NICER CALIBRATION: Release Notes of xti20200202 (optmv7,consim135o)

C. B. Markwardt

Version 1.0 2020-02-02

Introduction

This document describes developments and performance of NICER Calibration release xti20200202. This release contains improvements of:

- Energy scale solution “optmv7”
- Significantly revised effective area (ARF) titled “consim135o”

Download

The files are available to the public in NICER’s CALDB. Additional per-module ARF data is available separately. Please see the following NICER discussion thread for how to access and use these products.
https://heasarc.gsfc.nasa.gov/docs/nicer/analysis_threads/arf-rmf/

What Has Changed?

For the ARF, considerable new work has taken place to improve the effective area (throughput) calculations. The result is now based on the NICER physics-based ray-tracing program called CONSIM which has many physical effects not included in the original semi-analytical model which was the previously available version (old version was named v1.02).

Along the way, the physical structure of the modules was improved (e.g. the "dumbbell"), the code uses newer gold reflectivity constants, the physics of scattering has been much improved, and the results have been custom-tuned for each module. All modules are now "lined up" in terms of effective area so there should not be flux offsets between modules.

Where will you see the biggest ARF changes?

1. Norms of each module have been adjusted (affects all energies)
2. Features around the Gold transmission edge near 2.2 keV are much reduced
3. High energy features 6-10 keV are much reduced.

4. Low energy response "shape" has not changed very much (but norm has changed).

Domain of Applicability

Use both files for the following:

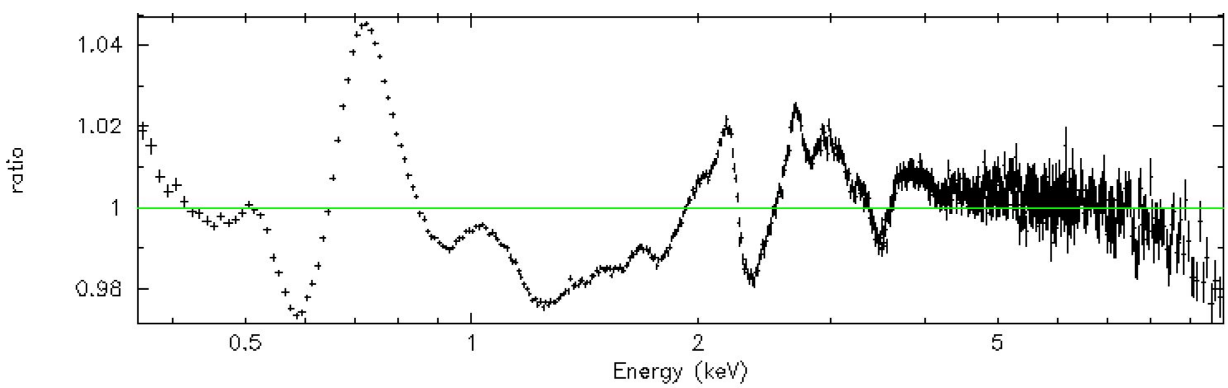
1. Spectral fitting 0.2 - 10 keV
2. On-axis science observations
3. Undershoots 0-200 ct/s (setting underonly_range=0-200 to nicerl2 or nimaketime)
   (if you can get away with 0-50 ct/s that is even better)

What this release is NOT tuned for:

1. Not tuned for "off-axis" observations.
   (But the good news is that for small off-axis pointings you should see a flux error and not a spectral error, to within 1%)
2. Performance very poor above 10 keV and no calculations were done at all above 13 keV. Do not try to go above 10 keV and expect anything useful.
3. Extremely high optical loading (undershoots >200 ct/s must be removed for spectral analysis)

Performance

Here is an example of the Crab residuals. See the end of this email for which parameters we used.

