Spectroscopic and archival studies of ultracool dwarf candidates

Antoaneta Antonova[1],
P.Pessev[2], V. Golev[3], D. Dimitrov[1,4]

(1) Institute of Astronomy, 72 Tsarigradsko Chaussee Blvd. 1784, Sofia, BG;
(2) Astronomical Institute of University of Bern, Sidlerstrasse 5, 3012 Bern, Switzerland;
(3) Faculty of Physics, St. Kliment Ohridski University of Sofia, 5 James Bourchier Blvd., 1164 Sofia, Bulgaria;
(4) Shumen University, 115 Universitetska Str, 9700 Shumen, Bulgaria

This research is supported by National Science Fund Grant No. KP-06-N58/3 (2021)

XVIII годишна конференция на Съюза на астрономите в България, 15 - 16 май 2025 г., Белоградчик

Aim of the study

The studies of the nearby stars are paramount for addressing a wide range of astrophysical problems:

- star formation, evolution, the stellar luminosity & mass functions, etc.;
- provide much of our understanding of their nature;
- a complete census of the solar neighbourhood (including spectral classification and magnetic activity indicators) is highly desirable for both earth and space-based planetary searches and exoplanet habitability.

Here we present the results from low-resolution GTC/OSIRIS observations of 45 poorly studied high proper motion candidates for ultracool dwarfs with the aim of both obtaining optical spectral classification and determining the levels of their Hα activity for the first time. In addition, using the GAIA DR2 and DR3 archival data, we determine basic parameters of the sample such as distances and absolute magnitudes.

The sample selection

- colour selection criteria - as described in Metodieva et al. (2015, MNRAS, 446,3878), based on 2MASS colour indices

SpT	$J-H$	$H-K$	$J-K$
M6.5	0.625	0.378	1.003
M7.0	0.649	0.399	1.048
M7.5	0.659	0.416	1.075
M8.0	0.676	0.440	1.116
M8.5	0.696	0.457	1.153
M9.0	0.719	0.475	1.194
M9.5	0.742	0.493	1.235
L0.0	0.765	0.512	1.277

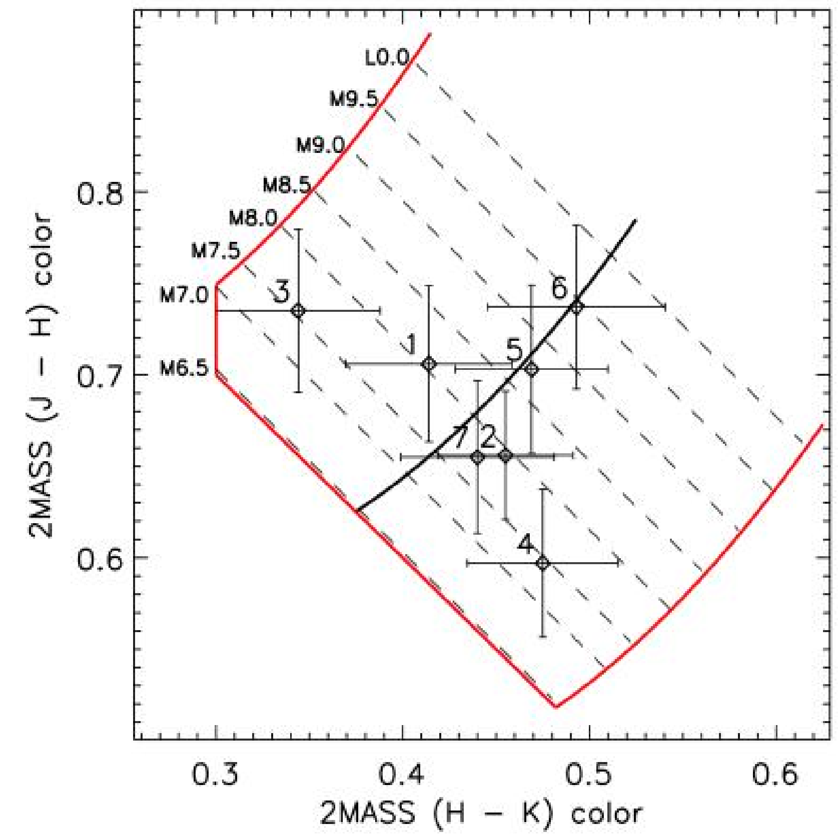


Figure 1. Colour–colour diagram for the late-M dwarf candidates. The thick black line is the polynomial fit to the data for known dwarfs; red curves denote the 3σ deviations from the fit; the straight red lines represent the requirements $(H-K) \geqslant 0.3$, and $(J-K) \geqslant 1.0$. The dashed black lines show the resultant spectral classes as listed in Table 1. The candidates are: 1 – 2MASS J1746+29, 2 – 2MASS J1746+45, 3 – 2MASS J1857+50. 4 – 2MASS J2001+64. 5 – 2MASS J2151+35. 6 – 2MAS:

