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

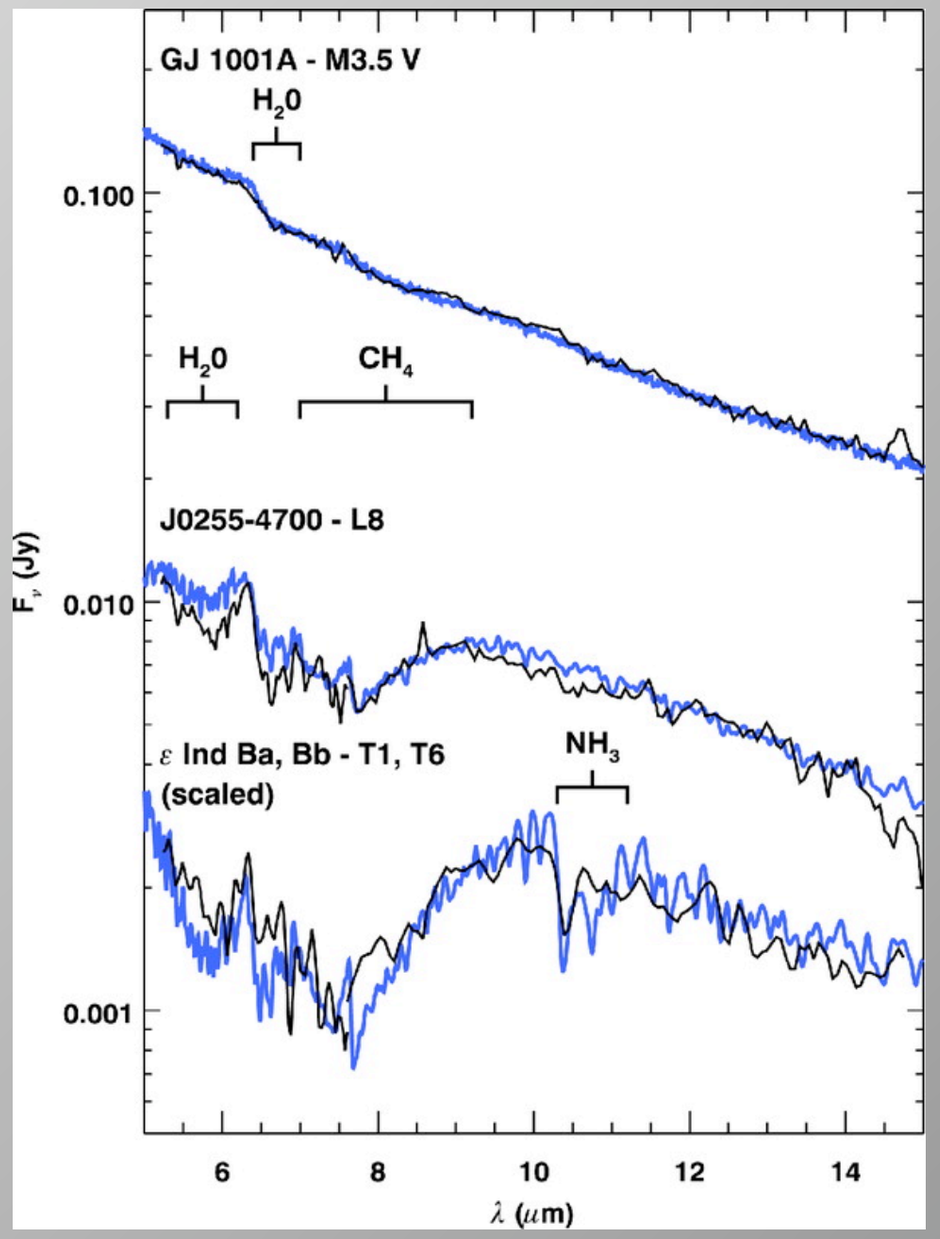
- discriminate atmospheric models

The case of ε Ind B

- SPITZER IRS from Roelling, 2004:
- Matches cloudless combo of Saumon, Marley, Lodders (2003)
- 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)

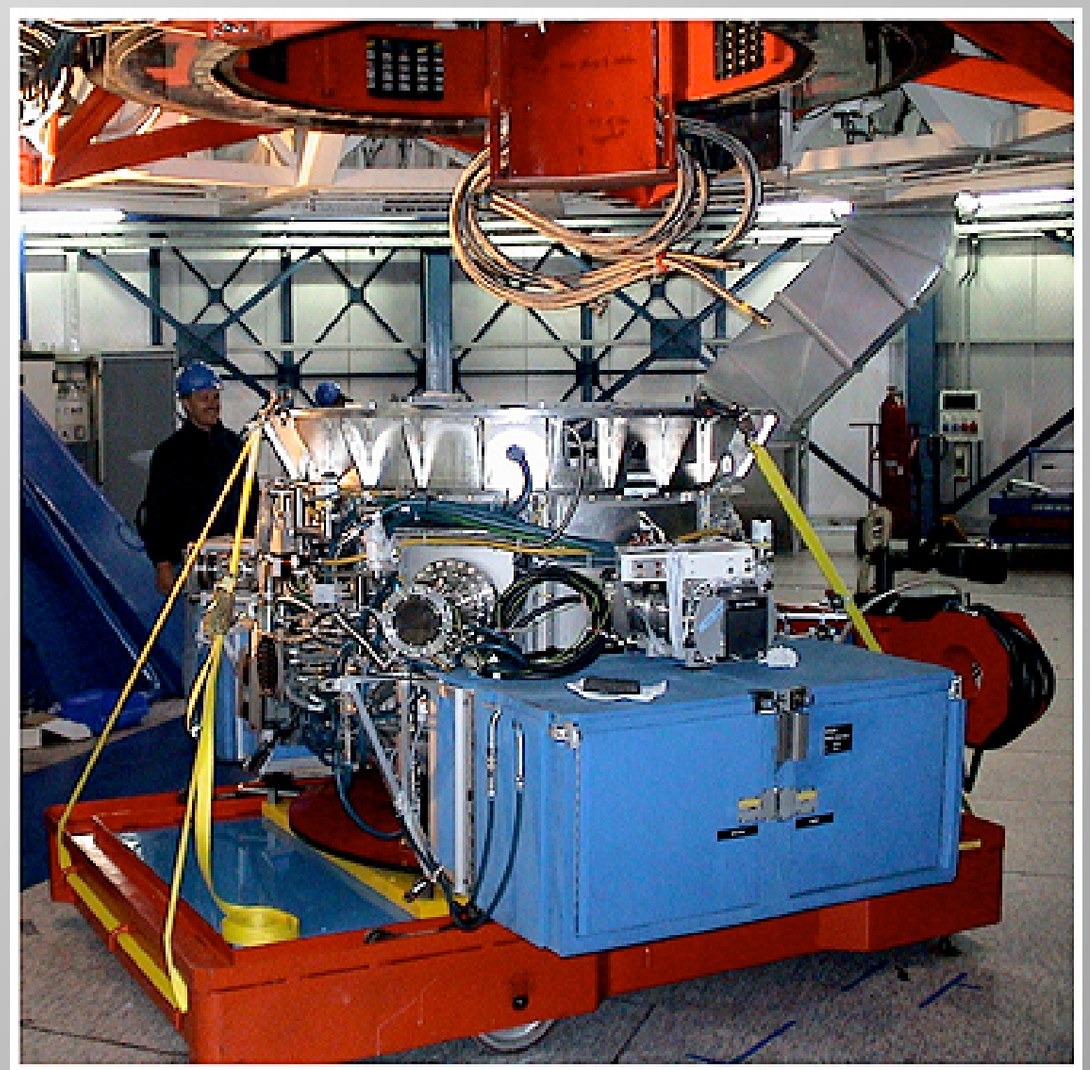
- high sensitivity N-band imaging (5mJy 10σ /hr)

