Comparison Of Different Analytical Models and Approaches of Star Formation

Zhuoyi Wu*

Department of Physics, University of Rochester, Rochester, US

* Corresponding Author Email: zwu47@u.rochester.edu

Abstract. Star formation is a hot topic in astrophysics and cosmology which have been studied and investigated for mean years. Since the importance of understanding stars is obvious as they are the fundamental component of the universe. With this in mind, the general process of the four-step star formation would be briefly introduced in this paper, followed by a discussion about more details and debate about the theory star formation. To be specific, this study will include the evidence of when the star is formed and grains in protostars' disks. The connection between various theories and the solar system would also be shown and demonstrated. The connection also reflects the significance of the research in low-mass star formation for understanding the solar system and the sun. In addition, the limitations of current theoretical analysis and models will be discussed and the future prospects will be proposed accordingly. Overall, these results shed light on guiding further exploration of star formation analysis.

Keywords: Star formation; Low-mass star, G-type star; Protostars; Solar system.

1. Introduction

In general, star formation is a vital aspect that many researchers in the field of astrophysics and cosmology dedicate their life studying. The reason why it is so important is because those stars are one of the most fundamental phenomena and influential components of the universe that determine how the galaxies are shaped and evolves. In addition, the sun is also related tightly to human beings. By its definition, it is a type of low-mass star (as a G-type star, the third small type of main sequence star). Understanding how low-mass stars are formed would indeed contribute to knowledge of star formations in our solar system and a better understanding of researchers about the details and background of the sun formation and its effect to us human beings [1-3].

The current mainstream opinion is that the general theories of low-mass star formation is based on the theory of star formation. To be specific, previous scholars illustrate the four steps of the formation of stars, which includes them generated from molecular clouds' slowly rotating cores and then transferred into a vital process, protostars (it is a young and relatively long stage of stars, hence young that stars are still attracting mass from molecular clouds in order to grow mass), which deserves further explanation [4-6].

Though with a relatively complete general theory of star formation, a considerable number of details about it are still for debate. Other scholars stated that several questions remained undetermined in this fields with different theories, which includes why hydrogen could be transformed into heavier matters naturally [6, 7]. It also introduces the different classifications of stars which matches different researchers' theories of star formation. In addition, other researches also emphasize their claim of beginning phase for the formation, i.e., before the stage of Class II protostars but in disks of Class 0 and Class I protostars [8]. To specifically discuss the formation of those stars with lower mass and its connection to the solar system, especially about the sun, scholar carried out simulations for star formation and the solar system. The paper focuses more specifically on how low-mass stars formation theories could inspire researchers to understand the formation of the solar system. Finally, remaining questions to be answered by future researchers are shown accordingly [9].

In this paper, the different theoretical models and approaches will be compared and discussed in this paper with discussions and debates of the observations based on the state-of-art facilities. The rest part of the paper is organized as follows. The Sec. 2 will give the basic concepts and descriptions

of the star formation and the observations results. The Sec. 3 will offer the debates of the models. Afterwards, the limitations of the current models and improvements suggestions will be given in Sec. 4. Eventually, a brief summary will be given in Sec. 5.

2. Basic Descriptions and Observations of Star Formation

First of all, a general process of star formation is summarized. The context of the paper is not only about low-mass star formation, but its conclusion is still important to be mentioned since it shows the general procedure, which also fixes the process of low-mass star formation, that an individual star must go through [9-11]. Some vital concepts in understanding star formation, which include the origins of stellar masses, bimodal star formation, the initial mass function, spontaneous and induced star formation, and characteristics of molecule clouds. They then discussed the process step by step, indicating that the process starts with the formation of condensed, slowly rotating cores of a molecular cloud, which then become unstable and collapse dynamically from "inside-out" (in-fall stage) and later transfer into protostars. After deuterium ignites in protostars' core, convection is likely to appear and promotes the star to create a stellar wind, which rushes the weaker parts and causes stellar jets and bipolar outflows. The stars thus go under the fourth stag, i.e., a T Tauri star with unstable nebular disks. Eventually, the disks disappear. For low-mass stars, such objects are called the naked T Tauri stars. Moreover, the process is more likely to be regarded as the pre-main-sequence evolution, since high-mass stars join the main sequence in the accretion phase before pre-main-sequence evolution is completed. A typict skech of the galaxy is given in Fig. 1.



