Preparation of the CARMENES Input Catalogue: Mining Public Archives for Stellar Parameters and Spectra of M Dwarfs with Master Thesis Students

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Abstract. We help compiling the most comprehensive database of M dwarfs ever built, CARMENCITA, the CARMENES Cool dwarf Information and daTa Archive, which will be the CARMENES 'input catalogue'. In addition to the science preparation with low- and high-resolution spectrographs and lucky imagers (see the other contributions in this volume), we compile a huge pile of public data on over 2100 M dwarfs, and analyze them, mostly using virtual-observatory tools. Here we describe four specific actions carried out by master and grade students. They mine public archives for additional high-resolution spectroscopy (UVES, FEROS and HARPS), multi-band photometry (FUV-NUV-u-B-g-V-r-R-i-J-H-Ks-$W1$-$W2$-$W3$-$W4$), X-ray data (*ROSAT*, *XMM-Newton* and *Chandra*), periods, rotational velocities and Hα pseudo-equivalent widths. As described, there are many interdependences between all these data.

1. Contributing to the CARMENES 'input catalogue'

The main goal of the CARMENES[1] instrument is to find exoearths around M dwarfs by the radial velocity technique (see Quirrenbach et al. 2012, 2014a,b). To ensure an efficient use of CARMENES guaranteed time, and the highest chances of success, it is necessary first to select the most promising targets. To achieve this, we are compiling the most comprehensive database of M dwarfs ever built, CARMENCITA, the CARMENES Cool dwarf Information and daTa Archive, which will be our 'input catalogue' (Caballero et al. 2013). As part of the target science preparation, we carry out low-resolution spectroscopy with CAFOS, high resolution spectroscopy with FEROS, CAFE and HRS (Alonso-Floriano et al. 2014) and direct image to identify M dwarfs at close and wide physical separations (Cortés-Contreras et al. 2014). With the help of master and grade students at the Universidad Complutense de Madrid[2], we are mining public archives for additional high-resolution spectra and compiling additional information from the literature on photometry, rotational periods, projected rotational velocity and chromospheric and coronal activity of these M dwarfs.

2. Photometry of M dwarfs

During his MSc thesis, Gonzalo Holgado compiled photometric data in the bands FUV-NUV-u-B-g-V-r-R-i-J-H-Ks-$W1$-$W2$-$W3$-$W4$ from *GALEX*, SDSS, Tycho-2, UCAC4, CMC14, 2MASS and *WISE* archives by using the Aladin Virtual Observatory tool. He have developed a software with the Python programming language in order to study the spectral energy distributions (SEDs) of our potential targets. Each star was studied individually. We discarded photometric data that clearly deviated from the general trend of the stellar SED and of template SEDs of the same spectral type. As a result of the analysis, we generated cleansed SEDs for almost 400 M dwarfs (see an example in Fig. .1).

For further characterization, he studied color-spectral type and color-color relations, and compared them with those tabulated by Bochanski et al. (2007) and Davenport et al. (2014). In addition, he also studied the quality of the photometric filters by contrasting the proportion of data erased in the cleansed data, as well as the relevance of the different color indices in order to assign a spectral sub-type to the stars. Finally, he also quantified the ultraviolet-excess emission comparing the $GALEX$ near ultraviolet band (NUV) with the visible band (V) and identified active early M dwarfs, such as FF And, HD 79211, LP 787–52, OT Ser and GSC 02187–00512 (Fig. .2).

