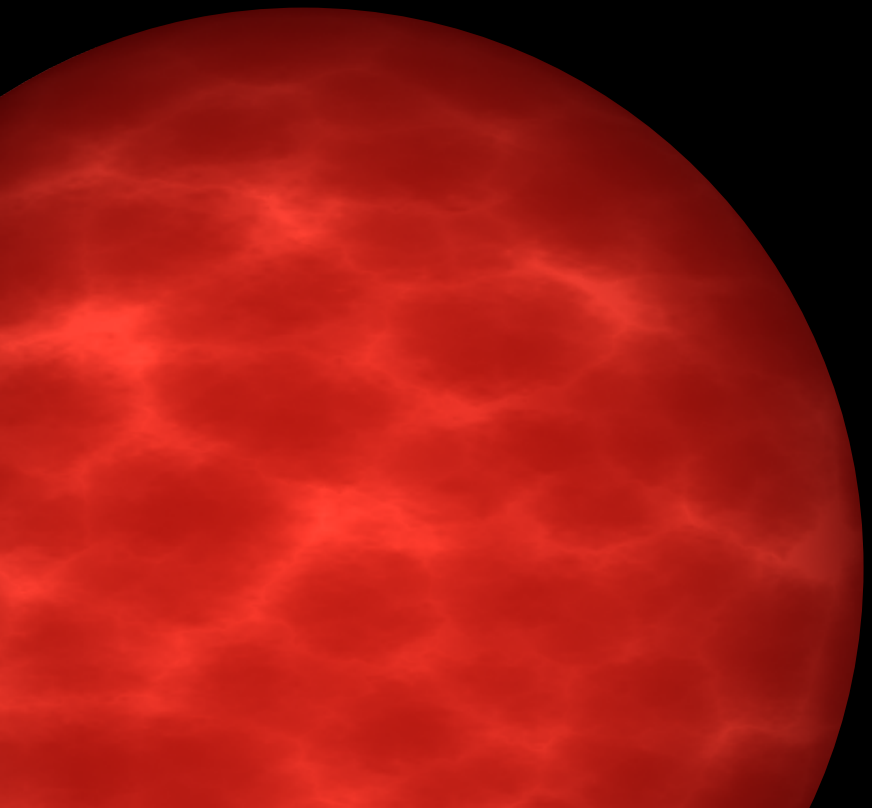


Galactic Diversity

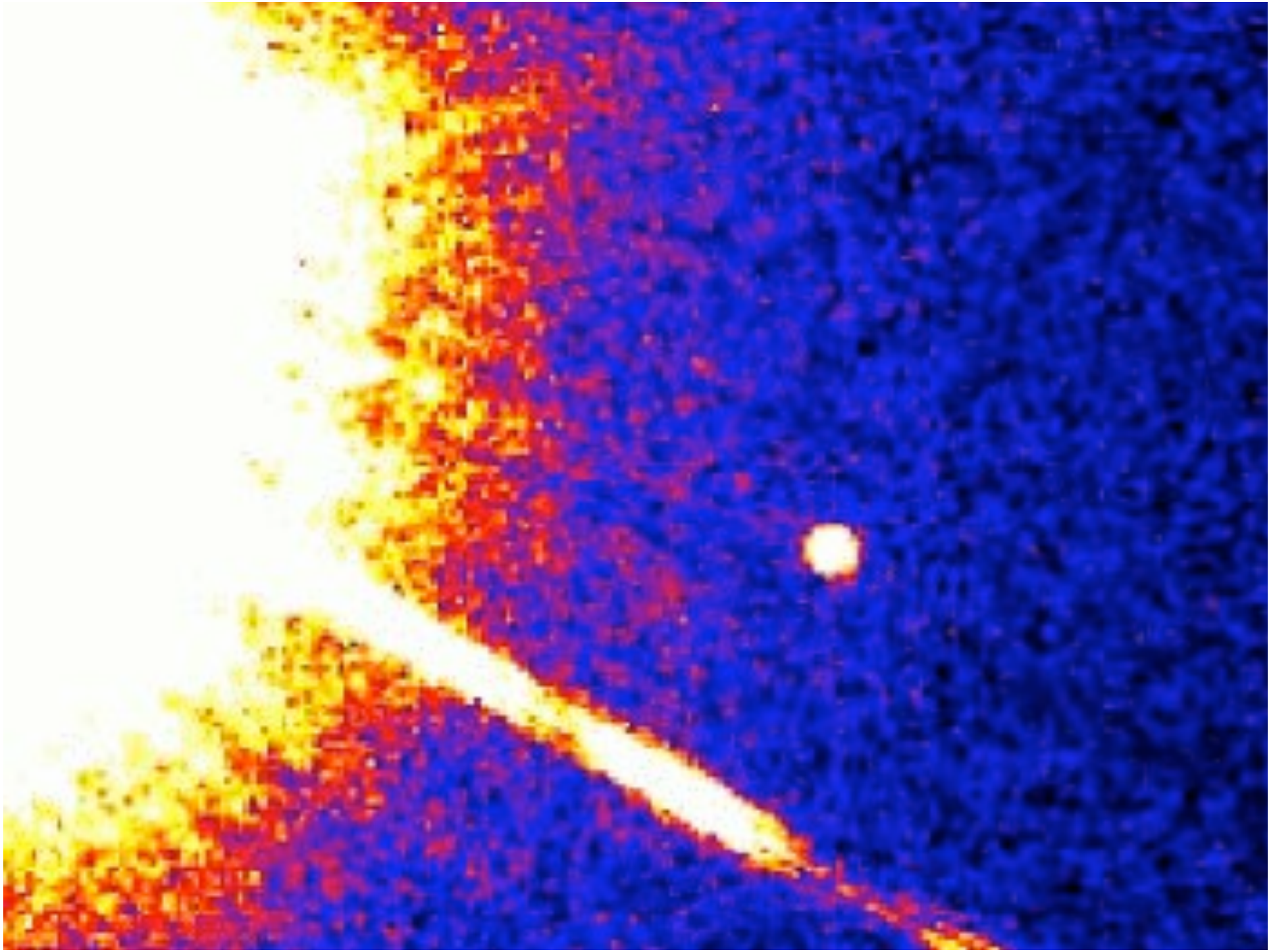
The Many Colors of Brown Dwarfs

Adam J. Burgasser

Massachusetts Institute of Technology

⇩

UC San Diego



DwarfArchives.org

Photometry, spectroscopy, and astrometry of M, L, and T dwarfs

The Archives | News & Updates | Citing Us | Publications | For Educators | Interesting Links | FAQs | Help Desk

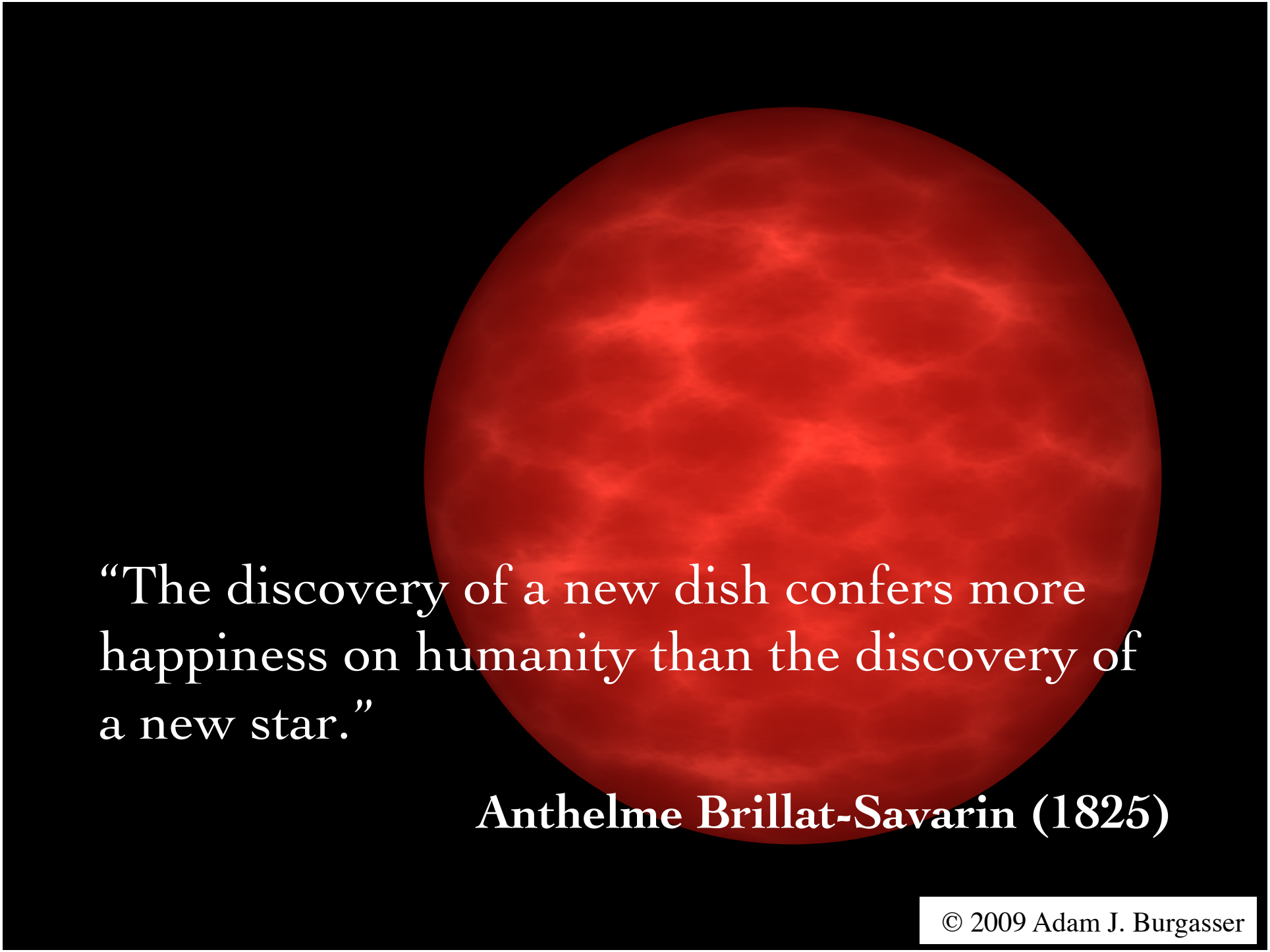
L Dwarfs and T Dwarfs

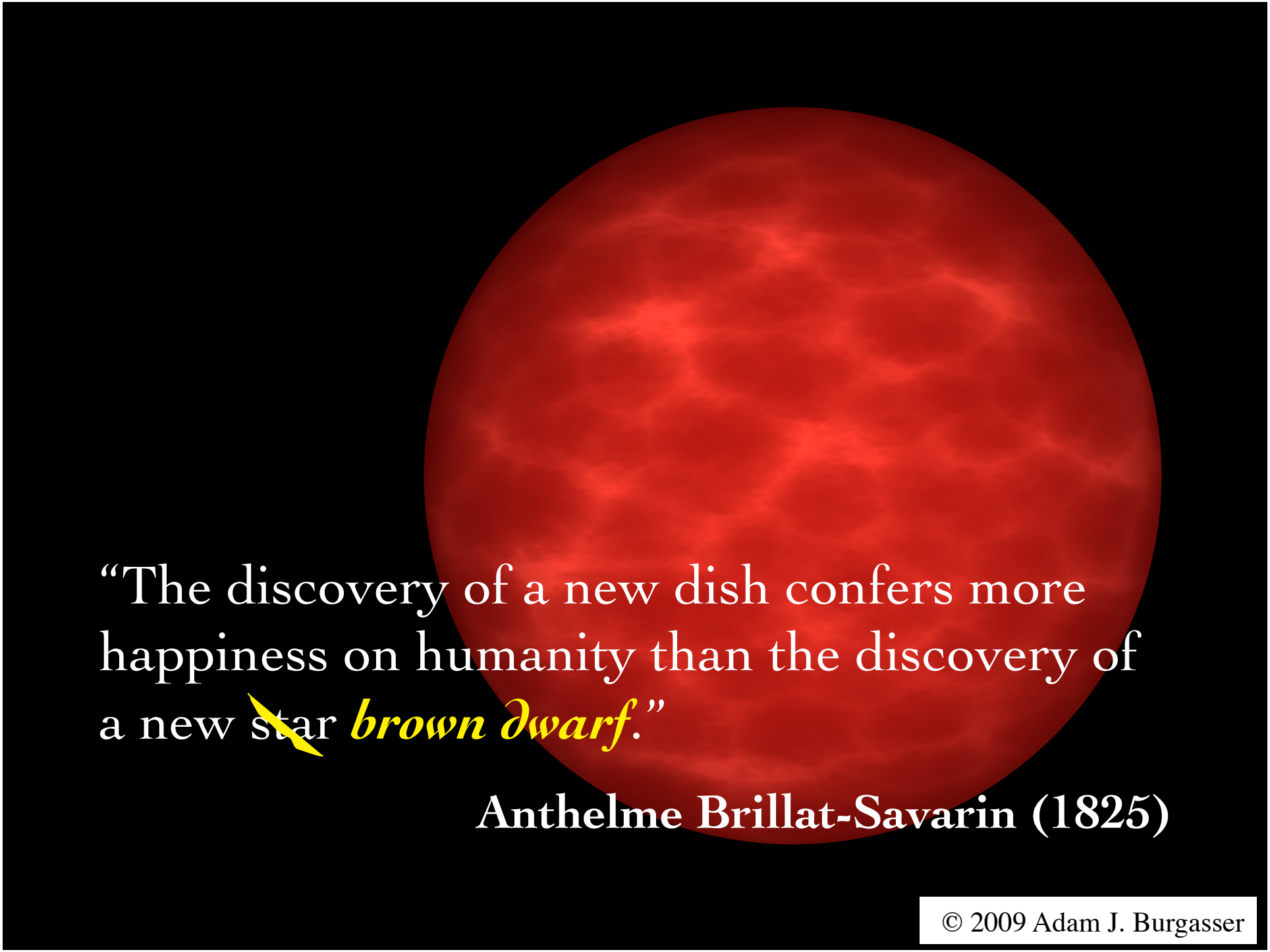
Last update 7 Jan 2009

A compendium of all 700 known L and T dwarfs:

- Archive Search
- List of L and T dwarfs: HTML, ASCII
  - L dwarfs only: HTML, ASCII
  - T dwarfs only: HTML, ASCII
- Parallaxes: HTML, ASCII

dwarfarchives.org maintained by Chris Gelino, Davy Kirkpatri

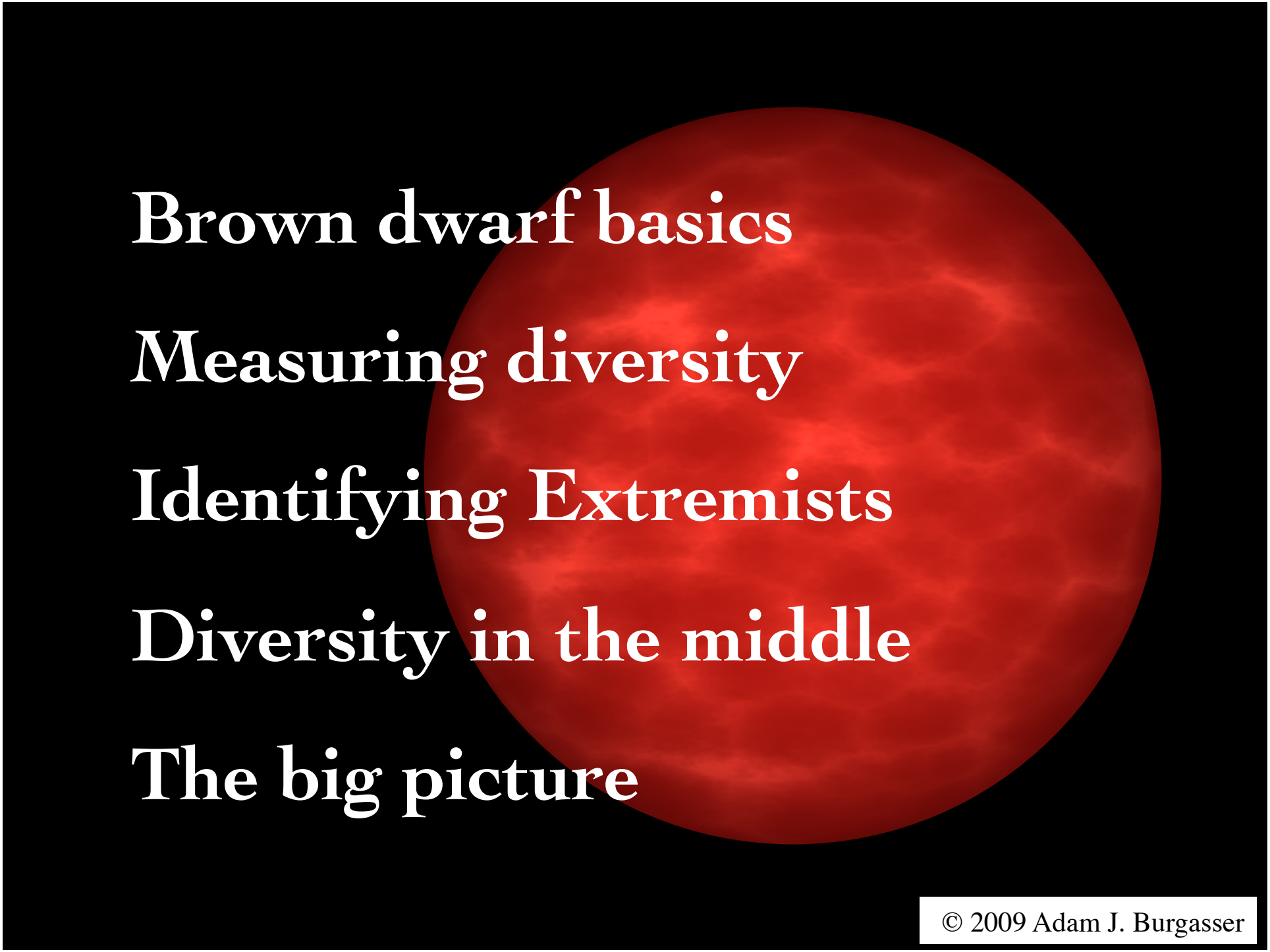




The punchlines:

(1) Several distinct subgroups of brown dwarfs have been identified, whose observational characteristics can be related to **distinct physical traits**.

(2) Calibration of these characteristics will make it possible to use brown dwarfs as **precise standard candles** for Galactic studies.



meet your neighbors

The New York Times
Wednesday, February 11, 2009

U.S.

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Cosmic Players That Could've Been Stars

By JOHN NOBLE WILFORD
Published: June 8, 2001

FOXNEWS.COM HOME > SCITECH

'Missing Link' Between Stars, Planets Found

Sunday, April 13, 2008

USA TODAY Home News

Science & Space | Inside Technology

Wild weather: Iron rain on failed stars

Updated 7/5/2006 9:16 AM ET

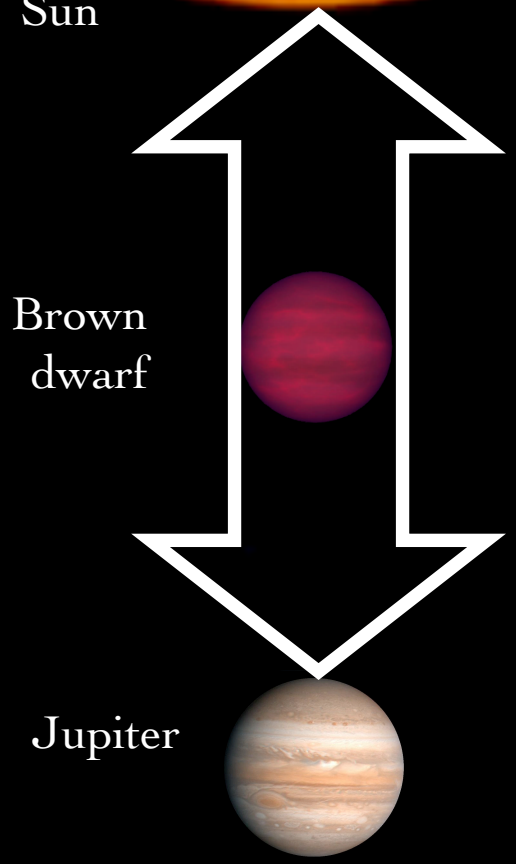
Brown dwarfs are dull, but they shed light on planets

By Chris Oliver
Advertiser Staff Writer

Brown Dwarfs, Poorly Understood, Poorly Named

By Robert Roy Britt
Senior Science Writer
posted: 12:22 pm ET
07 June 2001

what is a **brown dwarf?**

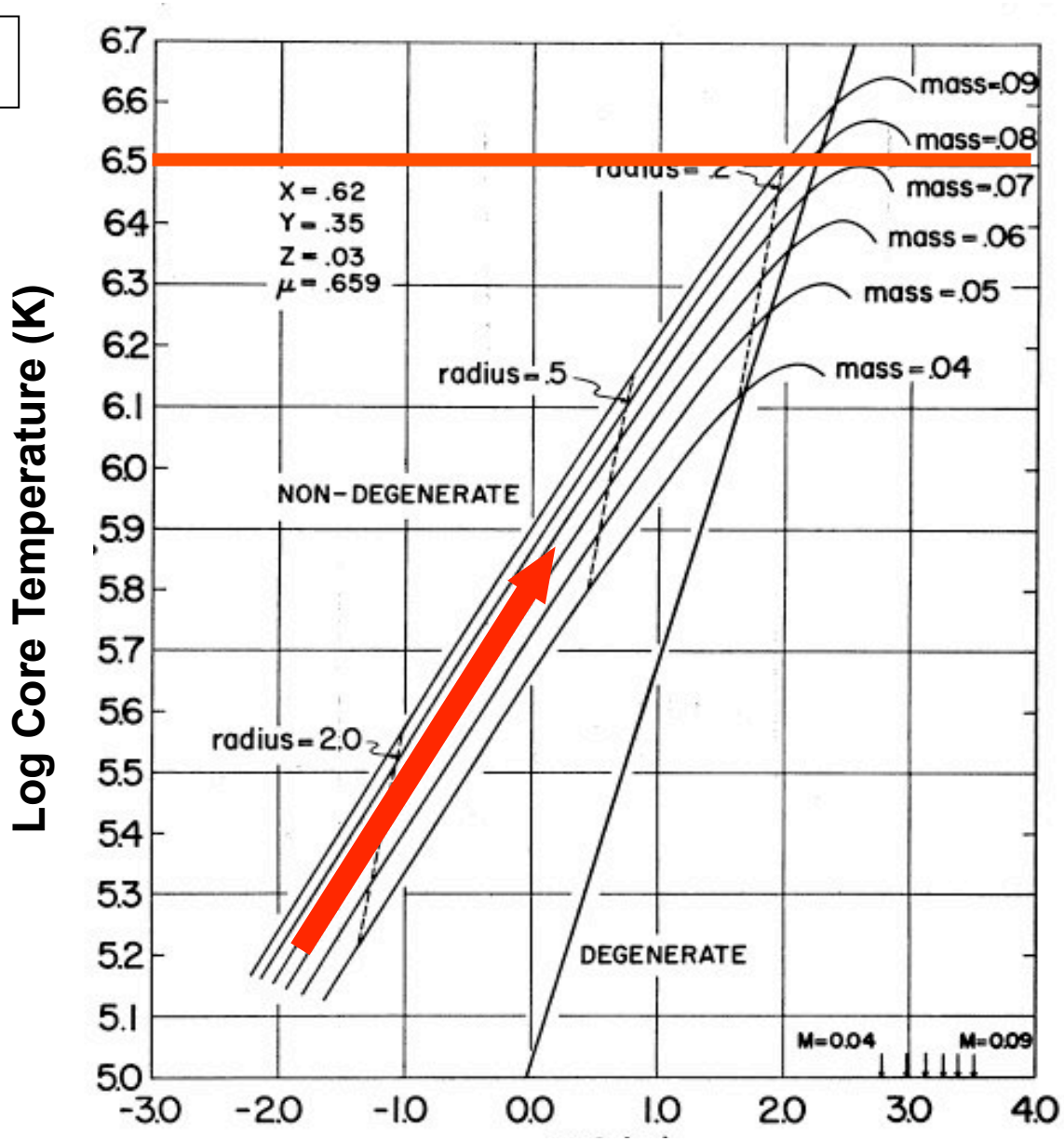


Low-mass objects with properties intermediate between stars and planets.

