
# A NICER Look at Cross-calibration using 3C 273 and the Crab

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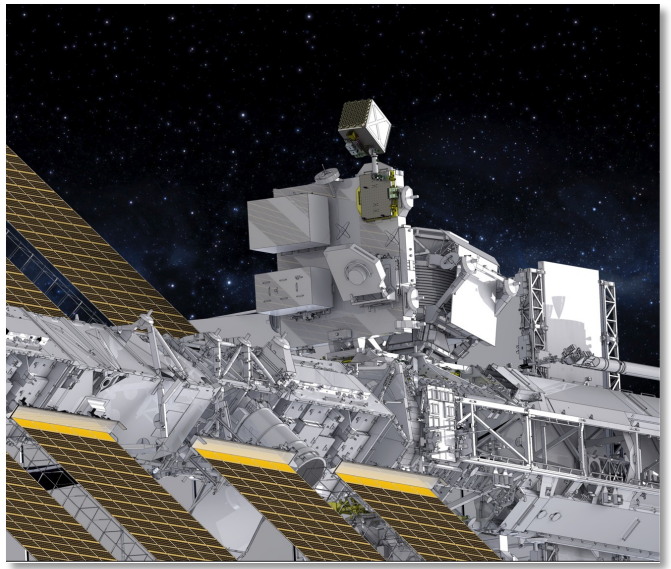
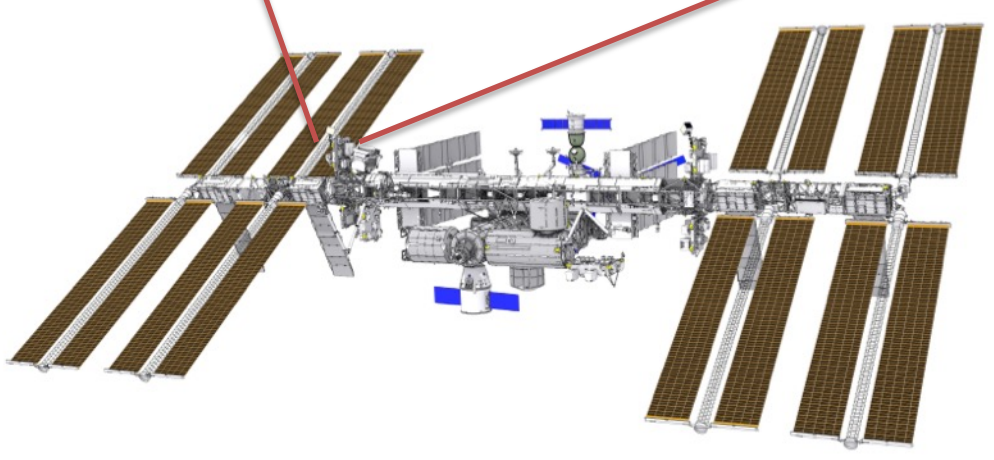
on behalf of the NICER team

# Overview

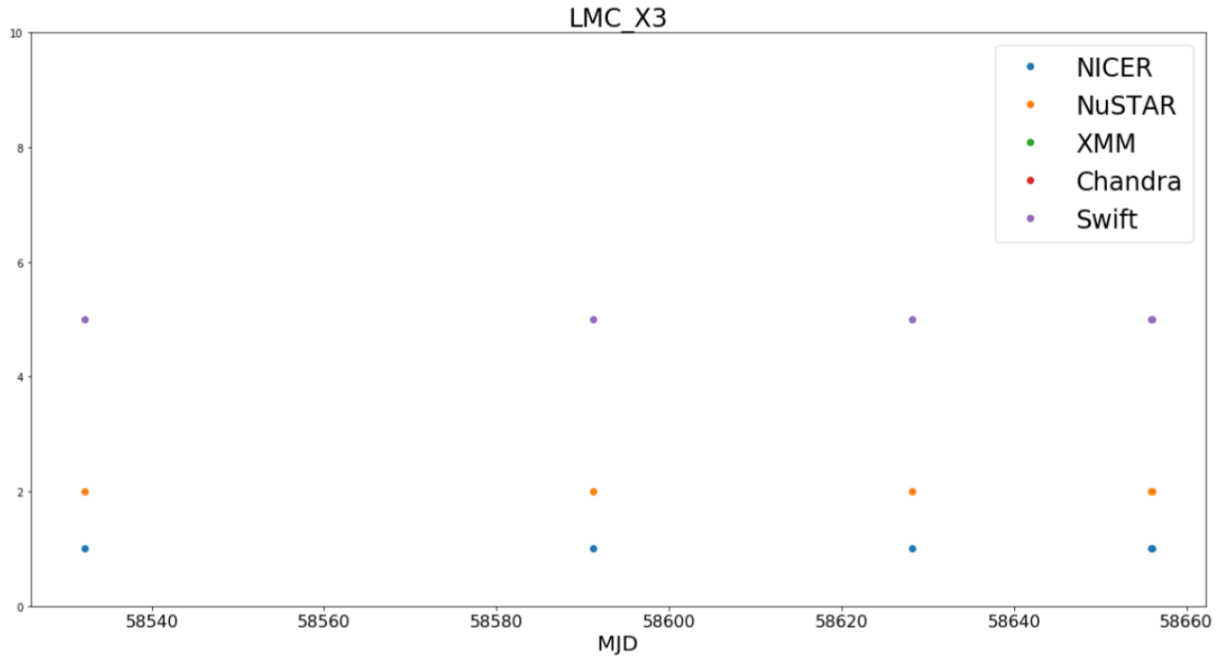
1) NICER Calibration Obs
2) NICER Background
3) 3C 273 observing campaign
4) Procedure
5) Results
6) Crab Peak
7) Summary