[1] http://carmenes.caha.es

[2] http://www.ucm.es/masterastrofisica/

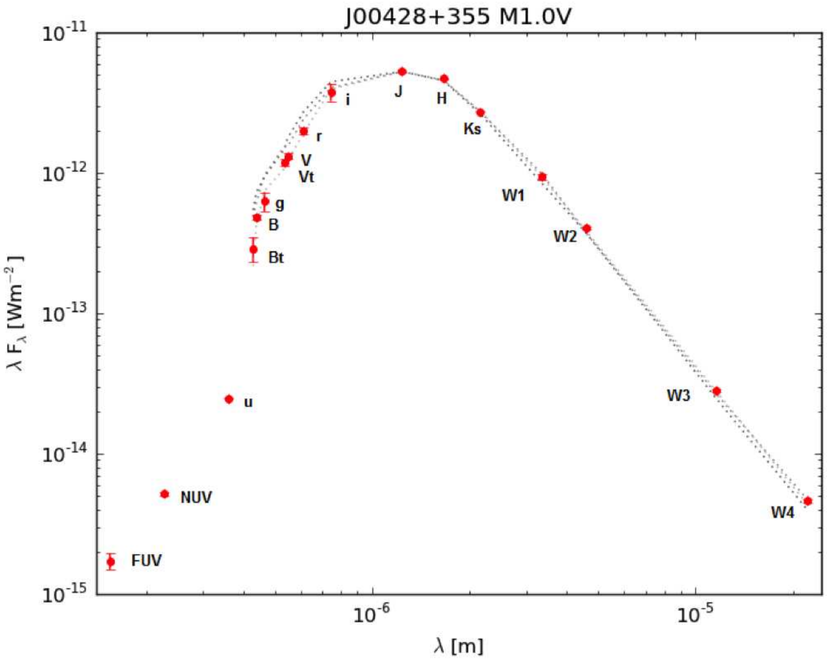

Figure .1: Example of SED for the M1.0 V star FF And. The three dotted lines are the template SEDs for spectral types M0.5, 1.0 and 1.5 V.

3. Mining public archives for high-resolution spectra of M dwarfs

During his MSc thesis, Héctor Martínez-Rodríguez downloaded 128 UVES/VLT spectra from the ESO archive (advanced data products)[3] of 61 CARMENCITA stars in eight channels (see representative spectra of channel BLU437 in Fig. .3) and measured pseudo-equivalent widths (pEWs) of Hα to Hη, Ca II H&K, Na I D_1&D_2 and He I D_3. He measured pEW(Hα) of 27 M dwarfs for the first time and studied its relation to other lines in emission (see pEW(Hβ) vs. pEW(Hα) in Fig. .4). He applied a cross-correlation technique to determine rotational velocities ($v \sin i$). M stars with low Hα emission and slow rotation were used as templates and to calibrate the relation between the cross-correlation function (CCF) width and $v \sin i$ (see Montes et al. 2000; López-Santiago et al. 2003, 2010). By using this method, the student measured $v \sin i$ of 24 stars (7 new) and identified wrong values published in the literature.

A grade student (Manuel Llamas) continued this work by downloading 67 FEROS + 2 HARPS spectra from the ESO archive of 59 CARMENCITA stars determining also pEW(Hα) and $v \sin i$ in the same way. In his CCF analysis, he has identified double and triple peaks in some stars that result to be double-line spectroscopic binaries (GJ 1284, G 272–145, LP 675–076, HG 7–206 and G 050–001) or even spectroscopic triples (LP 653–008). Of them, only one (GJ 1284) was previously known to be an SB2 (Torres et al. 2006).

[3] http://archive.eso.org/eso/eso_archive_adp.html

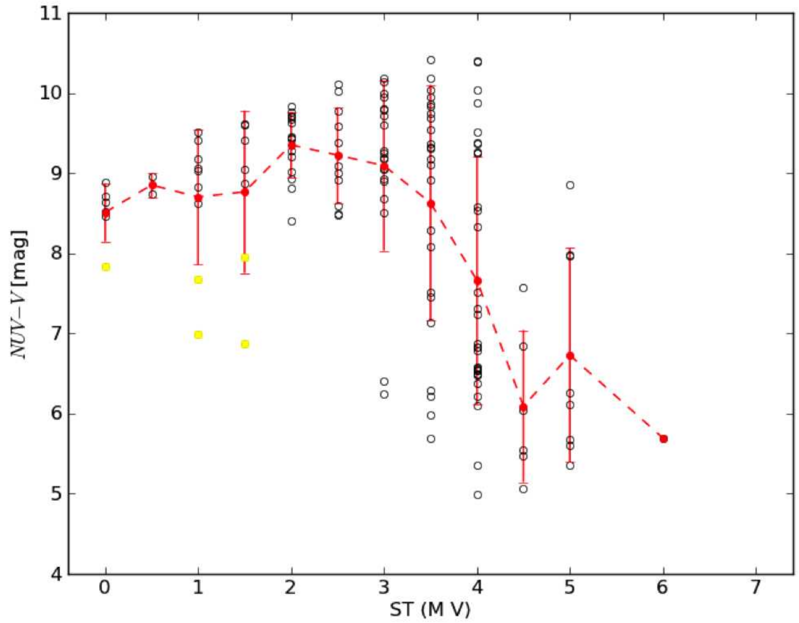

Figure .2: $NUV–V$ vs. spectral type diagram. Red dots are the mean value for each spectral sub-type. Yellow squares are the early M dwarfs with $NUV–V$ excess.

