The Lives and Death-Throes of Massive Stars
Proceedings IAU Symposium No. 329, 2016
J.J. Eldridge, J.C. Bray, L.A.S. McClelland
& L. Xiao, eds.

doi:10.1017/S1743921317004446

Talks also presented at the Symposium

Difference between Iib/Ib/Ic/Ic-BL
Fed Bianco
New York University

The Stellar Ultrasound
Matteo Cantiello
KITP - UCSB

Internal rotation and magnetism are key ingredients that largely affect explosive stellar deaths (Supernovae and Gamma Ray Bursts) and the properties of stellar remnants (White Dwarfs, Neutron Stars and Black Holes). However, the study of these subtle internal stellar properties has been limited to very indirect proxies. In the last couple of years, exciting asteroseismic results have been obtained by the Kepler satellite. Among these results are 1) The direct measure of the degree of radial differential rotation in many evolved low-mass stars and in a few massive stars, and 2) The detection of strong ($> 10^5$ G) internal magnetic fields in thousands of red giant stars that had convective cores during their main sequence. I will discuss the impact of these important findings for our understanding of massive star evolution.

Red Supergiants as Cosmic Abundance Probes
Benjamin Davies
Liverpool JMU

Over the past 6 years we have been establishing a novel method for determining chemical abundances from only moderate resolution near-IR spectroscopy of Red Supergiants (RSGs), the brightest stars at infrared wavelengths. We show that we can now routinely perform stellar abundance analysis at distances of 4Mpc, and around 10x this distance for young RSG-dominated clusters. This is a substantial volume of the local Universe, containing hundreds of star-forming galaxies, and we are now determining accurate metallicities and abundance gradients for a substantial sample of galaxies. Ultimately we will provide a robust measurement of the mass-metallicity relation at low redshift, free of the systematic errors that plague HII-region-based work.

Probing the Extremes of Pre-SN Mass Loss with the PanSTARRS1 Medium-Deep Survey
Maria R. Drout
Carnegie Observatories

A non-negligible fraction of massive stars undergo enhanced (possibly violent/eruptive) mass-loss in the final decades before core collapse. Theoretical models of such mass-loss are challenging and observational probes are necessary to help constrain the full diversity of pre-SN mass-loss (e.g. density profile, physical extent), the mechanism by which this mass is ejected, and the progenitors of various sub-classes of events. In this talk I will present new results from PS1 observations of super-luminous Type IIn SN (SLSN-II). In particular, I will highlight new constraints on the progenitors of SLSN-II based on a joint analysis of their explosion/CSM properties and host galaxy environments.

Asteroseismology of massive stars

Jim Fuller
California Institute of Technology

The basic principles of asteroseismic techniques applied to massive stars will first be explained for a non-expert audience and it will be addressed which stellar interior physics can be tested from studying their stellar oscillations. Afterwards, an overview of the main achievements over the last decade will be presented by means of several relevant case studies, especially in the framework of past and ongoing space missions. It will also be illustrated how asteroseismology and spectropolarimetry can be combined to probe magnetic hot stars. The review will end with a discussion on the current challenges and future prospects.

The Elusive Population of Massive Binary Star Products: the far UV Spectra of Stripped Stars

Ylva Louise Linsdotter Goetberg
Anton Pannekoek Institute for Astronomy, University of Amsterdam

Young massive stars are very frequently found in close binary systems, implying that the majority of massive stars interact with a companion during their lives. This raises two questions: How do we identify binary products and why do they appear to be so rare?

Models predict that Roche lobe overflow strips the hydrogen rich envelope of the primary star, exposing its hot helium core. These long-lasting, post-interaction systems are of wide astrophysical interest as (1) direct progenitors of Ib/c supernovae, as (2) unconventional sources of UV radiation and for (3) their capability of calibrating models and thus the theory of binary interaction. Surprisingly, very few stars stripped through binary interaction have been identified observationally - a clear contradiction with theoretical predictions.

We have conducted an extensive computational study using the binary evolutionary code MESA and the radiative transfer code CMFGEN to provide grids of tailor-made atmosphere models of stripped stars. We compute the contribution of stripped stars to the emitted radiation of stellar populations with focus in particular on their high UV-flux. We also propose several concrete observing strategies to systematically search for this elusive population.

