NICER

Neutron star Interior Composition ExploreR

Mission Status

July 20, 2017

GSFC

MIT KAVLI INSTITUTE

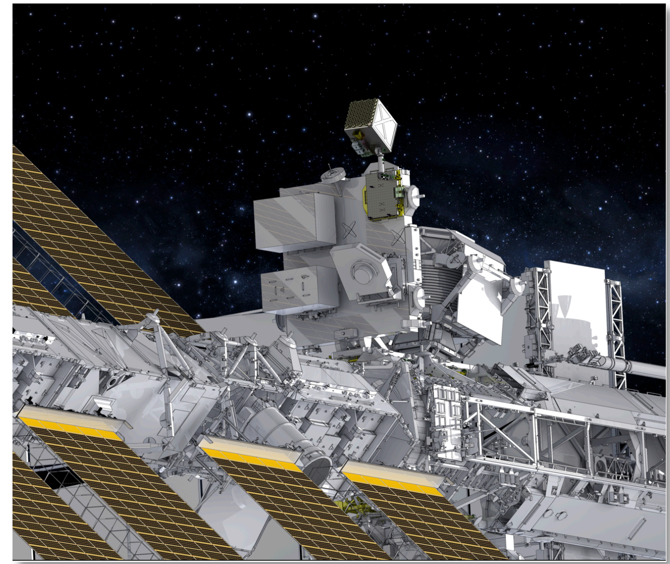
DTU

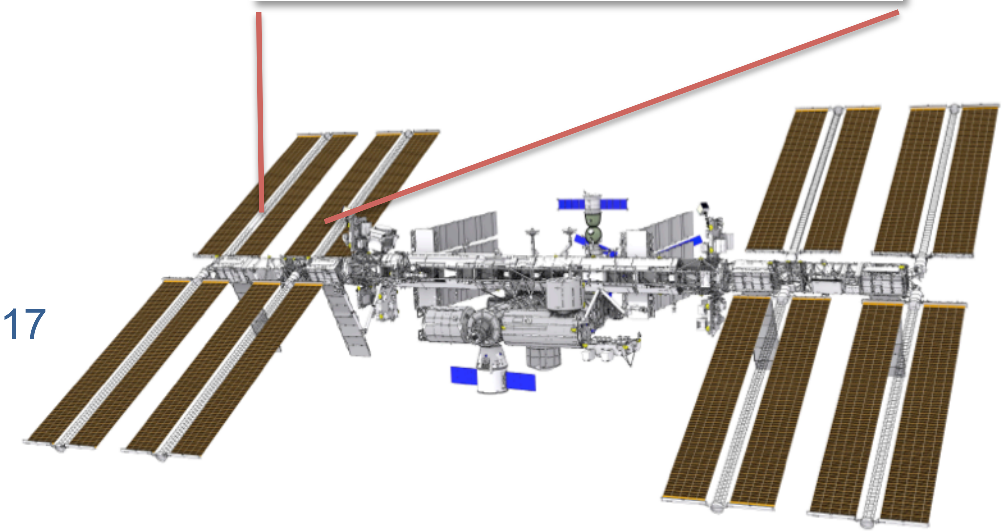
BROAD REACH

MOOG

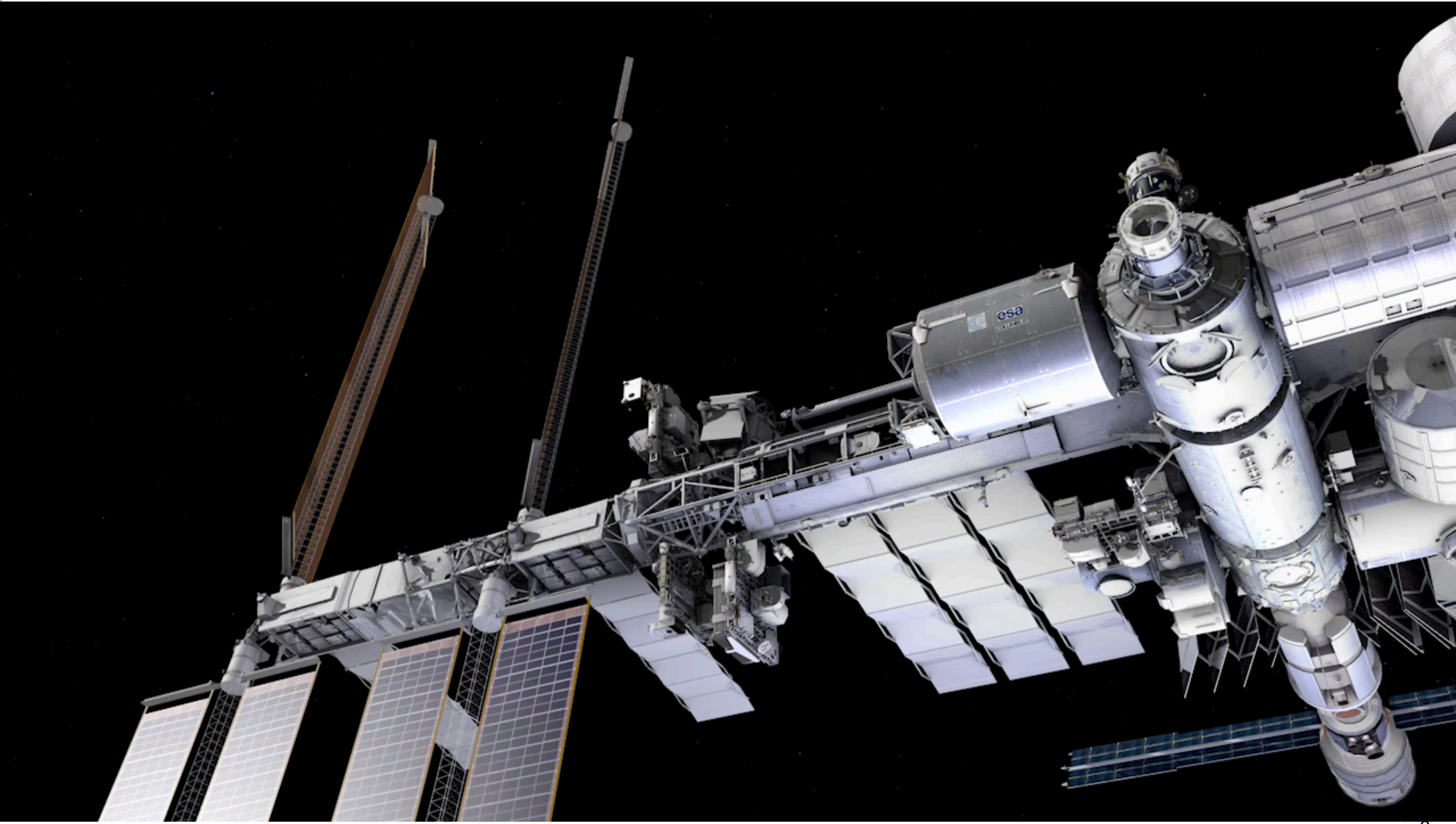
An Astrophysics Mission of Opportunity on the International Space Station

- ***Science:*** Understanding ultra-dense matter through observations of neutron stars in the soft X-ray band
- ***Launch:*** Completed on June 3, 2017, SpaceX-11
- ***Platform:*** ISS ExPRESS Logistics Carrier (ELC), with active pointing over nearly a full hemisphere
- ***Duration:*** 24 months including Guest Observer program
- ***Instrument:*** X-ray (0.2–12 keV) “concentrator” optics and silicon-drift detectors. GPS position & absolute time reference
- ***Enhancements:***
  - Guest Observer program
  - Demonstration of pulsar-based spacecraft navigation
- ***Status:***
  - NICER installed on ISS on June 13, 2017
  - Commissioning completed
  - Payload performing very well



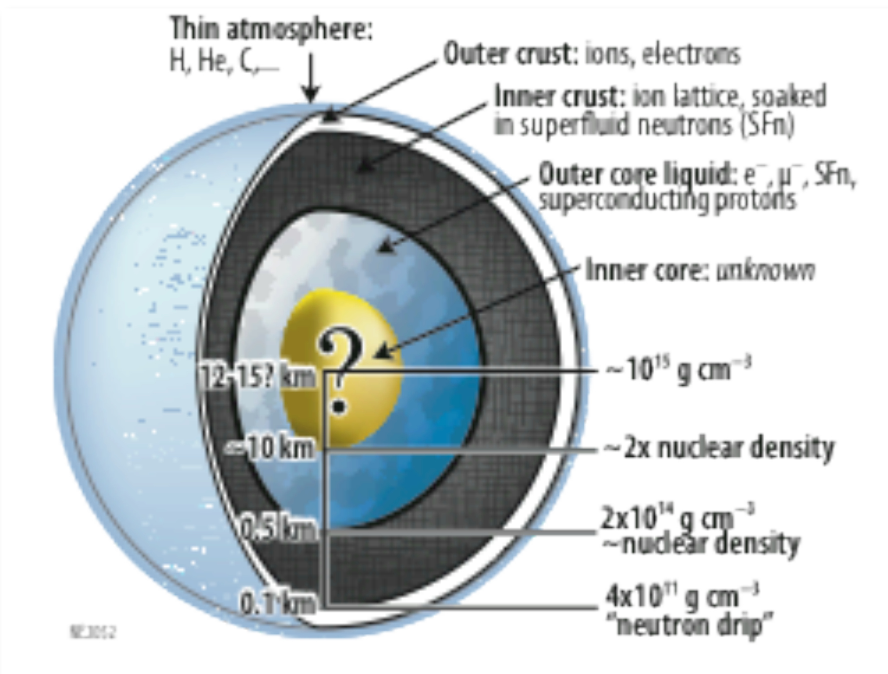


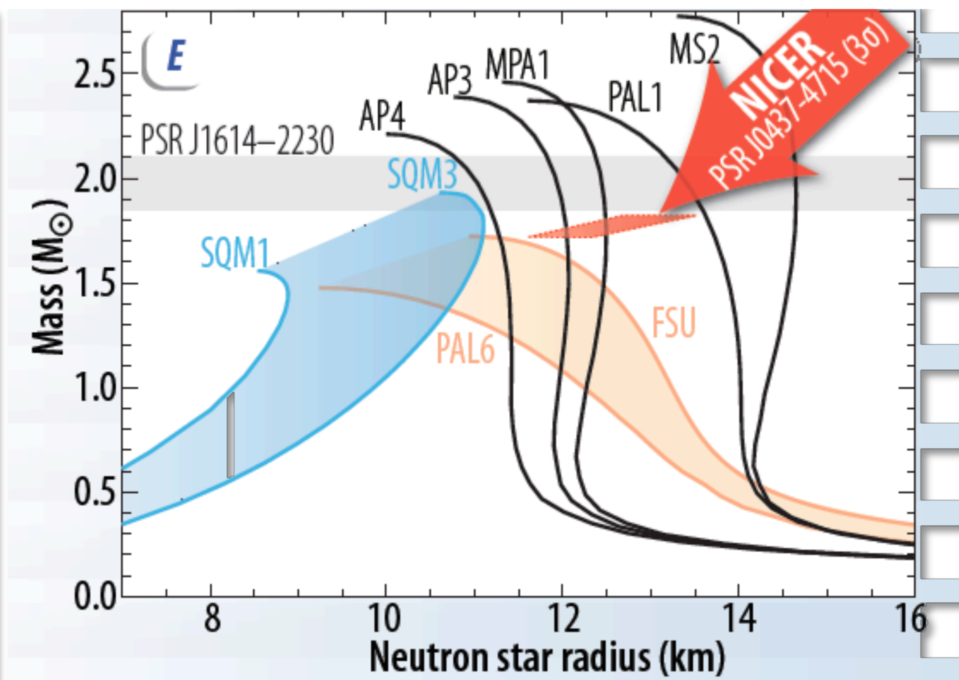
NICER on the ISS



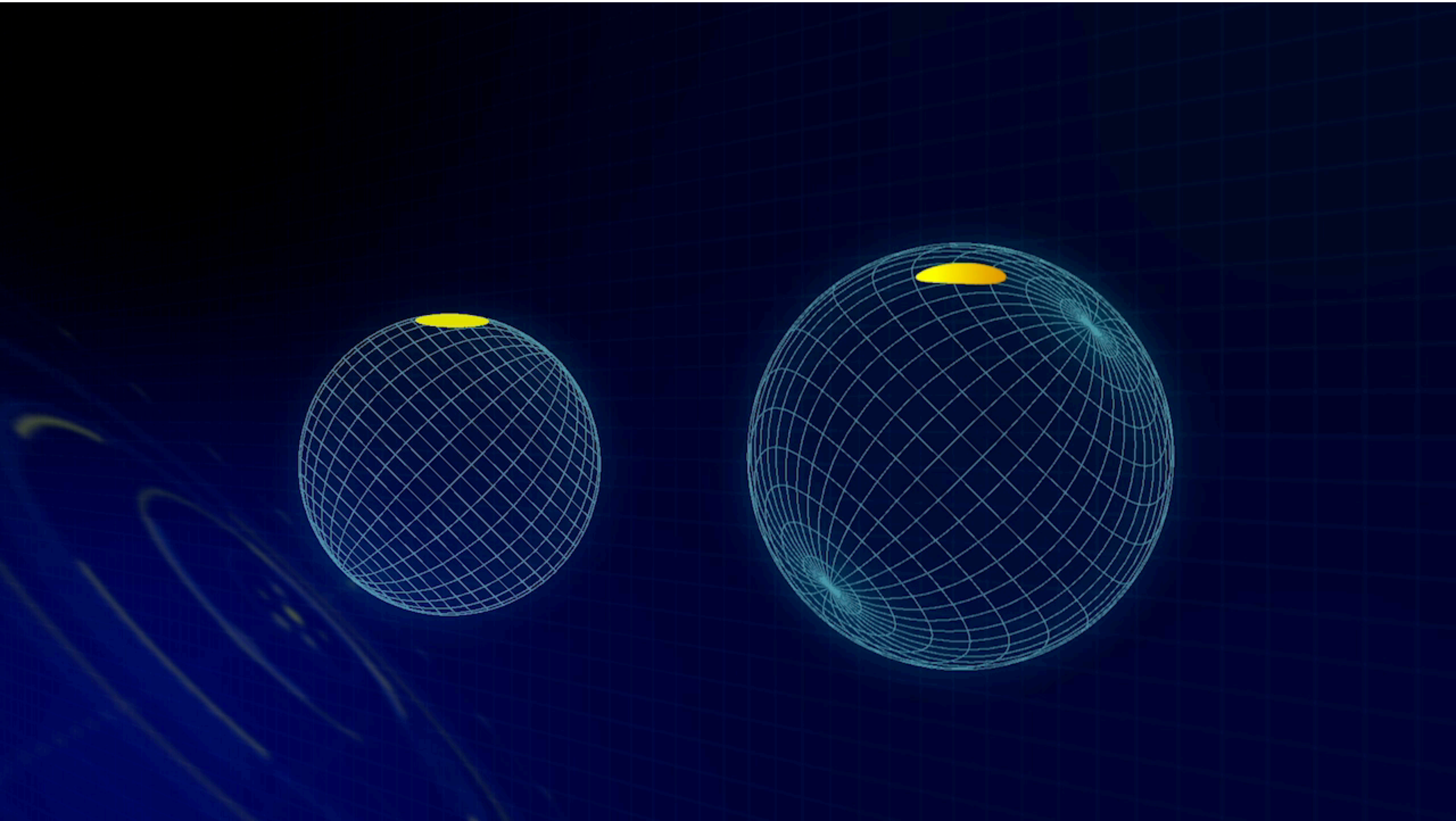
Mission Success Criterion

NICER shall use rotation phase-resolved spectroscopy in X-rays to discriminate among strange-quark, soft nucleonic, and stiff nucleonic equation-of-state models of neutron star structure in at least 2 neutron stars.



