CHAPTER 9

The Stellar Universe

A. Introduction

Without a telescope, the information that can be learned about the stars is very limited. With just the eye one may only determine:

1. The positions of the stars relative to one another (make a star chart or map of the sky)
2. The relative brigntnesses of the stars
3. The colors of the stars
4. Possibly the motions of stars (proper motion). The latter would require comparing star charts made at epochs separated by at least several hundred years. This was not done until the 18th century AD.

With a telescope of sufficiently large size, one may determine:

1. The distances of the stars
2. A relative scale of absolute brightness
3. The positions of many fainter stars and thereby, study the distribution of stars in space around the Sun. This would lead to the existence of Our Galaxy as well as others.
4. By adding photometers and spectroscopes to a telescope it becomes possible to determine various physical properties of the stars, such as:

    a. temperatures
    b. sizes (radii)
    c. chemical composition
    d. masses
    e. speed in radial direction (along line of sight)
    f. rate of rotation
    g. age
    h. magnetic field

As a result of such studies, we now know that stars are hot, self-luminous, entirely gaseous bodies that generate energy through thermonuclear fusion (TNF) reactions of various kinds, and are composed of mostly of H and He. This is to be contrasted with the Earth which contains very little He and is composed mainly of O, Si, Al, and Mg.

B. Constellations

A constellation is a visual grouping of stars that forms a pattern. There is no physical connection among the stars of a constellation and the stars are usually at vastly different distances. The just happen to be nearly along the same line of sight.

1. Today, there are 88 internationally recognized constellations covering the entire sky.

2. Forty-eight of these constellations originate from the ancient peoples of the Mediterranean region, such as the Phoenicians. These original 48 constellations date back to about 2500 BC and are first described by the ancient Greek scholar Aratus, c. 270 BC.

3. The 48 original constellations are related to the mythologies of the Mediterranean Peoples. Twelve of these girdle the ecliptic and referred to as the zodiacal constellations.

4. Forty new constellations, covering mostly the southern sky, were added beginning with the 16th century. These constellations are not associated with mythology but mostly depict inventions or devices.

5. The original boundaries of the constellations were ill-defined with some stars belonging to more than one constellation. This confusion was eliminated In 1928, when the IAU established definite boundaries for each constellation.

6. Constellations are used by modern astronomers mainly for identifying stars. This is discussed below.

C. Stellar Nomenclature and Catalogs

The naming of stars was first done in pre-history. Some 50 bright stars have ancient names assigned by the Arabs, Phoenicians, and Greeks. Many of the names merely describe the position that a star marks in a constellation. For example, the star Betelgeuse has a name derived from Arabic meaning "the armpit of the giant." This was the only way of designating stars until the 17th century AD.

In 1603, Johann Bayer made stars chart whereon he identified stars by lower case Greek letters. These were assigned to the stars of a given constellation in order of apparent brightness. For example, the brightest star in a constellation was assigned the letter alpha, and the next brightest was designated beta, and so on. For example, the star Betelgeuse, which is the brightest star in the constellation Orion is referred to as Alpha Orionis. Orionis is the Latin genitive case of the constellation name Orion. Latin letters were used after the end of the Greek alphabet.

In the 18th century, the astronomer royal of Great Britain, John Flamsteed, made a catalog , “Historia Coelestis”, which assigns numbers to the stars in a constellation sequentially by right ascension. That is, the western most star of a constellation is designated 1 followed by the latin genitive of the constellation, e.g. 1 Geminorum, which is abbreviated 1 Gem.

The BD (Bonner Durchmusterung) Catalog was an 1859-1862 undertaking of Argelander and his assistants at the Bonn Observatory in Germany. Charts were published in 1898. In the BD catalog, stars are designated by numbers according to right ascension in 1^o bands of declination around the sky. An example of a desingation in the BD catalog would be: BD+22^o5428.

The Henry Draper (HD) catalog was an early 20th century effort at the Harvard College Observatory to classify the spectra of about 225,000 thousand stars. In the catalog, stars were assigned a number according to right ascension. E.G., the star HD159176 has a right ascension of $17^h 28^m$.

The Variable Star Catalog: Argelander introduced the plan of designating variable stars with upper case Latin letters, if a star had no Bayer letter for a given constellation. For each constellation, a letter is assigned in order of discovery beginning with R, S, T,….Z; then RR, RS, …; SS, ST….SZ and so on until ZZ is reached. Subsequent variables are lettered AA, AB, …Az; BB…..BZ, etc. The letter J is not used. By the time QZ is reached, 334 variable stars have been designated in a constellation. Following this would be V335, V336, etc.

The above designations are the primary ways that astronomers refer to the stars. There are a few other catalog designations that are of minor significance.

D. The Aberration of Starlight

As far back as 350 BC, Aristotle concluded that nearby stars would appear to suffer parallaxes or angular displacements in their positions in the sky as a result of any orbital motion the Earth would have. Such displacements could not be measured because of the enormous distances of even the nearest stars to the Sun, until 1837. Not knowing the actual distances of any stars, many observers tried to detect such parallaxes but failed. Up until 1727, there had been no direct detection of the Earth's motion. However, in attempt to measure such a parallax, Bradley, discovered the aberration of starlight, which is caused by the orbital motion of the Earth.

