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COMMISSION 27 VARIABLE STARS

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TRIENNIAL REPORT 2006 - 2009

1. Introduction

The Organizing Committee of Commission 27 has decided to again provide a somewhat abbreviated bibliography as part of this triennial report, as astronomy-centered search engines and on-line publications continue to blossom. We focus on selected highlights in variable star research over the past three years. Further results can be found in numerous proceedings of conferences held in the time frame covered by this report.

Following the IAU XXVI General Assembly, 2006, a number of international meetings considered intrinsically variable stars as a significant element of their program. In September 2006, the *Vienna Workshop on the Future of Asteroseismology* (Handler & Houdek 2007) celebrated Michel Breger's 65th birthday. The November 2006 joint *CoRoT*/ESTA workshop on *Solar/Stellar Models and Seismic Analysis Tools*, has proceedings edited by Straka, Lebreton & Monteiro. The community gathered in July 2007 to honor Prof. Douglas Gough with a conference on *Unsolved Problems in Stellar Physics*, the proceedings of which were edited by Stancliffe *et al.* (2007). The long series of pulsating star meetings continued in July 2007 with *Stellar Pulsation & Cycles of Discovery*. Also in July 2007, the *3rd Meeting on Hot Subdwarf Stars and Related Objects* was held in Bamberg (Heber *et al.* 2008). In April 2008, IAU Symposium No. 252 on *The Art of Modeling Stars in the 21st Century* was held in Sanya, China (Deng *et al.* 2008).

2. Solar-like variables

General reviews of asteroseismology that concentrate on solar-like oscillations include Bazot *et al.* (2008) and Bedding & Kjeldsen (2007), which discuss how we are now exploring interesting stars using their solar-like oscillations to extend our understanding of solar phenomena to other realms. Carrier, Eggenberger and colleagues measured oscillations in the visual binary 70 Oph (Carrier & Eggenberger 2006) and used these for an asteroseismic analysis (Eggenberger *et al.* 2008). Vauclair *et al.* (2008) used the oscillation frequencies in the star ι Hor, already known to host an exoplanet, to determine that this star is an evaporated member of the primordial Hyades cluster.

Subgiant stars also show solar-like oscillations; examples include the metal-poor subgiant ν Indi (Bedding *et al.* 2006; Carrier *et al.* 2007), β Hydri (Bedding *et al.* 2007; North *et al.* 2007), and μ Her (Bonanno *et al.* 2008). Climbing to and up the giant branch, solar-like oscillations were examined in a number of targets. While radial velocity measurements were used to uncover oscillations from ϵ Oph (De Ridder *et al.* 2006). Notably, space-based photometry with *SMEI*, *MOST*, and *WIRE* has now revealed solar-like oscillations in K-type giants (Tarrant *et al.* 2007; Barban *et al.* 2007; Stello *et al.* 2008).

3. Main Sequence Stars

Pigulski & Pojmański (2008) significantly update earlier compilations of β Cep stars, confirm the basic properties of these variables, and more than doubles the number of known variables. The authors also identify interesting new members such as pulsators with eclipses. There are a growing number of 'hybrid' pulsators that show p and g modes among the main sequence pulsators, blurring the lines between these variable types.A new example of a hybrid β Cep/SPB star (Handler *et al.* 2006) was modeled by Dziembowski & Pamyatnykh (2008). In the δ Scuti/ γ Dor stars realm, two hybrid examples were found using *MOST* (King *et al.* 2006; Rowe *et al.* 2006).

New interferometry results complement and reinforce asteroseismic inference (Cunha *et al.* 2007). The first direct determination of the angular diameter of a roAp star (α Cir; Bruntt *et al.* 2008), gave an independent, and lower, determination of the star's effective temperature. This confirmed earlier suspicions that effective temperatures of cool Ap stars determined by traditional methods might be biased towards hotter values. With the new effective temperature of α Cir, the seismic data acquired with *WIRE* now agrees with that derived from theoretical models.

High-resolution spectroscopic data on roAp stars probes the dynamics associated with pulsations in their atmospheres. Such data provide evidence for the co-existence of running and standing waves (e.g., Ryabchikova *et al.* 2007), and reveal the effect of shock waves driven by pulsations (Shibahashi *et al.* 2008).

