The AAVSO Photoelectric Photometry Program in Its Scientific and Socio-Historic Context

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Abstract In this paper, I review the work of the AAVSO in the area of photoelectric photometry (PEP). This work was influenced by several trends: in science, in technology, and in the sociology of amateur astronomy. Through the 1980s, the AAVSO photoelectric photometry program competed with other such programs and, in recent years, has been overshadowed by CCD photometry programs. Nevertheless, the AAVSO PEP program has, through careful organization, motivation, and feedback, produced extensive scientific results, and can continue to do so. In the case of my own research, AAVSO PEP observations have also contributed significantly to the education of my students.

1. Introduction

The AAVSO Photoelectric Photometry (PEP) program tends to be overshadowed by the venerable visual program, and by the charge-coupled device (CCD) program which is now generating hundreds of thousands of observations each year. Nevertheless, the PEP program has played a significant scientific and technological role in the evolution of AAVSO variable star research; it has produced good science—dozens of research papers—and continues to do so. It has also demonstrated the way in which observers with diverse talents and interests can engage with and contribute to variable star astronomy in their own preferred way.

The history of PEP observing in the AAVSO has been formally and professionally examined in the centennial history of the AAVSO (Williams and Saladyga 2011), and more informally in the last issue of the *AAVSO Photoelectric Photometry Newsletter* (Percy 2008), which can be found at: http://www.aavso.org/sites/default/files/newsletter/PEP/lastpepnl.pdf

2. Photoelectric photometry

Photoelectric photometry developed over a century ago, when physicists developed the quantum theory of light. Light consists of bundles of energy called *photons*. The photon energy is inversely proportional to the wavelength of the light—light has both wave and particle properties. When light illuminates certain materials, the photons liberate electrons from that material. This is called *the photoelectric effect*. It was for this that Albert Einstein received his Nobel Prize in Physics, not for his development of the theory of relativity. The number of these *photoelectrons* could be measured; it was proportional to the brightness of the light. *Photoelectric photometry* was born.

The photoelectric effect was soon applied to measuring the brightness of stars and other celestial objects, especially by Joel Stebbins in the United States and by Paul Guthnick in Germany. Early photometers, with detectors based on selenium, were relatively insensitive, and were therefore usable only on bright stars. They were also idiosyncratic, and observers had to understand their instruments well. However, the brightness could be measured to an accuracy of 0.01 magnitude or better—an order of magnitude better than with photographic or visual photometry. It was also possible to insert standard color filters into the light path (UBV: near-ultraviolet, blue, and yellow, for instance), and measure a “standard” magnitude, or measure the color of the star.

3. The development of amateur photoelectric photometry

Not surprisingly, some amateur scientists soon took up photoelectric photometry. There were no off-the-shelf photometers in the early days; you had to make your own. Electronics was a popular pursuit among amateur scientists, right through to the 1960s and beyond. When I was in high school in the 1950s, there was no science club, just a radio club! The American Radio Relay League had been founded in 1914, and was a magnet for amateur scientists and hobbyists. Radio amateurs also provided crucial communication services in times of emergency, so there was a sense of “citizen science” (or technology) in the hobby—especially during WWII. Amateur interest in electronics re-emerged with the post-war availability of electronic (including photometer) components. Electronics was the future!

Amateur telescope making blossomed in the 1920s, with the publication of articles by Russell W. Porter and Albert G. Ingalls, and the latter’s three-volume book *Amateur Telescope Making* (Ingalls 1926). The Stellafane clubhouse and observatory were founded in 1923, and the annual Stellafane convention started shortly after.

In the 1950s, the “space bug” struck, in many ways. The Smithsonian Astrophysical Observatory established *Operation Moonwatch* as a citizen science (and patriotism) project in 1956, to track the anticipated artificial satellites to be launched by the USSR and USA. “Professional” optical tracking stations were not operational until two years later. *Operation Moonwatch* grew out of *Operation Skywatch*, in which hundreds of thousands of volunteers in the Ground Observers Corps watched for Soviet bombers—another fusion of citizen science and patriotic civil defence.

As well, the Space Age produced widespread and varied interest in both space science and technology, and in astronomy in general. This interest extended to young people, especially as school science and math curricula were expanded and strengthened in response to the Space Race.

