Spatial and temporal variations of the Chandra ACIS particle-induced background and development of a spectral-model generation tool

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ABSTRACT

Context. In X-ray observations, estimating the particle-induced background is important, especially for faint and/or diffuse sources. Although software exists to generate total (sky and detector) background data suitable for a given *Chandra* ACIS observation, no public software exists to model the particle-induced background separately.
Aims. We aimed to understand the spatial and temporal variations of the particle-induced background of *Chandra* ACIS obtained in the two data modes, VFAINT and FAINT.
Methods. Observations performed with ACIS in the stowed position shielded from the sky and the *Chandra* Deep Field South (CDF-S) data sets were used. The spectra were modeled with a combination of the instrumental lines of Al, Si, Ni, and Au and

Purpose and Method

- **Purpose**

Predicting the particle-induced background spectrum of ACIS
for an arbitrary observation
Particularly important for diffuse & faint sources

- **Method**
  - Use data in which background is dominant (cal. data & blank-sky: ~8 Ms)
  - Investigate the time and spatial dependence of the background spectra
  - Develop a tool to predict the background spectral model for an arbitrary observation

Data sets

ACIS-stowed observations

ACIS out of the focus = only particle-induced background events

Observation ID	Date	Exposure (ksec)
62850	2002-09-03	52.49
62848	2003-05-04	47.46
62846	2003-12-08	45.86
62836	2004-11-04	46.62
62831	2005-06-10	47.20
62824	2005-11-13	47.17
62823	2006-06-01	44.11
62819	2006-11-18	47.29
62816	2007-05-28	46.28
62815	2007-11-08	46.45
62814	2008-07-26	48.72
62813	2008-11-03	49.02
62812	2009-06-18	33.15
62811	2009-06-19	12.38
62810	2009-11-04	49.86
62809	2010-03-06	45.60
62808	2010-11-12	47.38
62804	2011-07-12	47.45
62802	2011-11-09	50.56
62678	2012-06-15	47.38
62668	2015-12-09	47.38
62667	2016-09-26	10.64
62666	2016-10-14	9.00
62665	2016-11-03	9.10
62664	2016-12-08	9.11

25 observations (~1 Ms)

Blank-sky observations

Chandra Deep Field South (CDF-S)

Observation ID	Date	Exposure (ksec)
8591	2007-09-20	45.43
9593	2007-09-22	46.43
9718	2007-10-03	49.38
8593	2007-10-06	49.49
8597	2007-10-17	59.28
8595	2007-10-19	115.42
8592	2007-10-22	86.64
8596	2007-10-24	115.12
9575	2007-10-27	108.69
9578	2007-10-30	38.57
8594	2007-11-01	141.40
9596	2007-11-04	111.89
12043	2010-03-18	129.58
12123	2010-03-21	24.79
12044	2010-03-23	99.53
12128	2010-03-27	22.80
12045	2010-03-28	99.72
12129	2010-04-03	77.14
12135	2010-04-06	62.53
12046	2010-04-08	78.02
12047	2010-04-12	10.14
12137	2010-04-16	92.78
12138	2010-04-18	38.53
12055	2010-05-15	80.68
12213	2010-05-17	61.29
12048	2010-05-23	138.10
12049	2010-05-28	86.94
12050	2010-06-03	29.66
12222	2010-06-05	30.64
12219	2010-06-06	33.66
12051	2010-06-10	57.29
12218	2010-06-11	87.98
12223	2010-06-13	100.71

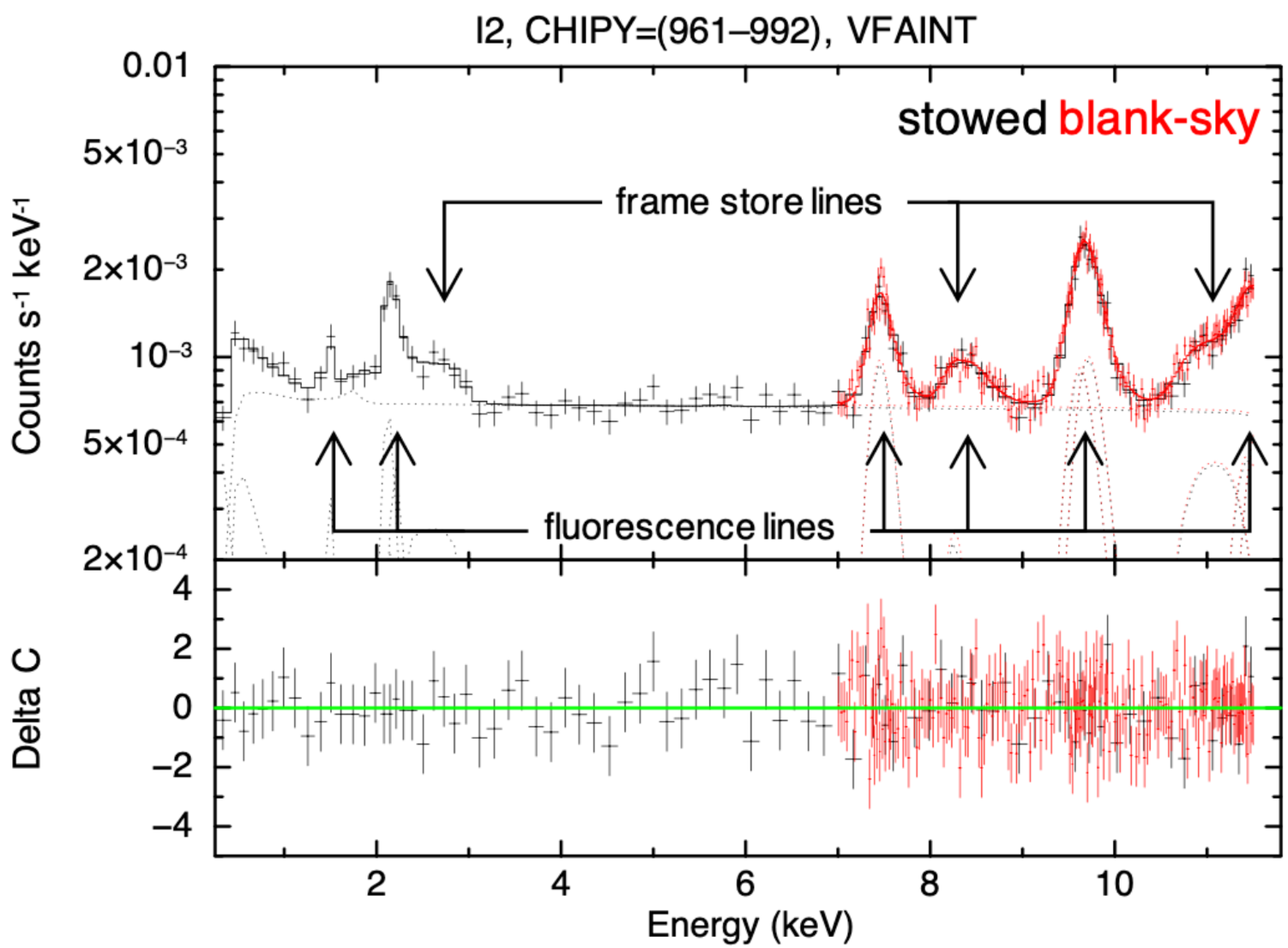
… ~120 observations (~7 Ms)

Analysis: spectral model

Spectral model includes: (Bartalucci et al. 2014)

- Al, Si, Ni and Au fluorescence lines as zero-width Gaussians
- "frame store lines" as broad Gaussians
- continuum (power-law, broken power-law, exponential and broad Gaussians)

