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XX Cygni: Fourier Analysis

High amplitude delta 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 star XX Cygni (XX Cyg) for the purpose of deducing the dominant frequencies of pulsation for XX Cyg. For the years 2010 to 2017, data reduction was completed to produce light curves displaying the time of maximum light for XX Cyg at the Allan I. Carswell Observatory located at York University in Toronto, Canada. With over 100 new data points coming from the Allan I. Carswell Observatory, the total observed times of maximum light is 12,895 data points. Frequency analysis of the light curve has shown the energy is being distributed primarily into the main pulsation, with a fundamental frequency of 7.3 cycles/day.

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Keywords: High amplitude delta Scuti (HADS) stars, Fourier analysis, fundamental frequency

INTRODUCTION

High Amplitude δ (delta) Scuti (HADS) stars are short period pulsating variable stars, with pulsation periods of several hours. Pulsation in this context means that the star expands and contracts its outer atmospheric gas layers causing it to enlarge during expansion and shrink during contraction. This results in changes to the star's brightness (and temperature). During pulsation, HADS will have most of their energy distributed into the main or fundamental pulsation period (or frequency), but other pulsation periods can and do occur simultaneously.

In this research, a Fourier spectrum was generated for the star XX Cygni (XX Cyg) for the purpose of identifying the dominant frequencies of pulsation for this star. Frequency refers to how many times the star goes through an expansion-and-contraction cycle (pulsation) during a specific period of time. For comparison, when a musical instrument produces sound, it is rarely a pure tone but rather a mix of many different frequencies, with each frequency having a certain strength (or energy). Similarly, pulsating stars do not "breathe" with simply one frequency. A Fourier analysis is conducted on data collected from a star to allow the determination of the frequencies involved in the star's pulsation, and this in turn enables stellar properties like age and evolution (energy generating processes) to be better understood.

Observational data for XX Cyg were collected at York University's Allan I. Carswell Observatory (AICO) in Toronto, Canada, for the years 2010 to 2017. Data reduction was completed to produce light curves displaying the star's brightness as a function of observing time, thus revealing the time of maximum light that occurred during a pulsation. With over 100 new times of maximum light coming from the new AICO data, the total observed number of data points available for the Fourier analysis was 12,895. Frequency analysis of the light curve data was completed using Period04 (Lenz & Breger, 2005) and VStar (Benn, 2012) software packages, and has shown the energy during pulsation was distributed primarily into the main pulsation, with a fundamental frequency of 7.3 cycles/day.

HADS STARS AND XX CYGNI

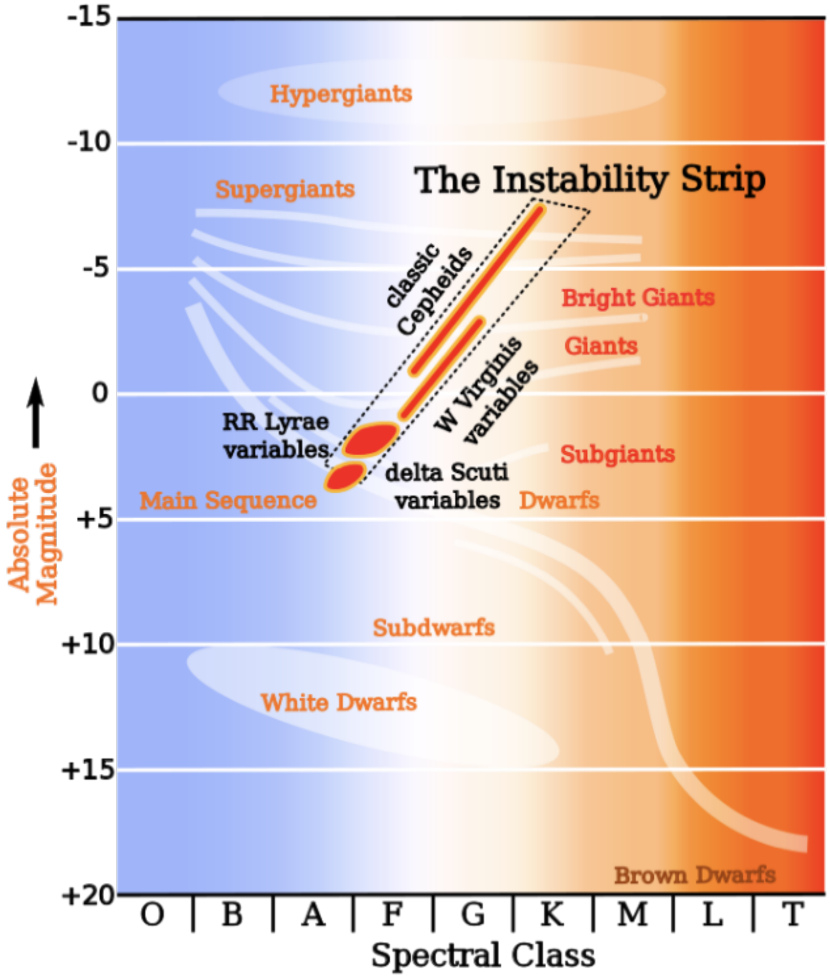
HADS stars are stars in which thermonuclear fusion in their cores has stopped, moving the star off the main sequence of the Hertzsprung-Russell diagram (HRD) and onto the instability strip. Thermonuclear fusion for most stars (and for most of a star's life) is when they are actively converting hydrogen into helium in their cores. Figure 1 shows a typical HRD with the instability strip outlined in black. A HRD plots Spectral Class (essentially temperature) versus Absolute Magnitude (essentially brightness or energy output). For example, "O" type stars are the hottest and brightest stars and are located towards the upper left of the diagram. Our Sun is a "G" star and can be found on the Main Sequence at this stage of its evolution (near the very center of the diagram). All stars can be placed onto an HRD revealing evolutionary patterns.

