Background Models & Screening for Quality Control

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Outline

- Why/What/How of Data Screening ?
- Define GTIs to avoid systematic errors
- Effects of Screening on Light Curves
- Reality vs.BG at GTI timescales (300 s) or less
- Systematics at Very Long Timescales

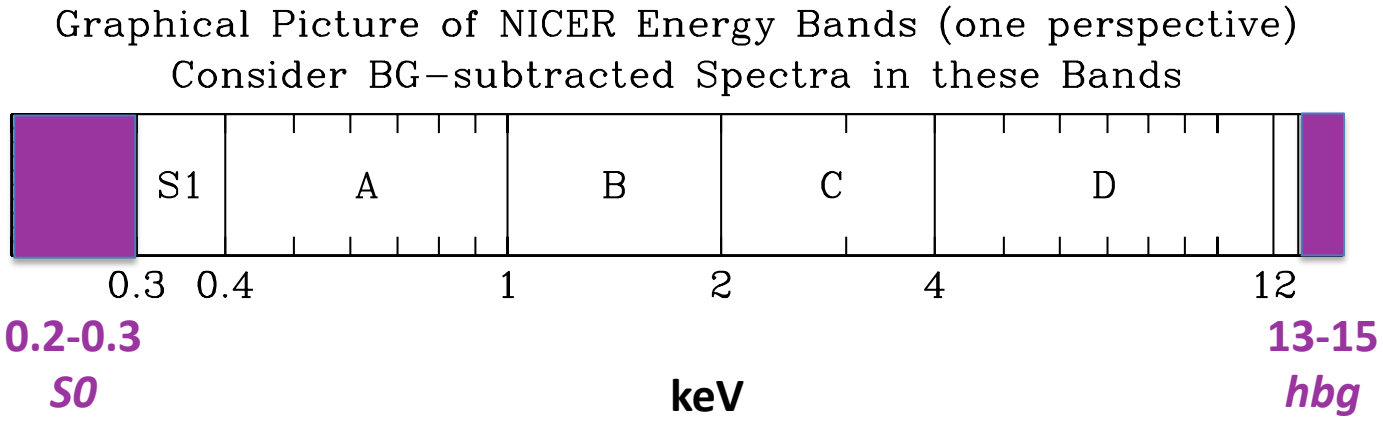
NICER data analyses is best approached with informed efforts for quality control

Need Screening for Data Quality

Why Screen BG-subtracted Spectra?:

- NICER Background (BG) is complicated (Craig's talk yesterday)
- Detectors are single channel ; no separate BG obs. per target
- BG residuals for BKGD pointings: problems, especially when BG is high (for 3C450 model, see Remillard et al. 2022, AJ, 163, 130)
- Optical Loading (obs. in sunlight) increases noise above 0.2 keV and must be modeled

Visualizing Screening



- extractions from cleaned event lists → 0.2-15 keV
- $S0_{net}$ and hbg_{net} are the screening bands (usually expect zero)
- $S0_{net}$ informs safe use of *S1* in spectral fits, when noise is increased by optical loading (or *S1* informs safety of *A* edge)
- hbg_{net} gives feedback on correct shape of hard X-ray BG prediction
- can be relevant to any BG model

Screening Levels

Suggestions for 3C50 model (Remillard et al. 2022, AJ, 163, 130)

- Level 1 (all sources) select: $-30 < S0_{net} < 30$ c/s ; $-0.5 < hbg_{net} < 0.5$
- Level 2 (20-300 c/s*) select: $-10 < S0_{net} < 10$ c/s ; $-0.1 < hbg_{net} < 0.1$
- Level 3 (< 20 c/s*) select: $-2.0 < S0_{net} < 2.0$ c/s ; $-0.05 < hbg_{net} < 0.05$

Soft, rotation-powered, msec pulsars (Salmi et al. 2022, submitted)

- Level 4 soft (< 1 c/s**) select: $-0.15 < S0_{net} < 0.15$ c/s ; $-0.05 < hbg_{net} < 0.05$
  $-0.1 < C_{net} < 0.1$; $-0.3 < D_{net} < 0.3$

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* net count rate at 0.4-12 keV

