EYUBOGLU HIGH SCHOOL

EXTENDED ESSAY

PHYSICS

Which truths I can learn about Sun's evolution by analyzing EH Lib's light curve?

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ABSTRACT

The study of stellar evolution and the life and death of stars has direct implications for our knowledge about the future of our planet.

In this project, I will try to find an answer to the question below:

"Which truths I can learn about Sun's evolution by analyzing EH Lib's light curve?"

I analyzed CCD observations' data on EH Lib in details. EH Lib is a Delta Scuti star placed in Libra Constellation. My photometric CCD observations were made at Eyuboglu Twin Observatories in Istanbul with an unfiltered Meade Pictor 416 x T model CCD and a MEADE LX200 Schmidt-Cassegrain model telescope (D=305mm, F=3084mm-f/10).

My analysis is based on 2 nights of observations, with a total of 207 data points. I used several computer programmes and formulas to calculate EH Lib's luminosity, distance, mass, density, volume and radius. Then I compared my results with the Sun's values. The rest was estimating about the past of EH Lib and the future of the Sun.

As a result, the Sun will leave the main sequence since the hydrogen helium reaction in its core will be finished. After experiencing the same instabilities as EH Lib, the Sun will become a variable star, too. During night observations, I encountered several difficulties like light pollution and technical problems on CCD especially. I easily came over those problems; however, there is always a chance for them to create inaccuracies in my results.

Introduction

In this project I am looking for an answer to "Which truths I can learn about Sun's evolution by analyzing EH Lib's light curve?" Furthermore I do have some other personal reasons in choosing this star; EH Lib. When I was in AAVSO club here in school, I started to work on variable stars and then more deeply on Delta Scuti Variables. Little by little I improved myself in this area and learned more about the subject. Then I started to work on EH Lib personally and collected my own brightness data by using CCD[1]. In this respect I will work on physical (external) parameters of my star. My star's specific name is *Eh Lib,* which goes under Delta Scuti Stars.

Through out this essay, I will briefly give general information about the evolution of Sun-like stars, variable stars and Delta Scuti stars. Starting from the beginning; the audience will have a background to be able to understand what has been done and why these things have been done. Right after this entry, I will talk about my own observations of Eh Lib.

For each of these steps I used different tools and a photometric method, and I got to use these methods while working for AAVSO[2] which is a non-profit worldwide educational and scientific organization of both amateurs and professionals who are all interested in variable stars. As the first step I used CCD (Charge Coupled Device) to get my photometric photos of EH Lib directly on computer *(bib-3,8)*. The model I was using was *Pictor 416 XT* and I used *MAXIM DL 3.0* as the software of the CCD. Right after these parts I started to analyse photometric photos with another computer programme so called *MIDAS* [3] *(Munich Image Data Analysis System).* Then, there comes the part that I drew my light curve with Microsoft Excel. The rest

[1] CCDs are semiconductor chips divided up into rectangular grids of pixels that convert light into electrons. A photon of light strikes a CCD. The amount of charge accumulated in each pixel indicates how much light struck that pixel.
[2] AAVSO: (American Association of Variable Star Observers) http://www.aavso.org
[3] MIDAS: This program provides general tools for image processing and data reduction.

was composed of calculations based on the period value of EH Lib which is found from my data with Period98[4].

Finally, I will discuss a possible systematic effect of observational errors on the absolute magnitudes and how they can affect the results and try to enlighten the audience about the wide boundaries of this searching area. Equally important, I will try to compare my results with Sun and make some estimates about Sun's evolution. Because EH Lib is a Sun-like star which had just enters the instability state of its evolution and this can give us clues for the future of Sun.

[4] Period98: The software used to make calculate the period of a variable star from its light curves.

<u>BACKGROUND INFORMATION</u>

*** EH Lib is a Sun-like star and to be able to understand the change in its brightness, first we should talk about evolution and then determine both the Sun's and EH Lib's places in their evolution. (While writing this 'background information' part, I used some of my pervious knowledge on evolution from Astronomy Lessons, as well.)

<u>How is the evolution of a Sun-like star?</u> *(bib-1)*

In the very beginning, gas and dust particles collapse by their own gravity in the nebula. As a result of this fact, temperature rises and after a limit of temperature, the star is born as a proto-star. If the mass of the star is greater than the critical mass, a hydrogen helium reaction starts in its core. Critical mass means the sufficient amount of mass to start the hydrogen helium reaction in the core of the star.

During this reaction, hydrogen is changed into helium and when the reaction ends, there will be a helium core and hydrogen gas around it. Then with the end of the reaction, the star starts to collapse towards its core and when density gets high enough, the necessary temperature occurs. The star starts to collapse because the reaction stops in its core and that's why the energy, that holds the star's outer layers high, runs out. Also the massive stars run the reactions faster.

Meanwhile the hydrogen which creates the outer layers of star now, catches fire and with the help of this necessary heat in the star, this time the helium carbon reaction begins. Besides carbon is a more powerful element than hydrogen, this will create a more powerful pushing effect on the outer layers and that's why star will get bigger this time; its volume will increase.

The stars are lying in the main sequence while hydrogen helium reaction occurs in their core *(App.2)*. When this reaction turns to helium carbon reaction, the star starts to be a variable and gets our of main sequence.

Origin of Pulsation and evolutionary state *(bib-9)*

It is definitely established that is primaly the outer layers of the stars are pulsating. The fundamental cause was first recognized about 1960, after many authors had performed important preliminary work *(Newton-Teece, 368)*.

There are several different reasons for pulsation of variable stars. The two major reasons are; kappa mechanism and highly ionized helium layer. However, the most important reason for Delta Scuti Stars *(bib-2)* is the last one; highly ionized helium layer.

In the main, it is the zone where helium is doubly ionized which is responsible for driving the pulsation and this region lies a few hundred thousand km below the stellar surface. Within this zone, helium is increasingly ionized as the temperature rises towards the interior parts of the star, eventually with the increasing temperature helium becomes completely ionized. With a slight compression such as can always occur through some small disturbance, that is with an increase in pressure and temperature, there is a rise in the absorption of radiation within this zone. This additional energy over-compensates for the normal heat loss found in stable stars (which has a damping effect), and the expansion of the affected layers of gas overshoots the original rest position. This expansion now produces the opposite effect to that just described and an undamped oscillation results. In principle this can persist as long as the general evolutionary process maintains the dimensions and properties of the excitation zone within the star *(Newton-Teece, 374)*.