- 11 narrow N band filters

- long slit R=350/3000/25000 spectroscopy

- queue (service) and visitor mode

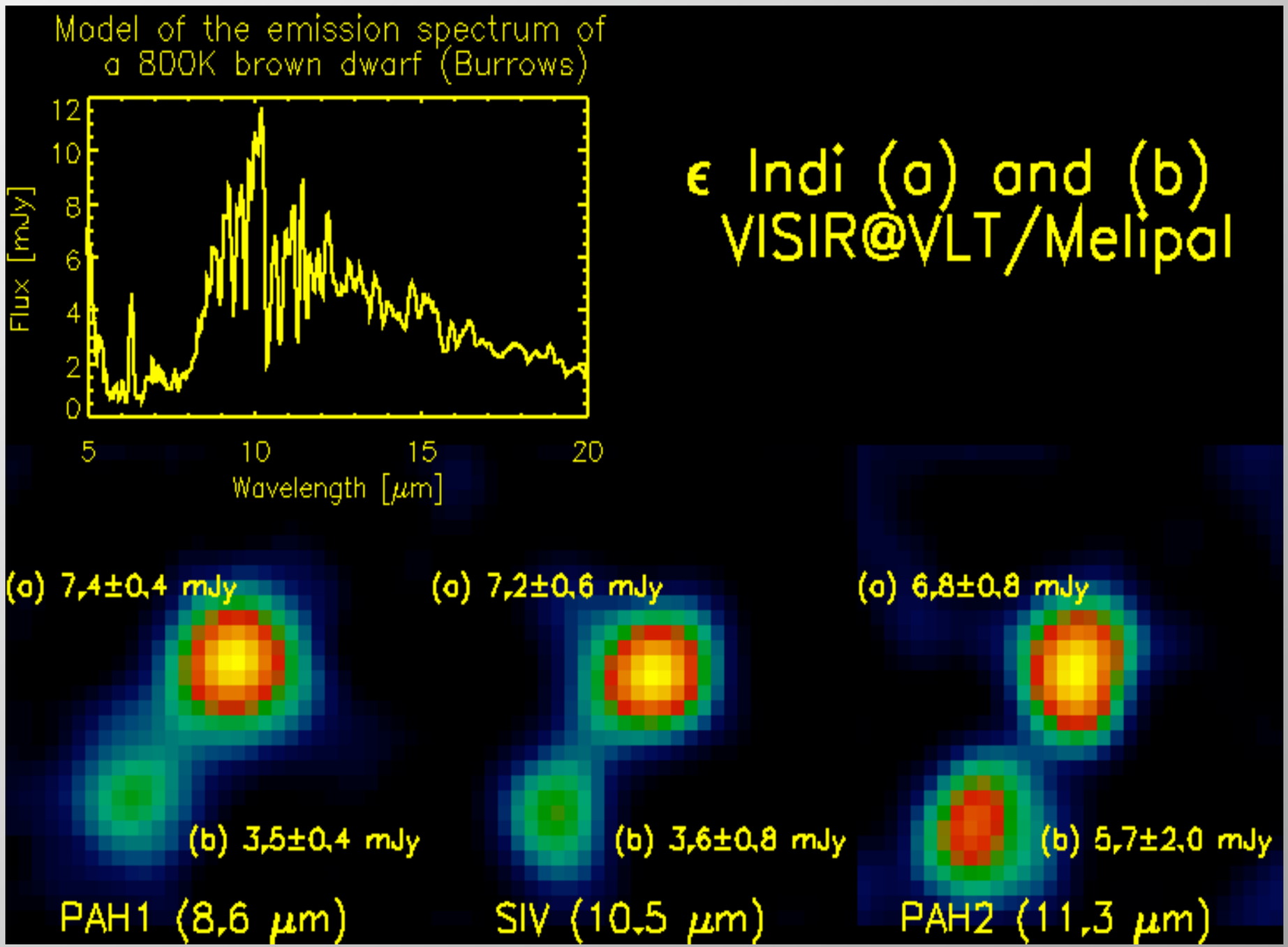
- reduction pipeline



VISIR under the Cassegrain Focus of the 8.2-m VLT Melipal Telescope

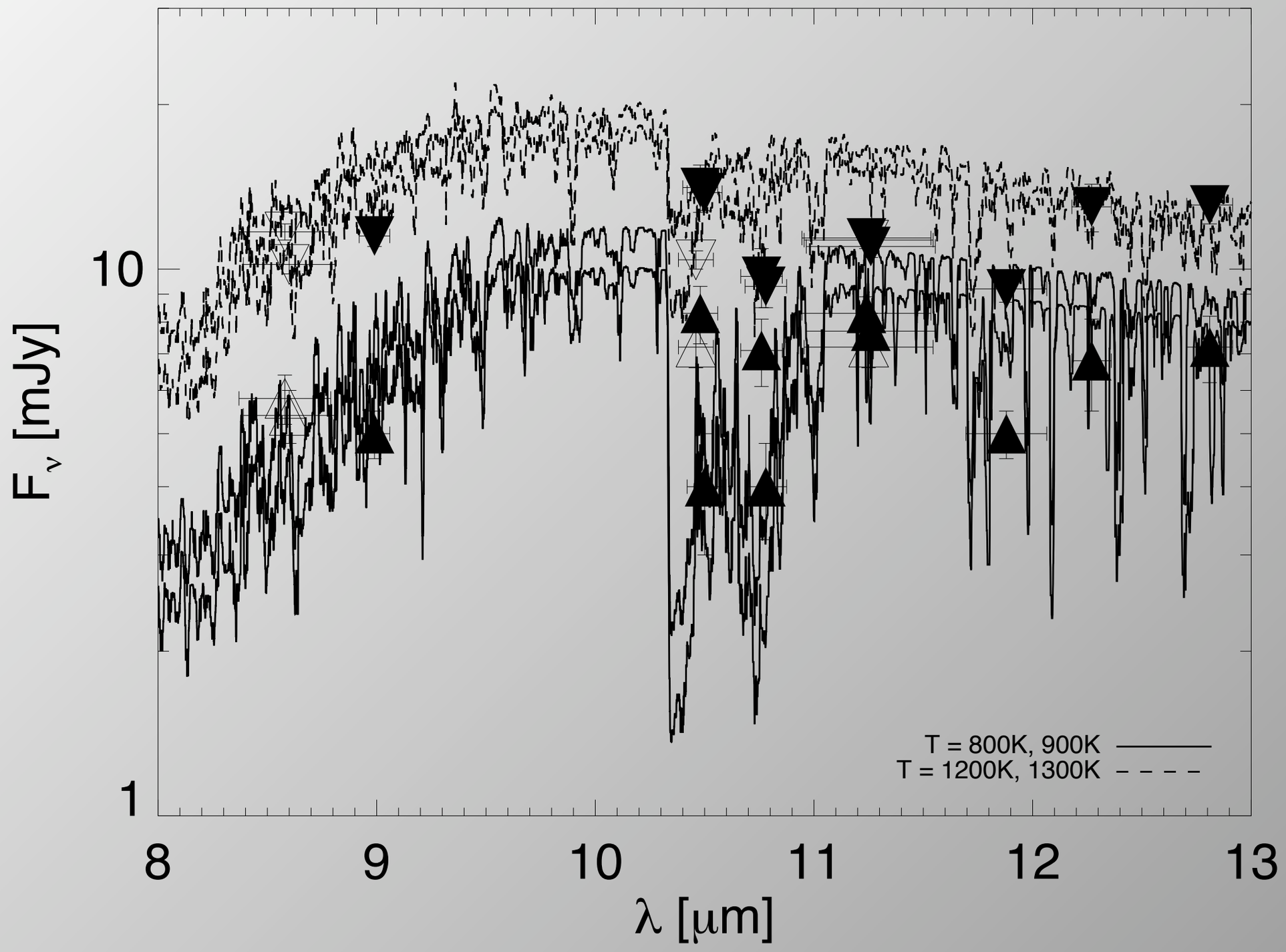
ESO PR Photo 16a/04 (12 May 2004)

