THE HOT STAR NEWSLETTER

An electronic publication dedicated to A, B, O, Of, LBV and Wolf-Rayet stars and related phenomena in galaxies

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Contents of this newsletter

Obituary

Keith C. Smith died on 2000 June 3, at the age of 35, after a five-year battle against progressive paralysis resulting from Motor Neurone Disease (ALS, or Lou Gherig Disease as it is commonly known in the USA).

Keith's initial research, for his PhD, represented a remarkable opus: a complete analysis of the abundances of elements observed in the IUE spectra of Mercury-Manganese stars. He went on to use his expertise in spectroscopic modelling in a series of investigations of O-supergiant spectra, and his last published journal paper, which will be familiar to many readers of this Newsletter, was a seminal study of the effects of microturbulence in the interpretation of O stars [MNRAS 299, 1146, 1998]. During his brief career, Keith was an author on 14 further substantial papers in refereed journals, as well as 7 major conference contributions and various reviews and notes; his review paper on chemically peculiar hot stars [Astrophys. Space Sci., 237, 77-105, 1996] is one of the most useful summaries of the field to date. A considerable body of his research remains unpublished as a consequence of the increasing burden that his disease put on him.

Before his illness made it impossible to pursue outdoor activities, Keith was always keen to take up new physical challenges. Examples include his initiation into windsurfing during an IAU Symposium at Golden Sands, Bulgaria; his enthusiasm for skiing and for scuba diving (where he took advantage of observing trips to the AAO to explore the Barrier Reef); and, most spectacularly, his bungee jump. His death at a tragically early age, after much suffering, deprives us of a talented young scientist who had much to contribute to research and teaching. He is survived by his widow, Joan, whom he married in an outdoor ceremony on the tropical island of Mauritius; their union is commemorated in the assignment of the name "Kejosmith" to minor planet 5402.

Mike Dworetsky & Ian Howarth

Accepted Papers

Non-LTE line formation for neutral oxygen

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An extensive model atom for non-LTE line formation calculations for O I is presented, taking into account recent improvements in the atomic data. Based on line-blanketed LTE model atmospheres equivalent widths are computed in LTE and non-LTE for the diagnostic O I lines of A- and late B-type stars in the range $T_{\rm eff}$ = 7500 K to 15000 K and luminosity classes V to Ia. Non-LTE abundance corrections are provided: they span a wide range in magnitude, from less than 0.1 dex for the weak lines in main sequence stars to more than 1.5 dex for the near-infrared lines in some supergiants.

The dependence of the non-LTE effects on the atmospheric parameters is discussed with special emphasis on supergiants. In particular, the near-infrared transitions are found to react sensitively to the collisional excitation cross sections used in the calculations. Further investigations concentrate on the influence of microturbulence and on the rôle of wind outflow velocity fields on the line formation.

As a test and first application of the model, oxygen abundances for Vega (A0 V), η Leo (A0 Ib) and HD 92207 (A0 Iae) are derived. The analysis of Vega confirms a slight oxygen underabundance ($\sim$0.3 dex) in this star while η Leo and HD 92207 show a nearly solar value. For Vega the observed spectrum can be reproduced accurately by the calculated line profiles. In supergiants consistent abundances can be derived from the weak lines in the visible. At high luminosities the prominent near-infrared features – among other strong lines from different elemental species – are subject to additional broadening by an unidentified process which prevents an equally accurate theoretical interpretation.

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What is the nature of the spectroscopic companion of the early B Star λ Sco?

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The B star λ Sco is known to be a spectroscopic binary system. The companion which is in a short periodic orbit with the B star is so far unknown. X-ray observations with ROSAT have shown a super soft X-ray excess (Berghöfer et al. 1997), unusual for B stars of spectral type B1.5IV. Here we present an analysis of our long EUVE observation of λ Sco. Based on these data and all available X-ray observations of this star we constrain the physical parameters of the companion. As long as no other explanation is available for the EUV/soft X-ray excess, the spectroscopic companion of λ Sco is most likely an ultramassive white dwarf. The primary B star is thus the most massive star known to have a white dwarf companion. Such a stellar system can only have evolved by mass transfer. Stellar evolution scenarios predict the existence of such binary systems which are expected to be precursors of the ultrasoft X-ray sources and finally explode in a supernova type Ia. The EUV light curve of λ Sco shows significant short term variations on a 20% level. A period folding search carried out to further investigate the EUV light curve of λ Sco does not provide clear evidence for any periodicity present in the data. It is worthwhile to mention that the analysis of variance periodogram shows a 2σ feature at 4.7 cycles d^{-1} which is close to the main pulsation frequency of the β Cep-type B star. Further observations have to confirm the existence of such a periodicity in the EUV light curve. Furthermore, when folded with the orbital period the EUV light curve of λ Sco shows two broader dips of 30% intensity loss at phases $\phi = 0.56$ and 0.11. At these two phases the stars pass each other in the line of sight. We discuss these features in the EUV light curve of λ Sco in terms of orbital dependent changes in the absorption column of the primary's wind along the line of sight towards the white dwarf companion.

