Session 1: Stellar winds, diagnostics across the electromagnetic spectrum

Invited Reviews

Radio observations of massive stars

Ronny Blomme

Detectable radio emission occurs during all phases of massive star evolution.I will concentrate on the thermal and non-thermal continuum emission from early-type stars. The thermal radio emission is due to free-free interactions in the ionized stellar wind material. Early ideas that this would lead to an easy and straightforward way of measuring the mass-loss rates were thwarted by the presence of clumping in the stellar wind. Multi-wavelength radio observations provide important constraints on this clumping, but do not allow its full determination.
Non-thermal radio emission is associated with binarity. This conclusion was already known for some time for Wolf-Rayet stars and in recent years it has become clear that it is also true for O stars. In a massive star binary the two stellar winds collide and around the shocks a fraction of the electrons are accelerated to relativistic speeds. Spiralling in the magnetic field these electrons emit synchrotron radiation, which we detect as non-thermal radio emission. The many parameters that influence the resulting non-thermal radio fluxes make the modelling of these systems particularly challenging, but their study will provide interesting new insight into massive stars.

UV, optical and near-IR diagnostics of massive stars

Fabrice Martins

In this review we will summarize the main diagnostics available in the UV, optical and infrared ranges to constrain the stellar and wind properties of massive stars. We will describe how the current generation of atmosphere models allows accurate determinations of fundamental parameters: Teff, luminosity, gravity, surface abundances. We will see how the wind properties (mass loss rate, terminal velocity, clumping) can be derived by means of direct and indirect methods. The determination of rotational velocities will also be presented, with emphasis on the role of macroturbulence. Finally, we will describe the detection of magnetic fields in O stars.

X-rays, clumping and wind structures

Lida Oskinova

X-ray emission is ubiquitous among massive stars. In the last decade, X-ray observations revolutionized our perception of stellar winds but opened a Pandora's box of urgent problems. Shocks, magnetic fields, and rotation, which are typically ignored in classical models must be accounted for to understand X-rays from massive stars. The predictions of the theories on the generation of X-rays in stellar winds can now be tested by observations. I will review the recent progress in studying the origin of X-rays in massive stars. We have fairly good ideas of how X-rays are produced in O stars, we can guess what may be the mechanisms in B stars, but we have little understanding yet about X-rays from WR stars. X-rays penetrating stellar winds suffer mainly continuum absorption, which greatly simplifies the radiative transfer treatment. The analysis of X-ray lines can allow to infer the parameters of wind clumping. Understanding the wind clumping is prerequisite to obtain empirically correct stellar mass-loss rates. Albeit the work is still in progress, it is becoming clear that the concept of macroclumping can be successfully used to overcome the problem of the "discordance of mass-loss rates". The "superionization" by X-rays is another possible way to address this problem.

Theory of stellar winds

Stan Owocki

The high luminosity of massive stars can drive strong stellar winds, through line scattering of the star's continuum radiation. This talk reviews the dynamics of such line driving, building first upon the standard CAK model, and then discussing subtleties associated with the development and saturation of instabilities, and with the rotation, pulsation, and/or magnetic field of the underlying star. I also emphasize key differences between the CAK-type driving of optically thin OB star winds, and the more complex case of optically thick winds from WR and LBV phases, wherein the excitation and ionization that sets the driving opacity has an inherent feedback from the mass loss itself. An overall goal is to illuminate the rich physics of radiative driving and the challenges that lie ahead in developing dynamical models for the often complex structure and variability observed in massive-star outflows.

Contributed Talks

Pulsations in Wolf-Rayet stars: Observations with MOST

Andre-Nicolas Chene, Anthony F. J. Moffat

The wind momentum (dM/dt × v) of the Wolf-Rrayet stars is a factor ~10 times higher than the radiative momentum outflow rate (L/c); radiation pressure doesn't seem to be sufficient to drive the strong winds. Photometry obtained with the first Canadian space telescope MOST (Microvariability and Oscillations of STars) has revealed multimode oscillations mainly in continuum light that suggest stellar pulsations could be a significant contributing factor to the mass-loss rates. Since the first clear detection of a pulsation period of P = 9.8h in WR123 (Lefevre et al. 2005), two other stars have also shown periods of a few days, which must be related to stellar pulsations. A review of all the Wolf-Rayet star results to date from MOST and their implications will be presented.

Mass loss from the most massive stars: a multi-wavelength view on the central part of 30Dor.

G. Graefener, J.S. Vink, J. Bestenlehner, and the FLAMES consortium

The most massive stars are believed to form Wolf-Rayet like emission line spectra already in the main sequence phase. To understand the nature of such 'O stars on steroids', and to investigate the transition from normal O star to WR-type mass loss, we have obtained integral field K-band spectra of the central region of 30 Dor with VLT/SINFONI. 30 Dor is the closest starburst-like region in our neighborhood, and hosts 30-50 extremely massive stars. In this talk we present first results from a (UV-IR) multi-wavelength study of these objects, which is performed in the framework of the FLAMES Tarantula survey. We discuss the results in the context of our theoretical work on stellar mass loss in the O-WR transition phase.

The most luminous stars in the Galaxy and Magellanic Clouds

Wolf-Rainer Hamann

Some of the Wolf-Rayet (WR) stars are found to have very high bolometric luminosities (log L/L_{sun} > 6). We employ the Potsdam Wolf-Rayet (PoWR) model atmospheres for their spectral analysis, which yields the bolometric corrections. Distance and interstellar reddening also enter the luminosity estimates. Among the Galactic stars, there is a group of very luminous WNL stars (i.e. WR stars of the nitrogen sequence of late subtype with hydrogen being depleted in their atmosphere, but not absent). Distance is here often the major source of uncertainty. From K-band spectroscopy we found a very luminous star (log $L/L_{sun} = 6.5$) in the Galactic center region, which we termed the Peony Star because of the form of its surrounding dusty nebula. A similar group of seven very luminous WNL stars is found in the Large Magellanic Cloud, disregarding all objects with indications of binarity. In the Small Magellanic Cloud (SMC) the fraction of confirmed binaries is high. We analyzed the composite WN+O spectra as such and obtained very high luminosities for the WN component in a few cases. We conclude that very luminous WNL stars exist in a significant number. With initial masses between 60 and 120 M_{sun}, they apparently evolved directly to the WNL stage without prior excursion to the red side of the HRD. At low metallicities the binary channel is dominant.

Massive Stars in Polarized Light

Jennifer L. Hoffman

Polarimetry is an important observational technique in the study of hot stars. Practiced across the full range of wavelengths, polarimetry provides a window into a variety of stellar phenomena not accessible by other means. For example, polarimetry constrains the properties of circumstellar disks, unveils details of the magnetic fields in molecular cloud cores, and reveals the complex geometries of dusty star-forming regions. I will focus on the applications of spectropolarimetry to the study of the atmospheres, winds, and circumstellar material of massive stars and their supernova descendents. When polarized light is produced by electron and dust scattering, spectropolarimetry allows mapping of clumpy and aspherical structures in the atmospheres, winds, and circumstellar surroundings of hot stars and core-collapse supernovae. When polarization arises from magnetic phenomena such as the Zeeman and Hanle effects, spectropolarimetry probes the complex circumstellar magnetic fields threading the disks and winds of massive stars. I will discuss recent results in both these areas and look to the near future, when the combination of polarimetry with interferometric and synoptic observations will open new frontiers in our understanding of massive stellar evolution.

3-D Radiative Transfer Modeling of Structured Winds in Massive Hot Stars with Wind3D

A. Lobel, J. A. Toala, and R. Blomme

We update the Wind3D radiative transfer (RT) code for parallel processing of a new type of 3-D input models that adequately parameterize large-scale structures in the winds of massive hot stars. The parameterized models offer crucial advantages for high-performance RT calculations over ab-initio hydrodynamic input models. The acceleration of the input model computations allows us to model and investigate a broad range of physical 3-D wind conditions with Wind3D. The new parameterization method is very flexible for constraining the physical properties of Co-rotating Interaction wind Regions (CIRs) with detailed fits to DACs observed in SiIV λ1400. We compare the results of the parameterized modeling method to the hydrodynamic model for CIRs in the B-type supergiant HD 64760. We develop new models that adequately parameterize the density- and velocity-structure of equatorial wind regions (called "Rotational Modulation Regions" or RMRs) that cause the Rotational Modulations of HD 64760. We find that the Rotational Modulations are due to a very regular pattern of radial density enhancements almost linearly shaped across the equatorial wind. We show that the Rotational Modulations are nearly linearly shaped ("spoke-like") extended wind regions that co-exist with more curved CIRs in the equatorial plane. We present a hydrodynamic model computed with Zeus3D for the RMRs caused by mechanical wave excitation at the stellar surface of this fast-rotating hot supergiant.

General X-ray properties of hot, massive stars

Y. Nazé

The recent X-ray observatories have not yet provided a large survey comparable to that based upon the ROSAT All-Sky Survey (RASS). However, two limited surveys exist : the 2XMM catalog for XMM-Newton (300 OB stars detected) and the Carina large-scale survey from Chandra (119 OB stars detected). Medium-resolution (CCD) spectra were analyzed and led to new results on the relationship between the X-ray luminosity and the bolometric luminosity, as well as on the typical properties (plasma temperature, variability) of these objects. This contribution will thus present the results of the first high-sensitivity investigation of the overall high-energy properties of a sizable sample of hot stars.

Is macroturbulent broadening in OB Supergiants related to pulsations?

S. Simon-Diaz et al.

The spectrum of O and B Supergiants is known to be affected by an important extra line-broadening (usually called macroturbulence) that adds to stellar rotation. Recent analysis of high resolution spectra has shown that the interpretation of this line-broadening as a consequence of large-scale turbulent motions implies highly super-sonic velocity fields, making this scenario quite improbable. Stellar oscillations has been recently proposed as a likely alternative explanation. We present an overview and the first motivating results of a observational project aimed at investigating the macroturbulent broadening in O and B Supergiants and its possible connection with spectroscopic variability phenomena and stellar oscillations. To summarize the main results of this study obtained up to now: a) the B-Sgs show LPVs, quantified by means of the first (RV) and third velocity (v^3) moments of the lines, which are not detected in the MS stars, b) there is a strong correlation between the peak-to-peak amplitudes of RV and v^3 variability and the size of the extra-broadening, c) the RV variations in the B-Sgs suggest variabilities on two time-scales: a variation of the order of half a day to several days, with amplitudes of the order of 1-9 km/s, and a faster variation of tens of minutes at low amplitude (< 2 km/s).

A proper description of clumping in hot star winds: The key to obtaining reliable mass-loss rates?

J.O. Sundqvist, J. Puls, A. Feldmeier, S.P. Owocki

Small-scale inhomogeneities, or "clumping", in the winds of hot, massive stars are conventionally included in spectral analyses by the so-called microclumping technique. To reconcile investigations of different diagnostics using this technique, very low mass-loss rates must be invoked for O stars (reductions of previously accepted values by factors of 3-10, or even more). Recently it has been suggested that by using the microclumping approximation one may actually drastically underestimate the mass-loss rates. In this talk we will present a new, improved description of clumpy winds and show how corresponding models, in a combined UV and optical analysis, can alleviate discrepancies between recent observed values, values predicted by the line-driven wind theory, and values included in current models of massive star evolution. We will also demonstrate how the structures predicted by present day time-dependent, radiation-hydrodynamic wind models are unable to consistently and simultaneously reproduce diagnostic lines in the UV and optical, and discuss the primary reasons for this failure.

Posters

P1.1 The Stellar Wind of LS 5039

Christina Aragona, M. V. McSwain, M. S. E. Roberts

LS 5039 is an unusual high mass X-ray binary that also has γ-ray emission modulated with its orbital period. The system consists of an ON6.5V((f)) star and an unidentified compact companion. Using the Australia Telescope Compact Array (ATCA), we have measured radio fluxes at 20cm, 13cm, 6cm, and 3cm between 2008 February and 2009 July. We will also observe the Hα line with the Goodman High Throughput Spectrograph on the Southern Astrophysical Research (SOAR) telescope from 2010 June 2-4. Here we combine these multiwavelength data to examine the structure of the massive star wind.

P1.2 Ion fractions and the weak wind problem

Matthew Austin, Raman Prinja

The current problems concerning apparent weak winds in some O stars and uncertainty about the nature of wind clumping need resolving in order to fully understand the hot star picture. We describe an effort to compute reliable ion fractions for C, N, O, P, S and Si, using non-LTE code CMFGEN, taking into account microclumping and X-rays. These ion fractions mean that empirical fits to ultraviolet resonance lines can lead to a correct determination of the mass-loss rate, M dot. We discuss a project to fit unsaturated CIV lines in late O dwarfs, and show that the weak wind scenario is still a major problem with some rates of mass-loss indicated to be at least an order of magnitude lower than hydrodynamical predictions, and radio and optical measurements.

P1.3 Using the orbiting companion to trace WR wind structures in the 29d WC8 + O9 binary CV Ser

Alexandre David-Uraz, Tony Moffat

We have used continuous, high-precision, broadband visible photometry from the MOST satellite to trace wind structures in the WR component of CV Ser over more than a full orbit. Most of the small-scale light-curve variations are likely due to extinction by clumps along the line of sight to the O companion as it orbits and shines through varying columns of the WR wind. Parallel optical spectroscopy from the Mont Mégantic Observatory is used to refine the orbital and wind-collision parameters, as well as to reveal line emission from clumps.

P1.4 A VLT/UVES spectroscopic study of the earliest O stars in the LMC

E. Doran, P. Crowther (University of Sheffield)

We present a quantitative spectroscopic study of O2 stars in the Large Magellanic Cloud based upon VLT/UVES spectroscopy, supplemented by HST/FUSE ultraviolet observations. Physical, chemical and wind properties are determined, allowing us to address whether O2 dwarfs evolve on to giants, through to supergiants, or if this sequence corresponds to progressively higher mass stars close to their zero-age main sequence. We also re-assess how luminous, hydrogen-rich WN stars, such as those within R136 in 30 Doradus, fit within this evolutionary/mass sequence.

P1.5 The radio emission of the massive stars in Westerlund 1

Sean M. Dougherty, J.S. Clark, I. Negueruela

Current mass-loss estimates imply that line-driven winds are insufficient to strip away the H-rich envelope to yield WR stars. The rich population of transitional massive stars in the young super-star cluster Westerlund 1 (Wd 1) provides an ideal opportunity to deduce the characterisitcs across all evolutionary stages of massive stars. We have completed deep radio observations of Wd1 that detect 18 cluster members, dominated by cool hypergiants, with some detections of OB supergiants and WR stars. This paper will describe the observations and the diverse properties of the detected sample, especially the radio luminous star W9 and our detection of a closely constant mass-loss rate across all transitional types, and the requirement of a period of enhanced mass-loss rate to form WR stars.

