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Accepted Papers

Dust formation by the colliding-wind WC5+O9 binary WR19 at periastron passage

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We present infrared photometry of the episodic dust-making Wolf-Rayet system WR19 (LS3), tracking its fading from a third observed dust-formation episode in 2007 and strengthening the view that these episodes are periodic ($P = 10.1 \pm 0.1y$). Radial velocities of the O9 component observed between 2001 and 2008 show RV variations consistent with WC19 being a spectroscopic binary of high eccentricity ($e = 0.8$), having periastron passage in 2007.14, shortly before the phase of dust formation. In this respect, WR19 resembles the archetypical episodic dust-making colliding-wind binary system WR 140.

Reference: MNRAS

On the web at: `ftp://ftp.roe.ac.uk/pub/pmw/wr19periastron.ps.gz`

Preprints from: `pmw@roe.ac.uk`

Orbitally modulated dust formation by the WC7+O5 colliding-wind binary WR140

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We present high-resolution infrared (2–18 μm) images of the archetypal periodic dust-making Wolf-Rayet binary system WR140 (HD 193793) taken between 2001 and 2005, and multi-colour ($J-[19.5]$) photometry observed between 1989 and 2001. The images resolve the dust cloud formed by WR140 in 2001, allowing us to track its expansion and cooling, while the photometry allows tracking the average temperature and total mass of the dust. The combination of the two datasets constrains the optical properties of the dust, and suggest that they differ from those of the dust made by the WC9 dust-makers, including the classical 'pinwheel', WR104. Photometry of individual dust emission features shows them to be significantly redder in (nbL'–[3.99]), but bluer in ([7.9]–[12.5]), than the binary, as expected from the spectra of heated dust and the stellar wind of a Wolf-Rayet star. The most persistent dust features, two concentrations at the ends of a 'bar' of emission to the south of the star, were observed to move with constant proper motions of 324 ± 8 and 243 ± 7 mas y^{-1}. Longer wavelength (4.68-μm and 12.5-μm) images shows dust emission from the corresponding features from the previous (1993) periastron passage and dust-formation episode, showing that the dust expanded freely in a low-density void for over a decade, with dust features repeating from one cycle to the next. A third persistent dust concentration to the east of the binary (the 'arm') was found to have a proper motion sim 320 mas y^{-1}, and a dust mass about one-quarter that of the 'bar'. Extrapolation of the motions of the concentrations back to the binary suggests that the eastern 'arm' began expansion 4–5 months earlier than those in the southern 'bar', consistent with the projected rotation of the binary axis and wind-collision region (WCR) on the sky. Comparison of model dust images and the observations constrain the intervals when the WCR was producing sufficiently compressed wind for dust nucleation in the WCR, and suggests that the distribution of this material was not uniform about the axis of the WCR, but more abundant in the following edge in the orbital plane.

Reference: MNRAS

On the web at: `ftp://ftp.roe.ac.uk/pub/pmw/wr140dust.ps.gz`

Preprints from: `pmw@roe.ac.uk`

Sub-surface convection zones in hot massive stars and their observable consequences

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We study the convection zones in the outer envelope of hot massive stars which are caused by opacity peaks associated with iron and helium ionization. We determine the occurrence and properties of these convection zones as function of the stellar parameters. We then confront our results with observations of OB stars. A stellar evolution code is used to compute a grid of massive star models at different metallicities. In these models, the mixing length theory is used to characterize the envelope convection zones. We find the iron convection zone (FeCZ) to be more prominent for lower surface gravity, higher luminosity and higher initial metallicity. It is absent for luminosities below about $10^{3.2}L_\odot$, $10^{3.9}L_\odot$, and $10^{4.2}L_\odot$ for the Galaxy, LMC and SMC, respectively. We map the strength of the FeCZ on the Hertzsprung-Russell diagram for three metallicities, and compare this with the occurrence of observational phenomena in O stars: microturbulence, non-radial pulsations, wind clumping, and line profile variability. The confirmation of all three trends for the FeCZ as function of stellar parameters by empirical microturbulent velocities argues for a physical connection between sub-photospheric convective motions and small scale stochastic velocities in the photosphere of O- and B-type stars. We further suggest that clumping in the inner parts of the winds of OB stars could be caused by the same mechanism, and that magnetic fields produced in the FeCZ could appear at the surface of OB stars as diagnosed by discrete absorption components in ultraviolet absorption lines.

