RRL 2022 CEP | RR Lyrae & Cepheid Stars Conference

RR Lyrae and Cepheids IV

Large-scale surveys as bridges between spectroscopy and photometry

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ABSTRACT BOOK

SPECTROSCOPIC SURVEYS

Large scale spectroscopic surveys

C. Chiappini (Rev.)

The focus of this talk will be to show how spectroscopic surveys can make the link between classical pulsators and galactic archaeology.
I will first show the current mapping of the MW via spectroscopic surveys and what we expect to have in the near future.
I will then highlight specific cases of results obtained with Cepheids, seismic targets and RRLyrae with spectroscopic information, again in the context of Galactic Archaeology.

VELOCE DR1: A new reference for VELOcities of CEpheids

G. Viviani, Richard I. Anderson, Giordano Viviani, Shreeya S. Shetye, et al.

We present the first data release of VELOCE, a project dedicated to measuring high-precision radial velocities (RVs) of Galactic classical Cepheids from both Hemispheres over up to 10 year baselines targeting dense phase coverage. VELOCE DR1 comprises more than 18,100 individual observations of 256 bona fide classical Cepheids spanning pulsation period and V-band magnitude ranges from 1.9-69d and 2-13mag. RV uncertainties are photon noise limited in most cases and the average per-observation RV uncertainty is 0.065 km/s. For bright stars, RV uncertainties can be as low as 2 m/s. Pulsation-averaged (vgamma) velocities of stars with more than 10 observations are measured to an average uncertainty of 0.42 km/s, reaching as low as 2 m/s uncertainty in some cases. VELOCE RVs are consistent with the IAU RV standard star system to within ~ 20m/s and we determine zero-point differences between VELOCE and 30 literature data sets by template fitting. Spectroscopic binaries identified using VELOCE data alone, or in conjunction with literature data, are presented in a companion paper (Shetye et al.).
VELOCE data enable several new insights into the pulsational variability of Cepheids. Chiefly among these are: a high-definition view of the Hertzsprung progression in RVs, the identification of double-peaked bumps in the pulsation curve, and clear evidence that virtually all Cepheids observed in sufficient detail feature variance unexplained by periodic Fourier series models, that is, additional modulation signals are ubiquitous in Cepheids. We identify 4 previously unknown ``modulators'' that exhibit orbital motion in addition to RV amplitude variations and/or time-variable phase shifts. We will close by highlighting further features that elucidate systematic uncertainties involving Baade-Wesselink projection factor calibration.

C-MetaLL project: UVES@VLT Chemical abundances for 65 metal-poor Galactic Cepheids and a new multi-band Period-Luminosity-Metallicity calibration.

E. Trentin, V. Ripepi, G. Catanzaro, J. Storm and the C-MetaLL collaboration

Classical Cepheids (DCEPs) are the first fundamental step in the calibration of the cosmological distance ladder and represent powerful tracers in the context of Galactic studies. In the context of the C-MetaLL (Cepheids-Metallicity in the Leavitt Law) survey, we collected high-resolution spectroscopy with UVES@VLT for a sample of 65 DCEPs. Most of them are among the faintest DCEPs ever observed spectroscopically in the Milky Way (MW), out to Galactocentric radii as large as ~20 Kpc. For each target we derived accurate atmospheric parameters, radial velocities, and abundances for 24 different species. The resulting iron abundances range between +0.3 and −1.1 dex, while the bulk of stars has [Fe/H]~ −0.5 dex. We complemented our sample with literature data obtaining a total sample of 637 DCEPs. Taking advantage of the Gaia Early Data Release 3 (EDR3) and the 2MASS survey, we collected the photometry in V, I, G, GBP, GRP, J, H, Ks bands, which were also used to build a variety of reddening-free Wesenheit magnitudes. We use all these photometric and spectroscopic data, in conjunction with Gaia DR3 parallaxes to discuss the dependence on metallicity of the DCEPs Period-Luminosity and Period-Wesenheit relations, on a spectroscopically measured metallicity range never explored before.

Empirical relation for metallicity determination of classical Cepheids

V. Hocdé, R. Smolec , O. Ziołkowska, R. Singh Rathour and P. Moskalik

Estimating metallicity of classical Cepheids is of prime importance for studying chemical evolution of galaxies, metallicity effect on stellar evolution and ultimately its impact on period-luminosity relation used in the extragalactic distance scale.
We aim at establishing new empirical relations for estimating the iron content of classical Cepheids for short and long-periods based on Fourier parameters of the V-band light curves. We retrieved metallicity of fundamental Cepheids from spectroscopic determinations in the literature and we retrieved well sampled light curves for these stars in V-band. We then describe the shape of theses light curves by applying Fourier decomposition and we use the Fourier parameters to fit empirical relations for short (2<P<6 days) and long-periods (12<P<40 days). These empirical relations accurately derive the mean metallicity of the OGLE sample of SMC and LMC Cepheids and thus can be used for other metal-poor extragalactic Cepheids. These relations can be useful for space and ground-based telescopes with V-band filter. Further spectroscopic observations and homogeneous light-curves are necessary to improve the calibration.

Non-LTE analysis of WINERED Cepheid spectra

A. Ebenbichler, N. Przybilla et al.

The measurement of the expansion of the local universe depends on the correct calibration of the cosmic distance ladder which heavily relies on the period-luminosity relation of Cepheids. The metallicity dependence of this relation is still an open question and can contribute to the Hubble tension. Spectrum synthesis accounting for the effects of deviations from the assumption of local thermodynamic equilibrium (non-LTE) is the most reliable method to determine the metallicity of Cepheids, given the potential for non-LTE effects on diagnostic lines in these yellow supergiant stars. New generations of extremely large telescopes (ELTs) and advancements in adaptive optics will enable astronomers to observe Cepheids at much larger distances than possible currently, however diffraction-limited observations will be limited to near-infrared (NIR) wavelengths. Highly sensitive spectrographs like WINERED (*W*arm *IN*frared *E*chelle spectrograph to *R*ealize *E*xtreme *D*ispersion and sensitivity) have enormous potential not only for groundbreaking spectroscopy of dust-obscured Cepheids in the Milky Way, but also to facilitate preparing spectroscopy of extragalactic Cepheids with the ELTs.

A spectroscopic study of Cepheids at NIR wavelengths was conducted to test new analysis methods and non-LTE effects on the metallicity determination. A hybrid non-LTE spectral modelling approach was used for the analysis of WINERED spectra of 10 Cepheids in the Milky Way and the Large Magellanic Cloud. Atmospheric parameters were determined using purely spectroscopic indicators like the Stark-broadend hydrogen Paschen lines as effective temperature indicator, the Mg II ionization equilibrium as surface gravity indicator and numerous C I lines as indicator for the microturbulent velocity. Abundances were determined for several additional chemical species. Most diagnostic lines show pronounced non-LTE effects, implying systematic shifts in atmospheric parameters and leading to abundance deviations of up to 0.3,dex when compared to LTE results.

The WEAVE Galactic Archaeology surveys

G. Battaglia (Inv.)

The Gaia mission has already brought about a revolution in our understanding of the Milky Way system. Spectroscopic surveys obtaining accurate radial velocities and elemental abundances for stars that are too faint for Gaia's Radial Velocity Spectrometer are however an essential complement to exploit the Gaia data in their full potential. In this presentation I will review the plans for Galactic Archaeology surveys with WEAVE, a wide-area multi-object survey spectrograph about the start operations on the 4.2-m William Herschel Telescope at the Observatorio del Roque de los Muchachos. I will give an introduction to the instrument, the various planned surveys and the modalities to ask for observing time. I will then describe the plans for the Galactic Archaeology surveys, in particular those that will target RRLyrae variable stars.

Automatic analysis of RR Lyrae variables within large spectroscopic surveys

N. Britavskiy, G. Battaglia

Next-generation of multi-fiber spectrographs will provide huge spectroscopic datasets which require only an automatic tools to analyze them in a short timescale. For such purposes we developed the WEAVE Contributed Software in order to investigate the kinematic properties and physical parameters of RR Lyr variables. This tool was designed specifically for such types of variables by taking into account their phenomenological peculiarities. We will present our approach of analyzing the low- and high-resolution spectra within the scientific verification phase of the WEAVE Galactic Archeology survey. In our work, we will discuss how the different physical processes of RR Lyraes (shock phases, etc) could affect such spectroscopic analysis and what is the best strategy to make this analysis reliable for further in-depth study of the chemical composition of these stars.

Kinematics of APOGEE and VVV RR Lyrae stars in the Milky Way bulge region

Julio Olivares Carvajal, Manuela Zoccali, Elena Valenti, Rodrigo Contreras Ramos, Álvaro Rojas-Arriagada, Carlos Quezada

I will present the results of a spectroscopic analysis of more than 4000 APOGEE RRLs in the Milky Way bulge region (-8 < l < 8 and 1 < |b|< 6) aimed at characterizing the kinematics and spatial distribution of this old population. By combining APOGEE spectra with Gaia and VVV proper motions, we trace the orbits of the RRLs and further constrain the bulge 3D structure.
Additionally, in an ongoing project, we use the PMs of more than 12000 new VVV RRLs at |b|<2.5 degrees to obtain the rotation curves in a region closer to the plane than in every previous study.

First High-Resolution Spectroscopic analysis of Galactic Anomalous Cepheids

V. Ripepi, G. Catanzaro, E. Trentin et al.

Anomalous Cepheids (ACEPs) are intermediate-mass (1−2 $M_{\odot}$), low-metallicity, core-He burning stars that are thought to ignite helium under partial electron-degeneracy conditions. They have been found preferentially in old, low metallicity dwarf galaxies of the local group as well as in the Large and Small Magellanic Clouds. Until recently, only a few ACs were known in the Milky Way (MW). However, the advent of large photometric surveys investigating the MW halo, disk and bulge (e.g. Catalina, OGLE, Gaia mission) allowed us to discover hundredts of ACs in our Galaxy. The investigation of the origin of Galactic ACs can help us in understing the details about the formatin of the MW. In this context, we used UVES@VLT to obtain high-resolution spectroscopy of nine Galactic ACEPs, obtaining the abundances for 13 species. This data is presented in combination with literature results for four stars and the implications for the nature of these pulsators as well as their role as stellar population tracers are discussed.

PHOTOMETRIC SURVEYS

Photometric ground-based surveys

M. Catelan (Rev.)

Photometric surveys have for many decades played a crucial role in the area of variable star research, bringing pulsating stars and their use as tracers of the structure and evolution of our cosmic vicinity, and indeed beyond, into the forefront of astrophysics. In this talk, I will provide an overview of the developments that have set the stage for the current generation of large-scale photometric surveys. I will highlight some results of particular interest that have been found along the way, and discuss some of the challenges that still await us, in the era of large étendue facilities as epitomized by the Vera C. Rubin Observatory's Legacy Survey of Space and Time.

Multi-Band Study of Galactic Cepheid and RR Lyrae Stars: The DECAT Perspective

K. Baeza-Villagra, N. Rodríguez-Segovia, M. Catelan, A. Rest, A. Papageorgiou, C. Aravena, F. Bianco, E. D. Feigelson, F. Förster, V. Garrido, M. Graham, C. Martínez-Vázquez

As part of the DECam Alliance for Transients (DECAT), a consortium of time-domain DECam programs, the DECam Deep Drilling Program (DDP) is being run at the Blanco 4m telescope, located at Cerro Tololo Inter-American Observatory, Chile. DDP fields include the so-called DECaPS East field, located in the Galactic bulge at coordinates (RA, DEC)(J2000) = (18:03:34, -29:32:02). We carried out two nights of high-cadence multi-band (griz) observations of the latter field, also using DECam. This dataset constitutes a treasure trove for studies of rapid stellar variability, and will provide, when combined with additional available DDP images of the same field, high-quality multi-band templates that can be used in the future to inform the variable star classifiers that are currently being developed for the Vera C. Rubin Observatory's Legacy Survey of Space and Time (LSST). These data can also be used for studies of the structure, origin, and evolution of the Galaxy's innermost regions, where most of its stars, dust, and gas are currently located. In this contribution, we present our first results on Cepheid and RR Lyrae stars using this combined dataset. These pulsating stars are excellent tracers of our galaxy's old and young populations, respectively. We describe the steps we took in building our variability catalog, present the corresponding multi-band light curves, and use their respective period-luminosity and absolute magnitude-metallicity relations to analyze foreground extinction and distances, comparing our results with expectations based on Galactic 3D models and previous studies of the same region using different tracers.