P1.6 Observational signatures of rapidly rotating massive pulsating stars

C.A. Engelbrecht, F.A.M. Frescura, S. Moonsamy

The effect of the geometric distortion of a rapidly rotating star on the relative amplitudes of radial velocity and luminosity variations is discussed. Specifically, we consider the possibility of determining the inclination angle of a rapidly rotating star from observations of radial velocity and luminosity variations.

P1.7 Exploring the connection of weak winds and magnetic fields

M. Garcia, F. Najarro, A. Herrero

The theory of radiatively driven winds successfully explains the key points of the stellar winds of hot massive stars. However, there is an apparent break-down of this paradigm at log L/L_{sun}<5.2: the stellar wind momentum is smaller than predicted for low luminosity early-type stars from metal poor environments, and there are also some Galactic examples. We still lack an explanation for weak wind stars: in this work we analyse whether magnetic fields are playing a role. We study a sample of O9-B0 young dwarfs in the Orion star forming region, together with Tau Sco, a known magnetic star. Our first analysis of UV spectra (1150-1800 Å) with WM-basic models revealed that all targets have smaller wind momentum than predicted by the theory, although Tau Sco's was larger and closer to the theoretical relation. However, this analysis was not conclusive, as the photospheric properties (T_{eff} and log g) were adopted from optical studies. We present here an improved multiwavelength analysis (from UV to the optical range) for the same sample of stars, using CMFGEN synthetic spectra to fit the observations, where stellar and wind parameters are determined consistently.

P1.8 Hot, Massive Stars in the extremely metal-poor galaxy, I Zw 18

Sara R. Heap, Eliot M. Malumuth

The extremely metal-poor galaxy, I Zw 18, is the Rosetta Stone for understanding z=7-8 galaxies now being discovered by Hubble’s Wide Field Camera 3 (HST/WFC3). Using HST/STIS images and recently obtained HST/COS ultraviolet spectra, we derive information about the hot, massive stars in this galaxy including stellar abundances, constraints on the stellar IMF and mass distribution of young clusters containing hot, massive stars.

P1.9 Effect of porosity on emergent synthetic spectra of massive stars in the X-ray domain

Anthony Hervé, Gregor Rauw

Massive stars possess powerful stellar winds. Studies over the last decade revealed the importance of wind fragmentation and clumping and led to a downwards revision of the mass-loss rates. In this poster, we present the results of our code that allows to compare two models of wind fragmentation, and their consequences on the emergent X-ray spectra of massive stars.

P1.10 Stellar Archeology: Probing Stellar Mass Loss with Interacting Supernovae

Jennifer L. Hoffman

In recent years, increasing numbers of core-collapse supernovae have been discovered that show signatures of interaction with pre-existing circumstellar material (CSM). This CSM arises from the winds and outbursts of the progenitor star and thus preserves a record of its mass loss history. The study of supernova CSM through improved observational strategies and detailed numerical modeling promises to make possible a more detailed study of these massive progenitors than has yet been feasible. Correlations between the circumstellar structures of interacting supernovae and those of massive stars provide a way to probe the characteristics of pre-supernova mass loss at cosmological distances. This becomes increasingly important at lower metallicities and higher redshifts, where observational constraints are lacking. Understanding interacting supernovae as the next stage in the evolution of very massive stars can increase the sample size of these rare objects and lead to investigations of mass-loss behavior with different galactic environments. I will show examples of how such studies can yield valuable clues to the nature, evolutionary status, and mass-loss histories of the stars that become supernovae.

P1.11 Near-IR K-band analysis of Wolf-Rayet stars in the Quintuplet

A. Liermann, W.-R. Hamann, L. M. Oskinova, H. Todt

The Galactic center region is heavily obscured by dust in the UV and VIS. We present a catalog of near-IR K-Band spectra of massive stars located in the Quintuplet cluster at about 35 pc projected distance of the GC. Among several O stars the cluster hosts a number of massive stars in their late evolutionary stages, i.e. Wolf-Rayet stars of the nitrogen (WN) and carbon (WC) sequence. Tailored analyses with the Potsdam models for expanding atmospheres (PoWR) are presented for the WN stars. We find that the stars belong to a group of rather cool ($T_* \sim 25$ -36 kK) but very luminous WNL stars ($\log(L/L_{sun}) > 6.0$). The derived stellar parameters are discussed in the context of stellar evolution and show that the stars are descendants from massive stars with initial masses of $M_{init} \geq 60\ M_{sun}$.

P1.12 Mass loss in 2D Rotating Stellar Models

C.C. Lovekin, R.G. Deupree

Radiatively driven mass loss is an important factor in the evolution of massive stars. The mass loss rates depend on a number of stellar parameters, including the effective temperature and luminosity. Massive stars are also often rapidly rotating, which affects their structure and evolution. In sufficiently rapidly rotating stars, both the effective temperature and surface flux vary significantly as a function of latitude, and hence mass loss rates can vary appreciably between the poles and the equator. In this work, we discuss the addition of mass loss to a 2D stellar evolution code (ROTORC) and compare evolution sequences with and without mass loss.

P1.13 Imaging the close environment of unclassified and supergiant B[e] stars

Millour, F., Meilland, A., Borges Fernandes, M., Chesneau, O., Groh, J., Driebe, T., Weigelt, G. Liermann, A.

Stars with the B[e] phenomenon exhibit emission lines of hydrogen plus allowed and forbidden metallic lines, and a large amount of dust. Supergiant B[e] stars might play a critical role in massive stars evolution, and the evolutionary status and mass of unclassified B[e] stars still need to be determined. A combination of multi-wavelength, high spectral resolution and high angular resolution observations has the potential to unveil the nature, evolutionary status, and mass of the central hot source. I will present two very recent results on the stars HD87643 and HD62623, where infrared interferometric observations, together with the large amount of information provided by other wavelengths observations, are a key to understanding the systems.

P1.14 The MONS campaign on OB stars

Morel, T., et al.

In parallel with the monitoring of the periastron passage of WR 140, a number of B supergiants and Oe stars have been observed in the framework of a 3-month spectroscopic campaign using the MONS telescope at Teide observatory. We present an overview of the spectral variations observed in the Hα line that will allow us to investigate the properties of the large-scale wind structures in the B supergiants and of the circumstellar material in the Oe stars.

P1.15 High-resolution near-IR spectroscopy of OB stars

Maria-Fernanda Nieva

Massive OB-type stars are associated with star-formation regions. Their high luminosity allows us to derive present-day chemical abundances over large distances, in the Milky Way and the Magellanic Clouds. We discuss first quantitative results from an analysis of high-quality spectra of early B-type stars in the solar vicinity obtained with CRIRES on the VLT/UT1. This work includes the identification of metal lines never resolved before and benchmark tests of spectrum synthesis, which is more challenging than in the optical because of the amplification of non-LTE effects in the near-IR. Results from the visual and near-IR spectra agree for those elements with reliably calibrated model atoms. The ionisation equilibria of He I/II and C II/III are established simultaneously for both spectral ranges, which confirms the self-consistency of the analysis. This will allow us to derive reliable chemical abundances in (dust-enshrouded) regions throughout the Galactic disk, which are observable only at near-IR wavelengths.

P1.16 Spectral analyses of Wolf-Rayet stars in the Small Magellanic Cloud

D. Pasemann, U. Ruehling, W-R. Hamann

Metallicity is a parameter that critically influences the evolution of massive stars via the mass-loss rate. The theory of radiation-driven winds predicts a correlation between the mass-loss and the metallicity of a star. The metallicity in the SMC is about ten times lower than in the Galaxy. Consequently the SMC stars may not evolve a sufficiently strong wind to remove their hydrogen envelope and enter the Wolf-Rayet phase. If so, the WR stars in the SMC must all originate from close-binary evolution. We have performed spectral analyses of all known Wolf-Rayet stars (single or binary) in the SMC. For this purpose we have employed the Potsdam Wolf-Rayet (PoWR) model atmosphere code. For the 11 WR stars of the nitrogen sequence (WN) we calculated four grids of models with different hydrogen abundances. We also established a series of O-star models, in order to construct the composite spectra of WN+O binaries. The one WO-type (i.e. oxygen-sequence

WR) star in the SMC is also analyzed with the help of an adequate grid of models. The poster will present the spectral analyses of the 12 known WR stars in the SMC, with special regard to the composite spectra of the binaries. Based on these results, we will discuss the evolution of massive stars with low metallicity.

P1.17 Revised spectral analyses of Galactic WC stars

A. Sander, W-R. Hamann, H. Todt

A grid of models for Wolf-Rayet stars of the carbon sequence (WC) has been established with the Potsdam Wolf-Rayet (PoWR) model atmosphere code. In contrast to earlier versions, clumping and iron line blanketing are now taken into account. The spectra of more than 30 Galactic WC stars with subtypes ranging from WC4 to WC9 are analyzed by finding the best-fitting model. While for the spectra of Wolf-Rayet stars of the nitrogen sequence (WN) we generally achieve a nice agreement with the model simulations, the WC spectra show a couple of features that cannot be consistently reproduced by one model. Nevertheless, our analyses yield the stellar parameters for the stars of different WC subtypes. The obtained positions of the WC stars in the Hertzsprung-Russell diagram are discussed with regard to the stellar evolution.

P1.18 Large Amplitude Optical Spectroscopic Variability of 9 WC9 stars

Nicole St-Louis, Vincent Hénault-Brunet, Antoine de la Chevrotière, Dominique Soutière, Simon Péloquin, André-Nicolas Chené

We present the results of a one month spectroscopic monitoring campaign of 9 apparently single WC9 stars known to present large-amplitude (8-10% of line flux) spectroscopic variability. Among these are the only three WC9 stars for which no evidence of dust production has yet been found, WR81, WR88 and WR92. Our aim is to attempt to shed some light mainly on two questions: (i) Why do single WC9 stars show such a high level of wind variability? and (ii) What is the origin of (or lack of!) the dust in single WC9 stars? One premise we wish to explore is that these stars are in fact binaries; this would provide a natural explanation for both the spectroscopic variability and for the presence of dust in the wind. In such a scenario, however, the absence of dust for some stars would still remain a mystery.

P1.19 Heated dust around the LMC Wolf-Rayet system HD 36402

Peredur Williams

Infrared photometry of the probable triple WC4(+O?)+O8I: system HD 36402 (BAT99-38) in the LMC shows emission characteristic of heated dust. Simple modelling indicates a dust temperature of 800K and dust mass of about 1.5×10^{-7} M_{Sun} assuming amorphous carbon grains. The dust emission appears to be variable. It is apparent that Wolf-Rayet dust formation occurs also in metal-poor environments.

Session 2: Massive star formation, confronting theory and observation

Invited Reviews

Long-wavelength (mid-IR to mm) studies of massive star formation

Henrik Beuther

Since massive stars form in a clustered mode deeply embedded within their natal clouds, high spatial resolution as well as observations at mid-/far-infrared to submm wavelengths is mandatory. I will present recent results addressing different questions, for example: What are the initial conditions for high-mass star formation (first results from Herschel)? What are the rotational/disk properties of massive cores? How do magnetic fields influence high-mass star formation? What are the fragmentation and density structures within high-mass cores?

The multi-wavelength review of the 30 Dor starburst cluster and giant H II region

Hans Zinnecker

We use the example of the 30 Dor starburst cluster and giant H II region (the largest H II region in the Local Group and maybe the progenitor of a future globular cluster) to review how multi-wavelength studies of a massive star formation complex can be dissected and analyzed. We discuss UV/optical as well as near-, mid- and far-infrared observations, and also X-ray and gamma-ray data. Furthermore, radio maps of atomic and molecular gas and submm dust continuum maps of the region will be shown and put into context. The importance of positive and negative feedback effects of the massive stars (i.e. triggering or quenching further star formation) will be assessed. The occurrence of dynamical effects in the dense cluster center such as stellar collisions and stellar ejections (runaway stars) will be investigated. The issue of mass segregation and the mass distribution (IMF) will briefly be touched, including the role of massive close binaries. The age distribution of stars in the region will be used to infer an idea how this starburst cluster might have originated in this particular location and at this particular time.

Contributed Talks

Physical Properties and Evolutionary Stages of Massive Young Stellar Objects in the Large Magellanic Cloud

Rosie Chen, Remy Indebetouw, Jonathan Seale, Leslie Looney, You-Hua Chu, Robert Gruendl, Barbara Whitney

Massive stars drive the evolution of galactic interstellar media, yet their formation remains poorly understood. Spitzer infrared (IR) surveys have recently revealed many individual massive young stellar objects (YSOs) in the Magellanic system, offering a new opportunity to study massive star formation at reduced metallicity and galactic environments different from the Galaxy. We use the Spitzer Infrared Spectrometer (IRS) observations of ~300 massive YSOs in the Large Magellanic Cloud (LMC), by far the largest mid-IR spectroscopic sample of confirmed extragalactic YSOs, and combine with multi-wavelength broadband photometry from U to 70 micron to construct and model their spectral energy distribution, to deduce their evolutionary stage and circumstellar dust distribution. During the processes of massive star formation, they undergo energetic mass ejection in the form of outflows that produce maser phenomena and can also ionize the circumstellar gas to form small, dense HII regions. To understand when these phases happen and what physical conditions of circumstellar dust are, we compare the inferred mass and accretion rate of the YSOs to their IR spectral features classified in Seale et al. (2009), and also to known masers and ultra-compact HII regions (Ellingsen et al. 2010; Indebetouw et al. 2004), as shown in Figure 1.

As massive stars are often formed in groups and clusters, we have used high resolution ground-based optical and near-IR images to examine the multiplicities of these Spitzer YSOs and to investigate whether there is a trend on mass and evolutionary stage, in order to better understand the processes of massive star formation.

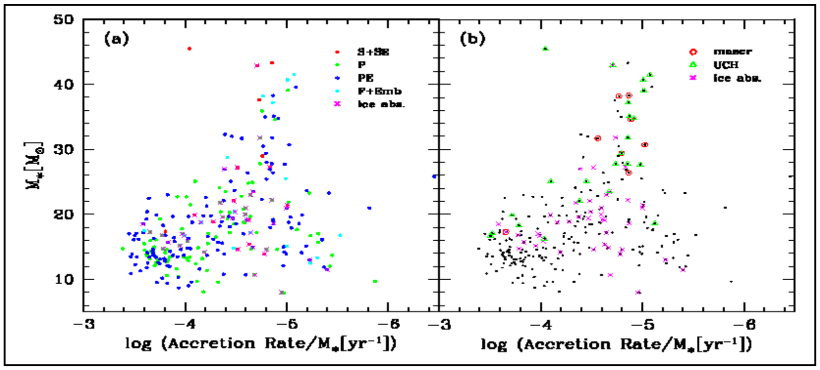

Figure 1: Masses vs. accretion rates ~300 LMC YSOs with Spitzer IRS spectra. Masses and accretion rates are derived by comparing YSO models to multi-wavelength SEDs with inclusion of spectral data (Chen et al. 2009ab;2010). (a) Classifications of YSOs based on IRS spectral features (Seale et al. 2009; 2010) are shown in different colors (see legends). (b) YSOs that have maser or ultra-compact HII counterparts or exhibit molecular ice absorptions are marked with additional circles, triangles, and crosses (Ellingsen et al. 2010; Indebetouw et al. 2004; Seale et al. 2010).

