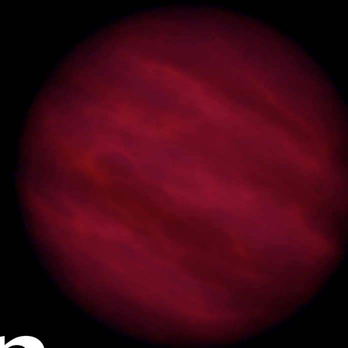
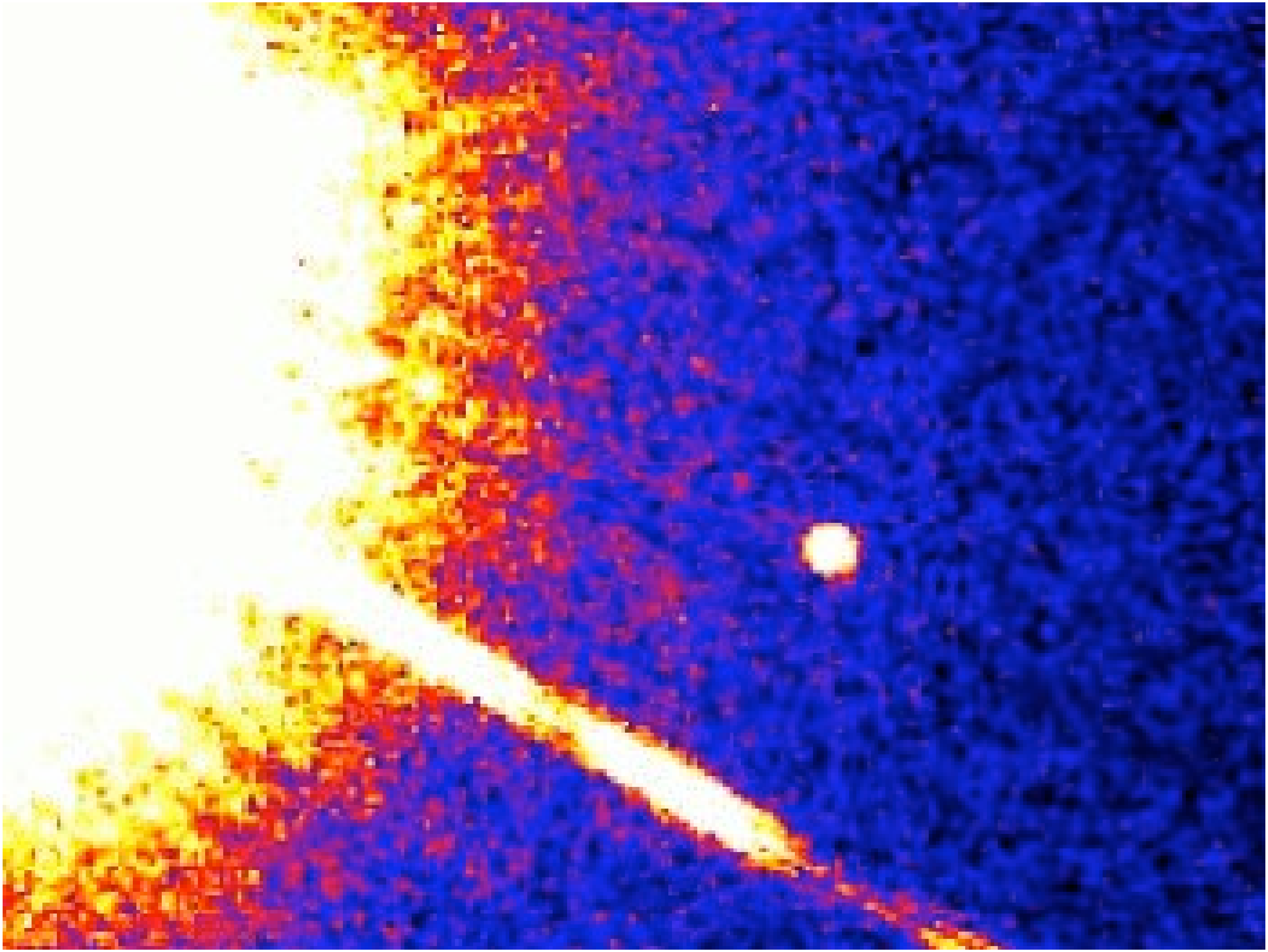
The Brown Dwarf - Exoplanet Connection

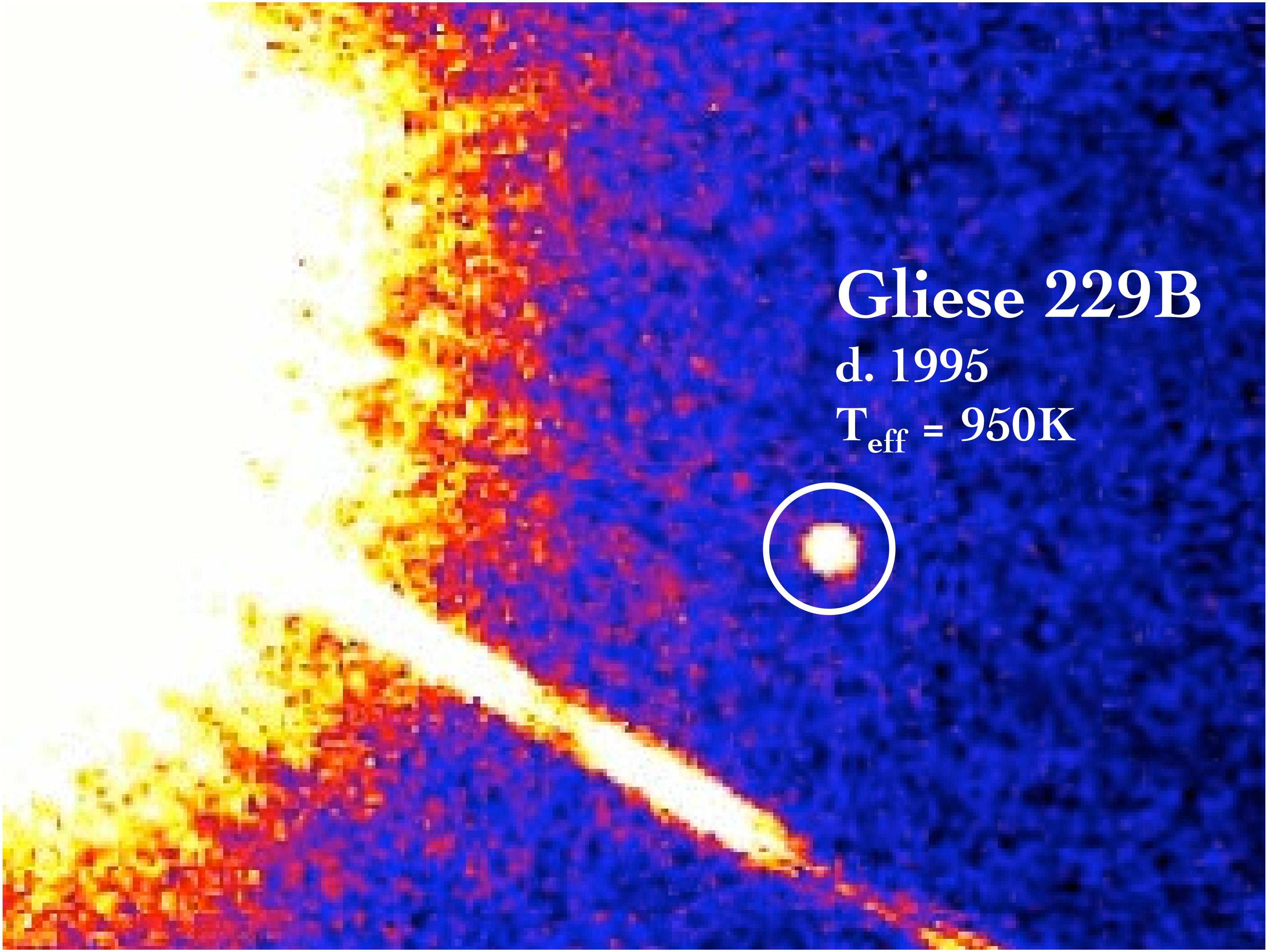


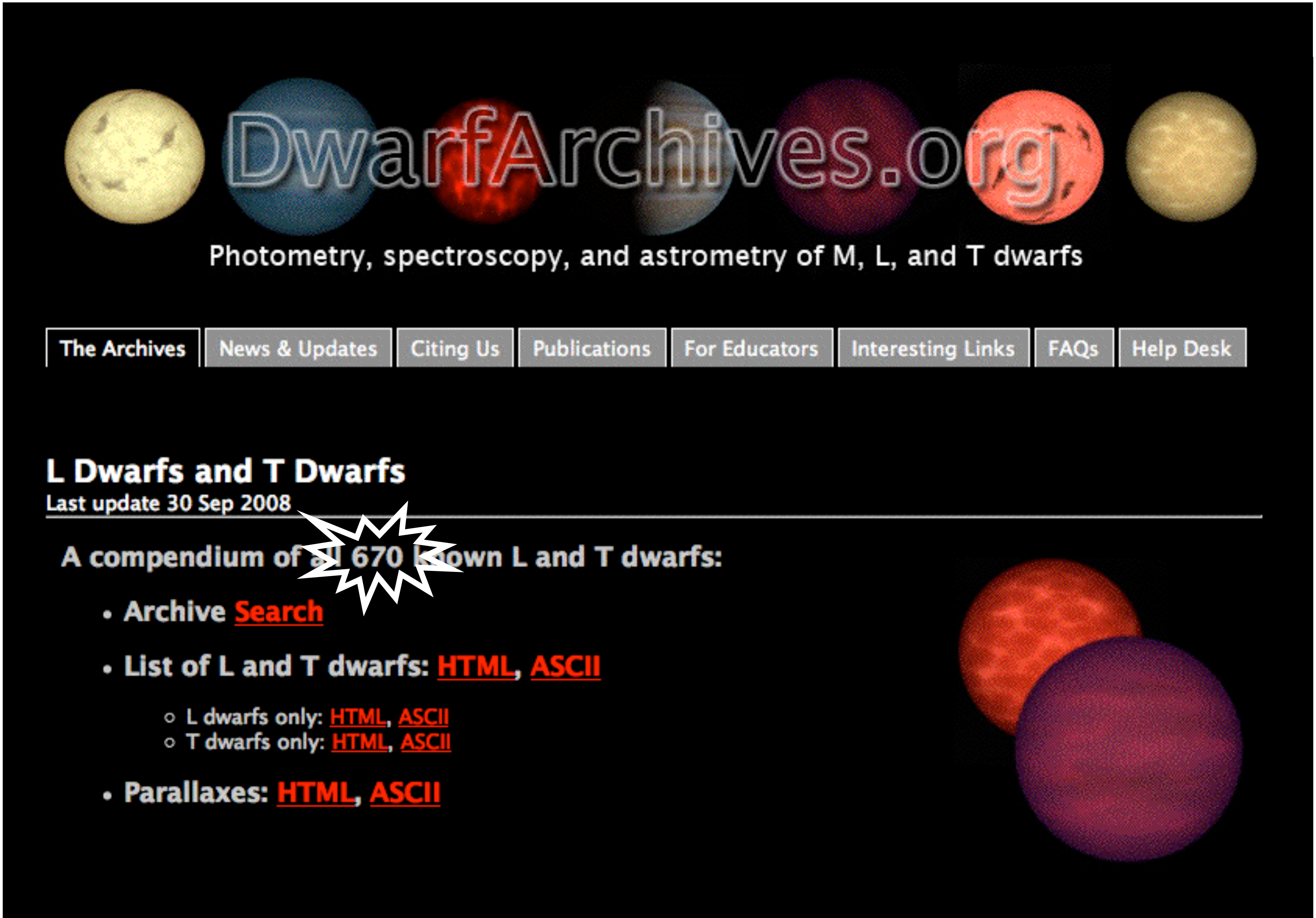
Molecules in Brown Dwarf Atmospheres

Adam J. Burgasser

$1/\sqrt{2}\,(|\mathrm{MIT}\rangle + |\mathrm{UCSD}\rangle)$

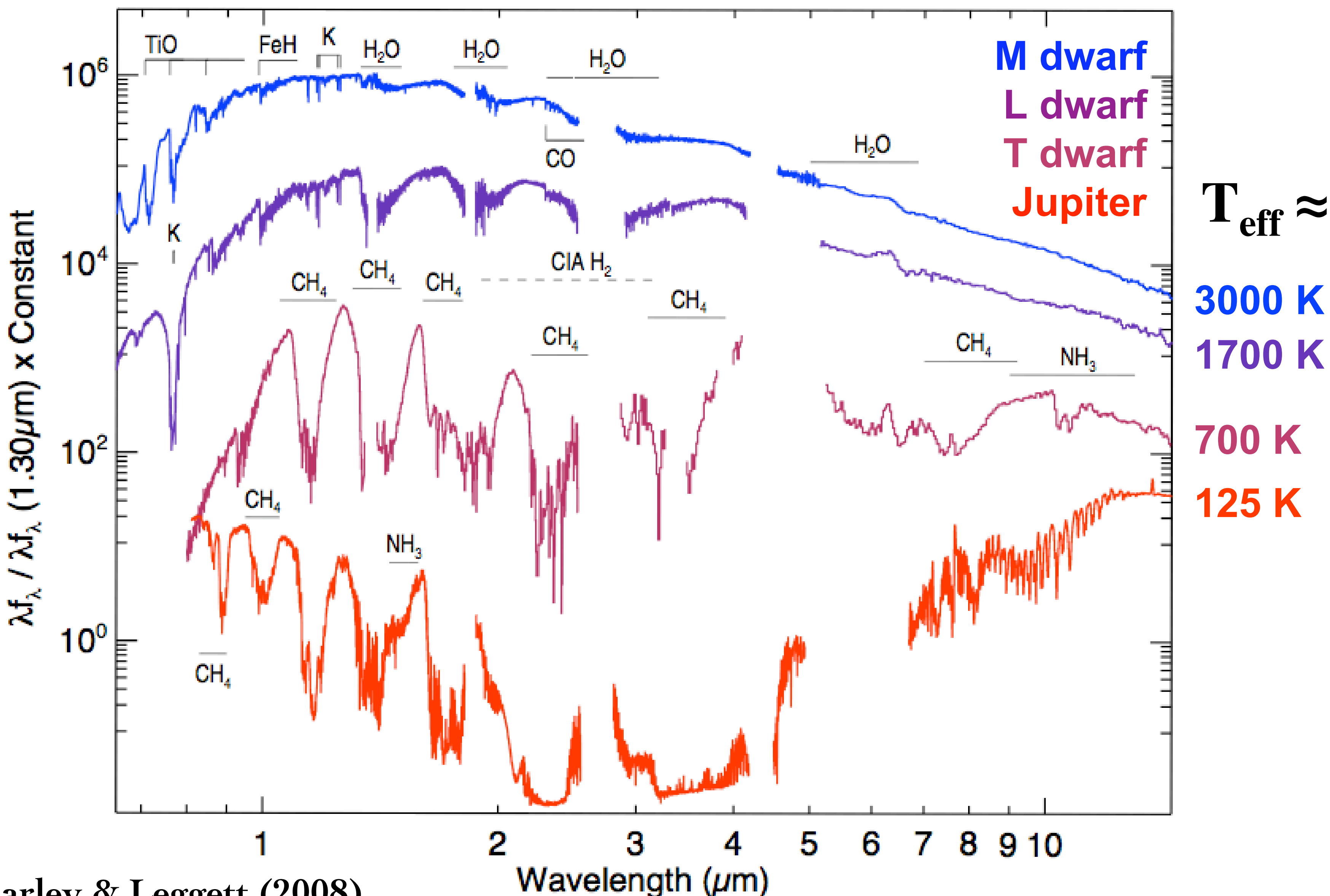



Gliese 229B
d. 1995
T_{eff} = 950K



dwarfarchives.org *maintained by Chris Gelino, Davy Kirkpatrick & Adam Burgasser*

