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# The 2006-2007 Observing Campaign on VX Hydrae

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## Abstract

We present the results of the 2006-2007 observing campaign on the double-mode delta Scuti star VX Hydrae. Nearly 8800 V-band CCD observations were obtained during the two observing seasons. Although the data were taken with small telescopes (0.3-m or less) and using consumer-grade CCD cameras, the data quality is very high, enabling the detection of variability at the millimagnitude level at some frequencies. Analysis of the data yields only two primary pulsation frequencies: f(0) = 4.4765 c/d, and f(1) = 5.7899 c/d. The two modes have comparable amplitude, although the amplitude of f(1) appears to have increased slightly from 2006 to 2007 by 0.01 mag. Only two pulsation modes are detected, but at least 18 additional linear combination frequencies are also clearly detected, some having amplitudes as low as 1 mmag. We discuss the evidence for amplitude variation in VX Hydrae, along with prospects for future study of this and other similar delta Scuti stars by AAVSO observers.


## Introduction

Delta Scuti variables are a class of regular pulsators lying within the lower Cepheid instability strip. They are a mix of stars of various ages on or near the main sequence, divided into subtypes according to pulsation amplitude and metal abundance. The basic astrophysics of the delta Scuti class is well understood, but there are several observational problems which are not, including long-term period and amplitude changes, mode selection and excitation, and structural effects on the pulsation behavior. Many of these problems cannot be studied without concentrated, long-term observing campaigns targeting individual stars.

VX Hydrae is a high-amplitude delta Scuti star with a very complex light curve. The star was observed irregularly by Lause (1938) and Fitch (1961, 1966) in the middle of the 20th Century, and was extensively observed visually by M. Baldwin of the AAVSO to define times of maximum for nearly 40 years. Historical observations were not densely sampled enough to unambiguously describe the variations, but it was clear that several frequencies were present in the Fourier spectrum, and that the spectrum was changing with time; Fitch (1966) suggested that the amplitudes of one or more frequencies were changing with time.

In 2006, G. Samolyk initiated a multi-site observing campaign within the RR Lyrae Committee of the AAVSO to intensively observe VX Hydrae and better characterize its pulsation spectrum at the present time. Observers were located in Wisconsin (Samolyk, Poklar, Gerner), Florida (Dvorak), and Queensland, Australia (Butterworth). The observers collected 5400 untransformed V-band observations in 2006, and 3400 observations in 2007. In this poster, we present an analysis of the collected photometry, and discuss the physical implications of the current results and suggest how additional observations may provide more insight into the behavior of this interesting system.

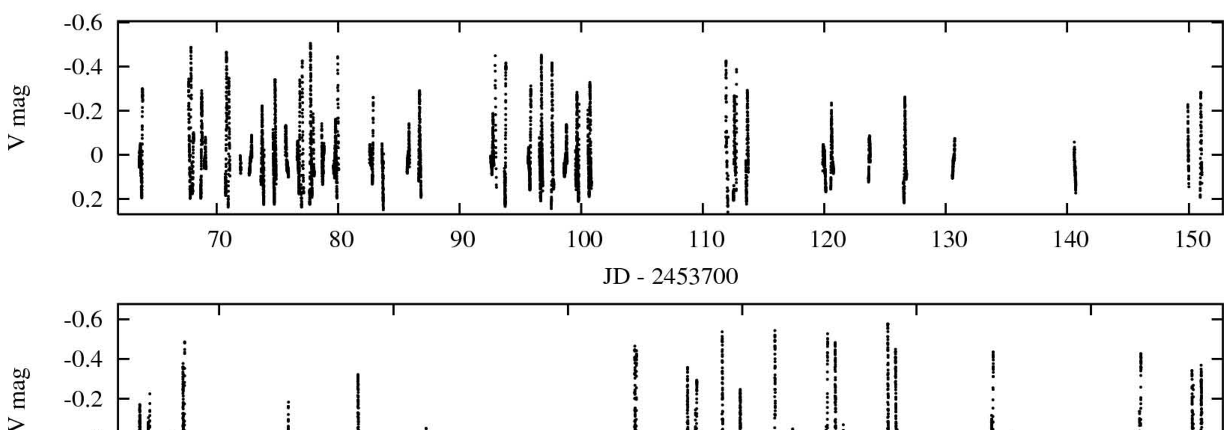


**Figure 1**: The 2006 (top) and 2007 (bottom) light curves of VX Hydrae. The 2006 light curve spans 89 days, while the 2007 light curve spans 122 days. The photometric errors per point and sampling rate vary from observer to observer and night to night, but errors are typically < 0.01 mag, and sampling rates are on the order of 90 seconds. To avoid oversampling and overlapping data, the light curve was averaged into temporal bins of 0.001 days prior to Fourier analysis.