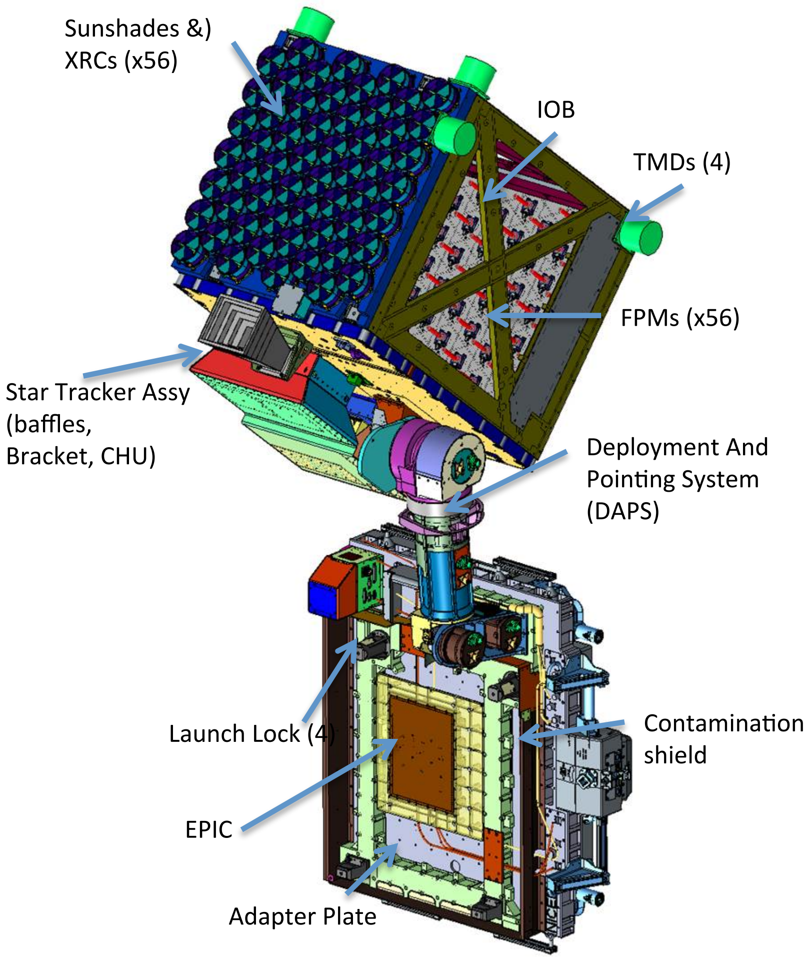


Strong Gravity and Light Curves



The NICER Payload

An innovative combination of high-heritage components



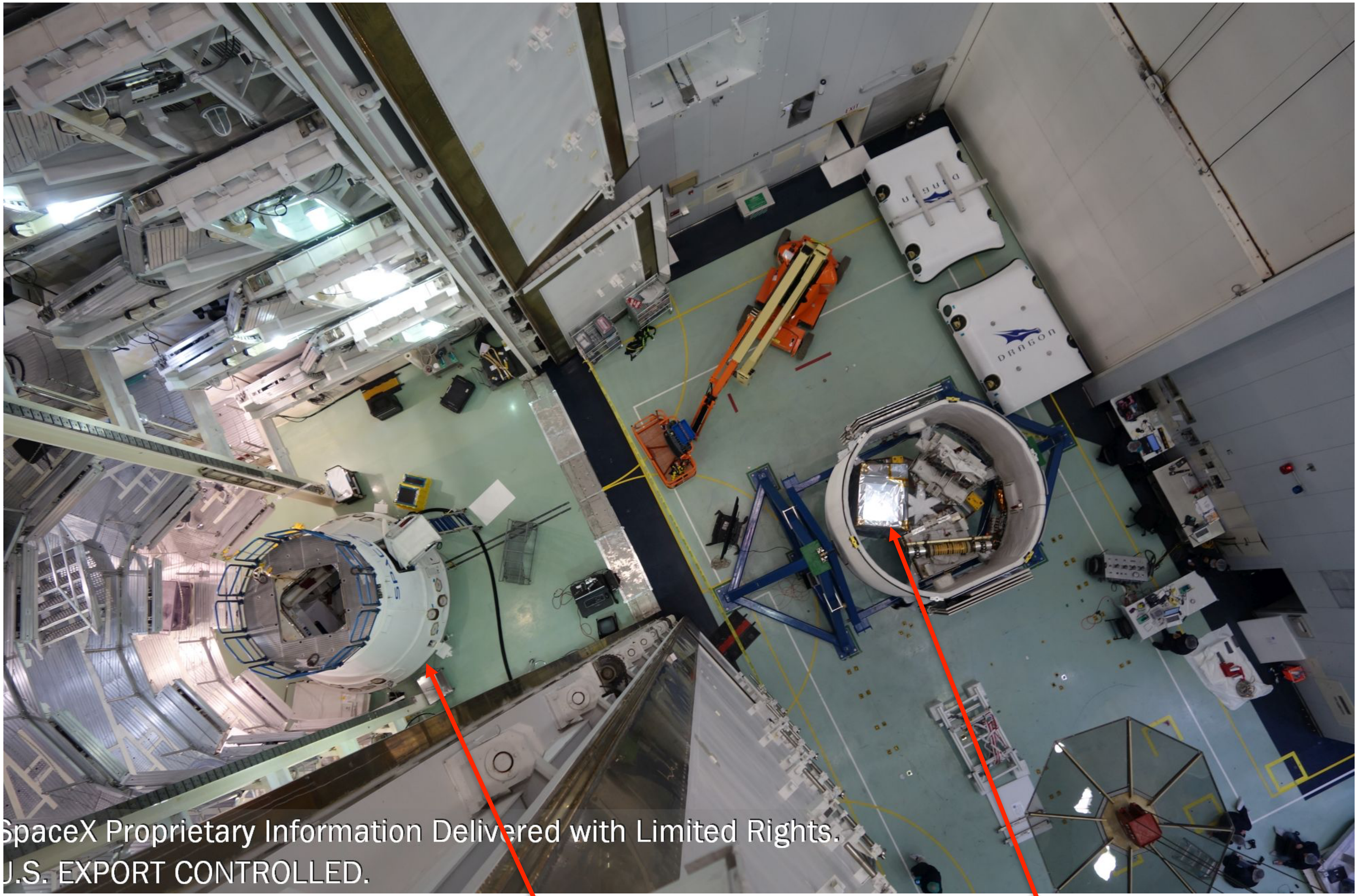
- **X-ray Timing Instrument (XTI)**
  - Assembly of 56 X-ray concentrators and detectors
  - Detects individual X-ray photons, returns energy and time of arrival
  - Held together in the Instrument Optical Bench
- **Thermal system**
  - Maintains thermal-mechanical alignment
- **Pointing System**
  - Composed of high-heritage components
  - Allows the XTI to track pulsars
  - Slews XTI between targets
- **C&DH**
  - Digital interface to ISS for commands, data
  - Supports pointing system
- **Flight Releasable Attachment Mechanism**
  - Electrical & mechanical interface to ISS and transfer vehicle
  - Provided by ISS program

NICER in SSPF
Prior to Dragon Trunk Integration

NICER in Dragon Trunk

NICER installed in the Dragon trunk along with companion payloads MUSES and ROSA

NICER in Dragon Trunk



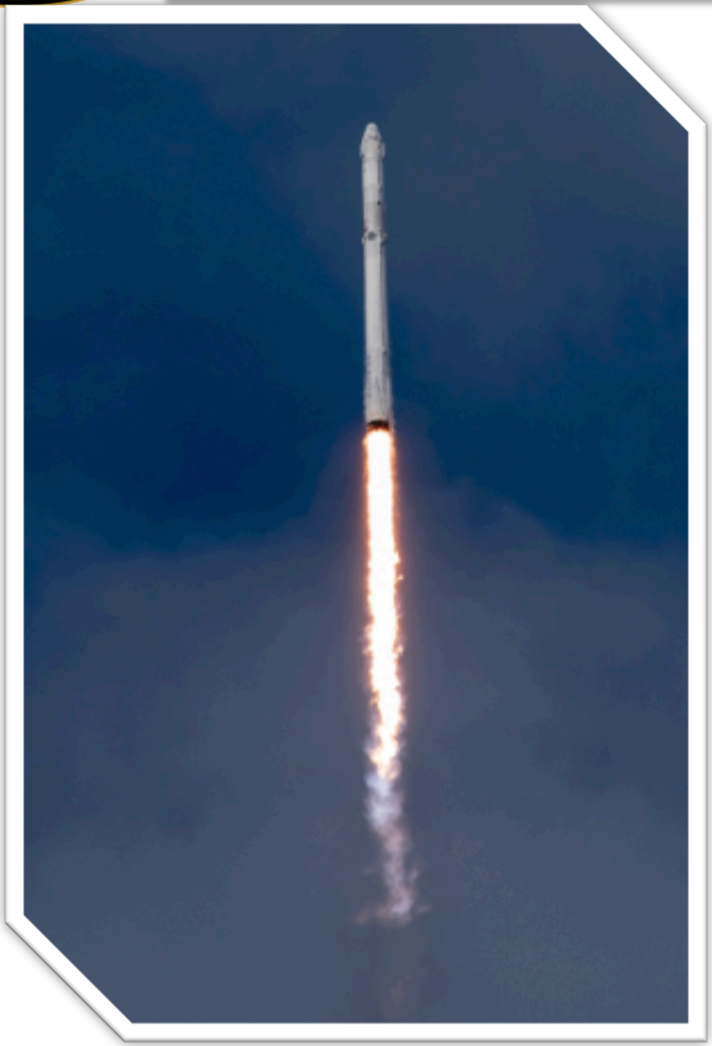
Birdseye view of Dragon and Dragon Trunk (with NICER)