Brown dwarf "uber-spectra"



Marley & Leggett (2008)
data from Cushing et al. (2005,2007)

Similarities

- Compact radii ($R_{BD} \sim R_{jup}$ for t > 100 Myr)
- Cool atmospheres ($T_{eff} \sim$ 3000 - 575 K)
- *Similar* (but not identical) surface gravities
  - EP: log g = 2.8-4.3
  - BD: log g = 3.5 (1 Myr) - 5.5 (1 Gyr)

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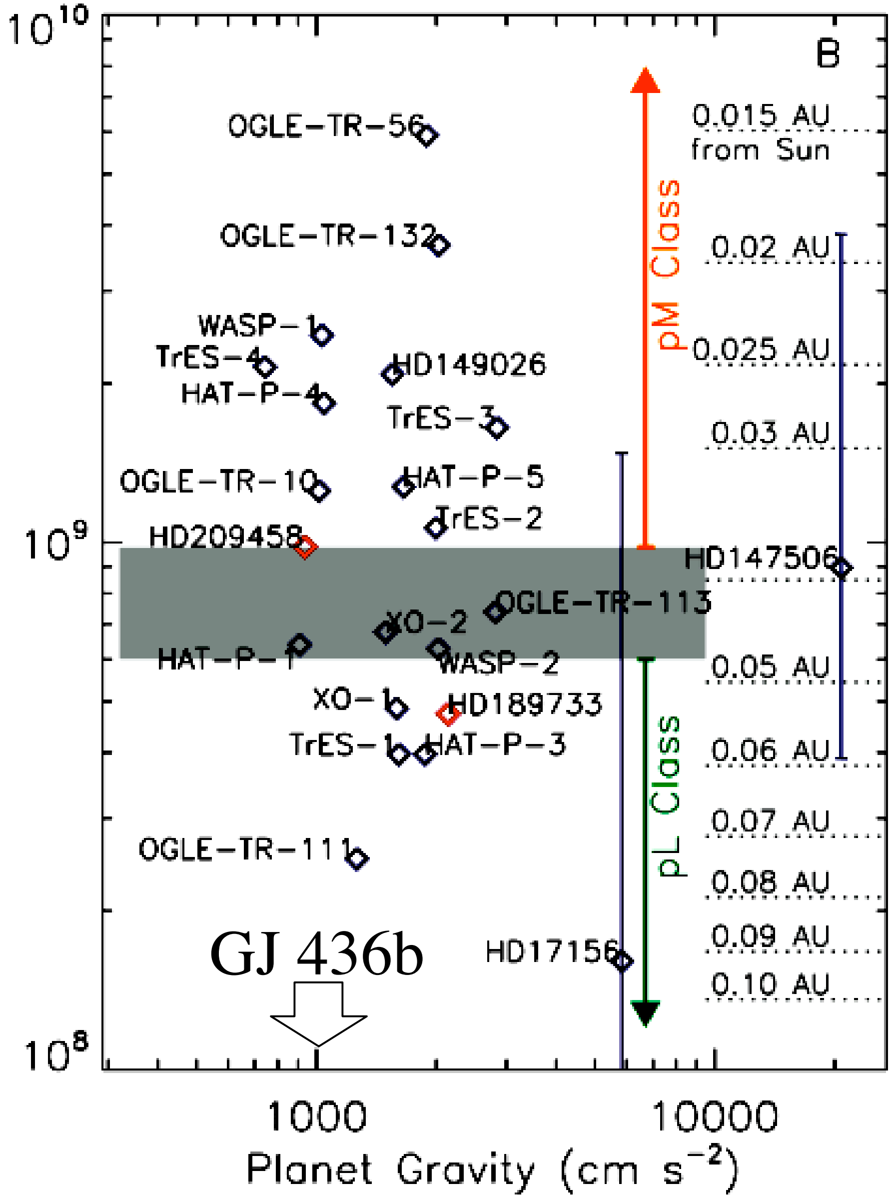
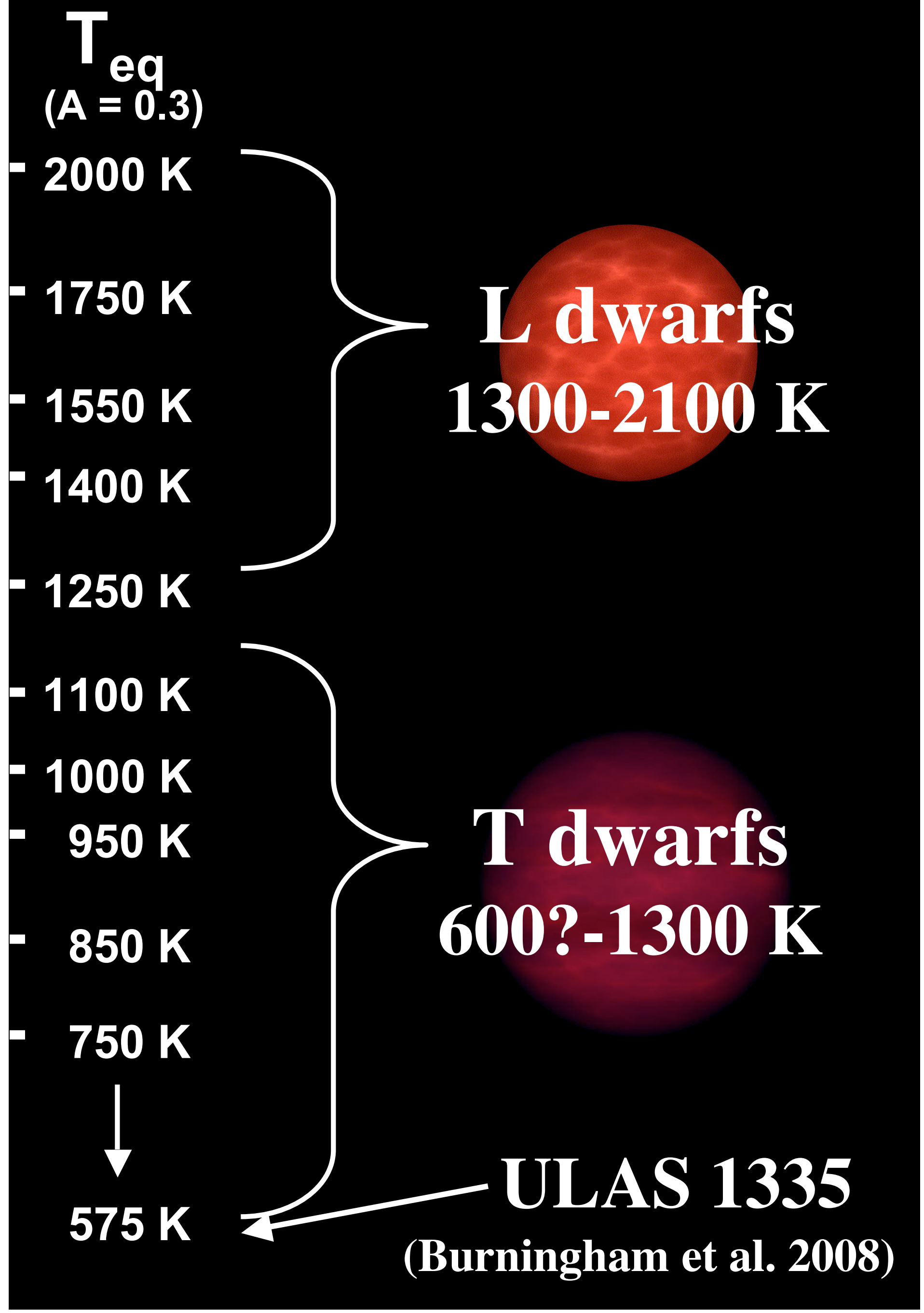
Hot Exoplanets



Fortney et al. (2008)

Cool Brown Dwarfs



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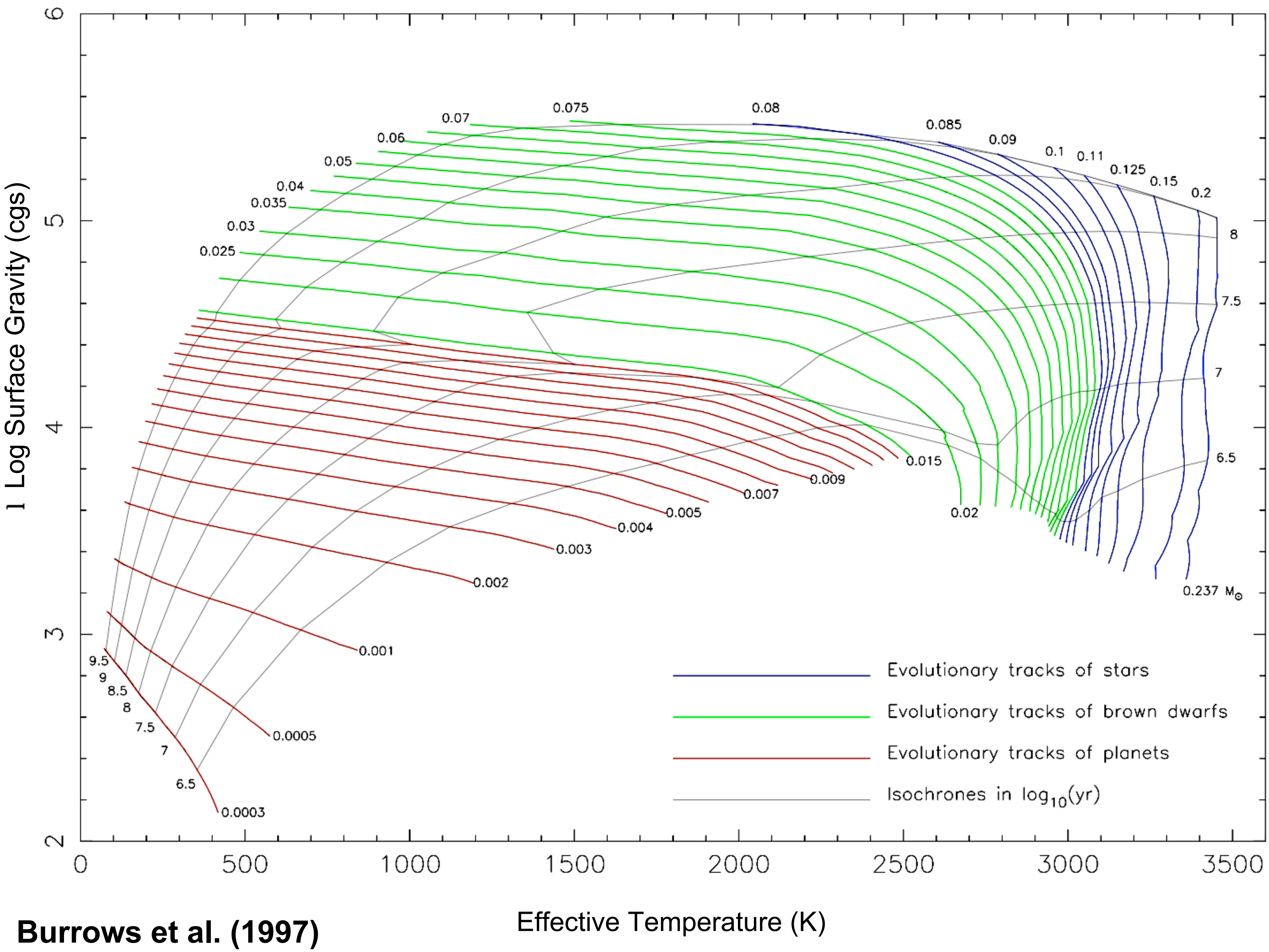
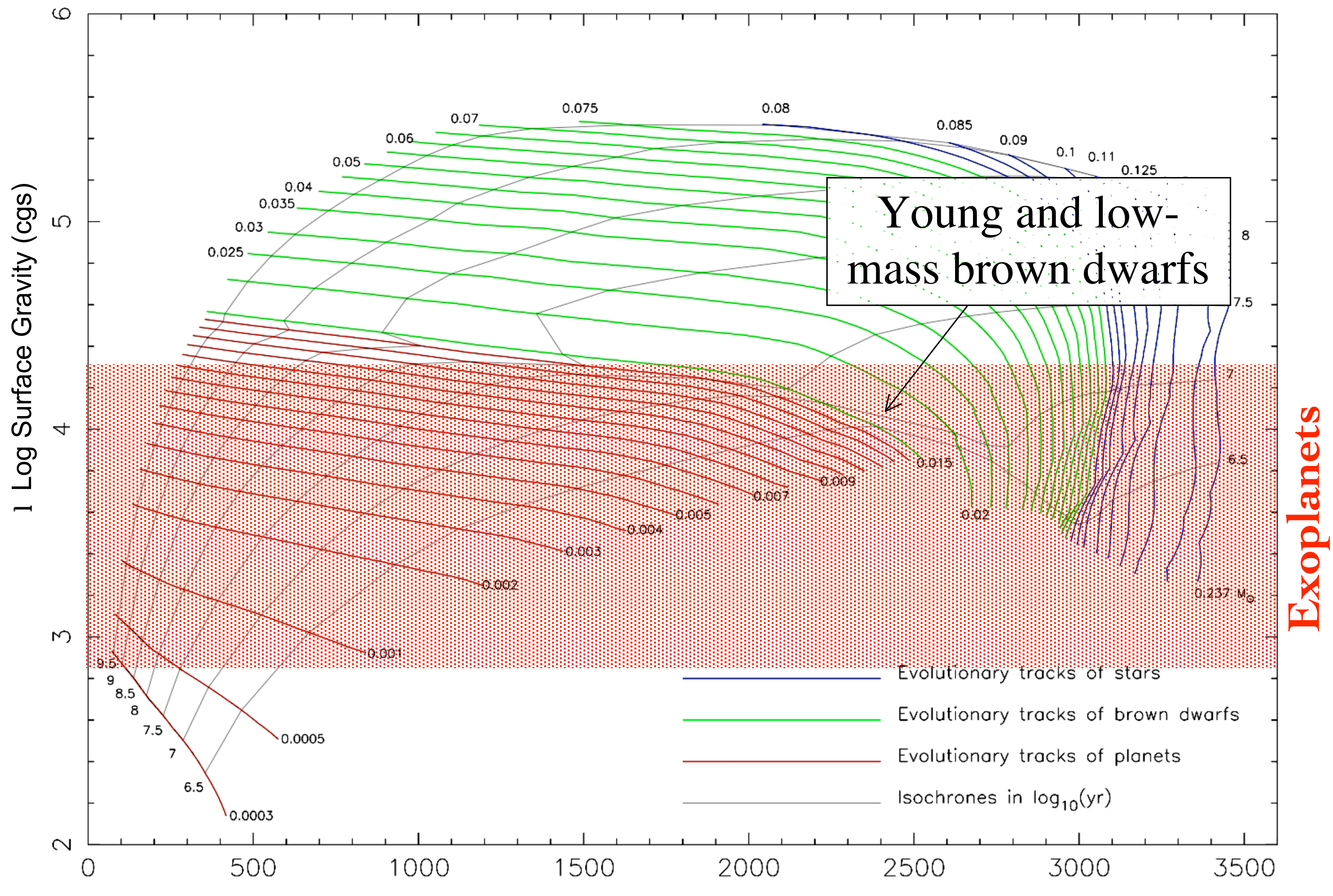
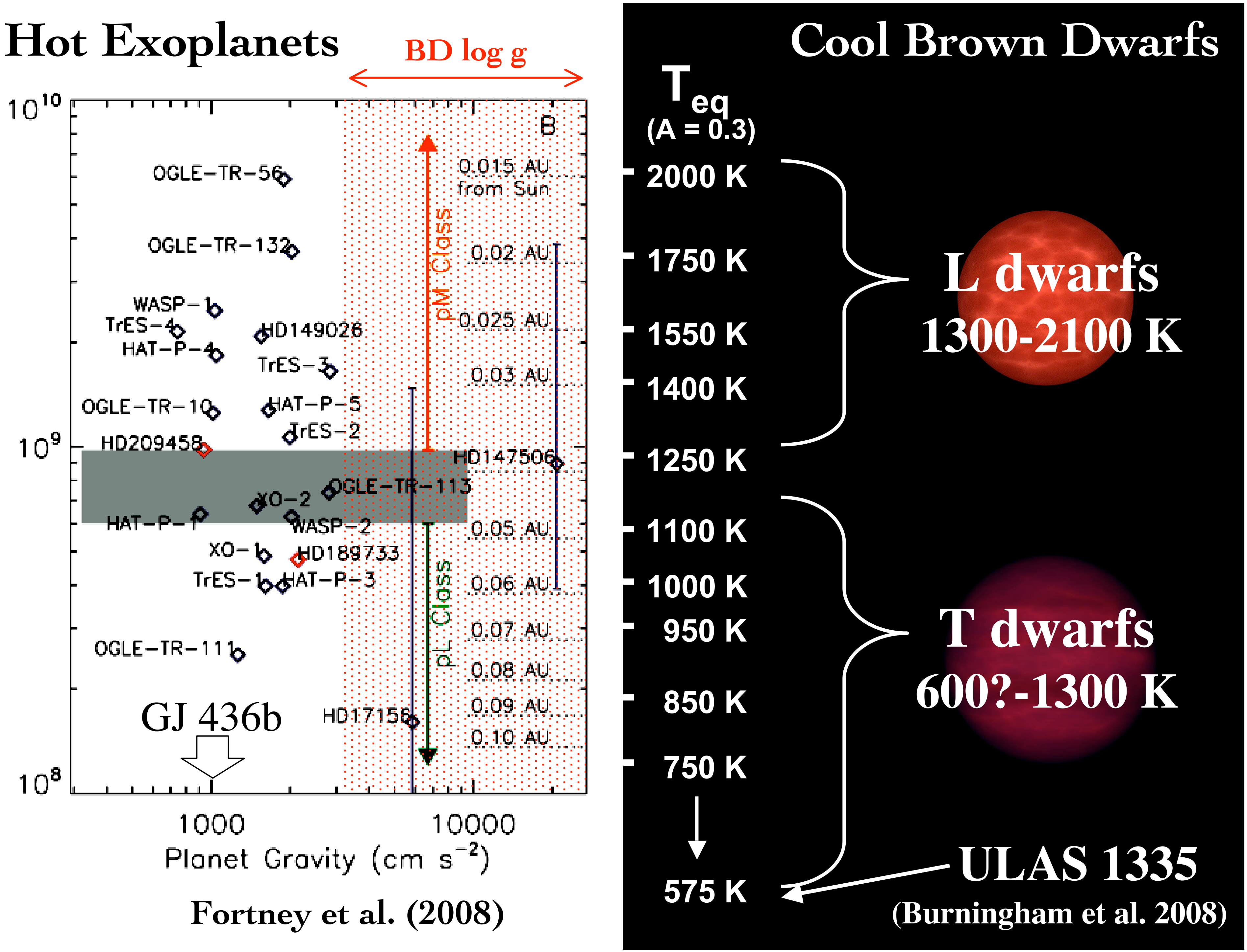


