NICER

Neutron star Interior Composition ExploreR

NICER Instrument/Calibration

Jeremy Hare (NASA/GSFC/CRESST/CUA)
on behalf of the NICER team

NASA GSFC MIT KAVLI INSTITUTE DTU BROAD REACH MOOG

Thanks to:

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Software/Calibration

Elizabeth Ferrara
NICER GOF

Overview

1) Instrument

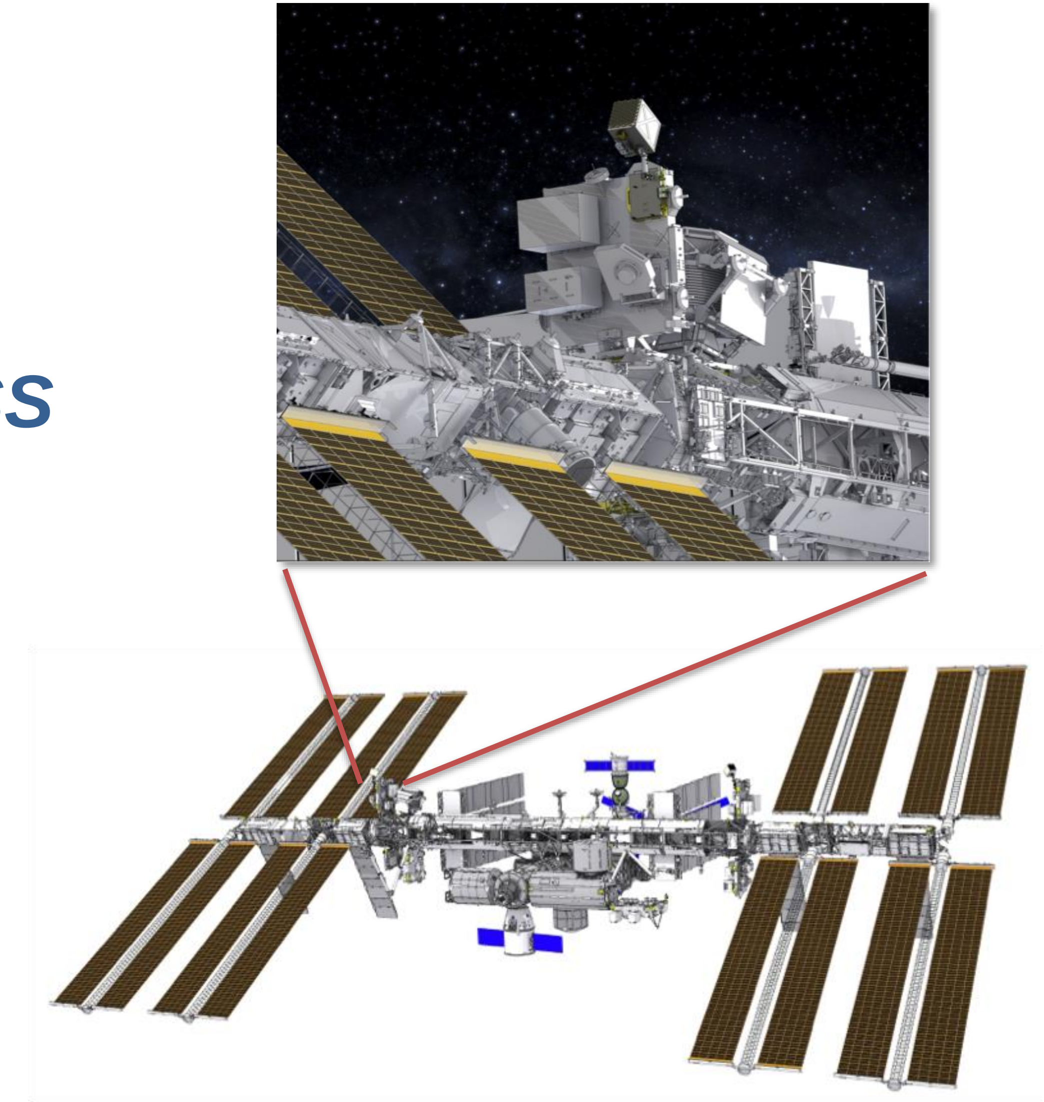
2) Launch

3) Observing from the ISS

4) Science Capabilities

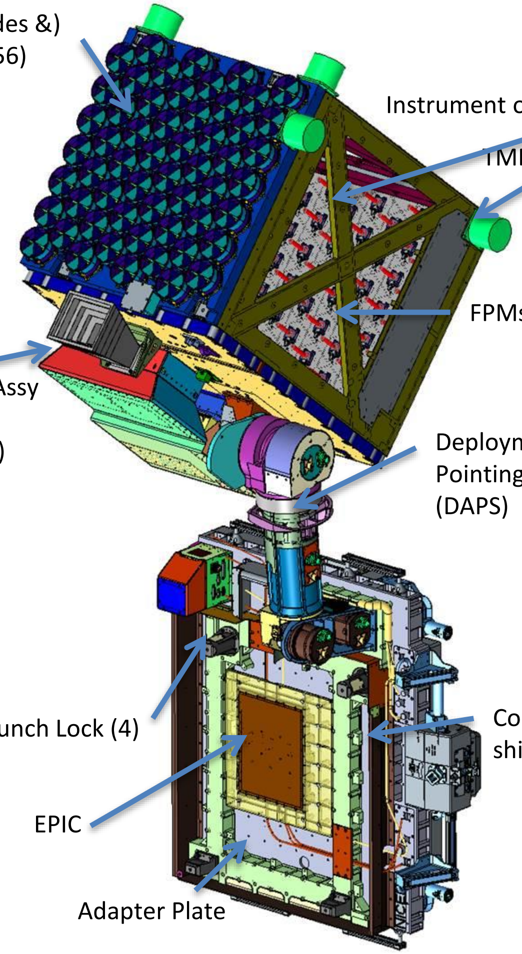
5) Calibration

6) Guest Observer Facility/TOOs



The NICER Payload

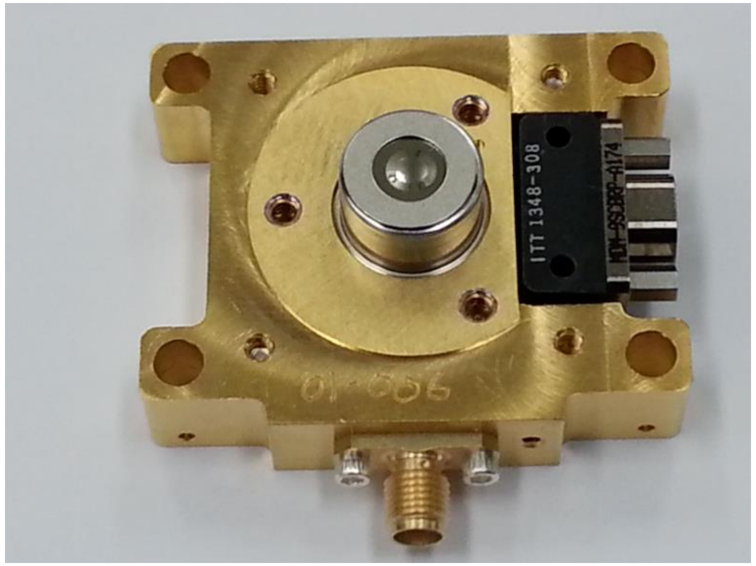
An innovative combination of high-heritage components

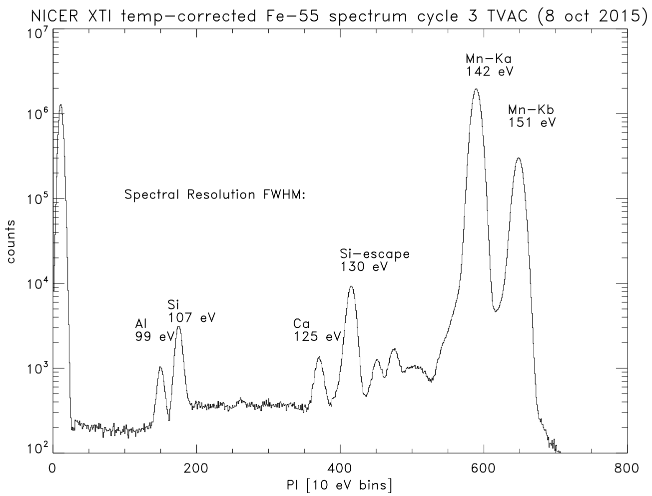


- **X-ray Timing Instrument (XTI)**
  - Assembly of 56 X-ray concentrators and detectors (52 operational)
  - Detects individual X-ray photons, returns energy and time of arrival
  - Held together in the Instrument Optical Bench
- **Thermal system**
  - Maintains thermal-mechanical alignment
- **Pointing 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

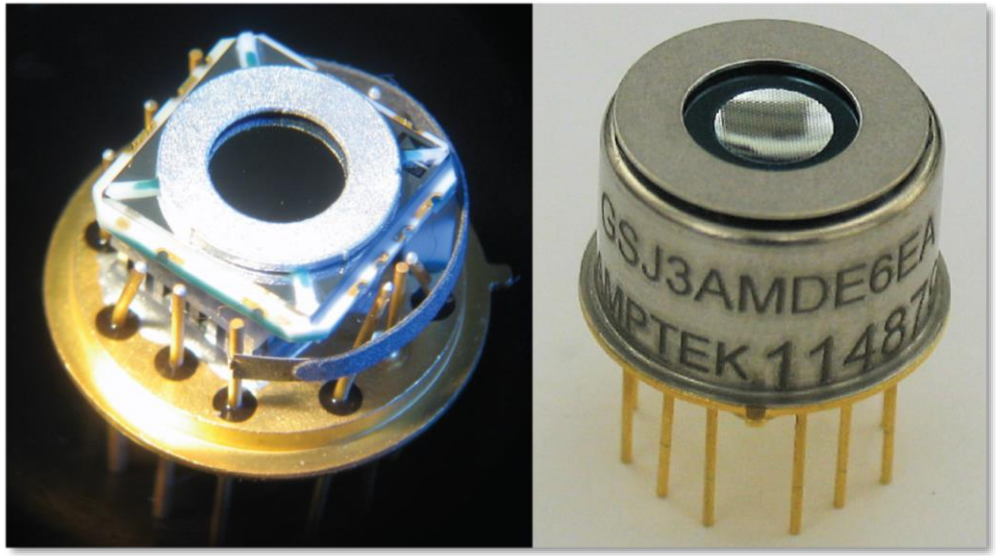
Focal Plane Module (FPM)

Flight lot detector in flight housing

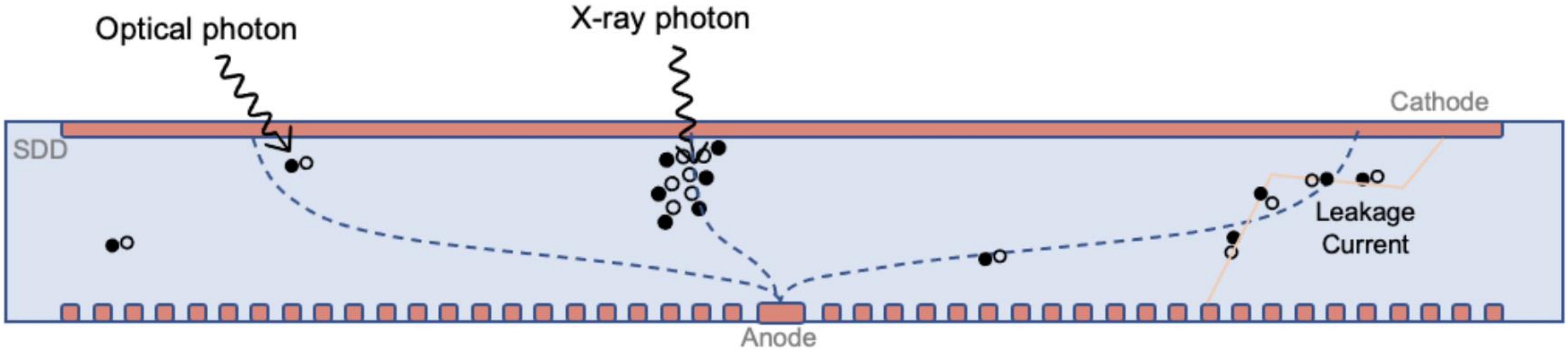




- Commercial Silicon Drift Detectors (SDD) from AMPTEK provide CCD like energy resolution and < 100 nsec time resolution with built in Thermo Electric Cooler (TEC; -55° C)
- Detector window F consists of 40nm of Si_3N_4 and 30nm of Al. Transmits very low energy X-rays (better than 200 eV) while maintaining a hermetic seal.