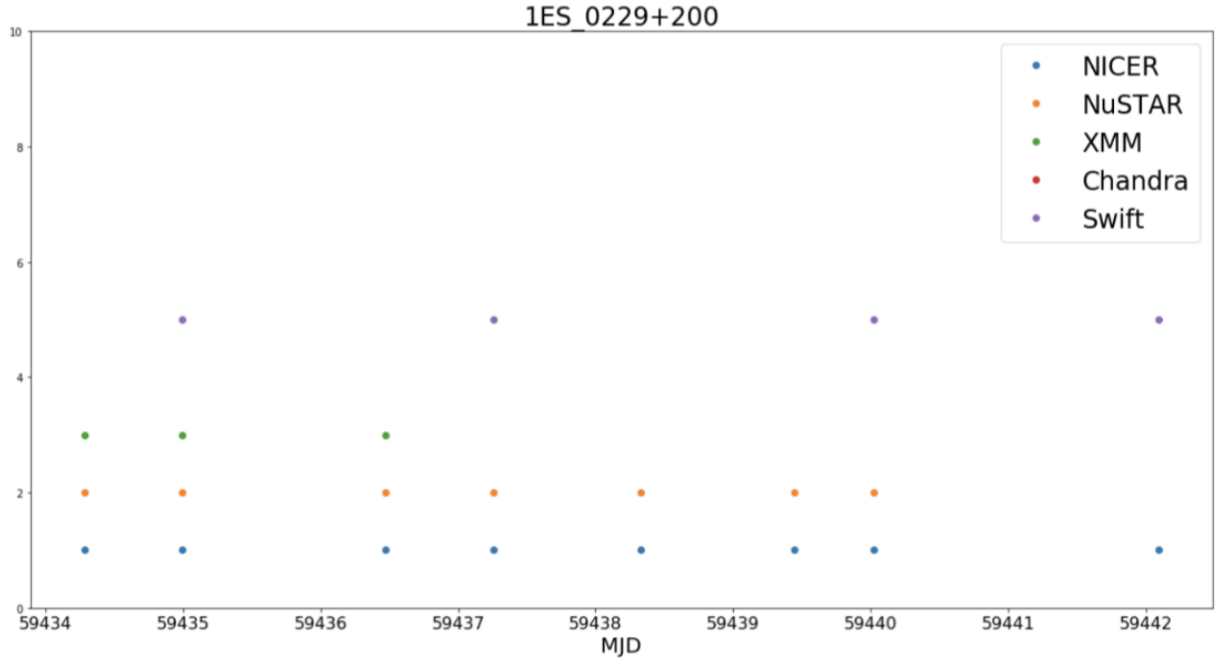




# NICER Cross-Calibration Observations

## ~115 Simultaneous observations of calibration targets (e.g., RX J1856-3754, Sco X-1)



# NICER Cross-Calibration Observations

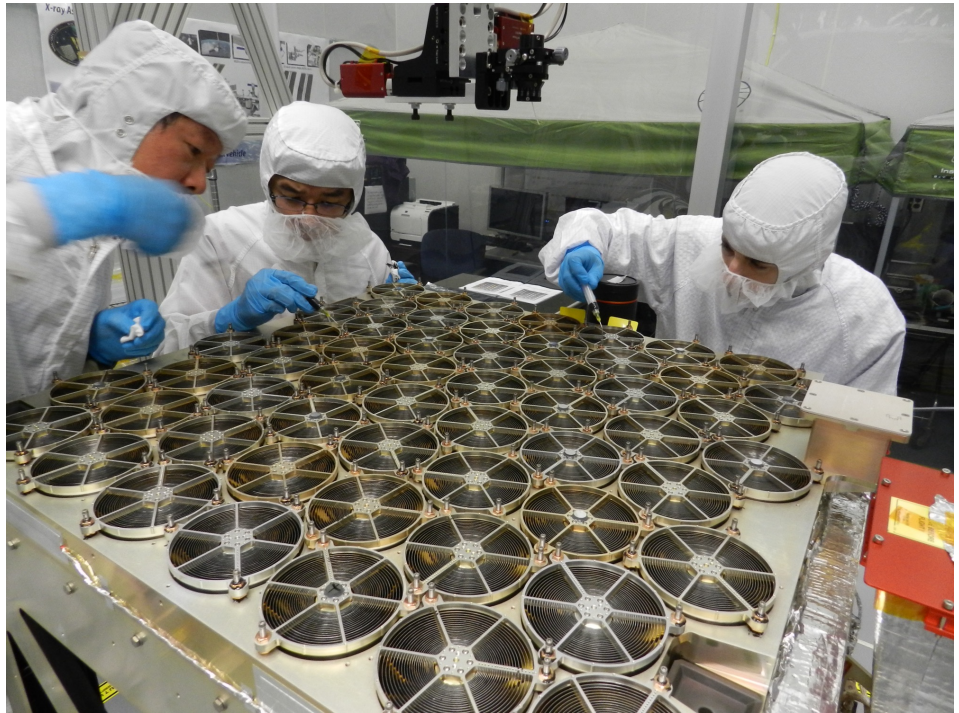
*~quasi-simultaneous observations of science targets*

| | |
|---|---|
| *NICER/NuSTAR* | *350 total observations* |
| *NICER/XMM* | *196 total observations* |
| *NICER/Chandra* | *187 total observations* |
| *NICER/Swift* | *1718 total observations* |

*Hundreds of non-simultaneous observations of non-variable calibration targets (e.g., Cas A, 1E 0102.2-7219)*

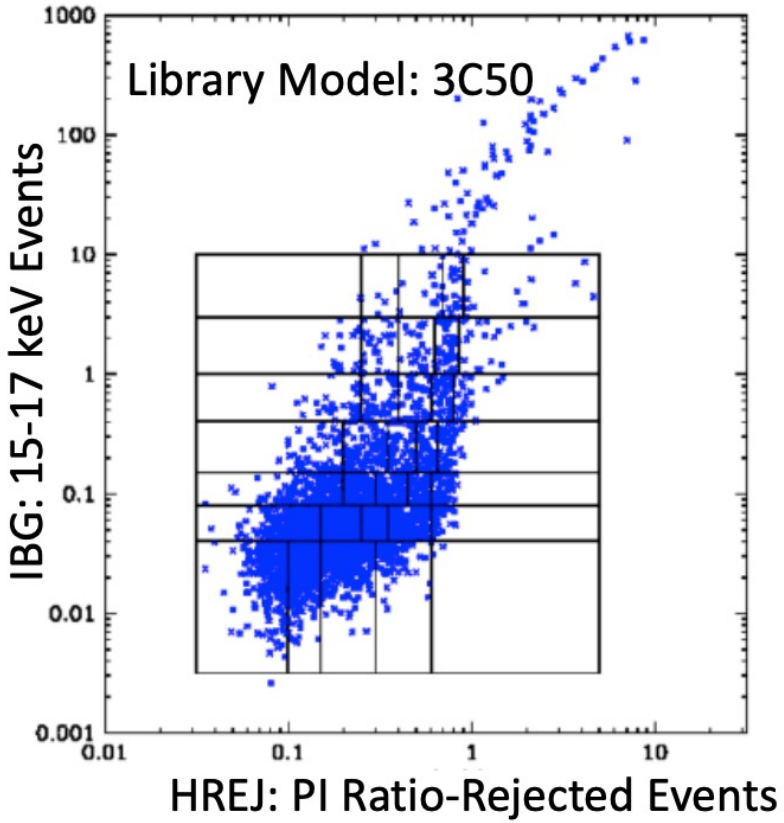
# Background

- *NICER is a non-imaging instrument so no simultaneous background is obtained*
- *Must rely on blank sky backgrounds and/or background models to subtract background*



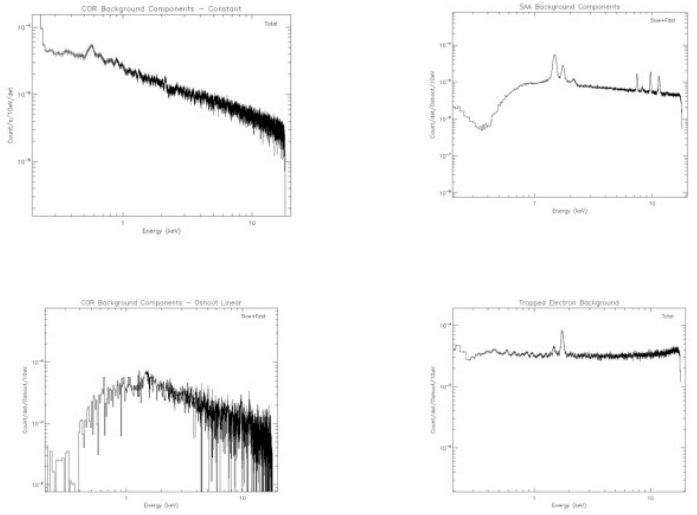
# Two ways of handling background

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



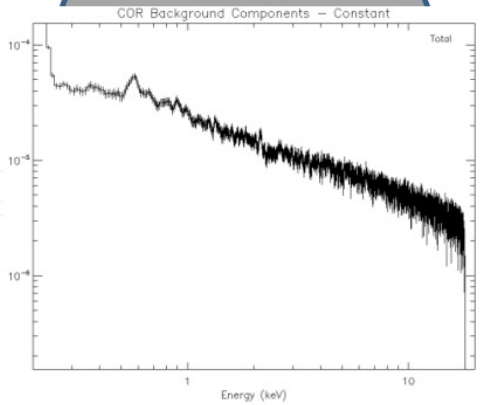
- Measure "basis vector" of each unique component
  - Make smoothed version of template as XSPEC model
- Normalized based on known telemetry (overshoots, etc)
- Application: predict norms from telemetry & load into XSPEC