Fig. 1 A diagram of the star.

Other scholar reveal the observations of the star formation in the ρ Ophiuchi cloud complex, which includes those related to low mass stars and massive cores in the molecular cloud. Using X-ray emission, infrared photometric surveys and spectroscopic surveys of L1688, they list over 300 The observations which include the full range of evolutionary states for young stellar objects. Their observations are live examples of the general theory of star formation, showing the correctness of it. A typical skech of the mechanims is illustrated in Fig. 2.

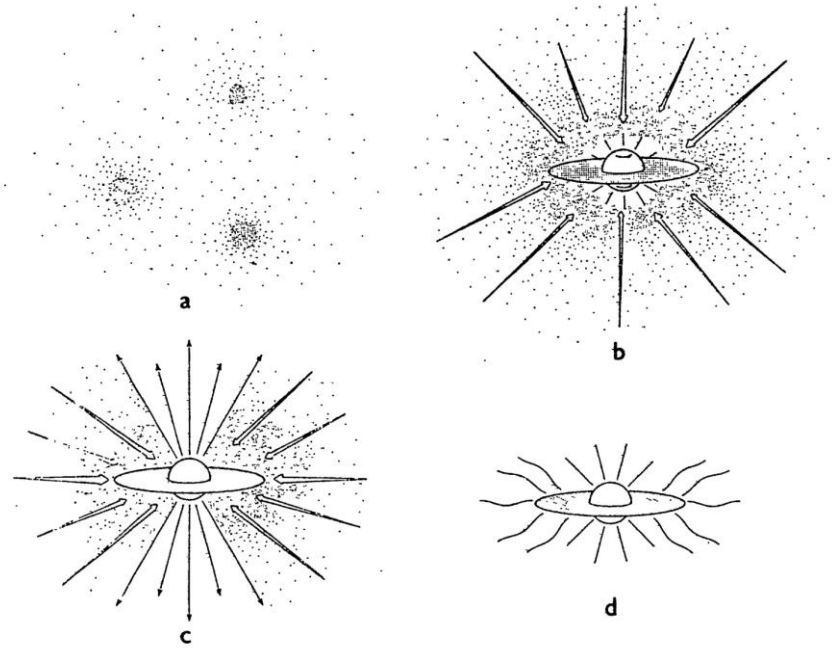


Fig. 2 A sketch of the star formation evolution.

