Project 3 - X-ray Astronomy

Basic Analysis of X-ray Observations

Due date: April 4th

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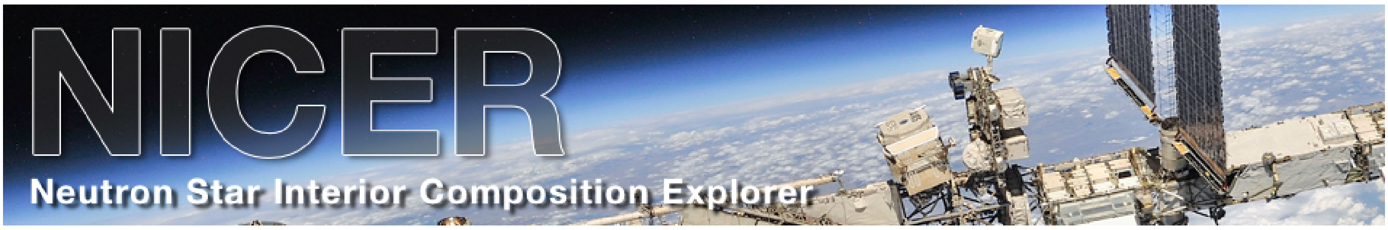
Office Hours: Scheduled on Request with min 18 hrs notice

If there is anything ambiguous about the assignment please send me an email! Please do **not** send emails to the NICER team before reaching out to me!

Submission format: All commands sent to the command line and their output should be copied to a *.txt* file that is attached along with a *.pdf* submission that contains the requested plots and the answers to the questions asked in the following parts. Necessary links to documentation are provided throughout the document. You may need to do a little additional research for some sections.

Background



We will be investigating data from the Neutron Star Interior Composition Explorer (NICER). NICER is a X-ray telescope that specializes in high time resolution (<300 nsec) observations between 0.2-12 keV. NICER is located on the ISS, and recently has even undergone repairs (https://science.nasa.gov/missions/station/iss-research/nicer/astronauts-to-patch-up-nasas-nicer-telescope/). We will be basing this project on the paper "**A NICER thermonuclear burst from the millisecond X-ray pulsar SAX J1808.4–3658**" (https://arxiv.org/pdf/1909.03595). Please feel free to reference this to check your results. You may end up with slightly different results because of versioning and minor difference between analyses. If your answers are dramatically different then you are probably on the wrong track.

For additional resources and general explanations you can explore the NICER documentation (https://heasarc.gsfc.nasa.gov/docs/nicer/nicer_analysis.html).

Installation

The software that is required can be found here:
https://heasarc.gsfc.nasa.gov/docs/software/lheasoft/download.html

1. Please check the "NICER" box in step 2. HEASOFT is fairly storage intensive (~3 Gb). If you have limited computing resources please reach out in the first 1-2 days and we can accommodate you. If you are using Windows, you can use Windows Subsystem for Linux to install the software using the Linux instructions. Installation takes several hours, so be prepared. Run the command *nicerversion* when complete, what is the output of this command?
2. Download and install CALDB (https://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/install.html) and install the NICER *goodfiles*, as listed in the installation instructions. What is the output of "*caldbinfo INST NICER XTI".* In the folder there should now be a file: *./data/nicer/xti/cpf/arf/nixtiaveonaxis20170601v001.arf*. Load this fits file into python and plot the spectral response against energy. Using the documentation (https://heasarc.gsfc.nasa.gov/docs/nicer/analysis_threads/arf-rmf/) describe what feature you are seeing in your plot of the *ARF* and then describe what is contained in the *RMF* files.
3. Create a folder and set the variable: *GEOMAG_PATH.* In that folder run *nigeodown* to download the necessary calibration files. From the documentation (https://heasarc.gsfc.nasa.gov/docs/nicer/analysis_threads/geomag/) describe in your own words the need for these geomagnetic quantities.

Data Retrieval

The project will require quite a bit of computer storage. We've tried to keep it minimal with a single exposure on a source. You will still require ~1 Gb of space.

1. Go to the NICERMASTR catalog (https://heasarc.gsfc.nasa.gov/W3Browse/nicer/nicermastr.html) and select "Browse..." in top right. In the paper (https://arxiv.org/pdf/1909.03595), identify the Observation ID used and enter this value into the table query under the "obsid". What is this value? You should now have retrieved a single row. Select that row, and select the "Create Download Script" button. You should now have a *wget* command that you can use to download the directory containing the files necessary for this analysis. Run this command locally in a directory with adequate storage.

