Relation Between the Luminosity of the Star at Different Stages of its Life & its Correlation With Goldilocks Zone to Discover another Unique Pale Blue Dot

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Abstract— Astrophysics revolves around speculating and then quantifying the speculations to make it universally acceptable. The events that take place in the universe are either too quick or too slow for the human to register it without the aid of technology. Hence simulations come as a boon. A stellar evolution virtual experiment was used to closely examine the evolution of a star right from its birth to its death. Through this simulator, luminosity data of a star at various stages of its life has been taken. A mathematical relation for the luminosity at different stages of the star has been formulated. Using this relation and the concept of Goldilocks Zone, within the scope of this project, lies the possibility of finding an Earth like planet. With the correct equipments and technology we may make ground breaking revelations.

Index Terms— Goldilocks Zone, Luminosity, Pale blue dot, , Star

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1. INTRODUCTION

Universe is a swelling dark ocean, through which sweeps waves of mysteries, waiting for mariners to explore its vastness. There is truth waiting to be unveiled which can change our perception of life as we know it. Question of the era for a long time has been, to find another planet like Earth. Referred to as the "Pale Blue Dot" by the renowned Cosmologist, Carl Sagan, our Earth is truly unique due to its ability to sustain life. However, Earth is threatened by global warming, population, explosion, fate of sun and other such impending doom. This sets us on a quest to find probable habitable planets so that human race can rage on. This calls for an idea that can yield the location of another pale blue dot, efficiently and effectively. In this research paper, this very question has been dealt with.

In this paper, a mathematical relation of luminosity of a star at different stages of its life has been established. This was achieved by using a simulation by Schlumberger Excellence in Education Development (SEED) which is a non- profit organization which aims to spread knowledge and make science more interesting. Through the simulation, data was obtained, using which graphs were plotted. Although data cannot be verified easily, technique of verification has been provided below. The paper contains an idea, which in the coming future can act as a key to many solutions.

2. EXPERIMENTAL DETAILS

Mass: 100 Solar Mass
Metallicity: 0.02

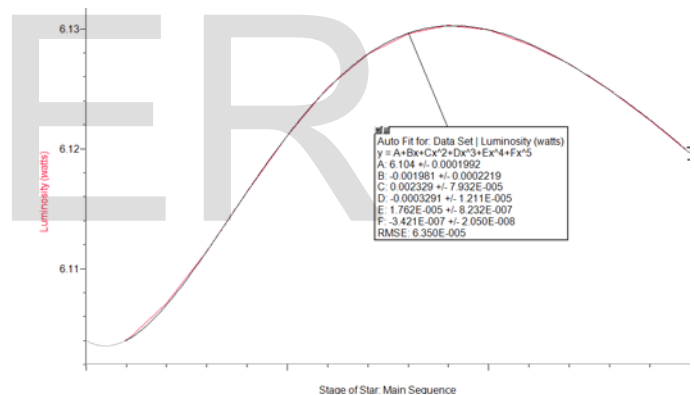## 3. RESULTS AND DISCUSSIONS

3.1 Main Sequence Stage

Fig.1. Main sequence stage

The first graph shows the varying luminosity as the star's age increases in the main sequence stage of the star. The equation that best fit the curve is;

$$y = A + Bx + Cx^2 + Dx^3 + Ex^4 + Fx^5$$

Where A, B, C, D, E and F are constants;
A= 6.104
B=-0.009181
C=0.002329
D=-0.0003291
E=1.762x10^{-5}
F=-3.421x10^{-7}

As can be seen from the RMSE (Root Mean Square Value)

which is 6.350×10^{-005} which is a very small value and hence can be neglected and we can deem this curve to be a near perfect fit. As can be seen, its luminosity is increasing and then it decreases. This is true even theoretically as the luminosity of a star gradually decreases with time.
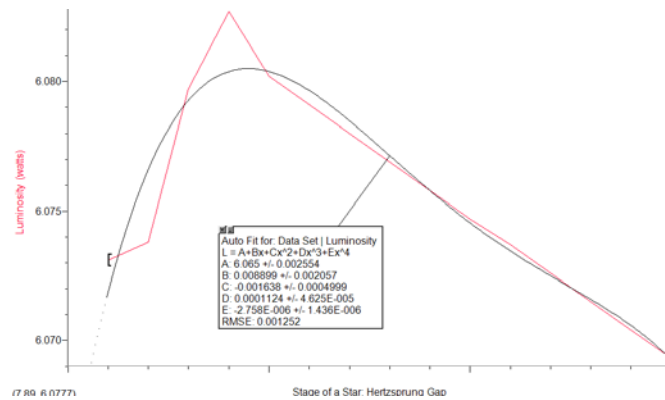
3.2 Hertzsprung Gap Stage


