

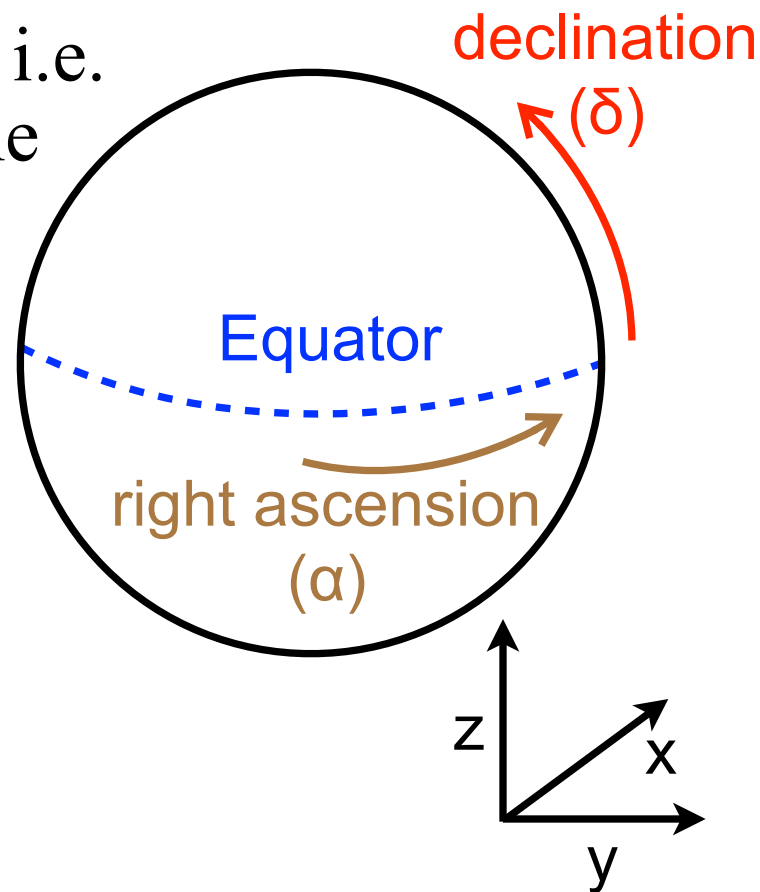
Coordinate Transforms

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:

- $x = \cos(\alpha) \cos(\delta)$
- $y = \sin(\alpha) \cos(\delta)$
- $z = \sin(\delta)$

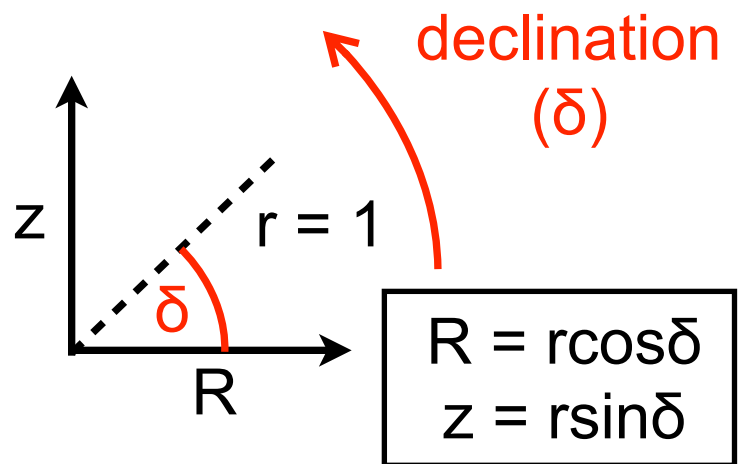
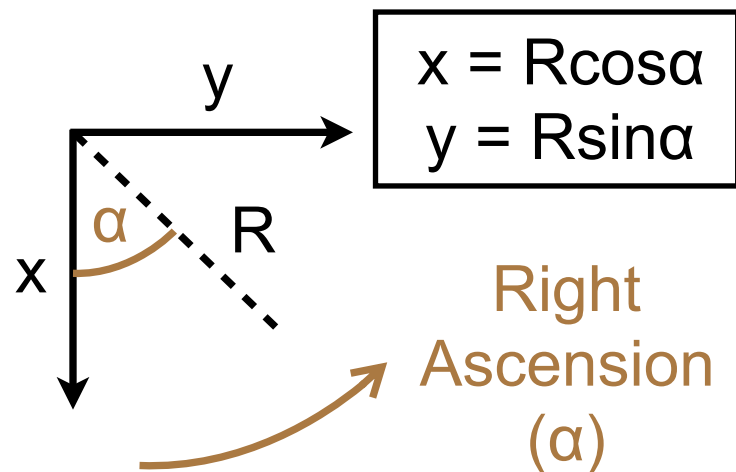


