ISS Science Nugget, 9/22/17 (1 of 2)

LIGO has recently observed the merger of two stellar-mass black holes through the direct detection of gravitational wave radiation from these rare events. Further analysis of the gravitational wave data was able to constrain the spin of the newly formed black hole. NICER is ideally suited to measurements of black hole spin in X-ray binaries in the Milky Way and nearby galaxies. These parallel abilities mark an exciting new era for astrophysics. What are X-ray binaries? Black hole X-ray binaries are systems wherein a normal star orbits a black hole. Many of these systems have extended quiescent periods, wherein their X-ray luminosity hardly exceeds that of our Sun. However, when the black hole actively accretes from the atmosphere of the companion star, the X-ray luminosity can jump upward by eight orders of magnitude. Then, the X-ray emission from hot gas orbiting close to the black hole can be used to study the hole itself. Emission lines produced in this region are shaped by relativistic Doppler effects (the train whistle effect), shifting light to higher and lower energy, and by gravitational red-shifts (photons lose energy just escaping from the extreme gravitational potential).

Three weeks ago, the ISS experiment MAXI discovered a previously unknown black hole, leading to the designation MAXI J1535-571. NICER observations of MAXI J1535-571 put the unique capabilities of the mission on full display. Even in short exposures, NICER is able to record spectra with iron lines that have been shaped by the innermost relativistic regime close to the black hole. The attached figure illustrates the shape of the iron emission line observed by NICER, and three theoretical line profiles (black: a line produced far from a black hole; blue: a line produced near to a non-spinning black hole; red: a line produced close to a rapidly spinning black hole;). A preliminary analysis finds that the NICER data are consistent with a black hole spinning close to its theoretical maximum rate. NICER coordination with NASA's NuSTAR and ESA's INTEGRAL observatories will help to develop a more complete physical picture of MAXI J1535-571.

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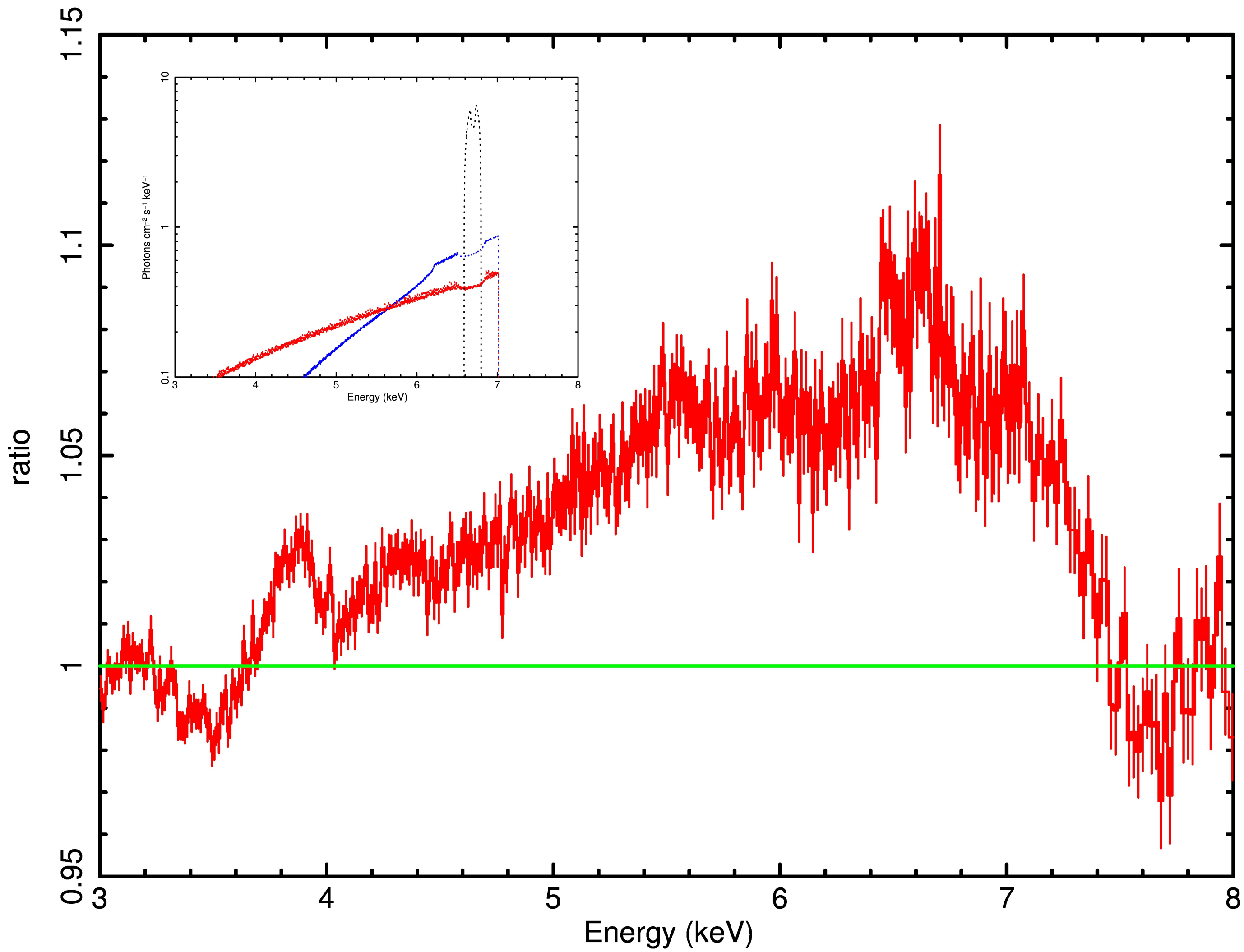

ISS Science Nugget, 9/29/17 (1 of 2)

Of the millions of black holes lurking in our Galaxy, we are aware of just over two dozen. This is because most black holes are dormant and not actively "feeding" on nearby material. Every now and then, however, a black hole will go on an eating spree during which it pulls huge amounts of gas from a companion star. The infalling gas is heated to millions of degrees, resulting in a sudden outburst of radiation, primarily in X-rays. NICER has been observing a black hole candidate, MAXI J1535-571, following a remarkable outburst reported by the MAXI ISS investigation (on JEM-EF) on September 2nd, 2017. Analysis of NICER's time-resolved data reveals that the X-ray brightness varies in a peculiar periodic manner, with two modulation periods of roughly 0.38 and 0.19 seconds. Such modulations have been seen before in other black-hole binaries and are thought to reveal how the hot material moves under the influence of the black hole's strong gravity. The study of these modulations allows us to probe the extreme conditions at the edge of a black hole's event horizon. The attached figure shows the power spectrum (a measure of brightness as a function of modulation frequency) for MAXI J1535-571 in a segment of NICER data. Strong peaks at 2.6 and 5.2 Hz are evident, representing variability with periods of 0.38 and 0.19 seconds, respectively.

NICER continues to monitor this source and is coordinating observations with NASA's NuSTAR observatory, the IRSF telescope in South Africa, and other resources in space and around the world.

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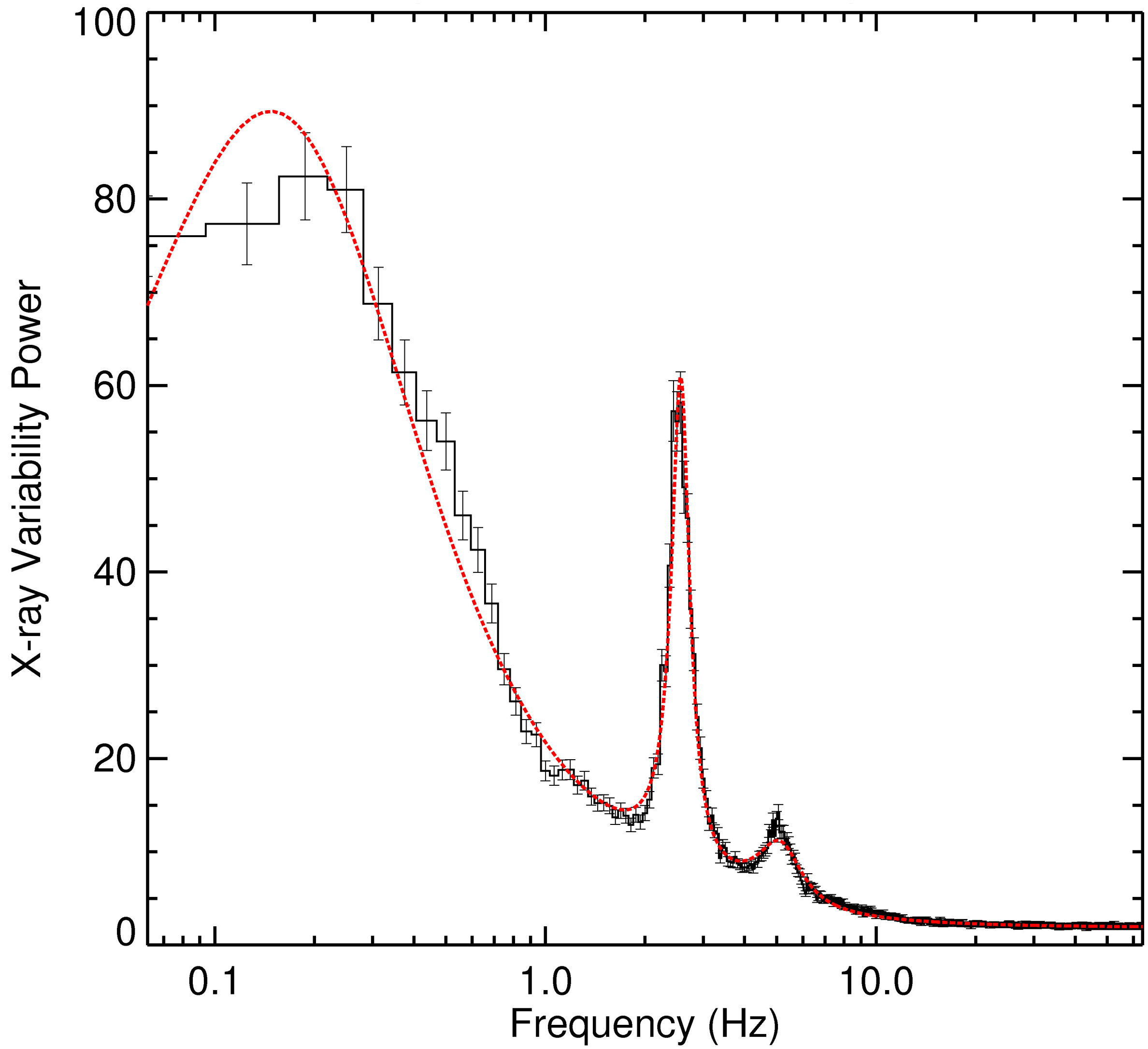
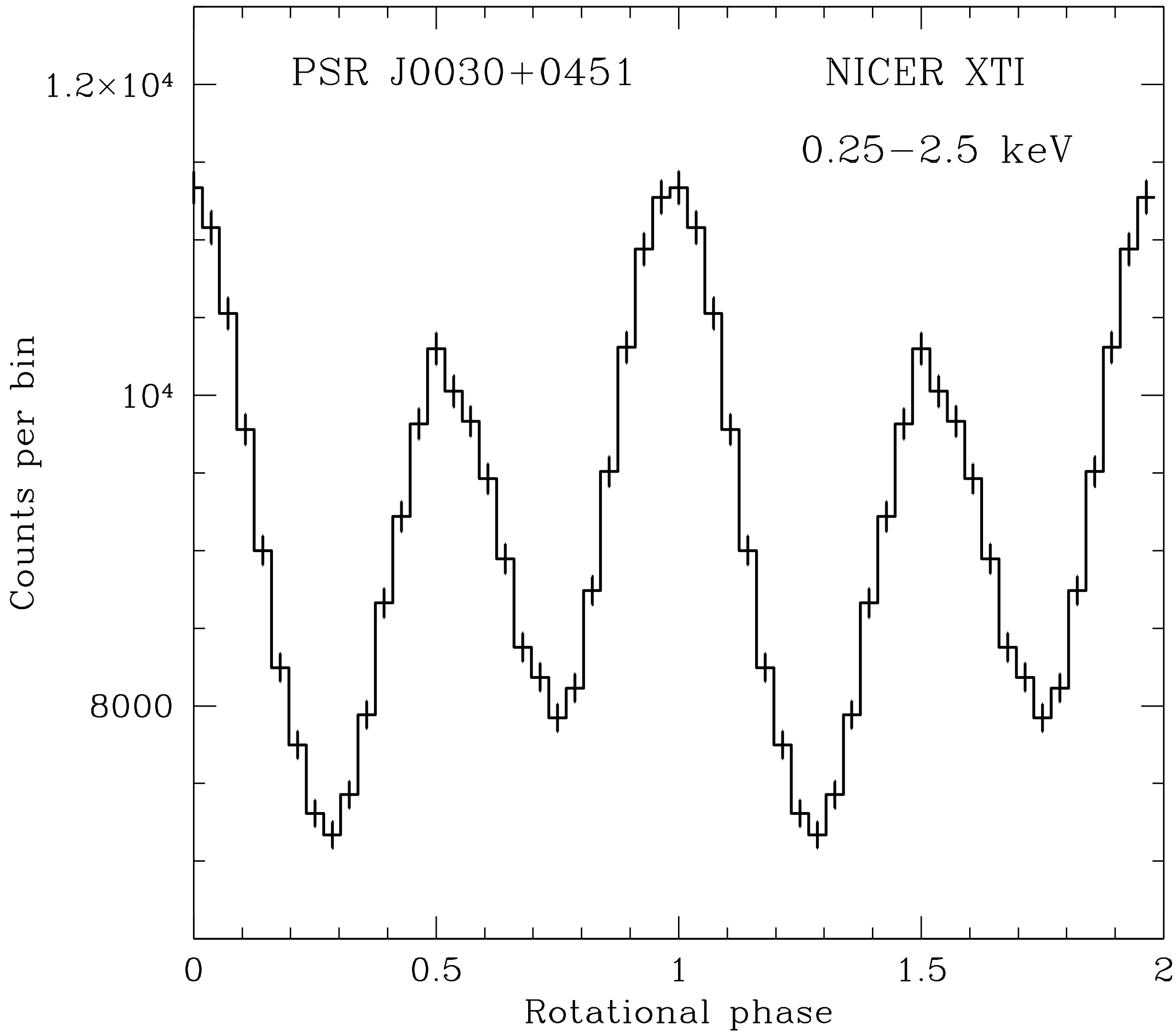
NICER Power spectrum of MAXI J1535-571 (~800 sec exposure)



ISS Science Nugget, 10/6/17 (1 of 2)

One of NICER's Level 1 Science requirements is to make measurements of neutron star radii to ±5% accuracy, representing an order-of-magnitude improvement over our current knowledge of the sizes of neutron stars. "Lightcurve modeling" is a key method that NICER employs. Rapidly spinning, or strongly magnetic, neutron stars are hotter at their magnetic poles, for reasons similar to those that generate aurorae (Northern and Southern Lights) here on Earth: particle radiation streaming down along magnetic field lines. As the stars spin -- sometimes hundreds of times per second -- the magnetic-pole hot spots rotate in and out of our view so that these neutron stars, appearing to pulse, come to be known as "pulsars." Modeling lightcurves (the modulation profiles of the pulses) makes use of the fact that a neutron star's gravity is strong enough to bend the trajectory of light; the magnitude of light-bending is a function of the ratio of the star's mass to its radius (M/R). For pulsars, this means that when a hot spot is on the far side of the star (in other circumstances invisible to us), the bending of light in strong gravity enables us to see a portion of its emissions. The basic effect is to change the depth of modulation of the pulses we see from spinning neutron stars. Lightcurve modeling exploits this fact to infer the M/R ratio, enabling us to determine radius when coupled with information about the star's mass. To achieve 5% accuracy, we require very high signal-to-noise lightcurves. Accompanying this text is the lightcurve for a 300,000 sec exposure of the pulsar known as J0030+0451, which rotates almost 206 times each second, accumulated so far by NICER. This is a factor of 7 higher in quality than the previous-best X-ray lightcurve for this pulsar. Another 1.2 million seconds of exposure is needed to achieve the 5% radius measurement goal for this pulsar. NICER continues to accumulate data toward that end, on this and several other neutron stars.

NICER lightcurve of PSR J0030+0451 in 305 ksec



The extreme gravity on neutron stars is sufficiently strong to induce nuclear fusion of light elements on the stellar surface. Once ignited, thermonuclear flames wrap around the star within seconds, powering a bright burst of X-ray emission that lasts a comparable time. On August 29th, NICER on the ISS detected such a burst (top panel- attached figure) from the binary star system 4U 1820-30, which resides at a distance of 20,000 light years in the star cluster NGC 6624 in our Galaxy. The system's orbital period is just 11 minutes. This was an exceptionally bright event, with peak photon rate several times higher than for regular bursts. From the spectrum of photon energies measured in very fine time bins, we can derive the evolution of the temperature and radius of the star's surface (middle and bottom panels). For regular bursts, the nuclear burning heats up the star but the strong gravity confines the burning material to the surface, at a nominal radius of about 10 km. In this so-called "superexpansion" burst, we see the star's surface expand to over 140 km radius at a rate in excess of 500 km/s: despite the extreme gravity, the thermonuclear burst ejects the top layer of the neutron star. When the radius of this shell increases, its temperature decreases, such that the total brightness remains constant. The onset of a superexpansion burst had been seen previously with NASA's Rossi X-ray Timing Explorer, but that telescope's sensitivity was such that it lost the signal when the temperature dropped below 1 keV — it was unable to detect the peak of the expansion, making our NICER observation a first. Furthermore, superexpansion bursts are rare, and this spectacular observation was made possible by NICER's flexibility to quickly schedule observations of this star at the appropriate time. Currently, we are studying the burst spectrum for signatures of nuclear ashes that may constrain the mass-to-radius ratio of the neutron star.

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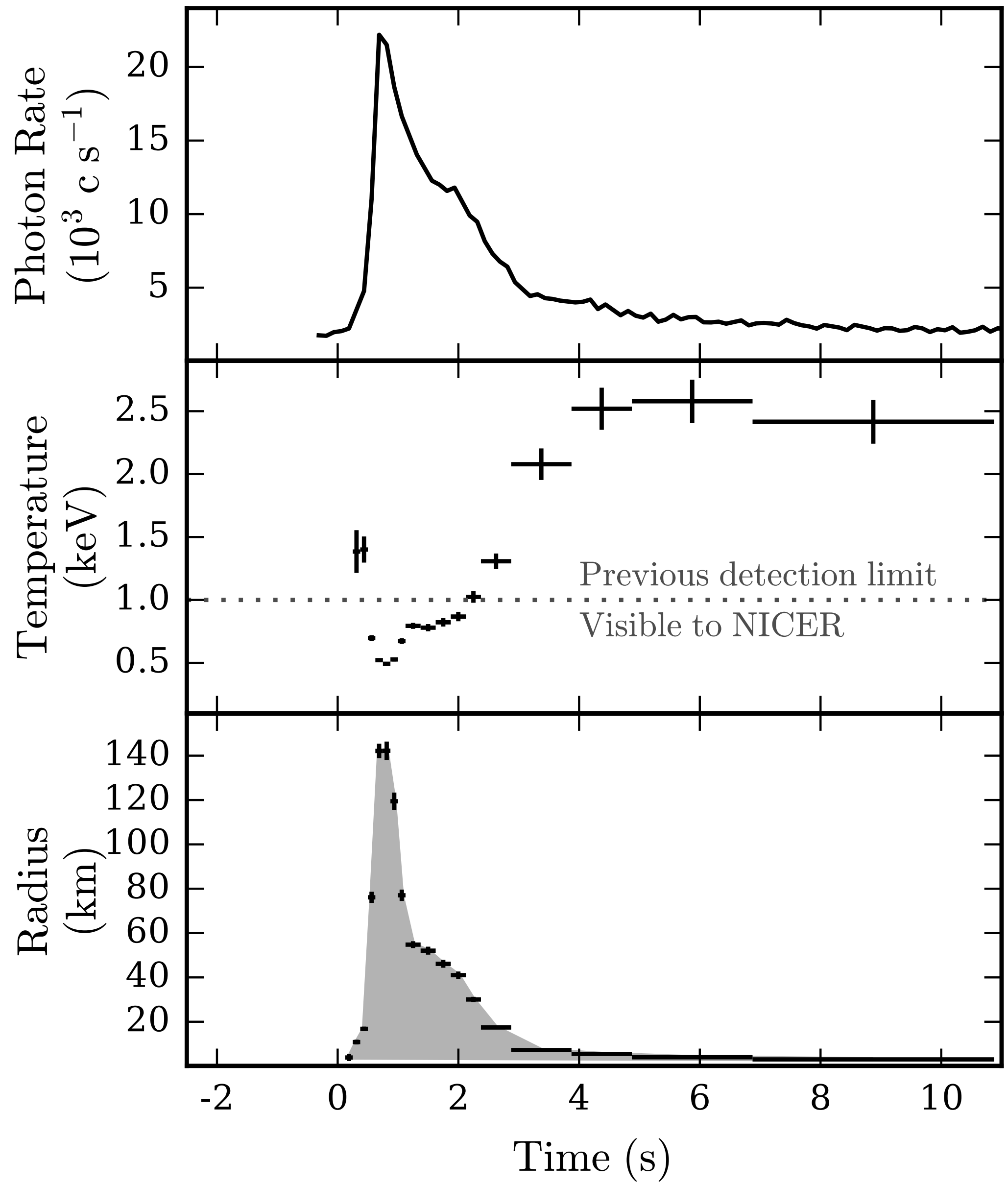

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[A more condensed version submitted to ISS…]

Cyg X-1 is one of the first X-ray sources recognized as a black hole binary, i.e., a binary system consisting of a black hole (in this case, with 15 solar masses) that is accreting mass from its stellar companion (in this case, a 20 solar mass supergiant star). The gas swirling into the black hole becomes heated to millions of degrees, before it disappears at the black hole event horizon, and this heat produces a great X-ray glow that we can see thousands of light years away, across the Milky Way.

Another interesting characteristic of Cyg X-1 is that the X-rays sometimes show intense flares that rise and fall with timescales in the range 1-100 msec. These flares are sometimes investigated in terms of "shot noise" characteristics (e.g., Pottschmidt et al, 1998, A&A, 334, 201). Investigators search for the most intense events to gain measurements of rise times, decay times, peak luminosities, and spectral changes. The goals are to determine their origin and their relationship to the smaller-amplitude variations that are very common in accreting black holes and neutron stars. Gierlinski & Zdziarski (2003, MNRAS, 343, L84) found 13 intense fast-flares in their inventory of 2.3 Ms of observations of Cyg X-1 with NASA's Rossi X-ray Timing Explorer (RXTE). In their search, they first measured the mean and sample standard deviation (sigma) for each interval of continuous exposure (~2 ks), and they then selected events with maxima that exceeded 10 sigma above the mean level. For the X-ray sources considered here, sigma is dominated by intrinsic flickering in the source, rather than fluctuations due to counting statistics, and so the 10-sigma search is tantamount to looking for events that are well past the range where log-normal statistics still governs the local behavior of the X-ray source. From these events, Gierlinski & Zdziarski found timescales and patterns of spectral evolution that differed, depending on whether Cyg X-1 was found to be in a "hard" or "soft" X-ray state. Uttley & McHardy (2001, MNRAS, 323, L26) also studied X-ray variations in Cyg X-1, and they discuss more physical interpretations of statistical analyses, i.e. links to large coronal flares or to the propagation of mass accretion fluctuations through the accretion disk.

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NICER made a series of observations of Cyg X-1 during 10 days near the end of the Commissioning period (2017 July). This netted 86 continuous exposure intervals with an average span of 10 minutes. This turned out to be a fortunate schedule choice. Radio observations showed that Cyg X-1 was producing unusually fast radio flares (6 min each) during August 2017 (Pooley at al. 2017, Atel. #10648), and our NICER observations captured fast flares in X-rays, several weeks earlier.

Figure 1 shows the NICER intensity history for Cyg X-1 (blue and red crosses), superposed on the monitoring observation of the MAXI instrument (black triangles), which also operates from the International Space Station. Each plotted point for NICER represents the mean intensity of that exposure. We applied the sigma-based search criteria to the NICER data, using a bin size of 10 msec. We find 25 exposures (of the 86) containing one or more flares at the 7-sigma level, and these observations are plotted in Fig. 1 in red, rather than blue. Two observations show peaks that exceeded 10-sigma. Both exposures were made on 2017 July 6, and their light curves are shown in Figure 2. The double-horned flare in the top panel is the most intense flare that we see, while the flares in the lower panel display the assortment in intensity/timescale that we have sampled.

Attention now shifts to the detailed analyses that may constrain the origin of these flares as either related to the energy source of the corona (perhaps magnetic reconnection events?) or to changes we can tie to the accretion disk. Toward this goal, the notable advantages of NICER are its high count rates (higher than RXTE) and also its spectral window (0.2-12 keV). NICER affords visibility to both the disk and corona spectral components, something not possible with RXTE (mostly viewing the corona at 3-40 keV).