Evidence for disks around young high-mass stars

Rolf Chini, Vera H. Hoffmeister, Dieter Nürnberger

The stellar cluster in M17 has been investigated with unprecedented sensitivity, leading to the detection of more than 40 new exciting stars; multiplicity for the most massive (O4 - O8) stars could be established. Direct imaging of O and early B stars reveals circumstellar disks and jets associated with types as early as O6. The total IR excess frequency of the cluster members is at least 74%, increasing with decreasing stellar mass. The high excess rate of 62% for stars earlier A4 suggests that the accretion scenario works also in the high-mass regime.

Multiple populations of massive (proto-)stars in cluster forming complexes

J S Clark, M. Messineo, H. Parsons, B. Davies, M. Thompson, F. Najarro, P. Crowther

Increasingly, evidence suggests that massive stars form in clusters, which in turn are found within extended complexes associated with Giant Molecular clouds, although the detailed physics of the processes leading to these stars and structures is currently poorly understood. In order to address this we have undertaken an extensive multiwavelength campaign from near-IR to radio wavelengths aimed at constraining the (proto-) stellar populations of two galactic examples - the W51 and G305 star forming complexes - and here we present the first results from this study. Near IR imaging and spectroscopy obtained with the VLT and HST are used to constrain the stellar populations which we show, via non-LTE model atmosphere analysis, to contain very massive O and WNL stars suggesting ongoing star formation for several Myrs. Mid-IR and radio observations

(Spitzer, ATCA) are utilised to identify an earlier phase of embedded massive stars, while sub-mm continuum and molecular observations (APEX/LABOCA & the JCMT) identify cold molecular cores - the earliest detectable stages of star formation. A synthesis of these datasets enables us to construct a full census of all stages of massive star formation within the complexes, the duration of this process, the location of currently active areas of star formation and their (triggered) propagation through the host GMCs. Finally, the relative populations of the different (proto-)stars and their mass functions enable us to infer the durations of each phase as well as constraining the processes leading to the fragmentation of the natal GMC and subsequent assembly of the stars and clusters.

The radiation pressure barrier in the formation of massive stars

Rolf Kuiper, Hubert Klahr, Henrik Beuther, Thomas Henning

We investigate the radiation pressure problem in the formation of massive stars in 1, 2, and 3D radiation-hydrodynamical core collapse simulations. In contrast to previous research, we

- consider frequency dependent radiation feedback,
- resolve the dust condensation front in the vicinity of the forming star down to 1.27 AU,
- compute the evolution for several 100 kyr, and
- perform a broad survey of the parameter space (37 initial conditions by now).

The most fundamental result is that the formation of a massive accretion disk in slowly rotating cores bypasses the radiative flux through the optically thin atmosphere. Gravitational torques in the disk drive a sufficiently high accretion rate to overcome the residual radiation pressure. For an initial core mass of 60, 120, and 240 M_{sun} these mechanisms allow the star to grow up to 27, 57, and 93 M_{sun} respectively.

A near IR imaging survey of high and intermediate-mass young stellar outflow candidates

Ramsay, S.K., Varricatt, W.P., Davis, C.J., Todd, S.P.

We will present a new near-infrared imaging survey of 50 luminous young stellar outflow candidates. Using high spatial resolution observations in the v=1-0 S(1) line of H_2 we detect the outflows with a high success rate - 76% of the objects exhibit H_2 emission and 50% or more of the objects exhibit aligned H_2 emission features suggesting collimated outflows. Many of these are new detections. The young stellar objects responsible for the outflows are positively identified in many of our images based on their locations with respect to the outflow lobes, 2MASS colours and association with MSX, IRAS, millimetre and radio sources. The main results of our survey are as follows. The observations suggest that disk accretion is probably the leading mechanism in the formation of stars, at least up to late O spectral types. The close association of molecular outflows detected in CO with the H_2 emission features produced by shock excitation by jets from the young stellar objects suggests that the outflows from these objects are jet-driven. Towards strong radio emitting sources, H_2 jets were either not detected or were weak when detected, implying that most of the accretion happens in the pre-UCH II phase; accretion and outflows are probably weak when the YSO has advanced to its UCH II stage.

Posters

P2.1 Resolving a Circumstellar Disk in the Massive Protostar IRAS 18162-2048

Carlos Carrasco-Gonzalez, Roberto Galvan-Madrid, Mayra Osorio, Luis F. Rodriguez, Guillem Anglada

Collimated outflows and disks are though to be present at the earliest stages in the formation of both low-mass and high-mass stars. However, while in the case of low-mass stars observations frequently indicate the presence of disks around the central protostar, in high-mass stars it has been difficult to establish the presence of accretion disks. In this talk, I will present the results of recent Very Large Array observations that allowed us to resolve a circumstellar disk around the massive protostar IRAS 18162 –2048.

P2.2 Mid-infrared interferometry and imaging of massive young stellar objects in NGC 3603

Christian Hummel

We present results from our high angular resolution observations of the brightest high-mass young stellar object in NGC 3603, IRS 9A. Both MIDI at the VLTI and T-ReCS equipped with an aperture mask at Gemini South have resolved the mid-infrared dust emission on scales of 30 mas to 300 mas, corresponding to scales of 200 AU to 2000 AU. A flattened envelope or disk-like dust structure is the only way to explain why MIDI was able to detect a compact warm source in the presence of extended emission fully resolved even on 8 meter baselines. We have therefore described the structure using disks and envelopes based on models by Witney et al., and can find reasonable agreement with the visibility measurements and the SED as measured by SPITZER. We discuss these results and their limitations in the context of other interferometric observations of high-mass stars, of which there are few however due to the strong dust extinction normally encountered towards young high-mass stars.

P2.3 Spitzer Studies of Massive Protostellar Candidates and UCHII regions

M. S. N. Kumar, J. M. C. Grave, T. Velusamy, L. K. Dewangan.

I will describe an on-going study of massive protostellar candidates and UCHII regions using Spitzer Space Telescope and multiwavelength data. An increasing number of isolated infraread counterparts of massive stars are being studied and their spectral energy distributions carefully analysed. Modelling suggests generally large radii and lower temperatures for the so called "photospheres" of massive protostellar candidates. The IR counterparts of UCHII regions clearly indicates driving engines that are more massive and hotter compared to the FIR/Submm selected samples of massive protostellar candidates. Using Hi-Resolution deconvolution of the Spitzer images we show toroidal features around isolated B-Type stars. The toroidal features are visible in the Spitzer images and also in molecular hydrogen emission with a certain relationship. We also analyse the properties of infrared counterparts of massive molecular outflows.

P2.4 The interactions of winds from massive young stellar objects

Ross Parkin

The supersonic stellar and disk winds possessed by massive young stellar objects will produce shocks when they collide against the interior of a pre-existing bipolar cavity (resulting from an earlier phase of jet activity). The shock heated gas emits thermal X-rays which may be observable by spaceborne observatories such as the *Chandra X-ray Observatory*. Hydrodynamical models are used to explore the wind-cavity interaction. Radiative transfer calculations are performed on the simulation output to produce synthetic X-ray observations, allowing constraints to be placed on model parameters through comparisons with observations. The model reveals an intricate interplay between the inflowing and outflowing material and is successful in reproducing the observed X-ray count rates from massive young stellar objects.

P2.5 A young, compact star-forming region in the Small Magellanic Cloud

R. Selier, M. Heydari-Malayeri

We present a study of the compact H II region N66A in the SMC starburst region N66/NGC 346. This analysis is based on our ESO NTT observations coupled with archive HST ACS data and Spitzer IRAC data. We present a global view of the whole region and emphasize the importance of N66A. We obtain a number of physical characteristics of N66A. Moreover we derive the spectral classification of the main exciting star of N66A for the first time using spectroscopy. N66A belongs to a rare class of H II regions in the Magellanic Clouds, called High-Excitation Blobs (HEBs). N66A most probably represents a very young massive star formation event in the N66 complex.

P2.6 The chemical composition of the Orion star forming region: stars, gas, and dust.

S. Simon-Diaz et al.

The Orion star forming region is an ideal laboratory for many astrophysical studies. In this talk I will present an study of the chemical composition of early B-type stars in the Orion OB1 association. The main ideas I will talk about are: (1) The importance of self-consistent spectrocopic techniques for the abundance analyses in this type of stellar objects; (2) the study of the homogeneity of abundances in stars from the various stellar subgroups in OriOB1; (3) the comparation of O stellar abundances with recent Solar determinations; (4) the comparation of stellarabundances with those resulting from the analysis of the emission line spectra of the Orion nebula (M42); (5) the study of the oxygen depletion onto dust grains in the Orion nebula.

P2.7 Seeing the unseen behaviour of young massive stars: Methanol masers as probes of variability in hyper/ultra compact HII regions

DJ van der Walt

Although small in number, high mass stars play for various reasons a very important role in galaxies. Studying very young high mass stars is particularly difficult due to the fact that the young star is completely obscured for the observer even in the near-infrared. Information about very young high mass stars are usually obtained by studying their direct environments, viz. the hyper/ultra compact HII regions or the circumstellar dust and gas. Another possible tool to study young high mass stars is masers. The most common masers found to be associated with young high mass stars are water, hydroxyl, and methanol masers. Of these three, class II methanol masers are now known to be associated exclusively with young high mass stars. Although the class II methanol masers are widespread and have been studied in detail by numerous researchers, it is not yet clear where in the circumstellar environment they occur. Different studies yield different answers, ranging from the masers being associated with shocks, disks, or outflows. It is therefore not yet clear what information about the circumstellar environment or about the young massive star can be gained from studying the masers. A phenomenon that still appears to be unique to class II methanol masers is that a small number of these show periodic/regular variability with some having very well defined light curves. The first periodic methanol masers discovered are those associated with the high mass star forming region G9.62+0.20E. In this presentation I will show that periodic class II methanol masers in G9.62+0.20E can be explained very well within the framework of G9.62+0.20E being a very young colliding-wind binary system. The variability of the masers is due to changes in the free-free flux of seed photons from the HII region, which in turn is due to an ionization pulse originating in the shock heated gas due to the interaction of the stellar winds, propagating into partially ionized regions of the HII region. The decay of the maser flare is well described as being due to the recombination of a thermal hydrogen plasma from a higher to a lower state of ionization.

I will also present evidence for the recombination of a thermal hydrogen plasma from the behaviour of one of the methanol masers in the high mass star forming region G188.95+0.85. The above results suggest that at least for some very young high mass stars the associated methanol masers may be very useful and sensitive probes for the HII region which in turn carries information about the young massive star.

Session3: Evolution and interaction of massive stars with their environment

Invited Reviews

Feedback from massive YSOs and massive main-sequence stars

You-Hua Chu

Massive stars inject energies into the ambient medium via ouflows before reaching the main sequence, UV radiation and fast stellar wind during the main sequence, and ultimate supernova explosion at the end of stellar evolution. The effects of energy feedback vary, depending on not only the distribution and physical conditions of the ambient medium, but also the density and velocity. of an outflow/wind. To study the feedback effects thus needs multi-wavelength observations. Unlike star formation, there is no simple recipe to quantify the feedback process. While the Galactic objects can be studied in great detail, the LMC offers a clear view allowing less ambiguous associations between massive stars and the interstellar medium they act on. I will use both Galactic and LMC objects to illustrate the feedback from massive YSOs and main sequence stars, and compare observations to theoretical expectations.

Evolution of single massive stars with special emphasis on the LBV and RSG phase

Georges Meynet

In this review we shall begin by recalling the main observational constraints concerning Luminous Blue Variables (LBV) and Red Supergiants (RSG). We shall then review the impacts of mass loss, initial metallicity and rotation on the formation and lifetimes of these types of stars and see to which extent the most recent stellar models succeed to reproduce the main observational constraints. Finally, we shall discuss the links between LBV and RSG populations and the populations of Wolf-Rayet stars.

Circumstellar matter around evolved massive stars

Nathan Smith

Contributed Talks

A search for Ejecta Nebulae around Wolf-Rayet Stars using the SHS Hα survey

D.J. Stock, M.J. Barlow

Recent large scale Galactic Plane Hα surveys allow a re-examination of the environs of Wolf-Rayet (WR) stars for the presence of a circumstellar nebula. Using the morphologies of WR nebulae known to be composed of stellar ejecta as a guide, we constructed ejecta nebula criteria similar to those of Chu (1981) and searched for likely WR ejecta nebula in the SHS Hα survey. A new Wolf-Rayet ejecta nebula around HD 69210, WR 8 is found and its morphology discussed. The fraction of WR stars with ejecta type nebulae is roughly consistent between the Milky Way (MW) and LMC at around 5-6% with the MW sample dominated by nitrogen rich WR central stars (WN type) and the LMC stars seemingly having a higher proportion of carbon rich WR central stars (WC type). We compare our results with those of previous surveys, including those of Marston (1997) and Miller & Chu (1993), and find broad consistency once factors such as cluster membership are taken into account. We also investigate several trends in the sample: most of the clear examples of ejecta nebulae have WNh central stars; and very few ejecta nebulae have binary central stars.

The nebulae around LBVs: a multiwavelengths approach.

G. Umana, C. Buemi, P. Leto, C. Trigilio

We present first results of our study of a sample of Galactic LBV, aimed to contribute to a better understanding of the LBV phenomenon, by recovering the mass-loss history of the central object from the analysis of its associated nebula. Mass-loss properties have been derived by a synergistic use of different techniques, at different wavelengths, to obtain high-resolution, multi wavelengths maps, tracing the different emitting components coexisting in the stellar ejecta:the ionized/neutral gas and the dust. The study of these components provides two kind of information: current mass-loss, via direct observations of stellar winds (ionized gas component), and mass loss History of the central star, by analysis of the dust component/s. Evidence for asymmetric mass-loss and observational evidences of possible mutual interaction between gas and dust components have been pointed out by the comparison of mid-IR (IRAC@SST, VISIR@VLT) and radio (VLA) images of the nebulae, while important information on the gas and dust composition have been derived from IRS@SST spectra.

