ISSN 2959-6157

The Possible Factors that Influence the Stability of Binary Star System

Luxinming Yin

Fountain Valley School, Colorado Springs, CO 80911, The United States
lyin27@fvs.edu

Abstract:

Binary star systems are a crucial subject in astrophysics, as they provide insights into stellar formation, evolution, and dynamics. Despite extensive research, there remains a gap in understanding the factors influencing the long-term stability of such systems. This paper discusses the factors that may affect the stability of binary star systems by analyzing and exploring the physical laws and formulas of the operation of binary star systems and using the operation data of specific binary star systems as evidence. It can be concluded that the factors affecting the stability of a binary star system may be as follows: 1. Mass ratio of two stars, 2. Stellar spacing, 3. Orbital eccentricity, 4. Influence of stellar evolution stage, 5. The influence of external bodies. Future research should further explore the combined effects of these factors in more complex systems to better understand binary star stability in various astrophysical environments. Additionally, understanding how these factors interact in multi-body systems could provide deeper insights into the evolution of complex stellar systems.

Keywords: Binary Star System, Orbital dynamics, Stellar evolution.

1. Introduction

As humans gaze at the night sky, the “stars” that gleam with intensity are predominantly stellar objects. Stars are huge spheres or globular celestial bodies composed of hot gas in the universe, which continuously release light and heat to the outside world through their own nuclear fusion reactions. Stars are mainly made of light elements such as hydrogen and helium, which release huge amounts of energy through nuclear fusion reactions, making stars some of the most dazzling objects in the universe. Stars not only shine brightly in the night sky but also provide a source of energy for many important phenomena and processes in the universe, such as, by transforming gas into stars, star formation reflects the structure and evolution of galaxies [1]. Therefore, stars are not only one of the important celestial bodies in the universe but also an important window for human understanding of the mysteries of the universe.

Mankind’s longing for the universe has never stopped since ancient times. From the simple observation of looking up at the stars in ancient times to the in-depth study of complex celestial systems by astronomers today, the pace of scientific exploration has been moving forward. Among them, as a unique and common celestial phenomenon, binary star system has been widely concerned. Binary star systems, in which two stars gravitationally move around their common center of mass, are a very common phenomenon in the universe. Studying binary star systems not only helps physicists to understand the formation and evolution of stars but also provides indispensable and important information for revealing the evolution history of the galaxy and even the entire universe. Through the in-depth study of binary star systems, astronomers have revealed a variety of possible ways of star formation, such as gravitational capture, mutual perturbation, mass transport, and accretion, which provide important clues to human’s understanding of the evolution of stars and galaxies [2].

The interaction and evolution of two stars in a binary system can produce some unique and complex astronomical phenomena. Even in a separate system, it is still possible for stars to have tidal interactions. When a binary star tends to equilibrium with the least energy, tides can synchronize the spin of the star with its orbit and round out the eccentric orbit [3]. As a result of this interaction, the member stars of binary star systems often exhibit different characteristics from those of isolated star systems in terms of color, emission line intensity, infrared luminosity, and nuclear activity level.

This paper will rely on the observable data of binary star systems, combined with the existing astrophysical theories and formulas, to explore the various factors affecting the stability of binary star systems. These factors include the mass ratio of the star, the distance between the stars, the eccentricity of the orbit, the evolution stage of the star, and the influence of other external bodies. Through these discussions, this paper hopes to deeply understand the stability and evolution process of binary star systems, and provide theoretical support for further astrophysical research.

2. Formation and Basic Principles of Binary Star Systems

Binary star systems can form in a variety of ways, the most common being the simultaneous birth of a star in a giant molecular cloud or the formation of a system through gravitational capture between stars. Collisions between stable molecular cloud clumps create dense layers of shock waves that radiate cool and break apart under gravity. The resulting debris then coalesced to form a protostellar disk, where they fell together at the same time, trapping each other to form a binary star system due to tidal and viscous interactions [4]. In such a system, two stars move in a uniform circle around their common center of mass, and it is the gravitational force between the stars that provides the centripetal force required for this motion. According to the law of universal gravitation, the magnitude of the centripetal force can be expressed as:

$$F = G\frac{Mm}{r^2} \tag{1}$$

where G is the gravitational constant, M and m are the masses of the two stars respectively, and r is the distance between them. Two stars move in a uniform circle around their common center of mass, which means that their orbital period and angular velocity are equal, and their orbital radius satisfy the relation R1 + R2 = r, that is, the sum of the orbital radius of the two stars is equal to the distance between them.

