NuSTAR 2016 IACHEC Observatory Update

Kristin Kruse Madsen & Karl Forster

Overview

- **Observatory Overview**

- **2015 upgrades**
  - 2015 Calibration Observations
  - Observatory Planning and Pointing Improvements
  - New High Background Period Filtering algorithms
    - The SAA has changed with Solar activity and orbit evolution
  - Observing mode "6"
    - Observing without the primary star-tracker
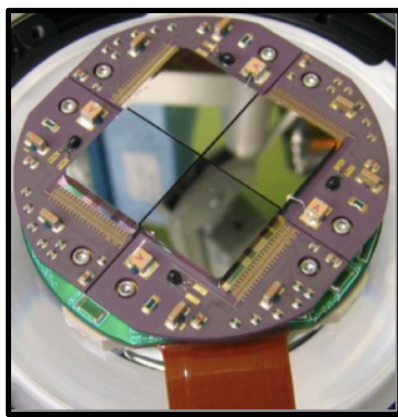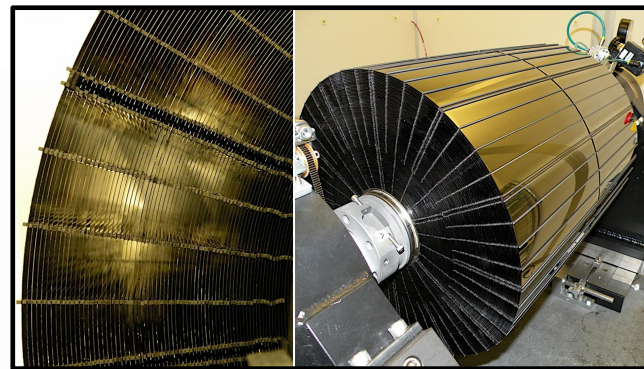
- **Observatory status**

NuSTAR

Observatory Overview

NuSTAR observatory components
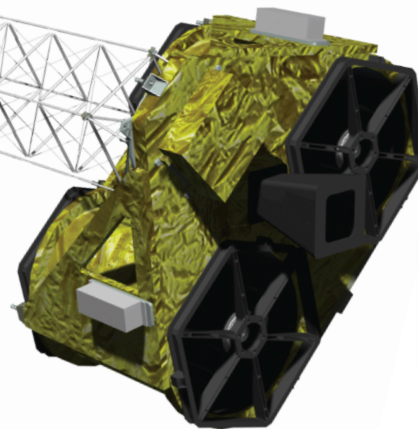
Energy Range: 3 – 78 keV

- NASA small explorer astrophysics mission
- PI Fiona Harrison (Caltech)
- Partners: ASI, ASDC, DTK, HEASARC
- Launched June 2012, 620 km 6° orbit

Conical Wolter-I approximation
133 shells (43 W/Si, 90 Pt/C)
HPD = 1 arcminute

CdZnTe detectors
4x(32x32 pixels)
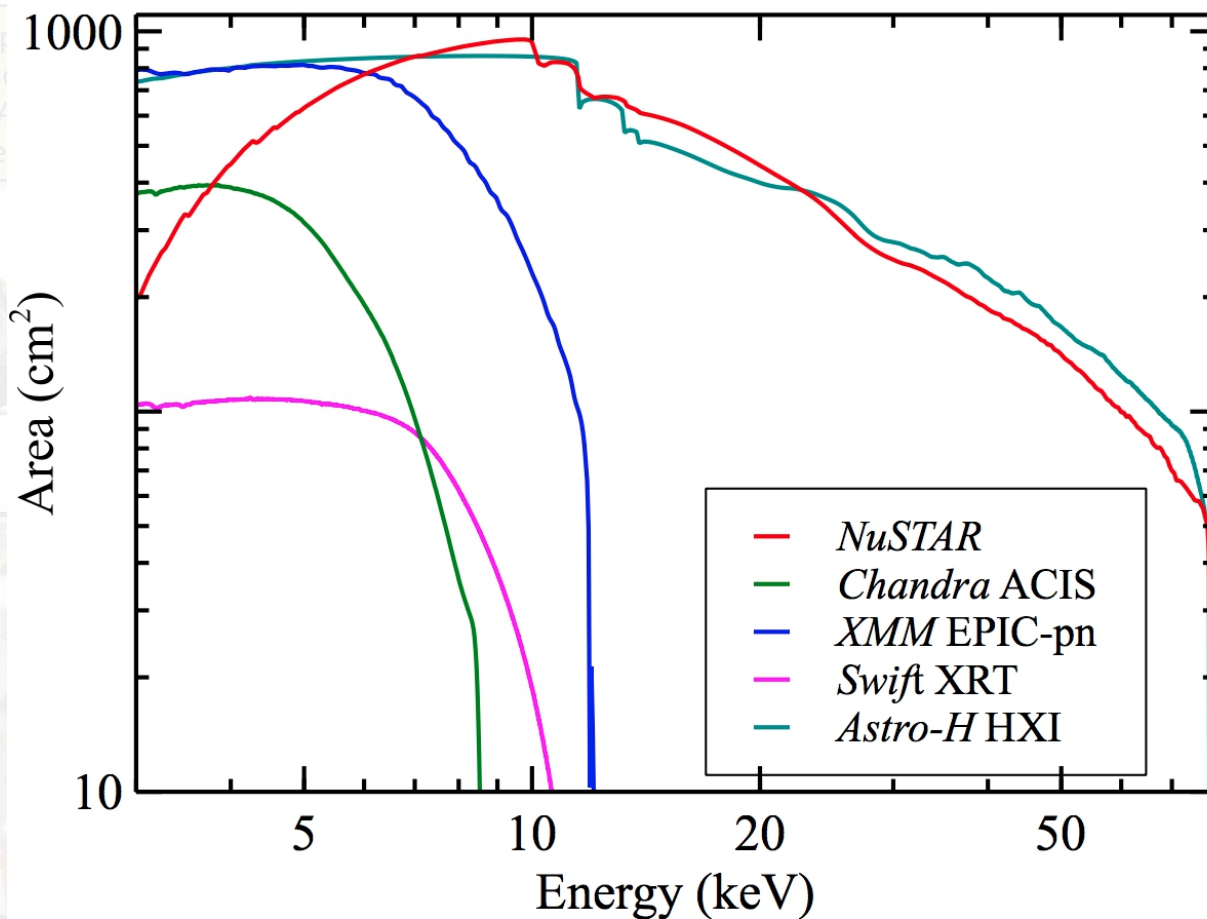
Resolution:
400 eV @ 6 keV
900 eV @ 60 keV

- No consumables
- Single string
- 10 year lifetime

NuSTAR observatory components

Energy Range: 3 – 78 keV

Calibration observations in 2015

2014-2015 calibration observations

- Crab calibration with XMM and Integral (October 2 2014)

- IACHEC cross calibration campaign on 3C273 (July 14 2015)

- Crab Stray-Light (October 18 2015)

- Coordinated with Astrosat

  - Cyg X-1 (October 8 2015)

  - Cyg X-3 (November 13 2015)

  - GRS 1915+105 (November 14 2015)

- We remain confident that we understand the observatory calibration to within ~5%

Just flagging the status…

- Crab with XMM & Integral
  - Data has been sent to XMM contacts Michael Smith and Jacob Ebero

- IACHEC 2015 cross-calibration campaign on 3C273
  - It was decided not to include it in the 2013-2014 3C273/PKS2155-304 paper.

