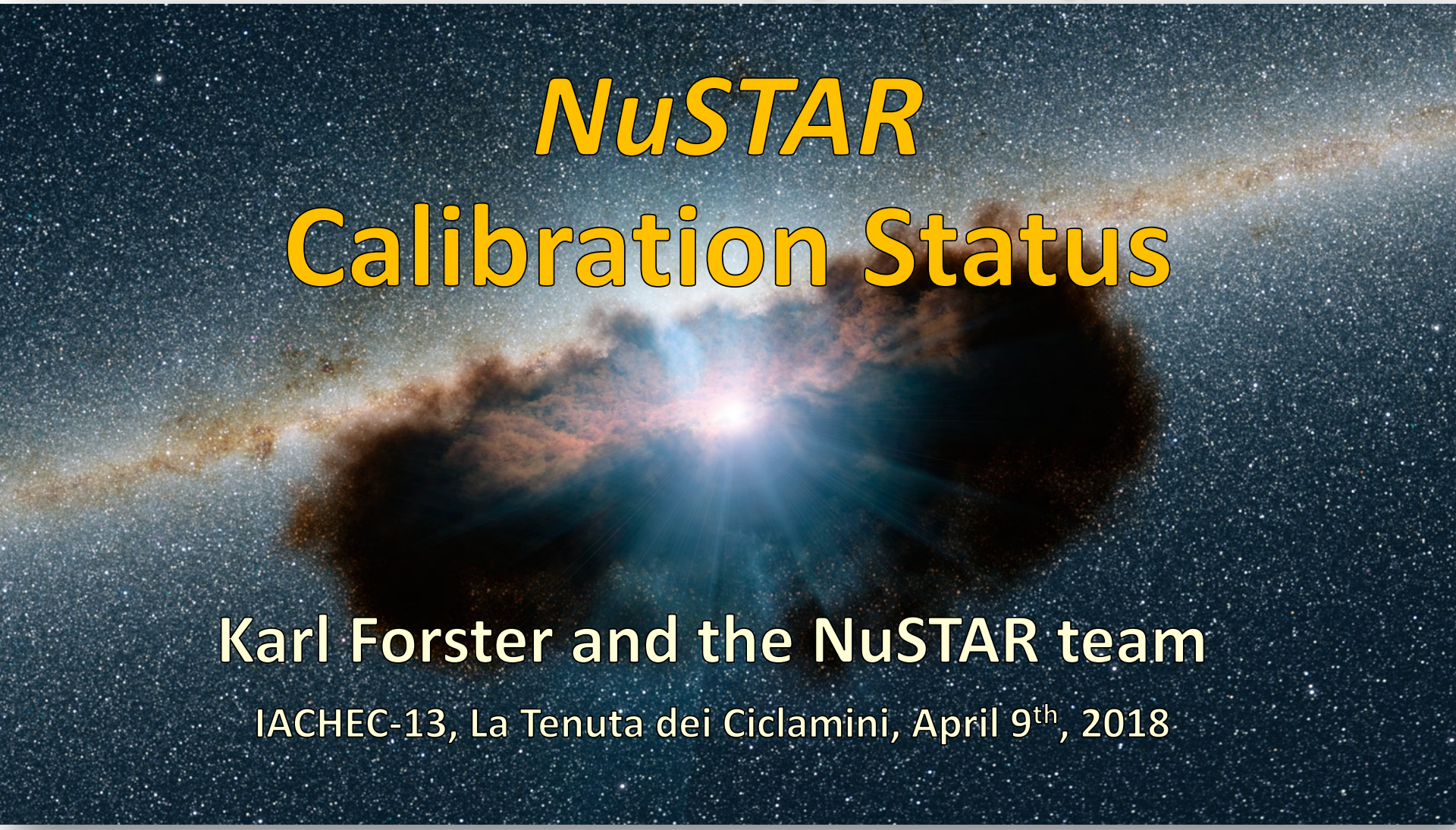


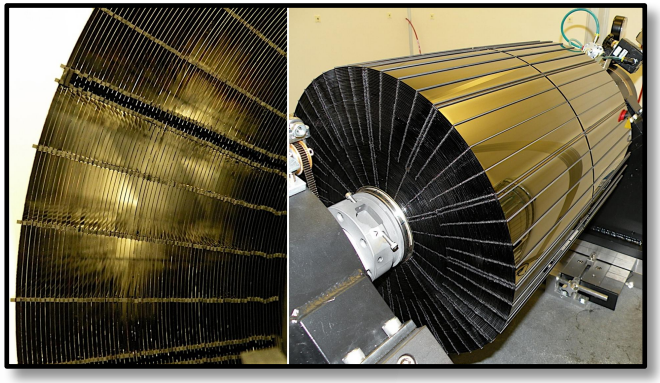
NuSTAR Calibration Status

Karl Forster and the NuSTAR team

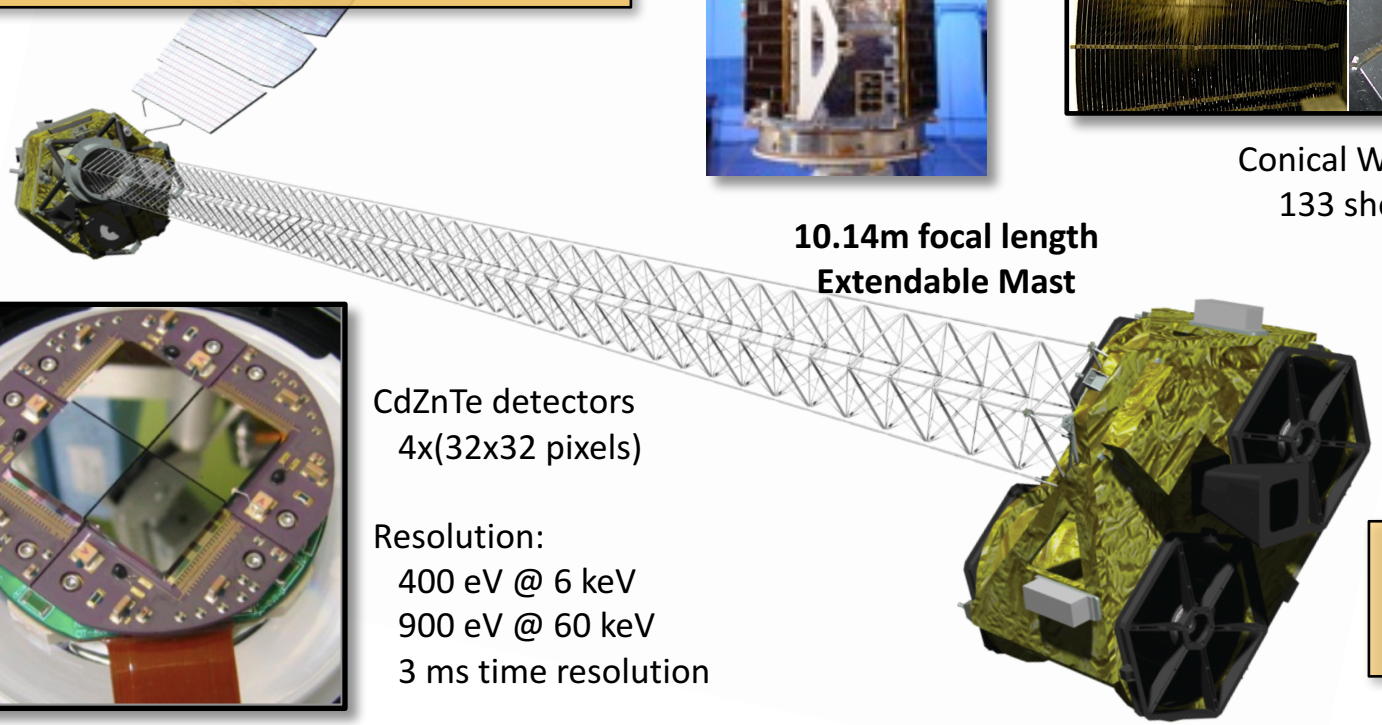
IACHEC-13, La Tenuta dei Ciclamini, April 9th, 2018

NuSTAR Observatory

- NASA small explorer astrophysics mission
- PI Fiona Harrison (Caltech)