** soft, net count rate at 0.3-2.0 keV ; no detection C_{net}, D_{net} in 100 ks

Define GTIs to Avoid Systematic Errors

GTI intervals to avoid systematic problems (3C50 model)

- Sample ISS orbit (5560 s) with 4-5 intervals for each (of 4) passages, equator to polar (52^o) to reduce nonlinear effects; → 300 s target interval per GTI
- Avoid GTIs < 50 s: weak statistics in ***ibg*** (***hrej*** can be replaced by ***corsax***)
- Sunshine transitions can show jumps in ***nz*** ; Mask +/- 30-s from each transition (early sunlight from ISS structures ; ***nz*** rampdown in FPMs after ISS sunset).

Steps for GTI-based BG modeling

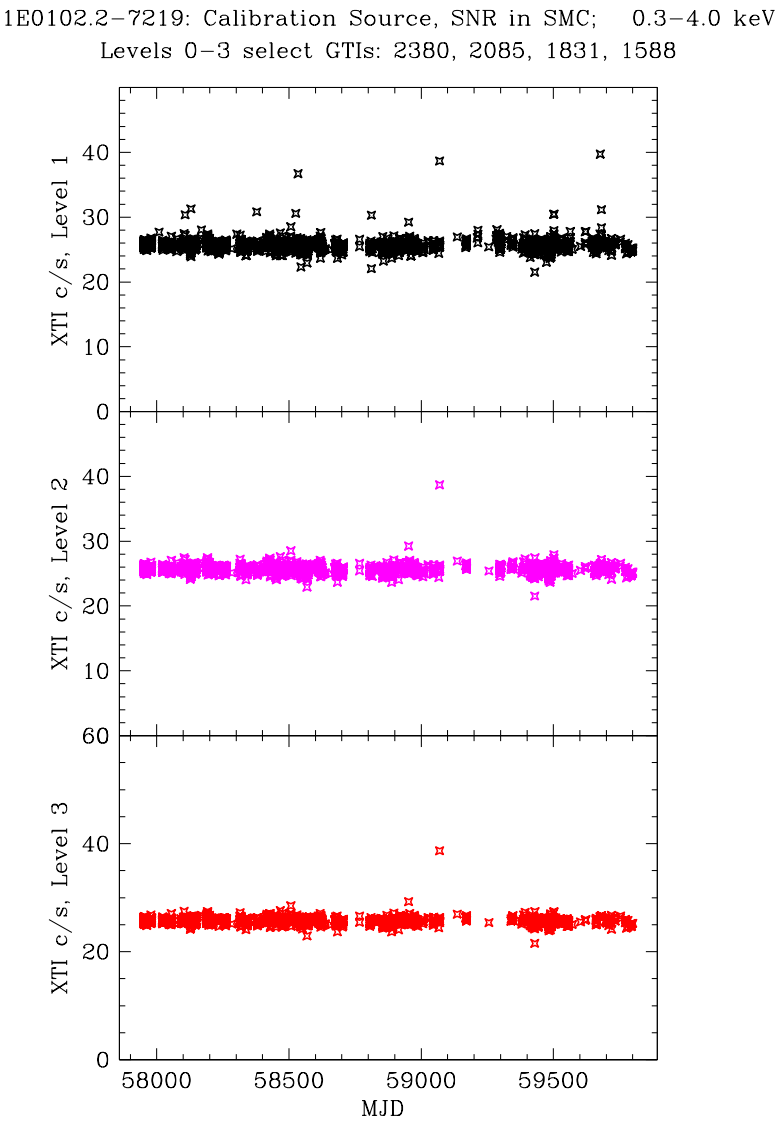
- run nimaketime twice ("… .and.SUNSHINE.eq.0") and ("… .and.SUNSHINE.eq.1")
- collect each GTI set (MET start and stop) and add a column 1/0 for SUNSHINE
- merge GTI tables and make a tool to mask 30 s on each side of any 1/0 transition
- ignore gaps <= 2 s at fixed SUNSHINE ; then ignore GTIs with *dt* < 50 s
- break up any interval *dt* > 450 s into *N* GTIs, *N* = int (*dt* / 300 + 0.5)
- index the final GTI list and use index number in all downstream extractions