"**Failed stars**" - form like stars, found as isolated systems, can host their own planetary systems

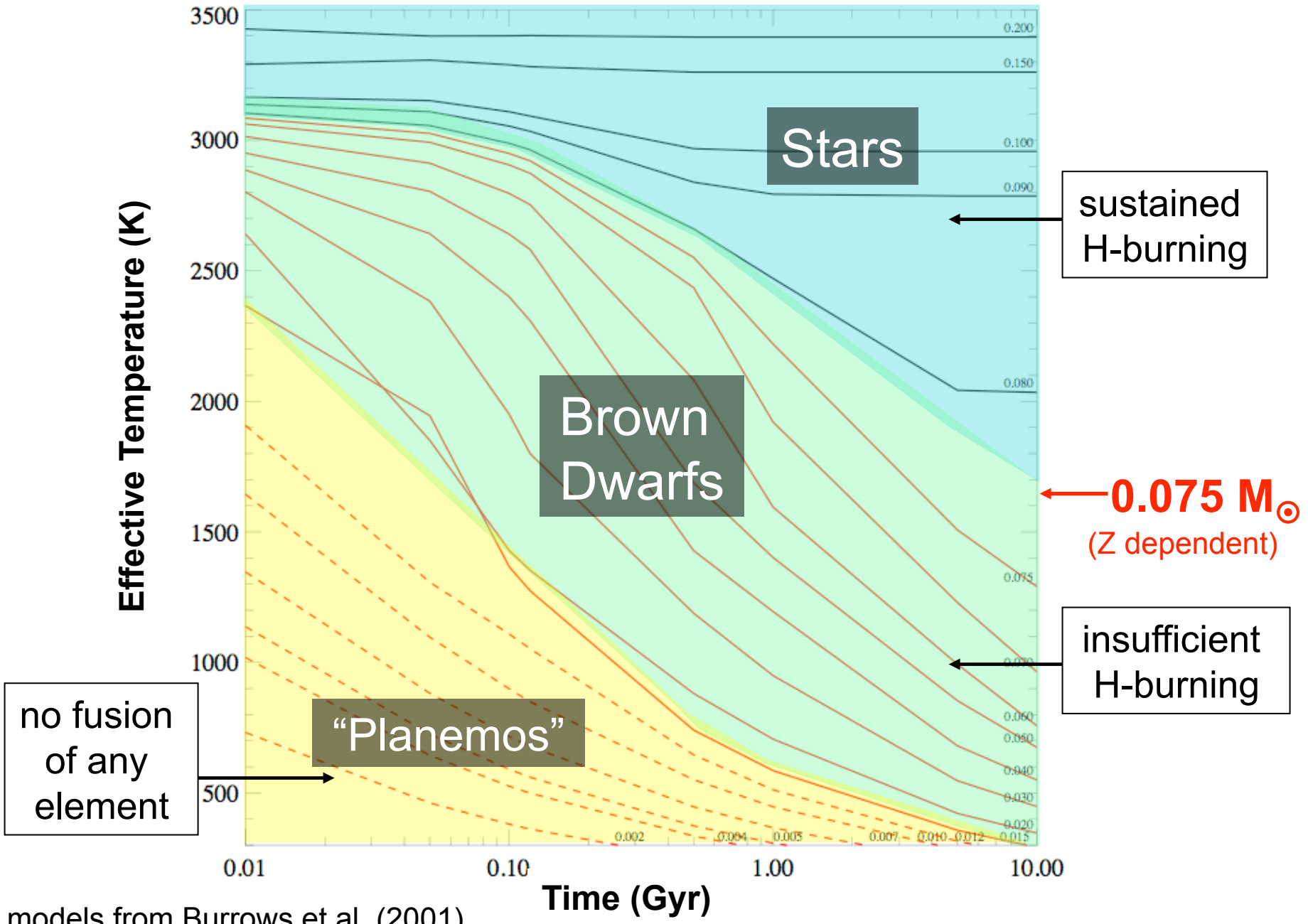
"**Super-Jupiters**" - do not fuse hydrogen, sizes comparable to Jupiter, planetary atmospheres

ca. 1963



H-burning threshold ≈ 3×10^6 K

Kumar (1962, 1963)
see also Hayashi & Nakano (1963)

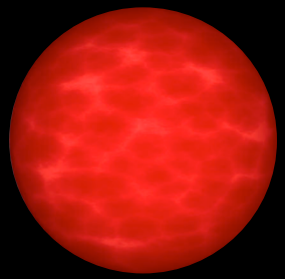


models from Burrows et al. (2001)

spectral types

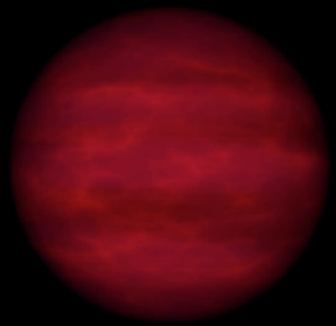
M dwarfs (3500-2100 K)

magnetically active, only the youngest brown dwarfs are classified M-type



L dwarfs (2100-1300 K)

molecule-rich atmospheres contain clouds of "hot dirt" and other condensates

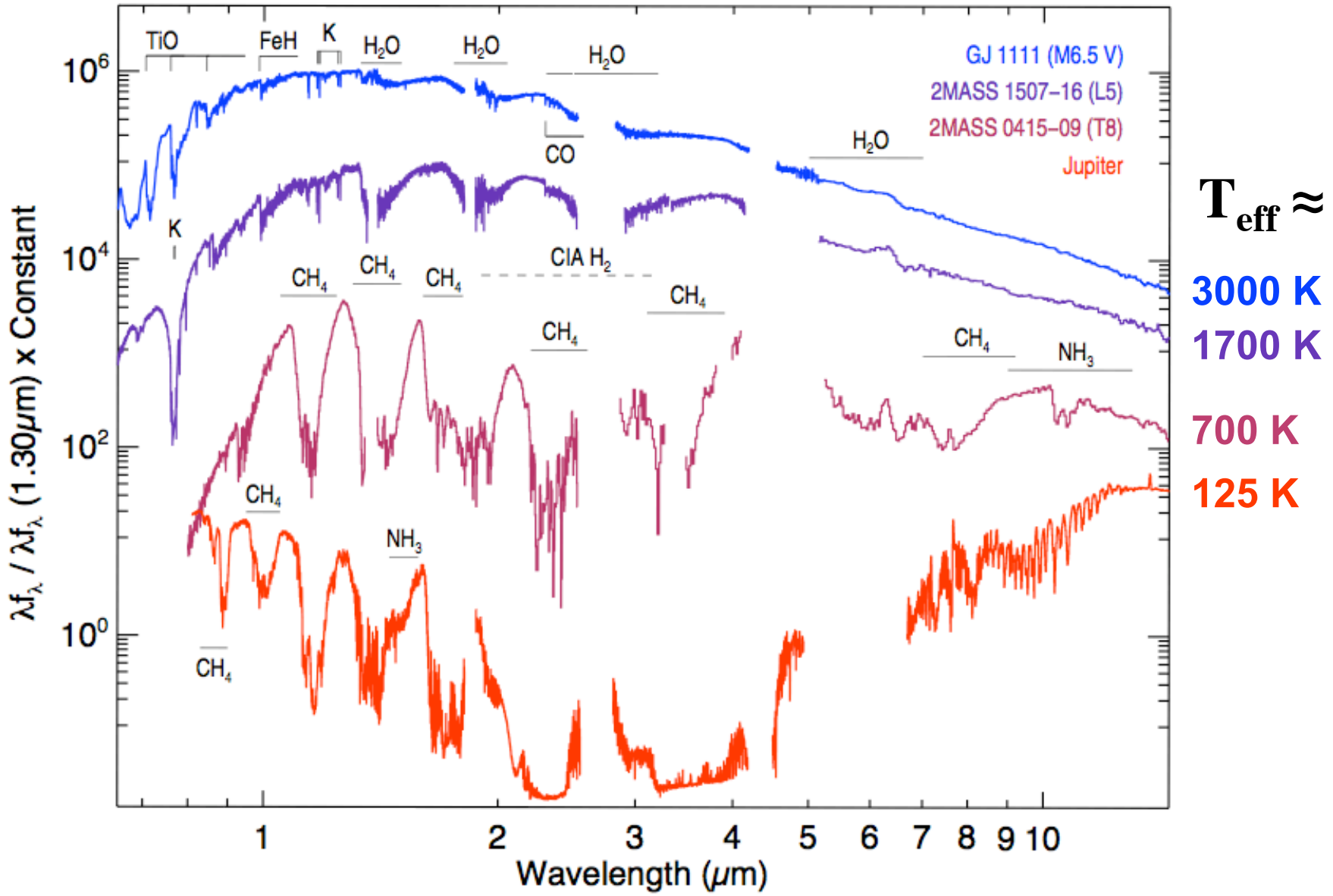


T dwarfs (1300-600? K)

coldest known brown dwarfs, atmospheres contain CH_4 and NH_3 gases

O
B
A
F
G
K
M
L
T
Y

Obama's
Bailout
A
Federal
Government
Killer
Much
Luck
To
You



$T_{eff} \approx$

3000 K

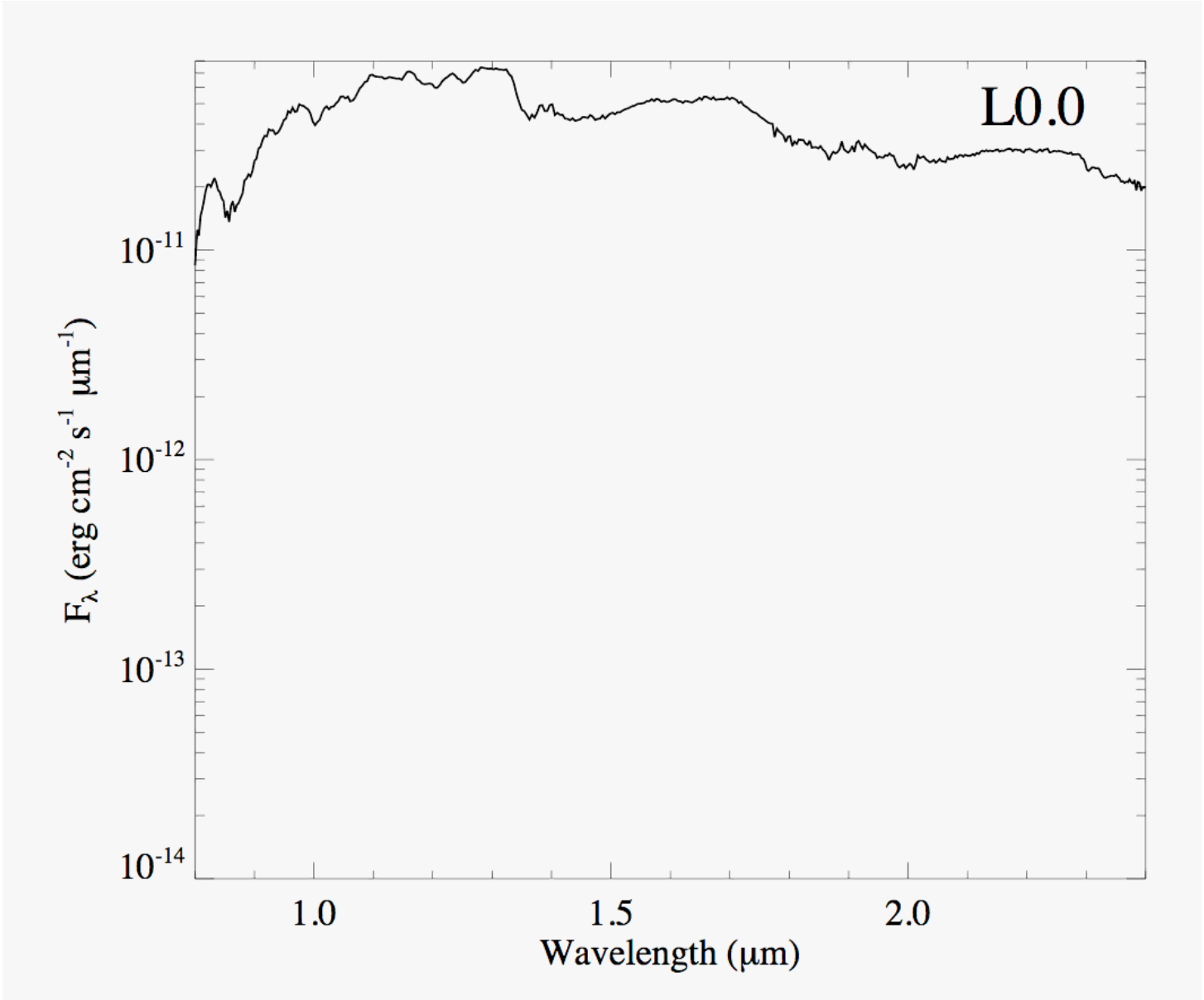
1700 K

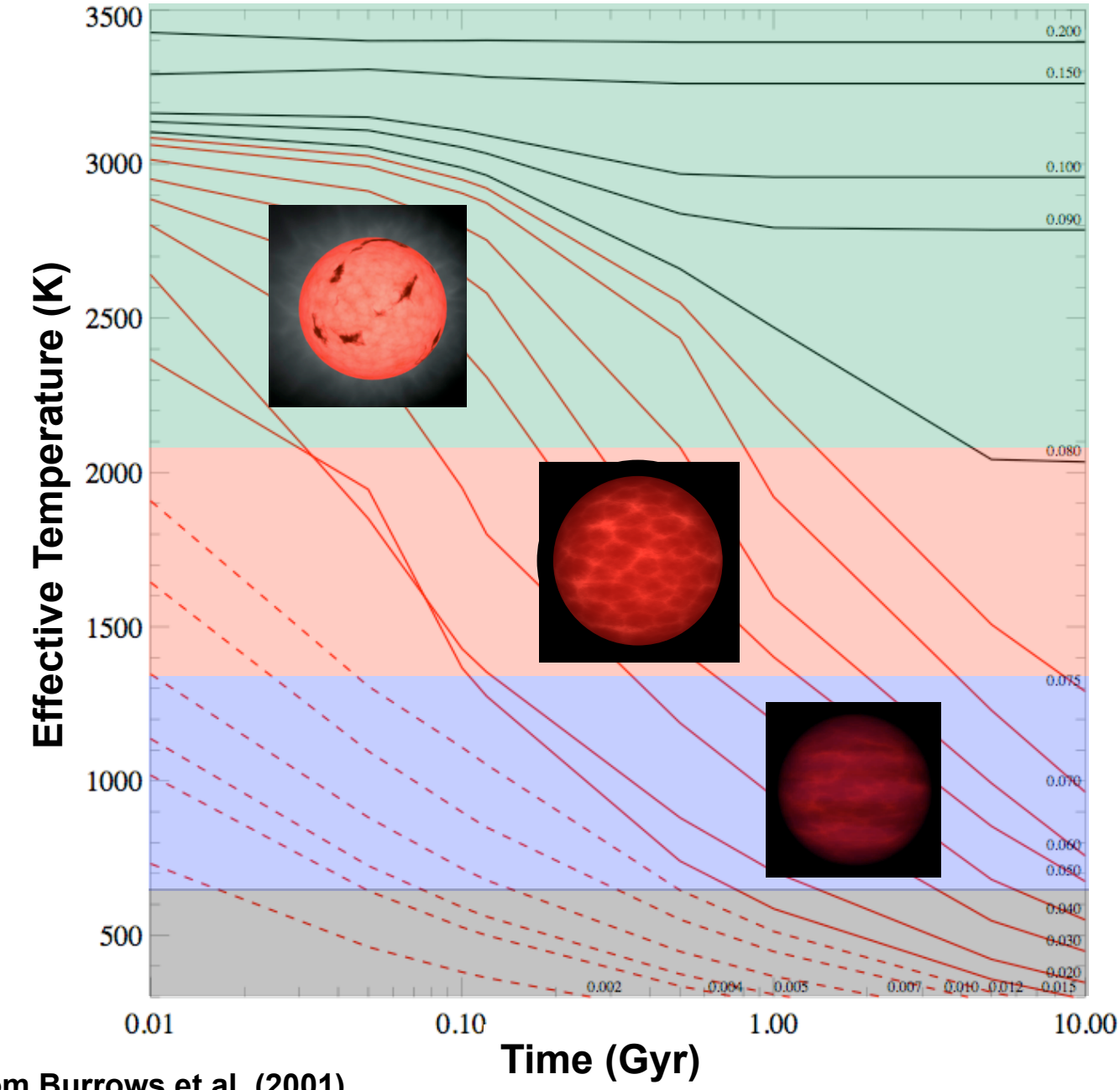
700 K

125 K

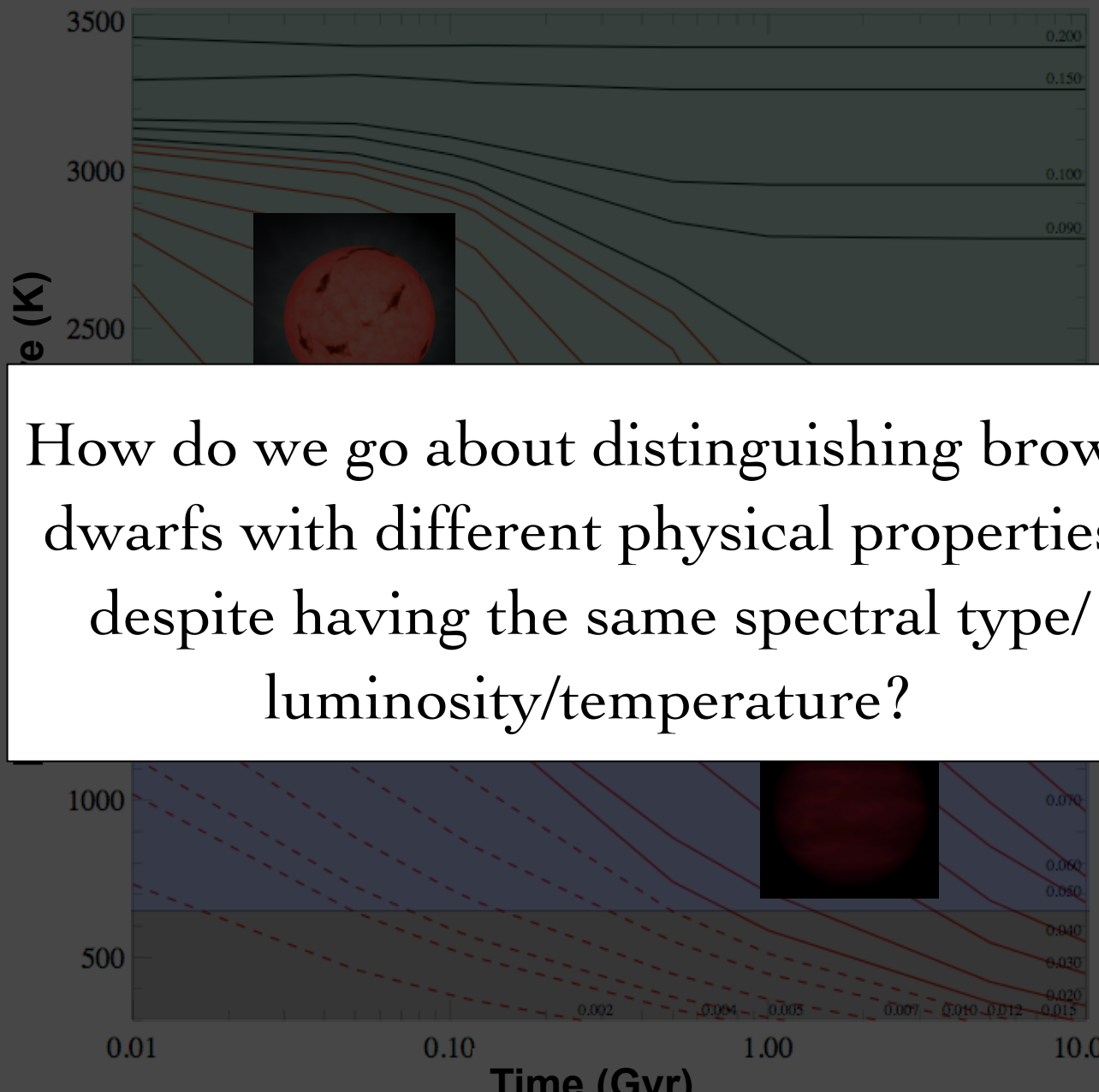
Marley & Leggett (2008)

data from Cushing et al. (2005,2007)





models from Burrows et al. (2001)



How do we go about distinguishing brown dwarfs with different physical properties despite having the same spectral type/ luminosity/temperature?

M dwarfs

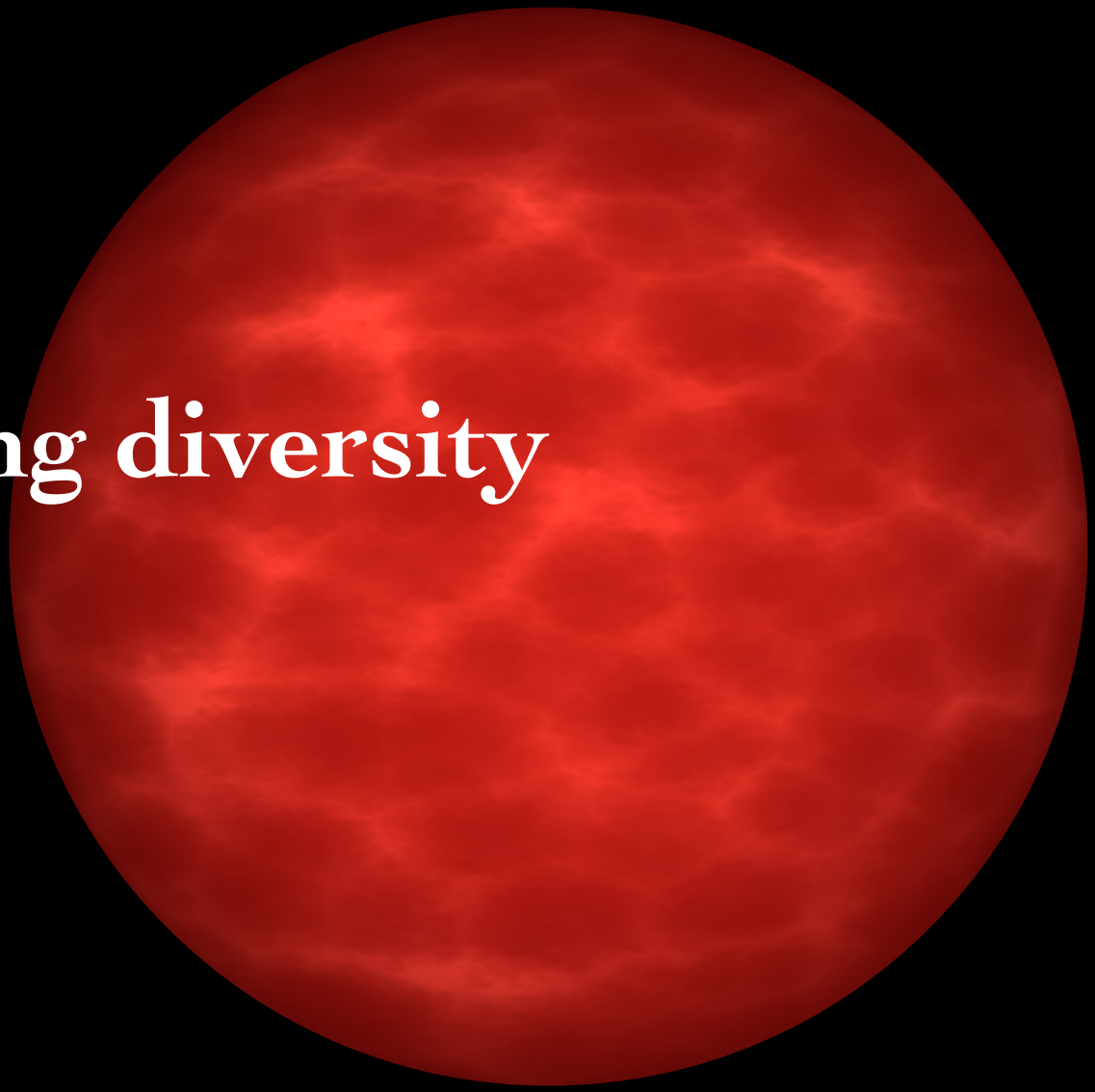
dwarfs

T dwarfs

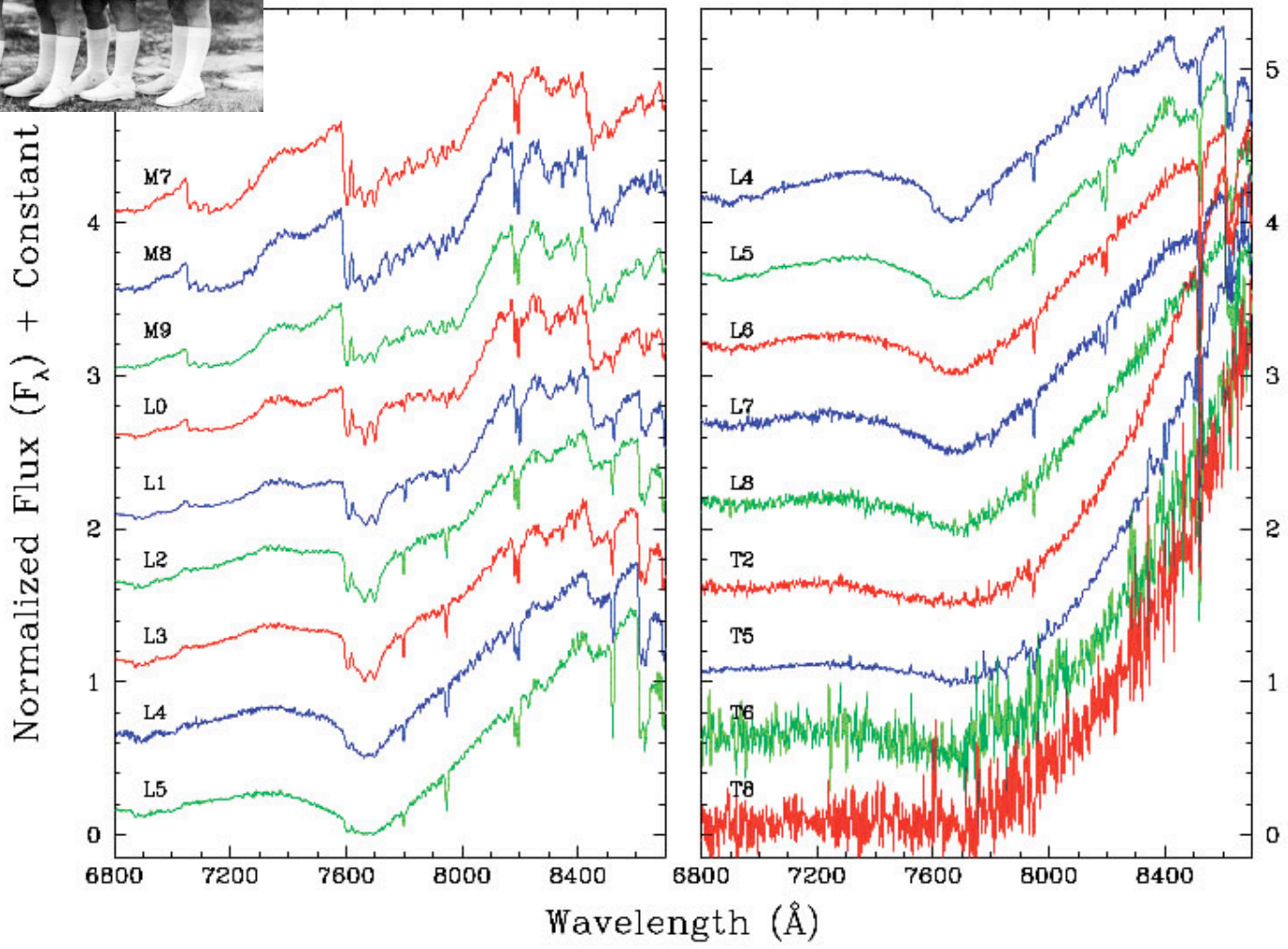
Y dwarfs?

models from Burrows et al. (2001)

measuring diversity

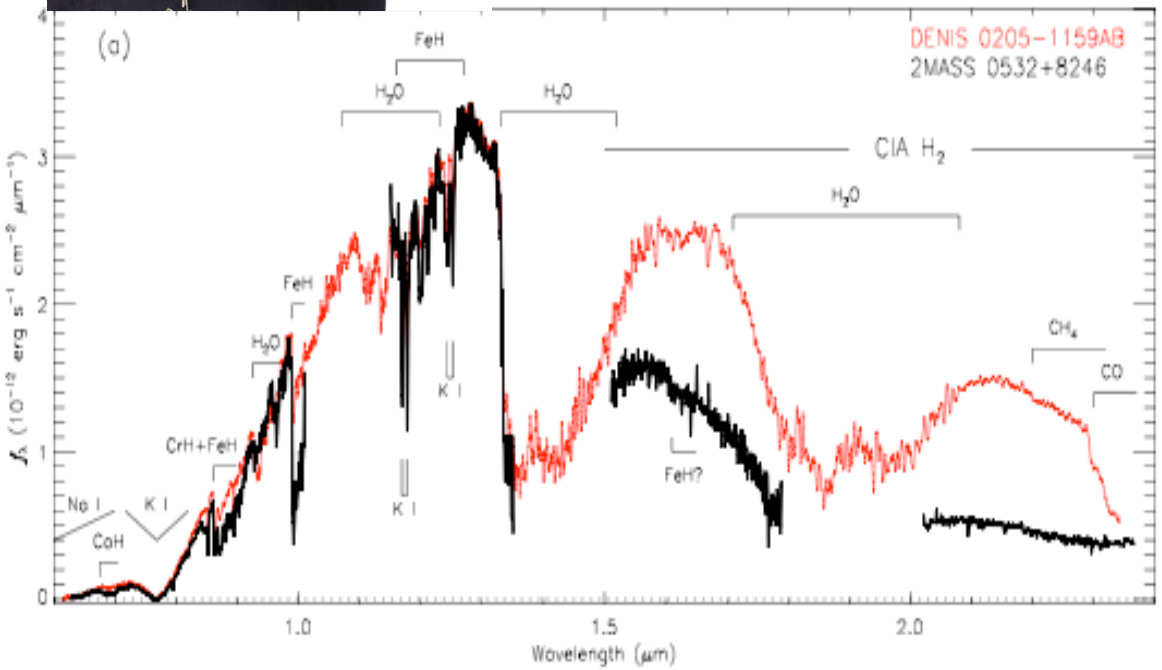


conformists

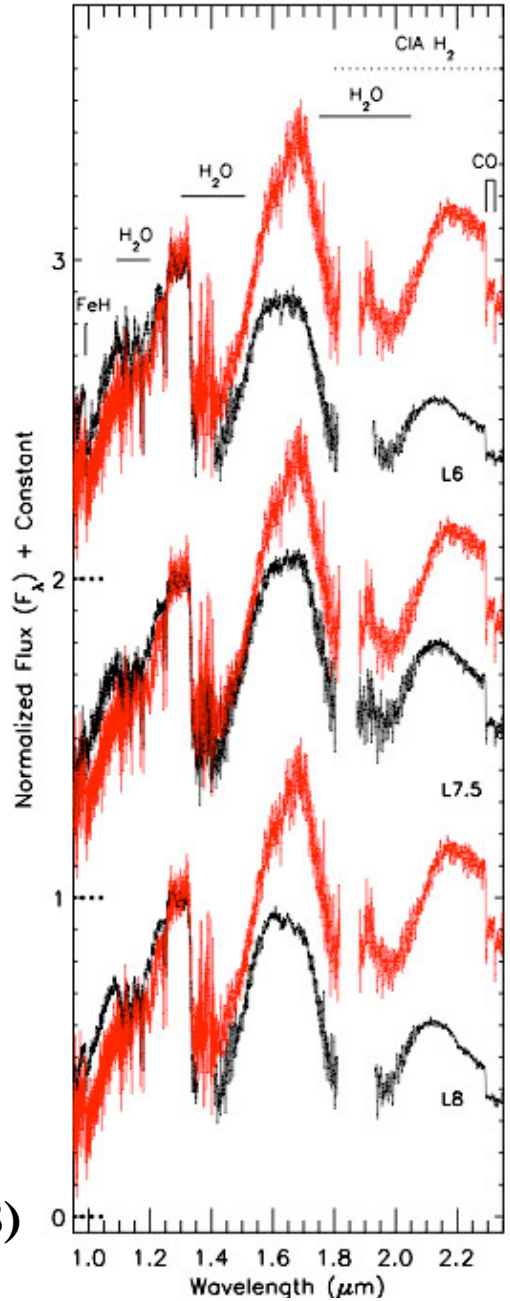


Kirkpatrick (2005)

