eROSITA Observations of 1E 0102.2-7219 and N132D

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Scientific Proposal:

I propose to collaborate with the *eROSITA* instrument team on the analysis, modeling, and interpretation of the observations of the *Small Magellanic Cloud* (SMC) supernova remnant (SNR) 1E 0102.2-7219 (hereafter E0102) and the *Large Magellanic Cloud* (LMC) SNR N132D. The bright lines in the spectra of both objects have been well-characterized by the gratings instruments on *XMM-Newton* and *Chandra*. Our standard spectral model for E0102 (developed by the thermal SNRs working group of the International Astronomical Consortium for High Energy Calibration (IACHEC), see Plucinsky et al. 2017) has been used by all operational missions with response to low energy X-rays in order to improve their respective calibrations. The application of the standard IACHEC models for E0102 and N132D to the *eROSITA* data will quickly identify any issues with the calibration of the cameras and will allow a meaningful comparison of the *eROSITA* absolute effective area to the currently operating missions which should benefit the entire *eROSITA* community. In addition, the *eROSITA* data promise to be the definitive CCD-resolution spectra of these SNRs to characterize the emission from C, N, O, Ne, and Mg and the temperature and ionization state of the plasma.

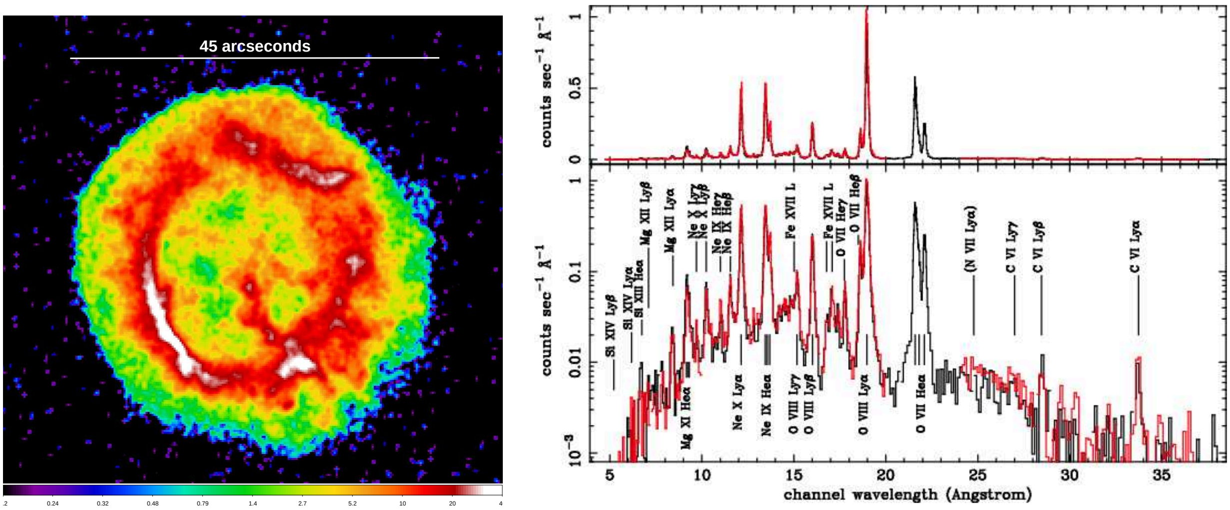

Figure 1: [LEFT] *Chandra* ACIS image of E0102 (18.9 ks, $0.3 < E < 8.0$ keV). [RIGHT] The *XMM-Newton* RGS spectrum of E0102 from Rasmussen et al. 2001. Note the strong, well-separated lines of O, Ne, and Mg and the weak Fe lines.

E0102 is the brightest extended source in the SMC with an X-ray flux of $F_x = 2.4 \times 10^{-11} \mathrm{ergs\,cm^{-2}\,s^{-1}}$ in the 0.3–10.0 keV band. The remnant is spherically symmetric in X-rays with a diameter of $\sim 45''$ (see Figure 1 and Gaetz et al. 2000). Our recent results (Xi et al. 2019), comparing multiple epochs of *Chandra* data, estimate an age of $\sim 2,000$ yr and a shock velocity of $1,600\ \mathrm{km\,s^{-1}}$. The X-ray spectra is rather soft, dominated by strong emission lines of O, Ne, and Mg, with a relatively weak continuum and little emission above 2.0 keV. The high resolution spectra provided by the *Reflection Gratings Spectrometers* (RGS) on *XMM-Newton* (Rasmussen et al. 2001, see Figure 1) resolves the emission lines of O, Ne, & Mg.

N132D is the brightest SNR in the LMC with an X-ray flux of $F_x = 1.2 \times 10^{-10} \mathrm{ergs\,cm^{-2}\,s^{-1}}$ in the 0.3–10.0 keV band. The remnant has a complicated morphology in X-rays as shown by the *Chandra* image in Figure 2. The *XMM-Newton* RGS spectrum (see Figure 2) shows strong lines of O, Ne, and Mg similar to E0102, but unlike E0102, the N132D spectrum has a strong contribution from Fe-L as evidenced by the additional lines between 14.0 and 17.0 Å. Also different from E0102, N132D has a higher temperature continuum emission and relatively strong lines of Si, S, Ar, Ca, and Fe-K.