Flux (3-7 keV) = 33e-12 ergs/cm^2/s

  (in 2012 ~ 40e-12 ergs/cm^2/s)

Γ = 1.67   (similar to 2012)

E_{cutoff} = 380 keV   (higher than in 2012)

data and folded model
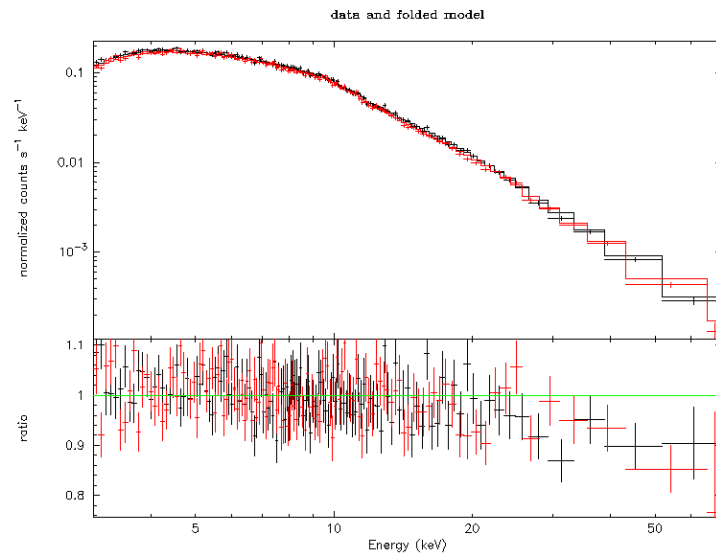
Crab Stray-Light

Motivation

Below 5 keV the NuSTAR response is controlled by four elements:

1. Be window and MLI (thermal covers) – well-known

2. Mirror effective area
   - Above 5 keV well modeled as total external reflection
   - Not well-known below 5 keV

3. Actual Crab N_H – Range between 0.1 - 0.6 x 10^{21} cm^{-2}

4. Detector surface absorption elements not well understood
   - CZT dead-layer
   - Pt from the contact coating

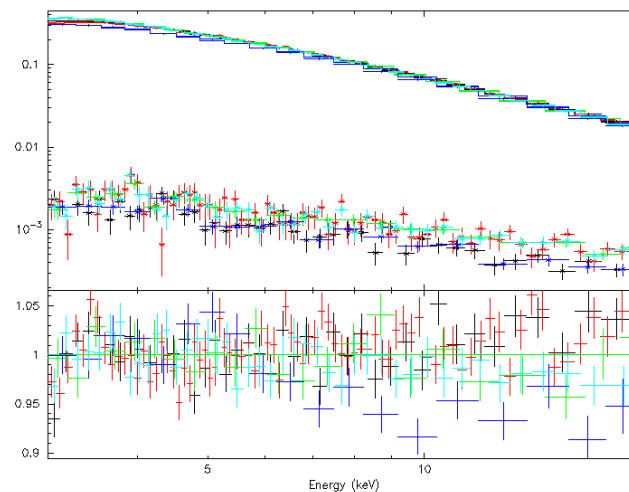**2 – 4 are degenerate with each other.**

Crab Stray-Light

- We can eliminate the effective area by performing observations of the Crab using it as a stray-light source.

- We placed it ~1.5 degrees off-axis and observe the light that slips past the observatory and the aperture stops.

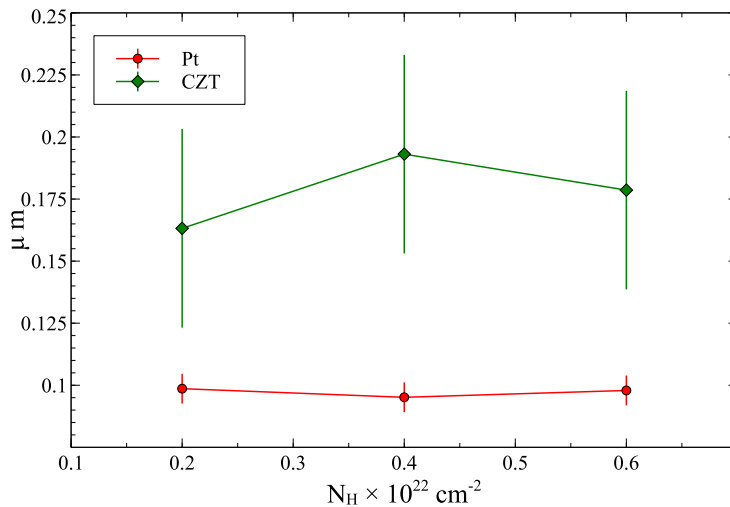- Only response is Be, MLI, and RMF.

20 ksec
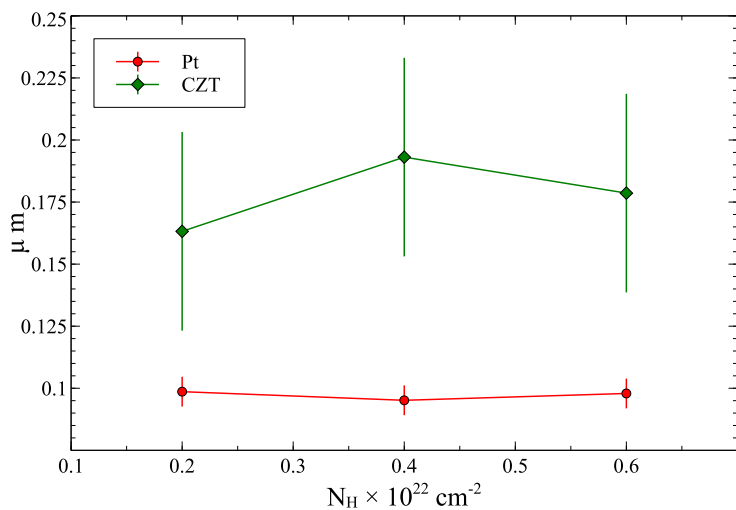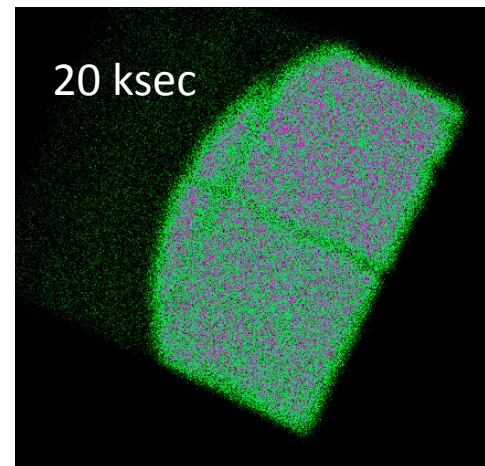
OLD values:

CZT = 0.187

Pt = 0.138

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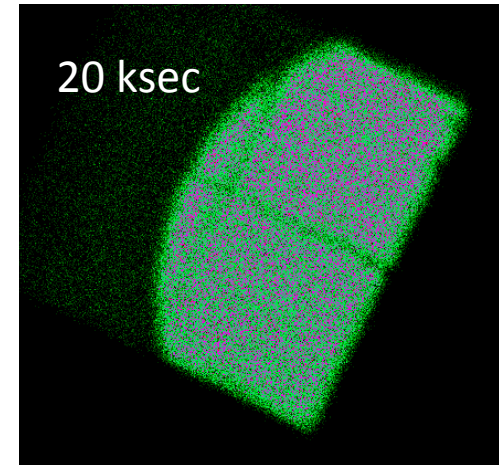
- Only response is Be, MLI, and RMF.

20 ksec

OLD values:

CZT = 0.187

Pt = 0.138

i.e. not ARF related
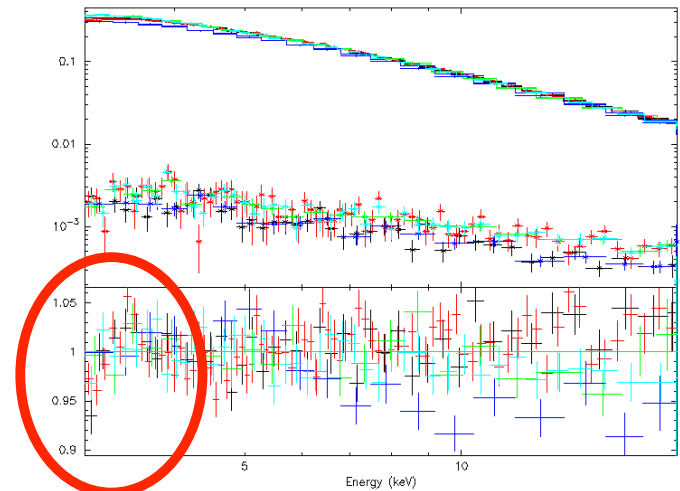
Path forward

- The difference between old and new detector absorption parameters were mitigated by the effective area and in net effect did not influence the responses, because we used the Crab as calibrator.

