ASTR469 Lecture 9: Time and Planning Observations (Ch. 2)

Assess yourself/study guide after lecture & reading (without peeking at notes)...

1. Numbers worth knowing: find on Google the latitude and longitude of Morgantown.

2. New York City and Morgantown are in the same time zone. Does the Sun rise and set at the same clock time in both locations (if not, how do Sun rise/set appear differently in Morgantown? Ignore the fact that we're at a higher altitude.

3. Check your grasp on terminology:
   - What is the hour angle of an object when it "transits"?
   - What are the two causes of analemma?

4. How many hours per 24-hour period does an object of declination +60 spend in the sky in Morgantown?

5. How many hours per 24-hour period does an object of declination -25 spend in the sky in Morgantown?

6. You are looking up your LST, and find that the LST and wall-clock times happen to be the same. Pretty soon, they are no longer equal. What period of time elapses before the LST and wall-clock times are equal again?

7. What is the approximate LST at noon on July 20? *Reminder: at noon, the Sun is approximately on your meridian, and the sun is at RA, Dec (0, 0) on March 20.*

8. Imagine you're on Earth's equator (let's dream big and say we're at the Galapagos). What is the approximate hour angle of the Sun at sunrise? How long does the Sun take to traverse the whole sky?

1 Time and Humans

Time is infinite, but as biological beings on Earth it is convenient to think about the passage of time in cycles. Historically, people have used the Sun to tell time. Even before numbers, we could define significant points in the Sun's path in the sky: Sunrise, Sunset, Noon (when the Sun transits), equinox, solstice.

But in our not-flat-Earth society, we realize there are many obvious issues with this! Different parts of Earth disagree on when "noon" appears;[1] "noon" actually appears at different times, and sunset and sunrise shift in an oscillatory way, throughout the year. Additionally, both astronomers and astrologers realize that **stars and other distant objects do not follow the same apparent cycle as the Sun**.

We will discuss a few different astronomical treatments of time-keeping, and how these are useful for planning observations.

2 Solar-defined Time Standards

2.1 Universal Coordinated Time

Telescopes often use a system called Universal Coordinated Time (UTC; the acronym follows the French translation). UTC is what is used to define our time zones: it is convenient for determining what the local Solar time is at any location on Earth, compared to a fixed reference point on Earth. For historical reasons, UTC is referenced to the Solar cycles in Greenwich, England (lon = 0°). It is also sometimes called "Greenwich Mean Time" (GMT).

Time zones are somewhat arbitrarily defined by geographic and political boundaries, but each time zone increment tries to account for a 1-hour difference in when the Sun crosses the local meridian. Hence, any time zone that you find will be in reference to UTC 0; our time zone is "UTC-5".

UTC does not ever undergo "daylight savings," although various time zones do use daylight savings to account for analemma, described below.

Here is a useful web tool for finding the current UTC and translating time zones:
`https://www.timeanddate.com/worldclock/timezone/utc`

A practical note: while we often use UTC at telescopes and to report the time of occurrence of transient events, you'll often see UTC used as a confusion-free way to indicate a time for a telecon that spans members from multiple time zones.

A final note: leap seconds are occasionally added to UTC to account for the fact that, over time, Earth's rotation is very gradually slowing down. It is currently under debate as to whether we should re-define UTC to include this effect, but the issue is yet unresolved.

[1] It is, as they say, always 5pm somewhere.

2.2 Analemma: Wall-clock time vs. the location of the Sun

As implied in the previous section, the clock time you see on your wall is defined by your time zone and whether your local politicians decide to use Daylight Savings Time corrections. Daylight Savings corrections are used because the Sun is actually at a smoothly varying declination throughout the year, and thus has smoothly varying rise/meridian-crossing/set times throughout the year. Thus, sometimes the Sun appears "late" or "early" compared to your wall clock time.

You saw in the planetarium that the Sun travels on different paths throughout the year; it is higher in the summer than in the winter, and oscillates around the meridian. If we take a picture of the Sun at noon every day throughout the year, we find that it traces out a figure-8 pattern known as an analemma. See the lecture slides for images of this.

The analemma is intimately related to something called the "Equation of Time," which shows how "fast" or "slow" the Sun's peak crossing is relative to the mean. "Fast" is when the Sun at noon is west of the meridian, "slow" is when it is east of the meridian.

The analemma is caused by the Earth's orbit and tilt. If the Earth's axis were not tilted (normal to ecliptic plane), and the orbit was perfectly circular, the Sun would be found in the same part of the sky at noon every day. The altitude variation in the analemma is caused by the tilt of the Earth's axis. For an object with an eccentric orbit but no axial tilt, the analemma would be a straight east-west line along the celestial equator. For an object with a circular orbit but significant axial tilt, the analemma would be a figure of eight with northern and southern lobes equal in size (equinoxes at intersection).

