Report from the NICER Users Group - Spring 2021 Meeting

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Executive Summary

The NUG met (virtually) on four separate occasions between the end of May and early June 2021. Since this was the first meeting of the NUG, we systematically reviewed all topics laid out in the NUG Charter (https://heasarc.gsfc.nasa.gov/docs/nicer/nug/nug_charter.html). Below we go through each topic in turn, and at the end we include a separate set of recommendations on 'Increasing the number of NICER users'.

The NUG notes the many successes of NICER to date, and the number of high impact results that have already been published. The NUG praises the work of the NICER team, especially regarding the responsiveness of the mission to new transient events. The datasets that are being obtained will be a significant legacy. NICER has impressively expanded well beyond its primary science goal of constraining the neutron star equation of state, and interest in NICER is growing beyond the X-ray community. This strongly motivates continued improvements in making NICER data analysis as accessible and user-friendly as possible.

This report contains a wide range of recommendations to the NICER team, which reflects the willingness and desire of the NUG to help maximize the scientific reach and impact of NICER. Many of the recommendations here are simply a 'wish list' with this purpose in mind. The most critical recommendations are those regarding calibration and background in Section 4. We recognize the limited size of the NICER team and realize that there would be significant additional effort required to implement all the recommendations in this report, which may not be feasible.

Below is a summary of the most important recommendations. Recommendations 1-4 are the highest priority and presented in order. More details and further recommendations appear throughout the main report.

1. Calibration: investigate the deviation of the best-fitting Crab model below 1 keV. Perform a systematic study and comparison of the ISM abundances and edge shapes needed to fit NICER data with those from high-resolution instruments.
2. Analysis threads: develop start-to-finish walk-through analysis threads to go from unfiltered event files to background-subtracted spectra, light curves and power spectra
3. Background: adopt a single background model as the 'default' that provides the most reliable starting point for analysis
4. GO program: introduce a 'Key Projects' category to encourage the proposal of large, high impact projects requiring significant observing time
5. Data distribution: have a publicly available quick-look data website for fast access to data from new transients
6. Data delivery and analysis tools: deliver quick-look data products (spectra, light curves etc) along with data in the archive, moreover include a single pipeline tool that allows creation of these products from the unfiltered event files
7. Light curves page: develop a public light curves page showing the latest evolution of transient and variable source monitored by NICER

1. NICER data analysis software and data distribution

1.1 Data analysis software

The NUG acknowledges that there has been a significant effort that has gone into developing the NICER analysis software tools. Generally these work very well. In Section 2, we outline a number of recommendations on describing the usage of the NICER tools. The NUG was encouraged to hear of the development of tools to generate observation specific RMF and ARFs, the development of a background light curve tool and the on-going work looking at off-axis response of the detectors. These will be very useful.

One criticism noted was that the *nicerl2* and *nimaketime* tools can clash with each other - for instance *nicerl2* does not allow for filtering on KP or 3C50 columns that are added to the .mkf via the *nicerl2* tool itself. This requires using *nimaketime* to be able to select on these through the "expr=" call. However, *nimaketime* calls many of the default filters in *nicerl2* such as 'underonly_range="0-200"', so if a user relaxes this to 0-300 in *nicerl2* (due to non-optimal observing conditions) and then goes to filter on KP with nimaketime, they will suddenly have no useable events and spend a long time trying to track down the problem. An easy solution to this would be to include a warning/note in the analysis threads.

One recommendation was to consider including a '*nupipeline*' type tool that wraps together the individual steps to go from the unfiltered event files to high-level scientific products in one step. This would provide a quicker route to obtaining products for analysis, especially for new/inexperienced users.

1.2 Data distribution

Data for new transients are often distributed to the proposers and working groups directly by the NICER PI. This provides investigators quick access to the latest data, often in near real-time.

The NUG praises the responsiveness of the NICER team to ToO requests and their distribution of the data afterwards.

That being said, there was discussion on how to improve this further in order to both automate the process and to provide quick data access to as large a community as possible. For those data that are not part of a proprietary GO program, it was suggested to have a 'Quick-Look' data access site including event files as well as quick-look spectra and light curves. The data need only remain available there until the 'final' processed data hits the archive (usually within 2 weeks of the observation). A successful approach to model would be the Swift quick-look page: https://swift.gsfc.nasa.gov/cgi-bin/sdc/ql

2. Support (e.g., helpdesk) for NICER data analysis and proposal preparation tools

The helpdesk and proposal preparation tools work well. One additional tool that would help the preparation of proposals would be a bright source checker that allows users to easily verify whether or not a significant X-ray source (other than the target of interest) will fall into NICER's field of view.

