Long-term, multicolor photometry of Type II Cepheids and other variables

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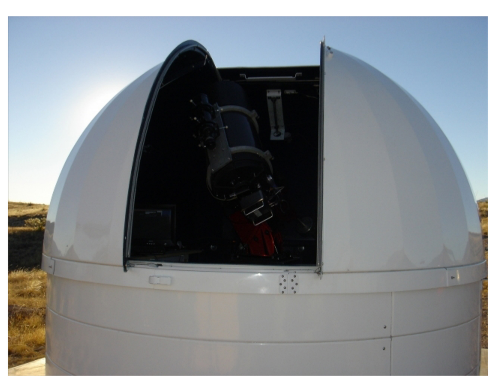
Abstract

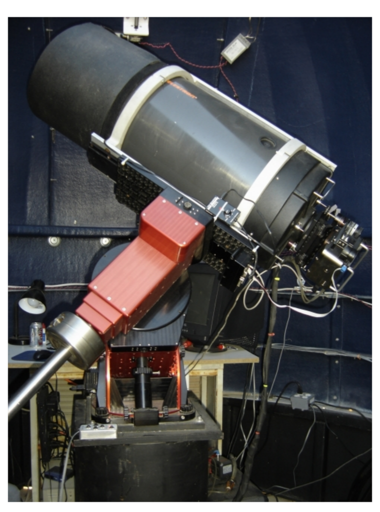
Long-term, multicolor photometry of W Virginis has revealed the presence of regularly alternating minima, identified as arising from fundamental-first overtone pulsation with a period ratio of P(1) = 2P(0)/3. Such behavior was suspected in W Vir as early as the 1950s, but had not been conclusively identified until now. The presence of an identifiable secondary pulsation mode in the pulsations of this star raises several interesting possibilities for modeling and future observations. Observations of more long-period Type II Cepheids may prove fruitful, particularly as regards the phenomenon of alternating minima; some work has already been done data mining of the MACHO (Pollard et al. 2000) and ASAS (Wils & Otero 2008) databases, and current and upcoming photometric monitoring systems may provide much more useful data on these stars. In this poster, we present a few examples from the long-term photometric program of the AAVSO obtained with the *Sonoita Research Observatory* in Arizona, with a view toward modeling these interesting stars and their light curves.

Introduction

In Templeton & Henden (2007) we used a long-term, four-color light curve of W Vir to confirm a long-standing observational claim about this star -- the presence of alternating minima. Our analysis conclusively showed both the presence of alternating minima as well as their cause: double-mode pulsation with a resonance between the fundamental and first overtone periods, P(1) = 2P(0)/3. While weak irregularity among the long-period stars of the W Vir class is a known phenomenon, this result for W Vir raises the question: is "irregularity" in all W Vir stars simply double-mode pulsation that hasn't yet been resolved? This question cannot be addressed without intensive time-series observations, which is becoming increasingly rare for brighter Milky Way variables, and rarer still using multiple filters.

A comprehensive study of several W Vir and RV Tau stars could reveal much about the observational similarities between these classes of stars,as well as providing very well-defined references for evolution and pulsation modeling. We are more likely to obtain accurate temperatures, chemical compositions, and radial velocity information for brighter stars than for fainter extragalactic or Bulge stars. We show light curves and results for W Vir and ST Pup along with FN Aql and TU Cas obtained with the *Sonoita Research Observatory* 0.35-meter telescope as examples of what a small, dedicated telescope can provide.





