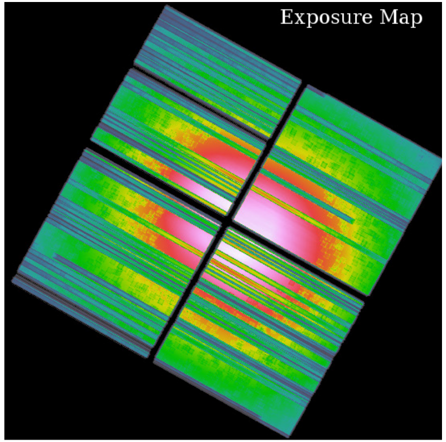
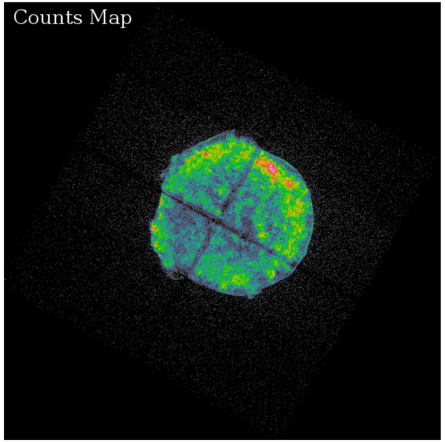
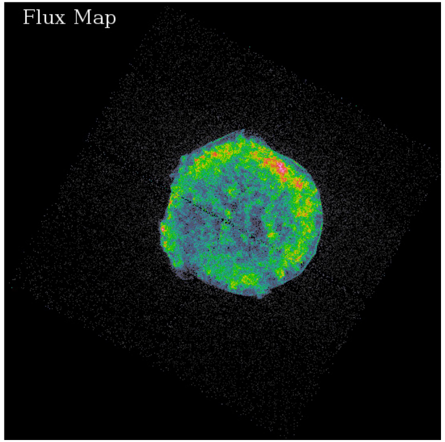
How Does The ARF Vary Over The Field?









- Instrument map records the instrument sensitivity in detector coordinates
- Exposure map is the instrument map convolved with the aspect solution
- Instrument/exposure maps are created on a per observation basis since the detector sensitivity, among other variables, changes with time
- *Chandra*'s instrument and exposure maps typically have units of cm^2 s counts/photon

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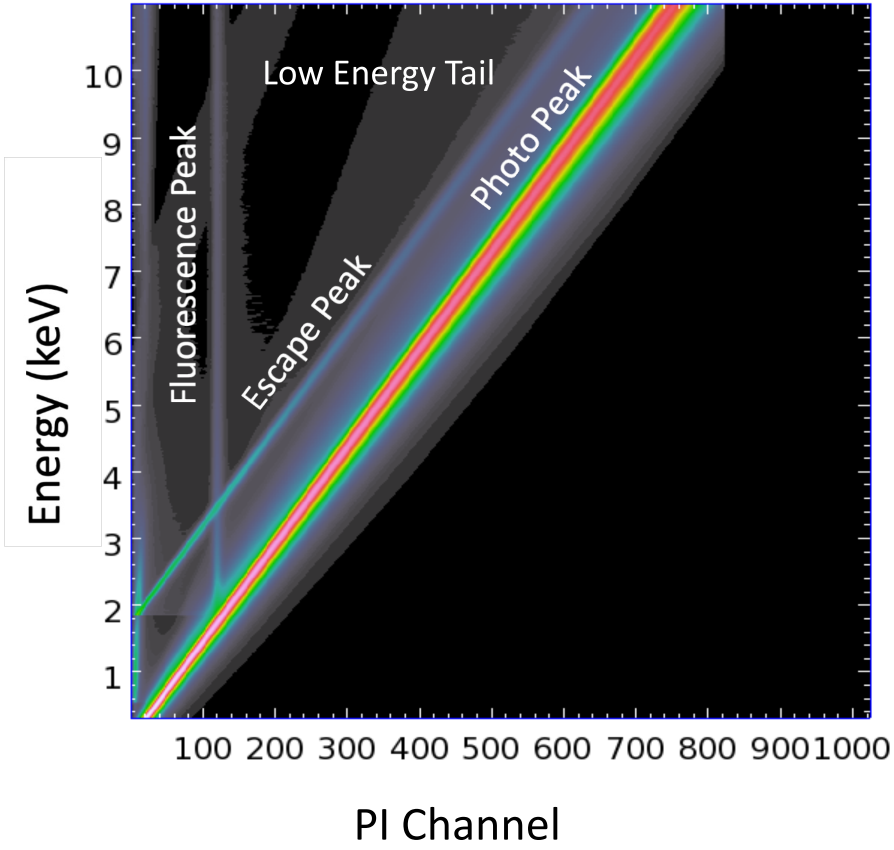
Redistribution Matrix File



- Maps the relationship between the incident photon energy and the detected signal distribution over detector channels (*i.e.*, the event pulse height)
- The RMF provides the probability that a photon of a given energy is detected in a given detector channel
- Uses HEASARC OGIP-standard RMF FITS file format

Making *Chandra* Response Files

- The *CIAO*[1] downloadable data analysis package includes ~30 user tools and scripts to create and manipulate responses, including ARFs, RMFs, Instrument Maps, Exposure Maps, etc.

addresp	Add multiple RMFs, weighted by ARFs and exposures; add multiple ARFs, weighted by exposures
mkacisrmf	Generate an RMF for Chandra imaging data
mkarf	Generate an ARF for Chandra imaging data (and grating 0th order)
mkexpmap	Generate a Chandra imaging exposure map (effective area vs. sky position)
mkinstmap	Generate a Chandra instrument map (effective area vs. detector position)
mkwarf	Generate a weighted ARF

- The tools typically take observation data products, detector position or region information, Calibration Database files to create the responses for an observation and detector region

```
mkarf asphistfile="acis_s3_asphist.fits[asphist]" outfile=acis_s3_arf.fits
sourcepixelx=4146.05 sourcepixely=4045.95 engrid="grid(s3_rmf.fits[MATRIX][cols
ENERG_LO,ENERG_HI])" obsfile=observation_evt2.fits detsubsys=ACIS-S3 dafile=CALDB
```

- CIAO's *Sherpa*[2] modeling and fitting package can use the created responses to fit spectral models to the associated observation pulse height spectra

[1] https://cxc.cfa.harvard.edu/ciao/ [2] https://cxc.cfa.harvard.edu/sherpa/

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