HADS that are of Population II (meaning they are metal poor with elements heavier than hydrogen and helium significantly depleted in the star) are called SX Phoenicis stars (SX Phe) and these Population II stars are more evolved than their Population I (metal rich) counterparts (Conidis, 2011; Pigulski et al., 2006). Population II HADS stars are usually discovered in globular clusters (old star clusters that typically contain tens of thousands of stars), with about 150 HADS stars located in the Galactic Field. Out of these 150 HADS stars, only 13 of them are known SX Phe stars (Rodríguez & López-González, 2000; Clement et al., 2001; Yang et al., 2012).

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 (speed) through space of -108 km/second, with a radial velocity amplitude of 37 km/seconds (Conidis, 2011; Joner, 1982). Descriptive information specific to XX Cyg is summarized in Table 1. XX Cyg has a mass of 1.7 M_{sun} and a spectral class of A5-F5

(Yang et al., 2012). The Right Assentation (RA) is the location of an object in the sky according to its east-west coordinates. It essentially represents the celestial longitude of a star. The Declination (Dec) is where the object is located in the sky according to its north-south coordinates, essentially the celestial latitude. Effective temperature is the temperature a Black Body (an object that would absorb all electromagnetic [light] radiation) would be if it was the same size of the star. Metallicity is the ratio between the elements iron and hydrogen in the star.

Figure 1. A typical Hertzsprung-Russell Diagram (HRD)



Note. The x-axis (spectral class) represents the types of stars based on temperature (hottest to coolest from left to right), and the y-axis (absolute magnitude) represents the brightness of the star (brightest to dimmest from top to bottom). The Instability Strip represents the area of stars where thermonuclear fusion in their cores has stopped. The HADS stars can be located on the bottom-left location of the Instability Strip.

Table 1. Summary Descriptive Information on XX Cyg

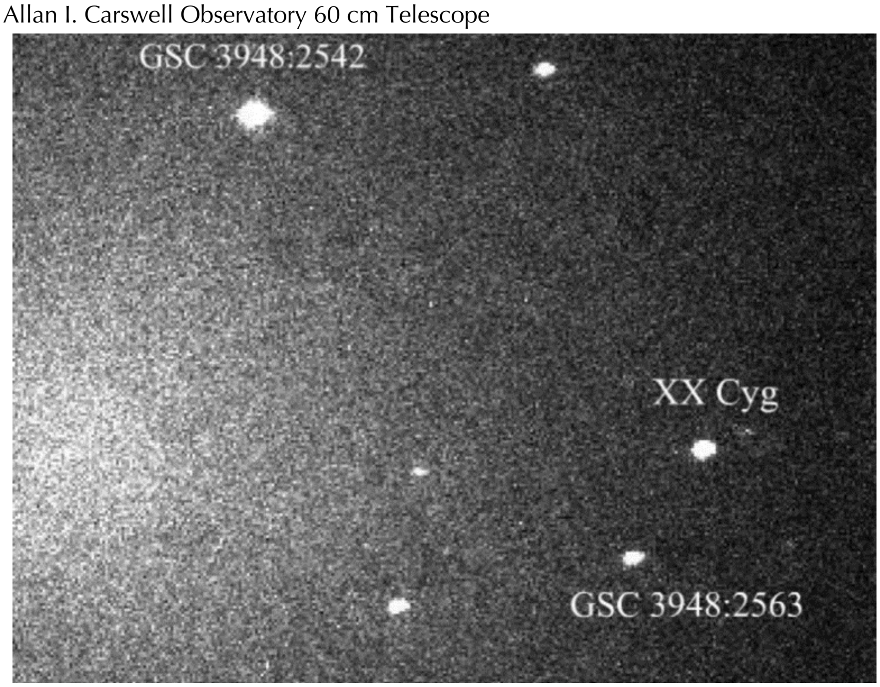
Descriptor	Value
Spectral Type	A5-F5
RA	20h 3m 15.6s
Dec	+58 57′ 16.5′′
Effective Temperature (Teff)	7530 K
Metallicity (Fe/H)	-0.49

Note. RA = Right Assentation, Dec = Declination.