Events produced by photons which convert in the frame store array (not the imaging array)

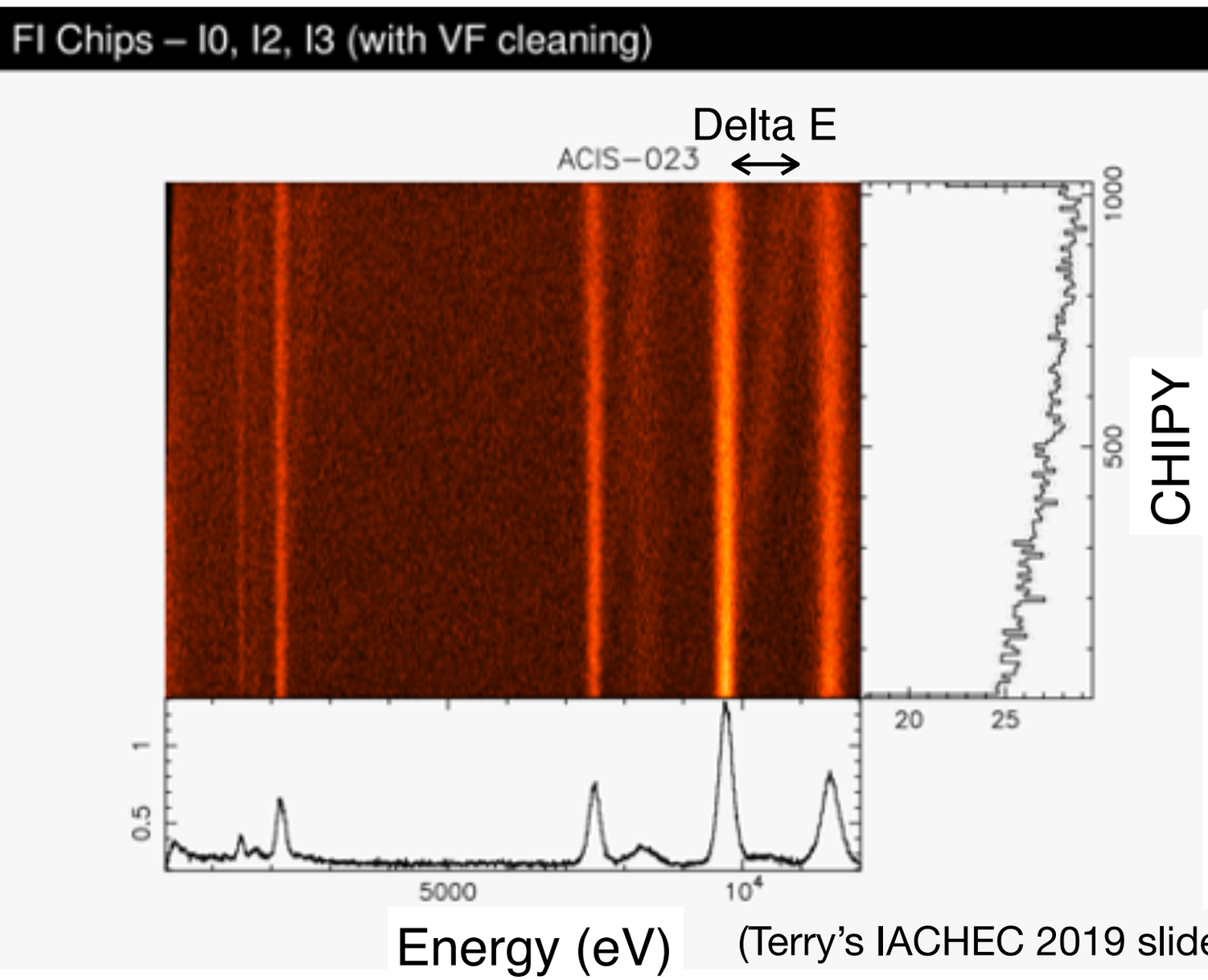


Element	Type	Energy (keV)
Al	Kα	1.487
	Kβ	1.557
Si	Kα	1.740
Au	Mα_1	2.123
	Mα_2	2.118
	Mβ	2.205
	Mγ	2.410
Ni	Kα_1	7.478
	Kα_2	7.461
	Kβ	8.265
Au	L$_1$	8.494
	Lα_1	9.713
	Lα_2	9.628
	Lβ_1	11.442
	Lβ_2	11.585

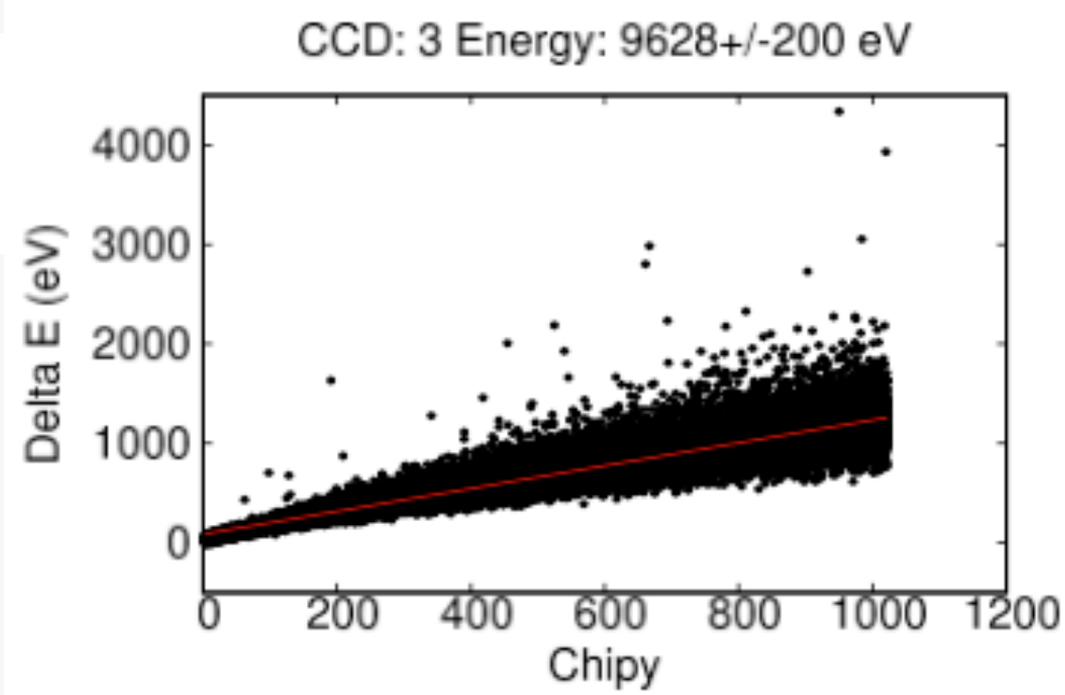
Analysis: spatial variation

Spatial variation: (Bartalucci et al. 2014)

