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Letter to the Editor

APMPM J0559−2903: The coolest extreme subdwarf known

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Abstract. We present the discovery of the coolest extreme subdwarf known to date. APMPM J0559−2903 was measured to be esdM7. Unlike for solar metallicity dwarfs, there are no very late type objects known among the extreme subdwarfs.

APMPM J0559−2903 was discovered in a new southern high proper motion survey. Follow up spectroscopy at Keck was used to identify the spectral type with the help of spectral indices.

Using the NextGen grid of model atmospheres by Hauschildt et al. (1999) we measured the effective temperature to be 3100 K and the metallicity to be $\frac{\mathrm{M}}{\mathrm{H}}$=$-1.5$. The theoretical parameters place APMPM J0559−2903 at a distance of 100 pc with a space velocity of 260 km s^{-1} relative to the local standard of rest.

Key words: stars: individual: APMPM J0559−2903 – stars: subdwarfs – stars: late-type – stars: low-mass, brown dwarfs – stars: fundamental parameters

1. Introduction

As noted by Monet et al. (1992) and Gizis (1997) there is a lack of very late type extremely metal deficient M dwarfs. While for solar metallicity stars the end of the main sequence has been observationally reached and the substellar regime has been entered, there are no ultra cool extreme subdwarfs known. Gizis (1997) reports an esdM5.5 star (LHS 1742a) as the latest extreme subdwarf.

Extreme subdwarfs are predominantly members of the galactic halo and the existence or non-existence of the ultra cool extreme subdwarfs poses strong constraints on the physics of the halo and its mass function.

High proper motion surveys represent an excellent source for finding low luminosity stars. From about 280 stars within 10 pc there is only one M dwarf with a proper motion less than 0.18 arcsec/yr which is the limit of the NLTT catalogue by Luyten (1980).

However, in the southern sky with $\delta < -33°$ the proper motion surveys are known to be incomplete. Therefore, Scholz et al. (1999a) started a new high proper motion survey based on APM measurements of the southern sky taken with UK Schmidt plates. The main aim of this survey is to complete the proper motion catalogues for proper motions larger than 0.3 arcsec/yr at fainter magnitudes. First results can be found in Scholz et al. (1999a,b).

Here we present the discovery of a very cool extreme subdwarf found in this survey.

2. Discovery and observations

APMPM J0559−2903 was discovered within the new high proper motion survey based on APM measurements of sky survey plates taken with the UK Schmidt telescope. After the pilot study (Scholz et al. 1999a) including 40 UKST survey fields covering mainly the region between 0^h and 7^h in right ascension and $-63°$ and $-32°$ in declination (about 1000 square degrees), the survey was extended to all available fields south of $-20°$ (altogether now more than 140 partly overlapping UKST survey fields corresponding to about 4000 square degrees). In the region north of $-33°$ most stars with $\mu > 0.3$ arcsec/yr detected in our survey are already known NLTT stars. However, since our survey reaches a fainter magnitude limit than the NLTT, we have still found new high proper motion stars with $R > 17$ in this relatively well investigated sky region.

For the Keck observations a small number of faint and red stars were selected within a small sky region as complimentary targets visible at the end of the nights during the November 24–26, 1999 observing run. These were two APM discoveries with $R > 18$ and red colour ($B_J - R > 2.3$) and three red NLTT stars with APM measured magnitudes ($E > 17.5, O - E > 3.2$). From these five stars four turned out to be late-type M dwarfs (dM5 and dM6.5/dM7) and subdwarfs (sdM4 and esdM7) as already reported with preliminary results by Schweitzer et al. (1999) , whereas one object was featureless

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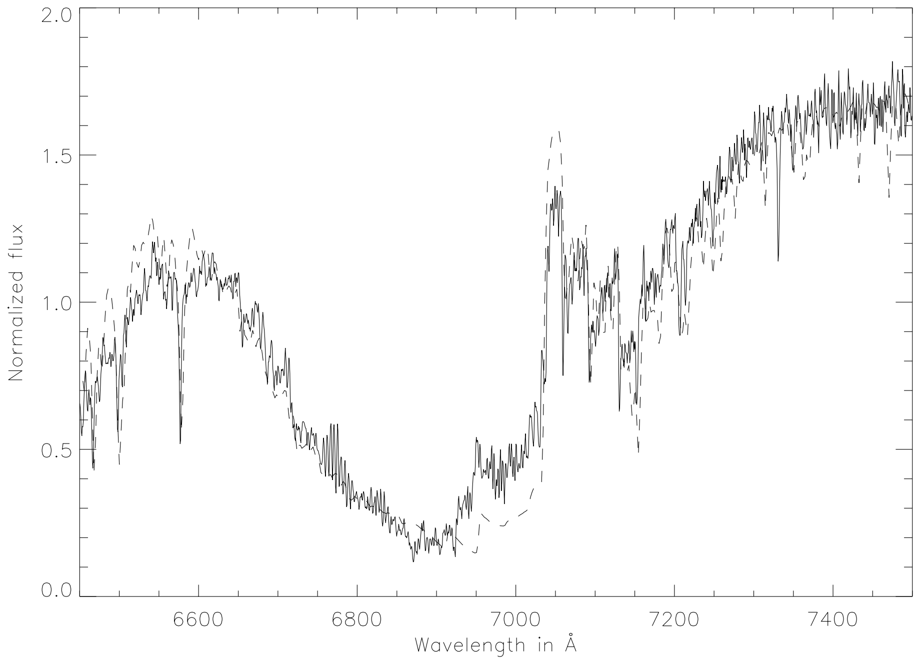