A multi-dimensional study of circumstellar nebulae around massive stars

Allard Jan van Marle, Rony Keppens

As massive stars evolve, their stellar winds change. This causes a series of hydrodynamical interactions in the surrounding medium. Whenever a fast wind phase follows a slow wind phase, the fast wind sweeps up the slow wind in a shell, which can be observed as a circumstellar nebula. One of the most striking examples of such an interaction is when a massive star changes from a red supergiant into a Wolf-Rayet star. Nebulae resulting from such a transition have been observed around many Wolf-Rayet stars and show detailed, complicated structures due to local instabilities in the swept-up shells. Using the MPI-AMRVAC hydrodynamics code we have made high resolution, two- and three-dimensional simulations of this interaction in order to model the formation and evolution of these circumstellar nebulae and explore the question whether full 3D simulations are necessary to obtain accurate models such nebulae.

Evolution of massive Be and Oe stars at low metallicity towards the Long Gamma Ray bursts.

C. Martayan, J. Zorec, D. Baade, Y. Fremat, J. Fabregat, S. Ekstrom

Several studies have shown recently that at low metallicity B-type stars rotate faster than in environments of high metallicity. This is a typical case in the SMC. As a consequence, it is expected that a larger number of fast rotators be found in the SMC than in the Galaxy, in particular a higher fraction of Be/Oe stars. Using the ESO-WFI in its slitless mode, the data from the SMC open clusters were examined and an occurrence of Be stars 3 to 5 times larger than in the Galaxy was found. The evolution of the angular rotational velocity at different metallicities seems to be the main key to understand the specific behavior and evolution of these stars. According to the results from this WFI study, the observational clues obtained from the SMC WR stars and massive stars, and the theoretical predictions of the characteristics must have the long gamma-ray burst progenitors, we have identified the low metallicity massive Be and Oe stars as potential LGRB progenitors. To this end, the ZAMS rotational velocities of the SMC Be/Oe stars were determined and compared to models. The expected rates and the numbers of LGRB were then calculated and compared to the observed ones. Thus, a high probability was found that low metallicity Be/Oe stars can be LGRB progenitors. In this presentation, we describe the different steps followed in these studies: determination of the number of Be/Oe stars at different metallicities, identification of the clues that lead to suppose the low metallicity Be/Oe stars as LGRB progenitors, comparison of models with observations.

The supergiant sequence in Westerlund 1 and the nature of B hypergiants

Ignacio Negueruela, J. Simon Clark, Benedict W. Ritchie, Francisco Najarro, Miguel A. Urbaneja

Accurate spectral types and isochrone fits reveal a sequence of >40 luminous supergiants in the starburst cluster Westerlund 1, covering spectral types from O9Iab to M6Ia. The data for the blue stars are consistent with a single burst of star formation, with an age 5.5 ± 1.0 Myr and an age spread < 1 Myr. Theoretical isochrones, though, have serious difficulties to reproduce the population of cool super-/hypergiants. At this age, the blue supergiants are expected to have initial masses ~35M_{sun}, in good agreement with the previous determination of progenitor masses for the Wolf-Rayet population. The high initial masses are confirmed by the dynamical solution for the eclipsing binary Wd1-W13, and may explain the important variability (>4 spectral subtypes) seen in both F and M hypergiants. A number of blue hypergiants with M_V~ -9 seem to follow the cluster isochrone and thus be stars moving away from the main sequence. We compare their properties to those of two of the most luminous B hypergiants known, Cygnus OB2 #12 and HD 80077, for which we present detailed modelling for the first time. Model fits show that, in spite of huge luminosities and initial masses >50 M_{sun}, these objects have undergone little chemical evolution. These results suggest that a number of very massive stars may appear as relatively normal, but extremely luminous B supergiants close to the end of the hydrogen core burning phase. In all, the new data seem to suggest the existence of significant gaps in our understanding of the post-main-sequence evolution of the most massive stars.

A Hidden Population of Massive Stars with Circumstellar Shells Discovered with the Spitzer Space Telescope

Stefanie Wachter

We have discovered a large number of circular and elliptical shells at 24μm around luminous central sources with the MIPS instrument on-board the Spitzer Space Telescope. Our archival follow-up effort has revealed 90% of these circumstellar shells to be previously unknown. The majority of the shells is only visible at 24μm, but many of the central stars are detected at multiple wavelengths from the mid- to the near-IR regime. The general lack of optical counterparts, however, indicates that these sources represent a population of highly obscured objects. We obtained optical and near-IR spectroscopic observations of the central stars and find most of these objects to be massive stars. In particular, we identify a large population of sources that we argue represents a narrow evolutionary phase, closely related or identical to the LBV stage of massive stellar evolution. We will also present preliminary results of our search for similar shells with the WISE mission.

Rotational Mixing in Massive Stars, More Puzzling than Ever !

I. Brott,C. Evans, A. de Koter, N. Langer et al.

The VLT-FLAMES Survey of Massive Stars (FLAMES-I) provided a homogeneous analysis of nitrogen abundances of B-type stars for a large sample (100+x stars) spanning a wide range of projected rotational velocities. This allows for the first time a statistically significant test of models of rotational mixing in massive stars. We have developed the detailed population synthesis code, STARMAKER, which we apply to simulate the FLAMES-I results in the Large Magellanic Cloud. This entailed the calculation of a dense grid of state-of-the-art stellar evolution models, with uncertain physics calibrated to the FLAMES-I observations and using initial conditions (chemistry, rotation) tailored to the FLAMES-I LMC sample. Our population synthesis results provide some remarkable surprises. Several groups of stars in the FLAMES-I sample imply that the current model of rotational mixing is too simple. We find that it is likely that additional fundamental physical processes need to be considered to understand the data. While binary physics may help to alleviate the problem, it is insufficient to fully resolve the issue. We emphasize indications that effects of magnetic fields in stars might be the root for the remaining discrepancies. Empirical constraints on this puzzle are one of the motivations behind the ongoing new multi-epoch VLT-FLAMES Tarantula Survey (FLAMES-II).

Mixing of CNO-cycled matter in massive stars

Norbert Przybilla, Markus Firnstein, Maria-Fernanda Nieva, Georges Meynet, Andre Maeder

Anomalies in the light element abundances in massive stars on the main sequence and more pronounced in their evolved stages are known since long. These are explained by evolution models for rotating stars as the consequence of mixing of nuclear-processed matter into the stellar atmosphere. However, recent analyses of large star samples have challenged the concept of rotational mixing. We report on the abundances of helium, carbon, nitrogen and oxygen in a sample of Galactic massive stars covering the main sequence to the blue supergiant stage in the mass range ~9 to 25 M_{sun}. High-quality spectra are homogeneously analysed throughout the optical to near-IR using improved NLTE line-formation and comprehensive analysis strategies. Extremely tight trends among the light element abundances are found for the first time, tracing the nuclear paths of the CNO-cycles quantitatively. The improved observational constraints facilitate model predictions to be tested in unprecedented detail and they may guide future improvements to the models.

Posters

P3.1 The nature of the massive stellar transient in DDO 68

Dominik J. Bomans, Kerstin Weis

When measuring the metallicity of several HII regions in the the very low metallicity dwarf galaxy DDO 68, Pustilnik et al. (2008) noted a spectral change of one HII region within 2 years. The lines in the residual spectrum and the brightening of the continuum in their spectrum lead them to interpret this transient event to be due to a variable massive star, possibly an LBV. Using archival and new imaging and spectroscopy of very low metallicity dwarf galaxy DDO 68, we present a study of the variability of the transient and search for effects on its environment. Using the derived photometric variability and analysis of the properties of the host cluster we constrain the evolutionary state and mass range of the star responsible for the transient event. Our results will be discussed in context with the very low (1/36 solar) metallicity of the host galaxy and the evolution of massive, very low metallicity stars with and without rotation.

P3.2 The infrared properties of massive stars in the Magellanic Clouds

Bonanos, A.Z., Lennon, D.J., Massa, D.L., Sewilo, M., Koehlinger, F., Panagia, J.Th. van Loon, N., Smith, L.J., Meixner, M., Gordon, K.

We present results of our study of the infrared properties of massive stars in the Large and

Small Magellanic Clouds, which are based on the Spitzer SAGE surveys of these galaxies. We have compiled catalogs of spectroscopically confirmed massive stars in each galaxy, as well as photometric catalogs for a subset of these stars that have infrared counterparts in the SAGE database, with uniform photometry from 0.3 to 24 μm in the UBVIJHKs +IRAC+MIPS24 bands. These catalogs enable a comparative study of infrared excesses of OB stars, classical Be stars, yellow and red supergiants, Wolf-Rayet stars, Luminous Blue Variables and supergiant B[e] stars, as a function of metallicity, and provide the first roadmaps for interpreting luminous, massive, resolved stellar populations in nearby galaxies at infrared wavelengths.

P3.3 Photometric monitoring of Luminous Blue Variables

Buemi, C.S., Di Stefano, E., Leto, P., Trigilio, C., Umana, G., Bernabei, S., Cutispoto, G., Messina, S., Schilliro', F.

The class of Luminous Blue Variables (LBVs) consists of luminous and massive stars, that are believed to go through a short but violent transition phase of evolution from the main sequence towards the Wolf-Rayet stage. LBVs are well know to show a combination of spectral and photometric variability (S-Doradus type variability and/or Eta-Car type eruptions), whose origin is not yet well understood, despite the crucial role that such objects play in the stellar evolution of massive stars. A detailed analysis of the time scale variability of LBV stars can provide usefull insights in the understanding the evolution of such objects and in the knowledge of the physical mechanism that trigger the great giant eruption, but up to now only few objects have been monitored on the years time-scale and with a regular time sampling rate. We are thus conducting a long term multiwavelength photometric monitoring of of a sample of confirmed and candidate LBVs. We present the most interesting results of the first two years of observations, performed by using the REMIR infrared imaging camera available at the REM (Rapid Eye Mount) telescope located in the La Silla premises of the ESO Chilean Observatory.

P3.4 (Semi-)Periodic Long-Term Variability of LBVs in M33

B. Burggraf, K. Weis, D. J. Bomans

Luminous Blue Variables (LBVs) are characterised by irregular photometric (and spectral) variabilities on different time scales (from months up to years or even decades) and with different amplitudes (from some tenth of magnitudes up to >2mag). So far the underlying mechanism for these variations is not known. It is still not known under which circumstances massive stars become LBVs, what triggers the instabilities causing the variabilities, and if all massive stars in a certain mass range evolve into LBVs or not. To find out more about the nature of the variabilities of LBVs, we investigated the long-term photometric behaviour. One aspect of our analysis was the check for periodicity in the variations. Periodicity on smaller timescales in the order of approximately one year is already known to occur in LBVs (van Genderen 2001). Detecting possible periodicity on lager scales (in the order of decades) was always difficult since most of the light curves do not reach back far enough and/or are much to fragmentary. Combining historical and new data, we produced a light curve of significant length to perform a systematic search for long-term periodicity on. We found long-term (semi-)periodicity of approximately 40 years being present in one of the LBVs in M33. Seeing more than two full cycles gave us the possibility to make a prediction for the next maximum.

P3.5 Long term monitoring of new LBV candidates

Simon Clark

Recent Galactic IR surveys have revealed a number of new candidate Luminous Blue Variables. In order to verify this assertion we have been undertaking a long term spectroscopic and photometric monitoring campaign of a subset of these sources, supplemented with tailored non-LTE model atmosphere analysis of the resultant datasets. Here we present an overview of this program including results and modeling which strongly support the classification of a number of new LBVs.

P3.6 A Near-Infrared Narrow-band Imaging Survey of Massive Stars in Cl 1806-20

Michelle L. Edwards, R. M. Bandyopadhyay, S. S. Eikenberry, D. Moon, V. J. Mikles

We survey the environment surrounding Cl 1806-20 using near-infrared narrow-band imaging to search for Brγ features indicative of massive stars. Using this technique, we successfully detect previously identified massive stars in the cluster. While we detect no new emission line stars, establishing a firm upper limit on the number of Wolf Rayets and Luminous Blue Variables in the cluster, we do find several candidate OBI stars, which likely represent the bulk of the heretofore undiscovered massive star population. Finally, we present spectroscopic evidence for emission-line variability in LBV 1806-20. Our results highlight the advantages of using narrow-band imaging to search for massive stars.

P3.7 Observations of Be Disk Building: Optical Spectra of NW Serpentis (HD168797) over 35 days

Grundstrom, Erika; McSwain, M. V.; Aragona, C.; Boyajian, T. S.; Marsh, A. N.; Roettenbacher, R. M.

The classical Be star NW Serpentis (HD 168797) is part of the COROT field and has long been studied photometrically and is known to have multi-periodic pulsational modes. Such pulsations are thought to be a way to generate the Be equatorial circumstellar disk. In an earlier survey, we identified this star as a possible non-radial pulsator and a known B → Be variable. During fall 2008, we obtained 23 spectra over 35 nights in the Hα region. During this time, we observed Hα to go from purely photospheric absorption to double-peaked emission then "fade" back toward photospheric absorption. We present our determination of stellar parameters, our analysis of the circumstellar disk construction, and the possibility of a binary companion. These observations also suggest that frequent observations of Be stars known to be non-radial pulsators may yield more opportunities to study the disk-building phenomenon and thus assist in constraining theoretical models of disk generation.

P3.8 Improving mass and age estimates of unresolved Stellar Clusters

Margaret M. Hanson

Stellar clusters provide astronomers with powerful diagnostics to derive the history and evolution of the galaxies they reside in. Even with the Hubble Space Telescope, galaxies beyond our Local Group are too distant for the individual stars within these clusters to be resolved. The entire stellar cluster must be studied as a single unresolved entity. Interpreting the integrated photometry of stellar clusters relies entirely on models to generate predicted colors of unresolved stellar systems. However, previous methods can lead to inaccurate estimates of cluster age because of the statistical fluctuations in the cluster's stellar mass function that leads to real and large ranges in integrated stellar cluster photometry. I will introduce a new stellar cluster-modeling program we have designed that populates and evolves a realistic sample of stars and derives integrated properties as a function of age and total cluster mass. We have used our model to generate a Monte Carlo database of 50 million stellar clusters to derive likelihood photometric properties as a function of cluster age and mass. This allows the user to work back, through statistical inference, to find the most probable age and mass of their stellar cluster based on integrated photometry alone.

P3.9 The kinematics of ionized gas in 30 Doradus

Vincent Hénault-Brunet, Chris Evans, et al.

The VLT-FLAMES Tarantula Survey offers a unique opportunity to study the gas kinematics of 30 Doradus in the LMC, the nearest giant extragalactic HII region. Using the nebular emission lines present in the spectra of ~1000 stars distributed across the region, we map the radial velocity structure of ionized gas. Based on these results, we discuss the interaction between the massive stars in 30 Dor and their environment, and the manifestations of recent and ongoing massive star formation. The gas velocities also serve as a good reference frame to compare to the systemic stellar velocities obtained as part of the survey. This will prove useful, for example, in identifying massive runaway stars and commoving stellar groups.