Launch and Extraction – 1 of 4

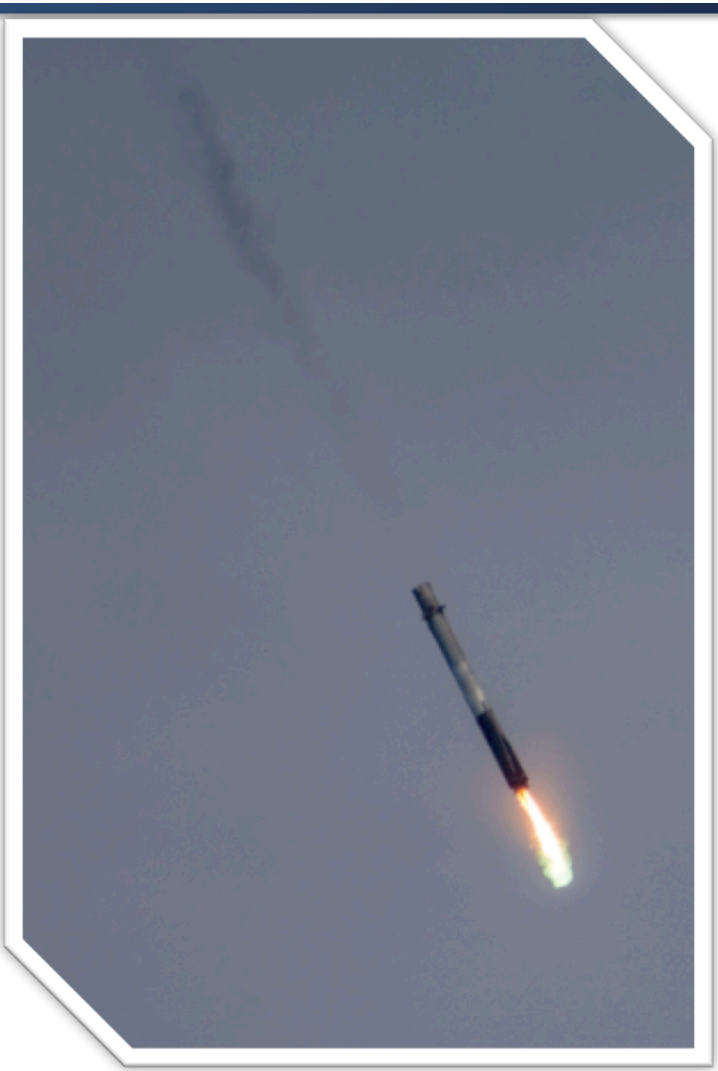
SpaceX-11 Launch

Launch and Extraction – 2 of 4

June 3, 2017



Ascent



Stage-1 Re-entry Burn

Launch and Extraction – 3 of 4

Time Lapse

June 3, 2017

NICER in Space

Launch and Extraction – 4 of 4

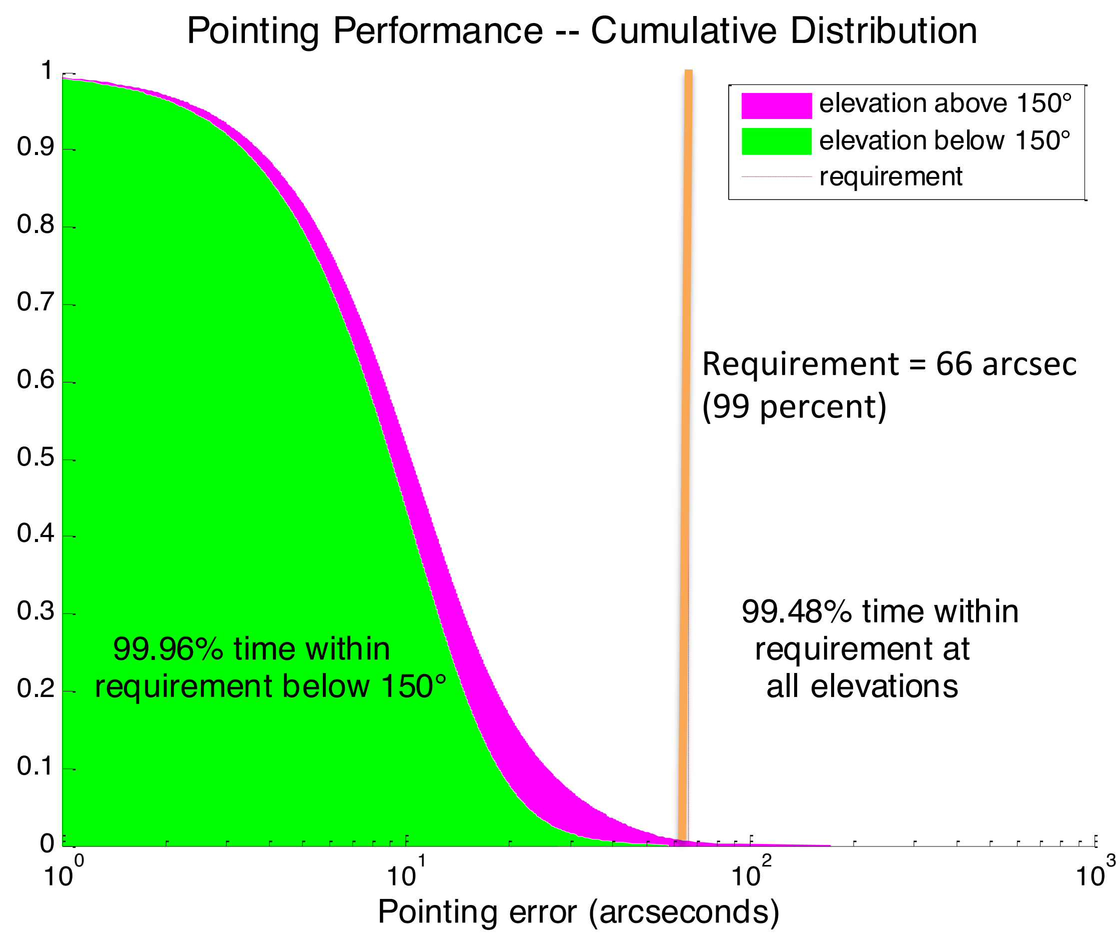
Installation and Deployment Video

Mission Status

- Completed Robotic installation on ELC2
- Resolved Launch Lock issue
- Completed NICER commissioning
  - Verified subsystem functionality
  - Completed range of motion testing
  - Aligned star tracker to XTI boresight
  - Refined operational constraints to address ISS glint
  - Automated pipeline processing being optimized
  - Completed observations and analysis of several well-known, celestial objects, demonstrating that measured flux and frequency is in agreement with measurements of other observatories
    - So far, over 70 targets have been observed
  - Completed initial calibration (calibration is ongoing activity throughout mission)
  - Transitioning from Commissioning to Science Operations Mode

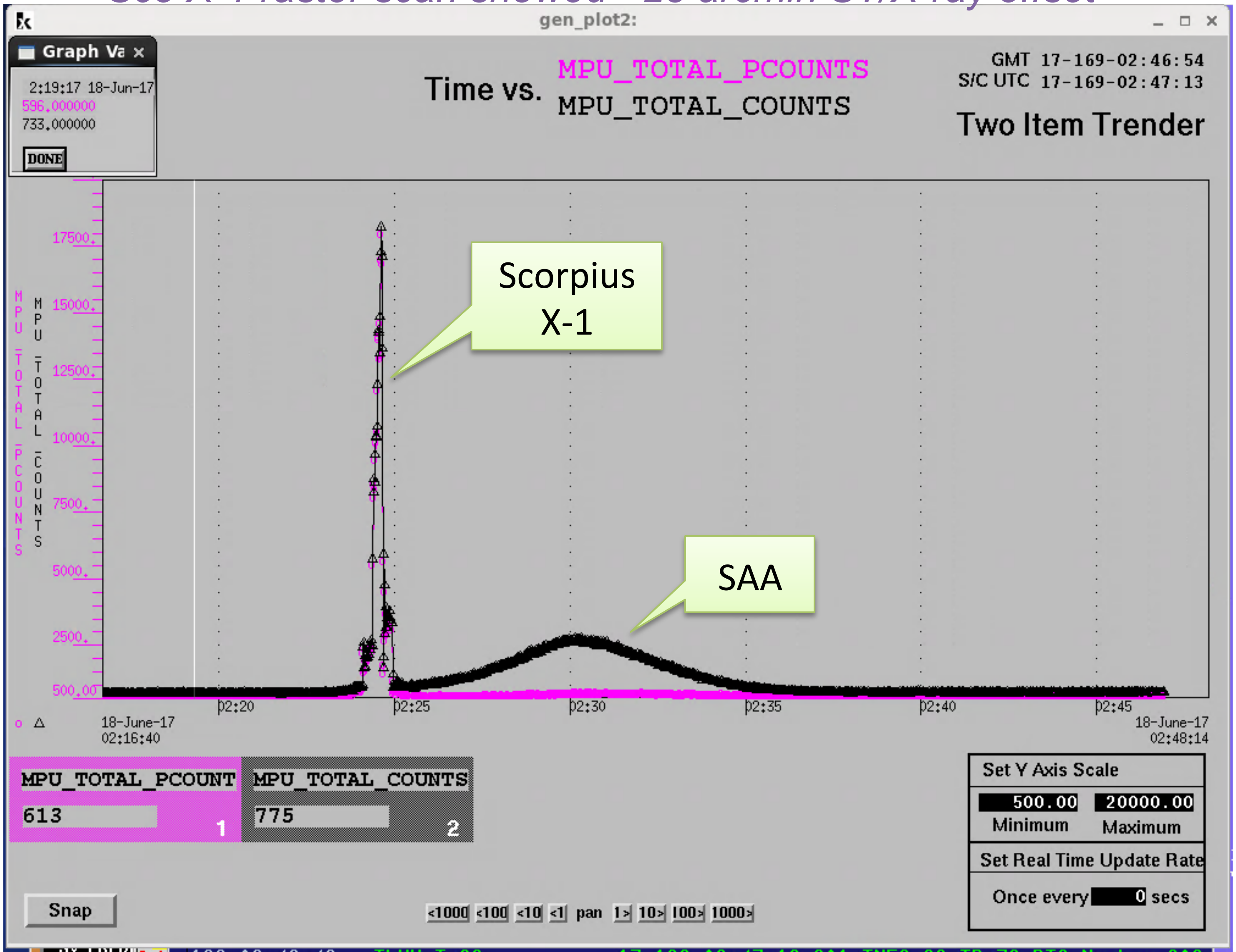
Science Target Tracking Statistics

- Pointing performance requirement = 66 arcsec (99 percent)
- Pre-launch prediction shows requirement can be met for EL angle lower than ~145 deg.
- Flight data shows requirement is met almost all the time for EL angle lower than 150 deg.
- Pointing System meets requirements under all conditions
- No operational constraint is required for operating at high EL angles.



