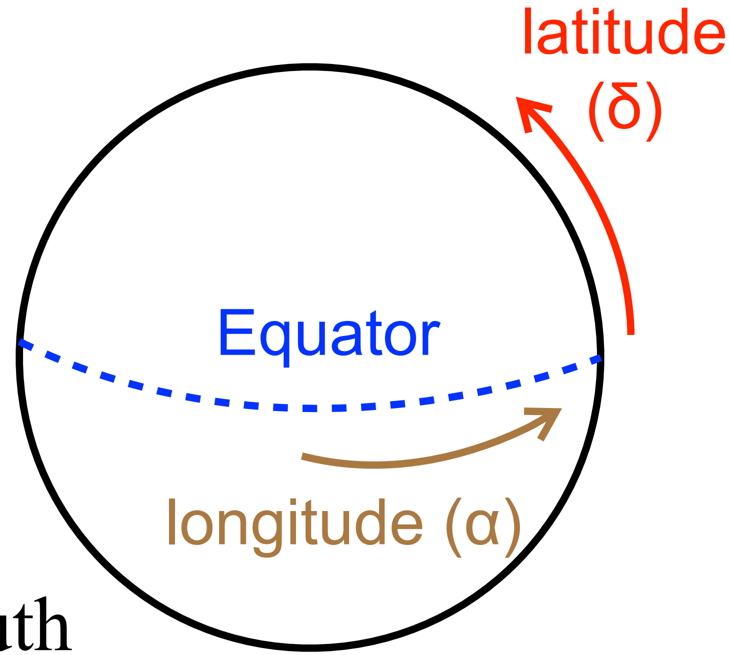
Survey Observations

Coordinates on the Sphere

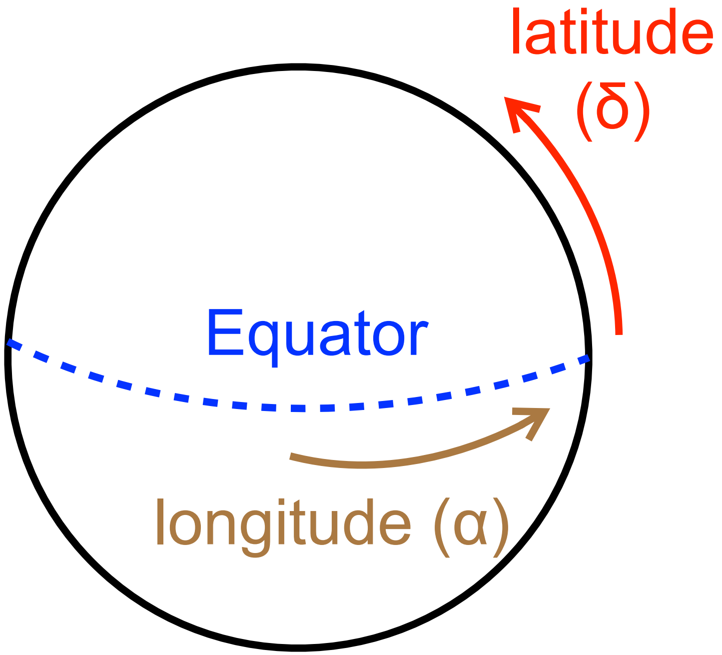
- Any position on the surface of a sphere (such as the Earth or the night sky) can be expressed in terms of the angular coordinates *latitude* and *longitude*



- Latitude runs from -90° to 90°
- -90° is a sphere's south pole (South Pole on Earth, South Celestial Pole in the sky)
- 90° is a sphere's north pole (North Pole on Earth, North Celestial Pole in the sky)
- 0° is a sphere's equator (the Equator on Earth, the Celestial Equator in the sky)