RR Lyrae Photometric Metallicity at Optical and Infrared Bands

Joseph P. Mullen, Massimo Marengo, Clara E. Martínez-Vázquez, Giuseppe Bono, Vittorio F. Braga, Brian Chaboyer, Juliana Crestani, Massimo Dall'Ora, Michele Fabrizio, Giuliana Fiorentino, Christina K. Gilligan, Matteo Monelli, Jillian R. Neeley, Peter B. Stetson, and Frédéric Thévenin

The number of known RRL in the Milky Way and Local Group galaxies has significantly increased with the advent of large area photometric surveys. However, RRLs with known metal abundances remain limited due to the reliance on spectra, which require large amounts of telescope/analysis time to acquire. This talk presents the calibration of a quick and reliable method to derive [Fe/H] abundances solely from available photometric time series, as the shape of both RRab and RRc light curves are inherently tied to their metallic abundance. We present our newly published period-Fourier-metallicity relations at optical and, for the first time, mid-infrared wavelengths. Extension to the infrared will allow metallicity measurements to be readily made in both high-extinction environments and at much greater distances with large-aperture infrared space telescopes like Webb.

On the large variety of delta Scuti stars from the OGLE survey

Pawel Pietrukowicz

I will describe the recently revealed huge collection of nearly 25,000 delta Scuti-type stars detected in OGLE fields toward the Galactic bulge and disk. I will present the variety of light curve shapes and observed properties of these pulsating stars. The collection contains dozens of unique objects, such as members of eclipsing binaries, stars with period and amplitude changes, members of Galactic stellar clusters and the Sagittarius Dwarf Spheroidal Galaxy. A detailed frequency analysis has led to the first identification of delta Scuti stars pulsating in the fundamental mode, first overtone, and third overtone simultaneously. Finally, I will report on the extension of the OGLE collection for two dozen spectroscopically confirmed multi-mode delta Scuti stars with ultra short periods in the range 20-60 min.

Recent advances in the field of photometry of classical pulsators with Kepler/K2 and TESS missions

E. Plachy (Rev.)

Nearly continuous, densely sampled space based photometry allows us to recover the finest details in the light variations of stars. The number of such light curves have been rapidly increasing in the last few years thanks to the extended mission of the Kepler space telescope and the launch of the TESS mission. This new era brings us new perspectives in RR Lyrae and Cepheid studies, where low amplitude phenomena can be studied in a wide range of individual stars and on a statistical basis. In this talk I review the recent investigations of the Kepler, K2 and TESS fields, as well as the challenges in accurately reducing high-quality photometry. Finally, I provide insights into some ongoing projects, as well.

Pulsational properties of RR Lyrae stars in globular clusters through the eyes of the K2 mission

Csilla Kalup, László Molnár, Attila Bódi, András Pál

The Kepler space telescope observed several globular clusters during the K2 mission. Most of them (M9, M19, NGC5897, NGC6293, NGC6355 and Terzan 5) are still unprocessed, because the photometry of crowded fields is challenging and requires special methods, especially for clusters at low galactic latitudes. However, these high-quality and continuous measurements, supplemented by Gaia EDR3 data, provide us with a unique opportunity to identify known and candidate variable stars, and carry out precise asteroseismic investigations in order to discover low-amplitude modes and modulation. The main advantage of the globular clusters is their stars have nearly the same distance, age and metallicity, and they usually have older, more metal-poor stellar populations. Thus, if we can extract RR Lyrae samples from them, we get a chance to study their pulsational properties as a function of the physical properties of the clusters.

Here we present the first detailed asteroseismic analysis of the RR Lyrae stars from clusters observed in Campaigns 11 and 15. We performed our own differential-aperture photometry to obtain the light curves, then applied K2SC systematics correction and PDM-optimized trend removal steps to increase the signal-to-noise ratio of the data. This allowed us to detect new, low-amplitude pulsational frequencies of the stars via Fourier analysis. We also report a discovery of a new RRc star in the cluster NGC5897, based on its position on the horizontal branch in the Gaia color-magnitude diagram. Overall, we extracted more than 30 light curves, which we compared both on a cluster-to-cluster basis and to the bulge and field RR Lyrae stars. We found that not only do the cluster variables have larger periods than the usual mean RRab or RRc periods, but their Fourier parameters, the distribution and abundance of the low-amplitude additional modes and the frequency of stars that show modulation are also considerably different from the bulge and field stars.

The reason behind these observed properties can be the fact that the host clusters are older and more metal-poor than stars observed by Kepler, TESS or OGLE elsewhere, highlighting the importance of studying globular clusters through space-based photometry and the asteroseismology of their RR Lyrae populations.

RR Lyrae stars with TESS and Gaia: connections between mode content, colors and distances

László Molnár

RR Lyrae pulsations are easy to pick out from a sea of stars and they serve as distance markers throughout the Galaxy. What could then the TESS and Gaia missions, developed to measure the smallest light variations or the precise distances of stars, possibly tell us about them? A surprising number of things, as it turns out, starting from the simplest ones: whether all bright, cataloged RR Lyrae variables are truly pulsating stars. In this talk I will present our first results based on TESS observations of over a hundred nearby RR Lyrae stars, supplemented with measurements from the Gaia mission. We first revised the classification of all selected targets in TESS Sectors 1 and 2, and illustrate that eclipsing binaries and rotational variables can still lurk among the brightest pulsators. Gaia also allows us to put field stars onto a color-magnitude diagram accurately, matching the precision of globular cluster studies, but without the need of a common distance modulus. We carefully analyzed the TESS light curves of these field stars, which revealed an abundance of millimagnitude-level modes hiding behind the main radial pulsation. Many of these modes still lack proper identification or explanation. However, we are now starting to see the first connections between the appearance of the new modes and the effective temperature and metallicity of stars. Pure overtone stars, for example, appear to exist only at the blue edge of the instability strip, with virtually all of the rest displaying various low-amplitude modes. We also see indications for less extra modes towards the red edge, but this result is not yet significant. Metallicity differences also change the distribution of the extra modes in the Petersen diagram. Further, although TESS is not well-suited to study the Blazhko effect, we do see stars that are stable, single-mode pulsators, at least on month-long timescales. Our results showcase the power of combining TESS photometry with distances and colors from Gaia, both of which missions are currently precise enough down to about 15 mag for these kinds of analysis. The new developments may finally open up the possibility for a more detailed asteroseismic modeling of RR Lyrae stars, though the presence of a powerful radial mode still complicates this task.

A synoptic view of pulsating stars in the Sloan bands

Weronika Narloch, Gergely Hajdu, Grzegorz Pietrzyński

Since the discovery of the period-luminosity (PL) relation of Cepheids by Henritta Leavitt in 1912, the classical pulsators became very important distance indicators. Moreover, the respective PL and period-Wesenheit relations have been calibrated for a wide range of wavelengths from optical to the near-infrared. Such relations, however, are still missing in the Sloan bands. With the impending start of the Legacy Survey of Space and Time (LSST), large amounts of pulsating variable stars, especially Cepheids and RR Lyrae stars, are going to be uncovered in the outer halo of the Milky Way, as well as in other galaxies of the Local Group. Accurate PL relations of various pulsating stars in the Sloan bands are necessary in order to take full advantage of it. Therefore, we have carried out a time-series photometric survey of the Magellanic Clouds in the Sloan gri(z) bands using three different classes of instruments and telescopes: the DECam instrument on the 4m Blanco telescope, OmegaCAM on the 2.6m VLT Survey Telescope, and the Sinistro cameras of the 1m telescopes of the Las Cumbres Observatory. The combination of data from different instruments allowed us to obtain fully covered, accurate light curves for variables of vastly different periods (below half a day to over 100 days) and mean magnitudes (from the faintest RR Lyrae to the brightest Cepheids) in a relatively short period of time (two years), making the above goal achievable.

ROTATION, BINARITY, DYNAMICAL AND BLAZHKO EFFECTS

Classical Pulsators as distance ladders

N. Nardetto (Rev.)

Classical pulsators have long played a crucial role in the distance scale and the determination of the present value of the expansion rate of the universe. This is due to the relation which relates their period of pulsation to their intrinsic luminosity. In order to confirm the Hubble tension, it is mandatory to unveil all possible systematics in the calibration of the extragalactic distance scale, and also to find new roads. For this purpose, there is something important to keep in mind: correct astrophysics, correct cosmology. Classical pulsators are indeed fantastic laboratories to study stellar physics. In this review, we will illustrate how interferometry and spectroscopy have played a fundamental role in characterizing the photosphere/atmosphere/chromosphere of classical pulsators, as well as their close environment and binarity.

RR Lyrae variables in binary systems: results and surprises

Gergely Hajdu, Grzegorz Pietrzynski, Paulina Karczmarek, Bogumil Pilecki, Ian Thompson

The measurement of the mass of an RR Lyrae variable is a crucial step towards constraining models of stellar pulsation and evolution. With this aim, we have carried out a search for RR Lyrae variables in binary systems using the Light-Travel Time Effect (LTTE) in the light curves of bulge RR Lyrae published by the Optical Gravitational Lensing Experiment (OGLE). The detected 87 candidates allowed us to draw the first firm conclusions on the population of RR Lyrae stars in binary systems. Some, such as the approximately 1000 day lower limit on the binary periods, are easy to explain with natural selection effects imposed by binary (co-)evolution. Others, such as the large concentration of orbital eccentricities around 0.27, as well as the apparently trimodal distribution of companion masses (with modes of approximately 0.6, 0.2 and 0.067 solar masses) are lacking an explanation.
Here we provide a brief update and the latest results on the search for RR Lyrae variables in binary systems, with special emphasis on the radial velocity follow-up efforts of our candidates.

Towards a ten-fold increase in dynamical mass measurements and astrophysical explanation of classical Cepheids

Bogumił Pilecki, Javier Minniti, Felipe Espinoza

Although Cepheids are widely used for essential measurements (galactic and extragalactic distances, the Hubble constant), such critical physical parameter as their mass is mainly known from theoretical calculations. Surprisingly, we could measure accurate masses of as few as 6 Cepheids only thanks to their membership in double-lined binary (SB2) systems. We recently proposed a photometric method for identifying Cepheids in SB2 systems and have already confirmed spectroscopically 52 new candidates in the LMC and SMC to show double lines. For half of them, we have detected the orbital motion, which is the ultimate proof of their binarity. Among the new SB2 Cepheids, there are such that have never been found in SB2 systems before, namely high-mass Cepheids, cluster Cepheids, double-mode Cepheids, and short-period Cepheids, whose existence is poorly explained by theory, as well as those for which eclipses were detected. The masses obtained for all these Cepheids will be later used to measure mass-luminosity relations.

Surprisingly, one studied Cepheid resulted in residing in a system with an orbital period too short for the components to survive the evolution on the red giant branch. This Cepheid is probably on its first crossing, on the way to merging with its companion. We will describe the methods used, summarize the current discoveries, present the preliminary results for selected systems, including the orbital solutions, and finally draw the first conclusions from the study.

Finding the elusive RR Lyrae companions

R. Salinas, G. Hajdu, Z. Prudil, S. Howell, M. Catelan

Despite being one of the most classical markers for old stellar populations, and holders of a widely used period luminosity relation, the actual mass of RR Lyrae stars (RRL) remains a mystery, predicted by stellar evolution models, but never actually measured. This is because of the surprising lack of RRL in binary systems, with currently only one confirmed RRL on such systems.

In this talk I will present the results of a direct search for RRL companions using both Gemini telescopes and their speckle interferometers Zorro and 'Alopeke, reaching a spatial resolution of 20 miliarcseconds and a sensitivity down to main sequence companions of about 0.45 $M_{\odot}$. Speckle observations of 70 RRL in the solar neighborhood provide constraints on the mass fraction of these systems, as well as the very first direction detection of companions to RRL, representing about 10% of our sample

A systematic search for spectroscopic binary cepheids

Shreeya Shetye, Richard I. Anderson, Giordano Viviani

For more than a century now, Classical Cepheid variable stars have been crucial calibrators of the extragalactic distance scale thanks to the famous period-luminosity (P-L) relation. Cepheid binaries are very common (~60% among bright cepheids) and have been intensively studied to understand the impact of the companion on the calibration of the P-L relationship. Accompanying the first data release of 'VELOcities of CEpheids' (VELOCE; 10 years long monitoring program of Cepheids), in my talk I will present our analysis of the single-lined spectroscopic binaries (SB1) as part of the VELOCE project.

