Binary Star System- A Spectral Analysis

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(Received 3 February 2011; accepted 16 June 2011)

Abstract

A **binary star** is a star system consisting of two stars orbiting around their common center of mass. The brighter star is called the **primary** and the other is its **companion star**, **comes**, or **secondary**. Research between the early 1800s and today suggests that many stars are part of either binary star systems or star systems with more than two stars, called multiple star systems. The term double star may be used synonymously with binary star, but more generally, a double star may be either a binary star or an optical double star which consists of two stars with no physical connection but which appear close together in the sky as seen from the Earth. A double star may be determined to be optical if its components have sufficiently different proper motions or different radial velocities, or if parallax measurements reveal its two components to be at sufficiently different distances from the Earth. Most known double stars have not yet been determined to be either bound binary star systems or optical doubles.

Keywords: Binary Stars, Spectroscopic Binary, Astrometric Binary, Optical Doubles, Doppler Effect.

Resumen

Una estrella binaria es un sistema estelar compuesto por dos estrellas que orbitan alrededor de su centro de masa común. La estrella más brillante es llamada primaria y la otra es su estrella compañera, proviene, o secundaria. La investigación entre los años 1800 y hoy en día sugiere que muchas estrellas son parte de cualquiera de los sistemas de estrellas binarias o sistemas estelares con más de dos estrellas, llamados sistemas de estrellas múltiples. El término estrella doble puede emplearse como sinónimo de estrella binaria, pero más en general, una estrella doble puede ser una estrella binaria o una estrella doble óptica que consiste de dos estrellas sin conexión física, pero que aparecen juntas en el cielo como se ve desde de la Tierra. Una estrella doble puede ser determinada a ser óptica, si sus componentes tienen movimientos propios suficientemente diferentes o velocidades radiales diferentes, o si las mediciones de paralaje revelan sus dos componentes que se van a una distancia lo suficientemente diferente de la Tierra. La mayoría de las estrellas dobles conocidas no tiene que ser determinadas u obligadas a ser un sistema de estrellas binarias u ópticas dobles.

Palabras clave: Estrellas Binarias, Espectroscópicas Binarias, Astrométricas Binarias, Ópticas Dobles, Efecto Doppler.

PACS: 97.80.-d, 07.57.Kp **ISSN 1870-9095**

I. INTRODUCTION

A binary star, often called a double star, is a star system in which two stars linked by their mutual gravity orbit around a central point of mass. Binary stars are quite common. A recent survey of 123 nearby Sun-like stars showed that 57 percent had one or more companions. English astronomer William Herschel (1738–1822) made the first discovery of a true binary system in the 1700s. He observed the motion of a pair of stars and concluded that they were in orbit around each other. Herschel's discovery provided the first evidence that gravity exists out-side our solar system. Herschel discovered more than 800 double stars. He called these star systems binary stars. His son, John Herschel (1792–1871), continued the search for binaries and catalogued over 10,000 systems of two or more stars [1]. Binary system in which only one star can be seen, but the wobble of its orbit indicates the existence of another star in orbit around it.

Binary system in which the plane of the binary's orbit is nearly edgewise to our line of sight, so that each star is partially of totally hidden by the other as they revolve around a common point of gravity. The quantity of matter in the star as shown by its gravitational pull on another object. Energy in the form of waves or particles. A binary system that appears as one star producing two different light spectra. Range of individual wavelengths of radiation produced when light is broken down by the process related to spectroscopy.

Several kinds of binary stars [2] exist. A visual binary is a pair in which each star can be seen directly, either through a telescope or with the naked eye. In an astrometric binary, only one star can be seen, but the wobble of its orbit indicates the existence of another star in orbit around it. An eclipsing binary is a system in which the plane of the orbit of binary is nearly edgewise to our line of sight. Thus each star is partially or totally hidden by the other as they revolve. Sometimes a binary system can be detected only by using a spectroscope (a device for breaking light into its component frequencies). If a single star gives two different spectra (range of individual wavelengths of radiation), it is actually a pair of stars called a *spectroscopic binary.*

A binary star may be a member of one or more of these classes. For example, an eclipsing binary may also be a spectroscopic binary if it is bright enough so that its light spectrum can be photographed. The only accurate way to determine a star's mass is by studying its gravitational effect on another object. Binary stars have proven invaluable for this purpose. The masses of two stars in a binary system can be determined from the size of their orbit and the length of time it takes them to revolve around each other.

In many cases a binary system is too far away, or the stars are too close, or one star is so much brighter than the other that we cannot distinguish the two stars visually. In that case we may still infer that the system is binary by several indirect methods. One such method is to detect the presence of an unseen companion by its gravitational influence on the primary star. A binary discovered in this way is termed an *astrometric binary*.

