NICER Mission on the ISS and Initial Results of Magnetars

T. Enoto (Kyoto University)
Z. Arzoumanian, K. Gendreau,
and NICER Science Team

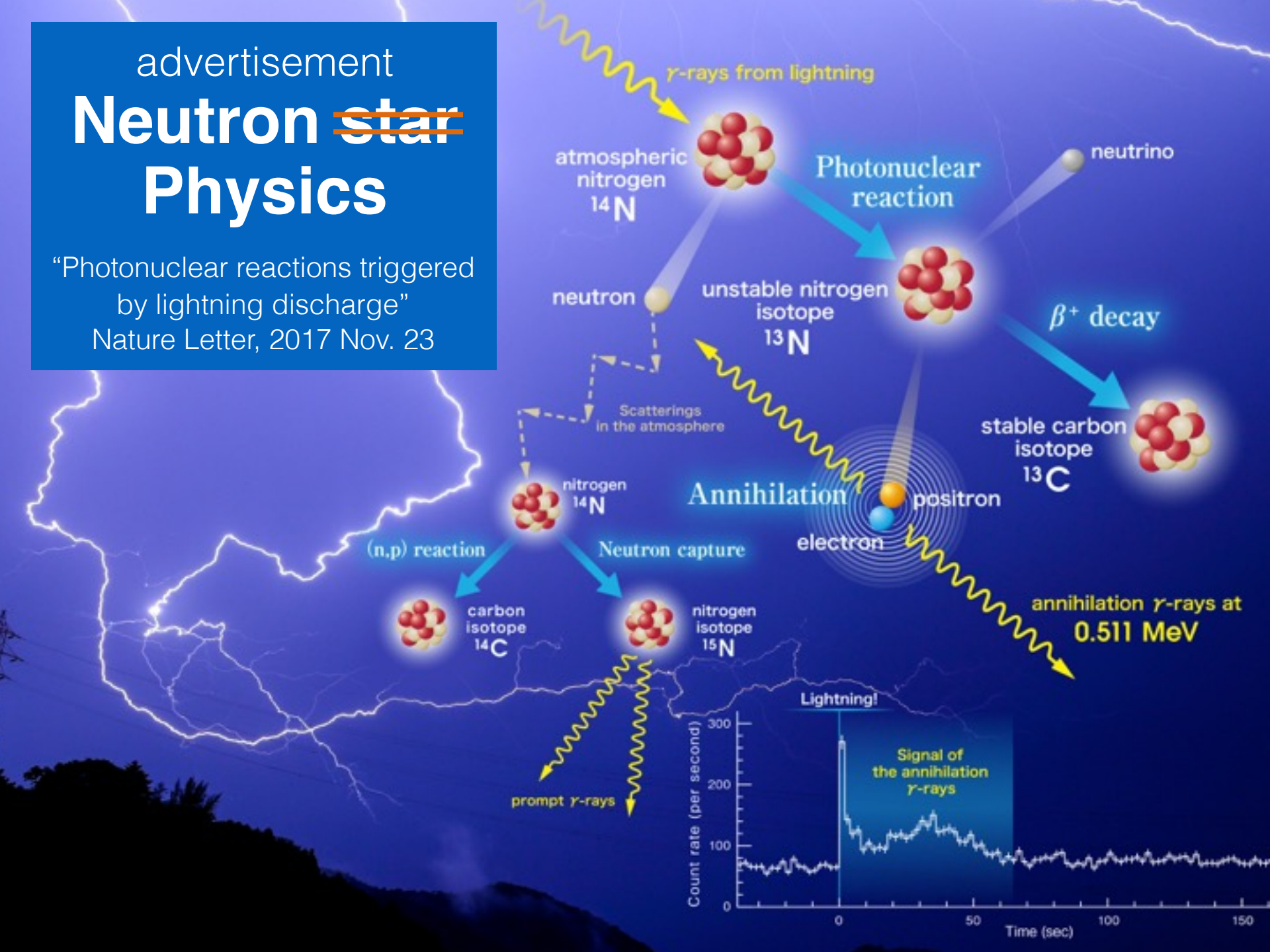
中性子星の観測と理論: 研究活性化ワークショップ2017
2017年11月25日＠国立天文台

June 3, 2017
SpaceX CRS-11
Cargo Mission Launch
Photo Credit: (NASA/Bill Ingalls)

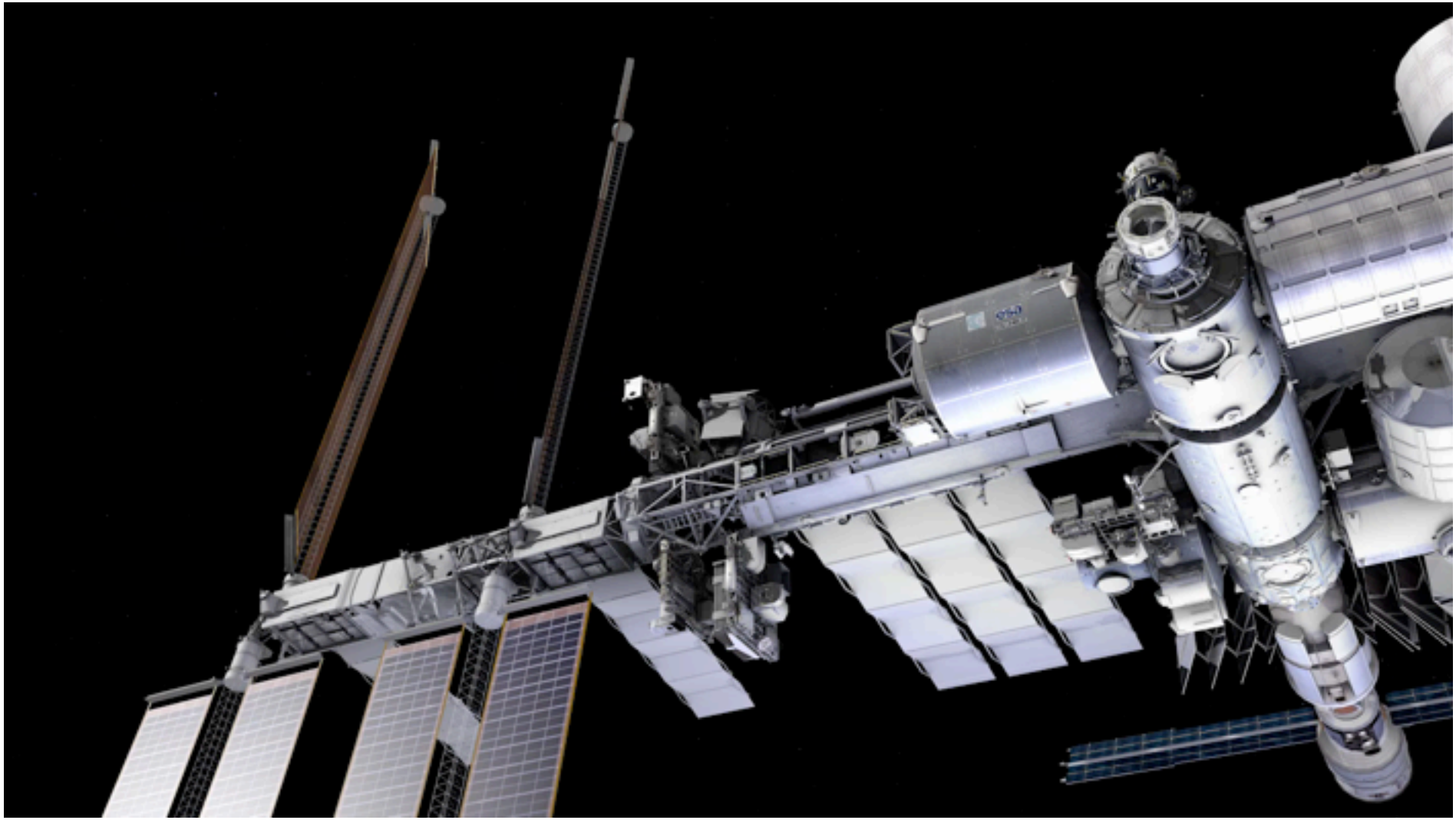
advertisement

Neutron ~~star~~ Physics

"Photonuclear reactions triggered by lightning discharge"
Nature Letter, 2017 Nov. 23

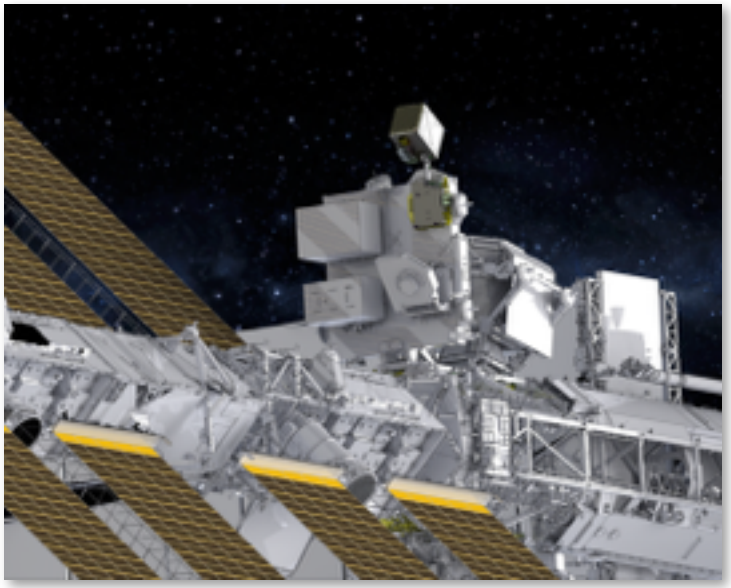


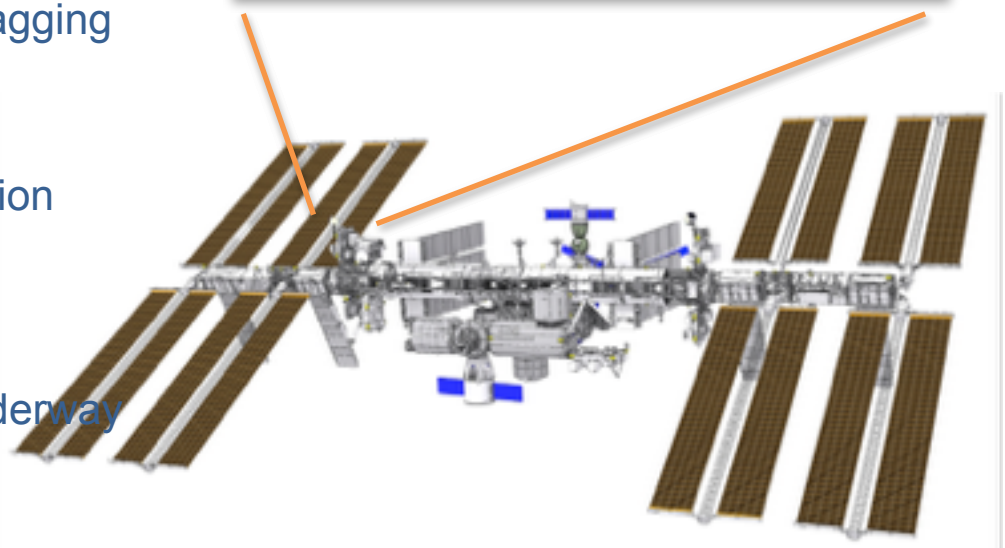
NICER at home on ISS



NICER/SEXTANT — Overview

- ***PI:*** Keith Gendreau, NASA GSFC
- ***Science:*** Neutron star structure, dynamics, & energetics through soft X-ray timing spectroscopy
- ***Launched***: June 3, 2017, SpaceX-11 resupply
- ***Platform:*** ISS external attached payload with active pointing
- ***Duration:*** 18 months baseline science mission; likely GO extension
- ***Instrument:*** 0.2–12 keV "concentrator" optics, silicon-drift detectors, GPS absolute time tagging and position
- ***Enhancements:***
  - Demonstration of pulsar-based navigation
  - PI discretionary & ToO time
- ***Status:***
  - Installed on ISS June 13, 2017
  - Commissioning complete, Phase E underway

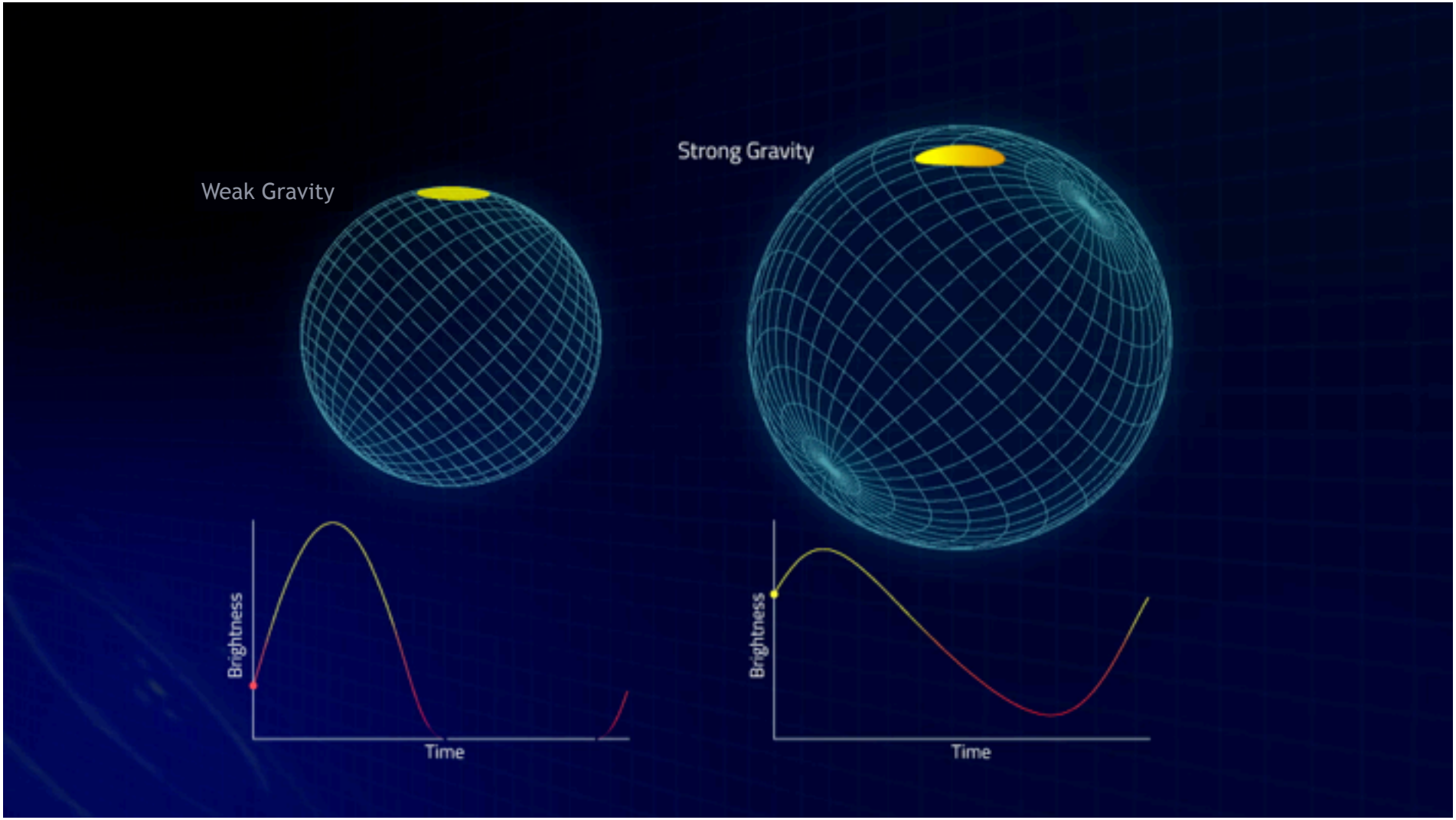




Courtesy: Gendreau & Arzoumanian

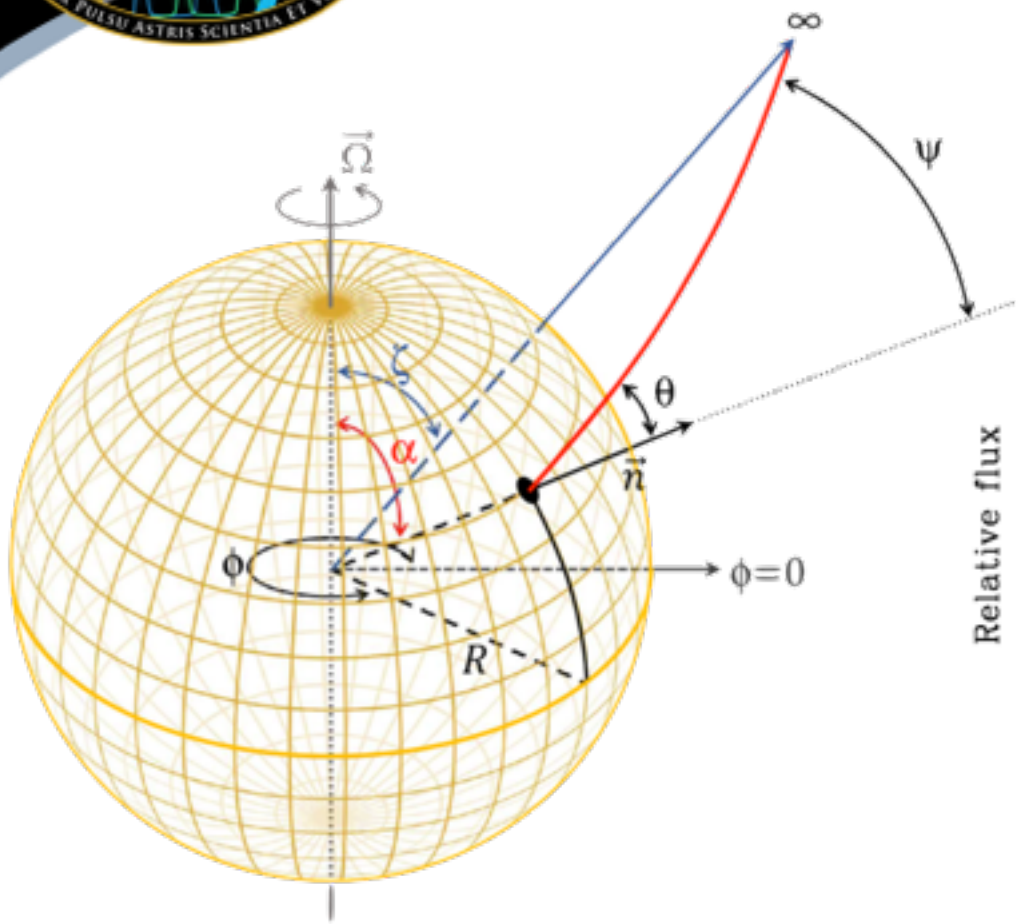
Modeling surface emission to infer M-R

Gravitational light-bending saves the day!

