爱因斯坦探针
einstein probe

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

Observation of the persistent ultra-compact binary 4U 0614+091 to verify the energy calibration and spectral resolution of FXT

2. ABSTRACT *(< 250 words)*

4U 0614+091 is an ultra-compact X-ray binary that consists of a neutron star accreting matter from a white dwarf in a tight orbit. We request a 15 ks EP FXT observation in order to verify the energy resolution and the absolute energy scale of FXT since the spectrum of the source is rich in emission lines of O and Ne and also hosts relativistic ally reflection features. Moreover, since it is an X-ray bright and persistent object, the spectral features can be detected with high signal to noise allowing to constrain the energy and equivalent width simultaneously with high precision. A near simultaneous XMM observation can further help in energy calibration. Additionally, if a type 1 X-ray burst is detected, this can help to verify the deadtime and associated high count rate capabilities of FXT.

3. RECOMMENDERS' INFORMATION

Principal Recommender	
***Recommender' Name**	Chandreyee Maitra
***Recommender' Email Address**	cmaitra@mpe.mpg.de
***Recommender' Expertise**	Chandreyee Maitra is an expert of the observational study of XRBs and pulsars

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***Recommender' STP(s)**	STP4
Co-Recommenders	
***Recommenders' Names**	Susanne Freidrich
***Recommenders' Email Addresses**	sfriedr@mpe.mpg.de
***Recommenders' Expertise**	Susanne Friedrich is an expert of the observational study of compact binaries and white dwarfs
***Recommenders' STP(s)**	STP4

4. TARGET FORM

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

***Target Name**				
***Target Type**	4U 0614+091			
***Target Coordinates**	***RA:**	06:17:07.3	***DEC:**	+09:08:13
***Expected Flux in 0.3-10 keV**	1.e-9 erg/cm^2/s			
***Primary Instrument**	FXT			
FXT Configuration	**FXT-A**	Full-frame	**FXT-B**	*Full-frame*

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(mandatory if the primary instrument is FXT, optional if the primary instrument is WXT)		*medium* filter		*medium* filter
***Exposure Time**	15 ksec			
Suggest Joint Observation with Other X-ray Telescopes	XMM-Newton			
Other remarks	A 15 ks XMM-Newton observation if scheduled quasi-simultaneously will be favorable but not essential			
*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.)

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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**

The object of our study is the ultra-compact X-ray binary (UCXB) 4U 0614+091 consisting of a neutron star that accretes gas from a white dwarf. The source is placed close to the Galactic plane at a distance of 3.2 kpc (Kuulkers et al. 2010) towards the Galactic anticenter. The source has a very short orbital period of ~ 50 min (Shahbaz et al. 2008). The light curve of this object does not show signs of eclipses or dips, which indicates the upper limit of the inclination of the system to be around 70 degree. The source experiences type I X-ray bursts (Swank et al. 1978; Brandt et al. 1992) and is classified as an atoll source (Mendez et al. 1997). The source however displays persistent flux which can predicted and is therefore suitable for CALPV phase observation (Ludlam et al. 2019). Mendez et al (1997) also detected kHz QPOs.
An interesting aspect of the source is that X-ray photons emitted from a neutron star can be reflected by the accretion disc, leading to an X-ray emission line spectrum and free-free continuum. Analysis of low and high-resolution spectra of 4U 0614+091 obtained by the *XMM-Newton* satellite revealed well resolved absorption edges (Ne K edge, Fe L edge and O K edge) and a prominent O VIII Lyman alpha emission feature caused by reflection (Madej et al. 2010). This makes it an ideal target to verify the spectroscopic capabilities of FXT with high S/N (since it is an X-ray bright target).
In addition if a type 1 X-ray burst is detected during the observation we can test the deadtime and high count rate capability of the instrument during these short intervals (lasting few seconds to few hundreds of seconds). Severe pile-up (> 10%) can be avoided in this case by excising the core of the PSF.

- **EP Capabilities to be Verified**

1. Spectral resolution of FXT
2. Energy scale of FXT
3. Deadtime, pile-up limits of FXT if X-ray burst is detected during the observation

- **Immediate Objectives**

(listed are the main objectives of the recommended targets and observations)

1. Extract spectrum from the source, verify flux calibration (favourable in case of near simultaneous XMM Newton), verify energy resolution and energy scale
2. Extract light curve, power spectrum, look for type 1 X-ray bursts, QPOs.
3. Verify the high count rate capability of FXT in case X-ray burst is detected.

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

Assuming a spectral shape from a previous XMM Newton observation (Madej et al. 2010) and an observed flux of 1e-9 erg/cm2/s we predict an average FXT count rate

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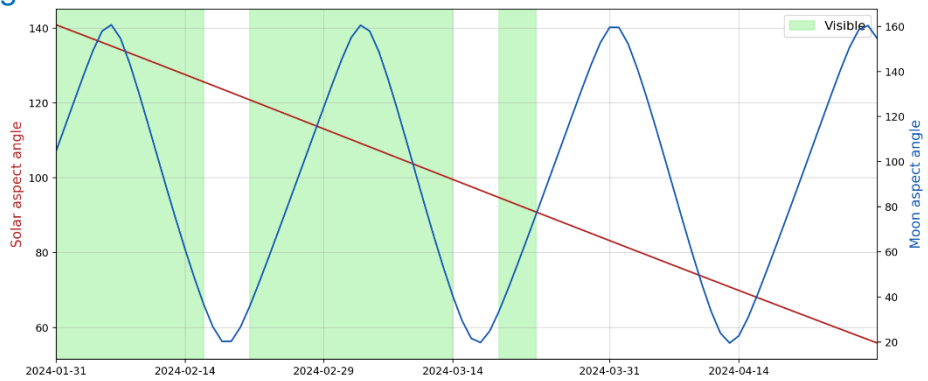
of 20.8 c/s which is <7% of the pile-up limit in full-frame mode and medium filter. No optical loading is expected as the optical counterpart is faint (> 18 mag in V band) and there are no other bright sources in the field of view.
A 15 ks observation is sufficient to achieve a very high signal to noise ratio comparable to existing XMM observations and to achieve all the goals of the PV target. In case of significant pile-up during a possible type I X-ray burst, the core of the PSF can be excised, this will still allow us to test the high count rate capability limit for FXT.
In the figure below, the target visibility periods during the PV phase are shown in green. Between 2024-01-31 and 2024-03-31 it can be observed almost constantly.



- **References**

Brandt et al. 1992, A&A, 262, L15, Detection of a type-I X-ray burst from 4U 0614+09

Kuulkers et al. 2010, A&A, 514, 65, What ignites on the neutron star of 4U 0614+091?

Ludlam et al. 2019, ApJ, 873, 99L, NuSTAR Observations of the Accreting Atolls GX 3+1, 4U 1702-429, 4U 0614+091, and 4U 1746-371

Madej et al. 2010, MNRAS, 407L, 11M, A relativistically broadened OVIII Ly{\ensuremath{\alpha}} line in the ultracompact X-ray binary 4U 0614+091

Mendez et al. 1997, ApJ, 485, 37L, Kilohertz Quasi-periodic Oscillation and Atoll Source States in 4U 0614+09

Shahbaz et al. 2008, PASP, 120, 848, Time-Resolved Optical Photometry of the Ultracompact Binary 4U 0614+091

Swank et al. 1978, MNRAS, 182, 349, The case for a burst from 3U 0614+09