All calculations are in very good agreement with the observational evidence that Delta Scuti stars are at their evolutionary stage which the tendency to pulsations appears, and that the stars are only found within the region of the H-R Diagram *(App.2)* known as the instability strip. Massive stars reach this region considerably earlier and at a somewhat different position than the stars of just a single solar mass.

δ Scuti Stars *(bib-4)*

Stars, that change brightness, are called Variable Stars. (δ) Delta Scuties are stars that change brightness because they show periodic expansion and contraction of their surface layer as explained above and they are running helium carbon reaction in their core.

Delta Scuti stars is located on and just above the main sequence in an extension of the classical instability strip *(app.2)*. They have masses around 2 solar masses and spectral class A-F *(app.1)*. Typical pulsation periods range from half an hour to half a day, with amplitudes from 0.8 mag and down to the current photometric detection limit. They represent a later stage of stellar evolution of the Sun, burning hydrogen in a shell around a convective core.

Besides δ Scuti stars are Sun-like stars, hardly the Sun has a fairly average mass and lies in the middle part of the main sequence in contrast with δ Scuti stars. δ Scuti stars are lying in front of the Sun in the main sequence as can be seen in H-R Diagram *(app.2)*.

Most of these variable stars are thus only enable to photoelectric determination of their light curves and my star; EH Lib, is one of them. That's why I made CCD observations. Furthermore light curve is a graph which shows the brightness of an object over a period of time. In the study of objects which change their brightness over time, such as variable stars, the light curve is a sample but valuable tool to a scientist or an amateur observer like me to learn a variable star's period, phase and magnitude range. If we want to get some information about a star that is too far from us, only its light can be used because it is the only data that we can get from the star.

Research on variable stars is important because it provides information about stellar properties, such as mass, radius, luminosity, temperature, internal and external structure, composition and directly evolution *(bib-16).* Mostly a star's mass and temperature are the simplest values which can easily tell; in which step of its evolution the star does.

Studying δ Scuti stars *(bib-17)* will expand our knowledge about the Sun and the stars that have larger masses or that have evolved. Additionally, this will enable us to make comparison between the stars which are studied and the stars which has too many unknowns. For example, if we have two similar stars in hand, we can compare them if and only they are in the different stages of their evolution. This means one of them will give us the clues for the other's future.

EH Lib is in Libra constellation and my geographic location was suitable to observe that constellation in April and May. On the other hand the sky was clear enough to make a variable star observation in those months.

<u>What can we learn about Sun by studying of δ Scuti Stars?</u> *(bib-9)*

In the field of Astrophysics, studying δ Scuti Stars includes topics like chemical content of stars, physical movements and evolution. Therefore, we can learn some information about the future of the Sun by studying them. Because Delta Scuti stars are Sun-like stars and they are one step in front of the Sun in terms of their evolution (The Sun is running hydrogen helium reaction in its core while EH Lib is running helium carbon reaction in its core). So we can see what is going to happen to our Sun by studying Delta Scuti stars.

*** After all these background knowledge, now we can talk about my Observations which are the main source of my project;

OBSERVATION

DATA COLLECTION

How to make a variable star observation: *(bib-10)*

- Before Begin To Observation...

1. Turn on the power units and telescope. Open the dome set the physical mechanism ready for a night observation.
2. Make polar setting[5]. (Use *Guide 5.0* [6] when there is a need like finding an unknown star's position on the sky.)

- During The Observation…

3. I found EH Lib's coordinates (RA and Dec) from Guide. Enter the values, again by using keypad, to telescope and make sure that it finds the correct region. (Double-check the views; the one, which you see in Guide, and the one, which you obtain from telescope's ocular-view.)
4. Assemble the CCD camera on telescope and connect it to PC. Open MAXIM and set the options. Also I double-checked the focus of the telescope to be able to get a clear image.
5. I gave 10 seconds as exposure time. EH Lib has a short period, that's why I took one or two photos within a minute and after every 25 photos, I took dark photo for calibration which is used at the end by MIDAS.
6. I continued until I got sufficient data.
7. Disassemble the mechanism.

DATA TABLE *(App.3)*

[5] Polar Setting: After opening the telescope, we set declination 90^o and RA 0^o. Then we found polar star and middle it, we press ENTER from keypad. After this, telescope wants us to find a star to correct our setting. We find the star and enter it to keypad. If it finds it well then our polar setting is correct. We can find whatever we want just by entering its codes to the keypad.

[6] Guide: Guide is a Planetarium Computer Program, which uses a database of over 15 million star, thousands of deep-sky objects and thousands of asteroids and comets.