X-ray detection in Silicon Drift Detectors

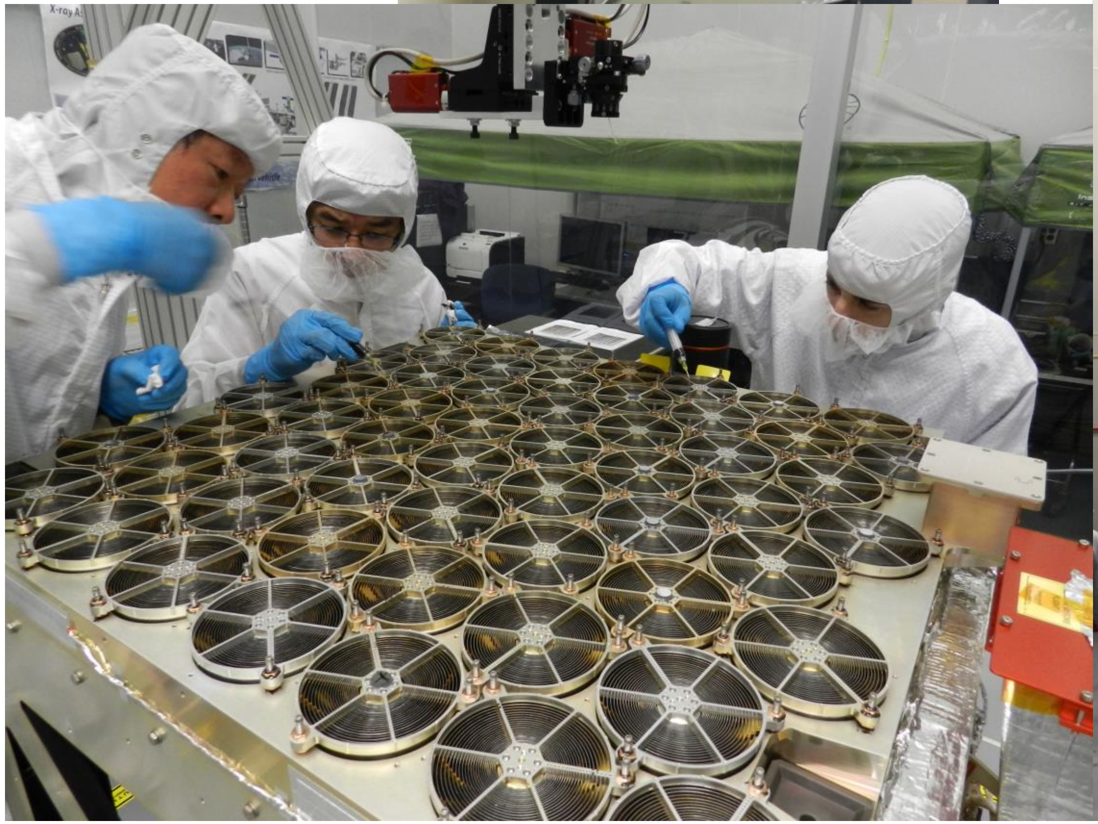


Small anodes -> Low read noise

NICER Concentrators

- NICER Concentrators are thin foil optics with heritage from ASCA, Suzaku, and Astro-H
- Single reflection optic-concentrators- to maximize throughput for isolated point sources with limited mass
- Advances compared to previous GSFC optics:
  - Single shell- not quadrants
  - Parabolic shape and not a conical approximation
  - Improved replication and alignment technique

Collimator Structure for Alignment



NICER in SSPF
Prior to Dragon Trunk Integration

Launch and Extraction – 1 of 4

June 3, 2017

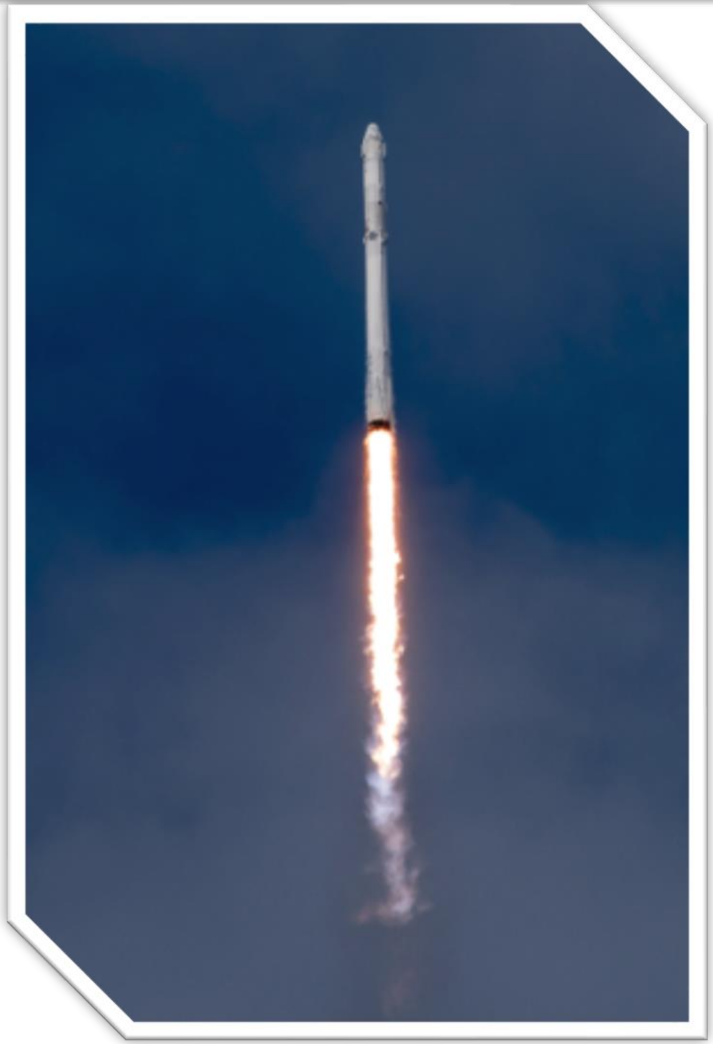
SpaceX-11 Launch

NICER was the 100th launch out of Pad 39A where humans first left for the moon.

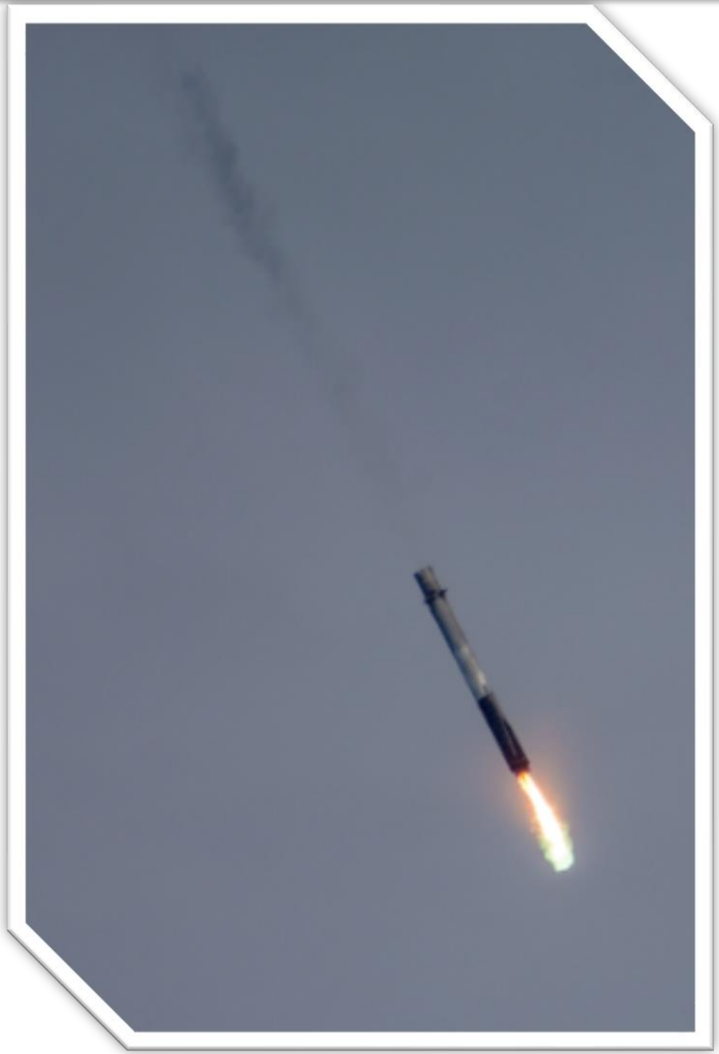
50ish years after pulsar discovery

Launch and Extraction – 2 of 4

June 3, 2017

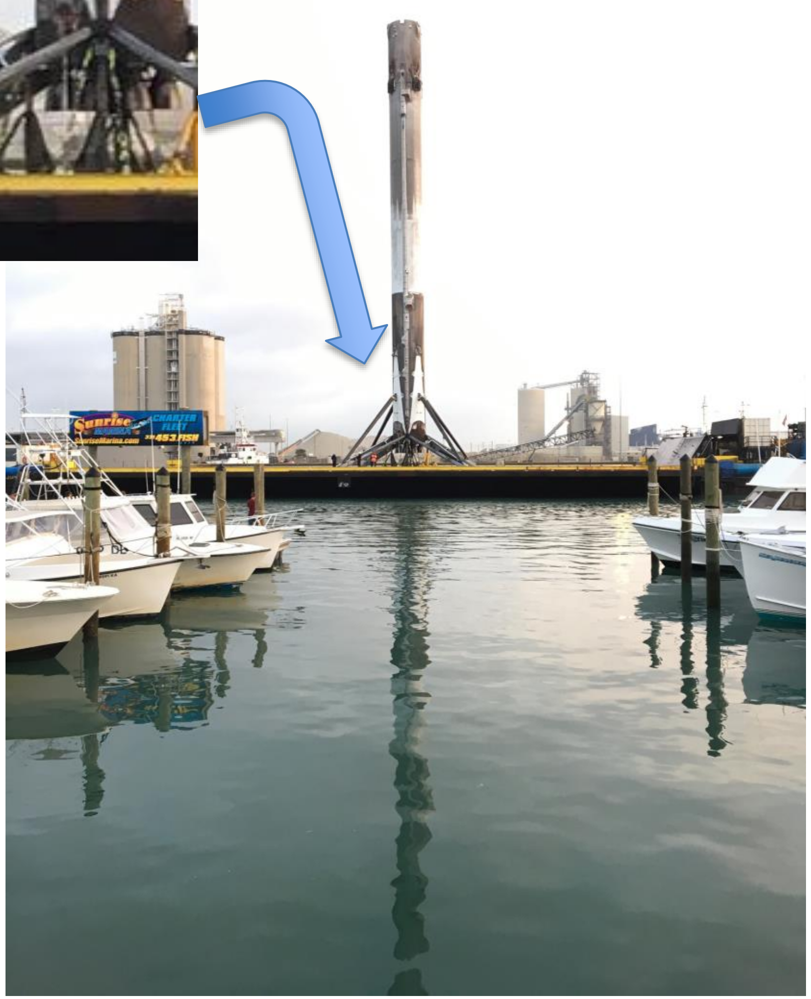


Ascent



Stage-1 Re-entry Burn

Space-X lands a big rocket!



Launch and Extraction – 3 of 4

June 3, 2017

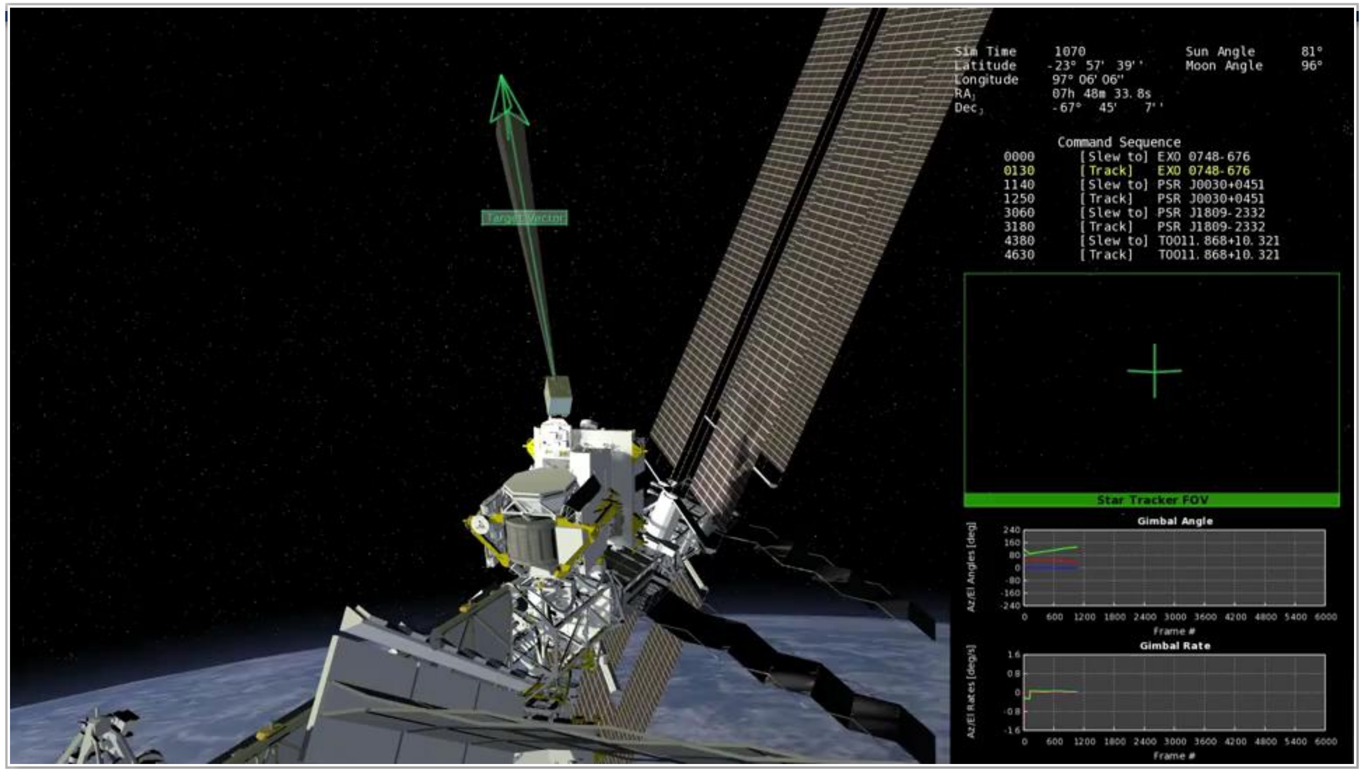
Launch and Extraction – 4 of 4

NICER on the ISS

60x real speed   85% tracking 15% slew

NICER on the ISS

Established platform, benign environment — ISS is a great place to do NICER science!



