NICER

Neutron star Interior Composition ExploreR

NICER Calibration 20200202: Effective Area (ARF)

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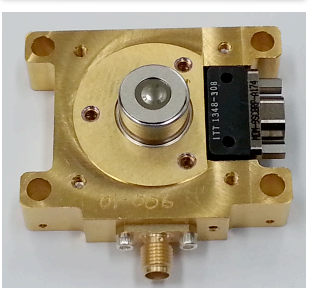
NICER Effective Area Throughput

- Much intense effort has been going on the past ~8 months to improve the ARF
  - ARF = Ancillary Response File = Effective Area
- The ARF is basically the throughput function of an observatory
- This content is released as NICER on-axis average effective area file in CALDB 20200202

Effective Area Components

X-rays



Thermal Film

MODEL: transmission model (thickness)
GROUND MEASUREMENT: BESSY samples

X-ray Concentrator

MODEL: X-ray ray tracing (mirror area)

GROUND MEASUREMENT: Area & PSF @ X-ray beam

IN-FLIGHT: Crab

Detector Window

MODEL: X-ray transmission model (thickness)

GROUND MEASUREMENT: BESSY samples

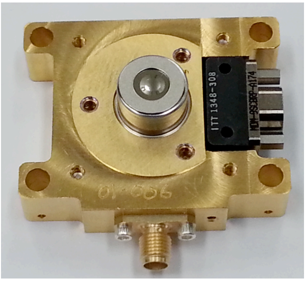
FPM Silicon Drift Detector QE Only

MODEL: Silicon / X-ray (Scholze & Procop 2009)

GROUND MEASUREMENT: quantum efficiency ("dea"d layer, partial charge collection, silicon detection efficiency)

Effective Area Components (In-Flight Adjustments)

X-rays



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Paths of ARF Model Development

- Two paths
- "Semi-analytical" approach (T. Enoto)
  - Currently the public ARF
  - Analytical values for scattering and reflectivity, averaged over reflecting surface
  - More complicated geometry items like "dumbbell" or "traffic cone" not included
  - Matched to the Crab
- CONSIM
  - Physics-based ray tracing (ASCARAY heritage)
  - NICER XRC detailed geometry
  - Includes scattering physics, aperture stops, etc
  - Subject of this current development

Recent ARF Development Work

- CONSIM development
  - Improved XRC geometry
    - Inclusion of dumbbell and other features
  - Improved X-ray scattering physics
  - Improved X-ray reflectivity data
  - Improved techniques to match NICER data
    - Per-shell fitting

CONSIM X-ray Scattering Physics

- Old CONSIM code had semi-empirical scattering formula that was not really related to physics
- Updated CONSIM to include ”real” Rayleigh-Rice scattering physics
  – Code is documented with techniques and references

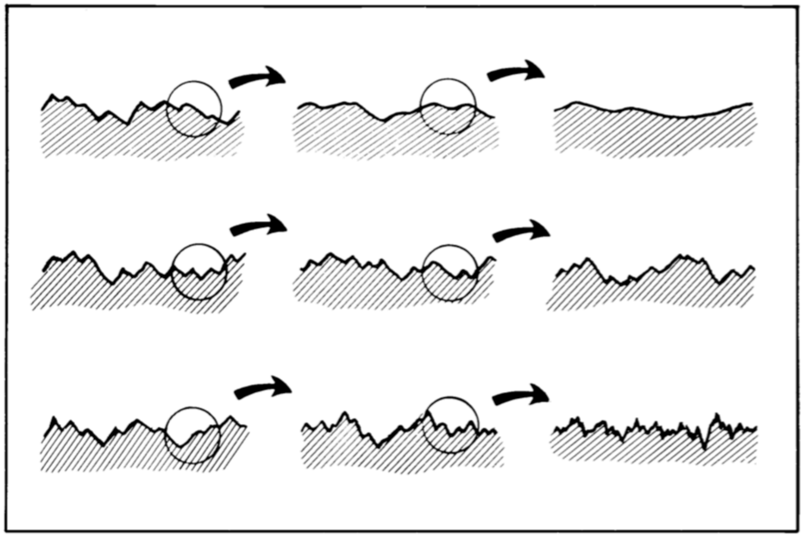
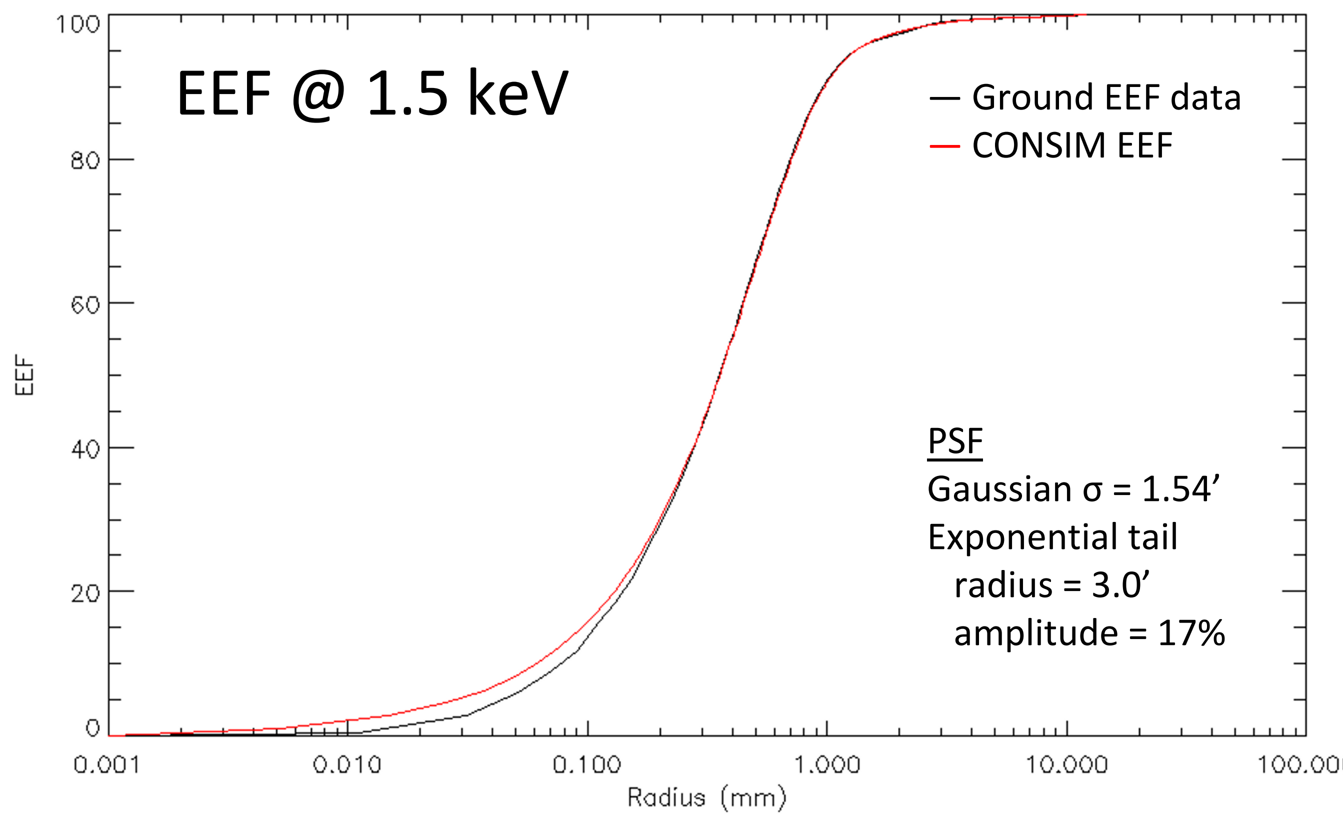