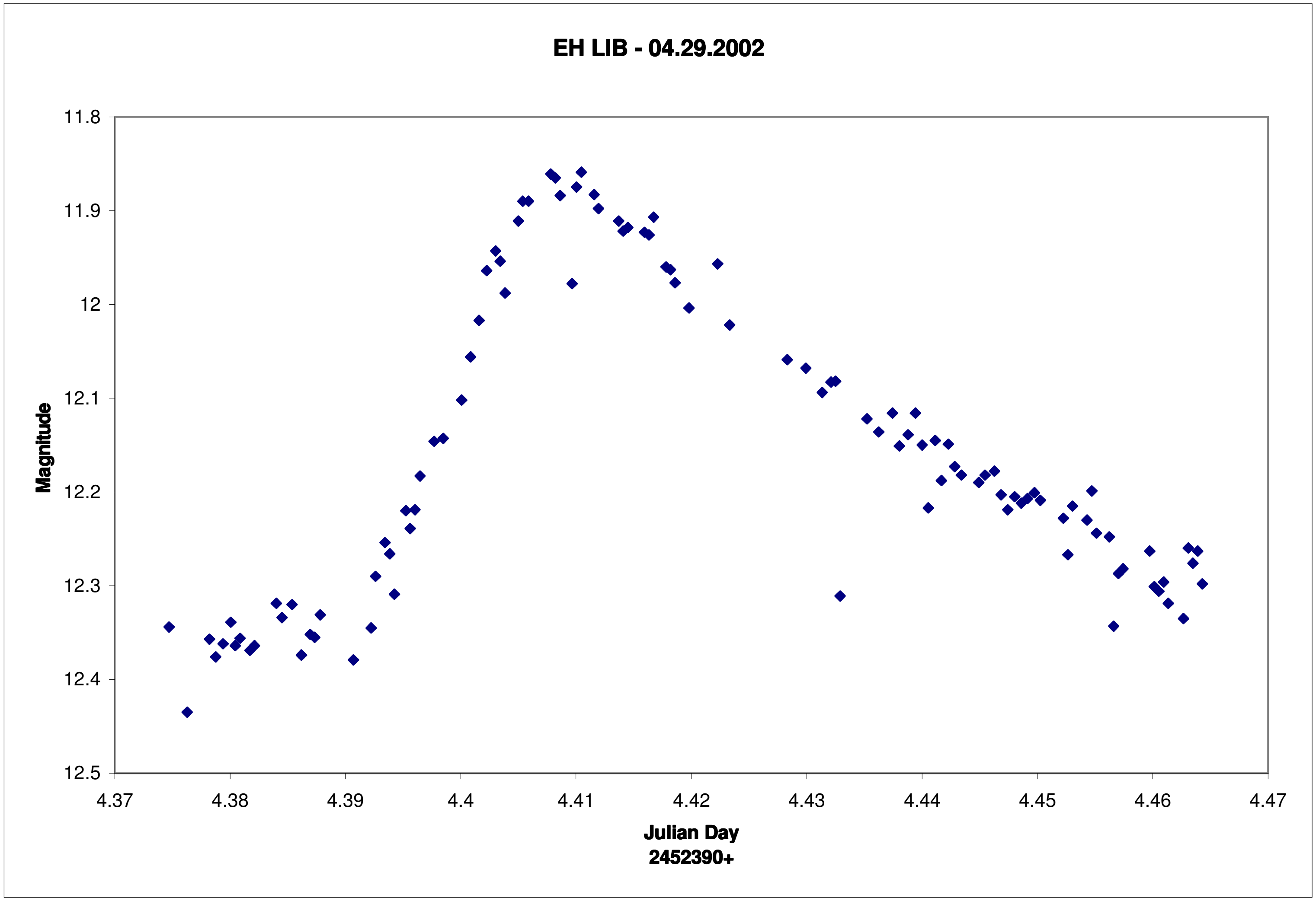
Background for Data Analysis: *(bib-12)*

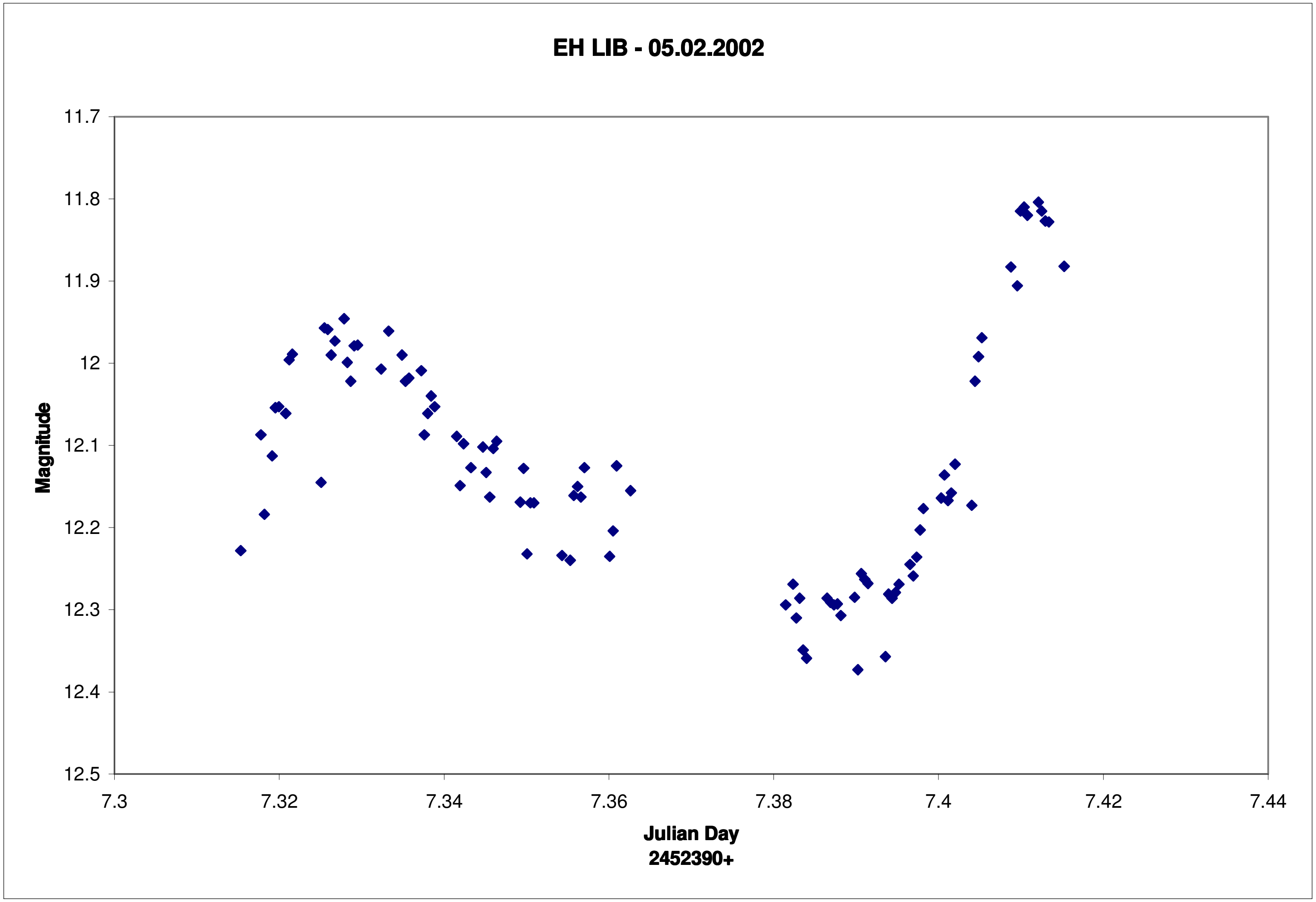
- MIDAS runs the magnitudes that listed in my Data Table. MIDAS is the software, which works on my CCD images and gives the magnitudes. The base, it uses, is DAOPHOT II which is a computer program for obtaining precise photometric indices and astrometric positions for stellar objects in two-dimensional digital images.
- The time is also written in Julian Date in my Data Table; I converted normal dates into JD because both the amateur and professional astronomers use it all around the world. Julian day 0 started at noon (UT) on January1, 4713 B.C. and for example; JD 2435000 is September 14, 1954. This is the way in which dates are written in all scientific astronomy works.