The case of ε Ind B

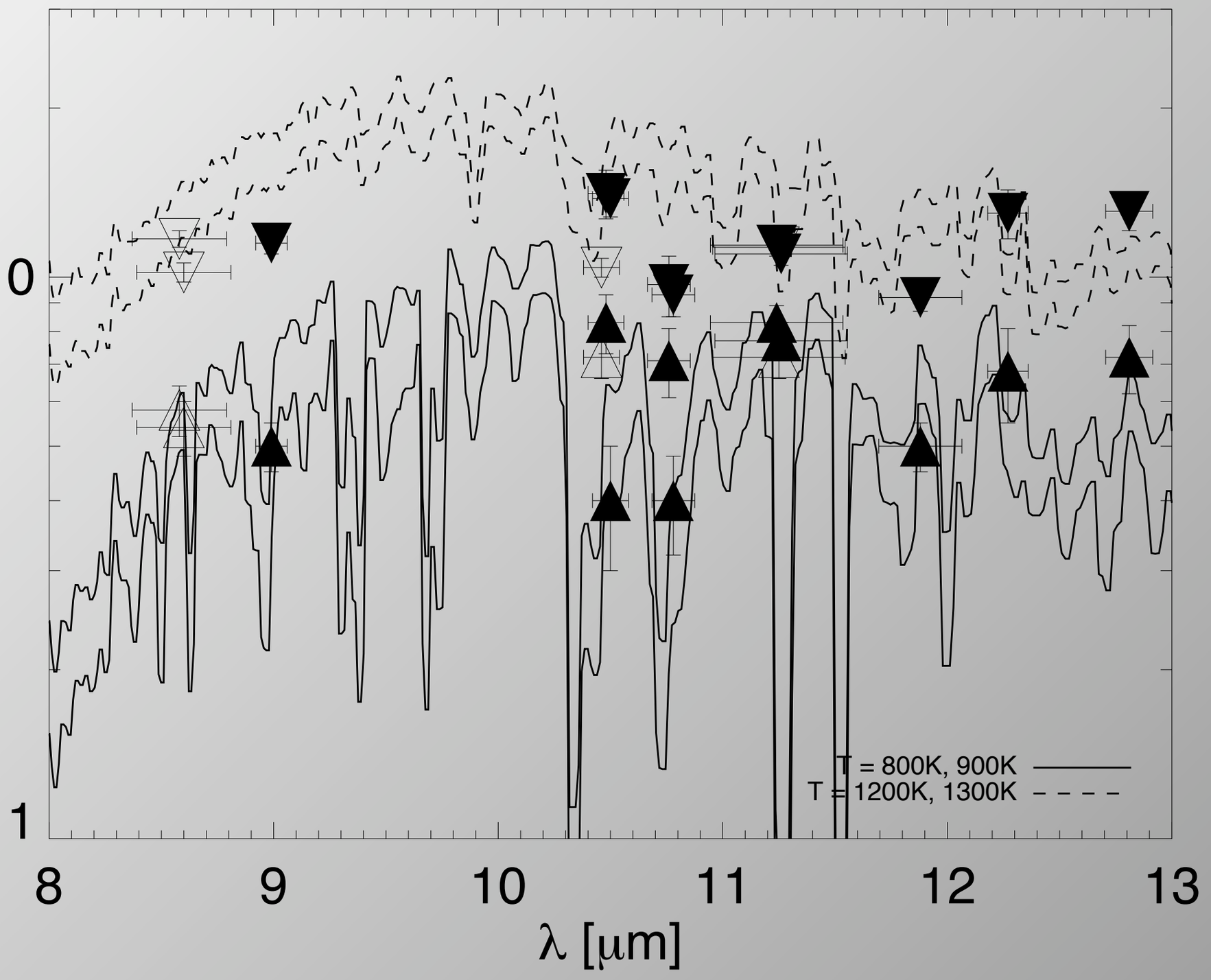


Sterzik et al., 2004

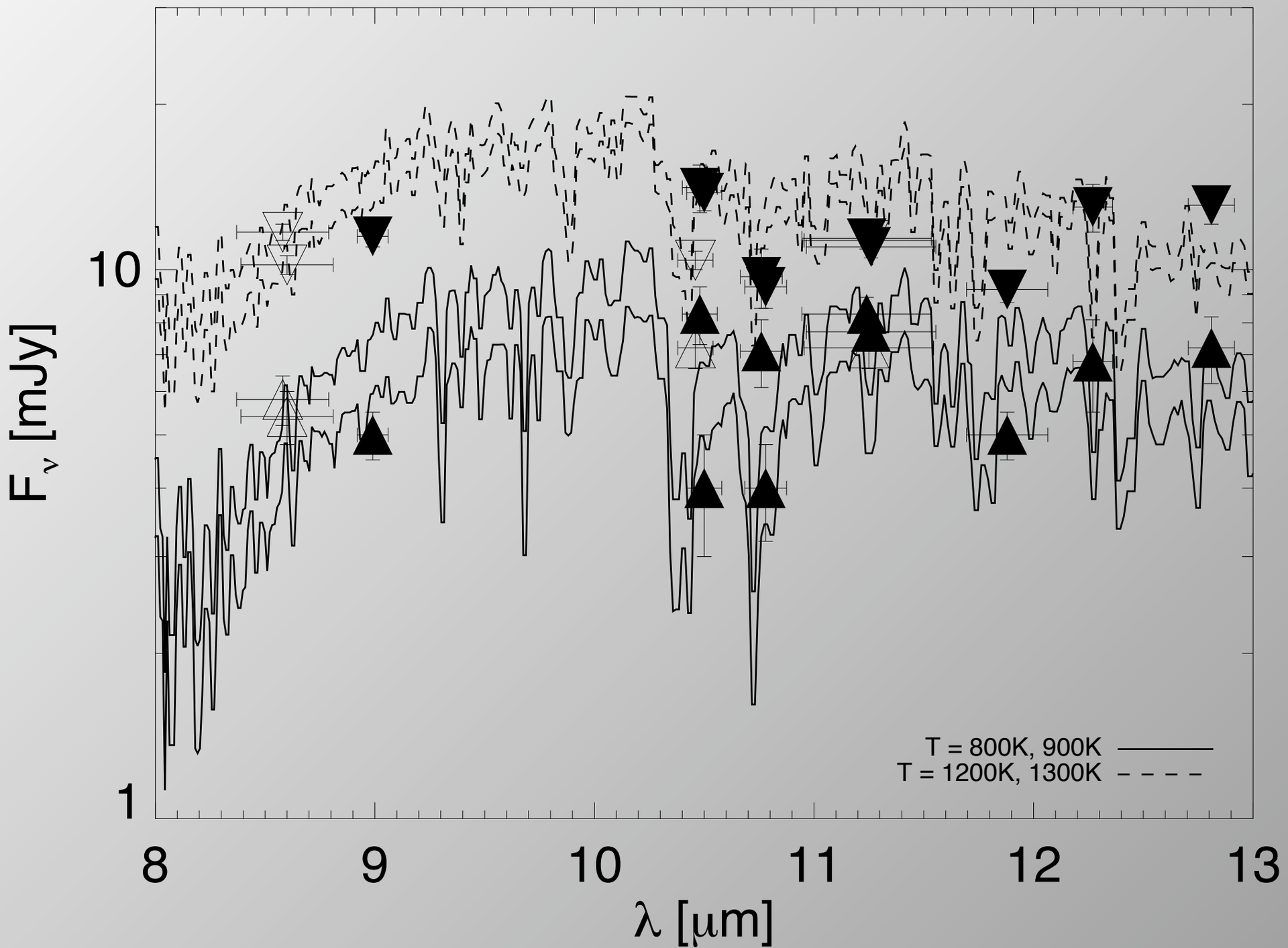
ε Indi Bab and AMES-cond. models



ε Indi B and Burrows, Sudarsky, Hubeny (2006) model



Hubeny & Burrows (2007) models



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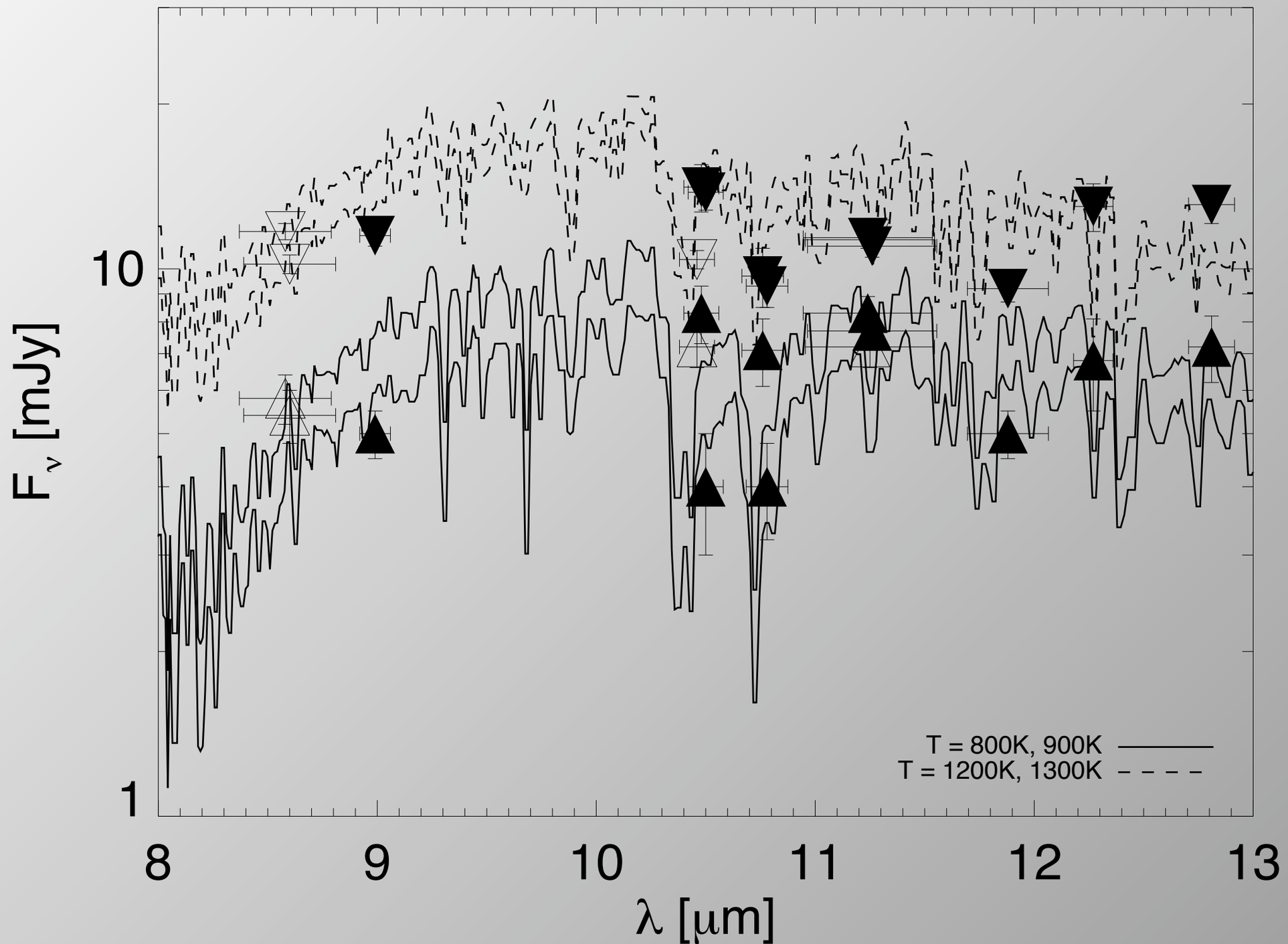

indication for non-equilibrium atmosphere

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
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Geissler, Chauvin & Sterzik, 2008

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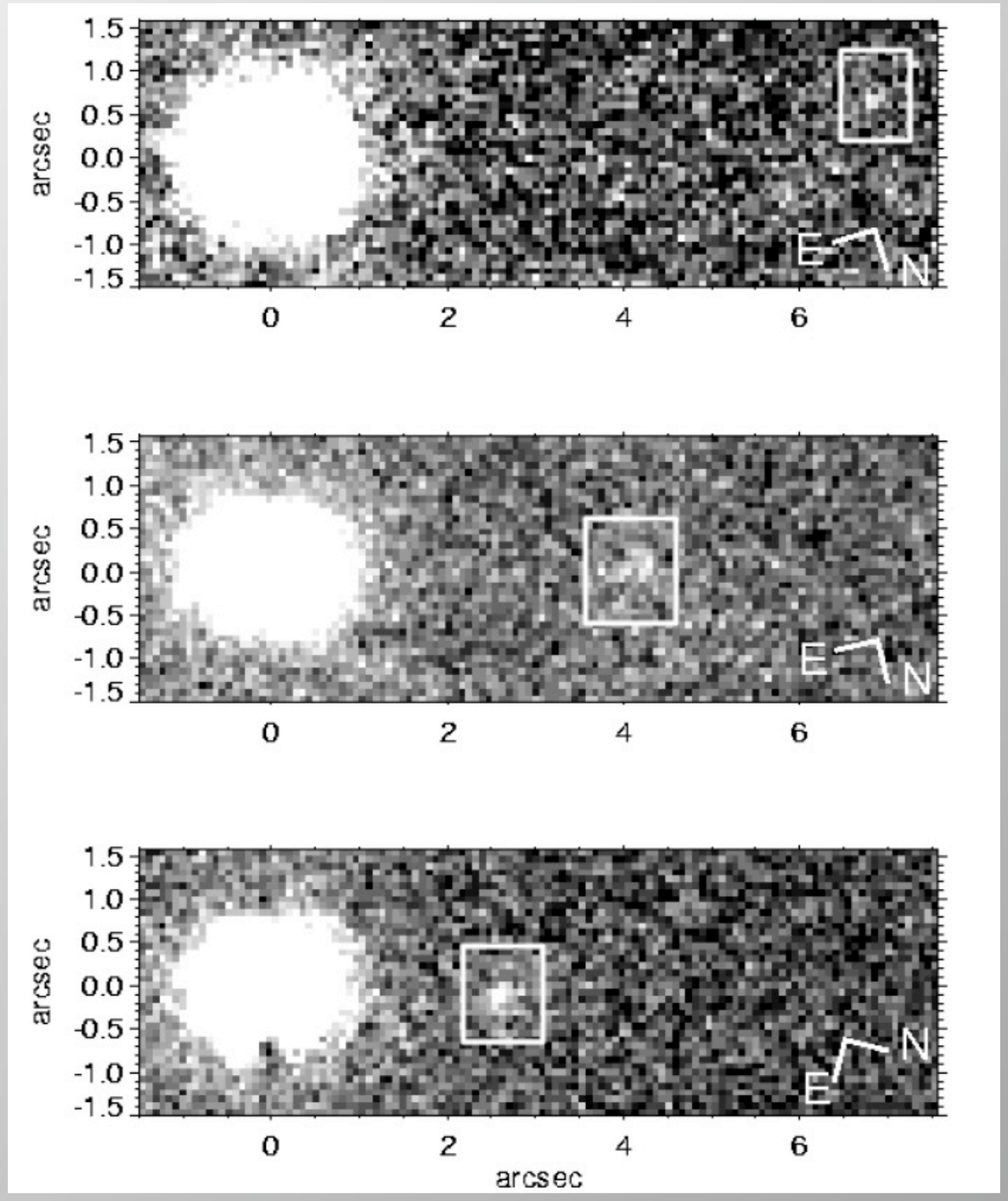