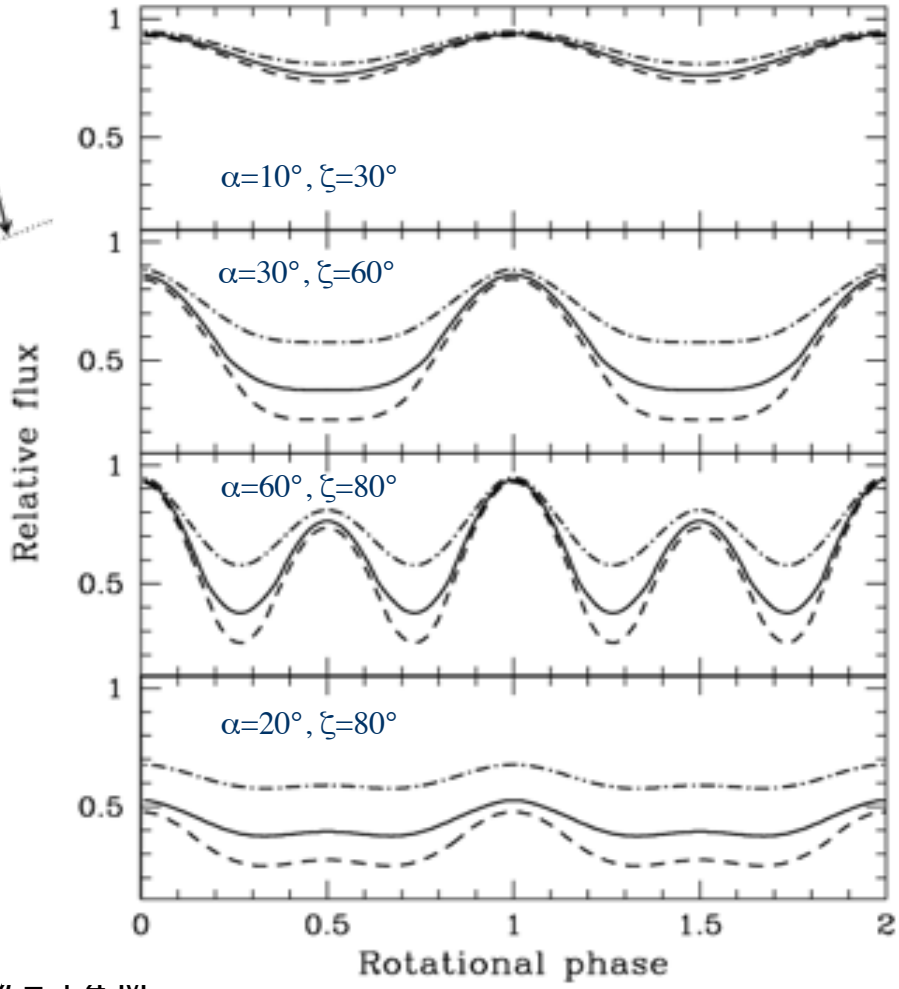


Courtesy: Gendreau & Arzoumanian

Inferring neutron star radii through lightcurve modeling — geometry



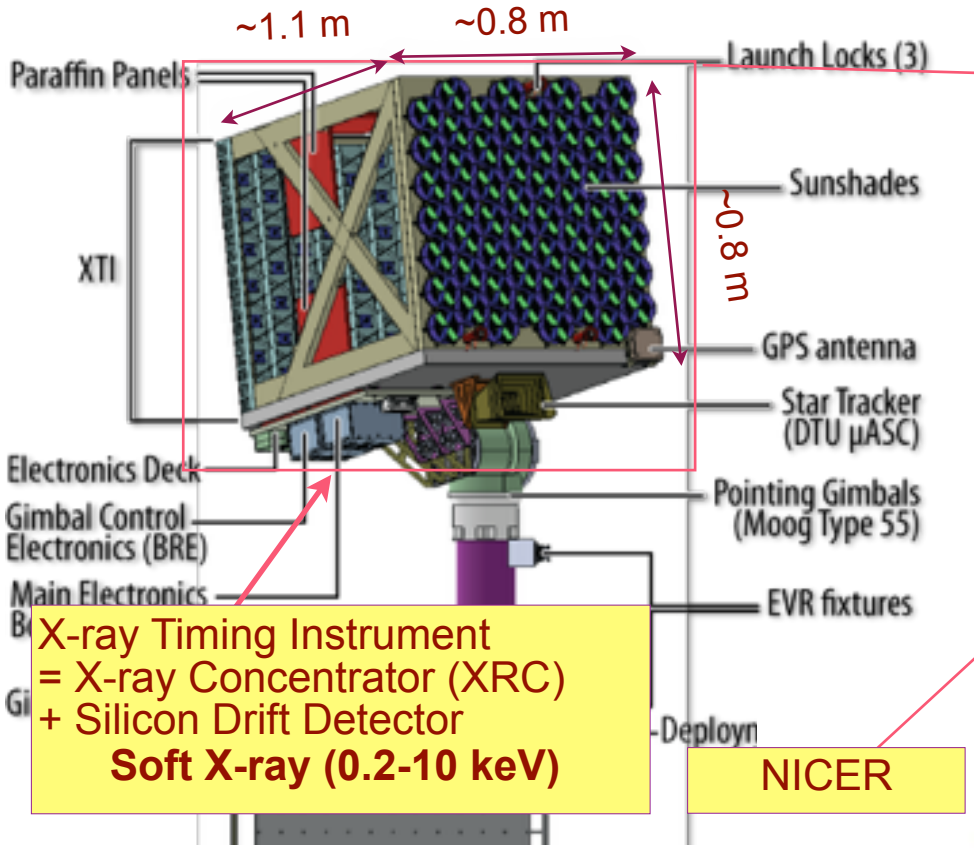
Bogdanov, Rybicki, & Grindlay, *ApJ*, 670, 668 (2007)



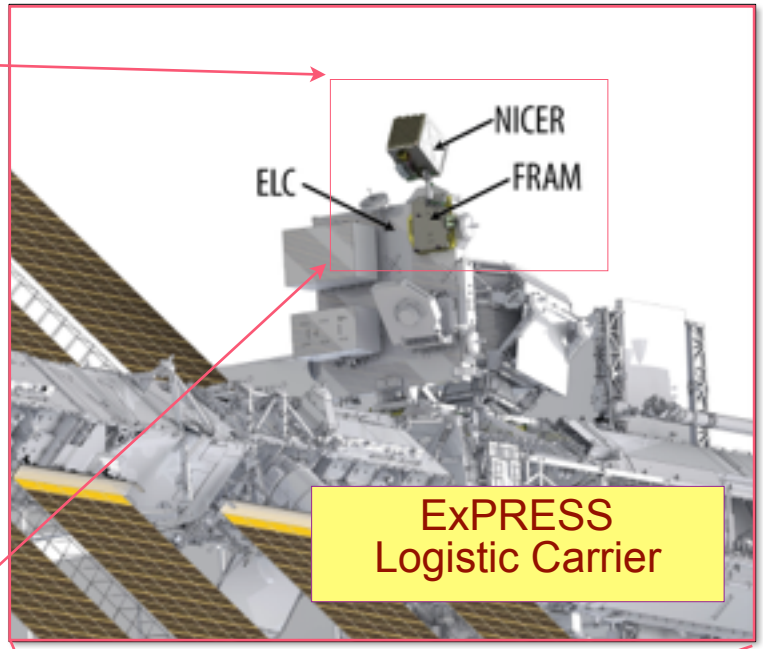
9 km
12 km
16 km
} for M = 1.4 $M_\odot$

Courtesy: Gendreau & Arzoumanian

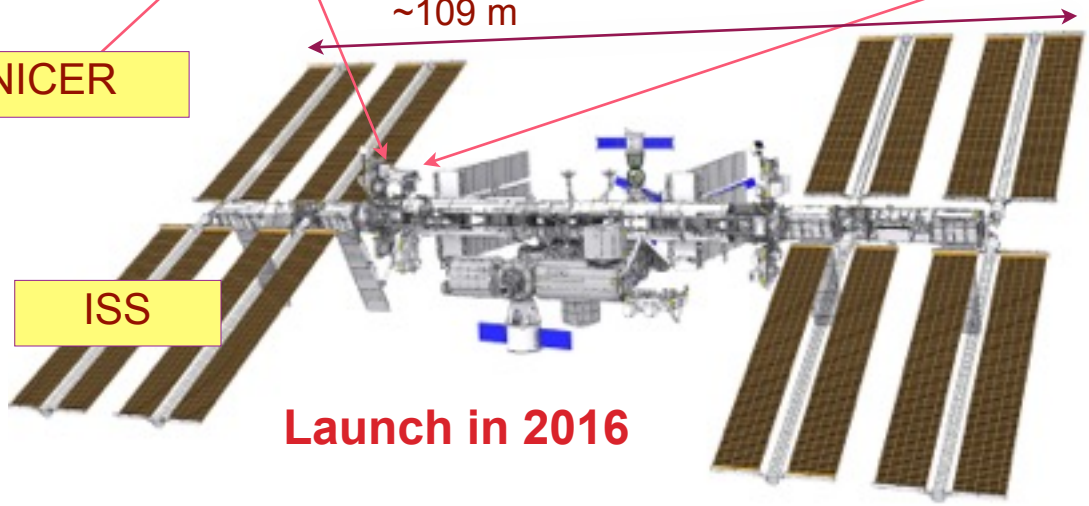
NICER X-ray Observatory



X-ray Timing Instrument
= X-ray Concentrator (XRC)
+ Silicon Drift Detector
Soft X-ray (0.2-10 keV)



NICER

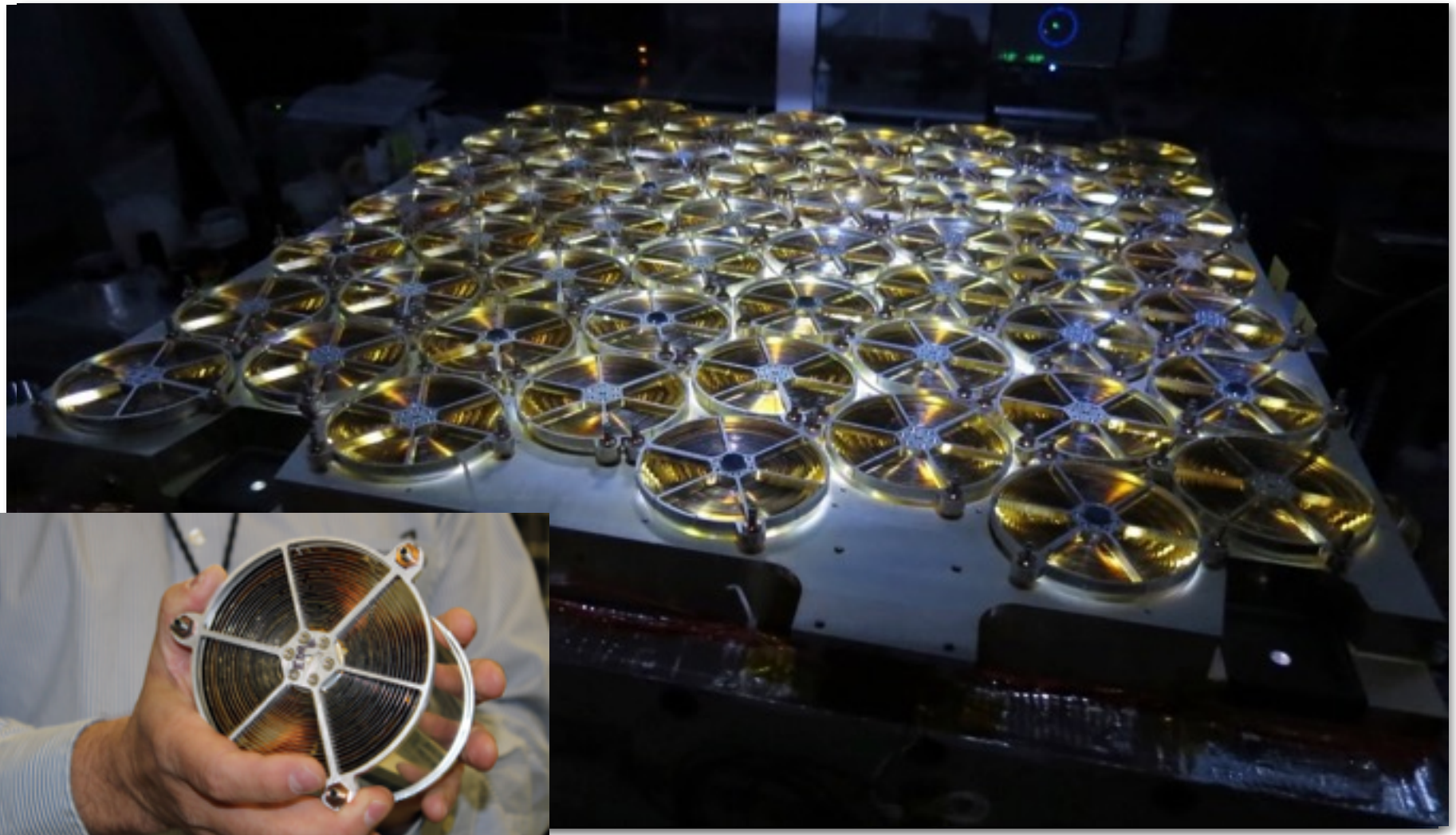


- Large effective area (x2 of XMM-Newton at 1.5 keV)
- High time resolution (<300 ns time tag)

Launch in 2016

X-ray Concentrator optics

Single reflection, grazing-incidence nested gold-coated Al foils

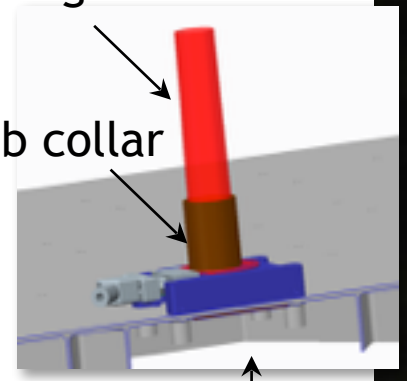


Courtesy: Gendreau & Arzoumanian

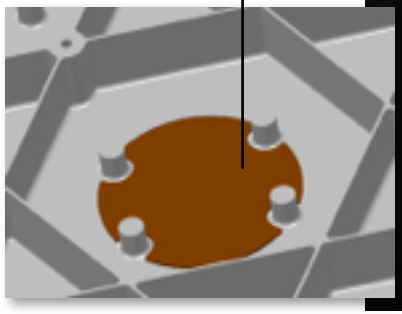
Detector plate

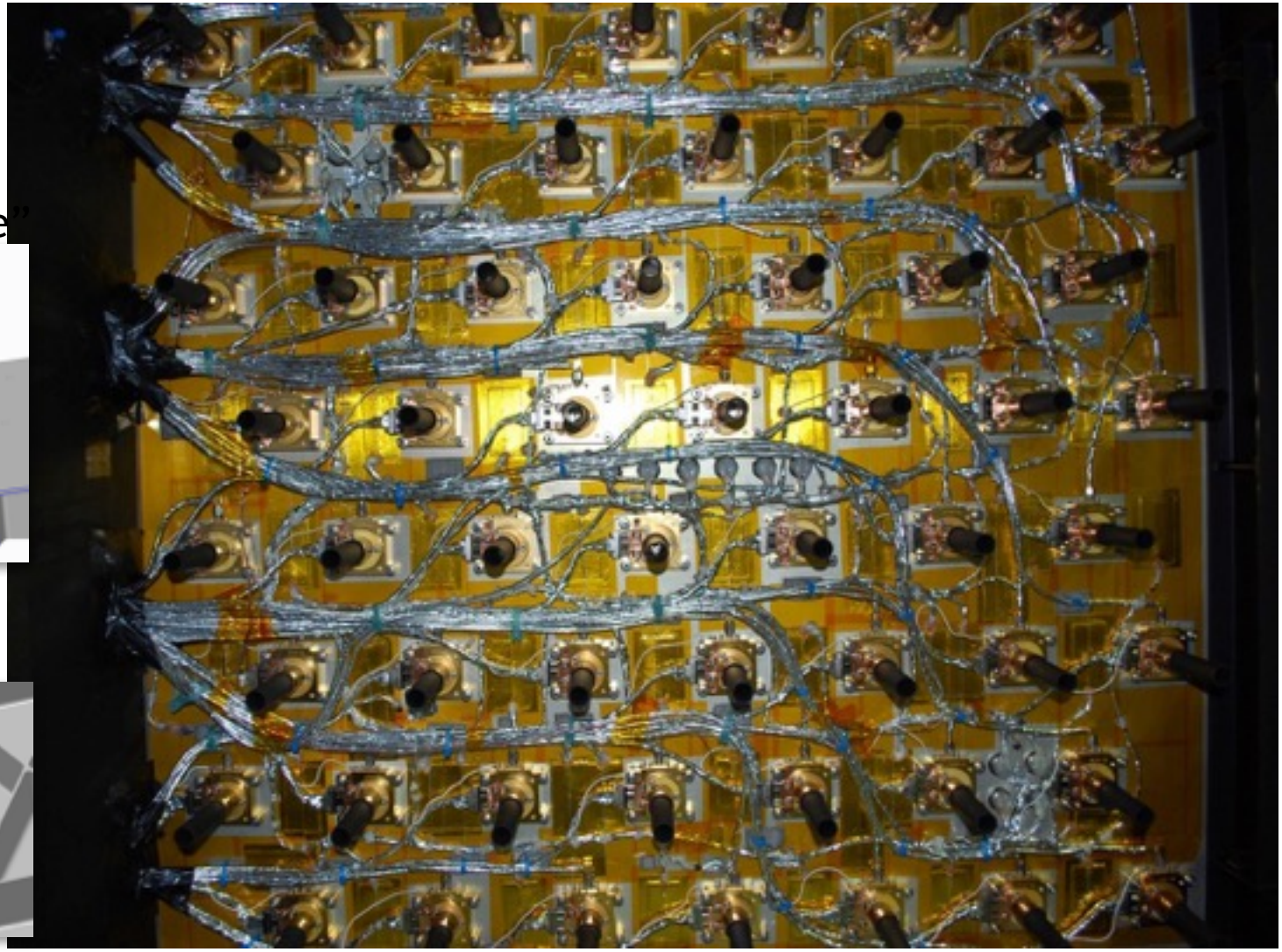
Radiation shielding

Au/Ag “traffic cone”