In this process, the mass and distance of the star have a crucial effect on the stability of the binary system. The greater the mass, the stronger the attraction and the more stable the system; The closer the distance, the stronger the gravitational effect, the shorter the orbital period of the system, and the more stable. On the contrary, the farther the distance is, the gravitational effect is weakened, the orbital period of the system is extended, and the stability of the system is also reduced. These basic principles provide a theoretical basis for understanding the stability of binary star systems.

3. Stability Factors of Binary Star Systems

3.1 Mass Ratio of Two Stars

The stability of a binary system is first affected by the mass ratio of the two stars. According to the gravity formula (1) and the binary system centroid formula:

$$M \times D = m \times d \tag{2}$$

Where M and m refer to the masses of two stars respectively, and D refers to the distance from the centroid of the star with mass M, d refers to the distance from the centroid of the star with mass m. It can be seen that the closer the mass ratio of two stars is to 1, the higher the stability of the system. This is because the gravity between the two stars is more balanced than when the mass is close to 1, the center of mass is closer to the center of the system, and the orbit of the system is more stable. When the mass ratio deviates from 1, the stability of the system will decrease. Because in this case, the gravitational difference between the two stars is large, the center of mass will be tilted to the side of the more massive star, resulting in the orbit of the system susceptible to perturbations by external factors. It can be seen that mass ratio is one of the important factors affecting the stability of the binary star system.

3.2 Stellar Spacing

The distance between the two stars is also an important factor in determining the stability of a binary system. According to the law of gravity, the closer two stars are to each other, the stronger the gravitational interaction between them, and the higher the stability of the system. This is because when the stars are closer together, the gravitational effect is strengthened and the orbital period of the system is shortened, making the system less susceptible to outside interference. On the contrary, when the distance between the stars is far, the gravitational effect is weakened, the orbital period of the system is prolonged, the stability of the system is reduced, and the system is vulnerable to external interference. It can use an example to explain the effect of the distance between stars on their stability. For a wide variety of initial semi-major axes and formation times, the scientists found that the quantity density exhibits a minimum at several times the Jacobian radius rJ, equal to 1.7 pc for a binary star with a solar mass. The outer density, which peaks at about 100-300pc separation, is produced by the slow separation of the previously combined binary stars. The outer peaks produce significant long-range correlations in the positions and velocities of disk stars.[5] Therefore, the distance between the stars is another key factor affecting the stability of binary systems.

3.3 Orbital Eccentricity

Orbital eccentricity is an important parameter to describe the orbital shape of two stars in a binary system, which determines the variation of distance and velocity between the stars. Eccentricity ranges from 0 to 1, and the closer the value is to 0, the closer the orbit is to a circle; The closer the value is to 1, the closer the orbit is to the ellipse.

When the eccentricity is close to 0, the stability of the system is higher, because the distance between the two stars changes less, the speed changes are more stable, and the system is closer to uniform circular motion. Conversely, when the eccentricity increases, the stability of the system decreases, because the distance between the two stars varies greatly, the speed changes dramatically, and the system is susceptible to perturbations and tidal forces.

Orbital eccentricity not only affects the orbital stability of stars but also causes tidal effects. When two stars are close together, tidal forces trigger the flow of material on the star's surface, and may even cause mass loss and changes in the star's rotation rate. In addition, the radiation of gravitational waves is also an important phenomenon related to orbital eccentricity. When the two stars move in elliptical orbits, gravitational waves carry away the energy and angular momentum of the system, which affects the stability of the system.

3.4 Influence of Stellar Evolution Stage

The stability of binary systems is also affected by the stage of stellar evolution. The stellar evolution stage predicts how stars are formed, how their complex internal structure changes and how different evolution stages correspond to different physical and radiation characteristics of stars [6]. When the two stars in a binary system are at similar stages of evolution, the stability of the system is higher. This is because, at similar stages of evolution, the physical and radiation characteristics of the two stars are more similar, the system is more stable, and less mass transfer and accretion occur. When the two stars are in different evolutionary stages, the stability of the system will be reduced, because the physical and radiation characteristics of the stars are quite different at this time, and the system is prone to mass transfer and accretion, which will affect the dynamic balance of the system.

Mass transfer and accretion of stars are common physical processes in binary systems.

At a later stage of evolution, it may increase its mass by accreting material from another star, altering the mass distribution of the entire system. This process of mass redistribution may lead to changes in the stability of the system, and even lead to violent astronomical phenomena, such as the outbreak of new stars, supernovae, and so on. Therefore, the evolution stage of stars has a profound effect on the stability of binary star systems and is one of the important contents of the study of binary star systems.