Spectroscopic evolution of supernova progenitors

Jose Groh
Trinity College Dublin

Quantitative spectroscopy of supernovae

D. J. Hillier
University of Denver

Current deep, high cadence, untargeted surveys of the sky are revealing the great diversity of core-collapse supernovae of all types. These massive star explosions, understood to follow the gravitational collapse ouillierf the progenitor iron core, produce two distinct types of supernova with a comparable rate. Type II supernovae stem from the explosion of H-rich supergiant stars, while Type Ib/c supernovae stem from the explosion of H-poor and more compact progenitor stars.

For the most nearby SNe II, progenitor identification is sometimes possible. However, in general, all our inferrences on such explosions rely on the analysis of the supernova radiation. This will be even more true for the forthcoming deep surveys of the transient sky (e.g., with the Large Synoptic Survey Telescope). Understanding massive star explosions therefore requires detailed radiative transfer tools to connect progenitor/explosion and supernova observables.

In this talk, I will review the basic properties of core-collapse supernova ejecta and their observed properties. I will then describe the various methods used to model supernova radiation, and focus in particular on two approaches. The first is a local approach that treats the photospheric regions and assumes steady state. The second is a global approach that treats the entire ejecta in a time dependent way. This allows for the accurate computation of the evolution of the escaping radiation, providing multi-band light curves and spectra.

I will show the results from recent studies obtained with the code CMFGEN to emphasize the importance of line blanketing, non-LTE effects, time dependence, and non-thermal processes. I will also summarize the inferrences based on such studies concerning the explosion mechanism and progenitors of core-collapse supernovae.

3D Radiation Magnetohydrodynamic Simulations of Massive Star Envelopes at the Iron Opacity Peak

Yan-Fei Jiang

Smithsonian Astrophysical Observatory

I will describe a set of three-dimensional radiation (magneto-) hydrodynamic simulations of the structure and dynamics of the radiation dominated envelopes of massive stars at the location of the iron opacity peak. One-dimensional hydrostatic calculations predict an unstable density inversion at this location, whereas our simulations reveal a complex interplay of convective and radiative transport whose behavior depends on the ratio of the photon diffusion time to the dynamical time. Our simulations provide the first numerical calibration of mixing length theory in the radiation dominated regime. When diffusion time is shorter than the dynamic time scale, the envelopes show large amplitude oscillations and density fluctuations that allow photons to preferentially diffuse out through low-density regions. Magnetic field enhances the advective energy transport through magnetic buoyancy and increases the density fluctuation as well as the porosity effect. The simulations show that the turbulent velocity field may affect the broadening of spectral lines and therefore stellar rotation measurements in massive stars, while the time variable outer atmosphere could lead to variations in their mass loss and stellar radius.

Massive binary stars

S. Justham
University of the Chinese Academy of Sciences & NAOC

The Spatial Distribution of Massive Stars and Stellar Evolution

Jeremiah Murphy
Physics, Florida State University

We propose that the spatial distribution of O stars encodes information about their evolution, in particular their binary evolution. Smith & Tombleson 2015 noted that Luminous Blue Variables are very far away from other massive O stars, and they suggested that LBVs, as a class, are highly associated with binary evolution, kicks, and mass gainers. We have attempted to model the spatial distribution of O stars and LBVs hoping to provide theoretical constraints on the Smith & Tombleson 2015 observation. In just modeling the distribution of O stars, we are able to reproduce the average separation among O stars, but it is much more difficult to model the variance in separations with simple models. This implies that something is missing in these simple models and that we can learn about stellar evolution from the spatial distribution of O stars. In addition, we crudely model the spatial distribution of LBVs, and we find two models that are consistent with the very large separations between LBVs and other O stars. In model one, LBVs are mass gainers in binary evolution and receive, on average, 200 km/s kick when the primary star explodes, and in model two, LBVs are the product of mergers, in which the merger is triggered by the post main sequence evolution of at least a 17 solar mass star.

Binary Evolution and the Final Fate of Massive Stars

Philipp Podsiadlowski
Oxford University

Binary interactions do not only affect the envelope structure of massive supernova progenitors, thereby determining the appearance of the resulting supernova, but also the final fate of the core, specifically whether the core collapses to a neutron star or black hole or produces a gamma-ray burst or other exotic event. In this talk I will summarize how various binary interactions (mass loss, accretion, mergers, tidal interactions) affect the final fate of stars and its potential implications for a variety of "normal" and exotic supernova events, including supernovae with a circumstellar medium ("LBV supernovae"), superluminous supernovae, gamma-ray burst sources, pair-instability supernovae and aLIGO gravitational-waves sources.