Screening NICER Light Curves

1E0102-7129 SNR in SMC

0.3-4.0 keV
screening levels 1,2,3

- screening level 2 sufficient
- polar declination;
  obs. latitudes +10.7 to -51.7
- two additional points off scale in all plots
- three worst level-2 GTIs:
  sat_lat -49.6, -49.0, -50.9,
  with hard flares (predicted BG shape is wrong)
- however, many more GTIs with sat_lat < -49 are OK

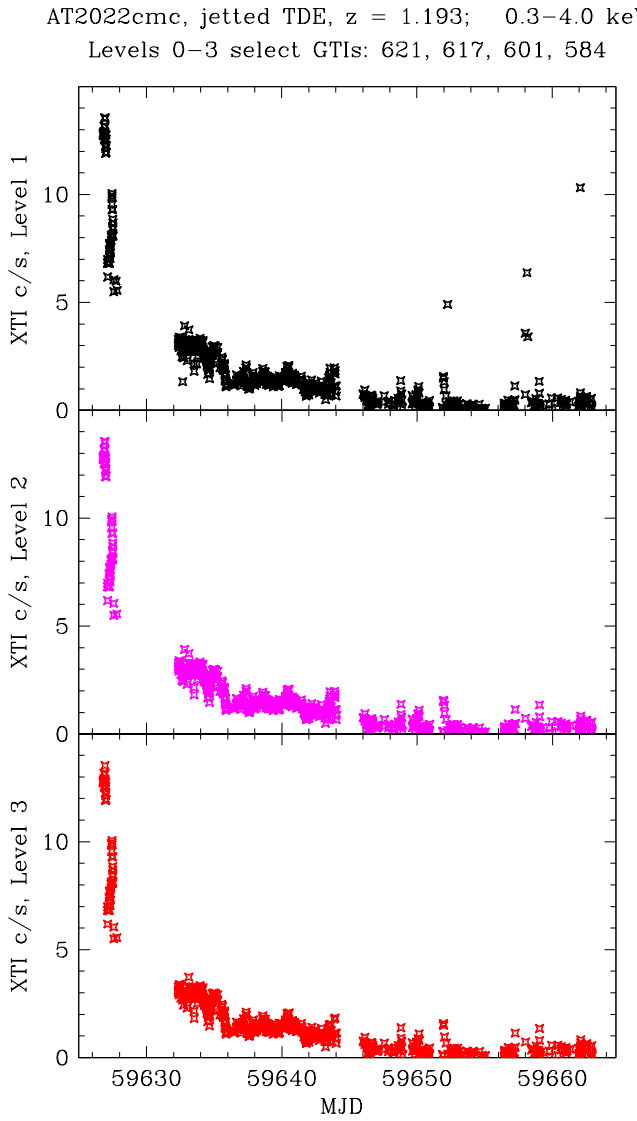


Screening NICER Light Curves

AT2022cmc, Jetted TDE, z = 1.193
Pasham et al 2022, submitted
