AAVSO PHOTOELECTRIC PHOTOMETRY NEWSLETTER

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Editor: John R. Percy

Contributions to this *Newsletter* are gratefully received at any time. [They might help the editor to overcome his chronic tardiness in putting this *Newsletter* together.] Please send them to: John Percy, Erindale Campus, University of Toronto, Mississauga ON, Canada L5L 1C6; e-mail: jpercy@utm.utoronto.ca

All material has been written by the Editor, unless otherwise indicated.

Welcome to Arne Henden!

In March 2005, Dr. Arne Henden was appointed Director of the AAVSO, only the fourth director in the 94-year history of the Association. Arne is well-known for his research in photometry and variable stars, and for his support for the AAVSO and for amateur astronomy in general. He is especially well-known to photoelectric photometrists as co-author (with R.H. Kaitchuck) of the book *Astronomical Photometry* (Van Nostrand Reinhold 1982). We welcome him to the AAVSO and to this *Newsletter*. For more about Arne, go to:

http://www.aavso.org/news/henden.shtml

What is Photoelectric Photometry?

Photoelectric photometry is the measurement of the brightness of a star, or other object, using a light-sensitive electronic device such as a photodiode or photomultiplier. When carefully done, its accuracy can be anything from 0.01 down to 0.001 magnitude, or even better if done from space. Conventional PEP differs from CCD (charge-coupled device) photometry in that it measures one star at a time, rather than being "panoramic" and measuring all stars in a field of view. CCD photometry has many advantages, but conventional PEP is still useful and competitive, especially for brighter stars. PEP is usually "differential"; the brightness of the variable star is measured relative to the brightness of a non-variable comparison star. For bright variable stars, the comparison star is rarely in the same CCD field of view as the variable, so there is no advantage to a panoramic detector. The value of PEP is demonstrated by the success of the AAVSO PEP program.

The AAVSO Photoelectric Photometry Program

The AAVSO PEP Program was developed in the early 1980's by the late Janet Mattei, with increasing involvement from John Percy. The majority of program stars were ones on the AAVSO visual program which showed forms of variability which were too small-amplitude to be well-studied visually. At that time, the visual program was heavily populated by Mira stars and their relatives, so the PEP program stars were mainly small-amplitude (a magnitude or less) pulsating red giants. This was a prescient decision on Janet's part, because pulsating red giants turn out to have types of small-amplitude variability which can be revealed by long-term PEP.

For the last year or so, the AAVSO PEP Program has been coasting along, quite successfully, like a plane on autopilot. With the resignation of PEP Committee Chair Phil Manker for medical reasons, and the illness and death of Janet Mattei, we have had limited ability to reduce and archive the PEP data. But Acting Director Elizabeth Waagen was watching carefully to make sure that the data were coming in, and was preparing for a careful transition to a new system for reducing and archiving the data (probably at AAVSO HQ), and making them available on-line. On June 9, 2005, I spent part of the day with Arne Henden and Elizabeth Waagen at AAVSO HQ. They have developed a plan to reduce the data – perhaps with a more up-to-date reduction program (the present one was written in the 1980's) – and to ensure that all past, present, and future data is both archived and available. Arne has a special interest in involving AAVSO observers (PEP and otherwise) in "campaigns" – a concept discussed below. Here's a message which Arne circulated on June 14:

"The PEP committee has been inactive since Phil Manker stepped down as Chair a couple of years ago. At that time, we asked observers to send their observations to HQ, where they would be processed and archived. This email is to let you know the current status and where we intend to head in the future. I wanted to reassure everyone that PEP is not forgotten and that we intend to support you in the forseeable future.

The observations have all been kept, but they have not yet been processed. I've tasked Elizabeth Waagen and Michael Saladyga to start working on this database. The first step will be to get all observations entered in machine-readable form, and that is underway.

Our next step is to gather the various software programs that Howard used to process the data, and make sure they both work on an existing computer at HQ and that they produce reasonable output.

