2. Solar properties

The Sun's angular radius at the mean Earth distance is 0.26656°. It thus subtends 6.000×10^{-5} steradian. It is approximately a 5900K *blackbody* (Chapter 4), a particularly good approximation in the visible near 600 nm. We will shortly introduce the solar structure that averages out to this blackbody approximation. The total solar irradiance is 1368 W m^{-2}, averaged over the cycles of solar activity.

The solar radius is 6.960×10^{5} km; the radius is defined as that distance from the center (in the *photosphere*), where the local gas kinetic temperature is equal to the equivalent blackbody temperature.

Additional solar properties are summarized in Appendix C.

2.1 Solar structure

Figure 2.1 is an idealized and simplified view of the solar structure, where the major feature, for issues of planetary spectroscopy and radiative transfer, is the narrow photosphere. The temperature of the photosphere ranges from ~6600 °K at the bottom to ~4300 °K at the top, thus encompassing the 5900 °K blackbody equivalent. The great complexity of the solar spectrum in the ultraviolet, visible, and infrared is due to absorption in the photosphere, chiefly by atoms and ions, but also to refractory molecular species.

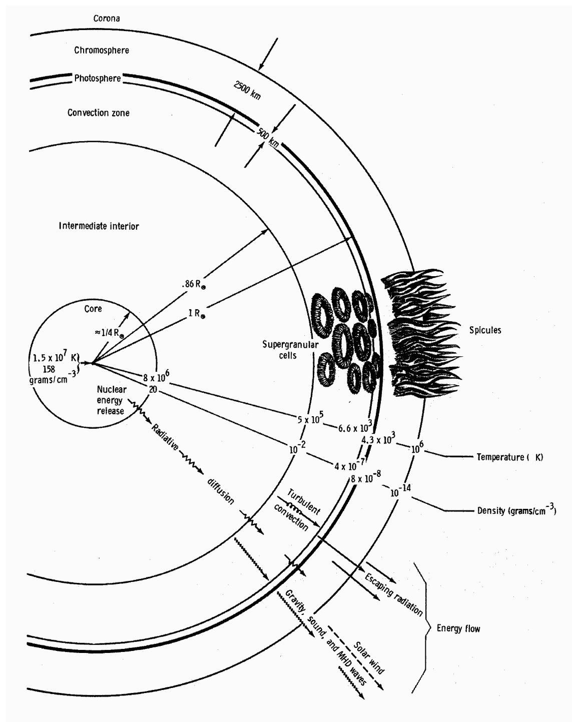

Figure 2.1 Idealized general solar properties, structure, and modes of outward energy flow, from Gibson, Edward G., The Quiet Sun, NASA SP-303, 1973.

2.2 The solar cycle, variability

The solar output varies temporally over a number of scales, particularly by about 0.1% in total irradiance over the 11-year solar magnetic cycle notable for the number of sunspots. Sunspot activity and the number of solar flares are in phase with irradiance over the cycle. An overview of the irradiance, its transmission to the Earth's surface and its variability between solar maximum and solar minimum is given in Figure 2.2. For remote sensing of the Earth's atmosphere,

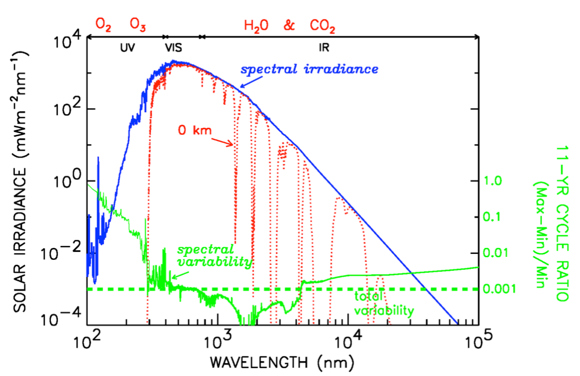

Figure 2.2 Solar spectral irradiance, atmospheric attenuation, and 11-year solar cycle variability. *Courtesy J. Lean, U.S. Naval Research Laboratory*.

the variability over the cycle is less than 1%, substantially less for much of the ultraviolet, visible, and infrared region employed for spectroscopic measurements.

