- **"Q1. What is the best method for estimating source detection significance (i.e., > or < 3 sigma) or estimating an upper limit based on non-detection?"**
- The dominant source of uncertainty is background subtraction.
- Remillard et al. (2020, submitted) estimate 3-sigma upper limits for the 3C50 model to be
  - 1.2 ct/s (full array rate; 0.4-12 keV)
  - 0.51 ct/s (full array rate; 0.3-2.0 keV)
- These values (converted to 1 sigma) should be added in quadrature with Poisson errors to determine significance or upper limits.
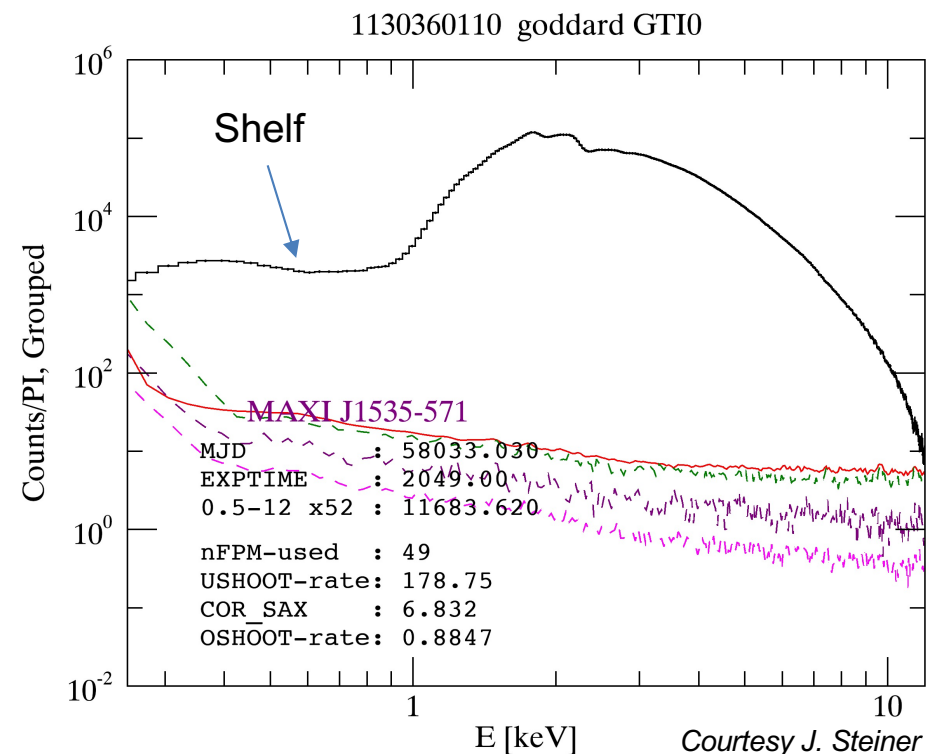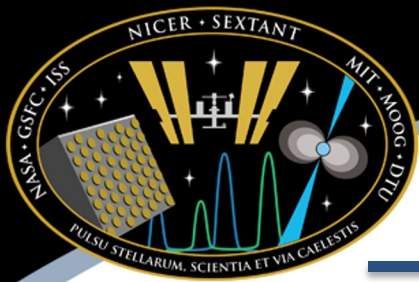
Q2. Background Subtraction below 1.5 keV

- **"In my spectrum I have subtracted off the background (estimated using nibackgen3C50), but still believe that <1.5 keV is background (as it is flat and deviates from an expected power law model). Is there a way to be certain the background estimation is accurate enough for fitting over the entire energy range - or would you suggest to fit only >1.5 keV?"**

- It's hard to answer this definitively without more details on the spectrum. If the source is highly absorbed, the systematic uncertainty in the background estimate might indeed be an issue. Or the uncertainty in the RMF-related shelf could be important (see next slide). Except for very high backgrounds, the 3C50 library spectra tend to be rising at low energies rather than flat – but, again, one would need to scrutinize the particulars of this case to make an assessment.

Q2. Background (cont'd)

- For highly absorbed sources, there can be a "shelf" at low energies
  - MAXI J1535 example (right)
- This is a detector redistribution effect
  - High energy photons redistributed into low pulse height bins
  - Visible when attenuation due to nH is stronger than redistribution shelf
  - This is completely normal and visible in almost all highly absorbed X-ray spectra (not just NICER)
- In this kind of situation, fitting to the shelf won't add much to spectral fit
  - RMF is designed to handle this case, but may be systematics & background dominated
  - Might consider ignoring low energies; it's a scientific judgement

1130360110 goddard GTI0

Shelf

MAXI J1535-571

MJD   : 58033.030
EXPTIME   : 2049.00
0.5-12 x52 : 11683.620

nFPM-used : 49
USHOOT-rate: 178.75
COR_SAX   : 6.832
OSHOOT-rate: 0.8847

Counts/PI, Grouped

E [keV]

Courtesy J. Steiner

Q3. 3C50 Background Model Outputs

- **"How can I use the files 'nibackgen3C50_bkg_day.pi' and 'nibackgen3C50_bkg_ngt.pi' ?"**

- One approach to spectral fitting is to fit the background rather than subtract it. In doing so, one might simultaneously fit the unsubtracted source spectrum (to a model that includes day and night background components), the day background spectrum (day background component only) and the night background spectra (night background component only).

