

Radial Velocity Studies of Eclipsing Binary Systems

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By
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DECLARATION

I, **Ms. Priyanka Chaturvedi**, D/o Mr. Rakesh Kumar Chaturvedi and Mrs. Neerja Chaturvedi, resident of 113, PRL Thaltej Hostel, Ahmedabad 380054, hereby declare that the research work incorporated in the present thesis entitled, “**Radial Velocity Studies of Eclipsing Binary Systems**” is my own work and is original. This work (in part or in full) has not been submitted to any University for the award of a Degree or a Diploma. I have properly acknowledged the material collected from secondary sources wherever required. I solely own the responsibility for the originality of the entire content.

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CERTIFICATE

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Dedicated
to my beloved Baba-Dadi

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ABSTRACT

Eclipsing Binaries (EB) are systems in which two stars orbit around the common center of mass at such an angle that they are seen transiting each other to an observer on Earth. Mass and radius, the two fundamental properties of a star that allow us to infer its age, evolution and luminosity, can be determined precisely from observations of such EB systems. Stars having masses $\geq 1 M_{\odot}$ observationally match well with the theoretical models of convective interiors and radiative atmospheres. However, there have been discrepancies reported for the observed and model-derived stellar radii of very low mass stars (VLMS) of masses $\leq 0.6 M_{\odot}$ (Torres, Andersen and Giménez, 2010). With the motivation to study these VLMS, which are poorly modelled due to limited observational data, we shortlisted a collection of 10 potential EB candidates from the photometric catalogues of Kepler, *STEREO*, and *Super-Wasp* for the EB programme initiated at Physical Research Laboratory (PRL). The aim of the study is to look for single-lined EB systems (for which spectra of only the primary can be recorded), where VLMS occur as companions to F, G, K type primaries, for precise characterization of masses and radii at better accuracies. Radial velocity (RV) data of these sources were obtained using the high-resolution spectrograph, Physical Research Laboratory Advanced Radial velocity Abu-sky Search (PARAS) (Chakraborty *et al.*, 2014) coupled with the 1.2 m telescope at Gurushikhar Observatory, Mount Abu, India. Wideband differential photometry with the help of a 10 inch telescope located at PRL's Mount Abu Observatory has also been performed to complement the spectroscopy. In addition, for a few sources, the archival photometry data have been analysed and included in our study. A software code, PARAS SPEC has been developed to determine the stellar properties of the host star (T_{eff} , $[Fe/H]$ and $\log g$), essential to determine the mass and radius of its companion, based on the synthetic spectral fitting and equivalent width methods. The basic principles and methodology utilized to develop this tool and results obtained when applied to some of the programme stars are discussed.

The major result that has emerged from the work is the confirmation of

discovery and characterization of stellar parameters of four VLMS out of which three are mid M dwarf secondaries (M3/M4 spectral type) in three F+M EB systems namely, HD 213597, HD 23765 and SAO 106989. Orbital parameters and system properties such as period, RV semi-amplitude, semi-major axis, masses, radii of the components and inclination in all but one system are derived here at accuracies of 5 – 8%. The fourth EB, J2343+29, is a K+M EB where the secondary has a mass of $0.098 \pm 0.003 M_{\odot}$, the second least massive star discovered till date, for which masses and radii are determined with accuracies of 4 – 5%. A comparison has been made between the values determined from observations and those derived theoretically for all the M dwarfs. It is seen that for the M dwarfs, HD 213597B and HD 23765B, the radii derived from observations are larger than the model derived values ([Baraffe et al., 2015](#)); while for J2343+29B, the observed value is in agreement with the model. However, for the fourth M dwarf studied here, namely, SAO 106989B, the observationally reported value of the radius based on SW photometry is smaller than the theoretically derived one. We suspect noisy photometry data for erroneous measurements for the radius, demanding thus, the need for accurate ground based photometry. The study of mass-radius relation for VLMS at high accuracies has been limited. A significant contribution from this work is the addition of four VLMS to the existing 26 VLMS studied in literature previously for the determination of their masses and radii at similar high accuracies.

