Astrophys Space Sci (2009) 320: 149–157
DOI 10.1007/s10509-008-9974-5

INVITED REVIEW

Outflows from massive blue stars

A. Herrero · M. Garcia · F. Najarro

Received: 21 April 2008 / Accepted: 23 December 2008 / Published online: 4 February 2009

Abstract We present in this contribution a revision of the origin, main properties and open issues in the field of winds of massive blue stars, with a particular emphasis in the ultraviolet observations

Keywords Stars: massive · Stars: mass-loss · Stars: atmospheres · Stars: UV

1 Introducing massive stars and their winds

The first evidence of outflows from massive stars was collected by Morton (1967) through observations with the UV spectrograph onboard an Aerobee rocket. The spectrograph, sensitive to wavelengths larger than 1200 Å and with $\Delta\lambda =$ 3 Å, detected absorption and emission in the SiIV and CIV doublets of ζ Ori (O9.5 Ib) and ϵ Ori (B0 Ia) with shifts of 1800–3800 $\mathrm{km\,s^{-1}}$. The important detail is that these two stars are spectroscopic *standards* in the optical, hinting that strong outflows are a common feature among massive blue stars.

A. Herrero (✉)
Departamento de Astrofísica, Avda Francisco Sánchez 2, 38206 La Laguna, Spain
e-mail: ahd@iac.es

M. Garcia
Instituto de Astrofísica de Canarias, C/ Vía Láctea s/n, 38200 La Laguna, Spain

F. Najarro
Departamento de Astrofísica Molecular e Infrarroja, Instituto de Estructura de la Materia, CSIC, C/ Serrano 117, 28000 Madrid, Spain

This ubiquity can be appreciated for example in Fig. 1, where we have collected UV spectra of massive early-type stars in the OB association Cyg OB2 (see also Walborn et al. 1985). All spectral types display P-Cygni profiles, stronger as we go to earlier types and thus higher temperatures, indicating a correlation between the outflow phenomenon and the radiation field. Their intense winds ($\dot{M} = 10^{-8}$ to 10^{-4} $M_\odot\,\mathrm{yr}^{-1}$, $v_\infty = 300$ to 3000 $\mathrm{km\,s^{-1}}$, see Kudritzki and Puls 2000) are therefore a result of their strong luminosities (10^5–10^6 $L_\odot$).

As a consequence of the high temperatures, the UV spectrum of these stars is dominated by the presence of highly ionized elements, like SiIV ($\lambda\lambda$1394, 1403), NV ($\lambda\lambda$1239, 1243), CIV ($\lambda\lambda$1548, 1551), CIII + CIV (λ1176), OV (λ1371), OIV ($\lambda\lambda$1139, 1343) or HeII (λ1640). At shorter wavelengths we may find OVI ($\lambda\lambda$1032, 1038) or PV ($\lambda\lambda$1118, 1128), although in this region the spectrum is heavily contaminated by H_2 absorptions (see Bianchi and García 2002). Moreover, these UV lines (among many others of iron and other heavy elements) have a strong influence in the structure of the stellar atmospheres by blocking the radiation field and producing the corresponding blanketing effects. They are also sensitive to the presence of shocks and X-rays, and are thus excellent diagnostics of physical processes that are difficult to detect at other wavelengths.

Being very luminous, massive stars dominate the light of galaxies with strong star formation and can be seen at large distances. In Fig. 2 we can see how the main features of a star-forming galaxy at intermediate redshift resemble those of nearby galaxies and moreover, they are present in the spectrum of a single M33 B supergiant. It is clear that to understand the early universe we have to understand the local blue massive stars.