## Data

Observations were obtained by five observers over the course of 449 days in 2006 and 2007. During 2006, approximately 5400 observations were collected over the course of 89 days (JD 2453763 -- 2453851); during 2007, 3400 observations were collected over the course of 122 days (JD 2454090 -- 2454212). Observations were made with small telescopes below 0.3-m in aperture, using consumer-grade CCD cameras and photometric standard V filters. The data are of very high photometric quality, with photometric errors per point typically less than 0.01 magnitude. Data were not transformed or extinction corrected, and so photometric zero points were established for individual observers prior to assembly of the final light curve. Highly discrepant points were removed from the light curve prior to Fourier analysis. Temporal sampling rates and nightly coverage vary from observer to observer and throughout the observing season. The complete, two-season light curve is shown in Figure 1.

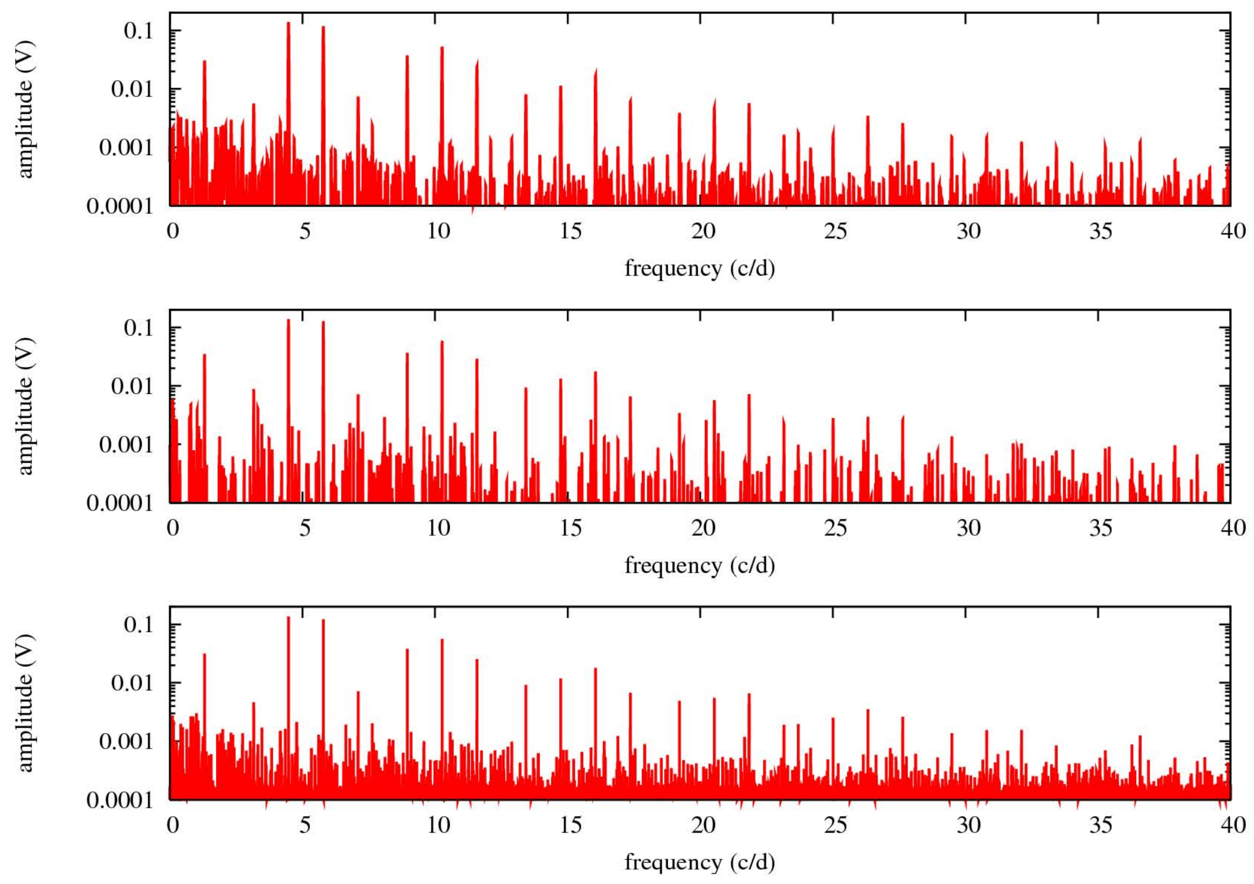


**Figure 2**: The Fourier spectra for the 2006 (top), 2007 (middle) and combined (bottom) light curves of VX Hya. Amplitudes are plotted logarithmically to make the low-amplitude peaks more apparent against the background. The three spectra are very similar, with the main difference being a higher noise level in the 2007 season, and slightly different amplitudes for f(1) and a few of the beat frequencies from year to year. Aside from the amplitudes, the observed beat frequencies appear to be constant from year to year, with no measurable change in frequency.

| frequency (c/d) | amp (V) | phase (rad) | i | j | \|i\|+\|j\| | freq (calc) | delta freq (o-c) |
|---|---|---|---|---|---|---|---|
| 4.47646788 | 0.1373 | 2.9755 | 1 | 0 | 1 | 4.47646788 | (na) |
| 5.7898669 | 0.1225 | -0.8956 | 0 | 1 | 1 | 5.7898669 | (na) |
