

Letter to the Editor

Discovery of a faint field methane brown dwarf from ESO NTT and VLT observations

J.G. Cuby¹, P. Saracco², A.F.M Moorwood³, S. D'Odorico³, C. Lidman¹, F. Comerón³, and J. Spyromilio¹

¹ ESO, Paranal Observatory, Alonso de Cordova 3107, Vitacura, Casilla 19001, Santiago 19, Chile

² Osservatorio Astronomico di Brera, Via Bianchi 46, I-23807 Merate, Italy

³ ESO, Karl-Schwarzschild-Strasse 2, D-85748 Garching, Germany

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Abstract. We report the discovery of an isolated brown dwarf with similar properties to the binary object Gliese 229B and to the newly discovered field brown dwarfs from the SDSS and 2MASS surveys. Although exhibiting similar colors, its magnitude of ~ 20.5 is about 6 magnitudes fainter than Gliese 229B. This is the most distant of the several methane brown dwarfs reported to date, at a distance of ~ 90 pc. Its IR spectrum, although at low S/N given the faintness of the object, is remarkably similar to those of the other methane brown dwarfs.

Key words: stars: low-mass, brown dwarfs – techniques: spectroscopic – Galaxy: stellar content – infrared: stars

1. Introduction

Despite large observational efforts during recent years in both wide field (see e.g. Reid et al. 1999) and targeted searches for very cold brown dwarfs, the number of such objects known so far remains extremely small. Since 1995, and until June 1999, the only genuine one identified was Gliese 229B (Nakajima et al. 1995, Oppenheimer et al. 1996), the coolest substellar object known, with a temperature below 1000 K, a mass in the range 20–50 M_J (Jupiter mass), and an age in the range 0.5–1 Gyr. A second object of this class, SDSS 1624+00, has been discovered recently in the Sloan Digital Sky Survey (Strauss et al. 1999), after identification from the survey database by its unusual red color. Follow-up spectroscopy of this object in the visible with the Apache Point 3.5m telescope and in the IR with UKIRT identified it as a methane brown dwarf like Gliese 229B. A couple of similar objects have since then been identified (Tzetanov, private communication) from the SDSS survey. At almost the same time, 4 other similar objects were identified from the Two Micron All-Sky Survey (2MASS) (Burgasser et al. 1999), and confirmed as methane brown dwarfs from visible spectroscopy at Palomar and IR spectroscopy at Keck.

In this paper we report our discovery of a new methane brown dwarf in the NTT Deep Field, a small area of the sky that was the target of very deep exposures in the visible and the near-infrared using the SUSI and SOFI instruments at the ESO New Technology Telescope (NTT) (Arnouts et al. 1999, Saracco et al. 1999). One object, NTTDF J1205–0744, stands out in these images for its very red $(i-J) > 6$ color index. However, it is very blue at longer wavelengths, with $(J-K_s) = -0.15$. Near-infrared spectroscopy with SOFI, and with ISAAC at the ESO Very Large Telescope (VLT), has confirmed the remarkable similarity of this object to Gliese 229B. The powerful combinations NTT/SOFI and VLT/ISAAC made the observations reported here possible, in spite of the faint apparent magnitude of NTTDF J1205–0744. Although the raw S/N is limited (1 to 2 per pixel, 5 to 10 after rebinning), our results secure the identification of NTTDF J1205–0744 as a new field methane brown dwarf.

2. Observations and data reduction

The NTT Deep Field covers an area of 2.3×2.3 arcminutes in the visible down to AB magnitude limits of 27.2, 27.0, 26.7 and 26.3 in B, V, r, and i, and 5×5 arcminutes in the IR down to magnitude limits of 24.6 and 22.8 in J and Ks.

The entire dataset of the NTT Deep Field Project, primarily targeted to the study of faint galaxy populations, as well as a detailed information on data acquisition and reduction, are publicly available at <http://www.eso.org>.

J and i band images of the field containing NTTDF J1205–0744 are shown in Fig. 1.

