NICER

Neutron star Interior Composition ExploreR

NICER Software

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on behalf of the NICER team

GSFC MIT KAVLI INSTITUTE BROAD REACH MOOG

Thanks to:

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Deputy PI

Craig Markwardt
Software/Calibration

Elizabeth Ferrara
NICER GOF

Overview

1) Accessing data

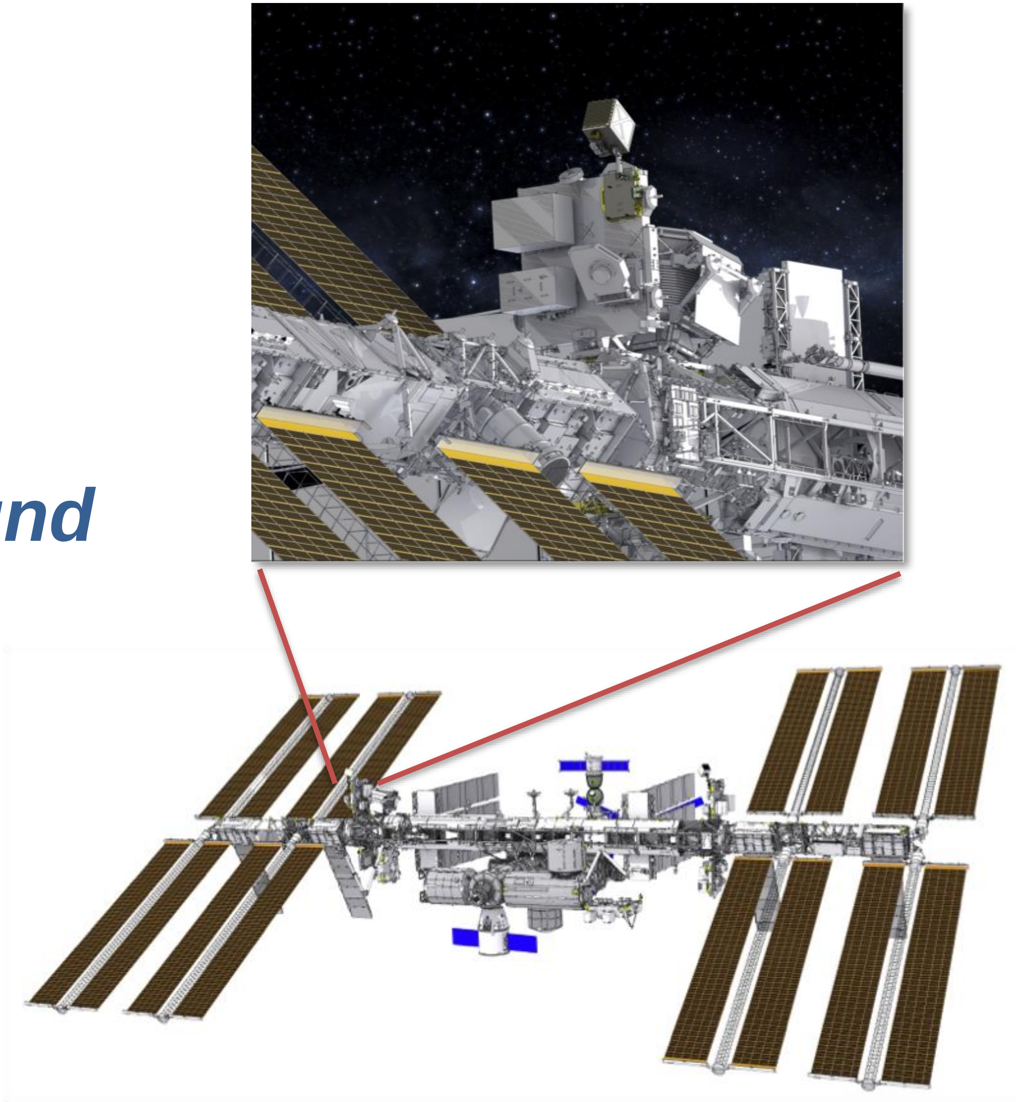
2) NICER software

3)Spectral extraction

3) Dealing with Background

4) Light curve extraction

5) Things to look out for



HEASOFT

Patches for existing 6.31 installations:

- For users who already have HEASoft 6.31, please see our 6.31.1 patch page for information about updating your installation to 6.31.1.

STEP 1 - Select the type of software:

SOURCE CODE DISTRIBUTION (Recommended):

Please note that the source code distribution is recommended - *particularly for Linux users* - due to portability issues that can affect the pre-compiled binaries. Also, a source code distribution is **required** for users who wish to use **local models in XSPEC / PyXspec**.

( ) **Source Code**

PRE-COMPILED BINARY DISTRIBUTIONS (May experience portability issues):

Please note that the pre-compiled binaries are **not recommended** - *particularly for Linux users* - due to Perl portability issues. Also, note that users who wish to use **local models in XSPEC** or **PyXspec** must get the source code distribution instead. **Pre-compiled binaries for Silicon Macs are currently unavailable but may be added at a later date.**

( ) **PC - Ubuntu Linux 20.04**
( ) **PC - Fedora Linux 36**
( ) **PC - Red Hat Enterprise Linux 8.5**
( ) **PC - Scientific Linux 7.9**
( ) **Mac Intel - Darwin 22.x (OS 13.x.x)**
( ) **Mac Intel - Darwin 21.x (OS 12.x.x)**

STEP 2 - Download the desired packages:

Selecting an individual mission package will automatically select a set of recommended general-use tools.

- [ ] All
- [ ] Mission-Specific Tools
  - [ ] **ASCA** [ ] **Einstein** [ ] **EXOSAT** [ ] **CGRO** [ ] **HEAO-1** [ ] **Hitomi** [ ] **INTEGRAL** [ ] **IXPE** [ ] **MAXI**
  - [x] **NICER** [ ] **NuSTAR** [ ] **OSO-8** [ ] **ROSAT** [ ] **Suzaku** [ ] **Swift** [ ] **Vela** [ ] **XTE**
- [ ] General-Use FTOOLS
  - [x] **Attitude** [x] **Caltools** [x] **Futils** [x] **Fimage** [x] **HEASARC** [ ] **HEASim** [x] **HEASPtools**
  - [x] **HEATools** [x] **HEAGen** [ ] **FV** [x] **Time**
- [ ] XANADU
  - [ ] **Ximage** [x] **Xronos** [x] **Xspec ***
- [ ] XSTAR

Submit | Reset

CALDB

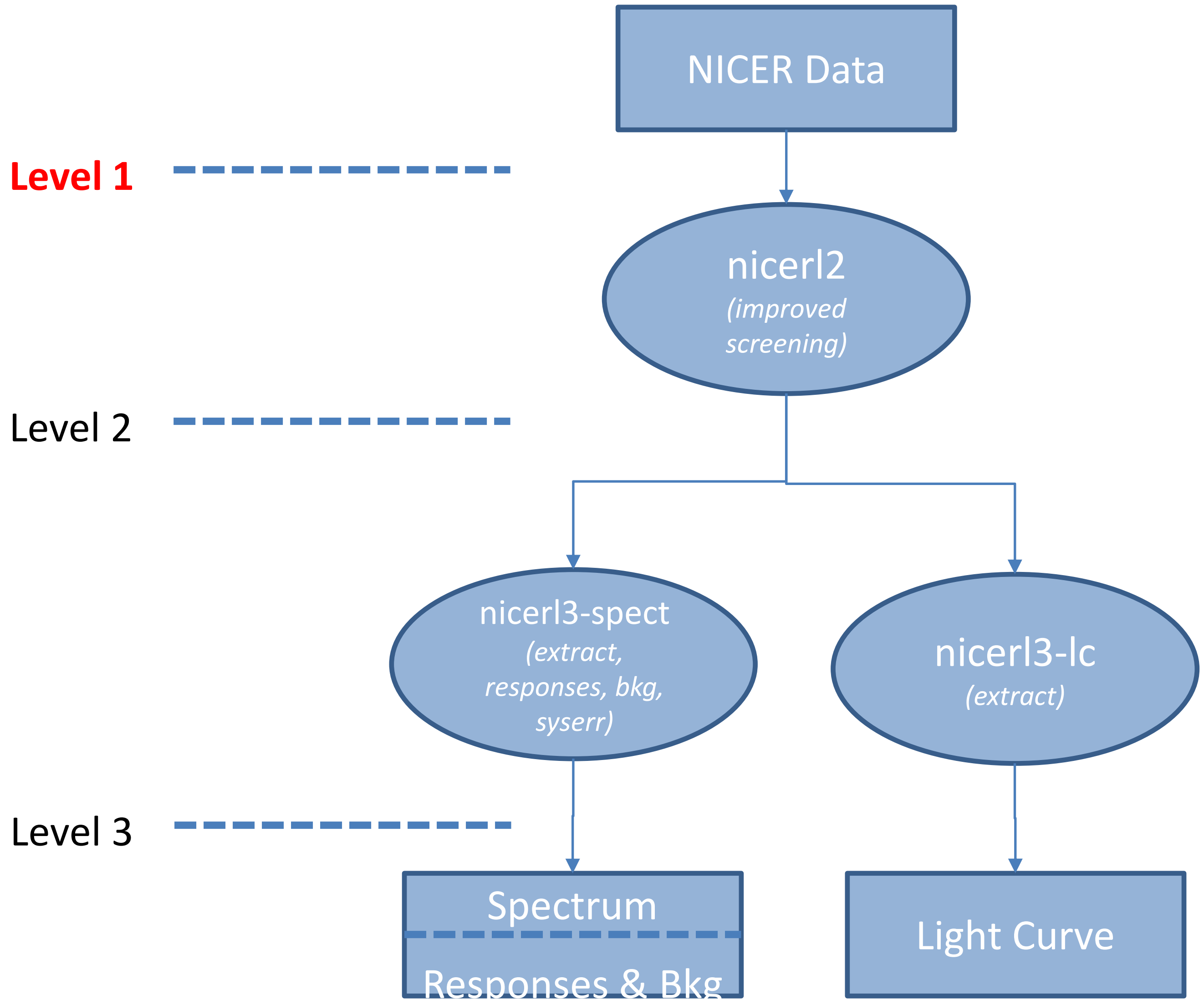
https://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/caldb_supported_missions.html

NICER					
	XTI	October 1, 2022	ascii list	Tar file (61 MB)	Index File Summary

```
export GEOMAG_PATH=/home/myname/geomag
```

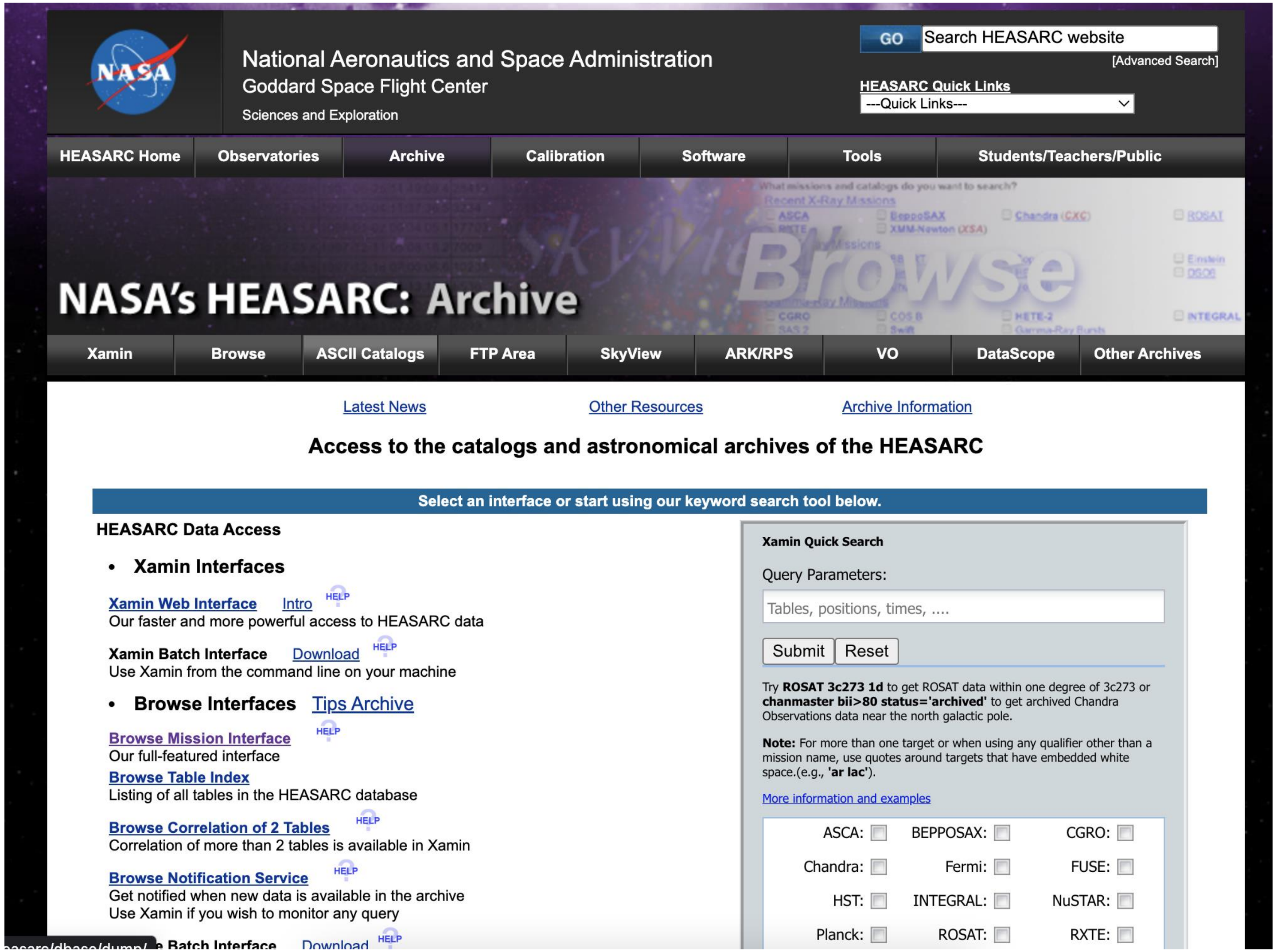
Geomag path must be set for background models, unique to NICER

New Workflow: Streamlined



HEASARC Data Archive

https://heasarc.gsfc.nasa.gov/docs/archive.html



HEASARC Data Archive

HEASARC Home | Observatories | Archive | Calibration | Software | Tools | Students/Teachers/Public

Archive — **HEASARC Browse** — Tip Archive | Hera | HELP

Other Browse interfaces:
Notification Service | Batch | Correlation | Index of All Tables

Query File And Session Uploads

Start Search | Reset | Detailed Mission/Catalog Search

1. Do you want to search around a position ... ?
(If you want to search on parameters other than object name or coordinates, select "Detailed Mission/Catalog Search".)

