Mem. S.A.It. Vol. 75, 1

Memorie della

Luhman 16AB: A Remarkable, Variable L/T Transition Binary 2 pc from the Sun

A. J. Burgasser[1], J. Faherty[2], Y. Beletsky[3], P. Plavchan[4], M. Gillon[5], J. Radigan[6], E. Jehin[5], L. Delrez[5], C. Opitom[5], N. Morrell[3], R. Osten[6], R. Street[7], C. Melis[1], A. Triaud[8], and R. Simcoe[8]

[1] UC San Diego, 9500 Gilman Drive, Mail Code 0424, La Jolla, CA 92093, USA
[2] Universidad de Chile, Camino El Observatorio #1515, Las Condes, Chile
[3] Las Campanas Observatory, Carnegie Observatories, Casilla 601, La Serena, Chile
[4] Caltech/IPAC, 770 S Wilson Ave Pasadena, CA 91125, USA
[5] Université de Liège, Allée du 6 août 17, Sart Tilman, Liège 1, Belgium
[6] Space Telescope Science Institute, 3700 San Martin Dr., Baltimore, MD 21218, USA
[7] Las Cumbres Observatory, 6740 Cortona Drive Suite 102, Goleta, CA 93117, USA
[8] MIT, 77 Massachusetts Avenue, Cambridge, MA 02139, USA
e-mail: aburgasser@ucsd.edu

Abstract. Luhman (2013) has reported the discovery of a brown dwarf binary system only 2.01±0.15 pc from the Sun. The binary is well-resolved with a projected separation of 1.″5, and spectroscopic observations have identified the components as late-L and early-T dwarfs. The system exhibits several remarkable traits, including a "flux reversal", where the T dwarf is brighter over 0.9–1.3 μm but fainter at other wavelengths; and significant (~10%) short-period (~4.9 hr) photometric variability with a complex light curve. These observations suggest spatial variations in condensate cloud structure, which is known to evolve substantially across the L dwarf/T dwarf transition. Here we report preliminary results from a multi-site monitoring campaign aimed at probing the spectral and temporal properties of this source. Focusing on our spectroscopic observations, we report the first detections of NIR spectral variability, present detailed analysis of K I lines that confirm differences in condensate opacity between the components; and preliminary determinations of radial and rotational velocities based on high-resolution NIR spectroscopy.

Key words. Stars: binaries – Stars: fundamental parameters – Stars: Brown Dwarfs

1. Introduction

The transition between the L dwarf and T dwarf spectral classes has emerged as one of the outstanding problems in brown dwarf astrophysics. Spectroscopically, this transition is defined by the appearance of CH_4 absorption at near-infrared (NIR) wavelengths (e.g., Burgasser et al. 2006a) and a reduction in condensate cloud opacity (e.g., Marley et al. 2002), both leading to large changes in NIR spectral energy distributions (SEDs). Among field brown dwarfs, this transition takes place

Send offprint requests to: A. J. Burgasser over a surprisingly narrow range of effective temperatures ($\Delta T_{\rm eff} \approx$ 100–200 K) and luminosities ($\Delta M_{bol} \approx$ 0.1–0.3 dex; Golimowski et al. 2004; Stephens et al. 2009). Even more remarkable is the existence of so-called “flip” binaries, whose components straddle the L/T transition and in which the later-type secondary can be brighter at 1 μm than the primary (Burgasser et al. 2006b; Liu et al. 2006). The most likely origin for these trends is a universal, “rapid” and possibly heterogeneous depletion of photospheric condensates at the L/T transition, the mechanism of which remains unclear to this day (Ackerman & Marley 2001; Burgasser et al. 2002b; Knapp et al. 2004; Saumon & Marley 2008).

The recently-discovered binary brown dwarf WISE J104915.57−531906.1AB (hereafter Luhman 16AB; Luhman 2013) has emerged as a key laboratory for studying the L/T transition. Its components straddle the transition, and it is a flip binary (Kniazev et al. 2013; Burgasser et al. 2013). Its proximity (2.02±0.15 pc) implies its components are both easily resolved (1.″5) and bright, permitting detailed investigation of their atmospheres; yet the system is compact enough for orbit determination in a 20–30 yr timeframe. Finally, this source has been shown to be variable (Gillon et al. 2013) with a peak-to-peak amplitude of ~10% and period of 4.87±0.01 hr.

