Aum Varadarajan

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A Short Study of Variable Stars

By Aum Varadarajan

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Abbreviations Used

Abbreviation	Meaning	Value
M⊙	Solar Mass	1.985×10^{30} kg
L⊙	Solar Luminosity	3.828×10^{26} W
R⊙	Solar Radius	695,000 km
TESS	Transiting Exoplanet surveying Satellite	-
LS Periodogram	Lomb-Scargle Periodogram	-
px	pixel	-

Introduction

Definition

A Variable Star is any star whose Luminosity or Brightness changes with respect to time, while technically correct this is actually a very vague and generalized definition since the star can change in brightness slightly or massively, Gradually or Sharply and/or they can change in brightness irregularly or regularly with time, for ease of processing I've chosen stars that have a predictable cyclical pattern, that is they vary in luminosity over short regular intervals.

Types of variable stars

There are several types of variable stars depending on internal or external factors, long or short periods and the way they brighten up or dim down as shown in the flowchart below [1]. The boxes in orange are the variable stars chosen for my study due to their ease of processing, Regularity and relatively short time periods.

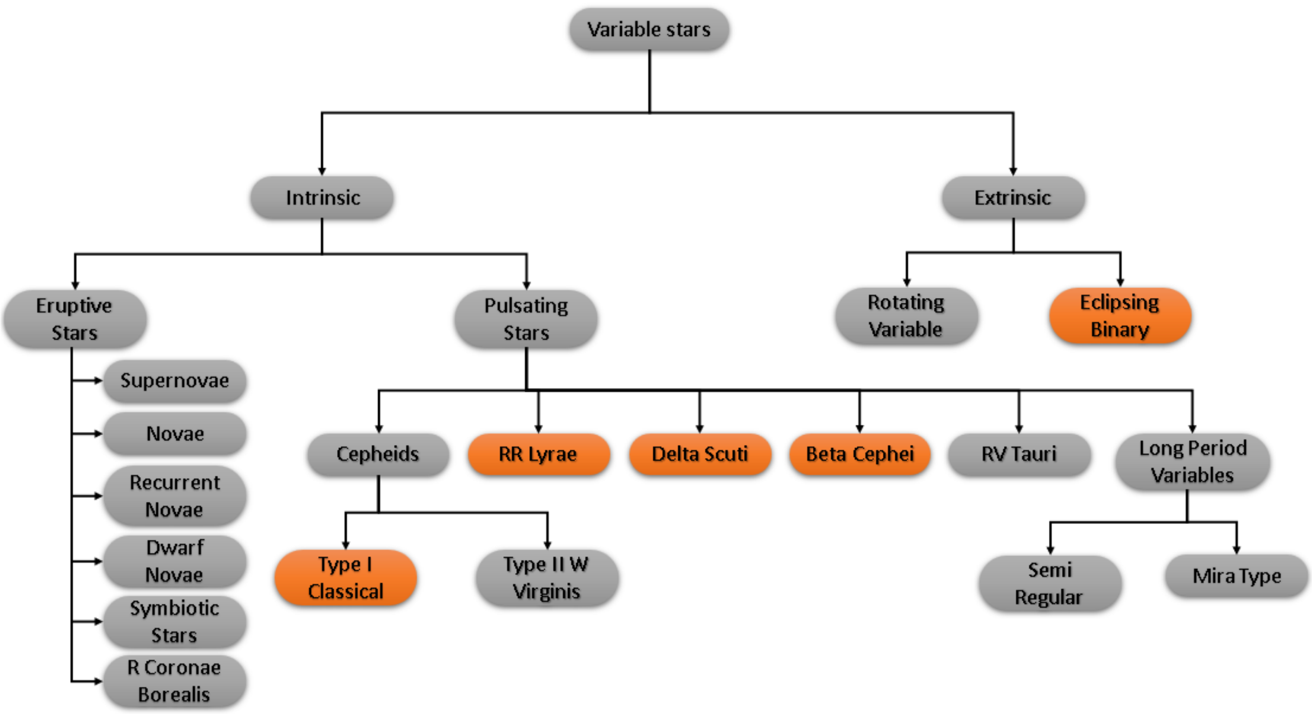


Fig 1: Flowchart of variable stars

Brief Overview of Selected types:

1. Eclipsing Binary

Eclipsing binaries are extrinsic variable stars i.e. Their variability In luminosity depends on external variables, like a star occulting or eclipsing one and other. For an Eclipsing binary to be detected the orbital plane of binary system must be edge on or close to edge on so that the two stars eclipse each other and the dip in luminosity can be observed.

2

2. RR Lyrae Type

RR Lyrae variable stars are usually low mass stars that have passed the main sequence phase,

1

red giant phase and have started helium fusion in their core with short periods of just a few hours. They are commonly found in globular clusters. the name comes from RR Lyrae, the brightest star in its class

3. Classical Cepheid Type

Classical cepheids are relatively high mass and high luminosity stars ranging from 4-10 M⊙ with fairly long periods ranging from a few days to months. Cepheids are known for their near perfect consistency in maintaining their regular periods, This regularity enables us to determine distances to other galaxies due to the period-luminosity relationship. The name of this class of stars comes from Delta Cephei, which was one of the first discovered cepheids.

2

4. Delta Scuti type

Delta Scuti type variable stars are similar to classical cepheids but have a much shorter period (few minutes to hours) and generally lower mass ranging from 1.5-2.5 M⊙ and with only minor variations in brightness compared to classical cepheids. This class is named after the most famous star in its class, Delta Scuti.

5. Beta Cephei type

Beta Cephei type variable stars share the shorter period and minor magnitude changes of the delta Scuti type variable stars but are much more massive and in the main sequence ranging from 7-20 M⊙ this class of stars is named after Beta Cephei.

Stars Selected for the study:

These stars have been selected due the large amount of variability, masses, spectral types, popularity and ease of processing using Python plugins like LightKurve and Astropy. The LightKurve plugin extracts the open-source data from NASA's Transiting Exoplanet Survey Satellite (TESS). All data except my calculated time and percentage error are pulled from Wikipedia and TESS databases [2] [3]

Bayer Classification of Star	Common Name	Constellation	Right Ascension	Declination	Hemisphere	Variable Star Type	Magnitude	Spectral Class	Distance (Lyr)	Mass (M⊙)
RR Lyrae	-	Lyra	$19^h 25^m 27.9129^s$	+42° 47′ 03.6942″	Northern	RR Lyrae Type	7.06 -8.12	A7-F8	900 ± 60	0.65
α Ursae Minoris	Polaris	Ursa Minor	$02^h 31^m 49.09^s$	+89° 15′ 50.8″	Northern	Classical Cepheid Type	1.86 - 2.13	F7Ib	446.5±1.1	5.13
β Persei	Algol	Perseus	$03^h 08^m 10.1325^s$	+40° 57′ 20.3280″	Northern	Eclipsing Binary (Algol type)	2.1 - 3.4	B8V	94 ± 2	3.17
δ Scuti	-	Scutum	$18^h 42^m 16.4269^s$	-09°01′ 37.3"	Southern	Delta Scuti Type	4.60 - 4.79	F2 IIIp	201 ± 1	1.97
β Cephei	Alfirk	Cephus	$21^h 28^m 39.5969^s$	+70° 33′ 38.5747″	Northern	Beta Cephei Type	3.16 - 3.27	B1 IV	690 ± 40	7.4
XZ Cygni	-	Cygnus	$19^h 32^m 29.4^s$	+56° 23′ 37.0"	Northern	RR Lyrae Type	8.7 - 10.4	A5	1424	-
TU Ursae Majoris	-	Ursa Major	$11^h 29^m 48.489^s$	+30° 04′ 02.38″	Northern	RR Lyrae Type	9.26 - 10.24	A2-F0	2,090 ± 30	0.55
V397 Puppis	-	Puppis	$07^h 49^m 14.6^s$	-35°14′ 18.3"	Southern	Eclipsing Binary (Algol type)	5.91	B9V	486	3.08
PT Velorum	-	Vela	$09^h 10^m 57.1^s$	-43° 15′ 45.9"	Southern	Eclipsing Binary (Algol type)	7.03	A0V	557.7	2.2
BG Crucis	-	Crux	$12^h 31^m 40.33011^s$	−59° 25′ 26.1224″	Southern	Classical Cepheid Type	5.34 - 5.58	F5Ib - G0p	1,830 ± 90	4.3/ 6.3
Gamma Pegasi	Algenib	Pegasus	$00^h 13^m 14.15123^s$	+15° 11′ 00.9368″	Northern	Beta Cephei Type	2.78 -2.89	B2 IV	470 ± 30	8.8
AI Velorum	-	Vela	$08^h 14^m 05.146^s$	−44° 34′ 32.85″	Southern	Delta Scuti Type	6.15 - 6.76	A9IV-V	327.1 ± 0.6	1.55
V473 Lyrae	-	Lyra	$19^h 15^m 59.48949^s$	+27° 55′ 34.6870″	Northern	Classical Cepheid Type	5.99 - 6.35	F7 II	1803.4	3.0
59 Orionis	-	Orion	$05^h 58^m 24.44302^s$	+01° 50′ 13.5902″	Northern	Eclipsing Binary (Algol Type) Delta Scuti Type	5.88 - 5.92	A7-F5	348 ± 1	2.15
Beta Crucis	Mimosa	Crux	$12^h 47^m 43.26877^s$	−59° 41′ 19.5792″	Southern	Beta Cephei Type	1.23 - 1.31	B0.5 III - B2V	280 ± 20	14.5

Steps involved in processing

Step 1

we first begin by initializing and importing the relevant python plugins like lightkurve to obtain data, astropy for period determination using the Lomb Scargle algorithm, numpy and matplotlib for normalising and plotting the raw data

Step 2

We use the lc_search function to search the light curve data for the star in question from the TESS library and then use the .download() function to save the light curve

Step 3

After obtaining the data from the TESS database we first have to normalise and center the data to ensure consistency across stars with varying brightnesses and dips. After normalisation and centering we plot the data as a flux vs time graph.

Step 4

We extract the luminous flux and time of the light curve and set a range or frequency of the predicted period depending on the type of variable star for example, in a RR Lyrae type star we would set the min and max time between a few minutes and a day. The Lomb-Scargle Periodogram algorithm is used to find and detect periodic signals (drop in luminosity in this case) using the function LombScargle (time, flux) and plot a graph between the "power" and frequency/ time, a higher power means a higher probability of the period lying at that point. Usually the frequency/ time at which the power is the highest is where the true period of the star lies. Due to the periodic nature of the signal there are peaks at the harmonics of the signal too i.e. Peaks at N/2, N/3, 2N, 3N etc but in good quality and consistent data the real time period N is chosen by the algorithm.

Step 5

In the fifth step we plot the scatter plot of the light curve data over a specific range to show the oscillation of the luminosity with the best period of the LS periodogram at the top of the graph.

Results

The flux vs time plots of the nine stars with the star's time periods are obtained using the python processing workflow below segregated into their respective variable star types.