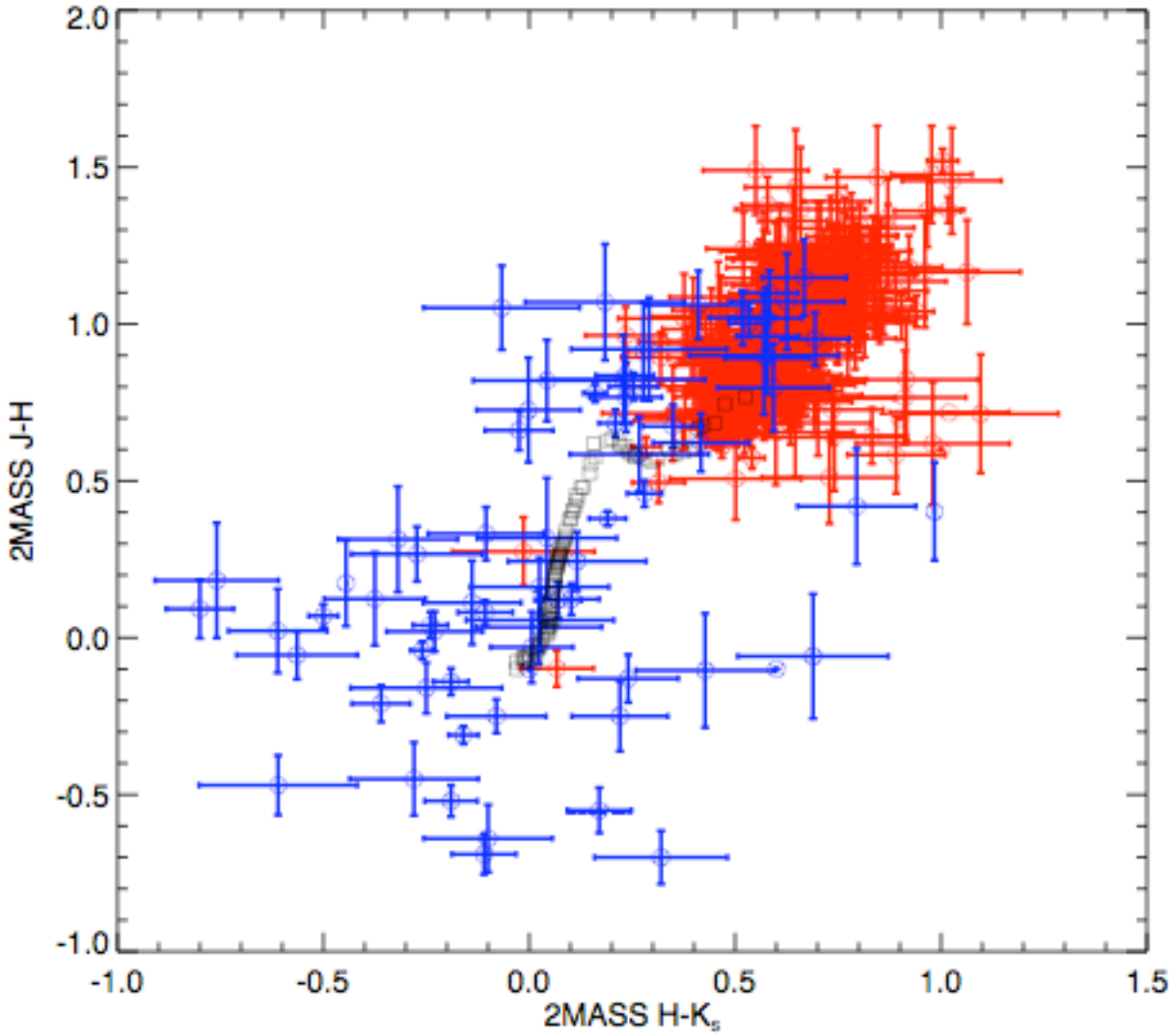
nonconformists



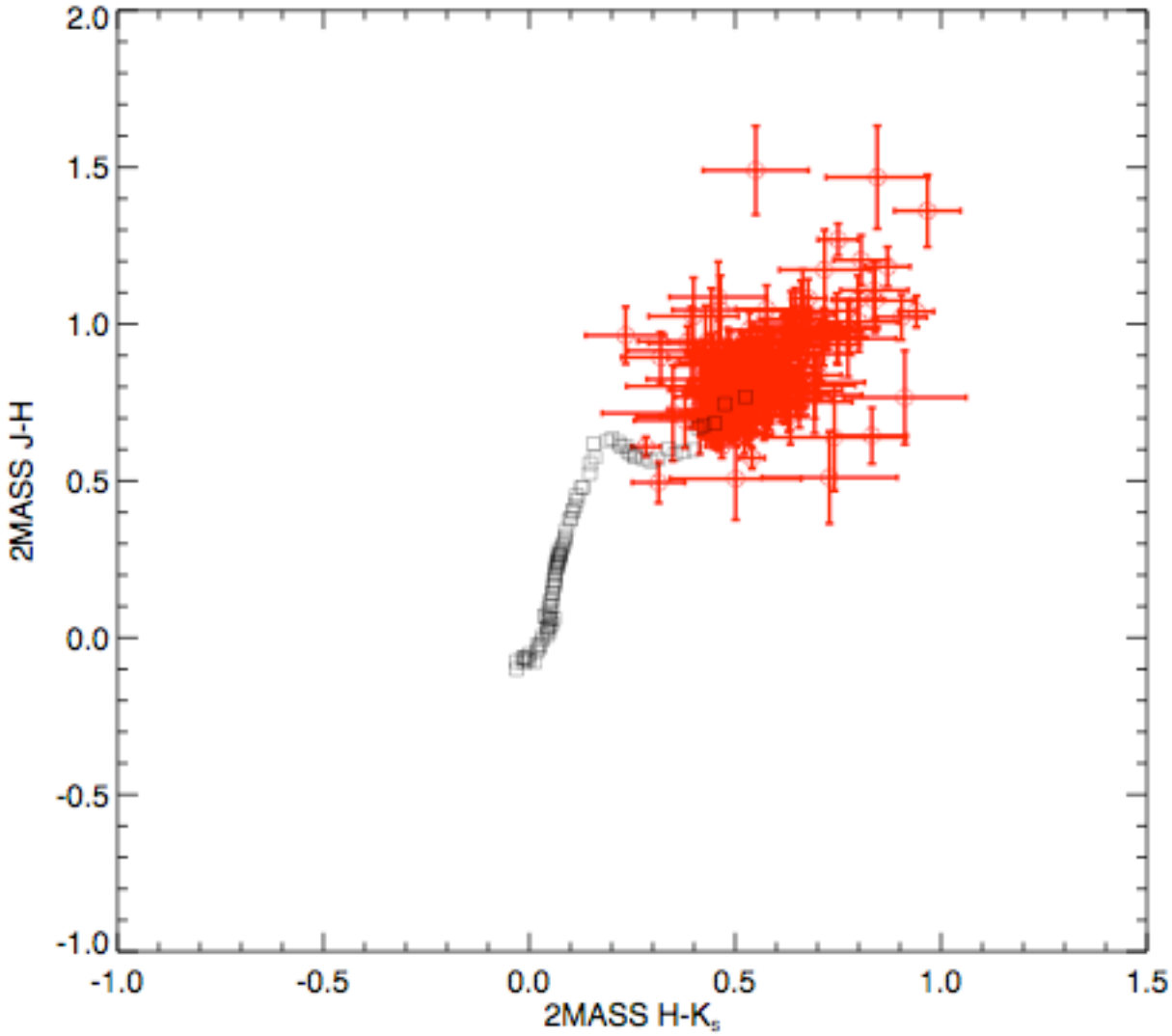
Burgasser et al. (2003)



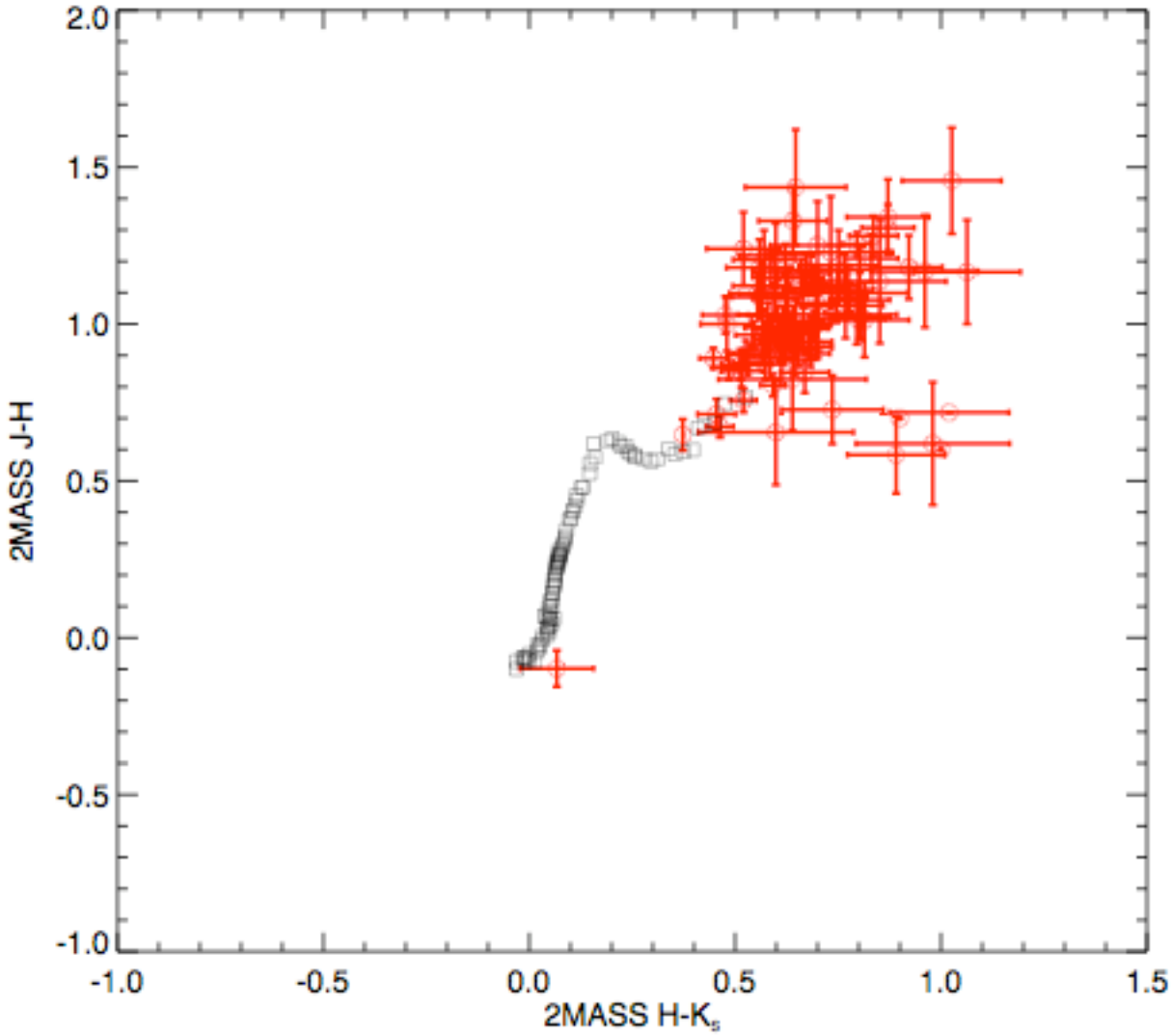
Looper et al. (2008)



