Highlights of Spanish Astrophysics XII, Proceedings of the XVI Scientific Meeting of the Spanish Astronomical Society held on July 15 - 19, 2024, in Granada, Spain. M. Manteiga, F. González Galindo, A. Labiano Ortega, M. Martínez González, N. Rea, M. Romero Gómez, A. Ulla Miguel, G. Yepes, C. Rodríguez López, A. Gómez García and C. Dafonte (eds.), 2025

Mathematical insights in X-ray data processing or why sometimes less is more

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Abstract

Exploring the mysteries of the universe relies heavily on advanced instrumentation both in space and on ground observatories. However, effective processing of the data collected by these instruments is crucial for optimizing performance and, particularly in the case of space missions, minimizing computational costs.
The forthcoming Athena revolutionary X-IFU instrument introduces a cutting-edge TES detector that demands onboard processing and therefore resource optimization. Each X-ray photon interacting with the X-IFU generates a current pulse, the magnitude of which correlates directly with the photon's energy. Extracting essential information such as pulse energy, position, and arrival time constitutes the primary objective of the onboard software. Traditionally, the optimal filter algorithm has been employed for this task. However, in an initial research with simulations we demonstrated that a modification to this algorithm, known as 0-padding, significantly enhances performance while reducing computational overhead. Although the precise mathematical rationale behind its success was initially unclear, a recent study we conducted with extensive simulations and real data elucidated its efficacy. By analyzing the propagation of random uncertainties, we established that the truncated segment of the filter introduces additional uncertainty, thereby potentially compromising the energy resolution of the detector.
In our current work, we advance this research by deriving the covariance matrix and integrating it into the uncertainty propagation analysis. By comprehensively examining all relevant factors, we reaffirm that truncating the filter yields the smallest uncertainties, consolidating its status as the optimal processing option. Our findings represent a significant stride towards enhancing the efficiency and accuracy of data processing techniques for next-generation space instrumentation.
Grant PID2021_122955OB-C41 funded by MCIN/AEI/10.13039/501100011033 and by "ERDF A way of making Europe"

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