Scientific Program and Abstract Booklet

Venue:

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POEMS

Monday, June 24

09:00-09:40 Registration

09:40-09:50 Welcome

09:50-10:10 Michaela Kraus
Physics of Extreme Massive Stars

I. Fundamental parameters of massive stars

10:10-10:55 Lydia Cidale (**invited**)
Determination of fundamental parameters of massive stars

10:55-11:15 Péter Németh
Analysis of Time Series Spectra with Non-LTE Models

11:15-11:45 **Coffee-break**

11:45-12:05 Ronaldo Levenhagen
ZPEKTR - A code for spectral synthesis of massive, fast rotating stars

12:05-12:25 Rodrigo Meneses Pacheco
Spectral numerical methodology to describe the line broadening effect produced by the stellar rotation

12:25-12:45 Raquel Pezoa
Deep learning models for analyzing massive star data: towards accurate and unbiased results

12:45-14:00 **Lunch**

II. Theory of stellar winds of massive stars

14:00-14:45 Michel Curé (**invited**)
Hydrodynamical view of massive stars' winds

14:45-15:05 Roberto Oscar José Venero
Stellar Winds from B Supergiant Stars: Exploring the Delta-Slow Hydrodynamic Solution

15:05-15:25 Melina Carla Fernandez
Hydrodynamic solutions for radiation-driven winds in transitions regions

15:25-15:55 **Coffee-break**

III. Modeling of stellar atmospheres and winds

15:55-16:40 Andreas Sander (**invited**)
Winds of massive stars

16:40-17:00 Nicolas Moens
From multi-dimensional stellar wind models to spectral synthesis

17:00-17:20 Dwaipayan Debnath
3D unified atmospheric and wind models of OB stars

17:20-17:40 Lara Delbroek
Toward spectral analysis with 3D model atmospheres

17:40-18:30 **Welcome Reception**

Tuesday, June 25

09:30-09:50 Gemma Gonzalez-Tora
Combined efforts: 1D vs multi-dimensional atmospheric model comparison for O and WR stars

09:50-10:10 Elisson de Almeida
Probing the weak wind phenomenon in massive stars through hydrodynamical simulations

10:10-10:30 Ignacio Araya
Stellar Atmosphere and Hydrodynamic Modeling with ISOSCELES v2.0

10:33-10:50 Felipe Figueroa-Tapia
Self-consistent formulae for theoretical mass-loss rate and terminal velocity of O stars

10:50-11:20 **Coffee-break**

11:20-11:40 Wagner Marcolino
Massive stars at low metallicity - grids of CMFGEN models

11:40-12:00 Shrriya Kapoor
Spectra and Ionizing Fluxes of Pop III Stars

IV. Be stars

12:00-12:45 Yanina Cochetti (**invited**)
The importance of the infrared spectral data to study Be stars

12:45-14:00 **Lunch**

14:00-14:20 Anahi Granada
The Origins of Be Stars: Investigating the Intra-cluster Environments of NGC 663 and NGC 7419

V. Evolution of massive stars

14:20-14:40 Bhawna Mukhija
Numerical Experiment of mass loss and mass accretion mechanics in Massive stars

14:40-15:00 Joris Josiek
Spectral evolution of very massive stars on the main sequence

15:00-15:20 Alex Gormaz-Matamala
Impact of the stellar evolution adopting m-CAK self-consistent winds

15:20-15:50 **Coffee-break**

15:50-16:35 Michalis Kourniotis (**invited**)
Evolution of massive stars post the main sequence

VI. Blue supergiants

16:35-16:55 Julieta Paz Sánchez Arias
Uncovering the challanges to assess the evolution of B supergiants

16:55-17:15 Olivier Verhamme
Detailed mass-loss rates of B-supergiants across the bi-stability jump using UV+optical spectroscopy

17:15-17:45 **Poster Flashes**

Wednesday, June 26

09:30-09:50 Aldana Alberici Adam
Exploring variability in B supergiant stars: a theoretical and photometric approach to pulsation modes and detection of binary systems

09:50-10:10 Vitalii Checha
Variability in B supergiant star HD91316 (rho Leo)

10:10-10:30 Suryani Guha
Characterization of the Variability of the B-Supergiant HD 14134

10:30-11:00 **Coffee-break**

VII. Red Supergiants

11:00-11:20 Evaggelia Christodoulou
J-band spectroscopy of dusty, mass losing red supergiants in low metallicity galaxies

11:20-11:40 Gonzalo Munoz-Sanchez
Episodic mass loss discovered in two extreme RSG in the LMC

VIII. Yellow Hypergiants and Luminous Blue Variables

11:40-12:25 Alex Lobel (**invited**)
Yellow Hypergiants and Luminous Blue Variables

12:25-14:00 **Lunch**

Excursion & Dinner

Thursday, June 27

09:30-09:50 Anni Kasikov
The post-outburst evolution of RW Cep

09:50-10:10 Athos Silva
Stellar Parameters from LBVs R110, R40 and R71 Quiescent and Eruptive Stages by Fitting FEROS' Spectroscopic Observations with CMFGEN

10:10-10:30 Matheus Bernini Peron
Hydrodynamically consistent models of LBVs and BHGs

10:30-10:50 Augusto Damineli
Eta Carinae: 100 years of stability

10:50-11:20 **Coffee-break**

11:20-11:40 Diego Falceta Gonçalves
X-rays, Gamma-rays and High energy particles from Colliding Wind Binaries: the case of Eta Carinae

IX. Wolf-Rayet stars

11:40-12:00 Roel Lefever
A Bi-stability Jump for Wolf-Rayet stars?

12:00-12:20 Cassandra Van der Sijpt
Structure formation in the envelopes of massive stars

12:20-12:40 Aynur Abdulkarimova
Unveiling the Evolutionary Journey of J040901.83+323955.6

12:40-14:20 **Lunch**

X. Supernovae

14:20-14:40 Francesco Gabrielli
The cosmic rate of pair-instability supernovae

XI. Circumstellar environments

14:40-15:25 Alex Carciofi (**invited**)
Mass loss in Dwarf and Evolved B stars

15:25-15:55 **Coffee-break**

15:55-16:15 Kuljeet Singh Saddal
Local Dynamics at the Apex of an Astropause: Insights from 3D Resistive MHD Solutions

16:15-16:35 Arup Kumar Maity
Cloud-Cloud Collision: Formation of Hub-Filament Systems and Associated Gas Kinematics

16:35-16:55 Katarzyna Nowak
Testing the Supermassive Star Scenario for Early Massive Cluster Evolution

16:55-17:25 **Poster Flashes**

Friday, June 28

XII. Massive star binarity across the HRD

09:30-10:15 René Oudmaijer (**invited**)
Massive star binarity across the HRD

10:15-10:35 Emma Bordier
A high-angular resolution insight into the onset of stellar multiplicity in massive star formation

10:35-10:55 Carlos Guerrero Peña
Identification of Possible Stellar Companions via Speckle Interferometry in a Sample of Be Stars

10:55-11:25 **Coffee-break**

11:25-11:45 Robert Klement
Interferometric campaign on the multiplicity of classical Be stars: new detections and orbits of stripped subdwarf companions

11:45-12:05 Lucas de Sá
Constraining massive binary formation and evolution from compact object mergers

12:05-12:25 Koushik Sen
Whispering in the dark: X-ray faint black holes around OB stars

12:25-13:15 Marcelo Borges Fernandes & Michaela Kraus
Conference Summary

13:15-14:30 **Lunch**

END OF THE CONFERENCE

Talk Abstracts

Stellar Parameters of massive stars

(*Invited Talk*)

Lydia Cidale[1,2]

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[2] Departamento de Espectroscopía, Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata (UNLP), Paseo del Bosque s/n, B1900FWA, La Plata, Argentina

Understanding the physical parameters of stars, including luminosity and radius, is a crucial aspect of modern astrophysics and vital in studying stellar evolution, stellar pulsations, and mass loss from massive stars. Observations are often compared with state-of-the-art radiative transfer codes and new modeling approaches to derive the physical properties of massive stars. Empirical photometric relationships and direct methods are also very useful. However, first-order set of fundamental parameters may not be reliable or sufficient for more detailed studies of stellar physics, especially if stars in certain evolutionary stages, emission-line stars, or binary systems are considered.

This talk reviews the traditional methods and discusses new results from analyzing stellar parameters among evolved B-type stars.

Analysis of Time Series Spectra with Non-LTE Models

P. Németh[1,2], E.S.G. de Almeida[3], J.P. Sánchez Arias[1] and O. Maryeva[1]

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Quantitative spectroscopy plays a key role in unraveling the details of stellar atmospheres and their evolution. We propose an innovative approach to enhance precision in stellar parameter determination by combining time series spectra through automated iterative fitting procedures employing non-LTE (Tlusty, CMFGEN) models. Our methodology capitalizes on exploiting consistent stellar properties such as mass, luminosity, and element abundances across multiple spectra of the same star, specifically targeting massive stars.

Traditionally, spectroscopic analyses have been hindered by the challenge of precisely determining stellar parameters due to various uncertainties and complexities inherent in the process. However, our novel approach offers a promising solution by simultaneously fitting time series spectra using advanced non-LTE models. By leveraging the wealth of information contained within these spectra and incorporating physical models that account for non-LTE radiative transfer and the effects of mass loss, we aim to achieve improved precision in characterizing stellar atmospheres.

Through applications on real data, we demonstrate the performance of the fitting procedure in extracting stellar parameters, including effective temperature, surface gravity, and chemical abundances. This approach not only improves the precision of individual parameter estimates but also offers insights into temporal variations in stellar atmospheres, shedding light on dynamic processes such as stellar pulsations and convective motions.

Our work represents a significant advancement in quantitative spectroscopy, providing astronomers with a powerful tool for in-depth analyses of stellar properties. By harnessing the synergy between time series spectroscopy and sophisticated non-LTE modeling techniques, we pave the way for a deeper understanding of the physics of massive stars and the broader implications for astrophysical research.

ZPEKTR - A code for spectral synthesis of massive, fast rotating stars

Ronaldo Levenhagen

Universidade Federal de São Paulo, Brazil

Estimating the physical states on the surfaces of fast-rotating stars is challenging due to several intrinsic processes. Among them are the radiative flux inhomogeneities on the photosphere induced by rotation and circumstellar signatures in their spectra. The analysis of their spectra ultimately requires the use of synthetic spectra grids accounting for all these physical processes. In this contribution, we present the ZPEKTR code, aimed to perform the spectral synthesis of massive, fast-rotating stars, accounting for limb-darkening effects in the continuum and geometrical deformation induced by fast rotation. We consider co-latitudinal temperature and surface gravity variations, assuming both the classical prescription developed by von Zeipel and the new formulation by Espinosa-Lara. We envisage near-future improvements in the code, such as the inclusion of differential rotation and treatment of tidal in binary stellar systems.