Fig. 2.Hertzsprung Gap Stage

The next graph shows the luminosities as the time progresses and the star has reached the Hertzsprung Gap Stage. The equation of the best fit curve is;

$$y = A + Bx + Cx^2 + Dx^3 + Ex^4$$

Where A, B, C, D and E are constants;
A= 6.065
B= 0.008899
C= -0.001638
D= 0.0001124
E= -2.758x10^{-6}

The RMSE (Root Mean Square Value) is 0.001252, which is a very small value and hence can be neglected and we can deem this curve to be a near perfect fit. As visible, its general trend shows an increase in the beginning and decrease later. Unlike the previous graph this has a spikey maxima. This may be due to various reasons. Most suitable would be that during this phase, the size of the star increases. The spike could indicate an increase in the size of the star for luminosity and mass of a star are directly proportional. Furthermore, there is fusion reaction taking place at the surfaces, fusions are unpredictable and sudden
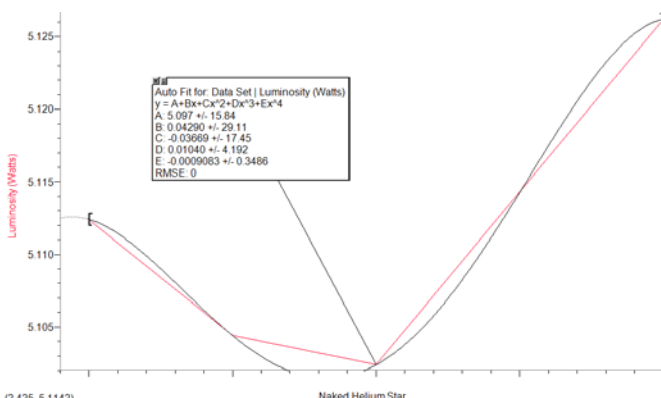
outburst may lead to sudden increase in luminosity.

3.3 Naked Helium Stage

Fig. 3.The Naked Helium Stage

The best fit curve suggested the equation which satisfies the varying luminosities in the Naked Helium stage to be;

$$y = A + Bx + Cx^2 + Dx^3 + Ex^4$$

Where A, B, C, D and E are constants;
A= 5.097
B= 0.04290
C= -0.03669
D= 0.01040
E= -0.0009083

Then, different luminosities of Naked Helium stage were analyzed. Through this graph we notice initially a huge decrease in the luminosity and then an increase. This may be explained by the fact that in the Naked Helium stage, the star loses much of its outer surface to the stellar winds. The mass decreases as only the helium core is left behind. And since mass is directly proportional to the luminosity hence then is a sudden decrease. However, there are still fusion reactions taking place, the metallicity of the star is increasing. Once the equilibrium is again reached, the luminosity increases, although not as much as it was in previous stages.

When examined for the best suitable equation that defines the curve, a sinusoidal curve showed a promising result with RMSE value 0.00183680. However, when we see the graph as a whole, we see that the curve increases and decreases periodically. This does not support any theory unless it is a Cepheid variable which needs to occur in pair. Hence this equation had to be rejected. Then the quartic equation curve was implemented which fit the data perfectly with RMSE value being zero!

As it entered the Naked Helium stage, its luminosity decreases to a certain point and from there it reestablished its luminosity but at a lesser value. When the curve is extrapolated on its path, we see that the curve will tend downwards and continues decreasing. This result suggests the theoretical knowledge since now that mass has decreased considerably and shall continue in the future. Helium will fuse into a heavier metal and the core will ultimately collapse under its own gravity and hence luminosity will decrease and tend towards zero.

