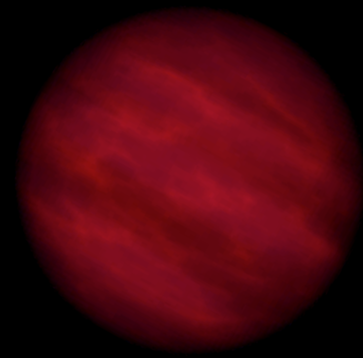
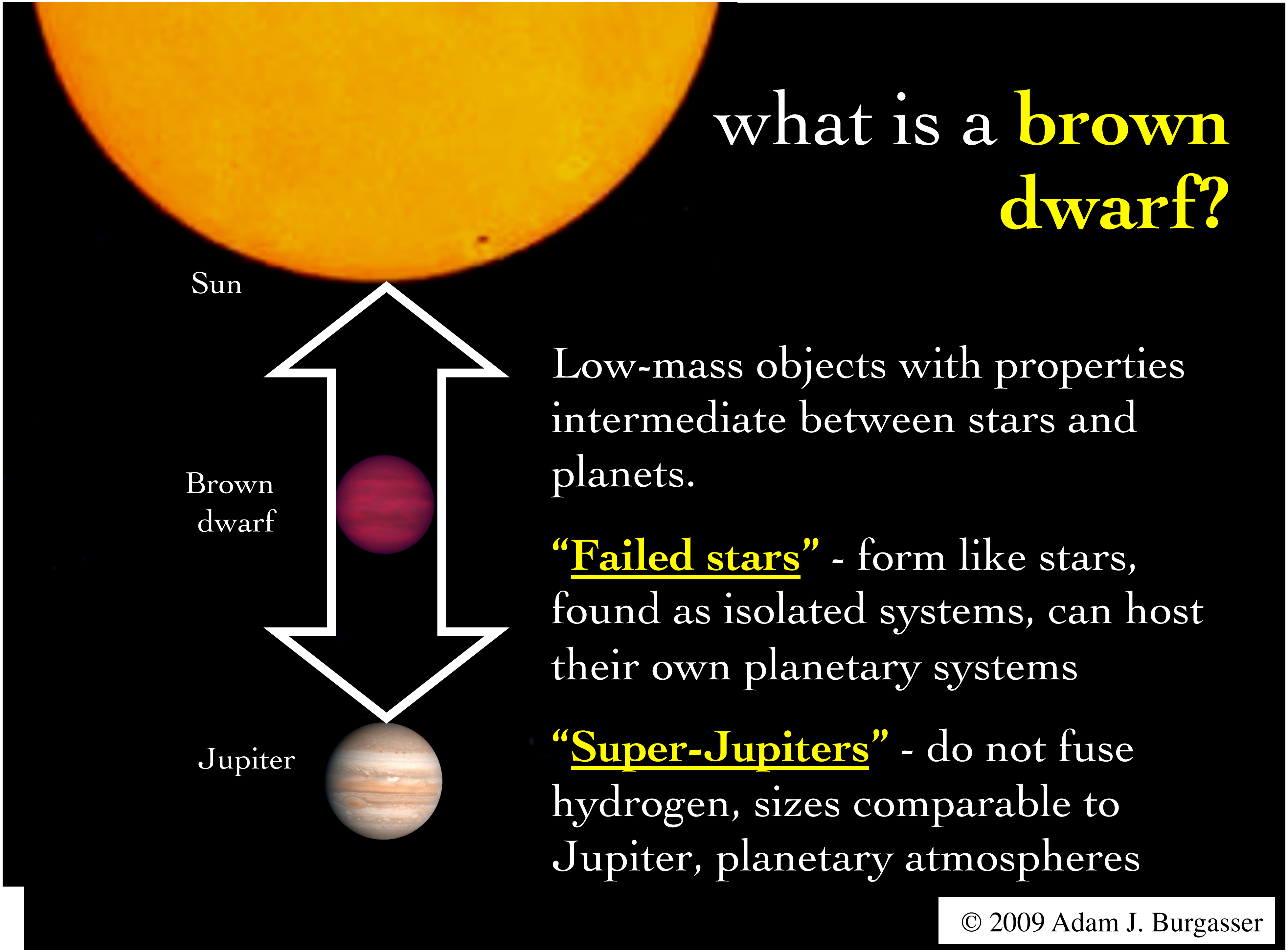


The Brown Dwarf - Exoplanet Connection

Adam J. Burgasser

$1/\sqrt{2}$ (|MIT> + |UCSD>)


what is a brown dwarf?
Sun
Brown dwarf
Jupiter
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
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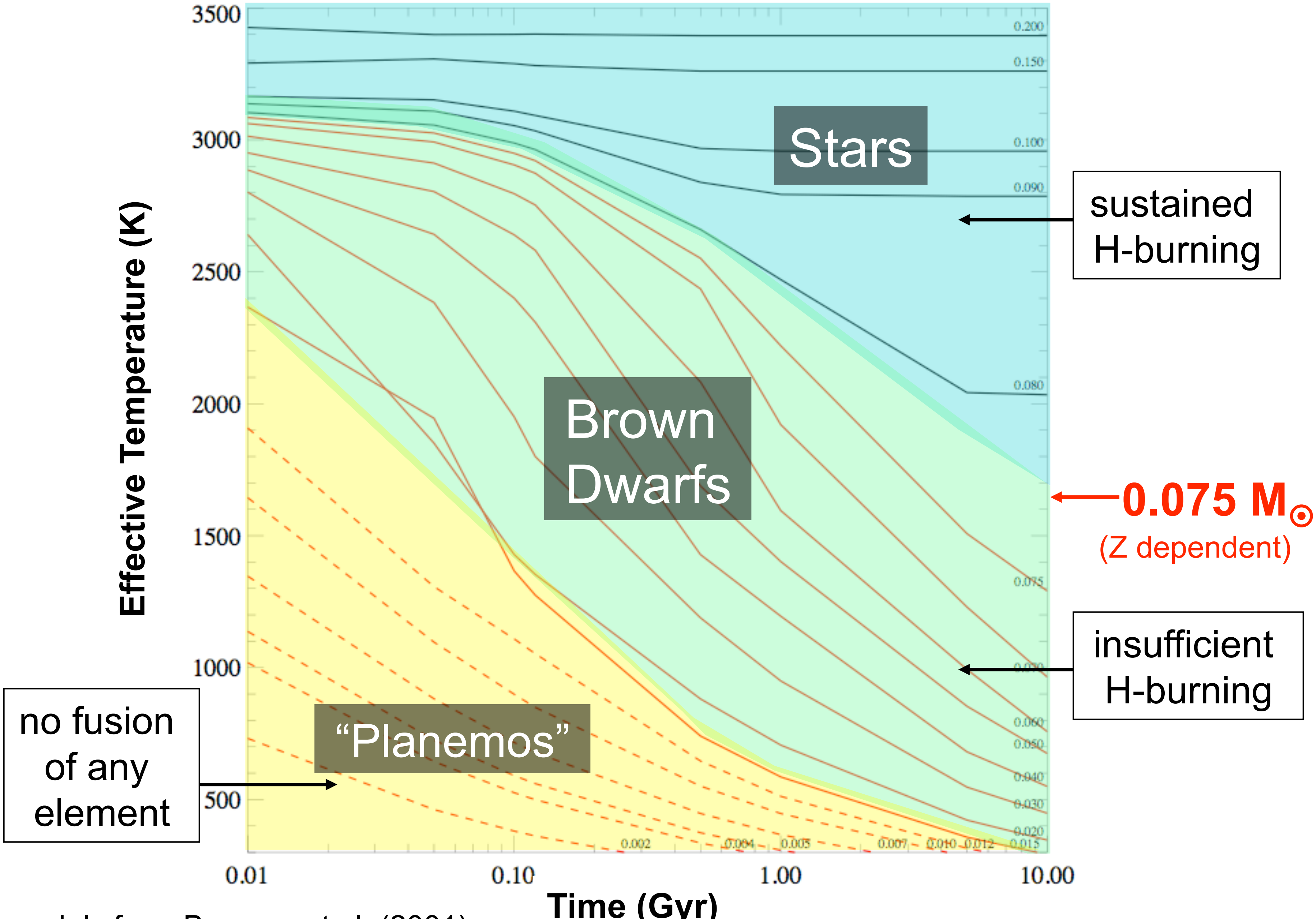
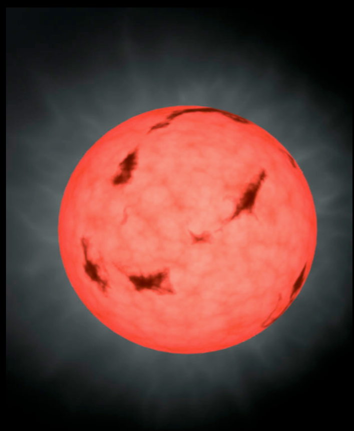


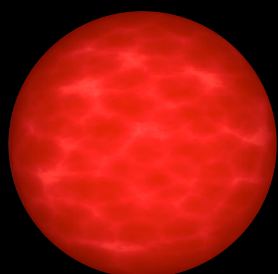
models from Burrows et al. (2001)

spectral types



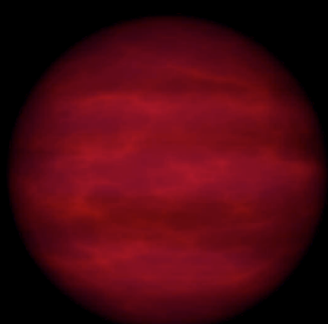
M dwarfs (3500-2100 K)

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



L dwarfs (2100-1300 K)

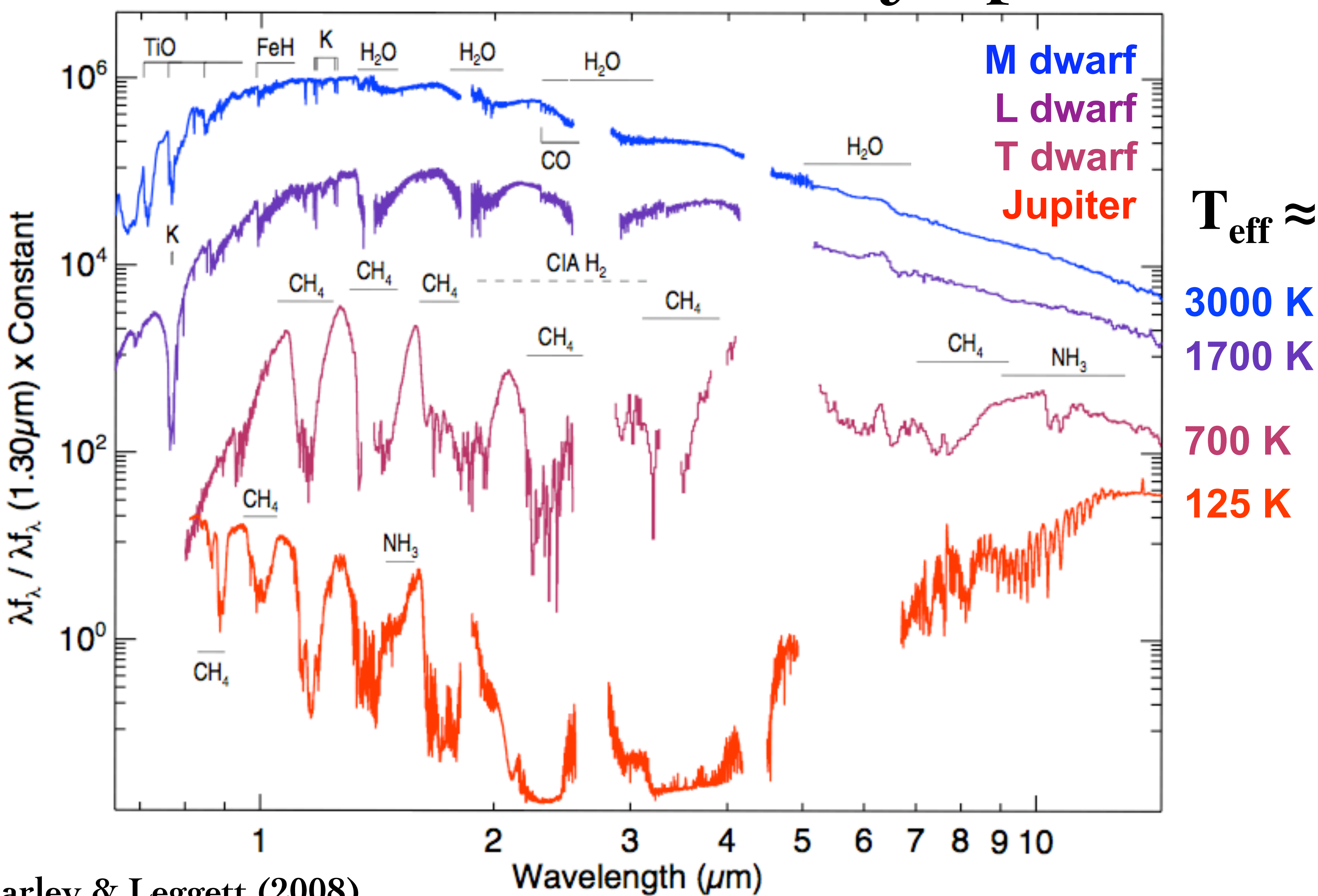
molecule-rich atmospheres contain clouds of “hot dirt” and other condensates