2.3 Julian Date and Modified Julian Date

It is often convenient to have a running number for the day, so you may encounter a "Julian date." The Julian date begins with a value of "1" on January 1, 4713 BC at noon. Each day since then has added one JD. Hours, minutes, and seconds are given in decimals, and increase in the normal way from that date and time. Note that because the system is defined from noon, midnight corresponds to half a day (thus any midnight has a fractional Julian date of 0.5).

It's been a long time since 4713 BC, so current Julian dates are on the order of several million (Midnight 1 Jan 2019 was JD 2458484.5 — note the 0.5). To make these numbers more manageable for modern astronomers, we often now use the "Modified Julian Day" (MJD), which is just:

$$\mathrm{MJD} = \mathrm{JD} - 2400000.5 \qquad (1)$$

Note that *MJD has a zero-point at midnight.* So, Midnight 1 Jan 2019 was MJD 58484.0 ... nicer than having to write down 2458484.5!

As with most time standards, there are also several nice online converters for standard dates to JD or MJD:

https://aa.usno.navy.mil/data/docs/JulianDate.php
https://heasarc.gsfc.nasa.gov/cgi-bin/Tools/xTime/xTime.pl

3 The Sidereal Day and Local Sidereal Time

The Earth's orbit and its spin both are in roughly the same plane of rotation, and so actually the stars appear to rise and set at a different rate than the Sun does! The actual spin of the Earth, in reference to distant celestial bodies is called the Sidereal Day.

The sidereal day has a duration of 23 hours, 56 minutes, 4.0905s. Thus, it is about 4 minutes (minus 4 seconds) shorter than a Solar day.

3.1 Reminder: Notation of R.A. in the Equatorial System

[This is described in more detail in Sec 3.2.1 in the last lecture notes, but it is useful to review here] Recall that R.A. can be expressed in hours:minutes:seconds or in degrees. There are 24 hours in a clock circle. There are 360 degrees in a circle. So there are 360deg/24h or 15 degrees in each R.A. hour. Thus, note well that:

$$\text{“arcminutes”} \neq \text{“minutes”} \tag{2}$$

3.2 Local Sidereal Time and Hour Angle

One sidereal day is equivalent to the true rotation period of the Earth with respect to background stars. As it revolves around the Sun, the Earth completes one extra rotation on its axis. Thus the sidereal day is 365.25/366.25 = 99.727% as long as the Solar day, or about 23h, 56m, 4s.

Universal time (UT), Greenwich mean time (GMT), Eastern daylight time (EDT) etc. are all based on solar time. However, when talking about the positions of celestial sources, we must use sidereal time (ST).

Because it is tied to your sequence in Earth's rotation, ST is relative to the observer's longitude. The LST is always zero when a source of R.A. 00h00m00s "transits," or passes the peak point in the sky at your location. One sidereal hour later, a source of R.A. 01h00m00s transits, and your LST is 01:00:00. One sidereal hour, 15 sidereal minutes, and 33.3 sidereal seconds later than that, a source of RA=02h15m33.3s transits, and your LST is 02:15:33.3. After one full sidereal day, your R.A. 00h00m00s source is transits again at the same altitude and azimuth that it did before.

And so on. I'm sure you can see a trend there. This is true for the LST on all points on Earth. We can define an absolute sidereal time that is defined at the Greenwich meridian as Greenwich Sidereal Time (GST). For us, the most practical thing is to know that sidereal time we need for all calculations is the local sidereal time (LST) defined as LST = GST - West longitude.

3.3 Hour Angle

Each hour, the Earth goes through one sidereal hour of rotation. Hour Angle (HA) is the angle between the celestial meridian (from the local coordinate system) to the object's RA. This is a useful additional parameter when observing, because it can also be thought of as "how long will be before the source crosses its peak point in the sky", or "how long has it been since the source crossed its peak point in the sky."

Here's a mental exercise for you to solidify this idea:

- Think of the earth rotating as you watch a source of R.A.=10h00m00s cross the sky.
- At LST 07:00, Earth will take three more hours until your LST is 10:00. Your object is at an hour angle of -3.
- The source will cross your local meridian at LST 10:00, when the LST and RA are equal.
- Two more hours go by, and it's now LST 12:00. Your source is going down in the sky now, and is currently at an hour angle of +2h from its peak point.

It follows that:

$$HA = LST - RA \tag{3}$$

For circumpolar sources, we say that it is in "upper culmination" when it crosses the prime meridian closest to zenith. There is a corresponding lower culmination 12 hours later when it crosses the prime meridian furthest from zenith.

When planning observations, we can approximate that one sidereal hour is approximately 60 regular minutes, or 3600 regular seconds.

Note that epochs do come somewhat into play here. If the year is 2016 and we are using J2000 coordinates, the HA is not exactly equal to the LST−RA. This is only exactly true at the current epoch, although we usually don't care too much about this small change in transit (and rise/set) time because it's fairly small, and most telescopes have internal softwares that correct for epochs when scheduling observing time.

4 Tying it all together: Planning observations!

There are a few questions about observations that closely relate to time, including:

- When will my target be above the horizon?
- What time should I observe my target to minimize extinction (you want it to be as high as possible in the sky!)?
- (If observing at UV/optical/IR bands) will it be daytime or night-time when my target is in the sky?

