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COMMISSION G4 PULSATING STARS

(ÉTOILES PULSANTES)

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TRIENNIAL REPORT 2015–2018

1. Introduction

"The observation and discussion of variable stars form an important part in the development of modern astronomy." Those were the opening words of the report of Commission 27 on Variable Stars to the first general assembly of the International Astronomical Union in Rome, 1922 (**?**), and have been echoed in succeeding reports up to 2015. The interests of Commission 27 started broad: "observations of all variable stars of all classes will be useful" (ibid.). During the 2015 restructuring of IAU commissions, the Organizing Committee recognized that some of these classes (binaries, novae) were being better addressed by other commissions, and that recent Commission 27 activity had focused primarily on pulsating stars and asteroseismology. To reflect this shift in focus, Commission G4 "Pulsating Stars" was formed, with the following prospectus.

1.1. *Description*

Pulsations occur in stars across the Hertzsprung-Russell diagram, from hot white dwarfs to cool supergiants. Once thought to be confined to exclusive instability strips, modern precision photometry has revealed multi-frequency low-level oscillations in tens of stellar classes previously thought to be stable. The fact that the frequency spectrum of oscillations is directly linked to internal structure has launched a science which allows the invisible parts of a star to be explored in unprecedented detail.

The interests of IAU Commission G4 span the entire range of observation, modeling, and understanding of pulsating stars, i.e. stars that vary in brightness due to global oscillations, either radial or non-radial. This interest encompasses many sub-areas, including techniques, variability surveys, classification and naming, interpretation and modeling, and using pulsating stars for the detection of exoplanets, as probes of stellar clusters and the Galaxy, and as cosmological distance indicators. Together these topics form the vibrant and increasingly precise science of asteroseismology.

Using multi-instrument, multi-wavelength and multi-methodology approaches to the study of related objects demands collaborative and cross-discipline research. The overall aim of the Commission is to study the astrophysics of pulsating stars, employing the full range of methodologies and theoretical and instrumental approaches at the disposal of the contemporary astronomer. The results obtained from such studies provide fundamental inputs to scientific domains including stellar evolution, stellar and planetary atmospheres, binary and multiple star systems, and massive stars.

1.2. *Topics*

- Pulsations across the Hertzsprung-Russell Diagram including: classical Cepheids, RR Lyrae stars, main-sequence stars, red-giant branch stars, asymptotic giant branch stars, extreme horizontal branch stars, and white-dwarfs.
- Methods for detecting, observing and resolving stellar oscillations.
- The physics of stellar pulsations.
- Tools for resolving stellar structure and internal rotation, and testing stellar evolution.
- Tools for detecting exoplanets, and characterizing planetary systems.
- Tools for detecting non-transit binaries at intermediate periods (100-1000d).
- Pulsating stars as probes of stellar systems, galaxies and the cosmic distance scale.

1.3. *Work Plan*

Recognizing that our understanding of physical processes in stars contributes significantly to astrophysical research, including, but not limited to the Sun as a star, and to stars as hosts of planets and planetary systems, universal laboratories for fundamental astrophysics, fundamental components of galaxies, probes of chemical evolution of galaxies, and key distance indicators for the distance scale of the universe, the Commission aims to:

- Support cross-divisional and cross-commission information exchange, discussion and research.
- Promote biennial IAU Symposia on Stellar Pulsation. Following *CoRoT*, *Kepler/K2*, OGLE and the commencement of new wide-field synoptic surveys (such as LSST, TESS, and Plato), as well as more focused efforts (such as SONG and *BRITE*), these Symposia continue to define progress in the field.
- Support other conferences to facilitate collaboration and communication,
- Develop a strategy to encourage dialogue between scientific consortia, in particular between long-term ground-based surveys and high-cadence space missions.
- Develop a coherent body of information based around a redesigned Commission web site to promote communication amongst scientists working in the field.