The physical process responsible for reflecting the high frequency oscillations at the surface of roAp stars has been debated for many years. Sousa & Cunha (2008) show that mode conversion in these stars can deposit a significant amount of the mode energy on magnetic waves in the outer magnetically dominated layers. The energy in the magnetic waves will be kept in the oscillation, providing a natural explanation for the (partial) reflection of the oscillations. This new understanding should allow the development of a new generation of theoretical models with an appropriate outer boundary condition, which is essential to study pulsations in these stars.

4. Large amplitude radial pulsators

A recent analysis of the Cepheid P-L relation by Fouqué *et al.* (2007) that includes traditional metrics as well as newer interferometric studies (e.g., Kervella *et al.* 2008) and parallaxes (Benedict *et al.* 2007; van Leeuwen *et al.* 2007) reveals a universality to the slope of the period-luminosity (PL) relation with negligible dependence on color. The parallax studies provide a zero point favoring a distance modulus for the LMC of $(m-M)_0 = 18.40 \pm 0.05$ mag. *Spitzer* data also show that the slope of the PL relation is constant through the mid-IR (Ngeow & Kanbur 2008; Freedman *et al.* 2008).

Among RV Tauri and other evolved stars, recent evidence (optical and infrared photometry [Gielen *et al.* 2007], interferometry [Deroo *et al.* 2007] and polarimetry) suggests the existence of long-lived and highly-processed dust disks. There is mounting evidence that those variables which show long-term (500 - 2500 d) photometric periods are in binary systems and possess unusual abundances in their atmospheres (Reyniers & Van Winckel 2007). The observed abundances can result from accretion of material from a circumbinary dust disk which has been depleted of refractory elements.

The Sloan Digital Sky Survey (SDSS) led to important developments through identification of RR Lyrae stars in several of the dwarf spheroidal satellites of the Milky Way. The RR Lyrae content in these galaxies can tell us about the small building blocks that we now think were assembled into big galaxies like the Milky Way. This assembly happened nearly 10 Gyr ago, which is precisely the age of the RR Lyrae stars. In a very real sense, any RR Lyrae stars in existence today were eyewitnesses to the formation history of the Milky Way. Several recent studies compared the properties of the RR Lyrae stars in the Milky Way and in the newly discovered dwarf spheroidal galaxies, to see if the former could have been assembled from protogalactic fragments resembling the early counterparts of the latter. Such papers include Siegel (2006) and Dall'Ora *et al.* (2006) for the Bootes dSph, Kuehn *et al.* (2008) for the CVn I dSph, and Greco *et al.* (2008) for the CVn II dSph. Similar such studies are being carried out in other dSph galaxies, e.g., Greco *et al.* 2007, for a globular cluster in the Fornax dSph.

These results reveal that the ancient RR Lyrae population of the dwarf spheroidal satellite system of the Milky Way differs in some fundamental respects from the bona-fide RR Lyrae population in the Galactic halo. This suggests that the Milky Way cannot have been formed from fragments resembling the dSph galaxies, even as they looked more than 10 Gyr ago. In particular, it turns out that the famous 'Oosterhoff dichotomy', which is a marked property of the Milky Way, is not present in the oldest populations of the dwarf satellites of the Milky Way. Had the Galaxy formed from accretion of smaller structures like these dwarf galaxies, the Oosterhoff dichotomy would simply not exist.

Another notable development is the fact that PL and period-color relations have recently become available for RR Lyrae stars in the near-infrared bandpasses of the Johnson-Cousins-Glass system and in the bandpasses of the Strömgren and SDSS systems. With these new calibrations, Catelan & Cortés (2008) use the trigonometric parallax of RR Lyrae itself to show that it is intrinsically brighter than previously thought, by 0.064 ± 0.013 mag. They provide a recalibrated relationship between the absolute magnitudes of RR Lyrae stars and the metallicity, and apply it to the LMC to obtain a revised distance modulus of $(m - M)_0 = 18.44 \pm 0.11$ mag.

Martin *et al.* (2007) used ultraviolet observations with *GALEX* to discover a spectacular comet-like tail extending 2 degrees behind Mira, the prototype long-period variable. The bow shock and tail appear to arise from the interaction between Mira's wind and the surrounding interstellar medium (Wareing *et al.* 2007).

Meanwhile, MACHO and OGLE observations of pulsating red giants continue to produce interesting new results on their PL relations that have motivated theoretical studies (Xiong & Deng 2007), but we still await a definitive solution to the origin of the mysterious long secondary periods (Derekas *et al.* 2006; Soszyński 2007).