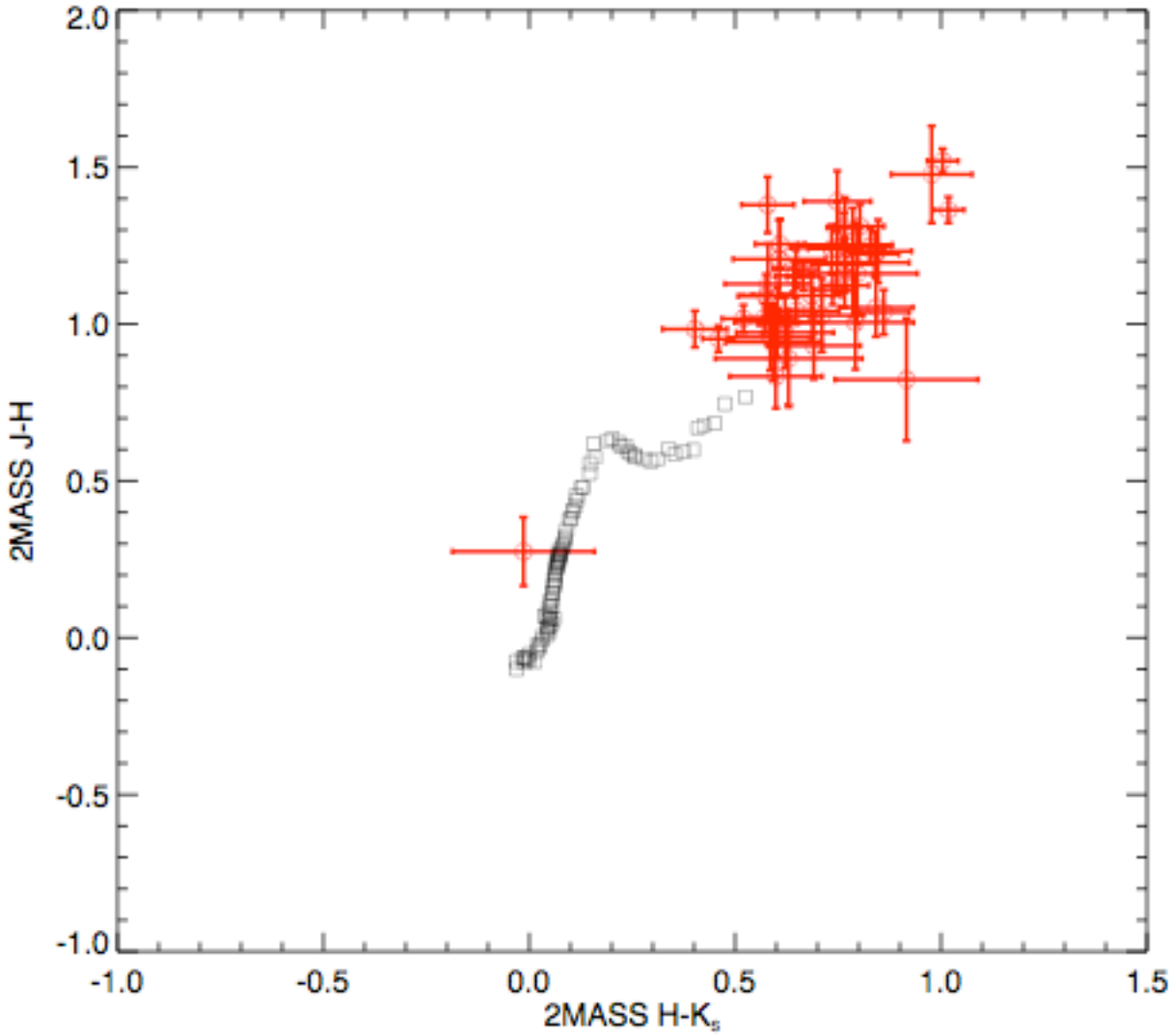
498 L & T dwarfs



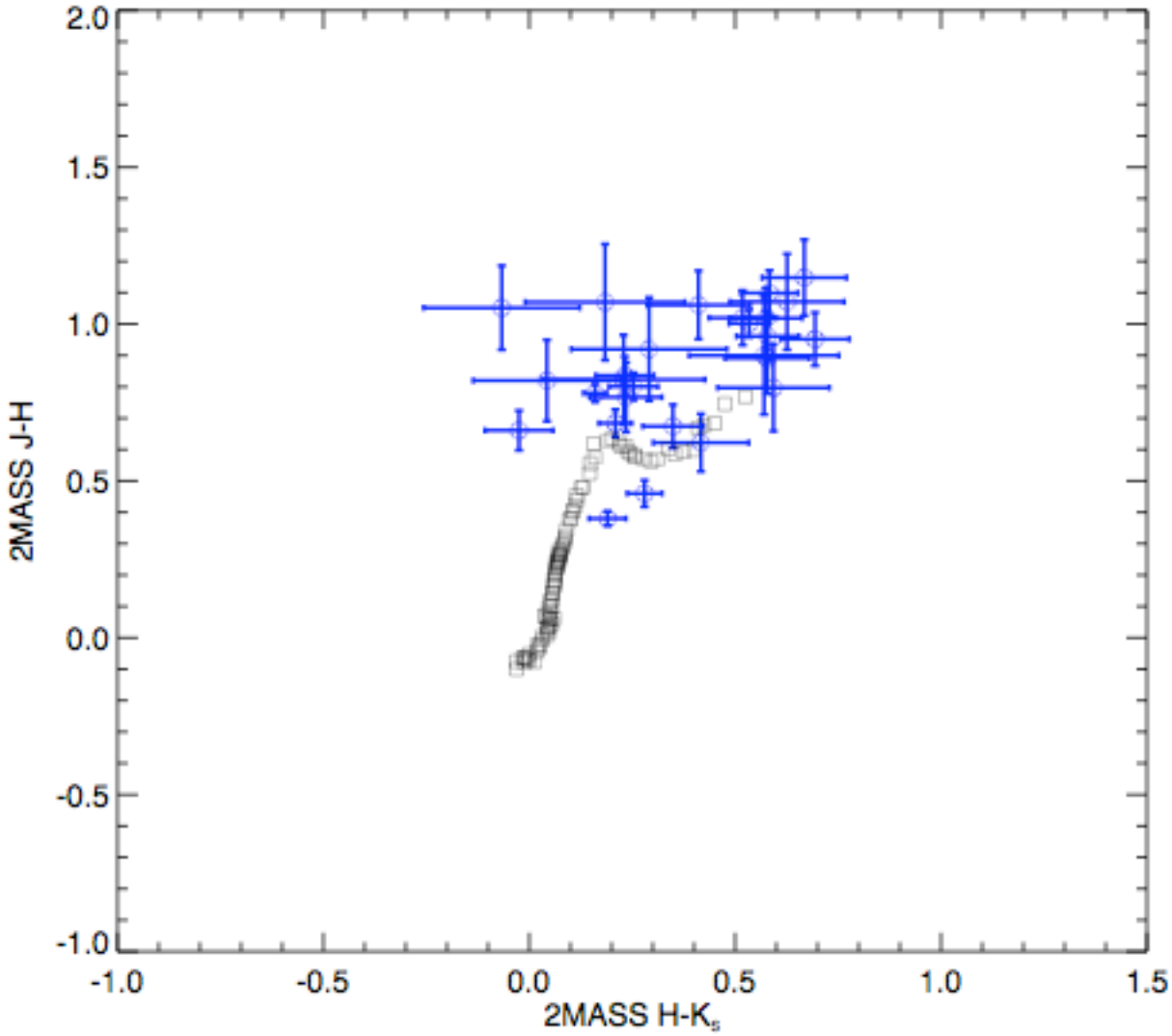
237 L0-L2 dwarfs



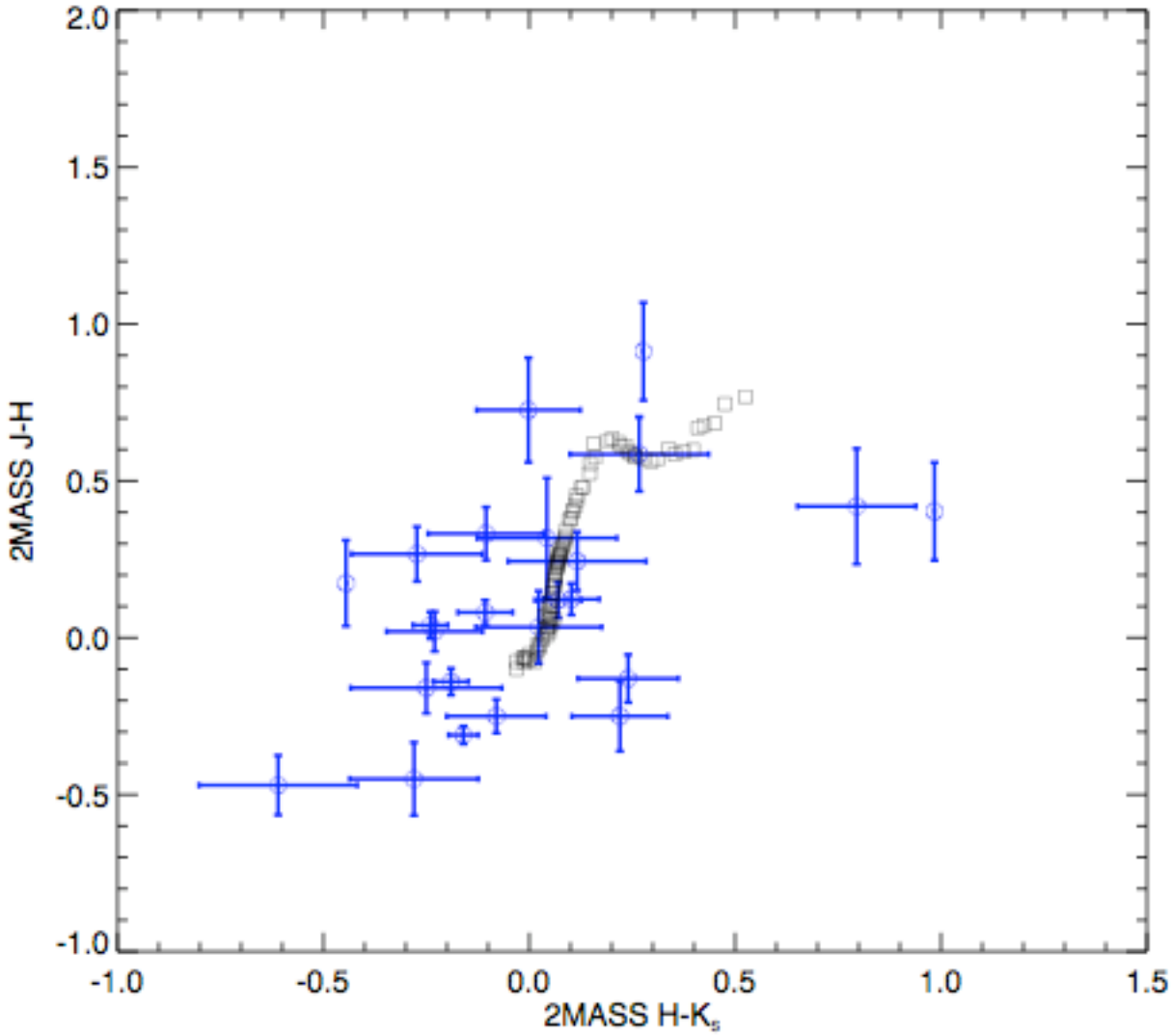
98 L3-L5 dwarfs



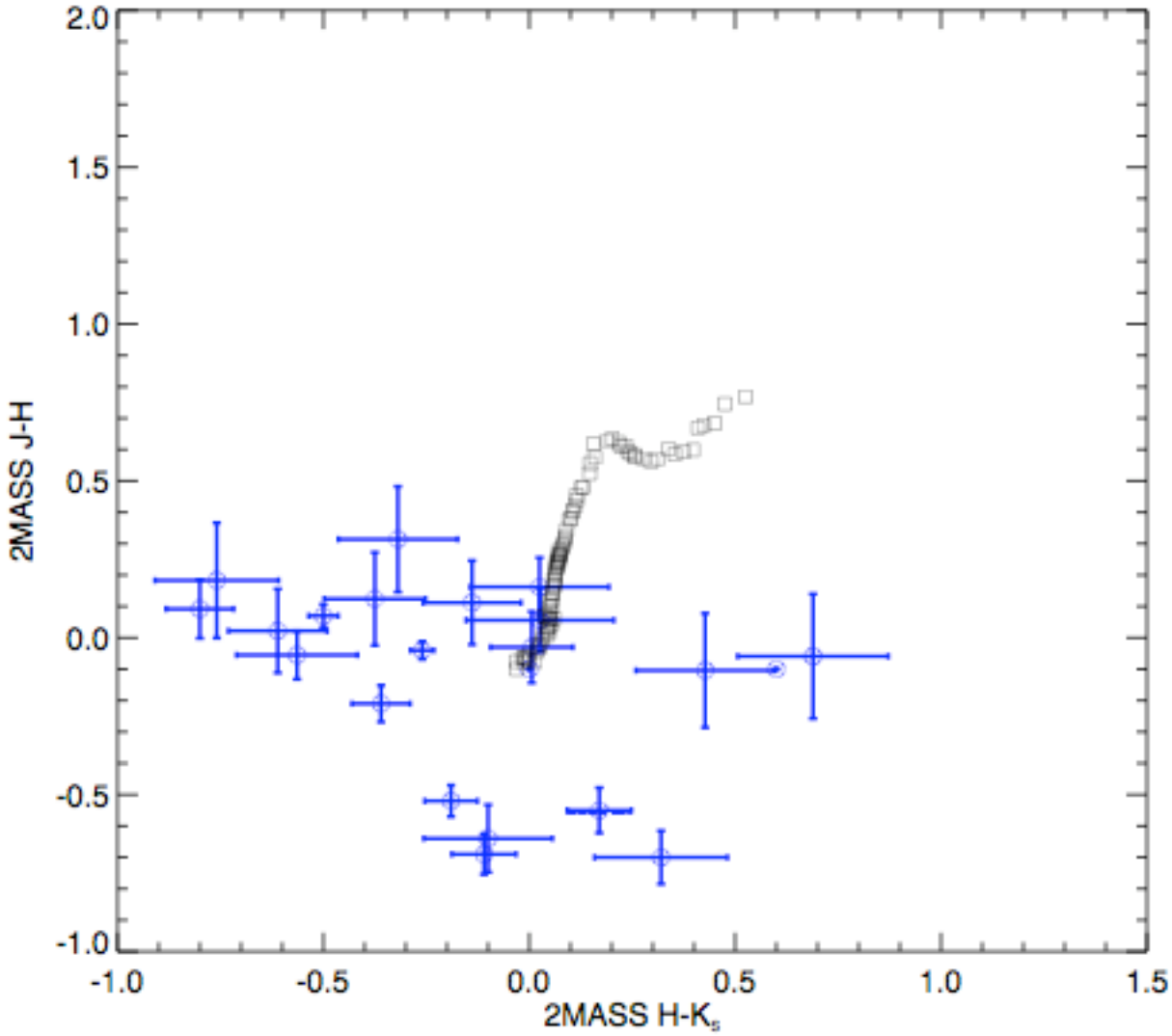
47 L6-L8 dwarfs



27 T0-T2 dwarfs

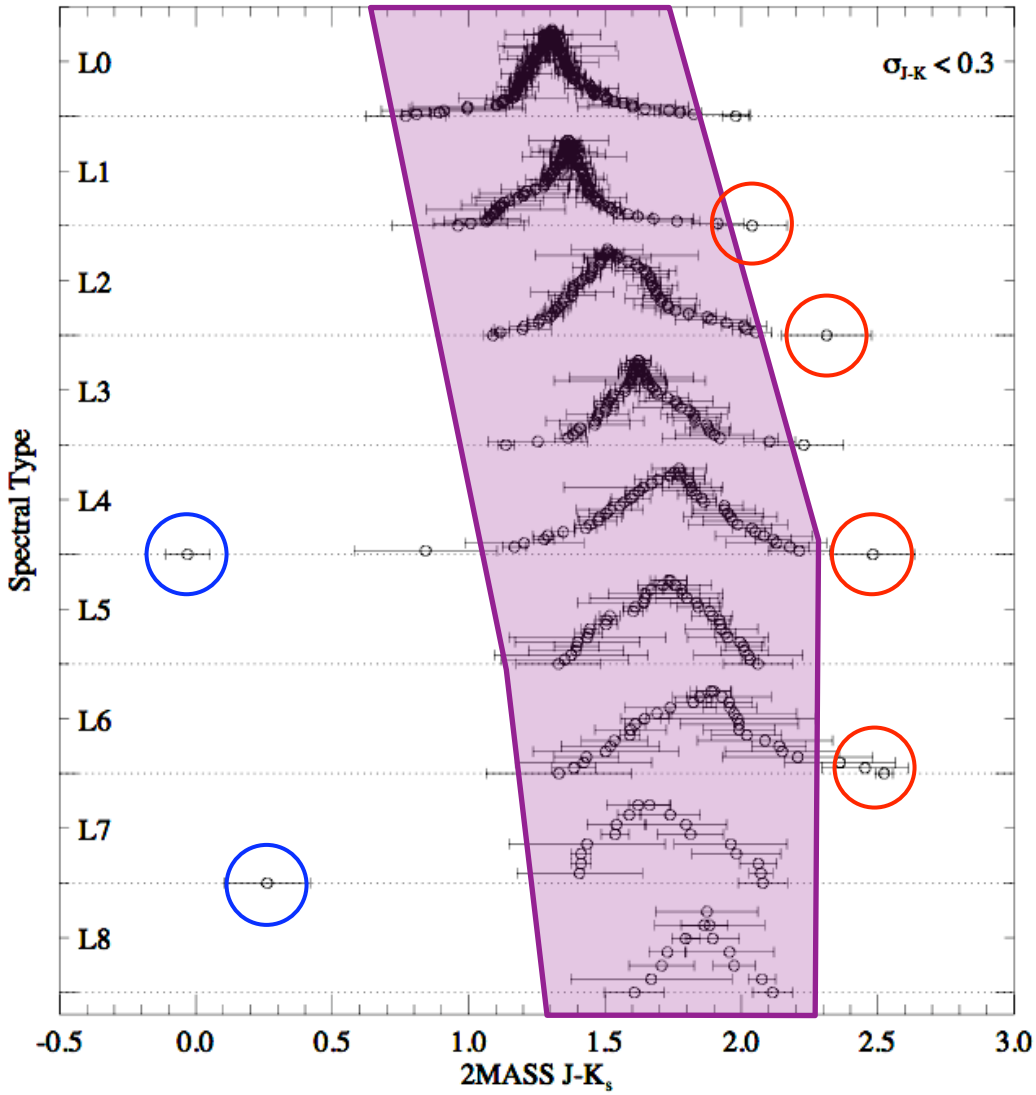


24 T3-T5 dwarfs



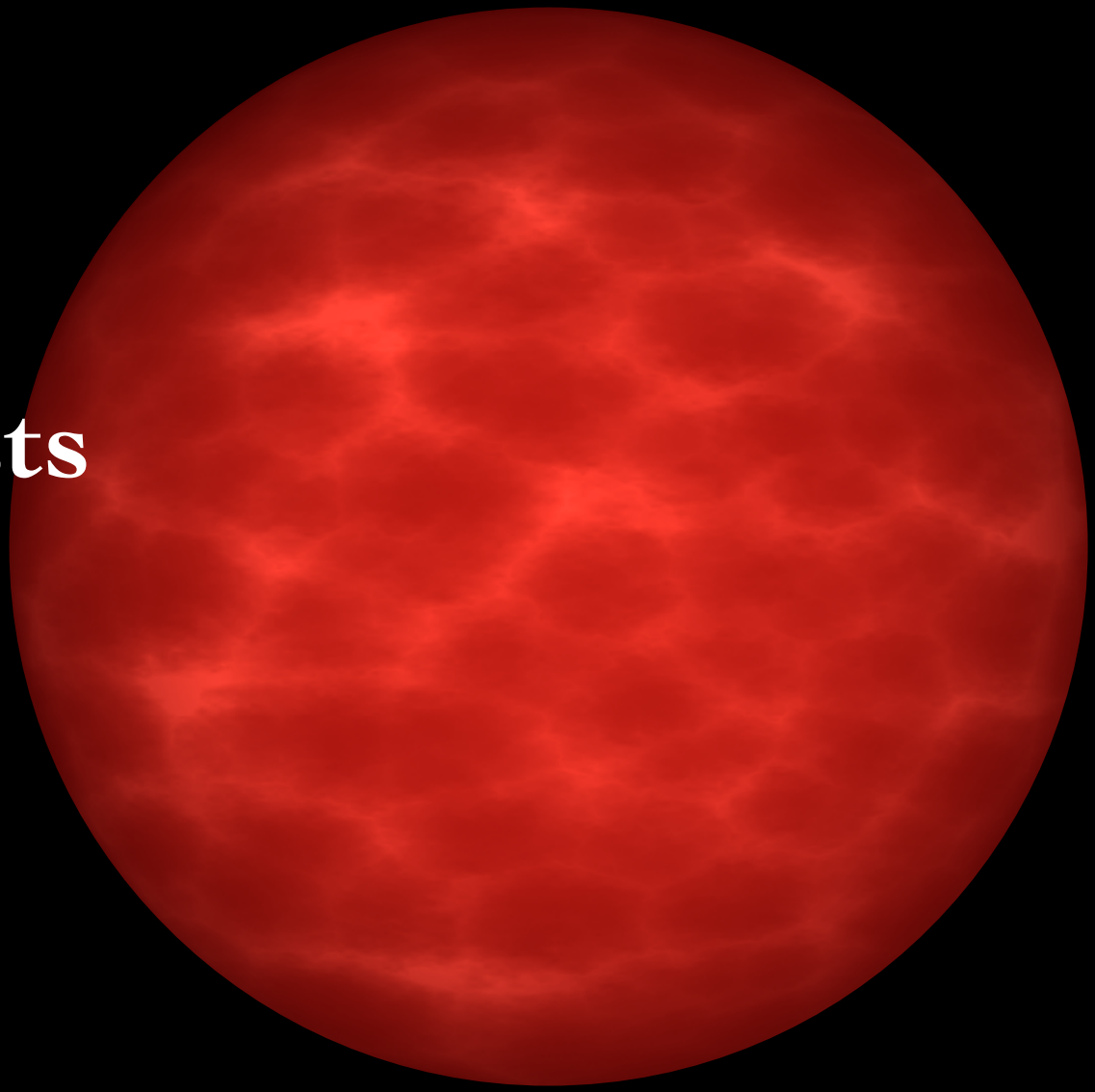
22 T6-T8+ dwarfs

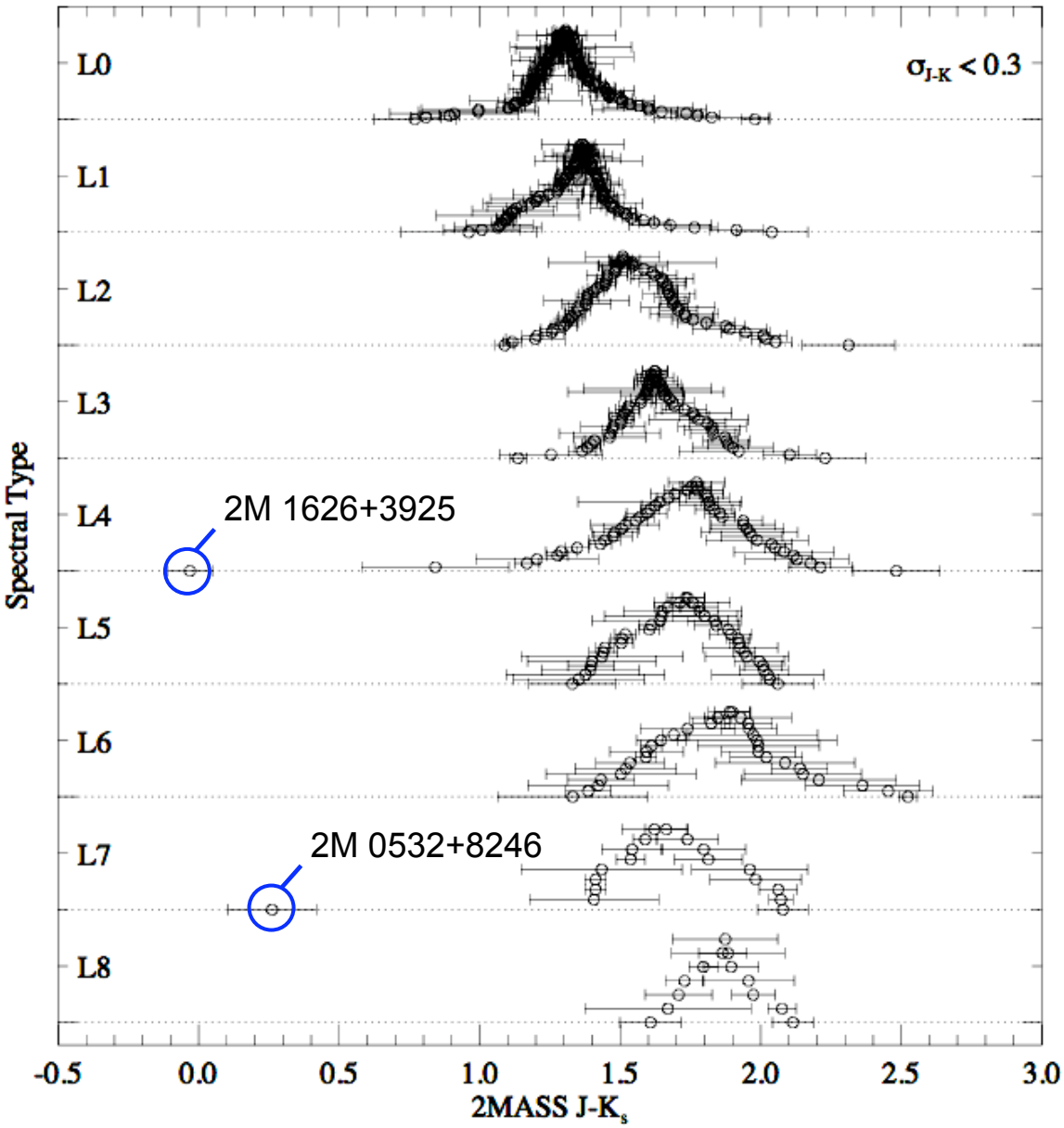
the "shrimp plot"

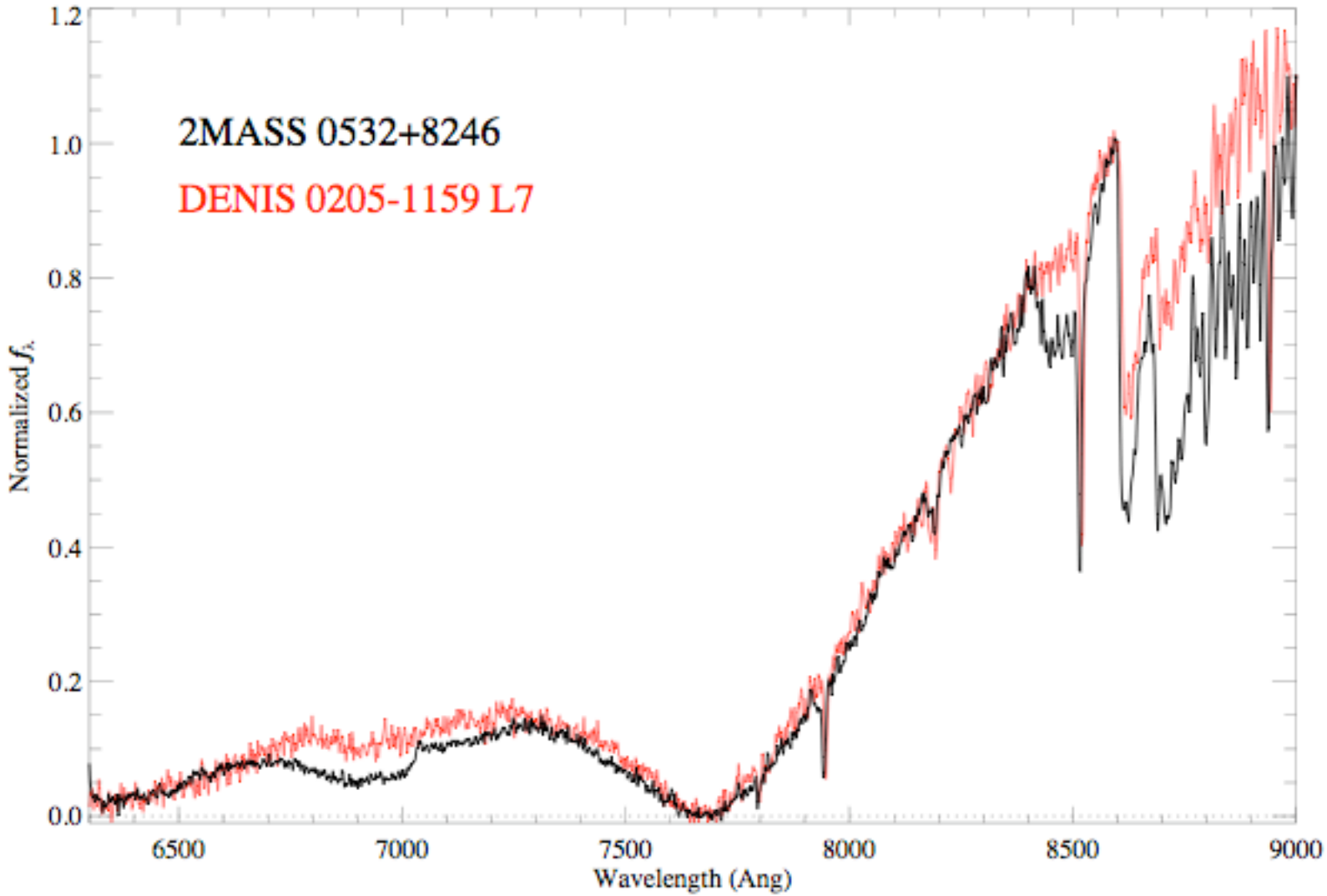


Kirkpatrick et al. (in prep.)

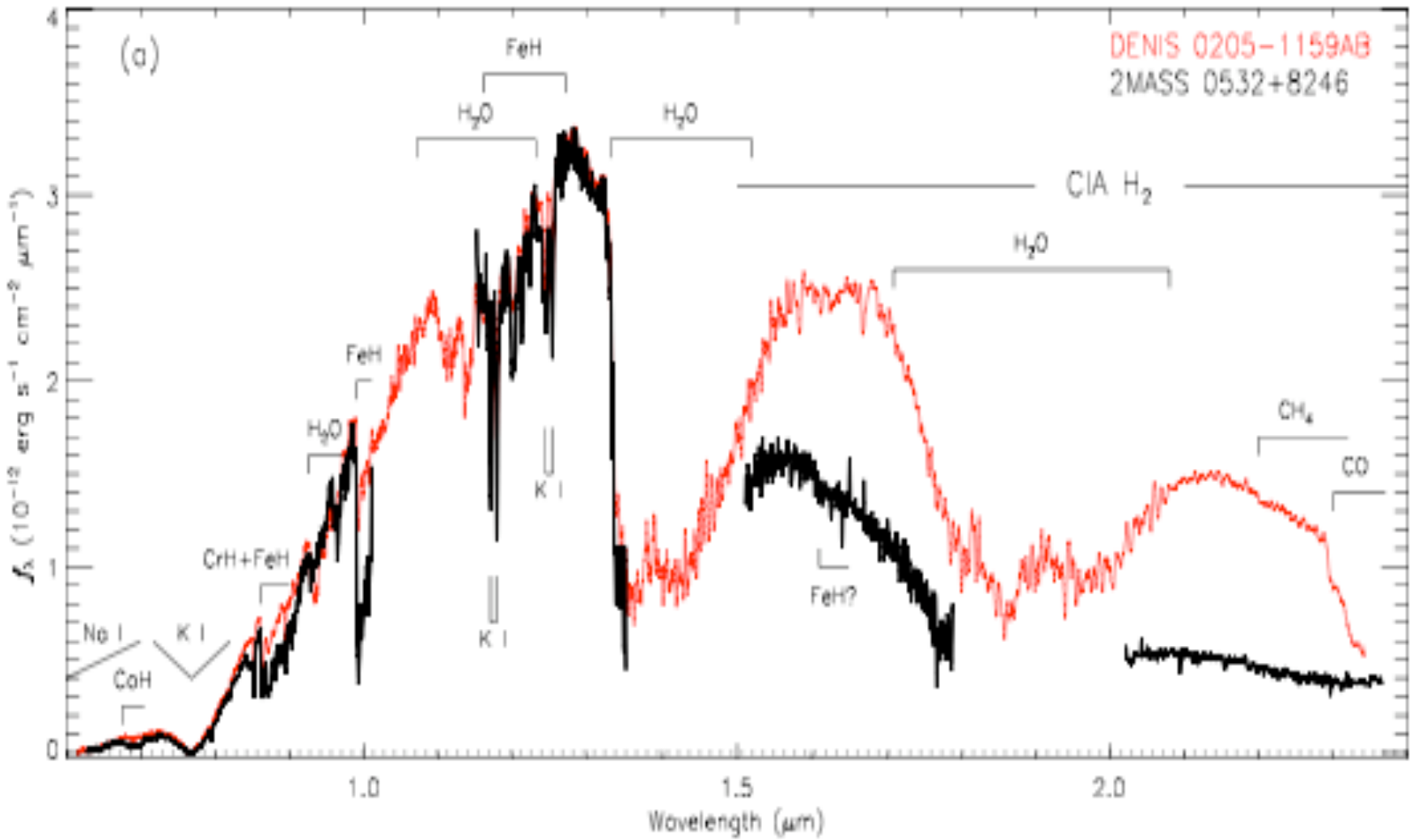
extremists



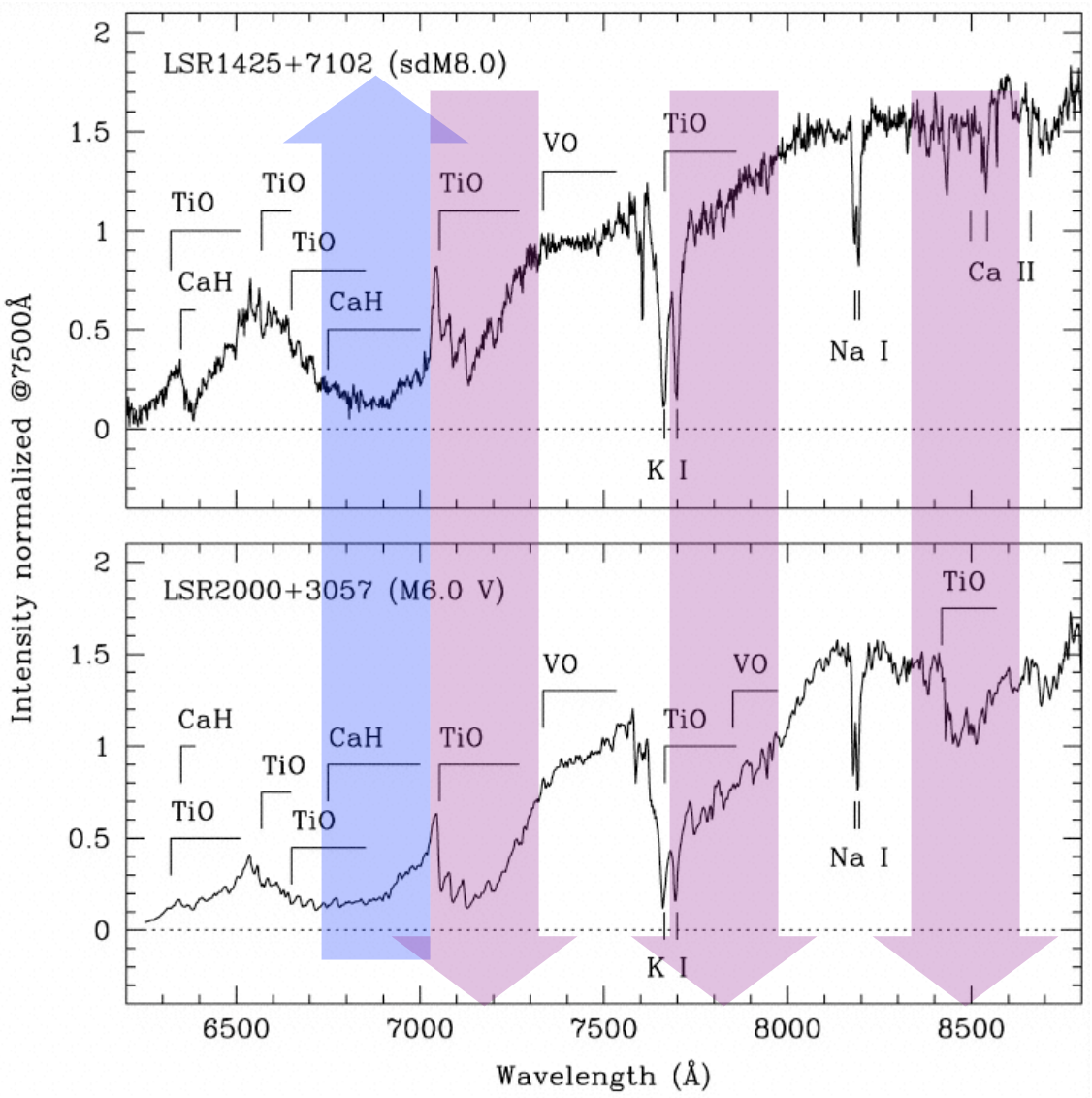




Burgasser, Kirkpatrick & Cruz (2006)



Burgasser et al. (2003)

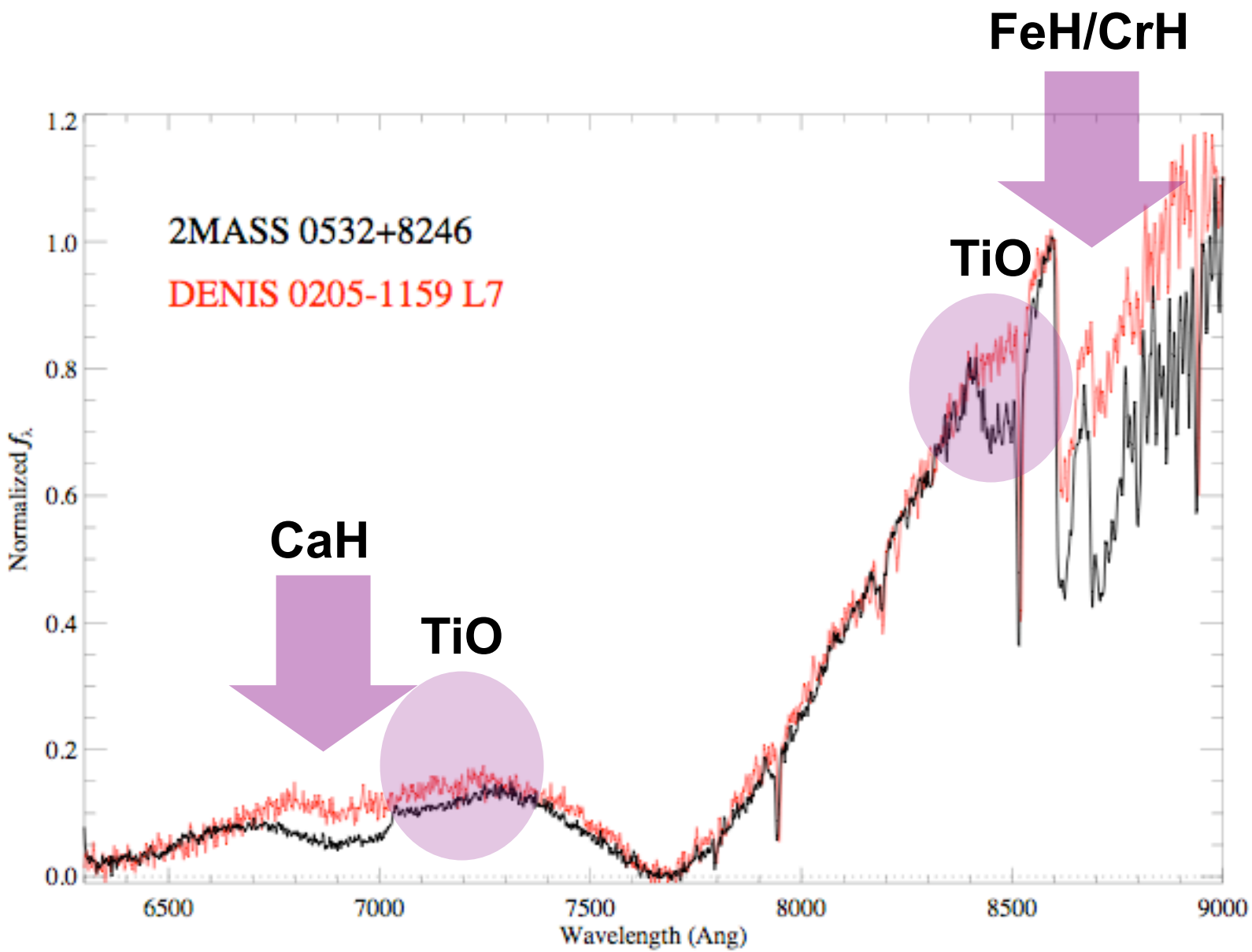


Lepine et al. (2003)
see also Gizis (1997); Lepine et al. (2004); Burgasser et al. (2006)

