爱因斯坦探针
einstein probe

EP Performance Verification (PV) Targets Recommendation Form

Submission Due Date: 15th October 2023

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1. TITLE

Using supernova semnant G156.2+5.7 to verify FXT's ability to observe diffuse emission

2. ABSTRACT *(< 250 words)*

Sedov-Taylor solution is the widely used self-similar solution describing the evolution of a mid-aged supernova remnant (SNR) in an isotropic ambient medium. However, there is a lack of a real remnant as a template to test this solution. With a round morphology and collisionless shocks, the mid-aged SNR G156.2+5.7 is hopeful to be a such template. With a large size (~1.8°) and luminous flux, SNR G156.2+5.7 is an ideal target to be observed by EP-FXT with a large field of view. The observation will not only give the first complete view of this SNR from the center to the boundary but also verify FXT's imaging ability by comparing it with existing ROSAT and XMM-Newton observations. The O, Ne, Mg, Si, and S lines from the remnant can also be used to calibrate the energy response of almost the whole field of view. Therefore, we propose a 36 ks EP-FXT observation on the northwest of SNR G156.2+5.7, aiming to study the Sedov phase of SNRs and charge exchange features. We will establish analysis processes of extended sources using this observation, and the analysis method will be applied to future studies of large SNRs, pulsar wind nebulae, and superbubbles.

3. RECOMMENDERS' INFORMATION

Principal Recommender	
***Recommender' Name**	Fangjun Lu
***Recommender' Email Address**	lufj@ihep.ac.cn
***Recommender' Expertise**	Fangjun Lu is an expert of high-energy astrophysics and has extensive experience in X-ray study of supernova remnants.
***Recommender' STP(s)**	STP5
Co-Recommenders	
***Recommenders' Names**	Ping Zhou

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***Recommenders' Email Addresses**	pingzhou@nju.edu.cn
***Recommenders' Expertise**	Ping Zhou is an expert of supernova remnants and isolated neutron stars.
***Recommenders' STP(s)**	STP5

4. TARGET FORM

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

***Target Name**	SNR G156.2+5.7 NW			
***Target Type**	supernova remnant			
***Target Coordinates**	***RA:**	04:59:00.00	***DEC:**	+52:20:00.0
***Expected Flux in 0.3-10 keV**	5e-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, Thin filter	**FXT-B**	Full-Frame, Thin filter
***Exposure Time**	36 ksec			
Suggest Joint Observation with Other X-ray Telescopes	N/A			

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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.)

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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**

Sedov-Taylor solution is the most widely-used self-similar solution to describe the evolution of a mid-aged supernova remnant (SNR) before its radiation cooling matters. By applying the solution, we can estimate crucial evolution and explosion properties including the SNR age and explosion energy. However, there is a lack of a "template" remnant to systematically verify the solution. It is a tough task to select such a sample as the Sedov-Taylor model requires the SNR to evolve adiabatically in a uniform ambient medium. Most mid-aged remnants are likely to interact with an inhomogeneous medium, and some leave the adiabatic phase due to radiative energy losses.

SNR G156.2+5.7 was discovered by ROSAT (Pfeffermann et al. 1991) as the first SNR discovered from the X-ray band. Located at the high Galactic latitude, the round morphology, and non-radiative optical filaments of the SNR (Gerardy & Fesen 2007) suggest a uniform ambient and negligible radiation cooling, in favor of a Sedov-Taylor phase. Moreover, as one of the largest and brightest supernova remnants, it allows a spatially resolved spectroscopy to map the plasma properties including temperature, density, and ionization timescale (see Figure 1). The verification of the Sedov-Taylor solution can deepen our knowledge of SNR evolution. The proposed observation allows us to apply spatially resolved spectroscopy on this SNR for the first time. We will use the observation to establish a pipeline/method for analyzing extended X-ray emission observed by EP-FXT. A similar analysis method can be applied to future studies of large SNRs, pulsar wind nebulae, and superbubbles.

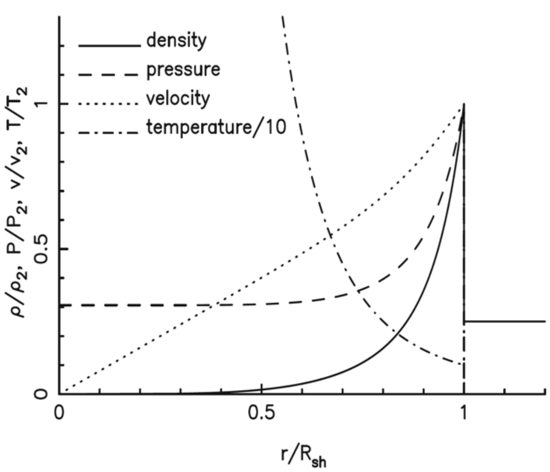

Figure 2: Radial profiles of density, pressure, velocity, and temperature expected by the Sedov-Taylor solution (Vink 2020). R_{sh} is the radius of the remnant.

