Basic Brown Dwarf Science

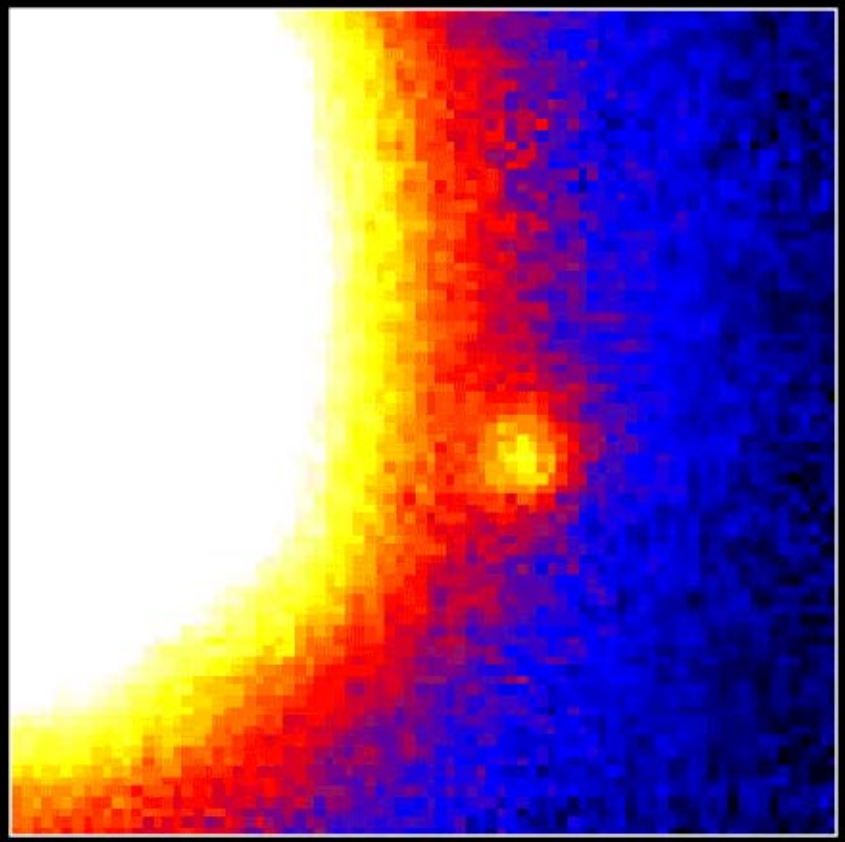
Theory and Astronomy:

1) Brown Dwarfs;

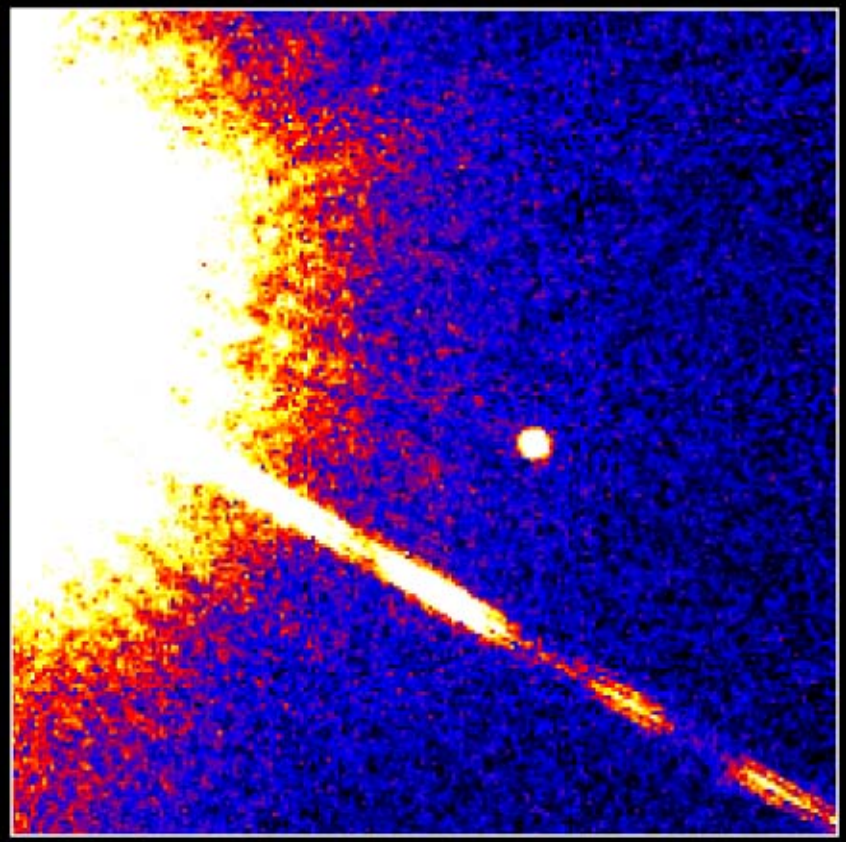
2) Similarities with Extrasolar Giant Planets

Scientific Themes: Physics, Chemistry, Structure, Spectra, Composition, Clouds, Evolution, Remote Sensing

Brown Dwarf Gliese 229B



Palomar Observatory
Discovery Image
October 27, 1994



Hubble Space Telescope
Wide Field Planetary Camera
November 17, 1995

PRC95-48 • ST ScI OPO • November 29, 1995 • T. Nakajima and S. Kulkarni (CalTech), S. Durrance and D. Golimowski (JHU), NASA

Brown Dwarf Exotica

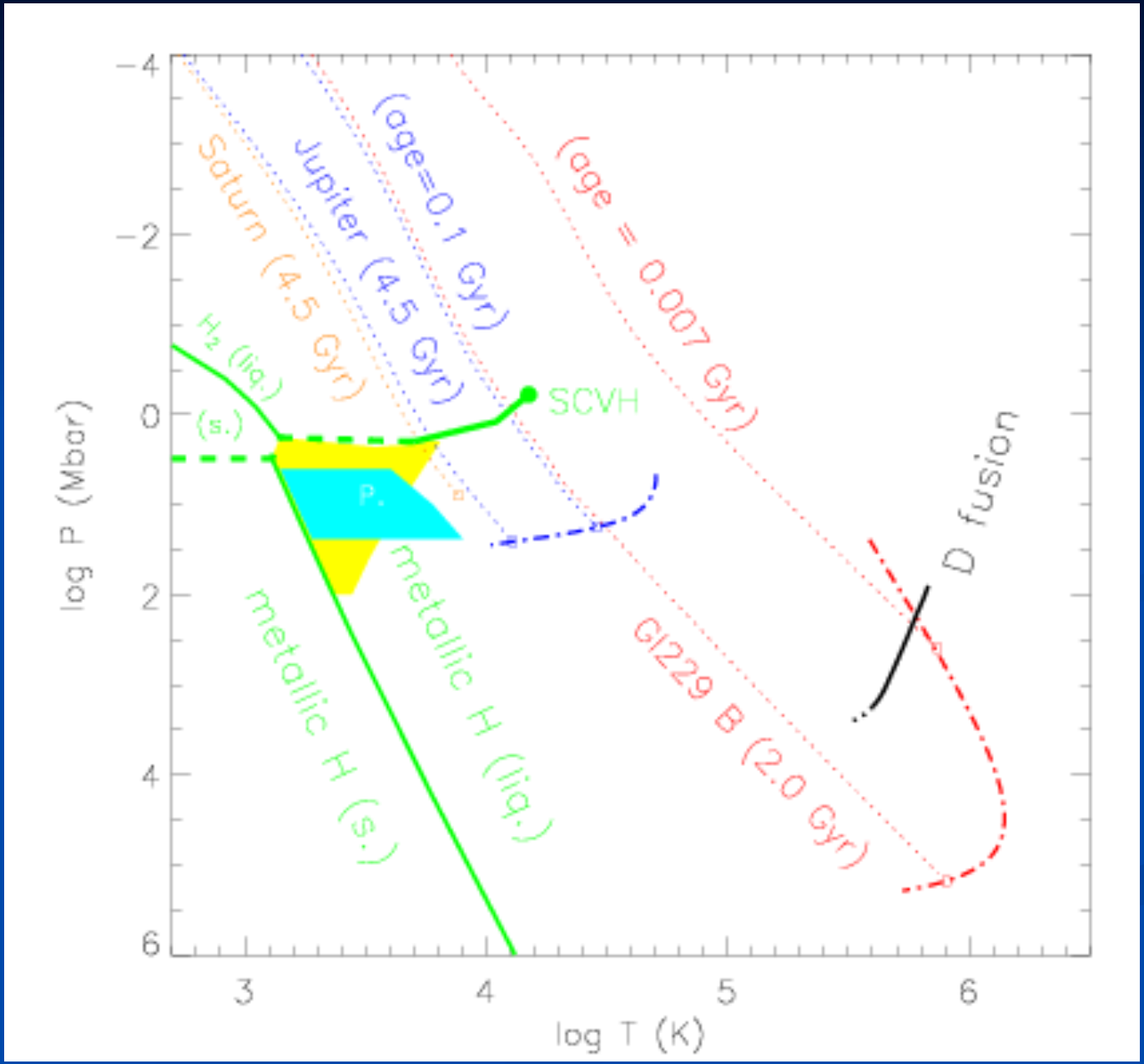
- Deuterium Burning
- Metallic H/He cores
- Molecular Atmospheres
- H_2, H_2O, CH_4, CO, N_2, NH_3, FeH, CrH, Na, K, silicates, …..
- $L < 6 \times 10^{-5} L_O$
- $R \sim 0.1 R_O$ for "all" masses
- $T_e < 1800$ K
- g ~ 1 to 300 g's
- Infrared
- Silicate clouds (L dwarfs)
- Depleted atmospheres (rainout) in T dwarfs
- Broad alkali metal lines
- Mass function still rising at main-sequence edge
- *J, H, K* fluxes much higher that blackbody
- T dwarfs get <u>bluer</u> with decreasing T_e (in the IR)
- *J, Z* fluxes <u>increase</u> near L/T transition

EOS of H_2 :

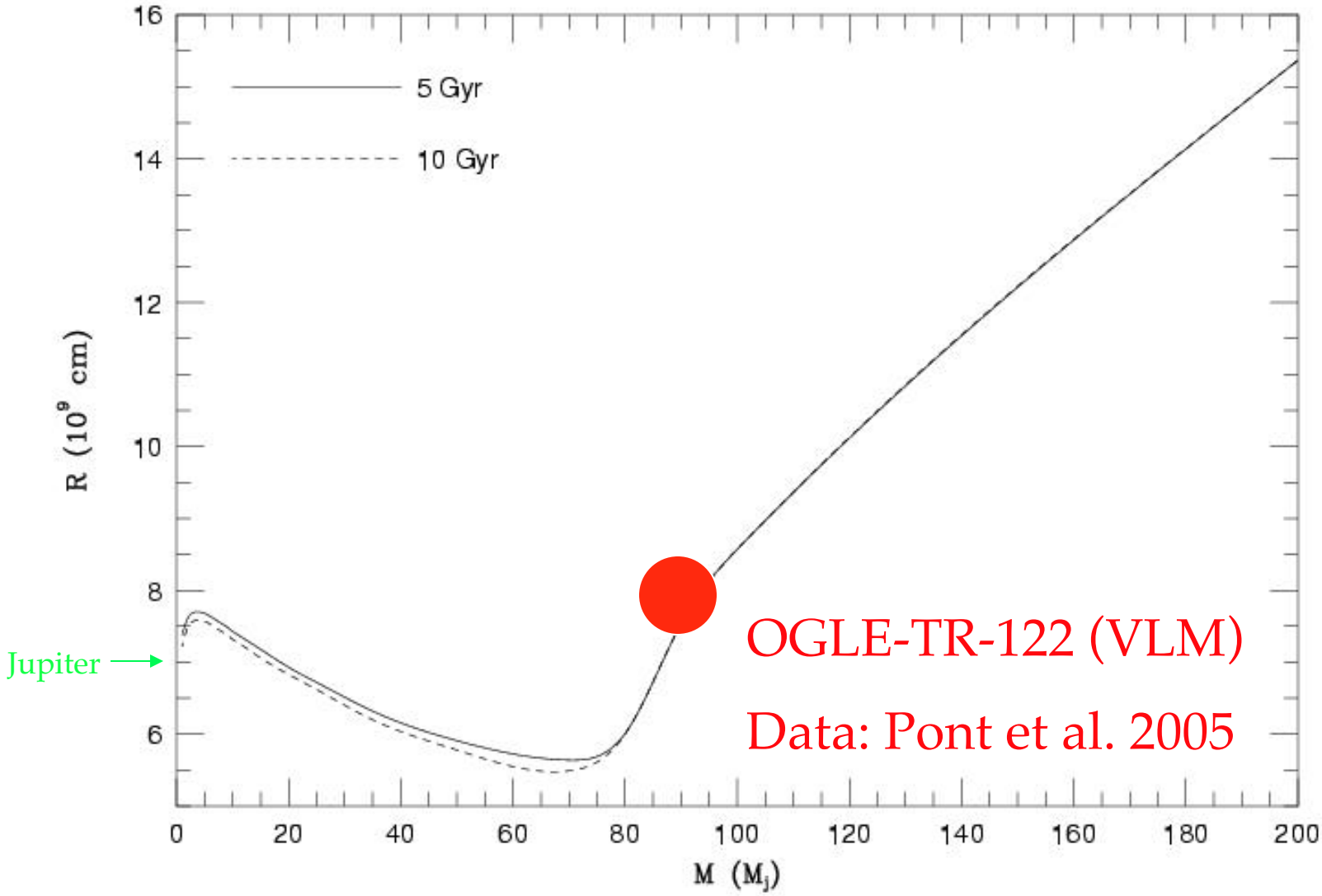
Coulomb interactions vs.