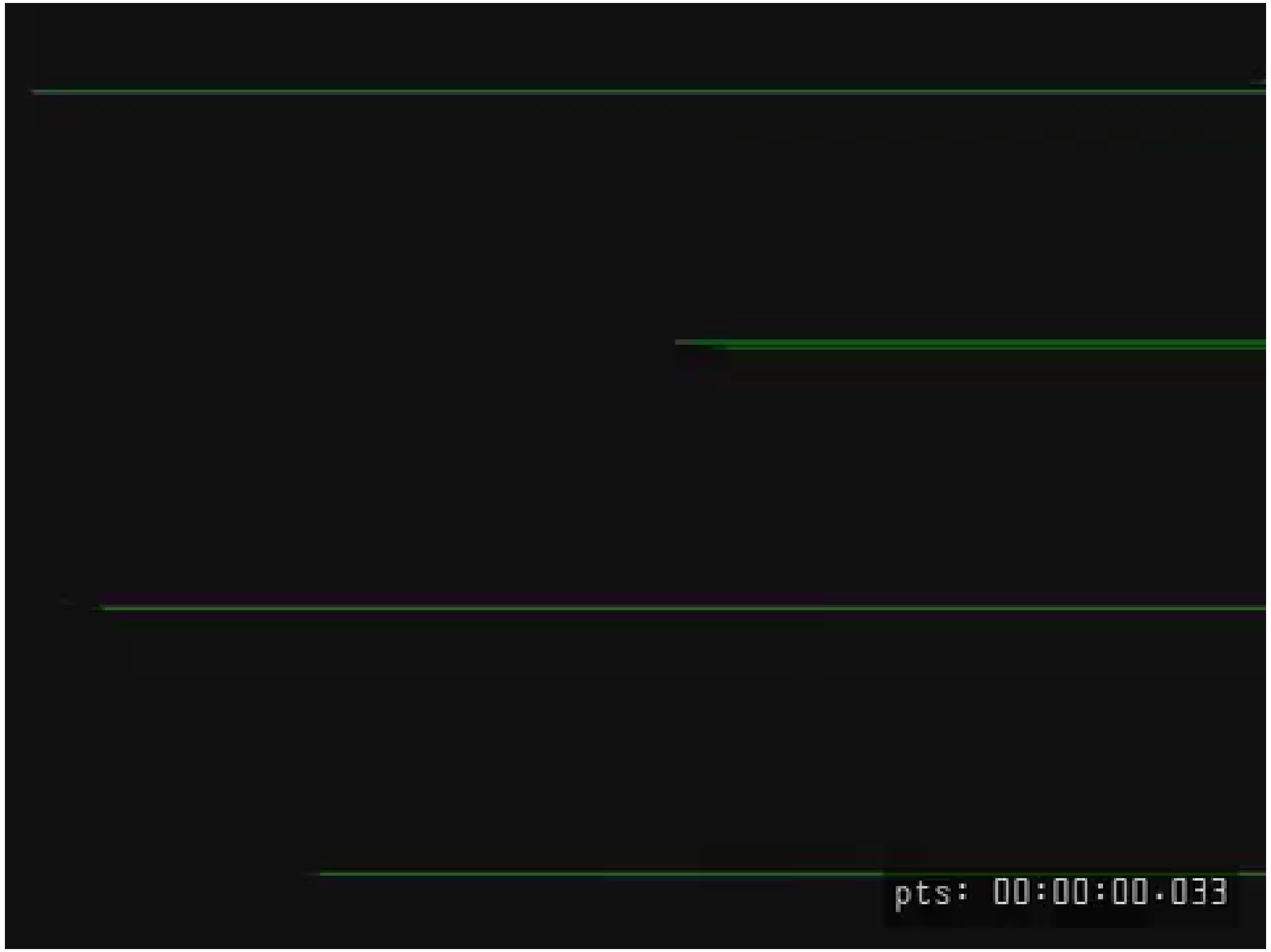
ISS offers:

- Established infrastructure (transport, power, comm, etc.) that reduces risk
- Generous resources that simplify design, reduce cost
- A stable platform for arcmin pointing

NICER's design:

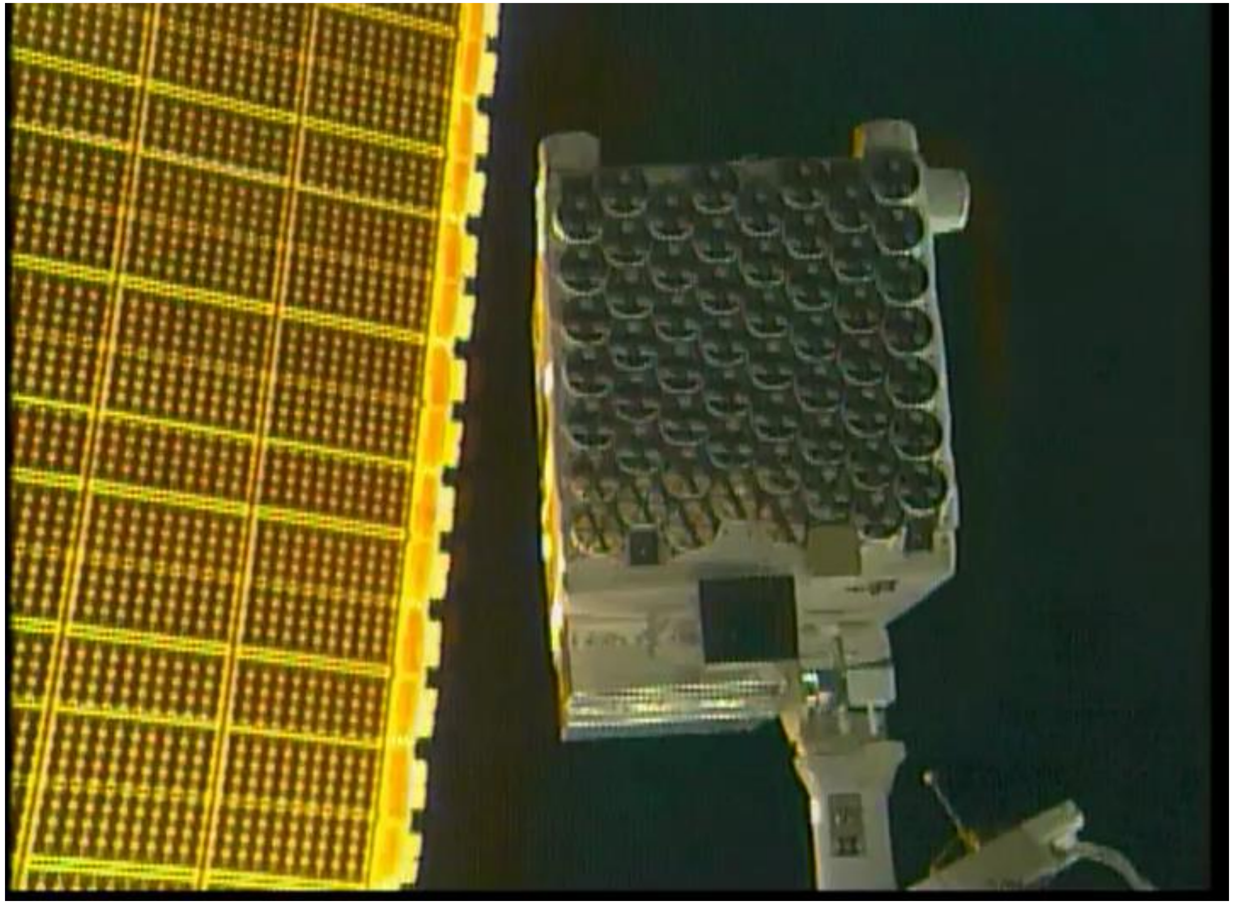
- Is tolerant of ISS vibrations
- Is insensitive to the ISS contamination & radiation environments, with safe-stow capability
- Provides high (54%) observing efficiency

Looking Into Camera



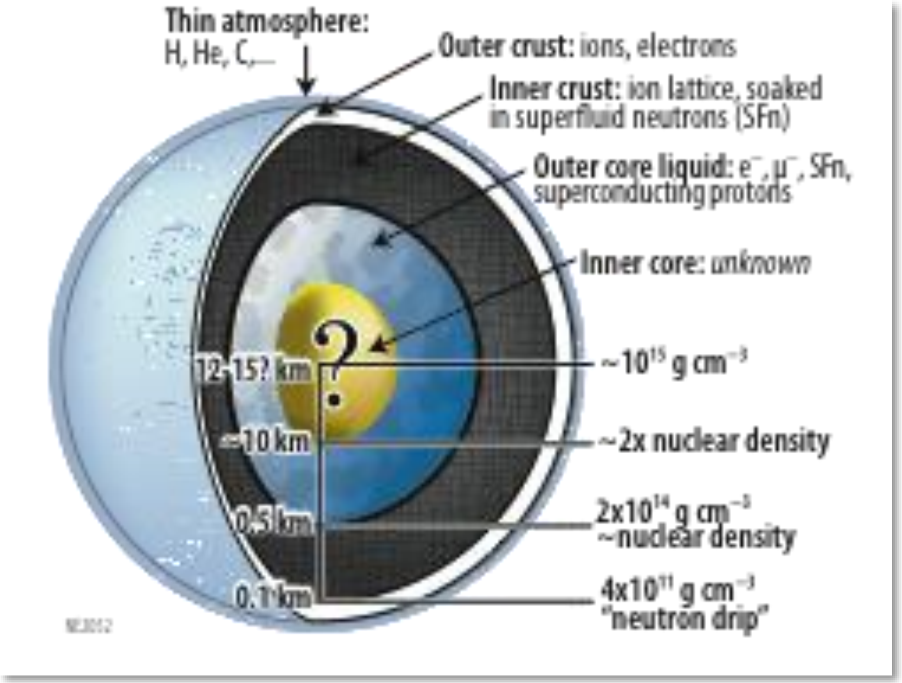
Watch NICER collect your photons!

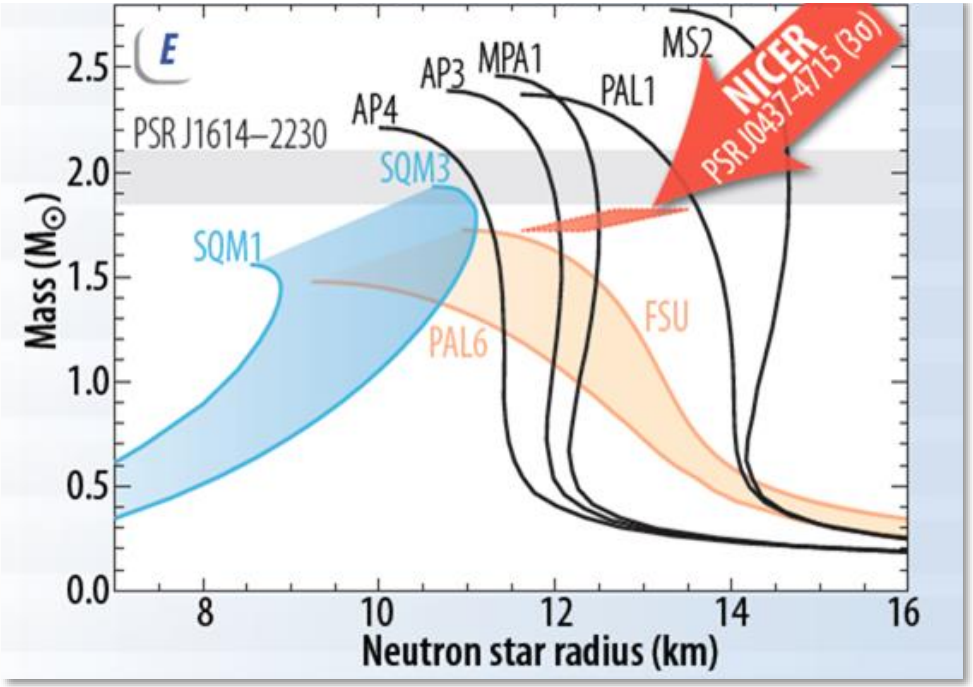
Occasional / on-demand live ISS video as well as inspection



