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Sensitivity of strong lenses to substructure with machine learning

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Strong gravitational lensing has become one of the most important tools for investigating the nature of dark matter (DM). With a technique called *gravitational imaging*, the number and mass of dark matter subhaloes can be measured in strong lenses, constraining the underlying DM model.

Gravitational imaging however is an expensive method and requires adaptation in astronomy's current "big data" era. This is due to a stage of the analysis called *sensitivity mapping*. Here, the observation is analysed to find the smallest detectable subhalo in each pixel. This information can be used to turn a set of subhalo detections and non-detections into an inference on the dark matter model.

In this talk, we cover our previously introduced machine learning method for estimating sensitivity and its results. For example, we produced tens of thousands of sensitivity maps for simulated *Euclid* strong lenses (1). Our method was able to detect substructures with mass $M > 10^{8.8} M_{\odot}$. This allowed us to forecast the number of substructure detections available in *Euclid*, that is, ~ 2500 in a cold dark matter universe.

More recently, we used the method to examine a critical systematic in substructure detection, the angular structure of the lens galaxy (2). We used an ensemble of models trained with different amounts of lens galaxy angular complexity in the training data, based on realistic HST strong lens images. We found that small perturbations beyond elliptical symmetry, typical in elliptical galaxy isophotes, were highly degenerate with dark matter substructure. The introduction of this complexity to the model reduces the area on the sky where a substructure can be detected by a factor ~ 3.

In both cases, our work required large numbers of sensitivity maps which would not have been possible without the acceleration of the machine learning method. We finally discuss the application of our method to data from ground-based (*Keck AO*) and sky-based (*Euclid*) telescopes, and other prospects for the future.

References

1. O'Riordan C. M., Despali, G., Vegetti, S., Moliné, Á., Lovell, M., MNRAS (2023)
2. O'Riordan C. M., Vegetti, S., MNRAS (2023)

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