electron degeneracy

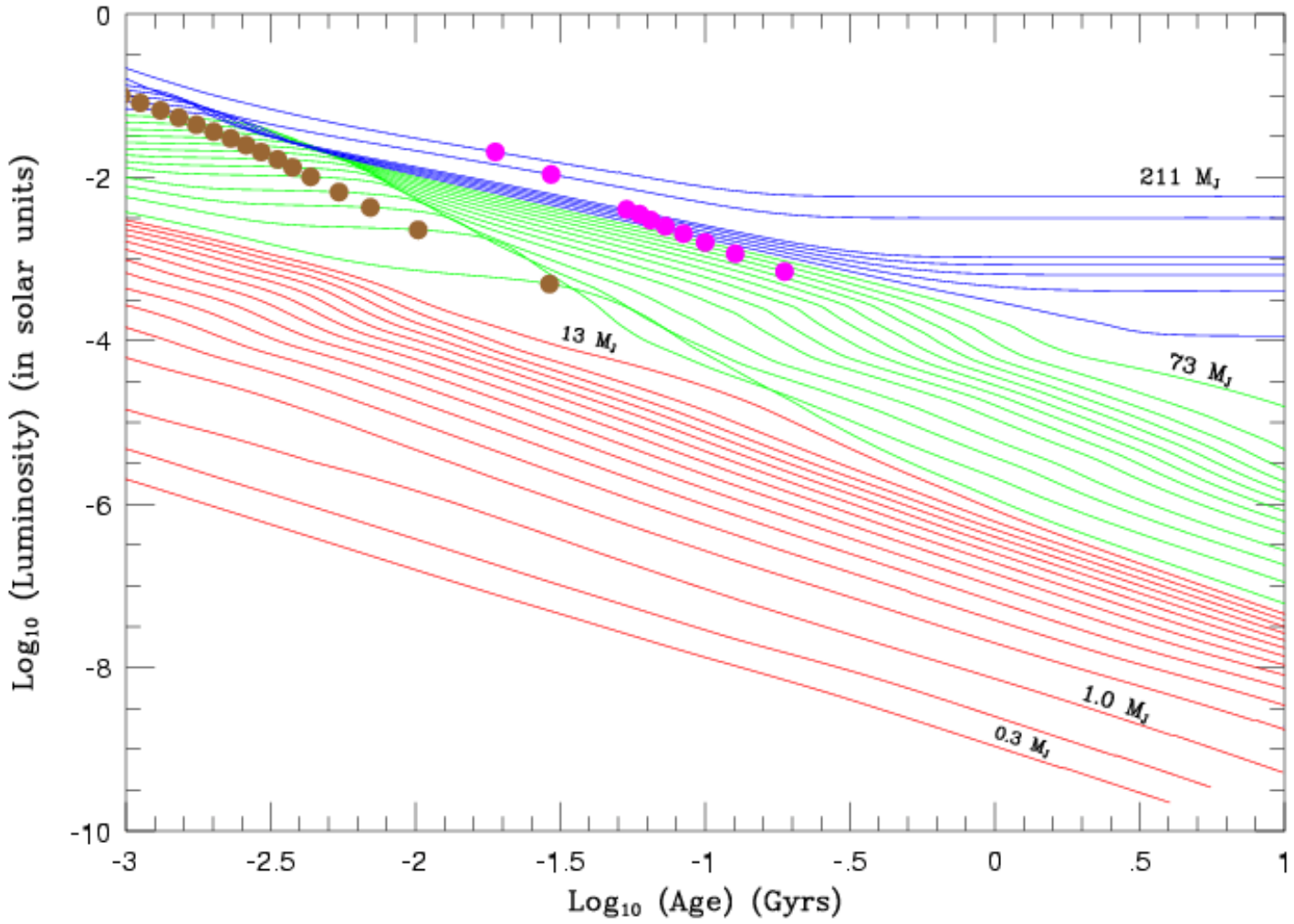
Wigner and Huntington (1935)