We exploited the VELOCE radial velocity (RV) data to discover new and to confirm the literature-known SB1s. Depending on the sampling and coverage of the data, we applied different methods to investigate the binary aspect of different sample systems. Following our systematic approach to constrain binarity of VELOCE cepheids, we report clear orbital RV signatures in 64 milky-way Cepheids on timescales spanning up to ~40 years, which includes around 25 new discoveries. We detect these 64 SB1 Cepheids from the 235 VELOCE sample of bona fide Cepheids, hence resulting into 27% binary fraction within VELOCE. Furthermore, we present highly-precise orbital elements of 36 SB1 Cepheids, amongst which 22 are totally new and were never discussed in the literature. We discover a diverse range in orbital parameters of SB1 Cepheids, including binaries with 80% eccentricity or very low semi-amplitudes. Given the upcoming DR3, it will be interesting to compare our binaries with differences in EDR3 and DR3 astrometry (DR3 will have non-single star solutions). Lastly, we will also present the comparison of our spectroscopic analysis with other literature-studies (also including other methods for binary detection like the proper motion anomaly) and a summary on the nature of the companion of VELOCE SB1 Cepheids.

Additional modes, phase variations and more on TESS RRc stars

Benkő, J.M., Plachy, E., Bódi, A., Netzel, H., Molnár, L., Pál, A.

Using two years of data from the TESS space telescope, we have investigated the light curves of RRc stars on a 670-element, homogeneous sample. Our results show that the vast majority (88.3%) of stars contain pulsation modes beyond the main radial pulsation. The incidence rates of the frequencies associated with these modes (and their harmonics/sub-harmonics and linear combinations) were determined. We have identified a new frequency in many stars, probably belonging to the l=10 non-radial mode. The Galactic distributions of RRc stars with and without additional modes proved to be identical. The amplitude distribution of the additional frequencies can be described by Weibull distributions. Separating the quasi-periodic amplitude and phase variations (observed in most stars) from the classical Blazhko effect, we have determined a 10.3% incidence rate for the latter phenomenon. Analying the phase variation functions of 33 RRc stars around the continuous viewing zone (CVZ) of TESS we have offered a plausible explanation for the `phase jump' phenomenon published in many RRc stars.

Blazhko effect and the Petersen diagram

Henryka Netzel (Rev.)

Pulsations in RR Lyrae stars and classical Cepheids were thought to be relatively simple since they typically pulsate only in one or two radial modes. This picture changes at a closer look when modulation or additional low-amplitude signals are detected. I will review different multi-periodic groups known among classical pulsators, including stars showing the Blazhko modulation.

Blazhko modulated RR Lyrae stars in the K2 observation fields

Attila Bódi, Emese Plachy, László Molnár

Space-based photometry allows us to study the changes of the Blazhko effect over time. Preliminary results have suggested that the correlation between amplitude and phase modulation may be different and/or variable. We investigated several hundred Blazhko stars observed by the K2 mission along the ecliptic plane by calculating the temporal behaviour of the Fourier amplitude and phase parameters using a template fitting approach. In this talk I present the first findings and statistical analysis of the sample.

Debiasing Observed Blazhko Occurrence Rates

Geza Kovacs

The discovery rate of low-amplitude and/or long-period modulations in periodic stellar pulsation signals can be seriously impaired by the quality of the data used in searching for the signal components causing the modulation. We use the amplitude and modulation period distributions derived from the short-survey data of the two-wheel Kepler (K2) mission and the long-survey data of the Optical Gravitational Lensing Experiment (OGLE) to assist in the estimation of the bias caused by observational noise and finite duration of target monitoring. When these two major bias sources are taken into account, reported modulation (i.e., Blazhko) rates for RR Lyrae stars are boosted up to 80-100%, indicating a high commonality of the Blazhko behavior

STELLAR MODELS AND THE HRD

Latest advances in theoretical models for classical pulsators

M. Marconi (Rev.)

Classical pulsating stars are important distance indicators and stellar population tracers. On this basis a comprehensive investigation of their properties based on both an observational and a theoretical approach is crucial.
The most important theoretical tools and results obtained for both classical Cepheids and RR Lyrae are outlined and their reliability is tested against observed pulsation properties.
Finally some open problems in the modeling of classical pulsators, mainly related to the treatment of convection, mass loss and rotation, as well as the adoption of static model atmospheres. are discussed together with the planned future development.

An updated theoretical scenario for Classical Cepheids in the Gaia era: exploring the metallicity dependence

Giulia De Somma, Marcella Marconi, Santi Cassisi, Vincenzo Ripepi

Modeling of radially pulsating stars, specifically Classical Cepheids, is fundamental to constrain the extragalactic distance scale. The various ingredients entering the theoretical calibration of the Classical Cepheid distance scale can affect the accuracy and reliability of the inferred distances and, as such, cast light on residual systematics in the local determination of the Hubble constant in the context of the debated topic on the so-called Hubble constant tension. By extending the set of nonlinear convective pulsation models published for solar metallicity (Z = 0.02 - De Somma et al. 2020) to Z = 0.004, Z = 0.008 and Z = 0.03, we provide a detailed homogeneous nonlinear model grid taking into account variations of the mass-luminosity (ML) relation, the efficiency of super-adiabatic convection and the chemical composition. A multiband light curve atlas was produced and in turn, period-luminosity-color (PLC) and period-Wesenheit (PW) relation for each assumed chemical composition, mass-luminosity relation, and efficiency of super-adiabatic convection were derived. The inclusion of the metallicity term in the derivation of PW relations allows us to properly predict the metallicity dependence of the Cepheid distance scale. The derived metal-dependent PW relations were then compared with similar results in the literature and applied to a sample of Gaia Early Data Release 3 Galactic Cepheids with known metal abundances so as to estimate their individual distances.

By combining this updated pulsation scenario with self-consistent updated stellar evolutionary predictions, we also derived period-age (PA) and multi-band period-age-color (PAC) relations that take into account variations in the ML relation. These relationships have been used to investigate the metallicity effect when using Classical Cepheids as age indicators, and to finally estimate the age of a sample of Classical Cepheids in the Gaia EDR3 dataset.

Quantifying the uncertainties of MESA evolutionary tracks for medium mass stars till end of core helium burning

Oliwia Ziółkowska, Radek Smolec

Contemporary one-dimensional stellar evolution codes, like MESA (Modules for Experiments in Stellar Astrophysics) come with a large quantity of free parameters that allow to model the physical processes in stellar interiors under many different assumptions.

Another set of parameters allows to control temporal and spatial resolution of the models, as well as numerical aspects of advancing stellar evolution models.

The uncertainties that arise from this freedom are rarely discussed in the literature despite their impact on the shape of evolutionary tracks, evolutionary time scales, surface abundances of CNO elements or internal model structure.
Helium burning stars, in particular Cepheids that are at focus of our research, are particularly difficult to model, as the choice of free parameters can greatly impact the shape of the blue loops – the part of the evolutionary track at which instability strip is crossed and on which core helium burning occurs. We calculated a grid of evolutionary models with MESA, varying several controls, like abundance mixture of heavy elements, mixing length theory prescription, nuclear reaction rates, convective mixing scheme, atmosphere model, temporal and spacial resolution. Then we investigated and quantified their impact on evolutionary tracks for evolutionary stages starting from main sequence till the end of core helium burning. Our investigation was conducted for a full range of masses and metallicities expected for classical Cepheids.

Comparative analyses and calibration of the Budapest-Florida and MESA-RSP radial stellar pulsation codes

G. B. Kovács, R. Szabó, J. Nuspl

Since the earliest success stories of the computational era in the sixties-seventies, one-dimensional pulsation calculations solved questions ranging from the driving mechanism of pulsation to the chaotic nature of given stars. However, stepping into the age of multi-dimensional calculations, some questions regarding these models are still unanswered.

In the presentation, we compare the two state-of-the-art 1D stellar pulsation codes, the Budapest-Florida and MESA-RSP codes, and show the calibration results of convection parameters. The codes are similar but implement slightly different convection models based on Stellingwerf, Kuhfuss, Gehmeyr, and Winkler's works. Despite the similarities, they give different results questioning, e.g., the solution of the double-mode cepheids problem. Although they were effectively used several times, their eight convective parameters were never calibrated to the observations.

Hence, we calibrated the convection parameters for non-Blazhko RR Lyrae stars with the simultaneous radial velocity and light curves from M3. We found that the parameters can be adjusted to describe most of the radial velocity curves but painfully fails at the minima of the light curves. In contrast, the parameters have different effects on these curves, and there is a correlation between the eddy viscosity parameter and the turbulence damping parameter. We also analyzed the models deeply, comparing them to describe the non-trivial differences and present the extent to which these codes can be utilized for stellar parameter estimations.

Ensemble asteroseismology in surveys

J. Montalban (Inv.)

Red horizontal branch stars with little envelope left: an asteroseismic perspective of the RR Lyrae instability strip edge

Massimiliano Matteuzzi, Andrea Miglio, Josefina Montalbán, Marco Tailo

Asteroseismic constraints, coupled with information on photospheric chemical abundances and temperature, have given us the ability to measure radii and masses of tens of thousands of red-giant stars. Precise masses of red-giant stars enable a robust inference of their ages, given the strong relation between the initial mass of a star and the duration of the main-sequence phase, and hence its age on the red-giant branch. However, there are cases where the estimates of age can be highly precise yet very inaccurate. An example are giants that have undergone mass transfer events that have significantly altered their mass. In this context, stars with “apparent” ages significantly higher than the age of the Universe provide candidates stripped stars, or stars that have lost more mass than expected, most likely via interaction with a companion star or because of the poorly understood mass-loss mechanism along the RGB. These stars are present in the Kepler database, both in clusters and among field stars. In our study we look at these objects from an asteroseismic perspective, investigating potential specific signatures of their structure in the frequency spectra. We model the structure and pulsational properties of these stars using MESA+GYRE and we generate realistic artificial pulsation spectra representative of Kepler and K2 observations with AADG3. We find that these stars are characterised by a rather extreme coupling between the pressure-mode and gravity-mode cavities, leading to a large number of detectable dipolar and quadrupolar mixed modes. These peculiar spectra, if observed with sufficient frequency resolution, hold detailed information about the structural properties of likely products of mass stripping, hence can potentially shed light on their formation mechanism and on the transition from the Red horizontal branch (RHB) to the RR Lyrae instability strip. On the other hand, our tests highlight the difficulties associated with measuring reliably the large frequency separation in shorter datasets, with impact on the reliability of the inferred masses and ages of low-mass RHB stars with e.g. K2 or TESS data.

Behavior of the hydrogen lines emission in the spectra of RR Lyr star

A. Benhida, F.L. Sefyani, Z. Benkhaldoun, K. Kolenberg, Y. Eljariri, K. Chafouai

In this talk we will develop the study of the spectra from the star RR Lyr recorded at the OHP in France and at the Oukaimeden site in Morocco, out of a total of 2437 spectra spread over 21 years. The objective is to determine the physical origin of the emission of the hydrogen Hα line and that of helium D3 in correlation with the pulsation and Blazhko cycles as well as the shock waves which cross its atmosphere.

We were able to detect, for the first time, the statistical correlation on the evolution of the shock wave velocity with the Blazhko phase despite the large shock velocity fluctuations from one pulse cycle to another and the irregularities of the Blazhko cycle. Thus, the velocity increases from the Blazhko minimum to its maximum, then having reached a maximum shock velocity, gradually decreases to the Blazhko minimum to start growing again. This observation result is consistent with the shock wave model proposed by Gillet in 2013. The velocity of the shock wave front, the expression of which was determined by Fadeyev and Gillet, was estimated between 100 and 160 approximately kms-1 corresponding to a Mach number between 10 and 16.

