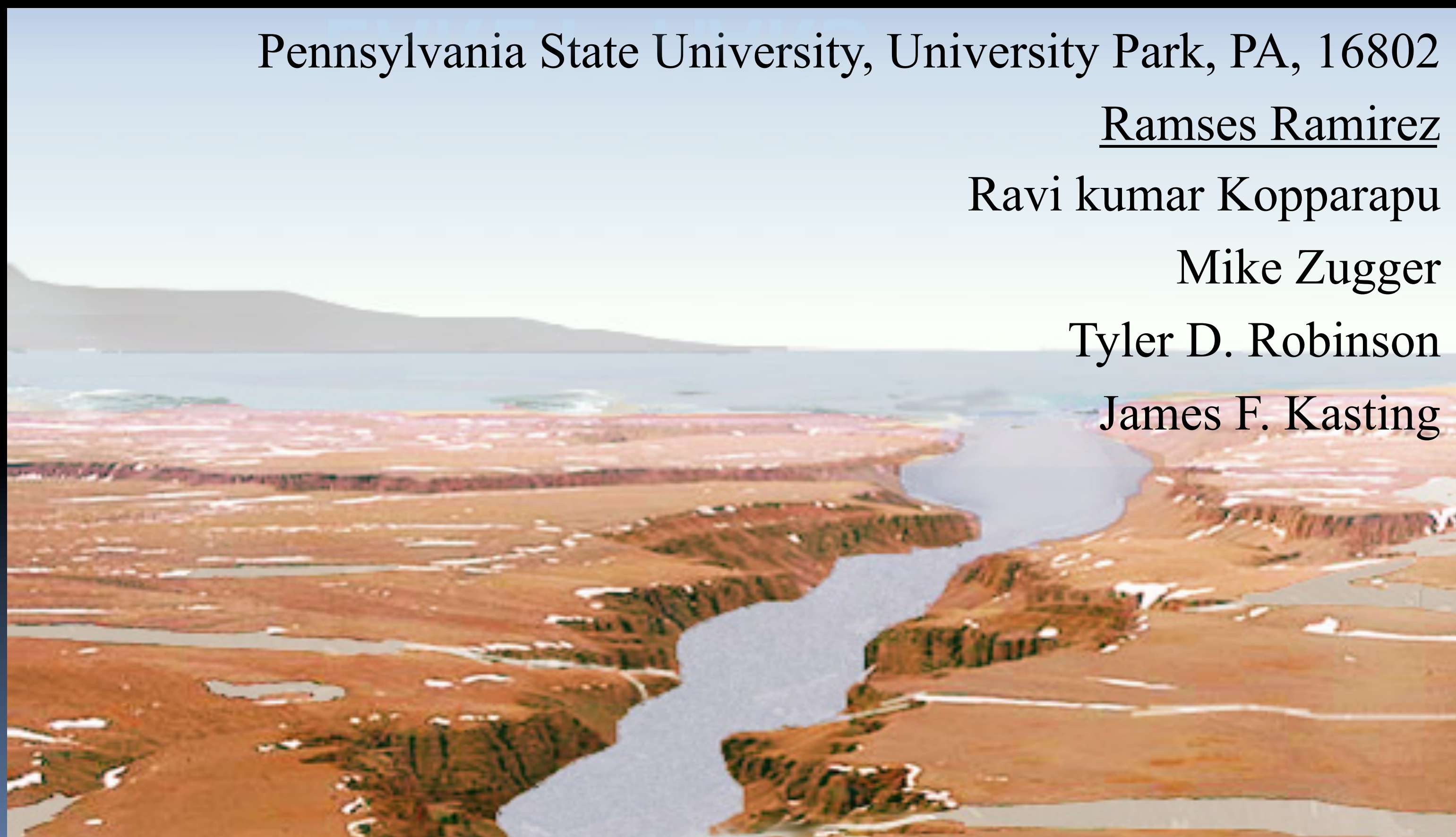
A CO_2-H_2 GREENHOUSE FOR EARLY MARS



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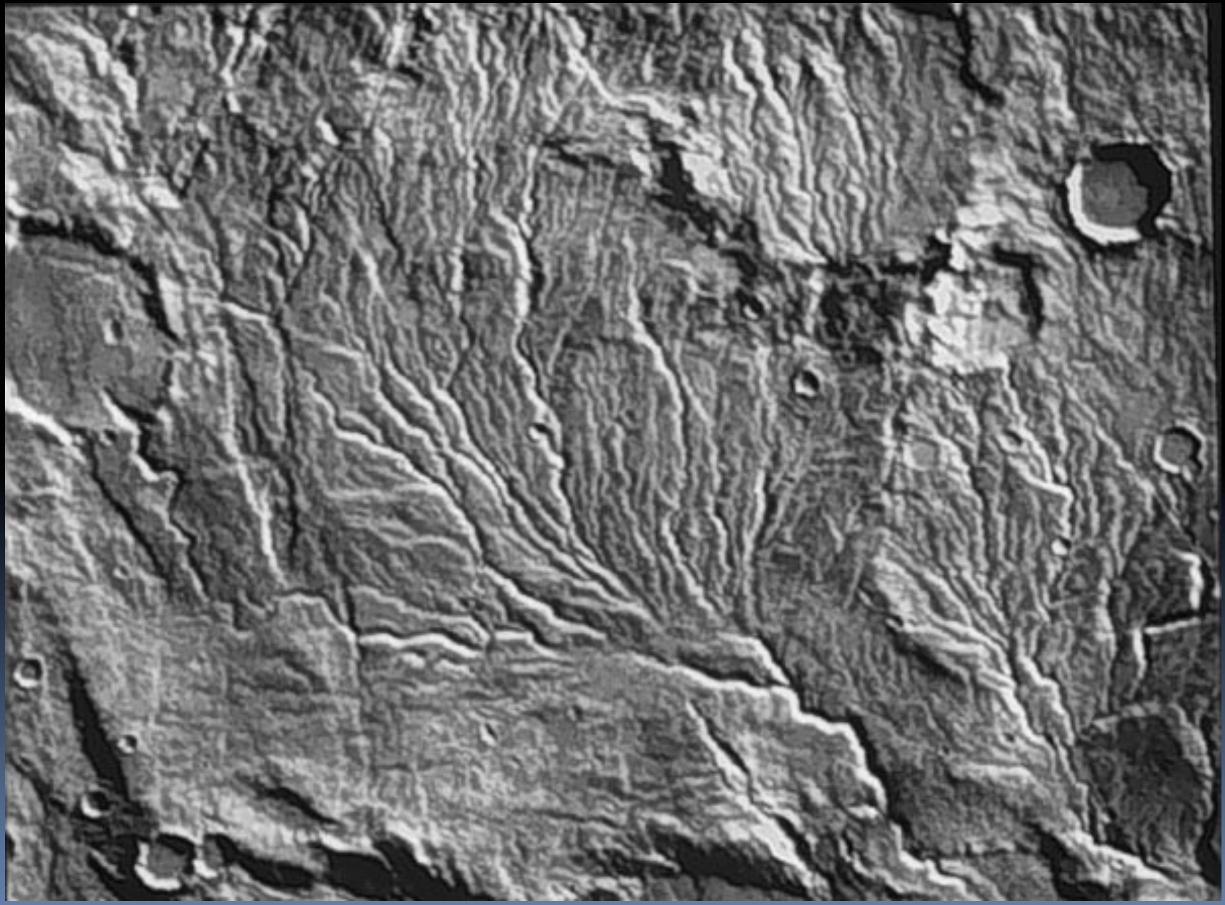
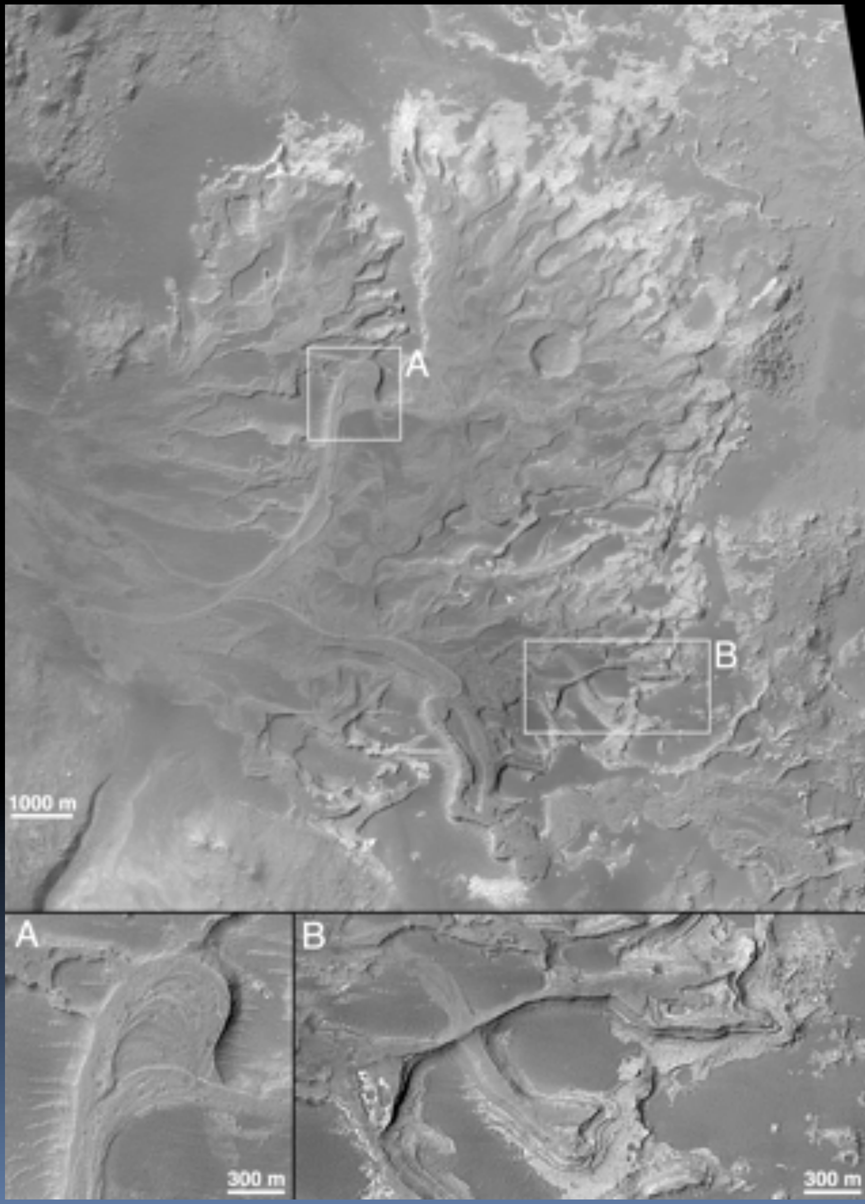
Background and Motivation