Reference: Astronomy & Astrophysics

On the web at: `www.astro.uu.nl/~cantiell/articles/convection.pdf`

Preprints from: `m.cantiello@uu.nl`

Fundamental parameters of B Supergiants from the BCD System. I. Calibration of the (λ_1, D) parameters into $T_{\rm eff}$

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Effective temperatures of early-type supergiants are important to test stellar atmosphere- and internal structure-models of massive and intermediate mass objects at different evolutionary phases. However, these $T_{\rm eff}$ values are more or less discrepant depending on the method used to determine them. We aim to obtain a new calibration of the $T_{\rm eff}$ parameter for early-type supergiants as a function of observational quantities that are: a) highly sensitive to the ionization balance in the photosphere and its gas pressure; b) independent of the interstellar extinction; c) as much as possible model-independent. The observational quantities that best address our aims are the (λ_1, D) parameters of the BCD spectrophotometric system. They describe the energy distribution around the Balmer discontinuity, which is highly sensitive to $T_{\rm eff}$ and log g. We perform a calibration of the (λ_1, D) parameters into $T_{\rm eff}$ using effective temperatures derived with the bolometric-flux method for 217 program stars, whose individual uncertainties are on average Δ $T_{\rm eff}/T_{\rm eff}$=0.05. We obtain a new and homogeneous calibration of the BCD (λ_1, D) parameters for OB supergiants and revisit the current calibration of the (λ_1, D) zone occupied by dwarfs and giants. The final comparison of calculated with obtained $T_{\rm eff}$ values in the (λ_1,D) calibration show that the latter have total uncertainties, which on average are $\epsilon T_{\rm eff}/T_{\rm eff}$ $\sim$0.05 for all spectral types and luminosity classes. The effective temperatures of OB supergiants derived in this work agree on average within some 2,000 K with other determinations found in the literature, except those issued from wind-free non-LTE plane-parallel models of stellar atmospheres, which produce effective temperatures that can be overestimated by up to more than 5,000 K near $T_{\rm eff}$=25,000 K. Since the stellar spectra needed to obtain the (λ_1, D) parameters are of low resolution, a calibration based on the BCD system is useful to study stars and stellar systems like open clusters, associations or stars in galaxies observed with multi-object spectrographs and/or spectro-imaging devices.

Reference: Astronomy and Astrophysics

On the web at: http://arxiv.org/abs/0903.5134

Preprints from: zorec@iap.fr

The nature of the light variability of the silicon star HR 7224

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Although photometric variations of chemically peculiar (CP) stars are frequently used to determine their rotational periods, the detailed mechanism of their light variability remains poorly understood. We simulate the light variability of the star HR 7224 using the observed surface distribution of silicon and iron. We used the TLUSTY model atmospheres calculated for the appropriate silicon and iron abundances to obtain the emergent flux and to predict the rotationally modulated light curve of

the star. We also obtained additional photometric measurements and employed our own regression procedure to derive a more precise estimate of the light elements. We show that the light variation of the star can be explained as a result of i) the uneven surface distribution of the elements, ii) the flux redistribution from the ultraviolet to the visible part of the spectrum, and iii) rotation of the star. We show that the silicon bound-free transitions and iron bound-bound transitions provide the main contribution to the flux redistribution, although an additional source of opacity is needed. We confirm that numerous iron lines significantly contribute to the well-known depression at 5200 A and discuss the connection between iron abundance and the value of peculiarity index a. The uneven surface distribution of silicon and iron is able to explain most of the rotationally modulated light variation in the star HR 7224.

Reference: A&A, in press

On the web at: `http://lanl.arxiv.org/abs/0904.0231`

Preprints from: `krticka@physics.muni.cz`

The Physical Properties of the Red Supergiant WOH G64: The Largest Star Known?