T dwarfs (1300-600? K)

coldest known brown dwarfs, atmospheres contain CH_4 and NH_3 gases

Brown dwarf & Planetary Spectra



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

Overview

Similarites between brown dwarf and exoplanet atmospheres

Differences between brown dwarf and exoplanet atmospheres

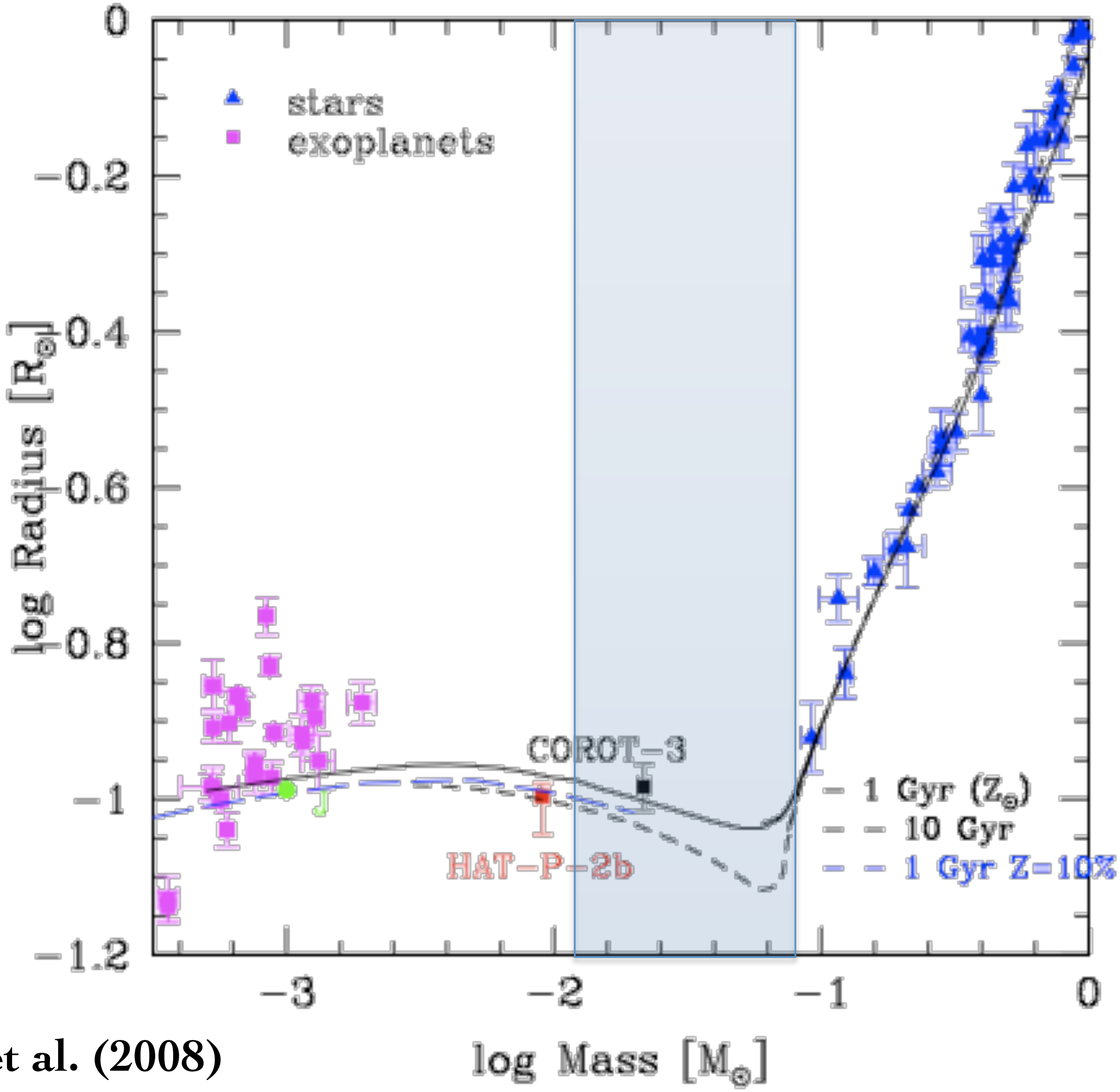
Focus on condensate cloud formation/ evolution

Similarities

Compact radii ($R_{BD} \sim R_{jup}$ for $t > 100$ Myr)

Cool atmospheres ($T_{eff} \sim 3000 - 550$ K)

Similar (but not identical) surface gravities



Chabrier et al. (2008)

models by Baraffe et al. (2003)

Similarities

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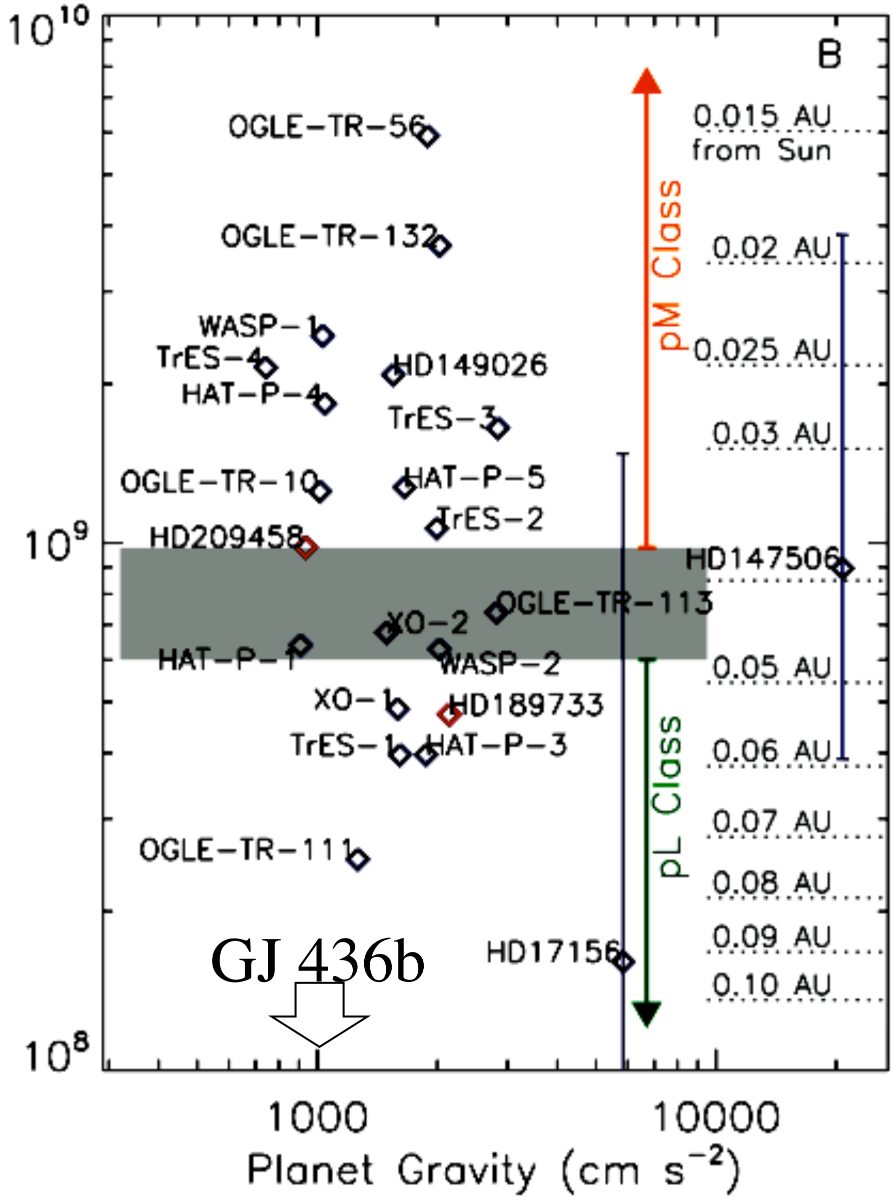
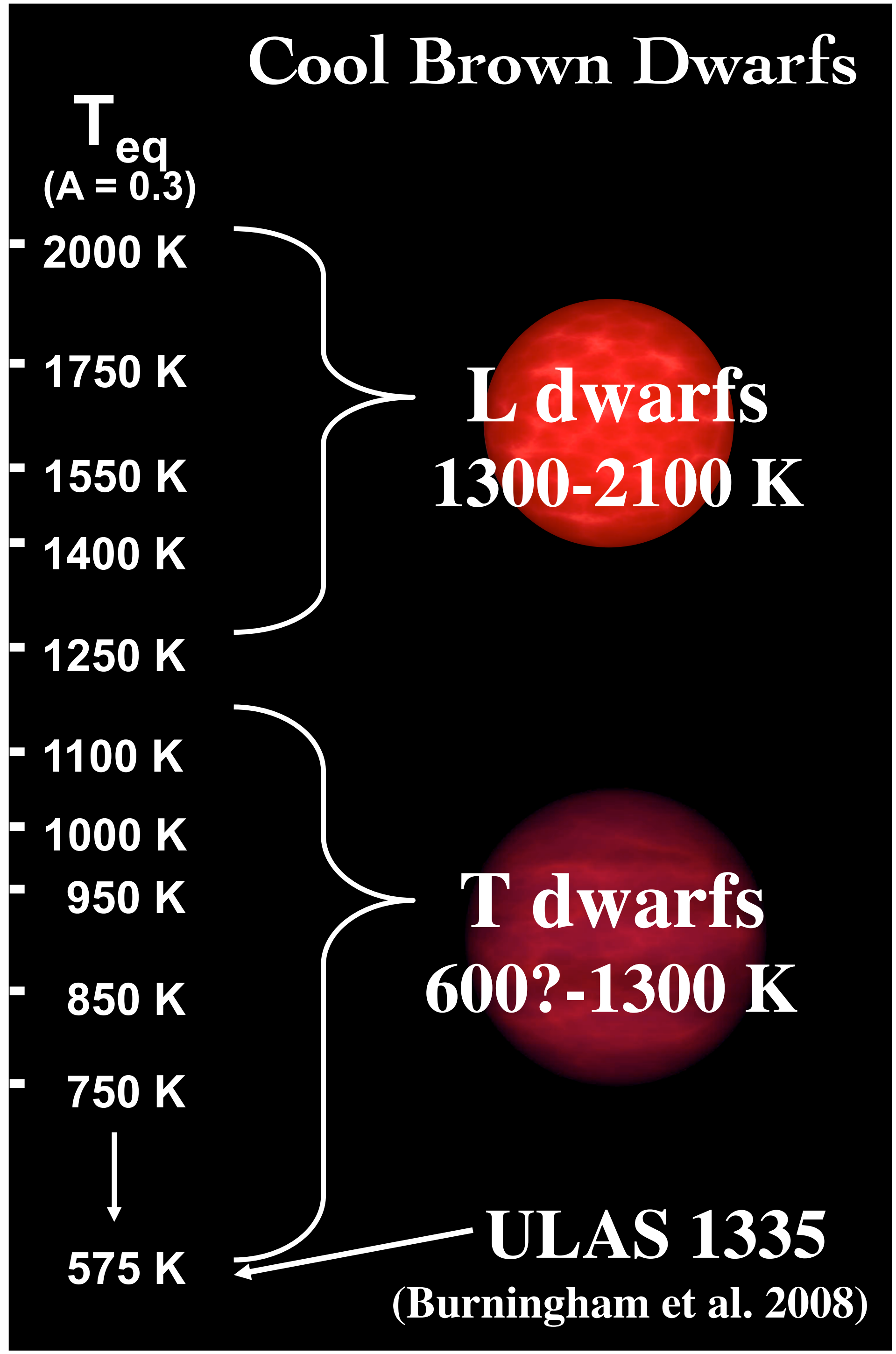
Similar (but not identical) surface gravities

