ASTR-1010: Astronomy I
Course Notes
Section II

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Abstract

These class notes are designed for use of the instructor and students of the course ASTR-1010: Astronomy I taught by Dr. Donald G. Luttermoser at East Tennessee State University.

II. The Night Sky

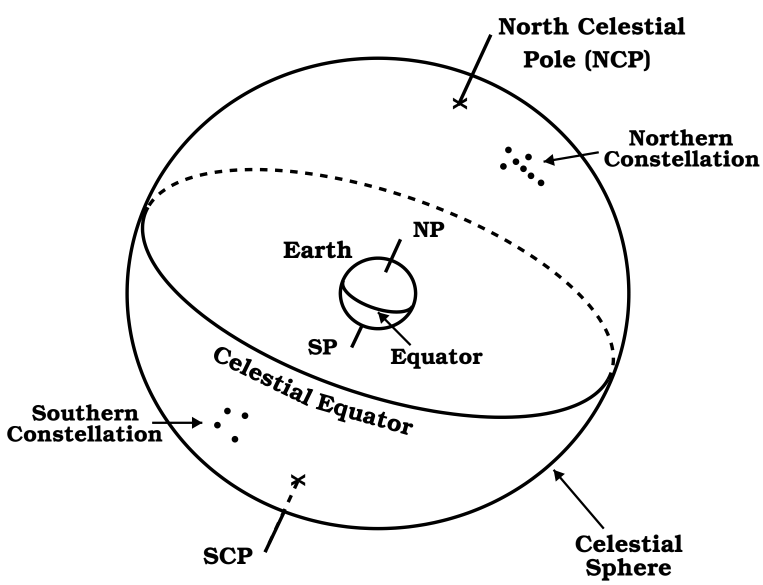
A. The Constellations

1. There 88 constellations (*i.e.*, star patterns) on the **celestial sphere** (*i.e.*, the sky).

a) The ancient Greeks defined the **celestial sphere** to be an imaginary clear sphere that surrounds the Earth in which the constellations are attached and the planets, Moon, and Sun move upon.

b) We still use the concept of the celestial sphere in modern astronomy, primarily for the definition of the coordinate system on the sky.

2. Constellations that lie over the Earth's northern hemisphere are called northern constellations and those over the southern hemisphere the southern constellations. These 2 regimes are divided by the **celestial equator** — the imaginary line on the sky that lies over the Earth's equator.



3. The stars that make up the constellations come in a variety of brightnesses, which depends upon their actual luminosities and their distances, and in a variety of colors depends upon their temperatures (the hottest stars are bluish and the coolest are reddish).

4. Just as all of the constellations have names, all stars in the sky also have names.

a) The brightest stars have proper names associated with them as well as catalogue names:

i) Bright Star (HR) Catalog: ∼10,000 entries. Note that the 'HR' stands for "Harvard Revised" since this catalog is based on the Harvard Revised Photometry paper of E.C. Pickering (1908).

ii) Henry Draper (HD) Catalog: ∼250,000 entries.

iii) Smithsonian Astrophysical Observatory (SAO) Catalog: ∼260,000 entries.

iv) Hubble Space Telescope (HST) Catalog: ∼5,000,000 entries.

b) Fainter stars typically just have catalog names associated with them.

Proper Name	**Constellation Name**	**Bright Star Catalogue**	**Henry Draper Catalogue**
Sirius	α CMa (Canis Major)	HR 2491	HD 48915
Betelgeuse	α Ori (Orion)	HR 2061	HD 39801
Rigel	β Ori	HR 1713	HD 34085
Mizar	ζ UMa (Ursa Major)	HR 5054	HD 116656
Polaris	α UMi (Ursa Minor)	HR 424	HD 8890

