ε Indi Ba, Bb: a spectroscopic study of the nearest known brown dwarfs

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Abstract.

The discovery of ε Indi Ba and Bb, a nearby binary brown dwarf system with a main-sequence companion, allows a concerted campaign to characterise the physical parameters of two T dwarfs providing benchmarks against which atmospheric and evolutionary models can be tested. Some recent observations suggest the models at low mass and intermediate age may not reflect reality with, however, few conclusive tests.

We are carrying out a comprehensive characterisation of these, the nearest known brown dwarfs, to allow constraints to be placed upon models of cool field dwarfs. We present broadband photometry from the V- to M′-band and the individual spectrum of both components from 0.6-5.1 μm at a resolution of up to R∼5000. A custom analytic profile fitting routine was implemented to extract the blended spectra and photometry of both components separated by ∼0.7". We confirm the spectral types to be T1 and T6, and notably, we do not detect lithium at 6708Å in the more massive object which may be indicative both of the age of the system and the mass of the components.

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INTRODUCTION

Studies of low mass stars and brown dwarfs are hampered by a lack of fundamental measurements: radii, masses, ages, and high resolution atmospheric observations. This is due to a number of factors including their intrinsic faintness, relatively low numbers of known objects, and the mass-age degeneracy of sub-stellar objects. Binary systems have an important role to play here: they can allow the determination of dynamical masses and radii, they provide the laboratory in which to compare objects at the same age and chemical composition, and where the systems contain previously well-studied main-sequence stars, they provide external determinations of metallicity and age which field objects lack, thus breaking the sub-stellar mass-age degeneracy. Previous studies which have attempted to constrain low mass evolutionary models have been hampered by ambiguous ages, possible unresolved binarity, and the difficulty of acquiring observations of close, faint companions (cf. AB Dor C; Close et al. [1], Luhman and Potter [2]). Spectroscopic observations of T dwarfs have mostly been either low resolution studies which allow
spectral classification and overall SED modelling to determine luminosities, or high resolution studies of relatively small wavelength regions, for example, to investigate gravity and effective temperature sensitive features. Here we present high signal-to-noise, moderate resolution optical to thermal-IR spectra of two T dwarfs which have important external constraints from their parent star, \( \varepsilon \) Indi A. A detailed analysis and comparison to atmospheric models is underway (King et al. 2008, in prep.).

ASSOCIATION WITH \( \varepsilon \) INDI A

The discovery of a very wide companion (\( \sim 1500 \)AU) to the high proper-motion (\( \sim 4.7''/\text{yr} \)) \( \varepsilon \) Indi was reported by Scholz et al. [3] in 2003. Being amongst the closest known stars to our Solar System, \( \varepsilon \) Indi A has a well-constrained parallax from Hipparcos putting the system at a distance of \( 3.626 \pm 0.009 \)pc. This initial discovery was followed by the discovery of the companion’s binary nature by McCaughrean et al. [4]. Model comparisons placed the masses at \( 47 \pm 10 \) and \( 28 \pm 7 \) M\( \text{Jup} \) for an age of 1.3Gyr.

\( \varepsilon \) Indi Ba and Bb are uniquely well-suited to provide key insights into the physics, chemistry, and evolution of sub-stellar sources. Although there are a number of other T dwarfs in binary systems, \( \varepsilon \) Indi B has a very well-determined distance, a reasonably well-determined age and metallicity, and has a short enough orbit (\( \sim 13 \) years) such that the system and individual dynamical masses can soon be determined (McCaughrean et al. 2008, in prep.; Cardoso et al., these proceedings). It is also bright and sufficiently separated to allow detailed photometric and spectroscopic studies of both components. Characterisation of this system will allow the mass-luminosity relation at low masses and intermediate age to be tested; will allow investigation of the atmospheric chemistry, such as the chemical equilibrium of CO and CH\(_4\), and will allow detailed investigation of the species in the atmosphere whilst matching the overall spectral morphology caused by very broad absorption lines.

OBSERVATIONS

\( \varepsilon \) Indi Ba, Bb was observed with the ESO VLT using FORS2 for optical photometry and spectroscopy, and ISAAC for near- and thermal-IR photometry and spectroscopy. In both the optical and near-IR observations the point-spread functions (PSFs) of the two sources were blended due to the \( \sim 0.7'' \) separation of the binary with typical 0.6'' seeing.