- Partners: ASI, SSDC, DTK, HEASARC
- Launched on June 2012, 620 km, 6° orbit
- Orbital-ATK LeoStar-2 spacecraft bus



Conical Wolter-I approximation
133 shells (43 W/Si, 90 Pt/C)
HPD = 1 arcminute
FOV = 12’ x 12'



10.14m focal length
Extendable Mast

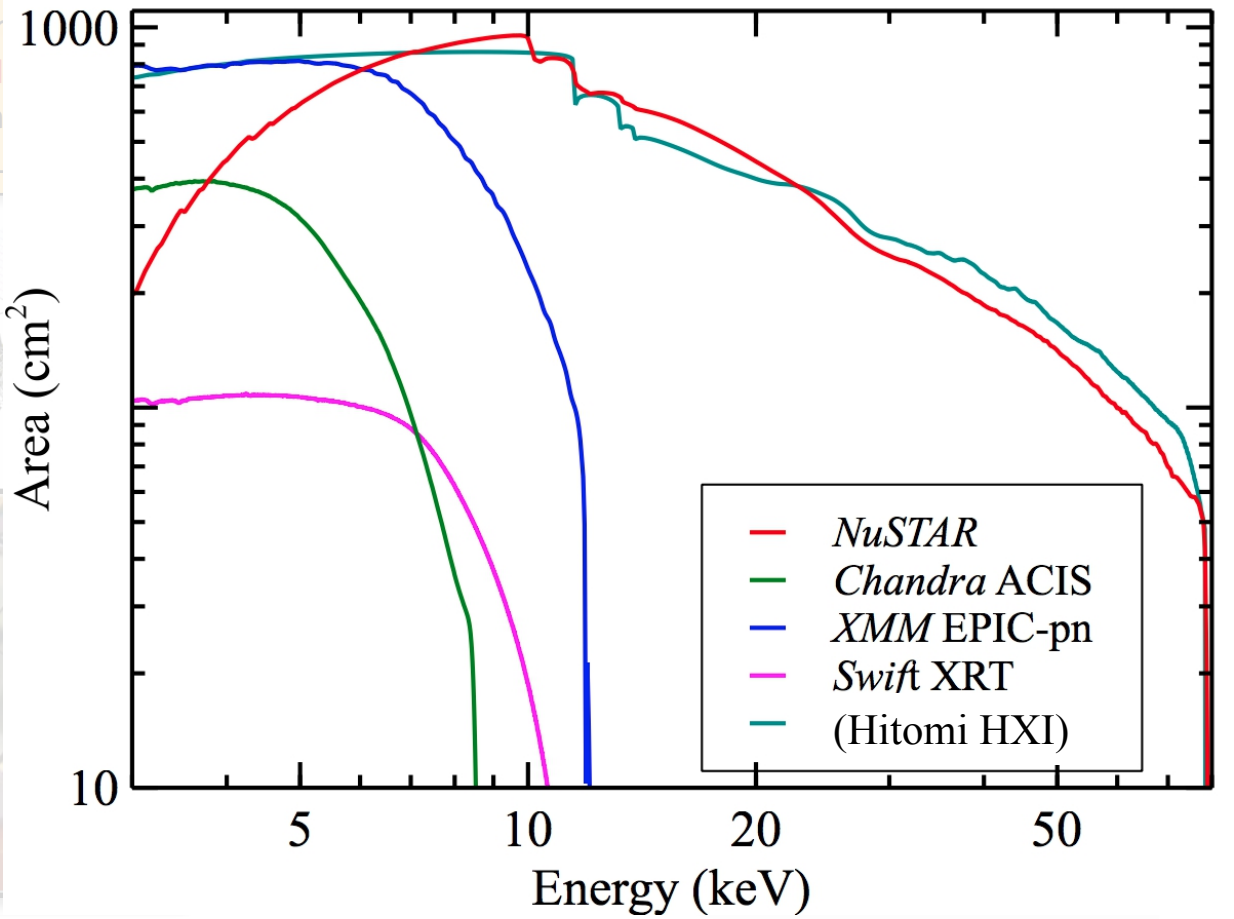
CdZnTe detectors
4x(32x32 pixels)