| 10.26635218 | 0.0566 | -0.1544 | 1 | 1 | 2 | 10.26633478 | 0.0000174 |
| 8.95293576 | 0.0381 | -2.5173 | 2 | 0 | 2 | 8.95293576 | 0 |
| 1.31332943 | 0.0319 | -0.835 | -1 | 1 | 2 | 1.31339902 | 0.00006959 |
| 11.57971641 | 0.0255 | 2.5889 | 0 | 2 | 2 | 11.5797338 | 0.00001739 |
| 16.05625387 | 0.0181 | 2.7591 | 1 | 2 | 3 | 16.05620168 | 0.00005219 |
| 14.74278527 | 0.012 | 0.8564 | 2 | 1 | 3 | 14.74280266 | 0.00001739 |
| 13.42942104 | 0.0091 | -1.5997 | 3 | 0 | 3 | 13.42940364 | 0.0000174 |
| 7.10323113 | 0.0071 | 1.7301 | -1 | 2 | 3 | 7.10326592 | 0.00003479 |
| 17.36944413 | 0.0068 | -0.3855 | 0 | 3 | 3 | 17.3696007 | 0.00015657 |
| 21.84612077 | 0.0066 | -0.2108 | 1 | 3 | 4 | 21.84606858 | 0.00005219 |
| 20.53273915 | 0.0055 | -2.4811 | 2 | 2 | 4 | 20.53266956 | 0.00006959 |
| 19.21923575 | 0.0049 | 1.6832 | 3 | 1 | 4 | 19.21927054 | 0.00003479 |
| 3.16308626 | 0.0047 | 1.3292 | 2 | -1 | 3 | 3.16306886 | 0.0000174 |
| 26.32257126 | 0.0036 | 0.2521 | 2 | 3 | 5 | 26.32253646 | 0.0000348 |
| 27.63597028 | 0.0026 | 3.0683 | 1 | 4 | 5 | 27.63593548 | 0.0000348 |
| 25.00925922 | 0.0025 | -1.9082 | 3 | 2 | 5 | 25.00913745 | 0.00012178 |
| 7.63958893 | 0.002 | 1.9391 | 3 | -1 | 4 | 7.63953674 | 0.00005219 |
| 23.69566884 | 0.002 | 2.4786 | 4 | 1 | 5 | 23.69573842 | 0.00006958 |
| 23.15934583 | 0.0019 | 2.9832 | 0 | 4 | 4 | 23.1594676 | 0.00012177 |
| 32.11243816 | 0.0016 | -2.8007 | 2 | 4 | 6 | 32.11240337 | 0.00003479 |
| 30.79909133 | 0.0016 | 1.0718 | 3 | 3 | 6 | 30.79900435 | 0.00008698 |
| 29.48569231 | 0.0014 | -1.2376 | 4 | 2 | 6 | 29.48560533 | 0.00008698 |
| 36.58897563 | 0.0013 | -2.2612 | 3 | 4 | 7 | 36.58887125 | 0.00010438 |
| 12.89320241 | 0.001 | -0.8909 | -1 | 3 | 4 | 12.89313282 | 0.00006959 |
| 17.9059759 | 0.0009 | -0.938 | 4 | 0 | 4 | 17.90587152 | 0.00010438 |

