When Worlds Collide: Thermal Emission Spectra of Post-Giant-Impact Earths

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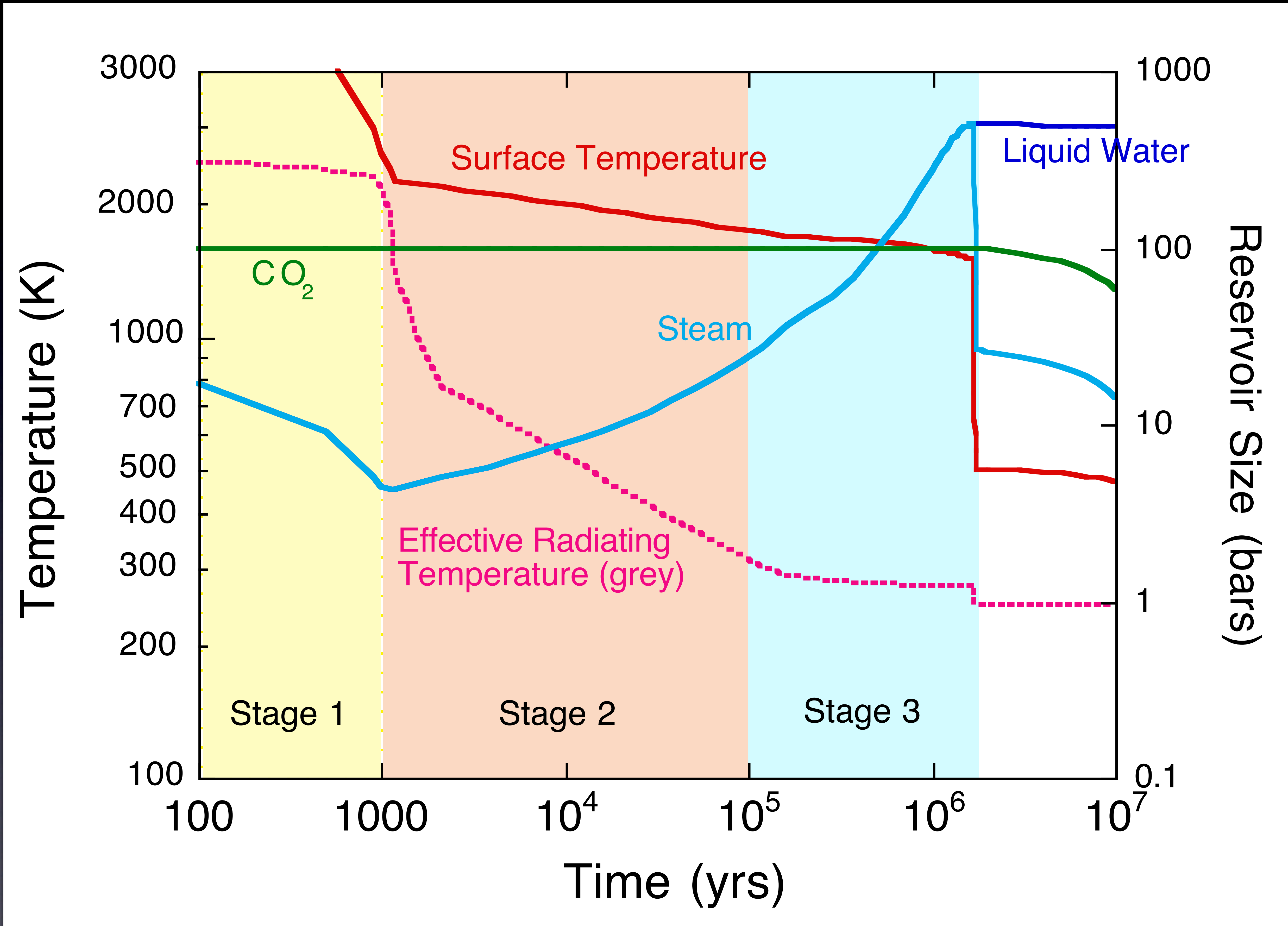
Collisions Rampant

- Final assembly of terrestrial planets: a series of giant impacts between planets
- Occurs over ~30-50 million years
- Earth's Moon-forming impact is archetype
- Takes ~10 collisions between planets to make an Earth
- Surviving planet hot for a long time


3000
2000
1000
700
500
400
300
200
100
Temperature (K)
1000
100
10
1
0.1
Reservoir Size (bars)
100
1000
10^4
10^5
10^6
10^7
Time (yrs)
Surface Temperature
Liquid Water
CO_2
Steam
Effective Radiating
Temperature (grey)
Stage 1
Stage 2
Stage 3

Zahnle (2006)

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THE DETECTABILITY OF EXTRASOLAR TERRESTRIAL AND GIANT PLANETS DURING THEIR LUMINOUS FINAL ACCRETION

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ON THE EMERGENT SPECTRA OF HOT PROTOPLANET COLLISION AFTERGLOWS

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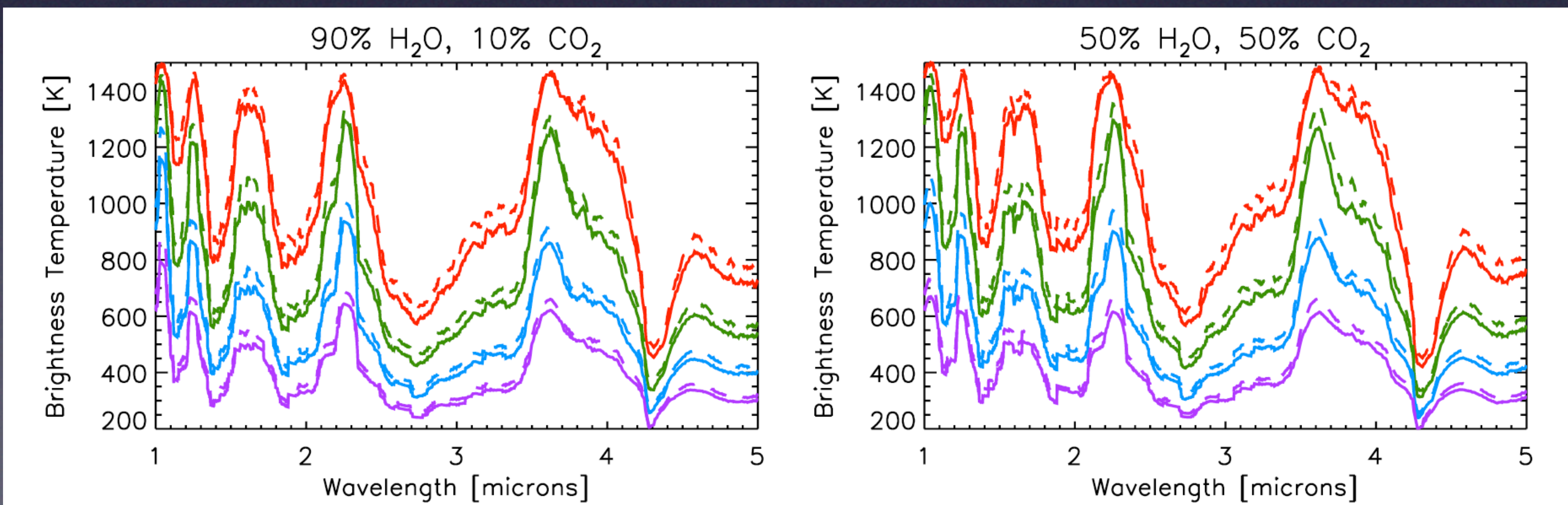
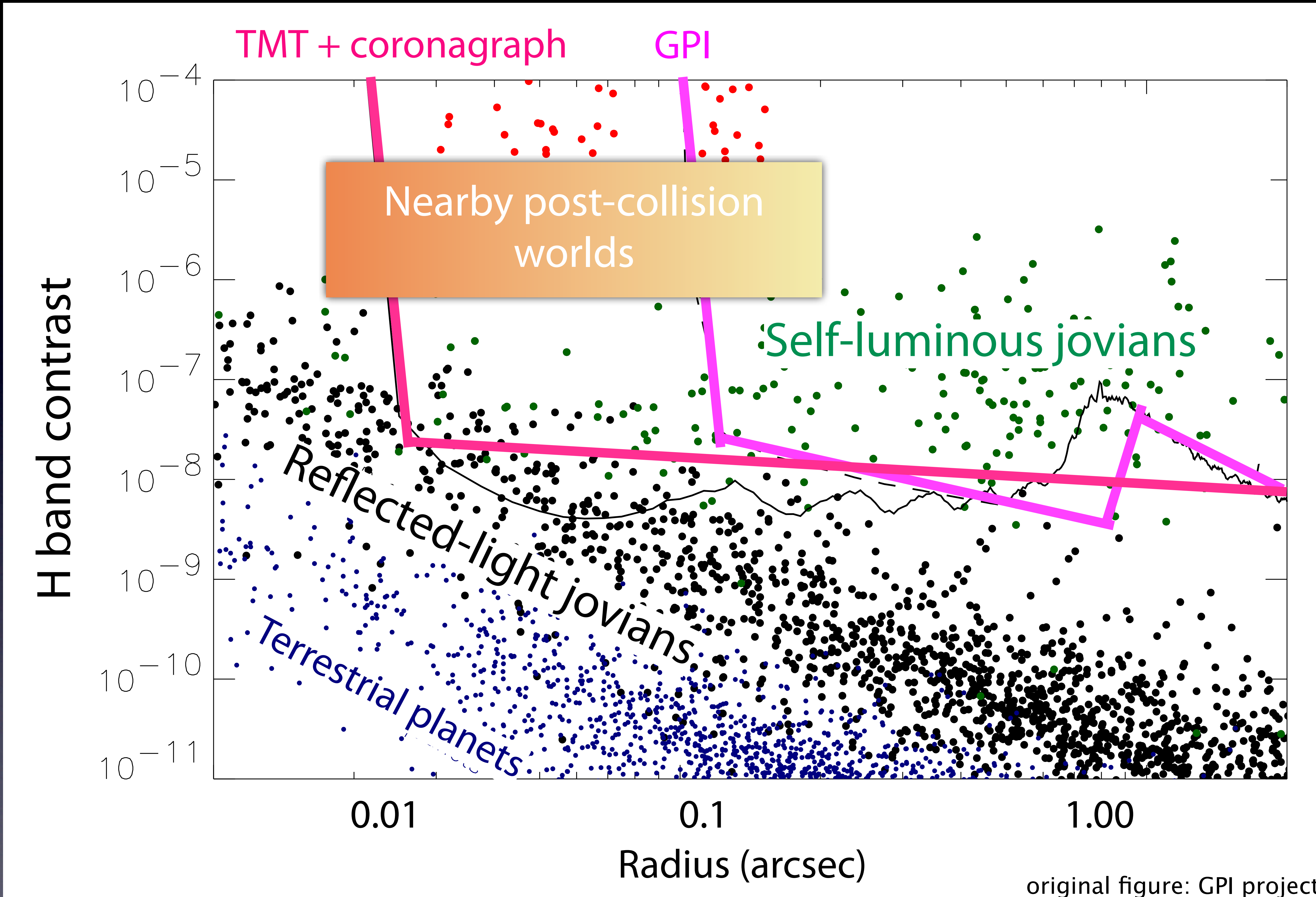




"Nearby" means < 50 pc, e.g., Tucana-Horologium Assoc. (10-30 Myr)

Chemistry of Molten Worlds

Assumed Elemental Composition

Table 2. Bulk compositions of vaporizing planets

Element	Continental Crust[1] (wt%)	Bulk Silicate Earth[2] (wt%)
O	47.20	44.42
Si	28.80	21.61
Al	7.96	2.12
Fe	4.32	6.27
Ca	3.85	2.46
Na	2.36	0.29
Mg	2.20	22.01
K	2.14	0.02
Ti	0.401	0.12
P	0.076	0.008
Cr	0.013	0.29
Mn	0.072	0.11
H	0.045	0.006
C	0.199	0.006
N	0.006	0.88×10^{-4}
S	0.070	0.027
F	0.053	0.002
Cl	0.047	0.004
TOTAL[3]	99.822	99.776

[1]Wedepohl (1995). [2] Kargel & Lewis (1993) [3]Totals are less than 100% because Ni is not considered.