0.3-4.0 keV

screening levels 1,2,3

- filter level 2 sufficient

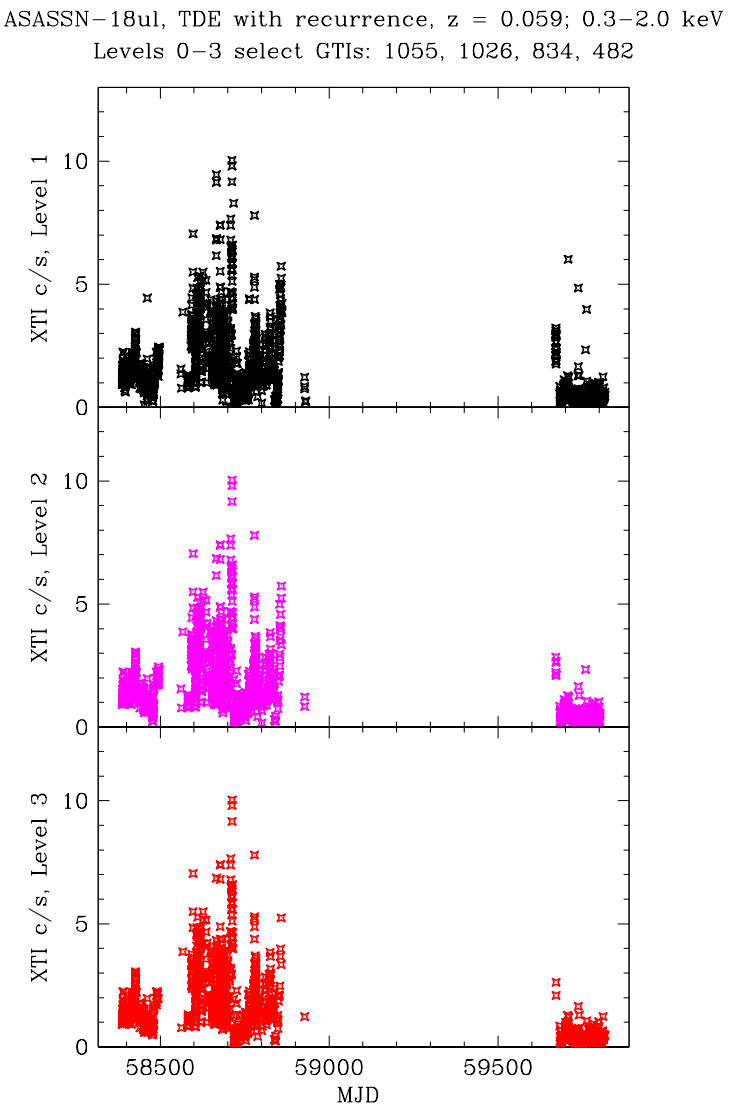


Screening NICER Light Curves

AT2018fyk (ASASSN-18ul)
TDE with recurrence ; z = 0.059

screening levels 1,2,3

- Level 2 usually sufficient
- Fast “flares” deserve additional investigation

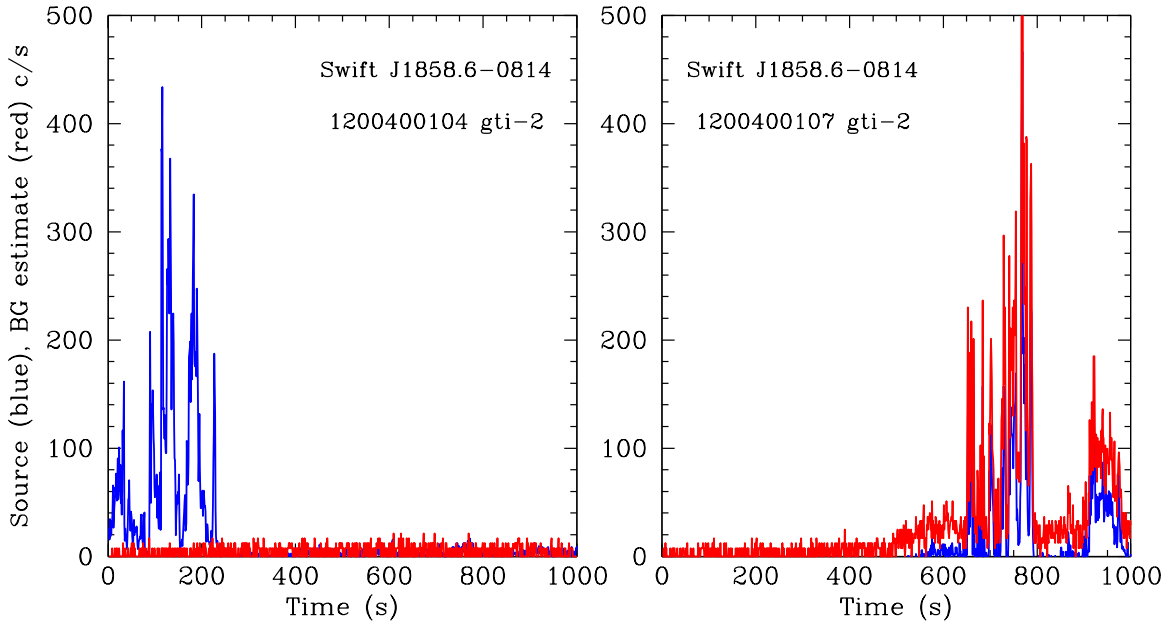


Reality Diagnostics at T < 300 s

Plot BG metrics vs. G-subtracted Light Curve

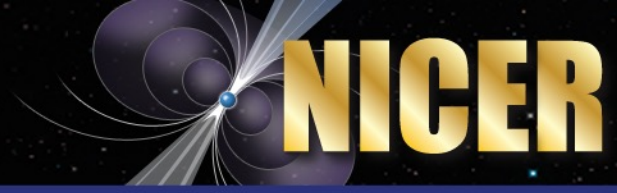
example: SAX J1858 (Remillard et al. 2022, AJ, 163, 130)

