AAVSO PHOTOELECTRIC PHOTOMETRY NEWSLETTER

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Contributions to this *Newsletter* are gratefully received at any time. Please send them to: John Percy, Erindale Campus, University of Toronto, Mississauga ON, Canada L5L 1C6; e-mail: jpercy@erin.utoronto.ca All material has been written by the Editor, unless otherwise indicated.

1 Janet A. Mattei (1943-2004): An Appreciation

Janet A. Mattei, Director of the AAVSO for over 30 years, passed away a few months ago after a courageous battle with leukemia. Janet's illness and death have profoundly affected the AAVSO, and will continue to do so for many years. It is fitting to begin this Newsletter with a tribute to Janet. It is based on an obituary which I have written for the *Journal of the Royal Astronomical Society of Canada* (JRASC).

I vividly remember meeting Janet Mattei for the first time. It was on a Winnipeg city bus, on a tour which was part of the 1974 RASC General Assembly. That General Assembly was a joint meeting with the AAVSO. Janet had become Director of the AAVSO in October 1973, after serving for a year as assistant to Margaret Mayall. Margaret's were large shoes to fill: the AAVSO has had only three Directors in its 93-year history: Leon Campbell, Margaret, and Janet. Little did I know, at the time, that she would become one of my closest colleagues, and friends.

Despite her tender age, Janet was eminently qualified. Born in Turkey, she had received a scholarship to attend Brandeis University in the US, receiving a BA there in 1965. After working in a hospital laboratory for a year and a half, she returned to Turkey, where she was a high school science and math teacher. But the heavens called, and she entered a graduate program in astronomy. A seminal event in her life occurred in 1969, when she was accepted into the summer program of the Maria Mitchell Observatory (MMO), on Nantucket, as one of "Dorrit's girls". "Dorrit" was the Director, Dorrit Hoffleit (who is still actively involved in astronomy at the age of 97). MMO provided summer research opportunities for women undergraduates in astronomy who, at that time, were significantly under-represented in the science. Dorrit became Janet's lifelong mentor and friend. MMO also hosted an AAVSO meeting that summer, and it was there that Janet met her future husband Michael Mattei, an optical technologist and amateur (and professional) telescope maker. Mike was a tower of strength for Janet throughout her life and career. Janet completed an MS degree at Ege University in Turkey in 1970, and another MS at University of Virginia in 1972. Later in her career, she completed a PhD at Ege University, with a thesis on cataclysmic variable stars.

One way to demonstrate Janet's impact on astronomy is to compare the AAVSO at the beginning and the end of her career. At the beginning, it was an important but simple organization. It collected visual observations, mostly of long-period and irregular variable stars, hand-plotted these on graph paper, and published descriptive information on the stars' behaviours. Occasionally, observations of specific stars would be requested by professional astronomers, for one purpose or another. During her directorship, the number of observations submitted each year increased three-fold, to almost half a million; they now total over 11 million. But there's an even more remarkable statistic: in the three decades of Janet's career, the *demand* by astronomers for AAVSO data and services *increased* by a factor of 25! Since this coincided with the first three decades of space astronomy, one might have thought that visual observations of variable stars by amateur astronomers would become obsolete. Quite the opposite! Many of the requests were for monitoring of unpredictable stars such as novae and dwarf novae, so they could be observed by space telescopes when the stars began to "perform". Janet co-ordinated over 600 projects of this sort. These projects benefitted from her organizational skills, judgement, and diplomacy, as well as from her expertise in variable stars. She was equally at ease with senior NASA administrators, leading astronomy researchers, amateur astronomers, teachers, and students.

The AAVSO also became much more international. Observers in many countries now submit their observations to the AAVSO's "International Database". About two-thirds come "from abroad" (as Janet put it). In 1990 the AAVSO held its first European meeting, in Brussels, Belgium, and in 1997, it held its second, in Sion, Switzerland. Janet formed collaborations and friendships with astronomers around the world. Janet and I were deeply involved in planning the 1999 "Partners in Astronomy" meeting in Toronto, which was a joint meeting of the RASC, the AAVSO, and the Astronomical Society of the Pacific (ASP).

One component of that meeting was a three-day symposium on *Amateur-Professional Partnerships in Astronomy Research and Education*, resulting in a book which is the ultimate guide to the subject. Janet played a major role, both nationally and internationally, in encouraging and supporting pro-am collaboration. She was the first Chair of the American Astronomical Society (AAS) Working Group on Pro-Am Collaboration, and she served on many other boards and committees.

In 1973, the AAVSO's observations were almost all visual. Now, there are photoelectric and CCD programs, search programs for novae and supernovae, and even programs to search for the visible after-glows from gamma-ray bursts – the most powerful explosions in the universe. These developments were enhanced by the workshops on CCD Photometry, and on High-Energy Astrophysics, which Janet organized with the help of experts who were keen to use these new AAVSO services.

In the early 1980's, Janet and I worked on the development of the AAVSO PEP program. We started with red variables which were on the visual program, but seemed to have small-amplitude variations which could best be revealed by photoelectric photometry.

Janet was always insistent that any AAVSO data published or disseminated should be as reliable as possible. It was tempting to put the AAVSO observations immediately on the Web. Janet was reluctant to do so. The conflict between quality control, volume of data, and speed and ease of dissemination was a challenge. But Janet and her staff have developed a system which resolves this conflict, and there is a project underway to verify *all* of the AAVSO's data, back to 1911 or before, and make it available on the Web by 2005. This remarkable database will be a monument to Janet's high standards and leadership.

In 1973, the AAVSO disseminated many of its results through a bi-monthly column in the JRASC. Janet's first column was in *JRASC*, **68**, 48-52, 1974. She also contributed a section to the RASC's *Observer's Handbook* and, in 1976 (when I was Editor of the *Handbook*), we introduced a *Variable Star of the Year*. At that time, there were also mimeographed (remember that technology?) newsletters for members. In 1972, the *Journal of the AAVSO* began, as a refereed journal for disseminating the results of AAVSO observations, and recording the business of the Association. Janet's annual report was always a highlight in the *Journal*, and at the annual meeting, because it conveyed both the scientific and human side of the AAVSO's work; it was delivered straight from the heart. Now, the AAVSO also has a comprehensive Website which disseminates not only data and charts, but excellent information about all aspects of variable stars, and variable star observing. All of this progress was possible because of the team of able, loyal staff which Janet developed and led.