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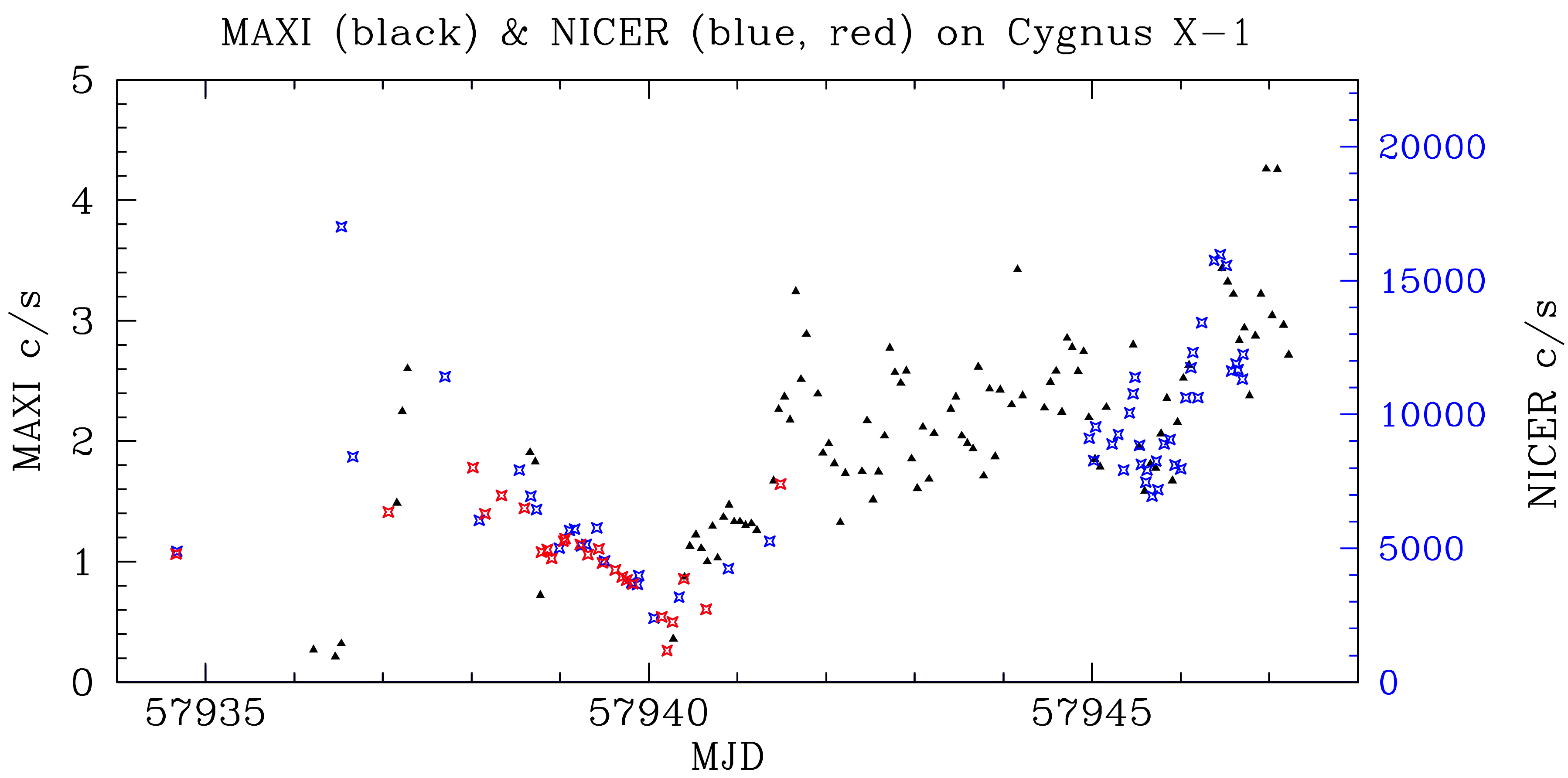
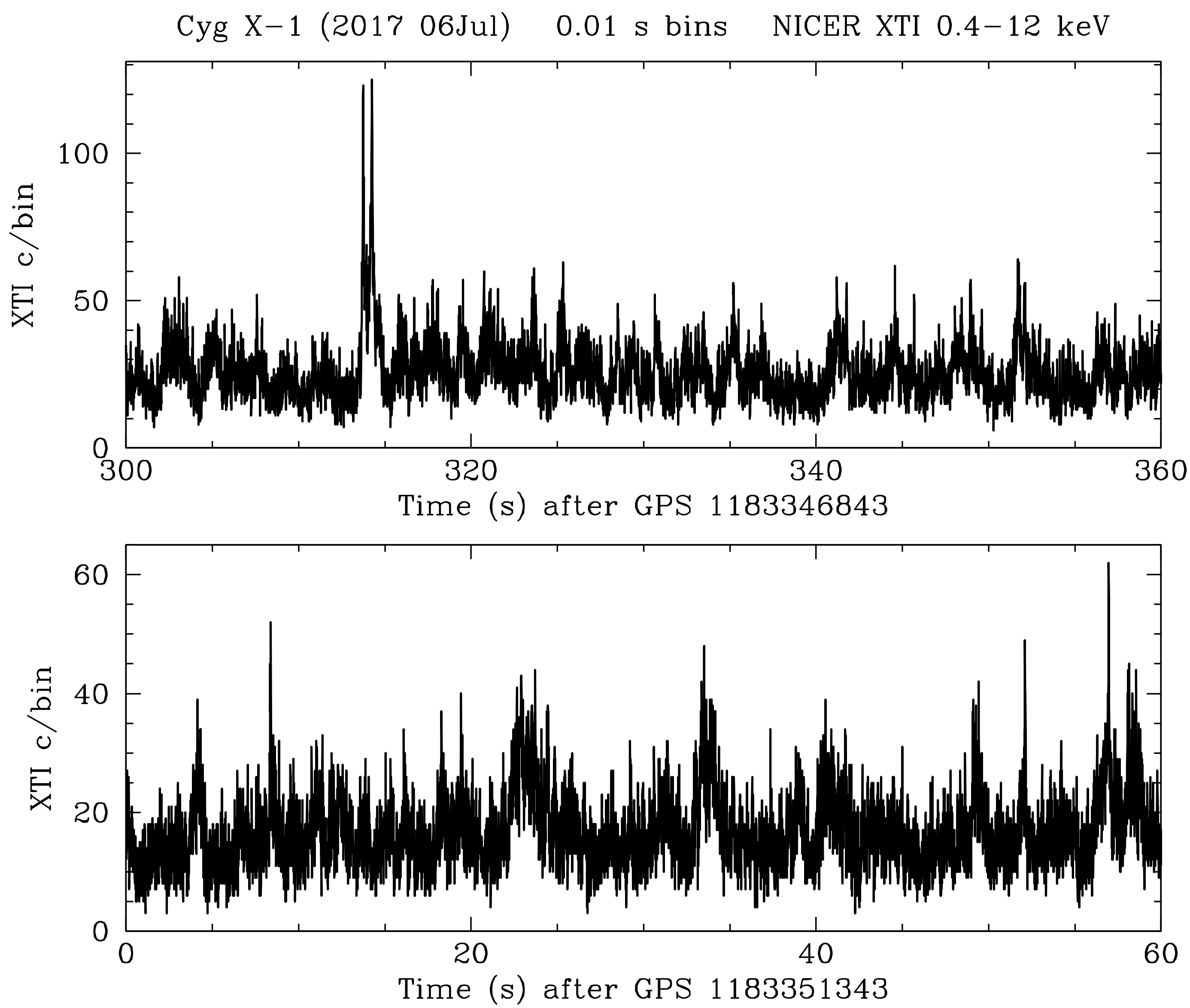


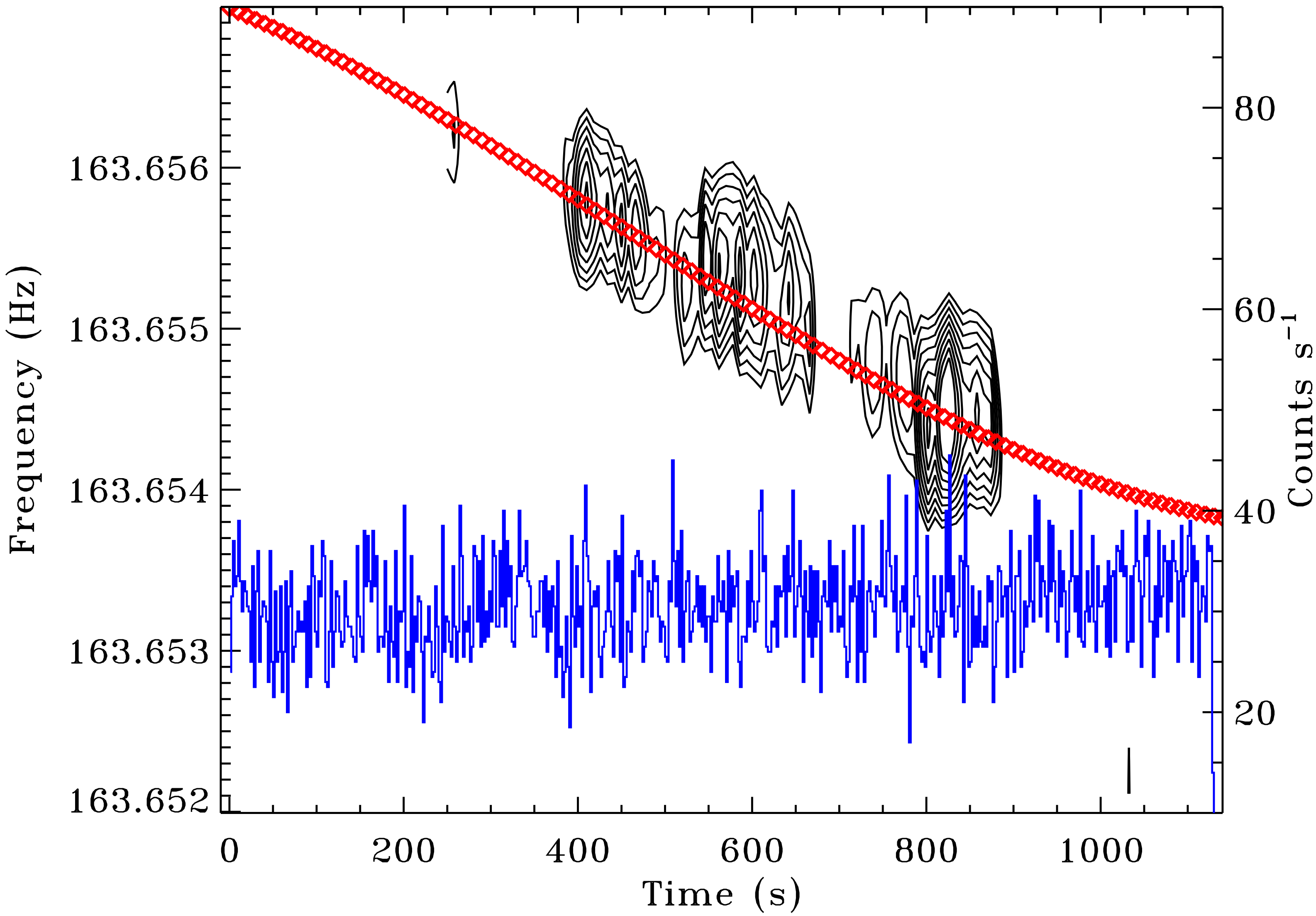


Cyg X−1 (2017 06Jul) 0.01 s bins NICER XTI 0.4−12 keV
XTI c/bin
0
50
100
300
320
340
360
Time (s) after GPS 1183346843
XTI c/bin
0
20
40
60
0
20
40
60
Time (s) after GPS 1183351343

ISS Science Nugget, 10/27/17 (1 of 2)

IGR J17062-6143 (J1706, for short) is the most recently discovered neutron star comprising the class of accreting millisecond X-ray pulsars (MXPs). These systems are fast-spinning neutron stars orbiting a low-mass companion star; the neutron star in J1706 is spinning at almost 164 revolutions per second. MXPs typically have very compact orbits—the two stars can be closer together than the Earth and Moon. The companion stars are also extreme, having only a fraction of the mass they were born with, after being "whittled away" by the strong X-ray emission from the neutron star. Matter stripped off of the companion flows through an accretion disk and is eventually channeled onto the neutron star, forming a bright, X-ray-emitting hot spot. As the star rotates, the hot spot appears as flashes of X-rays that NICER can precisely measure. MXPs are of great interest because observing neutron stars in such a binary system can provide a means to accurately weigh the neutron star, that is, determine its mass, a key measurement for NICER. Observations of J1706 with NICER are allowing us to accurately measure the orbital parameters of this system for the first time. This is illustrated in the accompanying figure. The blue trace shows the X-ray count rate (right vertical axis) from J1706 measured by NICER during one ISS orbit. The contours (black) indicate the X-ray pulse frequency (left vertical axis) measured by NICER, and show that the frequency was decreasing with time. This change in observed frequency is caused by the Doppler effect produced by the neutron star's orbital motion. Just as a police officer can catch speeding motorists using a "radar gun" employing the Doppler effect, NICER uses it to measure how fast the neutron star moves around its binary companion. The red curve shows the predicted change in frequency that would be produced if the neutron star were moving in a circular orbit with a period of 57 minutes. NICER caught this neutron star speeding away from us at almost 4 km/sec. Further study will map out the details of this neutron star's orbital motion, and perhaps eventually enable a measurement of its mass.

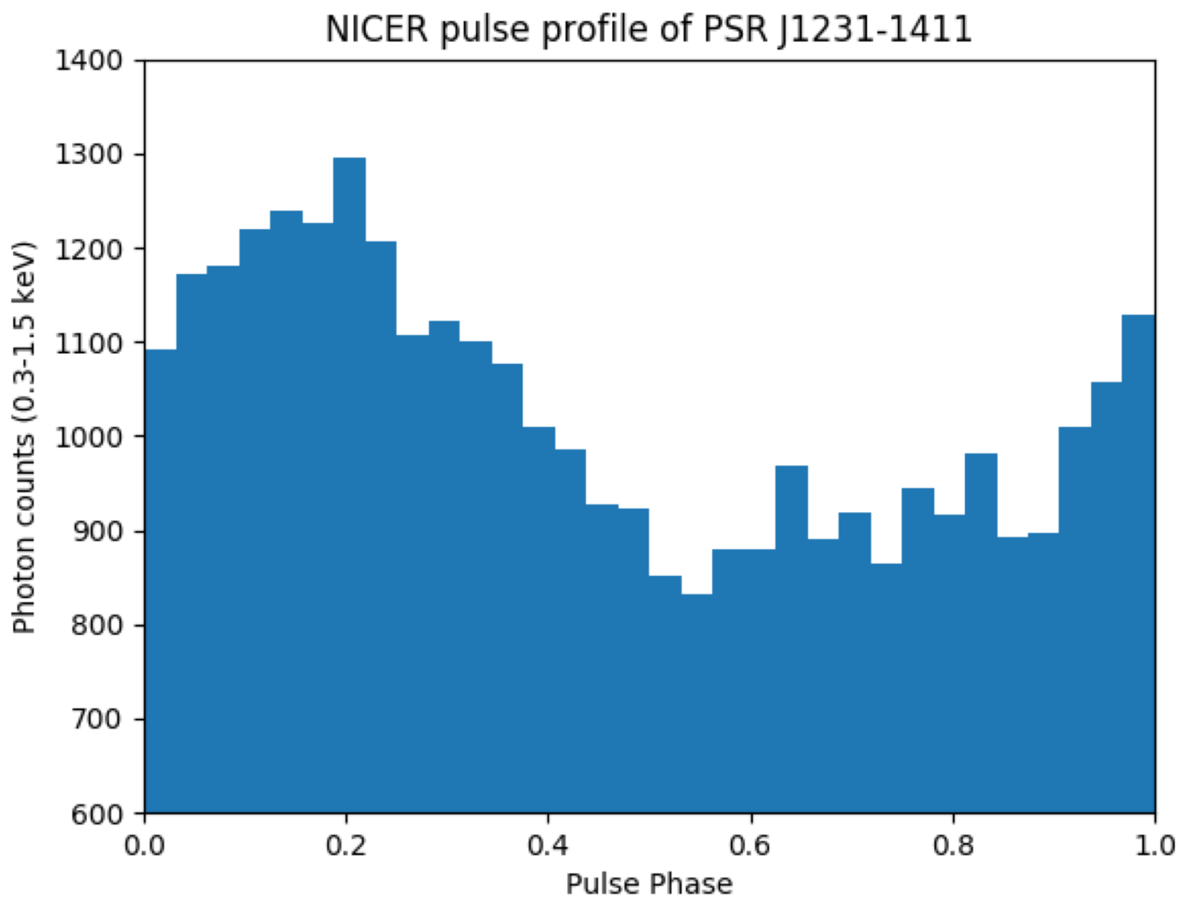
ISS Science Nugget, 10/27/17 (2 of 2)



ISS Science Nugget, 11/03/17 (1 of 2)

NICER has discovered X-ray pulsations from a neutron star spinning at 271 rotations per second (more than 16,000 RPM). This star is the millisecond pulsar PSR J1231-1411, which packs about 1.5 times the mass of our Sun into a sphere about 15 miles in diameter. The NICER observations show that the rapid spin of the pulsar is causing particles to be accelerated in its magnetosphere and to rain down onto the magnetic polar caps with enough energy to heat them to approximately 1 million degrees Celsius, hot enough to glow in X-rays. NICER sees sinusoidal X-ray brightness pulsations as the polar caps rotate in and out of our view. This is an important discovery for NICER because one of the mission's key science goals is to measure the radius of neutron stars by studying pulsed emission from the surface. Prior to NICER's launch, only a few suitable pulsars were known. This discovery adds a new source for these studies that will help constrain the nature of (stable) matter at super-nuclear densities, a regime that cannot be probed in Earth-based experiments.

ISS Science Nugget, 11/03/17 (2 of 2)



ISS Science Nugget, 11/11/17 (1 of 2)

Using NICER flight data recorded from 2017 DOY 260 to 265, the SEXTANT team ran its flight software on a ground computer, and successfully demonstrated navigation using only X-ray pulsar observations. The software's GEONS navigation filter was initialized with a degraded state designed to diverge rapidly from the truth state. The successful ground demonstration represents an essential milestone toward a fully autonomous on-orbit demonstration, initial trials of which are currently underway.

In the accompanying figure, system performance without measurements, depicted in green, rapidly diverges from the truth state, as expected. Performance while processing X-ray pulsar measurements, shown in blue, initially exceeds the current performance target of 10 km RSS, but reaches that performance target within one day and robustly remains below 10 km RSS for the remainder of the schedule. A total of 494 measurements were processed from the X-ray "beacon" pulsars J0437-4715 (143), B1937+21 (316), J0030+0451 (33), and J0218+4232 (2).

These ground results were used to tune the flight GEONS filter for the autonomous on-board navigation tests now running. The SEXTANT experiment on the ISS NICER payload is on track to demonstrate navigation technology that will eventually enable new deep-space exploration, to the outer planets and beyond.

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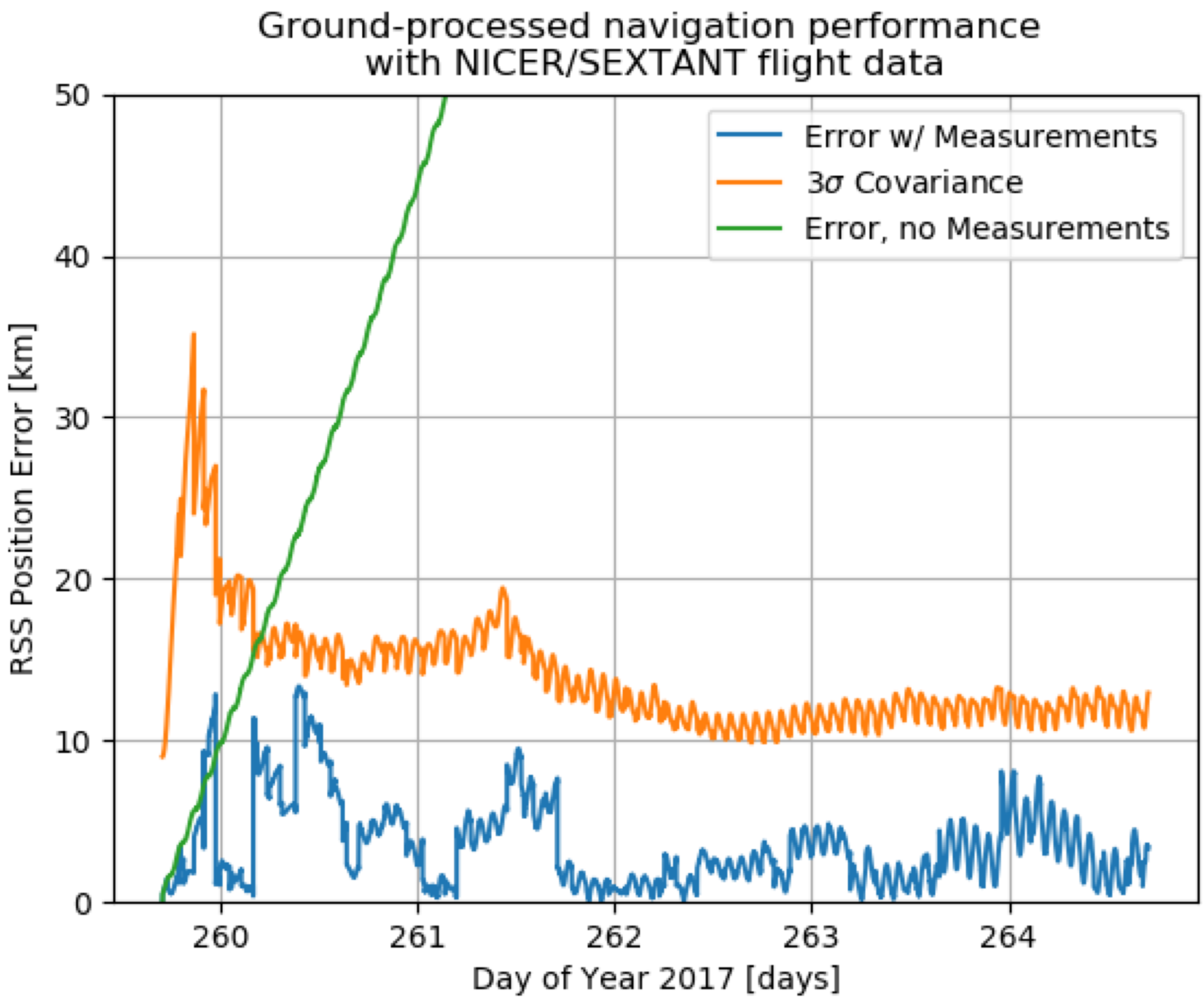

ISS Science Nugget, 11/17/17 (1 of 2)

In a technology first, the SEXTANT team has successfully demonstrated fully autonomous, real-time X-ray pulsar navigation (XNAV) on-board the NICER mission. SEXTANT's primary demonstration goal, or Key Performance Parameter (KPP), sought to achieve an orbit determination error of less than 10 km worst direction, taken as 17 km of Root-Sum-Squared (RSS) 1-σ error, using up to two weeks of X-ray pulsar observations. A future 'stretch' goal will seek to reach an error of less than 1 km worst direction, or 1.7 km RSS 1-σ.

On 2017-11-09, the SEXTANT and NICER team developed and loaded a millisecond pulsar-rich observation schedule informed by lessons learned through recent analysis of navigation performance in numerous ground processing evaluation campaigns using NICER flight data. At 20:33:27 UTC, the SEXTANT flight software was initiated, and the GEONS navigation filter was initialized with a degraded state—i.e., position and velocity knowledge—designed to diverge rapidly from the truth state without X-ray pulsar observations. During the following 2.2 day autonomous experiment, the SEXTANT flight software significantly surpassed the primary KPP by reaching < 10 km RSS error in approximately 7.5 hours and remaining well below that threshold for the duration of the experiment. A total of 78 measurements were generated from the X-ray "beacon" pulsars J0218+4232 (33), B1821-24 (30), J0030+0451 (13), and J0437-4715 (2).

In the accompanying figure, the flight system's predicted performance without measurements, represented in blue, rapidly diverges from the initial state, as expected. The autonomous flight software performance, while processing measurements, is shown in green and initially displays error growth similar to the no-measurement case. Within 7.5 hours, the real-time error reaches and remains below 10 km RSS for the duration of the experiment.

This successful demonstration firmly establishes the viability of X-ray pulsar navigation as a new autonomous navigation capability to enable and enhance deep-space exploration anywhere within the Solar System, and potentially beyond. The current flight results will be used to update and tune the flight software, as well as the ground segment software, for a second navigation experiment later in the NICER nominal mission, where SEXTANT's pulsar timing models will be developed using only NICER data.

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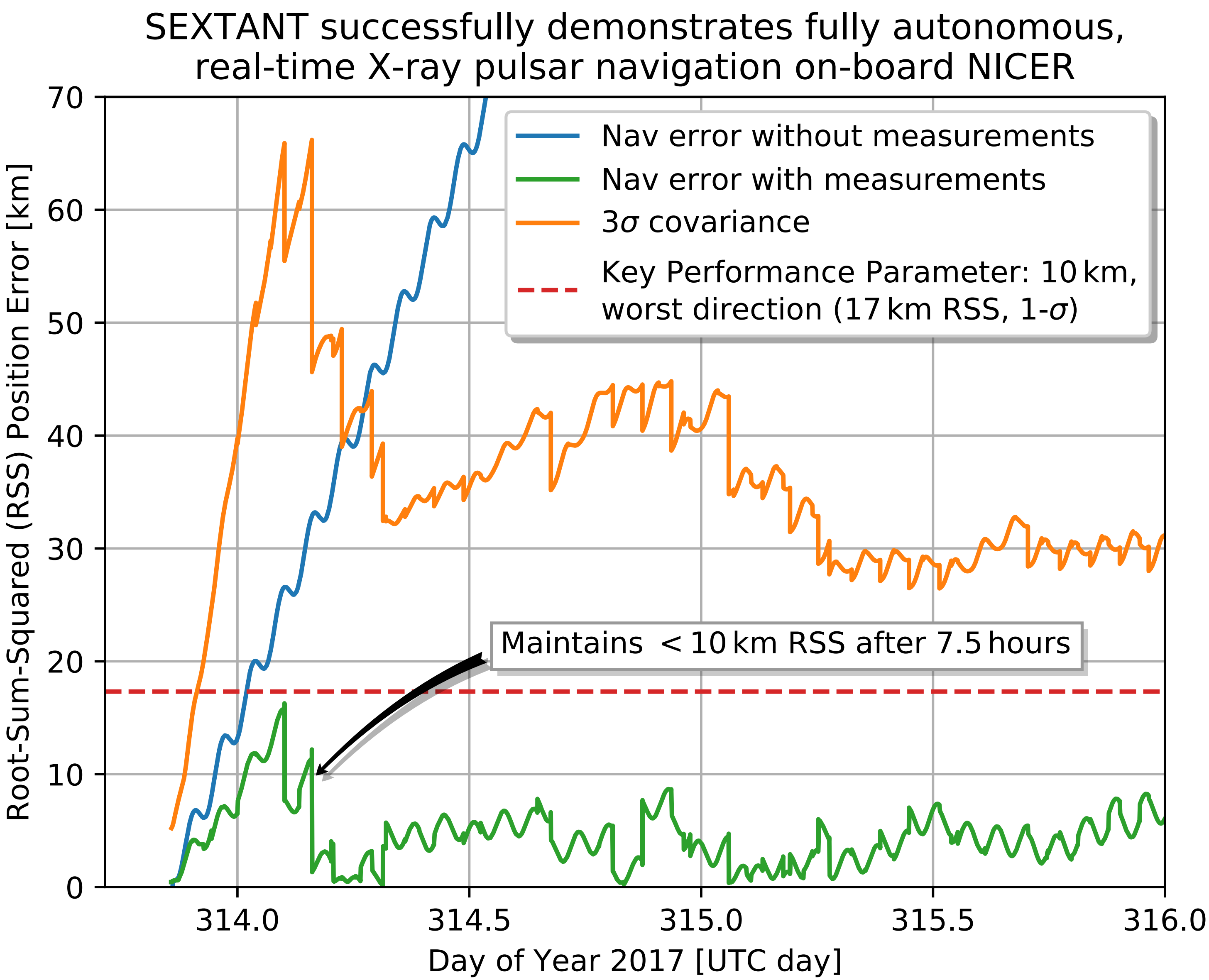

ISS Science Nugget, 12/1/17 (1 of 2)

The black hole binary, GRS 1915+105, is famous for its X-ray variability. This source first appeared to astronomers in 1992 as a bright X-ray Nova. Unlike others that erupt for typically a few months to 2 years, this transient source is now in its 25th year of accretion rage.

Figure 1 displays a sample of NICER light curves from GRS 1915+105 (6 of the 133 accumulated as of this writing). Each panel showing a second-by-second record of the X-ray brightness. The upper-left panel shows an interval of modest flickering, which is typical of black hole binaries. Such quasi-steady behavior is seen in GRS1915 about half of the time. The remaining panels show wild variations, with a remarkable assortment of variability timescales. The repetitive quality of the variations invites interpretation as some kind of instability cycle.

Figure 2 shows a "hardness-intensity diagram" (HID), where every second of all 133 observations (including those in Fig. 1) are plotted (small purple symbols) in terms of the X-ray intensity (vertical axis) versus X-ray color (horizontal axis), which is a simple count rate ratio, in two energy bands, that is a proxy for the spectral shape. There is an astonishing degree of organization in Figure 2, compared to Figure 1. GRS 1915 as more of an organized machine than a chaotic monster. The high density of points in three regions of Figure 2 suggests that the source behavior may be considered as flip-flops between three quasi-stable states. NICER is ideally suited to investigate this further, since the Instrument's energy range provides direct visibility to both of the spectral components that are changing with time (Fig. 1).

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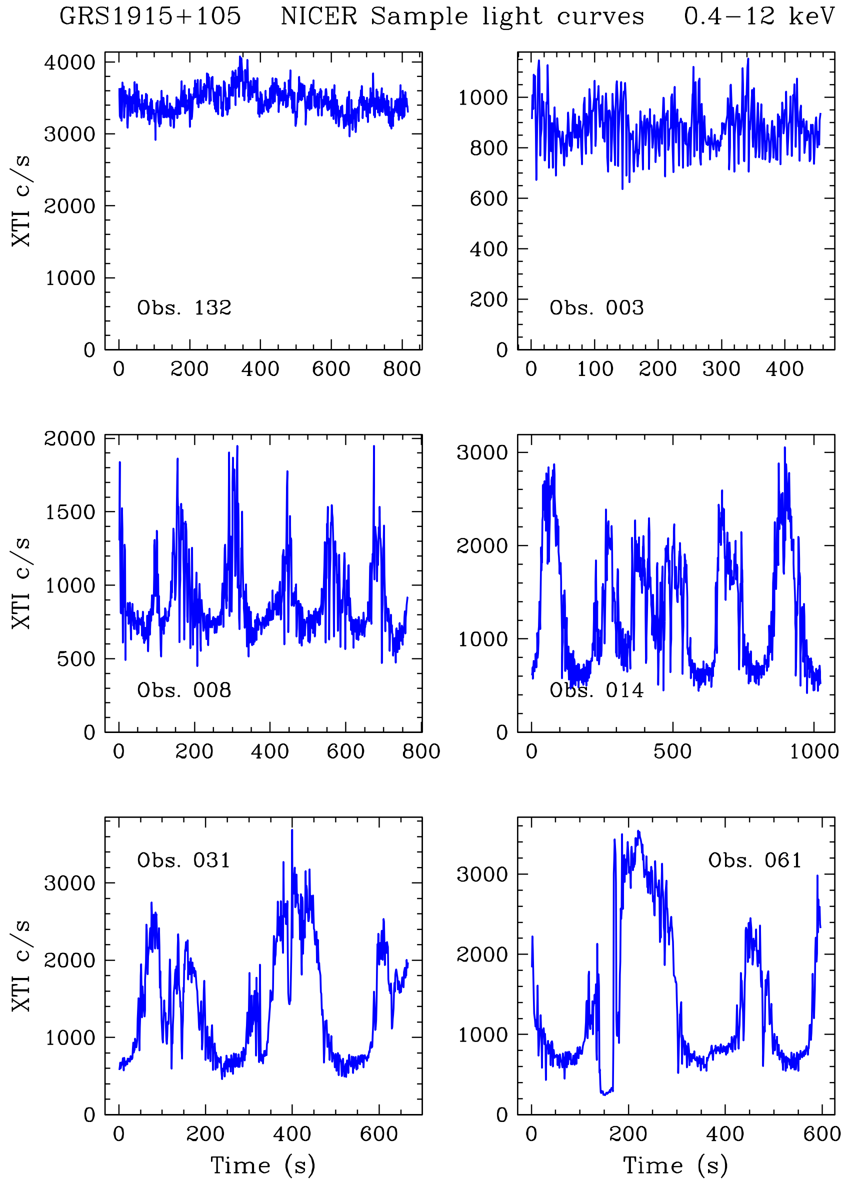

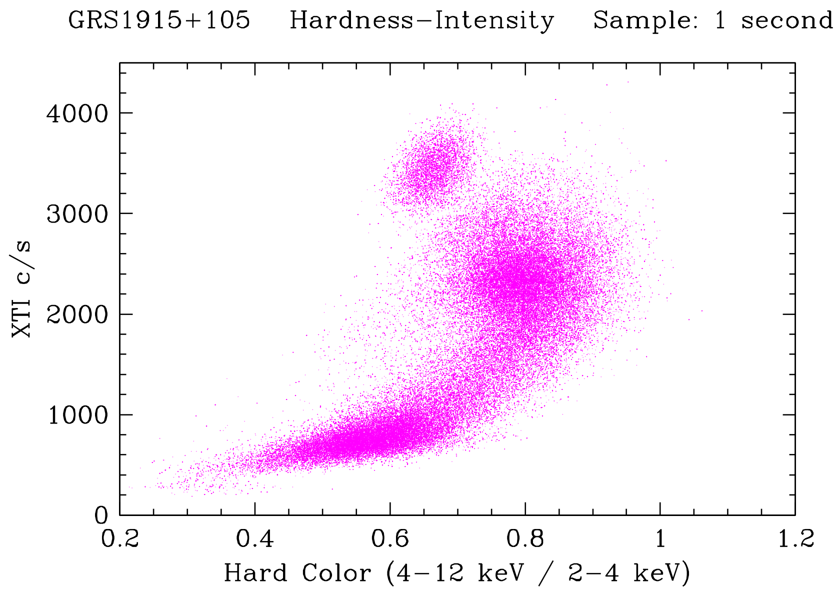

ISS Science Nugget, 12/8/17 (1 of 2)

Gigantic X-ray flares or “superflares” of solar- and lower-mass stars occur very rarely and apparently randomly, and decay quickly on timescales of a few days to a week. The current orbiting X-ray observatories such as Chandra and XMM-Newton are not optimized to repoint quickly in response to such fast transient events. NICER, however, has a rapid maneuvering capability and flexible scheduling, enabling follow-ups of these X-ray flares within about a day or two, and also has a larger collecting areas in the X-ray band, enabling the study of these events on timescales as short as 1 minute or less.

