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.

INTRODUCTION

A contact binary system has an extremely short period and close separation, causing stellar atmospheres to fill their Roche lobes. Mass transfers through the inner Lagrangian point (L1), altering angular momentum and shrinking the orbit. Light curve analysis models luminosity variations by deriving effective temperatures via the mass-temperature relation and Stefan–Boltzmann law. The model also accounts for gravity darkening and the reflection effect, which modify surface brightness due to stellar interaction.

METHODOLOGY

Orbital Dynamics

- Simulated binary orbits by solving Newton's Equations of Motion.
- Applied RK4 (Runge-Kutta 4th Order) integration scheme.

Stellar Geometry

- Defined surfaces using Roche Potential.
- Calculated Roche lobe radii via Eggleton's Approximation. [1]

Light Curve Synthesis

- Flux Integration: Summing local effects across visible stellar disks.
- Luminosity: Stefan-Boltzmann Law. Gravity Darkening: Temperature modulation based on Mass-Temperature relation.
- Reflection Effect: Accounting for mutual irradiation.
- Eclipse Mapping: Calculating projected overlapping areas.

Parameter Estimation

- Generated theoretical templates to determine inclination (i) and mass ratio.

Contact binary star system

↓ Input ; mass , distance

↓ Orbital Calculation via Runge-Kutta 4th Order (RK4)

↓ The stellar radius is set to equal the effective Roche lobe radius as derived from Eggleton's formula.

Light curve

↓ The luminosity is calculated using the Stefan–Boltzmann law.

↓ The calculation incorporates the effects of gravity darkening and the reflection effect.

↓ Calculate the light loss caused by mutual eclipses.

RESULTS

Results of Orbital Model Development for Contact Binary Systems

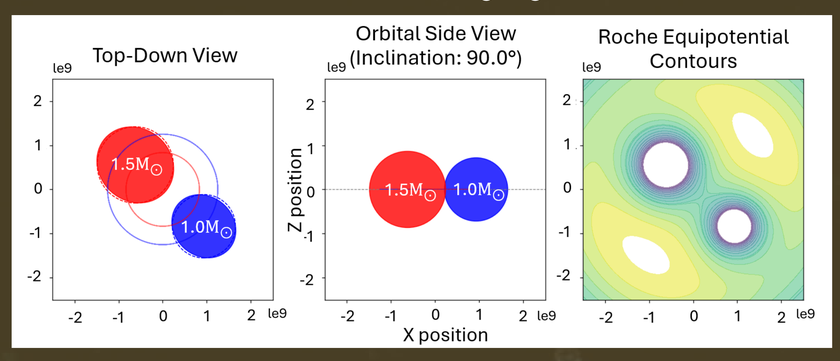

Figure 1: Geometric configuration including Top-Down View, Orbital Side View, and Roche Equipotential Contours.

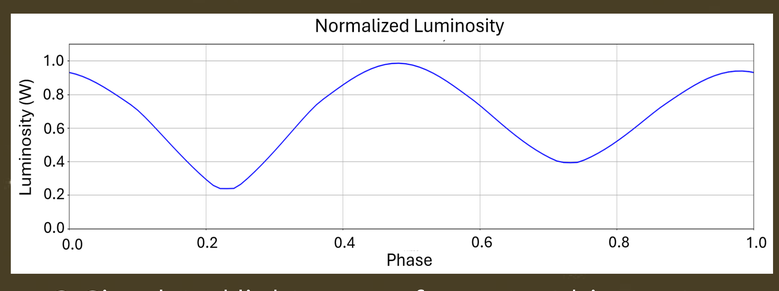

Figure 2: Simulated light curve of a contact binary star system over one orbital phase.

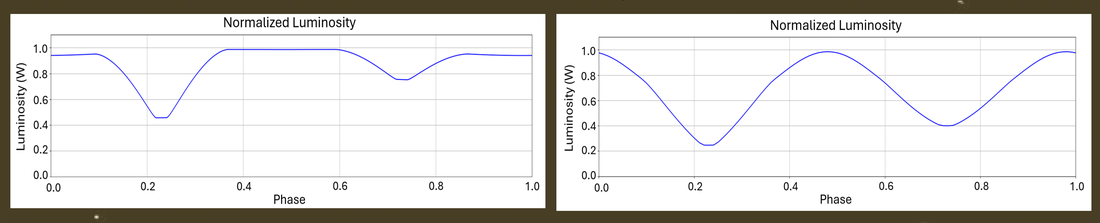

Figure 3: Simulated light curves excluding specific physical effects (Left) without Gravity Darkening and (Right) without the Reflection Effect.

The simulated light curves (Figure 2) successfully reproduce the key observational characteristics of contact binary systems
Eclipse Depth: The model accurately depicts the decrease in flux when the secondary (cooler) star occults the primary (hotter) star.
Gravity Darkening: Produces the characteristic rounded maxima of the light curve. Changes in the gravity darkening coefficient directly correlate with the degree of curvature in the light curve profile. [2].
Reflection Effect: Results in asymmetry within the light curve due to mutual irradiation between the stars. The irradiated hemispheres exhibit higher temperatures, influencing the flux distribution throughout the orbital phase. [3].

DISCUSSION

The results of the orbital model development for contact binary systems demonstrate strong consistency with observed physical characteristics. By utilizing initial parameters such as stellar masses and orbital separation, the model successfully generates light curves that match typical contact binary profiles. Notably, the light curves exhibit the influence of gravity darkening, which contributes to their characteristic rounded shape, as well as the clear impact of the reflection effect.

REFERENCES

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[3] Wilson, R. E. (1990). Accuracy and efficiency in the binary star reflection effect. Astrophysical Journal, Part 1 (ISSN 0004-637X), vol. 356, June 20, 1990, p. 613-622., 356, 613-622.