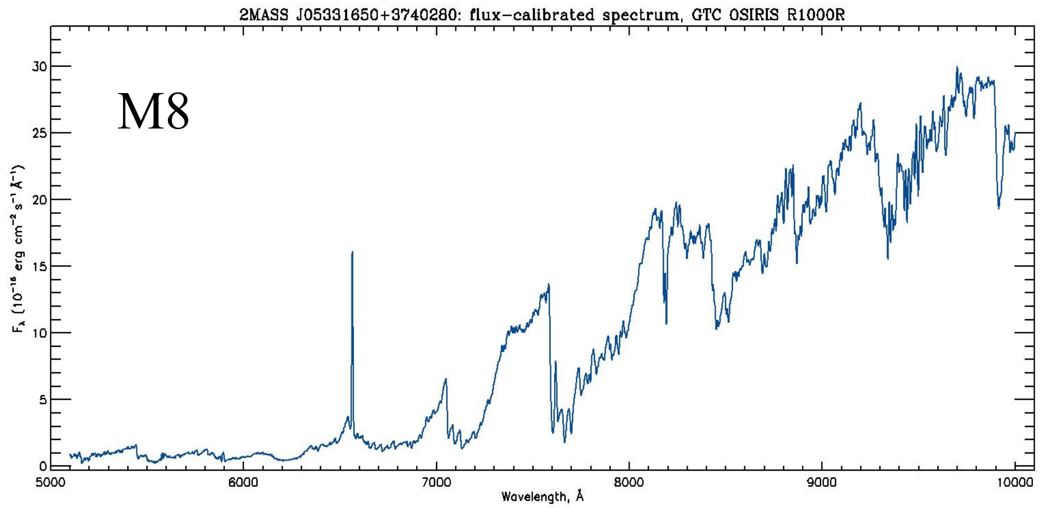
Metodieva, Y. et al., 2015, MNRAS, 446, 3878

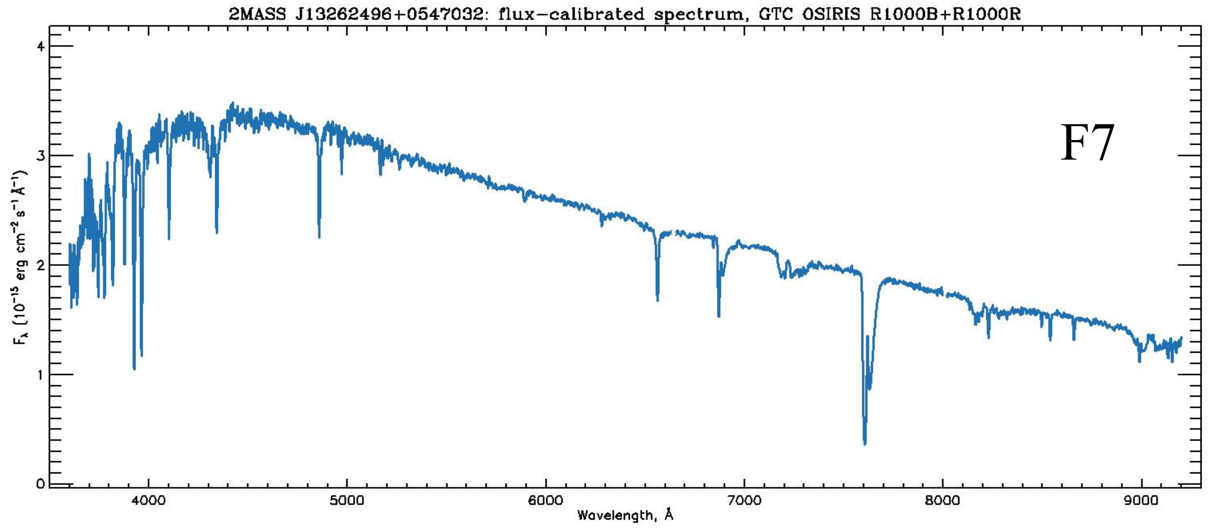
- to distinguish neighbouring from more distant dwarfs or giants - only objects with proper motions > 0.30 ″/year. PMs determined using at least two epoch of observations – first position from the 2MASS catalogue, second from WISE and in some cases there were third epochs from SDSS. The base of the observations varies between 9 and 13 years.

- bright enough to satisfy the observation programme requirements. We've constrained J magnitudes to the range 10 < J < 16.

