Astro 121, Spring 2014
Research Techniques in Observational Astronomy

Week 3 (February 6, 2014): Coordinate systems and time

Break: Jamie

Resources and reading: All of these books are on reserve in Cornell except for Chromey. (They are on the honors reserve shelf, which is on the opposite side of the low partition that's to your right as you enter the library.) You don't have to read all of these; read what you need to understand the essential concepts and do the problems. Definitely read Chromey, then I'd recommend Birney as a possible good supplement, with the others as needed for more technical information.

- *To Measure the Sky* by Fred Chromey, Chapter 3. Note that Appendix D has some useful information as well.

- Birney, *Observational Astronomy*, Chapters 1 (Coordinate systems) and 2 (Time). I think Birney is a little clearer than Chromey in explaining the equation of time.

- The website of the Astronomical Applications Department of the US Naval Observatory (USNO), http://aa.usno.navy.mil/index.php, has lots of good resources about astronomical time, including explanations of various terms, sunrise and sunset data, and tools for converting between Julian date and calendar date.

- *Astrophysical Formulae, Volume II: Space, Time, Matter, and Cosmology*, Section 5.1.2 on coordinates, Section 5.1.3 on transformation of coordinates (don't get bogged down in detailed formulae, but do understand precession and nutation), and Sections 5.3.1 to 5.3.7 on time. (Again, don't get bogged down in formulae, but do try to understand the concepts, especially UT, LST, Julian date, and the equation of time.)

- *The Explanatory Supplement to the Astronomical Almanac* has extensive discussions of coordinates (Chapter 1) and time (Chapter 2) if you want to look at a different discussion of anything you find in the other sources.

For some of the problems, you will find useful information in the current *Astronomical Almanac*, also on reserve in Cornell. This book is published yearly by the US Naval Observatory, and contains tables of sunrise/sunset times, coordinates of bright stars, moon phase tables, etc.

Important terms and concepts:

- Coordinates: equatorial coordinates, galactic coordinates, equinox, epoch, precession, nutation
- Time: UTC, UT1, TAI, LST, HA, Julian date, equation of time

Problems:

1. A G dwarf star observed at visible wavelengths has galactic coordinates $\ell = 283°$, $b = -2°$.

   a. What can you conclude regarding whether it is located in the disk or halo of the Galaxy?
   b. Same as (a), but for $\ell = 32°$, $b = 87°$.
   c. A radio source has galactic coordinates $\ell = 202°$, $b = 3°$. What can you conclude regarding its distance from the galactic center as compared to the Sun's distance from the galactic center?
   d. Same as (c), but for $\ell = 15°$, $b = -2°$.

2. We refer to the units of right ascension (RA) as hours, minutes, and seconds *of time* to distinguish them from arcminutes and arcseconds.

   a. Why is RA given in time rather than degrees? (It certainly *can* be given in degrees, and sometimes is, but usually not.)

   b. What kind of time is it? That is, is one second of RA a solar second or a sidereal second? What is the precise conversion factor between the two (and how might you derive it, at least to 3-4 decimal places or so)?

   c. How is the zero point of RA defined? At what time(s) of year could you observe an object with zero RA at optical wavelengths?

3. Consider two celestial objects that have the same declination δ and are separated by $\Delta\alpha$ in right ascension. Use the formulae of spherical trigonometry to show that, for small angular differences, the angular separation between them is $\theta = \Delta\alpha \cos\delta$. (You may find it useful to use a series expansion for one or more trig functions in your derivation.)

4. Consider two astronomical objects whose equatorial coordinates are 13 28 36.25 +43 18 31.2 and 13 28 39.13 +43 19 01.3, both equinox 2000.

   a. What is the angular separation (in degrees, arcminutes, or arcseconds) – whichever seems appropriate) between the two objects? (Note that this separation is small enough that you don't have to do a full-blown spherical trig solution to get it right; put another way, that small part of the sphere is effectively flat, so you can use what is essentially the Pythagorean Theorem to get the angular separation, as long as you take the result of the previous problem into account.)

   b. What is the precision with which the coordinates are given? In other words, what do you make of the fact that the seconds of RA are given to two decimal places and the seconds of declination are given to only one decimal place?

5. For this question, you may use any method you wish. There are coordinate precession and conversion facilities in IRAF and IDL, and a coordinate calculator on the NED web page. Alternatively, you may do the conversion analytically using data and formulae from the Astronomical Almanac. The choice is yours, but be sure to state what method you use and show your work as much as possible.

   You measure the position of an object on the Palomar Sky Survey (POSS I) prints to be 04 25 32.3 +62 18 19 (1950).

   a. What are the equinox 2000.0 coordinates of this object?
   b. What is the epoch of the equinox 2000 coordinates you found in part (a)?
   c. What are this object's galactic coordinates?

6. "Rule of thumb" department, part 2. Try to come up with a rule of thumb that would let you roughly calculate the coordinate change per year due to precession. You should use the information given in Chromey, and also do some empirical investigation by picking some sets of equatorial coordinates (some near the poles, some near the equator) and precessing them from equinox 1950 to equinox 2000. Does one rule suffice for both RA and Dec? Is your rule equally good in all parts of the sky, or is the behavior dramatically different in different parts of the sky? If

you have to choose between a rule that works well near the equator vs. one that works well near the poles, which would you choose, and why?

