
NICER
Neutron star Interior Composition ExploreR
NICERDAS Calibration Guide
2018-08-14
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Install Calibration Database (CALDB)

- HEASARC's Calibration Database is used to store calibration files for NICER use
- Please follow the standard instructions for installing NICER calibration files
- Test with the following command:

```
quzcif NICER XTI - - ALIGNMENT now now -
```

The expected output is similar to this:

```
/home/dtsops/caldb/local-
caldb/data/nicer/xti/bcf/pntmis/nixtipntmis20170601v001.te
ldef   0
```

NICER Spectral Calibration

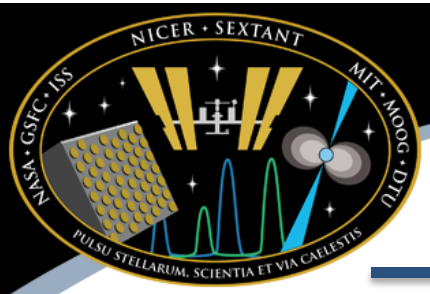
- NICER energy range
  - 0.25 – 10 keV
  - However, for data taken during orbit day, the low energy noise peak may intrude into the low energy band
    - Scientists may need to exclude data in 0.25-0.5 keV range on a case-by-case basis
- NICER energy scale (gain scale)
  - See following charts on gain performance
  - Generally speaking, energy assignment is within 5-10 eV, except in the 4-7 keV band and < 1 keV
- Response matrix and effective area
  - Residuals of ~15% remain
  - Some reproducible systematic features remain
    - See following charts on response

NICER Timing Calibration

- NICER absolute timing error
  - After Level 2 calibration, timing error better than 100 ns
  - Before calibration, an understood 1 second absolute timing offset exists
  - Archived data has a mix of calibration levels applied
    - **For reliable absolute timing results, user must apply most recent NICER software "nicerl2" and Calibration Database**
- Deadtime
  - Dead-time is recorded on a per-event basis in the "ufa" event file
    - Each MPU is parallel
  - Dead-time is also recorded in the .mkf file as the MPU_DEADTIME column
  - All events, including resets, overshoots and forced triggers, create deadtime
  - The "cleaned" event file (niNNNNNNNNNN_0mpu7_cl.evt) excludes
    - <0.25 keV pulse heights, 5 forced triggers/second/FPM, undershoot resets (dark current), overshoot resets (typically charged particles)

NICER Timing Calibration (page 2)

- Fragmented GTIs
  - For very bright targets, users must be aware of data processing artifacts
  - At high data rates, telemetry saturation will limit data throughput
  - The practical result of this is that event data can be fragmented into very short (millisecond) duration data segments
  - The NICER operations team attempts to avoid this condition but it is not always possible to predict target intensity or respond quickly to intensity changes
  - Fragmented event data is properly recorded in event meta data as many small GTIs
  - **Users creating power spectra must properly deal with the window function created by the good time intervals:** this is true for both unfragmented as well as heavily fragmented data