By the 1970s, the "computer bug" struck also. The first computers, developed during WWII, were large and unwieldy but, with the development of transistors and then microelectronic circuits, handheld calculators, programmable calculators, and then "personal computers" were developed. Some of these were available as kits, which appealed to electronics enthusiasts. The recent (October 2011) death of Apple computer co-founder Steve Jobs reminded us of the excitement and innovation of those times. It was not long before a few amateurs, such as David Skillman (Skillman and Sinnott 1981) were automating their telescopes and their photometers.

4. The amateur PEP revolution

Several things happened around 1980 that revolutionized the field of amateur PEP. One was the availability of moderate-sized commercial telescopes at reasonable price; observers no longer had to build their own telescopes. A second was the development of a relatively simple off-the-shelf photometer, the SSP-3, based on a solid-state photodiode detector, by Optec Inc. Another was the publication of two very useful textbooks on PEP: *Astronomical Photometry*, by Arne Henden and Ron Kaitchuck (1982) and *Photoelectric Photometry of Variable Stars: A Practical Guide for the Smaller Observatory* by Doug Hall and Russ Genet (1988; a preliminary edition had been published in 1982 by International Amateur-Professional Photoelectric Photometry (IAPPP), and Fairborn Observatory). Yet another was the formation of IAPPP itself: "bringing amateurs, students, and professionals together for research in astronomy since 1980" (to quote the cover of the *IAPPP Communications*). The IAPPP later spawned "wings" in regions of the United States and overseas. The *Communications* provided a forum for publication of instrumental developments, advice on observing programs, and preliminary results. Related to this was the organization of PEP conferences, and the publication of several books on PEP, such as *Advances in Photoelectric Photometry*, volumes 1 and 2, edited by Russell M. Genet, Robert C. Wolpert, and others. But by the early 2000s, the IAPPP was dormant; CCD photometry was on the rise; and PEP topics became a small but significant part of regular variable star conferences.

5. The AAVSO PEP program—origin

The first record of AAVSO-associated PEP is some correspondence in 1919 between AAVSO Recorder Leon Campbell and Lewis Judson Boss, who had constructed a primitive selenium photocell, and was experimenting with it on Frank Seagrave's 8-inch (or possibly 8.5-inch) Clark refractor (Williams and Saladyga 2011). Boss published two articles about his efforts in *Popular Astronomy*. He joined the AAVSO in 1921 and continued this work for a few years before his professional duties caused him to stop the project. He did, however, serve as the founding chair of the AAVSO PEP Committee from 1954 until 1967.

Organized AAVSO PEP goes back at least as far as 1952—perhaps earlier. John J. Ruiz had expressed an interest in PEP as far back as 1947 and, in 1957 (Ruiz 1957a) published a paper in *PASP* on "A Photoelectric Light Curve of u Herculis" (an Algol binary), based on photometry from 1952 to 1955, and indicating that he was a "Member of the Photoelectric Committee of the AAVSO." In the same year (Ruiz 1957b), he published "Photoelectric Observations of 12 Lacertae" (a β Cephei star) in the same journal.

AAVSO Director Margaret Mayall proposed the formation of the PEP committee in 1954, and Lewis Boss chaired it from its inception until 1966. Boss, however, acknowledged that it was Ruiz who had done most of the work of the committee (Boss 1980). In 1956, Ruiz had written the *AAVSO PEP Handbook*. In 1967, Art Stokes (1967) published PEP observations of Nova Delphini 1967; he also chaired the PEP Committee from 1966 to 1975. Throughout the 1970s, Howard Landis published many PEP papers, mostly on eclipsing and RS CVn variables in collaboration with Doug Hall (e.g. Landis *et al.* 1973). In 1975, Landis replaced Art Stokes as chair of the PEP Committee. Art and Howard were the PEP pioneers who introduced me to the potential of AAVSO PEP observations. Howard noted, in his 1978–1979 committee report, that 844 PEP observations of eclipsing binaries had been made in that year. So AAVSO PEP was well underway by then. Its organizational evolution, however, was affected by certain questions of observer recognition which are discussed in some detail by Williams and Saladyga (2011).

A more formal PEP program was organized by Janet Mattei in the early 1980s, primarily to complement the observations of some of the stars in the AAVSO visual program—ones that had both medium- and small-amplitude variability. Typical amplitudes were one magnitude or less. Most were small-amplitude pulsating red variables—giants and supergiants. I assisted in choosing the final set of program and comparison stars (no mean task for red variables!), and became the main scientific advisor to the program. The program grew from about sixty to about eighty stars, including stars that were added—or dropped because they proved to be non-variable. As of 1998, almost sixty observers had contributed to the program. For a discussion of the science and sociology of the program, see Percy (2000).

