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HIGH TIME-RESOLUTION ANALYSIS OF X-RAY DATA FROM PROXIMA CENTAURI

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Abstract. The presence of a stable atmosphere is usually considered a requirement for the development of life-as-we-know on an exoplanet. X-ray and extreme ultraviolet (together, XUV) radiation from stars is for this reason a major concern for habitability, both because it strongly affects planetary atmospheres retention and because of its ionizing effects. Stellar flares represent the extreme cases as not only we see a rise of orders of magnitude in the total flux but also a strong enhancement of XUV. Proxima Centauri represents one of the best candidates for in-depth studies of XUV radiation from flares because it is the closest star to us and presents high activity. We have analyzed archival data of Proxima Centauri from the XMM-Newton and Chandra telescopes, and produced time series of its X-ray spectra. We have paid special attention to calibration, time-resolution and uncertainties. We propose a simplified pile-up correction finding that total fluxes may vary by up to 30% because of this effect. We devised a sliding-window time-binning algorithm and a model regression routine that allows to reach time resolutions of few minutes both for fluxes and plasma parameters. The quiescent and the flaring emissions from Proxima Centauri are characterized both in energies and in frequencies using nearly 6 days of observations spanning 19 years. Fluxes scenarios in the 1-100 Å range are presented with uncertainties lesser than 10% and average time-resolution of 5 minutes.

Keywords: M dwarf, X-ray, EUV, flare, activity, exoplanets atmosphere, pileup

1 Introduction

In the search for habitable worlds the characterization of the high energy radiation (XUVs) from the host stars is of utmost importance as it strongly affects how the planetary atmosphere evolves and stabilize (Yelle 2004; García Muñoz 2007; Chen et al. 2025; Rockcliffe et al. 2025). XUV may vary by several orders of magnitude both over short and long timescales, because of the coronal activity of the star and its evolution (Favata & Micela 2003; Güdel et al. 2004; Kowalski 2024). The most dreadful events are stellar flares, when a great amount of magnetic energy is released in the corona of the star causing a heat pulse that can increase the emission of more than 2 orders of magnitude within a few seconds. Because of these events the properties of an atmosphere may change temporarily or permanently. Therefore, including short-term variability in atmospheric evolution models is necessary to better interpret the observations. High-energy radiation though, is highly absorbed by the interstellar medium. This greatly reduces the observed brightness of most sources, hindering detailed characterization across time and wavelength. Time-resolved analysis is generally possible, at high resolution, only for few close sources like Proxima Centauri. Even for these sources, careful data reduction is required to obtain high-quality time-resolved spectra.

2 Contents of the poster

Preliminary results from Damonte et al. (in review) are shown in this poster. We analyzed XMM-Newton archival data of Proxima Centauri. This M dwarf star is the closest star to our solar system and is highly active and frequently flaring. Given its proximity it has one of the best one of the best X-ray datasets among M stars, both for quantity and quality. In total we analyzed 8 observations with a total exposure of about

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250 ks. Because of its brightness, the observations are often affected by pile-up effect, an instrumental effect in high energy charge coupled devices that causes flux loss and spectral distortion, which increases with flux. We present a novel method to correct for this effect. This method is based on previous ideas from Ballet (1999); Molendi et al. (2003). The method estimates the amount of pile-up using relations from Jethwa et al. (2015) and generates a set of missing events from the single pattern photon-events, which are negligibly affected by pile-up. We continue the analysis by introducing a new, adaptive time-binning algorithm. This algorithm is based on the concept of a sliding window with variable length. Two consecutive time intervals share part of the photon-events. The length of the intervals is variable in a way that ensures a minimum signal-to-noise ratio, but improves the time resolution when the target is brighter, allowing improved resolution during stellar flares. Finally, we fit different thermal models to the obtained spectra and for each time interval we select the model with the best information criterion. We use the Akaike information criterion (AIC). We note though that when comparing the AIC values obtained from fitting with different models, they are really close, signifying that models are often almost equally probable. Finally, we reconstruct the EUV part of the spectrum by applying scaling relations from Sanz-Forcada et al. (2025).

3 Conclusion

Time-resolved analyses need a more careful reduction than usual. If not properly corrected the pile-up effect may cause a flux loss of up to 22% during the brightest flares of Proxima Centauri. The produced spectra have an average time resolution of 300 s, with a maximum resolution of 90 s and a minimum of 2000 s. Results may vary by factors of a few even when considering the same dataset depending on the reduction procedure, time resolution, and time-binning method. When looking at the overall averages obtained from different reductions of the same observations or, more generally, from different observations, total fluxes may vary by a factor of a few. A final dataset with fluxes and spectra between 1 and 920 Å and a time resolution of 30 s (interpolated) was obtained using our procedure and will be made publicly available with the publication of Damonte et al. (in review).

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