Figure 3. Pictorial representations of the cross-sectional profile of various types of surfaces as discussed in the text.

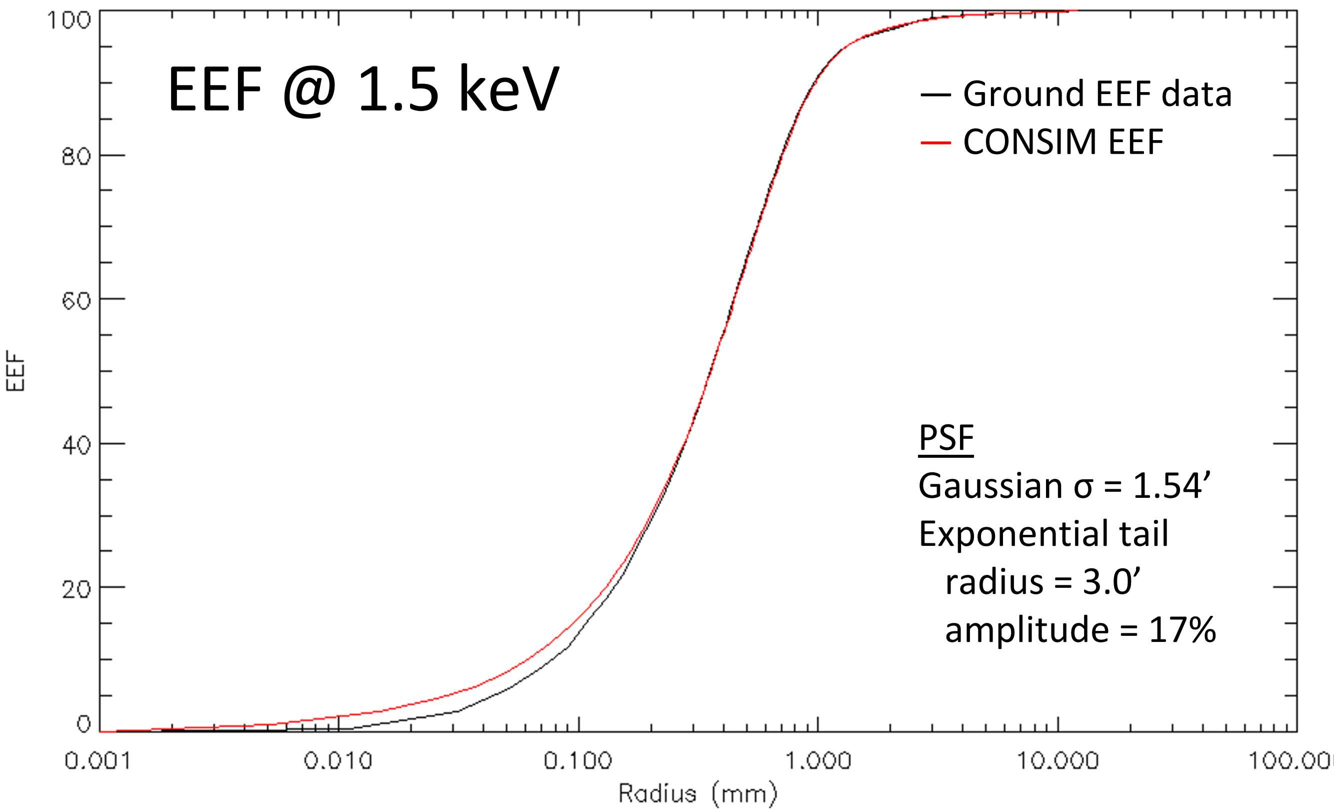
CONSIM Scattering / PSF Improvements

- Rayleigh-Rice X-ray scattering theory implemented properly in CONSIM, Au surface roughness 3.1 Å
  - PSF parameters matched to ground data