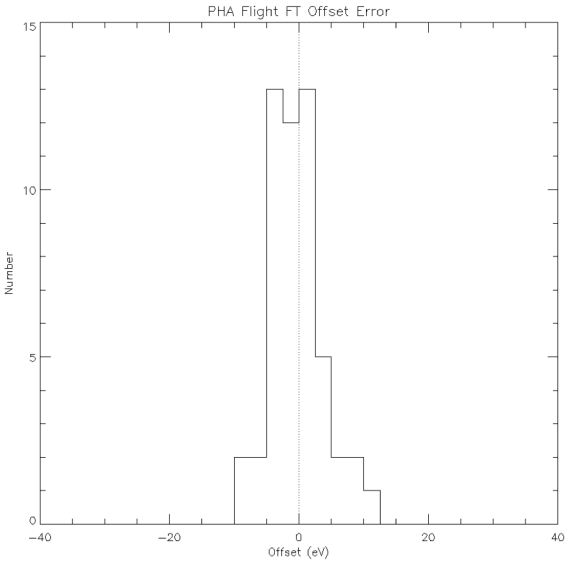


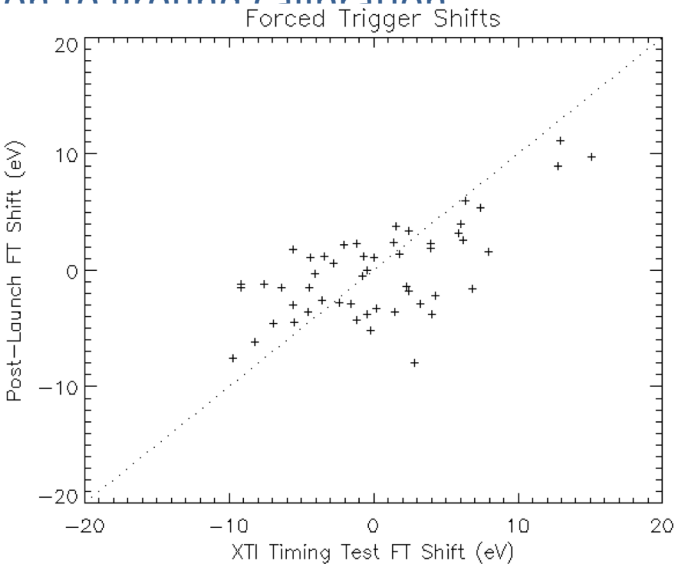
Detailed Caveats

- The following charts have detailed caveats on various NICER calibration topics

Major Improvements: Gain Calibration

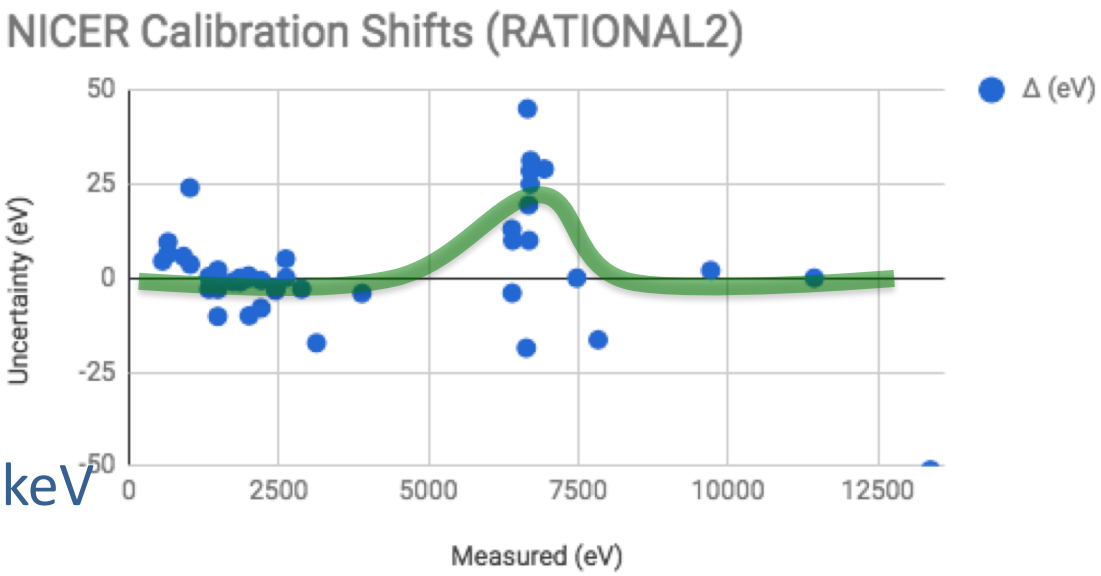
- NICER gain calibration is as good as time will allow
  - Per-detector offsets now ~5 eV or less
  - Temperature effects accounted for using method of MIT
  - Improved PI_FAST calibration
  - Energy range increased to 18 keV
- Major challenge discovered after Jan AAS meeting: the energy calibration
  - Evidence for shifts during ground testing and post-launch
  - Forced the team to consider a phenomenological correction to ground calibration
  - This calibration model is known as “RATIONAL2”
- Detailed investigation of ballistic deficit effect by MIT team for
  - <1.5 eV in 0-6 keV band (slow channel)
- Software development, calibration data file development and at-large team members



