1 Astronomical Coordinate Systems . . . Continued

1.1 The Equatorial Coordinate System

The most basic astronomical observation is that the stars "hang together" as they move across the sky in the diurnal motion. This indicates that we should define a coordinate system fixed with respect to the stars. Just like we can specify the latitude and longitude of a place on Earth, we can specify the coordinates of a star relative to a coordinate system fixed with respect to the stars. Look at Figure 1.5 of the textbook for a definition of this coordinate system.

The Equatorial Coordinate System is similar in concept to longitude and latitude.

- Right Ascension → longitude. The symbol for Right Ascension is α. The units of Right Ascension are hours, minutes, and seconds, just like time

- Declination → latitude. The symbol for Declination is δ. Declination $= 0°$ corresponds to the Celestial Equator, $\delta = 90°$ corresponds to the North Celestial Pole.

1.2 The Origin of Right Ascension

. It is not obvious where to set $\alpha = 0^h$. By convention, this is the *vernal equinox*, the location of the Sun on the first day of spring.

2 Star Charts

The first lab experiment is to become familiar with star charts. Today you will get a sneak preview of the SC1 star charts. → SC1 charts.

2.1 Further Remarks on the Equatorial Coordinate System

The Equatorial Coordinate System is fundamentally established by the rotation axis of the Earth. See Figure 1.10.

With the definition of the Equatorial Coordinate System, we can figure out the altitude at transit of any star. This is

$$Al = \bar{l} + \delta \tag{1}$$

Wake-up question: What is the azimuth angle of a star at transit?

2.2 The Equatorial Coordinates of Different Astronomical Objects

For stars, the Right Ascension and Declination are constant [1]. For the Sun, Moon, and planets, (α, δ) change with time. We will clearly see this during the course of the semester.

2.3 Why do the Right Ascension and Declination of the Sun Change?

2.4 The Celestial Equator and the Ecliptic

The Celestial Equator is the intersection of the Earth's equatorial plane with the celestial sphere, and it is a great circle on the celestial sphere. The ecliptic is the intersection of the plane of the ecliptic with the celestial sphere, and it is a great circle on the celestial sphere. They are not the same great circle, but are inclined with respect to each other at 23.5°.

Why is this so? What is it telling us about the solar system?

2.5 Seasonal Changes in the Night Sky

A very fundamental fact of astronomy, known to all human societies, is that the location of the constellations in the night sky changes through the year. We will clearly see this during the course of the semester.

This results from the revolution of the Earth around the Sun. The idea is illustrated in Figure 1.11 in the book. Another way of seeing it is via the SC1 charts. A particularly striking illustration of this is provided by the movies from the C3 coronagraph on the SOHO spacecraft (see the spacecraft web page on the course web page).

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[1]This isn't completely true; wait for later in the semester

2.6 The Motion of the Moon and Planets

The planets are moving, approximately in the plane of the ecliptic, with different orbital periods. We therefore see them approximately in the direction of the ecliptic.

The motion of the planets can be somewhat complicated. On the average, all the major planets move from west to east as part of their revolution around the Sun. However, the are also seen to undergo *retrograde* motion, in which they move from east to west for a while. This is called *retrograde motion*, and is particularly pronounced for Mars.

2.7 Precession of the Equinoxes

The Greek philosopher Hipparchus first noted that the right ascension and declination of stars were different in his time than they had been recorded by earlier astronomers.

We now know that this is due to the *precession of the equinoxes*. This is fundamentally due to the precession of the Earth's rotation axis. Precession occurs when a rotating object is subject to a torque. The precession period is 25800 years. Since the location of the north celestial pole is changing, the declination of stars will change. Furthermore, since the intersection of the celestial equator with the ecliptic changes as well, the right ascension changes.

The precession of the Earth's rotation axis, together with periodic variations of a number of properties of the Earth's orbit, is believed by many scientists to be responsible for the Ice Ages on Earth.

3 Astronomical Fundamentals of Time

Astronomical phenomena help define our idea of time, and the measurement of time is tied inextricably with astronomy. Our fundamental terms for units of time, the day, and month, and the year, all relate to astronomical cycles.

3.1 The Day

You might think the definition of the day is ridiculously simple. However, in reality you have to be careful on how you define it. The book defines the day as *"the interval between successive transits of a celestial object"*.

The most common (and seemingly only) choice for this celestial object is the Sun. This leads to the definition of the **Solar Day**.

However, you could also choose a star, such as Vega, and measure the day to be the time between successive transits. This is the definition of the **Sidereal Day**. Aren't these the same?

No they aren't. To see why, and estimate the difference, look at Figure 1.11. The crucial point is that the Sidereal Day is the rotation period of the Earth in an *inertial reference frame* defined by the distant stars. The Solar Day is the rotation period in a rotating reference frame in which one axis is defined by the direction from the Earth to the Sun.

At the end of one sidereal day, the Earth has to still turn through a little angle to be back to the direction of the Sun.

3.2   Numbers, numbers, numbers

Let's work out the difference between the sideral day and the solar day. One way of doing this is with the derivation in Equation 1.1 - 1.5. Here's an easier (although not as exact) way of seeing the same thing. Look at Figure 1.1.

After 1 sidereal day, the Earth has advanced in its orbit by an angle given by

$$\Delta\theta = \omega_E P_{sid} \tag{2}$$

Where ω_E is the *angular speed* (radians/sec) of the Earth's orbital motion around the Sun ($\omega_E = \frac{2\pi}{P_E}$), and P_{sid} is the length of the sidereal day.

The time Δt it takes for the Earth to rotate through this angle is (approximately)

$$\Delta\theta \simeq \omega_{sid}\Delta t \text{ so} \tag{3}$$

$$\omega_{sid}\Delta t \simeq \omega_E P_{sid} \tag{4}$$

$$\Delta t \simeq \frac{\omega_E}{\omega_{sid}} P_{sid} \tag{5}$$

$$\Delta t \simeq \frac{P_{sid}}{P_E} P_{sid} \tag{6}$$

To the extent that P_{sid} and P_{sol} are the same, this gives the same result as Equation (1.5) of the book, 1/365 of a day, or about 4 minutes.

The reason I used the "nearly equal" sign $\simeq$ rather than the mathematical identity symbol $=$ is that my calculation assumed that the Earth stayed put in its orbit while it rotates through the angle $\Delta\theta$.

The bottom line of this is the very important result that the sidereal day is 4 minutes shorter than the solar day. This fact provides another way of understanding seasonal variations in the appearance of the night sky.

You should look at the alternative (and more rigorous) derivation of this result on p18 and 19 of the book.

3.3   Choice of the Solar Day

We choose to organize our lives using the solar day because human beings are up and around during daylight. However, a major complication arises. *The solar day is not a constant; it varies through the year.*