NuSTAR Background

Origins, Mitigations, and Modeling

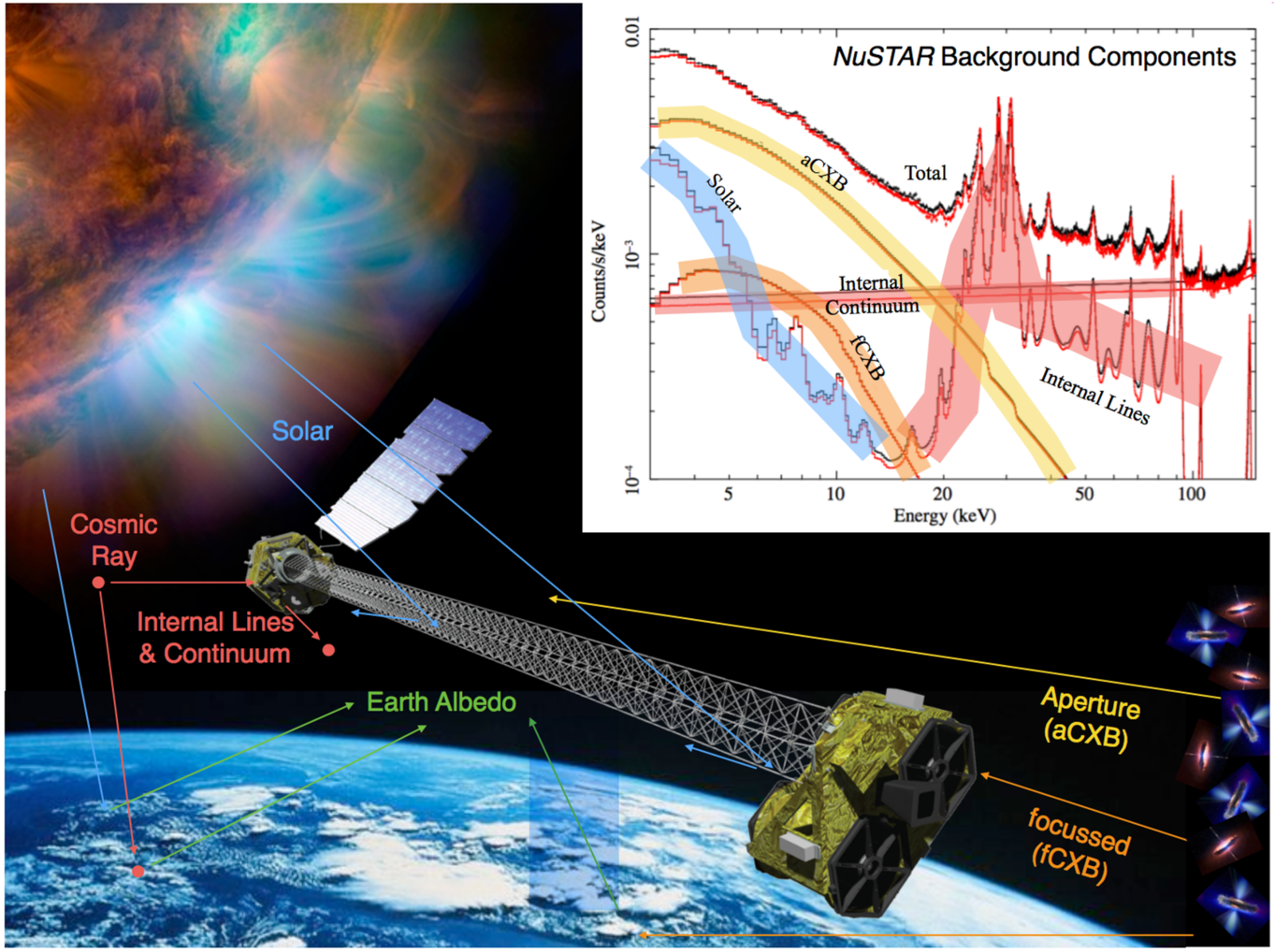
Brian Grefenstette, May 24, 2022 - IACHEC

Scope

How to handle and produce background models

- Origin of the NuSTAR background
- Mitigation strategies
- Background modeling techniques