4. X-rays emission in M dwarfs

During her MSc thesis, Esther González-Álvarez searched for information from X-ray data (*ROSAT*, *XMM-Newton* and *Chandra*) using the NASA HEASARC archive (High Energy Astrophysics Science Archive Research Center)[4], the SIMBAD astronomical data base and several publications (e.g. Hünsch et al. 1999; Sanz-Forcada et al. 2011). She studied each star individually to avoid assigning the X-ray emission to a wrong source. Many cases had nearby contaminant sources that hampered the identification of the emitting source. After this detailed study, she added new X-ray count-rate and hardness-ratio data of 188 M dwarfs to CARMENCITA. She calculated X-ray fluxes and luminosity ratios L_X/L_J for 770 stars in total and investigated its variation with spectral type (see Fig. .5) and rotational velocity (see Fig. .6). She corroborated with a large sample that close binaries (red dots in Figs. .5 and .6) are more active than single stars and that X-ray saturation starts at $v \sin i \approx 5$ km s^{-1}.

[4]http://heasarc.nasa.gov/docs/archive.html

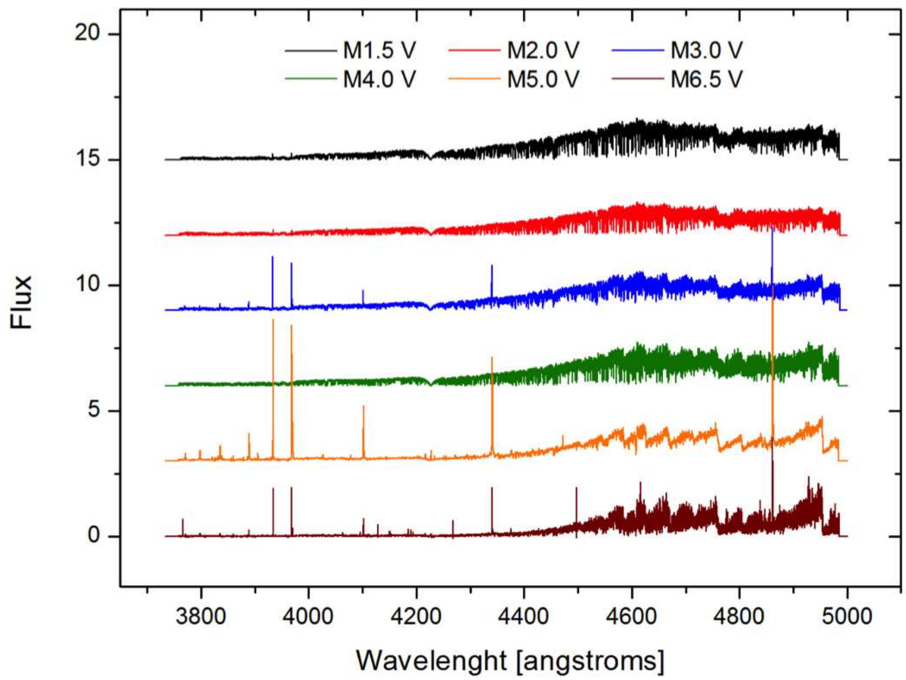

Figure .3: Representative UVES/VLT spectra (from M1.5 V to M6.5 V) of channel BLU437.

5. Activity and rotational periods of M dwarfs

During his MSc thesis, Diego Hidalgo ransacked dozens of publications and compiled rotational photometric periods for 217 CARMENCITA stars (e.g. the MEarth[5] project, Irwin et al. 2011a), rotational velocities ($v \sin i$) for 420 (e.g. Jenkins et al. 2009; Reiners et al. 2012), $pEW(\mathrm{H}\alpha)$s for 1766 (e.g. Hawley et al. 1996; Lépine et al. 2013; Alonso-Floriano et al. 2014), and membership in young moving groups (e.g. Montes et al. 2001; Torres et al. 2008; Shkolnik et al. 2012) for 44. He studied the relation between spectral type, Hα activity level (see Fig. .7), close multiplicity, rotational period (see Fig. .8) and $v \sin i$, from where he identified three stars with large inclination angles $i = 79^o.3$ to $81^o.6$: DT Vir AB, BD–21 1074 A and FFAnd.

