Mid-Infrared Variability in Binary Brown Dwarfs

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Ground-based MIR photometry of binary stars/b.d. systems

- spatial resolution < 2"

- precise relative photometry (<5%)

- good absolute photometry (<20%) constrain Teff and Lbol

- discriminate atmospheric models
The case of ε Ind B

- SPITZER IRS from Roelling, 2004:
  - $T_{bb} = 800K$ and $T_{ba} = 1200K$
  - NH3 absorption @ 10.5 μm

BUT:

- McCaughrean et al., 2004, AO assisted H-band R=1000 spectroscopy: $T_{bb} = 835K ... 875K$ and $T_{ba} = 1238K ... 1312K$ (0.8...2Gyr)
- Smith et al., 2003, combo R=50000, compared with Tsuji (2002) : $T_b \approx 1500K$
- MIR model spectra differ: Allard/Burrows/Saumon/Helling ...
- $T_{ba}$ is a tough one! (L/T transition: settling?, cond?, non-equilibrium chem?)
- if $T_{ba}$ hot, then problems with its radius ...

Roelling et al., 2004
VISIR - VLT Imager and Spectrometer for mid-IR

- diffraction limited (0.3” resolution)
- high sensitivity N-band imaging (5mJy 10σ /hr)
- 11 narrow N band filters
- long slit R=350/3000/25000 spectroscopy
- queue (service) and visitor mode
- reduction pipeline
The case of $\varepsilon$ Ind B

Model of the emission spectrum of a 800K brown dwarf (Burrows)

$\varepsilon$ Indi (a) and (b) VISIR@VLT/Melipal

(a) $7.4 \pm 0.4$ mJy
(b) $3.5 \pm 0.4$ mJy
PAH1 (8.6 $\mu$m)

(a) $7.2 \pm 0.6$ mJy
(b) $3.6 \pm 0.8$ mJy
SIV (10.5 $\mu$m)

(a) $6.8 \pm 0.8$ mJy
(b) $5.7 \pm 2.0$ mJy
PAH2 (11.3 $\mu$m)

Sterzik et al., 2004
$\varepsilon$ Indi B and Burrows, Sudarsky, Hubeny (2006) model

$F_v$ [mJy]

$\lambda$ [\(\mu\)m]

$T = 800K, 900K$

$T = 1200K, 1300K$
Hubeny & Burrows (2007) models

indication for non-equilibrium atmosphere
Star - Brown Dwarf binaries (8.6μ)

**GJ 229**
- dist ~ 6pc
- sep. 7".7
- SpTy T7
- T~1000K
- age 30-200 Myrs

**HR 7329**
- dist ~ 50pc
- sep. 4".2
- SpTy M7-M8
- T~2600K
- age 12 Myrs

**HD 130948**
- dist ~ 18pc
- sep. 2".6 + 0".13
- SpTy L4+L4
- T~1900K
- age 300-800 Myrs
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Geissler, Chauvin & Sterzik, 2008
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<td>jy</td>
<td>3.2(0.5)</td>
<td>&lt;3.2</td>
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<td>3.8(0.4)</td>
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n.o. <3.2 n.o.

Geissler, Chauvin & Sterzik, 2008
Comparison w/ atm. models (GJ229)

- **GJ229B**
  - Ames - cond
  - $T=900K$, $t=200$ Myr
  - L&L cloud free

- **PAH1 (3.2+-0.5 mJy)**
- **Siv (<3.2 mJy)**
- **PAH2 (<6.7 mJy)**

- **HD130948BC**
  - Ames - dusty
  - $T=1900K$, $t=300$ Myr
  - L&L cloudy

- **PAH1 (1.9+-0.4 mJy)**
- **Siv (<2.9+-0.4 mJy)**
- **PAH2 (<1.2 mJy)**

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*Wednesday, August 12, 2009*
## Comparison w/ atm. models (GJ229)

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<td>1.5</td>
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<td>Siv (2.9+-0.4 / &lt; 1.6 mJy)</td>
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Is HD 130948 variable @ 10.5μ?

5/Aug/06

3/Aug/06

simulated

5.7 ± 0.4 mJy

<3.2 (b.l. + 3σ) mJy

sim. source 4 mJy
Is HD 130948 variable @ 10.5μ?

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5.7 ± 0.4 mJy
Variability in B.D.s

The Quest for Weather: Silicates, Methane, Ammonia, CO
L/T transition: cloudy/clear...

A SENSITIVE SEARCH FOR VARIABILITY IN LATE L DWARFS: THE QUEST FOR WEATHER

M. Morales-Calderón, 1,2 J. R. Stauffer, 1 J. Davy Kirkpatrick, 4 S. Casey, 3 C. R. Gelino, 3
D. Barbado y Navascués, 1 L. Rebull, 2 P. Lowrance, 1 M. S. Marley, 3
D. Charbonneau, 6,7 B. M. Patten, 6 S. T. Megieath, 6 and D. Buzasi 1

Received 2006 June 2; accepted 2006 July 21

CLOUDS search for variability in brown dwarf atmospheres

Infrared spectroscopic time series of L/T transition brown dwarfs*

B. Goldman1,2, M. C. Cushing3, **, M. S. Marley4, É. Artigau5, K. S. Baliyan6, V. J. S. Béjar7, J. A. Caballero7,8,
N. Chanover4, M. Connolley9, R. Doyon10, T. Forveille11,12, S. Ganesh6, C. R. Gelino1,13, H. B. Hammel14,
R. Sagar15, and D. Stephens18
Variability in B.D.s @ 10.5 $\mu$m
L/T transition: cloudy/clear...
non-equilibrium chemistry / vertical mixing
heterogeneity of cloud patterns: Silicates, Ammonia, CO

Saumon, Marley & Lodders, 2003

Figure 2.13: Sequence of the March 2008 observations of HD 130948BC in PAH1 and SIV.
Systematic Monitoring of HD 130948

Figure 2.13: Sequence of the March 2008 observations of HD 130948BC in PAH1 and SIV.
Variability Analysis

- $\chi^2$ analysis (Morales-Calderon et al.)
- $\eta$ (Enoch et al. 2003, statistically more robust)

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<td>HD 130948 PAH I</td>
<td>1.8</td>
<td>0.99</td>
<td>0.4</td>
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<td>HD 130948 SIV</td>
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HD 130948 likely not variable in PAH1 and SIV!
Systematic Monitoring of ε Ind B

incl time series data from 2007
Photometric errors systematically measured through simulated sources

Wednesday, August 12, 2009
Systematic Monitoring of ε Ind B

Flux [mJy]


Wednesday, August 12, 2009
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$\varepsilon$ Ind Bb unlikely variable in PAH2 and SIV.
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$\varepsilon$ Ind Ba *maybe* variable in PAH2 and SIV, tentatively attributed to variable NH$_3$ absorption.

$\varepsilon$ Ind Bb unlikely variable in PAH2 and SIV.

Sterzik et al., in prep.