Hvar Stellar Meeting 2023

Variable and Binary Stars in the Era of Big Data and New Instrumentation

18 – 22 September 2023, Hvar, Croatia

Abstract Book

Figure on the cover: Bow figurine from the Hvar galley that was engaged in the naval battle of Lepanto on October 7, 1571 when the galley fleet of the Holy League defeated the Ottoman fleet.

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The Hvar Stellar Meeting 2023 "Variable and Binary Stars in the Era of Big Data and New Instrumentation" is organized jointly by Astronomical Institute of Charles University, Prague, Czech Republic and Hvar Observatory, Faculty of Geodesy, University of Zagreb, Croatia at the occasion of the 40th anniversary of the international Workshop on rapid variability of early-type stars, held at Hvar.

Hvar Astronomical Observatory was originally built as a collaborative project of – at that time Yugoslav and Czechoslovak – astronomical institutions.

The Cassegrain 0.65-m reflector, constructed by Pavel Mayer from the Astronomical Institute of Charles University and equipped with a single-channel photoelectric photometer and the Johnson UBV filters was installed there in the summer of 1972 and the observations with this instrument started on July 29, 1972 and have continued up to the present time. The main observing program was focused on Be stars, however, also selected binaries and CP stars were observed there.

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Petr Zasche (Charles University, Prague, CZ)(co-chair)
Jesús Maíz Apellániz (CAB, CSIC-INTA, Spain)
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CONFERENCE MEETING PLACE: Hotel Amfora, Hvar, Croatia

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an asterisk (*) denote participants of the Hvar 1983 workshop

Abstracts

DECIPHERING CELESTIAL VARIABLES ACROSS THE SKY: LEVERAGING GAIA'S MULTI-EPOCH, QUASI-SIMULTANEOUS ASTROMETRIC, PHOTOMETRIC, SPECTRO-PHOTOMETRIC, AND SPECTROSCOPIC MEASUREMENTS

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Gaia, through its multi-epoch, quasi-simultaneous data encompassing astrometry, photometry, spectro-photometry, and spectroscopy, serves as a formidable tool in unraveling the complexities of variable celestial phenomena over the entire celestial sphere. First, with its astrometric measurements, Gaia gives a depth to this celestial sphere. Then, its precise photometric capabilities enable the make a "living" Hertzsprung-Russell diagram. The cumulative efforts across successive Data Releases, the use of advanced Machine Learning techniques, the studies of specialists on specific variability types and the collaborative engagement of citizen scientists, as well as the integration of data from complementary surveys, collectively culminate in an unparalleled and unprecedented depiction of variable phenomena.

EXTINCTION, THE ELEPHANT IN THE ROOM THAT HINDERS ALL OPTICAL GALACTIC OBSERVATIONS

Jesús Maíz Apellániz

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To the vast majority of astronomers, extinction is simply a nuisance: a nasty effect that hampers the study or directly hides most of the stars in the Milky Way from our view. Therefore, there is a tendency to find quick and dirty solutions to correct for it and continue with the science of the extinguished objects. Unfortunately, on many occasions such solutions yield incorrect magnitudes and colors, hence producing biases in the results. In this talk I will provide a brief historical introduction to the problem and I will describe what works and what does not with respect to extinction corrections. I will pay special attention on how to deal with Gaia photometry.

OPTICAL INTERFEROMETRY: A DETAILED VISION OF STARS FOR A BETTER KNOWLEDGE OF THEIR PROPERTIES

Denis Mourard

Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, France

In this talk, I will give an introduction on modern optical interferometry and demonstrate how this high angular resolution observing technique is able to probe with unprecedented details our favorite astrophysical sources. I will in particular give some details of current stellar physics program. In a second step, I will introduce the recent 6-telescope visible combiner SPICA that starts to operate on the CHARA array in California. This instrument combines a visible spectrograph and a near-infrared fringe tracker. It has been designed to conduct a large and homogeneous survey of stellar parameters across the HR diagram.