- However, we have discovered features we thought were ARF related, but are not (sharp drop at ~ 3.5 keV). We sometimes observe this feature in bright sources. We plan to remove it with an additional correction in the detector absorption file.

- The detector absorption parameters are within errors not effected by choice of Crab N_H. However, we plan to explore the impact on the responses of varying N_H on bright sources (binaries).
  - Look for SPIE paper this summer

NuSTAR

Observatory Planning and Pointing Improvements

# Why is observatory planning so complicated for NuSTAR?

- We want to squeeze out the maximum amount of photons of each observation.

- Made difficult by the mast, which moves the optical axis around and therefore the optimal location of maximum throughput.
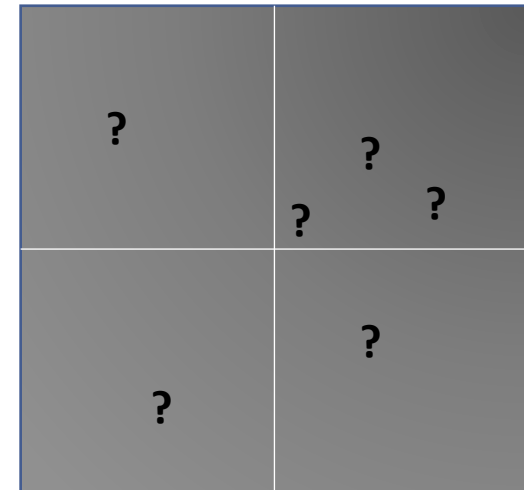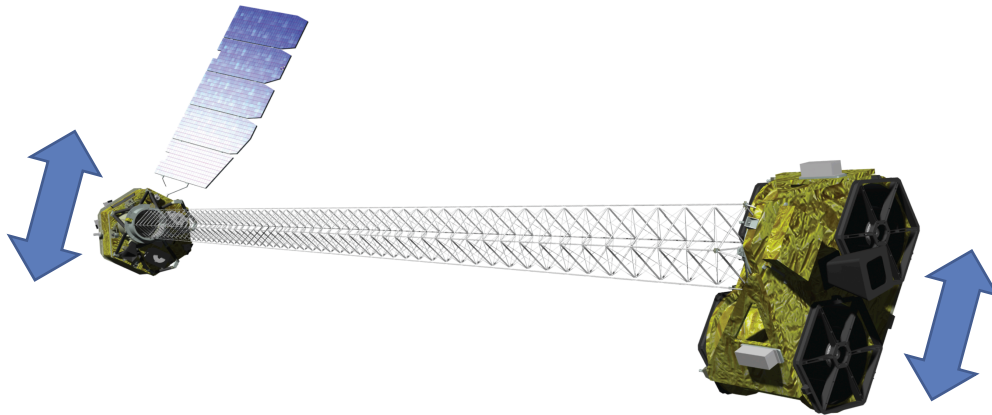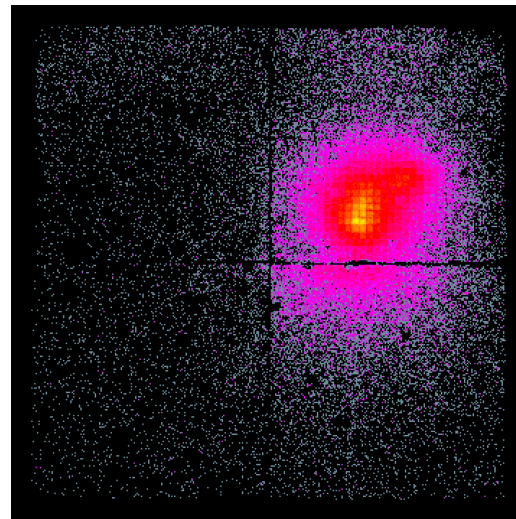

- **Challenge:** To predict the location of the Optical Axis and to accurately be able to position a source on the detector for any location on the sky.
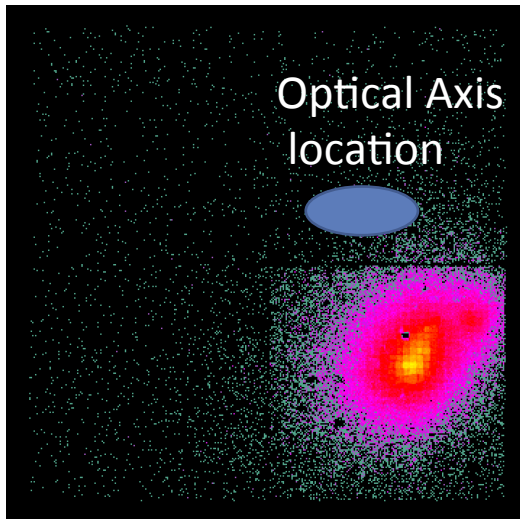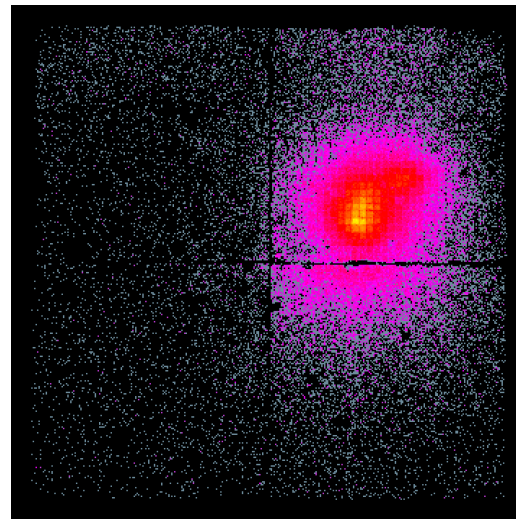
In the beginning...

First Light !

First Light 2

Optical Axis location
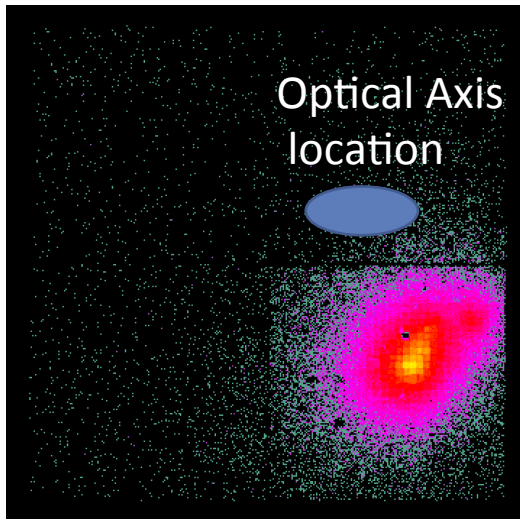
Cygnus X-1

We got this!

In the beginning…

First Light !