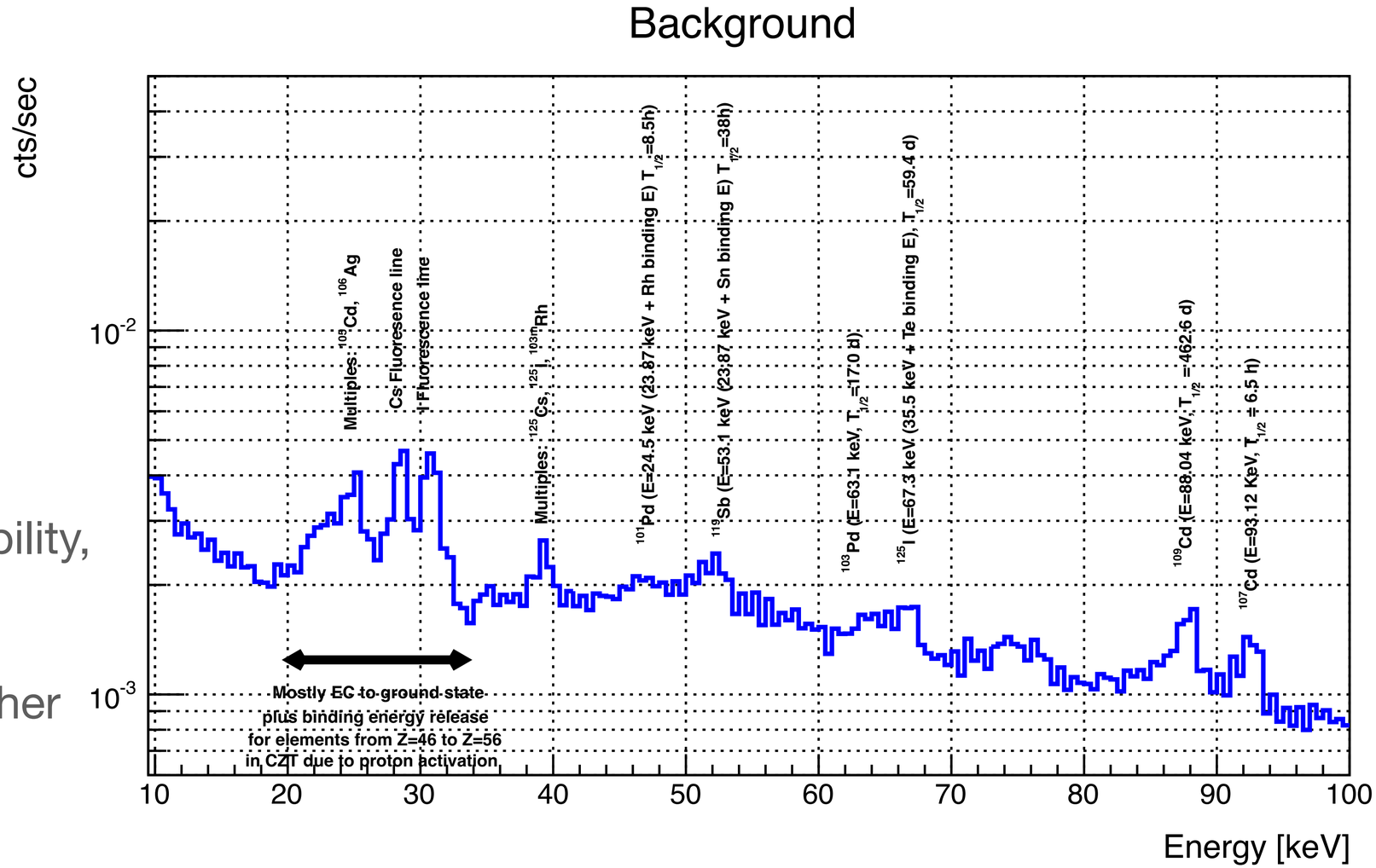
Origin of the NuSTAR Background



Slide courtesy Dan Wik

Origin of the NuSTAR Background

- Lines result (mostly) from proton activation
- Half-life ranges from hours to years
- Short-lived lines —> temporal variability, or “radiation belt memory”
- Continuum depends on space weather