- If fitting above 0.5 keV, one might choose to use only the night background spectrum – it has better statistics than the day component.

- If the background estimation seems off, having these separate components can help diagnose the source of the problem.

- Overall, we recommend to start with the total background estimate (nibackgen3C50_bkg.pi), and only consider the day/night components if there appear to be subtraction problems

Q4. Merging Observations

- **"What is the recommended way of merging one or more NICER observations?"**

- A more detailed analysis thread is being worked to provide guidance on this

- You have some choices

  - Do not merge observations: work on daily segments and keep files separate

  - Merge data

- Merging Data. You will need to merge the filter file and event file
  - Filter file. Use ftmerge to merge like this…

    ```
    ls */auxil/ni*.mkf* > mkfiles.lis
    ftmerge @mkfiles.lis merged.mkf
    ```
    Note that all data must be processed with same software. New HEASOFT release will make this easier.

  - Event data. Use niextract-events to merge "ufa" event files like this…

    ```
    ls */xti/event_cl/ni*_0mpu7_ufa.evt > events.lis
    niextract-events @events.lis merged_ufa.evt
    ```

- Then you can use nimaketime on filter file to generate GTI, followed by nicerclean to extract filtered events

    ```
    nimaketime merged.mkf merged.gti
    nicerclean merged_ufa.evt merged_cl.evt gtifile=merged.gti
    ```

- You can use additional screening options to nimaketime

Q5. Merging / Adding Spectra

- **"How do you merge spectral files? Should we use the ftool 'addascaspec' for the source and background spectral files?"**

- The NICER team does not normally recommend merging/adding spectral files. It is better to merge event files and then extract a single spectrum

- The addascaspec tool has not been tested with NICER data; we have used mathpha with success

Q6. HEASoft Versions

- **"I have Heasoft version 6.26.1 installed. I use MAC OS intel base (V 11.3.1). Xspec and other programs seems to be working fine. However when I click "nicerversion" I get. Segmentation fault: 11. What is causing this and is there is way I can fix this? Is my heasoft version too old for NICER data analyses?"**

- HEASoft 6.26.1 was released in July 2019, which is a bit old. The fact that you are experiencing errors indicates there are problems with the install. Installing a newer version of the software (currently 6.28.2) is recommended
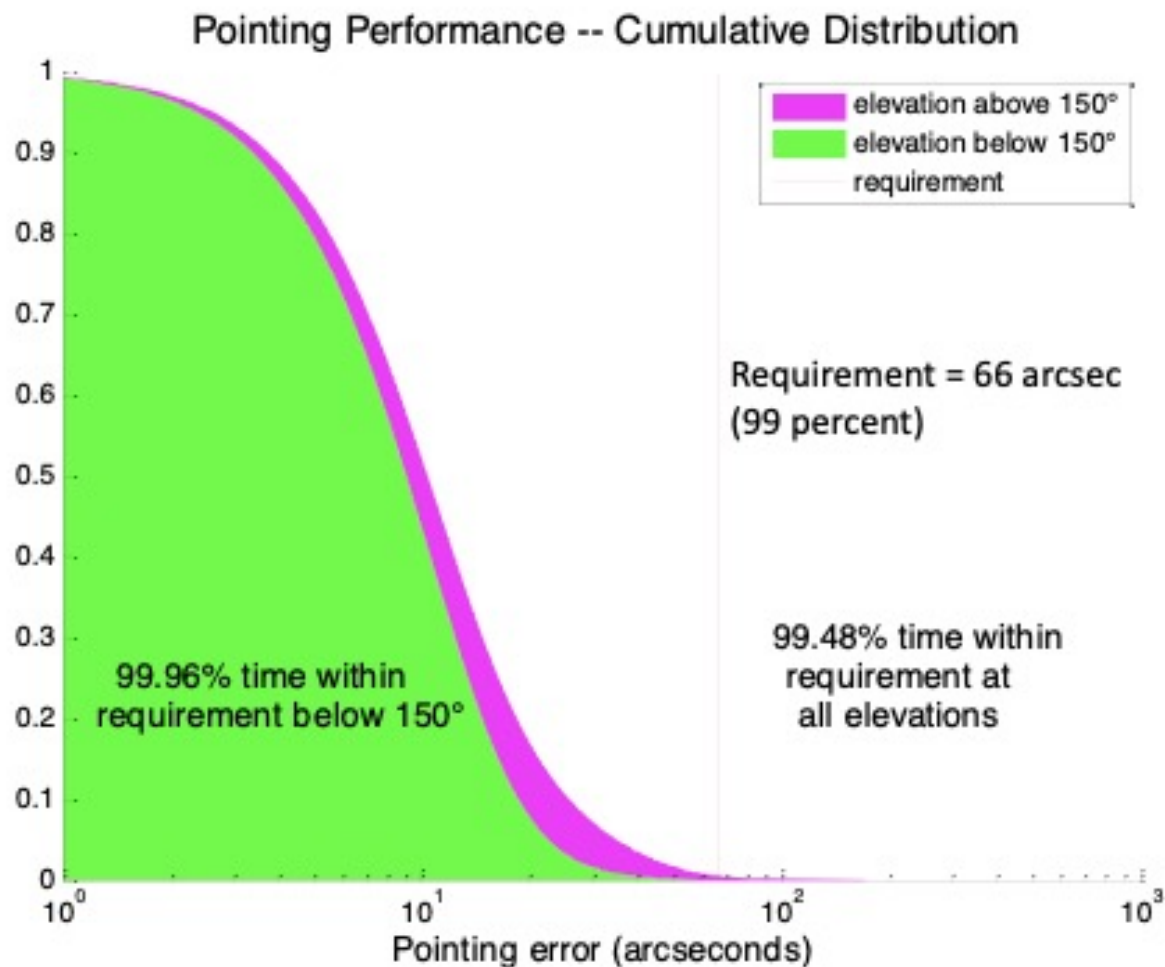
Q7. "Fake QPOs" Caused by Pointing