Data Preparation and Data Investigation

In this section we will pre-process our files and apply initial calibration and filtering. This is mostly done automatically but we will investigate some of the intermediate files to illuminate what's going on.

1. Run the cleaning algorithm *nicerl2* on the downloaded directory (https://heasarc.gsfc.nasa.gov/docs/software/lheasoft/help/nicerl2.html). This is the standard cleaning algorithm for level 2 NICER analysis. This is bundled script that runs 5 operations. Describe what these 5 operations do in your own words without the use of undefined acronyms or jargon. Note the name of the .cl file produced at the end.
2. Take the "cl.evt" file (in the *xti/event_cl* folder). What are the contents of this file? Plot two informative histograms in python that show the instrumental proxy distributions of energy, and time. Note ".evt" files are equivalent to ".fits" files. For information on the time see here: https://heasarc.gsfc.nasa.gov/docs/nicer/analysis_threads/time/. For information on the energy see

here : https://heasarc.gsfc.nasa.gov/docs/nicer/analysis_threads/gain-cal/. Don't perform any additional calibration just plot the values in the uncalibrated form.

3. Run the *barycorr* correction on your "cl.evt", producing a new file (don't clobber). You will need a *.orb* file which can be found in the *auxil* folder. Compare the events in the pre and post processed file. Describe what barycentering is, and compare the order of the time correction to the length scales involved. Why is barycentering important? (https://heasarc.gsfc.nasa.gov/lheasoft/help/barycorr.html). Only use this file for spectrum and not for the LC.

Light curves

We will generate three light curves and compare two of them to generate a "hardness ratio". From the documentation (https://heasarc.gsfc.nasa.gov/docs/nicer/analysis_threads/gain-cal/) you should be able to determine the conversion between channel and eV.

1. Run *nicerl3-lc 2584010501 ,* using the *suffix* option, with the following configurations:
   - 0.1 second time bins, 0.3-10 keV
   - 0.1 second time bin, 3-10 keV
   - 0.1 second time bin, 0.3-1 keV
2. Take your .lc files and import them into python. Determine the approximately 60 seconds of data dominated by the flare and plot the following only in that region:
   - Rate as a function of time (with errors), for 0.3-10 keV. This is a "light curve" what information is it providing to us?
   - The ratio of rates as a function of time, for 3-10/0.3-1. This is the so called hardness ratio. What information does this plot inform us of?

Spectrum

Now we will make a simple spectrum. We will be generating a specific RMF, ARF, and spectrum file for the data and using *xspec* to produce plots and do our fitting. *xspec* is notoriously difficult to use. We will be returning to using the barycentered events for this section.

1. Generate a .gti file. This is a FITS file, with a GTI header, that contains the region of interest for the analysis and should follow the same format as the GTI in the header of the *.evt.* (See here for one way of doing this: https://swift.gsfc.nasa.gov/analysis/threads/batlightcurvethread.html section 8)
2. Run *nicerl3-spect 2584010501 clobber=YES gtifile=test.gti*
3. Open *xspec*. Run the command similar to this *"@2584010501/xti/event_cl/ni2584010501mpu7_load.xcm"* that was output by the previous section. This will load the three files you have generated.
4. Generate a plot and save the image using the following:
   - `cpd /xs`

- `setplot energy`
- `setplot rebin 10 10`
- `plot ldata`

Describe what each of these steps does and explain the features of the plot (https://heasarc.gsfc.nasa.gov/docs/nicer/analysis_threads/nicerl3-spect/).

Marking

All sub parts are marked out of three. Comments are provided when appropriate.

1 point -> A substantial effort was put towards the question and there are clear steps taken towards the correct solution

2 points -> Some of the question has been done correctly and minor errors might be propagated throughout. This may also be given if there is a substantial misconception illustrated at some step that demonstrates a fundamental lack of understanding.

3 points -> The majority of question has been done correctly. Issues are minor and inconsequential.

In some cases half points may be given but the majority of times the divisions appear naturally in the subdivision of the question.

Progress Guidelines

Although there won't be strict progress markers you should roughly follow the time line:

- [ ] Thursday 27th - Finish Installation
- [ ] Tuesday April 1 - Finish Data preparation and LC
- [ ] Thursday April 3 - Finish Spectral Fitting

If you are falling beyond this timeline please reach out for help! **Don't leave the installation until the last minute!** There are many parts of the analysis that just require some irreducible computing time. Please anticipate this.