PROBING DUST AND GAS AROUND HOT STARS WITH OPTICAL INTERFEROMETRY

Anthony Meilland

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Hot stars are subject to high mass-loss due to radiative winds, fast-rotation, and a high binarity rate. These phenomena pose several challenges for understanding their observational properties and their evolution. Among all astronomical observation techniques, long-baseline interferometry is the only one to provide the milliarcsecond angular resolution necessary to resolve stellar surfaces and close-by environments, thus opening new perspectives on physics of these objects.

The last two decades have been crucial for the development of interferometry in the optical and infrared domains. Most of the achievements come from the construction, scientific operation and constant upgrading in terms of infrastructure and instruments of the two main interferometric facilities: the VLTI and CHARA array. In my talk I will present a selection of results obtained on hot stars, with emphasis on fast-rotation, binarity and the characterization of often complex environments such as gaseous or dusty disks around classical Be stars and B[e] stars and radiative winds of supergiants

MULTI-EPOCH PRECISE PHOTOMETRY FROM THE GROUND: MUDEHaR, MAGNETIC STARS AND EVERYTHING AROUND

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MUDEHaR is an on-going multi-epoch photometric survey with two narrow filters in Hα and the calcium triplet window that uses T80Cam at the JAST80 telescope at Javalambre spanish astronomical observatory. It will obtain 100 epochs/year per field for 20 fields in the Galactic disk, each of two square degrees, for a total of 40 square degrees. Focused on stellar clusters and HII regions including bright stars, it's main objective is to detect tens of thousands OB stars that present emission/variability in Hα on a days-months-years scale, including massive stars with a magnetic field, pulsating stars, and other types of variabl estars. Observations from the first MUDEHaR campaign will soon be available on the web. Here I present some of its singular characteristics such as its extensive dynamic range in magnitudes towards the brightest stars (AB mag 3-17 with S/N$>$ 100); and a powerful resolution capabilityin the sky (0.55 arcsec/pix). I will also present how to access to the data and some useful tools for the treatment of MUDEHaR data. One of the driving objectives of MUDEHaR observations is to identify potential magnetic candidates among massive stars. Only 10%-20% of OB stars present magnetic field, and the origin is still in debate. In this context, I outline here the multi-step process involved inidentifying OB magnetic stars, detailing my involvement in various stages and highlighting the significance of MUDEHaR observations in this process.

BINARIES UNDER THE VIEW OF OPTICAL INTERFEROMETRY

Juraj Jonák and Denis Mourard

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Spectroscopic binary systems provide direct information on stellar mass and structurefrom their mutual interaction. Interferometric observations allow us to reconstruct the orbitprojected on the sky, which alleviate the dependence of mass obtained from spectroscopy on orbital inclination. Furthermore, the combination of angular (from interferometry) andabsolute separation (from spectroscopy) of the components directly provides the distance of the system. Being independent of its parallax, it allows to verify the recent Gaia results. Using the new CHARA/SPICA 6-telescope interferometer operating in the visible domain (600 – 900 nm), our goal is to determine precise values of masses and distances for 54 detached spectroscopic binaries (out of which about half are also eclipsing) over the HR diagram, from early B-type to early K-type stars. To correctly resolve the orbit we plan on observing each target multiple times in different orbital phases. Furthermore, it is necessary to include further complementary data, namely radial velocities determined from spectra and, in the case of eclipsing targets, we can further constrain our model by deriving minima timings from photometric light curves. All these data, interferometric, spectroscopic and photometric, can then be modeled simultaneously. As of August 2023, the SPICA instrument is in its final stages of commissioning and we hope to have our first results during the fall of this year.

