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Challenges in Multimessenger Astronomy in the ET Era: From Interoperability to Multimodal Generative AI Systems

The Einstein Telescope (ET) opens a transformative era in gravitational wave astronomy, heralding the onset of big-data-driven multimessenger exploration. In this context, the adoption of interoperable standards promoted by the International Virtual Observatory Alliance (IVOA), becomes crucial for integrating and analyzing diverse and large-scale astronomical datasets. This study proposes a novel expansion of the MOC maps. MOC is a hierarchical data structure widely recognized for efficiently encoding and visualizing sky regions, has already demonstrated success by enabling cross-matching of astronomical catalogs, multi-wavelength surveys, and facilitating the collaborative data analysis essential to multimessenger astronomy. We introduce "Textual MOCs"—which incorporate detailed textual descriptions directly into sky regions—and "Semantic MOCs," which convert these textual contents into semantic embeddings. These embeddings represent textual meaning in multidimensional spaces and are stored in optimized vector databases, enabling sophisticated analytical operations such as similarity searches and complex semantic queries. The integration of Textual and Semantic MOCs substantially enhances sky maps by embedding rich contextual information and semantic insights, improving user engagement, and enabling the development of interactive and educational tools. Additionally, incorporating multimodal generative artificial intelligence systems further refines the analytical capabilities, supporting context-aware interactions, and enhancing accuracy in spatial, semantic, and visual operations. The seamless interoperability provided by adherence to IVOA standards ensures broad accessibility, facilitating global collaboration, and significantly advancing multimessenger astronomical research in the era of ET.

Primary authors: GRECO, Giuseppe; SCHRAMM, Steven (University of Geneva)

Presenter: GRECO, Giuseppe

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