Object Name or Coordinates: MAXI J1820+070 **and/or** **Select Local File:** Choose File No file chosen

e.g. **Cyg X-1** or **12 00 00, 4 12 6** or **Cyg X-2; 12.235, 15.345** (Note use of semicolons (;) to separate multiple object names and/or coordinate pairs.)

File should contain objects and/or coordinate pairs one per line or separated by semicolons.

Coordinate System: J2000

Search Radius: Default arcmin

Default uses the optimum radius for each catalog searched.

... and/or search by date?

Observation Dates: YYYY-MM-DD hh:mm:ss or MJD: DDDDD.ddd

Not all tables have observation dates. For those that do, the time portion of the date is optional. Times are always in UTC. Separate multiple dates/ranges with semicolons (;). Range operator is '..' (e.g. **1992-12-31; 48980.5; 1995-01-15 12:00:00; 1997-03-20 .. 2000-10-18**).

2. What missions and catalogs do you want to search? (Bold text indicates mission is active)

☐ Most Requested Missions

☐ **Chandra** [*CXC*,*CSC*]	☐ **Fermi**	☐ **HaloSat**	☐ **Hitomi**
☐ **IXPE** [*MSFC*]	☐ **MAXI** [*JAXA*]	☑ **NICER**	☐ **NuSTAR** [*Caltech*]
☐ ROSAT	☐ RXTE	☐ **Suzaku**	☐ **Swift**
☐ **WMAP**	☐ **XMM-Newton** [*XSA*]		

☐ Other X-Ray and EUV Missions

☐ Ariel V	☐ ASCA	☐ BBXRT/Astro-1	☐ BeppoSAX
☐ Copernicus	☐ Einstein	☐ EUVE [*MAST*]	☐ EXOSAT
☐ Ginga	☐ HEAO 1	☐ Kvant	☐ OSO8
☐ SAS 3	☐ **SRG/eROSITA** [*MPE*]	☐ Uhuru	☐ Vela 5B

☐ Other Gamma-Ray Missions

HEASARC Data Archive

NICER Master Catalog (nicermastr)   Bulletin

Search radius used: 15.00'

Select All	Services	name	ra	dec	time	obsid	exposure [s]	processing status	processing date	public date	obs type	Search Offset ['] from (target)
	O R N S D B	MAXI_J1820+070	18 20 21.89	+07 11 06.5	2018-03-24 23:35:38.00	1200120110	22132.43531	VALIDATED	2018-04-14 09:06:54	2018-04-30	DDT_TOO	0.018 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 21.91	+07 11 06.7	2018-03-22 00:34:59.00	1200120107	17859.76112	VALIDATED	2018-04-14 04:00:28	2018-04-30	DDT_TOO	0.013 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 21.91	+07 11 06.6	2018-03-26 00:16:49.00	1200120111	17819.20307	VALIDATED	2018-04-14 14:04:21	2018-04-30	DDT_TOO	0.014 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 21.98	+07 11 05.5	2018-06-28 04:29:40.00	1200120189	16706.71323	VALIDATED	2018-07-02 21:33:13	2018-07-12	DDT_TOO	0.031 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 21.74	+07 11 05.6	2018-03-26 23:50:00.00	1200120112	15183.90618	VALIDATED	2018-04-14 17:03:59	2018-04-30	DDT_TOO	0.056 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 21.94	+07 11 05.5	2018-03-24 00:36:00.00	1200120109	12975.48074	VALIDATED	2018-04-16 22:23:37	2018-04-30	DDT_TOO	0.030 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 21.86	+07 11 05.8	2019-03-24 00:10:21.00	2200120310	12001.00000	VALIDATED	2019-04-06 00:11:12	2019-04-07	DDT_TOO	0.032 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 22.15	+07 11 08.3	2018-04-16 01:37:17.00	1200120130	10618.55159	VALIDATED	2018-04-25 04:20:17	2018-04-30	DDT_TOO	0.055 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 21.86	+07 11 05.8	2018-03-31 08:28:18.00	1200120116	9926.57193	VALIDATED	2018-04-17 00:47:00	2018-04-30	DDT_TOO	0.032 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 21.96	+07 11 07.4	2018-03-13 23:56:12.00	1200120103	9508.00000	VALIDATED	2018-03-19 00:14:19	2018-03-28	DDT_TOO	0.005 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 21.94	+07 11 05.7	2018-04-02 00:37:18.00	1200120118	9276.43457	VALIDATED	2018-04-14 21:47:46	2018-04-30	DDT_TOO	0.027 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 22.01	+07 11 05.9	2019-02-08 06:58:00.00	1200120314	8834.54956	VALIDATED	2019-02-15 07:15:29	2019-02-22	DDT_TOO	0.028 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 21.82	+07 11 06.0	2019-03-27 00:51:20.00	2200120313	8798.00000	VALIDATED	2019-04-06 03:21:09	2019-04-10	DDT_TOO	0.038 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 21.98	+07 11 03.8	2018-04-17 00:44:57.00	1200120131	7340.77045	VALIDATED	2018-04-25 06:32:44	2018-05-01	DDT_TOO	0.058 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 21.84	+07 11 06.2	2019-03-26 00:06:42.00	2200120312	7306.00000	VALIDATED	2019-04-06 02:19:00	2019-04-09	DDT_TOO	0.031 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 21.89	+07 11 06.5	2019-03-20 00:21:10.00	2200120306	6973.00000	VALIDATED	2019-03-24 07:53:53	2019-04-03	DDT_TOO	0.019 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 22.13	+07 10 59.8	2018-04-21 23:35:18.00	1200120134	6963.77640	VALIDATED	2018-04-27 20:42:21	2018-05-06	DDT_TOO	0.133 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 22.06	+07 11 05.1	2018-04-25 00:34:34.00	1200120137	6938.44332	VALIDATED	2018-05-02 22:28:41	2018-05-09	DDT_TOO	0.046 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 21.98	+07 11 06.6	2018-03-22 23:43:18.00	1200120108	6764.75746	VALIDATED	2018-03-28 01:49:12	2018-04-06	DDT_TOO	0.016 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 22.75	+07 11 09.4	2018-05-22 05:36:12.00	1200120156	6683.97869	VALIDATED	2018-05-27 00:44:22	2018-06-05	DDT_TOO	0.204 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 22.15	+07 11 11.4	2018-03-12 13:51:20.00	1200120101	6496.00000	VALIDATED	2018-03-16 22:42:40	2018-03-26	DDT_TOO	0.086 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 21.98	+07 11 05.2	2018-04-04 00:30:01.00	1200120120	6486.60787	VALIDATED	2018-04-10 02:13:20	2018-04-18	DDT_TOO	0.036 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 21.89	+07 11 08.2	2018-05-05 05:45:40.00	1200120145	6405.78467	VALIDATED	2018-05-09 04:52:25	2018-05-19	DDT_TOO	0.020 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 21.86	+07 11 07.2	2018-03-15 00:36:04.00	1200120104	6235.00000	VALIDATED	2018-03-19 20:18:45	2018-03-29	DDT_TOO	0.020 (MAXI J1820+070)
	O R N S D B	MAXI_J1820+070	18 20 22.06	+07 11 01.7	2019-04-14 17:26:03.00	2200120323	6062.00000	VALIDATED	2019-04-29 18:59:01	2019-04-28	DDT_TOO	0.097 (MAXI J1820+070)

HEASARC Data Archive

☑ Select all products for all rows

NICER Master Catalog (nicermastr) FTOOLS

name	ra	dec	time	obsid	exposure	processing_status	processing_date	public_date	obs_type
MAXI_J1820+070	18 20 21.89	+07 11 06.5	2018-03-24 23:35:38.00	1200120110	22132.43531	VALIDATED	2018-04-14 09:06:54	2018-04-30	DDT_TOO

☐ Select all products in this row

Full Observation Dataset

☑ Auxiliary Files (auxil)	DIRECTORY	61999 kB	updated: 2018-05-01 08:44:36
☑ Full Observation Dataset (1200120110)	DIRECTORY	28128053 kB	updated: 2018-05-01 08:56:53
☑ Log Files (log)	DIRECTORY	319 kB	updated: 2018-05-01 08:56:53
☑ XTI All Data (xti)	DIRECTORY	28065735 kB	updated: 2018-05-01 08:49:39
☑ XTI Cleaned Data (event_cl)	DIRECTORY	20747158 kB	updated: 2018-05-01 08:54:07
☑ XTI Unfiltered Data (event_uf)	DIRECTORY	7303193 kB	updated: 2018-05-01 08:47:36

TAR selected products | Create Download Script | Reset

Save to Hera What is Hera?

Browse Feedback

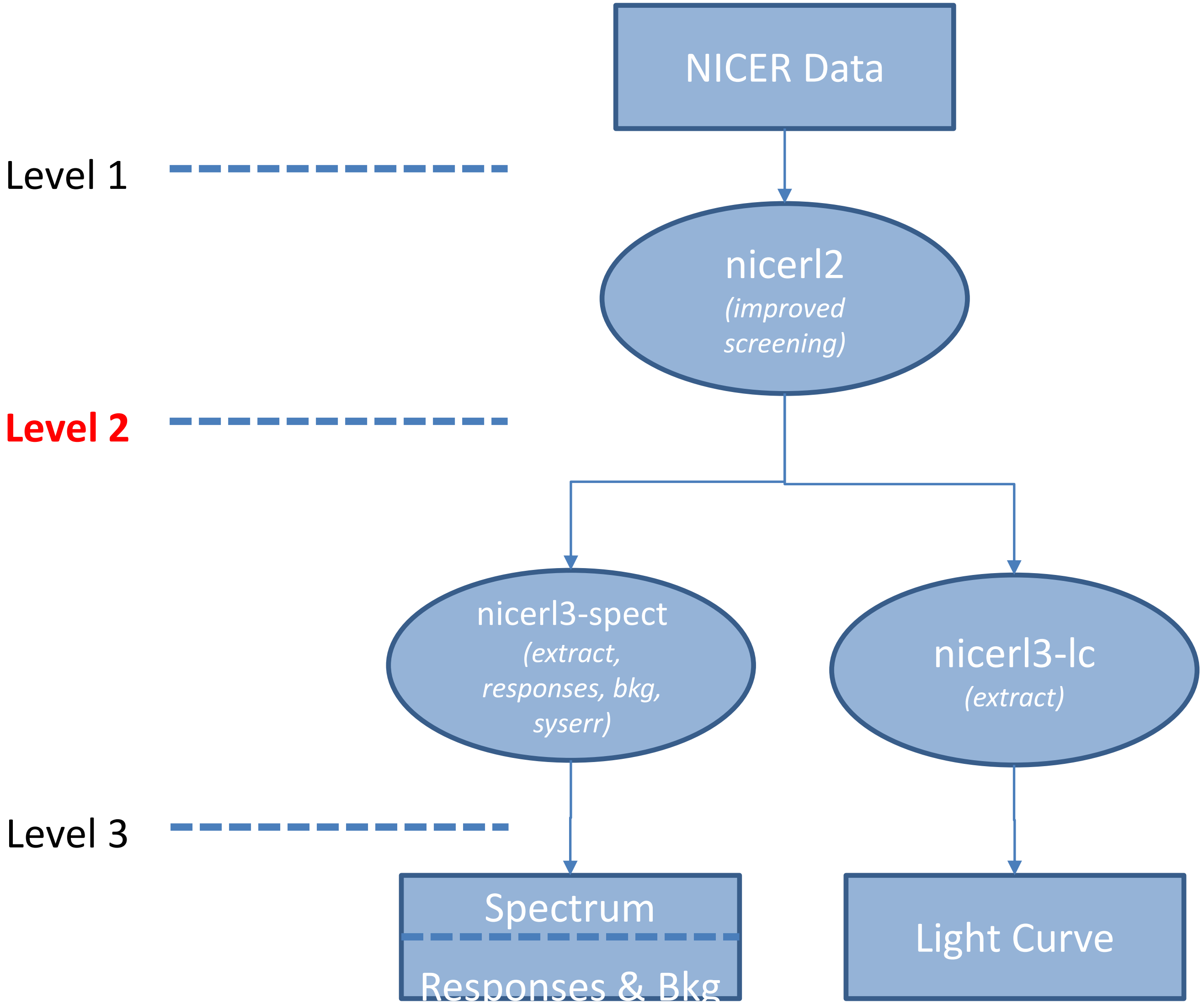
NICER Observational Data

- Data downloadable from NASA's HEASARC archive
  - Searchable using Browse or Xamin interfaces
  - Guest observers receive notification when data are ready
- A scientific observation is identified by its observational identifier (10-digit number)

  `PPPPTTVVss`

  - `PPPP` - Proposal number
  - `TT` - Proposed target number (e.g., proposer asked for two neutron star targets)
  - `VV` - Proposed visit number (e.g., proposer asked for five visits of 10 ks each)
  - `ss` - Segment number (observations crossing calendar day boundaries are split into multiple segments)
  - A day-long segment may have multiple "snapshots" or Good Time Intervals, since ISS is in a low-earth orbit, typically about 1000 seconds each

New Workflow: Streamlined



nicerl2

1. nicercal - apply standard NICER calibration
2. niprefilter2 - derive calibrated filter (MKF) file
3. nimaketime - create standard screening good time intervals
4. nicermergeclean - combine per-MPU data and filter/screen
5. niautoscreen - automatically screen for problematic per-FPM and per-MPU conditions

NICER High Level Recommendations

- Use the 'nicerl2' processing tool for all data
  - Applies calibration and standard processing
- Consult on-line NICER documentation for analysis issues
  - Software guide overview
  - Analysis "threads:" procedures for common issues
  - Analysis tips for specific known problems or issues you may encounter
  - Keep your CALDB up to date, and understand calibration limitations by reading calibration documents
  - **Systematic errors:** Relative systematic errors can be expected to be **less than 1.5% in the 0.4 - 10 keV range**.

