Precision Asteroseismology
Proceedings IAU Symposium No. 301, 2013
J. A. Guzik, W. J. Chaplin, G. Handler & A. Pigulski, eds.

doi:10.1017/S1743921313014981

Modeling non-radial oscillations on components of close binaries

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Abstract. We developed an advanced binary system model that includes stellar oscillations on one or both stars, with the goal of mode identification by fitting of the photometric light curves. The oscillations are modeled as perturbations of the local surface temperature and the local gravitational potential. In the case of tidally distorted stars, it is assumed that the pulsation axis coincides with the direction connecting the centers of the components rather than with the rotation axis. The mode identification method, originally devised by B. Bíró, is similar to eclipse mapping in that it utilizes the amplitude, phase and frequency modulation of oscillations during the eclipse; but the identification is achieved by grid-fitting of the observed light curve rather than by image reconstruction. The proposed model and the mode identification method have so far been tested on synthetic data with encouraging results.

Keywords. asteroseismology, methods: data analysis, methods: numerical, techniques: photometric, binaries: close, binaries: eclipsing, stars: oscillations

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The binary system modeling program, *Infinity*, was first presented on the IAU Symposium 282, "From Interacting Binaries to Exoplanets: Essential Modeling Tools" (Cséki & Latković 2012) as a work in progress. In the two years since the initial announcement, it has evolved into an elaborate tool for modeling a wide variety of binary stars: from well detached and eccentric, to close, interacting systems within the Roche formalism. The features that differentiate *Infinity* from other programs for modeling binary stars include:

- A novel approach to visibility detection (determining which elementary surfaces of the components are visible to the observer at a given time), using the "inverse painter's algorithm" that allows the inclusion of any number of additional components (like circumstellar and circumbinary disks, planets, or other stars and binaries in hierarchical systems) in the model;
- A novel approach to modeling the eclipse, using the "adaptive subdivision" of elementary surfaces that allows for arbitrary precision even when the eclipsing body is relatively small (like a planet);
- The capability of modeling conical and toroidal accretion disks;
- And finally, the feature most interesting in the context of asteroseismology: the capability of modeling non-radial oscillations on one or both components of the binary.

The oscillations are simulated as periodic perturbations in local effective temperature and/or local effective gravitational potential, where frequencies, amplitudes and phases, as well as the quantum numbers l and m of the associated spherical harmonic, are adjustable model parameters. The symmetry axis of the oscillations can also be specified in terms of its inclination to the rotational axis, which is presumed to be orthogonal to the orbital plane. It is therefore possible to use *Infinity* for modeling oblique pulsators. It is also possible to model oscillations on stars significantly distorted by tidal forces in close binary systems, with the pulsation axis aligned with the direction through the centres of the components.

The primary purpose of *Infinity* as a tool for modeling stellar oscillations is mode identification. Namely, the eclipse can be used as a spatial filter that samples the surface of the oscillating component and produces modulations in frequencies, amplitudes and phases of the oscillations. The "signature" of the modulation caused by the eclipse is unique for every mode, and can therefore be used to identify the mode. This is the principle that underpins the techniques of eclipse mapping (Bíró & Nuspl 2011) and direct light curve fitting (Latković & Bíró 2008).

In *Infinity*, the modes are identified by comparing the residual light curve with a grid of models that have different spherical harmonics representing each mode. The residual light curve is obtained by subtracting the orbital solution (the binary light curve) from the observations. Given the observed light curves in one or more passbands and the radial velocity curves, *Infinity* can be used to find the full spectrophotometric solution for a binary system by simultaneous fitting. After that, the residual light curve can be analyzed in order to measure the frequencies and amplitudes of oscillations. These are then used to create a grid of models in which all the binary and oscillation parameters other than the spherical harmonic quantum numbers, l and m, are fixed according to the results from previous steps. The identification is achieved by selecting the model which gives the best fit to the observations from the grid.

This procedure has been tested on simulated data with good results. The simulations were done for several representative system configurations (detached and close systems with total and partial eclipses) for all single modes with the degree $l \leqslant 4$, and for superpositions of up to three modes. In detached systems, where the pulsation axis coincides with the rotation axis, all the identifications were successful. In close systems, where the pulsation axis lies in the orbital plane as described above, the identifications were successful for single modes, but ambiguous for superpositions. This has to do with the fact that with an inclined pulsation axis, a single mode is detected as a multiplet with up to $2l + 1$ members, making for highly complex signatures in the light curves, as discussed in detail by Reed *et al.* (2005).

At the time of writing, we are making headway towards the first applications of mode identification on data from satellite observatories. The best candidates are short-period, but well-detached eclipsing binaries in which one of the components exhibits δ Sct or γ Dor oscillations.

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https://doi.org/10.1017/S1743921313014981 Published online by Cambridge University Press