Resolution:
400 eV @ 6 keV
900 eV @ 60 keV
3 ms time resolution

- No consumables
- Single string
- >10 year lifetime

NuSTAR Observatory

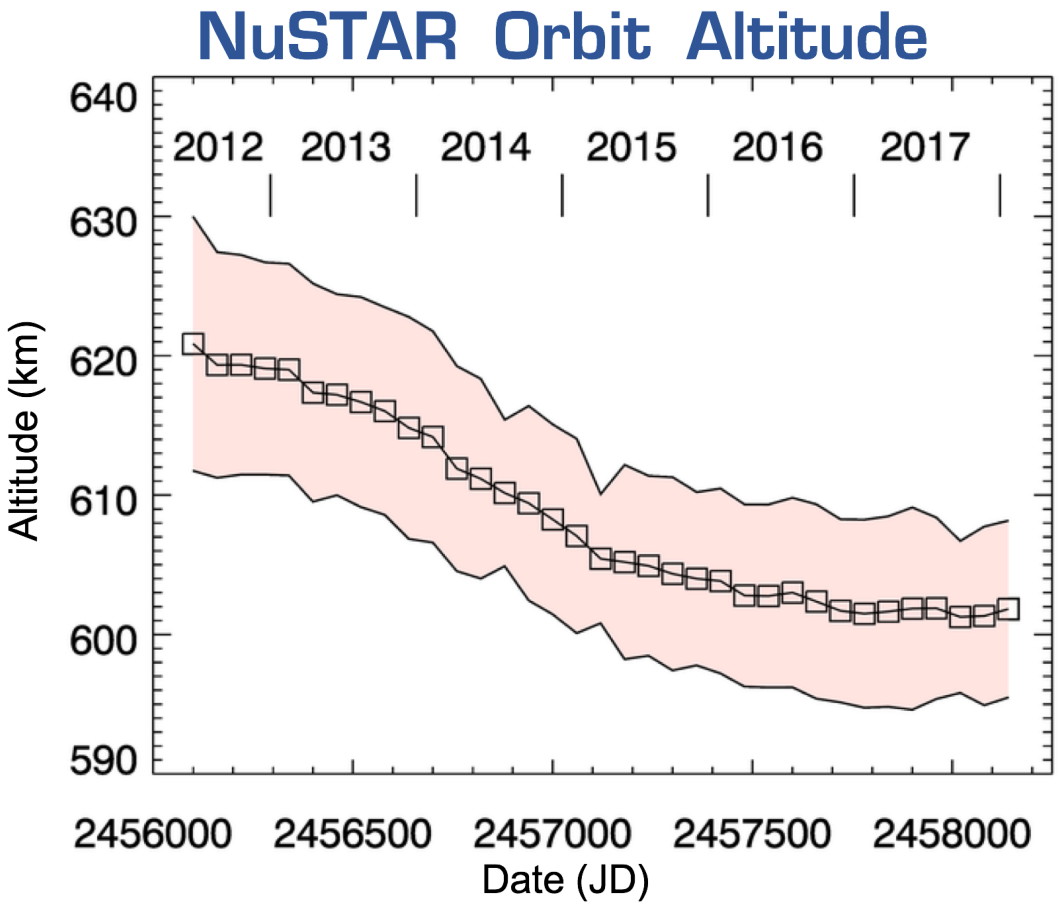
Energy Range: 3 – 78 keV



NuSTAR Observatory

- NASA small explore
- PI Fiona Harrison (C
- Partners: ASI, ASDC
- Launched on June 1
- Orbital-ATK LeoStar

Mission lifetime potentially past mid 2020's



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- No consumables
- Single string
- 10 year lifetime

Calibration & Status

Observatory status is green

2017 Calibration news

- Detector monitoring indicates gain has remained ~steady since 2016
  - ***Long term gain calibration of NuSTAR detectors*** - Brian Grefenstette - this afternoon
- Monthly Crab calibration observations – focussed and straylight
  - Monitor detector absorption parameters, absolute normalization and vignetting
  - ***Update on Crab cross-calibration*** - Kristin Madsen - Wednesday afternoon
- Timing calibration improvements
  - Goal is to provide relative timing accuracy of a few μs

2018 Operations news

- New observing constraints implemented in 2018
  - Sun avoidance update Saa > 43° (was 39°, improvement in knowledge of astrometry star tracker behavior)
  - Mast leaning constraints (-X 90 ° < Saa < 110 ° , +X 70 ° < Saa < 80 °)
  - Metrology calibration limit (104 ° < Saa < 106 °)
  - Optics thermal avoidance (145 ° < Saa < 160 °)
  - **Mast adjustment planned for 2018 May**
- Increase in multi-observatory coordinations for calibration (and science!)
  - Improvement in communication between operations teams, particularly for ToO's

