NICER Analysis Workshop

May 2021

NICER

Neutron star Interior Composition ExploreR

NICER Screening Tutorial

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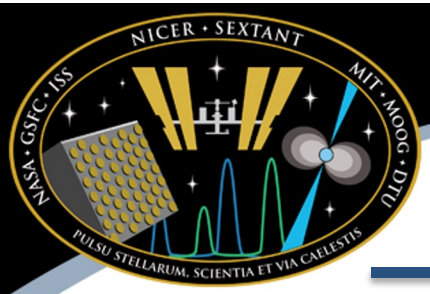
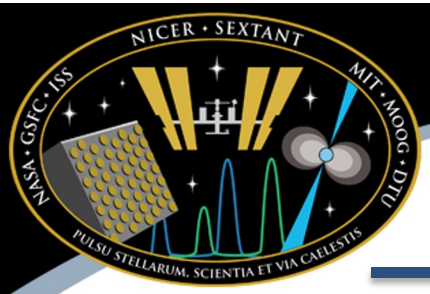


Overview

- This presentation discusses the NICER-standard screening criteria
  - Why they are set the way they are
  - How you can cautiously change them, and some of the impacts of doing so
  - What we recommend to not change
  - How to run nicerl2 or nimaketime to get these changes



Why is This Important?

- The standard NICER pipeline uses standard, **conservative**, screening settings
- This reduces the chances of ”bad” data getting mixed with good science data
- However, sometimes the screening is too conservative, and most or all of the data is lost
  - ”Where’s My Data?”
- Therefore, the analyst needs knowledge of ways to adjust the screening settings, and the impacts of doing so

Screening Options Being Discussed

- Detector resets (“Undershoots”) – a measure of leakage current and optical light
  - nicerl2 setting: underonly_range
- Overshoots resets – a measure of high energy particle backgrounds
  - nicerl2 setting: overonly_range
- Cut-off Rigidity Screening
  - nicerl2 setting: cor_range

Where Are Screening Values Stored?

- NICER maintains a Filter File (also known as .mkf file)
  - NNNNNNNNNN/auxil/niNNNNNNNNNN.mkf in your observation directory
- Filter file has MANY quantities that can be examined and screened on

Example Filter File

```
HDU 2   PREFILTER          BinTable   101 cols x 17827 rows

 Col  Name              Format[Units](Range)      Comment
   1 TIME               1D [s]                 seconds since mission epoch
   2 POSITION           3E [km]                ECI position of satellite [X,Y,Z]
   3 VELOCITY           3E [km/s]              ECI velocity of satellite [X,Y,Z]
  13 ELV                1E [deg]               angle between pointing and earth limb
  14 BR_EARTH           1E [deg]               angle between pointing and bright earth
  15 SUNSHINE           1I                     1=in sunshine; 0=not
  22 ANG_DIST           1E [deg]               angular distance of pointing from nominal
  23 SAA                1I                     1=in SAA; 0=not
  24 SAA_TIME           1E [s]                 time since entering/exiting SAA
  26 COR_SAX            1E [GeV/c]             magnetic cut off rigidity (IGRF map)
  57 NICER_SAA          1B                     NICER-specific SAA definition
  85 FPM_OVERONLY_COUNT 1E                     Per-FPM over-only reset count from events
  86 FPM_UNDERONLY_COUNT 1E                    Per-FPM under-only reset count from events
  87 FPM_FT_COUNT       1E                     Per-FPM forced trigger count from events
  88 FPM_NOISE25_COUNT  1E                     Per-FPM noise count <0.25 keV from events
```

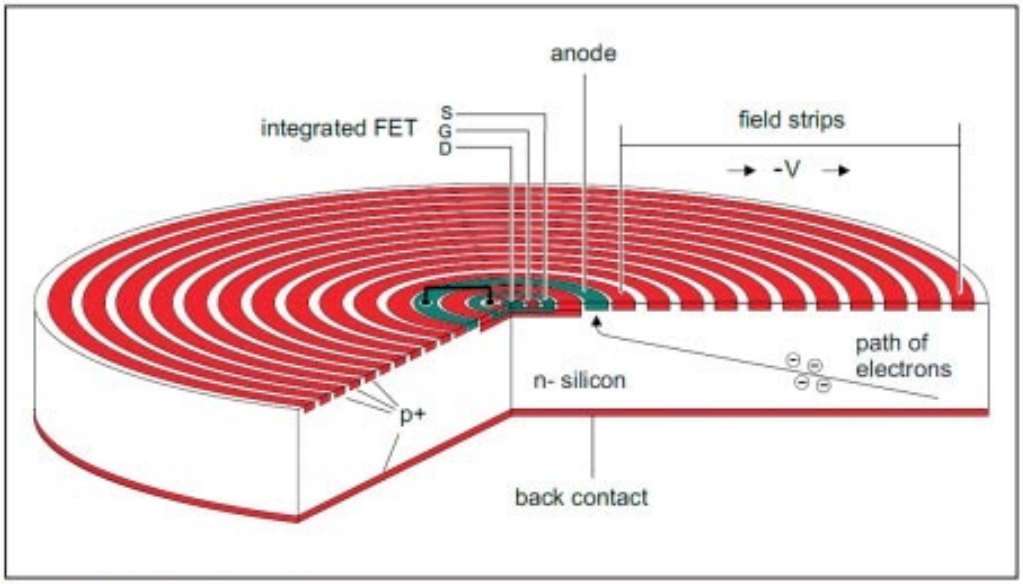
- Example of just a few of ~100 columns in filter file
- Command used:
  `ftlist 3010080128/auxil/ni3010080128.mkf HC`