- flux and spectral shape (mainly frame store lines) vary along CHIPY axis



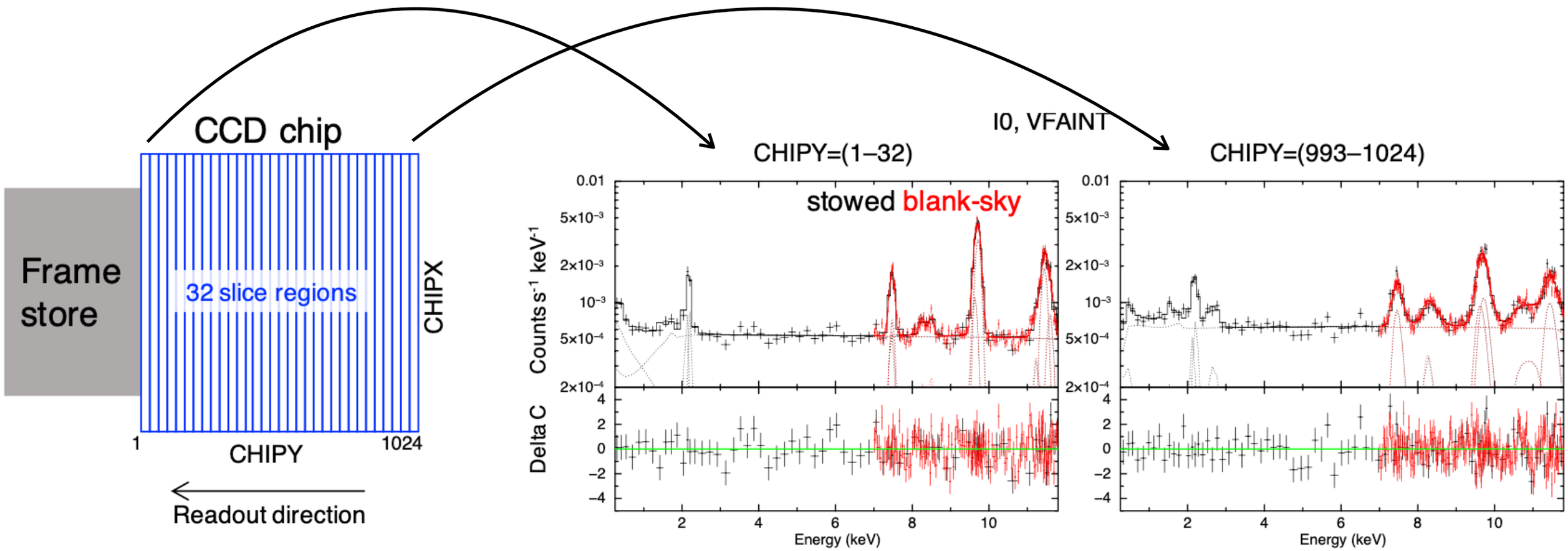
(Terry's IACHEC 2019 slide)



Analysis: spatial variation

Spatial variation:

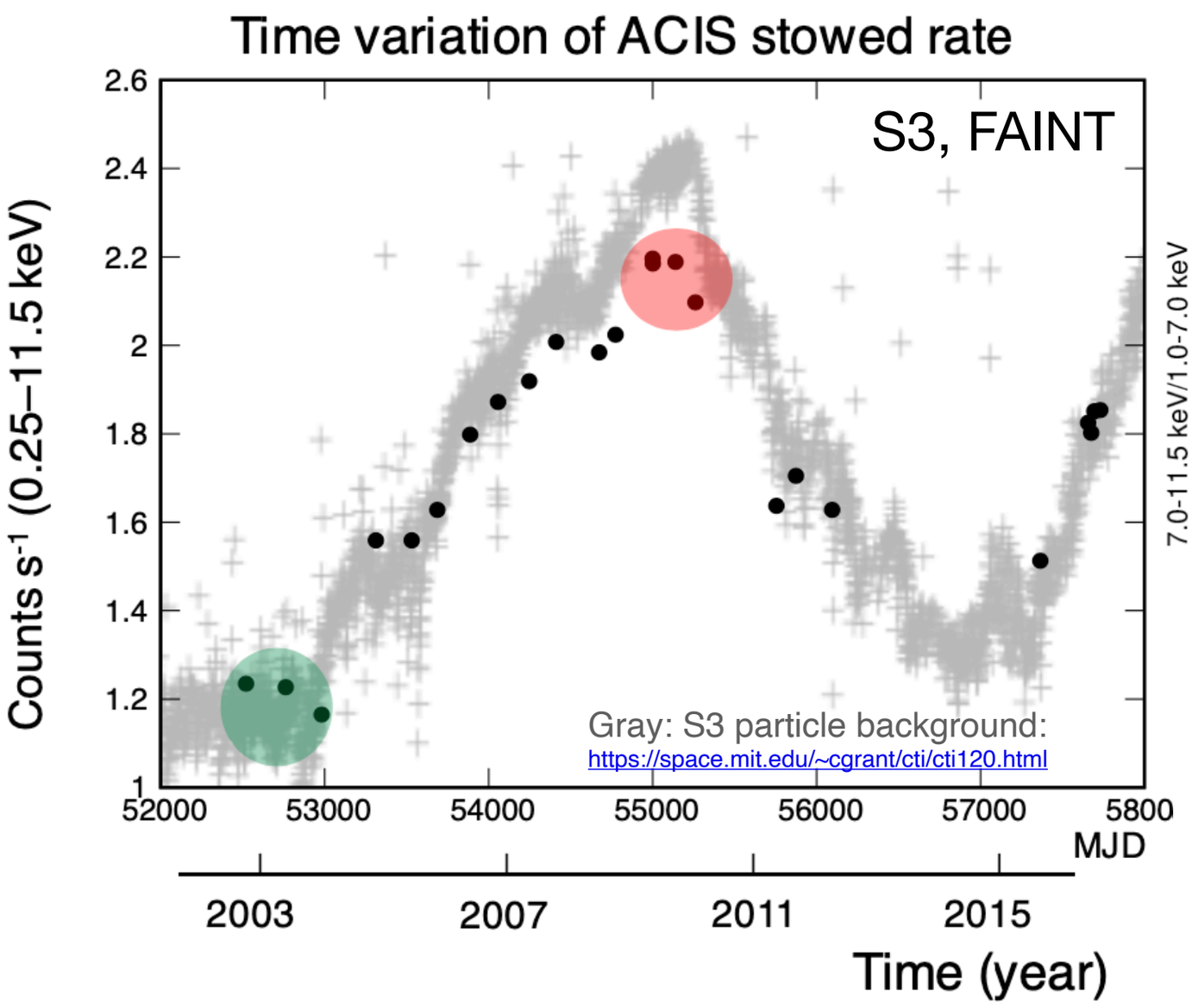
- flux and spectral shape (mainly frame store lines) vary along CHIPY axis
- each chip divided into 32 regions along CHIPY, and modeled (phenomenologically)