Analysis Threads

NICER Data Analysis Threads

Introduction

This page gives links to short, step-by-step recipes which NICER called "threads." They are meant to be self-contained analysis tasks, with links to other threads where appropriate. The modification date of each thread listed in parentheses.

Additional analysis resources, such as software guides and caveats, can be found on our NICER Data Analysis page.

Setup and Data Preparation

- Setting Up a NICER Analysis Environment (2023-01-09) ★
- Using the nicerl2 high-level processing script with NICER data (2022-10-20) ★
- How to report NICER software and calibration versions (2022-04-25)
- Release Notes for HEASoft 6.31 / 6.31.1 (2022-12-20) ★

Analysis: Spectra

- Complete Spectral Product Pipeline (nicerl3-spect) (2022-12-20) ★
- Step-by-step manual spectral analysis tasks
  - Manually Extracting NICER Spectra (2022-10-26)
  - Manually Applying QUALITY Flags (2022-10-26)
  - Manually Applying Spectral Systematic Errors (2022-12-08)
  - Manually applying optimal Binning (ftgrouppha) (2021-10-13)
  - NICER Responses (ARFs and RMFs) (2022-04-28)
  - Manually Estimating Backgrounds for your NICER spectrum (2022-11-30)
- NICER Response Common Issues (2022-04-28) ★
- What Residuals Plot Should I Use? (plot ratio) (2021-07-23)
- Simulating a NICER spectrum (2021-04-16)
- Please also see our Analysis Tips & Caveats for more information on analysis issues

Analysis: Light Curves

- Complete Light Curve Product Pipeline (nicerl3-lc) (2022-12-20) ★
- Creating NICER Light Curves (2022-06-08)

Background Estimation

- Overview of the SCORPEON Background Model (2022-12-14)
- Using SCORPEON Models in XSPEC (2023-01-04)
- Manually Estimating NICER Backgrounds for your NICER spectrum (2022-11-30)

https://heasarc.gsfc.nasa.gov/docs/nicer/analysis_threads/

Data Processing Recommendations

- Use the 'nicerl2' processing task to process all NICER observations (part of standard HEASoft)
  - nicerl2 applies standard calibrations and screenings
    - Calibration: energy scale, timing offsets
    - Screenings: pointing, optical light, high background, noisy detectors
  - Use nicerl2 even if you freshly download data from the archive
    - When new calibration becomes available, the NICER pipeline does not always reprocess old data or apply to immediately to new data, so you need to
  - How to run nicerl2:

```
nicerl2 indir=./1234567890 clobber=YES
```

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 ops 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:

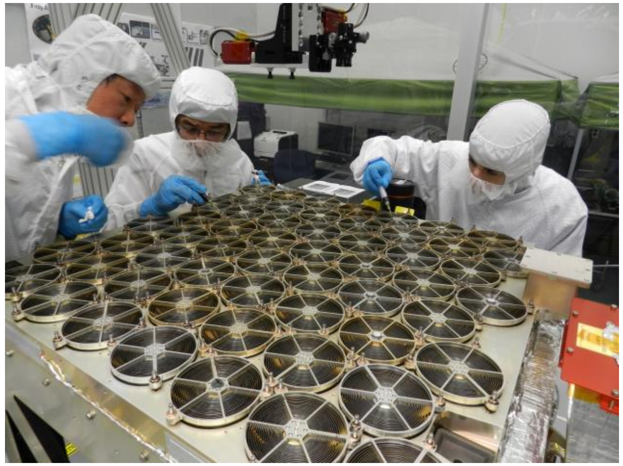
    ```
    ftstat niNNNNNNNNNN.mkf
    ```

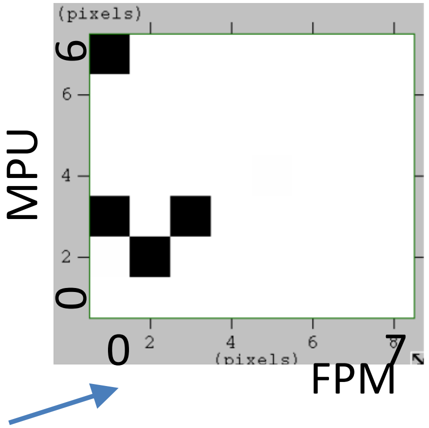
    (and check median of NUM_FPM_ON column)

  - Which detectors disabled:

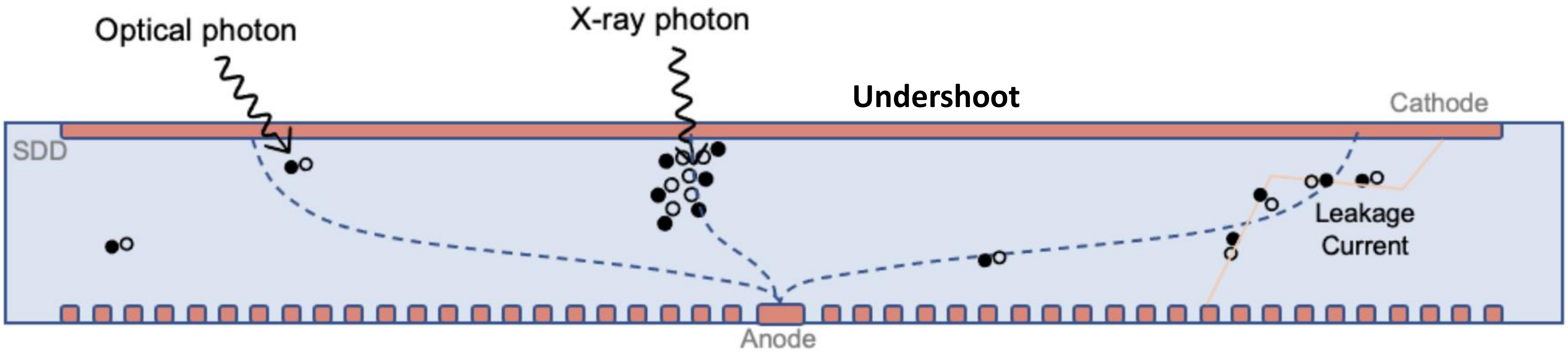
    ```
    fsumrows infile=niNNNNNNNNNN.mkf'[1][col F=(FPM_ON?1:0)]’ \
      outfile=fpm_on.fits cols=F rows=- operation=sum
    ```

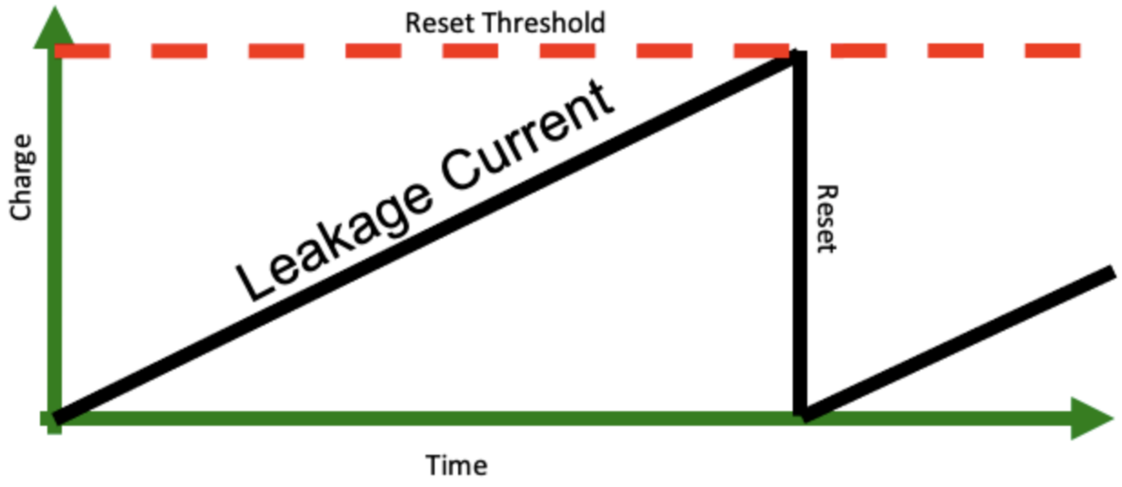
    (and use ‘fv’ to view resulting fpm_on.fits table image)
    DET_ID = (MPU x 10) + FPM
  - DET_ID’s 11, 20, 22 and 60 are always disabled, as shown in figure
- When making ARFs and RMFs for spectra, be sure to follow instructions on NICER Response thread to include only enabled detectors

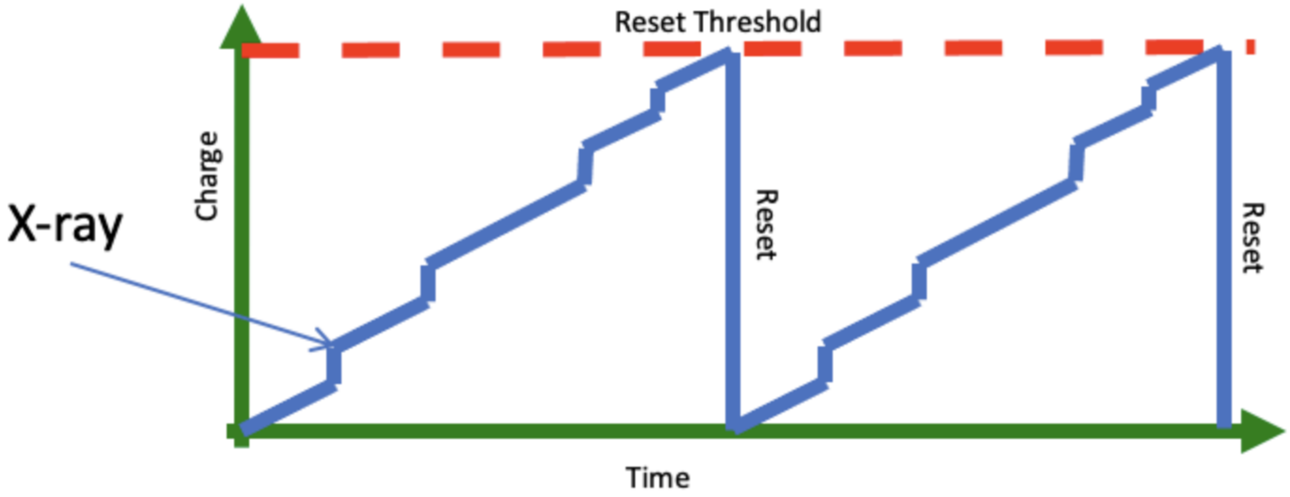




Undershoots and Overshoots







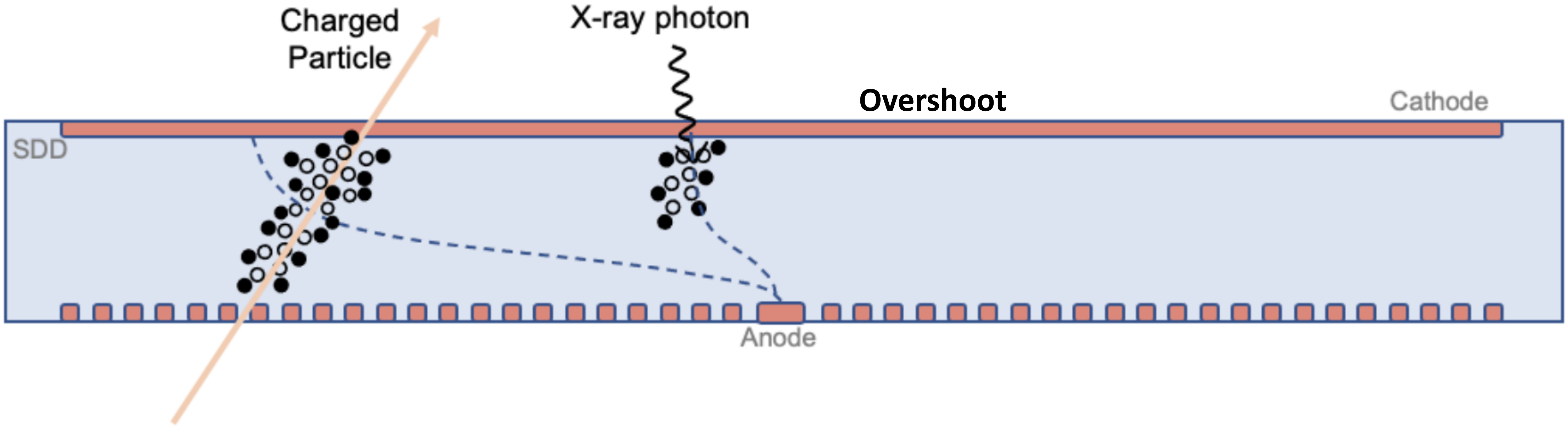
Where's My Data? Undershoots

- NICER's detectors are negatively impacted by optical light
  - Optical light measured by "undershoots" (FPM_UNDERONLY_COUNT in filter file)
- Standard screening requires undershoot rate < 200 ct/s
- If your observation is near the sun or has persistently high undershoots, most or all data may be excluded
  - Filter file SUN_ANGLE < 60 or FPM_UNDERONLY_COUNT > 200 would indicate this
- Relax this screening criteria with nicerl2 parameter

```
underonly_range=0-600
```

