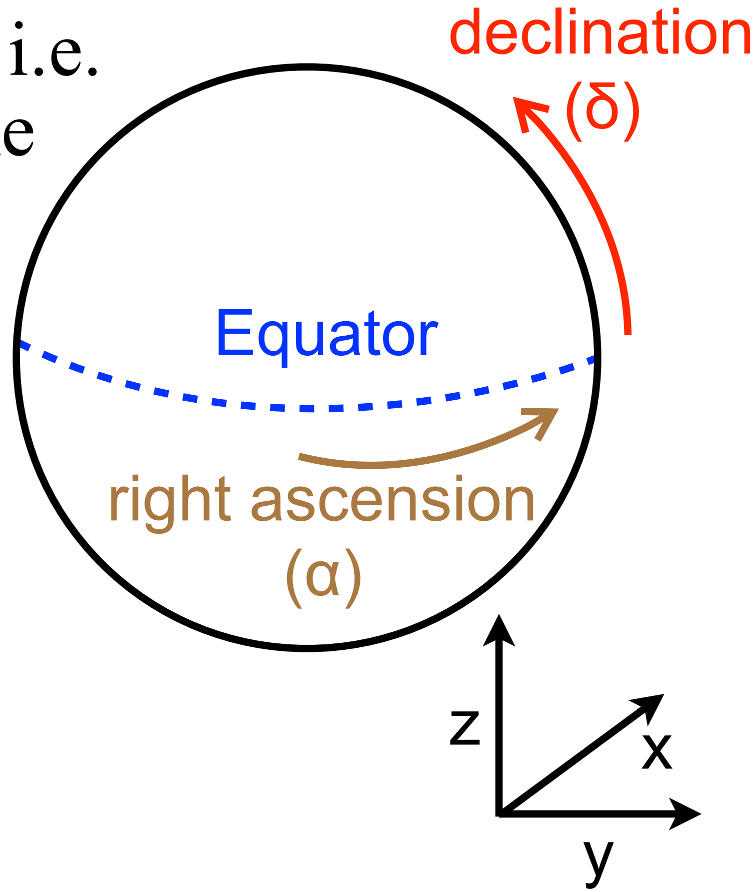
Coordinate Transforms

Equatorial and Cartesian Coordinates

- Consider the unit sphere ("unit": i.e. the distance from the center of the sphere to its surface is $r = 1$)



- Then the equatorial coordinates can be transformed into Cartesian coordinates:
  - $x = \cos(\alpha)\cos(\delta)$
  - $y = \sin(\alpha)\cos(\delta)$
  - $z = \sin(\delta)$

- It can be much easier to use Cartesian coordinates for some manipulations of geometry in the sky

