Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/17256
DOI URL: http://dx.doi.org/10.21474/IJAR01/17256

ISSN NO. 2320-5407

RESEARCH ARTICLE

COMPARING THE STAR FORMATION RATES OF 2 STAR FORMING REGIONS

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Manuscript Info

Manuscript History
Received: 15 May 2023
Final Accepted: 19 June 2023
Published: July 2023

Key words:-
NGC 3603, L 1641, Pre-Main Sequence Stars, Star Formation, Star Formation Rate (SFR)

Abstract

This paper introduces nebulae and the process of star formation. It then focuses on analysing the compositions and star formation rates of NGC 3603 (an open cluster in NGC 3372, also known as the Carina Nebula) and L 1641 (a molecular cloud in Orion A, part of the Orion Molecular Cloud Complex). It then compares both regions and concludes that NGC 3603 has a higher rate of star formation than L 1641.

Introduction:-

In the vast universe, there are uncountable celestial objects wandering around and going through multiple stages of their lives. Some of them may be violent, and some of them are extremely bright. Star formations are a great example of that. Stars are formed inside nebulae which are giant clouds composed of gas and dust. While the data for the number of nebulae is unclear, it is estimated[16] that there are, at the magnitude of, 10^4 planetary nebulae (which form when a star, like the Sun, is at the end of its lifetime) in the Milky Way Galaxy. There have also been estimates[9] claiming that the order of magnitude of the number of stars in our galaxy, The Milky Way, alone is about 10^{12} with the order of magnitude of the number of stars in the observable universe being at a range of 10^{21} to 10^{24}. The types of nebulae can also vary where the most common type is an emission nebula (part of diffuse nebulae, which are responsible for star formation). Another type of nebula is a dark nebula (also part of diffuse nebulae), where there are giant clouds which block the visible light of celestial objects like stars.

Star Formation

For star formation to occur, matter accumulates into dense concentrations of carbon monoxide and hydrogen (the most common elements in a nebula) and at a certain point that core collapses under its own gravity due to the extremely high density it procures. More matter clumps up and the core forms a protostar. Due to its gravity, the protostar attracts more matter which adds to its weight. During this process, the matter falling into the protostar has kinetic energy, which leads to the production of heat as a byproduct. Over a few million years, matter stops falling as the pressure of the protostar is stabilised and the rest of the matter coalesces around the protostar. The movement of this matter creates enough heat which eventually starts thermonuclear fusion, and the protostar is now a young star. This ignition creates a strong stellar wind which pushes back all the surrounding gas and dust which eventually forms planets. Note that this is only true for protostars which leave their nebulae and do not have other strong sources of gravity to affect this process. On the other hand, protostars which stay inside their nebula go through the same process until they become young stars where they are surrounded by many other young stars in the nebula, which can form globular clusters. At the end of their life, many stars of around a few solar masses explode and form nebulae, repeating the whole cycle all over again.

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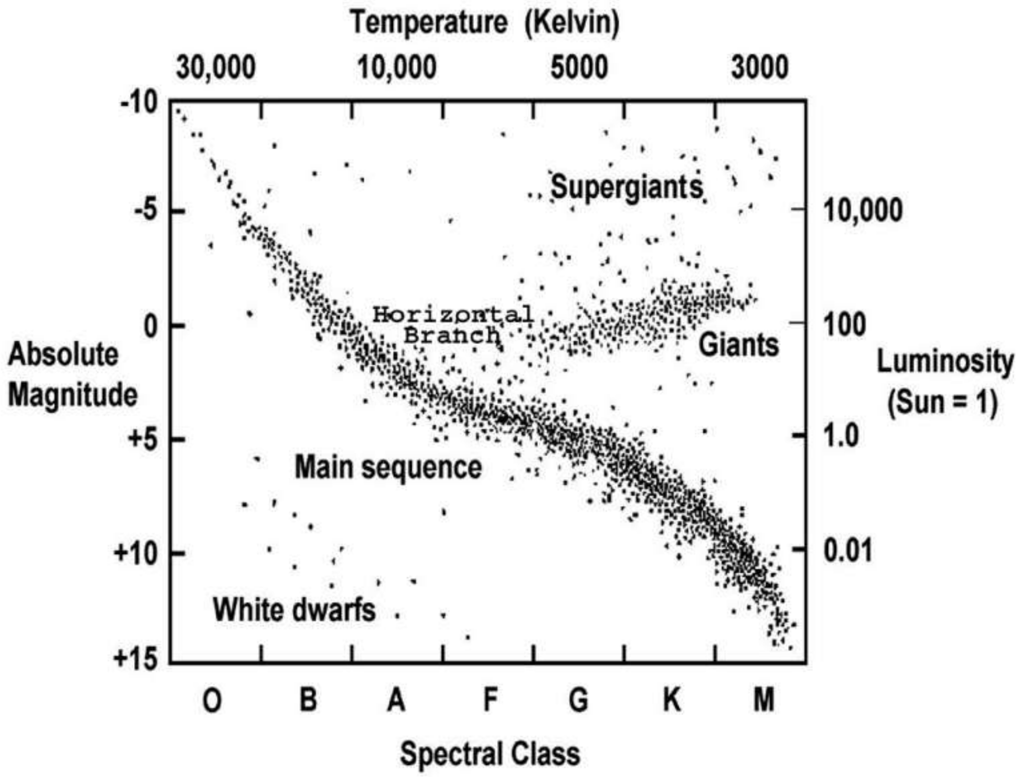
Since Main Sequence stars are the most abundant, they will be the focus of this report. Main Sequence stars are known to cover 90% of the population of all stars in the observable universe, and they have a great range of luminosity and mass which can go from around 10 to 200 times the mass of the sun, also known as 'solar masses'. The Hertzsprung-Russell diagram (or the H-R diagram) shows a trend between the luminosity and surface temperature of the different types of Main Sequence stars.



