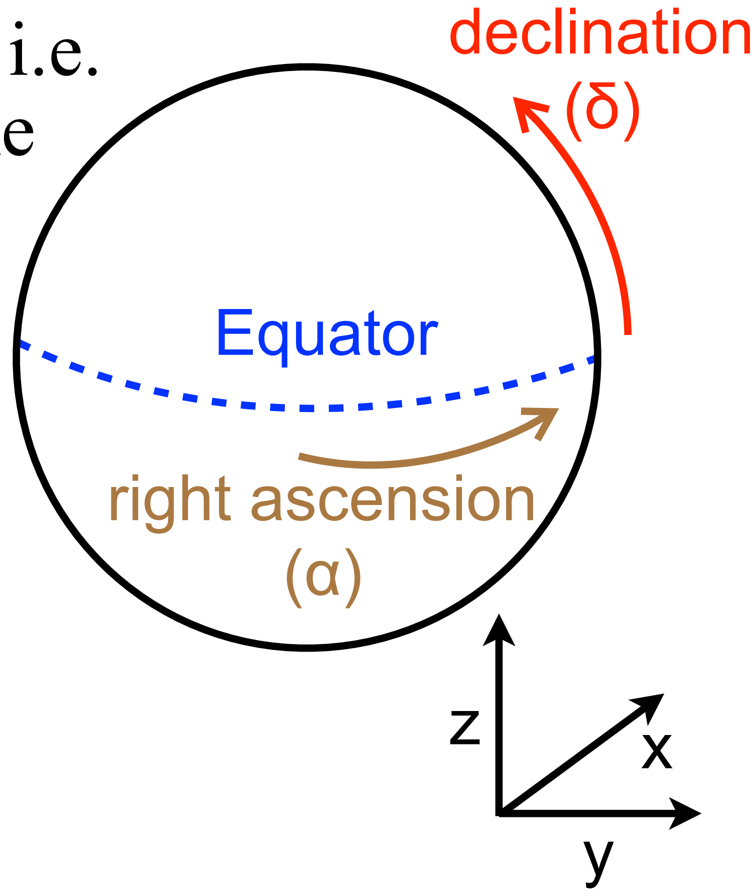
Coordinate Transforms

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

Equatorial and Cartesian Coordinates