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WOH G64 is an unusual red supergiant (RSG) in the Large Magellanic Cloud (LMC), with a number of properties that set it apart from the rest of the LMC RSG population, including a thick circumstellar dust torus, an unusually late spectral type, maser activity, and nebular emission lines. Its reported physical properties are also extreme, including the largest radius for any star known and an effective temperature that is much cooler than other RSGs in the LMC, both of which are at variance with stellar evolutionary theory. We fit moderate-resolution optical spectrophotometry of WOH G64 with the MARCS stellar atmosphere models, determining an effective temperature of 3400 +/- 25 K. We obtain a similar result from the star's broadband V - K colors. With this effective temperature, and taking into account the flux contribution from the aysmmetric circumstellar dust envelope, we calculate $\log(L/L_{\odot})$ = 5.45 +/- 0.05 for WOH G64, quite similar to the luminosity reported by Ohnaka and collaborators based on their radiative transfer modeling of the star's dust torus. We determine a radius of $R/R_{\odot}$= 1540, bringing the size of WOH G64 and its position on the H-R diagram into agreement with the largest known Galactic RSGs, although it is still extreme for the LMC. In addition, we use the Ca II triplet absorption feature to determine a radial velocity of 294 +/- 2 km/s for the star; this is the same radial velocity as the rotating gas in the LMC's disk, which confirms its membership in the LMC and precludes it from being an unusual Galactic halo giant. Finally, we describe the star's unusual nebula emission spectrum; the gas is nitrogen-rich and shock-heated, and displays a radial velocity that is significantly more positive than the star itself by 50 km/s.

Reference: AJ, in press

On the web at: `http://arxiv.org/abs/0903.2260`

Preprints from: `emsque@ifa.hawaii.edu`

X-Ray Spectroscopy of Stars

M. Guedel (for cool stars) and Y. Naze (for hot stars)

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Non-degenerate stars of essentially all spectral classes are soft X-ray sources. Their X-ray spectra have been important in constraining physical processes that heat plasma in stellar environments to temperatures exceeding one million degree. Low-mass stars on the cooler part of the main sequence and their pre-main sequencep redecessors define the dominant stellar population in the galaxy by number. Their X-ray spectra are reminiscent, in the broadest sense, of X-ray spectra from the solar corona. The Sun itself as a typical example of a main-sequence cool star has been a pivotal testbed for physical models to be applied to cool stars. X-ray emission from cool stars is indeed ascribed to magnetically trapped hot gas analogous to the solar coronal plasma, although plasma parameters such as temperature, density, and element abundances vary widely. Coronal structure, its thermal stratification and geometric extent can also be interpreted based on various spectral diagnostics. New features have been identified in pre-main sequence stars; some of these may be related to accretion shocks on the stellar surface, fluorescence on circumstellar disks due to X-ray irradiation, or shock heating in stellar outflows. Massive, hot stars clearly dominate the interaction with the galactic interstellar medium: they are the main sources of ionizing radiation, mechanical energy and chemical enrichment in galaxies. High-energy emission permits to probe some of the most important processes at work in these stars, and put constraints on their most peculiar feature: the stellar wind. Medium and high-resolution spectroscopy have shed new light on these objects as well. Here, we review recent advances in our understanding of cool and hot stars through the study of X-ray spectra, in particular high-resolution spectra now available from XMM and Chandra. We address issues related to coronal structure, flares, the composition of coronal plasma, X-ray production in accretion streams and outflows, X-rays from single OB-type stars, massive binaries, magnetic hot objects and evolved WR stars.

Reference: accepted for Astron. Astrophys. Rev.

On the web at: `http://fr.arxiv.org/abs/0904.3078`

Preprints from: `naze@astro.ulg.ac.be`

Recombination Lines and Free-Free Continua Formed in Asymptotic Ionized Winds: Analytic solution for the radiative transfer

Richard Ignace

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In dense hot star winds, the infrared and radio continua are dominated by free-free opacity and recombination emission line spectra. In the case of a spherically symmetric outflow that is isothermal and expanding at constant radial speed, the radiative transfer for the continuum emission from a dense wind is analytic. Even the emission profile shape for a recombination line can be derived. Key to these derivations is that the opacity scales with only the square of the density. These results are well-known. Here an extension of the derivation is developed that also allows for line blends and the inclusion of an additional power-law dependence beyond just the density dependence. The additional

power-law is promoted as a representation of a radius dependent clumping factor. It is shown that differences in the line widths and equivalent widths of the emission lines depend on the steepness of the clumping power-law. Assuming relative level populations in LTE in the upper levels of He II, an illustrative application of the model to em Spitzer/IRS spectral data of the carbon-rich star WR 90 is given.