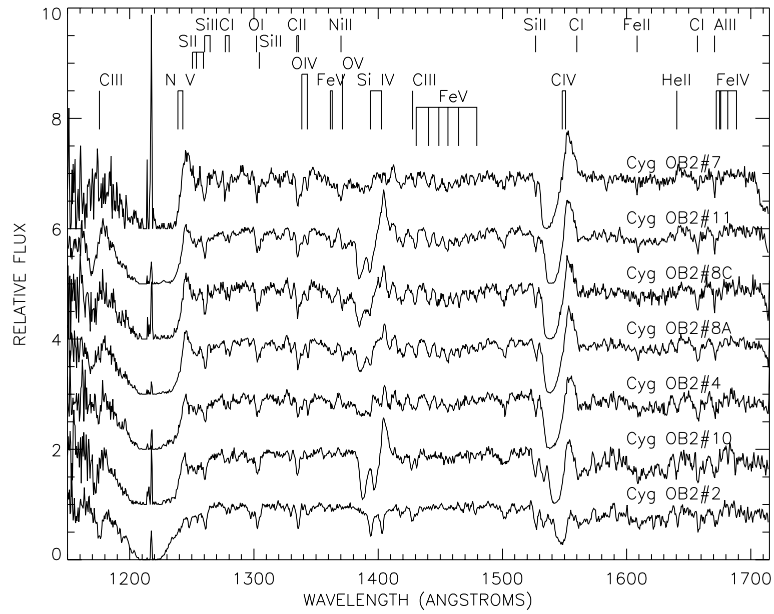

Fig. 1 UV spectra of stars in the OB association Cyg OB2 (adapted from Herrero et al. 2002). Spectral types (from *top* to *bottom*) are O3If, O5If, O5If, O5.5I(f), O7III((f)), O9.5I, B1I. We can see significant changes in the morphology with spectral type, particularly in Si IV and C IV

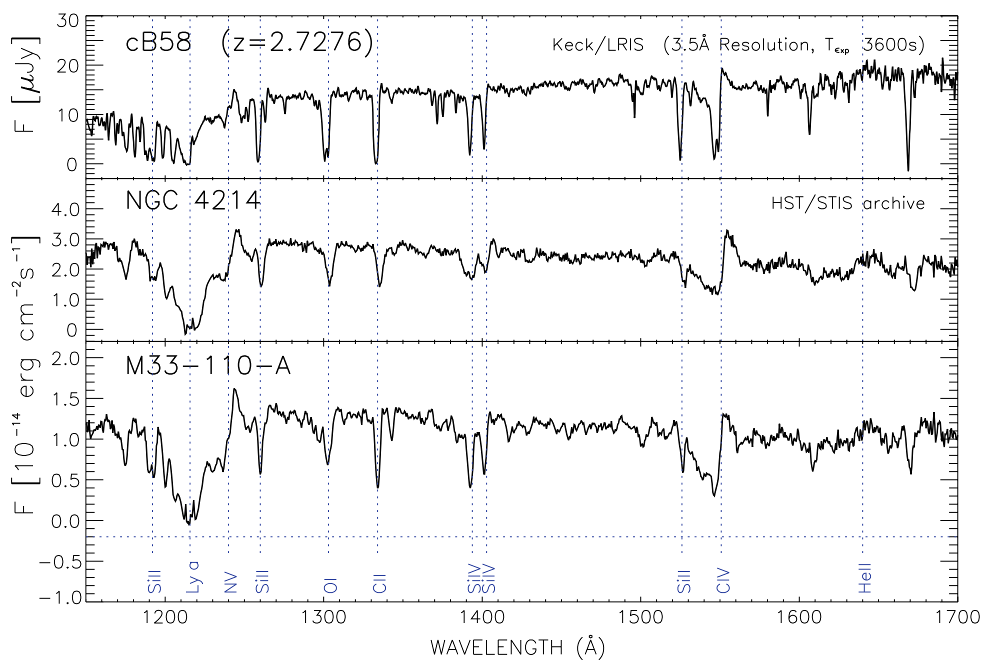

Fig. 2 Spectrum of a galaxy at very high redshift ($z = 2.7276$) compared to a local starburst (adapted from Kudritzki 1998) and a M33 B-type supergiant (from Urbaneja et al. 2002). Note that the high redshift galaxy has been observed in the optical and the local starburst galaxy spectrum has been shifted to match its reference frame. The potential of the UV spectrum of massive blue stars for the understanding of local starbursts and star-forming high redshift galaxies becomes evident from this figure

2 The origin of radiatively driven winds

Lucy and Solomon (1970) showed that the radiation field constitutes the origin of the strong outflows seen in hot stars. They showed that the momentum contained in the radiation field could be transferred to the gas through photon absorption with enough efficiency as to overcome gravity acceleration. Later, Castor et al. (1975) formulated the radiatively driven wind theory, in which they calculated the acceleration acquired by the atomic gas as a consequence of this momentum transfer, and they were able to explain the main characteristics of these stellar winds. The correct dependencies were finally determined by Pauldrach et al. (1986) when they took the finite cone angle correction into account.

The winds of massive OB stars are therefore driven by the absorption of photons from the radiation field by hundreds of thousands of spectral lines from highly ionized species of many atomic elements. The transferred photon momentum accelerates the atoms towards the empty surrounding space in such a way that the atom velocity increases with the distance from the stellar surface, until the material no longer absorbs them.

Because of the high temperatures of blue massive stars, most of the flux emitted by them is concentrated in the UV.