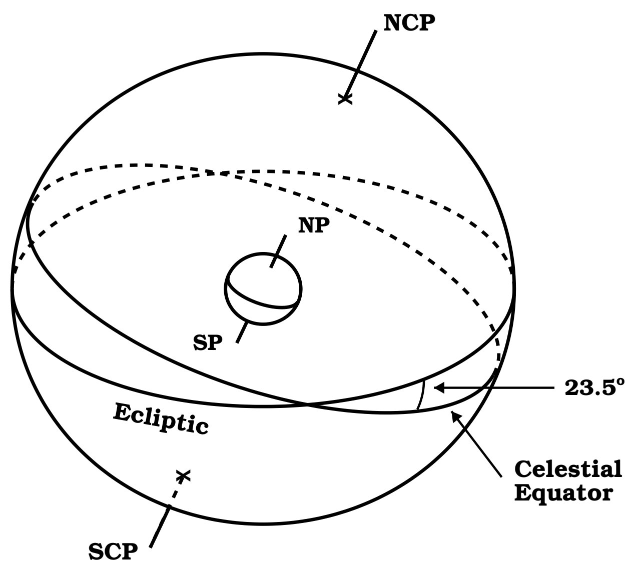
B. The Seasons

1. We have seasons due to the tilt of the Earth's rotation axis, and <u>**not**</u> due to the changing distance of the Earth from the Sun!

   a) The Earth's axis is tilted 23.5° with respect to the normal of the Earth's orbital plane.

   b) As the Earth orbits the Sun, the Sun follows an apparent path around the sky called the **ecliptic**.

   c) The ecliptic is tilted 23.5° with respect to the celestial equator.



2. The nodes where the ecliptic crosses the celestial equator are called the equinoxes.

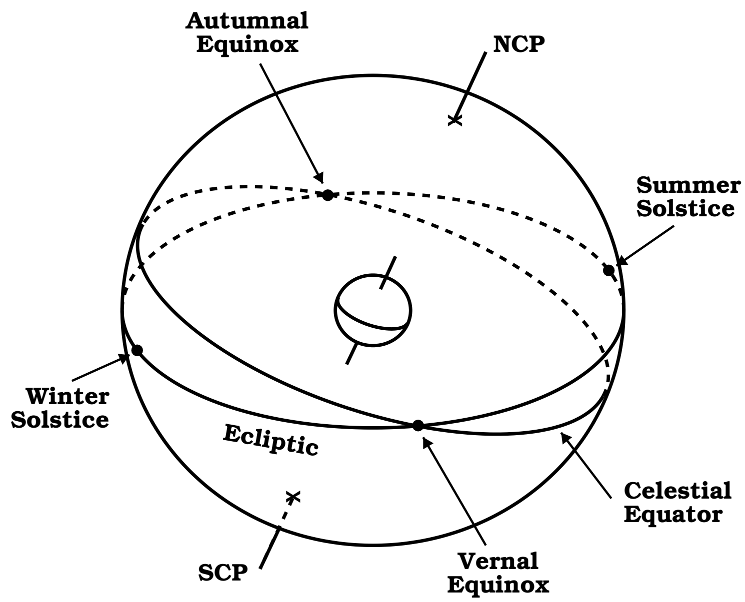
   a) The Sun moves from the southern hemisphere into the northern hemisphere on approximately March 21st $\Longrightarrow$ **vernal equinox**.

   b) The Sun moves from the northern hemisphere into the southern hemisphere on approximately September 21st $\Longrightarrow$ **autumnal equinox**.

3. The extrema on the ecliptic with respect to the celestial equator are called the solstices.

a) The Sun is farthest north of the celestial equator approximately on June 21st $\Longrightarrow$ **summer solstice**.

b) The Sun is farthest south of the celestial equator approximately on December 21st $\Longrightarrow$ **winter solstice**.



C. Terrestrial and Celestial Coordinates

1. We are all familiar with the Earth's coordinate system:

a) Great circles that encompass the Earth parallel to the equator are called lines of **latitude**.

i) Equator: 0° latitude.

ii) North pole: 90° north latitude.

iii) South pole: 90° south latitude.

