Astro 121, Spring 2014
Week 14 (May 1)

Topic: High-energy astronomy, basics of radio
Break: Jamie

Reading for next week (x-ray section). Note: you may come across some references to *AXAF* in your reading; that was the previous name of the *Chandra* x-ray observatory. Similarly, the current mission called *Fermi* was formerly called *GLAST*.

- McLean, *Electronic Imaging in Astronomy,* Section 12.1 on x-ray telescopes; Section 12.3 on x-ray detectors (mostly on CCDs).

- Gerald Skinner, "X-Ray Imaging with Coded Masks," *Scientific American*, August 1988, p. 84. Check out this article for a clear overview of how coded masks work. You can get it in the stacks in Cornell, or if you're on campus, you'll find it online at http://www.nature.com/scientificamerican/journal/v259/n2/index.html.

- McCammon, "Quantum Calorimetry," by Kilbourne et al., Physics Today (August 1999). Skim to get an overview of how microcalorimeters work. Article is online here or available in print (!) in the library.

Important concepts and problems (x-ray section):

1. *Detecting photons at x-ray wavelengths:* Explain the basic principles (i.e. how a photon gets converted to a detectable signal) of using each of the following detectors to detect high-energy photons:

   a. CCDs. (Example: ACIS on Chandra.) Explain how using CCDs at x-ray wavelengths is different from using them at optical wavelengths. What extra information do you receive? Any disadvantages? How does the quantum efficiency compare in the two regimes? How many electrons do you detect per incident photon?

   b. Microcalorimeters. (Example: the XRS spectrometer on the failed Astro-E mission and XRS-2 on the Suzaku mission.)

2. *Image formation at x-ray wavelengths:* There are two main approaches to forming images of x-ray sources: telescopes with nested parabolic mirrors (example: the HRMA on Chandra) and those with coded masks (example: the Burst Alert Telescope on the current Swift mission). Explain the basic idea of each method, and the advantages and disadvantages of each. To help make the discussion of advantages and disadvantages more concrete, compare the following quantities for the two telescopes mentioned above: energy range to which the telescopes are sensitive, spatial resolution, and total collecting area. (Note that there's a separate term, *effective area*, which incorporates collecting area, light losses, and detector sensitivity to specify how sensitive the whole system is, often as a function of wavelength.)

3. See the Chandra Proposer's Observatory Guide for an overview of Chandra capabilities. Section 6 gives a description of the operating principle of ACIS, the Advanced CCD Imaging Spectrometer.

a. What is the read noise of the ACIS CCD, and how does this affect its spectral resolution? (Be quantitative.) Based on the information given, is this noise the ultimate limit on the spectral resolution of the device? How does the spectral resolution of the Astro-E XRS microcalorimeter compare?

b. What is the readout time of the CCD? Why is it important that CCDs used in the x-ray regime be read out frequently and quickly? What are the advantages and disadvantages of using the "continuous clocking" mode?

c. What is the spatial resolution of ACIS? Is Chandra diffraction-limited when using this instrument, or does something else limit the spatial resolution? Calculate the diffraction limit for Chandra. Why might it be hard to build a telescope mirror to achieve this resolution? (Hint: what sets the maximum size of the imperfections a mirror can have if it is to be diffraction-limited?)

Reading for next week (radio section):

- 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*, 2nd edition. The section on pp. 3-1 – 3-16 (pp. 59–74 in the first edition) 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. 3-39 – 3-34 (pp. 97–104 in the first edition). [I have both editions on reserve, if two people want to read it in parallel.]

- *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 (radio section):

4. 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.

5. 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?)

6. 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. What would happen if you were observing two closely-spaced stars with a single-pixel CCD on a diffraction-limited optical telescope?)

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

7. 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.

8. 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?

9. 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?

10. 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?