We will then process all of the data and make sure an archive of the processed data resides on our web server.

No data has been lost, but there may be a few observations that were turned in to Phil that we might not have yet. We expect to be in touch with each observer to ensure that we have a complete list of observations.

For the future, I want to move the processing pipeline to a more modern computer platform, and to convert the differential magnitudes into standardized values. We will look at the PEP charts and improve them where possible. We are already starting some new campaigns for PEP observers, and this activity will increase in the future. There are existing campaigns (such as IM Peg) that should continue, and we will have some additional monitoring projects. I expect to have some NIR (near infra-red) campaigns as well, showing off that new area of expertise.

While John Percy has kindly offered to stay on as PEP scientific advisor, and to continue producing the PEP newsletter, the one thing we are missing from this program is a committee Chair. Previously, that person had to collect the data, process it, produce the observer totals, etc. This was a fairly intensive effort, and I applaud those who were willing to devote their time and energy! However, in the future, I'm expecting the duties to be far less, with the data being submitted directly to HQ and being processed there. The Chair will be the bridge between HQ and the observers, mentoring or selecting mentors for new observers, helping observers in determining their transformation coefficients, giving John a hand with the newsletter, etc. If you are willing to volunteer, or want to nominate someone for the position, let me know.

I'll keep everyone informed on an infrequent basis. Until next time, clear skies and good observing!" – Arne Henden

Campaigns

In his contribution above, Arne Henden expresses his enthusiasm for "campaigns" on variable stars, and I share his enthusiasm. I have taken part in several campaigns, of different kinds, in the past. For information about a current AAVSO PEP campaign on TU Cas (a double-mode Cepheid) and V2291 Oph (an eclipsing variable), go to the AAVSO website www.aavso.org and do a search on these two star names.

In one sense, part of the AAVSO PEP program contributes to a campaign, namely the Be stars in the program. Be stars are non-supergiant B type stars which have shown emission lines in their spectra at some time. As the definition suggests, the emission can be variable, and so is the brightness of the star. Be stars are called γ *Cas* variables. Many years ago, my collaborator Petr

Harmanec (Ondrejov Observatory, Czech Republic) pointed out the need for systematic long-term monitoring of Be stars. He suggested that we start with the Be stars in the *Yale Catalogue of Bright Stars*; there are about 200 there. He drew up a list of suggested comparison and check stars for the Be stars, and organized the campaign in such a way that all observers' observations would be consistent with those of all others, even if they were using different telescopes, photometers, and filters. He checked for any comparison stars which were slightly variable, and discovered a few interesting new variables in the process. Petr's photometry was done using a telescope on the island of Hvar, off the coast of Croatia, in collaboration with astronomers at the University of Zagreb. Their results have been described in Pavlovski et al. 1997, *Astron. Astrophys. Supplement*, 125, 75.

The workload, and the vagaries of weather, however, made it desirable for other observers to join in. I started to contribute observations, obtained either with a small telescope on the campus of the University of Toronto, or with a robotic telescope – the Automatic Photometric Telescope Service. Then I added a few of the campaign stars to the AAVSO PEP program. And my PhD student Christopher Stagg extended the campaign to the southern hemisphere using a telescope at the University of Toronto Southern Observatory, then in Chile (it has since been moved to Argentina).

This campaign was well suited for obtaining long-term (years to decades) photometry of these stars. These are the time scales over which the emission in the Be stars changes, as the star's circumstellar disc forms and disperses. For a light curve of this form of variability, see below.

But Be stars also vary on time scales of 0.3 to 2 days. The study of those variations requires a different kind of campaign – a *multilongitude* campaign. By having observers at different longitudes, observations can continue while any one observer is having daylight or bad weather. The star can be monitored almost continuously. This is necessary for deciphering the complex short-term variations in these stars using *time-series analysis.*

The Be Star Newsletter

One way to keep abreast of research on Be stars is through the *Be Star Newsletter*, published on behalf of the International Astronomical Union, and produced by Geraldine J. Peters, Douglas R. Gies, and David McDavid. It is available on-line at

http://www.astro.virginia.edu/~dam3ma/benews/

Recently-posted research abstracts deal with the evolutionary state of these stars, and a possible explanation for their low-amplitude pulsational variability.