My closest collaboration with Janet was the education project *Hands-On Astrophysics*. Janet and I had both been school teachers in our previous incarnations. We both had a deep interest in formal and informal education. We both realized that the observation and analysis of variable stars would be an excellent way for high school and university students to develop and integrate their skills in science and math, motivated by the excitement of doing real science, with real data - AAVSO data. With support from the US National Science Foundation, we developed software, datasets, charts, slides and prints (for indoor practice), three instructional videos, and a 600-page students' and teachers' manual for the project. Another of my vivid memories of Janet is of spending 19 hours with her and AAVSO staff member Mike Saladyga in a video editing studio in Toronto one rainy Easter Sunday (the only time that studio time was available), helping our video editor/producer Todd Hallam create three short videos from about 24 hours of tape. For several years thereafter, Janet delighted in working for a week each year with school teachers, as part of the *TOPS (Towards Other Planetary Systems)* program in Hawaii.

Janet's work was internationally recognized by a dozen major awards, of which the AAS Van Biesbroeck Award, the Astronomical League Award, and the Royal Astronomical Society's Jackson-Gwilt Medal are but three. Asteroid 1998 FA-74 was named in her honour. But Janet was more than just an award-winning professional. Her warm, caring, and generous personality endeared her to everyone she met. She discovered that my wife had a liking for Turkish Delight so, every Christmas, a predictable package would arrive by courier at our door. In return, I delivered or sent her a Canadian wildflower calendar, because her other passion in life was flowers. The obituary on the AAVSO Website begins "Flowers are the stars of the Earth; stars are the flowers of the Universe". Janet was often compared with a star - not the superficial stars of entertainment or sport, but the enduring stars that illuminate the night sky, as she illuminated everyone who knew her.

2 AAVSO PEP Committee Chair Phil Manker Resigns

Elizabeth O. Waagen, AAVSO Interim Director

AAVSO Photoelectric Photometry Committee Chair Phil Manker has resigned as Chair, effective immediately, for health reasons. Phil has Alzheimer's Disease, and he feels that it is time for him to give up the administrative work that the Chairmanship involves. Phil plans to continue his own PEP observing.

A search is underway to find a successor to Phil, who served as AAVSO PEP Committee Chair since November 2001, when he succeeded Howard Landis, who had been Chair for 26 years.

Please send all your PEP observations directly to AAVSO Headquarters from now on. If you send them by email, please use the monthly@aavso.org account; if you use a diskette or paper, please send it to HQ at 25 Birch St., Cambridge, MA 02138 USA (mark the diskette 'PEP').

We thank Phil most sincerely for everything he has done for the AAVSO PEP Committee and program, variable star observers, and photoelectric photometry. We are grateful to Phil for the time and wisdom he has contributed to this committee and program. He has made real contributions through his efforts, and they are very much appreciated by us all.

Phil, his wife Glenda, and their family will be in our thoughts.

3 Professional-Amateur Partnership in Astronomical Research

AAVSO photoelectric, visual, and other observers are exemplary *citizen scientists* - non-professionals who make important contributions to research. This month, I gave a talk at *StarFest* - Canada's largest star party - on pro-am research, so I have been reflecting on this topic which is at the heart of the AAVSO's work. The rest of this article is based on a short article which I wrote for that occasion.

What would motivate an amateur to do research? Probably the same thing that motivates a professional – the desire to create new knowledge. In fact, a recent survey by Sheila Kannappan at Harvard showed that this was an even stronger motivation for AAVSO-ers than it was for professional astronomers! The amateur must be genuinely motivated to participate in a pro-am project (which may be "1 percent inspiration, 99 percent perspiration"), and be diligent, conscientious, and willing to communicate and learn. The professional, of course, must be willing to mentor their partner and provide feedback, reimburse the amateur at least for his/her out-of-pocket expenses, and recognize the amateur in any publication resulting from the project.

Until a century ago, the borderline between amateur and professional was much less distinct than it is now. Any liberally-educated and well-equipped individual could contribute to research in astronomy – and other fields. With the growth of astrophysics and "big astronomy" in the twentieth century, the borderline became more rigid. Yet the opportunities for amateurs remained. The most striking example (and also the one I am most familar with, of course) was in variable star astronomy, where organizations such as the AAVSO (1) not only survived, but flourished. Each year, hundreds of observers contribute hundreds of thousands of simple visual measurements which require no special tools or skills. Yet, since the beginning of "space-age astronomy" in the 1970's, the demand for these simple measurements, from professional astronomers, has increased by a factor of 25! That's because these observations can be used to support space-astronomy missions, among many other things. As well as the visual observation program, the AAVSO has active photoelectric and CCD observing programs, and a program to observe and study gamma-ray bursts in the optical region of the spectrum.

But astronomical research is more than making frontier discoveries in space astronomy. There are a wide range of other important activities which professional astronomers do, which amateurs can do as well. For instance, the Astronomical Society of the Pacific's Amateur Achievement Award (2) has been won for computation (Jean Meeus, Syuichi Nakano), instrumentation (Russ Genet), organization (Walter Haas), sky surveys (Ben Mayer), imaging (Jack Newton, Don Parker, Paul Boltwood), as well as for the more classical areas of amateur astronomy research. And you don't have to be a superstar or a techie whiz to contribute; variable star observing (and similar activities) are still as simple and as useful as ever. Amateurs are also leaders in the battle against light pollution, which is a bane for both amateur and professional observers. And amateur astronomers make important contributions other than research. One which is dear to my heart is education and outreach. You don't need a PhD in cosmology to excite schoolchildren, or the public. And amateur astronomers have the advantage of enthusiasm, and of knowing the sky, and of having small telescopes – and knowing how to use them. The Royal Astronomical Society of Canada was a 2003 winner of Canada's highest award for science outreach – the Michael Smith Award (3).

By the 1990's, there was a revolution in possibilities for pro-am astronomy research. For $10,000 – the price of a good home theatre – an individual or club could buy a good off-the-shelf 8" telescope, a powerful CCD camera, and a computer to run these and to connect to information and communication on the Internet. Such instrumentation can reach magnitudes which were accessable only with the largest telescopes in the "photographic era" of a generation ago. An exemplary pro-am partnership using this equipment bundle is the *Center for Backyard Astrophysics* (4) co-ordinated by Joe Patterson at Columbia University.

At the same time, there were initiatives from the professional community to encourage and facilitate pro-am partnerships: the American Astronomical Society formed a Working Group on Pro-Am Collaboration – AAS-WGPAC (5) – initially chaired by Janet Mattei, then by Jay White, and now by Richard Fienberg, editor of *Sky & Telescope*. There was also a series of conferences including the 1999 "Partners in Astronomy" conference in Toronto. The proceedings of that conference, "Amateur-Professional Partnerships in Astronomy", edited by me and Joseph Wilson, and published by the Astronomical Society of the Pacific (6), is still the best print resource for pro-am collaboration. That book describes exciting projects in sky surveys; visual, photoelectric, and CCD observing of variable stars; discovery and study of novae, supernovae, and gamma-ray bursts; solar observing; discovery and study of asteroids, comets, and Kuiper Belt Objects; lunar and planetary occultations; planetary imaging, and many others. I especially recommend Leif Robinson's review of the frontiers of pro-am partnership; this article is also on the AAS-WGPAC website (5).