OB CARTOGRAPHY OF THE MILKY WAY WITH GAIA AND VARIABILITY IN THE ALS CATALOGUE

M. Pantaleoni González[1,2], J. Maíz Apellániz[1], R.H. Barbá[3], B. Cameron Reed[4] and S. Rodríguez Berlanas[5]

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The "Alma Luminous Star" project is the ongoing development of the most comprehensive Galactic OB star catalogue, now in its third iteration (with ∼20 000 objects to date). The catalogue relies on accurate spectral classifications from decades of literature, and is now been complemented with the high-resolution multi-epoch spectra acquired from the GOSSS, LiLiMaRlin and Gaia-ESO surveys. We are also beginning a systematic search for all the optically accesible OB stars in the Milky Way with Gaia and the GALANTE photometric survey. Using the high-precission astrometric solutions from the latest data release (DR3) of ESA's Gaia mission and the USNO bright star catalogue, paired with a Bayesian algorithm we have computed new accurate distances to single blue massive stars in the ∼4 kpc solar neighbourhood, with better results for this particular population than previous attempts. The new maps of this region of the Galaxy allow us to trace the spiral arm structure, the Cepheus and Sagittarius spurs, the Radcliffe wave, as well as the possible corrugation pattern in the vertical distribution of the disc (which might contain clues about past galactic encounters). A 3D visualization of these maps and example animations can be seen here: https://cloud.cab.inta-csic.es/index.php/s/3Ydqk3e96cFPt2K. We also use the Gaia DR3 photometric dispersions for the ALS III sample to characterize the stellar variability in the Galactic OB population.

LIFTING ASTEROSEISMOLOGY TO HIGHER DIMENSIONS: FROM GROUND- TO SPACE-BASED DATA

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We are celebrating 50 years of Hvar Observatory. With this, the observatory is older than the field of "Asteroseismology". First mentions of "stellar seismology" by Eric Fossat date back from the early 1980s and the term Asteroseismology became common since Joergen Christensen-Dalsgaard named our research field as such during a conference in Meudon in 1984 (the year I started my bachelor studies in mathematics). In this talk we will remind ourselves of the challenges of ground-based asteroseismology before lifting the field to the space era that led to so many successes the past decade. While the nominal Kepler space telescope so far delivered the best data for asteroseismology, we highlight the value of combined all-sky ground-based spectroscopy, Gaia astrometry, and TESS space photometry. We end with an outlook for the future of asteroseismic applications offered by the ESA PLATO space mission and efforts to improve the theory of stellar oscillations in fast rotators.

FUNDAMENTAL PROPERTIES OF BINARY HOT SUBLUMINOUS O/B STARS OBSERVED FROM SPACE

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Hot subdwarf stars represent one of the most enigmatic stages of stellar evolution. Theory shows they likely formed from red giants that lost their outer hydrogen envelopes due to Roche lobe overflow and common envelope interactions with a nearby companion. Observations seem to support this idea as the large majority of hot subdwarfs are, in fact, in binaries. Many hot subdwarfs show photometric variations, and detailed studies of their light curves help constrain stellar parameters through asteroseismological analyses or binary light curve modeling. Time–series photometry from recent space–based missions like em Kepler, em K2, and em TESS, has revolutionized work in this area and led to discoveries of systems that might shed further light on how substellar objects affect stellar evolution, whether planets can survive the red giant stage of their host stars, and how many Type 1a supernovae progenitor binaries exist in our Galaxy. In this talk, I will present a general overview of hot subdwarf stars, review their broader significance to astronomy, and present the results of recent studies to unlock their mysteries using space–based observatories.

