VFTS2024 Abstracts

Day 1 Monday 16th September

9.15 9.45 **BLOeM introduction**

Tomer Shenar & Julia Bodensteiner

Introduction to the BLOeM project. A final characterisation of the sample and description of sample selection

9.45 11.00 **Early BLOeM highlights**

Sara Rodríguez Berlanas, Jaime Villaseñor, Julia Bodensteiner, Nikolay Britavskiy, Lee Patrick

Highlights from multiple ongoing BLOeM multiplicity studies.

11.30 - 12.00 **Assessing the binary interaction products in the MCs**

Norbert Langer

With new grids of binary evolution models from detailed and rapid codes, and corresponding population synthesis predictions, and with new observations of the SMC WR stars, we compare model results and observations for OB runaway stars, Be stars, Be-XRBs, WR stars and OB-BH binaries.

12.00 12.45 **Binary properties of stripped helium stars in the Magellanic Clouds**

Ylva Götberg

A third of all massive stars are expected to lose their hydrogen-rich envelopes through binary interaction, leaving the hot and compact helium core exposed. By observing the spectra of stars exhibiting excess UV radiation compared to main-sequence stars in the Magellanic Clouds, we could identify a first sample of stars consistent with being helium-core burning stripped stars. We estimated their masses between 1.5 and 8 Msun, which is consistent with progenitor stars of masses 5-25 Msun.

Here, we present an update for the substantial observational effort to constrain the orbital parameters for a subset of these objects using radial velocity monitoring with the MagE spectrograph mounted on the Magellan/Baade 6.5 meter telescope at Las Campanas Observatory, Chile. Starting from systems where the stripped component dominates the optical spectrum, we identify orbital periods of order hours to years. These ranges are suggestive of both envelope-stripping mechanisms at play: (1) mass transfer, which is expected to result in long periods, and (2) successful common envelope ejection, which should tighten the orbits. Constraints on the companion masses reveal potential compact object companions.

12.45 1.30 **Evolved massive stars in young open clusters**

Chen Wang

In this talk, I will focus on our recent research into evolved stars in young Magellanic Cloud open clusters, including evolved massive binaries that comprise a compact object paired with a main-sequence star, red supergiants and blue supergiants. Our aim is to provide meaningful constraints on binary physics through a comparison of our theoretical models with the latest observational data, and to potentially outline a framework that could guide future observational efforts.

2.30 3.30 **Breakout: BONNSAI 2.0 - The Next Generation**

Vincent Bronner

The BONN Stellar Astrophysics Interface (BONNSAI) is a Bayesian inference tool for comparing stars with stellar evolution models. BONNSAI is still actively used in the VFTS community and beyond for inferring stellar model parameters from observational quantities of massive stars.
We present our current development of the next generation of BONNSAI. We have re-implemented BONNSAI in a Python framework, which offers a more flexible interface. The interpolation of the stellar models employs state-of-the-art machine-learning emulators, which allow for efficient, on-the-fly predictions of stellar observables that may also be used outside the BONNSAI framework. The posterior probability distribution of the model parameters (traditionally initial mass, age, and initial rotation velocity) is now sampled using a Markov Chain Monte Carlo (MCMC) algorithm. The new implementation significantly speeds up the inference time and allows for the usage of BONNSAI on much larger datasets and locally on any computer. The BONNSAI web-interface will be retained.
We plan a live demonstration of the new BONNSAI tool during the VFTS meeting to showcase the new features and to gather feedback from the community.
Having the Python implementation of BONNSAI offers a more flexible interface, which enables us to extend the tool in the future. Such features include the possibility to more easily include new grids of stellar models, expand the model parameter space (e.g. by physics parameters such as convective core overshooting), and use different likelihood functions that can be linked more directly to observations and atmosphere modeling. Ultimately, we aim to include binary star evolution models into the BONNSAI framework.