Geissler, Chauvin & Sterzik, 2008

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λ	8.6μ	10.5μ	11.3μ
mJy	3.2(0.5)	<3.2	<6.7

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mJy	3.2(2.3)	<1.9	<2.9

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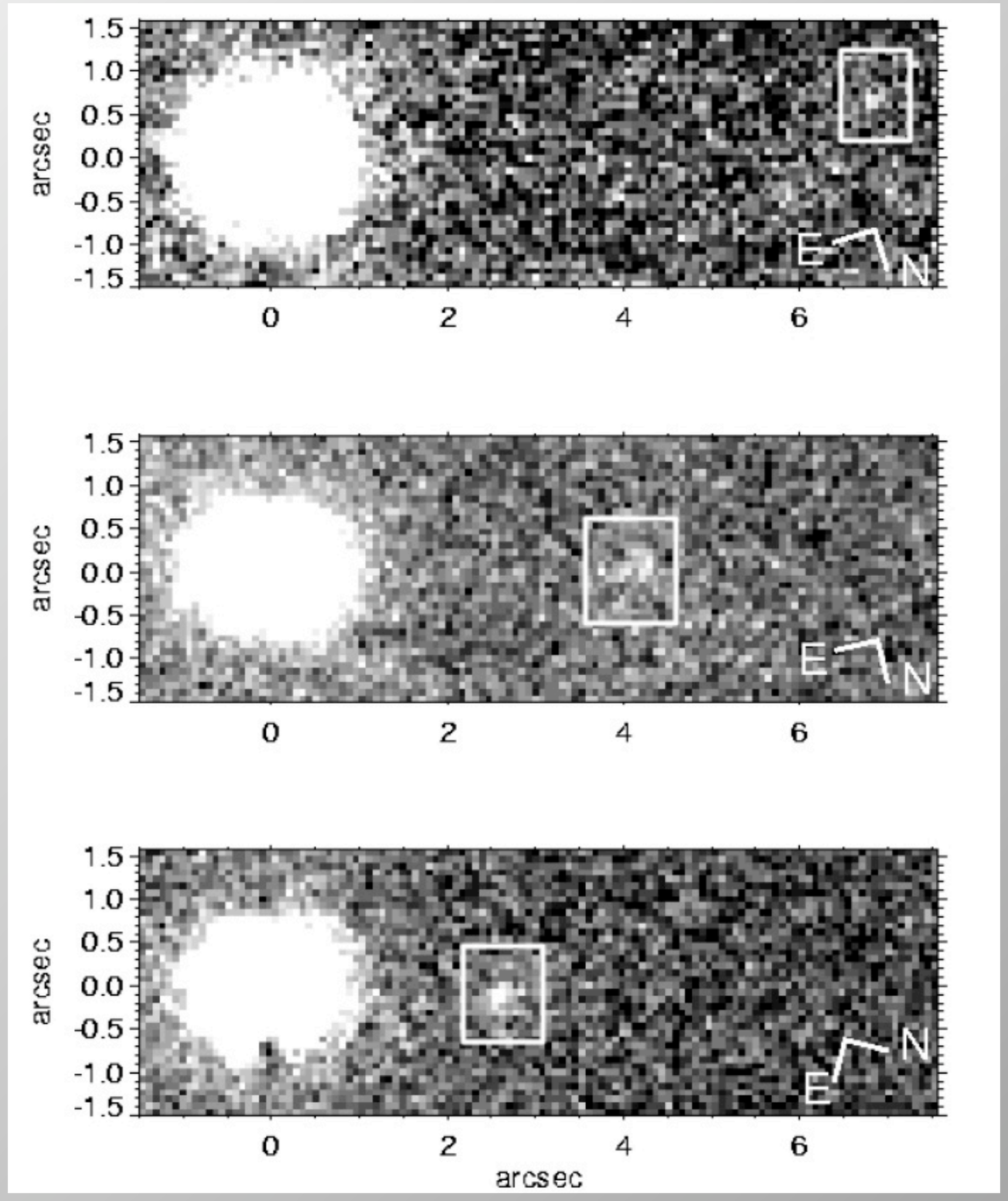

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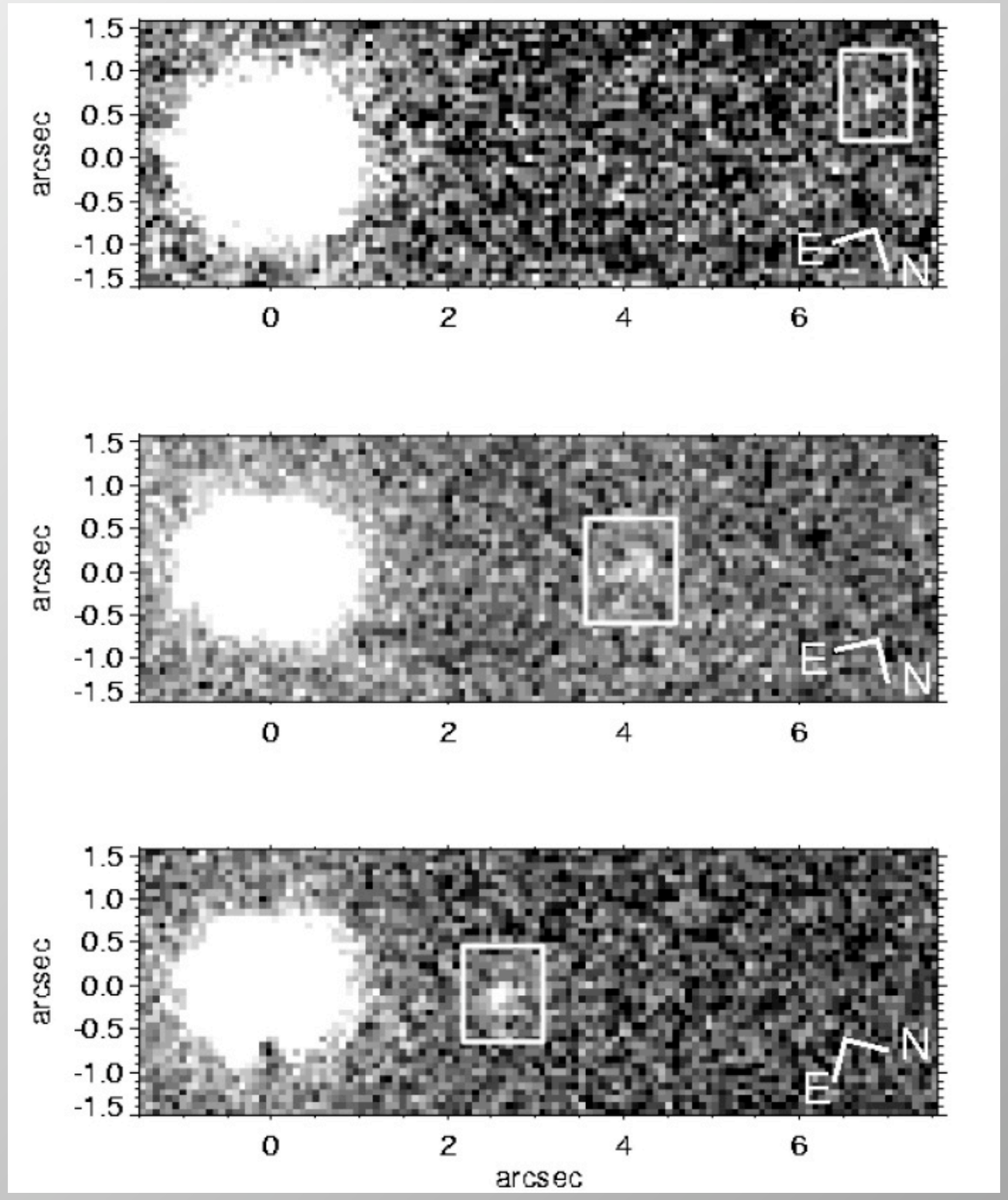
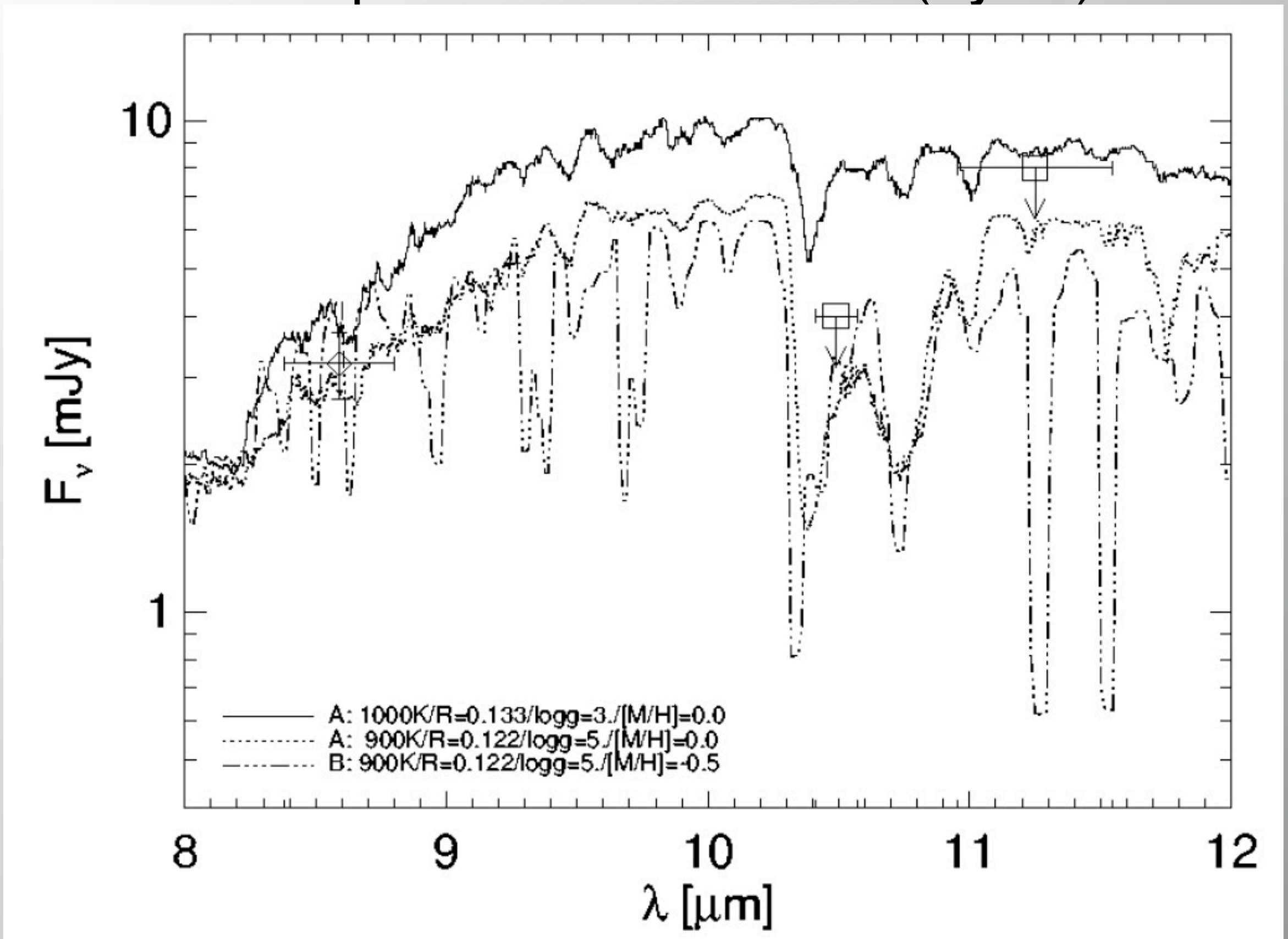
SpTy L4+L4
T~1900K
age 300-800 Myrs

