Mixing processes in atmospheres of magnetically active RS CVn giants

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INTRODUCTION

RS CVn detached binary systems have at least one giant or subgiant belonging to the G-K spectral type. Those systems are characterised by their rapid rotation, typically with periods ranging from a few days to a few weeks. These stars exhibit enhanced levels of magnetic activity, resulting in various observable phenomena such as photometric variability, chromospheric emission lines, spots and flares (Fekel et al. 1986; Schrijver & Zwaan 2000; Cao et al. 2023, and references therein). The strong magnetic fields and rotation exhibited by RS CVn stars may significantly influence on their atmospheres and mixing processes. Magnetic fields can suppress or enhance mixing, depending on their strength, topology, and interaction with convective motions (c.f. Tautvaišienė et al. 2010, 2011; Barisevičius et al. 2010, 2011; Drake et al. 2011; Xing et al. 2021) . The mixing affects the chemical abundances, energy transport, and angular momentum redistribution, thereby are influencing the stellar structure and evolution. In this work, we investigate 15 single-lined RS CVn stars: *29 Dra , *eps Leo, *39 Cet, HD 145742, V* V403 Aur, HD 191588, V* V834 Her, *62 Ser, *37 Com, V* KX Peg, *ksi Leo, HD 200740, *mu Leo, Gl 705, and V* BF Psc.

OBSERVATION

The 1.65 m Richey-Chrétien telescope at the Moletai Astronomical Observatory of Vilnius University in Lithuania was used to observe the 15 RS CVn stars. The Vilnius University Echelle Spectrograph (VUES), which has a wavelength covering of 400 to 900 nm with resolution modes of 36,000, 51,000, and 68,000, is set up on the telescope. We used the 36,000 mode to observe RS CVn stars. Depending on the star brightness, exposure lengths ranged from 1200 to 3600 s, and signal-to-noise ratios ranged from 75 to 200 with a median value of 96. The automated pipeline provided by Jurgenson et al. (2016) was used to reduce the VUES data onsite.

METHOD OF ANALYSIS

For determinations of the atmospheric parameters (effective temperature, T_{eff}; surface gravity, log *g*; microturbulence velocity, and metallicity [Fe/H]), we adopted the classical method of the equivalent widths of atomic neutral and ionized iron lines. The equivalent widths were measured using the SPLAT-VO software. The MOOG (Sneden 1973) codes were used in the same way as the Vilnius node used in the Gaia-ESO Survey (see Mikolaitis et al. 2018). The code was also used to calculate errors in the atmospheric parameters. The spectral analysis was done using a grid of MARCS stellar atmosphere models (Gustafsson et al. 2008) and the solar abundances by Grevesse et al. (2007). Atomic lines and their parameters were selected from the Gaia-ESO line list by Heiter et al. (2015).

In order to calculate stellar ages, we used the code UniDAM (the unified tool to estimate distances, ages, and masses) by Mints & Hekker (2017, 2018). The code uses a Bayesian approach and the PARSEC isochrones (Bressan et al. 2012). As an input, we used the stellar atmospheric parameters determined in this work together with the J, H, and K magnitudes from the Two Micron All-Sky Survey (2MASS; Skrutskie et al. 2006) and the W1 and W2 magnitudes from AllWISE (Cutri et al. 2014).

We cross-matched our sample of 15 stars with the WISE catalog, with a radius of 5 arcseconds. We discarded the unnecessary data from cross-matching and modified the table by adding the parameters necessary for the input file of UniDAM. For calculating the turn-off masses we analysed the evolutionary stages (the red giant branch (pre-core-helium burning; stage I), core-helium burning stars (stage II), and asymptotic giant branch stars (post-core-helium burning; stage III)) and quality flags (see 6.1 section of Mints & Hekker (2017, 2018).

CNO ANALYSIS : The spectral synthesis method was used to derive carbon and oxygen abundances with the TURBOSPECTRUM code (Plez 2012). We used the forbidden line at 6300.3 Å for the O abundance determination. Two C2 molecular bands at 5135 Å and 5635 Å were used to determine C abundance. The interval 7990 – 8010 Å containing 12C14N and 13C14N bands were used for the nitrogen abundance and carbon isotope ratio analysis. More details can be found in Tautvaišienė et al. (2015). Several iterations were performed until the determinations of carbon and oxygen abundances converged. After this, we used both carbon and oxygen values to determine the abundance of nitrogen, and then the carbon isotope ratios.