DATA PROCESSING AND PRESENTATION

Light Curves

The light curves below are drawn according to my two night observations data. One of them was in 29^{th} of April 2002 and the next one was in 2^{nd} of May 2002. In both of the light curves the vertical y-axis shows the magnitude and the horizontal x-axis shows the date. However, the *date* values are in Julian Day and they are calculated according to the year, day, local and universal times, hour, minute and second values. The reason for why we use this time unit is that my star EH Lib's period is 0.3 day which is shorter than a day, so there are changes in its magnitude even within minutes.


EH LIB - 04.29.2002
Magnitude
11.8
11.9
12
12.1
12.2
12.3
12.4
12.5
4.37
4.38
4.39
4.4
4.41
4.42
4.43
4.44
4.45
4.46
4.47
Julian Day
2452390+


EH LIB - 05.02.2002
Magnitude
11.7
11.8
11.9
12
12.1
12.2
12.3
12.4
12.5
7.3
7.32
7.34
7.36
7.38
7.4
7.42
7.44
Julian Day
2452390+

Formulas:

Pulsating variables repeat their changes and that's why they tend to be periodic. On this occasion, I started to analyse my data of EH Lib. The relationship between my star's period and luminosity called the *period-luminosity relationship*, lets me to find my star's luminosity because I already do have my period value which was calculated by Period98 (The computer programme which was used to find period of EH Lib from its light curve). Furthermore knowing that EH Lib's magnitude and its luminosity allow us to compute its absolute magnitude, which can be calculated by using the formula;

$$M_v = -3.58\log P - 1.96$$ *(bib-7)*

"Period-luminosity Relationship"

Thereby this enables us to use Pogson's Formula to calculate EH Lib's distance. We can find an observed Maximum value from the literature and combine these data to calculate its distance in forms of Parsec[7].

$$m - M_v = 5\log d - 5$$ *(bib-7)*

"Pogson's Formula"

The below formula will give us the mass of EH Lib in terms of Sun's mass. In this case, we can say that there is also a relationship between star's period and mass. This relation comes indirectly from series of equations but the main point is;

"$\log P = -0.3M_{bol} - 3\log T_{eff} - 0.5\log M + \log Q + \text{constant}$"

(bib-7) this equation includes magnitude, temperature, period, mass, pulsation constant and another constant. Starting from this equation the below formula comes out and lets us to calculate EH Lib's mass in terms of Sun's mass.

$$\log (M / M_{\odot}) = 0.575\log P + 0.795$$ *(bib-7)*

[7] Parsec (pc) : A unit of length normally used for distances beyond the solar system.

Actually the relation between the period of the star and its mass is not visually found yet, however, astronomers worked on statistical values of thousands of variable stars and result with an experimental relation between the period of the star and its mass.

Knowing the period of the variable star also lets us to calculate its density again in terms of Sun's density. However, we should use the pulsation constant which is calculated for δ Scuti Stars. This constant can be easily found from the astronomy literature. When EH Lib's brightness changes, this means its volume changes, too. This brightness changes are effecting the star's period. When the volume increases the star's density should decrease and when its volume decreases its density should increase. So this is the indirect reason of the relation between the star's period and its density.

$$P \sqrt{(\rho)} = Q$$ *(bib-7)*

Rest of the calculations is based on the simplest physics laws. To find EH Lib's volume, I use its mass value in terms of Sun and its density value again in terms of Sun. That's why I directly find EH Lib's volume in terms of Sun's volume.

$$\rho = M / V$$ *(bib-10)*

Lastly according to my volume value, I calculate the radius of EH Lib with the below formula which is used to find volume of a sphere where *r* is the radius. Eh Lib is a sphere and I know the volume and pi number, one unknown is left in the equation so that I can find the radius.

$$V_{sphere} = (4/3)\, \pi\, r^3$$ *(bib-10)*

<u>Variables:</u>

M_v : Absolute Magnitude

m : Max Magnitude

P : Period

d : Distance

M : Mass of star

$M_\odot$: Mass of Sun

T_{eff} : Effective Surface Temperature of the star (Temperature of the outer layers)

Q : Pulsation Constant (found experimentally according to the collected data on Delta Scuti stars) *[Astron. Astrophys. 327, 240]*

ρ : Density of star

r : Radius

V : Volume of star

*** Right after getting the light curves, Period98 calculated the period of EH Lib as *0.079* by analyzing the light curves. This software gives us more accurate results but if we try to find the star's period by ourselves; we should calculate the time passed between two crests or two troughs, which are seen in the light curves.

<u>Calculations:</u> (л is taken as 3.141592654)

1) Finding Absolute Magnitude: Brighter stars' periods are longer than fainter ones.

$M_v = -3.58\log P - 1.96$

$M_v = -3.58\log 0.079 - 1.96$ *(App.4)*

$M_v = -3.58 \times (-1.102372909) - 1.96$

$M_v = 3.946495013 - 1.96$

$M_v \approx 1^m.99$ *(nearest hundredth)*

2) Finding the distance of EH Lib:

$m - M_v = 5\log d - 5$

$9.35 - 1.99 = 5\log d - 5$ *(App.4)*

$7.36 = 5\log d - 5$

$12.36 = 5\log d$

$2.472 = \log d$

$d = \log^{-1}(2.472)$

$d \approx 296.48$ parsec *(nearest hundredth)*

3) Finding the mass of EH Lib in terms of Sun's mass: This gives us an approximate result because this period-mass relation is based on experimental mathematics. But after using this formula, we can have an idea about the mass of EH Lib and this will let us compare EH Lib and Sun in terms of their masses, too.

