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

Probing the spectral and timing capabilities of FXT through observations of bright magnetars

2. ABSTRACT *(< 250 words)*

Magnetars are neutron stars characterised by huge magnetic fields, often reaching strengths of up to 10 - 10^15 Gauss. These fields are thought to drive their emissions, leading to a variety of X-ray transient events: giant flares, short bursts, and prolonged outbursts. Observing magnetars in outburst is crucial to gain insights into emission mechanisms and potential triggers within the crust or magnetosphere. The WXT is expected to detect several transients, including magnetars in outburst. It is then crucial to test FXT's ability to promptly identify new magnetars among the newly detected transients. Typical key attributes of outbursting magnetars are: i) pulsed X-ray emission at periods of the order of seconds; ii) a spectrum well described by thermal and non-thermal components; iii) potential brief, intense bursts. We propose to evaluate FXT's proficiency in detecting and characterising these features in two magnetars, 1E 1547.0-5408 and 1RXS J170849.0-400910, which are currently found at an observed flux of >1E-11 erg/s/cm^2 in the FXT band. This proposal aims to optimise follow-up strategies for outbursting magnetars, enhancing the capacity to identify them efficiently already soon after the mission's onset. Moreover, we will test the WXT's capabilities in detecting pulsations at these relatively low flux levels.

3. RECOMMENDERS' INFORMATION

Principal Recommender	
***Recommender' Name**	Francesco Coti Zelati (ICE, CSIC)
***Recommender' Email Address**	cotizelati@ice.csic.es
***Recommender' Expertise**	An expert on observational studies of magnetars
***Recommender' STP(s)**	STP4
Co-Recommenders	

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***Recommenders' Names**	L. Lin, A. Marino, N. Rea
***Recommenders' Email Addresses**	llin@bnu.edu.cn , marino@ice.csic.es, rea@ice.csic.es
***Recommenders' Expertise**	All experts on observational studies of isolated neutron stars
***Recommenders' STP(s)**	STP4

4. TARGET FORM

- **TARGET 1**

***Target Name**	1E 1547.0-5408			
***Target Type**	Magnetar			
***Target Coordinates**	***RA:**	15:50:54.12	***DEC:**	-54:18:24.1
***Expected Flux in 0.3-10 keV**	1.e-11 erg/cm^2/s			
***Primary Instrument**	FXT			
FXT Configuration ***(mandatory if the primary instrument is FXT, optional if the primary instrument is WXT)***	**FXT-A**	*full frame/Partial-window/timing*; *thin* filter	**FXT-B**	*full frame/Partial-window/timing*; *thin* filter
***Exposure Time**	30 ksec (10 ks for each mode x 3 modes)			
Suggest Joint Observation with	Coordinated observation with NICER or Swift/XRT to crosscheck the result.			

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Other X-ray Telescopes	
Other remarks	(any other remarks)
*Note: * mandatory items*	

- **TARGET 2**

***Target Name**	1RXS J170849.0-400910			
***Target Type**	Magnetar			
***Target Coordinates**	***RA:**	17:08:46.87	***DEC:**	-40:08:52.44
***Expected Flux in 0.3-10 keV**	4e-11 erg/cm^2/s			
***Primary Instrument**	FXT			
FXT Configuration ***(mandatory if the primary instrument is FXT, optional if the primary instrument is WXT)***	**FXT-A**	*full frame/Partial-window/timing*; *thin* filter	**FXT-B**	*full frame/Partial-window/timing*; *thin* filter
***Exposure Time**	30 ksec (10 ks for each mode x 3 modes)			
Suggest Joint Observation with Other X-ray Telescopes	Coordinated observation with NICER or Swift/XRT to crosscheck the result.			
Other remarks	(any other remarks)			
*Note: * mandatory items*				

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5. SCIENTIFIC AND TECHNICAL JUSTIFICATION
(< 2 pages in total for this session, including figures, tables and references)

● Scientific Motivations and Values

Magnetars are neutron stars endowed with incredibly strong magnetic fields, reaching up to 10^{15} Gauss. This intense magnetic field is believed to be the driving force behind their emission. To date, we know of about 30 magnetars. They have been observed to exhibit a variety of high-energy transient events, such as giant flares, short X-ray bursts as well as prolonged outbursts where the X-ray luminosity increases by several orders of magnitude before returning to its quiescent state over a period ranging from months to years (e.g. Esposito et al. 2021). The largest amount of physical information about magnetars is gathered during outbursts. In particular, observing these events provides the best opportunity to deepen our understanding of magnetar emission mechanisms and test models regarding the possible crustal or magnetospheric trigger of their outbursts. The spectral and timing analysis of the data allow us to monitor changes in temperature, size, and location of the hot spot on the magnetar surface, measure the spin-down torques acting on the star, and assess changes in the emission pattern.