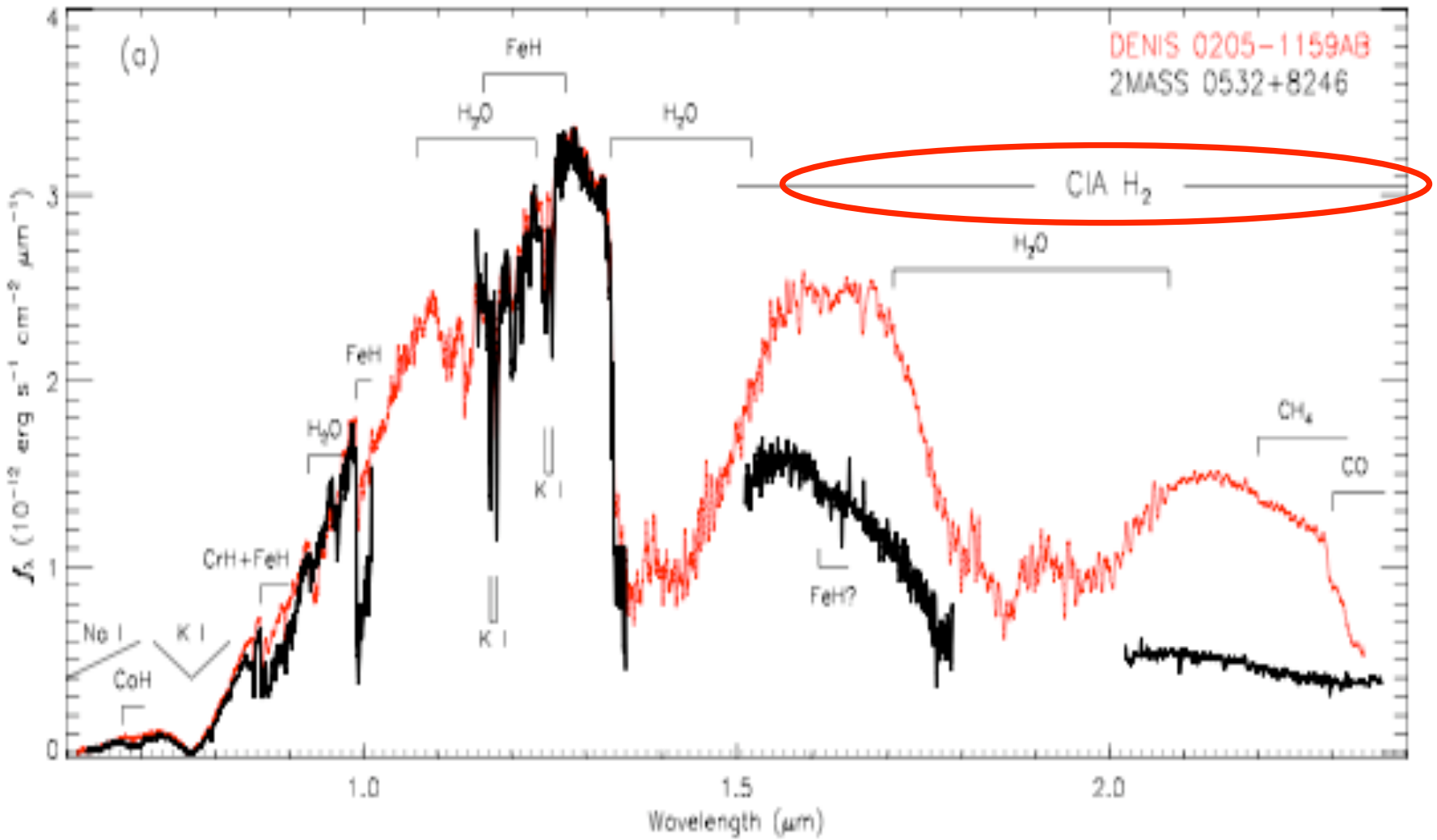
cf. M subdwarfs

Metal-poor M subdwarfs exhibit enhanced metal hydrides and single-metal species, reduced metal oxides - **classic metallicity effect**

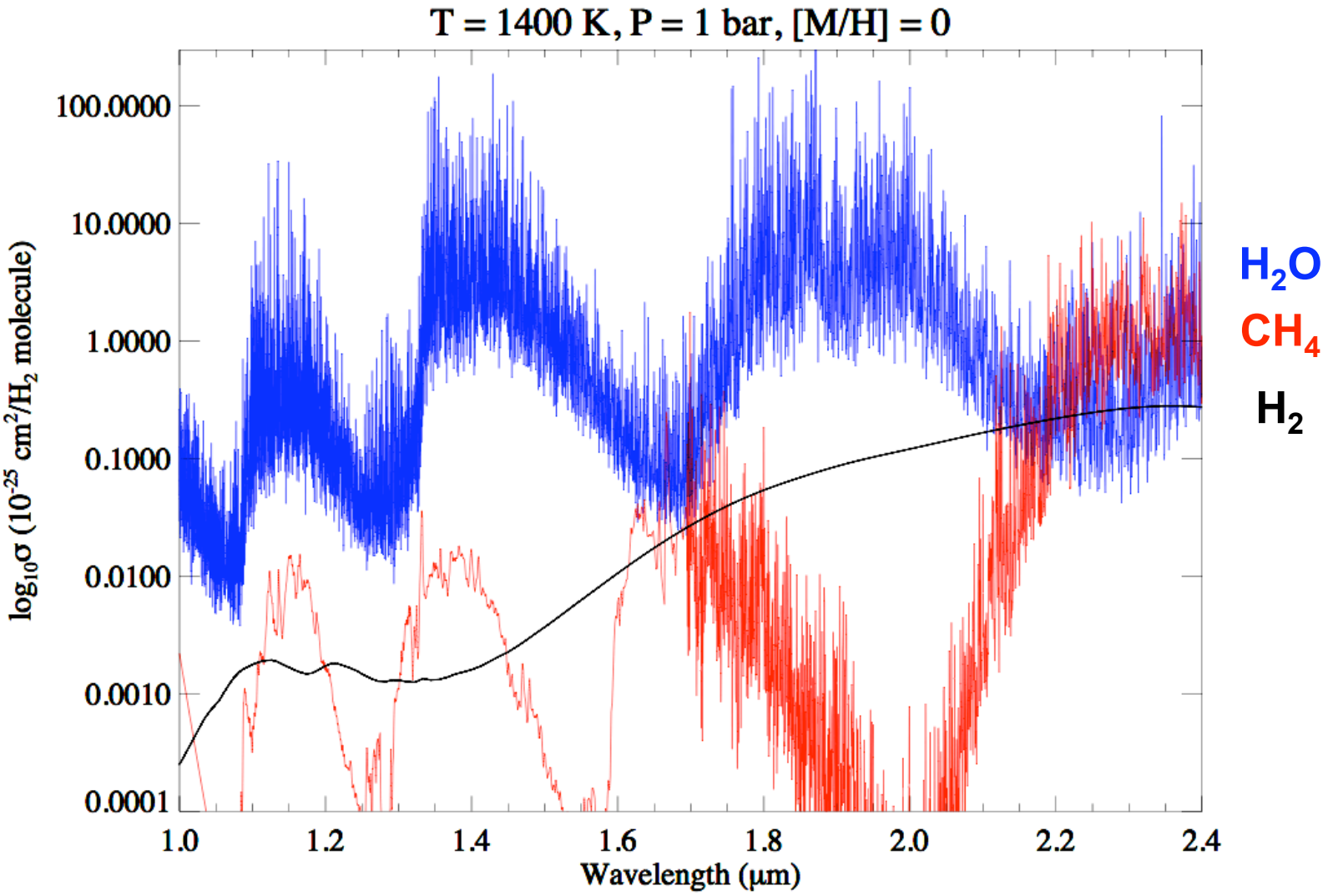
(e.g., Mould & Hyland 1976, Gizis 1997)



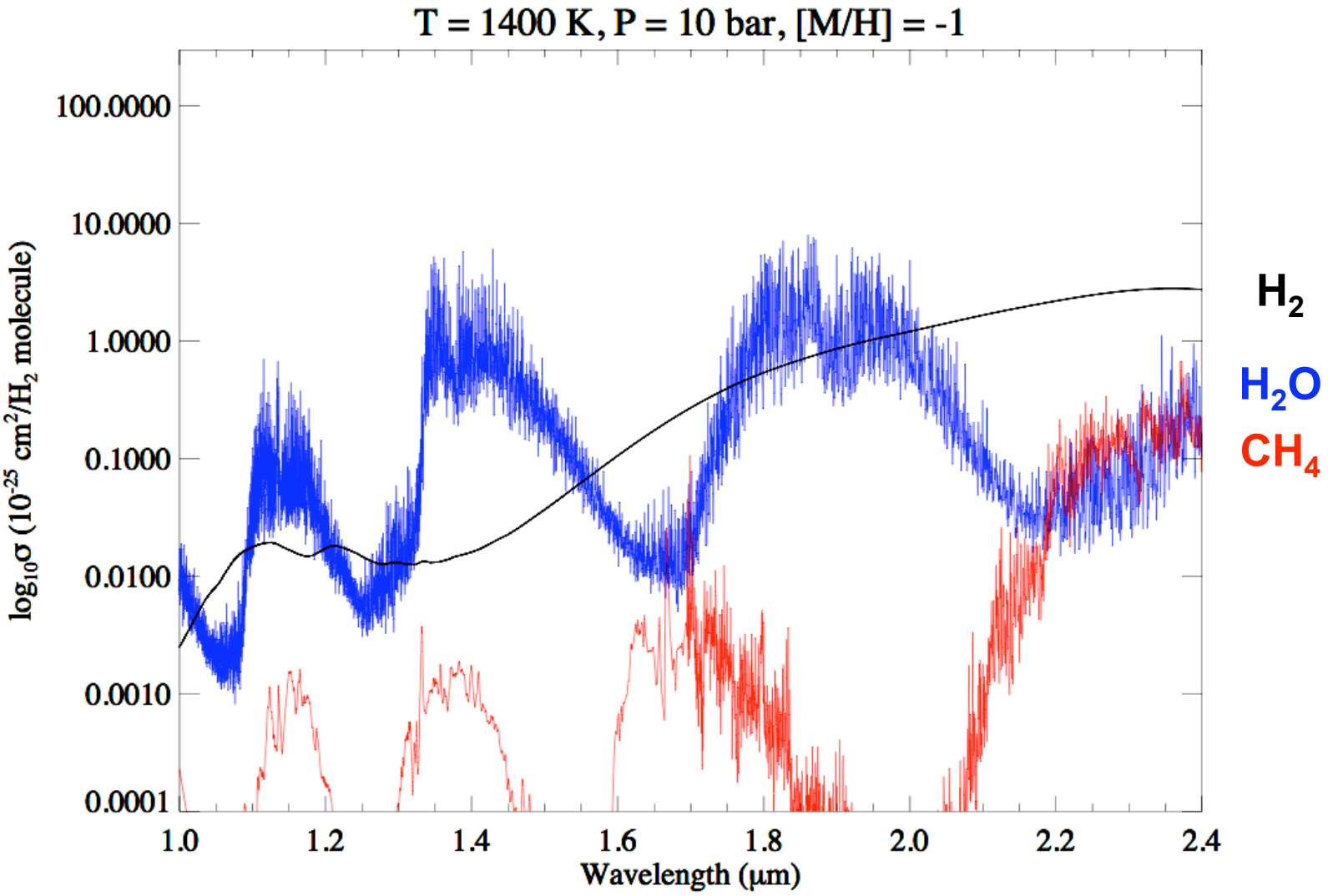
Burgasser, Kirkpatrick & Cruz (2007)



Burgasser et al. (2003)

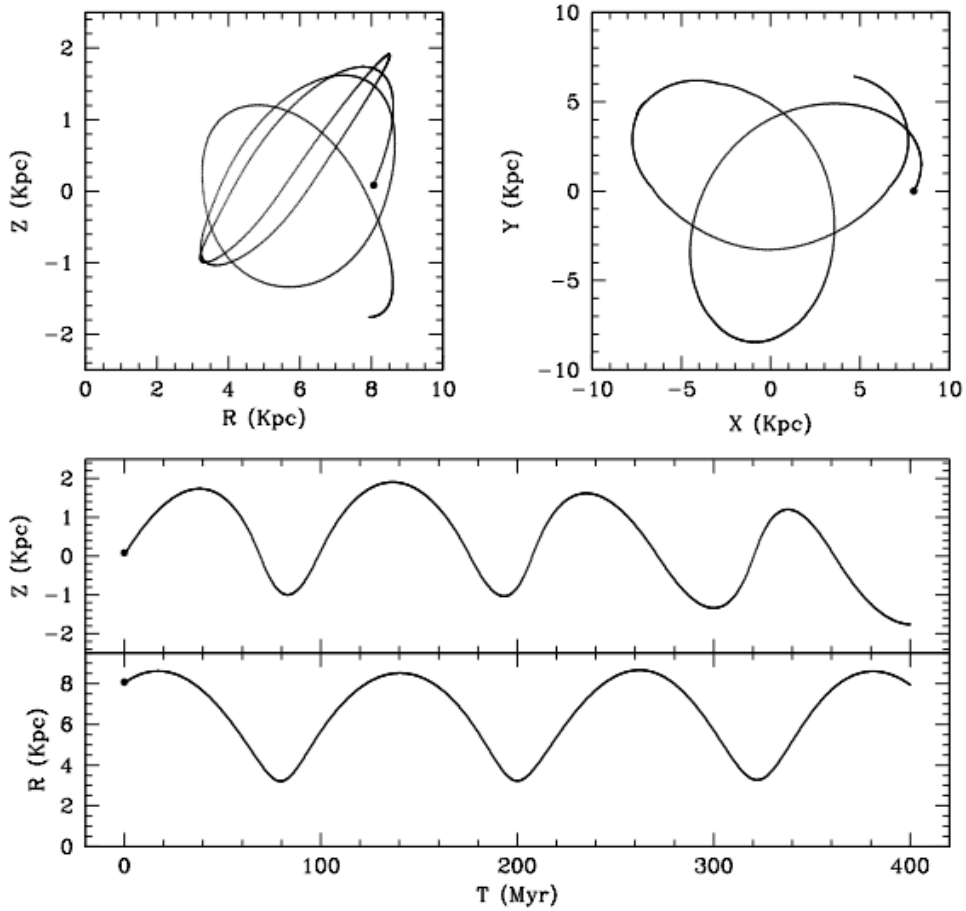


opacities from A. Burrows



opacities from A. Burrows

A halo brown dwarf



d = 26.7±1.2 pc

μ = 2623.1±1.8 mas/yr

V_r = -172±1 km/s

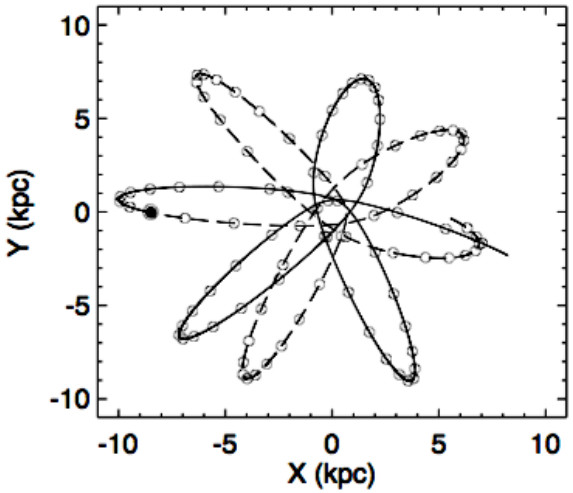
UVW = [-70,-354,78] km/s

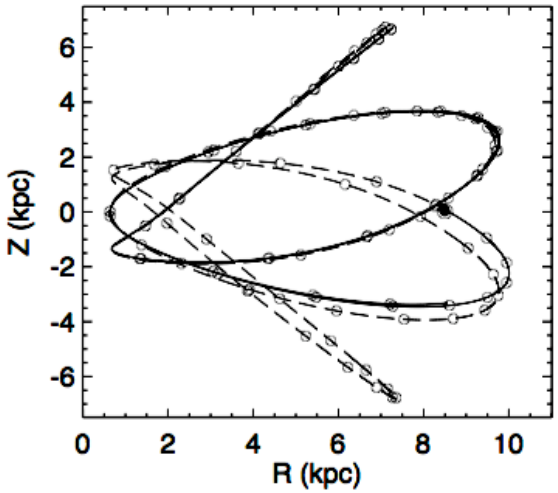
e ~ 0.5, Z_{max} ~ 2 kpc

"Inner halo" population

Burgasser et al. (2008)

see also Reiners & Basri (2006); Gizis & Harvin (2006); Burgasser et al. (2007)





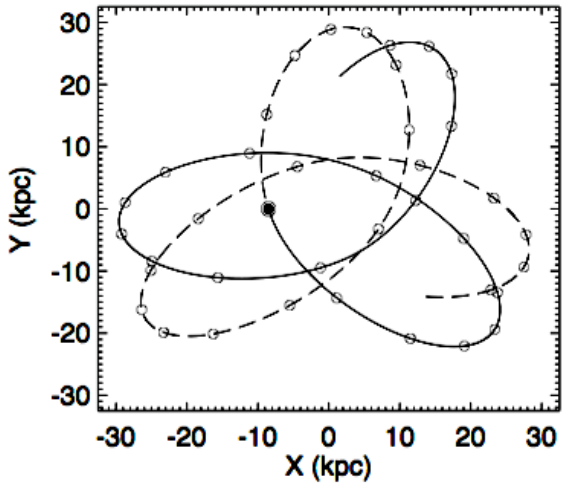
Burgasser et al. (2009)

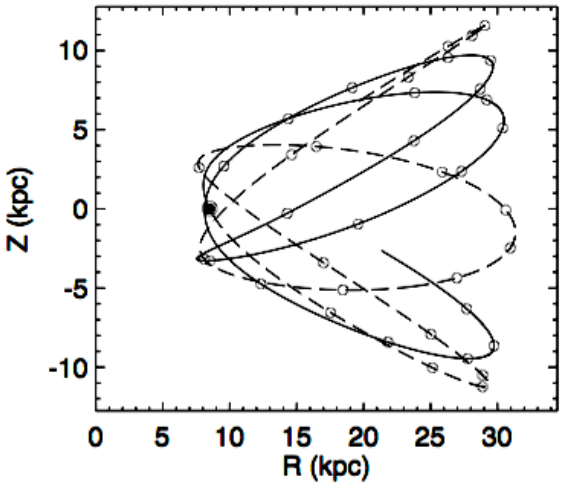
sdL3.5 SDSS 1256

prograde, e ~ 0.8,

Z_{max} ~ 6 kpc

"Inner halo"





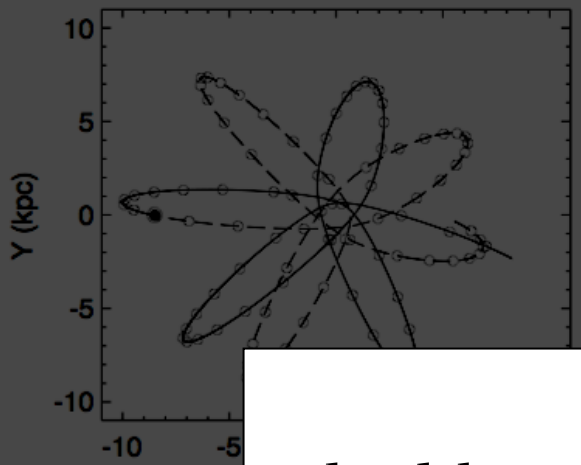
Cushing et al. (2009)

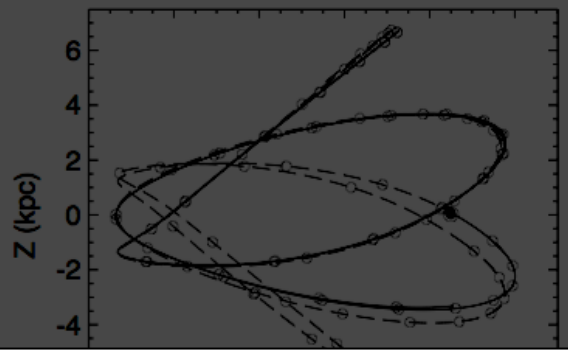
sdL6 2MASS 0616

retrograde, e ~ 0.6,

R_{max} ~ 30 kpc

"Outer halo"





Burgasser et al. (2009)

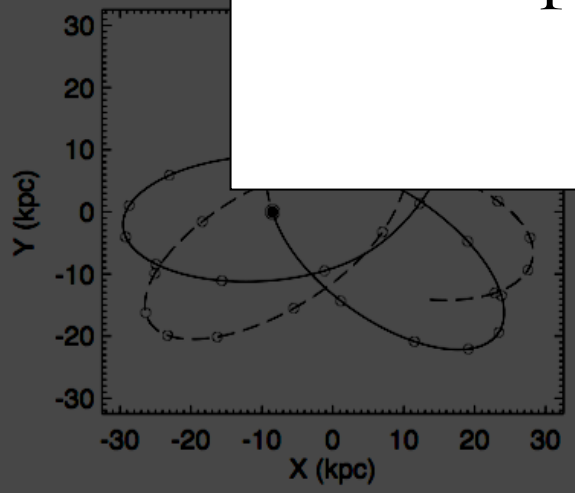
sdL3.5 SDSS 1256

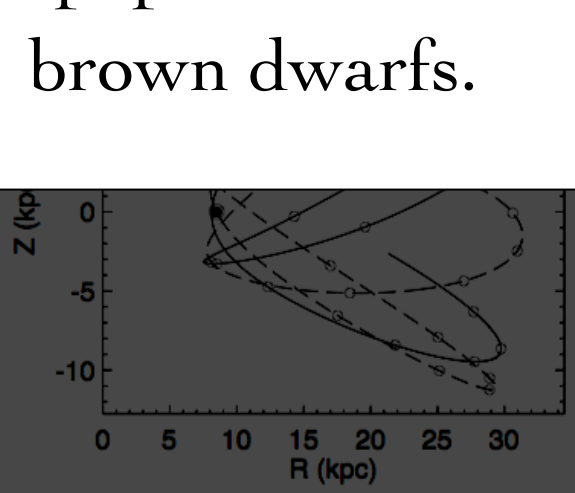
prograde, e ~ 0.8,

Z_{max} ~ 6 kpc

...alo"

The bluest L & T dwarfs probe older and/ or metal-poor populations, including halo brown dwarfs.





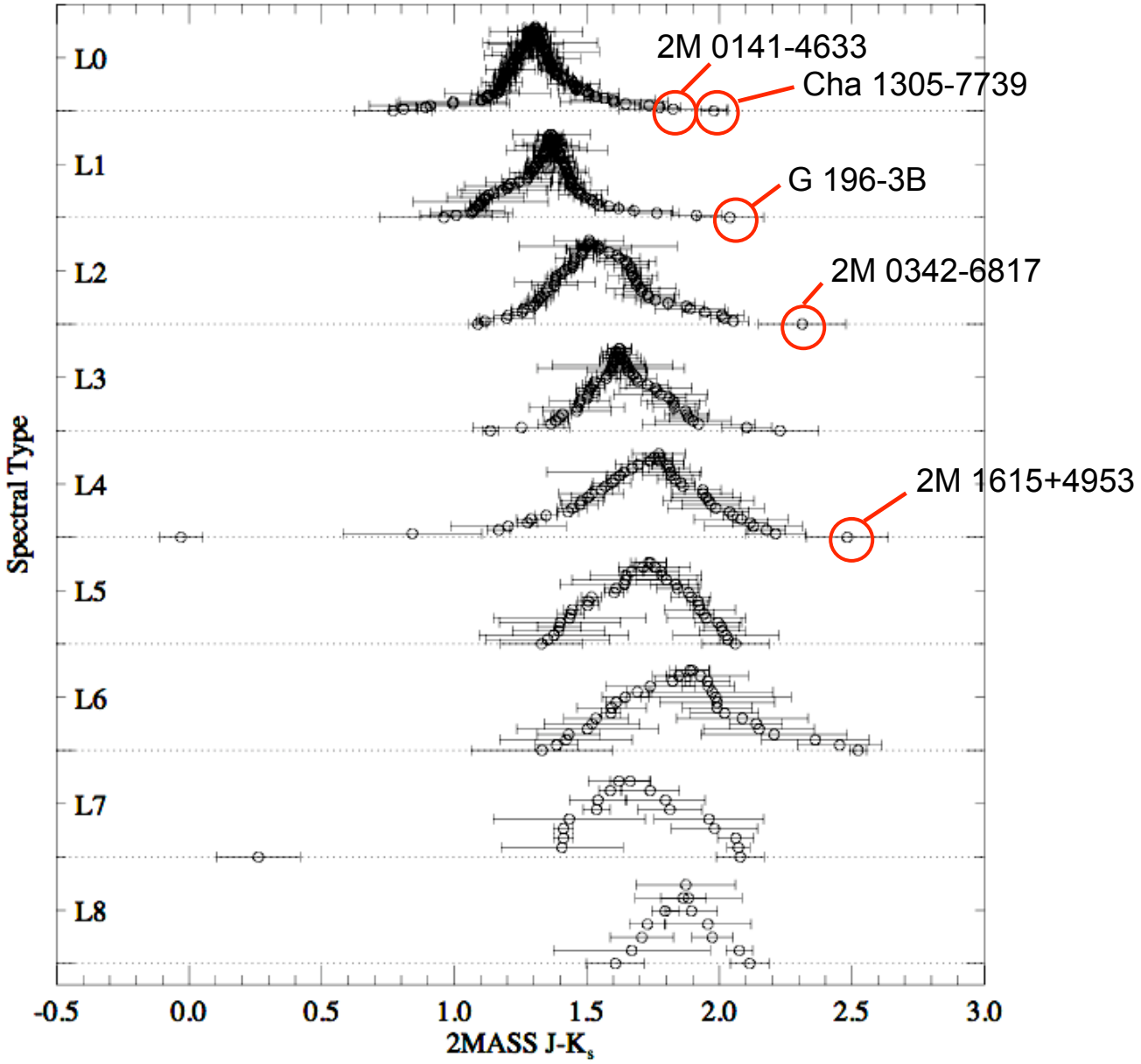
...(2009)

...S 0616

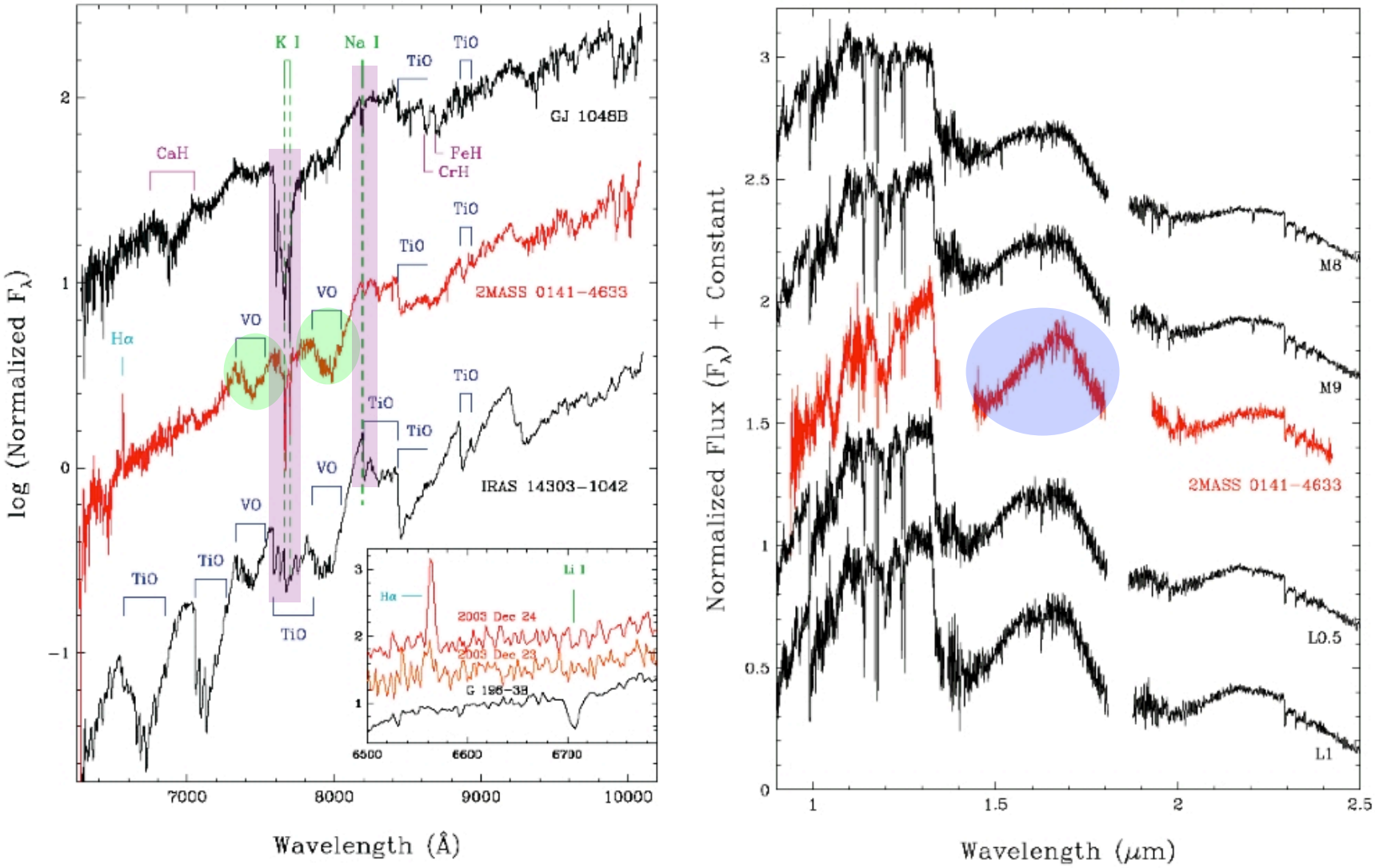
retrograde, e ~ 0.6,

R_{max} ~ 30 kpc

"Outer halo"