# A glimpse of Scorpeon

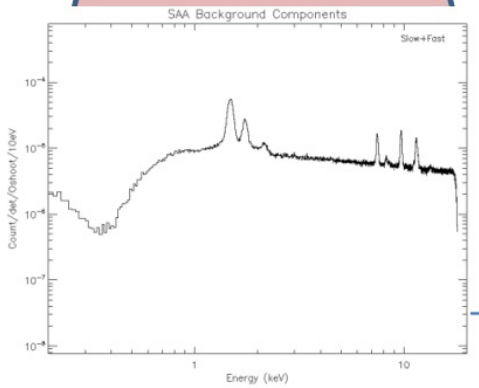
Hadron-Dominated

Electron-Dominated

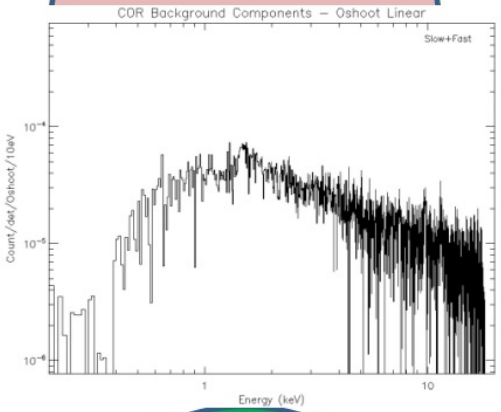
CON



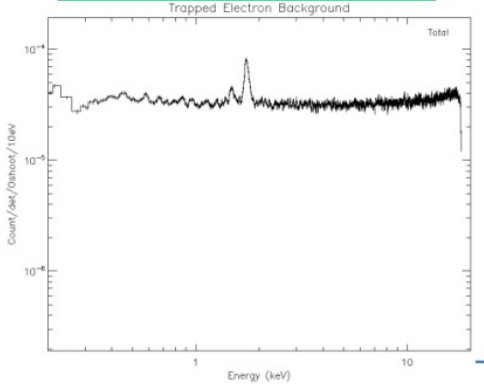

SAA



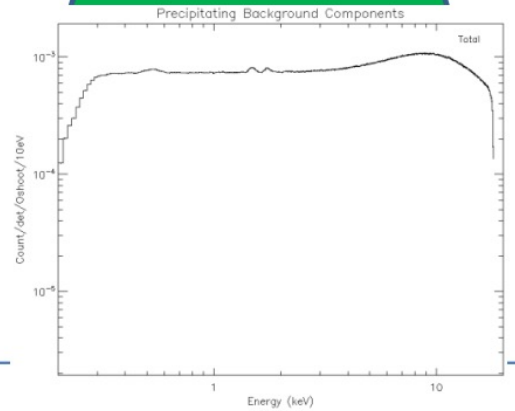

COR



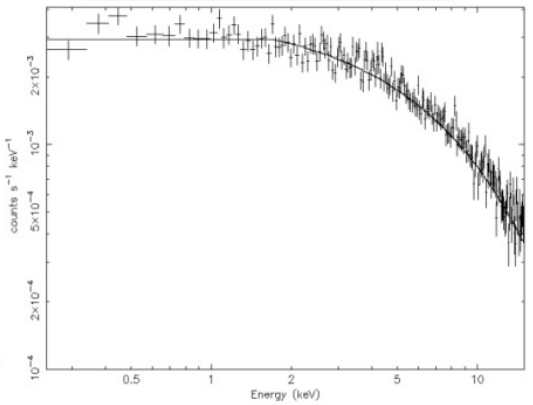

TREL



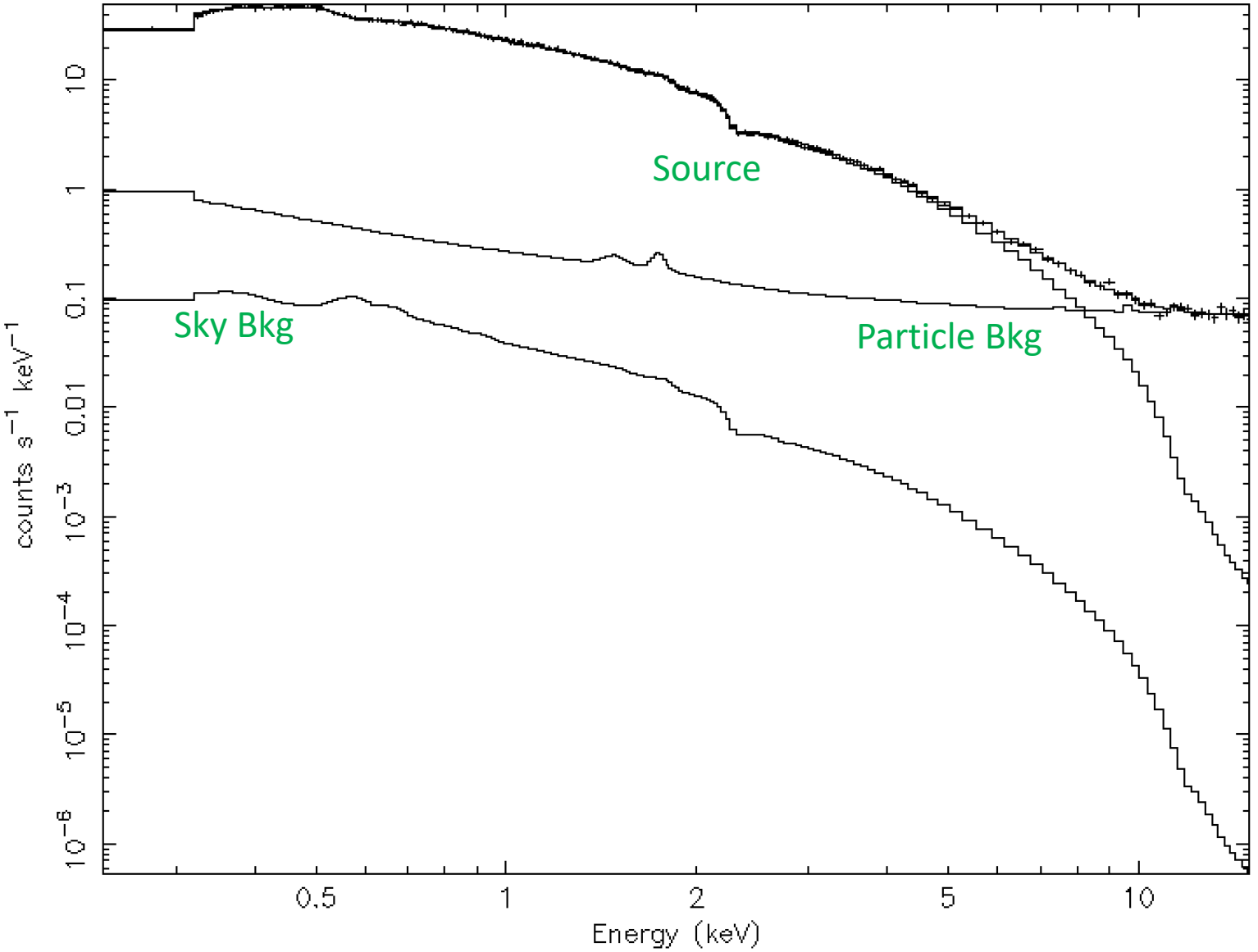

PREL




LEEL



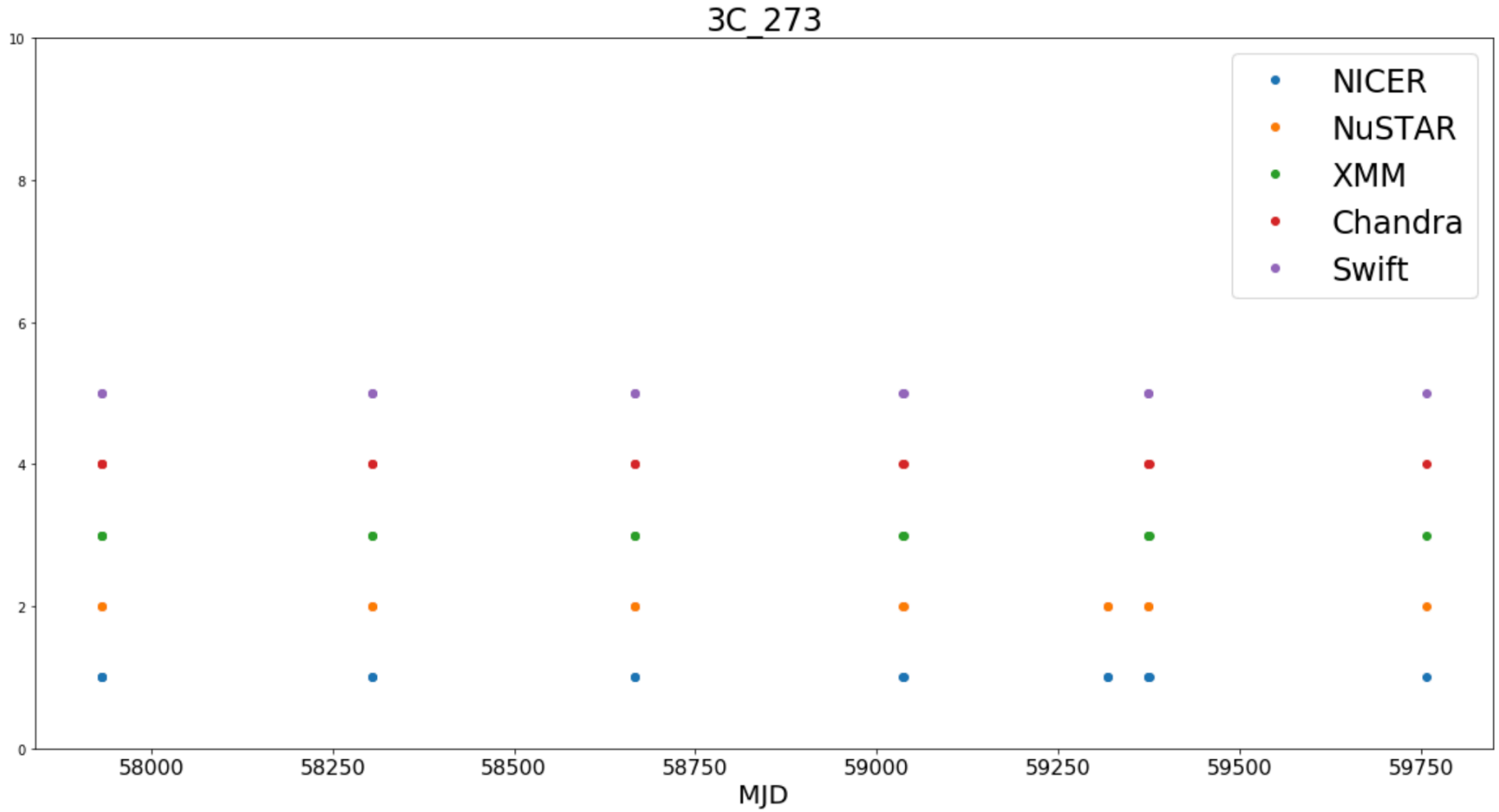
# NICER background Example 3c 273




# Mostly Agree to sometimes disagree

| Obs. | Bkg | ObsID | $N_{\rm H}$ | $\Gamma_1$ | $E_{\rm break}$ | $\Gamma_2$ | $F_{0.5-10\ \rm keV}$ | $\chi^2$/dof |
|---|---|---|---|---|---|---|---|---|
| | | | | $10^{20}$ cm$^{-2}$ | keV | | $10^{-11}$ cgs | |
| NIC | Sco | 2010100101 | 1.79$^b$ | 2.02(1) | 1.0$^b$ | 1.72(1) | 8.45(8) | 150.1/150 |
| NIC | 3C50 | 2010100101 | 1.79$^b$ | 2.03(3) | 1.0$^b$ | 1.71(1) | 8.51(8) | 109.9/114 |
| NIC | Sco | 2010100102 | 1.79$^b$ | 2.00(1) | 1.0$^b$ | 1.735(7) | $8.28^{+4}_{-6}$ | 113.7/177 |
| NIC | 3C50 | 2010100102 | 1.79$^b$ | 2.01(2) | 1.0$^b$ | 1.728(7) | 8.32(4) | 106.9/129 |
| NIC | Sco | 3010100101 | 1.79$^b$ | 2.06(1) | 1.0$^b$ | 1.630(6) | 9.98(5) | 172.5/175 |
| NIC | 3C50 | 3010100101 | 1.79$^b$ | 1.99(2) | 1.0$^b$ | 1.661(6) | 9.71(5) | 160.2/130 |
| NIC | Sco | 5010100105 | 1.79$^b$ | 2.15(1) | 1.0$^b$ | 1.67(1) | 7.89(5) | 160.6/156 |
| NIC | 3C50 | 5010100105 | 1.79$^b$ | 2.07(3) | 1.0$^b$ | 1.72(1) | 7.55(5) | 114.4/117 |