4.00 4.45 **Whispering in the dark: Faint X-ray emission from black holes with OB star companions**

Koushik Sen

Despite the potential of GAIA to reveal a large population of black holes (BHs), only a few BHs have been discovered to date in orbit with luminous stars without an X-ray counterpart. Black holes in orbit with main sequence companions seldom form accretion disks, from where observable X-ray flux is conventionally thought to be produced. Yet, even without accretion disks, dissipative processes in the hot, dilute and strongly magnetised plasma around the BH can lead to radiation. Particles accelerated through magnetic reconnection can produce non-thermal emission through synchrotron. We study the X-ray luminosity from this large unidentified population of black holes using detailed binary evolution models computed with MESA, having initial primary masses of 10-90 Msun, orbital periods from 1-3000 d. We show that a significant fraction (up to 50%) of the gravitational potential energy can be converted into non-thermal radiation for realistic particle acceleration efficiencies. A population synthesis analysis predicts at least 28 (up to 72) BH+OB star binaries in the Large Magellanic Cloud (LMC) to produce X-ray luminosity above 10**31 erg/s, observable through focused Chandra observations. We identify a population of observed SB1 systems in the LMC comprising O stars with unseen companions above 2.3 Msun that aligns well with our predictions and may be interesting sources for follow-up observations. The peak in the luminosity distribution of OB companions to these faint X-ray-emitting BHs lies around log(L/Lsun) ~ 4.5-5. Finally, the X-ray luminosity from hot accretion flows around the faint BH can be ~one order of magnitude above the typical X-ray luminosity expected from embedded shocks in the stellar wind of the OB star companion. Finding this population of faint X-ray-emitting black holes will help us understand the evolution from single to double degenerate binaries and the progenitors of gravitational wave mergers.

4.45 5.15 **Possible Binary Origin of Be Stars**

Ankur Jyoti Kalita

The rapid rotation of Be stars has long puzzled scientists, with various theories proposed to explain its origin. Recent work has established that the possibility of a primordial origin faces strong criticism when confronted with observation, leading to the emergence of two alternative hypotheses: a single-star origin and a binary origin. In the single-star scenario, efficient angular momentum transport from the core can spin up the star, bringing it closer to near-critical rotation. Conversely, the binary origin hypothesis posits that Be stars acquire their rapid rotation through mass and angular momentum transfer during interactions with a companion.

If binary interaction is indeed responsible for the observed rapid rotation, then a fraction of the Be stars should appear single as a result of a supernova kick from its companion that disrupts the system. The velocity distribution of the single Be stars will carry signatures of the pre-supernova orbital parameters and the geometry and the kick imparted during the supernova.

In this contribution, we present an analysis of a sample of single Be stars located in the Galactic disk and show that the velocity distribution shows a distinct double peak. Comparing our results with the predictions from rapid binary population synthesis, we demonstrate that the broad low-velocity peak around 30 km/s can be explained in terms of Be stars originating from binary systems. A purely binary population fails to predict the observed high-velocity peak at around 80 km/s which could be due to Be stars ejected dynamically from its parent cluster or through a two-step ejection process where the Be-binary system is ejected dynamically, followed by disruption of the binary due to supernova. Finally, we discuss our results in the context of the origin of the rapid rotation in

Be stars and conclude that the observed velocity distribution indicates that binary interactions are responsible for almost 80% of all known Be stars.

5.15 5.45 **He-rich O-type stars as potential tracers of past binary interaction**

Carlos Martínez-Sebastián

In recent years, it has been shown that single evolutionary models are unable to explain some of the physical properties of massive stars. Despite the effort made to make rotational mixing and other proposals reproduce the observational parameters, massive stars' evolution remains an open question. In this work, we study the nitrogen and helium abundances of about 200 main sequence O stars of the IACOB project with projected rotational velocities below 150 km/s. As a result, we find a subsample of about 30 stars that show an unusually high helium abundance relative to the nitrogen abundance. These results do not follow the typical CNO cycle evolution and are not explainable with any current single stellar evolutionary model. As a possible explanation, we propose that this sample is the result of past mass transfer events with post-main-sequence donors and main-sequence accretors. This theory is also supported by statistical differences in the current or past multiplicity clues between the two groups. In addition, we make a preliminary approach to the study of a larger sample of O stars with higher projected rotational velocities, finding statistical behaviors compatible with the proposed hypothesis.

