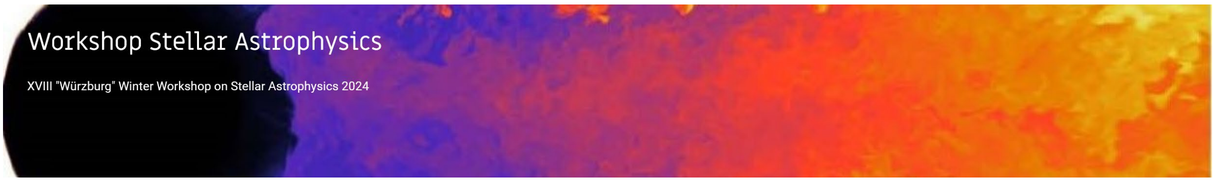

Talks – Titles and Abstracts

- *Philipp Podsiadlowski*

Dynamical Ejections from Pulsating Red Supergiants

Red supergiants (RSGs) with extended envelopes are known to be dynamically unstable, first to large-amplitude pulsations and, when the L/M ratio is sufficiently large, episodic, discrete mass ejection events. I will show recent results of studying these processes and discuss implications for SNe IIn, the observed RSG limit and the missing RSG problem for SNe IIP.

- *Ruediger Pakmor*

WD merger simulations

I will summarise the plan and setup to finally run a WD merger parameter study.

- *Christine Collins*

Kilonova radiative transfer

I will present our latest ARTIS kilonova simulations based on neutron star merger simulations from the group at GSI.

- *Oliver Just*

Helium and r-process heating in neutron star mergers

I will report on our investigations of helium as a potential tracer of neutrino driven winds in neutron star mergers, highlighting the possibility that a (non-)observation of helium in the observed kilonova AT2017gfo may severely constrain the nuclear EOS. I will also report of our recently developed tool RHINE that adopts machine learning to describe energy release connected to r-process nucleosynthesis in hydrodynamical simulations.

- *Stefan Taubenberger*

No rungs attached: A distance-ladder free determination of the Hubble constant through type II supernova spectral modelling

In this talk I will present the results of a study led by Christian Vogl, where the tailored expanding photosphere (EPM) method is applied to a set of ten SNe II at 0.01 < z < 0.04 with publicly available spectra and photometry to obtain a distance-ladder-independent local measurement of the Hubble constant. The tailored-EPM machinery includes recent advancements in spectral modelling such as the use of a spectral emulator to interpolate between radiative transfer models calculated with TARDIS. Our analysis demonstrates that the tailored EPM allows for H_0 measurements with precision comparable to the most competitive established techniques, even when applied to literature data not designed for cosmological applications. We find an independent H_0 value of 74.9+/-1.9 (stat) km/s/Mpc, which is consistent with most current local measurements. Considering dominant sources of systematic effects, we conclude that our systematic uncertainty is comparable to or less than the current statistical uncertainty. This proof-of-principle study highlights the potential of the tailored EPM as a robust and precise tool for investigating the Hubble tension independently of the local distance ladder.

- *Rajika Kuruwita*

Were all low-mass fast rotators born in a binary?

Many low-mass fast rotators (stars with rotation periods < 2 days) are found to lack planets and are overwhelmingly found in binaries. Using the ideal MHD code FLASH, we investigate how binary star formation pathways may lead to fast rotator formation. We simulated multiple star formation and tracked the spin evolution of the stars that formed. We find gravitational instabilities in the circumstellar disk can trigger bursts of accretion which spin-up the primary star. Strong instabilities can lead to disk fragmentation and the formation of close companions. Weaker instabilities are triggered by stellar flybys, which still produce some spin-up in the primary star. We argue that spin-up events either triggered by disk fragmentation or flybys, coupled with the shorter disc lifetime due to truncation can help produce fast rotators.