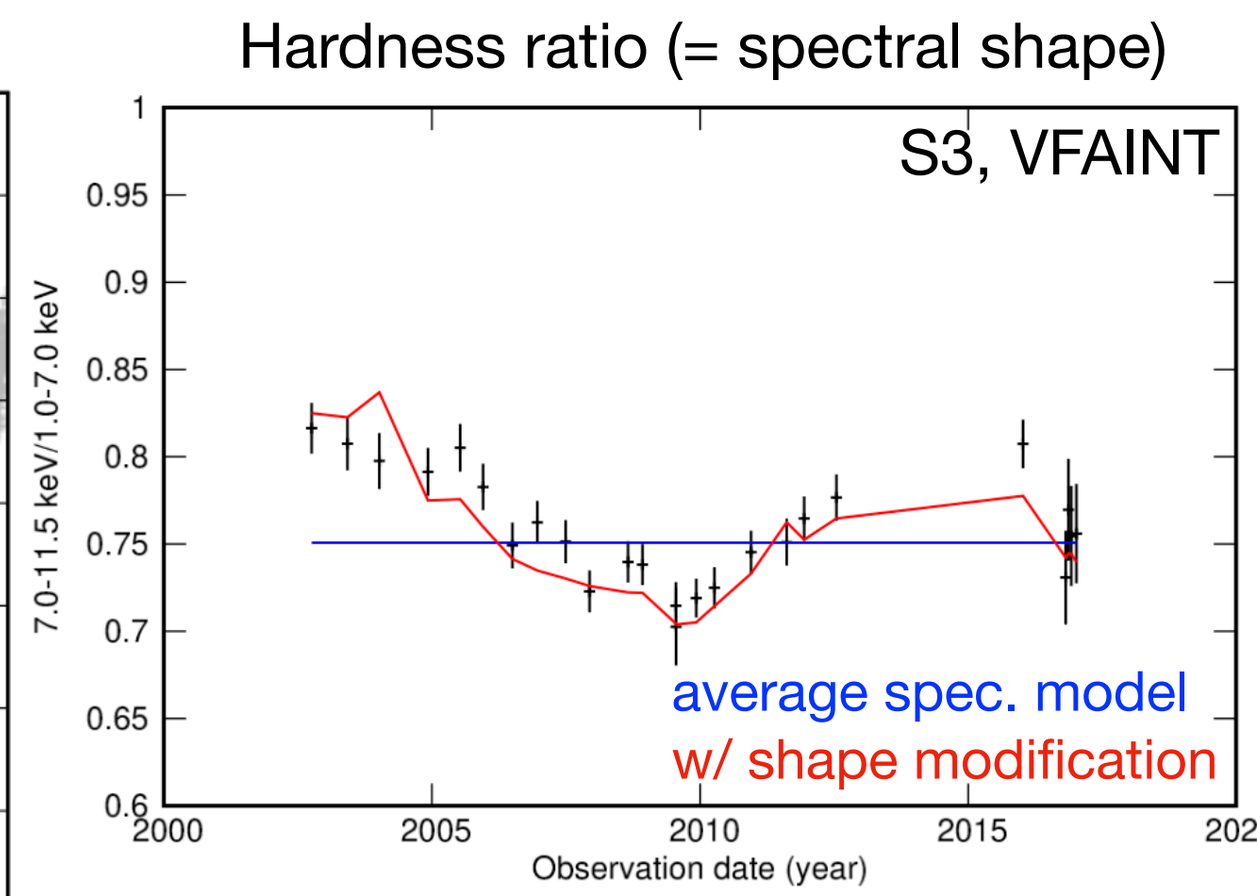


Analysis: time variation

Time variation:

- ACIS-stowed count rate varies depending on the solar activity
- < 10% variation of hardness ratio is modeled based on ACIS-stowed obs. set





Background spectra generation tool: *mkacispback*

https://github.com/hiromasasuzuki/mkacispback

INPUT:
level2 fits with analysis region (region file etc.)

↓

Merge the template models
corresponding to the analysis region
&
Hardness ratio modification
depending on total event rate