- However, beware that high optical light is not accounted for in calibration and may also caused enhanced low energy noise

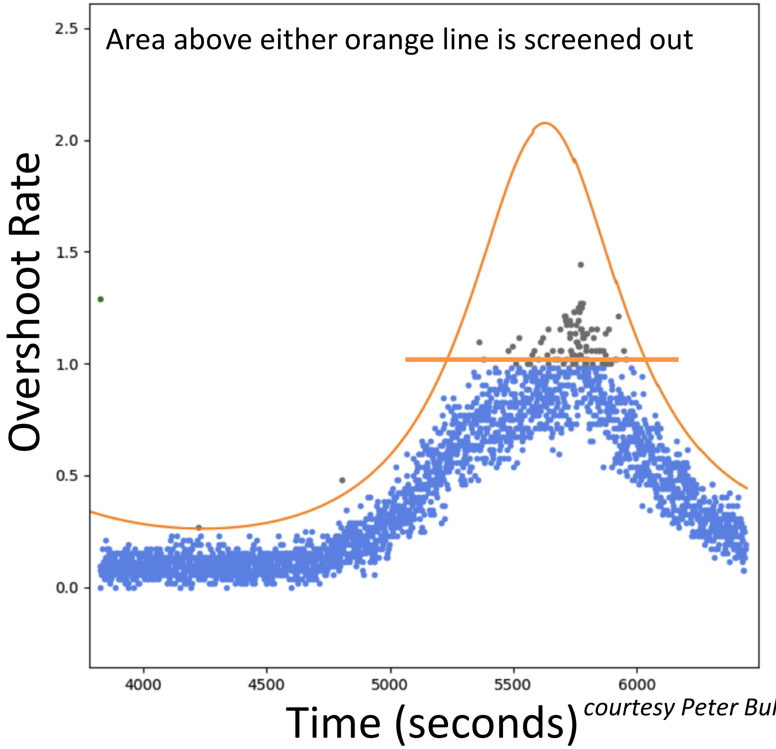
Undershoots and Overshoots



- *Also causes reset events*
- *Partial clipping CR events contribute to background!*

Where's My Data? Overshoots

- Particle background likely correlated with "overshoots"
  - FPM_OVERONLY_COUNT in filter file
- The standard screening excludes data with "high" overshoots, in an orbit dependent way (see orange line in figure)
- This can exclude too much data, especially near "polar horn" regions of high geomagnetic activity
  - Shows up as data drop-outs at certain parts of orbit
- Some evidence that solar modulation of cosmic rays has changed since we designed this screening criterium



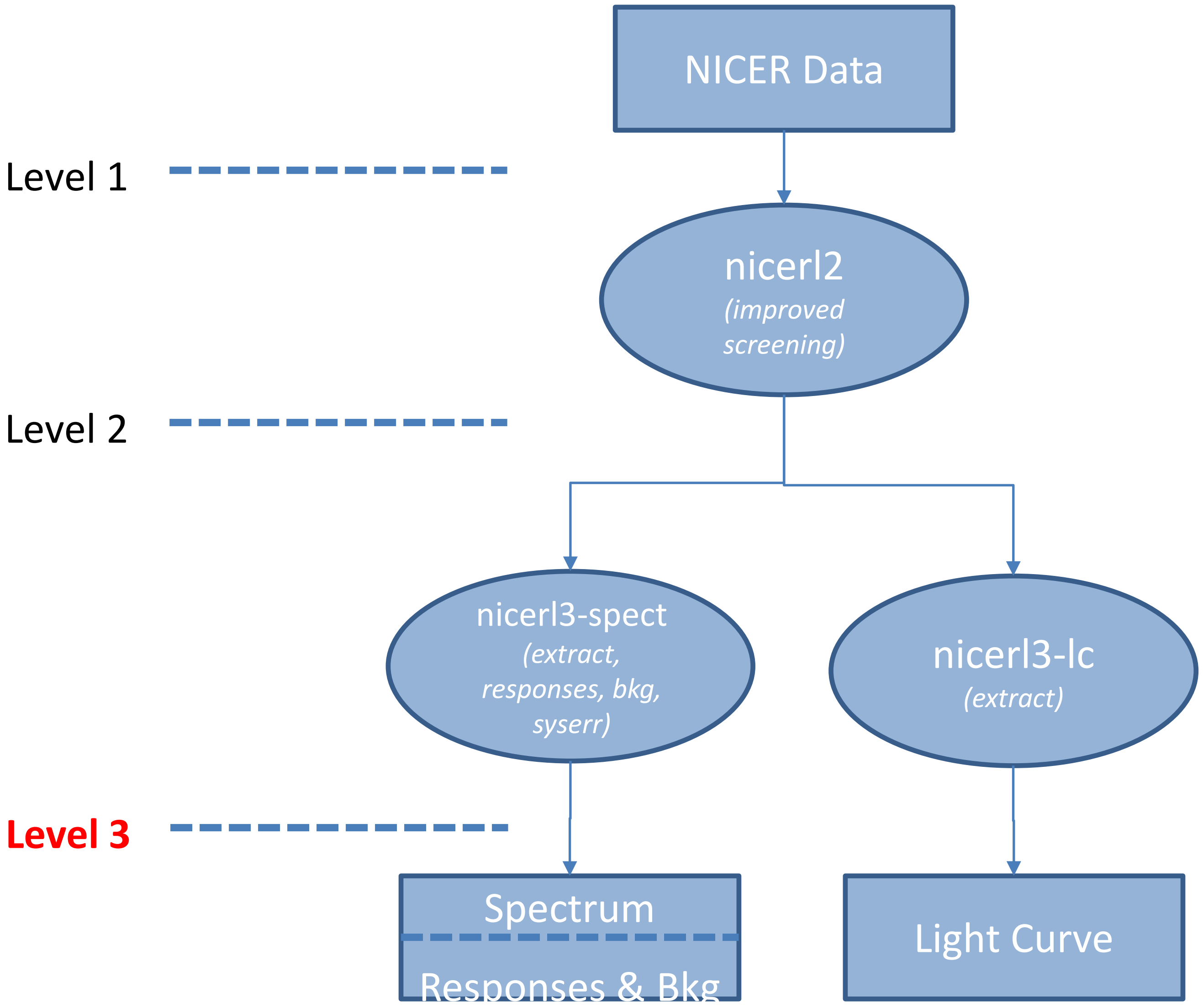
courtesy Peter Bult

Loosen this criterium with nicerl2 parameters:

`overonly_range=*-2`

Can also adjust norm of overonly_expr

New Workflow: Streamlined



Producing Spectra and Backgrounds

- Now two options to produce background spectra/model
- All automated by nicerl3
- Also produces script to load in spectrum and appropriate background
- Automatically bins spectrum “optimally” (see Kaastra & Bleeker 2016)

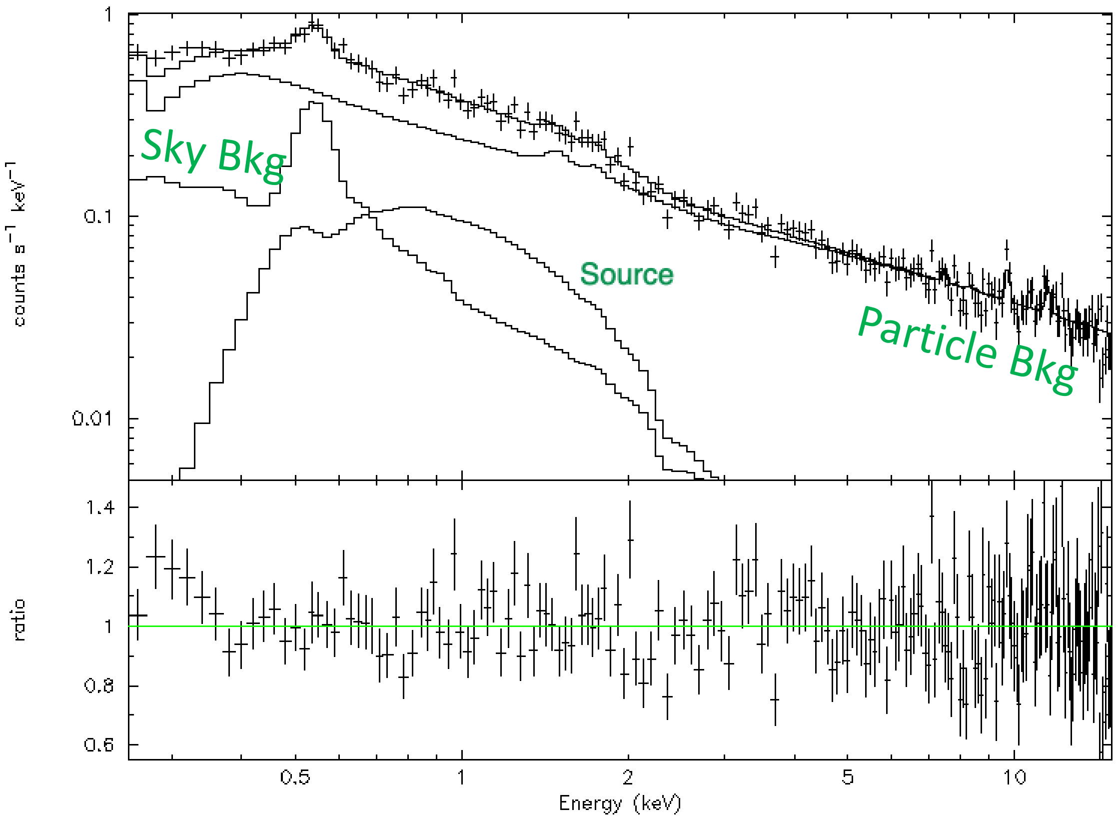
```
nicerl3-spect 1234567890 bkgmodeltype=3c50     suffix=3c50 clobber=YES
nicerl3-spect 1234567890 bkgmodeltype=scorpeon suffix=sco  clobber=YES
```

nicerl3-spect

As output, nicerl3-spect makes the following products:

- extracted spectrum from cleaned event file (phafile)
- Background spectrum file (bkgfile) or script (bkgscript) depending on the background model setting
- ARF response file (arffile) - effective area for target
- Sky ARF response file (skyarffile) - effective area for diffuse sky
- RMF response file (rmffile) - redistribution matrix for target
- Background response file (bkgrmffile) - redistribution matrix for particle background
- XSPEC "load" file (loadfile) - example script to load files into XSPEC