Pb disk



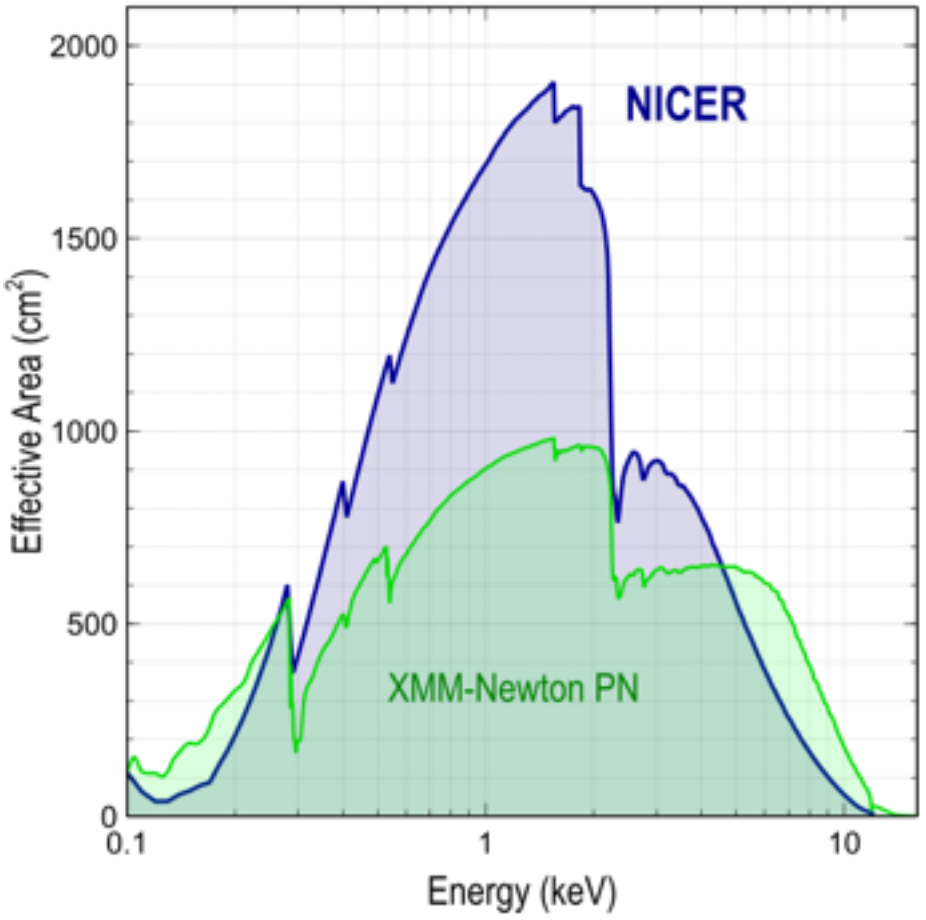


Courtesy: Gendreau & Arzoumanian

X-ray Timing Instrument (XTI) capabilities

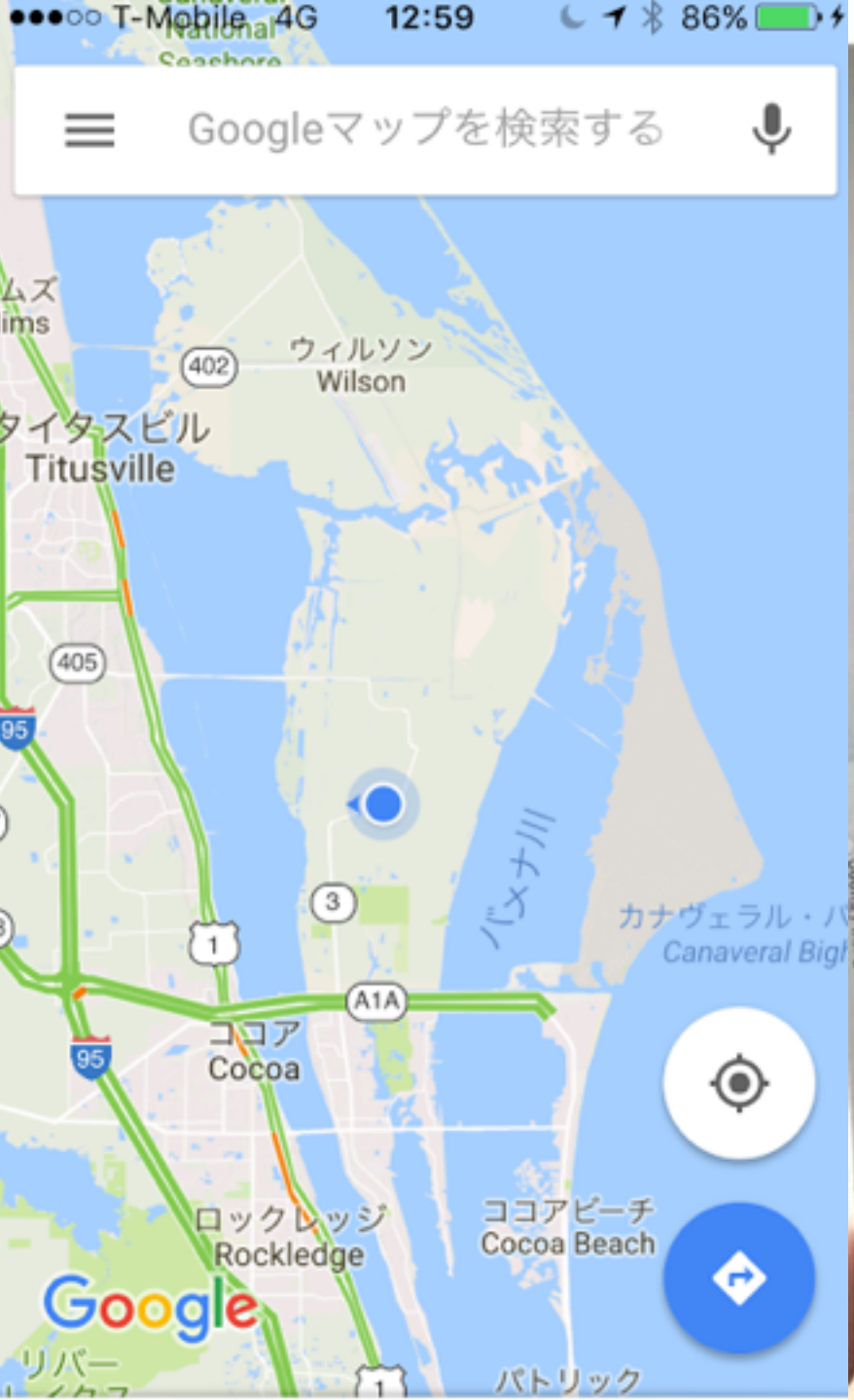
A novel combination of sensitivity, timing, and energy resolution

- Spectral band: 0.2–12 keV
- Timing resolution: < 100 nsec RMS absolute
- Energy resolution: 140 eV @ 6 keV
- Non-imaging FOV: 6 arcmin diameter
- Background: < 0.5 cps
- Sensitivity, 5σ: 1 x 10^{-13} erg/s/cm^2
  - 0.5–10 keV, 10 ksec (Crab-like)
  - ~3x better than XMM-*Newton*'s timing capability (PN clocked)
- Max countrate: ~38,000 cps (3.5 Crab)
  - Deadtime accounted for in telemetry



Gendreau et al., SPIE (2012), Arzoumanian et al., (2014)

Launch! 2017 June 3


T-Mobile 4G
12:59
86%
Googleマップを検索する
ウィルソン
Wilson
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Titusville
402
405
95
3
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バメナ川
カナヴェラル・バ
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ココア
Cocoa
ロックレッジ
Rockledge
ココアビーチ
Cocoa Beach
パトリック
Google


SPACEX
SPACEX
CRS-11
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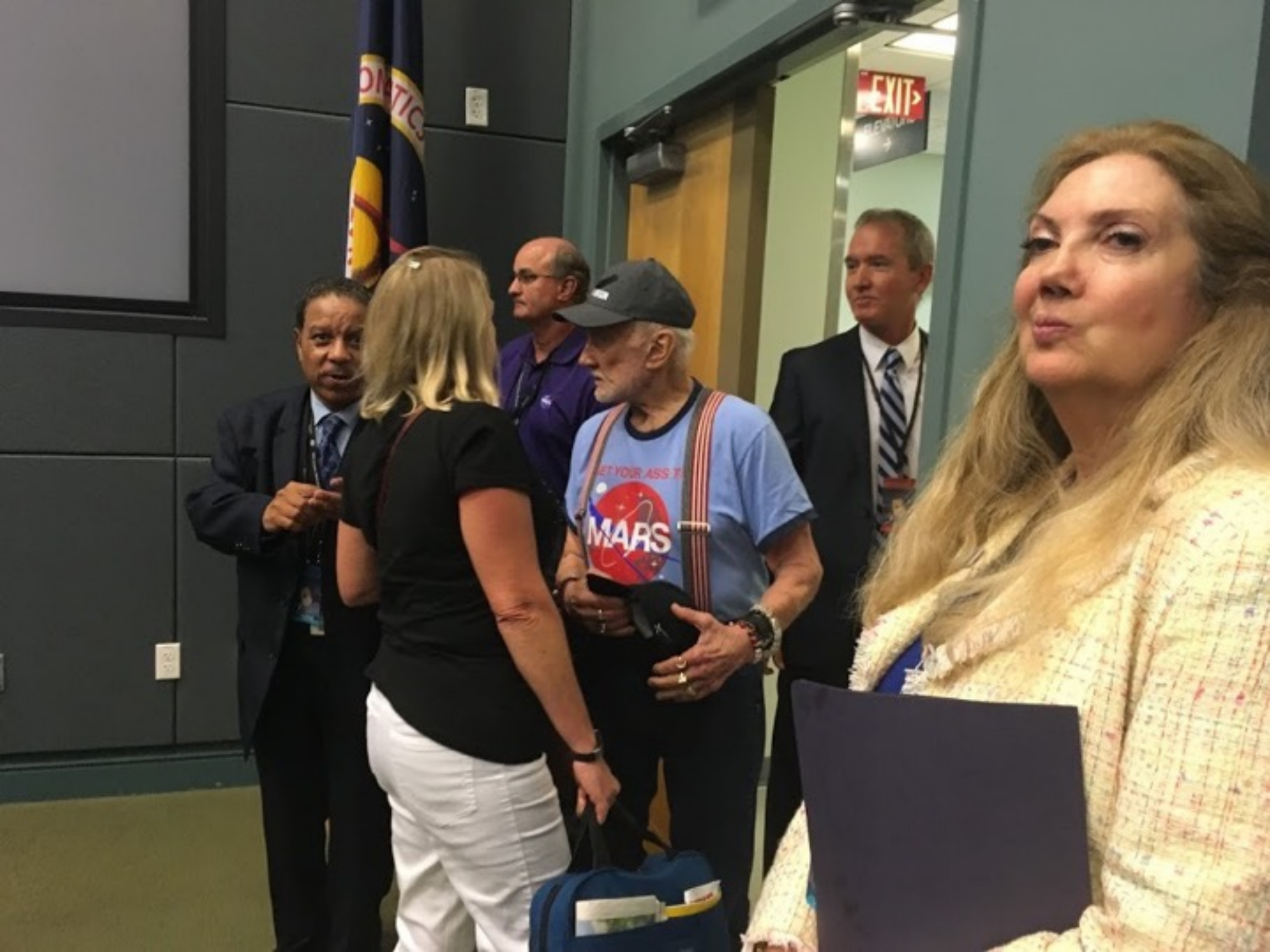

EXIT
MARS


NASA


NASA

Launch! 2017 June 3

SpaceX CRS-11 Cargo Mission Launch
June 3, 2017
Photo Credit: (NASA/Bill Ingalls)


Salt
Restaurant & Lounge
SPACEX
EXIT
PRIVATE
EVENT


PRIVATE
PARTY
SPACE X

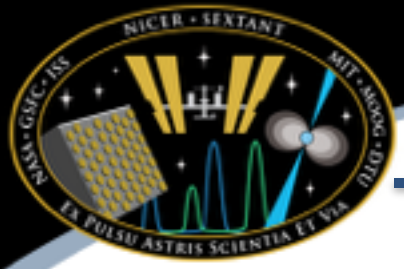
Transport and installation (cont.)

Dragon and NICER proceed to ISS transfer orbit

Transport and installation (cont.)

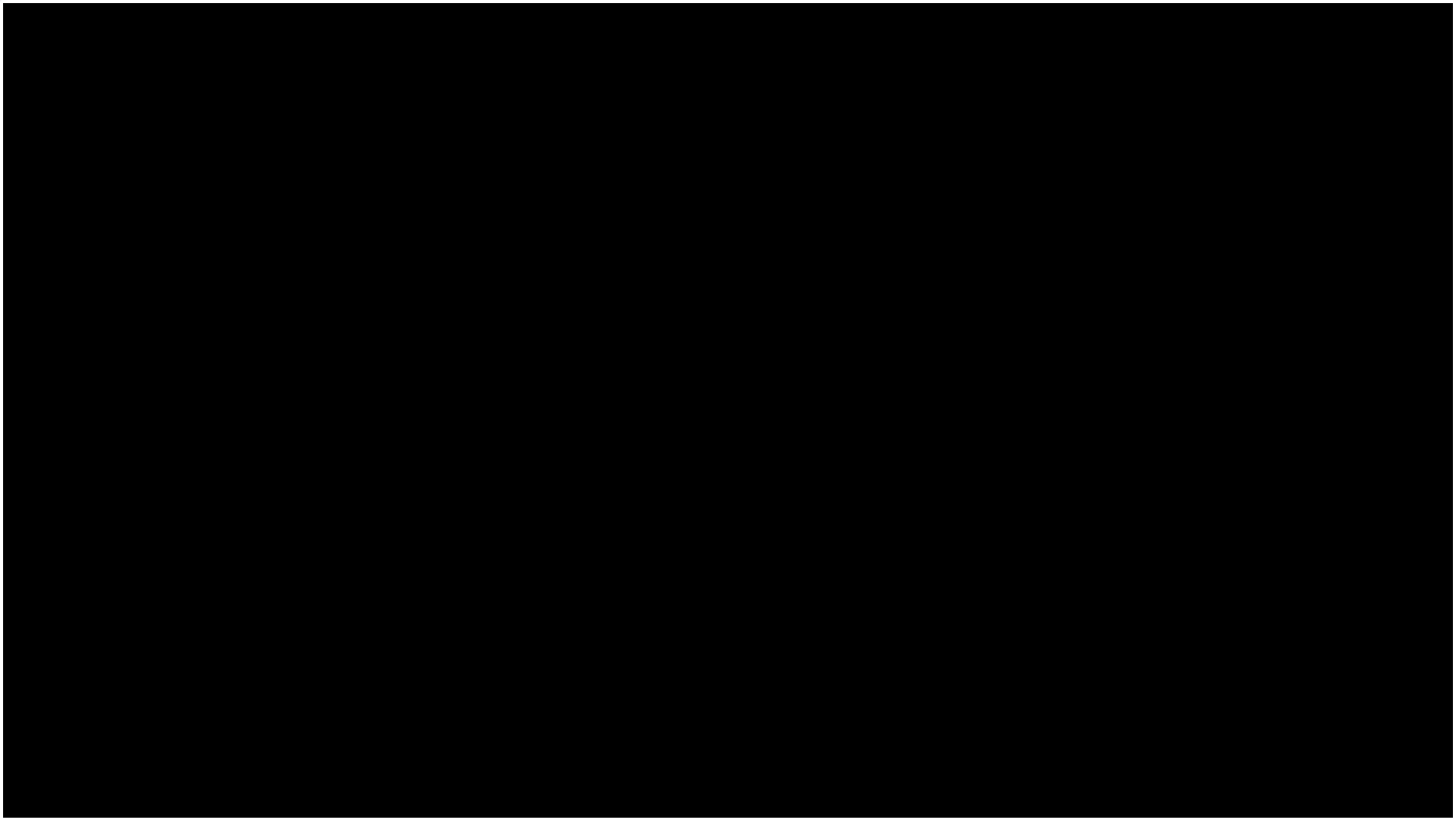
Extraction from Dragon was delicate…

Courtesy: Gendreau & Arzoumanian



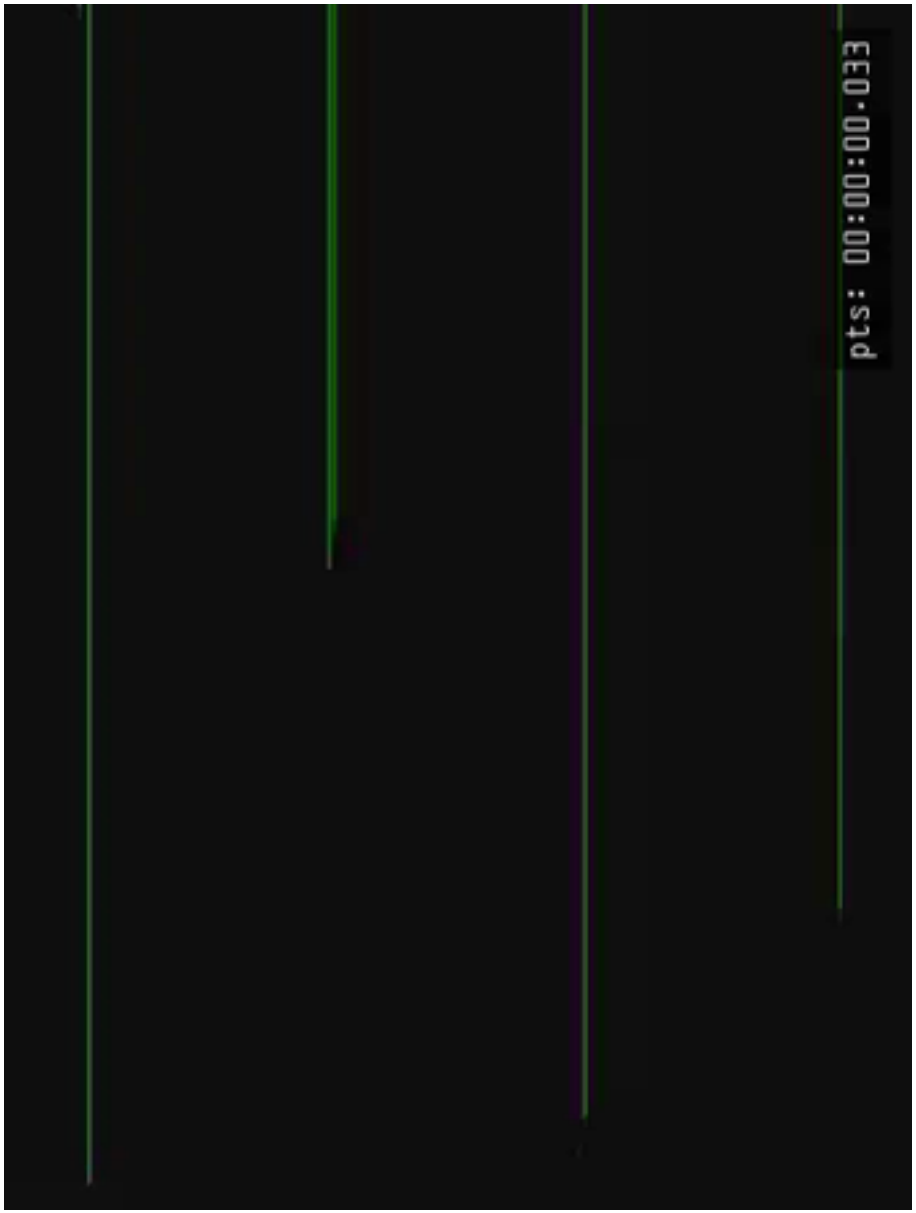
Installation and Deployment

… but not nearly as complicated as robotic installation!



Courtesy: Gendreau & Arzoumanian

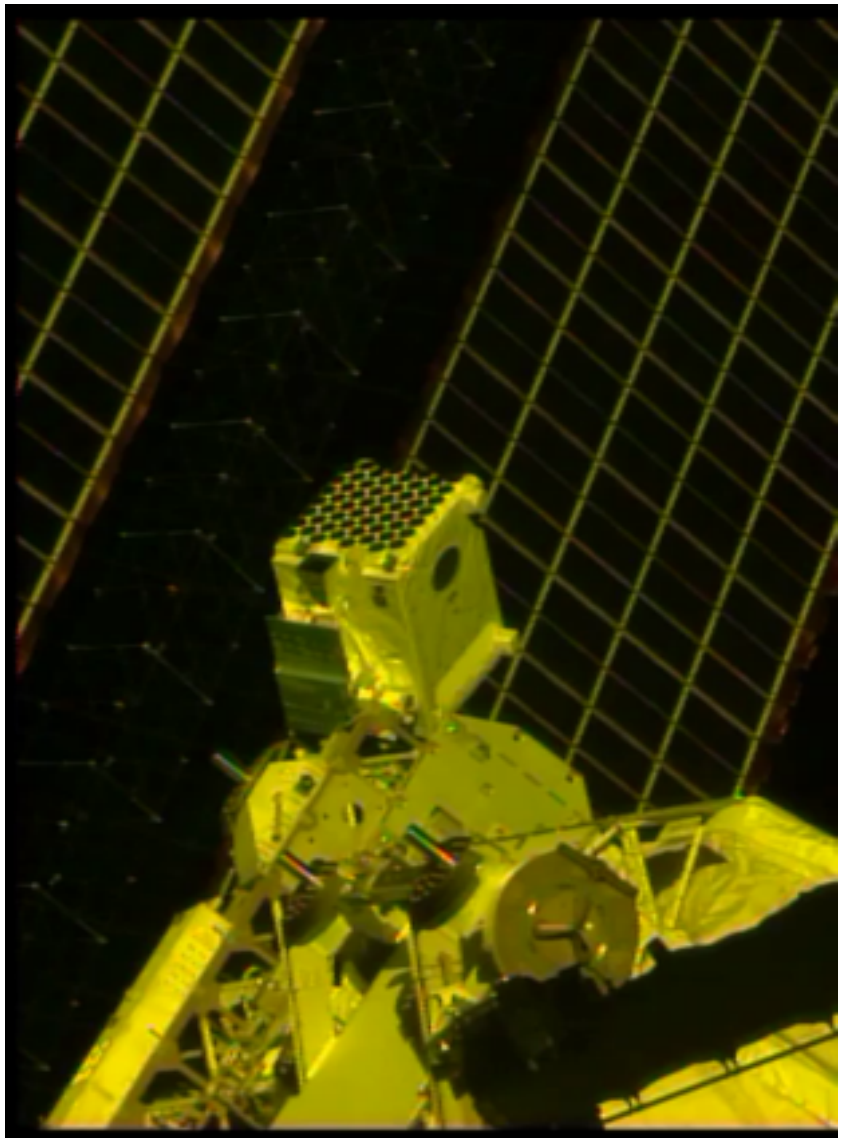
Range of motion test

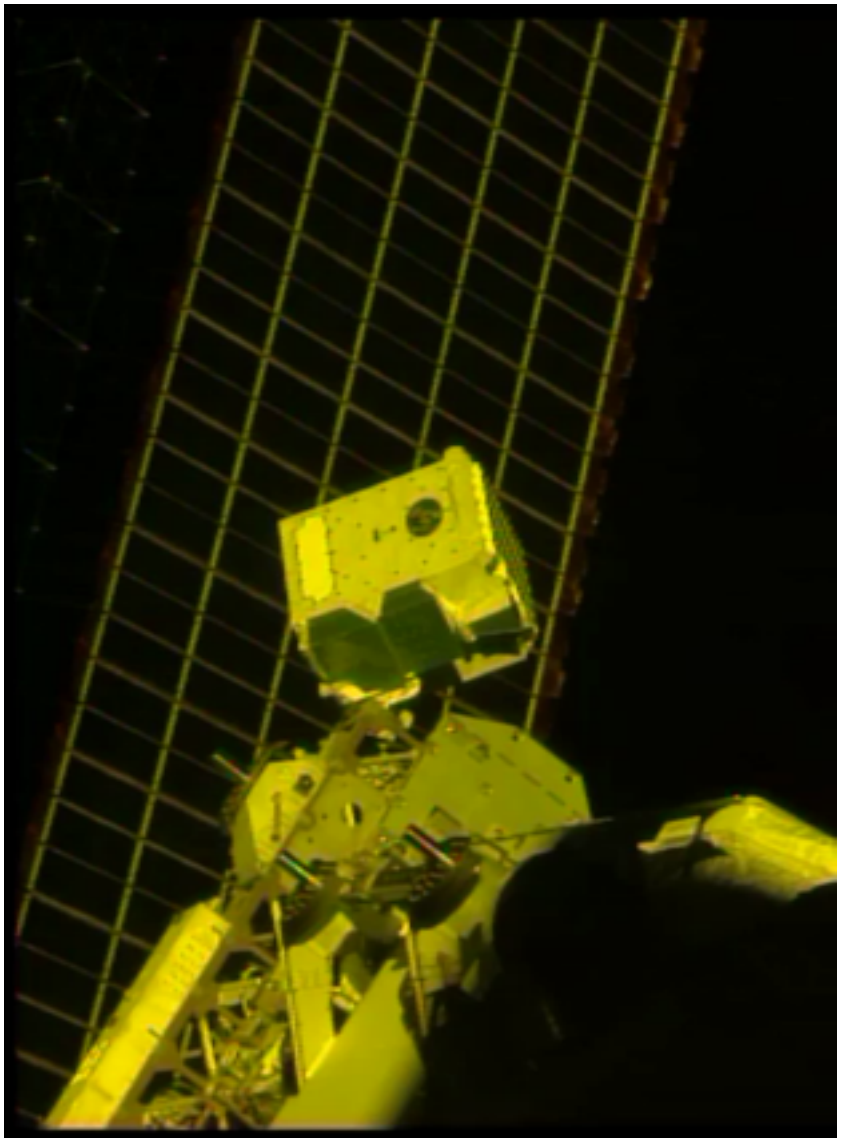


Courtesy: Gendreau & Arzoumanian

Watch NICER collect your photons!