**Table 1**: Frequencies, amplitudes, and phases of 27 observed frequencies matching a calculated beat frequency within 1 FWHM of the spectral resolution. Phases are relative to t(0)=HJD 2453988.1752. We are able to detect beat frequencies with |i|+|j| up to 7 for the higher frequency modes, several of which have amplitudes around 1 mmag. We note that many other peaks (not tabulated) are likely to be noise fluctuations, but these occur primarily at low frequencies where the noise level is higher.

## Analysis

The light curve was analyzed in three stages: the 2006 data by itself, the 2007 data by itself, and the combined 2006-2007 data set. This was done to check whether there was significant period, amplitude, and/or phase evolution over the course of the year. The data were analyzed using a cleaning discrete Fourier transform method developed by Roberts, Lehar, and Dreher (1987) for the analysis of irregularly sampled data with strong sidelobe interference.

We then selected the 100 highest peaks in the cleaned Fourier spectrum, and used the strongest two peaks (assumed to be f(0) and f(1)) to calculate the frequencies of all possible linear combinations of frequencies

$$f(beat) = (i*f(0)) + (j*f(1)) , -10 < i,j < +10 .$$

These were then compared to the strongest observed peaks, and all observed frequencies matching calculated beat frequencies were assumed to be real peaks. These were then subtracted out of the light curve, and the data reanalyzed to determine whether any peaks other than beat periods were present in either year individually or in the merged data set.

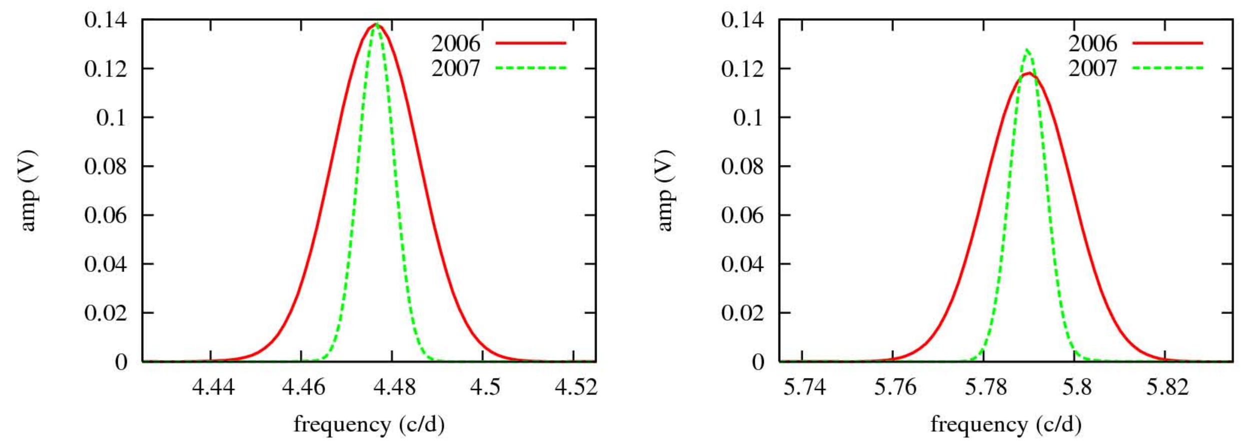


**Figure 3**: Amplitudes of f(0)=4.4765 c/d and f(1)=5.7899 c/d for the 2006 (red) and 2007 (green) observing seasons. Both seasons of data show the same frequencies within the errors for both modes. The amplitude of f(1) apparently changed from 2006 to 2007; the amount of the change (approximately 0.01 mag) is marginally larger than the noise level, suggesting that the change is real.

