爱因斯坦探针
einstein probe

EP Performance Verification (PV) Targets Recommendation Form

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

1. TITLE

Using NS-LMXB 4U 1636-53 to verify the spectral and timing capabilities of FXT

2. ABSTRACT *(< 250 words)*

(summarize the target properties, the EP capabilities to be verified, and justify why the proposed observations and targets should be considered for the PV phase)

4U 1636−53 is a well−studied neutron−star (NS) low−mass X−ray binary (LMXB). It is a persistent Atoll source with a clear long−term oscillation with a period of ~30 – 40 days. This source has exhibited numerous spectral and timing observational phenomena. (1) Strong variability from millihertz to kilohertz in the X−ray light curves of these systems, the socalled milihertz quasi−periodic oscillations (mHz QPOs) and kilohertz (kHz) QPOs, pulsations during X−ray bursts (~581 Hz), also known as burst oscillations. (2) Strong reflection component has been reported. (3) Single and multiple thermonuclear (type−I) X−ray bursts were discovered in different accretion states. All above spectral and timing observational phenomena are primarily evident in the 0.5−10 keV energy band. This make 4U 1636−53 the best target should be considered for the PV phase.

3. RECOMMENDERS' INFORMATION

Principal Recommender	
***Recommender' Name**	Guobao Zhang
***Recommender' Email Address**	zhangguobao@ynao.ac.cn
***Recommender' Expertise**	Guobao Zhang's research is studying the high-energy emission from the compact object, evolution of black holes and neutron stars, and thermonuclear X-ray bursts. He has experience in analysing data from RXTE, Chandra XMM Newton, NICER, NuSTAR, and HXMT.
***Recommender' STP(s)**	STP4
Co-Recommenders	
***Recommenders' Names**	Long Ji, Yupeng Chen, Zhaosheng Li
***Recommenders' Email Addresses**	jilong@mail.sysu.edu.cn; chenyp@ihep.ac.cn; lizhaosheng@xtu.edu.cn

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

***Recommenders' Expertise**	Long Ji has extensive experience with X-ray data analysis. His researches focus on studies of stellar-mass compact objects (i.e., black holes and neutron stars) in low and high mass X-ray binaries. He is mainly interested in observations, in particular related to accretion and radiation processes under strong gravitational and magnetic fields. Yu-Peng Chen is a member of the core science team of Insight-HXMT, specializing in X-ray binaries and possessing extensive expertise in X-ray bursts. He is highly experienced in data analysis using various X-ray telescopes such as Insight-HXMT, NICER, and NuSTAR. He has a remarkable publication record of approximately 100 papers in the field of X-ray binaries. Zhaosheng Li is an expert of the observational study of XRBs.
***Recommenders' STP(s)**	STP4

4. TARGET FORM

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

***Target Name**	4U 1636-53			
***Target Type**	Neutron-star low-mass X-ray Binary			
***Target Coordinates**	***RA:**	16:40:55.5	***DEC:**	-53:45:05
***Expected Flux in 0.3-10 keV**	1.5e-9 -- 5.0e-9 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**	(*timing* mode) (*medium* filter)	**FXT-B**	(*partial-window* mode) (*thin* filter)

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

***Exposure Time**	30 ksec
Suggest Joint Observation with Other X-ray Telescopes	Joint observation with Insight-HXMT
Other remarks	(any other remarks)
*Note: * mandatory items*	

- **TARGET 2 and more…**
  (optional, if there are more than one target in this recommendation, copy the entire target form above to the empty space below; note that this is only for the case that one observing proposal includes multiple targets; for targets of a different proposal with distinct technical and scientific goals, please submit them in separate proposals.)

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

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

- **Scientific Motivations and Values**
  (briefly describe the properties of targets, scientific motivations and values, and explain why the proposed target and observation should be considered for a PV program rather than a regular observing program)

One of the best-studied sources of NS-LMXBs is the 4U 1636−53. Also known as V801 Ara, 4U 1636−53 was discovered with OSO-8 (Swank et al. 1976) and was subsequently studied in great detail using observations with SAS-3, EXOSAT and RXTE (Lewin et al. 1993; Zhang et al. 2013). 4U 1636-53 is a persistent Atoll source with a clear long-term oscillation with a period of ~30–40 days, and shows a clear "C" pattern on the color-color diagram(Belloni et al. 2007). This source has exhibited numerous spectral and timing observational phenomena. (1) Strong variability from millihertz to kilohertz in the X-ray light curves of this system, the socalled milihertz quasi-periodic oscillations (mHz QPOs) and kilohertz (kHz) QPOs, pulsations during X-ray bursts (~581 Hz), also known as burst oscillations. (2) Strong reflection component has been reported. (3) Single and multiple thermonuclear (type-I) X-ray bursts were discovered in different accretion states.