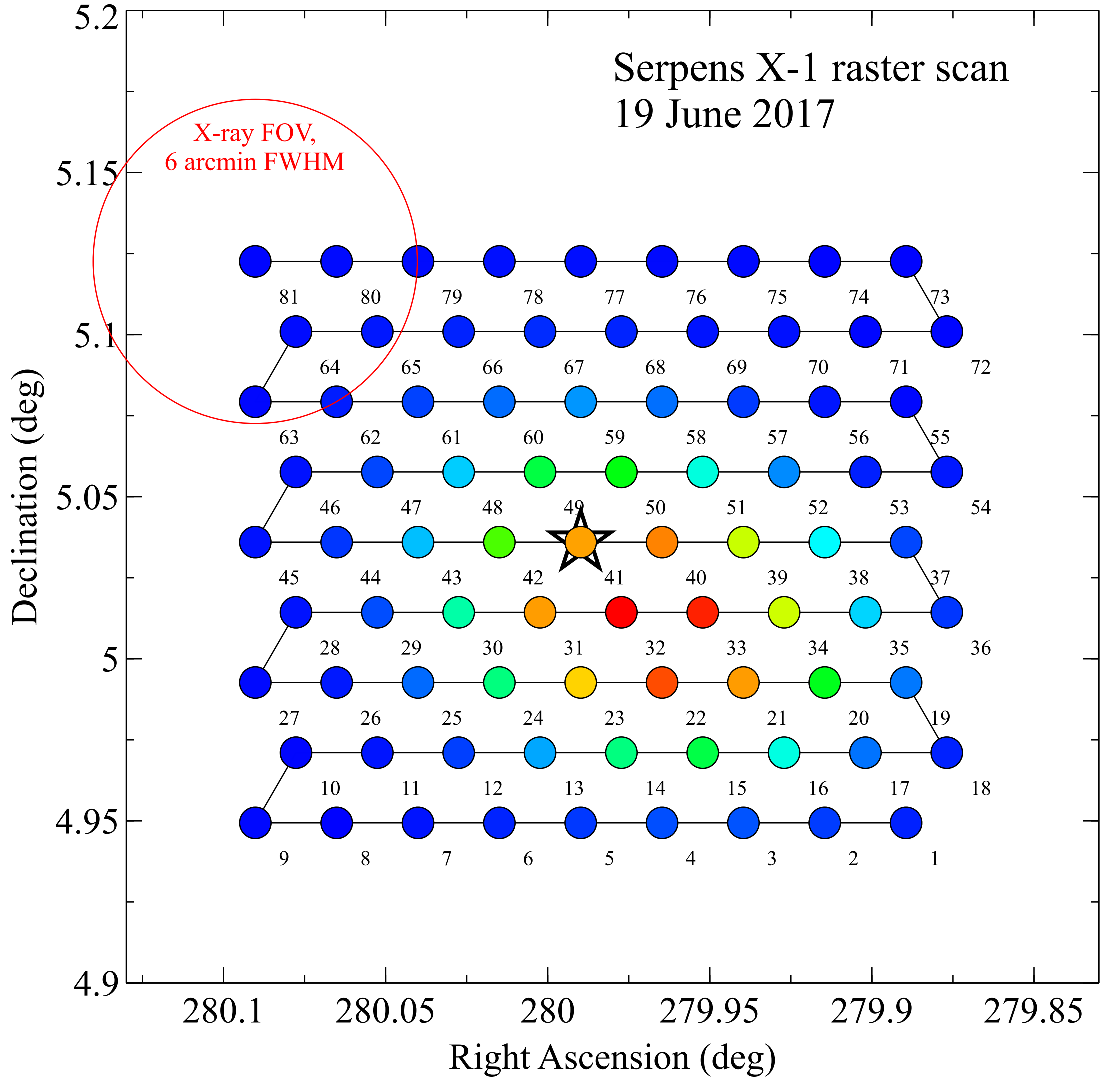
Alignment — First Target Detection

Sco X-1 raster scan showed ~23 arcmin ST/X-ray offset



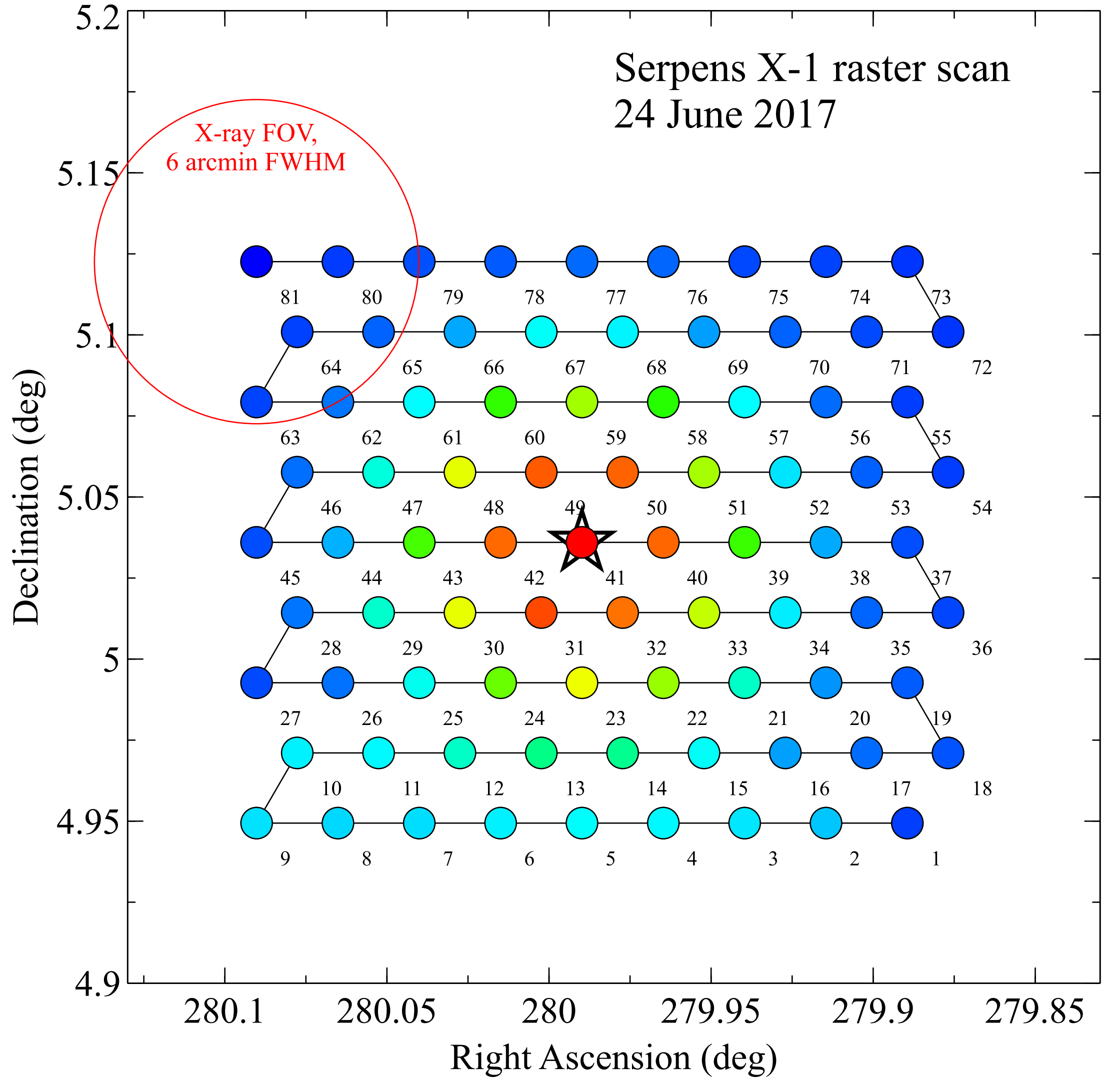
Alignment — First Correction

Initial correction good to ~3 arcmin…



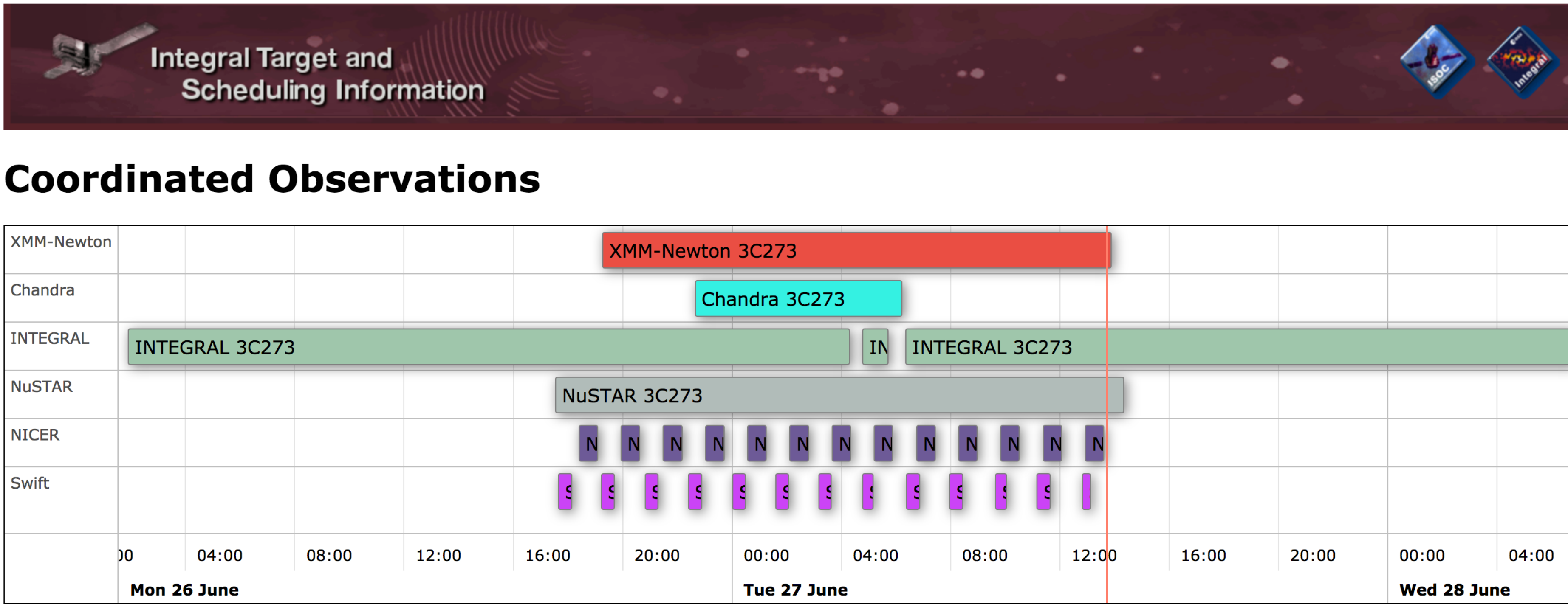
Alignment — Refined

Current correction good to 11 arcsec, meets 12 arcsec allocation



Effective Area

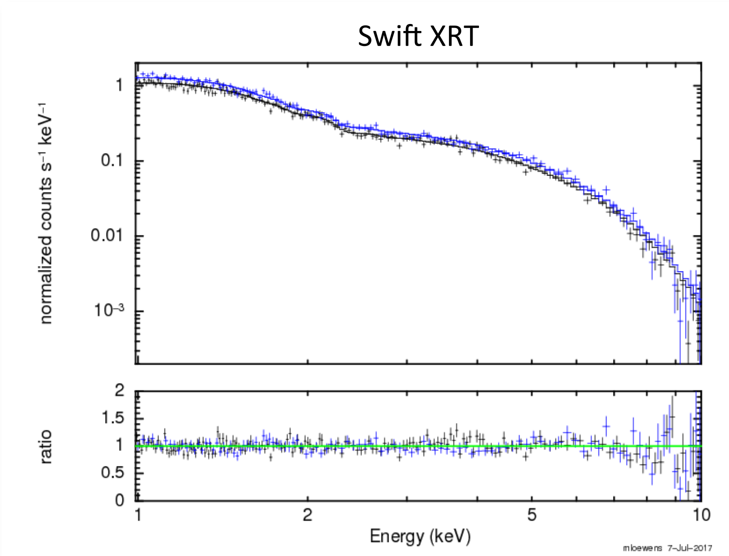
NICER participation in 3C 273 coordinated campaign

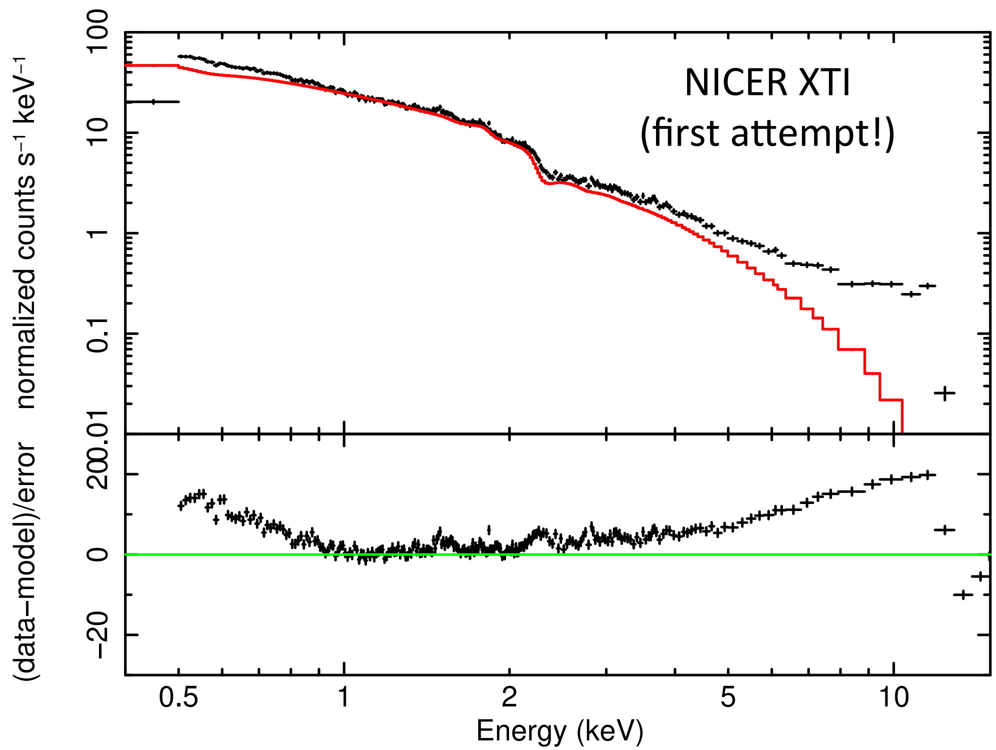


- Engagement in IACHEC led to early coordination with 5 other observatories
- Public *Swift* data already analyzed by NICER Team

Effective Area (cont.)

Still work to do, but basic agreement with predicted A_{eff}

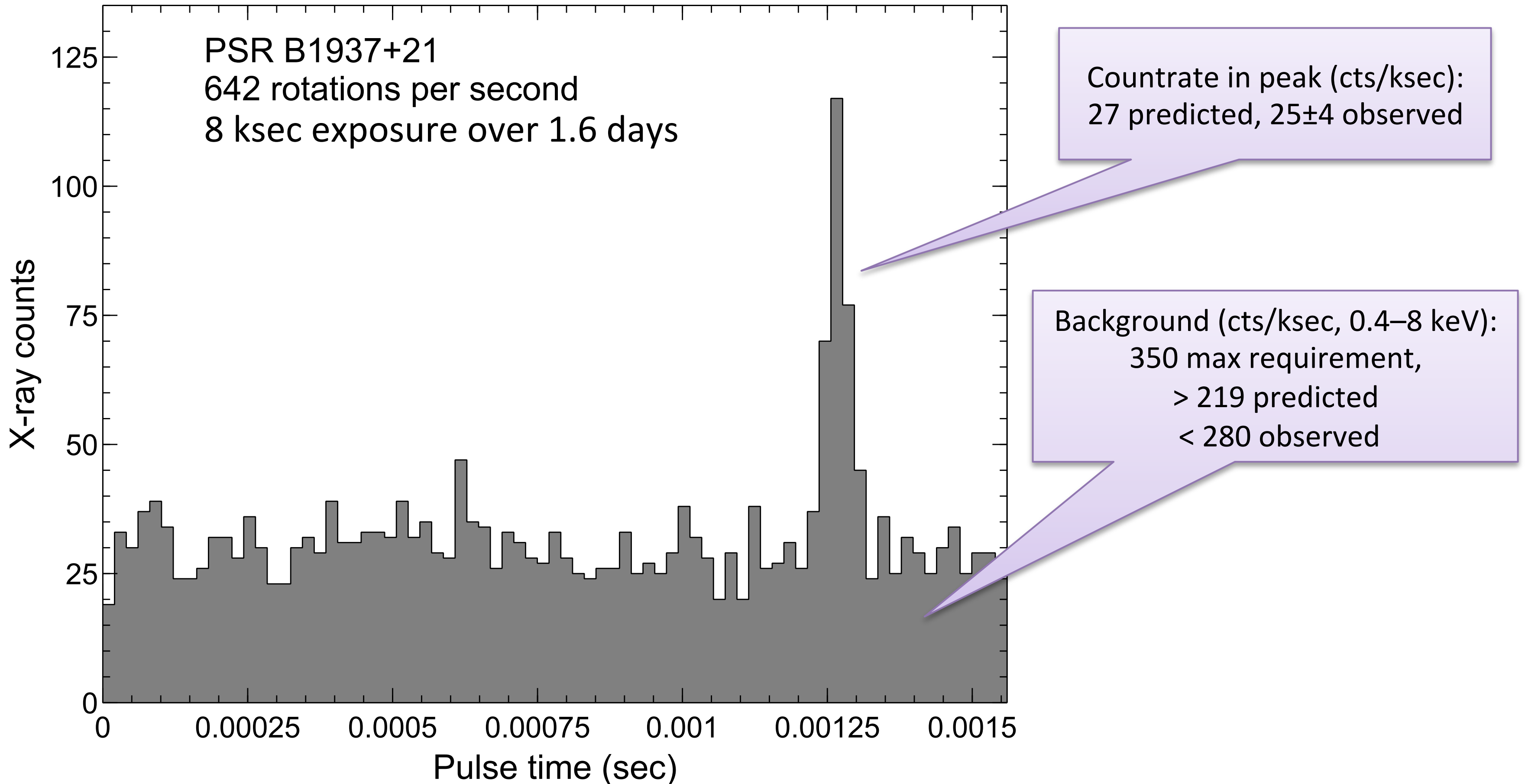




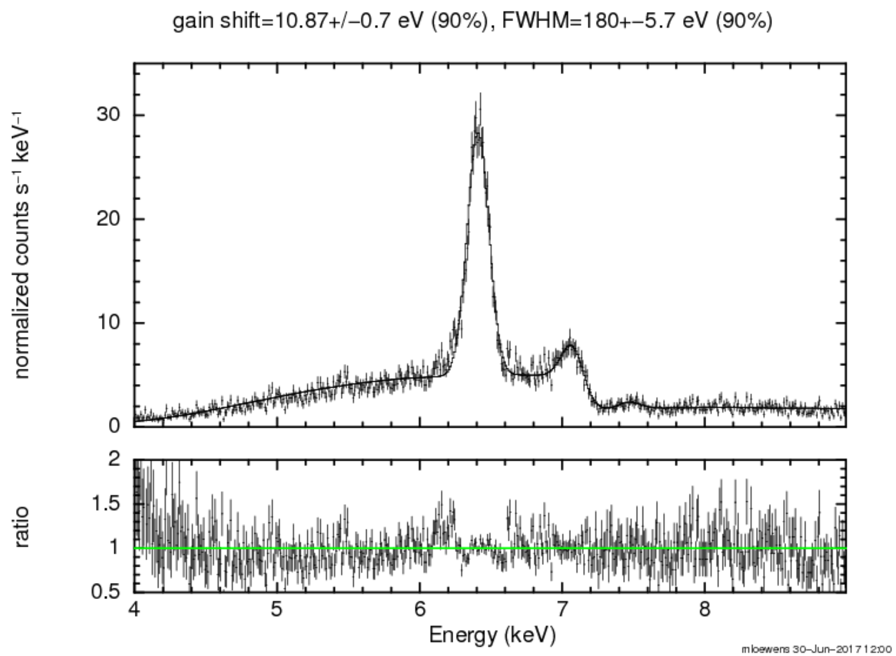
- Fit to *Swift* spectrum (left) with IACHEC-approved model transferred (red, at right) to NICER yields agreement to within 14% in the 1–2 keV band
- Much calibration work remains, but this is a fundamental verification of the pre-launch effective-area prediction.

