0. Assigned January 28, due February 6 To get up and running computationally:

0.1 Nadir look from space at a 100 km-thick spherical atmosphere: Program, calculate, and plot the total geometric path through the atmosphere versus solar zenith angle (SZA) for SZA = 0-90^{o} (later, we will add refraction to calculations).

0.2 Limb view from space, 100 km spherical atmosphere: Program, calculate, and plot the path through the atmosphere versus tangent height over the range 0-100 km (later we will add refraction and a more realistic atmosphere).

1. **Assigned January 30, due February 11**

1.1 Note the use of the ideal gas law to determine ρ. How much would the use of the van der Waals correction for non-ideal behavior change the P,T relationship in the Earth's atmosphere?

1.2 Use the data in us**76.dat** to determine the atmospheric scale height from the ground to the stratopause. Plot it against altitude and also against temperature.

2. **Assigned February 4, due February 13**

Calculate and plot the intensity of blackbody radiation arriving at the Earth from the mean solar distance for temperatures corresponding to the bottom and the top of the solar photosphere. Do this for 1 nm intervals, 300-500. Compare these results with the solar irradiance spectrum. Your conclusions?

3. Assigned February 6, due February 18

3.1 Construct a table showing wavelengths and frequencies (nm, μm, cm^{-1}, MHz, GHz, and THz) for: CO 1→0 and 2←0 band centers (2143.272 cm^{-1}; 4260.063 cm^{-1}); ClO MLS emission line (204.35 GHz); O_2 *A* band center (13120.909 cm^{-1}); CO_2 15 μm "greenhouse" band (667.380 cm^{-1}); O_3 TOMS "on" wavelength (317.35 nm).

3.2 Construct an example where one observes an extended source (*e.g.*, a cloud) with an instrument having a given étendue. Show that the étendue is the same for the cloud observing you.

4. Assigned February 11, due February 20

4.1 Demonstrate that the determination of fractional populations of states and energy levels using Boltzmann factors and the partition function is independent of the choice of the zero of energy (the origin of the energy levels).

4.2 Determine the blackbody radiance (emitted flux density per steradian) from Equation 4.10 by invoking Lambertian emission and integrating over solid angle.

4.3 The Sun may be approximated by a blackbody at 5900°K. The average temperature of the Earth is near 288°K. For these temperatures and for a satellite orbiting the Earth at 800 km, on the sunlit part of the orbit, at what wavenumber does the radiation received from the Earth equal that received from the Sun?

4.4 Calculate the fraction of radiation emitted at visible wavelengths for a typical incandescent light bulb (filament T = 3000 K). What is the wavelength of maximum emission?

5. Assigned February 13, due February 25

5.1 Demonstrate for Figure 5.2 how the geometric considerations cancel, permitting the plane-parallel approximation to be invoked.

5.2 Consider the problem of the measurement of atmospheric carbon monoxide (CO) by looking downward from an Earth satellite above the atmosphere. CO has a spectroscopic transition (the vibrational fundamental) at 4.7 micrometers ("microns," μm), and another at 2.3 μm (the first vibrational overtone). Assuming that the CO is distributed throughout the troposphere and that the Earth's surface is at nearly the same temperature as the lowest atmosphere, then (a) What sort of measurements may be made for each transition? (b) at what altitudes will measurements of each be sensitive to atmospheric CO? (c) Is there an advantage to measuring one or the other, or both, for determining atmospheric CO?

6. Spectroscopy fundamentals

6.1. Demonstrate that $g_0 B_{01} = g_1 B_{10}$ using detailed balance of populations.

7. Line shapes

7.1. (Assigned February 25, due March 4) Calculate the Doppler hw1e and pressure broadening HWHM for the following lines, using the temperature/pressure profile of the US1976 atmosphere:

Molecule	position	Pressure broadening coefficient (cm^{-1} atm^{-1})
ClO	650 GHz	0.06
HCl	125 cm^{-1}	0.08
O_3	9.6 μm	0.05
H_2O	1.02 μm	0.08
O_2	762 nm	0.03

Calculate for sea level, tropopause, mid-stratosphere (25 km), and stratopause.

7.2 (Assigned February 25, due March 6) Select a combination of spectral line and atmospheric location from problem 7.1 where the Doppler and Lorentz widths are comparable. For a range of (line intensity, *S*) × (column density, *N*), ranging from very small to quite large (optically thin to optically very thick), calculate the Voigt function, *V*, versus position and plot the results as either an emission line ($1-e^{-SNV(\sigma)}$) or an absorption line ($e^{-SNV(\sigma)}$).

7.3 Extra (non-credit) problem http://www.nasa.gov/mission_pages/LCROSS/main/

"LCROSS was launched June 18, 2009 as a companion mission to the Lunar Reconnaissance Orbiter, or LRO, from NASA's Kennedy Space Center in Florida. After separating from LRO, the LCROSS spacecraft held onto the spent Centaur upper stage rocket of the launch vehicle, executed a lunar swing-by and entered into a series of long looping orbits around the Earth.

"After traveling approximately 113 days and nearly 5.6 million miles (9 million km), the Centaur and LCROSS separated on final approach to the moon. Traveling as fast as a speeding bullet, the Centaur impacted the lunar surface shortly after 4:31 a.m. PDT Oct. 9 with LCROSS watching with its onboard instruments. Approximately four minutes of data was collected before the LCROSS itself impacted the lunar surface."

The impact (from the 1980-kilogram lunar impactor) ejected about 10^6 Kg of material, some of which was water. It should (from pre-impact materials) "send up a plume of vapor and debris … rising 30 to 40 miles above the surface." For simplicity's sake, assume the cloud is spherical and 25 km in diameter, and that it consists of x % H_2O and (100 - x) % dust, by weight. Assume that the cloud is optically thin in dust and H_2O (then you only need to calculate the BB and H_2O spectra once).

There is a nice infrared band of water at 6.3 μm (actually centered at 1594.7498 cm^{-1}). Calculate the emission spectrum for this band, plus the dust. Assume spectra are taken when the cloud of gas and dust has cooled to the temperature where the Wien's Law maximum in power is at the band center. Assume Doppler broadening only. I have put **01_hit04.4eps238.par** on the website. It contains the parameters for this band, $H_2{}^{16}O$ only, from 1300 – 1900 cm^{-1}, with many, many weak lines weeded out.

The lunar albedo is about 0.07 in the infrared: assume that the dust emission is 93% of blackbody. Assume the dust density is 2.5 grams cm^{-3}. Put the dust into 10 μm particles, to calculate emitting surface.

Assume the CMB is completely negligible (it is). I propose an instrument with 40 cm^{-1} hw1/e Gaussian line shape (although you may wish to try something else). Place a detector element to cover every 15 cm^{-1}.

Detectors and instrument: Rather than working out detector properties, instrument size, etc., assume that measurements can be made with signal-to-noise ratio (S/N) of 100 for 1 second of integration time, *t* (improving as $\sqrt{t}$) for the blackbody at the temperature determined above. Then you only need the column density through the cloud. **noise-for-**

extra-problem.dat contains a 2000-point noise spectrum with RMS = 0.01 (*i.e.*, S/N=100). You can also calculate your own with **noise.f90**.

Set the problem up with 10% H_2O, plot the result, and see if you see anything. If not, what combination of H_2O fraction and integration time would give you a reasonable observation (say S/N = 5)? Do we need better detectors, or a larger instrument?