SESSION I: Atmospheres of Massive Stars

Pulsational Seeding of Structure in a Line-Driven Stellar Wind

Nurdan Anilmis & Stan Owocki (University of Delaware)

Massive stars often exhibit signatures of radial or non-radial pulsation, and in principal these can play a key role in seeding structure in their radiatively driven stellar wind. We have been carrying out time-dependent hydrodynamical simulations of such winds with time-variable surface brightness and lower boundary conditions that are intended to mimic the forms expected from stellar pulsation. We present sample results for a strong radial pulsation, using also an SEI (Sobolev with Exact Integration) line-transfer code to derive characteristic line-profile signatures of the resulting wind structure. Future work will compare these with observed signatures in a variety of specific stars known to be radial and non-radial pulsators.

Wind and Photospheric Variability in Late-B Supergiants

Matt Austin (University College London), Nevyana Markova (National Astronomical Observatory, Bulgaria) & Raman Prinja (University College London)

There is currently a growing realisation that the time-variable properties of massive stars can have a fundamental influence in the determination of key parameters. Specifically, the fact that the winds may be highly clumped and structured can lead to significant downward revision in the mass-loss rates of OB stars. While wind clumping is generally well studied in O-type stars, it is by contrast poorly understood in B stars.

In this study we present the analysis of optical data of the B8 Iae star HD 199478. Data collected primarily from the Bulgarian NAO 2 m telescope is used to probe the temporal behaviour of the Hα line, and any potential connections to deep-seated photospheric changes. Of some interest is a rare "high velocity absorption" episode that was monitored during 2000. The role of pulsations and ordered magnetic fields are discussed in understanding the Hα changes.

Modeling Ultraviolet Wind Line Variability in Massive Hot Stars

Ronny Blomme & Alex Lobel (Royal Observatory of Belgium)

We model the detailed time-evolution of Discrete Absorption Components (DACs) observed in P Cygni profiles of the fast-rotating supergiant HD 64760 (B0.5 Ib). We assume that the DACs are caused by co-rotating interaction regions (CIRs) in the stellar wind. We use the Zeus3D code to calculate hydrodynamic models of these CIRs (limited to the equatorial plane). Our model assumes that the CIRs are due to "spots" on the stellar surface. We then perform 3-D radiative transfer to calculate the resulting DACs in the Si IV ultraviolet resonance line.

Our best-fit model for HD 64760 consists of two spots of unequal brightness and size on opposite sides of the equator. The additional mass-loss rate due to these spots is less than 1% of the smooth-wind mass-loss rate. The recurrence time of the observed DACs compared to the estimated rotational period shows that the spots move 5 times slower than the rotational velocity. This strongly suggests that the "spots" are due to a beat pattern of non-radial oscillations. The fact that DACs are observed in a large number

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of hot stars constrains the amount of clumping that can be present in their winds, as substantial amounts of clumping would tend to destroy the CIRs.

Clumping and Rotation in ζ Puppis

Jean-Claude Bouret (Laboratoire d'Astrophysique de Marseille), John D. Hillier (University of Pittsburgh) & Thierry Lanz (University of Maryland)

We have analyzed the spectrum of the Galactic O4 supergiant, ζ Puppis, with a special emphasis on its clumping and rotation properties. The wind has been modeled using the NLTE code CMFGEN. Synthetic spectra have been computed with a code recently developed for CMFGEN to compute synthetic spectra in two-dimensional geometry allowing for the effects of rotation. As already showed in recent studies, introducing clumping deep in the wind improves the agreement to FUV/UV lines compared to homogeneous models. The fit to Hα is also improved but requires that clumping starts at larger distances in the wind. We demonstrate that it is possible to have clumping occur close to the star while still achieving an excellent fit to Hα by consistently treating the wind's rotation in the spectral modeling. An excellent agreement to other important optical lines such as HeII 4686 Å and NIII 4634–4640 Å is also obtained for the first time.

First Estimation of the Rotation Rates of Wolf-Rayet Stars

André-Nicolas Chené (Herzberg Institute of Astrophysics-Canadian Gemini Office) & Nicole St-Louis (Université de Montréal)

See p. 139 for full article.

Shock Variations in η Carinae

Michael Corcoran, Kenji Hamaguchi (Center for Research and Exploration in Space Science & Technology, University of Maryland/Universities Space Research Association/Goddard Space Flight Center), David Henley (University of Georgia), *et al.*

η Carinae is a binary system composed of an extremely massive luminous blue variable star and a bright companion. Thermal X-ray emission generated where the wind from η Car collides with the companion's wind provides unique diagnostics of the mass loss phenomena in both stars. We use variations in resolved X-ray emission lines from HETGS spectra taken around the orbit and concentrating on the approach to periastron passage to constrain the wind-wind interaction, the flow of hot gas along the colliding wind boundary, and the orbital elements of the system.

Propagating Waves in Hot-Star Winds: Leakage of Long-Period Pulsations

Steven R. Cranmer (Harvard-Smithsonian Center for Astrophysics)

Massive stars have strong stellar winds that exhibit variability on timescales ranging from hours to years. Many classes of these stars are also seen, via photometric or line-profile variability, to pulsate radially or non-radially. It has been suspected for some time that these oscillations can induce periodic modulations in the surrounding stellar wind and produce observational signatures in line profiles or clumping effects in other diagnostics. The goal of this work is to investigate the detailed response of a line-driven wind to a given photospheric pulsation mode and amplitude. We ignore the short-wavelength radiative instability and utilize the Sobolev approximation, but we use a complete form of the momentum equation with finite-disk irradiation and finite gas pressure effects.

For large-scale perturbations appropriate for the Sobolev approximation, though, the standard WKB theory of stable "Abbott waves" is found to be inapplicable. The long periods corresponding to stellar pulsation modes (hours to days) excite wavelengths in the stellar wind that are large compared with the macroscopic scale heights. Thus, both non-WKB analytic techniques and numerical simulations are employed to study the evolution of fluctuations in the accelerating stellar wind. This progress report describes models computed with one-dimensional (radial) isothermal motions only. However, even this simple case produces a quite surprising complexity in the phases and amplitudes of velocity and density, as well as in the distribution of outward and inward propagating waves throughout the wind.

Empirical Calibration of Mid-IR Fine Structure Lines Based on O Stars

P.A. Crowther, J.P. Furness (University of Sheffield) & P.W. Morris (IPAC)

We present mid-IR Spitzer IRS spectroscopy, plus VLT ISAAC H- and K-band spectroscopy of O stars identified by Blum *et al.* (2001) within the W31 cluster. We provide an empirical calibration of [NeII/III] and [SIII/IV] fine-structure lines versus effective temperature for early- to mid-O stars, as derived from spectroscopic near-IR analysis. Comparisons with photoionization models are presented, suggesting a discrepancy between empirical and predicted mid-IR line ratios, as previously identified by Morisset *et al.* (2004). We also discuss the embedded timescales for high-mass stars, since W31 hosts O stars, massive young stellar objects, and UCHII regions.

Rotating Radiation Driven Winds of Massive Stars

M. Curé (Departamento de Física y Astronomía, Universidad de Valparaíso, Chile), L. Cidale & R. Venero (Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, Argentina)

Radiation driven wind theory, taking into account the centrifugal force due to the stellar rotation, has been re-examined. For rotational speeds above about 75% of the critical velocity, the wind solution can switch to an alternative mode (slow solution), characterized by a much slower outward acceleration. Together with a moderately enhanced mass flux, the resulting lower speed outflow then implies a substantial enhancement in density, relative to the standard (or fast) solution. We present different applications of these slow solutions, that may explain wind features, as the outflowing disk from B[e] supergiants and the winds of A supergiants and its influence in the wind momentum luminosity (WML) relationship.

A Multispectral View of the Periodic Events in η Carinae

Augusto Damineli (Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Universidade de São Paulo)

We present a multi-spectral analysis, ranging from X-rays to radio, of the 5.5-yr events in η Carinae. We show that the events are bimodal, composed by a short duration core that hides an eclipse and by a "main body" that encompasses the whole cycle, due to the immersion of the secondary star in the wind of the primary. We show anti-correlated radial velocity curves, giving indications of the orbital parameters. We make predictions to be tested in a monitoring campaign to cover the 2009 event.

η Carinae: The Central Counter-Paradigm for Very Massive Stars

Kris Davidson (University of Minnesota)

η Car is the only star above 120 $M_\odot$ that has been observed in great detail; it is the most accessible supernova impostor; and it has repeatedly exposed gaps and errors in existing theory. Two high-priority questions will be featured here. The first concerns η Car's 5.5-year spectroscopic cycle. Intensive HST spectroscopy indicates that each recurring "spectroscopic event" is a disruption in the latitude-dependent wind, probably triggered by a companion star's periastron approach. This indicates a surface instability that was not predicted and is stronger than one would normally have expected based on tidal and radiative effects. The hypothetical companion object continuously alters the primary star's surface parameters, revealing information that would otherwise have been hidden. HST data 1991–2007 also show that η Car recently accelerated its secular rate of change. This presumably involves the thermal/rotational recovery process following the supernova impostor event seen 160 years ago. Major variations in the recovery rate convey unique clues to the interior structure.

For almost 30 years we have recognized that very luminous stars can lose mass chiefly in eruptions rather than steady winds. Some theorists assume that this is metallicity-dependent, but the contrary has not been disproven. Thus it is premature to say that Pop III stars are immune to LBV-like eruptions.

Colliding-Wind Binaries As Non-Thermal X-ray Emitters: An Observational Investigation from XMM-Newton to Next Generation X-Ray Observatories

Michaël De Becker (Institut d'Astrophysique et Géophysique, Université de Liège)

The investigation of massive stars in the radio domain revealed about 25 years ago that some of them are synchrotron emitters, showing that these objects are able to accelerate particles up to relativistic velocities. In this context, non-thermal emission processes such as inverse Compton scattering are expected to be at work in the high-energy domain. For this reason, an observational campaign devoted to the X-ray investigation of non-thermal radio emitters has been carried out with XMM-Newton. However, considering the rather strong thermal X-ray emission from these systems below 10 keV, XMM-Newton does not appear to be the ideal observatory to detect their putative non-thermal X-rays. As a consequence, the advent of next generation X-ray observatories with a bandpass extending significantly above 10 keV (SIMBOL-X, XEUS, or NEXT) is expected to provide important results related to the non-thermal high-energy emission from colliding-wind binaries and their capability to accelerate particles.

Magnetic Fields in Wolf-Rayet Stars

Antoine de la Chevrotière, Nicole St-Louis & Anthony F. J. Moffat (Université de Montréal)

Independently of the possibility of internally generated fields, there are good reasons to believe that massive stars actually harbour significant magnetic fields of fossil origin. As the ISM itself possesses organized, large-scale magnetic fields, it is unavoidable because of magnetic flux conservation and flux freezing, that stars that result from cloud collapse have a magnetic field, at least at first. Magnetic fields have been observed and measured in a variety of hot stars, now including O stars. Furthermore, neutron stars (NS), the descendants of many massive stars including Wolf-Rayet stars (WR), display large magnetic fields. In the case of core He-burning WR stars, the hydrostatic core radii (R_*)

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are typically an order of magnitude smaller than those of their O progenitors, so the NS-extrapolated surface magnetic fields in WR stars could be ∼100 times higher than in O stars, i.e. $B \sim 200$–2000 G. However, the strong WR winds only allow us to see emission lines down to $\sim 4R_*$, where the magnetic fields vary as R^{-2} and will thus be smaller than at the hydrostatic core, assuming the likely scenario of a split monopole to best simulate the fields, pulled radially outward by the strong flows. This implies fields of ∼10–100 G expected in the inner observable parts of WR winds. The Zeeman effect is the most direct way to measure the strength of magnetic fields as more observations are needed.

Are WC9 as Violent as WN8?

Remi Fahed, Anthony F. J. Moffat (Université de Montréal) & Alceste Z. Bonanos (Carnegie Institution of Washington)

Do some WR stars owe their strong winds to something else besides radiation pressure? The answer to this question is still not obvious, especially in certain subclasses, mainly WN8 and WC9. Both of these types of WR stars are known to be highly variable, possibly due to pulsations. However, only the WN8 stars have so far been vigorously and systematically investigated for variability. We present here some preliminary results of a systematic survey during 3 consecutive weeks in 2007 June at Las Campanas Observatory, Chile, of 20 Galactic WC9 stars for photometric variability in two optical bands, V and I. Of particular interest are the variations in colour index in the context of carbon dust formation, which occurs frequently in WC9 stars.

Weak Winds in Orion?

Miriam Garcia, Artemio Herrero (Instituto de Astrofísica de Canarias, ULL) & Sergio Simón-Díaz (Observatoire de Genève)

The theory of radiatively driven winds apparently fails to predict the wind momentum of low luminosity ($\log L/L_\odot < 5.2$) early-type stars from metal poor environments like the SMC, but there are also some Galactic cases. The reason of this alleged theoretical breakdown is still unknown. While it may hint a metallicity-dependent threshold luminosity to initiate the wind, it may also relate to age, the discrepant objects being too young to have turned it on.

Starting from previous quantitative analyses of their optical spectra, we study the ultraviolet spectra of a sample of OB-type stars in Orion, to constrain their wind terminal velocity and mass-loss rate. Orion is a young star-forming region; thus our results will contribute to ascertain whether there is a “weak wind-young object” connection.

Analytical Wide and Thin Colliding-Wind Bow-Shock Asymptotics

Kenneth Gayley (University of Iowa), Stan Owocki (University of Delaware) & Peter Tuthill (University of Sydney)

Bow shocks from colliding winds and runaway hot stars are typically either modeled with detailed numerical simulations, or are approximated analytically in the thin-shell approximation. The latter allows for an elegant analytical treatment based on momentum conservation, but requires rapid radiative cooling to be valid. Many types of wind collisions yield low enough densities, high enough temperatures, or rapid enough flow times that the response is expected to be largely adiabatic. The shock heating and wind re-acceleration makes for a potentially wide interaction region. This poster considers simplifying assumptions that allow an analytic determination of the bow-shock angle far from the star, and argues that adiabaticity can significantly widen a bow shock only when the winds are fairly equal. However, adiabaticity may strongly constrain the fraction of a wind that avoids being asymptotically embroiled in the interaction zone.

Time-Dependent Effects in the Wind of Luminous Blue Variables

Jose H. Groh (Max-Planck-Institut für Radioastronomie), D. John Hillier (University of Pittsburgh) & Augusto Damineli (University of São Paulo)

LBVs are characterized by strong photometric and spectroscopic variability on timescales from days to decades, arising from changes in stellar and wind parameters. Therefore, the common assumption of a steady-state outflow is invalid for LBVs. We present a newly developed method to include the effects of time variability in the radiative transfer code CMFGEN. We show how time-dependent effects significantly change the velocity law and density structure of the wind, affecting the derivation of the mass-loss rate, volume filling factor, wind terminal velocity, and luminosity. We quantitatively show that striking features seen in the spectrum of LBVs are due to time variability, such as the presence of multiple absorption components in Fe II and Balmer lines, and high-velocity absorption in the UV resonance lines. The results of this work are directly applicable to all active LBVs, such as AG Car, S Dor, R 127, and HD5980, and can result in a revision of their stellar and wind parameters.