Simulation courtesy Andreas Zoglauer

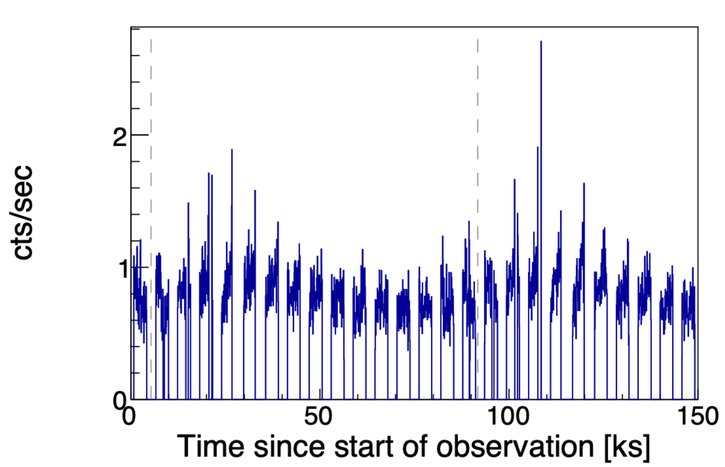
Mitigation

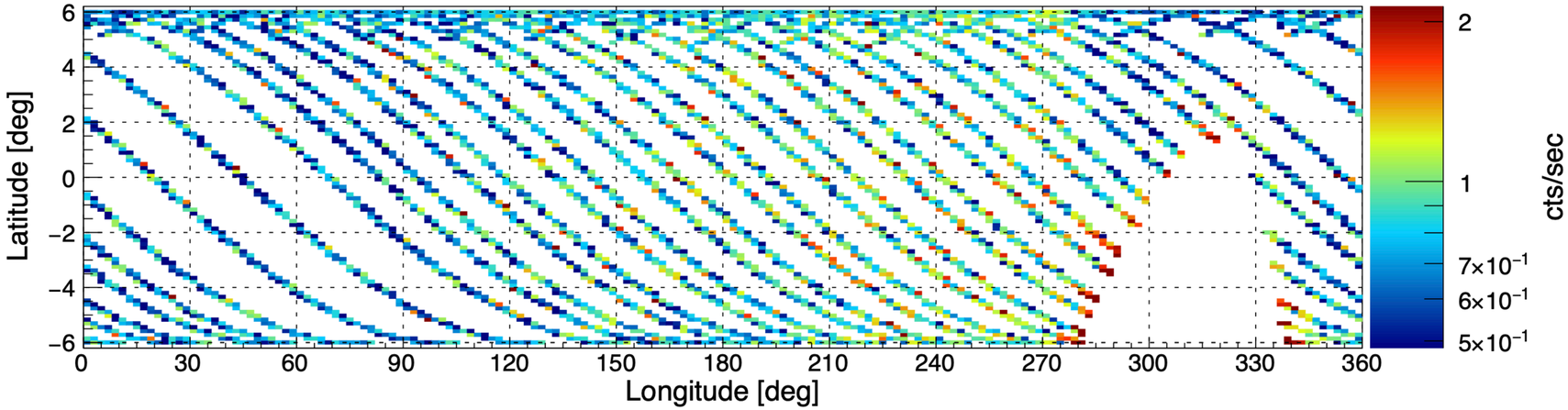
How do I know if the space weather was bad and what can I do?

- NuSTAR SOC provides automated checks and summary reports for standard filtering in nustardas
- Link here: https://nustarsoc.caltech.edu/NuSTAR_Public/NuSTAROperationSite/SAA_Filtering/SAA_Filter.php
- Available for every observation throughout the mission (updated automatically)
- Up to user to decide which combination of filters is appropriate / best utilizes the data

Mitigation

What does a “good” background look like?





“Spikes” associated with SAA ingress/egress

Slow variations associated with geomagnetic rigidity cutoff and orbital precession

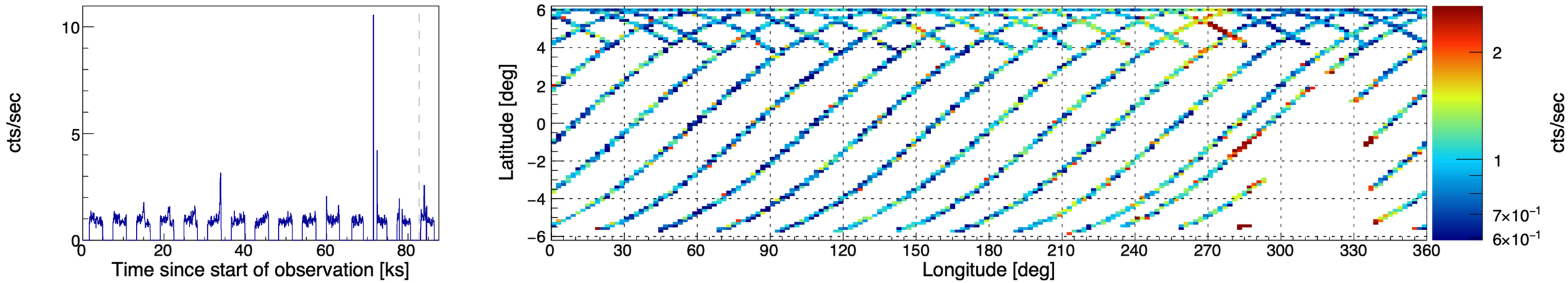
Grefenstette et al (2022), in prep to discuss “normal” background variations

Mitigation

What does a “radiation belt” background look like?

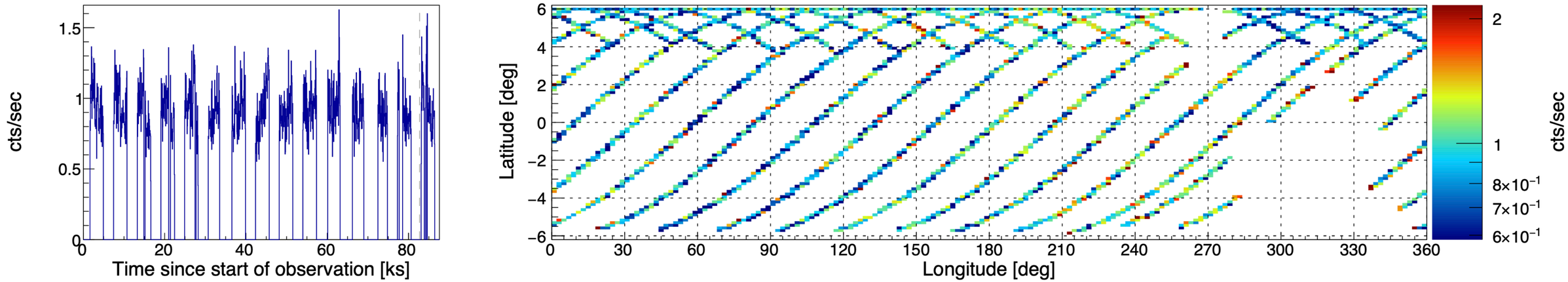
nucalcsaa options: nucalcsaa task not used!