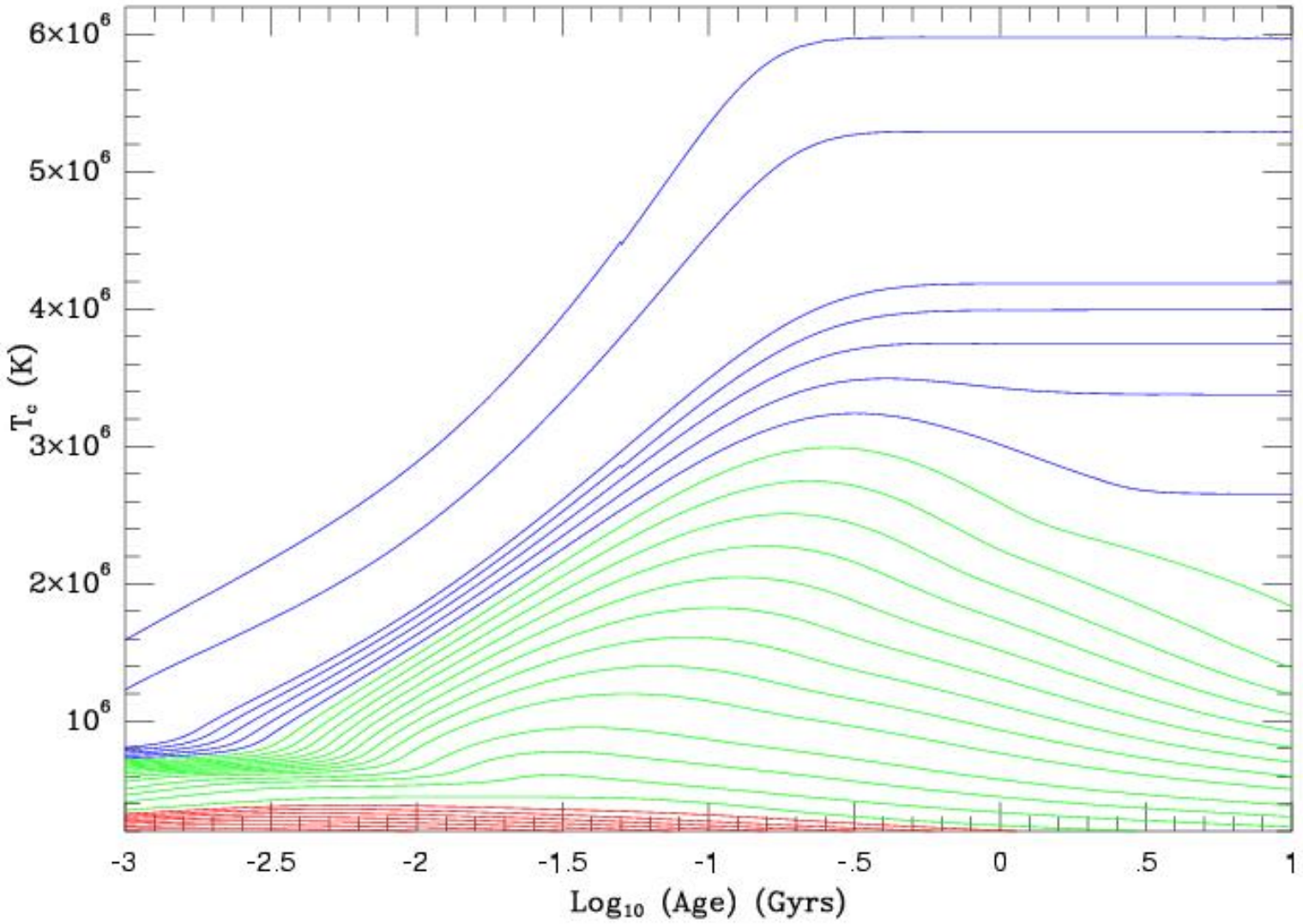
Radius-Mass Relation

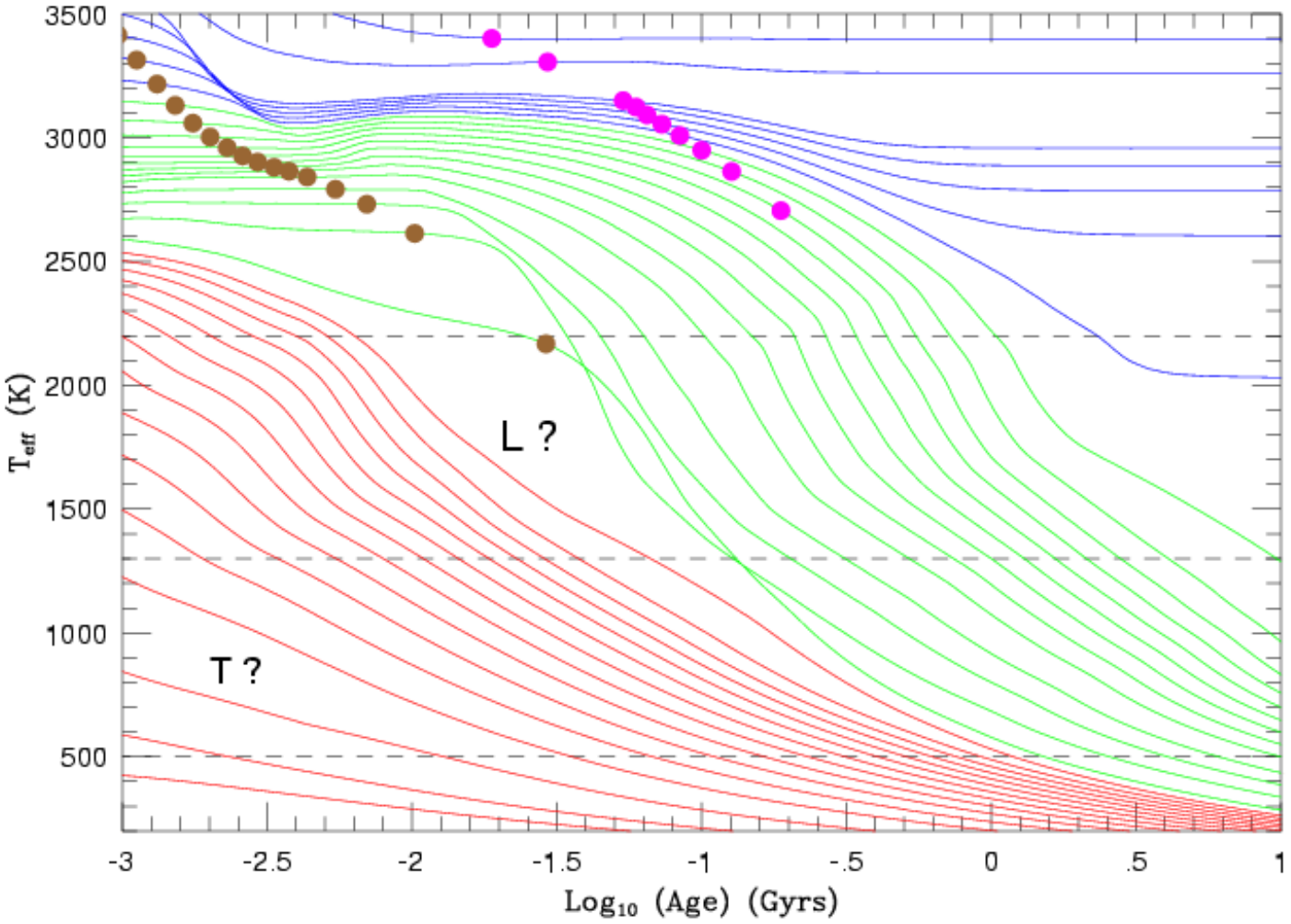


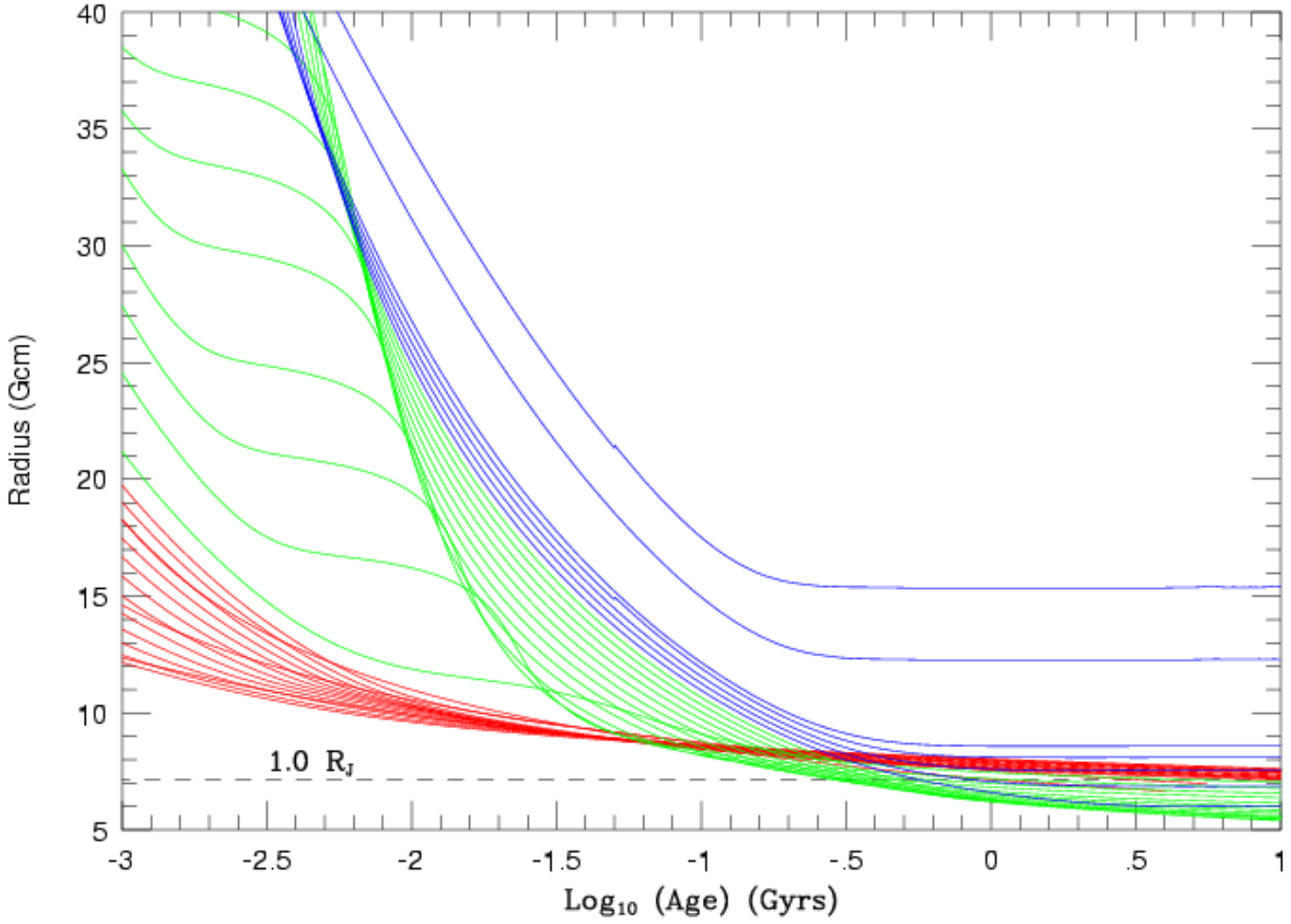
Luminosity vs. Age vs. Mass

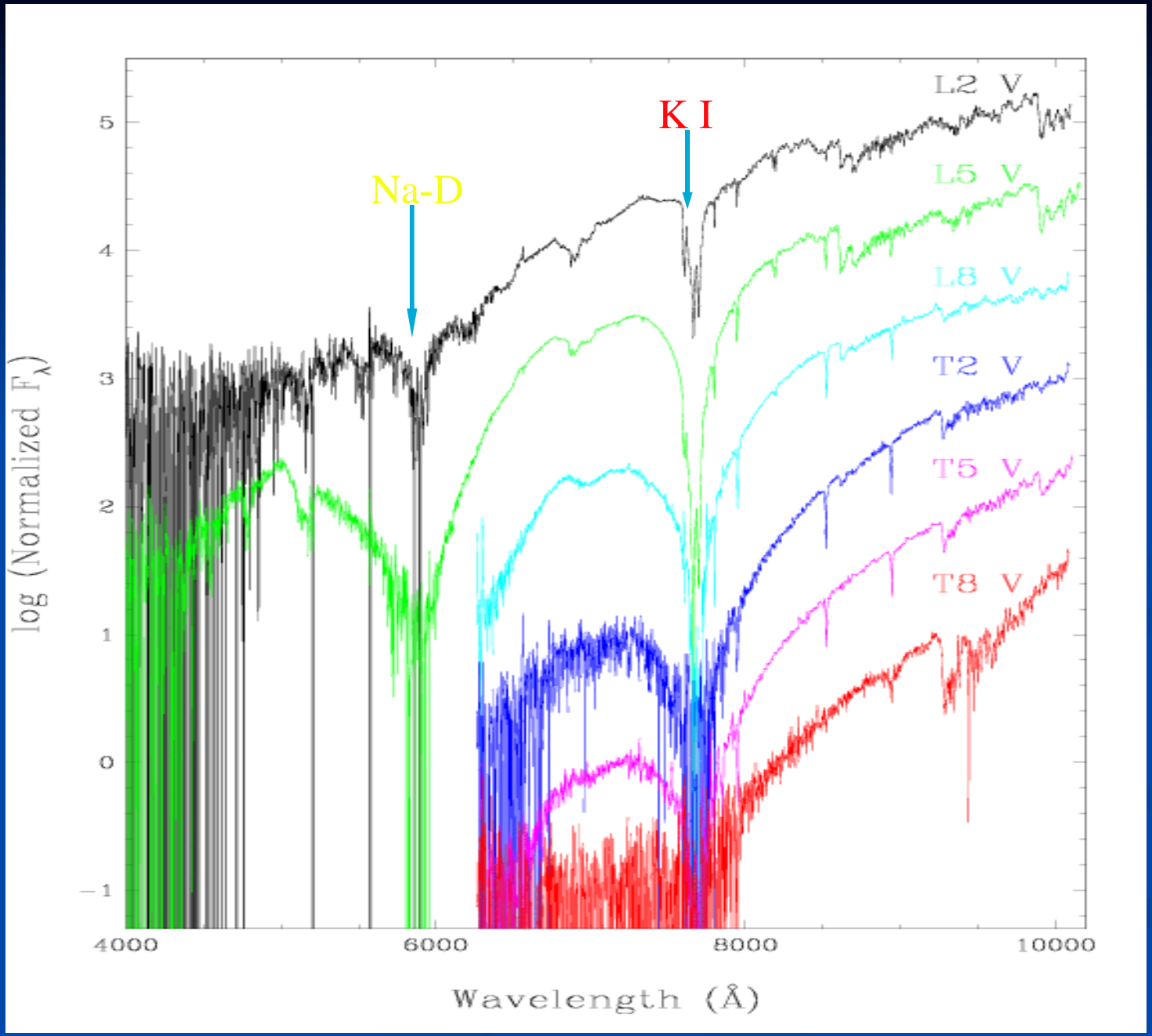


Burrows et al. 1997; Burrows et al. 2001


6×10^6
5×10^6
4×10^6
3×10^6
2×10^6
10^6
T_c (K)
-3
-2.5
-2
-1.5
-1
-.5
0
.5
1
Log10 (Age) (Gyrs)

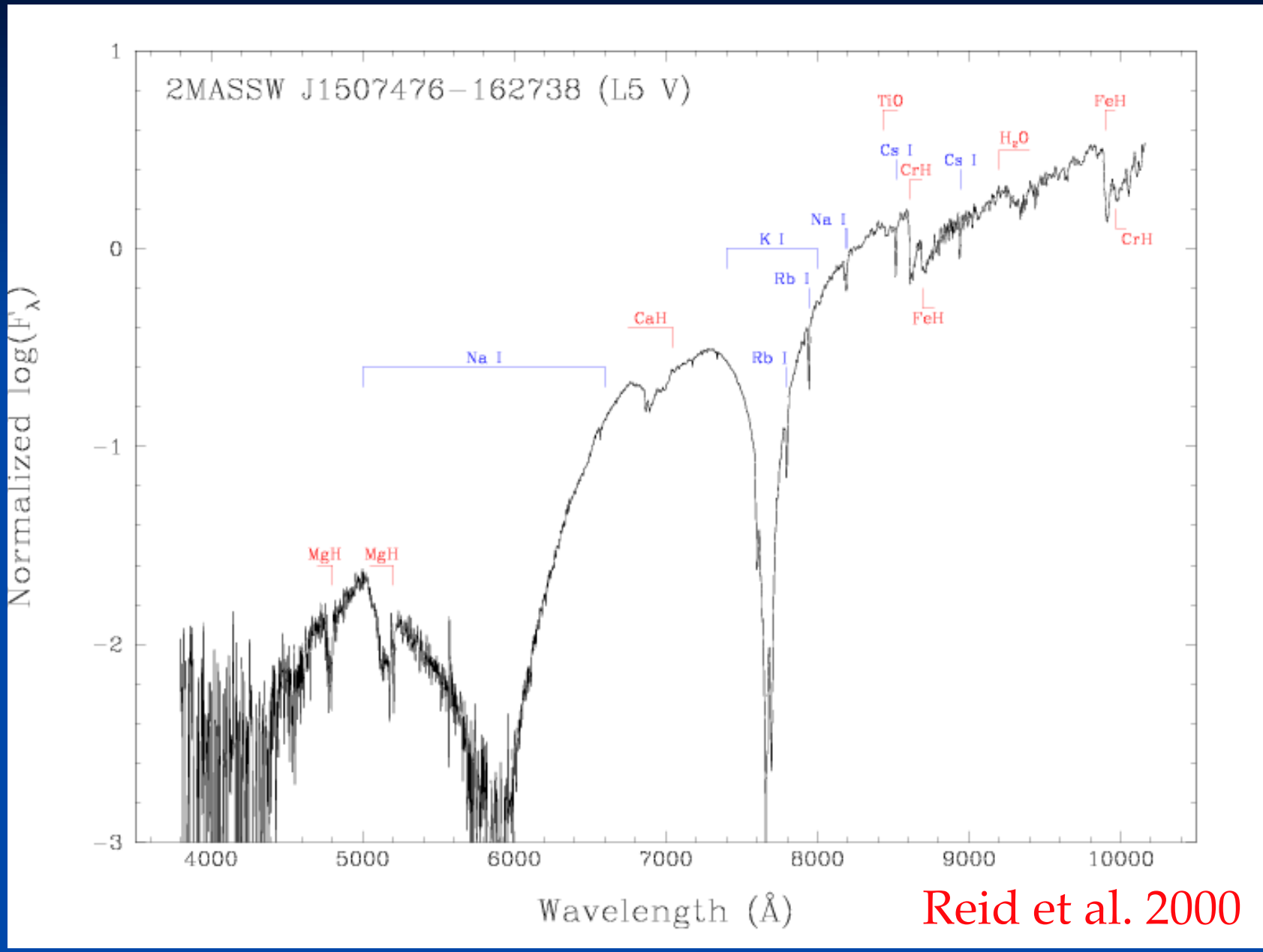

3500
3000
2500
2000
1500
1000
500
T_{eff} (K)
L ?
T ?
-3
-2.5
-2
-1.5
-1
-.5
0
.5
1
Log_{10} (Age) (Gyrs)


40
35
30
25
20
15
10
5
Radius (Gcm)
1.0 R_J
-3
-2.5
-2
-1.5
-1
-.5
0
.5
1
Log_{10} (Age) (Gyrs)

