Searching for detached EBs in large samples: the persistence of the radius anomaly in low-mass stars

Patricia Cruz[1,2], **John Aguilar**[3], **Hernán Garrido**[4], **Marcos Diaz**[5]

1: Centro de Astrobiología (CAB/INTA-CSIC), Spain; 2: Spanish Virtual Observatory (SVO); 3: Universidad Militar Nueva Granada, Colombia; 4: Universidad de Córdoba, Colombia; 5: Universidade de São Paulo (IAG/USP), Brazil.

Abstract: The majority of the short-period low-mass eclipsing binaries in the literature, with orbital periods of less than 2 days, presents measured stellar radii that are usually 5 to 20% larger than the expected values when compared to stellar models. This inflation trend is known as the radius anomaly of low-mass stars. We have searched for low-mass eclipsing binaries within the Catalina Sky Survey and the Kepler databases to determine their orbital and physical parameters. We adopted a purely photometric method to derive stellar parameters, such as the effective temperature, photometric mass, and fractional radius, by using the available light curves and the broad-band photometry from 2MASS, SDSS and Pan-STARRS. We performed the light-curve fitting with the JKTEBOP code (suitable for detached systems), associated with an asexual genetic algorithm, to derive the best orbital solution the radius of each component. The adopted method allowed an unprecedented analysis of a large sample with a homogeneous set of parameters for low-mass stars in short-period binary systems, despite large individual uncertainties. We characterized a sample of 230 detached EBs from the CSS and 35 detached systems from Kepler EB catalog. The distribution of the studied components in the mass-radius diagram not only confirms the radius inflation in low-mass main-sequence stars but also shows a relative increase of inflation towards lower masses. The distribution also suggests that the secondary components of these short-period systems are more inflated than the primary components, as they present larger radii than primaries of the same mass when compared to stellar evolutionary models.

Motivation

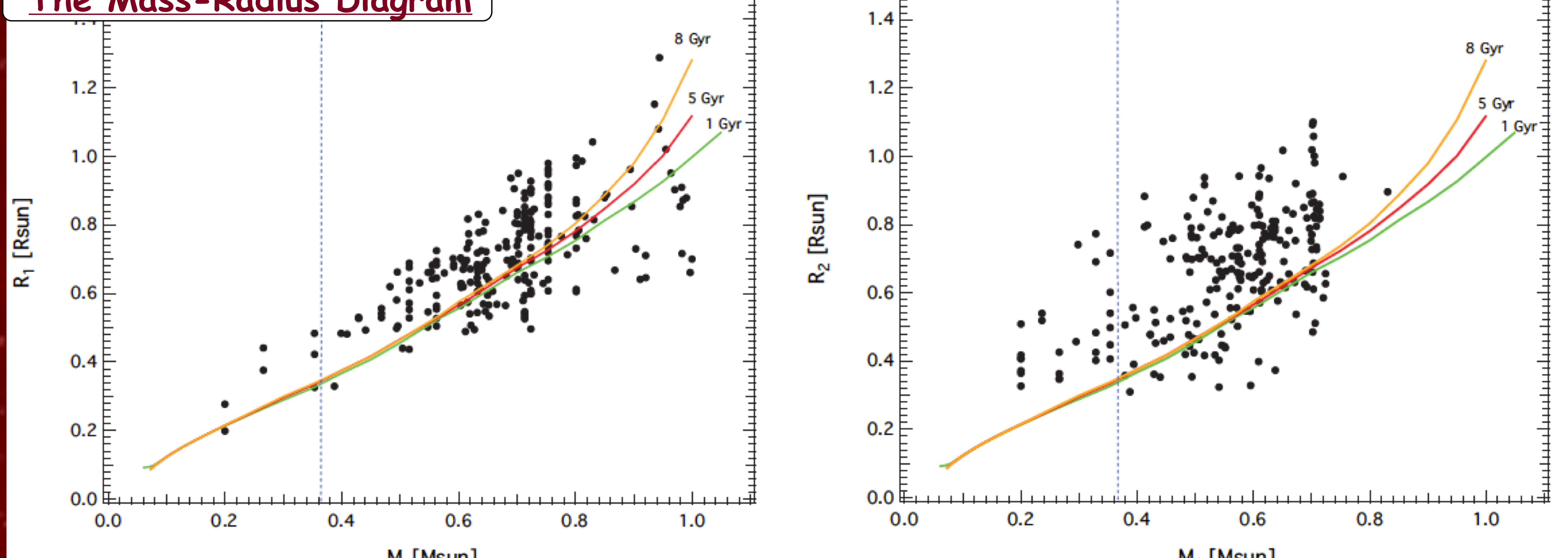
Close-orbiting eclipsing binaries (EBs) present an intriguing trend: the measured stellar radii are usually 5 to 20% larger than the expected value when compared to stellar models (López-Morales & Ribas 2005; Kraus et al. 2011; Cruz et al. 2018). Some of the proposed causes of the radius anomaly include a high stellar metallicity, which would increase the stellar opacity and make the star to inflate to conserve the radiative flux (López-Morales 2007), and a high magnetic activity (Chabrier et al. 2007; Kraus et al. 2011), which would suppress stellar convection and make the star to inflate. However, only a small number of well-characterized LMEBs are found in the literature (Southworth 2015) and a larger sample of detached short-period EBs is needed in order to study the causes of this radius inflation.