- Presence of fluvial features on the martian surface suggest that early Mars was warm and wet



Warrego Vallis (Viking)

Background and Motivation



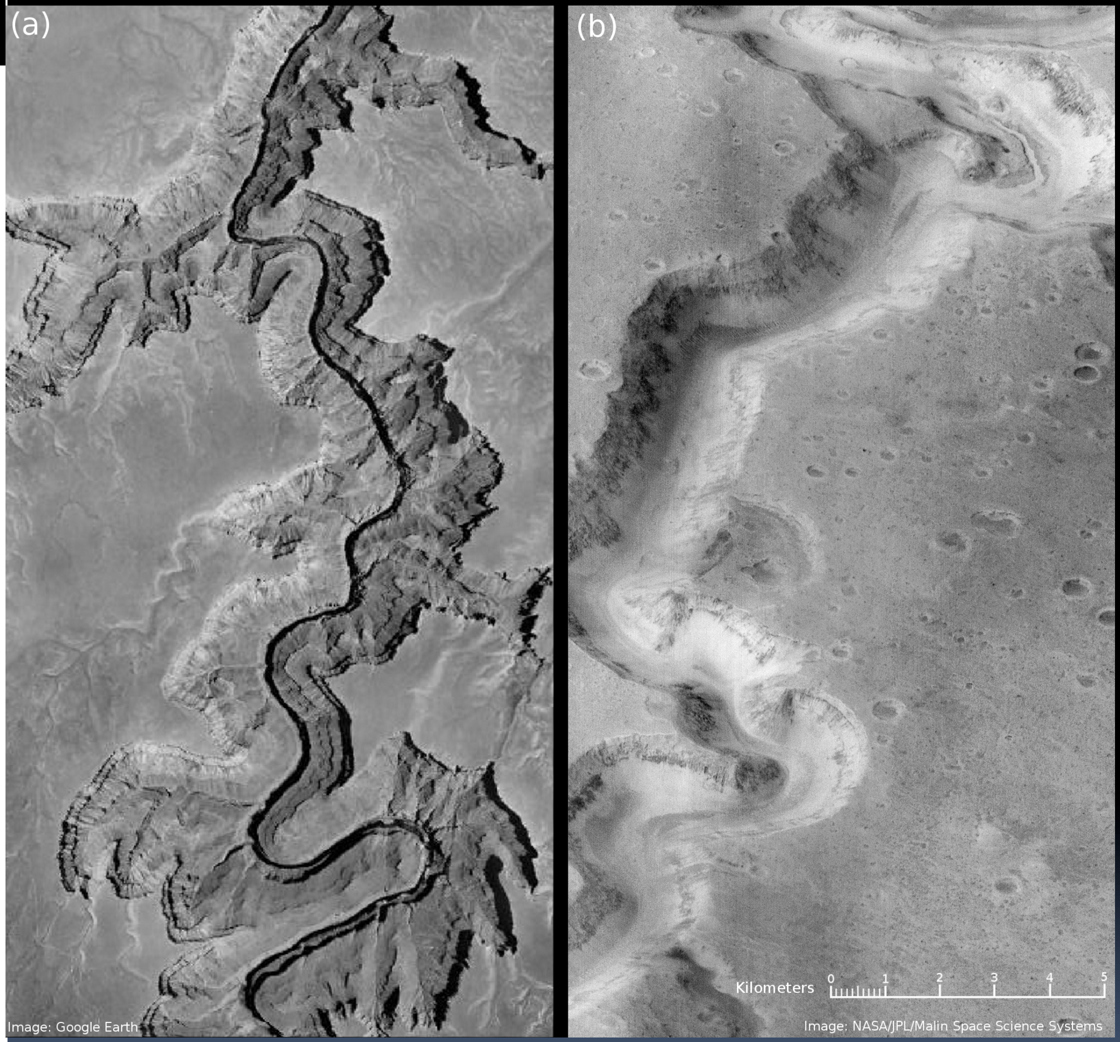
A) Cutoff channel meander

B) Cross-cutting channels

(inverted relief in both cases)

Malin and Edgett, *Science,* 2003

Background and Motivation



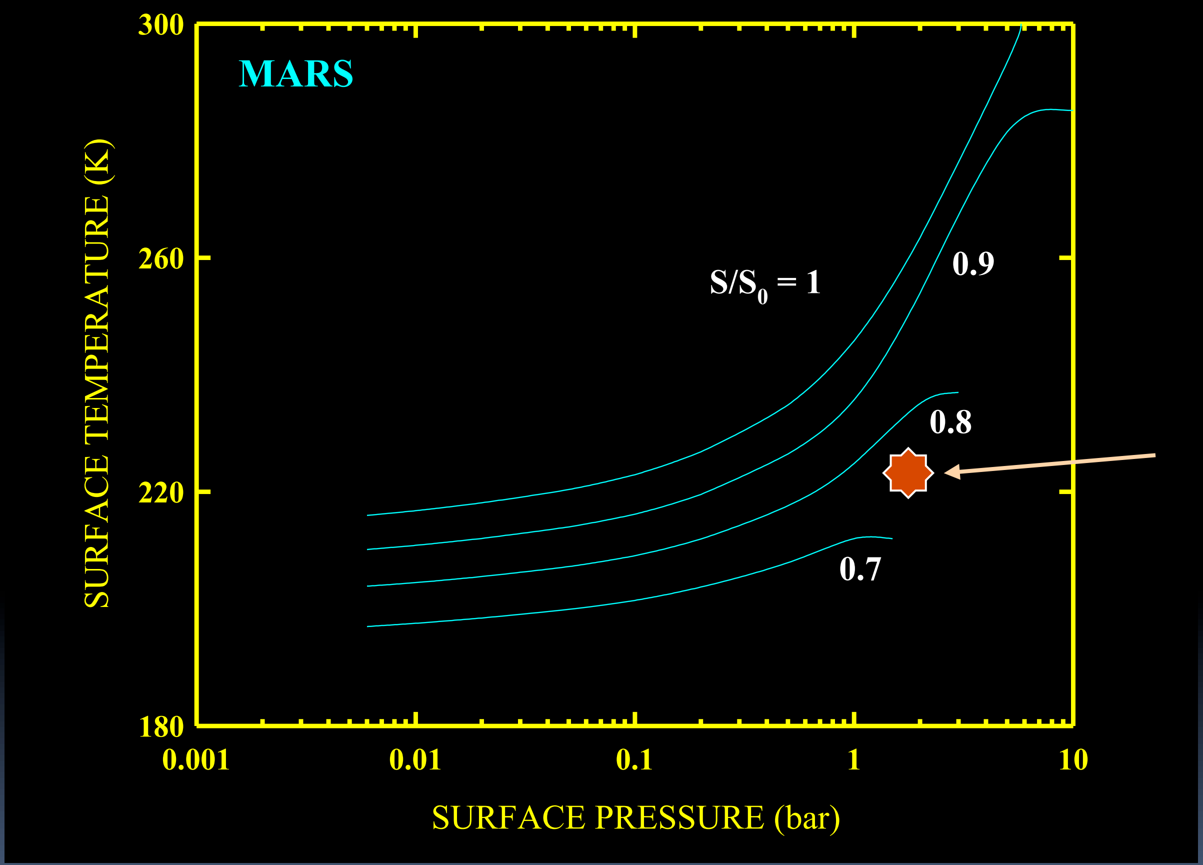
8 km

Grand Canyon

Nanedi Valles

- According to Hoke et al., episodic intermittent runoff averaging ~10 cm/yr for $(3\text{-}4)\times10^7$ yr, were needed to form the larger valleys (~ > $3\text{x}10^6$ m total runoff)