Mission Success Criterion

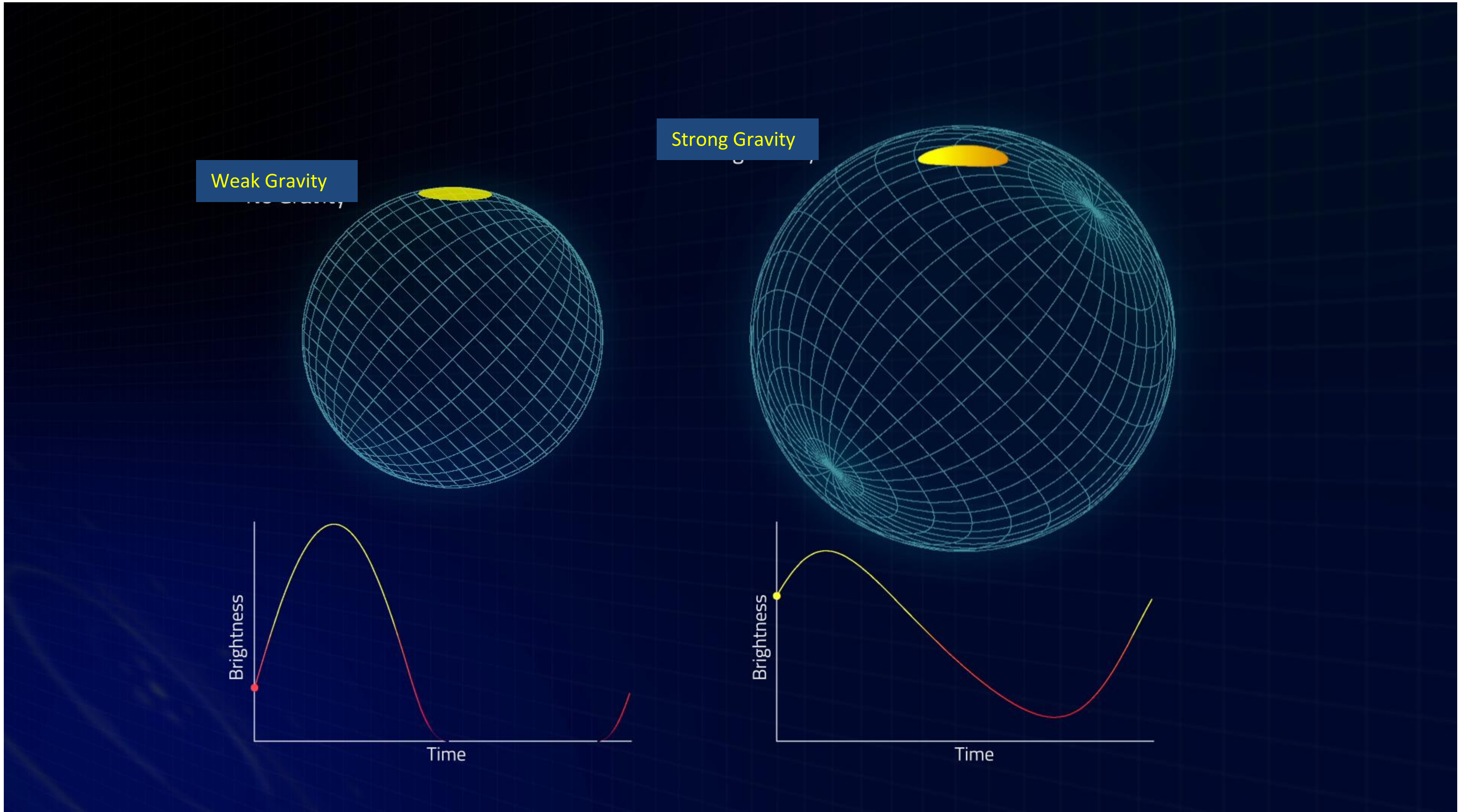
NICER shall use rotation phase-resolved spectroscopy in X-rays to discriminate among strange-quark, soft nucleonic, and stiff nucleonic equation-of-state models of neutron star structure in at least 2 neutron stars.





Strong Gravity and Light Curves

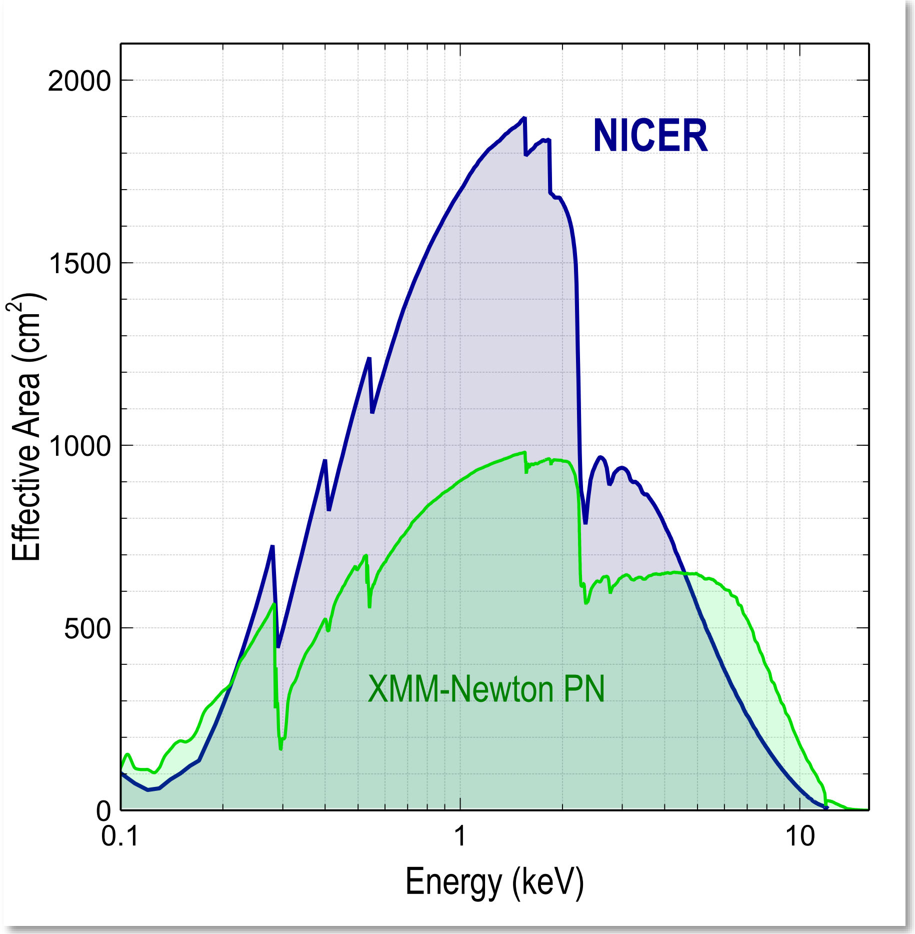
Figure credit: Sharon Morsink



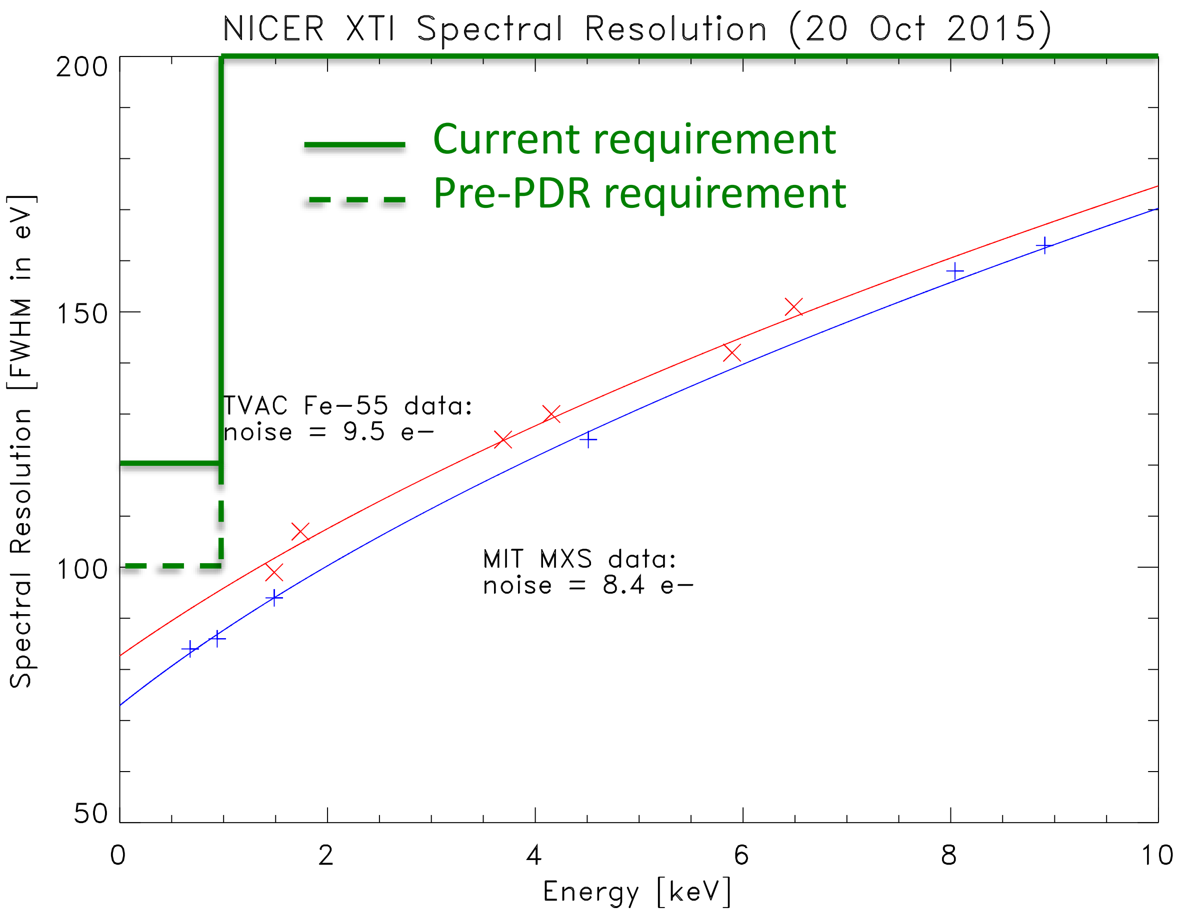
Science-enabling capabilities

An unprecedented combination of time resolution, energy resolution, and sensitivity

- Spectral band: 0.2–12 keV
  - Well matched to neutron stars
  - Overlaps RXTE and XMM-*Newton*
- Timing resolution: <100 nsec RMS absolute
  - 50x better than RXTE
  - >~100x better than XMM-*Newton*
- Energy resolution: 2.5% @ 6 keV
  - 10x better than RXTE
- Angular resolution: 6 arcmin (non-imaging)
  - 10x better than RXTE
- Sensitivity, 5σ: 5.3 x 10^{-14} erg/s/cm^2
  - 0.5–10 keV in 10 ksec (Crab-like spectrum)
  - 20x better than RXTE
  - 3x better than XMM-*Newton*'s timing capability

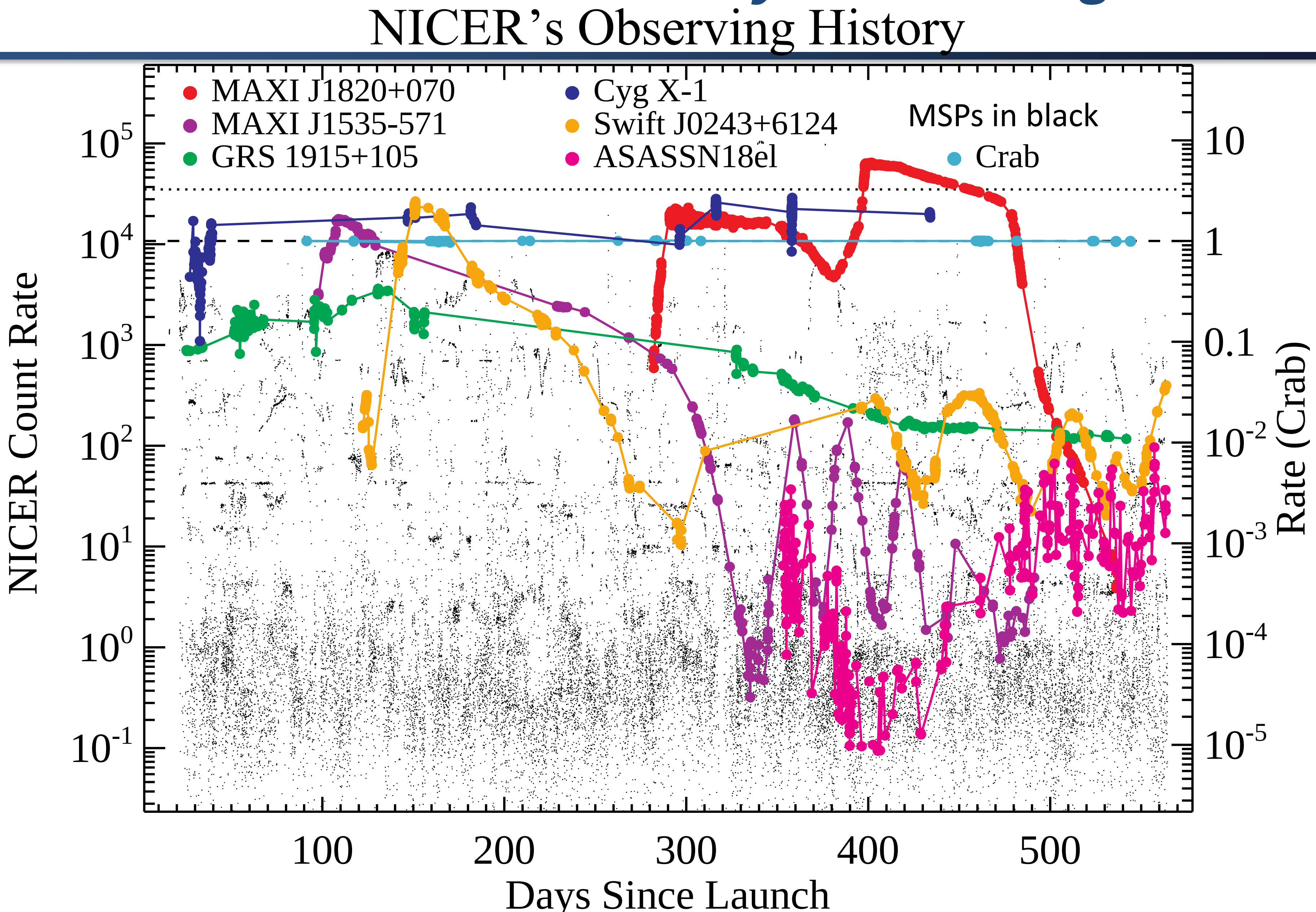


Energy Resolution Requirement Met



- *Red points:* TVAC data with Fe55 source, all detectors and all temperatures combined (Cycle 3, T = –5 ºC to +70 ºC)
- *Blue points:* FPM calibration data with multi-line modulated X-ray source @ MIT, all detectors combined, single temperature (T ~ 30 ºC)
- *Red & blue curves:* Fits to Fano-limited readout noise performance curves demonstrate that XTI's spectral resolution meets both the original and relaxed requirements.