Day 2 Tuesday 17th September

9.00 9.45 **A comparative study of 1D and multi-dimensional atmospheric modelling approaches for O and WR stars**

Gemma Gonzalez-Tora

The presence of stellar outflows in hot, massive stars should be taken into account to model their spectra and produce accurate predictions of their evolution and death. Advancements in hot star atmosphere modelling have enabled sophisticated predictions of O and WR star spectra, driving much of today's research on massive stars. Yet, many open questions and unsolved puzzles remain, prompting questions on whether our typical assumptions for 1D, spherically symmetric and stationary atmospheres are sufficient. Recent multi-dimensional, radiation-hydrodynamical (RHD) simulations of massive stellar atmospheres help to get a better understanding of the complexity involved in the onset of radiation-driven winds. However, the high computational costs and necessary approximations will hinder their widespread use in spectral analysis for the foreseeable future. We have compared both 1D and multi-dimensional modelling approaches on a combined effort to understand the shortcomings and strengths on the state-of-the-art atmospheric modelling for hot massive stars. In this talk, I will discuss how we can approximate insights from multi-dimensional calculations in 1D stellar atmosphere models and how this affects our current spectral diagnostics.

9.45 10.30 **Mass loss implementation of Very massive stars**

Gautham Narayana Sabhahit

Very massive stars (VMS) up to 200-300 Msun have been found to exist in the Local Universe. The spectral appearance of these VMSs closely resemble those of emission-line dominated Wolf-Rayet (WR) stars of the nitrogen sequence (WN), but with hydrogen (H) making them likely still core-H burning objects. The strong emission lines of these WNh stars are suggestive of strong stellar winds capable of substantially affecting the final fates of these stars. We use the Potsdam Wolf-Rayet (PoWR) stellar atmosphere code to run hydro-dynamical simulations of hydrogen-rich VMS winds and study their mass-loss properties in close proximity to the Eddington limit. Informed by these hydro-models and the Monte-Carlo models by Vink et al., we develop a new mass loss framework within the 1D stellar evolution code MESA, specifically tailored to study the evolution of VMSs. I will outline the evolutionary characteristics, chemical yields, and ultimate fates of VMSs, emphasizing the crucial role played by stellar winds in establishing a metallicity threshold for the occurrence of PISNe.

10.30 11.00 **Episodic mass loss discovered in two extreme RSG in the LMC**

Gonzalo Munoz-Sanchez

Red supergiants (RSGs) are evolved massive stars with initial masses between 8-25 Msun, which are assumed to be progenitors of Type II Supernova (SN). However, the lack of observations of Type II SNe produced by RSGs with an initial mass greater than 18 Msun creates a conflict. The well-known “RSG problem” suggests that massive RSGs either collapse directly into a black hole without an explosion or evolve to warmer stages, where they end their lives in a post-RSG phase. Yellow supergiants with circumstellar dust have already been proposed as post-RSG candidates. Nevertheless, the physical process that induces an RSG to become a warmer supergiant is currently unclear. According to current evolutionary models, the standard RSG winds are not strong enough to make them evolve to a warmer stage. Moreover, other processes might be needed to strip their envelopes, such as episodic mass-loss or binary interactions. In this talk, we present an in-depth study of two of the largest, most massive, and luminous RSGs in the Large Magellanic Cloud (LMC) that show evidence of significant mass loss and interaction with their circumstellar material (CSM). One of the RSGs is surrounded by clumpy shocked material, and its walkaway status places it as the first extragalactic candidate RSG with a bow shock. Furthermore, multi-epoch spectroscopy revealed recent episodic mass loss during a minimum in the light curve, exhibiting similarities to the Great Dimming of Betelgeuse. Our other RSG has recently changed from a late-M type to show spectral features of regular sgB[e], such as asymmetric P-Cygni profiles and emission in Fe II, hydrogen, and Ca II triplet, plus forbidden emission lines. The loss of periodicity in the light curve and the change in V-I color propose significant changes in the atmosphere, which might be associated with a severe episodic mass-loss event. Studying this new stage would shed light on the origin of sgB[e], the post-RSG evolution, and the connection with the RSG problem.