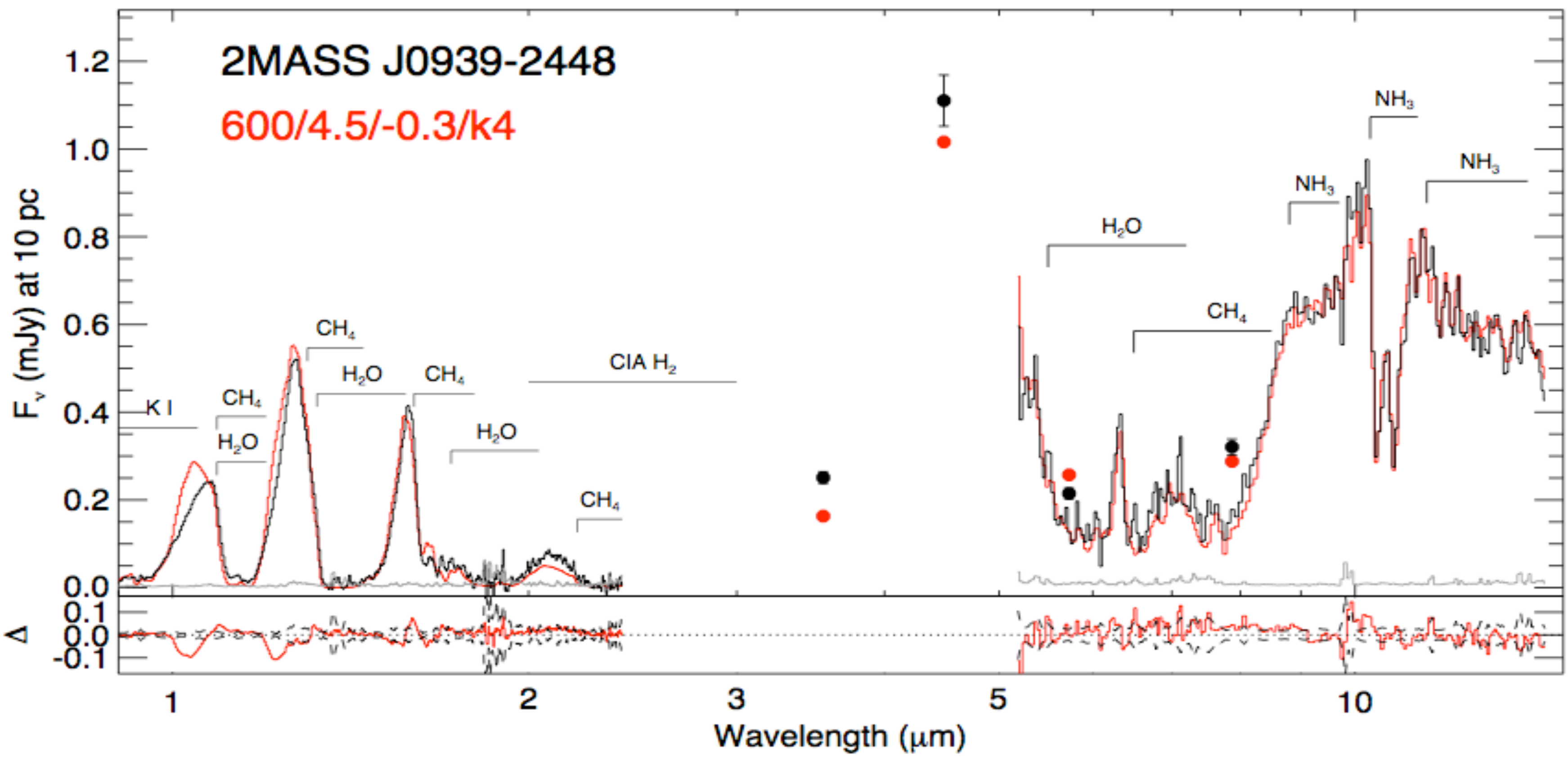
Hot Exoplanets



Fortney et al. (2008)



Cold Brown Dwarfs



2MASS 0939-2448

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

(Burgasser et al. 2008)

Similarities

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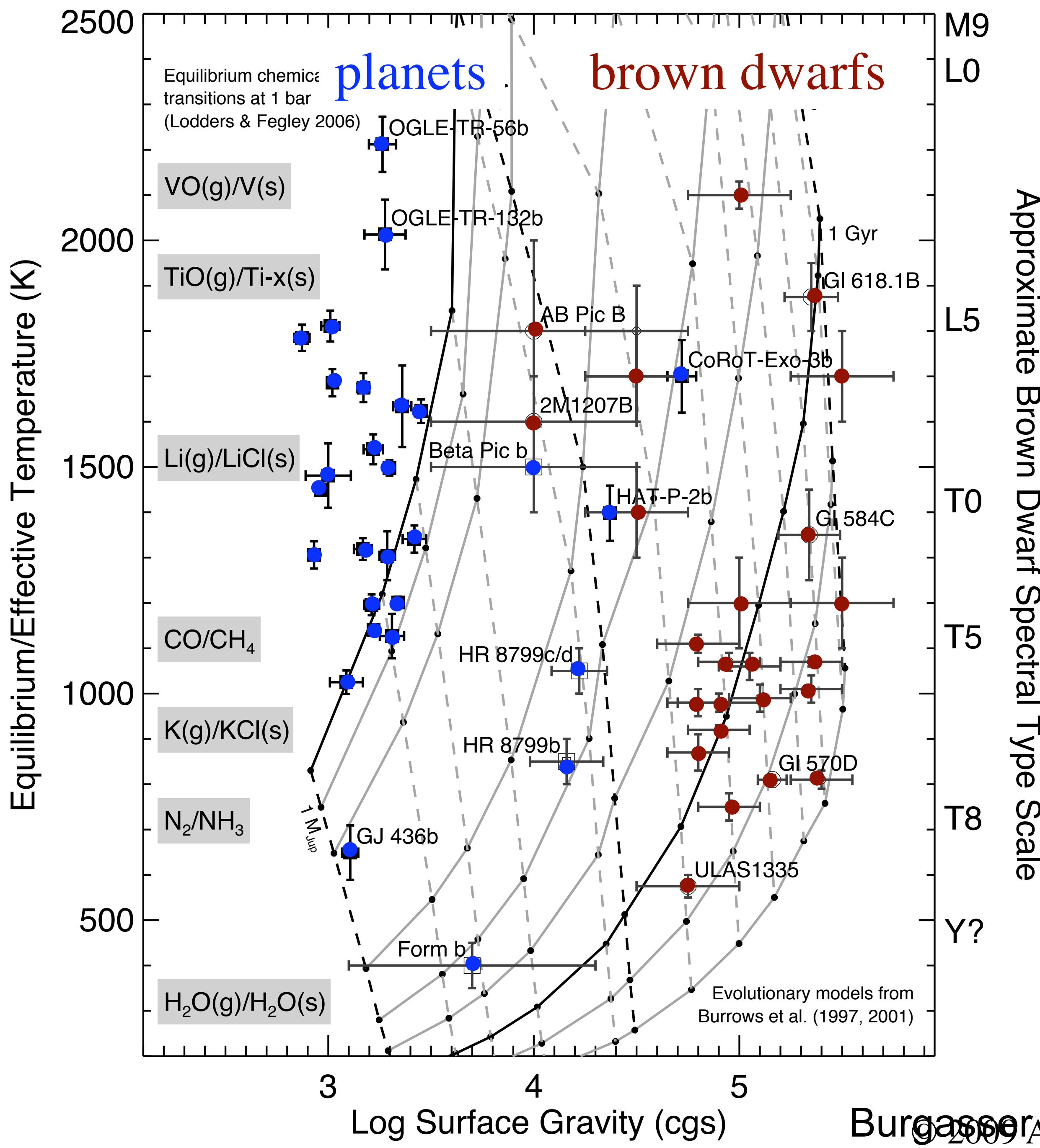
Cool atmospheres ($T_{eff} \sim 3000 - 550$ K)

Similar (but not identical) surface gravities



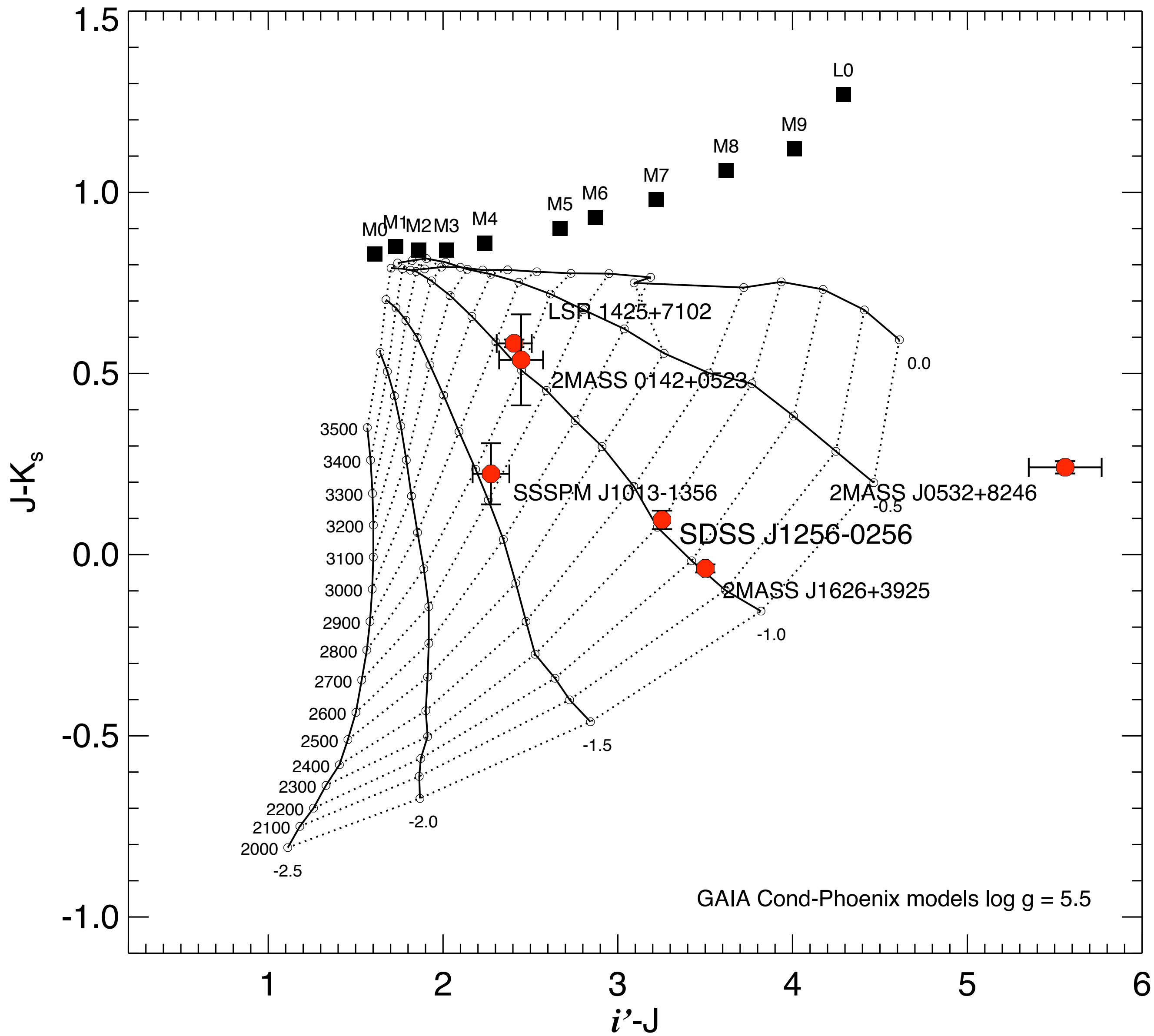
Burgasser et al. (2009)

Differences

Metallicities: [M/H] ~ -2…+0.75 (BDs)
vs. [M/H] ~ 0.5…1.6 (JSUN)

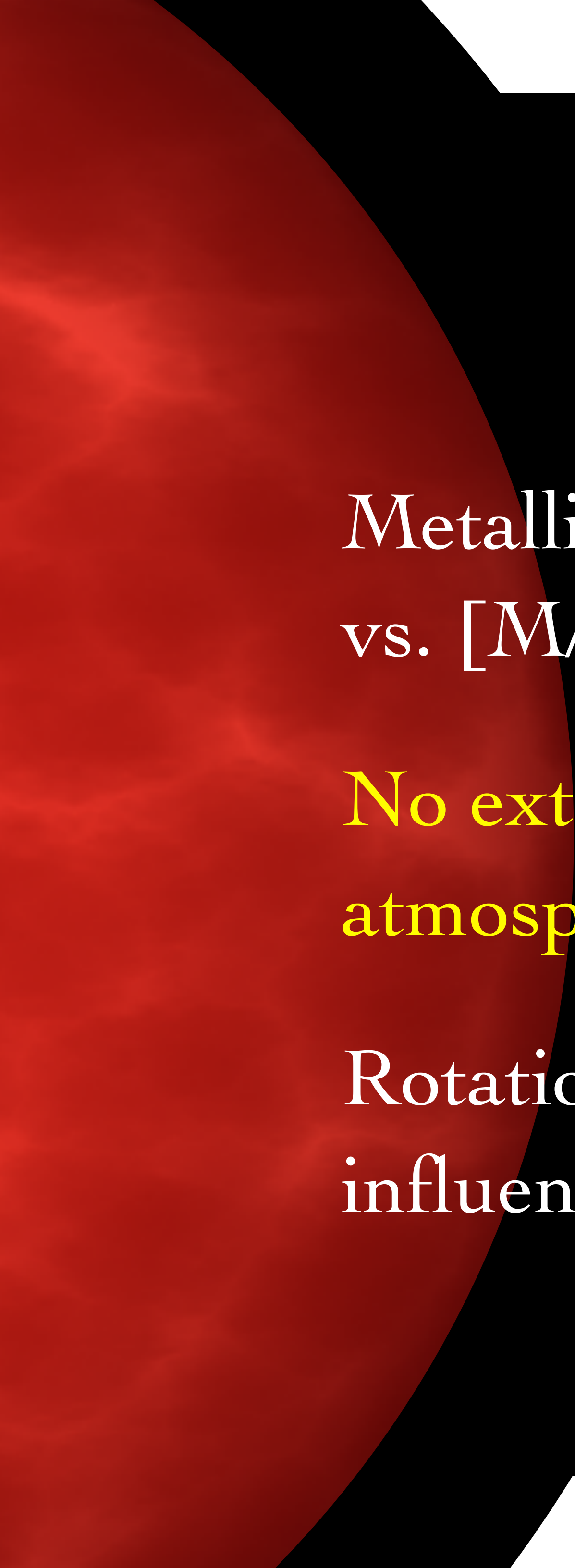
No external drivers for brown dwarf atmospheres – wind, jets & inversions?