II. MOTION AROUND THE CENTER OF MASS

The orbits in a binary system are illustrated schematically in the following Fig. 1.

Consider the diagram shown to the right. We may define a point called the *center of mass*[2] between two objects through the equations

$$m_1\vec{r}_1 = m_2\vec{r}_2\,, \tag{1}$$

$$\vec{r}_1 + \vec{r}_2 = \vec{R}\,, \tag{2}$$

where $\vec{R}$ is the total separation between the centers of the two objects.

This requires that Kepler's 3rd law be modified to read,

$$T^2 \propto (r_1 + r_2)^3\,,$$

or

$$T^2 \propto R^3\,. \tag{3}$$

(The equation in this form is only valid if the orbits are approximately circular; for more elliptical orbits a somewhat more complicated equation must be used.) Because the two stars revolve around the common center of mass, even if we cannot see one of them we may still infer its presence by observing the motion of the star that we can see around a center of mass between the two stars.

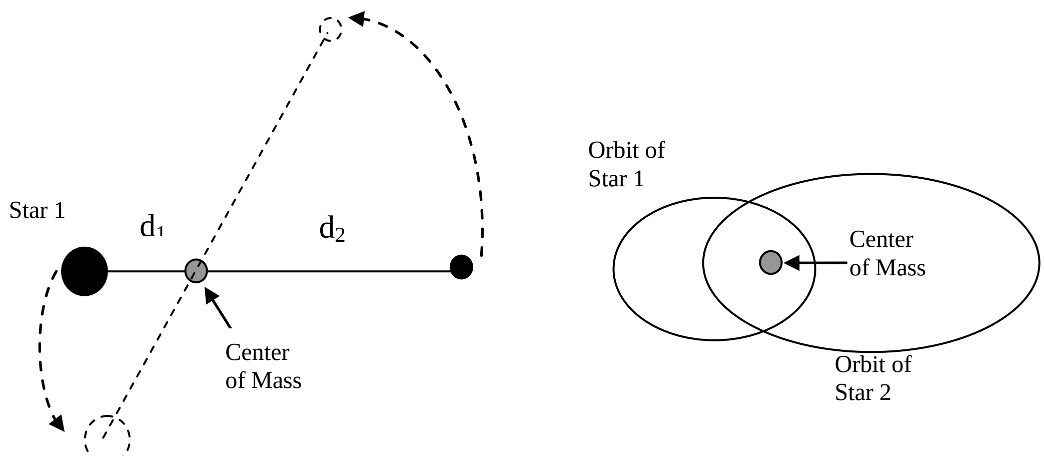

FIGURE 1. Orbits for binary star systems.

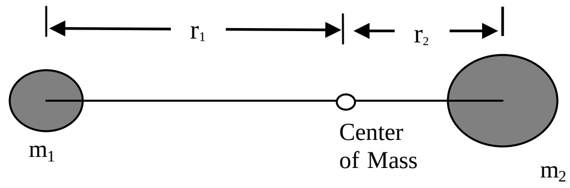

FIGURE 2. Wobbling Motion on the Celestial Sphere.

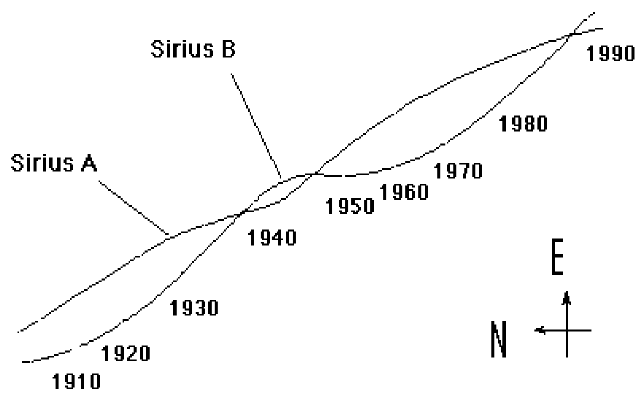

FIGURE 3. Wobbling motion of Sirius caused by companion star.

The combination of the motion around the center of mass and the proper motion on the celestial sphere gives rise to a wobbling motion on the celestial sphere, as illustrated in figure 3 for the Sirius System.

Notice that even if we could not see Sirius B, the wobbling path of Sirius A would be a clear sign of the presence of the unseen companion. In fact, Sirius B was discovered first as an astrometric [3] binary in this way, and only later were telescopes sufficiently good to pick out the faint companion in the glare of the primary star. Thus Sirius was originally an astrometric binary, but is now a visual binary.

III. DETERMINATION OF MASSES

From the three Equations. 1, 2 & 3 quoted above, it is possible to determine the masses in binary star systems if sufficient information can be obtained from observations. From these equations, we conclude that

1. If the period T and the total separation R between the stars can be determined, the sum of the masses of the two stars can be calculated.
2. If in addition the individual separations r_1 and r_2 can also be measured, the masses of each of the stars can be determined.