One recent activity of the AAS-WGPAC was a special session on pro-am partnership at the 2004 summer meeting of the AAS (7). The announcement began thus: "The landscape of astronomical research is dotted by a small number of intense, successful collaborative efforts by professional and amateur astronomers". [Of course, it's also dotted by a *large* number of AAVSO observers!] A second initiative is an on-line registry to "matchmake" pro-am partnerships (see (5) - should be operational soon). Maybe the landscape will soon become even more dotted! So check it out! And join the pro-am revolution!

(1) http://www.aavso.org
(2) http://128.241.173.3/membership/awards/pastamateur.html
(3) http://www.nserc.gc.ca/msmith/recipients/2003_e.htm
(4) http://cba.phys.columbia.edu/
(5) http://www.aas.org/wgpac/
(6) http://www.astrosociety.org
(7) http://www.aas.org/wgpac/meetings/denver2004/announcement.html

4 Variable Star Analysis Website

My summer students have been upgrading the little website that we have created for variable star analysis. The primary audience is undergraduate students and senior high school students who are undertaking research projects on variable stars, but the site might also be of interest to amateur astronomers – especially variable star observers. The site features links to data sources and software, including the packages available from the AAVSO. The self-correlation analysis program, mentioned below, is also available. Since this has recently been re-written in a more up-to-date language, I would be interested to get feedback from users. The URL:

http://www.astro.utoronto.ca/~percy/index.html

5 Environmental Effects on Photoelectric Photometry

Observer Win Jones (South Africa) has recently reminded me of a problem which some photometrists might face. Have you noticed that the count rate for a specific non-variable star has been declining over the years, even when observed through the same amount of atmosphere? The problem may not be with the star, or with the atmosphere, it may be with the detector in the photometer. Most photometers need a desiccant to keep the components dry. With time, the desiccant loses its power, and must be replaced. I am less familar with whether the detector may lose its sensitivity for other reasons.

Of course, you may also be affected by long-term changes in the atmosphere. Win Jones mentions some apparently-permanent changes which are occurring at his site, due to the incursions of tropic air. These, in turn, may be connected with the long-term changes in carbon dioxide content and temperature of the atmosphere. Those who have been observing for many years, with more-or-less constant equipment, might want to look for these effects in their observations.

There is also the issue of sky brightness. Most locations are suffering from an increase in sky brightness due to human activity – light pollution. A few municipalities have successfully kept light pollution at bay, often because of the efforts of professional and amateur astronomers, but increasingly because of the efforts of ordinary citizens. Again, long-time observers can look at how their sky readings have changed, when measured with the same equipment through the same aperture at the same sky position – the zenith, for instance.

6 Light Pollution

Light pollution is the unnecessary illumination of the night sky by human activity. In my part of the world, an unfortunate event, one year ago (14 August 2003) heightened public awareness of light pollution: that was the "Great Blackout", when most of eastern US and Canada were hit by an electricity blackout lasting a day or more. For at least one evening, city dwellers suddenly became aware of the beauty of the night sky. On the first anniversary of the blackout, there were many newspaper articles dealing with this revelation, and about the issue of light pollution. The Ontario Science Centre, in partnership with the Toronto branch of the Royal Astronomical Society of Canada, organized special events, including a star party, on the anniversary. The definitive source of information about dark skies and light pollution is the International Dark Sky Association:

http://www.darksky.org

7 A Symposium on Mira Stars

On Monday April 26, 2004, the AAVSO sponsored a one-day symposium on Mira stars. Since this was only a few weeks after Janet Mattei's death, there was sadness in the air. But the four review papers, by Wesley Traub (The Mira Imaging Project), Margarita Karovska (Miras and their Companions), Lee Anne Willson (Planets in Mira Winds), and Matthew Templeton (Mira Data in the AAVSO International Database), reminded us of how Janet had guided the AAVSO to the highest levels of scientific achievement, while nurturing the human aspects of variable star observing and the AAVSO. There were several poster papers, including the one by Ashley Harratt and me, described below. There were also opportunities for long conversations, about Miras, science, AAVSO, and Janet, with the several dozen participants, who included professional astronomers, AAVSO staff, members, and observers.

8 Photoelectric Photometry at AstroCon-2004

AstroCon is the annual conference of the Astronomical League, the "umbrella organization" of astronomy clubs in the US. This year, it was held in Berkeley CA, in partnership with the AAVSO, the Association of Lunar and Planetary Observers, and the Astronomical Society of the Pacific. In addition to the many excellent scientific sessions, there was a variety of formal and informal social events, the most exciting (for me) being the closing banquet on board the *USS Hornet*, the recovery ship for Apollo 11 and 12. This event celebrated the 35th anniversary of the recovery of Apollo 11. The after-dinner speaker was Alan Bean, one of the Apollo astronauts. He gave an enthusiastic, personal account of his experiences, illustrated by many of his own paintings; painting is what currently occupies most of his "work time".

One of the significant AAVSO projects, described in the sessions, was the creation of an Automatic Chart Plotter. Along with that project, the AAVSO is investigating the many suspected variables among the comparison stars on the visual charts. There are still a dozen or more possibly-variable comparison stars in the PEP program. We have tried to replace any comparison stars which were definitely variable, but there is still a bit of "cleaning up" to do.

Michael Koppelman reviewed recent HST and ground-based observations of η Car, a luminous blue variable (LBV) which, for a short time in the 1800's, rivalled Sirius in brightness. Unfortunately, this is star is not accessable to those of us in the northern hemisphere, but the other famous LBV – P Cygni – is on the AAVSO PEP program.

Dale Mais described spectroscopic and photometric monitoring of Mira stars. He is one of the few amateur astronomers who is actively involved in spectroscopic monitoring of variable stars, a field which is not well covered by professional astronomers. Keep in mind that most of the stars on the AAVSO PEP program are small-amplitude cousins of the Mira stars.

Matthew Templeton (AAVSO staff) continued on the theme of Mira stars, outlining some of the results, from the AAVSO visual program, on long-term secular evolution of Mira stars. The most significant events are the "helium flashes" which Mira undergo every few thousand years. In a few cases, AAVSO visual observations have caught stars in this phase. [The small-amplitude cousins of Mira stars have not reached the stage of helium flashes yet, but they do undergo interesting long-term variations of their own. The cause is unknown! This is a good scientific justification for the work that AAVSO PEP observers do.]

Perhaps the "sexiest" of the presentations was *Transitsearch*, a program whereby any observer with a small telescope, a photometer, and the capability of doing millimag photometry, can help to look for transits of exoplanets across the face of their star. The exoplanets have been discovered spectroscopically, from their gravitational effect on their star. The spectroscopic observations also provide an estimate of when a transit might occur – if the planet's orbit were seen edge-on, and permitted the planet to transit. One exoplanet – HD209458b – has already been observed to transit, using a small telescope. So the method does work.