Detached EBs in the Catalina Sky Survey (CSS)

We have searched for detached EBs (DEBs), with main-sequence objects only, within the catalogue of 47000 periodic variable stars from the CSS Data Release 1 and 2 (Drake et al. 2012, 2014). The first selection was done by applying two main criteria: selecting those systems with orbital period of less than 2 days, and selecting a limiting cut in a color–color diagram to keep only objects later than a G3 dwarf ($M < 1\ M_\odot$; see details in Garrido et al. 2019).

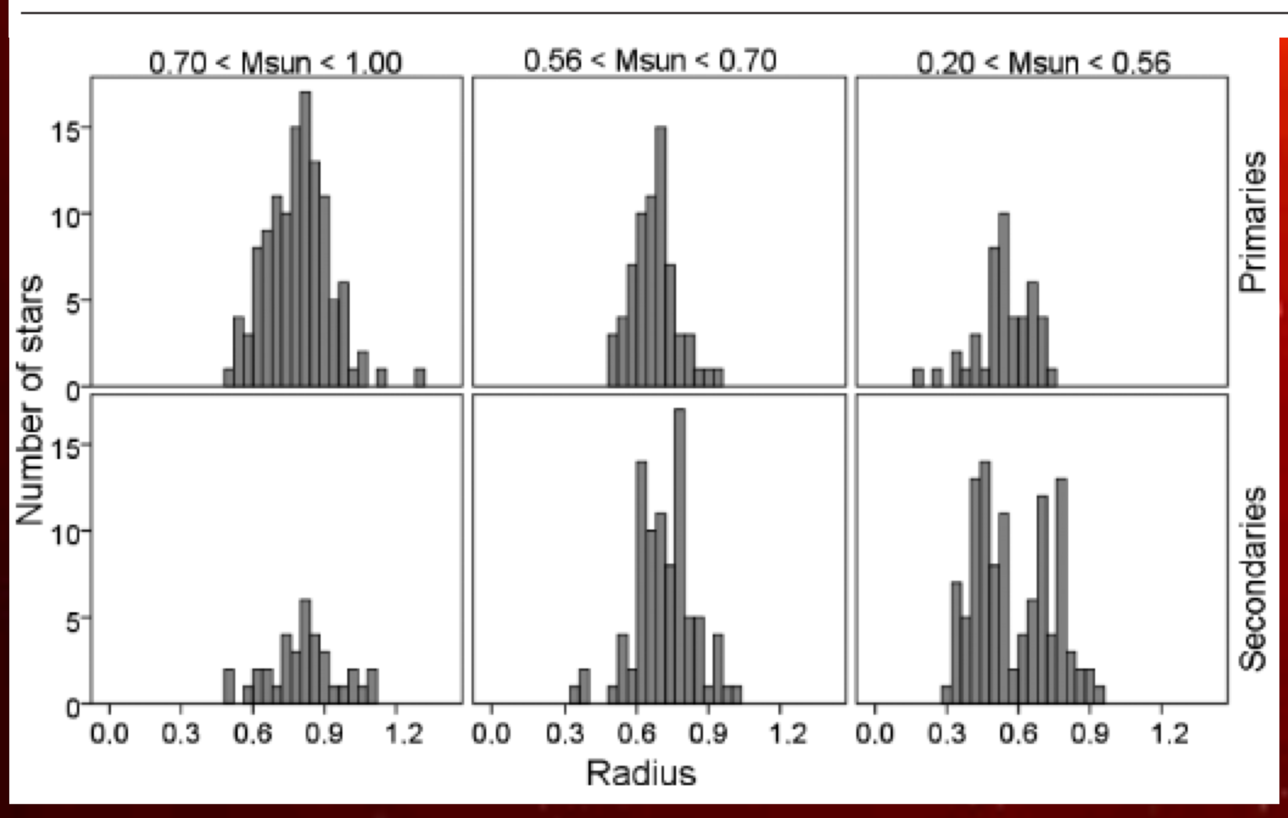
The DEB candidates went under a supervised statistical analysis which used the K-Nearest Neighbors classifiers method (Hartigan 1975), a clustering technique, to assign T_{eff} for each component of the system by searching for similarities between observed data and models based on a multi-color dataset. We then constructed a SDSS–2MASS ten-color calibration grid of synthetic composite colors using 990 synthetic binaries, based on the 1 and 3 Gyr models for dwarf and giant stars from Bressan et al. (2012). Photometric masses were then obtained from the semi-empirical values of stellar colors and effective temperature sequence by Pecaut & Mamajek (2013).