# IACHEC Observing Campaign 3C 273

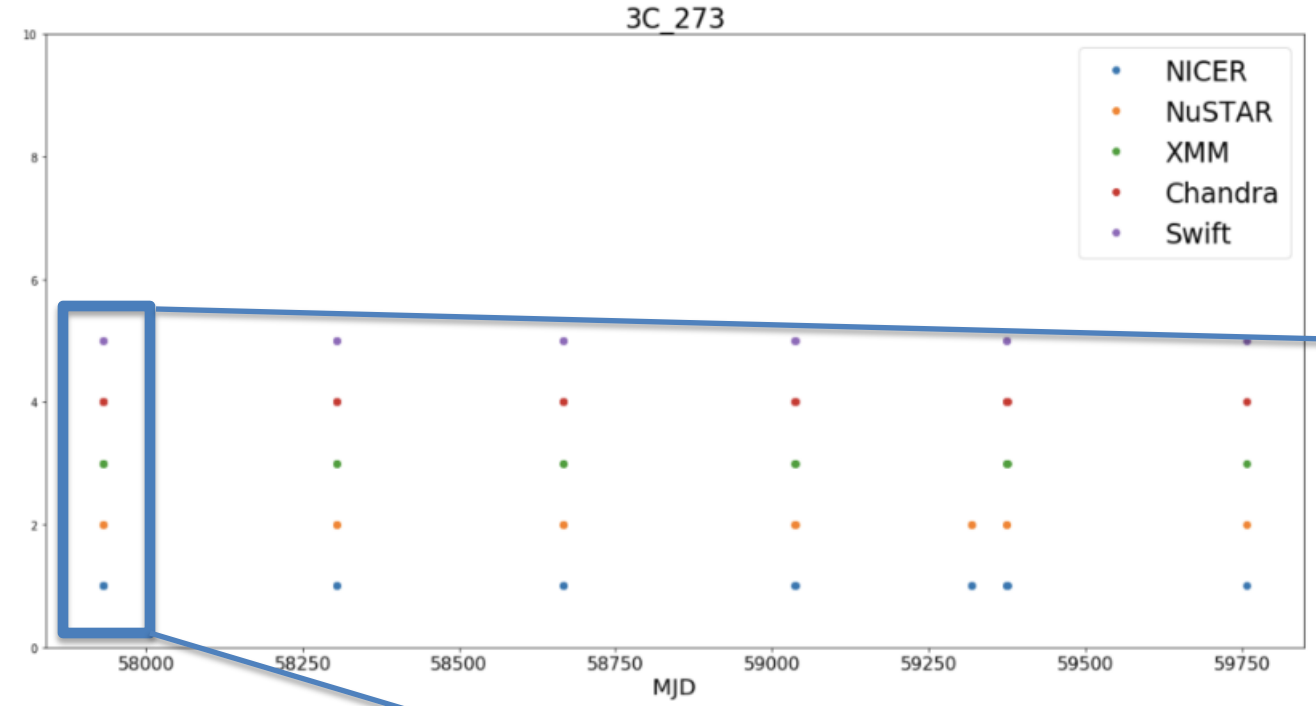


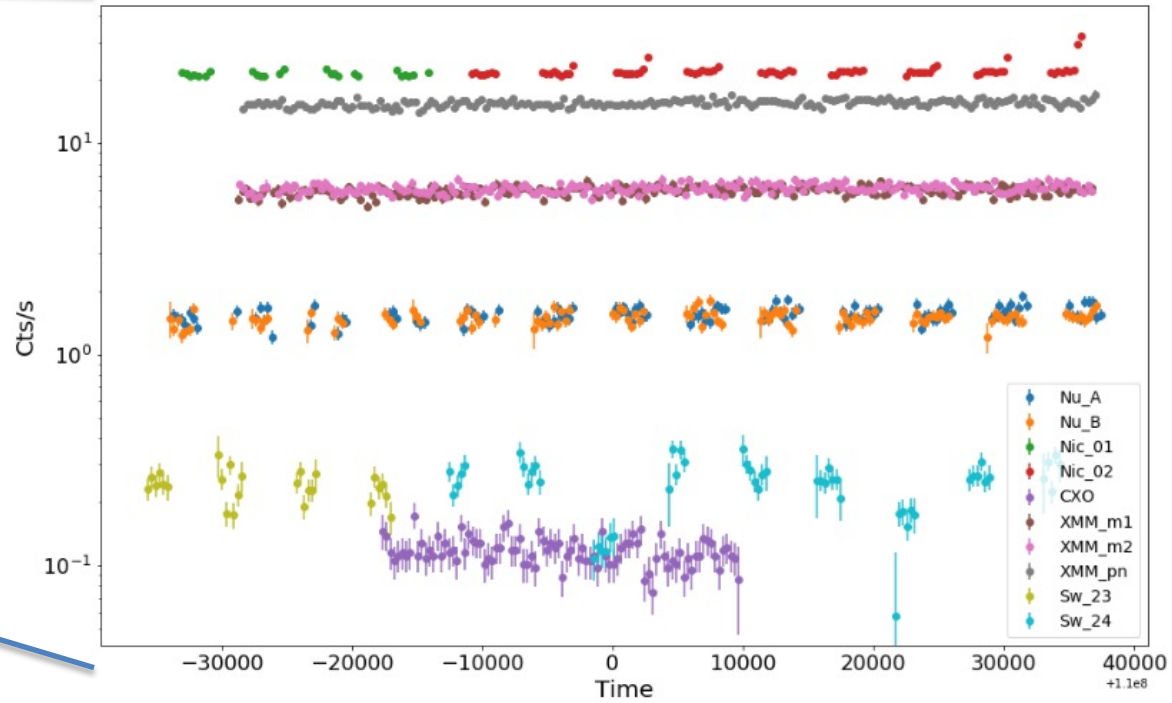

# IACHEC Observing Campaign 3C 273

## 7 total epochs since launch of NICER

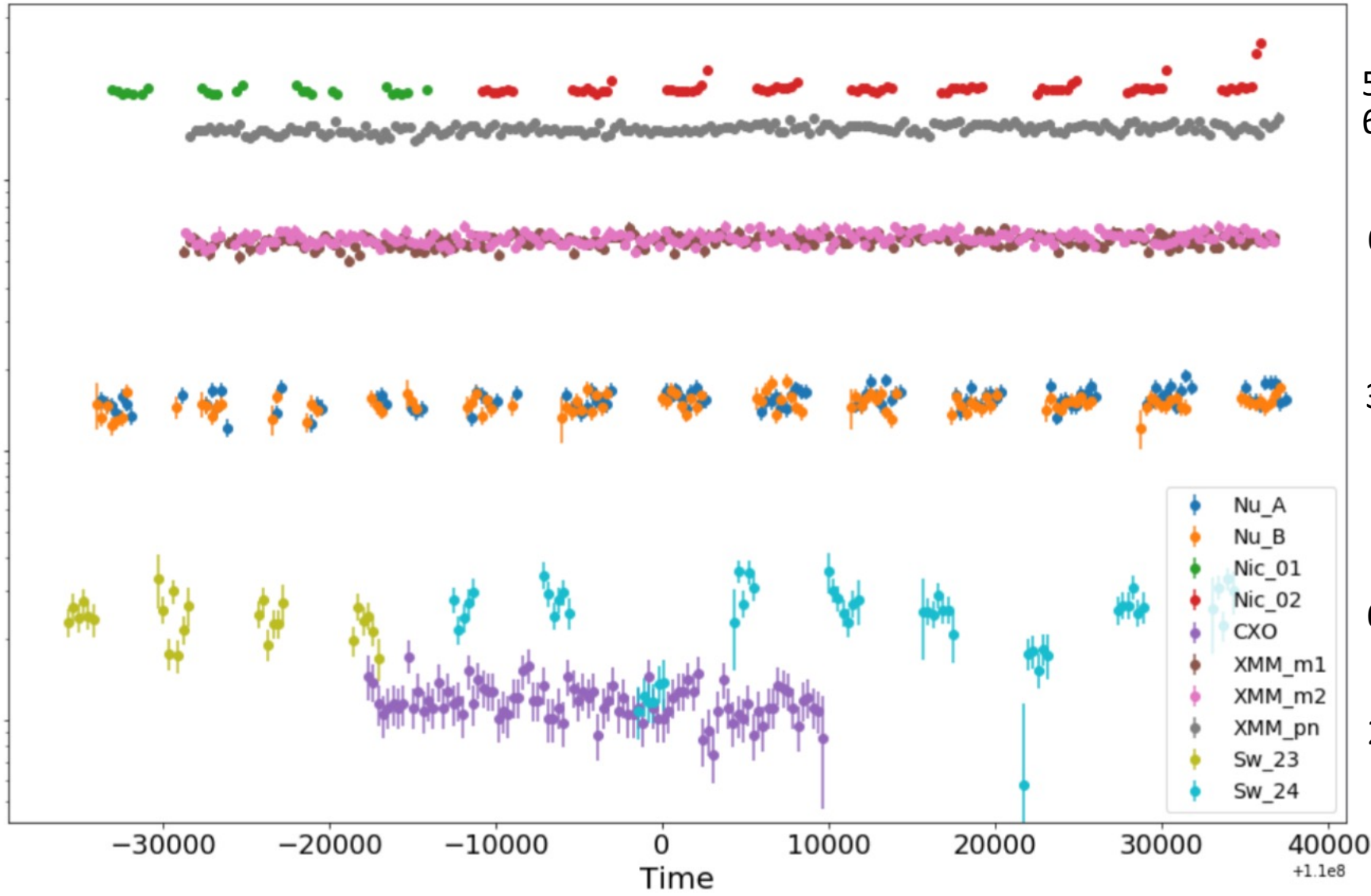
| TIME | NIC_ID | NU_ID | NU_S | CH_ID | CH_S | XMM_ID | XMM_S | SW_ID_1 | SW_S_1 |
|---|---|---|---|---|---|---|---|---|---|
| 57931 | 10100101 | 10302020002 | S | 19867 | S | 414191301 | S | 50900023 | S |
| 57931 | 10100102 | 10302020002 | S | 19867 | S | 414191301 | S | 50900024 | S |
| 57932 | 10100103 | ... | ... | 19867 | NS | 414191301 | NS | ... | ... |
| 58304 | 1010100104 | 10402020006 | S | 20709 | S | 414191401 | S | 50900025 | S |
| 58304 | 1010100105 | 10402020006 | S | 20709 | S | 414191401 | S | 50900025 | S |
| 58667 | 2010100101 | 10502620002 | S | 21815 | NS | 810820101 | S | 50900026 | S |
| 58667 | 2010100102 | 10502620002 | S | 21815 | S | 810820101 | S | 50900027 | S |
| 59036 | 3010100101 | 10602606002 | S | 22828 | S | 810821501 | S | 89029001 | S |
| 59037 | 3010100102 | 10602606002 | S | 22828 | NS | 810821501 | S | 89029002 | S |
| 59319 | 3626010102 | 60601004002 | S | ... | ... | ... | ... | ... | ... |