We also observed, for the first time, a statistical correlation between the emission intensity of the hydrogen Hα line and that of the helium D3 line and the shock wave velocity. Indeed, the emission intensity of the Hα and D3 lines increases with the shock wave velocity up to a maximum value around about Vshock = 125 kms-1, then decreases as the velocity of the shock wave increases again. This decrease occurs despite the continuous increase in the speed of the impact. There will therefore come a time when the number of neutral hydrogen atoms available in the wake will no longer allow the emission intensity of the line to be increased. Accordingly, there will be an appropriate value of the shock velocity, for which the intensity of the Hα and D3 lines will reach a maximum. The measurements we made on the observations analyzed in this work suggest that this intensity peak occurs around Vshock =125 kms-1. This effect would be the consequence of the increasingly important ionization of the atoms in the wake of radiative shock as the temperature increases, a consequence of the increase in the speed of the shock wave which crosses the atmosphere at this phase and which is modulated by the Blazhko effect. A similar ionization phenomenon also explains the disappearance of the FeI line (λ4934.006Å and λ4920.509Å) around φ=0.96, in favor of an increase in the intensity of the Fe II absorption line (λ4923.921Å) during the passage of the shock wave that we observed on the star RR Lyr.

THE MILKY WAY

The Milky Way structure

E. Grebel (Rev.)

Exploring the structure of our Milky Way is a major challenge since our observations are necessarily limited to a fixed location within our Galaxy and furthermore subject to dust extinction. Pulsating variable stars such as Cepheids and RR Lyrae stars, which provide information on distances, ages, and metallicities are a valuable tool for uncovering the properties of the different Galactic components. Considerable progress has been made in recent years thanks to the growing number of massive ground-based optical and infrared imaging surveys, complemented by data from the Gaia mission as well as ground-based spectroscopy. These data are revealing the three-dimensional structure of the old bulge components and their metallicity and kinematics, help us to characterize Galactic spiral structure, metallicity gradients across the thin disk, the stellar Galactic warp, permit us to explore the nearby and the distant stellar halo, and allow us to uncover and characterize accretion features. I will attempt to review the current state of our knowledge.

Young, (Metal) rich and not alone: the peculiar “case” of thin-disc RR Lyrae stars

Alexey Bobrick, Giuliano Iorio, Vasily Belokurov

Despite the classical interpretation of RR Lyrae as old and metal-poor population II stars, it is well known that metal-rich (up to solar values) RR Lyrae stars exist in the solar vicinity. Some of these stars are also consistent with Sun-like kinematics, i.e. they likely belong to the thin-disc population.

In this talk, I will present the results of the first comprehensive study of the chemo-kinematics of RR Lyrae stars in the Gaia DR2*. Thanks to the unprecedented Gaia capabilities, we found that the metal-rich RR Lyrae stars are present all over the Galactic disc, well beyond the Solar neighbourhood. The kinematics of these stars is consistent with a young (less than 5 Gyr) thin disc population, in particular for the first time I will show the Galactic rotation curve as traced by RR Lyrae stars. An age of only a few Gyrs would be very difficult to reconcile with the conventional scenarios of the RR Lyrae formation, for which more metal-rich stars are expected to be the oldest. At the same time, assuming that they are instead truly old implicates that they are tracing one of the oldest component of the Milky Way remained kinematically unperturbed. Alternative formation channels for RR Lyrae can be called into play to solve this conundrum. In particular, I will show that formation through binary evolution is theoretically capable to produce a population of metal-rich RR Lyrae with ages consistent with the thin-disc populations. It is plausible that almost all the metal-rich RR Lyrae in thin-disc have been formed through binary interactions. I will conclude my talk by describing how the next generation of spectroscopic surveys will be fundamental to shedding light on the nature of these peculiar pulsators.

*By the time of the conference, these results will be likely improved due to the release of the Gaia DR3 RR Lyrae catalogue.

Distribution of chemical abundances in the Galactic thin disk from classical Cepheids in the perspective of large spectroscopic surveys

B. Lemasle , H. N. Lala, M. Hanke , G. Bono , V. F. Braga , R. da Silva, M. Fabrizio, G. Fiorentino , P. Francois, E. K. Grebel , A. Kniazev, V. Kovtyukh , Z. Prudil , J. Storm

Classical Cepheids are an ideal tool to study the distribution of abundances in the Milky Way disk. They are ubiquitous; their distances are derived with great accuracy, even at large Galactocentric distances (where Gaia parallaxes are uninformative) thanks to period-luminosity relations; the abundances of numerous alpha, iron-peak, and neutron-capture elements can be derived from their spectra.

Using machine-learning techniques, we have identified groups of Cepheids matching well the Milky Way spiral arms located by other means, putting us in a good position to investigate whether spiral arms influence the radial and azimuthal abundance gradients. Our preliminary results regarding azimuthal variations support similar findings for nearby spiral galaxies as well as recent 2D chemo-dynamical models. However, both indicate that the effects are tenuous (<0.1 dex), calling for extremely accurate and precise abundance determinations. Therefore, I will also describe ongoing efforts aiming at improving the analysis of Cepheids' spectra.

Using the color of RR Lyrae Stars to map the interstellar reddening of the Bulge

K. Vivas, A. Saha

We characterize the absolute magnitudes and colors of RR Lyrae stars in the globular cluster M5 in the ugriz filter system of the Dark Energy Camera (DECam), installed at the Blanco 4 m telescope at Cerro Tololo Inter-American Observatory, Chile. As expected from earlier studies by Sturch, the dispersion of the color at minimum light was found to be small, supporting the use of this parameter as a means to obtain accurate interstellar extinctions along the line of sight up to the distance of the RR Lyrae star. We found a trend of color at minimum light with pulsational period that, if taken into account, brings the dispersion in color at minimum light to <0.016 mag for the (r-i), (i-z), and (r-z) colors. Such color calibration was applied to observations of fundamental mode RR Lyrae stars of six fields toward the Galactic bulge made with the same instrument to derive maps of interstellar reddening. The resulting color-magnitude diagram corrected by extinction and reddening using such maps allows to study the stellar population of the Bulge with exquisite detail.

The BRAVA-RR Lyrae stars: New metallicities and kinematics of the old spheroidal bulge stars

A. Kunder

The bulge RR Lyrae stars have been shown to be some of the oldest stars in the inner Galaxy, with ages of ~13.4 Gyr. The 3D motions of a sample of ~2500 RR Lyrae stars has been obtained by the BRAVA-RR survey. Here we derive new metallicities for a sub-sample of these stars and compare their chemodynamics with the younger, more metal-rich stars in the bulge/bar. We find that the inner Galaxy RR Lyrae star kinematics are complicated by a mix of a variety of Galactic components. After isolating only those RR Lyrae stars that are confined to the bulge, we find there are two different old and metal-poor populations in the bulge. The sample of stars closest to the Galactic plane have slower rotation and are less bared than the dominant bar/bulge. Old, metal-poor stars in the inner Galaxy need to be properly accounted for when discussing processes that gave rise to the formation of the inner Galaxy and the Galactic bar/bulge.

A multifaceted overlook of the galactic Halo through RR Lyrae

V. Braga (Inv.)

The Halo is a purely old component of the Milky Way (MW), however its formation is due to at least two different processes (in-situ formation and accretion). Information on the merging events and on the formation of the MW itself are encoded in the complex chemo-dynamical properties of the Halo. Since Gaia DR2, the Halo has been dissected into tens of streams and at least three major merger events were detected. Since the Halo is so crucial to investigate the birth and assembly of the MW, we are interested in adopting RR Lyrae (RRLs) that, being strictly old, are ideal tracers of this component of the Galaxy. Therefore, we have built the largest catalog of MW RRLs (>285,000), based on Gaia DR2 and recently updated to Gaia DR3. The catalog also includes the largest sample of RRL spectroscopic chemical abundances (>9,000). This is the reference catalog for a series of works on Halo RRLs that addressed several open questions, like the Oosterhoff dichothomy, the evolutionary interpretation of the Bailey diagram, the gradients of iron, alpha and neutron-capture elements, detection of streams and photometric metallicity indicators. We have also built the first radial velocity templates for both fundamental and first-overtone pulsators and for seven diagnostics (Lyman alpha-to-delta lines, Iron, Magnesium and Sodium).

The Orphan stellar stream in 7D using RR Lyrae stars

Zdenek Prudil, Michael Hanke, Bertrand Lemasle, Andreas Koch-Hansen, Juliana Crestani, Vittorio Francesco Braga, Michele Fabrizio, Giuseppe Bono, Eva K. Grebel

In this work, we describe the MW stellar streams using population II pulsating variables of the RR~Lyrae class, which provide precise distances (down to 3 percent), and can be detected up to 100 kpc. The assembled chemo-dynamical sample combines spectroscopic metallicities and systemic velocities and the Gaia EDR3 astrometric products provide a 7D view of some MW streams. Our pilot study focused on the northern part of the Orphan stellar stream, where employing a probabilistic approach we identified 20 RR~Lyrae variables as likely members of the stream. The acquired sample allowed us to examine possible metallicity gradient within the stream, expand our sample with known and new non-variable objects, and assess and rule out possible Orphan progenitors, like the ultra-faint dwarf galaxy Grus II. Our analysis showed that if we consider Grus II as the progenitor of the Orphan stream it would be the first case of reversed metallicity gradient which is to date unseen in the Local Group. Contrary to this assumption any potential Orphan progenitor, if not yet dissolved, could be hidden behind the Galactic plane.

Milky Way Archaeology using Cepheids, RR Lyrae, and Gaia: Creating a 7-D catalog and first results

Hitesh Lala, Bertrand Lemasle, Eva Grebel, Zdenek Prudil, Vittorio Braga, Juliana Crestani, Giuseppe Bono

We have created a carefully-curated catalog of ~245,000 RR Lyrae stars (RRab & RRc) and ~18,000 Cepheids (Classical, Type-II & Anomalous) containing 7-D information (positions, proper motions, distance, radial velocity, metallicity). In the process, we have homogeneously combined ten photometric and six spectroscopic surveys. We have ensured minimal contamination in our sample by cross-validating the classifications and periods across various surveys and also cleaning the sample by cross-matching against other variable stars whose light curve morphology is similar to our target stars. We have employed three independent calibrators for computing the distance to our stars: a. Astrometry-based Luminosity computed using Gaia (E)DR3 parallax; b. Large Magellanic Cloud population; c. Globular cluster members wrapped in a partially-pooled multi-level Hierarchical Bayesian model. The Period-Wesenheit laws obtained to get these three sets of distances were fit using Bayesian robust regression, which offers a complete treatment of uncertainties and is immune to outliers. After validation, we found these distances to be greater than 95% accurate (even at 150kpc) and have been estimated to a <5% precision. For our RR Lyrae sample (both RRab and RRc sub-types), we have also obtained photometric metallicity estimates on a new homogeneous scale creating the largest sample of RR Lyrae iron-abundances. Harnessing this catalog, we have discovered several new members of Galactic streams and over-densities. The re-discovery of already-identified members validates our distances, and metallicities, while the new ones enable precise measurement of these parameters for the very first time for many of these substructures.

With Gaia DR3 and future data releases, coverage of the light-curves and the precision of the astrometry will only improve, collectively resulting in even better classification, greater completeness, and more precise distances to these stars. Ultimately, our catalog places the community in good stead to exploit the imminent arrival of numerous spectra from WEAVE, 4MOST, SDSS-V, and Gaia DR3/4. The homogeneity of our catalog can be leveraged to uniformly study the Milky Way halo at unrivaled depths. It will facilitate not only the chemo-dynamical analysis but also the discovery of several other streams and over-densities.

Probing the Galactic outer halo using kinematics and stellar abundances of distant RR Lyrae

Gustavo Medina, Camilla J. Hansen, Ricardo Muñoz, Eva K. Grebel, Kathy Vivas, Jeffrey Carlin, Clara Martinez-Vazquez

In the current cosmological paradigm, the Milky Way was formed hierarchically through the accretion of smaller systems, and imprints of these interactions are visible in the present-day orbital and chemical properties of Galactic halo stellar populations. RR Lyrae stars are ideal tracers of these merger events, as their status of old and precise distance indicators removes distance as one of the biggest limitations in the study of the outer halo. However, deriving radial velocities and spectroscopic metallicities of remote RR Lyrae is challenging, owing to their variability in short time-scales and the need for dedicated time at large aperture telescopes.