There was significant discussion on the usability of the NICER Analysis Threads section of the NICER website. While the NICER analysis threads present a guide to using the NICER tools, the NUG felt strongly that a number of steps could be taken to help the first-time NICER user or inexperienced X-ray astronomer more quickly obtain usable results.

For instance, the NUG recommends that an analysis thread that gives a full, self-contained walk-through from start to finish on how to create a spectrum, or how to create a light curve and power spectrum would be extremely helpful. NUG members pointed to the XMM-Newton analysis threads (https://www.cosmos.esa.int/web/xmm-newton/sas-threads) as a good example of this. The threads could use a 'test' dataset that users could download and follow along with.

Similarly, threads relating to bright and faint sources (and the different considerations regarding filtering and background) would be useful.

A straightforward description of all of the filtering parameters (a sort of 'cheat sheet') would be of great use. This is especially relevant for terms that are specific to NICER or are not familiar to new NICER users (e.g. overshoots, undershoots, CORSAX etc). While these things are currently in the ftools help or elsewhere on the NICER website (e.g. presentations from NICER analysis workshop), presenting it in the 'Data Analysis' section of the website would be more accessible/easier to find.

3. Data rights and policy issues

The NUG had an in-depth discussion about the exclusive use data period. Currently proposers may request an exclusive use period of up to 6-months. The NUG was supportive of this

especially since the exclusive use period protects students and junior researchers who might be working with NICER data for the first time, and can therefore help promote diversity and inclusion within the field. Moreover, there remain complexities in the data analysis that require additional care from observers, and exclusive use time helps support this. The NUG felt strongly that it should be explicitly stated and made very clear in the proposal guidelines (and made clear to proposal reviewers also) that requesting the 6-month exclusive use period is not viewed negatively and will not affect the outcome of the proposal peer review.

4. Calibration considerations and products

4.1 Calibration

The NUG recognizes that the NICER team has worked tirelessly to continually improve the calibration. Significant progress and improvements have been made. The NUG thanks Craig Markwardt for an extremely helpful meeting with us to discuss the status of the calibration.

The NUG recognizes that much of the calibration effort falls on one person, and would strongly support additional FTEs going towards improving calibration and background models.

There was a lot of useful information presented on the detector calibration at the May 2021 NICER analysis workshop. We would encourage the information in the slides to be translated to a dedicated space on the NICER website discussing the calibration, including instrumental features to watch out for in spectra (detector edges, the escape peak etc).

With the high signal-to-noise ratio of NICER data it has been noted by the NICER team that the simple interstellar absorption models may not be satisfactory to fit the best-quality NICER data. For instance, a new ISM absorption model was adopted to perform the calibration to the Crab. A comprehensive and systematic study of this issue would be helpful, comparing ISM abundances and edge shapes needed to fit NICER data with those determined from fitting high spectral resolution data from Chandra and XMM-Newton.

The NUG was particularly concerned by the large difference seen below 1 keV between the best-fitting Crab model for NICER and XMM. The NICER best-fitting model appears to be a 40% mismatch from the Toor & Seward (1978) result at 0.5 keV. The NUG felt strongly that understanding this difference should be a high priority, especially since much of NICER's key science relies on its unparalleled effective area at low energies.

Several NUG members have noted that there remain residuals in spectral fits that appear at energies corresponding to detector absorption edges in the 1.5 - 2.5 keV region, which suggests some improvements in calibration can still be made.

Since many observers perform joint NICER and NuSTAR spectral fitting, the small difference in power-law index between the two missions should be documented clearly on the website.

The NUG would like to encourage the cross-calibration of NICER with other missions via IACHEC. The NUG understands that some joint/coordinated datasets exist for this purpose, and we would encourage the use of them in addition to the use of the Crab for calibration.

The NUG was a little surprised to hear that the NICER team has not received much feedback from guest observers and members of the working groups regarding the calibration. We suggest adding a dedicated 'feedback' form on the NICER website to encourage users to submit questions/comments/concerns regarding calibration and to be able to read responses from experts to previous questions.