After identification of NTTDF J1205–0744 from its unusual extremely red colour $(i-J)$ in April 98, we carried out spectroscopy with SOFI at the NTT using Target of Opportunity Time on 30 June–1 July 1998. The spectrum, covering the range 0.95–1.65 microns (dispersion: 7 Å per pixel), was obtained under non-photometric conditions using a 1'' slit, and nodding along the slit between two positions, for a total effective on-target integration time of 84 minutes. Spectrophotometric calibration and removal of telluric features was achieved using

Send offprint requests to: J.G. Cuby (jcuby@eso.org)

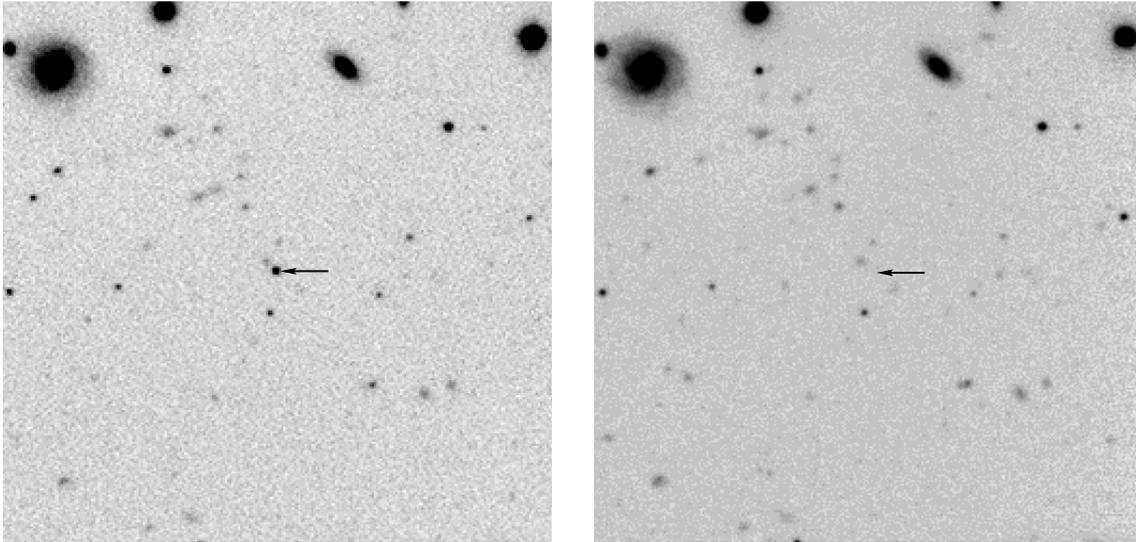


Fig. 1. Image of the NTTDF J1205–0744 field. Left: J SOFI image, Right: i SUSI image. The object position is indicated with an arrow, and is absent from the i image. The field is 1.3×1.3 arcminutes, N is up, E is left. The coordinates of NTTDF J1205–0744 are 12:05:20.21 and –07:44:01.0 (J2000).

the observation of a B9 type star. The spectrum was scaled to match the IR photometry in the J filter.

The spectrum shows clear H₂O absorptions, leaving peaks in the spectrum at 1.05 and 1.27 μm (the latter peak at a S/N of 1–1.5 per pixel), and a marginally significant detection of a third peak at 1.57 μm .

We subsequently obtained spectroscopy of NTTDF J1205–0744 with ISAAC at the VLT in the H and K bands. All the ISAAC observations were made with a 1'' slit and nodding along the slit.

The K observations were carried out during the nights of 6 and 9 February 1999, for a total amount of time of 1 hour. We used the Low Resolution grating in second order providing a dispersion per pixel of 7 \AA . Spectrophotometric calibration was achieved from the observation of a B6 type star observed on a different night. The signal to noise per pixel is below 1 on the peak at 2.1 μm .

The observations in H were carried out during the night of 23 March 1999, again for a total integration time of 1 hour. We used the same Low Resolution grating in third order, providing a dispersion per pixel of 4.7 \AA . Spectrophotometric calibration was achieved from the observation of a B8 type star. The spectrum was arbitrarily scaled so as to correspond to an H magnitude of 20.3. This scaling proved to properly match the SOFI spectrum. The signal to noise ratio per pixel is ~ 2 on the peak at 1.57 μm .

The combined, flux calibrated, spectrum is presented on Fig. 2, overlotted with the spectrum of Gliese 229B for reference (Geballe et al. 1996).

3. Discussion

The magnitudes, or magnitude lower limits of NTTDF J1205–0744 are given in Table 1.

