

Variable Star Astronomy in the 21st Century

John R. Percy, Editor, *JAASO*

Department of Astronomy and Astrophysics, University of Toronto, Toronto ON M5S 3H4, Canada

The AAVSO has just celebrated an exciting and important milestone in its history—its centenary. At the age of 100, it is in excellent health (unlike most people), with a new(ish) home, an able and dedicated staff and council, a worldwide network of volunteer observers and friends, respect and support from professional astronomers, impressive technology, and a continuing mandate to engage in and facilitate research in variable star astronomy.

It therefore seems appropriate to review variable star astronomy in 2011–2012. Several years have gone by since my book (Percy 2007) attempted to review the field and, as in most areas of astronomy, much has happened in a short period of time. We therefore commissioned a set of short reviews of variable star types which are of special interest to AAVSOers by professional-astronomer friends of the AAVSO with special expertise on these topics. We thank them for taking the time, in their busy schedules, to provide these reviews.

We begin, appropriately, with a review of young stellar objects (YSOs) by Bill Herbst, Van Vleck Professor of Astronomy, Wesleyan University. Bill has been a leader in this field for many years, especially through international long-term photometric monitoring campaigns, and through mentoring undergraduate research students. Bill is the science advisor to the AAVSO's recently-formed YSO Section. He's also an award-winning teacher, active in public outreach, and a skilled tennis player!

Bryce Croll, NASA Sagan Fellow at the Massachusetts Institute of Technology (MIT), reviews exoplanet transits, one of the hottest fields in which amateurs can contribute. Exoplanets are planets around other stars. If they transit their star and dim its light, that variability can provide evidence for the exoplanet, and much information about its properties. Bryce recently completed a Ph.D. in the exoplanet group at the University of Toronto, studying the atmospheres and other properties of exoplanets. He also had several variable star publications, as an undergraduate, based on photometry with *MOST* (Microvariability and Oscillations of STars), Canada's "humble space telescope." At Toronto, he was a driving force behind our public outreach programs. And he's a triathlete.

Ed Guinan, Professor of Astronomy and Astrophysics, Villanova University, reviews eclipsing binaries. These provide fundamental and unique information about the properties and evolution of stars. Ed is an international leader in the study of stars and binaries, especially through the Variable Star Division of the International Astronomical Union (IAU). He is also a leader in international astronomy education and development; he chairs the IAU's Program Group on "Teaching for Astronomical Development," and works for astronomical

education and development in many countries around the world. His research interests include pulsating stars, binaries, black holes, sun-like stars, robotic telescopes, and exoplanets. He has served on the AAVSO Council since 2008.

RR Lyrae stars, which provide essential information about the properties of the oldest stars in galaxies, are reviewed by Katrien Kolenberg, Harvard-Smithsonian Center for Astrophysics, on leave from the University of Leuven, Belgium. I first met Katrien in Leuven when she was a graduate student, at an IAU Colloquium on pulsating stars. There, she stood out as a result of both her scientific and her artistic talents. Much of her research focuses on one of the oldest and most puzzling mysteries in variable star astronomy—the nature and cause of the *Blazhko effect*. She is currently at CFA on a Marie Curie Scholarship, using *Kepler* data to study RR Lyrae stars in ways not previously possible.

Doug Welch, Professor at McMaster University, Hamilton, Ontario, reviews Population II Cepheids. Doug began his interest in astronomy as a keen amateur in Ottawa, survived two summers as my undergraduate research assistant, doing photometry of variable stars, and went on to a very successful career as a researcher, professor, administrator, and promoter of astronomy outreach. He served on AAVSO Council in 1995–1999 and 2007–2008, and has assisted the Association in many other ways, including establishing the on-line discussion group. His research interests are in pulsating stars and, more recently, light echoes from supernovae and other transients.

Cepheids are reviewed by Dave Turner, Saint Mary's University, Halifax, Nova Scotia. Dave's research encompasses star clusters, especially those which contain Cepheids. He also carries out long-term studies of period changes in Cepheids, which provide important and unique information about Cepheid evolution. He is also a long-time supporter of pro-am collaboration, both through the Royal Astronomical Society of Canada (RASC) (he served for many years as Editor of *JRASC*), through the AAVSO, in which he is currently a Councillor, and through his collaboration with amateurs in the Halifax area.

Lee Anne Willson, University Professor, Iowa State University, reviews Miras. Lee Anne and the AAVSO are a perfect fit: she is an expert in constructing and interpreting theoretical models of Mira pulsation, which AAVSO observers have studied productively for over a century. She has been deeply involved in the AAVSO, as a Councillor for many years, and as President in 1999–2001. She has been publishing in *AAVSO* for over thirty years. As Vice-President of the American Astronomical Society, she recently facilitated the May 2011 joint AAVSO-AAS meeting, part of the AAVSO centenary. Her extra-curricular interests include being the Founding President of the Creative Artists' Studio of Ames, Iowa.