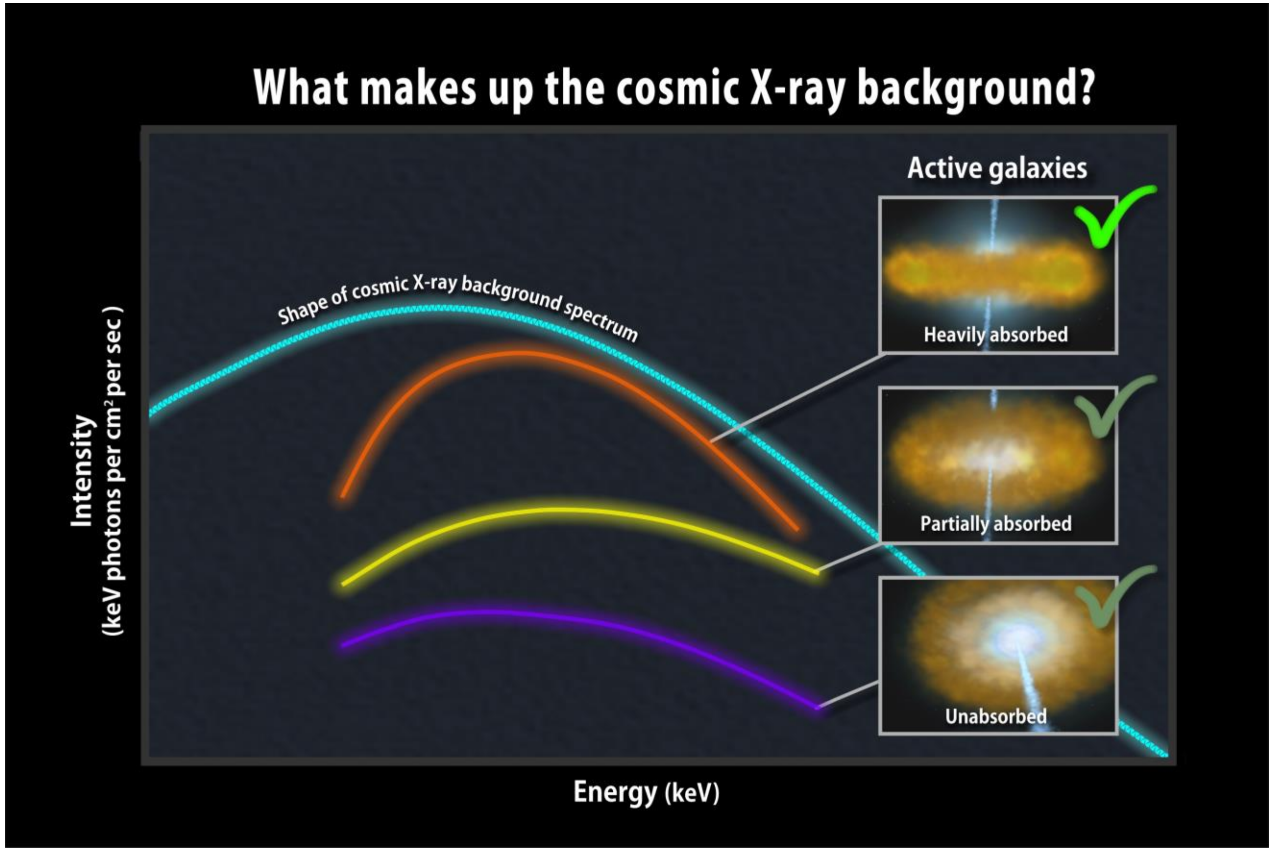
NICER Example Faint Source



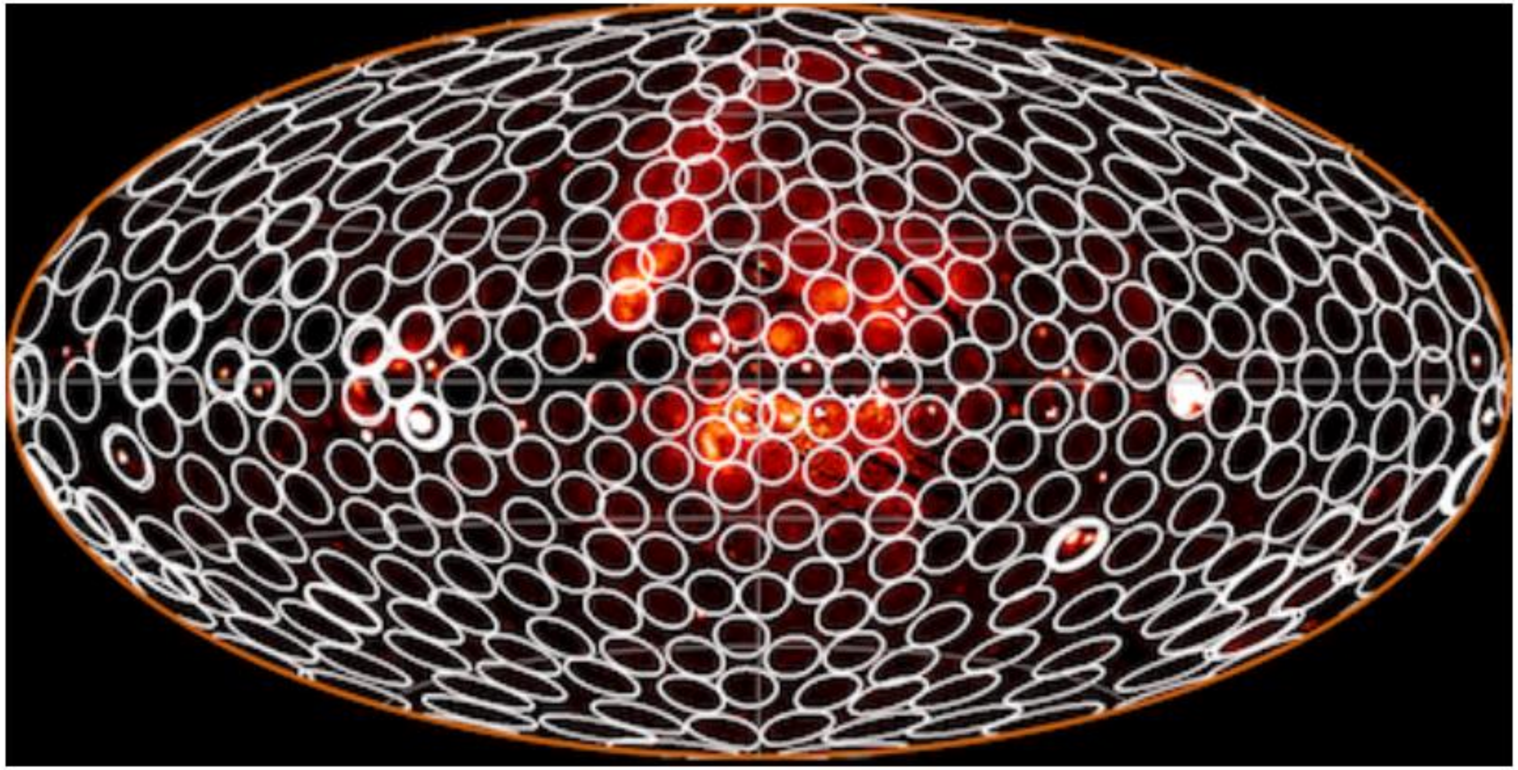
- Flux 1-sigma range is 0.87 – 1.15 x 10^{-13} erg/s/cm^2 (~4 µCrab; compare to ~300 µCrab RXTE PCA sensitivity)
- New SCORPEON model is adjustable to get ultimate fit to your data

Background Components

Cosmic X-ray Background (CXB). The cosmic X-ray background is the well-known flux of X-rays from cosmic distances, primarily from distant active galaxies. The normalization (cxb_norm) and spectral shape are taken from Cappelluti et al. (2017; ApJ 837 19). Although the CXB is constant in time, it does vary from point to point on the sky (i.e. cosmic variance), and for NICER's aperture size the variation can be 20% (1 sigma; see Moretti et al. 2009, A&A 493 501). The norm is in units of photons s^{-1} cm^{-2} sr^{-1}.

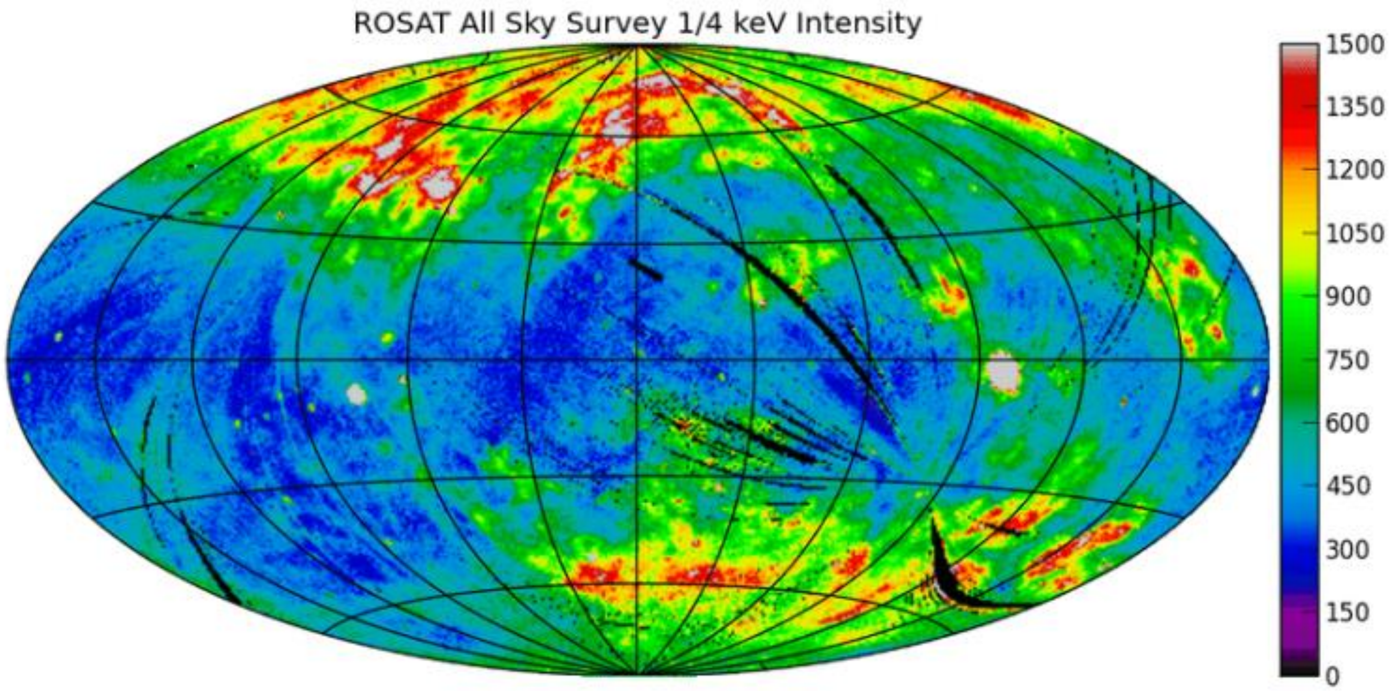


Background Components



Galactic X-ray Halo. The galactic X-ray halo has been proposed for some time to explain a portion of the diffuse X-ray background. HaloSat recently completed a survey of the halo (see figure above). We use the halo model of Kaaret et al. (2019; Nature Astronomy 4 1072), with a fixed temperature of 0.225 keV and normalization taken from their density model. However, the true distribution is clumpier than described by the model, so the NICER halo emission measure parameter (halo_em) is allowed to vary up to 50% around the a priori estimate.

Background Components

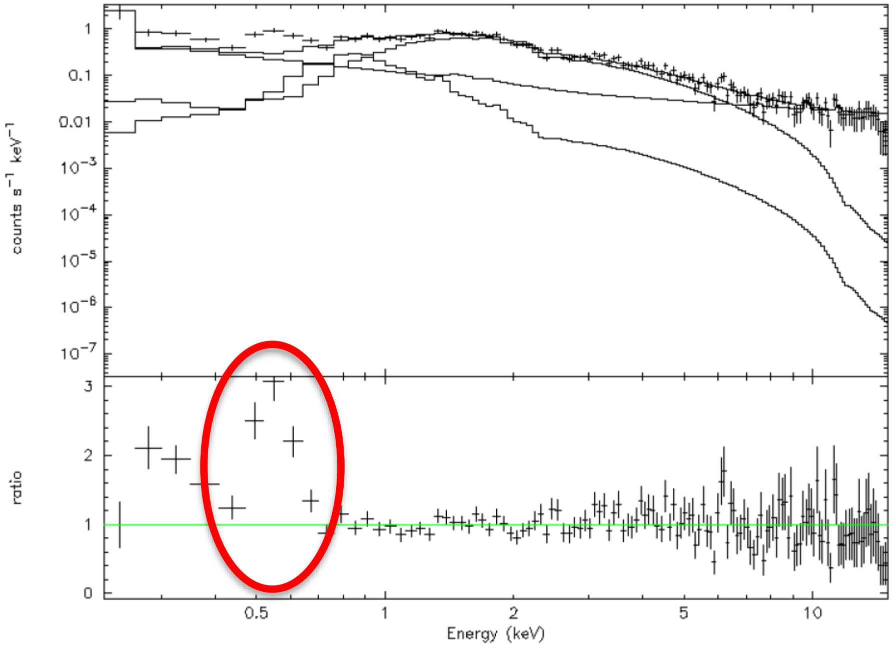


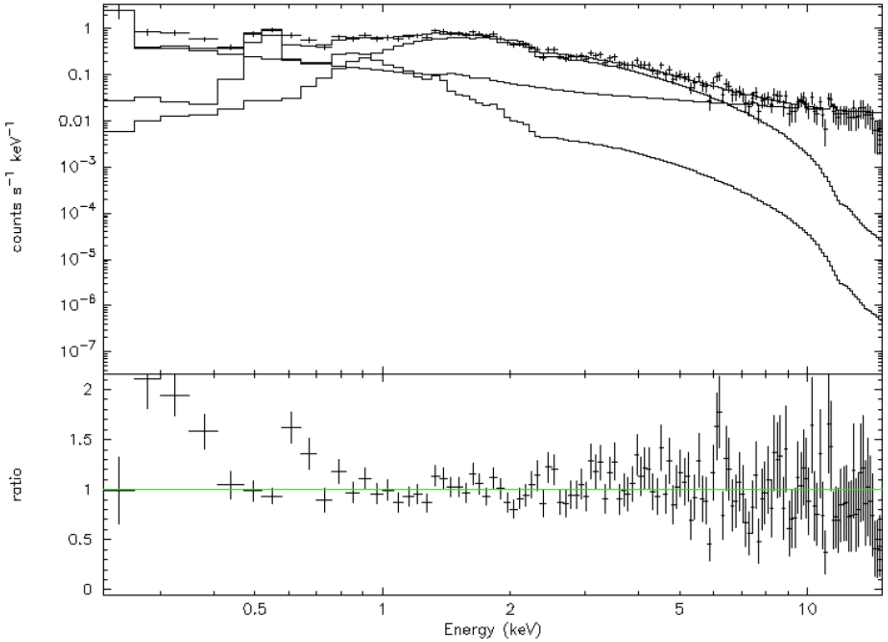
(Attribution: Slavin 2017 CC BY 3.0)

Local Hot Bubble (LHB). The local hot bubble is cavity of hot plasma in which the solar system is located. The SCORPEON model of the LHB is informed by Liu et al. (2017; ApJ 814 33), which in turn measured using the ROSAT All-Sky Survey (see above). The temperature of the thermal plasma is taken from that work. Unfortunately we were not given permission by the authors to distribute the LHB emission measure sky maps, so we provide an a priori emission measure estimate from crude contours estimated by hand from the published on-line paper. This emission measure norm (lhb_em) is allowed by vary by 50% during fitting.