Martian surface temperature vs. pCO_2 and solar luminosity



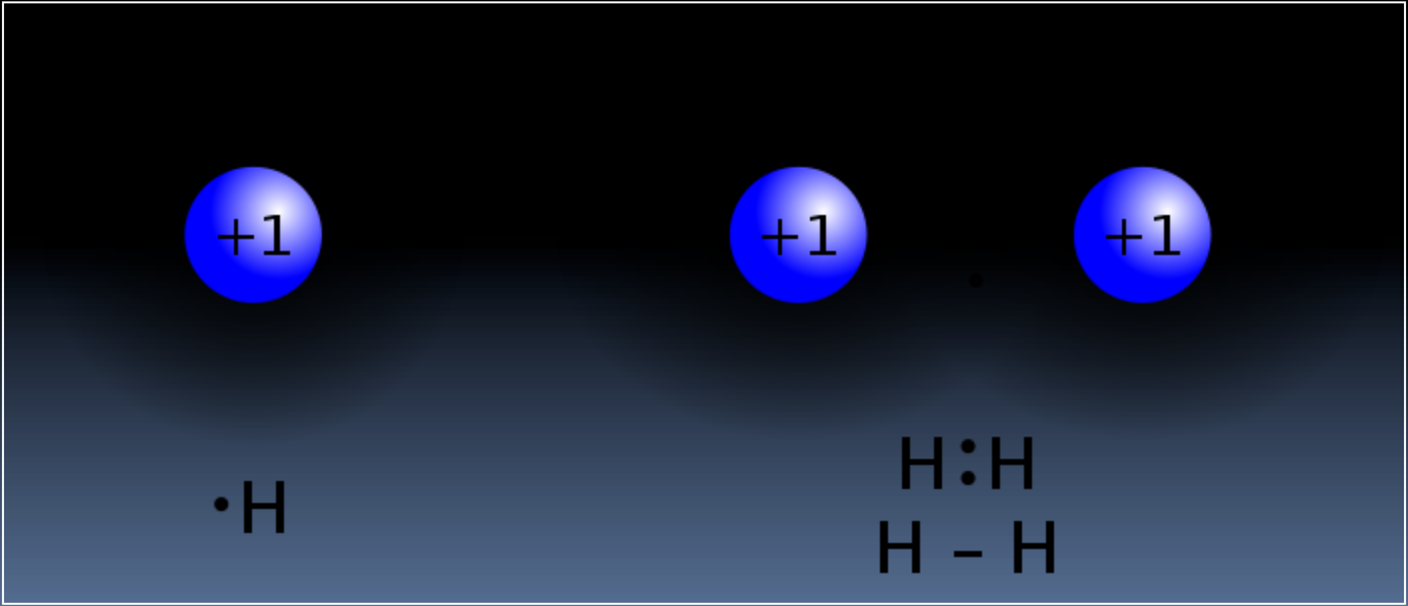
$S/S_0 = 0.75$ at 3.8. b.y. ago, when most of the valleys formed

- Previous calculations showed that greenhouse warming by CO_2 (and H_2O) could not have kept early Mars' mean surface above freezing

J. F. Kasting, *Icarus* (1991)

Background and Motivation

- Unfortunately, a standard CO_2-H_2O greenhouse cannot warm early Mars
- However, H_2 has been a potent greenhouse in H_2-dominated worlds (Pierrehumbert and Gaidos, 2011)
- We show that H_2 is also an effective secondary gas in warming the Martian surface



1-D Climate model

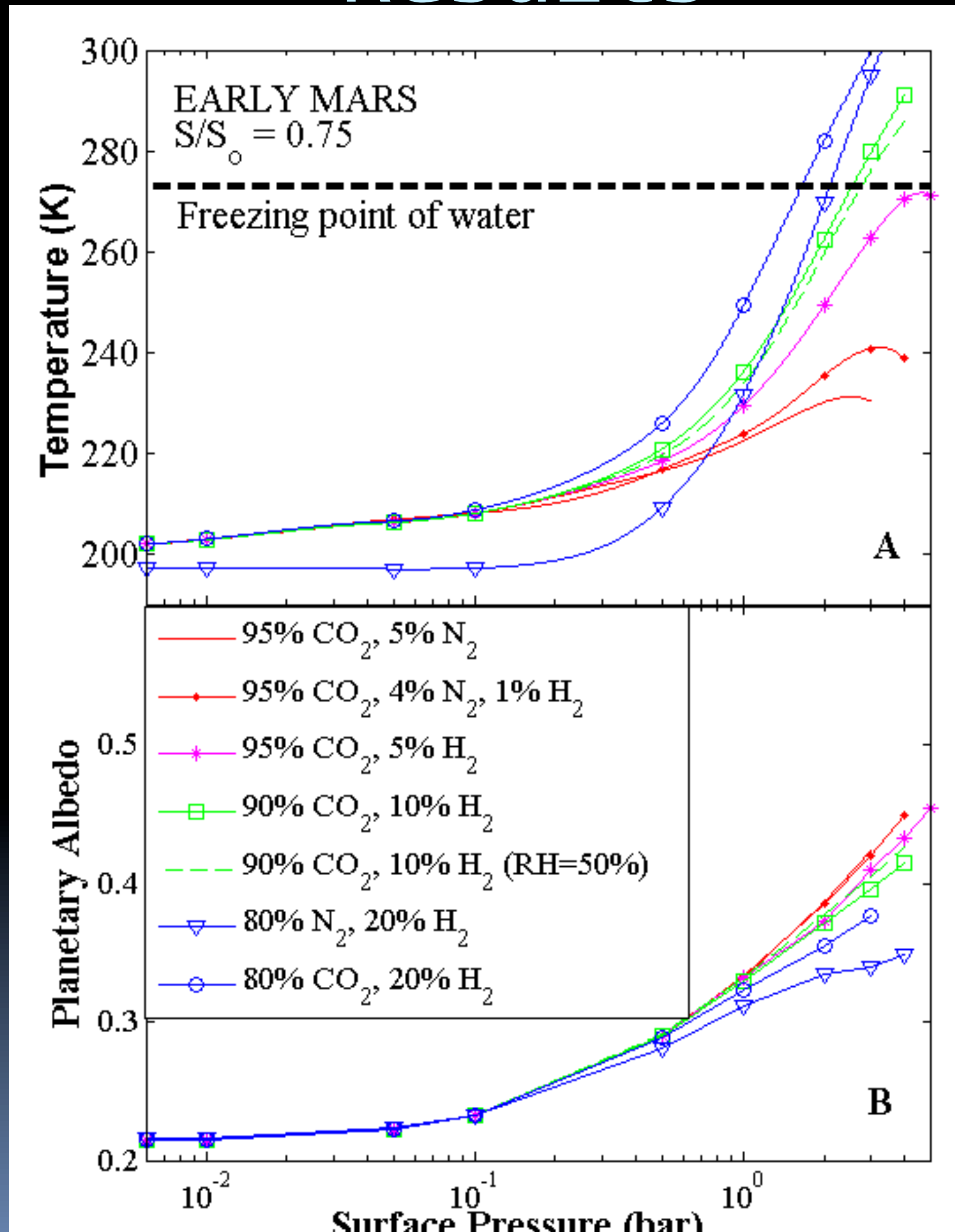
- 1-D radiative-convective climate model
- Cloud-free
- Delta two-stream approximation parameterizes gaseous absorption in 38 solar intervals
- 55 IR intervals that use time-stepping routine that iterates until:

  - Absorbed and emitted fluxes in stratosphere are balanced
  - Surface temperature converges to steady state