BSE = mantle + crust + ocean + atmosphere

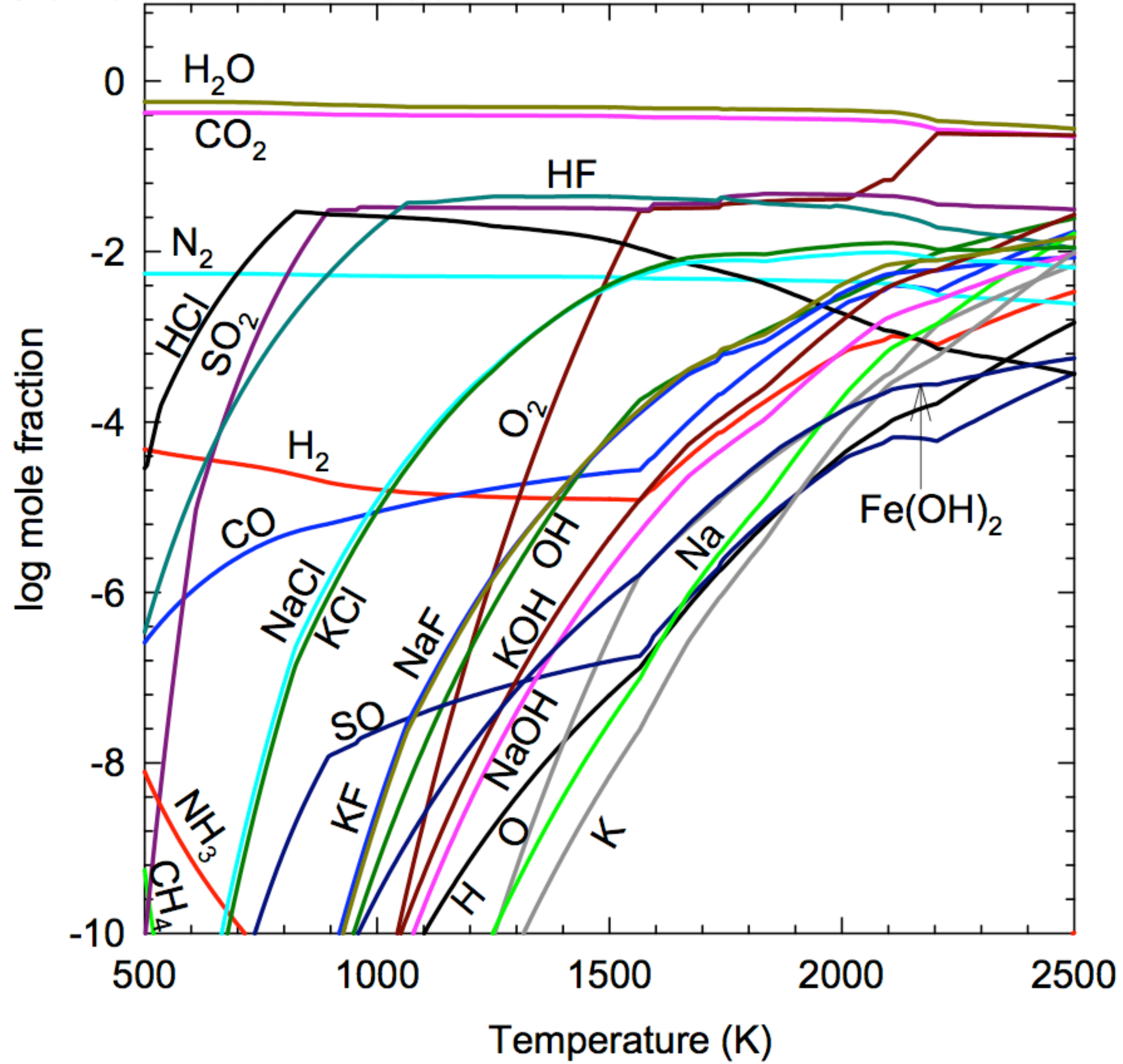
Lodders & Fegley (1997)

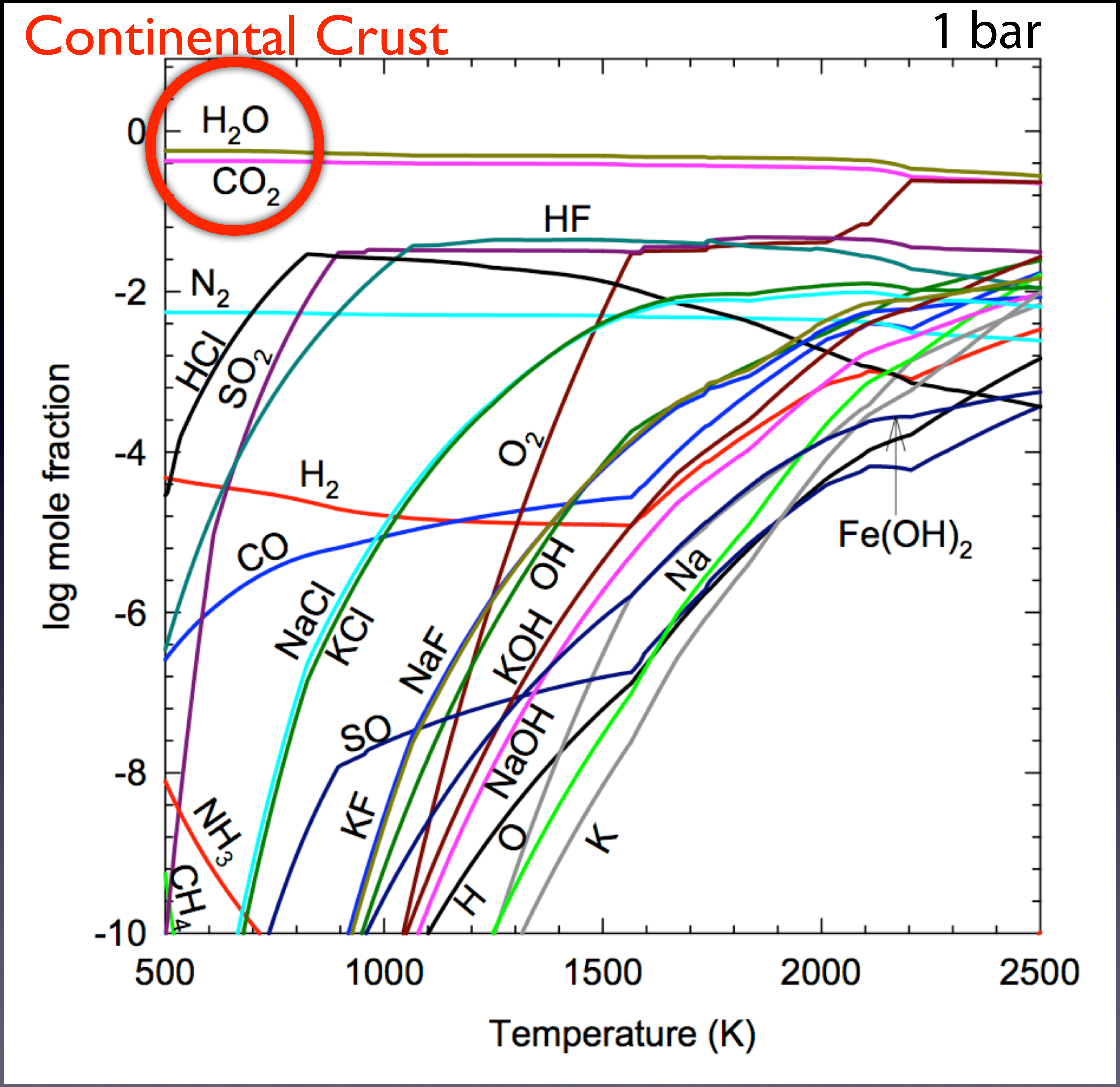
Atmospheric Composition

- Compute chemical equilibrium for each case at various pressures up to 100 bars
- Gibbs energy minimization by Fegley, Lodders, & Schaeffer
- 810 compounds