- *Christian Klingenberg*

On a semi-discrete Active Flux method for multi-dimensional conservation laws

The quest for numerical methods for conservation laws that take into account multi-dimensional flow structures motivate us to pursue the Active Flux method. A semi-discrete AF method for two space dimensions is described in Abgrall, Barsukow, Klingenberg (2024). It is a third order finite volume method with additional degrees of free- dom, namely point updates at points that are shared between neighboring cells. Thus the reconstructed solution is continuous between cells. We begin this lecture by introducing this semi-discrete Active Flux method. We shall discuss how Active Flux will resolve some multi-dimensional flow features well, even on a coarse grid. To this end we begin with the study of linear acoustics. On a cartesian grid in two space dimensions using Fourier analysis we can identify the class of those schemes that preserve discrete stationary states, in particular well-balanced schemes. For the acoustic equations the notion of a low Mach limit exists and it can be seen that the stationarity preserving schemes are automatically low Mach. This way one can see that the Active Flux method has these structure preserving properties. For the non-linear Euler equations the ability of Active Flux to maintain stationarity solutions and to resolve vortices well, also on a coarse grids, is shown by numerical experiments. The method also has the low Mach property for the Euler equations. Note that there are no fixes or modifications of Active Flux needed to achieve these properties. Taking the incompressible limit of the compressible Euler equations one arrives at a divergence free velocity field, which is non-trivial only in more than one space dimension. The Active Flux method has the ability to maintain both a solenoidal and a irrotational velocity field, which are multi-dimensional flow features. We end by giving an outlook on high order extensions of the method and on limiting.

- *Lisa Lechner*

A two-dimensional Active Flux method of arbitrarily high order

The Active Flux method is an extension of a finite volume method using point values at the cell interfaces in addition to cell averages as degrees of freedom. In this talk we present a generalized version of the Active Flux method for hyperbolic conservation laws and its extension to arbitrarily high order of accuracy in two spatial dimensions on Cartesian grids. It uses a conservative update of the cell averages and its higher moments, whereas the point values, for which exists no notion of a conservative update, are updated using a non-conservative form of the hyperbolic PDE. Numerical experiments with the extended scheme will be shown to illustrate the capabilities of the method.

- *Wasilij Barsukow:*

Bound-preserving limiting for Active Flux

The active flux (AF) method is a compact high-order finite volume method that simultaneously evolves cell averages and point values at cell interfaces. We present bound-preserving (BP) AF methods for hyperbolic conservation laws, with a focus on positive density and pressure for the compressible Euler equations. The update of the cell average is rewritten as a convex combination of the original high-order fluxes and robust low-order (local Lax-Friedrichs or Rusanov) fluxes, and the desired bounds are enforced by choosing the right amount of low-order fluxes. A similar blending strategy is used for the point value update. In addition, a shock sensor-based limiting is proposed to enhance the convex limiting for the cell average, which can suppress oscillations well. Several challenging tests are conducted to verify the robustness and effectiveness of the BP AF methods, including flow past a forward-facing step and high Mach number jets. This is joint work with Junming Duan and Christian Klingenberg (https://arxiv.org/abs/2411.00065).

- *Vishnu Varma*

Understanding the role of magnetic fields in core-collapse supernovae

Core-collapse supernovae (CCSNe) are some of the brightest, most energetic events in the universe. In order to model their explosion mechanism accurately, we need to have a diverse range of physics such as neutrino transport and neutrino interactions, general-relativistic gravity, detailed equations of state (EoS) of dense matter and detailed progenitor models. While improved computational performance and numerical methods have allowed us to simulate these events in 3D, much of the progress that has been made has ignored the role of magnetic fields. However, it has become clear in recent years that these magnetic effects need to be considered to get a full understanding of these explosions. I will present the recent work in the field, exploring the role of magnetic fields on the CCSN explosion mechanism, discuss the discrepencies that have developed between groups and my most recent attempts to disentangle them.

- *Stephan Hachinger*

Selected News from Leibniz Supercomputing Centre (LRZ)

This short talk gives a glimpse on a few LRZ developments in these days, with a focus on Research Data Management and status of HPC, GPU/AI and Cloud systems.

- *Federico Rizzuti*

Shell mergers in massive stars and their nucleosynthesis

For a long time, 1D stellar models have reported the occurrence of shell mergers in late phases of massive stars. These events occur when two convective shells are so close that convection can overcome the stable region that separates them, allowing for the mixing of material. These events can be very energetic, releasing enough energy to modify the structure and following evolution of the star. They can be differentiated into early merger, between H- and He-shells, and late merger, between C-, Ne- and O-shells. Although shell mergers are an outcome of 1D stellar models, they have always been difficult to study given the multi-dimensional processes involved. Recently, shell mergers have started to be investigated by 3D stellar models, with an unprecedented degree of realism and detail. In addition to their peculiar dynamics, also the alternative nuclear paths that can be enabled in shell mergers are of great interest for chemical evolution studies. In this talk, I will present results coming from a new set of hydrodynamic simulations of a C-Ne shell merger in a massive star, run with a nucleosynthesis network. I will also present the effects of H-He shell mergers on the fate and nucleosynthesis of massive stars. These results provide interesting constraints to convection theory, the physics of massive stars, and their final fate.