[5]http://www.cfa.harvard.edu/MEarth/

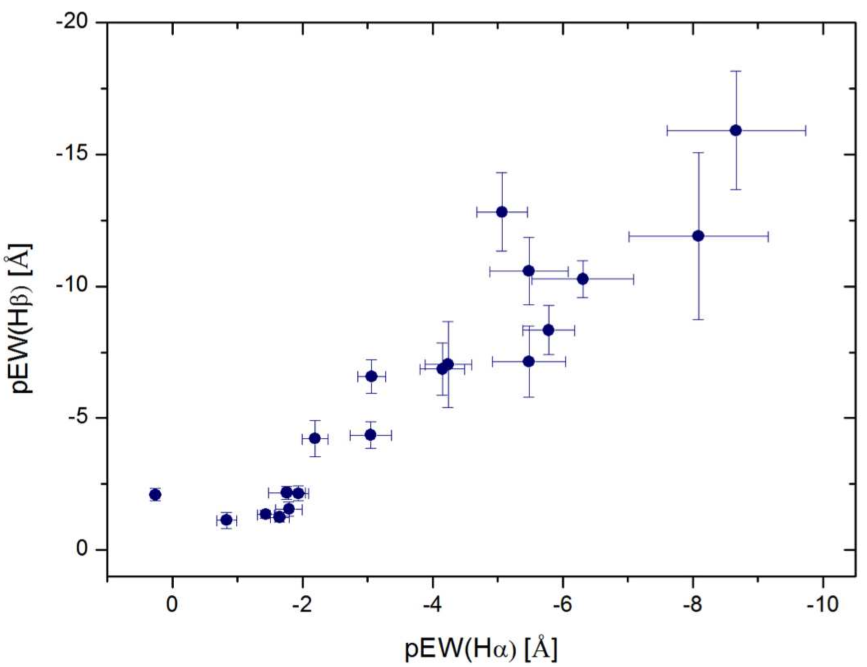

Figure .4: pEW(Hβ) vs. pEW(Hα) diagram.

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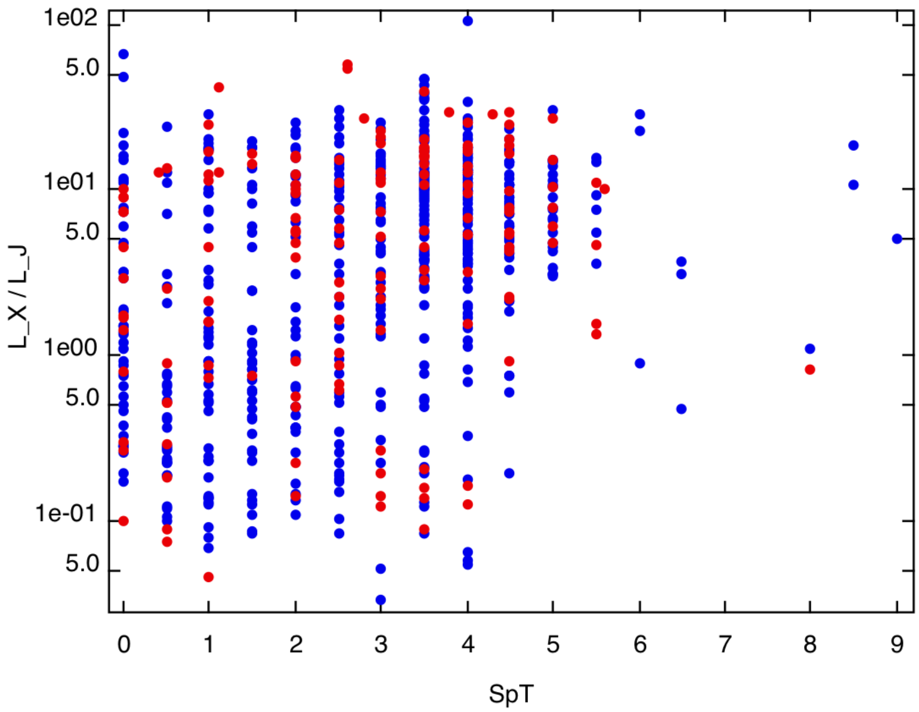

Figure .5: L_X/L_J vs. spectral type diagram (M0 V to M9 V). Blue dots are single stars and red dots binaries with separations less than 5 arcsec.