The Mass-Radius Diagram



The Kolmogorov-Smirnov test: For the less massive objects in our sample (with $M < 0.70\ M_\odot$), the significance of the KS test is of only 0.005, suggesting that primaries and secondaries present different radius distribution for the same mass range.

	Mass range ($M_\odot$)	Number of Primaries	Number of Secondaries	Number of stars per bin	Percentage (%)	Statistical significance
BIN 1	$0.70 < M < 1.00$	118	35	153	33.26	0.655
BIN 2	$0.56 < M < 0.70$	66	87	153	33.26	0.005
BIN 3	$0.20 < M < 0.56$	46	108	154	33.48	0.005



A Brief Discussion: These results suggest two different behavior:
1) the persistence of a global trend of inflation for low-mass stars; and
2) these secondary components seem more inflated than primaries.

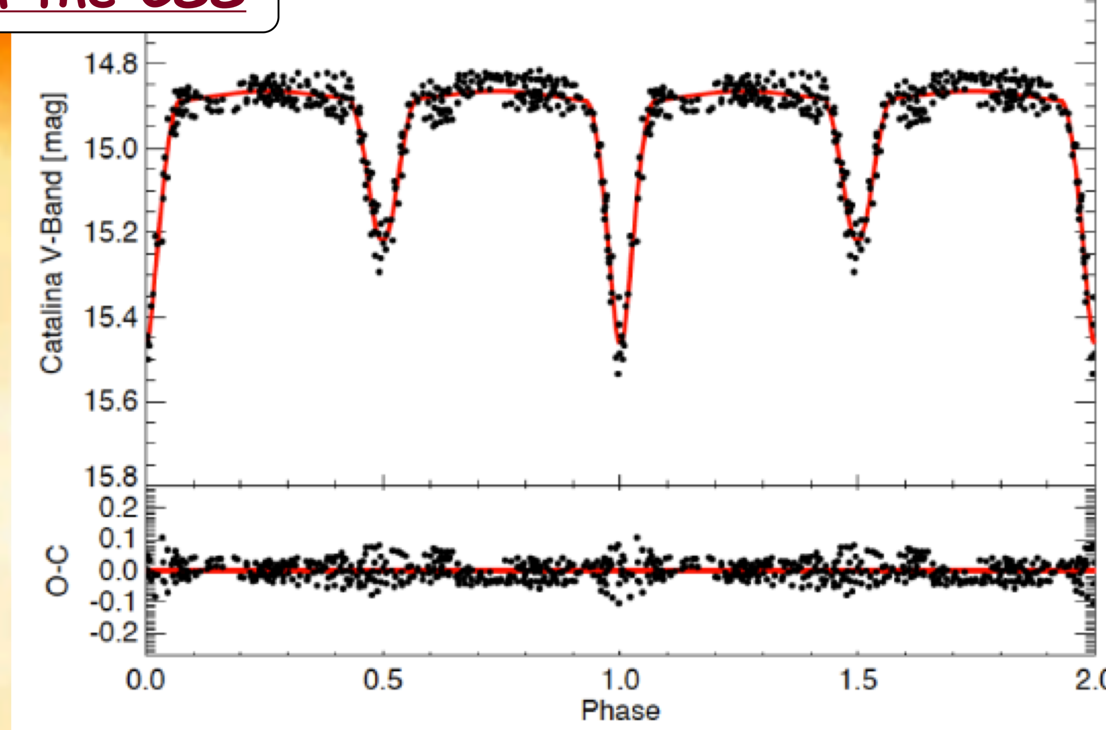
From the literature: 61% of the well-characterized short-period EBs also present more inflated secondary components. Despite the limitation on the precision of measured stellar parameters, the investigated sample follows an inflation trend, which is even more significant for secondary components with masses of less than ~0.6 Msun. We emphasize the importance of increasing the sample of known short-period detached EB systems, with homogeneously derived masses and radii, to investigate the causes of radius inflation.

Modeling Light Curves from the CSS and Kepler

For the light curve modeling, we used the JKTEBOP code (Southworth et al. 2004, 2013) modified with an asexual genetic algorithm (AGA; Coughlin et al. 2011) to obtain the orbital solution for each EB system and derive the stellar radii.

