Exercises accompanying lecture 11: atmospheric transmission

May 24, 2011

Extinction

1. Extinction can be described as the combined effect of absorption and scattering.

    a) [1 point] What is the fundamental difference between absorption and scattering of a photon? Consider what happens to the energy carried by the incoming photon.

    b) [1 point] In what case can the Rayleigh description of scattering be used, when do we need to use MIE theory?

    c) [2 points] At optical wavelengths, the atmospheric extinction is dominated by scattering, preventing some fraction of the photons from reaching our telescope. But scattering neither destroys nor creates photons. Where do the "lost" photons go, can we observe them?

Molecular absorption spectra

2. The absorption (and emission) spectra of molecules consist of, usually very many, individual lines, corresponding to transitions between different quantum states of the molecule.

a) [2 points] Describe which kinds of transitions you know, which quantum numbers are used to describe these transitions, and in what wavelength region (i.e. ΔE of the transition) the corresponding spectral lines occur.

b) [1 point] What is the main driver of the "complexity" of the line spectrum of a molecule, i.e. what determines whether a molecule has a relatively small or a very large number of spectral lines?

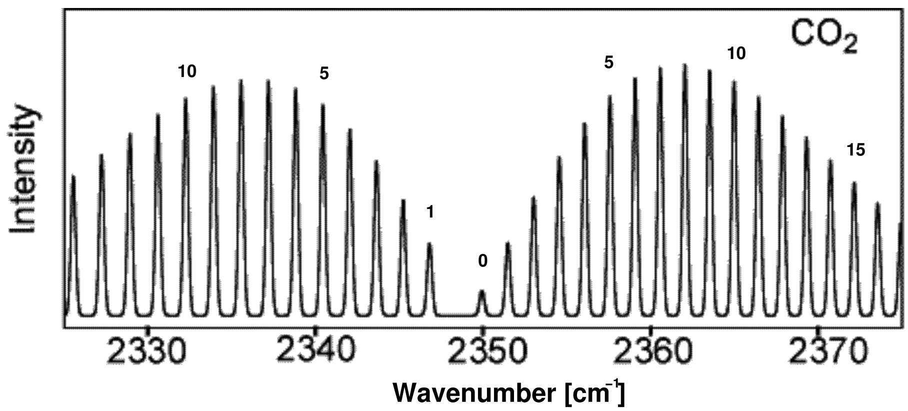

Figure 1: Measured absorption spectrum of the CO_2 "fundamental" rovibrational band. The rotational quantum numbers of the parent state of (some of) the transitions are indicated.

3. Inspect the measured absorption spectrum of the "fundamental" (i.e. the vibrational quantum number ν changes by 1) band of CO_2, shown in figure 1. Explain the appearance of this spectrum, considering the following aspects:

   a) [1 point] What is the approximate energy difference between adjacent vibrational levels in the CO_2 molecule?

   b) [1 point] Why do we see a multitude of lines instead of a single line?

   c) [2 points] What is the rotational moment of inertia of the CO_2 molecule?

   d) [2 points] Why do the strengths of the lines behave the way they do (i.e. they are strongest for intermediate values of J and weaker for low and high values of J)?

Atmospheric extinction & photometry

High precision photometry of stars is a classical tool to study the properties of individual stars or populations of stars. For example, much of our knowledge of stellar evolution has been based on photometric studies of globular clusters. These are comparatively compact systems of stars that formed long ago, are gravitationally bound together, and are "sattellite" systems to our Milky way galaxy. They harbor large numbers of stars which have the same age but have a range of masses, and consequently are in different stages of their evolution (high-mass stars evolve more quickly than low-mass stars). In such studies, the color of stars is used as a proxy for their effective temperature and their brightness as a measure of their luminosity. The inferred surface temperature and luminosity can then be compared to those given by theoretical models of evolving stars.