Sonoita Research Observatory

The *Sonoita Research Observatory* is a fully-automated Celestron C-14 situated on a telescope farm near Sonoita, Arizona, approximately 50 km SSE of Tucson. The facility is operated by J. Gross, in collaboration with A. Henden, D. Terrell (SWRI) and W. Cooney (Blackberry Obs., Baton Rouge, LA). The telescope uses an automated queue for efficient scheduling of observations, and data are acquired on all clear nights. The telescope currently has an SBIG STL 1001E camera with standard (Cousins) BVRI filters. Raw images are transferred nightly via the internet from the telescope to SWRI (Boulder, CO) and then to AAVSO for automated processing (with IRAF). The AAVSO nominally has a 25 percent share of this telescope; observing time is allocated primarily for field calibration work (photometric nights), as Director's discretionary time, or competitively to AAVSO members in good standing who request data for their own research programs.

All data shown in this poster was taken by A. Henden as part of a long-term research program on Cepheid variables. The data will soon be available for download from the AAVSO website to any interested researchers.

W Virginis

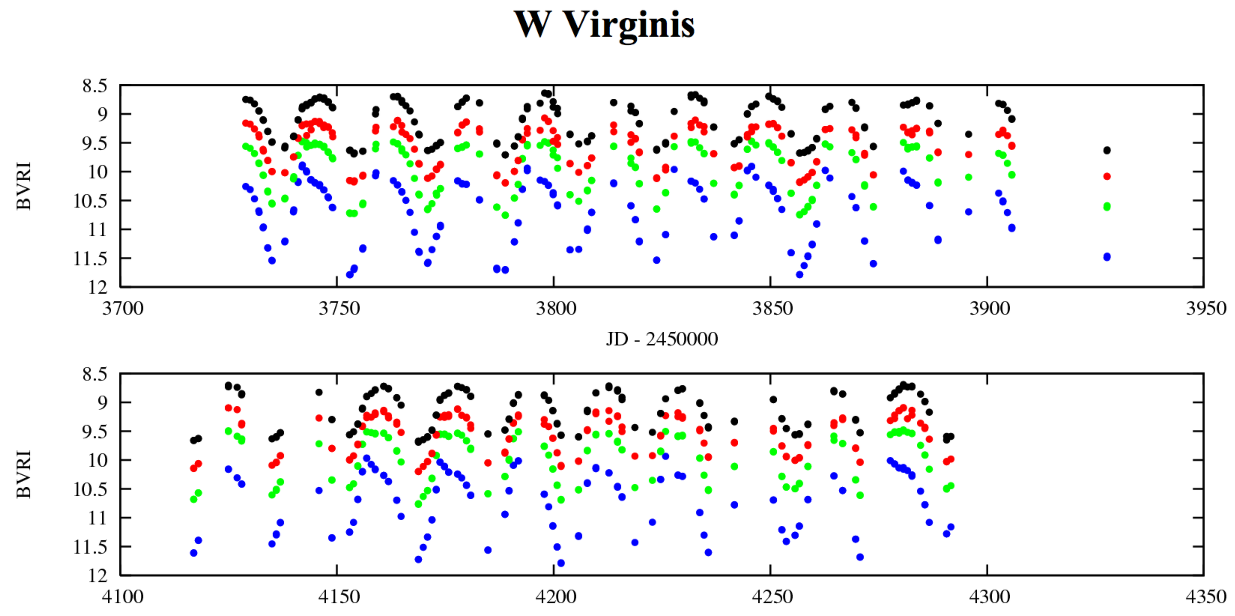


Figure 1: The two-year, *BVRI* light curve of W Virginis obtained with the SRO 0.35-meter telescope. Fourier analysis of these data indicate double-mode pulsation (F/1H) with a period ratio near the resonance P(1)=2P(0)/3 (P(0) = 17.27134 d), resulting in alternating minima. While the minima clearly alternate over the short term, the pattern is not strictly constant over several years. See Templeton & Henden (2007) for details.