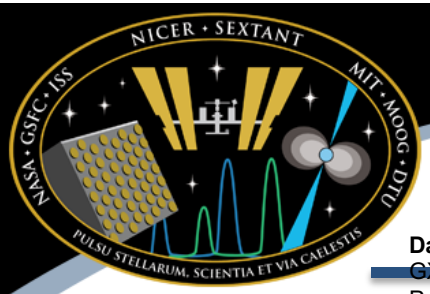


Major Improvements: Gain Performance 1

Residual Energy Shifts



- Generally performance is excellent across multiple temperature and lighting conditions
- Team tested against many astrophysical targets of different types
  - Lines 0.6-2.7, 6.4-7.5 keV keV
- Also used SAA data
  - Gold/Nickel fluorescence at 1.4,1.8, 7.5, 8.3, 9.5, 11.5, 13.3 keV
- Evidence of deviation in 5-7 keV range of about +20-30 eV
  - Difficult to adjust for without disturbing energy scale at other energies
  - **Analysts should be very careful about claiming red/blue shifts of 10s of eV in this range**

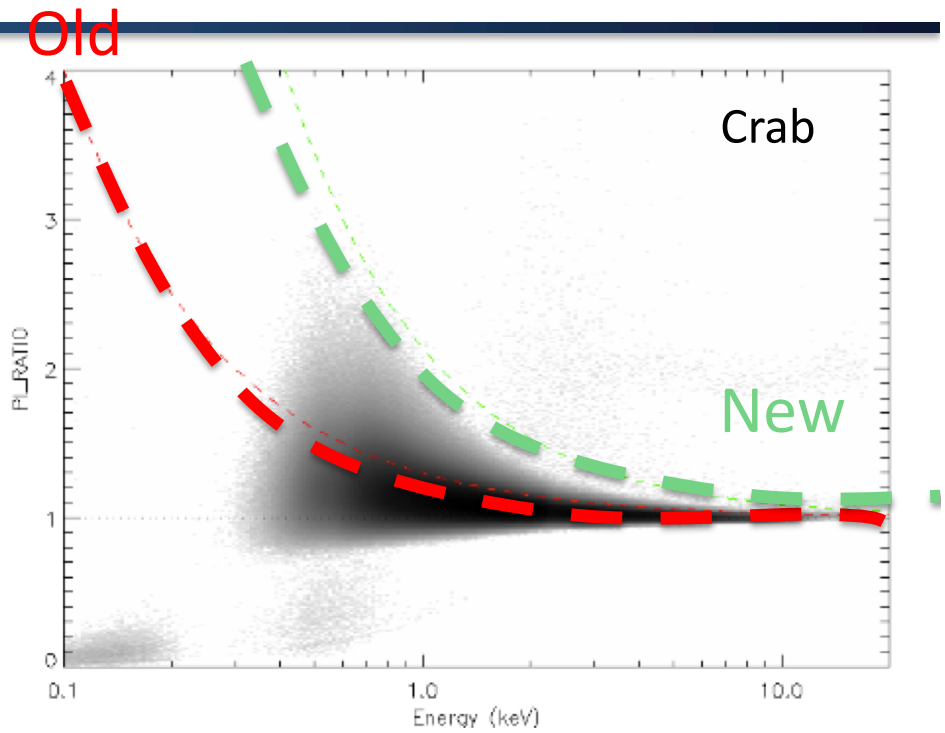


Major Improvements: Gain Performance 2

Dataset	Feature	Meas	Expect	Δ (eV)	σ (eV)	Comments
GX301-2	FeKa	6394.97	6399	-4	5.0	MikeL Analysis, +/- 5 eV
Perseus	Mg_XII	1490	1488	2	3.5	MikeL Analysis, +/- 3.5 eV
Perseus	Si_XIV	2004	2004	0	3.5	MikeL Analysis, +/- 3.5 eV
Perseus	S_XVI	2625	2620	5	5.1	MikeL Analysis, +/- 5.1 eV
Perseus	Fe_wxyz	6693	6673	19	3.3	MikeL Analysis, +/- 3.3 eV
Perseus	Ni	7818	7835	-16	15.0	MikeL Analysis, +/- 15 eV
WR 140	Fe XXV	6740	6709	31		Mike C analysis; corrected for redshift (-393 km/s) derived from HEG spectrum
Eta Car	Fe XXV	6730	6701	29		Mike C analysis; corrected for redshift (-66.7 km/s) derived from HEG spectrum
Cas_A	Mg_Xi	1346	1346	0	1.0	MikeL Analysis, +/- 1 eV; NOTE Cas A has redshifts of +/- 1000 km/s ~ 20 eV
Cas_A	Mg_XII	1474	1474	0	3.0	MikeL Analysis +/- 3 eV
Cas_A	Si_XIII	1857	1858	-1	0.2	MikeL Analysis +/- 0.2 eV
Cas_A	Si_XIV	2005	2005	1	1.0	MikeL Analysis +/- 1 eV
Cas_A	S_XIII	2200	2208	-8	1.5	MikeL Analysis +/- 1.5 eV
Cas_A	Si_XV	2448	2452	-3	1.0	MikeL Analysis +/- 1 eV