2. Developments within the past triennium

2.1. *Surveys*

Variable star surveys provide the raw material for pulsating star astronomy, both in terms of discovery and long-term analysis. The spectroscopic asteroseismology network SONG (Stellar Oscillation Network Group) is now producing regular results, including analyses of μ Her and 8 planet-hosting red giants (**?**, **?**). A Chinese node went online in 2017, and another node is under construction in Australia. A preoccupation with searches for exoplanets, dark matter and/or dark matter always provides benefits in other fields. The Optical Gravitational Lensing Experiment (OGLE) continues well into its IVth phase of operations (**?**), delivering large volumes of light curves for Cepheids and RR Lyare variables, as well as other long-period stars. The All-Sky Automated Survey for Supernovae (ASAS-SN) is based on at least 20 small wide-angle cameras operated by the Las Cumbres Observatory (`https://lco.global`) at eight sites across five continents. The serendipitous variable star count now stands a 27,753 periodic variables and 38,780 irregular variables (**?**). These few highlights under-represent the large number of currently active small and large-scale surveys, which, combined, represent a deluge of new data for exploration and analysis.

2.2. *Space Missions*

Two dedicated space missions have provided high-quality photometric time-series data for asteroseismology.

The *Kepler* spacecraft was successfully re-purposed as the *K2* mission in which fields along the ecliptic are each observed continuously for about 80 days. This has added many new discoveries and measurements of exquisite light curves of pulsating stars to those already made during the original *Kepler* pointing. The current expectations are that the spacecraft will run out of consumables in the course of 2018.

The *BRITE* (BRIght Target Explorer) Constellation continues to operate as a network of five nano-satellites tasked to investigate the structure and evolution of the brightest stars in the sky and their interaction with the local environment. Micropulsation, wind phenomena, and other forms of stellar variability are recorded via high precision photometry in two colours (red and blue) (*e.g.* **?**, **?**, **?**, **?**). The BRITE Constellation has partners in Poland, Austria and Canada.

In addition to these two missions, the *TESS* (Transiting Exoplanet Survey Satellite) has been developed and is scheduled to be launched in 2018. Asteroseismology will benefit from these data via the *TESS* Asteroseismic Science Consortium (TASC). Furthermore, in the past triennium ESA has selected *Plato* (Planetary Transits and Oscillations of Stars) as an M-size mission to be launched in 2026. Asteroseismology plays an integral part in the characterisation of planet-host stars.

2.3. *New stars*

One consequence of increasingly sensitive large-scale variability surveys is the discovery of new classes of variable star, including pulsating variables, hitherto undiscovered due to scarcity or low amplitude. Recent years have seen the discovery of the blue large-amplitude pulsating variables (**?**). These are early-type stars with brightness variations having periods in the range 20–40 min and amplitudes 0.2–0.4 mag. It is conjectured that these are associated with low-mass stars that have inflated helium-rich envelopes. Surveys are yielding increasing numbers of intrinsically faint pulsating stars, by which we mean white dwarfs. Those with new properties include mixed atmosphere low-mass white dwarfs (**?**), and pulsating DA white dwarfs which show sudden increases in amplitude (**?**) or brightness (**?**). More esoteric discoveries included the second "pulsating" member of a particularly rare group of hot subdwarfs rich in helium and heavy metals (including lead) (**?**). Pulsations have also been used to identify intermediate-period binaries and planetary systems, including a 12 Jovian mass planet in the habitable zone of a main-sequence A star (**?**, **?**).

2.4. *New physics*

Pulsating stars provide a laboratory to test physical models at high temperatures, pressures, and densities. Some of the physics input and models that continue to be confronted by pulsation data are opacities, equation of state, convective mixing, radiation transport, chemical transport (diffusive settling, radiative acceleration), and nuclear reaction cross sections. Many new capabilities and physics model options have been incorporated into the increasingly popular open-source MESA/GYRE stellar evolution/pulsation codes (**?**, **?**, **?**).

Examples of additional physics that has been examined in the past few years include discovery of magnetic fields in many pulsating star types (e.g., **?**, **?**, **?**); internal gravity waves, magnetic waves, and angular momentum transport (e.g., **?**, **?**, **?**); tidal excitations of pulsations (e.g., **?**); nonlocal, time-dependent convection and pulsation-convection interactions (e.g., **?**, **?**, **?**); effects of the screened coulomb potential on diffusion in DBV white dwarfs (?); constraints on dark matter (?) and on carbon crystallization (?) from DAV white dwarfs. On angular momentum transport, both helioseismology and asteroseismology reveal that core-to-envelope rotation ratios are more uniform in the Sun and some giants than expected, with almost uniform rotation detected in several main-sequence A, F, and G stars. Contradicting naive predictions from conservation laws, angular momentum from the core appears to be efficiently transported to the envelope to maintain uniform rotation as stars evolve.