1. Eclipsing Binaries

Types of binary eclipses

To understand the mechanics of a binary eclipse we will take the reference frame of the larger star for ease of understanding irrespective of temperature or spectral class. to understand why the brightness dips understand that the Hotter the star is the more flux is produced "per unit area" and the larger the star the lower flux is produced "per unit area". It's also important to note that the Luminosity of a star depends on the Square of the star's radius and to the fourth power of the temperature so doubling the radius increases the luminosity by a factor of 4 but doubling the temperature would increase the luminosity by a factor of 16 i.e. $L \propto R^2 T^4$. for the 2nd type due to this relation the hotter, smaller star is almost always is "brighter per unit area".

1. **Hotter, larger star and Cooler, Smaller star**

   This system consists of a Hotter, larger star and a Cooler, Smaller star. When the cooler star eclipses the larger star or is in "front" of it the dip in brightness is larger (Primary Eclipse) due to the dimmer star blocking some of the bright energetic light of the star. When the smaller star is "behind" the larger one the dip in brightness is lower (Secondary Eclipse) due to the brighter and hotter star being unobstructed.

2. **Hotter, smaller star and Cooler, larger star**

   This system consists of a Hotter, Smaller star and a Cooler, larger star. When the smaller star eclipses the larger star or is in "front" of it the dip in brightness is smaller (Secondary Eclipse) due to the hotter star blocking some of the low energy of the larger star. When the smaller star is "behind" the larger one the dip in brightness is larger (Primary Eclipse) due to the larger star completely obstructing the smaller star.

a. Beta Persei (Algol) System

The Beta Persei (Algol) system is the most studied eclipsing binary system and is the model star system for this type of eclipsing binary due to its familiarity and brightness. [2]

Period (days)	2.8959	
Eccentricity	0	
Star Characteristics	Beta Persei A (Primary)	Beta Persei B (Companion)
Mass (M⊙)	3.17	0.7
Luminosity (L⊙)	182	6.92
Radius (R⊙)	2.73	3.48
Spectral Class	B8V	K0IV

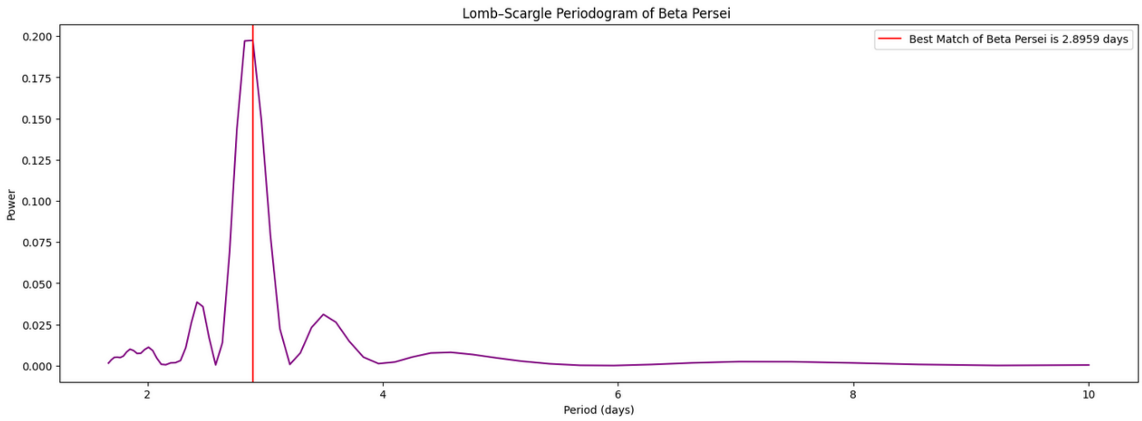
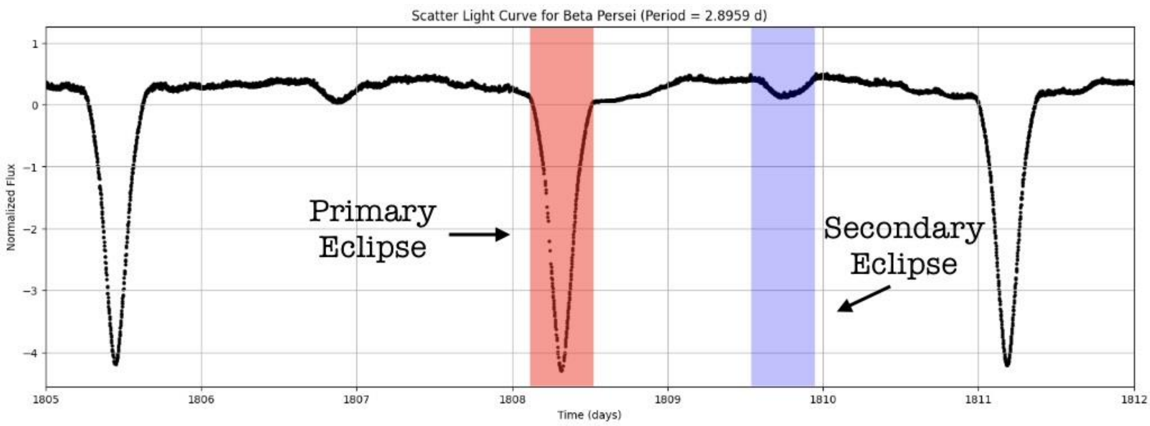


Fig 2: Lomb-Scargle Periodogram of the Beta Persei System



10 Fig 3: Scatter plot of the light curve of the Beta Persei System

b. V397 Puppis System

The mass, eccentricity, luminosity, spectral class and radius of the V397 puppis star system except for the primary star is largely unknown.

Period (days)	3.0394	
Eccentricity	-	
Star Characteristics	V387 Puppis Aa (Primary)	V387 Puppis Ab (Companion)
Mass (M⊙)	3.08	-
Luminosity (L⊙)	-	-
Radius (R⊙)	-	-
Spectral Class	B9V	-

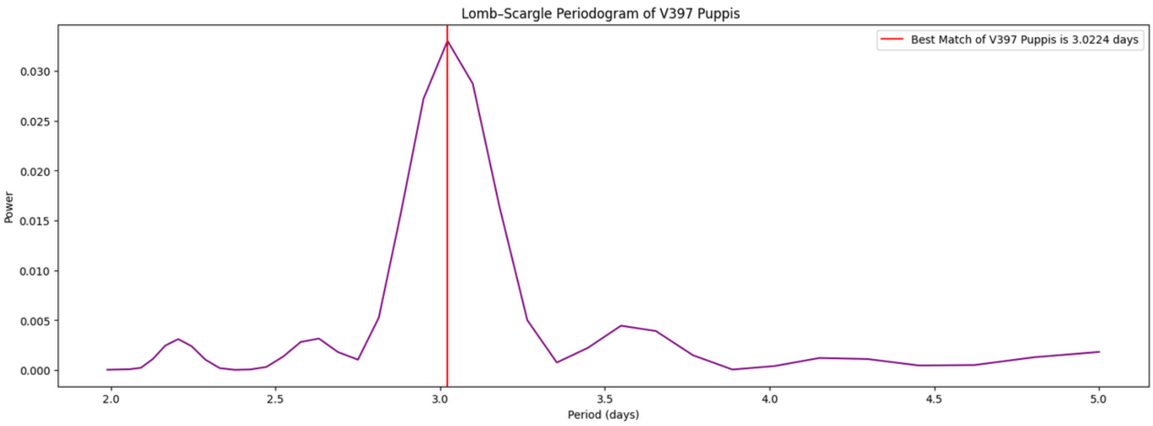


Fig 4: Lomb-Scargle Periodogram of the V397 Puppis System

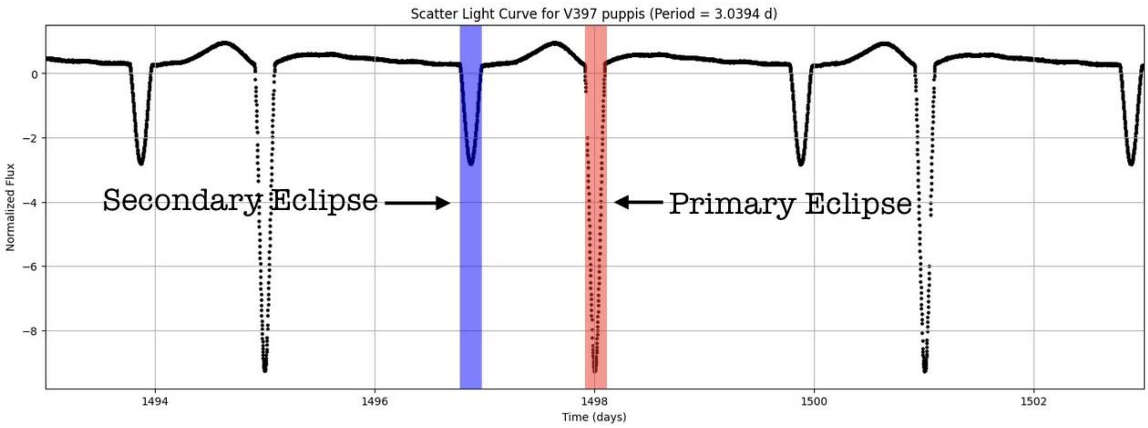


Fig 5: Scatter plot of the light curve of the V397 Puppis System

c. PT Velorum System

The mass, eccentricity, luminosity, spectral class and radius of the PT Velorum star system except for the primary star is largely unknown.

Period (days)	1.8127	
Eccentricity	-	
Star Characteristics	PT Velorum A (Primary)	PT Velorum B (Companion)
Mass (M⊙)	2.20	-
Luminosity (L⊙)	-	-
Radius (R⊙)	-	-
Spectral Class	A0V	-