Spectral numerical methodology to describe the line broadening effect produce by the stellar rotation

Rodrigo Meneses[1], Michel Curé[2], Felipe Ortiz[2]

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The analysis of spectral line profiles from celestial objects, as massive stars, allows us to estimate different characteristics of said objects: from their composition to their different parameters (effective temperature, mass, superficial gravity, etc.). However, the intrinsic shape of a line profile cannot be measured. The observed spectral line profile is affected by different phenomena that modify its shape. One of the most important of these is the Doppler broadening, produced by the projected rotation of the star which, as its name suggests, broadens the spectral line profile, but preserves the area of the line profile with respect to the continuum. In order to retrieve the intrinsic shape of the line profile an inverse problem must be solved, which involves an integral that does not have a direct analytic solution.

In this work, a spectral numerical methodology is presented for the description of the intrinsic shape of line profiles. The analysis is developed on an integral equation representing the convolution relationship between the non-rotating star profile and the observational spectral line. Our proposal utilizes Gegenbauer polynomials for the series description of the intrinsic line. Through this approach, the convolution term can be analytically described, transforming the problem into a system of linear equations in terms of the Fourier-Gegenbauer coefficients. We address the typical issue of illposedness in this inverse problem configuration by employing a minimization approach based on Tikhonov regularization. The effectiveness of our numerical procedure is assessed through comparison with other methods presented in previous literature, with synthetic spectral lines used for testing. Our numerical solutions reproduce expected behaviors, and the efficiency of our approach is analyzed by comparison to existing procedures in previous articles.

Deep learning models for analyzing massive star data: towards accurate and unbiased results

Raquel Pezoa[1], Michel Curé[2], Ignacio Araya[3], Felipe Ortiz[2], José Montecinos[1], Daniela Turis[2]

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Artificial intelligence has generated extraordinary transformations in the last few years, changing science, industry, and various aspects of our daily lives. Machine learning and deep learning-based systems have shown outstanding performance in solving complex problems, producing accurate results, and providing helpful support tools in diverse scientific fields, including astrophysics. Estimating wind and stellar parameters is a fundamental task in the domain of massive stars, and deep learning has emerged as a crucial tool, offering an alternative to the traditional and labor-intensive manual methods used to analyze the spectral lines of massive stars. Our research has focused on developing deep-learning models for classifying and estimating stellar parameters. The models include different deep learning architectures, such as traditional feed-forward and convolutional neural networks. In addition, we have used Deep Ensembles and Bayesian Neural Networks to estimate the uncertainties of the model's prediction.

This presentation will detail the methods developed and applied to different datasets, including the ISOSCELES database and sets of synthetic spectral lines generated with the TLUSTY software and ZPEKTR code. We will also present the challenges we have encountered and outline future work, including exploring probabilistic neural networks to enhance the reliability and unbiased of our results.

Hydrodynamical view of massive stars' winds

(*Invited Talk*)

Michel Curé

Instituto de Física y Astronomía, Universidad de Valparaíso. Av. Gran Bretaña 1111, Casilla 5030, Valparaíso, Chile

Massive stars undergo significant mass loss, which is crucial for their evolution along the upper Hertzsprung–Russell diagram. This mass loss process is governed by the line-driven wind theory (m-CAK), which describes the steady-state winds of these stars.

Determining the mass loss rate and wind velocity profile accurately is vital for quantitative spectroscopy analyses of these stars. Currently, the widely used beta-law provides an approximation only for the fast solution, but it lacks hydrodynamic justification when the derived value of beta exceeds 1.2- 1.3.
This talk focuses on

(1) An analysis of the m-CAK equation of motion (EoM),
(2) Numerical solutions for all three diPerent wind solutions (fast and two slow),
(3) Deriving analytical approximations for the velocity profile using the LambertW function, and
(4) Discussing the applicability of the slow solutions.

Stellar Winds from B Supergiant Stars: Exploring the Delta-Slow Hydrodynamic Solution

Roberto Oscar José Venero[1,2]

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The B-type supergiant stars form a heterogeneous group of objects, within which various types of peculiar stars coexist in brief and distinctly different evolutionary stages. Ordering the evolutionary sequences for these diverse stellar groups and assigning each star its respective phase poses a challenge. Nonetheless, the strong stellar winds of these stars produce observable spectral features that could serve as valuable diagnostic tools in addressing this question. In order to utilize these characteristics, it is necessary to know the structure of the wind in detail.

The fundamental hydrodynamic equations governing radiation-driven winds (m-CAK theory) predict three distinct solutions for rotating stellar winds. These solutions include the ‘fast’ solution (or classical), the ‘Omega-slow’ solution (applicable to rapidly rotating stars), and the ‘delta-slow’ solution (pertaining to winds with ionization changes). These solutions are primarily distinguished by the terminal speed achieved by the wind, with the ‘fast’ wind regime exhibiting the highest values for this parameter.

Excluding the ‘Omega-slow’ solutions due to the absence of fast rotation in B supergiants, the ‘fast’ and ‘delta-slow’ solutions are distributed in distinct domains within the classical parameter space of the radiation force (k, alpha, and delta). In this presentation, I will illustrate the distribution of these domains and, more specifically, asses the ability of the delta-slow solution in predicting the fundamental spectral characteristics observed in B supergiants, especially for the subgroup of the B hypergiants.

Hydrodynamic solutions for radiation-driven winds in transitions regions

Melina Carla Fernandez

Departamento de Espectroscopía, Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata (UNLP), Paseo del Bosque s/n, B1900FWA, La Plata, Argentina

The theoretical framework for modeling radiation-driven winds in hot stars is the “m-CAK theory”, which describes the radiation force using three parameters: α, δ, and k. In particular, δ introduces changes in the ionization of the material and can lead to two different types of solutions for the hydrodynamic equations of slowly or non-rotating winds. These solutions, known as the “fast” and “δ-slow” solutions, are principally distinguished by their markedly different terminal velocities. Both solutions are separated by a gap in the parameter space of δ, where no stationary solutions have been found so far. In this study, we employ the time-dependent hydrodynamic code ZEUS-3D, to solve the equation of motion, tracking the temporal evolution from a specified initial solution to obtain solutions in the gap. These novel solutions exhibit a stationary kink in the velocity profile at a fixed distance from the star, the position of which depends on the value of δ. Here we investigated if this discontinuity can lead to Discrete Absorption Components (DACs), solving the transfer equation in the comoving frame along with the non-LTE rate equations to derive UV line profiles for Si iv.

Stellar Parameters of massive stars

(*Invited Talk*)

Andreas Sander

ZAH/ARI, Universität Heidelberg, Germany

The life, impact and fate of massive stars is governed by the competition between the nuclear timescales in their core and the removal of mass on their surface. For this, stellar winds are a major and continuously operating channel. Revealed to be an almost ubiquitous phenomenon in the regime of massive stars, the physical mechanisms launching stellar winds are complex and their accurate physical description is still a major challenge. Different flavors of massive stars vary significantly in their winds with stellar evolution being challenged to connect the zoo of observed phenomena, in particular as the amount of mass loss is expected to change over cosmic time. For the winds of hot stars, the strong deviation from local thermodynamic equilibrium as well as the major role of line opacities do pose particular challenges which require dedicated physical and numerical treatments.

In this invited talk, I will review the current status in our understanding massive star winds, focusing mainly on hot star winds. This will include the available diagnostics, the challenges to create suitable stellar atmosphere models, as well as the opportunity to draw theoretical conclusions and predict the feedback of massive stars. Moreover, I will present recent efforts to compare the different spectral analysis methods for quantitative spectroscopy and provide a summary of the differences in the underlying atmosphere codes.

From multi-dimensional stellar wind models to spectral synthesis

Nicolas Moens

KU Leuven, Belgium

Massive stars are well understood to have convective cores surrounded by a radiative envelope. However, when stars are close enough to the Eddington limit, a peak in the opacity due to iron recombination can cause a radiation-driven convective region right underneath the stellar surface.

Where 1D codes fail to accurately model the stellar structure around this sub-surface convective zone, multi-D models are perfect for modeling the complex flow patterns that arise in these regions.

In this talk I will present a set of 2D radiation-hydrodynamics simulations that model the atmospheres as well as the winds of O stars on the zero age main sequence and beyond.

Our models show that the sub-surface convection not only contributes to the transport of energy trough the outer layers, but it also provides a turbulent pressure contribution which contributes to an inflation of the stellar envelope. This effect significantly moves the photosphere outwards which lowers the stars effective temperatures.

On top of these structural changes, the convective layers also affect the formation of spectral lines due to Doppler shifting from the turbulent motions. While these effects are typically modeled with free input parameters such as micro- or macro-broadening in 1D codes, performing radiative transfer on our multi-D models allows us to recover observed photospheric line-widths without any additional input parameters.

3D unified atmospheric and wind models of OB stars

Dwaipayan Debnath

Institute of Astronomy, KU Leuven, Belgium

Massive and luminous OB stellar atmospheres with winds have been primarily studied using 1D spherically symmetric and stationary models. Contrary to that, both observations and theory suggest that such stars have highly structured, time-dependent, turbulent atmospheres.

We present the first 3D time-dependent, radiation-hydrodynamic simulations of OB stars encapsulating both deeper subsurface layers as well as the supersonic line-driven outflow in one unified approach. The overarching aim of our work is to develop a framework free from ad-hoc prescriptions and "free-parameter hell" that plague present-day 1D models.

We discuss our first 3D models and make comparisons with previous 2D O-type star models by Debnath et al., 2024 and 3D envelope models by Schultz et al., 2023. We present key results of the models, involving, e.g., large photospheric turbulent velocities and a strong density-velocity anti-correlation in the outflowing wind. Finally, we outline future research directions such as 3D-effects on 'mass discrepancy' and calibrating the outer boundary of stellar evolution codes.

Toward spectral analysis with 3D model atmospheres

Lara Delbroek

KU Leuven, Belgium

In the classical view of higher mass stars, these stars have a convective core with a radiative envelope, which long were thought to lead to stable (1D) envelopes and atmospheres. However, when looking at spectroscopic observations, there are indications for 3D, time-dependent effects, e.g. very large ('micro'- or) 'macroturbulent' velocities and line-profile variability (Simon-Diaz et al. (2014), Lepine & Moffat 1999). These effects suggest that 3D model atmospheres are required for accurate spectral line diagnostic analysis. But for these objects, in contrast to the Sun, we can't resolve the surface of the stars. Hence we need 'quantitative spectroscopy' to test models and compare these models with observations.

In this talk, we will use 3D radiative transfer techniques (building from Hennicker et al. 2021) applied to the first 3D unified atmosphere and wind simulations of O-type stars (building from Debnath et al. 2024). We investigate how large velocity fields in 3D-simulated photospheres (and winds) influence the line widths, shapes, and shifts, and how previous ad-hoc parameters, e.g. micro- or macro-turbulence, are no longer needed to explain the broad absorption lines observed for O-type stars. Furthermore, we illustrate how the O-star surface is highly variable and characterised by large temperature and density fluctuations. We also discuss how these fluctuations will impact spectroscopic determinations of fundamental parameters, e.g. surface gravity and chemical abundances.