| 59319 | 3626010103 | 60601004002 | S | ... | ... | ... | ... | ... | ... |
| 59375 | 4010100101 | 10702608002 | S | 24585 | NS | 810821601 | S | 50900028 | S |
| 59375 | 4010100102 | 10702608002 | S | 24585 | S | 810821601 | S | 50900029 | S |
| 59376 | 4010100103 | ... | ... | 24585 | NS | 810821601 | NS | ... | ... |
| 59758 | 5010100105 | 10802608002 | S | 25691 | S | 810821901 | S | 89372001 | S |

# First NICER observation of 3C 273



# First observation light curves




NICER
XMM pn (SW)
XMM MOS1/2 SW
NuSTAR FMPA/B
Swift-XRT WT
Chandra HETGS

5.9/21.2 ks
65.5 ks
65.5 ks
35 ks
6.7/13.3 ks
26.9 ks


# Procedure

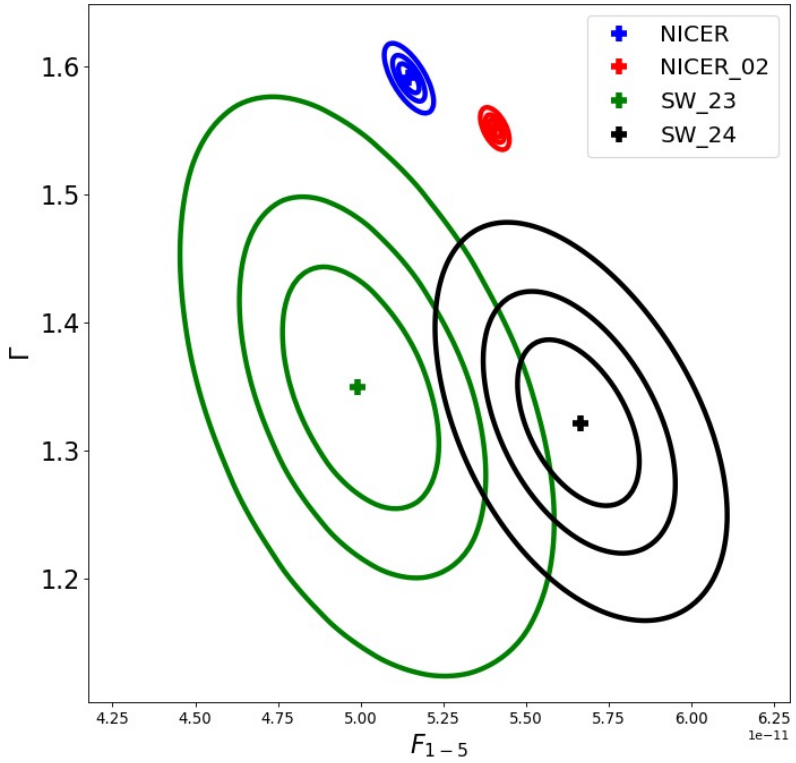
- Followed Madsen et al. (2017)
- Spectra extracted from each observatory following standard procedures (e.g., reprocessing, cleaning)
- Spectra binned to 1 count per bin for use with C-stat
- Spectra fit in 1-5 keV energy range
- Updated HI4PI $N_H$ maps give $1.69 \times 10^{20}$ $cm^{-2}$ (HI4PI collab. et al. 2016)
- $N_H$ fixed to $1.79 \times 10^{20}$ $cm^{-2}$ using Wilms abundances (Wilms et al. 2000) and Verner cross-sections (Verner et al. 1996)
- C-stat used for fitting spectra
- Chi-square/d.o.f. reported by loading in best-fit cstat model and using 50 cts/bin data