Occasional / on-demand live ISS video

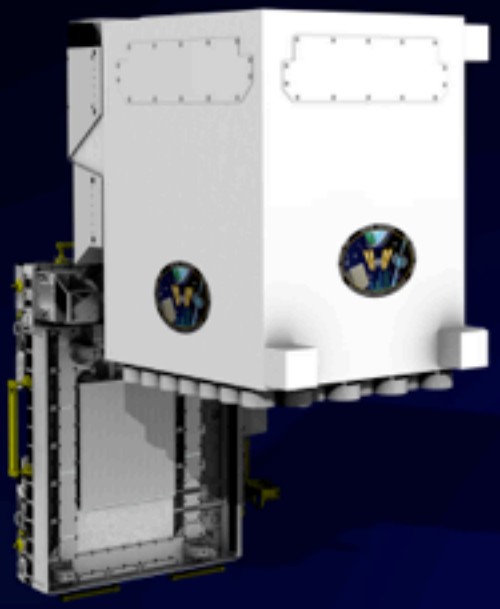




The NICER Payload

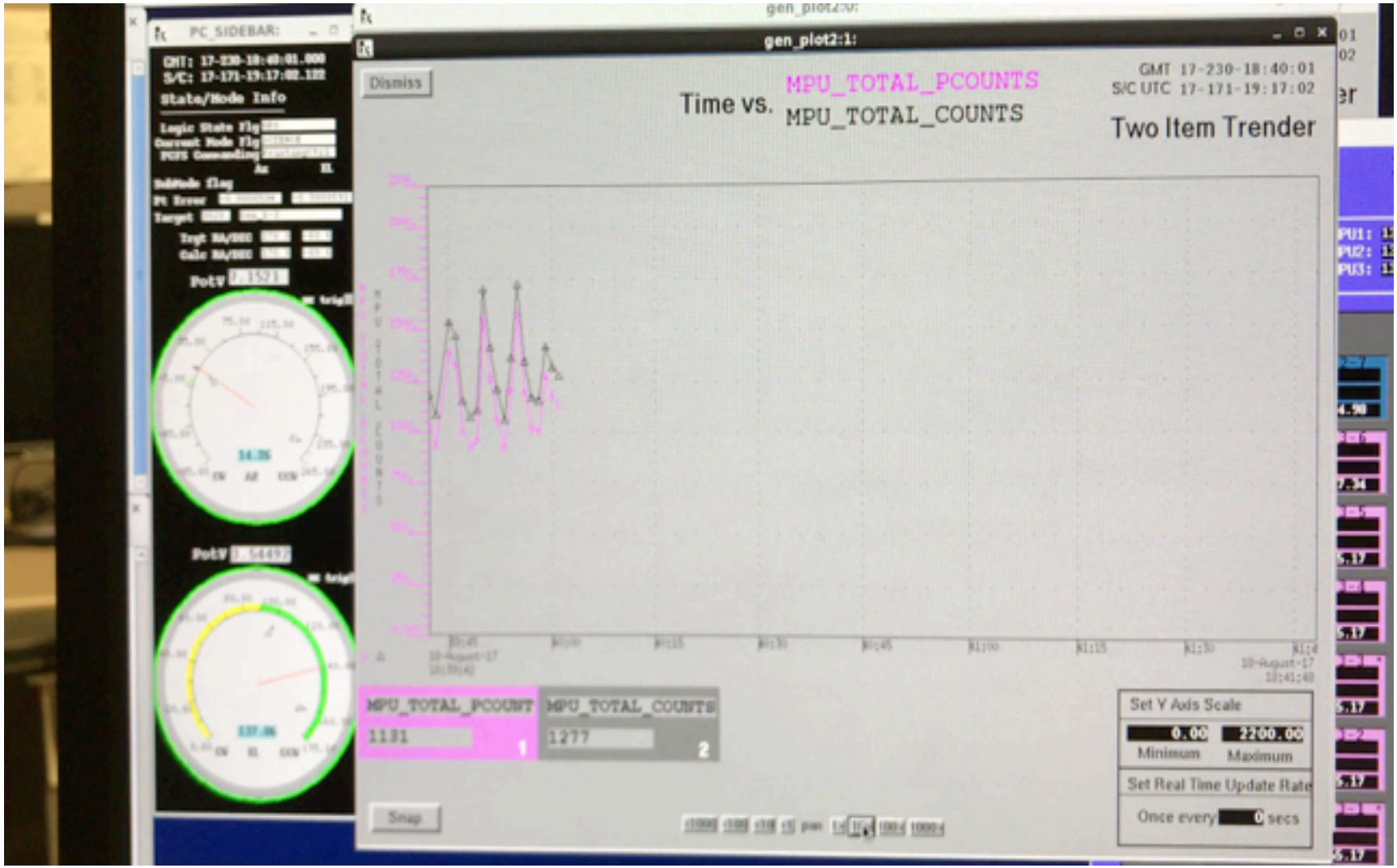
NICER

Neutron Star Interior Composition Explorer



Live ISS telemetry ~80% of the time

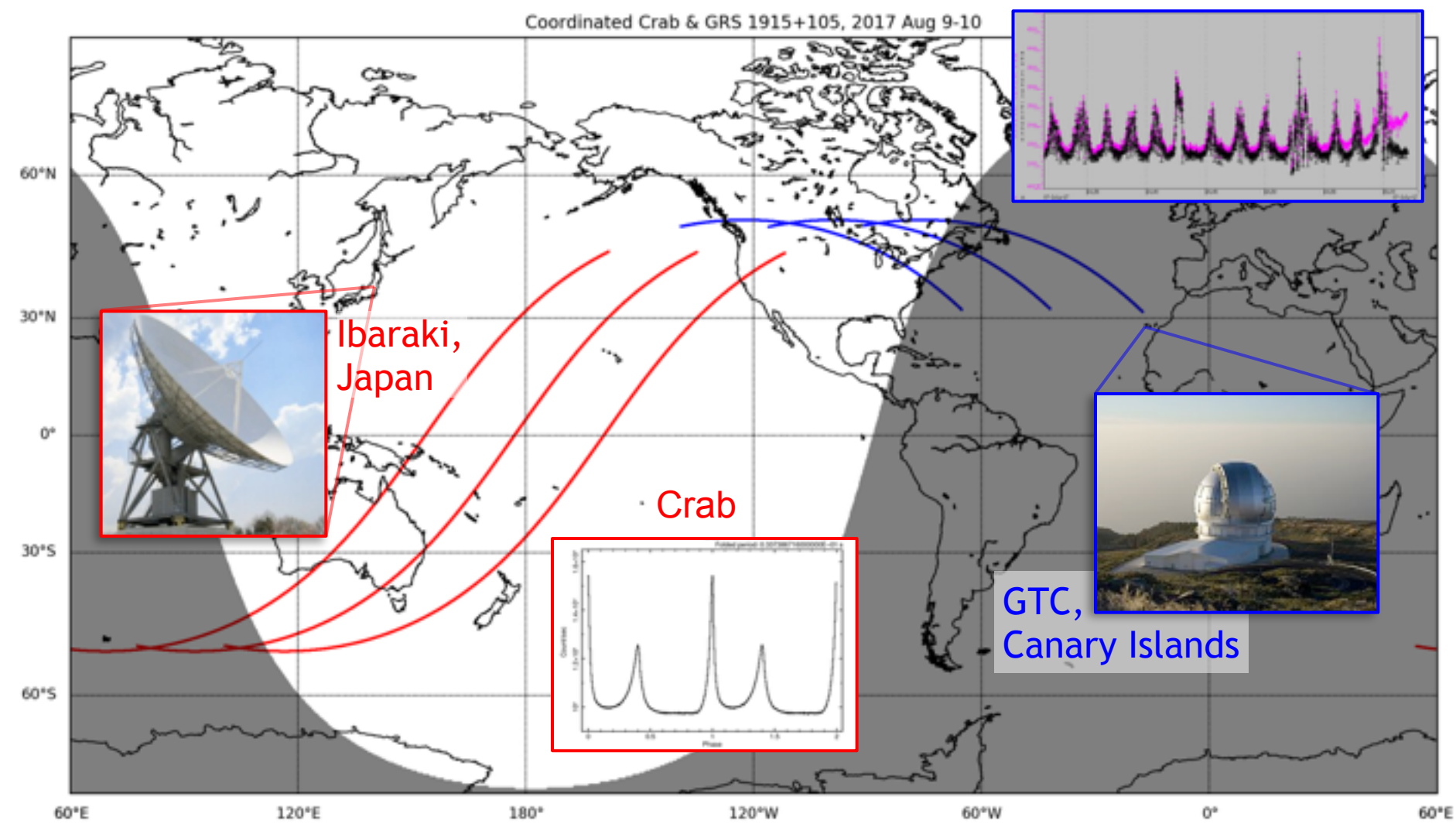
Cen X-3 pulsations in real time



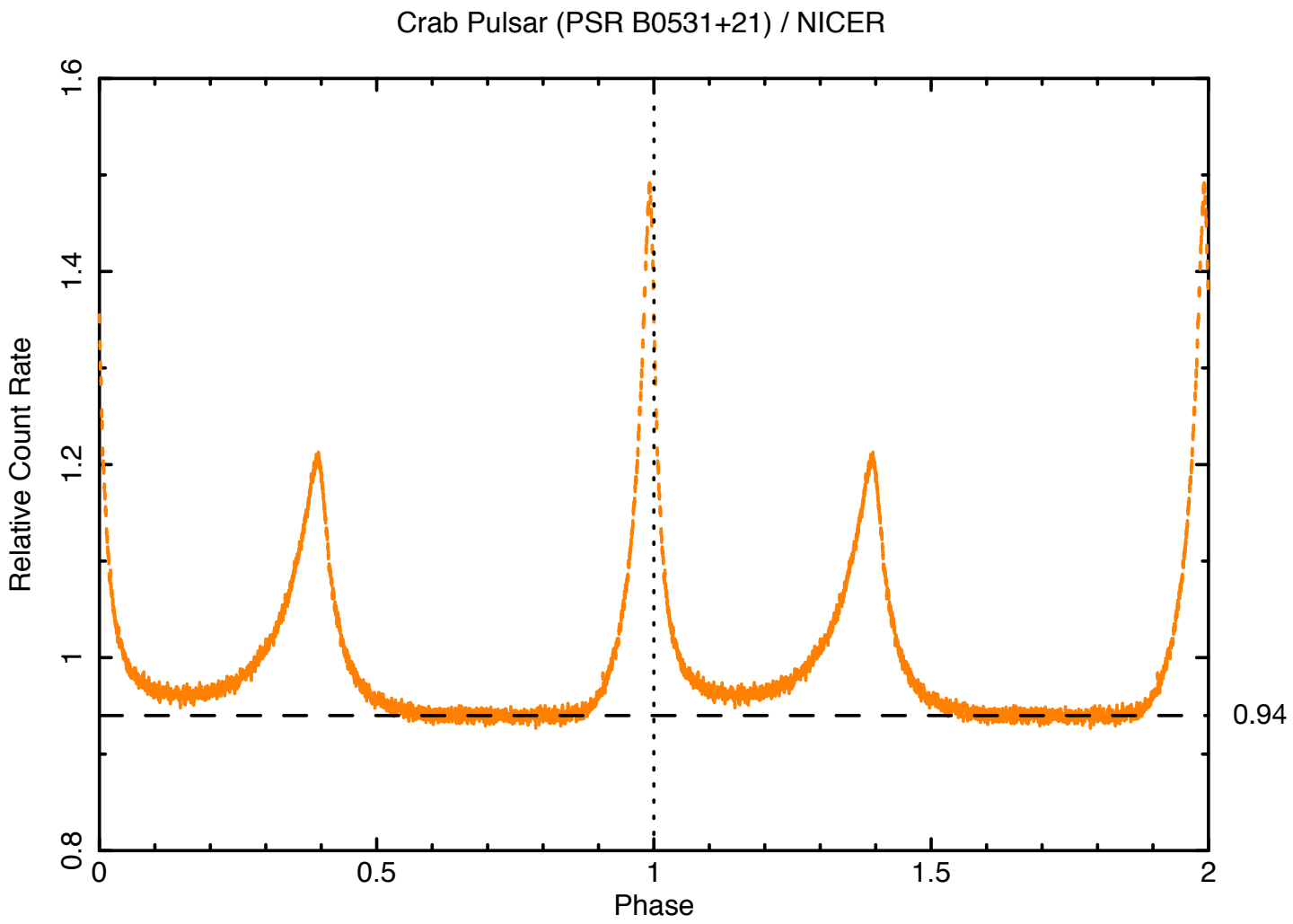
Courtesy: Gendreau & Arzoumanian

Coordination across wavelengths and facilities

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



Crab Pulse Profile Observed with NICER



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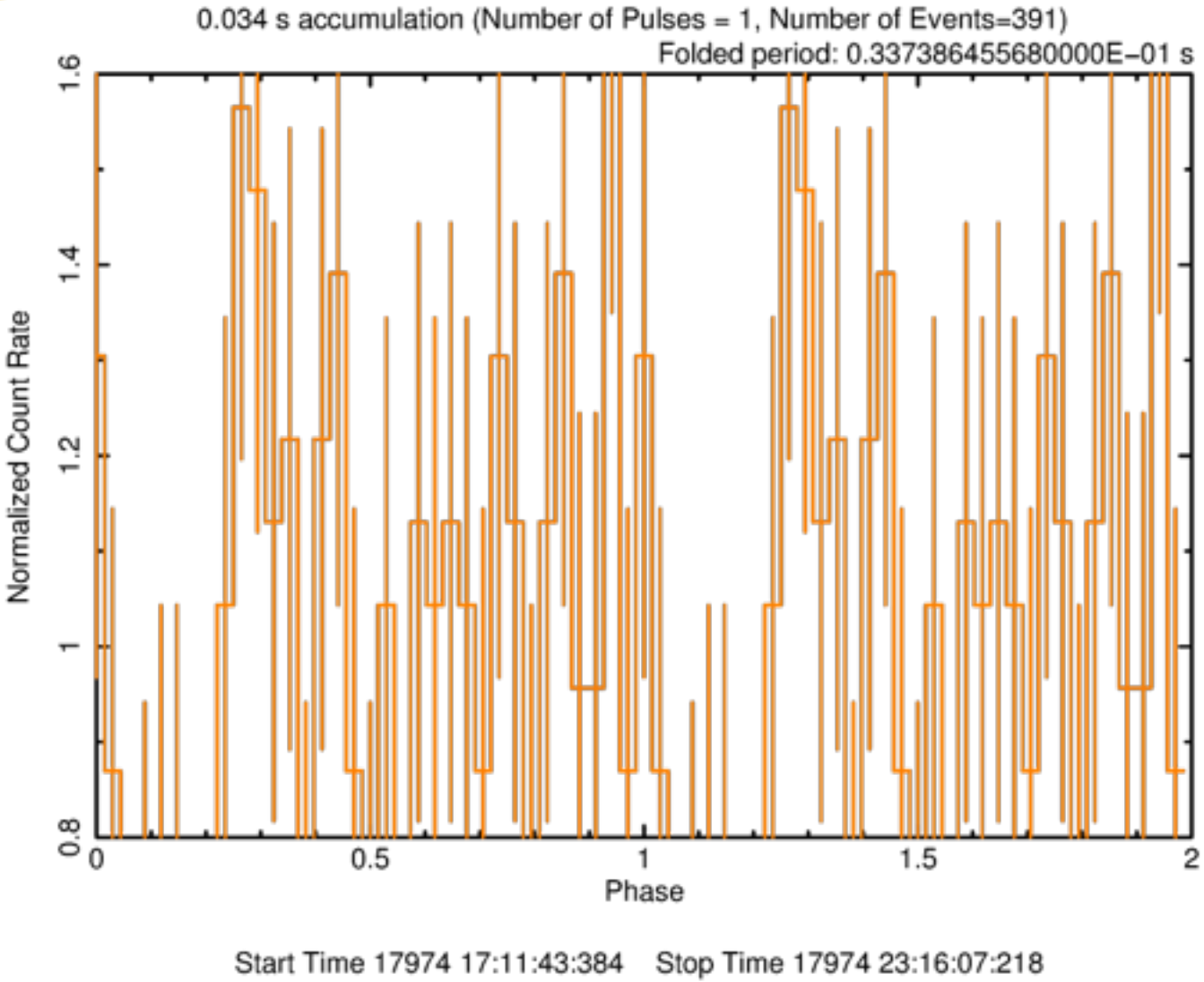
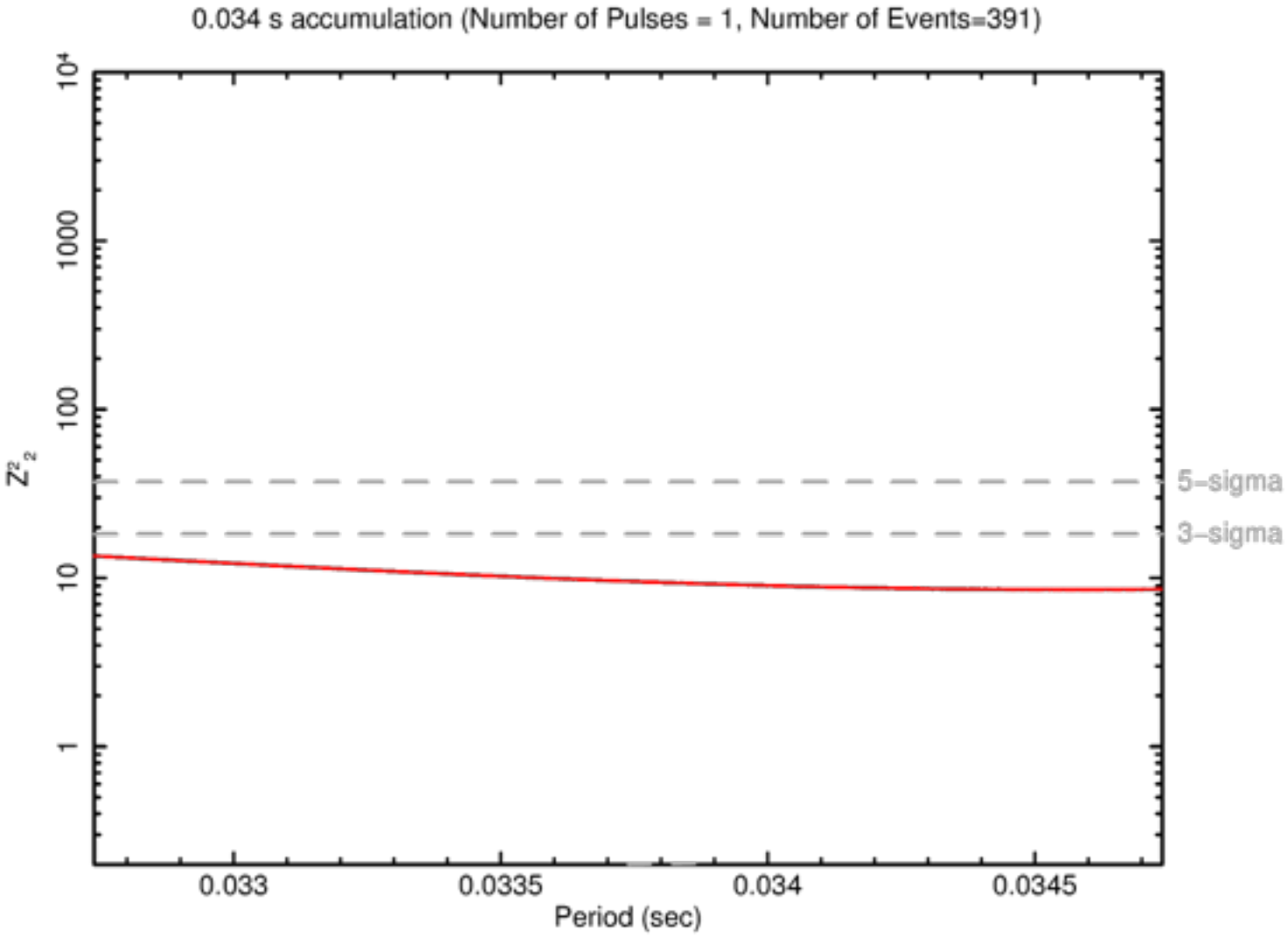
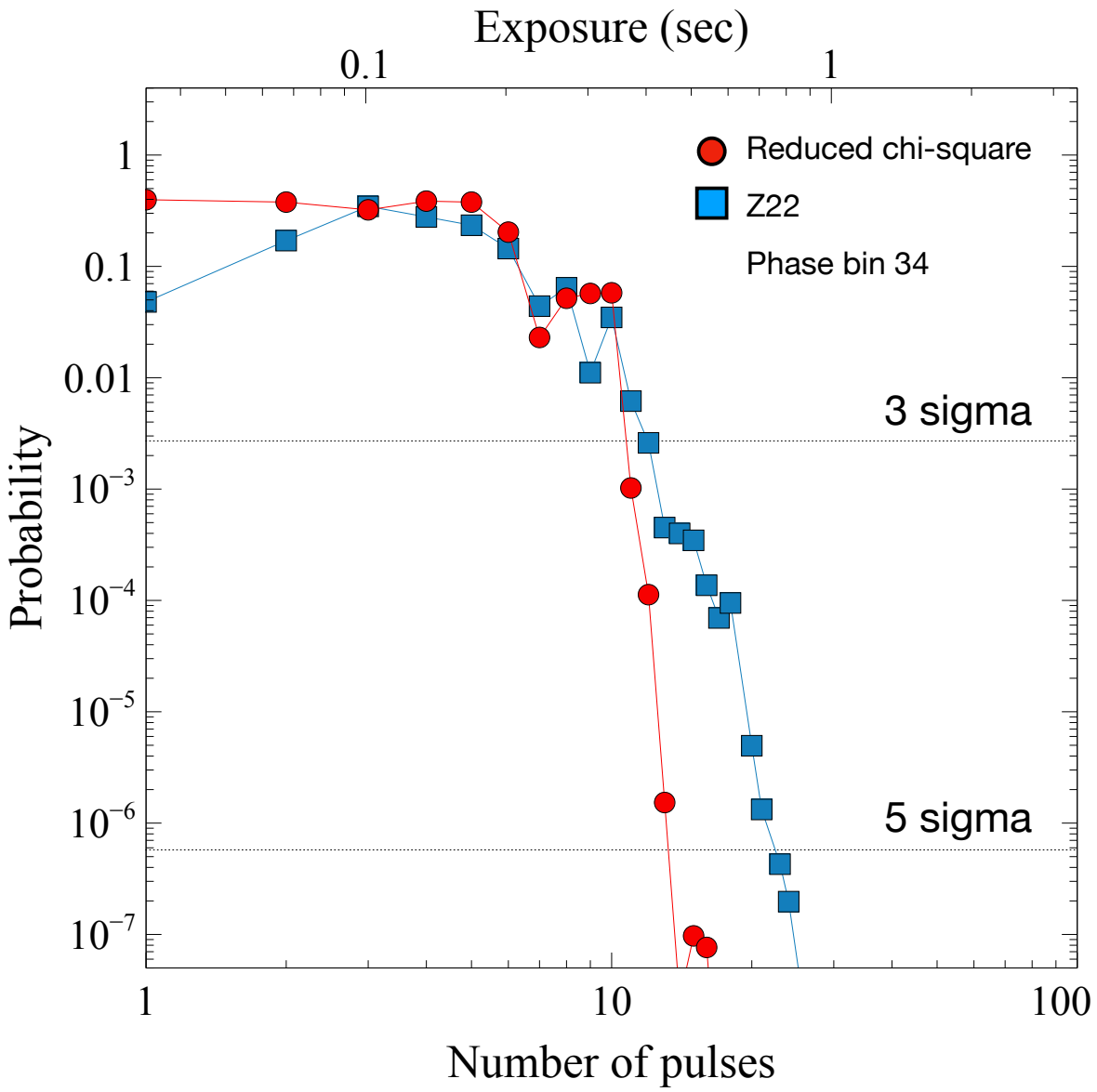


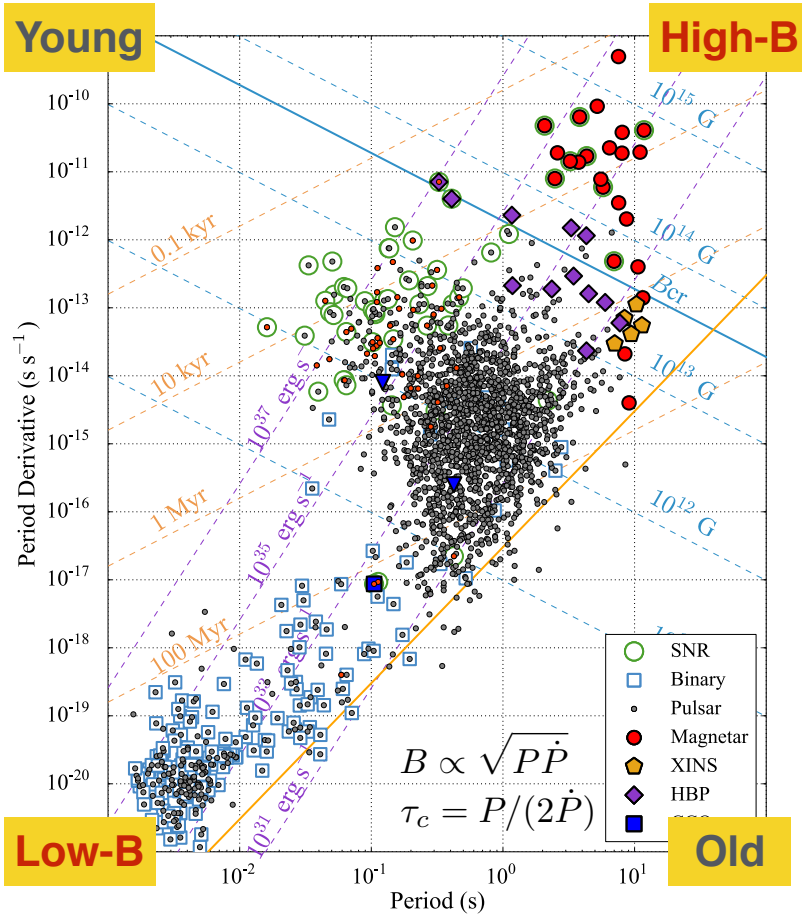
Detection Significance of the Crab Pulsar



Exposure required to the Crab Pulse



Magnetar & Magnetosphere (M&M) Group



- Covers highly magnetized neutron stars (NSs)
  - Diversity: magnetars, high-B pulsars, rotation-powered pulsars, X-ray isolated neutron stars
- Baseline science in the NICER proposal…
  - "Characterise spin variations and outbursts during glitches"
  - "NICER shall spectrally distinguish between thermal and non-thermal X-ray pulse spectra and measure their absolute phases to ±100 us(1σ)"
  - "Phase resolved spectroscopy with NICER will probe line origins by localising absorption sites relative to the magnetic axis and any non thermal emission"
