XX Cygni : Fourier Analysis

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High amplitude δ scuti (HADS) stars are short period pulsating variable stars, with a pulsation of several hours. They typically pulsate in radial modes, with most of their energy being distributed into the main pulsation. Fourier spectra was completed for XX Cygni (XX Cyg) for the purpose of deducing the dominant frequencies of pulsation for XX Cyg. A table with information on XX Cyg is located in Figure 1. For the years 2010 to 2017, data reduction was completed to produce light curves displaying the time of maximum light, Heliocentric Julian Date (HJD), for XX Cyg at the Allan I. Carswell Observatory located at York University in Toronto, Ontario. With over 100 new data points coming from the Allan I. Carswell Observatory, the total observed times of maximum light is 12,895. Frequency analysis of the light curve using Period04 and VStar software has shown the energy distribution is being distributed primarily into the main pulsation, with a fundamental frequency of $7.3 cycles day^{-1}$.

Data	Values
Spectral Type	A5-F5
R.A	20h3m15.6s
Dec	+58 57' 16.5"
[Fe/H]	-0.49dex
{Teff}	7530 K
{log(g)}	3.66
Q	0.0333 days

Fig. 1 Information on XX Cyg

I. Introduction

High amplitude δ scuti (HADS) stars are stars where the thermonuclear fusion has stopped in their cores, moving them off of the main sequence and onto the instability strip. Figure 2 shows the Hertzsprung - Russell (HR) diagram with the instability strip outlined in black. They typically pulsate in radial modes, with evidence suggesting most of the energy is being distributed into the main pulsation (Pigulski et al. 2004). Radial modes occur when the star expands and shrinks as a whole, while non radial modes occurs when one part of the star expands as the other part starts to

shrink. HADS that are of Population II are called SX Phoenicis stars (SX Phe) and these Population II stars are more evolved than their Population I counterparts (Conidis 2010; Pigulski et al. 2004). Population II HADS stars are usually discovered in globular clusters, with about 150 HADS stars located in the Galactic field. Out of the 150 HADS stars, only 13 of them are known SX Phe stars (Rodriguez et al. 2000 ; Clement et al. 2001; Yang et al. 2012). XX Cyg has been researched many times with data dating back to 1906 by Parkhurst. Resent research on XX Cyg has led to a continuous period increase with a rate of (1/P)(dP/dT) = 1.19(13)x$10^{-8}$$yr^{-1}$ (Yang et al. 2012).

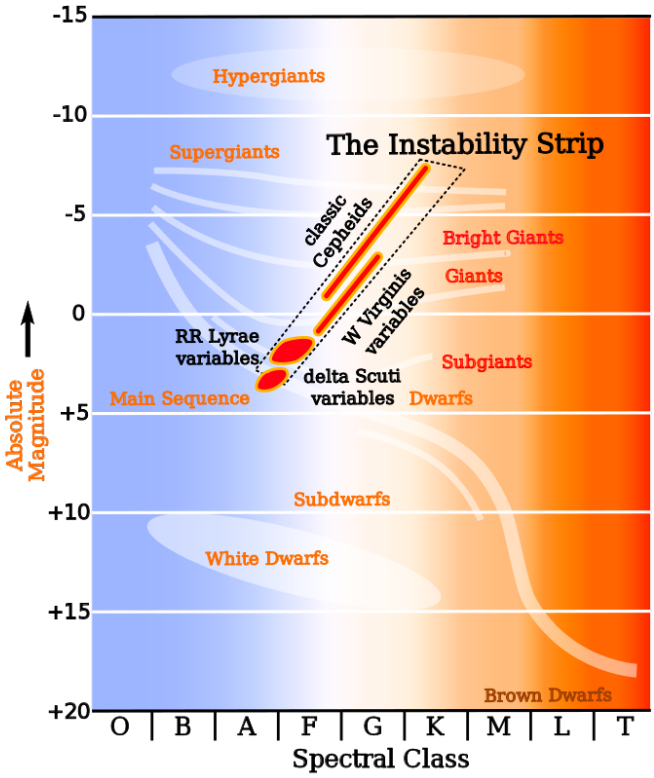

Fig. 2 HR Diagram

II. XX Cygni

The star discussed in this paper is the metal- poor, Population II SX Phe star, XX Cyg. XX Cyg has a mean visual magnitude of V = 11.7 and has a velocity of -108 km/seconds, with a radial velocity amplitude of 37 km/seconds (Conidis 2010; Joner 1982). XX Cyg has a mass of 1.7 M_{sun} and a spectral class of A5-F5 (Yang et al. 2012).