$\text{Log}\,(M/M_\odot) = 0.575\log P + 0.795$

$\text{Log}\,(M/M_\odot) = 0.575\log 0.079 + 0.795$ *(App.4)*

$\text{Log}\,(M/M_\odot) = 0.575 \times (-1.102372909) + 0.795$

$\text{Log}\,(M/M_\odot) = -0.6338644225 + 0.795$

$\text{Log}\,(M/M_\odot) = 0.1611355775$

$\text{Log}^{-1}(0.1611355775) = M / M_\odot$

$1.4492242 = M / M_\odot$

$1.45M_\odot \approx M$ *(nearest hundredth)*

>> $1.45 \times (2 \times 10^{30}) = 2.9 \times 10^{30}$ kg *(App.4)*

4) **Finding the density of EH Lib in terms of Sun's density:** As I have said before, maximum magnitude means the minimum diameter. Magnitude of the star changes and these periodic changes form its period. So when it is at its maximum magnitude, minimum diameter means density increases.

$P \sqrt{(\rho)} = Q$

$0.079 \sqrt{(\rho)} = 0.088$ *(App.4)*

$\sqrt{(\rho/\rho_\odot)} = 1.113924051$

$[\sqrt{(\rho/\rho_\odot)}\,]^2 = (1.113924051)^2$

$\rho/\rho_\odot = 1.240826791$

$\rho \approx 1.24\rho_\odot$ *(nearest hundredth)*

$>> 1.24 \times 1.41 = 1.7484\ g / cm^3$ *(App.4)*

5) **Finding the volume of EH Lib in terms of Sun's volume:**

$\rho = M / V$

$1.24 = 1.45 / V$

$0.8551724138 = V$

$0.86V_\odot \approx V$ *(nearest hundredth)*

$>> 0.86 \times 1.4 \times 10^{18} = 1.204 \times 10^{18}\ km^3$ *(App.4)*

6) **Finding the radius of EH Lib in terms of Sun's volume:**

$V_{sphere} = (4/3)\, \pi\, r^3$

$1.204 \times 10^{18} = (4/3)\, \pi\, r^3$

$[(1.204 \times 10^{18}) / (4/3)\, \pi]^{(1/3)} = [r^3]^{(1/3)}$

$[(1.204 \times 10^{18}) / 4.188790205]^{(1/3)} = r$

$[2.874338272 \times 10^{17}]^{(1/3)} = r$

$659952.42\ km \approx r$ *(nearest hundredth)*

CONCLUSION

	SUN	EH Lib
Mass (kg)	2 x 10^{30}	2.9 x 10^{30}
Volume (km^3)	1.4 x 10^{18}	1.1284 x 10^{19}
Density (g / cm^3)	1.41	1.7484
Radius (km)	7 x 10^5	2984636
Distance (pc)	8.20	296.48
Luminosity	$-26^{m}.81$	$1^{m}.99$

My research question was "Which truths I can learn about Sun's evolution by analyzing EH Lib's light curve?" Through the road in answering this question, I made variable star observations, I analyzed my data and according to these I formed the comparison chart above.

I drew my own light curves for EH Lib according to my two night observations' data, and I entered them to the computer program named Pictor98, which gave me the period of EH Lib as 0.079 days. First I used this value for period-luminosity relationship and calculated the luminosity of EH Lib. Obviously Sun seems to be much brighter to the observers on Earth. On the other hand, I used this luminosity value to calculate EH Lib's distance to our planet.

By computing this luminosity value into Pogson's formula, I calculated EH Lib's distance and the result was 296.48 parsec. Our Sun's distance to the Earth is 8.20 parsec and we also know that the closest galaxy to Milky Way is Andromeda, which is 7.8x10^5 parsec far from our system. For these reasons we can conclude that EH Lib is a Delta Scuti Star in our Galaxy. I suppose Sun and EH Lib were born at the same time because they are in the same galaxy. Equally important, finding the distance of variables in our galaxy gives us an idea about the boundaries of our galaxy.

As I have mentioned in the *Background Knowledge* part, δ Scuti Stars have masses around 2 solar masses. My result for EH Lib was 1.45 solar masses. This means

EH Lib has a larger mass than our Sun, and this makes EH Lib finish nuclear reactions in its core earlier. Because of this, EH Lib leaves main sequence earlier, too, and this results EH Lib to be one step ahead in evolution. This can be also seen in H-R Diagram.

The next thing, I found, was EH Lib's density. As can be seen in my comparison chart, EH Lib also has a different density than Sun's. We know the radius of EH Lib, so we can compute its volume. We know the mass of EH Lib, so we can divide to get its density. I found it as 1.7484 g/cm^3, certainly much more dense than the air in our atmosphere, because gravity compresses the gas in EH Lib and in Sun. EH Lib has a higher density than the Sun, caused by its higher mass. This higher density causes EH Lib to pass the main sequence faster.

Parallel to all these above statements, EH Lib's volume is also changing within its period. My result showed that EH Lib has a greater volume than that of Sun's. In addition to this, changes in volume can also explain the changes in density of EH Lib. In the equation *"density is equal to the mass over volume"*, if the mass stays constant and the density increases then volume should decrease and in the same situation, if density decreases then volume should increase this time. There are no such changes in Sun's nature right now. When the Sun becomes a variable, it will experience these changes.

That's why bigger volume also gives us a bigger radius. EH Lib's radius is also about 3 times bigger than that of Sun's. Additionally, maximum light corresponds to minimum diameter, because when a star gets denser, it reaches its maximum luminosity with increasing inside energy *(bib-1,9).* This also increases the radiation zone around the star which will affect the life on planets if there are such planets orbiting around such a star.

All these implements, totally, can drive us toward some results. First, we know that the Sun is still running the Hydrogen Helium reaction in its core and EH Lib is running Helium Carbon reaction in its core now. The Sun is approximately 5 billion years old. Eh Lib has a mass 1.45 times bigger than the Sun's mass so that as I have said in the previous parts, the massive stars run the reactions faster *(pg.4)*. This means if a star is massive, it will pass shorter time in the main. If EH Lib and the Sun were born at the same time, then EH Lib must also be 5 billion years old by now. However, EH Lib left the main sequence earlier, because its mass is larger than the Sun's. Therefore, if we make a simple reverse proportion; if a 1 solar massed star leaves the main sequence in 5 billion years, then a 1,45 solar massed star would leave the main sequence approximately in 3 billion years. In this case, when hydrogen helium reaction in the Sun's core is finished, it will leave the main sequence, experience the same instabilities as EH Lib and become a variable star.