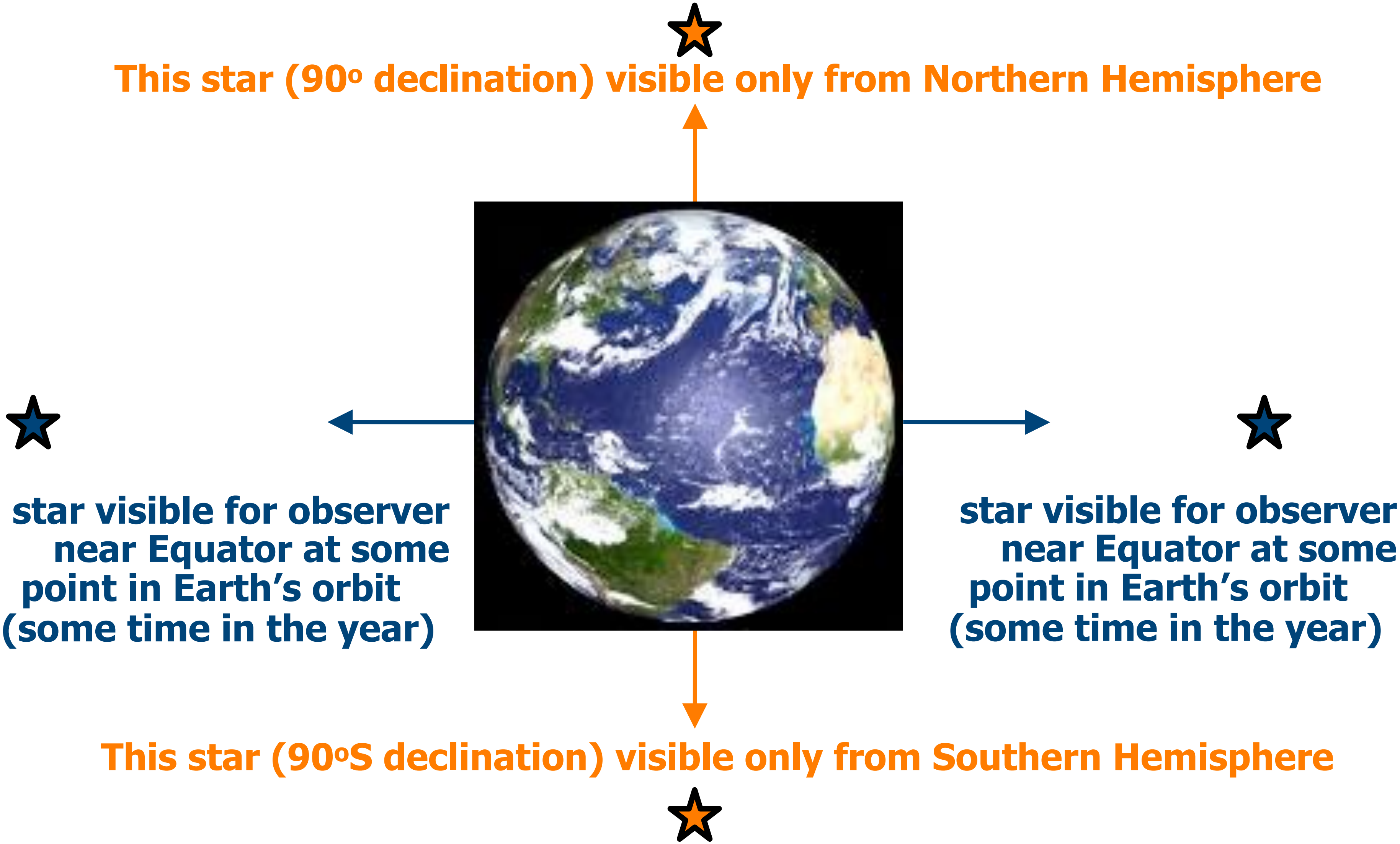
The Equatorial Coordinate System

- Longitude runs from 0° to 360° (-180° to 180° on the Earth)
- Astronomers *choose* longitude to increase to the right (to the east; counter-clockwise looking down on the north pole)