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The γ Velorum binary system. II. WR stellar parameters and the photon loss mechanism

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In this paper we derive stellar parameters for the Wolf-Rayet star in the γ Velorum binary system (WR11), from a detailed non-LTE model of its optical and infrared spectra. Compared to the study of Schaerer et al., the parameters of the WC8 star are revised to a hotter effective temperature ($T_{\rm eff} \sim 57$ kK), a higher luminosity ($\log(L/{\rm L}_{\odot}) = 5.00$), and a lower mass loss rate ($\log(\dot{M}$ / ${\rm M}_{\odot}$/yr) = −5.0 - using a 10% clumping filling factor. These changes lead to a significant decrease in wind efficiency number, from 144 to 7, so that the driving mechanism of the wind of this WR star may be simply radiation pressure on lines. The derived spectroscopic luminosity is found to be 40% lower than that derived by De Marco & Schmutz through the mass-luminosity relationship for WR stars ($\log(L/{\rm L}_{\odot}) = 5.2$).

The paper furthermore presents a comparison of the independently-developed modelling programs, CMFGEN and ISA-Wind . Overall, there seems to be very reasonable agreement between the derived

parameters for WR11, except for the carbon content, which is 2 times higher for CMFGEN (C/He=0.15 vs. 0.06, by number). The comparison also confirms a disparity in the predicted flux at λ<400 Å, found by Crowther et al., which will have effects on several nebular line strengths.

The paper also presents the first independent check of the photon loss mechanism proposed by Schmutz. We conclude that, not only is it important to include very many lines to realistically model line blanketing, but in particular those ones that critically interact with strong resonance lines (e.g. He II λ303.78). The inclusion of these latter lines may significantly alter the wind ionization structure.

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Mass-loss rates of Wolf–Rayet stars as a function of stellar parameters

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Clumping-corrected mass-loss rates of 64 Galactic Wolf–Rayet (WR) stars are used to study the dependence of mass-loss rates, momentum transfer efficiencies and terminal velocities on the basic stellar parameters and chemical composition. The luminosities of the WR stars have been determined either directly from the masses, using the dependence of L_* on mass predicted by stellar evolution theory, or they were determined from the absolute visual magnitudes and the bolometric corrections. For this purpose we improved the relation between the bolometric correction and the spectral subclass.
–(1) The momentum transfer efficiencies η (i.e. the ratio between the wind momentum loss and radiative momentum loss) of WR stars are found to lie in the range of 1.4 to 17.6, with the mean value of 6.2 for the 64 program stars. Such values can probably be explained by radiative driving due to multiple scattering of photons in a WR wind with an ionization stratification. However, there may be a problem in explaining the driving at low velocities.
–(2) We derived the linear regression relations for the dependence of the terminal velocity, the momentum transfer efficiency and the mass-loss rates on luminosity and chemical composition. We found a tight relation between the terminal velocity of the wind and the parameters of the hydrostatic core. This relation enables the determination of the mass of the WR stars from their observed terminal velocities and chemical composition with an accuracy of about 0.1 dex for WN and WC stars. Using evolutionary models of WR stars, the luminosity can then be determined with an accuracy of 0.25 dex or better.
–(3) We found that the mass-loss rates ($\dot{M}$) of WR stars depend strongly on luminosity and also quite strongly on chemical composition. For the combined sample of WN and WC stars we found that $\dot{M}$ in $M_\odot\ yr^{-1}$ can be expressed as

$$\dot{M} \simeq 1.0 \times 10^{-11}\ (L/L_\odot)^{1.29}\ Y^{1.7}\ Z^{0.5} \quad (1)$$