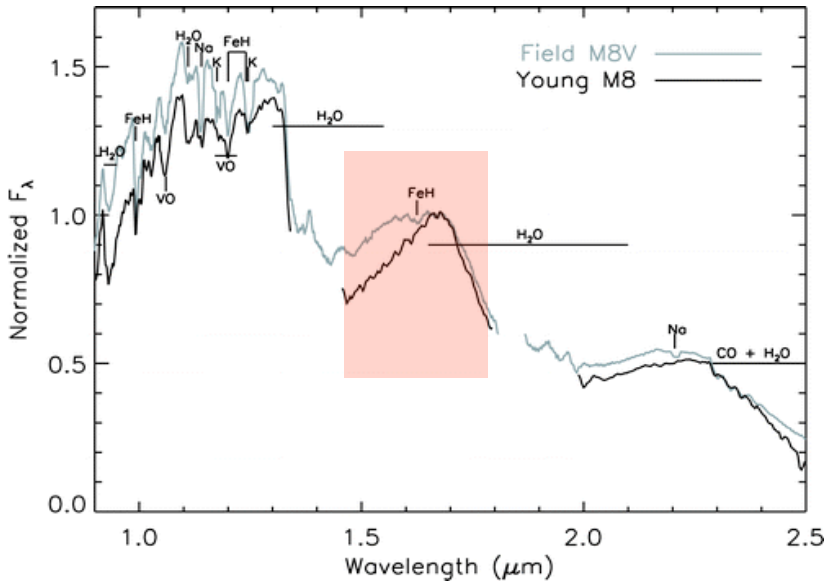


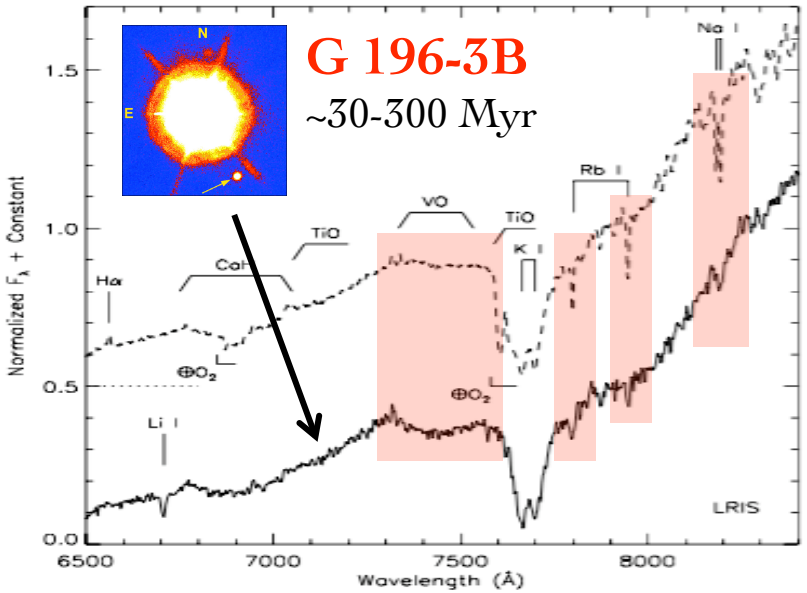
2MASS 0141-4633: ~10 Myr and nearby



Kirkpatrick et al. (2006)

spectral indicators of youth





Weak alkali lines in optical (Na I, K I, Rb I, Li I?)

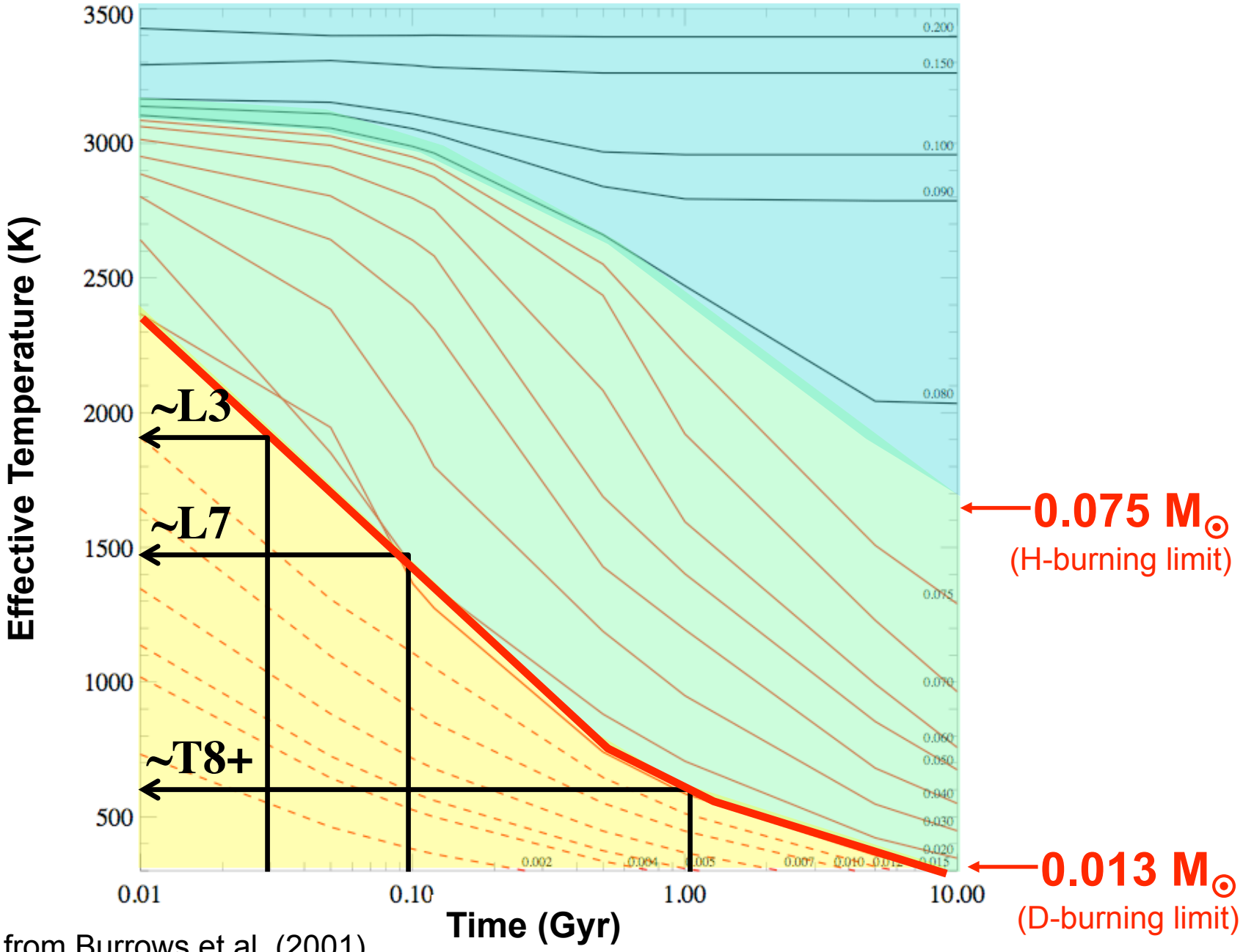
Enhanced VO, CO & H_2O

"Peaky" H-band peak

Red NIR SEDs - CIA H_2 effect

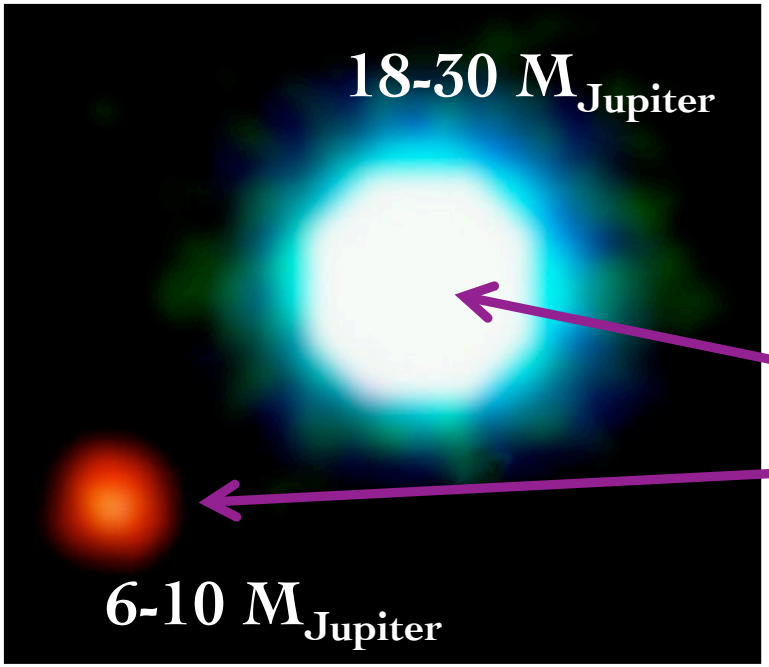
Allers et al. (2007); Kirkpatrick et al. (2008)

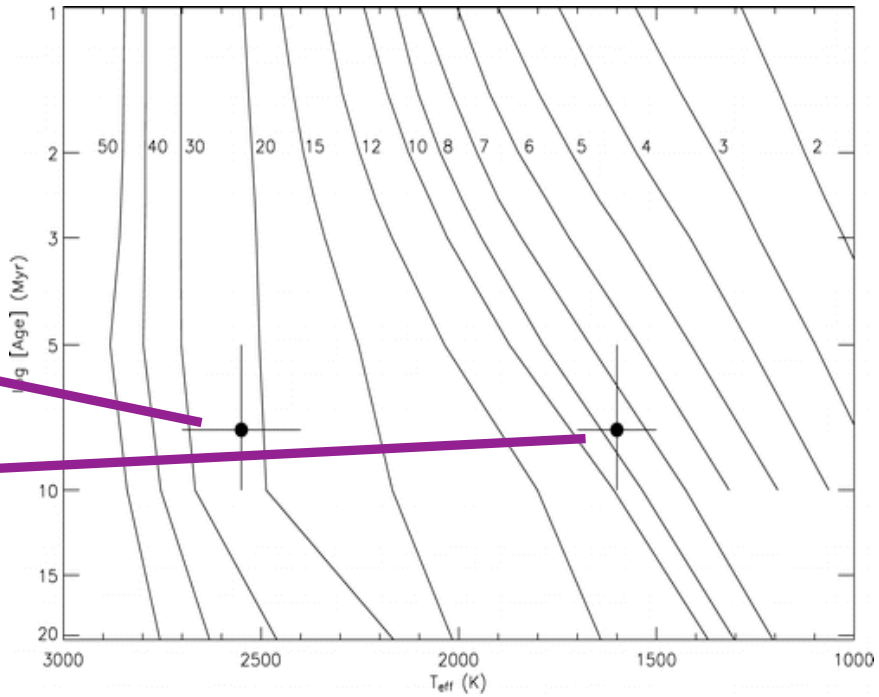
See also Martin et al. (1999); Gorlova et al. (2003); McGovern et al. (2004); Luhman et al. (2007)



models from Burrows et al. (2001)

2MASS 1207-3932AB: 8 Myr accreting Brown Dwarf + "Planet"

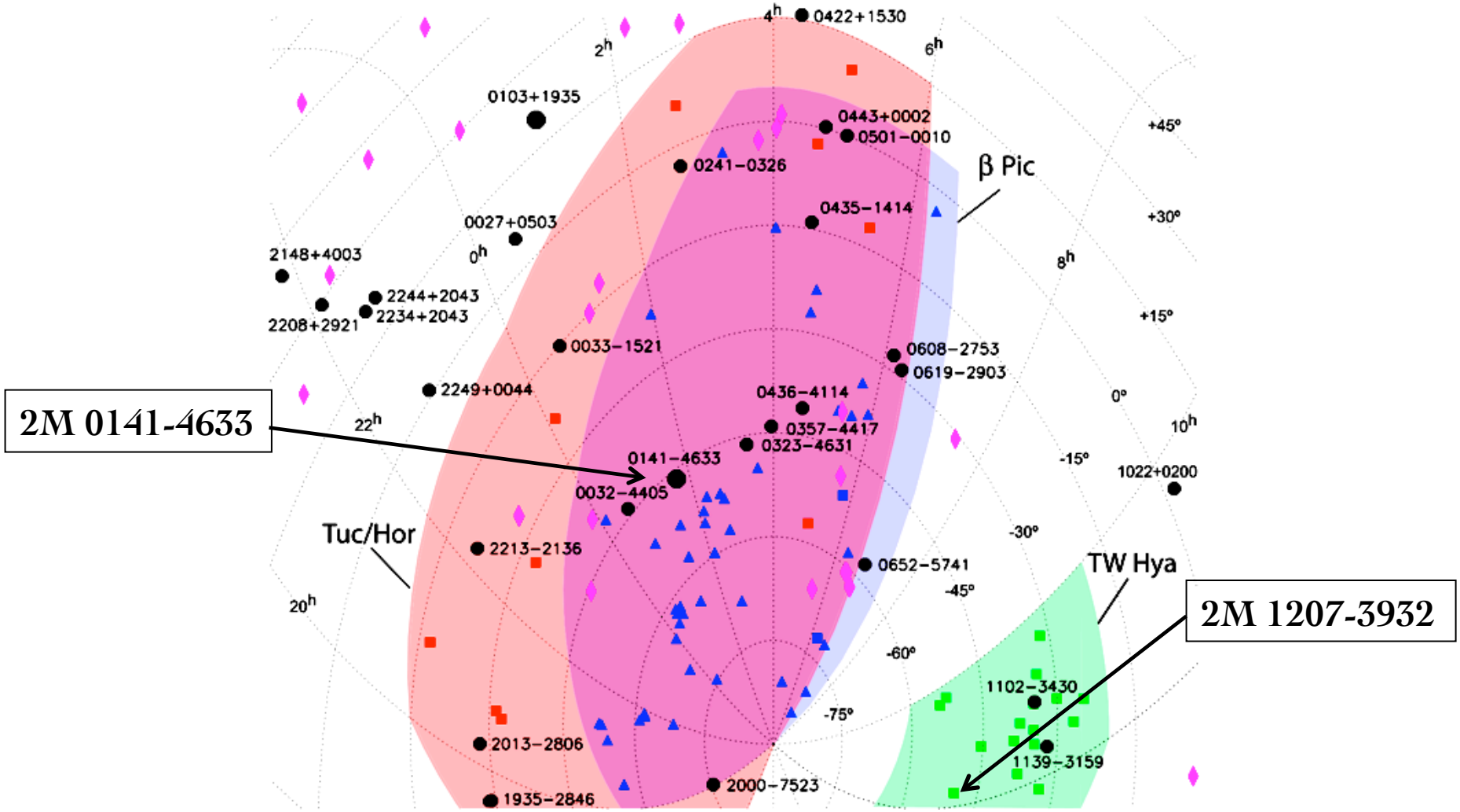




Chauvin et al. (2004); Mohanty et al. (2007)

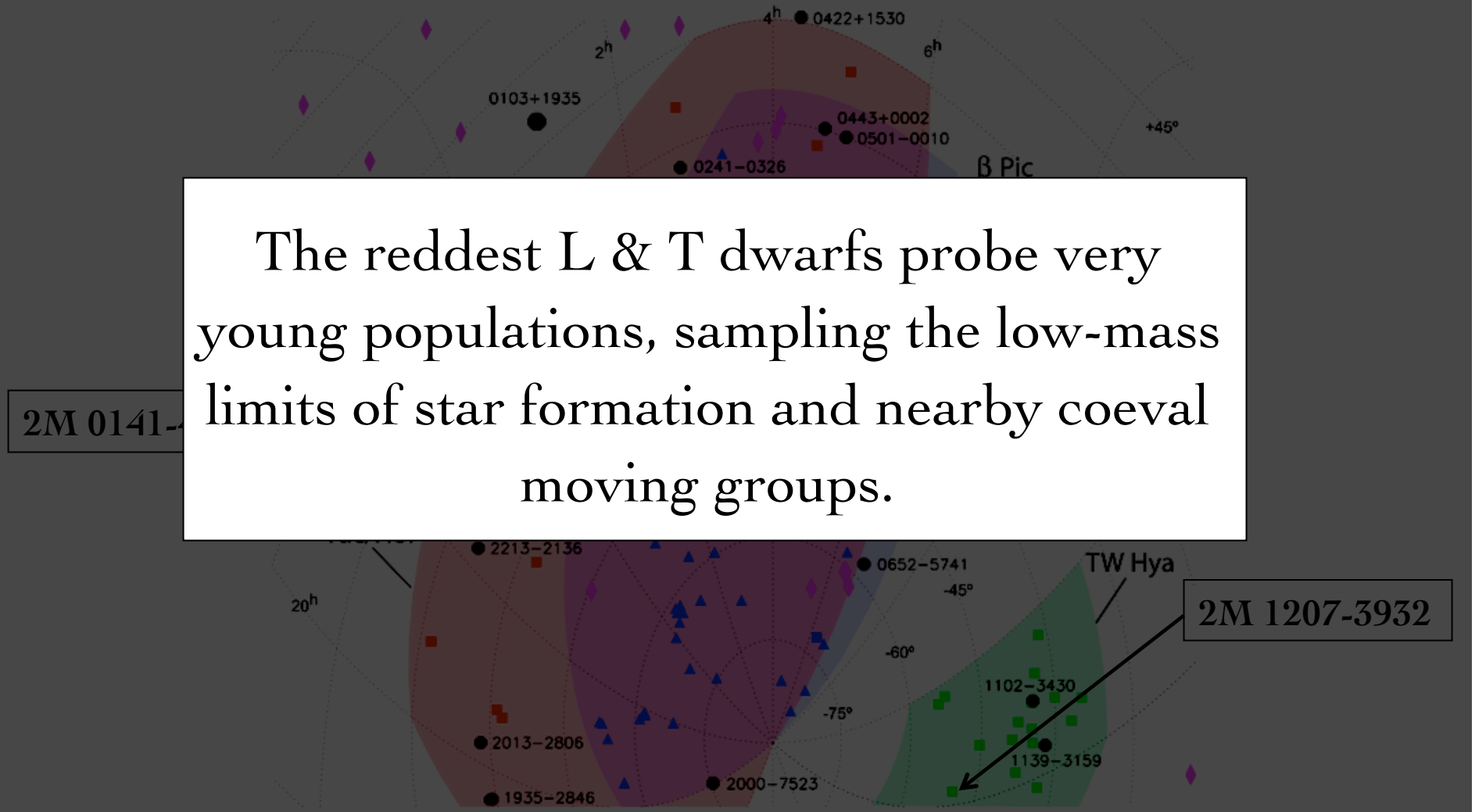
Gizis (2002); Jayawardhana et al. (2003); Mohanty et al. (2003,2005); Chauvin et al. (2005); Sterzik et al. (2004); Gizis et al. (2004; 2005); Mamjek (2005); Scholz et al. (2005, 2006); Barrado y Navascues (2006); Song et al. (2006); Gizis et al. (2007); Mamajek & Meyer (2007); Riaz & Gizis (2007); Stelzer et al. (2007); Whelan et al. (2007)

8-30 Myr brown dwarfs in the vicinity of the Sun



Cruz et al. (2006, 2009)

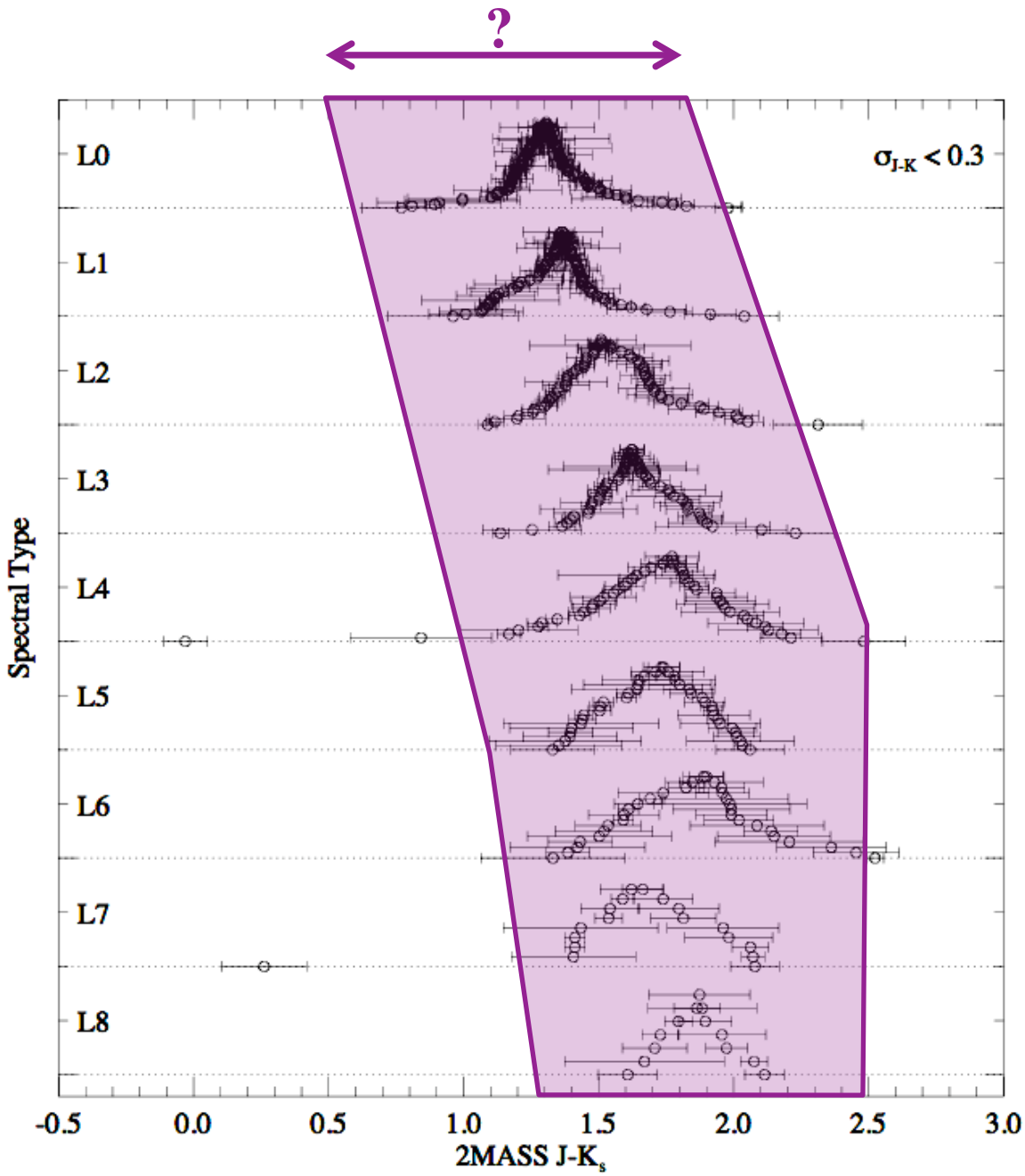
8-30 Myr brown dwarfs in the vicinity of the Sun



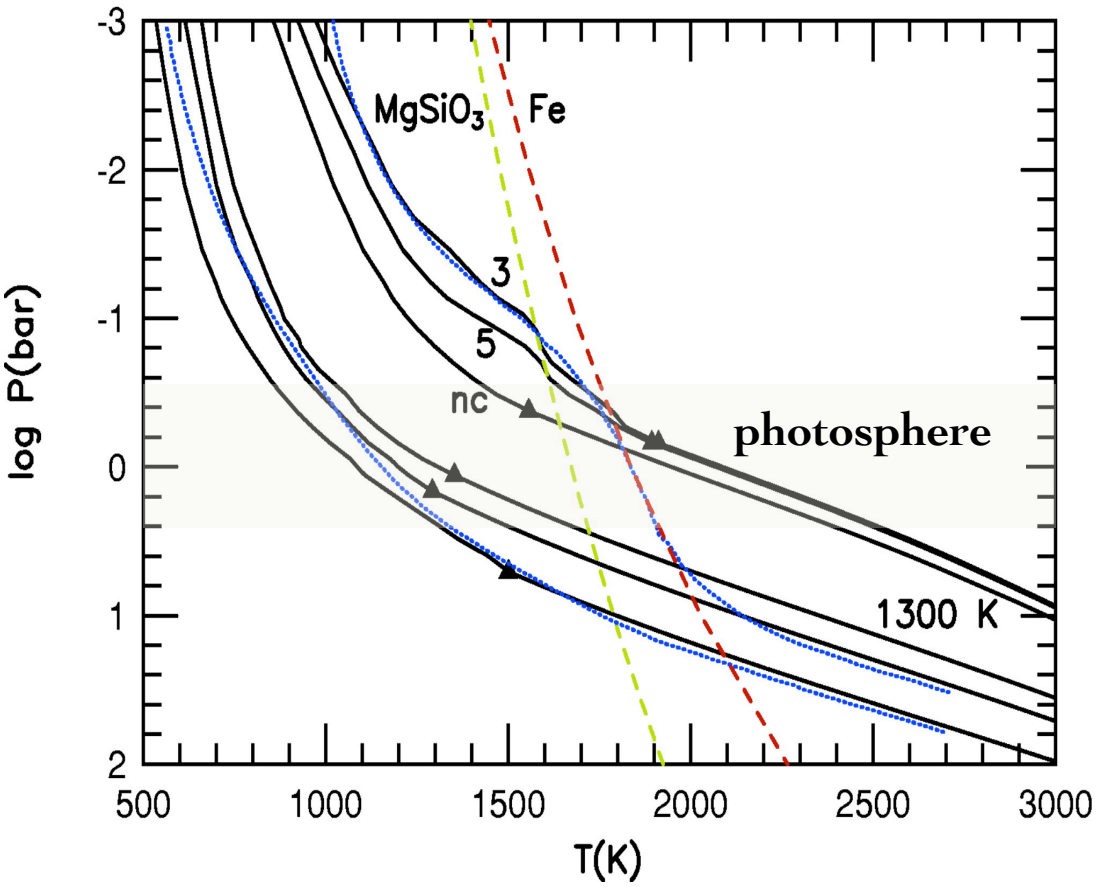
The reddest L & T dwarfs probe very young populations, sampling the low-mass limits of star formation and nearby coeval moving groups.