First Light 2

MKN 421

Optical Axis location

Cygnus X-1

We got this!
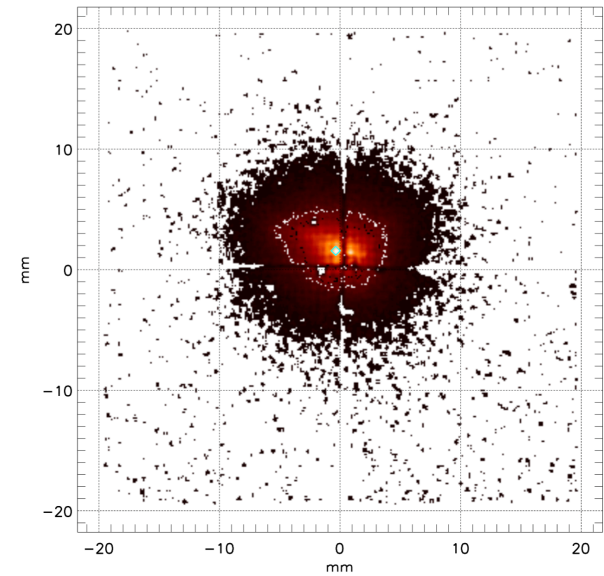
Nope, we don't…

How NuSTAR points

Inertial$_{OB}$

startracker

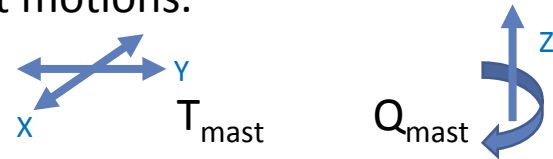Optical Bench (OB)

Mast

Focal Plane Bench (FB)
Spacecraft Bus

Inertial$_{FB}$

3 startrackers
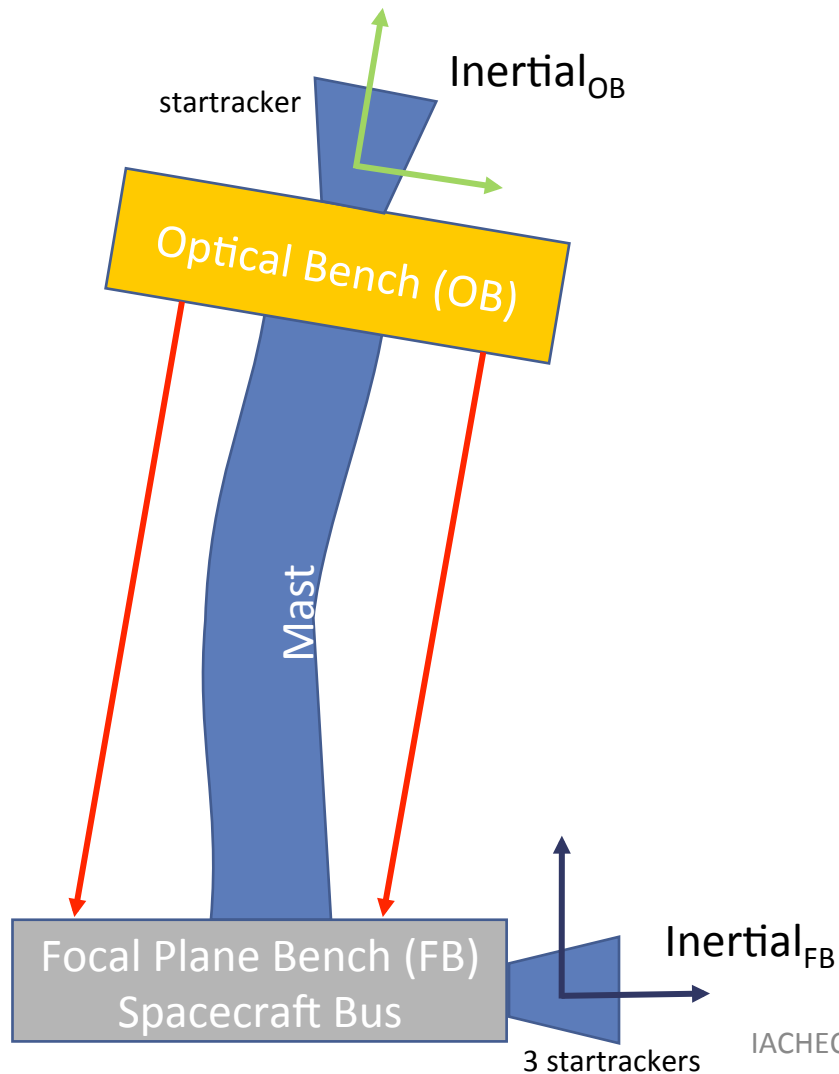
- We know the translational component of OB wrt FB in X-Y and the rotational component about Z. This is measured by the metrology system that traces the mast motions.
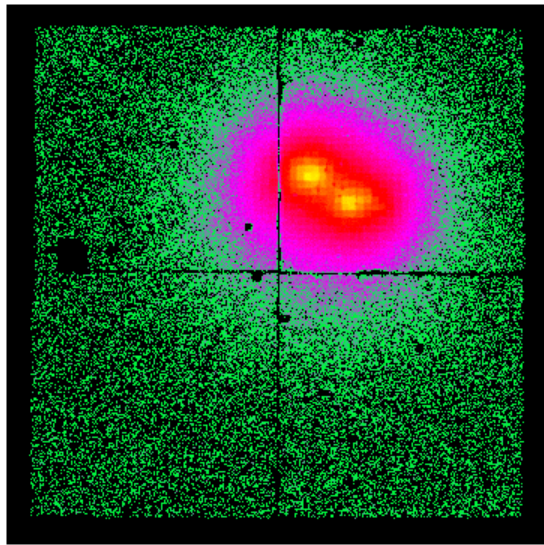
X Y T_{mast} Q_{mast} Z

- The pointing axis of FB and OB are offset *wrt* each other

Inertial$_{OB}$ = Inertial$_{FB}$ *$Q_{misalign}$(temperature)

- NuSTAR points from the rear (FB) and to get target on the correct location on the detector we need to know in advance the mast configuration (T_{mast},Q_{mast}) and the pointing misalignment (Q_{mis}).
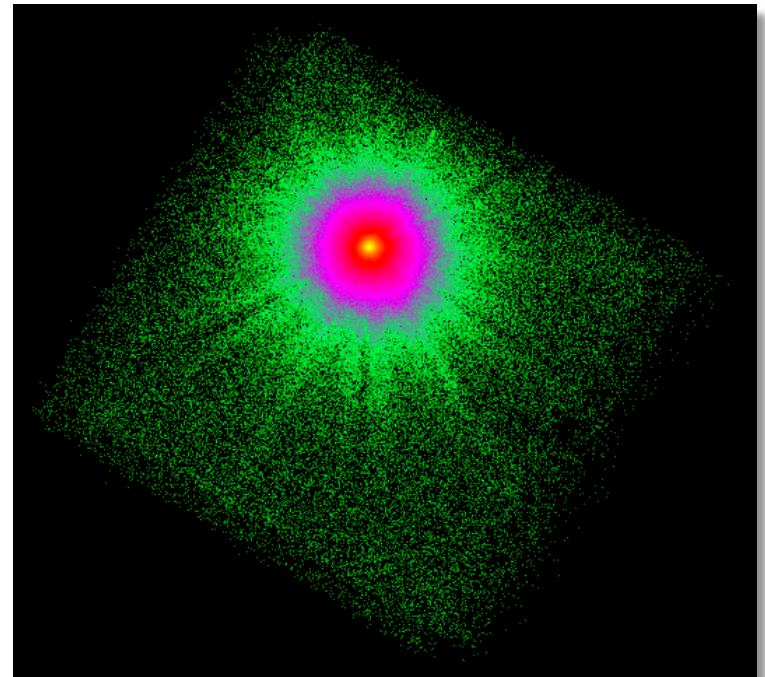
Reconstruction of sky images