Effective exposure time: 48003 sec (100.0%)



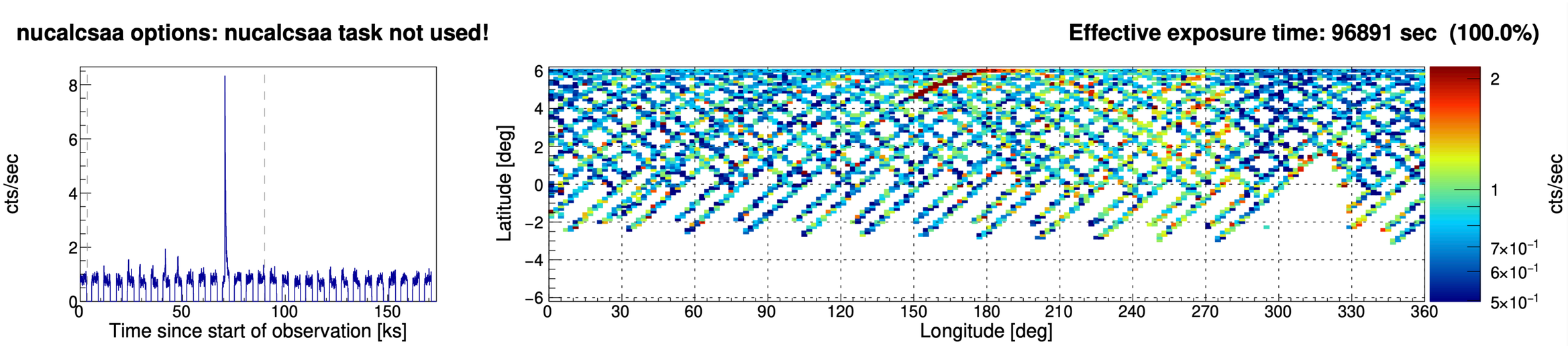
nucalcsaa options: --saacalc=3 --saamode=optimized --tentacle=yes

Effective exposure time: 45691 sec (95.18%)



Mitigation

What does a “solar flare” background look like?



M-class solar flare seen ~78-degrees from the Sun

No standard filters designed to remove these, but easy to identify

Can roll your own GTI to remove these in XSELECT

Mitigation

What does “stray light” look like?

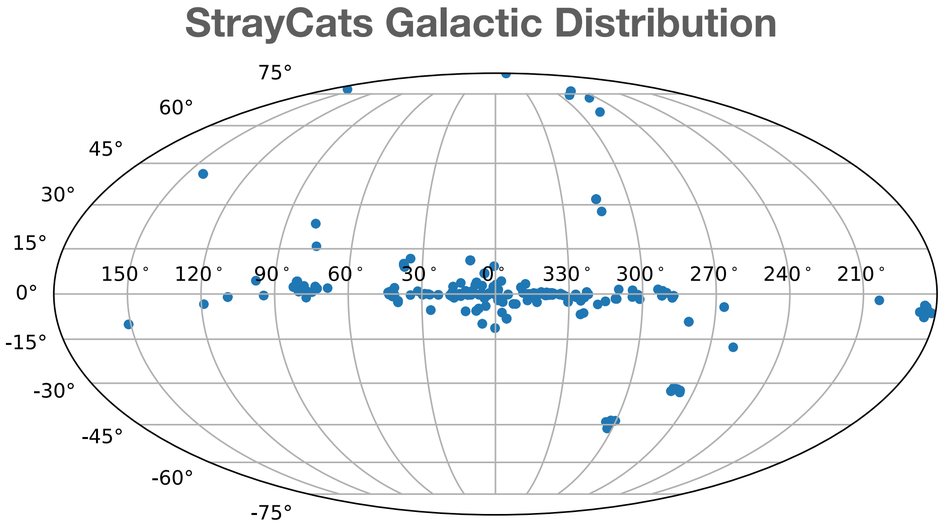
Flux from nearby sources (1-3 deg) illuminating FoV