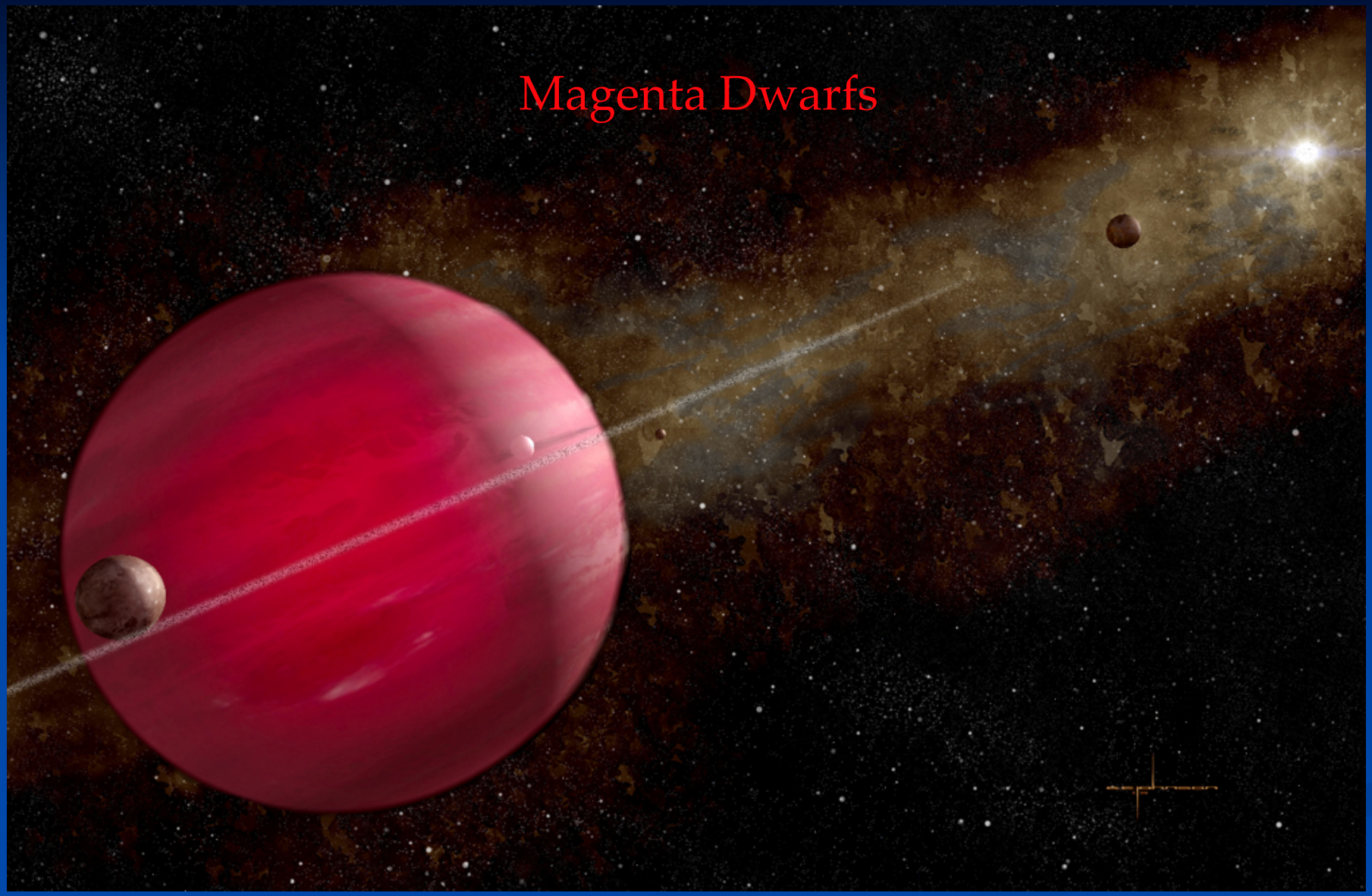


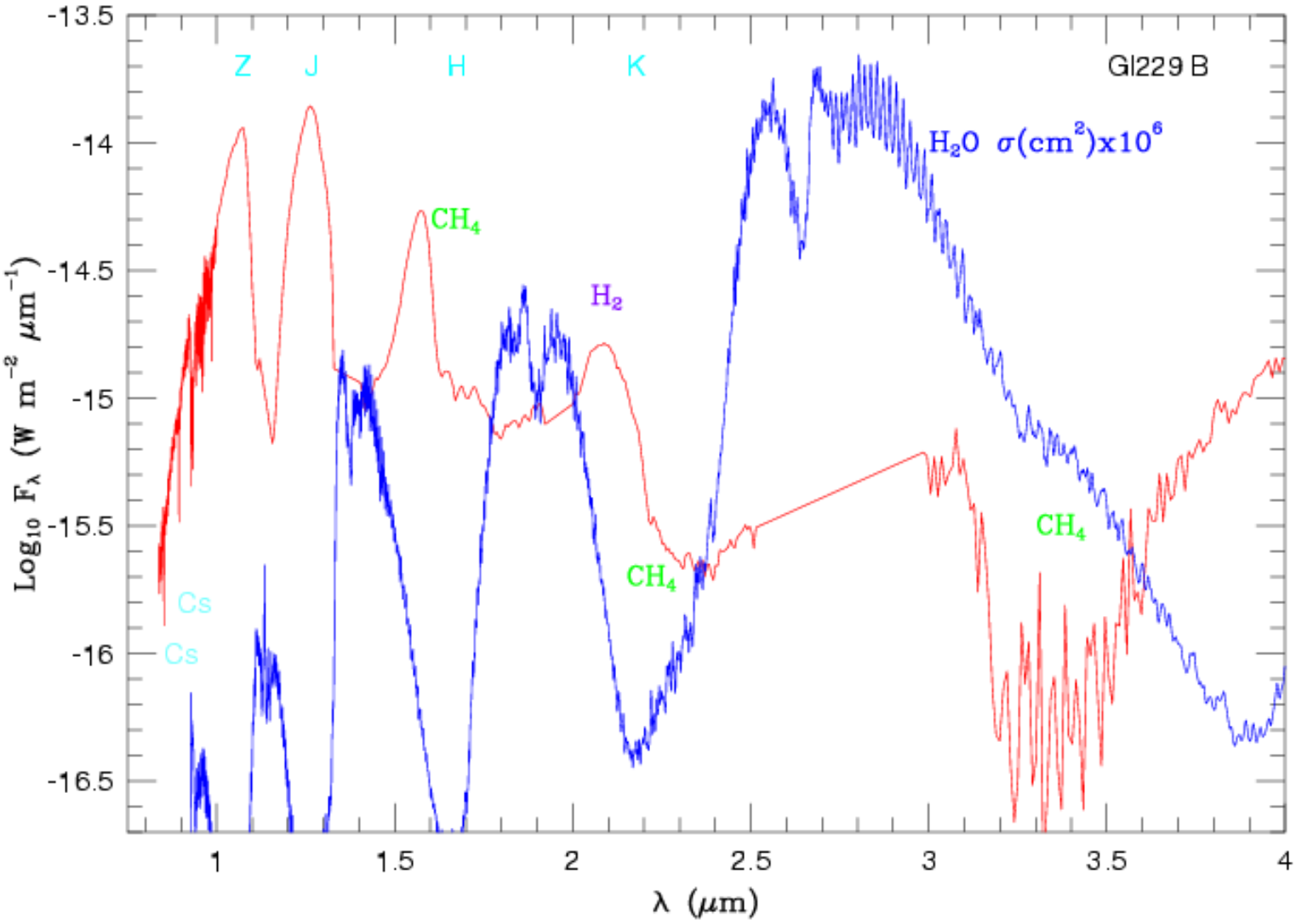
Burgasser et al. 2001

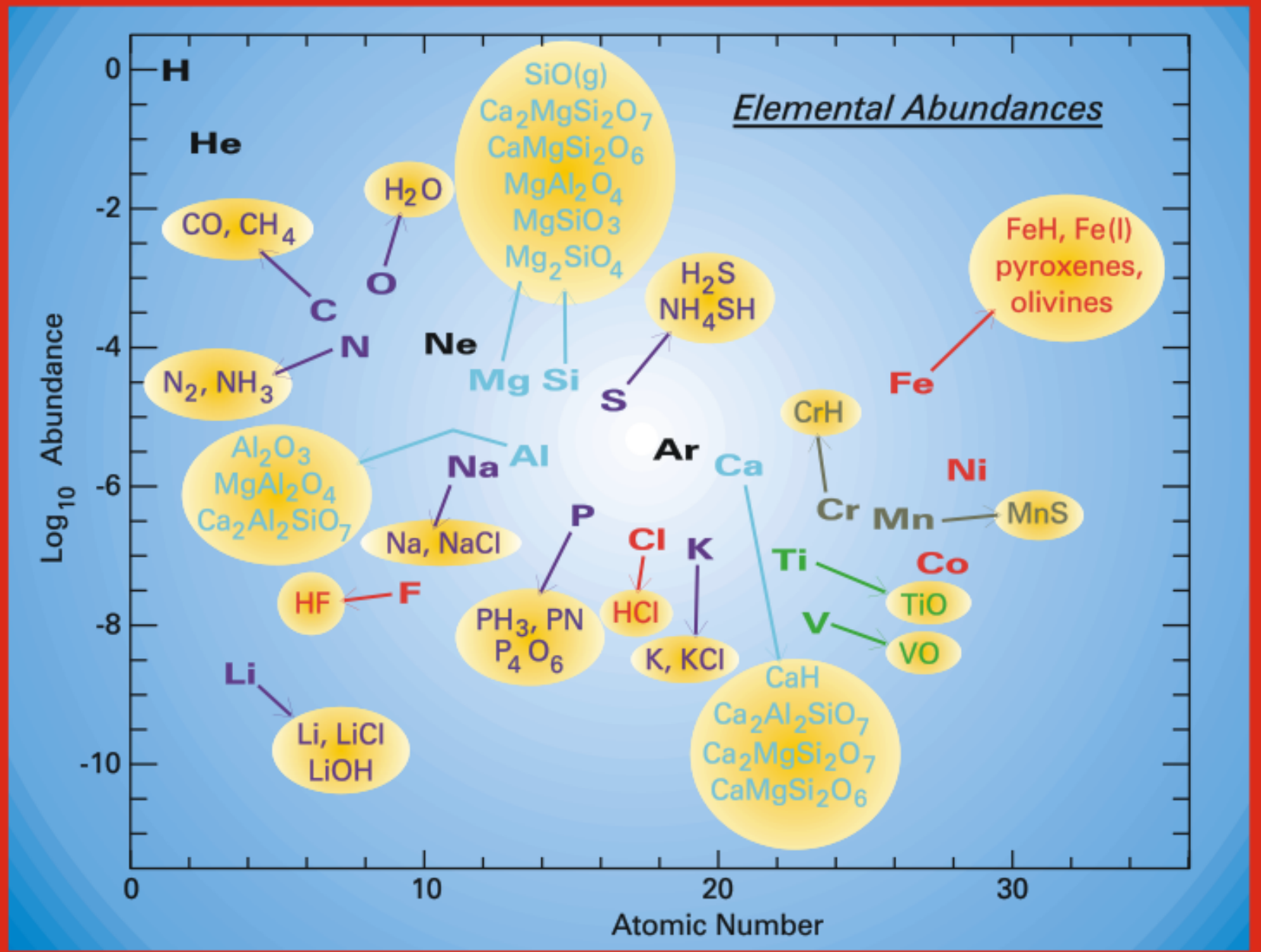
The Color of a Brown (L) Dwarf

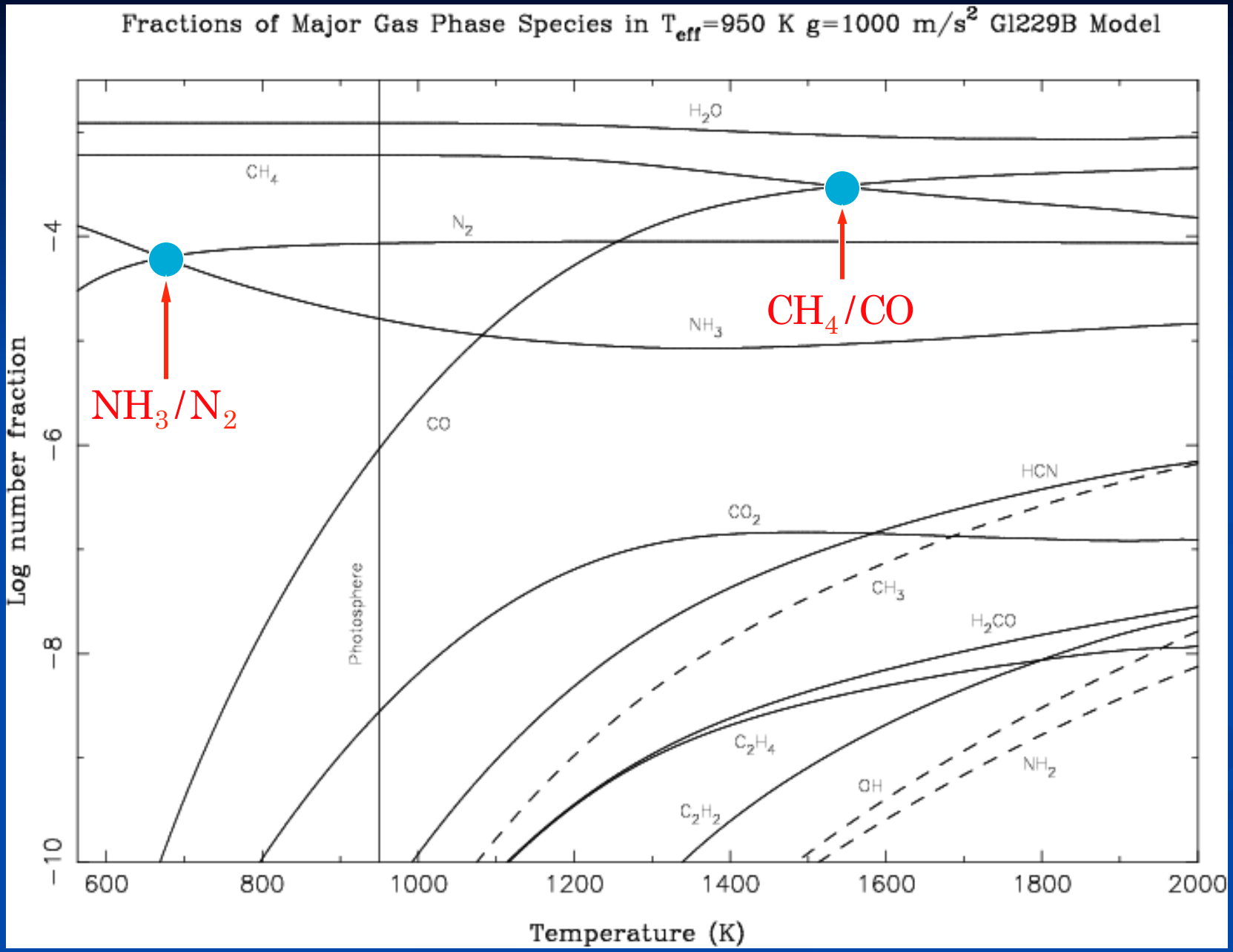


Reid et al. 2000

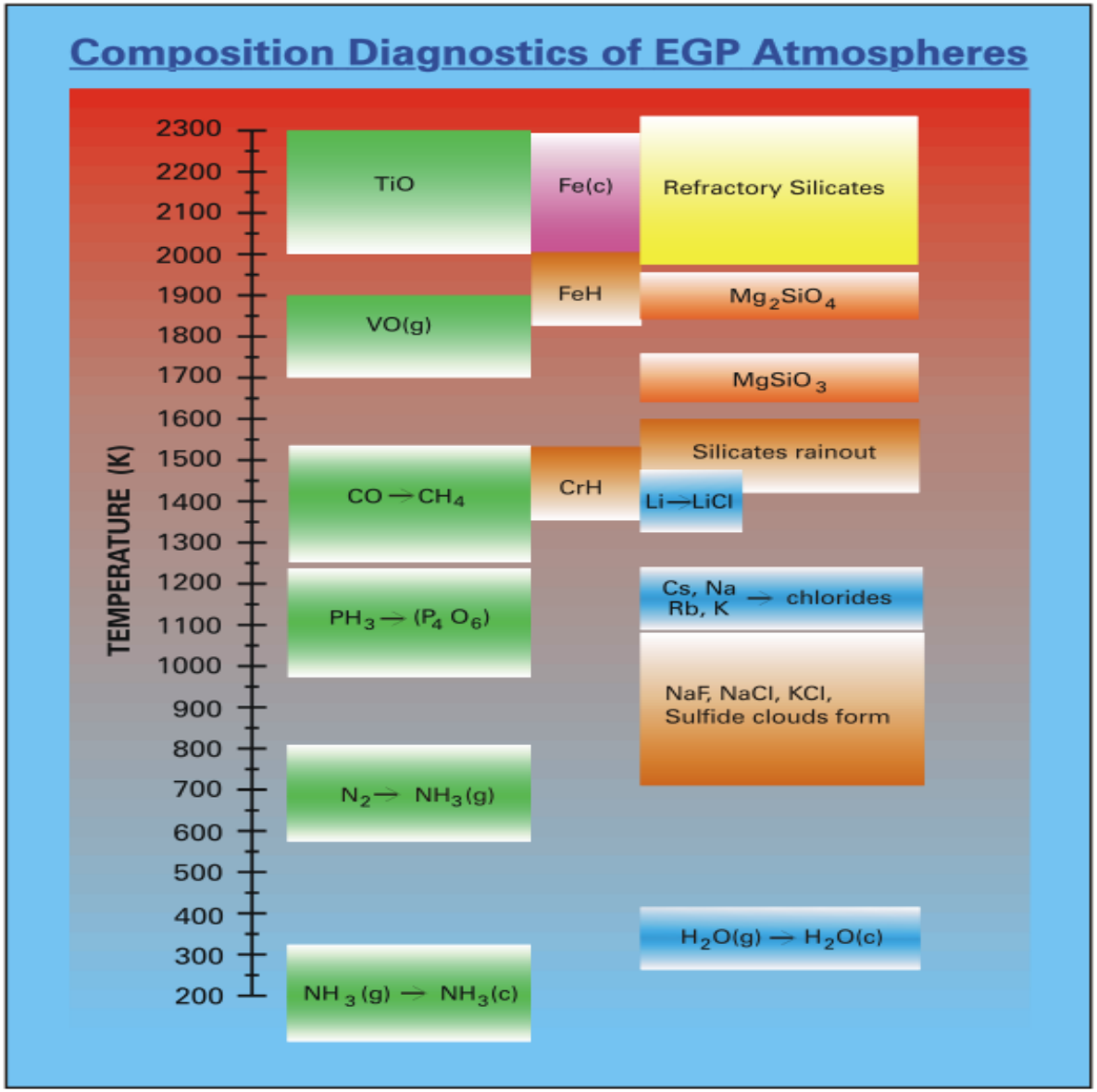

Magenta Dwarfs

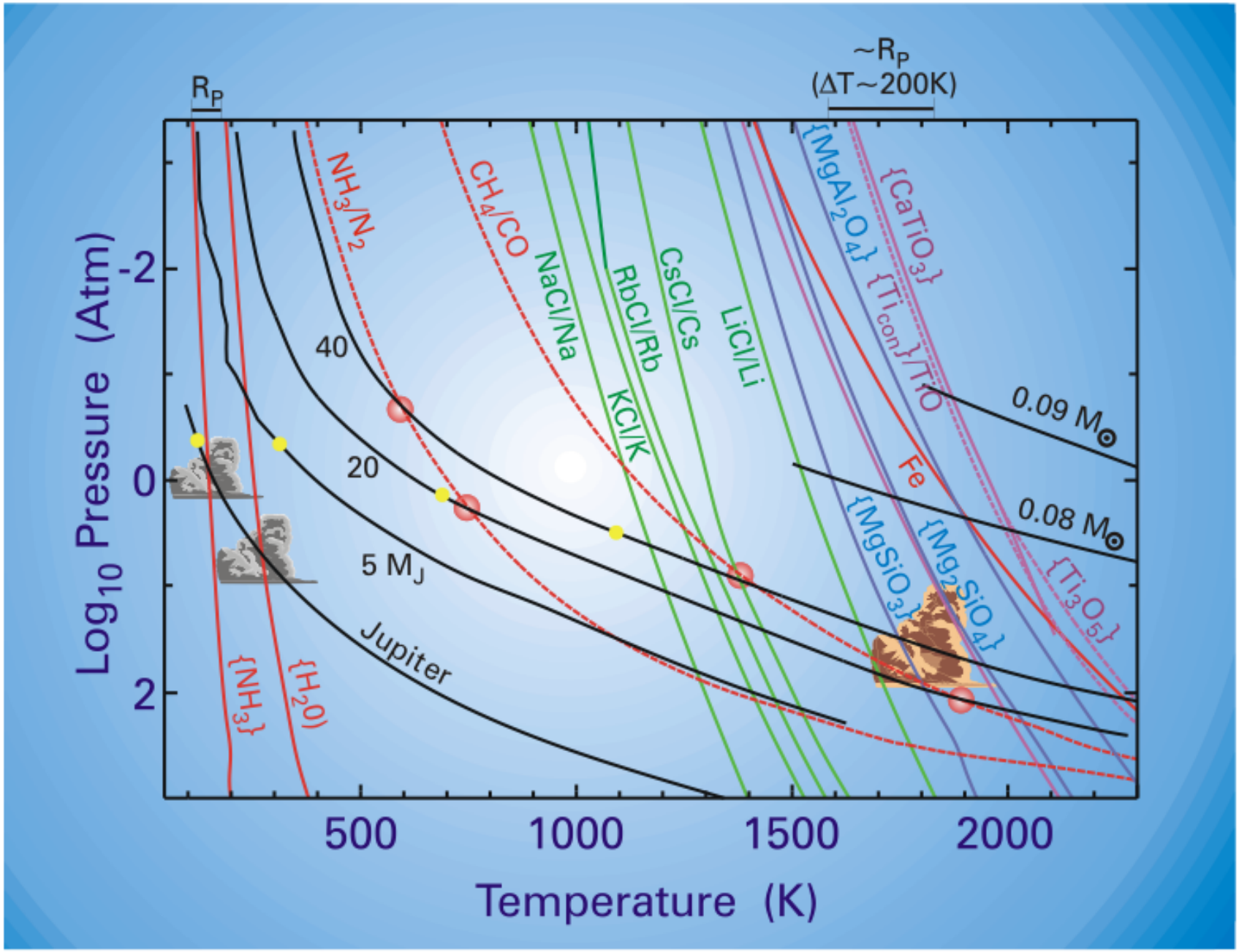

Z
J
H
K
Gl229 B
H_2O $\sigma(cm^2)x10^6$
CH_4
H_2
CH_4
CH_4
Cs
Cs
Log_{10} F_λ (W m^{-2} μm^{-1})
λ (μm)
-13.5
-14
-14.5
-15
-15.5
-16
-16.5
1
1.5
2
2.5
3
3.5
4