2. The Monitoring Campaign

Given its unique characteristics and importance for understanding the L/T transition, we coordinated a week-long monitoring campaign of Luhman 16AB using telescopes in Chile, Australia, Hawaii and South Africa. Our aim was to measure the components of this system panchromatically (radio, optical and infrared), spectroscopically (optical and near-infrared, low to high resolution), and temporally. The observations conducted are summarized in Table 1 and illustrated in Figure 1. Throughout this period, ESO/TRAPPIST (Jehin et al. 2011) was used to anchor the observations to a common light curve. These data show that Luhman 16AB has persisted in its strong variability. All of our spectroscopic observations

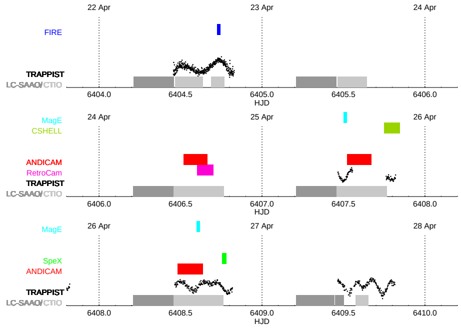

Fig. 1. Scheduling blocks of observations over 22-28 April 2013 (UT). ESO/TRAPPIST observations are indicated by the plotted lightcurve.

coincided with some period of TRAPPIST monitoring; the entire period is also blanketed by monitoring observations from the Las Cumbres Observatory Global Telescope Network (LCOGT; Street et al. 2012).

Here we report preliminary results from the spectroscopic components of our campaign.

2.1. Resolved FIRE Spectroscopy

Early NIR spectroscopy of Luhman 16AB were limited to low-resolution data (e.g., Burgasser et al. 2013). In contrast, the Folded-port Infrared Echellette (FIRE; Simcoe et al. 2010) on the Magellan 6.5m Baade Telescope provides moderate-resolution ($\lambda/\Delta\lambda \approx$ 8000) spectroscopy spanning the 0.8–2.4 μm band. We obtained resolved spectra on 22 April 2013 (UT), and several epochs thereafter, achieving S/N ≈ 500 in 200 s integration per source. The spectra reveal remarkable detail in atomic and molecular features, including detection of FeH and CH_4 absorption at H-band in both components, and clear detections of several alkali features at $\lambda < 1.3$ μm. Focusing on the 1.25 μm K I doublet (Figure 2), these lines are sufficiently strong that we can rule out either component having a low surface gravity, as would be expected if the system was a member of the ~40 Myr Argus association (Mamajek 2013).

Comparing the line shapes between sources, by normalizing at the continuum it appears that Luhman 16B has stronger, broader lines, consistent with previously de-

Table 1. Observations Conducted as Part of the Luhman 16AB Monitoring Campaign

Instrument	Program	Leads
ESO/TRAPPIST	Combined red optical monitoring	Gillon, Triaud
DuPont/RETROCAM	Resolved NIR monitoring	Faherty, Morell, Radigan
NTT/SOFI	Combined NIR monitoring	Radigan
CTIO/ANDICAM	Resolved optical & NIR monitoring	Faherty, Radigan
Magellan/FIRE	Resolved moderate resolution NIR spectroscopy	Faherty, Burgasser
Magellan/MagE	Resolved moderate resolution optical spectroscopy	Beletsky, Faherty
Magellan/MIKE	Resolved high resolution optical spectroscopy	Beletsky
IRTF/CSHELL	Resolved high resolution NIR spectroscopy	Plavchan, Burgasser
IRTF/SpeX	Resolved low resolution NIR spectral monitoring	Burgasser
ATCA	Resolved radio monitoring	Osten, Melis, Radigan
Las Cumbres Network	Resolved optical monitoring	Street

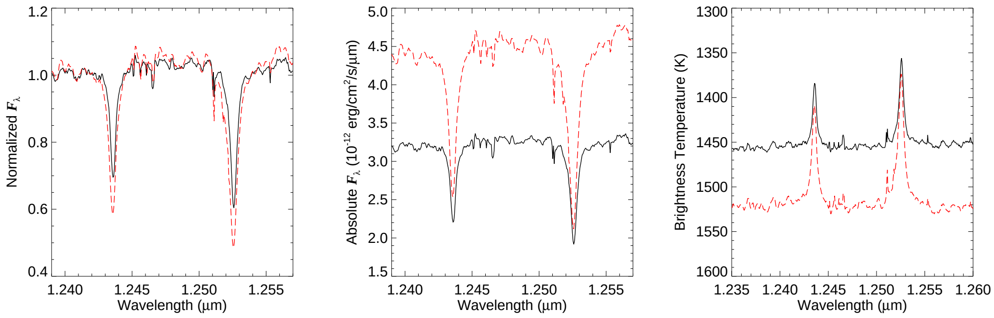

Fig. 2. The 1.25 μm K I doublet in FIRE data for Luhman 16A (solid black lines) and B (dashed red lines). (Left): Normalizing at the local continuum, it appears that Luhman 16B has deeper, broader lines, suggesting differences in abundances or $v \sin i$. (Middle): However, when scaled to absolute fluxes, it is clear that it is the continuum, not the lines, that varies between these sources. (Right): We can equate the absolute fluxes to brightness temperatures assuming radii R = 1 R_{Jup}. The ~70 K offset in the continuum between Luhman 16A and B (note inverse scale) can be attributed to reduced condensate opacity in the latter.