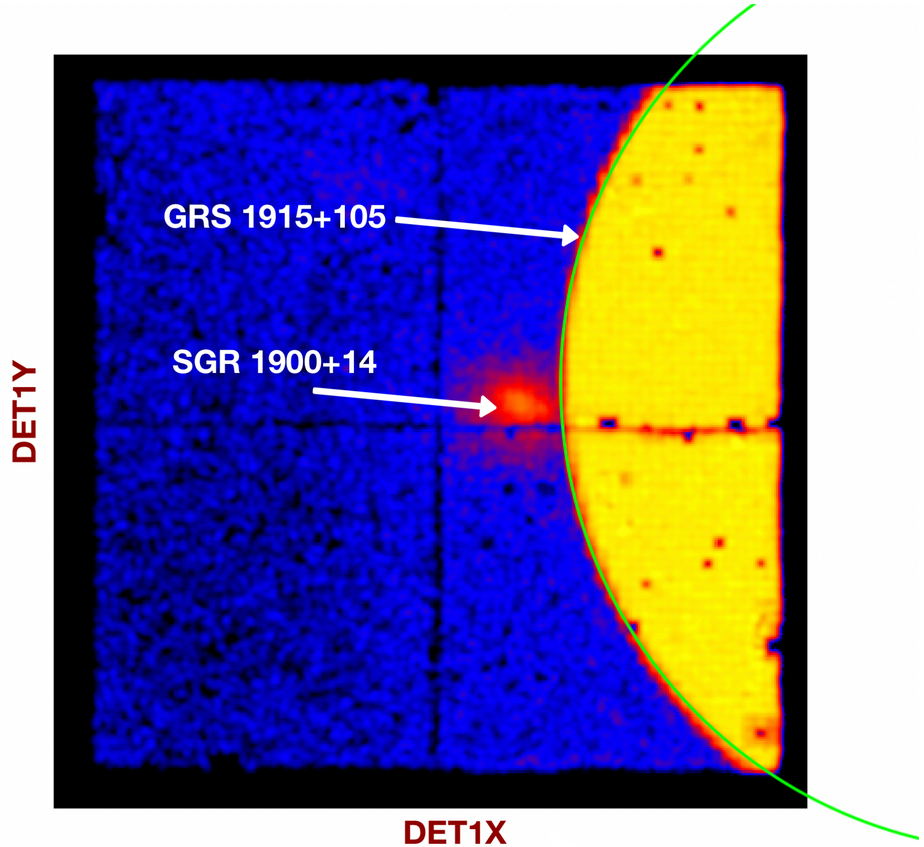
Important for galactic sources

Usually easy to identify, but not always

StrayCats team has checked almost all observations in detail

Check your observation:
https://nustarstraycats.github.io/straycats/





Modeling

I’ve done the best I can, but I hear you’re not supposed to subtract background….

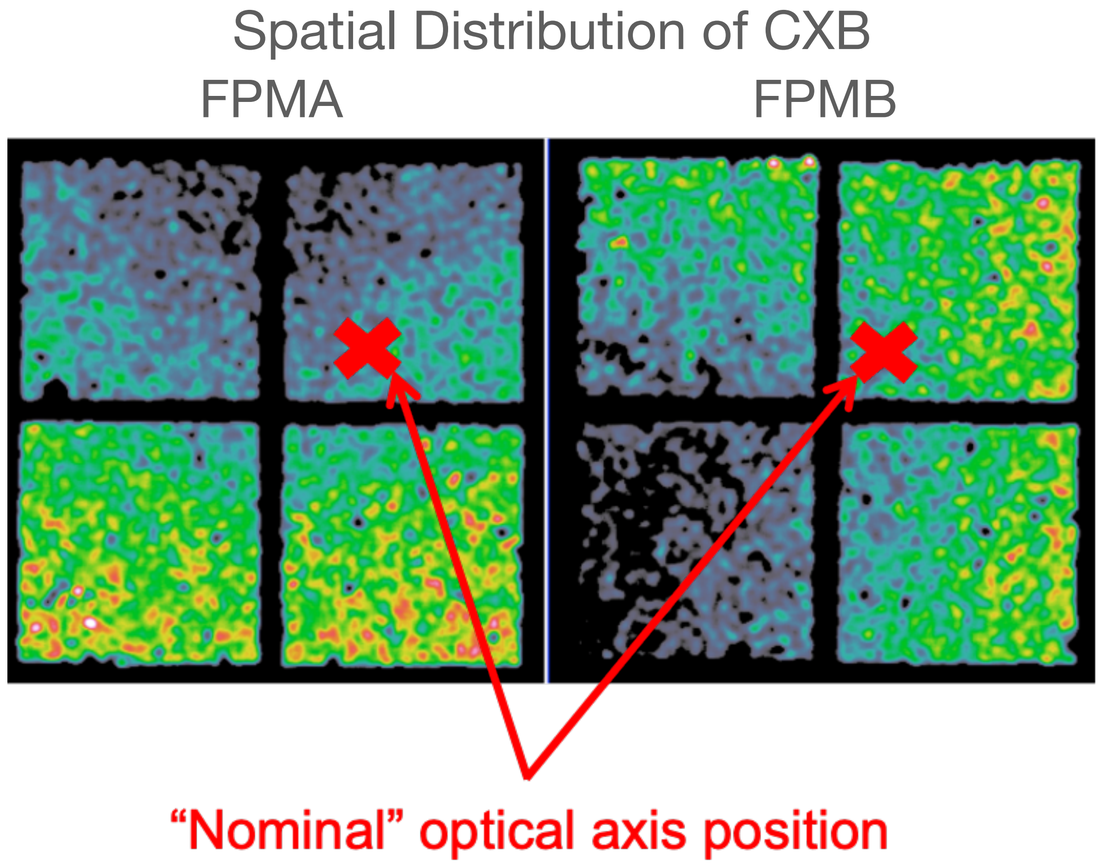
Aperture Cosmic X-ray Background:

- Spatial variations present due to geometry

Internal continuum + lines:

- Detector-to-detector variations due to CZT thickness

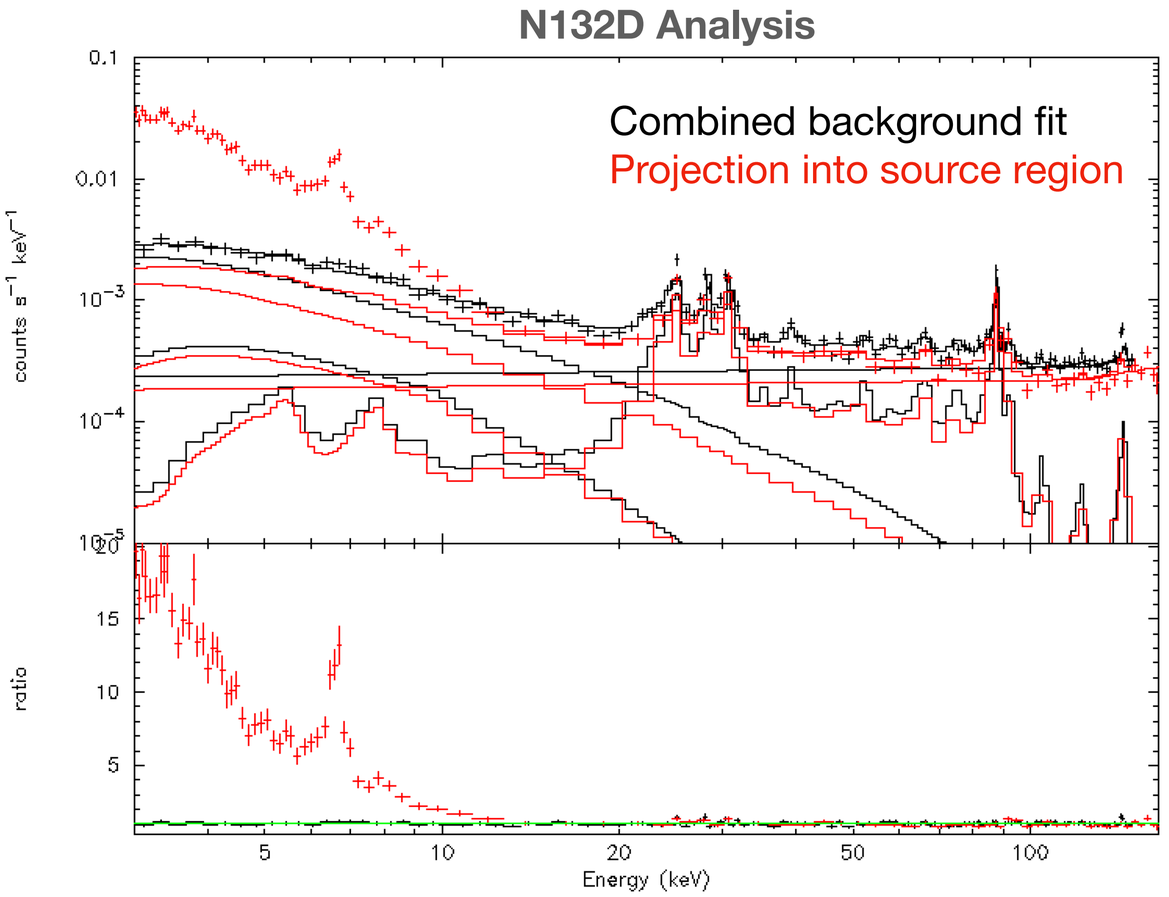
Spatial dependance modeled using nuskybgd



Modeling

nuskybgd

- Latest python implementation and walkthroughs here:
  - https://github.com/NuSTAR/nuskybgd-py
  - Original author Dan Wik
  - python port by Qian Wang
  - Further tweaks and examples by BG
- Capabilities:
  - Broadband (3-160 keV) background modeling with appropriate response
  - Produce background models for arbitrary source locations in FoV
  - Produce band-selected background images



Modeling - Caveats

What gremlins do you need to know about?

- Solar component currently un-modeled.
  - Mitigate solar flare backgrounds first
  - For extremely sensitive science, use NuSTAR only in Earthshadow
    - Details coming, see Grefenstette et al, in prep. Or ask me.