Combined efforts:
1D vs multi-dimensional atmospheric model comparison for O and WR stars

Gemma Gonzalez-Tora

ZAH/ARI, Universität Heidelberg, Germany

The presence of stellar winds in hot, massive stars has to be taken into account when modelling their spectra. Thanks to the manifold developments in the field of hot star atmosphere modelling over the last decade, sophisticated predictions of massive star spectra for both O and WR stars have become possible, building the backbone of many modern research efforts 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 inherent computational costs and necessary approximations will prevent their common usage for 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. In particular, I will focus on the impact of the sub-surface turbulence in O stars.

Hydrodynamic solutions for radiation-driven winds in transitions regions

Elisson S. D. G. de Almeida[1], M. Curé[1], C. Arcos[1], M. L. Arias[2,3], M. Borges Fernandes[4], W. L. F. Marcolino[5] and L. S. Cidale[2,3]

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(*Abridged*) Despite the establishment of theoretical foundations for line-driven winds nearly half a century ago, uncertainties persist regarding the actual mass-loss rates across various luminosity classes of O stars. One of the primary unresolved issues in the literature concerning massive stars is the phenomenon known as weak winds. Initially identified in late O dwarfs (O8-9V stars) with luminosity values below $\log(L_\star/L_\odot) = 5.2$, quantitative modeling of the ultraviolet (UV) spectra of these stars suggests mass-loss rates ($\dot{M}$) up to two orders of magnitude lower than the theoretical predictions.

Firstly, we provide an overview regarding the weak wind phenomenon in late O giants. Additionally, we present our ongoing findings concerning weak winds in late O dwarfs and giants using hydrodynamical simulations with the code HYDWIND. These hydrodynamical results serve as input parameters in state-of-the-art non-LTE radiative transfer codes, CMFGEN and FASTWIND, to compute synthetic spectra and validate them against observations in the UV and visible regions. We also discuss our ongoing analysis of weak wind stars in the mid-infrared region, particularly utilizing the Brα line profile. As highlighted by Najarro et al. (2011), the L-band encompasses lines, notably Brα (4.051 μm), which are more sensitive to changes in the wind's $\dot{M}$ compared to Hα in low-density wind regimes such as those found in weak wind stars.

Stellar Atmosphere and Hydrodynamic Modeling with ISOSCELES v2.0

Ignacio Araya

Centro Multidisciplinario de Física / Universidad Mayor, Chile

ISOSCELES (grId of Stellar atmOSphere and hydrodynamiC modELs of massivE Stars) represents a pioneering synthetic data grid for massive stars, integrating m-CAK hydrodynamics and NLTE radiative transport. Our research aims to elucidate whether the delta-slow solution can resolve discrepancies observed in predicted versus actual mass-loss rates and high beta values obtained from certain velocity laws. Initial findings suggest that models with beta values exceeding 1.5 can be accurately replicated using the delta-slow hydrodynamic solution. To advance our understanding further, we have developed novel tools and expanded the capabilities of ISOSCELES. This includes incorporating UV range spectra and other metallicities. Additionally, we are leveraging machine learning techniques for spectral line fitting. In this presentation, we provide an overview of the current progress of ISOSCELES and outline its future directions.

Self-consistent formulae for theoretical mass-loss rate and terminal velocity of O stars

Felipe Figueroa-Tapia[1], M. Curé[1,2], I. Araya[3], J. A. Panei[4,5], C. Arcos[1,2], and A. C. Gormaz-Matamala[6,7,8]

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Stellar winds emanating from O-type stars, renowned for their substantial mass and luminosity, exert a significant influence on galactic dynamics and interstellar environments, making them a compelling subject within stellar astrophysics. However, understanding this phenomenon requires adjusting numerous parameters using the m-CAK theory, which serves as the cornerstone of our field. One of the many objectives in studying stellar winds lies in elucidating the Momentum-Luminosity Relationship (MLR). By leveraging the values of the mass-loss rate and the terminal velocity of the wind, we can deduce the luminosity of the star, thereby deriving its distance.

In this study, we follow the methodology outlined by Gormaz-Matamala et al. (2019, 2022) and employ a self-consistent procedure. We construct three grids encompassing different elements (H, H-He, and H-He-C-N-O) coupled with both wind parameters (mass-loss rate, terminal velocity, k, α, and δ) and stellar parameters ($T_{\rm eff}$, log g, and R_*). With nearly 500 objects for each grid, we conduct a comprehensive statistical analysis for each wind parameter, enabling a theoretical estimation of the mass-loss rate and terminal velocity. Additionally, we introduce novel visualizations for the line-force parameters k, α, and δ, revealing an intriguing region in the $T_{\rm eff}$ - log g diagram, particularly near 40,000 K. Finally, we present a comparative analysis between previous works by Vink et al. (2001), Gormaz-Matamala et al. (2019), among others.

Massive stars at low metallicity - grids of CMFGEN models

Wagner Marcolino

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Quantitative spectral analysis of massive stars in the Local Group of galaxies is crucial to understand their properties, final fate, and ISM feedback at different metallicities. This task is extremely complex and computationally expensive due to their non-local thermodynamic equilibrium (NLTE) expanding atmospheres. The present work provides a large grid of atmosphere models for OB stars in the LMC and SMC, as those recently observed by the ULLYSES and XShootU programs. The grids were computed with the CMFGEN code. We converged a total of 609 models, taking into account an extensive atomic dataset and the associated effects of line blaketing. A metallicity of 0.5 $Z_\odot$ and 0.2 $Z_\odot$ was adopted for the LMC and SMC, respectively. We computed high-resolution spectra from the EUV to the mid-IR and several physical quantities of interest. We provide ionizing fluxes (SEDs and log Q's), photometry in several bands (e.g., UBVRIJHK and selected JWST filters), as well as colors and bolometric corrections. All of our data is going to be publicly available at the POLLUX database. The full models and spectra are anticipated to accelerate the analysis of massive stars across various metallicity environments, while also finding utility in diverse applications, spanning from hydrodynamic simulations to population synthesis analyses.

Spectra and Ionizing Fluxes of Pop III Stars

Shrriya Kapoor

Astronomisches Rechen-Institut (ARI), Heidelberg University, Germany

The study of massive stars is crucial to understand their evolution and impact, yielding insight into many fields such as the process of nucleosynthesis, the formation and chemical evolution of the circumstellar medium and their host galaxies. A special case of massive stars are the Population III (Pop III) stars, the first generation of stars formed after the Big Bang and initial producer of heavier elements. Presumed to be very massive, these stars are envisioned to be several 100 times the mass of our Sun, thus having very short lifetimes. Pop III stars are believed to have played an important role in cosmic reionization. Due to the inherent lack of heavier elements, the internal structure of these stars is different than in later generation (Pop II and Pop I) stars, leading to very high temperatures and pressures in their cores. The resulting harder radiation will also affect the star formation in the surrounding region and hence the further galactic evolution.

Although the importance of Pop III stars is undisputed, the physical and chemical processes of these hot and luminous gas giants are poorly constrained, especially due to the lack of direct observations. Stellar Atmosphere models can help us to determine the emergent properties of these stars, using their effective temperature, surface gravity, and chemical composition as an input. In my master project, I am modelling the stellar atmospheres for Pop III and very low metallicity stars to produce synthetic spectra and ionizing fluxes with detailed non-LTE, comoving frame models. I will conduct a comparative analysis between two types of stars: Population III stars with zero metallicity ($Z = 0$) and stars with very low-metallicity ($Z = 10^{-4}$). For these two types of stars, in particular the mass loss is presumed to be different. I will investigate the impact of radiation-driven as well as pulsation-driven winds on the resulting observables for these stars. The analysis will cover a range of stellar masses, and corresponding temperatures, luminosities, mass loss rates, and terminal velocities.

The main goal is to investigate whether the impact of stars with zero metallicity can be distinguished from stars with non-zero metallicity. Additionally, we will assess the distinct spectral imprints of the two types of stars. I will display the synthetic spectras generated, along with ionizing fluxes as compared to a black body.

The importance of the infrared spectral data to study Be stars

(*Invited Talk*)

Yanina Cochetti[1,2]

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Be stars are non-supergiant B-type stars whose spectrum has, or had at some time, one or more Balmer lines in emission. These stars rotate rapidly, and it is accepted that the emission comes from a circumstellar envelope, mostly compatible with a disc geometry in Keplerian rotation. Since their first report more than 150 years ago, the optical spectral range has been the most important data source to study these objects.

In the infrared (IR) spectral region, Be stars present a moderate flux excess and numerous hydrogen emission lines of the Paschen, Brackett, Pfund, and Humphreys series. These lines present a small photospheric absorption and are formed in a region closer to the star than those observed in the optical spectral range. Then, IR spectra of Be stars constitute a great tool for obtaining information about the physical structure and dynamics within the innermost part of the disc and, thanks to the increase in data quality, have gained importance in the last decades.

In this talk, we will review the relevance of studying the IR spectral range of Be stars, and the most interesting results obtained so far.

The Origins of Be Stars: Investigating the Intra-cluster Environments of NGC 663 and NGC 7419

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It is still debated whether the rapid rotation in Be stars is due to an amount of angular momentum acquired during the star formation process itself, or if the star acquired it subsequently, through mass transfer from a binary companion, through coalescence, or through some other energetic event that occurred in the vicinity. Given these still open questions, it is particularly interesting to investigate the environments that have given rise to a large number of Be stars. That is why in this work, we propose to investigate the stellar characteristics and intra-cluster medium of the two galactic open clusters with the largest number of known Be stars: NGC 663 and NGC 7419, using photometry and astrometry from Gaia DR3 and data from atomic gas emission and other interstellar matter tracers.

Numerical Experiment of mass loss and mass accretion mechanics in Massive stars

Bhawna Mukhija

Ariel University, Israel

The evolution and characteristics of massive stars are significantly influenced by mass loss and mass accretion, through the stellar winds, accretion disks, and binary interactions. These mechanisms have a notable impact on the stellar envelope as they approach the main sequence, leading to substantial changes in their structure. I use numerical simulations to investigate how massive stars react to eruptive mass loss and accretion of material, and analyze the resulting changes in their evolutionary track, energy transport, and internal structure.

In the talk I will present simulations results that show how mass loss leads to a decrease in luminosity in the evolutionary track, causing the star to become hotter and contract. This is not a monotonic process and includes a number of stages. I will also discuss simulations of accretion that lead to an increase luminosity and radial expansion of the star toward cooler temperatures. A discrepancy exists between high and low accretion rates: for low accretion rates the star remains hot, whereas higher accretion rates lead to the cooling of the star.

For each simulation, I monitor the star’s progression into the recovery phase as well. I will show a comparison of normal evolution without mass loss and accretion to evolution where either process takes place.