3.4 Black Hole

The Last stage for a huge mass, here, 100 times the mass of our Sun, is inevitably a Black Hole. A black hole is point of singularity which has zero luminosity. This poses a gigantic problem for the astrophysicists for, due to zero luminosity, it is not visible and hence its not possible to locate a Black Hole. However they have very strong gravitational pull, strong enough to cause a tear in space! This gravitational energy can be detected by technology and hence the location of a Black Hole can be known.
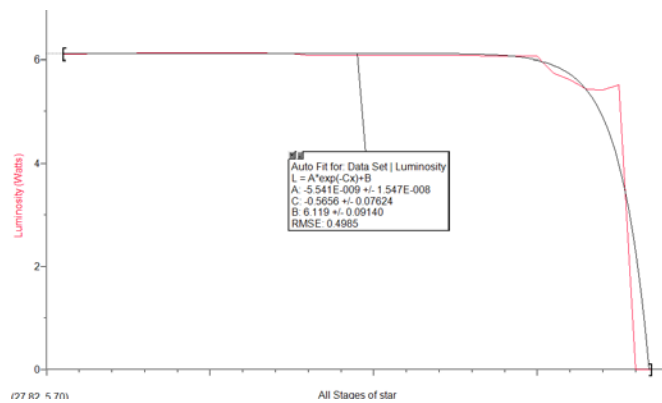
4. CONCLUSIONS

Fig. 4.All stages

Now after studying all the stages in separation, another graph was plotted that studied the all-round development of varying luminosity of the star at different stages of its life. The curve that best fit the points was of exponential equation.
It followed the equation;

$$y = Ae^{-Cx} + B$$

Where:
A= -5.541 $x10^{-9}$
B= 6.119
C= -0.5656
The graph however seems to be starting from infinity and approaching negative infinity which is not theoretically possible. Hence limits can be assumed to the equation stating that the equation is valid between two points only.
The graph suggests that the luminosity of a star through various stages of its life decreases exponentially.

5. VERIFICATION TECHNIQUE

5.1 The Sun

We are aware of the fact that our star, The Sun, is presently in a stage called the main sequence stage. The data from the virtual experiment can be compared with the actual data

from an observatory and graph can be plotted using the experimental and the laboratory values of Sun and its luminosity. Care needs to be taken in choosing the similar time frame, metallicity and mass in both the cases. The sun is considered to have metallicity 0.02. So now again the entire virtual experiment is repeated, with the changes of mass of star as 1 solar mass and metallicity as 0.02.
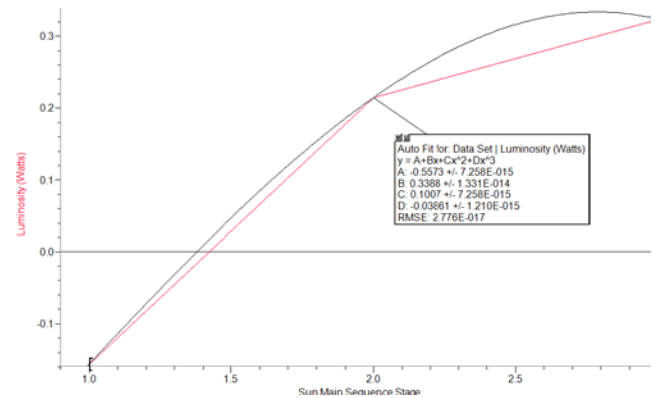

Fig. 5.Main Sequence Stage of Sun

This graph is made using the data procured from the simulation. This entire report's validity can be now tested by getting actual data of the sun's luminosity during the same age and then plotting a graph from the actual data and comparing it. Due to age factor, the possibility of obtaining results seems to be on hold. However, the paper holds promise can be carried on in later years to draw out a conclusion.

In the graph plotted, luminosity had been taken on the y-axis and time period on the x-axis and therefore the above equations contain two variables; Age of star (x) and Luminosity (y). If we have one value, either x or y, the other can be found using the equations. Now returning back to the question proposed in the introduction, "Finding another unique pale blue dot" For this two facts need to be considered;

- The age of star is enough to allow a planet to develop.
- The planet is placed at a correct distance from the star in order to have a sufficient quantity of liquid water.