Detector frame

Sky frame

T_{mast}, Q_{mast}
+ Inertial$_{OB}$
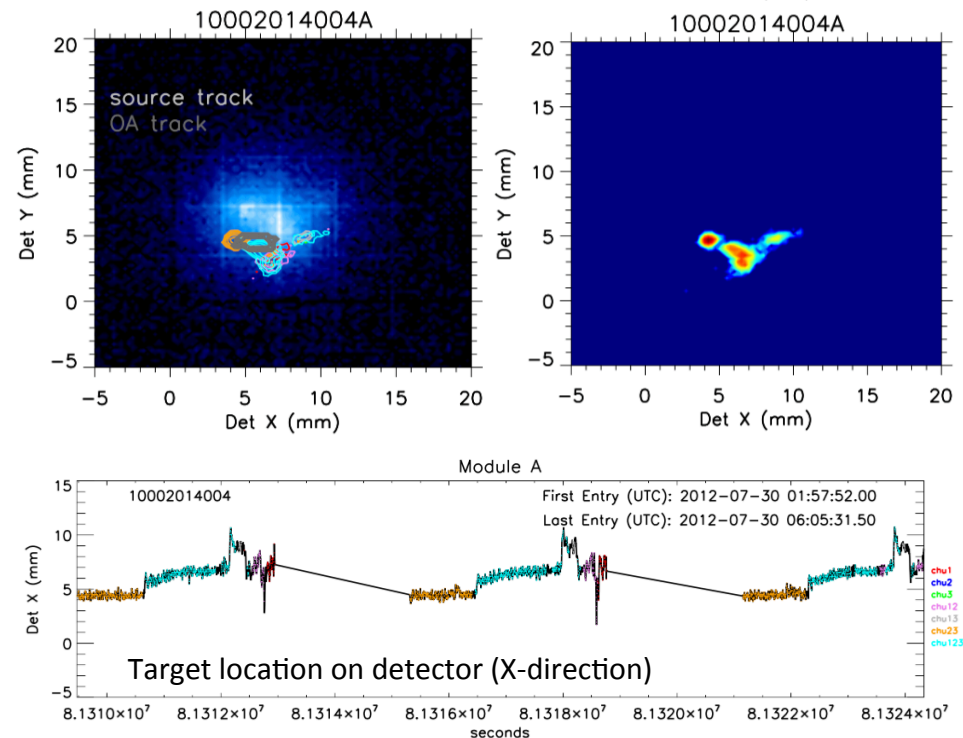
- Normal Aspect reconstruction does not require any attitude knowledge from the spacecraft bus.
- If Inertial$_{OB}$ is not present (e.g. observation within 39° of the Sun) we can reconstruct images using Inertial$_{FB}$ *$Q_{misalign}$ and that is mode "6" to be discussed later.

Variability with temperature

- Mast motions due to orbital sunlight and shade cycles
- Mast motion amplitudes are as expected from pre-launch modeling
- Measured by laser metrology system
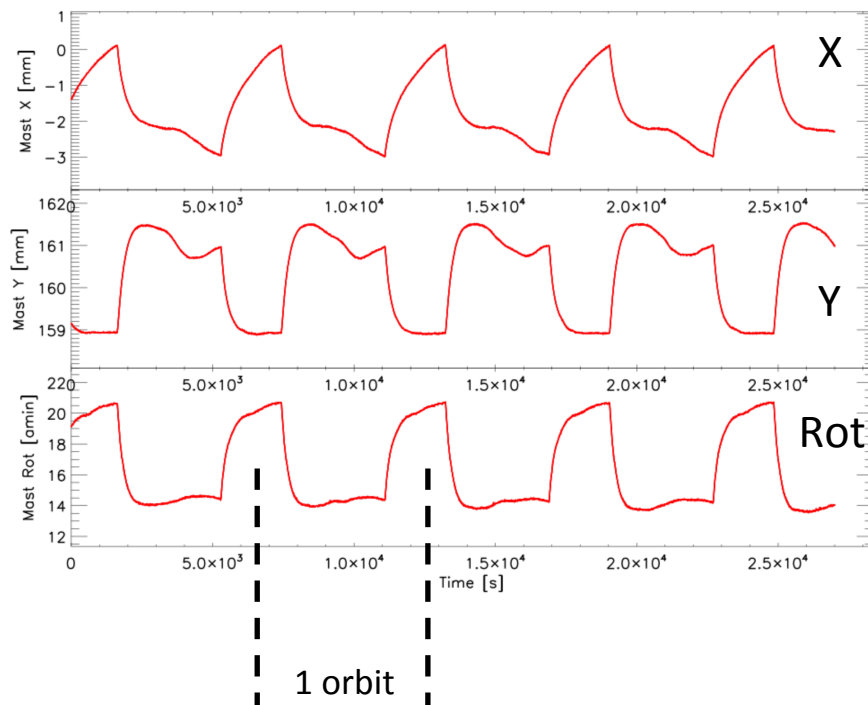
- Pointing jitter due to orbital thermal distortions of spacecraft mounted startrackers.
- Independent of the mast motion.

X

Y

Rot

1 orbit

source track
OA track

10002014004A

10002014004A

Module A

10002014004
First Entry (UTC): 2012-07-30 01:57:52.00
Last Entry (UTC): 2012-07-30 06:05:31.50

Target location on detector (X-direction)

Reference database

- 100% Empirically populated database that uses nearly all mission data sampled as a function of Solar aspect angle (Saa):
    - Mast roto-translational motion (T_{mast}, Q_{mast})
    - Optical Axis location
    - Center of Mass corrections (Spacecraft pointing jitter)
    - Misalignment quaternion between spacecraft (SC) and startracker (star)

        $$Q_{star} = Q_{sc} * Q_{mis}$$
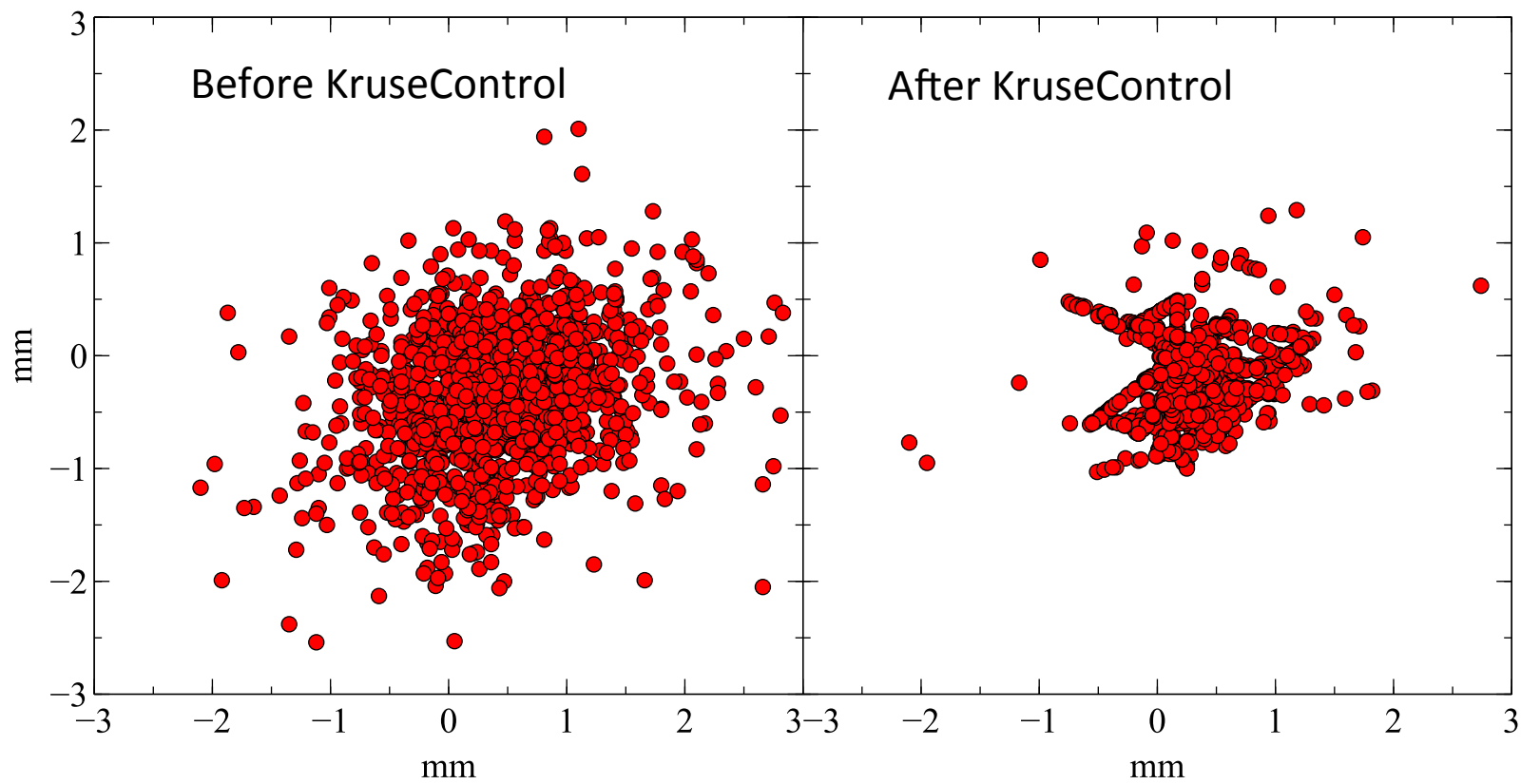   - Database is updated every 6 months

