NICER CALIBRATION: Background Model Parameter Files

C. B. Markwardt

Version 1.0 2022-10-25 - initial background model release
Version 2.0 2024-02-06 - updated 3C50 library

Summary and Release History

This document briefly describes release and development of NICER background model calibration files. Based on the current release, NICER delivers calibration files for the following models

- SCORPEON - a template-based fittable model (Markwardt et al)
- 3C50 - a library-based model based upon lBG, HREJ, and NZ (Remillard et al)
- Space Weather - a library-based model based upon COR_SAX and KP

3C50 Released Files

Public Release	NICER CALDB Ver	ID String	Comments
2019 thru 2022	Non-CALDB		Released by separate download on NICER pages
2022-10-20	xti20221001	rgv5_20170601v001 g2019d_20170601v001 g2020a_20170601v001 g2020b_20170601v001 g2021_20170601v001	First NICERDAS release of nibackgen3C50 tool. Each file corresponds to a different energy scale.
2024-02-06	xti20240206	g2022_20170601v001	Update to the “2022” gain epoch

Table Notes: All files appear in NICER Calibration Database as `nicer/xti/bcf/bkgparam/nixti3c50_<S>.fits`, where *<S>* is the ID String above.

SCORPEON Released Files

Public Release	NICER CALDB Ver	ID String	Comments
2022-10-20	xti20221001	20170601v001	First NICERDAS release of SCORPEON tool.

Table Notes: All files appear in NICER Calibration Database as `nicer/xti/bcf/bkgparam/nixtibkgparam<S>.fits`, where *<S>* is the ID String above.

Space Weather Released Files

Public Release	NICER CALDB Ver	ID String	Comments
2019 thru 2022	Non-CALDB		Released by separate download on NICER pages
2022-10-20	xti20221001	20170601v001	First NICERDAS release of Space Weather background tools.

Table Notes: All files appear in NICER Calibration Database as `nicer/xti/bcf/bkgparam/nixtispaceweather<S>.evt`, where *<S>* is the ID String above.

Introduction

By its nature, NICER is a non-imaging X-ray detector. This means that NICER has 52 independently-operated single-pixel devices that receive X-ray counts from the sky. However, in addition to X-rays, NICER experiences all of the other effects of the near-earth space environment. Specifically, this environment is populated with high (and low) energy charged particles and photons, which can enter the detector and leave non-X-ray-background artifacts.

Because NICER is non-imaging, background must be modeled. The ISS orbit takes NICER through a wide range of geomagnetic latitudes – each with its own background characteristics. At high latitudes, the background is dependent on space weather and the variability of the Sun. Individual observations thus have different background levels that must be understood to maximize the science return.

To calibrate the background, NICER has, to date, collected many megaseconds of exposure on background fields used and characterized by RXTE (Jahoda et al. 2006) and also a few select locations near some of NICER's long term and faint MSPs. These data form a database for two different and independently developed background modeling tools. At right is an example of a faint NICER source showing how well these tools capture the shape of the background spectrum.

Since launch, several background models have been developed, and in 2022 some of them have been published as a part of NICERDAS. Although an exhaustive review is impossible, here is a brief recap of background models.

- **SCORPEON**. SCORPEON provides the ability to perform very high quality background modeling in a range of conditions. Unlike other models which produce a background file that may be subtracted from the source spectrum, in its more sensitive the SCORPEON ftool form SCORPEON produces a background model that may be modeled in XSPEC along with the source parameters.
- **3C50**. The Remillard et al. 3C50 model, as implemented in the nibackgen3c50 tool, is a library-based model which depends upon the parameters known as HREJ, IBG and NZ. This tool and its auxiliary files were previously available as separate downloads. The tool is now integrated into HEASoft, and the auxiliary files are in CALDB.
- **Space Weather**. The Gendreau & Corcoran Space Weather background tool is also a library-based model which depends upon the COR_SAX and KP, parameters. Like 3C50, the Space Weather model previously required separate downloads and now is fully incorporated into HEASoft and CALDB.

Here, a “library-based” model means that the model divides parameter space up into cells, according to the designers preferred parameters and cell boundaries, and then accumulates dedicated background events from dedicated blank-sky observations into a spectrum in each cell. The group of accumulated spectra is a library. A user of the library interested in estimating

the background for a specific user spectrum would locate how much time the parameters for their user spectrum spend in each cell, and then build a weighted sum of the the library spectra, weighted by the exposure times.

The Space Weather model has a slightly different take on library models in that it maintains a full background event list without binning into cells, and then accumulates a spectrum from events that have similar parameter values to those of the user spectrum.

The SCORPEON model is template-based, in that the designer has generated smooth template spectra for various physically motivated components. The component norms are generally based upon the NICER overshoot count rate. However, these spectra are representable as a model within XSPEC and the parameters of the model are adjustable to better match the data. This allows for a tighter ultimate fit.

This document describes each of the data releases briefly.

3C50 Released Files

As noted, previously, the 3C50 model was previously available as separate downloads. The original author (Ronald Remillard) provides basic manipulation scripts; and the NICER GOF (Michael Loewenstein) provided a script called nibackgen3C50.pl which worked more in the HEASoft paradigm or run in a standalone mode. However, until October 2022, both the script and the data files were available as separate downloads from the NICER web page. For reference, this page is
https://heasarc.gsfc.nasa.gov/docs/nicer/tools/nicer_bkg_est_tools.html

The 3C50 auxiliary files contain the library spectra as well as index files.