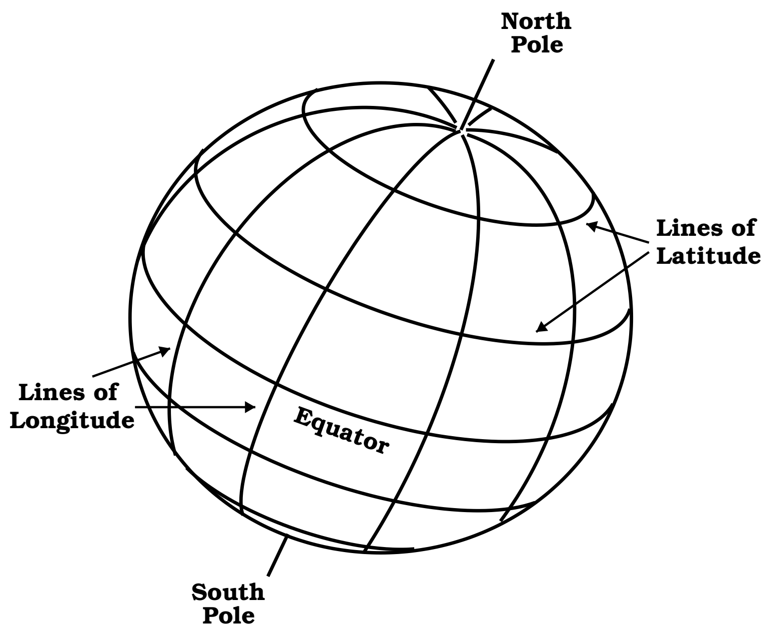
iv) Johnson City: 36.4° north latitude.

b) Lines that connect the poles and run $\perp$ to the lines of latitude are called lines of **longitude**.

i) Prime Meridian = longitude through Greenwich, England (Royal Observatory): 0° longitude $\Longrightarrow$ separates the eastern from western hemisphere.

ii) International Date Line: $\sim 180^\circ$ longitude.

iii) Johnson City: 82.5° west longitude.



2. The sky also has a coordinate system:

a) **Declination**:

i) Declination is designated with DEC or δ (Greek delta).

ii) This is the direct analogy to the Earth's latitude. The celestial equator is the imaginary line on the sky directly over the Earth's equator and is set to 0° declination.

iii) The north celestial pole (NCP) is directly over the Earth's north pole and is at $+90°$ declination.

iv) The south celestial pole (SCP) is directly over the Earth's south pole and is at -90° declination.

b) **Right Ascension**:

i) Right ascension is designated with RA or α (Greek alpha).

ii) RA is analogous to the Earth's longitude, however, it is measured in units of time instead of units of degrees $\Longrightarrow 24^h = 360° =$ a complete circle around the sky.

iii) 0^h RA is set at the position of the vernal equinox. The summer solstice is at 6^h RA, the autumnal equinox at 12^h RA, and the winter solstice at 18^h RA.

iv) Each star has an RA and DEC associated with it.

D. Time

1. The Celestial Meridian, Sidereal Time, and Hour Angles.

a) The point directly overhead on the celestial sphere is called the **zenith**.

b) The line that connects the north point on the horizon with the NCP, the zenith, and the south point on the horizon is call the **meridian** or *celestial meridian*.

c) The current RA coordinate that is on your celestial meridian gives your local **sidereal time** $t_{\rm sid}$ or *star time*. For instance, the star Rigel's RA is $5^h\ 13^m$, when Rigel is on your meridian, the sidereal time is $5^h\ 13^m$.

d) The **hour angle** (HA) of a star is the distance a star is away from your meridian in the RA coordinate. It is measured *positive* towards the west and *negative* towards the east.

$$\text{HA} \ = t_{\rm sid} - \ \text{RA}. \qquad \text{(II-1)}$$

For instance, if the current RA line on your meridian is $3^h\ 23^m$, then Rigel's hour angle would be $-1^h\ 50^m$, or 1^h 50^m to the east of the meridian.

e) In essence, sidereal time can be defined as the hour angle that the vernal equinox is from your celestial meridian.