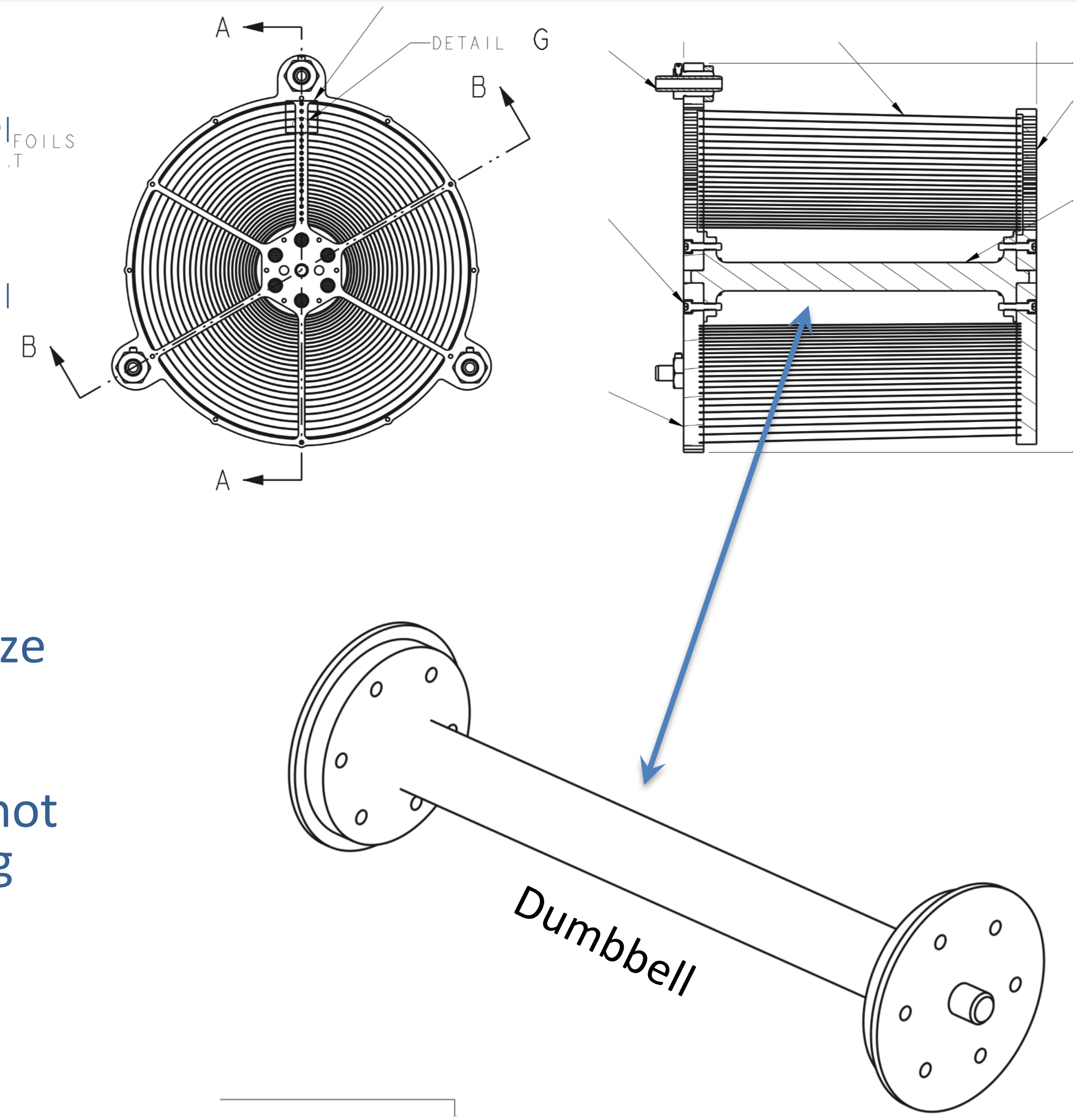
Revised "PSF" Parameters

- Adjustment to physics meant adjustment to "PSF" parameters
- Recovery of old ground cal measurements of single module at 4 keV
- Adjustment of PSF parameters in CONSIM to match 4 keV data



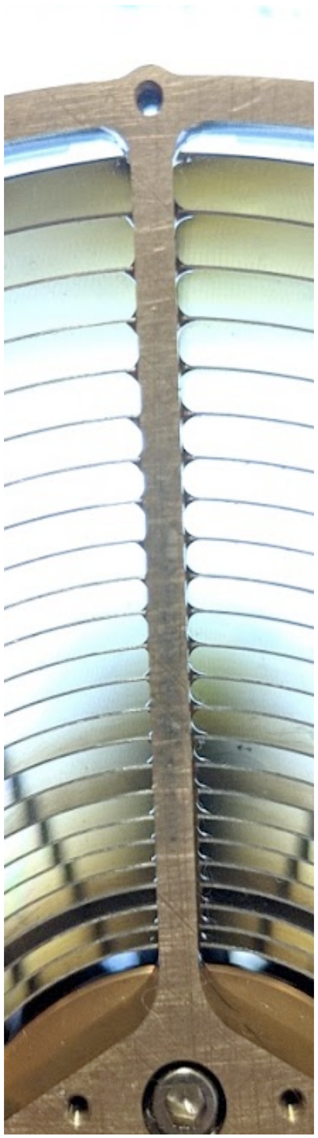
CONSIM Geometry Improvements

- X-ray Concentrator (XRC) includes a structural compone known as a “dumbbell”
- The rear portion of this component was not included i previous versions of CONSIM
- Full dumbbell now included
  - High-energy photons preferentially affected
- Additionally:
  - Empirical adjustment to size of dumbbell required to match astrophysical data
  - Cause of this adjustment not well understood and being investigated



Additional Improvements

- More geometry effects
  - Rounding of spider spokes
  - “Glue blobs” securing foils to spider spokes