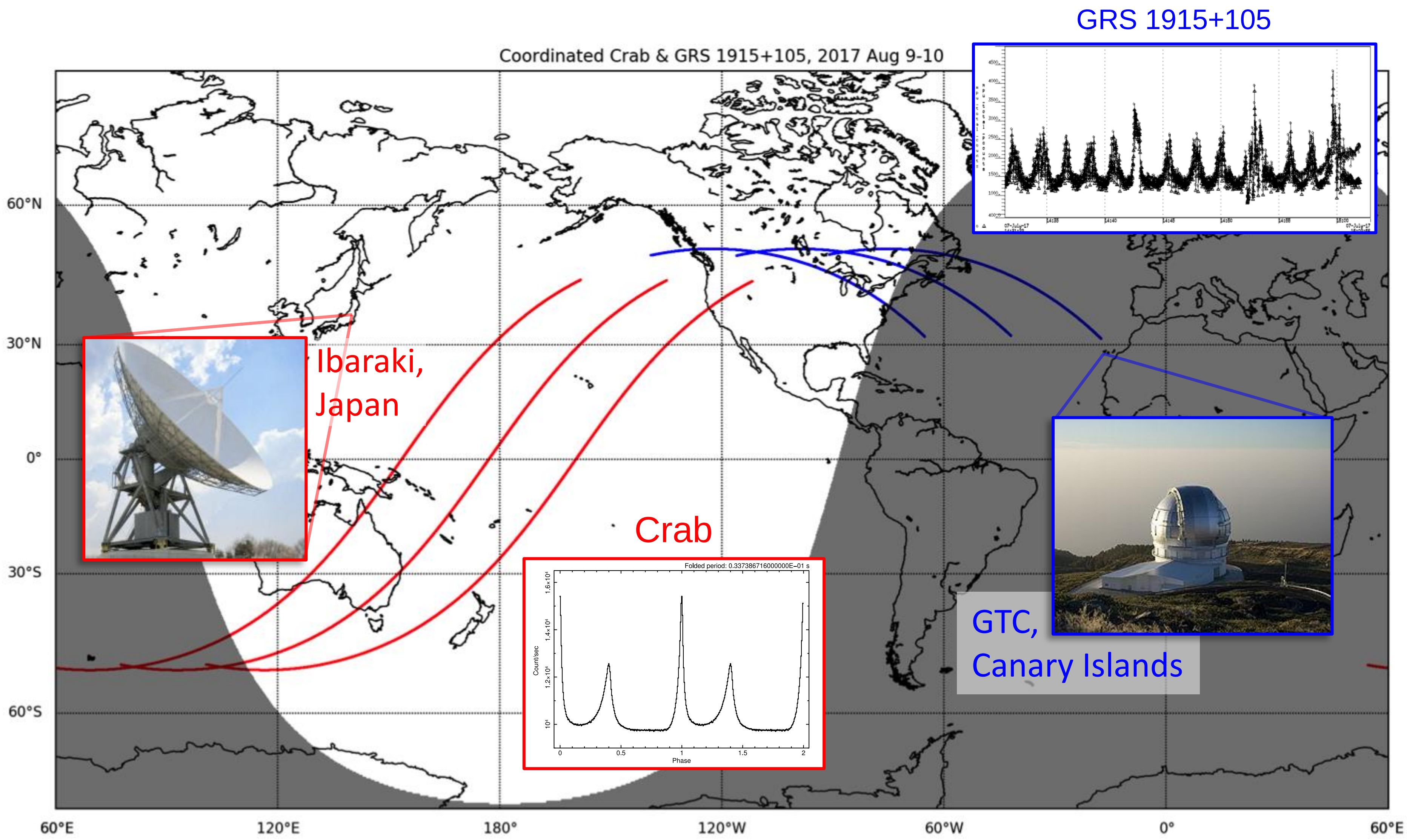
NICER has a wide dynamic range



Coordination across wavelengths and facilities

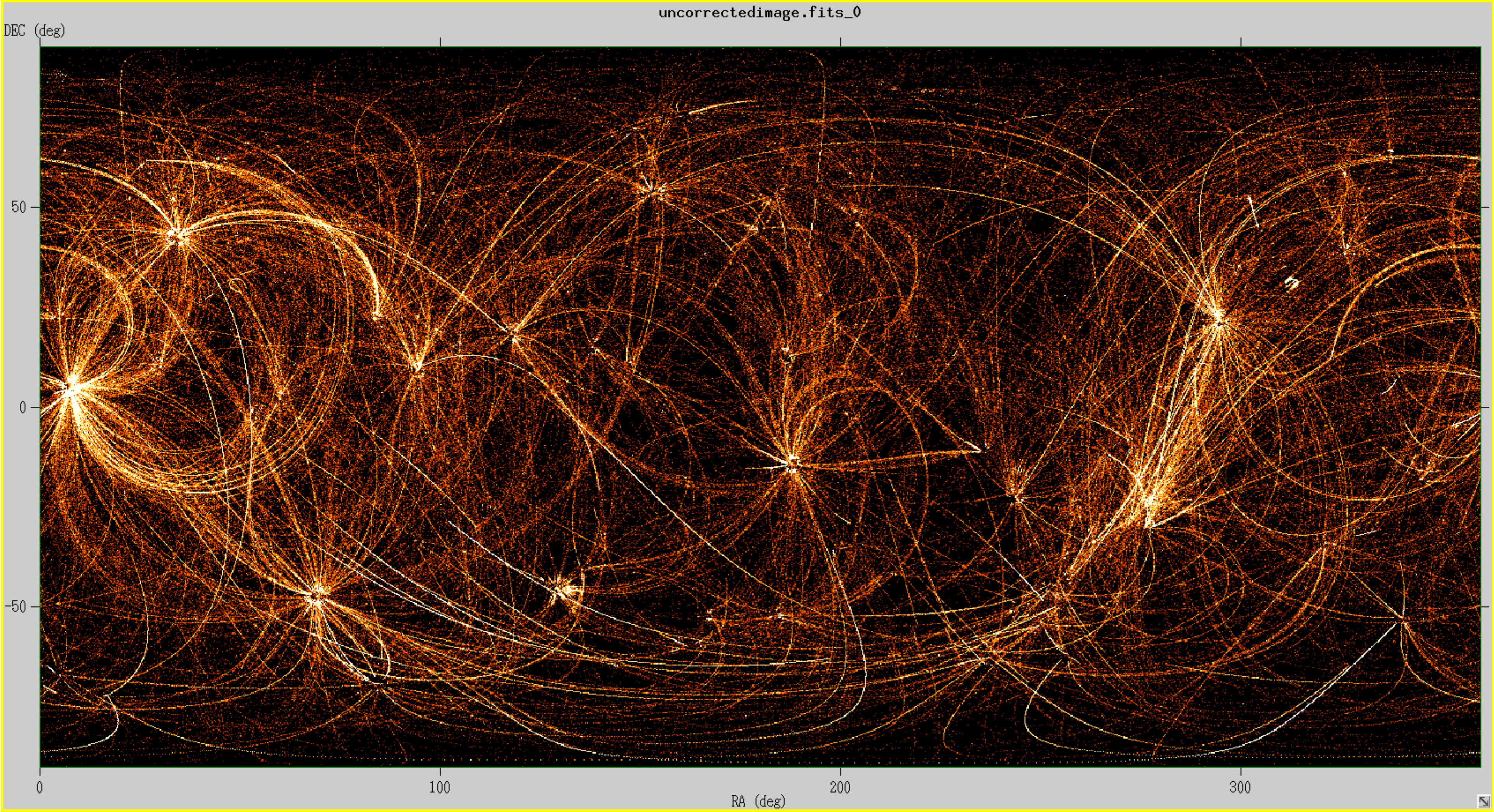
Two targets, two ground-based telescopes, three successive ISS orbits

Also many coordinated observations with SALT!



Initial NICER Slew Survey

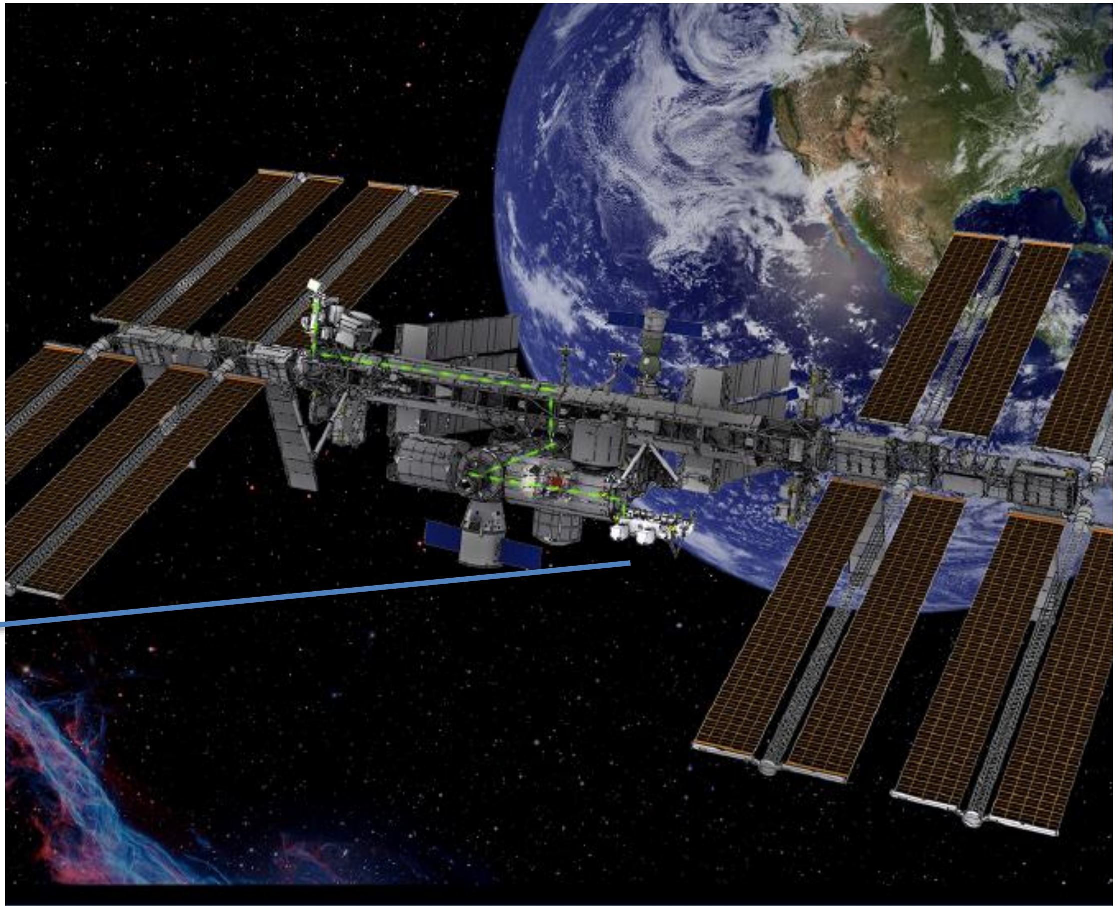
18 months of data



Typically observe 3-6 targets per orbit

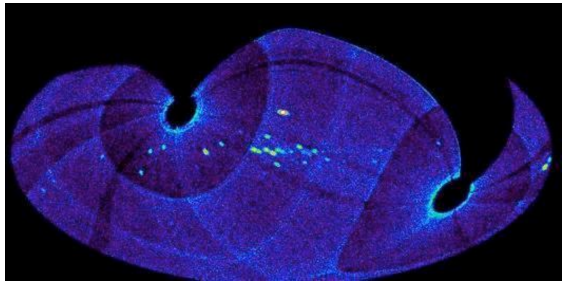
Using the ISS as a multitool laboratory

Connecting two ISS payloads using ISS infrastructure to enable science of fast transients, otherwise impossible