Rotation rates: Jup: 11 hr, BD: ~4 hr: influences magnetic activity, surface winds



Burgasser et al. (2009)

see also Scholz et al. (2004,2008); Lepine et al. (2003,2005,2007)



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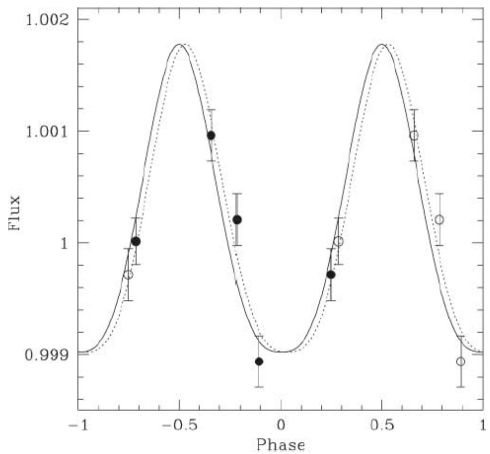
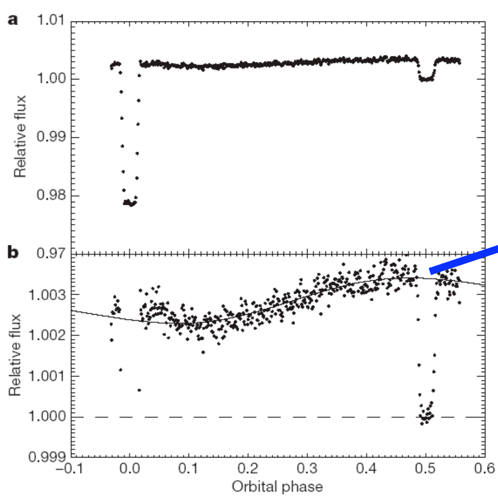
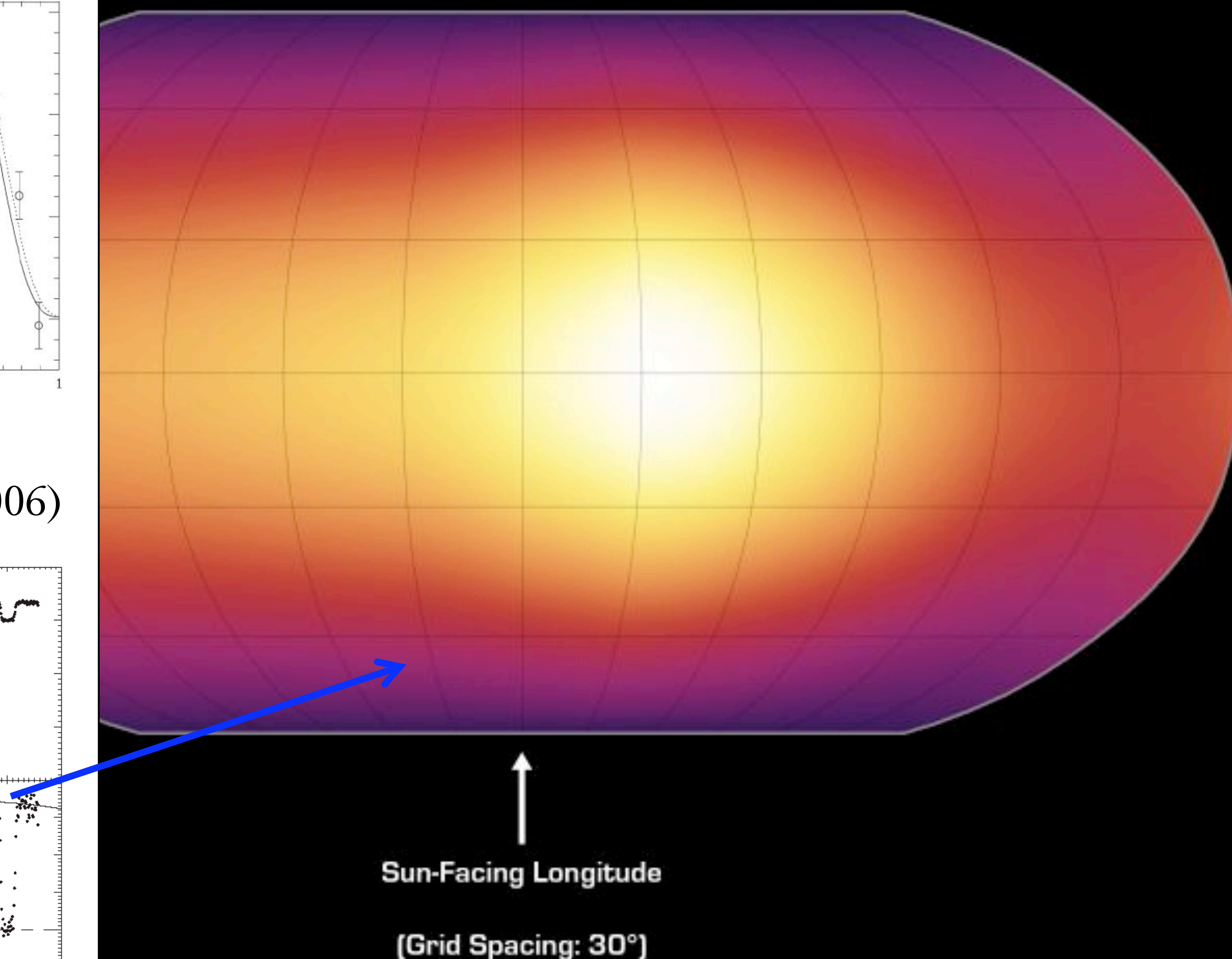


Ups And b
Harrington et al. (2006)

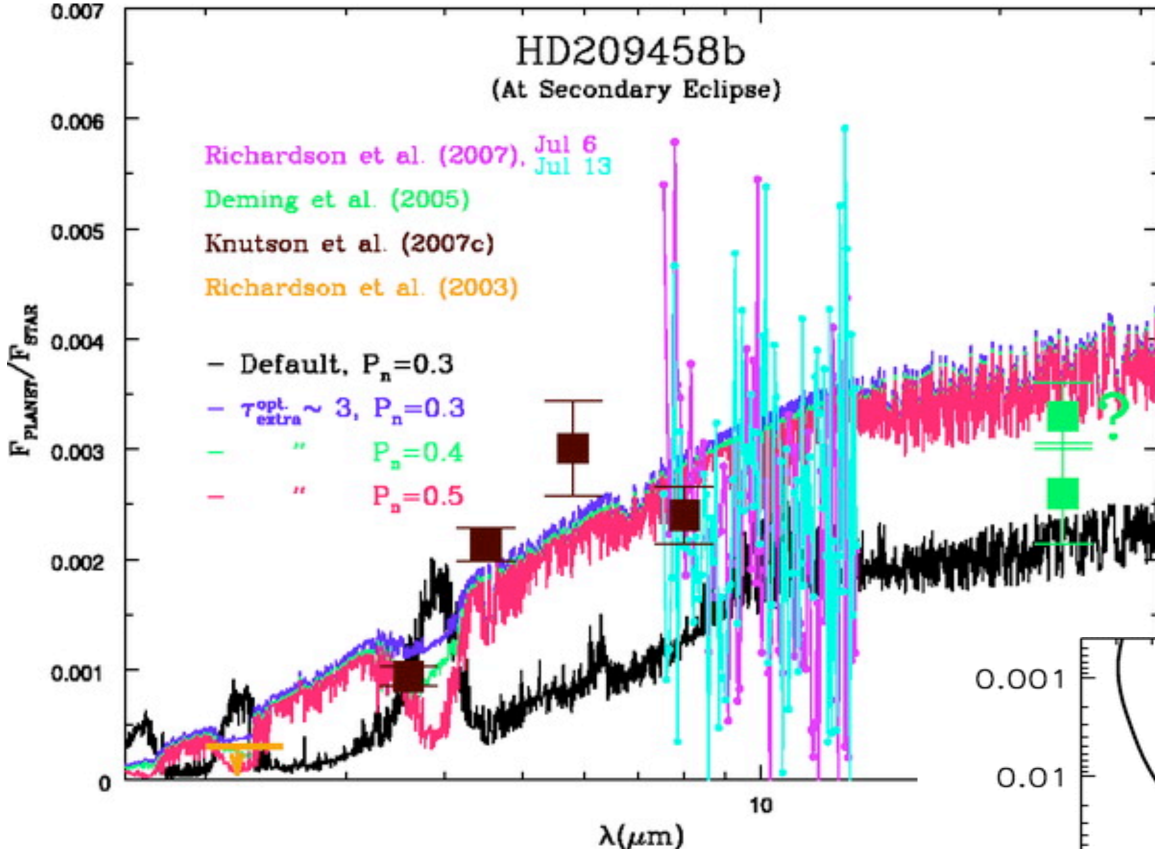


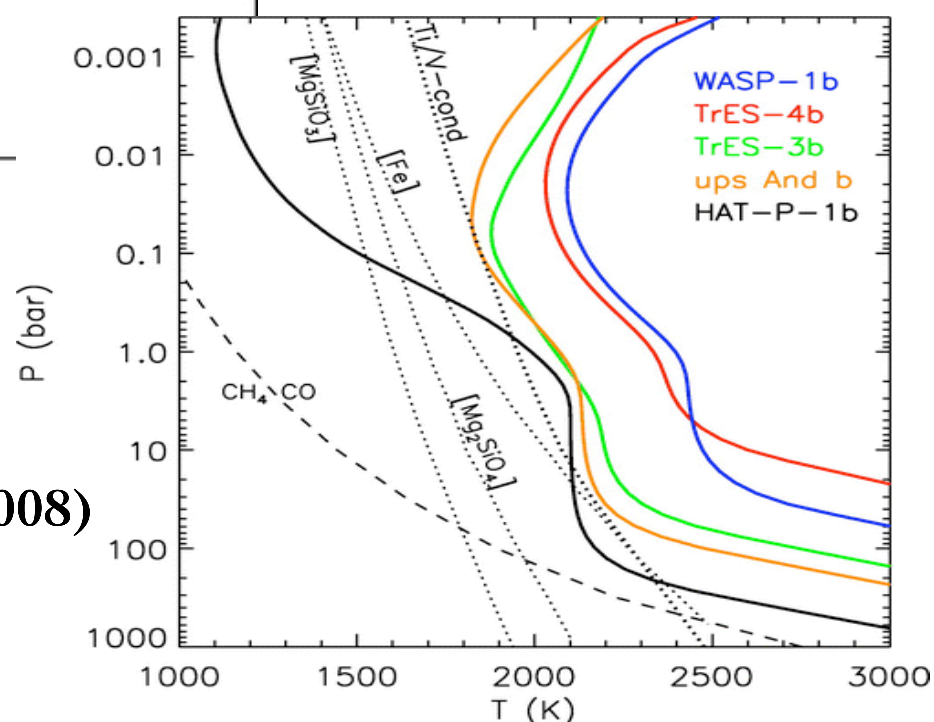
HD189733b
Knutson et al. (2007)



Harrington et al. (2006); Cowan et al. (2007); Knutson et al. (2007,2009)

