


# Why Has the Controlled Thermonuclear Reaction Not Succeeded So Far?

Qiuhe Peng<sup>1</sup>, Jingjing Liu<sup>2\*</sup> 

<sup>1</sup>Department of Astronomy, Nanjing University, Nanjing, China

<sup>2</sup>College of Science, Hainan Tropical Ocean University, Sanya, China

Email: \*syjliu68@hntou.edu.cn

**How to cite this paper:** Peng, Q.H. and Liu, J.J. (2025) Why Has the Controlled Thermonuclear Reaction Not Succeeded So Far? *Journal of High Energy Physics, Gravitation and Cosmology*, 11, 932-937.  
<https://doi.org/10.4236/jhepgc.2025.113059>

**Received:** May 17, 2025

**Accepted:** July 18, 2025

**Published:** July 21, 2025

Copyright © 2025 by author(s) and Scientific Research Publishing Inc.  
This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).  
<http://creativecommons.org/licenses/by/4.0/>



Open Access

## Abstract

The global industrial crisis and energy issues are among the most pressing challenges facing the world today. With the acceleration of industrialization and the continuous growth of the global economy, energy demand has risen sharply, while excessive reliance on traditional fossil fuels has led to severe environmental problems and the risk of resource depletion. Therefore, promoting energy transition, reducing dependence on fossil fuels, and developing sustainable industrial models have become urgent tasks. This is not only crucial for current economic and social development but also for the survival and well-being of future generations. Nuclear energy, as a low-carbon energy source, plays an important role, and fusion reactions may become a significant form of energy supply. Research on controlled thermonuclear reactions will have profound implications for solving energy problems. Based on the new concept of excess entropy production in non-equilibrium thermodynamics, we have studied the thermonuclear fusion reactions and hydrogen burning stability inside the Sun and stars. The results indicate that a necessary condition for the stability of hydrogen-helium fusion reactions is that, at the beginning of the reaction, the content of helium (He) cannot be too low (with a mass content no less than 1/8 of the hydrogen (H) content). The findings we have obtained may hold significant importance for further research in contemporary controlled thermonuclear reactions.

## Keywords

Thermonuclear Reactions, PPI Reaction, Stellar Evolution

## 1. Introduction

Currently, global energy supply still heavily relies on fossil fuels such as coal, oil, and natural gas. These energy sources are limited in reserves and unevenly dis-

tributed, leading to geopolitical tensions and resource competition. The rapid development of emerging economies (e.g., China, India) and global population growth have driven continuous increases in energy demand. The International Energy Agency (IEA) predicts that global energy demand could rise by more than 50% by 2050. Fossil fuels are non-renewable resources, and their reserves are rapidly depleting. For instance, the peak oil theory suggests that global oil production may reach its peak and begin to decline within the next few decades. The industrial sector is the primary consumer of global energy, accounting for approximately 40% of total energy consumption. Energy-intensive industries (e.g., steel, chemicals, manufacturing) are particularly reliant on energy. Unstable energy supply can directly lead to disruptions in industrial production, thereby impacting the global economy. The large amounts of greenhouse gases (e.g., carbon dioxide) emitted during industrial processes are major causes of climate change, and the increasing frequency of extreme weather events further exacerbates the vulnerability of energy and industrial systems. The use of fossil fuels is the primary source of greenhouse gas emissions, and global warming-induced extreme weather, rising sea levels, and ecosystem collapse pose direct threats to human society. According to the Paris Agreement, the world needs to achieve carbon neutrality by the mid-21st century, but current efforts to reduce emissions fall far short. Geopolitical conflicts (e.g., the Russia-Ukraine war) and disruptions in energy supply chains have exposed the fragility of the global energy system. Many countries are overly dependent on imported energy, facing severe energy security challenges. Fluctuations in energy prices and supply shortages can trigger inflation, economic recession, and social instability. For example, rising energy prices increase production and living costs, exacerbating wealth inequality. All of this highlights how solving the energy crisis is a challenge and an important research topic for scientists. The energy issue is a global challenge that requires strengthened international cooperation to jointly promote energy transition and technological innovation. Accelerating the shift to renewable energy sources (e.g., solar, wind, hydro) is key to addressing the energy crisis. Technological advancements and cost reductions are continuously enhancing the competitiveness of renewable energy. Through technological innovation and policy guidance, improving the efficiency of industrial production and energy utilization can reduce energy waste. Nuclear energy, as a low-carbon energy source, can play a significant role during the transition phase, and fusion reactions may become an important form of energy supply. Research on controlled thermonuclear reactions in global industry will have profound implications for solving energy problems. Based on this, we have studied fusion reactions inside stars, and the results we obtained may hold significant importance for further research in contemporary controlled thermonuclear reactions.