6. The AAVSO PEP program—growth

The best way to visualize the growth of the formal AAVSO PEP program is to look at Figure 1, which includes the prehistory of the program. The formal program started small, with only a few dozen observations the first year. But, especially through the patient work of Howard Landis, other observers gradually joined.

Initially, there was a "sociological" problem. The program was competing with Doug Hall's PEP program on RS CVn stars, and that yielded new results almost every season. Papers were published regularly, with the observers included as co-authors—as they should be. The AAVSO PEP program, on the other hand, was not designed to produce quick results; its power was in the information that it provided about the long-term behavior of the stars. But the program grew, as Figure 1 shows.

There are several reasons for the decline after 2000: the program was partly "in limbo" while it was being transferred to AAVSO Headquarters; some observers migrated to CCD observing; and some very active observers retired—champion observer Ray Thompson, for instance.

One way in which you can visualize the results of the program is to choose a star from the program, and go to the Light Curve Generator, entering its name (EU Del, for instance), choosing V data only, and asking for the last 10,000 days of data.

7. The *AAVSO PEP Newsletter*

The *AAVSO PEP Newsletter* was founded in 1979 with the name of *AAVSO PEP Bulletin*. By Volume 2, Number 1, dated February 21, 1980, it was *Newsletter*. It was produced by Howard Landis, Art Stokes, and Dave Skillman. The next issues are Volume 3, Numbers 1–4, which came from Russell M. Genet. The first that I edited was Volume 4, Number 1, dated June 1983. It begins by thanking "my predecessor Russell M. Genet for his enthusiastic and effective work in editing this newsletter." Apparently he wisely turned it over to willing hands (mine), because I continued to edit it, two or three times a year, often with an abject apology, in the editorial, for its lateness. Russ went on to other exciting things.

In 1992, I turned the *Newsletter* over to Michael S. Smith, in Tucson. He edited it for a few years, before handing it back to me in 1996. I edited it, with decreasing frequency, until 2008. As more and more of the work was done at AAVSO Headquarters, it has made more and more sense for communications to come from there.

During my editorships, there was a wide variety of content, usually provided by me, though I always appealed for contributions. Quite often (even before the age of widespread email), I would get brief notes and queries that I published. The most faithful contributor was Howard Landis, who always contributed a PEP Committee report, on time, with useful statistics, and acknowledgement of observers. We announced forthcoming PEP-related meetings and, where possible, summarized the contents. In particular: I published PEP highlights from the AAVSO Annual and Spring meetings. We published notices of "campaigns" (see below), and other special requests for observations. We discussed charts, the ins-and-outs of submitting and archiving observations, and data reduction and analysis. I cheerfully published mini-biographies of the observers. I often wrote about how my students had benefitted from analyzing AAVSO PEP observations for their projects, so that observers would know that their work had double benefit—to research and to education. Sometimes I would write mini-essays on the types of stars on the PEP program, or which turned up as annoying micro-variable comparison stars. Or I would summarize interesting photoelectric papers in the literature.

But most of my contributions were feedback to observers, telling them about new scientific results that their observations had produced. Often these were preliminary reports on results that were later published in *JAAVSO* or elsewhere.

8. Scientific results from the AAVSO PEP program

The scientific results from the AAVSO PEP program have been described by Percy (2008), and references given to select publications. Here, I shall review and update the results on small-amplitude pulsating red variables, which make up the majority of the program.

Until the 1980s, these very common variables were simply described as semiregular or irregular, and largely ignored. Thanks in part to the AAVSO PEP program, we now know that: all M giants are photometrically variable; these stars pulsate in one (or more) low-order radial modes; they occasionally switch modes; many have a long secondary period (LSP) of unknown cause; the amplitude is greater in cooler stars; since cooler stars are more luminous (because they lie on the giant branch in the H-R diagram), the cooler stars have longer periods. For each pulsation mode, these stars obey a period-luminosity relation almost as tight as that for Cepheids. An ensemble of these stars shows a series of period-luminosity relations, corresponding to different pulsation modes. For this reason, these stars can be especially powerful astrophysical tools.

One part of the program was *Project SARV*, in which a total of sixty-one bright red giants, suspected to be variable, were assigned to interested AAVSO PEP observers. The result was an eighteen-author paper, Percy *et al.* (1994).