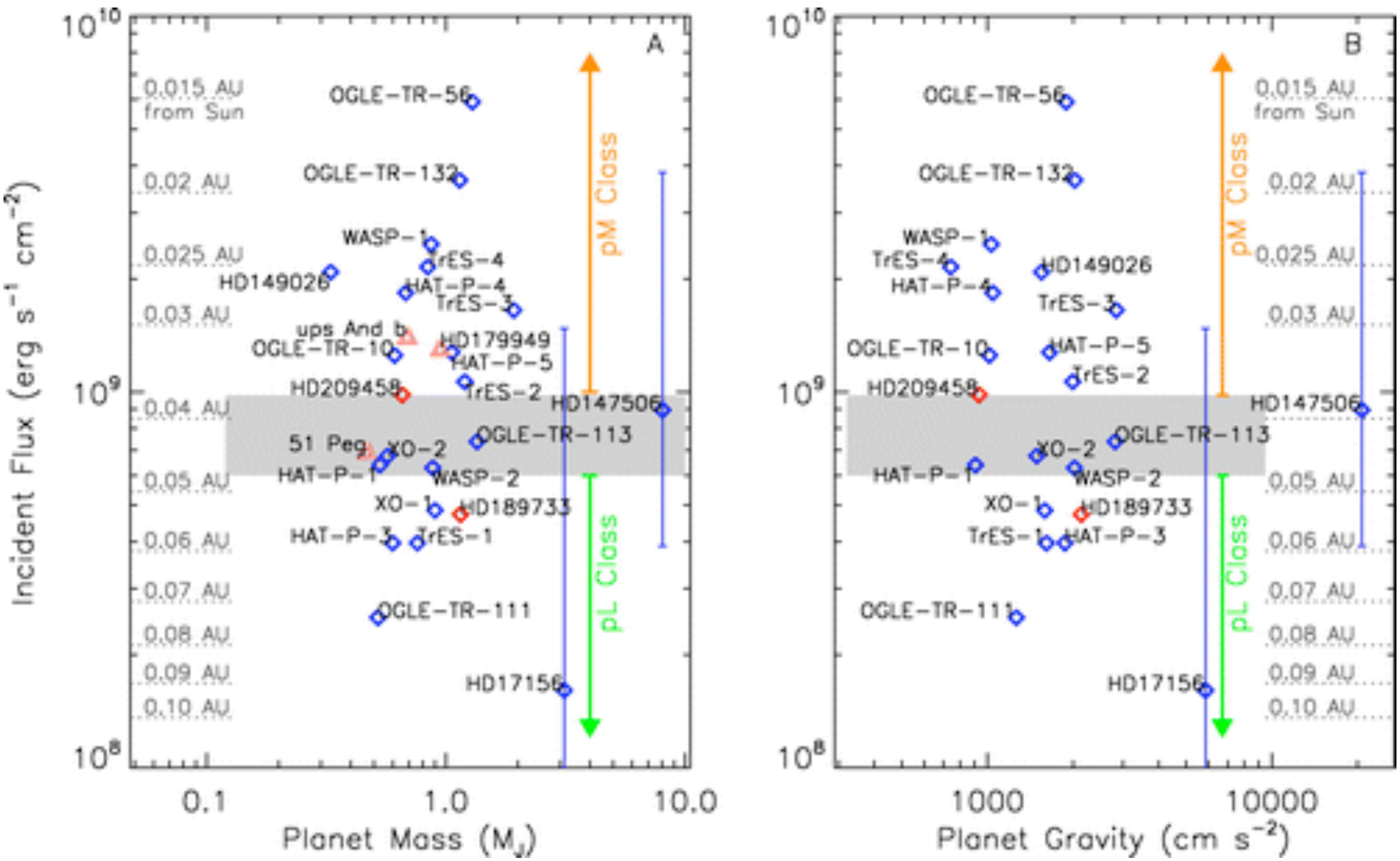
Thermal inversions in exoplanet spectra





Burrows et al. (2007); Fortney et al. (2008)
also Deming et al. (2005); Richardson et al. (2007); Knutson et al. (2008)

exoplanets with & without stratospheres



Fortney et al. (2008)

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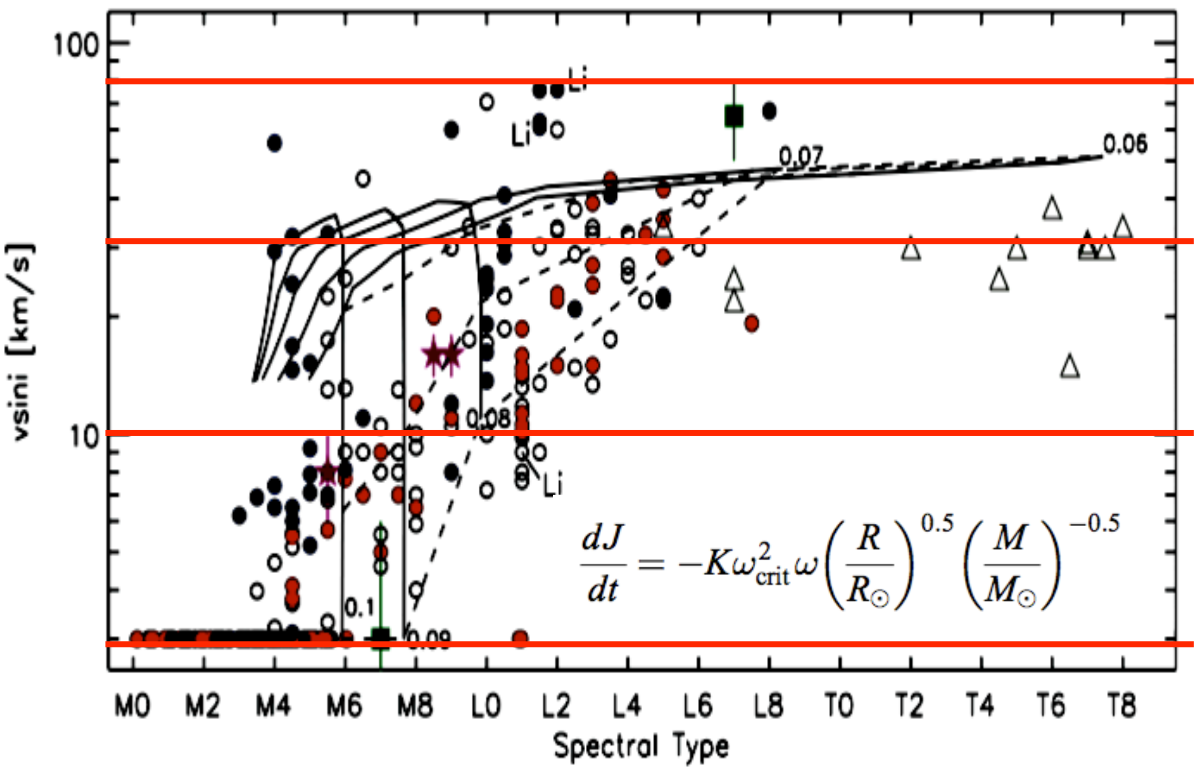
Brown Dwarfs are Dizzy



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)

Detailed Physics Revealed in Brown Dwarf Atmospheres

Warm (high J) molecular opacities

Heavily pressure-broadened line profiles

Condensate grain and cloud formation

Vertical mixing and non-equilibrium chemistry

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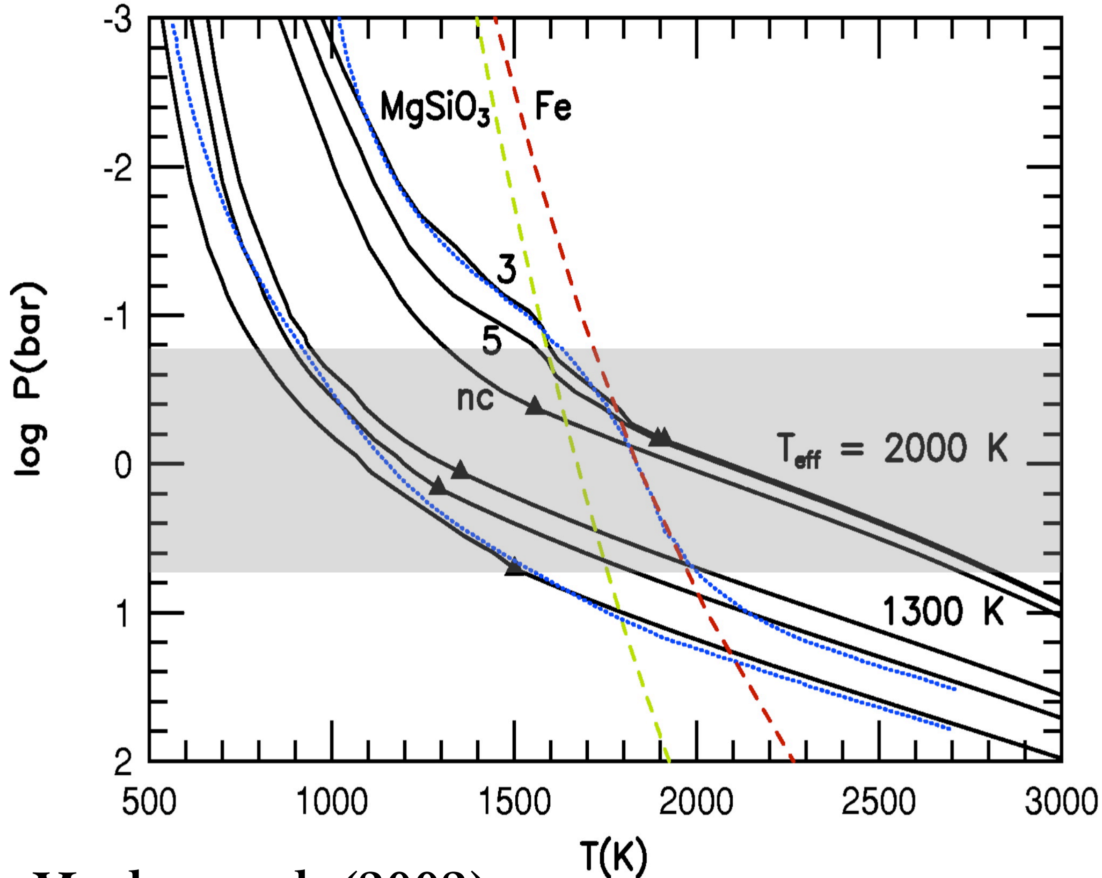
Condensation in BD Atmospheres

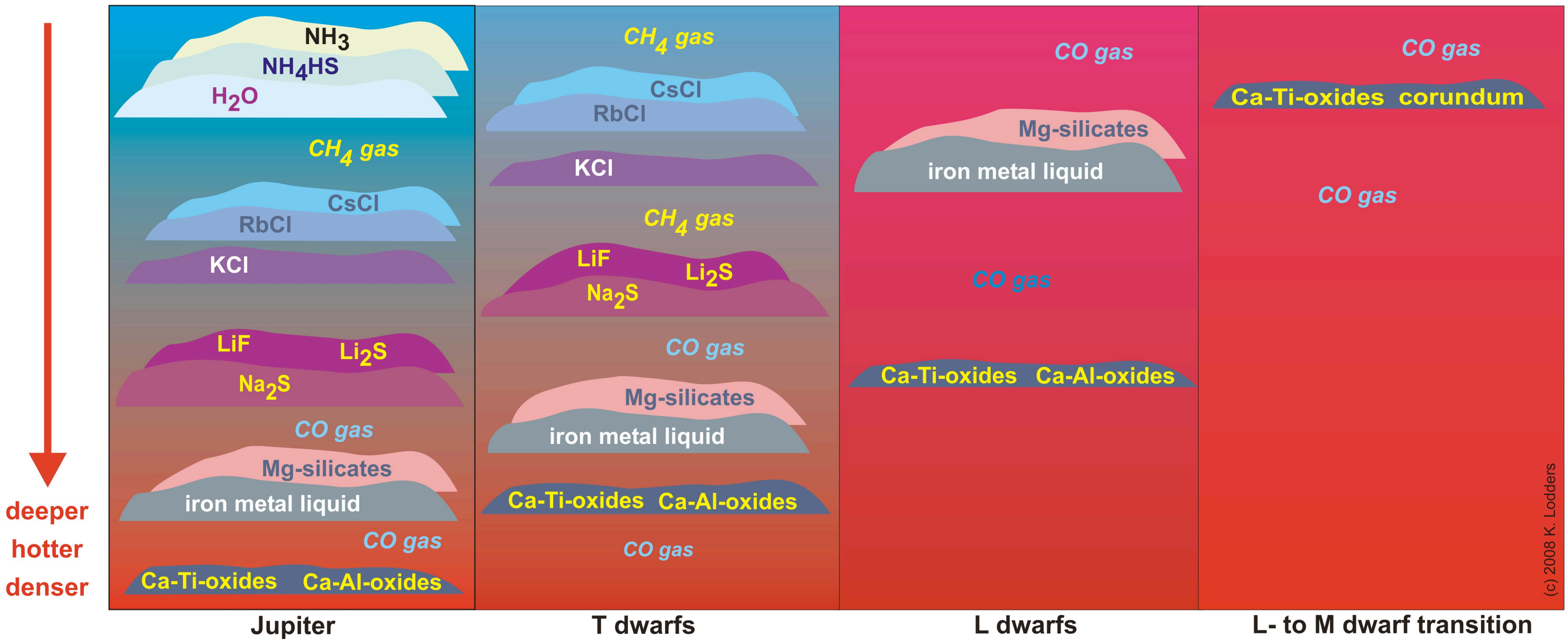


Marley et al. (2002)