NICER has observed two giant X-ray flares from active binary systems, in response to their detections by the MAXI all-sky X-ray monitor onboard the ISS JEM-EF. These X-ray flares are believed to be driven by the reconnection of magnetic loops on one or both component stars. The present-day Sun also produces similar X-ray flares but with much smaller (by a factor of about 100,000) energies, which however can still disrupt the magnetosphere and upper atmosphere of the Earth. The young Sun once produced much more energetic X-ray flares, which likely affected and/or delayed the development of life on Earth. The study of such flares is thus important for the present day, e.g., operations in space, the terrestrial power grid, etc., as well as for understanding the conditions under which life can potentially originate.

NICER began observing the X-ray flare in the active binary system GT Muscae in 2017 July about 1-2 days after its onset. It intermittently monitored the decay for the next 2.5 days, collecting roughly 380,000 photons in just 1,600 seconds of exposure. The light curve showed a smooth, gradual flux decline by a factor of two, followed by an apparent flattening (figure, left). The plasma stayed hot, at a temperature of about 40 million K (igure, right), suggesting an ongoing continuous heating during the decay phase. NICER also witnessed a flare on another active system, UX Arietis, in October 2017. NICER's X-ray spectrum shows clear neon and oxygen lines (figure, right), while the emission from highly ionized iron ions (Fe XXV) is not as prominent as it is in the flare of GT Muscae and other earlier flares. This result provides useful constraints on the stellar magnetic field structures and the elemental composition of the flaring plasmas.

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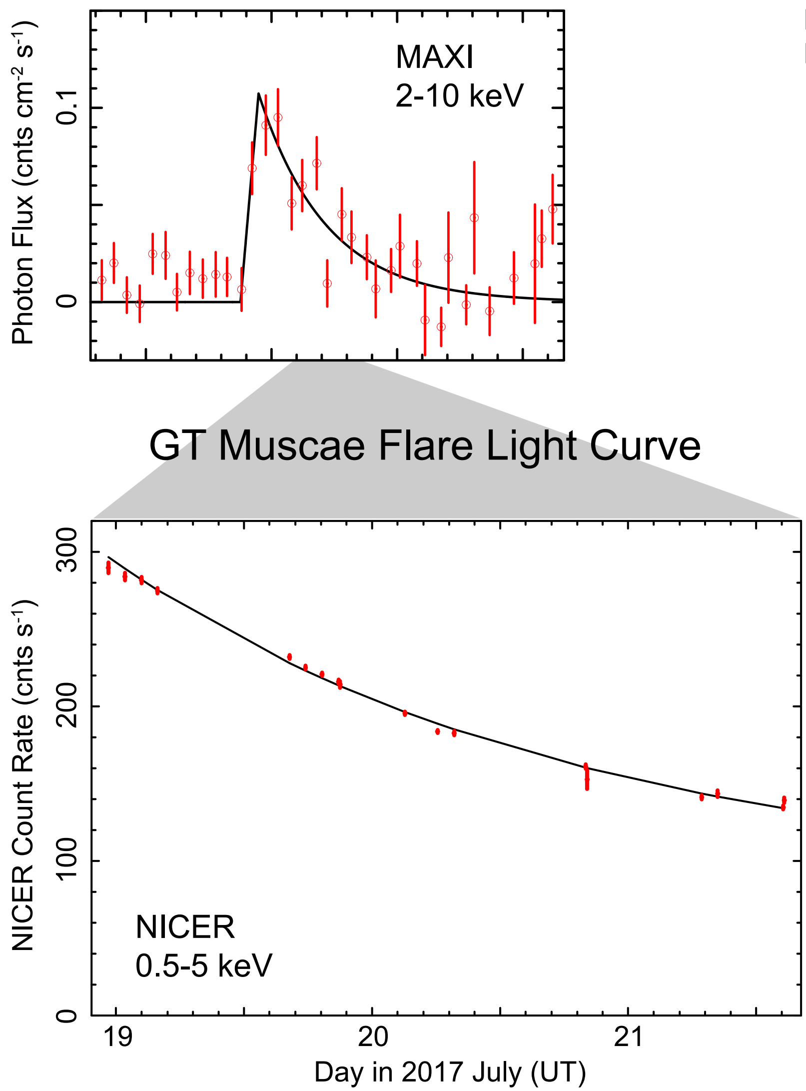
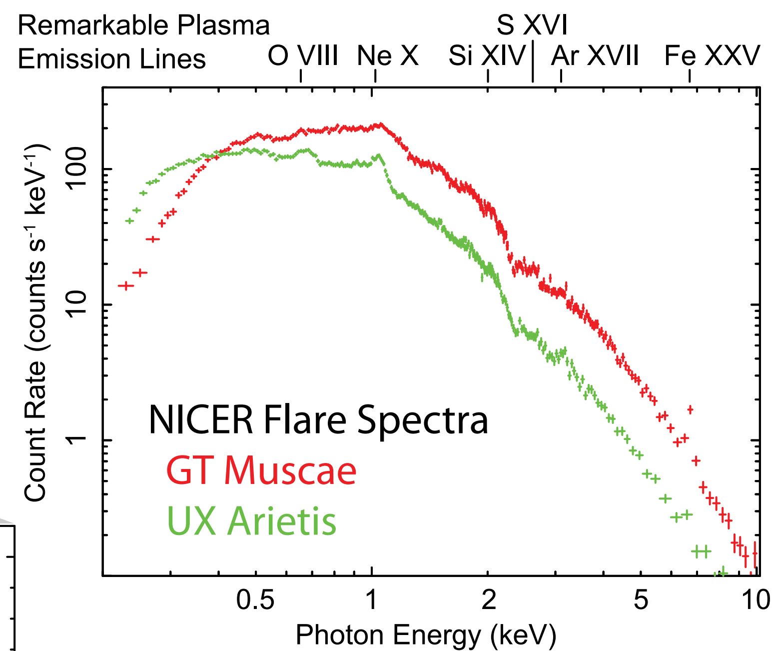


GT Muscae Flare Light Curve



ISS Science Nugget, 12/15/17 (1 of 2)

Over the 9-10 December weekend, NICER conducted a Target of Opportunity (TOO) observation of the "cataclysmic variable" (CV) binary star system TT Arietis. The TOO was triggered by scientists at the University of Southampton, Northwestern University, and other institutions who arranged a broad multiwavelength coordinated campaign to observe TT Arietis simultaneously (to the extent possible) with the Very Large Array (VLA) radio telescope in New Mexico, the Boyden observatory in South Africa, NASA's Swift observatory, the Asiago Observatory in Italy, the Palomar observatory in California, the Apache Point Observatory in New Mexico, the Center for Backyard Astrophysics (CBA) and the American Association of Variable Star Observers (AAVSO) across the United States, in addition to NICER on the ISS. NICER provides substantial sensitivity and spectral capability in X-rays to complete the full physical picture of TT Arietis through this campaign.

Why TT Ari? Thanks to the sensitivity upgrades in radio telescopes, we have only recently discovered that weakly-magnetic CVs are significant radio emitters. The radio emission mechanism is not yet understood, and to date we only have radio observations for a handful of them. For the majority of those observed, the emission is consistent with synchrotron radiation. An interesting question then is: do they launch jets? It has been accepted for many years that CVs do not launch jets; they have even been used to constrain jet-launching models. TT Ari, however, is an outlier, showing highly circularly-polarized flares that look more like solar flare analogues. This brings up an interesting possibility about the secondary (mass donor) star in the system. It is an M-dwarf, and isolated M-dwarfs can be flare stars, so it is possible that the secondary star is flaring. But the secondary star is rotating with a period of about 3.3 hours (significantly faster than isolated stars). Because magnetic activity is believed to correlate with spin rate, CVs could offer a unique, previously inaccessible opportunity to test "dynamo mechanism" theoretical models for how stellar magnetic fields are generated, including at extreme rotational velocities. Finding out what causes the radio emission in CVs will therefore have broad implications. By virtue of the flexibility afforded by being on the ISS, NICER could be quickly incorporated into this massive observing campaign. NICER's sensitive X-ray measurements of TT Ari will be used to determine the level of flaring from the M-dwarf on short timescales as a measure of stellar activity, and to look for correlations and time lags between the radio, optical, and X-ray variations.

NICER collected 4,127 seconds of data during this campaign and recorded significant variability. The figure shows detail of one of the observation periods exhibiting rapid X-ray flaring.

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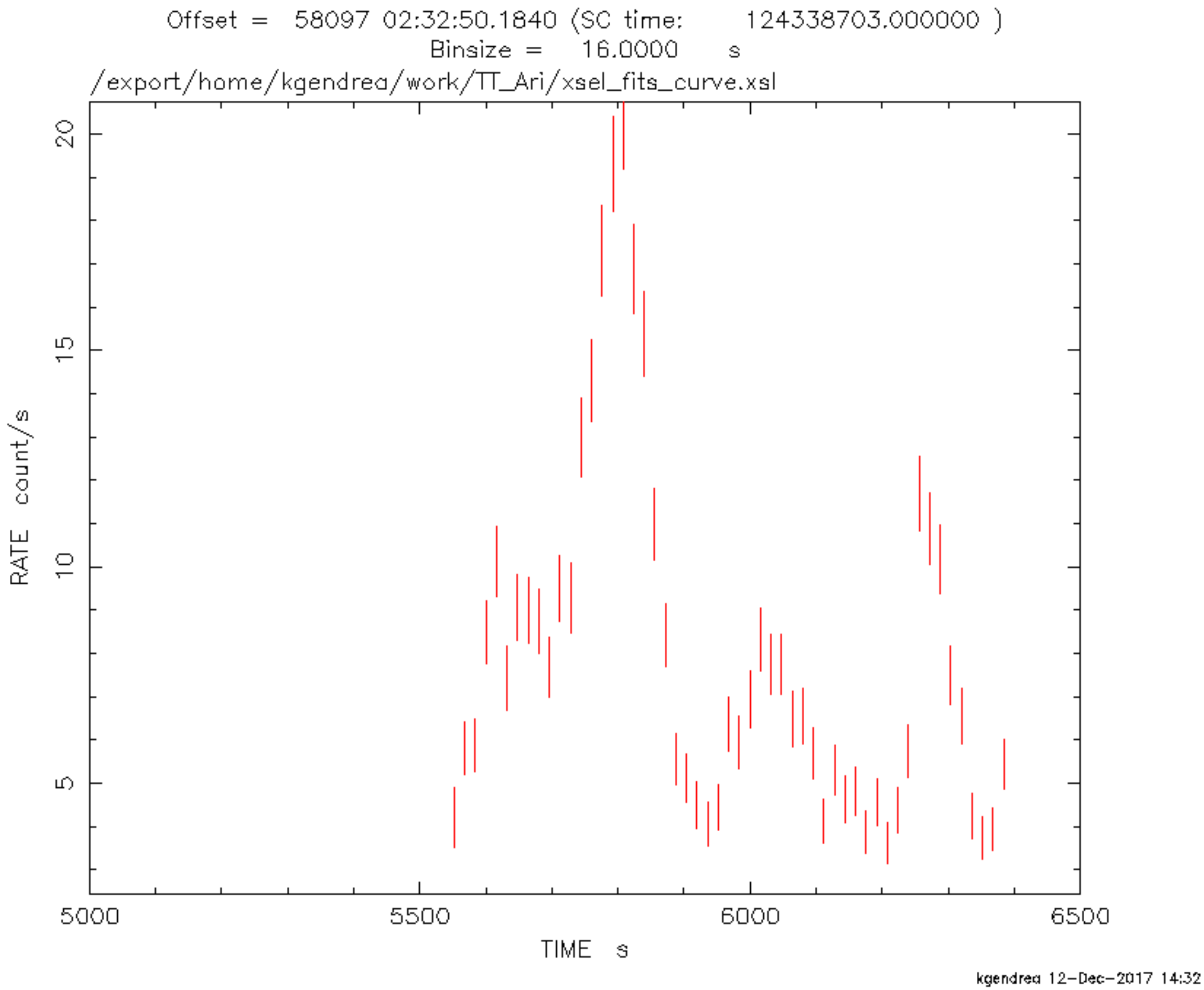
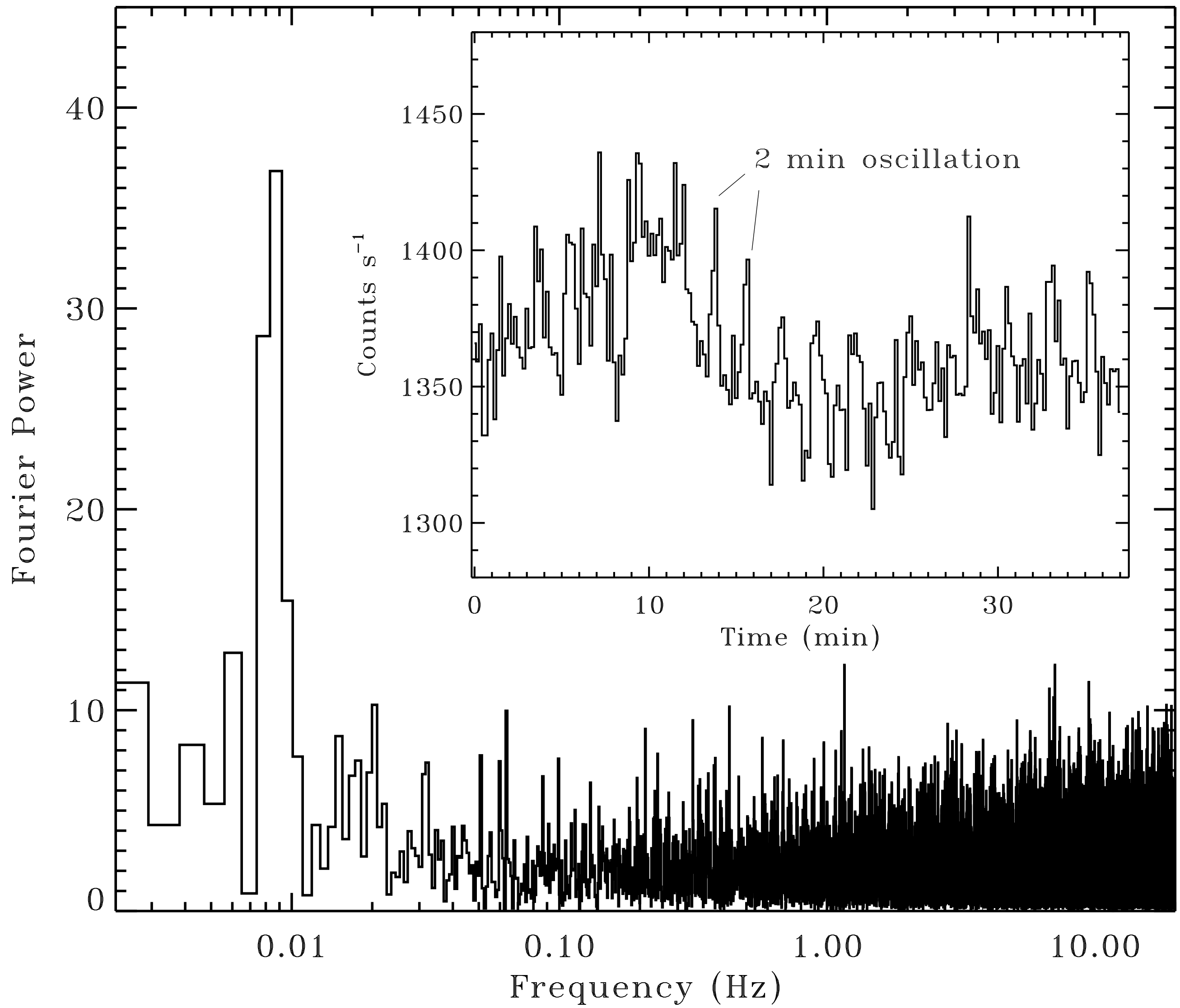


ISS Science Nugget 12/21/17 (1/2)

GS 1826-24 is an accreting neutron star binary system known as a Low Mass X-ray Binary (LMXB). In these objects a low-mass companion star loses matter to the heavier neutron star. This accretion of matter into the powerful gravitational field of the neutron star drives strong X-ray emission. In about 100 of these systems another kind of energy also powers X-ray emission: thermonuclear fusion, the same energy source that powers our Sun. The accreted matter, mostly hydrogen and helium with a mix of heavier elements, piles onto the neutron star. When enough matter has piled up, the pressure and density at the base of the accreted layer is sufficient to trigger fusion of hydrogen and helium into heavier elements. This rapidly releases an enormous amount of energy, resulting in a bright flash of X-rays known as a thermonuclear X-ray burst. How much energy? A typical burst can produce energy equivalent to one hundred 15 Megaton H-bombs exploding over every square centimeter of its surface!

NICER has an extensive observing program to study such explosions, including from GS 1826-24, because they directly illuminate the neutron star surface and its immediate surroundings, providing a unique and detailed view. This typical bursting behavior is called unstable burning, but less frequently these systems can display another type of burning. In this "marginally stable" regime the conditions allow the burning layer to cool rapidly enough that the whole surface doesn't explode all at once. Rather, a pulsating mode of burning occurs, with alternating periods of thermonuclear heating followed by cooling. Theoretical calculations indicate that the X-ray emission should pulse with a period of about 2 minutes. So far, this has only been seen in a handful of LMXBs, and never before in GS 1826-24. However, on at least three separate occasions NICER observed GS 1826-24 to be pulsing with a period close to 2 minutes, consistent with marginally-stable burning. The figure illustrates one example. The main panel shows a power spectrum (brightness as a function of variability frequency) from NICER data with a strong peak at about 9 mHz, corresponding to an oscillation period of 110 seconds. Indeed, the pulsing can be seen directly in the time-variable X-ray brightness observed with NICER (inset). Further study with NICER will provide important new information about the neutron star in this system.

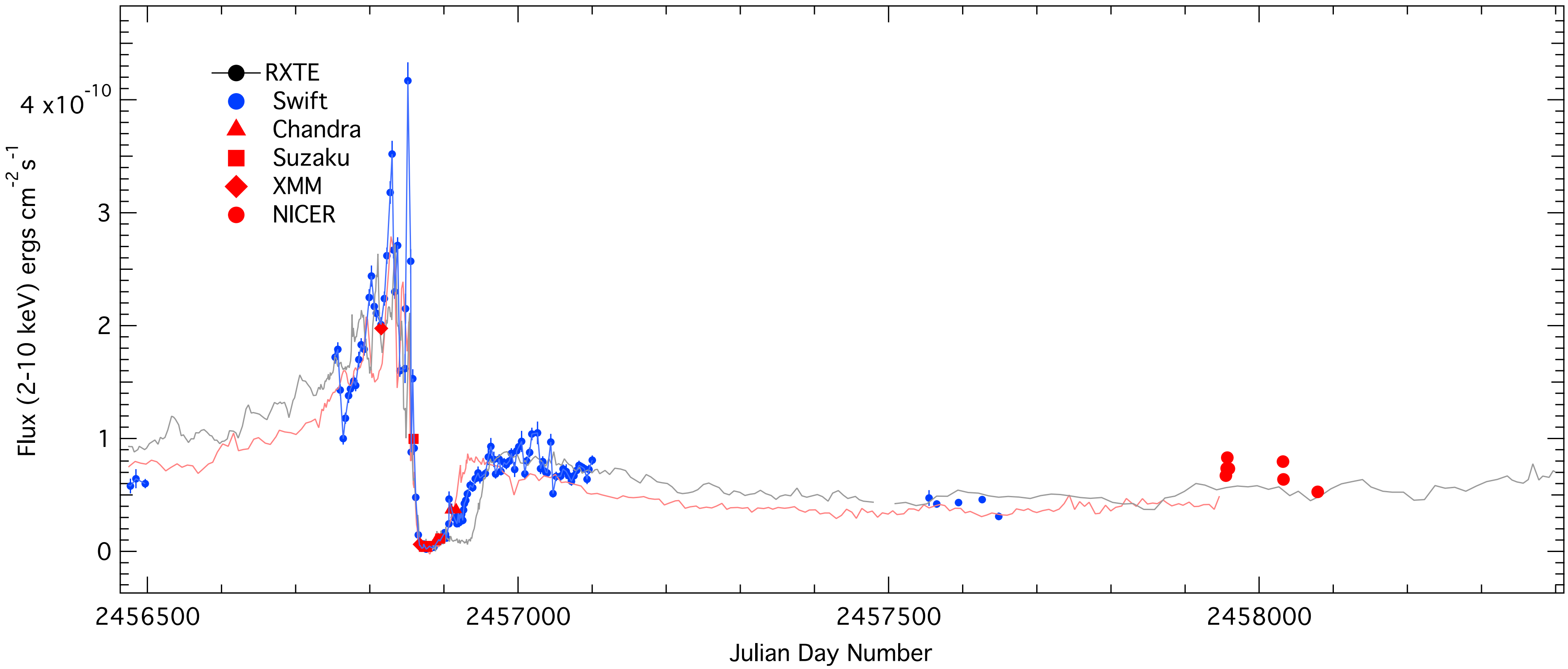
ISS Science Nugget 12/21/17 (2/2)



ISS Science Nugget 12/28/17 (1/2)

A current NICER target was recently the subject of an answer on the game show "Jeopardy." On the December 6 episode, under the category "Greek Letter Phrases," the $1,000 answer was "NASA intently studies the changing luminosity of this most massive star system within 10,000 lightyears of earth". The correct answer was "What is Eta Carinae?". Eta Carinae is a contender for the most massive and luminous star system known, and (as noted by the writers of Jeopardy) the most massive star within 10,000 lightyears of earth. It's also notoriously unstable, having experienced a powerful eruption in the 1840's, when it became the second brightest star in the night sky. Monitoring observations of the X-ray emission from Eta Carinae starting in the 1990's using available NASA X-ray observatories helped establish that the star is in fact a binary system with a lower-mass companion star that orbits the more massive star in a 5.5-year, highly elliptical orbit. The X-ray emission helps diagnose the material still being blown off of both stars, and helps us better understand the eventual fate of this star system. The amount of mass being lost from Eta Carinae varies with the orbit but also seems to vary from one orbital cycle to the next, for reasons we still don't understand. Now NICER has become the latest X-ray telescope to monitor the X-ray emission from Eta Carinae. NICER's flexible pointing capability and its sensitivity to the 2-10 keV X-ray band (where Eta Carinae emits most of its stellar X-ray emission) make NICER perhaps the best X-ray telescope yet to keep an eye on the high-energy emission from Eta Carinae. The accompanying figure shows the current NICER observations of Eta Carinae (as red circles) in the context of previous observations with other NASA, European, and Japanese satellites. The preliminary NICER observations show that the star appears slightly brighter than expected for this part of the stellar orbit (which happens to be when the two stars were near their point of maximum separation). It will be extremely interesting to carry out intensive NICER observations of the system as the two stars approach minimum separation, since this is a time when the X-ray emission changes wildly, almost disappearing for a period of 3 months. If you'd like to match wits with the Jeopardy contestants on Eta Carinae (or other topics), the video of this Jeopardy episode is available at https://www.dailymotion.com/video/x6c99hp (the Eta Carinae question is at the 8 minute 30 second mark).

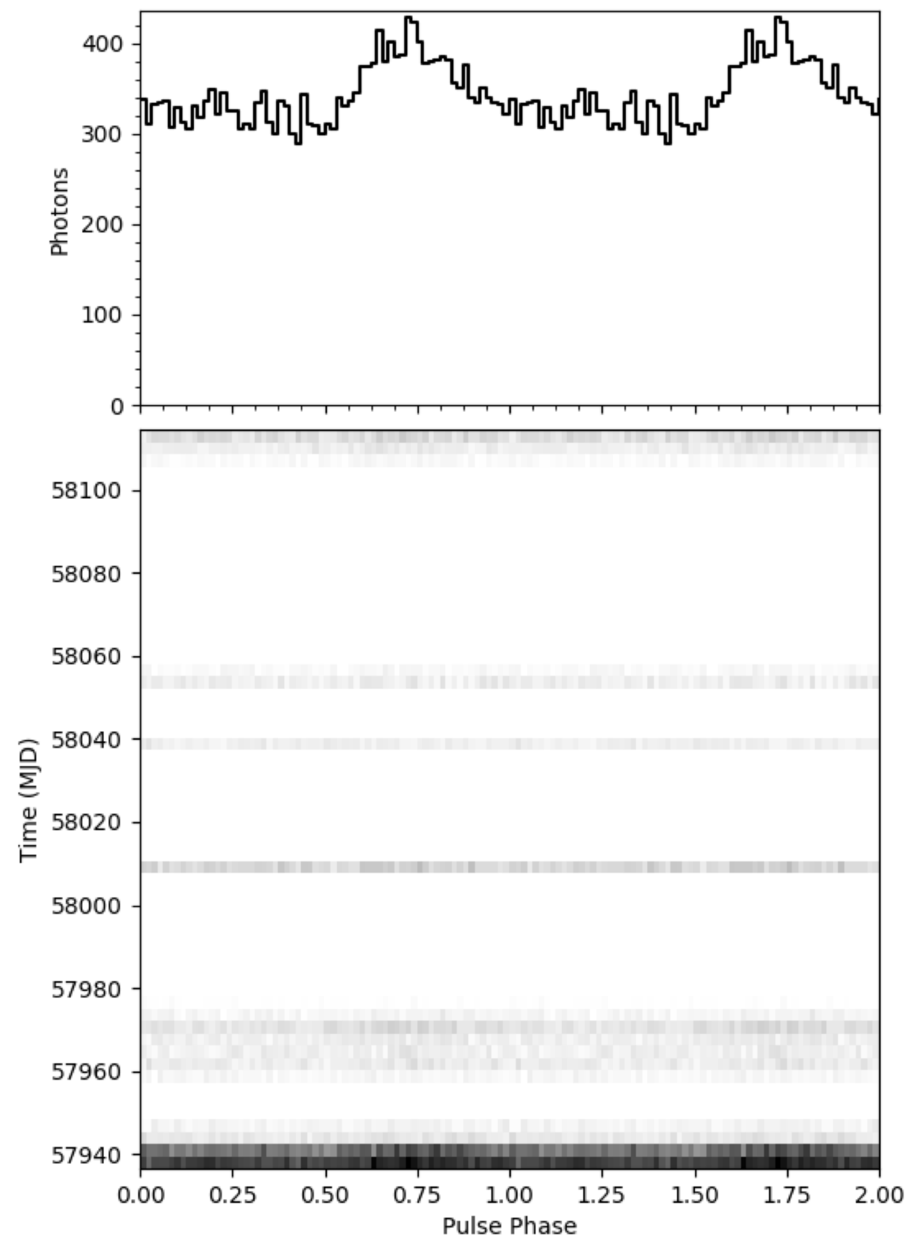
ISS Science Nugget 12/28/17 (2/2)



ISS Science Nugget, 1/12/17

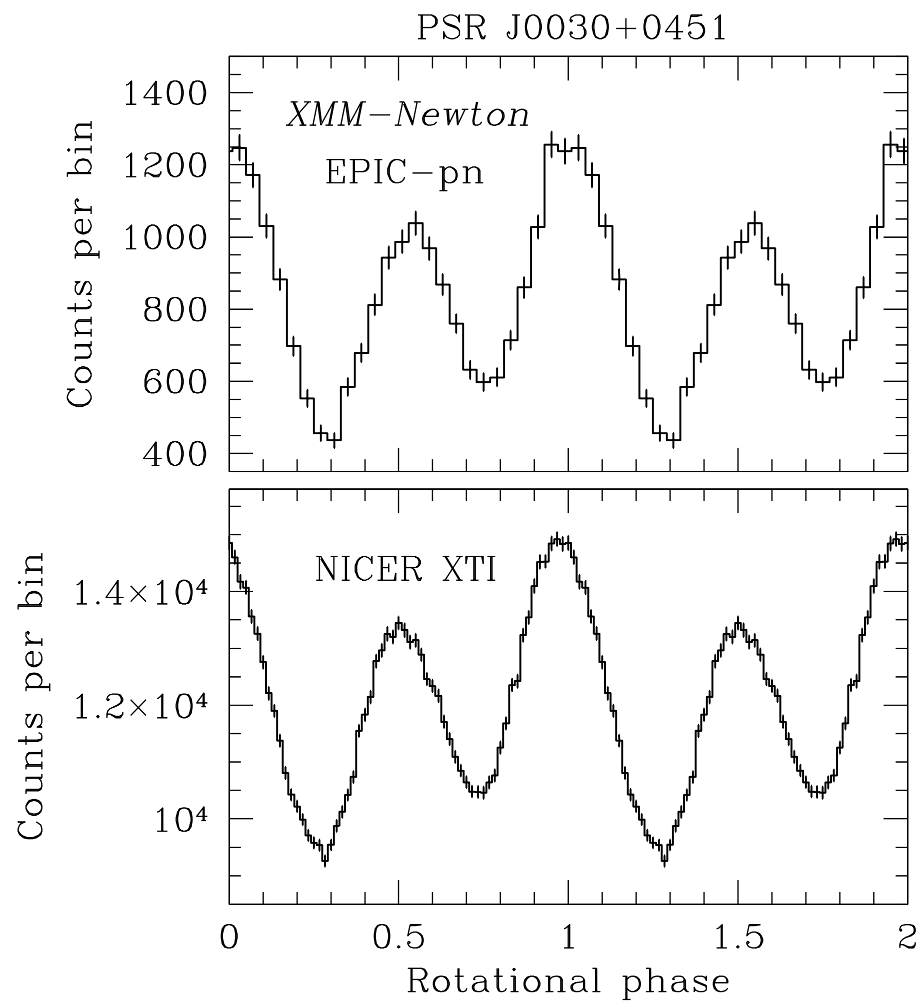
The NICER search working group has strongly detected (10.5 sigma) the very bright gamma-ray (and not-so-bright radio) millisecond pulsar (MSP) J0614-3329 with about 88ks of good exposure time. The pulsations appear to be primarily thermal, with a count rate of ~0.04 cts/sec. The pulsar is at a distance, determined using the radio-measured Dispersion Measure, of about 2 kpc.

