EP Performance Verification (PV) Targets Recommendation Form

Submission Due Date: 15th October 2023

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

1. TITLE

Using nearby X-ray isolated neutron stars to verify the timing and spectral capabilities of FXT

2. ABSTRACT *(< 250 words)*

The Magnificent Seven are seven nearby radio-quiet X-ray isolated neutron stars (XINSs) with pulsations periods of a few seconds. They are relatively old isolated neutron stars with clean thermal spectrum. X-ray observations, combined with parallax distance measurements, allow us to obtain both time-averaged and phase-resolved spectrum and subsequently put constraints on their key physical properties, including the neutron star EoS as well as the magnetic field structure. We propose to observe four of the seven objects (due to visibility limit) in the performance verification phase of the Einstein Probe mission. With these observations, we will be able to verify the both the timing and spectral capabilities of EP/FXT, constrain their physical properties, and study the long-term spectral variability of these objects.

3. RECOMMENDERS' INFORMATION

Principal Recommender	
***Recommender' Name**	Wenda Zhang
***Recommender' Email Address**	wdzhang@nao.cas.cn
***Recommender' Expertise**	XRB, AGN, TDE
***Recommender' STP(s)**	STP1, STP4, STP6
Co-Recommenders	
***Recommenders' Names**	
***Recommenders' Email Addresses**	

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***Recommenders' Expertise**	
***Recommenders' STP(s)**	

4. TARGET FORM

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

***Target Name**	RX J0720.4−3125			
***Target Type**	neutron star			
***Target Coordinates**	***RA:**	07:20:24.961	***DEC:**	-31:25:50.21
***Expected Flux in 0.3-10 keV**	5.0e-12 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**	partial-window thin filter	**FXT-B**	partial-window thin filter
***Exposure Time**	3.6 ks			
Suggest Joint Observation with Other X-ray Telescopes				
Other remarks				
*Note: * mandatory items*				

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- **TARGET 2 and more…**

<table>
<tr><td>*Target Name</td><td colspan="4">RX J0806.4−4123</td></tr>
<tr><td>*Target Type</td><td colspan="4">neutron star</td></tr>
<tr><td>*Target Coordinates</td><td>*RA:</td><td>08:06:23.0</td><td>*DEC:</td><td>-41:22:33</td></tr>
<tr><td>*Expected Flux in 0.3-10 keV</td><td colspan="4">1.2e-12 erg/cm^2/s</td></tr>
<tr><td>*Primary Instrument</td><td colspan="4">FXT</td></tr>
<tr><td>FXT Configuration
(mandatory if the primary instrument is FXT, optional if the primary instrument is WXT)</td><td>FXT-A</td><td>partial-window thin filter</td><td>FXT-B</td><td>partial-window thin filter</td></tr>
<tr><td>*Exposure Time</td><td colspan="4">3.6 ks</td></tr>
<tr><td>Suggest Joint Observation with Other X-ray Telescopes</td><td colspan="4"></td></tr>
<tr><td>Other remarks</td><td colspan="4"></td></tr>
<tr><td colspan="5">Note: * mandatory items</td></tr>
</table>

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<table>
<tr><td>*Target Name</td><td colspan="4">RX J1308.6+2127</td></tr>
<tr><td>*Target Type</td><td colspan="4">neutron star</td></tr>
<tr><td>*Target Coordinates</td><td>*RA:</td><td>13:08:48.7</td><td>*DEC:</td><td>+21:27:08</td></tr>
<tr><td>*Expected Flux in 0.3-10 keV</td><td colspan="4">5.0e-12 erg/cm^2/s</td></tr>
<tr><td>*Primary Instrument</td><td colspan="4">FXT</td></tr>
<tr><td>FXT Configuration
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<tr><td colspan="5">Note: * mandatory items</td></tr>
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***Target Name**	RX J1605.3+3249			
***Target Type**	neutron star			
***Target Coordinates**	***RA:**	16:05:18.9	***DEC:**	+32:49:07
***Expected Flux in 0.3-10 keV**	6.0e-12 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**	partial-window thin filter	**FXT-B**	partial-window thin filter
***Exposure Time**	3.6 ks			
Suggest Joint Observation with Other X-ray Telescopes				
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**

