IACHEC 2020

Observer Symposium
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NICER
Neutron star Interior Composition ExploreR

NICER Best Practices and Calibration

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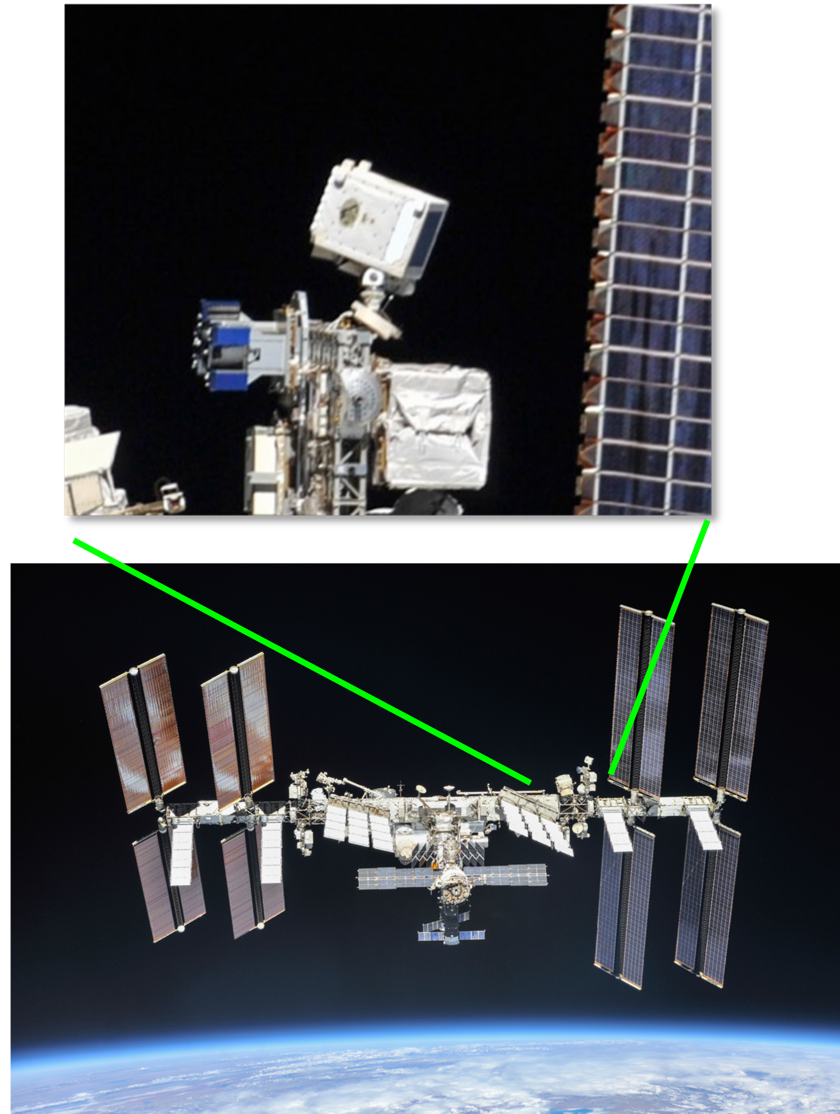
Overview

- Summary of NICER's capabilities
- Recommendations for NICER observers
  - Standard processing recommendations
- Calibration status
  - Common features in NICER spectra
  - How to retrieve response files
  - Background modeling
  - Concerns for bright and faint targets
- "Where's My Data?" – common ways the standard screening may fail and how to remedy
- Dealing with common concerns
  - Disabled detectors
  - Combining multiple observations
- Focus for the future