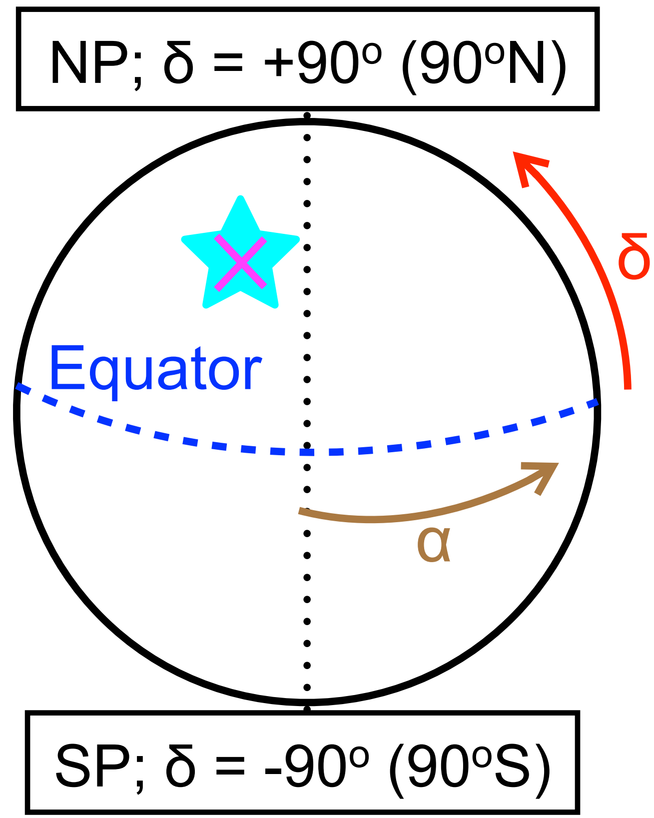
- On the Earth 0° of longitude is chosen to be the Greenwich Meridian
- In the sky 0° of longitude is chosen to be the Vernal Equinox, the first day of spring
- In this *equatorial coordinate system* used in astronomy longitude is *right ascension* and latitude is *declination*

The Earth turns around an axis through its poles



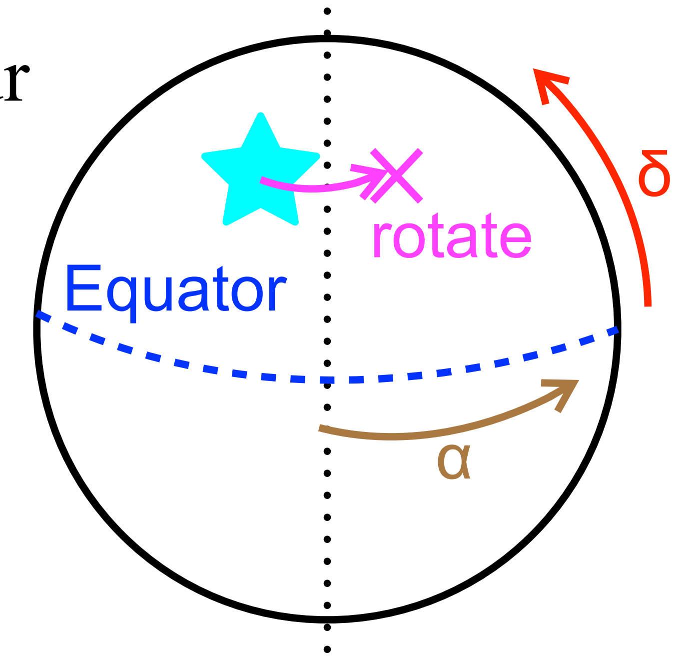
Declination is static with time

- The Earth turns around its axis through the (geometric) poles
- Declination remains the same with time (δ=35°N is always the same circle in the sky)
- For instance, Nashville is at 35°N latitude on the Earth, so a star above your head (*at zenith*) is always at a coordinate of 35°N declination in the sky, no matter the time of day or year
- Note, though that the right ascension at zenith *changes with time* as the Earth rotates from west to east



Local Sidereal Time and Hour Angle

- At any given time, the right ascension at zenith is called your *local mean sidereal time*



- The difference between your local mean sidereal time and the actual right ascension of a star of interest is called the *hour angle* where
  - $HA = LMST - \alpha_{star}$
- A star starts east of your meridian, with -HA passes through your meridian with zero HA, then moves west of your meridian, with +HA

