NuSTAR 2016 IACHEC Observatory Update

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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 components

**Energy Range:** 3 – 78 keV

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

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

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

- No consumables
- Single string
- 10 year lifetime
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Energy Range: 3 – 78 keV

- NuSTAR
- Chandra ACIS
- XMM EPIC-pn
- Swift XRT
- Astro-H HXI

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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/cm²/s
  (in 2012 ~ 40e-12 ergs/cm²/s)

$\Gamma = 1.67$
  (similar to 2012)

$E_{\text{cutoff}} = 380$ keV
  (higher than in 2012)
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 $0.1 - 0.6 \times 10^{21}$ 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.

OLD values:
CZT = 0.187
Pt = 0.138
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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
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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!

Optical Axis location

First Light 2

Cygnus X-1

We got this!
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In the beginning...

First Light!
Optical Axis location
Cygnus X-1

First Light 2

MKN 421

We got this!

Nope, we don’t...
How NuSTAR points

- 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.

\[
\text{Inertial}_{OB} = \text{Inertial}_{FB} \times Q_{\text{misalign}} \text{ (temperature)}
\]

- The pointing axis of FB and OB are offset \textit{wrt} each other.

- 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 \((T_{\text{mast}}, Q_{\text{mast}})\) and the pointing misalignment \((Q_{\text{mis}})\).
Reconstruction of sky images

- Normal Aspect reconstruction does not require any attitude knowledge from the spacecraft bus.
- If Inertial\textsubscript{OB} is not present (e.g. observation within 39° of the Sun) we can reconstruct images using Inertial\textsubscript{FB} * Q\textsubscript{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.
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 \((T_{\text{mast}}, Q_{\text{mast}})\)
  • Optical Axis location
  • Center of Mass corrections (Spacecraft pointing jitter)
  • Misalignment quaternion between spacecraft (SC) and startracker (star)
    \[
    Q_{\text{star}} = Q_{\text{sc}} * Q_{\text{mis}}
    \]
  • 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

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

Old best filtering  
New best
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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
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%. 

IACHEC 2016 Pune
• 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