Second, once upon a time EH Lib was also in the main sequence and running Hydrogen Helium reaction in its core. Stars which are in main sequence are not variable which means their brightness does not change and also their volumes do not change. This can make us think if there were planets orbiting around EH Lib while it was in the main sequence, it could have a system like our Solar System. Let's say there were planets orbiting around EH Lib and there was life on one of them. Organisms, on that planet, had to be resistant to the temperature and radiation, because EH Lib is a hotter star than the Sun. Also it scatters more radioactive particles to the outer space more than the Sun because it is massive than the Sun.

Third, one day the Sun will also finish Hydrogen Helium reaction and leave the main sequence and it will become a variable star, too. However, as can be also seen in the above statements, the Sun will enter that instability region later than EH Lib. That's why by looking at EH Lib we can see the Sun's probable future. When the Sun begins Helium Carbon reaction, it will become a variable on that day. Its volume will increase and probably the first three planets (Mercury, Venus, and Earth) will be swallowed by the Sun. After this, there will be some changes on the atmospheres and surfaces of the Mars, Jupiter, Saturn, Neptune, and Uranus because the Sun will be closer to them.

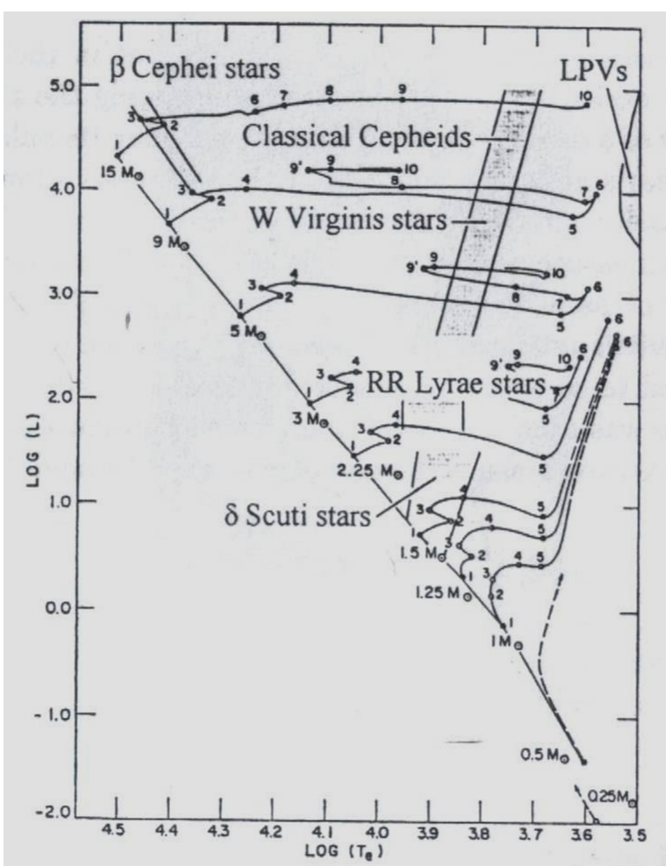
<u>APPENDIX</u>

1) *SPECTRAL CLASSES:* A classification system for stars according to their temperature values. The spectral classes are O, B, A, F, G, K, L, M. *(bib-5)*

<u>Type A</u> *Ex: Sirius, Vega*	*Degree: 20000 ^{o}F* *Color: blue* *Spectral character: Hydrogen predominant*
<u>Type F</u> *Ex: Procyon*	*Degree: 13500 ^{o}F* *Color: yellowish-white* *Spectral character : Hydrogen decreasing, metals increasing*
<u>Type G</u> Ex: Sun, Capella	Degree: 11000 ^{o}F Color: yellow Spectral character : Metals prominent

* The above spectral classes (A, F, G) are the ones which concern us in this project.

2) The H-R diagram is a way of showing the main properties of stars on a chart usually plotted with the star's colour, or spectral type along the bottom axis, and its brightness, or absolute magnitude up the side. The positions of actual stars can be plotted on the diagram, and the patterns we find can teach us a lot about the life cycle of stars.



3) Data Table:

Number of Data	Date	Julian Date (JD)	Time (h:m:s)	Magnitude (^{m})
1	29.04.2002	2452394,3747	20:51:35	12,344
2	29.04.2002	2452394,3763	20:53:50	12,435
3	29.04.2002	2452394,3782	20:56:38	12,357
4	29.04.2002	2452394,3788	20:57:24	12,376
5	29.04.2002	2452394,3794	20:58:20	12,362
6	29.04.2002	2452394,3801	20:59:17	12,339
7	29.04.2002	2452394,3804	20:59:50	12,364
8	29.04.2002	2452394,3809	21:00:26	12,356
9	29.04.2002	2452394,3817	21:01:40	12,369
10	29.04.2002	2452394,3821	21:02:14	12,364
11	29.04.2002	2452394,3840	21:04:59	12,319
12	29.04.2002	2452394,3845	21:05:40	12,334
13	29.04.2002	2452394,3854	21:06:56	12,320
14	29.04.2002	2452394,3862	21:08:05	12,374
15	29.04.2002	2452394,3862	21:08:05	12,374
16	29.04.2002	2452394,3869	21:09:12	12,352
17	29.04.2002	2452394,3873	21:09:46	12,355
18	29.04.2002	2452394,3878	21:10:26	12,331
19	29.04.2002	2452394,3907	21:14:02	12,379
20	29.04.2002	2452394,3922	21:14:36	12,345
21	29.04.2002	2452394,3926	21:16:49	12,290
22	29.04.2002	2452394,3934	21:17:22	12,254
23	29.04.2002	2452394,3938	21:18:33	12,266
24	29.04.2002	2452394,3942	21:19:07	12,309
25	29.04.2002	2452394,3952	21:19:42	12,220
26	29.04.2002	2452394,3956	21:21:09	12,239
27	29.04.2002	2452394,3960	21:21:42	12,219
28	29.04.2002	2452394,3965	21:22:18	12,183
29	29.04.2002	2452394,3977	21:22:54	12,146
30	29.04.2002	2452394,3985	21:24:41	12,143
31	29.04.2002	2452394,4001	21:25:49	12,102
32	29.04.2002	2452394,4009	21:28:06	12,056
33	29.04.2002	2452394,4016	21:29:15	12,017
34	29.04.2002	2452394,4022	21:30:17	11,964
35	29.04.2002	2452394,4030	21:31:14	11,943
36	29.04.2002	2452394,4034	21:32:22	11,954
37	29.04.2002	2452394,4038	21:32:56	11,988
38	29.04.2002	2452394,4050	21:33:31	11,911
39	29.04.2002	2452394,4054	21:35:11	11,890
40	29.04.2002	2452394,4059	21:35:45	11,890
41	29.04.2002	2452394,4078	21:36:27	11,861