The short-term variations in Be stars may be closely related to those in β Cephei stars, which are B0-B3 stars which are pulsating in radial modes. See my on-line essay at:

http://www.aavso.org/vstar/vsots/winter05.shtml

One of the abstracts mentioned above deals with such a possible connection. And photometry of the related star ζ Oph (which is also classified as a Be star or γ Cas variable) by the *MOST* satellite (see below) suggests that its complex non-radial pulsation is driven by the same process which drives the β Cephei stars.

Pulsating Red Giants

The majority of stars in the AAVSO PEP program are bright pulsating red giants, and these continue to generate great interest among professional astronomers. About a third of pulsating red giants have *long secondary periods*, an order of magnitude longer than the primary (pulsation) period. Peter Wood, in the proceedings of the 2003 meeting on *Variable Stars in the Local*

Group (ASP Conf. Series, #310, page 322) states that "the long secondary periods are the only unexplained type of large-amplitude stellar variability known at this time".

Figure 1: Long-term (left) and short-term (right) variability of ST UMa, a pulsating red giant. Its periods are 81 days (pulsation) and 625 days (cause unknown).

One of the more interesting hypotheses about the cause of the long secondary periods was recently put forth by Alon Retter in a preprint "A Model of Planets Orbiting Inside Envelopes of Giant Stars for the Long Secondary Periods and the Fraction of Stars with Planets". According to this hypothesis, the long secondary periods result from the presence of Jupiter-like planets in eccentric orbits in the outer envelopes of the giants. If this hypothesis is true, then exoplanets were discovered by those who discovered the long secondary periods in pulsating red giants – including the AAVSO PEP observers!

Simple Analysis and Science with AAVSO PEP and Visual Data, or What My Students Did Last Year

As usual, I supervised several research projects by undergraduate students, and by senior high school students in the University of Toronto Mentorship Program, which enables outstanding high school students to work on research projects at the university. Their projects illustrate a wide range of "simple science" which can be addressed using the kind of data which AAVSO visual and PEP observers generate, and which some AAVSO observers might want to try for themselves.

(O-C) Analysis. In a periodic variable, the observed (O) time of maximum or minimum can be compared with the calculated (C) time, based on the assumption that the star is perfectly periodic. Using times of maximum or minimum made over years or decades, astronomers can determine the exact value of the period, and whether it is changing due to the evolution of the star's characteristics, or due to other processes. The AAVSO's Eclipsing Binary, and RR Lyrae programs are built around this technique. There was an excellent article on this subject by Lee Anne Willson, in *The Study of Variable Stars using Small Telescopes*, but this article is unfortunately not available on-line.

Pietro Cimino studied random cycle-to-cycle period changes in δ Scuti stars and SX Phe stars. These are both classes of short-period (hours) pulsators with spectral types of A7-F2, but the δ Scuti stars are young objects, and the SX Phe stars are older objects. When we think of pulsation, we normally think of regular in-and-out motion. But stars are not necessarily radially symmetric. Cool stars like Mira stars are dominated by large convection cells in their atmospheres, so it is not surprising that their pulsation periods vary randomly, from cycle to cycle, by several percent. This phenomenon was discovered over 75 years ago, by Eddington and Plakidis, and was found to be present in almost all of the bright Mira stars in the AAVSO visual program. We have also found random period fluctuations in RV Tauri stars (see below). In BW Vul, a massive β Cephei star, however, there were no random fluctuations. Would δ Scuti and SX Phe stars show such fluctuations? Pietro used tables of observed times of maximum and minimum brightness of a δ Scuti star (VZ Cnc) and 3 SX Phe stars (CY Aqr, XX Cyg, and DY Peg). The data had been accumulated by many astronomers over many years. Of the four stars, only XX Cyg (an SX Phe star) showed random cycle-to-cycle period fluctuations at the 3-σ level of significance.