In this contribution, I will present the spectroscopic analysis of 20 outer halo RR Lyrae (with distances between 15 and 165 kpc) in the context of the Halo Outskirts With Variable Stars (HOWVAST) survey, conducted using medium-resolution spectra from the MIKE spectrograph. In combination with Gaia eDR3 data, we model the orbits of our stars considering the gravitational perturbation of the halo by the Large Magellanic Cloud, and determine atmospheric parameters and chemical abundance ratios (including alpha-elements, Fe, and neutron-capture elements) for a subsample of them. We search for associations between these distant RR Lyrae with known satellites and accretion events by studying their chemodynamics and speculate about their parent populations and origins (formed in-situ vs. accreted). We test the hypothesis that the accretion of sub-haloes largely contributes to the outer halo stellar populations, and report on the limitations of state-of-the-art distant halo RR Lyrae spectroscopic surveys. I will discuss the implications of our findings, and their impact on our preparation for the analysis of large samples of halo RR Lyrae in the upcoming era of large scale photometric and spectroscopic surveys.

THE LOCAL GROUP

Pulsating stars in Local Group galaxies

C. Martínez-Vázquez (Rev.)

Pulsating stars are considered standard candles because they obey well established period luminosity relations and, therefore, they are used very often to derive accurate and precise distances. By far, the most frequent and common pulsating stars found among Local Group dwarf galaxies are RR Lyrae stars. Since the discovery of the first RR Lyrae star by Wilhelmina Fleming at the beginning of the last century and thanks to their well-know period-luminosity relation (Henrietta Leavitt Law), the popularity of this kind of stellar pulsators has increased exponentially, specially over the past decades. The enormous amount of detections of RR Lyrae stars in surveys like ASAS, Catalina, DES, Gaia, OGLE, PanSTARRS, ZTF (and the future Vera Rubin LSST survey), and the fact that RR Lyrae stars are stellar tracers of old stellar populations makes them powerful archaeological tools. They have been used to detect/confirm new ultra-faint and ultra-diffuse dwarf galaxies and to obtain accurate distances to those systems, where the large contamination by field stars makes the determination of distances using isochrone fitting a challenging task. In addition, in those systems where the rate of RR Lyrae stars is large enough, RR Lyrae stars can be also used as metallicity tracers, and provide insight into the chemical evolution of the old population they belong to. Thus helping us not only to reveal their formation history and chemical evolutions but also to provide clues about the contribution of dwarf galaxies in the formation of the halo of the larger galaxies they are bound to.

Variable stars in NGC6822

M. Tantalo

We performed the deepest and widest optical photometric investigation of the nearby dwarf irregular NGC~6822 by using multi-band (g,r,i) images collected with Hyper Suprime-Cam at the Subaru Telescope. We ended up with a photometric catalog including more than one million stars covering more than two square degrees across the center of the galaxy. These data were complemented with images collected with wide field imagers at 2/4m telescopes (ING, CTIO, CFHT) and cover a time interval of two dozen years. We pian to discuss preliminary results concerning the identification of variable stars (hundreds) located inside the Cepheid instability strip (classical, Type II, Anomalous, RR Lyrae) and of Long Period Variables together with the comparison with similar investigations available in the literature. Finally, we will outilne peculiarities in the radial distribuzion of different stellar tracers and the 3D shape of the galaxy.

VV124: A Rosetta Stone Dwarf Galaxy for the Distance Scale

M. Marengo, M. Monelli, J. R. Neeley, C. E. Martinez-Vazquez, G. Fiorentino, A. K. Vivas, A. Walker, C. Gallart, G. Bono, S. Cassisi, M. Marconi, M. Dall'Ora, A. Sarajedini

VV124 is an isolated dwarf in the outskirts of the Local Group of galaxies, yet close enough to allow for a detailed census of its variable stars. Despite its isolation, VV 124 hosts stellar populations with a wide range of ages (>10 Gyr to present), making it a home for all types of classical stellar pulsators, including Classical, Anomalous and Type II Cepheids, RR Lyrae and pulsating late-type giants. These unique characteristics allows this dwarf galaxy to be the ideal test case for stellar distance indicators based on pulsating stars. In this contribution we present our comprehensive analysis of the pulsating stars population in VV 124 and we compare its distances derived with different methods based on its pulsating stars, using new data we have obtained with the Advanced Camera for Surveys onboard the Hubble space telescope.

Pulsating stars in Magellanic Clouds

V. Skowron (Inv.)

Since the first discoveries of classical Cepheids in the Large Magellanic Cloud over a century ago, the numbers of known pulsating stars in the Magellanic System have vastly increased. And so has our knowledge about the two galaxies, and about observational and physical properties of various classes of pulsating stars.
In this talk I will summarize what we have learned about the Magellanic Clouds from classical pulsating stars, both in terms of their structure and content. I will also present what we know about the properties of pulsating stars themselves and how it affects our understanding of their counterparts in the Milky Way.

SCIENCE WITH GAIA DR3

Pulsators in Gaia DR3

G. Clementini (Rev.)

The last couple of decades have seen a true revolution in the field of pulsating stars because of the increasing number of ground-based/space-borne surveys that have been collecting multi-epoch photometry over large portions of the celestial sphere.
A leading role in this revolution is played by Gaia, the ESA cornerstone mission that monitors the whole sky since July 2014 collecting astrometry (positions, parallaxes and proper motions) and multi-epoch (spectro)-photometry in three different pass-bands (Gaia G, G_BP and G_RP) of sources down to a limiting magnitude G = 21 mag. The spacecraft also simultaneously collects spectroscopy with the Radial Velocity Spectrometer (RVS) of sources brighter than V ~ 16 mag.

The second instalment of the Gaia third data release (DR3) on June 2022 published time series multi-band photometry and parameters for about 11 million variable sources. The pulsation is the mechanism driving the light variation in more than one third of these variable stars. Epoch radial velocities from the RVS have also been released for 1096 RR Lyrae stars and 799 Cepheids.

We briefly outline aspects of the variability data processing in the Gaia mission, then review the main properties and results for pulsating stars published in DR3.
We focus specifically on RR Lyrae and Cepheids, in light of the impact these variable stars have on the definition of the cosmic distance ladder and the study of resolved stellar populations in and beyond the Milky Way.

BL Her stars in the Gaia DR3 Era: Models vs Observations

Susmita Das, László Molnár

We present new theoretical period-luminosity and period-Wesenheit, W=G-1.90*(GBP-GRP) relations in the Gaia bands for a fine grid of convective BL Herculis models computed using the non-linear radial stellar pulsation tool MESA-RSP. The non-linear models were computed for periods typical for BL Her stars, i.e. 1<P<4 covering a wide range of input parameters: metallicity (-2.0 dex < [Fe/H] < 0.0 dex), stellar mass (0.5M-0.8M?), luminosity (50L?-300L?) and effective temperature (full extent of the instability strip; in steps of 50K). For the BL Her stars in the LMC, we find the empirical PL relations in the G-band to match better with models computed using radiative cooling; the empirical PW relations are statistically similar with the theoretical PW relations over all four sets of convection parameters. We also compared the observed Fourier parameters in the G-band (shown in grey) with the theoretical FPs computed using the four sets of convection parameters: We constrained the periods and FPs of the models and observations in the G-band to obtain a subset of 17 matches and thereby estimated the distance modulus to LMC of ?LMC=18.47±0.17 (?LMC=18.49±0.09 from de Grijs+ 2014). We are also extending our study to include the comparison of the photometric metallicities with the model values, as well as of the theoretical radial velocity curves with those from Gaia RVS observations.

RR Lyrae as tracers of Galactic Globular Clusters

Garro Elisa Rita, Minniti Dante, Alonso-García Javier, Ripepi Vincenzo

RR Lyrae (RRL) variable stars, found in the Galactic halo and bulge, represent a very old population in the Milky Way (MW). These stars are considered powerful tools mainly for two reasons: first, because they are good distance indicators; second, they allow confirming the nature of GC candidate, because if detected in a stellar cluster, RRL guarantee the old age (>10 Gyr). We searched for these variables in many new GC candidates in the VVV/VVVX footprint. This allowed us to confirm the GC nature for Garro 01, Patchick 99, VVV-CL131, VVV-CL143, FSR1775, FSR1767, ESO393-12, ESO456-09, Patchick 125, and Riddle 15 in our Galaxy, and also for recently discovered GCs in the inner part of the Sagittarius dwarf galaxy. We also adopted the known period-luminosity-metallicity relations in order to derive the cluster distance as independent methods. In summary, we present the physical parameters for the 10 new Galactic GCs listed above.

RR Lyrae Magnitude Calibrations in the light of GAIA (E)DR3

J. Lub

DISTANCE SCALE

Distance Scale: Young Stellar Indicators

R. Anderson (Rev.)

Distance measurements are of fundamental importance for astronomy and astrophysics since they transform interpretations of apparent brightness to insights of luminosity, thereby offering insights into the physical nature of astronomical objects. In particular, classical Cepheids are pulsating stars whose luminosity can be calibrated, notably using individual trigonometic parallax measurements, thanks to the Leavitt law (period-luminosity relation). Thus, Cepheids are standard candles that light the way for determining distances well beyond the reach of direct, geometric distance measurements, for example to study Galactic structure on scales of 100 - 20000 kpc and to measure precise distances to galaxies as far as 70 Mpc. Thus, classical Cepheids form the basis of an extragalactic distance ladder that calibrates type Ia supernova luminosity, and allows to measure the local expansion rate of the Universe, Hubble's constant H0, to a current precision of 1 km/s/Mpc.

Recent developments have shown that the late-Universe value of H0 differs systematically from the early-Universe value inferred from the cosmic microwave background interpreted in the flat LambdaCDM paradigm. The significance of this so-called Hubble Tension is currently quantified at the 5.3 sigma level, rendering the need for modifications of the concordance cosmological model increasingly likely.

In this invited review, I will explain the basic ideas behind the Cepheids plus Supernovae distance ladder built by the SH0ES team since 2005 that has improved the precision on H0 by a factor of 7 since the Hubble key project on the Hubble constant. In particular, I will focus on improvements related to Cepheid photometry, the absolute calibration based on trigonometric parallaxes measured by the ESA mission Gaia, and progress in the quantification and mitigation of systematic uncertainties or biases that underlines the accuracy of the late-time H0 measurement and corroborates the significance of the Tension.

Are the ULP cosmological standard candles?

Ilaria Musella, Marcella Marconi, Giuliana Fiorentino, Vincenzo Ripepi, Felice Cusano, Giulia De Somma

Ultra Long Period Cepheids are becoming a very interesting and important topic thanks to the contribution they can give to understanding the current tension existing between the early-universe and local Hubble constant measurements. These bright pulsating variables are hypothesized to be the
counterparts at higher luminosity and mass of the Classical Cepheids. They are observable up to cosmological distances (larger than 100 Mpc) allowing us, in principle, to measure the Hubble constant without the need for secondary indicators, thus reducing the possible systematic errors in the calibration of the extragalactic distance scale. The Ultra Long Period Cepheids also represent a useful tool to get information on the star formation history of the host galaxy and a challenge for the evolutionary and pulsation models in particular in the very metal poor regime.

The impact of binary Cepheids on the extragalactic distance scale

Paulina Karczmarek, Radosław Smolec, Gergely Hajdu, Grzegorz Pietrzyński, Wolfgang Gieren, Weronika Narloch, Grzegorz Wiktorowicz, Krzysztof Belczynski

Classical Cepheids - famous for their period-luminosity relation (PLR) - are the most extensively used distance indicators, and a crucial rung in the cosmic distance ladder, enabling the determination of the Hubble constant. The majority of classical Cepheids are binary stars, yet the contribution of companions' light has been long assumed negligible and lacked thorough, quantitative evaluation. I present a comprehensive collection of synthetic populations of binary Cepheids for the Milky Way and the Magellanic Clouds, which serves as a tool to quantify the contribution of companions' light to the total brightness of the systems. This light excess shifts the zero point of the PLR, which now can be recognised as a systematic error associated with the Cepheid PLR, and, by extension, with the Hubble constant.