Ejecta of η Carinae: Clues to Mass Ejection

Theodore R. Gull (Goddard Space Flight Center)

We have used the spatially resolved spectra of HST/STIS and VLT/UVES to gain insight on the structure of the current extended interacting binary wind and the material ejected in the 1840s and 1890s. Much has been learned about the very N-rich, O- and C-poor ejecta, the abundant metals not ordinarily seen in the ISM (for example, V, Sr, Sc, Ti) and some molecules that formed. The dust is very peculiar, likely formed of SiO, AlO, and metal complexes (such as TiN, TiC, FeN). Abundances of these metals and the chemistry in N-rich, O- and C-starved gas will be discussed.

Time-Resolved FUSE Observations of the Mysterious WR46

Vincent Hénault-Brunet, Nicole St-Louis (Université de Montréal), Sergey V. Marchenko (Western Kentucky University), *et al.*

The Wolf-Rayet star WR46 (of spectral type WN3p) is known to exhibit a very complex variability pattern on relatively short timescales of a few hours. Eight-hour periodic radial velocity variations in the highest ionization lines have been found but seem to intermittently disappear. In addition, multiple photometric periods have been claimed by various authors. Nonradial oscillations of the Wolf-Rayet star or the presence of a yet-to-be-confirmed compact companion have been proposed to explain the observed short-term behavior, but the true nature of this system is still a mystery. In an effort to better constrain the above scenarios, we present time-resolved *FUSE* observations of WR46 extending over approximately 50 hours and covering several variability cycles. A TVS analysis performed on our time series of spectra confirms a significant variability in the blue wing of the absorption trough of the shock-sensitive O VI doublet (1032,1038 Å) P Cygni profile. We also obtain the far-UV continuum light curve and find a dominant photometric period close to 8 hours. The blue wing of the absorption trough of the O VI

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P Cygni profile varies on the same timescale. We discuss the implication of these new results in terms of the different hypotheses for the cause of the short-term variability.

Is WR 104 Really a Face-on Colliding-Wind Binary?

Grant M. Hill (Keck Observatory)

WR 104 is the prototype for a small but growing group of stars that present the remarkably striking appearance of pinwheels. Many of them appear to be nearly face-on spirals. The assumption that these objects are dust producing, low-inclination, colliding-wind binaries has been very successful in modeling the imaging. This assumption remains largely untested by spectroscopy, though.

Confrontation of the colliding-wind binary model with six years of spectroscopy, offering full phase coverage of WR 104, is presented. A number of predictions are examined, and the results imply there is more to these systems than currently understood.

The Magnetic O Star HD191612

Ian Howarth (University College London), Nolan R. Walborn (Space Telescope Science Institute), Danny Lennon (The Isaac Newton Group of Telescopes, La Palma), *et al.*

We present extensive optical spectroscopy of the early-type magnetic star HD 191612 (O6.5f?pe–O8fp). The Balmer and He I lines show strongly variable emission which is highly reproducible on a well-determined 538-d period. Metal lines and He II absorptions (including many selective emission lines but excluding He II λ4686 Å emission) are essentially constant in line strength, but are variable in velocity, establishing a double-lined binary orbit with $P_{\rm orb} = 1542$d, $e = 0.45$. We conduct a model-atmosphere analysis of the spectrum, and find that the system is consistent with a $\sim$O8 giant with a $\sim$B1 main-sequence secondary. Since the periodic 538-d changes are unrelated to orbital motion, rotational modulation of a magnetically constrained plasma is strongly favoured as the most likely underlying 'clock'. An upper limit on the equatorial rotation is consistent with this hypothesis, but is too weak to provide a strong constraint.

A Study of the Peculiar B0 Star θ Carinae.

S. Hubrig (European Southern Observatory), M. Briquet, T. Morel (Universiteit Leuven), *et al.*

Massive stars end their evolution, with a final supernova explosion, as neutron stars or black holes. The initial masses of these stars range from 8–10 $M_\odot$ to 100 $M_\odot$ or more, which corresponds to spectral types earlier than about B2. While magnetic fields in the Sun and solar-like stars have been studied intensively, very little is known about their existence, origin, and role in massive stars. We present the results of our recent study of the magnetic field and abundances in the peculiar B0 star θ Car. This star was already "preselected" as a suitable candidate for a magnetic field study by Walborn (2006, *IAU Joint Discussion*, 4E, 19) because it has a peculiar, variable spectrum both in the optical and UV, a high $L_X/L_{\rm bol}$ ratio, and enhanced nitrogen (Walborn 1976, *ApJ*, 205, 419).

Phase Resolved FUV Spectra of Massive Binaries

Rosina C. Iping (Goddard Space Flight Center & CUA), George Sonneborn (GSFC) & Doug Gies (Georgia State University)

We present FUV observations of massive binary stars in the Galaxy, LMC, and SMC. A large sample of close, massive binaries including detached and semi-detached systems that are at pre- and post-Roche lobe overflow evolutionary stages is presented. The binaries are generally double-line spectroscopic binaries, many are eclipsing systems, with well-determined orbits and periods in the range 1.6–12 days. The FUV spectra are used to determine stellar wind mass-loss rates and terminal velocities from species tracing a range of wind ionization states. Each system was observed more than once to sample different orbital phases and spectral variability. The spectral features are modeled to study photospheric abundances. We searched for evidence for CNO enhancements as the result of mass transfer and measured projected rotational velocities.

The Wind Properties of O-type Stars Constrained with Millimeter Observations

Eric Josselin, Fabrice Martins (GRAAL, Université Montpellier) & Jean-Claude Bouret (Laboratoire d'Astrophysique de Marseille)

Clumping in hot stars winds is currently one of the main questions in massive stars astrophysics. In particular, the variation of clumping with distance is not well constrained. A first step towards a determination of this variation was made by Puls *et al.* (2006, *A&A*, 454, 625). Here, we present millimeter observation of a sample of late-type O supergiants conducted at IRAM aiming at better constraining the clumping behavior in those objects. Complemented by UV-optical-IR data already obtained, these data will probe different parts of the atmospheres and clumping factors in those regions will be analysed with CMFGEN models.

New Massive Stars in Cyg OB2

Daniel C. Kiminki, Henry A. Kobulnicky (University of Wyoming) & M. Virginia McSwain (Lehigh University)

As part of an ongoing study to determine the distribution of orbital parameters for massive binaries in the Cygnus OB2 association, we present the orbital solutions for two new single-lined spectroscopic binaries, MT059 (O8V) & MT258 (O8V), and one double-lined eclipsing binary (Schulte 3). We also constrain the orbital elements of three additional double-lined systems (MT252, MT720, MT771). Periods for all systems range from 1.5–19 days and eccentricities range from 0–0.11. The six new OB binary systems bring the total number of multiple systems within the core region of Cyg OB2 to 11.

Energy Dissipation Variations and Periastron Passage Events

Gloria Koenigsberger, Edmundo Moreno (Universidad Nacional Autonoma de Mexico) & Andrea Avena (UAEM)

Numerous examples are now emerging of binary systems in which activity levels significantly increase around periastron passage. In some cases, the activity is so intense that it is classified as an eruptive event, as in WR 140 and other such systems. This raises the question of how the increasing tidal perturbations at periastron passage and the observational manifestations of stellar activity may be linked. We have constructed a model

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that computes how the tidal shear energy dissipation rates change over the orbital cycle, and in this poster we illustrate the results for particular binary systems. A noteworthy feature of our model is that it predicts maximum dissipation rates after periastron passage, similar to what is observed in many systems where periastron passage events are reported. We speculate that the degree of activity may correlate with the rate of change in the magnitude of the tidal interactions over the orbital cycle and, thus, depends on orbital period and separation, as well as stellar radius and equatorial rotational velocity.

Resonance Scattering in the X-ray Emission-Line Doppler Profiles of ζ Puppis

Maurice A. Leutenegger (Goddard Space Flight Center), Stanley P. Owocki (Bartol Research Institute, University of Delaware), Steven M. Kahn (KIPA/SLAC/Stanford University), *et al.*

We present XMM-Newton Reflection Grating Spectrometer observations of pairs of X-ray emission line profiles from the O star ζ Pup that originate from the same He-like ion. The two profiles in each pair have different shapes and cannot both be consistently fit by models assuming the same wind parameters. We show that the differences in profile shape can be accounted for in a model including the effects of resonance scattering, which affects the resonance line in the pair but not the intercombination line. This implies that resonance scattering is also important in single resonance lines, where its effect is difficult to distinguish from a low effective continuum optical depth in the wind. Thus, resonance scattering may help reconcile X-ray line profile shapes with literature mass-loss rates.

The Coolest Stars in the Clouds: Late-Type Red Supergiants in the Magellanic Clouds

Emily M. Levesque (Institute for Astronomy, University of Hawaii), Philip Massey (Lowell Observatory), K. A. G. Olsen (NOAO), *et al.*

Red supergiants (RSGs) are a He-burning phase in the evolution of moderately high-mass stars (10–25 solar masses). The physical properties of these stars continue to challenge our understanding of their evolutionary theory, particularly at low metallicities. The latest-type RSGs in the LMC and SMC are cooler than the current evolutionary tracks allow, occupying the “forbidden” region to the right of the Hayashi limit, which shifts to warmer temperatures at lower metallicities. Among these outliers, we have discovered four Cloud RSGs that display remarkably similar and unusual variations in their physical properties, varying dramatically in their V magnitudes and effective temperatures (and hence their spectral types). When these stars are warmer, they are also brighter, more luminous, and show an increased amount of extinction, with these substantial physical changes happening in timescales on the order of months. At their greatest, the amount of extinction is characteristic of that due to circumstellar dust around other RSGs, and thus suggests that we are seeing sporadic dust production from these stars while they are in their cooler states. Two of the SMC RSGs, HV 11423 and [M2002] SMC 055188, have been observed in an M4.5 I state, making them considerably later and cooler than any other supergiant in the SMC. We believe that this unusual behavior is indicative of a unstable, short-lived, and previously unobserved evolutionary phase in RSGs, and consider the implications such behavior could have for our understanding of the latest stages of massive star evolution in low-metallicity environments.

Hydrodynamic Modeling of UV Line Profiles in the η Carinae System: The Search for η Car's Missing Companion

Thomas I. Madura (Department of Physics & Astronomy, University of Delaware), Theodore Gull (Goddard Space Flight Center, Astrophysics Science Division), Stanley Owocki (Bartol Research Institute, University of Delaware), *et al.*

The extremely massive and luminous star η Carinae, with its bipolar Homunculus nebula, comprises one of the most remarkable and intensely observed stellar systems in the galaxy. Observed X-ray variations are interpreted as being due to the interaction of a massive wind from the primary star with the fast, less dense wind from a hot companion star. There are still no direct detections of the companion, but UV ionization signatures from the "Weigelt blobs" and other regions of the surrounding nebula generally support this binary scenario. This poster presents recent work aimed at modeling UV line profiles of η Car as a function of orbital phase by analyzing the results of smoothed particle hydrodynamics (SPH) simulations of the binary interactions in the system and comparing these to spectra obtained with the Hubble Space Telescope Space Telescope Imaging Spectrograph (HST STIS). The primary goals are to further constrain the parameters of the binary orbit (including the stellar mass ratio), determine how/where UV light is escaping in the system, and ascertain what, if any, direct signatures of the companion are present in the HST spectra.

Disentangling the Radio Emission Nature in Wolf Rayet Stars

Gabriela Montes, Miguel A. Perez-Torres & Antonio Alberdi (Instituto de Astrofísica de Andalucía, Consejo Superior de Investigaciones Científicas)

We present simultaneous, multiwavelength (at 1.3, 3.6, and 6 cm) VLA observations in D configuration of a sample of WR stars, aimed at disentangling the nature of their radio emission. Wolf-Rayet (WR) stars display high-mass loss rates and terminal velocities that result in strong winds. These winds are expected to have a positive spectral index at radio wavelengths. However, several WR sources have been found to present variable emission and negative spectral indices characteristics of non-thermal emission. Our sample sources have been detected at least at one wavelength; however, due to the variable nature of their radio emission, simultaneous multiwavelength observations are the best way to determine spectral indices and therefore disentangle their radio emission nature from thermal or non-thermal. We have found variability in the radio emission and the spectral indices, suggesting the presence of an emission process in addition to the thermal radio emission described for ionized stellar winds in single stars.

Systematic Uncertainties in OB Star Analysis

M. Fernanda Nieva & Norbert Przybilla (Bamberg Observatory, University of Erlangen-Nuremberg)

Precise stellar parameters and chemical abundances are crucial for constraining theories of stellar and galactochemical evolution. These constraints can be inferred through quantitative spectroscopic analyses where the sources of systematic errors are not always fully recognised. We show that (a) accurate input atomic data for the non-LTE modelling are often underestimated, which may lead to systematic biases when only a few strongly non-LTE affected lines are used for the analysis; and (b) accurate atmospheric parameters are also often underestimated, which may give larger biases than the neglect of non-LTE effects on many strategic lines. We present an improved spectral modelling

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and a self-consistent analysis methodology for OB-type dwarfs and giants that help us to reduce the major sources of systematic uncertainties. The spectrum synthesis is based on model atoms built from precise atomic data, and it employs a hybrid non-LTE approach, appropriate for this kind of star. The analysis technique is able to reproduce the entire H and He spectra simultaneously from the visual to the near-IR. Spectral energy distributions, Stark-broadened lines, and multiple ionization equilibria are employed to derive precise atmospheric parameters, resulting in a simultaneous tight agreement from 6 independent spectral indicators and therefore demonstrating a large reduction of systematic errors. The metal abundances (CNO + alpha elements) of our programme stars in the solar vicinity also show high accuracy from the consideration of the entire line spectra. This allows stellar and Galactic chemical evolution models to be tested in unprecedented detail.

A 3-D Geometric Model of the Colliding Winds in η Carinae

E. Ross Parkin, Julian M. Pittard (School of Physics and Astronomy, University of Leeds), Mike F. Corcoran (Exploration of the Universe Division, Goddard Space Flight Center), *et al.*

We have developed a 3-D geometric model of the wind collision region (WCR) in a colliding wind binary (CWB), where the curvature of the WCR due to the orbital motion of the stars is accounted for. We have used this model to simulate the X-ray light curve and spectra from the massive CWB η Carinae, and are able to constrain the orbital orientation and wind parameters of the system. A notable success is the ability to match the long duration of the X-ray minimum without recourse to additional mass ejection during periastron passage, though the exact shape of the minimum remains to be explained.