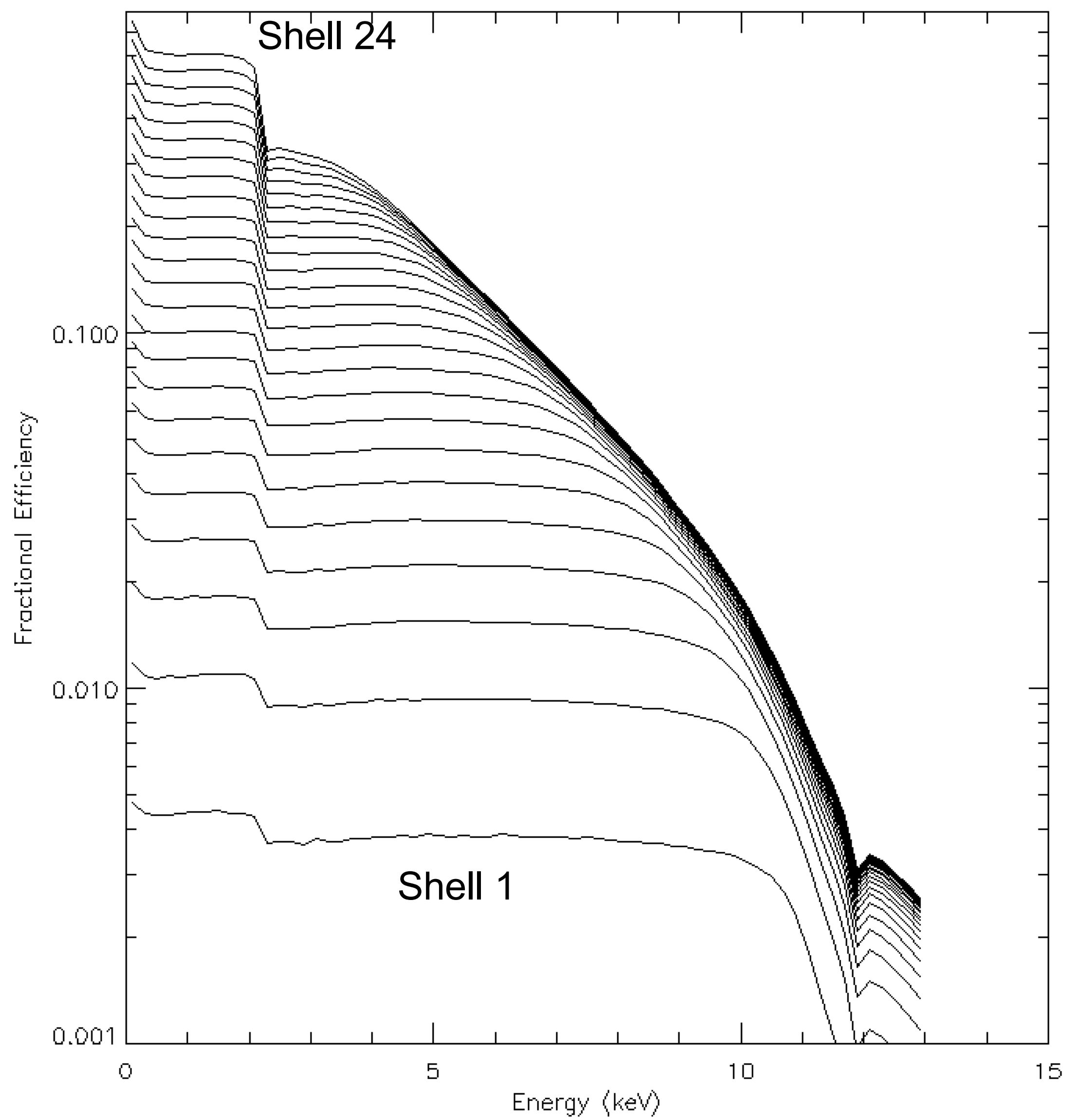


Geometry Experiments

- We experimented with adjusting the geometry arbitrarily
  - Particularly the “dumbbell”
    - Adjusting size and depth of dumbbell
    - Results led to unphysical values
    - Fits were not particularly good

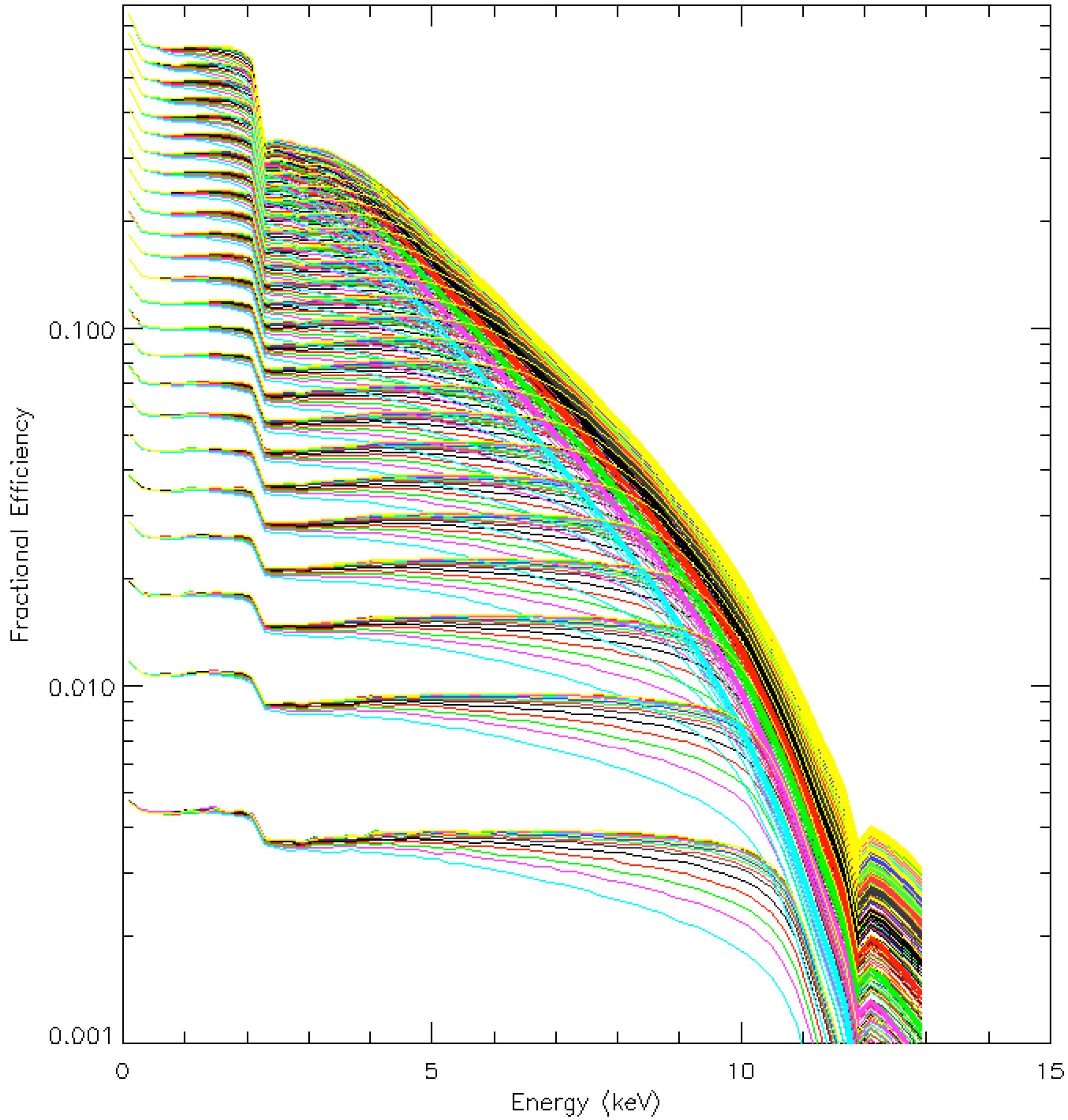
Effective Area Rackup

- Per-shell effective area rack-and-stack for an idealized module
- Can see the effects of shell radius
  - Inner shells are more reflective at higher energies but lower geometric area
  - Outer shells have most effective area at soft energies
- Gold edges at 2.2 keV and 13.9 keV