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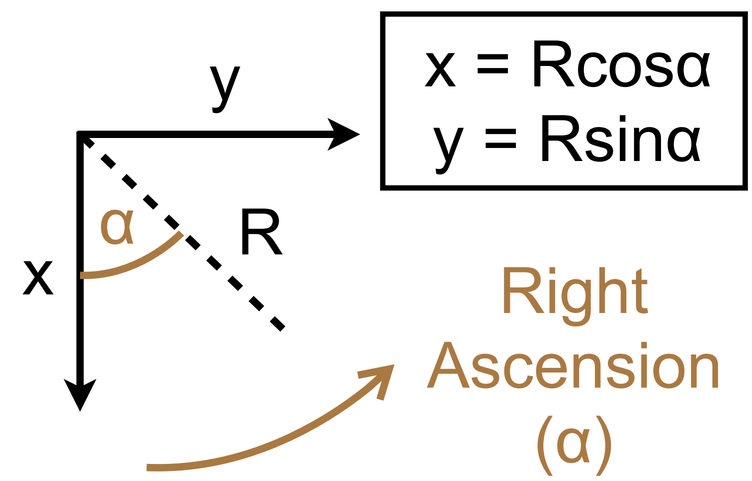
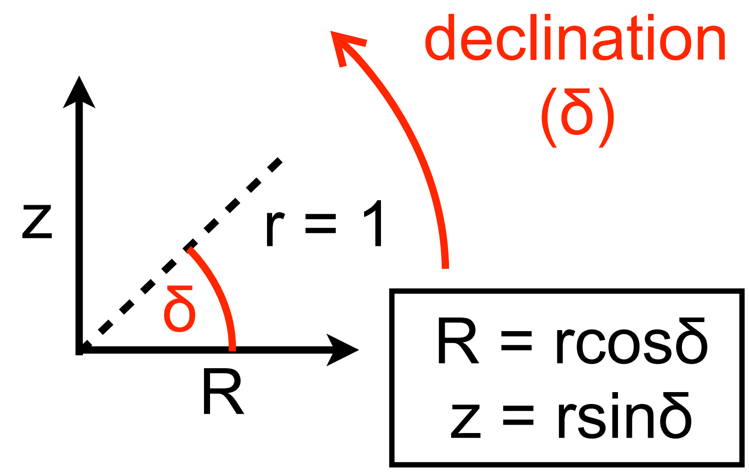
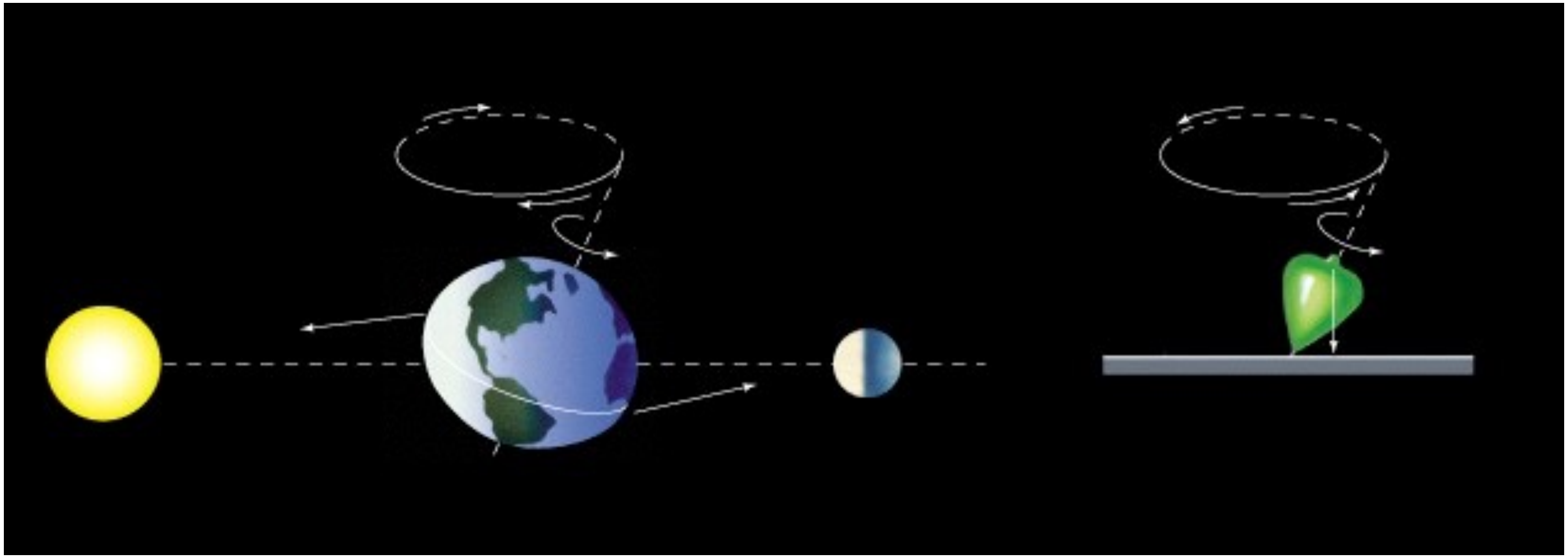




