From Interacting Binaries to Exoplanets: Essential Modeling Tools
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Infinity – A New Program for Modeling Binary Systems

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Abstract. INFINITY is a new program for modeling binary systems. The model is based on Roche geometry with asynchronous rotation, including an assortment of effects like gravity and limb darkening, mutual irradiation, bright and dark spots and so on. However, INFINITY brings innovations in the modeling of accretion disks, and introduces the modeling of radial and non-radial oscillations on one or both components of the system.

At this stage of development, INFINITY can produce light curves, spectra and radial velocity curves; solving the inverse problem is still a work in progress. In terms of programming, INFINITY is being developed in the object-oriented language C#, and great care is taken to produce readable, easily extensible and verifiable code. INFINITY is fully optimized to take advantage of modern multi-core CPUs, and the code is thoroughly covered with unit-tests. We expect to make a public release during 2012.

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1. Modeling the binary system

The physics of INFINITY follows closely the physics of the model developed by Djurašević (1992a). The shape and the basic temperature distribution of the stellar surface are determined by the Roche potential and Von Zeipel's law; this base distribution can subsequently be modified by various effects, like dark and bright spots, stellar pulsations and mutual irradiation. At the moment, we treat the stars as black bodies and calculate the emergent fluxes from the Plank law, but we will make the transition to using models of stellar atmospheres in the near future.

INFINITY uses the geodesic mesh to represent the stellar surface. The mesh is generated from an icosahedron and subdivided into elementary triangles, which are then positioned so as to match the Roche equipotential corresponding to the surface of the star. This approach was inspired by the model of Hendry & Mochnacki (1992). One of the main advantages of using this type of surface division is that the triangles comprising the geodesic mesh are all of fairly similar areas. The smoothness of the mesh is controlled by the level of geodesic subdivision; at level 5, there are about 20 000 triangles per mesh, and at level 6, about 80 000. We are looking into alternative subdivision algorithms that will allow a gentler increase of the number of elementary surfaces per level.

The visibility of an elementary triangle in any given phase is determined by a method similar to the Painter's algorithm in computer graphics (Foley *et al.* 1990). A triangle is either visible (nothing in front), or invisible (some part covered); in other words, INFINITY doesn't account for partial visibility. Instead, INFINITY implements "adaptive subdivision" that automatically increases the number of elementary surfaces in the region of the eclipse, allowing for arbitrary accuracy.

2. Modeling the accretion disk

Our model of the binary system can include an optional, geometrically and optically thick accretion disk in the orbital plane. Following the model of Djurašević (1992b), the disk may be flat or conical, and the conical disk may further be modeled as concave (outer edge thicker than the inner edge) or convex (outer edge thinner than the inner edge). INFINITY expands the geometrical model of the accretion disk to allow almost any shape, illustrated by the example of a toroidal disk that is already implemented: the shape of the disk in INFINITY is determined by a parameterized cross-section in the meridional plane; the cross-section for the flat disk is a rectangle, for the conical disk, a trapeze, and for a toroidal disk, an ellipse. In addition, INFINITY can model disks that are eccentric and inclined to the orbital plane.

3. Modeling the pulsations

One of the most important aspects of INFINITY is the ability to model radial and non-radial stellar pulsations on one or both components of the binary system. The pulsation model that we are using was originally developed by Bíró & Nuspl (2011) for the purpose of mode identification in eclipsing binaries using the technique of eclipse mapping. The modes are approximated by spherical harmonics, and the periodic changes in the observables are produced by perturbing the emergent flux from the spherical stellar surface. We made slight improvements to this model; first, in the sense that the pulsation modes are modeled as perturbations in both the shape and the temperature of the stellar surface, and second, in the sense that the pulsations can be modeled on both quasi-spherical and gravitationally/rotationally distorted stars.

4. Fitting & mode identification

In addition to fitting the system and component parameters, INFINITY will be able to fit the parameters of stellar pulsations: the amplitudes and quantum mode numbers ℓ and m. This method of mode identification, the direct fitting of spherical harmonics has been tested on artificial data and a model with spherical stars by Bíró & Latković (2009), but we will attempt to apply it on distorted stars in Roche geometry. The fitting algorithm we're working on is a variation of the Nelder-Mead simplex with constraints and parameter mutations.

5. Availability

As of this writing, INFINITY is still a work in progress. We expect to publish the details of the methods and example applications by the end of 2012, after which we will make INFINITY available for public use.

References

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