Light curves, of course, are the standard way in which astronomers display the behaviour of variable stars, and begin to analyze and interpret their behaviour. For many years, I have been gathering PEP data on Be stars, and supplementing it with data from the AAVSO PEP data. The AAVSO data are especially useful in the summer, when the robotic telescope is "rained out" by the Arizona monsoon season. Sadly, the stalwart robotic telescope which I have been using for over 20 years, thanks to the *APT Service*, is on its last legs. [As I approach my formal retirement date, I can sympathize.] Fortunately, at least one AAVSO observer has expressed an interest in observing more Be stars, so we may add more to the program. Incidentally, amateur astronomers could make a useful contribution by observing these *spectroscopically* in a consistent, long-term way. Very little work of this kind is being done by professional astronomers.

Figure 2: What Be stars do: AAVSO PEP observations of the Be star V832 Cyg from 1987.7 to 1999.7. The cause of the brightenings is still uncertain, though it may be due to a combination of rapid rotation, a stellar wind, and low-amplitude pulsation.

Time-series analysis, as the term suggests, refers to the statistical methods which are used to analyze sets of data such as brightness measurements of variable stars. There is an excellent article by Matthew Templeton of AAVSO HQ which is available at:

http://www.aavso.org/publications/ejaavso/v32n1/41.pdf

The most popular method is Fourier analysis, and there is an excellent Fourier analysis software package available from the AAVSO. Another method, which my students and I have developed, is *self-correlation analysis*; our software is available at:

http://www.astro.utoronto.ca/~percy/web/scs.zip

It has been described in some recent articles in the JAAVSO, such as:

http://www.aavso.org/publications/ejaavso/v32n1/9.pdf

Ivan Dimitrov, in the University of Toronto's Mentorship Program which enables outstanding senior high school students to work on research projects at the university, worked on two projects, one of which was a continuation of the one by **Ashley Harrett** mentioned in the last issue of this *Newsletter*; it was a study of the variability of *symbiotic stars* – interacting binaries consisting of a red giant and a hot star, usually a white dwarf. See:

http://www.aavso.org/publications/ejaavso/ej4.pdf

Ivan was using photoelectric photometry supplied by Joanna Mikolajewska, Copernicus Astronomical Centre, Poland. In two stars – CI Cyg and YY Her – he was able to study both the variations caused by the orbital motion, and also the low-amplitude pulsation of the red giant, which had not been observed before. So this project studies the same kind of stars as those which make up the majority of the AAVSO PEP Program – pulsating red giants – but ones which are located in bizarre binary systems.

Long-Term Changes in Variable Stars: One of the great advantages of the AAVSO visual and PEP data is that they enable astronomers to study the long-term behaviour of stars over up to a century – thanks to the AAVSO's organization, and the dedication of generations of observers. Here's another example of the use of (O-C) analysis to study evolutionary (and other) processes in variable stars:

Jennifer Hoe continued a project started last year by **Jaime Coffey**, described in the last issue of this *Newsletter* – a study of the period changes in 5 SRd and RV Tauri stars. When we started the project, AAVSO visual data were not available on-line, so we used AFOEV and VSOLJ data, as well as times of maximum and minimum in the literature. This year, we were able to use the newly on-line AAVSO visual data to supplement this. From the (O-C) diagram, we were able to obtain a measure of the characteristic time scale of the period changes in the stars – thousands of years. These stars are in a relatively rapid phase of evolution, undergoing thermal loops from the asymptotic giant branch, or changing from asymptotic giant branch stars to white dwarfs. Evolutionary period changes should be detectable, and perhaps have been (our results are consistent with evolutionary predictions). But we also detected evidence for random cycle-to-cycle period changes, as described above, and these tended to dominate the (O-C) diagrams.