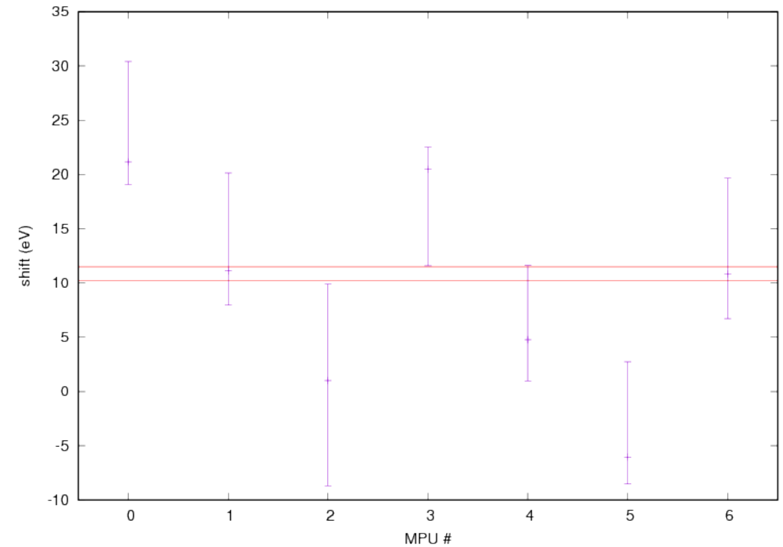
Timing with Millisecond Pulsars

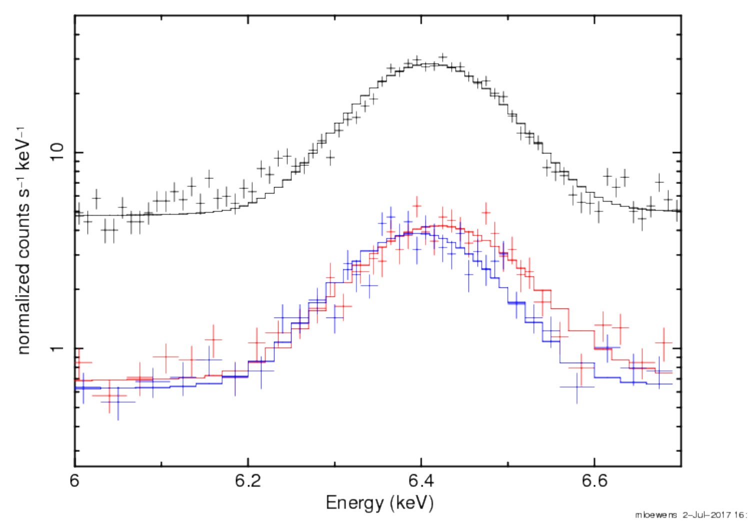
- Folded lightcurve of PSR B1937+21, one of the fastest MSPs known (1.56 ms period; 29 μs FWHM peak)



Energy Resolution & Gain Scale



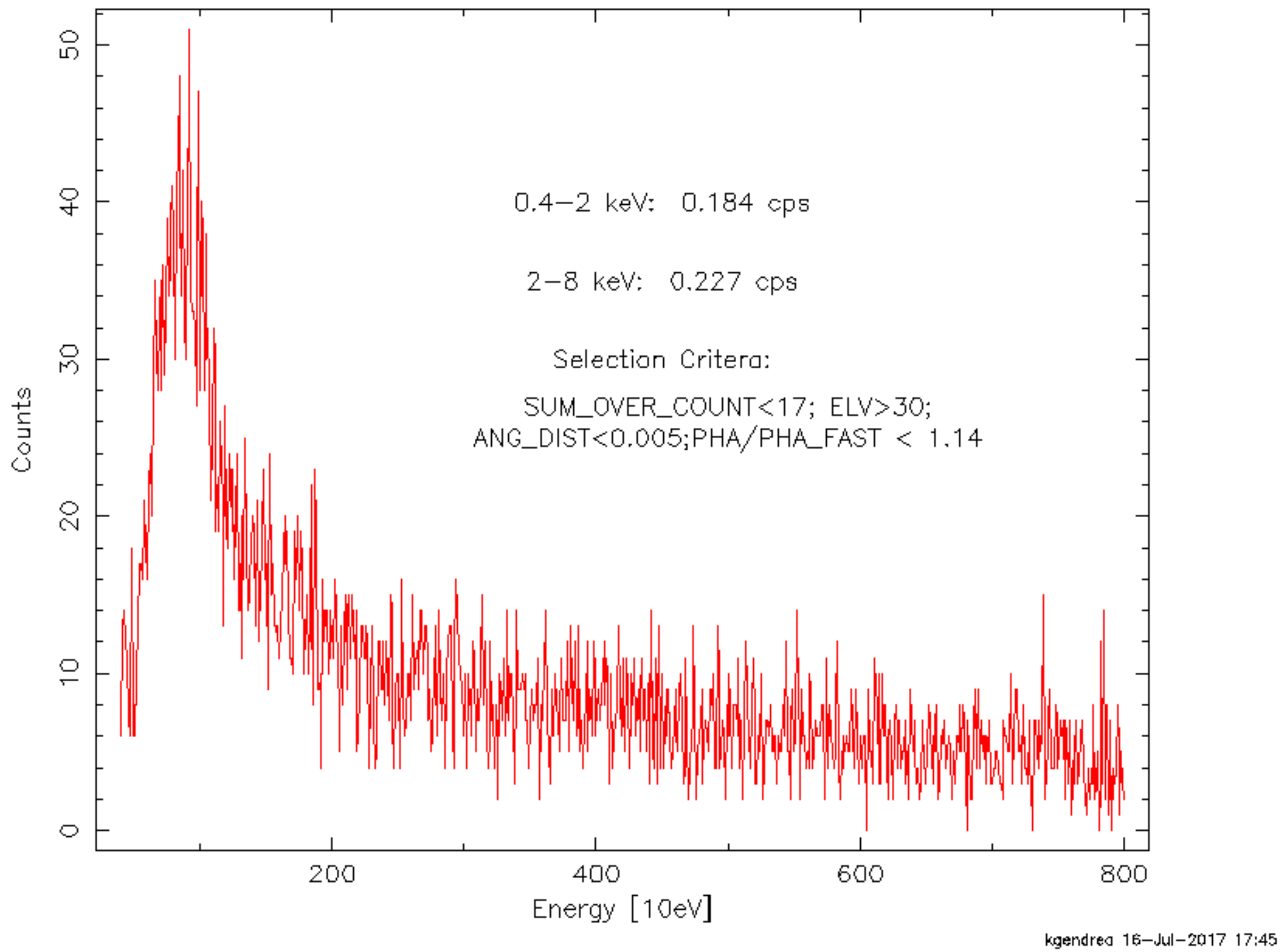




- Total XTI spectrum (above) meets requirement at iron line with *ground calibration* applied
- Observations of iron-line calibrator GX 301–2 provide gain shift knowledge, improving XTI-level energy resolution
- Sun illumination changes zero-point of energy scale; we track this in telemetry so straightforward to calibrate around it.

Background Spectrum- Initial Results

18,517 sec of night background



Observing Efficiency

- Generation of target sequences with AGS continues to produce ~80% efficiencies, as seen pre-launch, accounting for all visibility constraints
  – Rise & set time predictions occasionally show offsets of tens of sec; AGS validation in work, will improve overall efficiency further
- Essentially no interruptions from ISS operations so far
  – Continued to operate through two small attitude changes
  – AGS takes into account before & after configurations, while we saw expected differences between predicts and actual pointing *during* the maneuvers
- No significant telemetry issues
- Pointing & GPS-related losses minimal, as expected
- No experience yet at high beta angles.

Observing Efficiency

Source of inefficiency	Allocation			Pre-launch predict			Status @ PLAR
	Effic.	Good time (Msec)	Cumul. effic.	Effic.	Good time (Msec)	Cumul. effic.	
18-month mission lifetime	-	47.3	100%	-	47.3	100%	Given
High-radiation orbit phases	55%	26.0	55.0%	81%	38.3	81.0%	65% (est.)+
Visibility (including slewing)	78%	20.3	42.9%	80%	30.7	64.8%	83.3% — incl. telem, GPS, & pointing*
ISS operations	90%	18.3	38.6%	90.9%	27.9	58.9%	No interruptions so far
Telemetry losses	96%	17.5	37.1%	99%	27.6	58.3%	Included in vis. above
High beta periods	93.8%	16.5	34.8%	93.8%	25.9	54.7%	Fixed by ISS orbit
No GPS solution	98%	16.1	34.1%	99%	25.6	54.2%	Included in vis. above
Pointing out of spec	98%	15.8	33.4%	98%	25.1	53.1%	Included in vis. above
Anti-*Soyuz* avoidance	99%	15.6	33.1%	99.3%	25.0	52.7%	Included in rad. above

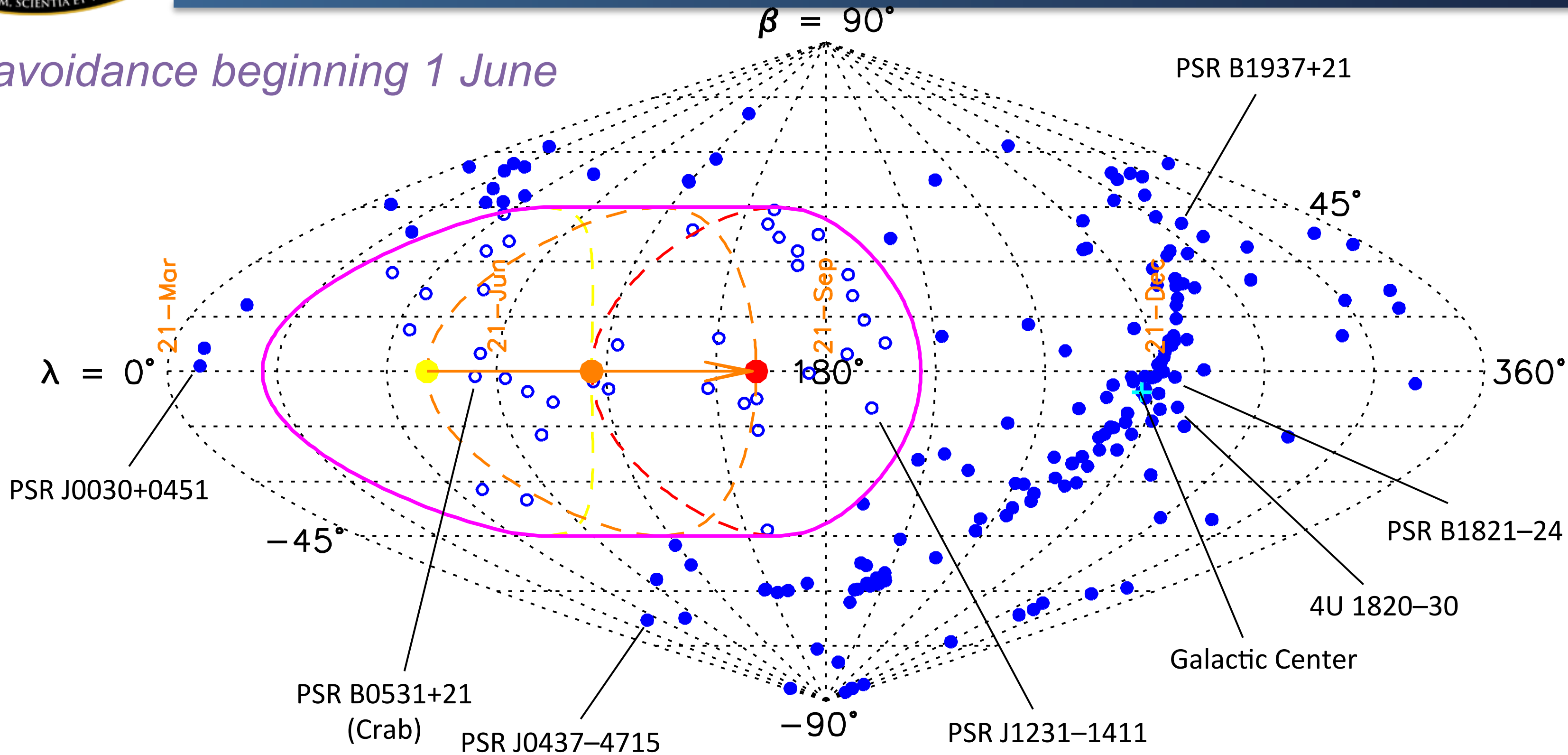
+ Based on overshoot analysis (slide 14), can still accomplish bright-source science in moderate radiation/background regions—e.g., 17 < SUM_OVER < 23 or higher. To be refined…

* Combined effects of visibility/slews/scheduling, telemetry losses, GPS unavailability, and pointing performance assessed over the last 19 days: 1.35 Msec of good on-target data collection (actual total GTI) over 1.62 Msec elapsed time is 83.3%, compared to 71.9% allocated.

Still expect to achieve ~50% overall efficiency.