On the X-ray Emission and the Incidence of Magnetic Fields in Massive Stars of the Orion Nebula Cluster

Véronique Petit (Université Laval), Gregg A. Wade (Royal Military College of Canada) & Laurent Drissen (Université Laval)

Magnetic fields have been frequently proposed as a likely source of variability and confinement of the winds of massive stars. Recently, Stelzer *et al.* (2005, *ApJS*, 160, 557) found significant X-ray emission from all massive stars in the Orion Nebula Cluster (ONC). Periodic rotational modulation in X-rays and other indicators suggested that there might be many magnetic B- and O-type stars in this star-forming region. We have carried out sensitive ESPaDOnS observations to search for direct evidence of such fields, detecting unambiguous Zeeman signatures in three objects. We also obtained dipole field upper limits for the remaining stars with a state-of-the-art Bayesian analysis, resulting in a precise magnetic characterisation of all ONC massive stars. This allows us to explore for the first time the connections between fields, winds, and X-rays in a complete, co-eval and co-environmental sample of massive stars. These remarkable results bring forth new challenges for understanding the processes leading to X-ray emission in massive stars. We also expect to provide unique data regarding the incidence of magnetic fields in massive stars with which to confront models of magnetic field origin in neutron stars and magnetars, such as that proposed by Ferrario & Wickramasinghe (2006, *MNRAS*, 367, 1323).

Colliding Wind Binaries: Mass-Loss Rates and Particle Acceleration

Julian M. Pittard (University of Leeds)

Clumping in hot star winds can significantly affect estimates of mass-loss rates, the inferred evolution of the star, and the environmental impact of the wind. I present hydrodynamical simulations of colliding wind binary systems with clumpy winds, and demonstrate that in many cases the clumps are rapidly destroyed in the wind-wind collision region. X-ray emission from this region is thus a clumping-independent measure of the mass-loss rates. I also discuss the implications for a variety of other phenomena, including particle acceleration, non-equilibrium ionization, and electron heating.

New Observations of the Non-radial Pulsator HD93521

Gregor Rauw (Université de Liège), *et al.*

We present the results of long-term spectroscopic monitoring, as well as of an intensive photometric campaign on the runaway O9.5Vp star HD93521. This star has a very high rotational velocity and is known to display line profile variability probably due to non-radial pulsations. Our observations indicate that the amplitude of the dominant pulsation modes with periods of 1.75 ($l = 8$) and 2.89 hr ($l = 4$) change with time. Whilst light variations are detected, they are apparently not related to these periodicities.

Comprehensive Analysis of the WN Stars in the LMC

Ute Ruehling, Götz Gräfener & Wolf-Rainer Hamann (Universität Potsdam)

We present preliminary results from an analysis of almost all known WN stars in the LMC. We fit ~100 archival spectra from the UV to the IR range with PoWR atmosphere models, taking Fe-group line-blanketing and wind clumping into account. In this way we are able to determine reliable stellar parameters like luminosities, effective temperatures, and mass-loss rates for all stars of the sample. This allows us to perform a statistical study of the WN properties in the LMC without selection bias. Among the objects, we find candidates for fast rotators, binaries, and stars with peculiar surface abundances. To investigate the impact of the low LMC metallicity, we compare our results to previous analyses of the Galactic WN population.

The X-Ray Light Curve of η Carinae from a 3-D SPH Binary Colliding Wind

Christopher M. P. Russell (Department of Physics and Astronomy, University of Delaware), Stanley P. Owocki (Bartol Research Institute, University of Delaware) & Atsuo T. Okazaki (Department of Architecture and Building Engineering, Hokkai-Gakuen University)

We model the RXTE X-ray light curve for η Carinae using a 3-D smoothed particle hydrodynamics (SPH) simulation of the collision of the strong wind from the primary star with a weaker but faster wind of an assumed secondary star. For a reasonable choice of stellar, wind, and orbital parameters, the SPH simulations provide a dynamical model of the relatively low-density cavity carved out by the secondary wind, and how this varies with orbital phase. Assuming then the main X-ray emission occurs near the head of the wind-wind interaction cone, and varies in intensity with the inverse of the binary separation at any given orbital phase, we generate trial X-ray light curves by computing the phase variation of absorption to observers at various assumed lines of sight.

Comparison with the RXTE light curve suggests an optimal viewing angle approximately 36 degrees out of the orbital plane and 36 degrees from apastron in the prograde direction. Such a viewing angle is consistent with the orbit being in roughly the same plane as the equatorial skirt. Our derived synthetic light curve naturally reproduces many of the key features of the RXTE light curve, namely the increase in X-rays approaching periastron, the sudden decline into the X-ray eclipse, the appropriate duration of the X-ray eclipse, and the less sharp incline out of the eclipse. The naturalness of the fit provides strong evidence in favor of the basic wind-wind binary interaction model, and with further analysis of, e.g., X-ray and UV spectra, it should be possible to place further constraints on the basic stellar, wind, and orbital parameters.

Spectroscopic Analysis of Deneb: A Hybrid Non-LTE Approach

Florian Schiller & Norbert Przybilla (Dr. Remeis Sternwarte Bamberg)

Quantitative spectroscopy of luminous BA-type supergiants offers a high potential for modern astrophysics. The degree to which we can rely on quantitative studies of this class of stars as a whole depends on the quality of the analyses for benchmark objects. We constrain the basic atmospheric parameters and fundamental stellar parameters as well as chemical abundances of the prototype A-type supergiant Deneb to unprecedented accuracy ($T_{\rm eff} = 8525 \pm 75\,$K, $\log g = 1.10 \pm 0.05\,$dex, $M_{\rm spec} = 19 \pm 3\,M_{\odot}$, $L = 1.96 \pm 0.32 \cdot 10^5\,L_{\odot}$, $R = 203 \pm 17\,R_{\odot}$, enrichment with CN-processed matter) by applying a sophisticated hybrid NLTE spectrum synthesis technique which has recently been developed and tested. The study is based on a high-resolution and high-S/N spectrum obtained with the Echelle spectrograph FOCES on the Calar Alto 2.2 m telescope. Practically all inconsistencies reported in earlier studies are resolved. Multiple metal ionization equilibria and numerous hydrogen lines from the Balmer, Paschen, Brackett, and Pfund series are brought into match simultaneously for the stellar parameter determination. Stellar wind properties are derived from Hα line-profile fitting using line-blanketed hydrodynamic non-LTE models. A self-consistent view of Deneb is thus obtained, allowing us to discuss its evolutionary state in detail by comparison with the most recent generation of evolution models for massive stars.

Wind Clumping and Neon Abundances in Galactic WC Stars

Olivier Schnurr, Paul A. Crowther (University of Sheffield), Patrick W. Morris (IPAC/Caltech), *et al.*

We have obtained high-quality, flux-calibrated, mid-IR Spitzer/IRS spectroscopy of six Galactic WC4–8 Wolf-Rayet stars including the key fine-structure neon lines [Ne II] 12.8 μm and [Ne III] 15.5 μm. In addition, we carry out tailored line-blanketed, non-LTE model atmosphere analyses using UV/optical and near-IR spectroscopy, to obtain quantitative stellar and wind properties of our program stars, necessary to measure abundances of neon, which in WC stars is expected to be greatly enhanced. Wolf-Rayet stars display a strong free-free continuum emission at IR and radio wavelengths, whose slope can be used as a diagnostic of clumping in the outer wind. We find that, while UV/optical diagnostics confirm that the inner wind is clumped, there appears to be no difference in clumping for the outer wind, contrary to what is expected from hydrodynamical considerations. From our derived wind and chemical properties, we are able to accurately determine the neon abundance in our program WC4–8 stars. Taking into account the latest correction to the solar abundances by Asplund *et al.* (2004, *A&A*, 417, 751), we find that the neon abundances in our WC stars are in excellent agreement with predictions from evolutionary models.

Using HII Region Spectra to Probe the Ionizing Radiation from Massive Stars

Sergio Simón-Díaz (Observatoire de Genève), Jorge García-Rojas (Universidad Nacional Autonoma de Mexico), Grazyna Stasińska (LUTH, Observatoire de Paris-Meudon), *et al.*

We are performing a study of HII regions ionized by a single massive star to test the prediction of the new generation of stellar atmosphere codes in the H Lyman continuum (below 911 Å). The observations collected for this study comprise the optical spectra of the corresponding ionizing stars, along with imaging and long-slit spatially resolved nebular observations. The analysis of the stellar spectra allow us to obtain the stellar parameters of the ionizing star and Q(H^0), while the nebular observations provide us constraints on the nebular gas distribution and nebular abundances. Finally, the ionized SEDs predicted by the stellar atmosphere codes are being tested by comparing various diagnostic line ratios predicted by a photoionization code with the observed line ratios across the nebulae. We will present some results on this on-going project.

A Complete Spectroscopic Survey of O stars

Alfredo Sota (Universidad Autónoma de Madrid), Jesús Maíz Apellániz (Instituto de Astrofísica de Andalucía), Rodolfo Barbá (Universidad de La Serena), *et al.*

We have recently compiled the most complete Galactic O star catalog with accurate spectral types (Maíz Apellániz *et al.* 2004, *ApJS*, 151, 103), and now we are conducting a spectroscopic survey to observe all known Galactic O stars with $B < 14$ based on v2.0 of the catalog. 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 kinematic 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 atlas of massive stars to date. The northern part of the survey is being carried out from the Sierra Nevada Observatory (Spain), and the southern part from Las Campanas (Chile), La Silla (Chile), and CASLEO (Argentina). As part of our early results we have discovered 13 new massive spectroscopic binary systems.

The Nature of WC9 stars–Hints from Variability

Nicole St-Louis (Université de Montréal) & André-Nicolas Chené (Herzberg Institute of Astrophysics-Canadian Gemini Office)

We have carried out a spectroscopic variability survey of all apparently single Galactic Wolf-Rayet stars brighter than $V \simeq 13$ (e.g. Chené & St-Louis 2007, *ASP Conf* 367, 117). One intriguing result from this project is that *all* WC9-type stars in our sample present large-scale (more than 6% of the line flux) variability. Among these are three of the rare (only 10%) WC9 stars for which evidence of dust formation has *not* been found: WR 81, WR 88, and WR 92. These stars have been monitored in photometry for more than two decades without any evidence for episodic dust formation events (Williams & van der Hucht 2000, *MNRAS*, 314, 23). The variability we have found for these three stars is in the form of rather large excess emissions on the top of the normal wind lines that move across the profile on relatively short timescales (on the order of days). These can either be caused by the presence of co-rotating interaction regions in the wind of the Wolf-Rayet star or by colliding winds. In the latter case, the relatively short timescale

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of the changes would indicate that the orbital period is much shorter than that of other dust-making WC9 stars in binaries such as WR 140 or WR 137, which have periods on the order of several years. This might be a clue as to why these stars are dust free.

Observations of a New Massive Binary in the Cygnus OB2 Association.

Vanessa Stroud (LCOGTN/The Open University), Ignacio Negueruela (Universidad de Alicante) & Simon Clark (The Open University)

We present optical spectroscopy and photometry of a newly discovered binary system in the Cygnus OB2 Association. The system is likely to contain two O-type supergiants, one of them perhaps in a transitional state. If correct, this would make it one of the most massive binaries in the Galaxy.

A Near-Infrared View of the Homunculus Nebula Around η Carinae

M. Teodoro, A. Damineli (Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Universidade de São Paulo), R. Sharp (Anglo-Australian Observatory), *et al.*

We present a near-infrared view of the Homunculus nebula around η Car using the Gemini/CIRPASS spectrograph. We show the velocity maps in the light of [FeII] 12567, which confirm the presence of a hole in the polar region of both lobes. Using this result and a model for the shape of the Homunculus, we could derive its thickness at the polar region, which is consistent with values found by other authors. Furthermore, we confirm the presence of regions with intrinsic components of HeI 10830, which might be formed by UV photons coming from the central source. Considering the Little Homunculus as a small HII region, we could use the radio flux to estimate the nature of the hot companion of η Car.

The Inner Wind Structure of Supergiant Stars

Jose M. Torrejon-Vazquez (Massachusetts Institute of Technology), Ignacio Negueruela (Universidad de Alicante) & David M. Smith (University of California, Santa Cruz)

The newly discovered phenomenon of the fast X-ray transients in supergiants is straightforwardly explained if the wind is highly structured in clumps. The existence of these hypothetical clumps, however, could be at odds with the persistent emission displayed by classical supergiant X-ray binaries. In this paper we present a coherent picture that unifies the emission behavior of all supergiant X-ray binaries in terms of the porous winds in the supergiant stars. Within the framework of the porous wind model, we discuss the implications of the available X-ray observations on the model parameters.

Winds of Magellanic Cloud B Supergiants

Carrie Trundle (Queen's University Belfast)

The analysis of radiation driven winds in B-type supergiants has highlighted discrepancies between the predictions of these massive star winds and observational results. These inconsistencies will have an important impact on the later stages of stellar evolution due to stellar winds being drivers of the evolution of massive stars during the core hydrogen burning phase. The discrepancies between observations and theory will be reviewed here along with some new results from the Magellanic Cloud B star population.

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The Effects of Field-Aligned Rotation on Magnetically Channeled Line-Driven Stellar Winds

Asif ud-Doula (University of Delaware)

Based on a MHD simulation study of magnetic channeling in radiatively driven stellar winds, we examine here the dynamical effects of stellar rotation in the 2-D axisymmetric case of an aligned dipole surface field. We characterize the stellar rotation in terms of a parameter W($= V_{\rm rot}/V_{\rm orb}$) (the ratio of the equatorial surface rotation speed to orbital speed). We find that rotation effects are weak for models with Alfven radius (RA) smaller than the Kepler co-rotation radius (RK), RA $<$ RK, but can be substantial and even dominant for models with RA $>$ RK. In particular, by extending our simulations to the very strong magnetic confinement case, we find that these do indeed show clear formation of the rigid-body disk predicted in previous analytic models, with however a rather complex, dynamic behavior characterized by both episodes of downward infall and outward breakout that limit the buildup of disk mass. Overall, the results provide an intriguing glimpse into the complex interplay between rotation and magnetic confinement, and form the basis for a full MHD description of the rigid-body disks expected in strongly magnetic Bp stars like σ Ori E.

Numerical Simulations of Continuum-Driven Winds of Super-Eddington Stars

Allard Jan van Marle, Stanley P. Owocki (University of Delaware) & Nir J. Shaviv (Hebrew University)

Continuum driving is an effective method to drive a strong stellar wind. It is governed by two limits: the Eddington limit and the photon-tiring limit. A star must exceed the effective Eddington limit for continuum driving to overcome the stellar gravity. The photon-tiring limit places an upper limit on the mass-loss rate that can be driven to infinity, based on the energy available in the radiation field of the star. Because continuum driving does not require the presence of metals in the stellar atmosphere, it is particularly suited to removing mass from low- and zero-metallicity stars and can play a crucial part in their evolution.