λ	8.6μ	10.5μ	11.3μ
mJy	3.8(0.4)	5.7(0.4)	<2.4
	n.o.	<3.2	n.o.



Geissler, Chauvin & Sterzik, 2008

Comparison w/ atm. models (GJ229)

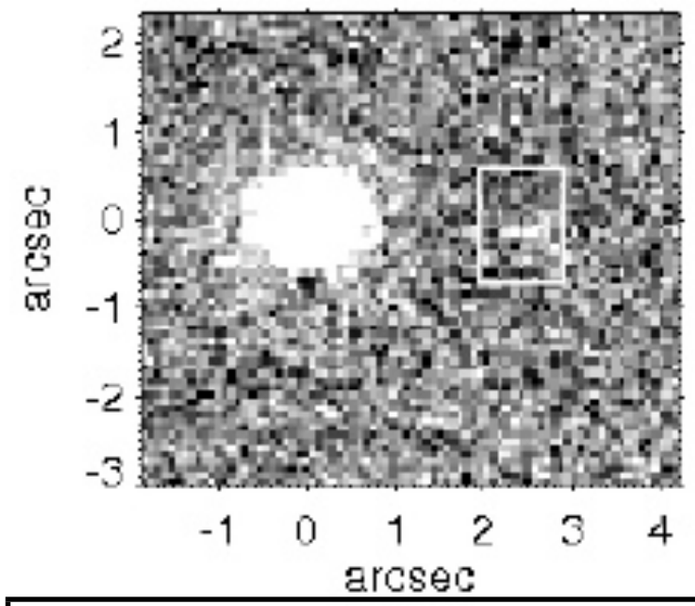
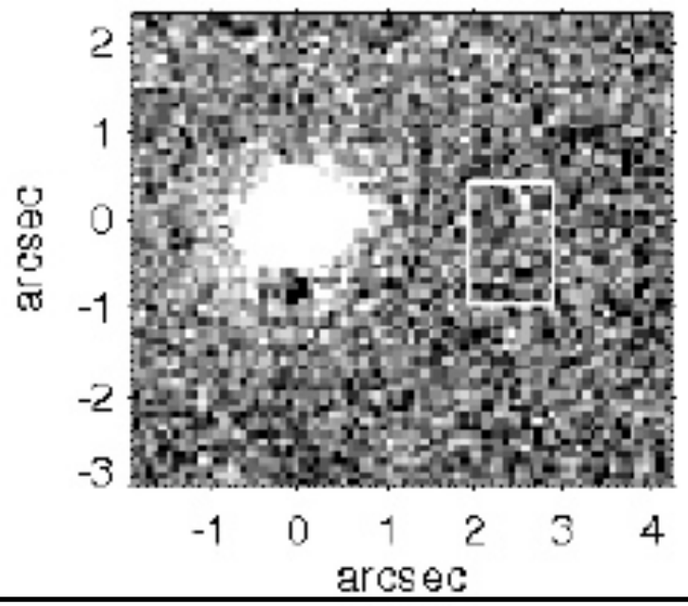
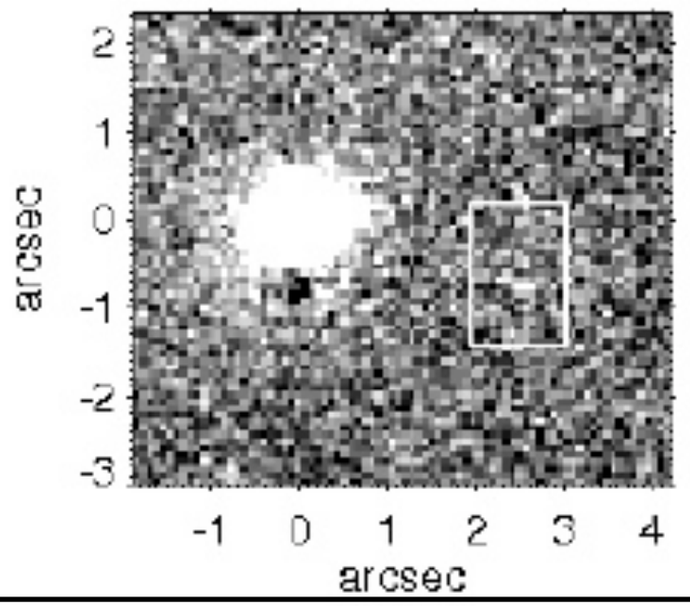


Comparison w/ atm. models (GJ229)

GJ229B	AMES - cond T=900K t=200Myr	L&T cloud free T=900K t=200Myr
PAH1 (3.2+-0.5 mJy)	3.3	3.4
Siv (<3.2 mJy)	3.0	3.0
PAH2 (<6.7mJy)	5.1	4.3

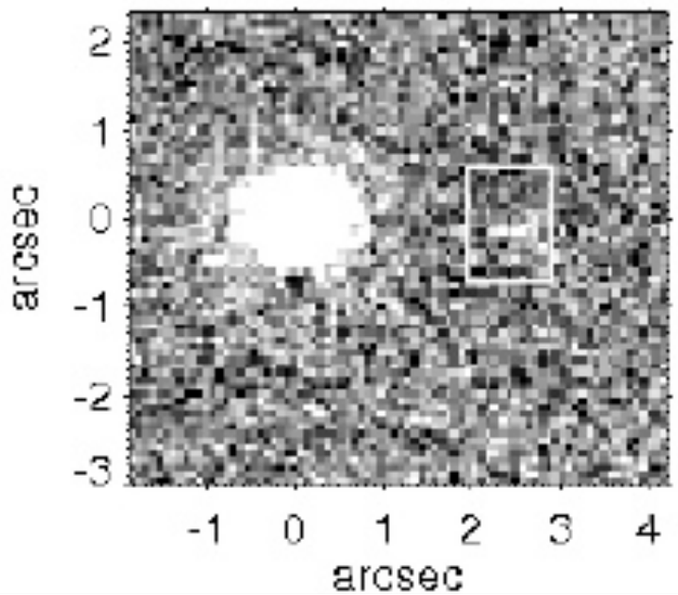
HD130948BC	AMES - dusty T=1900K t=300Myr	L&T cloudy T=1900K t=300Myr
PAH1 (1.9+-0.4 mJy)	2.1	1.5
Siv (2.9+-0.4 / < 1.6 mJy)	1.6	1.3
PAH2 (<1.2mJy)	1.4	1.2

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?