7. You are at the telescope and you receive word that a new extrasolar planet has just been discovered around a nearby star. You want to observe the star, but the only catalog you can find gives the coordinates of the star in equinox 1950, epoch 1962.5; it also lists the proper motion. The telescope control software requires that the coordinates be input in equinox 2000. Describe the steps you would go through to determine the proper coordinates to enter for pointing the telescope tonight (whichever is the nearest night to when you are doing this problem, presumably close to February 4 or 5, 2014).

8. Our next seminar meeting will be on Thursday, February 6, 2014, at 1:15 PM. Determine the following dates and times. (Again, you can do the calculations below by hand using information in the Astronomical Almanac, or you can find some computer program to do the calculation.)

   a. What is the Julian date at that time? Give your answer to three decimal places. (Why three places?)
   b. What is the local sidereal time at that time? Before you look it up, work it out approximately from first principles. You should be able to get the right time to within less than an hour if you think it through carefully. Explain your reasoning, and then check it against the right time.
   c. What is the Universal Time at that time?
   d. What is the hour angle of the objects whose coordinates are given in problem 4?

9. You are studying an eclipsing binary system, which has a third star orbiting the eclipsing pair in a much wider (and thus longer-period) orbit. You want to determine whether the distant companion has perturbed the orbit of the eclipsing pair enough over the years that the timing of eclipses as observed from Earth will have changed. To test this, you plan to observe the next eclipse of the system, to see if arrives at the predicted time. You find a paper on the system in *Astrophysical Journal,* which says that an eclipse was observed on May 4, 1965, at 02:05:12.2 UTC. The orbital period of the system is given as 342.60355981 days.

   a. When will the next eclipse occur? Be as precise as possible in your answer.

   b. If you are aiming only to measure differences in eclipse times on the order of hours, or even tens of minutes, your calculation can be simpler than if you are looking for time differences on the order of minutes or seconds. What extra effects do you need to account for in this case? (There are at least two.) You don't necessarily need to account for these effects in your calculation above (though do so if you easily can), but explain what they are, and if possible the direction in which they would influence your answer.

10. Chromey, problem 3.12, on determining the motion of a possible asteroid.

11. On what date would you expect the following events to occur?

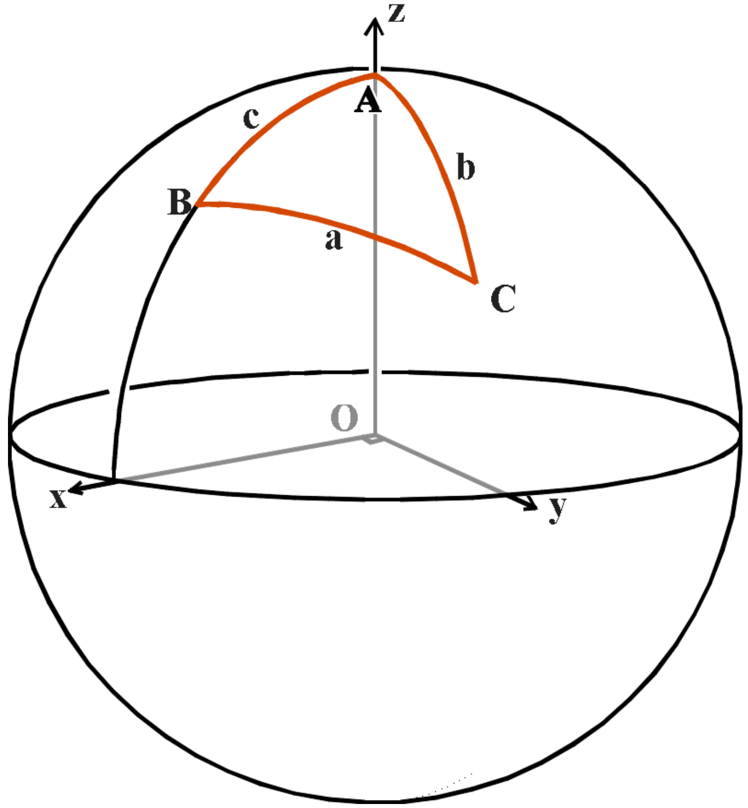
    - The latest sunrise of the year.
    - The earliest sunset of the year.

    Before consulting any reference materials, write down what you think the answers should be and explain your reasoning. Then consult the Astronomical Almanac to check your answer. If it's not correct, figure out why and explain. (Also check the answer for other latitudes and see if you can understand what you find.)

Basic formulae of spherical trigonometry

A spherical triangle is a triangle on the surface of a sphere, each side of which is part of a great circle, i.e. a circle whose center is the center of the sphere. (For example, lines of longitude on the Earth are great circles, while lines of latitude [except for the equator] are not.)

In the diagram below, uppercase letters denote the interior angles of the triangle, while lowercase letters denote the sides of the triangle. Note, however, that the lengths of the sides are expressed in angular units; they are the size of the angle subtended by that arc at the center of the sphere. Side *a* is opposite angle *A*, side *b* is opposite angle *B*, etc.



Law of sines: $$\frac{\sin A}{\sin a} = \frac{\sin B}{\sin b} = \frac{\sin C}{\sin c}$$

Law of cosines: $$\cos a = \cos b \, \cos c + \sin b \, \sin c \, \cos A$$

A third formula with no planar analogue:

$$\sin a \, \cos B = \cos b \, \sin c - \sin b \, \cos c \, \cos A$$