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Thorne – Żytkow Object [TZO]

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Abstract: ***A star with unique chemical signatures, highly luminous and consisting of abundant elements was found in the Small Magellanic Cloud, 40 years after its prediction by Kip Thorne and Anna Żytkow, named as TŻO – Thorne Żytkow Object. The merging of red super giant star and neutron star orbiting in a binary system forms TŻO. The neutron star takes place of the core of the red super giant star and is enveloped by the burning shell, which produces heavy elements in abundance. Decades later a TŻO candidate – HV2112 was found in Small Magellanic Cloud by a team of astronomers lead by Levesque. HV2112 displayed properties that were predicted theoretically by Kip Thorne and Anna Żytkow. The discovery of TŻO revolutionized the standard model of stellar interiors. This paper lists the prediction of the TŻO and its discovery in the Milky Way galaxy.***

Keywords: TŻO, convection, thermonuclear reactions, nucleosynthesis, hybrid star.

1. Introduction

Thorne - Żytkow Object - TŻO is a theoretical class hybrid red super giant star having a degenerate neutron core. TŻO derived its name from Kip Thorne (Physicist) and Anna Żytkow (Astronomer). TZO were first predicted by Kip Thorne and Anna Żytkow in 1975. TŻO's are red super-giant stars that are highly luminous in the range of . TŻO's are very similar to the regular M type red super giants in appearance, but exhibit different properties [2]. In a binary system of massive stars, the massive star amongst the two explodes into a supernova and forms a highly dense neutron star whose mass is greater than 1.4 times the solar mass. This newly formed neutron star orbits the companion red super giant star, which is 10-15 times the solar mass [6]. The red giant star drags and swallows the neutron star due to common envelope state caused by the expansion of the envelope. The merged neutron star takes place of the core of the red super giant. Another theory proposed by Peter Leonard and Jack Hills at Los Alamos and Rachel Dewey at JPL says, the supernova explosion gives a kick to the newly formed neutron star which spirals into the companion star and merges with the core of the massive companion star [5]. Another theory suggests that TŻO is also formed when the neutron star collides with the red super giant star. TŻO exhibit unique chemical properties never seen before in regular red giant stars. Due to the unique activity taking place inside the TŻO their chemical signatures are different from the other M type red super giants. Where regular super giants are powered by the nuclear activity, the TŻO's are powered by the thermonuclear reactions at the neutron core [2]. A strong candidate for TŻO was first found in Small Magellanic Cloud in the Milky Way Galaxy named HV2112.

2. Theoretical Predictions

TArne and Żytkow weren't the first ones to think about stars with neutron cores. Around mid 1930's,George Gamow, was the first one to wonder about stars with neutron cores and if sun might have a neutron star at its core, right after Fritz Zwicky of Caltech conceived the concept of neutron star. It was due to Bohdan Paczynski, astrophysicist at University of Warsaw, that the notion of pursuing stars with neutron cores was possible. Paczynski advised Anna to look into the subject of stars having neutron cores, which became the subject of Anna's second postdoctoral. Anna Żytkow along with Kip Thorne worked together and predicted TŻO theoretically in 1975 [5]. The name Thorne - Żytkow Object, also known as TŻO, comes from the name of the two astronomers Thorne and Żytkow. Thorne and Żytkow predicted that a star would be a red super-giant; extremely large and luminous, if it consisted of a neutron star as its core. They also predicted that these stars would have elements in abundance. Thorne-Żytkow hypothesized through calculations that the red super giant stars of masses around 11 times the solar masses are supposed to have a burning shell of elements enveloping the neutron core of the star. This burning shell consists of elements that keep burning all the time, thus forming strong and heavy elements. Because of convection, the hot gas circulating in the interiors of the stars, these elements are carried to the surface of the giant stars before the burning of the elements is complete [5]. This convection was an unusual activity never seen in any other kind of star. In massive binary systems, the massive star has to go through common envelope (CE) stage, according to the modern binary stellar evolution (Paczynski 1976). The common envelope evolution causes merging of the two cores that form the TŻO. An atypical system is thus created by the merger where there is a neutron star surrounded by a large, diffuse envelope of materials. Although most of the energy of the system is still produced at the core of the material envelope through thermonuclear energy, a small amount (5% of total energy) is produced from the gravitational accretion of material onto the neutron star [7].The heat flow during the common envelope state causes the cold neutron core to burn that leads to the formation of heavy elements. According to the hydro-dynamical calculations of Livio (1990) the neutron core takes about years to reach near the core of the red super giant, but takes a month to merge with the core. This convective layer merging with the neutron core causes elimination of mass in the massive star due to gravitational radiations [3]. Thus, Thorne and Żytkow concluded that there would be excess mass loss in the TŻO. Thorne-Żytkow also calculated theoretically that these stars would have elements in abundance according to the stellar models but it was unclear then what the products of nuclear burning would be. Around 1990's it was Garrett Biehle, a graduate student, calculated and predicted that the elements formed due to the thermonuclear reactions would be large amounts of Molybdenum (Mo) and Rubidium (Rb). Later Philipp

Podsiadlowski, Robert Cannon and Martin Rees of University of Cambridge showed that Lithium (Li) would be in over abundance [5]. These elements are found in abundance in the regular red super giants, but it would have Lithium in over abundance than the regular red super giants. In the TŻO, the burning neutron star core causes different unusual fusion reactions known as 'interrupted-rapid-proton' process. This process in TŻO forms the Molybdenum and rubidium, which is also formed by the s-process in the SAGB [1]. There is additional element formed in abundance in the TŻO – Lithium, which is observed in abundance in the surface spectrum of TŻO through detailed spectroscopy. Lithium is formed by the burning of the lower layer of the convective envelope at the base, which is then carried to the surface due to convection. Presence of Lithium in abundance in the atmosphere pattern of TŻO and the rapid proton process elements are the essential factors of distinguishing TŻO from other regular red super-giants and the SAGB's [2].