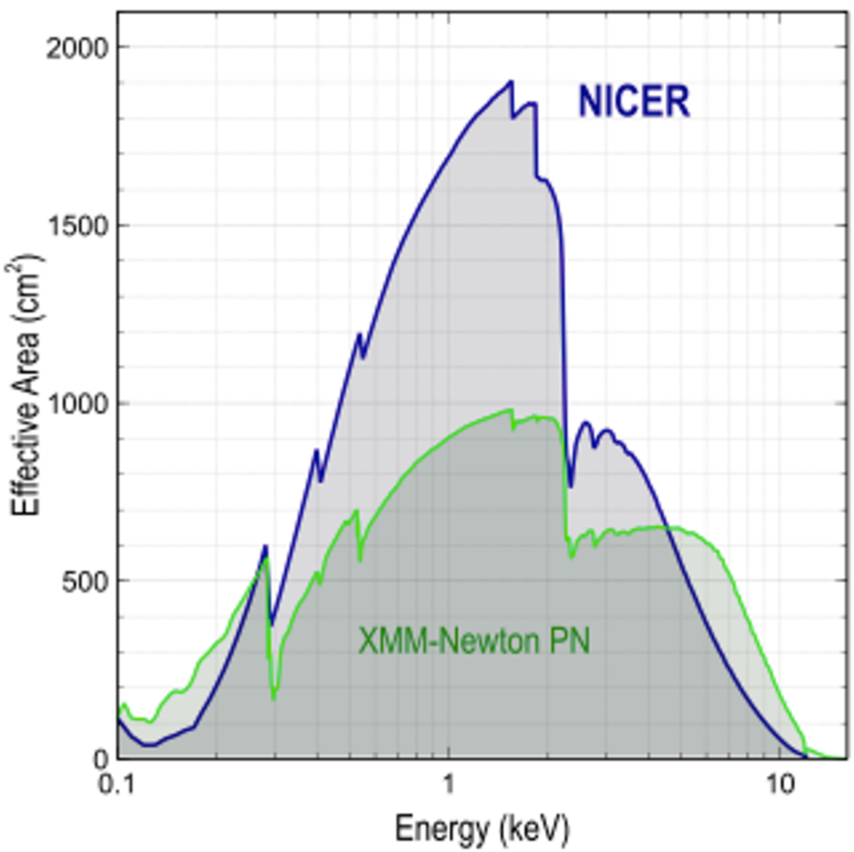
What is NICER?

- PI: Keith Gendreau, NASA GSFC
- Science: Understanding ultra-dense matter via soft X-ray timing spectroscopy of neutron stars
- Platform: International Space Station ExPRESS Logistics Carrier external attached payload, with active pointing
- Launch: June 2017
- Instrument: X-ray (0.2–12 keV) “concentrator” optics and silicon-drift detectors; GPS position & absolute time tagging
- Status:
  - Public archive opened March 2018
  - Guest Observer Cycle 3 proposal submissions just closed
  - Extended under NASA’s Senior Review of ongoing Astrophysics missions