Table 1. Magnitude and magnitude lower limits for NTTDF J1205–0744.

B	V	r	i	J	Ks
>27.2	>27.0	>26.7	>26.3	20.15	20.3

Both the i–J and the J–Ks color indices match within less than 0.2 magnitude the color indices of both Gliese 229B and of the SDSS and 2MASS brown dwarfs.

Our infrared spectrum shown in Fig. 2 has relatively low s/n and some flux calibration uncertainties due to the fact that the observations were made at different times and with different instruments. A detailed discussion of the smaller features is therefore not warranted. For example, the feature in the Ks peak could be real but corresponds to a region of crowded OH sky lines and may just be noise. The most important result here is its striking overall similarity with the spectra of Gliese 229B and of the recently discovered methane brown dwarfs, in particular, the clear presence of the strongest H₂O and CH₄ absorption features, which clearly identify it as a methane brown dwarf, and the relative flux distribution which implies a similar temperature.

Assuming not only that the colours but also the absolute magnitude is similar to Gliese 229B which is at 5.8 pc we obtain a distance of ~ 90 pc to NTTDF J1205–0744 ($\Delta J = 6$ magnitudes). The assumption of a similar absolute magnitude may be justified on the basis of brown dwarf model predictions (Burrows et al. 1997). Although both the colour and the magnitude change over a very large range at any particular brown dwarf age, theoretical isochrones practically overlap in color-magnitude diagrams for the range of colors of interest here. Therefore, even if the mass and the age of NTTDF J1205–0744 may be very different from those of the other methane brown dwarfs, the similar (J–Ks) color is indicative of a similar ab-