2. Solar or Tropical Time.

a) Meanwhile, **solar time** (sometimes called *tropical time*), the time for which we are all accustomed, is based upon the hour angle that the Sun is away from your meridian.

b) Local noon is defined to be the time when the Sun just crosses your local meridian.

c) If the Sun is $3^h\ 12^m$ to the west of your meridian, it is 3:12 p.m. in the afternoon *local time*.

3. Time Zones.

a) Since we live in a society which requires local communities all to be at the same time, the concept of time zones were invented by the United States in the 1880's, primarily to keep trains from smashing into each other. The rest of the world followed suit.

b) Each time zone has a width of 15° in longitude. Johnson City is in the eastern time zone (EST).

c) Benjamin Franklin suggested the use of daylight savings time to help farmers $\Longrightarrow$ local noon is pushed forward by one hour in the summer which causes sunset to occur one hour later (and sunrise to occur one hour later too). Johnson City follows eastern daylight time (EDT) from the second Sunday in March through the first Sunday in November.

4. Universal and Ephemeris Time.

a) Since there are 24 time zones on Earth, it is confusing to list a time that an astronomical event will happen. To avoid this confusion, astronomers have invented a standard time that is the same everywhere on the planet at each moment.

b) This time is referred to **Universal Time** (UT) (sometimes called *Greenwich Mean Time*). It is the current solar time at 0° longitude (*i.e.*, the Royal Observatory).

c) Astronomical events are typically given in terms of UT.

d) The EST zone is 5 hours west of Greenwich, England. As such, to get the time in Johnson City, TN, you would subtract 5 hours from the current UT. When daylight savings time is in effect, you would subtract only 4 hours from the current UT to get EDT.

e) The Earth's rotation rate is subject to extremely small, but unpredictable, variations due to gravitational perturbations from the planets, Moon, and Sun. To precisely predict the positions of bodies in the Solar System we require a steady time standard, so Universal Time is replaced by **Ephemeris Time** (ET) in celestial mechanics.

f) At the beginning of 1900 AD, an *ephemeris second* was defined as 1/31,556,925.97474 the length of the tropical year 1900 and both UT and ET were in agreement, but today these times differ by about 40 seconds.

g) Ephemeris Time is determined each year by comparing observations of the planets, Sun, and (mostly) Moon to predicted positions. Each year a table of ET corrections with respect to UT is constructed based upon observations of the previous year. ET tables for years beyond the current year cannot be made due to the unpredictable variations of the Earth's rotation rate mentioned above.

5. The Week and Month.

a) Both the *week* and *month* are of ancient origin and are derived from the cycle of the Moon's phases (its so-called **synodic** orbital period of 29.53 days). The Moon's actual period to orbit the Earth, the so-called **sidereal** (*i.e.*, motion with respect to the background stars) period, is 27.32 days.

b) To fit within the year, months have been given conventional lengths of 28 (29 during leap years), 30, and 31 days.

c) The week of seven days is based upon the quarter phases of the Moon ($29.53/4 = 7.38 \approx 7$ days). In ancient times, there were only 7 astronomical bodies that were known to moved on the celestial sphere (the Sun, Moon, and planets Mercury, Venus, Mars, Jupiter, and Saturn). As such, each day was named after one of these celestial bodies (the ancients considered each of these objects to be gods). The name of some of the days do not match the English names of these planets since they were obtained from either Teutonic (Anglo-Saxon), Latin/Roman, or Norse deity names (see the table below).

d) The month (that is, the Moon's synodic period) gets progressively longer by a small amount (about 0.0006 seconds/century) due to tidal friction of the Earth-Moon system. At the same time, the length of a day increases (*i.e.*, the Earth's spin slows) by 0.0016 seconds/century due to this tidal friction. As the Earth's spin slows, conservation of angular momentum causes the Moon to slowly spiral away from the Earth which results in an increase of its orbital period from Kepler's 3rd law (see §II.B.4. of these notes).