Burrows et al. (1997)



Burrows et al. (1997)



Hot Exoplanets
BD log g
B
0.015 AU
from Sun
0.02 AU
0.025 AU
0.03 AU
0.05 AU
0.06 AU
0.07 AU
0.08 AU
0.09 AU
0.10 AU
pM Class
pL Class
OGLE−TR−56
OGLE−TR−132
WASP−1
TrES−4
HAT−P−4
HD149026
TrES−3
OGLE−TR−10
HAT−P−5
TrES−2
HD209458
HD147506
OGLE−TR−113
XO−2
HAT−P−1
WASP−2
XO−1
HD189733
TrES−1
HAT−P−3
OGLE−TR−111
HD17156
GJ 436b
1000
10000
Planet Gravity (cm s−2)
Fortney et al. (2008)
Cool Brown Dwarfs
Teq
(A = 0.3)
2000 K
1750 K
1550 K
1400 K
1250 K
1100 K
1000 K
950 K
850 K
750 K
575 K
L dwarfs
1300-2100 K
T dwarfs
600?-1300 K
ULAS 1335
(Burningham et al. 2008)

Differences

- Metallicities: [M/H] ~ –2…+0.75 (BDs) vs. [M/H] ~ 0.5…1.6 (JSUN)
- No external drivers for brown dwarf atmospheres - winds & inversions?
- No (massive) solid cores in brown dwarfs - super-Neptunes/Earths
- Rotation rates: Jup: 11 hr, BD: ~4 hr: influences magnetic activity, surface winds

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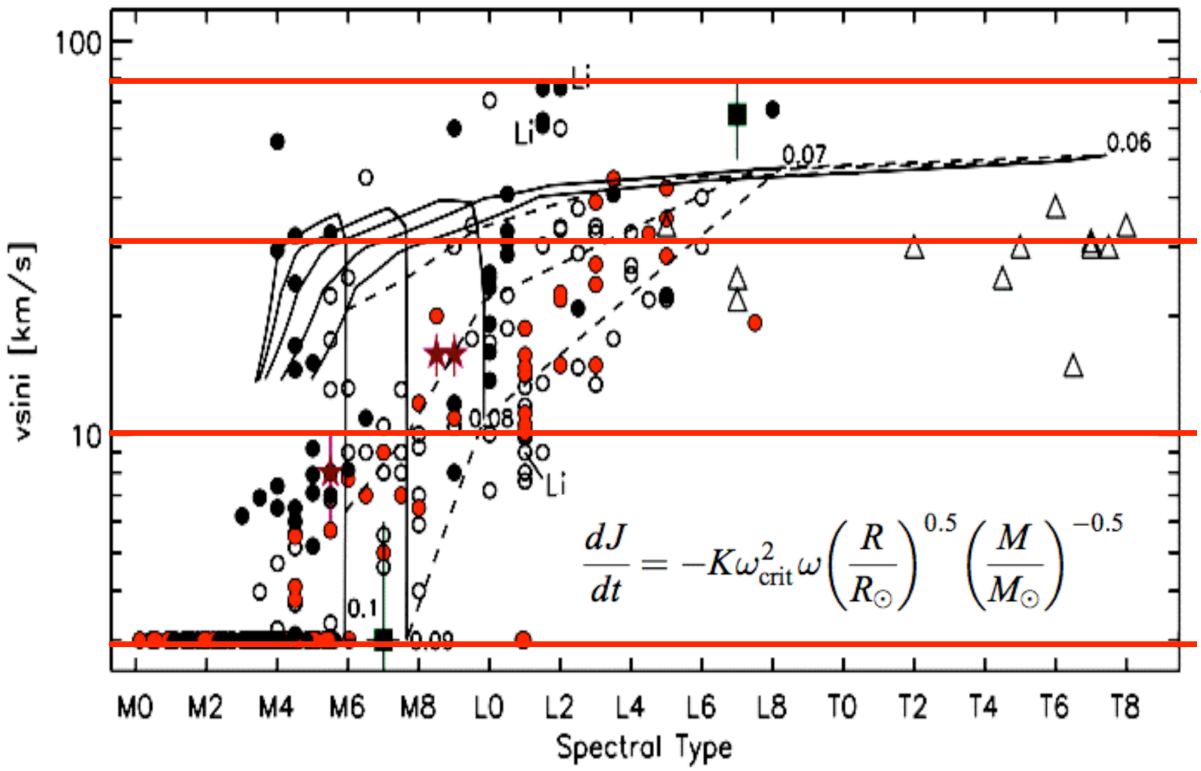
Brown Dwarfs are Dizzy



80 km/s max (P<1.5 hr)

30 km/s typical (P<4 hr)

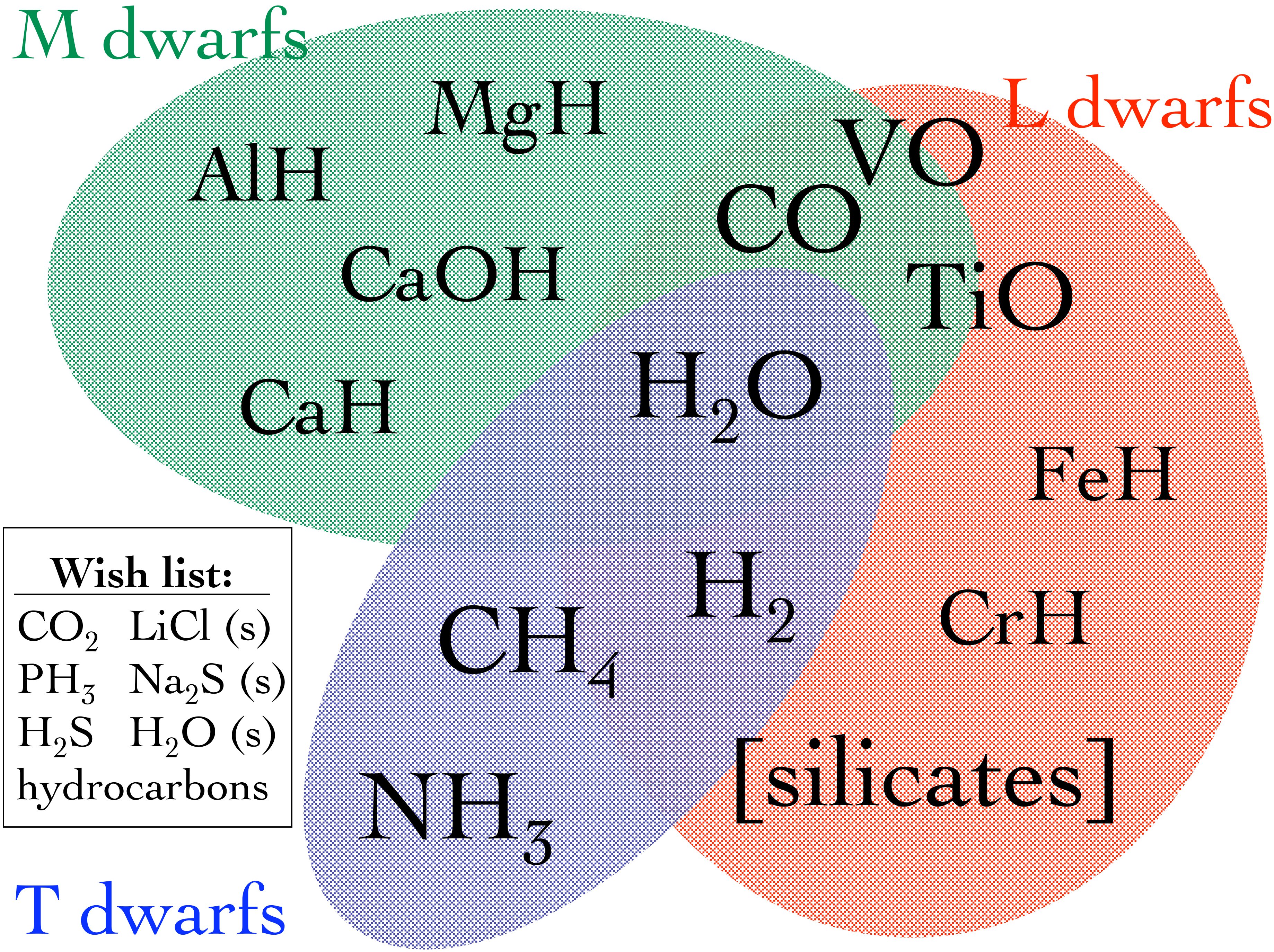
10 km/s “floor” (P<12 hr)
(similar to Jupiter)