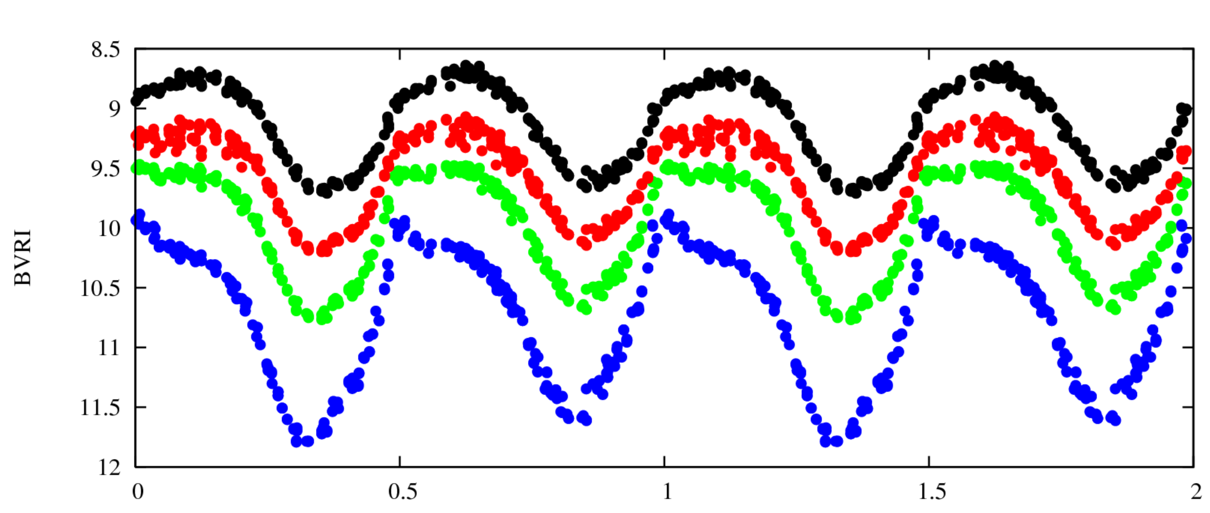


Figure 2: The W Vir light curve shown in Figure 1, folded with a period of 2P(0). The alternating minima are nearly constant during the 400-day span of these data, although the depth of the secondary minimum appears to vary. We note that the *R*-band light curve shows significantly higher scatter at maximum, which can be attributed to time-variable H-alpha emission, presumably from irregular shock waves in the atmosphere.

