
NICER
Neutron star Interior Composition ExploreR
NICER Data Introduction
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Summary

- NICER project delivering first "unvalidated" data sets to team for evaluation and validation
- More than 1600 data sets in the archive delivered
- Contents of the file are described
- Caveats

Important Changes Since Pre-Release Data (1)

- HEASoft version 6.22 has been released. NICER software is included
- NICER calibration data is now part of HEASARC CALDB
- Changes to "Initial Release Data"
  - Naming of datasets no long has target name in directory name
  - The "UFA" event file, nominally unfiltered, now has been lightly filtered for disk space and performance reasons. (Undershoots and overshoots removed)
  - Filter file (auxil/ni*.mkf) has many new columns. See 'fhelp niprefilter' for descriptions. New task 'nimaketime' can be used for standard time screening.
  - Attitude processing is now improved. Both star tracker (ST) and instrument (INST) attitudes are preserved, but ST attitude is now used for processing.
  - Orbit file now includes Single Point Solution GPS solution for rare cases when filtered GEONS solution is not available. This extension is ORB
  - Metadata keywords are populated
  - Processing log file is complete

Important Changes Since Pre-Release Data (2)

- Changes to NICER event data
  - Both PI and PI_FAST pulse heights are calibrated
  - New event file column MPU_UNDER_COUNT used for calibration purposes
  - Merged-MPU event file GTI is combined with "AND" logic (intersection of individual MPU GTIs)
  - Individual MPU GTIs are preserved in the merged file as GTI_MPUn extensions
  - In cleaned event file, there is a GTI_SEL extension which is the input time selection GTI used for final screening, for reproducibility reasons

Structure of Observation Data

- Each "observation segment" will be in a separate directory identified by its 10-digit observation ID
  - Observation ID is unique to a segment
  - Science ops may split segments at ~daily boundaries
  - An observation segment may contain more than one NICER orbit
    - Captured in event file good time intervals (GTIs)
- Directory layout
  - NNNNNNNNNN/ (observation directory)
    - xti/ - X-ray Timing Instrument data
      - event_uf/ - unfiltered X-ray events
      - event_cl/ - cleaned & calibrated X-ray events
      - hk/ - XTI housekeeping files
    - auxil/ "Mission-level" orbit, attitude & HK
    - log/ Processing log files

Event Data Levels

- Fundamental science product is X-ray event data
  - Level 1 uncalibrated unfiltered event data stored in xti/event_uf
  - Level 2 calibrated and calibrated+screened data are stored in xti/event_cl
  - Level 1 & higher data is delivered with every observation
- The event file naming scheme is,
  - niNNNNNNNNNN_0mpuN_UU.evt
    - N is MPU number 0-6 individually
    - N=7 indicates all MPUs combined
    - UU indicates level
      - uf = unfiltered
      - ufa = calibrated unfiltered ("lightly filtered" to remove over and under shoots)
      - cl = calibrated and filtered (cleaned)
  - Example: ni1707030136_0mpu7_cl.evt
    - Obsid 1707030136, cleaned data, all MPUs combined

Contents of Event File

- There are two extensions of interest
  - Extension 1: EVENTS – X-ray event list
  - Extension 2: GTI – Good Time Interval table
- NICER follows standardized formats for event lists and GTIs, so X-ray astronomers should be familiar with them. (See next page)
- Level 1 “uf” files are original data stream from each MPU
  - There are seven files, one for each MPU
- Level 2 “ufa” and “cl” files have all 7 MPUs merged into one file, calibrations applied

FITS Event Files (Level 2 Calibrated)