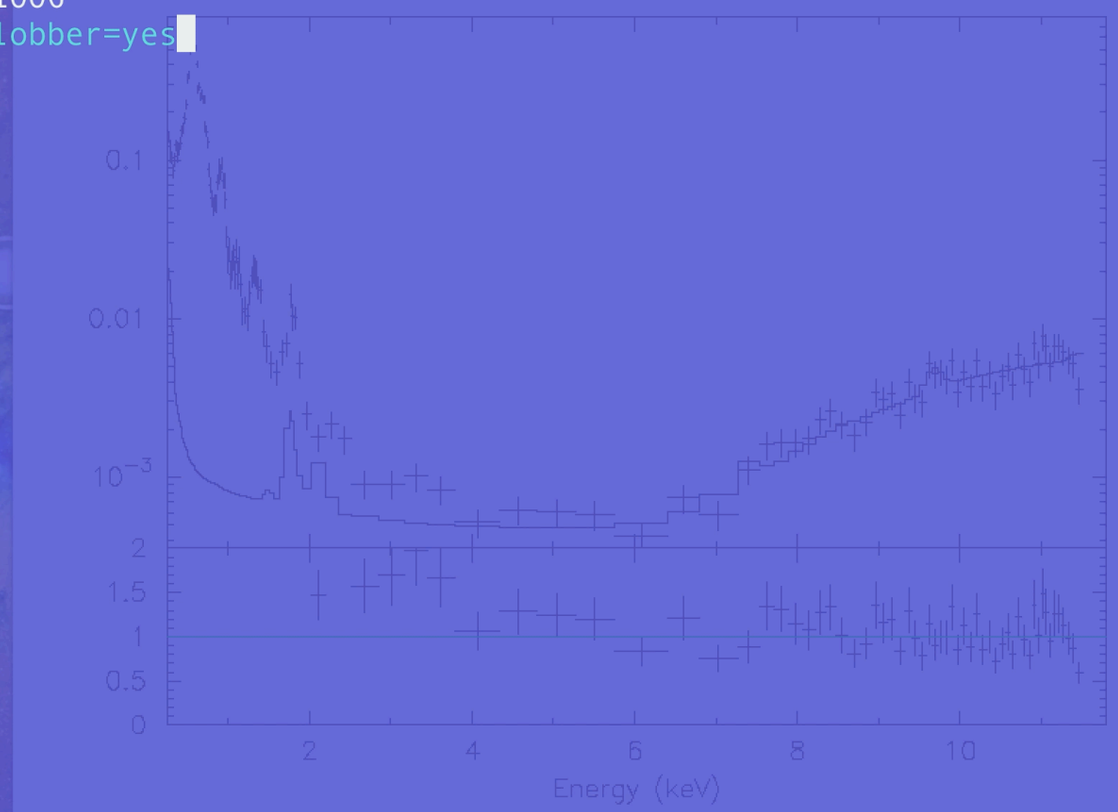
↓

OUTPUT:
local model package

mkacispback: demonstration

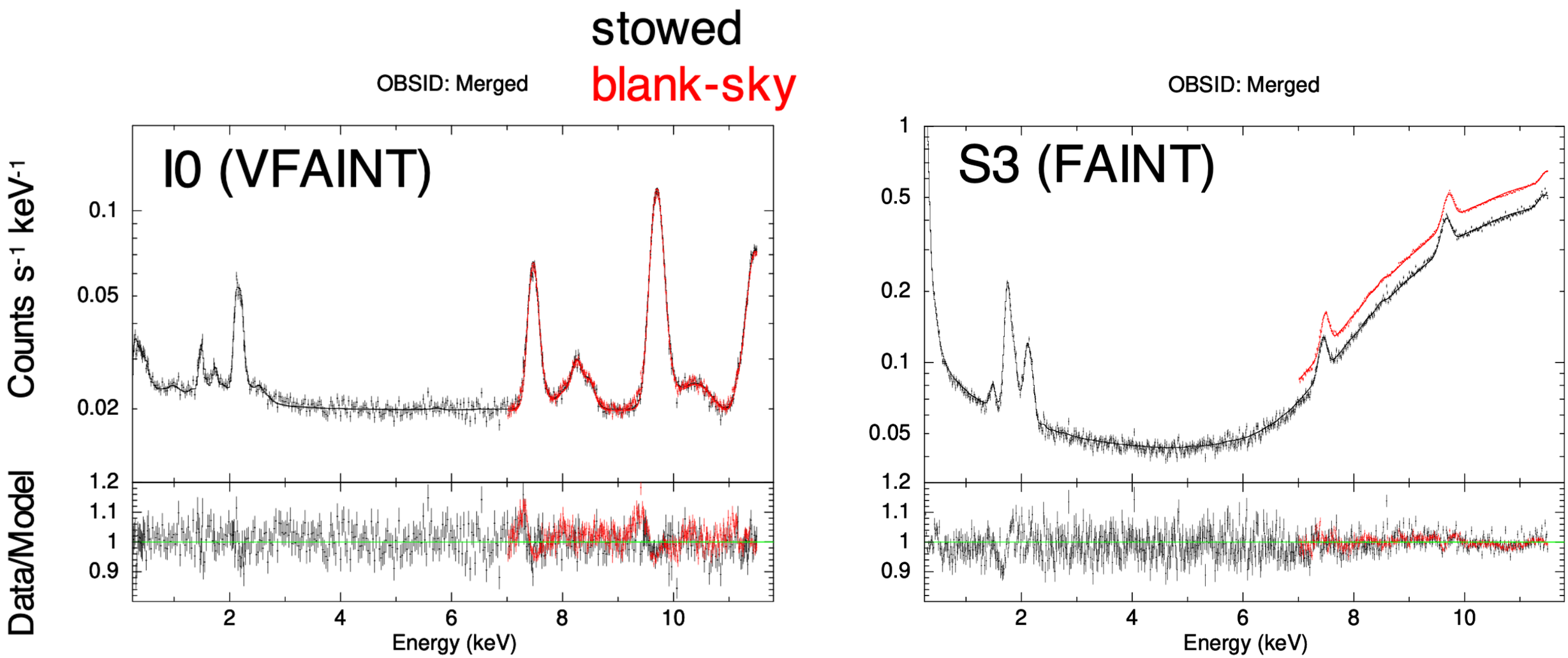
```
[Tue May 24 13:25:23 JST 2022] Mac-PC-local  (130)
/Users/suzuki/work/chandra/pback_predict_tool/analysis-faint/test/sn1006
$ ls
acisf01959_repro_evt2.fits acispback                    source.reg          xselect.log

[Tue May 24 13:25:24 JST 2022] Mac-PC-local  (0)
/Users/suzuki/work/chandra/pback_predict_tool/analysis-faint/test/sn1006
$ mkacispback "acisf01959_repro_evt2.fits[sky=region(source.reg)]" clobber=yes
```



Comparison: data vs. *mkacispback*

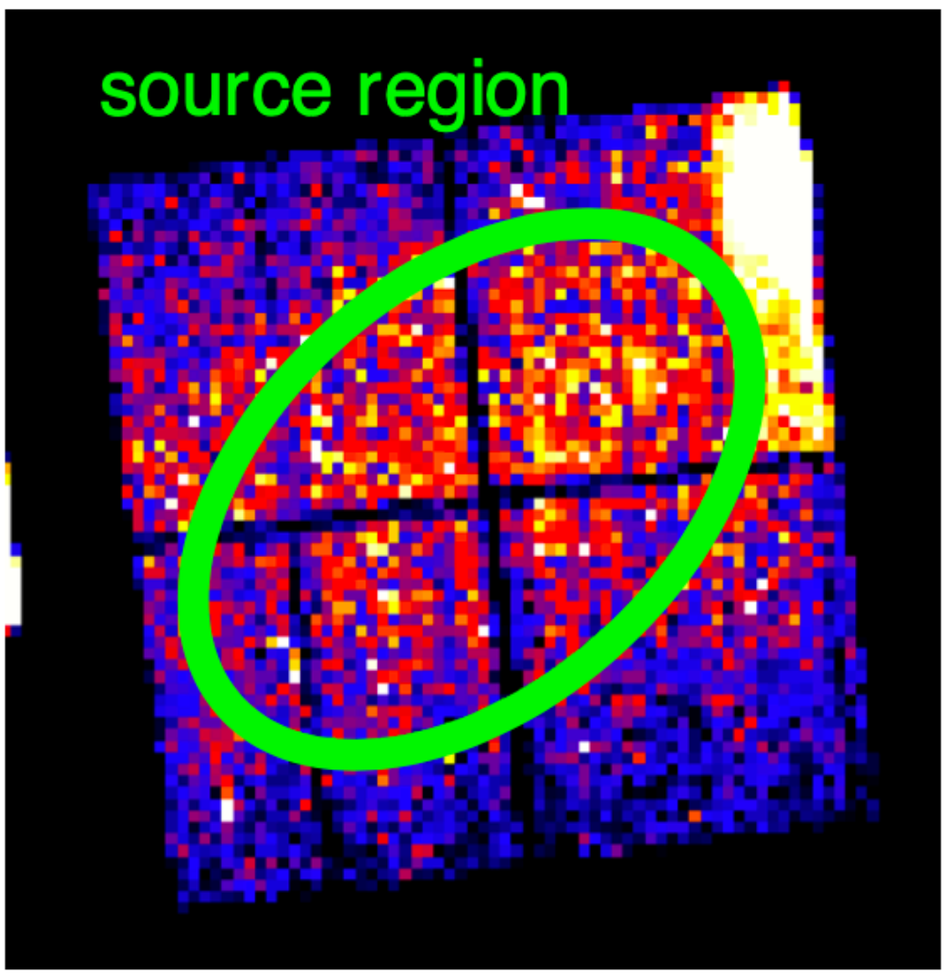
Data: total ACIS-stowed & blank-sky observations