Cas_A	S_XVI	2626	2626	0	5.0	MikeL Analysis +/- 5 eV
Cas_A	S_XVI	2882	2885	-3	4.0	MikeL Analysis +/- 4 eV
Cas_A	Ar_XVII	3118	3136	-17	2.0	MikeL Analysis +/- 2 eV
Cas_A	Ca_XIX	3888	3892	-4	4.0	MikeL Analysis +/- 4 eV
Cas_A	Fe_XXV	6616	6635	-19	5.5	MikeL Analysis +/- 5.5 eV; actual remnant has ~1000 km/s Dopler ~ 20 eV
HR 1099	Fe XXV	6725	6700	25		Mike C Analysis: assumes real redshift of Fe XXV line = 0 km/s
Coma	Fe_XXV	6691	6681	10	15.0	MikeL Analysis +/- 15 eV
Coma	Fe_XXVI	6965	6936	29	24.0	MikeL Analysis +/- 24 eV
E0102	O_VIIa	570	565	5		MikeL Analysis
E0102	O_VIIb	665	655	10		MikeL Analysis
E0102	Ne_IXa	919	913	6		MikeL Analysis
E0102	Ne_IXb	1033	1029	4		MikeL Analysis
E0102	Mg_XI	1335	1338	-3		MikeL Analysis
N132D	Mg_Xi	1340	1340	0	2.0	MikeL Analysis
N132D	Mg_XII	1475	1485	-10	6.0	MikeL Analysis
N132D	Si_XIII	1860	1860	0	4.0	MikeL Analysis
N132D	Si_XIV	2000	2010	-10	10.0	MikeL Analysis
N132D	S_XIII	2213	2213	-1	15.0	MikeL Analysis
N132D	Si_XV	2449	2452	-3	8.0	MikeL Analysis
Cen X-3	Fe K	6409	6396	13		Mike C analysis - Fe K line energy from fit to heg spectrum tgcat/obs_7511_tgid_4068
Cen X-3	Fe XXV	6701	6656	45		Mike C analysis - Fe XXV line in heg spectrum
Vela X-1	Fe K	6417	6407	10		Mike C - Fe K line energy derived from HEG tgcat obs_1928_tgid_5097
SAA	Al Ka	1483	1486	-3	2.0	CM
SAA	Si Ka	1739	1740	-1	4	CM
SAA	Ni Ka	7478	7478	0	2	CM
SAA	Au La	9715	9713	2	1	CM
SAA	Au Lb	11442	11442	0	2	CM; 60 eV extra broadening
SAA	Au Lg	13330	13381	-51	25	CM; really dodgy
UX Ari	O VIII	660.2	653.8	6.4	20.0	Mike C Analysis ux_ari-rational2.pha; line velocity (+89 km/s) determined from MEG -1 order spectr
GT Mus	Ne X	1046	1022	24.0		Mike C - line velocity uncertain