EXPERIENCE WITH FITTING OF MULTI-TECHNIQUE OBSERVATIONS (WITH EXAMPLES: QZ CAR, δ ORI A, β LYR A, (216))

Miroslav Brož

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Multi-technique observations in the case of stellar applicationsmight include: absolute astrometry, relative astrometry, RV, eclipse timings, eclipse durations, interferometric visibility, closure phase, triple product, light curves, relative spectra, or absolute spectra. In the case of solar-system applications, also: adaptive-optics silhouettes, direct imaging, light curves with illumination/scattering, angular velocity, or occultations. However, all these datasets are 'never' in a perfect agreement. In order to identify the reason(s), it is necessary to identify 2 (or more) critical parameters. An extensive grid of models should then be computed, i.e., not a simple χ^2 map, but a convergence. Some of the parameters might be fixed; others must be free. Some of the parameters must be pre-computed, especially if correlations are expected (e.g., between the orbital period P and oblateness C_{20}), in order to be close to a statistically significant, i.e., *not/* local, minimum. Individual χ^2 contributions must be plotted, not only the total. Only then, a 'tension' between individual datasets can

be clearly seen. Ideally, one should also know a state of the respective instrument ('night log'). As examples, where this kind of analysis was performed, we will present QZ Car (Brož et al. 2022), δ Ori A (Opluštilová et al. 2023), β Lyr A (Brož et al. 2021), or (216) (Brož et al. 2021). A key question is, whether the underlying model is sufficient or not. Currently, the dynamics includes not only Kepler, but all N-body perturbations, mean-motion resonances, secular resonances, PPN, multipole expansion of the central body, internal tides, or external tides. Recently, we also improved our modelling tools by implementing the polygonal algorithm(Vatti 1992, Prša et al. 2018, Brož et al. 2023), which computes light curves exactly by accounting for partial eclipses and partial visibility of polygons, or the so-called 'cliptracing' algorithm (Brož et al. 2023), which computes synthetic images exactly by clipping of polygons by polygons (i.e., pixels).

BLUE LARGE AMPLITUDE PULSATORS – THE BINARY CONTEXT OF THEIR ORIGIN AND LIFE

Andrzej Pigulski, Piotr Kołaczek-Szymański, Krzysztof Kotysz, Piotr Łojko, Kacper Kowalski, Marta Święch, Krzesimir Knobloch, Mateusz Wojtasik

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Blue large-amplitude pulsators (BLAPs), a distinctive group of pulsating stars, were discovered a few years ago and currently number around 70 identified members. These stars exhibit pulsation periods ranging from 15 to 60 minutes, characterized by non-sinusoidal light curves with peak-to-peak amplitudes of 0.2 to 0.4 mag in the V band. Their unique saw-tooth light curves bear resemblance to those of RRab and high-amplitude δ Sct stars, suggesting a fundamental radial mode of pulsation. This hypothesis was confirmed through time-resolved spectroscopic observations. In the Hertzsprung-Russell (H-R) diagram, BLAPs are located between hot massive main-sequence stars and hot subdwarfs. Unraveling the evolutionary phase of BLAPs stands as a significant challenge. To address this, five distinct evolutionary scenarios have been proposed to elucidate the origin of BLAPs. Crucial for these scenarios is the notion that these stars are, or were, members of binary systems. Using data collected from the TESS mission and complemented by ground-based photometric observations, we have discovered the binary nature of HD 133729. This system consists of at least two stars, a BLAP and a late B-type main-sequence star, representing the first case of a BLAP in a binary system. In addition, another BLAP shows clear signs of binarity, manifested by cyclic changes in the $O - C$ diagram for the pulsation period. This phenomenon was explained using the light travel time effect in a wide binary system. In our presentation, we will summarize the current findings related to the binarity of BLAPs and discuss them in the context of the proposed evolutionary scenarios.