We compute numerical simulations of super-Eddington, continuum-driven winds using a porosity length formalism. We find that below the photon-tiring limit, continuum driving can produce a large, steady mass-loss rate at velocities on the order of the escape velocity.

If the star exceeds the photon-tiring limit, a steady solution is no longer possible. While the effective mass loss rate is still very large, the wind velocity is quite small. These objects will show a highly variable luminosity as radiation escapes from the dense circumstellar wind in short bursts. Since most of the radiative energy is used to maintain the high mass-loss rate, such a star would appear to be quite dim.

Since continuum driving can use a large fraction of the available energy, an accurate estimate of the luminosity of super-Eddington objects must include both mechanical and radiative luminosity.

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High Angular Resolution Interferometric Observations of Evolved Massive Stars

Debra J. Wallace (College of Charleston), Douglas R. Gies (Georgia State University), William C. Danchi (Goddard Space Flight Center), *et al.*

Recent aperture-masking and interferometric observations of late-type WC Wolf-Rayet stars strongly support the theory that dust formation in these objects is a result of colliding winds in binary systems. To explore and quantify this possible explanation, and build on our high-resolution HST WFPC2 imaging results, we have conducted a high-resolution interferometric survey of late-type massive stars utilizing the VLTI, KI, IOTA, and FGS1r interferometers. We present here the first results from the MIDI instrument on the VLTI, and the KI and IOTA observations. Our VLTI study is aimed primarily at resolving and characterizing the dust around the WC9 star WR 85a and the LBV WR 122, both dust-producing but at different phases of massive star evolution. Our IOTA and KI interferometric observations resolve the WR star WR 137 into a dust-producing binary system.

The Progenitors of Gamma-Ray Bursts; A New Spectropolarimetric Survey of Galactic Wolf-Rayet Stars

G. Grant Williams (MMT Observatory), G. Schmidt & P. Smith (Steward Observatory)

We present results from a spectropolarimetric survey of 18 Galactic Wolf-Rayet (WR) stars that were not included in the Harries et al. (1998, *MNRAS*, 296, 1072) survey. Our observations increase the number of spectropolarimetrically studied Galactic Wolf-Rayet stars by more than 50%. The results from this survey are used to further characterize the progenitors of gamma-ray bursts (GRBs). The collapsar model is the most widely accepted model for producing GRBs. In this model, a massive star that has shed its hydrogen envelope undergoes core collapse, resulting in a black hole and an accretion disk. A preferred axis, which is generally attributed to rapid rotation, provides a path for the relativistic jet. This preferred axis may produce asymmetries in the geometrical mass-loss structure that can be measured with spectropolarimetry. Therefore, our results provide insight into the parameters and/or environment surrounding progenitors of GRBs.

The Massive LMC Binary [L72] LH 54-425

Stephen J. Williams, Douglas R. Gies, Todd Henry (Department of Physics and Astronomy, Georgia State University), *et al.*

We present results from an optical spectroscopic investigation of the massive binary system [L72] LH 54-425. We find an orbital period of 2.247409 ± 0.00001 days. We find spectral types of O3 V for the primary and O5 V for the secondary. We made a combined solution of the radial velocities and previously published V-band photometry to determine the inclination of the system, $i = 52^{+2}_{-3}$ degrees, and obtain radii and masses for each star in the system: $M_1 = 53^{+7}_{-4}\ M_\odot$ and $R_1 = 11.0^{+0.7}_{-0.3}\ R_\odot$ for the primary, and $M_2 = 30^{+4}_{-2}\ M_\odot$ and $R_2 = 9.7^{+1.0}_{-0.2}\ R_\odot$ for the secondary. Based on the position of the two stars plotted on a theoretical H-R diagram, we find the age of the system to match most closely with a $\sim$2 Myr isochrone.

HD 45166: A Causal Connection between Photospheric and Wind Structure and Variability

Allan Willis (University College London)

What are the true mass-loss rates of O stars and WR stars? Currently, there are discrepancies of factors of 10–100 between UV and radio studies, with severe implications for stellar and galaxy evolution models. Inherent in modelling stellar wind emissions (UV P Cyg profiles, radio continua, etc.) is the realization that the winds are highly structured and variable. This is epitomized by the ubiquitous appearance of discrete absorption components (DACs) in OB and WR winds. However, the physical origin of DACs is unknown. HD 4516 is a low-mass, hot star, with $T_{\rm eff}$ recently determined from FUSE spectra to be 37000 K. IUE high-resolution spectra at many epochs show substantial DAC variability in CIV, NV, SiIV resonance P-Cyg profiles. In addition, the *photospheric* absorption lines in FeV show substantial strength changes that appear to be directly associated with those seen in the DACs. This is the first time that a direct observational link has been isolated between photospheric and wind activity—a facet probably linked to the relatively low mass-loss rate and wind density. It is suggested that this apparent photospheric-wind variation linkage in HD 45166 may also be operating in massive O and WR analogues. This may open up a route to explaining the physical origin of massive star wind structure and variability, and to a proper understanding of their true mass-loss rates.

Implementation of Plasma Emission Calculations into the Non-LTE Radiative Transfer Program, CMFGEN

Janos Zsargo & D. John Hillier (University of Pittsburgh)

We present preliminary X-ray emission results for ζ Puppis calculated by a stellar atmosphere code that combines CMFGEN (Hillier & Miller 1998, *ApJ*, 496, 407) and the Astrophysical Plasma Emission Code (APEC, Smith *et al.* 2001, *ApJ*, 556, L91). The merged codes will allow for the combined spectral analysis of all observable wavelengths (from X-ray to IR) and will provide stellar parameters, wind parameters, and the temperature and location of the X-ray emitting plasma. Furthermore, the attenuation of the X-ray emission by the cool wind will be self-consistently accounted for. Our progress, so far, includes the modification of APEC to take into account photo-excitation by UV radiation (calculated by CMFGEN) in the statistical equilibrium equations for the He-like ions. The resulting emission measures are then used to produce observed spectra.

SESSION II: Physics and Evolution of Massive Stars

Core Overshoot and Nonrigid Interior Rotation of Massive Stars: Current Status from Asteroseismology

Conny Aerts (Instituut voor Sterrenkunde, Katholieke Universiteit Leuven)

See p. 237 for full article.

Can Envelope Convection Zones in Hot Stars Cause Wind Clumping?

Matteo Cantiello (Astronomical Institute, Utrecht University), *et al.*

We study convection zones in the envelopes of hot massive stars. These regions are caused by opacity peaks associated with iron and helium ionization. Such convective regions can be very close to the stellar surface and we discuss possible implications. We argue that convection close to the surface may affect the stellar mass loss by triggering wind clumping. We present a simple model for this 'convection-driven clumping'.

End of Massive Stars and GRBs

Pascal Chardonnet (Université de Savoie)

In this poster, I will present a new scenario for gamma-ray bursts. I found observational evidence to support this theory. I will explain some enigmatic facts like the "Amati Relation," and I will draw some interesting perspectives in terms of global stellar evolution.

Homogeneous Evolving Stars in Close Binaries

S. E. de Mink, M. Cantiello & N. Langer (Utrecht University)

Rotational mixing is proposed to explain observed N and He enhancements in OB stars. If the rotation rate is of the order of 30% of the critical rotation rate or higher, rotational mixing can be so efficient that the star evolves chemically homogeneously: the star stays compact, gradually becoming an Wolf-Rayet star. This evolutionary scenario was proposed for the formation of long gamma-ray burst progenitors.

Rotation rates needed for homogeneous evolution can be achieved in close, massive, pre-mass transfer binaries (primary mass > 40 solar masses, periods 2–5 days), in which the tidal forces lock the rotation of the stars with the rotation of the orbit. Hence we consider the possibility of forming GRB progenitors in this way.

In less massive or wider binaries, current models predict N and He enhancements. These systems are suggested to constitute potentially stringent test cases for the physics of rotational mixing. We indicate 5 double lined eclipsing binaries in the SMC that may be particularly suitable for such a test.

Simulations of Magnetically Driven Supernova Explosions

Luc Dessart (Steward Observatory), *et al.*

I will present results from 2-D rotating, multi-group, radiation magneto-hydrodynamics simulations of supernova core collapse, bounce, and explosion. In the context of rapid rotation, magnetic stresses at the neutron-star surface lead to the creation and propagation of MHD jets that are powered by the energy extracted from the differentially rotating core. I will review the properties of the resulting ejecta and discuss the implications for the collapsar model of long-duration GRBs.

The Massive Star Newsletter

Philippe Eenens (Universidad de Guanajuato)

We present the newsletter of the IAU Working Group on Massive Stars. We retrace its history after 100 issues. We analyze its role and discuss its future.

Unveiling the Internal Structure of Massive Supergiants with Asteroseismology: Effect of Mass-loss

Mélanie Godart (Université de Liège), Marc-Antoine Dupret (Observatoire de Paris-Meudon), Arlette Noels (Université de Liège) *et al.*

Saio *et al.* (2006, *ApJ* 650, 1111) have detected p and g-modes in a B supergiant star HD 163899 with MOST. The presence of excited g-modes in a post-main sequence star is explained by the existence of a convective shell which prevents some modes from entering into the damping radiative core.

We show that this intermediate convective zone disappears when sufficient mass loss is included in the models. Hence, the non-radial p- and g-modes are not excited anymore. Our study is one of the first showing how asteroseismology allows us to get precise information on the physics of the very deep layers of massive stars.

New Measurements of Magnetic Fields in SPB and β Cephei Stars.

S. Hubrig (ESO, Chile), M. Briquet (Universiteit Leuven), M. Schöller (ESO, Chile), *et al.*

Our recent study of the evolutionary state of Bp and SPB stars indicates that Bp stars are younger that SPBs and stars with stronger magnetic fields have much lower pulsation amplitudes. We present the results of new magnetic field measurements of SPBs and beta Cephei stars which are important to establish the link between the presence of a magnetic field and other fundamental properties of pulsating stars.

Rotational Mixing in Rapidly Rotating Massive Stars

Ian Hunter (Queen's University Belfast), Ines Brott (Utrecht University), Danny Lennon (Isaac Newton Group of Telescopes), *et al.*

Rotation has become an important element in evolutionary models of massive stars, specifically the prediction of rotational mixing. Here detailed non-LTE surface chemical compositions are presented for 135 early B-type stars in the Large Magellanic Cloud. These objects have projected rotational velocities up to 300 $\mathrm{km\,s^{-1}}$ with over 40% having rotational velocities greater than 100 $\mathrm{km\,s^{-1}}$. This represents the largest sample to date of fast rotators with chemical abundance estimates and allows the effects of rotation on stellar evolution to be examined in detail. Specifically we find no significant evidence that the amount of material mixed into the surface is correlated with the rotational velocity. Indeed, we find both fast rotators that are not enriched and slow rotators that are highly enriched. These observations are in conflict with theoretical predictions. Additionally, the blue supergiants generally are more enriched than normal core hydrogen burning objects which suggests that their enrichment is not due to rotational mixing. We conclude that rotational mixing is not the dominant enrichment process in massive stars.

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Black Hole Formation: Progenitors and Kicks

Vicky Kalogera, Tassos Fragos, Bart Willems (Northwestern University), *et al.*

In recent years, an increasing number of proper motions have been measured for Galactic X-ray binaries. When supplemented with accurate determinations of the component masses, orbital period, and donor luminosity and effective temperature, these kinematical constraints harbor a wealth of information on the systems' past evolution. We have developed an analysis that allows us to consider all this available information and reconstruct the full evolutionary history of X-ray binaries back to the time of core collapse and compact object formation. This analysis accounts for four evolutionary phases: mass transfer through the ongoing X-ray phase, tidal circularization before the onset of Roche-lobe overflow, motion through the Galactic potential after the formation of the compact object, and binary orbital dynamics at the time of core collapse. The constraints on compact object progenitors and kicks derived from this are of immense value for understanding compact object formation and exposing common threads and fundamental differences between black hole and neutron star formation. Here, we present the results of such an analysis for the black hole X-ray binary XTE J1118+480 (and also GRO J1655-40). Assuming that the system originated in the Galactic disk and the donor had solar metallicity, we find that a high-magnitude ($>$100 km s^{-1}) asymmetric natal kick is not only plausible but required for the formation of the system. We also investigate a globular cluster origin of XTE J1118+480 that would require a low-metallicity donor star. It turns out that such a scenario involves a lot of fine tuning and seems rather improbable.

Be Stars and Stellar Evolution

C. Martayan (Royal Observatory of Belgium, GEPI Observatoire de Paris), Y. Frémat (Royal Observatory of Belgium), A.-M. Hubert (GEPI Observatoire de Paris), *et al.*

In this poster we present the impact of the star-formation conditions and stellar evolution on the appearance of Be stars in environments with different metallicities. Using the observations obtained with the VLT-FLAMES, we focus on the incidence of the ZAMS rotational velocities and the metallicity of the environment on the evolution of B-type stars. Specifically, we show at what evolutionary status the Be phenomenon can appear in the Milky Way and in the Magellanic Clouds as a function of the stellar mass. To validate a given diagram of the evolutionary status of Be stars, it is important to observe very young clusters with emission line stars (ELS) present in environments with different metallicities and to distinguish clearly, which of them are classical Be stars and which are Herbig Be stars. To this purpose, we present new results on ELS in the very young open clusters NGC 6611, Trumpler 14, Trumpler 15, Trumpler 16, Collinder 232 (MW), and NGC 346 (SMC).

A Magnetosynthesis Model for Massive Stars

Mary E. Oksala & Richard Townsend (University of Delaware)

Magnetic fields in massive stars are often accompanied by inhomogeneous surface abundance distributions. It is well understood how rotational modulation of abundance inhomogeneities leads to spectroscopic and photometric variability. However, the possibility that the inhomogeneities can also impact magnetic field measurements has not yet been investigated. This motivated us to develop a new "magnetosynthesis" model for simulating the effective field strength of magnetic massive stars having arbitrary surface abundance distributions.

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The effective field strength of a magnetic star is determined from spectropolarimetry as a weighted average of the field component along the line of sight. The weighting function is proportional to the local equivalent width (EW) of the absorption line used in the measurement, and therefore depends on the local surface abundance of the element responsible for the line. In our magnetosynthesis model, we specify the abundance distribution on a triangle-based mesh representing the stellar photosphere. For each triangular element, the EW is calculated from specific intensity data in a 5-dimensional (temperature, gravity, wavelength, angle, abundance) grid of pre-computed TLUSTY/SYNSPEC spectra. The effective field strength is then found by integrating the weighted longitudinal field component over all visible elements.