Addition of Roughness as Parameter

- Same as previous but now colors represent roughness gradient (2A-12A)
- Effect of roughness is to clip corner of highest energy response



"Last Ditch" Solution

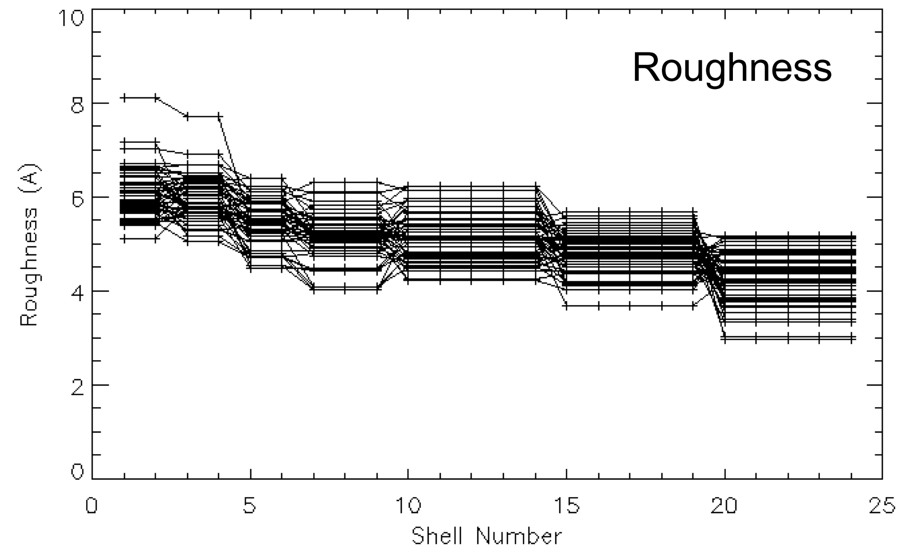
- Adjust normalization and roughness of "each shell" of each module
- Match the Crab spectrum
- Craig was going to the hospital to have a baby 6 hours later so this had to be the solution
- Computers hummed over the newborn period calculating the "version 1" ARF that was sent out in early July (CONSIM135)

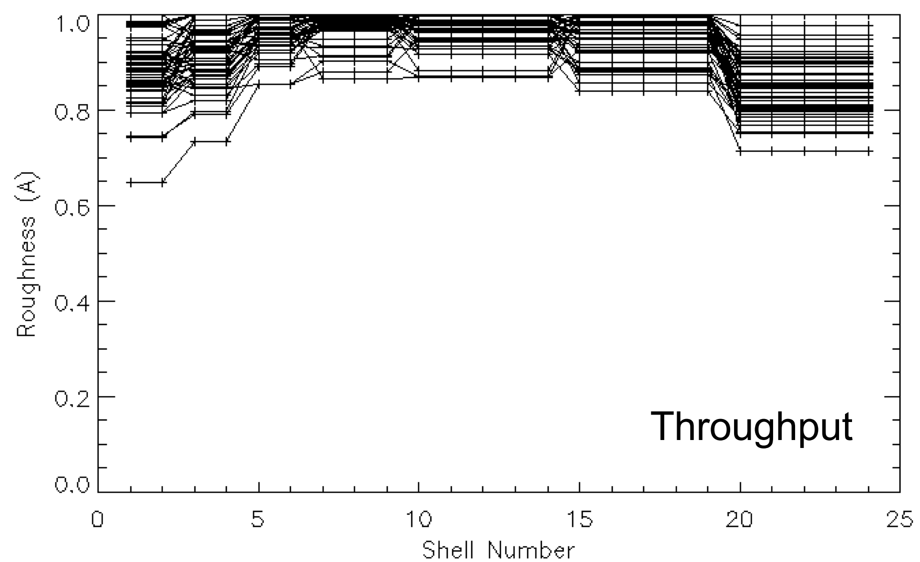
Revision Work Since Then

- Make the per-shell fit more stable
- Group shells more physically
- Establish some “prior” knowledge to steer the fits

Results of per-Shell Fitting

- Adjustment of each shell to match Crab
- Typical roughness is 5-6A
  - Worse performance is innermost shells where we know the design was challenging
- Worse throughput performance for innermost and outermost shells