In 1980, we started from the new idea of excess entropy production in non-equilibrium thermodynamics proposed by Belgian physicist Prof. Prigogine, who won the Nobel Prize [1], to judge whether a non-equilibrium thermodynamic sys-

tem is stable. In 1979, Prof. Hao Bolin, who is an academician of the famous Statistical Physics of the Institute of Theoretical Physics in China, invited Prof. Prigogine came to Beijing for giving lectures about his idea. In the early days of Deng Xiaoping's reform and opening up, I had completely got rid of almost ten years of political persecution. During the period from 1960 to 1965, I taught astrophysics at Peking University, and at the same time, I went to listen to the specialized courses of theoretical physics (later postgraduate courses) taught by the top professors of Peking University. I have learned the frontier knowledge of theoretical physics. So when I listened to the excess entropy production of non-equilibrium thermodynamics taught by Prigogine can be used to discuss the hidden problems of non-equilibrium thermodynamics in 1979, I am very excited to use this new concept to discuss the stability of  ${}^4\text{H}\rightarrow{}^4\text{He}$  fusion thermonuclear reaction in the sun, which has been studied very clearly in the world. In 1980, a paper was published in the *Acta Astronomica Sinica*. We discussed the stability study of stellar structure in nonequilibrium thermodynamics in detailed [2]. We subsequently published a series of papers on the stability of stellar structures in non-equilibrium thermodynamics [3]-[5].

## 2. Our Ideals and Discussions

This is the first paper on this issue in *Astronomy* on the stability of hydrogen burning in the interior of the sun and stars by using the concept of excess entropy production in the world. To date, when studying the structure of stars, people often utilize the principle of minimum energy under isentropic conditions to seek the structure of stars in equilibrium. This method essentially assumes that a star is a thermodynamic system in equilibrium. However, in reality, stars generally have the following characteristics: Firstly, a star is an open system that continuously radiates a large amount of energy into the surrounding space in the form of photons and neutrinos. Many stars also eject matter in various forms. These materials, as well as the radiated photons and neutrinos, carry entropy, thus, for stars, there exists a negative entropy flow. Secondly, the thermonuclear reactions inside stars (such as the  ${}^4\text{H}\rightarrow{}^4\text{He}$  fusion reaction in main-sequence stars) are usually unidirectional and irreversible. Due to these two characteristics, a star is a system in a non-thermodynamic equilibrium state. Therefore, strictly speaking, nonlinear non-equilibrium thermodynamic theory should be used to study it. Furthermore, the vast majority of stars remain in a relatively stable state for long periods, except for brief periods of instability. This relatively stable timescale generally ranges from millions to billions of years, or even longer. This characteristic indicates that although stars are in a non-thermodynamic equilibrium state, they have a long-term stable structure. Therefore, when discussing the structure of stars, their self-gravity should be considered, which often greatly increases the complexity of the problem. Based on the nonlinear non-equilibrium thermodynamic theory proposed by Prof. Prigogine and others, more and more facts prove that it is a powerful tool for studying the behavior of thermodynamic systems that are in non-

