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Galactic panel
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Unlocking the full potential of eclipsing binaries for precise and accurate distance measurement

Abstract

We propose to obtain high precision spectroscopic observations of 25 EA-type eclipsing binaries having excellent light curves mostly obtained with the Kepler and TESS satellites. Combining the existing photometric light curves with spectroscopic radial velocity curves the stellar parameters including radii, masses and luminosities will be obtained with very high accuracy (0.1 - 0.5% typically). Then, using Gaia parallaxes we will obtain a very precise surface brightness - color relationship (SBCR) for stars having spectral types in the range from A to G. We will improve the existing calibration of the SBCR by about an order of magnitude in this range of spectral types. The resulting new calibration will allow to massively use eclipsing binaries for precise and accurate distance measurements. It will be also very important for improving distance determinations of Cepheids with the Baade - Wesselink method, and will have strong impact on many other fields of modern astrophysics.

Observing Blocks

Instrument/Telescope	Req. time	Min. time	1^{st} Option	2^{nd} Option
FEROS/MPG 2.2-m	3 nights	2 nights	February Any	March Any
FEROS/MPG 2.2-m	3 nights	2 nights	September Any	October Any

CoIs

Name	Institution	e-mail	Observer?
Paulina Karczmarek	UdeC	pkarczmarek@astro-udec.cl	True
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Weronika Narloch	UdeC	wnarloch@astro-udec.cl	True
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Status of the project

- Past nights: 5
- Future nights: 3
- Long term: False
- Large program: False
- Thesis: False

List of Targets

ID	RA	DEC	Mag
HD142883	15:57:40.46	-20:58:59.0	5.83
V365Pup	07:19:06.53	-35:11:03.2	7.82
HD-3212	05:01:28.28	15:05:28.6	9.09
V338Vir	13:11:17.40	-11:06:21.2	9.13
V358Pup	06:57:39.09	-41:17:40.7	9.65
BD171832	08:23:58.32	17:06:50.6	9.61
HD149946	16:39:03.39	-28:47:13.4	9.85
HD159246	17:34:21.10	-18:36:21.6	9.88
TYC718-1	11:11:33.46	02:47:13	10.26
BD-184538	17:27:47.07	-18:34:54.5	10.67
CD-41-1394	04:22:35.22	-41:29:00.1	10.67
V400Gem	06:37:36.02	17:47:32.6	11.36
EPIC23765	17:12:17.9	-22:38:14	11.11
Mel22	03:41:14.25	20:12:53.5	11.37
HD69863	08:15:15.91	-62:54:56.3	5.16
HD27476	04:17:59.17	-48:23:45.1	8.73
HD212373	22:25:03.14	-53:48:36.9	8.86
AWCol	06:05:11.28	-32:43:51.2	10.31
HD50876	06:54:25.72	-14:27:02.7	7.77
UWLMi	10:43:30.20	28:41:09.0	8.91
HD142883	15:57:40.46	-20:58:59.0	5.83
V4090Sgr	19:39:55.52	-39:25:58.4	6.6

SCIENTIFIC AIM AND RATIONALE

Detached eclipsing double-lined spectroscopic binaries offer a unique opportunity to measure directly, and very accurately, stellar parameters like mass, luminosity, and radius (e.g. Torres et al. 2010), and the distance (Pietrzynski et al. 2019, Nature, 596, 200, see also Kruszewski and Semeniuk 2000, Acta Astron., 49, 561, for a very detailed historical review). It has been demonstrated (Pietrzynski et al. 2019, Graczyk et al. 2014, ApJ, 780, 59) that with current observational facilities, and applying an appropriate surface brightness-color relation, eclipsing binaries have the potential to yield the most direct (one step), and the most accurate (about 1-2%) distances to individual systems within the Local Group galaxies.

A detailed description of this approach can be found in Pietrzynski et al. (2019, Nature, 596, 200) and Kruszewski and Semeniuk (2000, Acta Astron., 49, 561). Briefly, using high-quality spectroscopic and photometric observations, standard fitting routines (e.g. Wilson 1990, ApJ, 356, 613) provide very accurate masses, sizes, and surface brightness ratios for the components of a double-lined eclipsing binary. The distance to an eclipsing binary follows from the dimensions determined this way, plus the angular diameters obtained from the absolute surface brightness, which can best be inferred from the observed V-K colors through a purely empirical calibration. An empirical surface brightness-color relation is at the heart of this very powerful geometrical method.