Hünsch, M., Schmitt, J. H. M. M., Sterzik, M. F., & Voges, W. 1999, A&AS, 135, 319

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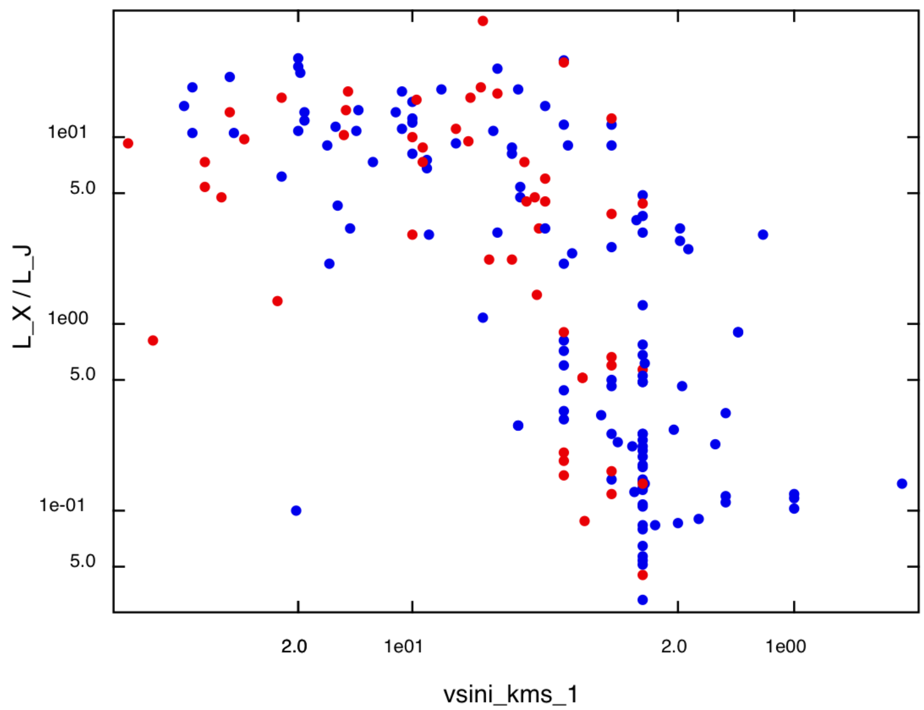

Figure .6: Same as Fig. .5, but for L_X/L_J vs. rotational velocity ($v \sin i$) diagram.

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Torres, C. A. O., Quast, G. R., Melo, C. H. F., & Sterzik, M. F. 2008, Handbook of Star Forming Regions, Volume II, 757

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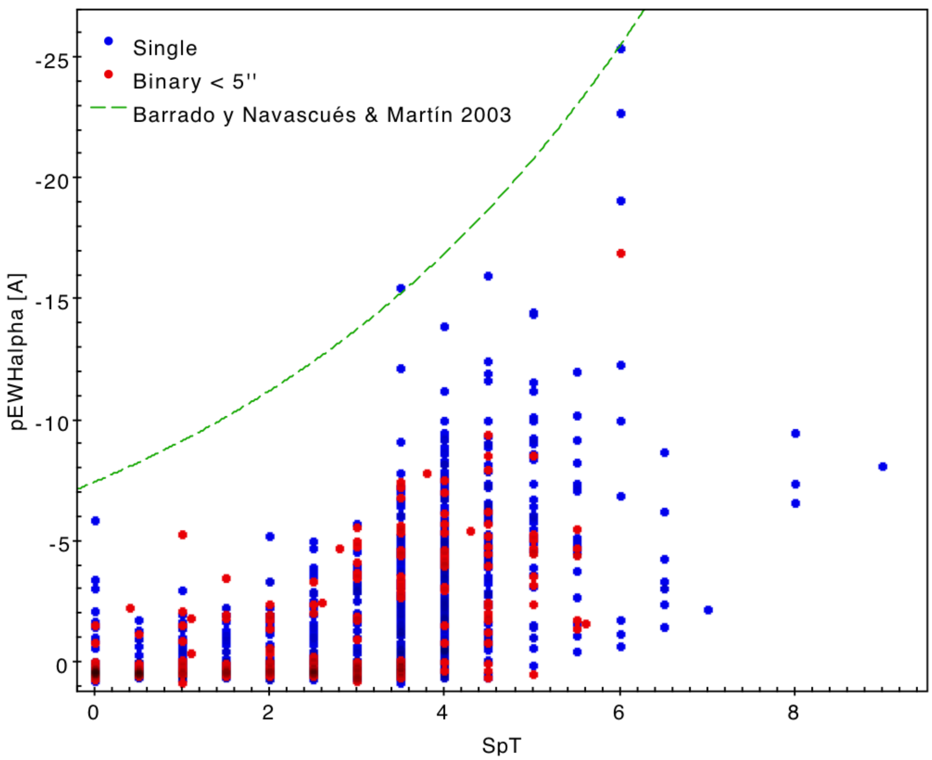


Figure .7: $pEW(\text{H}\alpha)$ vs. spectral type diagram (M0 V to M9 V). The green dashed line is the empirical boundary between accreting and non-accreting objects based on the saturation limit of chromospheric activity of (Barrado y Navascués & Martín 2003).