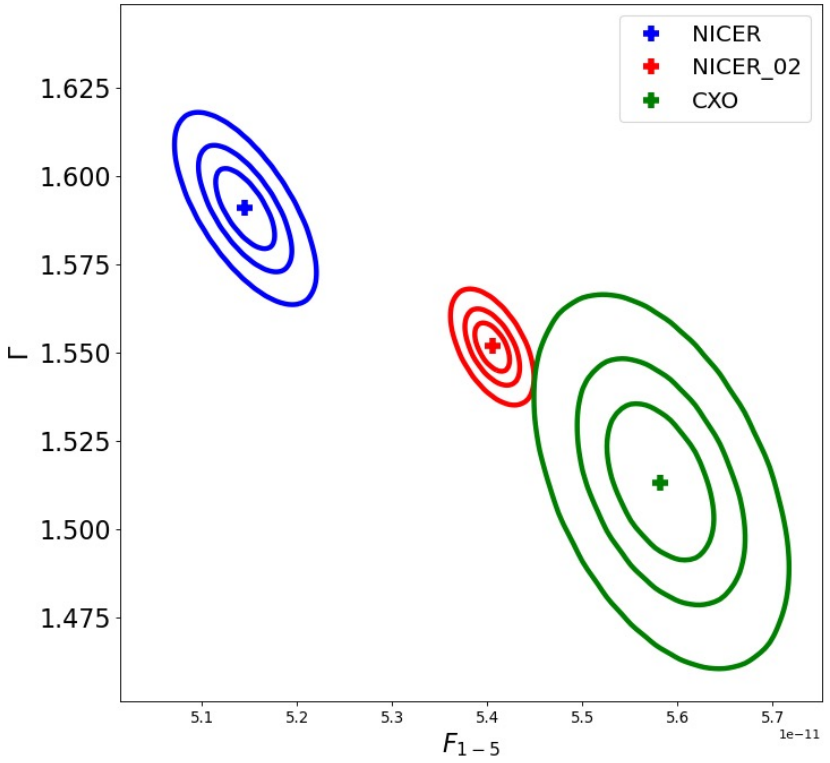
# Preliminary Results

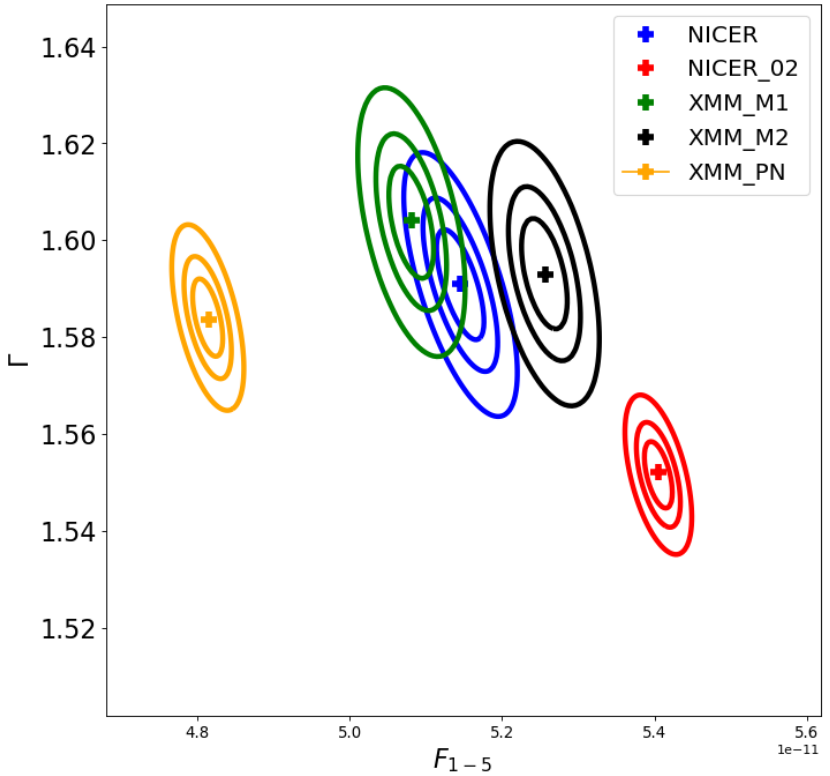
**Table 2.** Fits performed in the 1-5 keV energy range using cstat.

| Obs. | Bkg | ObsID | $N_H$ | $\Gamma$ | $F_{1-5\ keV}$ | $\chi^2$/dof |
|---|---|---|---|---|---|---|
| | | | $10^{20}$ cm$^{-2}$ | | $10^{-11}$ cgs | |
| NIC | 3C50 | 10100101 | 1.79 | 1.591(7) | 5.14(2) | 378.5/379 |
| NIC | Sco | 10100101 | 1.79 | $1.570^{+0.008}_{-0.007}$ | 5.19(4) | 402.3/392 |
| NIC | 3C50 | 10100102 | 1.79 | 1.551(4) | 5.41(1) | 337.0/397 |
| NIC | Sco | 10100102 | 1.79 | 1.551(4) | 5.38(3) | 372.9/396 |
| $XMM_{PN}$ | Sub | 0414191301 | 1.79 | 1.585(5) | 4.18(1) | 858.0/799 |
| $XMM_{M1}$ | Sub | 0414191301 | 1.79 | 1.604(7) | 5.08(2) | 803.1/668 |
| $XMM_{M2}$ | Sub | 0414191301 | 1.79 | 1.593(7) | 5.26(2) | 741.8/677 |
| CXO | Sub | 19867 | 1.79 | 1.51(1) | 5.58(4) | 69.7/232 |
| Swift | Sub | 00050900023 | 1.79 | 1.35(6) | 5.0(1) | 20.4/27 |
| Swift | Sub | 00050900024 | 1.79 | 1.32(4) | 5.7(1) | 28.1/29 |