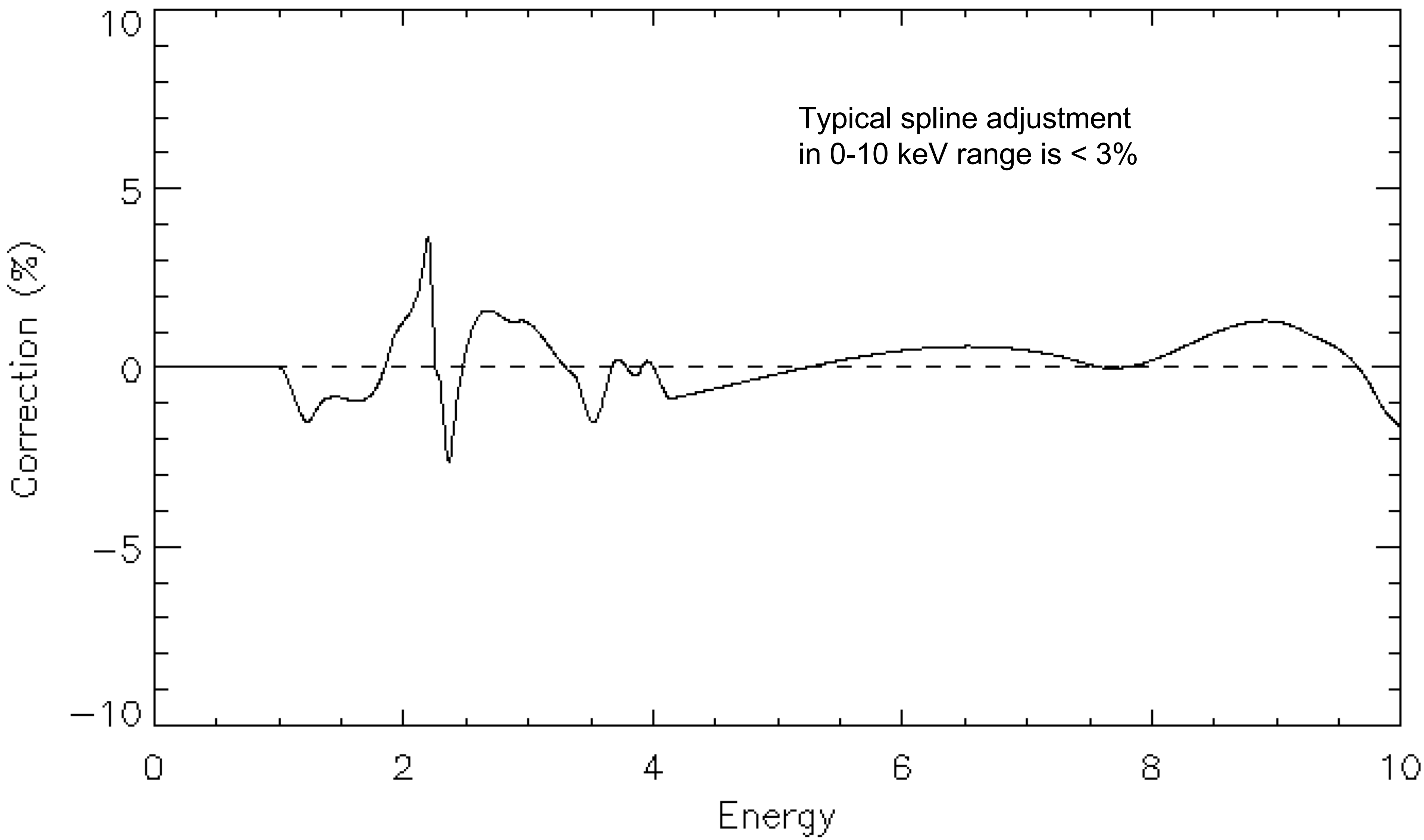




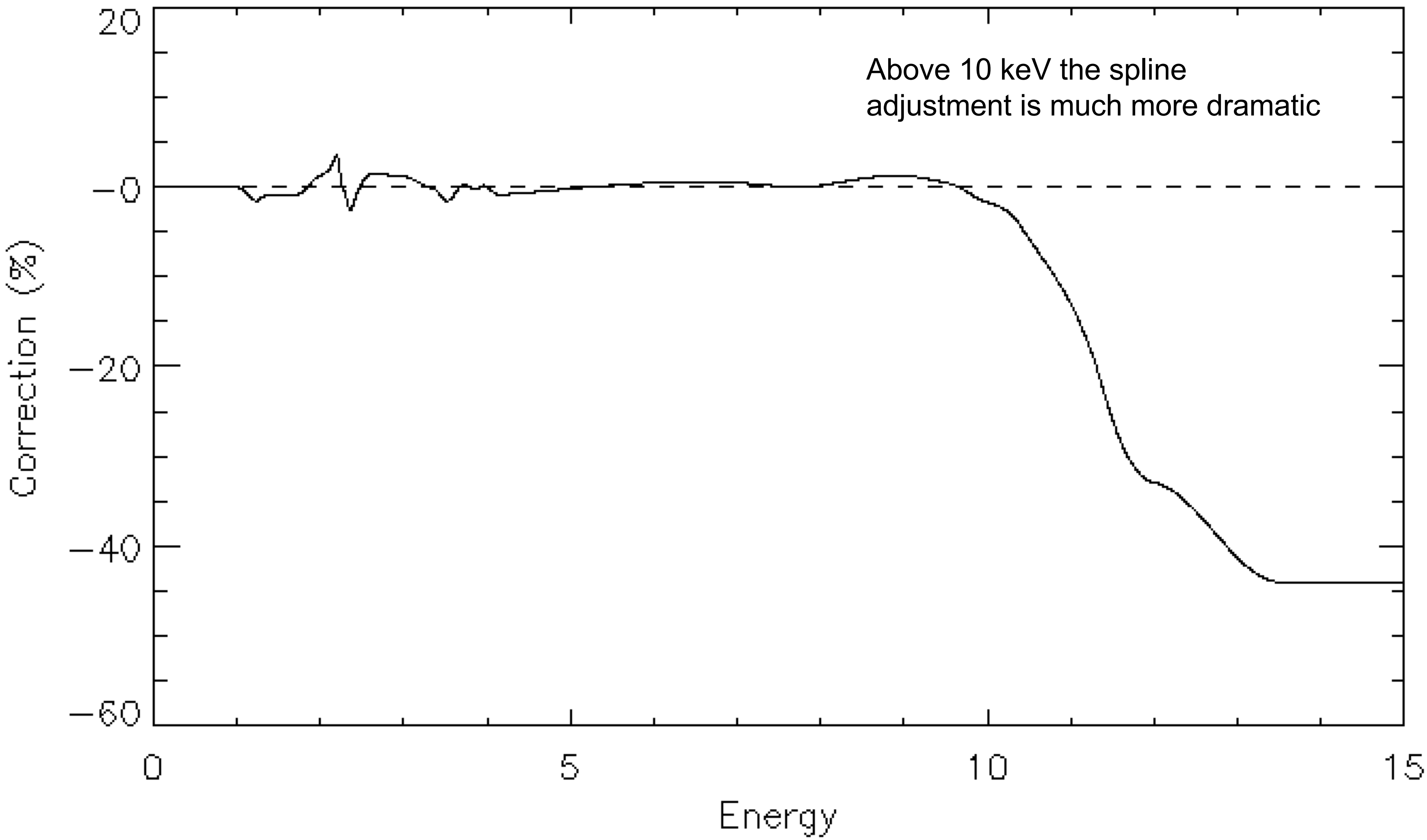
Spline Correction

- After doing this, there are still some unresolved residuals for the Crab
  - 1-10 keV these residuals are a few percent
  - Above 10 keV the residuals are 10s of percent
    - The cause of these deviations is not certain at this time
- "Crab-corrected" model uses array-average spline to adjust overall throughput >1 keV based on unknown effects