- **"I've read in data analysis caveats that NICER data can be affected by ISS vibrations/oscillations, leading to potential "fake" QPOs in the power spectrum. Is there a study of these ISS vibrations (i.e. characterisation in terms of frequency, duration, and RMS amplitude)?"**

- We have seen rare instances where rapid pointing jitter occurs
  - ~few Hz, could be as large as ~100 arcsec (10s of percent)
  - This may show up in timing data as QPO
  - Also a reduction in counts due to off-axis pointing

- In next release, a new filter file column will be available called XTI_PNT_JITTER which will allow diagnosing periods of high pointing jitter

Science Target Tracking Statistics

- Pointing performance requirement = 66 arcsec (99 percent)
- Pre-launch prediction shows requirement can be met for EL angle lower than ~145 deg.
- Flight data shows requirement is met almost all the time for EL angle lower than 150 deg.
- Pointing System meets requirements under all conditions
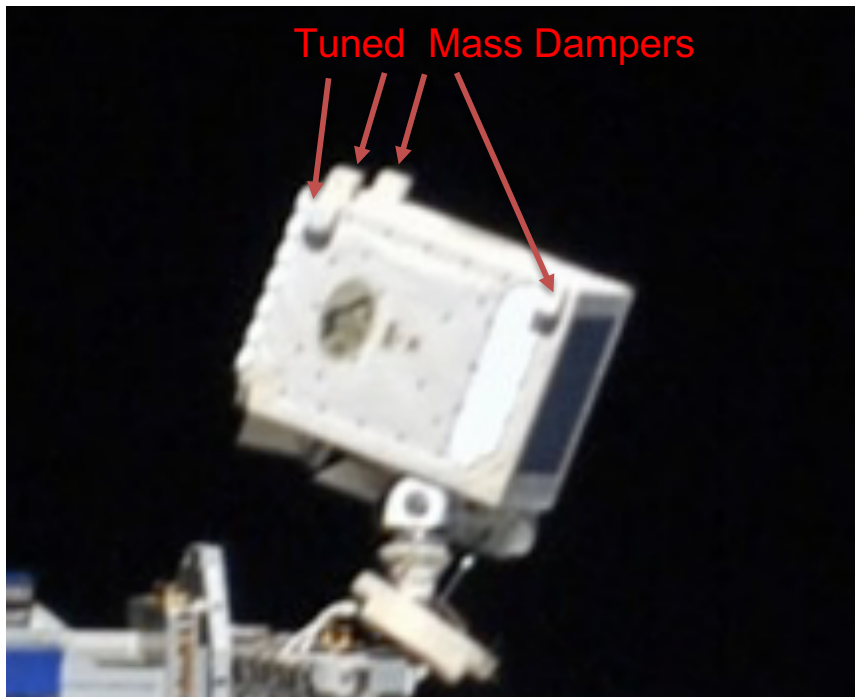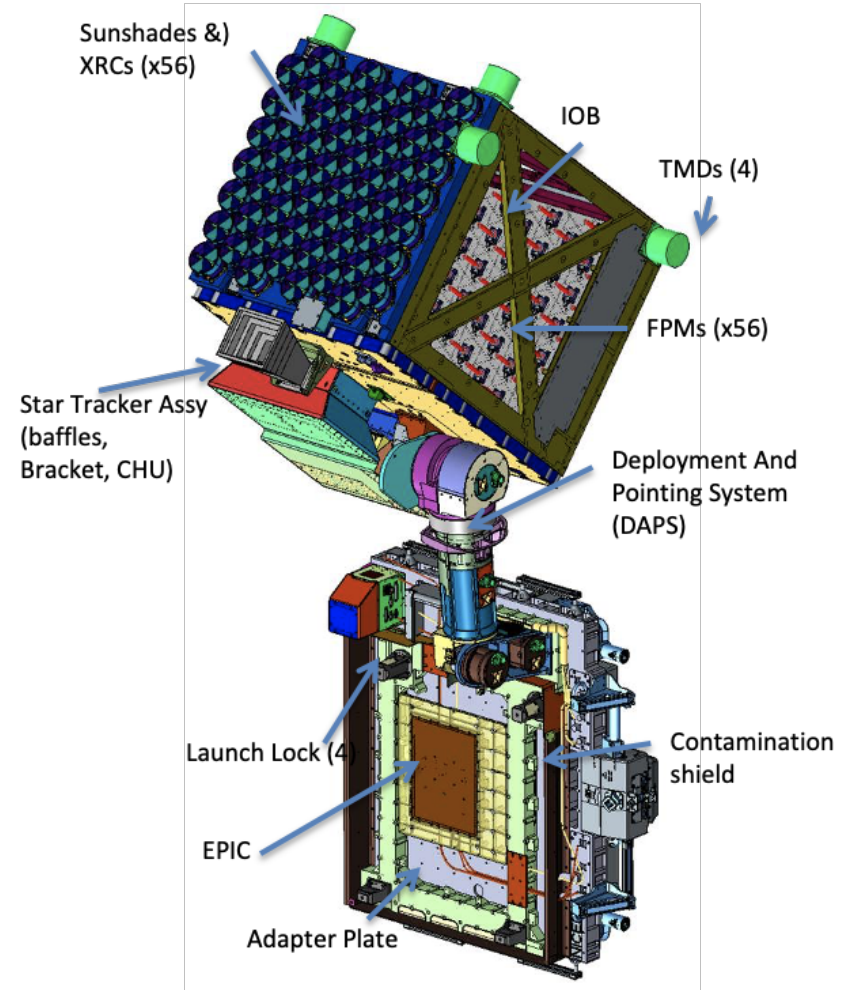- No operational constraint is required for operating at high EL angles.