2.3 Reference solar irradiance

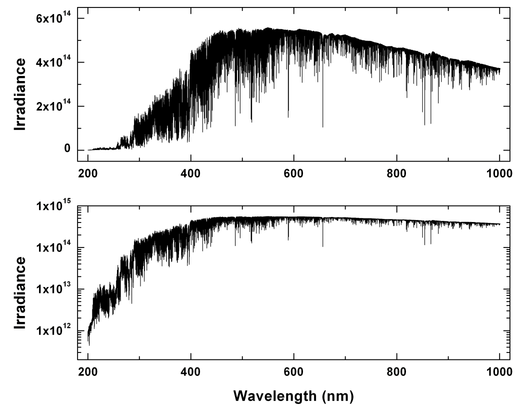

Figure 2.3. Upper panel: The SAO2010 irradiance reference spectrum (photons s^{-1} cm^{-2} nm^{-1}). Lower panel: Irradiance on a logarithmic scale.

A standard solar irradiance spectrum from 200.07 nm in the ultraviolet through 1000.99 nm in the infrared was derived by Chance and Kurucz [2010] by re-reducing the Kitt Peak Solar Flux Atlas [Kurucz et al., 1984]. It has been corrected for atmospheric absorption and rescaled in intensity to a near-solar maximum spectrum from Thuillier et al. [2004] (a standard solar irradiance spectrum at substantially lower spectral resolution than available from [Kurucz et al., 1984]. It has absolute vacuum wavelength accuracy of $\leq 3.2\times10^{-4}$ nm above 305 nm and $\leq 3\times10^{-3}$ nm below 305 nm. It is shown in linear and logarithmic scales in Figure 2.3 and is available at www.cfa.harvard.edu/atmosphere/. Also, see **rkurucz-solar-irrad.jpeg** and **colorspectrum.ps.printme** on the website.

This SAO2010 solar reference spectrum has many uses in the analysis of atmospheric spectra, including: Accurate wavelength calibration of field radiance and irradiance measurements using cross-correlation; Determination of the instrument transfer (slit) function versus wavelength for instruments in the field (including in space); Correction for atmospheric Raman scattering (the "Ring effect) and ocean Raman scattering; Correction for most of the effects of spectral undersampling, due to not properly Nyquist sampling spectra by field instruments. These uses are referenced in Chance and Kurucz [2010]. The underlying physics leading to the need for such corrections is developed in later chapters.

2.4 Limb darkening

Limb darkening is a phenomenon whereby the *limb* (the part next to the horizon) of the Sun (and other stars) is darker than the central portion. This is due to the facts that we see further into the Sun's atmosphere in the central portion, due to increased *opacity* or *optical thickness* in the longer limb view, and that the temperature is increasing from the top of the photosphere down.. Note that for some objects, at some wavelengths, *limb brightening* is also possible; this should become clear soon.

References

Chance, K.V., and R.L. Kurucz, An improved high-resolution solar reference spectrum for Earth's atmosphere measurements in the ultraviolet, visible, and near infrared, *J. Quant. Spectrosc. Radiat. Transfer*, **111**, 1289-1295, 2010.

Gibson, E.G., The Quiet Sun, NASA SP-303, 1973.

Kurucz, R.L., I. Furenlid, J. Brault, and L. Testerman, Solar flux atlas from 296 to 1300 nm, National Solar Observatory, Sunspot, New Mexico, 1984.

Thuillier, G., L. Floyd, T.N. Woods, R. Cebula, E. Hilsenrath, M. Hersé, and D. Labs, Solar irradiance reference spectra, in J.M. Pap *et al*., Eds., Solar Variability and its Effect on the Earth's Atmosphere and Climate System, AGU, Washington, DC, pp 171-194, 2004.

Problems (assigned February 4, due February 13)

2.1 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?