Climate model updates

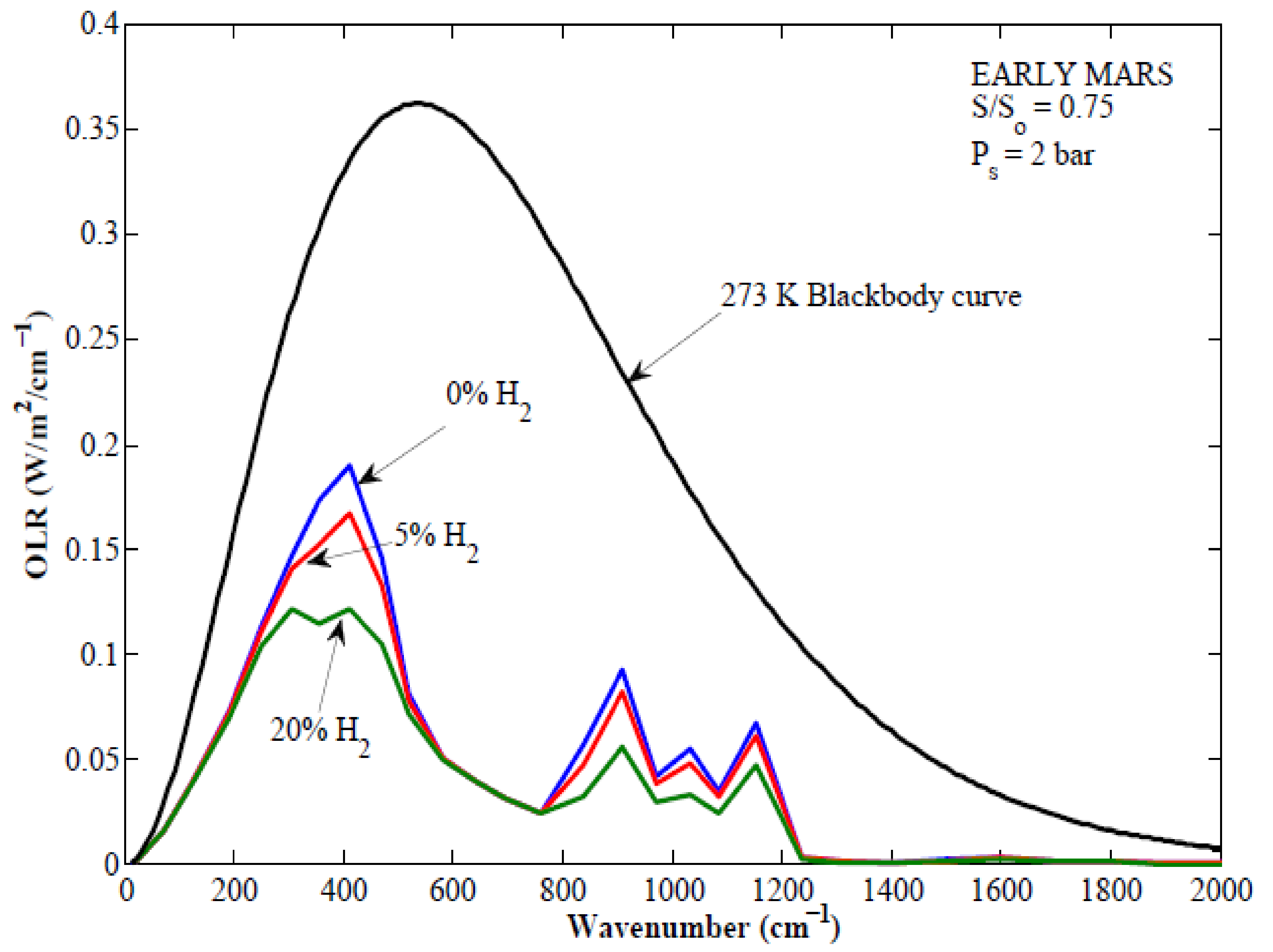
- We derived new HITRAN 2008 coefficients for CO_2 and HITEMP 2010 coefficients for H_2O
- The H_2-N_2 CIA data of Lothar and Frommhold (1986) are used as a proxy for H_2-CO_2
- Self-broadening by H_2-H_2 pairs was also incorporated (Borysow, 2002)
- H_2 Rayleigh scattering was added (Dalgarno and Williams, 1962)
- The Shomate Equation was used to compute the heat capacity of H_2

Results



Ramirez et al., (2013), *in review*

Results



Ramirez et al., (2013), *in review*

Are high H_2 amounts possible?

$$2H_2O \overset{K_{eq}}{\leftrightarrow} 2H_2 + O_2$$

$$K_{eq} = \frac{pH_2^{\;2} fO_2}{pH_2O^2}$$

$$\frac{pH_2}{pH_2O} = \sqrt{\frac{K_{eq}}{fO_2}}$$

$$\left(\frac{pH_2}{pH_2O}\right)_{Earth} \cong 0.02$$

At P = 5 atm and 1300C

Grott et al. (2011) argue that early Mars's mantle fugacity state could gave been as low as IW-1 (or FMQ -5)

$$fO_2^{\;Earth} \cong 10^{-8} atm(FMQ)$$

$$fO_2 \cong 10^{-12} atm(IW)$$

Outgas more H_2 on Mars because of reduced mantle

Are high H_2 amounts possible?

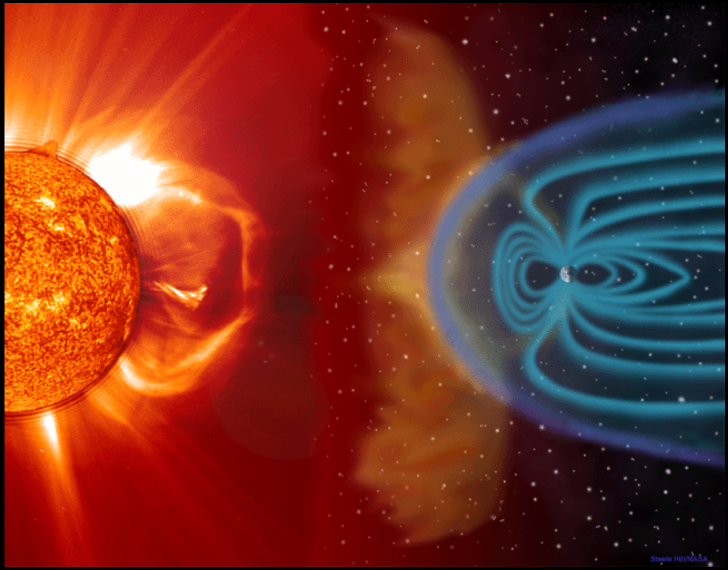
$$\Phi_l(H_2) = \frac{b_i}{H_a} \cdot \frac{f_T(H_2)}{1 + f_T(H_2)} \cong \frac{b_i f_T(H_2)}{H_a}$$

- For IW+1, H_2 outgassing rates ~ 20x greater than that of Earth or $4\text{x}10^{11}$ molec./$\text{cm}^{-2}\text{s}^{-1}$
- For a homopause temperature of 160K, bi/Ha~$1.6\text{x}10^{13}$ $\text{cm}^{-2}\text{s}^{-1}$
- So, $f_t(H_2)$ ~ 2.5%. Within a factor of 2 of 5%
- SNC meteorites (i.e. ALH84001) suggest IW-1 : f_t(H2) >5% may be possible

-Works better for Mars than Earth because scale height (H_a) for Mars is bigger

Are high H_2 amounts possible?