Figure 3: The (O-C) diagram for AG Aur, an SRd (semi-regular pulsating yellow supergiant) variable. The line is the best-fit parabola; it corresponds to a period increase on a time scale of 4000 years, and is probably due to evolution. The deviations from the line are due to a combination of error in measuring times of maximum or minimum light, and random cycle-to-cycle period fluctuations.

The Remarkable V725 Sgr: Here's a unique example of long-term change in a variable star. Usually, period changes are very small. Luckily, the (O-C) method enables astronomers to detect and study very slow changes in period. The analogy that I usually use is that of a rather poor watch, which runs more slowly by 1 second each day: after 1 day, it has lost 1 second; after 2 days, it has lost 1 + 2 = 3 seconds; after 3 days, it has lost 3 + 3 = 6 seconds and so on; the error of the watch, compared to a perfect watch, accumulates as the *square* of the elapsed time, and is soon noticeable. But the following star is changing its period by an order of magnitude in one person's lifetime!

Anna Molak has been studying V725 Sgr, one of the most remarkable variable stars known. In the last century, the period of this old low-mass pulsating yellow supergiant has increased from a few days to almost 100 days. The remarkble nature of this star was discovered by the famous astronomer Henrietta Swope during the first three decades of the 20th century. Then the star was rather neglected for several decades. Starting in the 1980's, the star was observed visually by Danie Overbeek (South Africa) in his typical careful and systematic way. Since Danie's death, the star has continued to be observed visually and photoelectrically by amateur astronomers in the southern hemisphere.

This star is very difficult to analyze, because most techniques of period analysis assume that the period is not changing rapidly (an exception is *wavelet analysis*; there is wavelet analysis software on the AAVSO website). Anna has been using the program *Period04* which is the latest in a family of period-anaysis programs created at the University of Vienna. It uses Fourier analysis initially, but can then fit periods to intervals of data using the method of least squares. Anna is finishing her project this summer, and I am looking forward to reporting on it in the fall.

And here are two more examples of how AAVSO observations can be used to study *long-term variations in variable stars.* The first deals with the mysterious long secondary periods in pulsation red giants, mentioned before. The second deals with a better-known but similar phenomenon in pulsating yellow supergiants.

Michelle Sciortino studied the problem of long secondary periods in pulsating red giants. These long secondary periods are one of the major discoveries of the AAVSO PEP program.

But there are decades of *visual* measurements of hundreds of pulsating red giants, especially in the AAVSO International Database. Can the long secondary periods be detected and measured in these data, even though the individual measurements are less accurate than PEP observations would be?

Michelle looked at several bright pulsating red giants, some of which were in both the AAVSO PEP and visual programs, so we had a sense of which stars should show long secondary periods. Michelle used both light curves and self-correlation analysis to search for and study the long-term variations. These were clearly present in SS Cep, TX Dra, g Her, and V UMi. In EU Del, which is the "prototype" of small-amplitude pulsating red giants, there was some evidence for a long secondary period in the light curve, but not in the self-correlation diagram. It may be present with small amplitude, or it may be irregular to be detected with self-correlation analysis.

Claudia Ursprung studied AAVSO visual observations of old low-mass pulsating yellow supergiants of two kinds. One was RV Tauri stars, which are characterized by alternating deep and shallow minima in their light curves. The other was SRd variables, which are similar stars whose light curves are less regular (SR stands for semi-regular). A significant fraction of RVT variables have long secondary periods; these are sub-classified as RVB stars. Those without long secondary periods are sub-classified as RVA stars. There are two RVT stars in the AAVSO PEP program – AC Her which is an RVA star, and U Mon which is an RVB star.

The nature and origin of long secondary periods in the RVB stars is puzzling, but appears to be connected with binarity. RVT and SRd stars are very similar in their physical and variability properties. Do any SRd variables have long secondary periods? If they are due to binarity, there is no reason why SRd stars should not also occur in binary systems.