APSIDAL MOTION IN (MASSIVE) BINARIES

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One of the most efficient and reliable observational technique allowing to probe the internal structure of a star is the determination of the apsidal motion in close eccentric binary systems. This secular precession of the binary orbit's major axis depends on the tidal interactions occurring between the two stars. The rate of this motion is directly related to the internal structure of the stars, in particular their inner density profile. Based on radial velocity and light curve measurements made over a long timescale, the rate of apsidal motion can be constrained, together with the fundamental parameters of the stars. Comparing the observationally determined parameters to theoretical models of stellar structure and evolution then constrains the internal structure of the stars. This powerful technique has been known for years but has been seldom applied. We are reviewing its interest and reveal recent results. While standard 1D stellar evolution models predict stars having a smaller internal stellar structure constant, that is to say, stars having a smaller density contrast, than expected from observations, we demonstrate that the addition of turbulent mixing inside the models helps to solve, at least partially, this discrepancy. Whether this additional mixing might be fully explained by rotational mixing is still under investigation. Ongoing studies with the non-perturbative code MoBiDICT show that the perturbative model assumption is not justified in high distorted cases, in which cases the apsidal motion is underestimated, exacerbating even more the need for enhanced mixing inside the models.

PREDICTIONS OF THE EFFECT OF CLUMPING ON THE MASSIVE HOT STAR WIND PROPERTIES

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There are several observational diagnostics which are commonly used to determine the wind mass-loss rate. Typically used tracers of the mass-loss rate are the shape of the emission line profiles in the X-ray domain, the strength of the ultraviolet P–Cygni lines in the UV domain, the H emission line in the optical region, and the strength of the infrared recombination lines and radio excess. Ideally, all these diagnostics should give the same mass-loss rate for the same star, which should also agree with theoretical predictions. However, these values may differ by one or more orders of magnitude. Consequently, this can have a drastic effect for the predicted (and actual) evolution of massive stars. These discrepancy between the individual mass-loss diagnostics may be most likely attributed to the influence of the small scale wind inhomogeneities (i.e. clumping), which are one of the most important ingredients for reliable mass-loss rate determination. In this talk the most striking challenges in observational and theoretical studies of the massive star winds will be presented. The critical uncertainties in mass-loss rate determination that are mostly connected with clumping will be discussed. The new sophisticated 3–D model of radiation transfer in inhomogeneous expanding media which we developed in order to elucidate the physics of stellar winds and improve classical empiric mass–loss rate diagnostics will also be presented.

WHAT ARE BE STARS? AND HOW DO THEY TICK? A JOURNEY OF EXPLORATION

Dietrich Baade

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If Be stars were defined by two handful of properties, each of which is shared by 60% of all Be stars, Be stars would hardly exist. If instead the difference between B stars at large and the subclass of Be stars is fully characterized by the two most prominent observational symptoms of Be stars, namely (i) the presence of a circumstellar disk and (ii) the complex temporal patterns of the disk-feeding process, the combination of rapid rotation and multi-mode nonradial pulsation suffices as the explanation of this so-called Be phenomenon.

It is widely believed that the rapid rotation of (most or even all) Be stars is due to spin-up in an interacting binary. But, in order to understand what makes these progenitors develop a circumstellar disk, the subsequent evolution as quasi-single stars must also be taken into account. The angular momentum (AM) rising from the core probably causes an angular-momentum (AM) crisis in the outer layers. This process may be instrumental in selecting the pulsation modes of Be stars. Perhaps, it even contributes to the driving of the pulsations.

Multi-mode nonradial pulsation explains the complex temporal mass-loss pattern observed in Be stars. The central mechanism involves difference frequencies that are shared by multiple pairs of pulsation modes so that their energies and AM can be bundled to power mass-loss outbursts. Through the associated AM loss, the pulsations prevent the star from becoming rotationally unstable. Differences of difference frequencies may control the en/disabling of such mass-loss cycles. Many of the governing difference frequencies may be too low to be detectable in single-season data.

To date, no other mechanism has claimed to achieve a similarly broad qualitative explanation of the Be phenomenon.

HIGHLIGHTS OF A HALF CENTURY OF THE UBV PHOTOMETRY AT HVAR

Hrvoje Božić[1] and Petr Harmanec[2]

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A brief summary of a half century of UBV photoelectric observations of Be stars, various binaries, and CP stars is presented. All observations were carefully reduced to the standard Johnson system, based on robust averages of original individual UBV observations of the Johnson primary, and selected secondary standards.

