Colours and luminosities of M dwarfs in the CARMENES input catalogue

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We have carried out a comprehensive multi-band photometric analysis involving spectral energy distributions, luminosities, absolute magnitudes, colours, and spectral types, from which we have derived basic astrophysical parameters. We have carefully compiled photometry in 20 passbands from the ultraviolet to the mid infrared, and combined it with the latest parallactic distances and close-multiplicity information, mostly from *Gaia* DR2, of a sample of 2479 K5 V to L8 stars and ultracool dwarfs, including 2210 nearby, bright, M dwarfs. For that, we have made extensive use of Virtual Observatory tools. We have homogeneously computed accurate bolometric luminosities, effective temperatures of 1843 single stars, derived their radii and masses, studied the impact of metallicity, and compared our results with the literature. The over 40 000 individually-inspected magnitudes, together with the basic data and derived parameters of the stars, one by one and averaged by spectral type, have been made public to the astronomical community. In addition, we have reported 40 new close multiple systems and candidates ($\rho < 3.3$ arcsec) and 36 overluminous stars that are assigned to young Galactic populations.

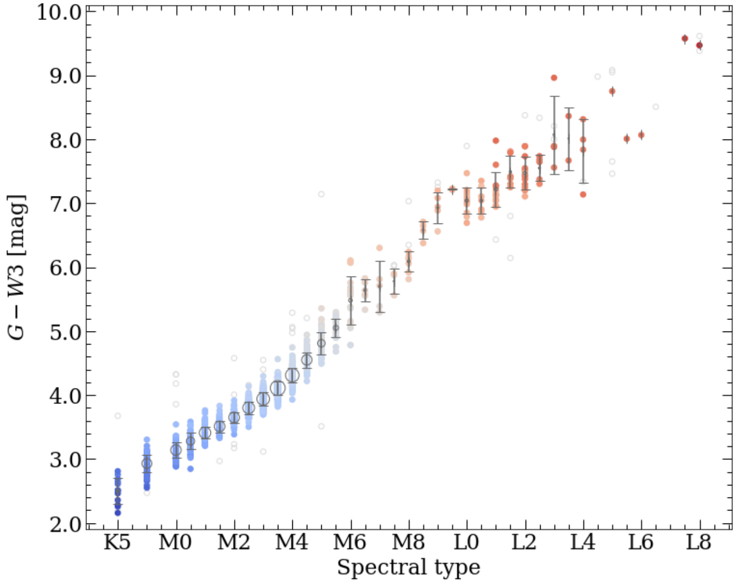
Context

- **M dwarfs** are the most common type of star in the Milky Way. They are excellent candidates for the discovery of **Earth-sized, temperate, rocky planets** in radial velocity surveys (e.g., CARMENES).
- Determining **precise stellar parameters of M dwarfs** has a positive impact on our understanding of how planetary systems form and evolve.
- **Multi-wavelength analysis** provides a powerful tool to relate the empirical observations (e.g., apparent magnitudes, distances, or colours) with these fundamental parameters (e.g., luminosities, masses or radii).
- **Colour diagrams** convey very relevant information about the nature of the stars. Youth or abundance of metals can be usually revealed in one or many colours.