The Cepheid distance scale and its metallicity dependence

Louise Breuval, Adam Riess, Pierre Kervella

Cepheid variables are the best calibrated primary standard candles: they are used to standardize the brightness of Type Ia supernovae (SNIa) in nearby galaxies and therefore are central in the determination of the local value of the Hubble constant (H0). The empirical measurement of the Hubble constant obtained by the SH0ES team from the Cepheid-SNIa method is now in 5-sigma tension with the Planck prediction based on the lambda-CDM model. While both estimates have reached a great precision, the source of the Hubble tension remains unknown and suggests evidence of new physics beyond the standard model. In this talk I will describe recent progress on the Cepheid distance scale involving Gaia parallaxes and HST photometry and I will identify the remaining issues and systematics associated with the calibration of their period-luminosity relation. In particular, differences in Cepheid metallicities between the Milky Way, Magellanic Clouds and nearby galaxies hosting SNIa must be corrected in order to provide a consistent distance calibration. Finally I will discuss how future missions and promising techniques are expected to improve again the precision of the empirical H0 value.

Type II Cepheids in the solar neighborhood in the Gaia era

Piotr Wielgorski, Grzegorz Pietrzynski, Bogumil Pilecki, Wolfgang Gieren, Bartlomiej Zgirski, Marek Gorski, Gergely Hajdu, Weronika Narloch, Paulina Karczmarek, Radoslaw Smolec, Pierre Kervella, Jesper Storm, Alexandre Gallenne, Louise Breuval, Megan Lewis, Mikolaj Kaluszynski, Dariusz Graczyk, Wojciech Pych, Ksenia Suchomska, Monica Taormina, Gonzalo Rojas Garcia

Type II Cepheids are old population pulsating stars which lies about 2mag below Classical Cepheids on the period-luminosity diagram. I will show recent results of the Araucaria project where we use Gaia EDR3 parallaxes of nearby Type II Cepheids and photometry obtained in the Cerro Armazones Observatory in order to improve the accuracy of distance measurements with these old stars. First, I will show our calibration of the period-luminosity relations in the near-infrared J, H and Ks passbands (Wielgorski et al, 2022, ApJ, 927, 89) and compare it to calibrations in the other stellar systems. The influence of the metallicity on Type II Cepheids absolute magnitudes will be also discussed. The second method which can be applied to measure the distance of a radially pulsating star is the so-called Baade-Wesselink method. I will show the very first calibration of the projection factor, parameter required in the Baade-Wesselink analysis, for a sample of BL Herculis and W Virginis stars in the solar neighbourhood. Precision calibration of the projection factor will allow to measure geometrical distances of Type II Cepheids in e.g. globular clusters and dwarf spheroidal galaxies.

Distance scale: old stellar indicators

B. Madore (Rev.)

In the context of their application to the extragalactic distance scale, three distinct groups of old and intermediate-aged stars will be discussed.
(1) An update of the Tip of the Red Giant Branch (TRGB) method and its impact on the value of the Hubble constant will be given.
(2) A unification of the Period, Amplitude and Color properties of RR Lyrae variables will be presented, along with an astrophysically-motivated revision of the multi-wavelength RR Lyrae Period-Luminosity relation, which will be discussed for the first time.
(3) The J-Branch AGB stars will be shown to be highly competitive with both Classical Cepheids and the TRGB stars in their precision, accuracy and high luminosities in the near-infrared, especially in the era of JWS.

RR Lyrae variables in globular clusters: NIR Period-Luminosity-Metallicity relations

Anupam Bhardwaj

RR Lyrae variables are sensitive probes for the precision stellar astrophysics and also for the distance scale thanks to their tight Period-Luminosity-Metallicity (PLZ) relations at infrared wavelengths. Theoretical models of RR Lyrae predict a significant metallicity coefficient of their PLZ relations, but the metallicity term is relatively smaller and not well-constrained in most empirical calibrations. Despite the improvements in Gaia parallaxes, the precision of the absolute calibration of Galactic PLZ relations is limited due to inhomogeneous photometry and spectroscopy of field RR Lyrae variables. We present new NIR time-series observations of RR Lyrae in 8 globular clusters with CFHT-WIRCam and Gemini-F2 covering a wide metallicity range (-0.4<[Fe/H]<-2.4). Combining with literature NIR data and Gaia parallaxes, RR Lyrae variables in 10 globular clusters are used to derive JHK_S PLZ relations with unprecedented precision. Our preliminary results show a good agreement with theoretical predictions. We discuss the implications of RR Lyrae PLZ relations for the independent calibration of the first rung of the population II distance ladder with our ongoing NIR observations of nearby dwarf spheroidal galaxies.

Near-infrared period-luminosity-metallicity relations for RR Lyrae based on GAIA EDR3 parallaxes and photometry from the Cerro Armazones Observatory

Bartłomiej Zgirski, Grzegorz Pietrzyński, Piotr Wielgórski, Marek Górski

RR Lyrae stars are important distance indicators that serve us to test the calibration of the cosmic distance ladder in the direct neighborhood of the Milky Way.
I am presenting a new calibration of period-luminosity and period-luminosity-metallicity relations for Galactic RR Lyrae in JHKs bands based on the photometry gathered using the 0.8 m IRIS telescope from the Cerro Armazones Observatory and GAIA EDR3 parallaxes. Metallicities of 23 stars had been taken from the work of Crestani et al. (2021).
I am comparing the new relations with those available in the literature. The zero point of the new calibration is in very good agreement with the very accurate distance to the Large Magellanic Cloud (LMC) based on eclipsing binaries (Pietrzyński et al. 2019) and the VMC photometry of RR Lyrae stars from the LMC (e.g. Cusano et al. 2021).
Finally, I am presenting the impact of the new relations on distance determinations to a few nearby galaxies - LMC, SMC, Fornax, and Carina.

First direct measurement of the stellar association bias in the SNeIa host anchor M101

Zoi T. Spetsieri, Richard. I. Anderson et al.

We aim at measuring directly for the first time the stellar association bias caused by the physical association of Cepheids with their natal environments in order to validate and improve the stellar association bias corrections applied to the late-Universe Ho measurement. For this purpose, we quantify the occurrence of Cepheids in (or near) open clusters in the SNeIa host anchor M101.

We used HST/WFC3 UV observations of the Cepheids previously identified by the SH0ES project. UV observations allow to discover clusters that would not be detectable without UV photometry. We visually inspected the UV images for UV flux at the location of the Cepheids and checked whether there was evidence of that flux in the other available passbands (optical and near-IR).

We evaluated the properties of the Cepheids occurring in open clusters in terms of period, magnitude and galactic location (e.g. star forming regions) and created an inventory with the properties of the Cepheids in the WFC3 footprint. Early results show that the fraction of Cepheids in open clusters in M101 is larger than the equivalent one measured in its analog M31. We found that the majority of the Cepheids found in open clusters are in star forming regions and have a period larger than 10 days. We estimated the effect of the stellar association bias on the distance ladder and our results are in agreement with the corrections currently applied in the measurement of H_0 These observations, enable the first direct measurement of stellar association bias in a SN host galaxy and provide a crucial sanity check for the measurement of H_0 and allow the development of improved selection criteria that could further reduce the impact of stellar association bias at distances beyond the Local Group.

FUTURE FACILITIES

Future facilities for classical pulsators: the Rubin Observatory and LSST

Z. Ivezic (Rev.)

The Legacy Survey of Space and Time (LSST), the first project to be undertaken at the new Vera C. Rubin Observatory, will be the most comprehensive optical astronomical sky survey ever undertaken. Starting in a couple of years, Rubin Observatory will obtain panoramic images covering the sky visible from its location in Chile every clear night for ten years. Close to a thousand observations of each position across half of the celestial sphere will represent an excellent observational material to study variable faint sky, including hundreds of millions of variable stars. I will briefly describe scientific goals behind this project, illustrate the progress of its ongoing construction, and finish by showing a few results from simulated LSST cadence analysis relevant for periodic variables.

Pulsation an evolutionary diagnostics for variable stars in the LSST era

G. Bono et al.

LSST is going to be a game changer concerning the accuracy and the homogeneity of multi-band time series data of variable stars. The difference is driven by a) entire southern hemiphere, b) photometric accuracy, c) cadence of the observations and) time interval of the experiment. This means the unique opportunity to use several pulsation (luminosity amplitude, multi-periodicity, shape of the light curves, modal stability, period distribution) and evolutionary (star counts, luminosity function, evolutionary timescale, mass loss, age distribution) diagnostics to investigate resolved stellar populations. We plan to adress several key issues concerning individual metallicity estimates of Cepheids (classical, anomalous, type II) using photometric indices. Moreover, we also plan to discuss recent finings concerning the Hertzsprung progression, and in particular, its depenence on the metallicity.

Waiting for the Legacy: a pilot project on the Globular Cluster NGC 6569

M. Dall'Ora on behalf of the TVS-SMWLV Crowded Stellar Fields Task Force

Rubin-LSST will represent the giant leap in the time-domain astronomy for the next decade. The enormous amount of expected data will be both an unprecedented scientific opportunity and technical challenge. The Galactic Bulge and similar heavily crowded environments will pose even harder challenges, because of the combined effects of the crowding and dust, that will affect our efficiency in detecting and characterizing variable stars. It is therefore crucial to test the available techniques and tools, and eventually develop new ones, to effectively extract the scientific information from the data. Here we present the results of a pilot project started within the Rubin-LSST Transient and Variable Stars Science Collaboration, based on archive DECam data and focused on the characterization of the periodic stars in the field of the Bulge globular cluster NGC 6569.

POSTERS

Magnetic properties of classical pulsators

James A. Barron, Gregg A. Wade

While magnetic fields are known to impact stellar processes on dynamical and evolutionary timescales, the magnetic properties of evolved pulsating stars remain poorly constrained. Surface magnetic fields have been detected in a small but growing number of classical pulsators, including delta Scuti, Mira, RV Tauri and Cepheid variables. The detected magnetic signatures are diverse, and many show the influences of atmospheric dynamics. We present an overview of the magnetic field properties in the classical instability strip and discuss the next steps in this emerging field. In particular, we report recent results from our ongoing magnetic survey of the brightest twenty-five Cepheids. We detect magnetic signatures in eight of fifteen observed targets, including Polaris. The detected magnetic Stokes V signatures show a surprising diversity of morphologies and may provide a new and unique probe of Cepheid atmospheric dynamics. We have begun a monitoring campaign of Polaris to perform a magnetic mapping using Zeeman Doppler Imaging, the first for any Cepheid.

First results of a magnetic survey of classical Cepheids

James A. Barron, Gregg A. Wade, Colin P. Folsom and Oleg Kochukhov

Classical Cepheid variables are essential tools in studying stellar evolution and cosmology due to their radial pulsations and period-luminosity relation (Leavitt Law). Cepheids exhibit a number of poorly understood phenomena, including cycle-to-cycle line variability, infrared excess and phase-dependent UV/X-ray `flashes'. While Cepheids have been studied for over a century, we know surprisingly little about their magnetic properties and what role magnetic fields may play in their evolution and these observed phenomena. We report recent ESPaDOnS and HARPSpol observations from our ongoing magnetic survey of the brightest ~25 Galactic Cepheids. We detect Stokes V signatures (which we interpret to be of Zeeman origin) in eight targets, over half the sample observed to date. The magnetic detections include the well studied Cepheids Polaris, del Cep and eta Aql. The detected magnetic Stokes V signatures show a diversity of morphologies with corresponding longitudinal field measurements of order 1 G. Many of the Stokes V profiles are difficult to interpret in the context of the normal Zeeman effect, consisting of approximately unipolar single/double lobe(s) of positive or negative circular polarization. We tentatively attribute these unusual signatures to the presence of atmospheric velocity and magnetic gradients. We discuss the next steps in our survey and how circular polarization can probe the dynamic atmospheres of classical Cepheids.

Light curve fluctuations of Classical Cepheids as observed by SMEI

Géza Csörnyei, László Molnár, László Szabados

Although not directly dedicated to variable stars, the Solar Mass Ejection Imager (SMEI) onboard the Coriolis satellite observed a handful of bright Cepheids throughout its eight years long campaign. The resulting time series are not only sampled with a short cadence of a few hours, but they cover several years without any major gaps, which properties make the SMEI dataset perfect for studying fluctuations present in the pulsation of Cepheid variables. However, this potential has not been fully exploited yet, due to the presence of long and short term systematics on the light curves, which degrade their quality significantly.

