

Methods for Detecting Gravitational Waves from mini-Extreme-Mass-Ratio Inspirals: A Spectral-Leakage-Aware Framework

Sunday, 25 October 2026 15:50 (20)

Mini-extreme-mass-ratio inspirals (mini-EMRIs), in which a subsolar-mass compact object orbits a much heavier compact object, are long-duration gravitational-wave sources of interest to ground-based detectors. Their signals can remain in band for hours to years, making fully coherent matched-filter searches computationally expensive. Semicoherent time-frequency searches reduce this cost by dividing the data into short Fourier segments and combining segment-level powers or related statistics. Conventional implementations, however, often require the signal to remain approximately monochromatic within each segment, thereby limiting the coherent duration when the signal frequency evolves appreciably.

We extend the Σ Track framework beyond the quasi-monochromatic regime in two steps. First, we derive a linear-chirp model for the spectral leakage produced within a short-time Fourier segment. Second, we construct the ΣR statistic, a weighted sum of power ratios over a finite multi-pixel track, to recover signal power distributed among neighboring frequency bins. The resulting sensitivity model further motivates a frequency-layered search in which the coherent duration is optimized separately in different frequency intervals.

For a fiducial $(1.5, 10^{-5}) M_{\odot}$ mini-EMRI and under the assumptions of our analytic comparison, the optimized ΣR configuration yields an effective detection volume about an order of magnitude larger than that of the Hough-like reference statistic considered here.

More broadly, the proposed framework provides a systematic way to incorporate spectral leakage into semicoherent time-frequency statistics and to optimize the coherence time across the signal band, thereby extending power-track searches to long-duration signals with appreciable frequency evolution.

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Session Classification : Gravitational Wave Physics (Room A)