Long term gain monitoring – Highlights

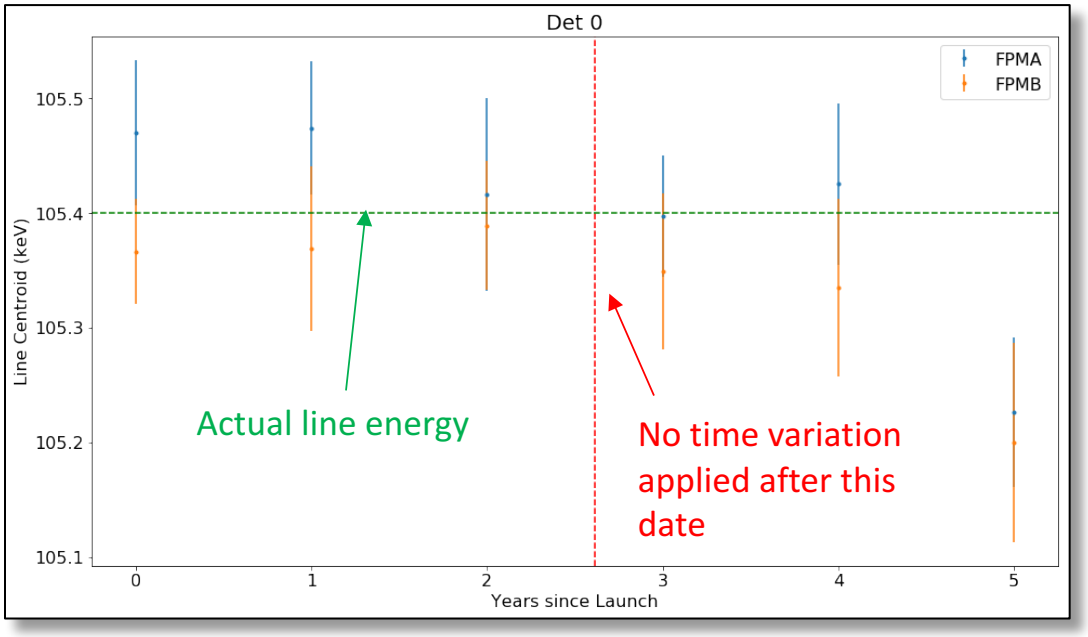
Brian Grefenstette

- Large dynamic range (2-200 keV) of NuSTAR CZT detectors requires two methods to determine any variations of the transfer function with time.

$$PI = PI_0 * SLOPE + OFFSET$$

- **Method 1**: Use background lines at 105, 121, and 144 keV to monitor the SLOPE variations with time.
- Method 2: Use routine observations of Kepler to monitor any OFFSET variations with time

- Gain has plateau'd since 2016.
- Plot shows the measured line centroid per year for Det0 on **FPMA** and **FPMB** **with** linear 0.2% / year SLOPE change.
- Investigating last data point and overall trend (non-linear?)



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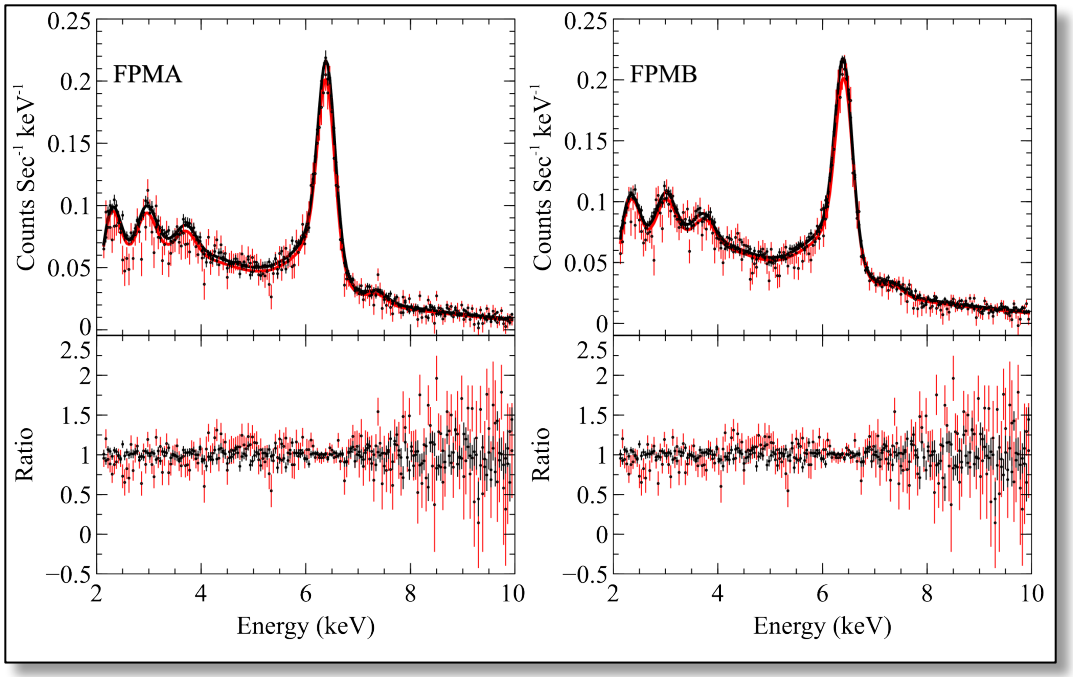
- **Method 2**: Use routine observations of Kepler to monitor any OFFSET variations with time

- Offset shows no time-dependence.
- Will continue to monitor Kepler at ~6 month intervals to confirm stability of offset.
- Multi-epoch fits to Kepler show OFFSET variations over a few years of ~20+/-10 eV.