The plot shows the phaseogram of the NICER data -- This is the first detection of X-ray pulsations from this source.



ISS Science Nugget, 1/18/17

One of NICER's primary science goals is to determine the radius of several neutron stars with a precision of 5%. This is being done by several methods. One method involves looking in detail at the shape of millisecond pulsar light curves to look for strong gravity effects. Specifically, the compactness (M/R) where M is the neutron star mass and R is the radius is a parameter that describes gravitational light bending. Large compactness leads to strong gravitational light bending. The pulses from many neutron stars are the result of hot spots on the surface of the neutron star coming into and out of our field of view as the star spins. Strong gravity can cause us to see the backside of the star- allowing us to watch a hot spot go around to where we would otherwise we would not see it without gravitational light bending. PSR_J0030+0451 is one neutron star for which NICER is building a very long exposure to make such a measurement. As of January, NICER has accumulated 1.08 million seconds (Msec) of data (see attachment) compared to the 1.6 Msec needed to achieve a 5% measurement of radius.

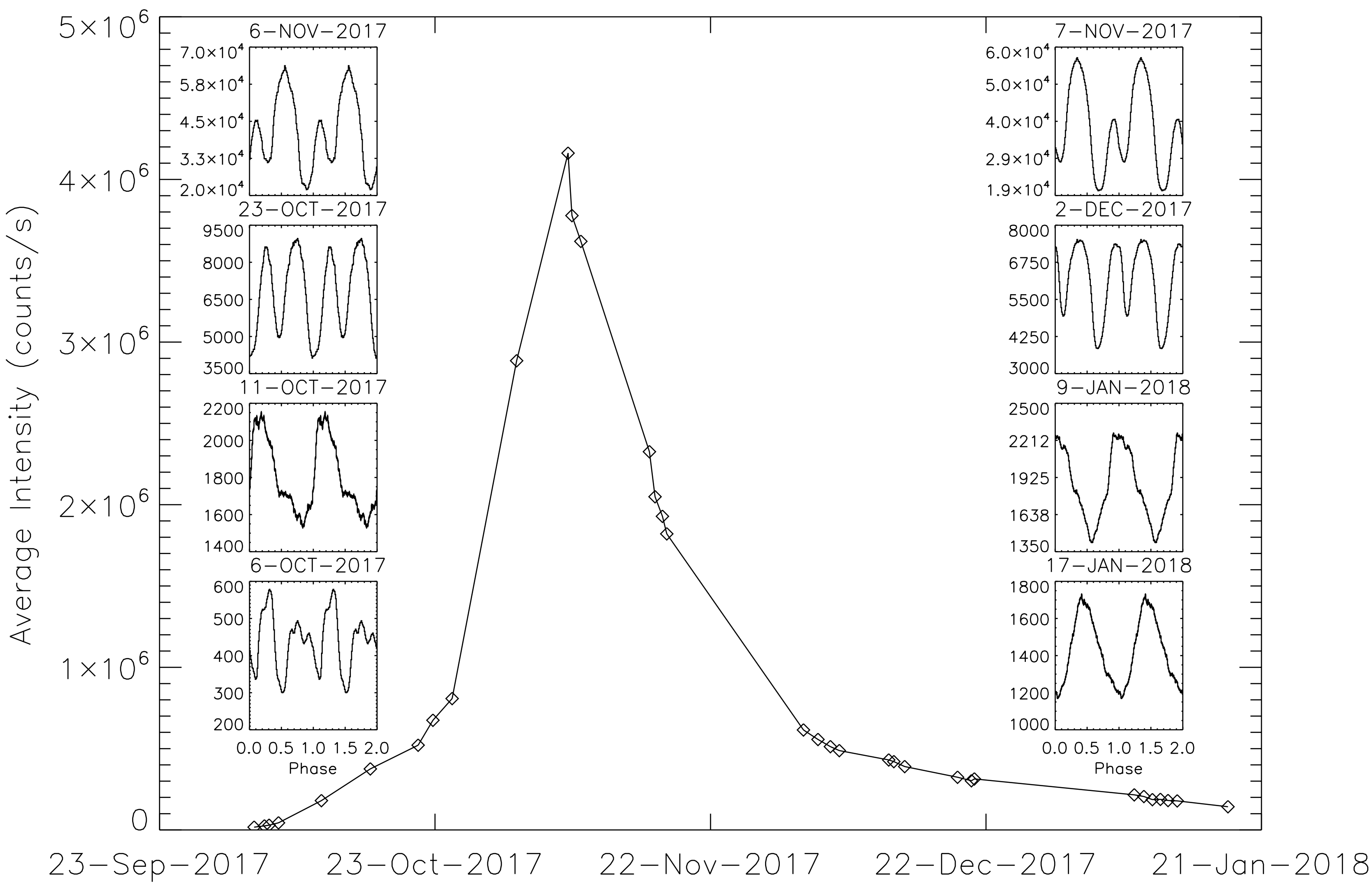


ISS Science Nugget, 1/23/18

Swift J0243.6+6124 is a 9.8 second pulsar discovered last Fall. It has been undergoing a very bright outburst, reaching an observed flux nearly 6 times that of the Crab nebula and its pulsar. This translates to an observed dead time-corrected count rate in NICER of 63,000 photons/s (see top left inset). The neutron star in this binary system is accreting from a 'Be' star companion, a B-type star with emission lines that arise from an "excretion" disk outflow around it. When this disk is particularly large or dense, a giant outburst like this one can occur. The pulsar emits X-rays as material from the Be star's disk falls onto its poles, guided by the neutron star's strong magnetic field. During this outburst, NICER has observed dramatic spin-up of the neutron star, an increase in its rotation rate, as well as very large variations in the observed X-ray intensity and the shape of the pulse profiles (see figure); the pulse profile maps out the X-ray intensity as the neutron star rotates. It evolves from a complex shape at lower mass accretion rates to a single peaked shape at moderate rates, and smooth double-peaked shape at high rates. These changes in shape are likely due to changes in the accretion flow onto the pulsar at first, and changes in the accretion column at higher intensities. As the outburst begins to fade, the pulse profiles are similar to those observed at the same intensities as the outburst rose.

Figure caption: The large central figure shows the average intensity of the pulsar for each NICER observation. It was at its brightest on Nov 6, 2017. The insets on the left-hand sideshow the evolution of the pulse profile as the outburst rises. Time progresses from the bottom to the top of the page. The insets on the right show the profiles as the outburst fades. Time progresses down the page. Similar profile shapes are seen at similar intensities in both the profile rise and fall. The outburst has not yet faded to the intensity at the bottom left inset. We await more observations to learn if this complex shape is also repeated.

ISS Science Nugget, 1/23/18



ISS Science Nugget, 2/2/18

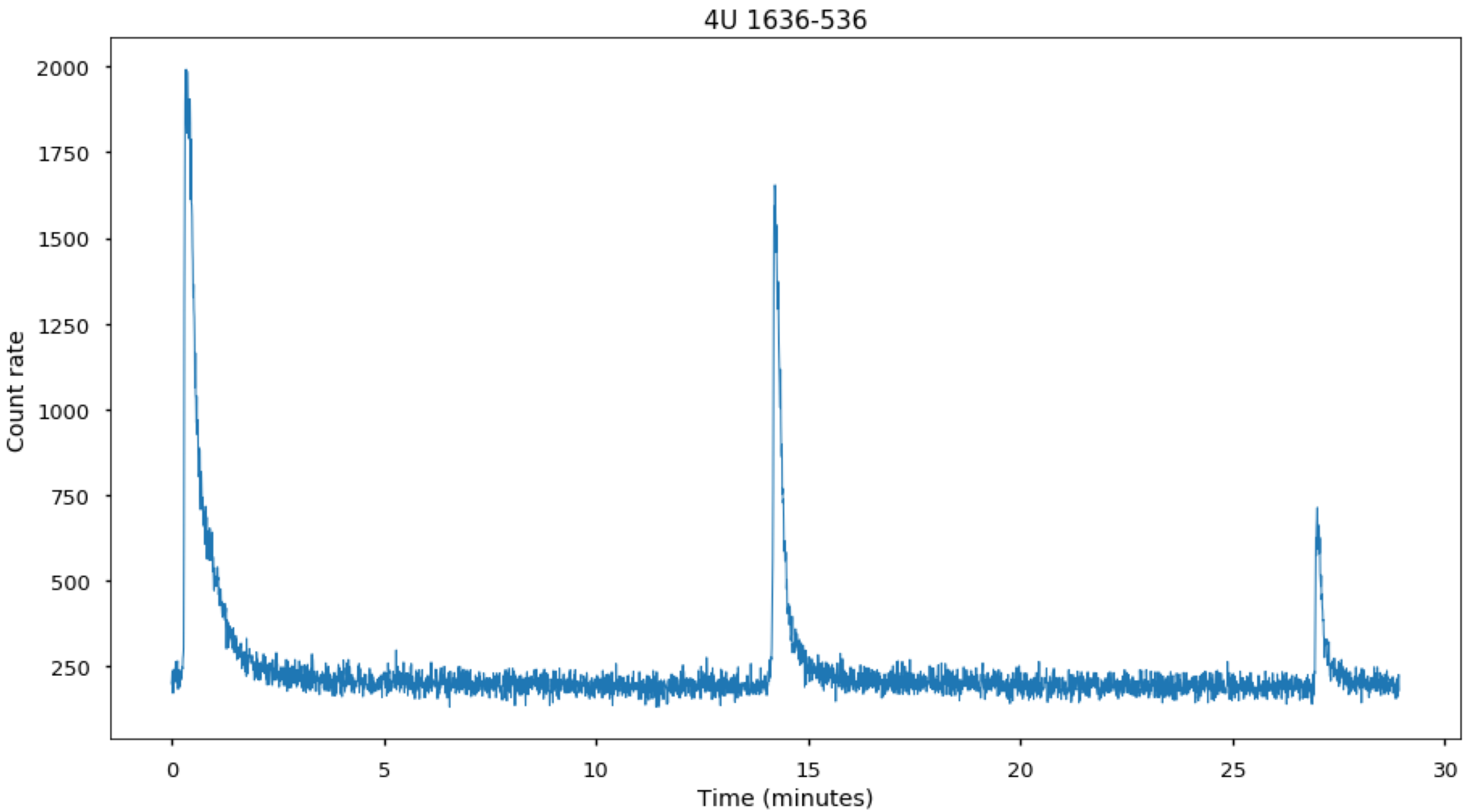
NICER observes rare short-recurrence X-ray bursts

The gravitational pull of a neutron star is sufficiently strong that any matter landing on it will be rapidly compressed. This compression is so extreme that the outer layers of the atmosphere become dense enough to trigger thermonuclear fusion. Once ignited, this fusion reaction rapidly spreads over the entire neutron star surface, burning up all available material and producing a brief, but intense, burst of X-ray emission.

In X-ray binary systems an orbiting companion star provides a steady supply of fresh material to accrete on the neutron star. Still, it typically takes many hours to several days before a neutron star atmosphere is replenished to the point that it can reignite.

On January 14th, NICER observed a triplet of X-ray bursts in the X-ray binary 4U 1636-536, each separated by only 13 minutes (see figure, next slide). Such ‘short recurrence bursts’ are rare events, accounting for less than 5% of all X-ray bursts ever observed. Being spaced too close together for the atmosphere to have recovered, the study of these short recurrence bursts provides a handle on uncertain convective mixing processes that are predicted to occur there.

ISS Science Nugget, 2/2/18 (cont.)



ISS Science Nugget, 2/22/18

The first peer reviewed paper out of NICER has been accepted for publication in the Astrophysical Journal Letters, where it will be included in a Focus Issue on early NICER science results.

Its title is "NICER OBSERVES THE EFFECTS OF AN X-RAY BURST ON THE ACCRETION ENVIRONMENT IN AQL X-1" by L. Keek et al. The abstract is below.

Accretion disks around neutron stars regularly undergo sudden strong irradiation by Type I X-ray bursts powered by unstable thermonuclear burning on the stellar surface. We investigate the impact on the disk during one of the first X-ray burst observations with the Neutron Star Interior Composition Explorer (NICER) on the International Space Station. The burst is seen from Aql X-1 during the hard spectral state. In addition to thermal emission from the neutron star, the burst spectrum exhibits an excess of soft X-ray photons below 1 keV, where NICER's sensitivity peaks. We interpret the excess as a combination of reprocessing by the strongly photoionized disk and enhancement of the pre-burst persistent flux, possibly due to Poynting-Robertson drag or coronal reprocessing. This is the first such detection for a short sub-Eddington burst. As these bursts are observed frequently, NICER will be able to study how X-ray bursts affect the disk and corona for a range of accreting neutron star systems and disk states.The Figure shows the burst observed by NICER that supported this analysis.

ISS Science Nugget, 2/22/18 (cont.)

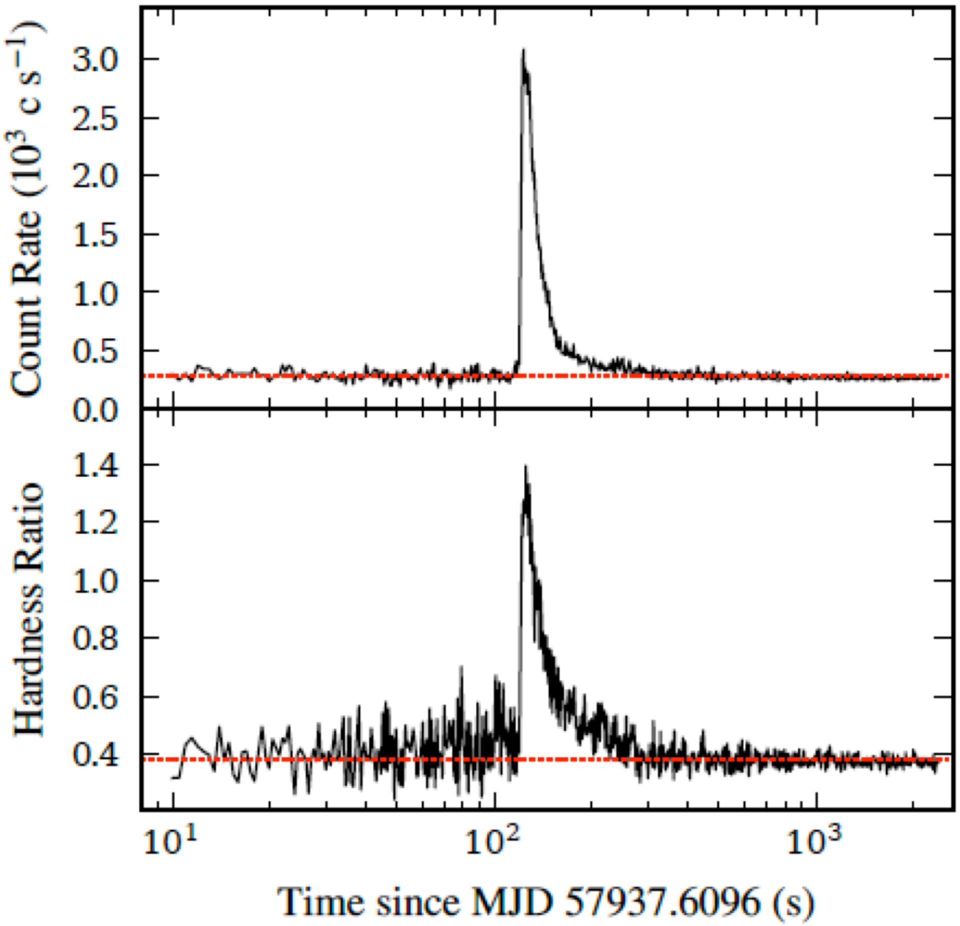


FIG. 1.— (Top) Light curve of the *NICER* pointing with the burst on 2017 July 3. Initially, the plotted resolution is 0.5 s, and 500 logarithmically spaced bins are employed after 150 s. (Bottom) Hardness ratio of count rate with $E > 2.5$ keV to $E < 2.5$ keV. The dotted lines indicate mean values over the first 100 s.

ISS Science Nugget, 3/1/18

Anomalous X-ray pulsars, a.k.a. magnetars, are a small group of neutron stars that are thought to possess the strongest magnetic fields in the Universe, on the order of 10^14 Gauss. (The Earth's magnetic field strength is about 0.5 Gauss.) This magnetic field has profound effects on the matter near the surface of a neutron star as well as on the propagation of radiation from the surface -- chiefly, the magnetic field's slow decay heats the star's crust at the magnetic poles and leads to X-ray emission.

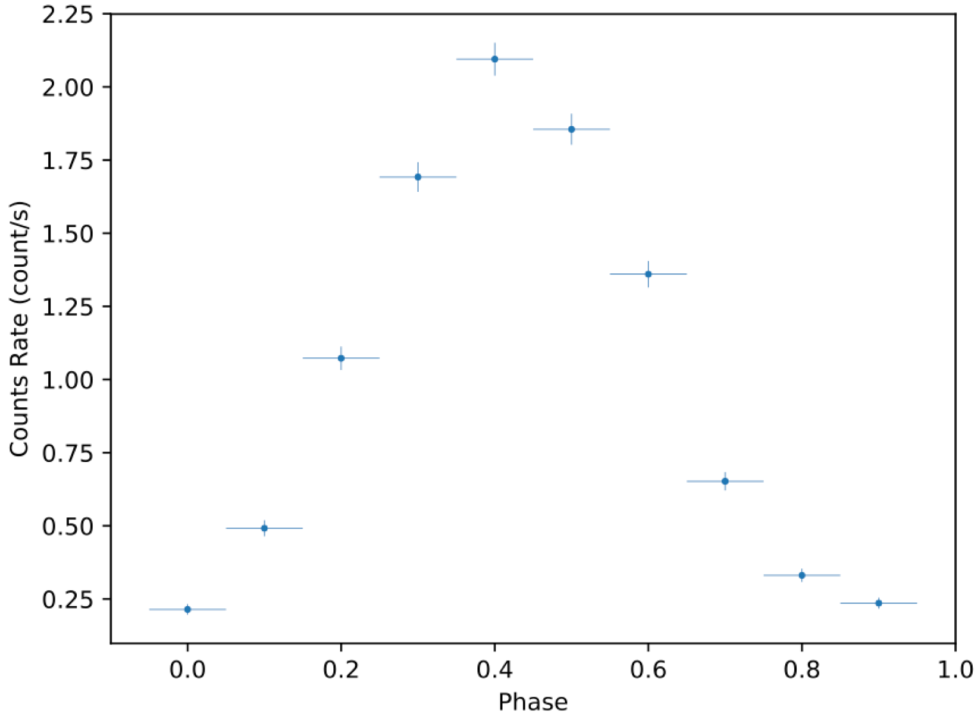
1E 1048.9-5937 is a persistently bright magnetar, approximately 30,000 light years from Earth. It was one of the first sources discovered and identified as a magnetar candidate. It is also a highly active source in X-rays, with several known outbursts, sudden flux increases lasting a few weeks to months. Previous studies hinted that the reason this source shows outbursts is that the X-ray emitting area on the surface enlarges without a significant change in temperature, which can be understood in terms of energy release from the star's inner crust.

Recently, magnetar 1E 1048 exhibited another outburst, which was detected by NASA's Gehrels Swift observatory. NICER performed follow-up observations within a few days of the initial Swift report, and thanks to its much larger effective photon collecting area it was possible to extract high quality spectra and test the prior suggestion of an increased hot-spot size. We analyzed X-ray spectra obtained at several epochs, including an XMM-Newton observation from 18 years ago, and showed that indeed the area on the surface of the neutron star emitting in X-rays enlarged by a factor of two (from 1.9 to 3.9 km in radius, assuming the above distance), without a significant change in other parameters of the system. This is also confirmed with NICER’s timing capabilities, via measurement of the pulsed fraction, the ratio of how much of the observed emission is pulsed vs. unpulsed. Pulsed photons are those from the surface hot spots, and because of the rotation of the object they show brightness modulations with the spin period whereas the unpulsed emission comes from the cooler areas on the surface. NICER observations revealed that the fraction of the pulsed emission decreased (see figure), which again can be interpreted as an enlargement of the hot spot, with this emission becoming more nearly isotropic so that the observed modulation is decreased.

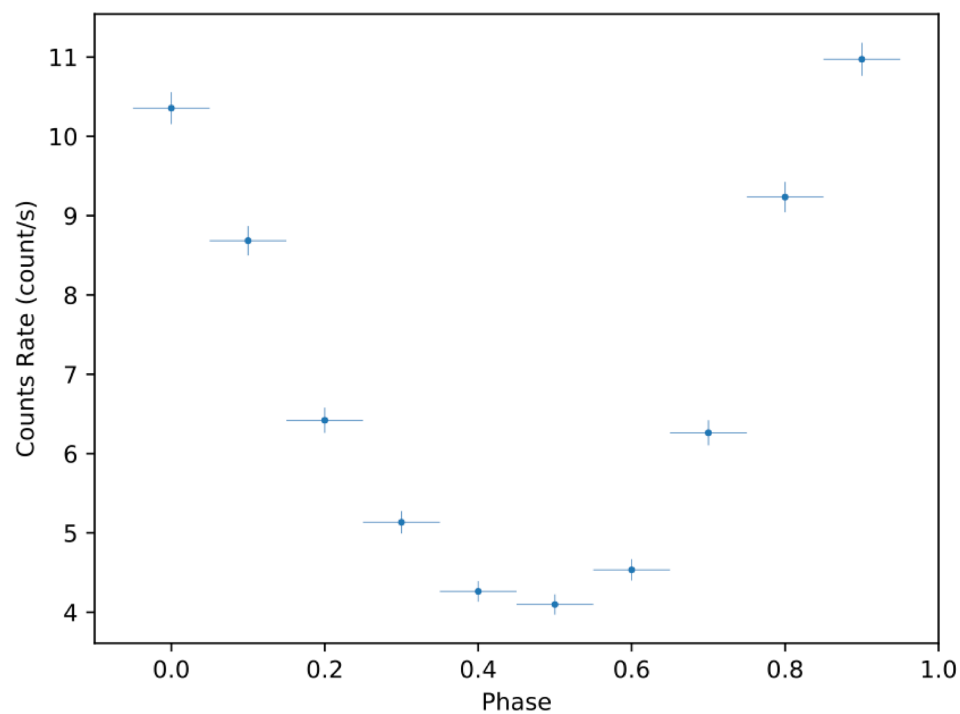
These observations showed the effectiveness of having a large photon collecting area X-ray detector on-board ISS, which allows astronomers to easily perform Target of Opportunity observations and obtain high quality data within relatively short exposure times.

ISS Science Nugget, 3/1/18 (cont.)

XMM-*Newton* (2000)
81% pulsed fraction

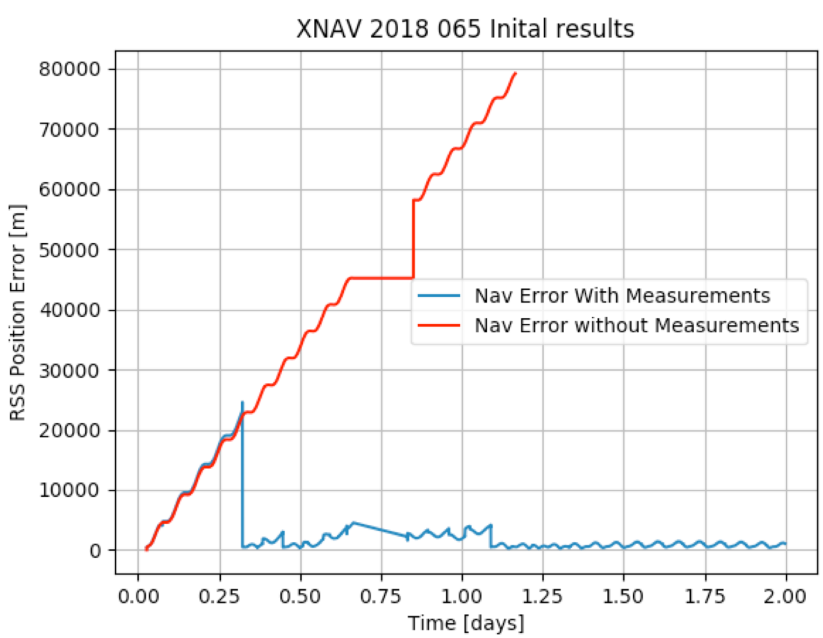


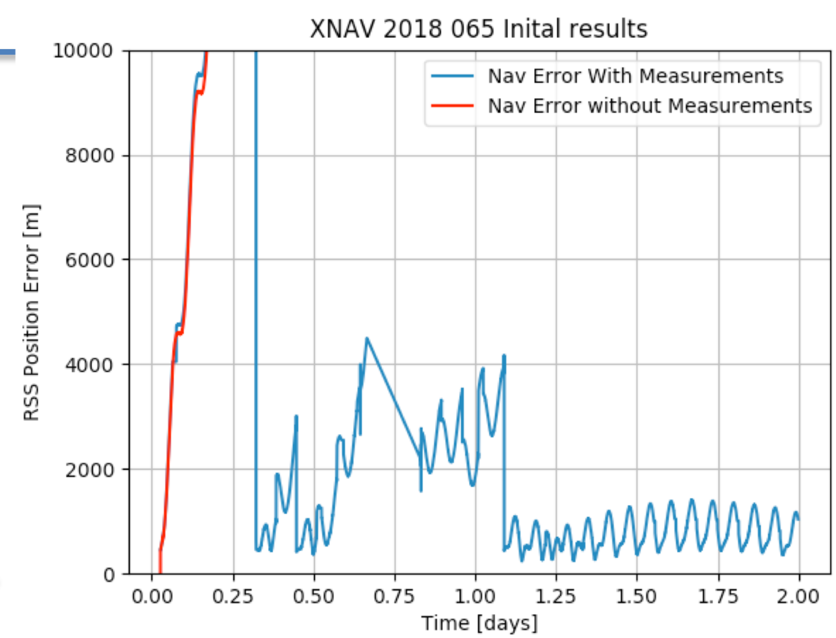
NICER (2018)
48% pulsed fraction



ISS Science Nugget, 3/9/18

On March 6, 2018, the XNAV application running the SEXTANT pulsar navigation software on NICER was able to successfully run in opportunistic mode while NICER was conducting its regular science program. The science program for NICER that day included observing PSR B1937+21, which is one of the primary SEXTANT navigation pulsars. As shown in the figure, the on-orbit XNAV application (shown in blue) was able to converge to less than 2km of error.   The same initial position (shown in red) was propagated on the ground and shown to diverge without XNAV measurements. This is a substantial improvement compared to the last pulsar navigation result from November 2017.