NICER's Unique Capabilities

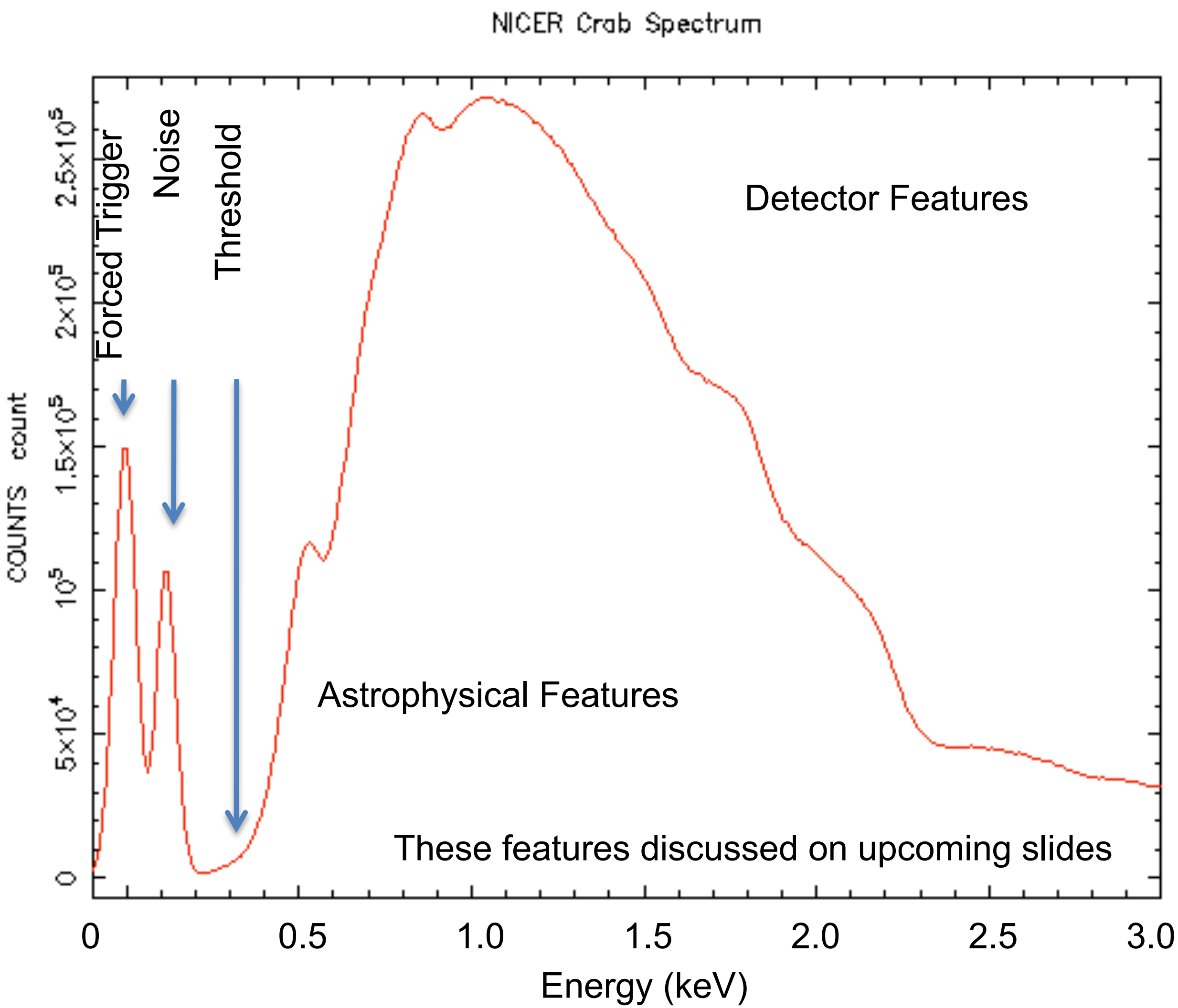
- Spectral band: 0.2–12 keV
  - 52 operating single-pixel silicon detectors
- Energy resolution: < 150 eV @ 6 keV
  - Comparable to X-ray CCDs
- Timing resolution:
  - 100 nsec RMS absolute
- Non-imaging field of view
  - 6 arcmin diam. (half-max)
- High throughput (3.5 Crabs with no pileup)
- SUMMARY: large area, fast timing, and excellent spectral performance, but single pixel



NICER High Level Recommendations

- Use the ‘nicerl2’ processing tool for all data
  - Applies calibration and standard processing
- Consult on-line NICER documentation for analysis issues
  - Software guide overview
  - Analysis “threads” - procedures for common tasks
  - Analysis tips for specific known problems or issues you may encounter
  - Keep your CALDB up to date, and understand calibration limitations by reading calibration documents
- Send questions to the NICER helpdesk: https://heasarc.gsfc.nasa.gov/cgi-bin/Feedback

"Typical" NICER Spectrum: Crab



Data Processing Recommendations

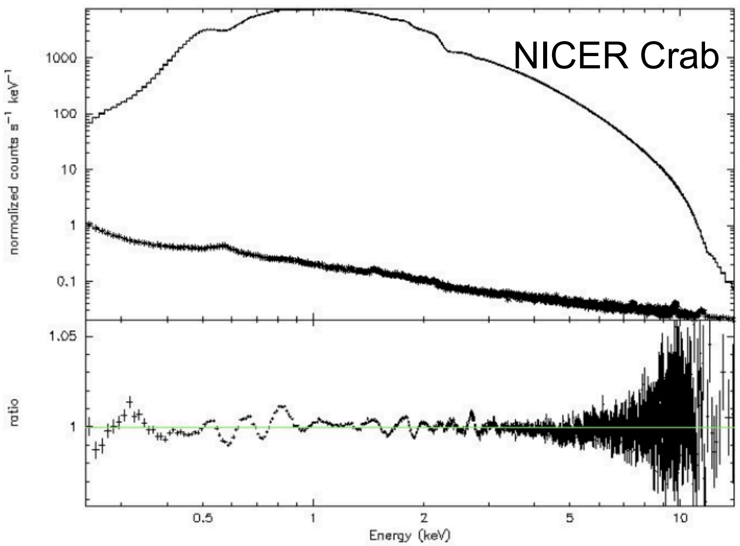
- Use the 'nicerl2' processing task to process all NICER observations (part of standard HEASoft)
  - nicerl2 applies standard calibrations and screenings
    - Calibration: energy scale, timing offsets
    - Screenings: pointing, optical light, high background
  - Use nicerl2 even if you freshly download data from the archive
    - When new calibration becomes available, the NICER pipeline does not always reprocess old data, or apply it immediately to new data, so you need to do it yourself
  - How to run nicerl2:

