NICER User's Group

Feb 2023

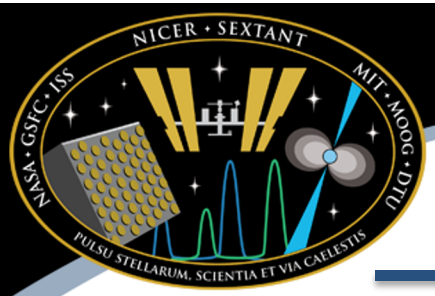
NICER

Neutron star Interior Composition ExploreR

NICER Software & Calibration Update

Craig Markwardt (NASA/GSFC)
on behalf of NICER Team

NASA GSFC MIT KAVLI INSTITUTE DTU BROAD REACH MOOG

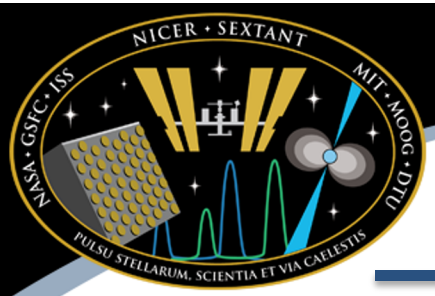


Overview

- Calibration updates
  - Background models now included
  - Jeremy Hare joins NICER team as calibration scientist
- Software updates
  - Background modeling software included
  - New end-to-end spectral and light curve extraction tools
  - Discussion of “Noise Ringers”
- Documentation Updates

Calibration Status

- Overall, the NICER calibration is extremely steady
  - Higher leakage currents experienced by some detectors lead to more undershoots and noise, but these are are calibrated
  - Electronic noise increasing at <0.1 eV/year!
  - Some small long-term energy scale drifts which team is monitoring (eV level)
  - Team has monitored soft sources for evidence of contamination build-up – none detected to date



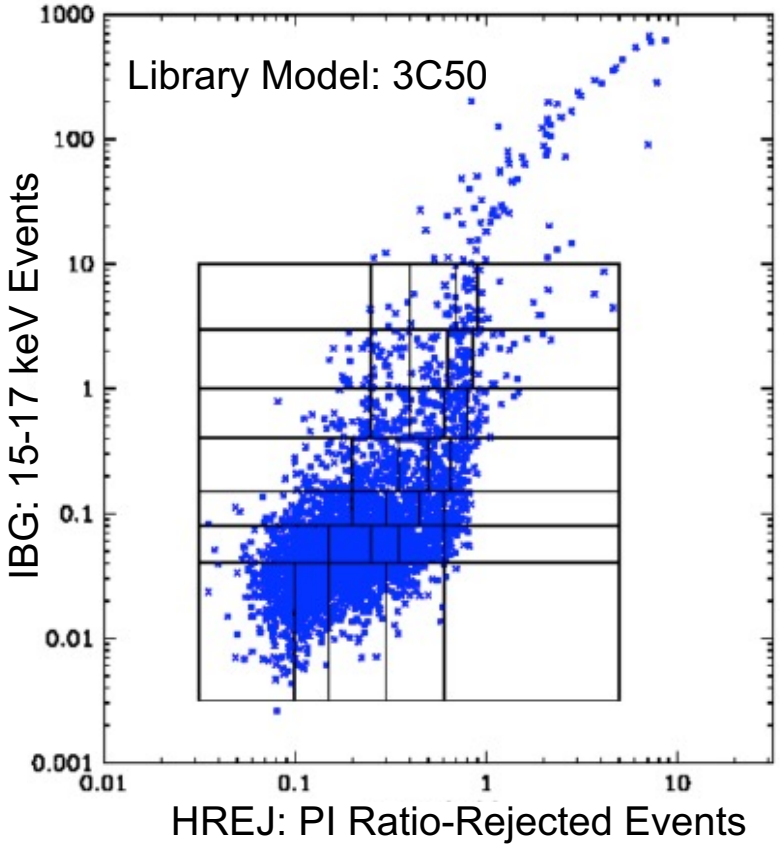
Calibration Releases

- Most recent release was xte20221001 (released with NICERDAS 10 in November 2022)
  - Background models are included in CALDB (3C50, Space Weather, SCORPEON)
  - Systematic error vector now included in CALDB
  - Known ”bad times” recorded
  - Energy scale “optmv13” – mostly affects >8 keV

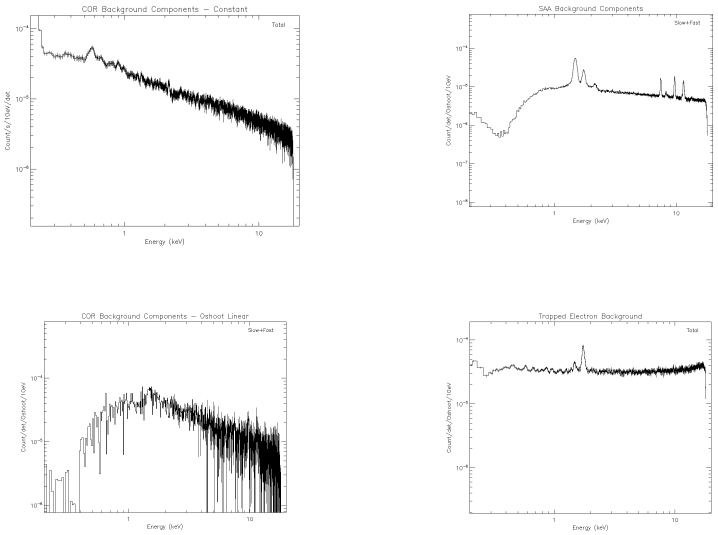
Major Update: Background Models

- Background models are now included in NICERDAS
  - SCORPEON (New)
  - 3C50
  - Space Weather
- All needed files are in CALDB
  - The behavior and results of 3C50 / Space Weather models is unchanged, just encapsulated in FTOOL format for NICERDAS
    - Users can decide when / how to migrate from standalone tools

Library Models vs Template Models



Template Model: SCORPEON

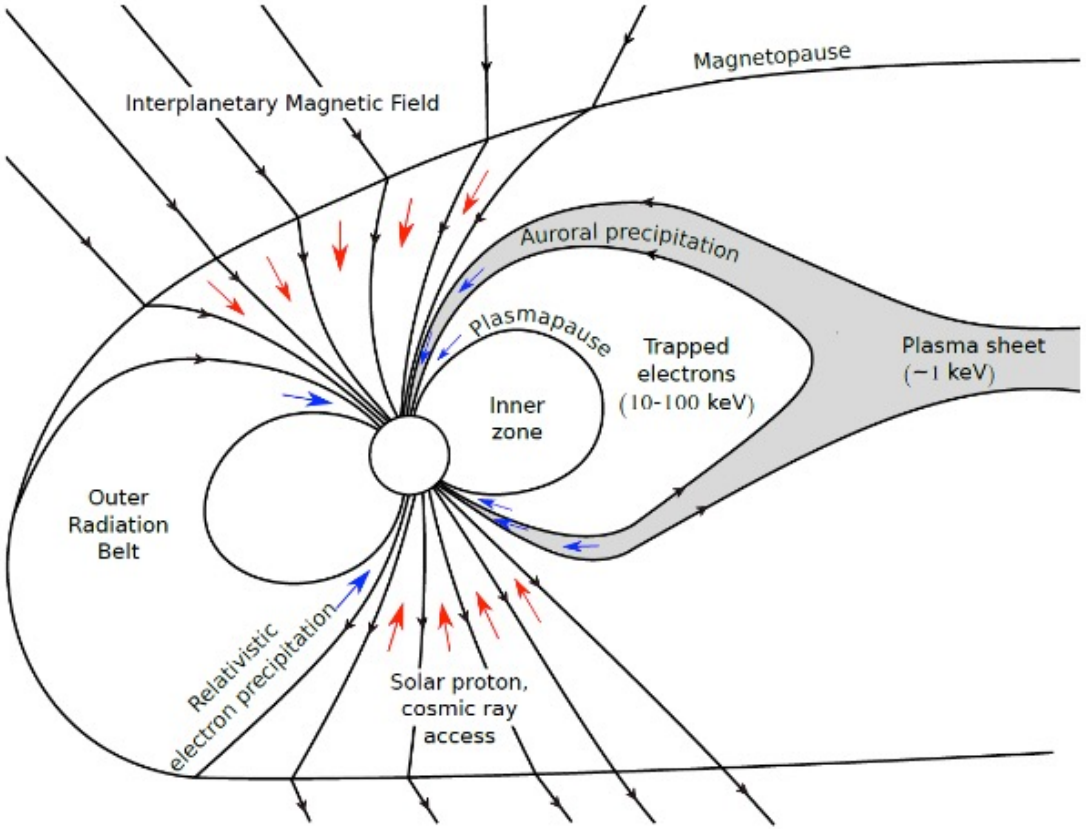


- Break parameter space into cells, measure background in each shell (library of spectra)
- Application: calculate exposure in each shell, make weighted sum of library spectra

- Measure ”basis vector” of each unique component
  - Make smoothed version of template as XSPEC model
- Normalized based on known telemetry (overshoots, etc)
- Application: predict norms from telemetry & load into XSPEC