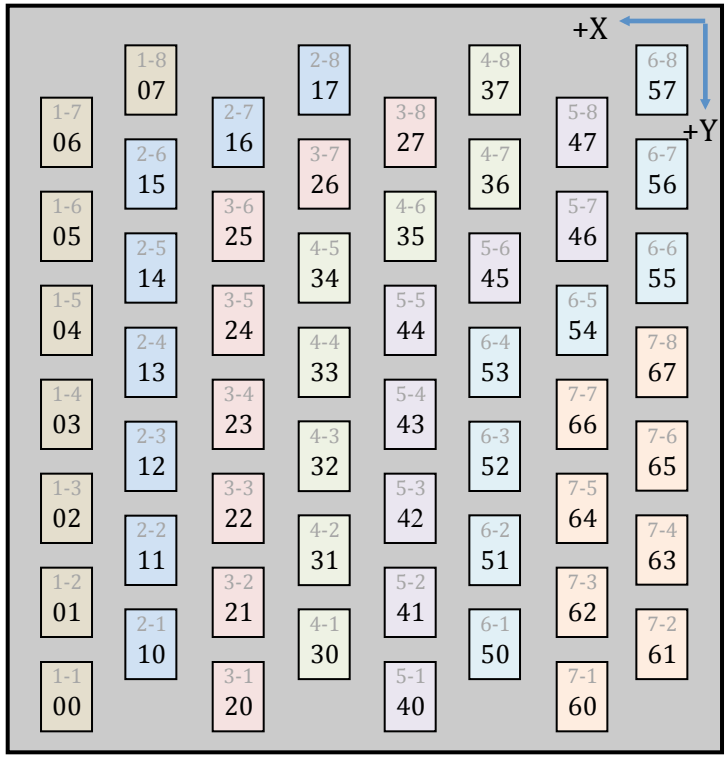
```
HDU 2   EVENTS            BinTable     9 cols x 16744802 rows

  Col  Name             Format[Units](Range)      Comment
    1 TIME               1D [s]                  Time of events
    2 RAWX               1B [pixel] (0:7)        Event X position RAW coordinates
    3 RAWY               1B [pixel] (0:6)        Event Y position RAW coordinates
    4 PHA                1I [chan] (0:4095)      Slow Pulse Height Analyzer
    5 PHA_FAST           1I [chan] (0:4095)      Fast Pulse Height Analyzer
    6 DET_ID             1B                      Detector ID number - 10*MPU+FPM
    7 DEADTIME           1B [s]                  Event dead time
    8 EVENT_FLAGS        8X                      MPU Event Flags
    9 TICK               1K                      MPU tick count of event
   10 PI                 1I                      Slow Pulse Invariant
   11 PI_FAST            1I                      Fast Pulse Invariant
   12 MPU_A_TEMP         1E                      MPU Analog Temperature
   13 MPU_UNDER_COUNT    1J                      MPU undershoot rate
   14 PI_RATIO           1E                      Ratio PI/PI_FAST

HDU 3   GTI               BinTable     2 cols x 13 rows

  Col  Name             Format[Units](Range)      Comment
    1 START              1D [s]                  GTI start time
    2 STOP               1D [s]                  GTI stop time

HDU 4   PPS_TREND         BinTable     3 cols x 11500 rows

  Col  Name             Format[Units](Range)      Comment
    1 TIME               1D [s]                  GPS reported time at 1-PPS
    2 TICK               1K                      MPU tick count at 1-PPS
    3 PKT_TICK           1K                      MPU tick count at time of X-ray packet accumula
```

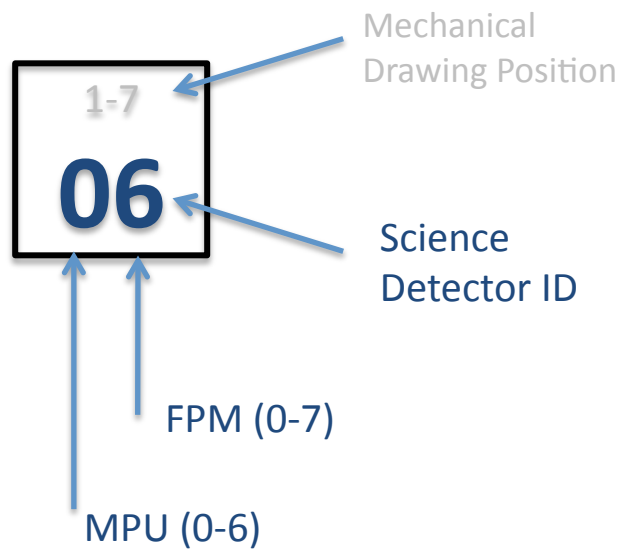
GREEN = Level 1→2 Additions

Detector Identification

- There are 56 modules arranged as follows (see following page):
  - seven MPUs labeled 0-6
  - eight FPMs per MPU, labeled 0-7
- The modules are labeled with a single integer DET_ID in the event list:
  - DET_ID = 10 x MPU + 1 x FPM
  - Example: 27 means MPU2, FPM7