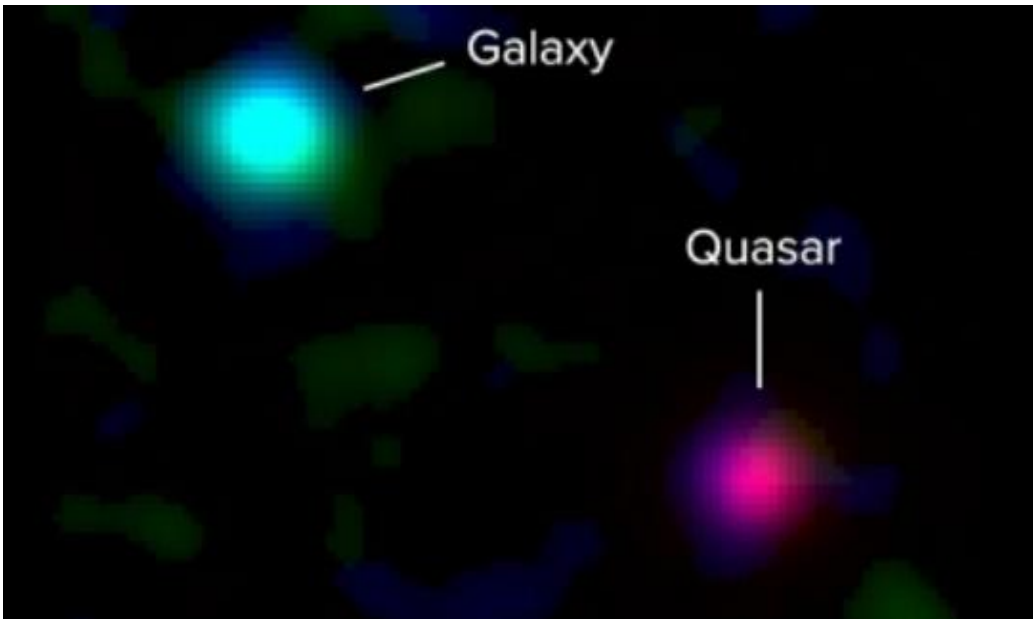


Fig. 3 An observation of star formation evolution.

The team, led by Professor Arthur M. Wolfe, has been studying distant galaxies in indirect ways since 1986, amassing a wealth of data. Their long planning and waiting have finally paid off, with exciting new data from ALMA by Wolf's last PhD student, Marcel Neeleman, giving us a more direct and deeper understanding of how galaxies form and evolve. The researchers used the Comprehensive Aperture radio telescope ALMA to collect electromagnetic waves at millimeter/submillimeter wavelengths invisible to the human eye. They focused on two sources of electromagnetic radiation from distant target galaxies: ionized carbon and warm dust, often found in the galactic core, where many stars are born [12, 13]. When the new data, collected directly, are combined with the old data, collected indirectly in the past, unexpected results emerge (seen in Fig. 3).

The ALMA data also uniquely revealed the internal motion of the galaxy's gas clouds. Analysis of the dynamics shows that the galaxy's gas cloud has formed a giant wheel, much like our own Milky Way, and is spinning at about 120 kilometers per second, which is consistent with some theoretical predictions about the formation of galaxies. The observations also detected thermal radiation from

the galaxy's "warm" dust (which is relatively warm, in this case, only about 30 degrees Celsius above absolute zero) [13].

There is reason to believe that the dust is being heated by young, large stars that have just formed. Estimates suggest that the galaxy is forming more than 100 stars a year, an alarming rate and a very active early growth process. ALMA has made outstanding contributions to the study of the early formation and development of galaxies. The high angular resolution and high sensitivity provided by the ALMA Large Integrated Aperture Radio Telescope make it possible to directly observe distant galaxies 12 billion light-years away.

Because radio telescopes operate at wavelengths many times larger than visible, the angular resolution of radio telescopes is, in general, much worse than that of optical telescopes. Increasing the diameter of the main mirror can improve the angular resolution of the radio telescope to a certain extent. However, making a huge main mirror is restricted by engineering technology. Even the angular resolution of the FAST single-antenna radio telescope with a diameter of 500 meters in Guizhou is not effective for the study of distant extragalanic galaxies [14]. The evolution dynamic diagram is shown in Fig. 4.