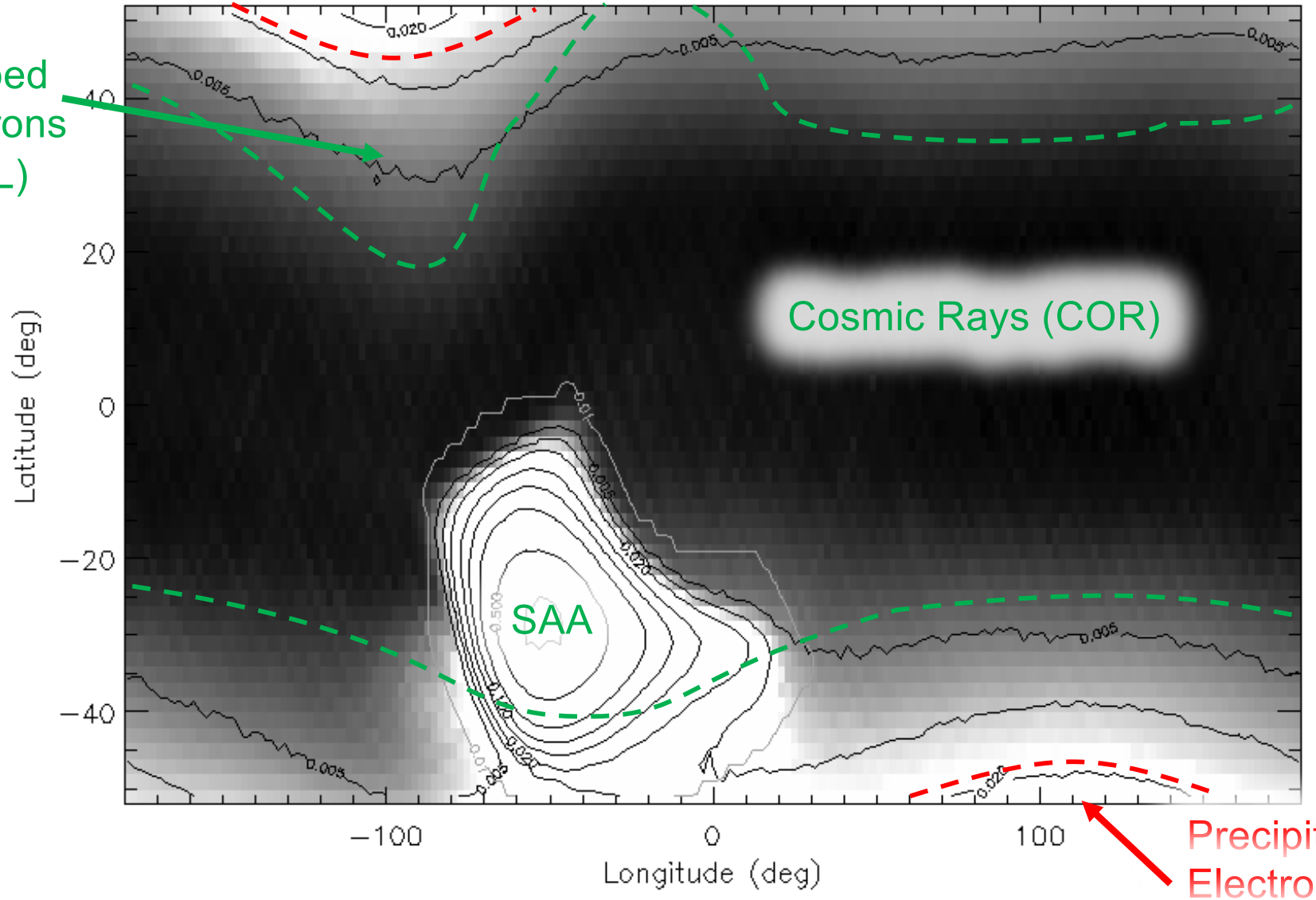
SCORPEON Background Modeling

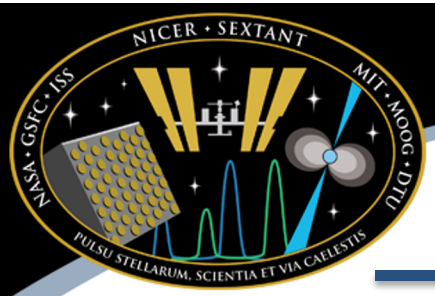
- SCORPEON Model
- Major goals
  - Break down background into physically-motivated components
  - Separate “data modes” (slow-only, slow+fast event types), and both
  - Assume that these components can be modeled with simple spectral models so they are easy to implement



Thorne et al 1980
Tyssoy presentation

Geographic Overview of Dominant NICER Background Contributors

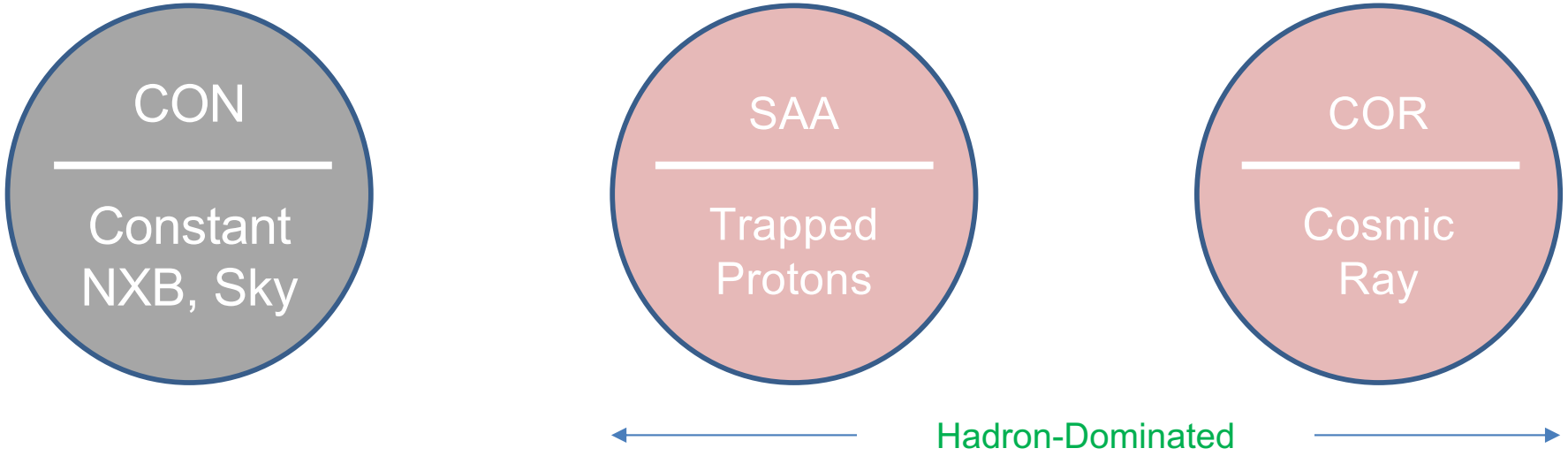




SCORPEON Name

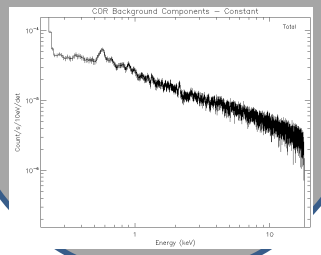
- S COR PE O N
  - S = **SAA**
  - COR = **CO**smic-**R**ay (COR_SAX)
  - PE = Precipitating & trapped Electrons
    - Precipitating electron population (PREL)
    - Trapped electron population (TREL)
    - Low energy electrons (LEEL) – solar storms
  - O = c**O**nstant
    - Astrophysical: CXB + Halo + LHB + SWCX
    - Non-varying Non-X-ray background
  - N = **N**oise peak (not dealt with here)