We present results from a preliminary application of the magnetosynthesis model to He-strong Bp stars. The principal findings are that (i) the shapes of effective field-strength curves depart from sinusoidal, and (ii) the amplitudes of these curves vary from element to element, and from line to line.

A Very Faint Core-Collapse SN in M85

A. Pastorello (Queen's University Belfast), M. Della Valle (INAF-Arcetri, Florence), S. J. Smartt (Queen's University Belfast), *et al.*

An anomalous transient in the early Hubble-type (S0) galaxy Messier 85 (M85) in the Virgo cluster was discovered by Kulkarni *et al.* (2007 *Nat*, 447, 458) on 7 January 2006 that had very low luminosity (peak absolute R-band magnitude $M_{\rm R}$ of about -12 mag) that was constant over more than 80 days, red colour and narrow spectral lines, which seem inconsistent with those observed in any known class of transient events. Kulkarni *et al.* (2007) suggest an exotic stellar merger as the possible origin. An alternative explanation is that the transient in M85 was a type II-plateau supernova of extremely low luminosity, exploding in a lenticular galaxy with residual star-forming activity. This intriguing transient might be the faintest supernova that has ever been discovered.

Massive Stars as Tracers for Stellar and Galactochemical Evolution

N. Przybilla, M. F. Nieva, M. Firnstein (Dr. Remeis Observatory Bamberg), *et al.*

Recent advances in the modelling of the atmospheres of massive stars, in particular by considering improved atomic data, allow stellar parameters and elemental abundances to be constrained with unprecedented accuracy: effective temperatures to $\sim$1%, surface gravity to $\sim$10–20%, and abundances to $\sim$10–20%, largely unbiased by systematic errors.

We discuss the implications of the modelling improvements for testing stellar evolution models observationally. This is done for a sample of stars from the OB-type main sequence to later evolution stages up to the BA-type supergiant phase in a homogeneous way. Particular emphasis is given to the light elements (He, CNO) as tracers of nuclear-processed material. The results imply that mixing appears to be more efficient than predicted by current evolution models accounting for mass loss and rotation, by a factor $\sim$2. This may favour scenarios with enhanced mixing due to the interaction of rotation and a magnetic field.

Abundances of the heavier elements, unchanged by nuclear burning, may be used for testing galactochemical evolution models. Our results imply a much higher homogeneity of elemental abundances from massive stars in the solar vicinity than reported before. This is finally in agreement with the chemical uniformity of the ISM and predictions of Galactic evolution models. Reference abundances for several astrophysically important elements are presented, which are often systematically higher than reported before. The study re-establishes the recently doubted status of massive stars as excellent proxies for present-day abundances. Implications for the derivation of Galactic abundance gradients are discussed.

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SESSION III: Massive Star Populations in the Nearby Universe

W51 IRS2: A Compact HII Region in Detail

Cassio Barbosa (IP&D, Universidade do Vale do Paraíba, Brazil), Robert Blum (NOAO), Peter Conti (JILA), *et al.*

We present the first results of a recent campaign on W51 IRS2 carried out at Gemini Observatories. We derived mid-infrared fluxes and luminosities as well as line-of-sight extinction from images taken with T-ReCS at 7.7, 9.8, 12.3, and 24.5 μm. We report the detection of a new source at 24.5 μm. Near-infrared spectra taken with high spatial resolution show nebular lines on all selected sources. We report for the first time the detection of the first overtone CO band in emission in IRS2E, a typical signature of circumstellar disks.

A Downward Revision to the Distance of the 1806-20 Cluster and Associated Magnetar from Gemini Near-Infrared Spectroscopy

Joanne L. Bibby, Paul A. Crowther, James P. Furness (Department of Physics & Astronomy, University of Sheffield), *et al.*

We present H- and K-band GNIRS spectroscopy of OB and Wolf-Rayet (WR) members of the Milky Way cluster 1806-20, obtaining a revised cluster distance relevant to the 2004 giant flare from the SGR 1806-20 magnetar. We confirm four candidate OB stars as late O/early B supergiants and support previous mid WN and late WC classifications for two WR stars.

The distance modulus (DM) achieved from theoretical isochrone fitting using the age inferred by the stellar content is combined with the DM from Ks-band magnitude calibration for B supergiants and WR stars, to produce a cluster DM of 14.7 ± 0.4 mag ($8.7^{+1.8}_{-1.5}$ kpc). This is significantly lower than the 15 kpc to the magnetar and reduces the peak luminosity of the giant flare to 7×10^{46} erg s^{-1}, hence contamination of BATSE short gamma ray bursts from such events is reduced to 8%. We infer a magnetar progenitor mass of $\sim 48^{+20}_{-8}$ M$_\odot$, in agreement with the magnetar in Westerlund 1.

A Survey of the Most Massive Stars in the Local Universe

Alceste Z. Bonanos (Carnegie Institution of Washington, Department of Terrestrial Magnetism)

The physical parameters of very massive stars ($>$30 M$_\odot$) remain unexplored. The most accurate method for deriving masses, radii, and luminosities of such distant stars is to measure them in eclipsing binary systems. Currently, the most massive eclipsing binary known is WR20a, which consists of two 80 solar mass stars in a 3.7 day orbit. In total, only $\sim$20 very massive stars ($>$30 M$_\odot$) belonging to our Galaxy and Local Group galaxies have accurate determinations of their parameters. I will present the first results of a wide-ranging survey targeting the brightest and thus most massive stars in eclipsing binaries in both young massive clusters in the Milky Way and in nearby galaxies. The measurement of fundamental parameters for massive stars at a range of metallicities will provide much needed constraints on theories that model the formation and evolution of massive stars and will observationally probe the upper limit on the stellar mass.

Massive Blue Stars in NGC 55

Norberto Castro, Artemio Herrero (Instituto de Astrofísica de Canarias, ULL), Miriam Garcia (IAC), *et al.*

We present the first spectral census of hot massive stars in NGC55, a spiral galaxy of the Sculptor group. Using VLT spectra taken with FORS2 in MXU mode, we have produced spectral classifications for 200 objects spread throughout the galaxy. The resulting catalogue will be published shortly. The metallicity and rotational velocity curve of the galaxy were estimated in an approximate way. This work is part of a larger project to determine stellar parameters, evolutionary status and abundances of B-supergiants in NGC55, and to use the results to probe the chemical composition of the galaxy.

The Massive Galactic Red Supergiant Clusters

Ben Davies, Don Figer (Rochester Institute of Technology), Rolf-Peter Kudritzki (Institute for Astronomy, University of Hawaii), *et al.*

I present the recent discoveries of two Galactic massive young clusters, which together contain 40 red supergiants (RSGs)—20% of all those known in the Galaxy—and as many in the entire Large Magellanic Cloud. From observations and evolutionary synthesis models, we argue that the cluster masses are comparable to the other Galactic "super star clusters" such as Westerlund 1 and the Arches Cluster. The distinctly different ages of the clusters, uniform metallicity, and large number of RSGs mean that these objects now offer an unprecedented opportunity to study the pre-supernova evolution of massive stars. Further, their location at the point where the Scutum-Crux spiral arm meets the bulge allows us to study the metallicity gradient at this location in the Galaxy, key to the constraining of Galaxy evolution models.

Mapping the 'Intimate' Spectral Properties of Gas Flows in the Orion Nebula: HH 202

César Esteban, Adal Mesa-Delgado, Luis López-Martín (Instituto de Astrofísica de Canarias), *et al.*

We present preliminary results on low-resolution 2-D and high-resolution echelle spectrophotometry of the head of the Herbig-Haro object HH 202 in the central part of the Orion Nebula. The 2-D maps, obtained with the Postdam Multi-Aperture Spectrophotometer (PMAS) at the 3.5m telescope in Calar Alto, show the spatial distribution of a large number of nebular properties (line fluxes, reddening coefficient, electron density and temperature, chemical abundances) permitting to carry out a thorough study of the effects of gas flows and shocks onto the nebular ionized gas. In addition, the echelle spectrum, obtained with the Ultraviolet Echelle Spectrograph (UVES) at the VLT in Cerro Paranal and covering from 3500 to 10000 Å, permits to resolve the nebular and shock components of the gas and study the physical conditions and chemical abundances of each kinematical component. One of the main aims of this work has been the measurement of very faint OII recombination lines, in order to compare the abundances of O^{++} determined from OII and [OIII] lines and, therefore, determine the so-called abundance discrepancy.

Spectroscopy of Resolved Stellar Populations with the E-ELT

Chris Evans (UK Astronomy Technology Centre) & Miska Le Louarn (ESO)

We present results from new adaptive optics simulations to illustrate the performance of the European Extremely Large Telescope (E-ELT). We also introduce EAGLE, one of the Phase A E-ELT instrument studies now underway, and how it will contribute to studies of resolved stellar populations.

Circumnuclear Activity in NGC 7469 as Revealed by Integral Field Spectroscopy with Subaru-Kyoto3DII

Takashi Hattori (Subaru Telescope, National Astronomical Observatory of Japan), Hajime Sugai (Kyoto University) & Hiroshi Ohtani (Okayama Astrophysical Observatory, NAOJ)

We present the results of an optical spectroscopic study of the circumnuclear region of the Seyfert 1 galaxy NGC 7469. High spatial resolution integral field spectroscopy performed with Subaru-Kyoto3DII allows us to investigate the spectroscopic properties of the nuclear starburst ring without contamination from the bright nucleus.

For the first time in NGC 7469, we detect a strong Wolf-Rayet emission feature at 4650 Å from a small part of the ring, indicating the presence of a few thousand late-type WN stars. Spectral properties of this region, located at the southern edge of the ring and coincident with a bright MIR peak, are consistent with a moderately reddened, young (several Myr), metal-rich, instantaneous starburst population. We also identify a star-forming region that is characterized by metal absorption lines such as FeII and MgII, suggesting an older (several 10 Myr) stellar population.

The high spatial resolution and careful analysis of the data cube also allow us to investigate the spatial structure of emission lines inside of the starburst ring. As a result, we find a spatially extended, highly blueshifted ($\sim\!-1000\ \mathrm{km\,s^{-1}}$) component in [SII] and [OIII] lines. In [OIII], the high velocity component is bright at the nucleus and extends toward the northeast, which corresponds to the direction of the minor axis of the nuclear gas disk. In contrast, it is distributed at the north to southwest side of the nucleus in [SII].

These observational results provide important clues to understanding the star-forming activity and outflow in this system, and demonstrate the importance of spatially resolved spectroscopy.

Star Formation in the Outer Disks of Dwarf Galaxies

Deidre Hunter, Bonnie Ludka (Lowell Observatory) & Bruce Elmegreen (IBM T. J. Watson Research Center)

Outer edges of dwarf galaxies present an extreme environment for star formation. Dwarf galaxies already challenge models of star formation because of their low gas densities even in the central regions. Outer parts of dwarfs, where the gas density is even lower, therefore, present a particularly difficult test of our understanding of the cloud/star formation process. Yet, we see that stars have formed in the outer parts to very low surface brightness levels. We are using UV images obtained with the GALEX satellite to trace and characterize star formation in the outer disks of dwarf galaxies where Hα may not be an effective tracer of recent star formation. Here we compare the far-UV surface brightness profiles to those of Hα and to those of the older stars.

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On the Binary Characteristics of Massive Stars

Chip Kobulnicky (University of Wyoming) & Chris Fryer (Los Alamos National Laboratory)

We compare radial velocity survey data on 114 early-type stars in the 2–3 Myr old Cygnus OB2 Association with the expectations of Monte Carlo models based on several popular binary system prescriptions to constrain the properties of massive binaries. We explore a range of true binary fraction, F, a range of power-law slopes, alpha describing the distribution of companion masses, between the limits $q_{\rm low} < 1$ and a range of power law slopes, beta, describing the distribution of orbital separations, between the limits $\rm r_{in}$ and $\rm r_{out}$. We also consider distributions of secondary masses described by a Miller-Scalo type initial mass function (IMF) and by a two-component IMF which includes a substantial "twin" population with $M_2 \sim M_1$. If the distribution of orbital separations is not far from the canonical Opik's Law distribution (i.e., flat; beta=0), several seemingly disparate formulations of the massive binary characteristics can be reconciled by adopting carefully specified values for $F, r_{\rm in}$ and $r_{\rm out}$. We show that binary fractions $F < 0.7$ are less probable than $F > 0.8$ for reasonable choices of $r_{\rm in}$ and $r_{\rm out}$. The secondary star mass function cannot be drawn from a Miller-Scalo-like IMF unless the lower end of the mass function is truncated below ~2–4 $M_{\odot}$. A Salpeter or Miller-Scalo IMF extending to low stellar masses can produce sufficiently large radial velocity variations consistent with the data if there exists a substantial "twin" population with $q \sim 1$ comprising ~40% of all systems.

A Spectroscopic Study of G61.48+0.09

A. Lenorzer, A. Herrero, A. Marin (Instituto de Astrofísica de Canarias), *et al.*

We present a study of the obscured Galactic cluster G61.48+0.09, based on *JHK* photometry and low-resolution *HK* multiobject spectroscopy obtained with LIRIS attached to the WHT. Based on this information, we investigate whether G61.48+0.09 is a nearby cluster (at about 2.5 kpc) or a far one (at about 8 kpc). In the first case, its mass (assuming a Salpeter IMF) is relatively modest (1000 solar masses), while in the second case, it is a very massive cluster (20000–40000 solar masses). Other intriguing aspects, like the main ionization source of G61.48+0.09 are also explored.

The Quintuplet Cluster

Adriane Liermann, Wolf-Rainer Hamann & Lida M. Oskinova (Institute for Physics, Potsdam University)

We present new near-infrared integral-field spectroscopy data of the central region of the Quintuplet cluster that is located about 30 pc (projected distance) from the Galactic center. The Quintuplet cluster is young (3–5 Myr old) and one of the most massive star clusters in the Galaxy with a rich population of hot massive stars. The observations were obtained with the ESO VLT SINFONI-SPIFFI instrument covering the inner parts of the Quintuplet cluster with 22 FOVs of 8×8 arcsec in the spectral range of 1.94 to 2.45 μm (K-band). The 3-D data cubes from the observations are flux-calibrated with standard stars and combined into a contiguous cube from which the spectra of all detected point sources are extracted. The spectral atlas and catalog of the sources, with coordinates and spectral classification, will be published soon (Liermann *et al.*, *A&A*, in prep.). We report the identification of two new Wolf-Rayet star candidates, adding to the 11 already-known

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WR stars in the Quintuplet cluster. These newly discovered WR stars are of spectral type WC9 or later.

The quantitative analysis of the extracted spectra is underway. Using the Potsdam Wolf-Rayet (PoWR) model atmosphere code, we will determine the parameters of all O-, B-, and WR-type stars in the cluster. This will shed light on the massive star population of the Quintuplet cluster, its formation and evolution.