11.00 11.30 **Exploring binarity and pulsations in massive stars: towards a comprehensive understanding**

Federica Nardini

The majority of massive stars are found in binary or multiple systems. Binarity introduces complexities in the physics of OB-type stars, yet it also offers significant advantages, the most important being the ability to determine the dynamical masses of the component stars. Correctly modelling the internal structure of massive stars is crucial, given their role as progenitors of supernovae and compact objects. Asteroseismology serves as a valuable tool. The combination of binarity and asteroseismology remains underutilised but holds immense potential. These include: deriving spectroscopic masses from binarity and core mass and interior rotation profiles from asteroseismic modelling and applying more stringent constraints on the age and mass of a star. In this talk, I will outline the initial results of my PhD project, which involves spectroscopic investigation and preliminary asteroseismic modelling of B-type stars within four young open galactic clusters of varying ages (13-30 Myr). I will discuss both the observed and intrinsic binary fraction of each cluster, shedding light on the prevalence of binary systems and their orbital parameter distributions. These results contribute to our understanding of binary incidence in intermediate-age open clusters, building upon previous surveys. Furthermore, I will address the characterisation and identification of B-type pulsators within the same four galactic clusters. This marks the first attempt at binary-asteroseismic modelling of these systems, providing new perspectives on previously identified binary systems. By characterising binary systems spectroscopically and conducting asteroseismic modelling, we aim to gain deeper insights into the fundamental properties of massive stars and refine our understanding of stellar evolution, including their interior rotation profiles and core masses. The goal of this work is to delve into the interplay between binary interactions and pulsations to better comprehend massive stars, especially a comparison of pre- and post-interaction binary systems.

2.15 3.00 **Probing massive stars with sub-SMC metallicity in the Magellanic Bridge**

Elisa Schösser

The fate of massive stars depends severely on the strength of their inherent stellar winds. During most of their life, massive stars experience line-driven winds, which strongly vary with metallicity. Yet, robust observational constraints for the mass-loss rate of stars in metal-poor environments resembling early cosmic epochs are scarce. Until recently, stars with metallicities lower than those in the Small Magellanic Cloud (SMC) were only known in compact dwarf galaxies, with observations in such distant locations suffering from limited signal-to-noise ratios and spatial resolution. Recently, we discovered three O stars and several early B-type stars in the Magellanic Bridge - a stream of gas and stars connecting the two Magellanic Clouds. Using newly acquired HST UV spectra combined with archival optical spectra, we measure for the first time the inherent iron abundances and characterize the wind properties of these stars. Our approach involves utilizing detailed expanding non-LTE atmosphere models to generate synthetic spectra, which we then compare against optical and novel UV observations. Thereby, we discovered the first nearby massive O star with a severely sub-SMC metallicity, reaching as low as 0.1 Zsol.

3.00 3.30 **Analyzing B supergiants in the SMC**

Matheus Bernini Peron

Through the ULLYSES and XShootU collaborations, we gained access to the largest multi-wavelength spectroscopic datasets for massive stars in the Magellanic Clouds. In this work, we focus on the analysis of B-supergiants (BSGs) within the SMC. They are especially important for both our understanding of massive star evolution and our knowledge on radiatively driven winds. In their temperature regime, a sharp increase of the wind mass-loss rate is predicted to happen due to ionization changes – also known as the bi-stability phenomenon. While such an increase of mass loss is currently the default in stellar evolution calculations, its required physical conditions – e.g., luminosities, metallicities – are still highly unclear. The situation is further complicated by the ambiguous evolutionary status of BSGs. Aiming to address both of these issues, we analyze a representative subsample of early- and late-types BSGs in the SMC using CMFGEN. We determine their stellar and wind properties, from which we obtain the following: (i) Early BSGs are described better by high-overshooting evolution models while the later types agree better with H-shell-burning models. (ii) For the first time in this metallicity regime, we constrain the necessary amount of X-rays required to explain high-ionization lines in the winds of SMC late BSGs. (ii) We find evidence for a clear jump in wind velocities similar to what is found in Galactic BSGs. (iv) Regarding wind mass-loss rates, we find a rather constant trend, being neither compatible with a clear jump nor a monotonic decrease when transitioning towards lower effective temperatures.