3.5 The Influence of External Bodies

In addition to the internal factors of the binary system, the presence of external objects can also have an important effect on the stability of the system. If a binary system is surrounded by other objects, such as stars, planets, small bodies, or black holes, their gravitational effects may disturb the stability of the system. The extent of this gravitational interference depends on factors such as the mass, distance, and relative speed of the external object. Generally speaking, the less gravitational interference from external bodies, the higher the stability of binary systems. On the other hand, if the gravitational interference of external objects is large, the system may undergo orbital perturbations and even trigger star collisions or mergers in extreme cases.

The gravitational interference of external objects will not only affect the stability of the binary system, but also may cause the mass transfer and accretion phenomenon inside the system, and may even cause the merger of stars and the formation of new objects. For example, when a massive star is close to a binary system, its gravity may upset the original dynamic balance of the system, causing material transfer among the stars in the system, and possibly even triggering explosive astronomical phenomena. Therefore, the influence of external celestial bodies is also one of the important factors to study the stability of binary star systems.

4. Scientific Research and Discovery of Binary Star Systems

Since ancient times, human beings have been full of infinite reverie to the stars. From the "descendants of the sun" in ancient mythology, to the formation of stars and galaxies in modern scientific exploration, mankind has never stopped exploring the universe. Binary star systems, as one of the important fields of astronomical research, not only show the wonderful diversity of the universe but also provide important clues for human understanding of the origin and evolution of the universe.

The history of the study of binary star systems dates back to the early 17th century when astronomers first observed the existence of binary star systems using simple telescopes [7]. With the continuous progress of astronomical observation technology, people gradually realize that the binary star system is a very common phenomenon in the universe. By studying binary star systems, astronomers can better understand the formation and evolution of stars and reveal the complex interactions between stars.

In recent years, with the further improvement of observation technology, scientists have made many important discoveries in the study of binary star systems. In 2015, for example, astronomers discovered for the first time a complex five-body star system consisting of two pairs of binary stars and a single star. This discovery greatly enriches human knowledge of the diversity of star systems and provides a new perspective for understanding the evolution of galaxies. In addition, through the study of gravitational wave radiation in binary star systems, scientists were able to directly detect the energy release during the star merger process, providing key evidence for understanding the mechanism of gravitational wave generation in the universe.

Although many important advances have been made in the study of binary star systems, human's understanding of those distant binary systems is still very limited. With the continuous development of observation technology and computer simulation technology, Scientists are expected to make more breakthroughs in the study of binary star systems in the future, providing more evidence for the exploration of the origin and fate of the universe.

5. Conclusion

The study of binary star systems not only gives us a deeper understanding of the formation and evolution of stars but also provides important clues for exploring the evolution of the galaxy and even the entire universe. By studying the stability of binary systems and their evolution, it can be revealed that the complex interactions between stars provide new perspectives for understanding the structure and evolution of the universe.

The significance of the study of binary star systems is not limited to astronomy but also provides an important reference for scientists' understanding of other celestial systems in the universe. Through further study of binary star systems, revealing more secrets about the evolution of the universe and provide clearer answers to the nature and fate of the universe will be the trend.

In short, stars, binary star systems, and their related phenomena are not only objects of astronomical research but also important Windows to the understanding of the mysteries of the universe. Whether in theoretical research or through observation means, human exploration of the universe will continue to deepen.

References

[1] Girichidis, P., Offner, S. S., Kritsuk, A. G., Klessen, R. S., Hennebelle, P., Kruijssen, J. D. Physical processes in star formation. Space Science Reviews, 2020, 216: 1-67.

[2] Morbidelli, A. Accretion processes. arXiv preprint arXiv:1803.06708, 2018.

[3] Goupil, M. J., Zahn, J. P., Mazeh, T. Observational evidence for tidal interaction in close binary systems. European Astronomical Society Publications Series, 2008, 29: 1-65.

[4] Marov, M. The formation and evolution of the Solar System. Oxford Research Encyclopedia of Planetary Science, 2018.

[5] Jiang, Y. F., Tremaine, S. The evolution of wide binary stars. Monthly Notices of the Royal Astronomical Society, 2010, 401(2): 977-994.

[6] Prialnik, D. An introduction to the theory of stellar structure and evolution. Cambridge University Press, 2009.

[7] Binder, A. Binary Star Measurements with a 17th Century, Long-Focal, Non-Achromatic Refractor. Journal of Double Star Observations, 2010, 6(4): 280-292.