Detector Layout





Time

- Time is reported in the TIME column
- TIME is elapsed TT seconds since the epoch 2014-01-01T00:00:00 UTC
- TSTART and TSTOP report the start and stop of good time
- EXPOSURE is total live time
- Conversion of NICER timestamps to absolute time in MJD can be done with the following:
  - MJD(TT) = MJDREFI+MJDREFF+(TIMEZERO+TIME)/86400
  - MJD(UTC) = MJD(TT) + LEAP_INIT
- **BUT: See the Caveats pages for important limitations!** Currently LEAP_INIT is not properly filled so you will need to use LEAP_INIT=2 manually.

Pulse Height

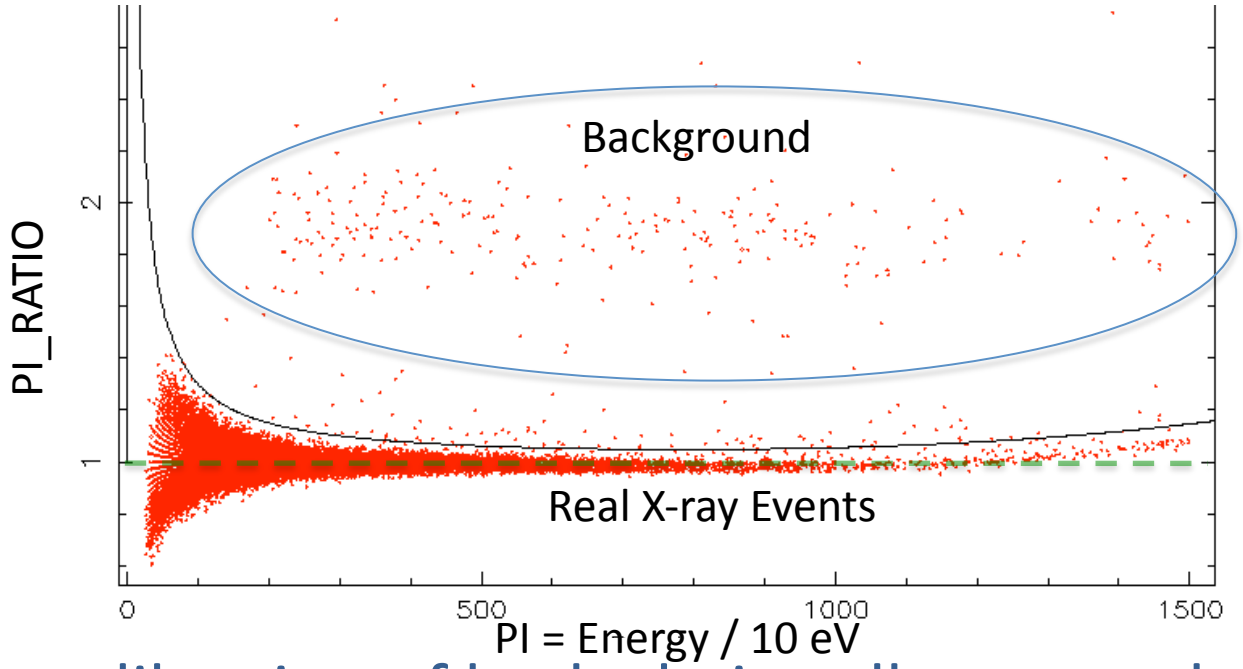
- Uncalibrated Level 1 in columns PHA and PHA_FAST
  - Each MPU and FPM has different PHA scale!
  - Thus, use of uncalibrated PHA is of limited use by scientists
- Calibrated Level 2 pulse height in PI and PI_FAST ("ufa" and "cl" files)
  - Every module is placed on same energy scale!
- PI = (ENERGY / 10 eV)
  - Example: PI = 110 corresponds to 1.10 keV
- NICER calibrated "ufa" and cleaned "cl" files have the pulse height calibration applied for both PI and PI_FAST
- NOTE: the NICER response below ~250 eV can be complicated; the standard screening removes events below 200 eV.