The released CALDB files are slightly different than the separately-downloadable files, although the numerical content is identical.

The separate downloads are organized into a single master index, which is indexed by energy scale (or gain) solution number; a “night” and “day” index for each gain solution; and a spectrum for each library cell.

The CALDB-released files are organized slightly differently. There is one file per gain solution. Each file contains multiple extensions:

- “Master” index containing only one entry, for the given file. This single entry is required to maintain compatibility with the existing software
- “Night” index table
- “Day” index table
- Spectrum for each library cell, as single extensions

The “night” and “day” indices point to files within the same file, unlike the separate downloads which point to a different directory and multiple library files. The numerical content of these files is the same, they have just been transposed to a more compact form.

The CALDB files have the following CALDB index keywords

- CCNM = BKG_3C50
- Boundary keyword DETNAM(99) - applies to all detectors
- BGYEAR(“name”) - applies to specific gain solution designated by name

Unfortunately the designer of 3C50 did not adhere to any known gain solution naming scheme, so here is a decoder table

- optmv7 = BGYEAR(“2018”) = rgv5
- optmv7h/he = BGYEAR(“2019”) = g2019d
- optmv10 = BGYEAR(“2020a”) = g2020a
- optmv11 = BGYEAR(“2020b”) = g2020b
- optmv12 = BGYEAR(“2021”) = g2021
- optmv13 = BGYEAR(“2022”) = g2022

As of the current release, the 3C50 model library files are up to date with NICER energy scale releases.

Space Weather Released Files

As mentioned above, the Space Weather background model is a library model developed both by Keith Gendreau and Michael Corcoran in collaboration with others. In this case the library is a table of background events. In estimating the NICER background, the nibkgestimator tool queries the table and retrieves events with similar COR_SAX and KP, parameter values, using those events to make an estimated background spectrum.

The nixtispaceweather20170601v001.evt file contains events from dedicated NICER background observations for the dates of 2017-06-24 through 2018-11-24. The file has an unknown gain solution.

The CALDB files have the following CALDB index keywords

- CCNM = SPACE_WEATHER_BKGLIB
- Boundary keyword DETNAM(99) - applies to all detectors
- Boundary keyword CHANTYPE(PI) - applies to slow channel
- Boundary keyword KP(0.0-6.0) - applies to the specified range of Kp values
- Boundary keyword COR_SAX(0.4-17.1) - applies to the range of COR values
- Boundary keyword SUN_ANGLE(52.3-177.6) - applies to the range of sun angles

SCORPEON Released Files

The SCORPEON background model was designed by C. Markwardt. Unlike the 3C50 and Space Weather models, SCORPEON is a template-based model. The templates are developed by examining various physically motivated components that have been selected out of the dedicated background database. Here the development database used data from 2017-06-24 through 2019-12-30.

The components were isolated using combinations of geographic selections (such as SAA) as well as parameter cuts (such as overshoots and trumpet-rejected counts). The isolated components are:

- "Constant" components
    - Sky/astrophysical backgrounds - derived from published literature
        - CXB - cosmic X-ray background
        - LHB - local hot bubble
        - Halo - galactic X-ray halo
    - Non-X-ray constant background (CON)
- COR - cosmic-ray related - derived from quiet-time (low-variance) portions of orbit
- SAA - south atlantic anomaly - derived from geographic SAA region
- TREL - trapped electrons - derived from high-variability portions of orbit
- PREL - precipitating electrons - derived from high-overshoot conditions
- LEEL - low-energy electrons - derived from residual variability found in quiet-time portions of orbit
- NOISE - detect-related noise peak - derived from full-mission data

Unlike other models, a significant portion of the required model is actually stored within the software itself. For example the template functions are stored as XSPEC "mdefine" commands. What is stored in CALDB is a file with the following entries.

A table extension "BKG_PARAM" with the following columns:

- FPM_BATCH = a "batch" identifier that identifies detectors with different detector behaviors
- CON_NORM = per-detector relative norm for the CON component
- COR_NORM = per-detector relative norm for the COR component
- LEEL_NORM = per-detector relative norm for the LEEL component
- TREL_NORM = per-detector relative norm for the TREL component
- PREL_NORM = per-detector relative norm for the PREL component
- SAA_NORM = per-detector relative norm for the SAA component

Note that since most of the templates are normalized on a per overshoot basis, it is a "simple" matter of summing the number of overshoots for the selected detectors in order to get the norm of a given component. The x_NORM columns listed above provide an additional per-detector

relative normalization that allows the tool to construct a background estimate, tailored for the selected detectors.

In addition to the above table, the file also contains two image extensions

- SAA_MAP - SAA-only overshoot map
- TREL_MAP - TREL-only overshoot map

These maps are used to disambiguate between SAA and TREL components, which overlap geographically.

The CALDB files have the following CALDB index keywords

- CCNM = BKG_PARAM
- Boundary keyword DETNAM(99) - applies to all detectors
- Boundary keyword CHANTYPE(PI) - applies to slow channel

References

Remillard, R. A. et al. 2021, “An Empirical Background Model for the NICER X-ray Timing Instrument,” AJ 163 130, https://doi.org/10.3847/1538-3881/ac4ae6 (https://arxiv.org/abs/2105.09901)

NICER Background Estimator Tools
https://heasarc.gsfc.nasa.gov/docs/nicer/tools/nicer_bkg_est_tools.html

Changes

xti20221001

This is the initial public release in NICER CALDB.

xti20240206

The 3C50 model was updated to include gain epoch “2022.”