Spectral evolution of very massive stars on the main sequence

Joris Josiek

ZAH/ARI, Universität Heidelberg, Germany

Very massive stars (VMS) are powerhouses of the Universe. With luminosities of more than a million suns and winds capable of ejecting enormous amounts of matter, these objects host some of the most extreme phenomena known in stellar physics. Despite the large impact on their environments, VMS are very scarce and only few resolved objects are known. Moreover, the predictions made by stellar evolution codes regarding VMS are quite uncertain, since their expanding, non-LTE atmospheres are fundamentally incompatible with the gray atmosphere approximation used in evolution codes. In this work, we aim to constrain the appearance of VMS by combining evolution models with detailed atmosphere calculations. We compute new evolution tracks with the Geneva code (GENEC) using a recent state-of-the-art mass-loss scheme for VMS between 100–300 solar masses. We then feed the output of these models at multiple points along their main sequence (MS) into the Potsdam atmosphere code (PoWR) to obtain detailed atmospheric structures and model spectra of these stars. From the simulations, we investigate the evolution of spectral features of VMS during the MS, and classify the stars according to the standard spectral classification scheme. We evaluate whether the classification criteria commonly used by evolution codes (e.g., hydrogen abundance) realistically reproduce the spectral types obtained from PoWR. Finally, we compare the detailed atmospheric structure of the PoWR models with the ones approximated by GENEC in order to identify systematic inconsistencies between the codes and possible corrections to apply to evolution tracks. This will constitute a first step towards future work to combine insights from spectroscopy and evolution into a more unified picture of massive stars.

Impact of the stellar evolution adopting m-CAK self-consistent winds

Alex Gormaz-Matamala

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We upgrade the recipes of mass loss based on state-of-the-art self-consistent wind solutions from the so-called m-CAK prescription, which are necessary for the study of the evolution of massive stars. We use GENEC to perform evolutionary tracks for stars in the range of 25-300 $M_\odot$, for metallicities from Z=0.014 (Galactic) to Z=0.002 (SMC). For very massive stars (VMS), we set the transition from thin to thick winds at Γ_e=0.5 instead of the original X_{surf}=0.3. Because the mass loss of new winds is lower, massive stars retain more mass during their evolution, besides being larger and rotating faster. For stars in the range of 20-32 $M_\odot$ at low metallicity, abundances are enhanced because faster rotation refuels the hydrogen core and extends the lifetime in the main sequence. Very massive stars at solar metallicity lose only half of their initial masses during the H-core burning stage, thus generating final masses of ~25.9 $M_\odot$ for M_{zams}=200 $M_\odot$, and ~27.4 $M_\odot$ for M_{zams}=300 $M_\odot$. The impact of overshooting, angular momentum transport (Taylor-Spruit dynamo vs meridional currents), and convection (Schwarzchild vs Ledoux criteria) over the expected mass remnants and spins for stellar black holes is also discussed.

Stellar Parameters of massive stars

(*Invited Talk*)

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Massive stars are cosmic engines that drive the evolution of galaxies and regulate the chemistry of gas via enrichment of material that is shed during the highly energetic lifetime. Nevertheless, the evolution of massive stars remains an open issue. It is perceived as a chain of diverse states of the star, where its properties are shaped by unclear mechanisms that take place in the deep interior and the atmosphere. In the current talk, I will discuss about the known ambiguities in the evolution of massive stars that emerge due to fundamental parameters such as mass loss, angular momentum transport, atmospheric instability, and binarity, being poorly constrained. The talk will be explicitly focused on the enigmatic post-main sequence evolution, with an emphasis on blue supergiants, the transition phases characterized by the high atmospheric instability, and their between evolutionary link. I will discuss on the observables that are currently assessed by means of spectroscopy and high-cadence photometry, which enable to gain a better understanding of the stellar nature. By constraining the number of free parameters, predictions can then be made on the fate of these objects with respect to the different types of supernovae and thereafter products.

Uncovering the challanges to assess the evolution of B supergiants

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Massive stars are of key importance in many areas of astrophysics. They are the cornerstone of the chemical, energetic and dynamical evolution of the interstellar medium through feedback from their stellar winds and supernova explosions, and they are the main tracers of star formation. However, the formation, evolution and ultimate fate of massive stars are still far from being understood. A synergy between asteroseismology, evolutionary models and spectroscopic analyses can provide a better understanding of the evolutionary state of these interesting stars. In this talk I will present our analysis on the evolutionary state of three well-known B supergiants: HD 42087 (PU Gem), HD 52089 (ϵ CMa) and HD 58350 (η CMa). We used the 2-minute cadence TESS data to study photometric variability and obtained new spectroscopic observations at the CASLEO observatory. We employed non-LTE radiative transfer models calculated with the CMFGEN code. These models were used in an iterative spectral analysis process to determine their CNO abundances and their stellar and wind parameters. The results are compared with different evolutionary model predictions and larger samples of abundance determination of B supergiants. We found HD 42087 to be the most consistent with a pre-RSG evolutionary stage, HD 58350 is most likely in a post-RSG evolution and HD 52089 shows stellar parameters compatible with a star at the TAMS. However, there is a systematic offset in the abundances ratio between B supergiants samples, the predicted abundances from evolutionary models and our selected stars, underlining the need for homogeneous studies of large samples of B supergiants and for verification of the processes involved in the evolution of massive stars, such as mass loss due to stellar oscillations.

Detailed mass-loss rates of B-supergiants across the bi-stability jump using UV+optical spectroscopy

Olivier Verhamme

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Radiation-driven mass loss is an important, but still highly debated, driver for the evolution of massive stars. Current massive star evolution models mostly rely on mass loss rate prescription for massive stars which include a sudden increase in mass loss below an effective temperature of about 25 000 K (Vink et al. 2001). However, new mass loss rate predictions show no such bi-stability jump (Björklund et al. 2022). Instead, stellar mass loss decreases with decreasing stellar luminosity/temperature. Reducing the mass loss by an order of magnitude, changes many of the fundamental parameters of the end-products such as mass and rotation. It even puts in doubt the formation channels of evolved massive star products such as WR stars.

By utilizing UV spectra (ULLYSES program) combined with X-shooter optical data it is possible to obtain mass-loss rate constraints, that are no longer degenerate to the effects of wind clumping, and derive novel empirical constraints on the mass-loss behavior across the temperature range of the presumed bi-stability jump.

We obtain stellar and wind parameters through spectral fitting using the 1D spectral synthesis code FASTWIND and genetic algorithm code Kiwi-GA. In my talk, I will show the results of this method on LMC and SMC B-supergiants. The discussion will focus on the lack of evidence for a bi-stability jump as implemented in evolutionary codes and on what this entails for envelope stripping of massive stars.

Exploring variability in B supergiant stars: a theoretical and photometric approach to pulsation modes and detection of binary systems

Aldana Alberici Adam

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It is well known that B supergiant stars evolve from O-type stars, however, there is still much uncertainty about their evolution after they leave the main sequence. The asteroseismological study of light curves of massive stars has revealed that they all pulsate in specific modes, defining regions of instability at the top of the HR diagram. Detecting and studying pulsating stars in binary systems is essential for exploring the internal structure of stars and verifying evolutionary models, as they allow the masses of each component to be measured accurately and independently. However, detecting binary systems among evolved B stars is challenging, either because of observational bias or, perhaps, due to the intrinsic variability of the more evolved primary component, leading to light curves and spectra variations.

In order to improve our knowledge of these phenomena, light curves of a sample of massive stars, with L/M ratio > 4, observed with the TESS satellite were studied to determine their periods and quasi-periods, which could be associated with pulsation, binarity, or both. In addition, the pulsation modes were studied on the basis of a linear non-adiabatic model and compared with the observationally detected frequencies, to estimate a theoretical mass for these stars and address the mass discrepancy problem. To obtain a detailed description of the periodic behaviour of the signals, two complementary tools were used: the Lomb-Scargle periodogram and the Weighted Wavelet Z-Transform (WWZ).

Variability in B supergiant star HD91316 (rho Leo)

Vitalii Checha

University of Tartu, Estonia

The post-main-sequence evolution of massive stars remains a challenging area of study, with many aspects still poorly understood. By investigating the pulsational behavior of evolved massive blue supergiants (BSGs), which hold place in instability region at the top of the HR diagram, we can gain insights into their internal structure and verify existing evolutionary models. We combine various methods of frequency analysis to investigate the variability of the BSG rho Leonis. We leverage long-term spectroscopic monitoring data collected at the Tartu Observatory, complemented by space photometry obtained from the K2 and TESS missions.

Characterization of the Variability of the B-Supergiant HD 14134

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B-supergiants are well known for their spectroscopic and photometric variability that has been assigned to pulsations and related changes in their stellar and wind properties. In particular, these objects that have passed through a red supergiant stage are known to present many pulsation modes, including radial strange modes. The latter have been proposed to facilitate mass loss. Photospheric lines in the stellar spectrum also contain the information about the effective temperature and surface gravity of the star. The B-supergiant HD 14134 displays prominent variability in both its light curve and spectra (in particular the Hα line). To analyze the cause of its variability we combine photometry from the TESS mission with optical spectroscopy collected over a 5-month period to search for pulsations. We identify a dominant and persistent period of ∼ 5 d from the Fourier analysis of the light curves which contradicts the literature values for possible periods reported by previous works on this star. Other detected periods seem to be stochastic in nature. Besides, we detect significant temporal changes in effective temperature from both our measurements of the equivalent width ratios of temperature sensitive photospheric lines and from NLTE models computed with the radiative transfer code CMFGEN. Additionally, abrupt changes in the wind conditions can be witnessed by the temporal variations in the Hα line profile, suggesting a sudden ejection of material. Whether this ejection might have been caused by some strange-mode instability needs to be further investigated.

J-band spectroscopy of dusty, mass losing red supergiants in low metallicity galaxies

Evaggelia Christodoulou

National Observatory of Athens, Greece

The role of episodic mass loss in the evolution of massive stars remains largely unknown and thus it is not included in the stellar models. The ASSESS project is conducting an optical survey in the nearby Universe (12 galaxies with Z ~ 0.1 to 1.5 $Z_\odot$) searching for evolved massive stars, primarily targeting those with infrared excess (i.e. circumstellar dust) which reveals mass loss. The results of this survey in the northern hemisphere have led to the secure spectral classification of twelve red supergiants (RSGs) in NGC 6822 and IC 10 (Z= 0.32 $Z_\odot$ and 0.45 $Z_\odot$). Follow up spectroscopy has been acquired in the J-band for eight of them using the EMIR spectrograph at the Grand Telescope of the Canarias. Also, we observed one target from the literature (WLM 14), expanding our metallicity range to 0.14 $Z_\odot$, as we aim to study mass loss in the low metallicity regime. Such observations are needed because the effective temperature (T_{eff}) measured from atomic lines in the J-band is more accurate than the one estimated using the TiO bands present in the optical spectra, as the latter form at larger radii and lower temperatures. Improved Teff estimations, as inputs of SED fitting codes, lead to more robust estimations of mass loss. We aspire to calibrate the temperature scale of RSG at low metallicities and use it to obtain mass loss measurements for the rest of our sample (~ 130 RSGs) for which infrared spectroscopy is not feasible. I will present results from the analysis and spectral modelling using NLTE MARCS models of these observations.

Episodic mass loss discovered in two extreme RSG in the LMC

Gonzalo Munoz-Sanchez

National Observatory of Athens, Greece

Red supergiants (RSGs) are evolved massive stars with initial masses between 8-25 $M_\odot$, 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 $M_\odot$ 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 runaway 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, similar 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], exhibiting 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 severe 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.