Nicerl2 Screening Options

- Use the ‘nicerl2’ processing task to process all NICER observations (part of standard HEASoft)
  - How to run nicerl2:
    `nicerl2 indir=./1234567890 clobber=YES`
    In this presentation, we will discuss additional command line options to **expand or adjust screening** of data
  - Some filter file columns have specific nicerl2/nimaketime options, but you can always use nimaketime_gtiexpr to screen on any column you wish
- Internally to ‘nicerl2’ is a task called ‘nimaketime’ which makes screening GTI
  - All nimaketime options are also bubbled up to nicerl2
  - You can re-run nimaketime, and do your own event screening with nicermergeclean later (more work)
  - Or, you can re-run nicerl2 with different options (more CPU time)

Filtering Discussion: Undershoots

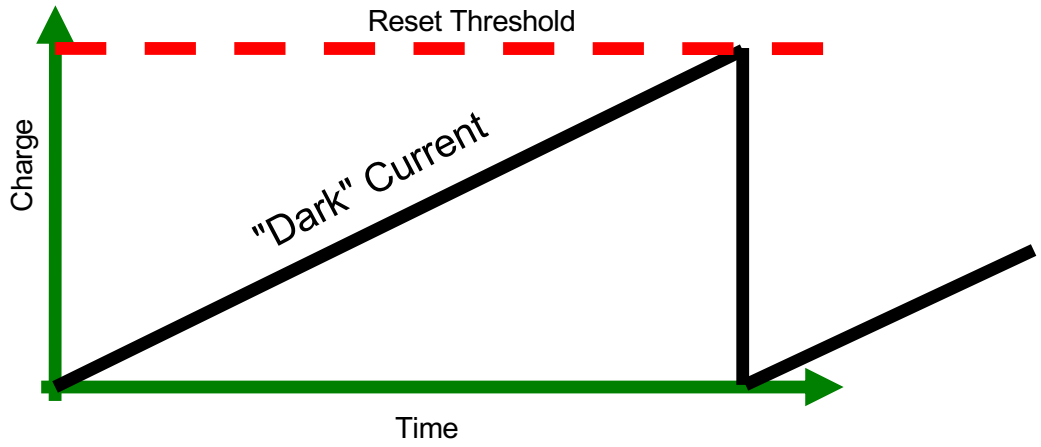
- NICER detectors are known as Silicon Drift Detectors (SDDs)

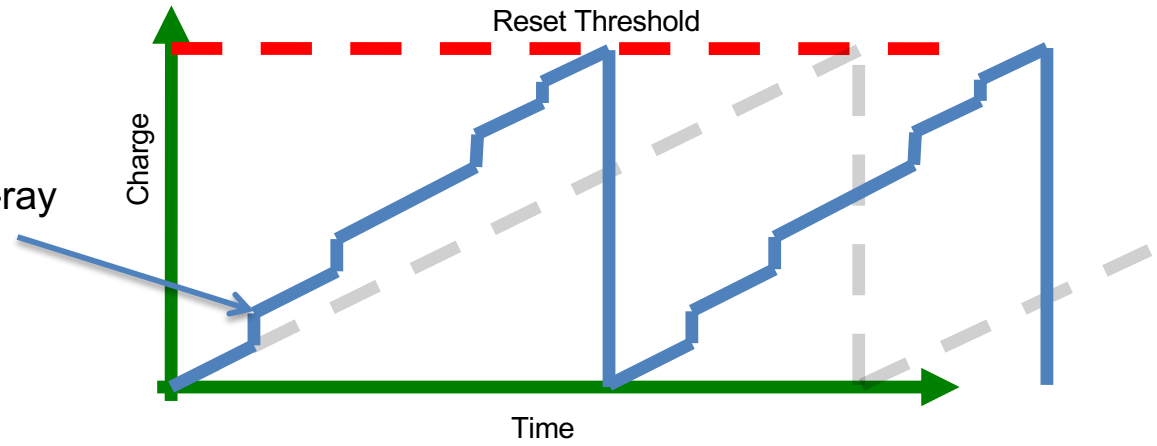


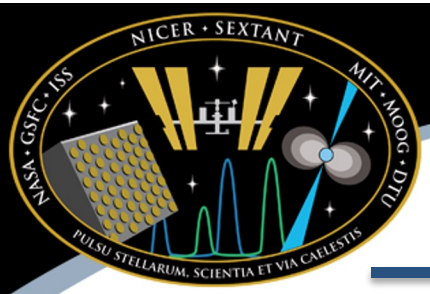
- As a part of normal operation, charge gradually builds up at the anode, and must occasionally be discharged
  - Detector reset, “Undershoot”

How NICER Detectors Work

- Amplified charge appears on capacitor and resets when full capacity reached (Undershoot)
- Unfiltered event files contain a mix of X-ray events, background events, and resets
- All of these are completely normal