SCORPEON Background Components

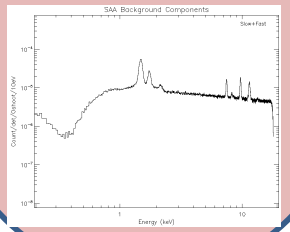


SCORPEON Background Components

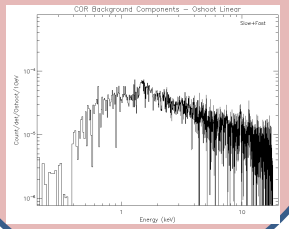
CON



SAA

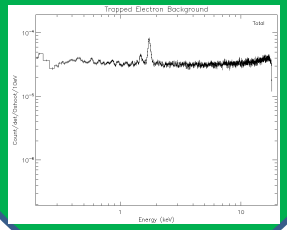


COR

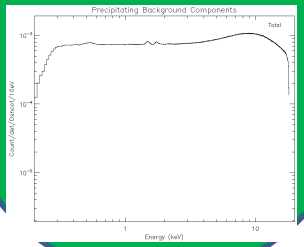


Hadron-Dominated

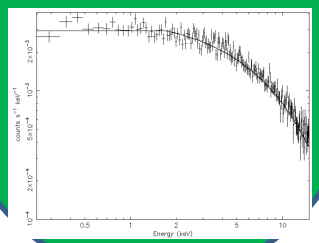
TREL



PREL

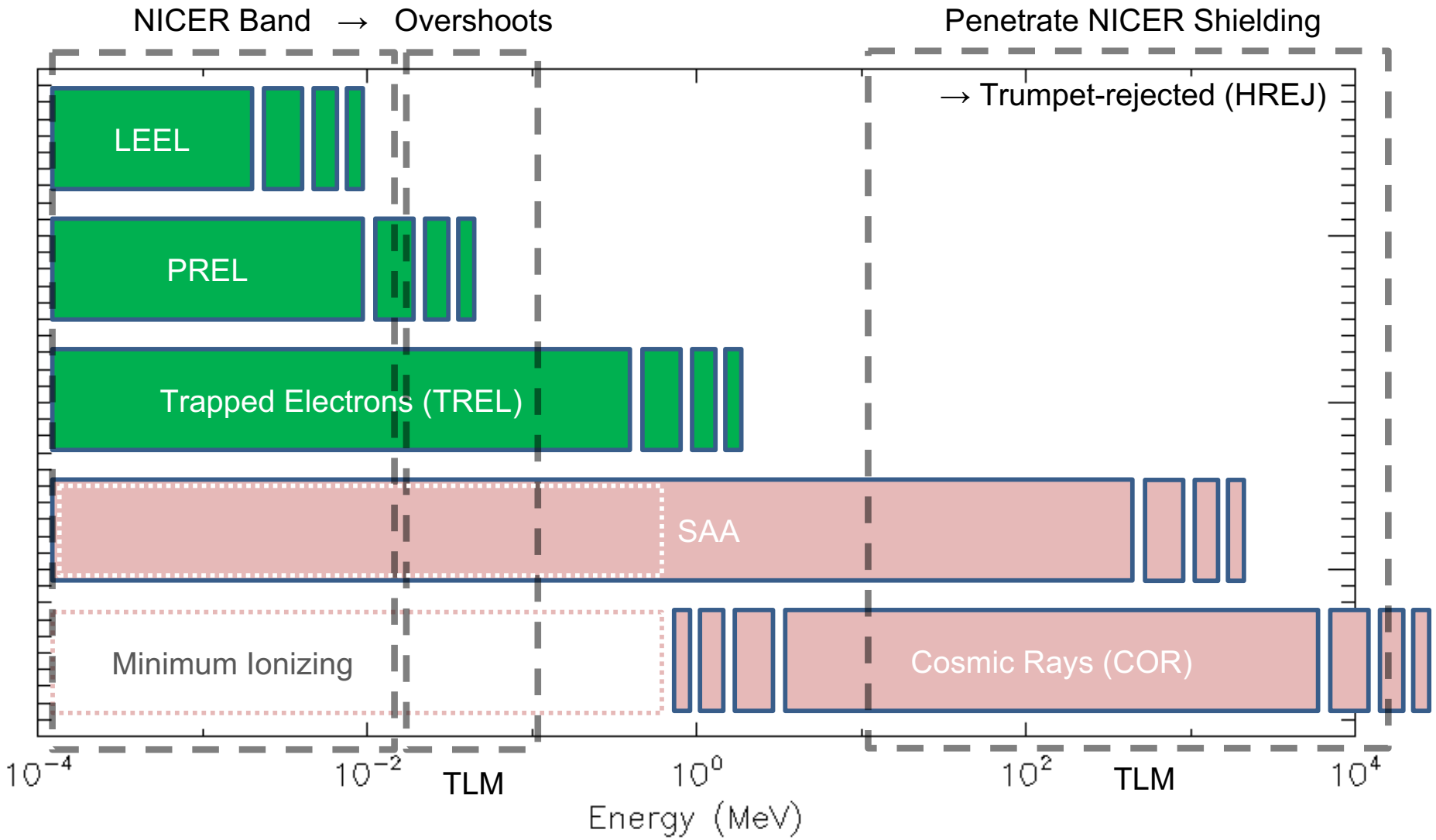


LEEL

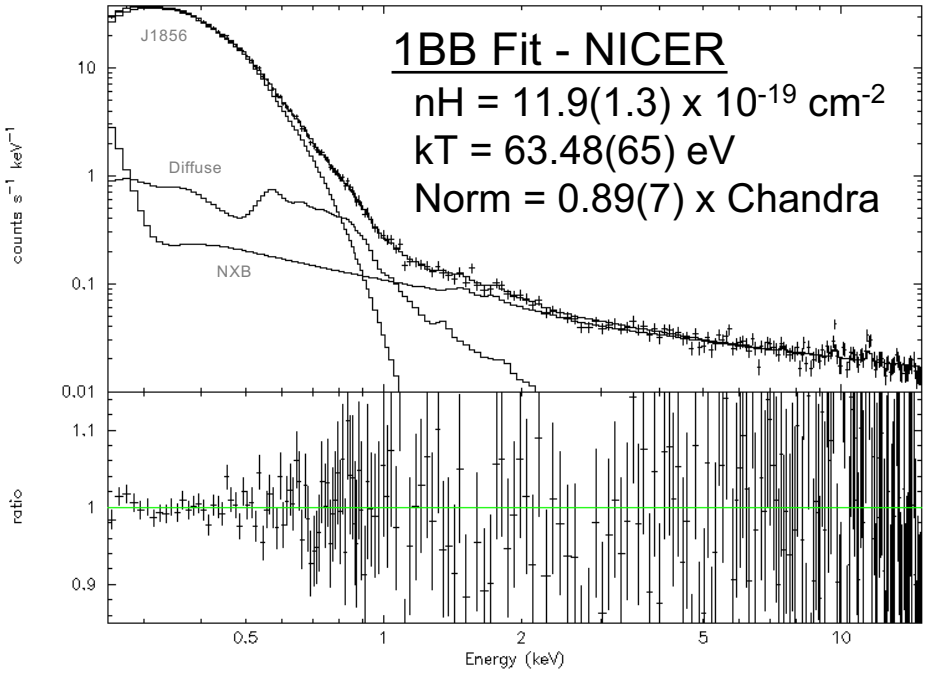


Electron-Dominated

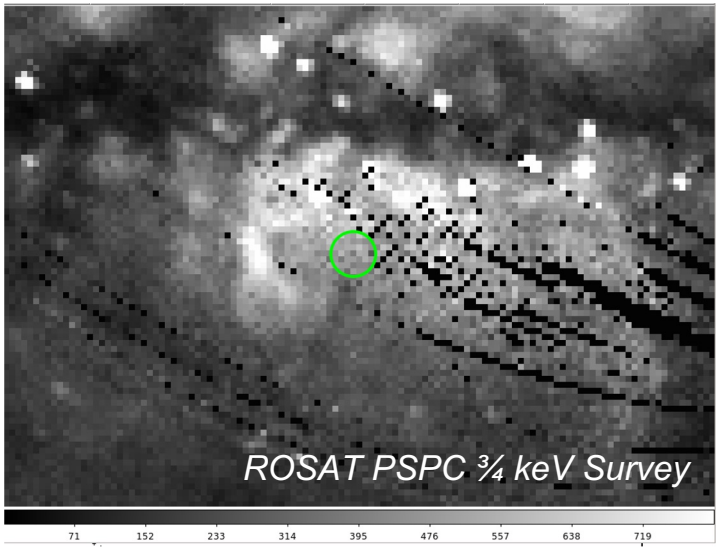
Energy Ranges of Components



SCORPEON Modeling of RX J1856

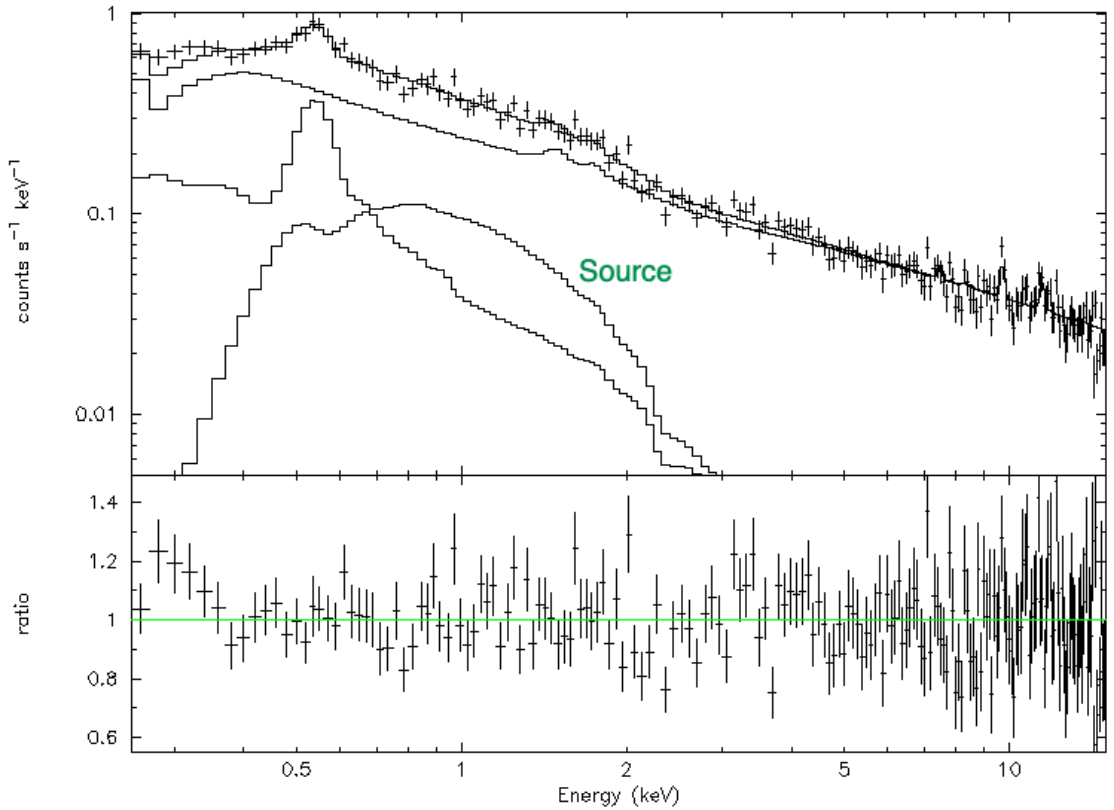


J1856 Embedded in Bulge Diffuse Emission

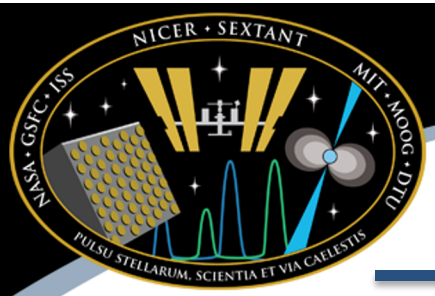


- New analysis of existing J1856 data with new tools
  - Includes 1BB for J1856 and Galactic Bulge, CXB, Local Hot Bubble, Galactic Halo, and other NXB components
  - NICER statistical error bars are ~1%
- J1856 parameters are coupled with background parameters but are reasonable overall; no evidence of ~1 keV excess

Faint Source Modeling

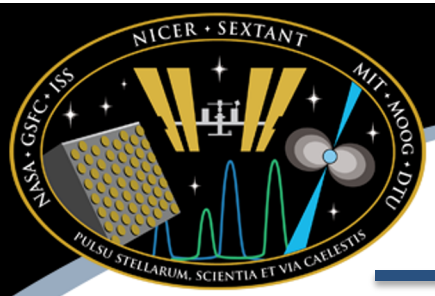


- NICER helpdesk question
- Flux 1-sigma range is 0.87 – 1.15 x 10^{-13} erg/s/cm2



Background Summary

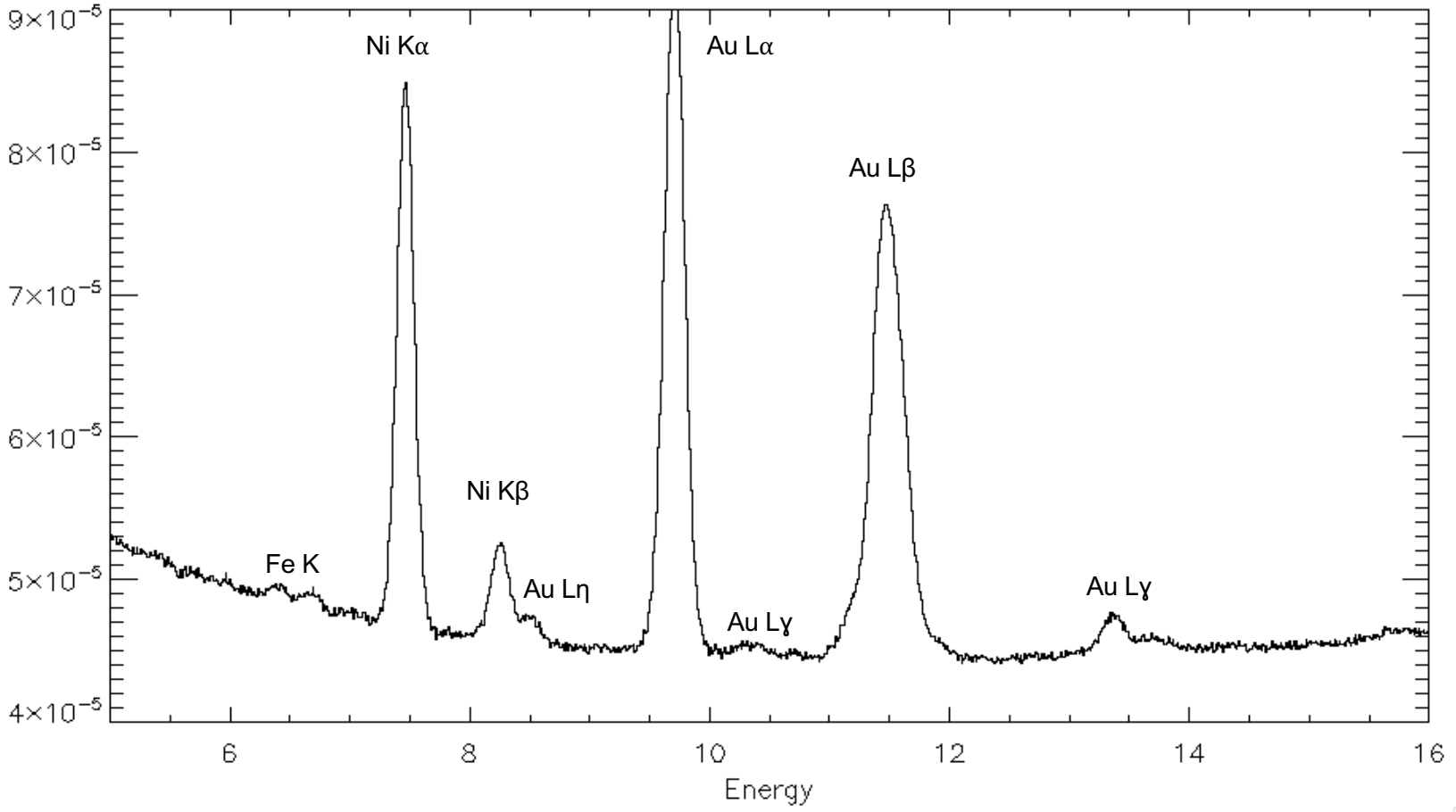
- New and existing background tools as a part of NICERDAS
- Major streamlining and ease of use improvement, especially for new users (no extra downloads)
- SCORPEON provides exciting new capability, especially for faint sources



Energy Scale Updates (optmv13)