Observations & reduction

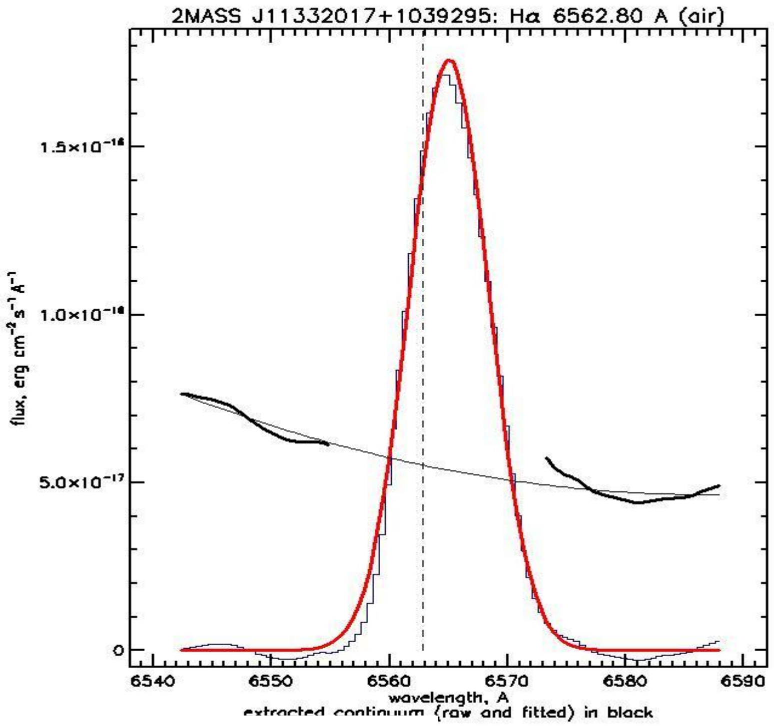
- Low-resolution spectroscopy with the Optical System for Imaging and Low Resolution Integrated Spectroscopy (OSIRIS) at the 10.4m Gran Telescopio Canarias (GTC), using R1000B (blue) and R1000R (red) grisms.
- Performed in service mode within the GTC ``filler'' programme on different nights in two observational seasons - 2016B (dM candidates) and 2017B (dC candidates).
- Data reduction with the software package IDL and its astronomical libraries (Landsman 1995, ASPC, 77, 437).
- The code is written by us and follows standard procedures, e.g. bias, flat-fielding, cosmic ray cleaning, wavelength calibration and flux calibration using standard stars.