3.30 4.00 **New evolutionary clues to understand the nature of massive stars**

Abel de Burgos

Massive stars play a crucial role in the Universe. Their intense UV radiation, hot stellar winds, and extremely energetic life-ends all heavily influence their circumstellar and interstellar medium, becoming important drivers of the dynamical evolution of galaxies. They are the primary source of heavy-element production, contributing to the chemical enrichment of galaxies, and they are also the progenitors of some of the most violent and exotic phenomena in the Universe, such as gamma ray bursts or gravitational waves. Despite their significance, comparisons between observational data and theoretical models of massive stars have given rise to long-standing and new discrepancies that have questioned our understanding of these objects. One of the main uncertainties arises from the overdensity of blue supergiants (BSGs) in the Hertzsprung-Russell diagram where models predict the termination of the main sequence (TAMS). Whether the location of the TAMS has to be redefined, or the overdensity is the result of overlapping populations following different evolutionary paths, is still uncertain. In this talk, I will present the main outcomes of my PhD thesis, which aims at improving this situation by carrying out a holistic empirical study of the physical, chemical, and pulsational properties of the largest spectroscopic sample of BSGs analyzed to date. For this, I combine high-resolution spectroscopic data with Gaia astrometry and TESS photometry of a sample of more than 700 Galactic BSGs. The results provide important clues about the nature of these objects and establish new solid constraints to the evolutionary models of massive stars, narrowing down existing discrepancies.

Day 3 Wednesday 18th September

9.00 9.45 **New O and Be runaways stars found with Gaia DR3**

Mar Carretero-Castrillo

A relevant fraction of massive stars are runaway stars, moving with a significant peculiar velocity with respect to their environment. The runaway origin can be explained by kicks produced in supernova explosions or by dynamical ejection of stars from clusters. Runaway stars can be detected using accurate proper motions and parallaxes such as the ones provided by Gaia. We present here a 2-dimensional method in the velocity space to discover runaway stars among GOSC and BeSS catalogs using Gaia DR3 data. We found 106 O runaway stars, 42 of them with no previous identification as runaways, and 69 Be runaway stars, 47 of them with no previous identification as runaways. We further characterize their velocity dispersion, spatial distribution and runaway percentage as a function of the spectral type. The percentage of runaways is 25.4% for O-type stars and decreases to 5.2% for Be-type stars. The higher percentages and larger velocities found for O-type runaways compared to Be-type ones reinforce the dominance of the dynamical ejection scenario versus the binary supernova one. Our results open the door to identify new high-energy systems or stellar bow shocks among our runaways by conducting detailed studies.

9.45 10.15 **Two waves of massive stars running away from the young cluster R136**.

Mitchel Stoop

A significant fraction of massive stars are observed to be runaway stars moving in the interstellar medium with high velocity (~ 25% for O stars). One of the two hypothesis is that in the first few million years of a cluster's life, these runaways can be created by dynamical interactions between three or more stars (the alternative being the sudden mass loss occurring in a supernova in a binary system). With Gaia Data Release 3, we investigated the massive runaway stars coming from the young and dense cluster R136. A total of 55 massive runaway stars, which reveal two channels of dynamically ejected runaways. The first channel ejects massive stars in all directions and is consistent with dynamical interactions during and after the birth of R136. The second channel launches stars in a preferred direction and may be related to a cluster interaction. A total of 23-33% of the most luminous stars born in R136 are runaways. We show how the dynamical escape fraction of massive stars has so far been underestimated in model predictions. We give implications for the initial mass function of massive stars in R136 and 30 Doradus, how they shape and heat the interstellar and galactic medium, along with their role in driving galactic outflows.