H-R Diagram by Chandra X-Ray Observatory

Other types of stars consist of either progressions of the main sequence star, or they are different classifications of the main sequence star, or they are brown dwarfs which are essentially stars which do not perform nuclear fusion like main sequence stars.

The type of star can have effects on the Star Formation Rate (SFR) of a nebula because some main sequence stars that are much more massive than the Sun can create strong shockwaves while forming which can reduce the star formation rate for first-generation stars since the solar wind from that shockwave can remove the matter required to form a star. However, it still increases the rate of star formation for new second-generation stars[2]. This has been observed inside the Orion Nebula where a newly formed star created a bubble which pushed matter to the edges, hampering the formation of new stars around it, but increasing the chances of new stars at those edges due to the high density of molecular gas[15]. If a relatively big star being formed is in close proximity with other stars in their infancy, it can interact with them by taking matter from those smaller protostars due to its stronger gravitational force. Another major factor for determining the star formation rate is the density of gas in the region. Through research[11], it has been found that regions with higher densities than 10^5 cm^{-3} result in higher Star Formation Efficiency (SFE) which leads to larger numbers of stars being formed, and vice versa for less dense regions. This table from a research report[10] published in the Astrophysical Journal further provides evidence.

Cloud	Mass ($M_\odot$)^b	No. of YSOs (Young Stellar Objects)	SFR (10^6 $M_\odot$ yr^{-1})
Orion A	13,721	2862	715

Orion B	7261	635	159
California	3199	279	70
Perseus	1880	598	150
Taurus	1766	335	84
Ophiuchus	1296	316	79
RCrA	258	100	25
Pipe	178	21	5
Lupus 3	163	69	17
Lupus 4	124	12	3
Lupus 1	75	13	3

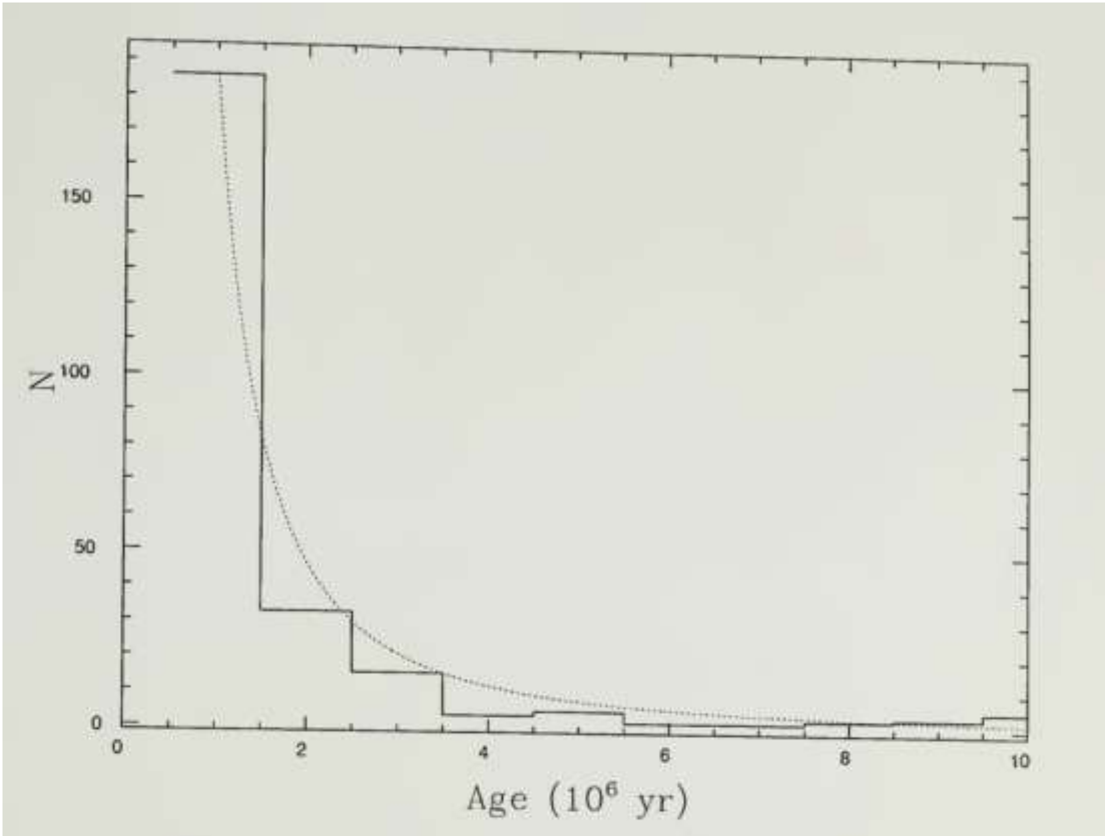
Note. Adapted from “On the star formation rates in molecular clouds”, by Lada et al., 2010, The Astrophysical Journal, 724(1), 3. Copyright 2010.