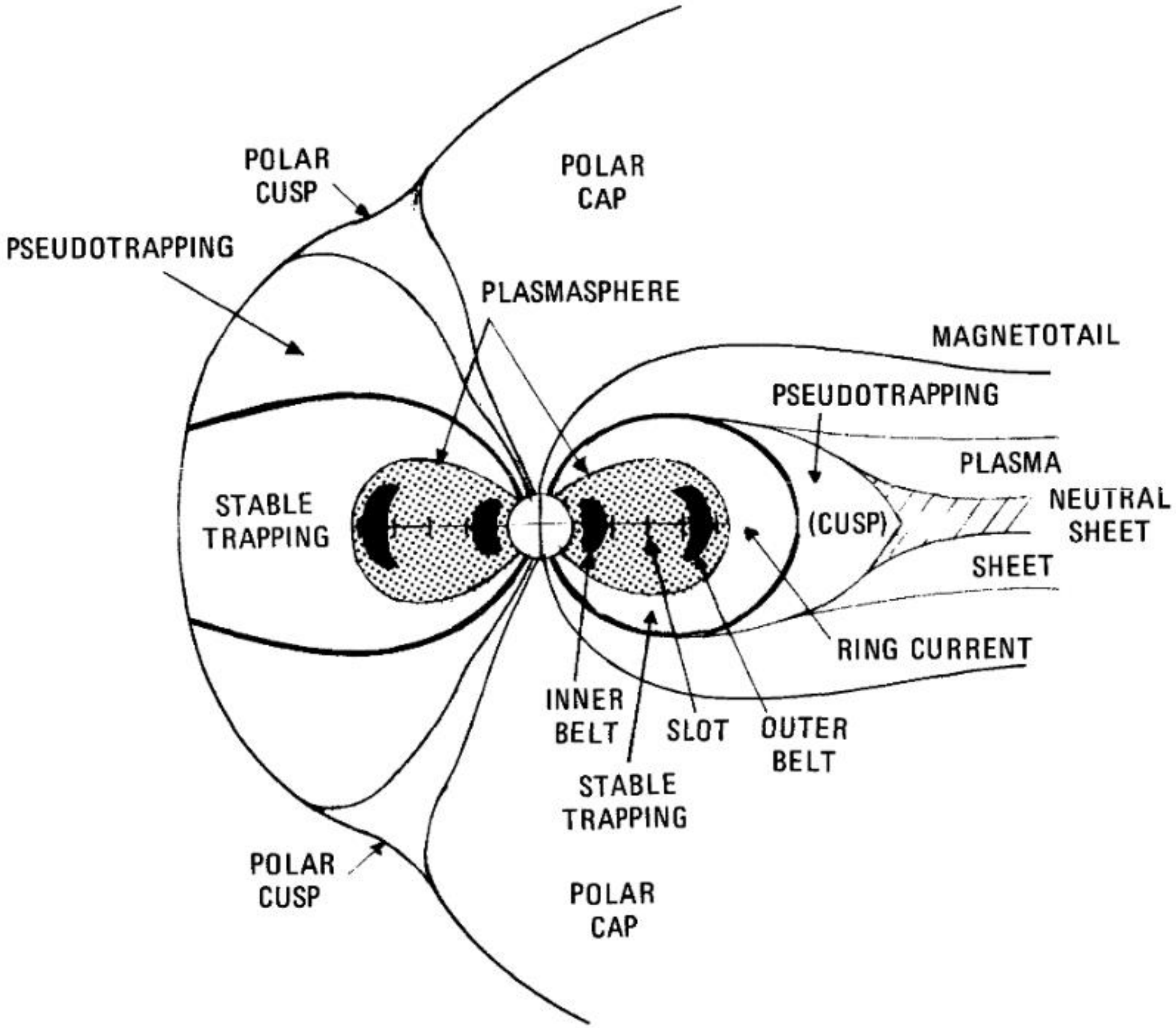
Background Components

Solar Wind Charge Exchange (SWCX) and Neutral Oxygen (OK). Solar wind charge exchange (SWCX) is a charge exchange interaction between the solar wind ions and atmospheric atoms within the geomagnetosphere. High speed ions can capture an electron from neutral atoms near the earth, and the resulting cascade to the ion's ground state results in X-ray emission. NICER has seen significant Kα emission from O VII (574 eV), O VIII (654 eV), and Ne IX (898 eV). This emission can vary on timescales of minutes and varies with look direction as well. The intensity is not predictable in a straightforward operational way. Oxygen K emission from neutral atoms has also been seen in NICER observations (Kα emission line at 533 eV). This phenomenon is an area of research, but the proposed mechanism is that solar X-rays ionize neutral oxygen that upwells into the polar cusp regions. In practice, while there is a rough correlation with the cusp regions, we have often seen emission from a much broader region, and sometimes not at all. Again, the intensity is not predictable in a straightforward way. Because of the behavior of both SWCX and neutral oxygen, these lines are included in the model but the norms default to zero. It is up to the user to recognized these lines and allow the norms to vary. The norms (ok_norm, ovii_norm, oviii_norm, neix_norm) are in units of photons s^{-1} cm^{-2} sr^{-1}.

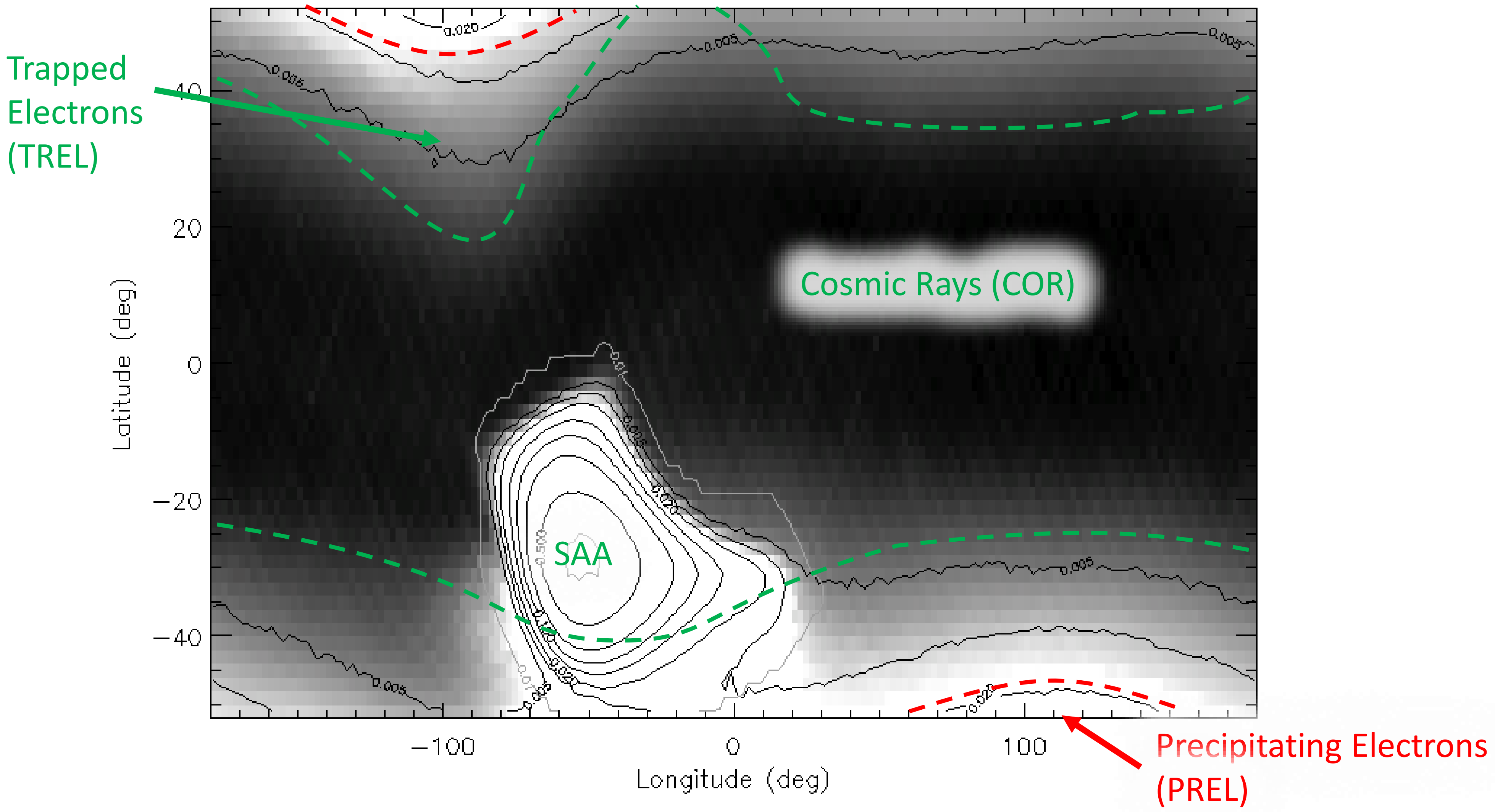




Background

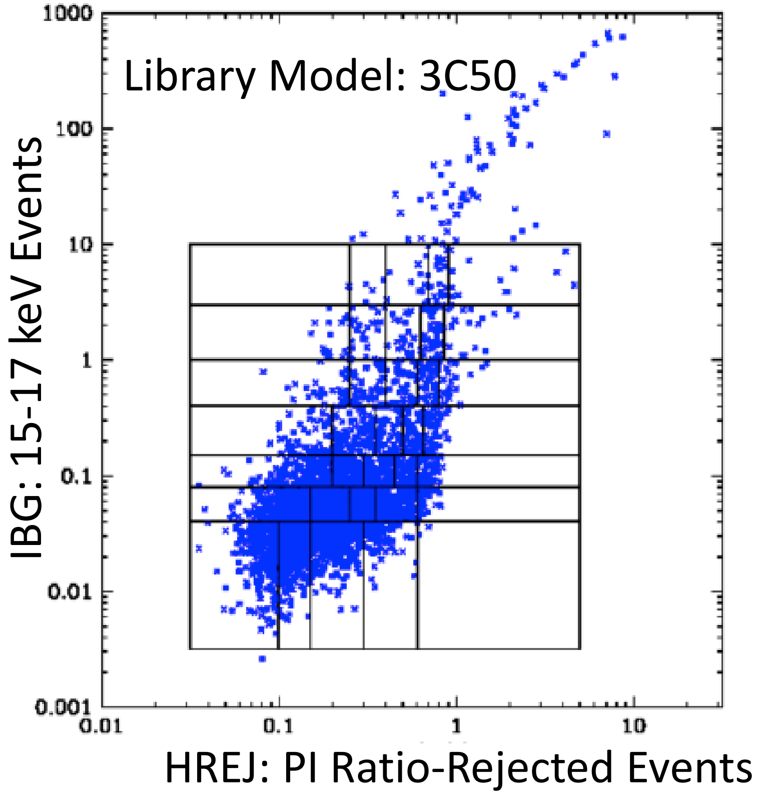

POLAR
CUSP
POLAR
CAP
PSEUDOTRAPPING
PLASMASPHERE
MAGNETOTAIL
PSEUDOTRAPPING
PLASMA
NEUTRAL
SHEET
STABLE
TRAPPING
(CUSP)
SHEET
RING CURRENT
INNER
BELT
SLOT
OUTER
BELT
STABLE
TRAPPING
POLAR
CUSP
POLAR
CAP

Geographic Overview of Dominant NICER Background Contributors



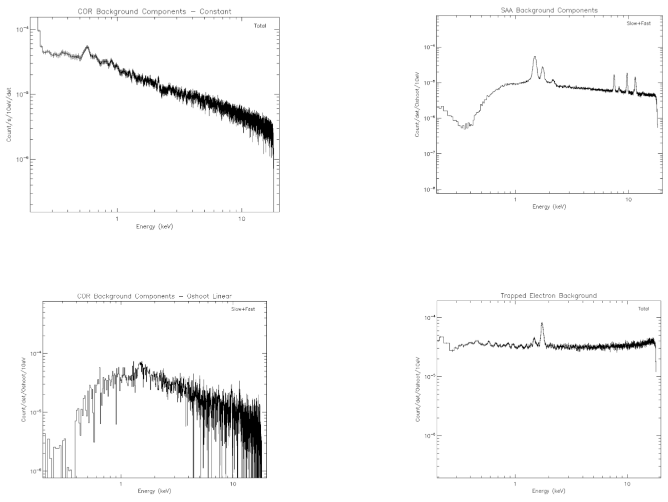
Library Models vs Template Models

Remillard et al. 2022



- Break parameter space into cells, measure background in each shell (library of spectra)
- Application: calculate exposure in each shell, make weighted sum of library spectra

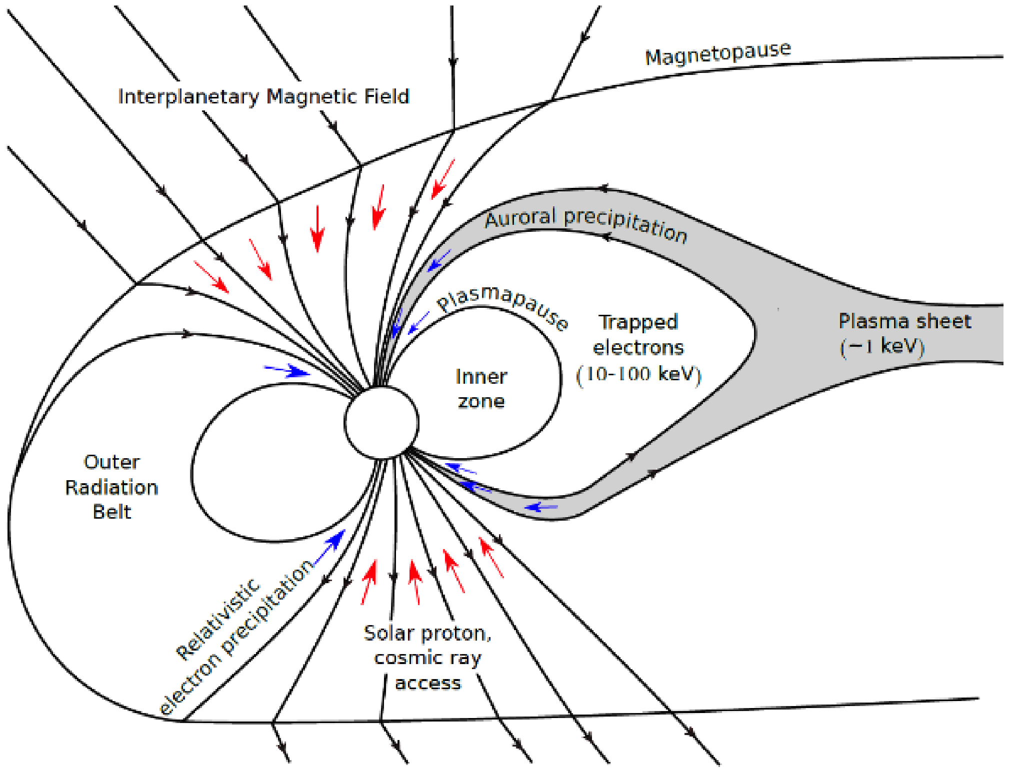
Template Model: SCORPEON



- Measure "basis vector" of each unique component
  - Make smoothed version of template as XSPEC model
- Normalized based on known telemetry (overshoots, etc)
- Application: predict norms from telemetry & load into XSPEC