It was discussed whether XX Cyg had a continuous period increase or period jump around the year 1942. Between the years of 1905 to 1942, XX Cyg showed a constant period, while after 1942, it experienced a period jump (Yang et al. 2012). Szeidl + Mahdy (1981) concluded that the pulsation period did in fact appear to have a period jump of $\Delta P/P = 6x10^7$ in 1942. Years later, Kiss + Derekes (2000) constructed a new Observed minus Calculated (O-C) diagram that included all available times of maxima light and concluded there was a period jump of $\Delta P/P = -3.95 \pm 0.82x10^8$

and $5.33 \pm 0.54x10^8$ before and after the 1942 period jump.

III. New Observations and Fourier Analysis

Fourier analysis for XX Cyg has been a fundamental tool in helping to understand different frequencies in a periodic signal, while fourier transformations are applied to look for significant peaks in amplitude spectra (Fiacconi et al. 2009 ; Yang et al. 2012). Yang et al. (2012) completed the most recent research on fourier analysis for XX Cyg using Period04, a program then used for a portion of this research. Fourier spectra in Period04 is constructed from the inputted time string, which is a column of HJDs and magnitudes extracted from the light curves, and then fitted with the equation below.

$$m = m_o + \Sigma A_i sin(2\pi(f_i + \Phi_i))$$

The constants here are : m_o being the magnitude, f being frequency, A being amplitude and ϕ is the phase shift, all for the wave.

The conclusion from Yang et al. (2012), was up to 20 new frequencies that had signal-to-noise ratios (SNR) of SNR > than 4.0, which is at a level where object detection is possible. At the Allan I. Carswell observatory, a CCD (Charged Coupled Device) is used. Since the images of XX Cyg have been obtained using a CCD, it is apparent to keep in mind that photons are converted to electrons, giving us the equation below to deduce the SNR:

$$S = F\tau A\epsilon Q_e$$

Fig. 3 Equation for signal to noise ratios

The constants here are : F is the Point Source Signal Flux on Telescope (photon s^{-1} cm^{-2}), the τ is Integration Time (s), A is Telescope Area (cm^2), ϵ is Telescope Efficiency (dimensionless), and Q_e is the Quantum efficiency (dimensionless) (Wolf + Lubin 2012).

For research purposes, images of XX Cyg were taken nightly, so the time of maximum light could be observed. An example of the field of view for XX Cyg is depicted in figure 4. Light curves are then used to understand the pulsating nature of variable stars. When light curves are constructed, they form a non - sinusoidal wave as evident in figure 5. The X- axis represents the time in Heliocentric Julian Date (HJD) while the Y-axis marks the differential magnitude. The differential magnitude being the average comparison stars instrumental magnitude subtracted from the variable star's instrumental magnitude. These light curves show the maximum time of light, depicted by the peak.

A. Data Analysis

Period04 is a computer program that houses many functions used to analyze data. For the purpose of this research, the fourier function was used. The program requires inputs that will allow for the production of a fourier spectra.