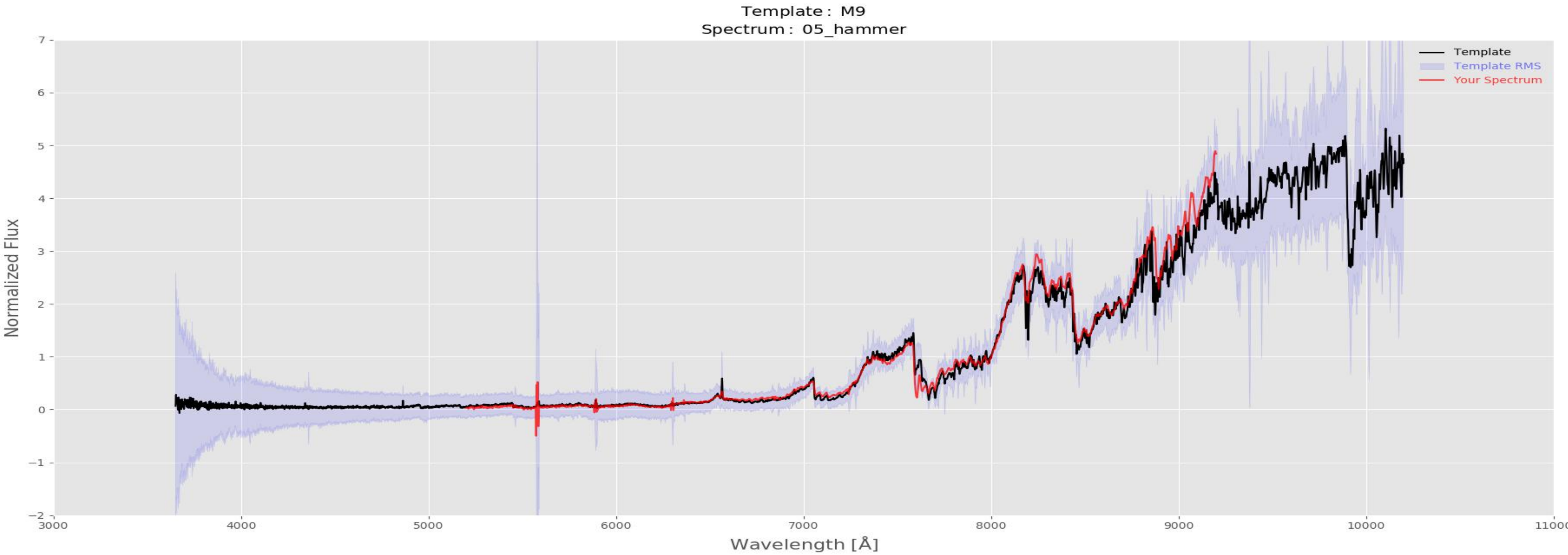




Results 1 - spectral clasiffication

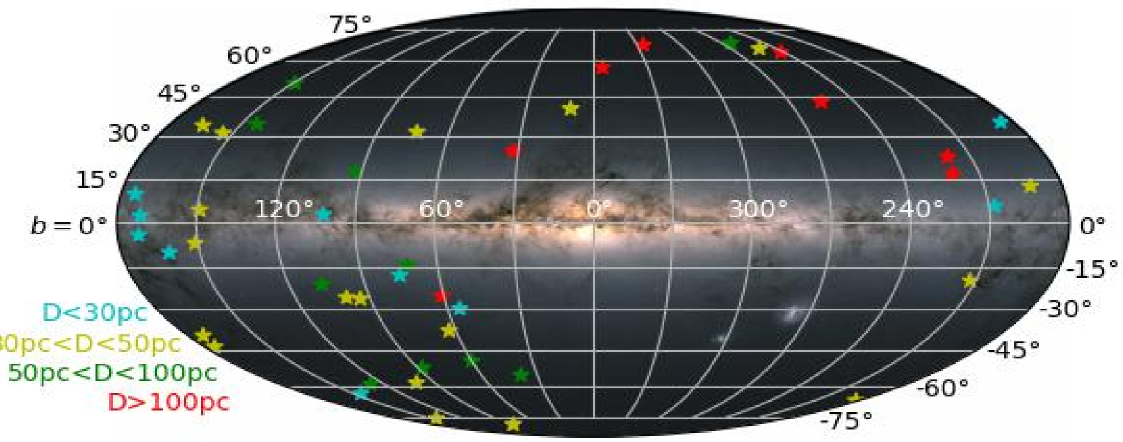
- Spectral classification using PyHammer (Kesseli et al., 2017, AAS, 229, 240.35) and Hammer (Covey, K. R. et al., 2007, AJ, 134, 2398)
- Hα fluxes measured (Table 1).



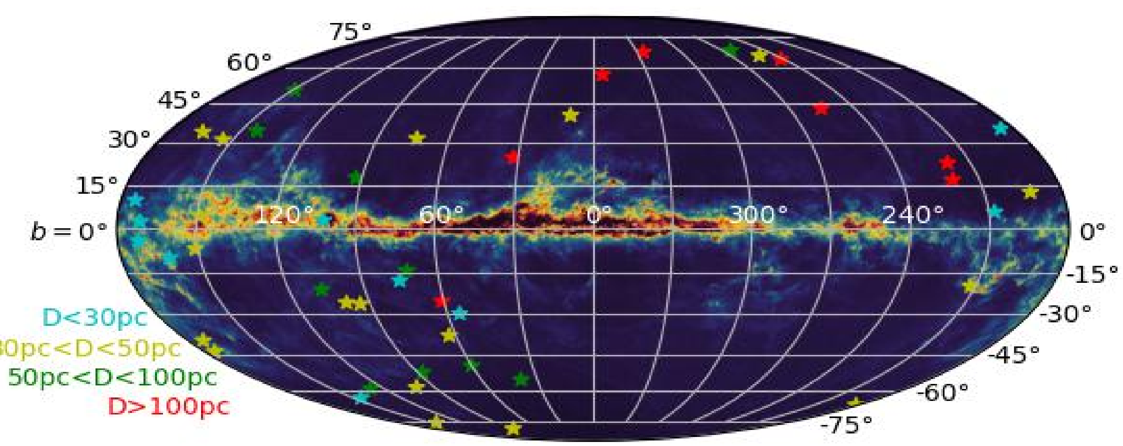


Results 2 - distances

- Distances (in Table1) are calcultaed based on averaged values from the GAIA DR2 and DR3 (Bailer-Jones et al., 2018, Bailer-Jones et al., 2021).
- Extinction is not included in further analyses due to either close proximity or location in a low-extinction area on the sky.
- Most of the objects have no stellar parameters listed in GAIA DR3 database (37 stars).



Position of the studied stars on the map of the Galaxy (top) and on the map of the galactic extincion (bottom). Data for the galactic maps is from GAIA DR3.