P3.10 In savvy pursuit of Local Group blue massive stars

M. Garcia, A. Herrero, N. Castro

The important role of metallicity on massive star evolution and the advent of multi-object spectrographs installed at 10m class telescopes, have lead to a boom on the studies of massive stars in Local Group galaxies. While color based quests of blue massive are relatively successful, they must be confirmed with spectroscopy and usually lead to lists dominated by B-type modest-mass stars. We have developed a friends of friends code to find OB associations in Local Group galaxies, presented in Garcia et al. (2009). One of the key points of the method is the photometric criterion to choose candidate OB stars, which is based on UBV colors at the moment, but could be easily extended to include GALEX to near-IR photometry. While not a new idea, our code's advantage compared to previous works on OB association are the electronic tables for the association members. The interpretation of the association HR-diagrams and the automatic determination of evolutionary masses for the members, allow a more insightful choice of candidates for spectroscopy and to spot out potential advanced evolutionary stages. The use of VO toos to correlate our electronic catalogues with other surveys or images (i.e. GALEX images, cepheid catalogues,...) plays an important role in finding the most interesting targets. We present our work on the very metal-poor irregular IC1613, (Garcia et al. 2010). The association properties are not only a powerful aid towards finding the most interesting candidate massive stars, but also reveal the galactic structure and the recent star formation history of the galaxy.

P3.11 Photometric study of Carina nebula region around WR22

Brajesh Kumar et al.

The Carina nebula is the southern hemisphere's largest and highest surface brightness nebula. It provides an ideal laboratory for the formation of star clusters by obtaining precise photometry and age estimates. We will present the preliminary photometric results of western region around WR22 of this nebula.

P3.12 Radiation-MHD models of elephant trunks and globules in HII regions

Jonathan Mackey, Andrew J. Lim

We study the formation and evolution of pillars of dense gas at the boundaries of HII regions due to shadowing of ionising radiation by pre-existing dense clumps. The effects of magnetic fields of various strengths and orientations on these models are investigated using 3D radiation-magnetohydrodynamics simulations. It is shown that a rather strong initial magnetic field (B ~ 0.15 mG) is required to significantly alter the hydrodynamic formation scenarios studied by Mackey and Lim (2010); with weaker fields the energy input from photoionisation remains the dominant driver of the dynamics. For weak and medium field strengths an initially perpendicular field is swept into alignment with the pillar during its dynamical evolution, in agreement with magnetic field polarimetry observations of M16 and some cometary globules (e.g. Sugitani et al. 2007, Bhatt et al. 2004). With a larger simulation domain it is seen that the pillar formation models studied in Mackey and Lim (2010) ultimately evolve to cometary structures in the absence of dense gas further from the star.

P3.13 The supergiant-rich open cluster NGC 7419

Amparo Marco, Ignacio Negueruela

NGC 7419 is an obscured open cluster in the Perseus Arm which has drawn considerable attention because it contains five red supergiants. We present classification spectra of a large sample of blue stars in the cluster. We also present for the first time Strömgren photometry for the cluster. In spite of the heavy reddening, Strömgren photometry seems to have transformed correctly to the standard system. We confirm the lack of blue supergiant in this cluster. From the spectral types around the main sequence turn-off, an age ~15 Myr is derived. We compare the stellar population of NGC 7419 to other clusters rich in Be stars such as NGC 663.

P3.14 Preliminary results about massive O and LBV stars at different metallicities observed with the VLT X-Shooter

C. Martayan, R. Blomme, Y. Fremat, A. Merand, J.-B. LeBouquin, F. Selman, J. Girard, G. Montagnier, F. Patru, F. Martins, D. Baade, T. Rivinius, S. Stefl, A. Lobel, A. Fox, J. Zorec, T. Semaan

In this poster, we present the first spectra obtained with the new 2nd generation VLT spectrograph X-SHOOTER of early O stars and LBV of different metallicities. X-SHOOTER allows to obtain simultaneously a spectrum from the UV to the K-band with a resolving power of ~15000. The objects presented in this poster were selected for their particular nature: early O stars with mass discrepancies between stellar evolution models and observations, discrepancies with the wind momentum luminosity relation, as well as emblematic stars with high extinction due to their mass-loss such as the Pistol star. The Pistol star has been claimed as the most massive star known, with 250 solar masses. We present the preliminary results based on X-Shooter spectra, as well as the observations performed with the VLTI-AMBER and the VLT-NACO adaptive optics.

P3.15 A "pinwheel" nebula around WR118?

Millour, F., Driebe, T., Groh, J., Chesneau, O., Weigelt, G. Liermann, A., Meilland, A., Borges Fernandes, M.

We present VLTI/AMBER observations on the dusty Wolf-Rayet star WR 118, which detect an asymmetric dust shell with sharp edges. This suggests that WR 118 is a new "pinwheel" nebula candidate detected, for the first time, by long-baseline interferometry. We discuss the future possibilities of interferometric characterization of dusty Wolf-Rayet stars. The long baselines made available by interferometers will enable one to correctly image the inner regions of dusty Wolf-Rayet stars, and check if all of them contain pinwheels. This will answer the question whether or not all dusty Wolf-Rayet stars are interacting binary systems. We discuss the potential to detect further pinwheels with the next generation of 4- and 8-telescope instruments of the ESO VLTI using simulations of observations under realistic conditions and with available image-synthesis software.

P3.16 Mixing in magnetic B stars

Morel, T.

Recent observations have revealed the existence of slowly-rotating, nitrogen-rich B dwarfs that are not predicted by evolutionary models including rotational mixing. However, magnetic fields may be the missing ingredient, as their incorporation in theoretical models may lead to a greater amount of core-processed material at the surface. To test this hypothesis, we present preliminary results of an abundance study of a number of magnetic B stars where the CNO abundances are used to examine the extent of mixing due to magnetic field phenomena.

P3.17 Escape of ionizing radiation in SMC HII regions

E.W. Pellegrini, M.S. Oey

We look for evidence of escaping ionizing radiation in SMC HII using the Magellanic Cloud Emission Line Surve. We use the available Hα, [OIII] λ 5007 and [SII] λλ 6716,6731 images evaluate the existence of H^+/H^0 ionization fronts as traced by the ratio of [SII] to Hα and compare these to 2-D projections of photoionization simulations. Our novel approach does not provide quantitative estimates of the escape fraction of escaping ionizing photons, but is independent from methods which compare ionization rates of massive stars to observed Hα luminosity. We identify HII regions as radiation bounded, open blister type, and density bounded. These morphological classifications are strongly correlated with the observed N(HI)column density.

P3.18 First results of the project MASGOMAS, MAssive Stars in Galactic Obscured MAssive clusterS.

Sebastián Ramírez Alegría, Antonio Marín-Franch, Artemio Herrero Davó, Carmen De Martino, Elena Puga, Francisco Najarro

We want to present our program MASGOMAS (MAssive Stars in Galactic Obscured MAssive clusterS), with its objectives, methodology and first results. MASGOMAS is a compilation of cluster candidates, from previous catalogue of galactic clusters (Bica et al. (2003); Dutra et al.(2003) and Mercer et al. (2005)), obtained using 2MASS infrared photometry. In order to increase the infrared information of the candidates, we completed near-infrared photometry and H-, K-filter spectroscopy for 9 of them, concluding with an full analysis of the stellar content for 3 of the candidates, deriving its distance, differential extinction, minimum stellar mass and age. Our near-infrared data was also complemented with SPITZER imaging of our candidates and visual spectroscopy for some specific stars in each of the 3 published clusters.

P3.19 The rapid magnetic rotator HR7355 (B2Vpn): Archetype or just exotic?

Rivinius Th., Townsend R., Wade G., Stefl S., Baade D., Oksala M., Grunhut J., etal.

For early type magnetic stars slow, at most moderate rotational velocities have been considered an observational fact. The detection of a multi-kiloGauss magnetic field in the B2Vpn star with P~0.52 d and v sin i~ 300 km/s has brought down this narrative. We have obtained almost

100 high-resolution, high-S/N echelle spectra in 2009. These data are used to investigate a) the circumstellar environment, characterized by a magnetosphere rotationally locked out to several stellar radii and showing Hydrogen emission, and b) the surface chemical abundance distribution, which seems to be characterized by much stronger abundance variations, at least for Helium, than slower rotating stars like σ Ori E. This is unexpected, since it was so far believed that the meridional circulation, necessarily present in a rapidly rotating early type star, would act to destroy any abundance pattern and homegenize the surface.

P3.20 Non-thermal radiation from a runaway massive star

Gustavo E. Romero, Paula Benaglia, Cintia Peri, Josep Marti

We present a study of the non-thermal emission from a massive runaway star. The star produces a bow shock that is clearly observed in the infrared. We have performed Very Large Array observations under the assumption that the reverse shock in the stellar wind might accelerate charged particles up to relativistic energies. Non-thermal radio emission of synchrotron origin has been detected, confirming the hypothesis. We have then modeled the system and we predict a spectral energy distribution that extends up to gamma-rays. The intensity at high energies is too low to be detected by current instruments, but the future Cherenkov Telescope Array might detect the source. Significant X-ray emission is expected.

P3.21 New LBV-star candidats in M33

O. Sholukhova, S. Fabrika, A. Valeev

We present two new LBV-like stars in M33 found among G-type star candidates ((B-V) = 0.6-0.9) with H-alpha emission in this galaxy (Valeev et al., 2010). Our follow-up spectroscopy has shown that these stars are intrinsically blue, but reddened by the dust extinction in M33. They show broad and strong H-alpha emission and numerous FeII and HeI absorption lines. We present their spectral energy distributions from optical to IR bands, estimate their temperatures and masses. The luminosities are M(bol) = -10.5 and -9.8, they are similar to well-known VarB and VarC LBV stars in this galaxy.

P3.22 The VLT-FLAMES Tarantula Survey of Massive Stars

W. D. Taylor, C. J. Evans and the VLT-FLMES Tarantula Consortium

With multi-epoch spectroscopy of 1000 stars, the VLT-FLAMES Tarantula Survey is poised to address fundamental questions in both stellar and cluster evolution. The survey contains an unprecedented 300 O-type and nearly 500 B-type stars: such large samples will inform both stellar evolution modelling and the debate on the role of rotational mixing. An observational overview of the survey will be given, and the forthcoming analysis will be outlined. The near 18 month time span of the six observational epochs provides excellent binary detection coverage and initial estimates of the binary fraction will be reported. Finally, to illustrate the potential of the data, a massive O2-type runaway star will be presented. From UV HST-COS spectroscopy the star is found to have one of the largest terminal velocities seen to date in an O-type star.

P3.23 Studying Nebulae Ejected from Massive Stars with Herschel-PACS

Vamvatira-Nakou, C., Exter, K., Hutsemékers, D., Nazé, Y., Rauw, G., Royer, P., Waelkens, C.

The study of the nebulae ejected from Luminous Blue Variables and the circumstellar bubbles around Wolf-Rayet stars, which radiate strongly in the IR due to the heating of dust, is crucial for understanding the massive stars evolution. With Herschel we are able to observe these objects in the full far-infrared. We have obtained imaging and spectroscopic observations of nebulae associated with Luminous Blue Variable and Wolf-Rayet stars using PACS, one of the three instruments onboard Herschel. A description of these observations and preliminary results of the data analysis will be presented.

P3.24 Gone with the wind: Nebulae around LBVs

Kerstin Weis

The LBV phase is a short and active phase of the very massive stars may pass. Strong stellar winds and possibly giant eruptions of the stars in this phase lead to the formation of small (≤ 5 pc) circumstellar nebulae. A significant fraction (at least 50%) of these nebulae show – to different degrees - a bipolar structure. Such a morphology, together with the presence of LBVs at lower bolometric luminosity, supports the newer stellar evolution models including rotation. Morphology, kinematics and the chemical composition of LBV nebulae are useful traces to reveal the stars previous history, answers questions about the stellar interior and finally the stellar evolution of massive stars in general. A summary of our knowledge of the currently known LBV nebulae will be presented with a short special emphasis on a new analysis of the nebula around AG Carinae. Deep images and echelle spectra of this nebula show it to be much larger in size as known so far, and reveal in much more detail the - so far only hinted –highly bipolar structure of the nebula.

P3.25 Ultraviolet spectroscopy of circumnuclear clusters in M83

Aida Wofford, Rupali Chandar, and Claus Leitherer

It is not yet clear whether the star formation in circumnuclear starbursts occurs in a single burst, or whether it is due to the propagation of star formation from one region to another. The high precision age-dating possible from ultraviolet spectra of very young star clusters provides a means of differentiating between these two scenarios. We analyze archival Hubble Space Telescope (HST) ultraviolet imaging and spectroscopy of compact star clusters located within the circumnuclear starburst of M83, the nearest such example. We compare the observed spectra with two sets of Starburst99 models, older, semi-empirical models (Robert et al. 1993) and new fully theoretical models (Leitherer et al. 2010) based on a new synthetic library of high-resolution UV spectra for hot massive stars. From this comparison, we determine the intrinsic reddenings, masses, and ages of the brightest clusters in M83's starburst and compare our results with those derived from optical HST photometry. We also study the upper initial mass functions of our high metallicity ($Z=1.5\ Z_{sun}$) clusters.

P3.26 Single-Star HII Regions as a Probe of Massive Star SEDs

J. Zastrow, M.S. Oey, E.W. Pellegrini

We exploit the strong dependence of HII region optical spectra on the SED of the photoionizing source to critically examine the stellar atmosphere models. We use spatially resolved, longslit observations of LMC single-star HII regions as constraints to test various predicted atmospheres of massive stars. For each star in our sample, the observed spectral types and luminosities are used to select stellar atmosphere models from the CoStar (Schaerer & de Koter, 1997), TLUSTY (Lanz & Hubeny, 2003), WM-basic (Pauldrach et al. 2001) and Smith et al. (2002)grids. These atmospheres are used to define the ionizing source in CLOUDY (Ferland et al. 1998) photoionization simulations. The initial cloud parameter space is selected based on the measured densities and sizes. To explore the morphology parameter space, we consider spheres, thick, and thin shells. We find it difficult to fit the predicted emission-line spectra to the observations. In particular, we see that the models significantly under-predict emission from low-excitation ions such as [N II] λλ6548,6584Å and [S II] λλ 6716,6731 Å and from the temperature dependent [O III] λ4363 Å line. Additionally, we examine the role gas density variations have in the model fits as well as the effects of additional heating sources.

Session 4: Future instrumentations and their application to massive star's research

Invited Review

Massive Star Research in the Era of ELTs

Christopher Evans

The next generation of optical-infrared telescopes, the Extremely Large Telescopes ELTs), are in their advanced planning stage. With primary apertures in the range of 24 to 42m, they will open a new window on studies of massive stars -from high angular-resolution imaging at milliarcsecond scales in heavily obscured Galactic clusters, out to spectroscopy of individual luminous supergiants at distances of tens of Mpc. I will summarise the three current ELT projects, their relevant instrumentation, and some of the exciting and unique observations of which they will be capable.