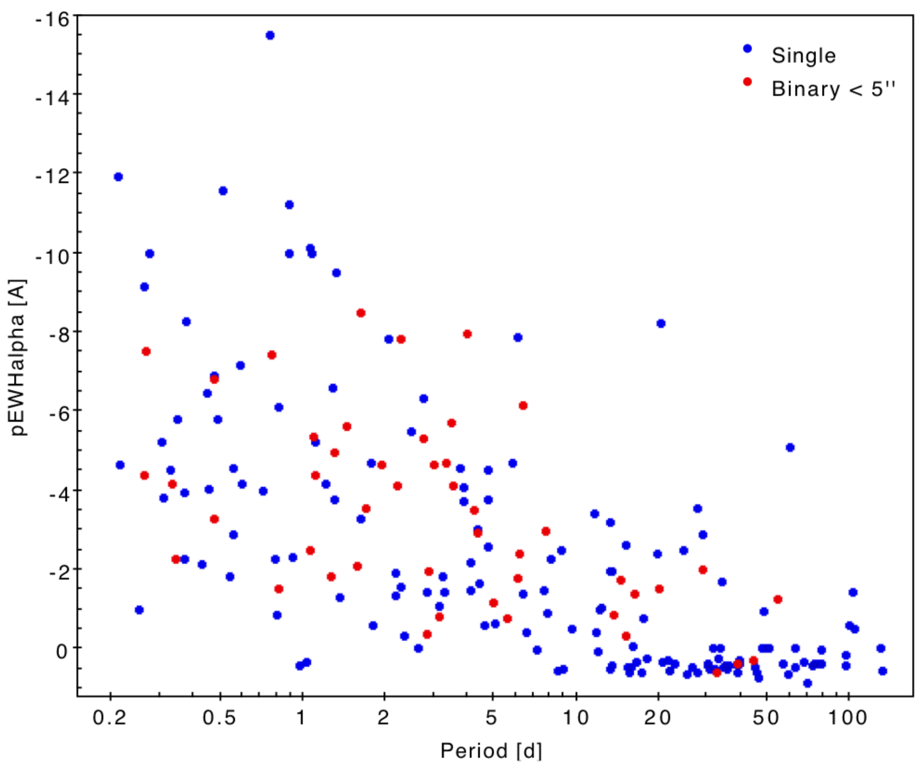
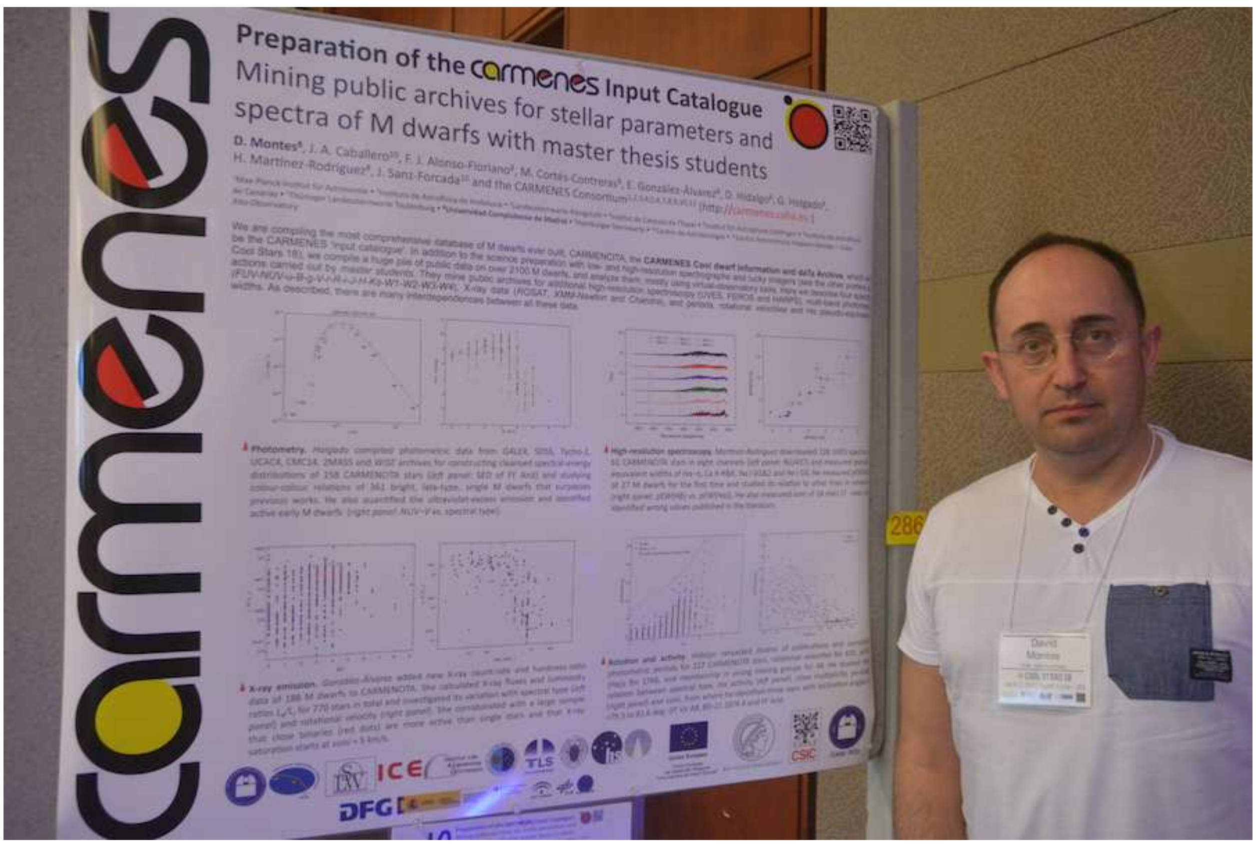