10.15 11.00 **Queen, Oasis, or Bruce Springsteen?**

Jesús Maíz Apellániz

Why do we find some massive stars in well defined clusters and some in loose OB associations? There are three competing mechanisms, as represented by three songs from the bands in the title of this talk. I will review recent results based on Gaia and other surveys that explore the contribution from each one of them.

11.30 12.15 **A Second Search for OB+BH Systems in Tarantula**

Kunal Deshmukh

VFTS 243 was the first quiescent OB+BH system discovered in the LMC as part of the Tarantula Massive Binary Monitoring (TMBM) survey. While it was the only system conclusively characterized, the survey also identified several systems as possible OB+BH candidates. The method of choice to analyze the sample was spectral disentangling - revealing the contribution of the binary companion to the spectrum, or the lack thereof. The primary limitation of the TMBM survey in this context was nebular contamination of certain spectral lines which complicates spectral disentangling. We revisited the OB+BH candidates with IFUs instead of single fibers, enabling local subtraction of nebular lines and making the spectral lines easier to disentangle. In this talk, I will present our analysis and results for a sample of 20 stars observed with GIRAFFE/IFUs and UVES in search of quiescent OB+BH systems.

12.15 12.45 **Hubble Space Telescope images of SN 1987A: Evolution of the ejecta and the equatorial ring from 2009 to 2022**

Sophie Rosu

Supernova (SN) 1987A offers a unique opportunity to study how a spatially resolved SN evolves into a young supernova remnant (SNR). We present and analyze Hubble Space Telescope (HST) imaging observations of SN 1987A obtained in 2022 and compare them with HST observations from 2009 to 2021. These observations allow us to follow the evolution of the equatorial ring (ER), the rapidly expanding ejecta, and emission from the center over a wide range in wavelength from 200 to 1100 nm. The ER has continued to fade since it reached its maximum ~8200 days after the explosion. In contrast, the ejecta brightened until day ~11000 before their emission levelled off; the west side brightening more than the east side, which we attribute to the stronger X-ray illumination emitted by the ER on that side. The asymmetric ejecta expand homologously in all filters, which are dominated by various emission lines from hydrogen, calcium, and iron. From this overall similarity, we infer the ejecta are chemically well-mixed on large scales. The exception is the diffuse morphology observed in the UV filters dominated by emission from the Mg II resonance lines that get scattered before escaping. The 2022 observations do not show any sign of the compact object that is inferred from highly-ionized emission near the remnant’s center observed with the James Webb Space Telescope. We determine an upper limit on the flux from a compact central source in the [O III] HST image. This indicates that the S and Ar emission observed with JWST either originates in the O free inner Si -- S -- Ar zone and/or is strongly affected by dust scattering.

12.45 1.15 **Progenitors of LGRBs: Are single stars enough?**

Rafia Sarwar

Stars more massive than $8M_\odot$ are ignited by nuclear-burning processes of chemical elements in their interior until the formation time of carbon-oxygen core that marks the end of their life cycle.These massive stars strongly affect their surrounding environments through processes such as star formation, stellar winds, ionizing radiation, feedback mechanisms, and core-collapse supernovae. The final fate of evolved massive stars is classically linked to

energetic and luminous transient sources, long-duration gamma-ray bursts (LGRBs). In this work, I present the revised and expanded single-star models using MESA along with new observational comparisons. My study demonstrates the impact of rotation during the evolution of these stars, leading to chemically homogeneous evolution followed by various types of supernova explosions. I also compare these theoretical models with the observed number of LGRBs to date with known redshifts. The comparison reveals a discrepancy between the population of single-star models and observations, most likely because the majority of massive stars are in binary systems, and single-star models alone are insufficient to explain progenitors of LGRB.