LC example from the CSS

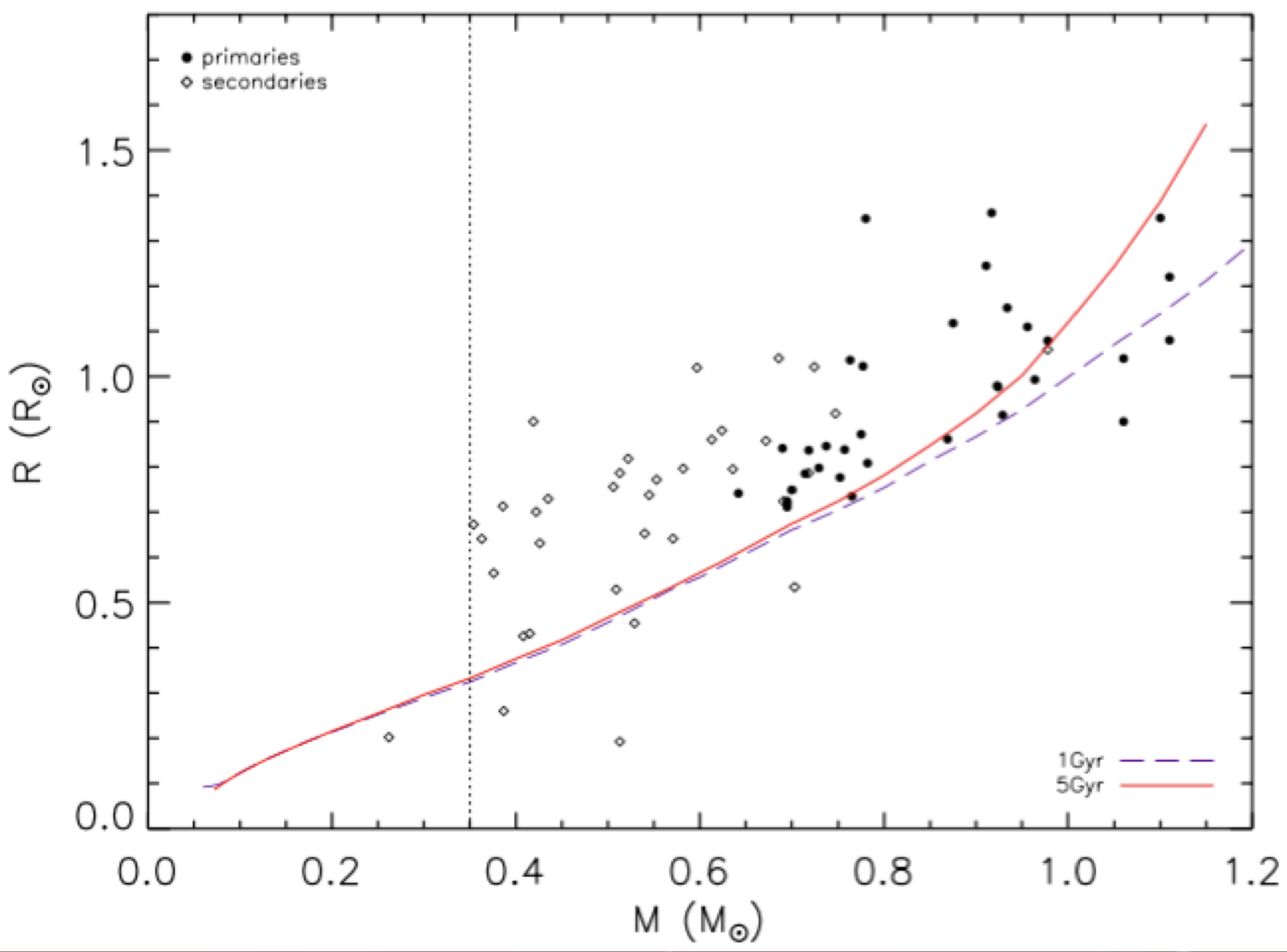
We identified 230 DEBs (Garrido et al. 2019) in the CSS that are composed only by low-mass main-sequence stars, and characterized 35 DEBs (Cruz et al. *in prep*) from the Kepler catalog.



Detached EBs from the Kepler EB Catalog

We also started an analysis of the EB systems from the Kepler Eclipsing Binary Catalog (3rd. Rev., Kirk et al. 2016). We have followed the same procedure described in Garrido et al. (2019), adopting a purely photometric approach. The grid of models constructed now was based on the broad-band photometry from Pan-STARRS and 2MASS, since SDSS was not available for the Kepler field, and we have constructed a more complete grid with over 180000 synthetic binaries (models). We have characterized 35 DEBs so far and these objects present the similar inflation trends mentioned before (Cruz et al. *in prep*).

The Mass-Radius Diagram



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