Accurate Distances to Nearby Massive Stars with the New Reduction of the Hipparcos Raw Data

Jesús Maíz Apellániz, Emilio Alfaro (Instituto de Astrofísica de Andalucía-CSIC) & Alfredo Sota (Universidad Autónoma de Madrid)

The new reduction of the Hipparcos raw data (Van Leeuwen 2007, *A&A*, 474, 653) has reduced its parallax uncertainties up to a factor of 4 for bright stars. In this work we use the new data to recalculate the spatial distribution of massive stars in the solar neighborhood and to provide for the first time accurate trigonometric distances for several tens of massive stars. We will discuss alternative measurements and will show that previous issues with the Hipparcos parallaxes (e.g., the distance to the Pleiades) have been significantly reduced or altogether eliminated.

The Open Cluster Pismis 11 and Its Hypergiant

Amparo Marco & Ignacio Negueruela (University of Alicante)

We present photometry and spectroscopy of stars in the open cluster Pismis 11, which contains one of the brightest hypergiants in the Galaxy, the B2Ia$^+$ star HD80077. We calculate cluster parameters and hence, the distance and luminosity of the hypergiant.

A Systematic Search for Stellar Clusters in the Galactic Plane

Maria Messineo (Rochester Institute of Technology)

The identification of stellar clusters in the plane of our Galaxy is of primary importance for gaining a better understanding of the Galactic structure and current star formation rate as well as to identify and characterize the most massive stars in the Galaxy. However, such a study is strongly hampered by interstellar extinction. Several hundred new Galactic stellar clusters have been discovered in the last few years thanks to large near- and mid-infrared surveys, such as 2MASS and GLIMPSE. However, their census remains highly incomplete. I will give an overview of the total number of stellar clusters known and present a list of a dozen of candidate massive stellar clusters towards the inner Galaxy, one of them a new discovery. The clusters have been selected on the basis of their infrared color-magnitude diagrams. We are currently following up these results with NIR spectroscopy to obtain a spectral classification of the brightest and probably more massive stars of each cluster and therefore to better characterize the nature of the cluster.

The Massive Star Content of NGC 1140

Sarah Moll (University of Sheffield), Sabine Mengel (European Southern Observatory), Richard de Grijs (University of Sheffield), *et al.*

We use new UVES spectroscopy and HST imaging to study the massive stellar content of the Wolf-Rayet (WR) dwarf starburst galaxy NGC 1140. We obtain $12 + \log(O/H) = 8.3$

from a nebular analysis of the brightest knot of the central giant HII region. We find that cluster 1 within this knot has an age of ∼5 Myr and a mass of 1×10^6 $M_\odot$, from which 6000 O stars are inferred. Fitting the blue WR bump with LMC metallicity WR templates, we estimate that cluster 1 contains 550 late WN and 200 early WC stars. In common with other studies of metal-poor WR clusters, we estimate N(WR)/N(O) ∼ 0.1, a factor of two higher than instantaneous burst predictions from Geneva or Padova evolutionary models.

The Multi-Wavelength Picture of the Open Cluster Westerlund 2 and the Very Massive Binary WR 20a

Yaël Nazé & G. Rauw (Université de Liège)

Westerlund 2 is a young open cluster in a blowout region of the HII region RCW 49. The cluster contains a dozen O-type stars and WR20a, the most massive binary (83+84 $M_\odot$) known to date. Recently, we have undertaken a large, multiwavelength monitoring of the cluster. In the optical domain, the new photometric and spectroscopic data have led to a significant revision of the massive star content (with several stars shown to be as early as O3-4) and the discovery of additional eclipsing binaries. In addition, the deepest exposure in the X-ray domain was obtained with the Chandra satellite. This unprecedented X-ray observation reveals a wealth of sources in the cluster. In this presentation, we will focus on the very first spatially resolved X-ray data of the colliding wind binary WR20a, and we highlight the results obtained for the other massive objects in the cluster.

Formation of High-Mass Stars in Violent Cluster Environments

Dieter E. A. Nürnberger (European Southern Observatory, Chile)

High-mass stars are usually forming deeply embedded in their natal environment, which can be penetrated only at wavelengths beyond the mid IR. In my presentation, I will summarize our recent efforts to search for and to characterize high-mass protostars in interfaces between Galactic HII regions and their adjacent molecular clouds, e.g. in NGC 3603 (Nürnberger 2003, *A&A*, 404, 255) and in M17 (Chini et al. 2004, *A&A*, 427, 849, Chini *et al.* 2006, *ApJ*, 645, L61; Hoffmeister *et al.* 2006, *A&A*, 457, L29; Nielbock *et al.* 2007, *ApJ*, 656, L81; Nürnberger *et al.* 2007, *A&A*, 465, 931). Taking advantage of 'curtain-lifting' stellar winds and energetic photons from the central clusters of early-type main sequence stars and making use of sensitive, high angular resolution observations in the near and mid IR, we have identified promising candidates that play a decisive role in our understanding of the basic formation processes of high-mass stars. In particular, as we see strong evidence for the existence of (accretion) disks around these sources, one has to favour the accretion scenario against the collision (coalescence) scenario.

LBT Discovery of a Yellow Supergiant Eclipsing Binary in the Dwarf Galaxy Holmberg IX

J. L. Prieto (Ohio State University), *et al.*

See p. 333 for full article.

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Massive Stars in Young Dense Clusters

Fred Rasio (Northwestern University), *et al.*

We will present results from recent N-body simulations of massive stars in young dense clusters, focusing on the role of stellar collisions, binaries, and the possibility of runaway growth through successive collisions.

The Molecular Gas in High-Density Environments: From Submillimeter (mid-J) to Far-Infrared (high-J) Observations

J. Ricardo Rizzo (Laboratorio de Astrofísica Espacial y Fisica Fundamental-INTA, Spain) & F. M. Jiménez-Esteban (Observatorio Astronómico Nacional, Spain)

The study of molecular line emission surrounding evolved massive stars (mostly Wolf-Rayet and LBV) has been developed in the last decade. The role played by the molecules in the whole feedback between massive stars and their surroundings has changed from merely testimonial to becoming a significant fraction of it.

In this contribution we report the first detection of mid-J CO lines surrounding LBVs and Wolf-Rayets ever recorded. The main advantages of these lines are the high critical density and the high energy of the lower level. We have detected high density (from 10^4 to several 10^5 cm^{-3}) and warm (above 70 K) molecular gas surrounding ionized nebulae. The detection are not only supported by the morphology, but also by the dynamics, including the identification of low-velocity shockfronts (less than 20 km s^{-1}). Masses span from a few solar to 60 solar masses.

Our first results may serve as templates for future studies in three directions: (1) they can help to improve the numerical models about the interplay between massive stars and their CSM; (2) they can provide inputs for high-J observations which will help us to learn about the excited molecular gas; (3) they can be used as guides for the search in other cases, particularly stars of similar evolutionary stages. The future in this field concerns the search for vibrationally excited H_2, high-J CO emission, complex molecules, and PAHs. The advent of new high-sensitivity IR and submillimeter instrumentation will give support to this ample set of new observational lines.

Massive Star Binary Fraction in Nearby Open Clusters

H. Sana (European Southern Observatory, Chile)

While it is generally accepted that most (if not all) massive stars form in a cluster environment, the relation (if any) between the properties of a cluster and those of the O star population it hosts remains unclear. We revise here the properties of the massive stars in nearby young open clusters, with an emphasis on the binary fraction and on the orbital parameters distribution. The aim pursued is to provide accurate observational constraints, that should serve as guidelines for the theories of massive star formation and evolution,

Spitzer and Near-Infrared Imaging of the Massive Protostar IRAS 20126+4104 and Its Shocked Outflow

Steve Skinner & John Bally (University of Colorado), Manuel Güdel (Paul Scherrer Institut), *et al.*

Previous observations of the massive protostar IRAS 20126+4104 have revealed complex structure including a candidate massive circumstellar disk, radio jets, an extended (and

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possibly precessing) bipolar outflow, and maser emission. High-resolution Gemini images reveal a tightly spaced cluster of 18.3 μm sources near the methanol maser positions (De Buizer 2007, *ApJ*, 654, L147). We present Spitzer IRAC observations of IRAS 20126+4104 and ground-based images of the outflow in the H_2 S(1) (2.12 μm) and [Fe II] (1.64 μm) lines. The IRAC images at 3.6, 4.5, and 5.8 μm show emission extending to the northwest and southeast of IRAS 20126+4104, but no peak is seen at the protostar. However, a dominant peak in the IRAC 8 μm image is offset by only about 1 arc-second from the methanol maser and 18.3 μm source group, and is likely associated with a heavily obscured protostar. The H_2 image traces shocks extending for over 2 arc-minutes from IRAS 20126+4104 in a S-shaped pattern. This S-shaped pattern was also noted in CO (3-2) maps obtained by Su *et al.* (2007, *ApJ*, 671, 571) and was interpreted in terms of a collimated precessing outflow. However, we note that the symmetric placement of several H_2 knots about stars embedded in the extended IRAS 20126 core region indicates that multiple outflow sources may be present and could confuse the interpretation of the outflow morphology.

Distance Determination for the Brightest Cool Stars in Galaxies Using the Wilson-Bappu and Wing Emission Line Correlations

Robert Stencel (Denver University)

An empirical correlation between the FHWM of the emission core of the CaII K-Line at 3933 Å and the intrinsic luminosity among late-type dwarf, giant, and supergiant stars was published first by Wilson & Bappu (1957, *ApJ*, 125, 661). Later on, Stencel (1977, *ApJ*, 215,176) extended this luminosity calibrator by using so-called wing emission lines in the wings of the H and K lines. Efforts to extend these techniques to the brightest supergiants in Local Group galaxies were frustrated by the limits of photographic coudé spectra even on 4-meter telescopes at the time. With the advent of CCD spectra and S/N possible with 8-meter telescopes, I advocate the potential for extragalactic hypergiant star distance calibration.

Using the Paranal Observatory library of high-resolution spectra (www.sc.eso.org/-santiago/uvespop/) obtained from the UVES instrument at an ESO Very Large Telescope, we measure the line widths of the CaII H and K lines and the wing emission lines in late-type stars. By plotting the measured FWHM and absolute magnitude, we re-evaluate the Wilson-Bappu line-width-to-luminosity correlation for the K core emission and $H-K$ core wing emission lines. Because the $H-K$ wing emission lines remain visible in very luminous stars cooler than F1 whereas circumstellar absorption obliterates the core emission, the line-width-to-luminosity correlation may be useful in estimating intrinsic luminosity for these stars, particularly in comparison with new angular diameters possible with interferometry.

Massive Stars in the Galactic Center as Traced by Compact HII Regions

Susan Stolovy (Spitzer Science Center/CalTech), *et al.*

We investigate massive star formation in the Galactic Center with a study of compact HII region candidates identified in a Spitzer/IRAC survey. The survey covers approximately 3 square degrees in 4 channels at 3.6, 4.5, 5.8, and 8.0 μm, with a spatial resolution of 2 arcsec. These candidate compact HII regions exhibit strong 8 μm emission, are compact (typically $<20'$), have a variety of morphologies, and are strongly clustered toward the Galactic plane. A search is conducted for counterparts at other wavelengths.

Quantitative Spectral Analysis of BA Supergiants in M33

Vivian U, Rolf P. Kudritzki, Miguel A. Urbaneja (Institute for Astronomy, University of Hawaii), *et al.*

We present atmospheric parameters and metallicities for a sample of 10 late-B and early-A supergiants in M33. High-resolution spectra have been obtained with DEIMOS on Keck II during a 2003 observing campaign. Spectral types, initially estimated by a qualitative comparison between models and observed spectra, were confirmed by numerical analysis of several spectral lines; luminosity class was obtained from measuring the equivalent width of Hγ. We measure the radial and rotational velocities empirically and provide well-characterized spectra for our objects. We use a model grid of 1600 detailed non-LTE spectra varying in $T_{\rm eff}$, g, and metallicity parameter space to determine stellar parameters and metallicity, and then we discuss the evolutionary status of our objects and the metallicity gradient in M33. Finally, we use the results to investigate the relationship between stellar luminosity and flux-weighted gravity and compare them with the findings from Kudritzki *et al.* (2003, *ApJ*, 582, L83; Kudritzki 2007, *AAS*, 210, 40.03).

Discovery of Two Dust Pillars near the Galactic Plane

Leonardo Ubeda (Université Laval) & Anne Pellerin (Johns Hopkins University)

We report the discovery of two dust pillars using GLIMPSE archival images obtained with the Infrared Array Camera on board the Spitzer Space Telescope. They are located close to the Galactic molecular cloud GRSMC45.453+0.060, and they appear to be aligned with the ionizing region associated with GRSMC45.478+0.131. Our three colour mosaics show that these stellar incubators present different morphologies as seen from planet Earth. One of them shows the unquestionable existence of young stellar objects in its head, whose influence on the original cocoon is evident, while the other presents a well defined bright-rimmed ionizing front. We argue that second-generation star formation has been triggered in these dust pillars by the action of massive stars present in the nearby H II regions.

FGLR Distance to WLM

Miguel A. Urbaneja, Rolf Kudritzki, Fabio Bresolin (Institute for Astronomy, University of Hawaii), *et al.*

This contribution presents the first practical application of the flux-weighted gravity–luminosity relation of BA Supergiants (Kudritzki, Bresolin & Przybilla 2003, *ApJ*, 582, L83), to determine the distance to the Local Group galaxy WLM. The FGLR distance is consistent with the recent result obtained by the ARAUCARIA project based on Cepheids. The potential application of the FGLR to other galaxies is also discussed.

The Open Cluster Berkeley 90

Ana Ursúa, Amparo Marco, Ignacio Negueruela (University of Alicante), *et al.*

We present a deep optical and infrared photometric study of the area around the young open cluster Berkeley 90 and spectroscopy of its OB population. In spite of the presence of two early O-type stars, we find a low number of members earlier than B3. We find evidence for triggered star formation in the vicinity of the cluster.

A Near-IR Imaging Survey of Intermediate- and High-Mass Young Stellar Outflow Candidates

Watson P. Varricatt, Christopher J. Davis (Joint Astronomy Centre, Hilo, Hawaii), Suzanne K. Ramsay Howat (Institute of Astronomy, Royal Observatory, Edinburgh), *et al.*

We have carried out a near-infrared imaging survey of luminous young stellar outflow candidates using the United Kingdom Infrared Telescope. Observations were obtained in the near-infrared K band (2.2 μm) and at the wavelengths of H_2 (2.122 μm) and Br_γ (2.166 μm) lines. Fifty regions were imaged with a field of view of $2.2' \times 2.2'$. Seventy-four percent of the objects exhibited H_2 emission, and 50% exhibited aligned H_2 emission features implying collimated outflows, many of which are new discoveries. These observations imply that accretion is probably the leading mechanism in the formation of stars at least up to early B and even late O type. The YSOs responsible for many of these outflows are positively identified in our near-IR images based on their locations with respect to the outflow lobes, 2MASS colours, and association with MSX, IRAS, millimetre, and radio sources. The close association of the molecular outflows detected in CO with the H_2 emission features produced due to shock excitation by the jets from the YSOs implies that the outflows in these objects are jet driven. Br_γ emission is not detected in any of the outflows; it is therefore a poor tracer of outflows.