Among the numerous transients that will be detected by the WXT, we anticipate discovering new or previously known magnetars in outburst. Hence, it is crucial to test the capability of FXT to promptly identify any new transient as a magnetar by means of an adequate characterisation of its timing and spectral X-ray properties soon after detection (ideally, as soon as FXT repoints towards a new transient source detected by WXT).

The hallmark signs of magnetars during outburst include pulsed X-ray emission at periods in the range from a fraction of second to about 15 seconds, a spectrum well described by the superposition of both thermal and non-thermal components (typically a blackbody and a power-law) and possibly short, bright bursts. In this proposal, we aim to test the ability of FXT to detect and characterise these properties in two magnetars that are currently lingering at a flux >1E-11 erg/s/cm^2 i.e., slightly below (or comparable to) what is typically observed for magnetars in the early stages of their outbursts.

These observations will be crucial to set the best observing strategy for identifying magnetars in outburst right from the beginning of the Einstein-Probe mission, and coordinate follow-up studies of these magnetars (e.g., those aimed at searching for polarised X-ray emission and/or detecting radio pulses and bursts).

While FXT plays a pivotal role in this proposal, the WXT data will also be crucial. Some outbursts may be bright enough in X-rays so that the associated magnetar may be promptly identified through a detection of its spin period using only WXT data. We aim to explore this possibility via PV observations of the two above-mentioned magnetars.

The sample.

- 1E 1547.0-5408 has been extremely active in the last fourteen years. Since its discovery, it has experienced at least three outbursts (in 2007, 2008 and 2009) during which emitted several energetic short X-ray bursts. The 2009 outburst coincided with the most powerful outburst hitherto detected from this source. The long-term X-ray light curve following the 2009 event unveils an extremely slow outburst decay, with the source caught at a 0.3-10 keV observed flux of ~1e-11 erg/s/cm^2 over the past ~8 years (with the exception of a minor outburst in 2022). This is a factor of ~30 above quiescence, and suggests that this source has reached a new stable state, different from that in 2006 (Coti Zelati et al. 2021 and refs. therein).

- 1RXS 1708-4009 was identified as a magnetar with a spin period of 11 s about 25 years ago (Sugizaki et al. 1997, Israel et al. 1999). It stands out from the magnetar population due to 3 characteristics. 1) It is a bright persistent magnetar, with an observed flux of ~4E-11 erg/s/cm^2 (0.3-10 keV). Remarkably, this flux has been stable for over a decade (Scholz et al. 2014). This ensures that the source can be detected using both WXT and FXT, aiding in timing and spectral assessments. 2) Abrupt changes have been observed in the magnetar spin frequency: over five glitches or potential glitches have been reported throughout a decade of monitoring (Scholz et al. 2014, Dib & Kaspi 2014). 3) An intriguing strong X-ray polarization signal was recently detected using IXPE (Zane et al. 2023).

• EP Capabilities to be Verified

The two selected targets will test FXT's timing and spectral capabilities and WXT's timing capabilities especially at flux levels approaching the sensitivity threshold. Both targets can be observed without causing pile-up in any of the three distinct observation modes of FXT. We thus propose to observe both targets using the FF/PW/TM modes to validate consistency in the results across different observing modes and guide the selection of the most suitable mode for subsequent EP follow-up observations of all magnetars that will be found at fluxes of a few 1E-11 erg/s/cm^2.

• Immediate Objectives

We aim to detect and characterize X-ray pulsations as well as to characterize the X-ray spectrum of the magnetars 1E 1547.0-5408 and 1RXS 1708-4009. We will compare the results obtained using all different FXT's observation modes to test the consistency of the results and establish the most optimal mode for future Einstein-Probe follow-up observations of magnetars at similar flux levels. We will also search for pulsations in WXT data.

• Technical Justification (e.g. target visibility during the PV phase)

1E 1547.0-5408 is visible from 2024 March 4th to March 30th. Its X-ray flux is stable at ~1E-11 erg/s/cm^2 over the 0.3-10 keV range.

1RXS 1708-4009 is visible from 2024 March 11th to March 29th. Its X-ray flux is stable at ~4E-11 erg/s/cm^2 over the 0.3-10 keV range.

• References

Coti Zelati et al. 2020, A&A, 633, 31; Dib, R. and Kaspi, V. M., et al. 2014, ApJ, 784, 37; Esposito et al. 2021, ASSL, 461, 97; Israel, G. L., Covino, S., Stella, L., et al. 1999, ApJL, 518, L107; Sugizaki, M., Nagase, F., Torii, K. I., et al. 1997, PASJ, 49, L25; Scholz, P., Archibald, R. F., Kaspi, V. M., et al. 2014, ApJ, 783, 99; Zane et al. 2023, ApJL, 944, 27

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