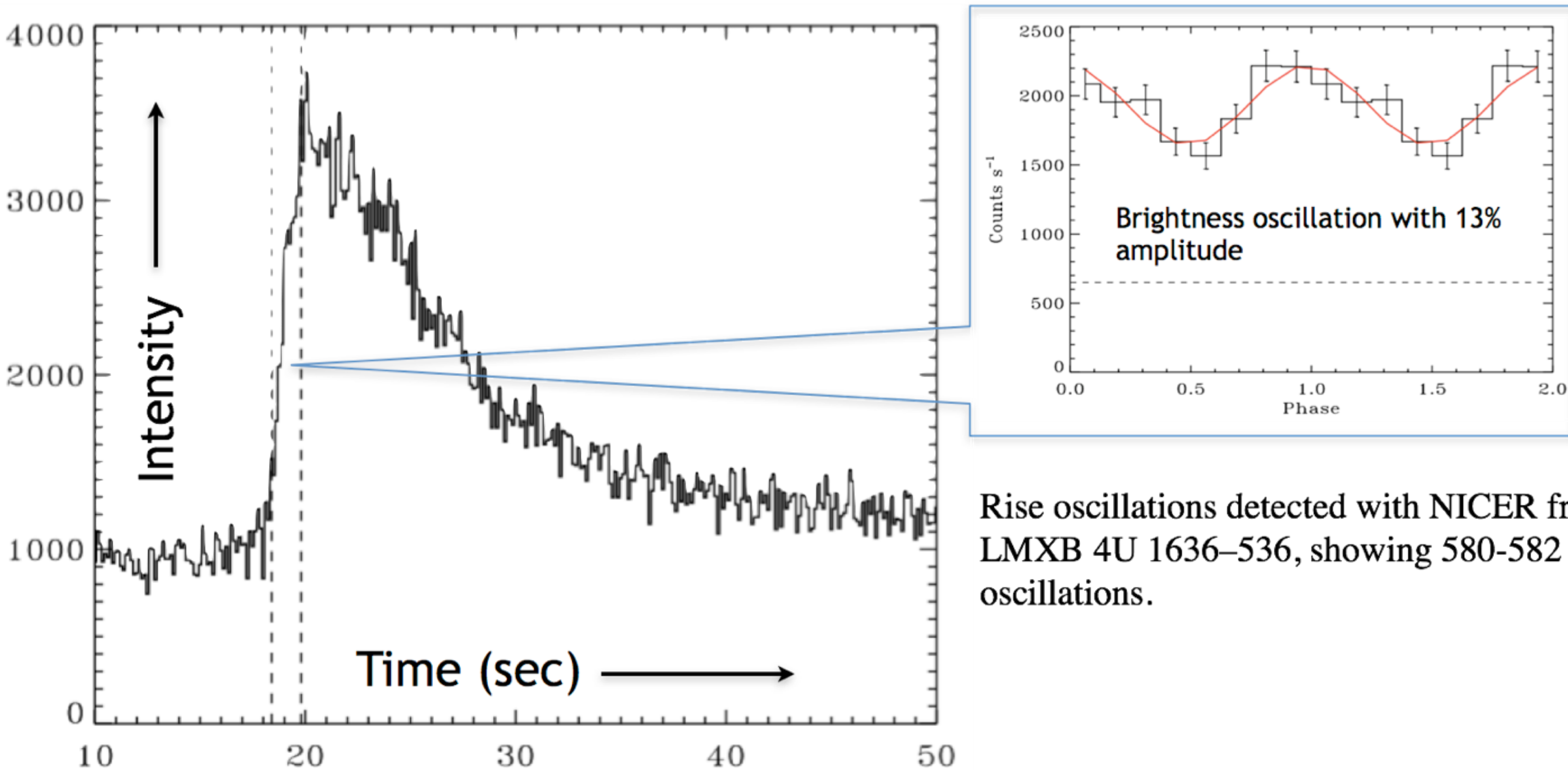




ISS Science Nugget, 3/16/18

Type I X-ray bursts, observed as X-ray flashes from neutron stars in low-mass X-ray binaries (LMXBs), are thermonuclear explosions caused by the unstable burning of material accreted onto a neutron star surface from a companion star. During a burst, the X-ray flux can rise by factors of 10 to 20 in a few seconds and then decay on longer timescales, tens to hundreds of seconds. Periodic brightness fluctuations have been detected, with high time-resolution instruments such as NICER, during the rise and/or decay of approximately 10% of Type I X-ray bursts, with oscillation frequencies representative of the neutron star spin rate. The oscillations during the rise can be explained by temperature asymmetries due to the spreading burning region on the surface of the neutron star. But the oscillation mechanism during the decaying phase of bursts is still unknown. NICER has already observed many X-ray bursts (see figure, next slide, for an example) and several burst oscillations from LMXBs and continues to do so, enabling us to better understand how these phenomena arise, and to probe the structure and properties of the underlying neutron stars.

ISS Science Nugget, 3/16/18

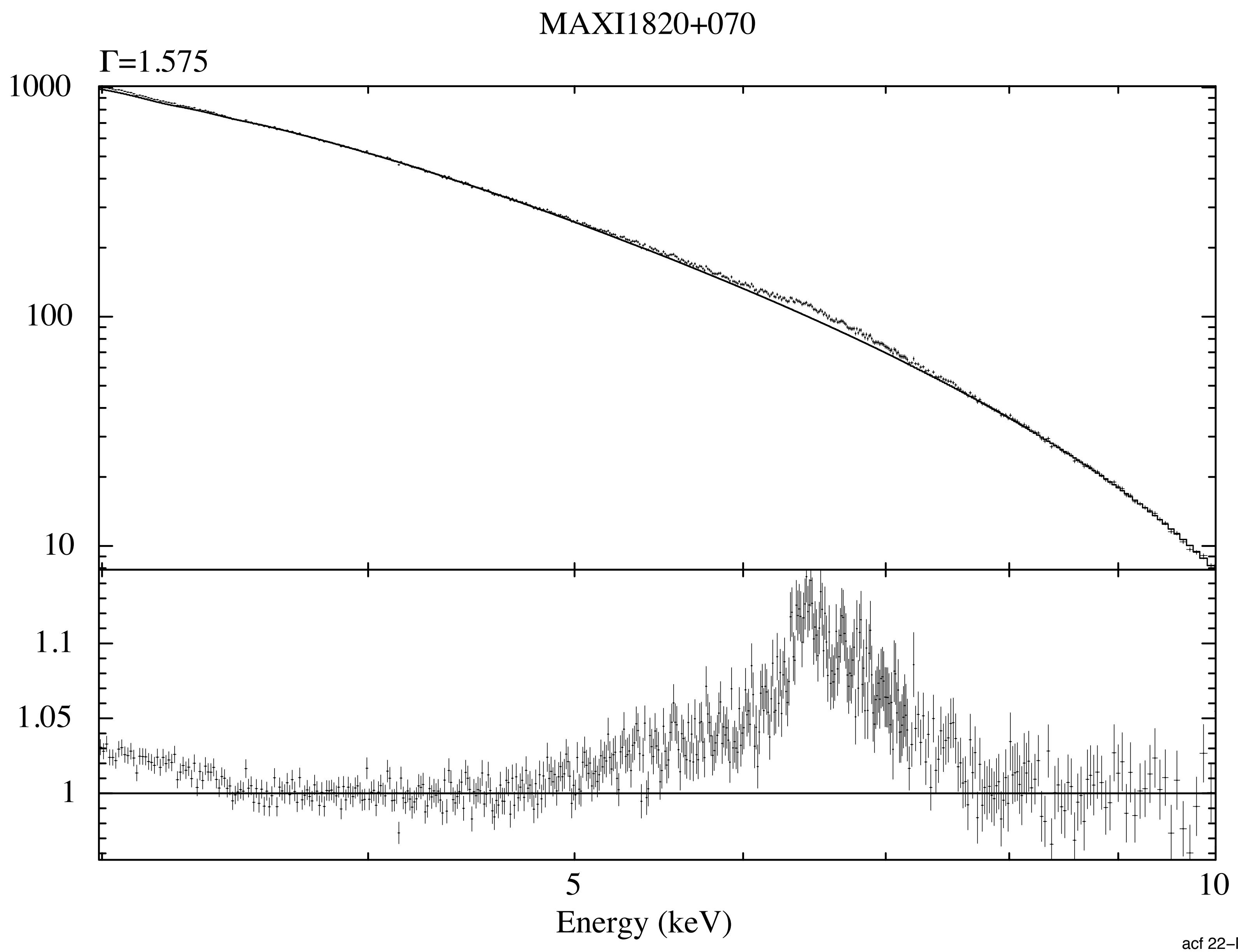


Rise oscillations detected with NICER from LMXB 4U 1636–536, showing 580-582 Hz oscillations.

ISS Science Nugget, 3/22/18

NICER responded to a Target of Opportunity (TOO) triggered by the ISS MAXI payload on March 12, 2018, and pointed to the new X-ray transient called MAXI J1820+070. From the first observation to the most recent (March 22), the measured flux has climbed from ~ 900 counts per second (cps) to more than 20,000 cps, making it the 2nd-brightest X-ray source in the sky. Observations today indicate that this source is also exhibiting extremely bright flashes of > 50,000 cps in less than 0.1 seconds. NICER is the only X-ray instrument capable of studying without distortion the combined spectrum and variability of sources with such high brightness. Spectral and timing analysis indicate that this source is a new black-hole binary transient. NICER has marginally detected a 66 Hz Quasi-Periodic Oscillation (QPO) in the early data. Although only a tentative detection, the QPO frequency is intriguing, since QPOs have been observed at a similar frequency in two black hole X-ray binaries (GRS 1915+105 and IGR J17091-3624). NICER has also detected a relativistically broadened iron K emission line (see figure). NICER is coordinating observations with a wide range of telescopes around the world and in orbit to help build a more complete physical picture of this intriguing source.

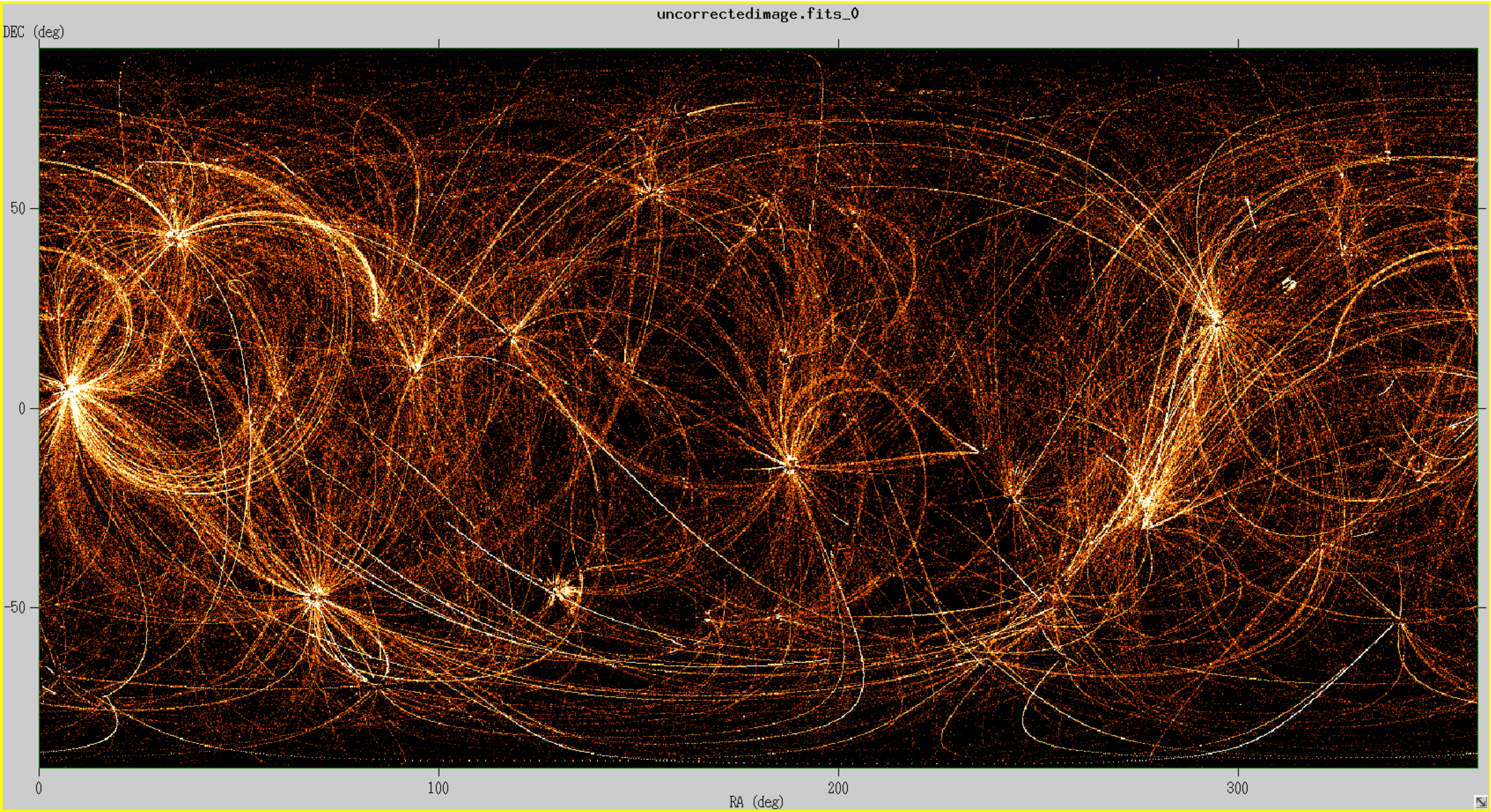
ISS Science Nugget, 3/22/18



ISS Science Nugget, 3/29/18

While NICER's primary science involves acquisition of photons from targets that can be tracked with NICER's pointing system, the instrument's detectors remain enabled during orbit-night slews between targets. This allows NICER to extract additional science by looking for new celestial targets along the great arcs that NICER's viewing direction traces across the sky. NICER typically slews 2-8 times each ISS orbit. Attached is the first photon map of the sky extracted by NICER's nighttime slews during the first 8 months of operations. In the image, one can see where these arcs converge on targets that NICER regularly visits. There are also objects across which NICER has serendipitously slewed. This image is a preliminary look, with further processing such as exposure correction still needed. However, even with minimal processing NICER has detected objects such as the Cygnus Loop, a supernova remnant from a star that exploded 5000-8000 years ago that now extends about 3 degrees across (at RA = 313 degrees, Dec = 31 degrees). The NICER team is now working to exposure-correct this image and extract other sources both known and unknown.

ISS Science Nugget, 3/29/18



ISS Science Nugget, 4/05/18

NICER sees an accreting millisecond pulsar

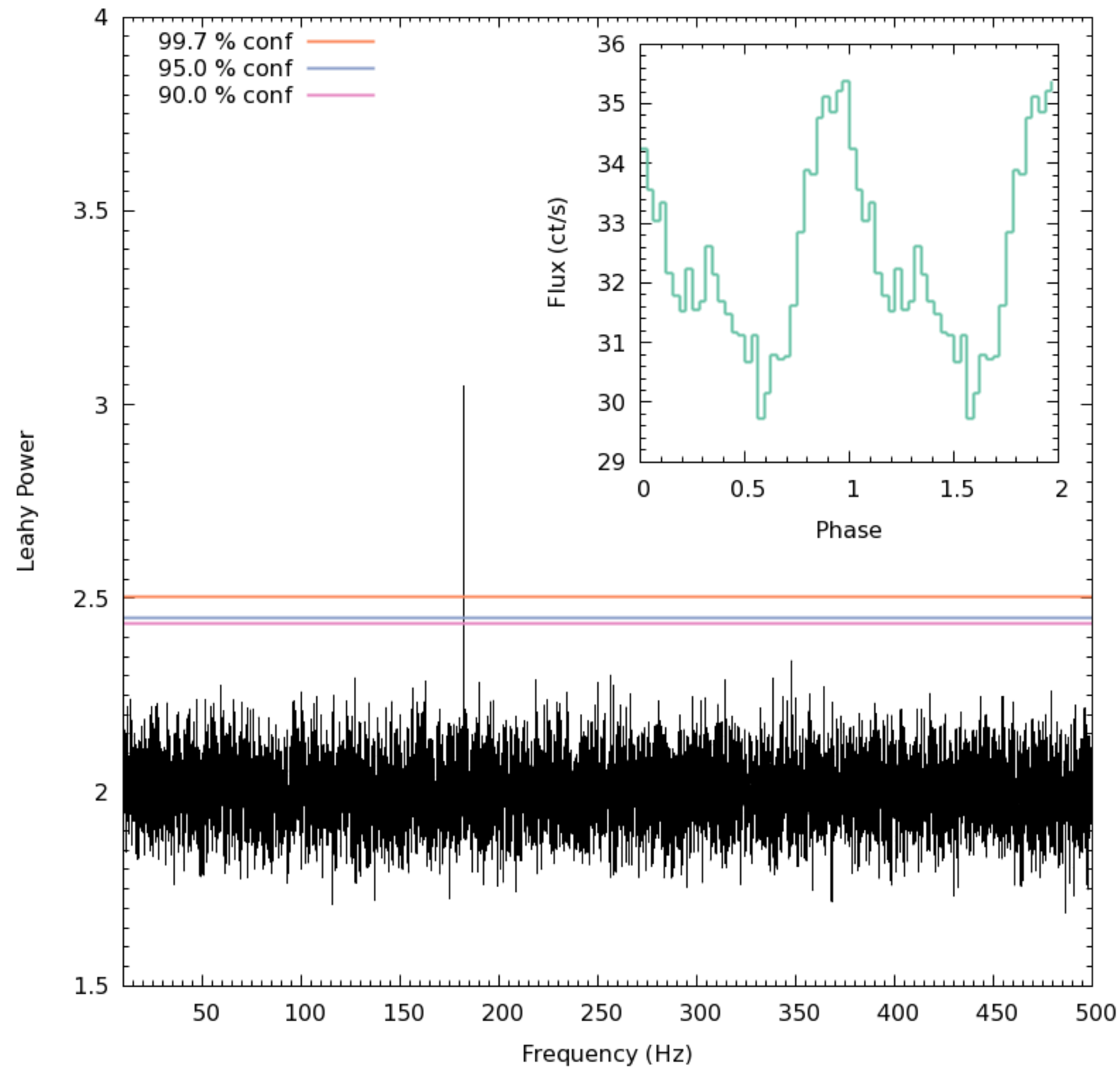
In a rapid response to a target-of-opportunity trigger, NICER executed a set of pointed observations of the X-ray transient Swift J1756.9-2508 on April 4. Within hours, the NICER team confirmed this object's new outburst through the detection of coherent brightness oscillations at a period of 5.5 milliseconds (182 Hz; see Figure). This initial detection, published on April 5 as Astronomer's Telegram #11502, opens up an exciting opportunity for NICER.

A known accreting millisecond pulsar, Swift J1756 has been seen in outburst only twice before: for the first time in 2007, and again in 2009. With NICER we now add the 2018 outburst, enabling high-precision timing of this pulsar over a span of 11 years. Such long baselines are crucial to establishing long-term changes in spin period, which are typically well under 1 microsecond per decade. Measured for only a handful of accreting systems, these spin changes are among the most informative observable parameters for a neutron star, with implications for their rotational ("clock") stability, magnetic field strength, and energy budget.

In addition to detecting spin evolution, measurement of the pulse profile -- the brightness variation as the star rotates -- offers a host of information. The profile encodes information about the neutron star's interior makeup and the dynamics of its interaction with the surrounding accretion flow, all of which is made possible through NICER's unique spectral-timing capability.

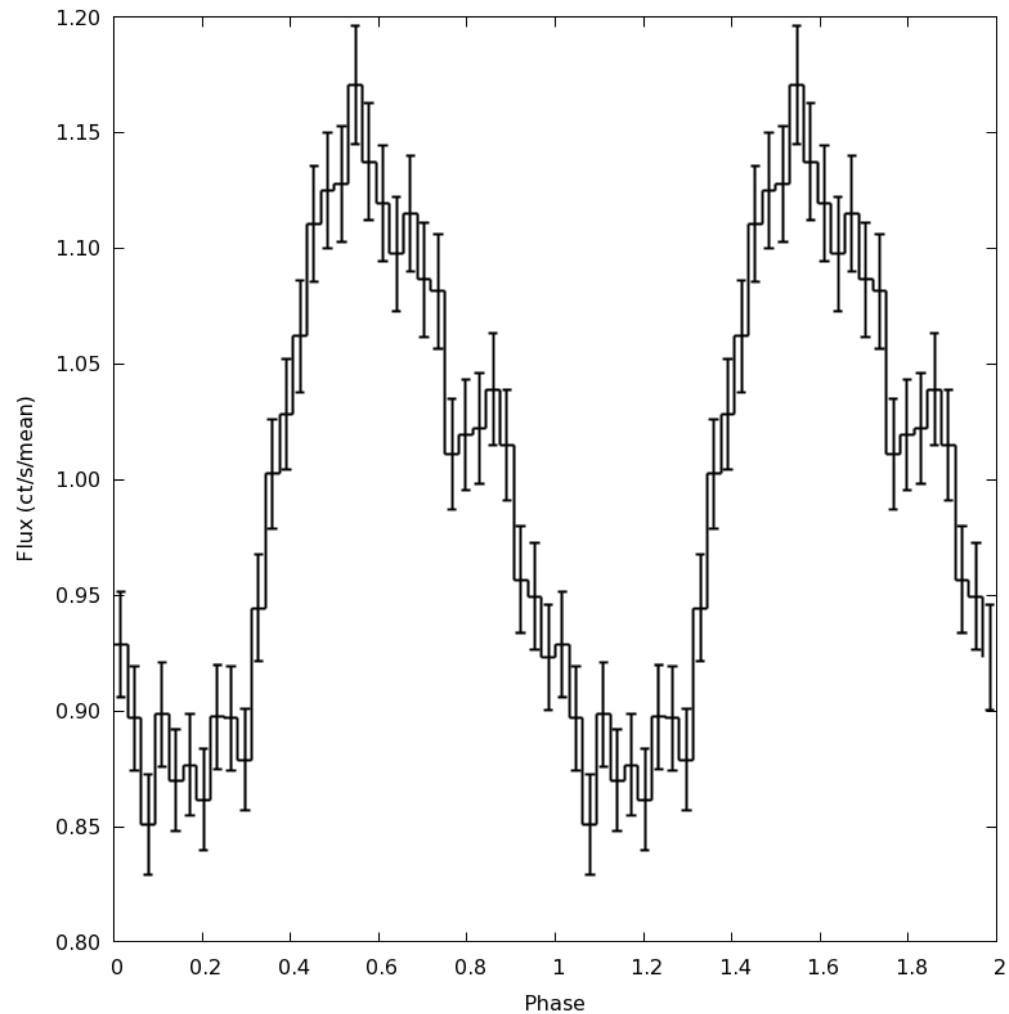
ISS Science Nugget, 4/05/18

Shown in the figure is the power spectrum from a 9,500 sec NICER exposure of Swift J1756.9-2508, with a narrow peak rising high above the noise level. This spike is essentially a "delta function", much narrower than the width of individual spectral bins. Accounting for the pulsar's motion in its 55-min orbit and co-adding the X-ray data at the pulsation period reveals the pulse profile (inset), a coherent, double-peaked brightness oscillation that makes much of the exciting science from this object possible.



ISS Science Nugget, 4/12/18

Following a 2018 March 19 alert from the ISS payload MAXI of a new outburst from the neutron star low-mass X-ray binary IGR J17379-3747, NICER has observed the source daily since 2018 March 29. From that date onward, the mean count rates detected each day through April 1 were 12.9, 11.0, 8.7, and 4.7 ct/s (0.5-12 keV), respectively. NICER detected a clear pulsation (> 7 sigma significance for a single trial) at a frequency of 468.05 Hz, making this NICER's first discovery of a previously unknown pulsar. Furthermore, NICER looked at variations in the detected pulse frequency with time to determine that this pulsar is in a binary with an orbital period of 1.88 hrs and a minimum companion mass of 0.055 Msun (assuming a 1.4 Msun neutron star). Correcting for the binary orbit, the pulse profile is shown in the attached figure. The NICER pulsation detection conclusively identifies IGR J17379-3747 as an accreting millisecond X-ray pulsar. NICER monitoring of the source continues. NICER reported these results in its 6th Astronomer's Telegram: ATEL #11507.

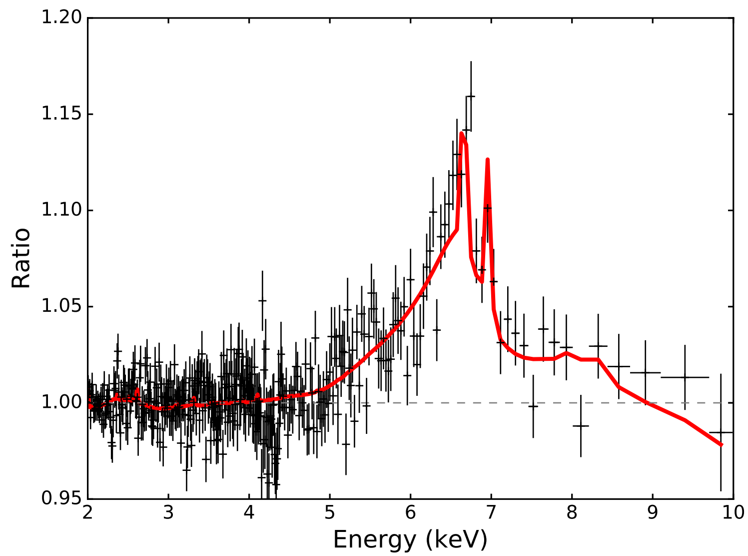


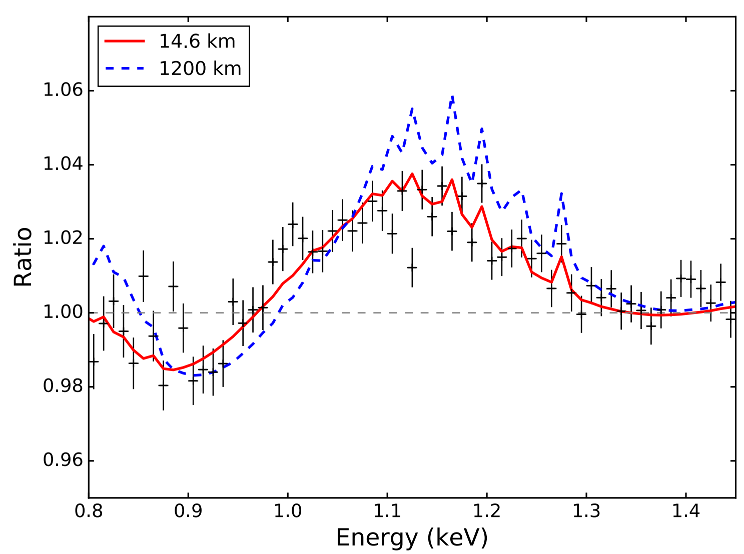
ISS Science Nugget, 4/19/18

NICER Detects Multiple “Reflection” Features In the Neutron Star Low-Mass X-ray Binary Serpens X-1

Serpens X-1 is a persistently accreting neutron star (NS) system, with a companion star of approximately one solar mass, located in the direction of the Galactic Center. This source has consistently shown spectral emission features that arise from the reprocessing (or "reflection") of high-energy X-rays by an irradiated accretion disk surrounding the NS. These hard X-rays may be produced in a corona, at the surface of the NS, or in a boundary layer between the disk and NS. The most prominent of these features is due to highly ionized iron K-shell emission between 6.4 and 6.97 keV photon energy. With the collecting area and spectral sensitivity of NICER, in just 4.5 kiloseconds worth of data we were able to detect structure within the Fe K line and, for the first time, also definitively within a cluster of lower-energy emission features due to Fe L-shell and lighter element K-shell transitions, near 1 keV. These lines are shaped by relativistic and Doppler effects within the innermost region of the accretion disk due to its proximity to the NS. The best fit reflection models (red, in the accompanying figure) indicate that the accretion disk extends down to 12.4-19.8 km, close to the star's surface. The blue dashed line in the lower-energy band indicates the local rest frame (non-relativistic) emission, to highlight the structure within this region. NICER's energy resolution and sensitivity, together with the recent development of self-consistent reflection models tailored for NSs, provide the opportunity to study the inner accretion flow in a new light and learn more about these extreme environments. This result has been accepted for publication as NICER's third post-launch peer-reviewed paper — Ludlam et al., “Detection of Reflection Features in the Neutron Star Low-mass X-ray Binary Serpens X-1 with NICER”, Astrophysical Journal Letters, April 2018.