Major Improvements: Trumpet Cut

- Trumpet cut is designed to exclude background events that interact at outer edges of detectors
  - Relies on “ballistic deficit” effect which primarily shows up in the fast channel
  - PI_RATIO = PI/PI_FAST can discern this effect
  - “Trumpet” shape occurs because of read-out noise in denominator of ratio at low energies
  - Standard trumpet intended to exclude bad data



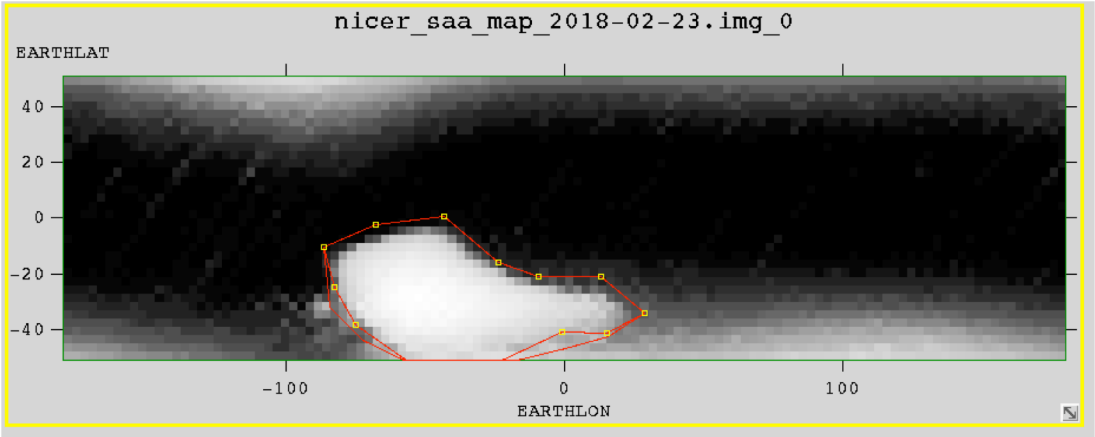
- However, in optical loading conditions (orbit day) additional noise in the PI_FAST channel broadens the trumpet beyond typical expectations
  - See example of Crab above
  - Spectral effect will be to truncate counts at low energies between 600-1100 eV where fast channel threshold is transitioning
- New trumpet definition is “120-1” and accomodates bright optical conditions
- Users will have to reprocess from “ufa” to get this improvement

Major Improvements: Time Calibration

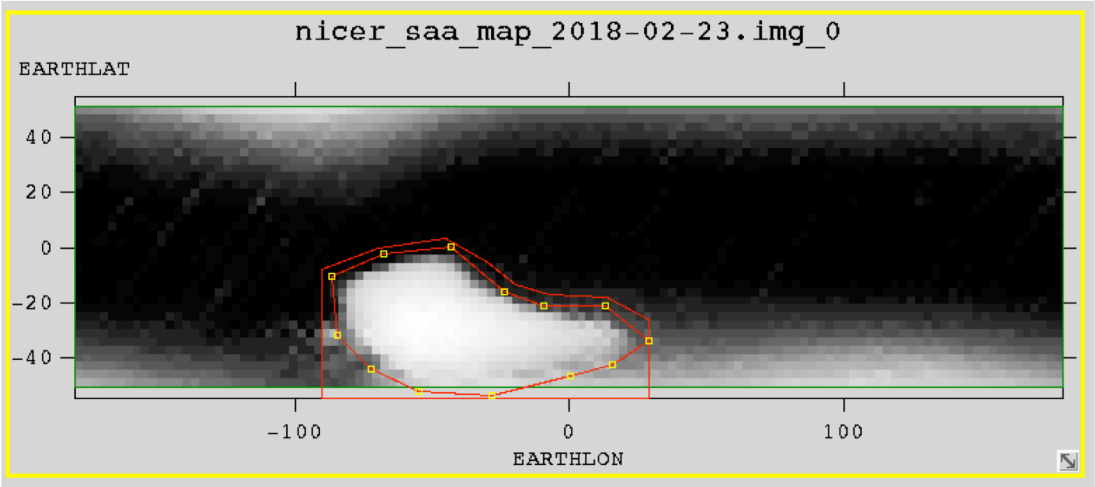
- NICER calibration now includes timestamp correction
  - NICER detector system known to have instrumental delays
    - ~440 nsec – fast channel (fast-only or fast+slow)
    - ~950 nsec – slow channel (slow-only)
  - New task nicertimecal compensates for these delays by adjusting TIME column on per-event basis
- Known absolute timestamp offset of +1 second
  - Now understood as improperly documented behavior of hardware clock system
  - Correction implemented as TIMEZERO keyword for event files, GTIs and filter files
  - Extractor will automatically adjust time values using TIMEZERO when creating light curves
  - Team member custom software will need to honor TIMEZERO
- Team members will need to re-apply calibration to obtain new absolute timestamps