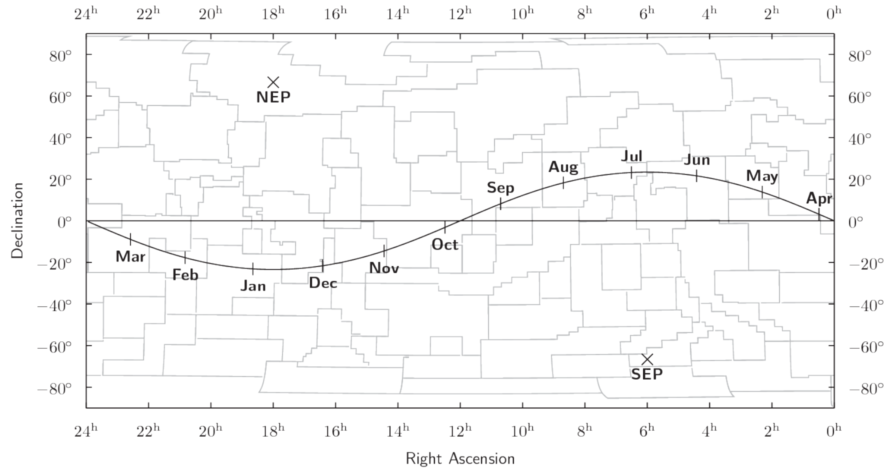

Figure 1: The position of the Sun over the year (note the near progresses right to left in this plot, following a forward advancement in R.A. because of the shorter Sidereal day). March 20 is the vernal equinox, when the Sun is at an R.A. and Dec of (0, 0).

For all of these questions, it is important to know the practical impacts of concepts we learned above: the hour angle, analemma, and the difference between sidereal and solar time.

4.1 What's my current LST?

Calculating LST by hand is tedious, and not all that illustrative. Let's try to get an intuitive sense for it.

First, it is practical to know that by definition, on the vernal equinox (March 20), the Sun is at exactly RA=00h00m00s, Dec=00:00:00. So when the Sun transits (HA=0) on March 20, it is LST 00:00.

We're here in January about two months before the vernal equinox. We know that Sidereal and Solar time are different by about four minutes, so the Sun marches through different RA throughout the year (Fig. 1). Specifically, it advances about 2h each month. So, right now the Sun should be at approximately RA=20:00.

At about noon, the Sun is close to meridian. So at noon, the LST should be around 20:00. We can add or subtract hours from that to estimate what the LST is at any time today.

Again, this is a very rough approximation. In real life we can also use an online calculator:
`http://www.jgiesen.de/astro/astroJS/siderealClock/`
This clock gives that on Jan 20 at noon local time, that the LST was about 19:40 for Morgantown's longitude (∼79.96°). Our back-of-the-envelope try was only 20 minutes off!

4.2 When will my source rise or where will it be at a certain time?

Recall from the last few lectures that you saw the conversion between local coordinates (alt, az) and equatorial coordinates (RA/α, Dec/δ). The altitude and azimuth tell you exactly where to look in the sky to see your target object.

So I remind you here of the conversion, which might make more sense now that we've discussed HA:

$$\sin(\mathrm{Az}) = -\frac{\sin(\mathrm{HA})\cos(\delta)}{\cos(\mathrm{Alt})} \tag{4}$$

$$\sin(\mathrm{Alt}) = \sin(\delta)\sin(\phi) + \cos(\delta)\cos(\phi)\cos(\mathrm{HA}) \tag{5}$$

where ϕ is your latitude on Earth. Note that the position of your object in the sky depends on HA, which makes sense because this tells us about how many hours have elapsed since (or must elapse before) some source's transit.

Note that Alt = 0 means a source is rising or setting. We can set that in Eq. 5 above and simplify this expression to get how many hours it takes for a source to go from horizon to transit:

$$\cos(\mathrm{HA}) = -\tan(\delta)\tan(\phi) \tag{6}$$

Of course, this only applies to sources that cross the horizon (not circumpolar ones, or ones that never rise!). A source will be above the horizon for $2 \times$ HA, if you calculate the HA using the above expression.

4.3 Will my source be out at night time?

Since the Sun changes in RA throughout the year, it sits above different stars as a function of the time. This, by the way, is one of the only ways that astronomy relates to astrology (the latter places importance on what constellation the Sun happens to be in front of when you're born). In reality, this just has to do with the sidereal day.

Just like in Section 4.1 above, we can use a similar deduction to understand whether the Sun will be near our target or not.

But if the RA of the sun and your target are different, how do you know whether the Sun will be above the horizon? As seen in Fig. 1, the Sun also oscillates its declination throughout the year due to analemma. We know that it must be at low declinations in the Morgantown wintertime (Declination ∼-25, shorter days!), and at higher declinations in our summertime (Declination ∼+25, longer days)! You can use this to guess the declination of the sun, and use the equations of the previous section to find how many hours the Sun will be in the sky on a given day depending on your latitude.