NuSTAR
Bringing the High Energy Universe into Focus

NuSTAR
Calibration Status

Karl Forster and the NuSTAR team
IACHEC-12, Lake Arrowhead, March 27th, 2017
NuSTAR

Bringing the High Energy Universe into Focus

NuSTAR Observatory

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

CdZnTe detectors
4x(32x32 pixels)

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

10.14m focal length
Extendable Mast

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

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

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• Single string
• 10 year lifetime

Hitomi HXI

IACHEC 2017 Lake Arrowhead
Calibration update

• Observatory status is green – no anomalies in 2016/17
• Monitoring of change in detector gain indicates continued trend of ~1% degradation / year

2016 calibration news

• Calibration observations measuring stray light from the Crab in 2015/16 used to update detector absorption parameters
  o Removed residual feature of order few % seen at ~3.5 keV in observations of bright, soft X-ray sources
  o CALDB release June 2016

• Using NuSTAR as a collimator provided a new measurement of the instantaneous absolute Crab flux.
  o Using ground calibrated detector responses only
    ▪ Known to better than 1% above 5 keV

• Absolute Crab flux measured to an accuracy of better than 4%
  o Madsen et al. 2017 (ApJL accepted)
  o Crab stray light monitoring observations planned throughout the year

• More details in Kristin’s presentation this afternoon
  o session II-b in Violet room
Calibration update

2016 calibration news – cont.

• Detailed investigation of the observational artifacts
  • Ghost-rays and stray-light characterized in detail
  • Absorbed stray light measurements by various combinations of aperture stops
    o Ask Kristin “where’s the Sn-man”

Calibration observations for 2017

• IACHEC campaign on 3C 273 in June
• Bullet cluster investigation of background modeling
• Pulsar observations to improve timing accuracy
• Dust scattering halos
  o Investigation of nearby binaries
    • See Kristin’s talk this afternoon

Orbit decay slowed in 2016

• Early Solar minimum
• Mission lifetime ~ 10 more years
Bullet nod & shuffle

Kristin Madsen and Daniel Wik

- Background estimation problematic for sources that fill the field of view
- NUSKYBGD was developed to model the instrumental and aperture background
  - Systematic uncertainties remain in model
- So a new observing style was developed to measure the Bullet galaxy cluster and nearby background emission
  - Aims to confirm NUSKYBGD accurately accounts for the aperture background component
  - Potentially free of systematic uncertainties inherent in the use of NUSKYBGD
- In February 2017 the Bullet cluster and an annulus around the cluster were observed for 44 orbits each
  - 1 orbit on the Bullet cluster followed by 1 orbit exposure 45 arcmin away
- 45 arcmin annulus was chosen to minimize ghost ray reflection from Bullet cluster
  - > 2 degree away then stray light from the Bullet will enter the aperture at some PA
- Observatory Position Angle and Solar aspect angle were within ~1 degree for all exposures
- The annulus was built up over 8 days, 44 positions provided multiple overlapping exposures of the same position on the sky
  - Created a Bullet cluster and background exposure of 160 ks each
Bullet nod & shuffle

Kristin Madsen and Daniel Wik

Reflection Type: Double
- Upper
- Lower
- Back

Fraction to on-axis Geometric Area

- Double Bounce (DB)
- Upper Reflection (GR_{upper})
- Lower Reflection (GR_{lower})
- Back Reflection (BR)

Off-axis Angle (arcmin)

Madsen et al. 2017 in prep
Timing Calibration
Matteo Bachetti, Craig Markwardt, Eric Gotthelf

- Accurate time of arrival of events requires the use of a clock correction file as part of FTOOL barycorr
- Corrections to the spacecraft clock applied during ground station passes
- Drifts are usually +/- 10ms from true (GPS) time
  - Database of clock adjustments provided by the MOC
- Interactive tool is used to fit a piecewise spline interpolation between the spacecraft clock corrections
  - Keeps relative accuracy to within +/- 2ms
  - Monthly updates to clock correction file released as CALDB updates
- Large unphysical variations were discovered in the clock correction file in 2016
  - During analysis of some pulsar observations (user community)
- A new fit to the data was performed, using only data from primary ground station
  - Data from backup ground stations (KSAT Singapore, USN Hawaii) only used for periods of Malindi station downtime
- Updated clockfile released 2016-12-07, significant improvement in the stability of clock correction
• Previously confirmed accuracy of relative timing to be +/- 3ms
  • Using Crab calibration data
• Absolute accuracy of event times found to be 1 +/- 2ms compared to measurements by Swift-XRT
  • Based on simultaneous observations of PSR B1509-58
• However residual drifts are seen in Crab data
  • 400 μs over an orbit
  • Due to residual temperature sensitivity of spacecraft crystal oscillator
    • Impacts analysis of pulsars with periods shorter than ~3ms
• Scale linearly with temperature of clock housing
  • ~0.4ppm over 6 ºC observed temperature range
  • Spacecraft clock uses a temperature compensated crystal oscillator
Timing Calibration
Matteo Bachetti, Craig Markwardt, Eric Gotthelf

Comparison of the TOAs of the Crab pulses and expected arrival times calculated through the Jodrell Bank Monthly Ephemeris

- October 2013 observation
- Clear shift by +/- 400 µs
- Originating in clock frequency variations
- Orbital timescales

**Can we do better than mission requirement of +/- 3 ms?**
• Model the temperature clock frequency variations frequency using the
• Calibrate using PSR B1821-24
  • 3ms pulsar in M28, very sharp pulse profile
  • Bright enough to measure in one orbit
• Follow transition from Sunlight to shadow in each orbit to track the
  variations in the pulse
  • Observations scheduled for 2017 April and September
  • Solar aspect angle +/- 90 degrees
  • Illuminate different sides of the spacecraft
• Model pulse variations with measured temperature of clock housing
  • Telemetry is recorded but not yet delivered to the SOC
• Goal is to provide an additional clock correction for the entire mission
• Preliminary models indicate that this method may improve relative
  timing to as small as a few µs
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The Moon and the CXB

George Lansbury, Brian Grefenstette

- NuSTAR Legacy Survey to measure the normalization of the Cosmic X-ray Background
- Using the Moon as a “shutter”
- Track the Moon while it oscillates (parallax) over 4° of sky
  - Building up a 200 ks exposure
- Observation planed for 2017 April

Simulated NuSTAR spectrum
- 100 ks exposure
- fCXB = focused CXB
- NXB = non X-ray background
  - Aperture background
  - Reflected Solar X-rays
  - Instrument Compton-scattered continuum
  - Instrument emission lines