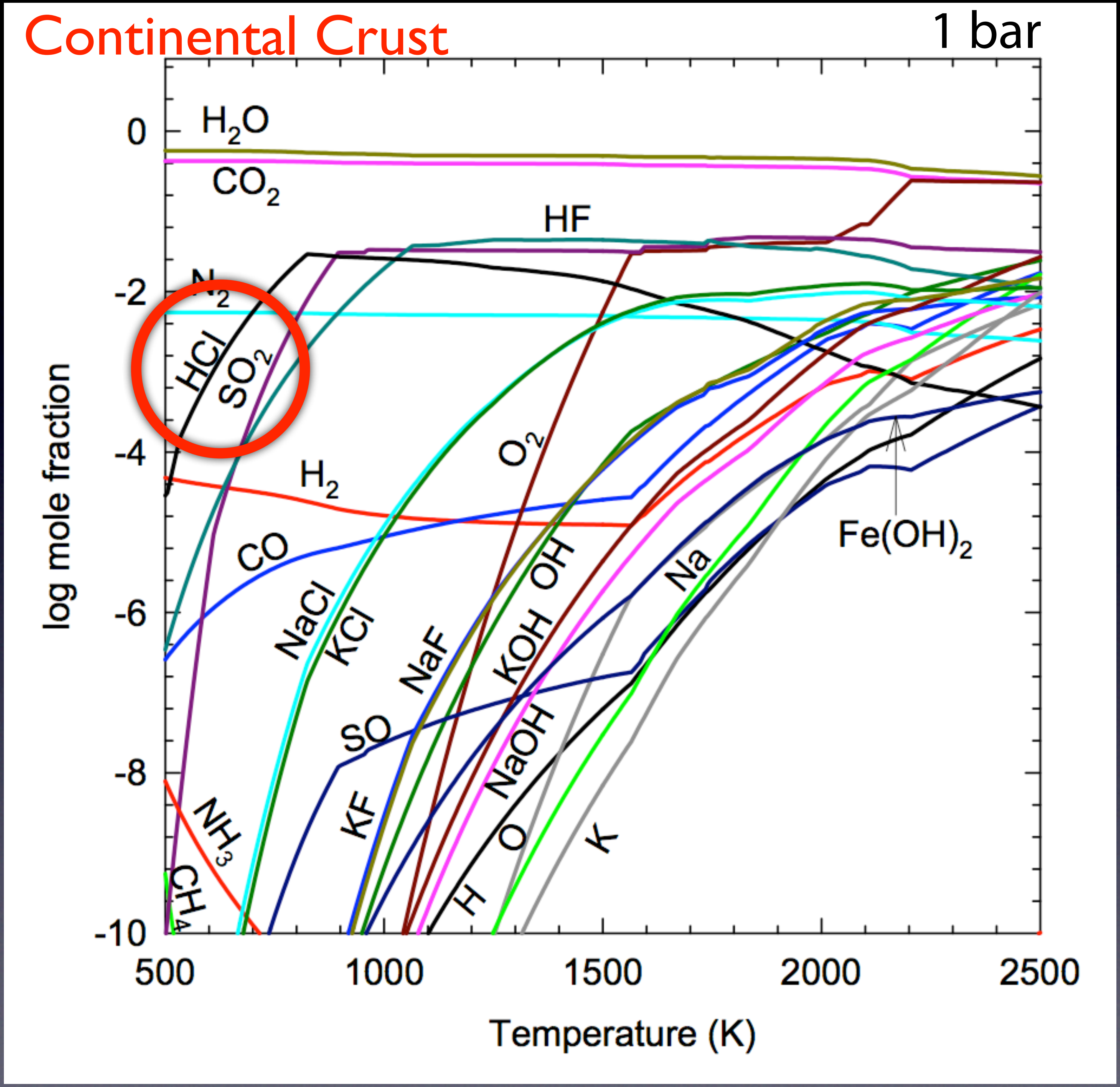
Continental Crust

1 bar





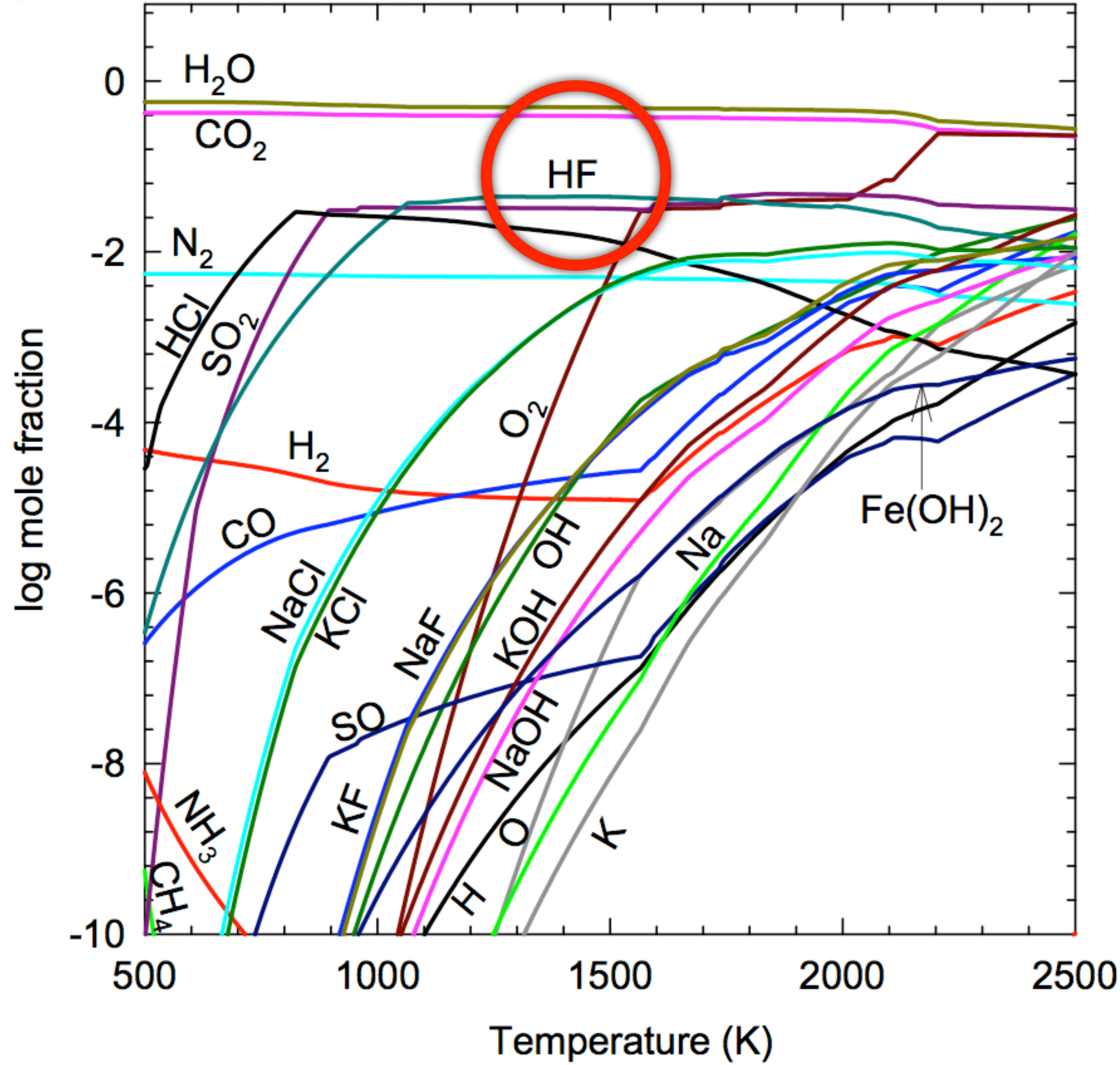
Continental Crust
1 bar
H2O
CO2
HF
N2
HCl
SO2
O2
H2
CO
NaCl
KCl
NaF
KOH
OH
SO
KF
NaOH
Na
Fe(OH)2
NH3
CH4
H
O
K
log mole fraction
Temperature (K)
0
-2
-4
-6
-8
-10
500
1000
1500
2000
2500

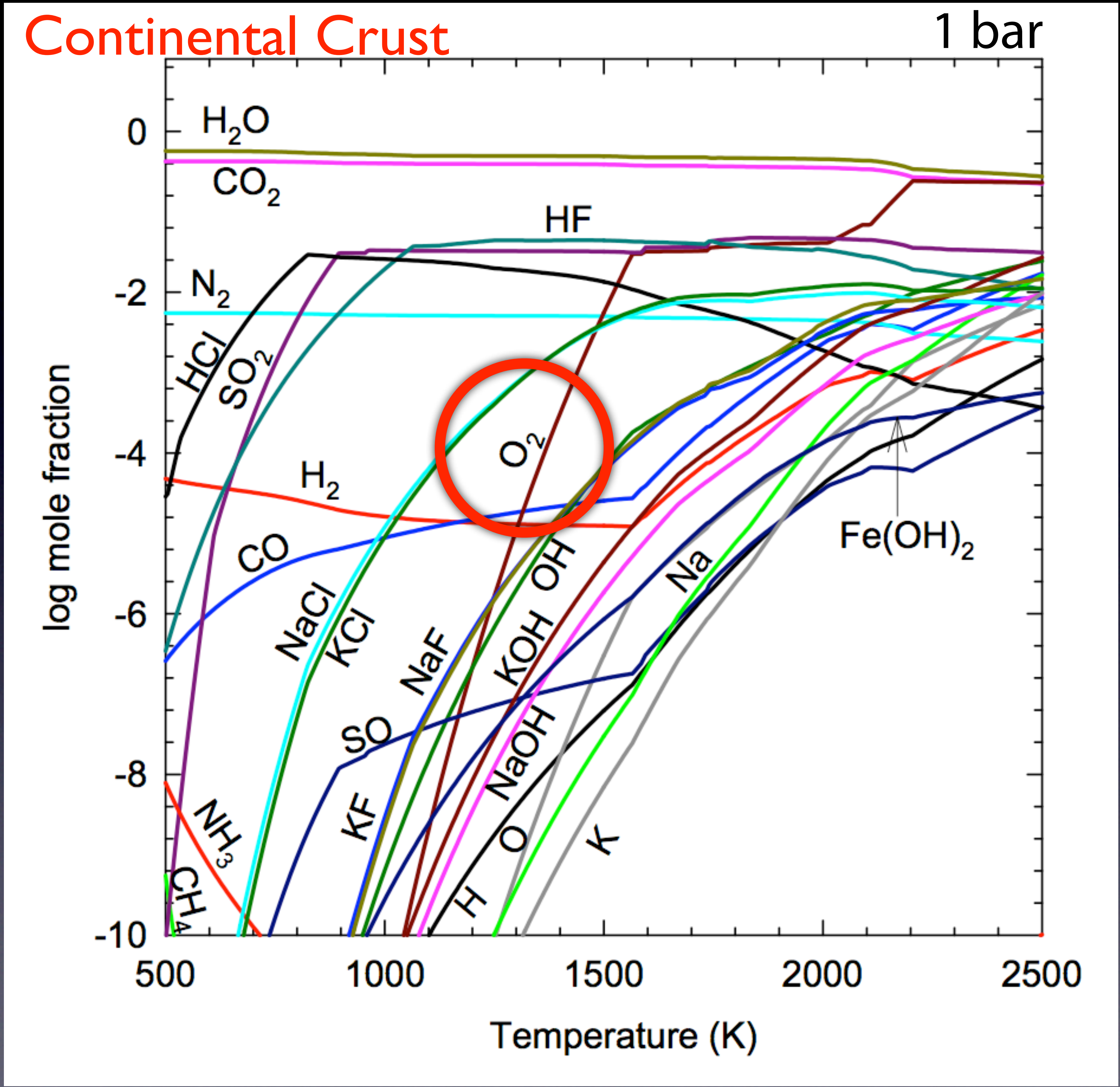


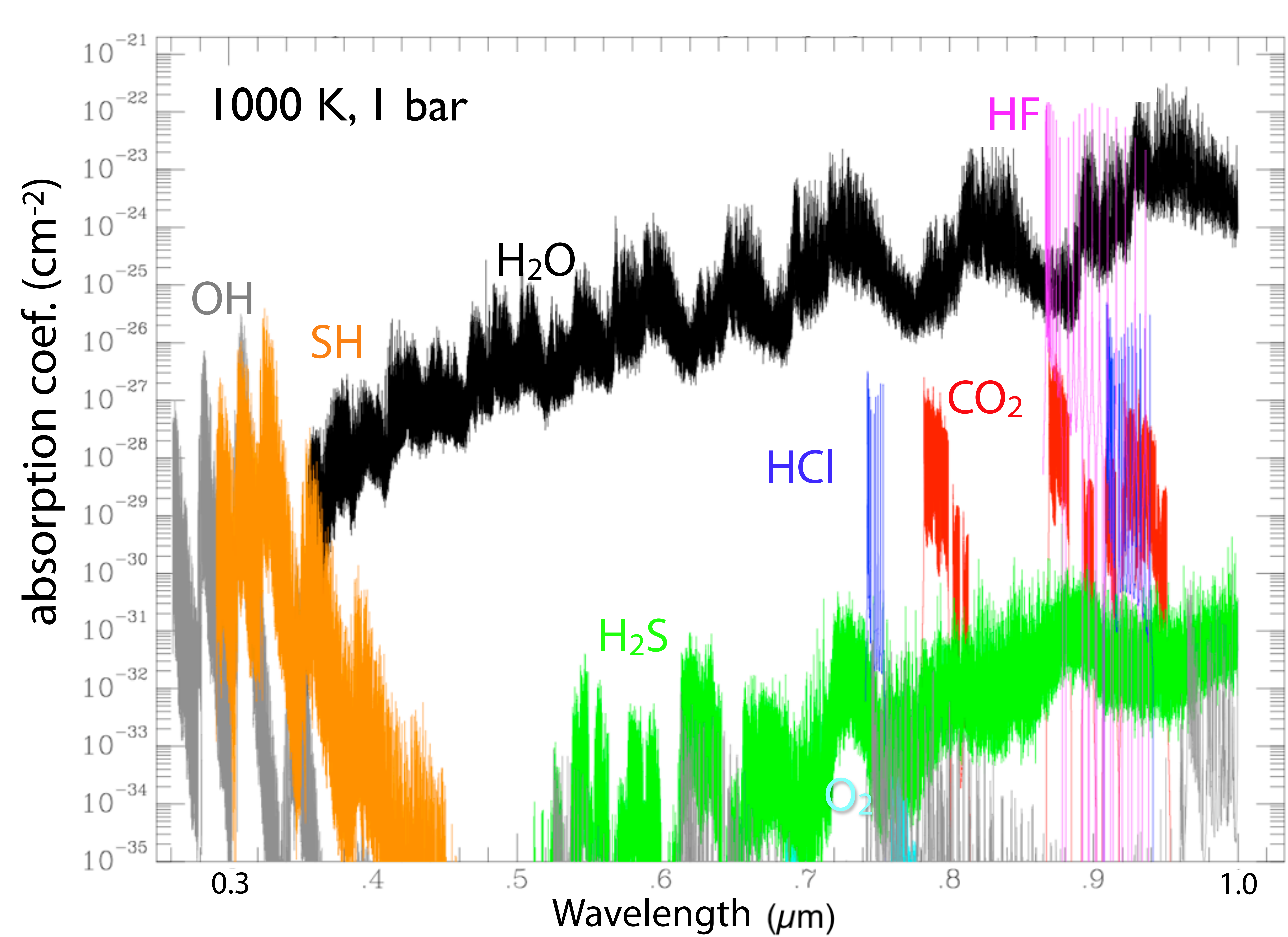
Continental Crust
1 bar
H_2O
CO_2
HF
N_2
HCl
SO_2
H_2
CO
O_2
NaCl
KCl
NaF
SO
KF
OH
KOH
NaOH
Na
H
O
K
NH_3
CH_4
$Fe(OH)_2$
log mole fraction
0
-2
-4
-6
-8
-10
500
1000
1500
2000
2500
Temperature (K)