Full discussion by Brian G. in the Detectors and Background WG this afternoon



Kepler SNR

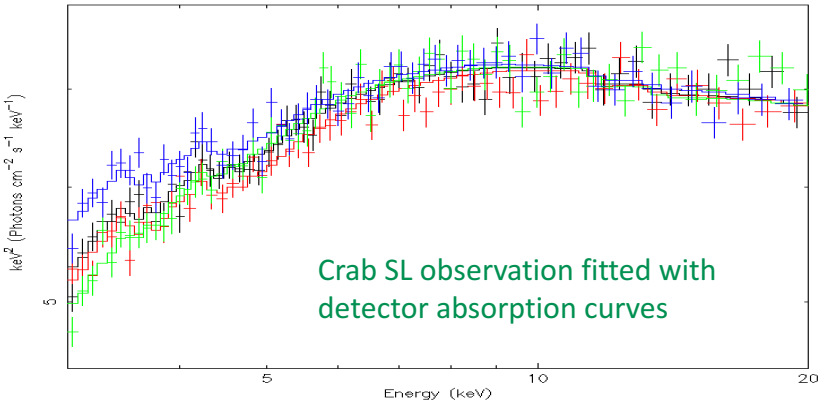
Crab calibration campaign

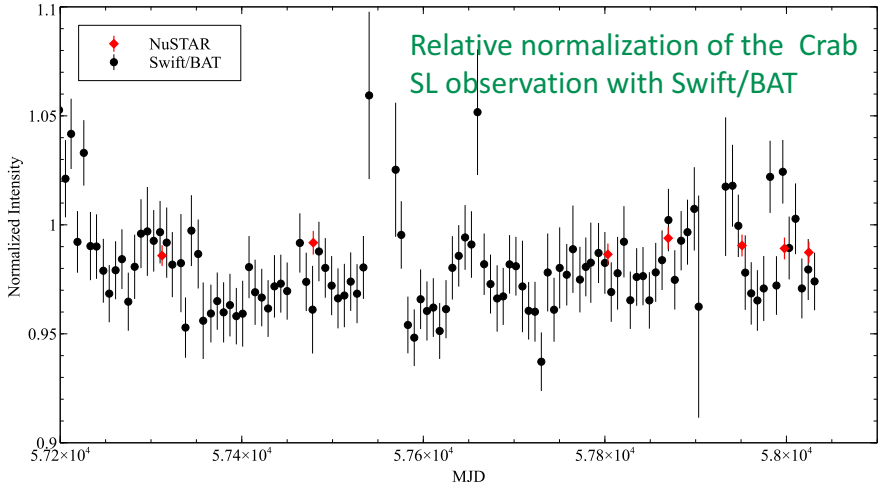
Kristin Madsen

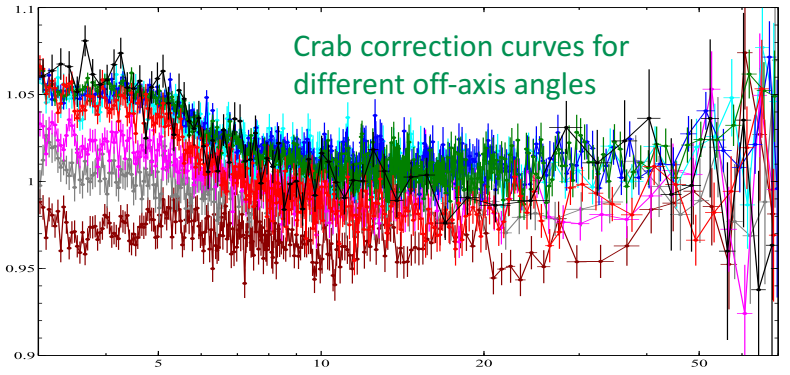
Re-calibration of detector absorption, absolute normalization, and the vignetting files

Scope: The new Crab campaign expands upon our focused Crab data base (50 observations) and complements it with StrayLight observations.

- Absolute normalization: StrayLight observations
- Detector absorption: StrayLight observations
- Vignetting files: focused Crab observations from the entire mission lifetime





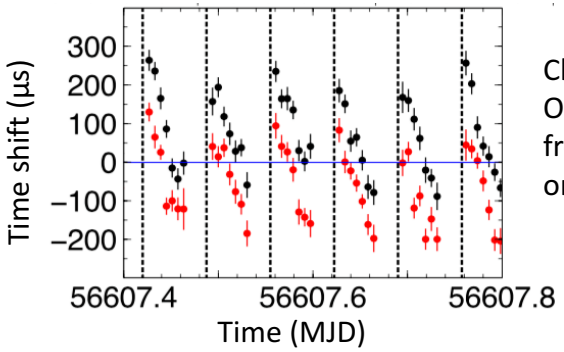


Full discussion by Kristin M. in the Coordinated Obs and Non-Thermal SNR WG's

Timing calibration status

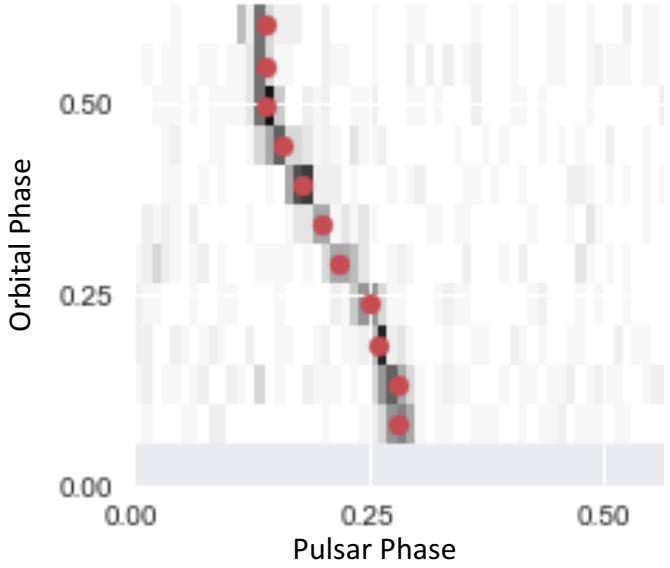
Matteo Bachetti, Craig Markwardt, Eric Gotthelf

- Current Method:
  - Based on point measurements of clock drift during ground-station passes.
  - Results in absolute and relative timing uncertainties on the order of a **few milliseconds** via barycorr.
  - Residual orbit-timescale variations in photon arrival times observed for millisecond pulsars.



Clear shift by +/- 400 μs
Originating in clock frequency variations on orbital timescales

- New method
  - Inclusion of a new engineering data point (the **clock oscillator temperature**) and trying a "first principles" clock correction.
  - Will result in some barycorr-like FTOOL for *NuSTAR*.
  - Work in progress; aim to have results by this summer's SPIE meeting.

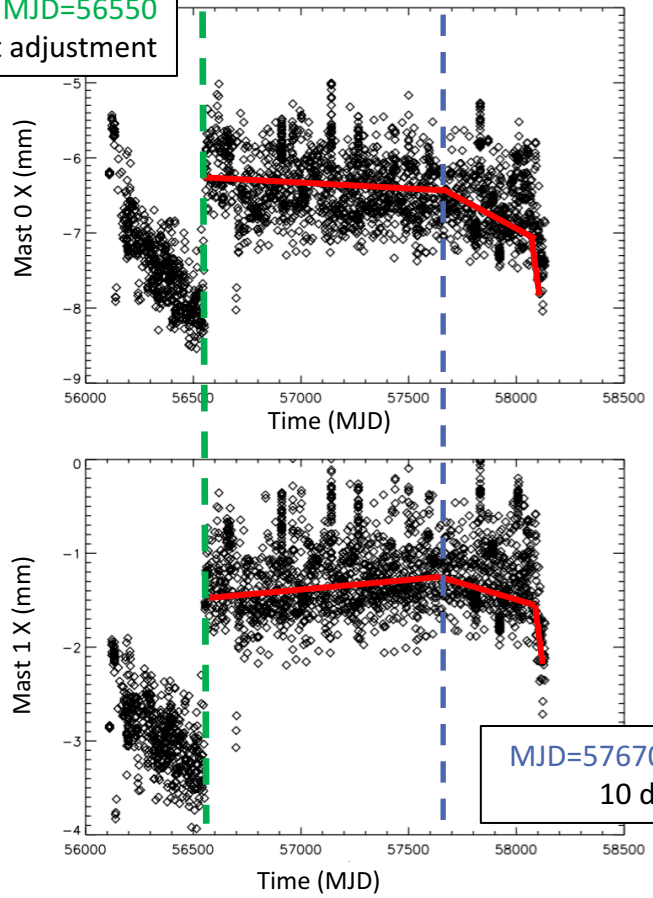


Pulse-phase drift for PSR B1821-24 (~3 ms period)

