ASTR 535 Lab notes

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Time, coordinate systems, observability tools

Time Systems

Systems of time: see Naval observatory reference for a full listing of different types of time.

Solar Time

Time tied to position of Sun. Note the distinction between *mean* solar time and *apparent* solar time (the "equation of time" and the analemma).

Most used solar time is Universal time. UT = local mean solar time at Greenwich = "Zulu". Tied to location of Sun, but average to "mean sun".

Local time: accounts for longitude of observer. For practicality, legal time is split into time zones.

In detail, official time is kept by atomic clocks (International Atomic Time, or TAI), and coordinated UT (UTC) is atomic time with leap seconds added to compensate for changes in earth's roation, where these are added to keep UTC within a second of solar time (UT1). See here for some details.

Sidereal time

Times based on position of stars, i.e. Earth's sidereal rotation period $\sim$ 23h 56m 4s. Local sidereal time is GMST (Greenwich mean sidereal time) minus longitude. At the vernal equinox (time in sky when Sun crosses the celestial equator as its declination is increasing), sidereal time = UT. Difference between UT and GMST is one rotation (day) over the course of a year, so about 2 hours per month.

Sideral is relevant for position of stars: stars come back to the same position every sidereal day. As we'll see below, a given star crosses the meridian when the local sidereal time equals the right ascension of the star.

Calendars

Standard calendar is Gregorian, with leap years, etc.

For astronomy, it is simpler to keep track of days rather then year/month/day. Most dates given by the `Juliandate` (number of days since UT noon, Monday, January 1, 4713 BC). Variations include modified Julian data (JD - 2400000.5 fewer digits and starts at midnight), heliocentric Julian date (JD adjusted to the frame of reference of the Sun, so can differ by up to 8.3 minutes).

Note that repeating events are often described as an event *ephemeris:* $t_i(event) = t_0 + i(period)$.

The term *ephemeris* is also used to describe how the position of an object changes over time, e.g. planetary ephemerides.

Coordinate systems

LPL website on astronomical coordinate systems

Celestial coordinate systems

(diagram)

- RA-DEC: tied to Earth rotation, longitude and latitude. Zero RA at vernal equinox
- ecliptic: tied to plane of Earth rotation around the Sun. Zero ecliptic longitude tied to vernal equinox.
- galactic: tied to plane of the Milky Way

At vernal equinox, RA = 12h crosses the meridian at midnight.

Note that for a celestial coordinate system tied to the Earth's rotation, coordinates of an object change over time because of the changing direction of the Earth's axis: precession and notation. Because of this, coordinates are always specified for some reference equinox: J2000/FK5, B1950, etc.; if using coordinates to point a telescope, you need to account for this (but generally, telescope software does this on its own). Note distinction between equinox and epoch, where the latter is relevant for objects that move (which everything does at some level).

Transformations between systems straightforward from spherical trigonometry.

Note the common usage of an Aitoff projection (equal areas) of the sky in celestial coordinates, with location of ecliptic and galactic plane. Software tools (Python, projection="aitoff" in subplot, IDL: aitoff and aitoff_grid in Astronomy users library).

Local coordinate systems

- Equatorial: HA-dec. $HA = LST - \alpha$. $LST = GMST - longitude$. Note normal convention for HA is to get larger to the west, i.e. opposite of RA. Objects at zenith have δ = latitude of observer.
- Horizon: alt-az or zd-az

Local coordinates are important for pointing telescopes. Note that there are various other effects that one has to consider for pointing a telescope at a source of known celestial position: proper motion, precession, nutation, "aberration of light", parallax, atmosphereic refraction.

Finding positions of celestial objects

- SIMBAD: look up coordinates of many objects outside solar system by name, etc., also provides much other reference information.
- VizieR catalog database Database of astronomical catalogs, with search and download possibilities.
- NED: NASA extragalactic database: galaxies, etc.
- solar system ephemerides: JPL HORIZONS

Orientations of objects in the sky

Usually specified by position angle: angle of object in degrees from NS line, measured counterclockwise.

An important observational position angle for spectroscopy: *parallactic angle*, the position angle of the line from zenith to horizon.