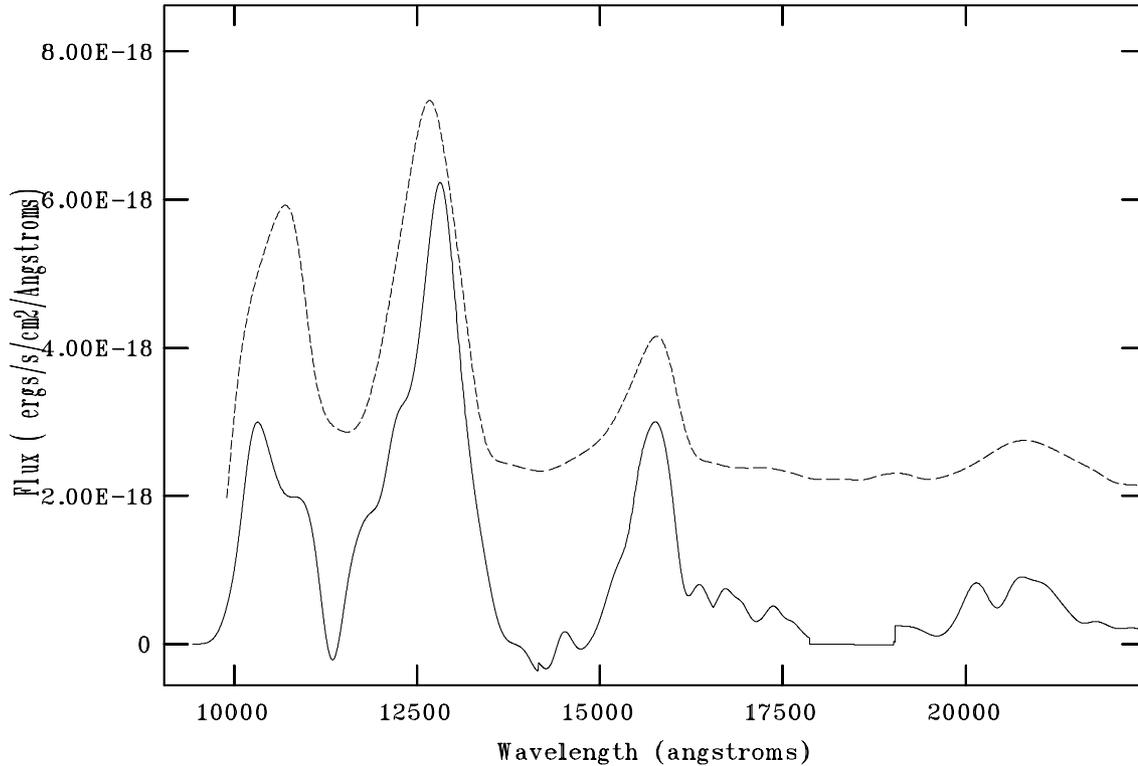


Fig. 2. Spectrum of NTTDF J1205–0744 (plain line). The extracted, flat fielded and wavelength calibrated spectrum has been smoothed with a gaussian of FWHM = 47 pixels in the dispersion direction, corresponding to a spectral resolution of ~ 50 . The spectrum of Gliese 229B (Geballe et al. 1996) smoothed at the same resolution, is overplotted (with an offset) for reference (dashed line). The similarity between both spectra is striking.

solute magnitude. Thus, although both mass and age are very poorly constrained by our observations (the spectral features placing however the mass safely in the brown dwarf domain), the distance of NTTDF J1205–0744 is considered to be relatively secure.

We have SOFI and ISAAC images taken ~ 14 months apart. We looked for possible proper motion, but nothing was detected at the level of 0.3 arcsec (2σ).

NTTDF J1205–0744 stands out as the only object of its type within the 2.3×2.3 arcminutes NTT deep field. Although of dubious reliability based on a single object, the implied volume density is ~ 1 per cubic parsec (assuming a recognition limit at $J=22$, see below, corresponding to a distance of ~ 200 pc). This is considerably higher than the 0.01–0.03 per cubic parsec tentatively quoted by Strauss et al. (1999) and than the 0.01 per cubic parsec derived from the discoveries of the 2MASS methane brown dwarfs (Burgasser et al. 1999). This implies that either our technique is considerably more sensitive or, more likely, that we were extremely lucky.

The probability of finding a very cold object in a random field with a given limiting magnitude can also be estimated using published brown dwarf models, the local density of low mass stars, and an extrapolation of the initial mass function towards lower masses. We have carried out this exercise using the Burrows et al. (1997) models and the local volume density at 0.1 solar masses from Scalo (1986). We have assumed a constant

Table 2. Probability of finding an object with $T < 1000$ K and $J < 22$ in 2.3×2.3 arcminutes, for different IMF power law indices, using the models of Burrows et al. (1997) relating masses, temperature, age and absolute J magnitudes.

IMF power law index	Probability
-1.5	1×10^{-4}
0	4×10^{-5}
1	2.3×10^{-5}

local formation rate of low mass stars over the last 10 Gyr. The initial mass function (IMF) below 0.1 solar masses has been represented by a power-law of the form $\Phi(M)dM \propto M^\alpha dM$, and we have considered values for α ranging from -1.5 to +1. We have then calculated the number of objects with a temperature lower than 1000 K that may be expected to appear in the field with an apparent J magnitude brighter than 22, under the assumption of the different values of α . Although objects much fainter than $J=22$ are still visible in the J image, the limit chosen is given by the need to be able to recognize the characteristic colors of possible brown dwarfs, namely the extremely red ($i-J$) and the blue ($J-K_s$). The limiting J magnitude that we use is thus actually defined by the limiting K_s magnitude, combined with the ($J-K_s$) colors expected for the objects of interest. The results are given in Table 2.

These values are much lower than the 1% probability one would expect for a volume density of 0.01 per cubic parsec, suggesting that a negative slope much steeper than -1.5 would be required for the IMF to fit with the observed density.

One of the most remarkable features of these objects is the huge I–J color index which make them difficult to find using visible data alone. Despite the spectacular success of the Sloan Digital Sky Survey which has led to the discovery of SDSS 1624+00, the main avenue for unveiling in a systematic way this new population of methane brown dwarfs is to resort to combined visible (I) and IR (J and H or J and Ks) deep observations, as demonstrated by the 2MASS discoveries and by the present work. It is interesting to note that the DENIS survey (Delfosse et al. 1999) did not detect so far such methane brown dwarfs, which might be explained by the relatively low detection limit in Ks (13.5). With a volume density of 0.01 per cubic parsec, the chance of finding a methane brown dwarf brighter than this limit is ~ 1 over the whole sky.

The high I–J (or any visible – J) color index, combined with an almost flat J–H or J–Ks color index, is a very clear indicator for these methane brown dwarfs.

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