# Preliminary Results

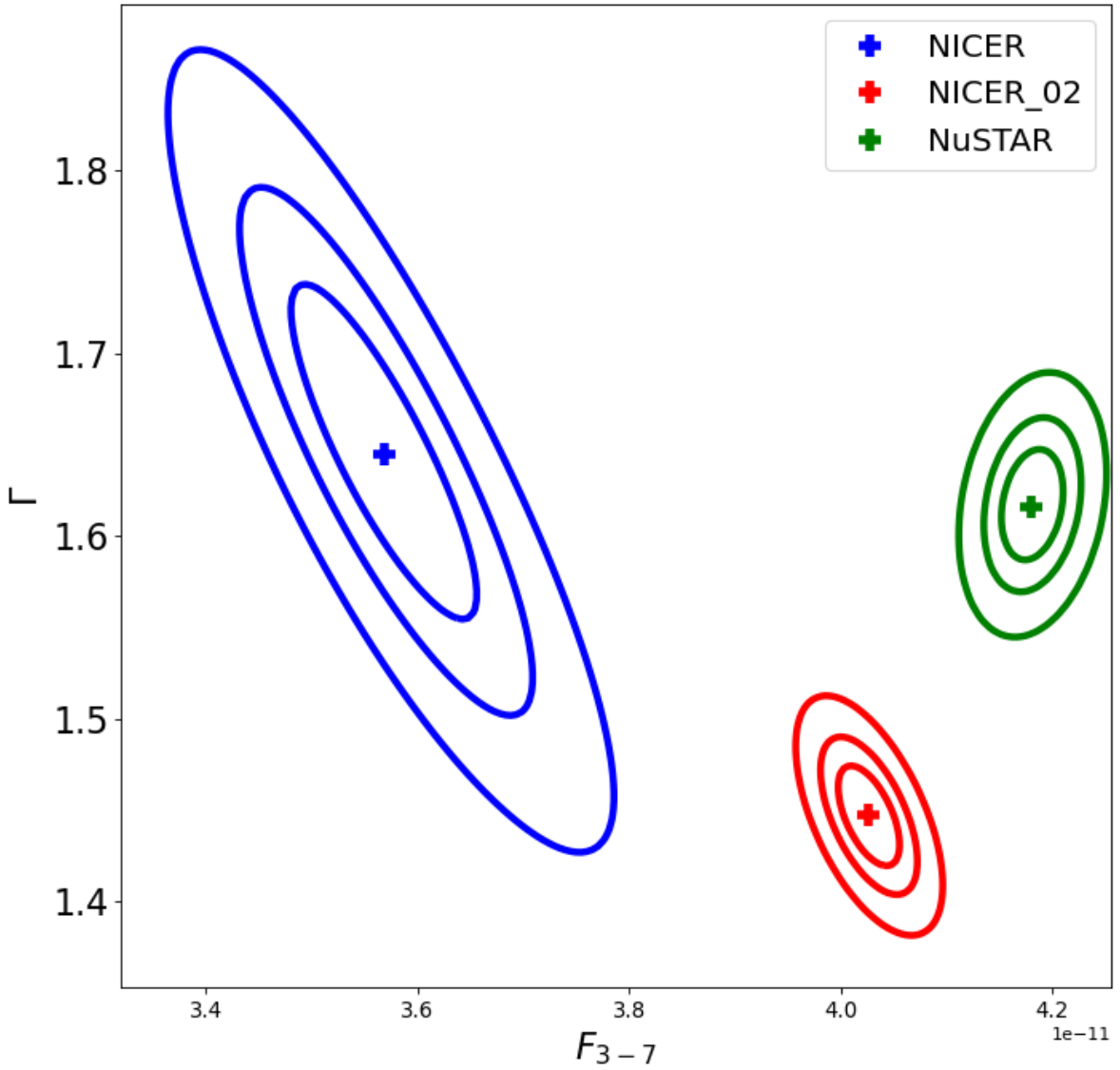


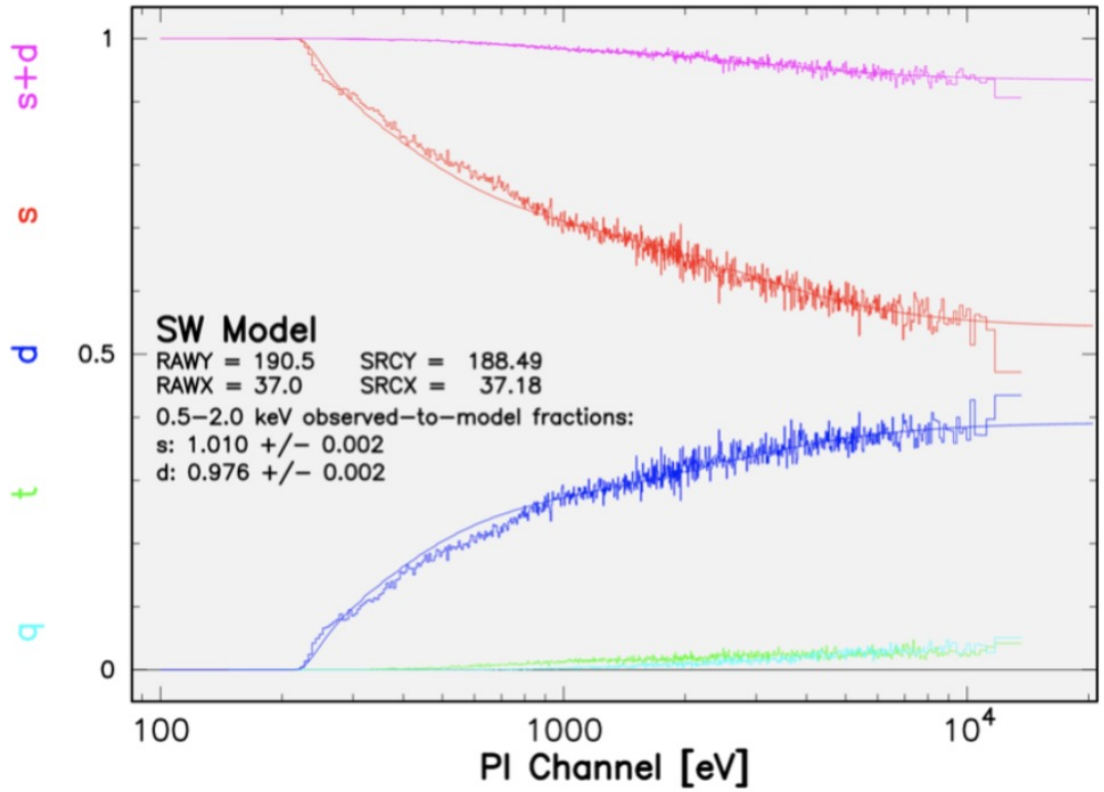



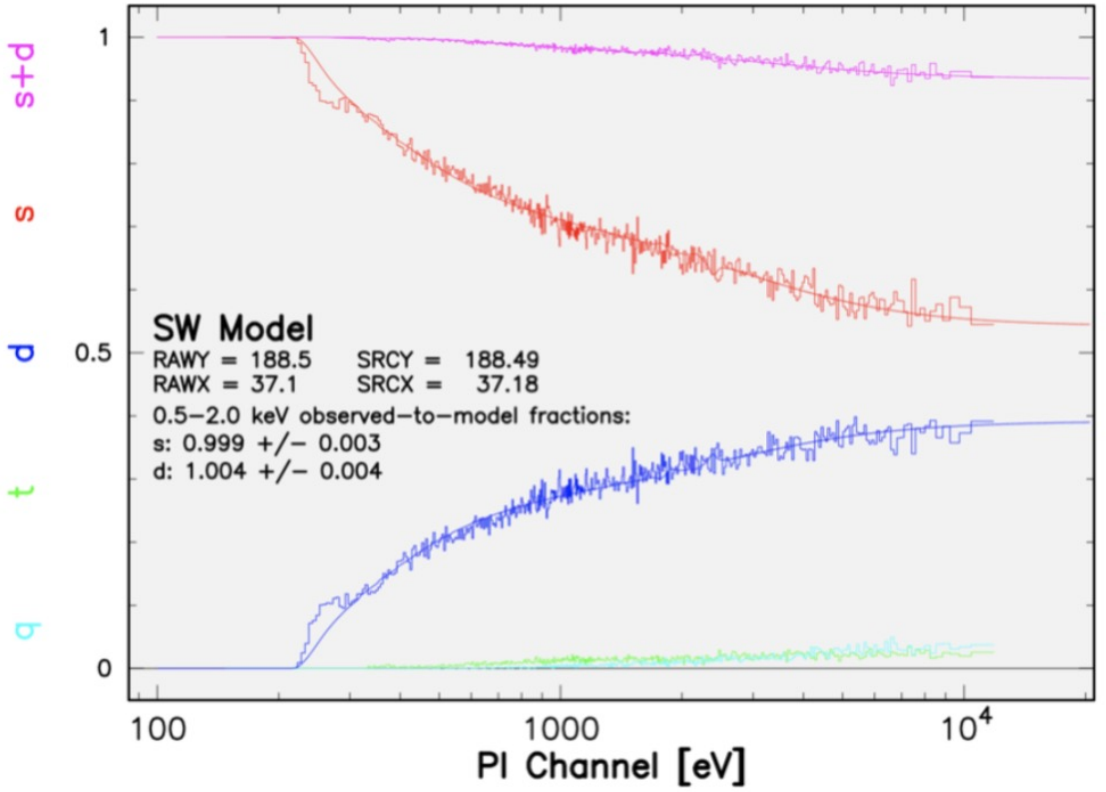

More or less consistent with results from Madsen et al. (2017)