Improvements: SAA Contour

- Standard NICER_SAA contour has been enlarged slightly on the southern edge

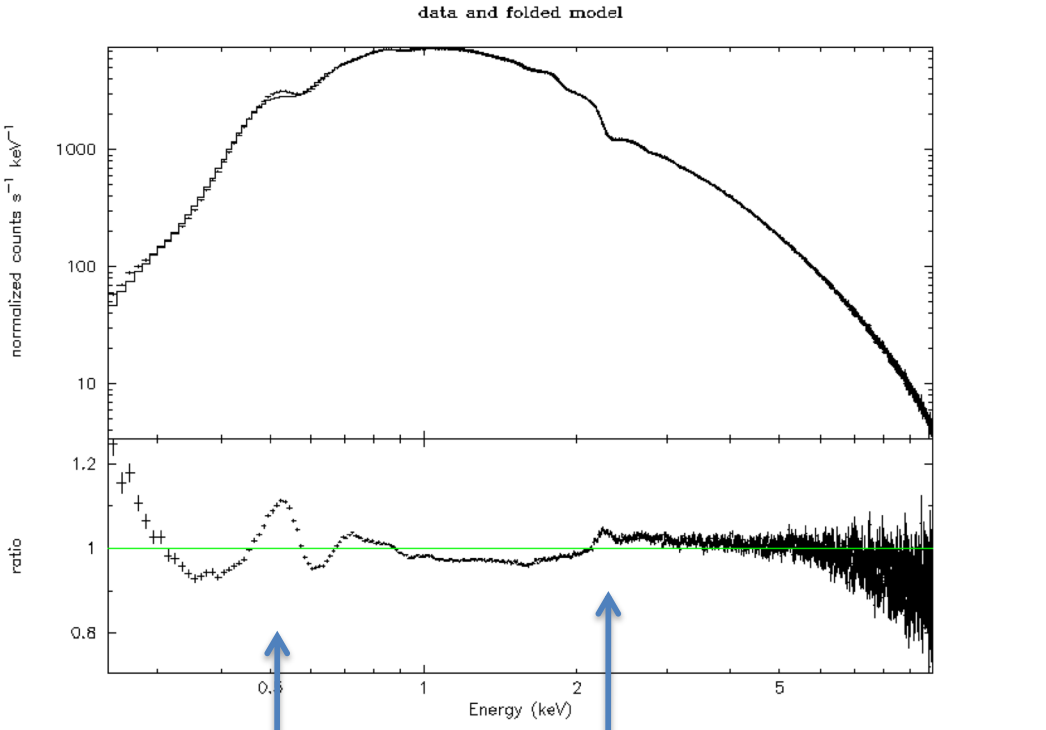


- Also including in CALDB a “fat” SAA for users very sensitive to background



Response Matrix: In Work

- Top priority: revised response matrix for spectral fitting
  - "Version 1.0" of response matrix tested within team shows residuals around 0.4 0.7 keV and > 2 keV
- Work areas
  - Adjust gold density & roughness parameters to account for residuals > 2 keV
  - In the 0.4-0.7 keV band we believe is related to improper gain scale in the 0-1 keV range



Residual "Oxygen"

Gold M-edge feature