Methodology

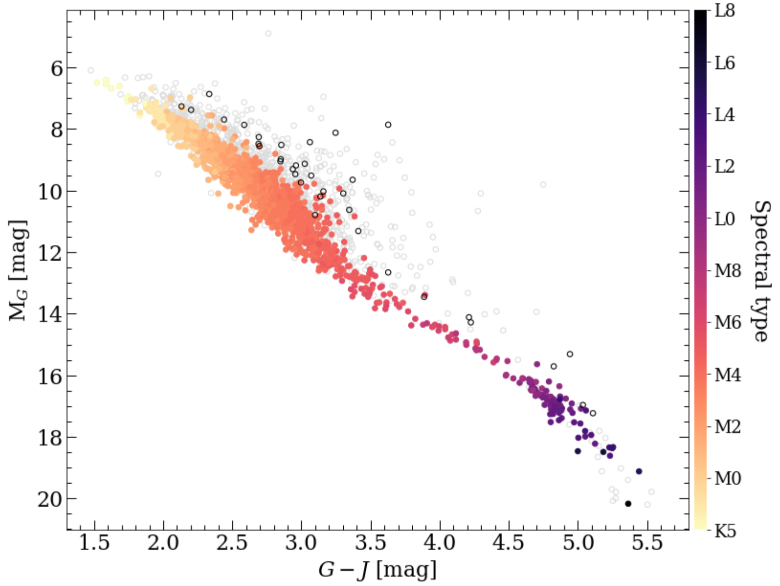
1. Elaboration of a sample of **2479** late-K dwarfs to mid-L objects, including **2210 M dwarfs**.
2. Compilation of their **astrometric information** (coordinates, proper motions, trigonometric parallaxes), mainly from *Gaia* DR2.
3. Compilation of multi-wavelength **broadband photometry**, from far ultraviolet (GALEX *FUV*) to mid-infrared (WISE *W4*) in up to 20 passbands, producing 40000 photometric data points.
4. Evaluation of the **quality indicators** in their respective surveys, in order to ensure well-behaved solutions and accurate relations.
5. Derivation of model-independent **luminosities** and model-fitted **effective temperatures** using the Virtual Observatory SED Analyzer (VOSA). Calculation of **masses and radii**.
6. Parametrisation of **empirical relations** between astrophysical parameters, absolute magnitudes and colours, available in GitHub.

Results



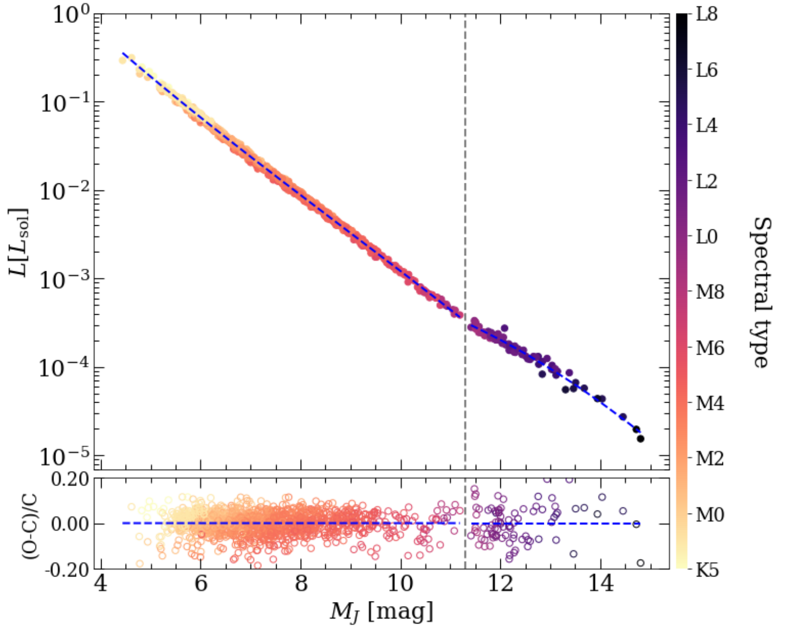
$G-W3$ colour against spectral type.

By using different colour combinations, one can provide a good estimation of the spectral type of a main sequence star.



Absolute magnitude M_G against $G-J$ colour, showing overluminous young stars as black empty circles.

Many outliers are waiting to be revealed as peculiar in some way – maybe binaries, or young objects.