Multidimensional stellar models and implications for pulsations are being explored more frequently as computational capabilities advance (see, e.g., ?, ?).

Theory for global Rossby waves (r modes) has been significantly developed and has allowed r modes to be identified in many γ Dor stars, the so-called heartbeat stars, and a frequently bursting Be star (?).

Even though the revision of opacities in 1992 (see, e.g., ?) greatly improved agreement between stellar pulsation models and observations, stellar opacities continue to be a focus as pulsation studies reveal further discrepancies for B-type stars and the solar interior. Improved stellar opacities in the region of the iron bump around 200,000 K and above could help to solve problems with interpreting observations of B-type stars (?, ?, ?, ?, ?) and the solar radiative interior (see, e.g., ?). They could possibly also resolve the 'solar abundance problem' that has persisted since solar abundances were revised downward in 2004. Experimental evidence for increased iron opacities for stellar interior conditions was found in experiments at the Sandia Z machine (?). Experimentalists are attempting to verify these results using other techniques and facilities (?, ?), while atomic physicists are searching for missing effects in theoretical atomic physics calculations that would provide higher opacities (?, ?, ?). Perhaps these problems, with far reaching implications for the fields of solar and stellar evolution and pulsation, will be resolved in the next triennium.

2.5. *Meetings*

In fulfilling its objectives to promote information exchange and support conferences, the Commission has supported or noted the following:

- Focus Meeting 17 at IAU XXIX: Advances in Stellar Physics from Asteroseismology, 12th - 14th August 2015, Honolulu, USA (?).
- Seismology of the Sun and the Distant Stars 2016: Using Todays Successes to Prepare the Future, Joint TASC2 & KASC9 Workshop, SPACEINN and HELAS8 Conference, 11th - 15th July 2016, Angra do Herosmo, Terceira-Aores, Portugal (?).
- Understanding the Rôles of Rotation, Pulsation and Chemical Peculiarities in the Upper Main Sequence 11th – 16th September 2016, Lake District, United Kingdom.
- Wide-Field Variability Surveys: A 21st Century Perspective 28th November – 2nd December 2016, San Pedro de Atacama, Chile (?).
- TESSting Stellar Astrophysics. Joint TASC3 & KASC10 Workshop, 16th – 21st July 2017, Birmingham, United Kingdom.
- Asteroseismology and Optical Interferometry. Measuring very accurate stellar diameters by high angular resolution techniques in the era of photometric space missions (K2, TESS, CHEOPS, PLATO) and Gaia, 4th –6th October 2017, Nice, France.

3. Closing remarks

Looking back to Bailey's (1922) report, it is evident just how far the study of pulsating stars has advanced in 100 years. Several sections (*.e.g* 'Photographic Observations', 'Scale of Magnitudes' and 'Charts') appear dated, although work done today would be impossible without massive strides in all of these areas. Meanwhile, sections on 'Lists of Variable Stars, Co-ordination of Observations', 'Catalogues and Ephemerides' and 'Nomenclature and Designation Numbers' are reminders of challenges that continue to increase in tandem with the breadth, depth and length of surveys.

GAIA, *TESS*, LSST and *PLATO*, as well as a forest of other ground-based wide-field synoptic observatories, will yield a tsunami of new data, routinely reduced, classified and catalogued automatically. Identifying new discoveries that drive our science forward will require new ways of working with these large datasets. Detailed spectroscopic follow-up will remain primarily the domain of scarce large telescopes. But it would be wrong to give the impression that the study of pulsating stars can only be done with massive resources. Persistent observations of well-known bright stars over several years can provide rich rewards. There is always room for more young and/or enthusiastic minds to study stellar pulsations, whether from a back-yard telescope, a space-age observatory, or by studying the theoretical physics. The commission would like to acknowledge the invaluable contribution of the AAVSO and similar organizations to our science.

With a healthy science and exciting new data in prospect, there is much to anticipate.

C. Simon Jeffery
president of the Commission

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