Pointing Performance -- Cumulative Distribution

- elevation above 150°
- elevation below 150°
- requirement

Requirement = 66 arcsec (99 percent)

99.96% time within requirement below 150°

99.48% time within requirement at all elevations

Pointing error (arcseconds)

Tuned Mass Dampers on NICER

NICER has 4 "tuned mass dampers" designed to take out mechanical modes due to instrument and ISS vibrations (which are less)

These are masses held by springs and also magnetically damped. Finally tuning happened after final build for highest accuracy. TMDs were installed last- at launch site.

Tuned Mass Dampers

Sunshades &) XRCs (x56)

IOB

TMDs (4)

FPMs (x56)

Star Tracker Assy (baffles, Bracket, CHU)

Deployment And Pointing System (DAPS)

Launch Lock (4)

Contamination shield

EPIC

Adapter Plate

TMD Damping Performance

- Four tuned mass dampers (TMDs) were implemented to reduce the NICER structural responses between 1.5 and 3 Hz.

- TMD damping ratio requirement is set at 3% for modes between 1.5 and 3 Hz.

- By using gyro data in the NICER ST, the damping ratios were estimated for modes up to 5 Hz.

  - Spectrum plot shows all dominant structural modes less than 5 Hz are well damped.

  - For TMD targeted modes, their estimated damping ratios are above 3%
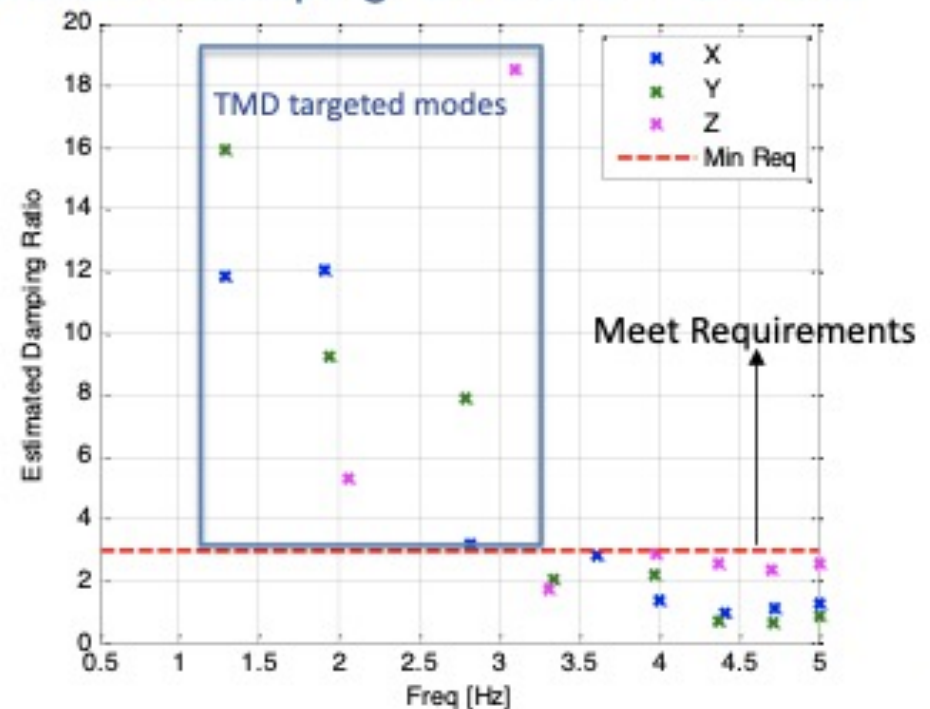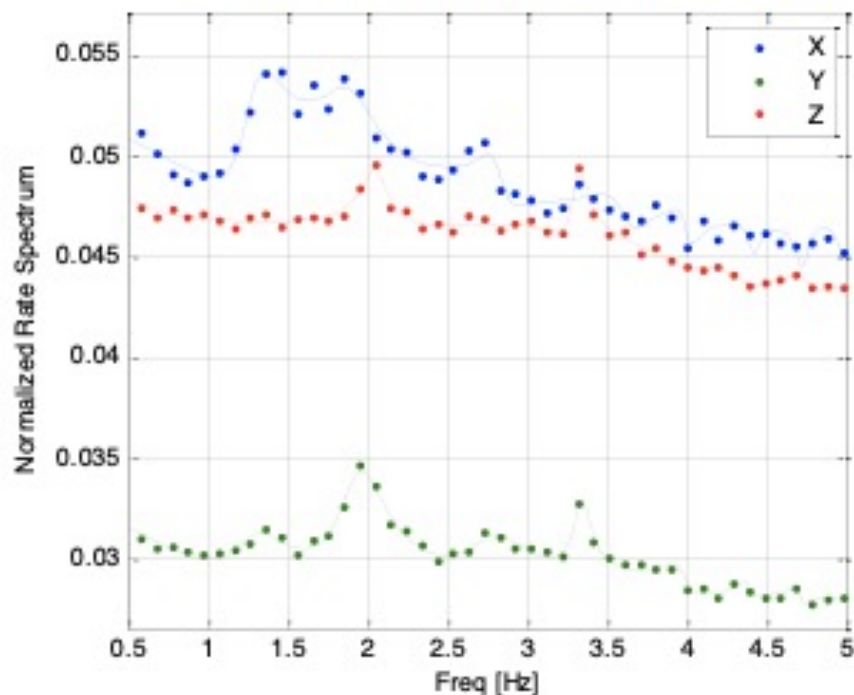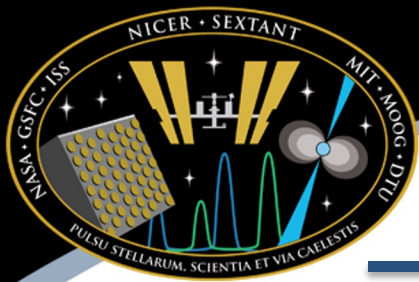
Q8. Special Procedures for DDT Observations

- **"In timing analysis of DDT observations (taken for several months), do you have some tips to share (besides waiting for the upcoming software version)?"**

- There is nothing special about DDT observations. All of the standard analysis tools and techniques described online and on this tutorial are recommended.