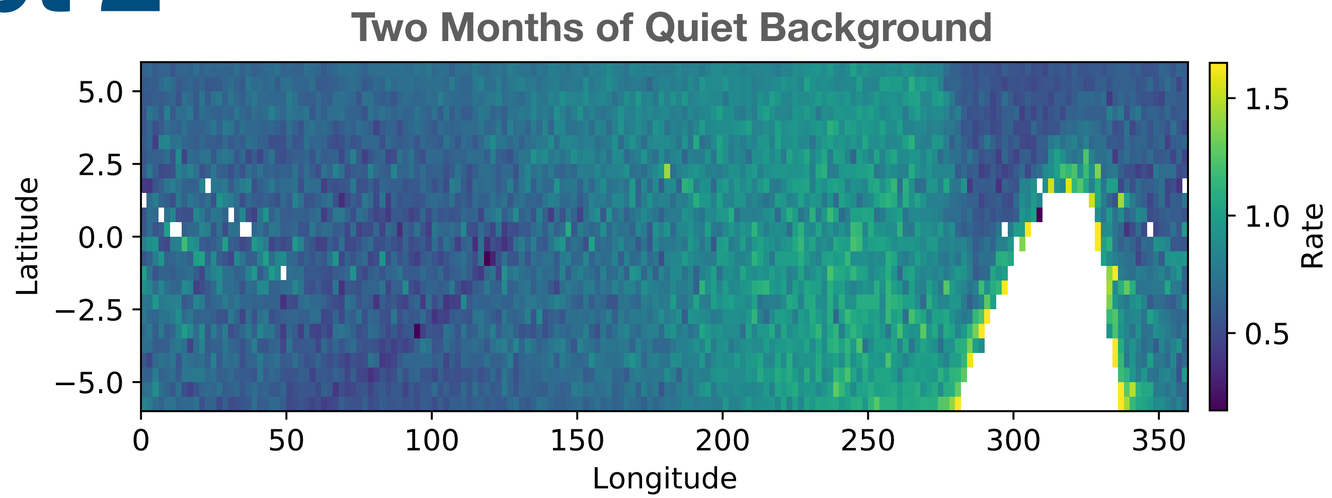
- Galactic ridge hard X-ray emission currently un-modeled in python version
  - IDL version has an early spatial template
  - Can be identified by “Fe lines” in background regions within ± 10 deg of the plane.

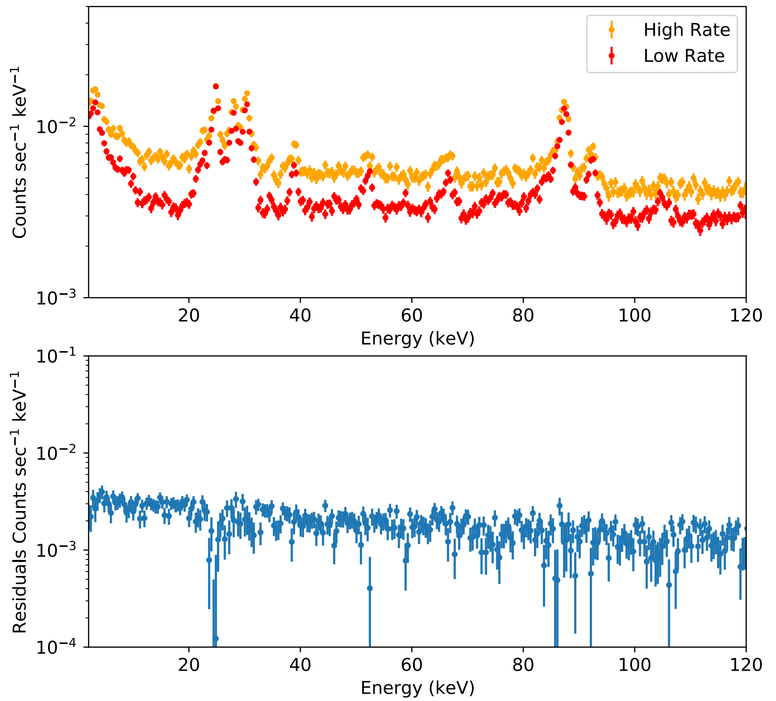
Modeling - Caveats pt 2

Time dependence

- Continuum has time dependence based on geomagnetic magnetic rigidity cutoff

- Strength will depend on space weather + location in orbit while source was being observed