- In comparison with 1-D results (i.e. Tian et al., 2009), hydrodynamic escape would have been slowed down by two things:
  1) Magnetic fields
  2) Spherical geometry*



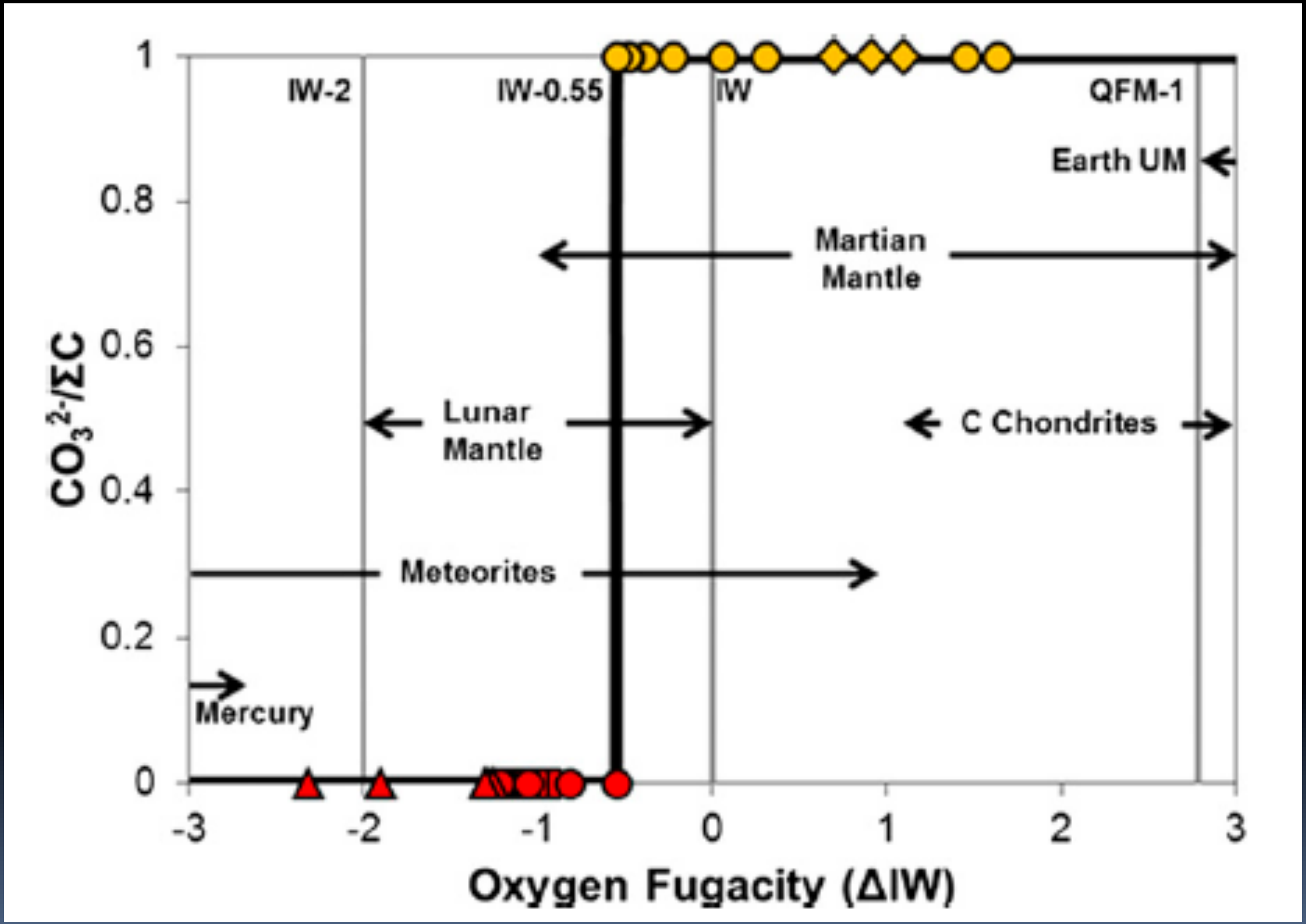
* Stone and Praga (2009) show that spherical geometry would have reduced escape rates by a factor of 4, making 20% H_2 achievable

Degassing of C

- Grott et al. (2011) state that C would have remained in graphite form and not outgas as CO_2 in a very reduced early Mars atmosphere
- However, C could have outgassed as Fe-carbonyl ($Fe(CO)_5$) + minor CH_4 and then get oxidized to CO_2

Degassing of reduced carbon from planetary basalts

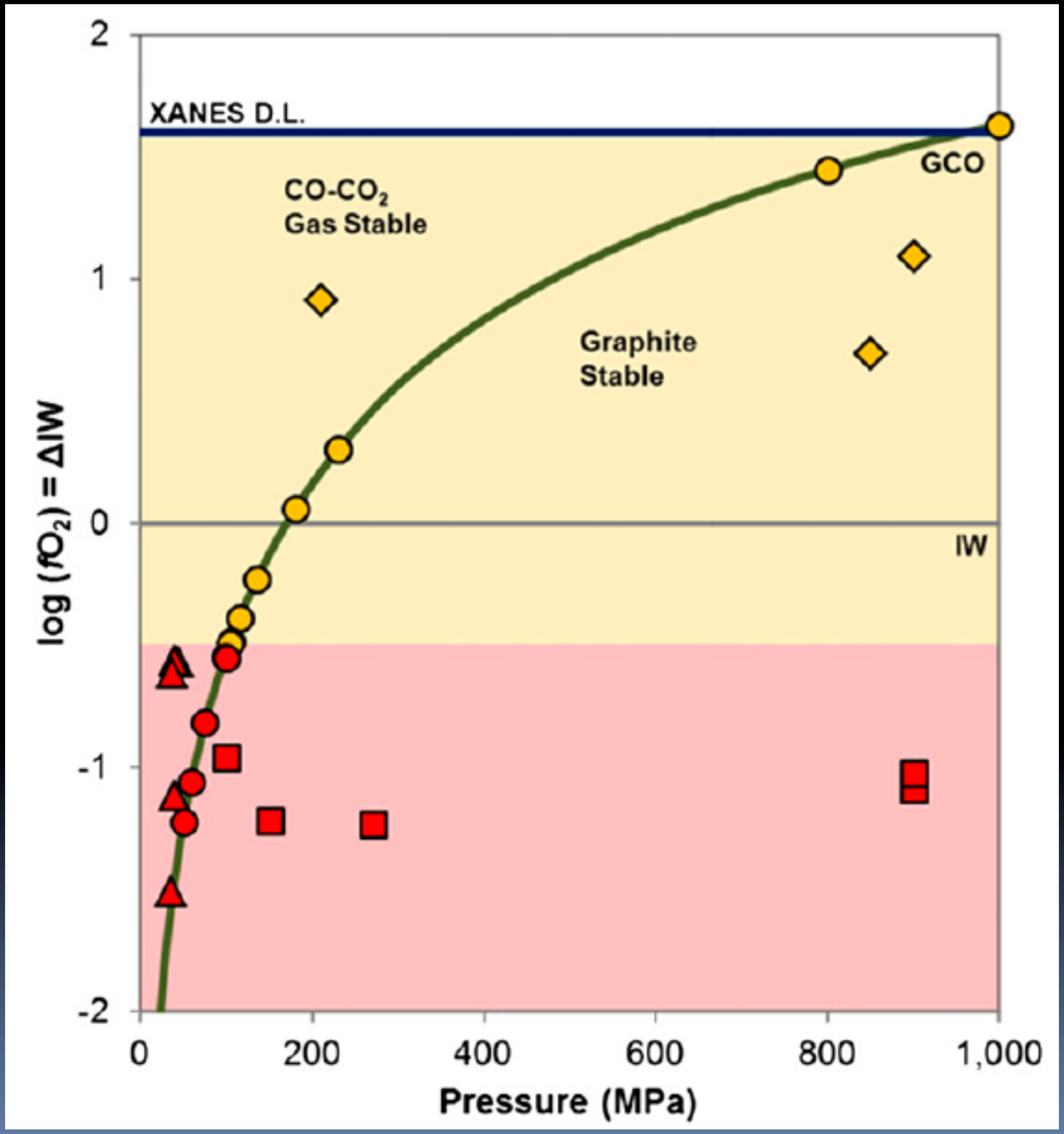
Diane T. Wetzel[a,1], Malcolm J. Rutherford[a], Steven D. Jacobsen[b], Erik H. Hauri[c], and Alberto E. Saal[a]



Wetzel et al., (2013), *PNAS*

Conclusions

- The abundance of fluvial features suggests that early Mars (3.8 Ga) was once a warm, wet place
- In contrast to Segura et al. (2008), Hoke et al. (2011) show that voluminous amounts of water over long time scales are required to form the ancient valley networks
- Early Mars could have been warmed with a combination of CO_2, H_2O, and H_2
- Future work requires a 2-D hydrodynamic model that includes spherical geometry
- Treatment of magnetic fields would require a 3-D model
- Come see me at my poster tomorrow to learn about this work's implications for the habitable zone


XANES D.L.
GCO
CO-CO_2
Gas Stable
Graphite
Stable
IW
log (fO_2) = ΔIW
2
1
0
-1
-2
0
200
400
600
800
1,000
Pressure (MPa)

Why is H_2 so effective?