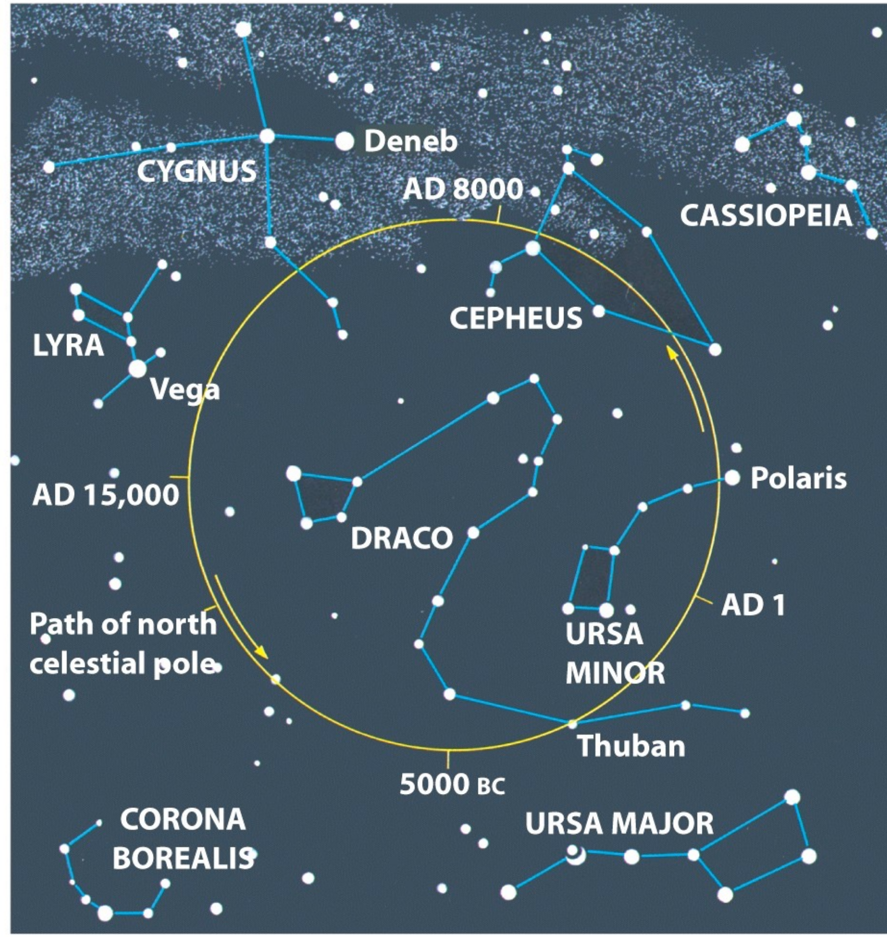
Precession

- 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, I once accidentally used *B1950.0* coordinates at a telescope and wasted hours
  - 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 February, 2022
- The telescope control software then takes account of precession and rotates your coordinates until they are at a coordinate system with an equinox of *J2022.2*
- The equinox in which coordinates are expressed by astronomers is almost never the true, current equinox

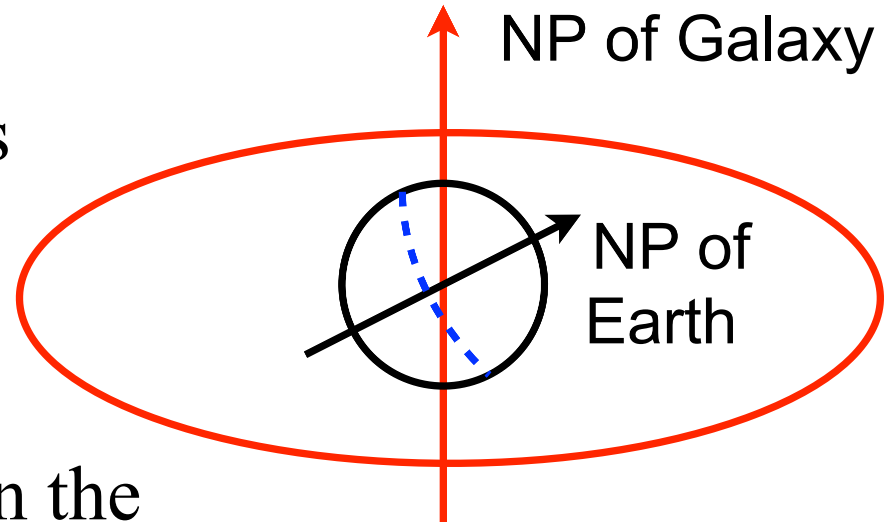
Rotations

- 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,-0.000271549514]
    [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*)
   - *c.representation_type = 'cartesian'* converts an RA/dec *SkyCoord* to Cartesian coordinates, *'spherical'* will transform back. *c.cartesian* will print in cartesian.
   - Check the *SkyCoord* result agrees 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 the syllabus links for constellation positions/maps)?
   - Consider the *frame* option and *transform_to()*. Also see *get_constellation()*.
3. For Nashville, $\delta = 36^{o}$N. Plot how (ℓ,*b*) changes through the year directly above your head

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

4. Current (α,δ) for the planets are available with *astropy.Time* and *astropy.get_body()*. Plot the positions of Mercury, Venus, and Mars in ecliptic *('heliocentrictrueecliptic'* in *astropy)* coordinates