In parallel with the analysis of the AAVSO PEP data on these stars (Percy *et al.* 1996), we analyzed data from a robotic telescope in Arizona (Percy *et al.* 2001). We subsequently combined the AAVSO data with the robotic telescope data for the thirteen stars in common (Percy *et al.* 2008). The combined data were especially powerful: the AAVSO data filled in the gaps in the robotic telescope data, caused by the summer monsoon season; and the AAVSO observations, which were continued long after the robotic telescope observations ceased, produced a dataset that was over two decades long. We were not only able to refine the primary periods, and LSPs, but we were also able to identify very-long-term variability.

The periods which were determined from the AAVSO PEP data have also contributed to a study of the period-luminosity relation(s) for pulsating red variables (Tabur *et al.* 2010). That was possible because our program stars are relatively bright, and therefore close enough for their parallaxes to be determined by the *Hipparcos* satellite.

9. The AAVSO near-infrared photometry program

Long-term near-infrared (NIR) photometry is valuable for all the same reasons that long-term V-band photometry is, especially for stars that emit much or most of their energy in the near-infrared. But few professional observatories were interested in or equipped for such photometry. Once again, skilled amateurs stepped into the breech. The AAVSO NIR PEP program was established in 2003. Much planning was needed, and a professional-amateur committee was formed to do this, with Doug West as a driving force. There were no off-the-shelf NIR photometers, so the AAVSO worked with Optec Inc. to develop one—called the SSP-4—that operated in the J (1.25 microns) and H (1.65 microns) bands. Five photometers were purchased by the AAVSO, and lent to interested, experienced observers. There are now about thirty stars in the program, mostly red giants, Cepheids, and eclipsing variables. See http://www.aavso.org/infrared-photoelectric-photometry-program for much more information.

10. PEP Campaigns

A *campaign* is a project in which one or a few carefully-selected stars are observed intensively for a period of time. In a sense, the AAVSO PEP program is a campaign! There are *multi-wavelength campaigns* in which the objects are observed simultaneously at a variety of wavelengths. There are *multi-longitude campaigns* in which the objects are observed from enough different longitudes to ensure continuous twenty-four-hour time coverage.

The AAVSO PEP program has participated in several campaigns. One notable one was organized by Roger Griffin, Cambridge University. ζ Aurigae binaries are long-period binaries in which one component is a supergiant. Eclipses, if they occur, would occur infrequently, but at predictable times, i.e., when one star was predicted to possibly be in front of the other. Roger provided times of possible eclipses in known or suspected ζ Aurigae binaries; we helped choose suitable comparison stars; and the observers determined which stars showed eclipses, and when, and how deep. The most significant campaign of this sort was the AAVSO's *Citizen Sky* project, in which dozens of new observers were recruited, trained, and motivated to observe the 2009–2011 eclipse of ε Aurigae; see: http://www.citizensky.org.

A more recent campaign was of a completely different kind: it was to monitor IM Peg, the guide star for the *Gravity Probe B* satellite; see http://einstein.stanford.edu. GPB was designed to test aspects of the theory of relativity by looking for two small, subtle effects on the orientation of the satellite. The RS CVn star IM Peg was chosen as the guide star because it was a point radio source whose position could be measured to milli-arc-second accuracy with radio telescopes, and it was bright enough to be seen by GPB's optical guide scope. But RS CVn stars have starspots, and the change in the starspot distribution on the star can artificially change its apparent position. Therefore a photometric campaign was organized to monitor the starspots through their effect on the brightness of the star. Much of the work was done by robotic telescopes, but these, being in Arizona, were "monsooned out" during the summer. That's where AAVSO PEP observers could fill in, and make a special contribution.

11. Educational spinoffs from the AAVSO PEP program

The observation and analysis of variable stars can be effectively connected to the goals of science and math education; that is the basis of the AAVSO's famous *Hands-On Astrophysics* project. It has since morphed into the much more powerful *Variable Star Astronomy* (http://www.aavso.org/education/vsa). The scientific research process involves elements of inquiry, investigation, problem-solving, discussion, and communication—the cornerstones of science education. Variable star observation, analysis, and interpretation is well suited for student projects and activities. Making measurements of variable star brightness visually may be simple, but the applications, analysis, and interpretation of the data involve a wide range of scientific and mathematical skills—some simple, but others quite challenging, even for experts.