- *Kristian Vitovsky*

Hydrodynamical Simulations of Flows in the Interiors of Blue Supergiants

The Blue Supergiant Problem refers to the overabundance of BSGs in observations compared to classic stellar evolution theory. The recent work of Ma et al. (preprint) presents a clearly defined peak in the astroseismic power spectra of BSGs in the LMC, at the same time

Henneco et al. (preprint) found long lasting H-burning convection shells in 1D evolution models of massive merger products. Initial estimates of the convective turnover timescale indicate a possible connection between the two discoveries. We are running 3D hydrodynamical simulations of the shell with the aim of extracting spectra of gravity waves that could be directly compared to the observations. In the talk, the project will be described and initial results will be presented.

- *Paul Christians*

Thermonuclear Ignition in Oxygen-Neon-Carbon Cores

Residual carbon can play a key role in the final evolutionary stages of oxygen-neon cores. Small residual carbon fractions can already lead to an oxygen ignition at significantly lower densities compared to the typical high densities required to reach an electron capture supernova, favoring a thermonuclear explosion over a collapse to a neutron star. By employing multi-D hydrodynamical simulations using the SLH code, while considering key forbidden rates, we want to study the ignition conditions and geometry in this setup.

- *Vijayalakshmi Vijayakumaran Nair*

Machine Learning Techniques for Advancing EOS in 3D Hydrodynamic Simulations

Hydrodynamical simulations of astrophysical processes in stars sometimes encounter numerical challenges where traditional numerical root-solving (NRS) algorithms fail to converge. For example, a transition between a high-density white dwarf and its low-density surrounding envelope presents a steep density contrast, causing the NRS to struggle with consistent temperature predictions. Similarly, problems arise during transitions from non-degenerate, ideal gas-like regions to electron-degenerate regions at lower temperatures, which are characterized by sharp declines in temperature over a narrow band in the (ρ, P) plane, where ρ represents density and P denotes inner pressure. My master's thesis focuses on leveraging machine learning techniques to model the Timmes EOS and integrate the fitted models into hydrodynamic codes. The motivation behind this work is that surrogate models of the Timmes EOS can be used in regimes where the NRS fails to generate thermodynamically consistent predictions. In my research, the proposed machine learning emulators address these challenges by providing accurate temperature predictions from input parameters, such as (ρ, U)—with U representing internal energy—or (ρ, P) to temperature. This approach is validated through preliminary experiments, including the Hot Bubble and Blastwave tests, which demonstrate the emulator's potential in real-world hydrodynamical applications. The Hot Bubble test, in particular, serves as a proof-of-concept by integrating the emulator into a Python-based hydrodynamic code to assess its ability to resolve classical numerical issues and evaluate error propagation effects. By facilitating more accurate EOS modeling, this work aims to improve the fidelity and efficiency of astrophysical simulations, providing a robust foundation for further exploration in the field.

- *Luke Shingles*

Synethetic spectra from kilonova models with addition ejecta components

The 3D kilonova models published in Shingles et al. (2023) show promising agreement with spectra from AT2017gfo. However, the spectral evolution was too rapid and the model was too dim, likely due to the inclusion of only the very earliest ejecta, neglecting most (~90%) of the total ejecta mass. I will show new results from models that include additional ejecta components, both from detailed models and simple scaling treatments. I will also discuss the current progress of our non-LTE modelling.