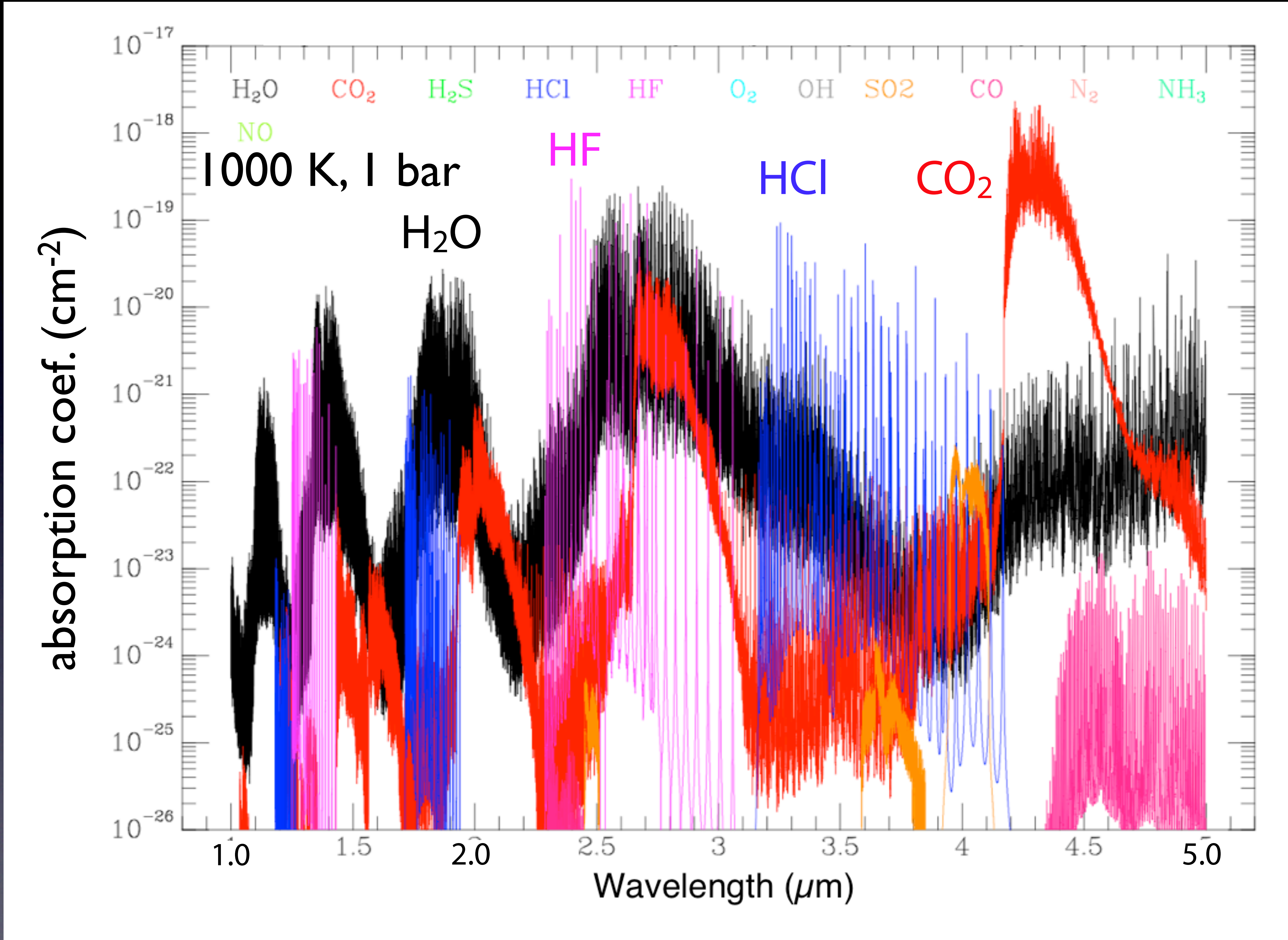
Continental Crust

1 bar



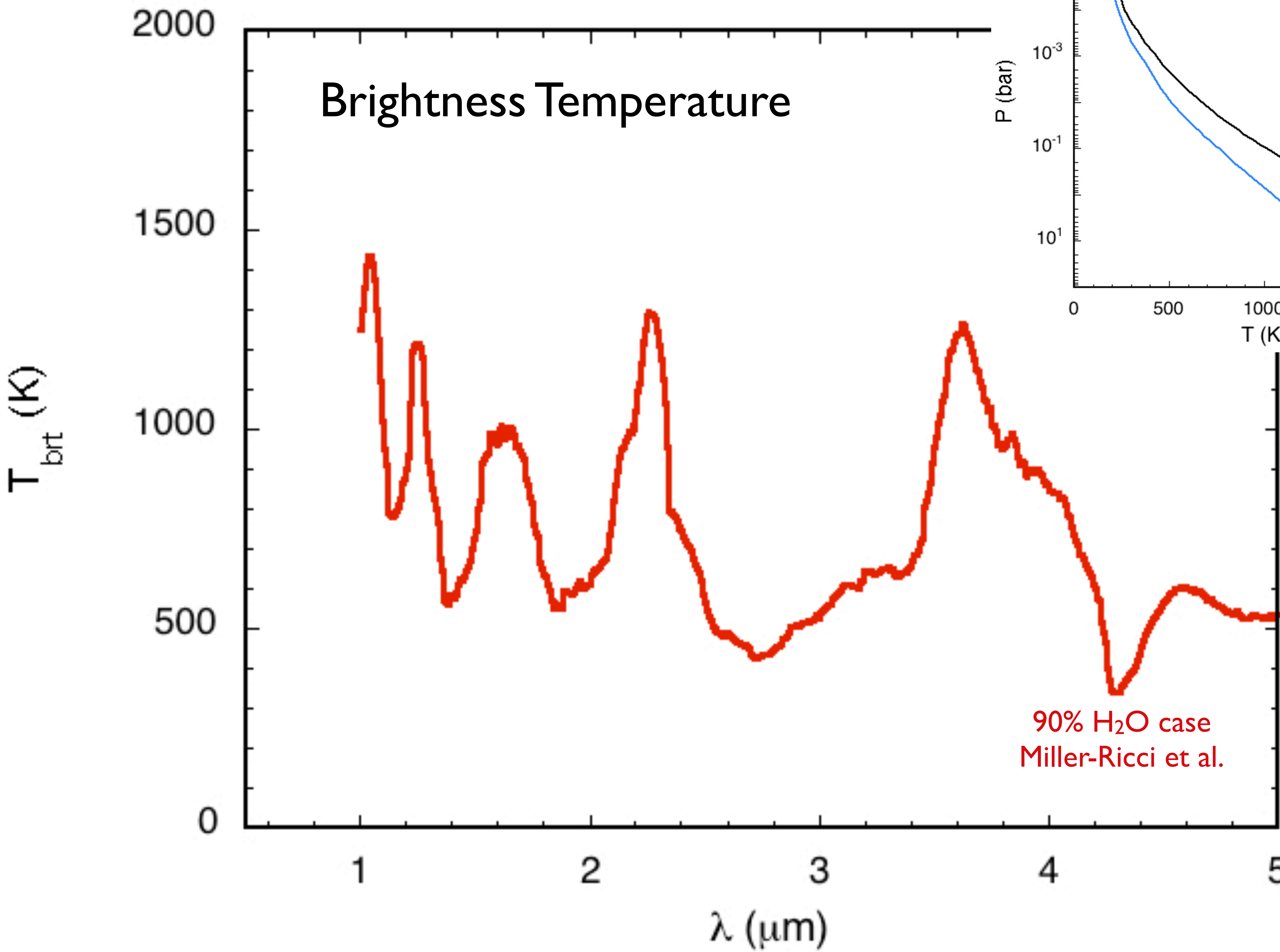

Continental Crust
1 bar
H2O
CO2
HF
N2
HCl
SO2
H2
O2
CO
NaCl
KCl
NaF
OH
KOH
Na
Fe(OH)2
SO
NaOH
KF
NH3
CH4
H
O
K
0
-2
-4
-6
-8
-10
500
1000
1500
2000
2500
log mole fraction
Temperature (K)

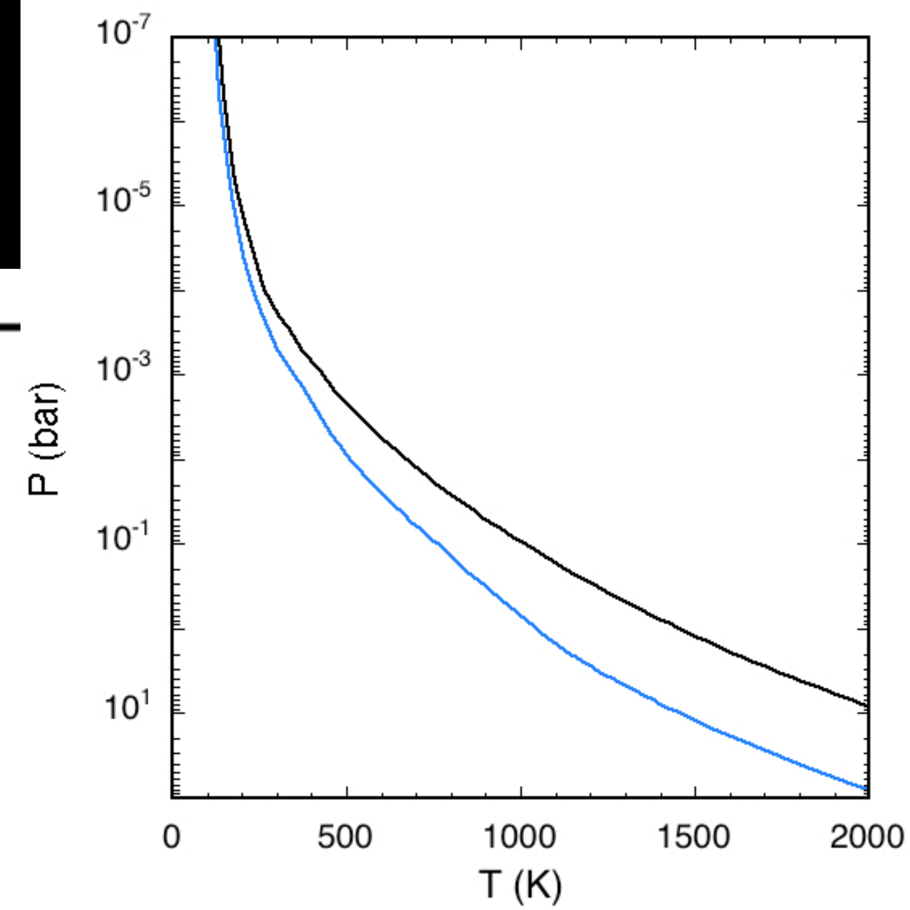

1000 K, 1 bar
absorption coef. (cm-2)
Wavelength (μm)
OH
SH
H2O
HCl
CO2
HF
H2S
O2
10−21
10−22
10−23
10−24
10−25
10−26
10−27
10−28
10−29
10−30
10−31
10−32
10−33
10−34
10−35
0.3
.4
.5
.6
.7
.8
.9
1.0