Cruz et al. (2006, 2009)

many shades of purple



Condensation in BD Atmospheres



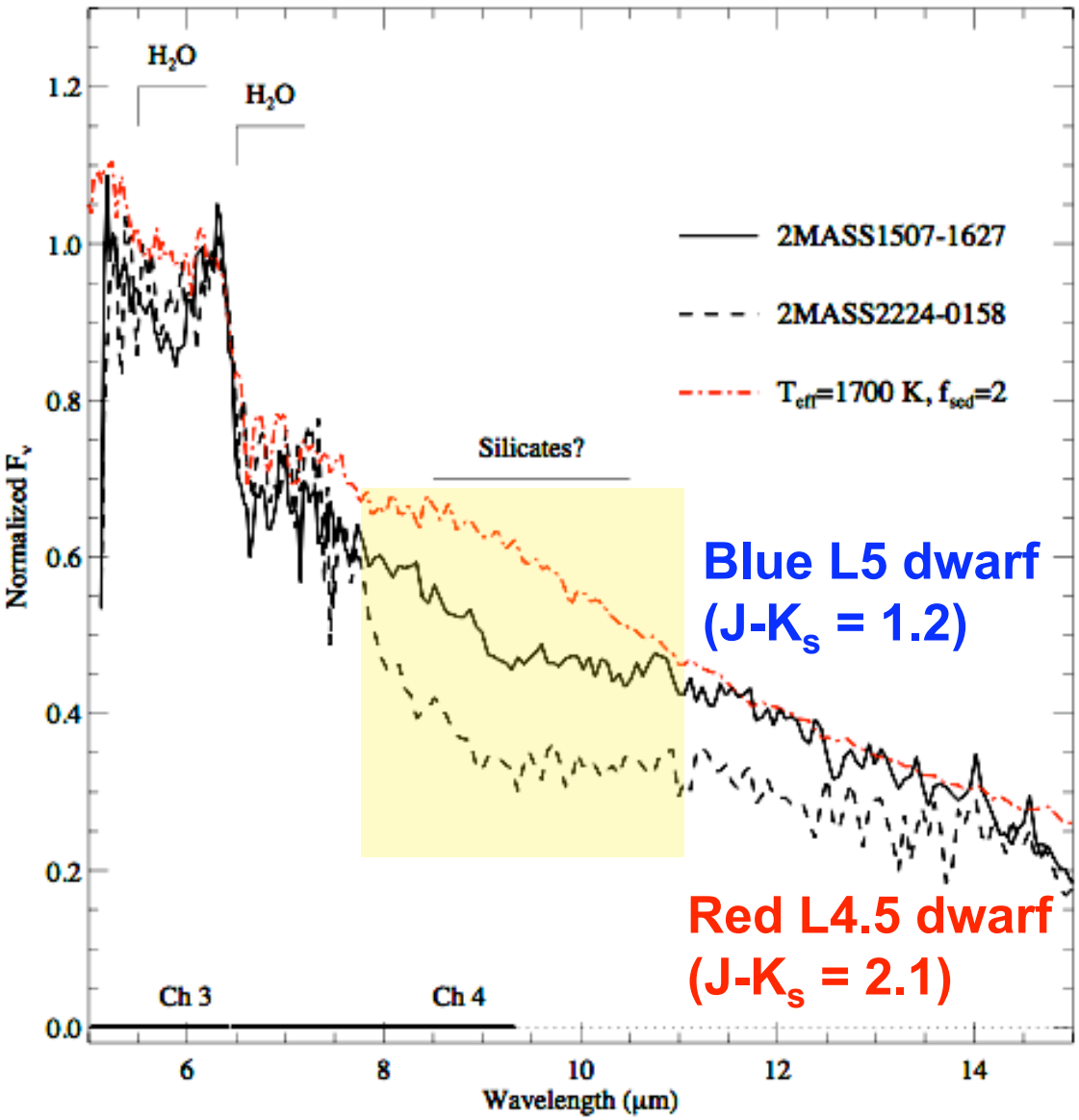
Marley et al. (2002)

see also Allard et al. (2001); Lodders (2002)

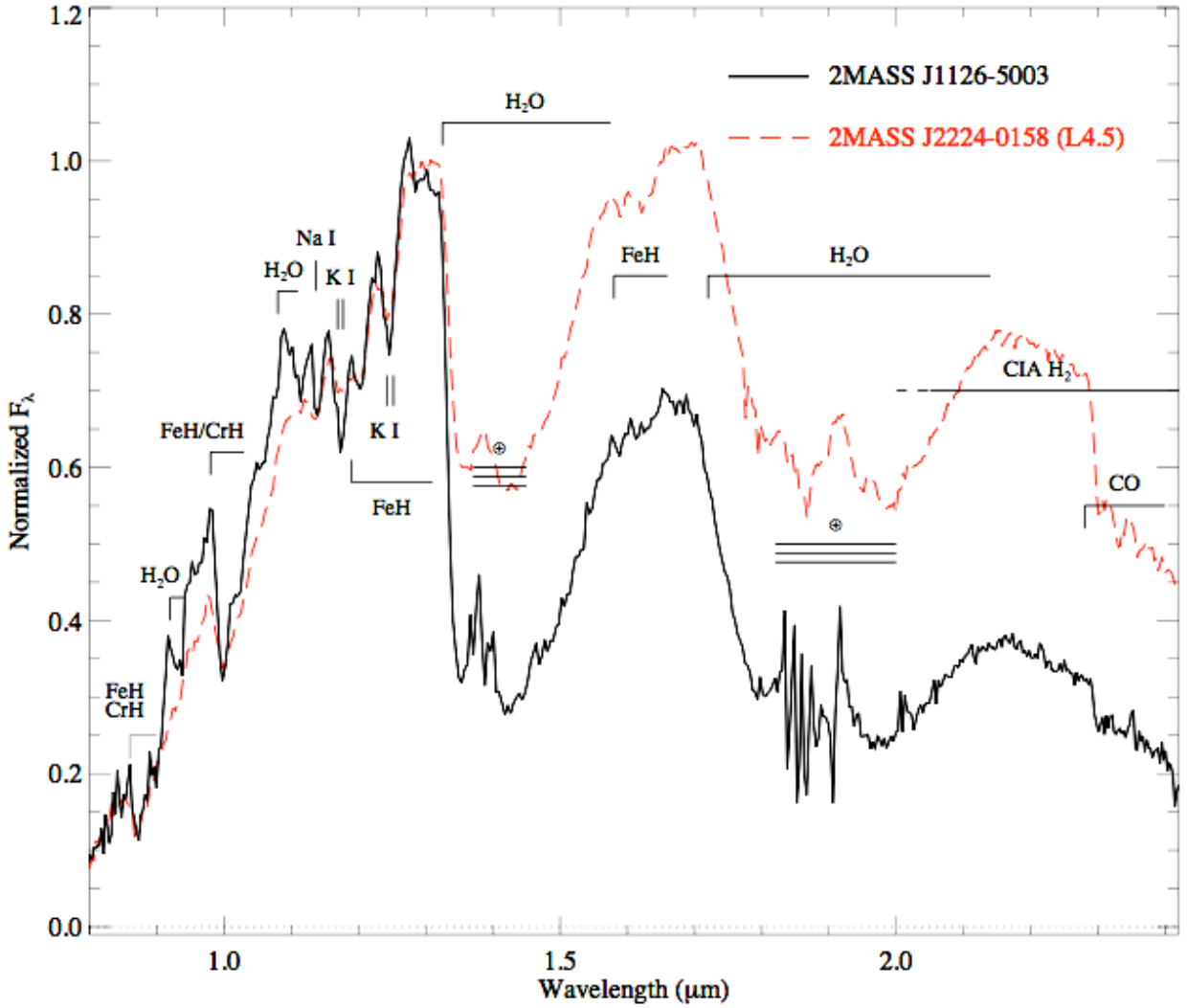
At the atmospheric temperatures and pressures of **late-M and L dwarfs**, several gaseous species form condensates.

e.g.:

- TiO → TiO_2(s), $CaTiO_3$(s)
- VO → VO(s)
- Fe → Fe(l)
- SiO → SiO_2(s), $MgSiO_3$(s)



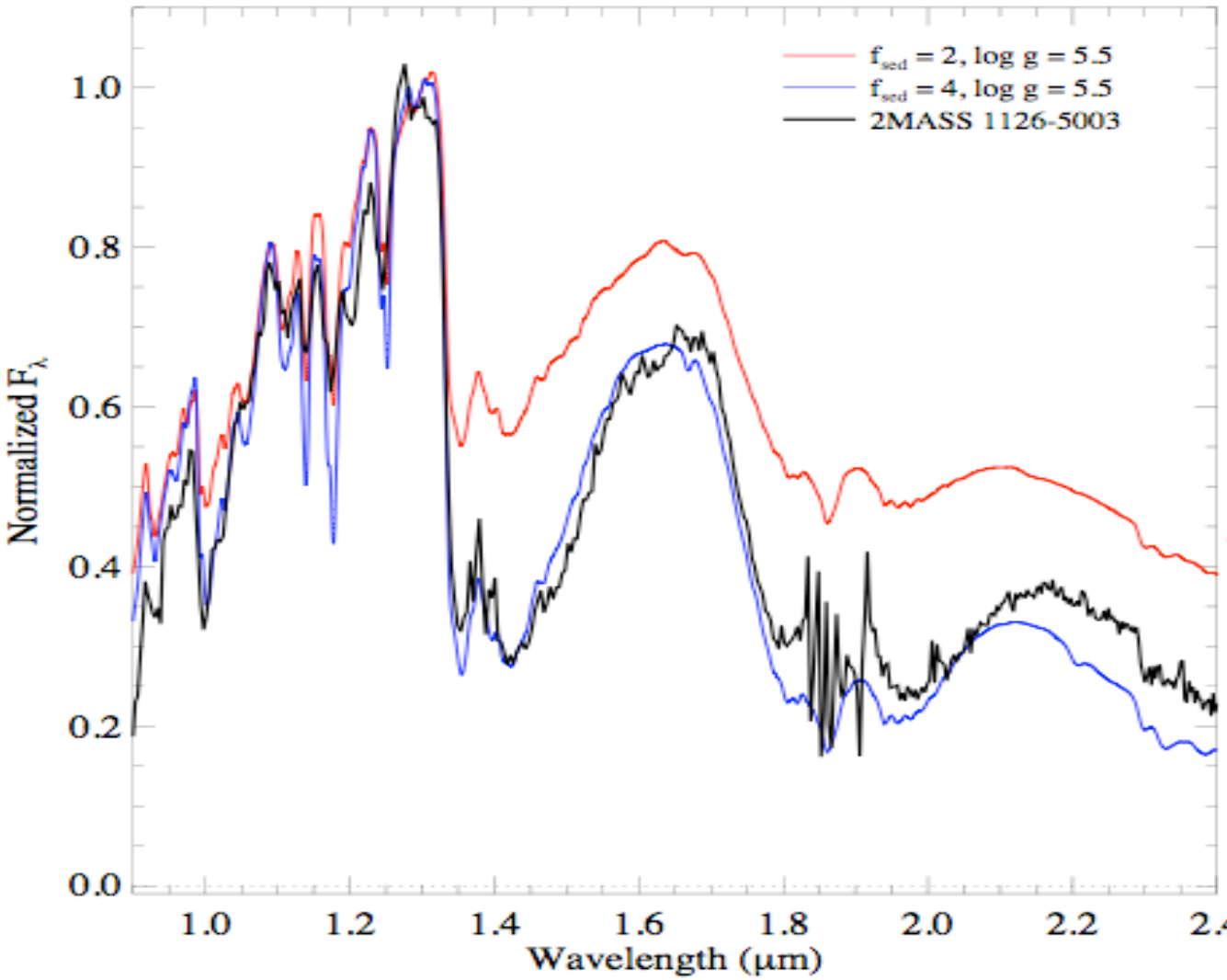
Burgasser et al. (2008)
See also Cushing et al. (2006); Looper et al. (2008)



Red L4.5 dwarf
($J-K_s$ = 2.1)

Blue L5 dwarf
($J-K_s$ = 1.2)

Burgasser et al. (2008)
see also Ackerman & Marley (2001); Knapp et al. (2004); Cruz et al. (2007); Cushing et al. (2008)



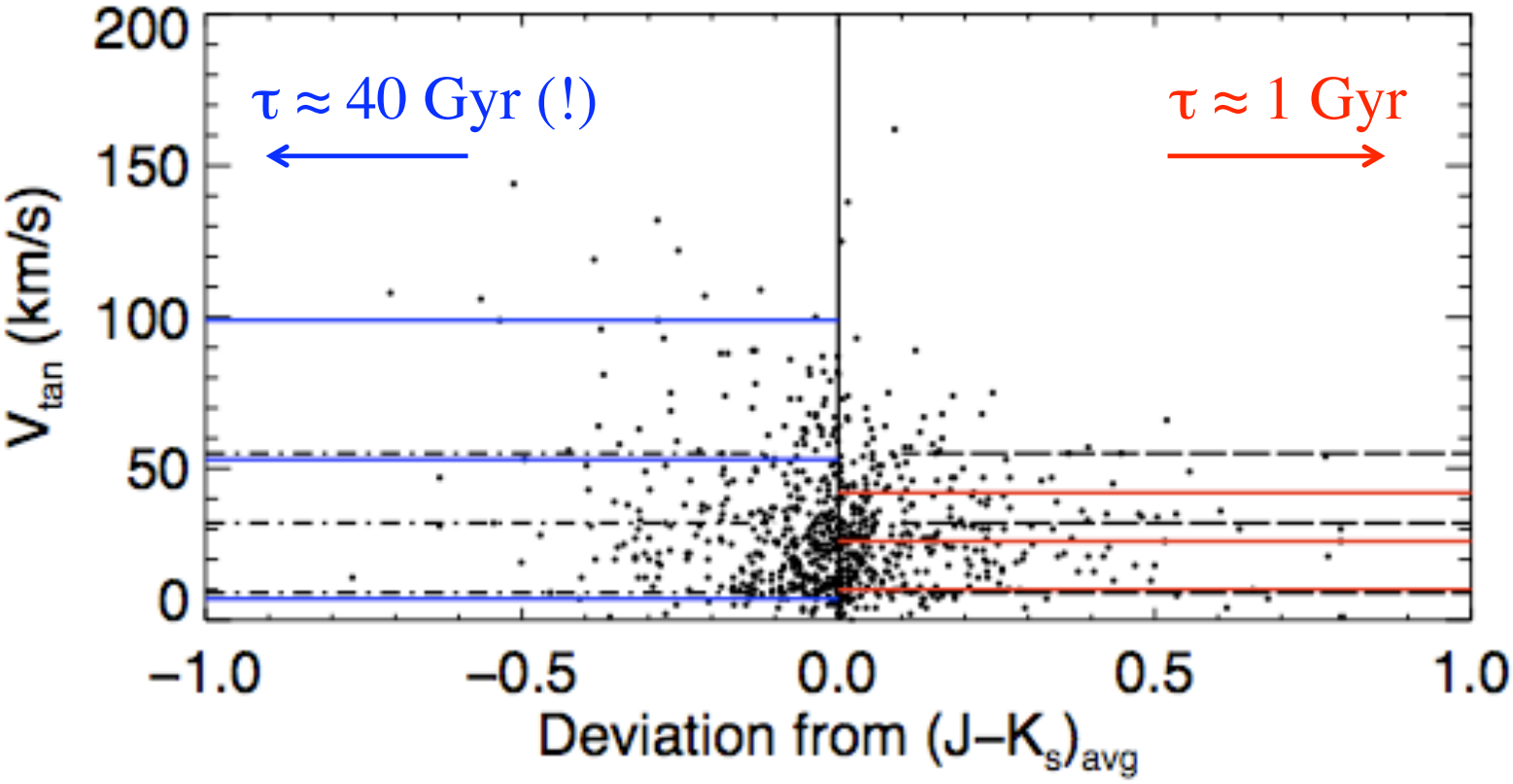
Thick clouds

Thin clouds

Burgasser et al. (2008)

see also Ackerman & Marley (2001); Knapp et al. (2004); Cruz et al. (2007); Cushing et al. (2008)

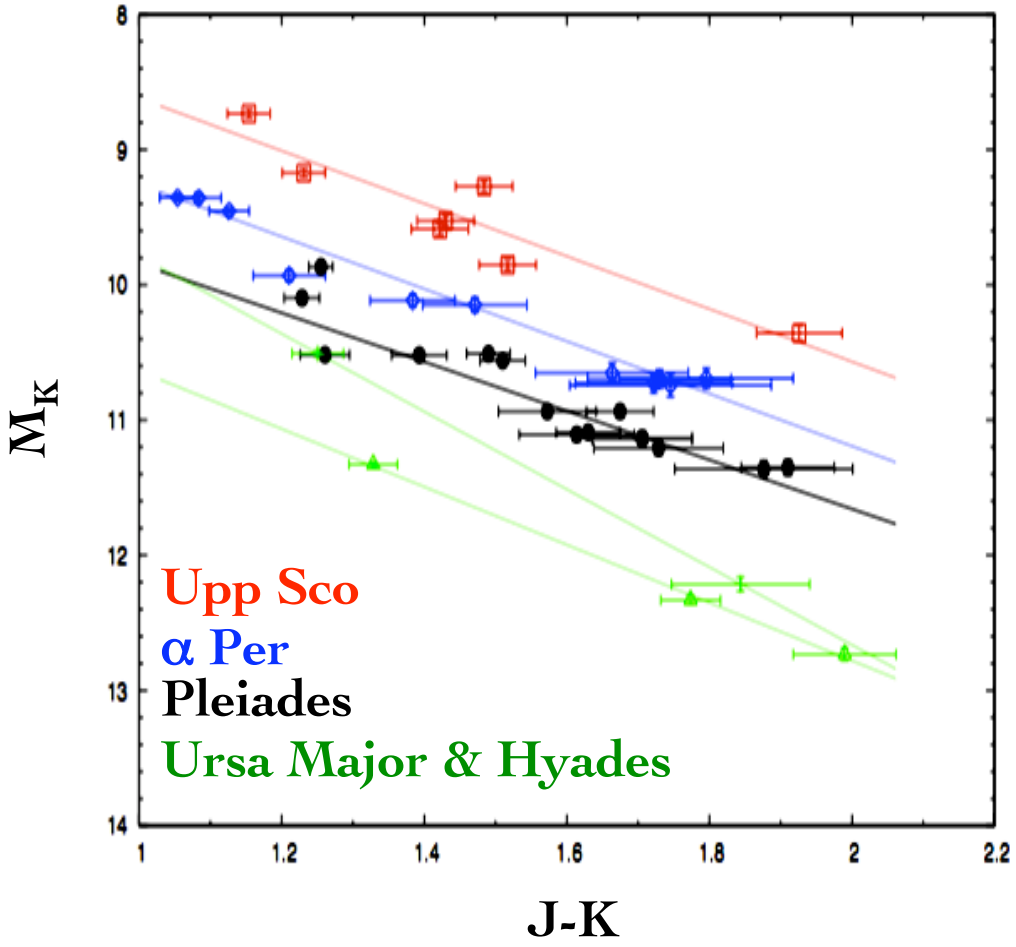
kinematic clues: color as an age proxy



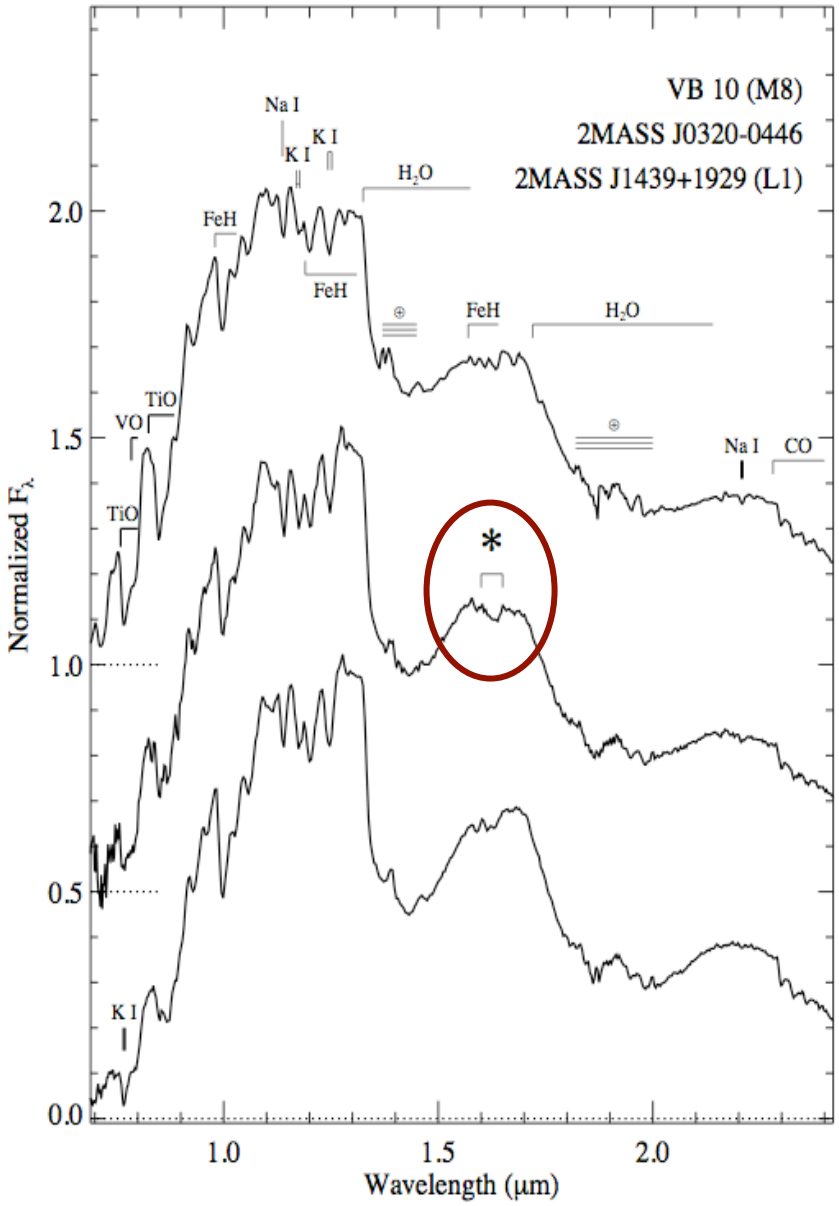
Faherty et al. (2008)

see also Schmidt et al. (2007); Jameson et al. (2007, 2008); Zapatero Osorio et al. (2007)

kinematic clues: color as an age proxy



Jameson et al. (2008)

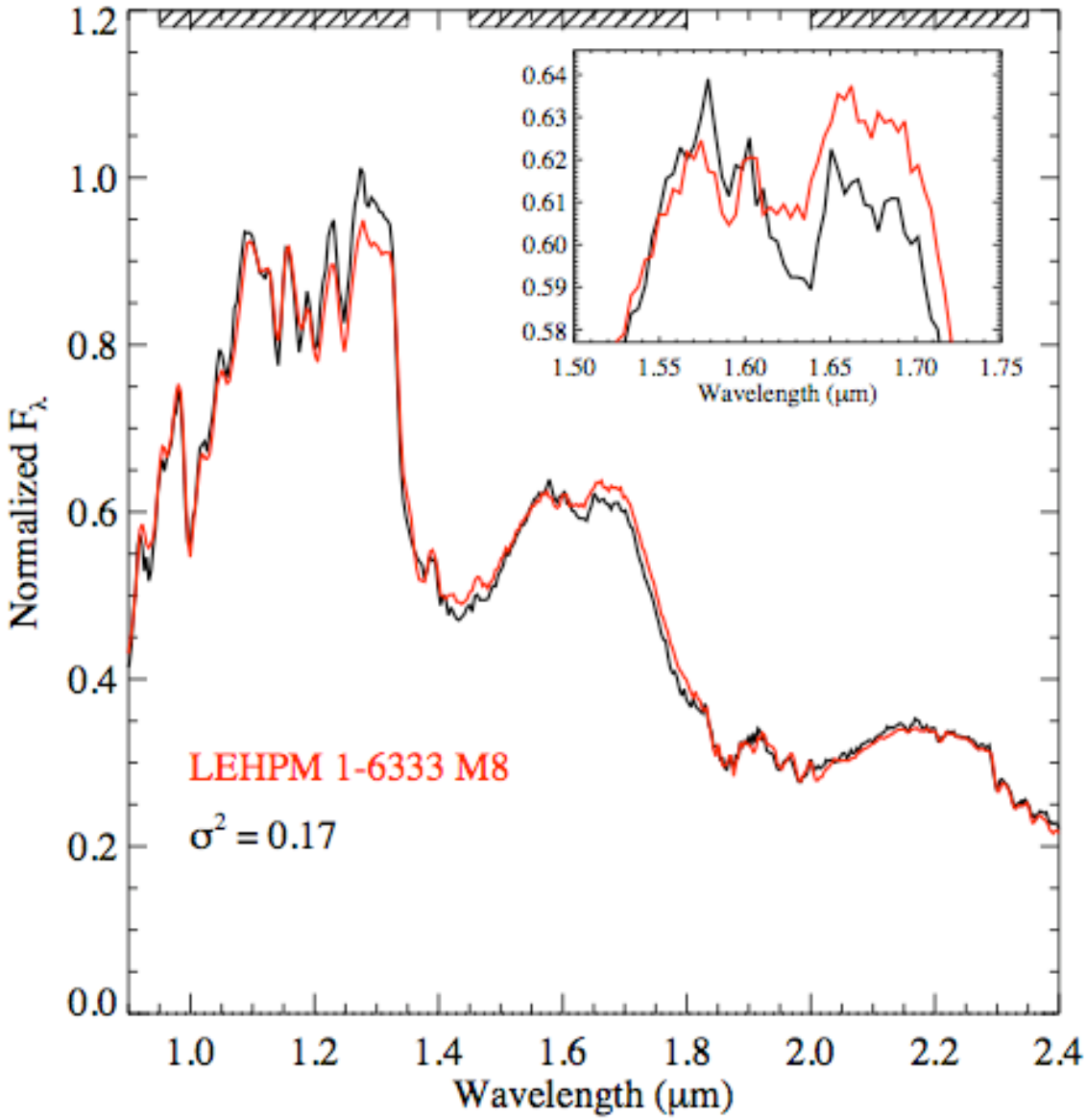


Burgasser et al. (2008)

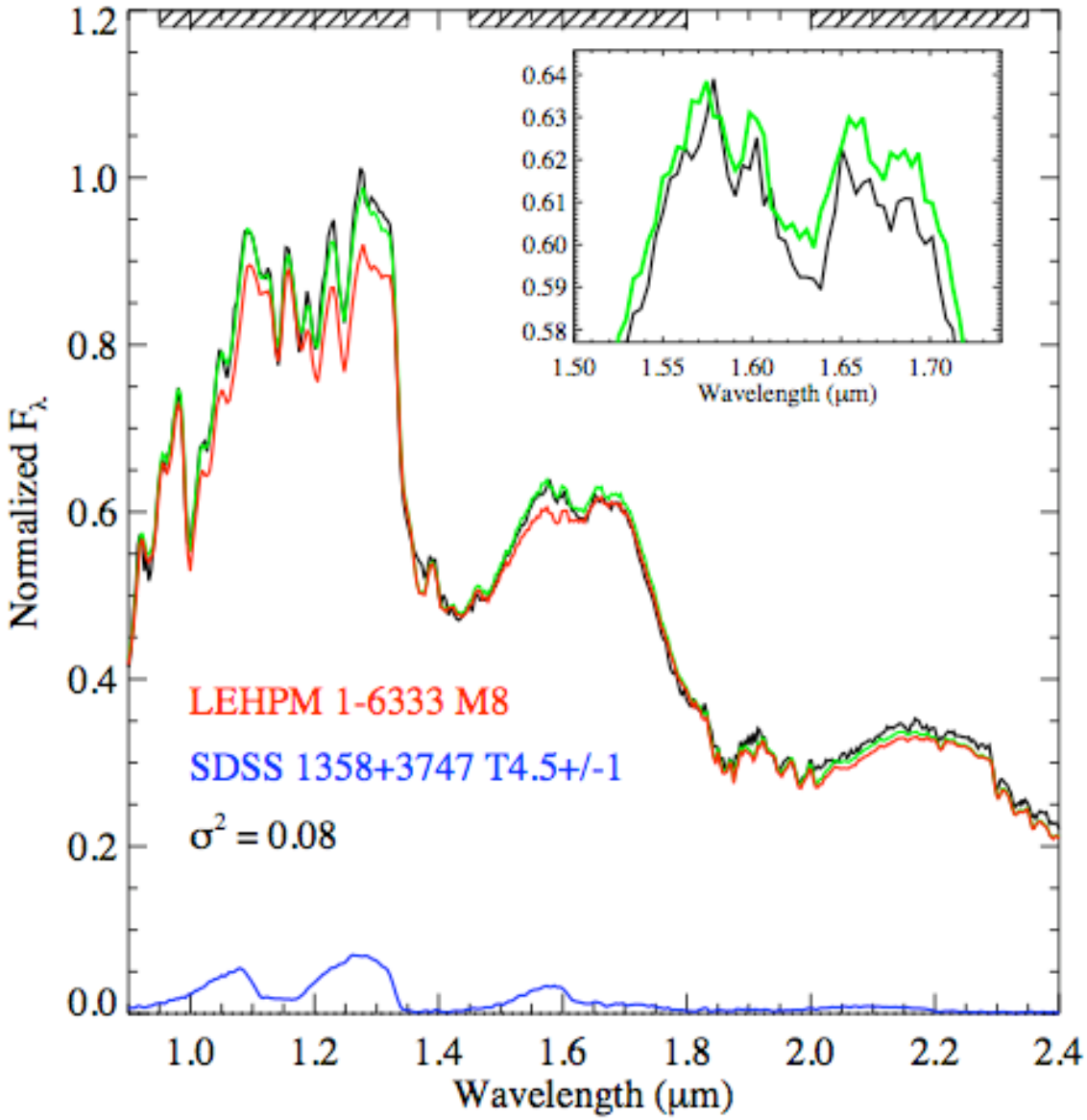
Unusually blue binaries

Binaries with T dwarf companions can have unusually blue colors and subtle spectral peculiarities