3. Discovery of TŻO

After 40 years of search astronomers have finally found an observational proof for the Thorne-Żytkow object in our Milky Way galaxy. A team of astronomers led by Emily Levesque was studying 22 objects in the Small Megallanic Cloud using one of the Magellan telescopes. The team found the TŻO candidate with the Astrophysical Research Consortium owned and operated 6.5m Magellan telescopes located at Las Campanas, Chile and the Apache Point Observatory 3.5-meter telescope [2]. The TŻO candidate was found in the Small Megallanic Cloud, a giant star named HV2112 in the Milky Way galaxy. The team had been studying the spectrum of light emitted from the stars present in the Small Megallanic Cloud, which gave the results of the elements present. But the team got different results from the spectrum of the star HV2112. After comparing the results with the other regular red supergiant stars, they found the presence strong and heavy elements like Lithium, Molybdenum and Rubidium in abundance. Molybdenum and Rubidium are present in the regular red super giants, but the presence of Lithium in abundance was predicted to be the significant property in TŻO. The team found large number of Li lines in the spectra of HV2112, which made HV2112 a strong candidate of a TŻO object [2].

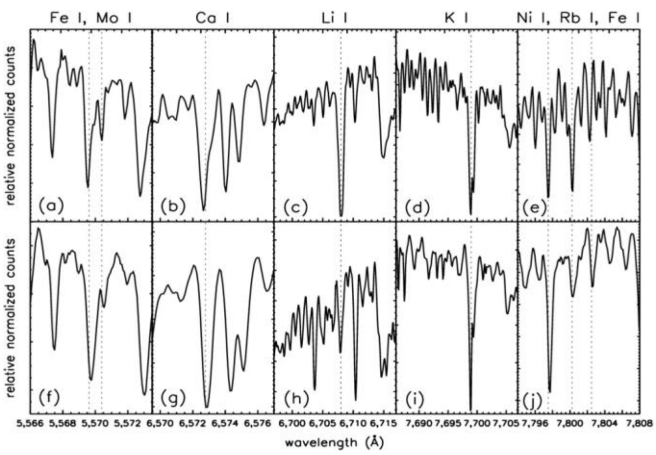

Figure 1: Comparison of the spectrums of regular red super giants and the TŻO candidate

The diagram above tells about the lines of elements exhibited by HV2112 spectrum. The spectrum indicates enhanced Li-I, Rb-I, Mo-I and Ca-I. Normally molybdenum and rubidium are products of s-process also that takes place in SAGB's. But Levesque et al. found barium in fewer amounts in HV2112 that indicates that the formation of molybdenum and rubidium is not due to s-process in HV2112. The presence of enhanced calcium in HV2112 was another factor that made it appear different. The self-synthesis of calcium in the end stages by the TŻO is not possible in the early stages of the SAGB or other giant stars [1]. The calcium is produced due to the capture of alpha particles during the end stages of nuclear life of the star. The nucleosynthesis processes taking place in the TŻO are not responsible for the formation of the enhanced calcium. Alternate theory is that calcium is produced during the formation of TŻO due to the merging process of neutron star and the degenerate core. The merging process creates suitable conditions in the accretion disc for higher burning of elements and formation of calcium [1]. Presence of calcium in abundance was not predicted before in the TŻO.

4. Additional Properties

The Thorne-Żytkow objects are extremely red in appearance. TŻO were predicted to be redder in appearance than the other red super giant stars because of thermonuclear reactions taking place around the dense degenerate core. The temperature of TŻO depends on its luminosity and less on its mass [1]. TŻO's are slightly redder than the regular red super giants by a factor of According to the modern stellar models and the improved theoretical calculations the estimated birth rate of TŻO's is predicted to be ~ 2*. The number of TŻO's estimated to be found in the galaxy is 20 – 200 depending on their life time of about 10^5 -10^6 years [4]. The HV2112 TŻO candidate display consistent hydrogen Balmer series, while the TŻO's display strong hydrogen Balmer emission features. HV2112 spectrum shows no other emission features typical of an ionized nebula [2].

5. Conclusions

The TŻO is a hybrid red super giant star having degenerate neutron core of theoretical class.Thorne - Żytkow Object are a product of the gravitational radiations in a binary system that cause the neutron star to merge with the convective envelope. This leads to the formation of the heavy elements in abundance. So far HV2112 stands as a strong candidate for TŻO due to the presence of abundant heavy elements as predicted earlier. But the discovery of other elements in its spectrum that were not predicted earlier, established a deeper understanding about TŻO and the nucleosynthesis processes happening in TŻO. The standard models of stellar interiors will get reformed due to the discovery of the additional elements formed as a result of the unusual nuclear activities taking place in the interiors of TŻO.

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