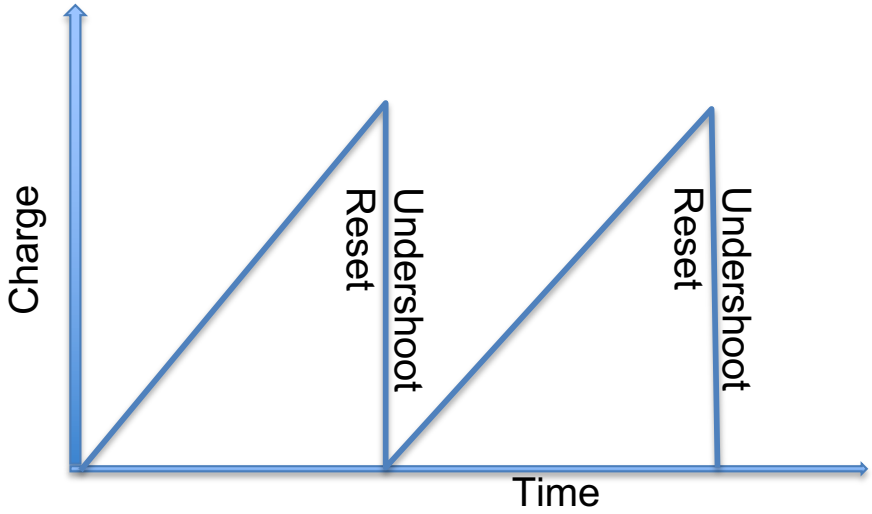




What Causes Detector Charging Current?

- X-rays
- Background charged particles
- Detector leakage currents
- Optical photons (“optical loading”)
  - This is typically the dominant source of charging and thus resets

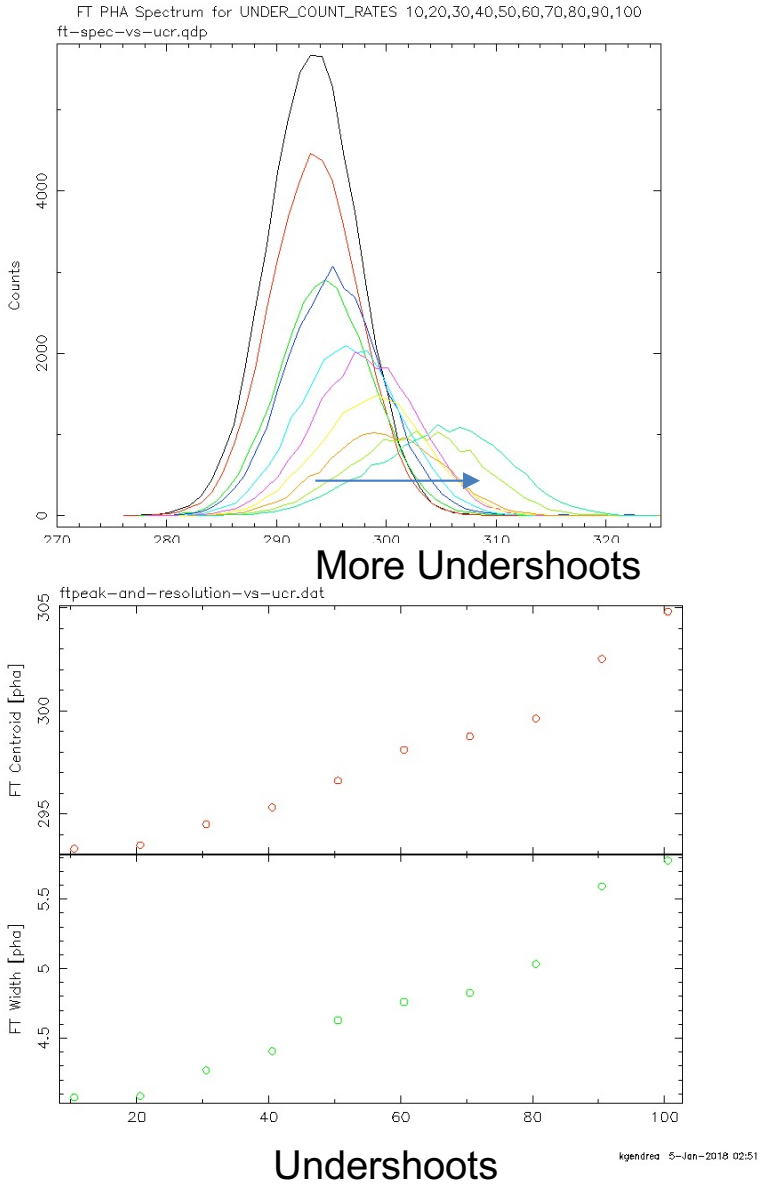
Typical Undershoot Rates

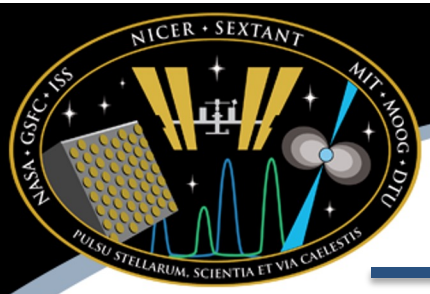


- Internally, detector system behaves as a charging capacitor
  - Charging rate (2-200 Me^-/s):
    - Leakage current (dark current)
    - **Electrons injected by optical photons** (optical loading)
    - Charged particles
    - X-rays (few hundred electrons/event)
  - Discharge rate: when full-well charge is reached, detector is reset, registered in filter file as an “undershoot” reset
    - Dark undershoot rate ~5-10 ct/s; brightest conditions >1000 ct/s (per detector)