Fig. 1. APMPM J0559−2903 (solid line) and a NextGen model (dashed line) with $T_{\rm eff}$=3100 K, $\log(g)$=5.0 and $\frac{\rm M}{\rm H}$=−1.5. The theoretical spectrum has been redshifted to match the observed spectrum.

in its spectrum and is probably a cool white dwarf. We concentrate here on the extreme late-type subdwarf, more details on the other objects will be presented elsewhere.

The proper motion of APMPM J0559−2903 was measured as $(\mu_x, \mu_y) = (+0.37, +0.06) \pm (0.02, 0.02)$ arcsec/yr from one pair of plates with an epoch difference of 14 years. The R magnitude obtained from the APM measurements was 18.14 and the $B_J - R$ colour index was $+2.80$. With this $B_J - R$ value, APMPM J0559−2903 is among the reddest objects in the whole sample of more than 800 high proper motion stars so far detected in the survey.

The follow up spectroscopy at Keck II for APMPM J0559−2903 was performed on November 26, 1998 using the Low-Resolution Imaging Spectrograph (LRIS) with a 1200 line mm^{-1} grating and a 1$''$ slit. The resultant dispersion was 0.63 Å pixel^{-1} and about 2 Å per resolution element. The covered wavelength region was 6431–7714 Å in order to cover the CaH and TiO bands up to the atmospheric A-band. Wavelength calibration was done with a comparison arc lamp and with the strong OH night sky lines present in the subtracted sky background spectrum. Flux calibration was done using spectrophotometric standards observed during the night. The whole data reduction was performed using standard IRAF tasks.

The spectrum excluding the atmospheric A-band can be found in Fig. 1. As can be seen the CaH band between 6100 and 7100 Å is very strong. Also, the TiO band between 7100 and 7200 Å is clearly visible. As noted by Gizis (1997) this TiO band is almost invisible for hotter extreme subdwarf but stronger for the cooler ones. There is no detectable H_α emission.

3. Analysis

We used the spectral features described in Reid et al. (1995) and Gizis (1997) to measure the spectral type. Since the spectral ranges used for these ratios are only a few Angstroms wide we corrected the spectrum for the geocentric radial velocity of about 200 km s^{-1} of APMPM J0559−2903 by measuring the shift of the very strong K 1 line at 7698.98Å and the Ca 1 line at 6572.78Å.

Table 1. The spectral indices from Gizis (1997) for APMPM J0559−2903

Spectral index	value
TiO5	0.60
CaH2	0.21
CaH3	0.32

The spectral ratios are given in Table 1. These ratios mean that it is later than any extreme subdwarf given in Gizis (1997). Although the sequence by Gizis (1997) is only defined down to about esdM6, the formulae given there can be reasonably extrapolated and APMPM J0559−2903 naturally fills into the empty spaces in the figures of Gizis (1997) where esdM7 stars are expected. Note, that the spectral index CaH1 was not in the observed wavelength region and, therefore, could not be measured.

We have furthermore used the so called NextGen grid of model atmospheres by Hauschildt et al. (1999) in order to determine the effective temperature and the metallicity. The best fitting model was determined using a χ^2 fitting technique with models for $T_{\rm eff}$=3000, 3100, 3200, 3300 K and $\frac{\rm M}{\rm H}$=−2.0, −1.5, −1.0, −0.5, 0.0 and was measured to have $T_{\rm eff}$=3100 K and $\frac{\rm M}{\rm H}$=−1.5. The spacing of the NextGen grid also represents its internal uncertainty (Hauschildt 1999, private communication) and, therefore, is taken as the error for the determined $T_{\rm eff}$ and $\frac{\rm M}{\rm H}$. We note that this error is larger than the error suggested by determining the best fitting model. We kept $\log(g)$ fixed at 5.0

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Table 2. The measured parameters for APMPM J0559−2903

