Machine learning the visible counterparts to gravitational waves: kilonovae

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Kilonovae are astronomical events that should occur during either a binary neutron star (BNS) or a neutron star black hole (NS-BH) merger [1]. There is a large community effort to detect and plan follow-up observations, which requires novel modelling techniques. Radiation is emitted across the electromagnetic spectrum. Such mergers are proposed to be responsible for the formation of heavy elements in the Universe [1]. Kilonovae can also break degeneracies in gravitational wave observations which may improve predictions about the expansion of the universe [2]. As they are a new set of transients, there has only been one confirmed measurement of a kilonova [3]. With more measurements expected, kilonova detection and follow-up can benefit from forecasting based on anticipated physical constraints. Theoretical work has progressed. Radiative transfer simulations predict light curves with increasing fidelity [4]. However, these models are computationally expensive, and may take more than 2 days to execute [5]. Without a faster model, parameter inference and forecasting would be difficult. We present a software that uses machine learning to predict light curves. Our model takes 1-2 seconds to predict, a speed up of 200,000 times.

The software we developed uses Gaussian processes and principal component analysis (PCA) to predict the light curves associated with kilonovae. It is trained on radiative transfer simulations and predicts new light curves at arbitrary points in the parameter space. Figure 1 illustrates the typical performance of the machine learning prediction. There is a 1σ chance the fractional error is less than 5% in flux or 10% in magnitudes. The software then incorporates Markov chain Monte Carlo (MCMC) methods to estimate the properties of a kilonova given a set of light curves. This is done using Bayesian inference where the parameters posterior distribution is estimated given a set of light curves.

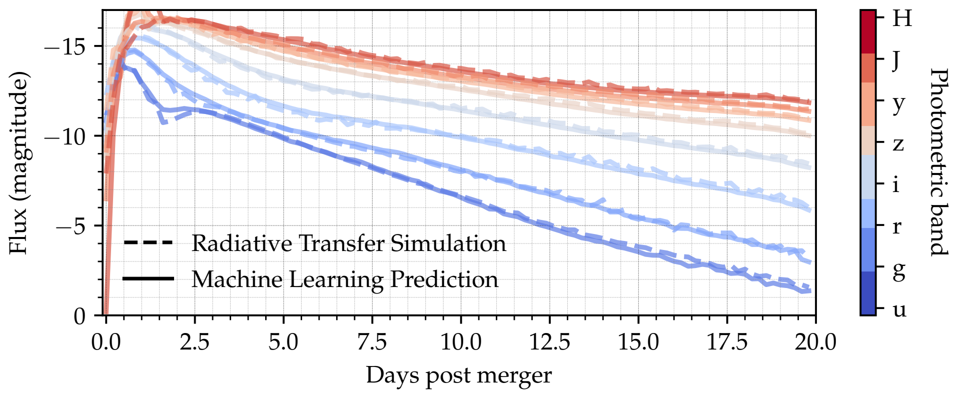

Figure 1: **A sample simulation of kilonova magnitude as a function of time. Eight photometric bands are shown with their respective ground truth (not in the machine learning set). There is good agreement between truth and prediction.**

Using an open-source version of this software, users that measure kilonova events from their telescopes can input the data into the software pipeline. The software will then recover the physical properties of the associated kilonova. In addition to this, the software can be used to forecast light curves given the properties of a kilonova. Other extensions include incorporating multiple different radiative transfer models to the training data. This will increase the reliability of software predictions.

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