ST Puppis

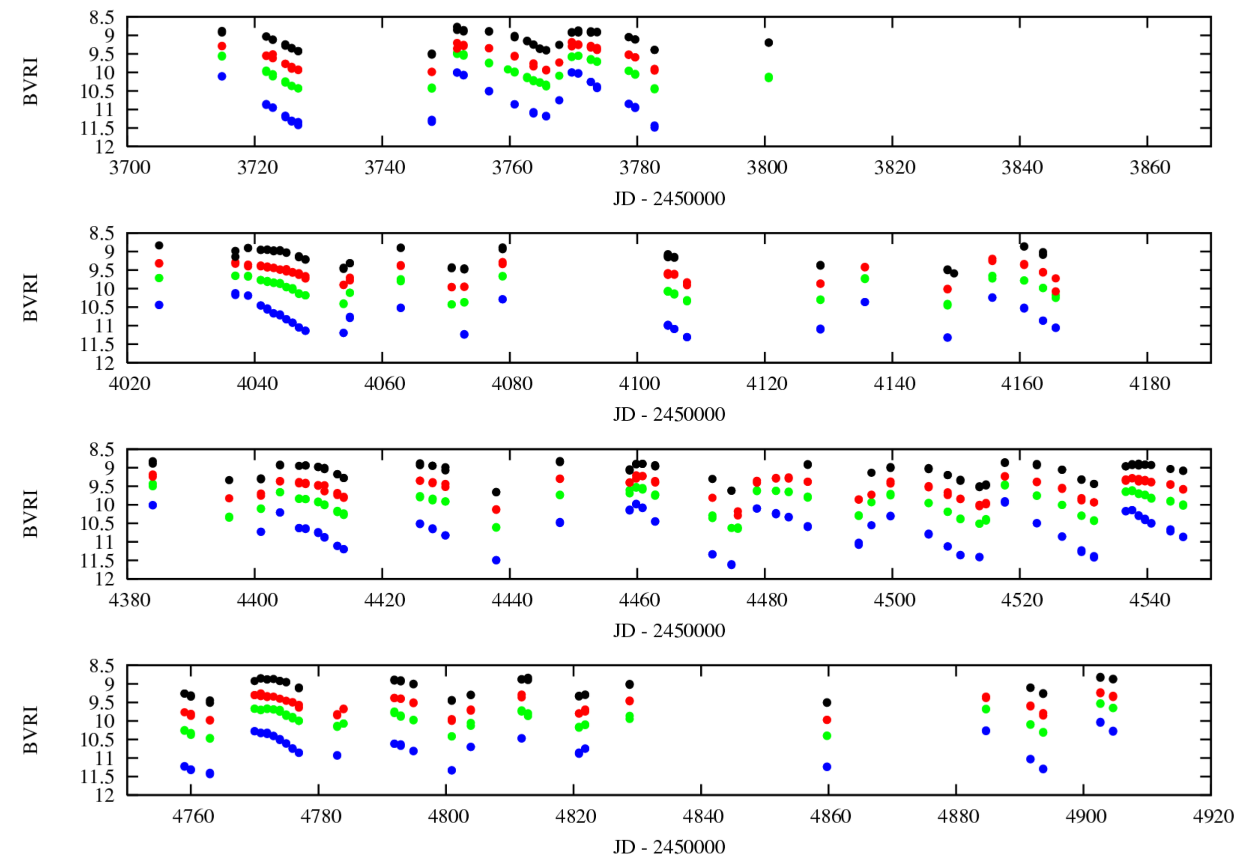


Figure 3: The four-year, *BVRI* light curve of ST Puppis obtained with the SRO telescope. The period derived from the *B*-band data is 19.18068 d; this is significantly different from the 18.462-day period derived by Kilkenny et al. (1993) for the 1989-1992 observing seasons. We note that ST Pup is a binary, and no account has been taken for light-time travel effects.