Keywords: Low Mass stars - Eclipsing Binaries: Techniques: High resolution Spectroscopy, Photometry, Radial Velocity: Spectral property of the star

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List of Publications

A. Refereed journals

1. **“The PRL Stabilized High-Resolution Echelle Fiber-fed Spectrograph: Instrument Description and First Radial Velocity Results”**

Chakraborty, A. Mahadevan, S. Roy, A.; Dixit, V.; Richardson, E. H.; Dongre, V.; Pathan, F. M. **Chaturvedi, P.**; Shah, V.; Ubale, G. P.; Anandarao, B. G.

2014, Publications of the Astronomical Society of the Pacific, 126, 133

2. **“Determination of mass and orbital parameters of a low-mass star HD 213597B”**

Chaturvedi, P.; , Deshpande, R.; Dixit, V.; Roy A.; Chakraborty, A.; Mahadevan, S.; Anandarao, B. G., Hebb, L.; Janardhan, P.

2014, Monthly Notices of Royal Astronomical Society, 442, 3737

3. **“World beyond our Own”**

Chaturvedi, P.; Singal, A.

2014, Planex Newsletter, Vol.4, Issue 4, 14

B. Conference Proceedings

1. **Precision radial-velocity measurements on bright Sun-like stars**

Dixit, V; **Chaturvedi, P.**; Chakraborty, Abhijit; Mahadevan, S; Roy, A; Dongre, V

2013, Astronomical Society of India Conference Series – 9

C. Communicated

1. “Detection of a very low mass star in an Eclipsing Binary system”

Chaturvedi, P.; Chakraborty, A.; Anandarao, B. G.; Roy A.; Mahadevan, S.

2015, Monthly Notices of Royal Astronomical Society, under revision

D. Under preparation

1. “Detection of two mid M-dwarfs in F+M Eclipsing Binary systems from PARAS”

Chaturvedi, P.; Chakraborty, A.; Anandarao, B. G.

under preparation

E. Presentations at Conferences and Symposia

1. Group Seminar on ‘Low mass stars in Eclipsing Binary systems’ on 5th July 2015 at MPE, Garching, Germany
2. Group Seminar on ‘Low mass stars in Eclipsing Binary systems’ on 01 July 2015 at Observatory de Meudon, Paris, France.
3. Presented a poster on ‘Study of low mass stars in eclipsing binary systems by Radial velocity with PARAS’ at a conference at IAP, Paris, France between 29th June to 3rd July 2015.
4. Planet Seminar on ‘Eclipsing Binary Stars by PARAS Spectrograph’ at Observatory de Geneva, Geneva, Switzerland on 26th June 2015
5. Contributed talk on ‘Low Mass Stars in Eclipsing Binaries’ on 26 November 2014 at Near Infra Red Workshop, TIFR, Hyderabad.
6. Contributed talk on ‘Low Mass Stars in Eclipsing Binaries’ on 22 August 2014 at APRIM meeting, Daejeon, South Korea.’

7. Contributed Oral presentation on ‘Orbital parameters of low mass stars in Eclipsing Binary systems’ at IISER-Mohali at the Astronomical Society of India (ASI) Meet on 21 March 2014.
8. Presented a poster on ‘Precision Radial-Velocity Measurements on bright Sun-like stars’ at ASI 2013 Meeting held at Trivandrum on 20 February 2013.

Publications attached with Thesis

1. “Determination of mass and orbital parameters of a low-mass star HD 213597B”
Chaturvedi, P.; , Deshpande, R.; Dixit, V.; Roy A.; Chakraborty, A.; Mahadevan, S.; Anandarao, B. G., Hebb, L.; Janardhan, P.
2014, Monthly Notices of Royal Astronomical Society, 442, 3737