thermodynamic equilibrium but have stable structures. However, it has not yet been applied to astrophysics. We have innovatively attempted to apply it for the first time to study the stability problem of stellar structures. We first discuss the stability of the structure of stars determined by the PP thermonuclear reaction inside smaller main-sequence stars, which we call solar-type stars. Among the three branches I, II, III of the PP reaction, since the PPI reaction dominates, we have discussed in detail the stability problem of the stellar structure determined by this reaction. We assume that the star is under mechanical equilibrium and local thermodynamic equilibrium. Since there are no convective core inside solar-type stars that use the PP reaction as a nuclear energy source, and the speed of the meridional circulation inside them is also very small, for the Sun, the speed of the meridional circulation is about  $10^3$  cm/million years, therefore, we ignore the effect of convective diffusion of matter. At the same time, we also assume that the temperature in the thermonuclear reaction region inside the star remains unchanged during the reaction process as an initial study, which is reasonable to some extent. Our results show that as long as the ratio of  $^1\text{H}$  to  $^4\text{He}$  abundance inside the star is less than 8.90, the structure of the star is stable.

Because China's science lagged far behind the advanced western countries, and at that time China had just reformed and opened up, the papers of our unknown scholars could not be published in international academic materials. However, Western scholars basically do not read papers published in Chinese academic journals. So the foreign scholars who published in the Chinese Astronomical Journal in 1980 did not know. As for our astrophysics research published in the Astronomical Journal, although our papers are about nuclear astrophysics, almost no nuclear physicists in our country have asked about it. I have followed the teaching methods of the professors of theoretical physics at Peking University and conducted serious and careful discussions and studies.

Of course, our paper is about the stability of hydrogen burning nuclear reactions in the interior of the sun, not about controlled thermonuclear reactions, and has nothing to do with complex technology. However, from the point of view of physics theory, nuclear reactions are the same, of course, the nature of stability should be the same, which has nothing to do with technology. We think that although this is different from the "controlled thermonuclear reaction" environment on the ground, the technology is different from the internal environment of the sun (in fact, only the difference in temperature and density), it should be similar in nature. The central question of why stability studies of terrestrial controlled thermonuclear reaction experiments have so far been how to sustain such very short nuclear burns using very complex magnetic confinement methods. The reason may be that none of the nuclear physicists all over the world engaged in the experimental research of "controlled thermonuclear reactions" paid attention to and knew that in China, an unknown astrophysicist first used the concept of "excess entropy production" in non-equilibrium state to explore the stability of hydrogen burning in the sun and stars. They do not know that the necessary condi-

tion for the stability of the thermonuclear reaction obtained in our paper is that the He content at the beginning of the reaction should not be too small (the mass content is not less than 1/8 of the hydrogen (H) content). Our conclusion is logically sound. When some scientists in the United States first studied the Tokamak controlled thermonuclear reaction device, they did not know the necessary conditions for stability given by us, and in order to make the higher efficiency, they naturally chose the idea that the initial content of  ${}^4\text{He}$  was zero. They didn't know and didn't study the rationality of our paper.

After nearly 70 years of experimental research on controlled thermonuclear reactions in the world (initially in the United States), their stability research in this area has turned to the use of strong magnetic fields to bind experimental devices, which can only last for a few hundred seconds. Our research in 1980 is to discuss the stability of hydrogen burning thermonuclear reactions in the interior of the sun and stars by using the new concept of excess entropy production proposed in the 1970s to judge whether a non-equilibrium thermodynamic system is stable or not. The necessary conditions for the  ${}^4\text{H}\rightarrow\text{He}$  fusion reaction we obtained are  $X(\text{He})/X(\text{H}) > 1/8$ , otherwise, the fusion reaction can not be stable.