As has been recently demonstrated the scatter on the SBCR can be as small as 0.017 mag, which means 0.8% precision in angular diameter determination and sub-percent precision in distance determination (Pietrzynski et al. 2019, Nature, 596, 200). This SBCR has been recently used to measure a 1% distance to the LMC, which is currently the most precise anchor for the whole extragalactic distance scale and allowed a 2% Hubble constant determination (e.g. Riess et al. 2019, ApJ, 876, 85, Freedman et al., 2019, ApJ, 882, 34).

However, as can bee appreciated in Figure 1, the exquisite calibration of the SBCR has been achieved so far only for a very narrow and specific range of colors: $2.0 < \text{V-K} < 2.7$ (e.g. spectral types from K0 to K5). For the bluer stars the scatter of the SBCR is much higher, currently yielding a precision of only about 10% on angular diameters for B and A typed stars (see Figure 1, right panel). This restricts very much the use of eclipsing binaries composed of relatively blue stars for precision distance measurements in a number of different environments (Galactic disk and bulge, stellar clusters, nearby galaxies, etc). Especially in the era of massive surveys many eclipsing binaries, excellent in principle for distance determination, have been discovered; most of them have components of the spectral types in the range from B to G for which we are not yet able to measure their distances precisely as long as we do not have a much improved SBCR in this color range.

The immediate objective of our project is to obtain high quality spectroscopic observations for a sample of 25 eclipsing binaries having excellent light curves obtained mostly by the Kepler and TESS satellites. This sample has been very carefully selected based on data from the literature (parallaxes, photometric light curves).

The new spectroscopic data and precision photometric light curves, together with IR (K-band) photometry already obtained for these systems by our group with our dedicated small telescopes at Cerro Armazones Observatory will result in a very precise and accurate determination of the physical parameters (0.1 - 0.8% masses, radii, etc) of our target binaries. Combining sub-percent linear radii with the corresponding precision Gaia parallaxes, angular diameters and thus surface brightnesses will be obtained for 50 stars in the spectral type range from B5 to G2.

A calibration of the SBCR based on eclipsing binaries with geometrically determined distances is the optimal approach (e.g. Kruszewski and Semeniuk, 2000, Acta Astron., 49, 561). Indeed, such an approach has several important advantages: 1) Analyzing the light curve of an eclipsing binary, limb darkenings of the components can be determined, so the component sizes should be free from the limb darkening uncertainty. 2) The surface brightness dependence on gravity is not very strong, but since our goal is to provide a tool for truly accurate distance determinations, this effect should be carefully investigated. The eclipsing binaries offer a unique opportunity to calibrate this dependence since the surface gravities can be accurately measured. 3) Possible third light can be precisely checked and modeled.

The new SBCR we hope to obtain from the requested data will allow to massively use eclipsing binaries to measure the distances to many different objects. As a result it will be extremely useful for the calibration of the whole extragalactic distance scale and a precision (1%) Hubble constant determination. We will also provide a unique catalog of ultra precise stellar parameters for a relatively large sample (50) of stars of greatly varying spectral types. Such a precision is currently needed to better constrain stellar evolutionary models. The SBCR, precisely calibrated for a wide range of colors, will be also very important for many other applications (Baade-Wesselink method for determining the distances of pulsating stars, microlensing, etc).