3 km/s (P~3d) Hot EPs

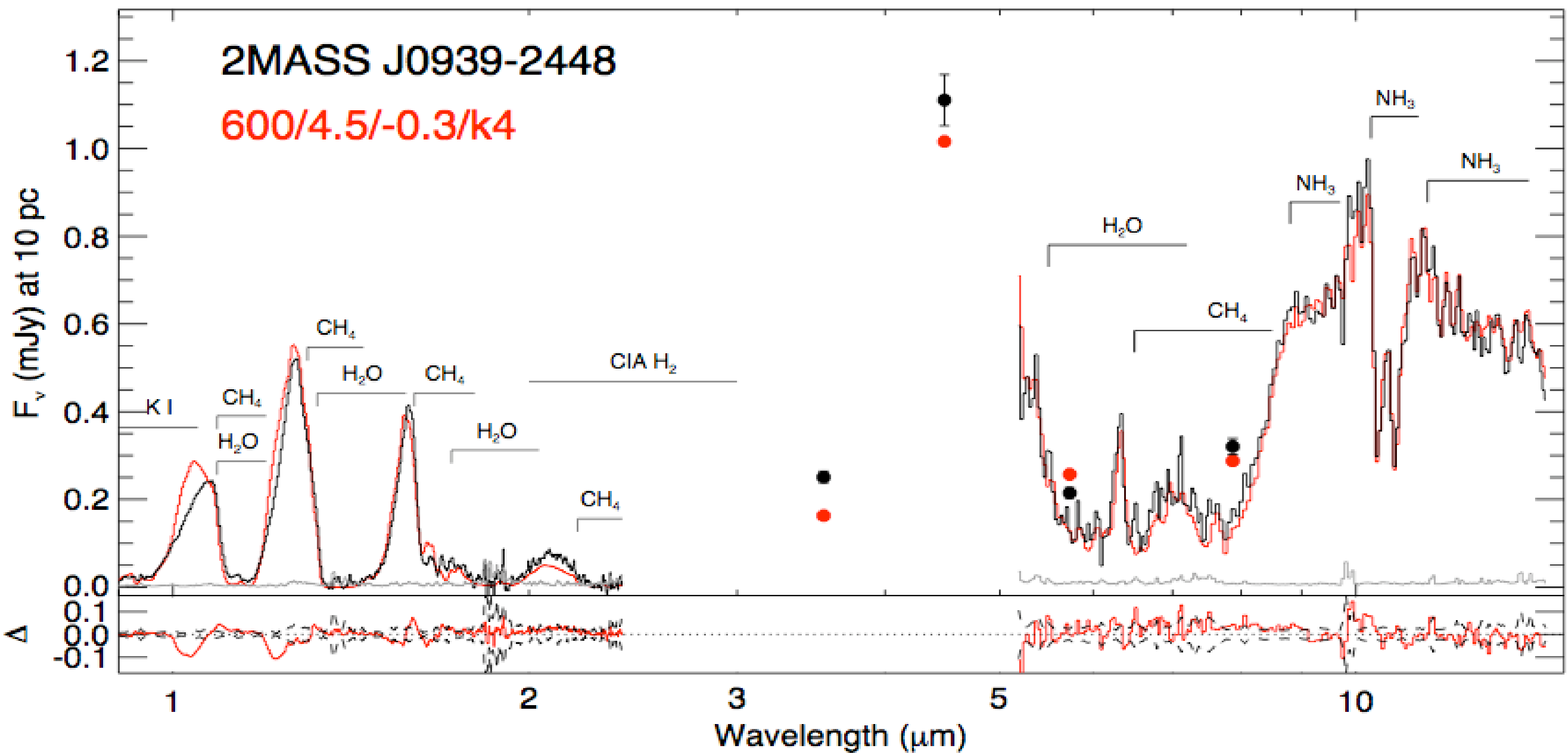
Reiners & Basri (2008)

see also Mohanty et al. (2002), Mohanty & Basri (2003), Bailer-Jones (2004); Reiners & Basri (2006), Blake et al. (2007)

Molecular Gases


M dwarfs
L dwarfs
T dwarfs
MgH
AlH
CaOH
CaH
VO
CO
TiO
H2O
FeH
H2
CrH
CH4
NH3
[silicates]
Wish list:
CO2 LiCl (s)
PH3 Na2S (s)
H2S H2O (s)
hydrocarbons

Clear Molecular Signatures



2MASS 0939-2448

T_{eff} = 600 K, L = 10^{-6} L_{sun} brown dwarf binary

(Burgasser et al. 2008)

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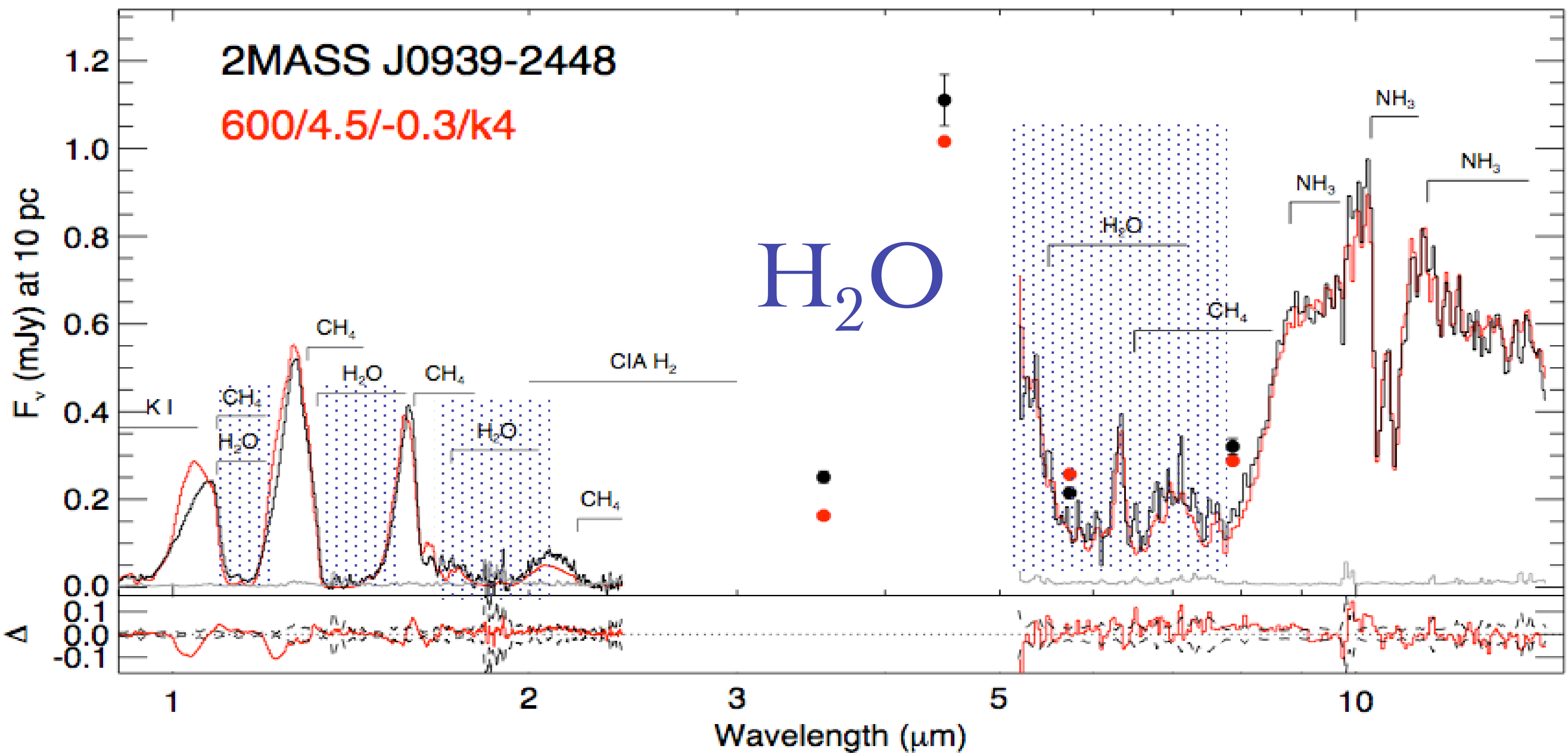

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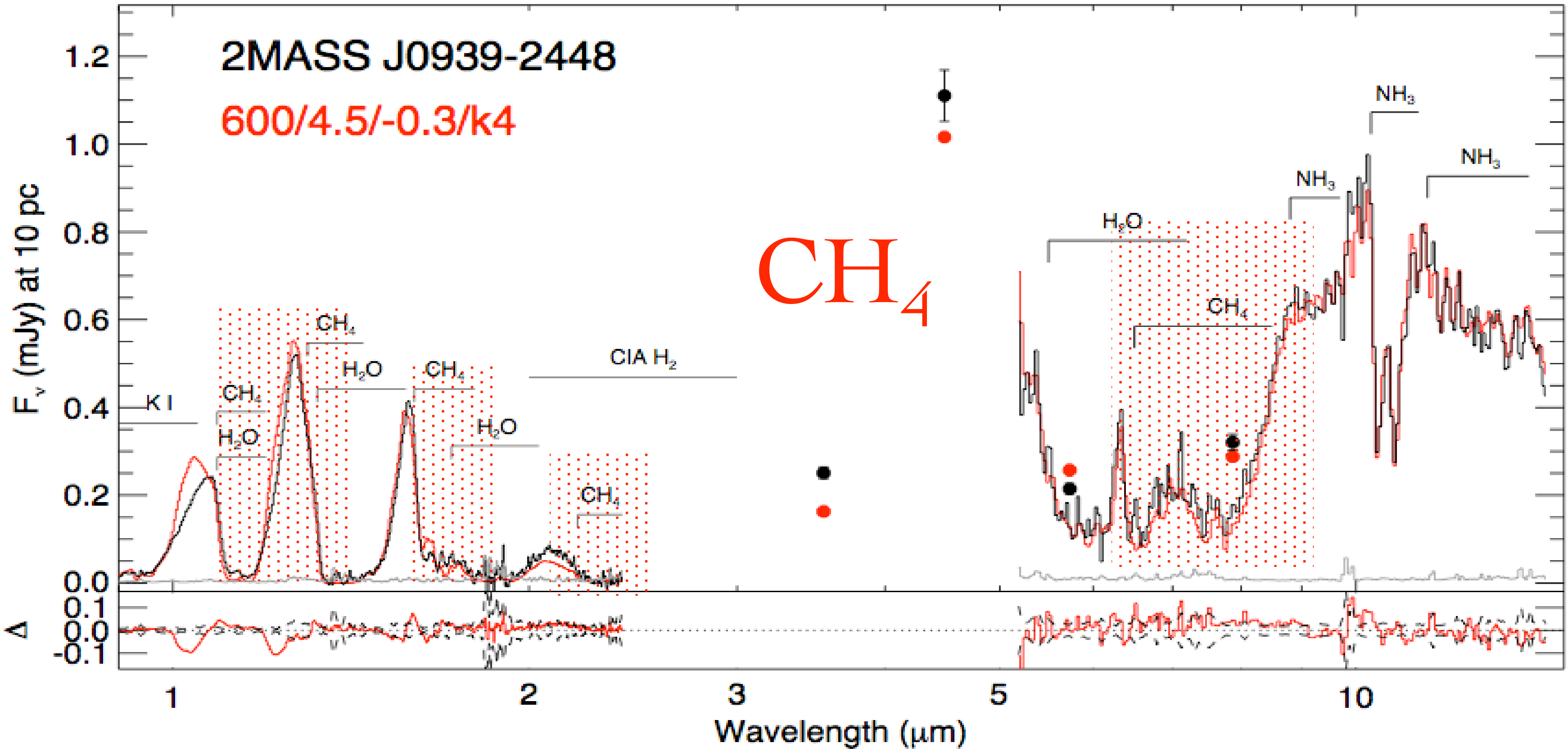

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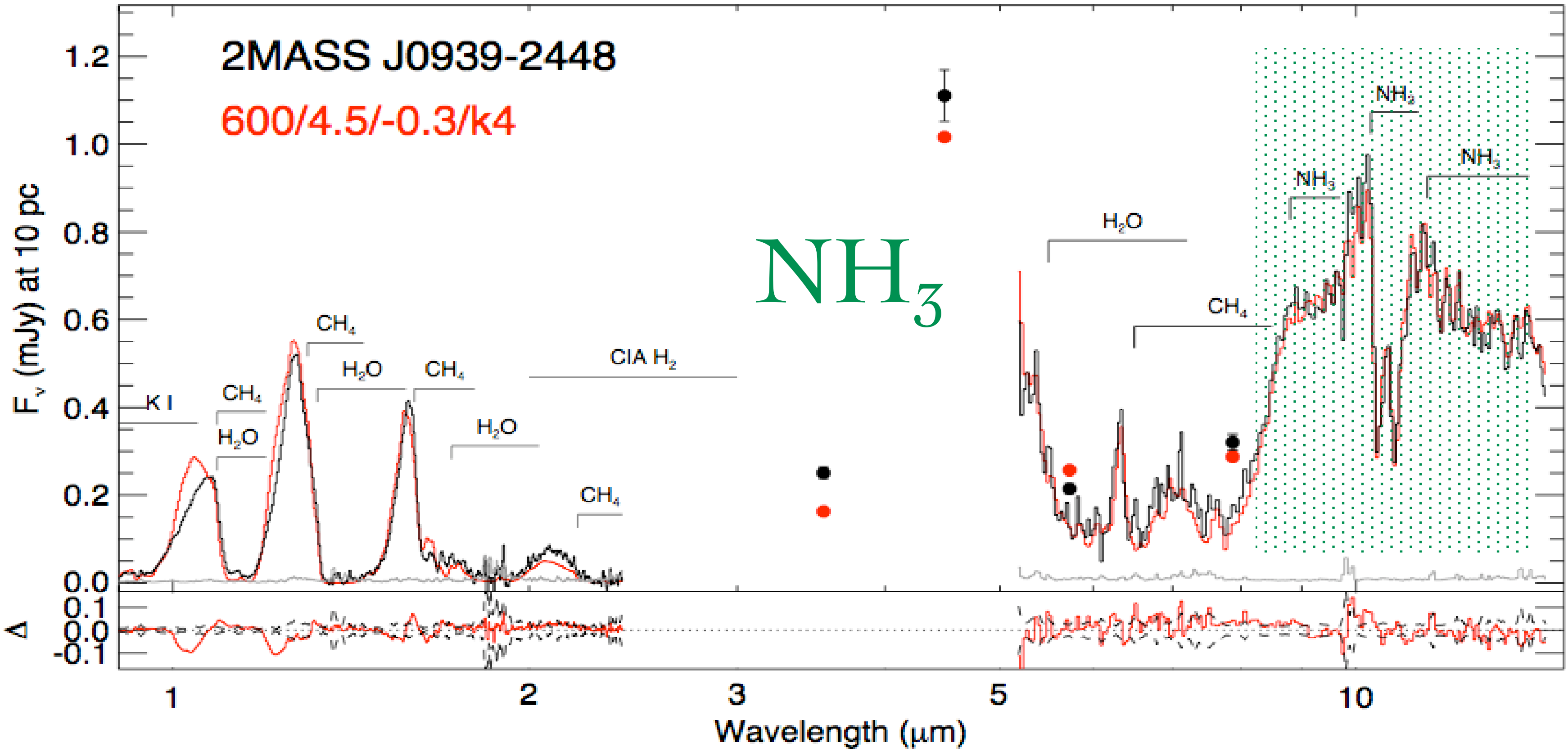