Impacts of Optical Loading

- Impacts
  - Energy scale is shifted
  - Narrow peaks are broadened
- Current Calibration
  - Energy scale variations calibrated in undershoot range 0-200 ct/s
  - There is no undershoot dependence in released RMF
- **This is why we recommend limiting undershoots to 0-200 ct/s range (default)**

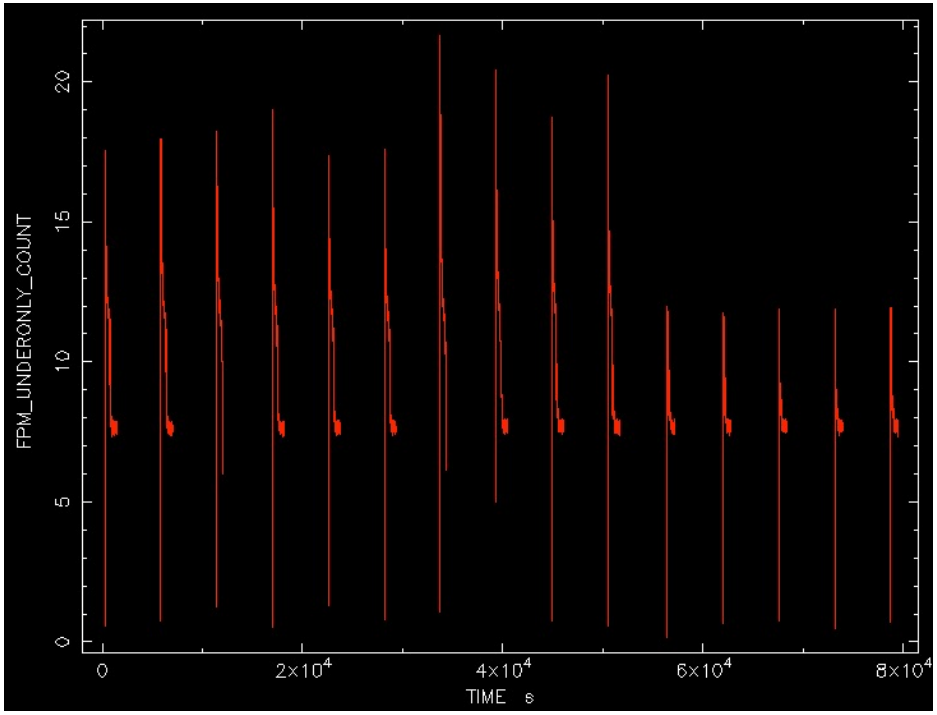




When Is Optical Loading an Issue?

- Not always, but most probable issues when
  - Target is near the sun (SUN_ANGLE < 60 [deg])
  - Observatory is in orbit day (SUNSHINE = 1)
  - Near the full moon

Checking Undershoots



Look to see if undershoot rate exceeds 200 ct/s, which is the default maximum.

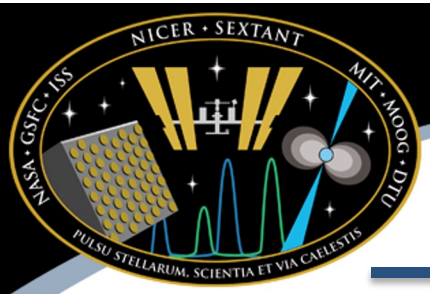
In our example dataset, the undershoots are low (0-20), so they are not a problem

- Command used:
  `fplot 3010080128/auxil/ni3010080128.mkf offset=YES`
  X Axis: `TIME`
  Y Axis: `FPM_UNDERONLY_COUNT`

Undershoot Screening

- Detector Undershoot resets primarily indicate optical light loading
  - Filter file quantity `FPM_UNDERONLY_COUNT` (mean per-FPM undershoot)
  - Calibrated range 0-200 ct/s/FPM (CALDB xti20200722)
  - Going outside that range will lead to degraded energy scale assignment (~25 eV) and degraded resolution (~10 eV FWHM added in quadrature)
- Sometimes default screening excludes all data
  - Cautiously expand the range (example 0-300 instead of 0-200)

```
nicerl2 … underonly_range=0-300
```

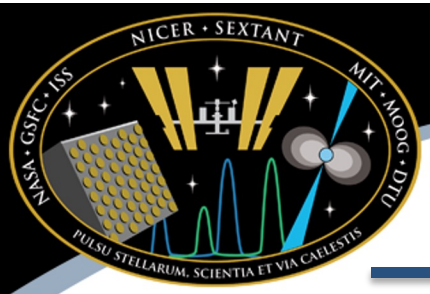


What To Look For When Increasing Undershoot Range

- Beware that the energy of features like lines and edges may be shifted from true Energy (10s of eV)
- Beware that narrow features like lines and edges may be broadened more than the released RMF indicates
- Discussion of improvements to situation in next presentation!