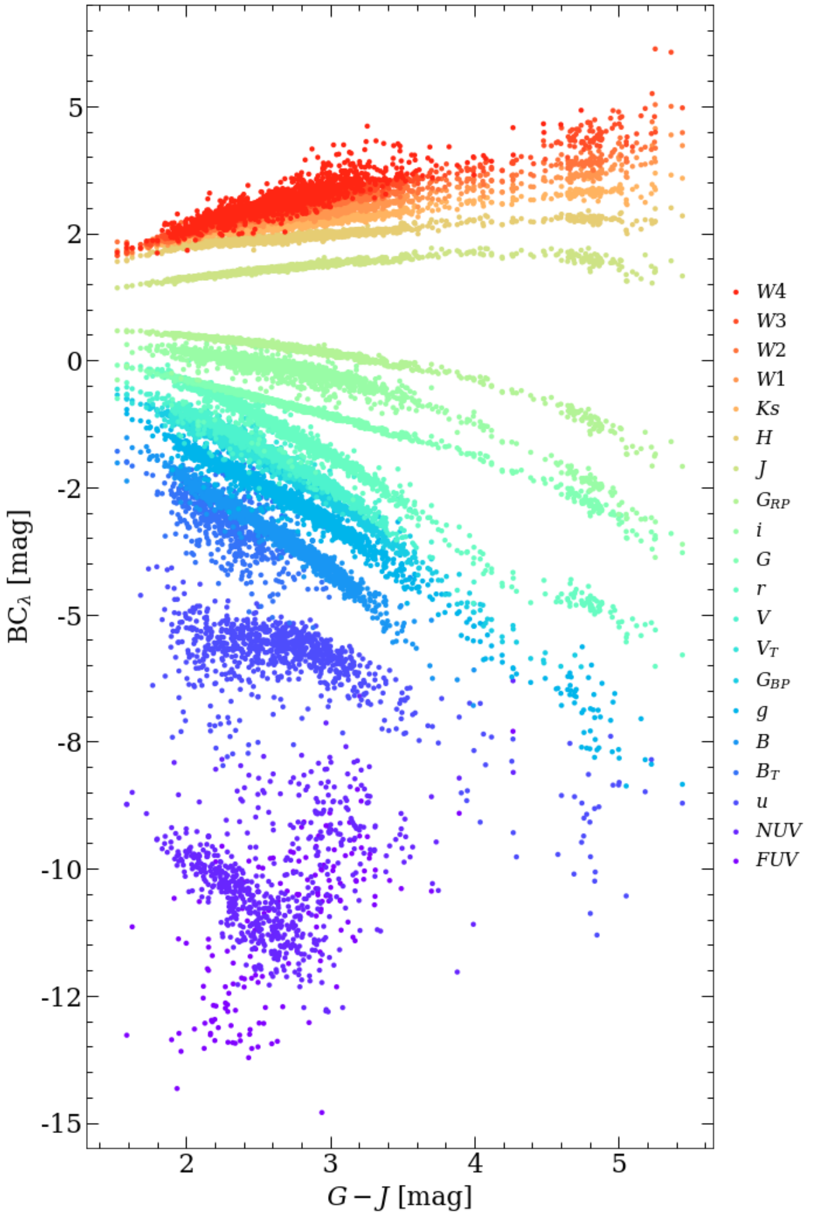
Bolometric luminosity against absolute magnitude M_J.

If J magnitude and a precise distance of a star are known, it is possible to derive its luminosity.