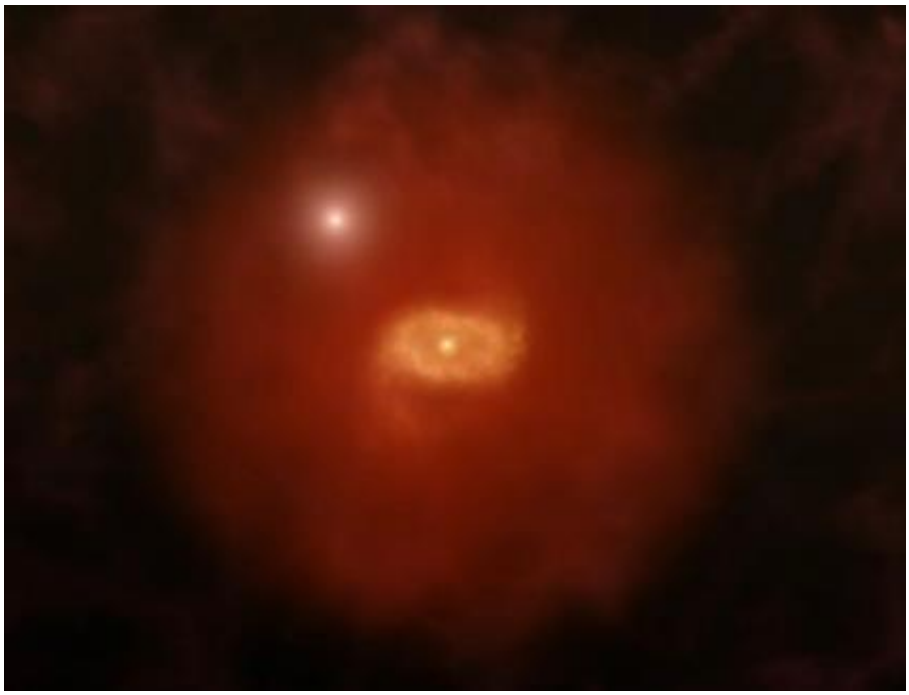


Fig. 4 An observation of star formation dynamic.

3. Debates of the Theory for Star Formation

Though the general theory of star formation gains consensus, details about it still arouse conflicts and theories that are not agreed up on. One of the controversial topics is about the protostars, which is a stage for cores formed in molecular clouds to transfer into stars. Some researches investiagte the grain growth during protostellar disc formation [15]. According to the analysis, it gives details about it, in which they show their simulations of the process of grains growing, accumulating, and colliding in the embedded protostar's disks. They give a full introduction to classes of protostars, which starts from Class 0 where protostars are mainly embedded in the surrounding envelope and later gain mass from the envelope to develop into protostars and protostellar disks. The disappearance of the disk symbolizes entering the Class III, where only the planet orbiting the star. They also mention that during the process of star formation, protostars' disks would become planets, which is a process researchers have no full comprehension. Their detailed summary of how protostellar disks are formed and disappear. Other scholars also demonstrate details about chemical evolution in the infalling envelope, where the protostars and their disks are formed. They mention that three main physical

origins for shocks (i.e., outflows, disk winds, and accretion shocks) and the shock tracers (i.e., the molecules SO and SO_2) [16].

4. Limitations & Prospects

Nevertheless, it should be noted that the nowadays results have some defects and drawbacks, which give strict limitations. In detail, observations and theories about star formation are limited, and lots of questions about star formation remain. For example, researchers indicate that the low efficiency of star-forming in molecular clouds and the ubiquity of outflows are controversial to the old theories of ultimate origin for the masses of forming stars [3], and there are still more things researchers do not know about details of the basic disk transport process. In addition, they have not yet found the answer to how stellar jets and bipolar flows are generated, which is a significant question in order to understand how stellar wind is influential in the process of star formation. Similarly, in "Star Formation in Normal Galaxies" which is mainly about how recent infrared observation has changed researcher's understandings of star formation in so-called normal galaxies, the authors propose questions researchers need to address, which include whether there is star formation in S0 galaxies and if star formation conditions in the center of spiral galaxies resemble those in the disks.

While the previous paper shows an overall picture of the formation of stars (mainly low-mass stars), star formation and the solar system reveals how theories of low-mass star formation are connected to our sun. Other scholars argue that they are easier to be observed and studied since the low-mass stars are likely to go through a longer period of their pre-main-sequence tracks. In addition, they more often have a less damaging effect on their surroundings, which reduce the difficulty of detection. Based on the X-ray and ultraviolet observations, researchers found that a considerable amount of T Tauri stars (a stage of star formation) could be simulated as a two-component model, which is also applied to the sun. The IRAS satellite observations offer more valuable information about a forming star with proto-planetary disks. In general, more technologies are helping researchers to know more about star formation, but still little dynamic information is obtained to form a better understanding of the formation of the solar system. It is believed that further explorations can be definitely achieved with the development of the techniques and theoretical analysis.