5/Aug/06 3/Aug/06 simulated



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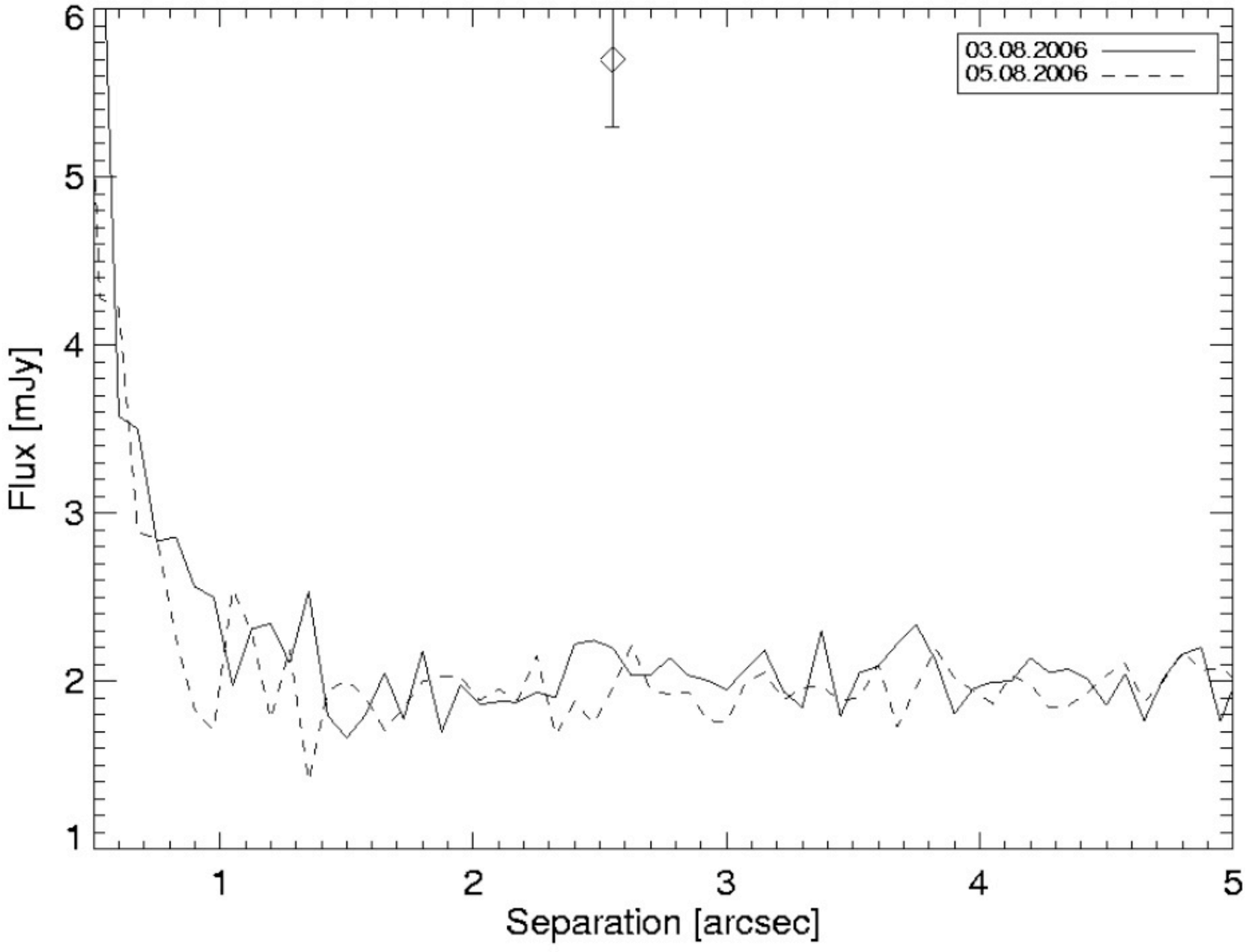


Variability in B.D.s

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

The Astrophysical Journal, 653:1454–1463, 2006 December 20

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

M. Morales-Calderón,[1,2] J. R. Stauffer,[3] J. Davy Kirkpatrick,[4] S. Carey,[3] C. R. Gelino,[3]
D. Barrado y Navascués,[1] L. Rebull,[3] P. Lowrance,[3] M. S. Marley,[5]
D. Charbonneau,[6,7] B. M. Patten,[6] S. T. Megeath,[6] and D. Buzasi[8]
Received 2006 June 2; accepted 2006 July 21

A&A 487, 277–292 (2008)
DOI: 10.1051/0004-6361:20065075

Astronomy & Astrophysics

CLOUDS search for variability in brown dwarf atmospheres

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

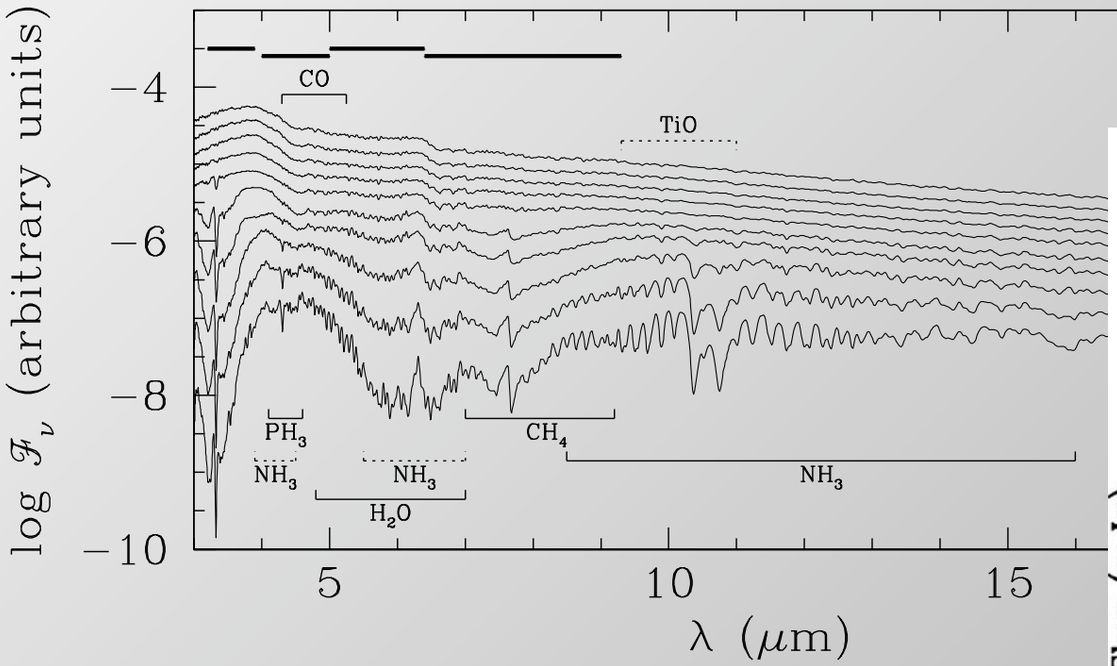
B. Goldman[1,2], M. C. Cushing[3,⋆⋆], M. S. Marley[4], É. Artigau[5], K. S. Baliyan[6], V. J. S. Béjar[7], J. A. Caballero[2,8], N. Chanover[1], M. Connelley[9], R. Doyon[10], T. Forveille[11,12], S. Ganesh[6], C. R. Gelino[1,13], H. B. Hammel[14], J. Holtzman[1], S. Joshi[15], U. C. Joshi[6], S. K. Leggett[16], M. C. Liu[9], E. L. Martín[8], V. Mohan[17], D. Nadeau[10], R. Sagar[15], and D. Stephens[18]

Variability in B.D.s @ 10.5μ

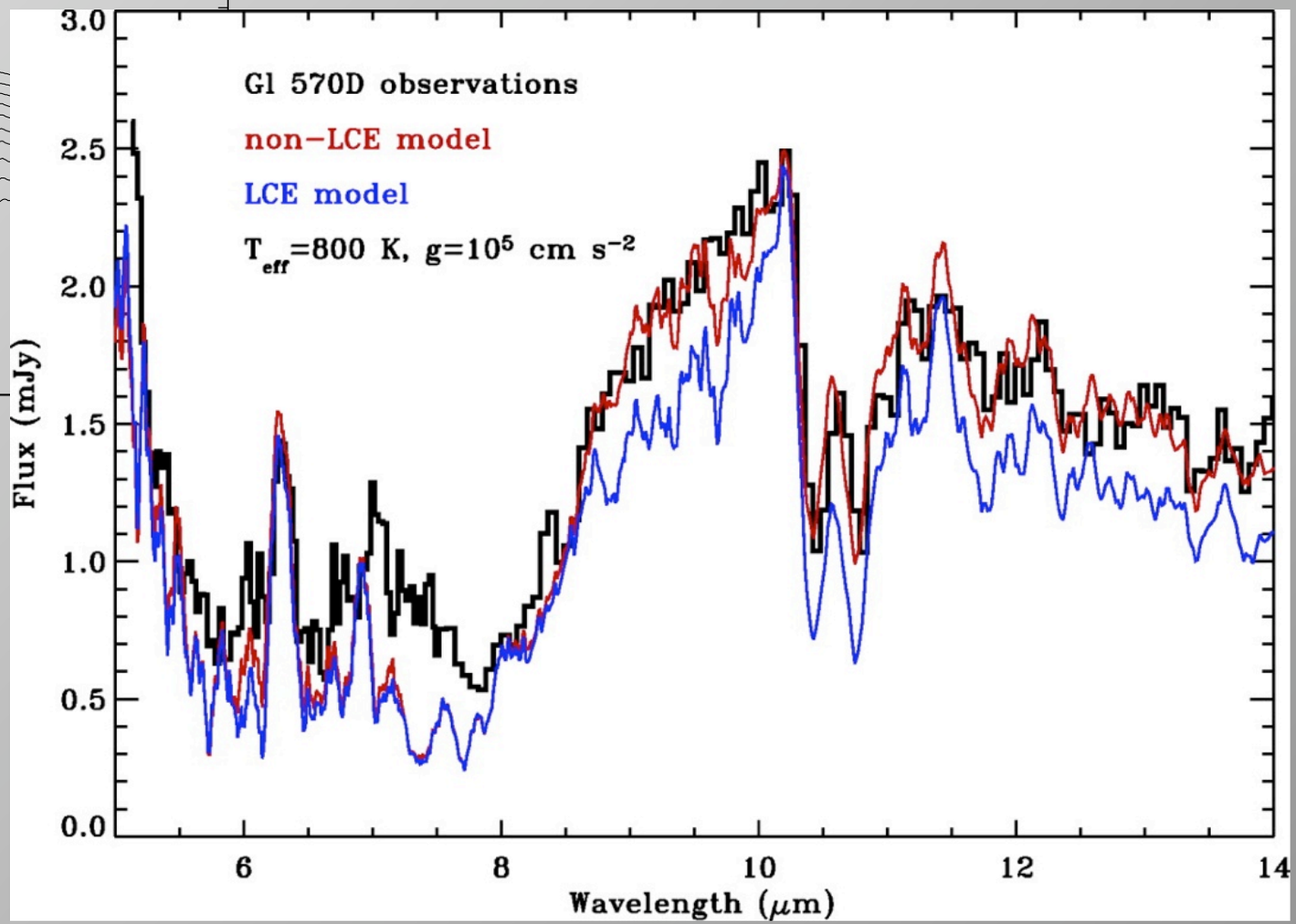
L/T transition: cloudy/clear...