Many NICER observations of bright sources are not statistics limited and are instead limited by the systematic uncertainty in both the calibration and background. An additional column indicating the systematic errors for each energy channel (or an easy way to add this to NICER spectra), would be a helpful tool.

4.2 Background

Currently there are two background models (the 3C50 model and the space weather model) available to estimate the background spectrum during a NICER observation. The NUG felt that too much is currently left to the user to determine how best to use these, and that better guidance should be provided.

For instance, the availability of two models can cause significant confusion among users ('which one should I use?', 'which one is better?'). We recommend choosing one model to be the default choice that provides the most reliable starting point - the additional model can still be available for use and details can be provided on an 'experts' page.

Details and examples of instances when the background model is not performing well would be helpful to users in assessing the quality of their data.

It may be necessary to have different analysis/filtering approaches for faint vs bright and/or hard vs soft sources. Providing as much guidance to users on this as possible would be beneficial.

As noted in Section 2, a tool to search for bright contaminating X-ray sources in the NICER field of view would be beneficial.

5. Planning for execution of GO programs

The GO program is excellently run!

6. Balance of resources for GO, legacy science, and target-of-opportunity/discretionary time (TOO/DT) programs

The NUG felt that the current split of observatory time between GO, TOO/DDT, Legacy science and Calibration was about right. Since the mission's quick response to transient events is a major strength we strongly recommend NOT to decrease this portion. We also recommend considering including a 'Key Projects' (or similar) category as part of the GO program. This would reserve a portion of the available GO time for large, high-impact projects requiring significant amounts of observing time (more than 300 ks or so), as is done for many other missions. These projects could get a larger portion of the available GO funds to ensure successful completion. While nothing currently prevents observers from submitting a large proposal, without having a separate category such proposals will take a substantial fraction of the available observing time in a given topic panel, and thus have little chance of success. Ring-fencing off time specifically for large projects will encourage investigators to propose for bigger, high impact projects with NICER.

7. Dissemination of NICER science results, through workshops, scientific meetings, and other community outreach.

The NUG was very positive about the NICER science analysis workshop that took place in May 2021. Attendance was excellent (approximately 300 registered participants) showing the strong interest in the mission.

The NUG recommends that the NICER team should consider also doing more hands-on workshops aimed specifically at graduate students/new users. There are several potential avenues for this, such as the IAU Hands-On Workshops (I-HOW: https://www.iau.org/training/iau-hands-on-workshops/) or COSPAR Capacity Building Workshops (https://cosparhq.cnes.fr/events/cospar-capacity-building-workshops/). Members of the NUG who have been involved in such workshops in the past noted that they have been very successful in widening the user base and providing young researchers with the skills needed to analyze data.

Other additional considerations would be to have a booth at AAS and/or HEAD meetings, and to continue to organize special sessions at these meetings as NICER has successfully done in the past. Consideration could be given to running thematic science workshops (similar to the XMM-Newton science workshops).

8. Increasing the number of NICER users

Throughout our discussions the NUG tried to think of ways in which NICER can further increase the number of users and its impact in the astronomical community. We came up with a number of recommendations to help with this, while acknowledging that achieving some of these will be tough with the limited available FTEs.

8.1 Delivering quicklook products with data

The NUG recommends including a ‘products’ (or similar) directory in the data available in the archive that contains quicklook spectra (including background spectra) and light curves that can be quickly analyzed using standard Heasoft tools, as well as jpg/gif images of these products too. Such an approach is taken by other missions (e.g. Swift) and is valuable to users to quickly assess the data. This would be especially helpful for new NICER users.

8.2 Light curve page

The NUG recommends that a light curve page be created that contains light curves for transients and other variable objects, following similar efforts in the past such as the RXTE/ASM, Swift/BAT and MAXI pages. This page should contain only publicly accessible data. This would be an extremely valuable tool for the community.

8.3 Joint facilities observing time

Currently proposers can request time for up to 400 ks NuSTAR time via the normal NICER Guest Observer program. However, other missions are also able to offer time on other facilities such as Chandra, XMM-Newton, Swift, Hubble, VLA. The NUG would encourage the NICER team to investigate further opportunities for accessing joint facilities (in addition to NuSTAR) via the NICER GO.