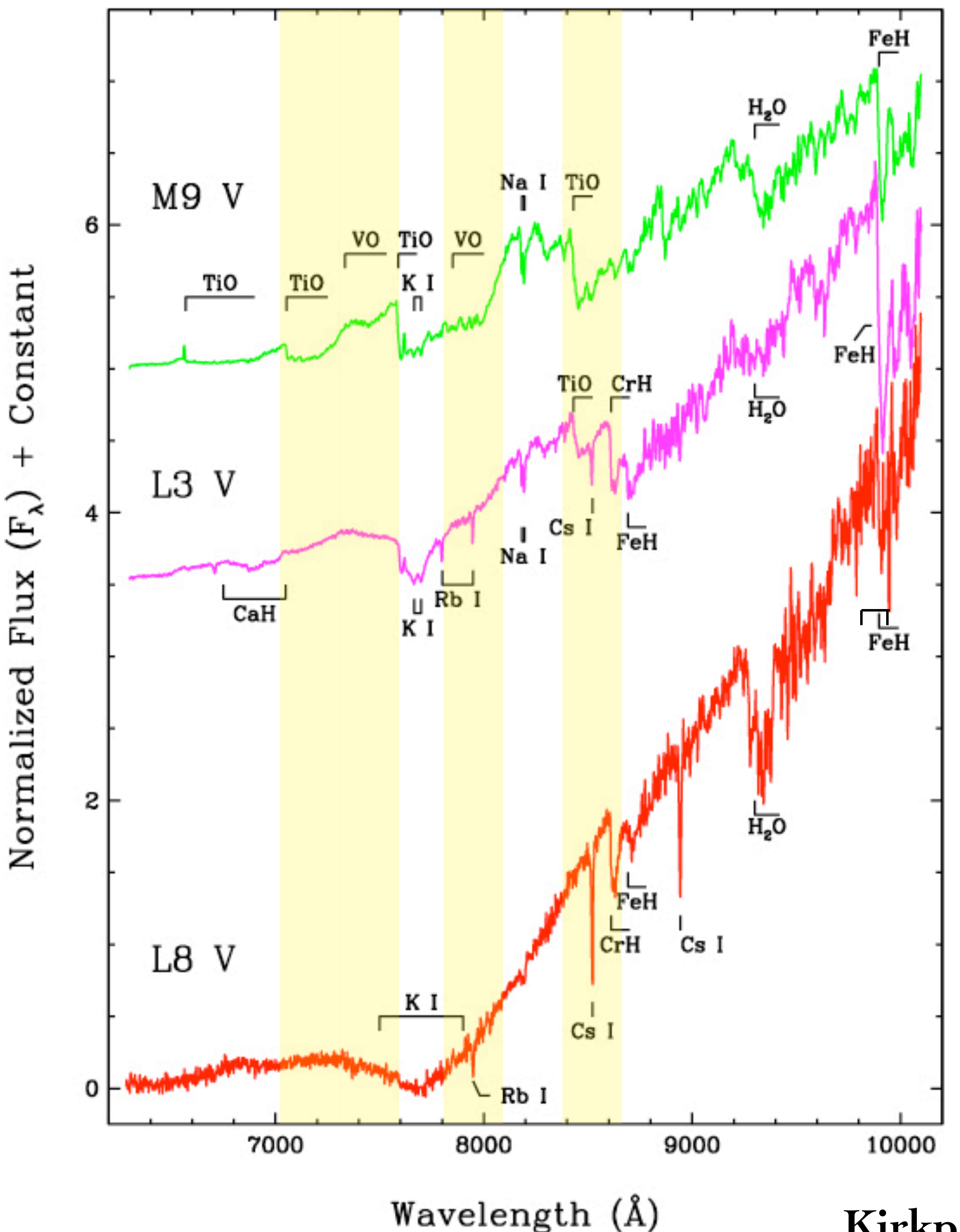
At the atmospheric temperatures and pressures of late-M and L dwarfs, several gaseous species form condensates.

e.g.:

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



Lodders & Fegley (2006)

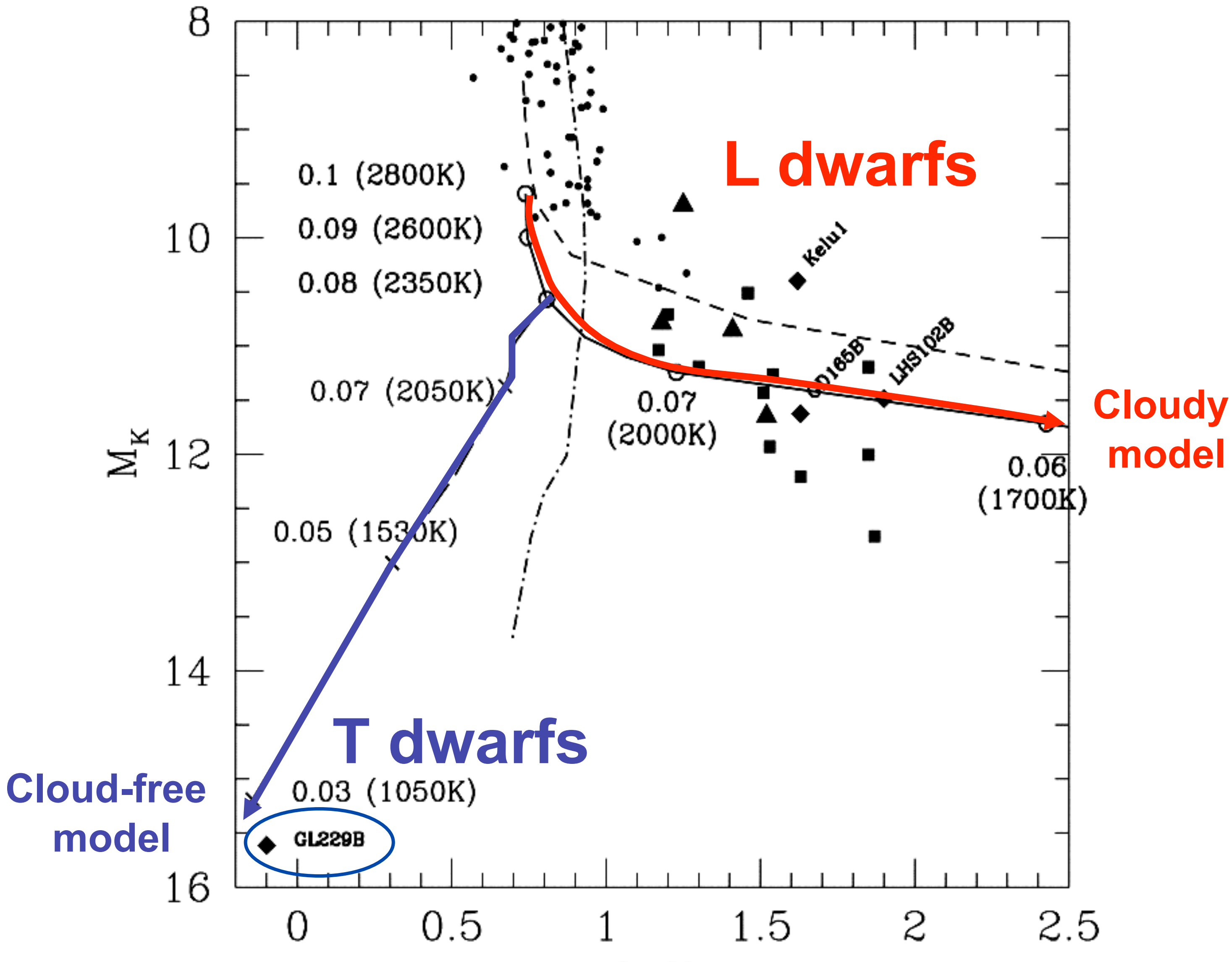


Condensation

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

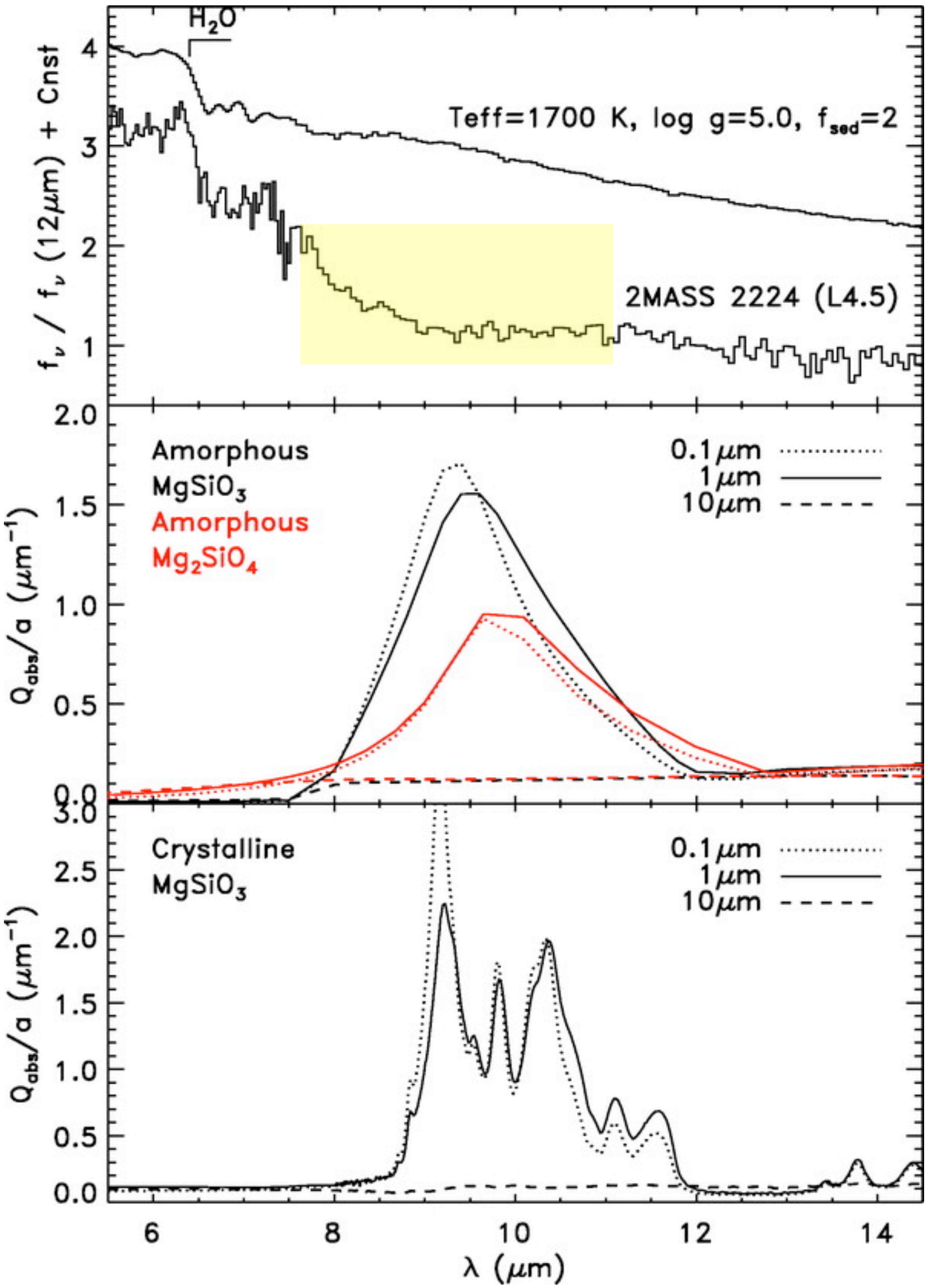
Removal of opacity strengthens other features, notably alkalis

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)



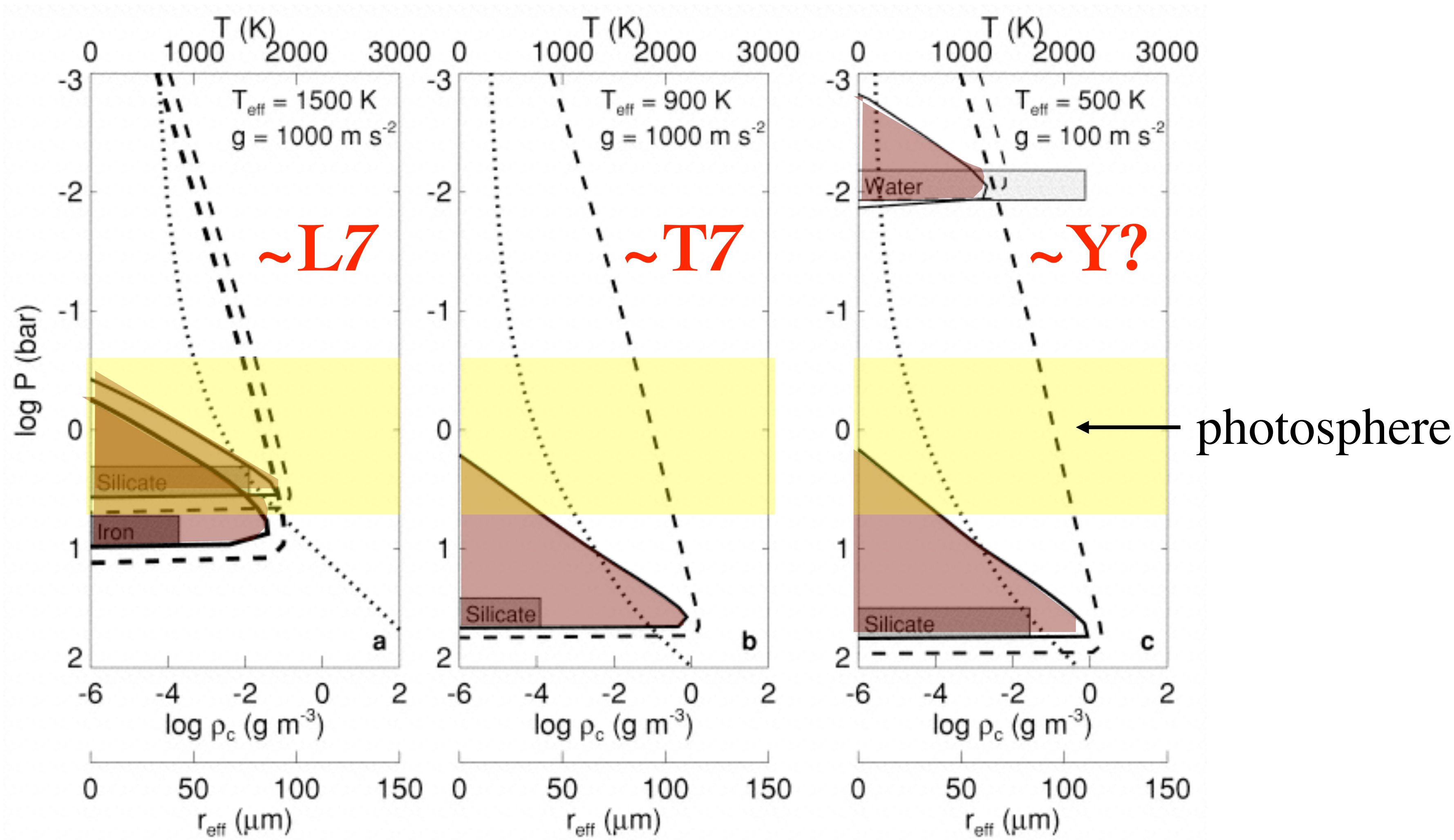
Direct detection of condensates

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)