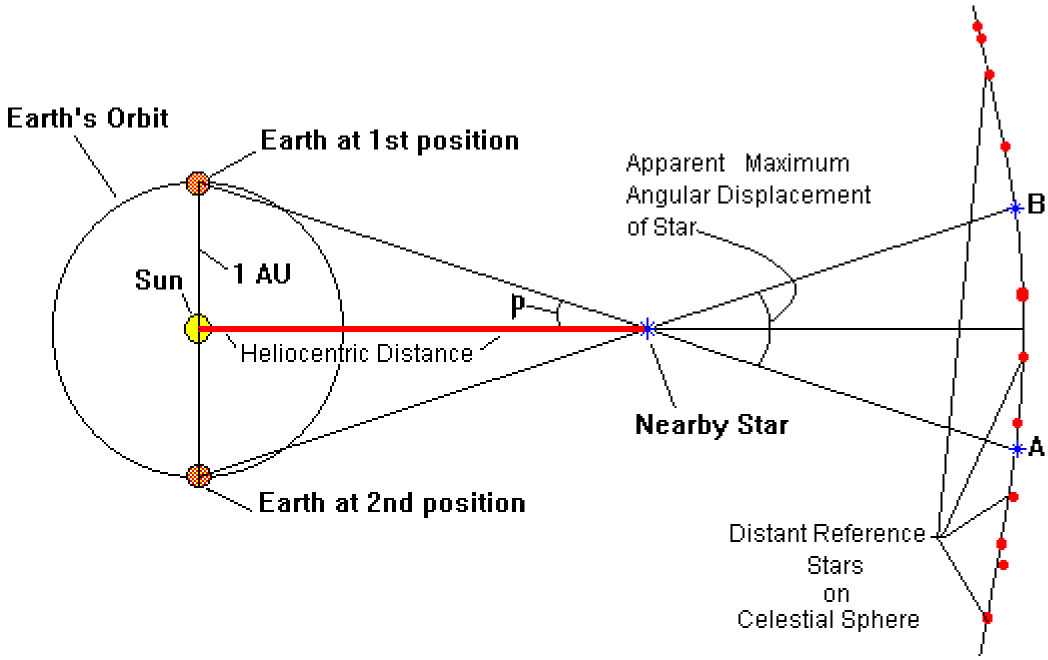
Definition: The apparent angular displacement of a star in the direction of the Earth's motion.

The effect is analogous to running in the rain with an umbrella. The latter must be tilted in the direction of motion to avoid getting wet.

The maximum amount of this displacement is 20.5 arcseconds, which is much larger than any parallax. For a star located at the north ecliptic pole (ecliptic latitude, β, equal to 90^o), the star would appear to move in a circle with a radius of 20.5 arcsecs about the NEP in one year. This is called the aberration orbit. For any other value of β, the orbit would be an ellipse. See Z&G, page 43 for more details.

E. Stellar Parallax And Distance

The idea of detecting the revolution of the Earth in its orbit around the Sun by measuring the parallactic displacements that would result for the nearby stars goes back to Aristotle's time, around 350 BC. However, these were never detected because the parallax of even the closest star is too small to be measured without a telescope. It took until 1837 A.D for the first parallax to be successfully measured. This was done independently by Bessel in Germany and Struve in Russia. The geometry for determining the parallaxes of the stars, and, thereby, calculating their distances is illustrated in the diagram below. In this diagram, the size of the Earth's orbit relative to the distance of the nearby star is greatly exaggerated for clarity.



As the Earth moves in orbit around the Sun, a nearby star appears to change its position on the celestial sphere with respect to much more distant stars. Very distant stars have negligible parallactic displacements and, therefore, serve as reference points for measuring the changing position of the star whose parallax we want to determine. When the Earth is at the 1st position in its orbit, the nearby star is seen on the celestial sphere at position A. Six months later, when the Earth has moved to the second position, the nearby star now is seen to be at position B on the celestial sphere. For any other position of the Earth in its orbit, the nearby star would be seen to have a position somewhere between these two extreme positions. Hence, in six months a star suffers its maximum angular displacement in the sky as a result of the Earth's revolution. Half of this angle is the parallax, p.

In the above diagram, the parallactic triangle consists of the radius of the Earth's orbit, the heliocentric distance of the star, and the angle p. Since this is a right triangle, once p is measured, the heliocentric distance of the star can be calculated. Even for the closest neighboring stars of the Sun, the heliocentric distances are at least 200 thousand times greater than the radius of the Earth's orbit. Hence, their parallaxes are very small fractions of a degree.

In general, the more distant the star, the smaller its parallax.

Astronomers prefer to express stellar distances in parsecs (pc), where:

1 parsec corresponds to a heliocentric distance in a parallactic triangle with p equal to 1 arcsecond.

If we use the equation from section I to calculate the distance of a hypothetical star that displays a parallax this large, we get: D=B/tan p, where B, the base of the parallactic triangle, is equal to 1 au (see the diagram above) and the tangent of 1 arcsecond, or 0.000278 degrees,

is 4.8×10^{-6}. Hence, if we divide 1 au by 4.8 x 10-6, we get that D=206,265 au. This means that

1 parsec must be 206,265 au or 3.26 light years.

But remember: There is no star this close to the Sun and even Alpha Centauri is more than 1 pc away. Hence, all stars have a parallax less than 1 arcsecond.

When we express the heliocentric distance D in parsecs and p is always expressed in arcseconds, then the equation D=B/tan p simplifies to

$$D=1/p.$$

For example, if a star were found to display a parallax of 0.25 arcseconds, its heliocentric distance would be D=1/0.25=4 parsecs.

The Sun 's nearest neighbor in space is the Alpha Centauri triple star-system. This system has a parallax of 0.750 arcseconds, which corresponds to a distance of approximately 4 light years. All other stars have parallaxes smaller than this.