α(J2000 at epoch 1991.12)	5 58 58.64
δ(J2000 at epoch 1991.12)	−29 03 27.2
APM R magnitude	18.14
APM $B_J - R$	+2.80
μ_x	+0.37±0.02 arcsec/yr
μ_y	+0.06±0.02 arcsec/yr
Spectral Type	esdM7
$T_{\rm eff}$	3100±100 K
$\frac{\rm M}{\rm H}$	−1.5±0.5
Distance	100±25 pc
Mass	0.095±0.005 $m_\odot$
v_t	175±40 km s^{-1}
$v_{r,\rm LSR}$	190±30 km s^{-1}
U	−115±12 km s^{-1}
V	−218±25 km s^{-1}
W	85±50 km s^{-1}

since $\log(g)$ only influences high resolution spectra (Schweitzer et al. 1996) and as APMPM J0559−2903 being a halo member it can be assumed to have reached the main sequence where its $\log(g)$ is about 5.0. The fit to APMPM J0559−2903 can be found in Fig. 1. For reference, Leggett et al. (1998) measured the effective temperature of the esdM5.5 star LHS 1742a to be approximately 3000 K. However, their determination is based on fitting model IR broadband colors to a sample of very late type dwarfs and they indicate values for $T_{\rm eff}$ only every 500 K.

With these parameters we could use the evolutionary models by Baraffe et al. (1997) to determine a mass of 0.095±0.005 $m_\odot$ and an absolute R magnitude of 13.2±0.6. The error bars come from the grid points given by Baraffe et al. (1997) bracketing 3100 K for $\frac{\rm M}{\rm H}$=−1.5 and are consistent with the accuracy of the NextGen grid of about 100 K and 0.5 dex in $\frac{\rm M}{\rm H}$. For comparison, the minimum stellar mass at this metallicity is 0.083 $m_\odot$ according to Baraffe et al. (1997).

Although the NextGen grid of model atmospheres is already superseded by better input physics for the models with high metallicities (Hauschildt 1999, private communication), it is very well suited for low metallicity stars since the new input physics involves dust condensation and opacities for oxygen compounds which do not significantly affect low metallicity stars.

The R magnitude places APMPM J0559−2903 at a distance of 100±25 pc and its tangential velocity is then 175±40 km s^{-1}. With the radial velocity it gives it a space velocity of 260 km s^{-1} relative to the Local Standard of Rest or, using Johnson & Soderblom (1987), $(\rm U, V, W) = (-115, -218, 85) \pm (12, 25, 50)$ km s^{-1}. This space velocity is completely consistent with APMPM J0559−2903 being a halo member.

A summary of all measured parameters of APMPM J0559−2903 can be found in Table 2.

4. Conclusions

We have discovered the extreme subdwarf of latest spectral type, esdM7. We measured its effective temperature $T_{\rm eff}$=3100 K and its metallicity $\frac{\rm M}{\rm H}$=−1.5 using NextGen model atmospheres. Using the theoretical parameters and its R magnitude of 18.14 we measured its distance of 100 pc and its space velocity of 260 km s^{-1} or $(\rm U, V, W) = (-115, -218, 85) \pm (12, 25, 50)$ km s^{-1} which is consistent for halo members.

This discovery pushes the limit of known extreme subdwarfs to cooler objects and helps to better define the cool end of the extreme subdwarf sequence. Besides this achievement it also offers the possibility to study very cool metal deficient stars via observations, not only via theory.

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References

Baraffe, I., Chabrier, G., Allard, F., and Hauschildt, P. H., 1997, A&A 327, 1054
Gizis, J., 1997, AJ 113, 806
Hauschildt, P. H., Allard, F., and Baron, E., 1999, ApJ 512, 377
Johnson, D. R. H. and Soderblom, D. R., 1987, AJ 93, 864
Leggett, S. K., Allard, F., and Hauschildt, P. H., 1998, ApJ 509, 836
Luyten, W., 1979–1980, New Luyten Catalogue of Stars with Proper Motions larger than Two Tenths of an Arcsecond, Technical report, University of Minnesota, Minneapolis, computer readable version on ADC selected Catalogs Vol.1-CD-ROM
Monet, D. G., Dahn, C. C., Vrba, F. J., Harris, H. C., Pier, J. R., Luginbuhl, C. B., and Ables, H. D., 1992, AJ 103, 638
Reid, I. N., Hawley, S. L., and Gizis, J. E., 1995, AJ 110, 1838
Scholz, R.-D., Irwin, M., Ibata, R., Jahreiß, H., and Malkov, O. Y., 1999a, A&A submitted
Scholz, R.-D., Irwin, M., Schweitzer, A., and Ibata, R., 1999b, A&A 345, L55
Schweitzer, A., Hauschildt, P. H., Allard, F., and Basri, G., 1996, MNRAS 283, 821
Schweitzer, A., Scholz, R.-D., Irwin, M., Ibata, R., Stauffer, J., McCaughrean, M., and Zinnecker, H., 1999, in D. Backman and T. Henry (eds.), Nearby Stars Workshop, NASA-Ames, in press