Spline Fitting Results: 0-10 keV



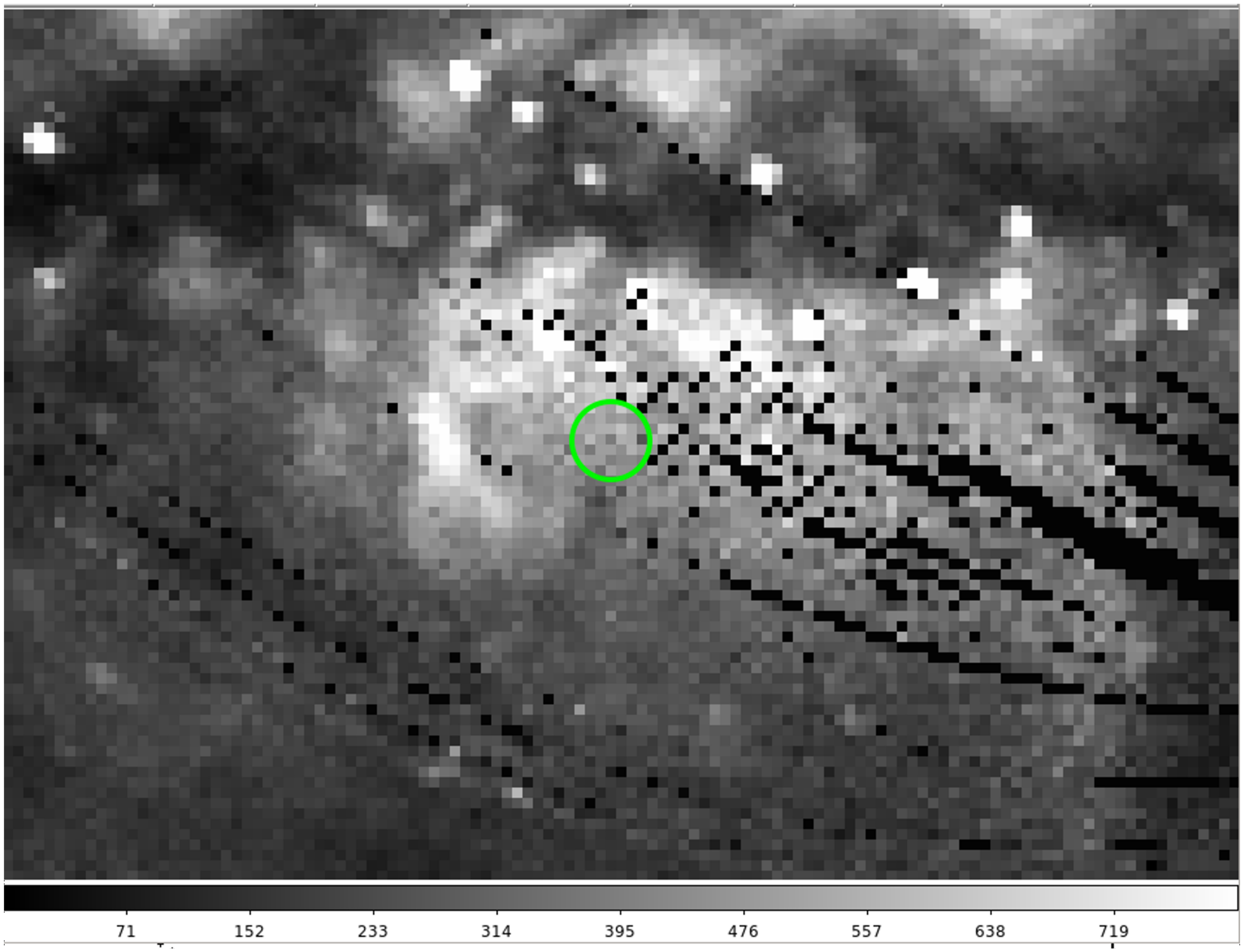
Spline Fitting Results: All Energies



NICER ARF Performance: RX J1856.6-3754

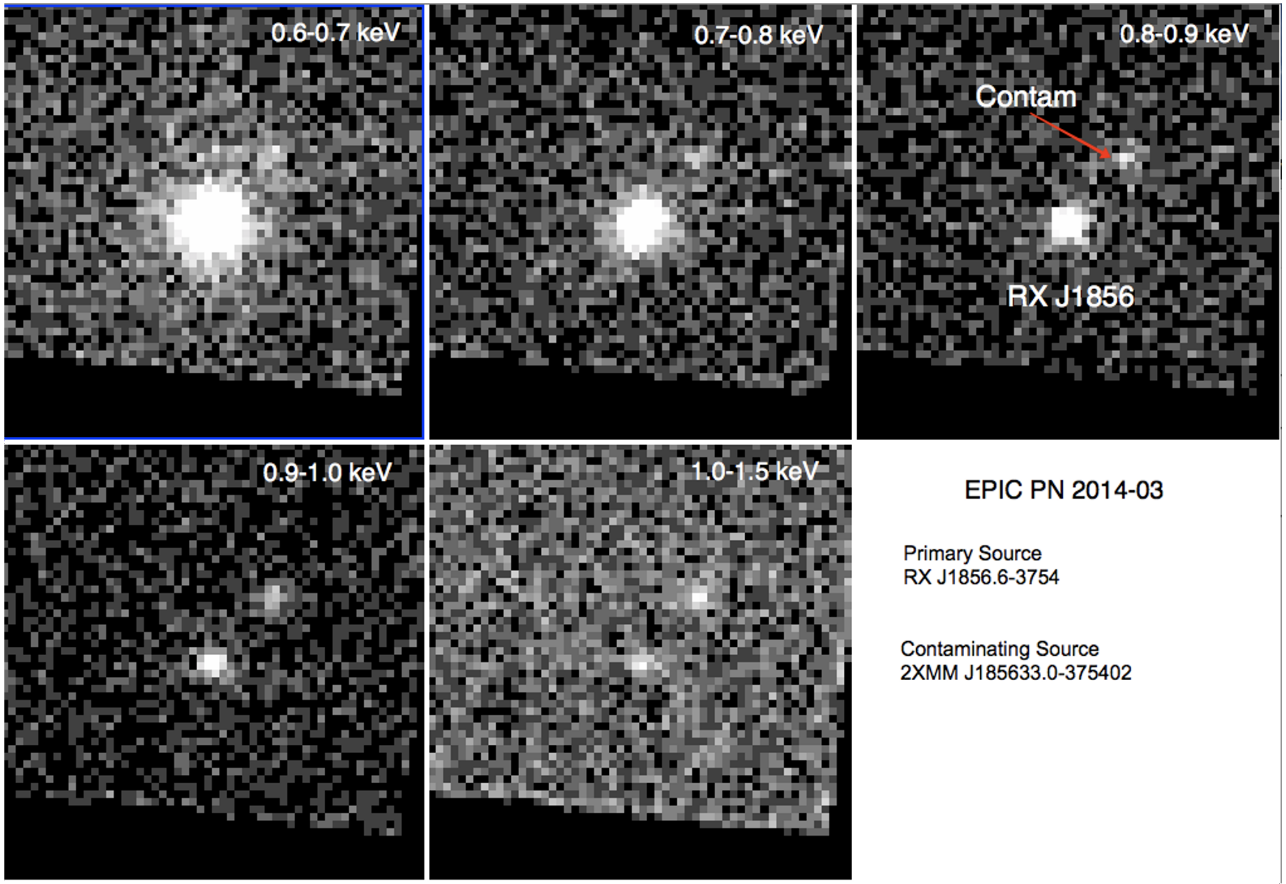
- RX J1856.6-3754 is isolated neutron star
  - soft spectrum (kT < 65 eV)
  - low absorption
  - constant intensity (assumed)
- Claims of hard X-ray tail by Yoneyama et al. 2017 (Suzaku XIS)
- Source is also embedded in Galactic bulge diffuse emission which is significant at ~10% level compared to point source

