Simulation of Contact Binary Star Systems to Study Light Curve Characteristics

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Abstract

We developed a simulation of contact binary star systems using Python to study their orbital dynamics and photometric characteristics. The model integrates 4th-order Runge-Kutta (RK4) methods for orbital mechanics and Eggleton's equation for Roche lobe geometry. Furthermore, we incorporated physical phenomena—gravity darkening, reflection effects, and eclipses—to generate synthetic light curves. The results demonstrate that the model successfully reproduces key features of contact binaries, including Roche lobe overfill and asymmetric light curves due to thermal interactions.

Research Background

Contact binary systems exhibit complex behaviors due to mass transfer and tidal distortion. Understanding their light curves requires modeling not just the geometry but also thermodynamic effects like gravity darkening and reflection. This project aims to simulate these systems numerically to visualize Roche geometry and analyze how physical parameters influence the observed light variations.

Method

We simulated the binary orbit by solving Newton's equations of motion using the RK4 integration scheme. The Roche potential was calculated to define stellar surfaces, determining the Roche lobe radius via Eggleton's approximation (Eggleton, (2006)). To generate light curves, we synthesized the flux from the stellar surfaces considering

1. Stefan–Boltzmann Law: Calculating the luminosity of each individual star.
2. Gravity Darkening: Modulating temperature based on the Mass-Temperature relation.
3. Reflection Effect: Accounting for the mutual irradiation, where the side of the star facing its companion absorbs and re-emits radiation, increasing the temperature of the irradiated hemisphere (Wilson, 1990).
4. Eclipse Mapping: Calculating the projected overlapping area along the line of sight.

The total flux is then synthesized by integrating these local effects across the visible stellar disks. This integrated approach, iterated over a full orbital cycle, produces a comprehensive light curved model that serves as a theoretical template for determining physical parameters such as orbital inclination and mass ratio through comparison with empirical data.

Results and discussion

Figure 1(a) illustrates the potential contours and the resulting contact configuration. The simulation confirms that the synthesized model aligns with the fundamental characteristics of W Ursae Majoris (W UMa) type contact binary systems. The synthesized light curve (Figure 1(b)) reveals distinct features corresponding to the physical model:

(1) Unequal Minima: The difference in the depths of the primary and secondary eclipses originates from the temperature gradient and the ratio of the stellar radii between the components.

(2) Continuous Variation: The curve is rounded due to continuous variation between eclipses. This is a result of the non-spherical, "teardrop" shape of the stars (Roche lobe deformation) combined with the gravity darkening effect (Lara & Rieutord, 2012).

(3) Asymmetry: The reflection effect causes the hemisphere facing the more luminous companion to be internally heated, leading to a non-uniform surface brightness distribution.

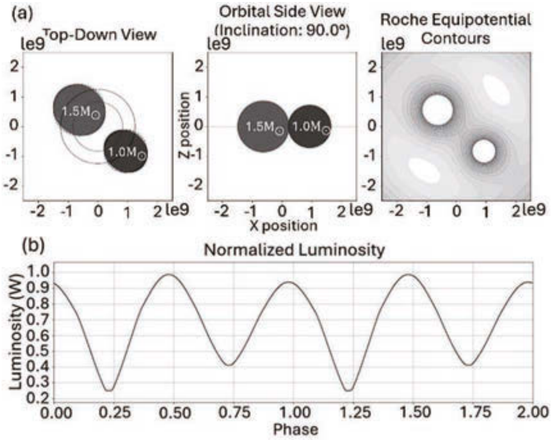

Figure 1: Simulation results based on initial conditions of $1.0M_{\odot}$ and $1.5M_{\odot}$ for the stellar masses, an initial distance of $3.0R_{\odot}$, and an inclination of 90°. (a) Geometric configuration including Top-Down View, Orbital Side View, and Roche Equipotential Contours. (b) Synthetic light curve illustrating phase-dependent luminosity variations.

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