    ```
    nicerl2 indir=./1234567890 clobber=YES
    ```

    (more details & recommendations here)

NICER Calibration Status

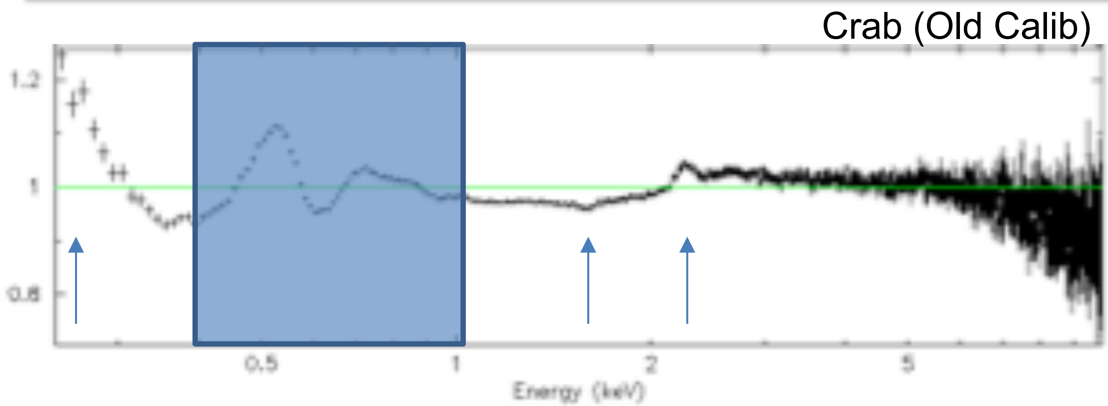
- NICER energy scale
  - After calibrations, all event files have “PI” column with common energy scale (“Pulse Invariant”)
    - **1 PI = 10 eV** (e.g. PI = 150 means E = 1.50 keV)
    - Estimated error ~5 eV (0-10 keV)
- NICER response
  - NICER calibrated against Crab nebula as a “smooth” continuum
  - Systematic errors <1% (0.4-10 keV)
  - Total effective area and slope comparable to Madsen et al. 2017 NuSTAR



NICER Response Access

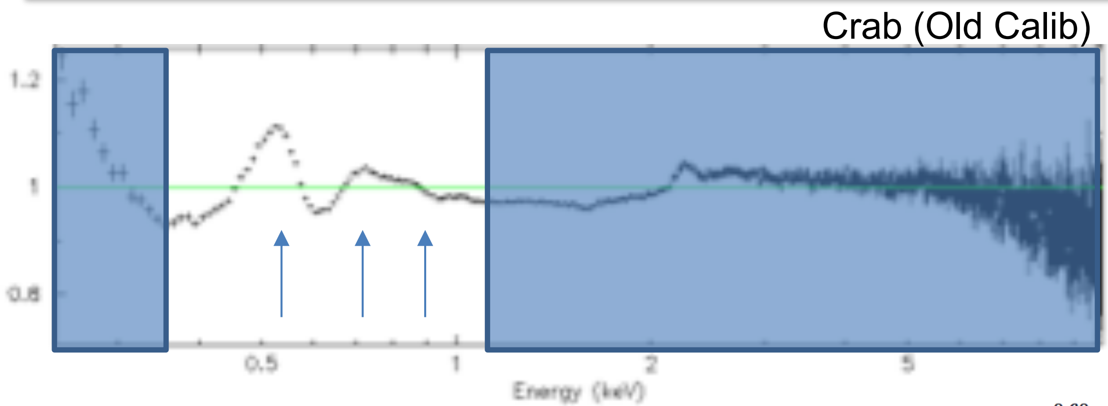
- Currently NICER responses are available as a separate download outside of CALDB
- A single ARF and RMF for each module, and simple tools to combine them for your observation
- Download information is here: https://heasarc.gsfc.nasa.gov/docs/nicer/analysis_threads/arf-rmf/
- In work: a response calculator which adjusts to conditions of a particular observation
  - Offset target (ARF)
  - Optical loading (RMF)