Star Formation Rate in L 1641

L 1641 is a molecular cloud which is a major part of Orion A which is one of the 2 Giant Molecular Clouds (GMCs) that are part of the Orion Molecular Cloud Complex (OMC). The OMC is found in the Orion Constellation, south of Orion’s Belt. L 1641 is under the Orion Nebula Cluster (ONC) which is in the heart of the well known Orion Nebula, also known as Messier 42 (M42). The L 1641 region also has a roughly estimated radius of approximately 70 pc and its mass is around 10^4 solar masses[5]. Through various surveys, including molecular surveys of IRAS (Infrared Astronomical Satellite) sources, it has been observed that L 1641 is made up of multiple organic compounds such as Hydrogen Cyanide (HCN), Formyl cations (CHO^+), and a few isotopes of Carbon Monoxide (CO), including ^{12}CO and ^{13}CO. Research[3] has found that there are 2 “clumpy” filaments of gas inside L 1641 where the main filament is made of 30% of ^{13}CO, and the brightness temperature of these “clumps” is about 25 Kelvin[14] with the molecular gas density being higher than an order of magnitude of 10^3 cm^{-3}.

As for the types of stars in L 1641, the molecular cloud mainly consists of protostars and Pre-Main Sequence (PMS) stars that “grow up” to become main sequence stars. Such are stars with low mass, T Tauri stars (which are stars that are close to being 10 million years old), and Herbig Ae/Be stars which are stars with intermediate mass that lie between the range of T Tauri stars and Massive Young Stellar Objects (MYSOs) with the largest in L 1641 being the B4 V Herbig Ae/Be star HD 38023. This provides evidence for the lack of rich clusters in L 1641 since it does not form very massive stars, but it still has a lot of Herbig-Haro (HH) objects.

HH-objects are known to aid in star formation rate since they occur when hot gas ejected by a star collides with cosmic dust around it, creating bright patches of shock waves called HH-shocks[6]. L 1641 specifically has had a constant star formation rate for at least 10^7 years which has been approximately 200 stars per million years[1]. A graphical illustration is also shown below, indicating a logarithmic relation between the number of stars and the age of L 1641:



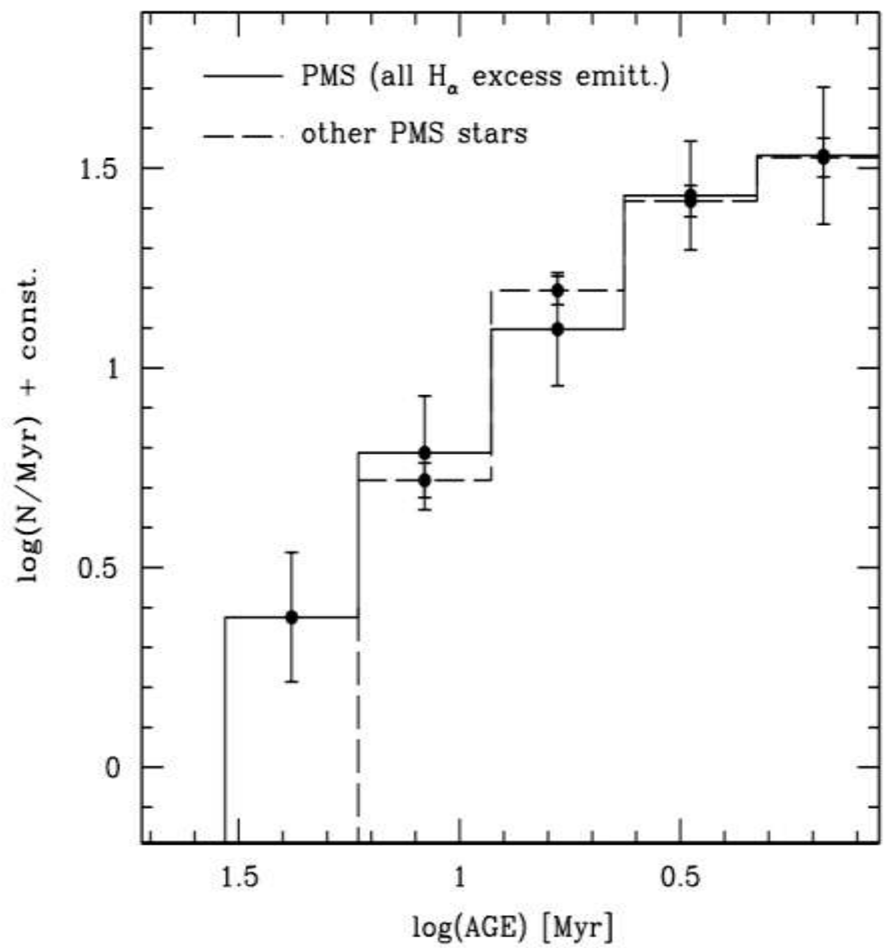
Note. Reprinted from “Star Formation in Lynds 1641”, by Allen, L.E., 1996, Doctoral Dissertations 1896, 53. Copyright 1996 by Lori E. Allen.

Star Formation Rate in NGC 3603

NGC 3603 is a very active star forming cluster that resides in the famous Eta Carinae (NGC 3372), more commonly known as the Carina Nebula, around 20 thousand light years (or 7 kpc) away from the solar system. It is sometimes referred to as a starburst cluster or a super star cluster since it is a massive H II region (an area which has huge clouds of glowing plasma and gas). A very rough estimate[7] of the radius of NGC 3603 is about 9 pc along with a total mass of 10^4 solar masses[8]. A research paper[18] found out that the elements that make up the cosmic dust and gas of this starburst cluster are various isotopes of Oxygen (O), Neon (Ne), Nitrogen (N), Sulphur (S), Helium (He), Hydrogen (H), and Argon (Ar) with the total gas density being higher than 10^4 cm^{-3}.

The kinds of stars that inhabit NGC 3603 are Type O and Type B stars (massive stars, usually being above 15 solar masses, that are at the left end of the horizontal axis on the H-R diagram shown above), some Pre-Main Sequence stars (mentioned above), and Wolf-Rayet Stars (WR stars). WR stars are split into 3 categories where WN stars have more nitrogen and very less carbon, WC stars have more carbon and very less nitrogen, and WO stars have very less amounts of carbon and oxygen[19]. WN stars are more prominent than the other WR stars in this starburst cluster.

The age of NGC 3603 has been estimated to be 1 million years; however, star formation has been happening near the star cluster for about 10 to 20 million years with the Star Formation Efficiency of 25%. While some researchers[13] found that the Star Formation Rate of NGC 3603 is approximately 2.6×10^{-3} stars per year (2600 stars per million years), others claim that the rate is not constant, but it is actually increasing. A linearised graph[4] of the age of NGC 3603 versus the number of stars per million years is showcased below:



Note. Reprinted from "Progressive Star Formation in the Young Galactic Super Star Cluster NGC 3603", by Beccari et al., 2010, The Astrophysical Journal, 720, 1116. Copyright 2010 by Beccari et al.

Comparison and Conclusion:-

Both L 1641 and NGC 3603 have been well studied for decades and will be great laboratories for scientists to study stellar evolution and formation due to their high star forming activity. Both regions have features that they have in common and features that make them unique from each other which determine their star formation history since their activity is highly dependent on what initial conditions they were formed on. NGC 3603 has a density which is an order of magnitude higher than L 1641 which helps explain the higher Star Formation Rate, and the fact that it has a smaller radius further aids in the rate mentioned since the building blocks of stars are much closer to each other, enabling the force of gravity to speed up the process. The types of stars present in NGC 3603 are also a critical aspect since low mass stars, unlike stars with high mass, will not provide more matter at the end of their life when they explode. In conclusion, taking all of these factors into account, NGC 3603 has a much higher Star Formation Rate than L 1641.

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