First 3 Months Target Plan

Sun avoidance beginning 1 June



June

- PSR J0437–4715, J0030+0451, J1231–1411 (80–100 ks; lightcurves)
- PSR J1614–2230, (100 ks), J0952–0608, J0614–3329, J2241–5236 (20 ks; searching)
- PSR B1937+21, B1821–24 (100 ks; timing), Vela (20 ks; magnetars)
- 4U 1728–34 (75 ks; bursts)

July

- PSR J0437–4715, J0030+0451, J1231–1411 (80–100 ks; lightcurves)
- IGR J17062–6143, SAX J1808.4–3658, Galactic Center (50 ks; searching)
- PSR B1937+21, B1821–24, J0952–0608 (100 ks; timing)
- 4U 1820–30, 4U 1728–34, 4U 1636– 536, 4U 1608–522 (100 ks; bursts)

August

- PSR J0437–4715, J0030+0451 (100 ks; lightcurves), Crab (magnetars)
- Cyg X-2, M15 (50 ks), CCO Hes1731 (200 ks; searching)
- PSR B1937+21, B1821–24, J0218+4232 (100 ks; timing)
- 4U 1820–30, 4U 1728–34, 4U 1636–536, 4U 1608–522 (100 ks; bursts)

Early Targets — Calibration + Science Team shared-risk priorities through Aug'17

Working Group	Exposure (ksec)	
Lightcurves		
PSR_J0437-4715	100	
PSR_J0030+0451	50	
PSR_J1614-2230	100	
		250 ksec
Bursts		
4U_1636-536	50	
4U_1702-429	25	
4U_1728-34	25	
Serpens_X-1	30	
Aquila_X-1	20	
		190 ksec
Precision Timing		
PSR_J0218+4232	50	
PSR_B1821-24	30	
PSR_B1937+21	150	
		230 ksec
Searching		
3FGL_J0212.1+5320	50	
PSR_J0614-3329	100	
PSR_J1012+5307	80	
PSR_J1231-1411	80	
1RXS_J154439.4–112820	60	
PSR_J1614-2230	0 (see Lightcurves)	
Sco_X-1	20	
PSR_J1744-1134	40	
Cyg_X-2	40	
		470 ksec

… continued

M&M		
SGR_0501+4516	10	
PSR_J0537-6910	20	
PSR_B0833-45	20	
PSR_J1119-6127	10	
1E_1207.4-5209	25	
CXO_J164710.2-455216	30	
XTE_J1810-197	10	
		125 ksec
Observatory Science		
RX_J0019.8+2156	20	
M82_X-1	40	
4U_1323-62	20	
MCG-6-30-15	45	
Sco_X-1	0 (see Searching)	
GRS_1915+105	6	
Cyg_X-1	6	
		137 ksec
Calibration		
PSR B0531+21	10	
3C_273	30	
Coma	20	
PSR_B1509-58	10	
SS_433	10	
GX_340+0	10	
GX_1+4	10	
4U_1820-30	10	
1E_0102.2-7219	60	
3C_273	30	
Vega	10	
PKS_2155-304	30	
Cas_A	10	
		250 ksec

Science Team/WG Membership

Calibration	Lightcurve modeling	Searches & Multi-Wavelength Coordination	High-Precision Timing	Magnetars & Mag'spheres	Bursts & Accretion Phenomena	Target Prioritization & Scheduling	Observatory Science
nicer-instrument	nicer-wg-lightcurves	nicer-wg-searching	nicer-wg-timing	nicer-wg-magnetars	nicer-wg-bursts	nicer-scheduling	nicer-observatory-science
Gendreau	*Gendreau*	*Gendreau*	*Gendreau*	*Gendreau*	*Gendreau*	*Gendreau*	*Gendreau*
Arzoumanian	*Arzoumanian*	*Arzoumanian*	*Arzoumanian*	*Arzoumanian*	*Arzoumanian*	***Arzoumanian***	*Arzoumanian*
Doty	Baubock	Bogdanov	Deneva	**Enoto**	Bult	Enoto	Bulbul
Enoto	**Bogdanov**	Bult	Enoto	Guver	Cackett	Markwardt	Bult
Keek	Chakrabarty	Chakrabarty	Facey	Harding	Chakrabarty	Ray	Cackett
Markwardt	Guillot	Deneva	Kerr	Ho	Chenevez	Remillard	Chakrabarty
Okajima	Harding	Enoto	**Lommen**	Kaspi	Fabian	Strohmayer	Corcoran
Prigozhin	Ho	Guillot	Majid	Link	Guillot	Wilson-Hodge	Drake
Remillard	Kaspi	Harding	Ransom	Majid	Guver	Wood	Eikenberry
Steiner	Keek	Ho	Ray	Venter	Homan	Yu	Enoto
Strohmayer	Kerr	Kaspi	Wood	Wood	Keek	Mitchell	Fabian
Wilson-Hodge	Lamb	Kerr			Lamb	Semper	Hamaguchi
Wood	Lattimer	Lamb			Lattimer	Winternitz	Homan
Black	Mahmoodifar	Lommen			Mahmoodifar		Jenke
LaMarr	Miller (Cole)	Mahmoodifar			Markwardt		Kara
Foster	Morsink	Miller (Cole)			Miller (Jon)		Loewenstein
Krizmanic	Ozel	Ozel			**Ozel**		Markwardt
Sturner	Psaltis	Psaltis			Psaltis		Miller (Jon)
	Ray	Ransom			Strohmayer		Neilsen
	Riley	**Ray**			Wilson-Hodge		Pasham
	Strohmayer	Strohmayer			Wolff		Ray
	Venter	Wilson-Hodge					**Remillard**
	Watts	Wolff					Steiner
	Wolff	Wood					Strohmayer
	Wood						Tombesi
							Uttley
							Wilson-Hodge
							Wood

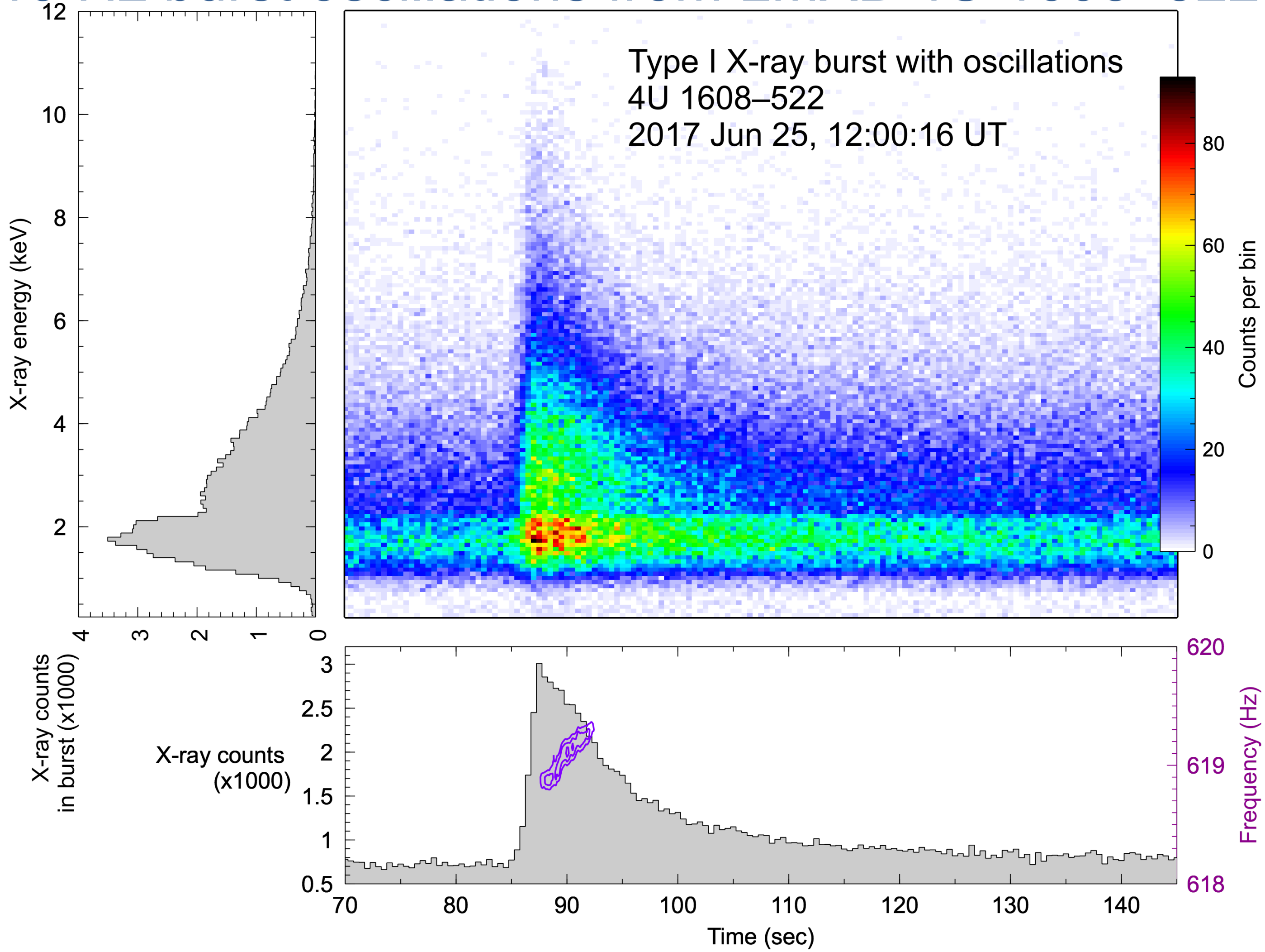
NASA HQ: Rita Sambruna (Program Scientist), Stefan Immler (Dep. Prog. Scientist)

Legend: *Ex-officio member of all WGs*
Full Member of Science Team (WG chair in **bold**)
Affiliated Scientist
Instrument development or SEXTANT team member (not on nicer-science mailing list)
Student (not on Science Team/nicer-science mailing list)

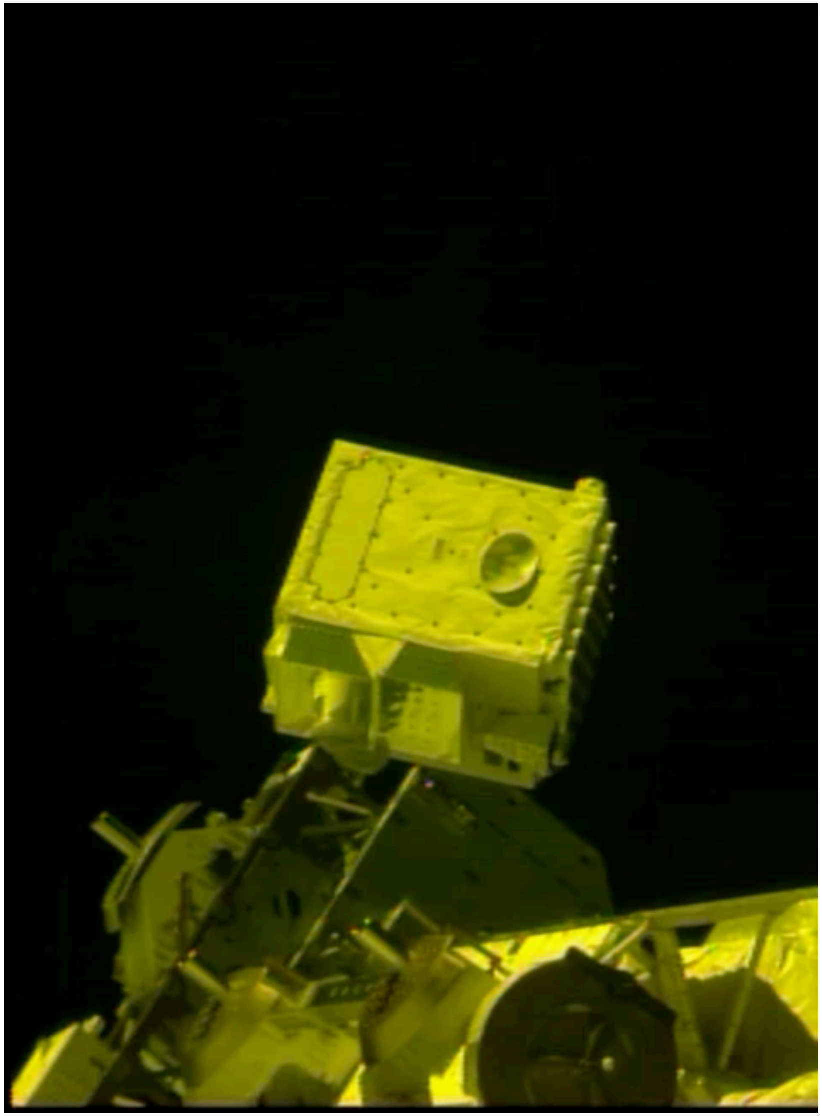
62 total + 3 students
14 affiliated slots remaining

First-light Highlights (cont.)

- 619 Hz burst oscillations from LMXB 4U 1608–522



Watch NICER get your photons!



BACKUP

Working Group Time Allocations

Assuming 33.8% observing efficiency, 16 Msec of good exposure time available.

Working Group	Est. number of targets	Est. average exposure per target (ksec)	Total exposure for investigation (Msec)
Lightcurve Modeling	4	1,000	4.0
Bursts & Accretion Phenomena	4	500	2.0
High-Precision Timing (Masses)	4	300	1.0
Searching & Multiwavelength	20	125	2.5
High-Precision Timing (Clocks)	4	1,000	4.0
Magnetars & Magnetospheres	8	180	1.5
Subtotal			**15.0**
Calibration			1.0
Total			**16.0**
Observatory Science*	25	100	2.5

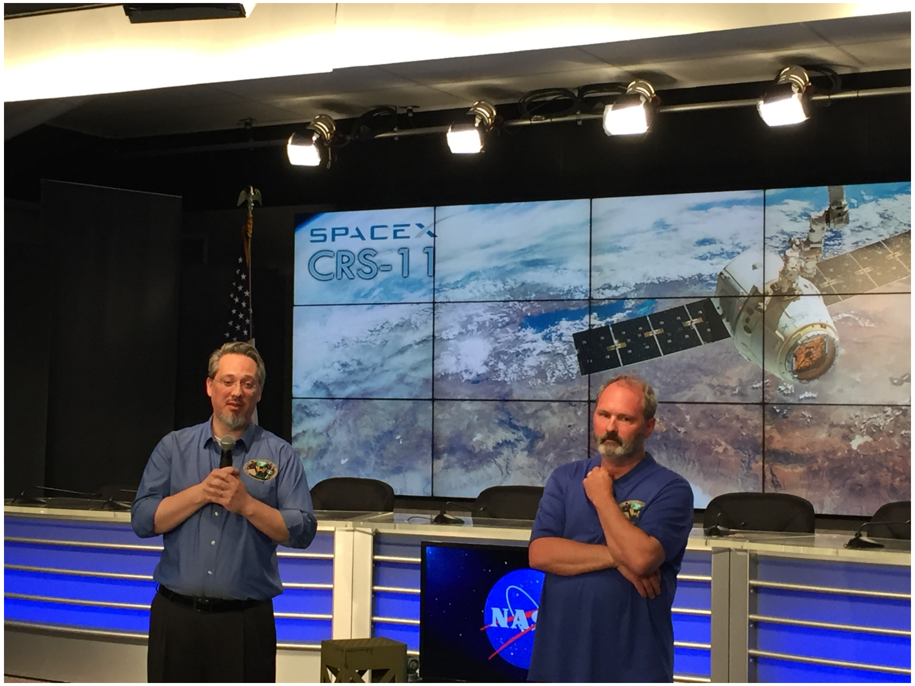
*OSWG tentatively allocated 5.3%. If realized efficiency is 50%, about 5.1 Msec remains.