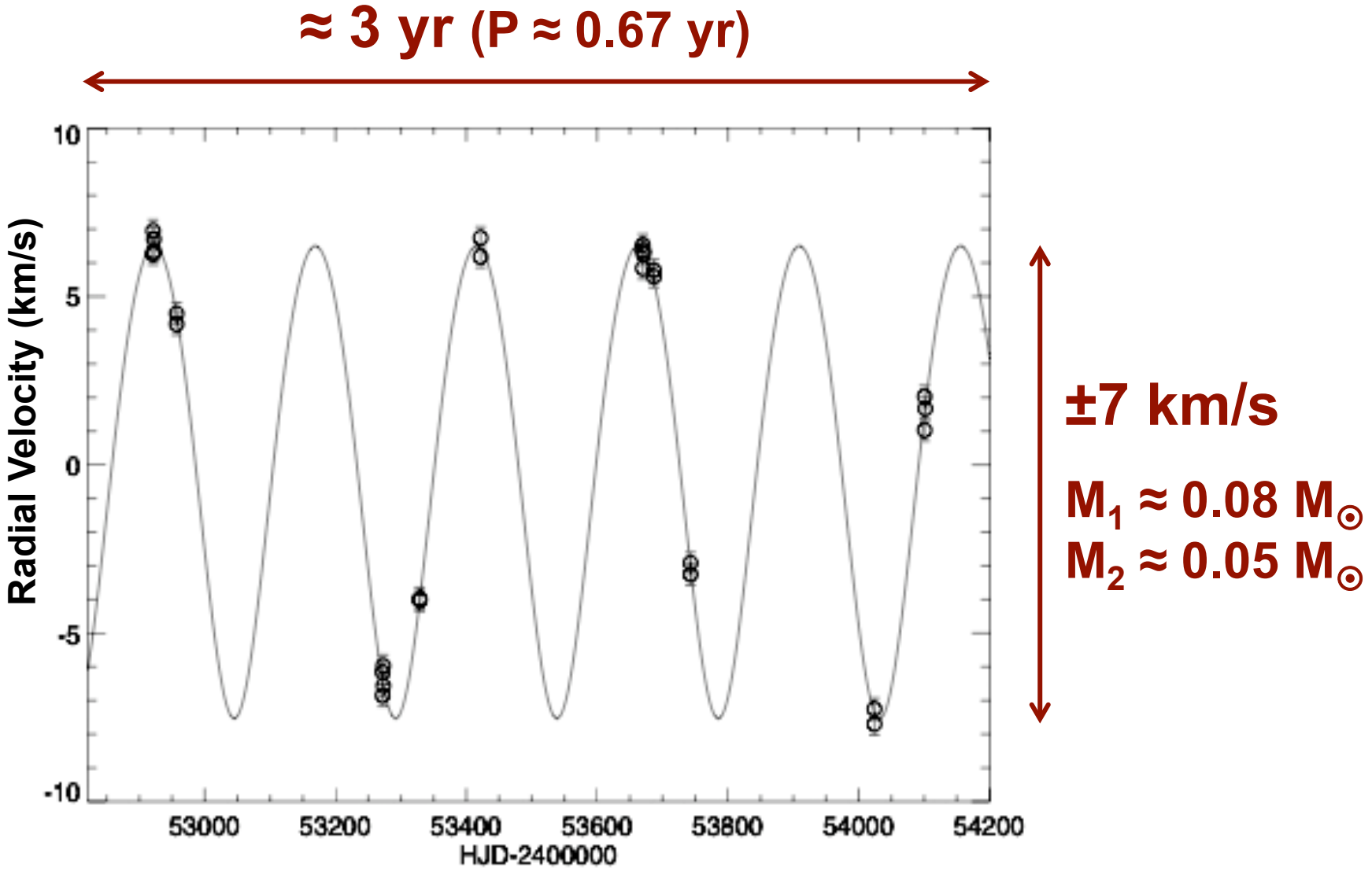
e.g. 2MASS 0320-0446



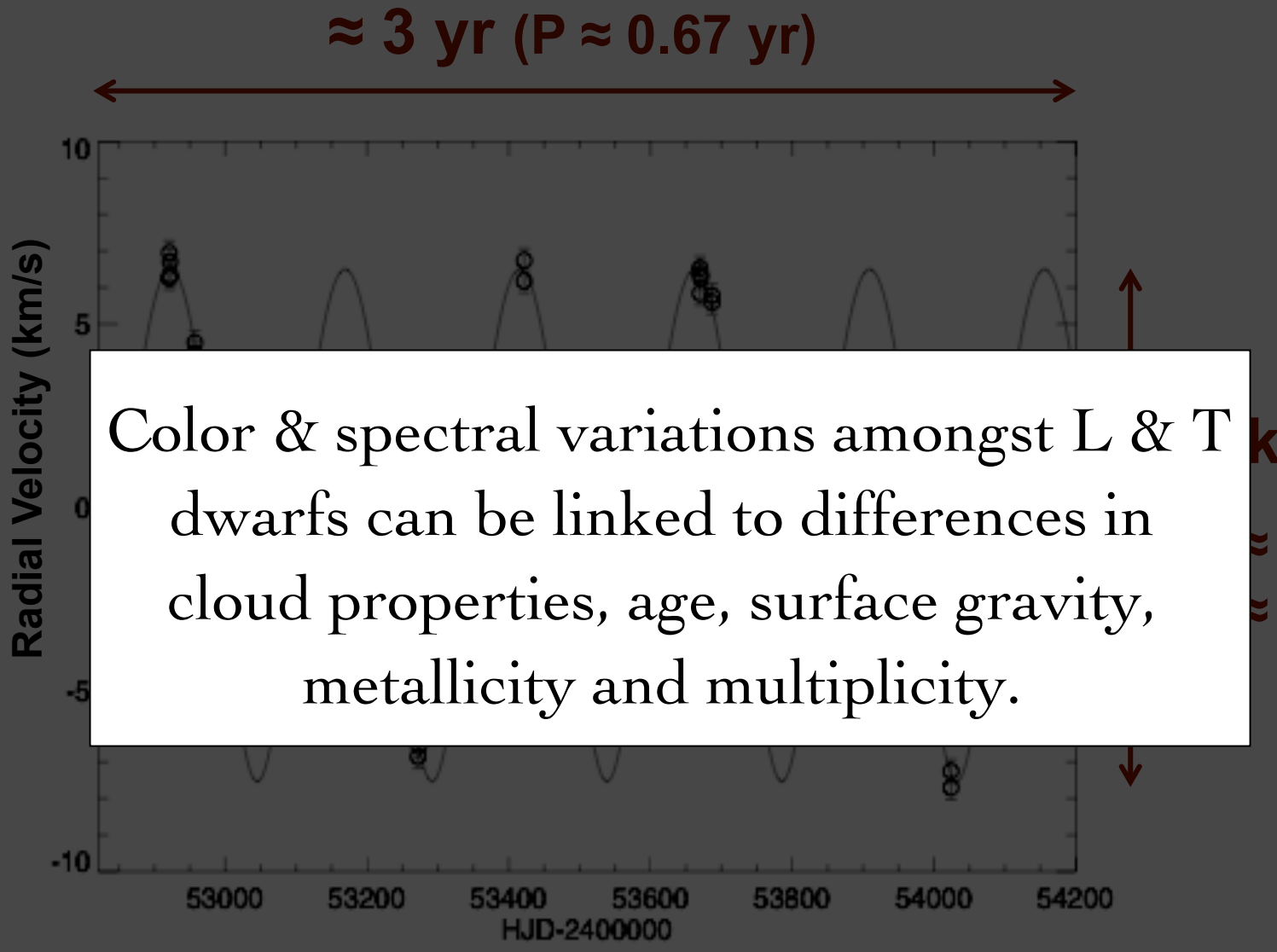
Single spectrum fit



Binary spectrum fit



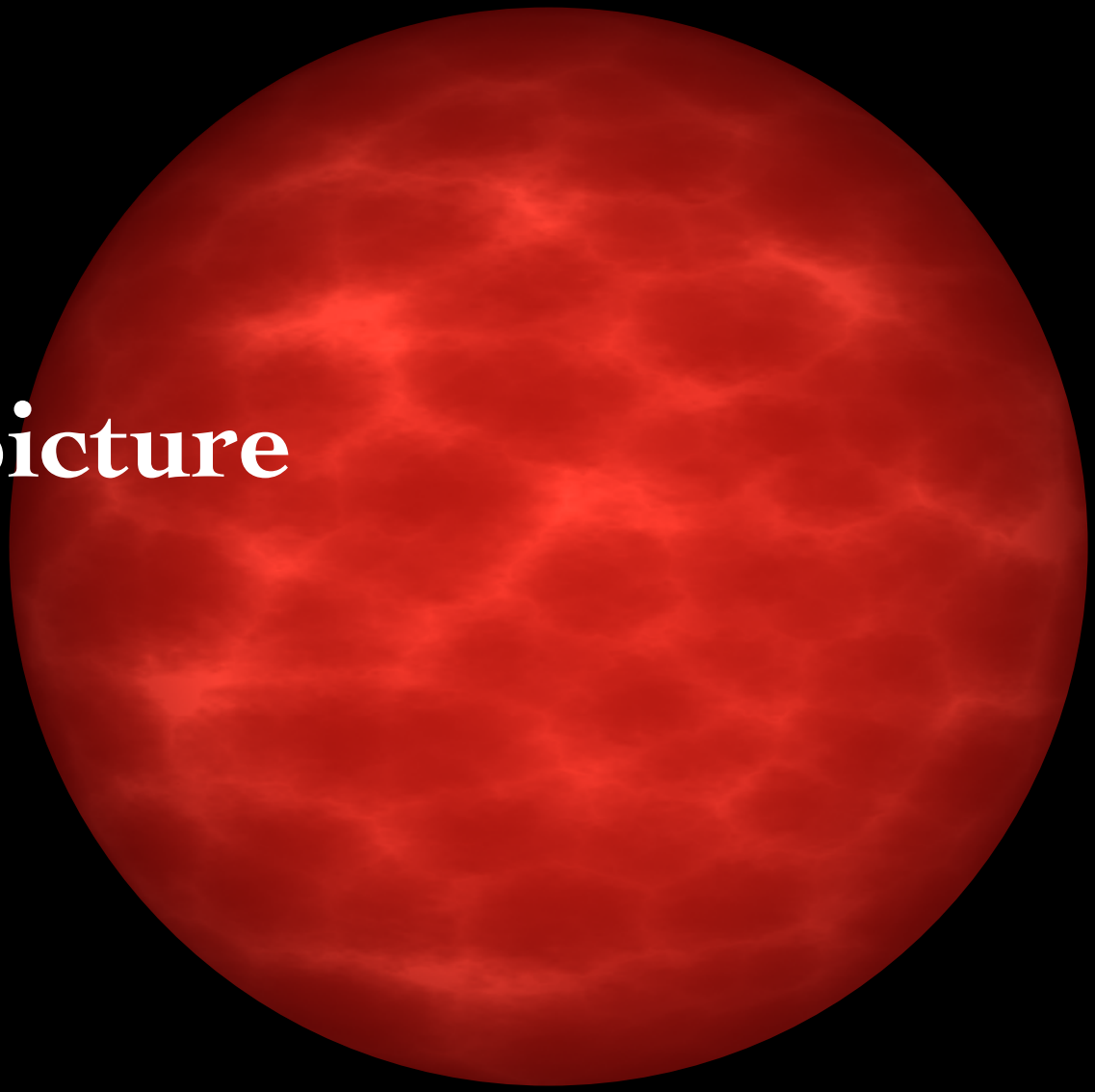
Blake et al. (2008): 2MASS 0320-0446 is a **spectroscopic binary**



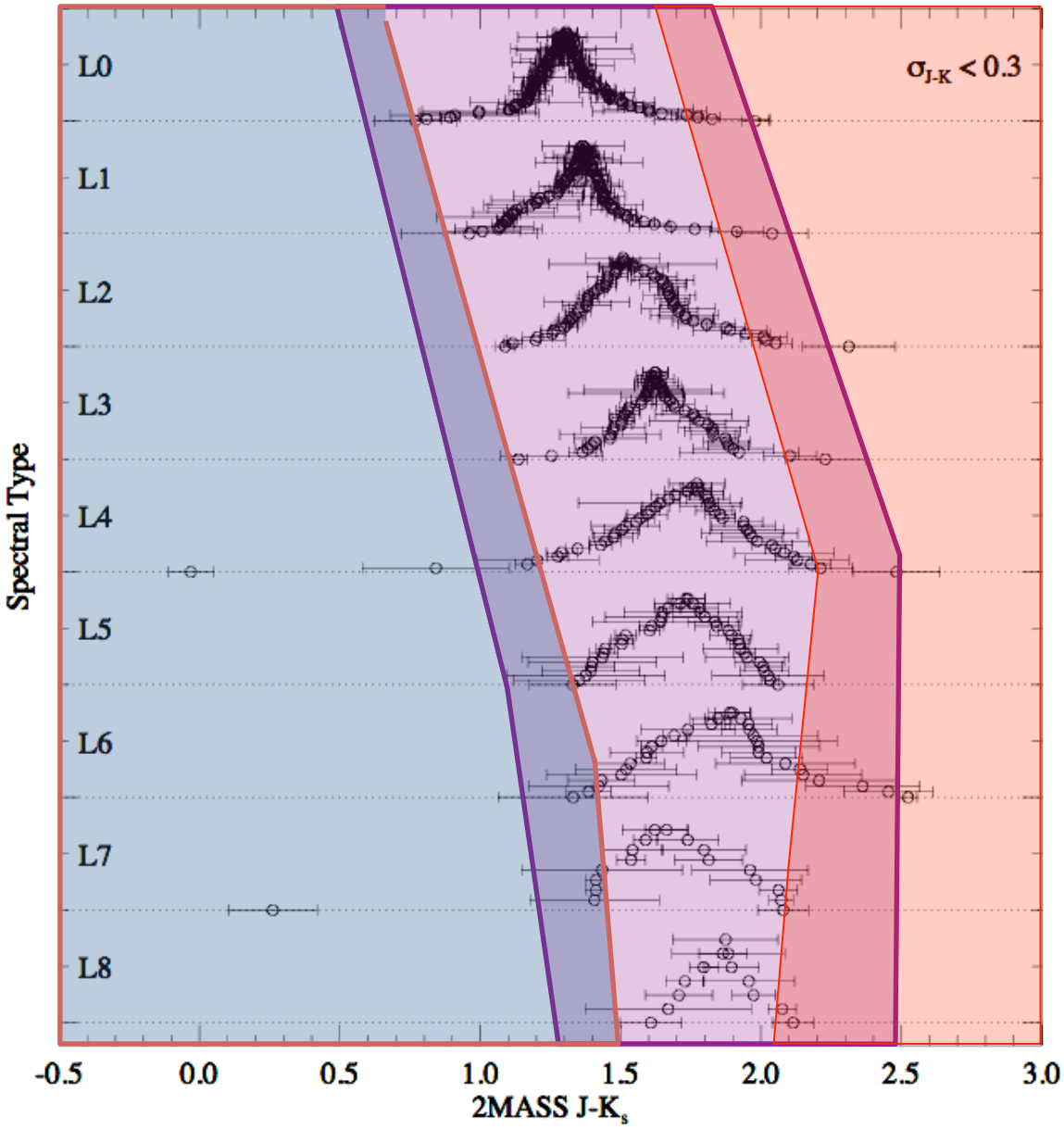
Color & spectral variations amongst L & T dwarfs can be linked to differences in cloud properties, age, surface gravity, metallicity and multiplicity.

Blake et al. (2008): 2MASS 0320-0446 is a **spectroscopic binary**

the big picture



clouds, gravity, age,
metallicity, multiplicity



youth, local
moving
groups

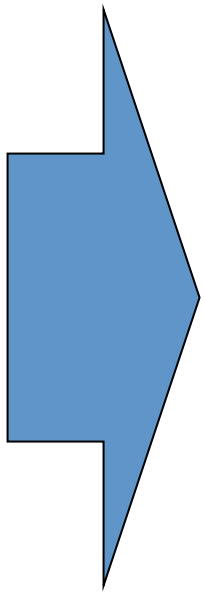
subsolar
metallicity,
halo pop.

a vision for the future…

Precise physical characterization of individual brown dwarfs will allow these objects to be used as **Galactic standard candles.**

Why?

- Large population
- Present in nearly all environments
- Readily distinguished
- Detectable at "large" distances



Distance standards

Temporal standards

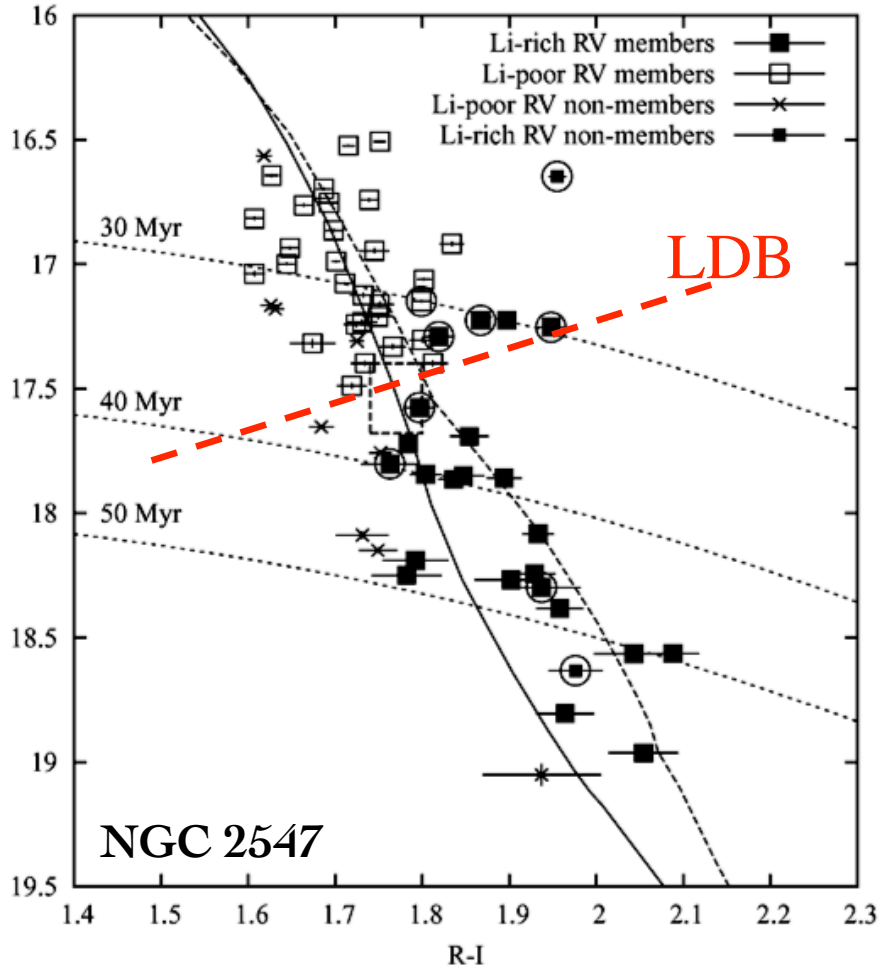
Mass standards

Composition standards

a vision for the future…

Several clusters are already age-dated by their brown dwarf population via the **lithium depletion boundary** technique

(e.g., Bildsten et al. 1997)

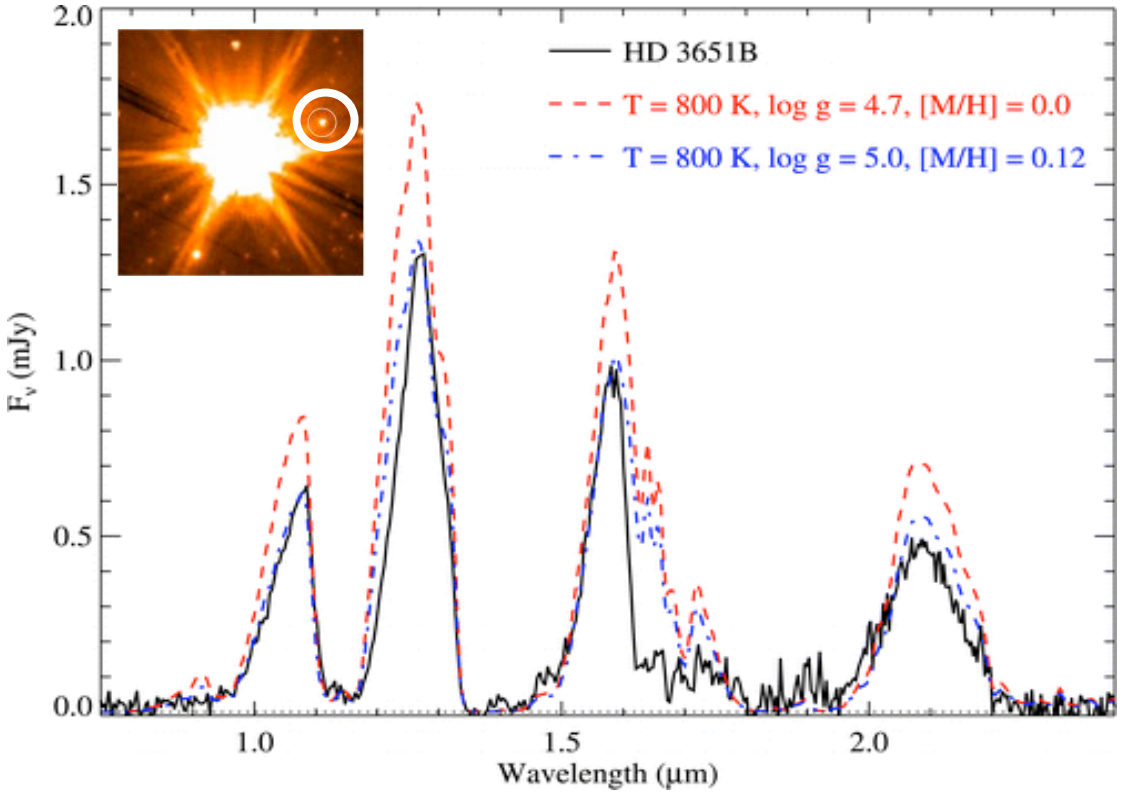


Jeffries & Oliviera (2005)

see also Barrado y Navascués et al. (1999); Stauffer et al. (1999); Oliveira et al. (2003)

a vision for the future…

Some stars & planetary systems can be more robustly characterized by their distant brown dwarf companion.

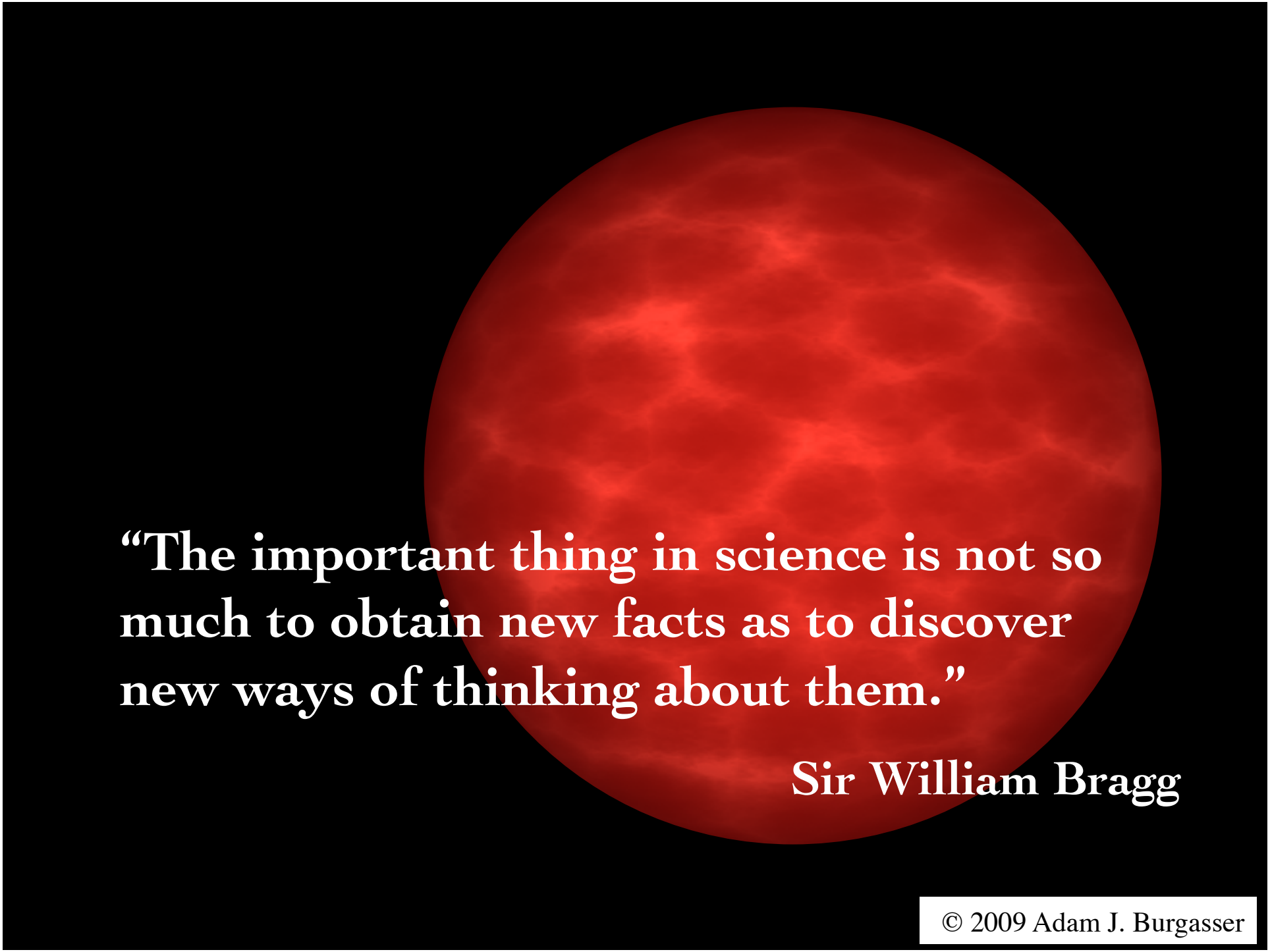


Burgasser (2007)
see also Luhman et al. (2006); Mugrauer et al. (2006); Liu et al. (2007); Leggett et al. (2008)

HD 3651ABb

K0+**T8**+planet

[M/H]=0.12, age = 0.7-4.7 Gyr



Thank you!