Observability

Obviously, to observe an object, one requires that it is visible above the horizon. In general, one would liek to observe objects through the shortest possible through Earth's atmosphere, i.e., when they are *transiting* (crossing the meridian, HA=0). The more atmosphere the light goes through, the more losses due to atmospheric absorption/scattering (more severe at shorter wavelengths), and the more image degradation from atmospheric seeing. Of course, it doesn't make sense to wait for an object to transit if you don't have anything else to do in the meantime; efficient use of telescope time is the primary concern. One *airmass* is the amount of air directly above an observer. If you are looking at the zenith, you are looking through one airmass. Generally, most observers attempt to observe at airmasses less than 2, i.e. within 60 degrees of zenith. Once you hit an airmass of 3, the object is rapidly setting (except at very high declination). Of course, for some solar system objects (objects near the sun), one has no choice but to observe at high airmass.

Note that HA gives some indication of observability, but that higher declination objects can be observed to higher HA than lower declination objects. Roughly, at the celestial equator, an HA of 3 hours is about an airmass of 2, and in many cases, one doesn't want to go much lower in the sky.

Another issue with observability has to do with the Moon, since it is harder to see fainter objects when the sky is brighter. Moon brightness is related to its phase, and to a lesser extent, to distance from your object. Of course, if the Moon is below the horizon, it does not have an effect. So for planning observations of faint objects, one also has to consider Moon phase and rise/set times. Note that the sky brightness from the Moon is a function of wavelength, and at IR wavelengths, it is not a very significant contributor to the total sky brightness; so often, telescopes spend bright time working in the IR.

Tools

Here are some useful software tools to do tasks related to coordinate systems and observability, though there are others out there. Anything that accomplishes the desired tasks adequately is fine to use; just make sure you're not limited by the tools that you choose.

- skycalc/skycalendar: text based programs; skycalendar gives daily almanac, position of moon, etc. skycalc allows you to enter coordinates of an object and obtain observability information for any specified date. Other features included as well: coordinate transformation, position of planets.
- JSkyCalc: (java-jar /home/local/java/JSkyCalc.jar): JAVA implementation of skycalc.
- WCSTOOLS: full set of useful coordinate system programs, e.g. coordinate system transformation (command skycoor). Largely useful for use with coordinate system information in image headers (more later).

Exercises

1. Predict the RA at midnight for the first of every month. Try the command `skycalendar` (give yourself a wide terminal window first) to see how well you did.
2. What time is it now? What is the sidereal time? What coordinates would it be most optimal to observe right now?
3. When are the dark (no moon above horizon) first half nights in fourth quarter?
4. APO schedules the 3.5m in half-night blocks (A and B), split at midnight (or 1am during daylight savings). What are the best half-nights in the next year (month and a half, e.g., Oct A, March B, etc.) to request to observe:
   - Virgo cluster of galaxies (note central galaxy is M87, look up the coordinates).
   - Galactic center (galactic coordinates are…). Use command `skycoor` to convert galactic to equatorial (`skycoor` with no arguments gives syntax).
   - Jupiter (look up its position using JPL HORIZONS).
5. Run `skycalc` (choose observatory A for APO. '?' gives list of command help. Look at r, d, y, and h commands). For the galactic center, what is the maximum amount of time it can be observed at an airmass of less than 2.5? How about the Virgo cluster? Why are these different?
6. Run `jskycalc`. Play with all of the buttons! What planets will be visible fall 2011, and at what times of night? Note that you can load files with a list of coordinates, and you can make airmass observability charts for them.
7. Make a plan for a 3 half-night observing run during early/mid November, A halves, when we are likely to take our APO trip. The plan should include a list of objects for each night with a tentative order of observation, taking into account how much times needs to be spent on each object. Our projects are still TBD, but will likely include:

- ARCES (echelle spectrograph) observations of several stars in the Kepler field (look this up if you don't know what it is, or where it is) to monitor velocity of eclipsing binaries (Patrick) and to measure rotation of rapid rotators (Dmitry).
- ARCES observations of bright stars observed by the SDSS-III APOGEE survey; these are located all over the sky.
- DIS observations of a candidate high velocity star from SEGUE (Young Sun) at RA=3h54m DEC=-6d14m.
- SPICAM observation of candidate low mass dwarf galaxies from SDSS (equatorial candidates between 21h and 3h RA).
- If it is clear, we will likely have time for some additional projects. Can you come up with some?

8. Prepare a web page with the plan, including relevant information: coordinates of objects, finder images if necessary, links to tabulated spectra, instrument manuals, etc.

Next Section