- *Josh Pollin*

3D Radiative Transfer Calculations of D6 models for Type Ia Supernovae

The double-detonation of a sub-Chandrasekhar mass white dwarf is one of the leading models for Type Ia supernovae. Double-detonations could be triggered either via accretion or during the merger of white dwarf binaries. Most previous double-detonation explosion simulations have included only the primary white dwarf, but for white dwarf mergers, the fate of the secondary can have significant consequences. Recently, simulations fully accounted for the secondary white dwarf in 3D hydrodynamic explosion simulations of double-degenerate double-detonation mergers. We present the first multidimensional nebular phase radiative transfer calculations for the double-degenerate double-detonation scenario, which utilises our full NLTE treatment of the plasma conditions. Similar to photospheric phase radiative transfer calculations, viewing angle variation is still important hundreds of days after the initial explosion. The range in viewing angle variation depends heavily on the level of asymmetry in the explosion models. Nebular phase radiative transfer modelling of D6 models has revealed that the exact evolutionary endpoint of the binary system has significant observational consequences. Specifically, when the secondary white dwarf detonates, the viewing angle variation produces a greater range of features and Doppler shifts. Additionally, JWST observations have enabled detailed comparisons of the theoretical spectra to infrared data. Thus allowing for a deeper understanding of how the morphology of the models' innermost ejecta aligns with observations. These calculations demonstrate how radiative transfer calculations in the nebular phase can reveal key spectroscopic characteristics in explosion models compared to photospheric phase calculations and highlights the importance of multidimensional effects.

- *Fionntan Callan*

Exploring the range of impacts of helium in the spectra of double detonation models for Type Ia supernovae

A key feature of double detonation models is unburnt He in the ejecta, which can show significant variation in both its mass and velocity distribution. Many previous radiative transfer simulations for double detonation models have neglected treatment of non-thermal ionization and excitation, preventing them from robustly assessing whether He spectral features are expected to form. In this talk I will present results from a NLTE radiative transfer simulation, including treatment for non-thermal electrons, for a double detonation model with a modest mass of He (0.04 $M_\odot$) ejected at reasonably low velocities (12000 km/s). Despite the simulation predicting no clear optical He features, a strong and persistent He I 10830 Å absorption feature forms that is significantly blended with the spectral contribution of Mg II 10927 Å. For some normal SNe Ia the Mg feature shows an extended blue wing, previously attributed to C I, however the simulated He feature shows its strongest absorption at wavelengths consistent with this wing, suggesting this extended wing is instead a spectral signature of He. The He feature predicted by this particular model is too strong and persistent to be consistent with normal SNe Ia, however, this motivates further work to use this observable signature to test the parameter space for double detonation models.

- *Fiona McNeill*

Effect of New Atomic Data Calculations on Radiative Transfer Modelling of Kilonovae

With the spectroscopic observations of the kilonova AT2017gfo, neutron star mergers have emerged as a viable location for the production of r-process elements. The spectra of such events are very complex, requiring detailed radiative transfer modelling to aid in the identification of spectral features. Therefore, there is an increased need for the best and most accurate atomic data for use in such simulations. I will present a comparison on the effect new, detailed atomic calculations performed by the theoretical atomic physics group at Queen's University Belfast have on RT modelling performed using TARDIS and ARTIS versus more established datasets. Whilst we find only a subtle effect on the overall spectra at early times, this comparison highlights the need to push for carefully calculated and calibrated atomic data to produce truly accurate models.

- *Boyang Guo*

Investigating the intrinsic color variation of Type Ia supernovae with 1-D radiative transfer calculations of TARDIS

Type Ia supernovae (SNe Ia) play an important role in the fields of cosmology because they have been used as cosmic distance indicators, which has led to the discovery of the accelerating expansion of the Universe. The empirical color-luminosity relations of SNe Ia have been used to calibrate their peak luminosities. However, it is found that there are still some deviations between the calibrated peak luminosities and colors and the empirical color-luminosity relations. This might be caused by intrinsic color variations of SNe Ia and dust extinctions of their host galaxies. In this talk, I will present some preliminary results of our 1D radiative transfer calculations of SNe Ia by combing the Artificial Intelligence–Assisted Inversion method with TARDIS code. I will also discuss which element abundances of SNe Ia would play an important role in dominating their intrinsic color variations.

- *Priyam Das*

Integral field spectroscopy of reverse shocked ejecta of type Ia supernova remnants

Integral field spectroscopy (IFS) of reverse shocked ejecta in Type Ia supernova remnants provides a detailed view of the physical processes and chemical composition occurring in these cosmic explosions. When a Type Ia supernova occurs, it typically results from the thermonuclear explosion of a white dwarf in a binary system. The ejecta from this explosion interact with the surrounding medium, creating complex structures and shock waves. IFS combines imaging and spectroscopy, to obtain spatially resolved spectra of astronomical objects. This allows us to analyze the spectrum from various regions of the remnant simultaneously, providing insights into the velocity, temperature, density, and composition of the ejecta. IFS of reverse shocked ejecta in Type Ia supernova remnants is a powerful tool for uncovering the intricacies of these explosive events, their progenitors, and the subsequent impact on the surrounding environment.