Scientific motivations and values

Probing Neutron Star Properties: Burst oscillations are observed during thermonuclear bursts on the surface of neutron stars. By analyzing their properties, such as frequencies and amplitudes, researchers can derive crucial information about the neutron star's mass and radius, which is important for understanding the equation of state of ultra-dense matter. Burst oscillations provide insights into the ignition and propagation of thermonuclear bursts on the neutron star's surface. This helps in understanding the nuclear reactions occurring in the extreme conditions of X-ray bursts. The properties of millihertz QPOs, such as their frequencies and harmonic content, can provide insights into the dynamics of matter in the neutron star's vicinity and its influence on the surrounding accretion disk. This contributes to our understanding of neutron star mass and radius as well.

Strong Gravity Tests: kHz QPOs offer a unique opportunity to probe strong gravitational fields close to neutron stars, enabling tests of General Relativity and alternative theories of gravity in this extreme regime. Iron lines originate in the accretion disks around neutron stars. The broadening and distortion of these lines provide information about the strong gravitational fields near the neutron star. Studying these lines can test General Relativity and alternative theories of gravity.

Why 4U 1636-53 should be considered for a PV program?

(1) The above spectral and timing observational phenomena are primarily evident in the 0.5-10 keV energy band, and can be observed by EP capabilities, especially the FXT.

(2) 4U 1636-53 is a bright and persistent (non-transient) source. The above observational phenomena are well studied, and then can be used to verify the EP capabilities with the new observations during PV phase.

(3) 4U 1636-53 is one of the NS-LMXBs with the highest burst occurrence frequency. We are highly likely to detect type-I bursts within the constraints of our observing time.

(4) We have HXMT proposal that was approved for the next year around March, and the EP PV phase time is well covered by our approved observing time. We will be able to have a broad band observation (0.3-200 keV) on 4U 1636-53.

- **EP Capabilities to be Verified**
  (briefly describe the capabilities that can be verified by the recommended targets and observations. For example: this target can demonstrate WXT's imaging capability of large field-of-view and sensitivity)

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

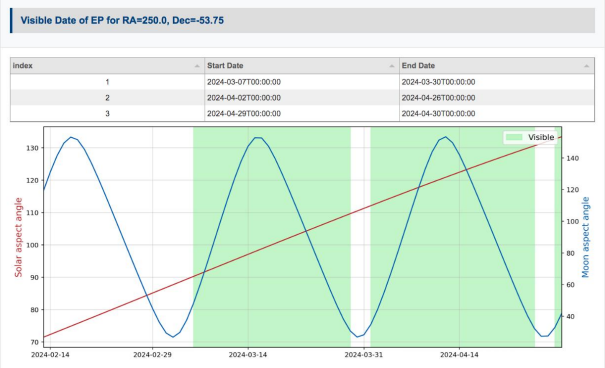
4U 1636-53 can demonstrate FXT's spectral and timing capability of fast timing and high spectral resolution in different modes. Since the peak flux of type-I burst is very high, it can also validate WXT's ability to detect transient signals.

- **Immediate Objectives**
  (listed the main objectives of the recommended targets and observations)

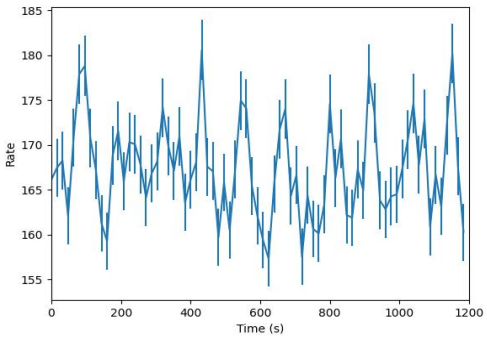
Since the source location is will known, we plan to use timing mode to conduct continuous uninterrupted observations of this source for 30ks. 4U 1636-53 is one of the NS-LMXBs with the highest burst occurrence frequency. Based on past observational data (Galloway et al. 2018), we are expected to capture 2-5 Type I X-ray bursts during 30 ksec long observation.

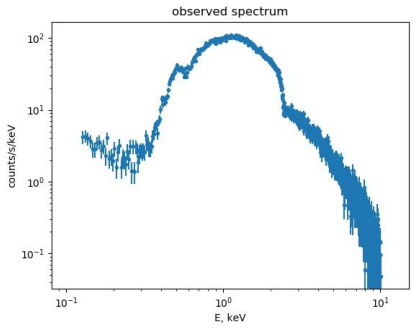
- **Technical Justification (e.g. target visibility during the PV phase)**
  (briefly justify the technical feasibility of the recommended target and observation, such as the target visibility during the PV phase, brightness, variability, etc.)

During the PV phase in March 2024, 4U 1636-53 will be visible



During the persistent state (~2.5e-9 erg/cm^2/s), the simulated light curve (1200 s) and spectrum are shown below. We will be able to have a very good quality data in the timing mode. Based on the previous XMM-Newton observations, the mHz QPO is clearly presented in the simulated light curve.





- **References**

*Swank et al. 1976, IAU, Circ, 3000, 1 *Belloni et al. 2007, MNRAS, 379, 247 *Lewin et al. 1993, SSRv, 62, 223 * Galloway et al. 2018 ApjL, 857, 24 * Zhang et, al. 2013, MNRAS, 413, 1913

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