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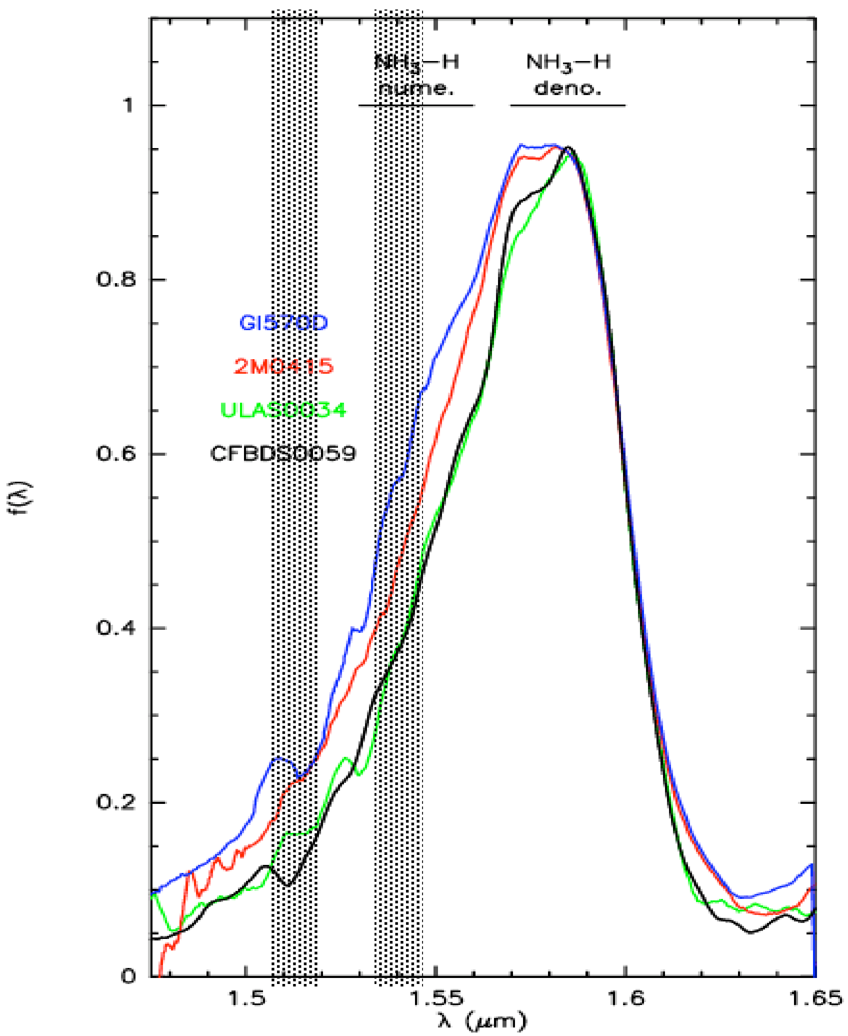
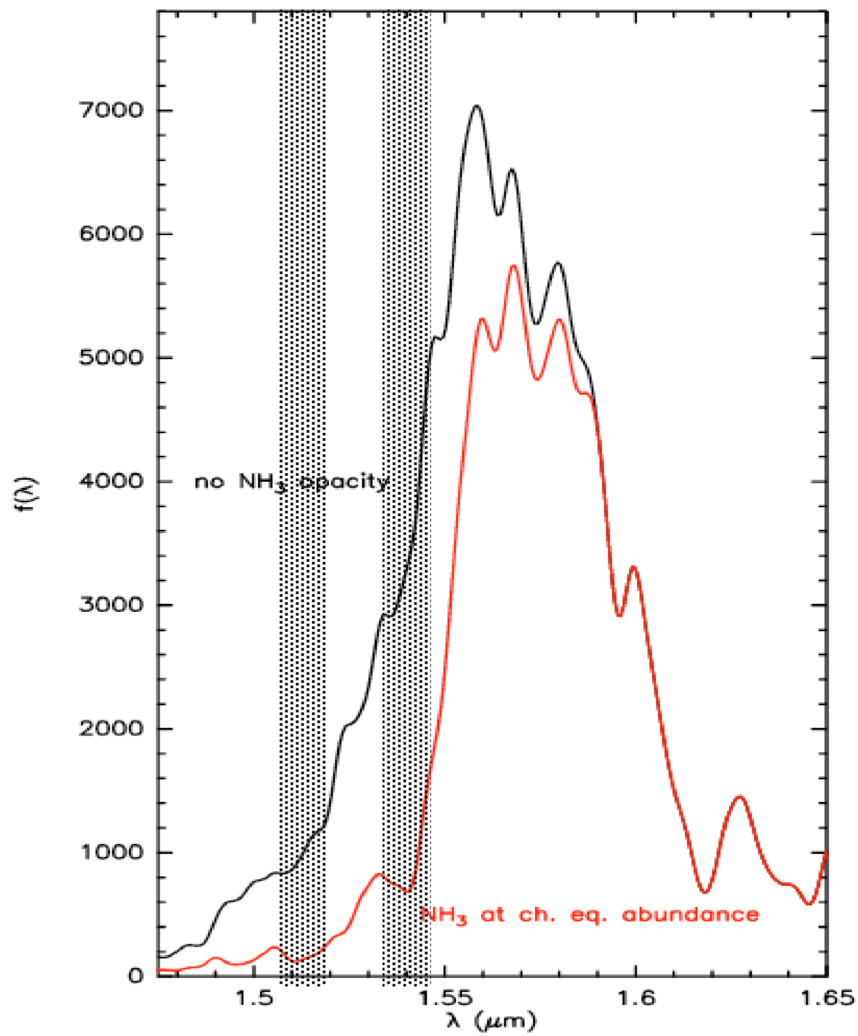
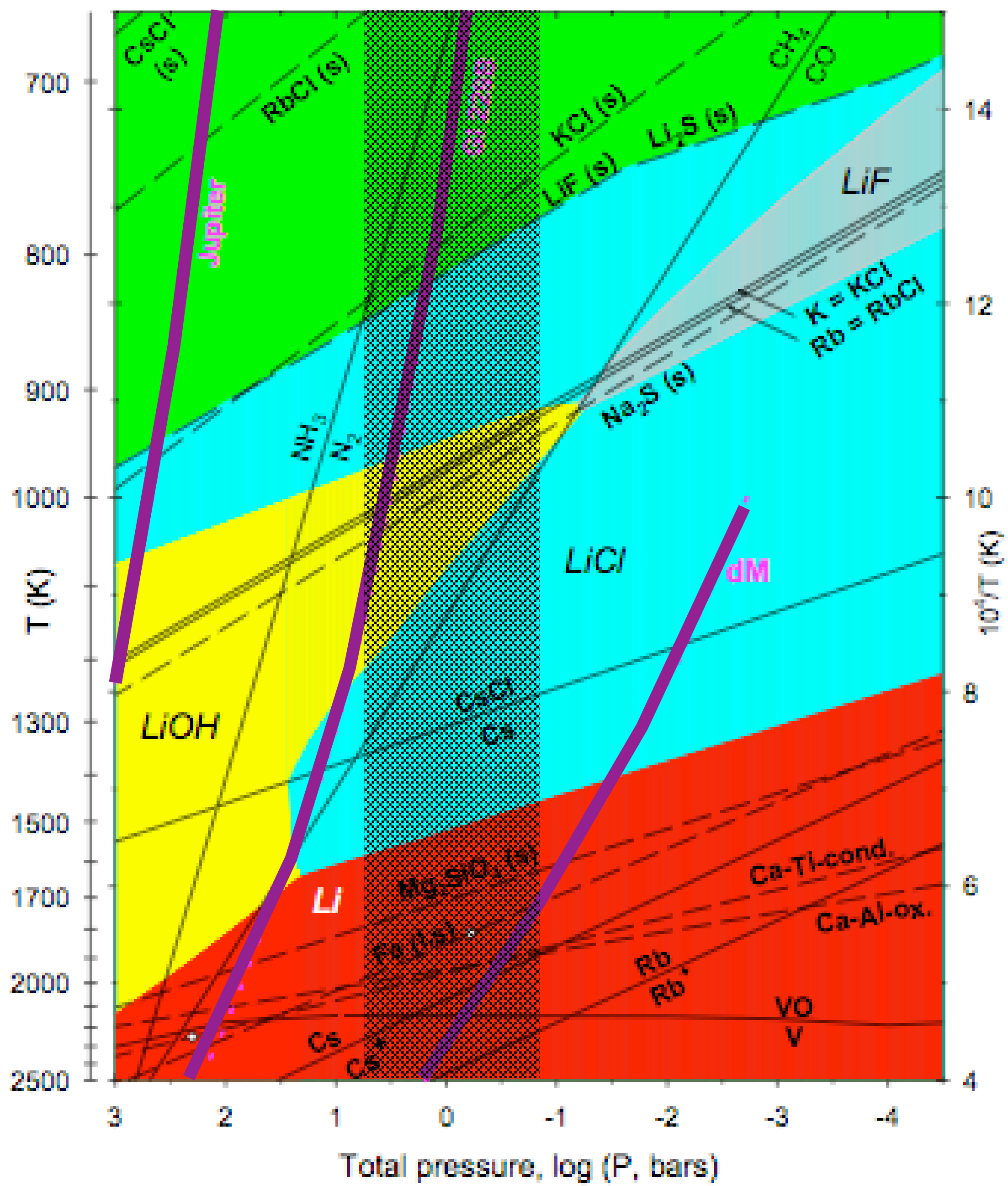
NH_3 in the Near-infrared?





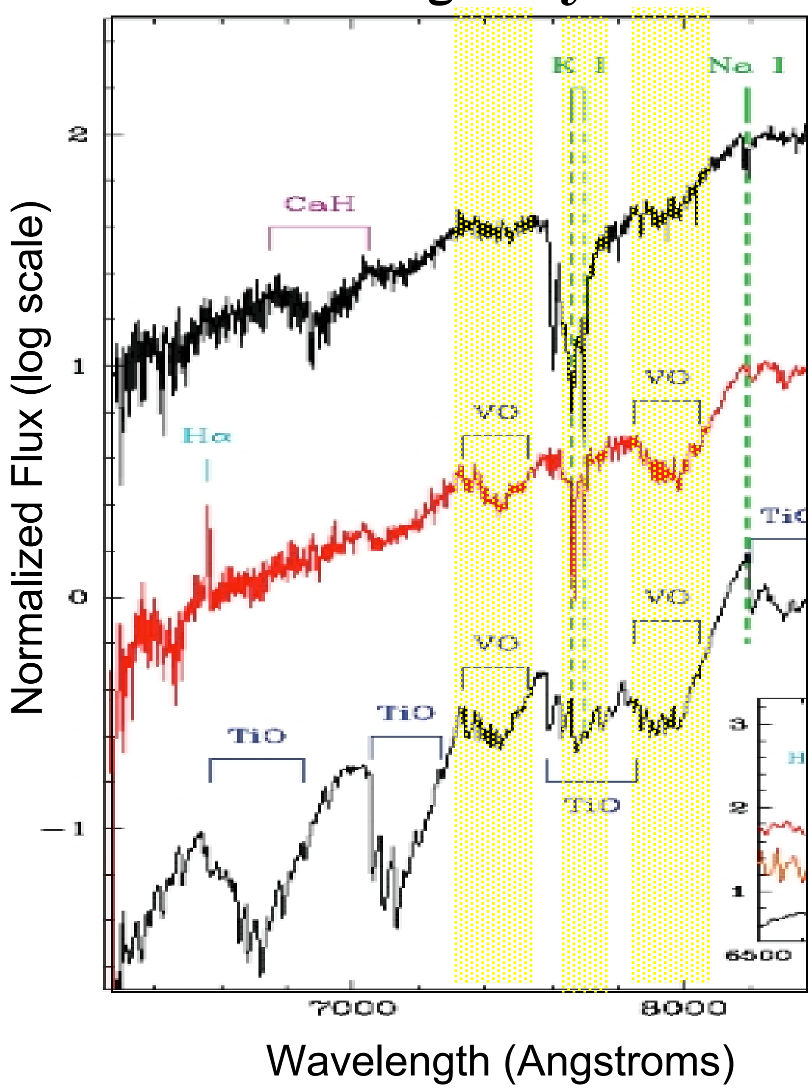
Delorme et al. (2008)

photosphere



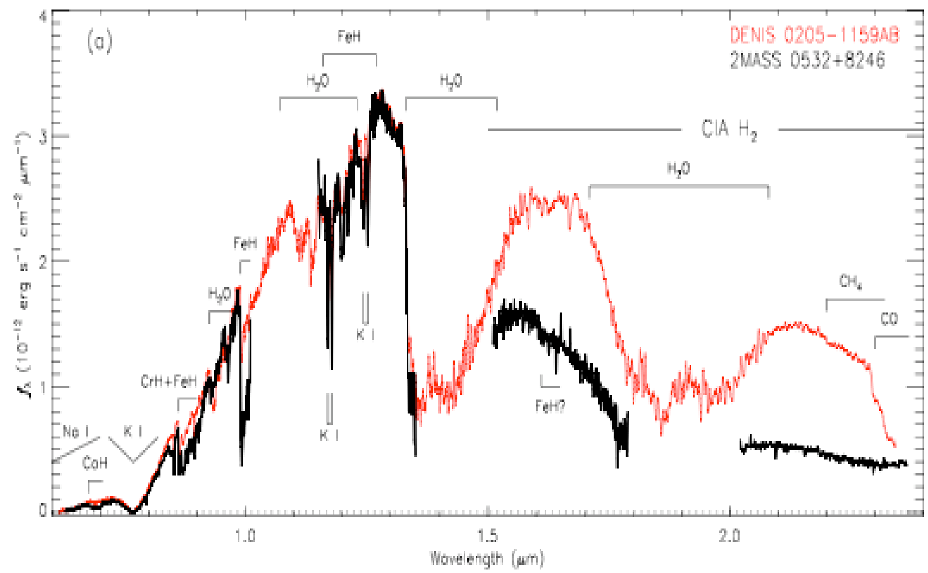
Lodders (1999)

surface gravity features



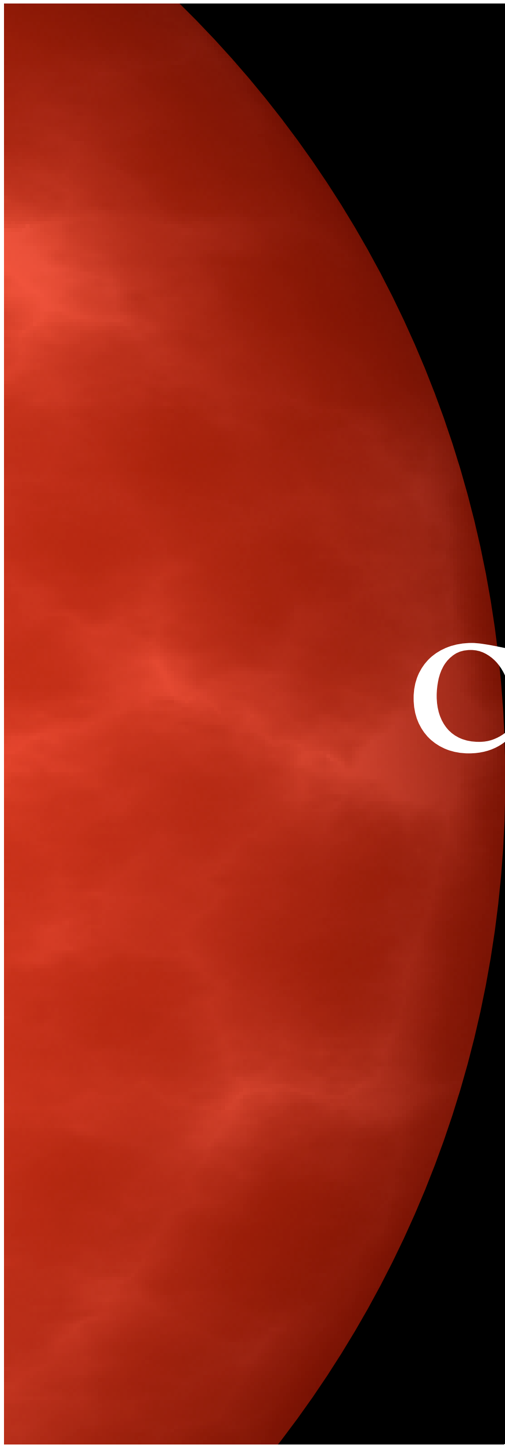
Kirkpatrick et al. (2006)
see also Martin et al. (1999); Cruz et al. (2007)