RX J1856 Diffuse Emission



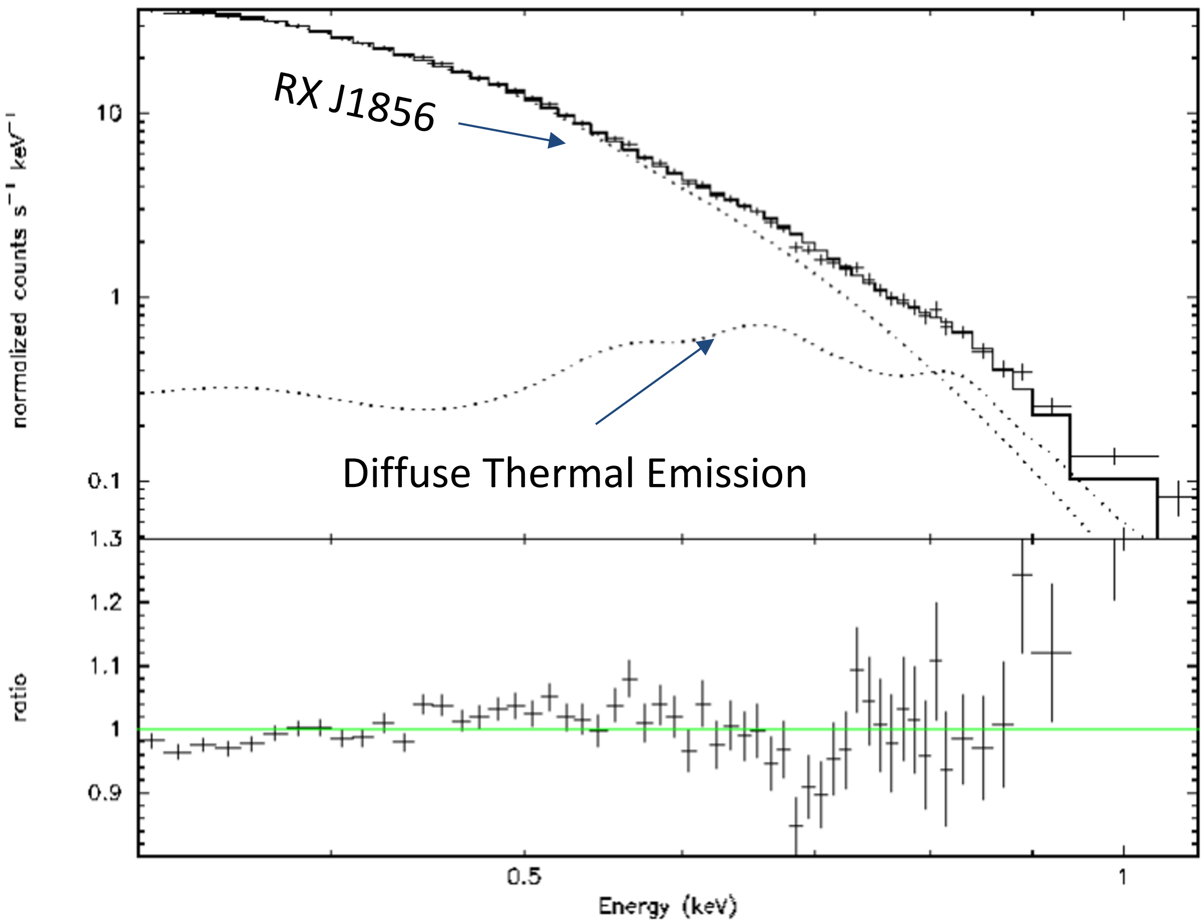
ROSAT All-Sky Survey ¾ keV ~ 500 ct/s/arcmin^2

RX J1856 Nearby Contaminator



Hard source 38” from RX J1856, spectrum consistent with kT=140 eV, highly variable on timescale of weeks-years; likely to be excess seen by Yoneyama et al 2017; far enough away to not contaminate XMM or Chandra spectra

RX J1856 NICER Spectrum



Spectral shape fixed at IACHEC values (NICER norm 93%), diffuse emission is consistent with ROSAT levels

NICER ARF Summary / Future work

- Significant effort in past year to improve ARF
- Instrumental residual artifacts < 2-3%
- NICER flux ~10% low compared to other observatories
- Future work - near term (ARF & RMF)
  - team validation of current effort
  - summation of ARF using known per-module alignment offsets and relative norms
  - inclusion of new low energy threshold info in RMF (<350 eV)
- Far term
  - Response calculator using per-observation off-axis and resolution information