Astro 121, Spring 2014
Week 13 (April 24)

Topic: Infrared astronomy
Break: Sara and Rebeka

**Reading** for this week:

As we switch to looking at observing at wavelengths other than visible light, we're moving beyond what Chromey covers. For this week, I've suggested reading from two sources. Glass gives a good introduction to the infrared and covers much of the practical material about filter systems, etc. McLean then fills in more details of practicalities of instrumentation for the infrared and how it is different from the optical.

- Chromey briefly discusses the main broadband IR filter system in Section 10.4.3.

- Glass, *Handbook of Infrared Astronomy*. In the same series as the book by Howell, this is a relatively new book with excellent coverage of infrared astronomy. Reading: Chapter 2 (The Infrared Sky); Chapter 3 (Photometry) through 3.2; and Chapter 6 (Instrumentation). You may also want to skim the rest of Chapter 3 and all of Chapter 4; they concentrate on applications of infrared photometry and spectroscopy, respectively.

- McLean, *Electronic Imaging in Astronomy* (second edition). Ian McLean was one of the people most closely involved in the development and use of the early infrared arrays, and this is an area where this book stands out. Read Chapter 11, skipping pp. 400–404 (and in general reading the chapter for understanding of concepts rather than lots of details).

One bit of physics that is worth reviewing for this week is the concept from thermodynamics that good absorbers are also good emitters, and correspondingly that the reflectivity R of some object is related to its emissivity $\varepsilon$ by $\varepsilon = 1 - R$. To first order, the emission from an object has a spectrum that looks like a blackbody, but modified by its wavelength-dependent emissivity, so $F_\lambda(\lambda) = \varepsilon(\lambda)B_\lambda(\lambda)$, where I've explicitly shown that both quantities on the right are wavelength-dependent.

**Important concepts and problems:**

1. The Johnson I filter stands for "Infrared", and indeed it is beyond the range of light visible to the human eye. But in many ways observing in the I band is much more like optical observing than observing at other infrared wavelengths is. What might be a better (and more fundamental) definition of the beginning of the infrared waveband?

2. Why bother with infrared astronomy? As we'll see, some aspects of observing in the IR are much more difficult than observing in the optical. What are our astrophysical motivations for wanting to observe at infrared wavelengths? (I can think of three broad categories here, though there may be more.)

3. Our reading talks about instruments for infrared observing, but it doesn't say much about how the telescope itself should be designed differently from an optical telescope in order to be efficient in the infrared. How should an infrared telescope be designed differently? (I'll probably fill in some extra information on this topic, but do the best you can with what you come across in your reading. More generally, think about what the issues are for an infrared telescope, especially at wavelengths of 10 microns and longer.)

4. Arrays that work in the mid-infrared tend to have fairly high read noise compared to optical CCDs. Why doesn't this make as much difference in the total noise of the image as it would for an optical image? In general, how are infrared arrays different from CCDs?

5. Describe the basic technique by which a bolometer detects light, i.e. how it goes from the arrival of a photon to recording an electrical signal.

6. One of the first infrared telescopes was constructed by Bill Hoffman at Columbia University, and it was launched on a balloon to survey for interstellar dust. The design constraints were as follows:

   a. The detector was a germanium bolometer that was 1 mm in diameter.

   b. The field of view needed to be 2° in diameter to encompass most of the width of the Milky Way in one pass.

   c. The fastest telescope mirror that they could easily build was f/1.

   Calculate the diameter of the primary mirror. Express your answer in centimeters.

7. Glass and McLean give some examples of infrared instrumentation, but such lists tend to go out of date quickly. Look at the web sites of some of the major observatories that do work in the infrared (UKIRT, IRTF, Keck, Gemini, VLT) and see what the state-of-the-art is in terms of both near-infrared (JHK) and mid-infrared (10–25 μm) arrays. Also take a look at the instrumentation for the Spitzer Space Telescope. How many pixels do such arrays have, what is their read noise, etc.? I'll bring in some student results from past years and we can see whether or not IR instrumentation is changing very quickly.

8. Go to the website for David Archer's book *Global Warming: Understanding the Forecast* (http://forecast.uchicago.edu/) and follow the link to run the MODTRAN code (under the "On-line models submenu at the top of the page). This code models transmission and emission of infrared radiation by the atmosphere. Choose a sensor altitude of 0 km (i.e. on the ground) and set it to "looking up", to get a sense of what the emission from the Earth's atmosphere looks like at various wavelengths. (The output is plotted as a function not of wavelength but of wavenumber, which is inverse wavelength in units of $cm^{-1}$, so you'll need to convert units.) For "Locality" choose "1976 U.S. Standard Atmosphere." Look at the output in the first plot, which shows atmospheric emission in red, compared to blackbody curves of different temperatures.

   a. In what wavelength ranges is the Earth's atmosphere (relatively) transparent? How can you tell? Print out some plots and annotate them to back up your conclusions.

   b. Now change the sensor altitude to simulate an observation from the top of Mauna Kea. How does the atmosphere change? What wavelengths are observable now?

   c. Finally, repeat the exercise for observations from SOFIA (Stratospheric Observatory for Infrared Astronomy).

9. As you may have found in one of the previous problems, Gemini South has an infrared camera called T-ReCS. Let's use the exposure time estimator for this camera (linked as "T-ReCS ITC" from the instrument page on the Gemini Observatory web page) to get a sense of how much background vs. source flux you get at 10 and 20 microns. Calculate the exposure time necessary to get a S/N = 5 detection of a K1 star (effective temperature of 5060 K) with a V magnitude of V=10. Do the calculation for both 10 microns (N band) and 20 microns (Q band). For both bands, note the total exposure time, as well as how much of the observed flux is from the source vs. from the background. There are lots of parameters that you could set in the calculator, but just leave most at their default values except for the things I've specified above. You also need to change the window to "KRS5" for the Q band. (Not to be confused with KRS-One, which is

something completely different…) After you've done the calculations with the defaults, try playing around with the weather conditions to see their effects.

10. I have placed two raw images from UKIRT's IRCAM3 infrared array on disk in /data/astro121/infrared/. The files are dq_m_1.fits and dq_m_2.fits. (These are images of the star DQ Tau in the M filter.) Take a look at the data in IRAF and see how the images compare to optical CCD data. (You may also find it useful to look at the IRCAM documentation on the UKIRT web site; you'll need to look at their web page anyway for one of the questions above. Since the instrument has been retired, it's hard to find the manual by navigating the website, but you can find it by a direct Google search.)

    a. First examine each raw image. Can you find the star? Now subtract the two frames from each other and examine them again.

    b. Look at the image header parameters EXPOSED, DEXPTIME, and NEXP. What do you think these mean? Why was the observation made in this way? What is different about an infrared array that allows such fast readout times?

    c. Check the background level in the raw frames. Is this mostly bias or mostly sky background? How can you tell? (Think about how the processes that produce bias and sky counts are statistically different.)