Aligned Circumstellar Disk Systems in Young Clusters

John P. Wisniewski (Goddard Space Flight Center), Karen S. Bjorkman (University of Toledo), Antonio M. Magalhaes (University of São Paulo), *et al.*

We have obtained and analyzed intrinsic polarization observations of Small Magellanic Cloud and Large Magellanic Cloud classical Be circumstellar disk systems. We found evidence of a single, cluster-wide preferential orientation of disk rotational axes in 2 of 11 (18%) clusters. The statistical significance of these trends has been confirmed via use of the Kuiper statistical test. For NGC 1948, the common orientation of disk rotational axes is parallel to the projected direction of the cluster's local magnetic field, whereas aligned disk systems in NGC 2100 do not have their rotational axes oriented parallel to the direction of the local magnetic field. We discuss the mechanisms that might be responsible for producing the observed alignment of disks in these two cluster environments.

The Physics of the Stellar Upper Mass Limit

Hans Zinnecker (Astrophysikalisches Institut Potsdam)

Is there an upper mass limit to the stellar IMF? And if yes, is it determined by stellar evolution physics (mass-loss mechanisms) or by star formation physics (mass accretion despite radiation pressure)?

Observational evidence suggests that there is a physical rather than a statistical upper limit to the mass of massive stars in rich young clusters such as R136 in the LMC (Weidner & Kroupa 2004, *MNRAS*, 348, 187; Oey & Clarke 2005, *ApJ*, 620, L43; Koen 2006, *MNRAS*, 365, 590) and the Arches cluster near the Galactic center (Figer 2005, *Nat*, 434, 192).

While in the past, pulsational instabilities near the Eddington limit were blamed for an upper mass limit (e.g., Smith & Owocki 2006, *ApJ*, 645, L45, for a review of η Car and other LBV stars), the current discussion focusses more on the mass accretion physics in the face of radiation pressure and the fragmentation or photo-evaporation

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of massive circumstellar disks (Keto & Wood 2006, *ApJ*, 637, 850; Kratter & Matzner 2006, *MNRAS*, 373, 1563; Krumholz 2006, *ApJ*, 641, L45). Cooperative rather than competitive accretion in dense ionized embedded OB clusters (Keto 2007, *ApJ*, 666, 976) and the merging of young massive close binaries (Bonnell & Bate 2005, *MNRAS*, 362, 915; Bally & Zinnecker 2005 *AJ*, 129, 2281) have also been suggested as important processes to limit the potentially infinite growth of massive stars.

The literature and the physical arguments are reviewed in a recent *Annual Reviews* article by Zinnecker & Yorke (2007, *ARA&A*, 45, 481).

In this contribution, I will present a summary of the physics of the upper mass limit of star formation, based on the *Annual Reviews* article, and also discuss future observational tests of the theoretical predictions (e.g., metallicity-dependence).

SESSION IV: Hydrodynamics and Feedback from Massive Stars in Galaxy Evolution

Winds of Embedded O Star Clusters

Sara Beck (Tel Aviv University)

Single O stars and WR stars drive powerful winds. How, then, do the small, dense supernebulae of embedded O star clusters persist long enough to be observed? Is it overpressure, gravitation, slow mass-loaded winds, or a combination? What does the IR and radio data on clusters suggest about this?

SPH Simulations of Star Formation Triggered by Expanding HII Regions

Thomas G. Bisbas, Anthony P. Whitworth & Richard Wunsch (School of Physics and Astronomy, Cardiff University)

We introduce a new 3-D SPH algorithm to study the evolution of HII regions. The algorithm constructs a set of rays around the source of ionizing photons using HEALPix (Górksi *et al.*, 2005, *ApJ*, 622, 759). Along each ray we locate the ionization front by applying the condition for photoionization equilibrium. We split the rays adaptively so that their angular separation is always comparable to the particle sizes in their neighbourhood. This ensures the necessary resolution of ray tracing while keeping the computational costs low.

We have used this new algorithm to study the properties of fragments formed by self gravity in the dense shells swept up by expanding HII regions. These simulations demonstrate that under suitable conditions the shell breaks up into massive ($\gtrsim 10\,M_\odot$) fragments some of which are likely to collapse to form massive stars. Therefore this is a viable mechanism for sequential self-propagating star formation.

NLTE Hydrostatic Equilibrium Solutions for Viscous Keplerian Disks

J. E. Bjorkman (University of Toledo) & A. C. Carciofi (University of São Paulo)

We investigate the interplay between the temperature structure and the geometrical structure of the disks around hot stars. Observational evidence suggests that these disks are Keplerian (rotationally supported) gaseous disks. The essential physics that determines the geometrical structure of Keplerian disks is reasonably well understood in the case of pre-main-sequence stars. The primary result is that the disks are hydrostatically supported in the vertical direction, while the radial structure is governed by the viscous transport. Since the disk is pressure-supported in the vertical direction, the geometrical structure (flaring) of the disk is determined by the radiative equilibrium temperature. Similarly the viscous transport of material is temperature dependent, so the radial density structure also depends on the radiative equilibrium temperature. To investigate the coupling between the temperature and density structures, we performed 3-D NLTE Monte Carlo simulations of the radiative transfer and solved self-consistently for the temperature and density structure of the disk. These simulations also calculate the emergent spectrum and its polarization. We find that the hydrostatic solution for the disk departs significantly from the often-assumed isothermal structure and simple power laws, with significant observational effects on the emergent spectrum.

Probing Variable Circumstellar Disks with Contemporaneous Optical and IR Spectroscopy

Karen S. Bjorkman, Erica N. Hesselbach (University of Toledo), John P. Wisniewski (Goddard Space Flight Center), *et al.*

Asymmetric double-peaked hydrogen emission line profiles in classical Be stars have been interpreted as evidence of one-armed density waves in the circumstellar disks. Contemporaneous optical and IR spectroscopy can aid in mapping the density structure of these putative one-armed waves as a function of radius. Variability has been detected in these stars over both short (days to weeks) and longer (months) timescales. We present preliminary results from contemporaneous Ritter Observatory (Hα) and IRTF SpeX (0.8–5.4 μm) spectroscopy of a selection of classical Be stars observed between 2004 and 2007. The data illustrate a range of line profiles common in Be stars and show significant variability, present in both the optical and IR lines. By combining with detailed models, these observations can be used to investigate the physical density distribution, temperature structure, and variability of the circumstellar disks.

The Carina Nebula: A Laboratory for Feedback and Triggered Star Formation

Kate Brooks (CSIRO Australia Telescope National Facility) & Nathan Smith (Astronomy Department, University of California, Berkeley)

The Carina Nebula (NGC 3372) is our richest nearby laboratory in which to study feedback through UV radiation and stellar winds from very massive stars during the formation of an OB association, before supernova explosions have disrupted the environment. In Carina, this feedback is triggering successive generations of new star formation around the periphery of the nebula, while simultaneously evaporating the gas and dust reservoirs out of which young stars are trying to accrete material. Carina is currently powered by UV radiation from 64 O stars and 3 WNL stars but for most of its lifetime when its most massive star (η Carinae) was on the main-sequence, the Carina Nebula was powered by 69 O stars that produced a hydrogen ionizing luminosity 200 times stronger than the Orion Nebula. At a distance of only 2.3 kpc, Carina has the most extreme stellar population within a few kpc of the Sun, and suffers little interstellar extinction. In this poster I will present a census of the Carina Nebula.

Circumstellar Medium around Massive Stars

Sabina Chita & Norbert Langer (Astronomical Institute Utrecht)

Massive stars interact with their surroundings by emitting winds and ionizing photons. Here we simulate the evolution of the circumstellar medium around stars of 12 solar masses from their birth up to the supernova stage. These stars are expected to expand at least twice into red supergiants with intermediate blue stages where fast winds are emitted. Stellar wind anisotropies expected during the blue loop will give rise to a latitudinal dependence of the shell structures as observed in Sher 25 and SN 1987A. We utilize the stellar parameters as function of time from detailed stellar evolution calculations as input for our hydrodynamic models.

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Filament Formation and X-ray Emission in Starburst Winds

Jackie L. Cooper (Research School of Astronomy and Astrophysics, The Australian National University), *et al.*

Galactic winds are an important component of feedback processes in galaxy formation and the enrichment of the intergalactic medium. We have performed a series of three-dimensional simulations of a starburst-driven galactic wind in an inhomogeneous interstellar medium. We find that the emission-line filaments, which are a spectacular feature of starburst winds, are formed from disk gas that has been accelerated into the outflow by the ram-pressure of the wind. Chandra observations of starburst winds have revealed a close spatial relationship between the filamentary gas and the soft X-ray emission. While higher resolution simulations are required in order to determine the importance of mixing processes, we propose four mechanisms that give rise to soft X-ray emission that is also naturally correlated with the filaments: (i) Mass-loading from ablated clouds, (ii) the intermediate temperature interface between the hot wind and cool filaments, (iii) bow shocks upstream of clouds accelerated into the outflow, and (iv) interactions between these bow shocks.

Kinematics of Small Starbursts: NGC 2363 and NGC 5253

Laurent Drissen, Leonardo Ubeda, Maxime Charlebois (Université Laval), *et al.*

I will present GMOS/IFU observations of young bursts of star formation in the nearby dwarf galaxies NGC 2366 and NGC 5253.

A High-Resolution Study of SN Ejecta and Circumstellar Mass-Loss Interactions

Robert Fesen & Jordan Zastrow (Dartmouth College)

We present HST images of the outer edges of the young, core-collapse supernova remnant Cas A which reveal dozens of small (<1 arcsec) knots of a SN's metal-rich, high-speed ejecta interacting with a clumpy, N-rich circumstellar mass loss medium. Such SN ejecta–CSM interactions are seen to give rise to substantial ejecta knot brightness variations on timescales as short as one year, along with trailing ablation emission "tails" extending along the direction of a knot's motion. We will primarily present and discuss SN ejecta–CSM interactions occurring along the remnant's eastern limb and in the northeastern "jet" containing especially high-velocity ejecta.

BLAST Observations of the Cassiopeia A Supernova Remnant

Peter Hargrave (Department of Physics & Astronomy, Cardiff University), *et al.*

We present BLAST observations at 250, 350, and 500 μm of the SNR Cassiopeia A (Cas A), and its surroundings. We find that the SED in the direction of Cas A is best fit by a two-temperature modified black-body function, whilst the surrounding cloud region SED can be fit by a single temperature. The temperature of the cloud region is found to be the same as the temperature of the cold component of the fit in the direction of Cas A. This suggests that the cold component of the Cas A SED may be associated with an extended foreground cloud structure, rather than with the remnant. This result does not exclude the possibility of cold dust associated with the remnant, but sets upper limits on the mass of any dust which may be present.

The Circumstellar Structure and Massive Progenitors of Interacting Supernovae

Jennifer L. Hoffman (University of Denver)

In the past few years, more and more supernovae whose spectra show signatures of interaction with circumstellar material ejected by their evolved progenitor stars have been discovered. Studying the environments of these "interacting supernovae," which include members of the Type IIn subclass, can yield important information about core-collapse progenitors and the role of mass loss in the end stages of massive stellar evolution. One obstacle to understanding these supernovae has been their heterogeneity as a group; the IIn supernovae alone span a broad range of spectral characteristics, light-curve morphologies, intrinsic brightnesses, and many other properties. Spectropolarimetric observations provide a way to break the degeneracies often inherent in supernova spectra; analysis of polarized spectra may thus hold the key to subdividing the category of interacting supernovae and thereby constraining the properties of their progenitors.

One common signature of interacting supernovae is the presence of a strong narrow Hα line, often consisting of several superposed components and often intrinsically polarized by scattering in the circumstellar envelope. I will present results from numerical modeling of Hα line profiles in direct and scattered light that provide clues to the geometrical structure of the circumstellar material around interacting supernovae. I will also review the observed line profile behavior of Type IIn supernovae and its correlations with other supernova characteristics. Finally, I will discuss what these results can tell us about the massive stellar progenitors of interacting supernovae.

High-Resolution Observations of Obscured LBV Nebulae

Cornelia Lang (Department of Physics & Astronomy, University of Iowa), *et al.*

Recent progress has been made on understanding the physical properties of LBVs and their circumstellar nebulae (LBVNe) in obscured regions of the Galaxy by using radio and infrared observations. We present high-resolution radio and infrared data on 7 new LBV sources in our Galaxy (including the Pistol Star, AFGL 2298, NaSt1, LBV 1806-20, and others). Multi-frequency radio data provide measurements of the stellar wind source and nebular spectral indices, the mass-loss rates for the central stellar winds, and parameters of the physical conditions of the LBVNe. We present interpretation of the radio data along with high-resolution infrared spectroscopy that provides new insight into the processes by which these stars are ejecting mass, and the interstellar environments into which they are expanding.

Evidence for a Mass Outflow from Our Galactic Center

Casey J. Law (Astronomical Institute, University of Amsterdam)

See p. 407 for full article.

SNR 4449-1: A Very Young Supernova Remnant from a Massive Progenitor Star

Dan Milisavljevic & Robert Fesen (Dartmouth College)

A young (age ~100 yr) and highly luminous O-rich supernova remnant in NGC 4449 shares many properties with the Galactic supernova remnant Cas A. Ground-based and

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HST optical images and spectra show 6000 $\mathrm{km\,s^{-1}}$ expanding O-rich ejecta. The remnant's high luminosity is likely due to a recent and strong interaction of the ejecta with dense, pre-SN circumstellar material. This is indicated by 500 $\mathrm{km\,s^{-1}}$ Hα and [N II] emissions, with line ratios suggesting a nitrogen overabundance around 10 times solar. The surrounding CSM appears clumpy ($n \sim 10^5$) with some portion possibly distributed in a ring. The remnant lies near the center of a rich OB + WR cluster, and we estimate a progenitor mass of at least 20 $M_\odot$. This object may represent a much more luminous version of the Cas A remnant seen at a considerably earlier stage of CSM interaction.