- Monitoring of timing behaviours of fainter magnetars and high-B pulsars, and their spectral comparison
- Phase-resolved spectroscopy of rotation-powered and isolated NSs: absorption feature, thermal/non-thermal

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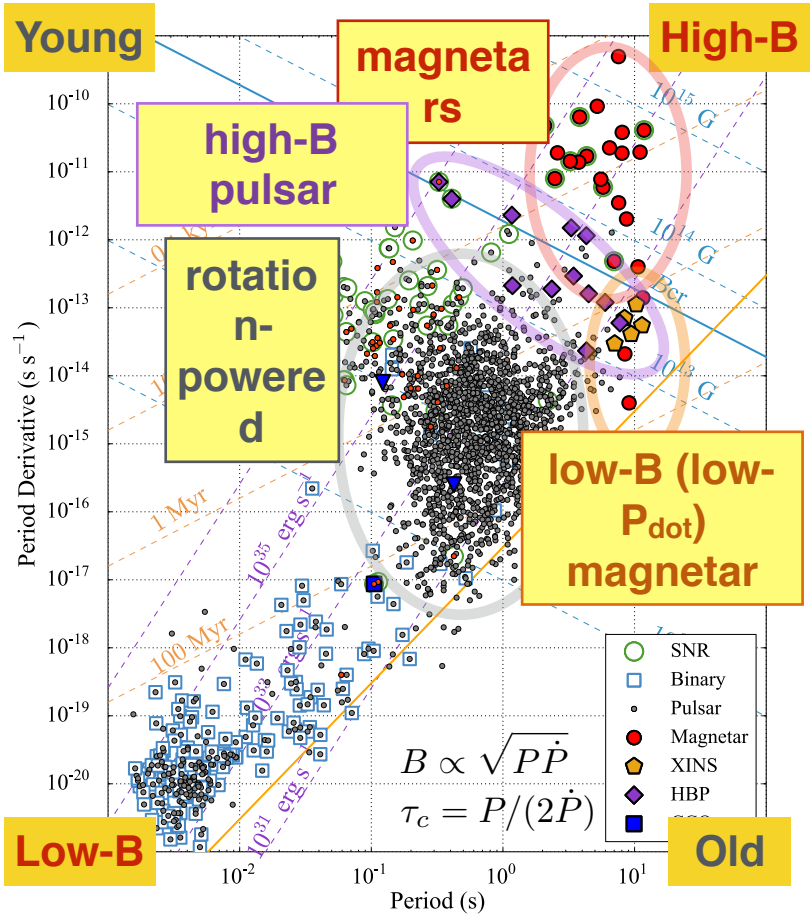

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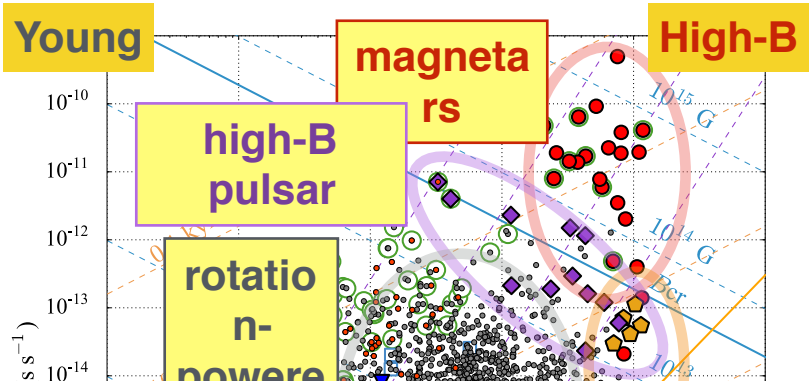

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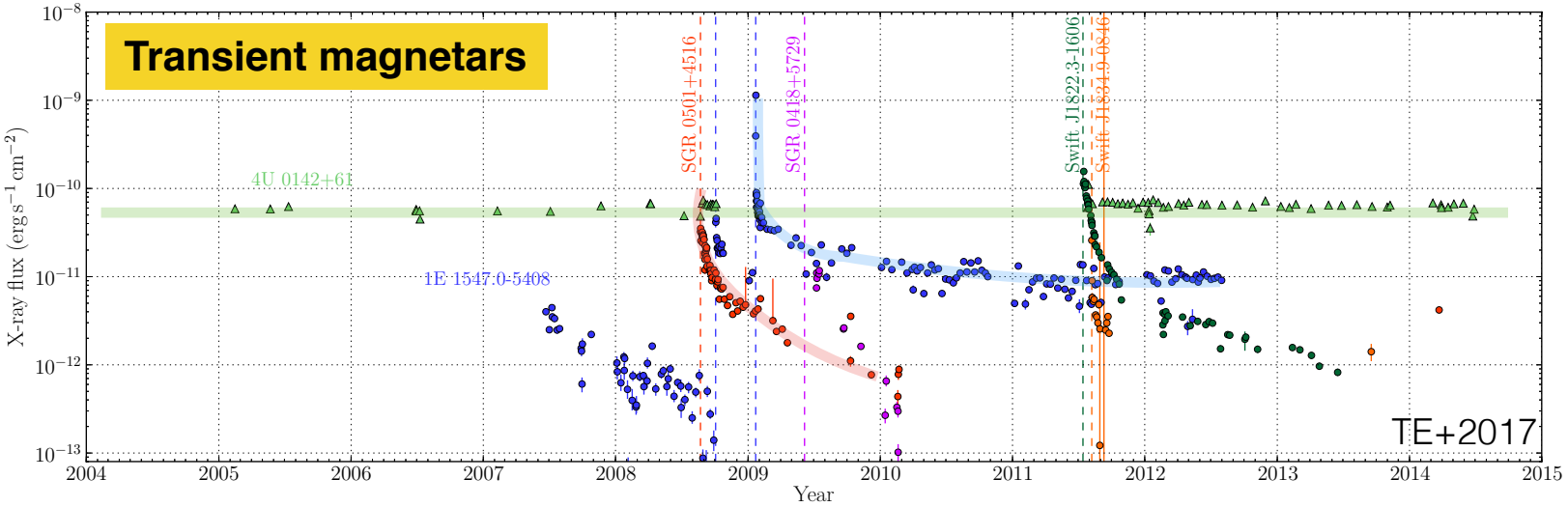

et al., (2014)

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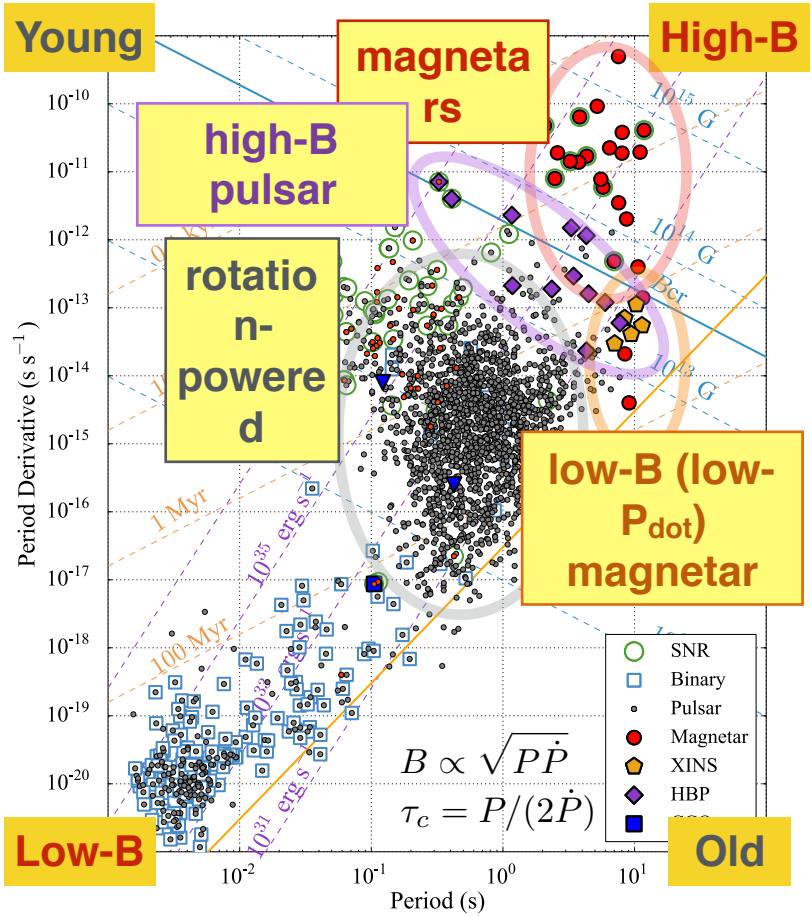

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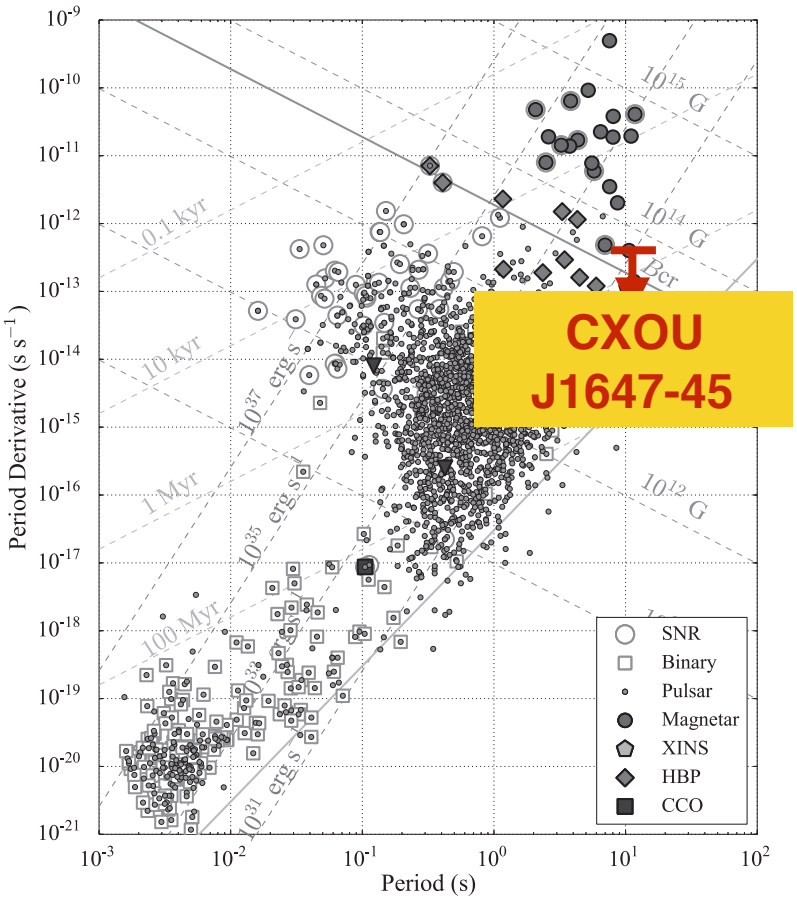

- Total 1.5 Ms exposure
  - Targets: Priority A (12 sources), B (7 sources)
  - (Reserved) ToO for transient sources (>200 ks)
- Magnetar
  - CXOU J164710.2-455216 — low-field magnetar? Outburst in 2006, precise measurement of P_{dot} (<4x10^{-13}, An+2013) with NICER
- High-B pulsars
  - PSR J1119-6127 — radio pulsar to exhibit a magnetar-like outburst in 2016 July. Now in declining state.
- Rotation powered
  - PSR B0656+14 —flux and timing variability analysis; non-thermal X-ray pulse to constrain the location of the high-energy emission
- Absorption feature of isolated NSs
  - 1E 1207.4-5209 — absorption features at 0.7 & 1.4 keV seen by XMM and Chandra. Other lines at higher energies, 2.1 and 2.8 keV?