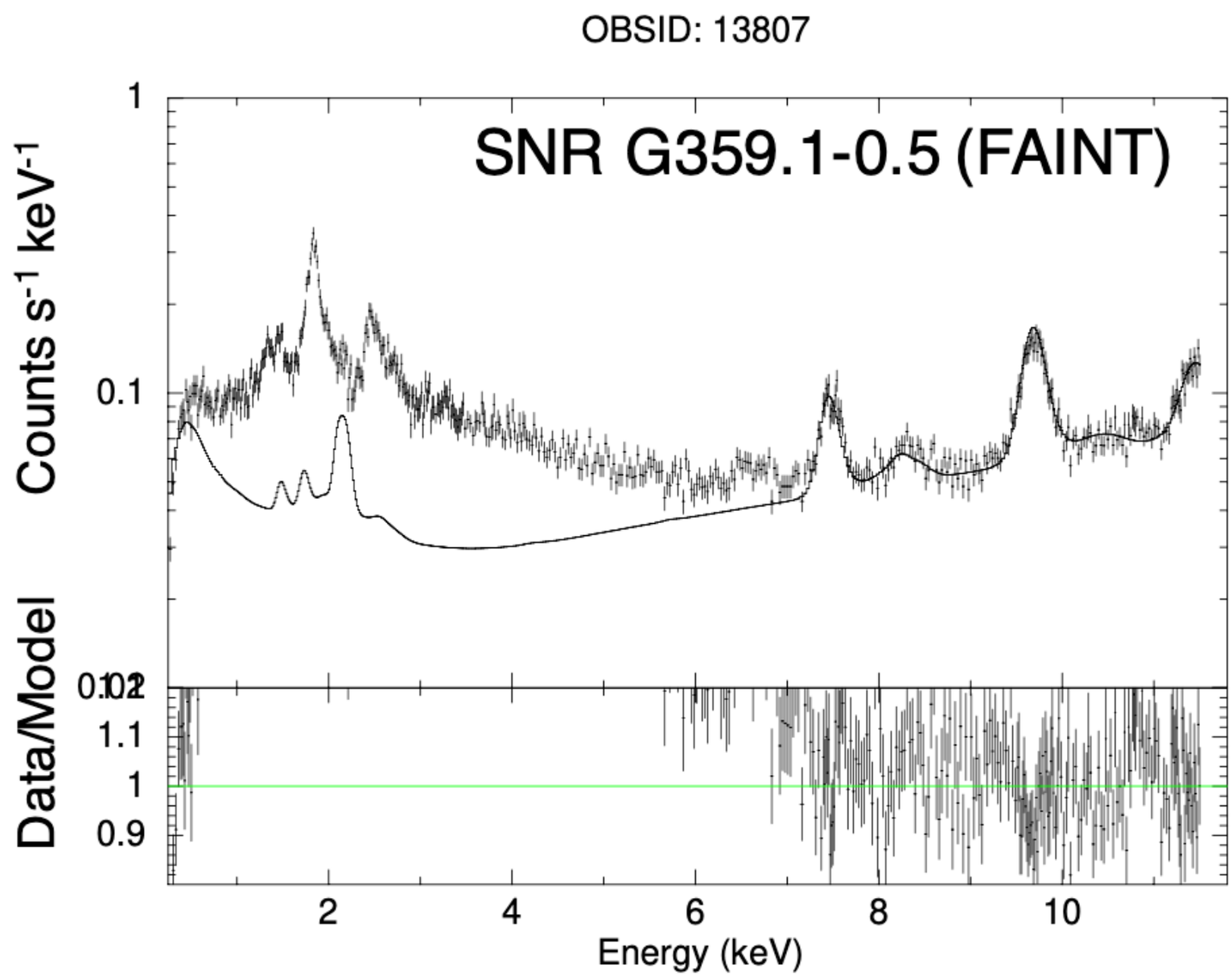


<5% accuracy for continuum, < 10% accuracy for lines

Comparison: data vs. *mkacispback*

Data: observation of a supernova remnant (faint & diffuse source)





Summary

- Particle-induced background of Chandra is investigated using 14-year ACIS-stowed & blank-sky observations (~8 Ms in total)
- Spatial & temporal variations are modeled (phenomenologically)
- Background spectrum generation tool *mkacispback* is developed

https://github.com/hiromasasuzuki/mkacispback

mkacispback

A software to generate spectral models for Chandra ACIS particle-induced background.
Version: 2021-07-15
Author: Hiromasa Suzuki (The University of Tokyo)
hiromasa050701 (at) gmail.com

Requirements:

- c++11 compiler (ver. 4.2.1, 4.8.5 tested)
- python (ver. 3.0 or later reguired; 3.5.4, 3.6.8, 3.8.5 tested) with "astropy" library
- CIAO (ver. 4.10, 4.11, 4.12, 4.14 tested)
- HEAsoft (ver. 6.20, 6.26, 6.27, 6.29 tested)

How to use the software:

1. Set three environment variables as below:

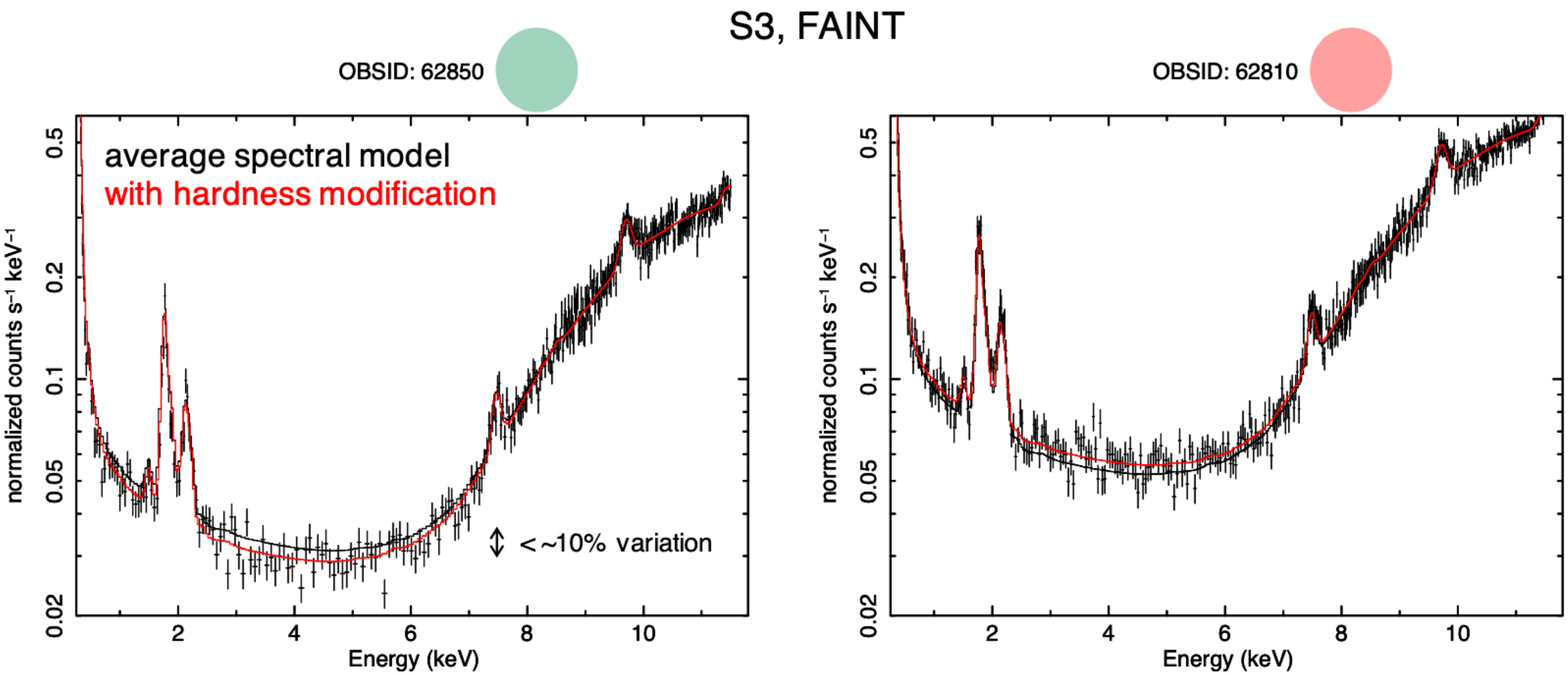
```
export ACISPBACK=</path/to/this directory>
export ACISPBACK_PYTHON=</path/to/python**>   # python with astropy library (ex. "export ACISPBA
export ACISPBACK_GXX=</path/to/g++**>   # g++ which supports c++11 (ex. "export ACISPBACK_GXX=/u
```

2. Copy the executable file "mkacispback" to /usr/local/bin (or somewhere in the $PATH).

Analysis: time variation

Time variation:

- ACIS-stowed data flux showed a negative correlation with the solar activities
- < 10% variation of hardness ratio is modeled based on ACIS-stowed obs. set



Modeling time variation of spectral shape

Here, we modeled the hardness-ratio variations only for the BI CCDs. As a simple model of this temporal variation of the spectral shapes, we let the continuum level in ≈1.0–7.0 keV ($N_{1.0\text{–}7.0\,\mathrm{keV}}$) vary with respect to the other spectral components (let this be $N'_{1.0\text{–}7.0\,\mathrm{keV}}$) depending on the count rate in 9.0–11.5 keV ($R_{9.0\text{–}11.5\,\mathrm{keV}}$) as

Free parameters

$$N'_{1.0\text{–}7.0\,\mathrm{keV}} = N_{1.0\text{–}7.0\,\mathrm{keV}} \left(\frac{R_{9.0\text{–}11.5\,\mathrm{keV}}}{R_0} \right)^{\alpha}, \tag{3}$$