plot 1-s **light curve** vs. BG estimator, $R_{est} = 2.91 * ibg + 4.67 * hrej$



- can plot other diagnostic quantities in same way
- get to know the filter files ($obsid/auxil/ni$obsid.mkf.gz)

Reality Diagnostics at T < 300 s



Filter Files: Information at 1 s relevant to evaluation data quality

- Satellite Parameters: use bincurve ; find avg/GTI — warnings
  - COR_SAX (cutoff rigidity for SAX) — cor_sax < 2.0
  - SAT_LAT (satellite position latitude) — |lat| > 45°

- Particle Environment [56] ; (use ftlist ; choose selected FPMs)
  - FPM_TRUMP_SEL_1500_1800 = ***ibg*** [56] — plot BG estimator for GTI
  - FPM_RATIO_REJ_300_1800 = ***hrej*** [56] — (previous slide)
  - MPU_OVERONLY_COUNT = overshoot rates [56] — plot overshoots during GTI

- Soft Noise [56]; (use ftlist ; choose selected FPMs)
  - MPU_NOISE25_COUNT [56] = ***nz*** [56] — plot *nz* during GTI
  - MPU_UNDER_COUNT [56] = undershoot rates [56] — plot undershoots in GTI

Pushing limits: Deep Spectra and BG uncertainty (3C50) for rotation powereed msec pulsars

(Salmi et al. 2022, submitted)

- Screening at level 4-soft
- Opportunity: Ms data sets, observing a constant, faint source
- Variations in subsamples (6-9 samples, 100-200 ks each) caused by systematic uncertainty in the BG model

Long Timescales: PSR J0030+0451

example: PSR J0030+0451: level 4-soft

Screening Step	#GTIs	Expos.(ks)	Percent
All GTIs (nimaketime w/defaults)	11196	**3038**	100.
GTIs within 3C50 Model Limits	11195	3037	100
Exposure > 200 s	9702	2857	94.1
Low noise (*nz* < 220 c/s)	8301	2446	80.5
Low BG (*ibg* < 0.2 c/s)	7848	2313	76.2
BGsub: $\|hbg_{net}\| < 0.05$	7700	2272	75.0
BGsub: $\|S0_{net}\| < 0.15$	7614	2247	74.8
BGsub: $\|D_{net}\| < 0.3$	7229	2133	60.2
BGsub: $\|C_{net}\| < 0.1$	6647	**1948**	**64.1**