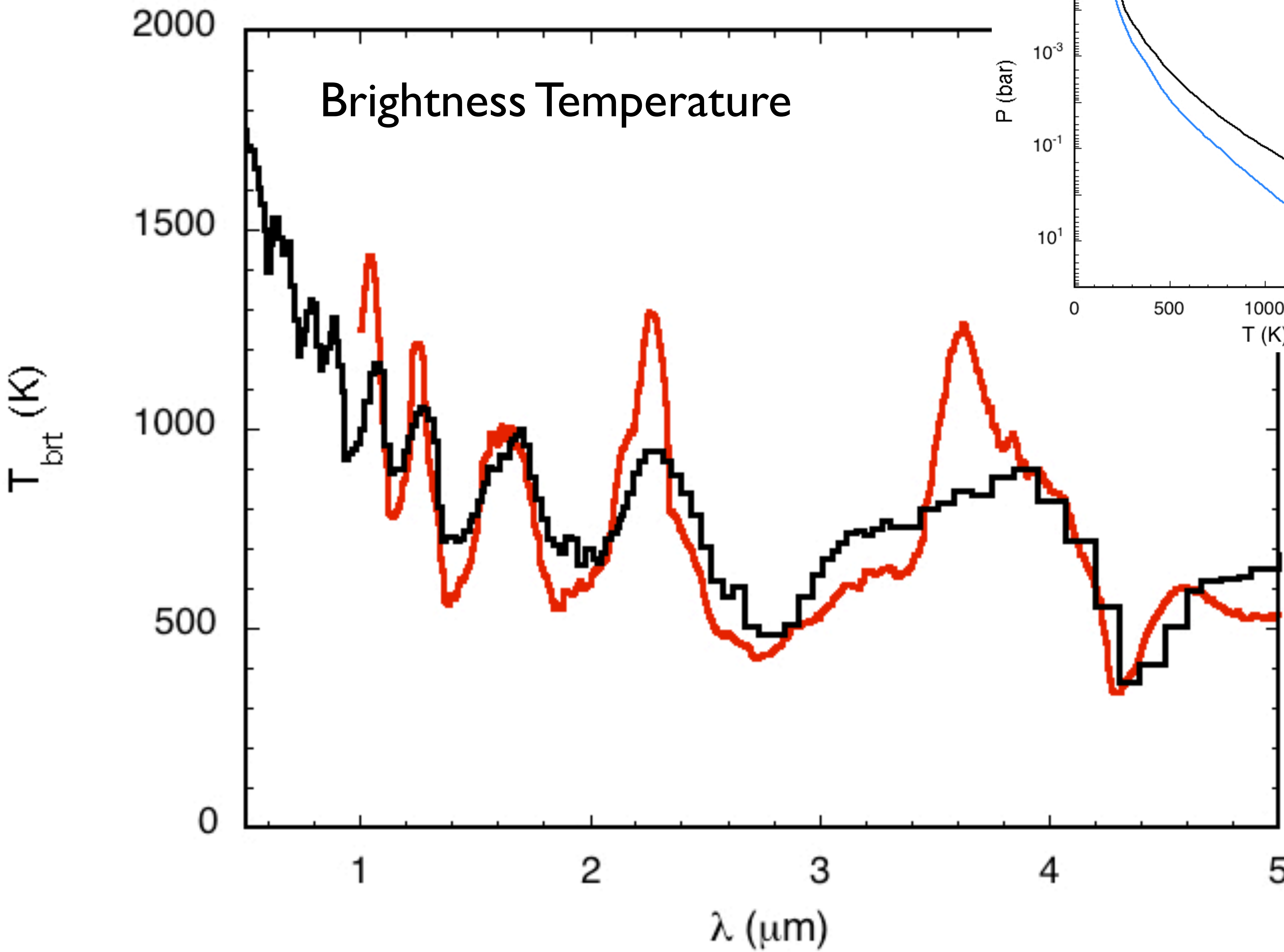
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
H_2O CO_2 H_2S HCl HF O_2 OH SO2 CO N_2 NH_3
NO
1000 K, 1 bar
HF
HCl
CO_2
H_2O
absorption coef. (cm^{-2})
1.0
1.5
2.0
2.5
3
3.5
4
4.5
5.0
Wavelength (μm)