ISS Science Nugget, 4/19/18

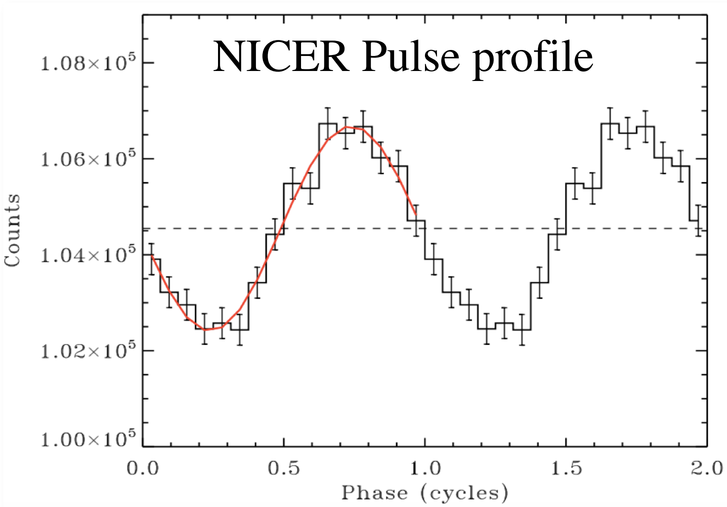


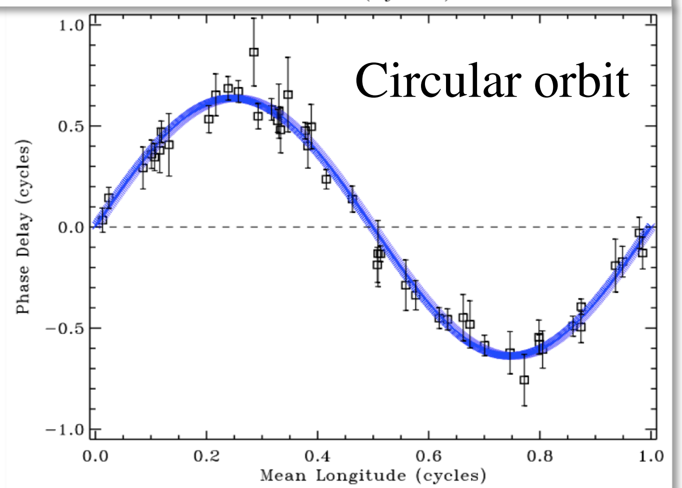


ISS Science Nugget, 4/26/18

NICER's fourth peer-reviewed paper was accepted for publication this week: Strohmayer et al., “NICER Discovers the Ultracompact Orbit of the Accreting Millisecond Pulsar IGR J17062−6143,” in The Astrophysical Journal Letters. NICER observations of this accreting millisecond X-ray pulsar (AMXP) clearly detected 163 Hz pulsations (figure, upper-left panel) from the neutron star in this binary system, confirming a past hint of these pulses seen with an earlier X-ray telescope. Data spanning several months were accumulated with NICER; they showed that the pulsations arrive at the telescope systematically early or late depending on the neutron star's orbital motion in the binary (figure, lower-left panel). Analysis of the NICER dataset revealed that the binary is the most compact AMXP known, with an orbital period of just 38 minutes. NICER data show that the system comprises a neutron star and a very low-mass (< 0.015 Solar mass) white dwarf companion separated by only 300,000 km, less than the Earth-to-Moon distance.

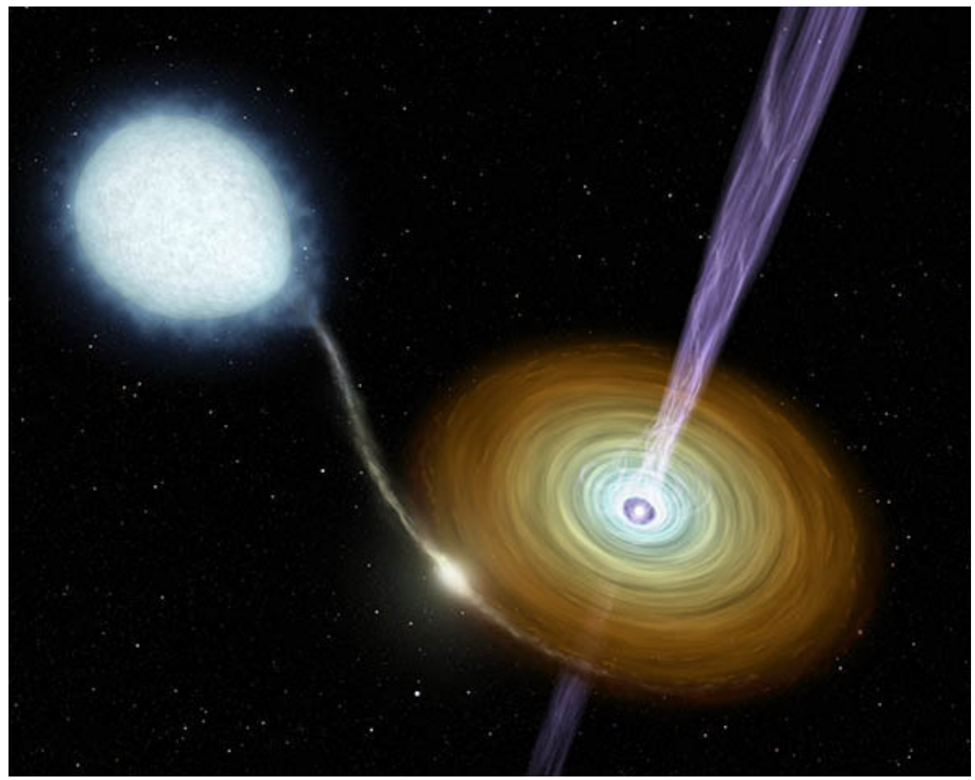
ISS Science Nugget, 4/26/18 (cont.)





IGR J17062-6143

Strohmayer et al. (2018)



ISS Science Nugget, 5/3/18

According to Einstein's theory of general relativity, black holes from collapsed massive stars are dense enough to significantly warp space and time. By studying X-ray emission from regions very close to a black hole, we can decipher the effects of strong gravity on physical processes and test general relativity in the strong-field limit. One type of rapid sub-second variability seen in the brightness "light curves" of accreting black holes is the enigmatic quasi-periodic oscillation (QPO). As part of her PhD research, Abigail Stevens developed a new technique to analyze the energy spectrum of a QPO as a function of the brightness oscillation's phase. This technique can be used to constrain the origin of the QPO signal and look for signatures of general relativity in NICER data.

In Chapter 5 of her thesis (the first PhD to be awarded based in part on NICER data!), Dr. Stevens presented the discovery of a weak "Type B" QPO in NICER observations of the newly-identified black hole transient MAXI J1535-571 from autumn 2017. NICER data track the spectral variations with QPO phase in low-energy X-rays, a band that was previously unobservable on such short timescales. The QPO-phase-resolved spectra (Figure 1) show that the low-energy X-rays from the accretion disk lag in time behind the high-energy X-rays by about a quarter of an oscillation period. This could be explained by an effect of general relativity known as "frame dragging," which causes the hot inner flow of gas to precess around the spin axis of the black hole like a wobbling top, illuminating adjacent regions of the accretion disk (Figure 2). The completed spectral calibration of NICER will now allow us to fit detailed models to the QPO-phase-resolved spectra for publication soon in The Astrophysical Journal.

MAXI J1535-571

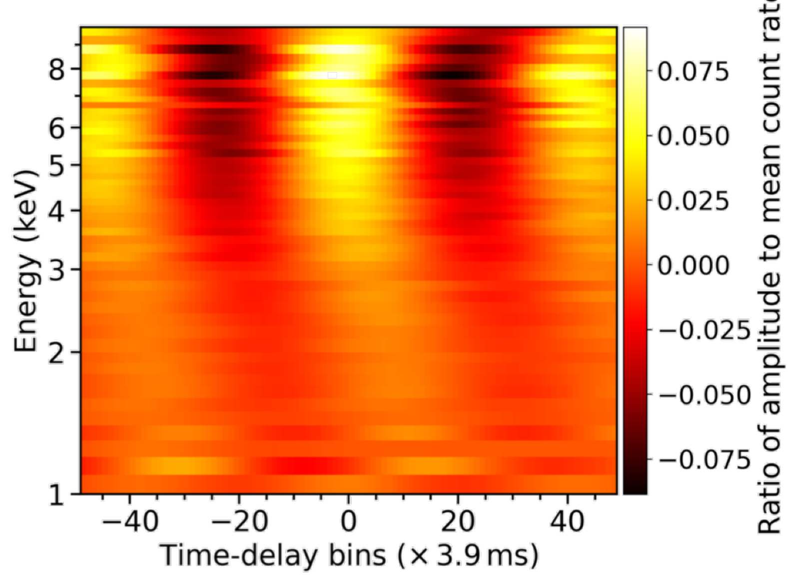
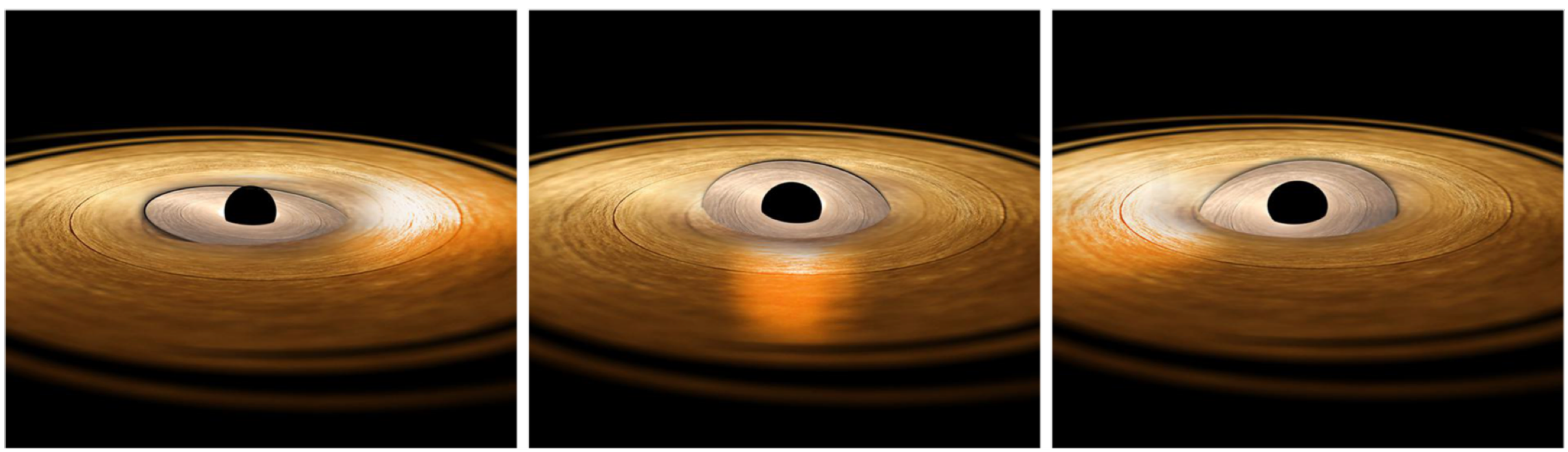


Figure 1 (left): The energy-dependent cross-correlation function of the 5.7 Hz QPO, showing relative time on the horizontal axis and X-ray energy on the vertical axis. We can see that the high-energy X-rays lead the low-energy X-rays by about a quarter of a period. Image credit: A.L. Stevens 2018.

Figure 2 (below): An illustration of a black hole with an accretion disk and hot inner gas flow. The hot inner gas flow is precessing around the spin axis of the black hole like a wobbling top and illuminating adjacent regions of the accretion disk. Image credit: ESA/ATG Medialab/A. Ingram.

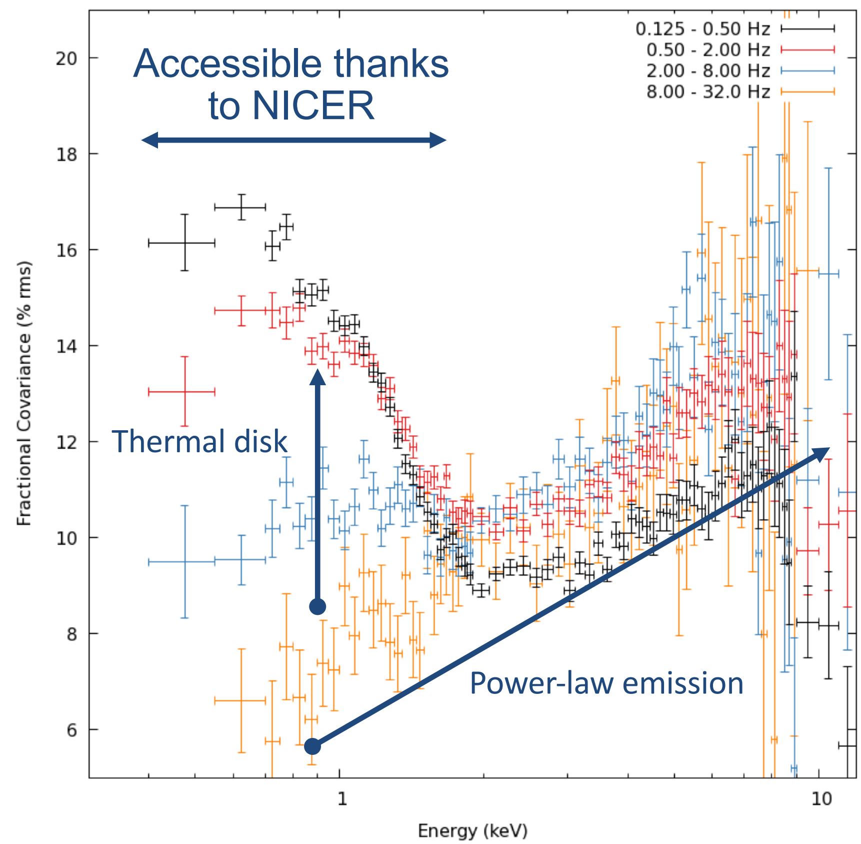


ISS Science Nugget, 5/10/18

A NICER look at the Aql X-1 hard state

NICER's 5th peer-reviewed paper post-launch was accepted for publication in the Astrophysical Journal Letters this past week. Its title is "A NICER look at the Aql X-1 hard state" by Bult et al.

In this paper we report on a spectral-timing analysis of the neutron star low-mass X-ray binary Aql X-1. We find that the slow variability (black & red data in the figure) show an unexpected excess in amplitude below 2 keV. By measuring time delays as a function of energy we found that low energy photons (0.5 keV) systematically arrive earlier than high energy photons (10 keV). These measurements demonstrate that the thermal emission from the disk is intrinsically variable, and drives the slow modulation of the higher energy power-law. These results are consistent with the disk propagation model proposed for accretion onto black holes, and now confirmed in a neutron star system thanks to NICER's excellent sensitivity below 2 keV.

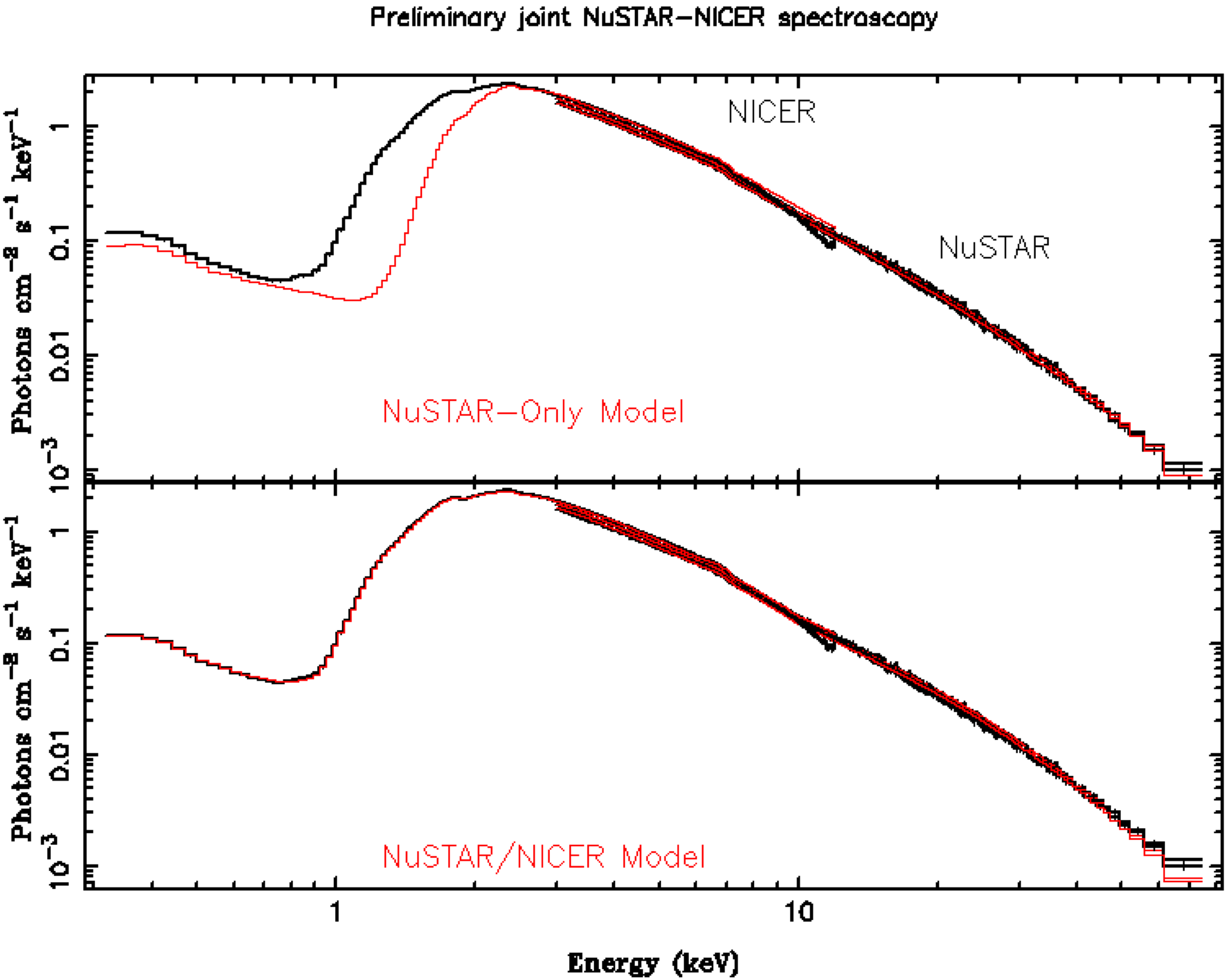


ISS Science Nugget, 5/17/18

Stellar mass black holes spend most of their time in quiescence (with little to no accretion and very low X-ray luminosity), but in their luminous outbursts they are ideal for studying black hole accretion. Much of the physics that drives these outbursts is yet to be determined. For example, how does the accretion disk around the black hole change during these enormous outbursts? To answer this question, we require accurate estimates of not only the disk spectrum but also the effect of absorption by the cold interstellar medium (ISM). This is an area where NICER excels: its soft X-ray sensitivity covers precisely the energy range most affected by changes in the luminous disk and by the ISM. A prime opportunity came last fall, when a new source called MAXI J1535-571 went into outburst. NICER observed this source frequently during its incredibly bright outburst, including coordinated observations with NuSTAR (a hard X-ray telescope that lacks NICER's low-energy response).

In the figure, we show NICER's effect on models of the resulting X-ray spectra (black curves are data, red are models). In the top panel, we show the model that best describes the NuSTAR data alone. It clearly matches the hard X-ray emission, but because of the large inferred column density of cold ISM gas (~1e23 cm^{-2}, see similar results in Xu et al. 2018), the NuSTAR-only model is completely inconsistent with the NICER spectrum. Fitting both spectra together (bottom panel) leads to a much lower column density (~4.5e22 cm^{-2}). This has a huge effect on the disk, which in the joint fits is inferred to be ~12x larger and nearly 3x cooler than in the NuSTAR-only model. Even from this preliminary look, it is clear that NICER will revolutionize studies of accretion disks and black hole outbursts.

ISS Science Nugget, 5/17/18



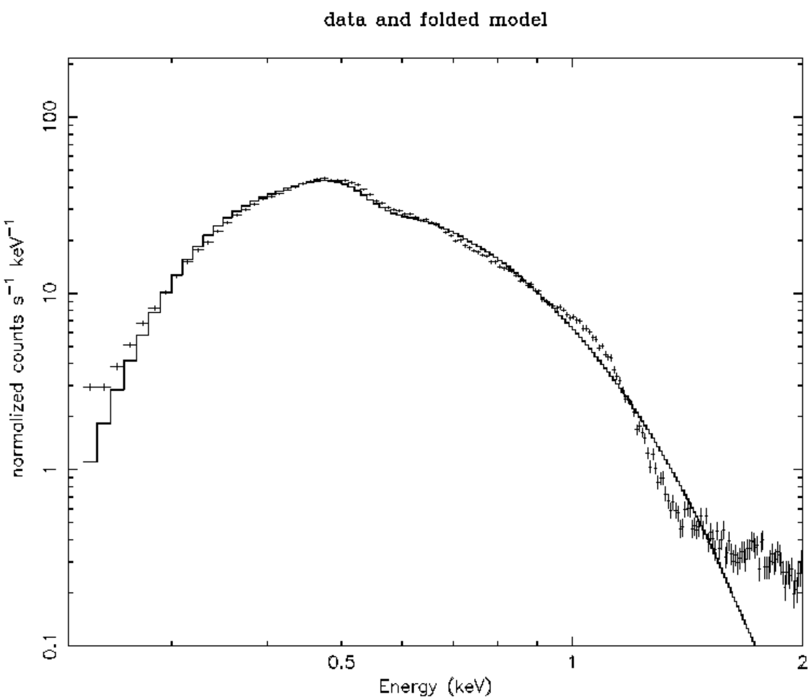
ISS Science Nugget, 5/24/18

This week, NICER responded to an extreme nuclear transient associated with a known active galaxy (of the "Seyfert 2" class). This extreme accretion event may be due to a "tidal disruption event" (TDE), where a star has ventured too close to the galaxy's central black hole. TDEs are near-pristine laboratories of relativistic accretion. NICER observed the target ASASSN-18el, discovered by the All Sky Automated Survey for SuperNovae (ASAS-SN) collection of telescopes distributed around the world. NICER investigations can help us understand the nature of this extreme accretion event, and can yield black hole masses, spins, and inclinations from TDEs, together with the structure of the extreme gravitational field just outside the event horizon of a black hole that was previously unobservable. In the figure, the X-ray light curve observed by NICER is shown as well as the X-ray spectrum, consistent with a 150 eV blackbody.

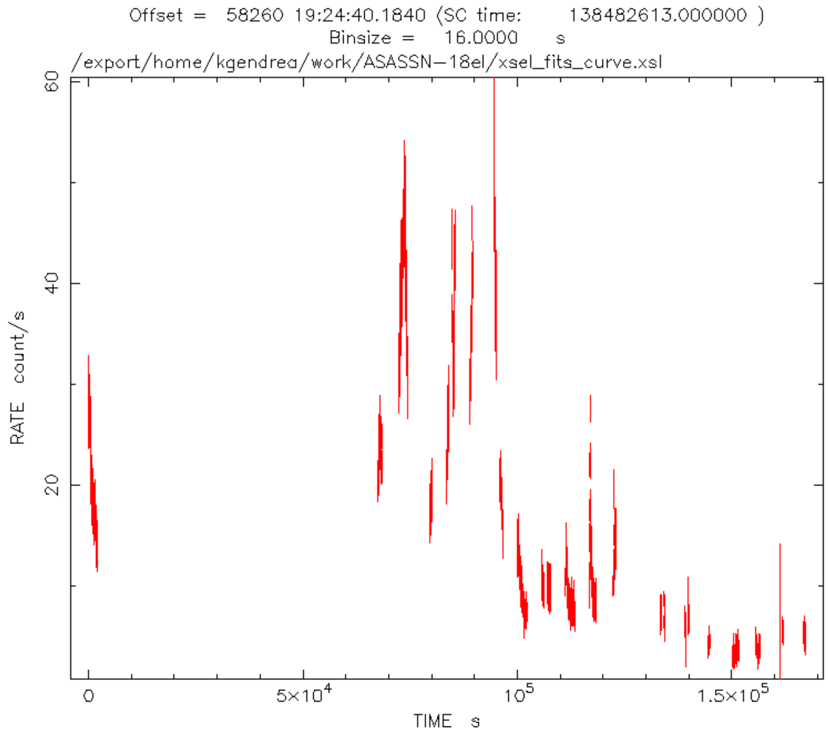
NICER will continue to observe this object and the science team is analyzing the data to determine the nature of this unusual X-ray activity.

ISS Science Nugget, 5/24/18

ASASSN-18el Target of Opportunity



Spectrum with 150 eV blackbody model



X-ray Light Curve

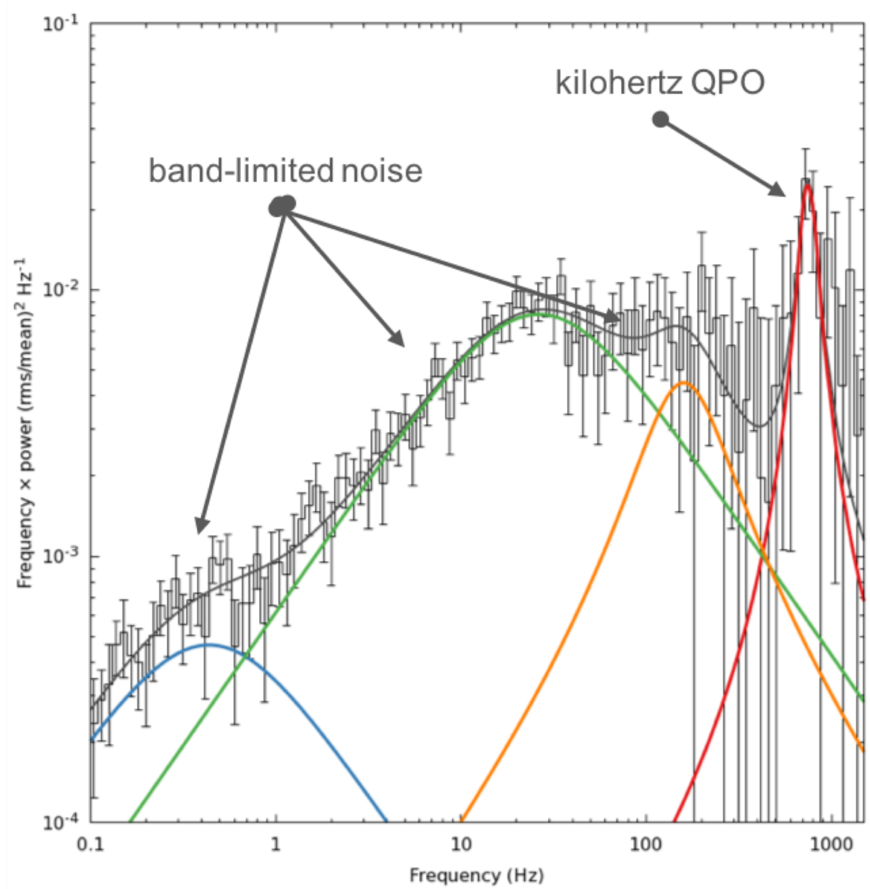
ISS Science Nugget, 6/01/18

NICER Detects a Soft X-ray kilohertz QPO in 4U 0614+09

A signature feature of accreting neutron stars, kilohertz Quasi-Periodic Oscillations (QPOs) are the fastest phenomena observed in X-ray binaries. Based on their millisecond periods it has long been argued that these signals must somehow be related to the innermost regions of the accretion disk, where matter is orbiting through strongly curved space-time only a few kilometers from the neutron star surface. Many competing theories have been proposed to explain these kHz QPOs, but lacking strong observational constraints the correct interpretation has remained elusive.

For the first time we were able to measure the amplitude of this QPO at photon energies <2 keV (See figure). This is an important regime where many models make diverging predictions. With this measurement we can now rule out a whole class of models and provide new input in a long standing debate.

This discovery has been accepted in a paper as NICER's 7th peer reviewed paper since launch. Bult et al. Astrophysical Journal Letters 2018.