Figure .8: $pEW(\mathrm{H}\alpha)$ vs. rotational period (in logarithmic scale) diagram.



David Montes in front of his CARMENES poster during the CS18 meeting.

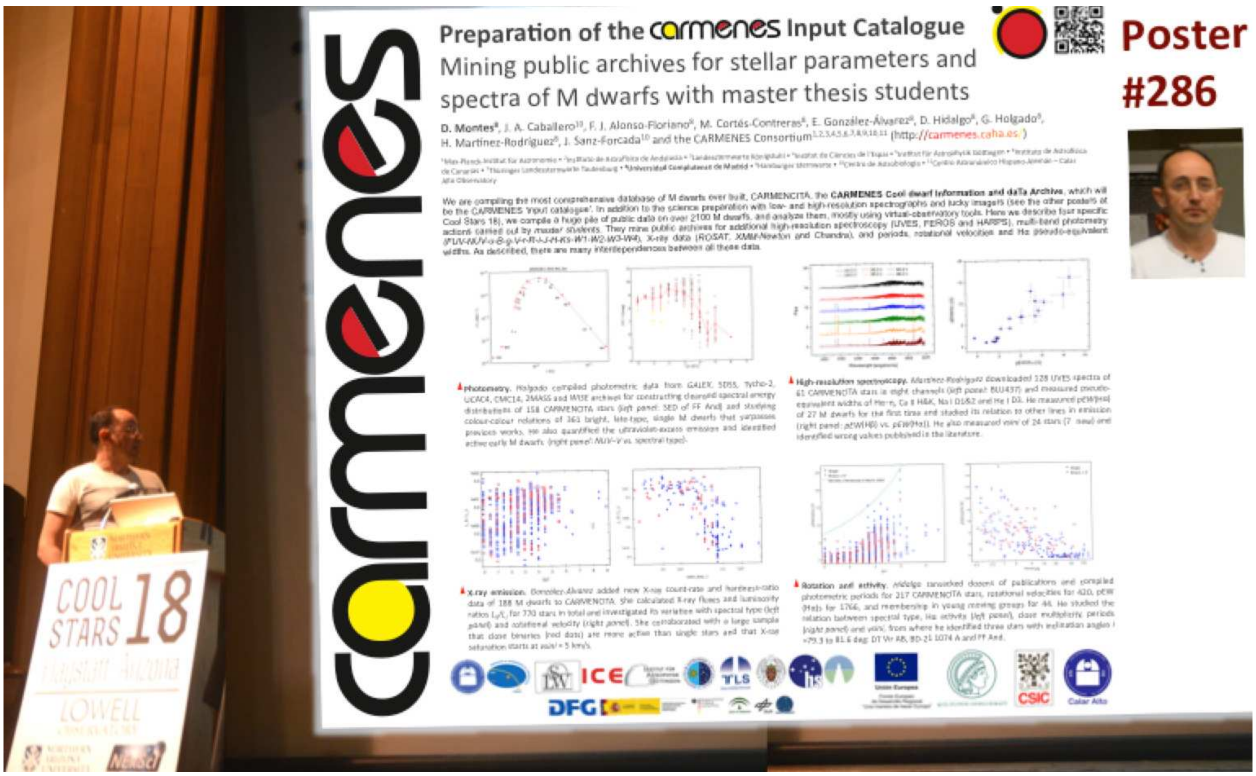


Figure .1: David Montes during the poster pop-up presentation of the splitter session: "Portraying The