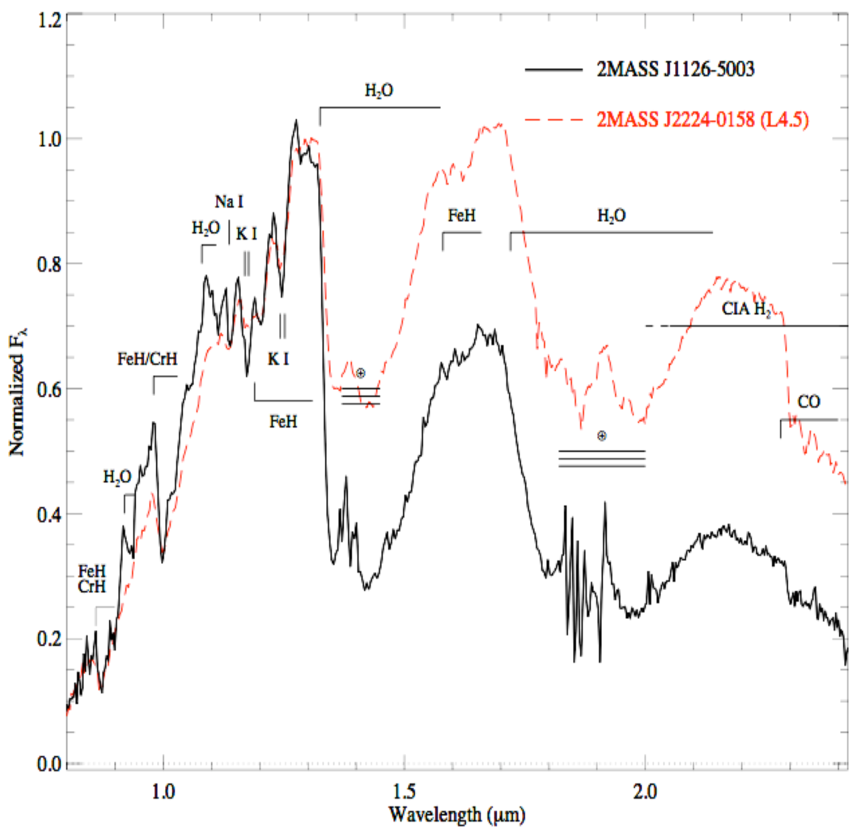
Clouds in L Dwarfs

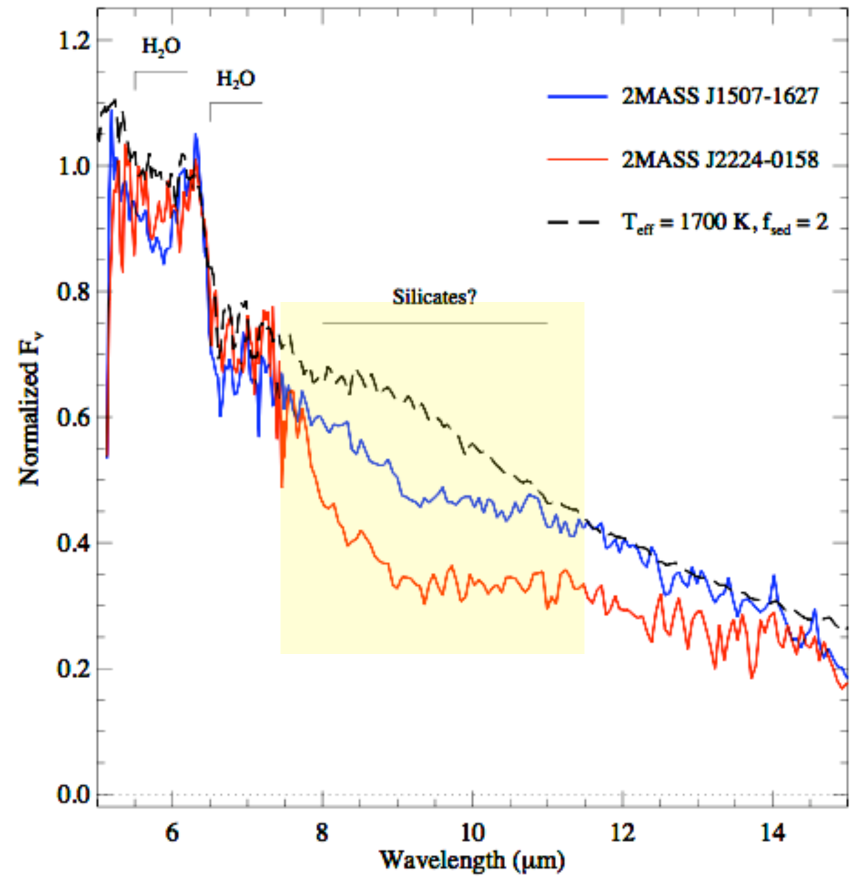


Ackerman & Marley (2001)

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

Cloud Variations



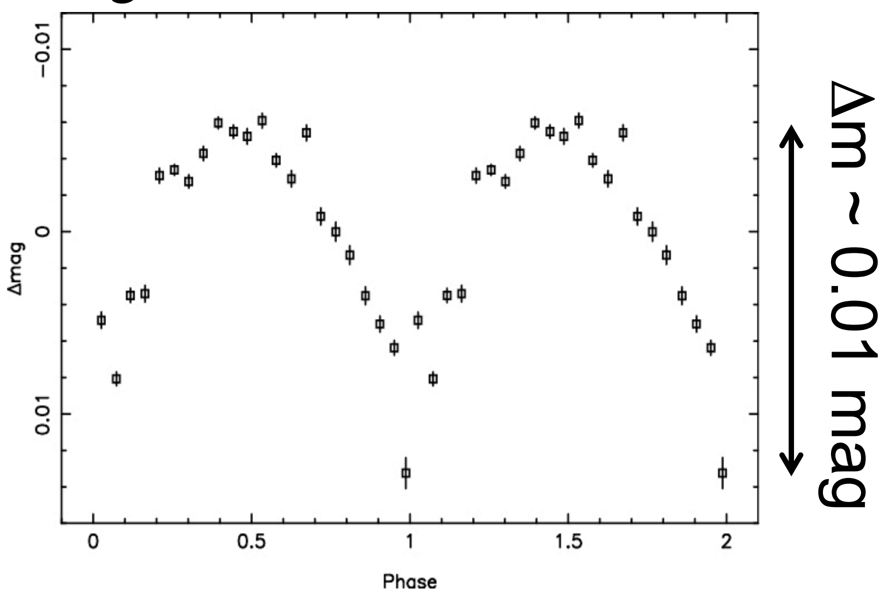


Burgasser et al. (2008)

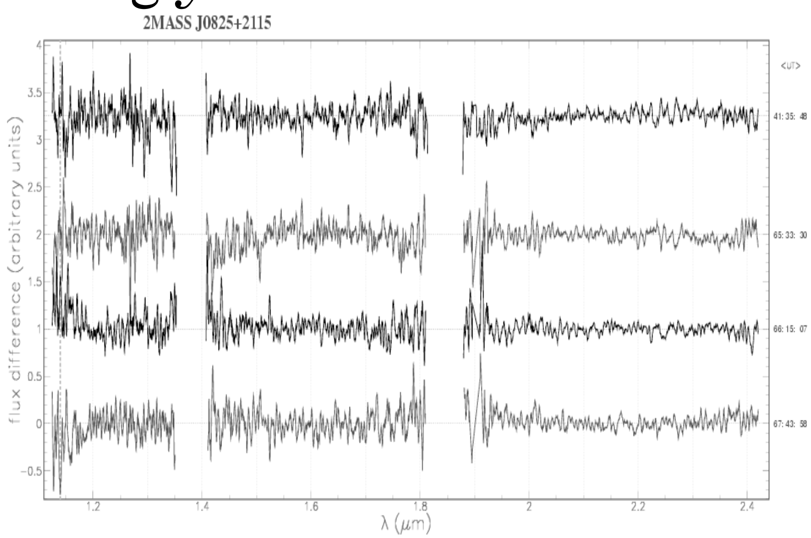
see also McLean et al. (2003); Knapp et al. (2004); Cruz et al. (2007); Cushing et al. (2008)

Temporal variations?

the good…



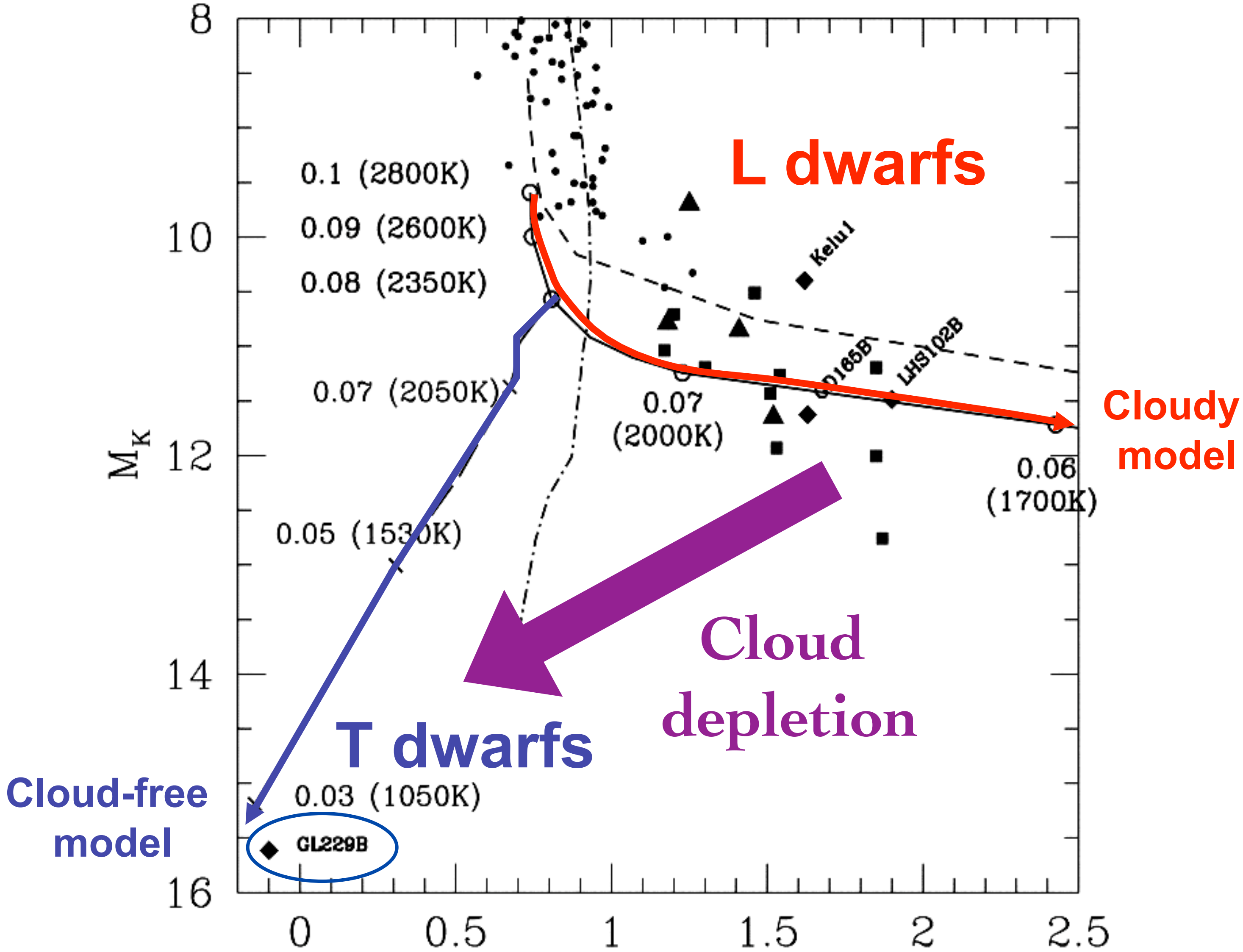
the ugly…



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)