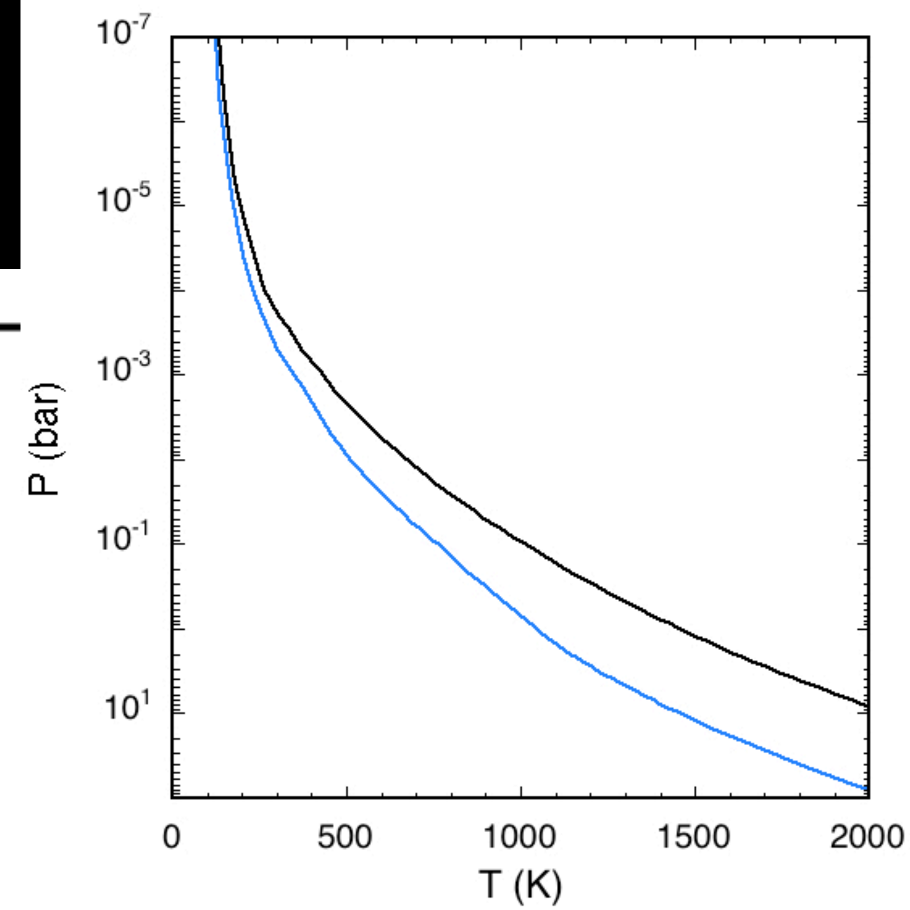
Surface Pressure = 10 bar

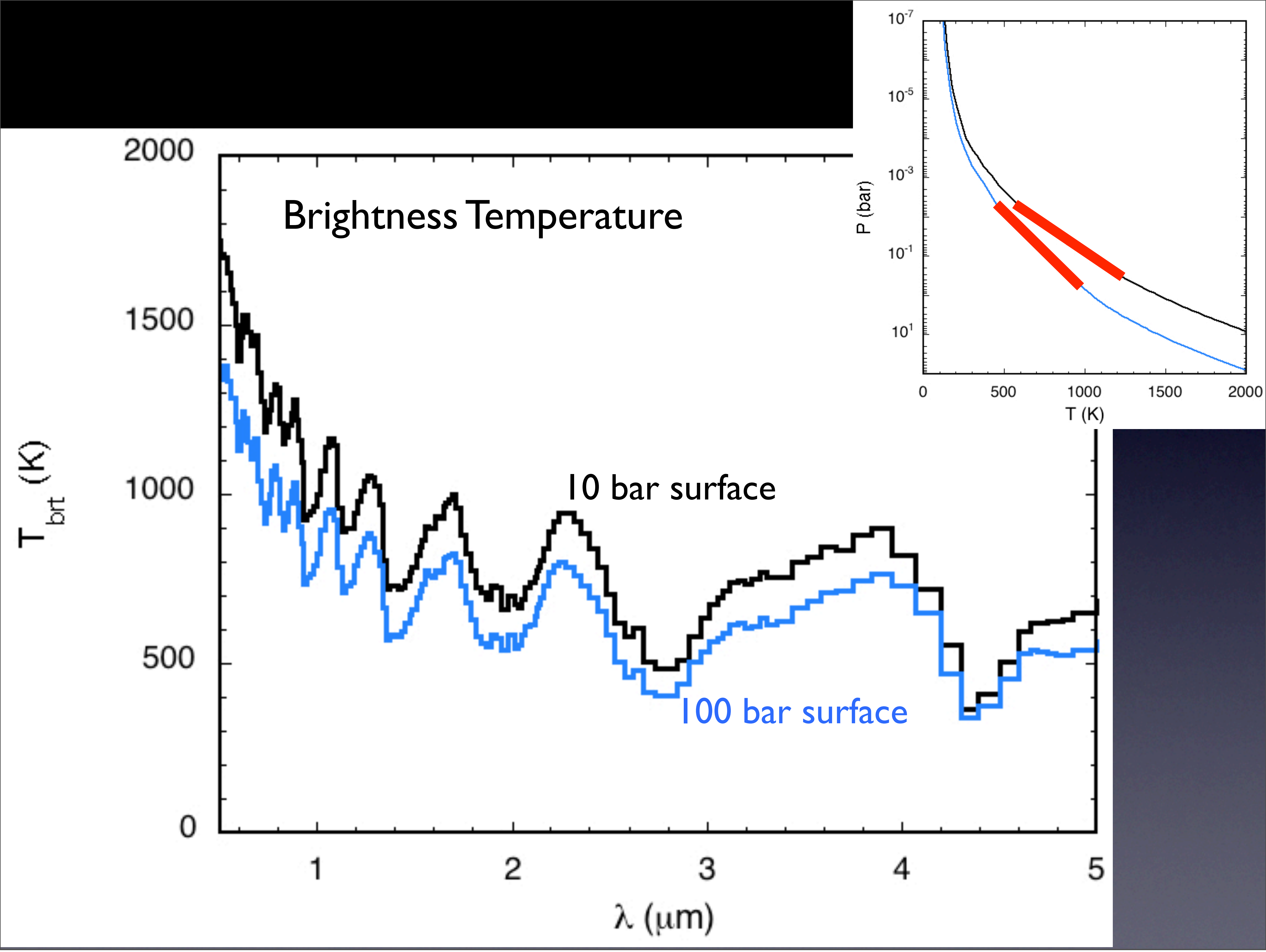


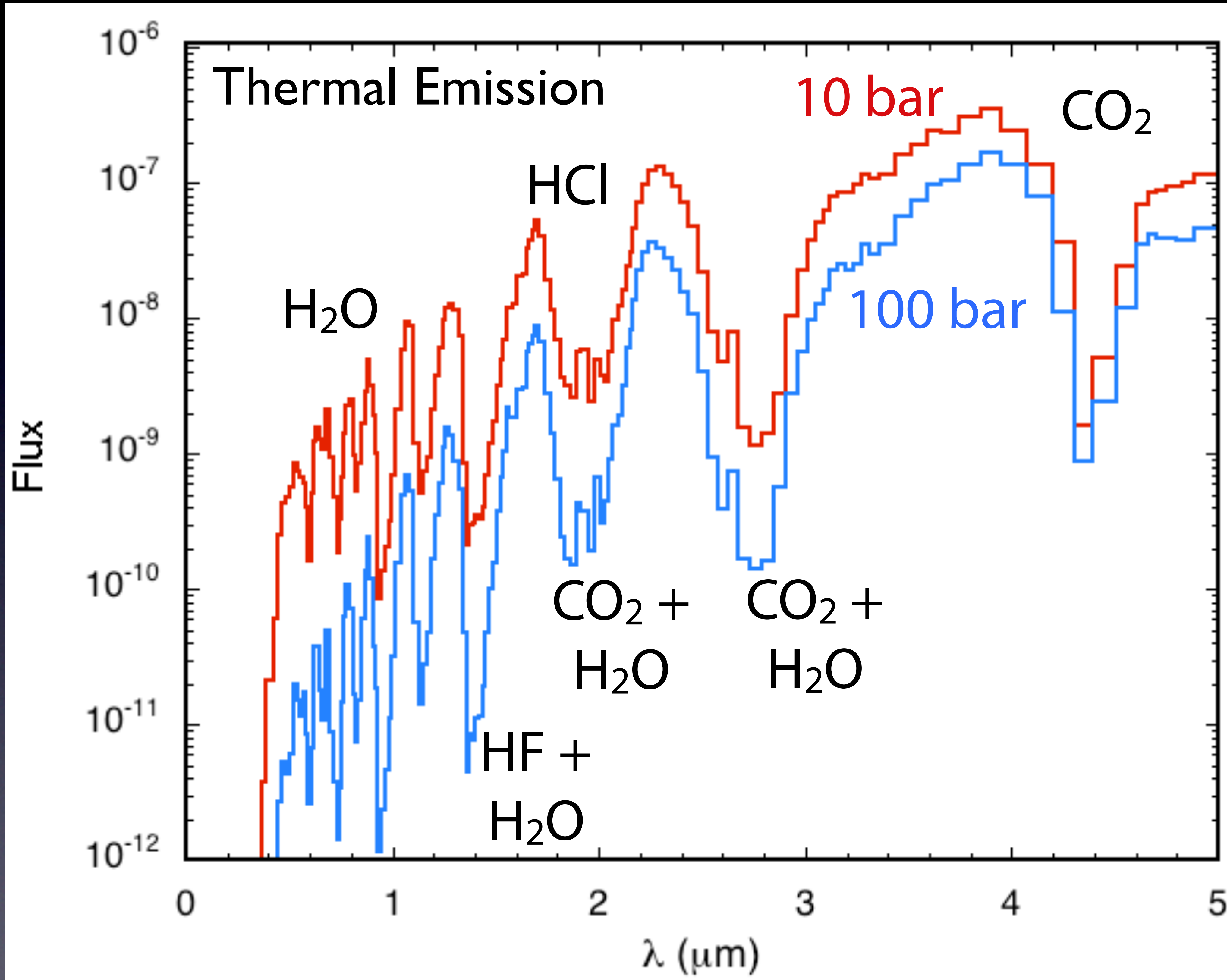


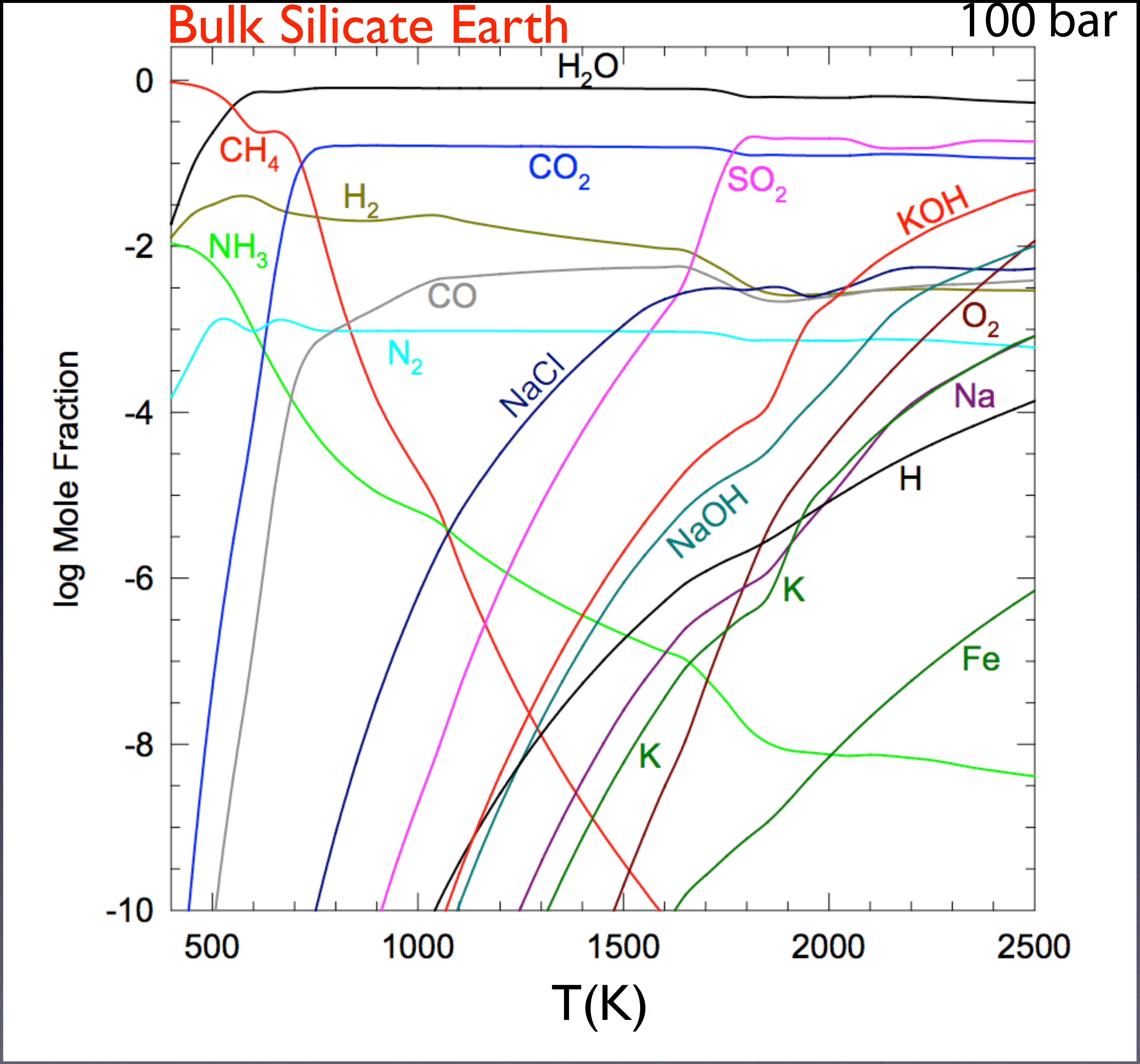
Surface Pressure = 10 bar

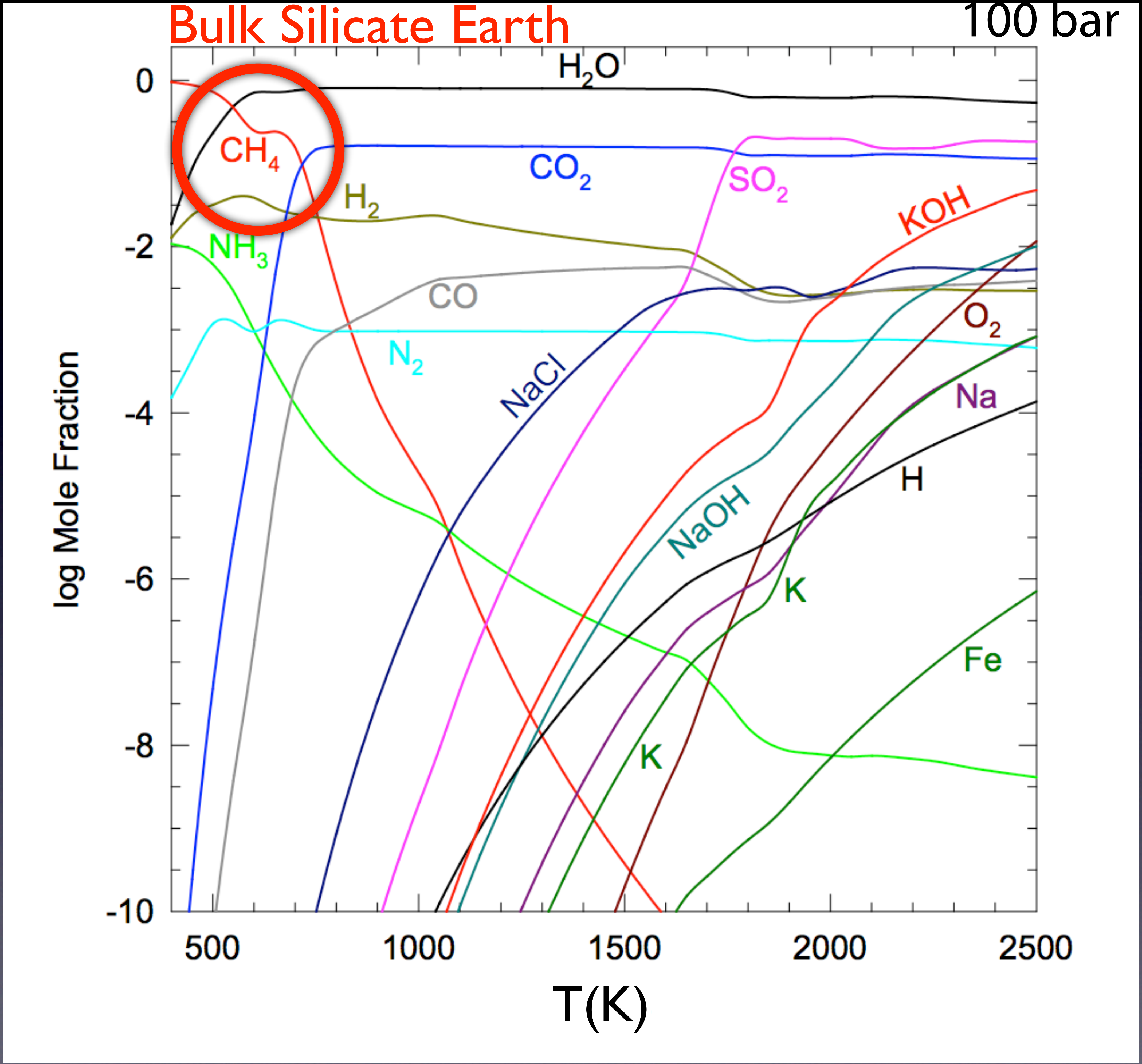





Brightness Temperature
10 bar surface
100 bar surface
T_{brt} (K)
λ (μm)
2000
1500
1000
500
0
1
2
3
4
5
P (bar)
T (K)
10^{-7}
10^{-5}
10^{-3}
10^{-1}
10^{1}
0
500
1000
1500
2000