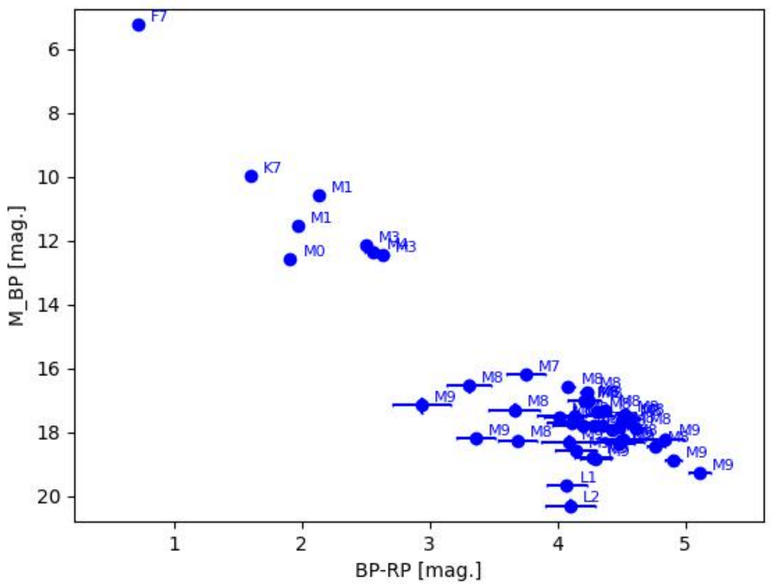
Results 3 - absolute magnitudes

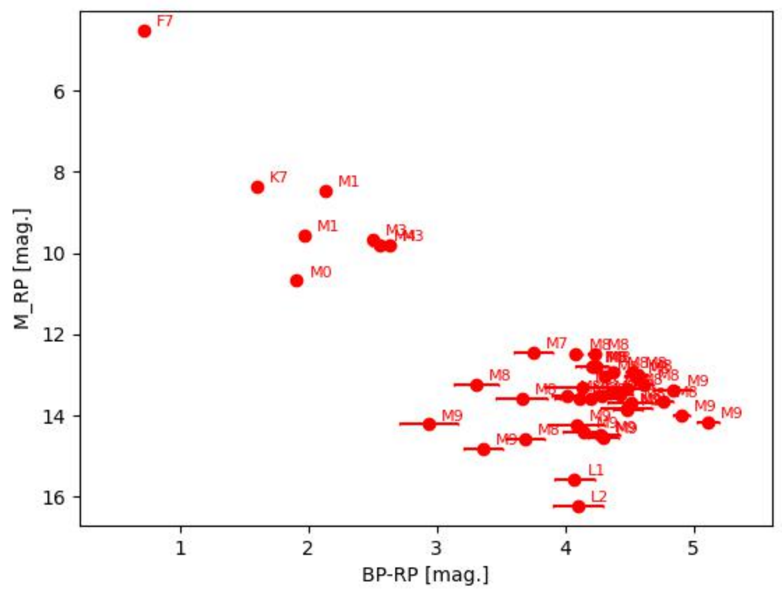
- Based on the calculated distances and GAIA eDR3 G magnitudes, we have calculated the absolute magnitudes for all observed stars, listed below.

Table 1. Derived parameters of the observed sources. Columns are: 2MASS designation; Spectral types (this work); distances (calculated averaging the values from GAIA DR2 and DR3); absolute magnitudes (GAIA using our calculated distances); Hα fluxes and metalicity.