tected upticks in K I equivalent widths across the L/T transition (Burgasser et al. 2002a). However, when the spectra are normalized to their absolute magnitudes, we find that the lines are simply nested, with Luhman 16B having a brighter continuum. By associating spectral fluxes with brightness temperatures (T_{br}), we infer a ~70 K difference in the photospheric temperature of these two dwarfs in the 1.25 μm continuum, with Luhman 16B being the hotter source. Importantly, this T_{br} offset is *not present* in regions where molecular gas opacity dominates the continuum (e.g., around the 1.175 μm K I doublet). As the continuum around 1.25 μm in L dwarfs is dominated by condensate grain scattering opacity (e.g., Ackerman & Marley 2001), we attribute the T_{br} offset here to reduced condensate opacity in Luhman 16B. Further analysis of these data will be presented in Faherty et al. (in prep.).

2.2. Spectral Monitoring with SpeX

Luhman 16AB was spectroscopically monitored with SpeX (Rayner et al. 2003) on the 3m NASA Infrared Telescope Facility (IRTF) on 26 April 2013 (UT), using that instrument's low-resolution ($\lambda/\Delta\lambda \approx 120$) prism-dispersed mode. The system was observed for 45 min with the slit aligned along the binary axis for simultaneous spectroscopy. As seeing was comparable to the binary separation, the data were forward-modeled using a 10-parameter profile model, then calibrated using standard techniques. These new observations confirm the "flip" reported in Burgasser et al. (2013), apparent even in the raw data. Slit losses and differential color refraction[1] limit our analysis to *relative* spectral fluxes between the components (B/A). Figure 3 shows that these relative fluxes decline over the observing period, coincident with the TRAPPIST lightcurve; this is consistent with a dimming of Luhman 16B. The decline notably occurs for regions sampling both low and high gas opacity. Simllar achromatic flux variations have been reported in other variable L/T dwarfs (Apai et al. 2013), suggesting a common origin.

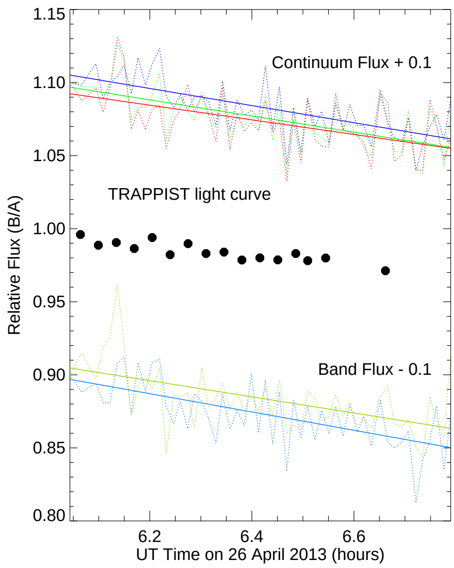

Fig. 3. Variations in relative flux (B/A) in several spectral regions sampling continuum and absorption band regions. The uniform declines are consistent with TRAPPIST combined-light data.

2.3. *High-resolution Spectroscopy with CSHELL*

For Luhman 16AB, high-resolution spectroscopy can constrain association membership (see above), orbital motion and individual component masses, and the orientation of the rotation axis on the sky. As a first step toward these measurements, we used CSHELL (Greene et al. 1993) on IRTF on 25 April 2013 (UT) to obtain high-resolution ($\lambda/\Delta\lambda \approx 43{,}000$) NIR spectroscopy over a ~60 Å window centered at 2.3124 μm. We deployed the $^{13}CH_4$ isotopologue gas cell to better determine our wavelength calibration (Anglada-Escudé et al. 2012). The binary was aligned with the 0″.5 slit, and a sequence of nine 900 s exposures was obtained for both components simultaneously. A preliminary reduction of the combined light spectrum is shown in Figure 4. With an average S/N ≈ 10, we are able to identify several features associated with CO absorption in the target spectra. These data can be reproduced with a 1500 K model with $v_{rad} \approx 20$ km/s (consistent with Kniazev et al. 2013) and $v \sin i \approx 25$ km/s, consistent with the variability period and a nearly equatorial orientation.

3. Next Steps

In addition to NIR spectroscopy, we obtained resolved optical spectroscopy (moderate and high resolution), resolved optical and NIR photometric monitoring, and a deep radio measurement. Because these observations occurred within a single campaign, we will be able to examine correlations between the measurements (e.g., SEDs at low and high brightnesses, spectral phase variations). Our detailed focus on Luhman 16AB will hopefully clarify some of the remarkable aspects of the L/T transition.

