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Space-Based Radio Interferometer Using Small Satellites

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1 Extended Abstract

Radio Interferometry is a powerful technique utilized in radio astronomy for mapping radio emissions of celestial sources [2]. However, an important aspect of any image is the angular resolution, which in ground-based radio interferometry is limited by the diameter of the earth [1, 3, 4]. This limitation can be overcome if we place the radio telescopes on satellites orbiting in space [1, 3]. This extension of radio interferometry to space is known as Space-based Very Long Baseline Interferometry (SVLBI). It utilizes multiple radio telescopes attached to satellites for doing radio interferometry, allowing for unprecedented resolution and sensitivity and pushing the boundaries of astronomical exploration by enabling us to probe the yet unexplored very low-frequency domain of the cosmos. Designing an optimal satellite constellation for SVLBI is, however, challenging due to the need for comprehensive (u,v) coverage, which determines the spatial information captured by the interferometer.

This study introduces the Antariksh Interferometry Simulator (AI-Sim), a simulation tool designed to optimize small satellite deployments in diverse Earth orbits for SVLBI missions. It evaluates various orbital configurations to enhance (u, v) coverage, examining how satellite numbers, inclinations, eccentricities, and apogee heights influence interferometric performance. A key focus is the comparison between identical versus diverse orbital configurations. While identical orbits offer simplicity, they can lead to gaps or redundancies in (u, v) coverage. In contrast, diverse orbits—with varying inclinations, eccentricities, and apogee heights—enhance coverage by filling the (u, v) plane, generating redundant baselines that improve data calibration and image quality. This is particularly beneficial for studying faint and distant objects such as compact objects and radio jets, which emit low-frequency radio waves. Three hybrid configurations demonstrated promising results: a four-satellite setup with two satellites in Medium Earth Orbit (MEO) and two in Low Earth Orbit (LEO), a five-satellite constellation with three in MEO and two in LEO, and a five-satellite configuration comprising one in High Earth Orbit (HEO), two in MEO, and two in LEO. These configurations were evaluated based on (u, v) coverage, point spread function, and imaging simulations of point and extended sources. To further refine SVLBI imaging capabilities, AI-Sim has been integrated with CASA, a widely used radio astronomy software package. This integration enables comprehensive assessments of (u, v) coverage and angular resolution, optimizing image quality and sensitivity. By analyzing the point spread function, AI-Sim identifies potential image quality limitations and simulates real-world observations to reconstruct images of various astronomical sources. The AI-Sim simulation tool and the findings of this study establish a crucial framework for future SVLBI mission designs, equipping astronomers with a powerful tool to analyze and optimize satellite configurations, ultimately driving advancements in astronomical research.

References

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