NICER Best Practices and Calibration
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on behalf of NICER Team
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

Detector Features

Astrophysical Features

These features discussed on upcoming slides
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
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
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 (.mkk) and spectrum, tool produces background spectrum and modified .mkk 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

![PSR J1231 – 1411](image)

NICER source count rate = 0.2 cps
[18 \mu Crab or 1.6\times10^{-13} \text{ erg/s/cm}^2 ]
• **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”
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)
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

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:
    \[ \text{ftstat niNNNNNNNNNN.mkf} \]
    (and check median of NUM_FPM_ON column)

  — Which detectors disabled:
    \[ \text{fsumrows infilesniNNNNNNNNNN.mkf'[1][col F=(FPM_ON?1:0)]' \text{outfile=fpm_on.fits cols=F rows=- operation=sum}} \]
    (and use ‘fv’ to view resulting fpm_on.fits table image)
    \[ \text{DET_ID = (MPU x 10) + FPM} \]
  — 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
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)
  - 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