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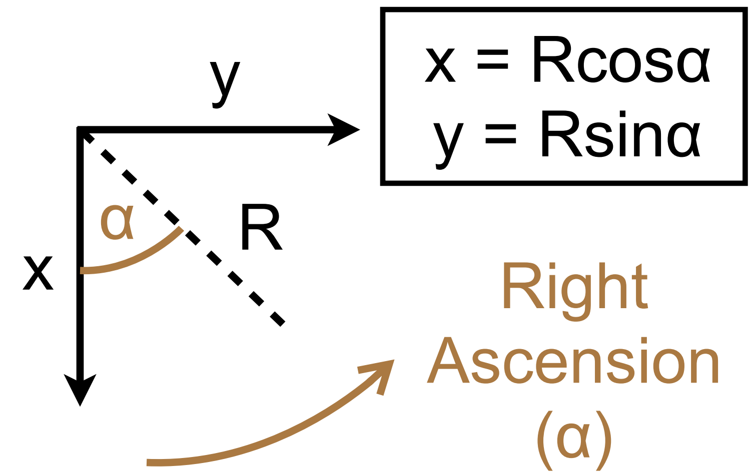
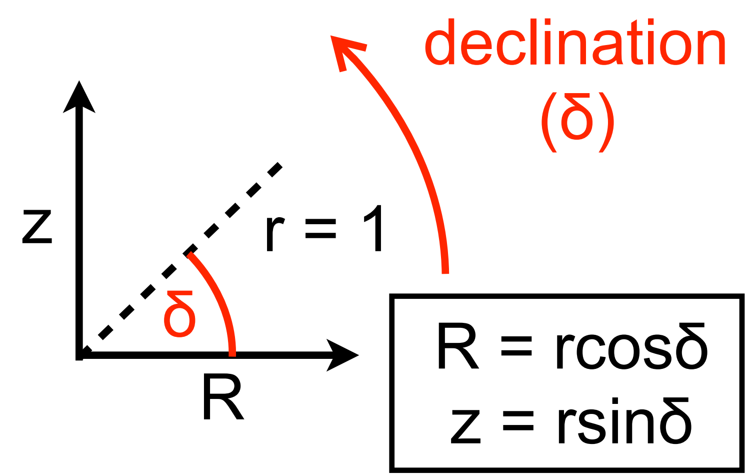
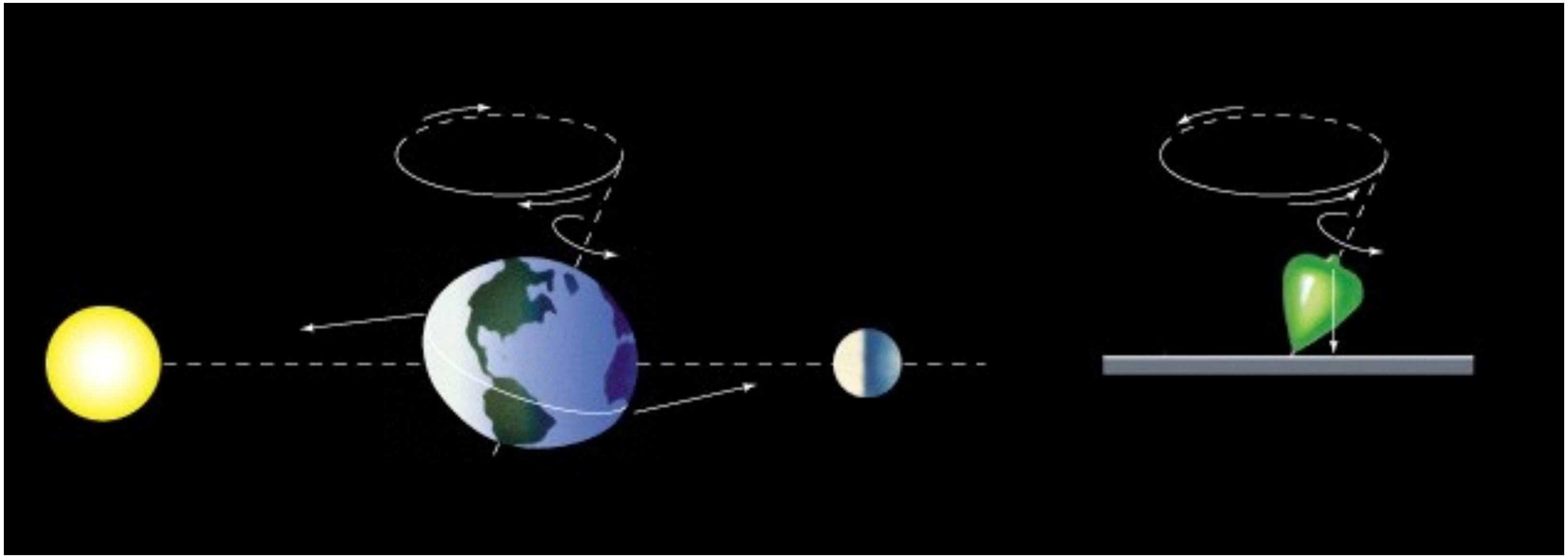