1–7 keV normalization is modified

Background spectra generation tool: *mkacispback*

https://github.com/hiromasasuzuki/mkacispback

Description of the mkacispback tool

INPUT: observational event file (with selections)

↓

Extract 32x32-binned image from input file in 9.0-11.5 keV

↓

Calculate weighted-sum over 32 template models per chip

↓

Modify spectral hardness based on 9.0-11.5 keV rate

↓

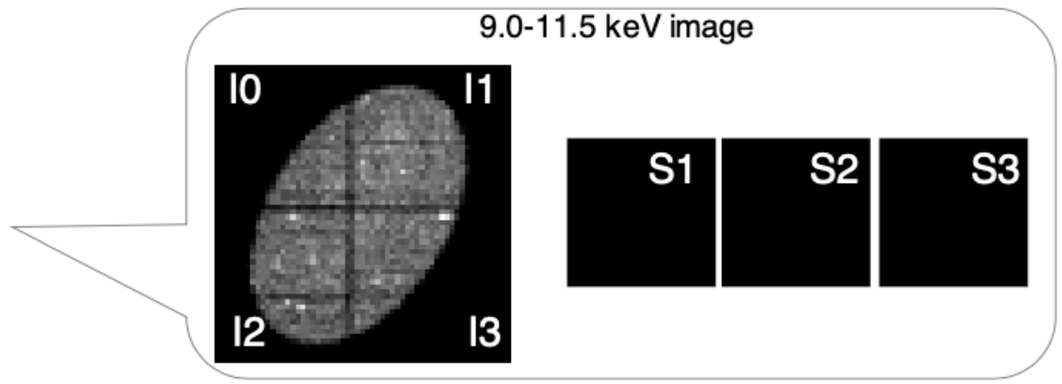
Sum the spectral models over the chips covered by the region of interest

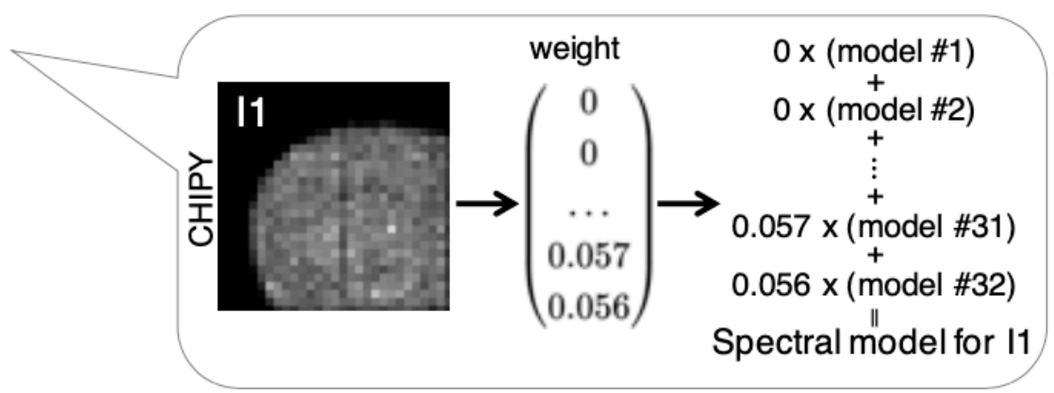
↓

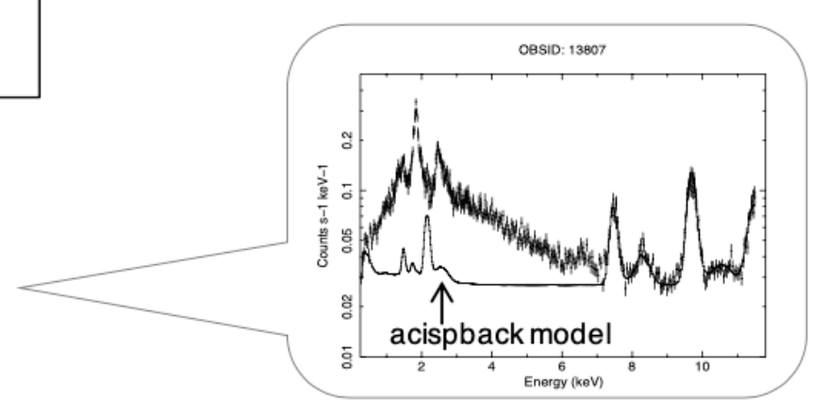
Scale the output spectral model to fit data in 9.0-11.5 keV

↓

OUTPUT: *XSPEC* spectral model "acispback"