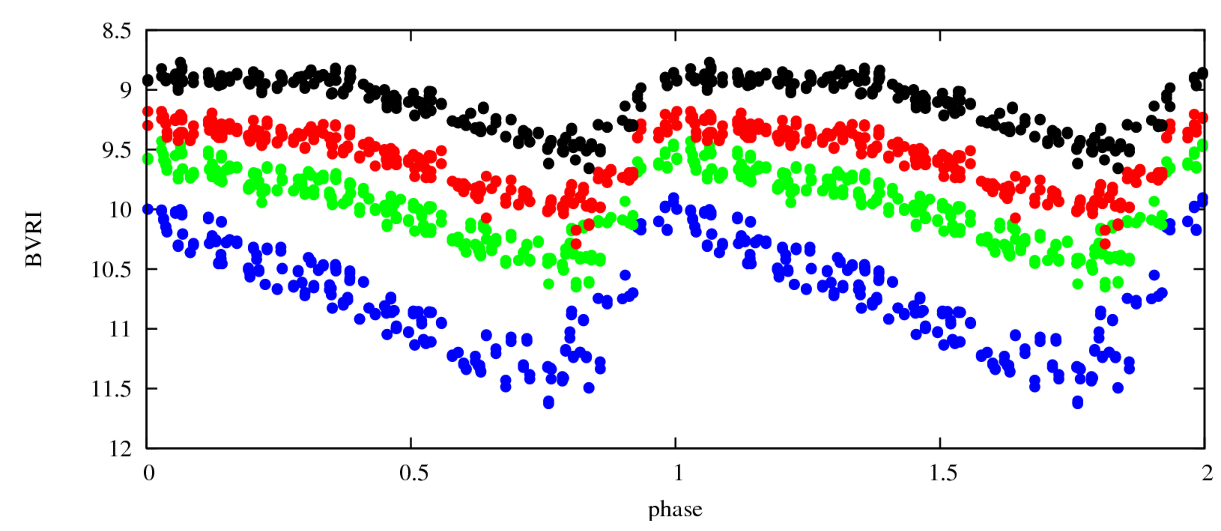


Figure 4: The ST Pup light curve shown in Figure 3 folded with the period of 19.18068 d. These data cannot be folded with the 18.462-day period derived by Kilkenny et al (1993). Although the primary pulsation period is apparent, the folded light curve shows irregularity, and the Fourier transform (Figure 5, below) shows a longer secondary period around 32 days.

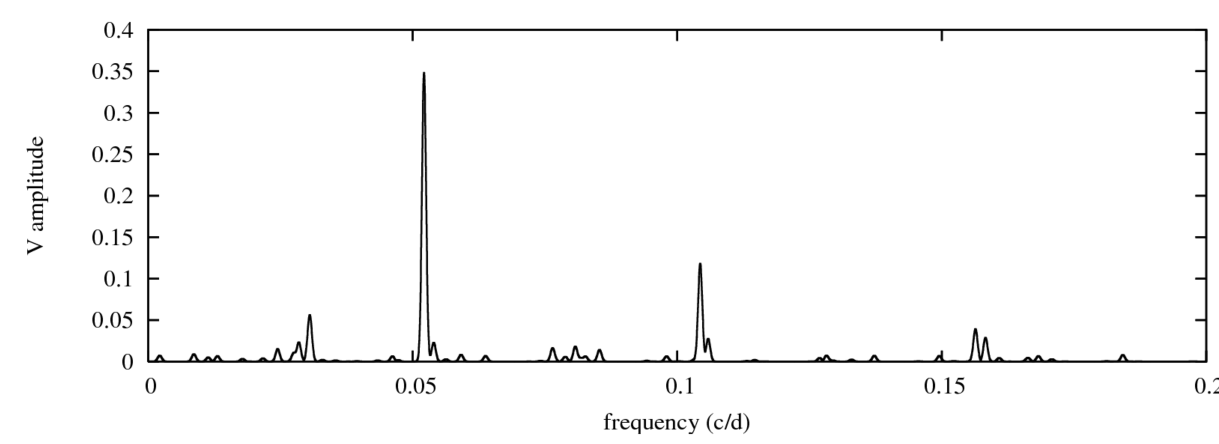


Figure 5: Fourier transform of the V-band data shown in Figure 3. The strongest peak is at a frequency of f = 0.0521358 c/d (P = 19.18068 d). The lower-frequency peak is f = 0.030537 c/d (P=32.74696 d). There is some evidence for additional peaks at f ~ 0.08 c/d which could be an overtone responsible for the low-frequency peak. Further analysis taking into account binary light-time travel effects is needed.