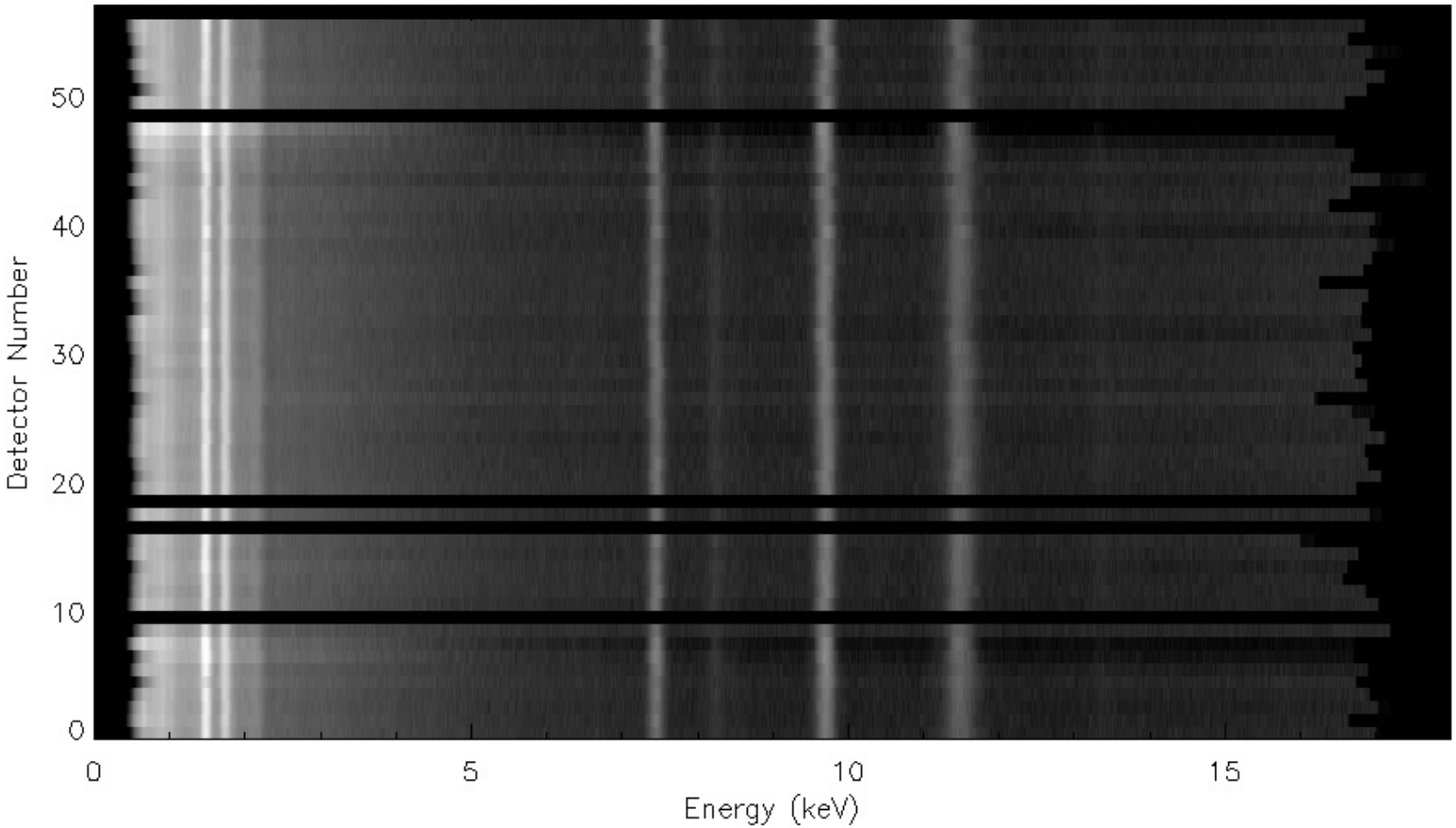
- New energy scale released in November
- "Minor" changes below 8 keV
  - More major changes above 8 keV
- No real lines above 8 keV, but continuum is also affected by energy scale
  - Source modeling
  - Background

SAA Lines Used for optmv13



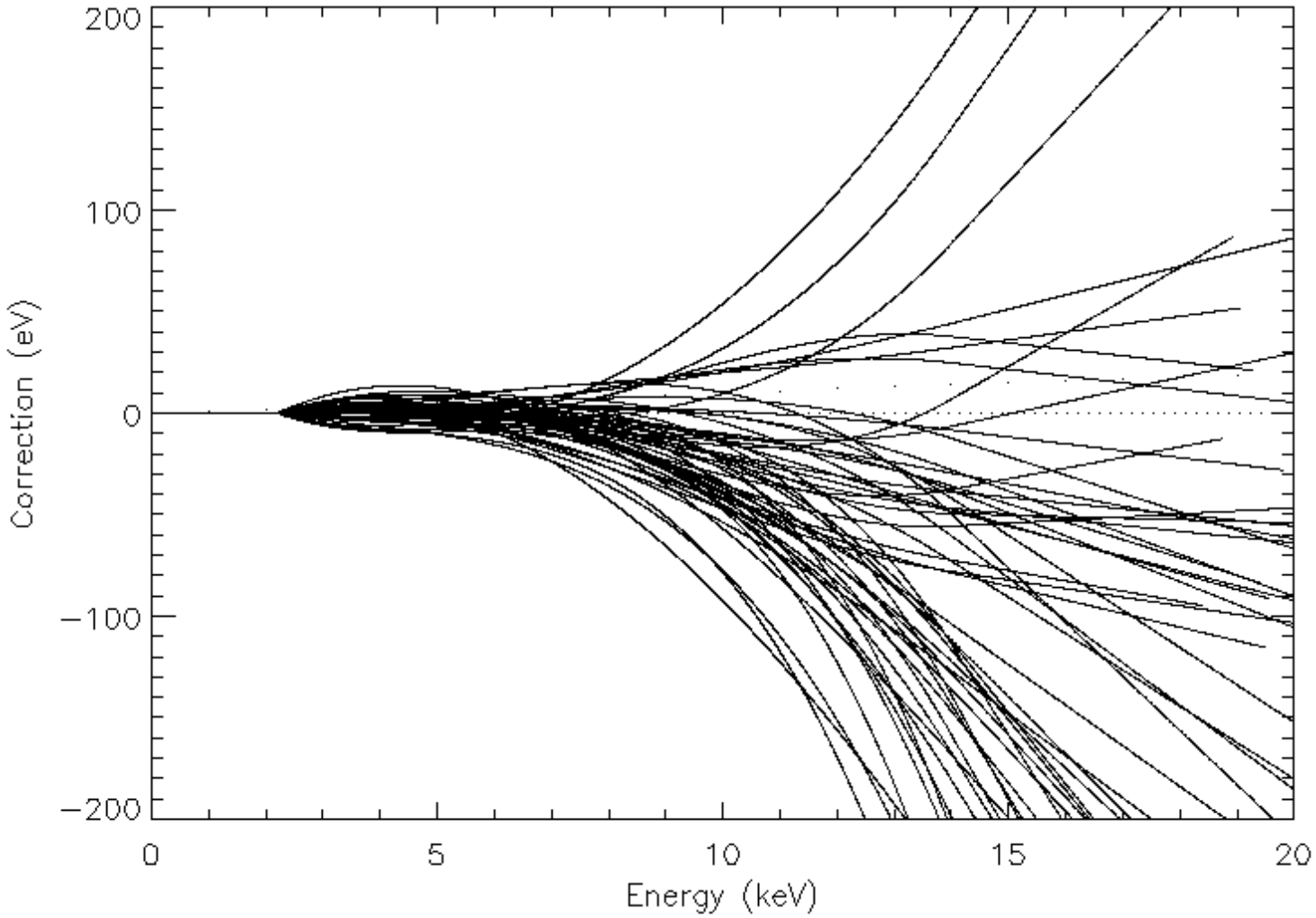
- Each line is actually a complex of several lines

Stack of All 52 Detectors (optmv12)



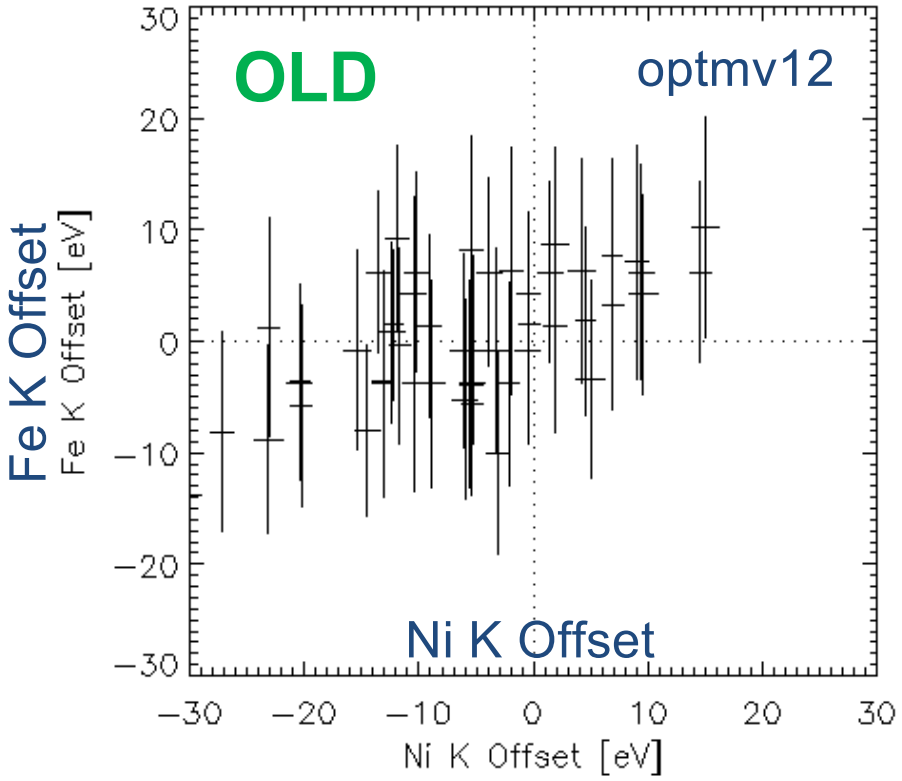
- All lines from 1.4 – 13.5 keV are visible
- Clear jitter in lines 7.5 keV and above

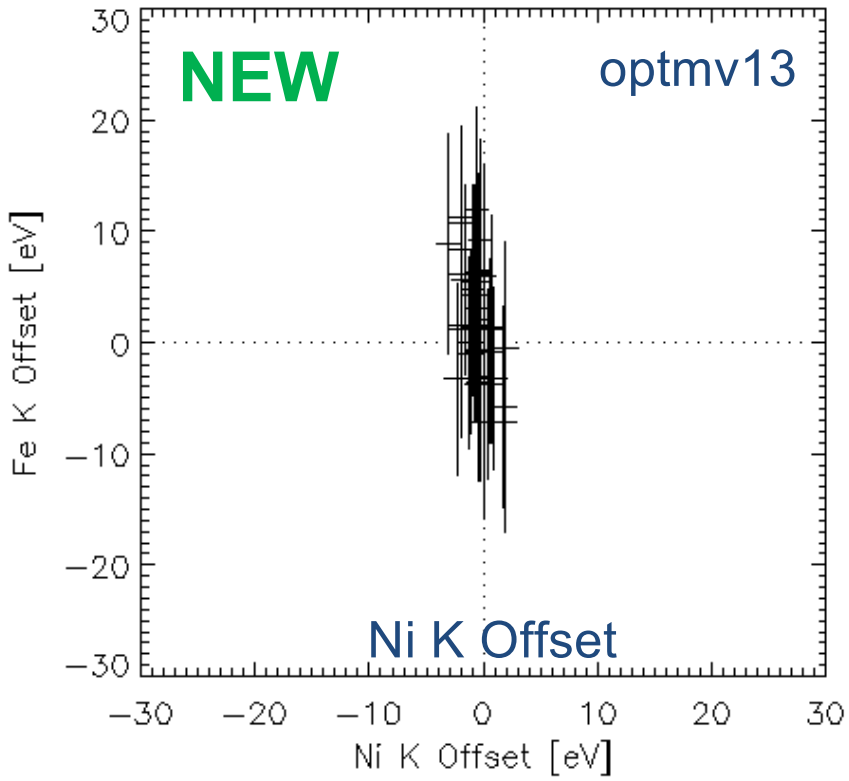
Per-detector energy scale changes



- ~10 eV (2-7 keV); up to 300 eV at high energies
  - No correction by construction below 2.2 keV