- Consider the quantum mechanical linear rigid rotor:
- Rotational energy is represented by:

$$E_l = Bl(l+1)$$

- The change in energy between levels is:

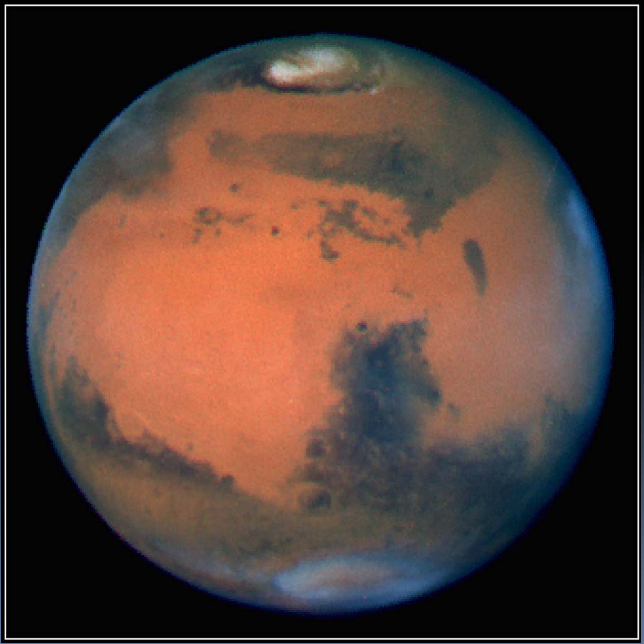
$$\Delta E = 2B(l+1)$$

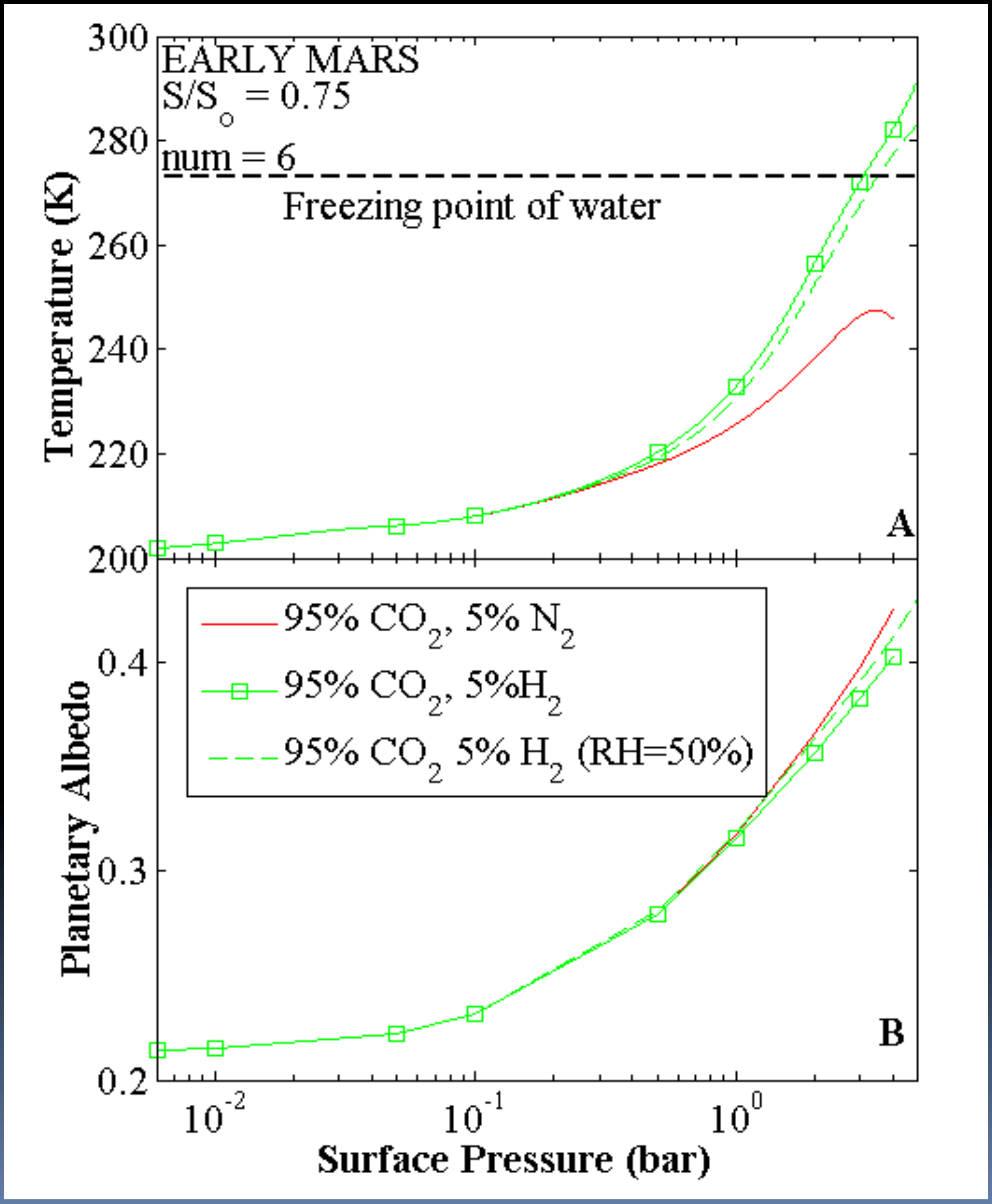
- Where:

$$B = \frac{\hbar^2}{2I} \qquad I = \mu R^2 \qquad \mu = \frac{m_1 m_2}{m_1 + m_2} = \frac{m}{2}$$

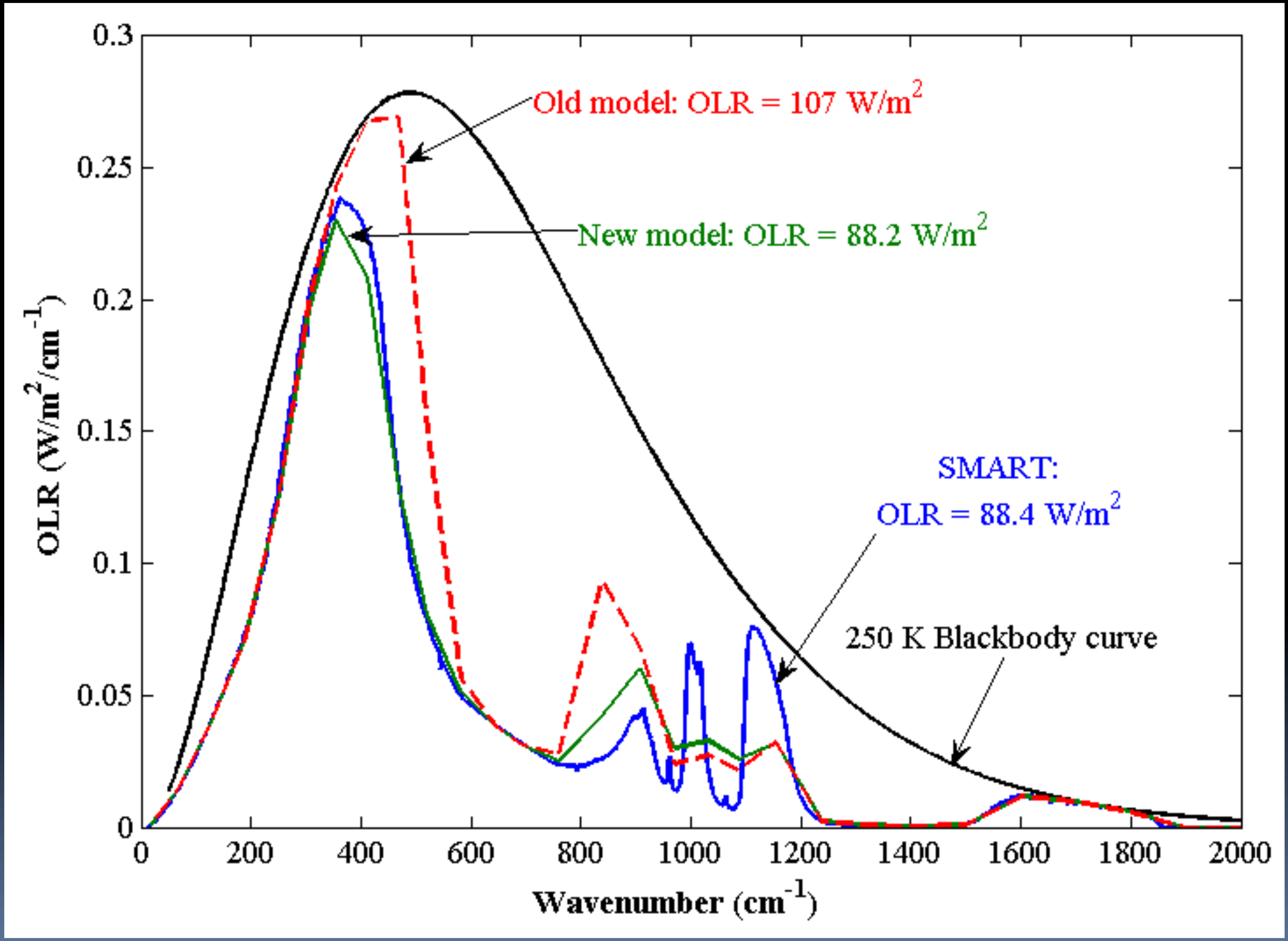
Why is H_2 so effective?