Yellow Hypergiants and Luminous Blue Variables

(*Invited Talk*)

Alex Lobel

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Spectroscopic and photometric monitoring of Yellow Hypergiants (YHG) and Luminous Blue Variables (LBV) are essential for advanced research of the atmospheric dynamics and wind physics in these rare massive stars near the stellar luminosity limit. This review discusses galactic YHGs (Rho Cas, HR 8752, HR 5171A) mainly terms of (recurring) pulsation-induced outburst events, together with detailed spectrum modelling efforts of the physical conditions in the radiatively-driven winds and structured circumstellar environments of some well-studied blue supergiants and c/LBVs (S Dor, P Cyg, HD 168607, V1429 Aql).

The post-outburst evolution of RW Cep

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The great dimming of hypergiant RW Cep at the end of 2022 piqued the interest of both the amateur and professional astronomy community (ATel #15800 by Vollmann and Sigismondi). The reported V-filter brightness dropped to 7.6 mag - down by about 0.9 mag from its previous mean level, comparable to the dimming of Betelgeuse in 2019. The dimming has been attributed to an ongoing mass-loss event. Spectra taken during the event have revealed newly-formed emission components in many absorption lines. We have monitored RW Cep using the medium-resolution spectrograph attached to the 1.5-m telescope at Tartu Observatory and complemented that data with high-resolution echelle spectra from the Nordic Optical Telescope. With our spectral time series we can follow the variability of RW Cep as it goes through the outburst event. We discuss the dynamics of the star's extensive atmosphere and consider the post-RSG evolution of RW Cep in the context of yellow hypergiants.

Stellar Parameters from LBVs R110, R40 and R71 Quiescent and Eruptive Stages by Fitting FEROS' Spectroscopic Observations with CMFGEN

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Luminous Blue Variables (LBV), also known as S Dor Variables, are mainly characterized by episodes of strong mass loss, resulting in irregular photometric and spectroscopic variabilities of different intensities, from a few decimals (microvariation) to a few units (eruption) of magnitude in the visible. This property confers them two main strips in the HR diagram, related to the quiescent and eruptive stages. LBVs are expected for massive stars with M ZAMS > $20M_{\odot}$, and in their temperature and luminosity range, other types of objects are also seen, such as blue supergiants (BSG) and late-type Wolf-Rayet (WNL) stars. Regardless, the role of LBVs in the stellar evolution of massive stars still remains an open question. Therefore, for this study, our targets will be three LBVs from the Small and Large Magellanic Cloud: RMC 110, RMC 40 and RMC 71. Our objective is to fit their observed spectra obtained from ESO's FEROS spectrograph with theoretical spectra generated from the radiative transfer code CMFGEN, which handles spherically-symmetric geometries in a non-LTE regime, in order to analyze their stellar and wind parameters (i.e., effective gravity and temperature, luminosity, mass-loss rate, chemical abundances and wind velocities) and infer more about the nature of their evolutionary stage.

Hydrodynamically consistent models of LBVs and BHGs

Matheus Bernini Peron

ZAH/ARI, Universität Heidelberg, Germany

Massive stars ($M > 8M_\odot$) deeply impact their host galaxies via their powerful feedback, making it vital to understand their properties and evolution. Despite important advance in the previous decades, large gaps in our knowledge about the evolution of these stars remain, especially for post-Main sequence stages and among stars with higher masses ($M > 25M_\odot$). On the cool end of the hot star regime (Teff < 20kK), we find the evolved B-supergiants, B-hypergiants (BHGs) and luminous blue variables (LBVs), whose knowledge about their properties and behaviour is fundamental to understand the complex evolutionary connections between the different types of massive stars. In this regime, important changes in the atmosphere/wind properties are expected to happen - in particular the bi-stability jump phenomenon. To investigate the wind launching mechanism in this crucial regime, we present a new, detailed study about the wind driving in the context of BHGs (and LBVs) using hydrodynamically consistent PoWR stellar atmosphere models.

Beside reporting on the different involved ionization stages, we further analyse how properties such as Teff, microturbulence and L/M-ratios can affect the mechanical wind output. We found an unexpectedly complex behaviour of the mass-loss rates in the temperature range of the bi-stability jump. Moreover, we also present the first spectroscopic fit of a BHG (Z1 Sco, B1.5Ia+) with dynamically-consistent models. We infer a minimal amount of clumping (D_∞=1.5) to be necessary, starting in the subsonic regime. The UV spectral appearance further demands the inclusion of X-rays to reproduce C IV and N V lines, which affects the ionization stages and thus the resulting radiative acceleration.

Eta Carinae: 100 years of stability

Augusto Damineli

IAGUSP

Recent studies have shown that eta Car have been quite stable since 1900. The only real stellar variations are periodic: rotating distorted shape, periastron passages. The long-term brightening was shown to be due to the dissipation of a dusty occulter placed to our side of the central stellar system. This leaves only a ½ century to the star to adjust from the violent Great and Lesser eruptions. This short relaxation time has been seen also in other stellar mergers and is in contradiction with the much longer that expected from the Kelvin-Helmholtz relaxation time.

X-rays, Gamma-rays and High energy particles from Colliding Wind Binaries: the case of Eta Carinae

Diego Falceta Gonçalves

Universidade de São Paulo, Brazil

Eta Carinae, a prominent and enigma c binary star system located in the Carina constellation, exhibits a plethora of astrophysical phenomena, including intense X-ray emission and high-energy particle acceleration within its shock structures. Eta Car presents a massive companion and the interaction between these stars generates powerful stellar winds and periodic outbursts, leading to the formation of shock fronts and colliding stellar winds regions. These shocks serve as sites for particle acceleration on and X-ray emission via mechanisms such as synchrotron radiation and inverse Compton scattering. Shock acceleration mechanisms, including diffusive shock acceleration and stochastic acceleration, are thought to operate within the complex shock structures, producing energetic particles that contribute to the observed non-thermal emission across the electromagnetic spectrum. In this work we provide a full set of kinetic-MHD simulations that elucidate the physical proper es of the shocked region and the acceleration of particles in it. The energy power spectrum is obtained. Magnetization level of the stars is discussed in terms of the comparison between the es mates emission and current data from HESS and FERMI.

A Bi-stability Jump for Wolf-Rayet stars?

Roel Lefever

ARI, Universität Heidelberg, Germany

The need for understanding the winds of Wolf-Rayet (WR) stars cannot be understated: the light of these stars, their mass-loss rates, ionization capabilities and ultimately their further evolution is all greatly affected by the behaviour of their wind. Despite WR-star winds being notoriously difficult to model, advancements on this matter have been made. One approach is using non-LTE, co-moving frame computations with the Potsdam Wolf-Rayet (PoWR) code where now hydrodynamic consistency throughout the wind domain is enforced. While already applied multiple times for the regime of hot, hydrogen-free WR stars, we now present their first wide-range application in the regime of nitrogen-rich late-type WN stars that still contain hydrogen in their spectra. A newly generated temperature sequence of these WNLh-star models reveals a sudden change in the wind regimes: Below 30 kK, the mass-loss rates increase significantly, while the terminal wind velocity drops strongly, accompanied with large changes in the emergent model spectra. This discontinuous behaviour greatly resembles the well-known bi-stability jump in B-supergiants. Examining the models, we discover that our obtained regime change does not correspond on the switch from Fe IV to Fe III as expected, but is linked to the higher ionization switch of Fe V to Fe IV, therefore also coinciding with higher stellar temperatures. In this talk, we want to discuss the behaviour of this WR-star "bi-stability jump", both in terms of metallicity and in luminosity-to-mass ratio. We will stress similarities and differences to the B-supergiant case as well as less impactful but noticeable ionization switches that influence the wind behaviour.

Structure formation in the envelopes of massive stars

Cassandra Van der Sijpt

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Excessive supersonic broadening of photospheric lines of massive stars indicates the presence of a very turbulent outer stellar envelope. Radiation-hydrodynamical models of massive stars (Jiang et al., 2015; Moens et al., 2022; Debnath et al., 2024) indeed show large structures being formed in the sub-surface layers, which may impact the energy transport and stellar structure just below the photosphere as well as observable properties. Therefore, it is very important to understand the origin and properties of this sub-surface turbulence.

In this talk, we investigate the physical origin of the predicted structures in the outer layers of massive stars, and we attempt to characterize the resulting non-linear turbulent properties. Following Blaes & Socrates (2003), who performed a linear stability analysis to predict multiple instabilities originating from the iron opacity bump, we study the linear growth phase of the structures in the Wolf-Rayet (WR) star models by Moens et al. (2022) and the O-star models by Debnath et al. (2024) and compare our results to theoretical predictions. Furthermore, we consider the fully developed non-linear turbulence and compute energy power spectra which we then compare to classical Kolmogorov theory. In particular, we study how the optically thick and optically thin winds of these WR stars and O-stars, respectively, can impact the emergent turbulent properties, both in the linear stage and in the non-linear stage.

Unveiling the Evolutionary Journey of J040901.83+323955.6

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The resemblance in wind conditions between low-mass post-asymptotic giant branch stars and evolved massive stars gives rise to the phenomenon of spectral mimicry. LAMOST J040901.83+323955.6 was identified as a WR star in the LAMOST spectroscopic database through machine learning methods. The various spectral type classifications of this object have created the initiative for a detailed investigation. The position of J040901.83+323955.6's in the Galaxy and its placement on the color-magnitude diagram, let us conclude that it is a low-mass object with WR phenomenon, i.e. [WR], or a central star of a planetary nebula (CSPN). The star shows irregular variability with an amplitude of up to ≈ 0.2 mag, as revealed by new and archival photometric data. Moreover, spectra obtained in 2022 and 2014 illustrate evidence of spectral variability. Estimations of J0409+3239's mass based on evolutionary tracks indicate that it is less than 0.9 $M_\odot$, with a luminosity of $L_* = 1000\ L_\odot$ and an effective temperature of $T_{eff} = 40{,}000$ K. The J040901.83+323955.6 is a low-mass star in a rare transitional phase towards becoming a central star of a planetary nebula.

The cosmic rate of pair-instability supernovae

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Pair-instability supernovae (PISNe) are explosions developing in the core of massive stars due to a thermonuclear, runaway process, ultimately leading to the total disruption of the progenitor. They are expected to be the endpoint of the evolution of low-metallicity stars in the mass range between ~ 140 and 260 solar masses, and responsible for the existence of the upper mass gap in the black hole mass spectrum. Despite the robust theoretical understanding of the pair-production mechanism, and their crucial implications for many astrophysical observations, PISNe have never been confidently observed. However, they are expected to be up to two orders of magnitude more luminous than typical core-collapse supernovae (CCSNe), for which we have hundreds of observations. This leads to naturally wonder what could be the reason of their missed detection.

In this talk, I will present new results on the PISN rate as a function of redshift, obtained using up-to-date stellar evolution tracks from the PARSEC code, and an up-to-date empirical determination of the galaxy star formation rate and metallicity evolution throughout cosmic history. The goal is to provide a robust theoretical framework to understand where PISNe are across cosmic time, and study their detectability with instruments like JWST. I will present estimates for the relative rate of PISNe and CCSNe, and discuss how the PISN rate is affected by various assumptions in the theoretical models, including the criterion adopted to identify stars unstable against pair production, the maximum stellar metallicity to have PISNe, the upper limit of the stellar initial mass function, and the dispersion of the galaxy metallicity distribution in redshift. Finally, I will discuss the relative PISN rate contribution coming from single star and isolated binary evolution, and how possible (or lack of) future PISN observations can help us constrain stellar and galaxy evolution models.