We shall discuss this more quantitatively below. Such methods are extremely important, because they are one of the only ways that we can reliably determine the masses of stars.

The second is the issue of whether in binary star systems there are planetary orbits that are (a) stable, and (b) conducive to the evolution of life [4].

We have already seen that even if both stars cannot be seen in a binary system we may be able to infer the presence of an unseen companion by its gravitational influence on the motion of the primary star. There is a second important method that allows us to infer that a system is binary, even if we cannot see that visually, provided we can collect enough light from the system to observe its spectrum.

IV. DOPPLER SHIFT FOR BINARY STARS

Consider the following image of an idealized binary star system where the two stars have equal masses and are in circular orbits. We further idealize the situation by assuming that each star has a single spectral line at the same frequency when the stars are at rest.

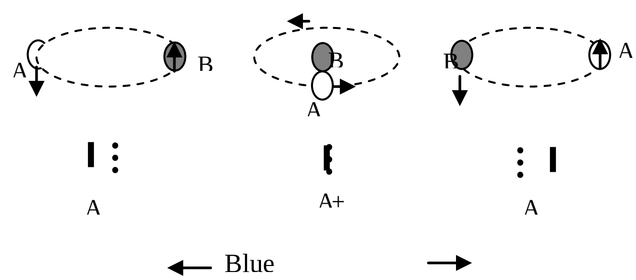

FIGURE 4. A Double-Line Spectroscopic Binary.

Because of the motion of the two stars around their common center of mass, each star is alternatively moving toward the observer and then away. But because of the Doppler effect [5], this means that the spectral lines will periodically be shifted up and down in wavelength, and that for the two stars this shift will be in the opposite direction: when star A is moving toward us, star B is moving away from us, and vice versa.

V. SPECTROSCOPIC BINARIES

Thus, if we consider an idealized situation where each star has a single spectral line at the same frequency when the stars are at rest, we get the situation in the adjacent animation. The spectral lines shift up and down periodically, and out of phase. This is a clear sign that there are two stars present in the system. If we cannot see them, but conclude that there are two stars because of these effects in the spectrum, we say that this is a *spectroscopic binary* [6]. Actually, most stars that are classified as binaries are not visual binaries, but instead it has been deduced that they are binaries from the spectrum. Thus, they are spectroscopic binaries.

VI. DOUBLE-LINE SPECTROSCOPIC BINARIES

The following figure illustrates a portion of an actual spectrum for a spectroscopic binary. The curves [7] represent light intensity, so the dips correspond to dark regions of the spectrum or absorption lines.

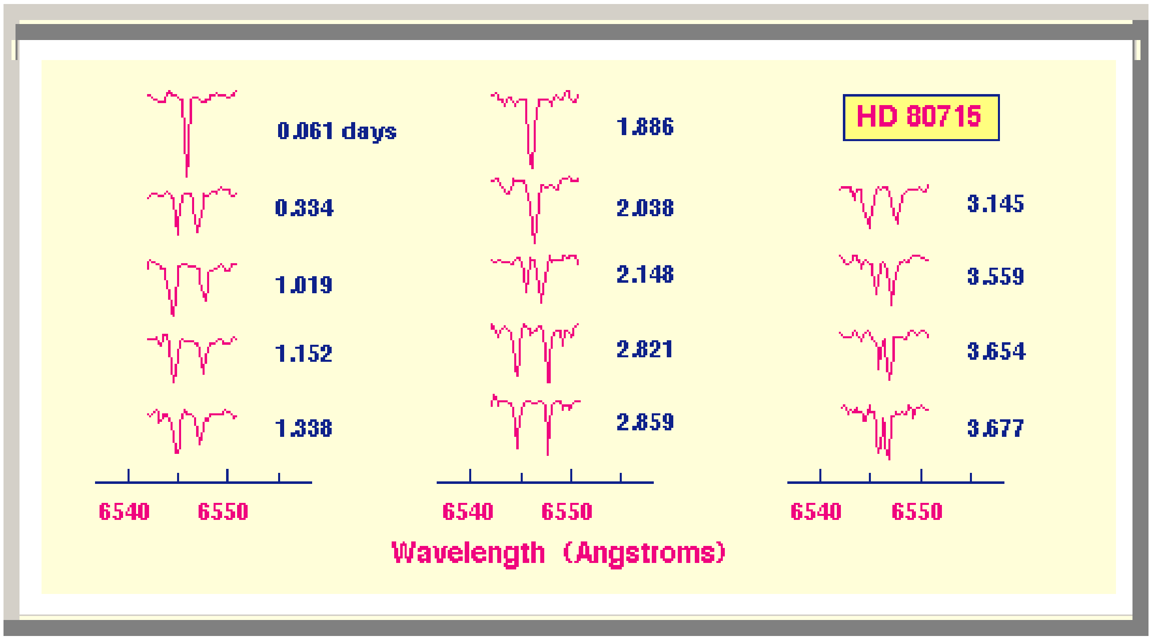

FIGURE 5. Spectral lines in a Spectroscopic Binary.