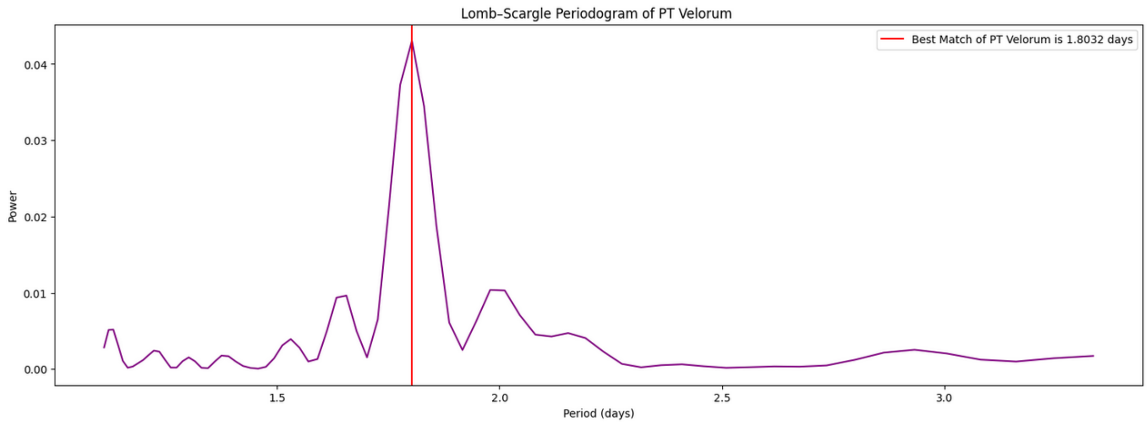


Fig 6: Lomb-Scargle Periodogram of the PT Velorum System

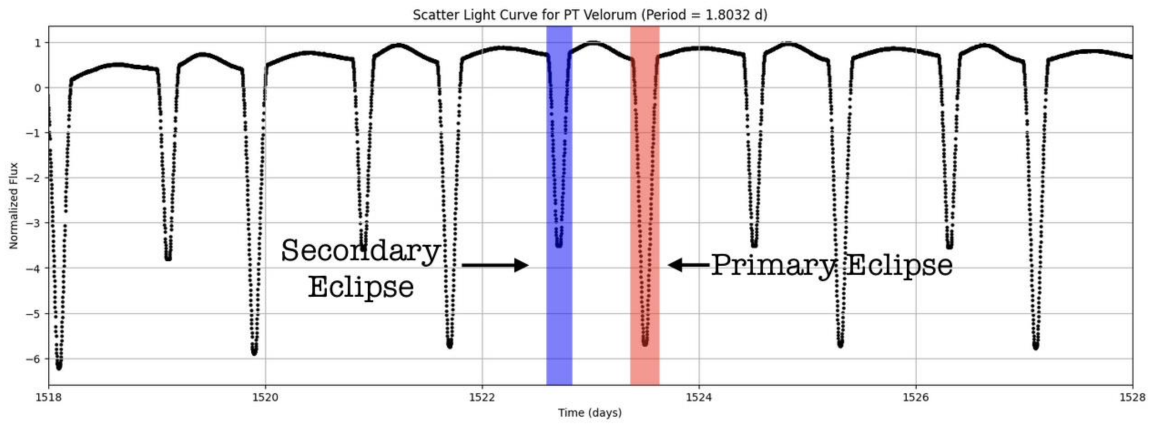


Fig 7: Scatter plot of the light curve of the PT Velorum System

10

d. 59 Orionis System

59 Orionis System is Unique in this list of stars as its both an eclipsing binary system and the primary star is a Delta Scuti Variable star as well hence we get the unique light curve. The Delta Scuti part of this system will be discussed in the Delta Scuti section. [2]

Period (days)	2.7449	
Eccentricity	0.02	
Star Characteristics	59 Orionis A (Primary)	59 Orionis B (Companion)
Mass (M⊙)	2.15	0.73
Luminosity (L⊙)	25	-
Radius (R⊙)	2.78	-
Spectral Class	A7-F5	-

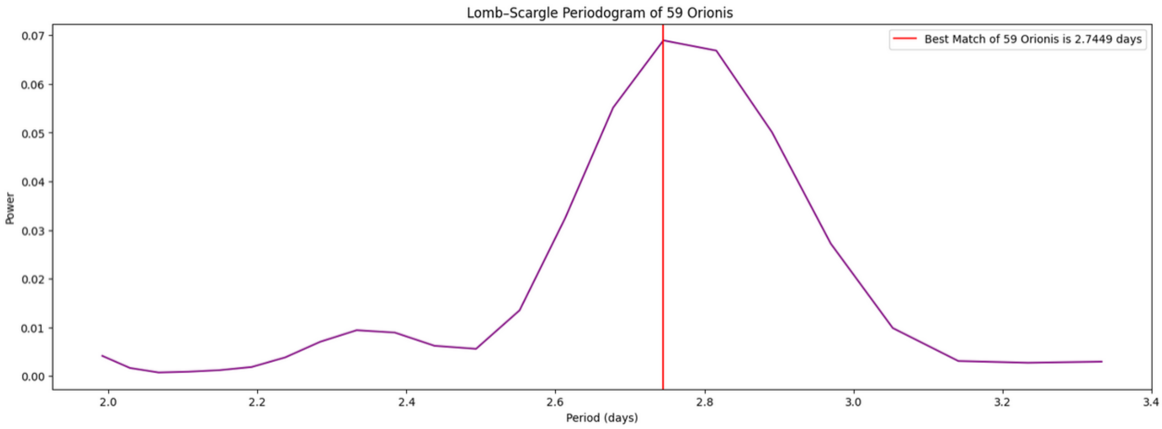


Fig 8: Lomb-Scargle Periodogram of the 59 Orionis System

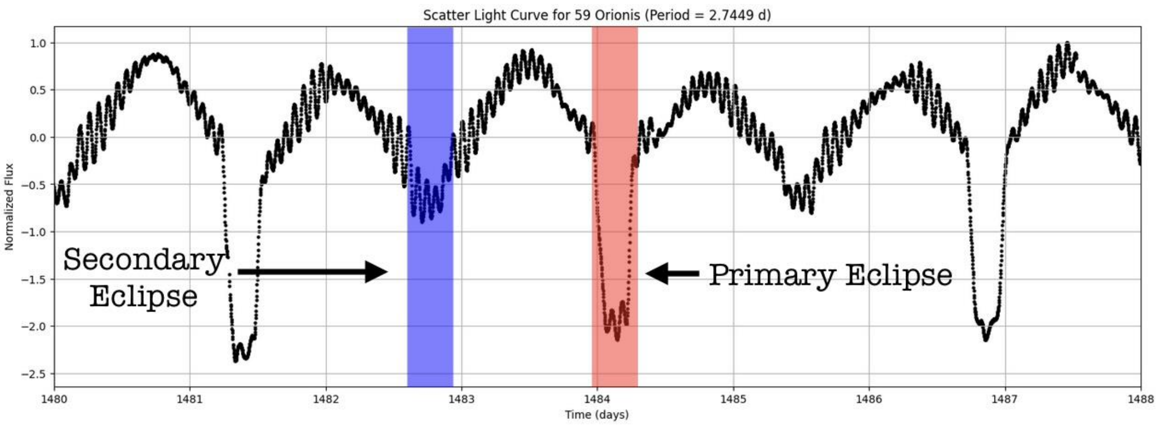


Fig 9: Scatter plot of the light curve of the 59 Orionis System

2. RR Lyrae Type

a. RR Lyrae

RR Lyrae is the model star and first documented star of this category. hence this category of variable stars is named after it.