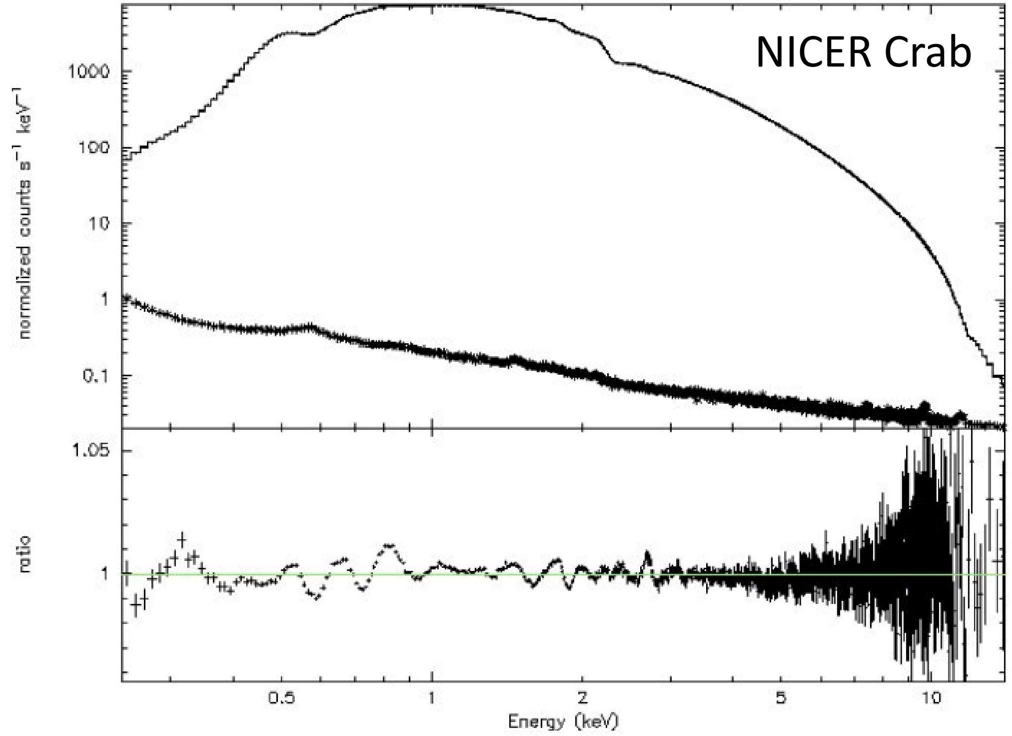
MAXI by JAXA-

- >900 deg^2 instantaneous
- *>95% of the sky each orbit*



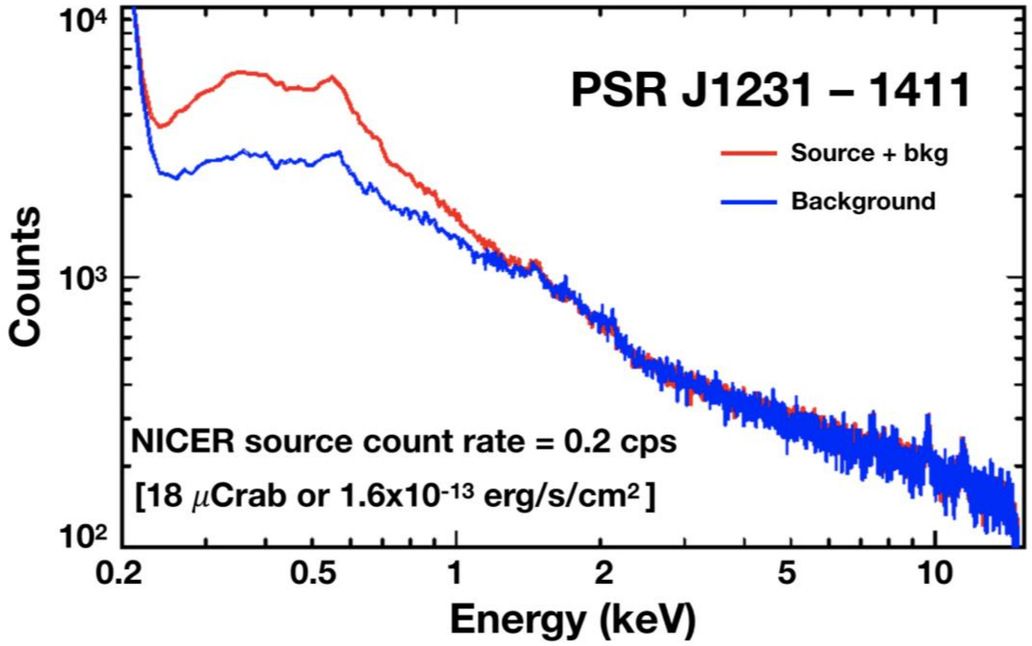
NICER Calibration Status

- NICER energy scale
  - After calibrations, all event files have "PI" column with common energy scale ("Pulse Invariant")
    - **1 PI = 10 eV** (e.g. PI = 150 means E = 1.50 keV)
    - Estimated error ~5 eV (0-10 keV)
- NICER on-axis response
  - NICER calibrated against Crab nebula as a "smooth" continuum
  - Systematic errors ~1-2% (0.4-10 keV)
  - Total effective area and slope comparable to Madsen et al. 2017 NuSTAR (within ~5%)
  - Often, **residuals are due to difficiencies in model**, not response



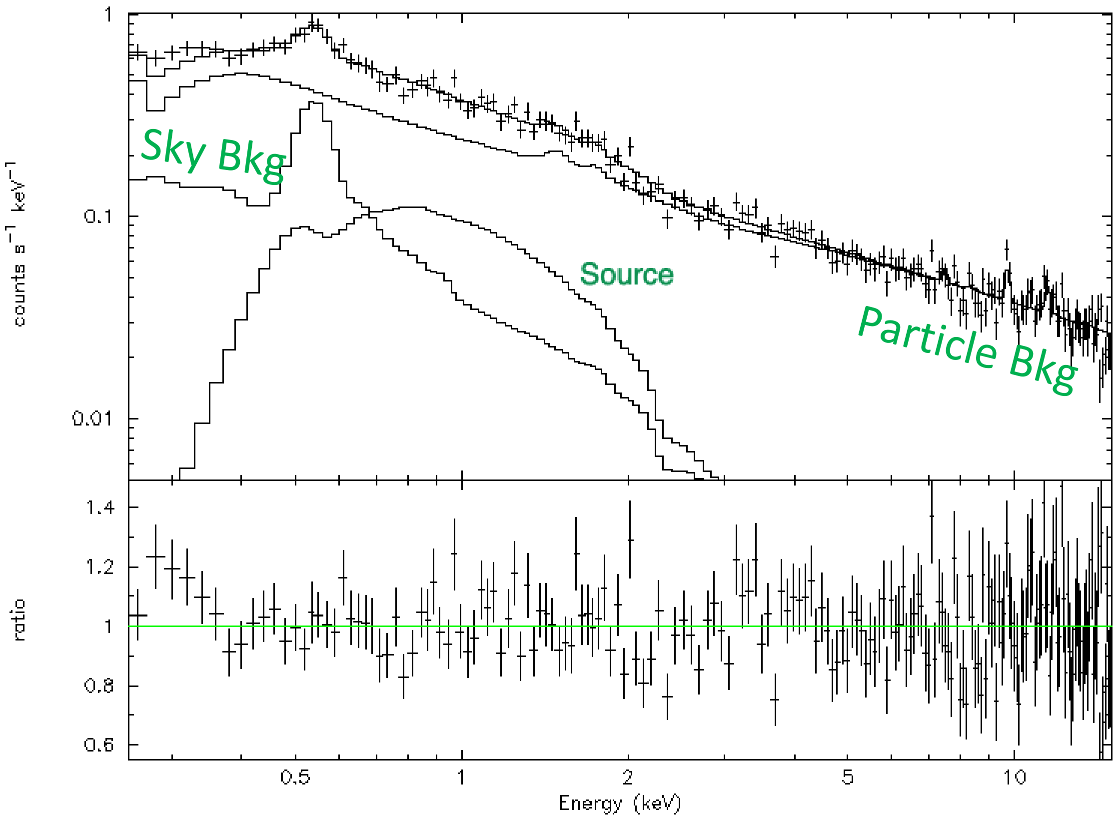
NICER Background Modeling

- NICER is an array of 52 single-pixel X-ray detectors so background must be modeled
- There are three contending background models available
  - 3C50 – popular
  - SCORPEON – new!
  - Space Weather – adjust to geomagnetic Kp



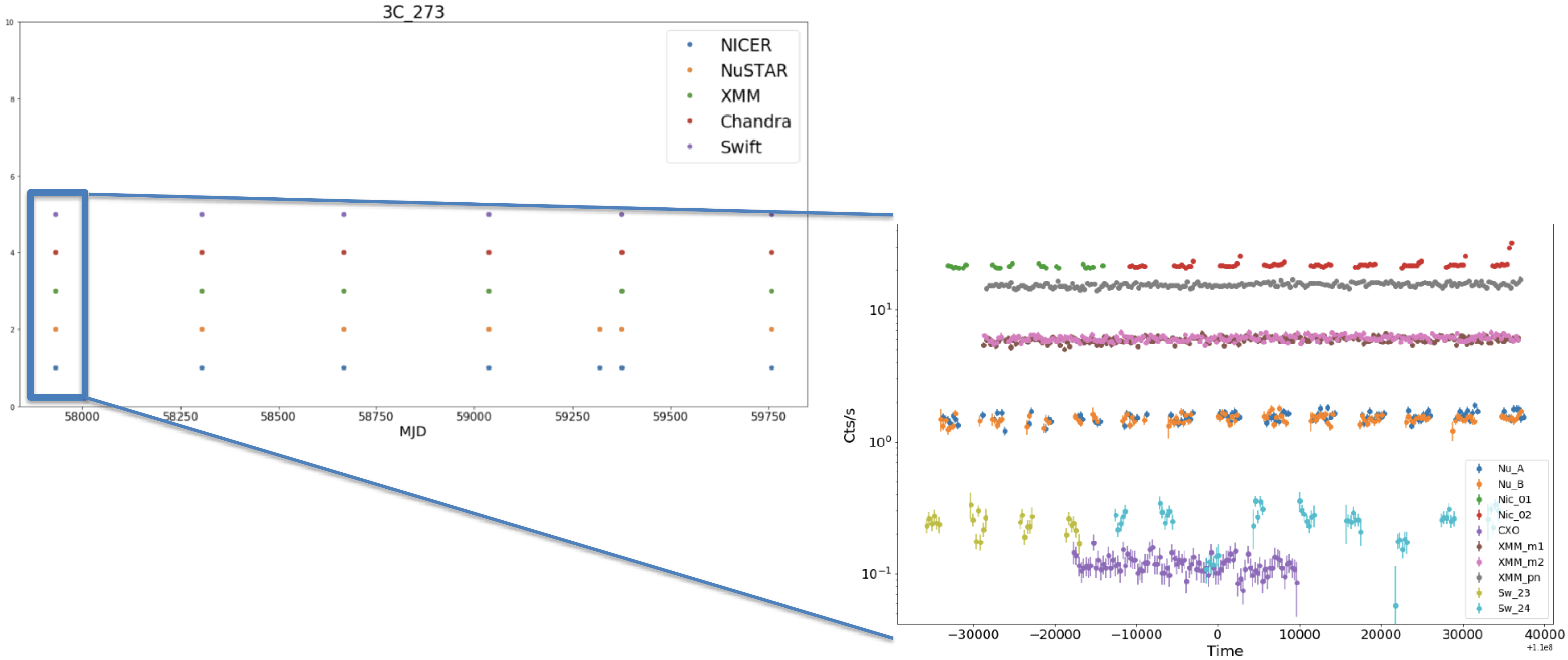
- All models now included in NICER analysis software (more tomorrow)

NICER Example Faint Source



- Flux 1-sigma range is 0.87 – 1.15 x 10^{-13} erg/s/cm^2 (~4 µCrab; compare to ~300 µCrab RXTE PCA sensitivity)