- *Giovanni Leidi*

Magnetohydrodynamic simulations of a carbon-burning shell

I will present 3D magnetohydrodynamic simulations of a convective carbon-burning shell of a stripped-envelope star using our Seven-League Hydro code. The considered carbon shell is in thermal equilibrium, so that its short-term evolution is mainly due to the turbulent entrainment of material at its upper convective boundary. The highly turbulent nature of the convective flows excites a small-scale dynamo, which amplifies the magnetic field up to 50% of the equipartition strength. I studied the bulk properties of the convective shell and the convective boundary mixing using mean-field analysis. I will show that the effect of the turbulent dynamo on the convective flows leads to a reduction of the mass entrainment rate from the upper stable layer by a factor of 2 compared to that found in purely hydrodynamic simulations, i.e. without magnetic fields. I will also show how the entrainment rates are well described by the Richardson entrainment law.

- *Dandan Wei*

Diversity of circumstellar material around stripped-envelope supernova progenitors from binary interactions

Many core-collapse supernovae observations exhibit signatures of interaction with pre-existing slower circumstellar material, which may be created by the extreme mass loss at the late stage of the progenitor evolution. Canonical stellar evolution theories do not expect such a significant increase in the mass-loss rate before the SN explosion, and the origin of which is still an open question. To investigate the density structure of CSM given by the mass loss from the binary system, we use MESA to simulate short-period binaries consisting of an evolved helium star and a compact companion. We find that different core and shell burning in the late phases of the stellar evolution leads to the variation of stellar expansion and shrinkage, changing the amount of mass lost from the binary and leading to the diversity of circumstellar material. Our results show that the material ejected from the outer Lagrangian point will be initially accelerated by the tidal interaction, hence changing the density profile of CSM. Investigating the CSM properties can help us to better understand the final evolution of massive stars and constrain the process of binary interaction.

- *Alexandra Kozyreva*

SN 2023ixf – an average-energy explosion with circumstellar medium and a precursor

The fortunate proximity of the Type II supernova (SN) 2023ixf allowed astronomers to follow its evolution from almost the moment of the collapse of the progenitor's core. SN 2023ixf can be explained as an explosion of a massive star with an energy of 0.7×10 51 erg, however with a greatly reduced envelope mass, probably because of binary interaction. In our radiative-transfer simulations, the SN ejecta of 6 $M_\odot$ interact with circumstellar material (CSM) of 0.55 – 0.83 $M_\odot$ extending to 1015 cm, which results in a light curve (LC) peak matching that of SN 2023ixf. The origin of this required CSM might be gravity waves originating from convective shell burning, which could enhance wind-like mass-loss during the late stages of stellar evolution. The steeply rising, low-luminosity flux during the first hours after observationally confirmed non-detection, however, cannot be explained by the collision of the energetic SN shock with the CSM. Instead, we considered it as a precursor that we could fit by the emission from 0.5 – 0.9 $M_\odot$ of matter that was ejected with an energy of ∼10^49 erg a fraction of a day before the main shock of the SN explosion reached the surface of the progenitor. The source of this energy injection into the outermost shell of the stellar envelope could also be dynamical processes related to the convective activity in the progenitor's interior or envelope. Alternatively, the early rise of the LC could point to the initial breakout of a highly non-spherical SN shock or of fast-moving, asymmetrically ejected matter that was swept out well ahead of the SN shock, potentially in a low-energy, nearly relativistic jet. We also discuss that pre-SN outbursts and LC precursors can be used to study or to constrain energy deposition in the outermost stellar layers by the decay of exotic particles, such as axions, which could be produced simultaneously with neutrinos in the newly formed, hot neutron star. A careful analysis of the earliest few hours of the LCs of Sne can reveal elusive precursors and provide a unique window to the surface activity of massive stars during their core collapse. This can greatly improve our understanding of stellar physics and consequently also offer new tools for searching for exotic particles.