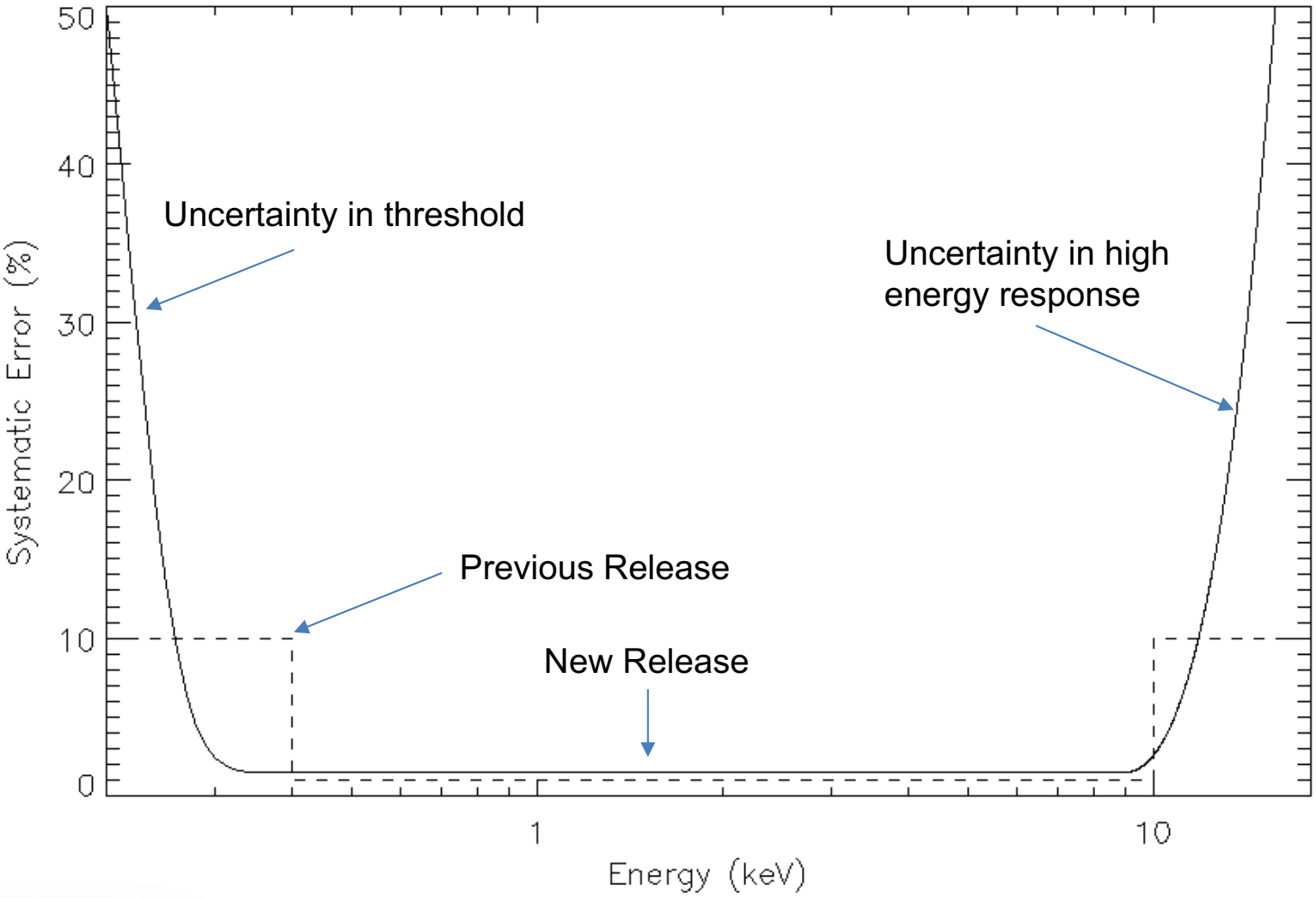
Post-optmv13 Improvements



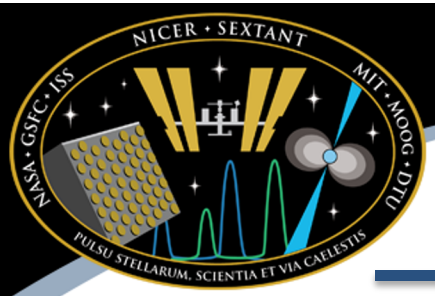


- Old Gain: Fe K (σ = 5.41 eV); Ni K (σ = 11.00 eV)
- New Gain: Fe K (σ = 4.65 eV); Ni K (σ = 0.98 eV)
- RMS improvements: Fe K (2.75 eV); Ni K (10.95 eV)
- Fe K is near statistical limit

Systematic Error Vector



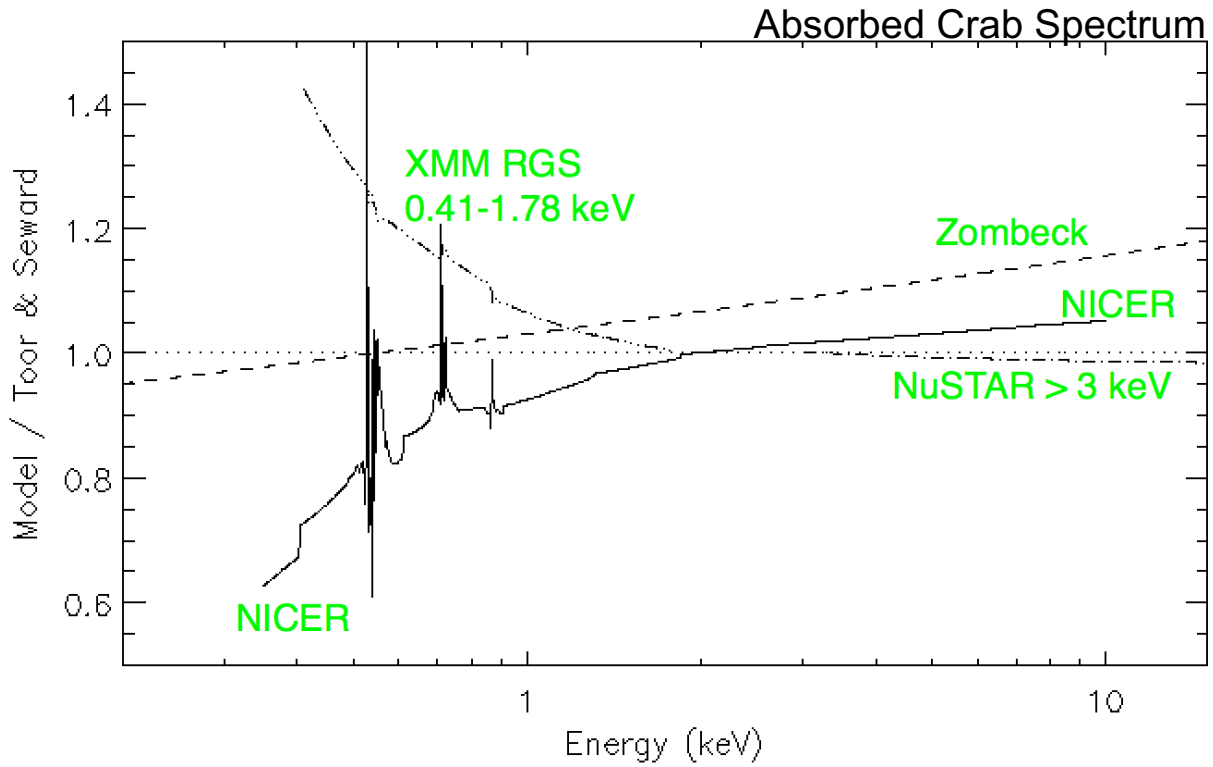
- Recommended systematic error vector
  - Applied automatically by new pipeline



Calibration Status Summary

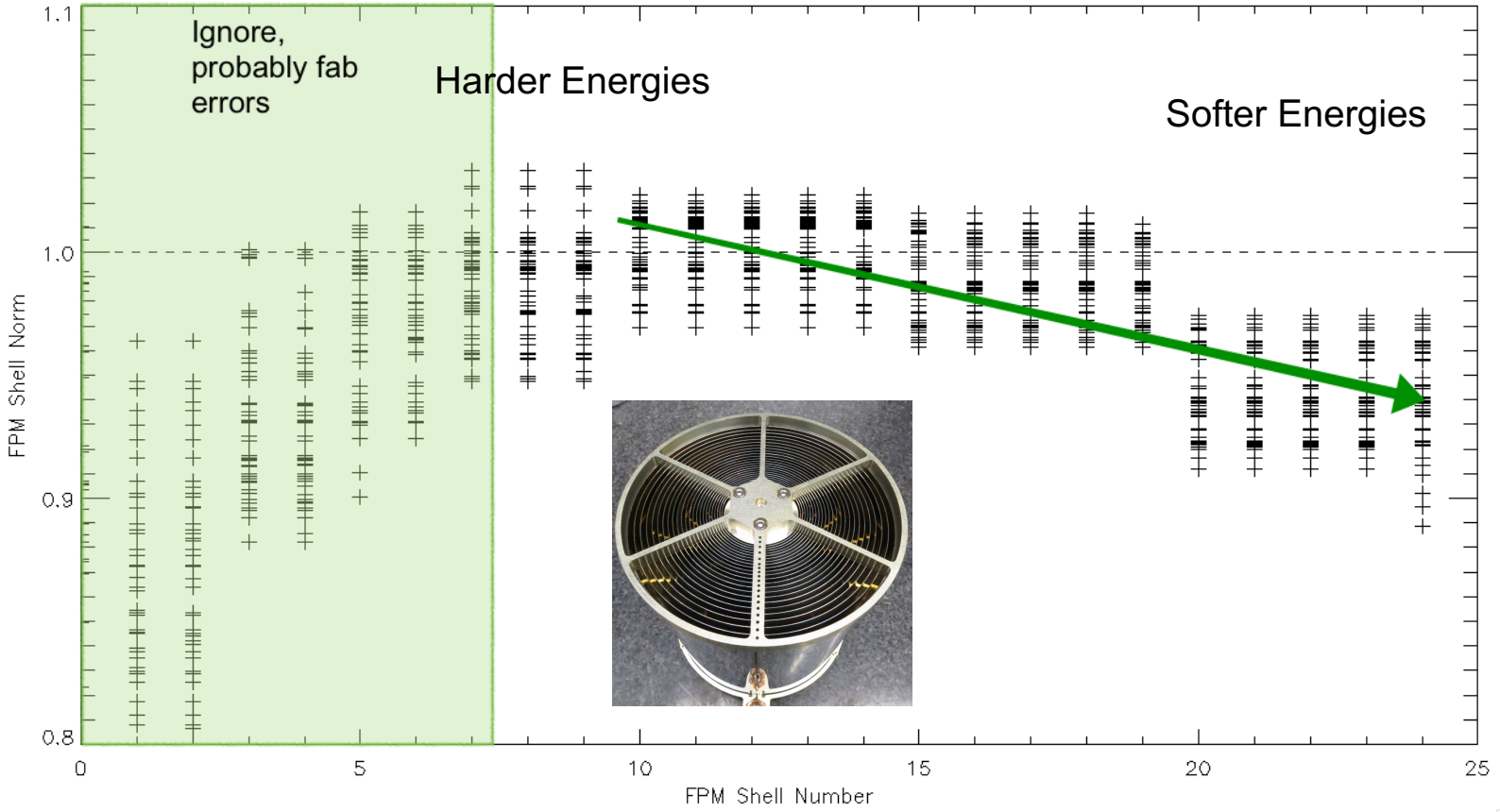
- NICER Calibration is in good shape overall
  - NICER team is monitoring very weak calibration drifts over years
- Previous NUG issues being addressed
  - Still some nagging questions about spectral shape (next slide) and overall cross-calibration normalizations
  - NICER has a lot of cross-calibration observations ”in the can”
  - Jeremy Hare has joined us (Fall 2022, 50% level) and is working on cross-calibration observations
  - Jeremy is working with other IACHEC members and is planning to lead next cross-cal paper
  - First cross-cal project is 3C 273, work in progress (NICER + Chandra + XMM + Swift)