Next Steps

- Optimize filtering criteria to bring down high-energy background, but note that background-sensitive science investigations are for soft targets
- Make Spectra for a few different SUM_OVER_COUNT limits
  - Data collected and it looks like background spectrum gets harder with increasing OVER_COUNT limit
- Figure out the spurious event seen in one background field
  - Suspect looking at Earth oxygen line, possibly an AGS error
- Develop tool to make equivalent of SUM_OVER_COUNT using fully telemetered events
  - Compare to MPU HKdata
  - Apply to night and compare to these results
  - Apply to day
- Systematic study on:
  - ELV angle
  - PHA/PHA_FAST ratio
  - Joint angle (Soyuz effect)

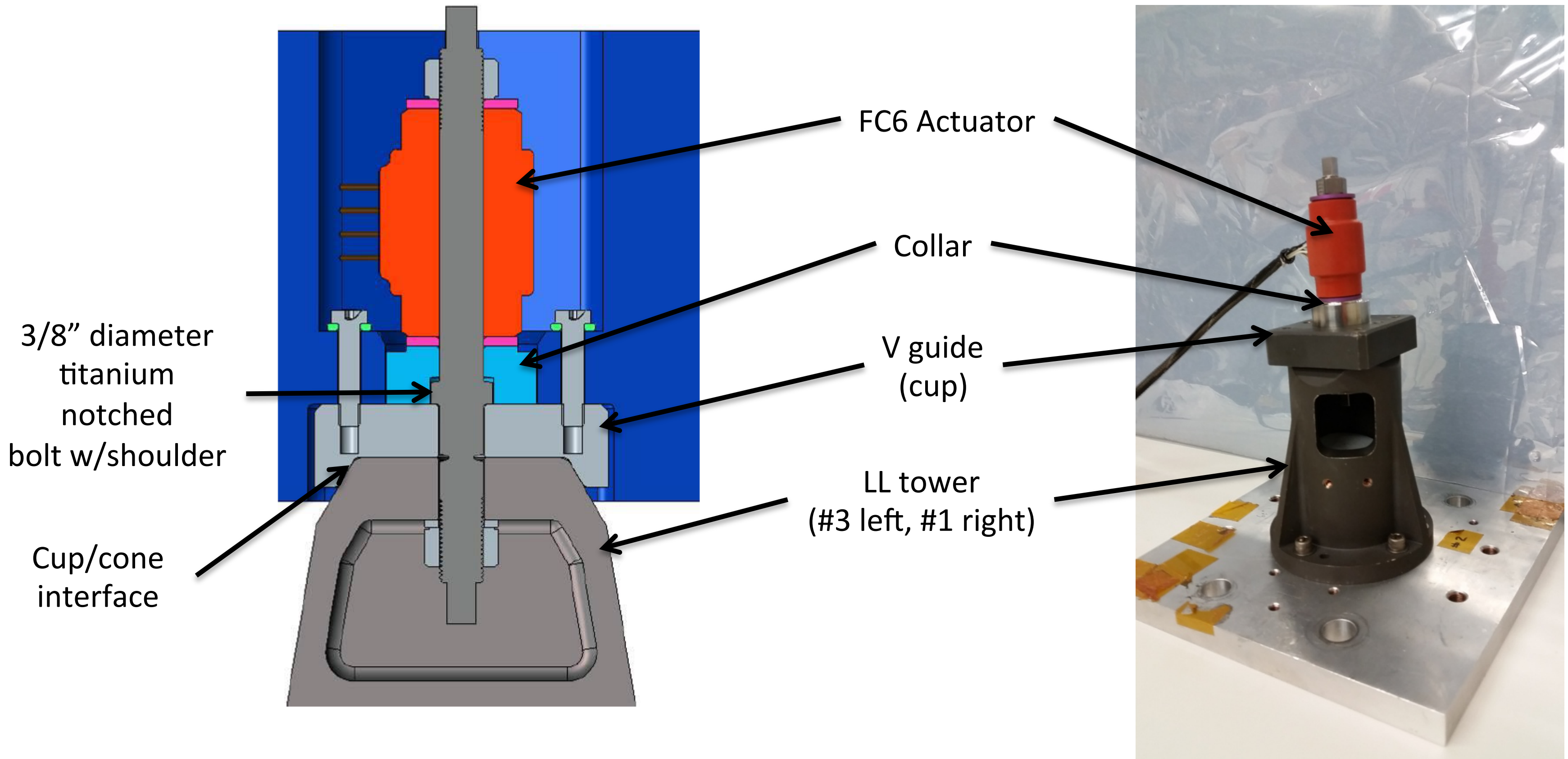
NICER Team at Launch Site

NICER Team at Launch Site



Keith Gendreau and Jason Mitchell
Supporting Pre-launch press briefing

Launch Lock Design (4 places)

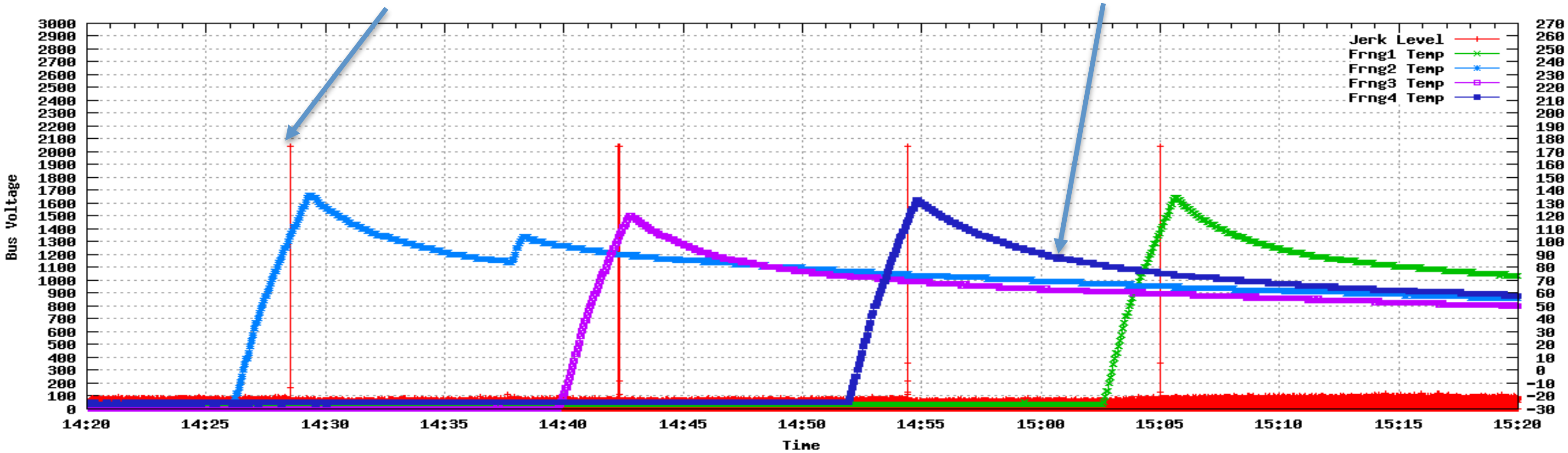


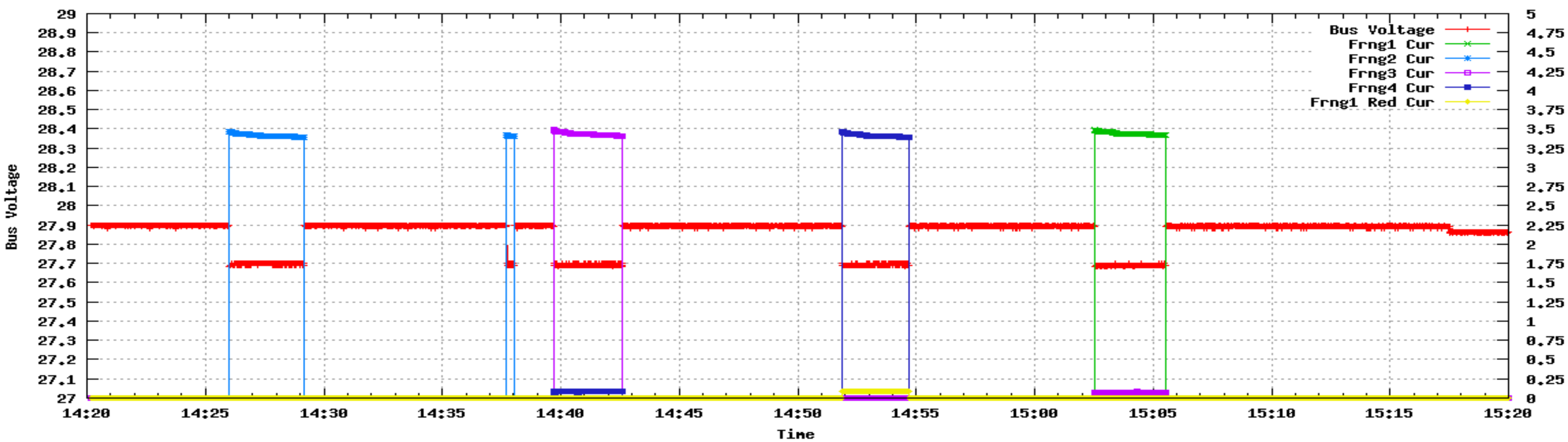
Unique feature of this design: The NICER design removes the Frangibolt actuator from the primary load path by use of the bolt shoulder and collar. This was done to prevent joint gapping as the Frangibolt would compress under high loads causing loss of preload if included in the load path. All testing of this design was successful.

Data from Successful Frangibolt Actuation from NICER TVAC with Flight Actuators and Pre-load

ST accel Jerk Level indicates
FB actuation at ~110 C

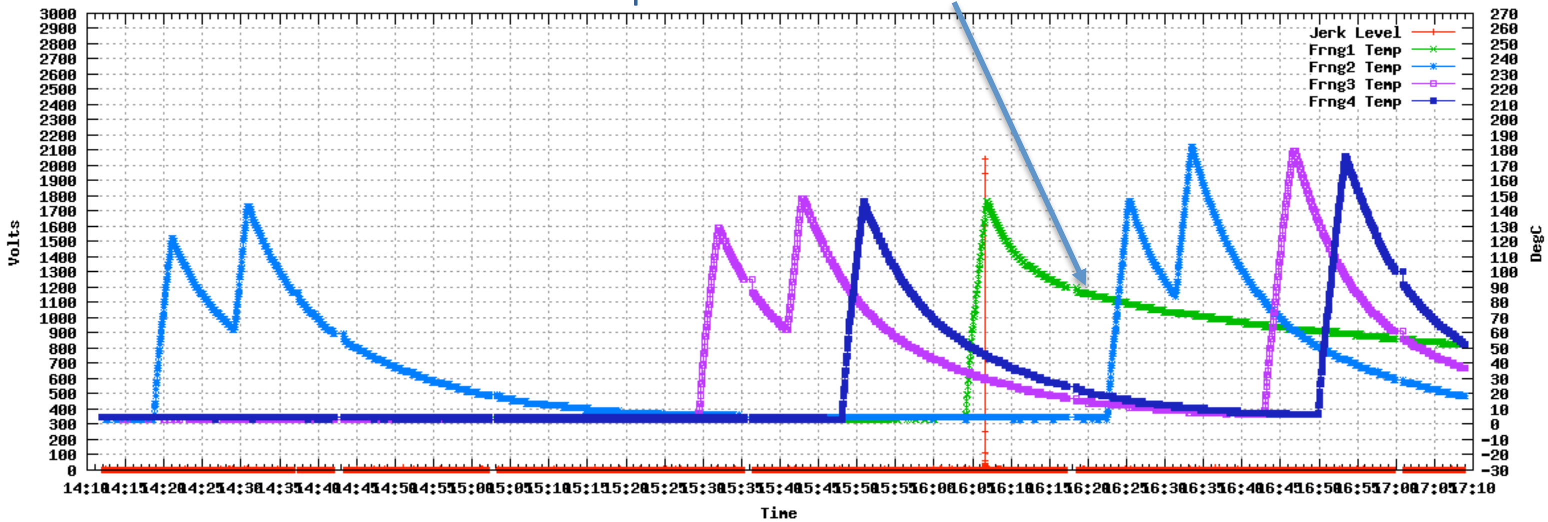
Slow cooldown slope indicates
loss of preload

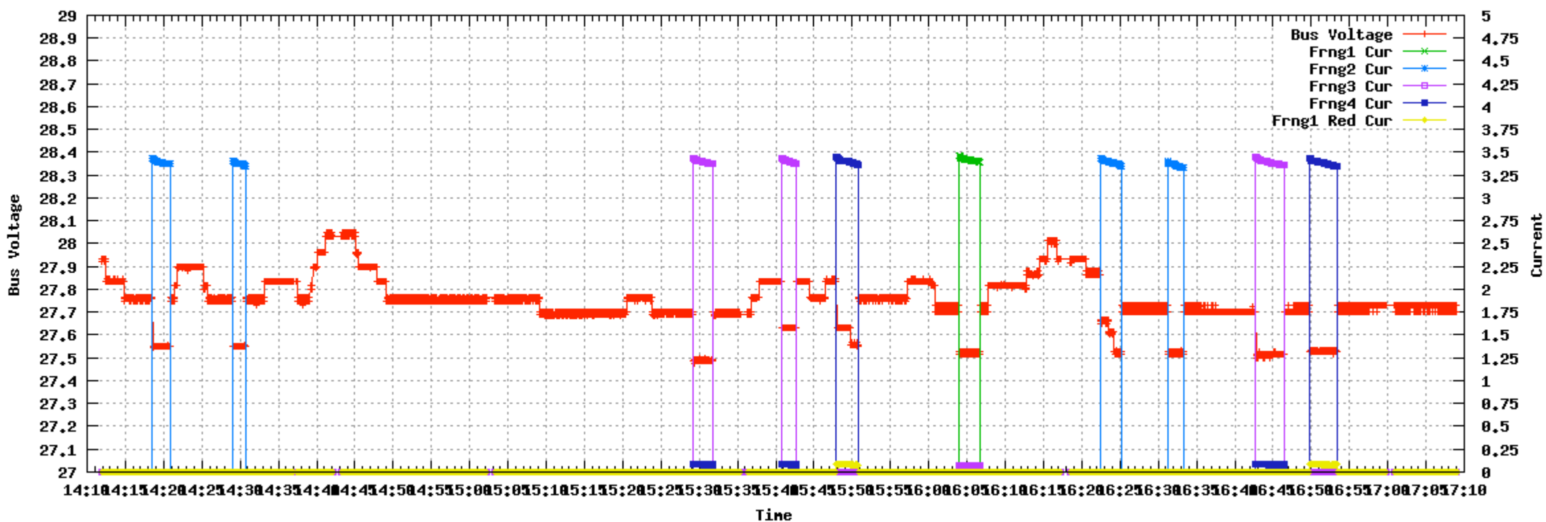




Flight Frangibolt Telemetry showing only FB1 with successful Actuation

Only Frangibolt 1 shows the Jerk Level response and characteristic long cool down time representative of successful actuation.