42	29.04.2002	2452394,4082	21:39:15	11,865
43	29.04.2002	2452394,4086	21:39:49	11,884
44	29.04.2002	2452394,4097	21:40:24	11,978
45	29.04.2002	2452394,4100	21:41:54	11,875
46	29.04.2002	2452394,4105	21:42:28	11,859
47	29.04.2002	2452394,4116	21:43:03	11,883
48	29.04.2002	2452394,4120	21:44:39	11,898
49	29.04.2002	2452394,4137	21:45:13	11,911
50	29.04.2002	2452394,4141	21:47:43	11,922
51	29.04.2002	2452394,4145	21:48:17	11,918
52	29.04.2002	2452394,4159	21:48:52	11,923
53	29.04.2002	2452394,4163	21:50:56	11,926
54	29.04.2002	2452394,4167	21:51:30	11,907
55	29.04.2002	2452394,4178	21:52:05	11,960
56	29.04.2002	2452394,4182	21:53:37	11,963
57	29.04.2002	2452394,4186	21:54:11	11,977
58	29.04.2002	2452394,4198	21:54:46	12,004
59	29.04.2002	2452394,4223	21:56:30	11,957
60	29.04.2002	2452394,4233	22:00:05	12,022
61	29.04.2002	2452394,4283	22:01:34	12,059
62	29.04.2002	2452394,4299	22:08:46	12,068
63	29.04.2002	2452394,4314	22:11:05	12,094
64	29.04.2002	2452394,4321	22:13:09	12,083
65	29.04.2002	2452394,4325	22:14:14	12,082
66	29.04.2002	2452394,4329	22:14:48	12,311
67	29.04.2002	2452394,4352	22:15:23	12,122
68	29.04.2002	2452394,4362	22:18:44	12,136
69	29.04.2002	2452394,4374	22:20:11	12,116
70	29.04.2002	2452394,4380	22:21:55	12,151
71	29.04.2002	2452394,4388	22:22:47	12,139
72	29.04.2002	2452394,4394	22:23:53	12,116
73	29.04.2002	2452394,4400	22:24:46	12,150
74	29.04.2002	2452394,4406	22:25:37	12,217
75	29.04.2002	2452394,4411	22:26:24	12,145
76	29.04.2002	2452394,4417	22:27:15	12,188
77	29.04.2002	2452394,4423	22:28:01	12,149
78	29.04.2002	2452394,4428	22:28:52	12,173
79	29.04.2002	2452394,4434	22:29:42	12,182
80	29.04.2002	2452394,4449	22:30:32	12,190
81	29.04.2002	2452394,4455	22:32:41	12,182
82	29.04.2002	2452394,4463	22:33:28	12,178
83	29.04.2002	2452394,4469	22:34:38	12,203
84	29.04.2002	2452394,4474	22:35:29	12,219
85	29.04.2002	2452394,4480	22:36:18	12,205
86	29.04.2002	2452394,4486	22:37:10	12,212
87	29.04.2002	2452394,4492	22:38:00	12,207

88	29.04.2002	2452394,4498	22:38:47	12,201
89	29.04.2002	2452394,4503	22:39:39	12,209
90	29.04.2002	2452394,4523	22:40:24	12,228
91	29.04.2002	2452394,4527	22:43:15	12,267
92	29.04.2002	2452394,4531	22:43:49	12,215
93	29.04.2002	2452394,4543	22:44:24	12,230
94	29.04.2002	2452394,4547	22:46:13	12,199
95	29.04.2002	2452394,4551	22:46:48	12,244
96	29.04.2002	2452394,4562	22:47:23	12,248
97	29.04.2002	2452394,4566	22:48:59	12,343
98	29.04.2002	2452394,4570	22:49:32	12,287
99	29.04.2002	2452394,4574	22:50:08	12,282
100	29.04.2002	2452394,4597	22:50:43	12,263
101	29.04.2002	2452394,4601	22:54:02	12,301
102	29.04.2002	2452394,4605	22:54:36	12,306
103	29.04.2002	2452394,4610	22:55:11	12,296
104	29.04.2002	2452394,4614	22:55:47	12,319
105	29.04.2002	2452394,4627	22:56:22	12,335
106	29.04.2002	2452394,4631	22:58:16	12,260
107	29.04.2002	2452394,4635	22:58:51	12,276
108	29.04.2002	2452394,4639	23:59:26	12,263
109	29.04.2002	2452394,4643	23:00:01	12,298
110	02.05.2002	2452397,3153	19:26:03	12,228
111	02.05.2002	2452397,3178	19:29:01	12,087
112	02.05.2002	2452397,3182	19:29:35	12,184
113	02.05.2002	2452397,3191	19:30:11	12,113
114	02.05.2002	2452397,3195	19:31:31	12,054
115	02.05.2002	2452397,3199	19:32:06	12,053
116	02.05.2002	2452397,3208	19:32:41	12,061
117	02.05.2002	2452397,3212	19:33:55	11,996
118	02.05.2002	2452397,3216	19:34:29	11,989
119	02.05.2002	2452397,3251	19:35:05	12,145
120	02.05.2002	2452397,3255	19:40:06	11,957
121	02.05.2002	2452397,3259	19:40:40	11,959
122	02.05.2002	2452397,3263	19:41:15	11,990
123	02.05.2002	2452397,3267	19:41:51	11,973
124	02.05.2002	2452397,3279	19:42:29	11,946
125	02.05.2002	2452397,3283	19:44:06	11,999
126	02.05.2002	2452397,3287	19:44:40	12,022
127	02.05.2002	2452397,3291	19:45:16	11,979
128	02.05.2002	2452397,3295	19:45:52	11,978
129	02.05.2002	2452397,3323	19:46:28	12,007
130	02.05.2002	2452397,3333	19:50:34	11,961
131	02.05.2002	2452397,3349	19:51:54	11,990
132	02.05.2002	2452397,3353	19:54:14	12,022
133	02.05.2002	2452397,3357	19:54:50	12,018