5. Stellar activity

Satellite observations have benefited the study of stellar activity. The high quality and continuity of *MOST* data can reveal differential rotation coefficients directly through spot modeling. Equatorial velocities and spot patterns on the stellar surfaces are given for ϵ Eri by Croll *et al.* (2006) and for κ^1 Ceti by Walker *et al.* (2007). Using ground- and space-based instruments together offers new possibilities. For example, the study of the coronal structure of the young, single cool star AB Doradus by Hussain *et al.* (2007) combined ground-based circularly polarized spectra from the AAT, and X-ray light curves and spectra from *Chandra*. They showed that the X-ray corona must be concentrated close to the stellar surface, with a height $H \simeq 0.3\text{-}0.4\,R_*$, determined by the high coronal density and complex multipolar magnetic field from the surface maps. The theoretical results of Morin *et al.* (2008) are very important: they find a stable magnetic field for the fully convective star V374 Peg from phase-resolved spectropolarimetric observations. They find that the contrast and fractional coverage of spots are much lower than those of non-fully convective active stars with similar rotation, and that the large-scale magnetic topology is remarkably stable on the time-scale of one year.

6. Evolved and compact pulsating stars

This period saw continued growth in the study of pulsating subdwarf B-type (sdB) stars. Reviews include Charpinet *et al.* (2007) and Kilkenny (2007). Further developments were made in mode identification using multicolor photometry (Baran *et al.* 2008), and time-series spectroscopy (Tillich *et al.* 2007; Telting & Ostensen 2006; Vučković *et al.* 2007). Large multisite campaigns also explored the photometric nature of the pulsations (i.e., Vučković *et al.* 2006). The long period sdB stars (PG 1716 variables) were explored in a number of investigations. Hybrid sdB stars that show both long and short periods were found and continue to be investigated (Baran *et al.* 2008; Schuh *et al.* 2006).

Models of pulsating sdB stars continue to teach us about diffusion in these stars in terms of the excitation and driving mechanism (Jeffery *et al.* 2006a,b). Comparison between the observed pulsation frequencies and model frequencies also continues to be an active area of exploration (i.e., Charpinet *et al.* 2006). A certain highlight during this interval involved the star HS 2201 (V391 Pegasi), a pulsating sdB star. Silvotti *et al.* (2007) announced the discovery of a giant planet orbiting the star that used timing of the pulsations to determine the star's reflex orbital motion.

White dwarf pulsation studies have been energized by the SDSS, which has uncovered a huge number of white dwarfs, resulting in discovery of a large number of well characterized (statistically) pulsators. In addition to nearly doubling the number of known pulsators (i.e., Gianninas *et al.* 2006), we can now explore the details of the boundary of the white dwarf instability strips (i.e., Castanheira *et al.* 2007). A number of new members of the class of ZZ Ceti-like pulsating white dwarfs that live within cataclysmic variable systems were also found (i.e., Nilsson *et al.* 2006).

The past three years has seen an increase in the sophistication of models of the internal structure of PG 1159 (GW Vir) stars based on asteroseismic constraints (Althaus *et al.* 2008a,b; Corsico & Althaus 2006). These investigations are in response to newly published observations of GW Vir stars (Costa *et al.* 2008; Fu *et al.* 2007).

7. Closing remarks – the space age

The future of variable star research is very bright. A newly developing capability for space-based observations has the potential to transform the field in ways that are (more than) hinted at with the success of *MOST* and *CoRoT*. Future missions of interest include *BRITE* (i.e Zwintz & Kaiser 2008), *Kepler*, and *Gaia*.

We anxiously await the launch of the *Kepler* mission in February 2009. One of the science components is the Kepler Asteroseismology Investigation (Christensen-Dalsgaard 2007), which oversees asteroseismic analysis of Kepler targets. With the potential of well over 100,000 stars observed continuously for up to 3.5 yr, the data flood should provide a dramatic expansion in the use of asteroseismology for studying a wide variety of stars.

ESA's *Gaia* satellite will survey one billion stars down to magnitude 20 over 5 years and detect about 50-100 million variable stars. It will provide distances, proper motions, and provide multi-epoch radial velocities, photometric (G-band), blue (BP) and red (RP) photometric data for a large fraction of these stars. The consortium to reduce the data has been formed; one international group is taking care of the Variability Analysis aiming at a systematic automated description and classification of the variable objects. Launch of *Gaia* is planned for the end of 2011. For more information, see `<www.rssd.esa.int/Gaia>`.

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