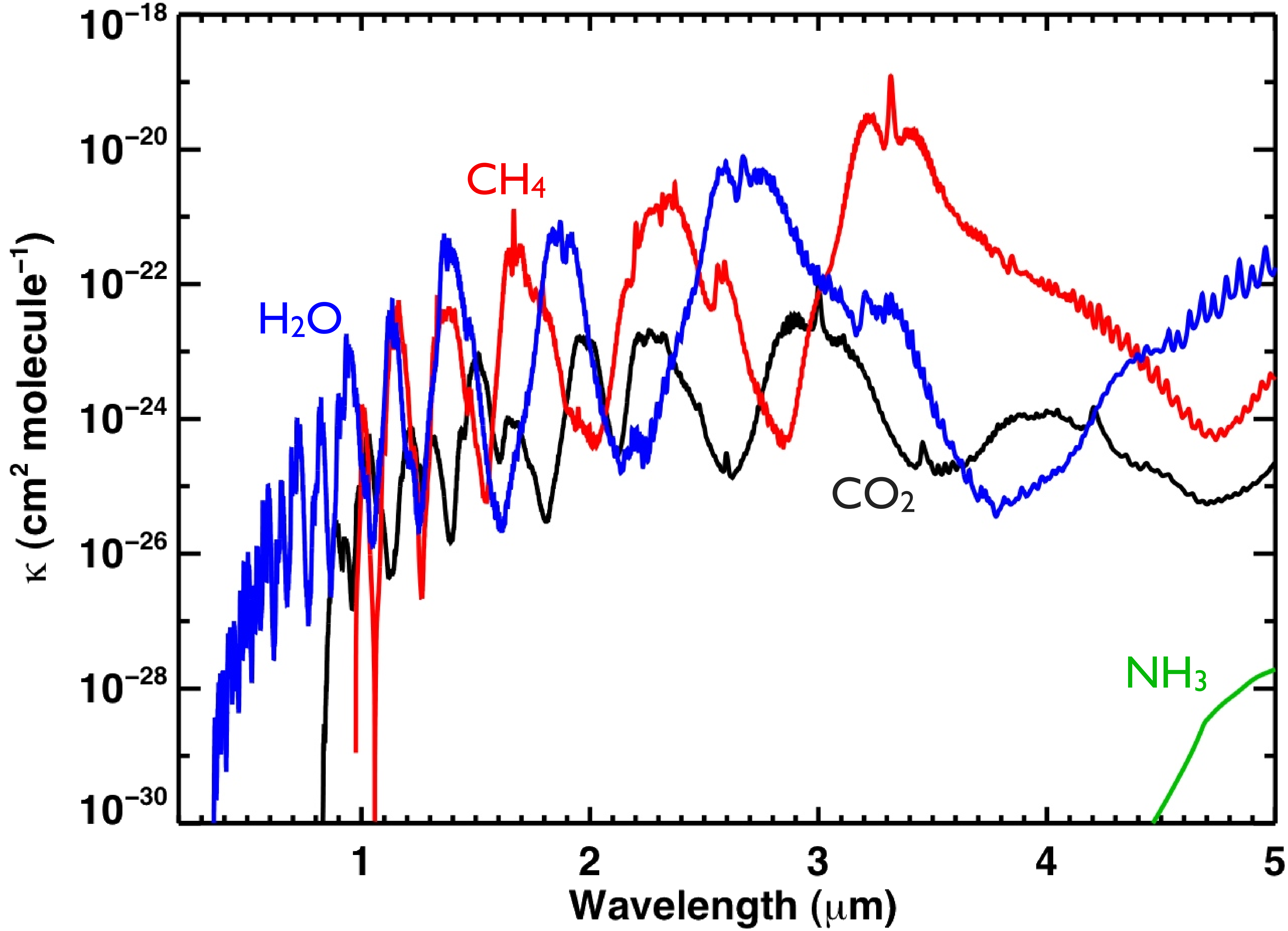

Thermal Emission
10 bar
100 bar
CO_2
HCl
H_2O
CO_2 + H_2O
CO_2 + H_2O
HF + H_2O
Flux
λ (μm)
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
0
1
2
3
4
5


Bulk Silicate Earth
100 bar
log Mole Fraction
T(K)
0
-2
-4
-6
-8
-10
500
1000
1500
2000
2500
H2O
CH4
CO2
SO2
H2
NH3
CO
KOH
N2
NaCl
O2
Na
H
NaOH
K
Fe
K

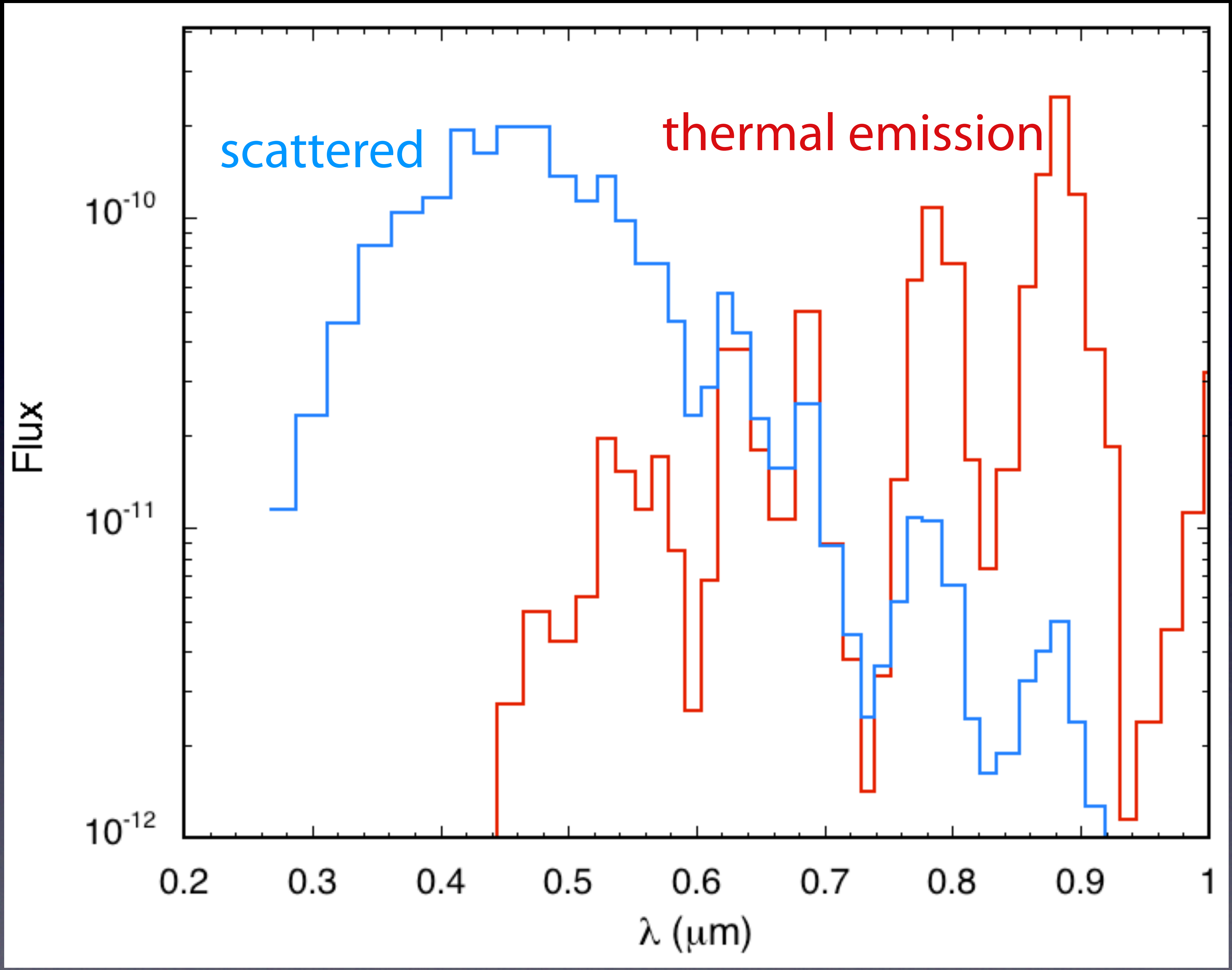


Bulk Silicate Earth
100 bar
H2O
CH4
CO2
SO2
H2
KOH
NH3
CO
NaCl
O2
N2
Na
NaOH
H
K
K
Fe
log Mole Fraction
0
-2
-4
-6
-8
-10
500
1000
1500
2000
2500
T(K)