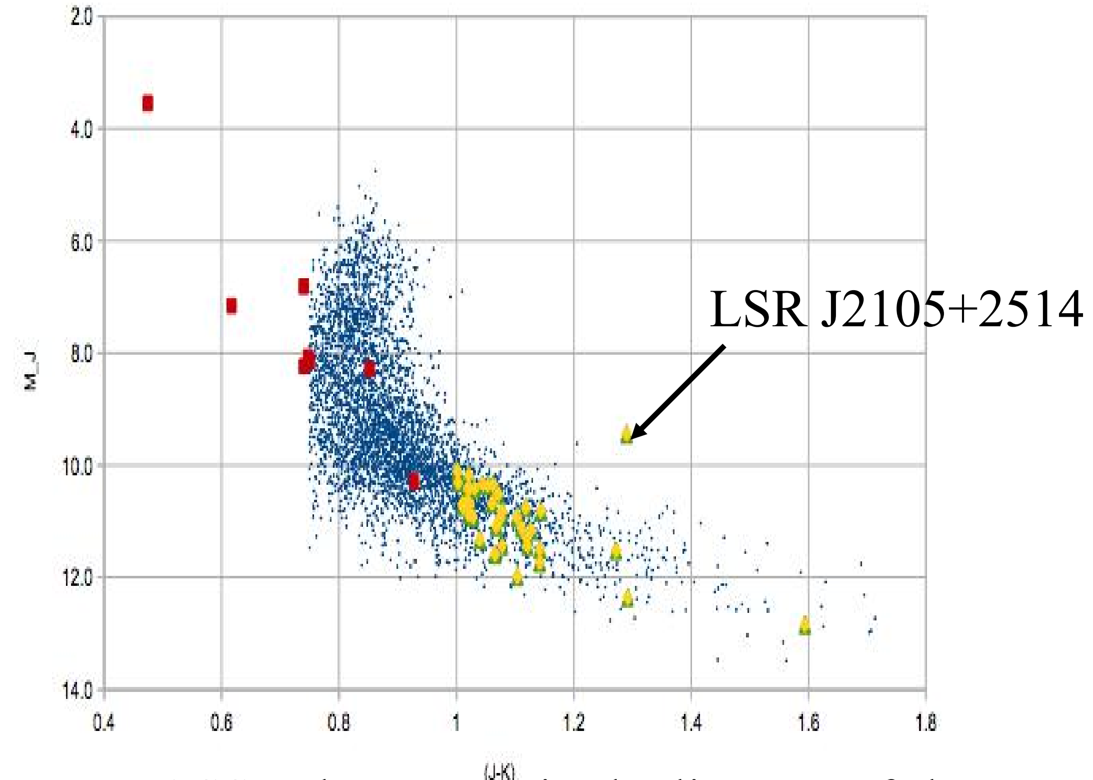
2MASS	Sp. typ (this work)	d pc	G (GAIA) DR3	M_G	$F(H\alpha) x10^{-17}$ erg/(cm^2 s A)	[Fe/H]	Notes
J00050184+0217120	M8	38.94± 0.17	17.836± 0.003	14.88±0.01	30.01 ± 0.78	0	
J00271090-1813097	M8	39.82± 0.17	17.571± 0.003	14.57±0.01	5.44 ± 0.86	0	
J01013443+0336216	M8/7.5	87.60± 2.4	19.482± 0.005	14.77±0.06	5.60 ± 0.25 8.96 ± 0.22	+0.5	var?
J01135973-1408174	M9	35.48±0.16	18.763± 0.004	16.01±0.01	3104.0 ± 24	0	var?
J01304280-0211294	M8	26.07±0.08	17.300± 0.003	15.22±0.01	112.07 ± 0.55	+0.5	
J02133713-1343228	M8	39.4± 0.3	19.116± 0.004	16.13±0.02	2.30 ± 0.39	+0.5	
J03110650+0417360	M9	42.5±0.3	18.558± 0.004	15.42±0.02	13.30 ± 0.26	0	
J03184214+0828002	M8	40.9±0.2	18.039± 0.004	14.98±0.01	43.92 ± 0.67	+0.5/+0.19	comp. to NLTT 10534
J03421129+4629365	M9	34.22±0.12	18.109± 0.003	15.44±0.01	18.89 ± 0.37	0	
J04134574+3709087	L1	19.26±0.05	18.620± 0.003	17.20±0.01	4.32 ± 0.39	0	
J04204796+5624202	M8	32.43±0.07	16.980± 0.003	14.43±0.01	18.24 ± 1.46	+0.5	
J05085506+3319272	L2	18.86±0.11	19.141± 0.004	17.76±0.01	1.38 ± 0.65	0	
J05331650+3740280	M8	26.20±0.04	16.482± 0.003	14.39±0.01	843.14 ± 0.65	0	
J05385671-0808296	M8	32.45±0.06	17.061± 0.003	14.51±0.01	26.04 ± 1.60	+0.5	
J06142970+3833415	M9	25.23±0.10	18.143± 0.004	16.13±0.01	14.81 ± 0.62	0	
J07011762+2401319	M8	35.68±0.10	16.742± 0.003	13.98±0.01	68.72 ± 2.36	0	
J07030328+0711008	M8	26.60±0.05	16.869± 0.003	14.75±0.01	94.77 ± 1.96	-0.5	
J07561916+6234493	M8	45.9±0.2	18.339± 0.003	15.03±0.01	23.92 ± 0.36	+0.5	
J08175223+5246117	M9	40.9±0.3	18.879± 0.004	15.82±0.02	16.28 ± 0.35	0	
J08330310+3706083	M8	24.02±0.03	16.438± 0.003	14.54±0.01	320.58 ± 5.34	0/+0.296	
J08440874+7101007	M8	67.7±0.5	18.422± 0.003	14.27±0.02	3.84 ± 0.56	+0.5	
J10365971+5932068	M8	51.9±0.2	17.850± 0.003	14.27±0.01	3.67 ± 1.39	0	
J11332017+1039295	M9	55.0±0.3	17.663± 0.003	14.91±0.01	153.02 ± 1.89	+0.5	
J11553775+0922227	M8	48.0±0.3	17.648± 0.003	13.95±0.01	17.51 ± 1.03	+0.5	
J15495293+0151167	M8	37.2±0.2	18.489± 0.003	15.08±0.01	17.48 ± 0.42	+0.5	
J17373855+4705511	M9	51.4± 0.3	19.237± 0.004	16.38±0.01	5.63 ± 0.25	0	
J19383880+6010182	M8	103.1±0.5	18.682± 0.004	15.13±0.01	12.18 ± 0.47	+0.5	
J21051653+2514486	dC,M0	29.01±0.12	16.697± 0.003	11.63±0.01	31.64 ± 1.61	0	
J21161051+0341294	M9	24.09±0.03	18.406± 0.003	16.09±0.01	2.16 ± 0.49	+0.5	
J21265788+2531080	M9	53.3± 0.4	17.002± 0.003	15.72±0.01	13.80 ± 0.63	0	
J21580211+0409197	M8	51.4± 0.3	17.804± 0.003	15.25±0.02	21.98 ± 0.73	+0.5	
J21580671+5836379	M9	47.3± 0.2	17.470± 0.003	15.56±0.01	–	–	noisy
J22240946-1852387	M8	44.9± 0.3	18.797± 0.004	15.16±0.02	4.27 ± 0.44	+0.5	
J22292894-0444005	M8	56.6± 1.2	18.401± 0.004	14.85±0.01	19.00 ± 0.55	+0.5	
J22512440+2952452	M8	50.5± 0.3	17.643± 0.003	14.27±0.01	12.78 ± 0.79	+0.5	
J23100915+3230083	M9	44.9±0.3	18.295± 0.003	15.03±0.02	28.54 ± 0.54	0	
J23274947+0450583	M9	56.6±1.2	19.485± 0.008	15.72±0.05	2.45 ± 0.14	0	comp. to HIP115819
J23333910+3925057	M8	50.5±0.3	18.661± 0.003	15.15±0.01	3.50 ± 0.29	+ 0.5	
J08052401+0119568	M3	270.6±5.6	18.146± 0.003	10.99±0.05	–	–	
J08242621+0507584	M1	476.1±18.1	17.868± 0.003	9.48±0.08	–	–	
J10392877-0715331	M7	103.2±1.7	18.931± 0.004	13.86±0.04	–	–	
J11172768+1236201	K7	398.3±12.7	17.198± 0.003	9.20±0.07	–	–	
J13262496+0547032	F7	1073.2±22.1	15.114± 0.003	4.96±0.05	–	–	
J14335012+0438461	M4	252.5±5.6	18.003± 0.003	10.99±0.05	–	–	
J17202427+1014397	M3	236.1±3.2	17.663± 0.003	10.80±0.03	–	–	
J21132391+1028051	M1	253.0±4.4	17.570± 0.003	10.55±0.04	–	–	