Hvar photometry helped to realization that all Be stars are light and colour variables on several distict time scales, and to classification of several types of long-term variability. In a number of cases, periodic changes with the orbital period of known binaries were found after prewhitening the data for variations on other time scales.

Many studies of individual objects have been published and two large summary reports on these observations are in preparation.

TESS PHOTOMETRY + SIMULTANEOUS SPECTROSCOPY OF CLASSICAL Be STARS: PULSATION, MASS EJECTION, AND DISK FORMATION

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Classical Be stars are massive main-sequence rapid-rotators that mechanically eject material, forming gaseous circumstellar 'decretion' disks. These stars are multi-mode pulsators, and evidence is mounting that pulsation plays a key role in the mass ejection mechanism. Analysis of TESS photometry for ∼1,000 Be stars reveals many types of variability, including stochastic variability, coherent and variable pulsation in both low and high frequencies, groups of closely-spaced frequencies and combination modes, and discrete mass ejection episodes. These systems are sufficiently complex that photometry alone, no matter how precise, is often ambiguous. We have therefore been monitoring ∼200 Be stars with time-series optical echelle spectroscopy contemporaneous with their TESS observations. These spectra probe the star and circumstellar environment in ways that are complementary to TESS. Combining these datasets allows for the characterization of: 1) stellar pulsation modes, 2) mass ejection events (and the concurrent changes in pulsational patterns), 3) the initial asymmetric distribution of ejecta and its evolution (on timescales of hours to days) into a circumstellar disk, and 4) stellar properties including rotation rate, mass, radius, and inclination angle. SPH and radiative transfer models are being developed to describe the behavior of the ejecta after it is launched into orbit, allowing us to quantify the efficiency of viscosity and the amount of mass and angular momentum that is ejected and subsequently carried out of the system. The simultaneous space photometry and spectroscopy provide tight constraints, as various regions in the disk are probed by different observational features.

GAMMA CAS PHENOMENA AS A LINK TO MASSIVE STAR EVOLUTION

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The well known Be category gathers early-type stars that show or have shown Balmer emission lines, attributed to the presence of a circumstellar decretion disk. Their fast rotation is often considered to be linked to past binary interactions, with the current companion being a compact object (WD, NS) or a stripped He-star. In the X-ray domain, Be stars have been shown to display various properties, with hard and bright thermal sources categorized as "gamma-Cas" analogs. In this contribution, we will present the latest information obtained on these objects, assessing their incidence as well as their potential multiplicity.

DETECTION AND CHARACTERIZATION OF Be+sdO(sdB) BINARIES

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Close binary interactions may play a critical role in the formation of the rapidly rotating Be stars. The gainer star may spin up by the accretion of mass and angular momentum through mass transfer, while the mass donor star may strip off its envelope to form a hot and faint helium subdwarf star. Here we present our works of searching for Be+sdO(sdB) binary systems using the far-UV spectroscopy from the International Ultraviolet Explorer by calculating the cross-correlation functions of the observed and model spectra. A re-assessment of these binaries from Hubble Space Telescope FUV observations led to the direct detection of the hot companions in ten of the Be+sdO systems. Further analysis of such binaries yields the temperatures and radii of the hot sdO stars. A comparison of these measurements to evolutionary tracks indicates that the sdO stars occupy the relatively long-lived helium core burning stage. We also report our ongoing long-term optical spectroscopy programs to monitor these Be+sdO binaries to determine their orbital periods and physical properties. The measured features are inconsistent compared to ones of the model prediction, suggesting that the current models may need further development to capture all the evolutionary processes of these binary systems.

