

Stellar Mapping Using Quadratic Limb-Darkening



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The following is an excerpt from a longer piece. For the full text, please visit https://scholar.colorado.edu/concern/undergraduate_honors_theses/5m6Oqt492 or scan the QR code.

Abstract

Transit photometry has been a popular method to find exoplanets and information about star and planet systems many light-years away. Since most stars are too far away to be seen directly, creating stellar visualizations is an important tool for modeling stars. In this paper, I create useful visualizations of stars empirically from transit observations and theoretically from stellar parameters. When creating visualizations, limb-darkening is considered. Limb-darkening is the visual darkening along the outer radius, or limbs, of a star. This effect is more dramatic at shorter wavelengths, such as visible light, making it easier to see the darkening of limbs. A recent transit of WASP-39 captured from the James Webb Space Telescope is used to create stellar models for this star using fitted empirical limb-darkening coefficients. Theoretical models for WASP-39 were also created using theoretically determined coefficients for various wavelengths. As the wavelength increases, the darkening effect of the limbs decreases. Due to slight differences in the limb-darkening coefficients between the theoretical model and empirical model of WASP-39b, the theoretical model is visually darker around the limbs. Errors within the data fitting while creating the empirical model could explain these discrepancies. While complicated, generating empirical and theoretical limb-darkening profiles is a useful way of modeling stars too far away to observe directly.

Lay summary

We can locate brand new exoplanets, many light years away, without ever actually seeing them. Better yet, we can classify and learn vital information about the star and planet system from the exoplanet detection methods. One commonly used detection method is the transit method. The transit method captures the slight dimming of a star's light as a planet crosses in front of it. This decrease in brightness is temporary and regular. Transits provide information about the composition and properties of stars. One such phenomenon is limb-darkening where the brightness of the star appears darker around its edges. Limb-darkening coefficients are calculated using a quadratic relationship between the intensity at a certain point of the star to the intensity at the center of the star. As the coefficients increase, the "limbs" or edges of the star appear darker. The wavelength in which we are measuring the transit also impacts the limb-darkening. At lower wavelengths, the darkening effect is more dramatic. Using these coefficients at different wavelengths we can create theoretical models to show what stars should look like without being able to see them.

The James Webb Telescope (JWST) is capturing numerous exoplanets through the transit method. Launched in December 2021, the JWST contains instruments capable of measuring the slightest changes in the brightness of distant stars. The transit data, collected from the JWST, are fit to infer the best limb-darkening coefficients. We also calculate theoretical coefficients using known physical properties of the star. One particular star captured by the JWST is WASP-39, located 700 light years away. WASP-39 is a dwarf star slightly smaller than our Sun. Models of WASP-39 are created using the empirical and theoretical coefficients. These stellar movies show the appearance of the star at various wavelengths and their corresponding limb-darkening coefficients. The appearances are compared to show how different actual data presents from theoretical models. Providing visual models for stars is an easy way to quantify differences, rather than numerical data.