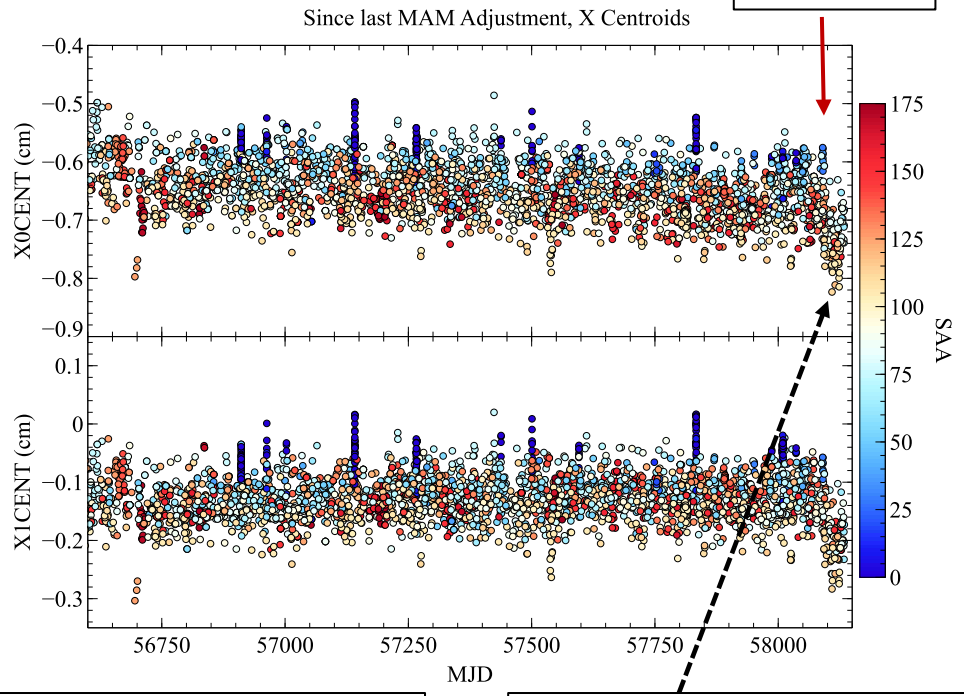
New observing constraints

- Avoid observing at certain ranges of Solar aspect angle (Saa)
  - Translates into scheduling constraints

MJD=56550
Mast adjustment



MJD=58090



MJD=57670 Change in mast position after 10 days of observations at SAA ~ 155°

Latest drift resulted in Metrology out of calibrated range for 2 observations

New observing constraints

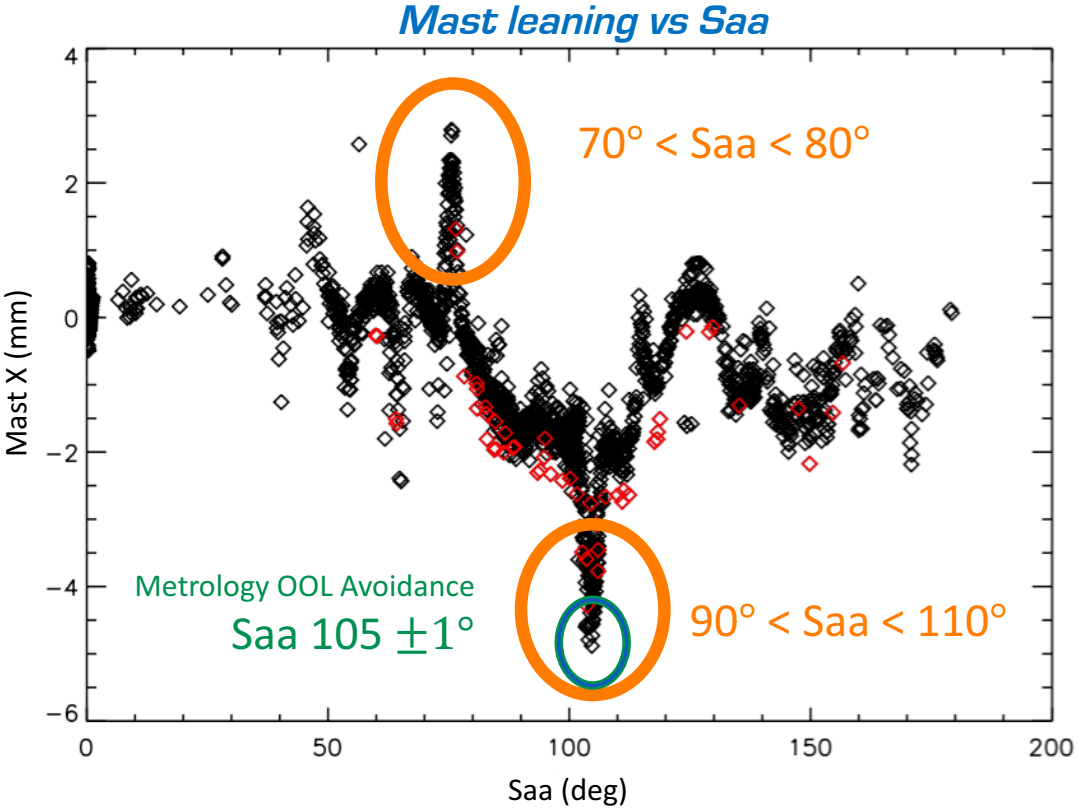
- Avoid observing at certain ranges of Solar aspect angle (Saa)
  - Translates into scheduling constraints