There were also papers dealing with CCD observations of occultations, of mutual eclipses of Jupiter's satellites, of cataclysmic variables, and there were papers on planetary photometry – such as by AAVSO observer Richard Schmude.

Abstracts and, in some cases, full versions of the AAVSO papers can be found on the AAVSO website, under "meetings" (spring 2004).

Finally, there was an AAVSO members' meeting. Some of the issues and discussion were about the sad events of the last year, but there were many indications that the AAVSO has survived, and is moving on to even greater achievements, thanks to the collective efforts of AAVSO Council, staff, members, and friends.

9 Special Congratulations and Thanks to Elizabeth Waagen

In July 2004, Elizabeth Waagen, Interim Director of the AAVSO, celebrated 25 years as an AAVSO staff member. Her efforts and accomplishments have always been apparent to those many of us who have dealt with her. But her ability and dedication have been especially apparent during the last year. During the time of Janet's illness, and after her death, she has provided stability and leadership to the AAVSO through her good judgement and cheerful, calm disposition. Congratulations, and thank you for your service and friendship!

10 Self-Correlation Analysis

Some of the projects, mentioned below, make use of *self-correlation analysis* – a simple form of auto-correlation analysis which my students and I have used for a variety of variable star research projects.

The visual inspection of light curves, and Fourier analysis (power spectra) are commonly used for analyzing variable star data. Self-correlation analysis has proven to be useful, in conjunction with the other two techniques, for some kinds of stars, especially if the stars are somewhat irregular, and if there are "aliases" in the power spectra due to regular gaps in the data. It can detect characteristic time scales τ in the data. It determines the cycle-to-cycle behavior of the star, averaged over all the data. The measurements do not have to be equally-spaced.

The algorithm works as follows: for all pairs of measurements, the difference in magnitude (Δmag) and the difference in time (Δt) are calculated. Then Δmag is plotted against Δt, from zero up to some appropriate upper limit (which if possible should be a few times greater than the expected time scales, but less than the total time span of the data). The Δmags are binned in Δt so that, if possible, there are at least a few values in each bin; the Δmags in each bin are then averaged. The average Δmag is plotted against the average Δt in a "self-correlation diagram", or SCD. The method is so simple that there is no equation involved – just the procedure described above!

The average Δmag will be a minimum at multiples of τ. Each minimum can be used to estimate τ. The Δt of the Nth minimum, divided by N, gives a measure of τ, so the periods derived from the several minima can be averaged to give a better estimate of the period.

If the variability were perfectly periodic, and the magnitudes had no error, then the minima should be well-defined, and fall to zero, because measurements which were an integral number of cycles apart should always be exactly the same. In fact, the height of the minima above the zero line is determined by the average error of the magnitudes, and by the degree of irregularity, if any.

Measurements which are a half-integral number of cycles apart may have a Δmag ranging from zero to the full amplitude of the variations. As long as there are a sufficient number of Δmags in each bin, the *height* of maximum will average out to about half the total amplitude. The difference between the maxima and the minima is therefore a measure of the average amplitude of the variability, and is approximately 0.5 times the average full range of the light curve. The persistence of the minima to large Δt's is also determined by the degree of irregularity.

For reasons already mentioned, our method requires of the order of ten or more Δmags in each bin. Although our method is not subject to "alias" periods due to the periodicity of the seasonal gaps in the data, there may be gaps in the SCD if there are no pairs of measurements with certain values of Δt — due to regular seasonal gaps in the data, for instance.

11 Self-Correlation Analysis of R CrB Stars at Maximum

This project was done by **Kaushala Bandara**, a second-year (sophomore) student at the University of Toronto, in the Research Opportunity Program (ROP) – a highly-competitive program which enables second-year students to carry out a research project for course credit.

R Coronae Borealis (RCB) stars are low-mass, carbon-rich, hydrogen-poor yellow supergiants which are in a short-lived, advanced stage of evolution. Only a few dozen are known in our Milky Way galaxy, though there may be more to be discovered.

Their most spectacular variations are sudden, unpredictable, rapid (weeks) fadings of up to 10 magnitudes, followed by slower (months) returns to normal. But most RCB stars also show small-amplitude (0.01 to 0.3 magnitude) pulsation, with periods of tens of days. These are best seen when the star is at maximum.

There are several questions about RCB stars: What is their evolutionary state: merged white dwarfs, final helium flash, or something else? What causes the fadings: they are thought to be due to the ejection of clouds of carbon dust (soot) which, if they lie along our line of sight to the star, will eclipse it, but what triggers the formation of the cloud, and how? What role, if any, does pulsation play?

Although pulsation is known to exist in most, if not all of these stars, the irregularity makes the analysis somewhat different. The purpose of this project, then, is *to use a different method*

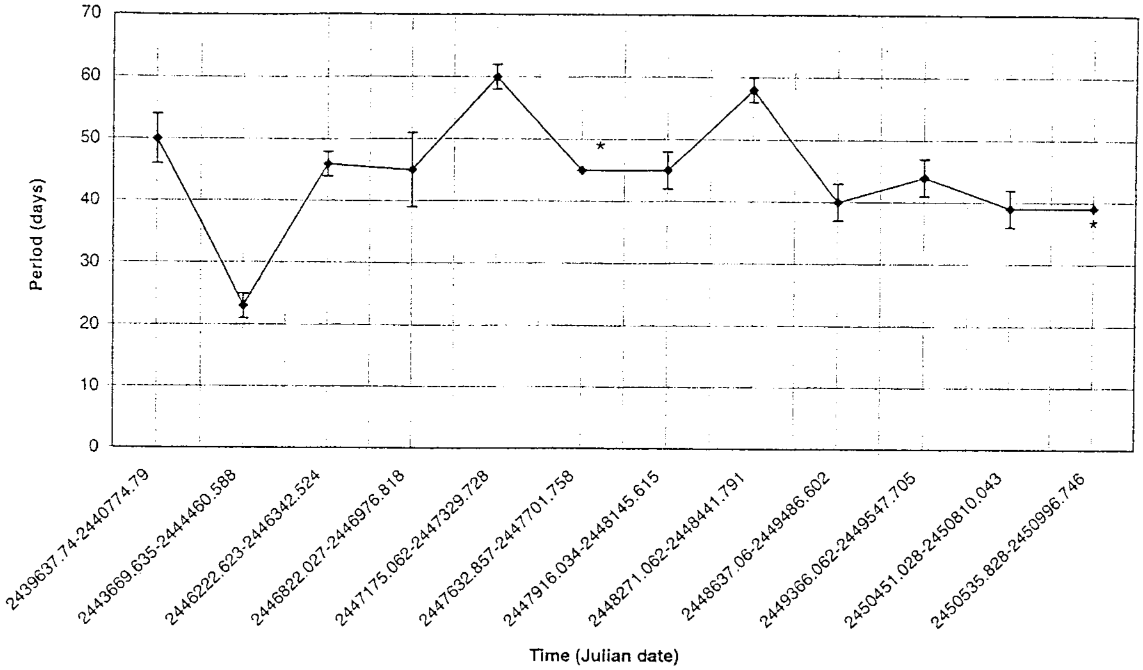

Figure 1: The period of the pulsation of R CrB in different seasons, determined by self-correlation analysis of data from J.D. Fernie. The period is not always the same, probably because of pulsation mode switches.

of time-series analysis – namely self-correlation – to see whether it would be a useful adjunct to Fourier analysis.