Background: SCORPEON

- SCORPEON Model
- Major goals
  - Break down background into physically-motivated components
  - Separate "data modes" (slow-only, slow+fast event types), and both
  - Assume that these components can be modeled with simple spectral models so they are easy to implement



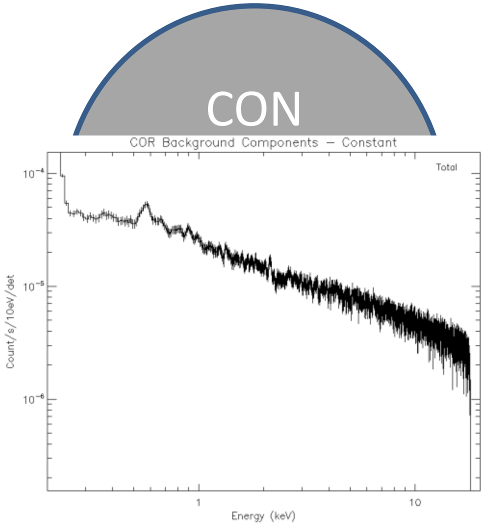
Thorne et al 1980
Tyssoy presentation

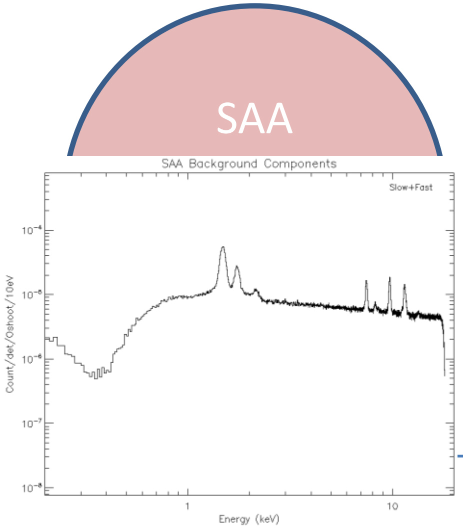
SCORPEON Name

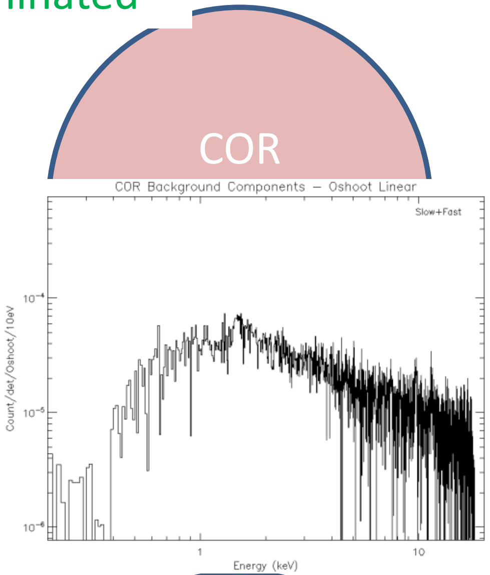
- S COR PE O N
  - S = **SAA**
  - COR = **CO**smic-**R**ay (COR_SAX)
  - PE = Precipitating & trapped Electrons
    - Precipitating electron population (PREL)
    - Trapped electron population (TREL)
    - Low energy electrons (LEEL) – solar storms
  - O = c**O**nstant
    - Astrophysical: CXB + Halo + LHB + SWCX
    - Non-varying Non-X-ray background
  - N = **N**oise peak (not dealt with here)

SCORPEON Background Components

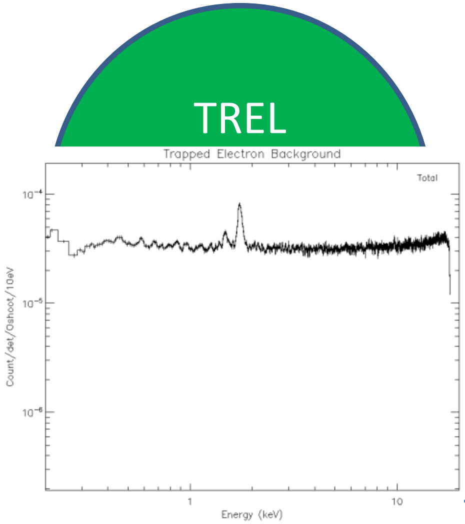
Hadron-Dominated

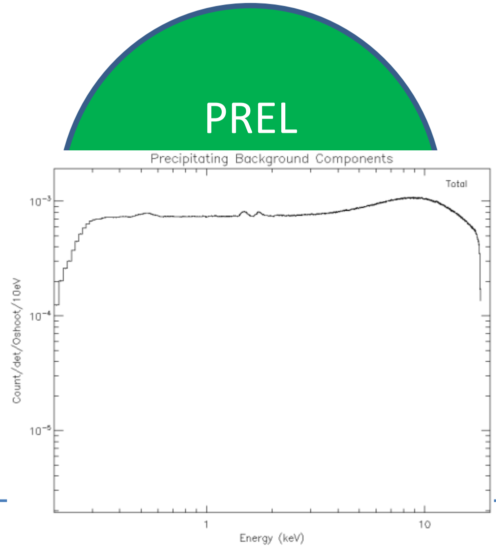


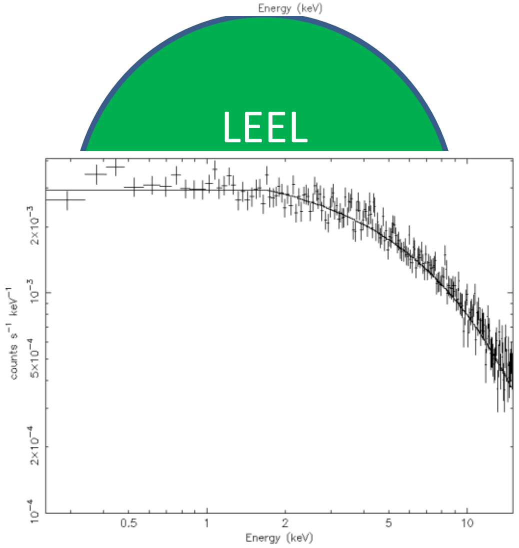




Electron-Dominated







Background: SCORPEON

`ni5030170101mpu7_loadsco.xcm`

- Script will load the background model and source spectra
- Frozen and free components set by observing conditions
- nxb is the non-X-ray background
- Sky is anticipated X-ray background
- Better capture of covariance between background uncertainty and science model parameter uncertainty

IMPORTANT: Scorpeon should be fit in the 0.22-15.0 keV energy range. Use “pgstat” or “cstat” when fitting.

```
========================================================================
Model nxb:niscorpv22_nxb<1> + niscorpv22_noise<2> Source No.: 99   Active/On
Model Model Component  Parameter  Unit     Value
 par  comp
   1    1   niscorpv22_nxbbatch1_frac          0.903904     frozen
   2    1   niscorpv22_nxbcon_norm             51.9686      frozen
   3    1   niscorpv22_nxbcor_norm             15.4170      +/-  1.58904
   4    1   niscorpv22_nxbtrel_norm            5.45548E-04  +/-  2.90710
   5    1   niscorpv22_nxbleel_norm            0.0          +/-  30.9903
   6    1   niscorpv22_nxbprel_norm            3.76703E-02  +/-  0.106915
   7    1   niscorpv22_nxbsaa_norm             0.0          frozen
   8    1   niscorpv22_nxbnorm                 1.00000      frozen
   9    2   niscorpv22_noisenoise_ecent          0.109723     frozen
  10    2   niscorpv22_noisenoise_sigma          2.73464E-02  frozen
  11    2   niscorpv22_noisenorm                 1.00000E+05  +/-  9.58000E+05
________________________________________________________________________
```

```
========================================================================
Model sky:niscorpv22_sky<1> + niscorpv22_swcx<2> Source No.: 98   Active/On
Model Model Component  Parameter  Unit     Value
 par  comp
   1    1   niscorpv22_skygal_nh               1.69820E-02  frozen
   2    1   niscorpv22_skycxb_ind             1.45000      frozen
   3    1   niscorpv22_skycxb_norm            10.9100      frozen
   4    1   niscorpv22_skyhalo_kT             0.225000     frozen
   5    1   niscorpv22_skyhalo_abund          0.300000     frozen
   6    1   niscorpv22_skyhalo_em             1.26630E-02  +/-  2.30023E-02
   7    1   niscorpv22_skylhb_kT              9.90000E-02  frozen
   8    1   niscorpv22_skylhb_em              3.52000E-03  +/-  2.02168E-02
   9    1   niscorpv22_skynorm                1.00000      frozen
  10    2   niscorpv22_swcxswcx_sigma          0.0           frozen
  11    2   niscorpv22_swcxok_norm             0.0           frozen
  12    2   niscorpv22_swcxovii_norm           0.0           frozen
  13    2   niscorpv22_swcxoviii_norm          0.0           frozen
  14    2   niscorpv22_swcxneix_norm           0.0           frozen
  15    2   niscorpv22_swcxnorm                1.00000       frozen
________________________________________________________________________
```

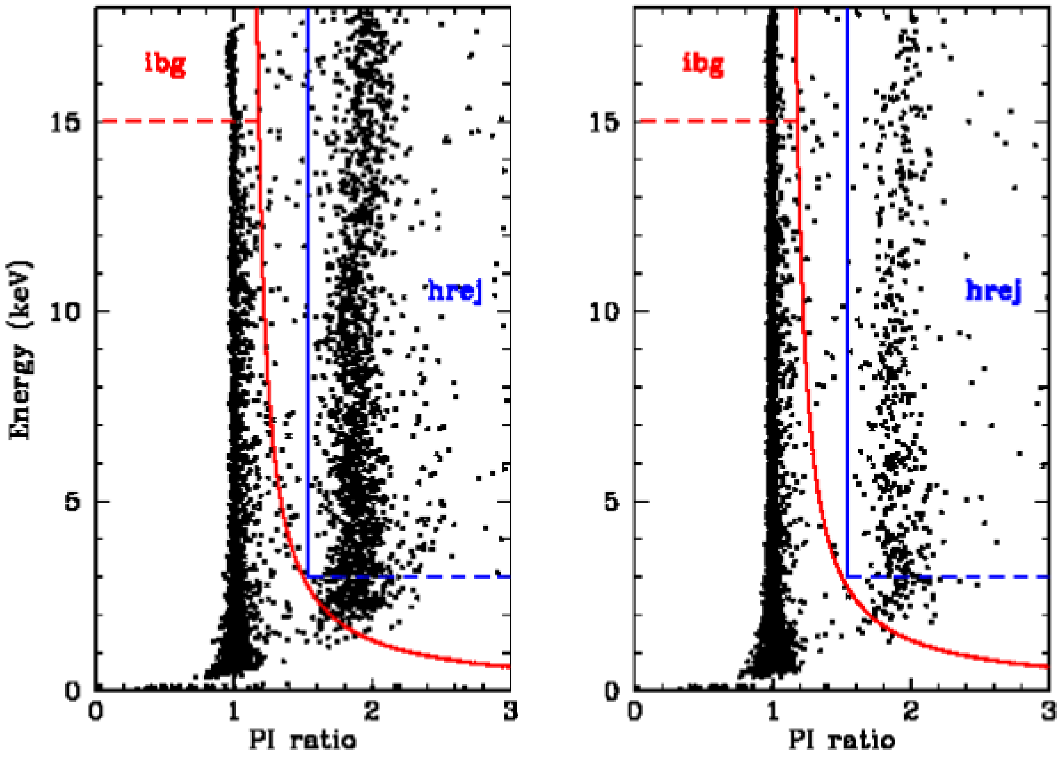
Background contains in-focus & spatially extended components that can vary independently ; Left: *hrej > ibg*; Right: *ibg >> hrej*

red curve: pipeline selection line (to left) for in-focus events

ibg: events "in focus", but at 15-18 keV, which is beyond the eff. area of the optics