Crab Spectral Comparison

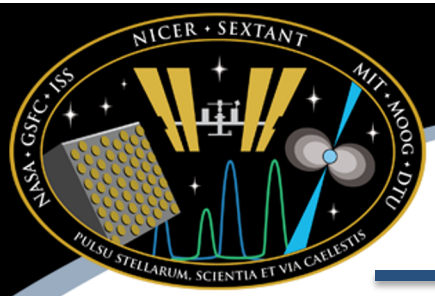


- Basis of comparison is Toor & Seward (1978) result, extended to lower energies
- NICER agrees with NuSTAR to with ~5%
- Very significant differences between XMM RGS (Kaastra et al. 2009) and NICER
  - These are primarily driven by minor differences in absorption and dust scattering which lead to large apparent differences in flux

Possible Explanation in ARF Construction



- Per-shell norms show unphysical trend, too high in middle shells, too low at outer shells
- May be that Craig assumed the wrong “reference” spectrum for Crab in 2018
  - Shift in power law index of ~0.05 could resolve this



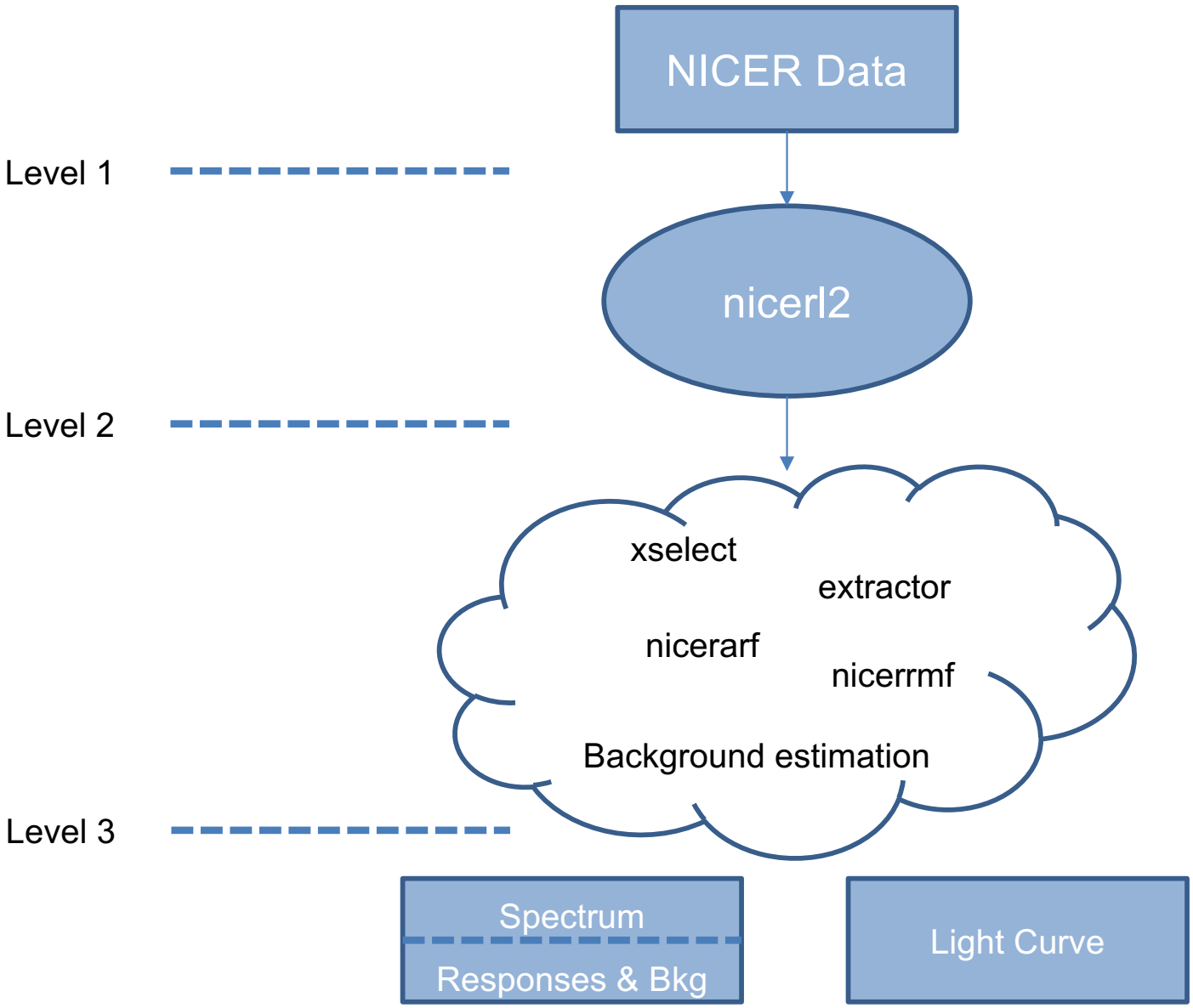
Calibration Release Roadmap

- Analysis is ongoing
  - Cross-calibration results available this spring
  - Re-analysis of the Crab
    - Slope change (~0.05 power law index)
    - Deadtime correction (~7% norm error)
    - Pulsed spectrum
- **Anticipate next release in the Summer 2023**
  - Both flux norm change, as well as spectral shape change
  - Will need to announce this in advance to give community a head's up
  - A way to select "old" versus "new" calibration??

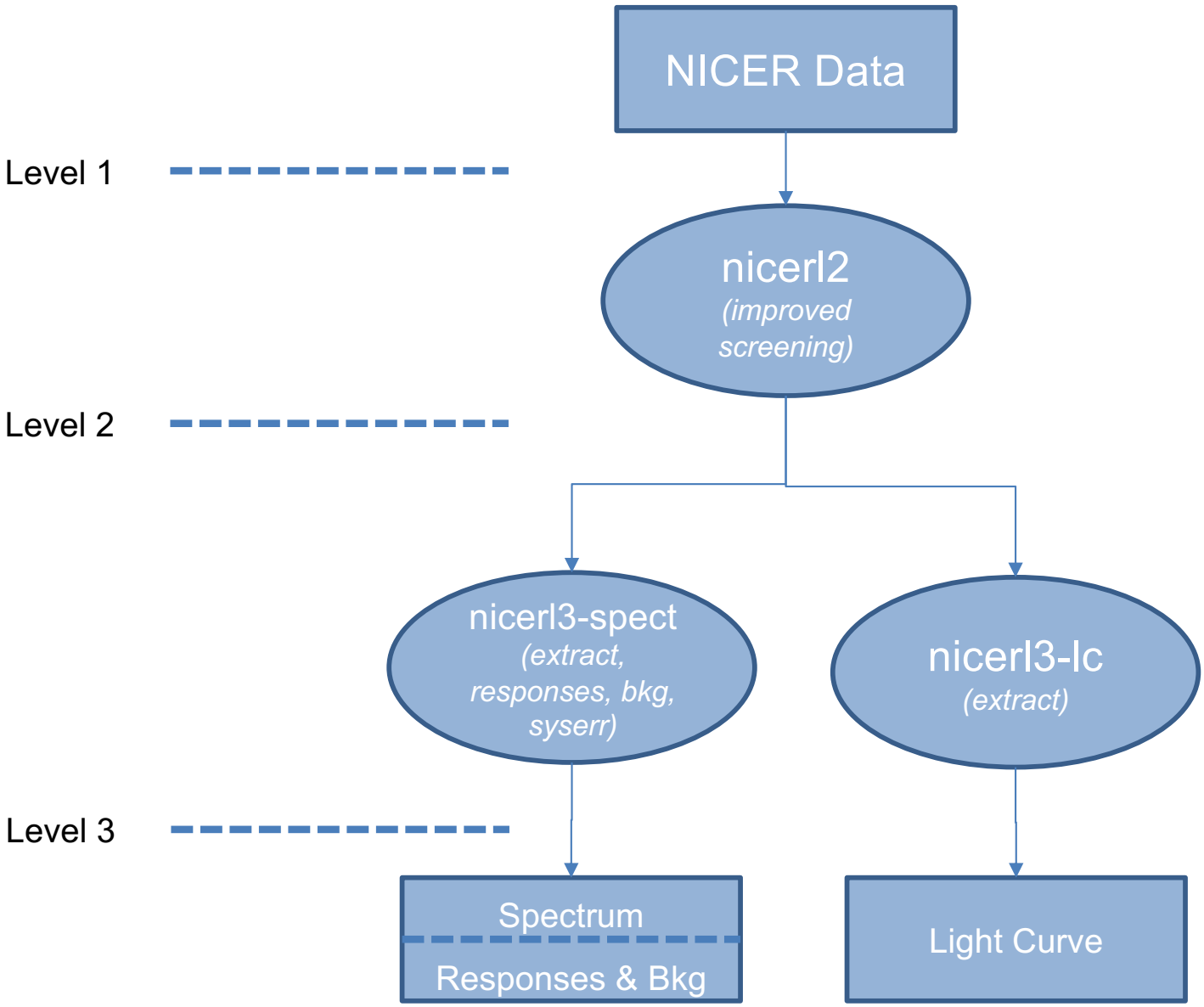
Software Updates

- Major software release HEASoft 6.31 and NICERDAS 10
  - Patch release 6.31.1 is fairly vital and recommended for all users
- Major updates
  - Standard pipeline products for light curves and spectra, including responses, backgrounds, etc
  - Background modeling tools
    - Users required to download geomagnetic data
  - Automatic screening for detectors that are off / noisy / high overshoot / high undershoot / “shredded GTI” conditions