Contributed Talks

Spectroscopic madness - A golden age for amateurs

Thomas Eversberg

Today, stellar astronomers are running into a technological cul-de-sac. Instrumentation becomes larger and larger but observation time acquisition is a serious problem for intermediate or even long-term observations (Gregor Rauw on a recent meeting about stellar spectroscopy). On the other hand, small scale observatories are often decommissioned due to reduced funding. The golden age of astronomy, though, has influence on amateur astronomy, as well. Today, non-professional enthusiasts run telescope equipment which has been state-of-the-art technology some forty years ago. In addition, spectroscopic applications become available in this domain by using off-the-shelf instruments as well as self-designed spectrographs for telescopes of up to 1m aperture, not to speak about modern CCD technology. I will give an overview about amateur work on massive stars (e.g., long-term Be star monitoring and intermediate-term campaigns) as well as the available technology. Needs for campaign management and necessities for potential pro-am collaborations are highlighted.

Studying massive stars with the International X-ray Observatory

G. Rauw & L. Oskinova

Chandra and XMM-Newton have deeply changed our view of the X-ray emission of massive stars. However, most massive stars being rather faint sources, the number of high-resolution X-ray spectra of massive stars remains rather limited and obtaining these spectra requires rather long exposure times. ESA, NASA and JAXA are currently designing the International X-ray Observatory (IXO) that will provide an quantum leap in collecting area compared to the current missions. In this contribution, we highlight the capabilities of IXO and its instrumentation for the study of massive stars in our Galaxy and beyond.

Posters

P4.1 Spectroscopic binaries as observed by the future space mission Gaia.

Damerdji, Y. et al.

The future satellite Gaia will observe a large number of stars through its main three channels: astrometric, photometric and, for the brigtest stars, spectroscopic. The spectroscopic channel contains the RVS spectropgraph that allows to produce medium resolution spectra in a small wavelength range. These spectra should allow us to recognize the stars exhibiting a composite spectrum either as due to chance alignment or to a true binarity. The data treatment aspects of the binary candidates is explained and the algorithm that will be included in the pipeline processing are discussed. Some statsitics about the binaries to be observed by Gaia are adressed and the impact on our knowledge of these objects is briefly discussed.

P4.2 Prospects for the multiplicity investigation of massive stars with the CARLINA interferometer

M. De Becker, H. Le Coroller, J. Dejonghe

The multiwavelength study of massive stars revealed many phenomena that are intimately related to their mutliplcity. Colliding winds in massive binaries play indeed a significant role in thermal X-ray emission, particle acceleration, or even dust formation in such systems. In this context, the identification of binaries and the determination of their orbital parameters is a pivotal issue. We describe first briefly the CARLINA project. The sensitivity and imaging capability of Carlina are perfectly adapted for the study of binary systems. Considering its expected specifications, Carlina will operate in complementarity with ELTs and long baseline interferometers. Then, we will discuss some prospects for the multiplicity investigation of massive stars, on the basis of the expected performances of the prototype currently studied at the Observatoire de Haute-Provence (OHP).

P4.3 The EVLA – new research capabilities for the world's largest radio telescope.

Sean Dougherty, Rick Perley

The EVLA project, a $90M partnership between the National Radio Astronomy Observatory (USA), the National Research Council (NRC), and Conacyt (Mexico), is nearing completion. The goal of this project is a minimum 10-fold enhancement of the Very Large Array's scientific capabilities: to provide microJy sensitivities, continuous frequency coverage from 1 to 50 GHz, and a new correlator of unprecedented spectral span and resolution. These enhanced capabilities make the EVLA the most sensitive and flexible radio astronomy facility in the world, which will enable new science discoveries over the coming decades, in conjunction with ALMA.
With the installation of the NRC-HIA designed and built 'WIDAR' correlator, and the recent completion by the NRAO of retrofits of all 28 VLA antennas to modern standards, the EVLA project has entered its final stage of instrumental verification. Astronomical observing using the new correlator recommenced in March 2010, immediately revealing some of the enhanced scientific capabilities of the new system, capabilities that will increase rapidly over the next few years.
In this poster, we will present the status of the project, focusing on enhanced scientific capabilities enabled by the combination of complete frequency coverage from 1 to 50 GHz with the capabilities of the WIDAR correlator. Examples of the new science already enabled by this project will be shown, and its impact on massive star research.

P4.4 A new focus for hot stars

Thomas Eversberg, Klaus Vollmann

The former main instrument of Munich University Wendelstein telescope has been saved for future scientific work. The 0.8m Ritchey-Chretien will be erected in central Germany in a remote mountain range. Spectroscopy of hot stars will be the main scientific aim. Equipped with an Echelle spectrograph we intend to monitor emission line stars, perform campaigns and offer engineering time for interested universities. Our plans include an infrared focal plane array (1 - 2.5microns) as well as a dedicated spectropolarimeter.

P4.5 Study of the possibility of a X-ray sensor based on the Plasmon Surface Resonance for the next generation of instruments.

Anthony Hervé, Juriy Hastanin, Gregor Rauw, Serge Habraken

With the new generation of X-ray observatories in preparation, we have explored the possibility of a new technology in order to increase the resolution and the sensitivity of future instruments compared to XMM or Chandra but also with different technologies currently considered for the future missions. We have studied the possibility to create a sensor based on the Surface Plasmon Resonance (SPR), and have determined the constraints on its size, energy resolution or working temperature.

P4.6 Massive binaries as seen with GAIA

Palate, M., Rauw, G., Gosset, E., Nazé, Y.

GAIA, ESA's forthcoming astrometric observatory, will observe a billion stars of our Galaxy, among which thousands of high-mass stars. In this contribution, we study the capabilities of GAIA's spectrometer (RVS) in the context of massive stars, especially the detectability of lower-mass companions to O-type stars. This preliminary study enables us to estimate to what extend GAIA will constrain the distribution of the physical and orbital parameters of massive binaries (luminosity, period, mass ratio, eccentricity...).

P4.7 CRIRES-POP: A new high resolution near-IR spectral library

Ramsay, S., Lebzelter, T., Seifahrt, A., Almeida, P., Bagnulo, S., Dall, T., Hartman, H., Hussain, G., Käufl, H.U., Nieva, M.-F., Przybilla, N., Seemann, U., Smette, A., Uttenthaler, S., Wahlgren, G., Wolff, B.

We report on an ongoing project to obtain a high signal--to--noise, high spectral resolution library of stellar spectra over from 1 – 5μm using CRIRES on the VLT. New instrumental capabilities make this an increasingly important wavelength range for high resolution spectroscopy, yet our detailed knowledge of the NIR spectral features is far from complete. The motivations of our group in conducting this survey are broad, ranging from the desire to provide fundamental line data for laboratory spectroscopists, through improvement of wavelength calibration and the removal of telluric lines for CRIRES to applications in a range of astrophysical topics from circumstellar matter to stellar magnetic fields. Substantial effort is being invested in producing a library of spectra reduced using a common procedure to ensure homogeneity of the results. So far, we have obtained spectra of 10 sources and hope to complete a sample size of ~25 to give good coverage of the HR diagram. Most of our targets were selected from the UVES-POP spectral library sources, so that complete coverage of the spectra from the UV to the NIR will be available. An important goal for the project is that the library is public and widely used. The raw and pipeline reduced data on five sources including e-Vel (A6II) and tau Sco (B0.2V) are already available at http://www.univie.ac.at/crirespop/.

P4.8 The IACOB spectroscopic database of Galactic OB stars

S. Simon-Diaz et al.

We present the IACOB spectroscopic database, an homogeneous set of high resolution, high signal-to-noise ratio spectra of Galactic O- and B-type stars obtained with the FIES spectrograph attached to the Nordic Optical Telescope. We also present some results from ongoing projects using the IACOB database, and a list of ideas illustrating its utility for other type of studies in the field of massive stars.

P4.9 The Galactic O-Star Spectroscopic Survey (GOSSS)

Alfredo Sota, Jesus Maiz Apellaniz, Rodolfo Barba, Nolan R. Walborn, Emilio Alfaro, Roberto Gamen, Nidia Morrell, and Julia Arias

The Galactic O-Star Spectroscopic Survey (GOSSS) is a project that will observe all known Galactic O stars with B < 13 in the blue-violet part of the spectrum with R~3000. It also includes companion spectroscopic surveys at R~1500 and R~40 000 as well as an imaging survey. It is based on v2.0 of the the most complete Galactic O star catalog with accurate spectral types (Maiz Apellaniz et al. 2004, Sota et al. 2008) that we have recently compiled. We have completed the first part of the main project and recently published the first article (Walborn et al. 2010) and two more will be submitted during this year (Sota et al. 2010a,b). The survey will be used for a number of purposes, such as a precise determination of the IMF for massive stars, the measurement of radial velocities for Galactic kinematical studies, and the detection of unknown massive binaries. Results will be made available through a dedicated web server, will be incorporated into the virtual observatory, and will include the most complete spectral library of massive stars to date. The Northern part of the survey is being carried out from the Sierra Nevada and Calar Alto observatories (Spain) and the Southern part from Las Campanas (Chile), La Silla (Chile), and CASLEO (Argentina).

P4.10 The Cygnus OB2 Radio Survey (COBRAS) using e-merlin

Allan J Willis, Raman K Prinja, Danielle Fenech

UCL is spearheading a major legacy project with e-merlin to assemble probing datasets of stellar populations in strategic star clusters which comprise large numbers of massive stars. This e-merlin CyG OB2 Radio Survey (COBRAS) will yield extensive and deep 5 GHz wide-field mapping of selected fields in the rich Cyg OB2 association. e_merlin provides a sensitivity increase of a factor of 50-100 over the VLA and we anticipate a factor of 50 fold increase in the number of radio detections, during the 350 hours of time allocated to this legacy programme. In particular we expect to secure the first radio detections of many OB and WR stars, including supergiants, giants and main-sequence stars. Observations at 1.5 GHz will also be secured. These data will address a number of scientific goals, inter alia, to further our understanding of wind structure and clumping at each evolutionary phase, to try and resolve the current, major uncertainties in mass loss rate estimates for massive stars.

Session 5: Massive binaries: interaction and evolution

Invited Reviews

Results of the 2009 multi-wavelength campaign on eta Carinae

M. Corcoran, K. Hamaguchi, T. Gull, A. Damineli, J. Groh, E. Fernandez-Lajus, C. Russell, J. Pittard, E. Pian, N. Richardson, J.-C. Leyder, M. Tavani

We present the results of a multiwavelength campaign of observations of eta Carinae during the most recent X-ray minimum/periastron passage which occurred in January 2009. Notable new results are the detection of a high-velocity component which appeared in the blueshifted wing of the He I 10830 feature, the recurrence of apparent eclipse-like event in UBV photometry, detailed monitoring of the variations at H-alpha, and an abrupt recovery from X-ray minimum. We compare these observational results to observations during previous minima, and discuss the implications of these observations on our understanding of the binary system.

Theoretical models of interacting winds in massive binaries

Julian Pittard

I review recent progress on the modelling of the wind-wind interaction in massive binaries and the resulting emission.

Signatures of binary evolution processes in massive stars

Dany Vanbeveren

Before the evolution of the components of massive binaries is affected by typical binary processes they evolve as single stars. I therefore first summarize my view of the present state of massive single star evolution. Next I discuss the typical binary processes and how they affect the evolution of the binary components. The third part deals with the effects of binaries on massive star population synthesis with special emphasis on the dynamical evolution of starburst regions.

Results of the 2009 multi-wavelength campaign on WR140

Peredur Williams

The archetypal colliding-wind Wolf-Rayet + O star binary went through periastron passage and maximum interaction in early 2009. To exploit this laboratory for studying high-energy and colliding wind phenomena, several groups mounted observing campaigns. These include multi-site optical spectroscopy to refine the orbit and study anomalous emission from the shock-compressed wind, infra-red spectroscopy, high-resolution radio imaging of the wind-collision shock and X-ray observations with RXTE, XMM, Chandra and Suzaku. Preliminary results from these campaigns will be surveyed.

Contributed Talks

The role of rotation on the evolution of massive stars in close binaries.

S.E. de Mink, N. Langer, M. Cantiello, R.G Izzard, O.R. Pols

Rotation can have severe consequences for the evolution of massive stars and is now considered as one of the main parameters (alongside mass and metallicity) determining the final fate of single stars. Especially in binaries high stellar rotation rates can be readily achieved as a result of (I) tides in close binaries, (II) mass transfer, which can drive the accreting star towards critical rotation probably resulting in severe mass loss from the system, and (III) mergers. We discuss the role of binary interaction on the distribution of rotation rates of hot massive stars and the role of mixing processes induced by rotation on the evolution of massive binaries. As a particular example, we discuss models of short-period binaries, where high rotation rates are induced by tides. In very massive systems mixing induced by rotation processes can become so important that, during the main sequence evolution, centrally produced helium is mixed throughout the envelope. The stars evolve nearly chemically homogeneously, remaining blue and compact while they gradually become Wolf-Rayet stars. The stars stay within their Roche lobe and avoid a mass transfer or a contact phase, contrary to what standard binary evolution theory predicts. We propose that this evolutionary path provides an alternative channel for the formation of tight Wolf-Rayet binaries and might explain massive black hole binaries such as the intriguing systems M33 X-7, IC 10 X-1 and NGC 300 X-1.

A Multiwavelength Study of the Runaway Binaries HD 14633 and HD 15137

M. Virginia McSwain, Michael De Becker, Mallory S. E. Roberts, Tabetha S. Boyajian

The runaway O-type binaries HD 14633 and HD 15137 were likely ejected from the cluster of their birth by supernovae explosions in close binaries. Here we present recent optical spectra to update the orbital solutions of the binaries and study the physical parameters of the O star primaries. We also present the first XMM-Newton observations of both systems that attempt to detect hard power-law emission from compact companions. EPIC spectra of HD 14633 at periastron and apastron reveal a soft, nonthermal X-ray flux that is variable during the orbit, and we discuss possible origins for the X-ray emission and its variability. Our EPIC spectra of HD 15137 indicate thermal X-ray emission consistent with an isolated O star. Neither star has a hard X-ray excess, and we provide upper limits on the emission from the proposed compact companions.

Solving light curves of WR+O binaries: a regularization approach.

I.I.Antokhin

Extended semi-transparent atmospheres of WR stars in eclipsing WR+O binaries present some difficulties for interpretation of their light curves. I will present a review of an approach to the problem based on solution of the most general form of integral equations describing a light curve of a WR+O binary: Fredholm's equations of the first kind. The unknown functions are the brightness and opacity distributions across the disk of the WR component. The equations represent an ill-posed problem. To get a unique solution one needs to impose some a-priori restrictions on the solution. I will review various physically justified sets of restrictions and, using artificially simulated light curves with known solutions, show how these restrictions and the corresponding mathematical algorithms work to retrieve the functions of interest. I will also discuss the influence of errors in the input light curve on the solutions. A real-world example of using the algorithms to solve a light curve of the WR+O binary V444 Cyg will also be shown. While this system has circular orbit, the algorithms can be used for binaries at eccentric orbits as well. The algorithms and the corresponding computer programs are open to the public.