Pulse Height Ratio

- The NICER team has now clearly identified the difference between PI and PI_FAST as a discriminator of background events
  - non X-rays that interact in outer regions of the detectors create different charge clouds than concentrated X-rays, which result in different pulse heights in slow and fast chains
- A column named PI_RATIO is defined

  PI_RATIO = PI / PI_FAST
- The NICER team will provide improved guidance how to use this column for background filtering

Background Filtering w/ PI_RATIO



- Gain calibration of both chains allows to calculate PI_RATIO = PI / PI_FAST, which is an indicator of background events
- Black cut above, included in nicermergeclean, will exclude background events

Details: Event Types

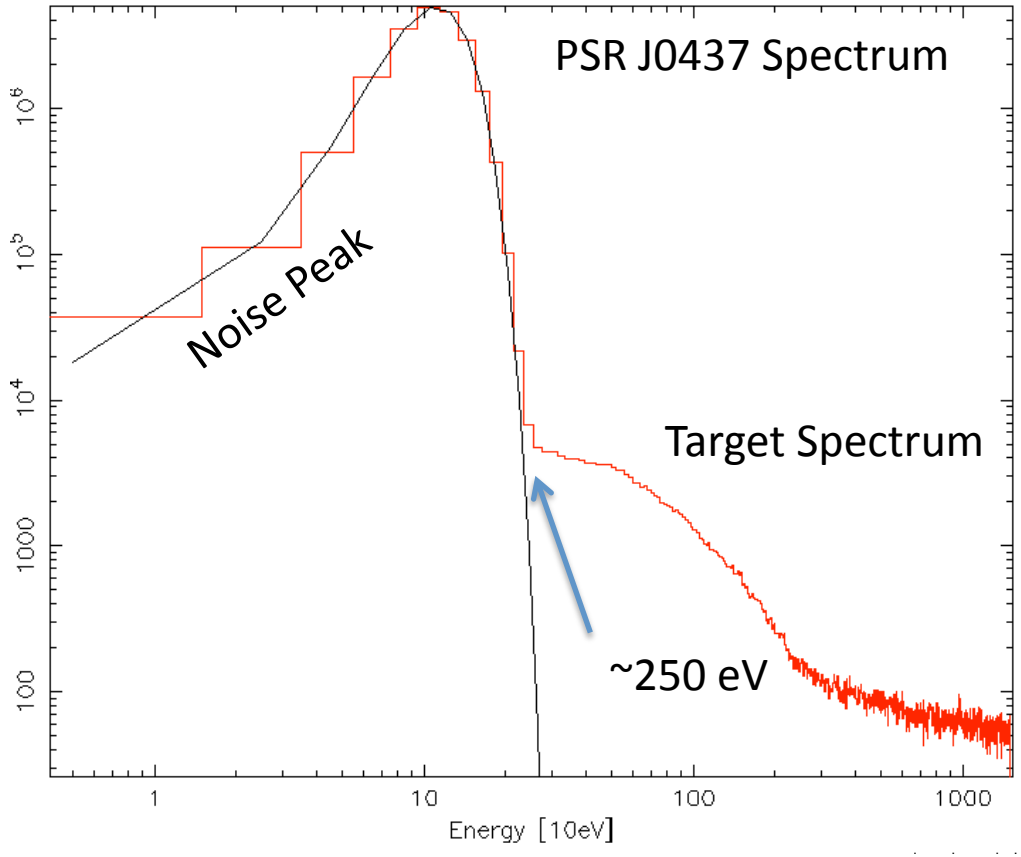
- There are several NON-X-ray event types. These are indicated in the EVENT_FLAGS bit column… ('x' means don't care)
  - EVENT_FLAGS == xxxxx1: "undershoot" reset
  - EVENT_FLAGS == xxxx1x: "overshoot" reset
  - EVENT_FLAGS == xxx1xx: software sample
  - EVENT_FLAGS == xx1xxx: fast signal chain triggered
  - EVENT_FLAGS == x1xxxx: slow signal chain triggered
  - EVENT_FLAGS == 1xxxxx: first event in MPU packet
- **There can be MANY, MANY more non X-rays than X-rays!**