- It can be much easier to use Cartesian coordinates for some manipulations of geometry in the sky
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Equatorial and Cartesian Coordinates

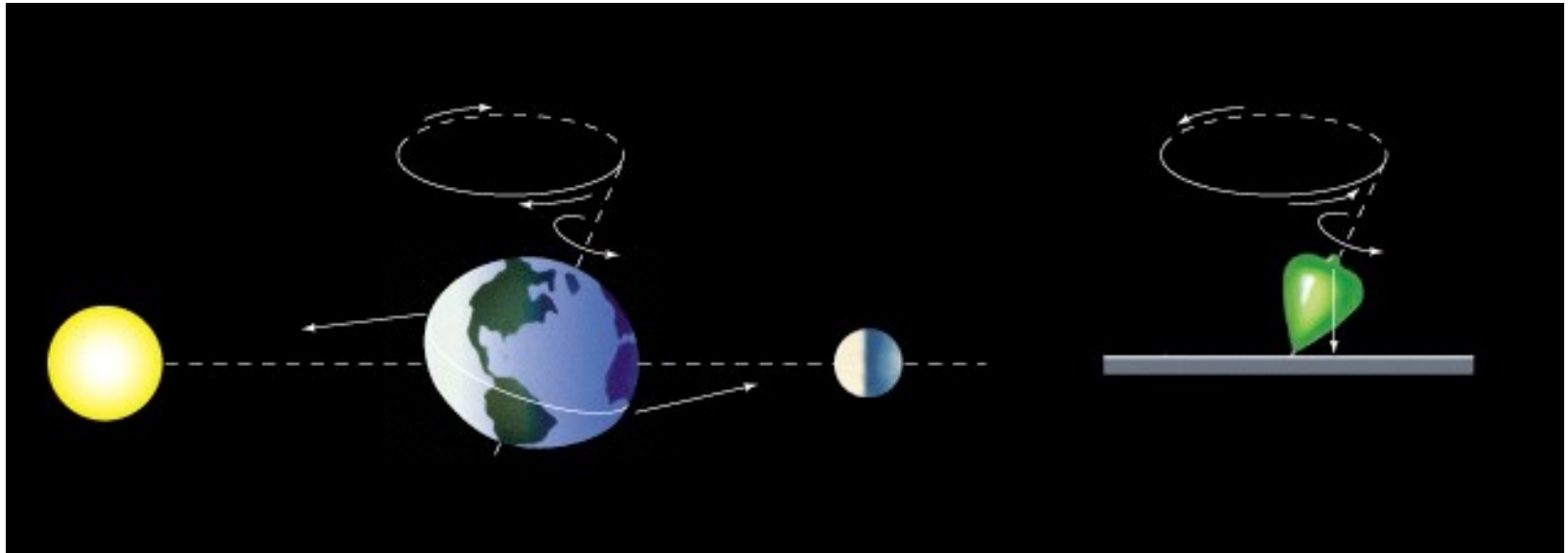
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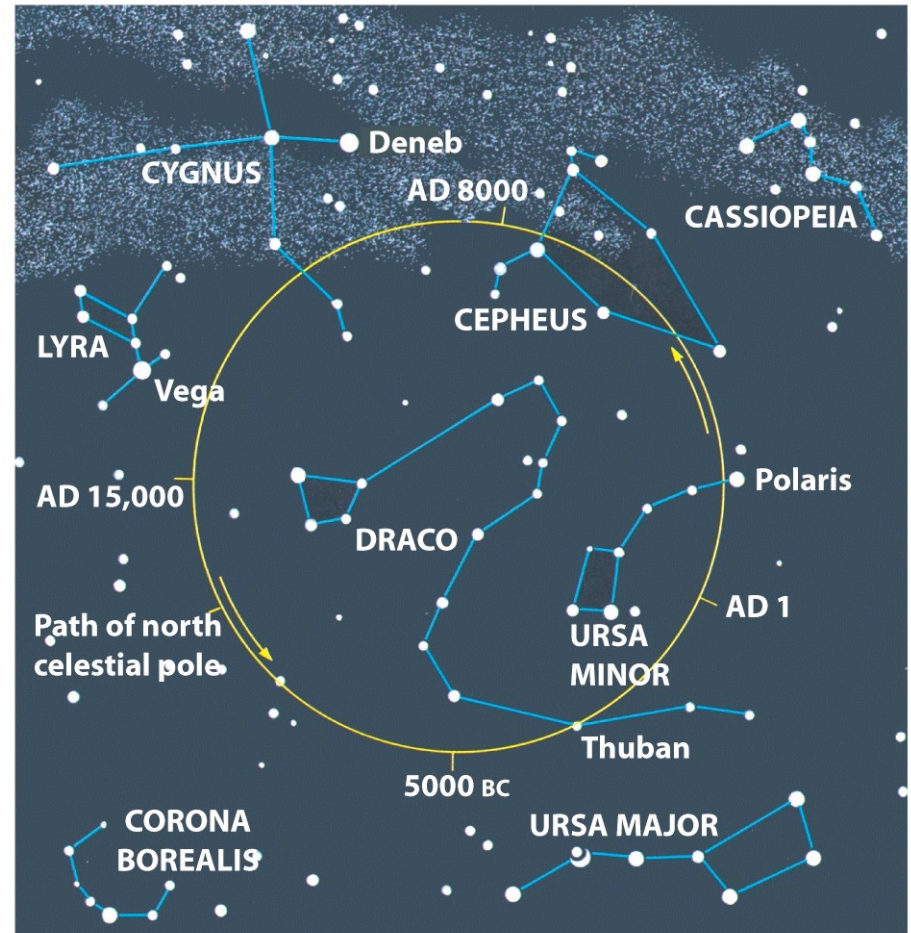
Precession