How massive are the most massive stars?

Schnurr, Crowther, Hirschi, Goodwin, Parker, Moffat, Chene

How massive are the most massive stars? Fundamental questions of stellar astrophysics suffer from an almost complete lack of truly empirical evidence when it comes to stars with the highest masses. Over the past years, considerable effort has been made to identify the most massive stars, and to determine their properties. I will present a census of the most massive stars known to date, and show our latest modeling results for the current record holder, NGC3603-A1. I will also present the application of thus calibrated models to other very massive stars, and discuss the far-reaching implications of our results for the upper-most initial-mass function.

Cygnus OB2: A Laboratory for Massive Binaries, Runaway Stars, and Triggered Star Formation

Chip Kobulnicky, Dan Kiminki

As one of the closest rich clusters of massive stars, Cygnus OB2 has provided foundational insights into the formation and evolution of OB stars. I will highlight the results of a long-term spectroscopic study of more than 100 massive OB2 members, including > 20 binaries with measured orbital parameters, the most in any single cluster. The intrinsic binary fraction is large (> 70%), and the measured mass ratios are consistent with a uniform distribution. There is a highly significant excess of short period systems in the range 4 – 8 days. Curiously no runaway systems are found in the spectroscopic survey, but *Spitzer Space Telescope* imaging has revealed a small number of early type stars generating bowshocks that may be moving with high space velocities. The physics of these objects provides a novel way of estimating time-averaged mass loss rates for such stars. Cygnus OB2 is also a site of "feedback" from massive stars where their mechanical and ionizing luminosity have plausibly promoted new generations of star formation in the surrounding molecular clouds. This influence is now seen vividly in Spitzer images of the region.

Multiplicity of O-type star in the young open cluster NGC 2244 and the Mon OB2 association

L.Mahy, Y.Nazé, G.Rauw, F.Martins, E.Gosset, H.Sana, M.De Becker, P.Eenens

O-type stars play a key role in the ecology of galaxies but the knowledge of their formation is still fragmented. The study of massive stars in clusters is thus interesting to distinguish between the different formation scenarios since they constitute a homogeneous population (same age, distance and chemical composition). The investigation of the multiplicity of massive stars is thus crucial to determine a robust binary fraction but also for understanding the physical properties of these objects. In this context, the main results from our long-term spectroscopic survey devoted to the young open cluster NGC 2244 will be presented. We will discuss the spectral classification, the v sin i and the multiplicity of O-stars. The stellar and wind parameters of each star obtained using the CMFGEN atmosphere code help us to better constrain the individual properties of these objects. Several of these stars were observed by the CoRoT satellite (SRa02) in Asteroseismology Channel. This intense monitoring and the unprecedented quality of the light curves allowed us to shed a new light on these objects, revealing periodic variations. Finally, this study will be put in perspective with other multi-epoch spectroscopic campaigns performed by our team on the multiplicity in young open clusters.

The massive binary population of the starburst cluster Westerlund 1.

B.W. Ritchie, J.S. Clark, I. Negueruela, P.A. Crowther

The galactic starburst cluster Westerlund 1 contains a rich, coeval population of evolved, massive stars that include large numbers of Wolf-Rayets, OB supergiants and cool hypergiants. Motivated by X-ray, infra-red and radio observations that show Wd1 to be binary-rich, we have undertaken an intensive multi-epoch radial velocity survey of Wd1 with VLT/FLAMES in order to obtain a census of massive binaries amongst both the highly-luminous transitional supergiants and the lower-luminosity stars just evolving off the main sequence. Photometric and radial velocity measurements of the WNVL + B1.5Ia binary W13 provide the first direct determination of the mass of a transitional supergiant in Wd1 and place a firm $35M_{sun}$ lower limit for the mass of the progenitor of the magnetar CXOU J164710.2-455216. When our radial velocity observations are combined with X-ray and radio data, we find that the high binary fraction inferred for the Wolf-Rayet population extends to the lower-mass supergiants, with ≥40% of the most luminous targets examined in our survey showing direct or indirect evidence for binarity and initial results showing that this high binary fraction extends to the lower-luminosity O8-9II/III population. The multi-epoch observations also reveal widespread pulsational instability from early-B to late-F spectral types, with radio observations of Wd1 showing extensive mass-loss amongst a population of cool hypergiants that offer the prospect of stringent tests for models of massive stellar evolution.

Multi-wavelength diagnostics of massive binary interaction in Eta Carinae

Jose Groh

Eta Carinae is one of the most luminous objects in the Galaxy, allowing for the study of massive stellar evolution under extreme conditions. Eta Car is generally accepted to be a binary system comprised of two massive stars with a total luminosity of $L_{tot} \geq 5\times 10^6 L_{sun}$ and total mass of at least 110 M_{sun}. The orbital parameters are uncertain, but most authors agree on a high eccentricity (e~0.9) and an orbital period of 2022.7 ± 1.3 days. I will present newly-developed two-dimensional radiative transfer models of Eta Car which account for the presence of the low-density cavity and wind-wind interaction zone created by the wind of the companion. Comparing synthetic line profiles with the available observations, I will show that such a cavity in the dense wind of the primary star directly affects multi-wavelength diagnostics such as the ultraviolet spectrum, the Hα line profile, and the shape of the near-infrared continuum region. All these diagnostics have been previously interpreted as being affected by a latitude-dependent wind of the primary. We found that, ultimately, the presence of the companion hampers the determination of the rotational velocity of the primary.

Understanding the non-thermal emission arising in the massive O-star binary Cyg OB2 #5

Marshall Kennedy, Sean Dougherty, Perry Williams.

Re-analysis of 50 observations from the Very Large Array reveal unequivocally that the previously identified variable non-thermal radio emission in the massive O-star binary system has a period of 6.7+/-0.2 yrs and is associated with the radio emission arising in the 6.6-day period binary system. This emission is attributed to a wind-collision region associated with the binary and nearby massive star. Supporting evidence for the existence of the companion to the binary is detected in apparent reflex motion of the binary. In addition, an unusually high mass-loss rate of $3.4 \times 10^{-5} M_{sun} yr^{-1}$ for the Of supergiant binary is comparable to that expected in WR stars, and consistent with an unusually strong He I 1.083 μm emission line, also redolent of WR stars.

3D modelling of massive star binary systems Eta Carinae, WR22, and WR140

Ross Parkin

Massive stars possess powerful stellar winds. Wind-wind collision in a massive star binary system generates a region of thermalized plasma which may emit prolifically at X-ray wavelengths. Results are presented from 3D adaptive-mesh refinement (AMR) hydrodynamical models which include radiative cooling and the radiative driving of the stellar winds. The models provide an exceptional insight into the turbulent nature of the wind-wind interaction regions. X-ray calculations are performed and model results allowing detailed comparisons against observational data. The results from investigations of Eta Carinae, WR22, and WR140 are discussed.

Posters

P5.1 The peculiar O9 star BD+53 2790, the massive counterpart to the X-ray binary system 4U 2206+54

Pere Blay

The X-ray binary system 4U 2206+54 hides many mysteries. Among them, the shocking behaviour of both of its components: the O9 dwarf star BD+53 2790 and a very slow rotating neutron star. BD+53 2790 misled the astronomers showing itself as a very likely Be star. However, a deeper spectral analysis and more intense monitoring, revealed that the real picture was a bit more complicated: a) Although it shows evidence of a circumstellar envelope, its observable properties differ from those analog envelopes in Be stars. b) Comparison to spectral standards and models indicate a possible overabundance in He. This would open the possibility to link the behaviour of BD+53 279 to the He-rich class of stars. c) UV spectra shows an abnormally slow and dense wind for an O9 star. Furthermore, spectral classification in this wavelength region indicates a supergiant nature of the source, in contradiction with the optical classification. d) The presence of an intense magnetic field is under investigation. BD+53 2790 stands as a perfect laboratory for testing stellar structure, as well as wind and evolutionary theories. The observable properties of this source in a wide range of spectral bands are discussed, and some interpretations outlined.

P5.2 Cyg OB2 Unveiled: A Search for Astrometric Companions to the Most Massive Stars

Caballero-Nieves, S.M., Gies, D.R., Baines, E.K., Roberts, L.C., Turner, N.H.

We present results from a high angular resolution survey of the most massive stars in the nearby Cygnus OB2 association. Using the NIRI instrument and ALTAIR AO system on Gemini North, we obtained J, H and K band observations of 75 O and B association members to search for astrometric companions. This search is sensitive to companions in the separation range of 0.08 - 10 arcsec with a magnitude difference less than 11 mag. Using Hubble's Fine Guidance Sensors, we observed 57 of our targets in the optical to search for companions between 0.08 – 1 arcsec with differential magnitudes less than 3 mag. The detected sample begins to fill in the period gap between astrometric and spectroscopic binaries. We discuss the preliminary detections, color information and binary frequency properties.

P5.3 On the origin of the X-ray emission excess in the O8V star Tr16-22. A multi-band study

J. A. Combi, J. F. Albacete-Colombo, P.L. Luque-Escamilla, J. Martí, J. Lopez Santiago, E. Sánchez-Ayaso, P. Benaglia, R. Gamen, G.E. Romero, A.J. Muñoz-Arjonilla, J.R. Sánchez-Sutil.

We report preliminary results of a multi-wavelength (Radio—Optical—X-ray) study of the massive star Tr16-22 in the Carina Nebula (NGC 3372). Tr16-22 has historically shown a large excess (log L_X/L_{bol} < -6 or even larger) beyond the scatter of this relationship. We search for non-thermal radio emission and use optical low-resolution spectroscopy (for a time baseline of a couple of years) to investigate the origin of the emission excess detected by XMM-*Newton*. The detection of long term X-ray variability indicates Tr16-22 may be a binary system. All these results suggest that the X-ray emission is probably produced by colliding wind shocks.

P5.4 First results on the optical campaign devoted to the gamma-ray binary candidate HD259440

M. De Becker, M.V. McSwain, C. Aragona

Quite recently, a very high-energy gamma-ray source has been detected in the Monoceros region. This source belongs to the category of TeV emitters with no identified counterpart at other wavelengths, even though it may be coincident with other high-energy sources detected with other observatories (ROSAT, CGRO). However, it is interesting to note that the error box of this TeV source admits the possibility that the Be star HD259440 is at the origin of the high-energy emission. This may be possible only if that Be star is member of a still undetected binary system including a compact (neutron star or black hole) companion, therefore belonging to the very scarce category of gamma-ray binaries. We describe here the first results of the optical campaign devoted to HD259440, with emphasis on the investigation of its multiplicity, using spectra obtained at the Observatoire de Haute-Provence (OHP) and at the Kitt Peak National Observatory (KPNO).

P5.5 The XMM-Newton view of the X-ray spectrum of WR140 across periastron passage

M. De Becker, J.M. Pittard, P.M. Williams

An XMM-Newton campaign dedicated to the study of the X-ray emission of the colliding wind massive binary WR140 across its 2009 periastron passage has been undertaken. The high quality EPIC spectra revealed a strong phase-locked variability both in flux and in spectral shape. The observed variations are consistently explained by the varying emission measure of the emitting plasma along the eccentric orbit, and by the changing absorption column density along the line of sight. Our results are first interpreted in the context of simple multi-temperature thermal emission models, and prospects for more sophisticated modelling are discussed.

P5.6 The orbit of WR 140 from high-resolution radio observations

Sean M. Dougherty, Vicki Trenton and Tony Beasley

The WR+O star binary system is the archetype massive star colliding-wind system, with many observations spanning all wavelengths and the complete 7.9-yr orbit over a number of cycles. In 2005, Dougherty et al. used 21 epochs of VLBA observations to deduce the orbit parameters, and most importantly constraining for the inclination to the orbital plane, leading to a distance estimate. Continued observations with the VLBA during the last orbit provide 16 epochs of high quality images throughout a larger range of orbital phases. We will describe these new observations and the refinement in the orbital parameters that have ramifications on other deduced properties of the system.

P5.7 Multiplicity in 5 M_{sun} Stars

Nancy Remage Evans

Multiwavelength opportunities have provided important new insights into binary/multiple properties of 5 M_{sun} stars. The combination of cool evolved primaries and hot secondaries in Cepheids (geriatric B stars) have yielded detailed information about the distribution of mass ratios.

They have also provided a surprisingly high fraction of triple systems. Ground-based radial orbits combined with satellite data from Hubble, FUSE, IUE, and Chandra can provide full information about the systems, including the masses. In particular, X-ray observations can identify low mass companions which are young enough to be physical companions. This provides important tests for star formation scenarios including differences between high and low mass results and differences between close and wide binaries. *(Funding for this work was provided by Chandra X-ray Center NASA Contract NAS8-39073.)*

P5.8 Spectroscopic follow-up of the colliding wind binary WR140 during its last periastron passage

Rémi Fahed

We present here the results from the spectroscopic follow-up of WR140 during its last periastron passage in January 2009. This object is known as the archetype of colliding-wind binaries and has a relatively large period (~8 years) and eccentricity (~0.89). We provide updated values for the orbital parameters of the system and new insights on the shock cone geometry and physics.

P5.9 An X-ray study of the high-mass colliding-wind binary V444 Cygni

Thomas Fauchez, Michaël De Becker, Yaël Nazé

We present our investigation of the XMM-Newton monitoring on the short period eclipsing binary V444 Cyg. The six observations spread over half a period reveal significant variations in flux that seem to be phase-locked. The analysis of the X-ray spectra point towards a thermal origin for the hot plasma, with a significant excess in the nitrogen abundance, in agreement with the WN type of the primary.

P5.10 A Combined Spectroscopic and Interferometric Orbit for HD 193322

D. Gies, T. ten Brummelaar, B. Mason, D. O'Brien, G. Schaefer, C. Farrington, N. Turner

The star HD 193322 is a remarkable multiple system that lies at the heart of the cluster Collinder 419. Here we report on a new spectroscopic orbit for the central binary (P = 312 d) based on spectra collected over the last few years. We have also obtained long baseline interferometry of the target in the K-band with the CHARA Array, and the fringe packet from the nearby speckle companion was used to calibrate the visibility of the fringes of the central binary. We performed an analysis of the fringe visibilities from many epochs, position angles, and baselines to obtain an astrometric orbit for the binary. We discuss the mass and distance properties of the binary from the combined spectroscopic and astrometric results.

P5.11 The X-ray emission of the WR+O binary WR79

Gosset E., Sana H., Rauw G., Nazé Y.