Reference Database
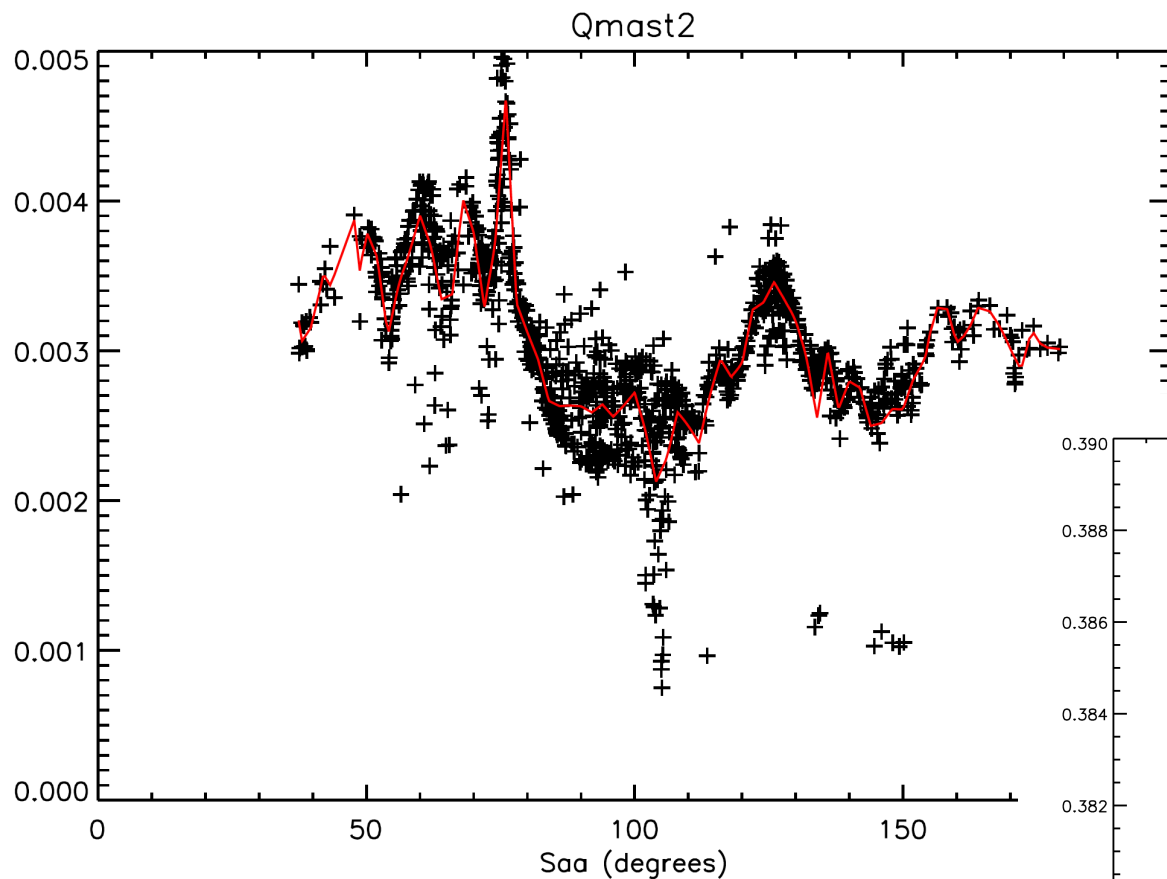
- Multiple components of quaternion
- spline fitted every 2° of Saa
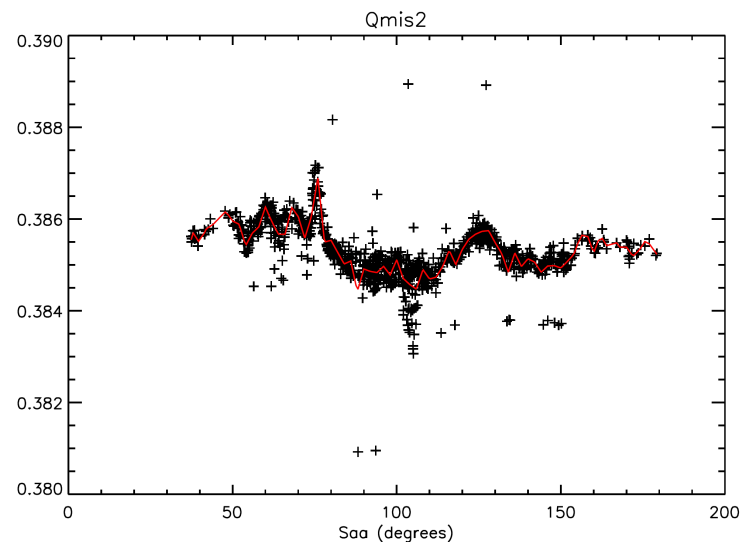
Performance improvements

Difference between where target should have landed and actually landed on focal plane
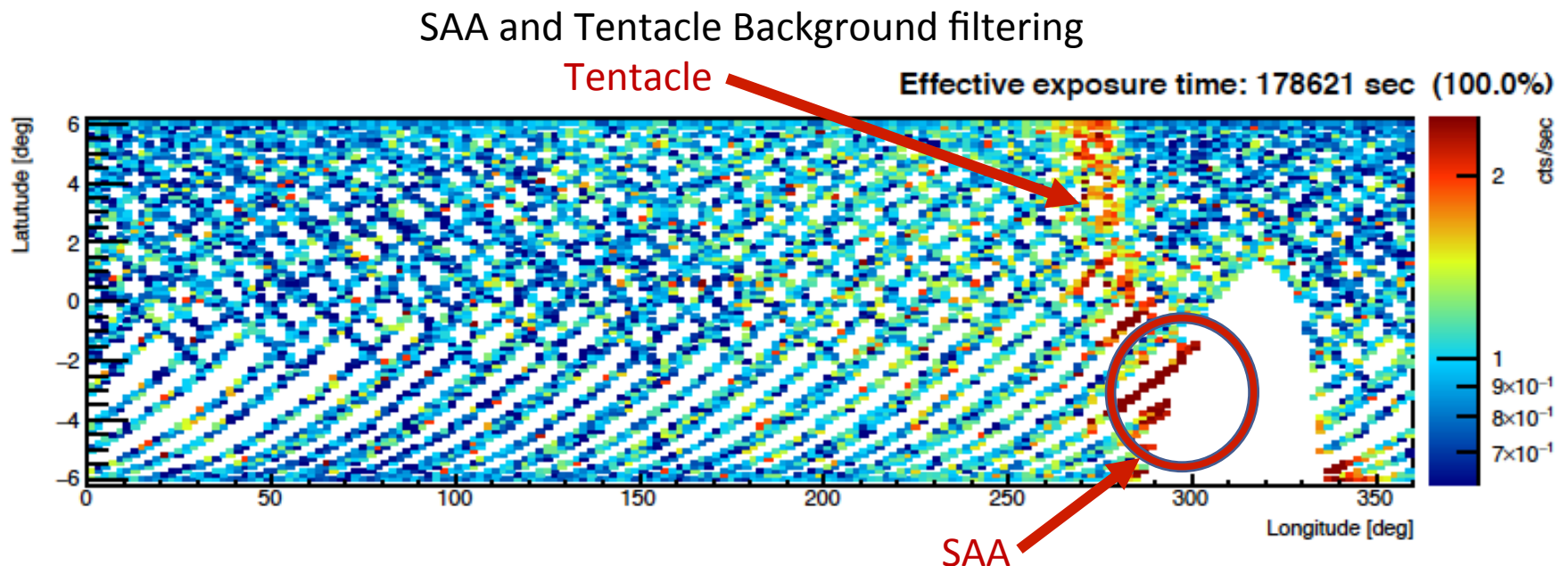