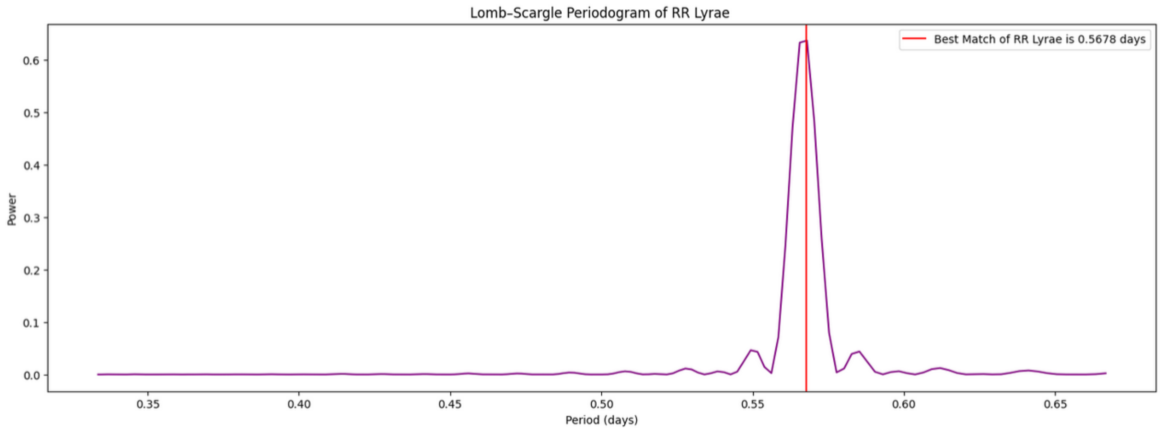


Fig 10: Lomb-Scargle Periodogram of RR Lyrae

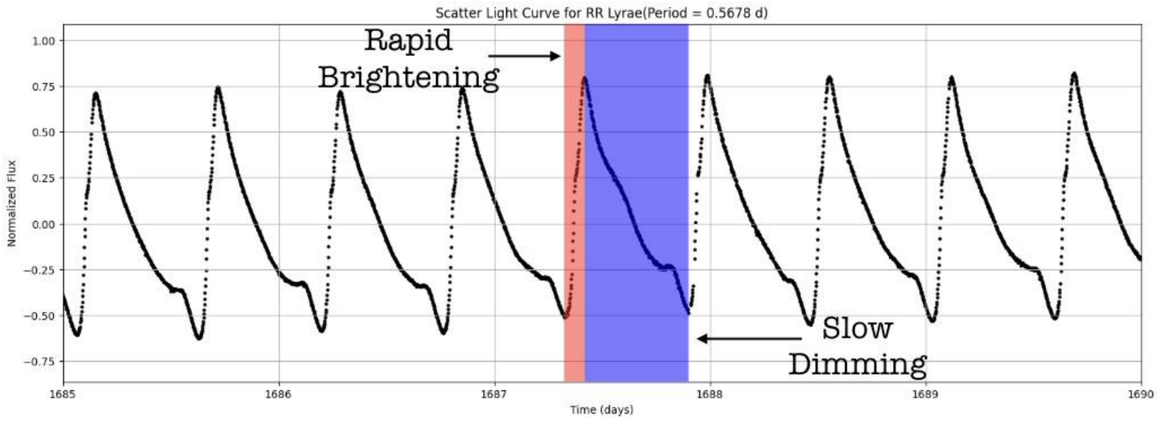


Fig 11: Scatter plot of the light curve of RR Lyrae

b. XZ Cygni

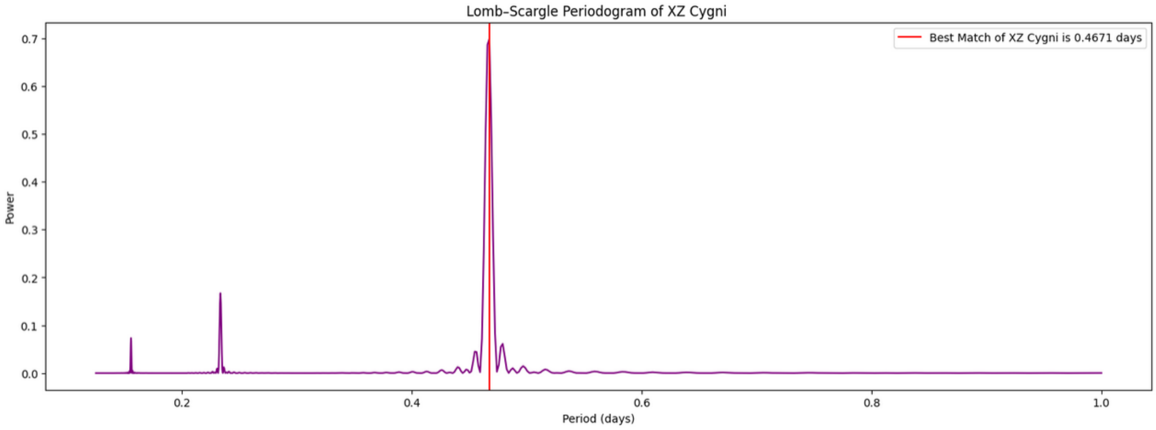


Fig 12: Lomb-Scargle Periodogram of XZ Cygni

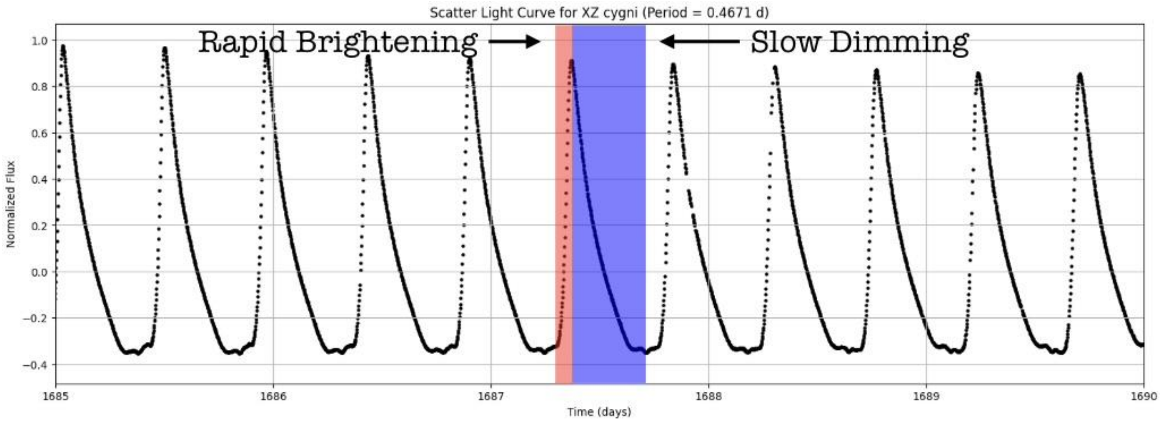


Fig 13: Scatter plot of the light curve of XZ Cygni

c. TU Ursae Majoris

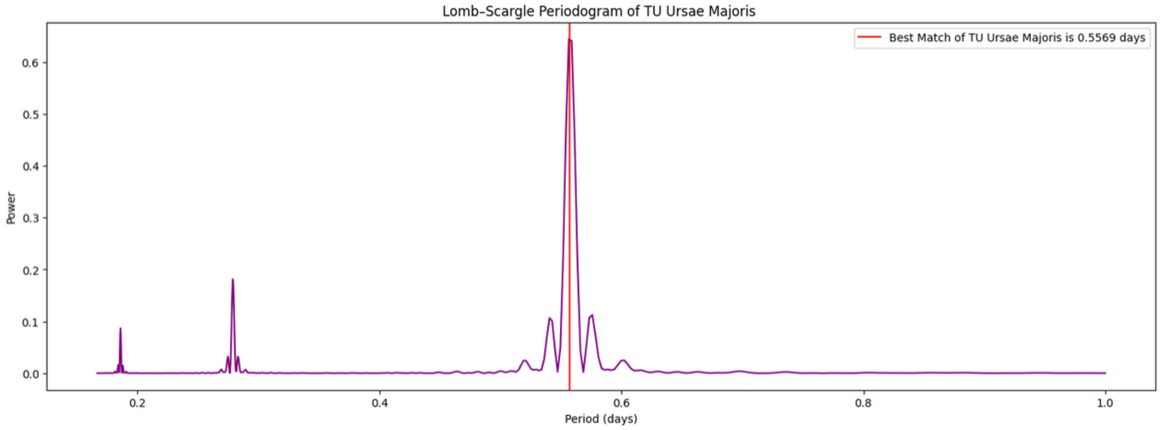


Fig 14: Lomb-Scargle Periodogram of TU Ursae Majoris

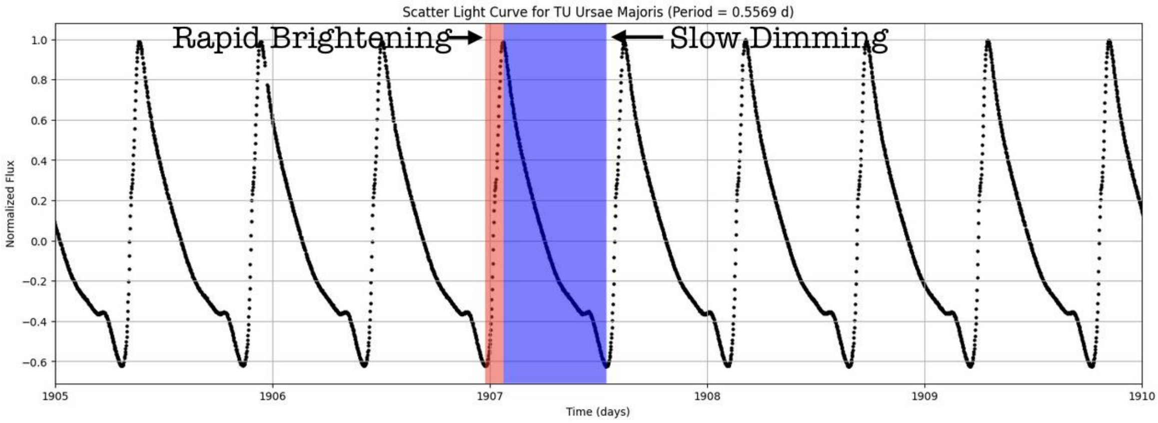


Fig 15: Scatter plot of the light curve of TU Ursae Majoris

3. Classical Cepheid

9

a. Alpha Ursae Minoris (Polaris)

The current Northern Pole Star or Polaris is a classical cepheid variable star

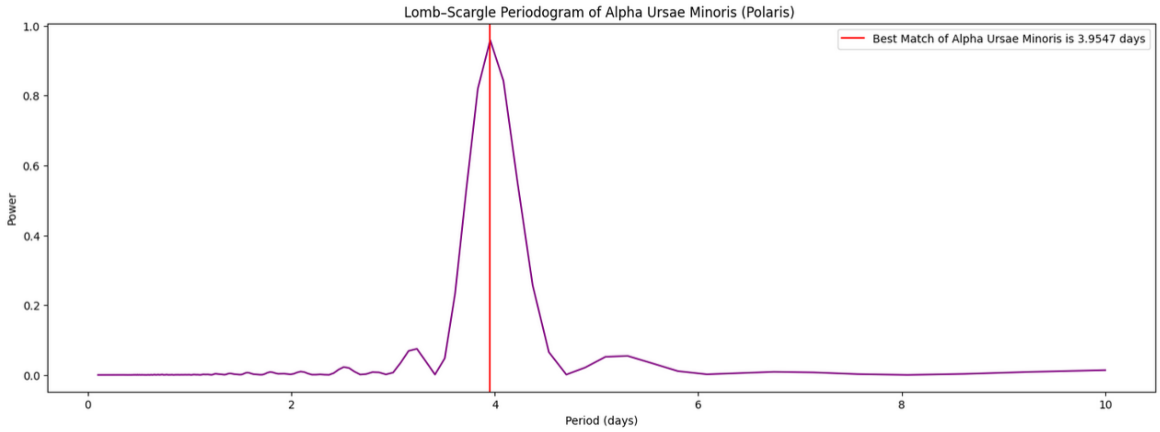


Fig 16: Lomb-Scargle Periodogram of Alpha Ursae Minoris (Polaris)

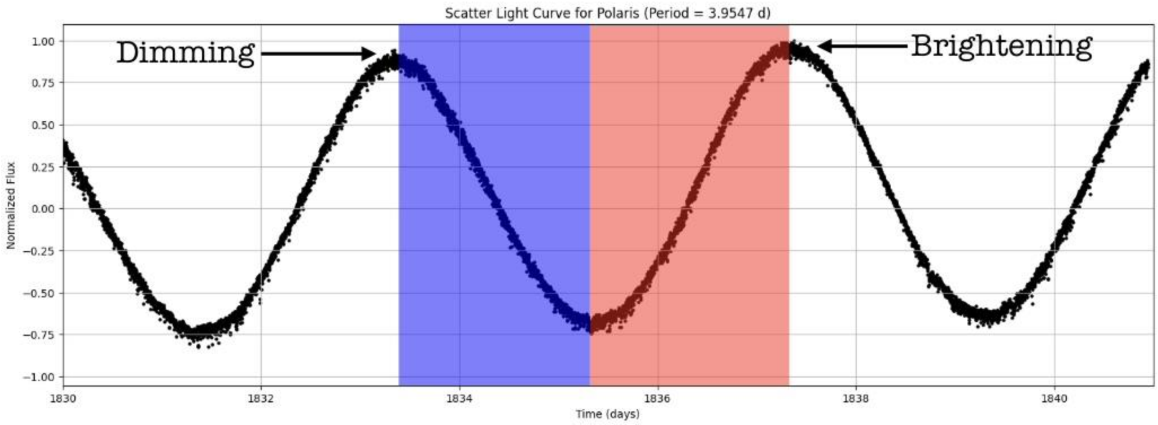


Fig 17: Scatter plot of the light curve of Alpha Ursae Minoris (Polaris)