In the framework of our multiwavelength study of the open cluster NGC6231, we observed the colliding-wind WR+O binary WR79 at six different epochs with the XMM-Newton observatory. These pointings offer the possibility to study the X-ray spectrum of WR79 and its possible variability. Our results are discussed and compared to the X-ray characteristics of other similar objects.

P5.12 New hard X-ray observations of EtaCarinae, and steadiness close to periastron

J.-C. Leyder, R. Walter, G. Rauw

The colliding-wind binary Eta Carinae exhibits a soft X-ray thermal emission that varies strongly around the periastron passage. It has been recently shown to have a non-thermal emission, thanks to its detection in hard X-rays using INTEGRAL and Suzaku, and also in gamma-rays with AGILE and Fermi. To expand the knowledge of the physical processes governing the X-ray lightcurve, we studied new hard X-ray images of Eta Carinae obtained with INTEGRAL at periastron, and compared them to previous observations far from periastron. We will show that the hard X-ray emission can be very firmly associated with Eta Carinae, as no other source detected in the 5-10 keV energy range within the ISGRI error circle is able to explain that emission. Close to periastron passage, we obtained a 3-sigma detection for the hard X-ray emission of Eta Carinae, with a flux similar to the average value far from periastron. This 3-sigma detection can be explained with a hydrogen column density not exceeding NH < 6E23 cm^{-2} without resorting to an intrinsic increase of the hard X-ray emission. The energy injected in hard X-rays (averaged over a month timescale) appears rather constant at least as close as a few stellar radius, well within the acceleration region of the wind.

P5.13 Spectropolarimetry of Beta Lyrae

Jamie R. Lomax, Dr. Jennifer L. Hoffman

Beta Lyrae is an eclipsing, semi-detached binary system whose state of active mass transfer can reveal details of the nonconservative evolution of binary stars. Roche lobe overflow has caused the system to evolve to a complex state. A thick accretion disk almost completely obscures the secondary, mass-gaining star while the rapid mass transfer likely drives mass-loss through the system's bipolar outflows. Polarimetry can provide important information about the physical structure of complex systems; in fact, the discovery of bipolar outflows in beta Lyrae was confirmed through polarimetry. Here we present 6 years of new and recalibrated spectropolarimetric data taken with the University of Wisconsin's Half-Wave Spectropolarimeter (HPOL). We discuss their implications for our current understanding of the system's disk-jet geometry. Using both broad band and line polarization analysis techniques, this data set can reveal new information about the structure of the disk, the presence and location of a hot spot, and the distribution of hot line-emitting gas.

P5.14 Constraining the Properties of the Eta Carinae System via 3D SPH Models of Ground- and Space-Based Observations

Thomas Madura, Stan Owocki, Theodore Gull, Atsuo Okazaki, Christopher Russell

We present recent work using three-dimensional (3D) Smoothed Particle Hydrodynamics (SPH) simulations to model the high ([Fe III], [Ar III], [Ne III] and [S III]) ionization forbidden emission lines observed in Eta Carinae using the HST/STIS and the periodic 'eclipse-like' events seen in ground-based photometric observations of Eta Car across multiple wavelengths. The forbidden line structures are interpreted as the time-averaged, outer extensions of the primary wind and the wind-wind interaction region directly excited by the FUV of the hot companion star. The photometric eclipse-like events are thought to be due to a 'Bore-Hole' effect, wherein the fast wind from the secondary carves a cavity in the dense primary wind, allowing increased escape of radiation from the hotter/deeper layers of the primary's extended photosphere. We discuss how analyzing the results of the 3D SPH simulations and synthetic observational diagnostics helps us

determine the absolute orientation of the binary orbit and helps remove the degeneracy inherent to models based solely on the observed RXTE X-ray light curve. Such models also provide insights on how/where light is escaping the system and the directional illumination of distant material.

P5.15 High-Mass X-ray Binaries in the NIR: Orbital solutions of two highly obscured systems.

A.B.Mason, A.J.Norton,J.S. Clark, I.Negueruela and P.Roche

I present NIR spectroscopy obtained using the VLT and ISAAC of two eclipsing X-ray pulsars, OAO 1657-415 and EXO 1722-363. Both of the high-mass donor stars in these systems have only recently been discovered, due to their high levels of extinction. I will initially discuss our work in spectrally classifying the two donor stars. The donor in the EXO 1722 system was found to be atypical of this class of HMXB. The donor within OAO 1657 was found to be a more evolved Ofpe/WN9 star. These results throw light on the unusual position of OAO 1657-415 in the Corbet diagram. We will also present NLTE atmosphere modelling of OAO 1657-415 using the radiative transfer code CMFGEN, which we have used to confirm the stellar parameters obtained from dynamical measurements. We have constructed radial velocity curves for both of these systems, and I will present orbital solutions and the first NS mass determinations made utilising NIR spectroscopy for each system.

P5.16 Thermal Radio Emission from a Radiative-shock in Colliding Stellar Winds

G. Montes, R. Gonzalez, M.A. Perez-Torres, and A. Alberdi

Radio observations of stellar winds from hot massive stars show spectral indices with values up to ~1, in contrast with the 0.6 expected for the thermal emission from smooth winds. For binary systems, a wind-wind colliding region (WCR) is expected to contribute to the emission (being thermal and/or non-thermal). In close systems, the non-thermal emission is expected to be absorbed and its radio spectrum is thought to be composed only by the stellar wind. However, theoretical studies suggest that a radiative WCR could be able to dominate the thermal spectrum from centimeter wavelengths, showing a steep spectral index and an excess of emission at millimeter wavelengths. We present a semi-analytic model for the thermal radio emission of a radiative shock with a thin shell approximation. This models allow us to determine the influence of this structure to the total thermal emission for close colliding wind binaries. We analyze the dependence of this influence with binary and stellar wind parameters.

P5.17 A first orbital solution for the non-thermal radio emitter Cyg OB2 #9

Nazé Y., Damerdji Y., Rauw G., Kiminki D.C., Mahy L., Kobulnicky H.A., Morel T., De Becker M., Eenens P., Barbieri C.

We reported in 2008 the first detection of the binary nature of Cyg OB2 #9. Since then, we have continued our spectroscopic monitoring of this object, doubling the number of available spectra of the star while covering a second periastron passage. Using a variety of techniques, the radial velocities could be estimated and a first, preliminary orbital solution was derived. The mass ratio appears close to unity and the eccentricity is large, 0.7-0.75.

P5.18 Observational approach to the chemical evolution of high-mass close binaries

K. Pavlovski, J. Southworth, E. Tamajo, & V. Kolbas

The complexity of composite spectra of close binaries makes the study of the individual

component spectra extremely difficult. For this reason there exists very little information on the chemical composition of high-mass stars in close binaries, despite the importance of this for understanding the evolution of massive stars and of close binary systems. A way round this problem exists: spectral disentangling allows a time-series of composite spectra to be decomposed into their individual components whilst preserving the total signal to noise ratio in the input spectra. Here we present the results of our ongoing project to obtain the atmospheric parameters of high-mass components in binary and multiple systems using spectral disentangling.
So far, we have performed detailed abundance studies for 14 stars in eight eclipsing binary systems. Of these, V380 Cyg and V453 Cyg are the most informative as their primary components are evolved either close to or beyond the TAMS. Contrary to theoretical predictions of rotational evolutionary models for single stars, both of these stars do not show any abundance changes relative to unevolved main sequence stars of the same mass. It is obvious that other effects are important in the chemical evolution of components in binary stars. Analyses are ongoing for further systems, including AH Cep, Y Cyg, CW Cep and V478 Cyg.

P5.19 The resonant phase lock riddle of the B0II+B0II binary BI108

Rivinius Th., Mennickent R., Kolaczkowski Z.

We have investigated the binary BI108 in the LMC. In OGLE and MACHO data the star shows a 10.73 d photometric period, that can be deconvolved into two sub-periods of 3.577 and 5.66 d, remaining resonantly phase-locked in a 3:2 ratio over the entire observing period, i.e. years. Both lightcurves can be classified as ellipsoidal, the shorter one being stronger and clearly double wave, the longer one weaker and, if taken as 5.66 d, with identical half-waves. However, a spectroscopic investigation with UVES at the VLT has shown that only the longer sub-period is due to a binary system with a circular orbit and almost equal mass and in the same evolutionary stage, being both very early B supergiants (B0 II+B0 II). No circumstellar gas is detected. The shorter sub-period only modulates the line strengths of both components, but not their radial velocity. The physical process behind the shorter period remains unknown, but that the photospheric deepest minima coincide with each other speaks against an orbital-rotational mechanism, while the line strenght modulation speaks in favor.

P5.20 X-Ray Modeling of Eta Carinae and WR140 from Hydrodynamic Simulations

Russell, C.M.P., Corcoran, M.F., Okazaki, A.T., Madura, T.I., Owocki, S.P.

The colliding wind binary (CWB) systems Eta Carinae and WR140 provide unique laboratories for X-ray astrophysics. Their wind-wind collisions produce hard X-rays that have been monitored extensively by several X-ray telescopes, such as RXTE and Chandra. To interpret these X-ray light curves and spectra, we apply 3D hydrodynamic simulations of the wind-wind collision using smoothed particle hydrodynamics (SPH). We find adiabatic simulations that account for the Absorption of X-rays from an assumed point source of X-ray emission at the apex of the wind-collision shock cone can closely match the RXTE light curves of both Eta Carinae and WR140. This point-source model can also explain the early recovery of Eta Carinae's X-ray light curve from the 2009.0 minimum by a factor of 2-4 reduction in the mass loss rate of Eta Carinae. Improving upon this model, an extended X-ray emission source has been fairly successful in reproducing WR140's RXTE light curve, while a hot, post-periastron bubble blown into Eta Carinae's wind via its companion prevents the same success.

P5.21 The variable X-ray spectrum of the Wolf-Rayet binary WR140 with Suzaku

Y. Sugawara, Y. Maeda, Y. Tsuboi, K. Hamaguchi, M. Corcoran, A. Pollock, A. Moffat, P.

Williams, S. Dougherty, J. Pittard

We report the results of the Suzaku observations of the W-R binary WR 140 (WC7+O5I). We executed the observations at four different epochs around periastron passage in Jan. 2009 to understand the W-R stellar wind as well as the wind-wind collision shocks. The total exposure was 210 ksec. We detected hard X-ray excess in the HXD band (> 10 keV) for the first time from a W-R binary. Another notable discovery was a soft component which is not absorbed even by the dense wind. The spectra can be fitted by three different components; one is for the stationary cool component with kT~0.1 keV, one for a dominant high temperature component with kT ~3 keV, and one for the hardest power-low component with Γ~ 1. The column density at periastron is 30 times higher than that at pre-periastron, which can be explained as self-absorption by the W-R wind. The emission measure of the dominant, high temperature component is not inversely proportional to the distance between the two stars.

P5.22 The most massive eclipsing binary with apsidal motion

Vilardell, F.; Ribas, I.; Jordi, C.; Tsodikovich, Y.; Mazeh, T.; Guinan, E.F.; Fitzpatrick, E.L.

Eclipsing binaries (EB) are powerful tools to determine the fundamental properties of massive stars (masses, radii, temperatures, etc). Specially valuable are those systems displaying apsidal motion, since they can be used to test general relativity or the internal distribution of matter. In the current work, we are presenting the fundamental properties of a detached and eccentric EB in M31 (M31V J00442326+4127082). The analysis of the obtained light and radial velocity curves, revealed an EB system composed by two very massive stars (with masses over 40 M_{sun}), with an important contribution for a tertiary component. In addition, the combination of the DIRECT photometry with our obtained data allowed the detection of an apsidal motion of ω dot=2.4±1.0 deg year^{-1}. This EB is, therefore, the most massive EB system with measured apsidal motion ever reported. Although further observations are required to confirm this scenario, the deformation of the components (dependent on the internal structure of the stars) seems to be the most likely explanation. However, the observed apsidal motion rate is discrepant (at the 2σ level) with current stellar interior models (ω dot=5.4±0.8 deg year^{-1}). Similar results have also been obtained for other B-type EBs (e.g., V380 Cyg), where stellar interior models for massive stars predict cores that are too small when compared with observations. Therefore, additional observations of the EB presented here could be used to test the internal structure of very massive stars.

P5.23 Modelling the synchrotron emission from O-star colliding wind binaries

D. Volpi

The binary OB stars are often observed to be non-thermal radio emitters. The non-thermal radiation is thought to be synchrotron emission produced by electrons accelerated up to relativistic energies by strong shocks. These strong shocks are produced by the interaction between the radiatively-driven winds from the primary and the secondary. The synchrotron radiation can be used to constrain the various parameters of the system, including some which are difficult to estimate, such as the mass loss rates from both components. In order to understand the physics of this non-thermal emission and to constrain the parameters we continued the development of a numerical model. This model calculates the particle acceleration at the shocks and follows the emitting electrons along the post-shock streamlines, while they are being cooled by Inverse Compton and adiabatic energy losses. We thus obtain the total (free-free plus synchrotron) radio flux and the spectral index at different orbital phases. We apply this model to Cyg OB 2 No 9. As the details of this binary are not well known, we need to explore the parameter space, comparing the theoretical Results with the corresponding observations. We present the first results of this modelling and we show how it constrains the stellar, orbital, and wind parameters of the system.

P5.24 VLTI/AMBER spectro-interferometric monitoring of the LBV η Carinae: Changes of the wind-wind interaction region across the 2009.0 spectroscopic event

G. Weigelt, J.H. Groh, K.-H. Hofmann, S. Kraus, D. Schertl, and the AMBER consortium

VLTI/AMBER spectro-interferometric observations of η Car allow us to study the aspherical primary wind and the wind-wind interaction region of the putative binary. Our previous observations resolved η Car's dense stellar wind region with high spatial resolution of 4 mas and high spectral resolution of R=12000 (Weigelt et al. 2007). These observations enabled us to investigate η Car's winds within the spectrally resolved Brγ 2.16 µm and HeI 2.06µm emission lines and to compare the observations with the available models. η Car's 2009.0 spectroscopic event provided a unique opportunity to study changes of η Car's winds, when the companion presumably dived deeply into the primary's dense wind during periastron passage. The goals of our new VLTI/AMBER observations in 2009 with spectral resolution of 12000 were to study changes of the wavelength-dependent shape of η Car's primary wind and wind-wind interaction region across the 2009.0 spectroscopic event. The VLTI/AMBER observations show, for example, that the size of the Brγ2.16 µm emitting primary wind region was almost the same during our event observations (2009 Jan 1-8) and before the event (March 2008). However, the size of the HeI 2.06µm emitting region collapsed from 17 mas (continuum-subtracted 50% encircled energy diameter) in March 2008 to less than 5 mas during the event. Therefore, we found strong evidence for the collapse of the HeI wind-wind interaction zone during periastron passage.