Undershoot Summary

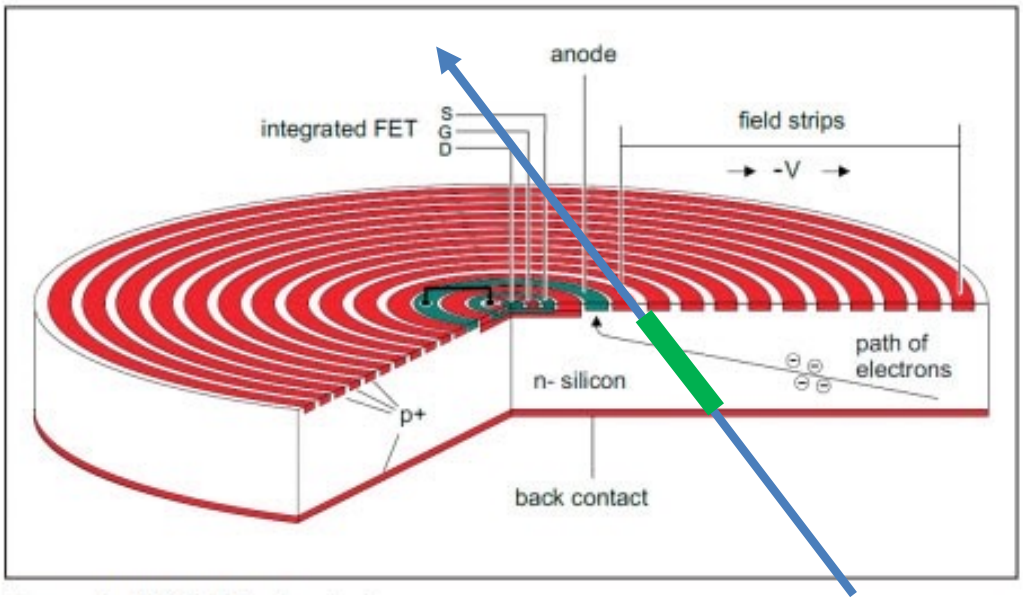
- If you find yourself with minimal (or zero) data after the default screening, check the filter file
- If most (or all) of undershoots are above 200 ct/s, consider increasing nicerl2's underonly_range parameter to 0-300, or higher
- Beware of the impact of doing this
  - Shift of features in energy
  - Broadening of features



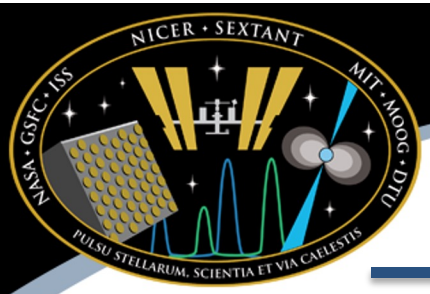
Overshoots Introduction

- Another of type of detector reset is known as an “Overshoot”
- These are events where the pulse height exceeded the maximum allowed value

What Causes Overshoots



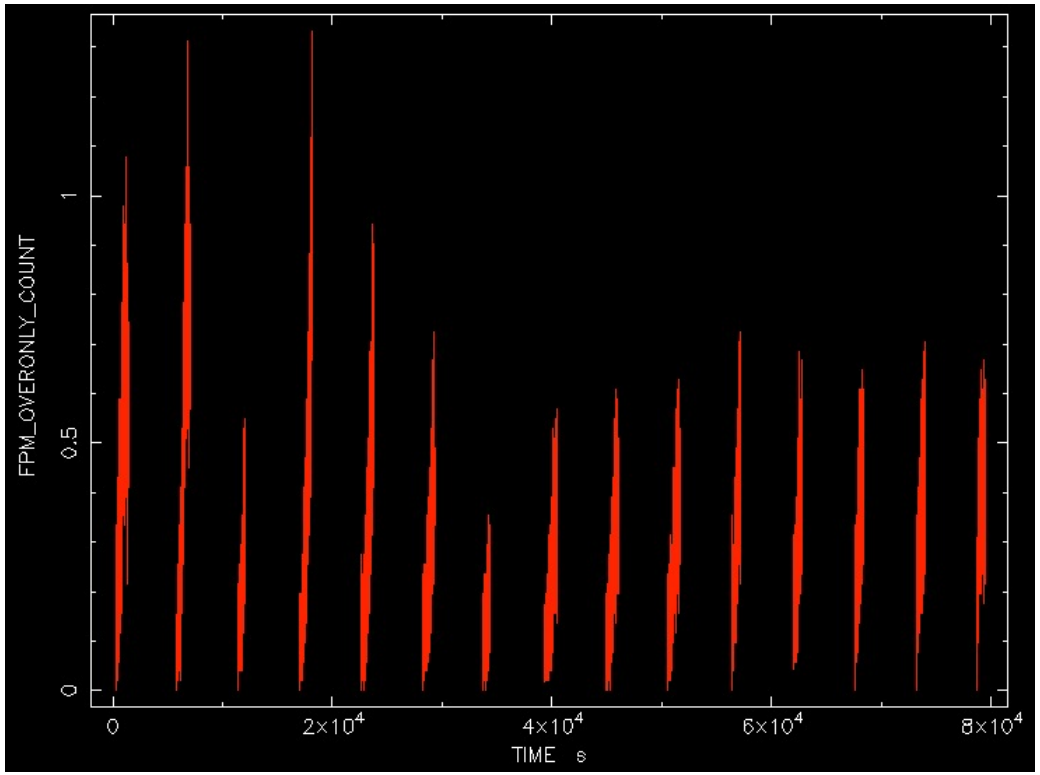
- Typically charged particle passes through detector and deposits energy
  - Cosmic rays and solar energetic particles
  - Trapped charges (electrons in polar horns and protons in SAA)
  - Typical kinetic energies of ~GeV for protons



Impacts of Overshoots

- Typical Overshoot rate is < 1 ct/s per detector
- Higher rates indicate higher detector background due to charged particles