Non-Mira pulsating red giants are reviewed by Laszlo Kiss and me. Laszlo graduated from the University of Szeged, Hungary, and spent several years at the University of Sydney, Australia, before returning to the Konkoly Observatory in Hungary. He already has 380 publications in the ADS data system, partly

because, in addition to his very productive professional career, he has been a very active participant and supporter of amateur astronomy, especially in Hungary. He is a member and good friend of the AAVSO. Professionally, he has a special interest in large-scale surveys of variable stars and, more recently, exoplanets (and exomoons), but he has made contributions to the understanding of many other types of variables as well.

Geoff Clayton, Ball Family Distinguished Professor of Physics at Louisiana State University, reviews R CrB stars, a field in which he has been a world leader for many years. He has written several comprehensive reviews of R CrB stars in the past, and we are honored that he has contributed his latest one to *JAAVSO*. He has served as an AAVSO Councillor and, like several of our reviewers, is a member of the Editorial Board of *JAAVSO*. For several years, he supervised summer undergraduate research students at the Maria Mitchell Observatory. His website is “The Centre for Fun Astrophysics; the home of ‘Team Clayton’”, expressing his enthusiasm for studying R CrB stars and interstellar matter.

The review of cataclysmic variables is contributed by Paula Szkody, Professor, University of Washington, and her colleague Boris Gaensicke. CVs have been a topic of great interest to AAVSO observers, especially since the dawn of the space age and high-energy astrophysics in the 1970s. Paula has been a user of AAVSO data for almost thirty years, a mentor to the Association and its observers and, more recently, a Councillor (2003–2009) and President (2007–2009). She has also served recently as Editor of *Publications of the Astronomical Society of the Pacific (PASP)*. Boris Gaensicke is a professor in the Department of Physics, University of Warwick, UK, where he is engaged in a wide variety of projects on binaries containing white dwarf stars. He co-edits a *Newsletter on Interacting Binaries*.

Ulisse Munari, National Institute of Astrophysics INAF, Osservatorio Astronomico di Padova, Italy, reviews the symbiotic stars, and also novae; we thank him especially for providing both these reviews. Symbiotic stars are among the most complex of all variables, since they vary on a wide range of time scales, for a wide range of reasons. And novae are the spectacular result of runaway thermonuclear reactions. Ulisse was the AAVSO’s second Janet A. Mattei Research Fellow; he worked with Arne Henden to improve observer quality, to provide spectra of new transient objects to decipher their classification, and to provide calibrated photometric sequences for many variables. He will be returning to AAVSO Headquarters in fall 2012 to collaborate on the APASS photometric survey. He has over 500 publications listed on ADS!

Peter Garnavich, Professor of Astrophysics and Cosmology, Notre Dame University, reviews supernovae. Peter is a distinguished scientist. He shared the Gruber Prize in Cosmology in 2007, and was an integral part of the research that won the Nobel Prize in Physics in 2011 (and was invited to attend the Nobel Prize ceremony in Stockholm). Peter is keenly involved in communicating with the public and the media about the excitement of astronomy. He is also a great

friend of the AAVSO, and served as Councillor from 1996 to 2000. His first publication was an *Information Bulletin on Variable Stars (IBVS)* with Janet Mattei and Lee Anne Willson, and his second publication was a sole-author paper in *JAAVSO!*

Other types of variable stars

There are other types of variable stars which are not included in the reviews, generally because they are less suitable for study by amateurs. Most of these types have small amplitudes, and are most often found as variable comparison stars for visual, PEP, or CCD photometry. They are “fair game” for skilled amateurs who can achieve millimag precision. Since many of them have periods of hours to days, joining a multi-longitude network of observers is often a good strategy. Here are short notes on some of those variable star types. Another useful resource is the 2012 triennial report of the IAU Commission on Variable Stars (Handler 2012). Other excellent resources are the AAVSO “Variable Star of the Season” articles (www.aavso.org/vsots_archive), especially the more recent ones, and the “For Observers” page (www.aavso.org/observers#sections) which contains links to the observing sections, including data mining, solar, and high energy network, which are not discussed explicitly in these short science reviews.

δ Scuti stars and γ Doradus stars These are A5-F2 stars, near the main sequence, which pulsate in a complex mixture of modes, with periods of a few hours to a few days. They are analogues of the Cepheids, in that they are driven by the same helium opacity mechanism. Most δ Scuti stars have very small amplitudes, but there are a few HADS—high-amplitude δ Scuti stars—which are amenable to visual observation. The most active work on δ Scuti stars continues to be: (1) detecting and studying them, especially with high-precision photometry from space; (2) interpreting the complex spectrum of periods with models, a process called *asteroseismology*. δ Scuti stars are radial pulsators, though many have non-radial modes as well; γ Doradus stars are pure non-radial pulsators. Both, through asteroseismology, provide important information about the interiors and evolution of these stars.

