

Astro 121, Fall 2005  
Week 11 (November 16)

Topic: High-energy astronomy

Break: Blair and Jennifer (the following week: Steve/Saurav/Andy)

**Reading** for next week. Note: you may come across some references to *AXAF* in your reading; that was the previous name of the *Chandra* x-ray observatory.

- Howell, *Handbook of CCD Astronomy*, Chapter 7. Howell provides some discussion of issues related to using CCDs in space (where x-ray and gamma-ray astronomy must be done), and a very brief overview of the use of CCDs in the UV and x-ray regimes. A good place to start, though not a lot of detail. (It's interesting to note that his primary source for the x-ray discussion seems to be McLean; if Howell were writing a student paper, I'd seriously consider turning him in for plagiarism...)
- Bradt, *Astronomy Methods*, pp. 106–112 on x-ray telescopes; pp. 133–137 on proportional counters; pp. 145–151 on gamma-ray instruments.
- McLean, *Electronic Imaging in Astronomy*, pp. 339–355.
- Kitchin, *Astrophysical Techniques*, pp. 120–141. Somewhat redundant with McLean and Bradt in terms of the detectors that the two sources have in common, but Kitchin covers a few more types of detectors and addresses some issues of pointing and telescope design. Have a look if you want a more detailed view of any particular topic.
- Longair, *High-Energy Astrophysics, Volume 1* Section 6.4 has a nice discussion of proportional counters, and Section 7.3 discusses x-ray telescopes.
- Gerald Skinner, "X-Ray Imaging with Coded Masks," *Scientific American*, August 1988, p. 84. I'll make copies of this and leave them outside my office; check out the original in the stacks in Cornell if you want to see the images in color.
- You'll also find some useful links at <http://astro.swarthmore.edu/astro121/>

**Important concepts and problems:**

1. *Detecting photons at x-ray wavelengths:* Explain the basic principles 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?
  - b. Microchannel plates. (Examples: HRI on ROSAT; HRC on Chandra)

- c. Proportional counters. (Example: PSPC on ROSAT.)
  - d. Microcalorimeters. (Example: the XRS spectrometer on the failed Astro-E mission and XRS-2 on the Suzaku mission; follow the link from the course web page to read about them.)
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 (often referred to as “effective area”—why is the effective area different from the true area?).
  3. Show that the spectral resolution  $\Delta E/E$  (or equivalently  $\Delta\lambda/\lambda$ ) of a proportional counter is proportional to  $E^{-1/2}$ . In other words, doubling the photon energy improves  $\Delta E/E$  by a factor of  $\sqrt{2}$ .
  4. The ROSAT mission had two main instruments: the high-resolution imager (HRI) and the position-sensitive proportional counter (PSPC). Why did the HRI function longer than the PSPC, and why was this not surprising? How could the PSPC have been designed so that it would have functioned longer, and what would the science tradeoff for this design decision have been?
  5. The signal-to-noise ratio of a long observation with the ROSAT HRI varies with position in the telescope field of view, being higher on-axis and lower off-axis for the same exposure time on two point sources with identical x-ray fluxes, even though the detector sensitivity is uniform across the field. Explain why. (Hint: you might find it helpful to find and examine an HRI image with a bunch of point sources in it. There is also a section in the HRI manual on signal-to-noise calculations.)
  6. See the Chandra Observatory Proposer’s Guide (linked from <http://astro.swarthmore.edu/astro121/>) for an overview of Chandra capabilities. Section 6 gives a description of the operating principle of ACIS, the AXAF 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?

7. To get a S/N ratio of 3 in measuring the flux of an astronomical source, you need to detect at least 9 photons. (Make sure you understand that sentence before going on!) However, to merely show that the source is there (i.e. its flux is not zero), you don't need that many photons. Chandra has very low background flux; the worst chip in ACIS (each chip is a 1024x1024 CCD) has a background flux of 1.41 counts/second/chip. (*Not* per pixel!) Show that this means that detection of 3 photons in one pixel in a 100,000 second observation is sufficient to show the presence of a source with  $> 99.7\%$  confidence.