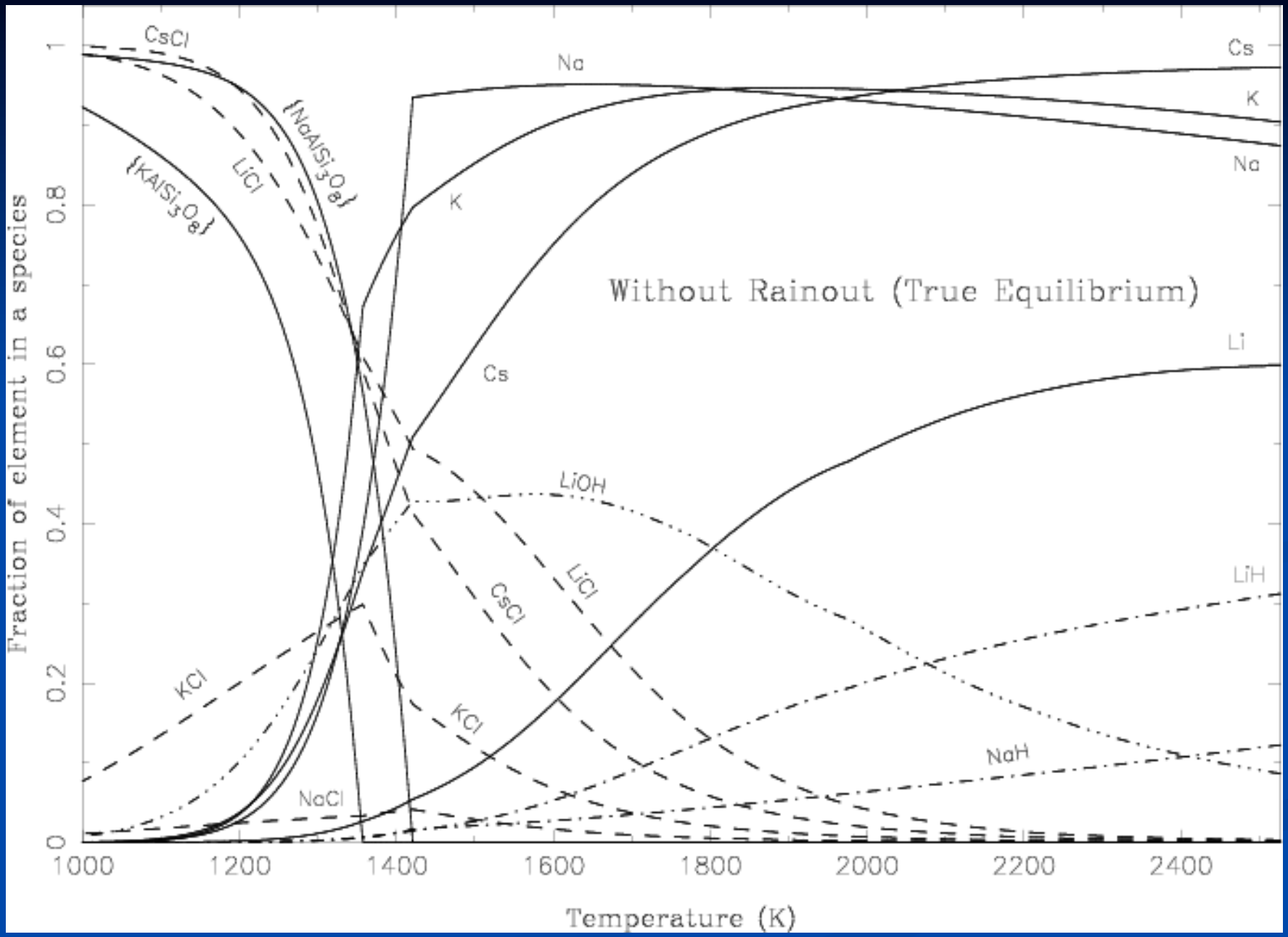

Elemental Abundances
H
He
SiO(g)
Ca2MgSi2O7
CaMgSi2O6
MgAl2O4
MgSiO3
Mg2SiO4
H2O
O
CO, CH4
C
N
N2, NH3
Ne
Mg
Si
H2S
NH4SH
S
FeH, Fe(l)
pyroxenes,
olivines
Fe
CrH
Cr
Ni
Mn
MnS
Co
Ti
TiO
V
VO
Al2O3
MgAl2O4
Ca2Al2SiO7
Al
Na
Na, NaCl
Ar
Ca
P
PH3, PN
P4O6
Cl
HCl
K
K, KCl
HF
F
Li
Li, LiCl
LiOH
CaH
Ca2Al2SiO7
Ca2MgSi2O7
CaMgSi2O6
Log10 Abundance
0
-2
-4
-6
-8
-10
0
10
20
30
Atomic Number

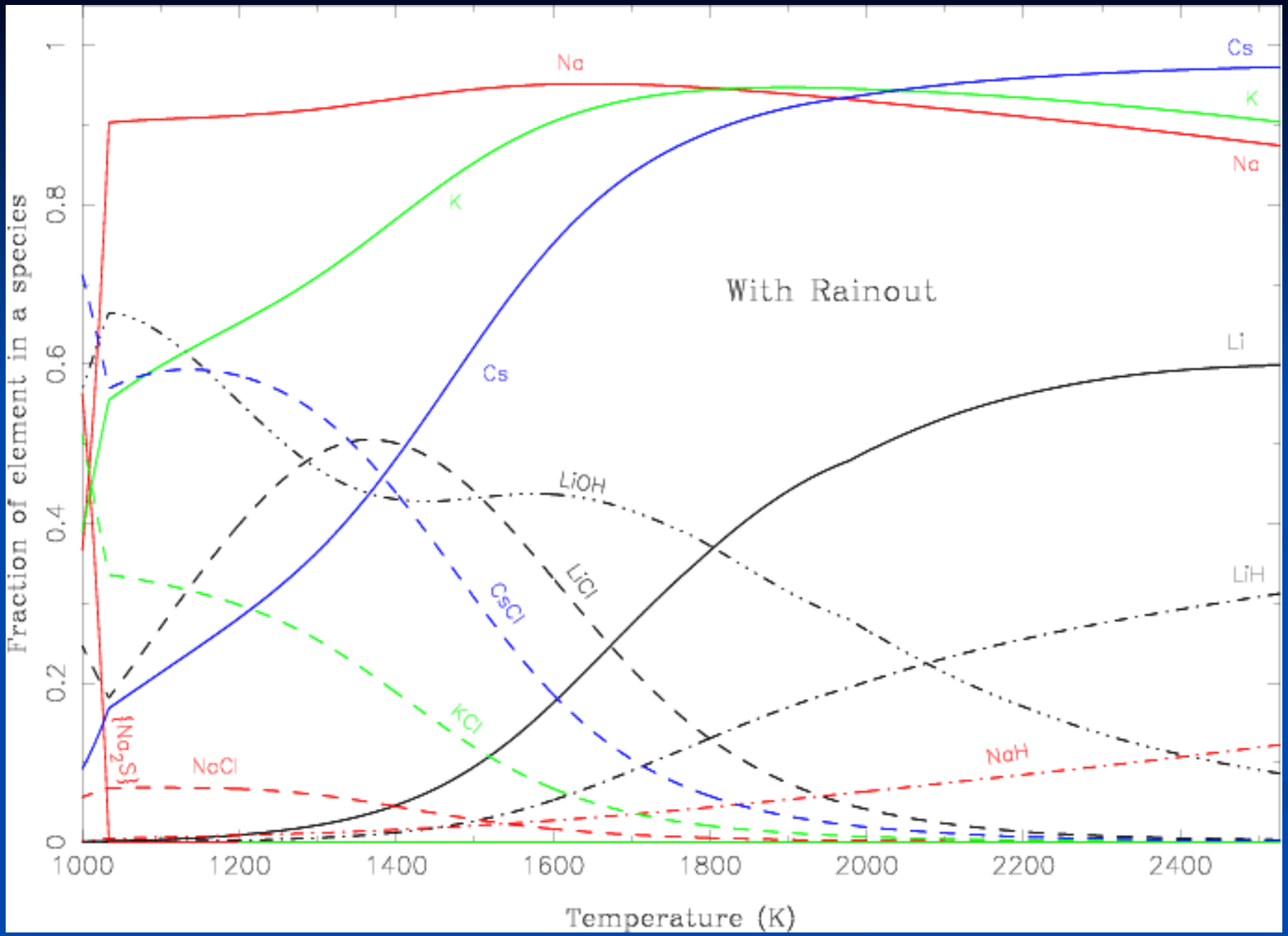

Fractions of Major Gas Phase Species in T_{eff}=950 K g=1000 m/s^2 Gl229B Model
Log number fraction
Temperature (K)
−4
−6
−8
−10
600
800
1000
1200
1400
1600
1800
2000
H_2O
CH_4
N_2
NH_3
CO
CO_2
HCN
CH_3
H_2CO
C_2H_4
C_2H_2
OH
NH_2
Photosphere
NH_3/N_2
CH_4/CO

M Dwarfs → L Dwarfs → T Dwarfs → Jupiter



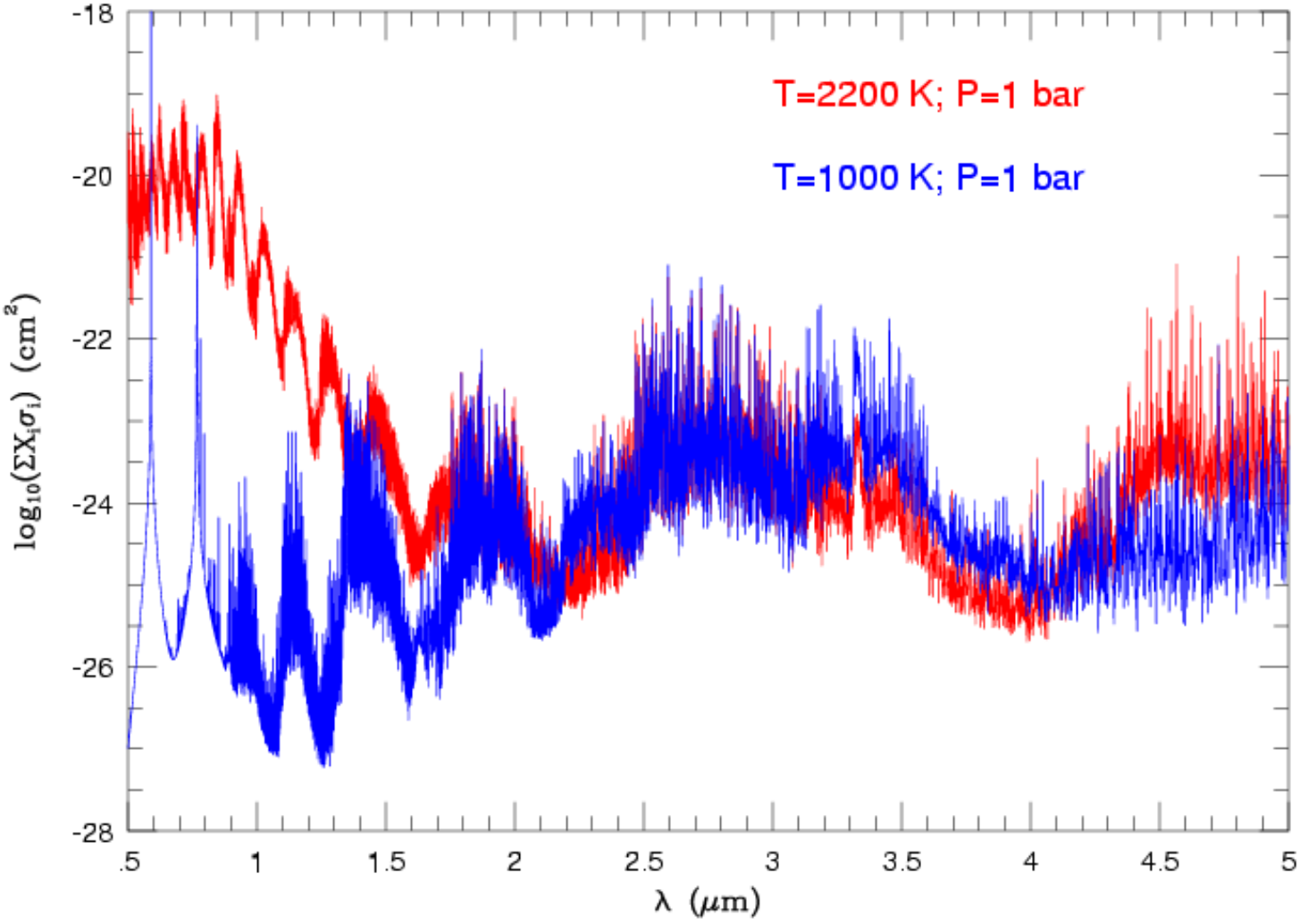

~R_P
(ΔT~200K)
R_P
NH3/N2
CH4/CO
NaCl/Na
RbCl/Rb
CsCl/Cs
LiCl/Li
{MgAl2O4}
{CaTiO3}
{Ti_con}/TiO
Fe
{Mg2SiO4}
{MgSiO3}
{Ti3O5}
0.09 M⊙
0.08 M⊙
40
20
5 M_J
Jupiter
{NH3}
{H2O}
Log10 Pressure (Atm)
-2
0
2
500
1000
1500
2000
Temperature (K)