FN Aquilae

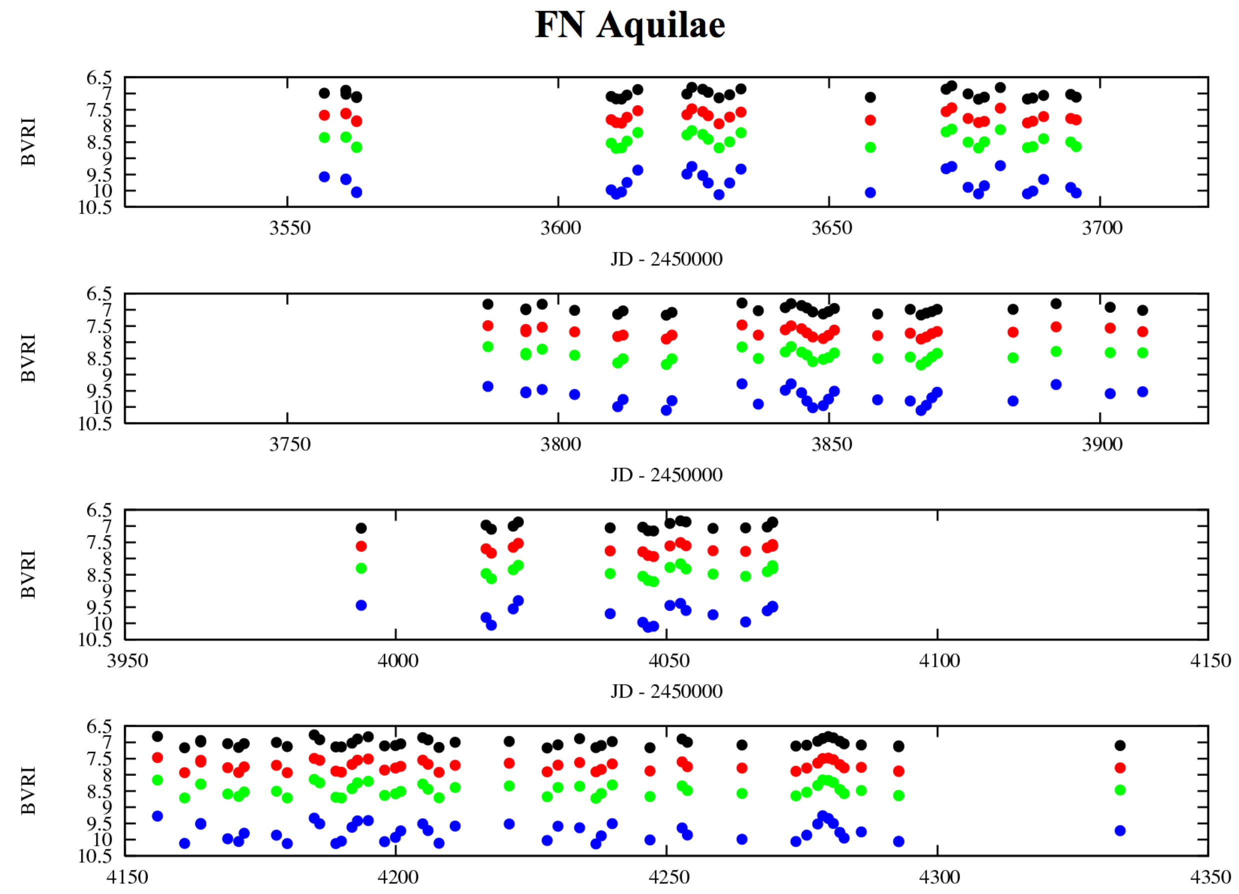


Figure 6: The four-year, *BVRI* light curve of the classical Cepheid FN Aquilae. Fourier analysis of this light curve yields a period of 9.482400 d.