EVENT_FLAGS Filtering

- To retrieve valid X-rays, use the following filter:
  - EVENT_FLAGS = x1x000
    (require slow chain, don't care fast chain, reject resets)
  - This screening criteria has been applied to generate the delivered cleaned "cl" file.
- To retrieve FAST+SLOW events, use the following filter:
  - EVENT_FLAGS = x11000
    (require fast+slow chain, reject resets)
- Example:
  - `niextract-events 'input.evt[EVENT_FLAGS=bx11000]' output.evt gti=GTI`

Noise Filtering: nicermergeclean

- We currently recommend that analysts use the tool nicermergeclean to screen data. This task will automatically remove non X-rays.
- The task will automatically screen out data below 200 eV.
- We are currently recommending that users will probably need to reject counts with PI < 250 eV.



Other Columns

- "Image" columns RAWX/RAWY can be used to make a rudimentary detector plane image (use "fv")
- DEADTIME is instrument dead time as recorded by the MPU for each event.
  - Each MPU operates independently for dead-time purposes
- TICK is the uncalibrated instrument-recorded event time in units of 40 nanoseconds.
  - NOTE that each MPU ticks at a different and time-variable rate. Use the TIME column.
- The PPS_TREND extension is housekeeping data

Analysis of Data

- Any software that understands basic X-ray event lists should work with NICER data.
- You will probably have to do some screening outside of xselect to remove non-X-rays.
- You can use xselect and extractor.
  - Example xselect session:

```
> read events ./ni1707030136_0mpu7_cl.evt
> set binsize 1
> extract curve
> plot curve
> set phaname PI
> extract spectrum
> plot spectrum
```

- Scientists typically use their own timing software!

Caveats

- These data are still considered unvalidated, and scientists should be on the look-out for odd or off-nominal behaviors.
- The next pages describe certain known issues that do not need to be reported

Caveat 1: 1 second absolute timing

- It has been reported that there may be a 1 second absolute timing offset of NICER timestamps
- This offset would manifest itself when comparing NICER data to other observatories and a 1-second difference.
- The NICER team is aware of this issue and is investigating, but wanted to get data out to the team without delay, for the many scientists who are not sensitive to 1 second timing offsets.
- If the issue is resolved and a time correction is needed, the team will provide a small tool needed to adjust data sets in-place.

Caveat 2: "PPS Noise"

- During pre-launch testing *and flight*, some detectors can produce a single event count within a few microseconds of the 1 second GPS timing pulse.
- This is known to MIT as "PPS Noise," although formally it is not noise.
- There are a number of ways this PPS noise may manifest itself
  - false X-ray counts at exact correlated with 1-second rollover
  - correlated dead-time at exact 1-second rollover
  - BEWARE of exact 1-second pulsars or QPOs
- Team is investigating how to screen these, but there will always at least be deadtime at 1-second rollover boundaries

Caveat 3: Deadtime

- Most of NICER analysis is geared toward screening out undesirable events for spectral or timing processing.
- For most sensitive analysis however, dead-time may be important.
- Considering deadtime,
  - Each MPU triggers independently
  - All MPU events should be considered to estimate deadtime, not just the cleaned event list
  - Each MPU estimates its amount of deadtime on a per-event basis
- Therefore, scientists wishing to contemplating detailed deadtime analysis should go back to the per-MPU "uf" files and tally deadtime from those events.

Caveat 4: LEAP_INIT not initialized

- Almost all of the metadata keywords are filled with proper information, but the LEAP_INIT keyword is not.
- This keyword is intended to aid scientists to convert between the TT time system and UTC (see previous slides)
- Currently LEAP_INIT is filled with zero, which is erroneous
  - For all NICER observations to date, LEAP_INIT=2
- Scientists should take care until this is fixed.