Pulsating B stars These include β Cephei stars, which have been known for a century, and Slowly Pulsating B (SPB) stars, which are a more recent discovery. Their pulsation is driven by a similar opacity mechanism as the Cepheids, but involving iron-group elements, rather than helium, deep within the star. There are many dozens of these among the naked-eye stars. These are complex, multi-mode pulsators. The β Cephei stars are primarily radial p-mode pulsators, with periods of a few hours; the SPB stars are primarily g-mode pulsators, with periods of hours to a day or two. However, there are stars which show both types of modes. The most important recent development has been the availability of ultra-precise photometry from space missions, *MOST*,

CoRoT, and *Kepler*. But De Cat *et al.* (2011), in a recent review, end by saying that “there is still a clear need for ground-based follow-up observations.” Another research frontier is the search for and study of magnetic fields in OB stars, which may explain some poorly-understood aspects of their behavior.

γ Cas (Be) stars These are non-supergiant B stars which have shown emission lines in their spectra on at least one occasion. They vary, photometrically and spectroscopically, on time scales from hours to years. They may brighten and fade unpredictably and, since there are about 200 among the naked-eye stars, they are well-suited for PEP and CCD monitoring. The emission lines and some of the photometric variability are due to an equatorial disc slowly moving away from the star. Now that spectroscopy of brighter stars is within the reach of suitably-equipped amateurs, Be stars can be monitored by amateurs using that technique as well. One of the most exciting new developments in Be star research is the ability, using optical interferometry, to image the discs of these stars.

A good place to learn about current research on Be stars is in the *Be Star Newsletter*, maintained by David McDavid at the University of Virginia: ([http://www.astro.virginia.edu/\\$sim\\$dam3ma/benews/](http://www.astro.virginia.edu/simdam3ma/benews/) (click on “abstracts”)).

Rotating variable stars and stellar activity Rotating variables are stars with non-uniform surfaces; their period of variability is their rotation period. Most have visual amplitudes less than 0.1 magnitude. They are of two types: (1) stars like the sun, or cooler, with starspots; and (2) peculiar A stars, with temperatures of typically 10,000K and strong global magnetic fields, inclined to the rotation axis (“oblique rotators”). Type (1) rotating variables are of current interest because they may host exoplanets. The rotational variability provides information on the rotation and activity of the star; it may also be confused with an exoplanet transit!

Related to the spotted rotating variables are the *flare stars* which, along with rotating variables, are the most numerous variable stars in our galaxy. That’s because over ninety percent of stars are main sequence stars, like the sun or cooler, and virtually all of these rotate, have spots, and flare. Spots and flares result from magnetic fields, which are generated by rotation and convection. Papers on classical flare stars are still published, but stellar flares have become a standard, mainstream process in astrophysics—especially as similar processes occur on the sun.

Solar-type oscillations The sun vibrates in thousands of complex, non-radial modes, driven by convective motions in its outer layers, but these vibrations are so small that they require specialized observation techniques. On other stars, they are observable from the ground only with great difficulty, but they are most effectively observed with high-precision photometry from space, with *MOST*, *CoRoT*, and *Kepler*. As described in the Kiss and Percy review, they have been observed in many red giants, and are revolutionizing our understanding of the nature and structure of these stars.

RV Tauri and SRd stars These are mentioned briefly in Doug Welch’s review, but I would like to highlight two continuing areas of interest in these stars: (1) the cause of the alternating deep and shallow minima in these stars—probably a combination of multiperiodicity, chaos, and convection effects—and (2) the nature of the long-period variability of the RVb stars—probably a result of binarity in a significant fraction of RV Tauri and other post-AGB stars.

Hypergiants The most luminous stars, of all temperatures, are unstable and variable in a variety of ways. Stars such as the hot P Cygni and the cooler ρ Cas are well-established targets for AAVSO observation, and there are current/recent AAVSO campaigns on the hot hypergiants S Dor (*AAVSO Alert Notice 453*) and on P Cygni (*AAVSO Alert Notice 440*). I was saddened, but also moved in a way to recently receive a copy of the last paper by Richard Stothers, who passed away in 2011, and who made important contributions to the theory and interpretation of stellar variability during his long career. His paper on “Yellow Hypergiants Show Long Secondary Periods?” (Stothers 2012) deals with the hypergiants ρ Cas and HR 8752—two of the first stars that I collaborated on with the AAVSO. It suggests that both show the mysterious “long secondary periods” found in pulsating red giants, red supergiants, and red hypergiants (see review by Kiss and Percy), and are regarded by some as being the most important unsolved problem in stellar pulsation theory. Stothers attributes these to the turnover of giant convection cells in the stars’ convective envelopes.

References

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