Old Workflow: Difficult for Beginners



New Workflow: Streamlined

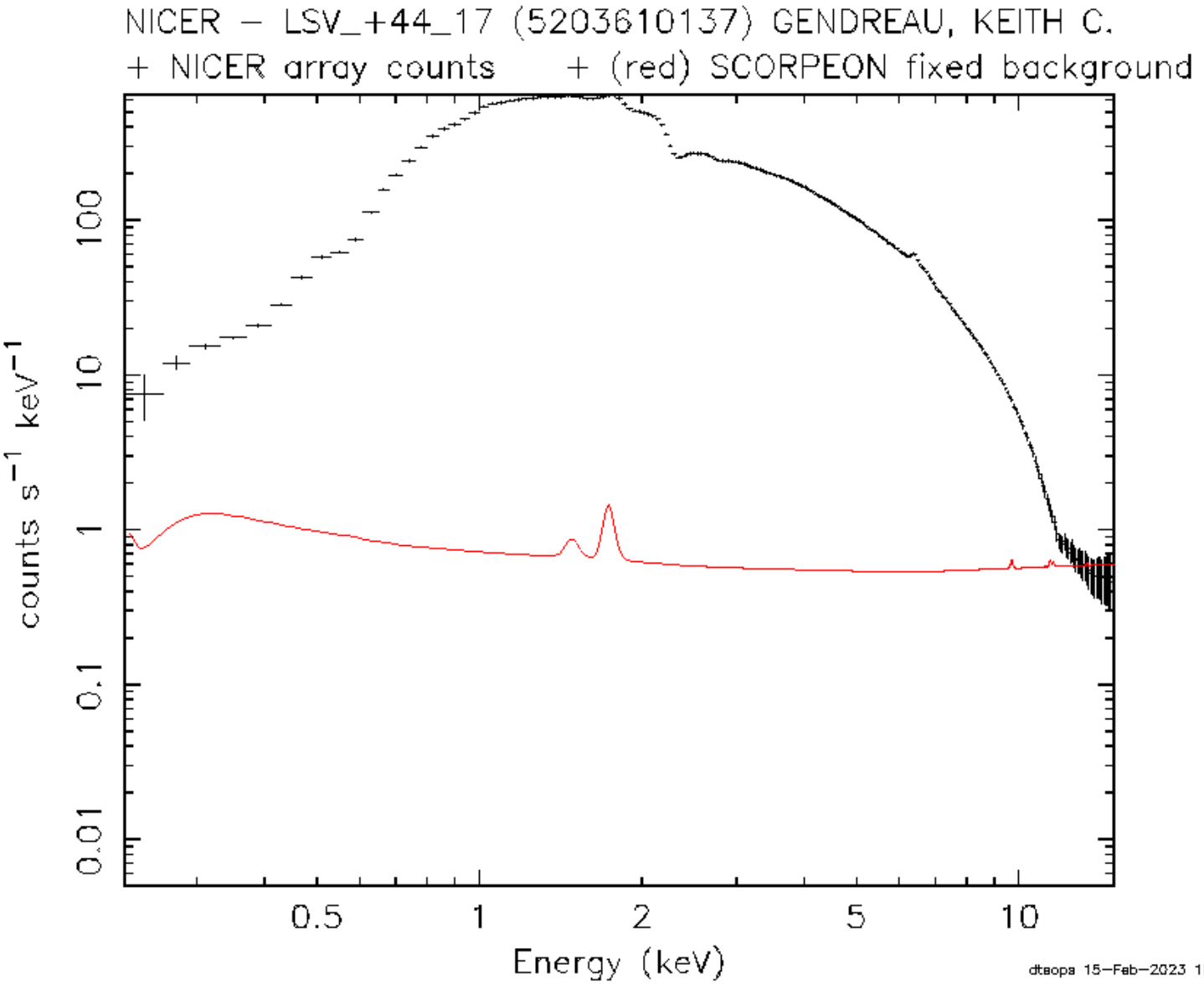


NOTE: Existing user-designed workflows continue to work unchanged

Standard Spectrum & Light Curves

- nicerl3-spect and nicerl3-lc are standard spectrum and light curve product tools
  - Useful for beginners because most defaults are reasonable
  - Useful for advanced users seeking to streamline their process or take advantage of automatic screening or background modeling
    - Advanced users can choose background model etc.
  - PyXSPEC supported
- Both tools have similar parameters so learning curve is reduced
- Note that as of January 2023, the NICER pipeline is also creating standard products (and previews), and delivering to HEASARC

Example Spectrum Preview



New Autoscreening Tool

- Task ‘niautoscreen’ checks data for known problematic conditions
  - Detectors that have high noise
  - High under/overshoots
  - ”Shredded GTI” (i.e. lost data for bright sources)
  - “Round Robbin” (i.e. MPU cycling detectors off during high count rate conditions)
- Automatically deselects such conditions
  - Criteria are user selectable
- Automatically reflected in FPM Selection data
  - ARF / RMF automatically calculated for correct number of “on” detectors
  - Background tools now also adjust for number of on detectors

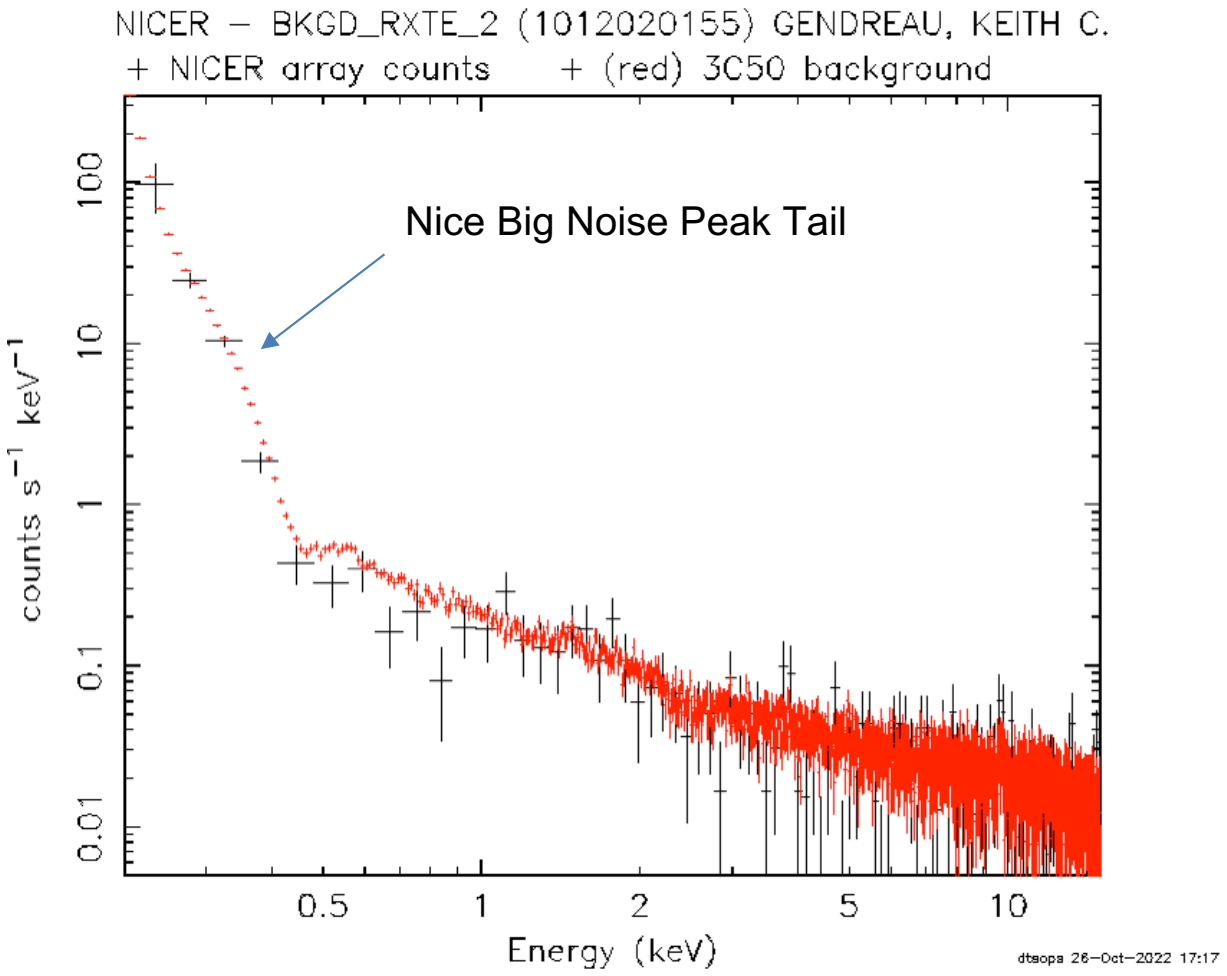
Software Release Roadmap

- Next NICERDAS Release
  - Either early April or late May
  - May need to be coordinated with other missions such as IXPE
- Not a major feature update, but significant improvements
  - Graphical report (HTML) indicating basic info about observation
  - SCORPEON background subtraction for light curves
  - Handling “noise ringers”

Noise Ringers

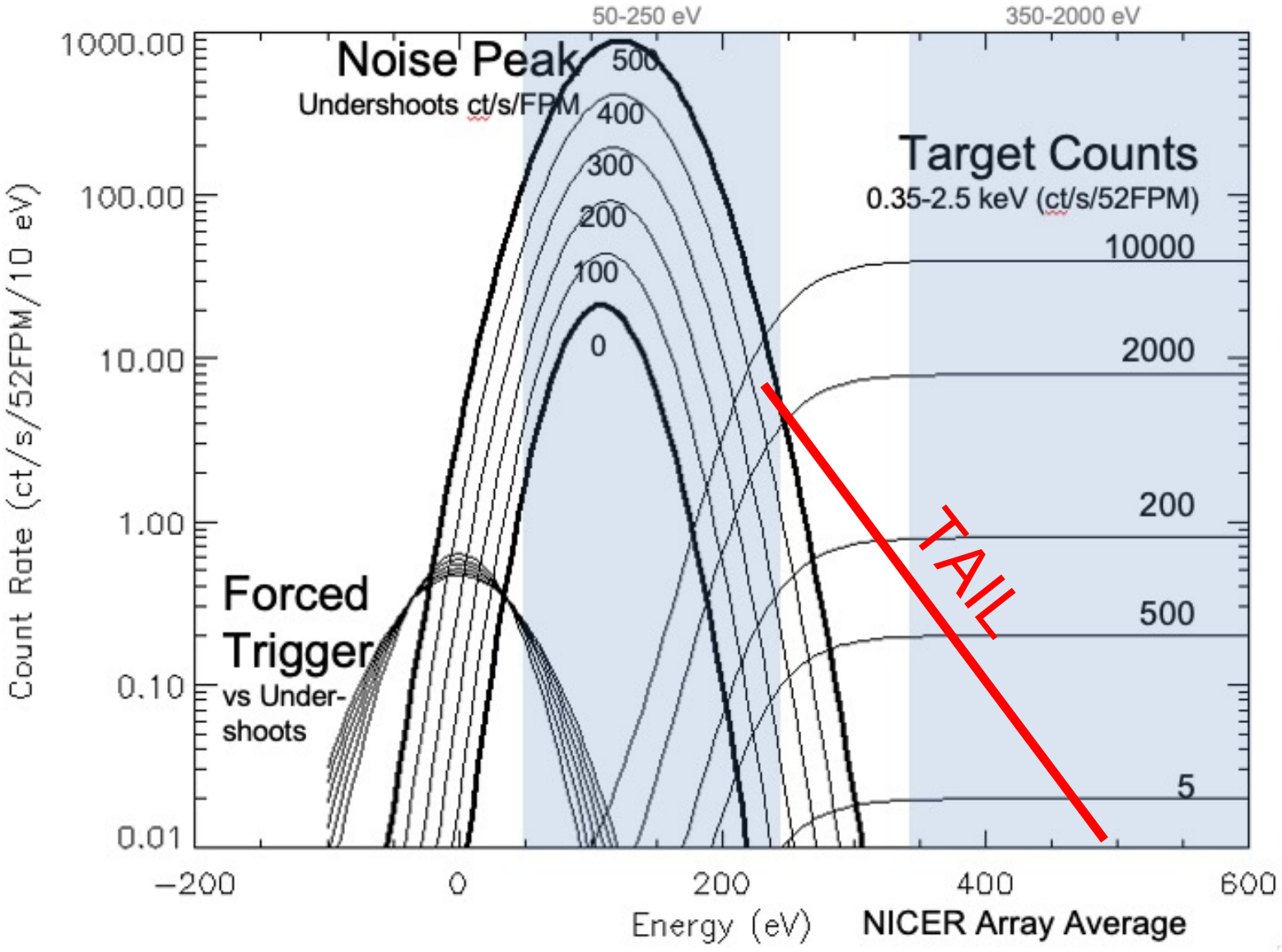
- NICER team has become newly aware of a phenomenon that can create low energy noise
- The phenomenon is now understood at a basic level (related to time since undershoot)
  - Occurs at high undershoots
  - Noise peak tail extending to 0.5 keV
  - Next software release can remove almost all of it

