爱因斯坦探针
einstein probe

EP Performance Verification (PV) Targets Recommendation Form

Submission Due Date: 27th October 2023

NOTE: Please do not change or delete the words marked in blue.

1. TITLE

Catching type-I X-ray bursts from the NS LMXB 4U 1728-34 with FXT

2. ABSTRACT *(< 250 words)*

Type-I X-ray bursts are X-ray flashes typically lasting for tens of s which can be observed in neutron star low-mass X-ray binaries. These transient phenomena are powered by the piling-up of accreting matter onto the neutron star surface suddenly leading to thermonuclear explosions. Analysing bursts allows to gain unique insights on, e.g., the chemical composition of the donor star, the radius and, through the study of burst oscillations, even the spin of the neutron star. One of the most prolific bursters is the persistently active 4U 1728-34, which exhibits bursts every ~3 hours. Burst oscillations are often detected during the bursts from this source, making 4U 1728-34 a perfect PV target to test how well FXT will be able to detect coherent, periodic millisecond X-ray signals. In addition, the persistent emission of the source displays an array of intriguing spectral-timing features including quasi-periodic oscillations at both low and high frequencies and a Fe K spectral line at about 6.5 keV.
We therefore propose to observe 4U 1728-34 for 20 ks during the PV stage, to both catch one or more type-I X-ray bursts and perform a detailed spectral and timing analysis.

3. RECOMMENDERS' INFORMATION

Principal Recommender	
***Recommender' Name**	Alessio Marino
***Recommender' Email Address**	marino@ice.csic.es
***Recommender' Expertise**	AM has expertise in X-rays analysis of Galactic compact objects, with a special focus on accreting neutron stars in binaries;

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***Recommender' STP(s)**	STP4
Co-Recommenders	
***Recommenders' Names**	F. Coti Zelati, N. Rea
***Recommenders' Email Addresses**	cotizelati@ice.csic.es, rea@ice.csic.es
***Recommenders' Expertise**	Both are renowned experts in high energy astrophysics and observations of neutron stars both isolated and in binaries.
***Recommenders' STP(s)**	STP4

4. TARGET FORM

- **TARGET 1 *(mandatory)***

***Target Name**	4U 1728-34			
***Target Type**	NS XRB			
***Target Coordinates**	***RA:**	17 31 57.73	***DEC:**	-33 50 02.5
***Expected Flux in 0.3-10 keV**	1e-09 erg cm-2 s-1			

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***Primary Instrument**	FXT			
FXT Configuration	**FXT-A**	Timing Mode, medium filter	**FXT-B**	Timing Mode, medium filter
***Exposure Time**	20 ksec			
Suggest Joint Observation with Other X-ray Telescopes	No			
Other remarks				
*Note: * mandatory items*				

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5. SCIENTIFIC AND TECHNICAL JUSTIFICATION

- ### Scientific Motivations and Values

  Neutron Stars Low Mass X-ray Binaries (NS LMXBs) are binary systems where an old, low-magnetised NS accretes matter from a companion star typically less massive than 1 Msun. The accretion flow around NSs forms an optically thick, geometrically thin disc and a less dense, optically thin region usually dubbed *hot corona*. Observational signatures of these regions can be found in the X-ray spectra from NS LMXBs as disc blackbody at soft X-rays and a Comptonization spectrum at hard X-rays, respectively. In addition, a reflection Fe K fluorescence line at 6-7 keV can be sometimes detected. According to whether the blackbody emission from the disc (and/or the NS) or the Comptonization spectrum from the corona dominates the X-ray spectra, we distinguish between two main spectral states, dubbed respectively soft and hard states. Drastically different timing properties characterise these states as well, with systems in soft states showing significantly less X-ray power (and therefore less aperiodic variability) than in hard states. In addition, these states appear to be coded also by the appearance of discrete features in their power density X-ray spectra labelled **Quasi-Periodic Oscillations** (QPOs), at frequencies from a few to hundreds of Hz (i.e. the so-called kHz QPOs [1]). Some persistently active NS LMXBs go back and forth between the two states over time-scales of months, drawing loops in a Hardness Intensity Diagram [2]. In some sources, the accreted material reaches the NS surface, piles up onto it and undergoes thermonuclear explosions known as **type-I X-ray bursts** (bursts hereafter). Bursts typically last tens to hundreds of seconds and can be orders of magnitudes brighter than the persistent emission from the X-ray binary, sometimes even reaching the Eddington limit at the peak [3]. Coherent periodic oscillations at hundreds of Hz frequencies, labelled ***burst oscillations***, have been sometimes discovered during bursts [4]. Bursts oscillations are likely to arise from confined hot spots where the burst energy is liberated, whose emission is then modulated by the NS rotation. The period of these oscillations is indeed associated with the spin period of the NS.The occurrence of these X-ray flashes is typically unpredictable, but some sources are known to be prolific bursters, the NS LMXB **4U 1728-34** being one of the prime examples. The system is indeed a persistent LMXB and is one of the most frequent X-ray bursters (average recurrence time of about 3.7 hrs, sometimes even lower than 2 hrs [3]). Burst oscillations are routinely detected during these bursts [5] at the spin frequency of the NS, i.e. 363 Hz [S96]. In addition, the system is known to display a variety of QPOs at different frequencies, including kHz QPOs [6].