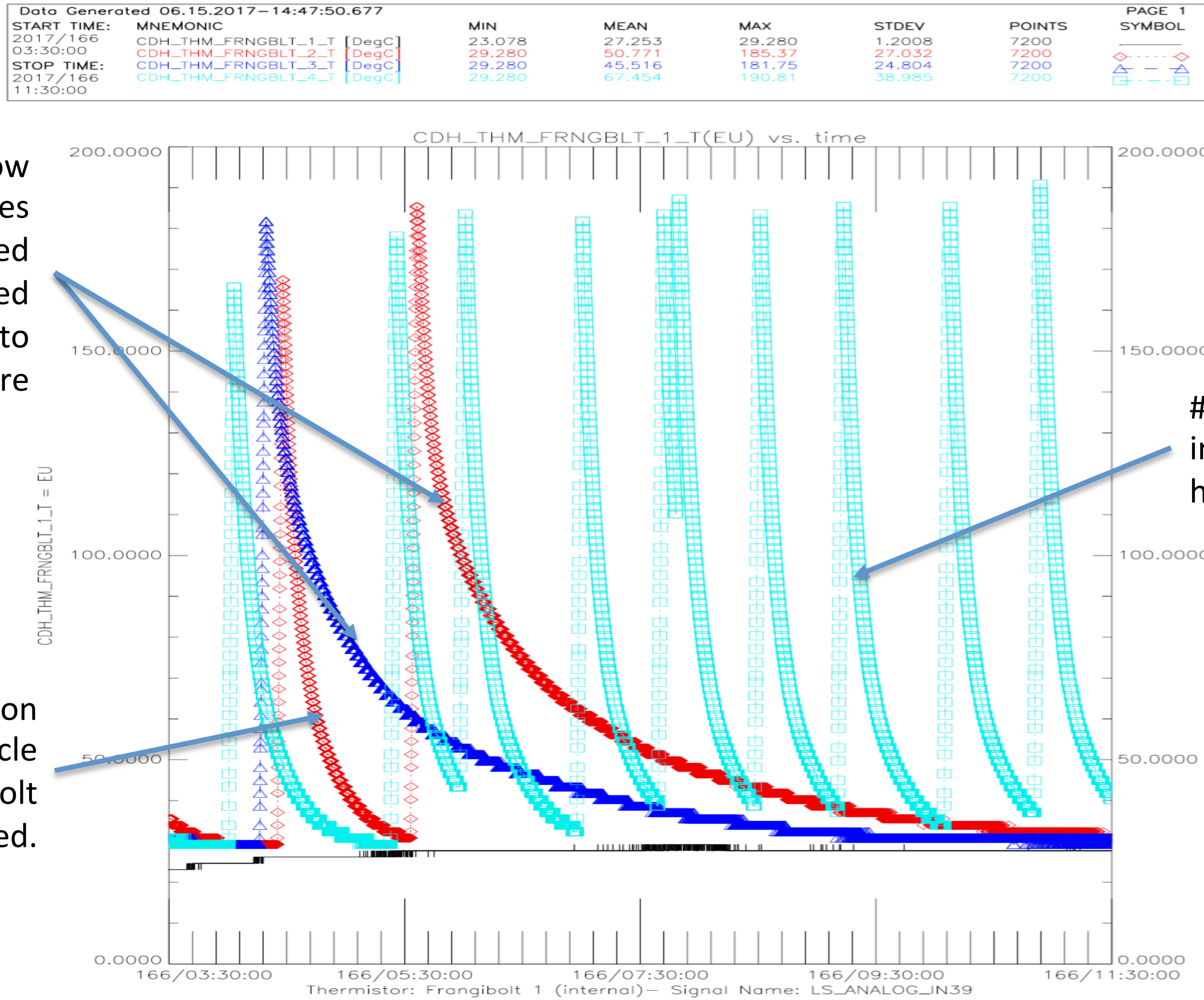
Immediate Response, 6/14/2017

- We held a telecon with TiNi. Included NICER team and Materials Branch attendance. Initial thoughts on the cause of the failure to release were:
  - Heat leak may be preventing the Frangibolts from reaching the desired temperature
  - Insufficient preload on the Frangibolt, Preload of 50 in-lb may be low. 160 in-lb min recommended by TiNi.
  - A different lot of bolts was used for the flight installation than was used in test
- We came away with the following recommendations:
  1. Heat the baseplate as high as possible to minimize the effect of any heat leak
  2. Start with bolt as cold as possible (mutually exclusive with #1)
  3. Heat the FBs to a higher temperature in case there is a heat leak and to maximize the stroke. TiNi recommended a max temperature of 225C.
  4. Keep cycling FBs, fatigue may cause the bolt to fail (L. Wang, Code 541, recommendation, estimated 20 cycles required). Since #1 fired, others are probably close to breaking.
- Decided to act immediately on recommendations 1, 2 and 4.
- None of these actions are outside the range of our payload design, nor did they present any safety concern to the ISS. ISS was kept informed and concurred with all our actions.

Resolution

- Overnight the ops team continued to cycle the Frangibolt actuators.
  - Warmed baseplate to 30 C to minimize any thermal leaks.
  - Increased the FB temperatures each cycle
- 6/15/17, after midnight. Frangibolts 2 and 3 successfully fired when cycled up to ~180 C
  - Both after 6 total cycles (3 cycles after temp changes made)
  - Determination made based on thermal cooldown profile
  - ST MIRU accel turned off due to temperature concerns with base plate at 30C
- Frangibolt 4 successfully fired when cycled up to ~225 C, 6/15/17 ~4:20 PM EDT
  - Cycled 23 times
  - Determination made based on thermal cooldown profile
- Successful NICER deployment on 6/16/17 confirmed LL release.
- Subsequent operations demonstrated no residual impact to Payload from this issue

Frangibolt Temperature Plots, #2 and #3 Firing



#2 and #3 slow cooldown indicates frangibolt has fired due to reduced thermal contact to structure

Fast cooldown on previous #2 cycle indicates frangibolt had not fired.

#4 fast cooldown indicates frangibolt has not fired.

Plan Forward

- NICER Project is working with Code 540 and Code 300 to determine the root cause of the failure of the LL mechanism to fire as planned.
  - Close call investigation includes independent experts including Joe Pelliciotti, Alfonso Stewart and Minh Pham
- Possible causes being investigated.
  - Heat leak prevented the Frangibolts from reaching the desired temperature
  - Insufficient initial preload on the Frangibolt
  - Flight bolts were from different lot than the test bolts, Flight bolts were ~5% stronger than test units.
  - Loss of preload in system
    - Due to unexpected launch loads
    - Due to unexpected extreme thermal environment during launch, cruise or installation, no temperature data during this time
    - Nuts backed off due to vibration
  - FOD in mechanism, FOD in collar could block bolt retraction.
  - Frangibolt improperly installed
  - NICER installed on a different AFRAM than the one tested on.
- Will develop recommendations, guidelines and lessons learned for using Frangibolts for this type of application in the future.

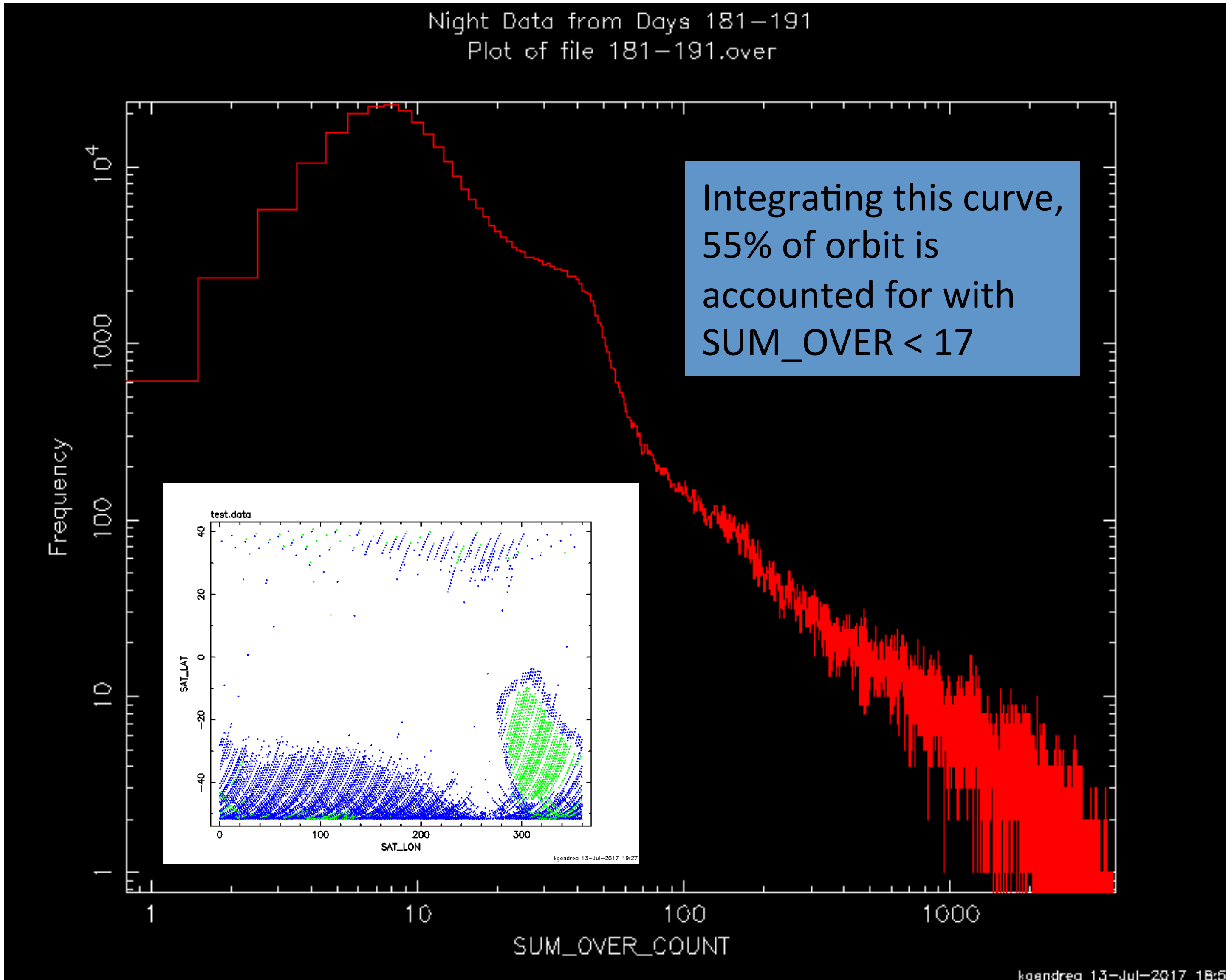
Background

- Basic validation of pre-launch predictions from observations of faint sources (e.g., PSR B1937+21) and “empty sky” fields used by RXTE
- Quantitative assessment of the extent of radiation zones (SAA and polar “horns”) as well as Soyuz impact in work (next slides), but will require more orbital coverage and data
- Solar and bright-Earth illumination-triggered “events” cause a small amount of additional background at the softest energies; efficient filtering will be possible for targets where soft-band sensitivity matters.
- Requirement: ≤ 200 cts/ksec (0.4–2 keV) and ≤ 150 cts/ksec (2–8 keV) for ≥ 55% of the time

Collection of Background Fields

- Collected 18,517 seconds of night-time data for RXTE Background fields 1–8 from June 17–July 13.
  - Chose night data because it is the only time one can use the MPU HK to effectively filter on overshoots alone, as the undershoot rates are much lower
  - Used niextract-events, maketime, and xselect
- Filtering:
  - ELV (Earth avoidance of pointing) > 30 degrees
  - SUM_OVER_COUNT < 17
    - Corresponds to roughly 55% of orbit (see next slide)
  - PHA/PHA_FAST < 1.14
    - Eliminates Edep on detector periphery not flagged as overshoot
  - ANG_DIST < 0.005, to remove slews
  - One spurious observation with VERY large rates at oxygen line removed manually
- Results (see spectrum, Slide 15)
  - 0.4–2 keV rate = 184 c/ks (allocation = 200)
  - 2–8 keV rate = 227 c/ks (allocation = 150)

Background (cont.)



Green:
OVER > 300

Blue:
23 < OVER < 60

Summary

- Measurement system performing as expected, with key effective area, timing, spectroscopy requirements fully met
- Alignment of X-ray boresight relative to star tracker has been established to within requirement, enabling faint-source science to proceed; further refinement with Crab starting Aug 1
- Observing efficiency has been excellent so far, with few/brief interruptions (ISS ops, downlink anomalies)
- Illumination-related issues will require additional calibration sophistication, but have no science impact; event filtering criteria for orbit day vs. night and different geomagnetic environments are being assessed.

Star Tracker Commissioning

Pointed Instrument to open part of sky that minimized glint and satisfied occultation constraints

- Checked # stars/objects detected within expected range – no star threshold tuning was required
- Captured uncompressed image – DTU checked lens/CCD calibration stability over launch and installation
- Captured valid attitude data to evaluate STR/ MIRU attitude noise

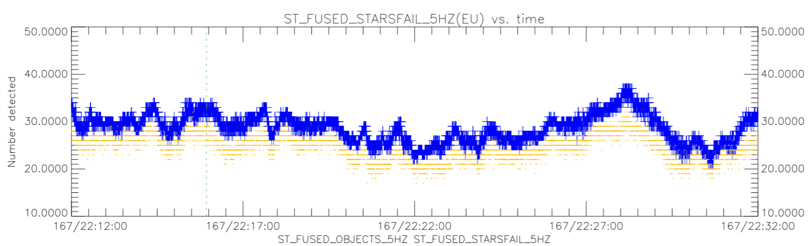
Observed Star Tracker behavior during blinding events

- Waited for solar array to rotate across Instrument boresight
- Slewed Instrument boresight across solar array

Demonstrated routine, on-orbit Star Tracker functions

- Generate attitude solutions when conditions include minimal glint and unobstructed view of stars
- Capture and downlink uncompressed and jpeg images
- Capture and downlink videos

NICER Tracking Gamma Cas



objects (blue) and stars (objects) tracked during Star Tracker commissioning

Slew + Settling Performance

- Slew requirements:
  - For slew angle less than 90 deg, the slew +settling time shall be less than 2.5 min.
  - For slew angles greater than 90 deg, the slew+settling time shall be less than 4 min.
- Flight data shows slew +settling time requirements are easily met with ~30 sec of margin in the worst case.