Sample Observation

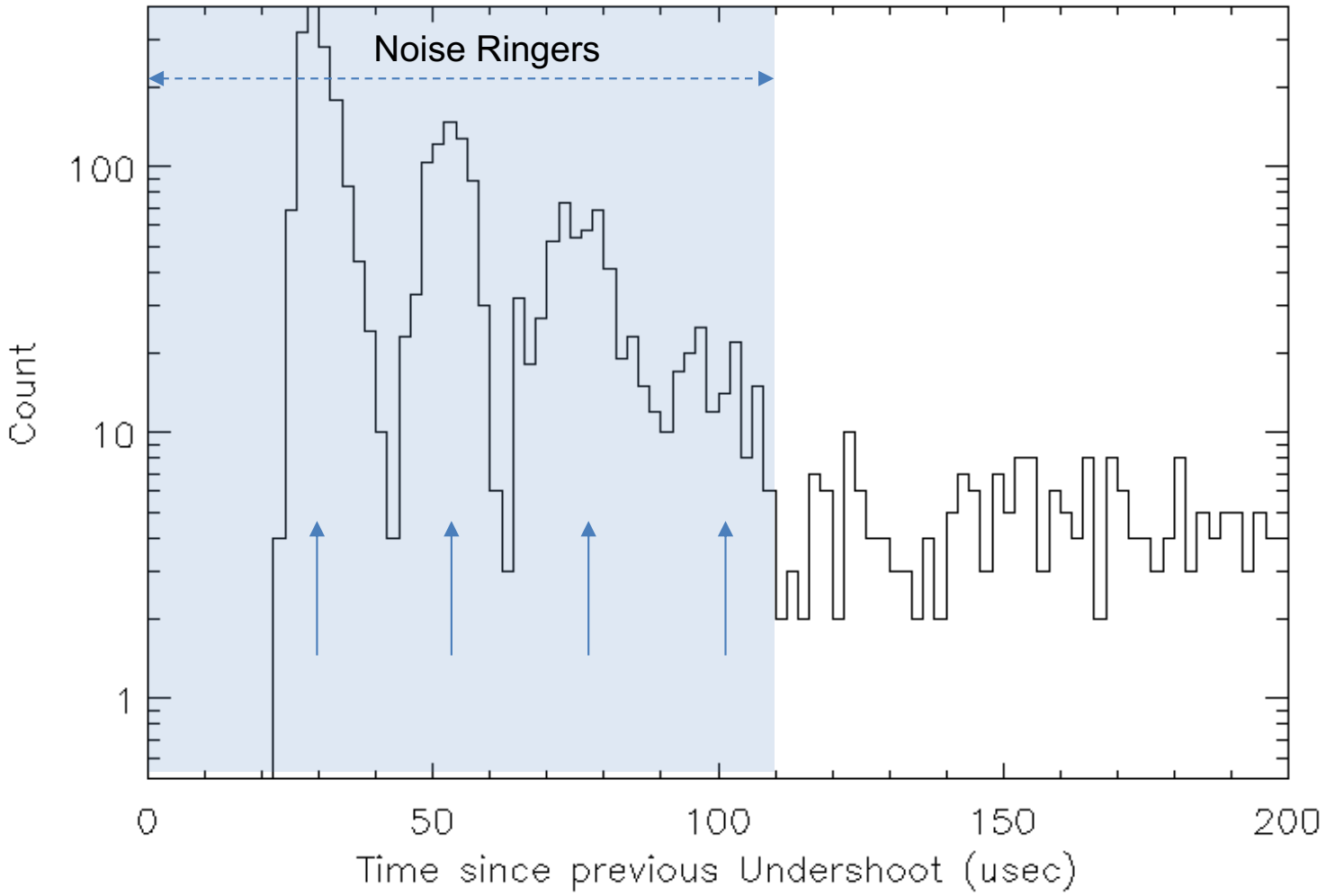


- Background data
- Mean undershoots ~310 ct/s, one detector ~1200 ct/s

Noise Peak versus Tail



Distribution of Times Since Undershoot

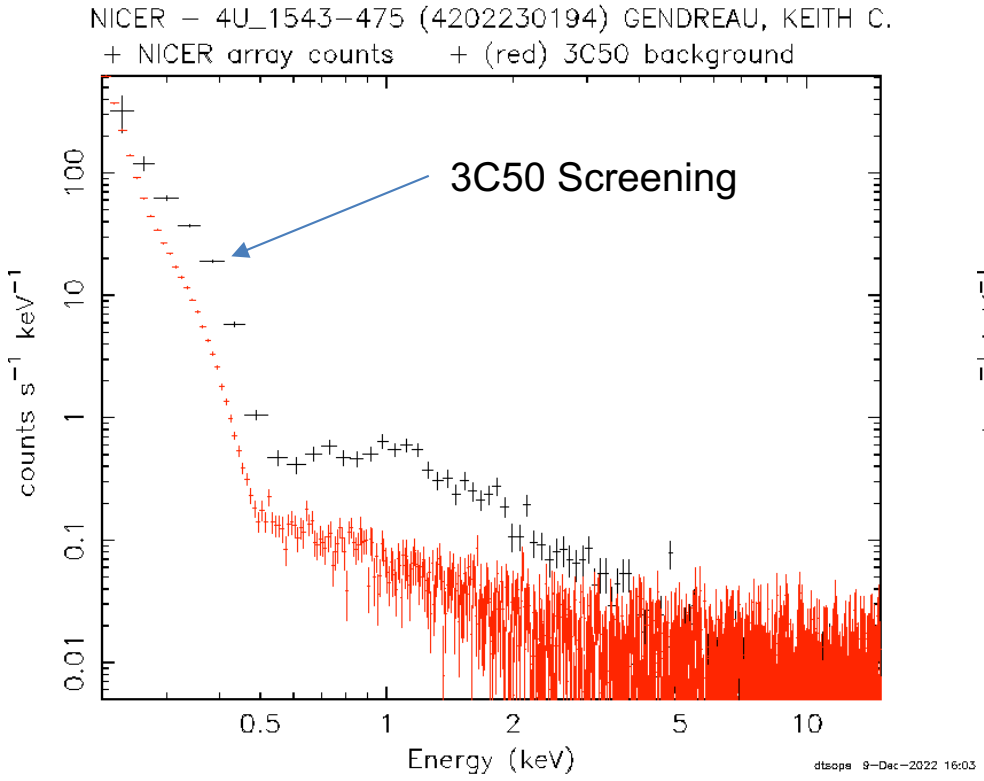


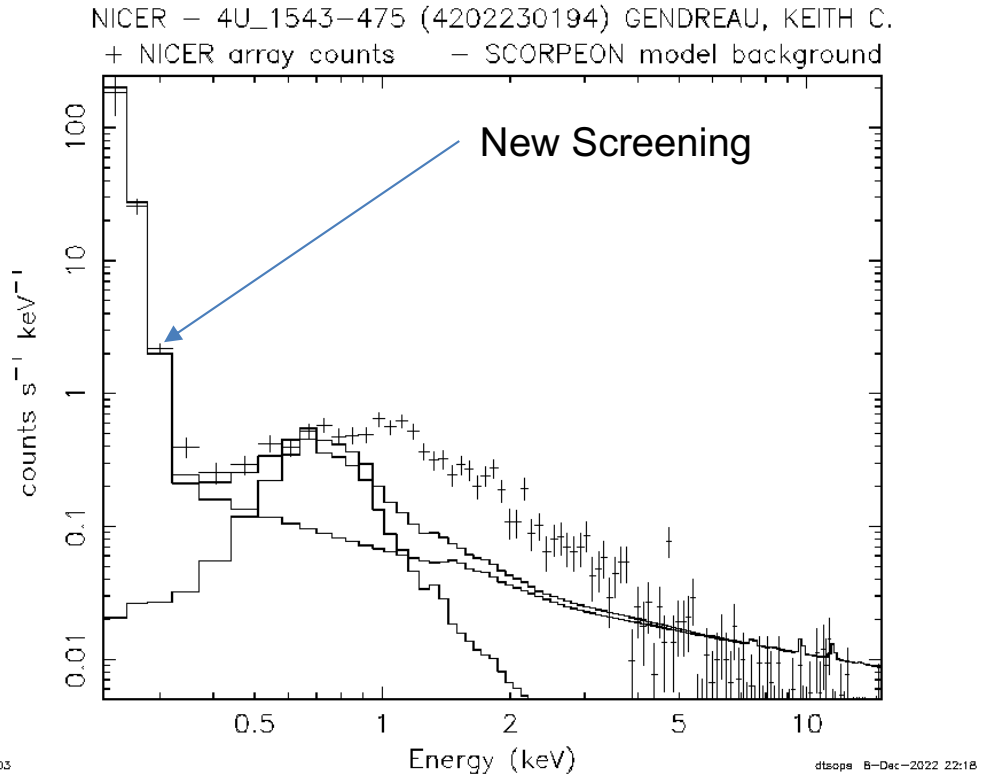
- Peaks at 30, 52, 78, 105 (~26 usec spacing)
- Detector ringing after an undershoot?
- 0-110 usec = “Noise Ringers”

Noise Ringers – Plan Forward

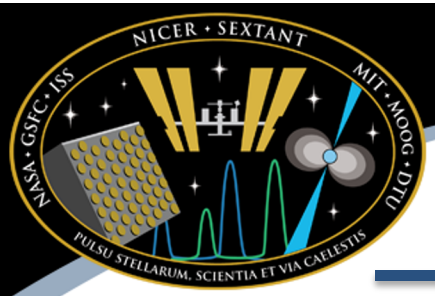
- Next release will have an event flag (“near undershoot” i.e. within 110 usec)
- Default screening will remove
  - Events near undershoot IF
  - Undershoot rate > 100 ct/s/FPM

Example: 4U 1543-473



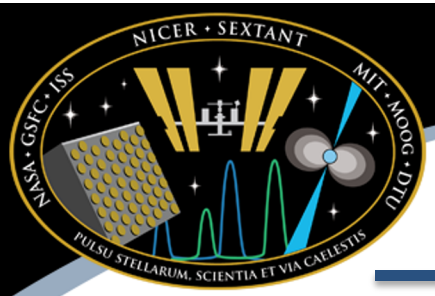


- Example: Using this filter removes all tail events, leaving pure gaussian noise peak



Noise Ringers – Until Then

- Before the next release, the best advice is
  - Exclude data where undershoots > 100 ("underonly_range=0-100")



NICER Documentation

- NICER now has 39 analysis threads
  - Almost all updated since previous release
  - Some obsoleted as needed
  - Highlights
    - NICER calibration recommendations updated
    - New spectral analysis & light curve analysis threads
    - Reference information and tips for background modeling, including SCORPEON
- In addition, every calibration release is documented
- Roadmap
  - More SCORPEON documentation
  - More end-to-end walkthroughs
  - “Combining observations” is a popular request