- 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 $\delta = 90^\circ\text{N}$)
- But, over the course of about 26,000 years a variety of different points in the sky will truly be at $\delta = 90^\circ\text{N}$
- 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 $\alpha = 12:34:56.78$, $\delta = +01:23:45.6$, **2000.0** is a slightly different point in the sky to $\alpha = 12:34:56.78$, $\delta = +01:23:45.6$, **1950.0**
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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
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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, 2020
 - The telescope control software then takes account of precession and rotates your coordinates until they are at a coordinate system with an equinox of $J2020.6$
 - The equinox in which coordinates are expressed by astronomers is almost never the true, current equinox
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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

$$\begin{aligned} \text{--- } (x_2, y_2, z_2) &= \begin{pmatrix} x_1 \\ R(y_1) \\ z_1 \end{pmatrix} \end{aligned}$$

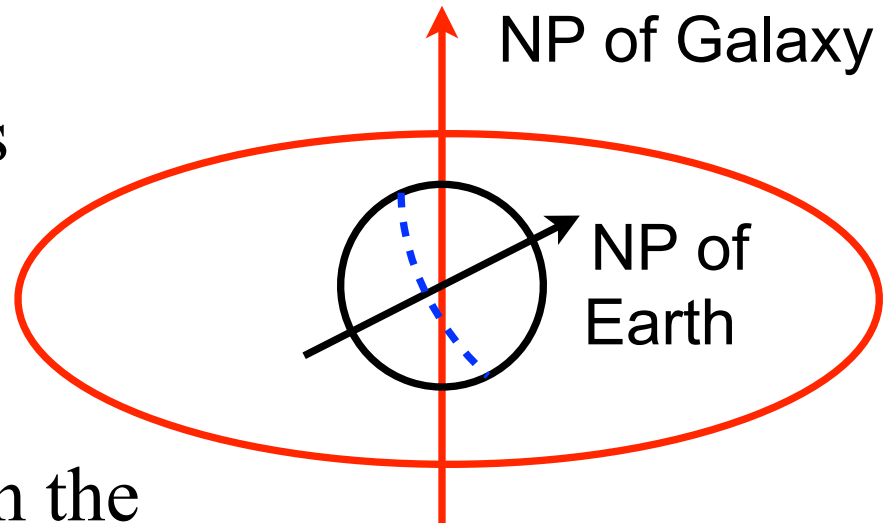
- e.g., to precess coordinates from B1950 to J2000:

```
R = [0.999925716, -0.0111783209, -0.00485873999]
     [0.011178321, 0.99993752, -0.0000271549514]
     [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)
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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); $(\ell, b) = (0^\circ, 0^\circ)$ towards the Galactic center and $(\ell, b) = (0^\circ, 90^\circ)$ 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, $\delta = 36^\circ\text{N}$. Plot how (ℓ, b) changes through the year directly above your head
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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