Hosts: Stellar Science From Planet Searches".

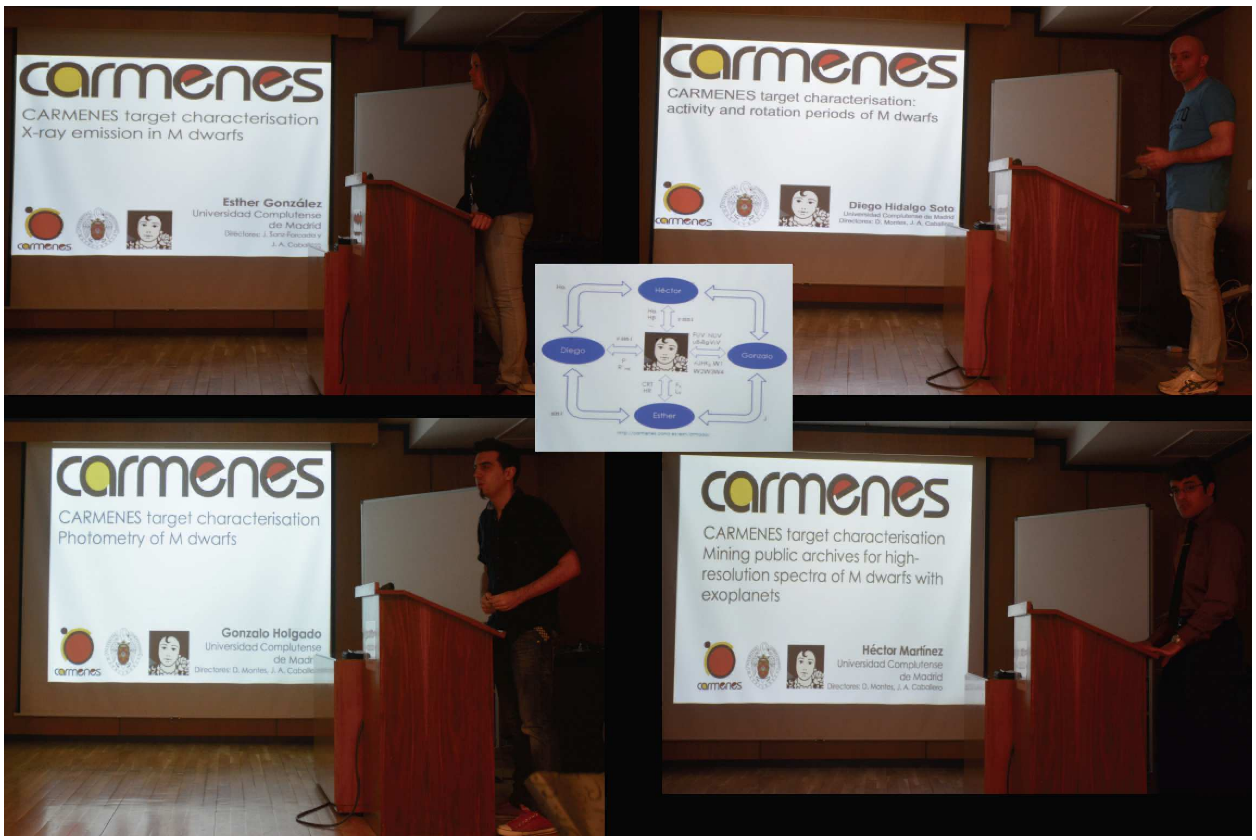


Figure .2: The four master students (E. González-Álvarez, D. Hidalgo, G. Holgado and H. Martínez-Rodríguez) during the presentation of their MSc theses at the Universidad Complutense de Madrid, Master in Astrophysics.