In this segment of the spectrum we see that the spectral line periodically doubles and then merges into a single line, indicating the presence of two stars giving opposite Doppler shifts [8]. In the more realistic case there will be a whole set of spectral lines in each star, and they will shift up and down out of phase. The situation illustrated here, where lines from both stars are seen in the spectrum, is called a *double-line spectroscopic binary* [9].

VII. SINGLE-LINE SPECTROSCOPIC BINARIES

In many cases the spectral lines from one of the stars in a spectroscopic binary are much stronger than those from the other star. In the most extreme case, the spectral lines from only one of the stars may be visible. Even in that case, it may be possible to infer that the system is a spectroscopic binary because the single set of lines will still shift up and down periodically in frequency (imagine deleting the line associated with star B in the above animation and note the motion of the remaining line associated with star A). A spectroscopic binary in which only the lines from one of the stars can be seen is called a *single-line spectroscopic binary* [10].

VIII. VELOCITY CURVES FOR SPECTROSCOPIC BINARIES

In the adjacent image the velocity curve for a spectroscopic binary is illustrated in Fig. 6. The corresponding positions on the orbits for two components are labeled with numbers correlated with diagrams shown below the graph, assuming the observer to be to the right.

Motion toward the observer gives a blue shift [10] (negative velocity) while motion away from the observer gives a red shift (positive velocity) [11]. For example, at position 1 the red star has maximal velocity away from the observer and the blue star has maximal velocity toward the observer, while at position 2 the radial velocity of each star relative to the observer is zero.

It is estimated that approximately 1/3 of the star systems [12] in the Milky Way are binary or multiple, with the remaining 2/3 consisting of single stars.

There is a direct correlation between the period of revolution of a binary star and the eccentricity of its orbit, with systems of short period having smaller eccentricity. Binary stars may be found with any conceivable separation, from pairs orbiting so closely that they are practically in contact with each other, to pairs so distantly separated that their connection is indicated only by their common proper motion through space. Among gravitationally bound binary star systems, there exists a so called log normal distribution of periods, with the majority of these systems orbiting with a period of about 100 years. This is supporting evidence for the theory that binary systems are formed during star formation.

In pairs where the two stars are of equal brightness, they are also of the same spectral type. In systems where the bright nesses are different, the fainter star is bluer if the brighter star is a giant star and redder if the brighter star belongs to the main sequence.

The mass of a star can be directly determined only from its gravitational attraction [13]. Apart from the Sun and stars which act as gravitational lenses, this can be done only in binary and multiple star systems, making the binary stars an important class of stars. In the case of a visual binary star, after the orbit and the stellar parallax of the system has been determined, the combined mass of the two stars may be obtained by a direct application of the Keplerian harmonic law. Unfortunately, it is impossible to obtain the complete orbit of a spectroscopic binary unless it is also a visual or an eclipsing binary, so from these objects only a determination of the joint product of mass and the sine of the angle of inclination relative to the line of sight is possible. In the case of eclipsing binaries which are also spectroscopic binaries, it is possible to find a complete solution for the specifications [14] (mass, density, size, luminosity, and approximate shape) of both members of the system.

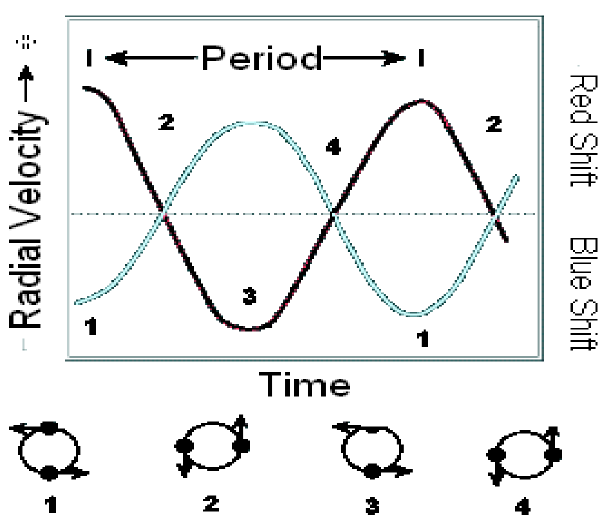

FIGURE 6. Velocity Curves for Spectroscopic Binaries.

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