Astro 121, Spring 2014
Week 10 (April 3)

Topic: Absolute photometry and photometric systems (plus model-fitting to data)
Break: Rebeka

Topics: This week, we'll look at photometry, or the quantitative measurement of starlight, in more detail, and see how to go beyond relative measurements to absolute ones. We'll also spend a little bit of time on fitting models to data, something we skipped in our discussion of statistics earlier in the semester.

Reading:

- Chromey, *To Measure the Sky*, Chapter 10. We already looked at the first part of this in a previous week, but this week we'll concentrate on material in the second half of the chapter. You may want to review the first part too, though.

- Notes on photometry by Steve Majewski at the University of Virginia, http://www.astro.virginia.edu/class/majewski/astr313/lectures/photometry/photometry_mags.html There are four pages on photometry; this first one should be mostly review, so you can skim it quickly, then follow the links at the bottom of the page to subsequent pages.

- *The Handbook of Astronomical Image Processing*, Berry and Burnell. Chapter 8.

Problems

1. Photometric filter systems. There are a large number of photometric systems in astronomy. Let's take a look at some of the important ones. For your assigned photometric system, come to seminar with a printed handout (one for each person in the class) that briefly describes the photometric system, including a list of the filter names, widths, and central wavelengths. Try to find something on why that filter system was created (i.e., why not just use a pre-existing filter system?) and what it is used for. There is some material in Chromey, but I'd like you to go beyond this to other sources as well. (I've just randomly assigned these – feel free to trade if you want.)

Rebeka	SDSS filters (similar to Thuan-Gunn filters)
Jamie	Strömgren filters (uvbyβ)
Sara	Johnson UBV filters, with Cousins R and I
Catherine	HST broadband filters

2. Chromey Ch. 10, problem 8 (on finding the relative brightness of two sources that yield the same photon flux).

3. Chromey Ch. 10, problem 10 (on determining extinction coefficients).

4. Another rule of thumb (I've lost track of what number this would be on our list). Show that a star with V = 0 delivers approximately 10^6 V-band photons / cm^2 / sec to the top of the atmosphere.

5. We previously discussed differential photometry (using comparison stars in the same field) as a way to be able to work around the hassles of atmospheric extinction. But even differential photometry is not completely immune from these problems, especially if one is interested in very small magnitude changes.

   a. If you observe a star from the zenith down to a higher airmass, and make a differential light curve using comp stars in the same field, describe what will happen to the apparent relative brightness of the target star if it is not the same color as the average color of your comparison star. For specificity, assume that the target is bluer than the average comparison star, and that you're observing in a relatively red filter, say Cousins R_C or SDSS r'. Assume that neither the target nor the comparison stars have any true variability – we're only concerned with atmospheric effects here. Will you end up with a flat light curve? Explain why or why not. Some drawings will help.

   b. Does the bandwidth of the filter make any difference here? For example, would the situation be better or worse with a narrow-band filter? Why or why not?

   c. Does the situation change when observing at other wavelengths, e.g. in a bluer filter (like B or SDSS g') or in an even redder filter (e.g. I_C or i')?

   d. What are the tradeoffs in comparison star selection? Specifically, why might we choose comparison stars that we know are not the same color as the target star?

Data modeling

Reading: All of these books are on reserve in Cornell unless otherwise noted. I'd suggest the Taylor reading as a good place to start, and then see if you need more after that.

- *An Introduction to Error Analysis*, by John R. Taylor. Chapter 12.
- *Data Reduction and Error Analysis for the Physical Sciences,* Bevington and Robinson, Section 4.3.
- "Practical Statistics for Astronomers – II. Correlation, Data-modeling, and Sample Comparison", J.V. Wall 1996, *Quarterly Journal of the Royal Astronomical Society*, **37**, 519–563. As I may have mentioned previously, this contains less theory than some of the other sources, but it is more closely aligned with our goals as astronomers, and it is pretty readable. Don't read the whole thing, but it's good to have on your shelf as a starting place if you want to find references to other works on statistics. For our purposes this week, look at Section 3. It covers chi-squared (with a slightly different definition than the other references) but has the advantage of comparing it to a number of other ways of estimating parameters of a fit. In particular it's good to be aware of Bayesian techniques for analyzing data.

Important terms and concepts: χ^2; reduced χ^2;

Problems

χ^2 fitting is often used in astronomy (and other sciences) to find the set of coefficients of a given function that give a curve that best fits the data. The basic idea is to find the set of coefficients that minimizes χ^2 ; this provides "best fit" parameters for a function that we specify to fit the data, but it also allows us to assess the probability that it is a "good" fit, i.e. that the remaining differences between the curve and the data arise just due to experimental uncertainty. Examples:

6. You fit a straight line to your set of 20 data points, determining a slope and an intercept. The total (not reduced) χ^2 of the fit is 15. What is the value of χ_ν^2 (also known as *reduced* χ^2)? What is the probability of this level of disagreement between model and data arising by chance? What do you conclude about whether a straight line is a good fit to the data? (You may find it helpful to look at Sec. 11.1, and Table C.4 on p. 258 of Bevington and Robinson; Taylor's Chapter 12 also provides a nice discussion of χ^2.)

7. In the paper by Herbst *et al*. 1997 (AJ 114:744; see pp. 748-749), the authors fit a model (with 6 free parameters) to their observations (11 data points) and obtain a χ^2 value of 0.4. They conclude that the model is a good fit to the data. What do you conclude? (It's not clear in the paper whether they are quoting χ^2 or reduced χ^2, so you may want to work the problem both ways.)

8. Find a paper in the astronomical literature (one you're already reading for some other purpose is fine) that does some statistical analysis, and, using the theory and resources that we've gone through in class, try to understand what the authors are doing. (An example using chi-squared, such as those above, is fine, but feel free to branch out and look at other techniques.) Come to class prepared to give a short presentation on what the authors were trying to do, what technique they used, what conclusions they reached, and whether or not you agree with those conclusions. This sequence of reasoning is exactly what you need to do as a scientist when you are reading the literature. If you find an example that interests you but are having a hard time understanding what the authors are doing, feel free to come talk to me about it.

9. You are interested in determining a good set of radial-velocity standard stars (stars whose radial velocity is known to high precision, and is not variable) in order to be able to accurately calibrate velocities measured in your new planet-search program. You observe the star DK Cep, and you measure the following radial velocities and uncertainties:

   34.2 ± 0.2 km/s
   34.5 ± 0.2 km/s
   33.9 ± 0.3 km/s
   34.1 ± 0.2 km/s

   a. What is the star's average radial velocity, and its uncertainty?

   b. What is the probability that the star is a good radial velocity standard, i.e. that its radial velocity is constant, based on your data? (Hint: use χ^2.)

10. Just for your interest, not to turn in: look at the page I created on a weird group of data called "Anscombe's Quartet", http://astro.swarthmore.edu/astro121/anscombe.html . It's important to look at your data before deciding how to fit them, and judging the quality of the fit!