The project used on-line photoelectric photometry of R CrB itself, by Don Fernie (University of Toronto), and photoelectric photometry of several southern R CrB stars, kindly provided by Professor Peter Cottrell (Canterbury University, Christchurch, New Zealand).

Periods were determined for all of the stars. The pulsation period of R CrB varies from season to season (see Figure 1), probably because the star changes pulsation modes, so it is best to do season-by-season analysis. For the southern stars, the periods found were consistent with previous results, though there was some evidence that RT Nor changed its pulsation mode in some seasons, and more marginal evidence that RZ Nor changed its pulsation mode.

12 Evolutionary Period Changes in RV Tauri and SRd Variables

This project was done by **Jaime Coffey**, another second-year student in the ROP at the University of Toronto.

RV Tauri stars are old low-mass pulsating yellow supergiants whose light curves show alternating deep and shallow minima. There are two RV Tauri stars in the AAVSO PEP program – AC Her and U Mon. SRd stars are like RV Tauri stars, except that the light curve is semi-regular, hence SR; the "d" signifies a yellow supergiant.

Both these classes of stars are in an advanced stage of evolution. They have exhausted their core hydrogen fuel, and are nearing the end of their helium fuel. As such, they have been *asymptotic-giant branch* (AGB) stars, which are like red giants, but a bit brighter and more evolved. The RVT and SRd stars are either in transition from the AGB to the white dwarf stage, or they are temporarily yellow giants because of a *helium flash* – a sort of "burp" in their nuclear processes. In either case, they should be evolving on a time scale of thousands of years, and that should be

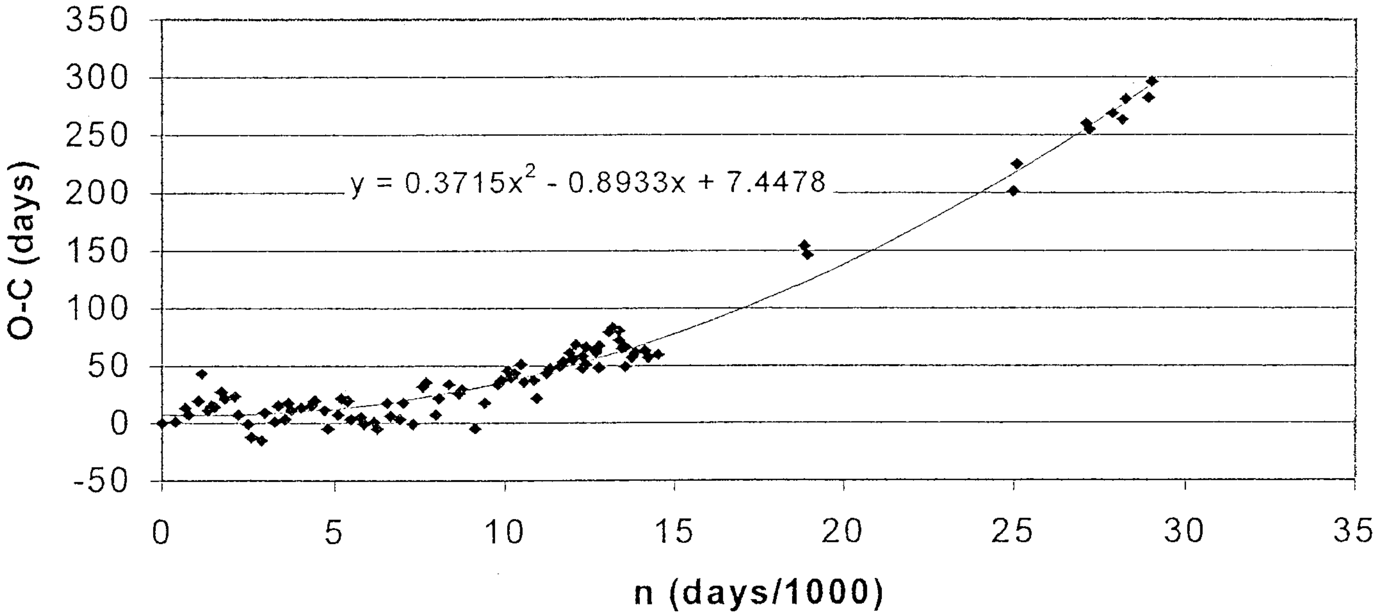

Figure 2: (O-C) diagram of AG Aur. The diagram is fitted with a parabola, which corresponds to a period changing at a constant rate. Because of the two large gaps in the observations, it is not certain whether a cycle has been missed during this interval. The wave-like patterns in the first half of the diagram are probably due to random cycle-to-cycle period fluctuations.

observable by the *(O-C) method*. That involves monitoring the times at which they are observed (O) to be at maximum brightness, and comparing the times with the predicted times (C). If the star is evolving quickly, then the period of pulsation (which depends strongly on the radius of the star) will slowly change and, since the effect is *cumulative* [just as a small error in the rate of your wristwatch will show up after a few weeks], the effect will add up, and soon be visible. Unfortunately there is a complication: these stars, like Mira stars, have random cycle-to-cycle fluctuations in period, and these tend to mask the evolutionary changes. Another problem is that there are often gaps of many years in the observations, and it is not always possible to know what the period was doing during these times.

The periods of these stars are typically 100 days, so it is necessary to have many decades of observations. Thanks to organizations such as the AAVSO and its visual observers, that is possible. Jaime studied five stars: AG Aur, AV Cyg, SX Her, TX Per, and UZ Oph. She used AAVSO and AFOEV data, and also times of maximum published in a variety of sources. She spent many hours in the library, going through dusty journals. Fortunately, there are extensive bibliographies of references on individual variable stars. Unfortunately, many of the references are in obscure publications which even my fine astronomy does not have access to. And these publications are not (yet) on-line.

