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Exploring Neural Network Methods for Sky Localisation of PTA sources

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Accurate localisation of continuous gravitational waves (CGWs) from supermassive black hole binaries (SMBHBs) remains one of the key challenges in Pulsar Timing Array (PTA) data analysis. Traditional searches based on the $\mathcal{F}_e$ statistic provide a robust analytic framework, but the resulting sky maps are strongly affected by the PTA antenna pattern, which redistributes signal power across the sky and generates secondary peaks that complicate the identification of the true source position. This degeneracy motivates the development of alternative approaches capable of disentangling instrumental artefacts from true localisation information.

In this work, we investigate whether neural networks (NNs) can improve CGW sky localisation by learning the correct position directly from $\mathcal{F}_e$ maps. We design and train a fully connected residual NN that takes as input the full sky map and outputs the source coordinates on the celestial sphere, encoded as $(\sin\phi, \cos\phi, \cos\theta)$. The loss function is dominated by the Haversine distance between predicted and true positions, providing a direct measure of angular separation.

The results show that the neural network consistently improves localisation performance relative to analytic expectations. In particular exceeding Fisher predictions by an order of magnitude in some of the cases. The network remains robust to changes in SNR, maintaining superior accuracy specially in low-SNR conditions. However, as expected, when the pulsar term is included in the signal model, performance decreases substantially.

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