NICER White Paper “Magnetar & Magnetosphere”

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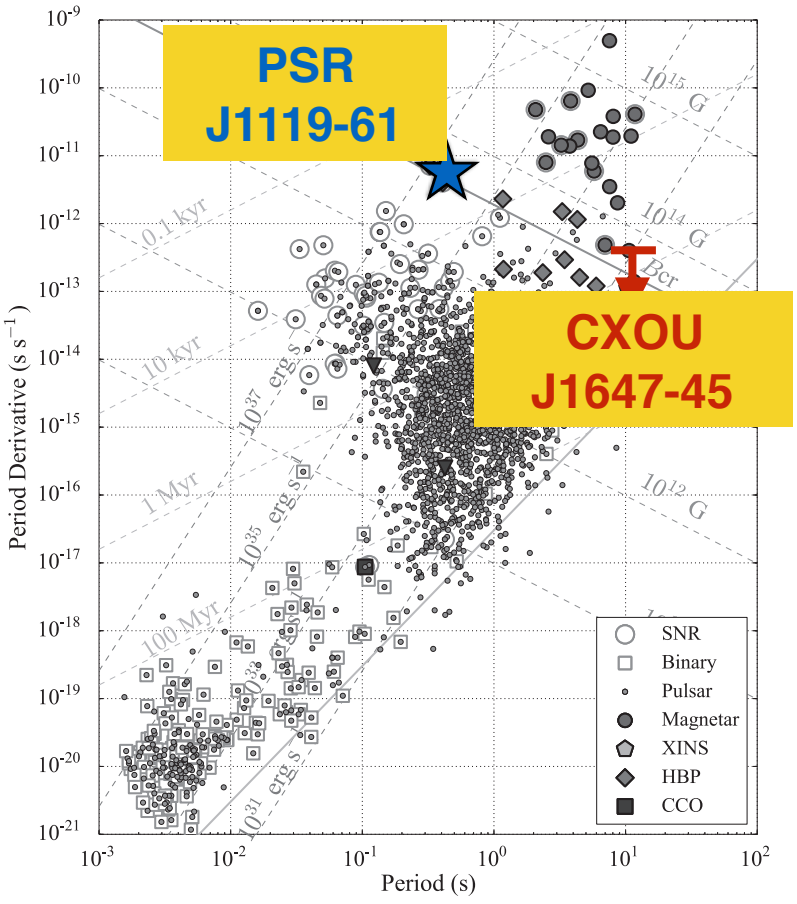

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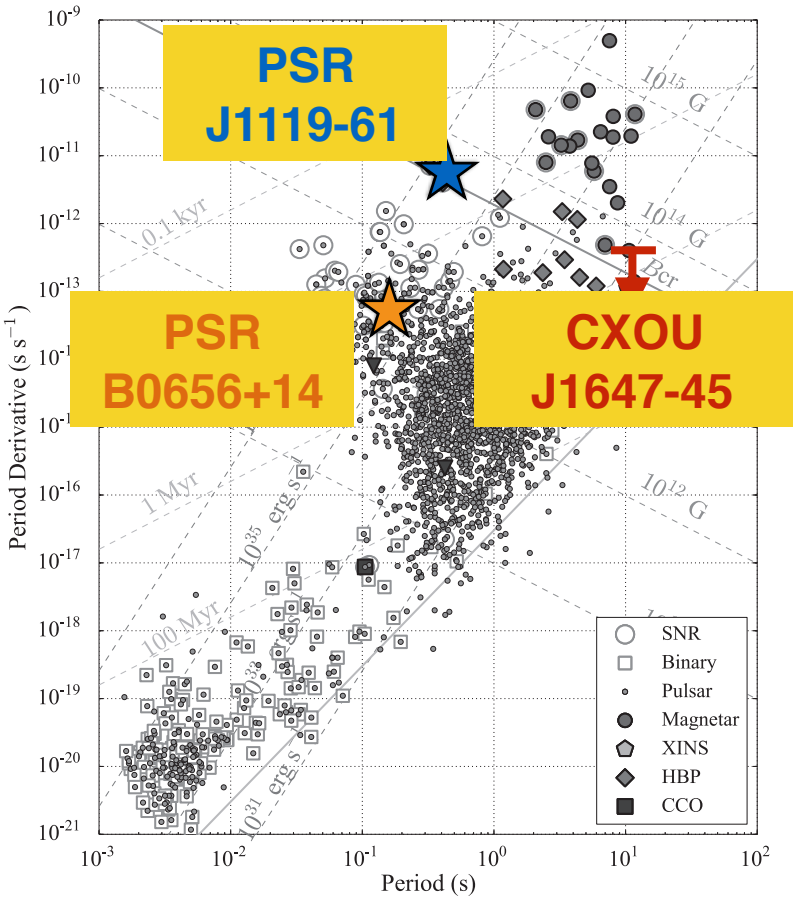

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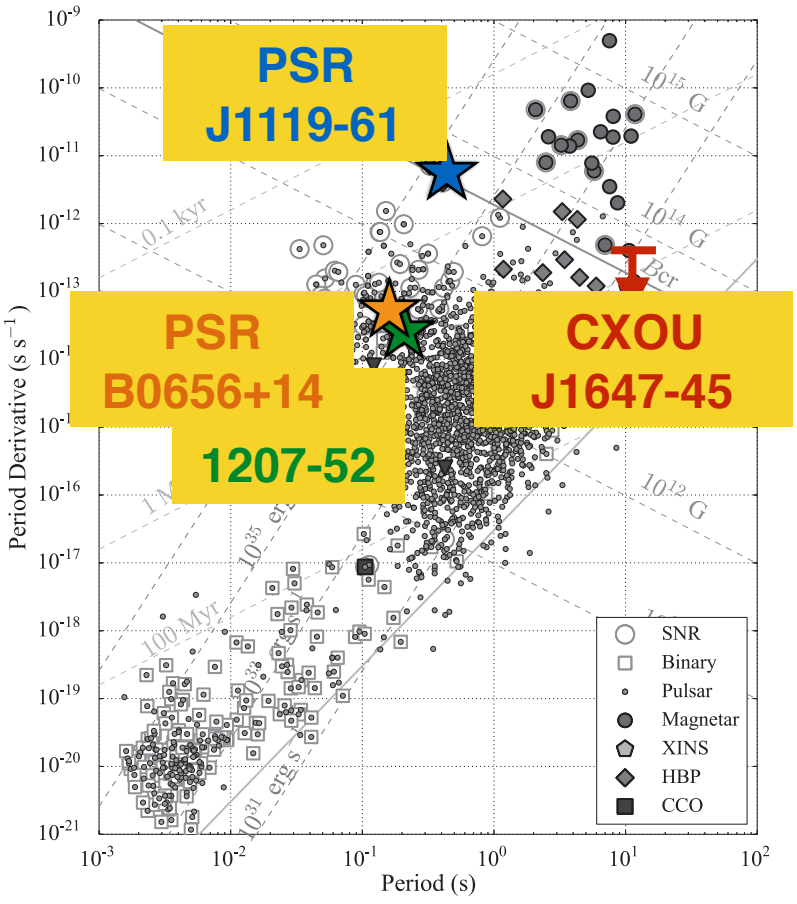

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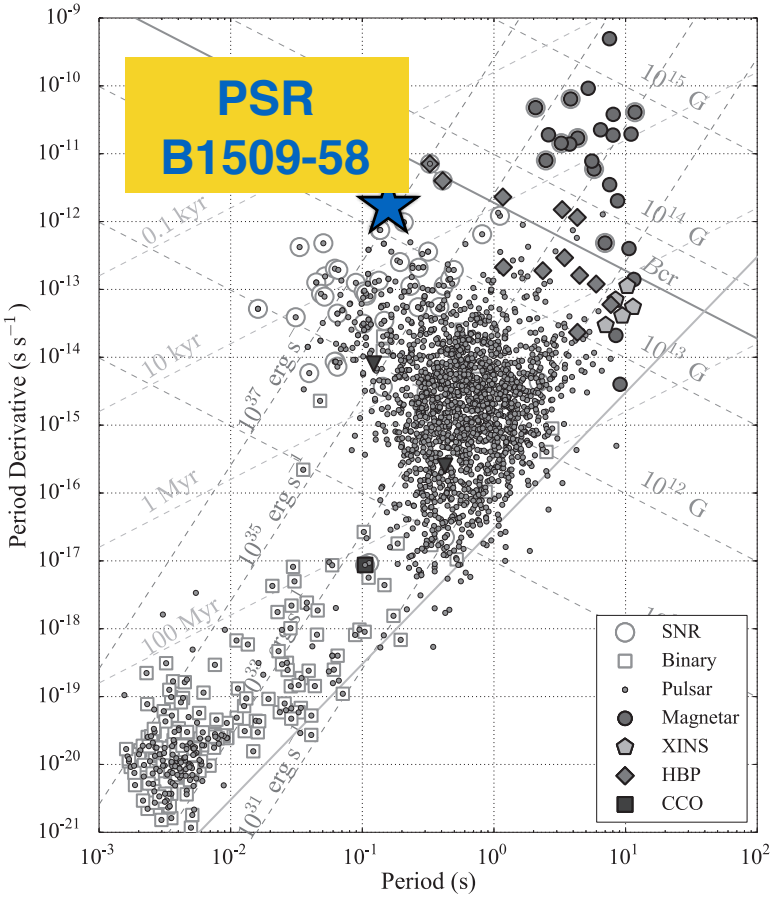
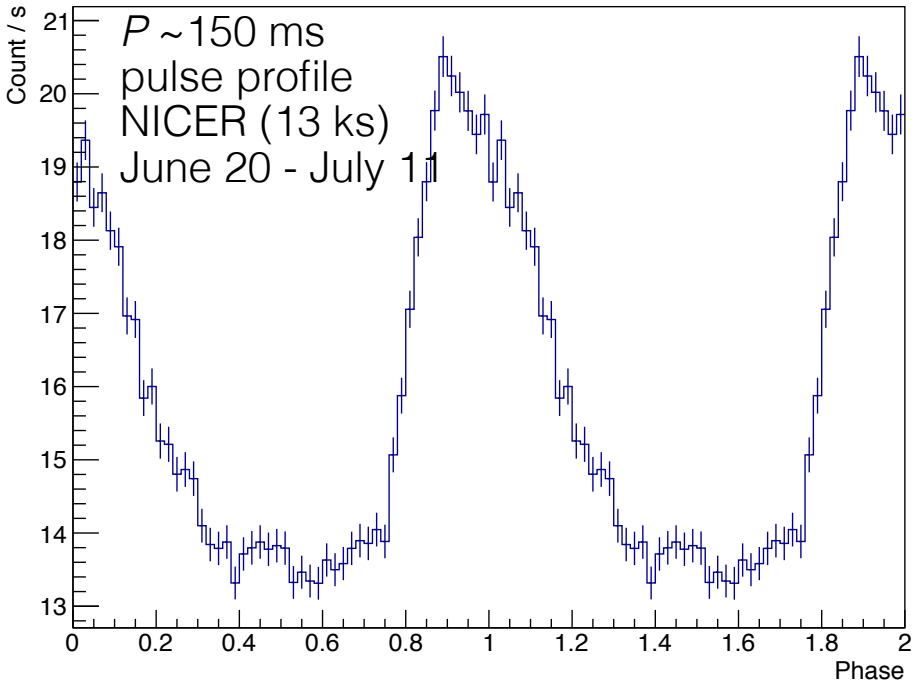
NICER White Paper “Magnetar & Magnetosphere”

NICER Example: PSR B1509-58





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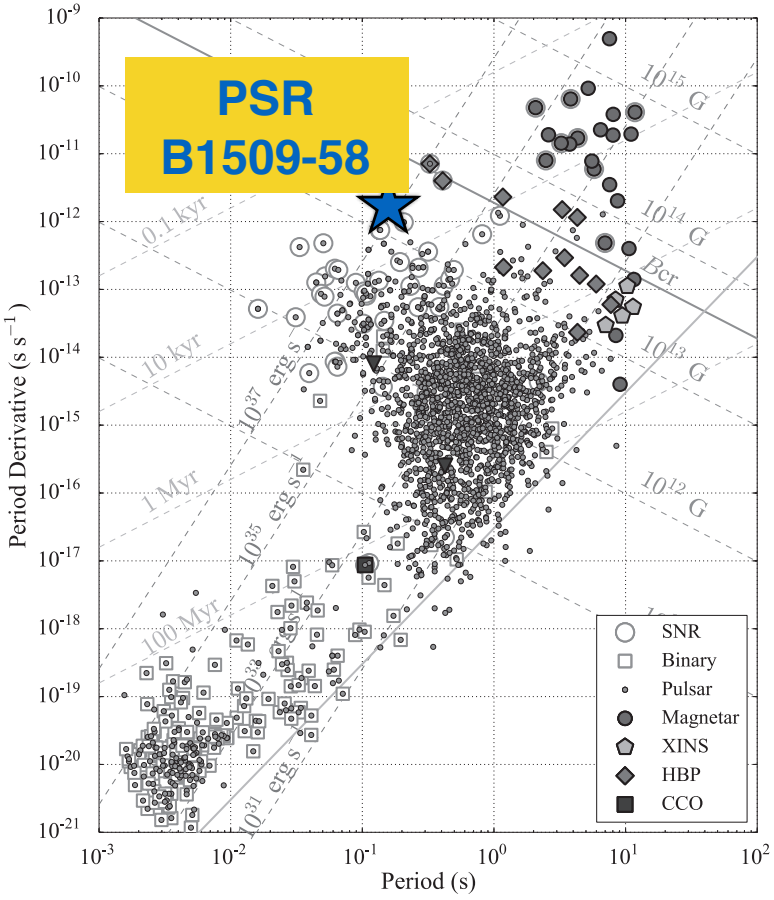

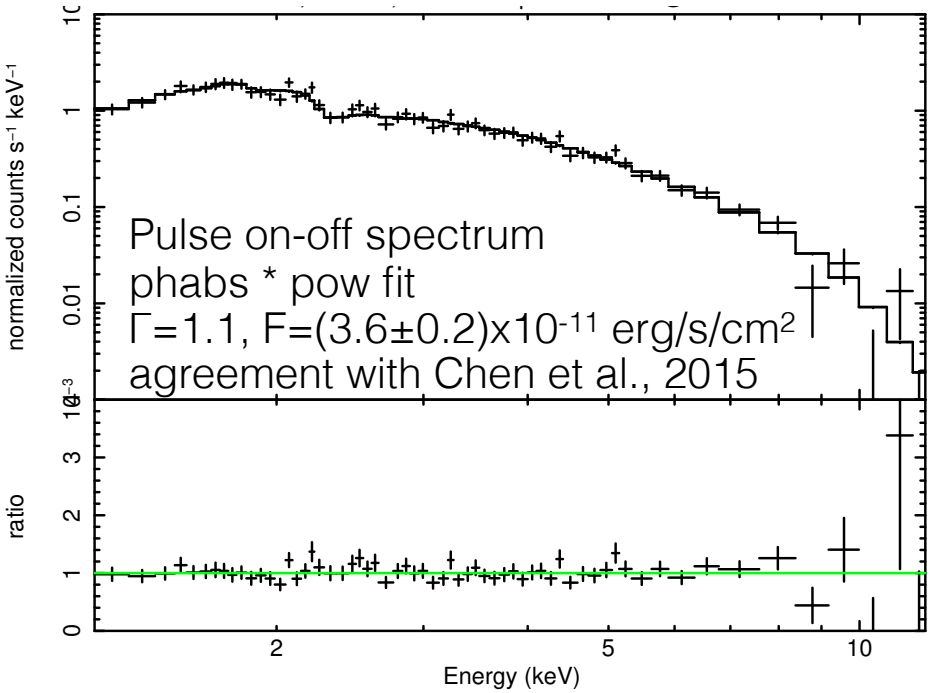

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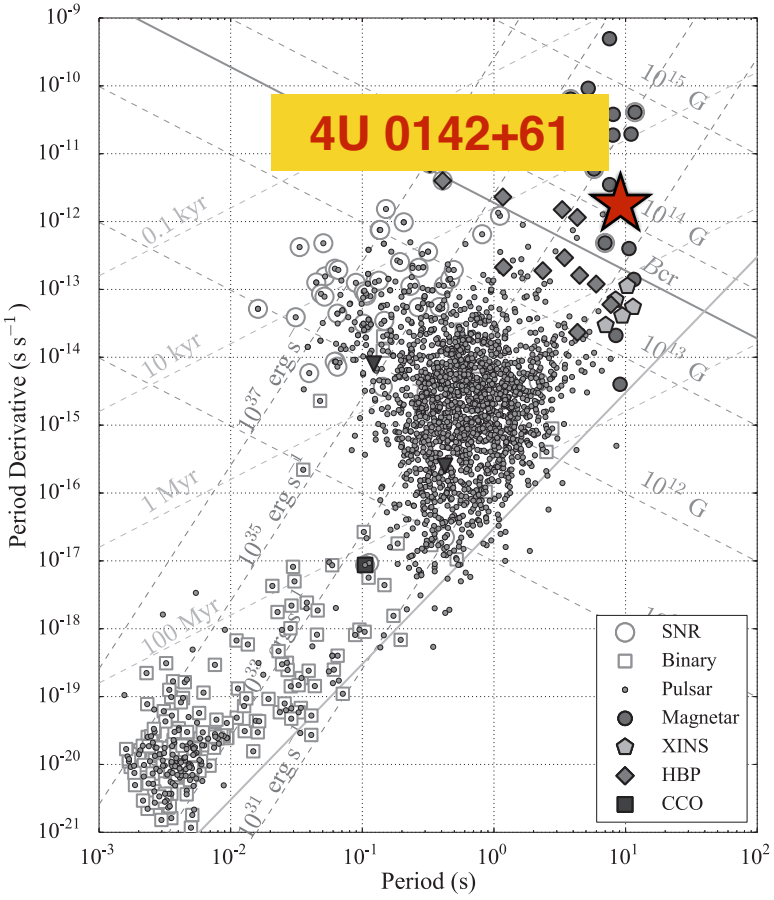
Magnetar Outburst : 4U 0142+61



- 4U 0142+61 — 8.9 s prototypical bright magnetar previously observed with most of past X-ray observatories
- Fermi GBM detected a SGR-like short burst at 23:54 UT on 13 July during the NICER's commissioning phase (GCN 21342).
- NICER follow-up ToO observations, ~0.88, 1.0, 2.0, 3.0, 4.0 days after the burst, from July 14 to 18 (total ~75 ks)
- Signature of a glitch around the outburst from Swift monitoring (Atel 10576)
- NICER observation was around the glitch?
- Additional coordinated observations with NuSTAR on August 11 to search for the hard X-ray enhancement (magnetosphere).