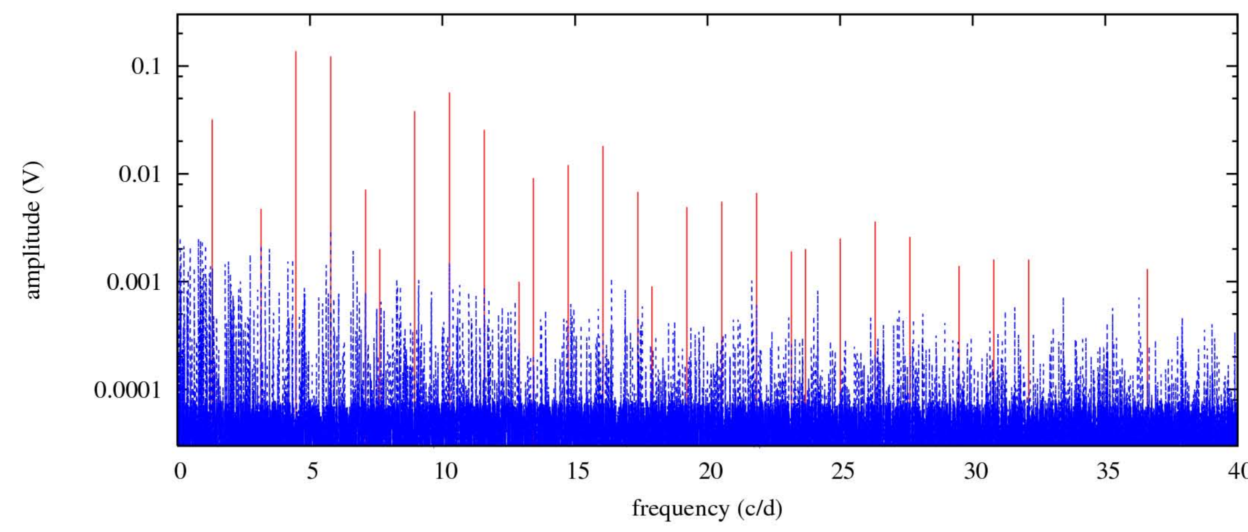


**Figure 4**: Fourier transform of the data prewhitened with all frequencies shown in Table 1 (blue), along with the subtracted peaks (red). There are no residual peaks larger than about 3 mmag, and the noise level has a clear frequency dependence with higher noise at lower frequencies. At a frequency of 25 c/d, the noise level is approximately 1 mmag, and we see several peaks corresponding to allowed beat frequencies in this frequency range with amplitudes clearly above the noise. We therefore believe that most of the frequencies in Table 1 are real.

## Discussion

The Fourier transforms of the 2006, 2007, and combined data sets are shown in Figure 2, and 27 detected and suspected frequencies are given in Table 1. We detect no significant peaks in VX Hya other than f(0), f(1), and more than two dozen suspected beat frequencies. We do not see evidence for a third radial pulsation mode, nor clear evidence for non-radial modes. Thus it appears that VX Hya is a purely radial pulsator, whose complexity comes mainly from the large amplitudes of f(0) and f(1) and the resulting beat periods. The ratio f(0)/f(1) of 0.7732 is consistent with a fundamental/first overtone pulsator with near solar metal abundance, and a mass at the high side of the delta Scuti instability strip ([Fe/H] ~ +0.05, M ~ 2.4 M(sun); see McNamara 1997, and Templeton 2000).

We detect no significant period change in VX Hya; f(0) and f(1) remained unchanged within the errors. There does appear to be a slight change in amplitude of f(1) (see Figure 3), which also results in amplitude changes in its harmonics and its beat frequencies with f(0). Continued monitoring of VX Hya in subsequent seasons with similar coverage and sensitivity would be very useful to determine whether there are systematic variations in amplitude. A longer time base would also aid in determining whether period changes occur.

From the standpoint of the data sensitivity, it is clear that we have detected a large number of beat frequencies in the spectrum, with 18 of 27 having amplitudes larger than 2 mmag. Although the remaining nine have low amplitudes, they are at or above the highest noise peaks in the residual spectrum (Figure 4), and they closely correspond to calculated beat frequencies. If they are real, this work shows that small telescopes run by amateurs are fully capable of detecting very low amplitude signals if enough data are collected with sufficient quality. The detectability of these signals is greatly aided by the regularity of delta Scuti pulsators generally and the sensitivity of the analysis method; it is unlikely that irregular variations with amplitudes at or below 1 mmag could be detected at this time. However, this work makes clear that small telescopes can be used to study systems as complex as delta Scuti pulsators, and they may have a role to play in the study of other systems of greater asteroseismic interest. We invite suggestions for other targets as well as collaboration on future research projects in this field.


## References

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