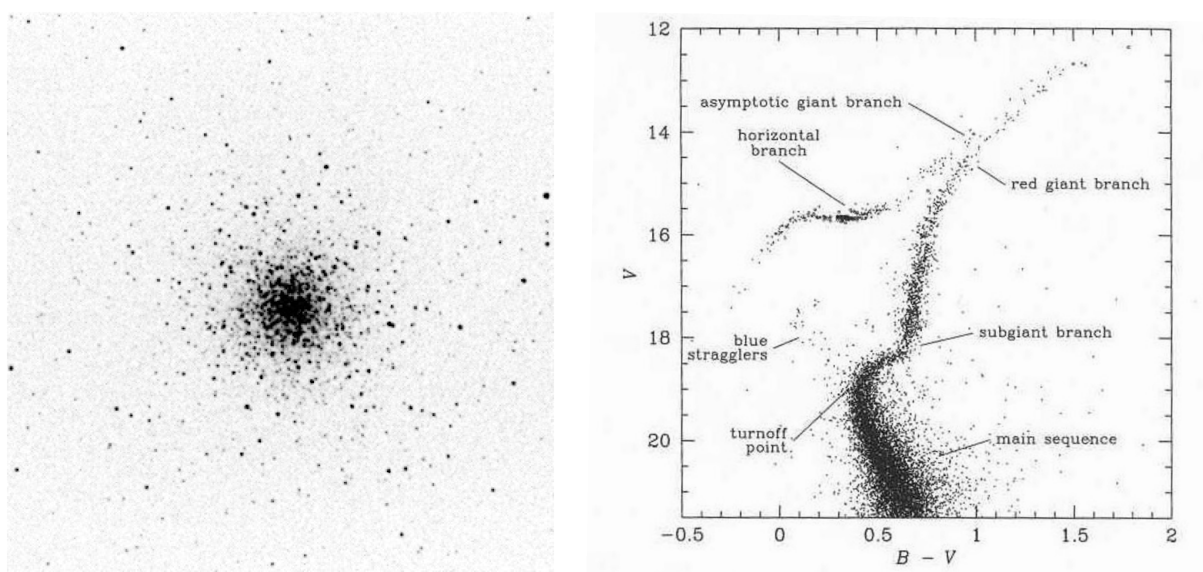

Figure 2: *Left*: an image of globular cluster M3. The apparent size of the object is about 0.5 degrees on the sky. *Right*: a color-magnitude diagram (CMD) of globular cluster M3.

4. [2 points] Give two reasons why globular clusters are particularly well

suited for studies of stellar evolution as described above (hint: consider the distance and age of stars in such systems).

5. Let us work through an example of doing ground-based photometry, correcting for the effects of atmospheric extinction. We are observing a star with a photometer that counts photons. We are using a telescope with a diameter of 10 cm which we have placed on the observing platform at Paranal observatory, and let us assume that the total efficiency of our system is 33%. Our target is 30 degrees above the horizon at the time of our observation. We find that we record 2 580 photons/second in the B-band filter, and 2 560 photons/second in the V-band filter.

   a) [1 point] Let us aproximate the throughput curves of our filters, i.e. which fraction of the light they transmit as a function of wavelength, by box functions, with a central wavelength of 440 and 550 nm, respectively, for the B- and V-band filter, and a width of 100 (B) and 120 (V) nanometers. Thus, the effective response curve of our whole system in e.g. the B-band is a box function with value 0.33 between 390 and 490 nm and zero elsewhere. What is the photon flux from our star after its light has passed through the atmosphere, just before the light enters our telescope? Express your answer in units of [photons/s/cm^2].

   b) [1 point] Astronomers like to express the brightness of objects in units of magnitudes. This is often convenient, as we will see later in the course, when we will also discuss the magnitude scale in more detail. For now, let us adopt the following working definition: $m_i = -2.5\,{}^{10}\log(\frac{f_i}{F_{0,i}})$, where m_i is the magnitude and f_i the photon flux of the object, and $F_{0,i}$ is the *zeropoint* of the magnitude scale in photometric band i, i.e. it denotes the photon flux of an object that has a brightness of 0 mag. The i indices are included in this example as a reminder that the zeropoints are generally different for different photometric bands. What are the observed magnitudes of our star? Take the photometric zeropoints to be 1.52×10^6 and 1.25×10^6 [photons/s/cm^2], respectively, for B and V. Do not (yet) make any correction for atmospheric extinction.

   c) [1 point] The atmospheric extinction is generally wavelength-dependent. In the optical range, on a clear night, it is dominated by Rayleigh scattering, which is strongest for short wavelengths. The extinction coefficients for Paranal Observatory in the B and V filters are approximately 0.23 and 0.13 [mag/airmass], respectively. What are the magnitudes of our star, as they would be observed above the Earth's atmosphere?

d) [1 point] What is the approximate spectral type of our star?

e) [1 point] A spectrum of our star shows that it is substantially hotter, and hence "bluer", than our observed B-V color implies. What is affecting the color of apparent our star? Hint: fairly hot stars ("early type") as the one we are observing tend to be located close to the galactic plane.