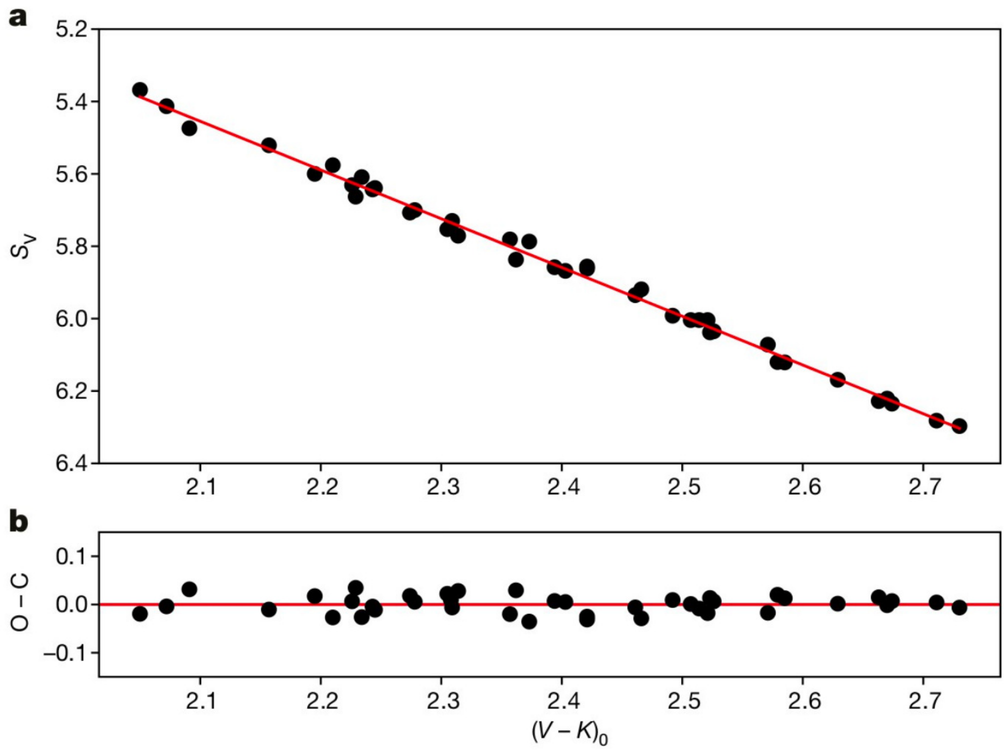

Figure 1: Left panel: newly calibrated SBCR by Pietrzynski et al. 2019 (Nature, 596, 200). The r.m.s. scatter on this relation is 0.018mag, which means an 0.8% precision in stellar angular diameters. The precision of this relationship is fundamental for measuring accurate cosmic distances. Residuals (observed minus calculated) for the fit are also shown. Both Sv and (V - K) are in magnitudes. Our results show that, when properly calibrated, a SBCR can serve as a very powerful tool for precise and accurate distance determinations with eclipsing binaries. However, this particular calibration was obtained for a very narrow range of colors and cannot be used for the majority of eclipsing binaries whose component stars are not in this particular color range.