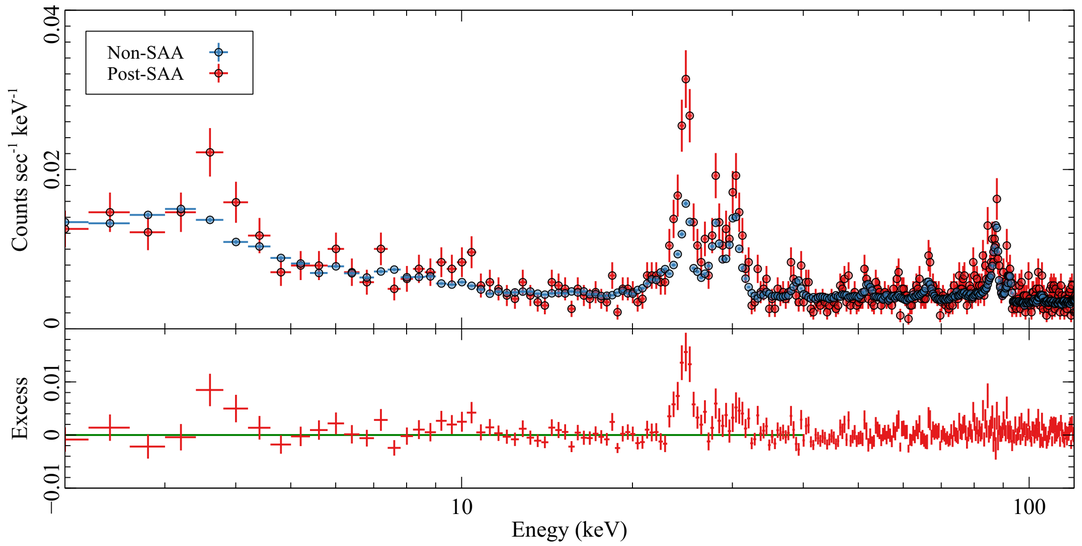


Modeling - Caveats pt 2

Time dependence

- 24 keV line has SAA-memory
  - Unclear what line this is (lots in this region), but seems to be strongest in ~10 minutes post-SAA

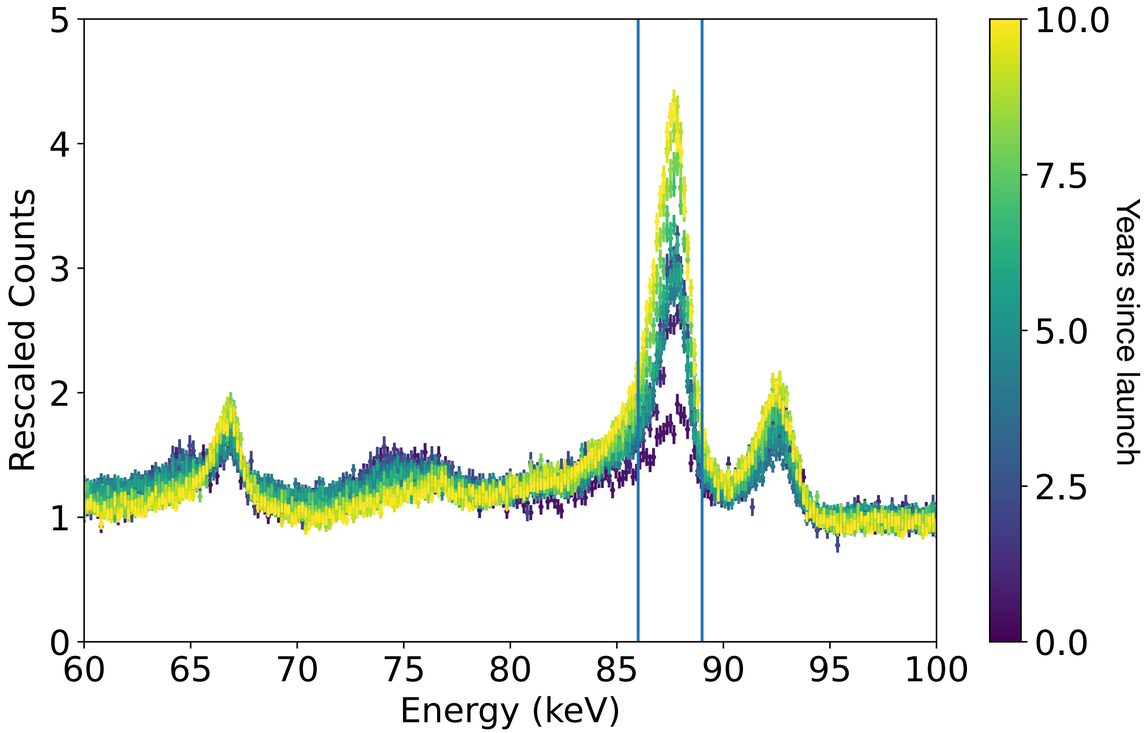
- Strength of line in total spectrum will depend on time spent in post-SAA region



Modeling - Caveats pt 2

Time dependence

- 88 keV line-to-continuum ratio has grown over time
  - Half-life is ~1.25 years
  - Monotonically (but not linearly) increasing with time
- Relative strength of line will depend on epoch of observation



Take aways

- Mitigate background first, when possible

- Various background components vary over time:
  - Will be further documented in upcoming paper
  - Time-dependence means that “database” of synthetic backgrounds probably not worth producing or useful

- Use nuskybgd to produce synthetic models
  - Need to allow strength of internal continuum, overall normalization of lines, and *relative* normalization of 88 keV, and 24 keV lines to vary
  - All demonstrated in worked example on GitHub