with an uncertainty of $\sigma = 0.19$ dex
–(4) The new mass-loss rates are significantly smaller than adopted in evolutionary calculations, by

about 0.2 to 0.6 dex, depending on the composition and on the evolutionary calculations. For H-rich WN stars the new mass-loss rates are 0.3 dex smaller than adopted in the evolutionary calculations of Meynet et al. (1994).
–(5) The lower mass-loss rates, derived in this paper compared to previously adopted values, facilitate the formation of black holes as end points of the evolution of massive stars. However they might create a problem in explaining the observed WN/WC ratios, unless rotational mixing or mass-loss due to eruptions is important.

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Deep optical imaging and spectroscopy of a sample of Wolf–Rayet galaxies

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We present results of narrow-band (Hα and adjacent continuum) and broad-band (U, B and V) optical CCD imaging together with high- and intermediate-resolution optical spectroscopy for a sample dwarf and/or irregular Wolf–Rayet (WR) galaxies with absolute B magnitudes in the range -14 to -22 mag, taken from the catalogue of Conti (1991). We find that the recent star formation processes in the galaxies of the sample are distributed in different knots. These knots are H II regions probably ionized by so-called super star clusters (or aggregates of them) found in space observations of WR and interacting galaxies. A comparative study of the $U-B$ colour and the $-W(\mathrm{H}\alpha)$ of the different star-forming knots of the galaxies indicates that these two magnitudes give consistent age estimates. However, the $B-V$ colour give comparatively greater ages, which can be explained by the presence of underlying stellar populations in many of the objects. This is confirmed by the presence of a much more extended and diffuse morphology (in some cases with a disc shape) in broad-band compared to Hα images. Our study has also revealed that a substantial fraction of irregular and dwarf WR galaxies at first classified as isolated objects, may in fact be interacting or merging with other low surface brightness companions that escaped detection in previous studies. These interaction processes could be the cause of the triggering of the strong star formation we are now seeing in many of the objects. The Hα morphology of the galaxies indicates that the presence of bubble-like and low surface brightness filamentary structures is a rather common characteristic of these kinds of objects. Spectroscopic observations reported in this and previous papers confirm the presence of high-velocity asymmetric flows that extend to the outer zones in several galaxies.

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WN stars in the LMC: parameters and atmospheric abundances

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The spectra of 18 WN stars in the Large Magellanic Cloud (LMC) are quantitatively analyzed by means of “standard” Wolf-Rayet model atmospheres, using the helium and nitrogen lines as well as

the spectral energy distribution. The hydrogen abundance is also determined. Carbon is included for a subset of 4 stars. The studied sample covers all spectral subtypes (WN2 ... WN9) and also includes one WN/WC transition object.

The luminosities of the program stars span a wide range ($\log L/L_{\odot} = 5.0 \ldots 6.5$). Due to the given LMC membership, these results are free from uncertainties inferred from the distance. 50% of the studied stars (both, late and early WN subtypes) have rather low luminosity ($\log L/L_{\odot} \leq 5.5$). This puts tough constraints on their evolutionary formation. If coming from single stars, it provides evidence for strong internal mixing processes.

The empirical mass-loss rates are scaled down by a factor of about two due to the impact of clumping, compared to previous studies adopting homogeneous winds. There is no obvious strong correlation between the mass-loss rates and other parameters like luminosity, temperature and composition.

The stellar parameters for the present LMC sample are not systematically different from those of the Galactic WN stars studied previously with the same techniques, in contrast to the expected metallicity effects.

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In Proceedings

Physics and Gas Dynamics of Wind-Blown Bubbles

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We review the recent hydrodynamic modelling of wind-blown bubbles (WBB) which are result of interaction of a stellar wind with the circumstellar matter or the wind(s) emitted during the previous stages of the central star evolution. The much faster computers becoming available in the last decade allow a more complete picture of the physics of these objects to be built. Recent hydrodynamic models are capable of treating in detail different mechanisms as radiative plasma cooling, electron thermal conduction and the efects of magnetic fields. We discuss the various mechanisms proposed for shaping these objects and we emphasize on the problems related to the development of various instabilities and the X-ray emission from WBB.

Invited talk given at the conference 'Progress in Cosmic Gas Dynamics' held in September 1999 in Moscow, Russia. To appear in Ap&SS
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