b. BG Crucis

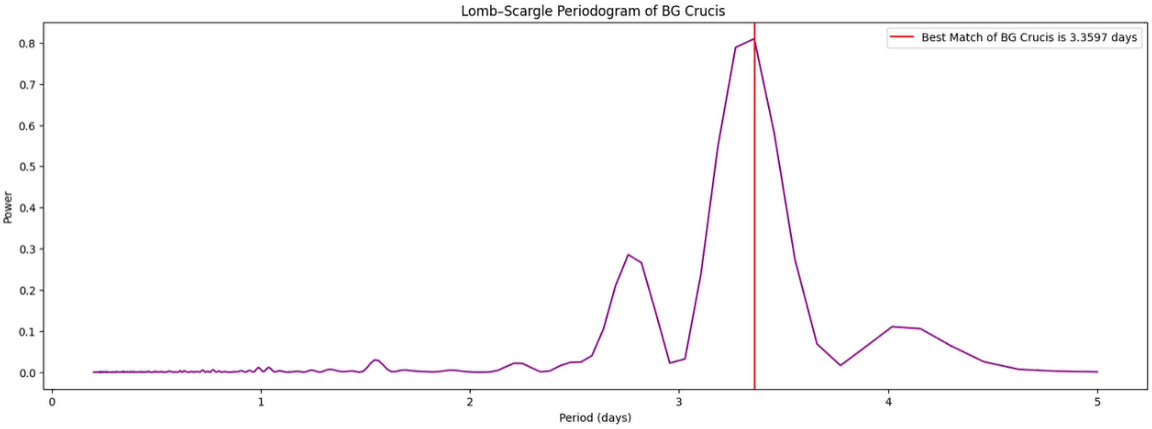


Fig 18: Lomb-Scargle Periodogram of BG Crucis

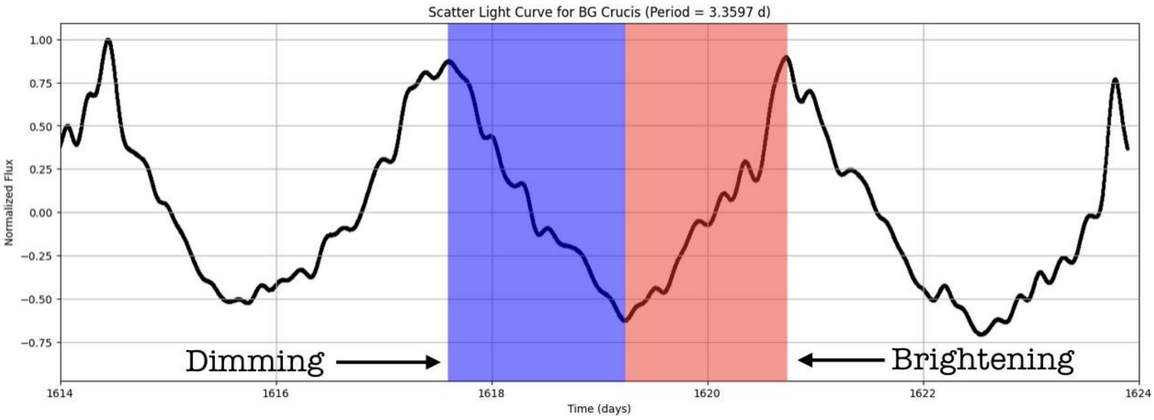


Fig 19: Scatter plot of the light curve of BG Crucis

c. V473 Lyrae

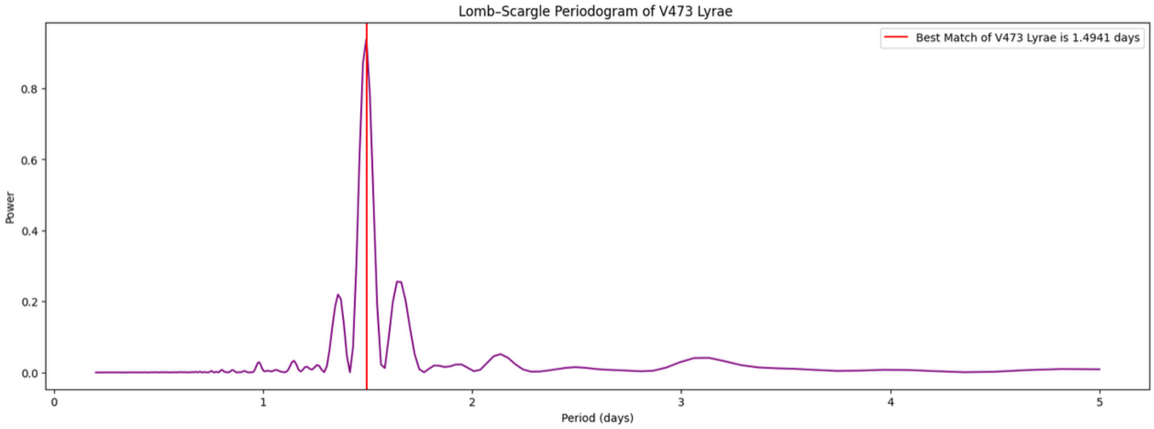


Fig 20: Lomb-Scargle Periodogram of V473 Lyrae

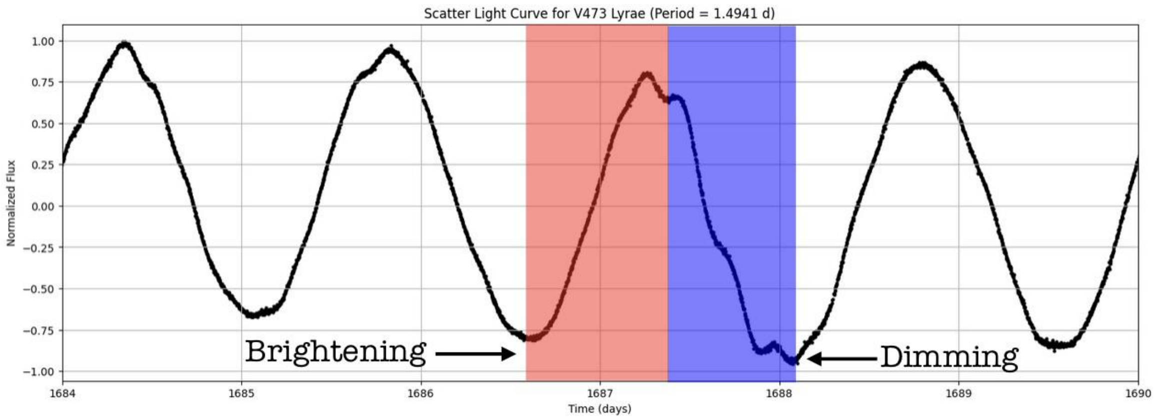


Fig 21: Scatter plot of the light curve of V473 Lyrae

4. Delta Scuti Type

a. Delta Scuti

Delta Scuti is the model and most popular star of this category to which the Delta Scuti category is named after.

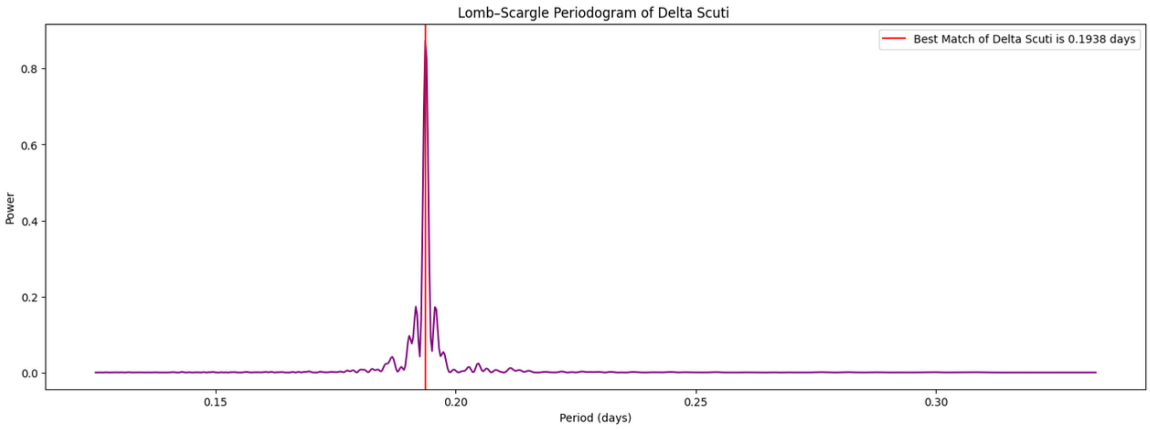


Fig 22: Lomb-Scargle Periodogram of Delta Scuti

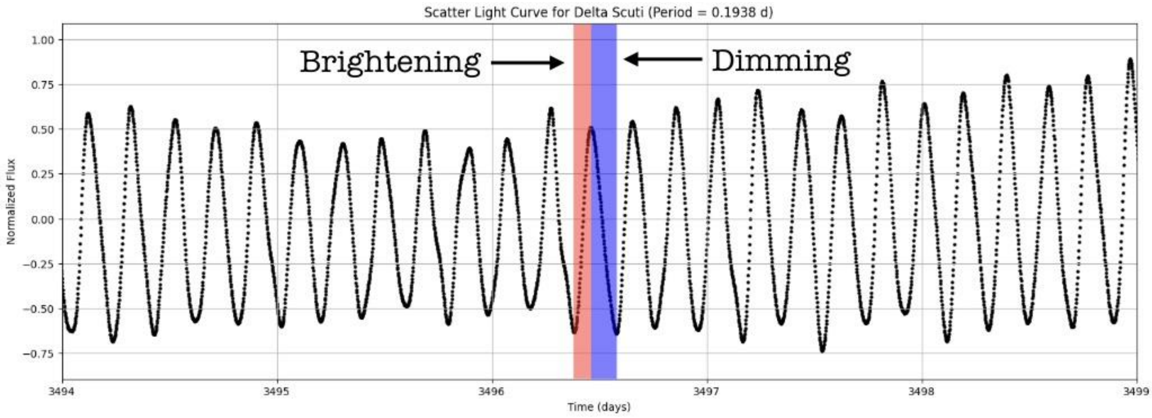


Fig 23: Scatter plot of the light curve of Delta Scuti

b. AI Velorum

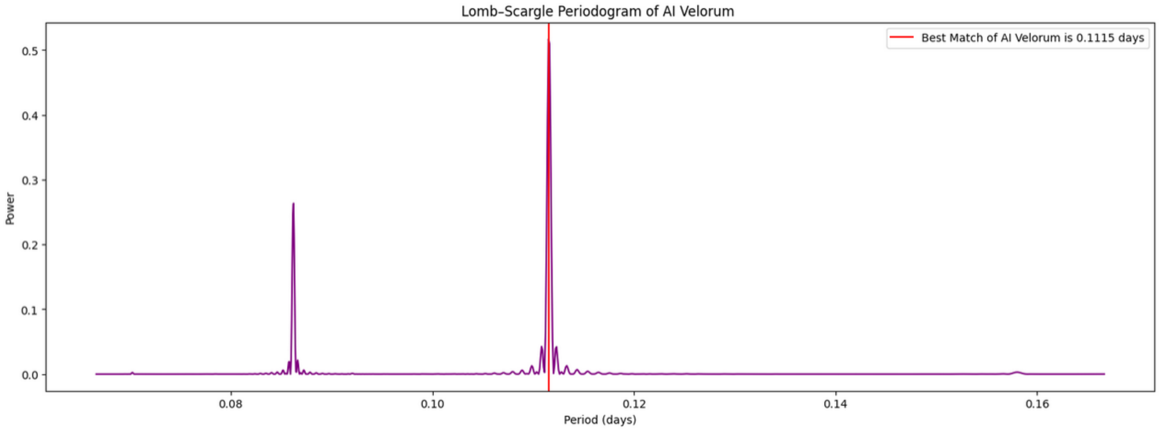


Fig 24: Lomb-Scargle Periodogram of AI Velorum

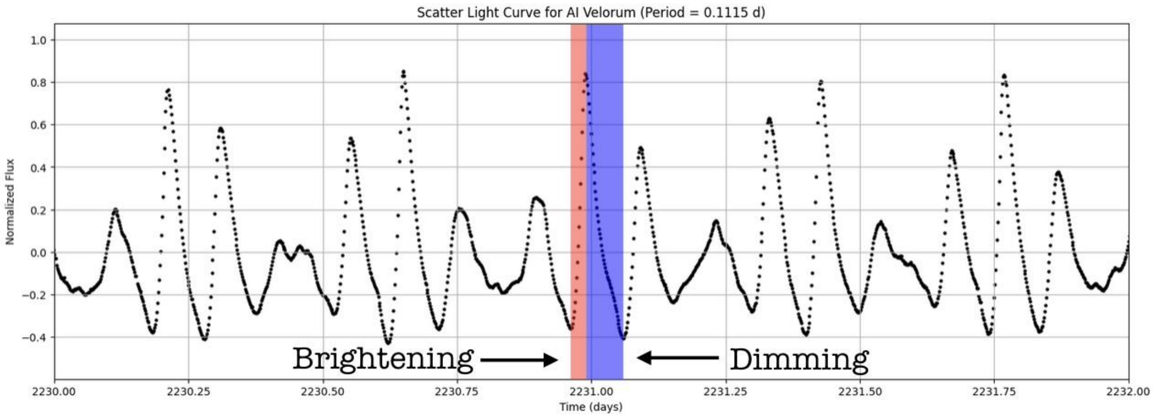


Fig 25: Scatter plot of the light curve of AI Velorum

c. 59 Orionis

The Eclipsing binary part of this star is done we will now focus on the intrinsic variability of this star we can see the oscillations in Luminosity in this Zoomed in plot of the light curve below

