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A model based approach to asteroid detection and characterisation using bistatic continuous wave radar

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The Southern Hemisphere Asteroid Radar Program (SHARP) has been detecting and classifying asteroids using the Canberra Deep Space Communication Complex (CDSCC), Parkes and Australian Telescope Compact Array (ATCA) radio telescopes since 2015. The CDSCC uses either a $34\,\mathrm{m}$ or $70\,\mathrm{m}$ antenna as an illuminator and Parkes or the ATCA is used as a receiver. So far, the CDSCC has only been able to transmit non-coded sine waves, also called continuous wave (CW) signals. While CW allows the measurement of Doppler, time delay cannot be measured directly.

The current configuration used for asteroid observations using SHARP is the CDSCC as illuminator using a single, right-hand polarised antenna, and ATCA as a receiver featuring both a right- and left-hand polarised antennae. This configuration allows the measurements of reflections with different polarisations.

This current work proposes a novel method that utilises a model-based approach to classify and detect asteroids and other near-Earth objects. When the illuminator transmits a CW, the signal contains a single Fourier component in the form of the sine wave that is emitted. Upon reflection by the asteroid, the CW signal is perturbed, with its amplitude affected by absorption and its frequency and phase affected by the asteroid's rotation and motion relative to the Earth. When using conventional Fourrier based spectral analysis methods this would be revealed as a Doppler spread in the periodograms. Additionally, some of the electromagnetic properties of the signal are perturbed such as the signal polarisation. This can be caused by multiple reflections and surface material properties. In theory the entire reflected signal could be modelled using a Fourier series. In practice, this will however be challenging, since the number of Fourier components and their parameters will be large.

A model-based asteroid detection and characterisation method would allow more detail to be extracted from an observation since one, instead of correlating sine waves through a Fourrier transform, would be correlating matched filters. This will improve the signal to noise ratio while simultaneously indicating what matched filter results in a high signal to noise ratio, and thereby revealing information about the shape of the asteroid. The matched filters can be obtained through radar simulations with an asteroid model.

In this work we present two initial results for model-based asteroid detection and classification: The first result consists of visual analysis of data received from observations, anechoic chamber experiments and simulations, which will include the 2024 ON observations. We will demonstrate examples and compare the results to Doppler delay images created by the Goldstone asteroid radar. Secondly, we will demonstrate numerical detection and classification of asteroids using correlation methods, where we compare simulated models with real data and/or other simulated models.

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Many further challenges related to model-based asteroid detection will need further investigations, of which some will be covered in this work. These challenges include the level of detail that is required on an asteroid model to correlate sufficiently strong with an observation, the parametric model order required and thereby the computational requirements to perform a detection. Other challenges include studies to determine to which degree the backscatter and nonlinear effects in the transmit and receive chain affect the proposed method.