- If you are provided quicklook data by the PI, you may only receive an event file. A full data set will be available in the archive within about two weeks from date of observation, which you can use for definitive analysis

Q9. More Conservative Filtering

- **"…I am interested in understanding how more restrictive cuts affect the goodness of bkg modeling. In other words, are there regions in the parameter space where the bkg models (both methods) are thought to be more accurate?"**

- Ron Remillard et al. are publishing a paper about the 3C50 model, which is in the refereeing process. They provide a more detailed discussion about what filtering works best when performing background estimation.

- Generally
  - Avoid low COR (use cor_range=1.5-*)
  - Use bigger SAA (saafilt=YES nicersaafilt=NO)
  - Keep restrictive cuts on overonly_range and overonly_expr (or only allow modest increase by ~50%)
  - If working at lowest energies (E<400 eV), avoid high undershoots (use underonly_range=0-200)

Q10. New ARF Calculator & Off-Axis

- **"Does the new arf for pointing offset observations work fine for any offset angle (e.g. a few arcmin)?"**

- Yes. The response is tabulated to offset angle of 6 arcmin. However, the accuracy of the off-axis model will become poorer

  – Beyond 100" AND

  – Above ~8 keV

  – For low energies and within 100" the off-axis model should be excellent

Q11. Barycorr errors

- "Sometimes when I run barycorr on an obsid I get the following error:

  "barycorr: error: error running hdaxbary [code=104, os=0]
  barycorr: warning:
  --- begin hdaxbary
  ERROR: no bracketing sample found for time
  186265756.00000000
  ERROR: failed to find valid orbit ephem data for time
  186265756.00000000
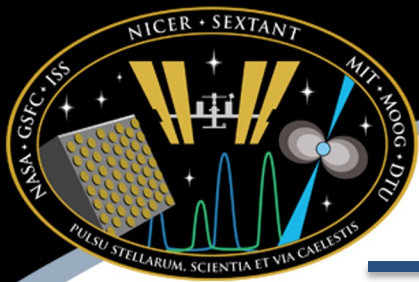 barycorr: Invalid Observatory/Spacecraft position vector"

  Does that mean the orbit files are corrupted? how can I solve this?"