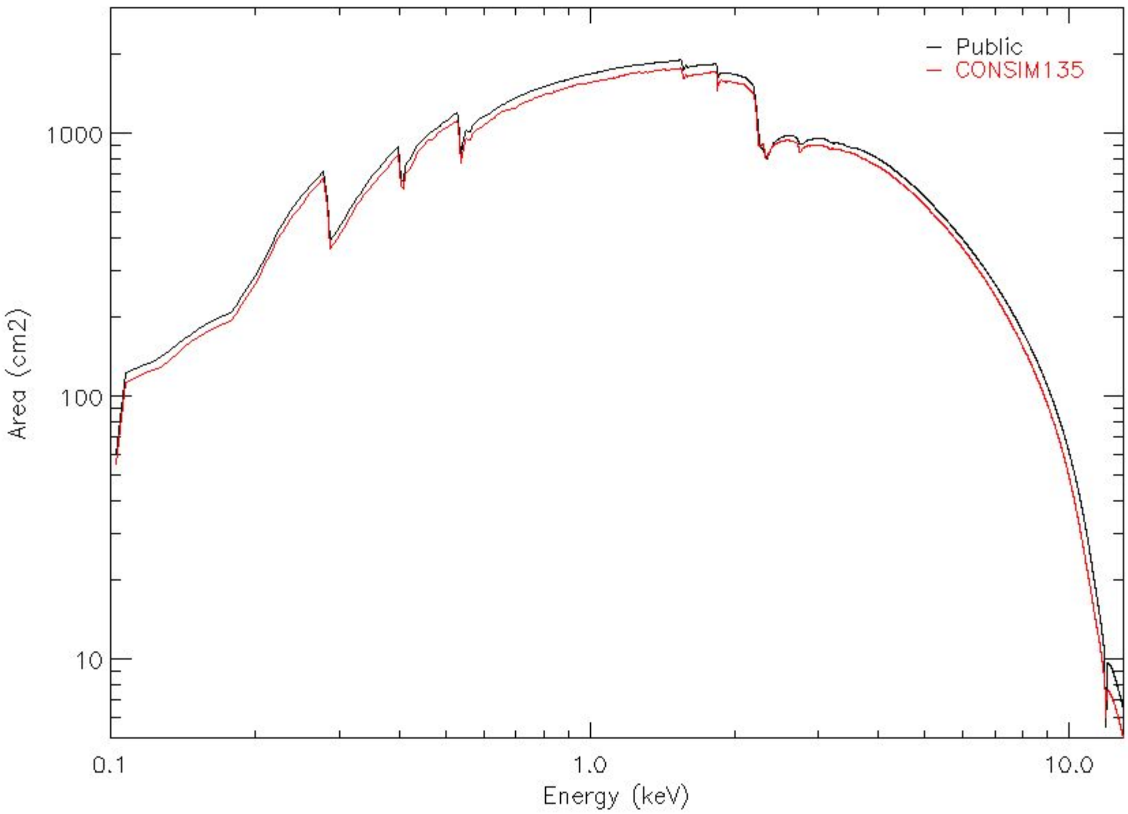


Note the vertical scale. As you can see, residuals are generally < 2% across the energy range 0.35-10 keV.

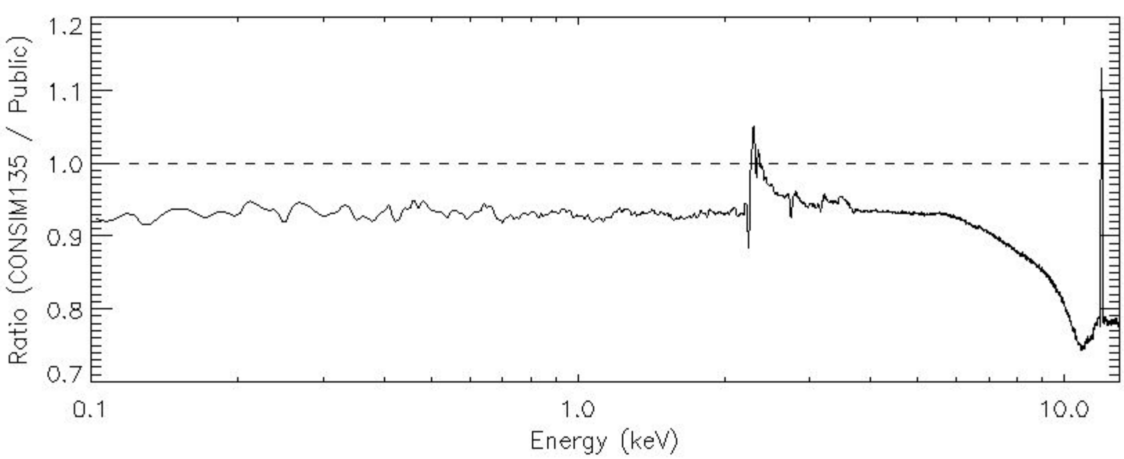
- Features in 0.5 - 0.8 keV range are thought to be astrophysical in origin and not detector features
- Features in 1.9 - 3.3 keV range are Gold reflectivity features of the X-ray concentrator optics; reflectivity is imperfectly modeled.

- tail-off above 7 keV starts to become apparent at few % level; this grows exponentially worse (~40% above 10 keV).

Here is a plot of both effective areas (old=baseline; red=CONSIM135)



and as a ratio of (CONSIM135/Baseline)



Do I Need to Reprocess My Data?

The question will come up, do I need to reprocess my data using nicerl2 or otherwise? The answer is probably not, for ARF/RMF purposes, but maybe yes if you are using an older energy scale calibration.

As long as you are already using the "optmv7" gain solution or more recent, you will get advertised performance. No need to reprocess.

However, separately from ARF/RMF issues you may need to reprocess if you wish to use the 3c50 background models. As documented previously, there is a new "extended" gain solution that changes only > 12 keV energy scale where the 3C50 model operates, and you would want to reprocess to capture those improvements.

Additional Caveats Discussion

This section discusses additional caveats regarding this calibration release. It is based on feedback after time to evaluate the model's performance, which suggested additional improvements. Such improvements are not included in this release, but we are documenting the issues here. Many of these improvements are most relevant for highly absorbed, hard, and bright targets.

Some of the changes below appear "large." When you see something change by 2-3x it seems alarmingly large, and in some circumstances it is large, particularly for highly absorbed sources. On the other hand, for the most part these effects will be "small" and relevant only in limited cases. We will try to be clear about what cases that is true, but ultimately the effects will depend on your source spectrum and we cannot provide exact numerical changes for every individual source.