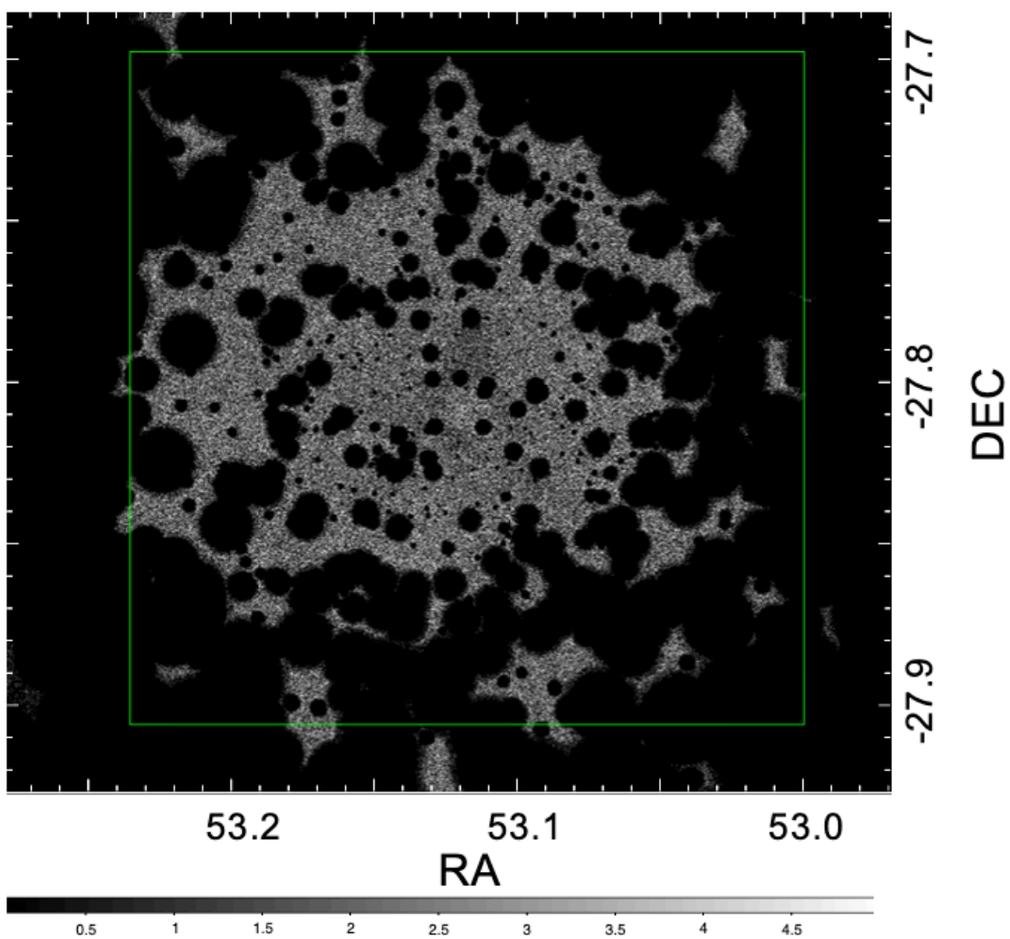


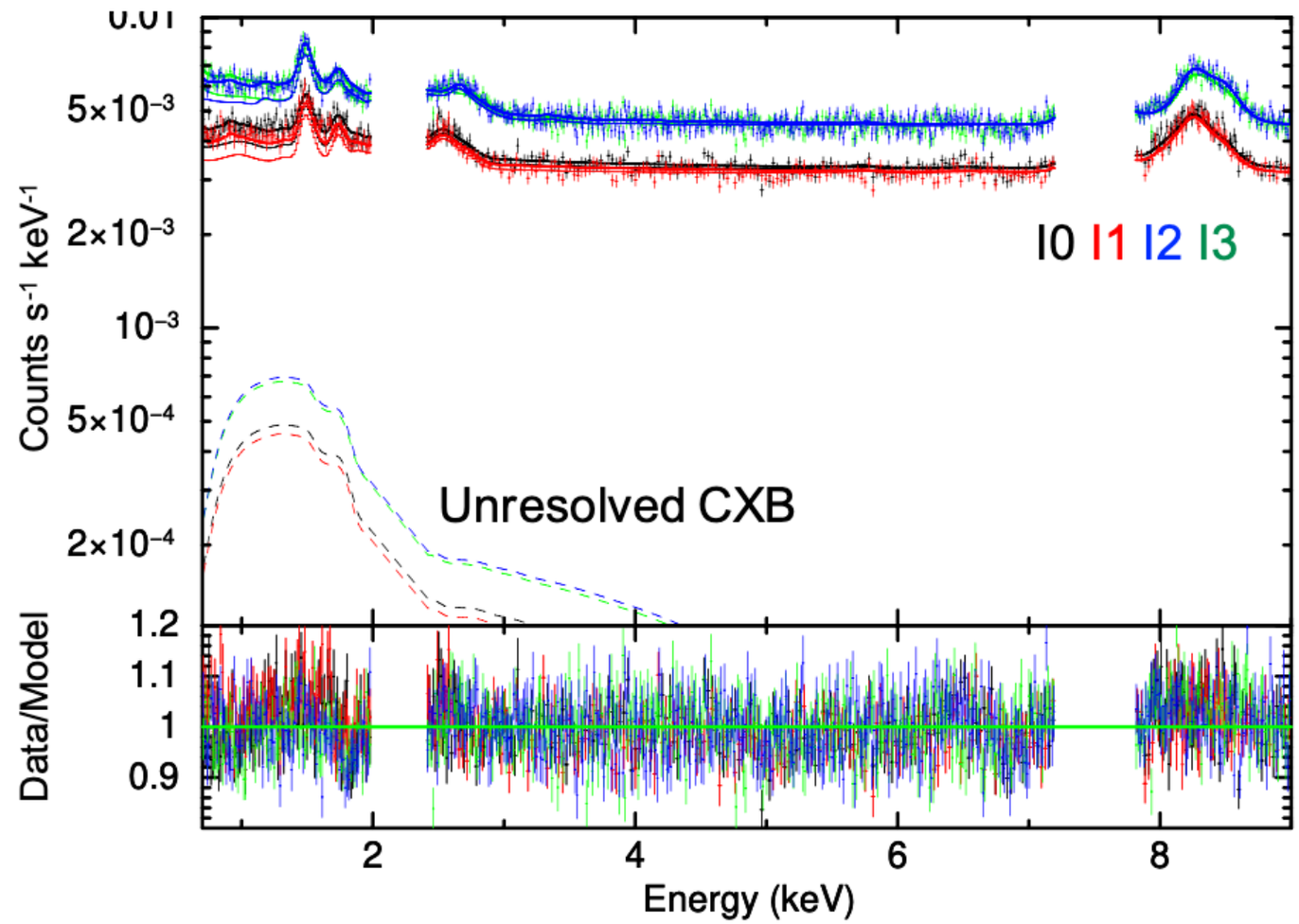


Comparison: data vs. *mkacispback*

Data: total blank-sky observations

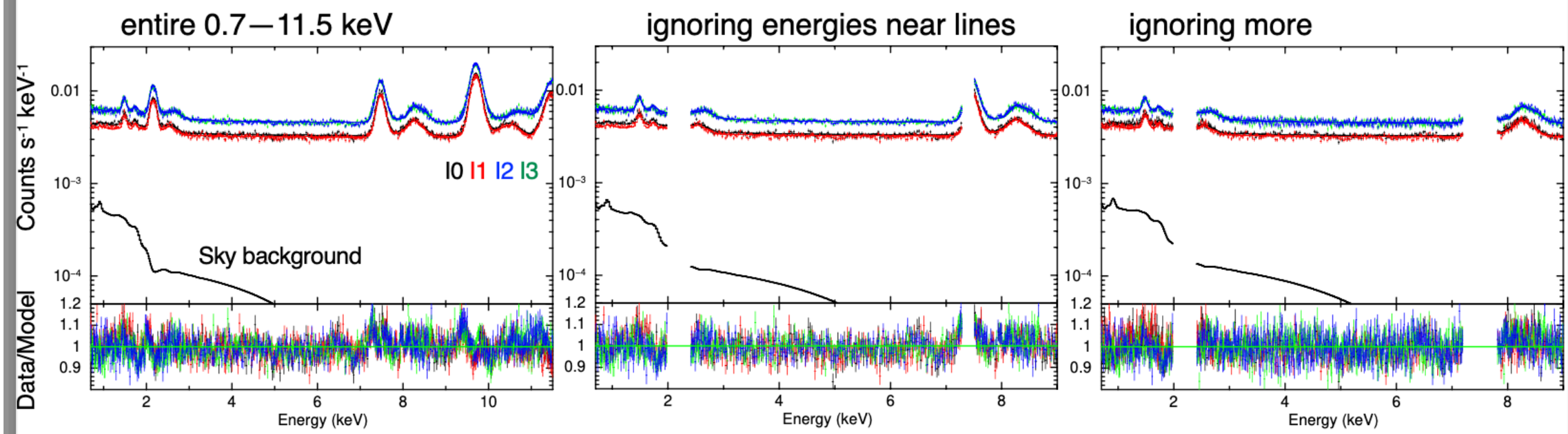
- Estimated unresolved CXB intensities (in erg s^{-1} cm^{-2} deg^{-2}):
  - 3.10 (2.98–3.21) × 10^{-12} (2–8 keV)
  - 8.35 (8.00–8.70) × 10^{-12} (1–2 keV)
- consistent with or lower than Hickox & Markevitch (2006), Bartalucci et al. (2014), Luo et al. (2017)





Point-source removed ~7 Msec blank-sky (CDF-S) image

Spectral modeling result



- unresolved CXB flux (2—8 keV, in erg s^{-1} cm^{-2} deg^{-2}):
  2.59e-12--2.81e-12 2.71e-12--2.95e-12 2.98e-12--3.21e-12
- unresolved CXB flux (1—2 keV):
  6.96e-13--7.52e-13 7.28e-13--7.91e-13 8.00e-13--8.70e-13

- Hickox & Markevitch 2006:
  1.04 +/-0.14 e-12 (1—2 keV), 3.4+/-1.7 e-12 (2—8 keV)
- Bartalucci et al. 2014:
  $1.02^{+0.05}_{-0.04}$ e-12 (1—2 keV), 3.8+/-0.2 e-12 (2—8 keV)
- Luo et al. 2017:
  < 2e-11 (2—7 keV) (not written explicitely in the paper)
- So, our results are consistent with or a bit lower than Hickox et al., Luo et al., and Bartalucci et al. Tighter constraints are obtained.

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