hrej: rejected events from particles near detector edge

ibg and ***hrej*** represent different types of particle events

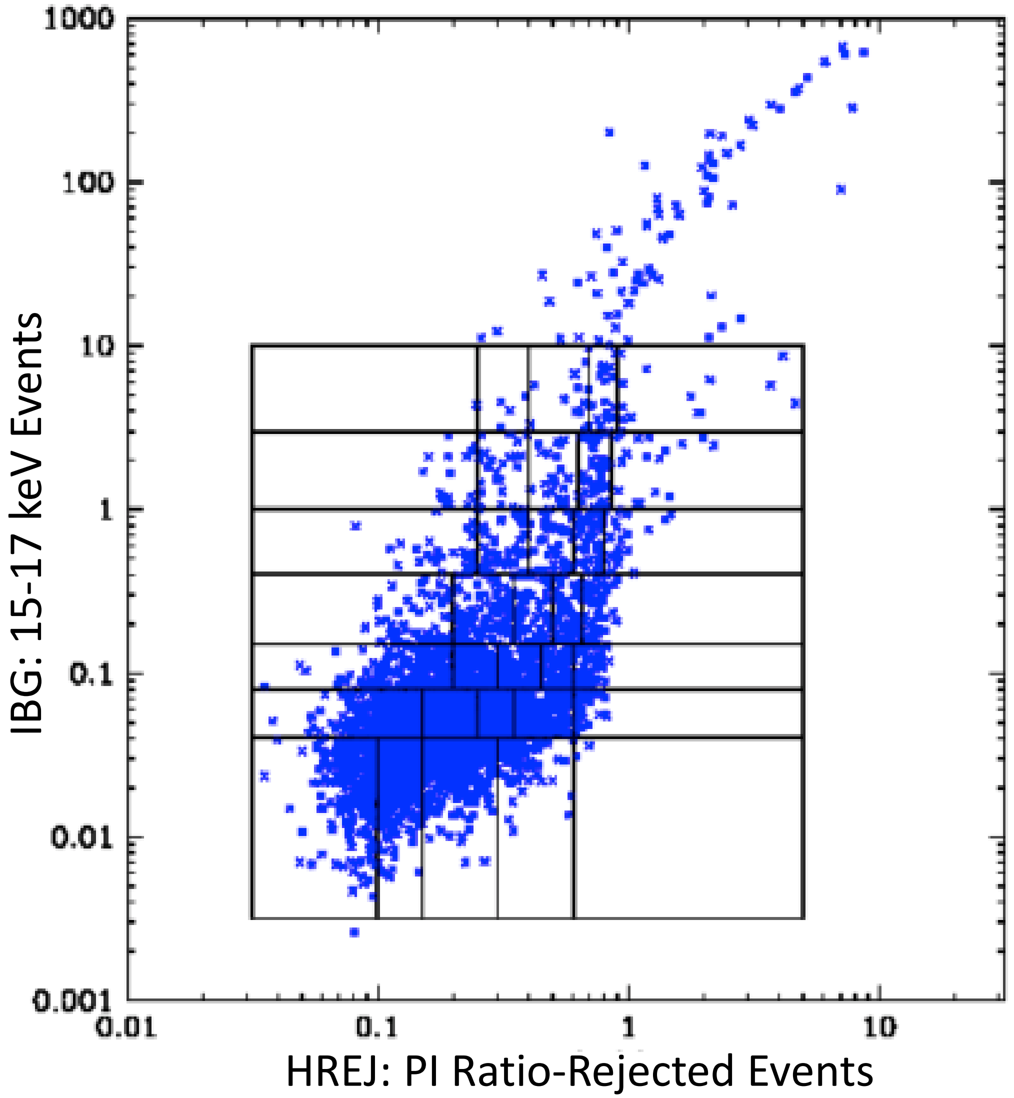


PI_RATIO = keV (slow chain) / keV (fast chain)

Remillard (2021)

Background: 3C50

- Template library created from blank sky observations under different observing conditions
- Nicerl3 takes observing conditions from target observation, pulls appropriate 3C50 library model, rescales normalization (for e.g., for number of detectors, exposure time, etc).
- Background is then simply subtracted from source spectrum (should use standard energy cuts)



Background Summary

Characteristic	SCORPEON	3C50	Space Weather
Model Type	Parameterized	Library	Library
Training Variables	COR_SAX Overshoots	HBG (15-18 keV) HREJ	COR_SAX KP
Background File	Optional	YES	YES
XSPEC Model	YES	NO	NO
Always Produces Estimate?	YES	NO	YES
X-ray Sky Backgrounds?	YES	Average	Average
Noise Peak	YES	YES	Average
Light Curves?	NO	NO	YES

Producing Light Curves

- Light curves are produced by the nicerl3-lc pipeline
- PI range sets energy range, PI = 10 eV (ex. Below shows 3-15 keV)
- Default is to run with no background
- Space-weather is only background option currently available in nicerl3-lc

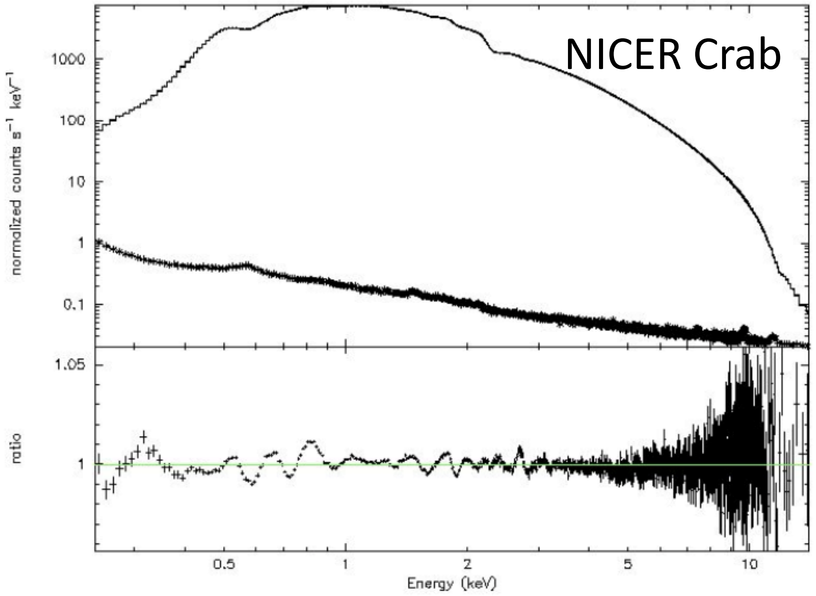
```
nicerl3-lc 1234567890 pirange=300-1500 timebin=60.0 clobber=YES
```

```
nicerl3-lc 1234567890 300-1500 60.0 bkgmodeltype=sw clobber=YES
```

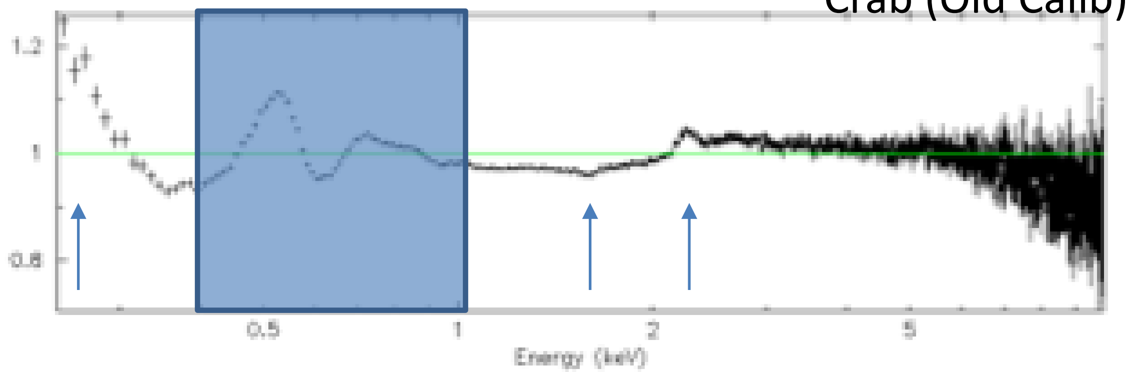
Space weather background model:
uses blank sky observations under comparable observing conditions to estimate the typical background count rate

NICER Calibration Status

- NICER energy scale
  - After calibrations, all event files have "PI" column with common energy scale ("Pulse Invariant")
    - **1 PI = 10 eV** (e.g. PI = 150 means E = 1.50 keV)
    - Estimated error ~5 eV (0-10 keV)
- NICER on-axis response
  - NICER calibrated against Crab nebula as a "smooth" continuum
  - Systematic errors ~1-2% (0.4-10 keV)
  - Total effective area and slope comparable to Madsen et al. 2017 NuSTAR (within ~5%)
  - Often, **residuals are due to difficiencies in model**, not response

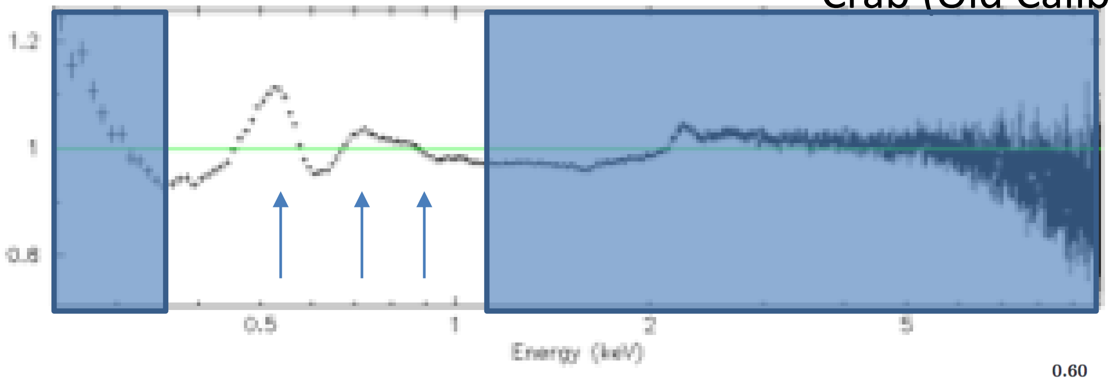


Detector Features to Watch Out For

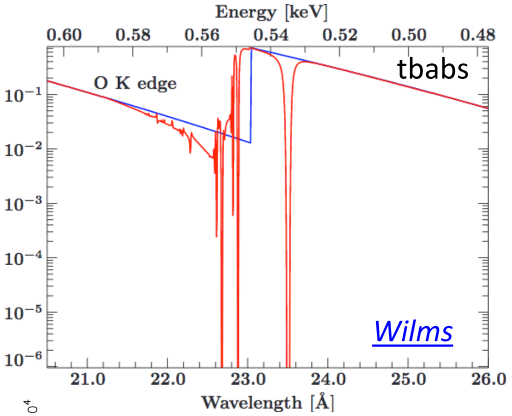


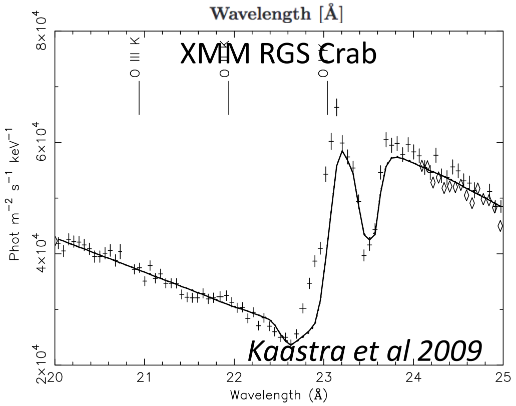
- ~2.2 keV – Gold M edge from XRC gold coating (actually a complex from 2.1 – 4.5 keV)
- 1.840 keV – Silicon K edge (window & bulk detector)
- 1.56 – Aluminum K edge/fluorescence (window)
- ~0.3 keV – Trigger efficiency cut-off (varies by det)
- ~0.2 keV – Noise peak (varies by det & lighting)
- At high optical light levels response is broadened but this is not yet modeled (will be in RMF calculator - in work)
  – Noise peak may intrude into spectrum
  – Sharp lines may be degraded

Astrophysical Features to Watch Out For



- The interstellar medium is often modeled with neutral N_H models such as wabs, tbabs (Wilms et al), etc.
- These models are general approximations to reality, especially with all parameters left at solar abundance
- Most common features:
  - Oxygen K edge (0.56 keV)
  - Iron K edge (0.71 keV)
  - Neon K edge (0.87 keV)
- If you see residuals in this consider using “tbfeo” or “tbvarabs” to allow abundances to vary; check literature for reported abundances
- Even so, actual line profiles may not match “perfect” profiles tabulated in tbabs model (due to ionization, molecular compound, or dust composition of ISM); See Crab to right
- Dust scattering halos – see bright target slide

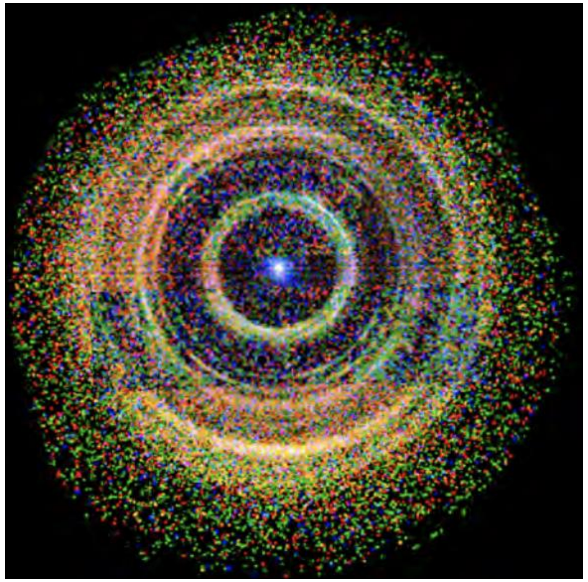




NICER Concerns: Bright Targets

- **Deadtime correction** affects all observations
  - Team is working on documentation and tools for deadtime corrections
- **Pile-up** is a concern only for the brightest targets (>2 Crab); this is a difficult issue to model
- **Dust scattering halos** have significant effects
  - Energy dependent
  - Aperture size dependent
    - interferes with comparing observatories with different apertures (NICER 360”, RXTE 1°, Imagers ~few “)
  - 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”

V404 Cyg
(Chandra ACIS)



Heinz & Corrales et al. 2016

Ways to Get Help

- Consult on-line NICER documentation for analysis issues
  - Software guide overview
  - Analysis “Threads” - procedures for common tasks
  - Analysis tips for specific known problems or issues you may encounter

- Send questions to the NICER helpdesk:
  https://heasarc.gsfc.nasa.gov/cgi-bin/Feedback

Thanks! Questions?

NICER PSR J0030+0451