Right ascension is usually expressed in hours

- Because RA is temporal, it is often expressed in hours, not degrees...an hour is 15^o
- You will see RA written in hours as, e.g., 23:12:11 or $23^h12^m11^s$ and declination written as, e.g. $-40^o12'13''$
- In this format, the m (') and s ('') are *minutes* and *seconds* of time (of arc) where a *m* is 1/60 of an hour (' is 1/60 a degree) and a *s* ('') is 1/60 of a minute (')
- To convert a dec of, e.g., $-40^o12^m13^s$ to degrees:
  - δ (degrees)= -1 x (40 + (12/60) + (13/3600))
- To convert an RA of, e.g., $23^h12^m11^s$ to degrees:
  - α (degrees)= **15** x (23 + (12/60) + (11/3600))

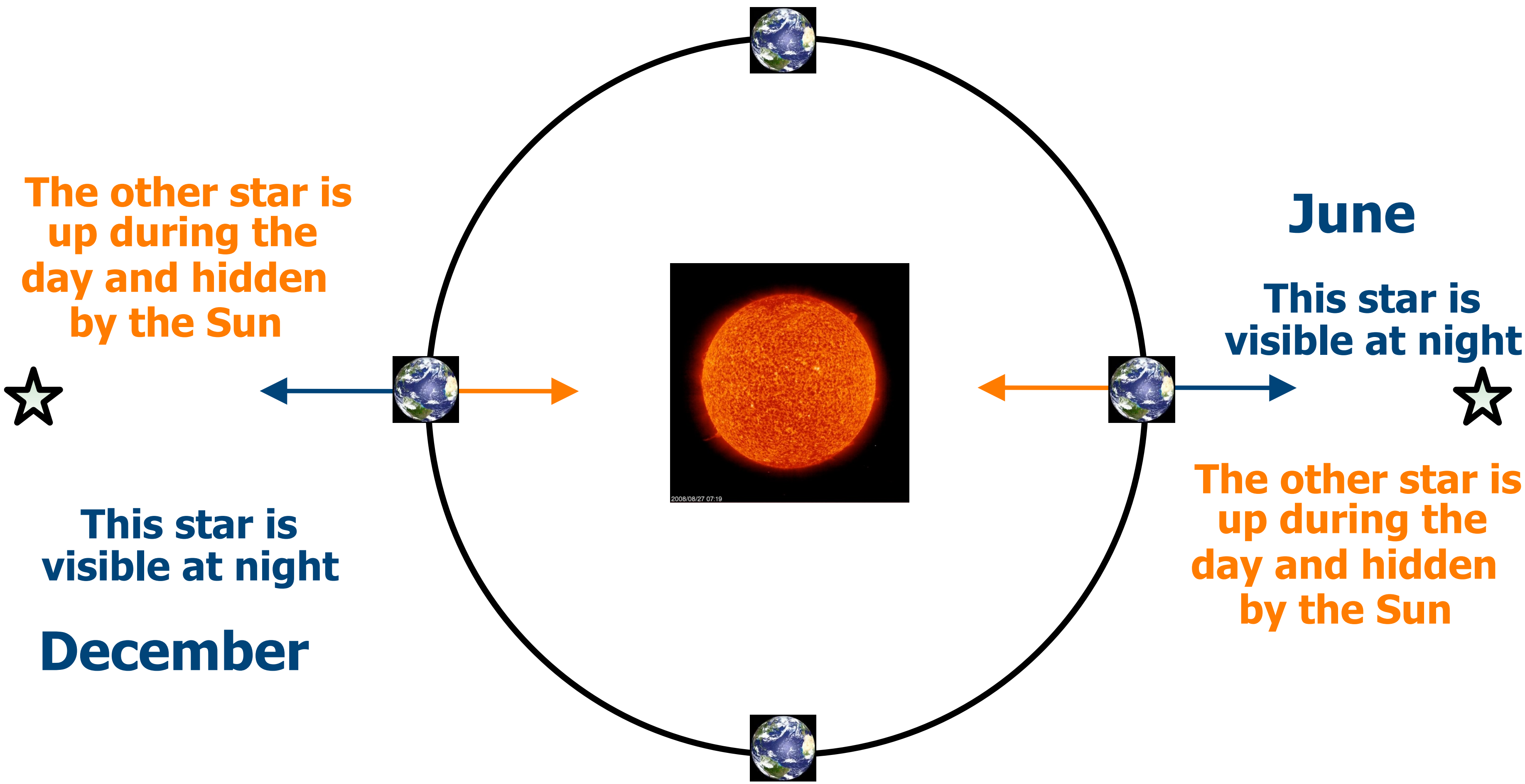
Airmass

- It becomes progressively more difficult to observe stars (and other astronomical objects) as you look through more of the Earth's atmosphere or "air"
- There are two reasons you look through more air:
  - As you move north or south in latitude on the Earth from a star's declination being at zenith, the star moves south or north of your zenith