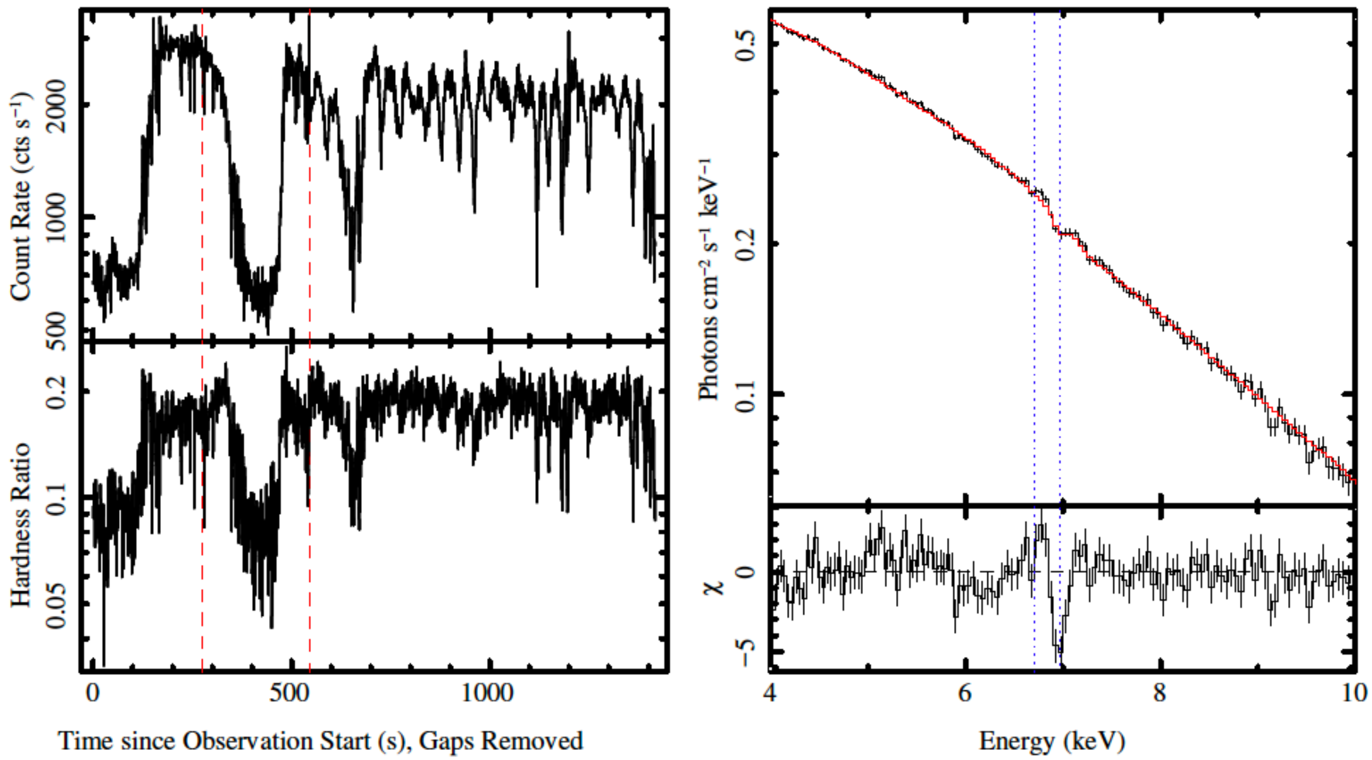
ISS Science Nugget, 6/7/18

Last week, NICER's first paper on black holes (titled "A Persistent Disk Wind in GRS 1915+105 with NICER" by Neilsen et al.) was accepted for publication in The Astrophysical Journal Letters. This is NICER's 7th peer-reviewed science result to be published.

GRS 1915+105 is not a typical stellar-mass black hole: it has been in outburst since 1992, its relativistic jets could span our Solar System 60 times over, and its ionized winds can carry > 2 Earth masses worth of gas away from the black hole every year. But what really makes this black hole a black sheep is its variability — 14 distinct states of bizarre oscillations on timescales ranging from seconds to hours. One example is shown in the figure (next slide), with strong variability in the NICER lightcurve (left) and an absorption line from the wind in the NICER spectrum (right).

One of the main questions for such an object is how to make sense of its behavior. Previous work has suggested a trade-off between the disk, wind, and jet, but there are few observations capable of exploring this relationship in detail; this is where NICER excels. NICER looked at GRS 1915 over three dozen times during 2017, tracking the wind signatures for correlating with the rest of the system's behavior. We found that the wind was remarkably persistent: it was detectable in more than 80% of our observations! Our results also indicate that more variable lightcurves are associated with weaker wind signatures, which we interpret as evidence that, like the jet, the wind can quickly toggle on and off in response to the rapid variability seen from the disk.

ISS Science Nugget, 6/7/18



NICER light curve (left) showing strong variability in brightness (top) and spectral shape (bottom). The red dashed lines are where gaps in the NICER data were removed. NICER X-ray spectrum (right) showing the total spectrum in black with a red model fit to the data (top) while the bottom shows the residuals of a fit with only a continuum model to emphasize the absorption features. The blue dashed lines show the expected positions of absorption features from ionized iron atoms in the wind.

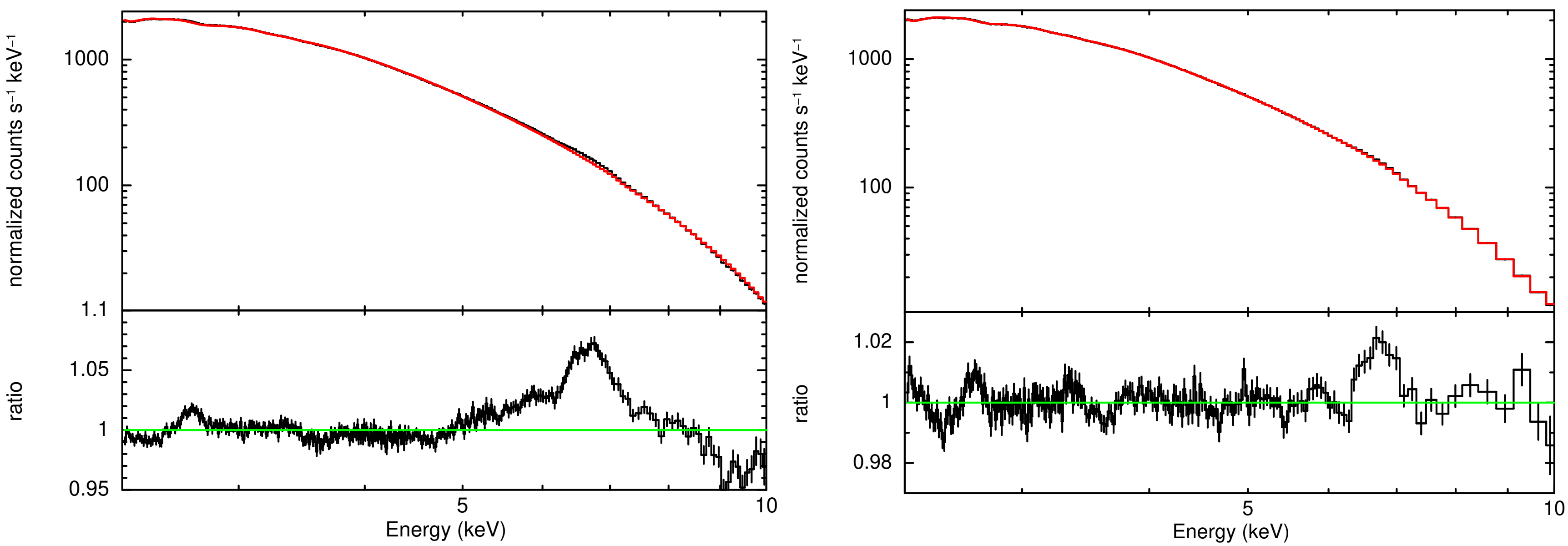
ISS Science Nugget, 6/15/18

Astrophysical black holes have only two properties: mass, and spin. Masses can be measured using Kepler's laws of orbital motion. But, how can the spin of a black hole be measured? General Relativity has provided a means: the spin of a black hole determines how closely matter can orbit before inevitably falling into the hole. Therefore, dynamical information imprinted on gas in the innermost orbits can be used to measure the spin. Gas in these regions is so hot that it emits in X-rays. The last two ionization states of iron (where 24/26 and 25/26 electrons have been stripped) can survive even in extremely hot gas, and X-ray emission lines (6.70 keV and 6.97 keV) tied to these states bear the imprints of relativistic Doppler shifts and gravitational red-shifts.

NICER has observed the Galactic stellar-mass black hole MAXI J1535-571 on numerous occasions through the Fall of 2017 and Spring of 2018. The throughput of NICER has enabled a robust measurement of the spin of the black hole in MAXI J1535-571 using iron emission lines. The spin appears to be near-maximal: $a > 0.99$ (where $a = cJ/GM^2$ is a measure of spin between -1 and +1, and J,M are respectively the black hole's angular momentum and mass). NICER's spectral resolution also revealed the existence of a narrow iron line on top of the relativistically broadened iron line (see figure). While the overall shape of the broadened line tells us about the black hole spin and mass parameters, the existence of the narrow spectral feature reveals that the accretion disk feeding the black hole is warped.

These results are now accepted for publication in the Astrophysical Journal Letters (Miller, J. M., et al., 2018, ApJ, in press). Going forward, the unparalleled capabilities of NICER will markedly increase the number of stellar-mass black hole spin measurements, building a population against which LIGO gravitational wave measurements can be compared. This will ultimately help scientists to understand how stellar-mass black holes form and evolve.

ISS Science Nugget, 6/15/18



NICER spectra of the black-hole binary MAXI J1535-571. X-ray brightness as a function of energy (black) is fit to a continuum model (red). On the left, the model excludes Doppler- and red-shifted iron emission, highlighting the broad feature in the 5-8 keV range (lower panel). On the right, the model includes the broad feature; left unmodeled is a narrow feature between 6.5 and 7 keV.

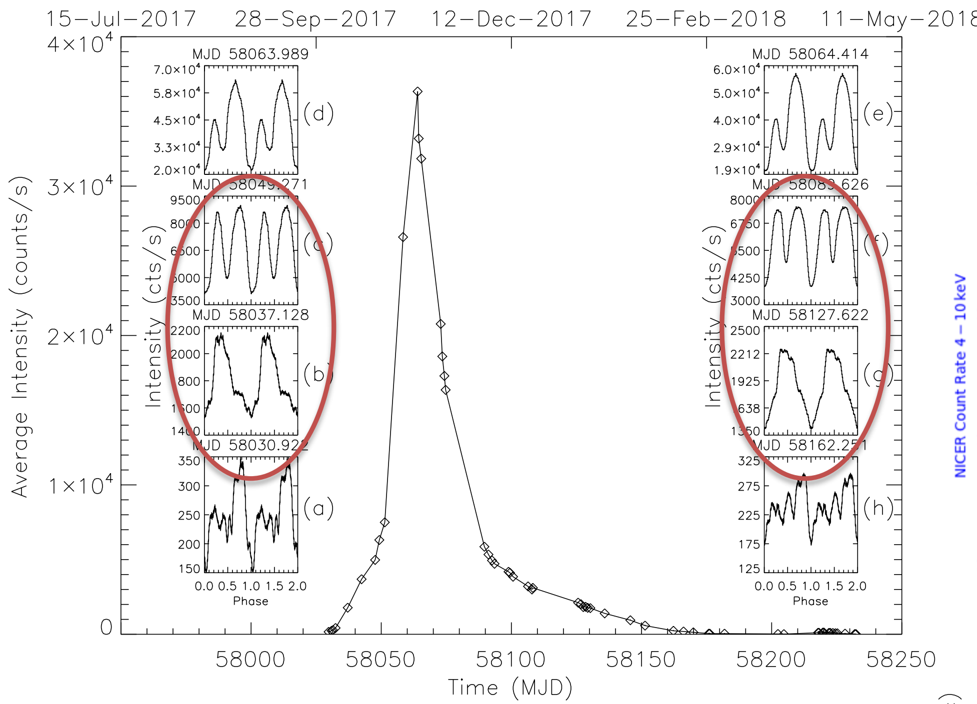
ISS Science Nugget, 6/21/18

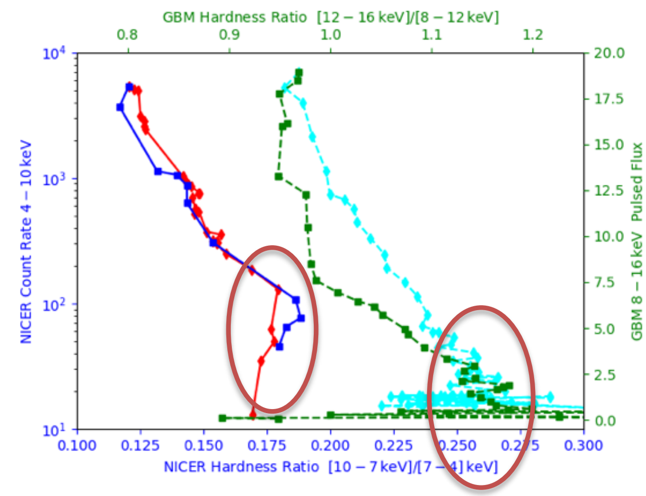
Last week, NICER's first paper on an Ultraluminous X-ray pulsar (titled "NICER and Fermi GBM Observations of the First Galactic Ultraluminous X-ray pulsar Swift J0243.6+6124" by Wilson-Hodge et al.) was accepted for publication in The Astrophysical Journal. This is NICER's 9th peer-reviewed science result to be published.

Ultraluminous X-ray (ULX) sources were first found in other galaxies and were once proposed to be due to intermediate-mass black holes (100-10,000 times the mass of the Sun). These sources are defined by their luminosity being greater than 1039 erg/s. Recently, four ULXs have been discovered to be pulsars. These pulsars are different from the typical rotation-powered pulsars observed with NICER, because they are powered by accretion from an orbiting companion star. Our Milky Way Galaxy contains many such accreting pulsars, but none were known to be ultraluminous. At a distance of about 7 kpc, measured using results from the European Gaia mission, Swift J0243.6+6124 reached a peak average luminosity of 1.8 x 1039 erg/s on November 6, 2017, making it the brightest pulsar in our Galaxy, and its first known ULX. Studying this object can help us to understand the ultraluminous X-ray pulsars in other galaxies.

The rich NICER dataset showed us that Swift J0243.6+6124 underwent a transition between two accretion regimes at a critical luminosity of about 1038 ergs/s. At this time, the pulse profile transitioned from single peaked to double peaked, the pulsed fraction reached a minimum, and the energy spectrum softened. This is the highest observed critical luminosity in any accretion-power pulsar, suggesting that the magnetic field for Swift J0243.6+6124 is unusually high, 1013 G. NICER observed these transitions during both the rise and declining phases of the outburst. These observations of Swift J0243.6+6124 suggest that the ultraluminous X-ray pulsars in other galaxies may also be accreting neutron stars with strong magnetic fields.

ISS Science Nugget, 6/21/18



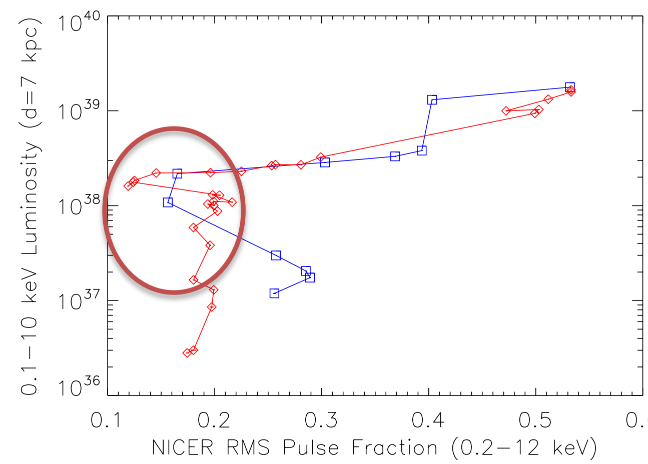


Top left: NICER 0.2-12 keV count rate vs. time for Swift J0243.6+6124

Top insets: Dramatic pulse profile variations. The profiles transition from single to double peaked at the critical luminosity of 10^{38} erg/s (red circles)

Top right: Spectral "hardness" ratios measured with NICER (red/blue) and Fermi GBM (teal/green) show a spectral softening with increasing intensity after a transition at the critical luminosity.

Bottom right: 0.2-12 keV luminosity vs. 0.2-12 keV pulse fraction. Above the critical luminosity, the pulse fraction increases with increasing intensity.



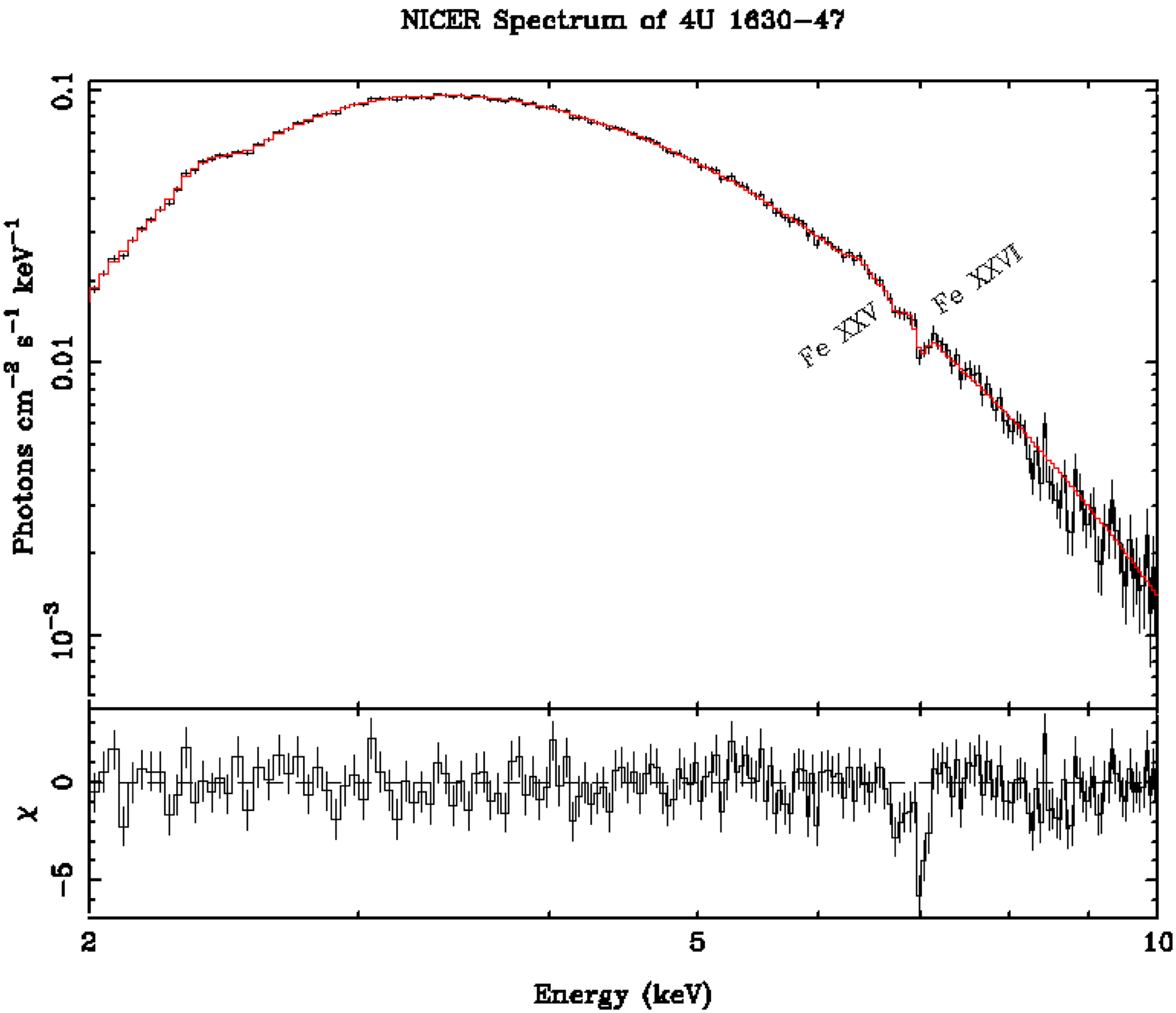
ISS Science Nugget, 6/28/18

As black hole transients go, 4U 1630-47 is both reliable and enigmatic. Since its discovery in 1969, 4U 1630 has gone into outburst more than twenty times, roughly once every 600-700 days (in contrast to famous sources like V404 Cyg and A0620-00, which can go decades between outbursts). Thus, it is an excellent case study for outbursts of a single object: what do they have in common, and in what ways are they different?

One thing they seem to have in common is strong winds. Across outbursts, X-ray telescopes including Chandra, Suzaku, NuSTAR, and now NICER have all observed blue-shifted iron absorption lines (see accompanying figure): signatures of multimillion-degree outflowing gas. In brief, the infalling gas shines so brightly in X-rays that it pushes itself away (here moving at 1700 km/s) from the black hole. But there are differences and puzzles as well. Normal black hole outbursts go through a progression of “states,” but 4U 1630-47 occasionally (including the current outburst), skips the early “hard" states and goes straight to the middle “soft” states, where winds are often seen. NICER can shed light on this behavior, which may be related to the unusually regular and frequent outbursts. Perhaps we will know more in 600 days. This result was the subject of NICER's 11th Astronomer's Telegram, "NICER Observation of Strong Wind Absorption in the Soft Outburst of 4U 1630-47” (ATel #11771), by J. Neilsen et al.

Figure caption: NICER X-ray spectrum of the black hole 4U 1630-47. The smooth continuum is dominated by thermal emission from the accretion disk, unusual for the early phases of an outburst. Superimposed on this continuum are absorption lines from multimillion-degree iron atoms, indicating gas flowing away from the black hole at 1,700 km/s. The top panel sows the NICER data (black) and this model (red); the bottom panel shows the residuals after subtracting the continuum (to highlight the wind absorption).

ISS Science Nugget, 6/28/18



ISS Science Nugget, 7/5/18

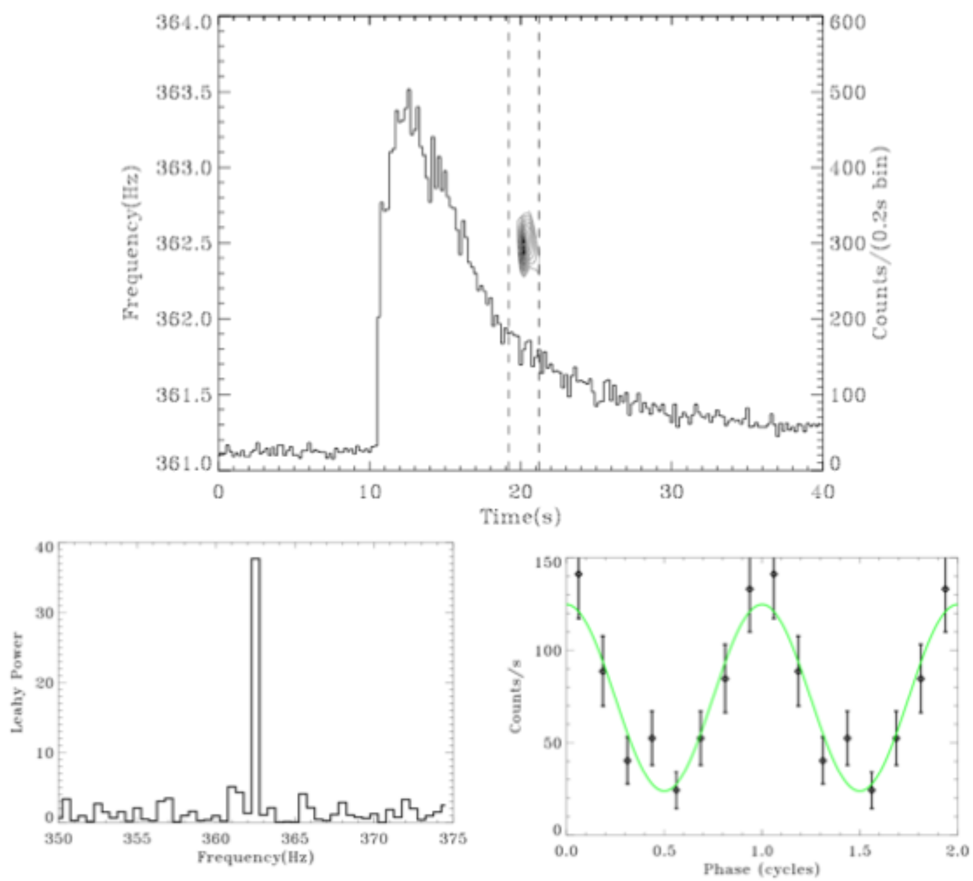
NICER Observes Unusual Burst Oscillations in 4U 1728-34

Type I X-ray bursts are thermonuclear explosions on the surfaces of neutron stars found in Low Mass X-ray Binaries (LMXBs). Lasting tens of seconds, these unpredictable flashes in X-rays are due to unstable burning of material accreted from a companion star.

Coherent pulsations in brightness, known as burst oscillations, have been observed in the rise and/or tail of some X-ray bursts. In 2003, the discovery of burst oscillations at a frequency of 401 Hz from the accretion-powered pulsar SAX J1808.4-3658 revealed that the oscillation frequency was very close to the star's known spin frequency, establishing burst oscillations as nuclear-powered pulsations that can be used to estimate the spin rates of other accreting neutron stars.

The fractional root-mean-squared (rms) amplitude of burst oscillation signals is usually between 5% and 20%. There are some cases where larger amplitudes have been observed in the rising phase of a burst, but burst oscillations seen in the tail usually have smaller amplitudes. NICER has observed an unusually large-amplitude burst oscillation, one that occurred in the tail of a burst from the LMXB 4U 1728-34, with a fractional rms of 51.7 ± 9.5%. This is the largest amplitude ever observed for oscillations in a burst tail. The fact that this signal has been observed only at high X-ray energies (above 6 keV) and with such a large amplitude is very puzzling, challenging our current theoretical models of thermonuclear explosions and flame propagation in the extreme gravitational, nuclear, and electromagnetic environment of a neutron star's surface.

ISS Science Nugget, 7/5/18



NICER Observes Unusual Burst Oscillations in 4U 1728-34

Upper panel: The solid trace shows the characteristic sudden onset and decaying tail of a Type I X-ray burst brightness profile or "lightcurve", referring to the right-hand vertical axis. The tight bundle of contours between the dashed vertical lines shows the result of a search for periodic fluctuations in brightness in narrow time intervals conducted across the entire burst; the periodic emission at 362.5 Hz (left vertical axis) was only seen in this part of the burst tail. Lower-left panel: A "periodogram" showing excess power at the pulsation frequency. Lower-right panel: the shape of the brightness oscillation at 362.5 Hz, with the best-fit sine curve in green.

ISS Science Nugget, 7/12/18

The Demon Star Winked in X-rays

Algol, the second-brightest star in the constellation Perseus, fascinated and frightened people in ancient times because it "winks." Every 2.87 days, this naked-eye star fades by one-third for several hours. For ancient peoples, who viewed the stars as fixed and constant, this variation must have been seen as a demon's omen. The truth is that Algol is not one star, but two, and these stars eclipse each other every 2.87 days - in fact, Algol was the first such eclipsing stellar system recognized. One of the two stars is a giant solar-mass star and the primary is a more massive but less evolved star - a paradox to astronomers that was the first indication that stars in binaries could exchange mass with each other. The lower-mass star shows signs of powerful magnetic activity, which can be observed efficiently in the X-ray band.

The MAXI all sky X-ray monitor onboard the ISS detected the strongest X-ray flare from Algol in 8 years on July 4 2018, stellar fireworks for U.S. Independence Day. NICER responded quickly to MAXI's flare alert. Its observations began during the decay of this giant X-ray flare and later detected an abrupt decline in X-ray brightness by half, lasting several hours. NICER caught an X-ray wink! Its timing was consistent with a stellar eclipse, indicating that X-ray emission from the less massive star was occulted by the more massive star.

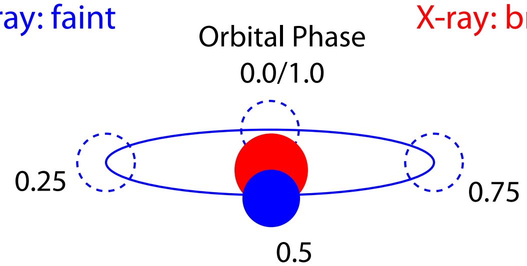
This is the first detection of such an X-ray eclipse from Algol since 1997. Since we know the precise stellar sizes and orbits, we can estimate the size and location of the X-ray-emitting magnetic plasma loop above the stellar surface. NICER's large collecting area also provided a high-quality spectrum for each stellar orbital phase, which should help uncover in great detail how the X-ray plasma cools as it flows along the magnetic loop.