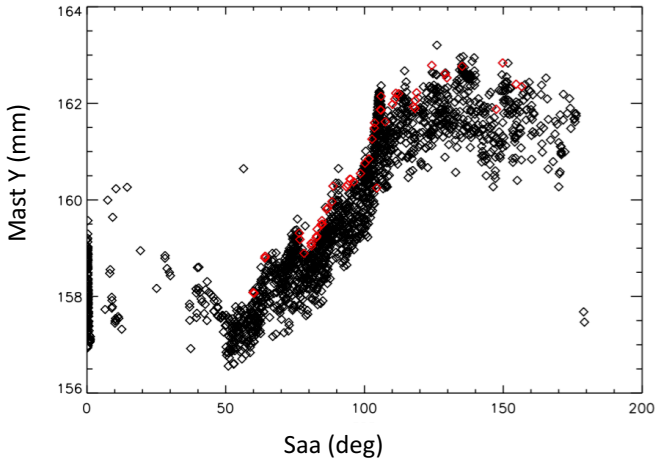
Extremes of mast leaning

- Time constrained observations are granted waivers

Metrology OOL avoidance

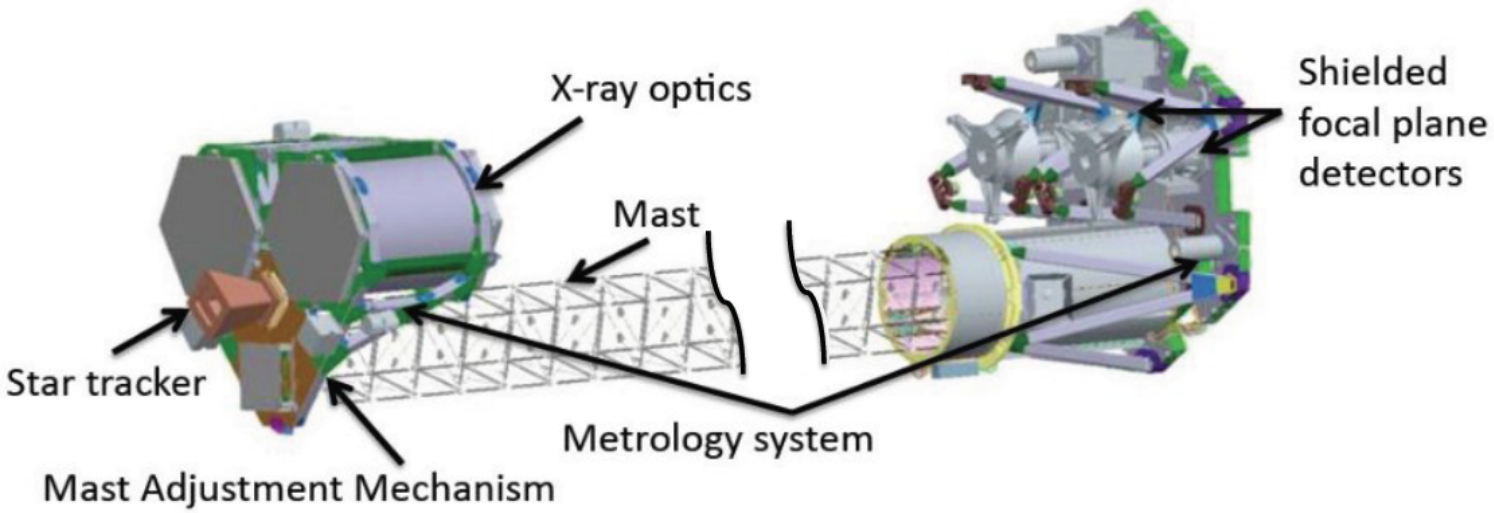
- Loss of calibration
- No waivers





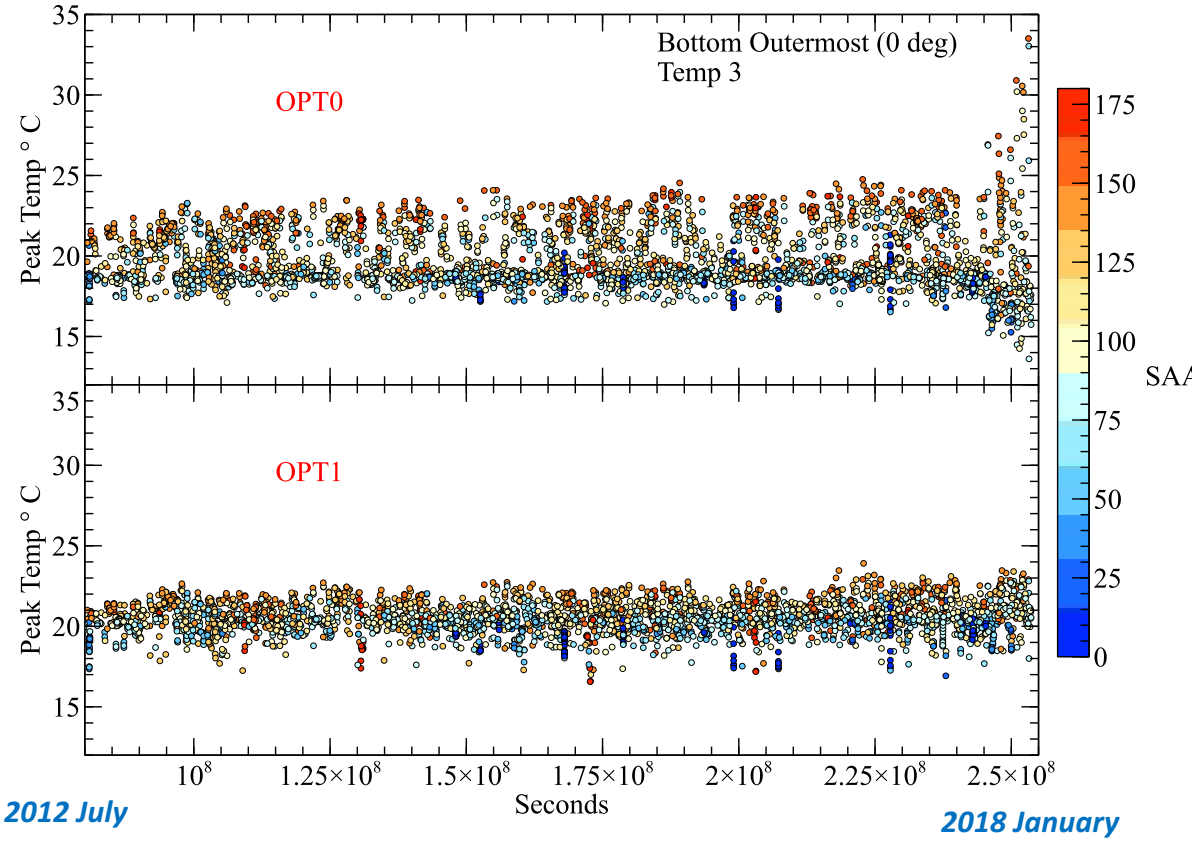
Mast adjustment - 2018

- We plan to perform another adjustment of the optics / mast interface
  - Periodic adjustments using the mast adjustment mechanism were expected
  - MAM adjustment performed twice before, during IOC and in 2013 September
  - Shift by a few mm in two directions
- Should bring Metrology system back into calibrated range for extremes of mast bending



Optics thermal constraints

- Avoid observing at certain ranges of Solar aspect angle (Saa)
  - Translates into scheduling constraints



Optics thermal behavior

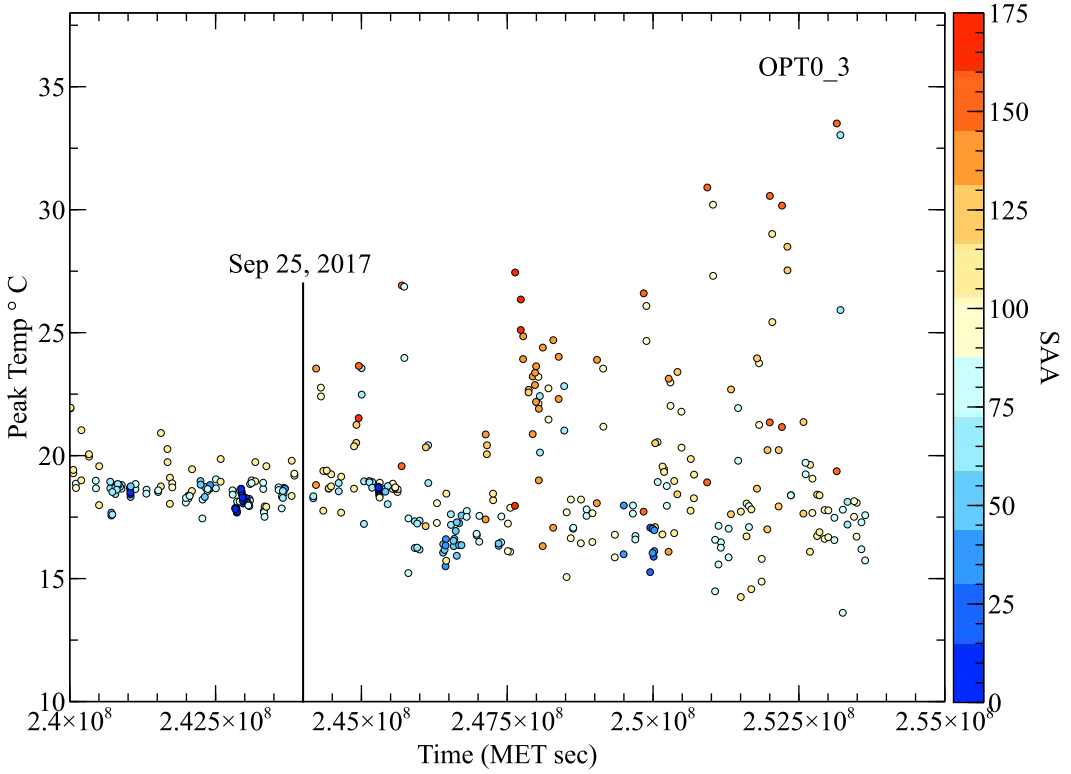
- Change in behavior occurred around 2017-09-25
- Most obvious on outermost sensor on optic 0
- Change not seen in optic 1

Optics thermal constraints

- Avoid observing at certain ranges of Solar aspect angle (Saa)
  - Translates into scheduling constraints

- Apparent degradation has occurred near the thermal sensor on the rear exterior of Optic 0
- Likely a hole or tear in optics cover
- Optics bench qualified to 70 °C
- Current Red limit set at 55 °C
- Avoid observations in range

  145 ° < Saa < 160 °
- Waivers for short observations of time constrained targets may be granted



2017-08-09

2018-01-17

Multi-observatory coordination

- **Steadily improving coordination between high energy missions**
  - Regular group notification of acceptance and timing unanticipated ToO observations