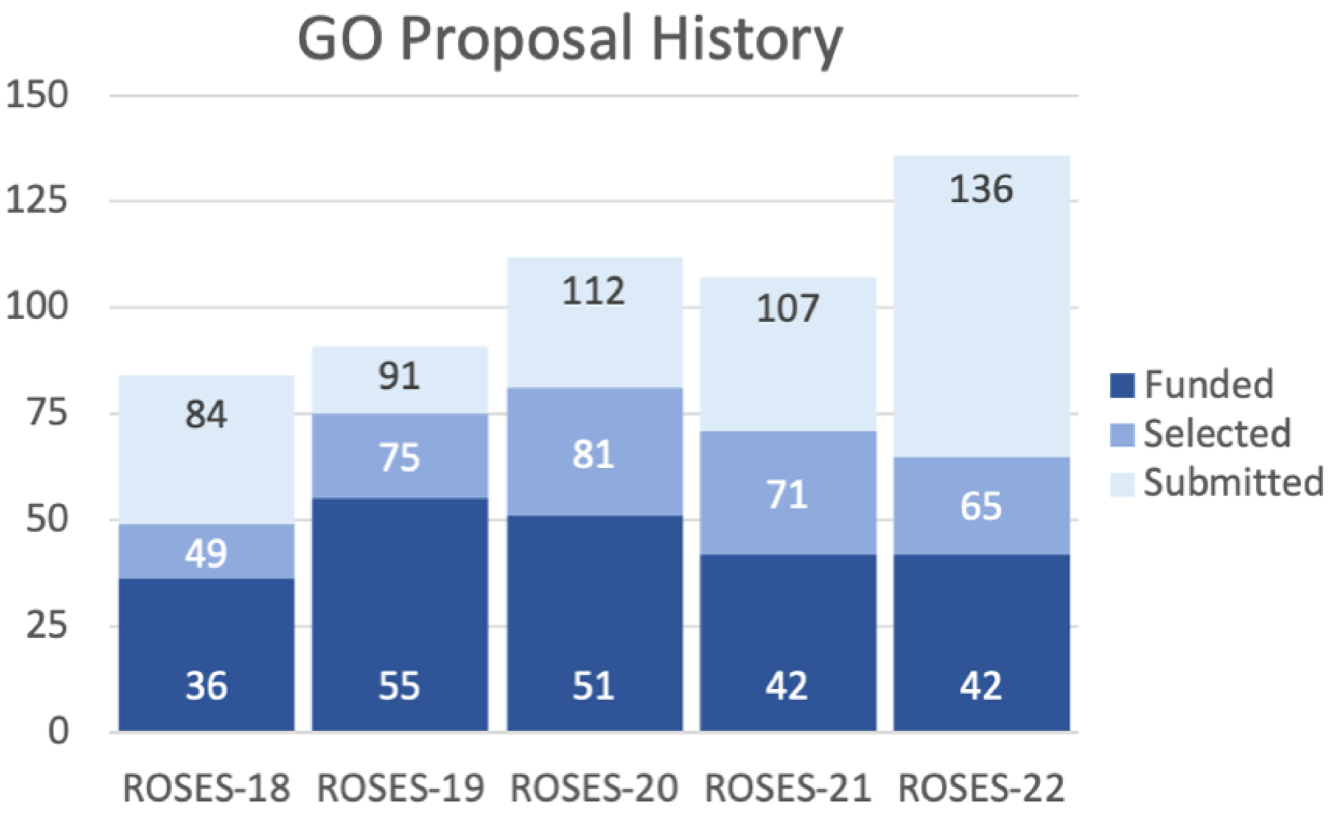
Ongoing NICER Calibration: 3C 273



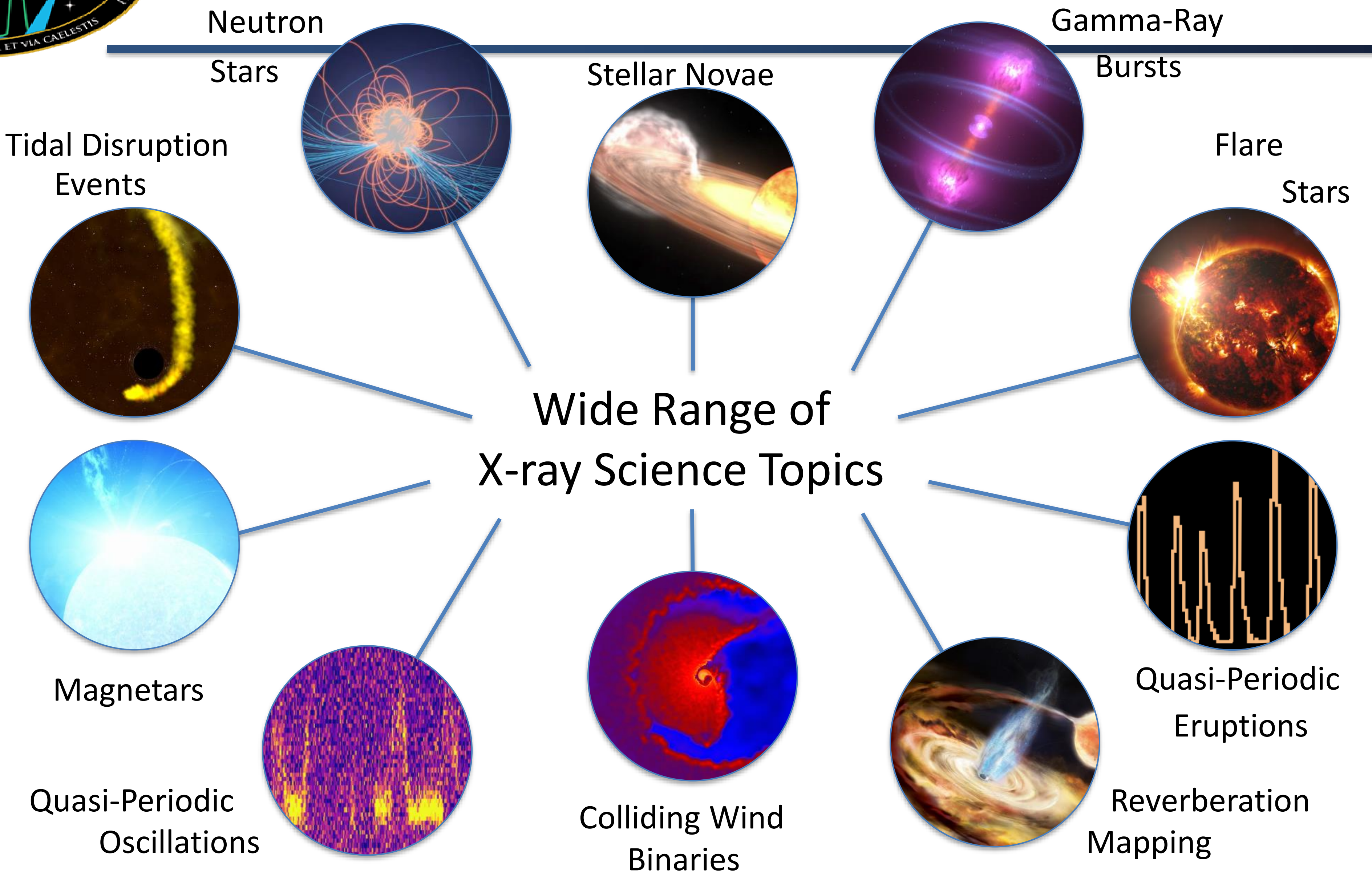
NICER's General Observer (GO) Program

- Provides small grants for data analysis and publication to PIs at US Institutions.
- Flexible observing strategy allows for many programs and long monitoring studies to run concurrently.

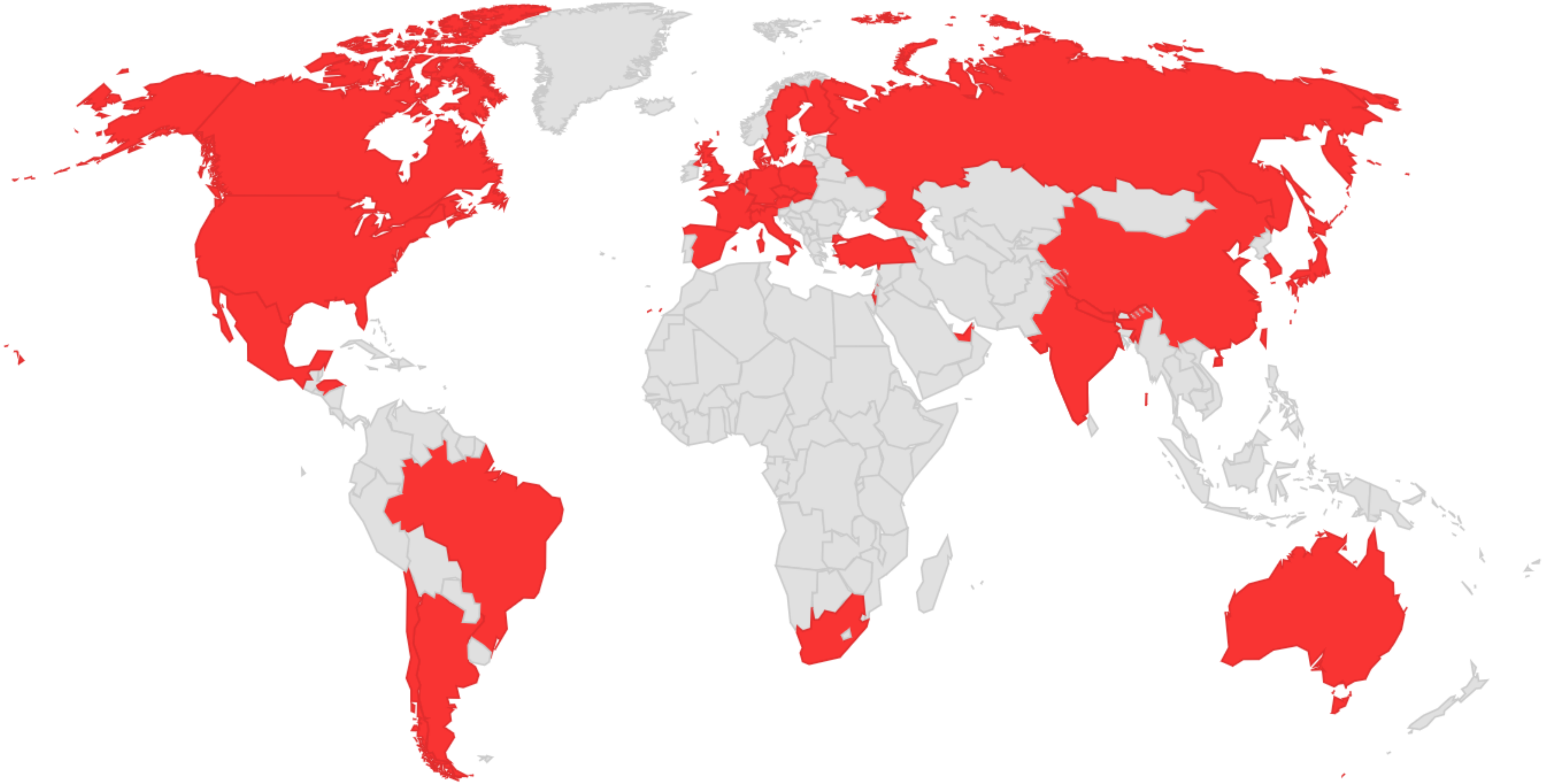
- Cycle 5 starts in March 2023.
  - Both known and unknown (ToO) targets.
  - Up to 6 months of exclusive data use, but must be justified scientifically.



NICER's General Observer (GO) Program



NICER GO Program – Global interest



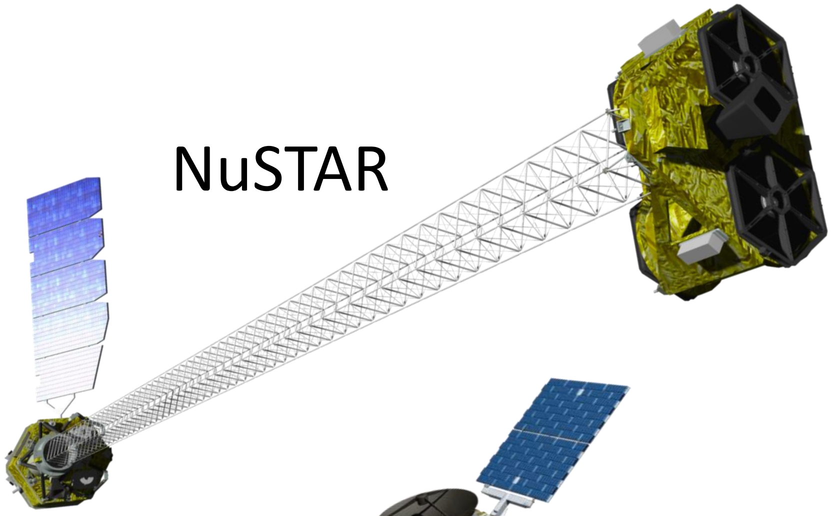
<u>NOTE:</u> Only US-based PIs are eligible for funding under the NICER GO program.

Joint GO Programs

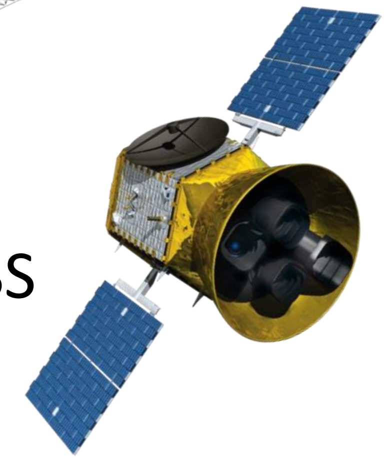
Proposers can request observations from NICER and joint observatories.

Extra space is provided to justify use of the joint program(s).

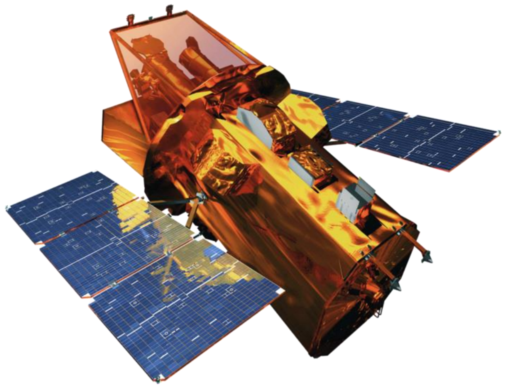
NuSTAR



TESS



NRAO



Swift

NICER's General Observer Facility

Tools available through NASA's HEASARC provide:

- Recent and upcoming observations
- Long-term and short-term target visibility
- TOO request form and history/disposition
- Data and software
- List of significant events that may have affected NICER data.
- Analysis Threads
- Guide for Proposers

Proposal Support Tools

- Please consult NICER Proposal page for more details about proposal content and submission
- Feasibility Simulation
  - HEASARC's WebPIMMS for count rates
  - HEASARC's WebSPEC for spectra
  - NICER Analysis Thread "Simulating a NICER Spectrum"
    https://heasarc.gsfc.nasa.gov/docs/nicer/analysis_threads/simulate/

NICER Target of Opportunity

Requesting Targets of Opportunity (ToOs) with NICER

NICER is capable of following up on Targets of Opportunity (ToO) within 4 hours (depending on source visibility). TOO requests should be submitted via the ARK/RPS NICER Target of Opportunity/Director's Discretionary Time Request form.