- For N_2: B~ 2cm^{-1} and both R and m are greater
- For H_2: B~ 60cm^{-1} and both R and m are smaller
- Thus, ΔE is big for H_2 and energy levels are widely-spaced
- For ΔE is 1000cm^{-1}, l = 6 for H_2 and ~250 for N_2!

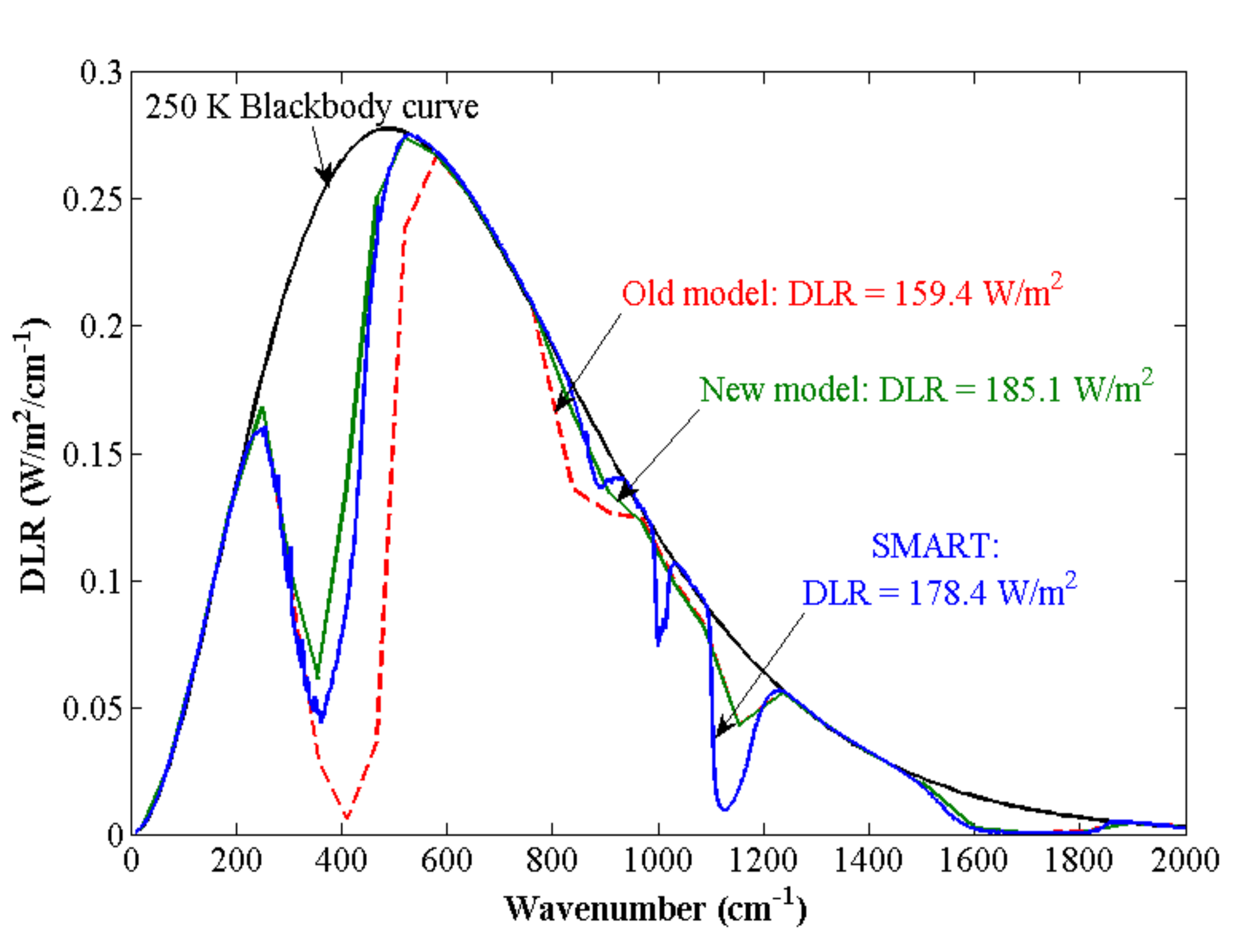




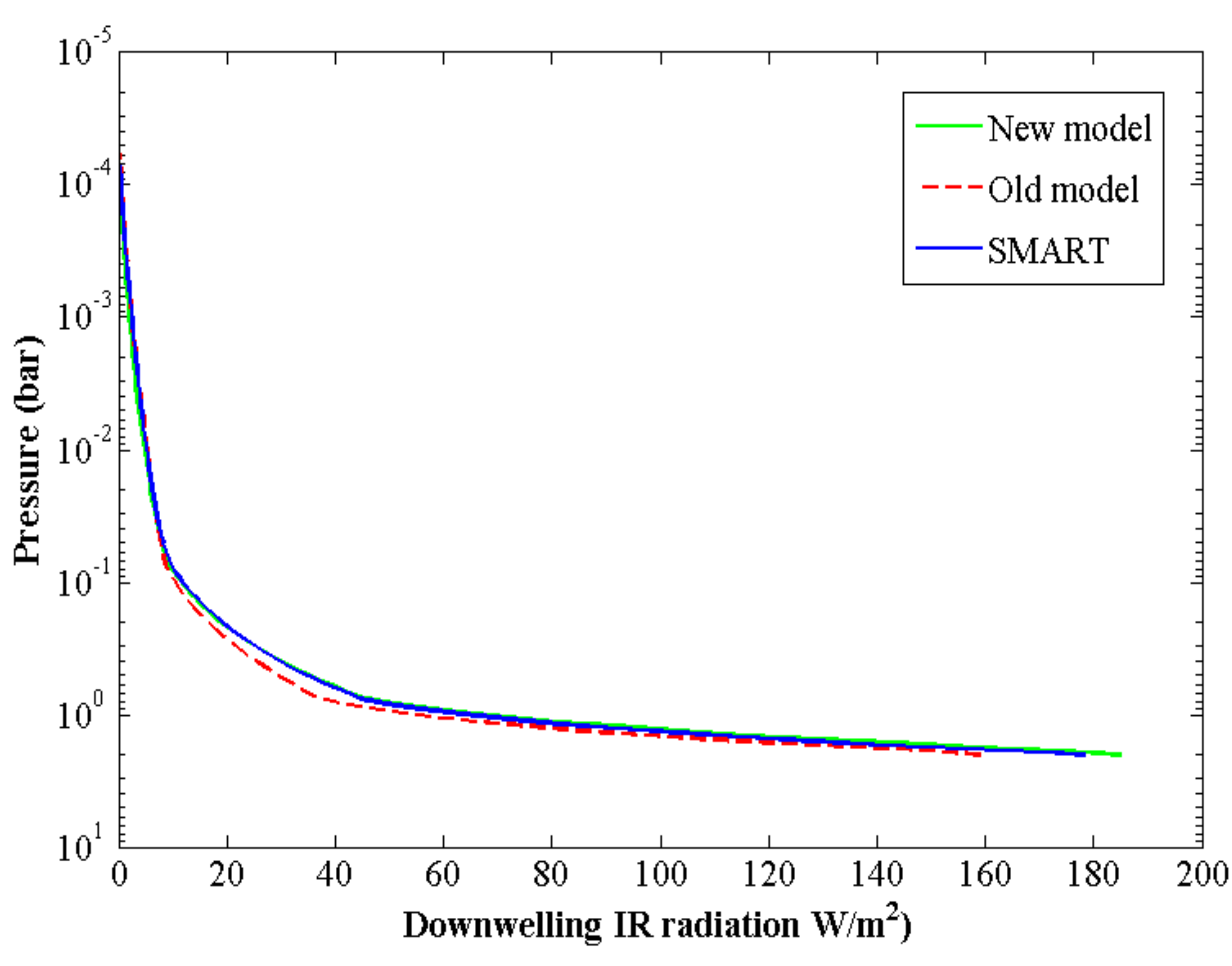
EARLY MARS
$S/S_o = 0.75$
num = 6
Freezing point of water
A
B
300
280
260
240
220
200
0.4
0.3
0.2
Temperature (K)
Planetary Albedo
$95\%\ CO_2,\ 5\%\ N_2$
$95\%\ CO_2,\ 5\%H_2$
$95\%\ CO_2\ 5\%\ H_2$ (RH=50%)
10^{-2}
10^{-1}
10^{0}
Surface Pressure (bar)