Subject of SPIE paper this summer…

New Background Filtering Algorithms

SAA and Tentacle Background filtering

- Detector Shields turn off during SAA passages
  - stop events recorded from CZT detectors (reduces data volume)

- However, sometimes that is not enough to avoid higher backgrounds near the SAA

- NuSTAR has additional background filtering modes available:
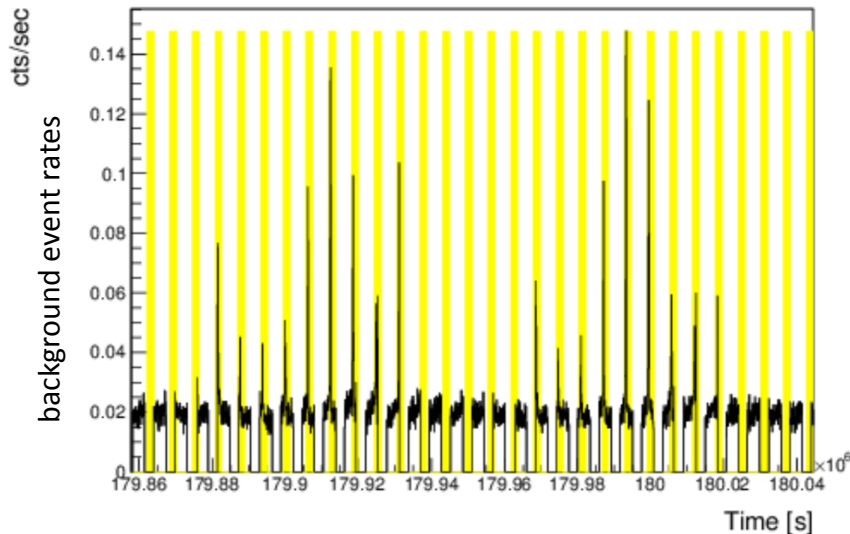 - SAA
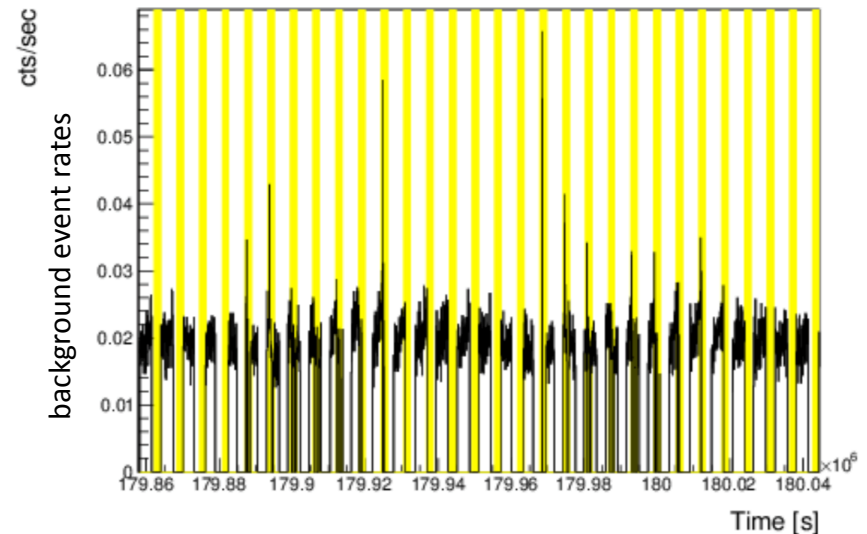 - Tentacle

SAA and Tentacle Background filtering

Tentacle

SAA

Effective exposure time: 178621 sec (100.0%)

SAA and Tentacle Background filtering

Recently the SAA and Tentacle filters have not been good enough to remove all high background spikes.

- Shield gains have changed
- the solar environment has become more active
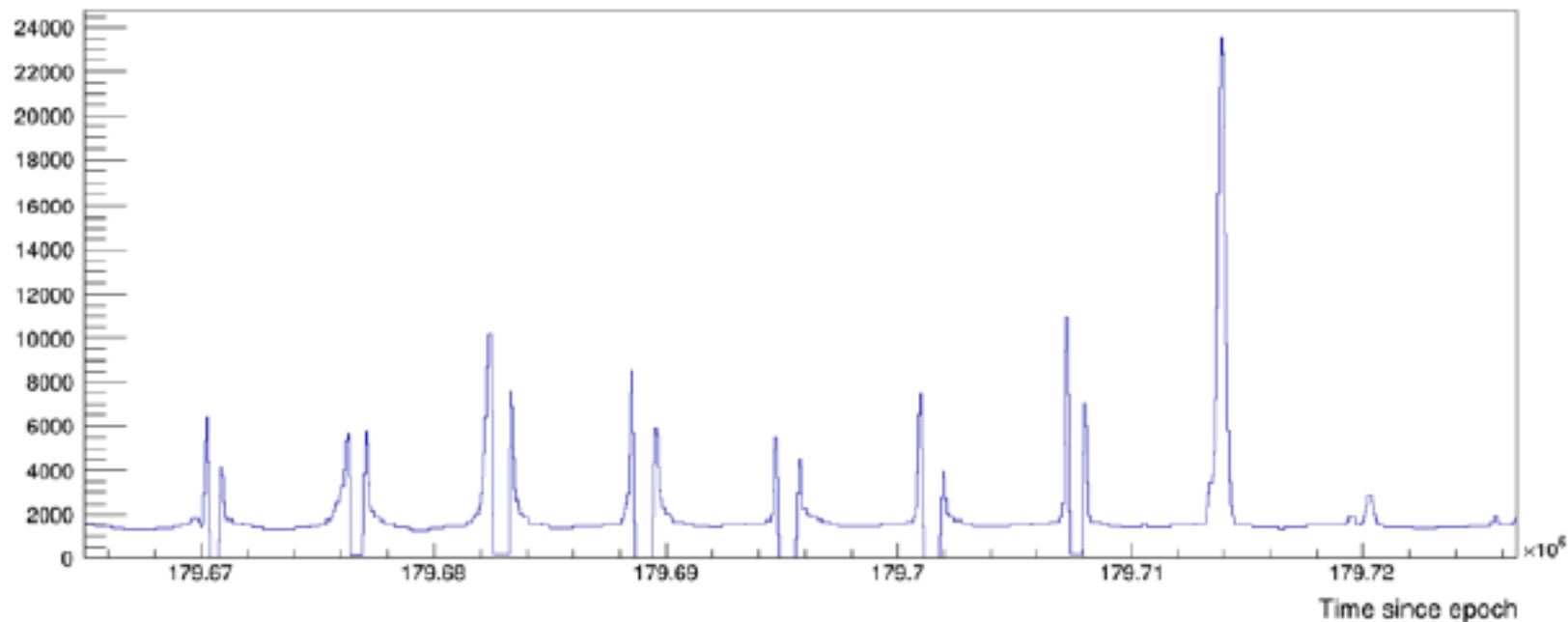- the spacecraft orbit has evolved