# Preliminary NuSTAR+NICER



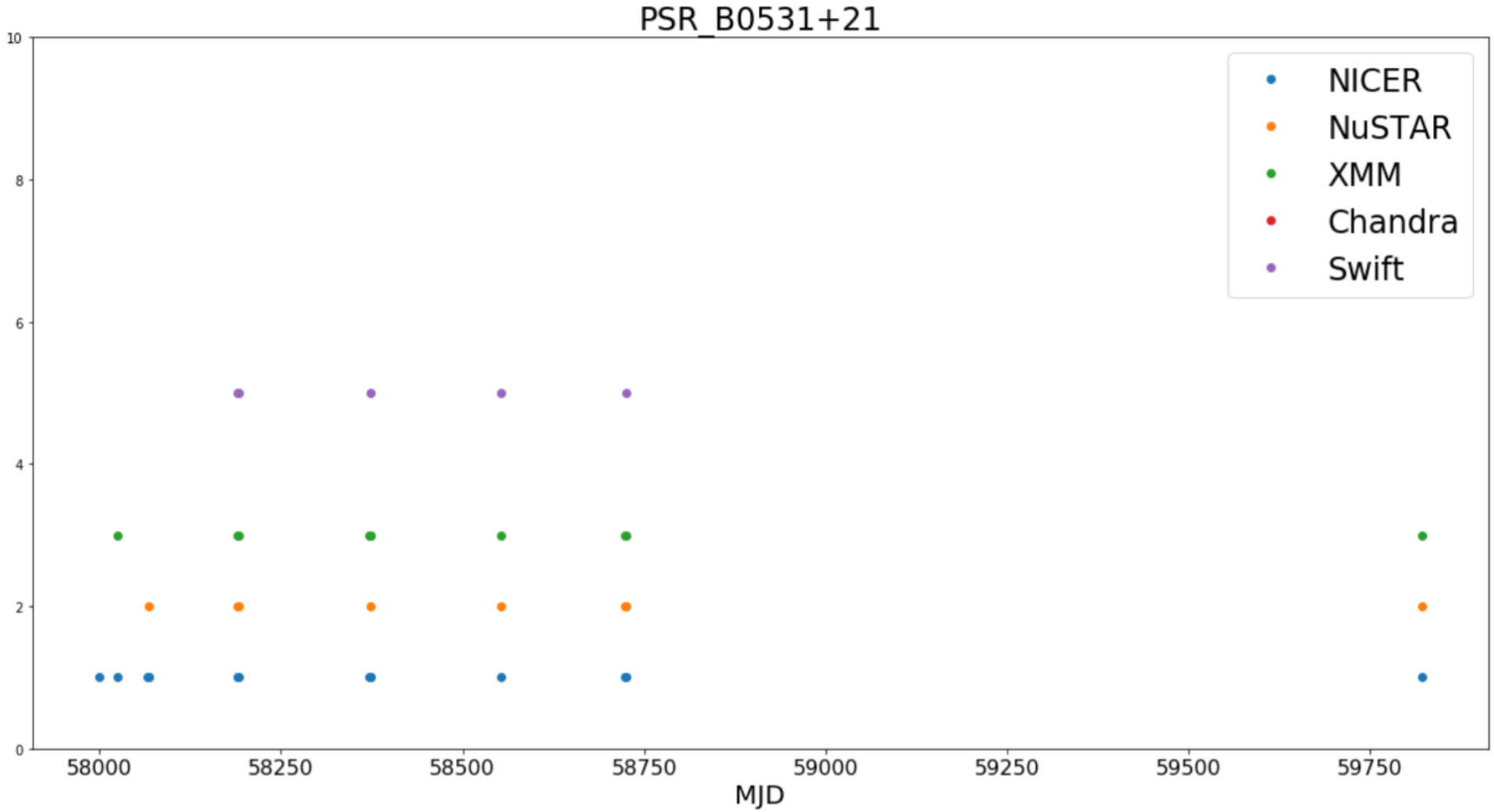
# Oddities and Questions




- XMM pile-up
- Swift Light curves

# Crab pulsar observing campaign




# Crab pulsar observing campaign

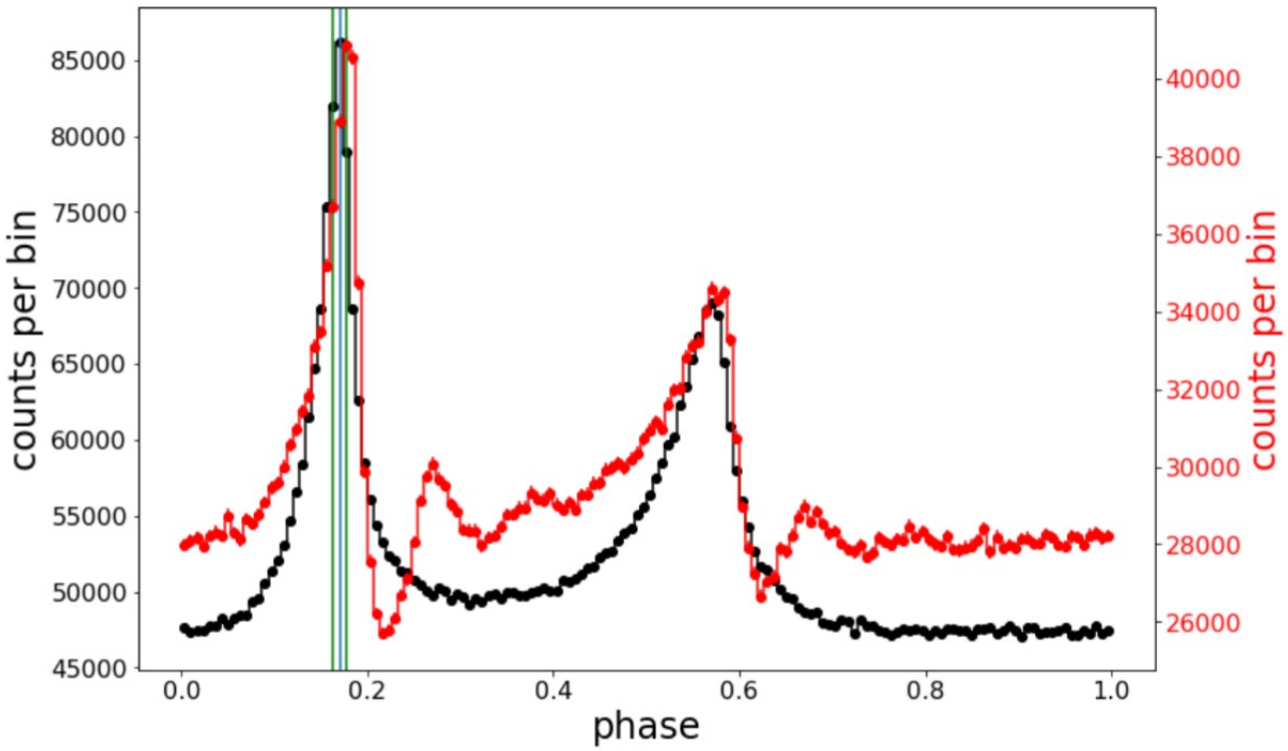
| TIME | NIC_ID | NU_ID | NU_S | CH_ID | CH_S | XMM_ID | XMM_S | SW_ID_1 | SW_S_1 |
|---|---|---|---|---|---|---|---|---|---|
| 58190 | 1013010125 | 10402001004 | S | ... | ... | 811022501 | NS | 50100040 | S |
| 58191 | 1013010126 | 10402001008 | S | ... | ... | 811022501 | S | 50100042 | S |
| 58725 | **2013010106** | **10502001015** | S | ... | ... | 811023401 | NS | 88840002 | S |
| 58371 | 1013010138 | ... | ... | ... | ... | 811022701 | NS | ... | ... |
| 58724 | 2013010105 | 10502001013 | S | ... | ... | 811023401 | S | ... | ... |
| 58068 | 1013010110 | 10302001005 | S | ... | ... | ... | ... | ... | ... |
| 57999 | 1013010108 | ... | ... | ... | ... | ... | ... | ... | ... |
| 58553 | 2013010101 | 10502001008 | S | ... | ... | 811023101 | S | 88840001 | S |
| 58025 | 1011010201 | ... | ... | ... | ... | 793980301 | S | ... | ... |
| 59822 | 5013010104 | 10802303004 | S | ... | ... | 811025001 | NS | ... | ... |
| 58373 | 1013010140 | 10402001012 | S | ... | ... | 811022701 | NS | ... | ... |
| 58373 | 1013010139 | ... | ... | ... | ... | 811022701 | NS | 59032002 | S |
| 58068 | 1013010111 | ... | ... | ... | ... | ... | ... | ... | ... |
| 58066 | 1013010109 | ... | ... | ... | ... | ... | ... | ... | ... |


# Motivation

- Wilson-Hodge et al. (2011) showed a 7% decline in hard X-ray flux
- This can lead to issues with absolute calibration due to flux variations over time
- Proposed solution: Use the pulsed emission from the Crab instead

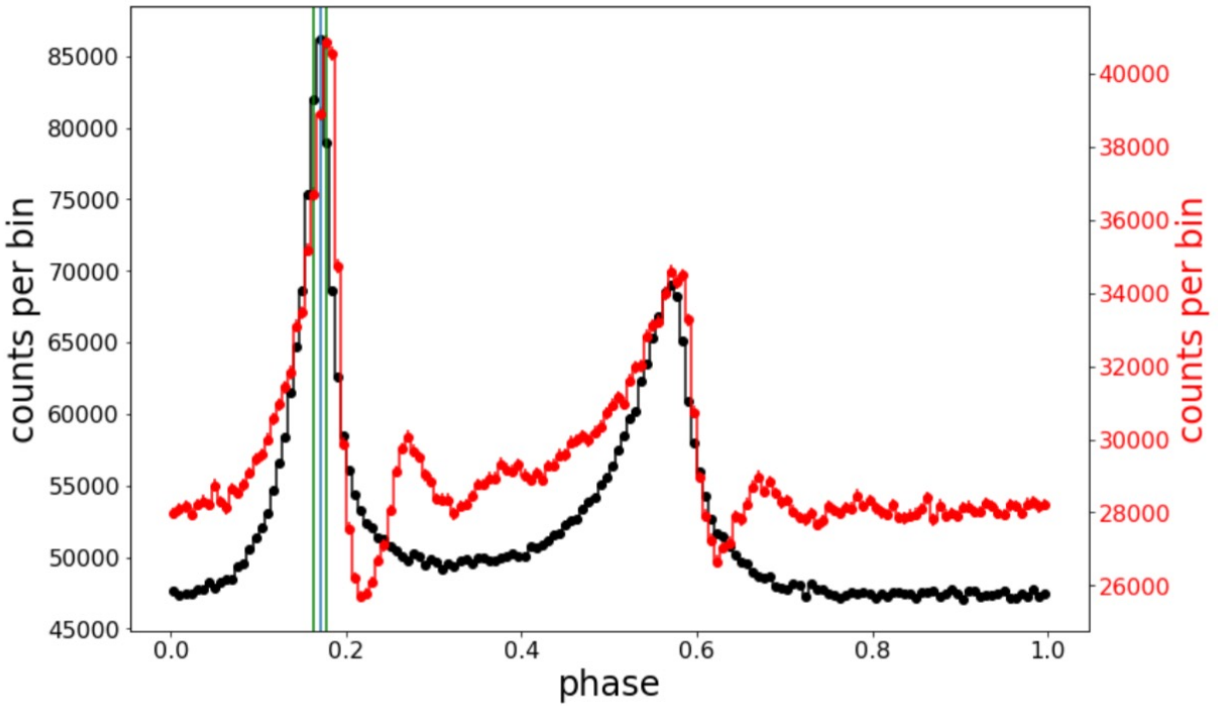
# NICER+NuSTAR Crab pulse peak

- Simultaneous Crab observations
- Fold the data using Jodrell Bank monthly ephemeris
- Use phase-resolved spectroscopy to extract spectrum from pulse peak
- Less sensitive to variations in PWN



# Preliminary Results

| Obs. | Bkg | ObsID | $N_{\rm H}$ | $\Gamma$ | Const. | $\chi^2$/dof |
|---|---|---|---|---|---|---|
| | | | $10^{21}$ cm$^{-2}$ | | A/B | |
| NIC | None | 2013010106 | $3^a$ | 1.97(1) | $1.0^a$ | 72.68/84 |
| Nu | Sub | 10502001015 | $3^a$ | 2.03(1) | 0.646(0.015)/0.627(0.015) | 56.12/63 |




# *Summary*

- NICER has taken part in 6 (7 with NuSTAR) calibration observing campaigns of 3C 273
- Analysis of these is observations is ongoing with preliminary results consistent with Madsen et al. (2017) so far
- Exploring using the pulsed Crab emission to avoid variability of nebula

- I appreciate any feedback, questions, and/or suggestions!