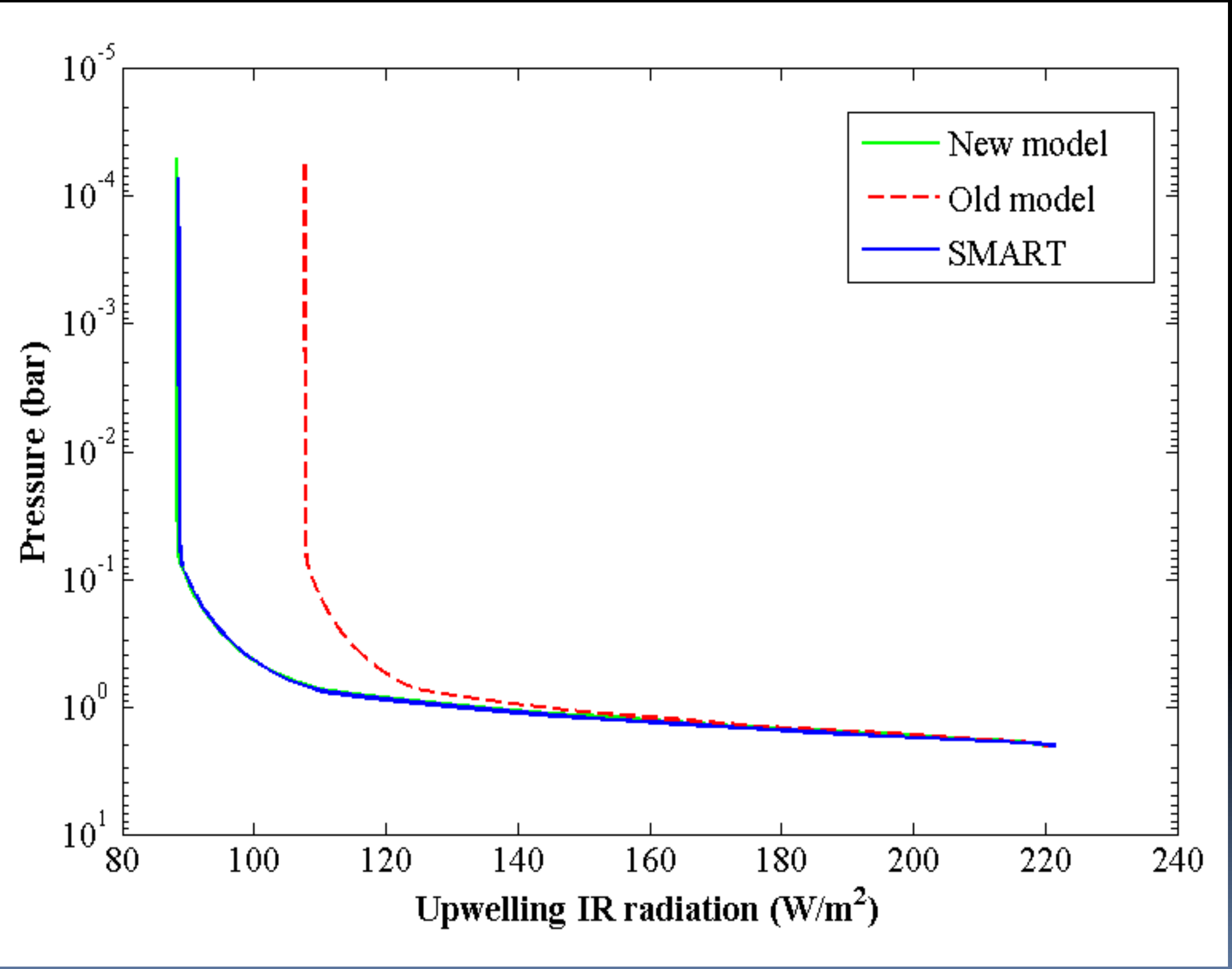
Old model: OLR = 107 W/m2
New model: OLR = 88.2 W/m2
SMART:
OLR = 88.4 W/m2
250 K Blackbody curve
OLR (W/m2/cm-1)
Wavenumber (cm-1)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000



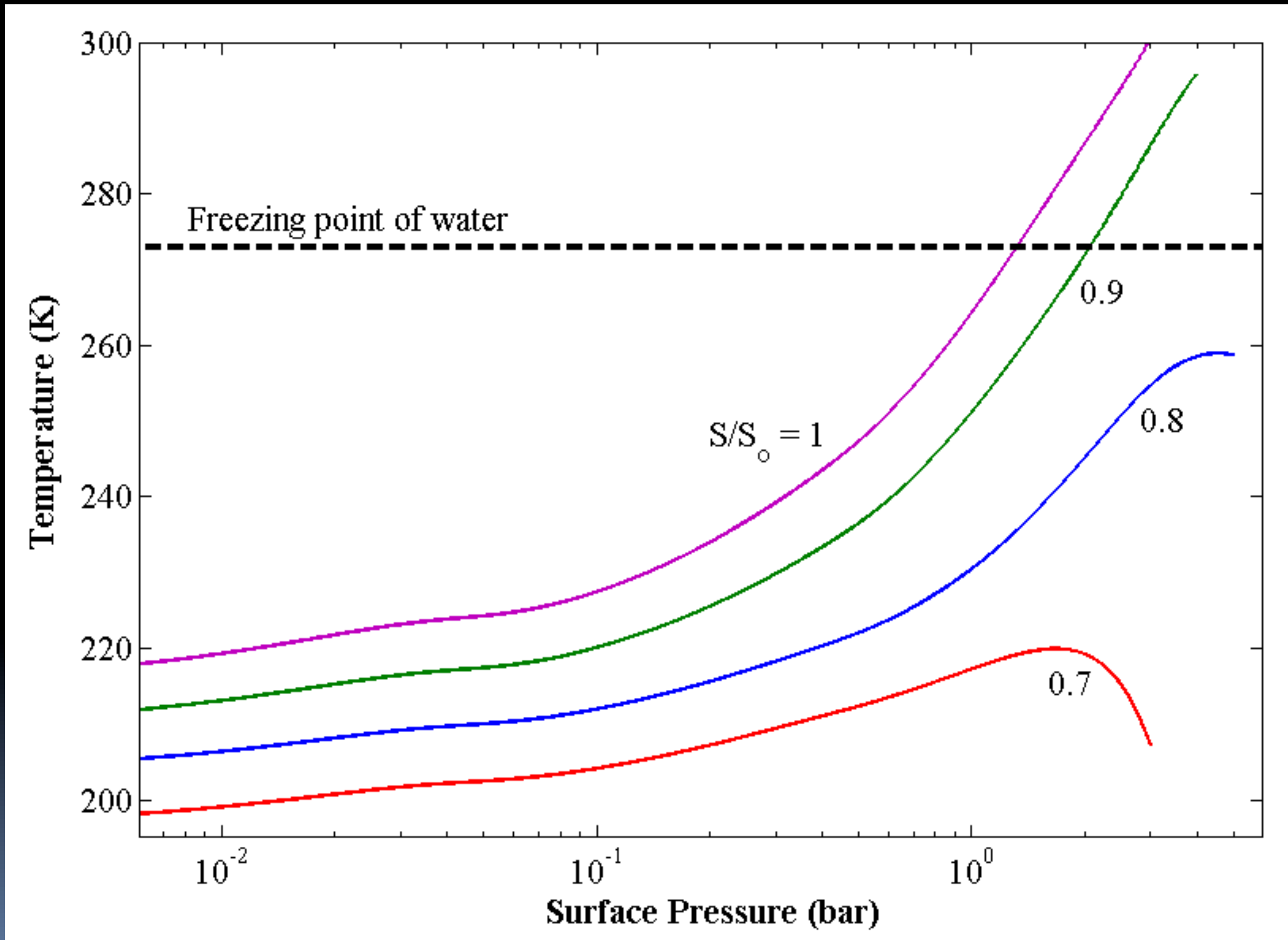
250 K Blackbody curve
Old model: DLR = 159.4 W/m2
New model: DLR = 185.1 W/m2
SMART:
DLR = 178.4 W/m2
DLR (W/m2/cm-1)
Wavenumber (cm-1)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000



New model
Old model
SMART
Pressure (bar)
Downwelling IR radiation W/m2)
0
20
40
60
80
100
120
140
160
180
200
10-5
10-4
10-3
10-2
10-1
100
101



New model
Old model
SMART
Pressure (bar)
Upwelling IR radiation (W/m2)
10-5
10-4
10-3
10-2
10-1
100
101
80
100
120
140
160
180
200
220
240



Ramirez et al., (2013), *in review*