GEOS 32060 – Winter 2020 – Homework 1

Due 5pm Thu 23 Jan. All homeworks must be typeset. (Printing out the text of your answer and then marking up equations by hand on the printout is OK). Homework can be submitted by email (kite@uchicago.edu), or in my mailbox on the first floor of the Hinds building (turn left as you enter the building, or in class. No credit will be given for answers without working. It is OK to use e.g. Mathematica, but if you do, please print out the work.

Q1. [modified from de Pater & Lissauer question 4.1] Estimate the pressure scale height near the surfaces of Earth, Venus, Mars, and Titan, and at the 1 bar levels of Jupiter and Neptune. Comment on similarities and differences. You can refer to Table 1.3 and Figure 1.2 from chapter 1 of Catling & Kasting (pdf on the class website).

Q2. What fraction of Earth's mass is in the atmosphere? What fraction of Earth's mass is in the atmosphere+ocean? Show your working.

Q3. Greenhouse effect + elementary models of radiation balance.

Venus surface temperature is ~750K, Mars surface temperature is ~210K.
(a)Draw the brightness temperature versus wavelength for Venus and Mars if they both radiated to space as a black-body at their observed surface temperatures (no atmosphere on either planet). (1/5 of credit)

(b)Below is brightness temperature versus wavelength for Venus and Mars. Why is the average brightness temperature for Venus and Mars similar? Explain in detail. (3/5 of credit)

(c) Suppose that the brightness temperature of Venus was slightly less at all infrared wavelengths than that of Mars. How might this be true, given that Venus is closer to the Sun? (1/5 of credit)

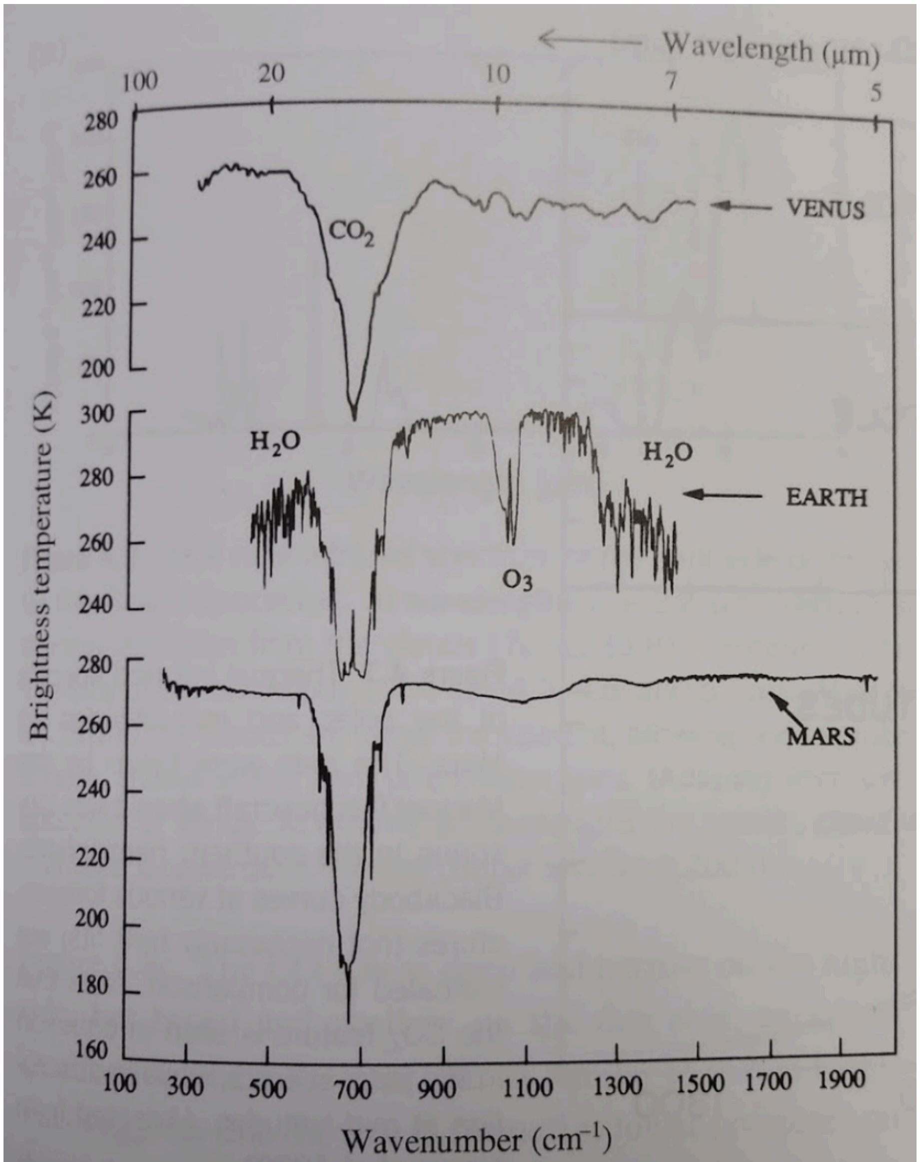


Figure 4.6 Thermal infrared emission spectra of Venus, Earth, and Mars. The Venus spectrum was recorded by Venera 15, the spectrum of the Earth by Nimbus 4, and that of Mars by Mariner 9. (Adapted from Hanel *et al.* 1992)

(from de Pater & Lissauer 2015)