The individual sources were extracted using a custom analytic profile fitting routine applied to both the imaging and spectroscopy. The results from these fits were confirmed by extracting the optical photometry with IRAF/DAOPHOT as these were the only observations with sufficient neighbours with which to model the PSF. The derived magnitudes are listed in Table 1 and the optical to thermal-IR spectra are shown in Figures 1 and 2. The optical spectrum of \( \varepsilon \) Indi Ba lacks lithium absorption at 6708Å which may be expected in spectra at this signal-to-noise and resolution for such an object below the lithium burning mass, indicating a mass in excess of the previously derived model mass of \( 47 \) M\( \text{Jup} \). This is consistent with our revised age estimate of \( \sim 5 \) Gyr for \( \varepsilon \) Indi A which will be discussed in a forthcoming paper (King et al. 2008, in prep.).
### TABLE 1. Photometry of ε Indi Ba and Bb

| Filter | ε Indi Ba | ε Indi Bb |
|--------|-----------|-----------|
| V      | 24.47±0.04| 26.92±0.09|
| R      | 20.08±0.02| 21.10±0.05|
| I      | 16.78±0.03| 18.51±0.03|
| z      | 15.20±0.03| 16.57±0.04|
| J      | 12.20±0.03| 12.96±0.03|
| H      | 11.60±0.02| 13.40±0.03|
| K      | 11.42±0.02| 13.64±0.02|
| L′     | 9.71±0.05 | 11.33±0.06|
| M′     | 10.67±0.23| 11.04±0.23|

### Optical, near-IR, and thermal-IR spectra

The proximity and separation of this system allow these moderate resolution spectra to be acquired for both objects over a wide wavelength range which is practical for few other T dwarfs. Here we show the full resolution spectra of both T dwarfs from 0.63-5.1μm (Figs. [1] and [2]). The optical has a maximum S/N ~350 (R~1000-2000), while the 1-2.5μm spectra have S/N~50-100 (R~5000) at the JHK-band peaks. The L- and M′-band spectra have S/N~5-40 (R~500 and 250, respectively). These can place important constraints on the atmospheric chemistry of T dwarfs. The 1.81-1.92μm regions have been median filtered to highlight the measure of the continuum level in this region of high telluric absorption. In particular, the vertical dispersion seen in the JHK-band spectra is not noise - these are real features. The dotted regions are shown in the inset plots. Notice the features present in both objects, some of which are stronger in ε Indi Bb.

### CONCLUSIONS

We have presented an overview of our comprehensive spectroscopic study of the individual components of the nearest known binary brown dwarf system, ε Indi Ba, Bb. The relative proximity of these T1 and T6 dwarfs ensures very high quality data and the parent star, ε Indi A, provides invaluable external constraints. In particular, ε Indi Ba shows no Li6708Å absorption, in contrast with some model predictions for younger, lower-mass sources. This absence of lithium is consistent with revised, higher age estimates from ε Indi A. Our spectrum of ε Indi Bb is consistent with either a non-detection or minimal Li6708Å absorption which would be expected at these lower temperatures where most of the monatomic lithium has been sequestered into LiCl and other molecules.

We plan to use VLT NACO and FORS2 astrometry data to search for any evidence of medium- to long-term photometric variability in these two T dwarfs. This may be complemented by a VLT/X-Shooter proposal to search for possible spectral variability signatures and to acquire a luminosity measurement at a single epoch.
**FIGURE 1.** The optical and thermal-IR spectra of $\varepsilon$ Indi Ba (red, upper line) and Bb. Note the lack of obvious lithium absorption at 6708Å (marked) in the brighter component. The two deep absorption features near 5$\mu$m are residuals of bright telluric emission.

**FIGURE 2.** The near-IR spectra of $\varepsilon$ Indi Ba (red, upper line) and Bb. The regions marked with dotted rectangles are shown inset, note the y-dispersion is indicative of the wealth of real features: this is not noise.

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**REFERENCES**

1. L. M. Close, R. Lenzen, J. C. Guirado, E. L. Nielsen, E. E. Mamajek, W. Brandner, M. Hartung, C. Lidman, and B. Biller, *Nature* 433, 286–289 (2005).
2. K. L. Luhman, and D. Potter, *Astrophysical Journal* 638, 887–896 (2006).
3. R.-D. Scholz, M. J. McCaughrean, N. Lodieu, and B. Kuhlbrodt, *Astronomy & Astrophysics* 398, L29–L33 (2003).
4. M. J. McCaughrean, L. M. Close, R.-D. Scholz, R. Lenzen, B. Biller, W. Brandner, M. Hartung, and N. Lodieu, *Astronomy & Astrophysics* 413, 1029–1036 (2004).