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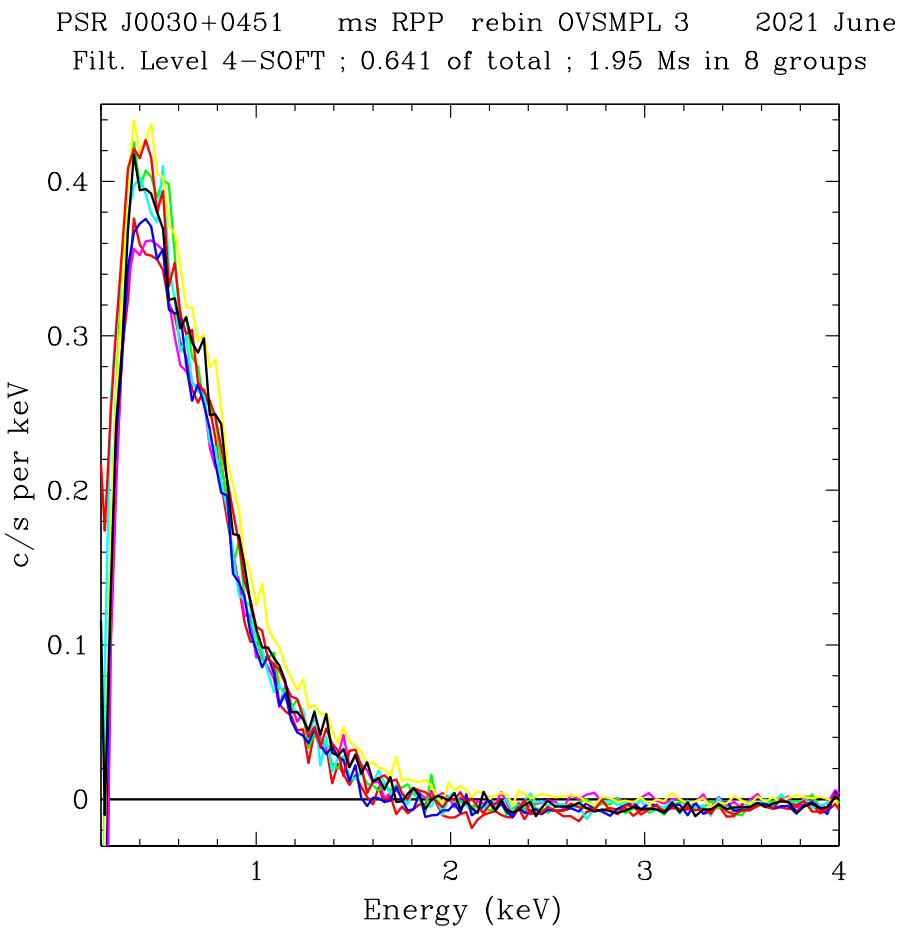
ibg: raw, in-focus, 15-18 keV
Filter: BG-subtracted hbg_{net} (13–15 keV)
Filter: BG-subtracted $S0_{net}$ (0.2–0.3 keV)
Filter: BG-subtracted D_{net} (4-12 keV)
Filter: BG-subtracted C_{net} (2-4 keV)

Long Timescales: PSR J0030+0451

Screening level 4-soft

selected (64.1%) GTIs: 1.95 Ms
in 9 intervals (~217 ks each)

0.3-2.0 keV 0.234 c/s
rms_9 0.018 c/s



Long Timescales: 8 Pulsars

Pulsar	Selected (ks)	sub#	c/s 0.3-2.0 keV	2-4 keV	4-12 keV
PSR B0656	194/283 (68.7%)	4	8.186 (0.020)	0.0004 (0.005)	-0.002 (0.007)
PSR B1821	789/1139 (69.3%)	8	0.666 (0.020)	**0.075*** (0.008)	0.024 (0.010)
PSR J0030	1984/3078 (64.4%)	9	0.234 (0.018)	-0.008 (0.005)	-0.002 (0.010)
PSR J1614	572/1049 (54.5%)	5	0.216 (0.018)	-0.003 (0.003)	0.006 (0.007)
PSR J1231	1670/2981 (55.3%)	8	0.163 (0.019)	-0.013 (0.006)	-0.009 (0.008)
PSR J0614	726/1250 (58.1%)	6	0.062 (0.016)	-0.011 (0.008)	-0.010 (0.011)
PSR J0740	1713/2790 (61.4%)	8	0.028 (0.020)	-0.004 (0.010)	-0.006 (0.011)
PSR B1937	1079/2562 (42.1%)	6	-0.085 (0.015)	0.004 (0.007)	-0.001 (0.012)

count rates are for the NICER FOV, not necessarily isolating the pulsar
additional systematic concerns : biases in the NICER BKGD fields (libraries) ; confusion limit
*this source was not filtered for C_{net}, D_{net}

- **Estimate BG + Systematic Uncertainty (1σ) from subsamples' avg. rms**
  0.018 0.007 0.010
- **Uncertainties scale to shape of BG spectrum ; uncertainty scale is 2%**
- **Test Bed for other BG Models**

Summary

- Background models are still evolving :
  SCORPEON and 6C50 (empirical companion)
- Screening BG-subtracted spectra in bands *S0* and *hbg* is a useful tool for quality control
- Despite model problems one can “go deep” with 60% of data and reach uncertainty ~2% of average background
- NICER users should embrace hands-on expectations (i.e., familiarity with diagnostics and filter files)