non-equilibrium chemistry / vertical mixing

heterogenity of cloud patterns: Silicates, Ammonia, CO



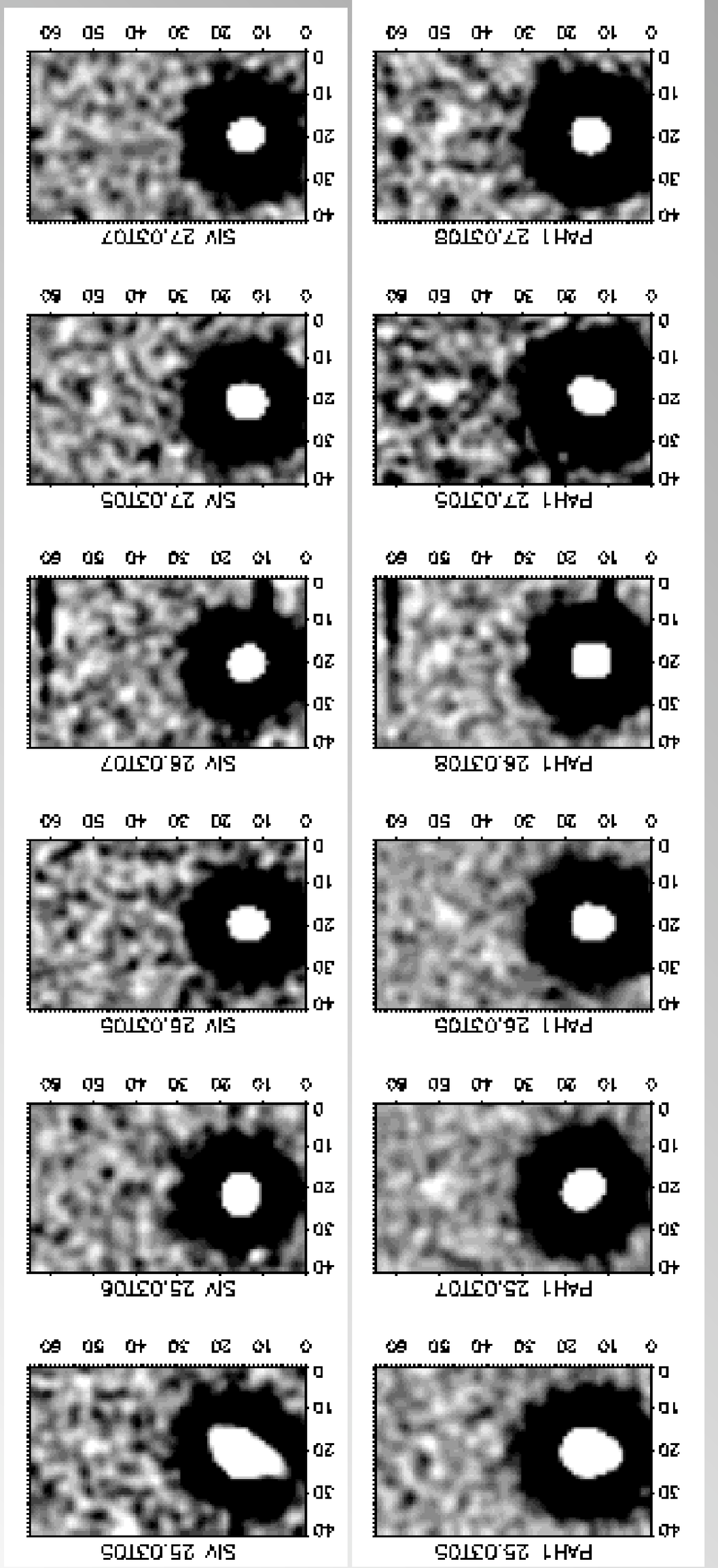
Saumon, Marley & Lodders, 2003



Hubeny & Burrows, 2007, ApJ669

Systematic Monitoring of HD 130948

SIV PAH1



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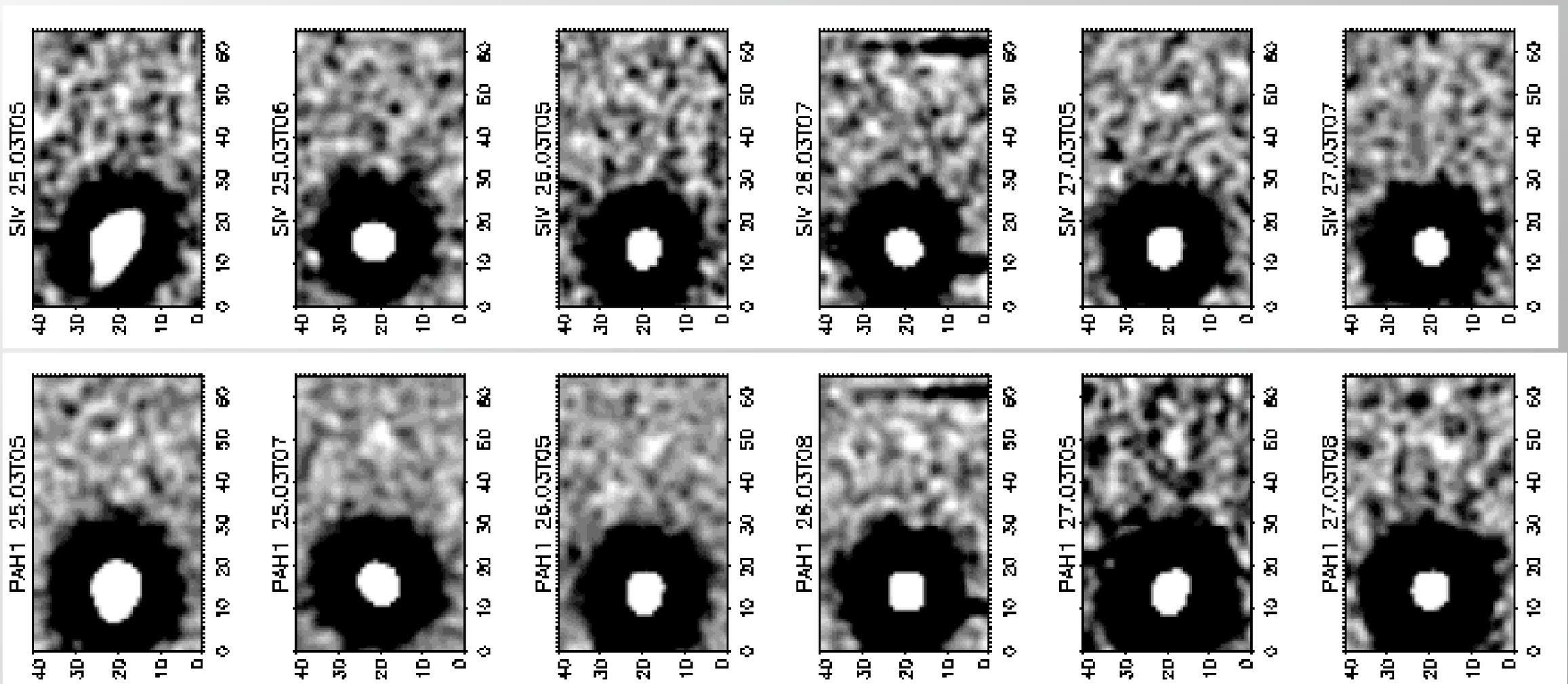

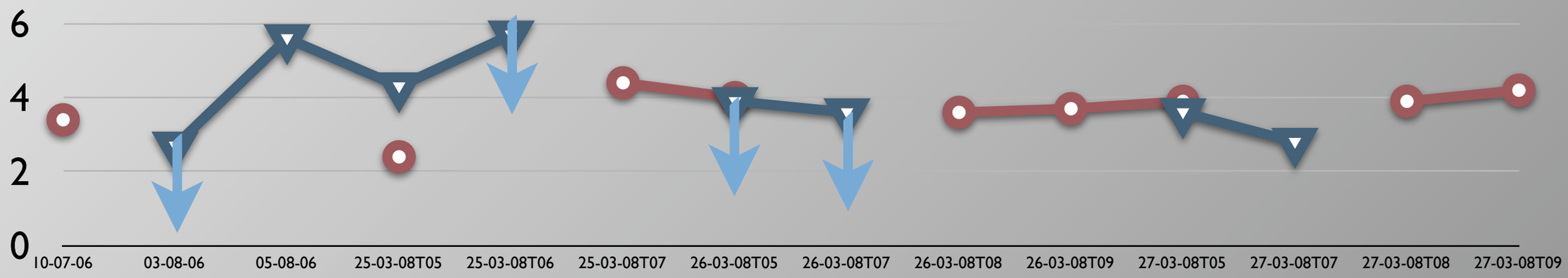

Variability Analysis

- X^2 analysis (Morales-Calderon et al.)
- η (Enoch et al. 2003, statistically more robust)

	X^2	P	η
HD 130948 PAH1	1.8	0.99	0.4
HD 130948 SIV	5.5	0.59	0.7

Geissler et al., Cool Stars

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HD 130948 likely not variable in PAH1 and SIV!