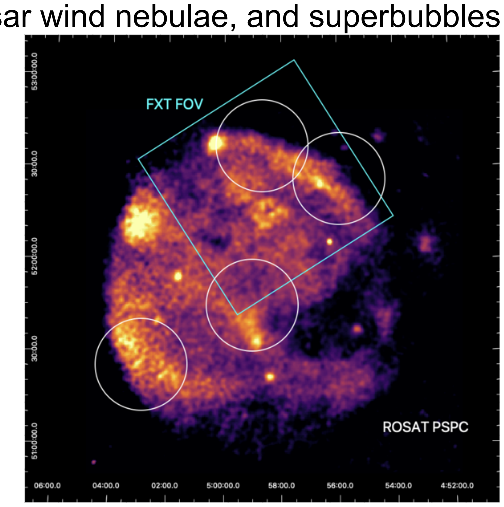

Figure 2: ROSAT PSPC mosaic of SNR G156.2+5.7. White circles and the cyan square are the field of view of current XMM-Newton observations and proposed FXT observations, respectively.

- **EP Capabilities to be Verified**

The large size and the high luminosity of SNR G156.2+5.7 make it an ideal pathfinder for future observations and studies on diffuse emissions. Here, we plan to use the proposed observation to verify FXT's performance in the following 2 aspects:

1) *Imaging ability of diffuse emission*

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Ground calibrations calculate the vignetting map with a point-like sources array, which is unavailable on orbit, let alone a flat for vignetting calibration. With a large size, SNR G156.2+5.7 can play a role like a flat field in optical observations. We will make flux maps from the proposed observations along with archival ROSAT and XMM-Newton data. We will calculate flux ratio maps from different telescopes and further calibrate the vignetting effects based on the ground calibration.

2) Off-axis energy calibration

Energy is usually calibrated through bright SNRs like N132D with rich emission lines. However, limited by the small angular size of these sources, the calibration only applies near the optical axis. Off-axis observations work but are time-consuming and cannot cover the whole field of view. G156.2+5.7 is a large SNR with O, Ne, Mg, Si, and S lines (Uchida et al. 2012), allowing us to extract spectra from any point in the remnant to compare with the calibrated optical axis.

- **Immediate Objectives**

We herein request EP-FXT observation toward the northwest of SNR G156.2+5.7, which was fully covered by ROSAT (lacks a good spectral capability) and partially observed with XMM-Newton. We will use an adaptive binning method (Cappellari & Copin 2003) to slice the remnant into several grids. For each bin, the temperature, density, and ionization timescale, will be obtained and compared to the expectation of the Sedov-Taylor solution. For instance, we expect the plasma with a lower electron temperature and more under-ionized in the remnant rim, where the density is higher (see Figure 1).

The spatially resolved spectroscopy will also reveal detailed physical processes happening at the interface between hot and cold gas, such as charge exchange. For SNR G156.2+5.7, we will also explore CX that significantly enhances forbidden lines of He-like triples in the remnant edge. CX feature has been found in the SNR Cygnus Loop, and our preliminary of XMM-Newton data found a hint of CX in SNR G156.2+5.7. With FXT, we expect to observe a redshift of O $_{\rm VII}$ and an anomalously higher ionization timescale from the Sedov-Talyor phase.

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

Thanks to a large field of view of ~1°, FXT can cover over 25% area of SNR G156.2+5.7. Based on the ROSAT observation (Pfeffermann et al. 1991), the flux is ~ 5×10^{-11}erg cm^{-2} s^{-1}. Using the online EP-FXT simulator, the total count rate of two FXT telescopes will be ~ 10 photons s^{-1}. We will obtain ~ 3.6×10^{5} photons through our 36 ks observation, i.e., 36 bins with 10000 photons for a good spatially resolved spectroscopy. This will be sufficient to “map” the physical parameters of the remnant.

SNR G156.2+5.7 will be visible from March 1st to March 9th during the performance verification epoch of EP. The observation should be taken by EP-FXT in Full-Frame mode with Medium filter and cost ~ 10 cycles.

- **References**

Cappellari M., & Copin Y. 2003, MNRAS, 342, 345
Gerardy, C. L., & Fesen, R. A. 2007, MNRAS, 376, 929
Kuntz K. D., & Snowden S. L., 2008, A&A, 478, 575
Pfeffermann, E., Aschenbach, B., & Predehl, P. 1991, A&A, 246, L28
Uchida, H., Tsunemi, H., Katsuda, S., et al. 2012, PASJ, 64, 61
Vink J., 2020, Physics and Evolution of Supernova Remnants. Springer Cham

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