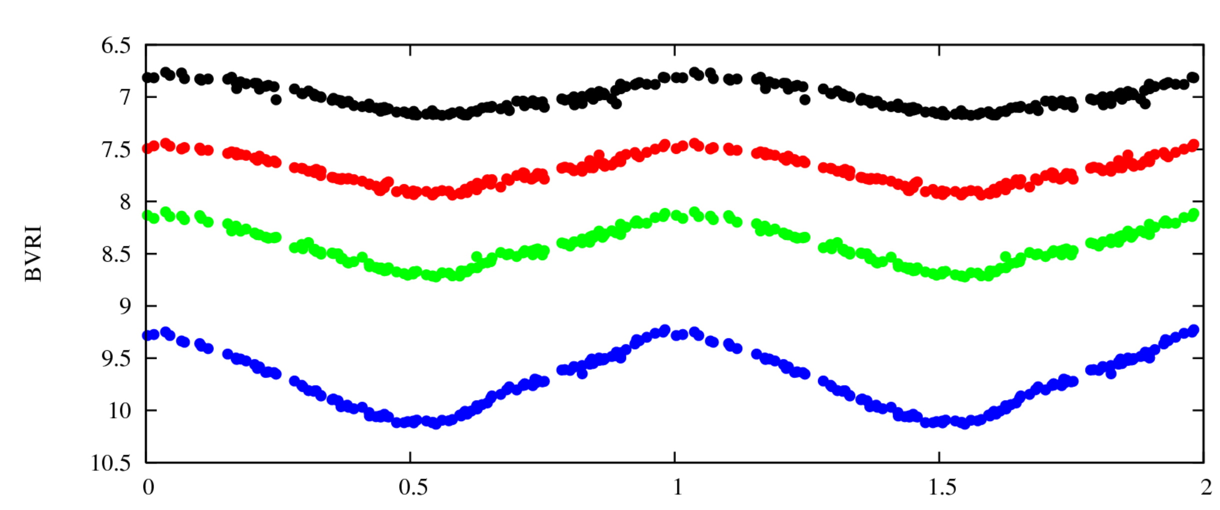


Figure 7: The FN Aql light curve shown in Figure 6, folded with a period of 9.482400 d. Like other classical Cepheids having periods near 10 days, the amplitudes are much lower and the light curves more sinusoidal. This light curve would provide an interesting comparison for nonlinear modeling of these stars.