metallicity features



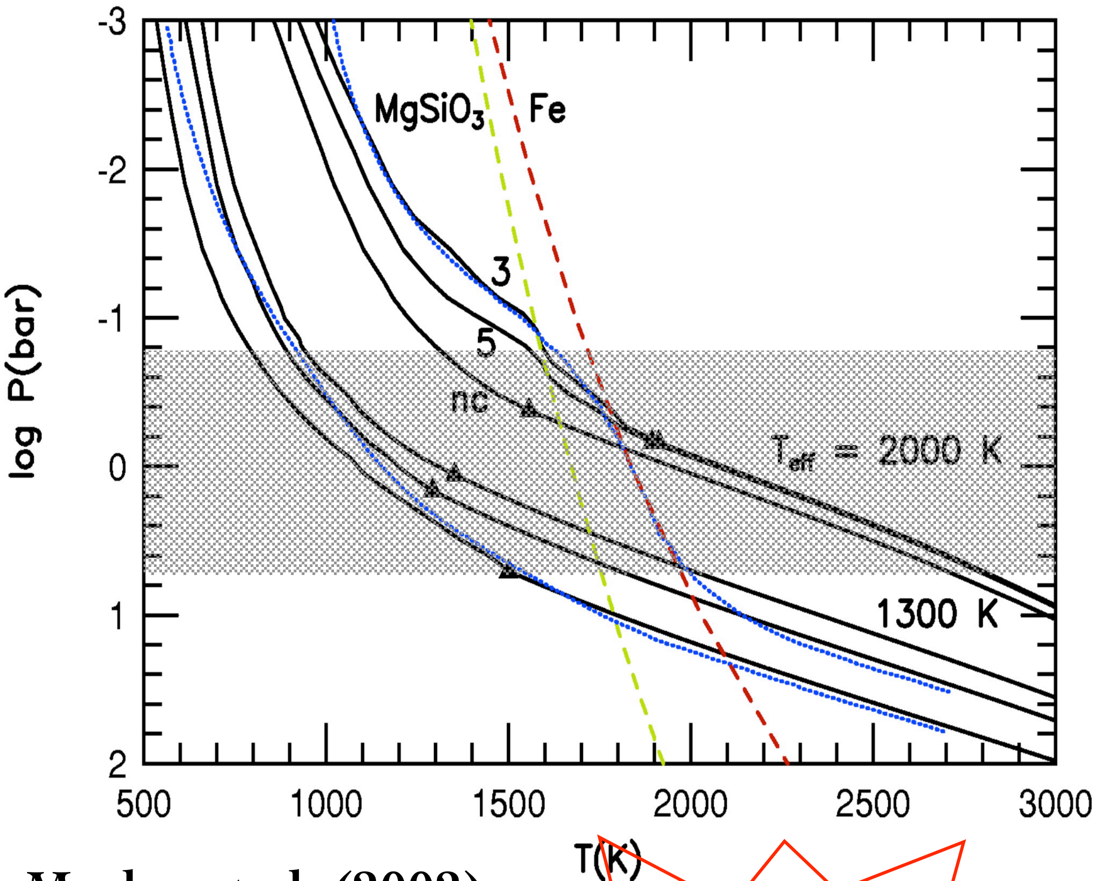
Burgasser et al. (2003)
see also Lepine et al. (2003); Gizis & Harvin (2006)

Molecular features are sensitive to secondary parameters (gravity, [M/H], mixing) via chemistry



Condensate clouds

Condensation in BD Atmospheres



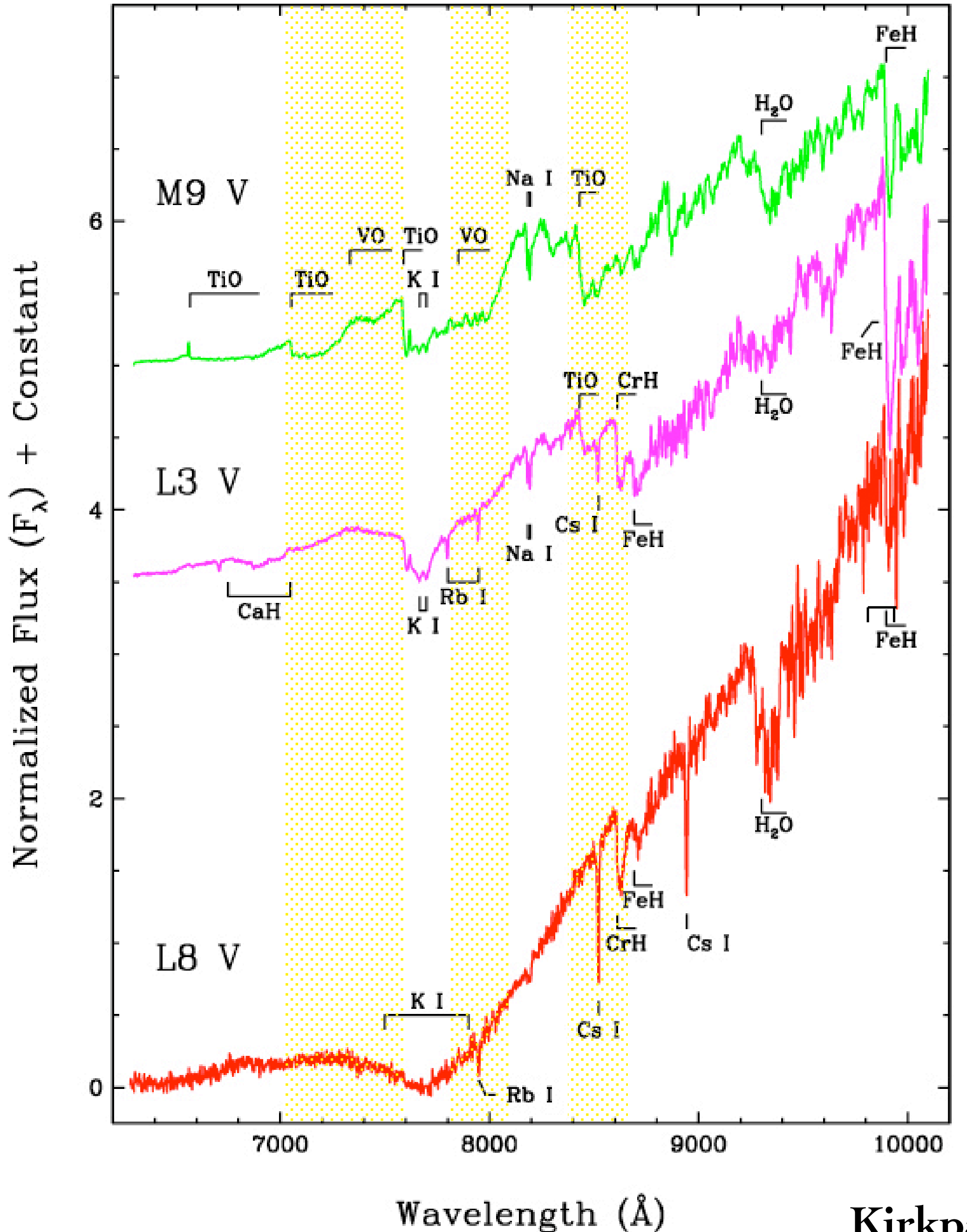
Marley et al. (2002)

Talks by Allard & Freytag

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)

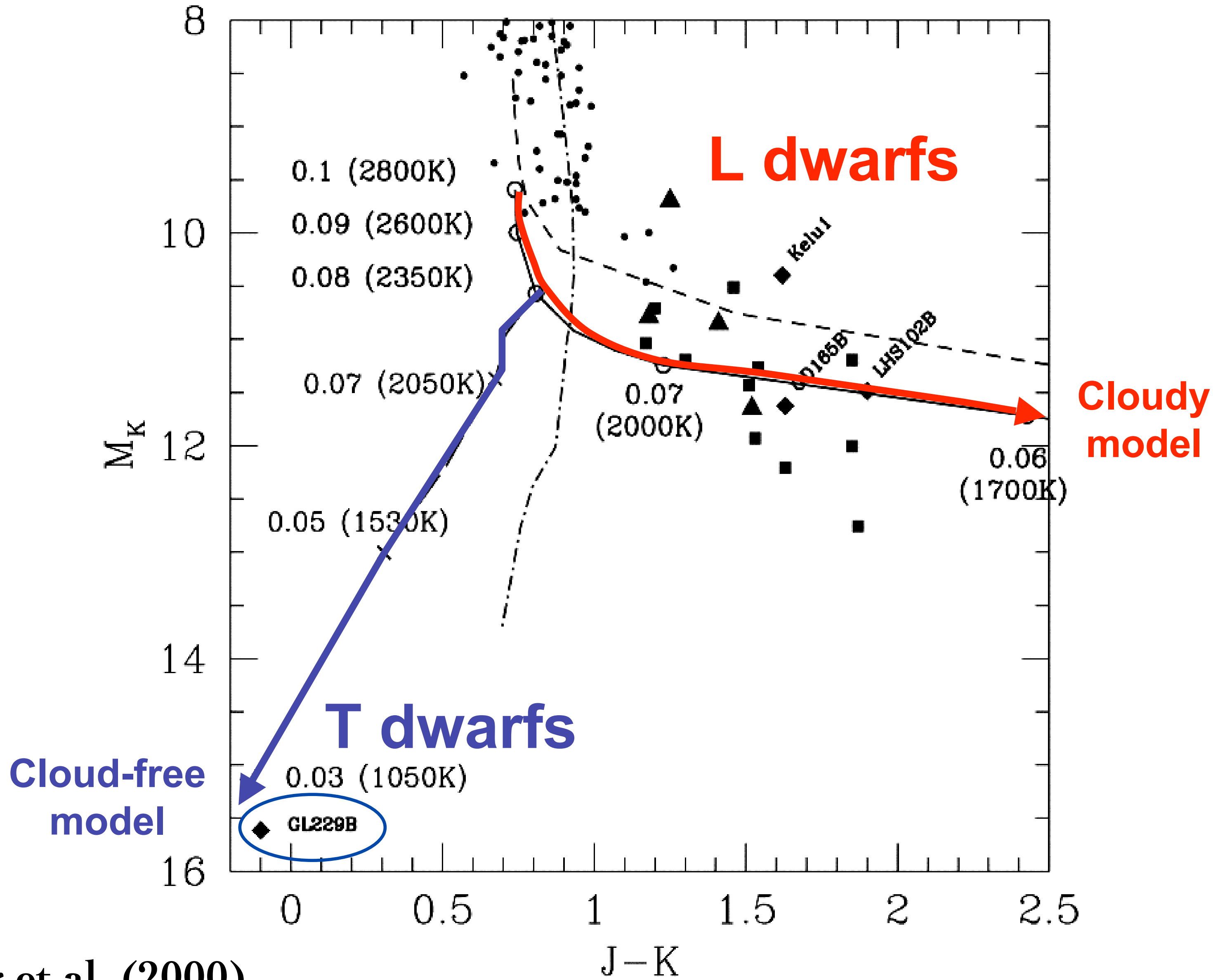


Condensation

Disappearance of TiO & VO bands signals transition between M and L spectral classes.

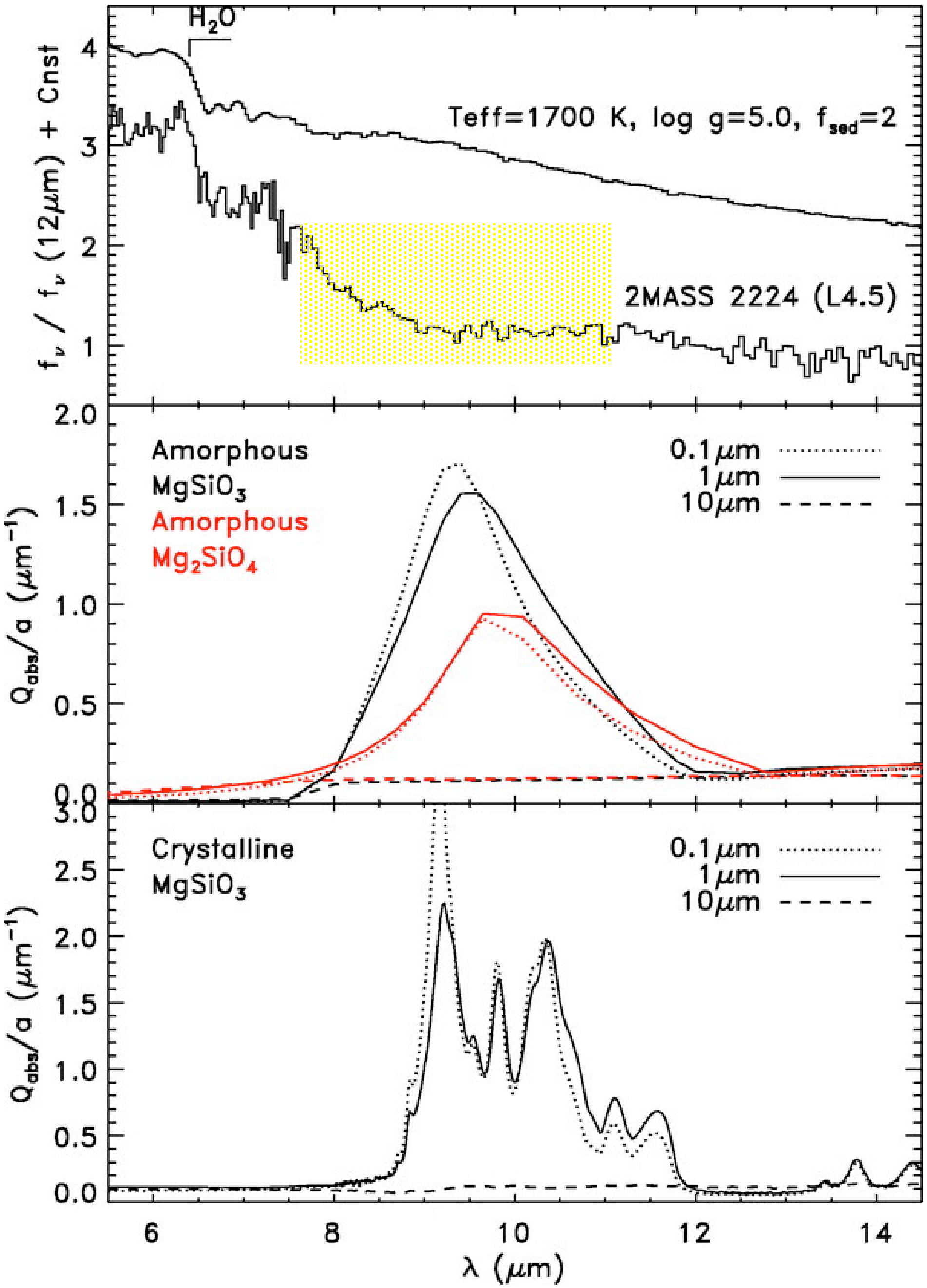
Removal of opacity strengthens other features, notably alkalis