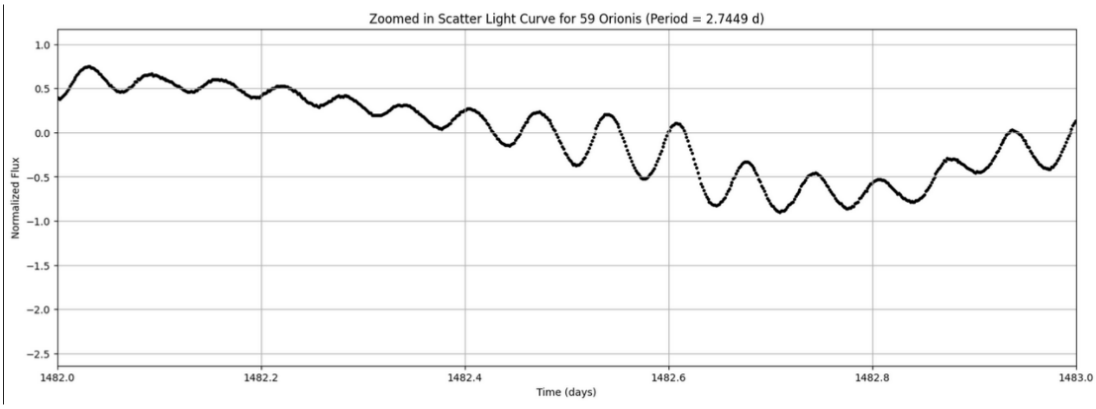


Fig 26: Zoomed in Scatter plot of the light curve of 59 Orionis

Calculating both the intrinsic and extrinsic variability in the same code is rather difficult so we can calculate the delta Scuti variability by just counting the number of “full cycles” that is the distance between 2 crests or troughs over a fixed time as shown in the figure below.

There are 3 full cycles between days 1482.4 and 1482.6 on the X or Time axis on the plot which gives us 3 full cycles over a span of approximately 0.2 days. For a single cycle this comes out to 0.0667 days per cycle or 96 minutes per cycle which is close enough to the actual value of 97 minutes, just being a minute short.

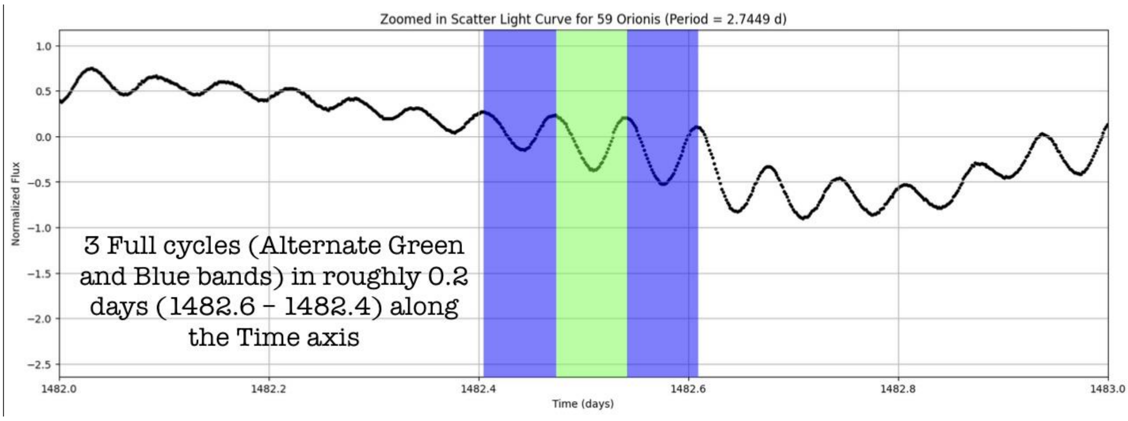


Fig 27: Zoomed in Scatter plot of the light curve of 59 Orionis with Luminosity cycles highlighted In blue and green

5. Beta Cephei Type

a. Beta Cephei

Beta Cephei is the model and most popular star of this category to which the Beta Cephei category is named after

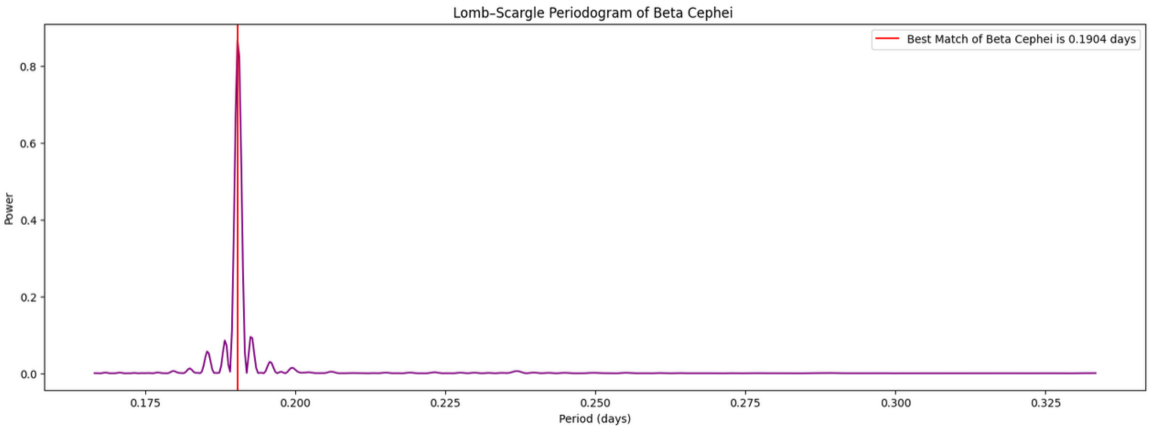


Fig 28: Lomb-Scargle Periodogram of Beta Cephei

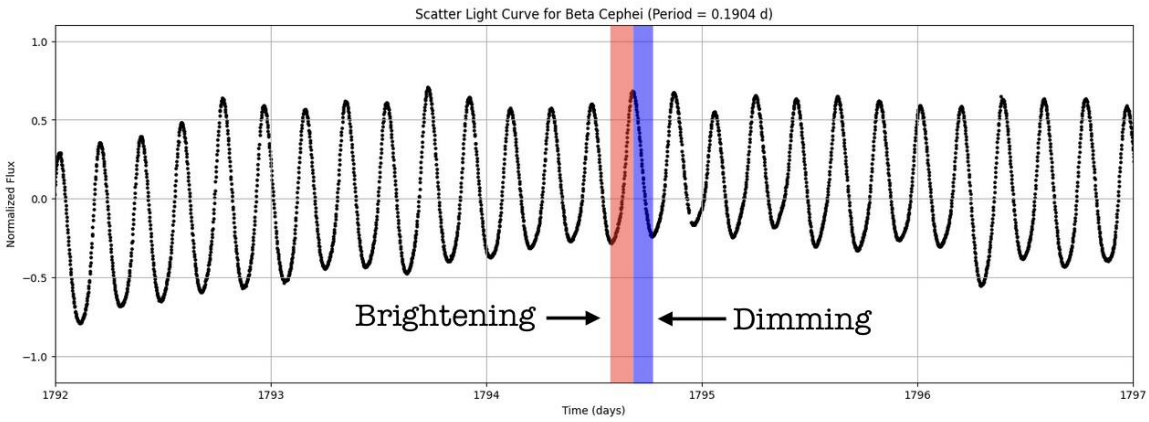


Fig 29: Scatter plot of the light curve of Beta Cephei

b. Gamma Pegasi (Algenib)

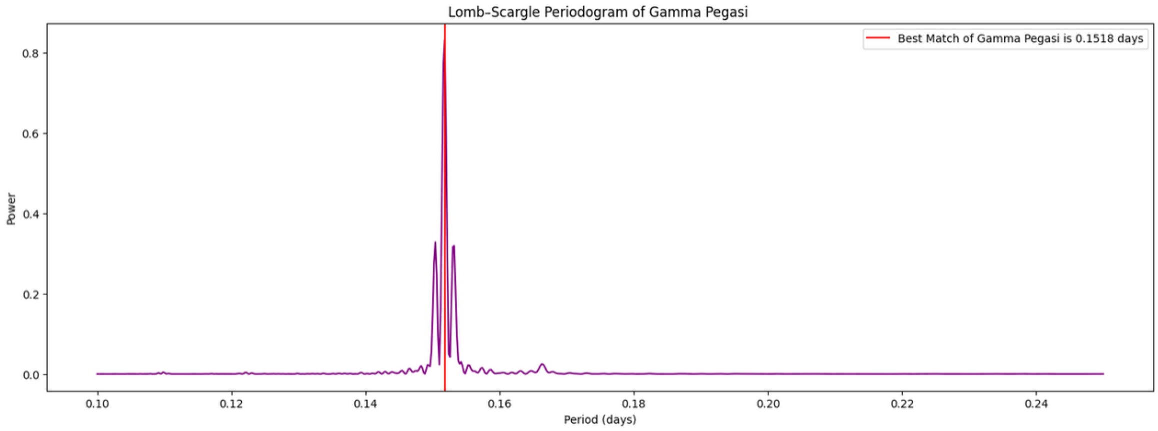


Fig 30: Lomb-Scargle Periodogram of Gamma Pegasi

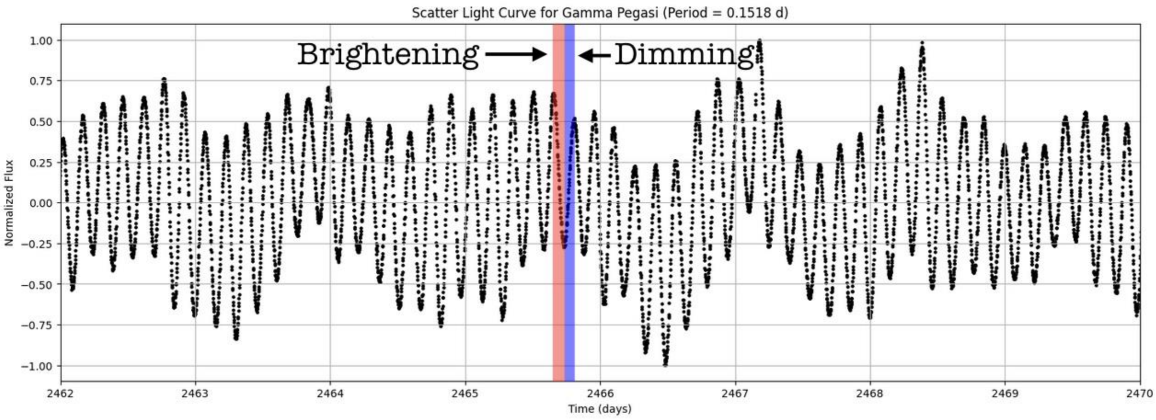


Fig 31: Scatter plot of the light curve of Gamma Pegasi

c. Beta Crucis (Mimosa)