The NICER team recommends that PIs use the NICER Enhanced Visibility Calculator to check the near term (~2 weeks) visbility for their source. This tool is especially useful for planning coordinated observations.

The NICER team monitors the Gamma-ray Coordination Network (GCN)/Transient Astronomy Network (TAN).

Please review the NICER ToO Policy. Any questions regarding how to make TOO requests should be sent to the NICER Helpdesk via the HEASARC's Feedback Form.

NICER ToO Request Summary

Category - MAG_RPP: Magnetars and Rotation-Powered Pulsars, XB: X-ray Binaries, WD_CV: White Dwarfs and Cataclysmic Variables, NC_STAR: Non-Compact Stellar Objects, SNR_EGS: Supernovae Remnants and Other Extended Galactic Sources, N_GAL: Normal Galaxies, AGN_QSO: Active Galaxies and Quasars, GC_EGEO: Galaxy Clusters and Extragalactic Extended Objects, GWS: Gravitational-Wave Sources, SSO: Solar System Objects, RP_NS: Rotation-Powered Neutron Stars, MAG: Magnetars, STAR_OGS: Stars/Cataclysmic Variables/Other Galactic Sources, BH: Black Holes, SN: Supernovae, EGAL_XS: Extended Galactic X-ray Sources, XP_NS: X-Ray Pulsars and Neutron Stars, OC: Other

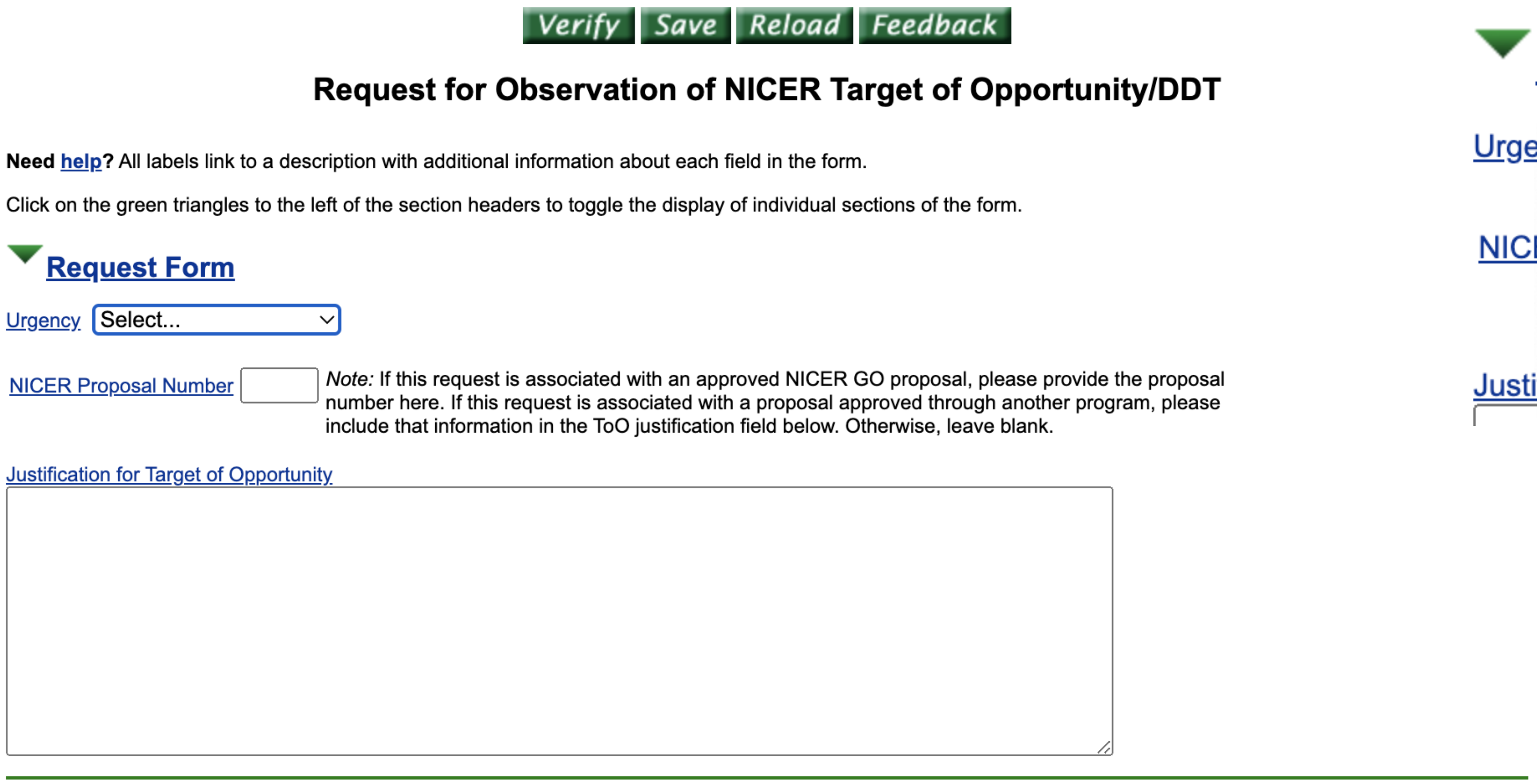
Tables Last Modified: 2023-02-01T11:27:18 UTC-0500

Click the column headings to sort

ID	Request Time UTC	PI (Last, First)	Target	Category	Target No.	RA (J2000)	Dec (J2000)	Exp (ks)	Disposition	Status
44887	2023-01-27 23:01:34	JENKE, PETER	GRO J2058+42	XB	5060	314.69874	41.77432	10	Accepted	Executing
44825	2023-01-26 19:39:07	RANI, BINDU	0313-192	AGN_QSO	5361	48.96708	-19.11233	6	Accepted	Executing
44677	2023-01-25 18:39:39	GUOLO, MURYEL	SWIFT J0230+28	OC	5282	37.57120	28.60120	14	Accepted	Executing
44635	2023-01-24 23:44:45	ALTAMIRANO, DIEGO	XTE J2012+381	XB	5356	303.15733	38.18355	60	Accepted	Executing
44629	2023-01-24 16:02:19	HOMAN, JEROEN	XTE J1701-462	XB	5335	255.24358	-46.18572	60	Accepted	Executing
44627	2023-01-24 15:23:47	RANI, BINDU	4C +29.45	AGN_QSO	5219	179.88264	29.24551	15	Accepted	Executing
44602	2023-01-20 16:55:25	ARCODIA, RICCARDO	ERASST_J044534-10120	N_GAL	5360	71.39085	-10.20131	56	Accepted	Executing
44590	2023-01-18 19:27:42	WANG, YANAN	AT 2019AVD	OC	5175	125.90320	4.38400	1	Accepted	Complete

https://heasarc.gsfc.nasa.gov/docs/nicer/schedule/nicer_too_request.html

NICER Target of Opportunity


Verify Save Reload Feedback

Request for Observation of NICER Target of Opportunity/DDT

Need help? All labels link to a description with additional information about each field in the form.

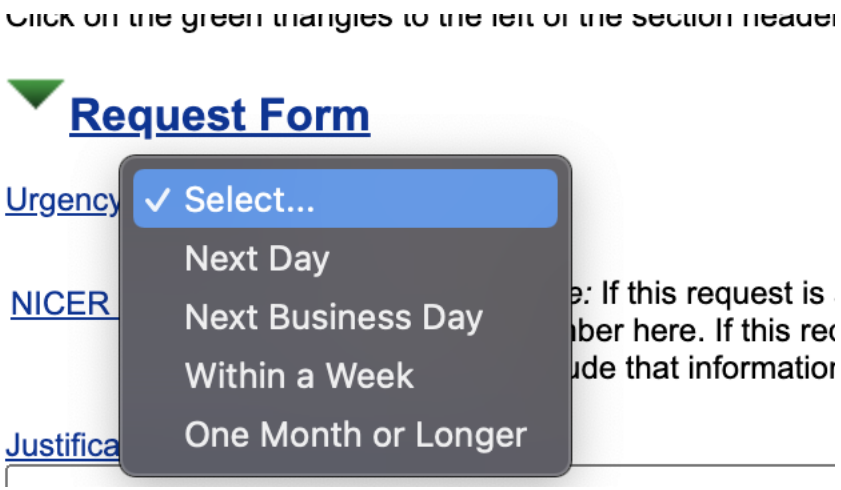
Click on the green triangles to the left of the section headers to toggle the display of individual sections of the form.

Request Form

Urgency Select...

NICER Proposal Number *Note:* If this request is associated with an approved NICER GO proposal, please provide the proposal number here. If this request is associated with a proposal approved through another program, please include that information in the ToO justification field below. Otherwise, leave blank.

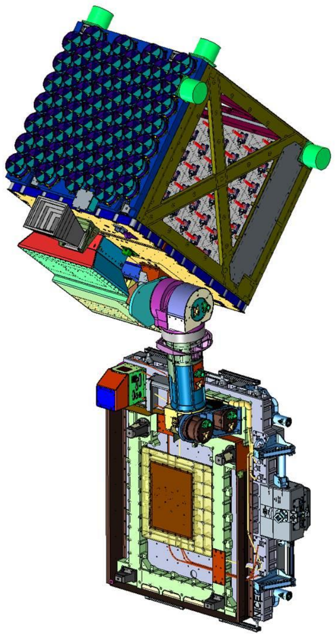
Justification for Target of Opportunity



NICER/Swift Target of Opportunity

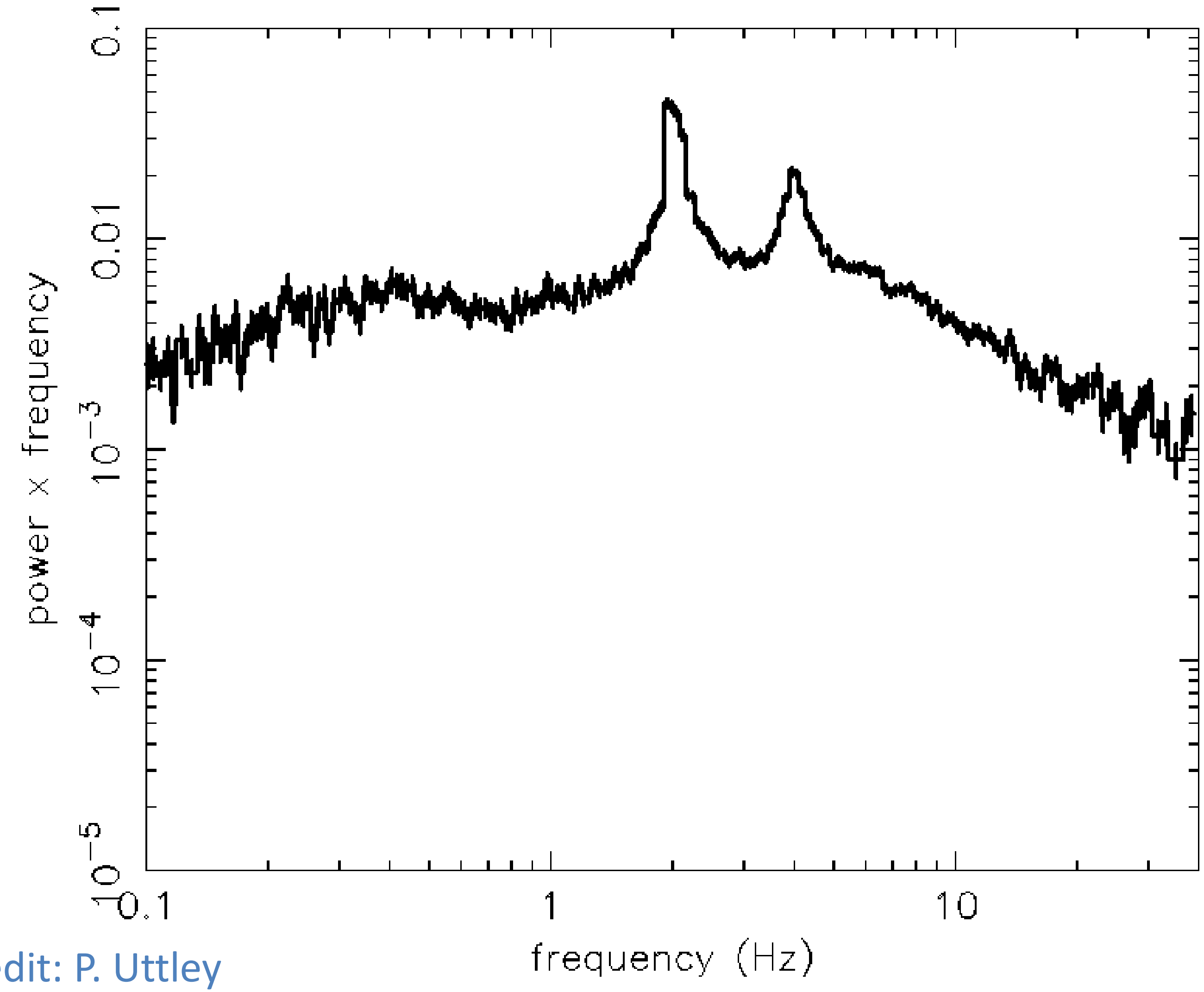
- Developing joint NICER/Swift-XRT TOO request capabilities

- TOO requests will be observed by Swift or NICER based on observability/schedule/brightness



Thanks! Questions?

MAXI J 1535-571 QPO Evolution



Credit: P. Uttley

BACKUP

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.

>50% overall efficiency.