Checking Overshoots



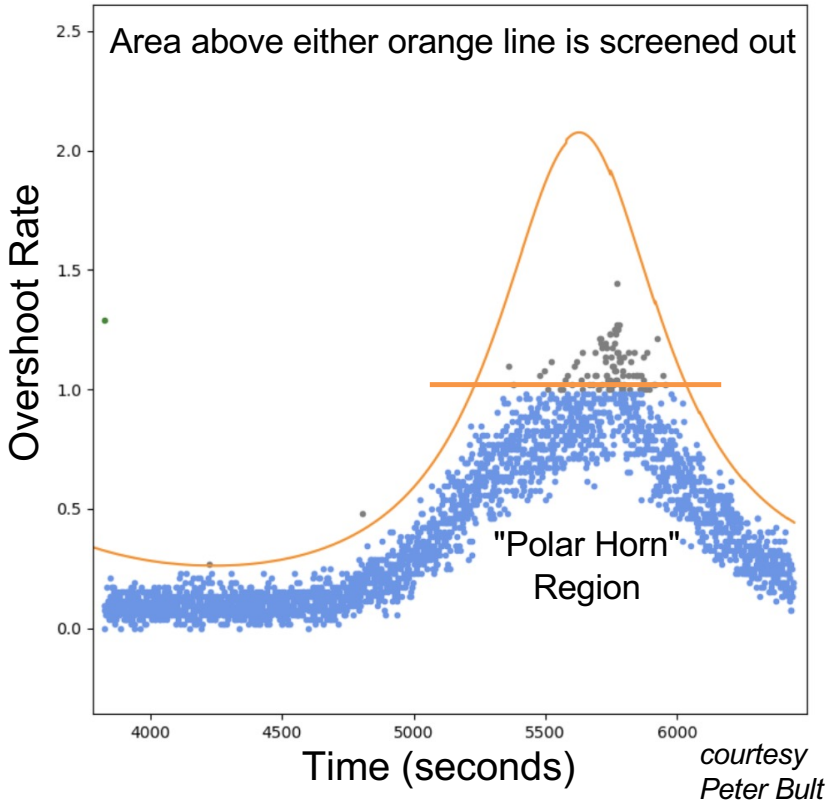
Look to see if undershoot rate exceeds 1 ct/s, which is the default maximum.

In our example dataset, the undershoots are exceed 1 in a few cases, but most values are below that threshold

- Command used:
  `fplot 3010080128/auxil/ni3010080128.mkf offset=YES`
  X Axis: `TIME`
  Y Axis: `FPM_OVERONLY_COUNT`

Default Overshoot Screening

- The overshoot screening is actually two different screenings
  - Overall range (0-1.0 default), set by overonly_range
  - COR_SAX based expression, set by overonly_expr



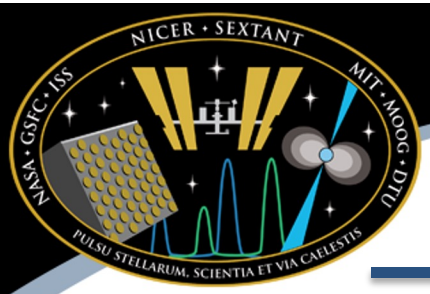
courtesy Peter Bult

How to Change Overshoot Screening

- Default screening was designed early in mission
  - We now know that solar modulation potential has changed since we developed this cut
  - Perhaps only data is in polar horn region
- Cautiously expand the range (example allow 150% of default)

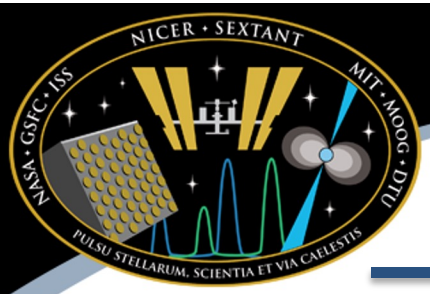
```
nicerl2 … overonly_range=0-1.5
overonly_expr="1.5*1.52*COR_SAX**(-0.633)"
```

  - Note the "1.5" in both overonly_range and overonly_expr
  - This will increase default 0–1 range to 0-1.5



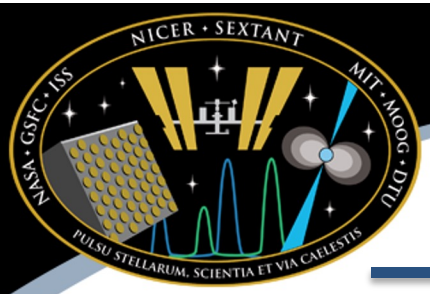
What to Look For When Changing Overshoot Screening

- Beware that higher overshoots usually indicate higher background levels
- Use caution when subtracting background



Overshoot Summary

- If you find yourself with minimal (or zero) data after the default screening, check the filter file
- If most (or all) of overshoots are above 1 ct/s, consider increasing nicerl2's overonly_range and overonly_expr parameters to higher values
- Beware of the impact of doing this
  - Shift of features in energy
  - Broadening of features