The high resolution spectra acquired by the *XMM-Newton* RGS and *Chandra* HETG have been used by the IACHEC Thermal SNRs Working Group to develop standard spectral models to improve the calibration of the moderate resolution CCD instruments currently flying. These are empirical models that represent the flux versus energy/wavelength for these two sources. We presented a comparison of the absolute effective area of the CCD instruments on *Chandra*,

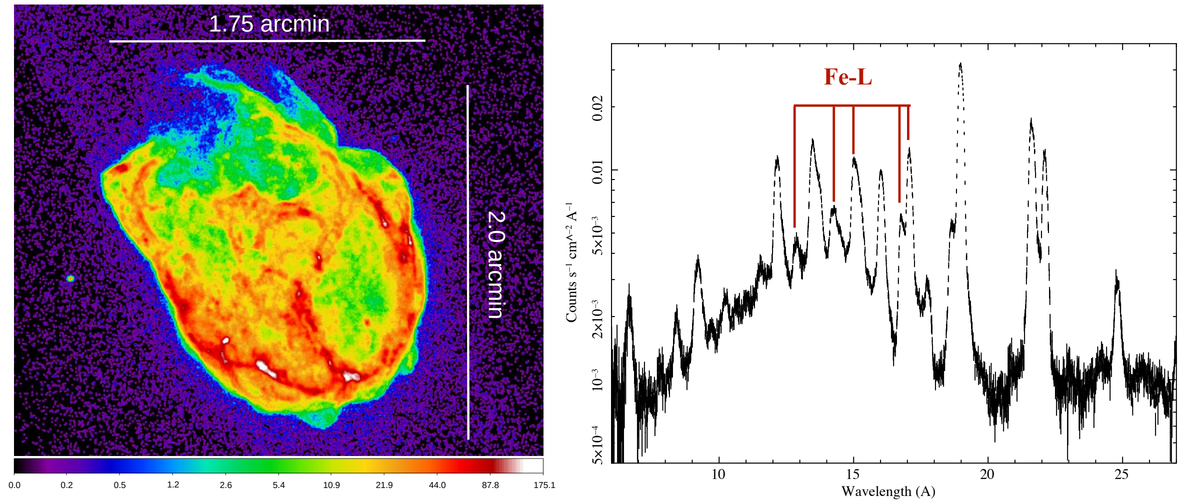

Figure 2: [LEFT] *Chandra* ACIS image of N132D (89 ks, $0.3 < E < 8.0$ keV). [RIGHT] The *XMM-Newton* RGS spectrum of N132D. Note the Fe-L lines between 14.0 and 17.0 Å that are present in the N132D spectrum but weak or absent in the E0102 spectrum.

XMM-Newton, *Suzaku*, *Swift*, and *ASTROSAT* using the IACHEC E0102 model in Plucinsky et al. 2017. The standard IACHEC model for N132D is under development. The well-characterized spectra of E0102 and N132D can be used for multiple on-orbit calibration purposes. They can be used to verify the gain calibration for each *eROSITA* detector at energies below 2.5 keV to complement the gain information provided by the on-board radioactive sources. The clean, well-separated lines can be used to verify the spectral redistribution function of the CCDs. The absolute effective area of the *eROSITA* instrument can be cross-checked against the other X-ray missions using the line fluxes of the strong emission lines of O, Ne, Mg, Si, and S. Repeated observations of E0102 and N132D can be used to identify changes in the instrument response with time, such as contamination buildup or radiation damage to the detectors. Finally, they can be used to compare and modify if necessry the response models for each of the cameras to improve the internal consistency of the calibration.

The combination of *eROSITA*'s spectral and angular resolution will allow a characterization of the plasma as a function of position within the remnants for the C, N, O, Ne, & Mg lines (and Si, S, & Fe for N132D). Spectra of these quality will allow more detailed spectral models to be fit to characterize these emission lines which in turn will constrain the temperature and ionization state of the plasma. These spectra will also allow the search for weak features which have escaped detection with the current generation of instruments, for example it has been assumed that the plasma in these remnants is composed entirely of an ionizing component but recent results from the *Suzaku* mission suggest a recombining plasma may be present in N132D. We will exploit the energy resolution of the *eROSITA* CCDs to search for any broadening or energy shifts in the line emission that might reveal the velocity structure within the ejecta of the supernova remnant. Our proposed analysis of E0102 and N132D will assist the *eROSITA* instrument team in producing the highest quality calibration at low energies and will provide a deeper understanding of the X-ray emission of these two important objects.

List of Potential Collaborators:

Michael Freyberg	Konrad Dennerl	Manami Sasaki
Werner Becker	Jörn Wilms	Vadim Burwitz

Expected Outcome:

The comparison of the *eROSITA* absolute effective area should presented at the first IACHEC meeting after the data are acquired and published in an SPIE paper. The analysis of the C, N, O, & Mg line emission should be published in an A&A paper.

Expected Duration of the Project:

One year, expected to start in August/September 2019.

References:

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