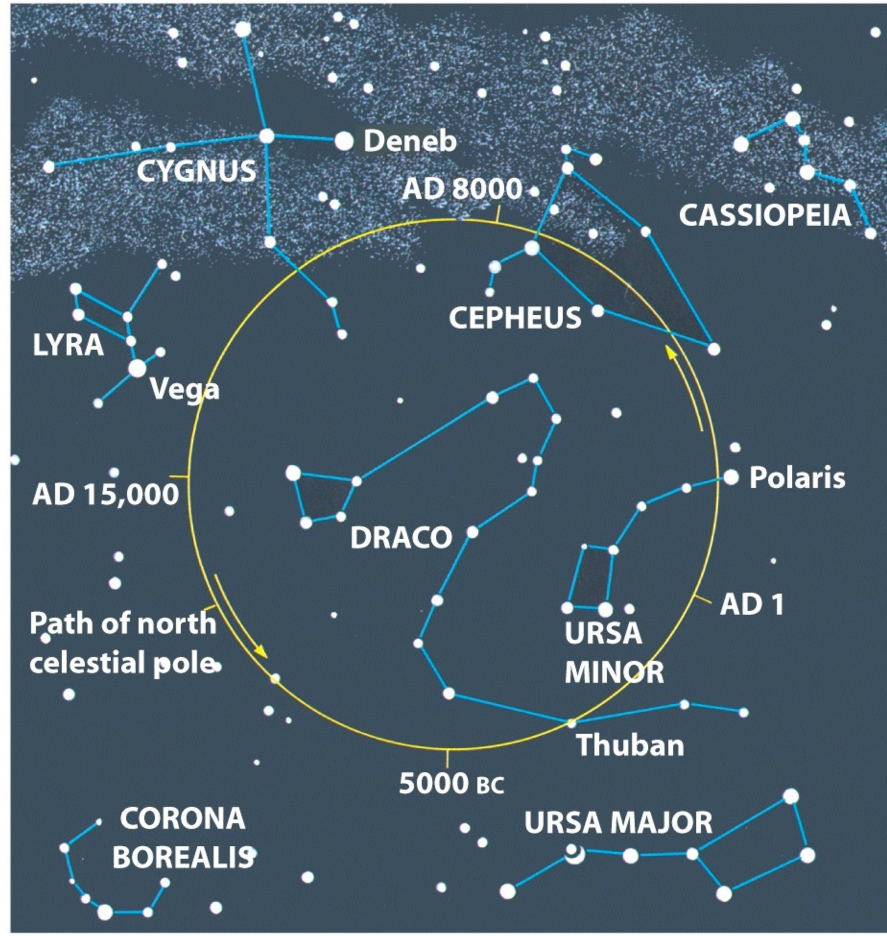
Precession

- Because the Earth is not a perfect sphere, it wobbles as it spins around its axis
- This effect is known as *precession*
- The *equatorial coordinate system* relies on the idea that the Earth rotates such that only Right Ascension, and not declination, is a time-dependent coordinate



The effects of Precession

- Currently, the star Polaris is the North Star (it lies roughly above the Earth's North Pole at $\delta = 90^{o}$N)
- But, over the course of about 26,000 years a variety of different points in the sky will truly be at $\delta = 90^{o}$N
- The declination coordinate *is time-dependent* albeit on very long timescales
- A precise astronomical coordinate system must account for this effect



Equatorial coordinates and equinoxes

- To account for precession, the *equatorial coordinate system* being used by an astronomer is always specified to be "at a certain time in history"
- For instance "2000.0" would specify coordinates in a system when the Earth's precession made the (distant) night sky look as it was at midnight on Jan 1, 2000
- Because the *equatorial coordinate system* is set by the position of the Sun on the Vernal Equinox, this specification (e.g., 2000.0) is called an *equinox*
- A point in the sky at α = 12:34:56.78, δ = +01:23:45.6, ***2000.0*** is a slightly different point in the sky to α = 12:34:56.78, δ = +01:23:45.6, ***1950.0***

Equatorial coordinates and equinoxes

- Precession is such a small effect that the system is only re-specified every 50 years or so
- When I was in grad school, *B1950.0* was still a common equinox to use
  - the *B* here stood for a now-obsolete way of measuring epochs called the Besselian system
- Astronomers currently use the equinox *J2000.0*
  - the *J* here denotes Julian date
- It is possible that in our lifetimes the International Astronomical Union will initiate a switch to *J2050.0* coordinates