Additional Topics

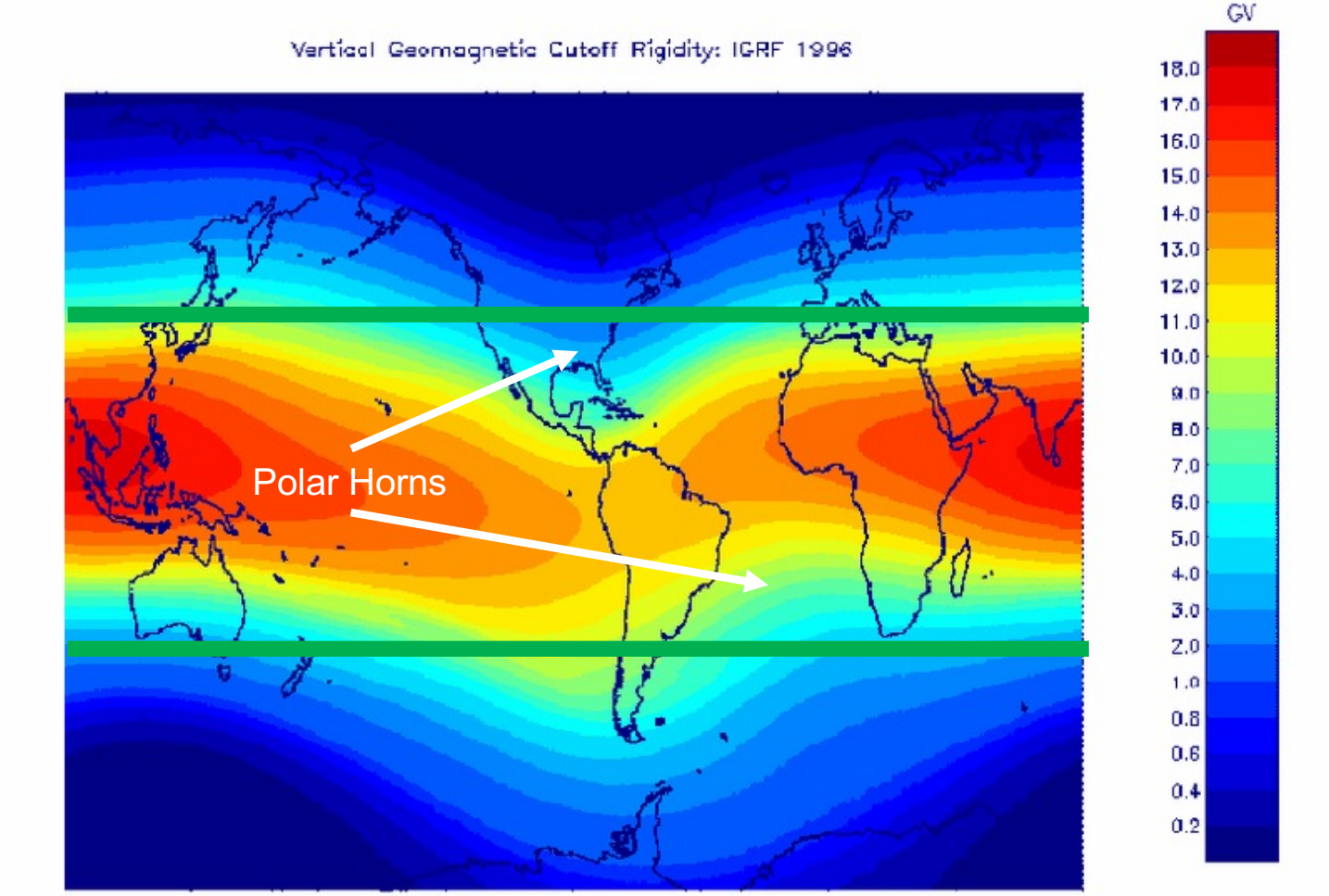
- Cutoff Rigidity filtering
- SAA filtering
- Pointing filtering

Cut-off Rigidity

- Cosmic rays, and to some extent trapped magnetospheric charges, are governed by cut-off rigidity (COR) of magnetic field
  - Measured in units of GeV/c
  - Fewer charged particles survive to higher cut-offs
  - Typical range: 0.8 - 15 GeV/c
  - Filter file column `COR_SAX`
- At low CORs, backgrounds will be higher, and more variable than at high cut-offs