RMF

RMF work has been a collaboration with the MIT detector group, who originally adapted the RMF code from the work of Scholze and Procop (2009). We have made some additional changes to accommodate NICER-specific details. There are some additional areas where the current model will need to be improved beyond this release.

Recall that the RMF deals with both resolution and redistribution of photon energy into counts. The resolution part is what analysts normally think of for the RMF, which is the spread of counts around the main photopeak. However, there are also redistribution effects which create very broad features that essentially are flat all the way down to low pulse heights. I.e. a 6 keV feature can produce apparent "shelf" counts between "0 eV" and 6 keV; typically, the counts in the shelf are at much less than a few % of the photopeak level. We have been refining the model of both resolution and redistribution.

"Back side" changes. We are now aware that at energies >9 keV, the 500 um silicon detectors are optically thin enough that photon interactions near the backside of the detector produce more redistribution "shelf" than we were expecting from the basic Scholze & Procop model.

- Future Change: improved model of escape peak and shelf for input photons >9 keV, tuned to BESSY ground-based data.
- Effect: the RMF shelf increases by a factor of about 2. The xti20200202 products under-predict the shelf by this factor. This mainly will be relevant only for sources that are extremely hard, bright, and heavily absorbed, so that many high-energy photons are converted to low pulse heights. For soft or faint sources, the low-energy photopeak will dominate over the shelf.
- Recommendation for users of xti20200202: adjust lower energy bound of fitting to avoid the "shelf."

"Front side" changes. The Scholze & Procop model appears to underpredict redistributed shelf counts for photon energies in the 0-1.8 keV range (below the Si K edge). We are considering adjusting this term.

- Future Change: enhance the shelf for photon energies 0-1.8 keV by ~1.6x.
- Effect: The xti20200202 products will under-predict the shelf by a ~2x factor. This will show up for highly absorbed spectra, and the energy range will depend on nH. The attenuation due to nH will cause a drop of counts toward low energies, but the measured counts will be much more than the model. For the Crab, with nH=3.5e21, the current Team model under-predicts by a factor ~2 in the energy range 200-400 eV. For GX 301-2, nH ~2-4e23, the underprediction should be about the same, but much more visible up to 0-600 eV.
- Recommendation for users of late-August products: adjust lower energy bound of fitting to avoid the shelf.

WARNING for CRAB-NORMALIZERS: Do not attempt to Crab-renormalize below about 0.45 keV. The shelf effect becomes dominant below that energy.

Resolution changes. The model of how the FWHM of the photopeak is simulated has been changed.

- Future Change: more physical Fano-like model of resolution is applied.
- Effect: not clear, probably minimal.

ARF

No changes to the analysis process, but the ARF will being "retuned" after a new RMF is developed.

- Future Changes: small adjustments to ARF to compensate some of RMF effects.
- Effects: spectra >9 keV will probably have small, ~5%, changes.

Energy Scale (Gain Solution)

The calibration team has found some additional problem areas in the current energy scale solution in the range 0.5 - 3 keV. The problems show up as small wiggles in the energy scale, especially in the 1-2.5 keV range.

- Future Change: adjustments to the energy scale to be more continuous. About 2 eV change at E=0.53 keV (O K edge) and <5 eV at 2 keV. Thus we are still (barely) maintaining our promise of better than 5 eV gain solution in the NICER energy range.
- Effects: the wiggles in the energy scale were absorbed in the ARF calculations, at least for sources with a Crab-like spectrum. These were typically ~2% in the 1-2 keV range and about 3% in the 2-3 keV range.
- Recommendation for users of xti20200202 products: please be aware of small features around the Gold M edge ~2-2.5 keV. These are probably response artifacts rather than real astrophysical features.

Appendix: Crab Reference Model

If you would like to download NICER Crab data and fit it for yourself, please use the following reference model for comparison. It is based on Kaastra 2009, and includes the pulsed and unpulsed components, and spectral curvature of the nebula.

```
ignore 1:**-0.35,10.0-**
method leven 20 0.01
abund angr
xsect vern
cosmo 70 0 0.73
xset delta 0.01
systematic 0.01
mdefine crab_pulsar
(726*e^(-1.276)exp(-0.07*ln(e)^2)+1464*e^(-1.165)exp(-0.159*ln(e)^2)+2021*e^(-2.022))/10000 :
add
mdefine curv (1.0+p1*exp(-e/p2)) : mul
model  TBfeo(curv*powerlaw + crab_pulsar)
        0.38017      0.001          0          0     100000      1e+06
        0.64662       0.01     -1e+38          0          5      1e+38
        0.73168       0.01     -1e+38          0          5      1e+38
              0      -0.01         -1          0         10         10
          0.411       -0.1      1e-22      1e-22      1e+22      1e+22
           0.46       -0.1      1e-22      1e-22      1e+22      1e+22
        2.10858       0.01         -3         -2          9         10
        9.45751       0.01          0          0      1e+20      1e+24
              1      -0.01          0          0      1e+20      1e+24
```