  - As time changes, a star at your zenith moves west of your zenith
- *Airmass* codifies how much atmosphere you must observe through, and so roughly the factor of extra time you need for a given observation

Airmass

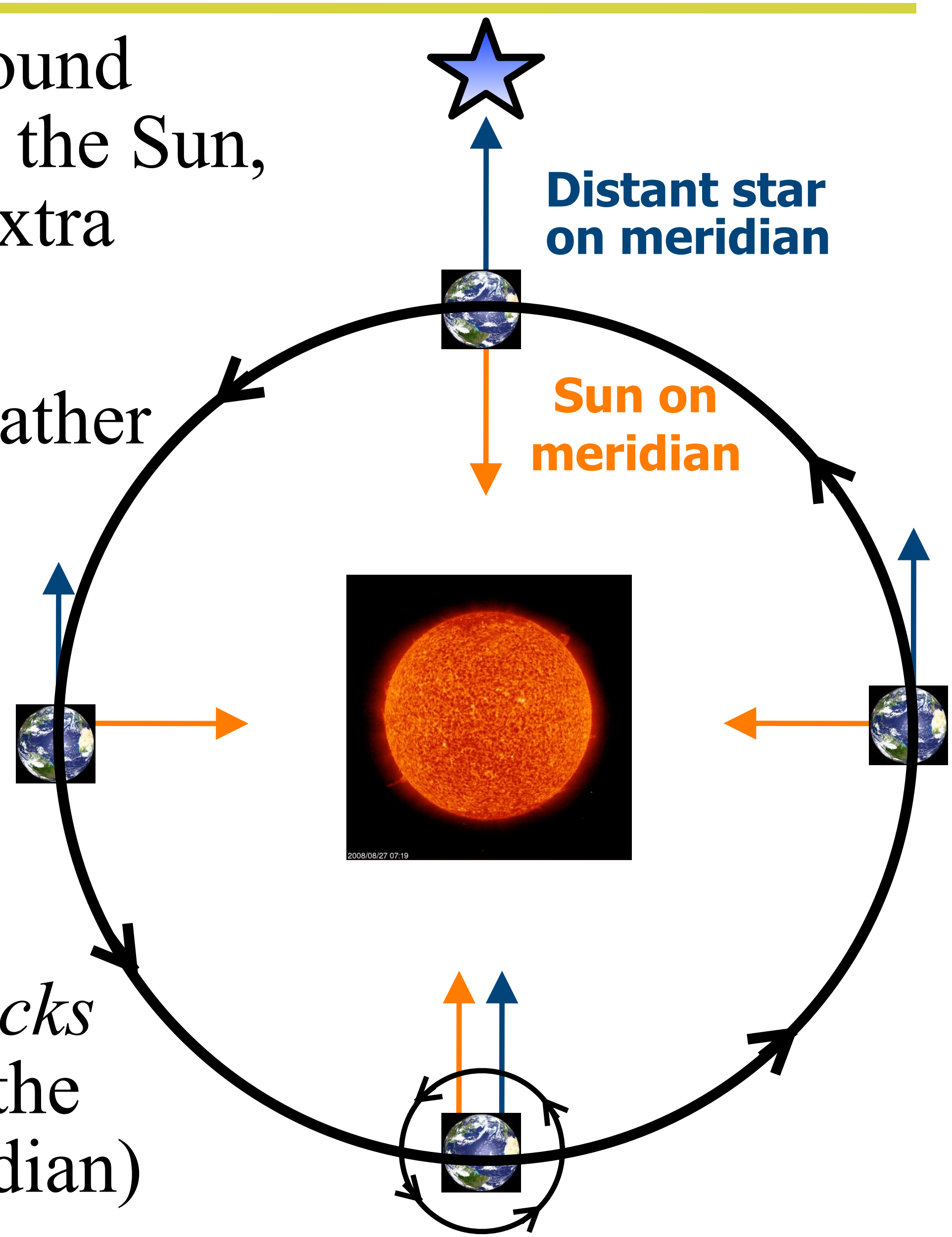
- If z is the angle between your zenith and the star (or other object) at which you are pointing your telescope, then a simple model of airmass (X) is: $X = 1/\cos(z)$
  - (better models are linked from the course links page)
- So, if you are in Nashville, at 35°N, and a star at your LMST has δ=12°N, then the star is 23° *south* of zenith and $X = 1/\cos(23^{o}) \sim 1.08$
- If you wait 2 hours and 50 minutes after a star passes through zenith to observe it, then the hour angle is $2^{h}50^{m}0^{s} = 42.5^{o}$. The star is then 42.5° *west* of zenith and $X = 1/\cos(42.5^{o}) \sim 1.36$
- **Both** *latitude* and *time* effect airmass. These effects can be easily combined in Cartesian coordinates (see later).