Acknowledgements. We are grateful to all of our telescope operators and instrument specialists for their assistance with the observations, and to A. Tokunaga and D. Osip for allowing observations to be conducted during engineering time.

[1] An illustration of how color refraction creates coordinated variability can be seen at `http://www.youtube.com/watch?v=DIJx0flF6uc`.

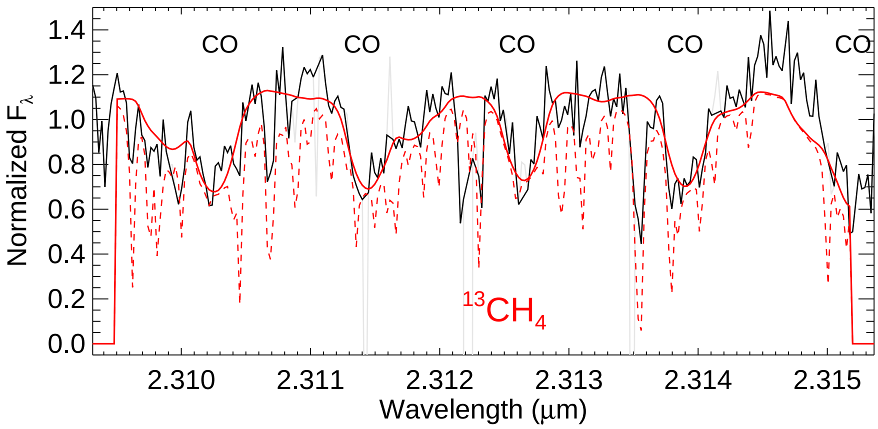

Fig. 4. Preliminary analysis of IRTF/CSHELL data, comparing the observed combined-light spectrum (black line) to a spectral model (solid red line) with v_{rad} = 20 km/s and $v \sin i$ = 25 km/s. Imprinted $^{13}CH_4$ lines on the model are shown as dashed red lines. Several CO features are detected.

References

Ackerman, A. S. & Marley, M. S. 2001, ApJ, 556, 872

Anglada-Escudé, G., Plavchan, P., Mills, S., et al. 2012, PASP, 124, 586

Apai, D., Radigan, J., Buenzli, E., et al. 2013, ApJ, 768, 121

Burgasser, A. J., Geballe, T. R., Leggett, S. K., Kirkpatrick, J. D., & Golimowski, D. A. 2006a, ApJ, 637, 1067

Burgasser, A. J., Kirkpatrick, J. D., Brown, M. E., et al. 2002a, ApJ, 564, 421

Burgasser, A. J., Kirkpatrick, J. D., Cruz, K. L., et al. 2006b, ApJS, 166, 585

Burgasser, A. J., Marley, M. S., Ackerman, A. S., et al. 2002b, ApJ, 571, L151

Burgasser, A. J., Sheppard, S. S., & Luhman, K. L. 2013, arXiv/1303.7283

Gillon, M., Triaud, A. H. M. J., Jehin, E., et al. 2013, arXiv/1304.0481

Golimowski, D. A., Leggett, S. K., Marley, M. S., et al. 2004, AJ, 127, 3516

Greene, T. P., Tokunaga, A. T., Toomey, D. W., & Carr, J. B. 1993, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 1946, Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, ed. A. M. Fowler, 313–324

Jehin, E., Gillon, M., Queloz, D., et al. 2011, The Messenger, 145, 2

Knapp, G. R., Leggett, S. K., Fan, X., et al. 2004, AJ, 127, 3553

Kniazev, A. Y., Vaisanen, P., Mužić, K., et al. 2013, ApJ, 770, 124

Liu, M. C., Leggett, S. K., Golimowski, D. A., et al. 2006, ApJ, 647, 1393

Luhman, K. L. 2013, ApJ, 767, L1

Mamajek, E. E. 2013, arXiv/1303.5345

Marley, M. S., Seager, S., Saumon, D., et al. 2002, ApJ, 568, 335

Rayner, J. T., Toomey, D. W., Onaka, P. M., et al. 2003, PASP, 115, 362

Saumon, D. & Marley, M. S. 2008, ApJ, 689, 1327

Simcoe, R. A., Burgasser, A. J., Bochanski, J. J., et al. 2010, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 7735, Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series

Stephens, D. C., Leggett, S. K., Cushing, M. C., et al. 2009, ApJ, 702, 154

Street, R. A., Lister, T. A., Tsapras, Y., et al. 2012, in IAU Symposium, Vol. 285, IAU Symposium, ed. E. Griffin, R. Hanisch, & R. Seaman, 408–410