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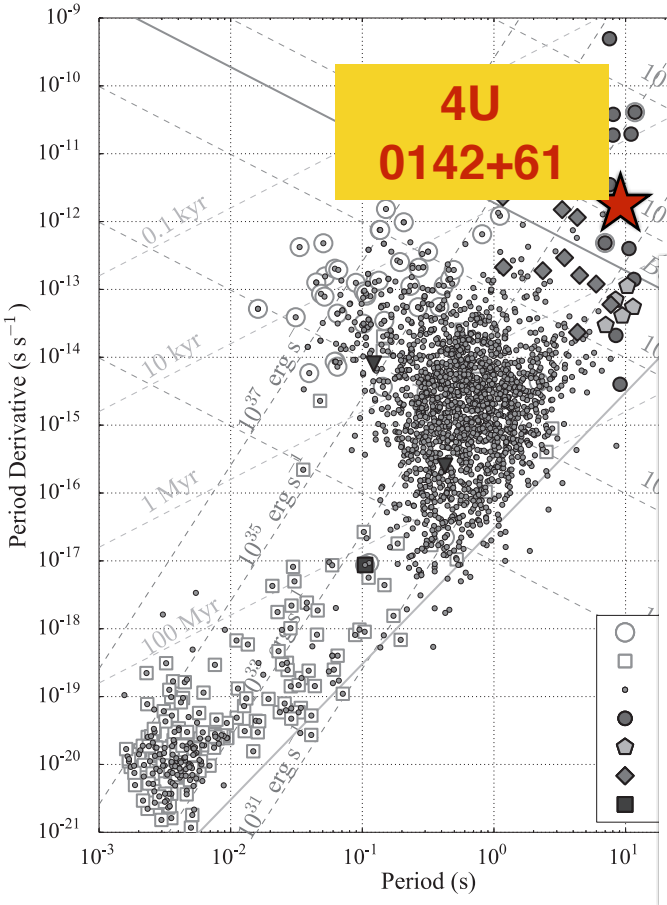

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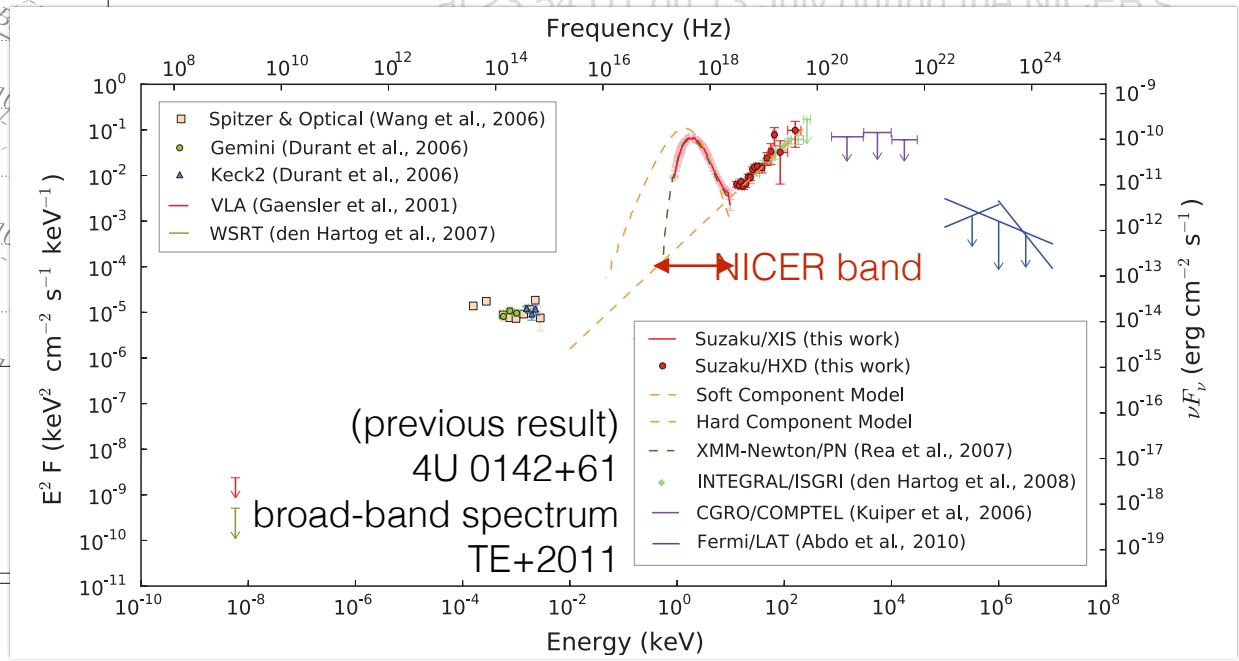

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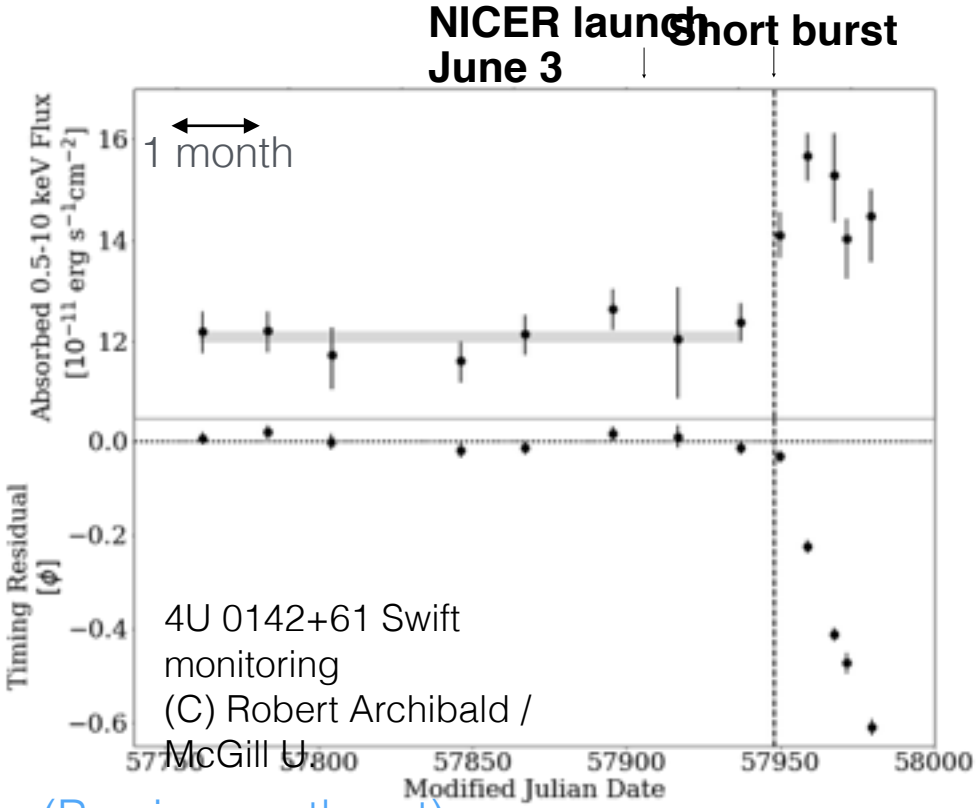

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Archibald+2017

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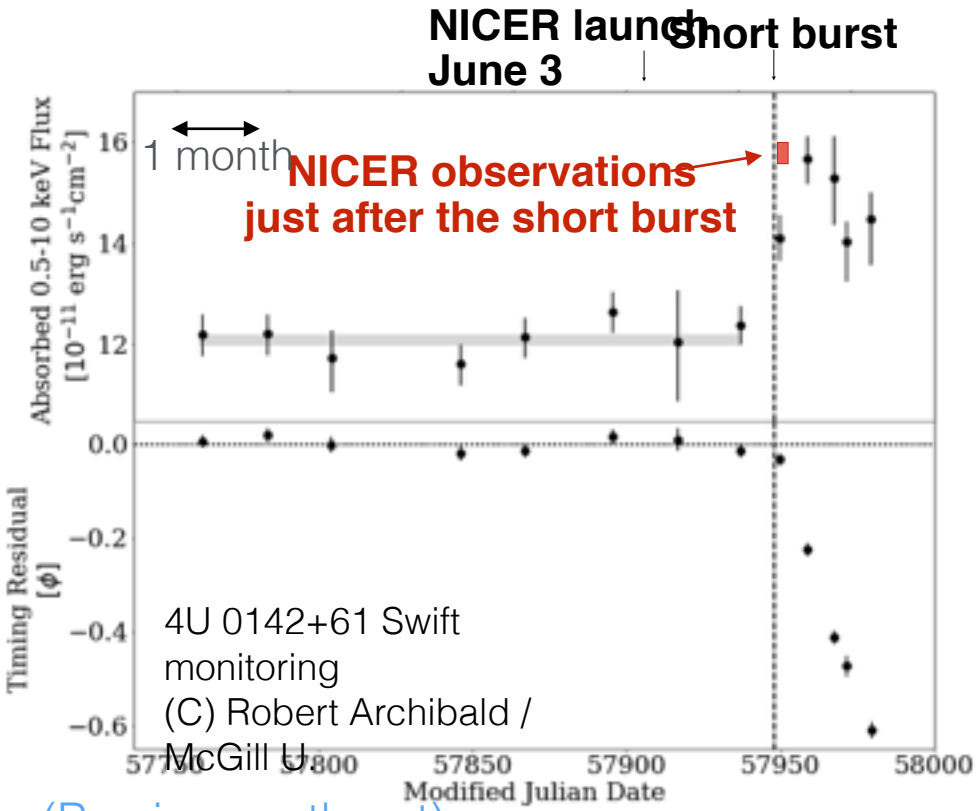

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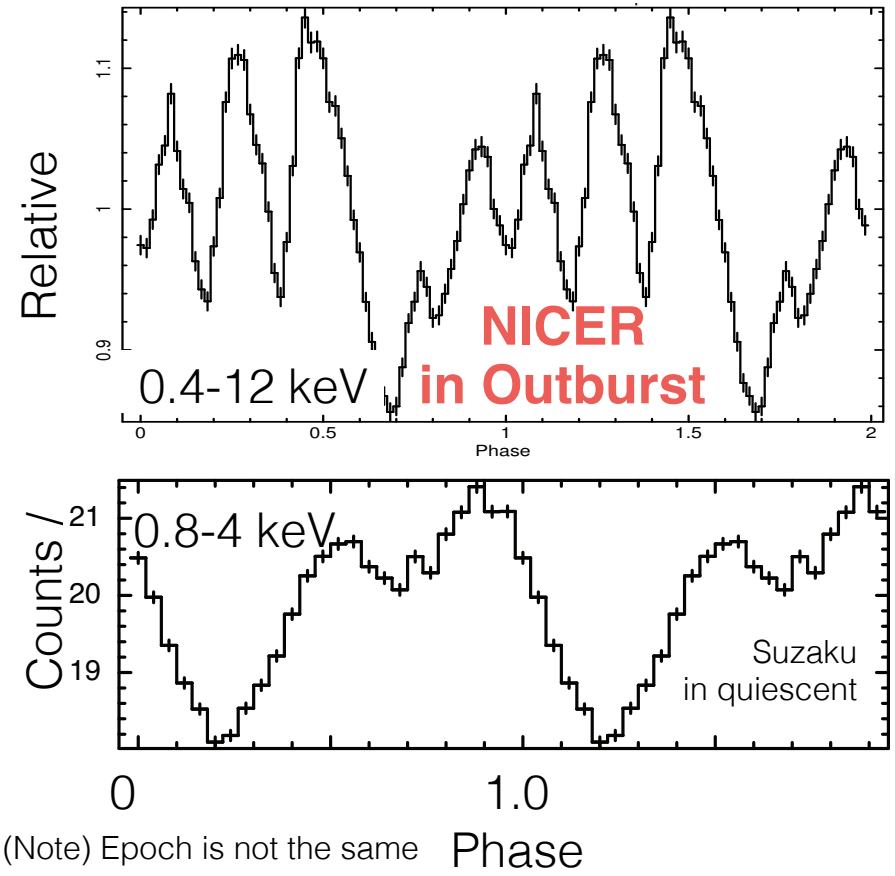
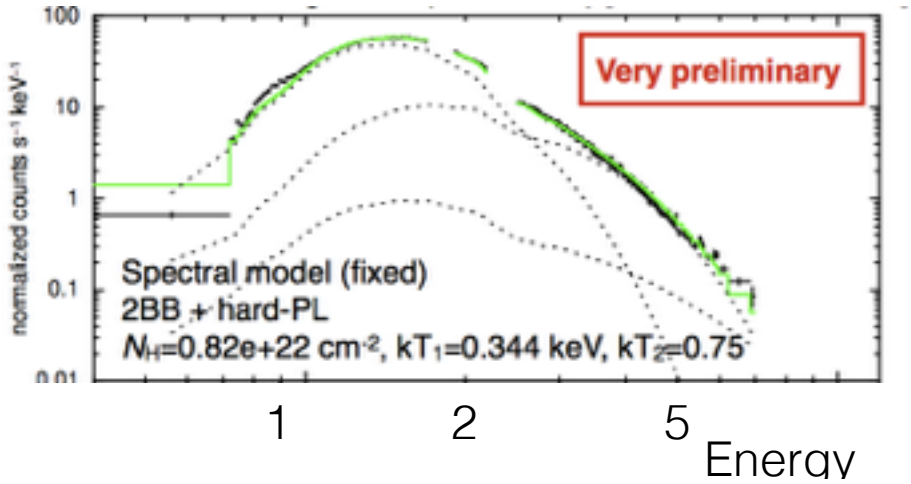
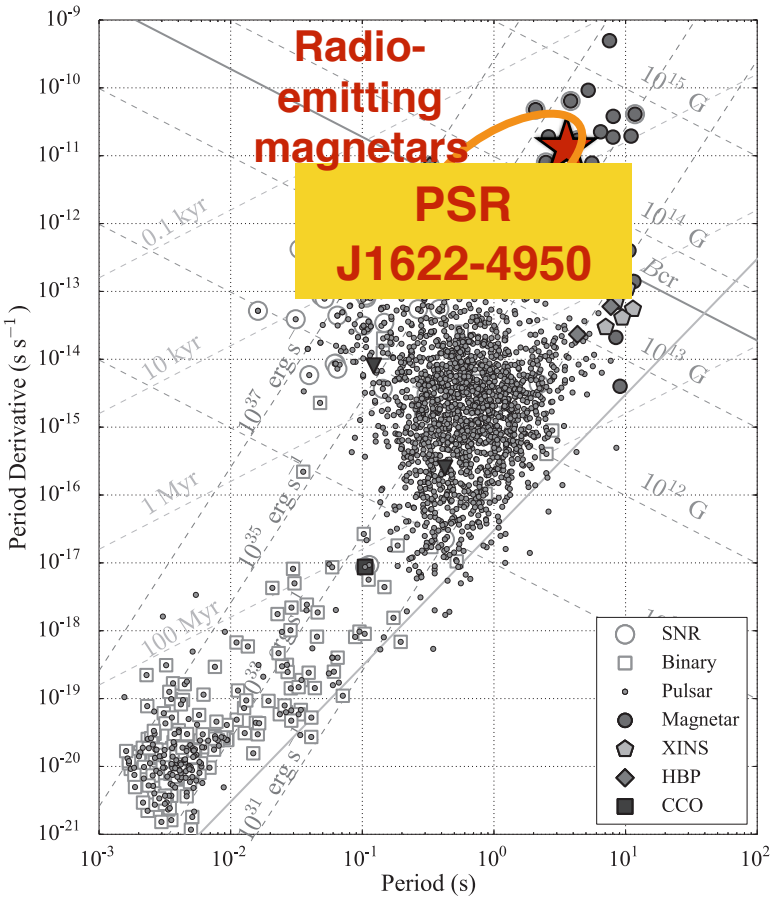


(Note) Epoch is not the same



- Pulse period is consistent with the Swift result.
- Pulse profile shows four-five peaks (two peaks at quiescent state). Additional hot spots on a stellar surface.
- Phase-average spectrum is approximated with 2BB model of kT ~ 0.34 and 0.75 keV.
- Analysis of the data is underway.

PSR J1622-4950 — Radio-loud magnetar



- Most of magnetars are radio quiet.
- PSR J1622-4960 is one of rare radio-loud magnetars (~5 known), discovered in 2009 at the Parkes radio observatory.
- Previous X-ray and radio observations in 2007-2011. Radio ceased in 2014 and remained undetectable during 2015-2016.
- Radio re-brightening in 2017 (Atel 10346). X-ray flux at 5×10^{-12} erg/s/cm2 (1-10 keV) from Swift on 27 April.

Ref: Levin+2010, Anderson+2012, Scholz +2017

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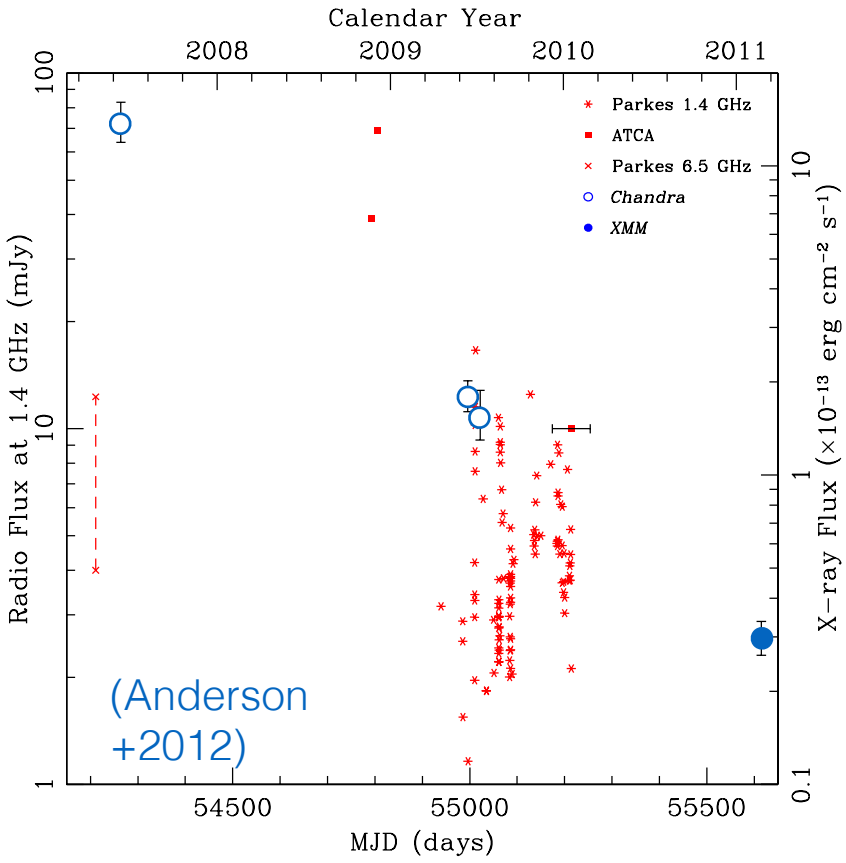

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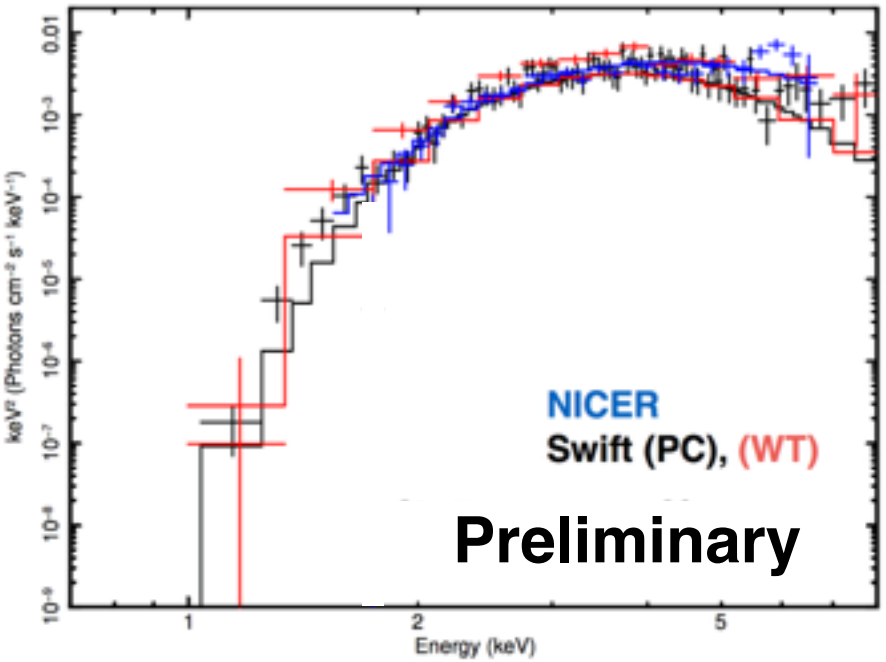
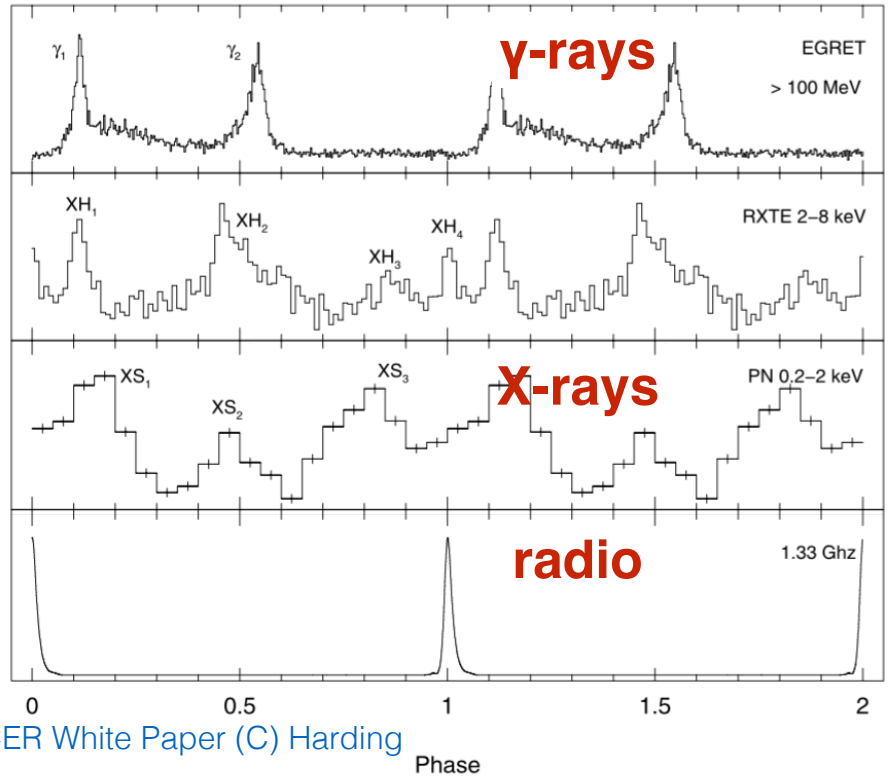


X-ray / radio coordinated observations with NICER

- Radio observations with Deep Space Network (DSN) 70-m diameter
  - at 2.3 and 8.4 GHz in Australia on 23 May 2015 (Atel 10581). Period is 4.327 sec.
- NICER observations from July 8 to 18 with a total 7.5 ks exposure.
  - NICER X-ray flux ~5x10^{-12} erg/s/cm2 (2-6 keV).
  - Obtained spectra are consistent with Swift follow-up observations in April-June 2017.
- No pulsation detected with NICER. Pulsed fraction upper-limit at 20% (3σ, 2-6 keV).
  - 70% upper-limit in the 0.3-4.0 keV (3σ) from the previous XMM EPIC-PN observations (Levin +2010).