NEW OBSERVATIONS AND FOURIER ANALYSIS

At the AICO, XX Cyg data were collected using a Charged Coupled Device (CCD), essentially an electronic camera containing thousands of light sensitive picture elements, or pixels, that was attached to the 60 cm telescope. The light (photons) striking these pixels creates a pattern of electric charge that can be read by a computer system and then analyzed.

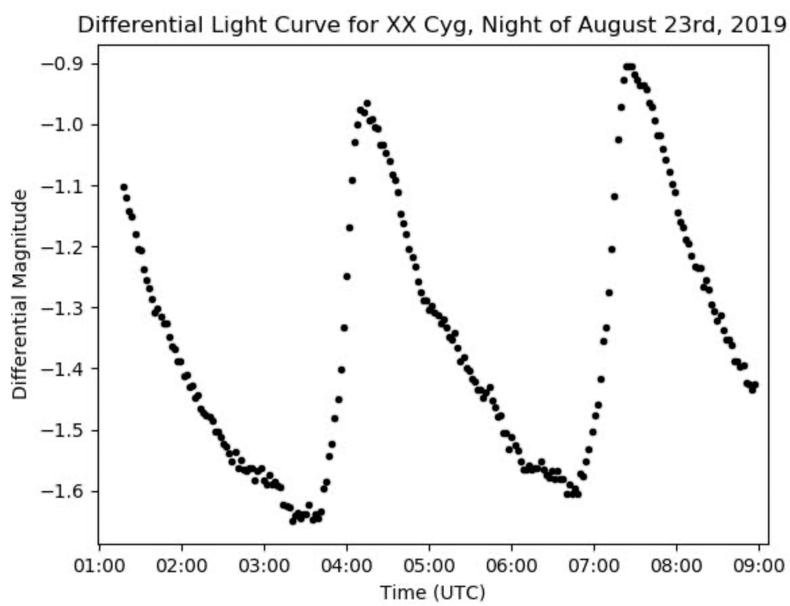
Figure 2. Field of View for XX Cyg on the Charged Coupled Device Attached to the Allan I. Carswell Observatory 60 cm Telescope



For this research, hundreds of images of XX Cyg were taken nightly, so the time of maximum light could be determined from an analysis of the brightness variation of the star measured over time. An example of the field of view for XX Cyg is depicted in Figure 2. Light curves are then used to understand the pulsating nature of the variable star. When light curves are constructed, they form a non-sinusoidal curve as evident in Figure 3, where the x-axis represents the time in Coordinated Universal Time (UTC) while the y-axis marks the differential magnitude. UTC is the world's time standard in which an Atomic Clock and Universal Time are used to get the basis for civil time. The differential magnitude is the difference between the comparison star's (instrumental) magnitude and the variable star's (instrumental) magnitude. The light curves show the maximum time of light, defined by the peak in brightness.

Fourier analysis is a fundamental tool in helping to understand the different frequencies present in a periodic signal (Fiacconi & Tinelli, 2009; Yang et al., 2012). Period04 is a computer program that takes a periodic signal and determines the contributions (strengths) from the different frequencies detected within the signal.