Radio-quiet X-ray isolated neutron stars (XINSs) are relatively old isolated neutron stars. Among them, seven nearby XINSs, dubbed "the Magnificent Seven", are of particular interests (e.g. Haberl 2007; Turolla 2009). They are not associated with supernova remnants. Their energy spectra are clean thermal spectrum with temperature of ~50-100 eV. At distances of a few hundreds of pc, they have reliable parallax distance measurements. For thermal spectrum, if the distance is known, one can directly measure the neutron star radius, and subsequently constrain the neutron star EoS.

Pulsations of a few seconds have been detected in six out of seven of them except for RX J1605. With long-term evolution of the pulsation period, one can also constrain the age of the neutron star. Combined with the temperature constrained by spectral fitting, this allows us to confront neutron star cooling models (e.g. Viganò et al. 2013; Potekhin et al. 2020), and probe a few key properties of the neutron stars, including e.g. the EoS and the neutron mass.

Interestingly, while usually we observe rather stable spectral properties of these objects over time, in RX J0720 spectral variability over a few year time-scale has been observed (Haberl et al. 2006; Hohle et al. 2010). It is under debate what causes the spectral variability, either due to precession of neutron star (e.g. Haberl et al. 2006) where we expect periodic variation of the spectral parameters, or a sudden heating that is accompanied with a glitch (e.g. Hohle et al. 2012) where we expect that the temperature gradually drops to the persistent level.

For objects with pulsations detected, one can also perform pulsation-phase-resolved spectroscopy. This would enable us to study the inhomogeneous temperature distribution on the neutron star surface, and take a step further to infer the magnetic field structure (e.g. Zane & Turolla 2006).

We propose to observe Magnificent Seven during the performance verification phase of the Einstein Probe mission. Limited by the visibility of EP, four of them can be reached during the PV phase. With these observations, we will be able to verify the both the spectral and timing capability of EP/FXT. We will be able to measure the spectral parameters of RX J0720 to discriminate different scenarios for its spectral variability, and also search for possible spectral variability in other objects. We will also be able to obtain both phase-averaged and phase-resolved spectra to put constraints on a few important physical properties of the neutron stars, including their EoS and magnetic field structure.

- **EP Capabilities to be Verified**

1	Verify the timing capability of FXT
2	Verify the spectral capability of FXT

- **Immediate Objectives**

1	Detections of pulsations
2	Phase-averaged and phase-resolved energy spectrum
3	Technical verifications

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

Out of the four objects we selected, three are visible by EP over the entire month in March. The last one, RX J1308.6+2127, is visible in most of the time in March except from Mar. 22nd to 26th.

For all objects we choose to use the thin filter and let FXT to be operated in the partial window (PW) mode. The fine time resolution of 2 ms of the PW mode makes pulsation detection and phase-resolved spectroscopy possible. We collect the spectral parameters of the proposed objects and utilize the FXT Filter & Window Mode Evaluation tool to evaluate the pile-up fraction, and find the pile-up to be negligible.

- **References**

1. Haberl F. 2006, A&A, 451, L17
2. Haberl F., 2007, Ap&SS, 308, 181
3. Hohle M. M. et al. 2012, MNRAS, 423, 1194
4. Potekhin A. Y. et al. 2020, MNRAS, 496, 5052
5. Turolla R., 2009, in Becker W., ed., ASP Conf. Ser. Vol. 357. Astrophysics and Space Science Library. Isolated Neutron Stars: The Challenge of Simplicity. Astron. Soc. Pac., San Francisco, p. 141
6. Viganò D. et al. 2013, MNRAS, 434, 123
7. Zane S. & Turolla R. 2006, MNRAS, 366, 727