RESULTS

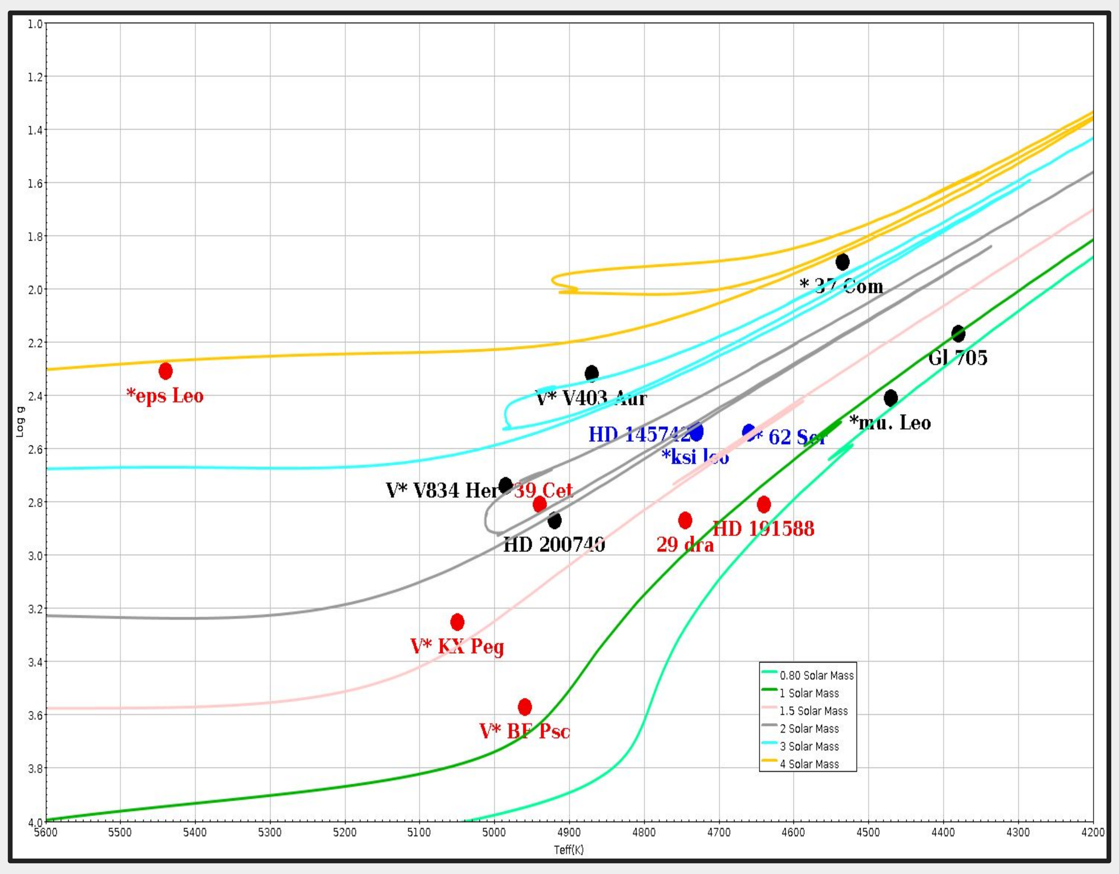

Figure 1: The investigated stars in the log *g* versus T_{eff} diagram along with the PADOVA evolutionary tracks taken from Bressan et al. (2012). The red symbols indicate the stars which are below the red giant branch (RGB) luminosity bump, the blue colour indicates the stars which are at the RGB bump, and the black colour marks the stars that are above the RGB bump.

We used Figure 1 to analyse the evolutionary stage of the stars. In Figure 2, we compare the $^{12}C/^{13}C$ and C/N ratios of the investigated stars with models of the thermohaline- and rotation-induced mixing by Lagarde et al. (2012), with the first dredge-up model, and just the thermohaline-induced mixing model by Charbonnel et al. (2017).The stars *29 Dra, *39 Cet, HD 191588, HD 200740, and V* BF Psc are below the RGB luminosity bump, but their positions in Figure 2 indicate that their carbon isotope ratio is already altered by extra mixing. This gives more evidences that extra-mixing processes may start acting in low-mass chromospherically active stars below the currently predicted place of the bump of the luminosity function of red giants.