Reference: to appear in Astronomische Nachrichten

On the web at: `http://arxiv.org/abs/0803.4507`

Preprints from: `ignace@etsu.edu`

Proceedings

A Census of Massive Stars Across the Hertsprung-Russell Diagram of Nearby Galaxies: What We Know and What We Don't

Philip Massey

Lowell Observatory

When we look at a nearby galaxy, we see a mixture of foreground stars and bona fide extragalactic stars. I will describe what we need to do to get meaningful statistics on the massive star populations across the H-R diagram. Such a census provides the means of a very powerful test of massive star evolutionary theory.

Reference: To appear in "Hot and Coo: Bridging Gaps in Massive Star Evolution
Comments: Also arXiv:0903.0155

On the web at: `http://www.lowell.edu/users/massey/masseyHotCool.pdf.gz`

Preprints from: `Phil.Massey@lowell.edu`

Young Massive Clusters as probes of stellar evolution

Ben Davies

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Young Massive Clusters (YMCs) represent ideal testbeds in which to study massive stellar evolution as they contain large, coeval, chemically homogeneous, samples of massive stars. By studying YMCs with a range of ages (and hence turn-off masses), we can investigate the post main-sequence evolution of massive stars as a function of initial mass. Recent discoveries of YMCs over a range of ages within our own Galaxy - where we can successfully resolve individual stars - offers the unprecedented opportunity to test our ideas of massive stellar evolution. Here, I review some of the recent works in this field, and describe how we can use YMCs to investigate several topics, including (a) the evolutionary state of H-rich Wolf-Rayet stars; (b) the influence of binarity on stellar evolution in dense clusters; and (c) Red Supergiants and the post-supernova remnants they leave behind.

Reference: Review article to appear in the proceedings of "Hot and Cool: bridging the gaps in massive star evolution"

On the web at: `http://adsabs.harvard.edu/abs/2009arXiv0903.0979D`

Preprints from: `b.davies@leeds.ac.uk`

Empirical Mass-Loss Rates across the Upper Hertzsprung-Russell-Diagram

Claus Leitherer

STScI

I provide an overview of the empirical mass-loss rates of hot and cool luminous stars. Stellar species included in this talk are luminous OB stars, Wolf-Rayet stars, asymptotic giant branch stars, and red supergiants. I discuss the scaling of mass loss with stellar properties, with special emphasis on the influences of chemical abundances. Observational errors and systematic uncertainties are still substantial and vary with stellar type. These uncertainties are a major impediment for the construction of reliable stellar evolution models.

Reference: To appear in "Hot And Cool: Bridging Gaps in Massive Star Evolution", eds. C. Leitherer, Ph. D. Bennett, P. W. Morris & J. Th. van Loon (San Francisco: ASP)

On the web at: `http://lanl.arxiv.org/abs/0903.0608`

Preprints from: `leitherer@stsci.edu`

Metallicity effects in the spectral classification of O-type stars. Theoretical consideration.

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Based on an exteded grid of NLTE, line blanketed model atmospheres with stellar winds as calculated by means of FASTWIND, we have investigated the change in the strengths of strategic Helium transitions in the optical as caused by a 0.3 decrease in metallicity with respect to solar abundances. Our calculations predict that only part of the observed increase in Teff of O-type dwarfs could be explained by metallicity effects on the spectral type indicators, while the rest must be attributed to other reasons (e.g., different stellar structures as a function of metallicity or differences between observed and theoretical wind parameters etc.). In addition, we found that using the He II 4686 line to classify stars in low metallicity environments (Z$\leq$ 0.3 solar) might artificially increase the number of low luminosity (dwarfs and giants) O-stars, on the expense of the number of O-supergiants.