Vela Pulsar — Simultaneous with Radio



NICER White Paper (C) Harding

- Vela Pulsar (PSR B0833-45)
  - Rotation-powered, $P = 89.3$ sec
  - Variability in radio pulse peak intensity — stronger pulses arriving earlier than that of the average profile
  - X-ray/radio correlation — flux of the main X-ray pulse is higher during the more intense radio pulses arriving earlier (Lommen+2007)
  - ➡ Non-thermal X-ray and radio emission are physically linked (Harding+2008)
- Simultaneous radio observations at 26-m at Mt. Pleasant observatory in Tasmania.
- NICER observations on July 7-21, NICER covers thermal and non-thermal emission

Radio observation at Mt. Pleasant / University of Tasmania (J. Dickey, J. Palfreyman et al.)

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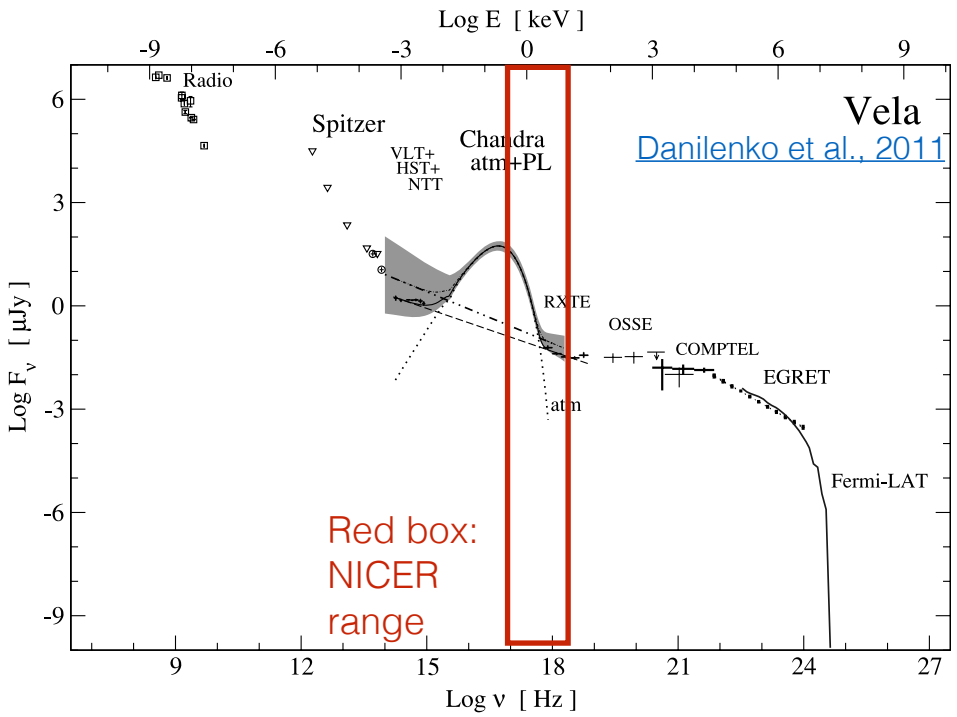

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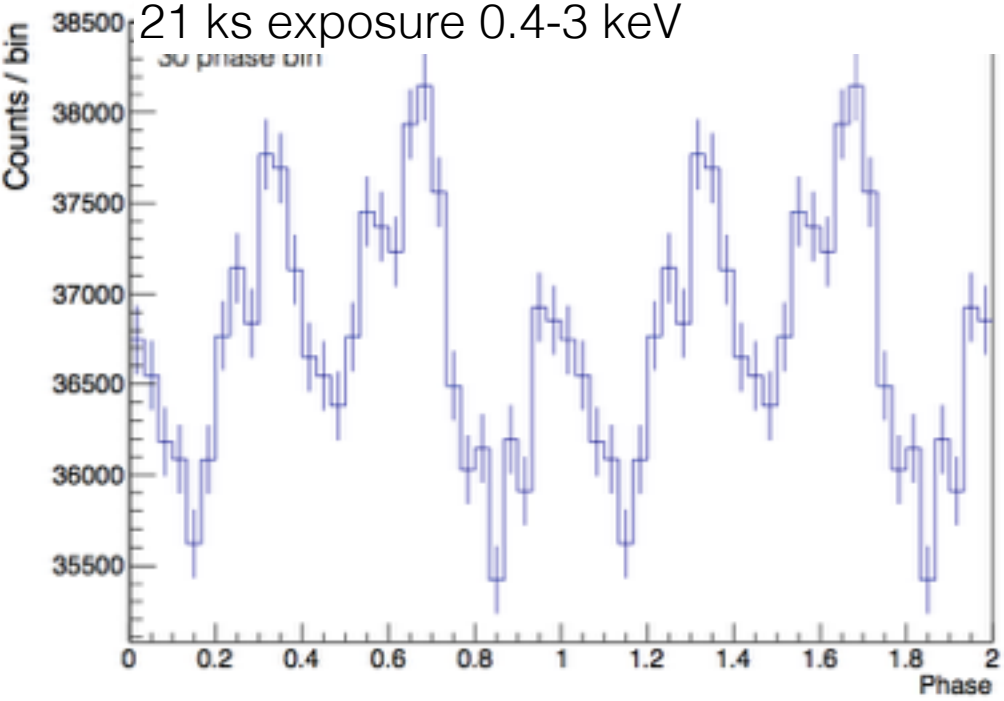
Vela Pulsar — Simultaneous with Radio

NICER pulse profile of Vela pulsar (**Preliminary**)
21 ks exposure 0.4-3 keV



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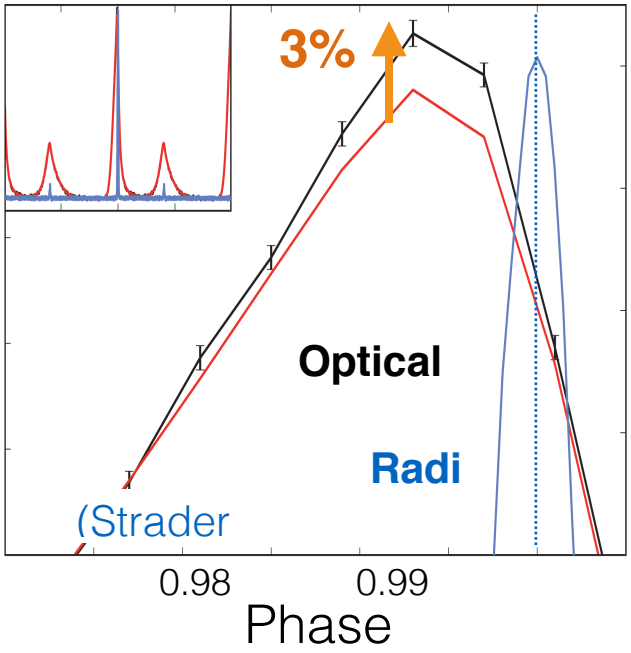
Giant Radio Pulses of Crab Pulsar



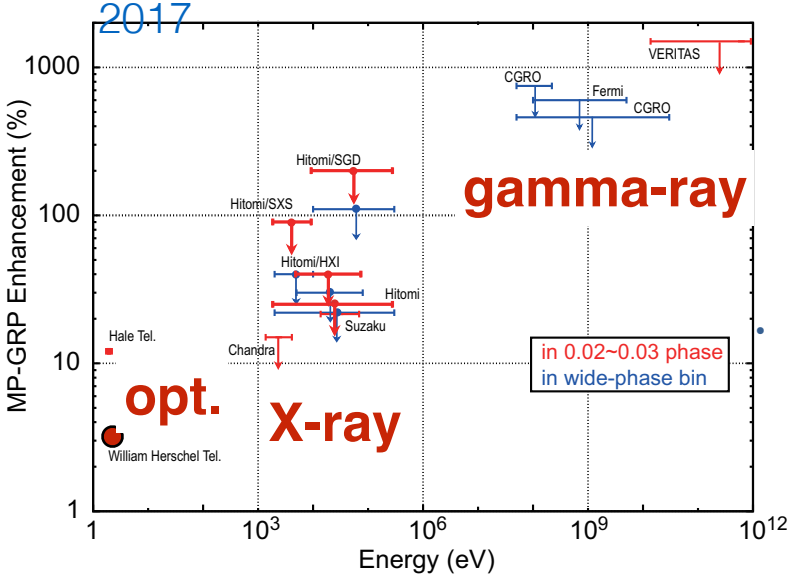
- **Giant Radio Pulses (GRPs)**
  - sporadic & bright (~MJy) radio pulse emission
  - flux is $10^{2\text{-}3}$ times stronger than regular pulses
  - detected from ~12 pulsars
  - randomly occur at either the main or inter pulses
  - power-law energy distribution (connection to FRBs?)
- **Multi-wavelength GRP studies**
  - optical enhancement has been discovered at GRPs
    - 3% brightness increase @ Crab main pulse
  - Upper-limits in the higher energy (X-ray, gamma-ray)

Radio coherent emission is somehow linked to incoherent radiation in optical-to-Xray? ➡ search for X-ray enhancement! (a few percent level enhancement?)

Shearer+2003, Bilous+2008, Majid+2011, Strader+2013, Lewandowska+2015

Giant Radio Pulses of Crab Pulsar

Hitomi collaboration 2017



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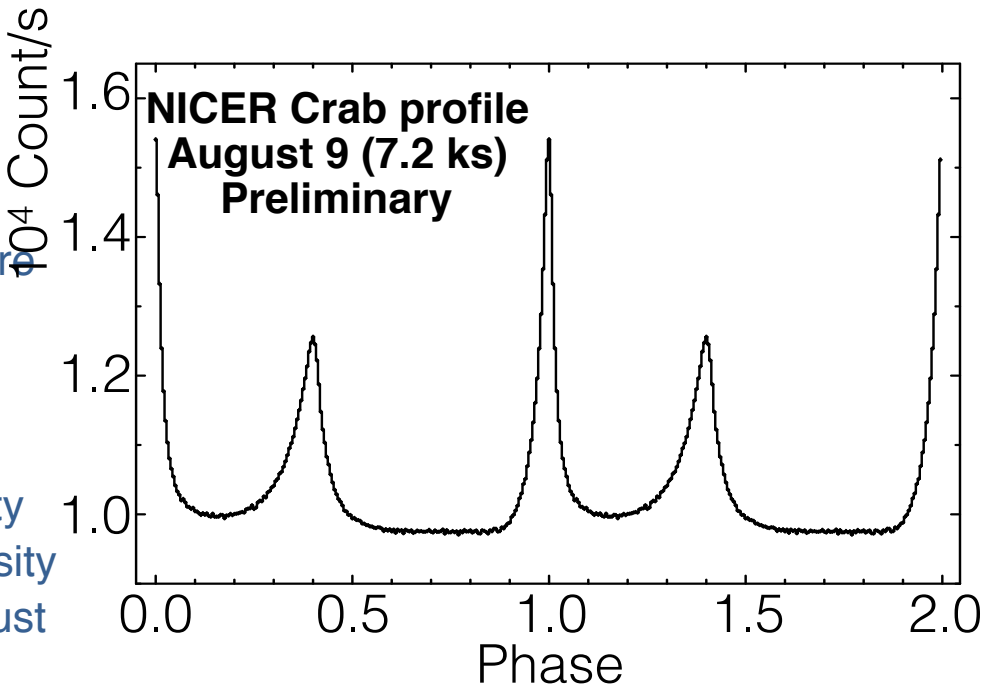
Radio Campaign Simultaneous with NICER

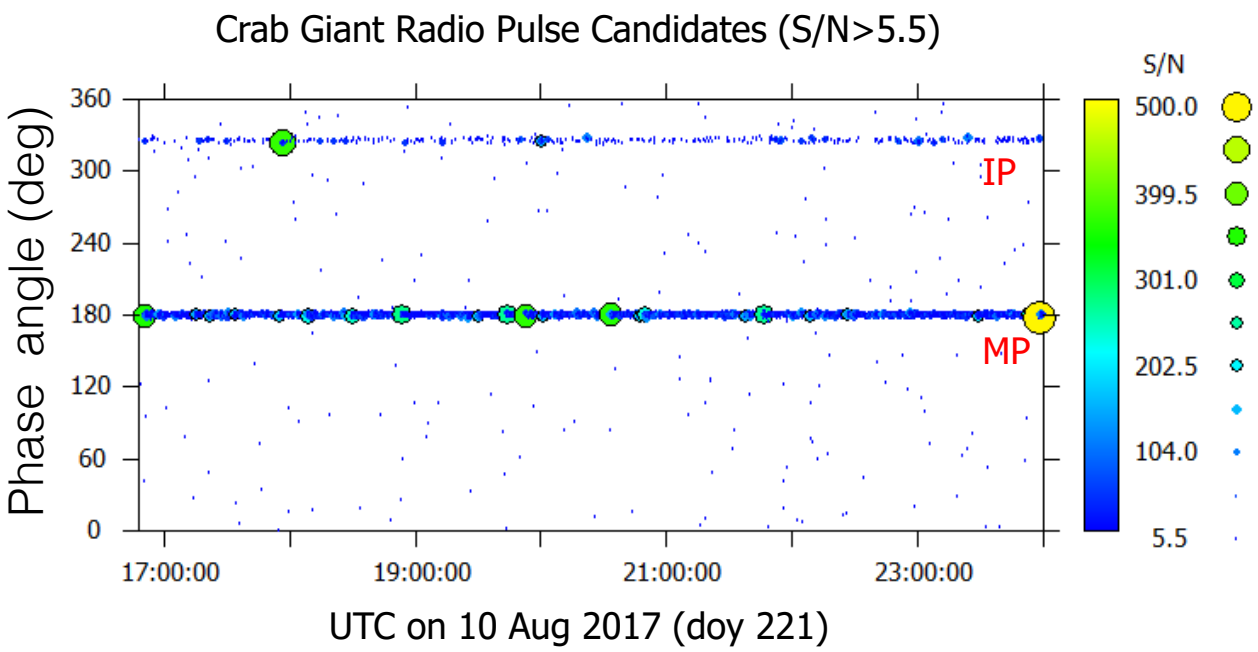
- **NICER observations of Crab**
  - Started from 2017 August 5
  - 1 Crab X-ray intensity ~ 10^4 counts/sec
  - Pulse detection only with a short exposure
  - GRP enhancement in X-rays? statistics!
- **Simultaneous radio monitoring**
  - 2, 8 GHz @ 64 m Usuda / JAXA
  - 6 GHz @ 32 m Hitachi / Ibaraki University
  - 325 MHz @ 31 m Iidate / Tohoku University
  - ~18 ks simultaneous with NICER in August

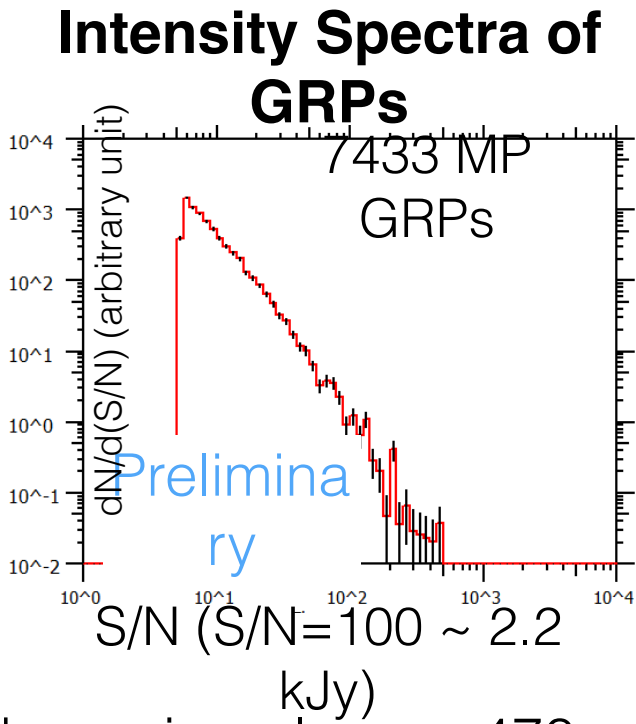


Identifying GRPs at radio ➡ X-ray studies with NICER
Additional Crab campaign in September? Campaign in optical / other observatories?

Mikami+2016, (Radio contribution from T. Terasawa, H. Takeuchi, Y. Murata, Y. Yonekura, H. Misawa, F. Tsuchiya, M. Sekido, K. Takefuji, T. Aoki, et al.,)

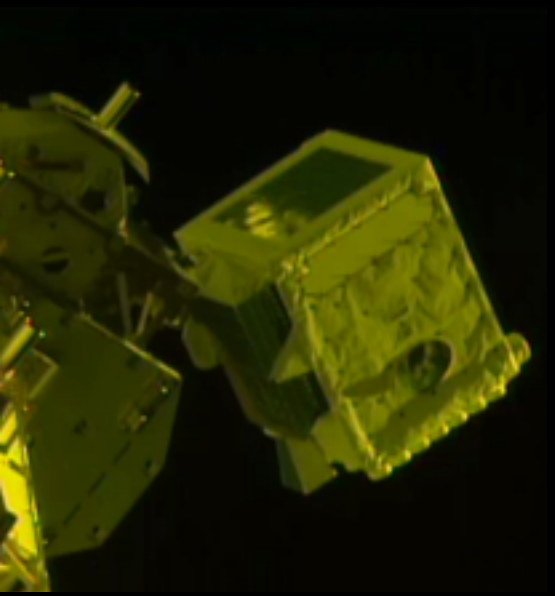
Usuda S-band (2194-2322 MHz) on 9 Aug 2017





GRP candidates (S/N>5.5) : ~7400 pulses for the main pulse + ~470 for the Interpulse

Summary



1. NICER Magnetar & Magnetosphere (M&M) working group covers highly magnetised young neutron stars.
2. Example scheduled targets are CXO J164710.2-455216 (low-B magnetar), PSR J1119-6127 (high-B pulsar), 1E 1207.4-5209 (absorption feature), PSR B0656+14 (rotation powered)
3. A prototypical magnetar 4U 0142+61 was observed with NICER during the outburst just after a SGR short burst. A pulsar glitch is suggested before or around the NICER observation.
4. We performed coordinated X-ray/radio observations for a radio-loud magnetar PSR J1622-4950 and Vela pulsar.
5. Simultaneous radio observations were performed with NICER for Crab pulsar in October to search for X-ray enhancement associated with giant radio pulses.