- Typically this means that the orbit file does not match the data being analyzed. I.e. you are using an orbit file from a different data set. Barycorr will extrapolate up to 20 seconds, but refuse to go beyond that

Q12. Bright Sources

- **"How to deal with the spectral analysis of the very bright sources during its telemetry saturated time? Any corrections need to be done to rectify the telemetry saturation?"**

- High data rates (>~ 35,000 cts/sec across the full XTI) MAY cause telemetry saturation; there is no way to recover event information during intervals of saturation.

- However, the saturation gaps are correctly accounted for in the event file GTIs, so exposures will be correct

- Pile-up is rarely seen. For Sco X-1, which is extremely bright by most X-ray standards, pile-up is very mild.

- Main issue that may be encountered is if you are doing timing analysis, you may run into "shredded GTI" issue, which will affect power spectra if you do not use correct window function

- IMPORTANT: you need to check if the number of detectors is different than 52. This may occur because of science operations planning, which is designed to reduce the total telemetry rate.
  - In Markwardt presentation on screening, this is discussed
  - Filter file column NUM_FPM_ON: median value is not 52
  - If different than 52, you will have to compute a new ARF and new RMF
  - New software will make this easier and more automated to do

NICER Concerns: Bright Targets

- **Deadtime correction** affects all observations, but typically a few percent
  - Team is working on documentation and tools for deadtime corrections
- **Pile-up** is a concern only for the brightest targets (>>3.5 Crab); this is a difficult issue to model
- **Dust scattering halos** have significant effects
  - Energy dependent
  - Aperture size dependent
    - complicates comparing observatories with different apertures (NICER 360", RXTE 1°, CCD imagers ~few arcsec)
  - Halo is time dependent if source varies
  - 'xscat' model in XSPEC recently updated by Randall Smith for larger radius apertures such as NICER. Use radius=180"

Crab Dust Halo
(Chandra ACIS)
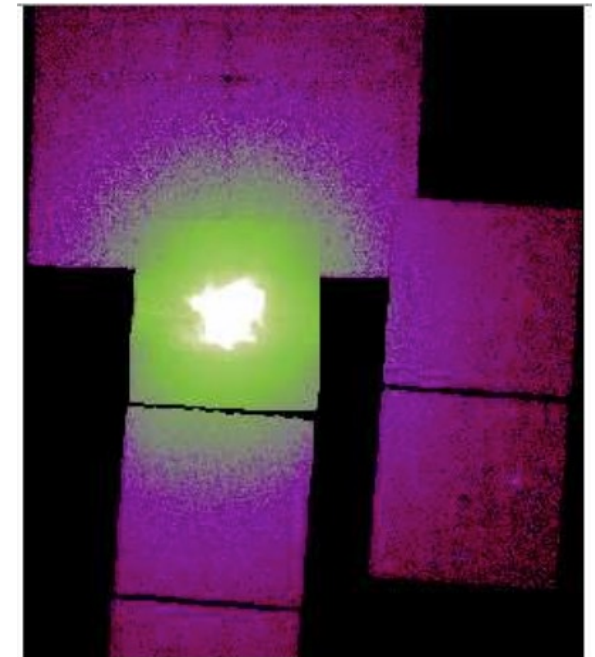
Seward et al. 2005

Q13. Timing Aliases

- **"Regarding timing analysis, most of the times when using an epoch folding algorithm, I see different alias (e.g., sub-peaks around the expected main peak) in the periodgram. Do you have any tips to minimize this effect?"**

- Aliasing is a fundamental issue of all timing analysis, not just NICER

- The best mitigation technique is long uninterrupted observations. Because NICER is in low-Earth orbit and typically observes targets in short "snapshots" across multiple 90-min orbits, the resulting gaps in the data impose a window function on periodograms.

- Prominent sub-peaks may indicate true aliases (i.e., true ambiguities in the assignment of pulse numbers)

- If you have strong background or DC level, this can magnify aliases. Analysts often subtract the DC level from bins with counts to reduce aliasing.