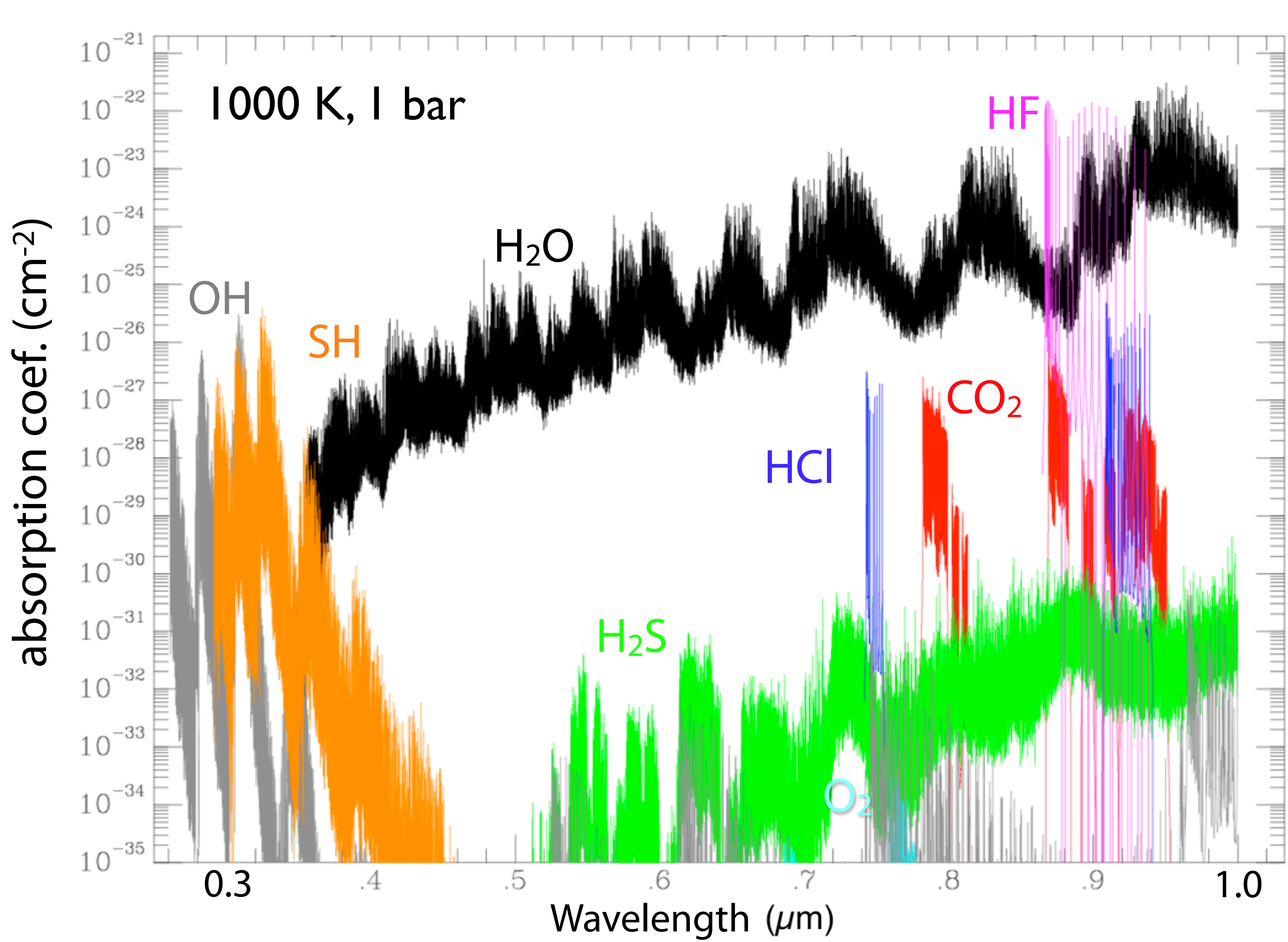
Bulk Silicate Earth 500 K



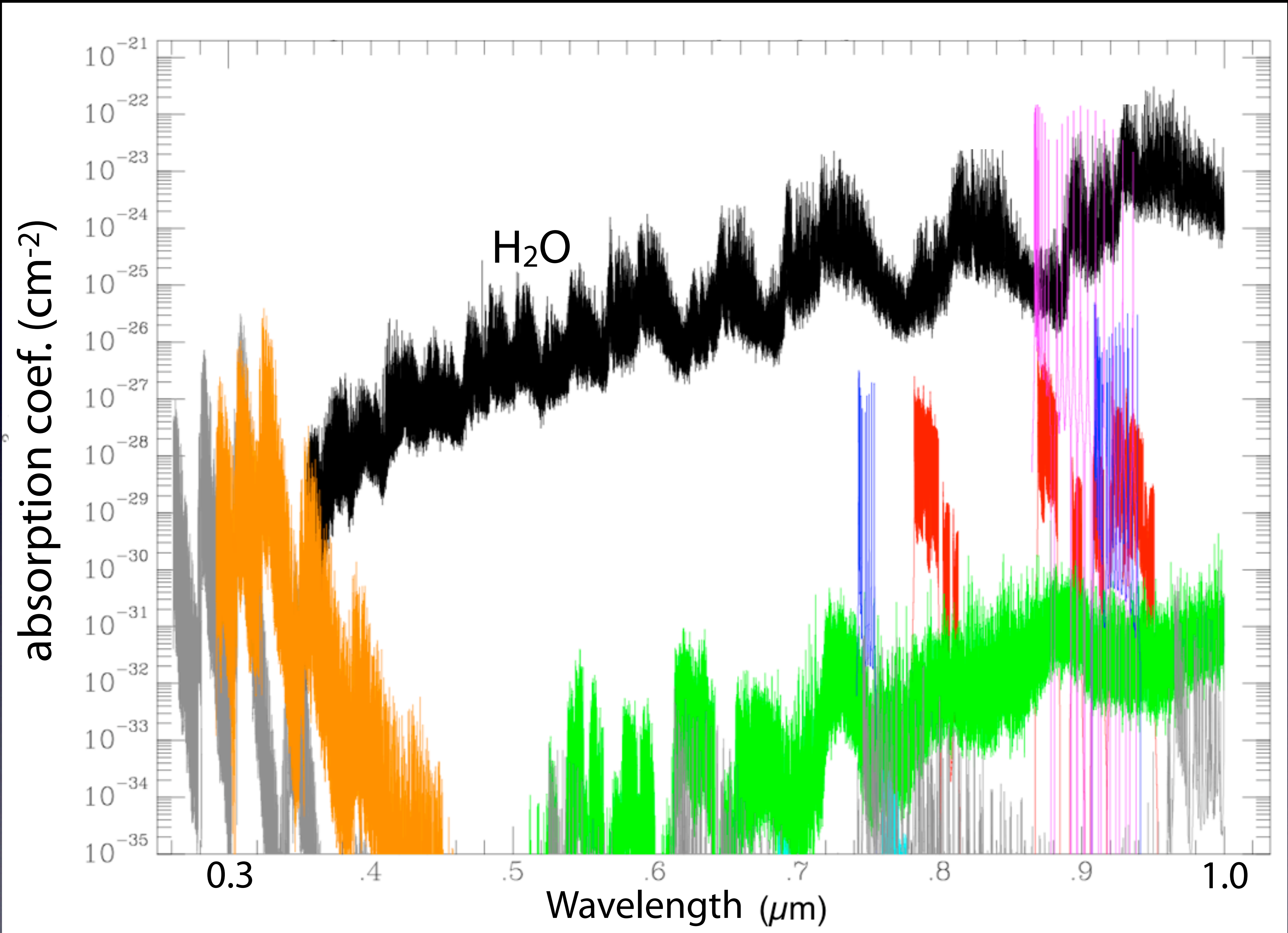
Cautionary Tale

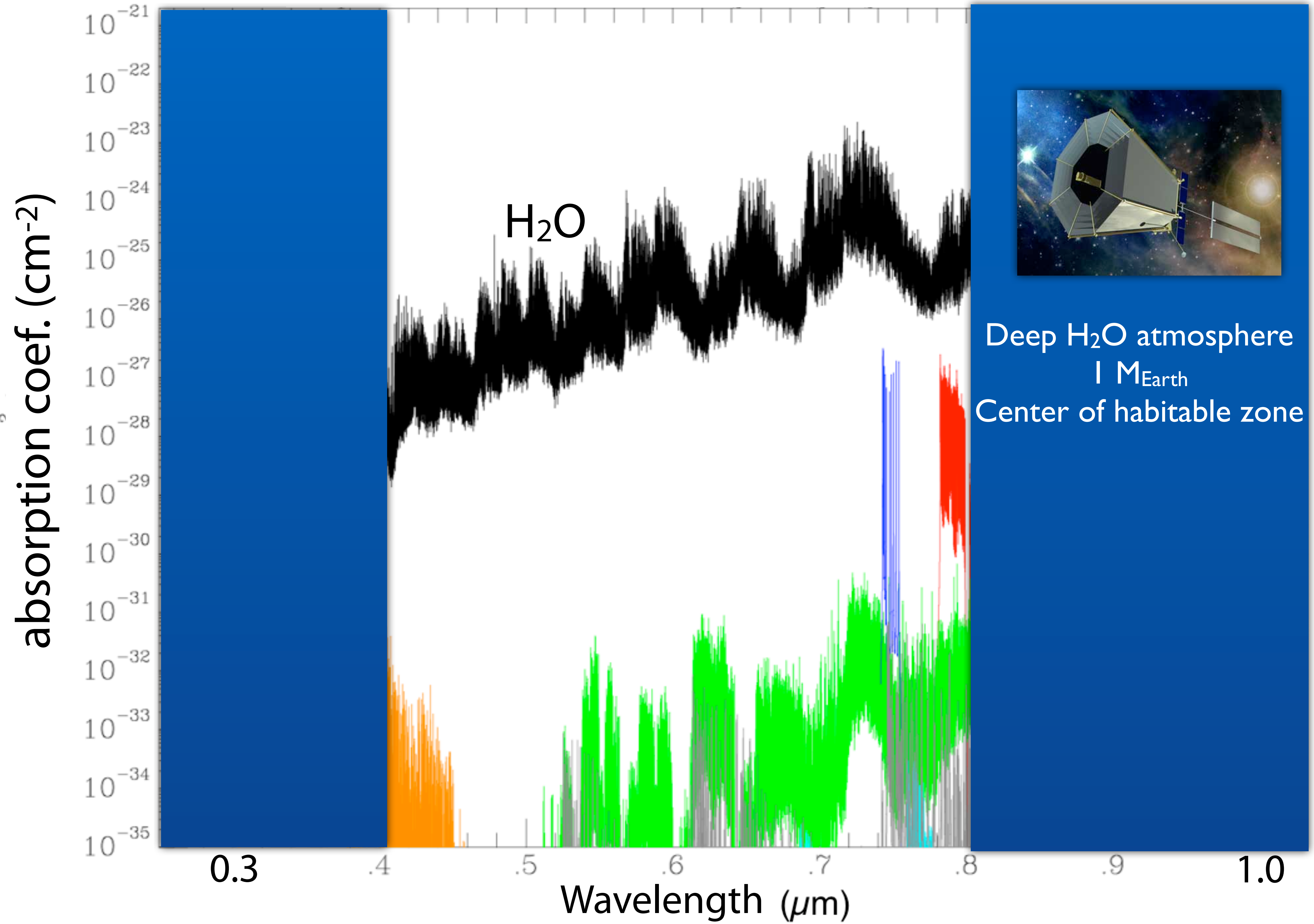


scattered
thermal emission
Flux
10-10
10-11
10-12
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
λ (μm)

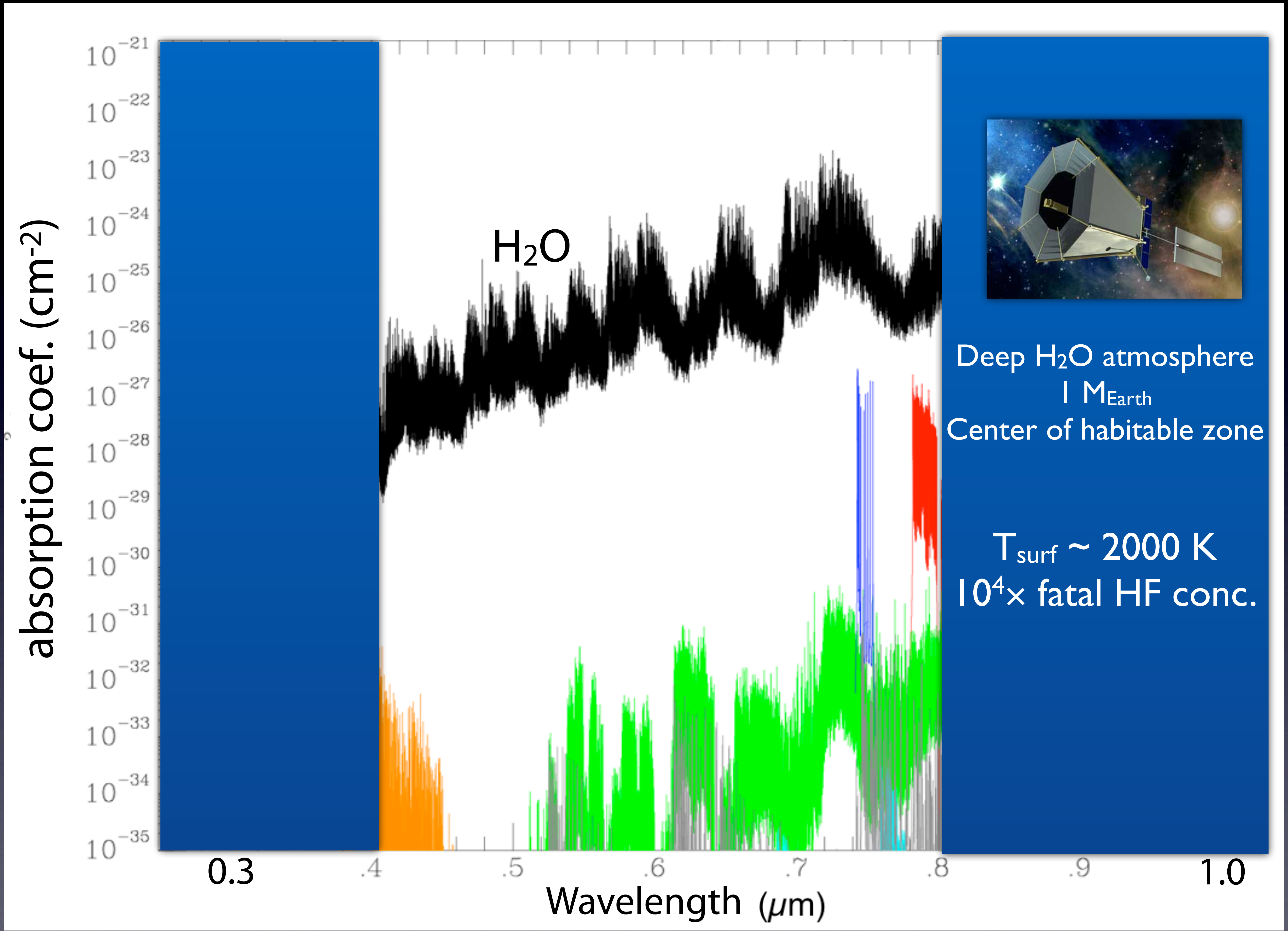


1000 K, 1 bar
absorption coef. (cm-2)
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^{-28}
10^{-29}
10^{-30}
10^{-31}
10^{-32}
10^{-33}
10^{-34}
10^{-35}
OH
SH
H_2O
HF
CO_2
HCl
H_2S
O_2
0.3
.4
.5
.6
.7
.8
.9
1.0
Wavelength (μm)


H_2O
absorption coef. (cm^{-2})
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^{-28}
10^{-29}
10^{-30}
10^{-31}
10^{-32}
10^{-33}
10^{-34}
10^{-35}
0.3
.4
.5
.6
.7
.8
.9
1.0
Wavelength (μm)



absorption coef. (cm-2)
10-21
10-22
10-23
10-24
10-25
10-26
10-27
10-28
10-29
10-30
10-31
10-32
10-33
10-34
10-35
H2O
Deep H2O atmosphere
1 MEarth
Center of habitable zone
0.3
.4
.5
.6
.7
.8
.9
1.0
Wavelength (μm)



absorption coef. (cm⁻²)
10^-21
10^-22
10^-23
10^-24
10^-25
10^-26
10^-27
10^-28
10^-29
10^-30
10^-31
10^-32
10^-33
10^-34
10^-35
H2O
0.3
.4
.5
.6
.7
.8
.9
1.0
Wavelength (μm)
Deep H2O atmosphere
1 MEarth
Center of habitable zone
Tsurf ~ 2000 K
10^4× fatal HF conc.

Conclusions

- Post-impact worlds are highly detectable
- Realistic cases somewhat less favorable than exploratory models by Miller-Ricci et al.
- HF & HCl are markers of T_{surf} > 1000 K.
- CH_4 is signature of BSE (Fe^{2+} vs. Fe^{3+})
- Remember....