In this work, we attempted to reanalyse the SMEI time series of 11 Cepheids by adopting and modifying a trend removal method, which was reliably used for more modern continuous time series produced by the Kepler and TESS missions. The resulting light curves allowed the investigation of short term, cycle-to-cycle fluctuations both in the phase curves shapes and the times of given phase for these Cepheids, and revealed a weak correlation between these two properties. Furthermore, the number of Cepheids present in the sample also enabled a tentative statistical study of these processes.

The effect of metallicity and convection parameters on new theoretical relations for MESA-computed BL Her models

Susmita Das

We present new multiwavelength (UBVRIJHKLL'M) period-luminosity (PL) and period-radius (PR) relations for a fine grid of convective BL Herculis models computed using the non-linear radial stellar pulsation tool *mesa-rsp*. The non-linear models were computed for periods typical for BL Her stars, i.e. $1 \leqslant P$ (days) $\leqslant 4$ covering a wide range of input parameters - metallicity (-2.0 dex $\leqslant$ [Fe/H] $\leqslant 0.0$ dex), stellar mass ($0.5M_{\odot}$-$0.8M_{\odot}$), luminosity ($50L_{\odot}$-$300L_{\odot}$) and effective temperature (full extent of the instability strip; in steps of 50K). We study the effect of metallicity and four sets of different convection parameters on the PL and PR relations at mean light. The theoretical PL and PR relations obtained using our computed BL Her models match well with empirical relations. However, PL slopes of the models with radiative cooling provide a better match to empirical relations for BL Her stars in the LMC in the HK_S bands. For each set of convection parameters, the effect of metallicity is negligible in infrared bands, consistent with empirical results. No significant metallicity effects are seen in the PR relations.

(Based on Das et al., 2021, MNRAS, 501, 875)

The variation of the optical SED of RR Lyrae stars with the multi-filter J-VAR survey

A. Domínguez, H. Vázquez Ramió, C. López-Sanjuan

Time domain surveys, whether in the form of wide-field photometric (like LSST) or spectroscopic (SDSS-V) surveys, will expand our knowledge in many aspects of stellar Astrophysics in the next decade. J-VAR constitutes a trade-off between such approximations, having a photometric-based approach but with some (low) spectral resolution around key stellar features thanks to its medium- and narrow-band filters (J0395, J0515, J0660, J0861).

RR Lyrae stars, intimately tracers of old (>10 Gyr) stellar populations, are classical pulsators with periods between around 0.2 to 1.2 d. They pulsate mainly in two modes: the fundamental (RRab/RR0) and the first-overtone (RRc/RR1) modes. Although they are present in all the MW components, their number stands out in the halo. They are very fair distance indicators, following a well-known and tight luminosity-period-metallicity relation.

In this talk, I explore the capabilities of J-VAR data to analyze how the Spectral Energy Distributions (SEDs) of RR Lyrae stars vary with the phase and what can we learn from it about the physics of these classical pulsators.

Empirical constraints for the instability strip from the analysis of LMC Cepheids

Felipe Espinoza-Arancibia, Bogumił Pilecki, Javier Minniti

In this work, we aim to obtain an empirical instability strip (IS) for the classical Cepheids in the Large Magellanic Cloud (LMC). For this purpose, we use data of classical fundamental-mode (F) and first-overtone (1O) LMC Cepheids from the OGLE-IV variable star catalog, together with a recent high-resolution reddening map from the literature. Our sample includes 2477 F and 1776 1O Cepheids. We study their position on the Hertzsprung-Russell diagram and determine the IS borders by tracing the color distribution along the strip. We note breaks in this distribution and provide a preliminary interpretation of this phenomenon. These breaks add complexity to the typically assumed shape of the IS. In addition, using the stellar evolution code Modules for Experiments in Stellar Astrophysics, we compare our empirical borders with theoretical ones. The differences between the latter can provide us with insights into the physical processes that determine the position of the IS boundaries. We also provide simplified wedge-shaped IS edges determined from the whole sample.

Background RR Lyrae stars in the primary Kepler mission field of view

Adrienn Forró, Róbert Szabó, Attila Bódi, Kornél Császár

The aim of the Kepler Pixel Project is to discover new pulsating and other types of variable stars in the individual pixels of the original Kepler field of view. The mission provided high precision, quasi-continuous light curves for almost 200,000 stars.
In the framework of this project, we thoroughly and consistently analyzed all individual pixels of the Q4 target pixel files in search of pulsating variable stars, specifically RR Lyrae stars. We looked for a period between 0.2 and 1 day, moreover, the candidates were expected to have at least two harmonics in their frequency spectrum. RR Lyrae stars were not the only type of variables the search yielded. In fact, the vast majority of the stars on the candidate list produced by the algorithm were eclipsing binaries.
After the vetting procedures, 26 new RR Lyrae stars were identified, all of them found in the background of a main target. Before this work, 52 RR Lyrae stars were known in the Kepler field, all of them were main targets. This is a significant addition to that list. There are two new classical RRd stars among those newly discovered, which is particularly important because there wasn't any known representative of this type among the know RR Lyrae stars. We provide stitched light curves for all the new background RR Lyrae stars using the data from all available quarters and we also analyzed their spectra.

The spectral energy distributions of classical Cepheids in the Magellanic Clouds

Martin Groenewegen

The spectral energy distributions of a sample of LMC and SMC fundamental mode classical Cepheids (CCs) are constructed using photometric data in the literature and fitted with model atmospheres.
The sample is build from stars of 'special interest', for example, that have a metallicity determination from high resolution spectroscopy, have been used in Baade-Wesselink type of analysis, in the theoretical modelling of the light- and radial-velocity curves, have Walraven photometry, or have their radial velocity curves published in Gaia DR3.
The SEDs are fitted with stellar photosphere models to derive the best-fitting luminosity and effective temperature. Distance and reddening are taken from the literature.
The stars are plotted in a Hertzsprung-Russell diagram (HRD) and compared to evolutionary tracks for CCs and to theoretical instability strips. For the large majority of stars, the position in the HRD is consistent with the instability strips.
Period-luminosity and period-radius relations are presented and compared to the relations found for Galactic CCs derived in the 2020 companion paper.

Mira Variables as Cosmological Distance Indicators

Caroline Huang, Adam Riess, Wenlong Yuan, Lucas Macri, Stefano Casertano, Samantha Hoffmann, Patricia Whitelock, Richard Anderson, Tarini Konchady

The increasing discordance between local measurements of the Hubble Constant (H_0) and the value inferred from observations of the cosmic microwave background (CMB) has posed a serious challenge to LambdaCDM. Direct, distance-ladder measurements of H_0 rely primarily on Cepheid variables and the Tip of the Red Giant Branch (TRGB) to calibrate the luminosity of Type Ia supernovae (SN Ia). Mira variables—radially-pulsating asymptotic giant branch stars—can provide an independent approach, checking existing Cepheid and TRGB distances while increasing the number of local calibrators for Type Ia Supernovae (SNe). In my talk, I will discuss the methodology and results of the first Mira-based H0 measurement, as well as upcoming work on an improved Mira-based H_0.

Light Curve Analysis of the High-Amplitude Delta Scuti Star GSC 4552-1498

Faezeh Jahediparizi, Javad Jafarzadeh, Atila Poro

We carried out observation of the HADS (High-Amplitude Delta Scuti) variable GSC 4552-1498 through three filters. Our goal was to consider its periodic behavior using our photometry data in addition to previous observations. A new ephemeris and determination of oscillation modes of the star based on Fourier analysis are presented. We analyzed its oscillation modes, presenting two main modes as 17.899 and 35.204 Hz. Their amplitudes are 0.267 and 0.102 respectively. The two-color diagram of a full period of the star's brightening-up and darkening phase is presented. Finally, according to standard models, different physical parameters such as bolometric magnitude, luminosity, mass and effective temperature were calculated for the star, which fit with an only slightly evolved A8 main-sequence star. Therefore, we find Mbol=2.344±0.264. Using the bolometric absolute magnitude of the sun of 4.74, we obtain the luminosity of the star L=(9.09±2.50)$L_{\odot}$. The mass of this star is estimated to be M=(1.68±0.10)$M_{\odot}$, and the radius is 1.67$R_{\odot}$.

The clues are in the details: bump variations and period doubling in Blazhko RR Lyrae stars

K. Kolenberg

In the light curves of fundamental mode RR Lyrae stars (RRab stars) the bump on the descending branch of the light variation is a distinct feature. It is associated with a shock wave in the stellar atmosphere. The strength of the bump varies between stars. Moreover, for modulated RRab stars, showing the so-called Blazhko effect, the strength of the bump varies in the course of the modulation cycle.

RR Lyr, the prototype classical pulsator, was observed with the Kepler mission in short cadence. This star showed a strong but variable Blazhko effect as well as period doubling, which may be connected to the cause of the modulation. Moreover, the strong variations of the hump and bump features can be studied in detail. Quantifying the bump strength allows us to distil the dynamics of the atmosphere of RR Lyr throughout the Blazhko cycle, based both on photometrically obtainable quantities, such as the amplitude and period, and on models of RR Lyrae atmospheres. Period doubling is strongly visible in the bump feature even when it is less obvious in the maximum light of the star. By analysing our data and the relations derived from literature, the evolution of the stellar parameters of RR Lyr throughout the Blazhko cycle is presented. This can then also be confronted with spectroscopy of the star.

Searching for RR Lyrae variables in the Second Data Release of the NoirLab Source Catalog

Kyle Matt, David Nidever

RR Lyrae are periodic variable stars generally with periods of less than one day. They can be used as standard candles for accurate distance measurements and thus are useful for studying the structure of the Milky Way and its stellar clusters. The second data release of the NoirLab Source Catalog (NSC DR2) is a large collection of 68 billion time-series measurements of 3.9 billion objects. To process such a large volume of data, we are designing a pipeline to automate the detection process for this catalog and measure their properties including period, magnitude, and amplitude of their pulsations by fitting their light curves to templates. In addition to identifying RR Lyrae, we are also exploring how to identify similar variable stars such as Cepheids in the same dataset. With our final catalog of bona fide RR Lyrae, we can map the stellar structure in the outer Milky Way, especially in the southern hemisphere. I will present initial results of our RRL catalog.

Using classical Cepheids to study the far side of the Milky Way disk

J. Minniti, M. Zoccali, A. Rojas-Arriagada, L. Sbordone, R. Contreras Ramos, D. Minniti, et al.

Classical Cepheids (CCs) are excellent standard candles and ideal tracers of the Galactic disk, since they are young, luminous and show characteristic light variations that make them - relatively - easily identifiable. Their location at the Milky Way disk complicates their identification, mainly due to the substantial reddening they are subject to. This is particularly true when studying them at the far side of the Galactic disk, but it can be surpassed with the use of infrared (IR) photometry. However, the classification based solely on near-IR light curves has proven difficult, and prone to providing highly contaminated samples.
We will show how the use of additional observable properties aids in the light-curve based classification process and present two different approaches to obtain clean samples of CCs: (1) Using spectroscopic follow-up data for a sample of CC candidates. (2) Using proper motions and colors obtained from the Vista Variables in the Vía Láctea Survey. Consequently, we have been able to significantly increase the number of bona fide CCs at the far disk. We present our results on the properties of the far Galactic disk (its structure, metallicity gradient and rotation curve) using these young tracers.

The first application of the parallax of pulsation method to accurately-parametrized Cepheids in eclipsing binary systems

Javier Minniti, Bogumił Pilecki

The determination of precise and consistent physical parameters of classical Cepheids is key to improving our understanding of the physical properties and the evolution of this important class of pulsating variable stars. In particular, Cepheids in detached eclipsing and spectroscopic double-lined binary systems allow us to measure their physical parameters very accurately, which can be then compared with the results obtained with other methods. We are exploring for the first time the use of the parallax of pulsation (PoP) method for a sample of LMC Cepheids for which their accurate physical parameters are known from the binary star model. For this purpose, we use the spectro-photo-interferometry of pulsating stars (SPIPS) algorithm (one of the PoP methods). We apply it to the available data for each Cepheid of the sample, freed of the companion's contribution. Our main aim is to test the accuracy of the derived parameters, especially of the Cepheid's radii and projection factors. We can also improve the characterization of Cepheids in binary systems by taking advantage of different strengths and compensating for weaknesses in the binary and PoP approaches. Moreover, this exercise will be beneficial for future uses of the SPIPS method to Cepheids in general, both single and in binary systems.