Q14. How to Perform QPO Analysis

- **"How to split properly all the data in GTIs to study the QPOs? How to do it step by step"**

- Most scientists develop their own software. The timing software "XRONOS" is available in HEASoft and the relevant software task is powspec

- Powspec is powerful but somewhat complicated to use

- Example here will be based on Cas A data from tutorial

 - GOAL: measure power spectrum evolution, for frequencies up to 10 Hz

Q14. QPO Analysis (cont'd)

- Run powspec on cleaned event list
  ```
  powspec ni3010080128_0mpu7_cl.evt
  ```
- Name of window file
  use '-' for default window
- Newbin Time: 0.05 seconds (= 0.5 / 10 Hz)
- Newbins / Interval: 8192 (scientific choice)
  - the result is spectra of dur. 8192 x 0.05 = 409.6 seconds
- Intervals / Frame
  - Use INDEF to average all spectra
  - Use number ≤ maximum for groups of averaged spectra
  - Max in this case is 194; we will use 10 here, power spectra will be averaged over 409.6 x 10 = 4096 sec, which is about one NICER orbit
- Binning is your choice (typically, for QPOs, use -1)
- Result is one spectrum per frame, one per NICER ~orbit
- Result can be plotted, and also saved in "ni3010080128_0mpu7_cl.fps"
  - One extension for each averaged spectrum
  - Plot with fplot ni3010080128_0mpu7_cl.evt+1
    X Axis: FREQUENCY
    Y Axis: POWER[ERROR]
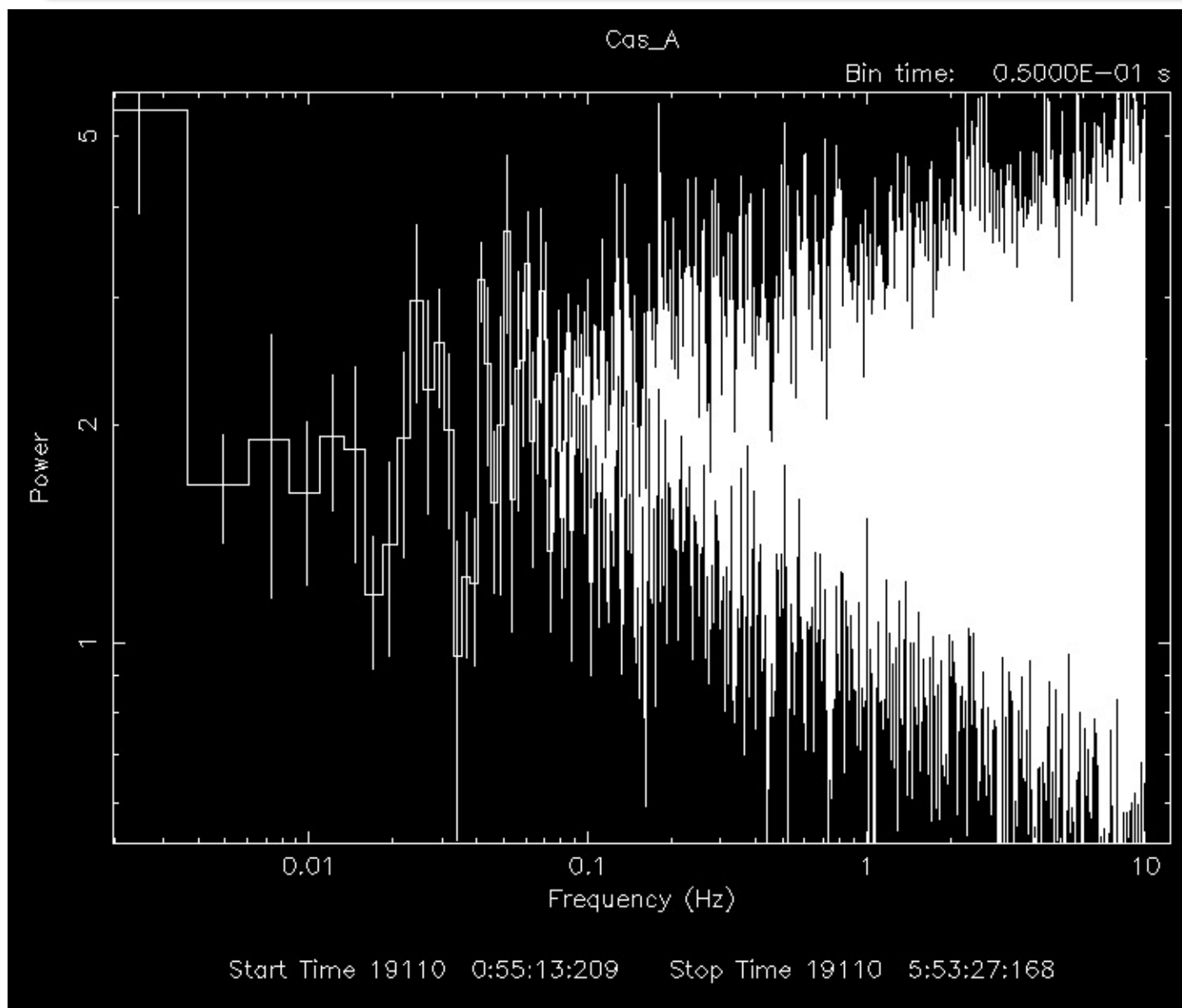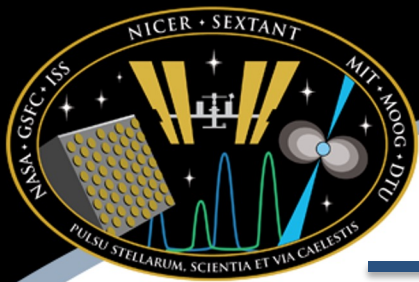
- **"Currently, what's the best way to properly subtract the background from a lightcurve? "**

Background lightcurve estimation is still under development. One method is to generate spectra for the time bins. The nicergof.bkg package includes a (**PRELIMINARY**) lightcurve background estimator called

mk_bkg_lc_evt(srclc, mkf3file)

which can be run from the python command line and which generates a background lightcurve file.