Mass loss in Dwarf and Evolved B stars

(*Invited Talk*)

Alex Carciofi

Universidade de São Paulo, Brazil

In this talk, I will present recent findings on two distinct topics. First, I will explore how classical Be stars, which are rapidly rotating main-sequence stars, lose mass to form their circumstellar disks. This discussion will include both observational data from a four-year observational program and theoretical insights from recent SPH simulations combined with radiative transfer analysis. Our main finding is that mass loss in Be stars is always asymmetrical, resulting in line asymmetries that can be qualitatively explained by a "hot spot" ejecting matter off the star's surface. I will also address the limitations of current models and outline necessary future steps.

Second, I will delve into the nature of the envelopes surrounding B[e] supergiants. I will examine how asymmetric mass loss contributes to the formation of their two-component envelopes, consisting of a slow equatorial outflow and a fast polar wind. I will examine recent findings on the SMC B[e] supergiant RMC 82, highlighting the critical need to simultaneously treat the gaseous and dusty components of its envelope. These components interact with each other, influencing key parameters such as the dust condensation radius and the strength of the H-alpha emission.

Local Dynamics at the Apex of an Astropause: Insights from 3D Resistive MHD Solutions

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Astrospheres represent dynamical interaction zones where stellar winds collide with the surrounding interstellar medium, and are characterized by complex HD or MHD discontinuities. At the center of this interaction is the astropause, which is the boundary that separates the two flows, and its structure is determined by one of the fluid flow separatrices or separatrices of the speed of the center of mass. We are aiming at finding and distinguishing reconnective and non-reconnective solutions by specific criteria. In the MHD description, there must be at least one null point for the magnetic field and a stagnation point for the velocity field close to the apex of the astropause. Assuming that both points are identical, we derive exact solutions to the resistive MHD equations in three-dimensional space. The topology of the magnetic field describes the nature of these solutions. We find flows that cross the Fan plane and the Spine line, possibly allowing us to identify real reconnective solutions. By employing these reconnective solutions we calculate the dissipation rates. With a known density profile at the apex, the derivation of pressure allows for the determination of temperature, thus allowing us to compute the radiance and to generate synthetic sky maps that can be compared to observations.

Cloud-Cloud Collision: Formation of Hub-Filament Systems and Associated Gas Kinematics

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The massive star-forming regions (MSFRs) are commonly associated with hub-filament systems (HFSs) and the sites of cloud-cloud collision (CCC). Recent observational studies of some Galactic and extragalactic MSFRs have revealed simultaneous signatures of CCC and the presence of HFSs. These observational works suggest a potential connection between CCC and the formation of HFSs. To understand the connection, we conducted an extensive analysis of the magneto-hydrodynamic simulation data from Inoue et al. (2018), 70(SP2), S53(1-11). This simulation involves the collision of molecular clouds at a relative velocity of about 10 km s^{-1} with a spatial resolution of approximately 2400 AU. The supersonic collision, characterized by a Mach number of about 33, develops a shock-compressed layer at the interface of the colliding cloud components. Over time, the width and density of this layer progressively increase. Following the collision, the turbulent and non-uniform cloud undergoes shock compression, rapidly developing filamentary structures within the compressed layer. Mass accumulation is facilitated along magnetic fields, promoting the development of heavier and denser filaments oriented perpendicular to the magnetic field. Ultimately, filaments converge toward a central junction under the influence of gravity, forming a HFS that hosts a massive core of approximately 15 Solar mass at its hub. Overall, the combined effects of turbulence, shock compression, magnetic fields, and gravity play pivotal roles in forming HFSs from CCC. Furthermore, the position-velocity diagrams and the spatial distribution of different velocity components at the various stages of evolution highlight the challenges associated with the observational detection of CCC. I will present these results in my talk.

Testing the Supermassive Star Scenario for Early Massive Cluster Evolution

Katarzyna Nowak

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For a long time, it was believed that globular clusters were simple structures consisting of only one population of stars that share the same chemical composition. However, recent extensive evidence shows that these old and massive stellar aggregates exhibit significant differences in lighter elements with the Na-O anticorrelation being the most prominent feature in most of them. Additionally, multiple sequences in the colour-magnitude diagram suggest a spread in helium abundance in most Galactic and extra-galactic globular clusters. Spectroscopic measurements taken in the 2000s also suggested that most globular clusters have multiple populations of stars. The most likely explanation for the chemical peculiarities observed in globular cluster is self-enrichment, where specific stars pollute the surrounding gas with their yields. Supermassive stars ($> 1000\ M_{\odot}$) are proposed candidates for polluters but at the present time it is very hard to observe them due to their location. The candidates forming massive clusters are located outside the Milky Way with very dense centers, where the hypothetical star would be obscured by gas and dust. The supermassive stars would form via runaway collisions, simultaneously with the cluster, hence their disc is perturbed by stellar flybys, as well as inspiralling and colliding stars. It has been proposed that kilomasers, generally associated with massive star formation, could arise from the accretion disc around supermassive stars.

To investigate the predicted maser spectrum of such a disc, we use a 3D hydrodynamic simulations set up around a supermassive star to examine how its accretion disc reacts to frequent stellar encounters. We examine if the disc survives and remains dense enough to mase water lines. We then model kilomasers and compare it to an interesting candidate in the starburst galaxy NGC 253.

Massive star binarity across the HRD

(*Invited Talk*)

René Oudmaijer

University of Leeds, United Kingdom

More than 90%, and perhaps all, high-mass main sequence stars are found in binary systems, while close massive binaries are responsible for some of the most energetic phenomena in the Universe. In order to understand massive stars and their evolution, it is therefore essential to find out how they formed in binary or multiple systems and how these primordial binaries evolve into the Main Sequence systems observed. At the same time, it is important to understand what will happen to the stars in these systems later in their lives. Indeed, about 25% of all massive binaries are expected to merge, while a further, substantial, fraction of the binary stars' evolution will be affected by binary interactions.

In the talk, I will attempt to give an overview of our knowledge of massive binary star formation and evolved massive binaries found in the upper parts of the HR diagram from an observational perspective.

A high-angular resolution insight into the onset of stellar multiplicity in massive star formation

Emma Bordier

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The high incidence of multiples and especially short-period binaries among the main-sequence massive stars questions the way they form. To understand how such close systems are built, we need to obtain strong constraints on the origin of the pairing mechanism and the birth orbital properties. Different scenarios try to explain the formation of these multiples such as core fragmentation, disk fragmentation (in which inward migration can occur) and the various dynamical interactions like capture of an unbound body or Kozai-Lidov effects in the case of triples. With the final goal of better understanding the origin of massive close binaries, I will show how optical interferometry (VLTI/GRAVITY and PIONIER) and high-angular resolution imaging (VLT/NACO) are of great importance to investigate key ingredients in massive star formation processes. The combination of both techniques and the addition of existing spectroscopic surveys provide high-mass binary statistics of young stars within a physical separation range of 1-35,000 au. We derive multiplicity and companion frequencies, mass ratios, and physical separation distributions in a consistent parameter space. We compare our results to other populations of stars, with different mass regimes and evolutionary stages and reconnect our findings to the most promising pathways that lead to massive multiples. In particular, we discuss the possibility of hardening binaries with the migration scenario and through Kozai-Lidov cycles.

Identification of Possible Stellar Companions via Speckle Interferometry in a Sample of Be Stars

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We conducted speckle interferometric measurements on a sample of 47 northern Be stars using the 2.1 m telescope at OAN-SPM México, using the V, R, and I filters, yielding astrometric data for 8 previously know doble systems, and the discovery if 5 new pairs, with angular separations ranging from 0.08” to 0.33”. The potential double systems not previously documented in literature are: HD 35079, HD 51893, HD 55606, HD 219523 and HD 232940. We investigated the possibility of these systems being gravitationally bound.

Interferometric campaign on the multiplicity of classical Be stars: new detections and orbits of stripped subdwarf companions

Robert Klement

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Rapid rotation and nonradial pulsations enable Be stars to build decretion disks, where the characteristic line emission forms. A major but unconstrained fraction of Be stars owe their rapid rotation to mass and angular-momentum transfer in a binary. The faint, stripped companions can be helium-burning subdwarf OB-type stars (sdOBs), white dwarfs (WDs), or neutron stars. In this contribution, I will present the results from an ongoing interferometric campaign on the multiplicity of Be stars, which has thus far led to seven new published orbital orbital solutions for Be + sdOB binaries based on CHARA observations, including distance-dependent dynamical masses for both components in each binary. These results quadruple the number of anchor points for evolutionary models of close binary stars leading to the formation of Be stars. Based on more recent observations from CHARA and VLTI, we detected several more similar systems, as well as a few systems where the companion is in a short-lived, 'bloated pre-subdwarf' phase immediately following the mass transfer between the two components. On the other hand, we failed to detect any companion to the six observed Be stars with γ Cas-like X-ray emission, with sdOB and main-sequence companions of the expected spectroscopic mass being ruled out for the X-ray-prototypical stars gamma Cas and pi Aqr. This leaves the elusive WD companions as the most likely companions for these stars, as well as a likely explanation of the observed X-rays. No low-mass main-sequence close companions were identified in the entire sample, providing further support to the importance and possible prevalence of the binary formation channel for classical Be stars.

Constraining massive binary formation and evolution from compact object mergers

Lucas de Sá

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Compact object binaries that merge within a Hubble time are a rare outcome from massive binary evolution. Gravitational radiation is a relatively inefficient means of shrinking an orbit, and thus any compact binaries that do merge within a Hubble time must have already been in a tight enough orbit after the second supernova. This outcome of binary evolution generally requires particular formation channels, involving various combinations of “lucky” supernova kicks, single- or double-core common envelope evolution, stable mass transfer and wind or pulsational mass loss. Recent work in binary population synthesis has continuously imposed stronger constraints on the most common formation channels, and started to delineate patterns in the compact mergers they lead to, such as typical masses and coalescence times. This opens the prospect that, with an increasingly larger catalog of gravitational-wave observations of compact mergers, we will be able to place constraints on theoretical models for massive binary formation and evolution by comparing synthetic populations to observations. In this talk, I will present an overview of current such constraints, including the prospect of extending them to the process of binary formation.

Whispering in the dark: X-ray faint black holes around OB stars

Koushik Sen

Nicolaus Copernicus University Torun, Poland

Abstract: Despite the potential of GAIA DR3 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. It has recently been shown that 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 magnetized plasma around the BH can lead to radiation. For instance, 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 donor masses from 10-90 $M_\odot$ and orbital periods from 1-3162 d. A significant fraction (0.1% to 50%) of the gravitational potential energy can be converted into non-thermal radiation for realistic particle acceleration efficiency. A population synthesis analysis predicts at least 28 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 1.8 $M_\odot$ that aligns well with our predictions of the orbital period and luminosity distribution of faint X-ray emitting BH+OB star binaries. The peak in the luminosity distribution of OB companions to these faint X-ray-emitting BHs lies around $\log(L/L_\odot) \sim 4.5$-5. Finally, the X-ray luminosity from hot accretion flows around the faint BH can be $\sim$one order of magnitude above the typical X-ray luminosity expected from embedded shocks in the stellar wind of the OB star companion.