HIGH LOW Background

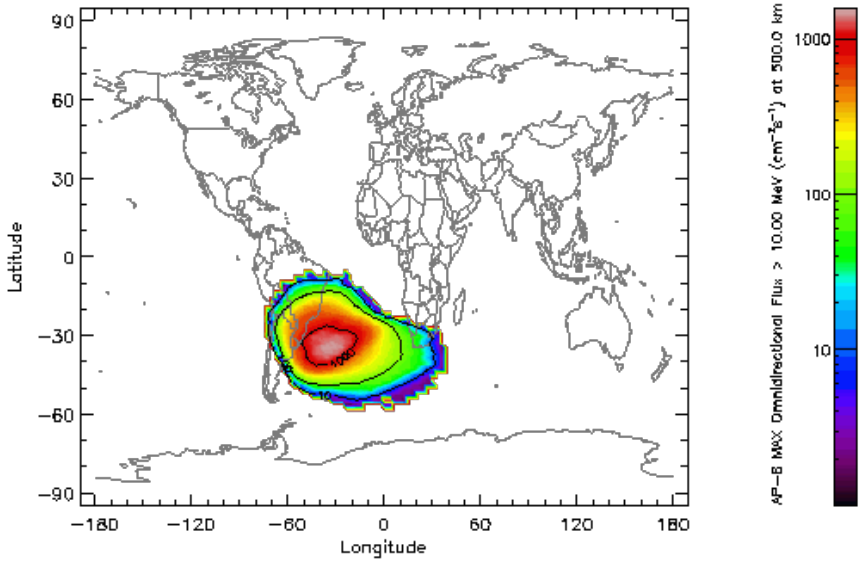
Cut-Off Ridigity Around the Globe

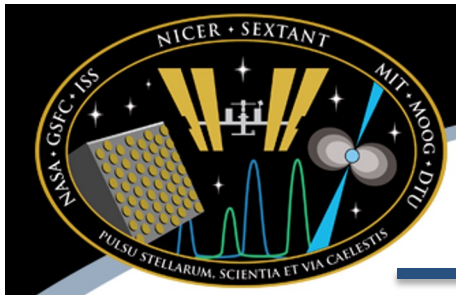


- Aside from SAA, “Polar Horns” have highest bkg

COR versus SAA

- Cut-off rigidity (COR) tends to indicate regions of high cosmic ray and trapped electron populations
  - Lowest COR (”polar horns”) has highest background rates
- South Atlantic Anomaly (SAA) is a specific geo-graphic region, composed of mostly trapped protons
  - Typically highest COR values



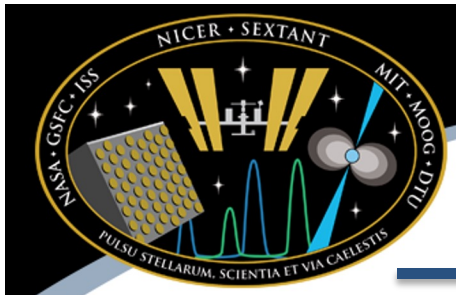


Screening on COR

- By default, NICER screening does not screen on COR
  - We now rely upon overshoot screening instead
- If you want to be more conservative, you can try narrowing the range

```
nicerl2 … cor_range=1.5-*
```

  - This will exclude COR in 0-1.5 range, which has highest and most variable background



SAA Screening

- There are actually two SAA contours calculated by NICER software
  - "SAA" – calculated by prefilter based on ASCA data (bigger contour)
  - "NICER_SAA" – derived from post-launch background data (smaller contour; default)
- By default, NICER_SAA is used, which results in more data, but potentially more background
- If you want to be more conservative (exclude more data) you can try the SAA contour instead

```
nicerl2 … nicersaafilt=NO saafilt=YES
```

Pointing Screening

- The standard screening attempts to make sure the target is on-axis for science analysis
  - trackfilt=YES (enable following screening checks)
  - ang_dist=0.015 (pointing offset allowed)
  - elv=15 (elevation above earth limb)
  - br_earth=30 (bright earth angle)
  - st_valid=YES (ensure good star tracker solution)
- The NICER team used to be more conservative with these screening cuts to avoid bright earth/ISS/sunlight, but now relies more on undershoot filtering
- The only reason to expand these cuts is if you would lose a time-sensitive event like a burst near earth limb

Common Issues: Disabled Detectors

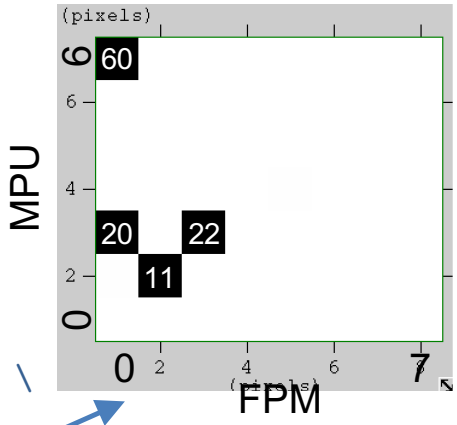
- While NICER has 52 operational detectors not all detectors are enabled for every observation. This is occurring more often now compared to post-launch
  - Occasionally, a detector auto-disables itself
  - NICER operators may disable detectors for high-rate targets
  - Detectors may be disabled for maintenance activities ("annealing")
- How to check using your filter file (.mkf file)
  - Number of detectors:

    ```
    ftstat niNNNNNNNNN.mkf
    ```

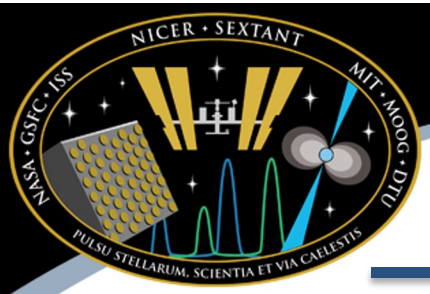
    (and check median of NUM_FPM_ON column)
  - Which detectors disabled:

    ```
    fsumrows infile=niNNNNNNNNN.mkf'[1][col F=(FPM_ON?1:0)]' \
      outfile=fpm_on.fits cols=F rows=- operation=sum
    ```

    (and use 'fv' to view resulting fpm_on.fits table image)
    DET_ID = (MPU x 10) + FPM
  - DET_ID's 11, 20, 22 and 60 are always disabled, as shown in figure



- When making ARFs and RMFs for spectra, be sure to follow instructions on NICER Response thread to include only enabled detectors



Summary

- If you have less than expected data, it is most likely due to
  - High optical loading
    - Change underonly_range parameter
  - High background
    - Change overonly_range and overonly_expr
- Check the filter file for these conditions, and loosen the filtering ranges with caution