Day of the Week	**Deity Name**	**Latin Name**	**Meaning**
Sunday	Sun (English)	dies solis	day of the Sun
Monday	Moon (English)	dies lunae	day of the Moon
Tuesday	Tiu (Teutonic)	dies Martis	day of Mars
Wednesday	Woden (Norse)	dies Merculi	day of Mercury
Thursday	Thor (Norse)	dies Jovis	day of Jupiter
Friday	Frigg (Norse)	dies Veneris	day of Venus
Saturday	Saturni (Latin)	dies Saturni	day of Saturn

6. The Year and Calendar.

a) We have already discussed the different systems of time. From this, we can introduce different types of *years*:

i) **Sidereal year**: One complete revolution of the Earth about the Sun with respect to the stars. The length of this year is 365.2564 mean solar days ($365^d\ 6^h\ 9^m\ 10^s$).

ii) **Tropical year**: One complete revolution of the Earth about the Sun with respect to the vernal equinox. The length of this year is 365.2422 mean solar days ($365^d\ 5^h\ 48^m\ 46^s$). The vernal equinox precesses about 50 arcseconds (or $20^m\ 24^s$ of time) westward along the ecliptic each year (see below), which accounts for the difference between this and the sidereal year.

iii) **Anomalistic year**: One complete revolution of the Earth about the Sun with respect to the Earth's perihelion (*i.e.*, closest approach to the Sun, see §III.B.4.) position in its orbit. The length of this year is 365.2596 mean solar days ($365^d\ 6^h\ 13^m\ 53^s$). The perihelion position moves due to gravitational perturbations of the other planets, particularly from Venus and Jupiter.

b) Today, there are two conventional ways to keep track of the passage of time.

i) The **Gregorian calendar**, which attempts to approximate the year of seasons (the tropical year), consists of 365 days per common year and 366 days in years divisible by four (leap years). To achieve accuracy of one day over 20,000 years:

- Century years (those ending in '00') remain common years (365 per year) — for instance, 1900 A.D. was a common year.

- However, those century years divisible by 400 remain leap years — for instance, 2000 A.D. was a leap year.

- Finally, those century years divisible by 4000 remain common (*e.g.*, 8000 A.D.).

ii) In astronomy, the more convenient, linear, **Julian Day** (JD) system is used. Days, and fractions thereof, are counted continuously from noon UT on January 1, 4713 B.C. Hence, at 6 p.m. UT on 22 March 2001, we have JD 2,451,991.25.

7. Precession.

a) As stated in §II.B.1.a), the Earth's axis is tilted 23.5° with respect to the plane of its orbit and its north pole points off in the direction close to the star Polaris (*i.e.*, the *north star*).

b) The Earth's axis wobbles due to gravitational perturbations from the Moon and Sun. The Earth's axis completes one *wobble* in approximately 26,000 years! This wobble is called **precession**.

c) This wobble also causes the vernal equinox to move along the ecliptic by 50 arcseconds per year (or $50'' \cos 23.5^\circ \approx 46''$ per year along the celestial equator).

i) This effect is known as **precession of the equinoxes**.

ii) Since right ascension (RA) is measured from the vernal equinox, this means that a star's coordinates are constantly changing over time. Star positions are typically given for 1 January 2000. An astronomer must make precessional shifts in a star's coordinates in order to properly find it with a telescope.

d) Because of the Earth's precession, Polaris will not always be the *north star*. Indeed, when astrology was first invented, the star Thuban in the constellation of Draco was the so-called *north star*. Twelve thousand years from now, the bright star Vega will be close to the NCP.

e) Much of the time during a precession cycle, there are no bright stars near the NCP $\Longrightarrow$ there are no *north stars* at these times. This also is true with the SCP — currently there is no *south star*.

f) The fact that astrology doesn't take precession into account is one of the main reasons why it cannot be valid!