Inputs:
source lightcurve (extracted with xselect, for example)
source mkf file (with KP column added - using niaddkp, for example)

Method
Assumes each time bin is its own GTI and calculates the predicted background from SW conditions

Output: A background lightcurve FITS file

- **"Currently, what's the best way to properly subtract the background from a lightcurve? " CONTINUED**

In [2]: from nicergof.bkg import bkg_estimator as be
In [3]: be.add_kp('3591011901/auxil/ni3591011901.mkf2')
In [4]: bklctab = be.mk_bkg_lc_evt('ni3591011901_0mpu7_cl.lc', mkf3, bevt=bevt, chanrange=[40,800])

Writing ni3591011901_0mpu7_cl_bkg.lc

… this would generate an estimate of the background lightcurve in the channel range 40-800 (0.4-8.0 keV) at the times corresponding to the bin times in the ni3591011901_0mpu7_cl.lc lightcurve file. (Note that chanrange should match the channel range in the lightcurve file.)

(see https://heasarc.gsfc.nasa.gov/docs/nicer/tools/nicer_bkg_est_tools.html for instructions on downloading and installing the SW background estimator)

Q16. Highly Absorbed Sources

- **"For highly absorbed bright sources (10^24), does the NICER response give a flat instrumental X-ray spectrum below 2keV like was seen for Suzaku/XIS? (e.g., Fig 2 of https://iopscience.iop.org/article/10.1088/0004-637X/745/2/124)"**

- This question is similar to Q2

Q17. Merging Observations

- **"What is the best way to reliably create a single event list when an observation has been split into multiple ObsIDs, and are there any caveats when (e.g.) calculating the background spectrum? "**

- This question is similar to Q4

- "Hello! So I missed the background tutorial due to poor connection. Here are my queries.
  1) How to set up the 3c50 software?
  2) After proper set up of 3c50, will the command 'nicerl2 …' produce cleaned event which is background subtracted?
  or, there is other way to use 3c50?"

- Please start with the NICER Background Estimator Tools web page
  https://heasarc.gsfc.nasa.gov/docs/nicer/tools/nicer_bkg_est_tools.html

Q19. Calibration Residuals 1-3 keV

- "There are calibration residual from Si and Au edge due to mirror coating between 1-3 keV due to instrument. Are these contributions included in the responses of CALDB? Thank you!"

- Please refer to Calibration Status information presented Monday

Crab (Old Calib!)
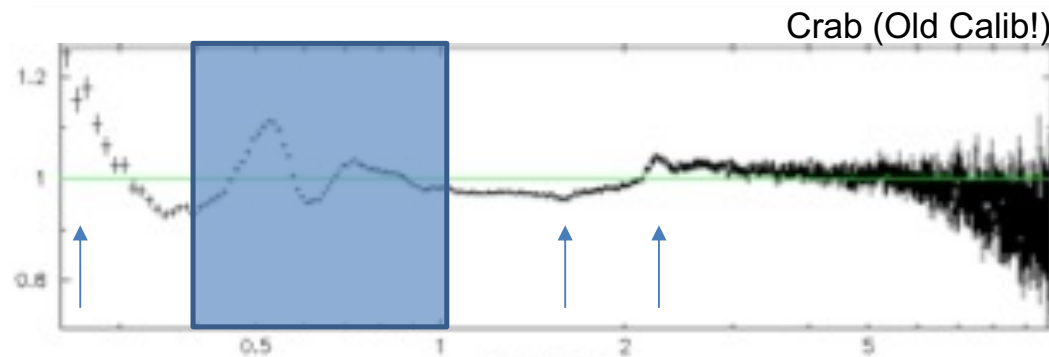
- ~2.2 keV – Gold M edge from XRC reflector gold coating (actually a complex from 2.1 – 4.5 keV)

- 1.84 keV – Silicon K edge (window & bulk detector)

- 1.56 keV – Aluminum K edge/fluorescence (detector window)

Live Question: NICER/NuSTAR cal

- **What is the range of cross normalisation constant in spectral fitting between NICER and NuSTAR?**
- NICER typically within about 5-8% of NuSTAR
- Presentation by Renee Ludlam in next sessions

Live Question: Deadtime

- **Is there a known dead time for NICER? If so what it is the frequency/period? and do we know of conditions where dead time will become an issue? (Ex: with nustar dead time is a major problem for timing with observations with >1cps).**

- Typical observations, deadtime < 1%, ignorable

- For the Crab, typical deadtime is ~0.5%
  - For very high undershoots (200 ct/s/det) Crab deadtime would be ~1%