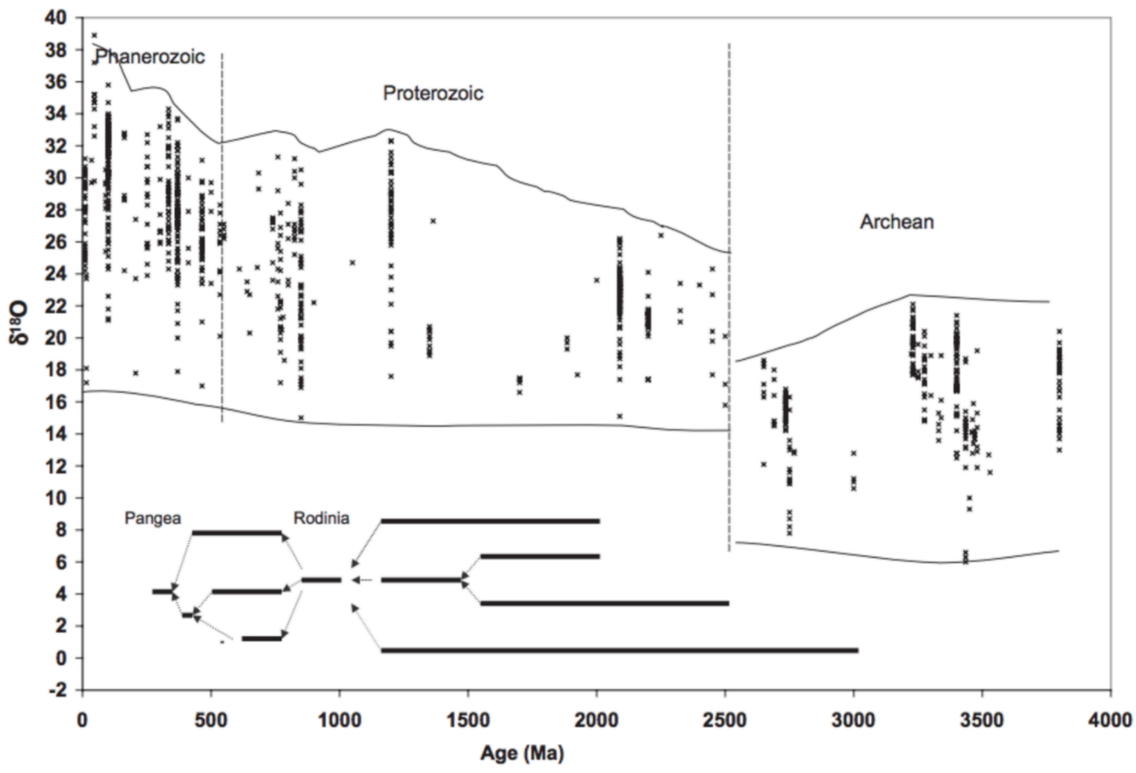
Q4. Planetary energy balance and day-night temperature contrasts.
(The following calculations are the starting point for exoplanet thermal emission analysis).

For an exoplanet with albedo 0.3 in a circular orbit at 1AU around a Solar-mass star the same age as the Sun, that is tidally locked (always keeping the same face pointed toward its star),

a) Calculate the equilibrium temperature assuming full redistribution of heat to the nightside.
b) Calculate the average dayside temperature assuming heat is evenly distributed around the dayside, but no heat is distributed to the nightside.
c) What is the spatial average surface temperature for the whole planet (average of dayside and nightside) in case (b)?
d) Explain why (c) is different from (a).

Q5. The integrity of the carbon isotope record.
In class we discussed the C-isotope record ($^{13}C/^{12}C$); the record of infrequent, but sometimes severe, glaciations; and the record of changing partial pressure of atmospheric oxygen (pO_2) over geologic time. Now we will look at one candidate paleo-temperature proxy, including its limitations: the O-isotope ($^{18}O/^{16}O$) record.

The following figure is from Knauth (2005, Palaeogeography Palaeoclimatology Palaeoecology); see also Knauth & Lowe (GSA Bulletin, 2003). The horizontal bars at the bottom show supercontinent breakup and dispersal (not needed to answer the question). "Delta notation" refers to parts-per-thousand enrichment relative to a standard. The data are for chert.



Assume that formation temperature of chert is given by

$$1000 \ln \alpha \text{ chert–}H_2O = 3.09 \times 10^6\, T^{-2} - 3.29,$$

where

$$\alpha = \frac{1000 + \delta^{18}O \text{ chert}}{1000 + \delta^{18}O\, H_2O}$$

and T = temperature in °K.

Assume the oxygen isotope composition of seawater has been constant over time and is zero on the del-18-O scale. What is the sign and magnitude of Earth temperature change since 3.5 Ga recorded by chert?

(b) Assume that burial and exhumation is a random walk with step size 250 m and step length 50 Myr. What is the typical peak burial depth of sediments initially at the seafloor, and now exposed at the surface, that are 500 Myr in age? What about 3 Gyr in age? (Remember that sediments cannot have a negative burial depth; this corresponds to sediment erosion and loss of the record).

(c) If geothermal heat flow is 0.1 W/m^2, thermal conductivity is 2 W/m/K, and sediment oxygen-isotope composition is reset to the temperatures at peak burial depth, what would be the typical percentage correction to your answer to part (a)? Hint: Use Fourier's law of heat conduction.