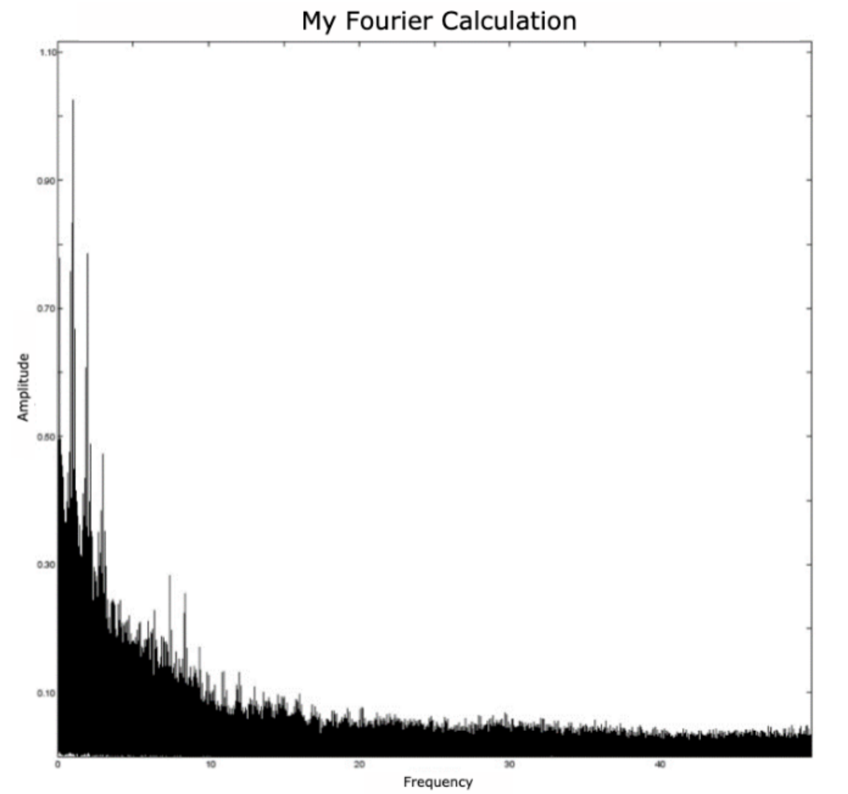
Figure 3. Typical Light Curve for XX Cyg Observed at the AICO for a Time Frame of Approximately Eight Hours



Between the years 2010–2017, 12,895 data points were obtained for XX Cyg at the AICO. The 60 cm telescope was used to collect the raw data for this research and the principal analysis program used to create the nightly light curves was Image Reduction and Analysis Facility (Tody, 1993), along with custom python codes in Linux. To obtain the Fourier spectrum, the Heliocentric Julian Date (HJD) and magnitudes were strung together to form one single time string for input into Period04. The HJD is the number of days since January 1, 4713 BCE, and corrected for Earth's position with respect to the center of the Sun. Period04 produced a Fourier spectrum that showed all the detected frequencies of pulsation for XX Cyg (Figure 4).

The larger (more intense) peaks that are evident in the spectrum represent the main frequencies of pulsation for XX Cyg. Once the spectrum was obtained, the research data was input to VStar, a similar program to Period04 that allows the generation of more quantitative information relating to the Fourier spectrum. With this program, fundamental frequencies were explicitly extracted from the time string inputted.

Figure 4. Fourier Spectrum of XX Cyg from Period04



Note. The x-axis is the frequency and ranges from 0–50 cycles per day. The y-axis shows the amplitude (energy or strength of pulsation) and ranges from 0–1.10 units.

FINDINGS

The five frequencies with the most energy were extracted from VStar and are shown in Table 2. A fundamental frequency of 7.3 cycles/day was successfully detected, in keeping with previous research results. The fundamental frequency is receiving the majority of the energy while at least four non-radial modes at other frequencies were present. Non-radial means that as some parts of the star are expanding, some areas are shrinking at the same time, while radial means the whole star is either contracting or expanding. Again, using a music analogy, a drum membrane when struck will have some portions moving "up" while other parts of the membrane are moving "down." Thus, the results from VStar confirm that XX Cyg is a radial mode pulsating star, but there is evidence showing energy is being distributed into non-radial pulsations modes.

Table 2. Pulsation Frequencies Detected from VStar for XX Cyg

Frequency (cycles/day)
7.3 (Fundamental Frequency)
15.07
22.84
29.5
37.27

Harmonics were also searched for with VStar. Harmonics are integer (1, 2, 3, etc.) multiples of the fundamental frequency. Looking at the top five frequencies primarily, there is no evidence of exact integer multiples being present. Examining the top 10 frequencies detected (based upon the energy available to these frequencies) revealed 58.4 cycles/day, 94.9 cycles/day and 109.5 cycles/day which are integer multiples of the fundamental pulsation frequency and therefore are harmonics.

CONCLUSION

XX Cyg is shown to have a fundamental pulsation frequency of 7.3 cycles/day with additional non-radial modes present in the star. With research data from the years 2010 to 2017, it is evident that XX Cyg is distributing most of its energy into the fundamental pulsation with other frequencies having smaller amounts of energy deployed to them. When examining the top 10 pulsation frequencies detected, harmonics were evident.

The determination of the principal pulsation frequencies helps to constrain the theoretical models for the energy regeneration processes occurring within the star as it traverses the Instability Strip of the HRD. Applying the Fourier analysis to the broader category of δ Scuti stars will further improve our understanding of these stars as they transition from hydrogen fusion energy generation (on the main sequence) into their later stages of stellar evolution.

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