ISS Science Nugget, 7/12/18

1. Algol Binary System

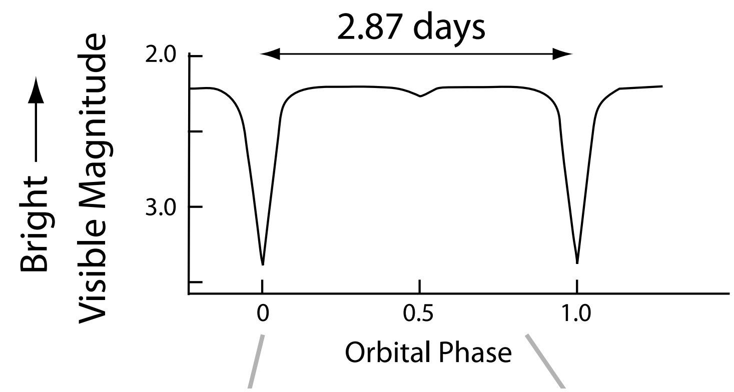
Primary (B8)
Visible: bright
X-ray: faint

Companion (K2)
Visible: faint
X-ray: bright



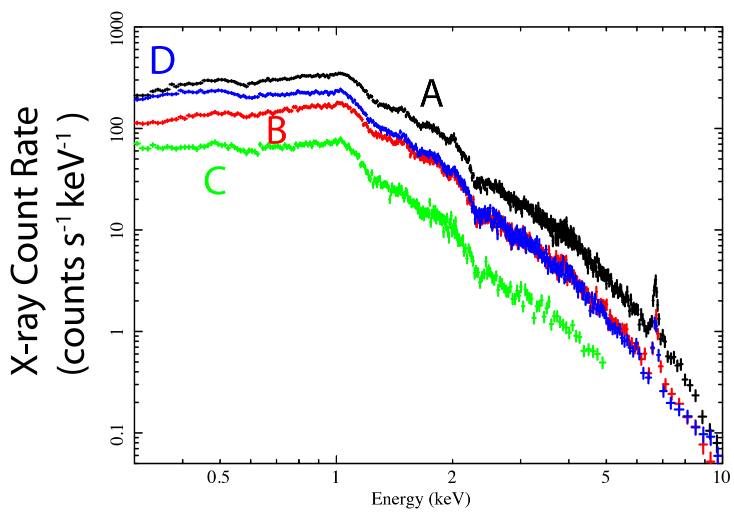
2. Typical Visible Light Curve

Faint at 0.0/1.0 when the primary is eclipsed.



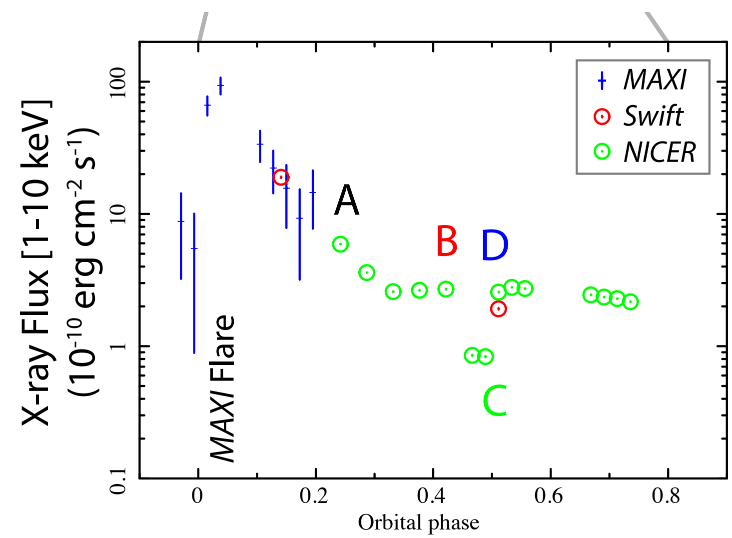
4. *NICER* X-ray Spectra

The flux is the lowest at C in all bands.
Soft X-rays are stronger at D than B. Why??



3. X-ray Light Curve after July 4th

Faint at 0.5 when the companion was eclipsed!



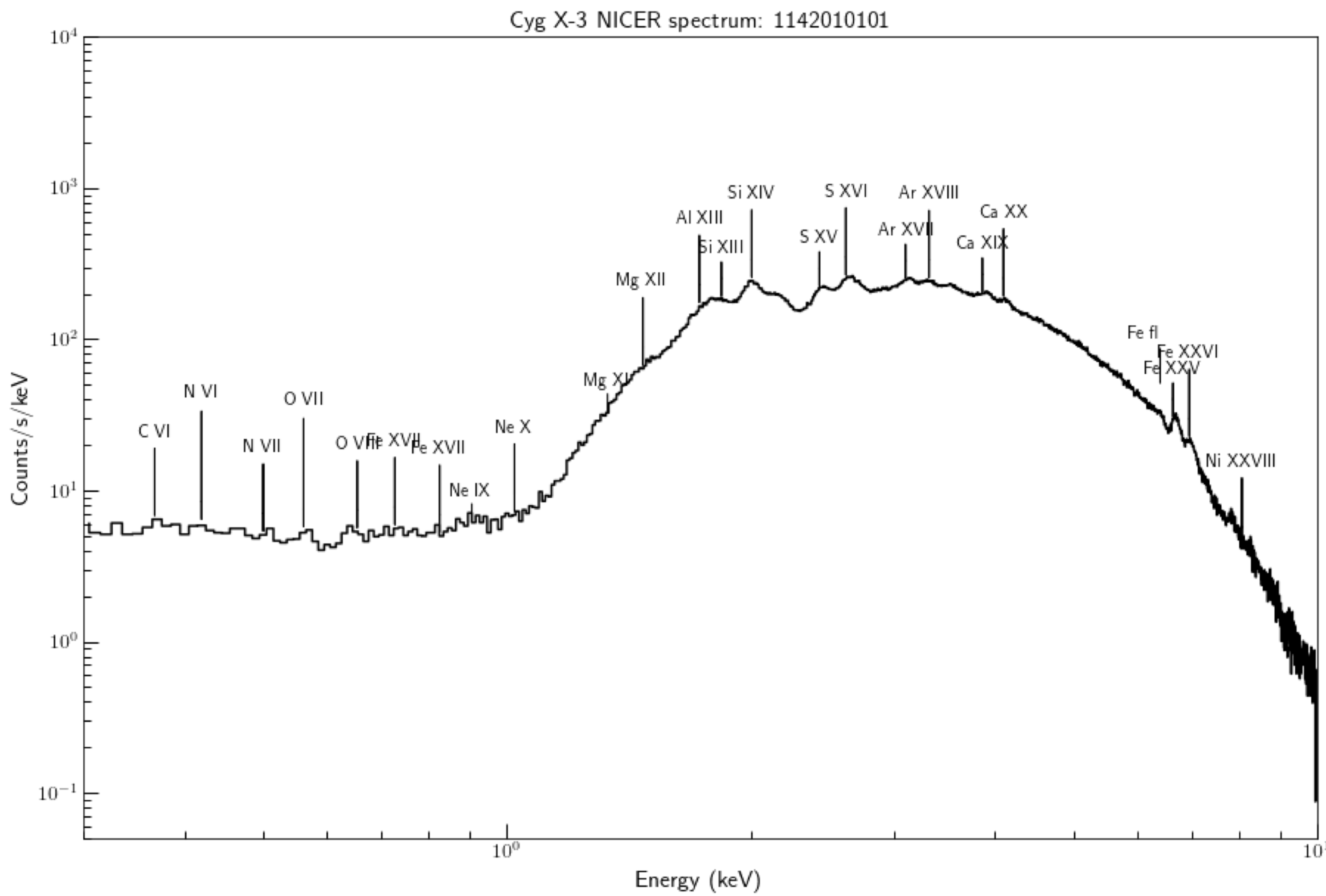
ISS Science Nugget, 7/19/18

NICER Observations of Cyg X-3

Cyg X-3 is one of the most intrinsically luminous X-ray binaries in the Galaxy, consisting of a high-mass star in orbit with, and feeding material to, an accreting compact object (likely a black hole although a neutron star is also possible). On June 29th, the Italian Space Agency's AGILE gamma-ray telescope detected enhanced gamma-ray emission from Cyg X-3. Beginning July 3rd, NICER performed several observations, with early results reported in Astronomers Telegram #11821, http://www.astronomerstelegram.org/?read=11821

NICER initially observed the source at a count rate of 345 XTI counts/s, declining to 270 XTI counts/s within 38 minutes. The NICER observations show orbit-phase-dependent variability of approximately a factor of 4 in count rate, from a maximum of 1069 counts/s to a minimum of 252 counts/s as the binary system follows its ~4.8 hour period. The spectrum shows significant line emission, especially between 1 and 7 keV (see figure, next slide). The spectrum can be simply approximated by a combination of an absorbed power-law plus an absorbed thermal emission component. Sulfur line emission near 2.6 keV is particularly strong, and the spectrum also shows prominent emission from the iron K-shell complex near 6.7 keV. The power-law component has a photon index of approximately 1.2 with a column density of about 8e22/cm^2. The thermal component has a temperature of 1-2 keV, with a somewhat lower column (about 4e22/cm^2). The initial NICER observation had a flux of 8.4e-9 ergs/cm^2/s in the 0.4-12 keV band. A power spectrum of a portion of the initial NICER observation indicates the appearance of a transient quasi-periodic oscillation (QPO) near 140 Hz at 4-sigma significance; QPOs, especially at high frequency, are of interest because they are thought to trace flows in the innermost regions of accretion disks, where relativistic gravity effects are most important. (The QPO was not, however, reliably detected again in subsequent observations.) Historically, gamma-ray flaring such as the June AGILE detection is followed some days later by strong flaring at radio frequencies, likely tied to the emission of powerful jets from the accreting object. NICER continues to monitor Cyg X-3 approximately daily, to track for the first time with high sensitivity in X-rays the evolution of the system between the gamma-ray and radio flares.

ISS Science Nugget, 7/19/18



ISS Science Nugget, 7/26/18

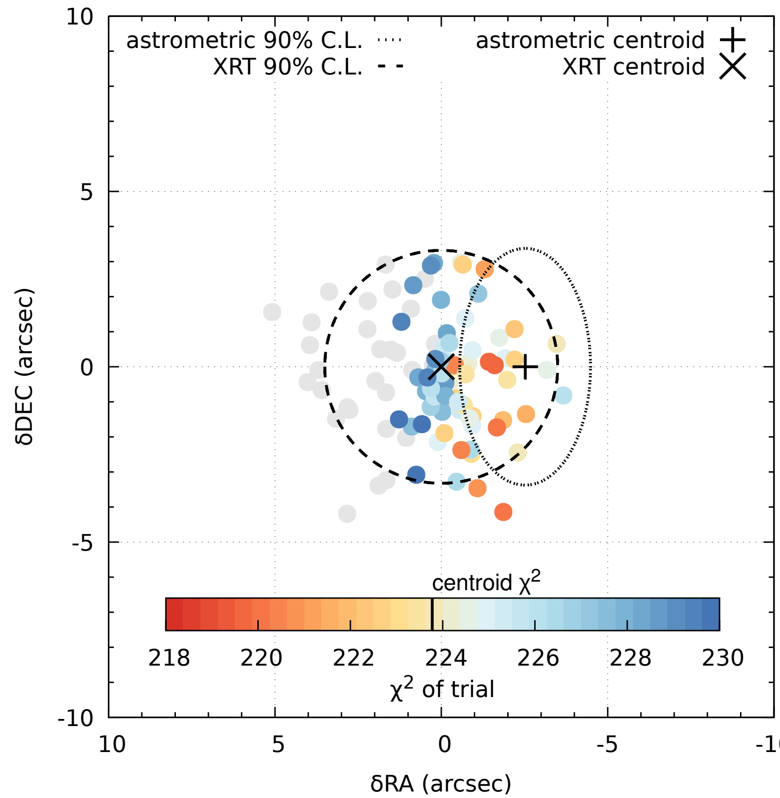
Accreting millisecond X-ray pulsars are fast-spinning neutron stars; their pulsations are visible thanks to episodes of infalling plasma (from a companion star) that is magnetically channelled to the neutron star's magnetic poles. Swift J1756 is one such pulsar. First discovered in June, 2007, this neutron star rotates once around every 5.5 milliseconds.

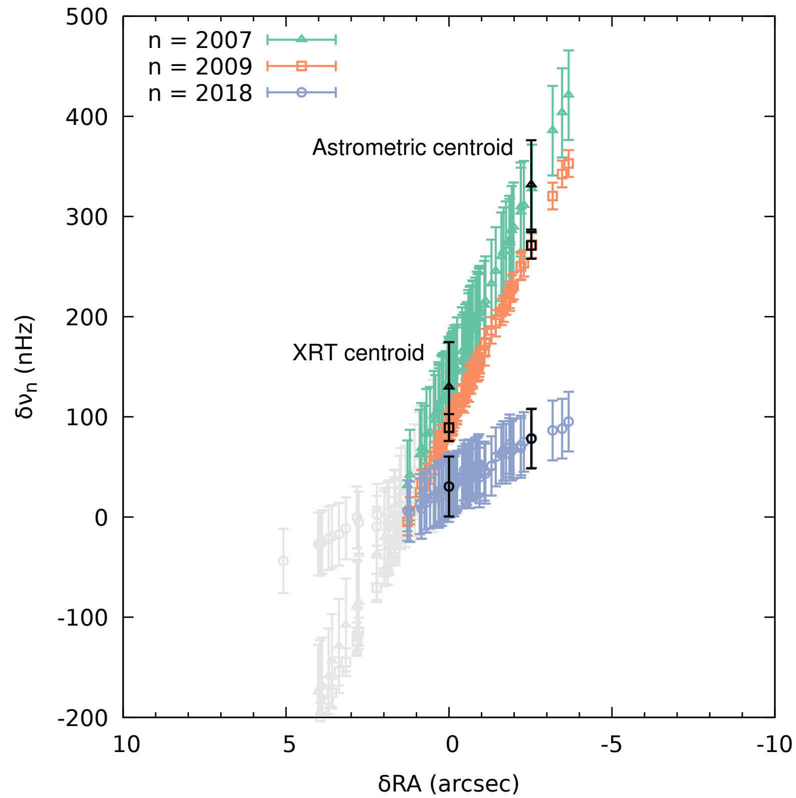
Swift J1756 was only visible for a few days in 2007, and another few days again in 2009. Its April 2018 X-ray outburst provided a rare opportunity for NICER to observe this neutron star and study its long-term evolution.

Thanks to excellent sampling of the 2018 outburst, the NICER data improved our knowledge of the binary orbit and, importantly, enabled the use of pulse timing to reduce uncertainty in the source coordinates on the sky (Fig. A) over those measured using the X-Ray Telescope (XRT) on-board NASA's Swift observatory. In the right panel (Fig. B), we see that, after applying this position correction, the pulsar's spin frequency shows a significant long-term trend, approximately 250 nHz over 10 years. This amounts to a rate of change in the neutron star spin period of about 2×10-20!

This work by P. Bult et al., accepted for publication in The Astrophysical Journal, represents NICER's 10th peer-reviewed paper.

ISS Science Nugget, 7/26/18





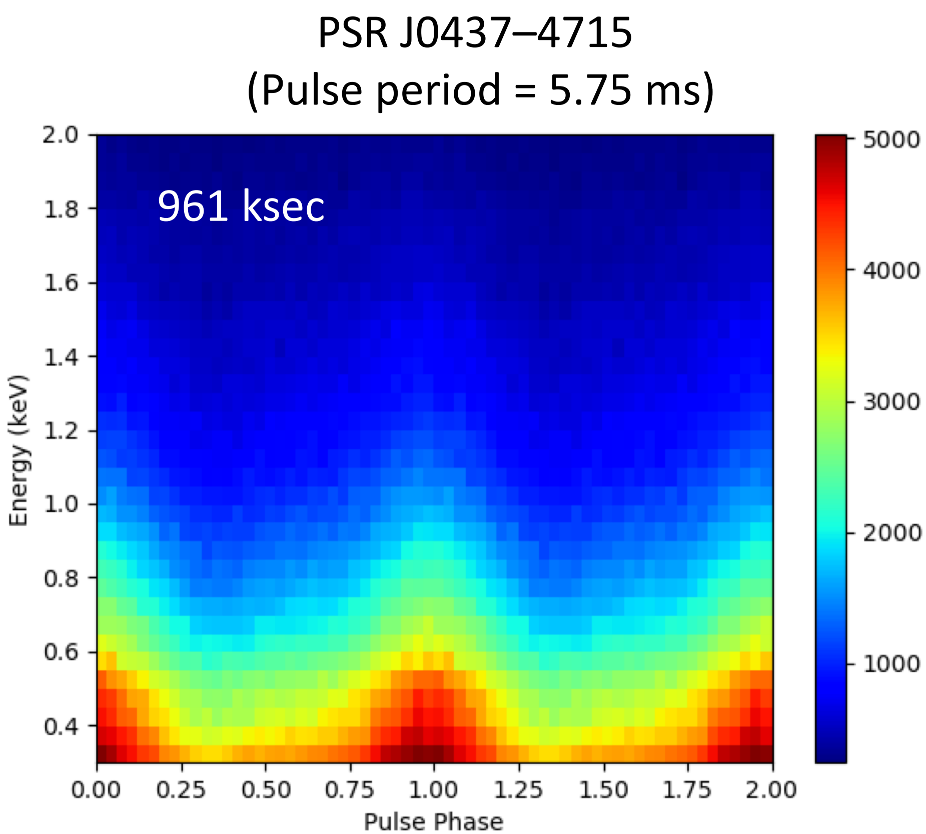
ISS Science Nugget, 8/03/18

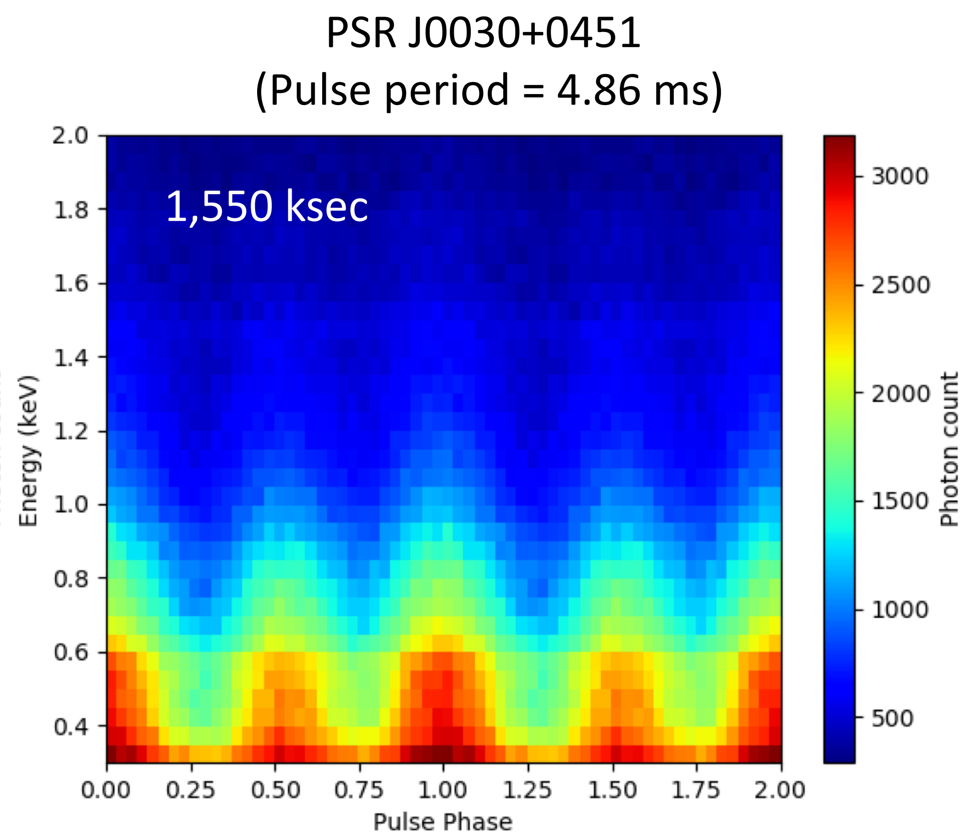
Neutron stars are the densest material objects known, consisting largely of an extreme, mysterious state of matter that can't be produced in any laboratory. NICER's principal scientific objective is to probe the physics of this dense matter by accurately measuring the radii and masses of a handful of specific neutron stars: those that are seen as pulsars with millisecond periods.

Glowing "X-ray hot" from their magnetic poles and rotating hundreds of times each second, these stars sweep their beams of radiation across NICER's sensitive X-ray Timing Instrument, which registers the detection times and energies of individual X-ray photons. Thanks to accurate time-stamping via a GPS receiver and fast detector electronics, these photons are accumulated over a million seconds (or more) of total exposure time for each object, across the mission's operational lifetime. Given the known spin rates of the pulsars, each photon is "folded" to its unique phase in the star's rotation, and the result — a phase-energy photon "map" (figure, next slide) — provides the most sensitive description to date of a pulsar hot-spot's variations in time and energy as seen by a distant observer as the star rotates. Depending on the observer's perspective on the spinning star (for example, whether viewing the star from a direction close to its spin pole or near its equator), and depending also on the degree of misalignment between the star's spin and magnetic poles, each pulsar presents itself differently: some show a single brightness peak with each rotation (e.g., PSR J0437–4715 at left), while others show two peaks (i.e., hot-spots from both magnetic poles are clearly distinguishable; PSR J0030+0451 at right).

These maps represent the key datasets that enable NICER's science goal. Because neutron stars are strongly gravitating objects, X-rays from the surface hot-spots are gravitationally lensed — the light paths bend around the star's horizon so that emission from the far side becomes visible to a distant observer. The degree to which this occurs depends sensitively on the star's mass and radius, and it is encoded in the photon-energy maps, or spectrally-resolved "lightcurves," of each pulsar. For the two (of four) target pulsars shown here, NICER has accumulated its planned total exposure, with the remaining two on track for completion by the end of the calendar year.

ISS Science Nugget, 8/03/18





ISS Science Nugget, 8/09/18

NICER's key science is very sensitive to the instrumental background level. NICER avoids collecting prime science data during passages through the South Atlantic Anomaly (SAA) which always has enhanced background. When the ISS is over the "Polar Horn" regions at the most northern and southern latitudes, the background is also high, but variable with space weather. This past summer, NICER interns examined using various space weather indices to filter archived data to select out the highest quality low background data. They found that the Geomagnetic Activity ("Kp") index provided by NOAA has an excellent correlation with Polar Horn background (see figure). Furthermore, NOAA predictions of "Kp" can be used to optimize NICER science planning 3 days ahead. This data is also being used to build a background spectral model that can be applied for all NICER observations.

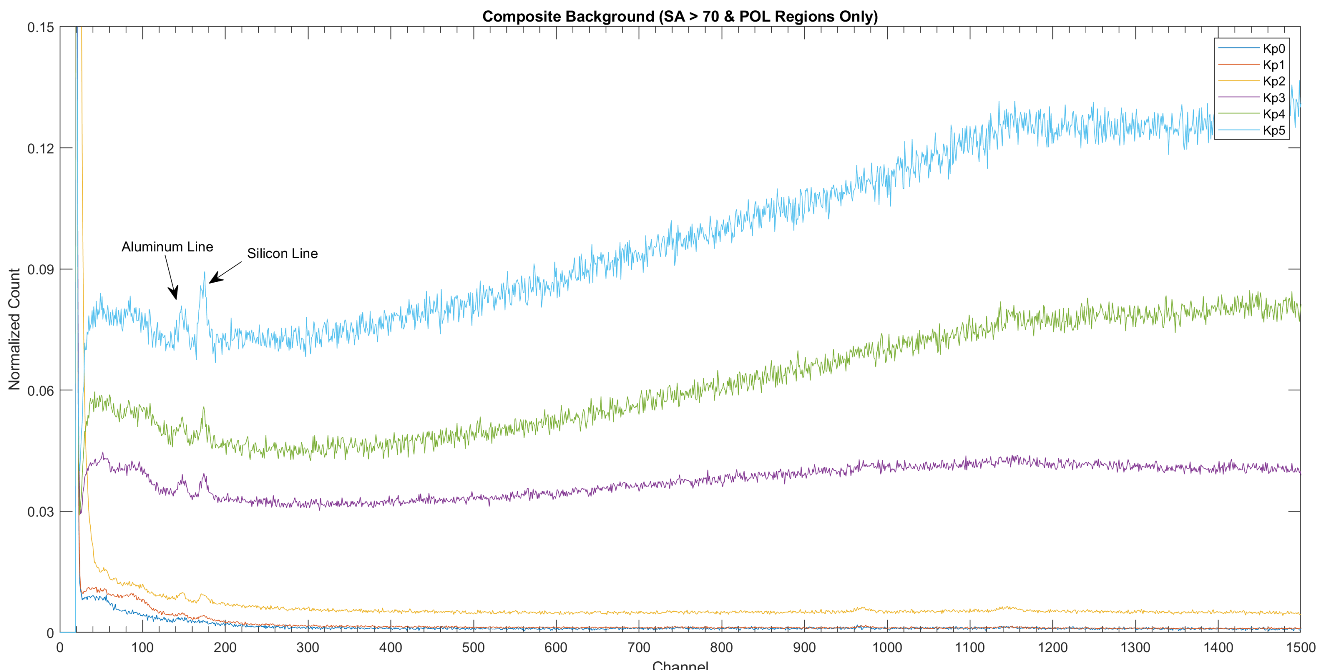


Figure Caption: The NICER X-ray background spectra (Counts/second vs Channel in units of 10 eV) collected in the Polar Horn Regions at various Space Weather "Kp" index values.

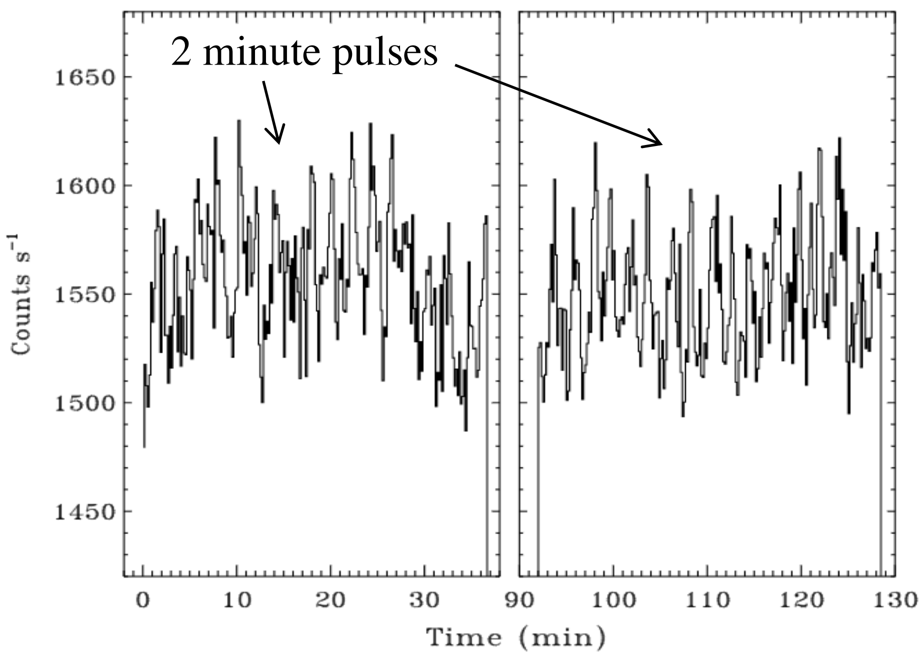
ISS Science Nugget, 8/16/18

GS 1826-238 is an accreting neutron star binary system known as a Low Mass X-ray Binary (LMXB). In these objects, a low-mass companion star loses matter to the neutron star. In about 100 such systems known, X-ray emission can be powered by thermonuclear fusion, the same energy source that fuels our Sun. The accreted matter, mostly hydrogen and helium with a mix of heavier elements, piles onto the neutron star. When enough matter has piled up, the pressure and density at the base of the accreted layer are sufficient to trigger fusion of hydrogen and helium into heavier elements. This releases an enormous amount of energy, resulting in a bright flash of X-rays known as a thermonuclear X-ray burst. How much energy? A typical burst can release energy equivalent to 100 15-Megaton H-bombs exploding over every square centimeter of surface area! NICER studies such explosions, including from GS 1826-238, because they light up the neutron star surface and its immediate surroundings, providing a unique and detailed view. This typical bursting behavior is called unstable burning, but less frequently these systems can display another type of burning. In this "marginally stable" regime the conditions allow the burning layer to cool rapidly enough that the whole surface doesn't explode all at once. Rather, a pulsating mode of burning occurs, with alternating periods of thermonuclear heating followed by cooling. Theoretical calculations indicate that the X-ray emission should pulse with a period of about 2 minutes. So far, this has only been seen in a handful of LMXBs, and never before in GS 1826-238. However, on at least five separate occasions NICER observed GS 1826-238 to be pulsing with a period close to 2 minutes, consistent with marginally stable burning. The accompanying slide describes some details of NICER's findings, and also shows an X-ray light curve from GS 1826-238 with these pulses. Further study with NICER will provide important new information about the neutron star in this system.

ISS Science Nugget, 8/16/18

NICER Discovers Oscillatory Nuclear Burning in GS 1826–238

- NICER see pulsations with a 2-minute period from the accreting neutron star GS 1826–238
- Pulsation is caused by oscillatory nuclear burning of H and He on the neutron star surface



- The X-ray spectrum is consistent with thermal emission from the neutron star surface, at temperatures of about 8 million Kelvin
- The brightness oscillation is consistent with temperature pulsing up and down by approximately 2%
- NICER data show that the presence and amplitude of pulses are sensitive to mass accretion rate
- Pulse properties depend on the star's surface gravity (M/R^2) and H abundance
- Details in NICER's 11^{th} peer-reviewed paper, published in The Astrophysical Journal, Strohmayer et al. (2018).