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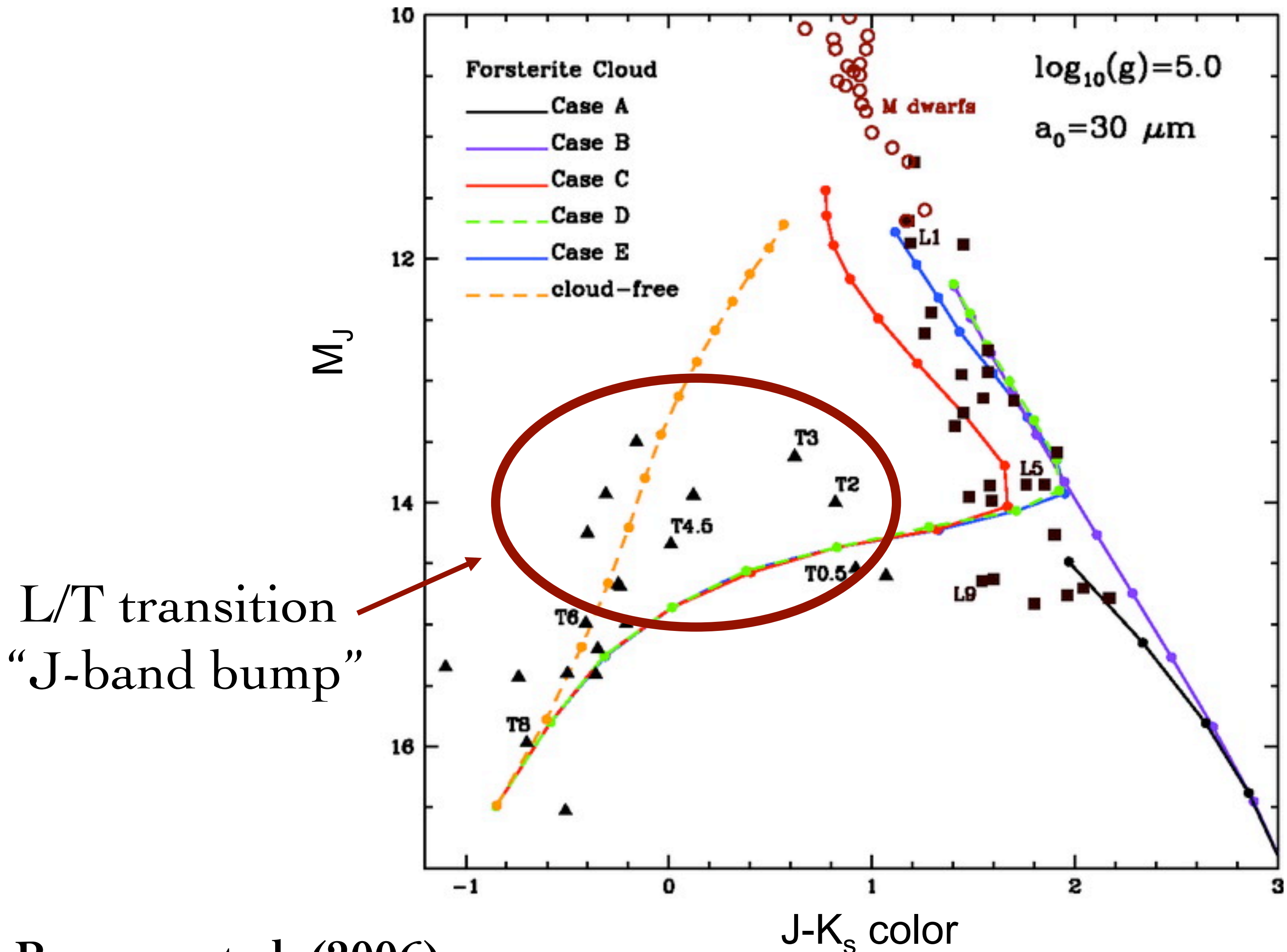
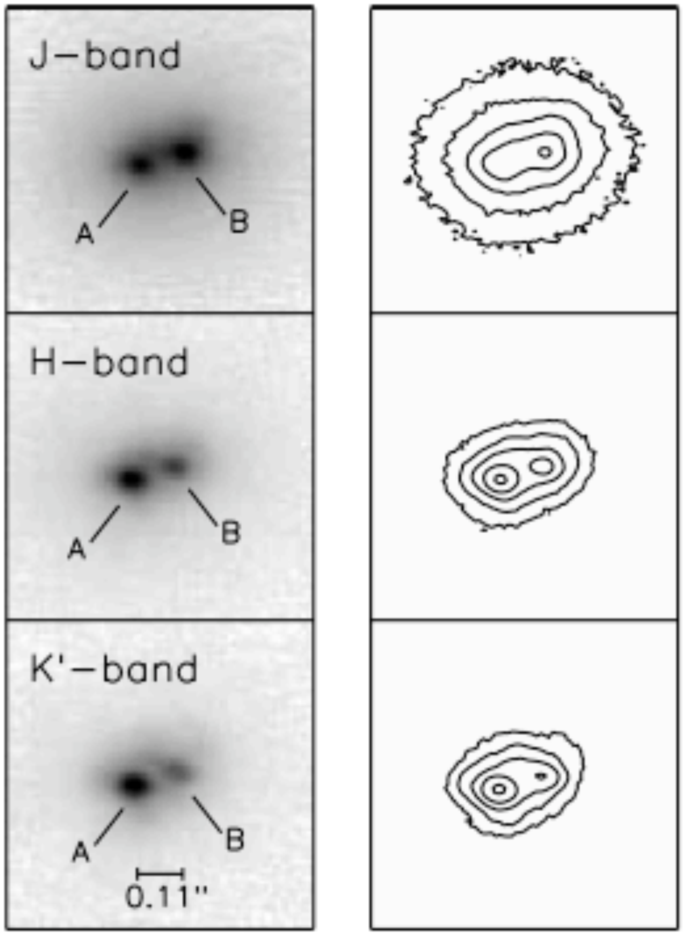
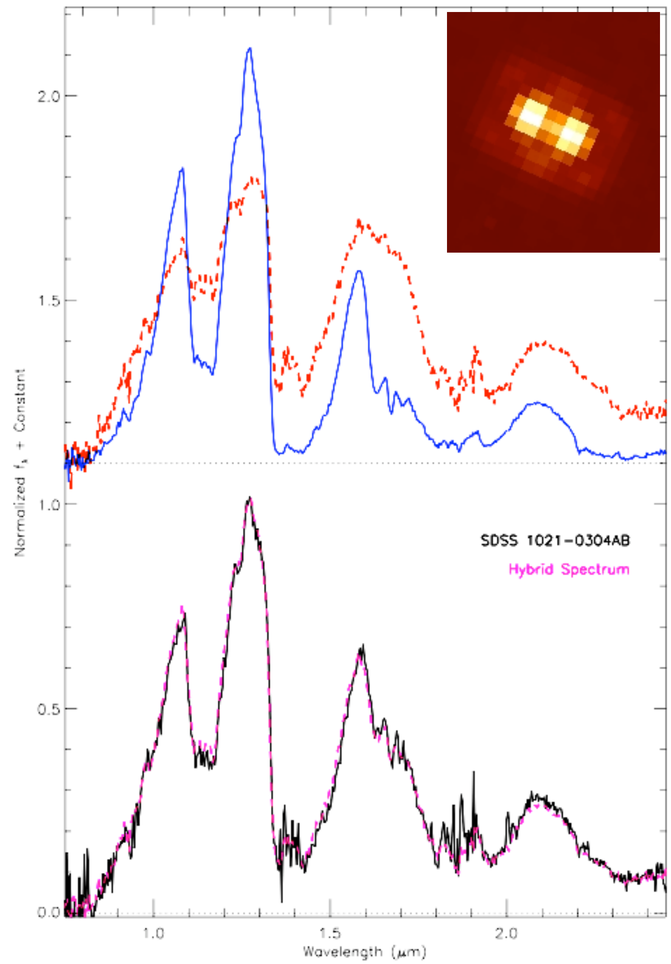


Burrows et al. (2006)

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

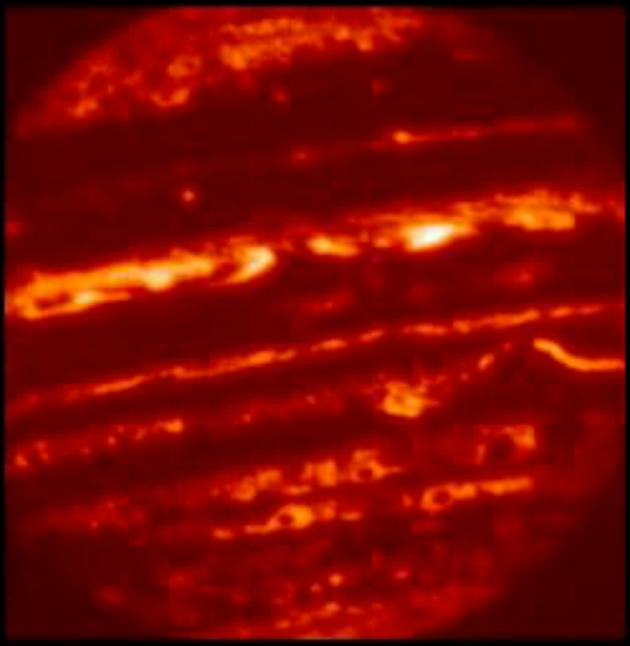




Liu et al. (2006); Burgasser et al. (2006)

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…

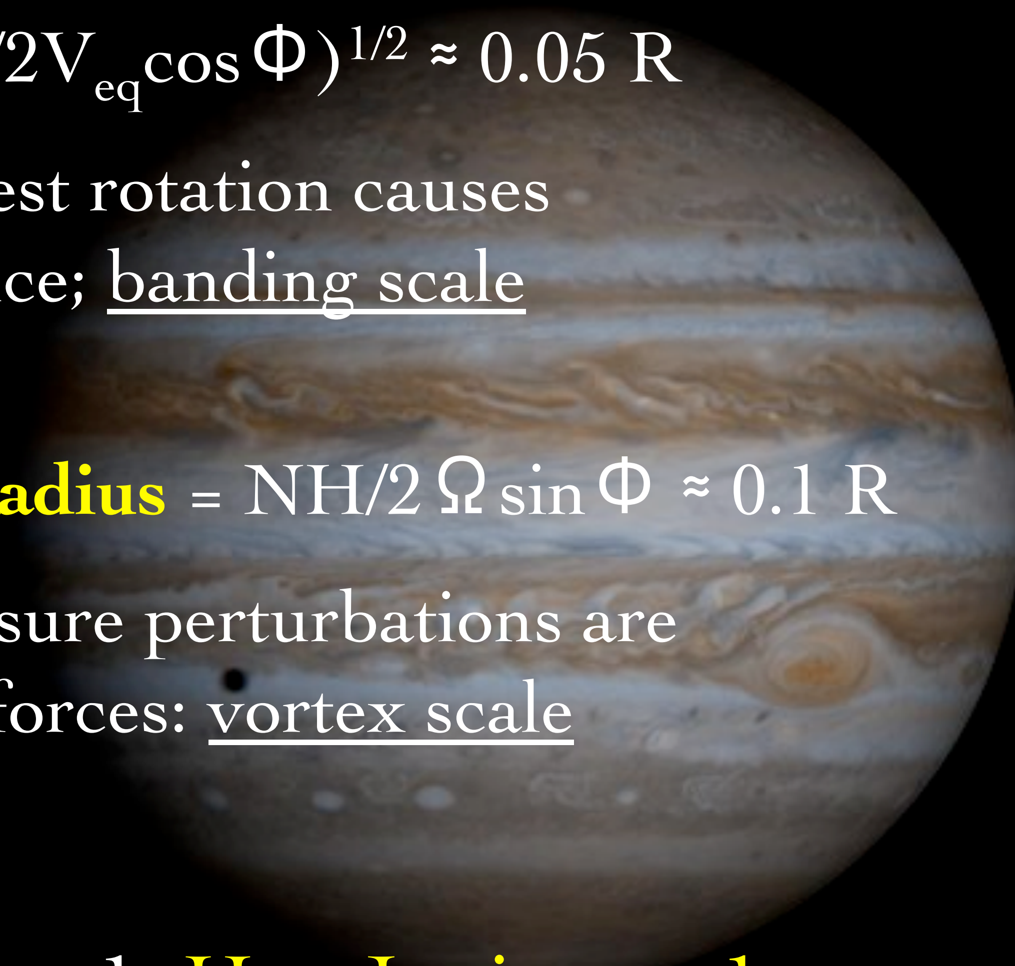
Several warm EPs have L/T transition T_{eff}s

Rhines Length = $R\times(U/2V_{eq}\cos\Phi)^{1/2} \approx 0.05\ R$

Scale at which east-west rotation causes elongation of turbulence; banding scale

Rossby Deformation Radius = $NH/2\Omega\sin\Phi \approx 0.1\ R$

Scale over which pressure perturbations are tempered by Coriolis forces: vortex scale



Jupiter, Saturn << 1; Hot Jupiters ≈ 1

brown dwarfs probably have global structures

Summary

Brown dwarfs & exoplanets share physical properties, but differ in fundamental ways – care must be taken in drawing analogies

Condensate clouds are prominent in brown dwarf & exoplanet atmospheres, dynamical (mixing) effects must be considered for both evolution & structure