### 3. Conclusions and Outlooks

Although the environment of the controlled thermonuclear reaction on the ground is quite different from that on the sun, we deduce that this stability condition is independent of the environment. We hope that it can be further studied in theory, it is urgent to test the theory through experiments. Astronomers have been discussing various theories about solar flares and their activities in astronomy for 80 or 90 years, but to no avail. Since 1995, the astronomical community in the United States has used many satellite observations to collect real astronomical observations, making solar physics observations completely modern. We just want to do a controlled thermonuclear reaction in the laboratory, not the initial He content of  $X(\text{He}) = 0$ , but  $X(\text{He}) > 1/8X(\text{H})$ . We think that the experiment doesn't cost much. If the experiment is still not successful, you can discuss my theoretical research in 1980. Why not do the experiment? It's just changing a physical concept. We believe that the hope of success is greater! Over the past 70 years, the international controlled thermonuclear reaction experiments have completely violated the stability conditions given in our paper 2. They have chosen a thermonuclear reaction similar to the fusion of hydrogen into helium in the first stars in the very early universe (all hydrogen, no helium), which is a very fast and unstable hydrogen burning. They violate the principle of stability, but they use the auxiliary strong magnetic field to restrain them, which has been difficult to succeed so far. Now we are only asking our country's experts in nuclear physics to carefully examine my paper in 1980 and examine whether it is reasonable? Peng Liang, Peng's youngest son, urged that the biggest crisis in the world's industry is the energy problem, and that if the research on controlled thermonuclear reactions is successful, it will benefit the entire human race.

## Acknowledgements

This work was supported in part by the National Natural Science Foundation of China under grants 11965010, 11565020, and the Natural Science Foundation of Hainan Province under grant 2019RC239, 118MS071, 114012 and the Counterpart Foundation of Sanya under grant 2016PT43, 2019PT76, the Special Foundation of Science and Technology Cooperation for Advanced Academy and Regional of Sanya under grant 2016YD28, the Scientific Research Starting Foundation for 515 Talented Project of Hainan Tropical Ocean University under grant RHDRC201701.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

## References

- [1] Nicolis, G. and Prigogine, I. (1977) Self-Organization in Non-Equilibrium Systems. Wiley.
- [2] Peng, Q.H., Huang, K.L. Zhan, K.H. and He, X.T. (1980) Stability of the Stellar Structure in Non-Equilibrium Thermodynamics. *Acta Astronomica Sinica*, **21**, 172-179. <https://ui.adsabs.harvard.edu/abs/1980AcASn...21..172P/abstract>
- [3] Peng, Q.H., Huang, K.L. Zhan, K.H. and He, X.T. (1981) Stability of Stellar Structure in Non-Equilibrium Thermodynamics. I. The PPI Reaction. *Chinese Astronomy and Astrophysics*, **5**, 103-110. <https://ui.adsabs.harvard.edu/abs/1981ChA%26A...5..103P/abstract> [https://doi.org/10.1016/0275-1062\(81\)90081-3](https://doi.org/10.1016/0275-1062(81)90081-3)
- [4] Huang, K.L. Peng, Q.H. Wang, Z.Y., *et al.* (1981) Stability of Stellar Structure in Non-Equilibrium Thermodynamics II. C-N-O Cycle. *Chinese Astronomy and Astrophysics*, **5**, 217-222. <https://ui.adsabs.harvard.edu/abs/1981ChA%26A...5..217H/abstract> [https://doi.org/10.1016/0275-1062\(81\)90035-7](https://doi.org/10.1016/0275-1062(81)90035-7)
- [5] Wang, Z.Y., Peng, Q.H. and Huang, K.L. (1984) The Stability of Stellar Structure in Non-Equilibrium Thermodynamics III. The PPI Reaction Allowing for Mass Loss. *Chinese Astronomy and Astrophysics*, **8**, 223-227. <https://ui.adsabs.harvard.edu/abs/1984ChA%26A...8..223W/abstract> [https://doi.org/10.1016/0275-1062\(84\)90026-2](https://doi.org/10.1016/0275-1062(84)90026-2)