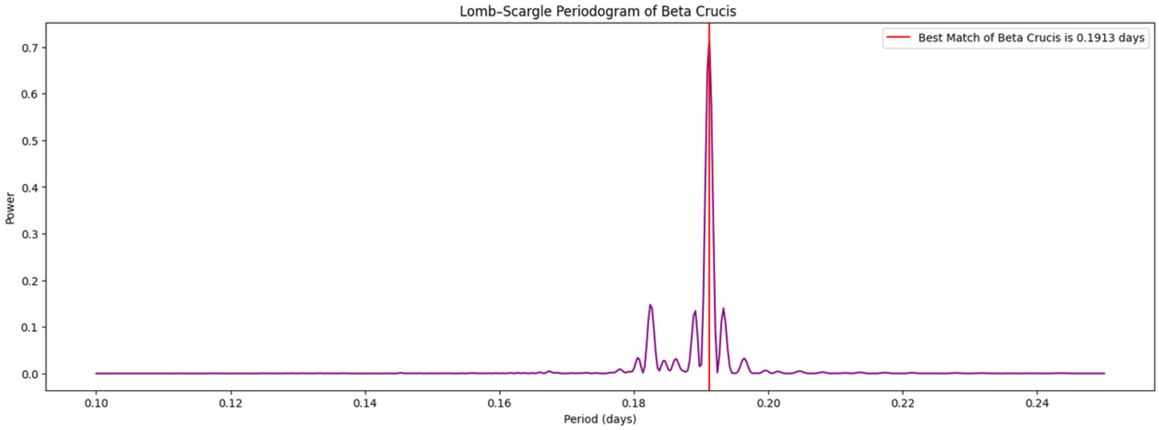


Fig 32: Lomb-Scargle Periodogram of Beta Crucis

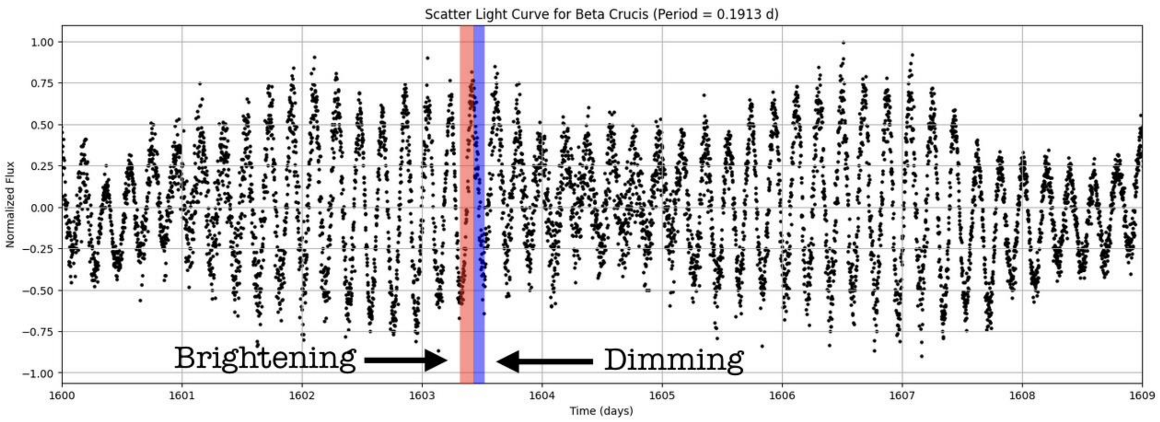


Fig 33: Scatter plot of the light curve of Beta Crucis

Observations & Calculations

All the calculated time periods using the Lomb-Scargle Algorithm of the 15 stars are tabulated and their percentage errors with the reference periods from TESS archives are also calculated [2] [3]

Bayer Classification of Star	Variable Star Type	Calculated period using python (days)	Reference Period (days)	Percentage Error (%)
RR Lyrae	RR Lyrae Type	0.5678	0.567	0.14
α Ursae Minoris	Classical Cepheid Type	3.9547	3.9696	-0.3754
β Persei	Eclipsing Binary (Algol type)	2.8959	2.9	-0.1414
δ Scuti	Delta Scuti Type	0.1938	0.19377	0.0155
β Cephei	Beta Cephei Type	0.1904	0.19048	-0.042
XZ Cygni	RR Lyrae Type	0.4671	0.4667	0.09286
TU Ursae Majoris	RR Lyrae Type	0.5569	0.5576	-0.1255
V397 Puppis	Eclipsing Binary (Algol type)	3.0224	3.004	0.6125
PT Velorum	Eclipsing Binary (Algol type)	1.8032	1.802	0.066
BG Crucis	Classical Cepheid Type	3.3597	3.3428	-0.503
γ Pegasi	Beta Cephei Type	0.1518	0.15175	0.03295
AI Velorum	Delta Scuti Type	0.1115	0.11158	-0.0717
		0.0862	0.08620	0
V473 Lyrae	Classical Cepheid Type	1.4941	1.49	0.2752
59 Orionis	Eclipsing Binary (Algol Type)	2.7449	2.7405	0.1606
	Delta Scuti Type	0.0667	0.06736	-0.9798
β Crucis	Beta Cephei Type	0.1913	0.19125	0.02614

There are lot of insights and knowledge to be gained from these simple plots about the intrinsic and extrinsic factors causing the variability in stars, lets unpack it all bit by bit.

Eclipsing Binaries

1. Eclipsing Binaries have 2 dips in brightness, the dips in brightness correspond with relative sizes and luminosities, the larger dip in the flux is always designated as the primary eclipse irrespective of which star eclipses the other. Eclipsing binaries have relatively constant fluxes as seen on the graph with little variation, the dips in brightness is caused by the star eclipsing it and not the internal characteristics of the star itself.

2. Eclipsing binaries with zero eccentricities have Alternating primary and secondary eclipses at exactly half the time period. For example the Beta Persei system has a measured eccentricity of zero with a time period of 2.8959 days (time between 2 primary/secondary eclipses) but at half this period of roughly 1.44 days is the gap between a primary and secondary eclipse this can also be considered at occurring at half the phase. In the example of V397 Puppis system the value of the eccentricity is not well known but since the primary and secondary eclipses are not “evenly spaced” we can safely assume that the orbit of this system is quite eccentric while the PT velorum system is not as evenly spaced as Beta Persei or 59 Orionis it appears to be less severe as V397 Puppis. The eccentricity of the four systems in ascending order can thus be predicted as Beta Persei < 59 Orionis < PT Velorum < V397 Puppis.

3. The eclipsing time of the star i.e. the width of the brightness dip depends on the eccentricity of the stars (the apparent sizes of the stars change when the orbit is eccentric due to different distances) and how the stars are eclipsing each other. For example while the Beta Persei system has an eccentricity of zero and thus the distances remain constant the smaller hotter star doesn’t pass

2

RR Lyrae Type

1 1. RR Lyrae Variable stars are low mass stars typically less massive than our sun but have evolved away from the main sequence phase into the red giant phase, their landmark characteristics are the rapid brightening and slow dimming with one cycle lasting less than a day as shown in the graphs.

2. This rapid and slow cycle is caused by the kappa or κ-mechanism in its helium layer. In
1 short, it's caused by the compression of the star's outer layers which increases the temperature and makes them "opaque" to radiation which causes energy to build up and makes the star swell rapidly, now that the outer layer has expanded it becomes "transparent" to radiation and releases the internal pressure. now the inherent gravity of the star takes over and compresses the outer layers and the cycle repeats

3. While I didn't use python to calculate the rise and decay of the graph it can be found out with decent accuracy as the 2 phases are easily distinguishable. By using the width of the cycle in pixels (Found out using photopea software crop feature that shows the width of the crop in pixels) [4] of the python plot and calculating the time period of the rise and fall of the plot using the formula, due to compression the pixel values will change but their relative sizes will remain constant.

Time of Brightening (T_B) = $\frac{T \times L_B}{L_C}$

Time of Dimming (T_D) = $\frac{T \times L_D}{L_C}$

Where,

Time period of one cycle (obtained using LS periodogram) = T

"width" of one cycle in pixels = L_c

"width" of Rise/Brightening phase in pixels = L_B

"width" of Decay/Dimming phase in pixels = L_D

The attached graphs show the values with the phases of the cycle colour coded with Red as the Brightening phase and blue as the dimming phase

a. RR Lyrae

Time period of one cycle obtained using LS periodogram (T) = 0.5678 days

"width" of one cycle in pixels (L_C) = 672 px

"width" of Rise/Brightening phase in pixels (L_B) = 105 px

"width" of Decay/Dimming phase in pixels (L_D) = 567 px

Time of Brightening (T_B) = $\frac{T \times L_B}{L_C}$ = 0.08871 days or 2.12904 hours

Time of Dimming (T_D) = $\frac{T \times L_D}{L_C}$ = 0.47908 days or 11.49792 hours

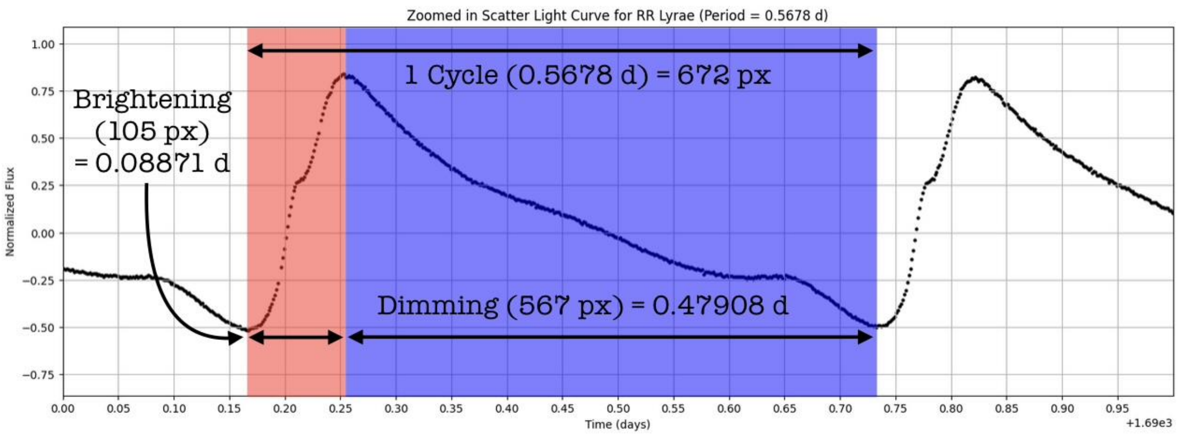


Fig 34: Zoomed in Scatter plot of the light curve of RR Lyrae

b. TU Ursae Majoris

Time period of one cycle obtained using LS periodogram (T) = 0.5569 days

"width" of one cycle in pixels (L_C) = 656 px

"width" of Rise/Brightening phase in pixels (L_B) = 87 px

"width" of Decay/Dimming phase in pixels (L_D) = 569 px

Time of Brightening (T_B) = $\frac{T \times L_B}{L_C}$ = 0.07385 days or 1.77240 hours