Spitzer Observations of the Young Core-Collapse Supernova Remnant E0102: Infrared Ejecta Emission and Dust Formation

Jeonghee Rho, William Reach (Spitzer Science Center/Caltech), Achim Tappe (Harvard-Smithsonian Center for Astrophysics), *et al.*

We present Spitzer IRS and IRAC observations of the young supernova remnant E0102 (SNR 0102.2-7219) in the Small Magellanic Cloud. E0102 has some notable similarities to Cas A: both had massive progenitors of comparable masses and show optically emission from highly enriched oxygen ejecta as high velocity knots. The infrared spectra of E0102 showed ejecta lines of Ne, Si, S, and O. Among these lines, Ne lines are dominant: two [Ne III] lines at 15.5 and 36.0 μm, and two [Ne V] lines of 14.3 and 24.3 μm. The main element difference in E0102 is lack of Ar and Fe lines, compared to those of Cas A. It implies different nucleosynthesis and/or emitting conditions between the two SNRs. The [Ne II] line at 12.8 μm shows high-velocity dispersion of $\sim$3000 $\mathrm{km\,s^{-1}}$, showing fast moving ejecta material. The continuum emission is from the same places as the ejecta lines, suggesting that dust forms in the supernova ejecta. The spectra also show a broad dust feature at 17 μm. IRAC 8 μm emission is detected from the strong optical ejecta knots. We will discuss the distribution and physical conditions of ejecta elements and the inferred total dust mass from freshly formed dust, and compare dust mass and composition with those of Cas A.

Kinematics of Superbubbles in Irregular Galaxies

Margarita Rosado & Patricia Ambrocio-Cruz (Instituto de Astronomia, Universidad Nacional Autonoma de Mexico)

This work presents three examples of previous kinematical studies on superbubbles in irregular galaxies: (i) the non-thermal superbubble in IC 10, possibly formed by a hypernova (Yang & Skillman 1993, *AJ*, 106, 1448; Bullejos & Rosado 2002, *Rev. Mex. A&A*, 12, 254; Lozinskaya & Moiseev, 2007, *MNRAS*, 381, L26), (ii) the network of supernova-plus wind-driven superbubbles that have perforated the ISM in IC 1613 (Valdez-Gutiérrez *et al.* 2001, *A&A*, 366, 35); (iii) the S3 nebula, hosting a WO star also in IC 1613 (Rosado *et al.* 2001; *AJ*, 122, 194; Borissova et al. 2004, *A&A*, 423, 97). These examples illustrate how massive stars of irregular galaxies have a profound influence in shaping the ISM in their host galaxies. The Fabry-Perot interferometer PUMA (Rosado *et al.* 1995, *Rev. Mex A&A*, 3, 263) was used to carry out the Hα and S II line observations.

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Investigating the Circumstellar Environments of the Cool Hypergiants

Michael T. Schuster (University of Minnesota), Massimo Marengo (Harvard-Smithsonian Center for Astrophysics) & Roberta Humphreys (University of Minnesota)

The cool hypergiants are among a few highly unstable, very massive stars that lie on or near the empirical upper luminosity boundary in the H-R diagram. As a consequence of their very high mass-loss rates many of these stars are expected to have extensive circumstellar (CS) nebulosity. We investigate the cool hypergiants' CS environments and discuss how the presence and extent of CS nebulosity provide a record of their evolutionary histories. Each star's local interstellar environment can also play an important role in shaping the CS nebulosity and determining what we observe. The extremely luminous OH/IR M-type hypergiant NML Cyg is surrounded by an inverted HII region, where gas is ionized externally by Lyman continuum radiation from Cyg OB2. High angular resolution, high-contrast HST and mid-IR AO images of NML Cyg reveal an enigmatic asymmetric CS cocoon likely shaped through photo-dissociation and grain destruction by the near-UV radiation from the massive, hot stars within Cyg OB2. High-resolution HST and mid-IR AO images of the peculiar F-type hypergiant ρ Cas, famous for its shell ejections, show no CS material. The G-type hypergiant HR5171A also has no discernible CS material, but Spitzer/IRAC images reveal that it once dominated its local environment by creating a large HII and photo-dissociation region.

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SESSION V: Massive Stars as Probes of the Early Universe

The Nucleosynthetic Products of the First Massive Stars

Ann Merchant Boesgaard, Emily M. Levesque & Jeffrey A. Rich (Institute for Astronomy, University of Hawaii)

The extremely metal-poor (EMP) stars ($-4.0 < [Fe/H] < -3.0$) were formed in the earliest days of the Galaxy. Such stars contain the products of the early generations of massive stars. During stellar evolution of the massive stars and through their supernovae explosions, atoms of C, N, and O are created. The production of CNO, in turn, produces the rare light elements, Li, Be, and B through spallation reactions, either in the vicinity of the supernovae or in the ambient interstellar gas. Both Be and O are tied to the rate of supernovae; the abundance of Be in EMP stars is a tracer of massive star formation within our Galaxy. We have obtained high-resolution, high signal-to-noise spectra of about 15 stars with $[Fe/H] < -2.8$ using HIRES on the Keck I telescope. We have determined abundances of Be from the resonance lines of Be II at 3130 and 3131 Å and O from 3 OH lines in the UV in order to investigate the early nucleosynthesis processes in the Galaxy. We have found the stellar effective temperatures and gravities of our sample spectroscopically, using equivalent widths of Fe I, Fe II, Ti I, and Ti II. Our results indicate that there is a linear relationship between the logarithmic abundances of Be and O. As O increases in the Galaxy by two orders of magnitude, Be increases by a factor of 170. The SNe type II processes can produce both the Be and the O. This is supported by NSF AST05-05899.

Type Ib/c and II SN Rates and the Hubble Sequence

Francesco Calura (INAF-Osservatorio Astronomico di Trieste)

We compute the type Ib/c and II supernova (SN) rates as functions of the cosmic time for galaxies of different morphological types. We use four different chemical evolution models, each one reproducing the features of a particular galactic morphological type: E/S0, S0a/b, Sbc/d, and Irr galaxies. These models are used to study the evolution of the SN rates per unit luminosity and per unit mass as functions of cosmic time and as functions of the Hubble type. We explain the increase of the Ibc and II SN rate per unit mass observed in local galaxies as due to the higher star formation rates per unit mass of the latest Hubble types, in agreement with the popular downsizing scenario for galaxy formation.

Massive Stars in Hickson Compact Groups as a Tracer of the Early Universe

Jane C. Charlton, Jason E. Young (Pennsylvania State University), Patrick R. Durrell (Youngstown State University, Ohio), *et al.*

Compact groups of galaxies have some important similarities to protogalactic groups in the early universe. They have frequent interactions, the velocities of encounters are similar, and their gas is often stripped from the galaxies. Thus the formation of massive stars in compact groups, particularly those that form outside of galaxies, and their influence on their environment could provide clues to how these processes work at high redshift. We have embarked on a multi-wavelength study of twelve Hickson compact groups.

We will summarize the results of our Spitzer study of these groups. We find that the groups that are most gas-rich have the most active star formation. About half of the

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giant galaxies in the groups show red, mid-infrared colors in their nuclei, characteristic of AGNs and/or star formation, and that there is more such activity in the gas-rich groups.

We also present an analysis of the star clusters populations and the extended tidal sources in the contrasting examples of HCG 7 and HCG 31. This analysis is based on our HST/ACS BVI images of these groups. HCG 31 has widespread extremely recent star formation in the debris outside of the galaxies while HCG 7 is relatively quiescent.

Two- and Three-Dimensional Simulations of Mixing in Type II Supernovae

Candace Church Joggerst (University of California, Santa Cruz)

We present 2- and 3-dimensional simulations of zero- and solar-metallicity stars in the last stages of their lives and estimate their resulting nucleosynthetic output. When primordial stars with masses less than about 100 solar masses explode as type II supernovae, some portion of the star falls back onto the black hole, while the rest escapes to enrich the next generation of stars. The composition of the escaped gas depends on processes, such as Rayleigh-Taylor-induced mixing, that cannot be adequately modeled in one dimension. Multidimensional simulations are needed to capture the inherently asymmetric processes that enrich the outer layers of the star and determine its final yield. We find that Rayleigh-Taylor-induced mixing operates more efficiently in solar-metallicity stars than in their zero-metallicity counterparts. Our nucleosynthetic yields for zero-metallicity stars reproduce the high [C/Fe] and [O/Fe] ratios observed in the most metal poor stars known.

Detecting $z > 2$ Type IIn Supernovae

Jeff Cooke (University of California, Irvine), Mark Sullivan (Oxford University) &
Elizabeth Barton (UC Irvine)

Luminous blue variables ($M \gtrsim 80\,M_\odot$) have been identified as the likely progenitors of Type IIn SNe (SNe IIn). The intrinsic bright and blue continua of SNe IIn enable photometric detection at $z > 2$ in existing deep optical surveys. In addition, observations of the bright emission lines in low-redshift SNe IIn indicate that the emission lines of $z > 2$ events are above the spectroscopic thresholds of existing facilities. Detections of $z > 2$ SNe IIn will measure the supernova rate and trace the sites of recent star formation during this early epoch. In addition, detections will provide a statistical means to quantify the SN contribution to galactic feedback, mass loss, and enrichment of the IGM and constrain the high-mass end of the IMF for targeted $z > 2$ galaxy populations. We present results from Phase I of our program to detect $z > 2$ SNe IIn monitoring color-selected galaxies in the CFHTLS Deep Synoptic survey. Our technique exploits (1) the efficiency of $z > 2$ galaxy photometric color selection, (2) the sensitivities and wide-field capabilities of existing optical facilities, and (3) the intrinsic brightness and dispersion ($= -19.0 \pm 0.9$) of Type IIn SNe that extends well into the FUV (1200–2000 Å).

Modelling Dust Formation of Supernovae Ejecta

Christa Gall, Anja C. Andersen (Dark Cosmology Center, University of Copenhagen),
Ernst A. Dorfi (Institute of Astronomy, University of Vienna), *et al.*

Dust grains play a crucial role in the formation and evolution history of stars and galaxies in the early Universe. The presence of dust at high redshift seems to require efficient condensation of dust grains in supernova ejecta. Yet, observations of a few well-studied supernova remnants imply condensation efficiencies, which are several orders of magnitude below what is predicted by some theoretical models.

The aim of this project is the development of a self-consistent model, which treats the evolution of core-collapse supernova ejecta, arising from the first population of stars in the Universe. The constructed model is based on radiation hydrodynamic and will simulate the dust nucleation and grain growth scenario and the possible survival of these grains during the forward and so-called "reverse shock," which develops out of the code in succession of the interaction with the ambient interstellar medium. Of particular interests are the abundance of the formed dust, the time of the whole dust forming process, the grain temperature and the grain-size distribution of the particles, the possible crystal structure, and the different mineral types, as well as the dust production efficiency.

Radiative Transport Using SimpleX

Chael Kruip, Vincent Icke & Jan-Pieter Paardekooper (Sterrewacht Leiden)

SimpleX is a new, versatile radiative transfer code applicable to a wide variety of problems. It describes the transport of radiation as a random walk on an unstructured grid which represents the physical problem. Using such a physical grid makes the method computationally very fast and allows for high spatial resolution. Furthermore, the computational cost does not scale with the number of sources, making SimpleX ideal for simulations of, for example, re-ionization. Because the number of sources is irrelevant, diffuse photons can be incorporated trivially. We are in the process of coupling SimpleX to the Flash hydro-code in order to model radiation driven outflows in stellar atmospheres.

Metallicities at the Sites of Nearby SNe Ic and Implications for the SN-GRB Connection

Maryam Modjaz (University of California, Berkeley), *et al.*

See p. 503 for full article.

BRIght Target Explorer Constellation

A. F. J. Moffat (Département de Physique, Université de Montréal), W.W. Weiss (Institut für Astronomie, Universität Wien), S. M. Rucinski (Department of Astronomy and Astrophysics, University of Toronto), *et al.*

The primary goal of BRITE-Constellation is to constrain the basic properties of intrinsically luminous stars—stars that most affect the ecology of the Universe—by measuring their oscillations in both brightness and temperature with precision down to 10's of micromagnitudes on hour to month timescales, based on dual-broadband photometric time-series from space. BRITE-Constellation is a fleet of 4 independently free-flying nanosatellites to be launched starting in 2009. Each nanosat contains a 30 mm telescope with either a blue or red optical filter and CCD detector to image the sky in a 24-degree field of view. This will enable mmag-precision photometry or better on timescales of $\sim$15 minutes for all the $\sim$300 stars in the sky brighter than $V \sim 3.5$. As it turns out, most of these stars are also among the intrinsically brightest stars, which fall into two broad classes: massive stars during their whole lifetimes and intermediate-mass stars at the end of their nuclear-burning phases. It may appear strange that the brightest naked-eye stars in the sky have not generally been photometrically scrutinized with the same high precision as many of their fainter cousins. The reason for this is that the brightest stars are relatively sparsely distributed across the sky and thus difficult to measure properly from the ground. Because its targets are the brightest naked-eye stars in the sky, BRITE Constellation will also provide a special appeal to the public. The three-axis pointing performance (1 arcminute RMS stability) of each BRITE satellite is a significant advancement over anything that has ever flown before on a nanosatellite and is an important factor that enables this relatively inexpensive high-precision photometry mission.

SN Less Long Duration GRBs: Clues to their Nature from Their Environment?

Christina C. Thöne, Johan P. U. Fynbo, Paul M. Vreeswijk (Dark Cosmology Centre), *et al.*

The connection between long-duration GRBs and supernovae (SNe) seemed to be an established fact when last year, two long-duration GRBs with no SN signature in their light curves were found. One of them, GRB 060505 was an especially interesting case to study as it was hosted in a star-forming region in a rather nearby spiral galaxy. The properties of the burst site are rather different from the rest of the galaxy and resemble the properties of the more usual long GRB hosts which are highly star-forming, low-metallicity dwarf galaxies. Similar studies can be done with a few other spiral galaxies that hosted long-duration GRBs of which one, GRB 980425, was clearly connected to a SN. Comparing these hosts and the conditions at the GRB site, we try to get a conclusion about the nature of the SN-less long GRBs.

Galaxy-wide Census of Massive Dust-Producing Stars

Earl S. Wood (Western Kentucky University)

Massive stars can produce copious amounts of dust. We attempt to define the relevant yields and pathways of dust-production and extrapolate them to the environment of the early Universe. For this purpose, we use the 2MASS database and conduct a Galaxy-wide search for relatively massive ($M_i > 2M_\odot$) dust-producing stars, with $\sim$1100 sources detected so far. Among them, $\sim$75% have no previous classification. Combining all the available optical-IR measurements and constructing optical-IR spectral energy distributions, we separate the known sources into four major categories: [extreme] carbon, OH/IR, Wolf-Rayet, and B[e]wd stars. As for the unknown sources, we have discovered that while [extreme] carbon stars and OH/IR stars likely comprise 85% of them, there is a handful of objects that could be classified as Wolf-Rayet WC-binary pinwheel candidates. We also single out $\sim$50 unclassifiable objects with rather exotic (extreme reddening, low envelope temperatures) spectral energy distributions.