Reference: To appear in the Bulgarian Astronomical Journal as part of the Proceeding of the 4th Conference of the Bulgarian Astronomical Society

On the web at: `http://xxx.lanl.gov/abs/0903.1706`

Preprints from: `nmarkova@astro.bas.bg`

Non-thermal processes in colliding-wind massive binaries: the contribution of Simbol-X to a multiwavelength investigation

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Several colliding-wind massive binaries are known to be non-thermal emitters in the radio domain. This constitutes strong evidence for the fact that an efficient particle acceleration process is at work in these objects. The acceleration mechanism is most probably the Diffusive Shock Acceleration (DSA) process in the presence of strong hydrodynamic shocks due to the colliding-winds. In order to investigate the physics of this particle acceleration, we initiated a multiwavelength campaign covering a large part of the electromagnetic spectrum. In this context, the detailed study of the hard X-ray emission from these sources in the SIMBOL-X bandpass constitutes a crucial element in order to probe this still poorly known topic of astrophysics. It should be noted that colliding-wind massive binaries should be considered as very valuable targets for the investigation of particle acceleration in a similar way as supernova remnants, but in a different region of the parameter space.

Reference: Proceedings of the Second international Simbol-X Symposium, held in Paris (France), 2-5 December 2008, to be published in AIP Conference Proceedings

On the web at: `http://xxx.lanl.gov/abs/0903.1824`

Preprints from: `debecker@astro.ulg.ac.be`

Model atmospheres for cool massive stars

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In this review given at the Hot and Cool: Bridging Gaps in Massive Star Evolution conference, I present the state of the art in red supergiant star atmosphere modelling. The last generation of hydrostatic 1D LTE MARCS models publicly released in 2008 have allowed great achievements in the past years, like the calibration of effective temperature scales. I rapidly describe this release, and then I discuss in some length the impact of the opacity sampling approximation on the thermal structure of

models and on their emergent spectra. I also insist on limitations inherent to these models. Estimates of collisional and radiative time scales for electronic transitions in e.g. TiO suggest that non-LTE effects are important, and should be further investigated. Classical 1D models are not capable either to provide the large and non-gaussian velocity fields we know exist in red supergiants atmospheres. I therefore also present current efforts in 3D radiative hydrodynamical simulation of RSGs. I show that line profiles and shifts are predicted by these simulations, without the need for fudge micro- and macroturbulence velocities. This is a great progress, although line depths and widths are slightly too shallow. This is probably caused by the simplified grey radiative transfer used in these heavy simulations. Future non-grey 3D simulations should provide a better fit to observations in terms of line strengths and widths.

Reference: invited talk at the Hot and Cool: Bridging Gaps in Massive Star Evolution conference, Pasadena, 2008, November, Eds: C. Leitherer, Ph. D. Bennett, P. W. Morris, J. Th. van Loon

On the web at: `http://fr.arxiv.org/abs/0903.3484`

Preprints from: `bertrand.plez@graal.univ-montp2.fr`

Prospects for the study of dust making Wolf-Rayet binaries with the VLTI-Spectro-Imager (VSI)

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In response to ESO's call for proposals for second generation instruments for the Very Large Telescope Interferometer (VLTI), a consortium is currently developing the VLTI-Spectro-Imager (VSI). In the context of the Phase A study, a science group has prepared a science case taking advantage of the expected performances of VSI. Among several science topics, the case of dust making Wolf-Rayet binaries producing the so-called pinwheel nebulae has been considered. Here, we review the main specifications of VSI, and we provide preliminary results expected to illustrate the imaging capabilities of VSI, and the interest for the study of pinwheel nebulae similar to those formed close to well-known systems such as WR98a and WR104.

Reference: To be published in the proceedings of the ESO conference "The interferometric view on hot stars" held in Vina del Mar, Chile (2-6 March 2009), RevMexAA

On the web at: `http://arxiv.org/abs/0904.3026`

Preprints from: `debecker@astro.ulg.ac.be`

Long baseline interferometry: a promising tool for multiplicity investigations of massive stars

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Massive binaries are crucial laboratories that allow us to investigate processes occurring in quite extreme conditions, such as particle acceleration, high-energy emission, or even dust formation. All these processes are intimately dependent on binarity. Our understanding of the underlying physics strongly requires preliminary multiplicity studies likely to uncover still undetected binaries, and determine their orbital parameters. However, classical spectroscopic approaches sometimes fail to provide a solution to this issue. Long baseline interferometry turns out to be a promising complementary technique to address the question of the multiplicity of massive stars. A campaign has been initiated with the VLTI to take benefit of this technique.

Reference: To be published in the proceedings of the ESO conference "The interferometric view on hot stars" held in Vina del Mar, Chile (2-6 March 2009), RevMexAA

On the web at: `http://arxiv.org/abs/0904.3025`

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