Poster Abstracts

Different recipes for the mass-loss rates of O and B stars

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We study the mass-loss rates of the winds for O and B spectral types. We analyze the different mass-loss rate recipes given by de Jager et al. (1988), Vink et al. (2000, 2001, 2021), Krtička & Kubat (2012) for O stars, Krtička (2014) for B stars, Gormaz et al. (2019), Gormaz et al. (2022), Björklund et al. (2023), and our new mass-loss law (Figueroa-Tapia 2024 in preparation). For this purpose, we calculate, with our stellar evolution code, the influence of these different recipes on the evolutionary tracks of these spectral types.

Spectroscopic Analysis of OB stars in the Carina Nebula

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We describe the procedures and results of a detailed spectroscopic analysis for a sample of OB stars located in 8 open clusters in the Carina Nebula, based on high-resolution spectra obtained with the FLAMES/GIRAFFE spectrograph coupled to the UT2 VLT 8 m telescope of the Gaia-ESO Public Spectroscopic Survey. Our study includes membership analysis and distribution of projected rotational velocity for a sample of 330 stars. For a subsample of 65 sharp-lined stars, the analysis has been extended to include the detemination of atmospheric parameters (effective temperature, surface gravity, projected rotational velocity, microturbulence and macroturbulence) and the abundances of silicon, oxygen, carbon and nitrogen. The average abundances of C, N, and O are consistent with the solar value, while being slightly subsolar for Si. Our results suggest that the Carina Nebula is chemically homogeneous to within ~ 0.10 dex and the average abundances of O and Si are consistent with its radial position in the Galactic disk.

Determining Inclination Angles in Rapidly Rotating Massive Stars via Spectroscopic Analysis

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Be stars are among the fastest-rotating stars. Therefore, several physical considerations must be considered to obtain stellar parameters using stellar atmosphere models. We employed the ZPEKTR code, which uses the SYNPEC/TLUSTY models and incorporates the oblate shape resulting from high rotational velocities, as well as limb darkening and gravity darkening effects. Focusing on the HeI 4471 line, we analysed a sample of 10 classical Be stars sourced from the BeSOS database. Our research involved determining the effective temperature, surface gravity at both the equator and the pole of the stars and the rotational velocity and the inclination angle. By comparing our inclination angle results with literature data obtained through interferometry, we can ascertain that an accurate value of this parameter can be derived using spectroscopy data from a small telescope.

Spectral modeling of OB-type stars and wind momentum luminosity relationship

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The theory of radiation-driven winds predicts a significant relationship between wind momentum and stellar luminosity, known as the Wind Momentum Luminosity Relationship (WLR). Recently, various hydrodynamical solutions have emerged in wind theory, which appear to impact this relationship. In this study, we present preliminary findings of the WLR, integrating wind hydrodynamics consistently with NLTE radiative transport calculations. To achieve this, a multiprocessing code was developed, employing a χ^2 test to find the model that best fits observed spectral lines from 100 OB-type stars utilizing the ISOSCELES grid. This grid, was built using the HYDWIND hydrodynamic code and the FASTWIND radiative transfer code, offering hydrodynamic solutions that yield a velocity profile with a better justification than the β-law. Our results exhibit a distinct correlation between solution type, spectral class of stars, and suggest a potential approach to calibrating distance measurements.

Classification of spectral Halpha lines from massive stars using machine learning methods

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Usually, the stellar winds from massive stars are modeled using the analytical approximation, called β-law, for the velocity field. However, in later years it has been suggested that massive stars have slower winds than the obtained from the classical fast solutions, and a better description of the winds of these stars could be achieved with the δ-slow hydrodynamic solution, obtained from the m-CAK theory.

Aiming to find the stellar and wind parameters of a massive star, in this work, a classifier is built for Hα synthetic line profiles from a large grid of models, considering only δ-slow solutions. Clustering is used to assign labels to the stars, and then a Deep Neural Network (DNN) is trained to find the corresponding class for an observed Hα deconvolved line profile. The best fitted model is obtained in a first approach computing the χ^2-test between the observed Hα line profile and the synthetic line profiles in the corresponding class, yielding a set of stellar and wind parameters, which are the predictions made by this method.

A further approach on this methodology implements Bayesian Neural Networks (BNN) instead of deterministic DNNs, predicting over the parameters space. This allows to obtain a distribution for each parameter, from which statistical predictions can be made directly: e.g., the mean of the distribution for the parameter prediction and the standard deviation for the error. These predictions, which have shown similar results as other works for a certain sample of stars, can be completed in less than a minute (for a single star), thus resulting in a very efficient methodology that is still in expansion, notably, implementing more line profiles besides Hα.

Application of the Ensemble Empirical Mode Decomposition (EEMD) method in astronomy

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While the Fourier method is widely known and used for frequency analysis, it has been found to be inadequate for signals with time-varying periods or with high amplitude noise. The empirical ensemble modal decomposition (EEMD) is a powerful tool that uses the Hilbert-Huang transform (HHT) to decompose nonstationary and nonlinear signals into finite and linear independent components called intrinsic modal functions (IMFs). To demonstrate its application, we choose a set of simple synthetic signals with single frequencies up to signals with multiple frequency components. In addition, we added random noise to the signal to test the sensitivity of this method in the presence of noise with different amplitudes. Furthermore, to investigate the effectiveness of this method, we apply EEMD for detecting frequencies in real light curves of selected known pulsating stars.

Revisiting the Spectral Evolution of μ Centauri: Insights from Historical Data Digitized by the ReTrOH Project

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μ Centauri (= HD 120324) is recognized as a non-radially pulsating Be star that has experienced multiple outbursts similar to those observed in γ Cas. These recurrent events have resulted in the temporary disappearance of its emission lines, with notable occurrences documented around 1918 for approximately a decade and again from 1977 to 1989.

As part of the ReTrOH project, aimed at recovering a vast repository of historical spectroscopic and photometric plates from the La Plata Observatory, we have successfully digitized plates associated with μ Centauri. This extensive collection encompasses spectra acquired during the periods 1904-1907, 1925-1936, and 1953-1971. Our poster presentation provides a glimpse of these spectra, accompanied by an initial morphological analysis and a comparative study with previously published data.

Modeling of Classical Be stars belonging to the BeSOS database

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Classical Be stars are variable non-supergiant B-type stars rotating fast and holding a dust-free Keplerian circumstellar disk. The equatorial disk is formed by gas ejected from the star under a mechanism that still is under debate. The variability shown by these stars can be observed by the change in the shape and intensity of the spectral lines, which may indicate the process of disk formation/dissipation. To study this variability and its origin, a spectroscopic catalog called the “Be Stars Observation Survey” (BeSOS) was created. The BeSOS catalog contains data of 71 southern Be stars observed and more than 300 multi-epoch mid-resolution spectra (R ∼ 17.000) in the visible region (4260-7300 Å). The main objective of this work is to obtain the disk parameters of the stars in the BeSOS catalog and to analyze their evolution over time. To this end, we use a grid of models called BeAtlas created with the 3D Monte Carlo code HDUST to modeling multi-epoch spectra. On this occasion, we will present the first results obtained for a sample of stars and their comparison with the literature.

Stellar parameters, disk-phases changes and new insight about the line-profile variability of the Be star π Aquari

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Be stars are rapidly rotating stars on the main sequence or above, holding an equatorial gas decretion disc in quasi-Keplerian rotation. The disc can appear and/or disappear more than once during the star's life, and the responsible mechanisms could be a combination of different phenomena, such as stellar rotation, non-radial pulsation, stellar winds, and binarity. In this work, we study the long-term variability from the optical spectra of the Be star pi Aquarii.

We identified several spectral lines and studied specific observation dates for Balmer, Helium, Silicon, and Iron emission lines in detail. Using stellar atmosphere models, we determined the stellar parameters, considering the oblate geometry due to the fast rotation. We studied the disk phases (density, size, and inclination disk) by modeling the Balmer lines with the radiative transfer code HDUST.

Spectroscopic Analysis of B and Be Stars in the open Cluster NGC 3766

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Open clusters can exhibit splits in the main sequence (MS), where rapidly rotating stars trend towards a redder MS, while slower rotators are predominantly found on the bluer segment of the MS. Notably, the open cluster NGC 3766 presents such a split in its MS, alongside a notably high ratio of Be/B stars. In this work, we examined a sample of 36 B and Be stars, utilizing high-resolution spectra from the Gaia-ESO Survey (GES). Our analysis revealed a range of projected rotational velocities (vsini), spanning from 9 to 322 km/s, as inferred from the widths of He I lines. For a subset of 17 stars, we conducted an extensive spectroscopic analysis, deriving stellar parameters and determining abundances of silicon, oxygen, carbon, and nitrogen. This was achieved through a semi-automatic method of non-ETL spectral synthesis. On average, the abundances observed in NGC 3766 align with solar values, although one star exhibits a notable deviation in its nitrogen-to-oxygen ratio (N/O). Furthermore, the distribution of vsini across the color-magnitude diagram (CMD) of NGC 3766 suggests the possibility of a dual-component MS attributed to rotation. The average abundances obtained for the open cluster NGC 3766 are consistent with the solar abundances.

Stellar Wind Parameter Determination through Modeling IR Line Profiles in B-type Supergiants

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The theory of radiation-driven winds based on the Sobolev's approximation adequately describes the wind of O-type stars. However, considerable discrepancies appear between the Hα line profile calculated with this theory and those observed in B supergiant stars. Fitting the synthetic line profiles to the observed spectra requires parameter values that are not predicted by the theory. To explore the velocity law parameters, we model the H I lines and analyze the physical conditions of their formation regions. For this purpose, we use an adapted version of the APPEL code. This code solves the NLTE radiative transfer equation in the comoving frame with spherical geometry, using a wind velocity β law. Synthetic line profiles are compared with high-resolution spectroscopic observations of B supergiants, acquired with the Gemini Near-Infrared Spectrograph (GNIRS) in the K- and L-band. We derive the parameters that describe the wind of the selected stars and discuss the obtained results.

Long-term Spectral Analysis of HD 41117

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HD 41117, a B Supergiant Star (BSG), exhibits a distinct Hα P Cygni profile, indicating significant stellar wind activity. Utilizing spectroscopic data obtained from the Perek Telescope in Ondrejov, Czech Republic, and the Jorge Sahade Telescope in San Juan, Argentina, spanning 2006 to 2024, we investigate it's spectral variability. Our analysis reveals changes in the Hα and He I 6667 Å line profiles, reflecting variations in the mass-loss rate and velocity structure of the stellar wind. In this study, we present our results and compare with lightcurves analysis. We also discuss the origin of the variability.