Results

Spectral type	BC_G (mag)	BC_J (mag)	L ($10^{-4} L_\odot$)	$T_{\rm eff}$ (K)	$\mathcal{R}$ ($\mathcal{R}_\odot$)	$\mathcal{M}$ ($\mathcal{M}_\odot$)	N
K5 V	–0.206 ± 0.065	1.490 ± 0.047	1800 ± 420	4400 ± 180	0.693 ± 0.054	0.707 ± 0.057	13
K7 V	–0.393 ± 0.046	1.615 ± 0.027	820 ± 240	3900 ± 130	0.624 ± 0.058	0.634 ± 0.061	75
M0.0 V	–0.488 ± 0.047	1.662 ± 0.031	757 ± 230	3900 ± 140	0.613 ± 0.060	0.622 ± 0.063	104
M0.5 V	–0.565 ± 0.052	1.695 ± 0.028	585 ± 210	3800 ± 110	0.571 ± 0.076	0.578 ± 0.080	60
M1.0 V	–0.598 ± 0.034	1.721 ± 0.029	496 ± 150	3700 ± 85	0.550 ± 0.075	0.556 ± 0.079	112
M1.5 V	–0.664 ± 0.043	1.737 ± 0.033	409 ± 160	3600 ± 90	0.519 ± 0.082	0.524 ± 0.086	96
M2.0 V	–0.740 ± 0.039	1.768 ± 0.022	306 ± 130	3500 ± 105	0.473 ± 0.088	0.475 ± 0.093	99
M2.5 V	–0.810 ± 0.046	1.793 ± 0.026	228 ± 96	3400 ± 97	0.433 ± 0.086	0.432 ± 0.090	118
M3.0 V	–0.898 ± 0.050	1.819 ± 0.030	161 ± 74	3300 ± 87	0.389 ± 0.085	0.386 ± 0.090	144
M3.5 V	–0.978 ± 0.049	1.859 ± 0.030	111 ± 57	3300 ± 92	0.343 ± 0.082	0.338 ± 0.087	193
M4.0 V	–1.080 ± 0.064	1.903 ± 0.025	87 ± 47	3200 ± 88	0.309 ± 0.079	0.302 ± 0.083	170
M4.5 V	–1.188 ± 0.066	1.944 ± 0.034	50 ± 27	3100 ± 88	0.263 ± 0.069	0.253 ± 0.073	88
M5.0 V	–1.363 ± 0.092	1.967 ± 0.034	28 ± 13	3100 ± 58	0.207 ± 0.041	0.195 ± 0.043	52
M5.5 V	–1.480 ± 0.085	2.046 ± 0.041	20.1 ± 8.3	3000 ± 85	0.173 ± 0.032	0.159 ± 0.034	22
M6.0 V	–1.758 ± 0.241	2.084 ± 0.069	11.1 ± 3.9	2900 ± 108	0.138 ± 0.020	0.121 ± 0.021	14
M6.5 V	–1.848 ± 0.064	2.146 ± 0.037	7.2 ± 1.7	2750 ± 124	0.123 ± 0.011	0.106 ± 0.011	6
M7.0 V	–2.020 ± 0.208	2.076 ± 0.036	6.3 ± 1.1	2700 ± 94	0.119 ± 0.009	0.101 ± 0.010	4
M7.5 V	–1.995 ± 0.164	2.055 ± 0.023	5.8 ± 1.2	2500 ± 82	0.121 ± 0.008	0.104 ± 0.009	2
M8.0 V	–2.187 ± 0.097	2.082 ± 0.048	5.1 ± 1.6	2500 ± 91	0.121 ± 0.014	0.104 ± 0.014	7
M8.5 V	–2.383 ± 0.049	2.143 ± 0.034	3.4 ± 1.5	2400 ± 88	0.107 ± 0.015	0.088 ± 0.016	4
M9.0 V	–2.544 ± 0.098	2.151 ± 0.042	2.69 ± 0.35	2350 ± 86	0.096 ± 0.013	0.077 ± 0.014	5
M9.5 V	–2.760 ± 0.123	1.975 ± 0.009	2.35 ± 0.43	2300 ± 45	0.096 ± 0.007	0.077 ± 0.008	2
L0.0	–2.632 ± 0.083	2.031 ± 0.052	2.30 ± 0.43	2275 ± 59	0.097 ± 0.003	0.079 ± 0.004	12
L0.5	–2.722 ± 0.114	2.082 ± 0.090	2.17 ± 0.15	2250 ± 61	0.098 ± 0.004	0.079 ± 0.004	6
L1.0	–2.853 ± 0.141	1.948 ± 0.069	2.08 ± 0.26	2150 ± 165	0.101 ± 0.005	0.083 ± 0.006	15
L1.5	–2.852 ± 0.081	2.004 ± 0.042	1.81 ± 0.35	2000 ± 172	0.112 ± 0.015	0.094 ± 0.016	7
L2.0	–2.943 ± 0.108	1.936 ± 0.110	1.55 ± 0.24	1850 ± 92	0.116 ± 0.013	0.098 ± 0.014	14

Average astrophysical parameters and bolometric corrections (see also right panel) of K5V to L2 stars.



Summary and prospects for the future

- We present the **most comprehensive photometric analysis** to date of M dwarfs in the close solar neighbourhood, collected in diagrams, empirical models, and tabulated average values.
- In the process we identify **40 new binary systems and candidates** not tabulated by the WDS.
- We make the **full Python code** for reproducing these results available in **GitHub**.
- Some **overluminous stars** in our diagrams, not tabulated by us nor classified as young star candidates in the literature, will deserve attention in forthcoming works.
- This work can greatly benefit from gaining accuracy and resolution of the grid in **synthetic models**, as well as from a new approach of model fitting, such as incorporating **Deep Learning capabilities**.
- Our empirical relations assume near-solar metallicities. The **impact of the metal content** of the star on its fundamental parameters still demands for further investigation.