Time of Dimming (T_D) = $\frac{T \times L_D}{L_C}$ = 0.48304 days or 11.59296 hours

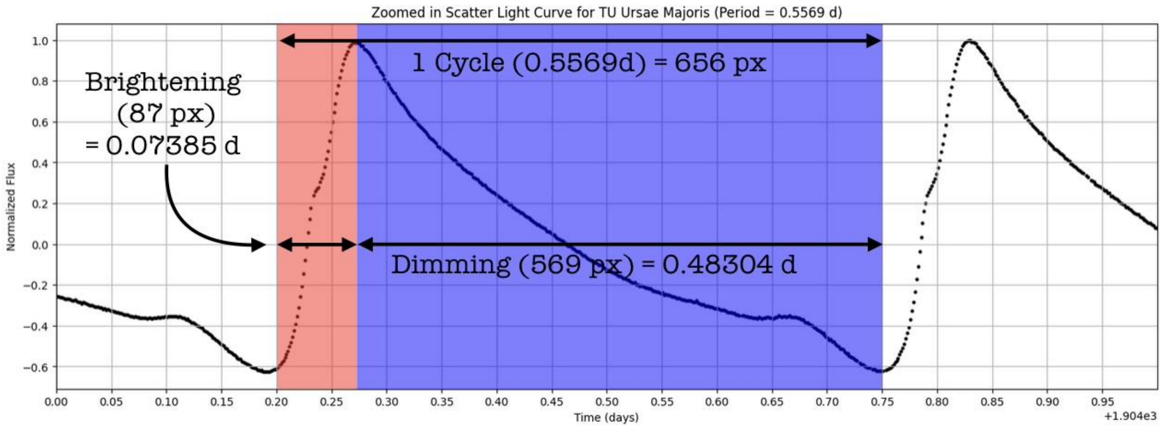


Fig 35:Zoomed in Scatter plot of the light curve of TU Ursae Majoris

c. **XZ Cygni**

Time period of one cycle obtained using LS periodogram (T) = 0.4671 days

“width” of one cycle in pixels (L_C) = 546 px

“width” of Rise/Brightening phase in pixels (L_B) = 76 px

“width” of Decay/Dimming phase in pixels (L_D) = 470 px

Time of Brightening (T_B) = $\frac{T \times L_B}{L_C}$ = 0.06501 days or 1.56024 hours

Time of Dimming (T_D) = $\frac{T \times L_D}{L_C}$ = 0.40208 days or 9.64992 hours

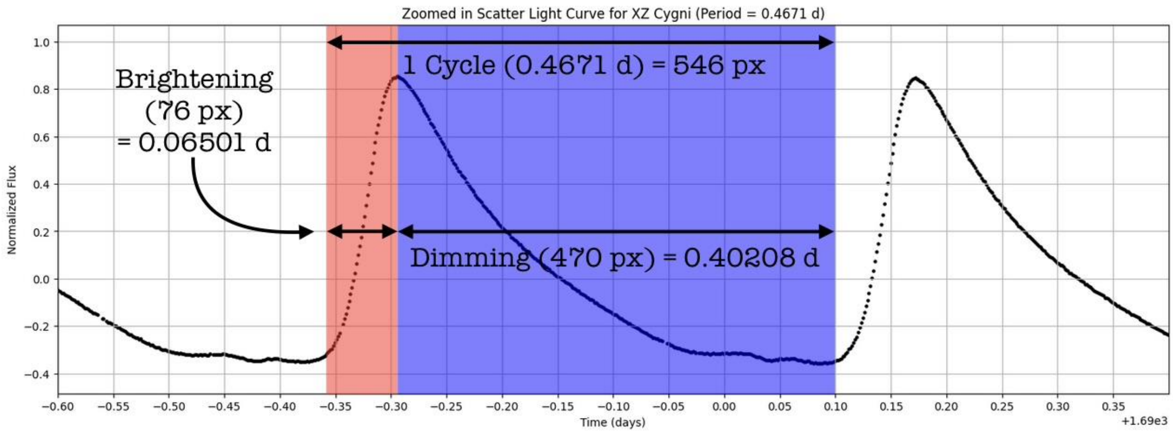


Fig 36: Zoomed in Scatter plot of the light curve of XZ Cygni

The periods of all the RR Lyrae variable stars split into their respective brightening and dimming periods and their percentages of the total time period are tabulated below.

Star	Time Period (days/hours)	Brightening Time (days/hours)	Dimming Time (days/hours)	Brightening Time as a % of Time period	Dimming Time as a % of Time period
RR Lyrae	0.5678 days 13.6272 hours	0.08871 days 2.12904 hours	0.47908 days 11.49792 hours	15.6234 %	84.3765 %
TU Ursae Majoris	0.5569 days 13.3656 hours	0.07385 days 1.77240 hours	0.48304 days 11.59296 hours	13.2609 %	86.7390 %
XZ Cygni	0.4671 days 11.2104 hours	0.06501 days 1.56024 hours	0.40208 days 9.64992 hours	13.9177 %	86.0822 %

Before doing the calculation we could qualitatively say that RR Lyrae variable stars have a short brightening burst and a long dimming phase but after the calculating using the "pixel scaling" method we can now qualitatively know how quick or slow the brightening and dimming phases are with the dimming phase taking 5.6 to 6.6 times longer than the brightening phase.

Classical Cepheids

1. Classical cepheid variable stars follow a roughly sinusoidal pattern of brightening and dimming due to the kappa or κ-mechanism in its helium layer usually lasting from several days to months, i.e. the time taken for a star to brighten/heat up and time taken for it to dim/cool down is roughly similar although there can be slight variations.

2. Another interesting about classical cepheids is the Period – Luminosity Relation which states that the time period of the cepheid variable is directly proportional to the luminosity of the star This law is also known as Lewitt's Law this law can be proven by plotting a graph between the Absolute magnitude vs the period and what we observe is a straight line highlighting the proportionality of these 2 properties. While

I've only taken 3 stars for my example the Period – Luminosity Relation still shows with the most luminous star, Alpha Ursae Majoris having the largest period of 3.9547 days and V473 the least luminous star having a period of only 1.4941 days as shown in the table below [3]

Star	Period (days)	Luminosity (L⊙)	Absolute Magnitude	Mass (M⊙)
α Ursae Minoris	3.9547	1260	-3.6	5.13
BG Crucis	3.3597	1033.93	-2.63	4.3 - 6.3
V473 Lyrae	1.4941	740	-2.5	3.0 - 4.6

1

3. The spectral class of a star is determined by the characteristics of emitted light of the star. Brighter, hotter stars emit more high frequency/low wavelength light like Ultraviolet, X-Rays and dimmer, cooler stars emit most of their radiation in the Infrared, Visible range. In ascending order of the star's temperature we have the classes: M, K, G, F, A, B, O with each class having a range of 0-9 with 0 being brighter and 9 being dimmer. M type stars are very dim, red dwarf stars and O type stars are extremely luminous, blue stars. Now for classical cepheid stars As they compress/ brighten their temperature rises which causes these stars to jump to a higher spectral class for example during contraction/ brightening Alpha Ursae Minoris jumps to F7 and then cools down to F8. An even more extreme example is BG Crucis which ranges from an F5 to a G0 class during its cycle.

Delta Scuti Type

1. Delta Scuti stars have a similar sinusoidal brightening/ dimming cycle due to the kappa or κ-mechanism in its helium layer similar to RR Lyrae and Classical Cepheid variable types happening at a higher frequency compared to classical cepheids with very short periods like AI Velorum having a period of just 0.1115 days or 2.676 hours per cycle

2. Delta Scuti and 59 Orionis (also an eclipsing binary) show a rather consistent periodic oscillation while AI Velorum shows a "twin peak" light curve as seen on Fig 25 with periods 0.1115 days and 0.0862 days as shown in the LS periodogram below.

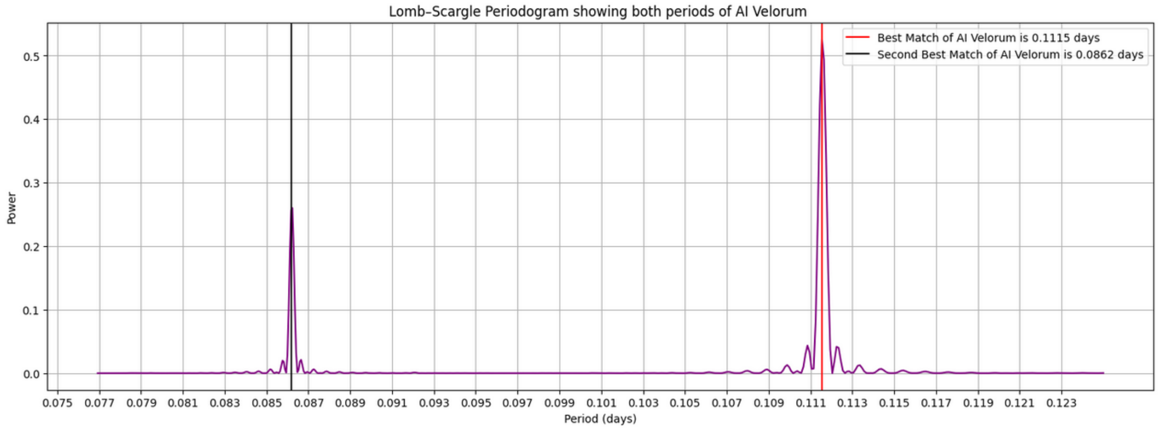


Fig 37: LS Periodogram of AI Velorum showing the periods of the twin peaks

Beta Cephei Type

Beta Cephei Variable stars have the similar and rapid sinusoidal oscillation of Delta Cephei Variable stars but their oscillations occur on a different kappa or κ-mechanism in the iron layer instead of the helium layer in Delta Scuti, Classical Cepheid and RR Lyrae variable stars.

Conclusion & Future Work

Just by plotting the light curve and figuring out the period using the Lomb-Scargle algorithm built into astropy of the 15 stars in question we can identify how long a star pulses and by making observations of the nature of the light curve we can gain a lot of insight on why and how those pulses occur and also by using existing values from TESS and Wikipedia we can compare the results of the program to verify the accuracy on the results obtained and validate the classifications of these stars as well.

As for the future work on this project I plan to add more types of variable stars, a phase folded light curve (was in the initial plan but I wanted to solidify my understanding of the LS Periodogram and light curve aspects of the code first) and a colour index phase folded light curve which is essentially a phase folded light curve but split into colours like blue, violet, red, infrared and so on.

References

1. Flowchart drawn with the paper STARLIGHT IN THE LAB – OBSERVING A VARIABLE STAR Chika C. Onuchukwu[1], ASTROLAB Group[2] as a reference
2. Publicly available TESS Archive data used for light curve and LS Periodogram plotting
3. Star parameters like Mass, Luminosity, Spectral class all obtained from Wikipedia pages
4. Pixel values of the RR Lyrae brightening and dimming time were obtained through the Photopea photo processing software

Python Plugins used

1. Astropy for period calculation (LS periodogram)
2. Lightkurve for extraction of data from TESS
3. Numpy and matplotlib for graphing values