Results 4 - GAIA and 2MASS CMDs





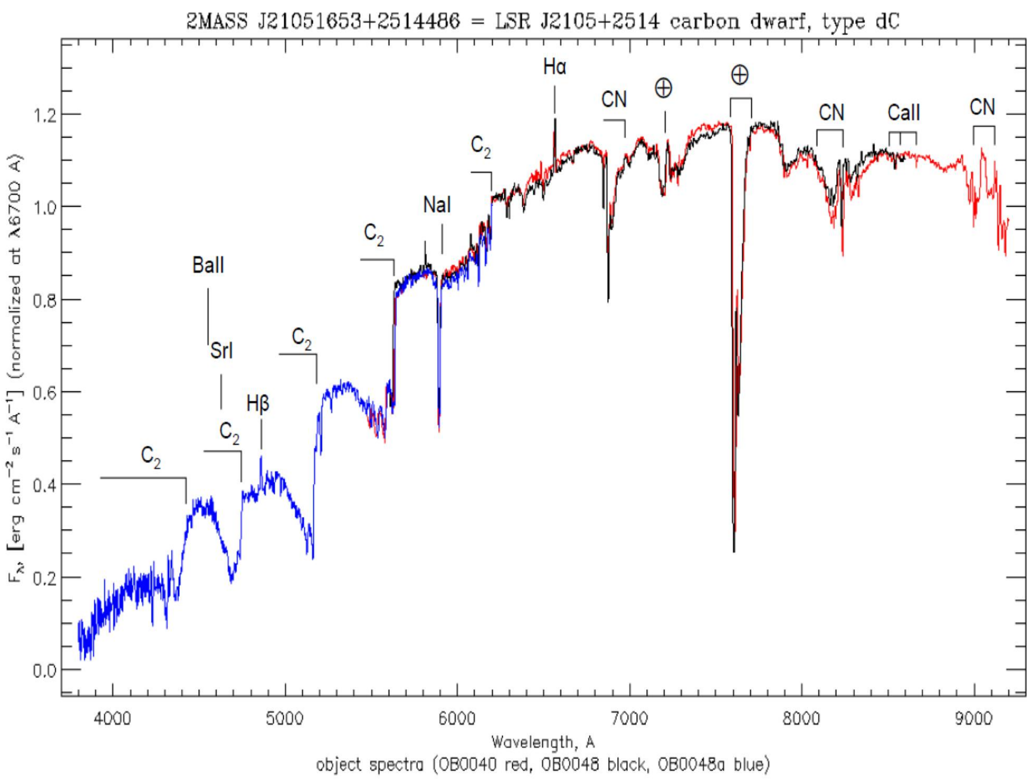
■ - the dC candidates; ◆- our dM stars; ●- dM stars from 2MASS with d<100 pc



2MASS colour-magnitude diagram of the studied stars.