134	02.05.2002	2452397,3372	19:55:26	12,009
135	02.05.2002	2452397,3376	19:57:34	12,087
136	02.05.2002	2452397,3380	19:58:07	12,061
137	02.05.2002	2452397,3384	19:58:43	12,040
138	02.05.2002	2452397,3388	19:59:19	12,053
139	02.05.2002	2452397,3415	19:59:54	12,089
140	02.05.2002	2452397,3424	20:03:48	12,098
141	02.05.2002	2452397,3419	20:04:59	12,149
142	02.05.2002	2452397,3432	20:04:22	12,127
143	02.05.2002	2452397,3447	20:06:15	12,102
144	02.05.2002	2452397,3451	20:08:22	12,133
145	02.05.2002	2452397,3455	20:08:56	12,163
146	02.05.2002	2452397,3459	20:09:32	12,104
147	02.05.2002	2452397,3464	20:10:09	12,095
148	02.05.2002	2452397,3492	20:10:46	12,169
149	02.05.2002	2452397,3496	20:14:54	12,128
150	02.05.2002	2452397,3501	20:15:28	12,232
151	02.05.2002	2452397,3505	20:16:04	12,170
152	02.05.2002	2452397,3509	20:16:40	12,170
153	02.05.2002	2452397,3543	20:17:16	12,234
154	02.05.2002	2452397,3553	20:22:11	12,240
155	02.05.2002	2452397,3557	20:23:37	12,161
156	02.05.2002	2452397,3562	20:24:15	12,150
157	02.05.2002	2452397,3566	20:24:53	12,163
158	02.05.2002	2452397,3570	20:25:29	12,127
159	02.05.2002	2452397,3601	20:26:06	12,235
160	02.05.2002	2452397,3605	20:30:30	12,204
161	02.05.2002	2452397,3609	20:31:07	12,125
162	02.05.2002	2452397,3626	20:31:43	12,155
163	02.05.2002	2452397,3815	20:34:10	12,294
164	02.05.2002	2452397,3823	21:01:17	12,269
165	02.05.2002	2452397,3827	21:02:34	12,310
166	02.05.2002	2452397,3832	21:03:08	12,286
167	02.05.2002	2452397,3836	21:03:44	12,349
168	02.05.2002	2452397,3840	21:04:20	12,359
169	02.05.2002	2452397,3865	21:04:56	12,286
170	02.05.2002	2452397,3869	21:08:30	12,291
171	02.05.2002	2452397,3873	21:09:07	12,294
172	02.05.2002	2452397,3877	21:09:43	12,293
173	02.05.2002	2452397,3881	21:10:19	12,307
174	02.05.2002	2452397,3898	21:10:55	12,285
175	02.05.2002	2452397,3902	21:13:18	12,373
176	02.05.2002	2452397,3906	21:13:52	12,256
177	02.05.2002	2452397,3910	21:14:28	12,263
178	02.05.2002	2452397,3914	21:15:04	12,268
179	02.05.2002	2452397,3936	21:15:40	12,357

180	02.05.2002	2452397,3939	21:18:42	12,281
181	02.05.2002	2452397,3944	21:19:16	12,286
182	02.05.2002	2452397,3948	21:19:52	12,279
183	02.05.2002	2452397,3952	21:20:28	12,269
184	02.05.2002	2452397,3965	21:21:04	12,245
185	02.05.2002	2452397,3969	21:23:00	12,259
186	02.05.2002	2452397,3973	21:23:34	12,236
187	02.05.2002	2452397,3978	21:24:09	12,203
188	02.05.2002	2452397,3982	21:24:45	12,177
189	02.05.2002	2452397,4003	21:25:20	12,164
190	02.05.2002	2452397,4007	21:28:26	12,136
191	02.05.2002	2452397,4011	21:29:01	12,167
192	02.05.2002	2452397,4016	21:29:38	12,158
193	02.05.2002	2452397,4020	21:30:14	12,123
194	02.05.2002	2452397,4040	21:30:51	12,173
195	02.05.2002	2452397,4044	21:33:47	12,022
196	02.05.2002	2452397,4048	21:34:22	11,992
197	02.05.2002	2452397,4053	21:34:58	11,969
198	02.05.2002	2452397,4088	21:35:34	11,883
199	02.05.2002	2452397,4095	21:40:38	11,906
200	02.05.2002	2452397,4100	21:41:44	11,815
201	02.05.2002	2452397,4104	21:42:19	11,810
202	02.05.2002	2452397,4108	21:42:56	11,820
203	02.05.2002	2452397,4121	21:43:32	11,804
204	02.05.2002	2452397,4125	21:45:27	11,815
205	02.05.2002	2452397,4130	21:46:01	11,827
206	02.05.2002	2452397,4134	21:46:38	11,828
207	02.05.2002	2452397,4152	21:47:14	11,882

4)

Some of the physical values of Sun which have to be known for this project *(bib-15)***:**		
V⊙	Volume of Sun	1.4×10^{18} km^3
r⊙	Radius of Sun	7×10^5 km
M⊙	Mass of Sun	2×10^{30} kg
ρ⊙	Density of Sun	1.41 g / cm^3
d⊙	Distance of Sun	8.20 pc
Luminosity of Sun *(bib-6)*		$-26^m.81$
EH Lib's phase value and maximum magnitude taken from literature:		
Q	Pulsation Constant	0.088
m	Maximum magnitude *(bib-13)*	$9^m.35$
P	Period	0.079

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