Nevertheless: for four stars, results were obtained (see Figure 2), and were consistent, within a factor of two, with the hypothesis that the stars evolve on a time scale of about 10,000 years. For UZ Oph, the gaps in the observations made it impossible to interpret the period changes.

Thanks to observations by the AAVSO and other such organizations, astronomers can actually *see* stars evolve!

13 Self-Correlation Analysis of T Tauri Stars

This project was done by **Wojciech Gryc** (Brébeuf College School) and **Janice Wong** (University of Toronto Schools), in the University of Toronto Mentorship Program, which enables outstanding senior high school students to work on research projects at the university.

T Tauri stars are a type of very young star in an early phase of evolution in which contraction (to the main sequence - the normal hydrogen-fusing stage of evolution) is still taking place. The prototype, T Tauri, is an irregular variable star within a dark cloud in the constellation Taurus . Classical T Tauri stars are defined on the basis of (i) (usually) cool spectrum; (ii) excess continuum emission; and (iii) strong emission in selected lines. T Tauri stars are newly-formed, rapidly-rotating (usually) low-mass stars, with a significant magnetic field, usually still surrounded by an accretion disc.

There are several sub-types of T Tauri stars: (i) Classical T Tauri Stars (CTTS) with evidence of an (inner) accretion disc; (ii) Weak-lined (WTTS) or "naked" T Tauri stars, which have little or no spectroscopically visible accretion disc [though there may be a cool, outer disc still present]; (iii) Herbig Ae/Be (HAEBE) stars, which are hotter higher-mass analogues of T Tauri stars; (iv) FU Orionis stars: T Tauri stars which exhibit brightenings of several magnitudes, followed by slow declines.

William Herbst has classified T Tauri stars according to their variability: (i) Type I Variables: cyclic variations with periods of 0.5 to 18 days or more; seen mostly in WTTS; amplitudes of a few tenths of a magnitude in V; due to rotational modulation by *cool spots.* (ii) Type II Variables: generally irregular variations on time scales of hours or more; seen almost entirely in CTTS; amplitudes typically a magnitude (occasionally larger); due to variations in *mass accretion rate* (and therefore in veiling continuum) producing *hot spots*, and some rotational variability. (iii) Type IIp Variables: like Type II, but quasi-periodic. (iv) Type III Variables: "UXors": generally irregular variations on timescales of days to weeks; seen in ETTS; amplitudes typically a magnitude (occasionally larger); may be due to *variable circumstellar obscuration.*

An important classification criterion is the presence of *periodicity*, due to rotation of cool or hot spots, or revolution of obscuring blobs of dust. But periodicity is difficult to establish:

"It soon became clear that most of the bright CTTS and ETTS (HAEBE) stars were not going to yield periodicities easily, if at all. Unlike the WTTS, where dogged monitoring is usually rewarded with a period ... the CTTS and HAEBE stars only rarely show significant periods. Claims to the contrary ... were based on a too-optimistic interpretation of noise peaks in periodograms" (Herbst 2001).

The *periodicity* of the photometric variability of T Tauri stars is due to rotational modulation by cool or hot spots, or by obscuration by orbiting inhomogeneities in the disc. Previous studies of T Tauri star periodicity have used Fourier analysis, and have been hampered by (i) variations in the amplitude of the periodicity; (ii) phase shifts in the periodicity due to the growth or decay of cool or hot spots; (iii) large non-periodic variability superimposed on the periodic component; (iv) possible aliasing due to the regularity of the observations, which are often made only once a night at the same hour angle.

Self-correlation provides an independent, adjunct approach, which can help to determine new periods, or confirm old periods (or not). It is especially useful in stars whose periodicity is not entirely regular.

This was therefore a *pilot project* to apply self-correlation to a sample of T Tauri stars, some whose periodicity is well-known, some whose periodicity needs confirmation, and some which are complex and challenging. We have analyzed about 30 stars in total. The original photometric data by Herbst and his collaborators are available at:

ftp://www.astro.wesleyan.edu/pub/ttauri/

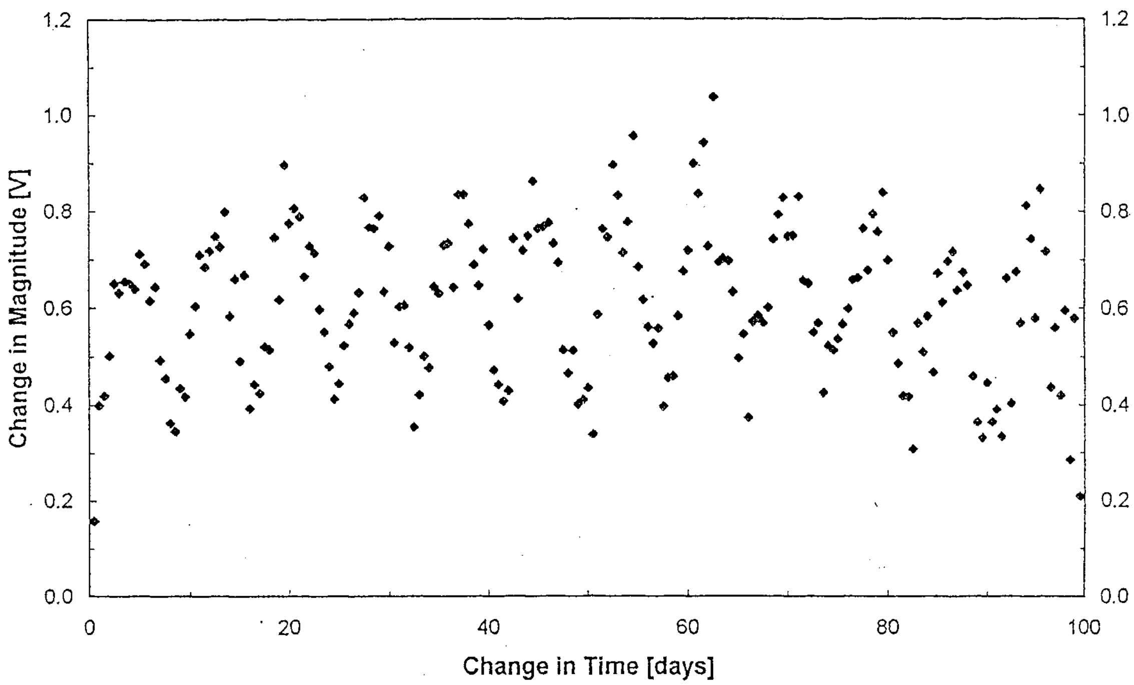

Figure 3: Self-correlation diagram of the T Tauri star DK Tau. Note the minima at multiples of the rotation period of about 8.1 days – much faster than the sun. Since the amplitude of the SCD is 0.5 magnitude, the full range of the light curve, due to rotation, must be a whole magnitude!