Multi Epoch views of massive stars

Sergio Simon-Diaz
Instituto de Astrofísica de Canarias, Spain

The beginning of the 21st century has witnessed the compilation of several high quality spectroscopic surveys of massive OB stars. The scientific exploitation of this unique observational material, in combination with the imminent information provided by the Gaia mission will, without any doubt, quantitatively change our view of the properties and evolution of massive stars. Some of these surveys include multi-epoch observations scheduled with different time-resolution. In this talk I will benefit from the

https://doi.org/10.1017/S1743921317004446 Published online by Cambridge University Press

spectroscopic observations gathered by the IACOB project (Simón-Díaz et al. 2015, http://www.iac.es/proyecto/iacob/) to present an illustrative summary of the spectroscopic variability phenomena which are commonly detected in the O and B star domain. I will also highlight the importance of complementing the empirical information provided by the spectroscopic analysis of single-epoch observations of large samples of O- and B- type stars with the compilation and analysis of specifically designed time-resolved observations.

Challenges to stellar evolution from LBVs, SN Impostors, and Supernovae with Dense CSM

Nathan Smith
Steward Observatory, University of Arizona

I will discuss luminous blue variables (LBVs) and their connections to extragalactic transients and supernova (SN) explosions, as well as the challenges they pose for our understanding of massive star evolution in general. Their role in single-star evolution as transition objects between H and He burning appears to be invalid, and some massive LBVs appear to be exploding as SNe. This makes it challenging to understand what LBVs are, and also poses fundamental challenges to models of single-star evolution. I will report new results from spectroscopic and photometric monitoring of the light echoes of Eta Carinae for the past several years, and will discuss critical clues they provide for understanding the physics of this classic LBV giant eruption and connections to recent spectroscopic studies SN impostors. All proposed physical models, including stellar merger events, still have severe shortcomings and open questions in trying to accound for LBV eruptions. I will also discuss the basic nature of LBVs and the viability of LBVs as progenitors of Type IIn supernovae, considering the environments of LBVs and SNe IIn, combined with the properties of their CSM, explosion parmeters, and direct progenitor detections.

Magnetic fields in massive stars

Gregg Wade
Department of Physics, Royal Military College of Canada

Magnetic fields are directly observable only at the surfaces of stars, and while surface magnetic fields have important consequences for the evolution of OB stars (see Z. Keszthelyi's presentation), interior fields are in principle even more significant. For example, modern models of massive star evolution including interior magnetic field prescriptions find that fields dominate the angular momentum transport. Such models differ fundamentally from non-magnetic models, and are characterized by rigidly-rotating envelopes and strong core-envelope coupling. These affects have fundamental consequences for predicted surface rotation rates and chemical abundances, and ultimately HR diagram positions and evolutionary pathways.

In this presentation we report first results of an effort to employ new and existing observational results to constrain the influence of interior magnetic fields on the internal structure and evolution of hot stars. We adopt two approaches. First, we examine the physical properties of stars with radiative envelopes and detected surface magnetism (in part a legacy of the MiMeS and BoB large surveys), comparing with the properties of their non-magnetic peers, searching for differences attributable to their (interior, fossil) magnetic fields. Second, we examine the larger population of (apparently) non-magnetic hot stars, searching for mass- and rotation-dependent behaviour as predicted by radiative envelope shear and turbulent dynamo models.

Very Massive Stars at Different Metallicities

Norhasliza Yusof
Department of Physics, University of Malaya

In the work, we will present the evolution of Very Massive Stars (M>100 Mo) at different metallicities (Z=0.001 to Z=0.02). This includes the general properties, impact on the chemical abundances due to the rotational impact, dependence on metallicities and mass loss of very massive stars. Very massive stars has very large convective core during the main sequence thus their evolution are not affected strongly by rotational mixing but more by the mass loss due to strong stellar winds. In this presentation, we will also present pair instability supernovae modelled with our VMS progenitor models and compare them to super-luminous supernovae.

https://doi.org/10.1017/S1743921317004446 Published online by Cambridge University Press