- The **Crab calibration** observations on 2018-03-13/14 Is an excellent example
  - Scheduled as monthly NuSTAR calibration observation
  - Request from XMM-Newton for simultaneous observations -> schedule adjustment
- Including straylight exposures during XMM-Newton exposures
  - To determine if adjustments in EPIC-pn calibration should be made
- Notification to other teams resulted in major cross calibration event
  - *Astrosat, Insight (HXMT), INTEGRAL, Swift-BAT, Fermi*
- Crab exhibited gamma-ray flare episode just before start of observations
  - Simultaneous radio telescope observations (Japan)
- Major transient events are now regularly scheduled with *unanticipated* contemporaneous observations
  - E.g. Swift J1658.2-4242, MAXI J1820+070
- Coordination will be improved by development of VO protocols for observatory operations
  - Led by ops team members at ESA (INTEGRAL + XMM) and CXC

Summary

- Calibration update planned for later this year
  - Absolute normalization, vignetting, detector absorption parameters
  - New clock correction FTOOL - relative timing accuracy improvement
- Yearly IACHEC cross calibration campaign on 3C 273 – July 2018
- Mast adjustment should solve metrology calibration limits for Saa ~ 105°
  - Mast bending will continue to be monitored
  - Saa constraints remain in place
- Optics thermal behavior also monitored
  - Saa avoidance remain in place
- The additional scheduling constraints will have minor impact on science (or calibration) observations
- Recommendation of NASA senior review in 2019 will determine if mission is extended another 3 years
- ***Observatory status is green***