Monitoring of the Yellow Hypergiant Rho Cas in 2018-2024

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We present an analysis of ongoing optical spectroscopic monitoring of the Yellow Hypergiant Rho Cas between 2014 and 2024, with an observation cadence of 7 days since 2018. We discuss the temporal line profile variability observed in Balmer Halpha and the variability of the stellar wind in selected photospheric absorption lines of Fe I, Fe II and Si II. We combine accurate measurements of various line parameters with multi-band photometric observations during this period and present an analysis of the pulsation periods in this notorius hypergiant star.

RMC 40 in eruptive phase: CNO and rare-earth elements

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Using high-resolution optical and infrared spectra of the LBV star in the Small Magellanic Cloud, RMC 40, obtained during the eruptive phase, we determined the chemical abundances of light (CNO) and rare-earth elements. We found a strong decrease in carbon abundance and strong enhancement in nitrogen abundance. The abundances of s- and r-process elements, such as Ba, La, Ce, Pr, Nd, and Dy, are increased compared to solar-scaled values by +(0.60 – 1.0) dex pointing to strong pollution of the stellar envelope (pseudo-photosphere) by the products of the CNO cycle and the r- and s-process.

Analysis of spectroscopic and photometric data of Luminous Blue Variable stars

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High-mass stars play a crucial role in the interstellar medium, as they not only enrich it but also significantly influence its dynamics. However, these objects are rare, and uncertainties persist regarding the evolutionary phases of massive stars. Of particular relevance to us is a short phase known as LBV (Luminous Blue Variables), which are characterized by high luminosity and sporadic, intense mass loss event of unknown origin.

It is noteworthy that LBVs generally exhibit luminosities on the order of 6×10^6 $L_\odot$, implying an initial mass higher than 50 $M_\odot$. Additionally, there is a subgroup of LBVs with lower luminosities ($L \leq 6 \times 10^5$ $L_\odot$) and reduced mass loss rates. Although they usually have high temperatures (T_{eff} > 10,000 K), LBVs may experience temperature decreases to values below 6,000 K during eruptive episodes.

Consequently, we conducted a comprehensive review of the literature and analyzed light curves for stars classified as LBVs and potential candidates, with a focus on 15 stars (η Car, AG Car, HR Car, S Dor, RMC 40, RMC 71, RMC 110, RMC 127, RMC 40, HD 269582, AF And, AE And, VRMF 55, [GKM2012]WS1, Wray 16-137, and Wray 17-96). Primarily, we searched for public photometric data from 2019 to 2023, supplementing previously data from the literature.

We will also present new spectroscopic data for some of these stars, named RMC40, RMC 71 and RMC 110 from Magellanic clouds and the galactic object WRAY 17-96.

Using interferometry to model the winds of red supergiants

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Red supergiants (RSGs) are evolved massive stars in a stage preceding core-collapse supernova. Understanding evolved-phases of these cool stars is key to understanding the cosmic matter cycle of our Universe, since they enrich the cosmos with newly formed elements. However, the physical processes that trigger mass loss in their atmospheres are still not fully understood, and remain one of the key questions in stellar astrophysics. In this talk, we propose a new method to study the extended atmospheres of these cold stars, reproducing the effect of a stellar wind to a well known stellar atmospheric model (MARCS). We then can compute the intensities, spectral energy distributions and visibilities matching the observations for the different instruments in the Very Large Telescope Interferometer (VLTI). Specifically, I will discuss the robustness of our results when comparing with brand new VLTI/GRAVITY and MATISSE data of the RSGs AH Sco, KW Sgr, V602 Car, CK Car and V460 Car. We find that our model can accurately match these observations comprising a large wavelength range of 1.8-5.0 μm, showing the enormous potential of this methodology to reproduce extended atmospheres of RSGs. This work is one of the first and most complete spectro-interferometrical studies of RSGs to date.

Clarifying the Parameters of Extragalactic WN Stars

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WN stars, as massive stars in a late evolutionary stage, exhibit strong, broad emission lines due to powerful stellar winds, significantly influencing their environments. Accurate determination of their parameters is crucial for understanding the life cycles of massive stars, stellar wind mechanics, and the chemical enrichment of galaxies.

As a case study, we began analyzing the WN stars in M33. To achieve more accurate modeling and obtain more reliable results, we utilized data from different photometric surveys in a wide spectral range, including the UV and IK bands. This dataset enables significant improvements in determining the physical parameters of stars, particularly their temperatures, which are modeled primarily using optical observations.

CMFGEN Models of WN3 BAT99-3

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Wolf-Rayet stars are considered some of the most evolved massive stars, though their origins as binary or single stars are poorly understood. Modeling their expansive stellar winds may help us to understand their fundamental stellar parameters, as well as their paths through stellar evolution. We present our analysis of the WN3 star BAT99-3 in the Large Magellanic Cloud. Visible and near-infrared spectra collected with the 6.5 m Baade Magellan telescope (Las Campanas, Chile) are joined with ultraviolet spectra taken with the International Ultraviolet Explorer (IUE) satellite. Together these observations instruct generations of modeled spectra, generated with CMFGEN. This work is being supported by the National Science Foundation under AST-2307594.

Mathematical discussion on a circumstellar matter model for massive stars

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The correct selection of the governing equations to describe structures in circumstellar matter around massive stars is fundamental for modeling the observed phenomenon. This kind of scenario arises in problems where it's necessary to model an interaction term through a constitutive rule, for example the density. From the fact that the model response must be able to also describe astronomical observations, the theoretical approach should maintain both rigor and adaptability. In this work a discussion on the formulation of mathematical stationary two-dimensional models in a magneto-hydrodynamic framework is presented. By employing assumptions similar to those used for incompressibility, a formulation in terms of stream potential is presented for the analysis. The focus lies on the impact of the representation used for terms describing the contributions due to pressure and gravity. Starting with a radial analysis to identify potential challenges in the modeling process, we address both a nonlinear model and its linear counterpart in this direction. Both formulations are solved analytically, and the solutions are presented in terms of special functions. We demonstrate that the solutions of the nonlinear model exhibit significantly different behaviors depending on the parameters used to describe boundary conditions. On the contrary, the linear model allows for the recovery of expected behaviors for density description. In this regard, we highlight the oscillatory behaviors and quasi-Keplerian rate decay for the orbit. The relationships for the parameters employed in the linear model, which result in oscillatory behaviors, reflect necessary physical conditions for the density description. We utilize the aforementioned results to propose a family of linear models for the two-dimensional problem, which we then solve using classical tools from the theory of differential equations. In addition, we use these results to present some analysis for the Grad-Shafranov nonlinear model related to stability properties of the solutions.

Modeling the Ca II forbidden lines arisen from a radiation-driven wind and circumstellar disk

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The generally extended envelopes around massive stars in late evolutionary phases account for the episodic or eruptive mass loss processes these objects undergo. Physical and kinematic conditions of these circumstellar shells and their interaction with the stellar radiation determine the observed spectra. Modeling line emission is the primary way to explore these physical properties. In this work, we focus on the forbidden emission lines of ionized calcium ([Ca II] λλ 7291, 7324 Å), which are good tracers of the kinematics within the disk of the B[e] supergiants, complementing the information provided by the [O I] emission lines. We model synthetic [Ca II] line profiles, assuming a scenario consisting of a radiation-driven wind and a circumstellar disk in Keplerian rotation. We discuss the diagnostic potential for probing the formation regions of Ca II forbidden lines in the B[e] supergiant environment.

High resolution near-IR spectroscopic observations of B[e]sg from the Magellanic Clouds

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The post-main sequence evolution of massive stars give place to several phases with strong, often eruptive mass-loss events, including the enigmatic B[e] supergiants. Stars in this group are surrounded by disks, which are cool and dense, and give rise to a complex chemistry, producing molecules and dust. Near infrared emission in CO bands has proven to be a major indicator for disk dynamics, as it originates typically from the inner edge of the molecular disk or ring. To better understand the mass-loss history in those objects, which is an essential ingredient for accurate predictions (e.g. of final stages) from stellar evolution calculations, a detailed study of their circumstellar material is crucial. In this work, we present our results on the analysis and modeling of high-resolution GEMINI/IGRINS observations of a sample of B[e] supergiants from the Magellanic Clouds.

Near-infrared characterization of evolved massive stars in M31 and M33

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Massive stars are cornerstone to the dynamical and chemical evolution of their host galaxies. With their intense winds and outbursts they enrich their environment with processed material and inject large amounts of energy into it. But the evolution of massive stars and the possible (or plausible) evolutionary connections between observed classes of objects (e.g. Luminous Blue Variables, α Cygni variables, B[e] supergiants, Yellow Hypergiants) are still far from being firmly settled. One major hindrance is that, for unambiguous classification of evolved massive stars, knowledge about their entire spectral characteristics and long-term photometric variability are essential. In this work, we present new near-infrared medium-resolution K-band spectra for a sample of evolved massive stars in M31 and M33, obtained with the GNIRS spectrograph at the Gemini North telescope. The detected spectral features are used to characterize the objects and their environments and help to resolve ambiguities of their classification.

Where the stellar wind impinges the interstellar medium

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Massive stars have strong radiation-driven winds, losing part of their mass. Where these winds encounter the interstellar medium, a separatrix surface can form, called astropause. The astropause separates the stellar wind region, the astrosphere, from the outer streaming interstellar medium. At the apex of the astropause the stagnation point is located, where the streaming velocity of both flows, namely the flow of the interstellar medium and the stellar wind flow, vanishes. The velocity fields in the astropause regions can be described by potential theory, while the m-CAK theory is used to describe the radiation-driven winds, in the proximity of the star. In this work, we aim to connect these two theories to describe the interaction between the stellar wind and their surroundings. We propose a criterion for delimiting validity regions for both theories, and we found a relation between the stellar wind parameters (mass-loss rate and terminal velocity), the interstellar medium conditions, and the distance between the star and the stagnation point, called the stagnation distance.

A structural and spectroscopy study of the clusters surrounding the Orion Nebula: NGC 1977 and NGC 1981

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Open clusters (OCs) belonging to star-forming complexes are the leftovers from the initial stellar generations. Among the various star-forming regions, the Orion complex stands out as an excellent laboratory for studying the high mass star formation process due its proximity and richness in ongoing star formation activities. NGC 1981 is a young OC located northward from the Orion Nebula that inhabits a relatively dust-free field, perhaps as a consequence of the feedback from its massive stellar content, while NGC 1977, located about 20' southwards of NGC 1981, remains embedded within its progenitor cloud. Aiming to deepen the understanding on the star formation and astrophysical processes occurring in NGC 1981 and NGC 1977, we have used astrometric and photometric data from Gaia to characterize them. We also have performed a metallicity and radial velocity characterization of the brightest stars of NGC 1981 through medium resolution spectroscopic data collected at OPD, CASLEO and from the Apogee archive. The spectroscopic data was necessary to improve the membership assignment because the brightest stars (early B type stars) of NGC 1981 exhibit a notable dispersion in the astrometric space, since the cluster may be in dissolution process. This data can also provide insights of the probable formation scenario of the clusters. In the near future, we aim to collect high resolution spectroscopy of the B stars of NGC 1981 and NGC 1977 to solve the interstellar medium components and complement with polarimetric data to unveil the star formation history of the region.