THE IMPACT OF SPACE-BORNE SURVEYS ON ECLIPSING BINARY SCIENCE

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The last couple of decades have transformed time domain astronomy in general, and eclipsing binary science in particular. Overcoming the adverse effects of Earth's atmosphere and Earth's diurnal cycle allows us to procure data of near-uninterrupted cadence. Coupled with an increased precision of photometric instruments onboard space-borne surveys that reaches 10ppm, such survey data allow us to study eclipsing binary components to unprecedented level of detail. In this review I will showcase some of the most spectacular findings of the last two decades and evaluate the impact space-borne surveys have had on the eclipsing binary field. With MOST, CoRoT and Kepler in the past, TESS in the present, and PLATO in the future, these are golden times for time domain astronomy.

ECLISPING BINARY SYSTEMS AS PRECISE AND ACCURATE DISTANCE INDICATORS

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Detached eclipsing offer a unique opportunity to measure stellar parameters (mass radius, etc.) and together with the surface brightness - color relation to measure directly distances in a volume of about 1 Mpc. I will discuss the method, its recent applications, and perspectives for the future in the context of calibration of the cosmic distance scale and H0 determination. I will laso present our new observatory in Chile, dedicated to study of eclipsing binaries.

MULTIPLY ECLIPSING SYSTEMS IN THE ERA OF SATELLITE TELESCOPES

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Doubly eclipsing stellar systems (i.e. these quadruples of 2+2 architecture containing two eclipsing binaries) were not known 15 years ago. Since then, there were discovered a few hundreds of candidates on such stars. But still only a small fraction of them were proved to be bound and orbit around a common barycenter. In my talk I will show several interesting examples of such stellar systems discovered recently, as well as show what can we learn from studying these multiples.

THE ROTATION OF O-STARS

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We determined the projected rotational velocity of 241 Galactic O-Stars. The determination of stellar rotation is based on 3500 high-resolution multi-epoch optical spectra and is performed by the Fourier Transform technique.The overall vsini statistic peaks at slow rotators (40-100 km/s) with a tail towards increased (100-200 km/s) and fast rotators (200-400 km/s). Compared to single stars, the spectroscopic binaries reveal a strong excess of increased rotators but a strong deficit of fast rotators. It might be plausible that a large fraction of fast rotators are post-merging products.Two thirds of the SB2/SB3 systems are close pairs with orbital periods shorter than 10 days. In most cases, both components are increased rotators, consistent with spin-orbit synchronization. Some have strong vsini differences as expected in a donor-gainer scenario.The remaining third of SB2/SB3 objects have long periods and their separation is sufficiently wide to discard spin-up by tidal friction or mass exchange. For half of these wide systems, one component is an increased rotator and one is a slow rotator. We suggest that the wide-orbiting increased rotators gained their spin from a previous merging event, possibly as proto-star before reaching the main sequence. This might indicate that O-stars are mostly formed from the merging of smaller fragments.

MASSIVE MULTIPLE STARS IN THE ORION BELT (δ, ϵ, ζ ORI)

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The Orion OB1 association includes the closest massive multiple stellar systems, which are most likely precursors of neutron stars, black holes, and consequently gravitational wave sources. We modelled the brightest member of the OB1b association δ Orionis A. The Gaia DR3 parallaxes of faint stars in OB1b association as well as of the faint component (Ca+Cb) constrain the distance of the system to (382 ± 8) pc. For the first time, we were able to constrain the orbit of the tertiary (Ab)–to 55 450 d or 152 yr –using variable γ velocities and new speckle interferometric measurements, which were published in the Washington Double Star Catalogue. We applied a two-step disentangling method to a series of spectra in the blue region (430 to 450 nm), and detected spectral lines of the secondary (Aa2). We used eight seasons of photometry from the BRITE satellites together with astrometry, radial velocities, eclipse timings, eclipse duration, spectral line profiles, and spectral energy distribution to refine radiative properties. Consequently, we found that the component masses according to the three-body model are 17.8, 8.5, and 8.7 $M_\odot$, for Aa1, Aa2, and Ab, respectively, with the uncertainties of the order of 1 $M_\odot$. The components, classified as O9.5 II +B2 V +B0 IV, have radii of 13.1, 4.1, and 12.0 $R_\odot$, which means that δ Ori A is a pre-mass-transfer object. The frequency of 0.478 cycles per day, known from the Fourier analysis of the residual light curve and X-ray observations, was identified as the rotation frequency of the tertiary. δ Ori could be related to other bright stars in Orion, in particular, ζ Ori, which has a very similar architecture, or ε Ori, which is a single supergiant, even though it shares the same birth environment as the multiple systems. The Gaia DR3 proper motions of their faint components enable us to study possible interactions between these systems. In particular, ε Orionis might be the result of mass transfer or a merger. To construct a common formation scenario, accurate diameters, orbital alignments and a possible presence of circumstellar matter must be measured by long-baseline interferometry.