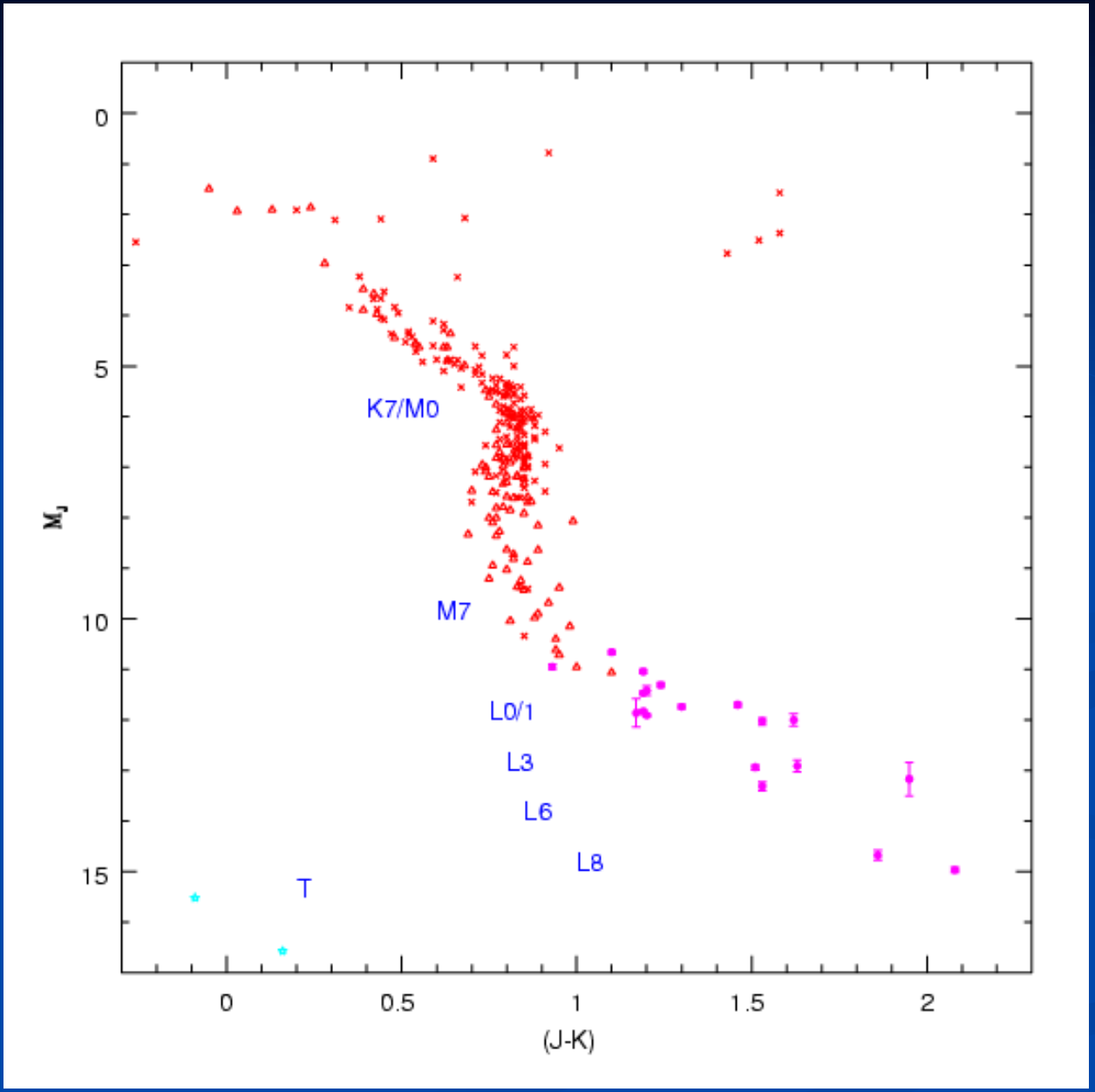

Without Rainout (True Equilibrium)
Fraction of element in a species
Temperature (K)
0
0.2
0.4
0.6
0.8
1
1000
1200
1400
1600
1800
2000
2200
2400
CsCl
LiCl
{NaAlSi3O8}
{KAlSi3O8}
Na
K
Cs
Li
LiOH
LiH
NaH
KCl
NaCl


With Rainout
Fraction of element in a species
Temperature (K)
0
0.2
0.4
0.6
0.8
1
1000
1200
1400
1600
1800
2000
2200
2400
Na
Cs
K
Na
Li
LiOH
LiCl
LiH
CsCl
KCl
NaCl
Na_2S
NaH

M Dwarfs

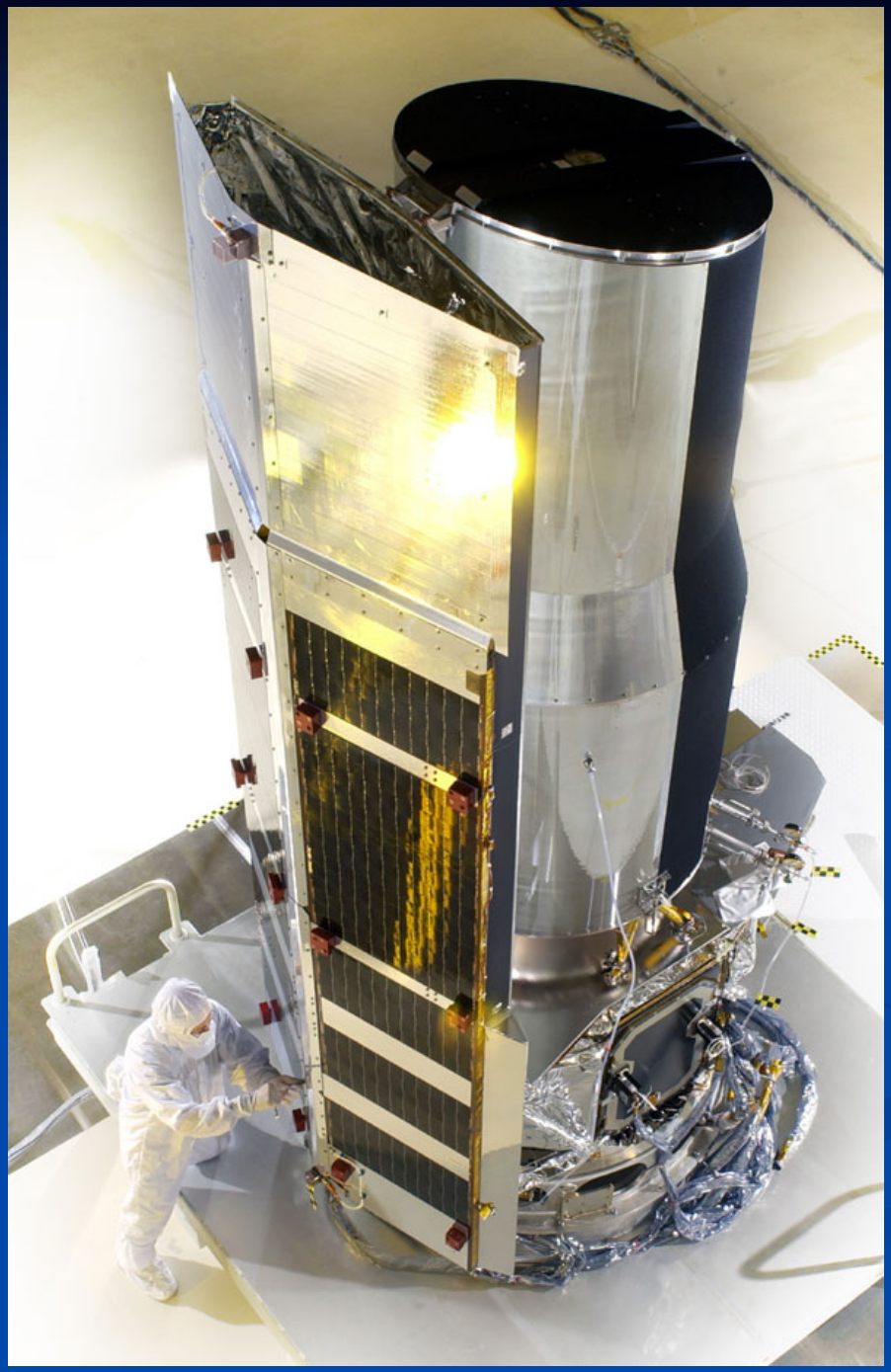
T Dwarfs

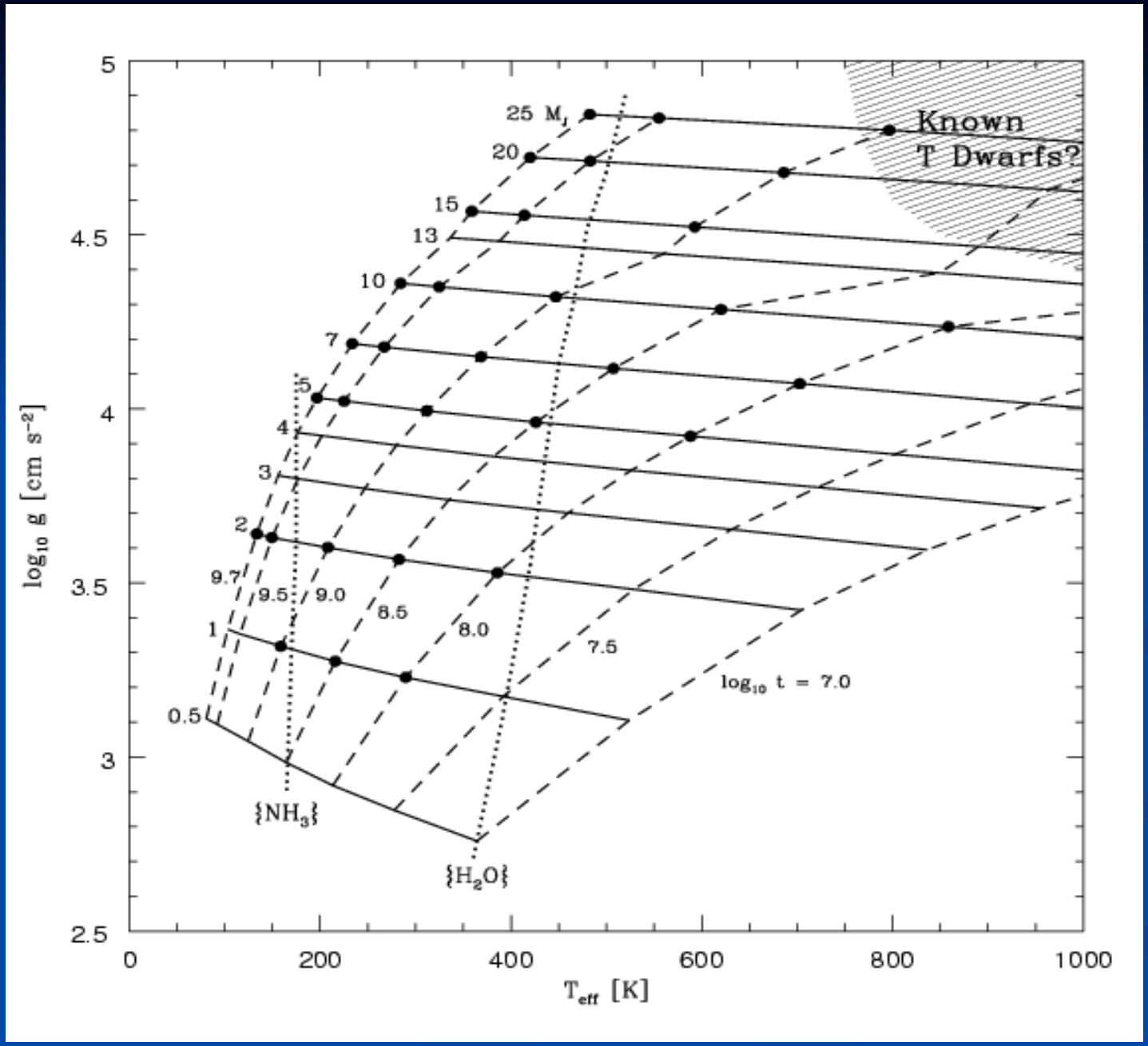




Reid et al. 2000

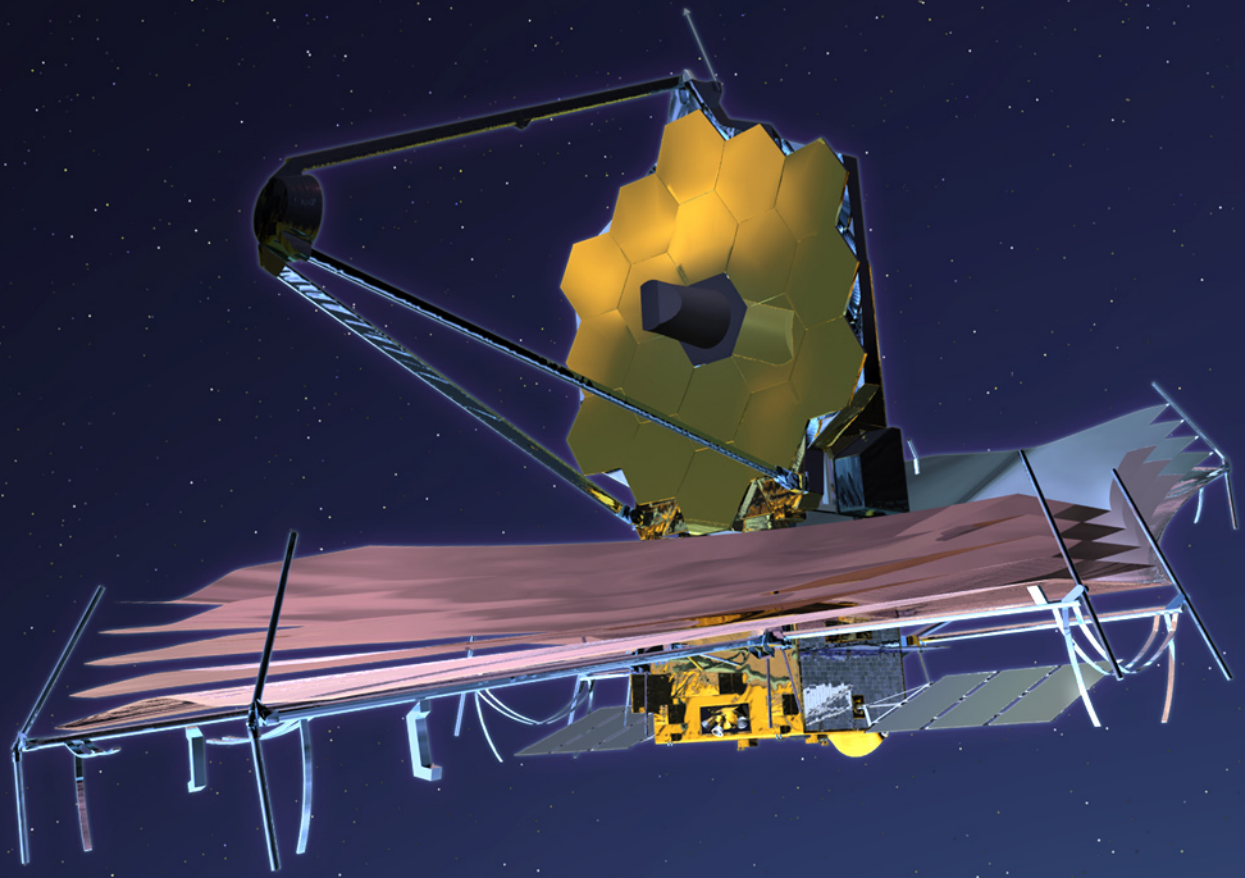
Spitzer ST:

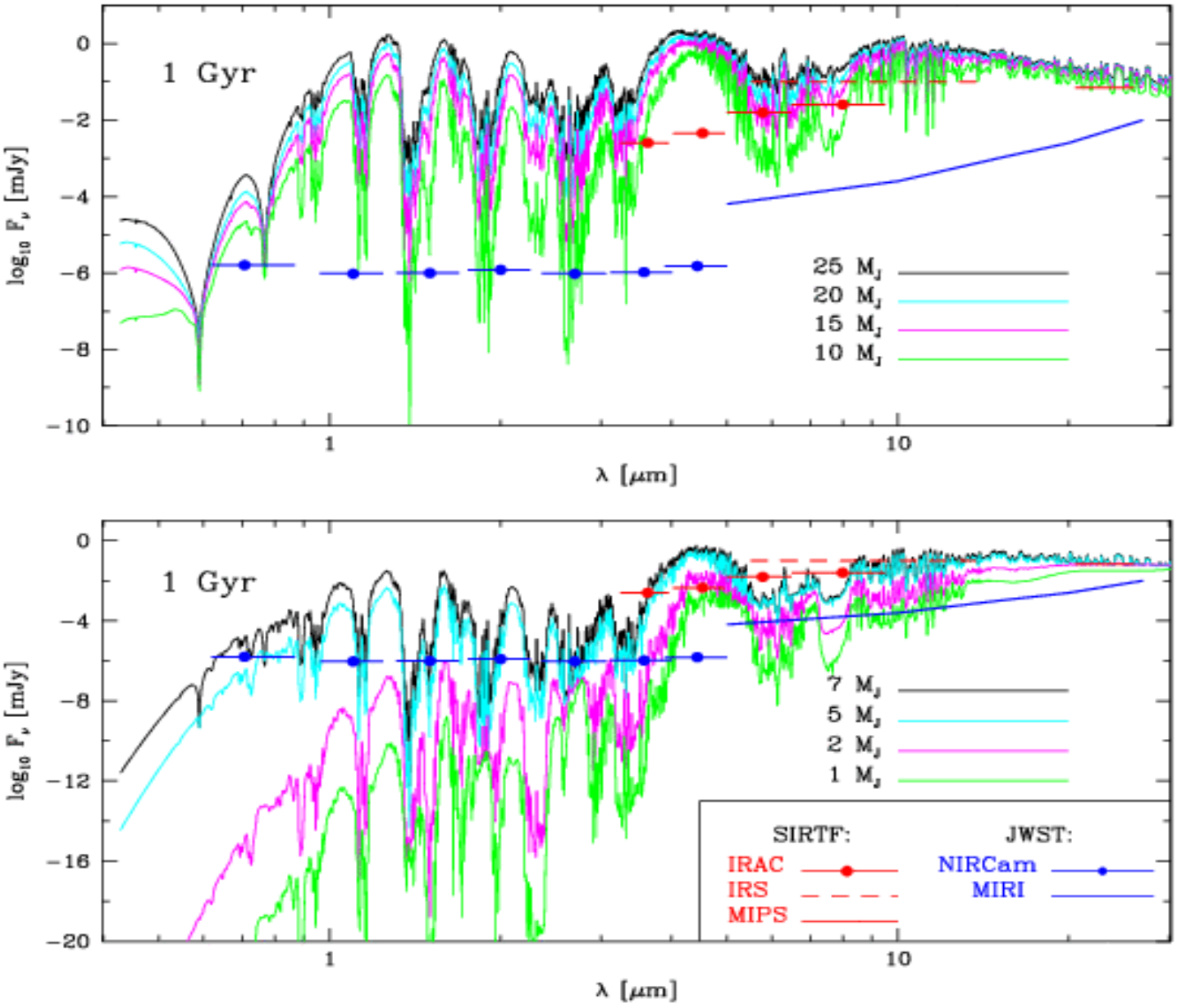




Burrows, Sudarsky, and Lunine 2003

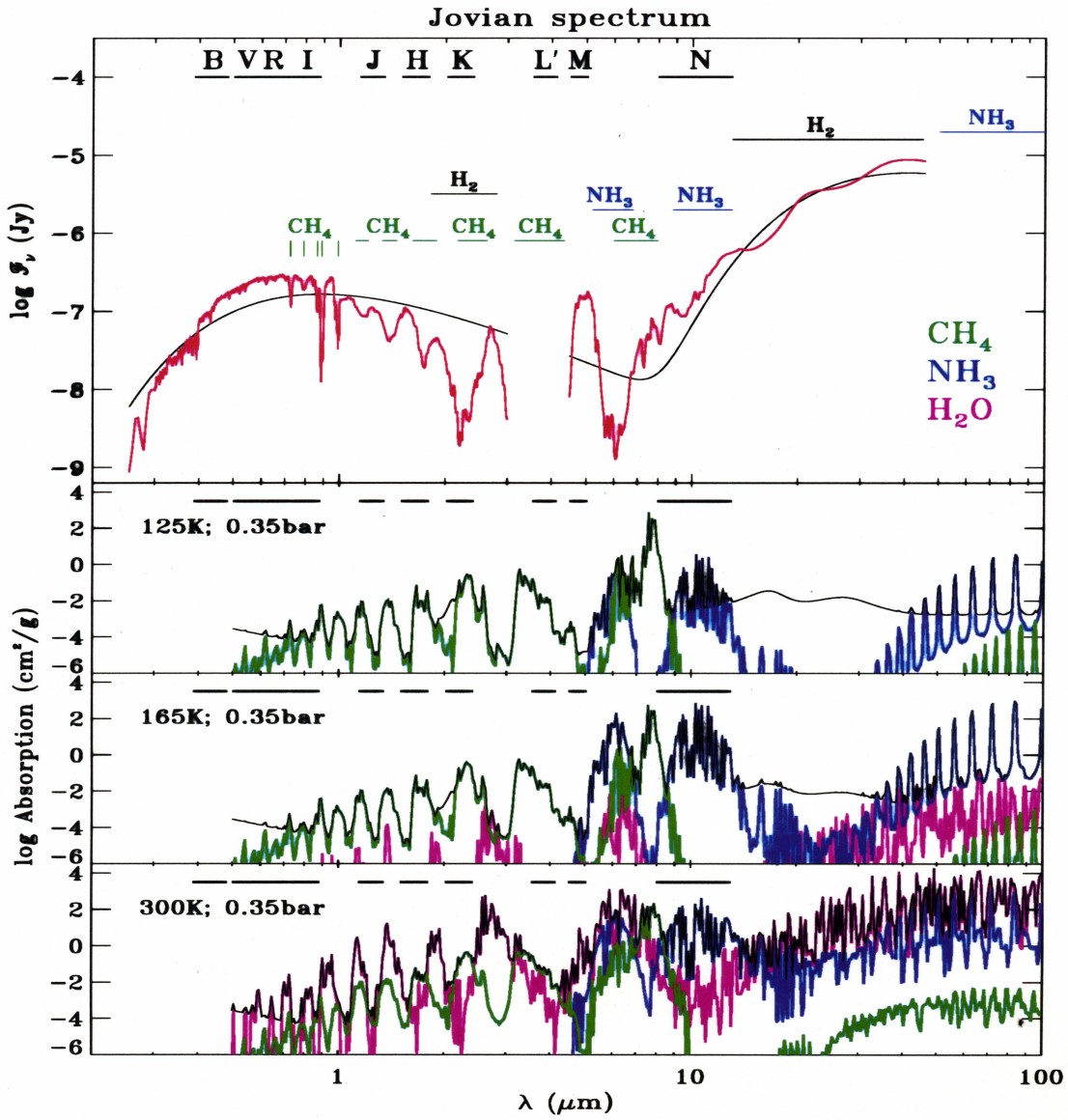
JWST



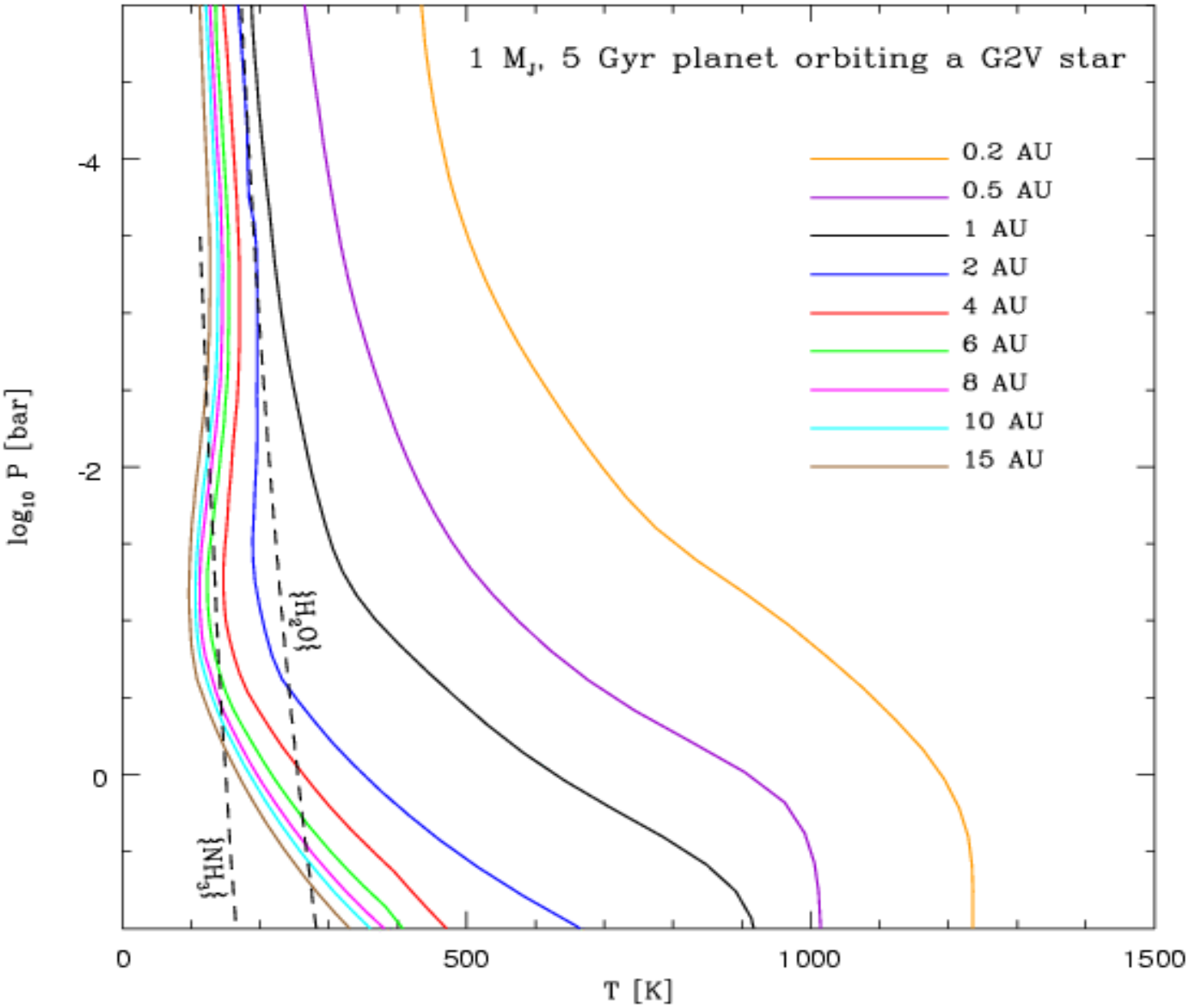

1 Gyr
log10 Fν [mJy]
λ [μm]
25 MJ
20 MJ
15 MJ
10 MJ
1 Gyr
7 MJ
5 MJ
2 MJ
1 MJ
SIRTF:
IRAC
IRS
MIPS
JWST:
NIRCam
MIRI

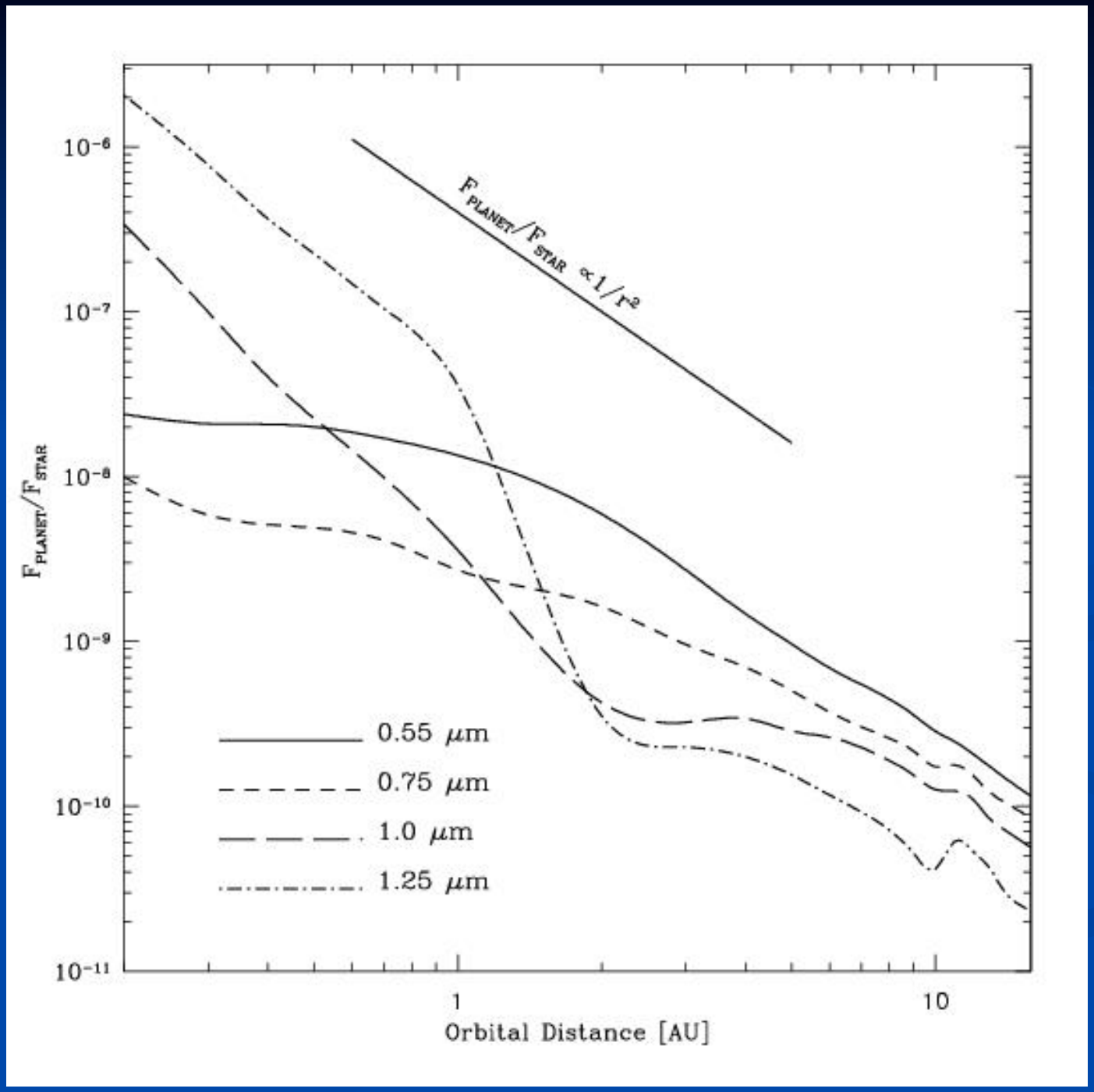
The Evolution and Measurement of EGPs:

Remote Sensing of Extrasolar Planets

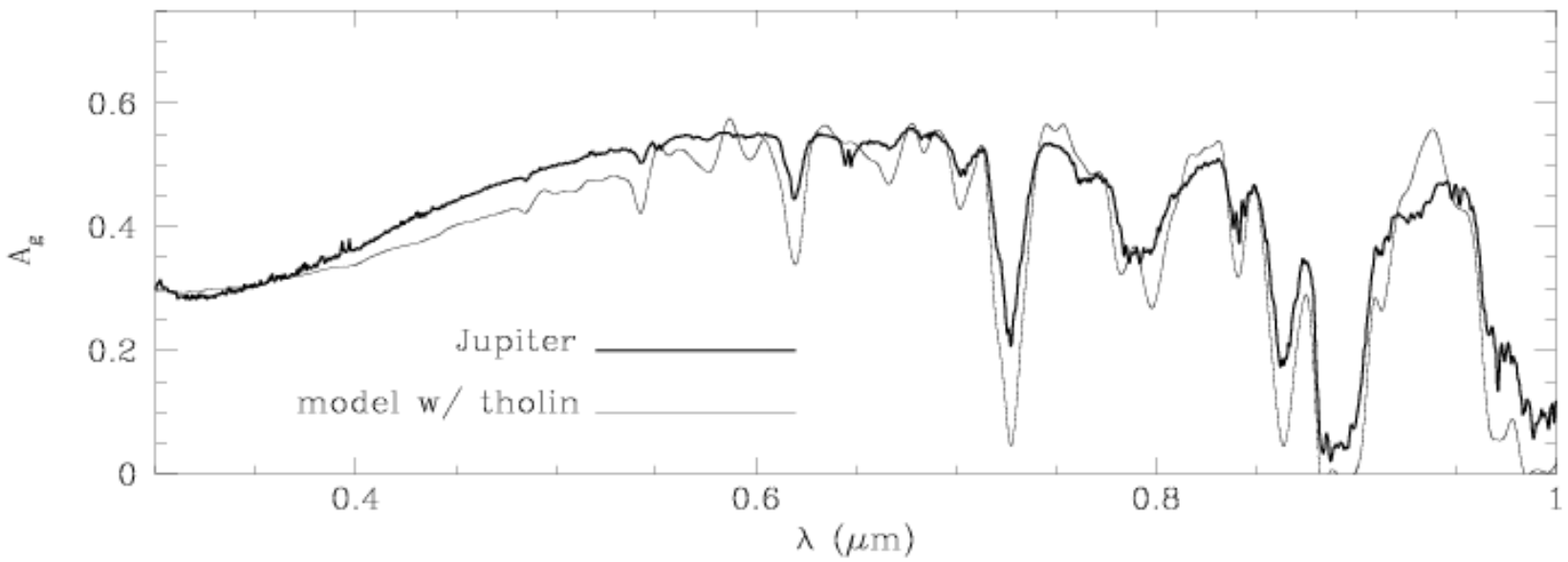

Jovian spectrum
B V R I
J H K
L′ M
N
H2
NH3
CH4
CH4
CH4
CH4
CH4
H2
NH3
NH3
CH4
NH3
H2O
log Sν (Jy)
125K; 0.35bar
165K; 0.35bar
300K; 0.35bar
log Absorption (cm²/g)
λ (μm)
1
10
100

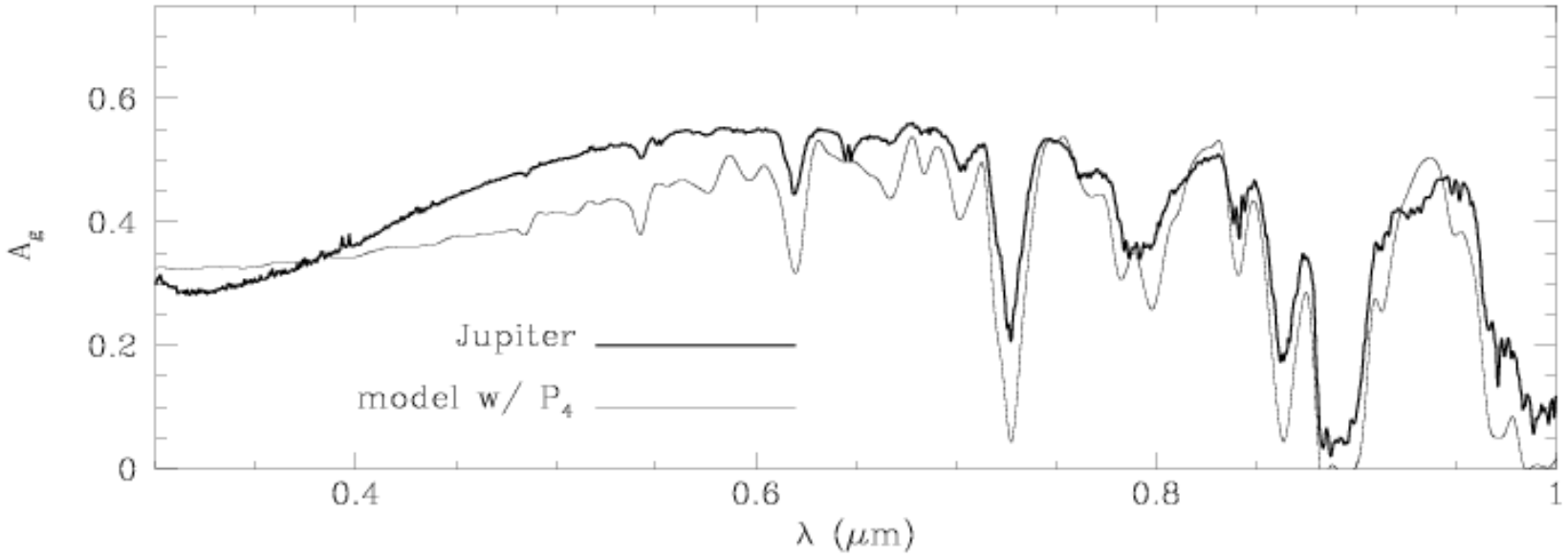
(T. Guillot)

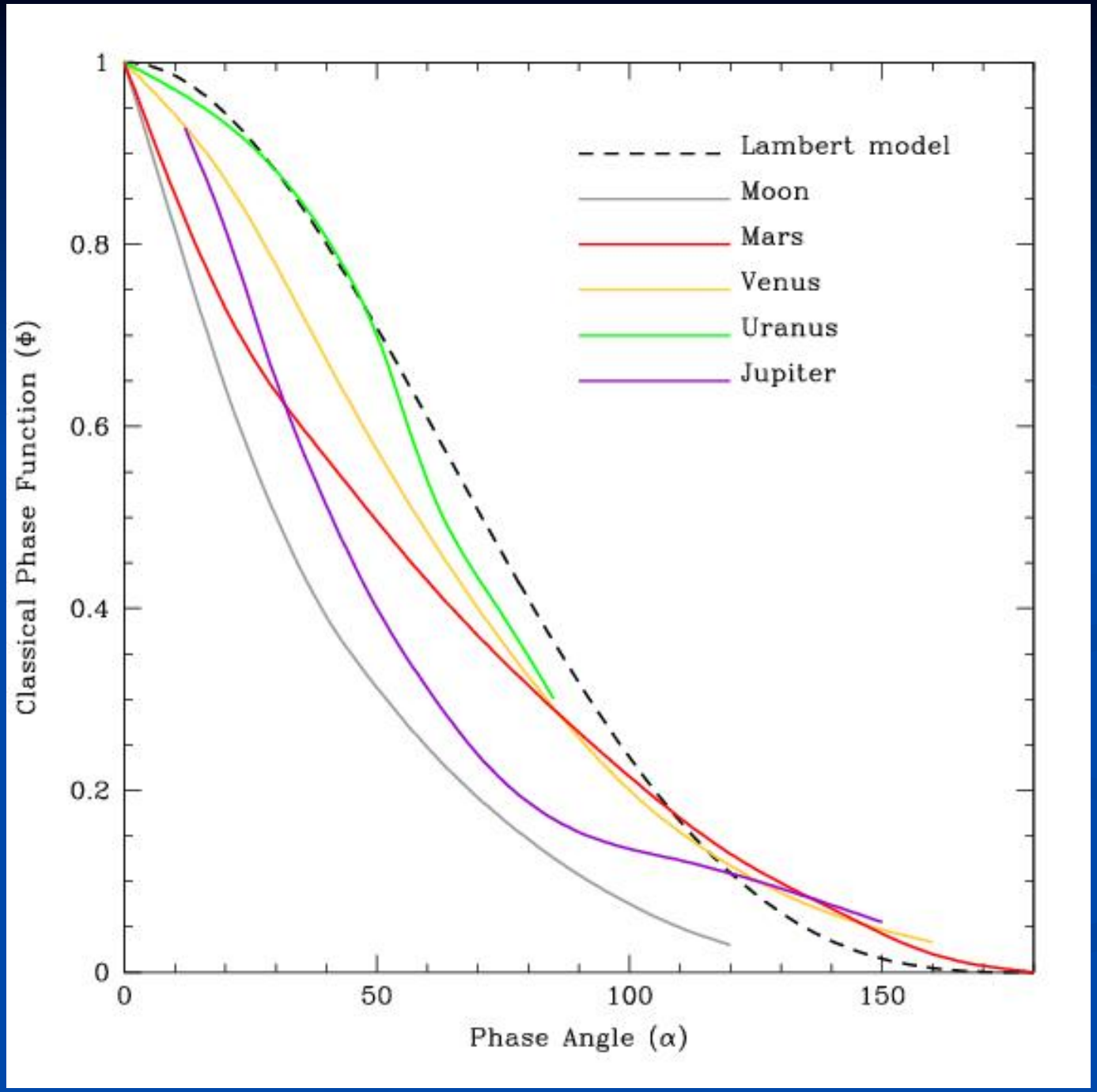

1 M$_J$, 5 Gyr planet orbiting a G2V star
0.2 AU
0.5 AU
1 AU
2 AU
4 AU
6 AU
8 AU
10 AU
15 AU
{H$_2$O}
{NH$_3$}
log$_{10}$ P [bar]
-4
-2
0
0
500
1 000
1500
T [K]


10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
F_{PLANET}/F_{STAR}
$F_{PLANET}/F_{STAR} \propto 1/r^2$
0.55 μm
0.75 μm
1.0 μm
1.25 μm
1
10
Orbital Distance [AU]

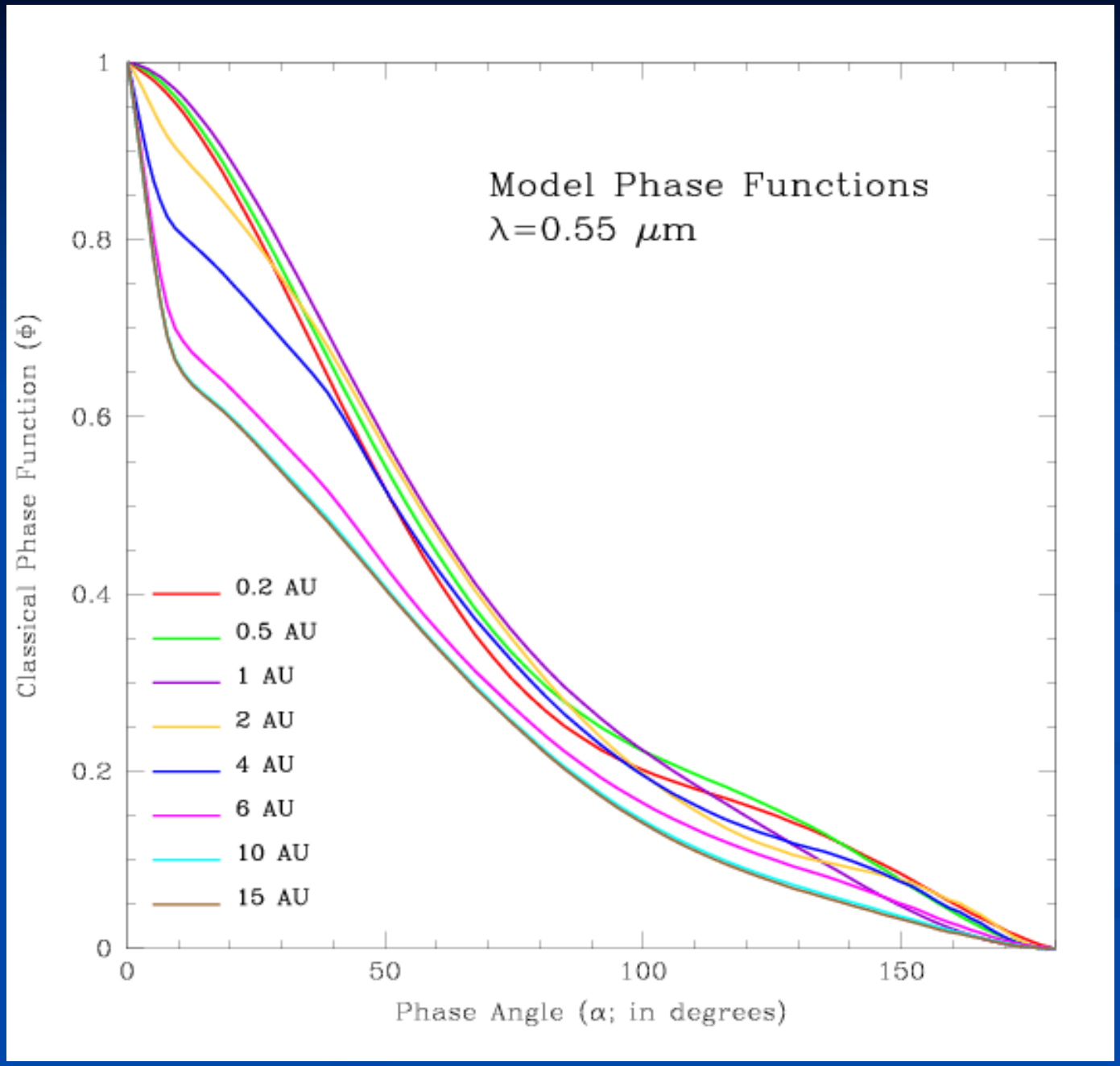
Sudarsky, Burrows 2000






Lambert model
Moon
Mars
Venus
Uranus
Jupiter
Classical Phase Function (Φ)
Phase Angle (α)
0
0.2
0.4
0.6
0.8
1
0
50
100
150

Phase Function at 0.55 microns vs. Orbital Distance



Phase Dependence of the EGP's Color