Self-correlation proved to be useful for identifying periods (or confirming or refuting periods identified by others using other techniques), especially in complex semi-regular stars (Figure 3). It does not suffer from aliasing, but it is not useful for multi-periodic stars, and its statistical properties are not known. It is best used as an adjunct to Fourier analysis. It can provide an upper limit to the amount of cyclic variability in a star.

In non-periodic variable stars, it provides a "profile" of the characteristic time scale and amount of variability.

In future, we plan a comprehensive study of several dozen T Tauri stars, especially the classical T Tauri stars and Herbig Ae/Be stars and others whose periodicity is presently in doubt.

14 The YoungStars Project

For many years, I have supervised individual research projects by undergraduate and senior high school students, like those described here. But I have always wished that there was some way to involve more students, without my time commitment becoming impossible. So last year, I tried a pilot project with a dozen grade 12 physics students from the University of Toronto's affiliated high school. We studied sun-like stars which vary slightly due to the rotation of the spotted star. The period of variability is the star's rotation period. The amplitude is typically 0.01 to 0.05, and depends on the area and distribution of the starspots. The students used the self-correlation program, and analyzed data on sun-like stars, which is freely available on the website of Tennessee State University. The data was obtained with small robotic telescopes in Arizona. The data had been previously analyzed with Fourier analysis, and the results had been published. There were enough stars so that each student had 3 or 4 stars to analyze. The URL:

http://schwab.tsuniv.edu/papers/aj/youngsuns/youngsuns.html

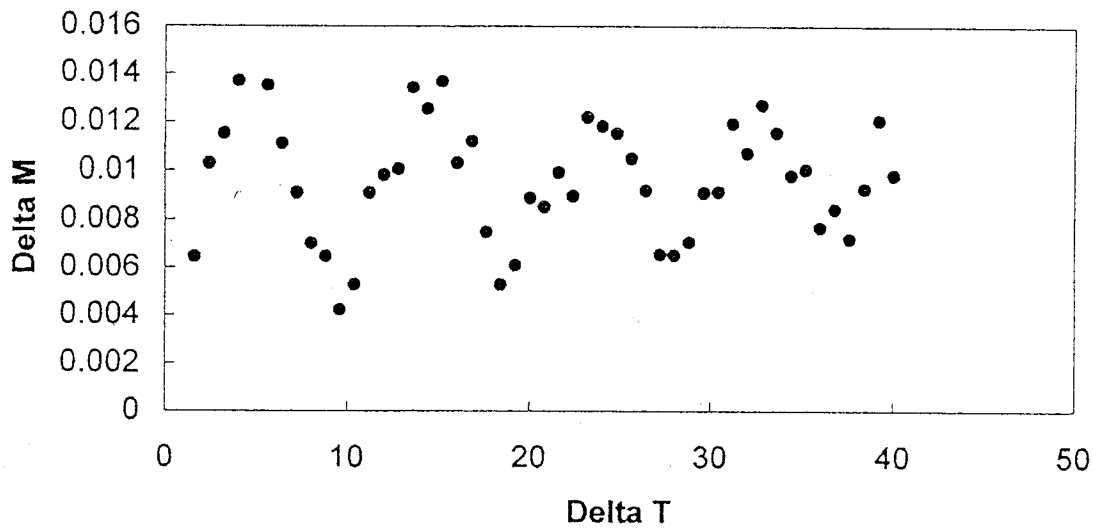

Figure 4: Self-correlation diagram of the sun-like star HD 20630. The data is differential photometry with a robotic telescope. Note the minima at multiples of 9 days, the rotation period of the star. The amplitude of the SCD is less than 0.01, so the full range is less than 0.02. Note, however, that the amplitude of the SCD decreases with increasing Δt. This means that the starspots are *changing* on a time scale of tens of days.

The length of the project, for each student, was nominally 10 hours. It would then satisfy the requirements for the "independent study project" in their physics course. At the start of the project, I gave them a short talk on variable stars, rotating variable stars, and self-correlation. It helped that my Mentorship Program student Janice Wong was one of the students in the class.

Almost all of the students succeeded in analyzing and interpreting "their" stars. In one or two cases, the analysis provided new results which were not apparent from the Fourier analysis (Figure 4). If I do a similar project again, I will monitor the students' results partway through the project, to make sure that they are not going astray. I would also like to schedule a session, at the end, in which student reports on the results for "their" stars.

15 Self-Correlation Analysis of Symbiotic Stars

This project was done by **Ashley Harratt**, a senior undergraduate student in physical and earth sciences at the University of Toronto. She is also Secretary of the university's astronomy and space club.

Symbiotic stars are ones whose spectra show the presence of both a hot star and a cool star. So they are binary systems. One component is always a red giant. The other is usually a white dwarf, or occasionally a hot main sequence star, in close orbit around the cool star. As a result of the cool star's wind, and/or tidal mass transfer in the system, matter is transferred towards the hot star, and forms an *accretion disc* around it. The variability of symbiotic stars is very complex. Due to the binary motion, they will show ellipsoidal and, sometimes eclipsing variability. There are occasional eruptions, something like a dwarf nova, probably due to instability of the accretion disc. There is flickering, due to the mass stream striking the accretion disc. And there is pulsation