IMPROVED ORBITAL ELEMENTS OF THE TRIPLE SYSTEM δ CIRCINI

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δ Cir is a hierarchical triple system that consist of an eclipsing binary and a more distant third star. All three components are OB stars. Moreover, there are some signs that the third star is also a binary. Using spectra of the system, I calculated a more precise mutual period of the eclipsing binary and the third star as well as its other orbital elements. I also combined spectroscopic and photometric data to determine more precise parameters of the eclipsing binary.

HD 93695 - A REMARKABLE B3 STAR BINARY SYSTEM

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HD 93695 served as one of the comparison stars in differential observations of quadruple system QZ Car, but was found to be a low-amplitude ellipsoidal variable from the TESS observations. 18 echelle spectra of HD 93695 were obtained in 2021 and 2022, covering range of 4500 Å to 8900 Å, indeed confirming that the object is double-lined spectroscopic binary with the period of 8.0819 d. Reduction of spectra was carried out, together with the measurement of radial velocities. While modeling the HD 93695 system, inconsistencies were found, which might be attributed to the presence of the third absorption component found in the Hα profiles between the lines of primary and secondary components in two spectra taken in similar orbital phases.

NEW ANSWERS TO OLD QUESTIONS IN STELLAR ACTIVITY

Katalin Olah, Lídia van Driel-Gesztelyi, Zsolt Kővári, Krisztián Vida, Levente Kriskovics, Bálint Seli, Anna Görgei

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Exactly 36 years + 1 day ago, at the Second Hvar Astrophysical Colloquium, Hvar, Yugoslavia (21 – 25 September 1987), I gave a talk about starspot modeling. In this review I will cite most of the magnetic activity features which were mentioned in that talk from a 36 years' perspective, with special attention on binary stars. The developments of the measuring and computational facilities helped to solve quite a few questions concerning starspot temperatures, lifetimes and differential rotation, and fostered new ones. Only one important

factor is beyond control by any means, and this is time. The past decades showed the importance of the long-lasting time-series observations to study the solar and stellar activity cycles. Finally, thanks to the then unforeseen techniques like massive and accurate space photometry, results will be presented about flare characteristics of active stars, and in case of close binaries the possibility of spot eclipse mapping by the secondaries.

CONTEMPORARY VIEW OF STELLAR SURFACE STRUCTURES

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Photospheric spots are the main tracers for detecting surface activity of stars. However, with the exception of the Sun, we could only study the surface structure of stars indirectly for a long time. From the photometric data series, the rotation period or the cycles can be examined with the help of the spots, but we do not get spatial information about the surface structures. In contrast to photometric time series, spectroscopic time series have already provided indirect (although still limited) information on the size and structure of starspots, thanks to the development of Doppler imaging techniques in the last 40 years. And it's only been 7 years since we saw the first direct image of a spotted star thanks to high-resolution optical/infrared interferometry. In my presentation, I will review the most important relevant results of the past decades, the possible new directions of stellar activity research, the actuality of which is also contributed by scientific endeavors of public interest, such as the search for extraterrestrial life, or e.g. unfolding the relationship between climate change and solar activity.