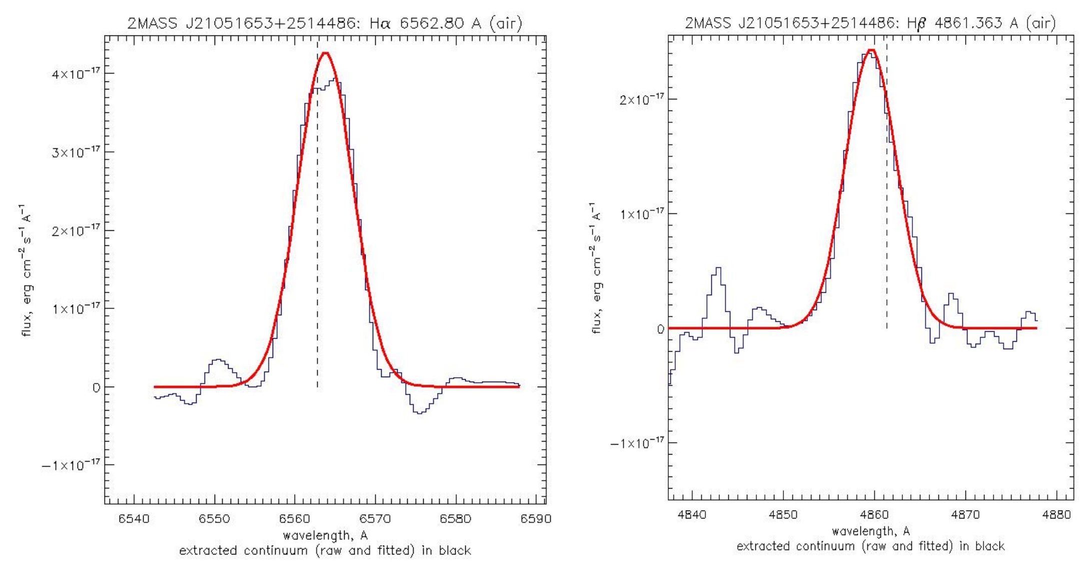
- Basic trend is maintained in the optical and IR CMD.
- Exception are several sources in the optical and the reason is not clear yet, but could be, e.g.:
  - lower metallicity object
  - subdwarfs

Results 5 - LSR J2105+2514 - a dC star



The combined spectrum of LSR J2105+2514 with indicated absorption and emission lines and bands.

Flux [erg s^{-1} cm^2 $Å^{-1}$]	Date of observation	
	10/10/2016	06/12/2016
Hα [10^{-16}]	3.096±0.163	3.676±0.109
Hβ [10^{-16}]	…	1.698±0.107



Balmer lines in the spectra of LSR J2105+2514 and their fluxes.

- First classified as dwarf carbon star dC by Lowrance et al., 2003, ApJ, 584, L95.
- dC spectra dominated by absorption bands of C_2, CH, or CN due to mass transfer in a close binary system.
- First detection of Balmer line emission. Can be due to: (a) intrinsic activity; (b) activity due to interaction with the companion; or (c) heating from the WD companion. No signs of a WD in GALEX.
- Harris et al., 2018, AJ, 155, 252 confirm that it belongs to the halo population.

To summarise

- 45 objects classified (36 are late-M dwarfs, 5 are early- to mid-M dwarfs, one is F7, one is K7 and one is dC);
- distances to all determined with high accuracy;
- absolute magnitudes ($M_{G,}$ M_{BP}, M_{RB}) determined for all stars;
- Almost all of the dM sample have detected Hα emission, including the dC star.
- While GAIA data provides acurate distances, the photometric system does not have the required colour baseline to achieve as reliable diagnostic fot the spectral sub-classes of late-type stars compared to e.g. 2MASS.

Next:

- determine how long-lived is the chromospheric activity for the dMe stars
- what is the source of the Balmer line emission from LSR J2105+2514.

Acknowledgements

- This research is based on observations made with the Gran Telescopio Canarias (GTC), installed in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofsica de Canarias, in the island of La Palma.

We also use:

- data from the SIMBAD database, operated at CDS, Strasbourg, France;
- data products from the Two Micron All Sky Survey, which is a joint project of the Uni- versity of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation;
- data from the Digitized Sky Surveys were produced at the Space Telescope Science Institute under U.S. Government grant NAG W- 2166. The images of these surveys are based on photographic data obtained using the Oschin Schmidt Telescope on Palomar Mountain and the UK Schmidt Telescope. The plates were processed into the present compressed digital form with the permission of these institutions. The National Geographic Society - Palomar Observatory Sky Atlas (POSS-I) was made by the California Institute of Technology with grants from the National Geographic Society.
- data from the European Space Agency (ESA) mission GAIA (https://www.cosmos.esa.int/gaia), processed by the Gaia Data Processing and Analysis Consortium (DPAC, https://www.cosmos.esa.int/web/gaia/dpac/consortium). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the Gaia Multilateral Agreement.

This research is supported by National Science Fund Grant No. KP-06-N58/3 (2021)