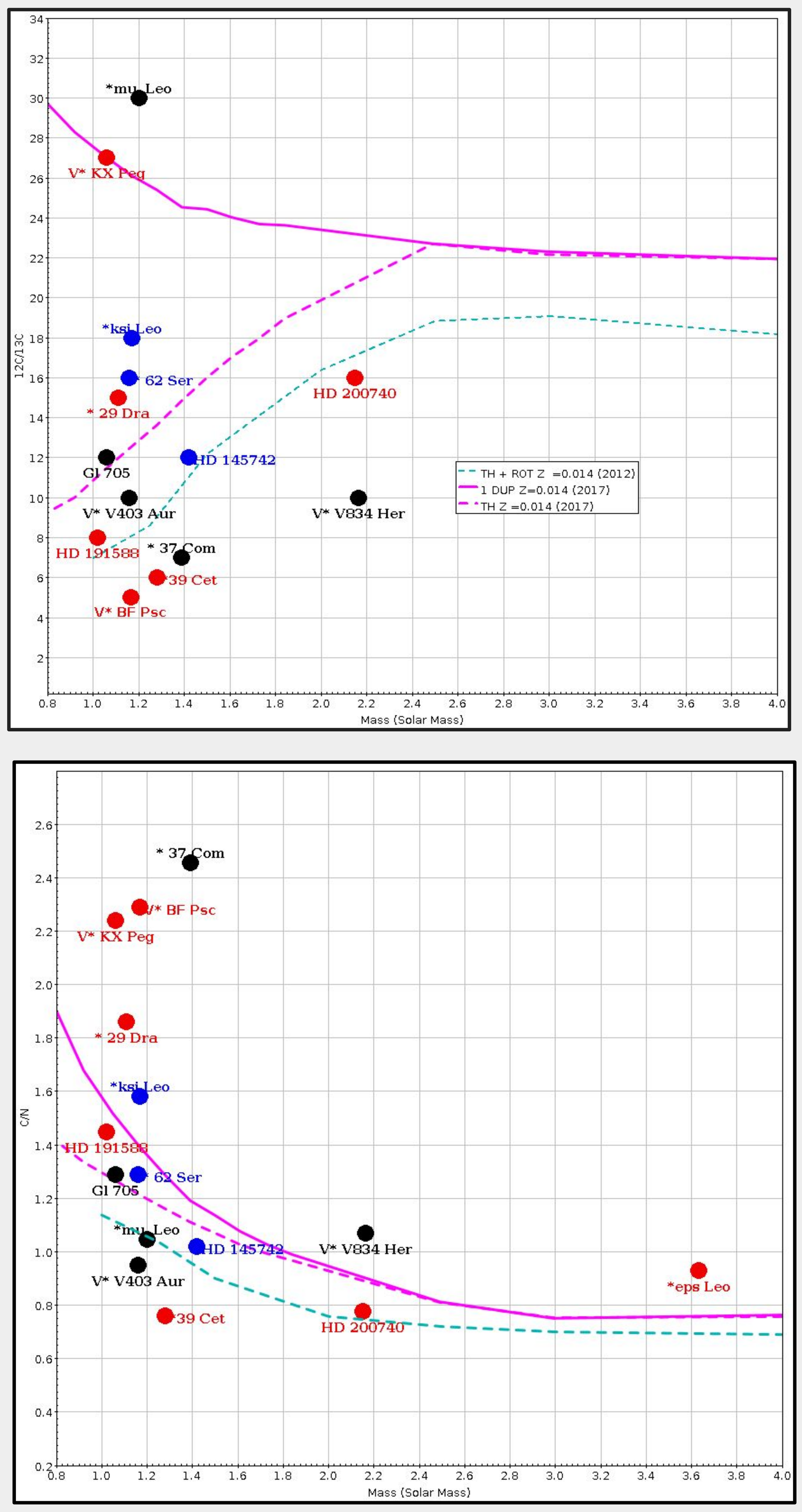

Figure 2: $^{12}C/^{13}C$ and C/N ratios of the investigated stars are compared with theoretical models. The thermohaline- and rotation-induced mixing model (TH+ROT) by Lagarde et al. (2012) is shown by the green dashed line. The solid pink line represents the $^{12}C/^{13}C$ and C/N ratios predicted for stars at the first dredge-up (1 DUP) by Charbonnel et al. (2017), and the pink dashed line represents the model with just thermohaline-induced mixing (Charbonnel et al. 2017).

CONCLUSIONS

In this work, among 15 low-mass chromospherically active RS CVn stars investigated, we found *29 Dra, *39 Cet, HD 191588, HD 200740, and V* BF Psc, which are in the evolutionary stage below the red giant luminosity bump, however already show the extra-mixing evidences in their lowered carbon isotope ratios like it was found in λ And and *29 Dra by Tautvaišienė et al. (2010) and Barisevičius et al. (2010), respectively.

REFERENCES