Claudia used *self-correlation analysis* to look for and study these long secondary periods (see recent issues of the JAAVSO for papers, by me and my students, which discuss this technique). She found the long secondary periods in 4 RVB stars, and derived improved values of the periods. She did *not* find long secondary periods in 4 RVA stars, though there is tantalizing evidence for one in AC Her, at the millimagnitude level.

She also did not find long secondary periods in 8 SRd stars, at the level of 0.01-0.02 magnitude. It is a mystery, to me, why this is so.

Figure 4: The self-correlation diagram for DF Cygni, an RVB star (one with a long secondary period). The minima at multiples of 780 days indicate that the light curve repeats on this time scale, which is the long secondary period. The short (pulsation) period is 49.8 days.

The possible small-amplitude long secondary period in AC Her is something which can and should be investigated by PEP. Fortunately, the star is on the AAVSO PEP program. As soon as we have assembled all of the PEP data (see earlier remarks), we can investigate this.

In fact, it's possible that there are long-term variations in other classes of variable stars. That's the kind of problem that the AAVSO PEP program is designed for!

Multiperiodic Pulsating Red Giants in the Large Magellanic Cloud

The analysis of measurements of bright pulsating red giants from the AAVSO PEP Program (Percy, Desjardins, Yu, and Landis 1996 PASP, 108, 139) and from a robotic telescope (Percy, Wilson, and Henry 2001 PASP, 113, 983) has provided a model for analyzing measurements of much fainter pulsating red giant variables. Thousands of such variables have been discovered in the Large and Small Magellanic Clouds, as a result of the Optical Gravitational Lensing Experiment (OGLE: L. Kiss and T. Bedding, 2004, MNRAS, 347, L83).

This summer, my student **Jennifer Golding** is analyzing some of those red giant variables which are pulsating in two or modes simultaneously. This makes it possible to derive two or three observational properties – the two or three periods – for comparison with theoretical models. In this way, it is possible to deduce what the modes are, and probably what the radii and masses of the stars are, and possibly whether they have lost mass as they have evolved through the red giant stage (see Percy et al. 2003, *Publ. Astron. Soc. Pacific*, 115, 479).

This project is being carried out in collaboration with Dr. Laszlo Kiss. Laszlo is known to many AAVSO-ers through his work with the Variable Star Section of the Hungarian Astronomical Association. They are major contributors to the AAVSO International Database, and Laszlo has been the driving force behind that group for many years. He is now a professional astronomer at the University of Sydney, Australia.

Campaign on IM Peg

The AAVSO PEP Program continues to monitor the RS CVn variable star IM Peg, which is being used as the guide star for the Gravity Probe B satellite, which is testing aspects of the Theory of Relativity. For more information, see:

http://www.aavso.org/publications/alerts/alertpep/pep2.shtml

http://einstein.stanford.edu

Another Application of AAVSO Data

AAVSO visual, photoelectric, and CCD data are used in a variety of ways by professional astronomers. One recent example, related to the pulsating red giants which are such a large part of the AAVSO PEP Program, was recently sent to me by Beverly J. Smith (East Tennessee State University) who, with Stephan D. Price and Amanda J. Moffett, has compared the infrared and visual light curves of several pulsating red giants. They find that, whereas the infrared and visual light curves of semi-regular variables are in phase, the infrared light curves of Mira stars lag the visual light curves. This is thought to be due to the effect of strong titanium oxide absorption in the visual part of the spectrum in the very cool Mira stars.

MOST!

It seems that some variable star astronomers, even professional astronomers, do not know of Canada's *MOST* (Microvariability and Oscillations of STars) satellite. Launched two years ago on a former USSR ICBM rocket, MOST has been successfully observing variable stars with a precision which is an order of magnitude better than any other ground- or space-based telescope. It is the first astronomical satellite dedicated to the study of variable stars. For more information, go to:

http://www.astro.ubc.ca/MOST/

MOST obtained interesting and unexpected results on the (non)pulsation of Procyon, on the first observation of differential rotation in another sun-like star, and on the complex multi-periodic pulsation of the O star ζ Oph. Read more about these results on the *MOST* website.