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AN INFRARED SPECTRAL SEQUENCE FOR M DWARFS

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ABSTRACT We present a spectral sequence from 1–2.5 μm of M dwarfs from GL411 which is classified as M2V to the best brown dwarf candidate GD165B (M10V). This sequence shows the progressive importance of water vapour in the atmospheres of M dwarfs. We take the strength of the water absorption bands as the basis of a new method to derive effective temperatures. We also identify many of the stronger atomic and molecular features and find that their strengths correlate with our derived temperature scale. GD165B has a temperature of 1860±160K and is the only star in the sample which may be a brown dwarf, but to decide its true nature a more accurate parallax and a representative model atmosphere will be necessary.

INTRODUCTION

M dwarfs are the most common stars in our stellar neighbourhood yet are also amongst the least understood stars largely due to their intrinsic faintness. While the numbers of known faint M dwarfs have increased dramatically over the last decade, our understanding of their fundamental properties has not. In particular, the scales used to convert the optical or infrared colours into bolometric luminosities and effective temperature (and by extension into estimates of mass) are poorly defined. The interpretation has relied on (i) the assumption that the observed colours are monotonic in effective temperature and (ii) a bolometric luminosity determined from spectrophotometry and from extrapolation of a blackbody curve into unmeasured parts of the star's energy distribution. However between 1–5μm, where a 2500K star emits 80% of its flux, there are four strong water absorption bands and thus spectra of cool dwarf stars do not resemble the blackbody curves which are shown by hotter stars across the infrared.

OBSERVATIONS OF A RANGE OF M DWARFS

We have observed a range of M dwarfs from M2 to M10, which includes the best candidate for a brown dwarf, GD165B and the well studied M dwarfs, GL699 and

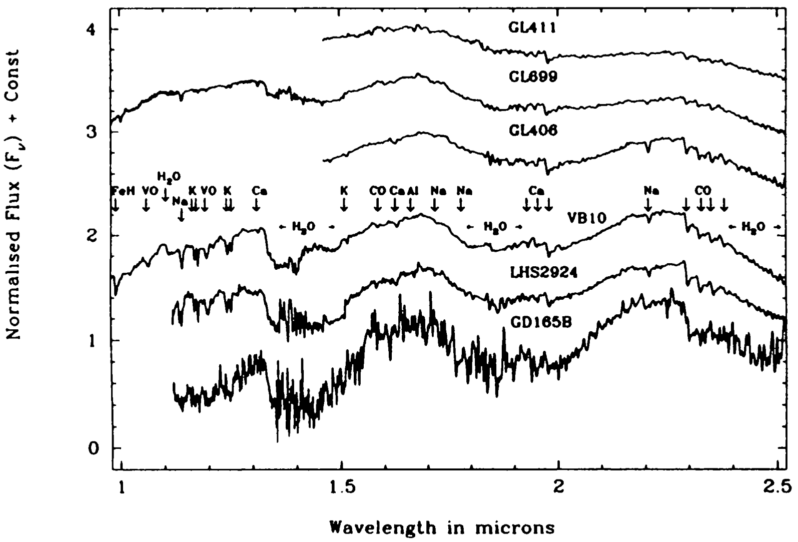

FIGURE I Infrared spectral sequence for M dwarfs.

VB10. Together they form a sample whose space motions and colours indicate they may belong to the old disk population (Becklin & Zuckerman 1988, Leggett 1992). Our observations were made with the Cooled Grating Spectrometer 4 (Mountain et al. 1991) on the UK Infrared Telescope on Mauna Kea, Hawaii. The instrument was used in six different configurations to cover the wavelength range from 1–2.5 μm with some overlap between each spectral segment. For the fainter objects GD165B, LHS2924 and VB10, integration times were about 30 mins. The combined spectra for all the stars are shown in Figure I.

A TEMPERATURE SCALE FOR M DWARFS

The spectra in Figure I are dominated by three deep water absorption bands centered on 1.4, 1.9 and 2.5 μm. Allard's models (1990) of M dwarf atmospheres show that H_2O dominates their broadband opacity between 1.4 and 2.5 μm. From Ludwig's (1971) laboratory determinations of the absorption coefficients for water at different temperatures, it can be seen that the oscillatory nature of the water vapour opacity means that there are a number of wavelengths at which the optical depth of water vapour will be almost equal for a range of temperatures between 1500 and 3000K. Stellar atmosphere theory tells us we should be able to fit a blackbody through points of constant optical depth; such a fit generates a temperature T, which can be used to calculate the effective temperature, T_e, as follows. We can calculate $(R/d)^2$ from the equation, $f_\lambda = R^2 F_\lambda (T) / d^2$, where f_λ is the measured flux at one of the wavelengths, R the radius and d the distance of the object and $F_\lambda(T)$ the Planck function. The effective temperature T_e can now be found from the bolometric flux, F_{bol}, using, $\sigma T_e^4 = (d/R)^2 F_{bol}$, where σ is the Stefan Boltzmann constant. F_{bol} is found by combining the infrared spectra from this study with optical spectra from Kirkpatrick, Henry & McCarthy (1991) and photometry from Berriman & Reid (1987) and Leggett (1992).

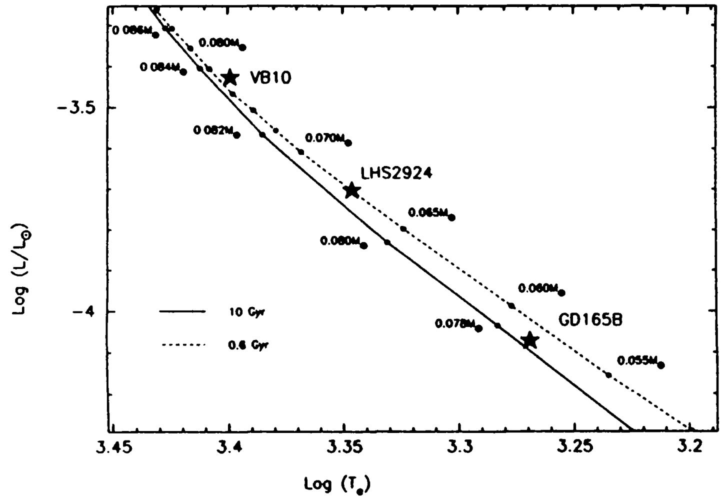

FIGURE II Models from Burrows et al. (1993) compared with the luminosity and temperature points from this study.

ANY BROWN DWARFS?

Burrows et al. (1993) find, for their standard model with solar metallicity, that an object can not sustain hydrogen burning and is thus a brown dwarf if its mass is below 0.0767 $M_{\odot}$. To assign masses for our sample, we plot in Figure II the standard model adopted by Burrows et al., for ages of 0.6 and 10 Gyr together with the luminosity and temperature points for VB10, LHS2924 and GD165B. Our method for calculating effective temperature and luminosity gives values which are close to those predicted by the evolutionary models. However the observational uncertainties are such that we are unable to distinguish the age of the stars using Figure II. It should also be noted that for a given mass star near the hydrogen burning limit there is a large age dependence on luminosity, temperature and metallicity. If indeed the members of this sample are from the old disk population, they will have ages of around 10 Gyr. Burrows et al.'s models predict that solar composition brown dwarfs of this age will have luminosities below 6.2×10^{-5} $L_{\odot}$ and temperatures below 1747K. Ignoring metallicity effects, unless any of the members of our sample are very young only GD165B can be considered a good brown dwarf candidate.

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PART VII

HIGH-RESOLUTION IMAGING