Detector Features to Watch Out For

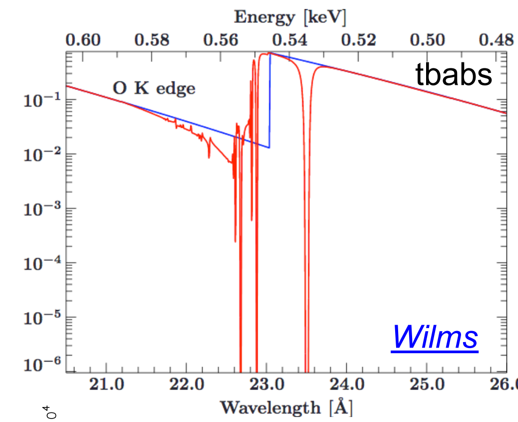


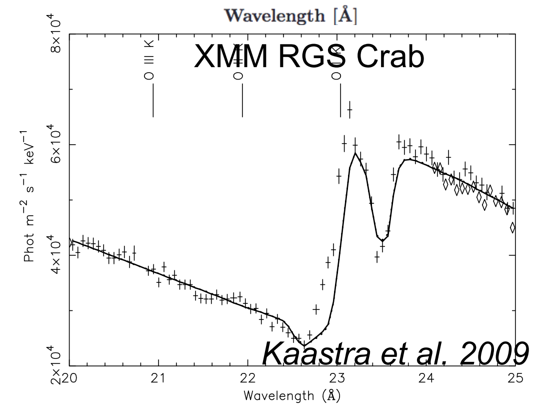
- ~2.2 keV – Gold M edge from XRC reflector gold coating (actually a complex from 2.1 – 4.5 keV)
- 1.84 keV – Silicon K edge (window & bulk detector)
- 1.56 keV – Aluminum K edge/fluorescence (detector window)
- ~0.3 keV – Trigger efficiency cut-off (varies by detector)
- ~0.15 keV – Noise peak (varies by detector & lighting)
- At high optical light levels response is broadened but this is not yet modeled (will be in RMF calculator - in work)
  - Noise peak may intrude into spectrum at low energies
  - Sharp lines may be degraded

Astrophysical Features to Watch Out For

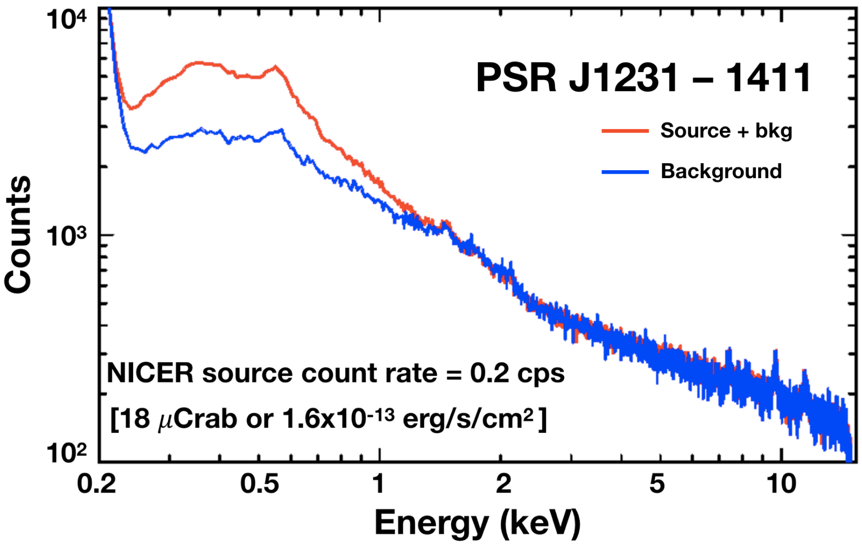


- The interstellar medium is often modeled with neutral N_H models such as wabs, tbabs (Wilms et al.), etc.
- These models are general approximations to reality, especially with all parameters left at solar abundance
- Most common features:
  - Oxygen K edge (0.56 keV)
  - Iron L edge (0.71 keV)
  - Neon K edge (0.87 keV)
- If you see residuals in this energy range, consider using “tbfeo” or “tbvarabs” to allow abundances to vary; check literature for reported abundances
- Even so, actual edge profiles may not match “perfect” profiles tabulated in tbabs model (due to ionization, molecular compounds, or dust composition of ISM); see Crab to right
- Dust scattering halos – see bright target slide





