Astro 121, Fall 2005
Week 12 (November 23)

Topic: Radio and millimeter astronomy. (We're only talking about single-dish telescopes this week; we'll cover interferometry next week, along with adaptive optics.)

Break: Steve/Saurav/Andy (the following and final week: Michael and Victoria)

Reading for next week:

- Burke and Graham-Smith, *An Introduction to Radio Astronomy*. Read the Preface (where the authors define what they consider to be radio astronomy), Chapter 1, Chapter 2 (Secs. 2.1 and 2.2 only)

- Bradt, *Astronomy Methods*, pp. 112–115 on telescope beams and point-spread functions.

- Kraus, *Radio Astronomy*. The section on pp. 59–74 covers beam patterns and various temperatures. The first few pages of this should be review, but are good to remind yourself of the terminology. Noise and signal detection are discussed on pp. 97–104. (Note that the definition of a Jansky that Kraus gives on p. 66 is outdated; what he calls a "flux unit" in the following sentence is what we now call a Jansky, abbreviated Jy. Also, his abbreviation "cps" is cycles per second, i.e. Hz.)

- *Methods of Experimental Physics*, Volume 12B. pp. 201–212 cover the basics of radio receivers.

- Franklin, *Glossary of Terms Frequently Used in Radio Astronomy*. This small 1962 pamphlet was written as a guide for science writers covering radio astronomy. It's not very technical, but it is helpful in some cases for understanding some of the terminology used. Browse through it, and be sure to read the entry on "bands". The code letters (K-band, X-band, Q-band) listed as "officially discouraged" there (in 1962!) are still in use among radio astronomers.

Important concepts and problems:

1. As we did with the infrared, let's consider why we should want to observe at radio or millimeter wavelengths. What types of sources and/or processes can we observe? What advantages are there (if any) of radio observations over observations at other wavelengths?

2. What sets the lower and upper wavelength bounds of the millimeter/radio wavelength range? Comment on the transparency of the atmosphere in the sub-millimeter and millimeter (λ = 0.45–7 mm) and radio (λ > 1 cm) bands compared to that in the optical and infrared.

3. Explain what the beam pattern of a radio telescope is. Draw the one-dimensional beam pattern of a radio telescope, labeling the main beam and the sidelobes. (What sort of graph is this? What does distance along this graph represent?

4. Sidelobes:

   a. What are the sidelobes of a radio telescope? Why do they occur? (Bradt doesn't say a lot about radio observations, but he does provide an important insight here.)

   b. What is the optical telescope equivalent of sidelobes? Why don't we generally have to worry about them in the same way we do at radio wavelengths? (Hint: a single-dish radio telescope is not an imaging device, so it effectively only has one "pixel" when measuring the flux of a source.)

   c. What does it mean to "taper the beam" of a radio telescope, and why would you do it?

5. The Rayleigh-Jeans limit to the Planck function is important in radio astronomy.

   a. Derive the Rayleigh-Jeans approximation to the Planck function.

   b. How good an approximation is it? Graph the percentage error in using the Rayleigh-Jeans approximation (vs. using the real Planck function) as a function of wavelength from 10 microns to 21 cm. Make separate curves for sources with temperatures of 5800 K, 100 K, and 2.73 K.

6. Temperature comes up a lot in the reading, as you'll see. One of the first kinds we need to understand is **brightness temperature**.

   a. Explain what is meant by brightness temperature of a source.

   b. What assumptions (if any) are you making when you give a source's emitted intensity in terms of a brightness temperature?

7. We must also consider **antenna temperature**.

   a. Explain what is meant by antenna temperature.

   b. In general, what is the relationship between the antenna temperature during an observation and the brightness temperature of the source? (I think this comparison gives a better feel for antenna temperature than the formal definition from part a., but it's useful to know that as well.)

   c. You observe a 1°-diameter molecular cloud with a noiseless radio telescope, and you measure an antenna temperature of 30 K. If the primary beam of your telescope is 0.5° in diameter, what can you say about the physical conditions in the cloud? What if the primary beam of your telescope is 2° in diameter?

8. How about **noise temperature**? The reading refers to several different kinds of temperatures as noise sources. What does noise have to do with temperature, and with resistors?

9. Explain the basic operation of a superheterodyne receiver. (You might find it helpful to review [or learn, if you've never seen it] the basic concepts of *beats* between two sources of different frequencies. See Crawford, *Waves*, for a nice discussion of this on pp. 28–31. He also explains what a square-law detector [used in a superheterodyne receiver] is in this section.) What is the difference between a single sideband receiver and a double sideband receiver? Do you agree with the statement on p. 212 of *Methods of Experimental Physics* that observing in both sidebands reduces the system noise by a factor of two?

10. The latest and greatest radio telescope is the GBT, or Green Bank Telescope at NRAO.

    a. Look at their web page at http://www.gb.nrao.edu/GBT/GBT.html. What is unusual about the design of the GBT, and why was it built that way?

    b. The diameter of the GBT is 100 meters. What is its spatial resolution at a wavelength of 1 cm?

    c. Look at the GBT Users' Manual. The section on receivers gives typical system temperatures when using various instruments, and the section "Observing Modes" discusses estimating the sensitivity of an observation. How long would you have to observe with the K-band[1] receiver to detect a point source with a continuum flux of 1 mJy at the 10σ level (i.e. to get a signal-to-noise ratio of 10)?

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[1] Note that this K band is completely different from the near-infrared K band. See the "bands" entry in the Franklin glossary to find its wavelength.