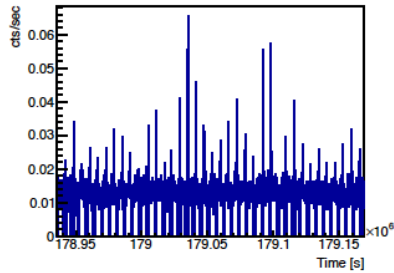No filtering

Tentacle and SAA filtering

SAA and Tentacle Background filtering

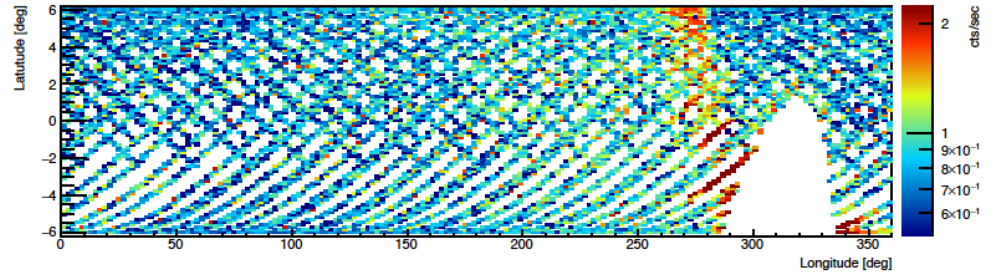New algorithms have been developed using Bayesian-blocks to histogram the low-shield rate.
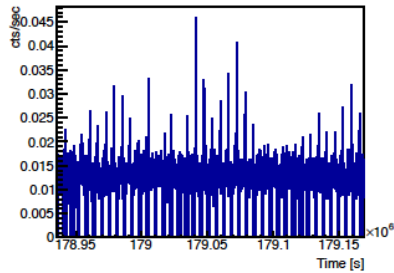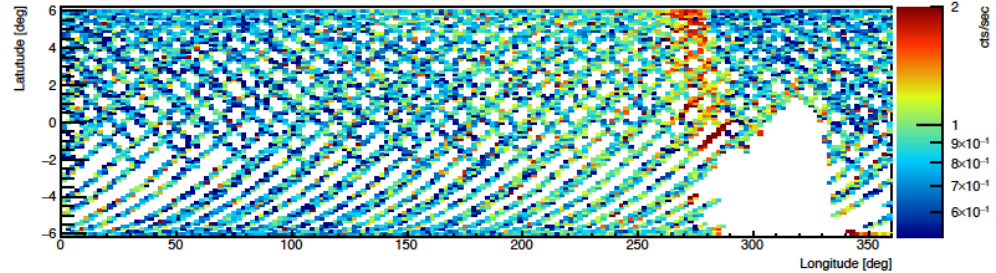
Example of improvement

Old best filtering

New best

Observing mode "6"
observing without the star-tracker

Mode "6" – SC mode

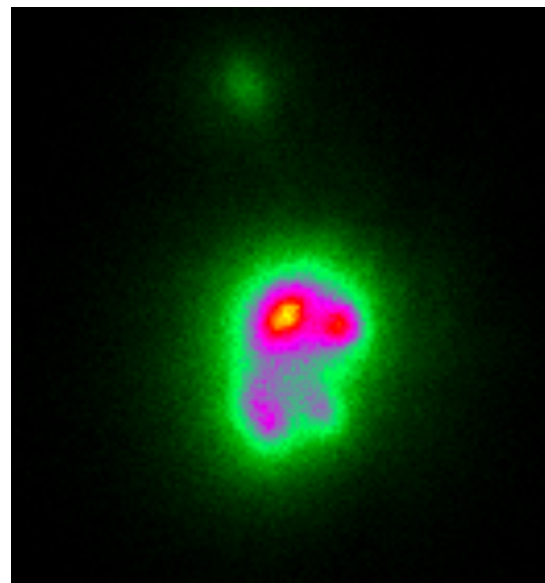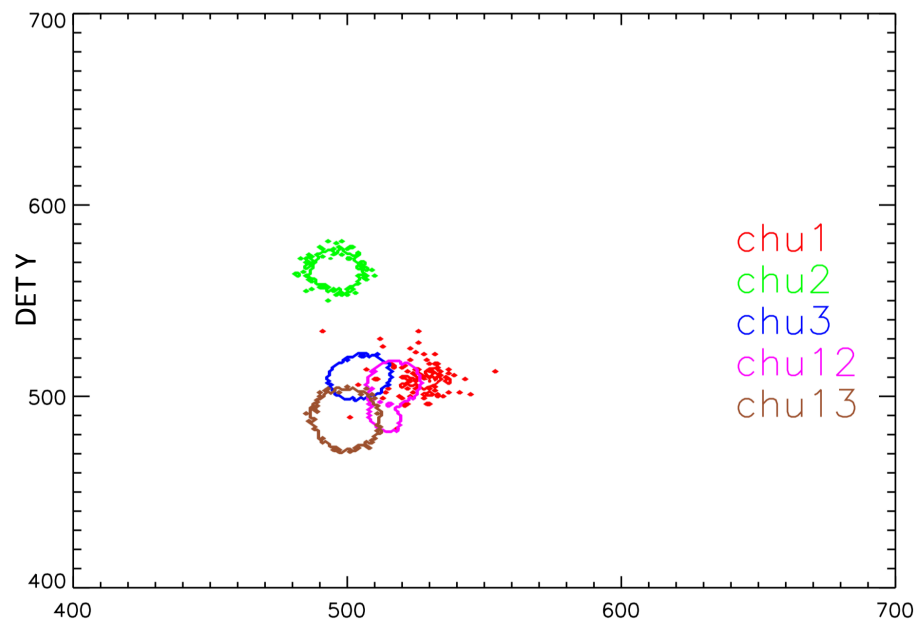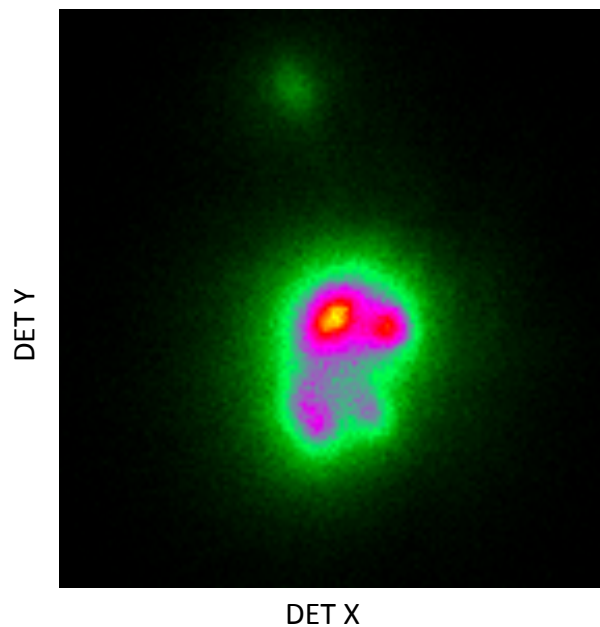- Mode "6" (due to the numbering in the pipeline) happens when the star-tracker on the OB, used for absolute aspect reconstruction, is blinded by something bright - Sun, bright Earth limb, Moon, UFOs, etc.

- We can reconstruct the aspect using the spacecraft pointing solution, which is not as accurate, and so this happens:

Cyg X-1 detector frame

Extracting spectra

We now have a pipeline ftool "*nusplitsc*" that splits observing mode 6 into separate event files and GTIs for each CHU (camera head unit) combination.

- ARF centroid is now correct for each CHU combination
- This feature will be released in the next NUSTARDAS update.

Because users are now able to access and utilize this data we have improved observatory efficiency by up to ~10%.

NuSTAR

Observatory Status

- NuSTAR GO cycle-2 peer review completed
  - Target lists will be released this week, observations start 2016 May 1st

- 100 ks of NuSTAR time available in the next INTEGRAL AO for joint programs

- NuSTAR project submitted proposal for continued operations to NASA senior review
  - Decision for 2 year mission extension expected in June
  - NuSTAR GO cycle-3 proposals will be due in 2017 January

STATUS