NICER Background Estimation

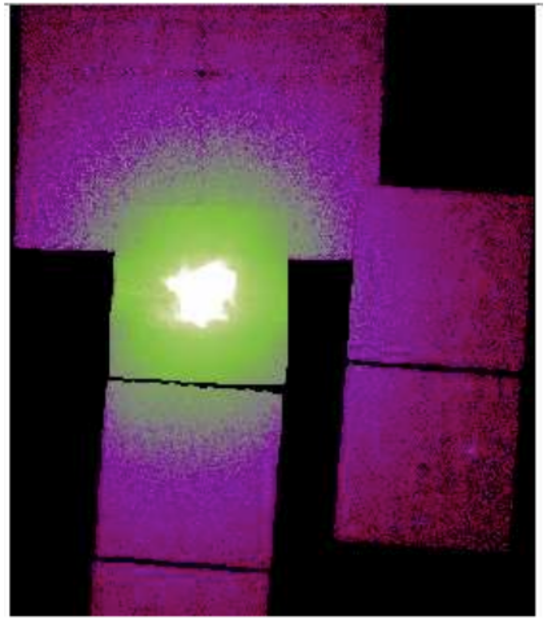


- NICER consists of **single-pixel detectors**
  - Background must be modeled
- Background models available from Background Estimator Tools page
- **"Space Weather" model** is based upon local space weather environment (nicer_bkg_estimator; Gendreau & Corcoran)
  - Scientist supplies filter file (.mkf) and spectrum, tool produces background spectrum and modified .mkf file with background rate estimates in various bands
- **"3C50" model** (nibackgen3C50; Remillard & Loewenstein; submitted for publication 2020)
  - Scientist supplies observation directory, tool produces source and background spectrum
- Both tools are based on array-averaged backgrounds (3C50 model will scale to actual number of detectors enabled)
  - Both tools may also require re-running nicerl2 with special settings, see their README documentation

NICER Concerns: Bright Targets

- **Deadtime correction** affects all observations, but typically a few percent
  - Team is working on documentation and tools for deadtime corrections
- **Pile-up** is a concern only for the brightest targets (>>3.5 Crab); this is a difficult issue to model
- **Dust scattering halos** have significant effects
  - Energy dependent
  - Aperture size dependent
    - complicates comparing observatories with different apertures (NICER 360", RXTE 1°, CCD imagers ~few arcsec)
  - Halo is time dependent if source varies
  - 'xscat' model in XSPEC recently updated by Randall Smith for larger radius apertures such as NICER. Use radius=180"

Crab Dust Halo (Chandra ACIS)