The Earth orbits the Sun



Sidereal Time

- Relative to distant background ("fixed") stars, rather than the Sun, the Earth makes one full extra rotation per year
- Keeping time using stars rather than the Sun, a clock runs about 4 minutes slower... (365.25/366.25) x 24 x 60mins per day rather than 24 x 60mins per day
- The clocks we read in everyday life are *solar clocks* (to keep local noon when the Sun is on or near the meridian)



Sidereal Time

- Basically, a star will rise 4 minutes earlier each night
  - 1 night after tonight, you must observe 4 minutes earlier for the same star to be on your meridian
  - each month, you must observe 2 hours earlier for the same star to be on you meridian (a given RA is on your meridian 2 hours earlier each month)
- Thus, the airmass of a star changes through the year as the star becomes easier or harder to observe
- The zero point of RA is set to be the Vernal Equinox (~March 20-21), when the Sun will have RA = $0^h0^m0^s$, (and so $12^h0^m0^s$ will be up in the middle of the night)
  - On ~April 20, ~14^h is up in the middle of the night

Precise timekeeping and MJD

- Given the different time systems, leap years etc. it is useful to have a calendar with which to express exact times of observations (referred to as *epochs*)
- In astronomy we use a calendar based on the original Julian calendar (established by Julius Caesar)
- Julian Date (JD) is a count in days from 0 at noon on January the 1st in the year -4712 (4713 BC)
- Modified Julian Date (MJD) is a count in days from 0 midnight on November 17 in the year 1858
  - The modification just makes the numbers smaller
  - MJD = JD - 2400000.5

Python tasks

1. Read course links for: *astropy.coordinates, astropy.time*
2. Use *Skycoord* from *astropy.coordinates* to convert a dec in (º,’,”) format to decimal degrees. Do the same for an RA in hms format
   - Check carefully that these conversions agree with my equations from earlier slides
   - Use dir() to see internal SkyCoord functions that will let you print RA in hms, hours, and deg.
3. Use *Time.now()* from *astropy.time* to obtain today’s MJD and today’s JD
   - Check that JD and MJD are related as is indicated by the equation on the previous slide

Python tasks

4. Use *numpy.arange* and the output from *Time.now()* to list some days near today's MJD
5. The SDSS telescope is at Apache Point Observatory, APO's longitude is 105°49'13.5"W, latitude is 32°46'49.30"N, and altitude is 2788m. Use *astropy.coordinates.EarthLocation* to set APO's location, e.g., something like:
   – *APO = EarthLocation(lat=,lon=,height=)*
6. What is the airmass from APO towards an object with α = 05h46m, δ = +28°56m at 11PM tonight and at 2AM three months ago. Plot airmass vs. UTC for a good time to observe this object.
   – see *hints on calculating airmass* on the links page