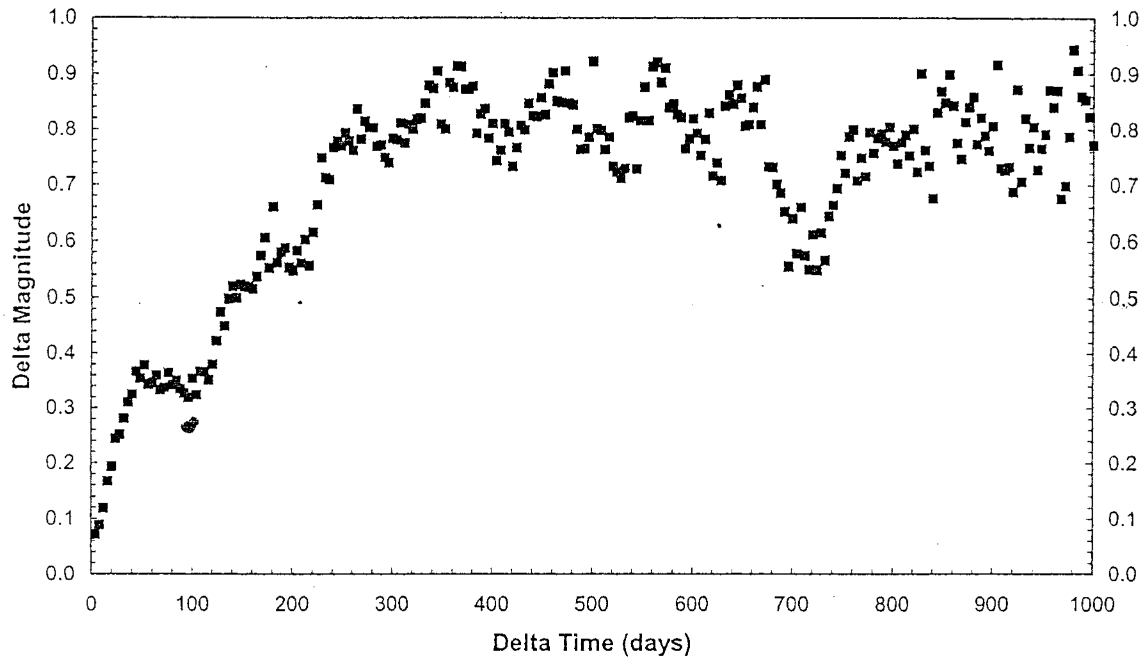

Figure 5: Self-correlation diagram of CH Cyg. The fact that the SCD rises from left to right means that the primary variability occurs on time scales of hundreds or thousands of days, but note the minima at multiples of about 100 days. These are due to the pulsation of the red giant.

of the red giant. The purpose of Ashley's project was to use self-correlation analysis of existing photoelectric datasets to look for pulsation in the red giant. In most symbiotic systems, this aspect of the variability has not been closely studied before.

Ashley got results on several stars. Unfortunately, they were limited by the rather sparse datasets which we had access to. Visual data were not sufficiently accurate, even though it was extensive. The best cases were EG And and CH Cyg (Figure 5), which are both on the AAVSO PEP program. EG And shows ellipsoidal variability, and 29-day pulsation. AX Per shows variability at the orbital period, perhaps because of illumination of the cool star by the hot one. CH Cyg has a 90-day pulsation period, which was previously known. CI Cyg shows variability at the orbital period, and possibly a 70-day pulsation period. AG Peg shows variability at the orbital period, and possibly a 25-day pulsation period. Z And shows variability at half the orbital period, and possibly a 23-day pulsation period. We would like to be able to confirm these pulsation periods with longer, better datasets. These may be available to us in the near future.

16 Understanding Rho Cassiopeiae – or Not

This project was done by **Bhairavi Shankar**, another second-year student in the ROP at the University of Toronto.

Rho Cas is a yellow hypergiant star, one of the largest and most luminous stars in our galaxy. It varies irregularly by a few tenths of a magnitude, on a time scale of hundreds of days, due to pulsation. Its additional "claim to fame" is that, every decade or two, it ejects a shell of gas and dust. These episodes appear in the light curve as unusually large and long cycles. The most recent example occurred between April 2000 and November 2001; as much as 10,000 Earth-masses of material were ejected. See the article by Alex Lobel in *Mercury*, 33.1, 13 (2004) for an excellent summary. Rho Cas is on the AAVSO visual and PEP programs.

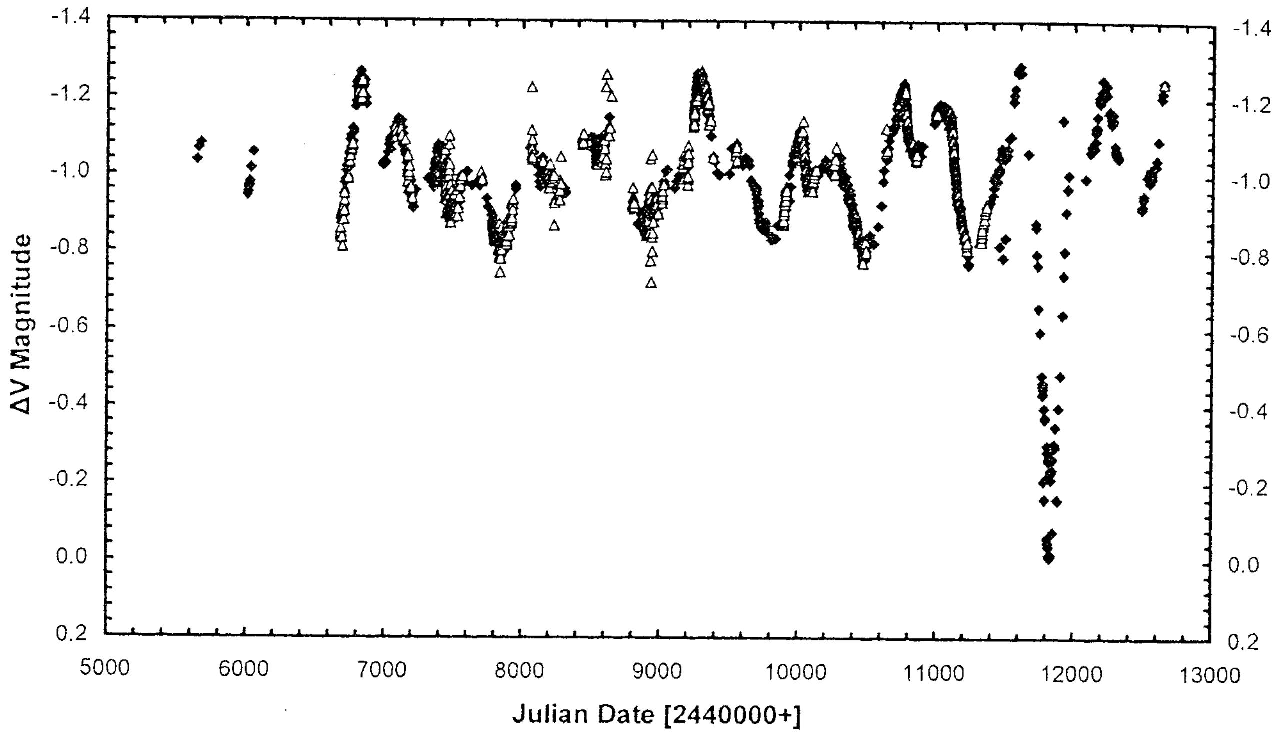

Figure 6: The long-term photoelectric light curve of ρ Cas, based on differential photoelectric photometry from the AAVSO PEP program, and from a robotic telescope. Note the very large cycle in 2000-2001, at the right.

The purpose of Bhairavi's project was to see whether there are any changes in the period or amplitude of pulsation which occur *before* or *after* the mass-loss episodes. These might help to show whether the pulsation was in any way responsible for the shell ejections. The star's variability was discovered in 1900, and there are brightness measurements going right back to that time. But they tend to be visual or photographic, sporadic, and published in obscure places. Bhairavi spent considerable time in the library! By the 1980's, when the second most recent shell ejection occurred, there was photoelectric photometry, but it was not necessarily continuous, either.

There was some suggestion that, just before the shell ejections, the star's period was unusually short – perhaps because an overtone pulsation mode had been excited. Otherwise, there was no clear pattern. This star continues to defy easy explanation. As usual: further observations are necessary!