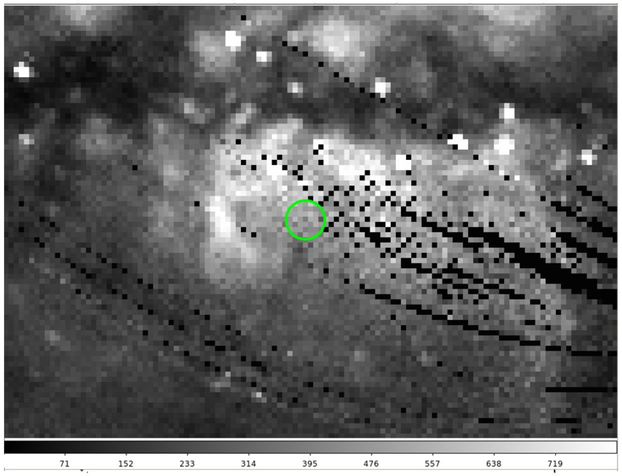


Seward et al. 2005

NICER Concerns: Faint Targets

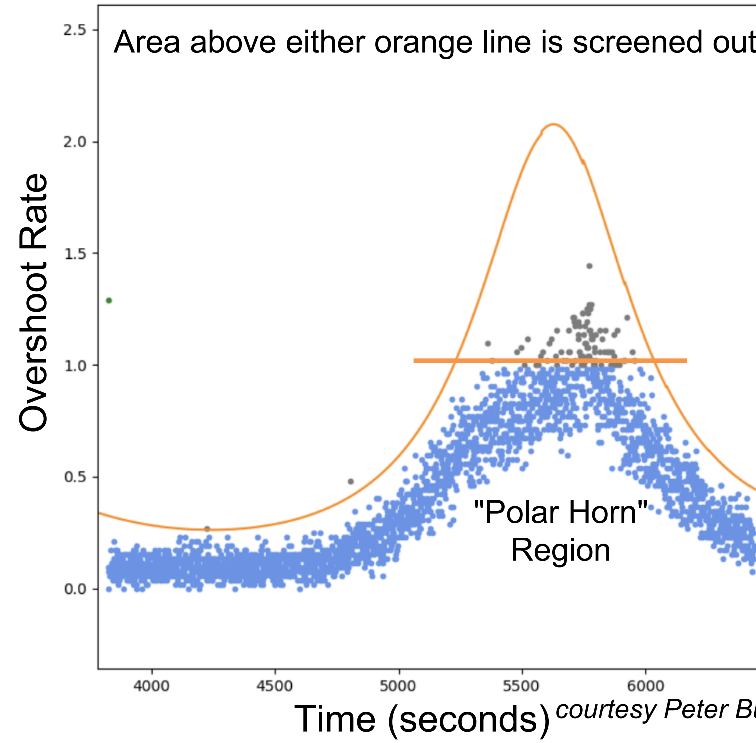
- The primary concern for faint targets is proper background subtraction
  - May be worth trying both available models
- Some detectors are known to be noisier and may be worth excluding: “14” and “34”
- Working near the galactic plane, beware of additional diffuse emission not in the background model (example of RX J1856)

ROSAT All-Sky Survey
RX J1856 Region



Where's My Data? Overshoots

- Particle background likely correlated with "overshoots"
  - FPM_OVERONLY_COUNT in filter file
- The standard screening excludes data with "high" overshoots, in an orbit dependent way (see orange line in figure)
- This can exclude too much data, especially near "polar horn" regions of high geomagnetic activity
  - Shows up as data drop-outs at certain parts of orbit
- Some evidence that solar modulation of cosmic rays has changed since we designed this screening criterion



courtesy Peter Bult

Loosen this criterion with nicerl2 parameters:

`overonly_range=*-2`

can also adjust norm of overonly_expr

Where's My Data? Undershoots

- NICER's detectors are negatively impacted by optical light
  - Optical light measured by "undershoots" (FPM_UNDERONLY_COUNT in filter file)
- Standard screening requires undershoot rate < 200 ct/s
- If your observation is near the Sun or has persistently high undershoots, most or all data may be excluded
  - Filter file SUN_ANGLE < 60 or FPM_UNDERONLY_COUNT > 200 would indicate this
- Relax this screening criterion with nicerl2 parameter

  ```
  underonly_range=0-600
  ```
- However, beware that high optical light is not accounted for in calibration and may also cause enhanced low energy noise or response degradation

Where's My Data? Too Few Detectors

- The NICER standard screening requires a minimum number of detectors
  - For a time, this minimum was 30, now 7
- For very bright targets, NICER ops have enabled fewer than 30 detectors to reduce telemetry burden
  - With older screening criterion of 30, no data would survive
- For almost all observations the new default of 7 will keep good data. However, you can further relax this constraint with nicerl2 parameter

```
min_fpm=1
```

Common Issues: Disabled Detectors

- While NICER has 52 operational detectors not all detectors are enabled for every observation. This is occurring more often now compared to post-launch
  - Occasionally, a detector auto-disables itself
  - NICER operators may disable detectors for high-rate targets
  - Detectors may be disabled for maintenance activities (“annealing”)
- How to check using your filter file (.mkf file)
  - Number of detectors:

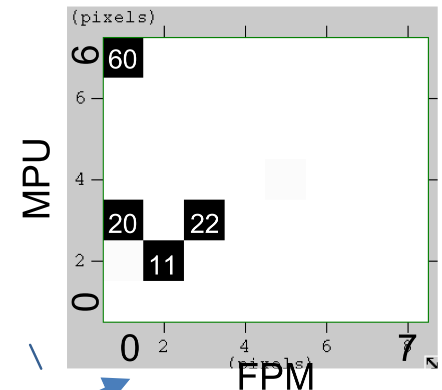
    ```
    ftstat niNNNNNNNNNN.mkf
    ```

    (and check median of NUM_FPM_ON column)

  - Which detectors disabled:

    ```
    fsumrows infile=niNNNNNNNNNN.mkf'[1][col F=(FPM_ON?1:0)]' \
      outfile=fpm_on.fits cols=F rows=- operation=sum
    ```

    (and use ‘fv’ to view resulting fpm_on.fits table image)
    DET_ID = (MPU x 10) + FPM



  - DET_ID’s 11, 20, 22 and 60 are always disabled, as shown in figure
- When making ARFs and RMFs for spectra, be sure to follow instructions on NICER Response thread to include only enabled detectors

Common Issues: Combining Data

- If you wish to combine multiple observational segments, you have several choices
- Option 1: Treat each segment separately. Easiest method up front, but may get bogged down when you have large number of data sets.
  - Extract spectrum from each segment
  - Retrieve background individually
  - Load into XSPEC separately, fit jointly
- Option 2: Combine data sets into merged products (events, mkf, etc.). More difficult up front, but allows you to extract single spectrum.
  - Combine event files (ufa = unfiltered event)
    ```
    ls */xti/event_cl/ni*_0mpu7_ufa.evt > ufalist.lis
    nimpumerge infiles=@ufalist.lis outfile=merged_ufa.evt mpulist=7
    ```
  - Combine filter files
    ```
    ls */auxil/ni*.mkf > filter.lis
    ftmerge @filter.lis merged.mkf
    ```
  - Run nimaketime for desired screening
    ```
    nimaketime merged.mkf merged.gti
    ```
  - Run nicerclean on ufa file to make clean event list with screening
    ```
    nicerclean infile=merged_ufa.evt outfile=merged_cl.evt gtifile=merged.gti
    ```
  - Extract spectrum from merged_cl.evt file as usual
- NICER team is working on making this process more streamlined

Focus of Future Efforts

- NICER continues to improve its calibration, software, and documentation for the community
- Calibration
  - Responses for off-axis targets
  - Responses for actual conditions including varying optical light loading
  - Background modeling
- Software
  - Improved handling of disabled detectors
  - Improved diagnostics for observers to catch potentially problematic conditions
  - Improved methods to combine data
- Documentation
  - NICER team has been posting new analysis "threads" to its website that document specific topics

BACKUP SLIDES

NICER Observations

- NICER's observations are a mix of legacy survey (PI-led) and Guest Observer (competitively awarded)
  - GO proposals due annually, Cycle 3 proposal deadline just past
  - Also joint award time program with NuSTAR
  - Funding available for US Guest Observer PIs
  - Pre-planned, Targets of Opportunity, monitoring and time-constrained observations allowed
  - Flexible coordination with many space and ground facilities
- NICER operations, pipeline processing and calibration performed by instrument team located at NASA Goddard
  - Observing timeline (predicted and past) available
  - NICER co-exists on International Space Station, which can constrain NICER's observations (significant events published)
- All data available from NASA's HEASARC archive
  - If exclusive use awarded, Guest Observer data encrypted for up to six months

NICER Observational Data

- Data downloadable from NASA's HEASARC archive
  - Searchable using Browse or Xamin interfaces
  - Guest observers receive notification when data are ready
- A scientific observation is identified by its observational identifier (10-digit number)

  `PPPPTTVVss`

  - `PPPP` - Proposal number
  - `TT` - Proposed target number (e.g., proposer asked for two neutron star targets)
  - `VV` - Proposed visit number (e.g., proposer asked for five visits of 10 ks each)
  - `ss` - Segment number (observations crossing calendar day boundaries are split into multiple segments)
  - A day-long segment may have multiple "snapshots" or Good Time Intervals, since ISS is in a low-earth orbit, typically 1-2 ks each