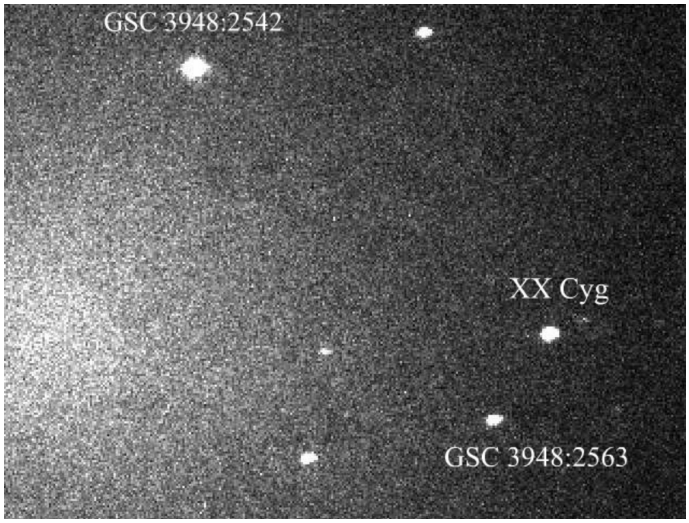

Fig. 4 Field of View for XX Cyg

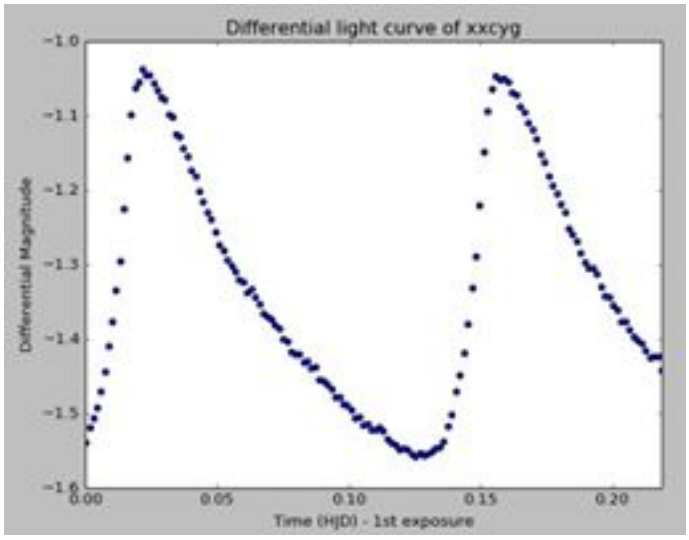

Fig. 5 Light Curve for XX Cyg

Between the years of 2010-2017, 12895 data points were obtained for XX Cyg at the Allan I. Carswell Observatory. The 60cm telescope was used for the purpose of this research and the principle program of IRAf along with python codes in Linux were used for the data reduction process. To obtain the fourier spectra, the HJDs and magnitudes were strung together to form one single time string. To obtain all the HJDs and magnitudes needed, pulling them out from the edited IRAF folders per year was needed. They were then all consecutively added into a .DAT file and strung into Period04. Period04 produced a fourier spectra that shows the dominant frequency for XX Cyg. Period04 plots frequency (cycles/day) on the X-Axis and amplitude on the Y- Axis. The main peaks that are prevalent on the spectra represent the main frequencies for XX Cyg. The fourier spectra obtained using Period04 is shown in figure 6. Once the fourier spectra was obtained, the research was moved to VStar. VStar is a similar program to Period04 as it allows the analysis

for light curves, including the fourier function. With this program, fundamental frequencies were extracted from the time string inputted.

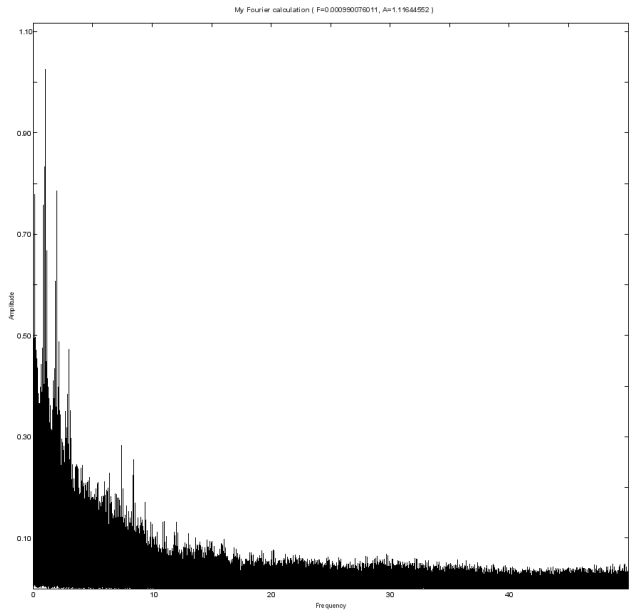

Fig. 6 Fourier Spectra of XX Cyg

IV. Findings

With the results from the research conducted, a fundamental frequency of $7.3 cycles day^{-1}$ was successfully found. The top five frequencies were extracted from VStar, showing that the fundamental frequency was receiving the majority of the energy while there are at least 4 non radial modes at other frequencies present. This shows that XX Cyg is a radial mode pulsating star but there is evidence showing energy is being distributed into non radial mode pulsations.

Frequency(cyclesday^{-1})

7.3 - Fundemental Frequency

15.07

22.84

29.5

37.27

Harmonics were also searched for with VStar. Harmonics are integer multiples of the main frequency that can be real, but might also be fake. Looking at the top five frequencies primarily, there is no evidence of exact integers being present, moving to the top 10, revealed 58.4 cyclesday^{-1}, 94.9 cyclesday^{-1} and 109.5 cyclesday^{-1} are integers of the

main pulsation and therefore are harmonics.

V. Conclusion

XX Cyg is shown to have a fundamental frequency of $7.3 cycles day^{-1}$ with non-radial modes present in the star. With research from the years 2010 to 2017, it is evident that XX Cyg is distributing its energy into the main pulsation with other minor frequencies having energy deployed to it. When looking at the top 10 frequencies, harmonics were evident showing a possible copy of the main frequency present.

VI. Acknowledgments

In the success of this research, data reduction for XX Cyg had to be completed to produce light curves for the purpose of being able to extract the HJDs and magnitudes for each data point. In order to do this, Sunna Withers helped with the data reduction process in summer 2018 for the future research done on XX Cyg. A secondary acknowledgment goes to Pruthvi Acharya for the help of producing a fourier spectra. After the completion of Period04, mathematica was set to be used for the rest of the research, help was needed for the purpose of coding. A thank you to both of these contributors for helping in the success of this research.

VII. References

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Image 1 taken from " “SPP Star Classes - AAVSO Short Period Pulsator Section.” Google Sites, sites.google.com/site/aavsosppsection/spp star-classes. "

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