Kirkpatrick et al. (1999)



Chabrier et al. (2000)

See also Ackerman & Marley (2001); Allard et al. (2001); Cooper et al. (2003); Helling et al. (2008)



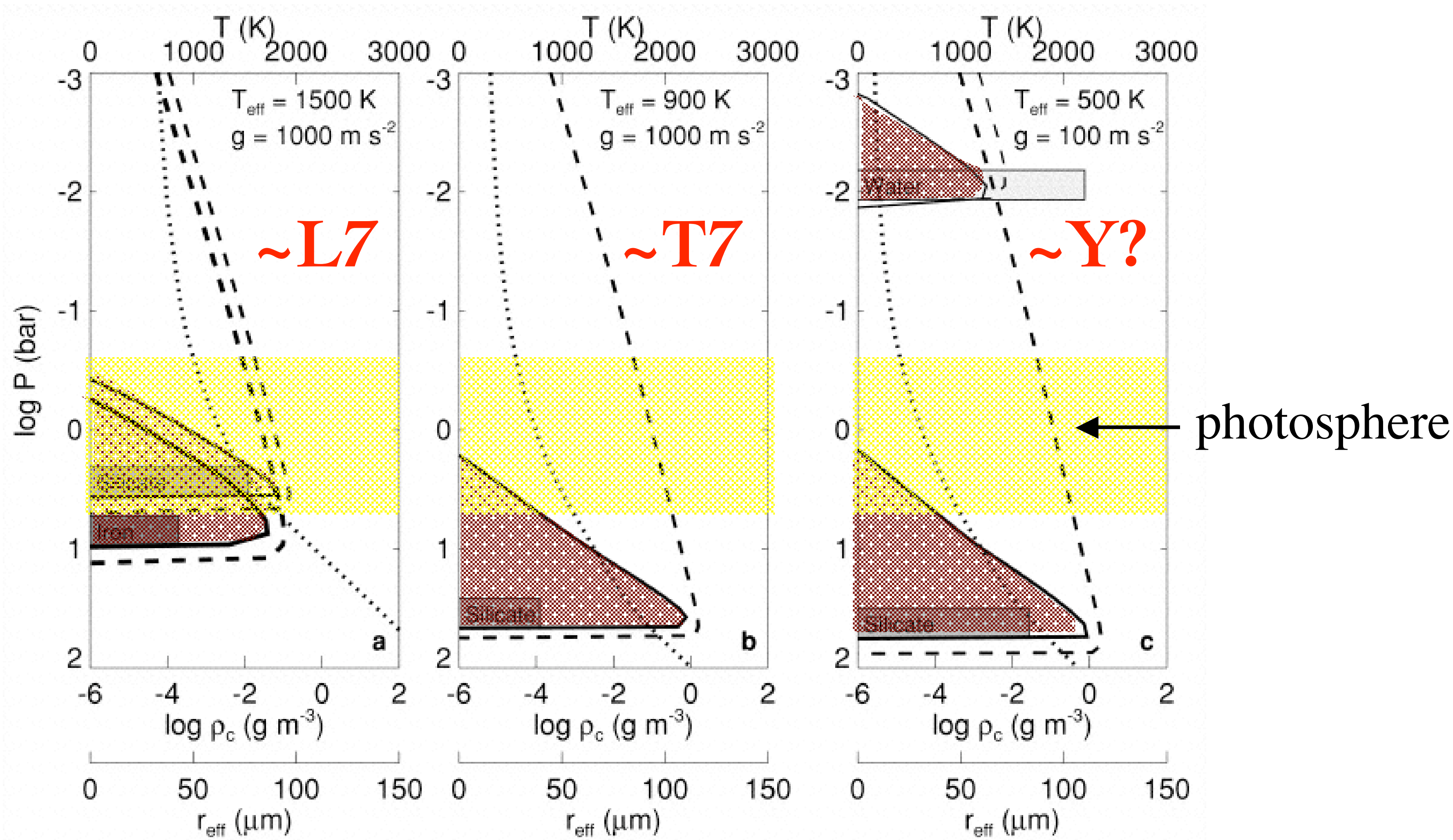
Direct detection of condensates

Excess absorption at 8-11 μm is coincident with silicate features, grain sizes < 1 μm.

Cushing et al. (2006)

see also Burgasser et al. (2007); Helling et al. (2007); Looper et al. (2008)

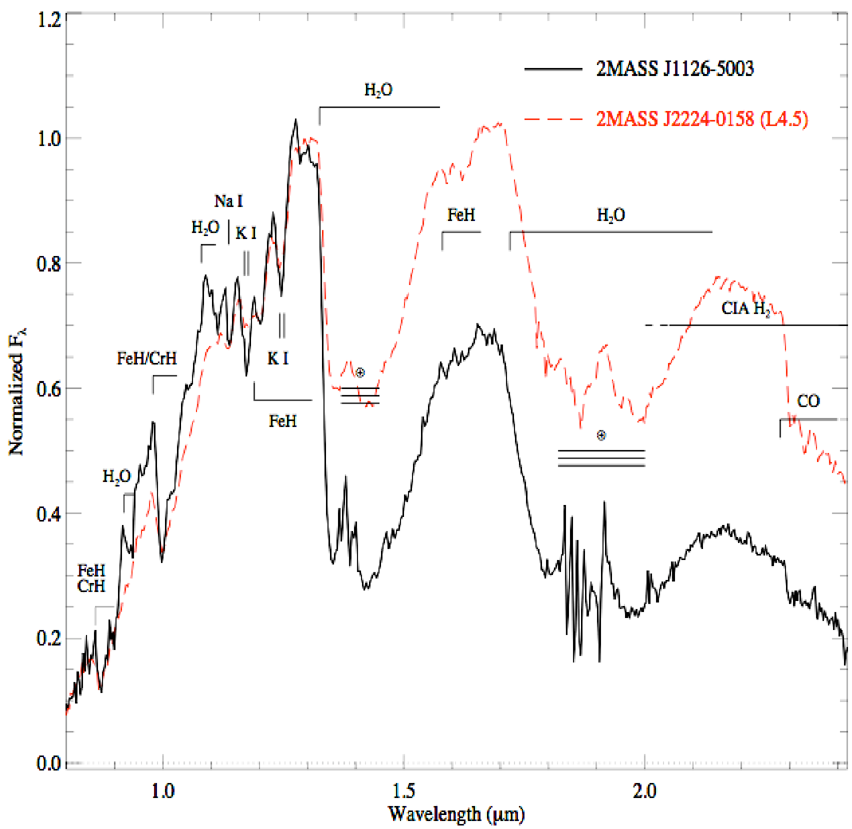
Clouds in L Dwarfs

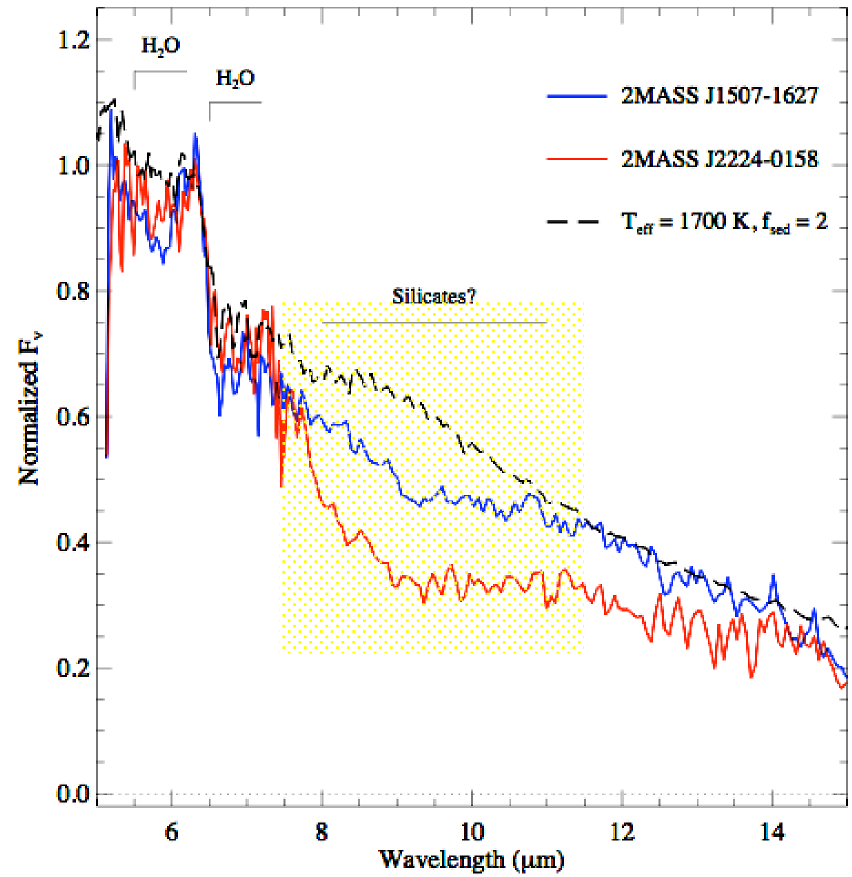


Ackerman & Marley (2001)

see also Allard et al. (2001); Cooper et al. (2003); Helling et al. (2008)

Cloud Variations



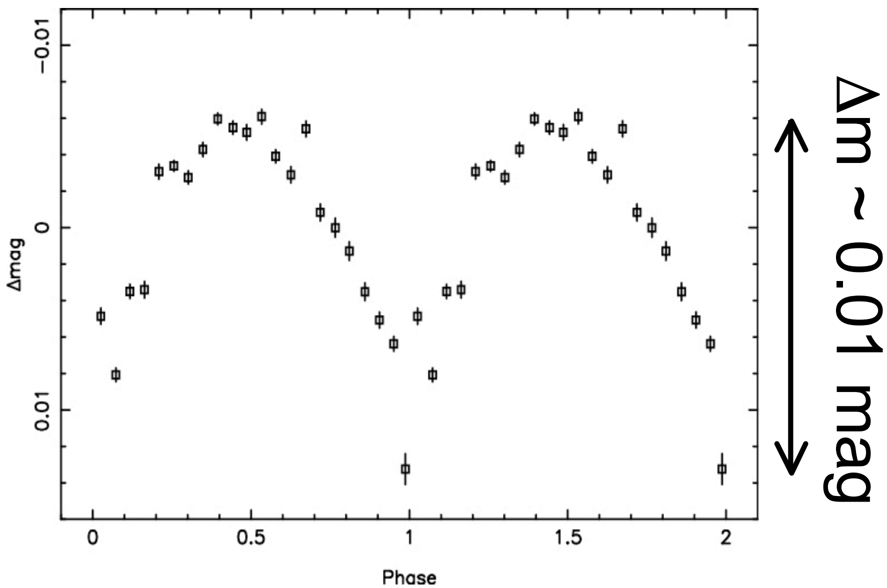


Burgasser et al. (2008)

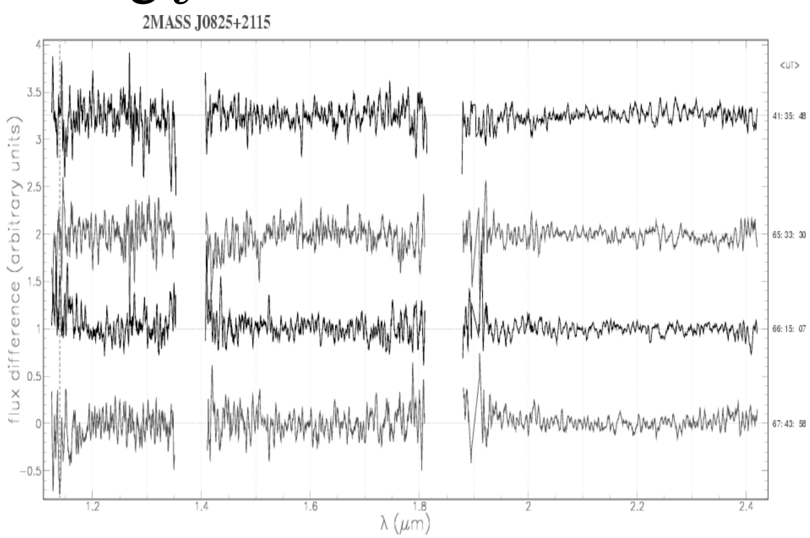
see also McLean et al. (2003); Knapp et al. (2004); Cruz et al. (2007); Cushing et al. (2008)

Temporal variations?

the good…



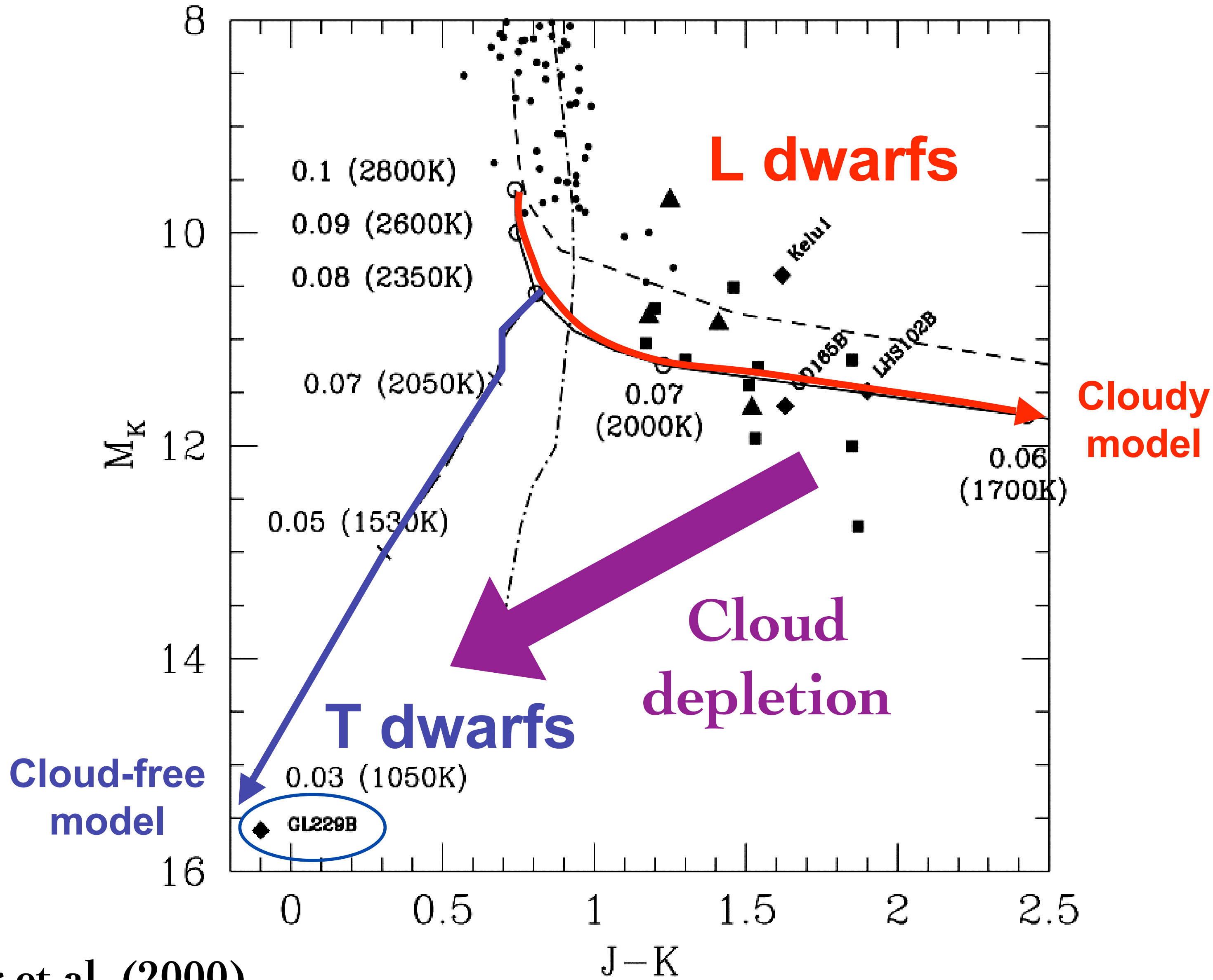
the ugly…



While there are clear indications of periodic variability in a few sources, they are weak and often aperiodic.