Geissler et al., Cool Stars

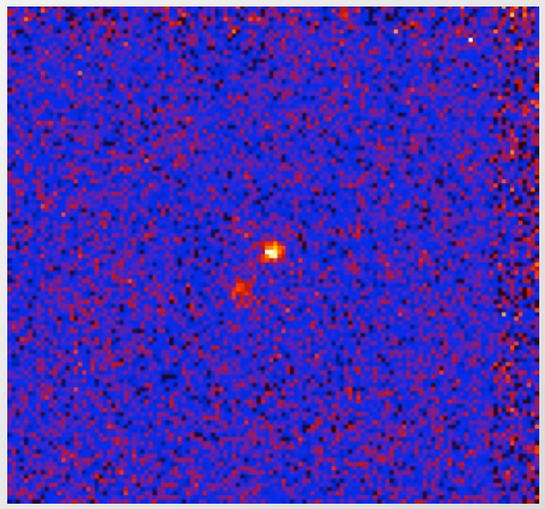
Systematic Monitoring of ε Ind B

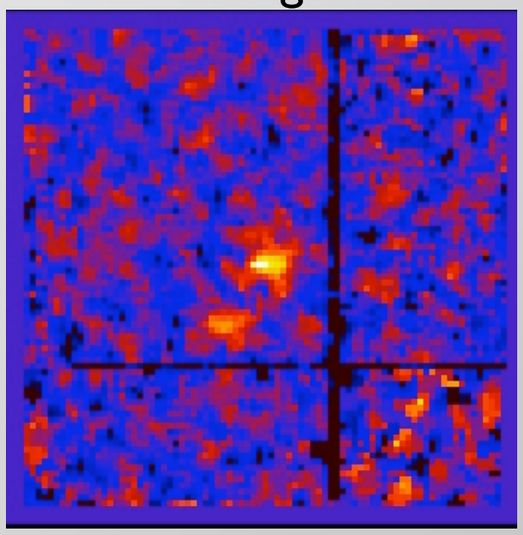
2/Oct/04

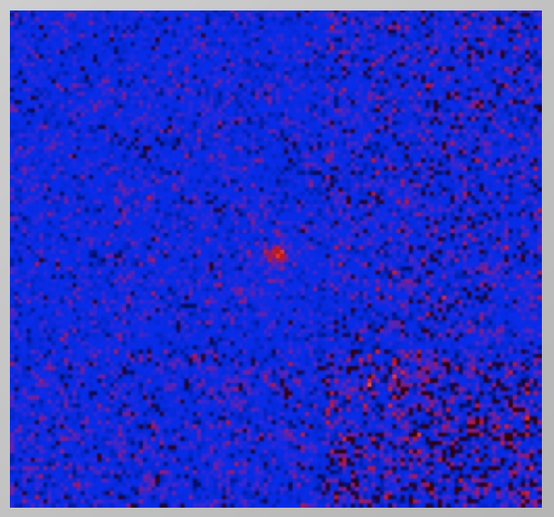
25/Aug/05

9/Sep/05

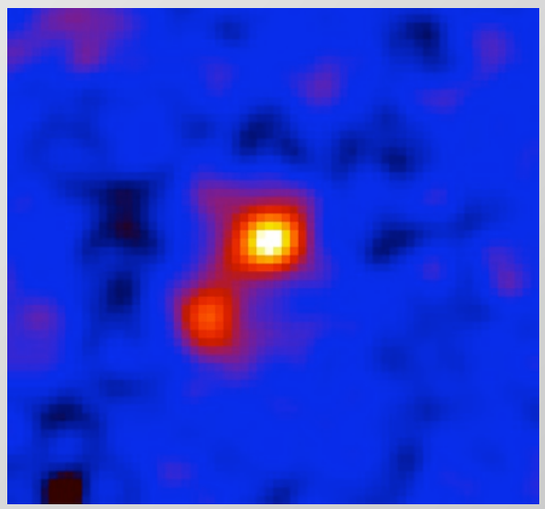
folded

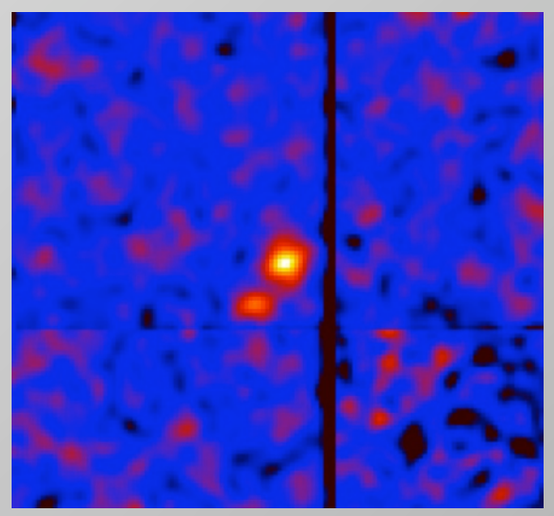


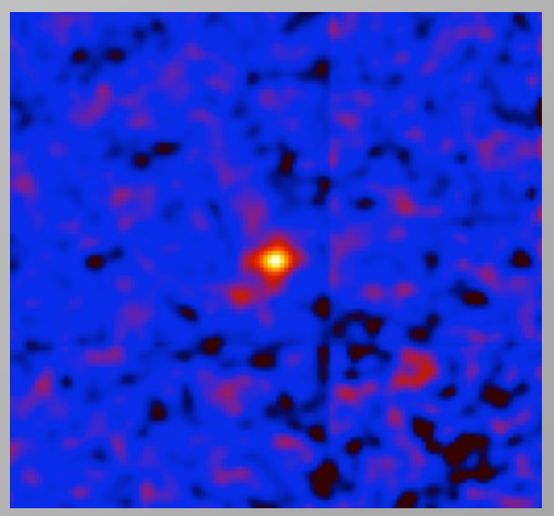




convol.
wavelet

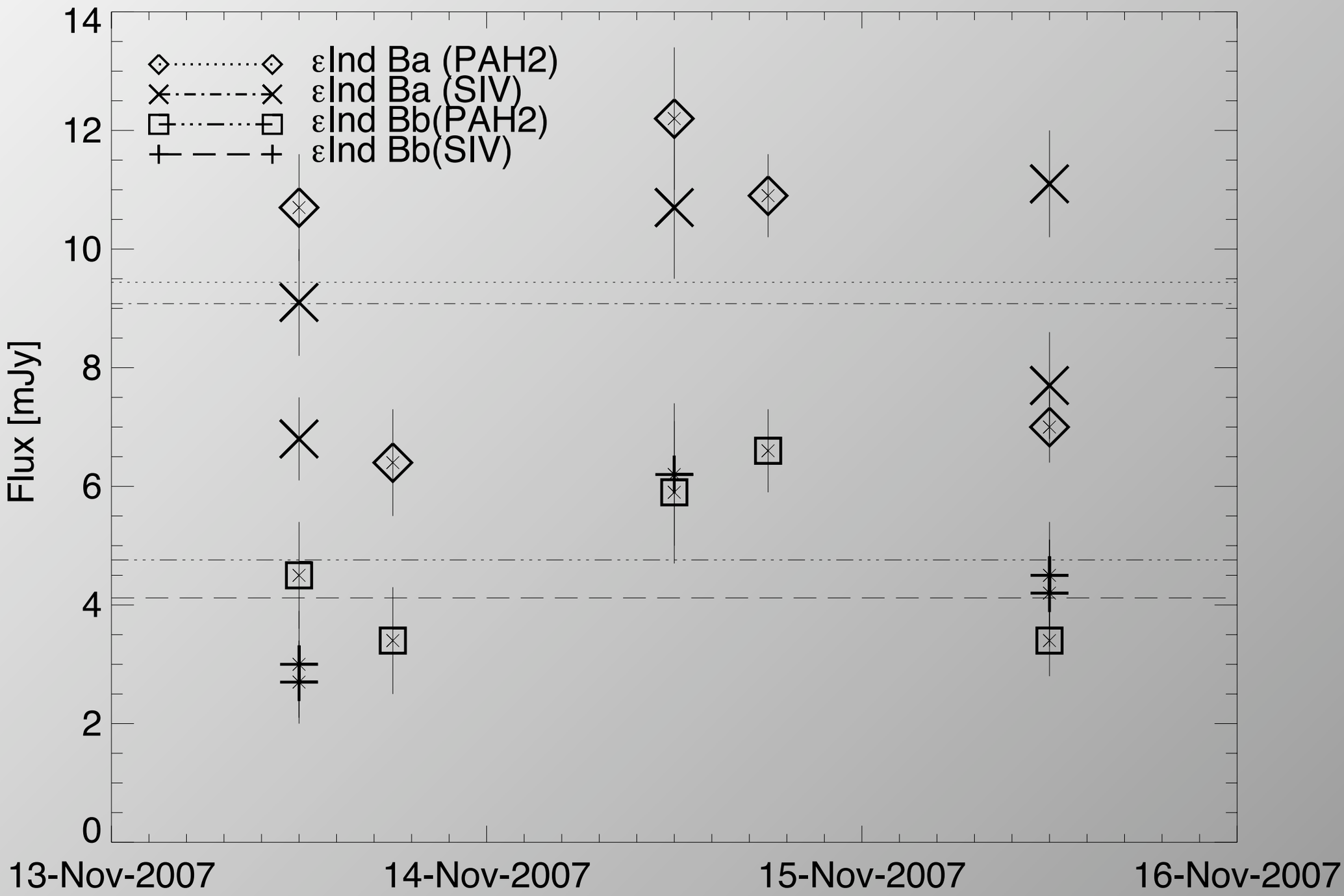






incl time series data from 2007
Photometric errors systematically measured through simulated sources

Systematic Monitoring of ε Ind B



Variability Analysis

	X^2	P	η
ε Ind Ba PAH2	40	10^{-7}	3.1
ε Ind Ba SIV	20	10^{-3}	2.1
ε Ind Bb PAH2	15	10^{-2}	1.8
ε Ind Bb SIV	9	10^{-1}	1.4

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ε Ind Bb unlikely variable in PAH2 and SIV.

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ε Ind Ba *maybe* variable in PAH2 and SIV, tentatively attributed to variable NH3 absorption.

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Sterzik et al., in prep.