- ### EP Capabilities to be Verified

  4U 1728-34 is a perfect target to test several key FXT capabilities. Being both persistent and a rather prolific burster, observing 4U 1728-34 over a few hours provides high chances of catching a type-I X-ray burst, which does not only constitute an interesting phenomenon *per se*, but it also allows to demonstrate how FXT can (i) **detect millisecond coherent signals such as burst oscillations**, (ii) **extract spectra resolved over few seconds**, (iii) deal with bright fluxes. While accreting millisecond X-ray pulsars would be best suited for testing (i), it is impossible to foresee whether any of them will be active during EP PV stage, given that they are all transients [7]. We therefore argue that 4U 1728-34 might be our best (and maybe only chance) to test FXT capability of detecting millisecond coherent X-ray periodicities. In addition, observing persistent emission from 4U 1728-34 will also allow us to test both spectral and timing FXT performances.

- **Immediate Objectives**

  We propose to observe the NS LMXB 4U 1728-34 during the PV stage of EP to: (1) **observe one or more type-I X-ray bursts**, to perform time-resolved spectroscopy and detect burst oscillations; (2) Investigate its persistent emission and perform **spectral and timing analysis**, with a focus on detecting the Fe K line and low and high frequency QPOs.

- **Technical Justification**

  We request FXT to observe in timing mode (TM) with medium filter. Its optimal time resolution in this mode (44 mus) will allow us to detect oscillations during bursts at the expected spin frequency of about 2.7 ms [8] and to investigate other fast variability phenomena in the persistent emission, such as kHz QPOs. In addition, timing mode observations will minimise any pile-up related distortion during bursts. Considering an average recurrence burst time of about 13 ks, we request 20 ks of continuous observations to maximise our chances to catch at least one burst during our pointing.

  Persistent emission. As the source evolves relentlessly between hard and soft states, the expected spectral shape in the 0.3-10 keV energy range changes from a power-law shape with Gamma~1.7 to one with Gamma~3.0 and increasing contribution from an underlying blackbody component with temperature of ~1 keV [9]. The absorbed flux in the same energy range would lie in between (0.9-2.0)e-09 erg cm-2 s-1, considering a N_H value of 4.5e22 cm-2 [9]. The corresponding expected count-rate for FXT in timing mode with medium filter goes from 10 to 40 cts/s, with no expected pile-up impact. For an exposure of 20 ks, we then expect to be able to collect enough statistics to perform a detailed spectral and timing analysis of the source.

  Burst emission. During the burst, the spectrum becomes dominated by a blackbody component of ~3 keV temperature and the estimated flux is expected to rise up to values of about 4e-08 erg cm-2 s-1 [5], corresponding to 200 cts/s. Using the FXT simulator provided by the EP team, we expect a negligible pile-up fraction (0.1%) for FXT observations performed in timing mode with a medium filter. Despite the short duration of the bursts (tens of seconds), we then expect to collect enough photons to extract a few excellent quality time-resolved spectra and to detect burst oscillations.

  Visibility. The target will be visible by Einstein Probe for half of the expected time window of the PV stage, i.e., between March 15th 2024 and March 29th 2024.

- **References**

[1] Mendez, M. & Belloni, T., ASSL, Vol. 461, 2021, pp. 263-331; [2] Muñoz-Darias et al., 2014, MNRAS, 443, 4, 3270; [3] Galloway, D. K. et al., 2020, ApJSS, 249, 2, 32 ; [4] Watts, A. L., (2012) ARAA, 50, 609; [5] Botanci et al., 2023, ApJ in press, eprint arXiv:2309.10041; [6] Di Salvo, T. et al., ApJ, 546, 2, 1107-1120; [7] Di Salvo, T. & Sanna, A., 2020, arXiv:2010.09005; [8] Strohmayer, T. E. et al., Astrophysical Journal Letters v.469, p.L9; [9] Wang Y., MNRAS, 484, 3, p.3004-3016