High-resolution spectroscopic and asteroseismic study of bright stars in the northern sky

Pakštienė, E.; Tautvaišienė, G.; Mikolaitis, Š.; Drazdauskas, A.; Minkevičiūtė, R.; Stonkutė, E.; Bagdonas, V.; Urbonavičiūtė, R.; Janulis, R.

Space missions, such as NASA TESS or ESA PLATO, focus on bright stars, which have been largely ignored by modern large surveys, especially in the northern sky. Spectroscopic information is of paramount importance in characterising the stars, analysing planets possibly orbiting them, and studying the Galactic disc evolution. Variable stars and asteroseismology have an advantage, as their analysis allows us to determine their physical parameters more precisely, furthermore to get information about their interior. Combining both spectroscopic and asteroseismic methods we can get more comprehensive information about the stars and their systems.
In our research, we analysed all bright (V < 8 mag) F, G, and K stars in TESS continuous viewing zone (CVZ) and 12° around CVZ in the northern sky using high-resolution spectra obtained at Moletai Astronomical Observatory (Lithuania) with 1.65 m telescope and a fibre-fed high-resolution spectrograph covering a full visible wavelength range (4000-8500 Å). For asteroseismic analysis, we used lightcurves obtained by the TESS space telescope with 60 min and 2 min cadences. Most of the variable stars in the field were recognised as solar-type variable red giants. We will present the survey of the analysed sample of 1017 stars.

Long secondary period phenomenon in the large sky surveys

Michał Pawlak

The long secondary period (LSP) is a phenomenon observed in a significant fraction of pulsating red giants. While the origin of LSP remains unclear, the proposed explanations include binarity and non-radial pulsations. In this work I studied the known sample of the OGLE LSPs in the Magellanic Clouds and the newly identified sample of the Galactic LSPs from the ASAS-SN survey. I used the photometric data combined with the astrometry from Gaia and spectroscopic data from the APOGEE, GALAH, and RAVE surveys, to investigate the properties of the LSP population. The LSP stars appear both on RGB and AGB, predominantly around the TRGB and the upper part of AGB, and seem to be on average more reddened than other giants. In the Galaxy, they have a spatial distribution that is more dispersed than the non-LSP giants, suggesting that they belong to an older population. Spectroscopically derived ages seem to confirm this. The LSP are also more C-rich than their non-LSP counterparts.

Investigation of the Period–Luminosity Relation of δ Scuti Stars by using Machine Learning

Atila Poro, Soroush Sarabi, Fatemeh Davoudi

We updated the δ Scuti period-luminosity relation using a number of δ Scuti stars and currently analyzed stars. A total of 520 stars were used. These stars are located on the HR diagram between the blue and red edges of the Instability Strip (IS) and above the ZAMS, which is consistent with the main population of δ Scuti stars as discussed by Breger (1990). These borders are not absolute, but pulsation beyond these borders is less probable (Murphy et al. 2019). We investigated the P–L relation and improved measurement accuracy. Thus, we have used Gaia EDR3 data which increased parallax accuracy by 30% over Gaia DR2 data (Gaia Collaboration, Brown et al. 2021). The extinction correction for the sample stars is calculated using 3D dust maps that consider the distance module. To recognize and classify data, we have used machine learning classification and fitted lines to the fundamental and overtone modes areas. As a result, we present a new P–L relation for the fundamental mode and overtone modes of δ Scuti variables.

RR Lyrae Variables in Globular Clusters

Wojtek Pych

We present the main results of the analysis of about 600 optical light-curves of RR Lyrae variables in Globular Clusters.
The observational data come from the CASE project. The photometric survey lasted from 1996 to 2018 and it covers more than 20 Globular Clusters.
The highlights are:
- calibration of absolute magnitudes M_V as a function of (a) metallicity and (b) the Fourier - parameters of light curves in the V band;
- discovery of non-radial pulsations;
- periodic nature of Blazhko effect;
- multiperiodic variability.

VVV/VVVx RR Lyrae ab-Type Catalog using machine learning

Carlos Quezada, Rodrigo Contreras-Ramos, Manuela Zoccali

I will present a RR Lyrae ab-type catalog made by automatic classification of variable stars in the most central region of the bulge (l within [-10°, 10°] and b within [-2.5°, 2.5°]) observed by the VVV/VVVx survey.
We use a machine learning technique based on Random Forest supervised classification algorithm trained from a cross-match set made with VVV and OGLE.

Looking beyond the regular: Study of irregular period changes in Magellanic Cepheids

Rajeev Singh Rathour; Radosław Smolec

Cepheids are ~4-14 $M_{\odot}$ core Helium burning giant stars which have a special place amongst the classical pulsators. They pulsate in a specific region of the H-R diagram called the instability strip (IS). As these stars move across the IS, they evolve, invoking changes in their internal structure, and hence changing the pulsation period. Thus, the period change rate is a direct measure of the evolution of the star. The evolutionary period changes are slow and monotonic in nature, and have been well studied in the past using O-C diagrams. However, there also exist irregular period changes in the O-C diagrams on a short time scale of a few hundred -- thousand days, which are non-evolutionary in nature. Although this phenomenon is reported in the literature, there is an absence of a systematic and quantitative description, along with a lack of underlying physical mechanism behind these irregular period changes.

Non-radial modes and modulation in Galactic Cepheids from OGLE-IV survey

Rajeev Singh Rathour; Radosław Smolec; Henryka Netzel

Cepheids are variable stars, earlier known to be pulsating only in single radial modes. With progress in studies of Magellanic Clouds, this notion was recently extended and later established that they not only have the presence of non-radial modes, but in some cases also show periodic modulation similar to Blazhko effect in RR Lyrae stars. Are such phenomena also frequent in Galactic Cepheids? If yes, is there a metallicity effect?

Our work involves a detailed search for additional low-amplitude variability phenomena such as the presence of non-radial mode or periodic modulation, in classical Cepheids of the Galactic fields. We perform frequency analysis of ~2000 Galactic Cepheids using the OGLE-IV photometry database and report findings on the above-mentioned phenomena and their correspondence with Magellanic Clouds Cepheids. In our study, we identify sixteen candidate detections for radial multi-mode pulsation, twelve first overtone (1O) Cepheids with associated non-radial mode signature and three Cepheids with periodic modulation of pulsation. These findings extend their respective samples in the Galactic fields and overall provide a basis to compare their properties with samples in the Magellanic Clouds. With non-radial mode candidates in our sample and literature candidates, we comprehensively show the systematic shift in the pulsation period coupled with the metallicity environment. Out of the three modulated Cepheid detections, one is a double-mode Cepheid pulsating simultaneously in fundamental and in first overtone modes. Only the former mode is modulated and it is the first detection of periodic modulation of pulsation in this type of double-mode Cepheids.

Refined Ephemeris of some δ Scuti Stars

Ahmad Sarostad, Atila Poro

The ephemerides of some δ Scuti stars were calculated based on the Markov Chain Monte Carlo (MCMC) method using the observed times of maxima and the period of the stars' oscillations. These stars were previously observed in several observatories from 2012 to 2015.
Calculating the ephemerides of δ Scuti stars is the usual method for finding period changes. This shows how times of maxima may change over time in comparison to the reference ephemeris. We first calculated the period of the stars' oscillations using Period04 software. After that, we extracted all light curves from the BVR filters separately. Then, we determined the times of maxima (T0) by fitting a sinusoidal curve to each light curve using the period that was calculated by Period04 analysis. Because some of the data from the first observation night was insufficient, we chose T0 based on observation nights with more complete and reliable data. All selected times of maximum were checked using the equation ($Tmax=T0+E´\times P$) and determined to be within the acceptable range. Then, we plotted the time of maxima diagram in terms of epochs and then calculated the ephemeris for each. For this plot, we applied the MCMC approach (100 walkers, 10000 step numbers, and 200 burn-in) using the emcee package in Python.

Multiband photometry of RR Lyrae field stars

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Pulsating variable stars provide further, complementary constraints to the properties of the parent populations, in terms of their age and metallicity. RR Lyrae (RRL) stars, Cepheids (Classical, Anomalous, Type II), Delta Scuti, Mira (and other long period variable stars) can be used to trace different stellar populations. In particular, RR Lyrae are low-mass, centrally He-burning Horizontal Branch stars, and are the best tracers of old (> 10 Gyr) stellar populations. They are therefore direct witnesses of the early evolutionary stages of the host galaxies.
In this context, we present the time series of several RR Lyrae field stars as a first taste of the photometric survey that is being prepared with to the data obtained with the IAC80 telescope, located at the Teide Observatory (Tenerife, Spain), managed by the Instituto Astrofísico de Canarias (IAC). This survey presents two main advantages: a high number of stars are observed in a large number of filters, i.e. Johnson UBVRI, and data from bright stars which cannot be observed in other programs due to saturation is obtained here.
We reduced the raw images and extracted the photometry with a semi-automatic pipeline based in GNU Astronomy Utilities (Gnuastro) and Python, calibrating them using homogenous photometry of Local Group dwarf galaxies and globular clusters

from the large database created by P.B. Stetson through a standardized method, therefore obtaining homogeneus photometry in the five Johnson optical bands.

Tidally excited oscillations in the OGLE heartbeat stars sample

Marcin Wrona, Piotr A. Kołaczek-Szymański, Szymon Kozłowski, Milena Ratajczak

Heartbeat stars (HBSs) are a subclass of the ellipsoidal variables with an eccentric orbit. Brightness variations of those systems are caused mainly by tidal deformation of at least one component, and they are most clearly visible near the periastron passage. The name of this type of variable stars refers to the most characteristic shape of the light curve, which is similar to an electrocardiogram signature. As a result of searching for HBSs in the Optical Gravitational Lensing Experiment (OGLE) project database, we have classified a sample of 991 candidates of those systems, which increased the number of cataloged HBSs fivefold [1].

The sample consists of two groups of HBSs with different physical properties. The main difference between the two groups is the evolutionary status of the primary. The first group of about 100 systems contains a hot main sequence or a Hertzsprung gap primary, while the second group of about 900 systems consists of a red giant which is located on the red giant branch or asymptotic giant branch, or less frequently on the horizontal branch. Orbital periods of our HBSs range from about 3 as far as 1250 days with the median of about 265 days and the eccentricities distribution reach even 0.8 with the median about 0.24.

The gravitational interactions between components of a binary system can induce tidally excited oscillations (TEOs). These oscillations, contrary to self-excited pulsations of the star, appear at frequencies exactly equal to integer multiples of the orbital frequency, therefore they phase well with the orbital period. In our sample of the HBSs, we found 52 systems exhibiting at least a single TEO [2], which is 5% of the whole sample, while the total number of detected TEOs amounts to 78. This sample of TEOs is the largest homogeneous sample of this kind known so far, which allowed us to statistically investigate the dependence between parameters like the TEO's orbital harmonic number, eccentricity, and the amplitude of a TEO.

Overview of the OGLE Collection of Variable Stars

Marcin Wrona & The OGLE Team

Optical Gravitational Lensing Experiment (OGLE) [1] is a long-term, large-scale variability survey monitoring dense stellar regions of the Galactic bulge, Galactic disk, and Magellanic Clouds. The project has discovered, classified, and published over one million variable stars of various types, increasing the number of known variables by one order of magnitude over the last three decades.

Our collection of periodic objects consists of about 500,000 eclipsing and ellipsoidal binary systems and over 500,000 pulsating stars, including over 400,000 long period variables (Miras, semi-regular variables, OSARGs, long secondary period variables), about 14,000 Cepheids (classical, type II, and anomalous), over 126,000 RR Lyrae-type stars, and about 27,000 delta Scuti stars.

The OGLE Collection of Variable Stars is characterized by very high levels of completeness and purity, for each star we publish high-quality time-series photometry obtained in the standard I- and V-band filters and these data led to many discoveries in various fields of astronomy.

Here, we present a quantitative summary of a periodic part of the collection and the top results obtained based on the cataloged stars.

[1] Udalski, A., Szymański, M.K., Szymański, G., 2015, OGLE-IV: Fourth Phase of the Optical Gravitational Lensing Experiment, Acta Astronomica 65, 1, 1;