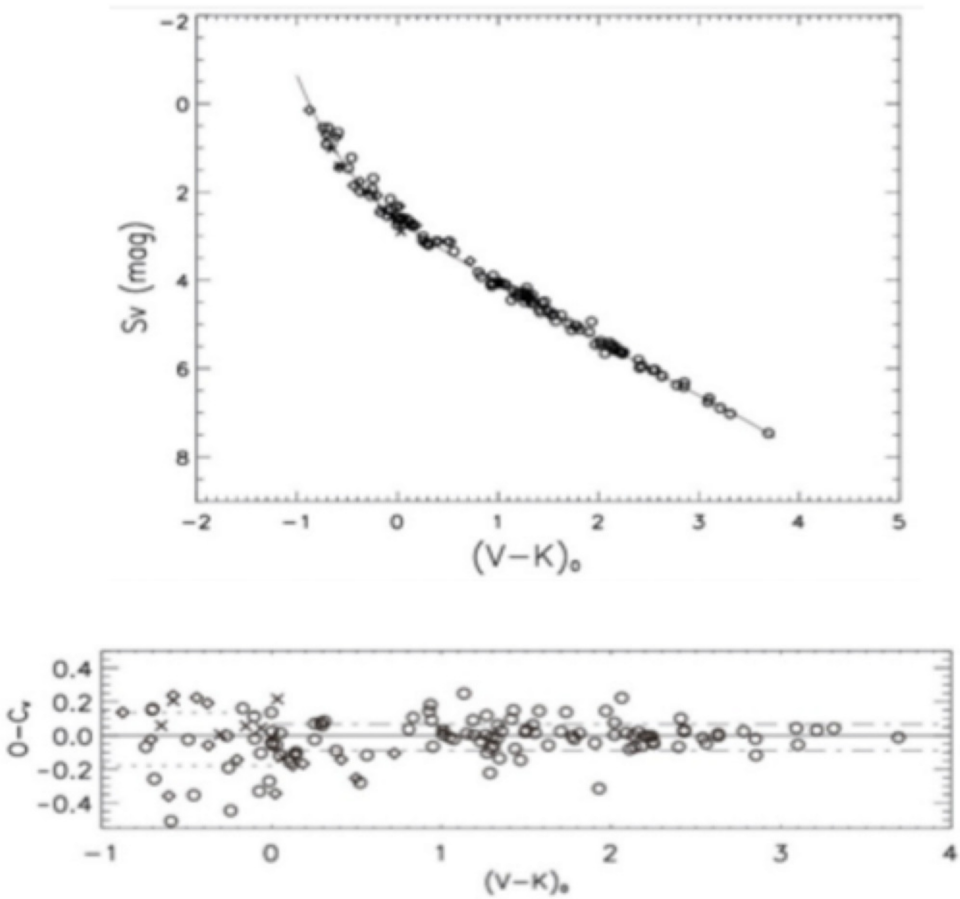

Figure 2: Calibration of the SBCR obtained for Di Benedetto (2005, A&A, 357, 174) for a wide range of colors (upper panel) and residuals (observed minus calulated, lower panel). As can be apreciated the relationship is for stars with colors -1 < V-K < 2, and there is a large scatter on the relationship. The main goal of this proposal is to significantly improve the SBCR calibration for the full range of colors and therefore unlock the potential of eclipsing binaries for massive distance determinations in very different environments, from solar vicinity through the Galactic disk, bulge, and stellar clusters out to Local Group Galaxies.

CURRENT STATUS OF THE PROJECT

Our group dedicated more than 20 years on developing and improving precision distance determination with eclipsing binaries and surface brightness - color relations (SBCR) which are able to accurately predict stellar angular diameters. We published some 30 refereed papers on this topic, including 4 papers in Nature. In particular we managed to measure, after many years of improving the technique, a 1-2% distance to the LMC with our newest calibration of the SBCR for late-type stars (Pietrzynski et al. 2019, Nature, 596, 200). We already tried to obtain a SBCR covering a broad range of spectral types using eclipsing binary systems in tandem with their parallaxes from the Gaia II data release (Graczyk et al. 2017, ApJ, 873, 7). Our first results show the huge potential of this approach to achieve accurate distance determinations not only for late-type, but also for early-type stars. However, better quality data for eclipsing binaries are needed together with final parallaxes from Gaia in order to fully harvest from eclipsing binaries as ultra-precise distance indicators. In 2020A 5 nights (two runs) were allocated to this project. The first run was canceled due to the covid-19. The second run is scheduled for September 2020.

TECHNICAL DESCRIPTION

In general we have a combination of bright early type systems (about 6-9 mag in V) and much fainter (10-12 mag in V) late type systems. For an early type system a S/N of 150 is a minimum to measure a precision radial velocity. For late type stars S/N = 30 is enough to measure very precise radial velocities and disentangle the spectra of both components. On average we can obtain the required S/N for both kind of systems with an exposure time of 300 s, or 650s respectively, taking into account all overheads. In order to reach the desired precision for a given system we need at least 20 observations per target (many of the binaries have eccentric orbits, more epochs are also needed for third light detection). Therefore in total we need 25 x 20 = 500 FEROS spectra. Adding 1h per night for frequent monitoring of radial velocity standards we need in total 101 hours or 12 nights. Due to the locations of our targets on the sky and their periods our observations should be ideally divided into 4 different 3-night runs. In period 2020A we obtained 5 FEROS nights. The first run was canceled due to covid-19. According to our plan we apply for 2x3 nights in 2020B and will apply for 3 nights in 2021A to compensate the canceled 2020A run. The relatively large number of binaries in our target list assures that in every moment we will have at least one target eclipsing binary at a good phase to observe. We used this approach in many previous runs and checked its high efficiency.