Many undergraduate students carry out PEP research at universities and colleges around the world. I have even heard of high school students doing PEP, often for science fair projects. One or two did so through the AAVSO PEP Committee. At one time, my undergraduate students made PEP observations from downtown Toronto, sometimes of AAVSO PEP program stars; Doug Welch, well-known to AAVSOers, was a "graduate" of that program. But, for the last decade or two, their work has consisted of analysis and interpretation—usually of AAVSO PEP or visual data. Such projects involve doing real science with real data. They develop and integrate a wide variety of science, math, and computing skills, starting from background reading and planning; research judgement, strategy and problem-solving; continuing with pattern recognition, interpolation and measurement; recognizing and understanding random and systematic errors; construction, analysis, and interpretation of graphs; concepts of regularity and prediction, curve fitting and other statistical and numerical procedures; all the way to the preparation and presentation of oral and written papers.

My own students are of two kinds. The first are undergraduate students, either summer research assistants, work-study students, or students in our Research Opportunities Program (ROP), a competitive, prestigious program in which second-year students can work on a research project for course credit. The second are students in the University of Toronto Mentorship Program (UTMP), which enables outstanding senior high school students to work on research projects at the university.

In 2007–2008, two of my former students received special awards. One, former UTMP student Wojciech Gryc, received a Rhodes Scholarship. Another, undergraduate Kathy Hayhoe (who subsequently evolved from astronomy to climatology), won 1/2000 of half of the Nobel Peace Prize, because she is now a member of the Inter-Governmental Panel on Climate Change!

12. Final reflections

The AAVSO PEP program still attracts fifteen to twenty observers from all over the world, and produces good data and good science. It is administered by AAVSO Headquarters, with Dr. Matt Templeton as scientific advisor, and Jim Fox as chair of the PEP Committee. Collectively, the program has produced over 52,000 observations over thirty years of a total of 223 stars which are or have been on the program, mostly small-amplitude pulsating red giants. The "official" list of program stars is at:

http://www.aavso.org/content/aavso-photoelectric-photometry-pep-program

What are the strengths of a good observing program? Obviously it should produce useful scientific results, in the short or long term. Therefore its scientific value should be regularly and critically reviewed, so it will continue to be of value. Ongoing advice and support from the astronomical research community, that is, professional astronomers, can help to provide this. The program should be well-coordinated and standardized; this is especially important for programs whose strength is long datasets. It should have the opportunity for continuity, which is much easier if it is run by a well-established organization like the AAVSO than if it is run by an individual professional astronomer whose interests or status may change. It will succeed if observers receive instruction, feedback, support, motivation, and recognition—all of which the AAVSO does admirably. In this way, the program not only provides useful scientific data, but it also provides enjoyment and satisfaction to human observers. Indeed, the strength of the AAVSO is its combination of scientific relevance and human spirit.

13. Acknowledgements

The success of the AAVSO PEP program is due to the skill and dedication of the sixty-plus observers who have contributed; to the AAVSO Headquarters staff who received, processed, and archived the data; and to the chairs and members of the PEP Committee who guided the program. My personal thanks go to Howard J. Landis and the late Janet A. Mattei. I am grateful to Tom Williams for inviting me to participate in the May 2011 AAS-AAVSO history session, and to Mike Saladyga for reading a draft of this paper. I thank the Natural Sciences and Engineering Research Council of Canada, the Ontario Work-Study Program, and the organizers of the University of Toronto Mentorship Program for facilitating my work, and that of my students—whose help and inspiration I also acknowledge here.