TU Cassiopeiae

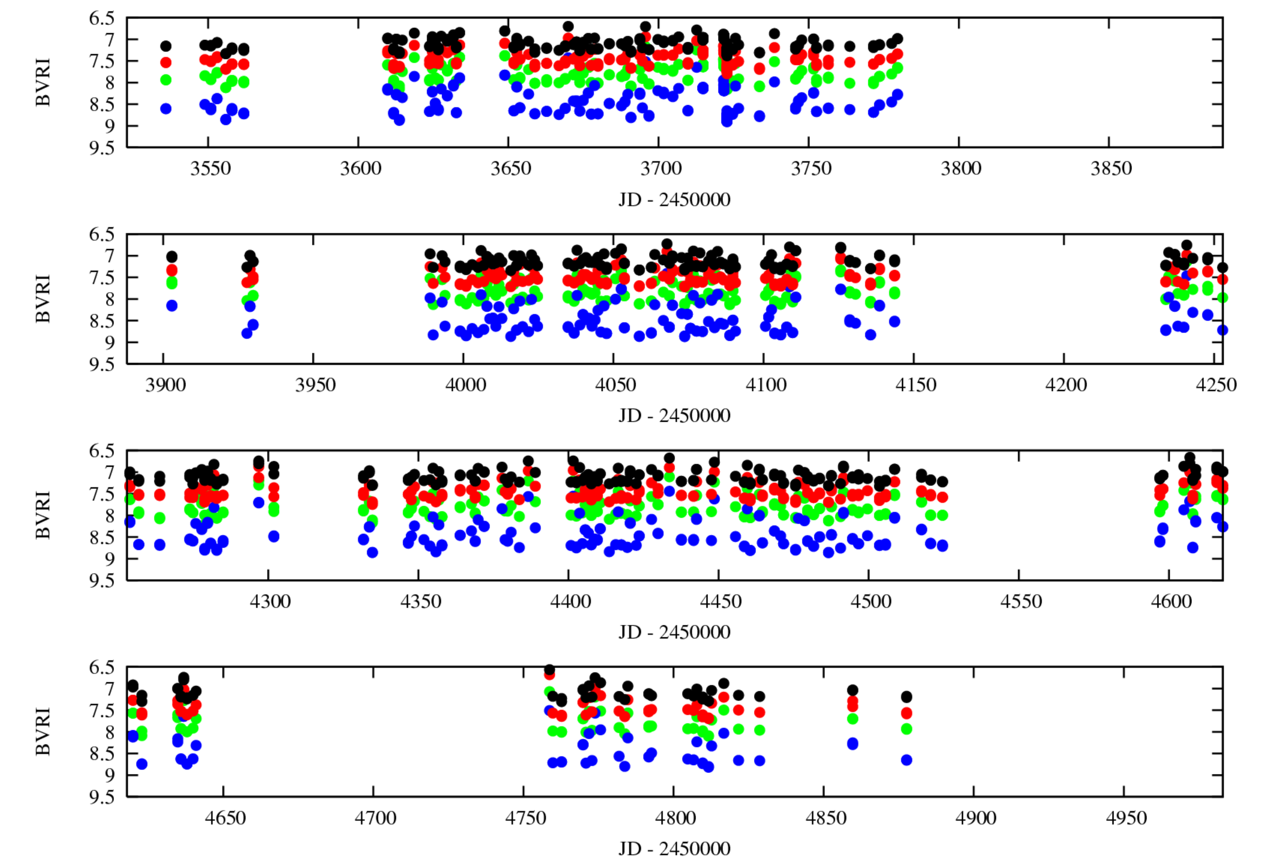


Figure 8: The four-year, *BVRI* light curve of the beat Cepheid TU Cas. These data yielded the 13 frequencies shown in Table 1 below. Prewhitening of the data with these frequencies and recalculation of the Fourier transform yields no additional signals except for a weak signal near f(0) due to incomplete subtraction.

frequency (c/d)	Period (d)	V amplitude	phase	i	j	|i|+|j|
0.467467	2.13918	0.2649	2.3566	1	0	1
0.658678	1.51819	0.0943	-0.3232	0	1	1
0.934910	1.06962	0.0876	2.5575	2	0	2
1.126113	0.88801	0.0596	-0.3100	1	1	2
1.593557	0.62753	0.0390	0.1254	2	1	3
0.191165	5.23107	0.0270	1.4724	-1	1	2
1.402377	0.71308	0.0266	2.9930	3	0	3
2.060964	0.48521	0.0098	0.3654	3	1	4
1.784819	0.56028	0.0097	-2.7784	1	2	3
2.252244	0.44400	0.0096	-2.2240	2	2	4
1.317309	0.75912	0.0051	-2.7030	0	2	2
1.869767	0.53483	0.0036	2.9243	4	0	4
2.528584	0.39548	0.0016	-0.4951	4	1	5

Table 1: Reliably detected frequencies in the TU Cas light curve shown in Figure 8. Phases are in radians relative to HJD=2454206.77745. All frequencies below the top two are linear combinations of f(0) and f(1). The values of **i** and **j** are the integer multiples of f(0) and f(1) which create the beat frequency.

Data for the asking: SRO and AAVSONet

The examples given in this poster are typical of what the *Sonoita* telescope is capable of doing with a long-term observing program. All of these light curves could provide excellent starting points for modeling programs, for example in the computation of precise LNA periods and period ratios from evolutionary calculations, or the calculation of nonlinear light and color curves. For most field stars, SRO can deliver useful, high-S/N light curves within a single season or less, and observations can continue for multiple observing seasons. The system could be used (for example) to determine the properties of poorly-studied Cepheids or RV Tauri stars, or be used to study long-term changes in pulsation behavior for a small sample of stars. As long as the observations and photometric reductions can be automated, the system is ready and waiting.

The Sonoita Research Observatory is the first telescope available in the new AAVSONet global telescope network, which will be composed of several small, research-quality telescopes at locations in both the *northern and southern hemispheres*. We hope to have additional telescopes in the United States and New Zealand online and ready to observe within the next 12-18 months.

As mentioned above, time on SRO is available both for Director's discretionary time, and competitively for AAVSO Members. The AAVSO is a *membership organization* composed of thousands of Professional and Amateur astronomers world-wide, and everyone is welcome and encouraged to join. If you're interested in becoming a member of the AAVSO, or want to learn more about our services and data products, please ask!

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