5. Conclusion

In summary, this study discusses several analytical and theoretical models for start formation. To be specific, in the above section, this study mainly discusses mainly interstellar grains (dust particles that are ubiquitous in galaxies) that may be discovered in the solar system. It is a valuable topic since grain-gas interactions are critical in star formation and play an important role in transporting materials that end up in planetary systems. Afterwards, later discussions in detail interstellar grains, including how the grain growth are demonstrated.

According to the analysis, low-mass star formation is a four-step process starting from molecular clous' rotating and forming a core. On account of the loss of magnetic fields' effect and turbulence, the core would collapse from inside-out and turn into a protostar. Arguably, the process starts from the disks of Class I and 0. Nevertheless, further accurate detections and data collection ought to be realized in order to obtain more precise results. In the future, it is believed that more researches will be carried out in this field with more advanced model. In addition, with the construction of the state-of-art facilities, it is confident to explore the truth of the star formation. Overall, these results offer a guideline for further exploration of star formation.

References

[1] Hayashi C, Nakazawa K, Nakagawa Y. Formation of the solar system. Protostars and planets II, 1985: 1100-1153.

[2] Pfalzner S, Davies M B, Gounelle M, et al. The formation of the solar system. Physica Scripta, 2015, 90(6): 068001.

[3] Adams F C, Fatuzzo M. A theory of the initial mass function for star formation in molecular clouds. The Astrophysical Journal, 1996, 464: 256.

[4] Basu S. Perspectives on Low-Mass Star Formation. arXiv preprint arXiv:1703.01542, 2017.

[5] Shu F H, Adams F C, Lizano S. Star formation in molecular clouds-Observation and theory. Annual review of astronomy and astrophysics, 1987, 25: 23-81.

[6] Klessen R S. Star formation in molecular clouds. EAS Publications Series, 2011, 51: 133-167.

[7] Dobbs C L, Krumholz M R, Ballesteros-Paredes J, et al. Formation of molecular clouds and global conditions for star formation. Protostars and Planets VI, 2014, 1312: 3-26.

[8] Fiorellino E, Tychoniec Ł, Manara C F, et al. The Relation between the Mass Accretion Rate and the Disk Mass in Class I Protostars. The Astrophysical Journal Letters, 2022, 937(1): L9.

[9] McKee C F, Ostriker E C. Theory of star formation. Annu. Rev. Astron. Astrophys., 2007, 45: 565-687.

[10] Schmidt M. The rate of star formation. The astrophysical journal, 1959, 129: 243.

[11] Larson R B. The physics of star formation. Reports on Progress in Physics, 2003, 66(10): 1651.

[12] Leauthaud A, Saito S, Hilbert S, et al. Lensing is low: cosmology, galaxy formation or new physics. Monthly Notices of the Royal Astronomical Society, 2017, 467(3): 3024-3047.

[13] Alam S, Zu Y, Peacock J A, et al. Cosmic web dependence of galaxy clustering and quenching in SDSS. Monthly Notices of the Royal Astronomical Society, 2019, 483(4): 4501-4517.

[14] Nan R, Li D, Jin C, et al. The five-hundred-meter aperture spherical radio telescope (FAST) project. International Journal of Modern Physics D, 2011, 20(06): 989-1024.

[15] Tu Y, Li Z Y, Lam K H. Grain growth during protostellar disc formation. Monthly Notices of the Royal Astronomical Society, 2022, 515(4): 4780-4796.

[16] de la Villarmois E A, Guzmán V V, Jørgensen J K, et al. Physical properties of accretion shocks toward the Class I protostellar system Oph-IRS 44. arXiv preprint arXiv:2209.02827, 2022.