References

Boss, L. 1980, *J. Amer. Assoc. Var. Star Obs.*, **9**, 48.
Hall, D. S., and Genet, R. M. 1988, *Photoelectric Photometry of Variable Stars: A Practical Guide for the Smaller Observatory*, 2nd ed., Willmann-Bell, Richmond, Virginia.
Henden, A. A., and Kaitchuck, R. H. 1982, *Astronomical Photometry*, Van Nostrand Reinhold, New York.
Ingalls, A. G. 1926, *Amateur Telescope Making*, *Scientific American Publ.*, New York.
Landis, H. J., Lovell, L. P., Frazier, T. H., and Hall, D. S. 1973, *J. Amer. Assoc. Var. Star Obs.*, **2**, 67.
Percy, J. R. 2000, in *Amateur-Professional Partnerships in Astronomy*, ed. J. R. Percy and J. B. Wilson, ASP Conf. Ser. 220, 57.
Percy, J . R. (ed.) 2008, *AAVSO PEP Newsletter*, **24**, No. 2.
Percy, J. R., Desjardins, A., and Yeung, D. 1996, *J. Amer. Assoc. Var. Star Obs.*, **25**, 14.
Percy, J. R., Mashintsova, M., Nasui, C. O., Palaniappan, R., Seneviratne, R., and Henry, G. W. 2008, *Publ. Astron. Soc. Pacific*, **120**, 523.
Percy, J. R., Wilson, J. B., and Henry, G. W. 2001, *Publ. Astron. Soc. Pacific*, **113**, 983.
Percy, J. R., *et al.* 1994, *Publ. Astron. Soc. Pacific*, **106**, 611.
Ruiz, J. J. 1957a, *Publ. Astron. Soc. Pacific*, **69**, 261.
Ruiz, J. J. 1957b, *Publ. Astron. Soc. Pacific*, **69**, 357.
Skillman, D. R., and Sinnott, R. W. 1981, *Sky & Telescope*, **61**, 71.
Stokes, A. 1967, *Inf. Bull. Var. Stars*, Nos. 224, 226, and 238.
Tabur, V., Bedding, T. R., Kiss, L. L., Giles, T., Derekas, A., and Moon, T. T. 2010, *Mon. Not. Roy. Astron. Soc.*, **409**, 777.
Williams, T. R., and Saladyga, M. 2011, *Advancing Variable Star Astronomy: The Centennial History of the American Association of Variable Star Observers*, Cambridge Univ. Press., Cambridge.

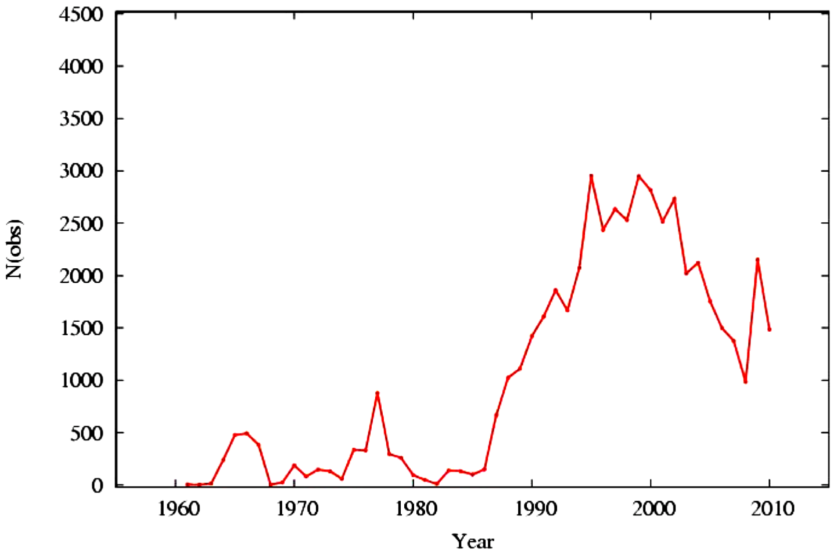

Figure 1. The number of PEP observations carried out through the AAVSO as a function of time. Data provided by the AAVSO.

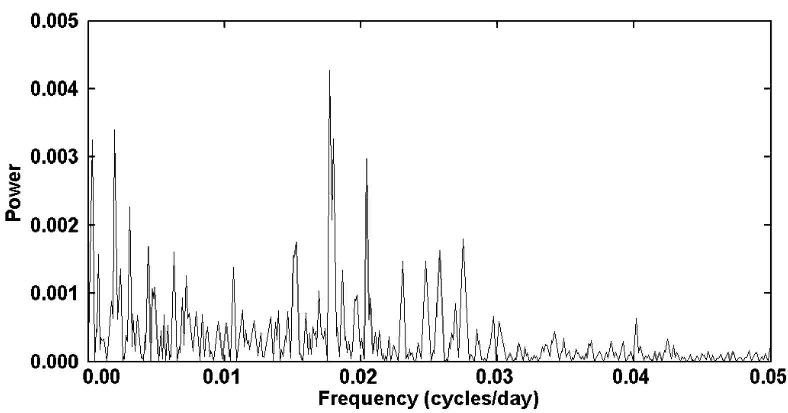

FIgure 2. The power spectrum of RZ Ari from combined AAVSO and robotic telescope photometry, showing periods of 56.5 days (0.0177 cycle/day), 37.7 days (0.0265 cycle/day), and 370 days (0.00270 cycle/day). The first two periods represent two different pulsation modes, the last period is a “long secondary period.” From Percy *et al.* 2008.