Equatorial coordinates and equinoxes

- Note that although coordinates are specified using a certain equinox, the true equinox *is always changing*
  - precession doesn't just stop between 1950 and 2000 and then again between 2000 and 2050
- So one might list coordinates of stars as *J2000.0* in a publication, and might take them to a telescope to make observations in June, 2015
- The telescope control software then takes account of precession and rotates your coordinates until they are at a coordinate system with an equinox of *J2015.6*
- The equinox in which coordinates are expressed by astronomers is almost never the true, current equinox

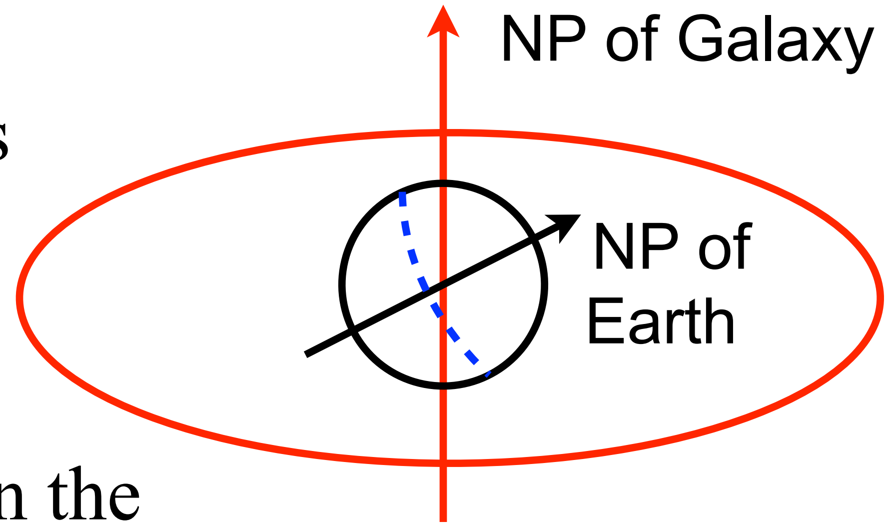
Rotations

- The method to precess coordinates to a new equinox is a common approach to coordinate transforms
- The general approach is to define (and measure) a rotation matrix, R that transforms between systems as
  - $(x_2,y_2,z_2) = R \begin{pmatrix} x_1 \\ y_1 \\ z_1 \end{pmatrix}$
- e.g., to precess coordinates from B1950 to J2000:

```
    [0.999925716,-0.0111783209,-0.00485873999]
R = [0.011178321, 0.99993752,-0.000027154951 4]
    [0.00485873997,-0.000027159609, 0.999988196]
```

- The approach is then, as before, to convert from (α,δ) to (x,y,z) apply R and convert back to the new (α,δ)

Rotations and Galactic Coordinates



- There are many common coordinate transformations in astronomy, each with its own rotation matrix
- For instance, Galactic coordinates are centered on the Sun. The longitude is called ℓ and the latitude b. The disk of our Galaxy is the "equator" (i.e. the equatorial plane); $(\ell,b) = (0^o,0^o)$ towards the Galactic center and $(\ell,b) = (0^o,90^o)$ towards the Galactic North Pole
- Another common system is the ecliptic coordinate system, in which the equatorial plane is the *ecliptic*, the plane in which all of the planets orbit the Sun

Python tasks *(all of these use astropy.coordinates!)*

1. Convert an RA and a dec to Cartesian coordinates (*xyz*)
   - Check carefully that you agree with my equations
2. Calculate the (α,δ) of the center of our Galaxy
   - In what constellation is the Galactic Center? Is it near the center or edge (qualitatively) of that constellation (see syllabus links for constellation positions/maps)?
3. For Laramie, $\delta = 40^{\circ}$N. Plot how (ℓ,b) changes through the year directly above your head
4. Current (α,δ) for the planets, Sun and Moon are linked from the syllabus. Plot the positions of these bodies in ecliptic *('heliocentrictrueecliptic'* in astropy*)* coordinates