The zone which is perfect for habitation is called Goldilocks zone. The size of habitable zone depends on the luminosity of the star. A variable, which now can be established for any stage of a star's life using the equations obtained above.
Hence instead of investing millions just to explore a planet

and play a bluff game in hopes of stumbling upon a planet suited for habitation, we know an absolute way of determining, when a star of say x luminosity at certain stage of its life will have an Earth like planet revolving around it at a particular distance (which can be found from the distance – luminosity relation) which can be used as our second home.

6. REFERENCES

[1]   "Distances to the Sun and Stars." Steven Dutch, Natural and Applied Sciences, University of Wisconsin - Green Bay, n.d. Web. <http%3A%2F%2Fwww.uwgb.edu%2Fdutchs%2Fcosmosnotes%2Fdistance.htm>.

[2]   "Imagine the Universe." National Aeronautics and Space Administration, n.d. Web. <http%3A%2F%2Fimagine.gsfc.nasa.gov%2Ffeatures%2Fyba%2FHTCas-size%2Fparallax3-derive.html>.

[3]   "Build Your Own Star." Schlumberger Excellence in Education Development, n.d. Web. <http%3A%2F%2Fwww.planetseed.com%2Flaboratory%2Fvirtual-experiment-build-your-own-star>.

[4]   "Build Your Own Star–Virtual Experiment." Build Your Own Star–Virtual Experiment. Schlumberger Excellence in Education Development, n.d. Web. 11 July 2015. <http://www.planetseed.com/files/flash/science/lab/airspace/byo_star/en/byostar.htm?width=805&height=550&popup=true>.

[5]   Tsokos, K. A. "Introduction to Astrophysics- Stellar Evolution." Physics for the IB Diploma. Cambridge: Cambridge UP, 2008. N. pag. Print.

[6]   "Protostar." Las Cumbres Observatory Global Telescope Network, n.d. Web. <https%3A%2F%2Flcogt.net%2Fspacebook%2Fprotostar%2F>.

[7]   Holland, Arthur, and Mark Williams. "Stellar Evolution : The Life and Death of Our Luminous Neighbors." Stellar. N.p., n.d. Web. 11 June 2015. <http://umich.edu/~gs265/star.htm>.

[8]   "Astroquizzical- Hertzsprung Gap." N.p., n.d. Web. <http%3A%2F%2Fastroquizzical.com%2Fpost%2F98649247018%2Fwhat-is-the-hertzsprung-gap-and-what-happens-to>.

[9]   Strain, Mark A. "Cosmic Entity: A Timeless Perception of the Universe."Google Books. N.p., n.d. Web. 11 July 2015. <https://books.google.co.in/books?id=Ic7YLrm0xvAC&pg=PA51&lpg=PA51&dq=Naked%2BHelium%2Bstage&source=bl&ots=inIm03AZz_&sig=-AM2xd7lB3R_ZbvqOE9SkLbeS4U&hl=en&sa=X&ved=0CEAQ6AEwBmoVChMIl8nQkbuFxgIVS6y8Ch1VlQAa#v=onepage&q=Naked%20Helium%20stage&f=false>.

[10]   Morris, Tom E. "Calculating the Habitable Zone." Planetary Biology. N.p., n.d. Web. <http%3A%2F%2Fwww.planetarybiology.com%2Fcalculating_habitable_zone.html>.

[11]   "The Habitable Zone." Department of Astronomy and Astrophysics- Pennstate University. N.p., n.d. Web. <https%3A%2F%2Fwww.e-education.psu.edu%2Fastro801%2Fcontent%2Fl12_p4.html>.

[12]   H. Foyle. "On the Main Sequence Band and the Hertzsprung Gap."1960MNRAS.120...22H Page 22. SAO/NASA Astrophysics Data System (ADS), n.d. Web. 1 July 2015. <http://articles.adsabs.harvard.edu/cgi-bin/nph-iarticle_query?bibcode=1960MNRAS.120...22H&db_key=AST&page_ind=0&data_type=GIF&type=SCREEN_VIEW&classic=YES>.

[13]   "Habitable Zone." SpringerReference (2011): n. pag. Web.