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Analysing gravitational waves recordings with seismological signal processing tools

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In his general theory of relativity Albert Einstein describes gravitational waves as ripples in space-time generated by accelerated masses. Gravitational waves offer an entirely new way of observing our Universe, allowing us to: get a better picture of it's structure, perform the most robust test of Einsteins' theory yet, and even shed light on the primordial Universe. Not to mention the possibility of discovering hither-to unknown physics and phenomena.

Building on the success of the interferometric detection of gravitational waves by the Earth based LIGO and Virgo experiments, the Laser Interferometry Space Antenna (LISA) is a space-based gravitational wave observatory that is due to launch in the early 2030s. It will consist of three satellites in a triangular formation separated by 2.5 million km. The separation distance will be closely monitored by six laser beams (each satellite will send a beam to the other two) and as a gravitational wave pass between the spacecraft, it will induce a phase shift in the laser beams. The whole ensemble orbit the Sun and cartwheel as it does so.

An important class of gravitational wave sources for LISA is composed of Galactic binaries emitting continuously quasi-monochromatic signals. However they are predicted to be so numerous (approximately 26 million in the LISA bandwidth) that, in the time domain, a single binary will be about two orders of magnitude less than that of the 'confusion noise' generated by the millions of others Extracting a single gravitational wave from the LISA measurements is, hence, a far from trivial task. To this end, the LISA consortium has produced series of year-long synthetic data sets to test the efficiency of prospective data analysis algorithms, and whilst a veritable zoo of algorithms has been created to meet the challenge, at their heart most of them rely on matched filtering using modelled source signatures.

Striking similarities exist between gravitational wave and seismic signals. Seismology is confronted daily with the analysis of noisy signals. In spite of the fact that significant differences exist between the LISA data and standard seismological datasets (e.g., the exceptionally large amount of noise and the fact that the detector is not stationary), we analyse the LISA data from a seismological multi-component and multi-station angle with the motivation to develop an alternative set of gravitational waves analysis tools. For example, we divide the three-channel time-series into multiple short time windows: instead of analysing one year-long time series, we split the data into several week-long windows equally spread out over one year. This splitting allows us to treat the data as if they were recorded by multiple stationary detectors as opposed to a single moving one. Then, multi-channel multi-station source-location techniques such as the multiple signal classification (MUSIC) algorithm can be used to extract the source parameters of the gravitational waves.