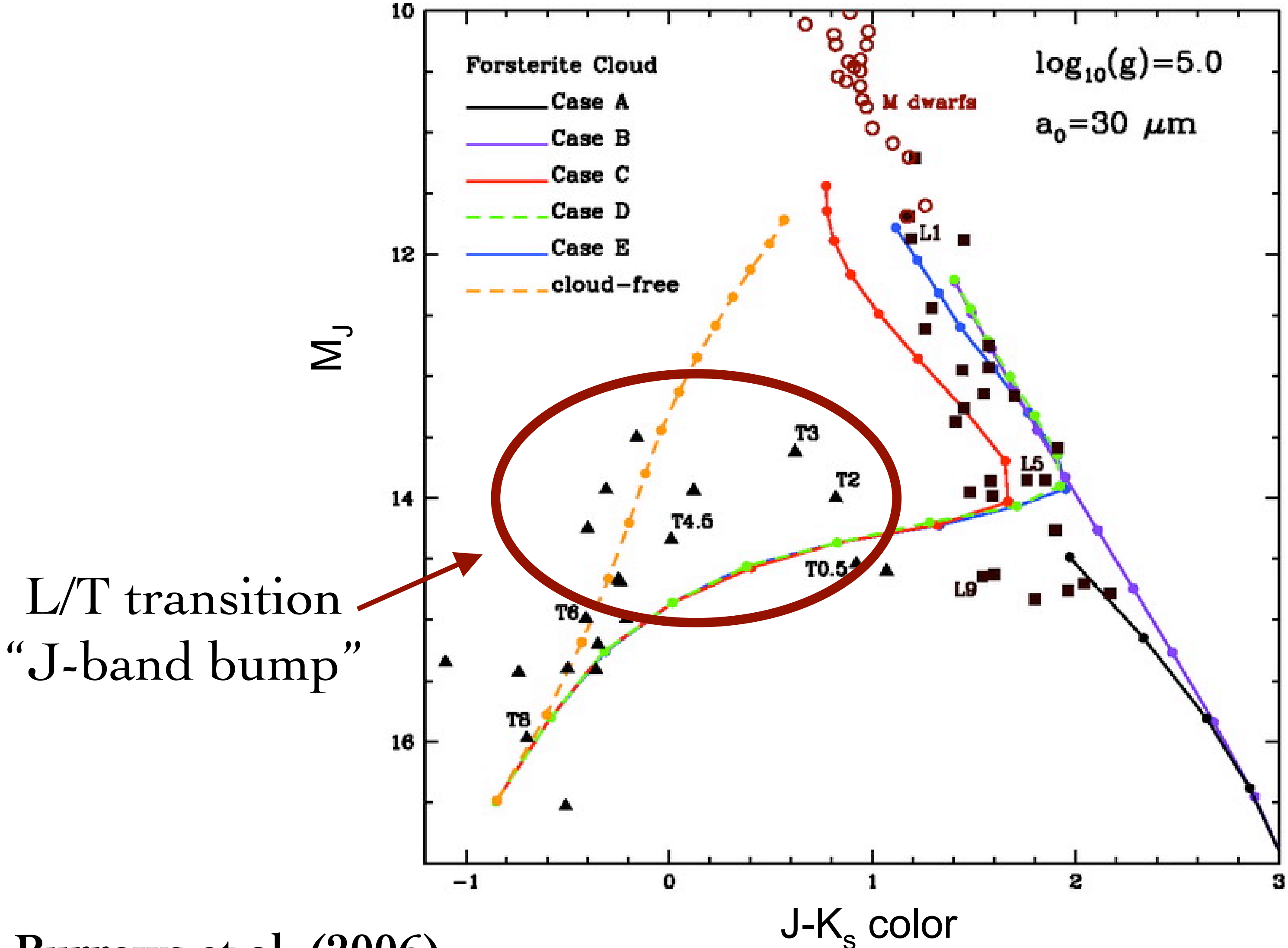
Clarke et al. (2002); Goldman et al. (2008)

See also Bailer-Jones & Mundt (1999, 2001); Bailer-Jones (2002, 2008); Bailer-Jones et al. (2003); Gelino et al. (2002); Enoch et al. (2003); Koen (2003 ,2004, 2005, 2006, 2008); Caballero et al. (2004); Morales-Calderon et al. (2006)



Chabrier et al. (2000)

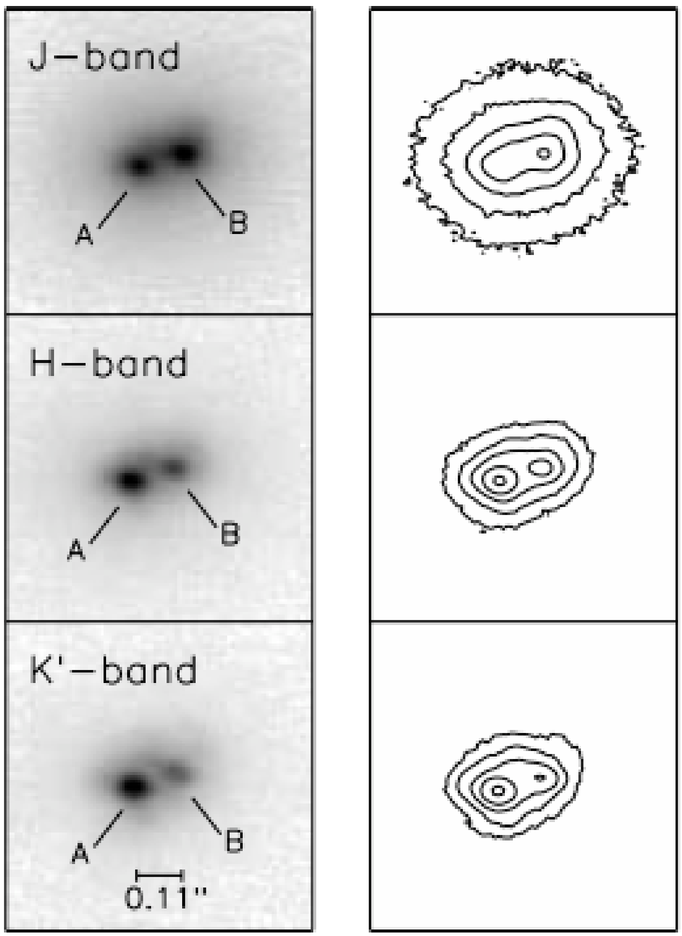
See also Ackerman & Marley (2001); Allard et al. (2001); Cooper et al. (2003); Helling et al. (2008)

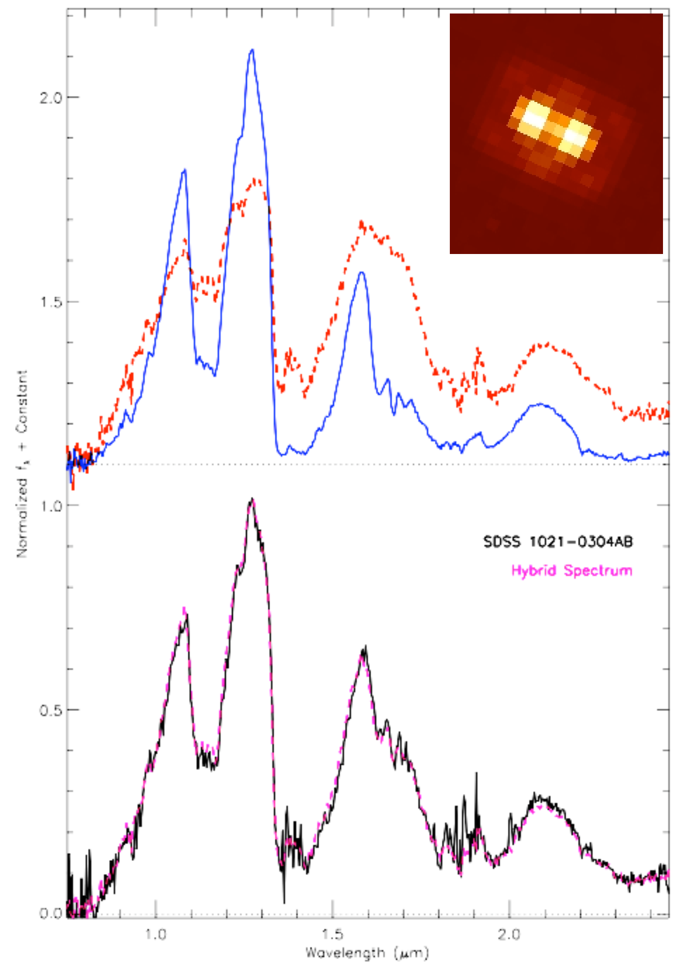


Burrows et al. (2006)

See also Dahn et al. (1999); Ackerman & Marley (2001); Marley et al. (2002); Tinney et al. (2003); Tsuji (2003,2005); Saumon & Marley (2008)

Flux-reversal binaries

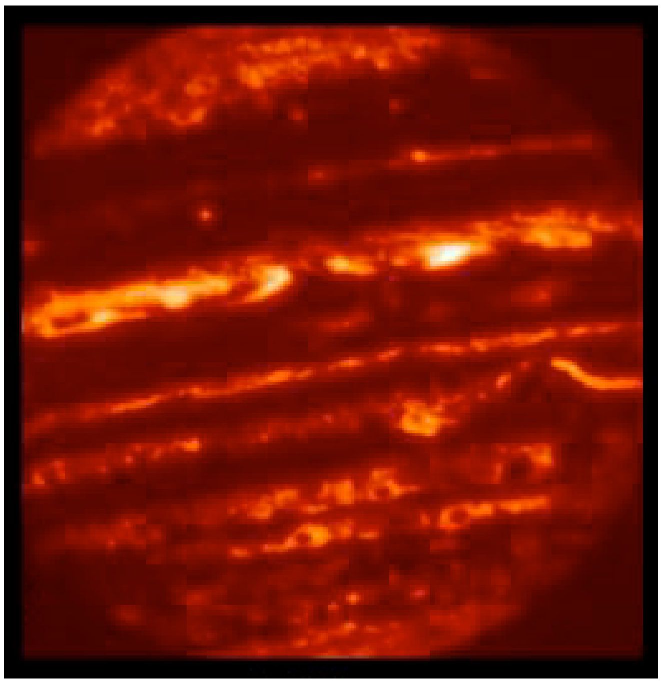




Liu et al. (2006); Burgasser et al. (2006)

See also Gizis et al. (2003); Cruz et al. (2004); Burgasser (2007,2008); Looper et al. (2008)

What Drives Cloud Loss?



Jupiter @ 5 μm

- Sudden change in sedimentation efficiency?
- "Break-up" of clouds? (cf. Jupiter)
- Compression of clouds?
- Transition T_{eff} varies with log g, [M/H], other…

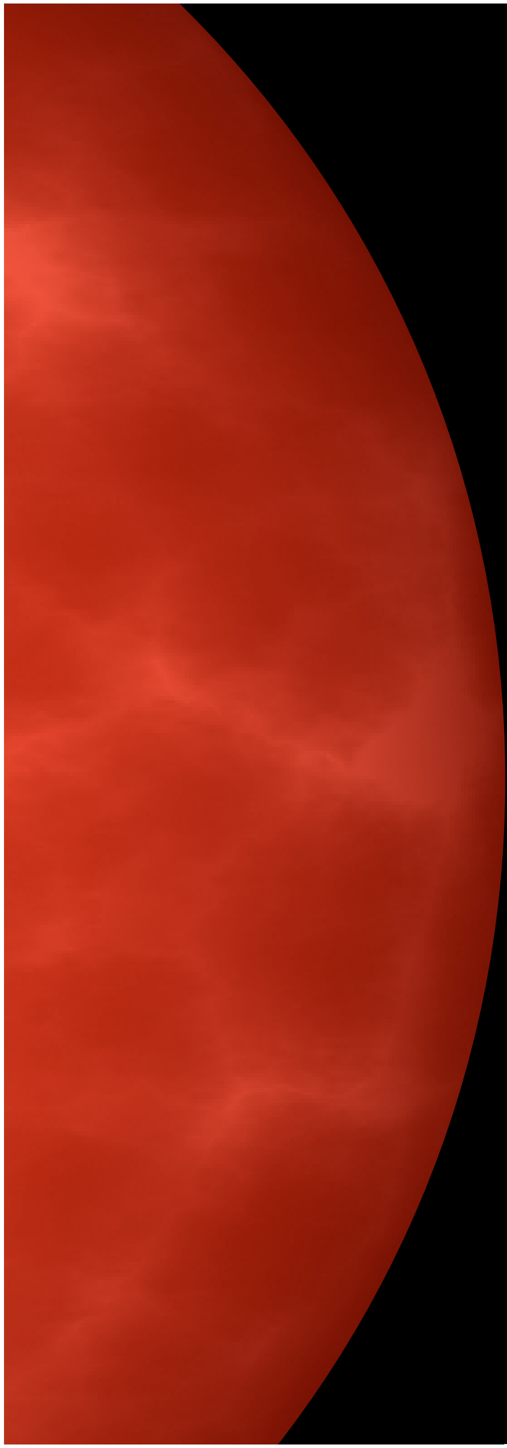
Several warm EPs have L/T transition T_{eff}s

Summary

Brown dwarfs & exoplanets share physical properties, but differ in fundamental ways

Molecular gases are prominent in BD atmospheres, abundances sensitive to chemistry & secondary parameters

Condensate clouds are prominent in L dwarf atmospheres, non-equilibrium depletion at L/T transition yet to be adequately explained



Merci!