A Massive Star Odyssey, from Main Sequence to Supernova
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Observed instabilities in OB and Wolf-Rayet stars

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Abstract. A wealth of recent observations confirms that the fast, dense winds of OB and Wolf-Rayet (WR) stars are highly structured, with the structures resulting from the inherently unstable nature of a radiatively-driven wind, as well as being triggered from the underlying photosphere. This review mainly addresses variability patterns observed in the winds and photospheric regions of presumably single stars. Schematically we divide the detectable structures into two broad categories: small-scale and large-scale inhomogeneities, with the former mainly of a stochastic behavior/origin, and the latter frequently demonstrating a recurrent, even periodic, behavior. We then discuss the nature and nurture of instabilities, highlighting phenomenological similarities and differences in the variability of OB and WR stars.

1. Introduction

1.1. Mass loss, X-ray production

Instabilities in OB and WR stars directly manifest themselves mainly (but not exclusively, *e.g.*, in X-rays) via temporal or spatial variations of: luminosity, mass loss, temperature, ionization, thus creating highly structured winds. The resulting non-monotonic velocity fields help to produce the black P-Cygni absorption troughs in saturated UV lines (Lucy 1983). Probably the most important issue is the factor 2-5 downward revision of the mass-loss rates in structured WR winds (Hamann & Koesterke 1998; Hillier & Miller 1999) with potential repercussions for OB stars (*e.g.*, Donati *et al.* 2002). X-ray generation in single OB and WR stars is intimately related to wind instabilities. The wind-distributed X-ray flux, while only moderately affecting the structure of O-star winds ('superionization' and production of N V and O VI), profoundly alters ionization state of the B-type star winds (MacFarlane *et al.* 1994).

1.2. Instabilities and the ISM

Connections between the inner (unresolved) wind instabilities and the directly observed large-scale structures are most evident in the case of luminous blue variables (see Nota 1999 and references therein; Exter *et al.* 2002). M1-67, the young ring nebula around WR 124 (WN8h), also bears clear imprints of numerous wind instabilities (Grosdidier *et al.* 1998).

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To simplify the discussion, we rather schematically divide the observed wind structures into two broad categories: large- and small-scale. There is a rationale behind this simplistic approach: the two categories, though overlapping, might have different 'seeding' mechanisms. The former, being fed by deeply rooted photospheric inhomogeneities, usually leads to recurrent, if not strictly periodic, phenomena. The latter, seemingly stochastic, stems from the intrinsically unstable radiative driving in a massive wind.

2. Observations

2.1. UV and optical spectroscopy, photometry and polarimetry

Large-scale, periodic or recurrent structures are usually detected in the form of slowly migrating discrete absorption components (DACs) in the UV P-Cygni absorption profiles of 80% of the observed OB stars (Howarth & Prinja 1989), but only in one (!) WR star, WR 24 (HD 93131, WN6ha, Prinja & Smith 1992). Some stars also show, along with DACs, periodic absorption modulations (PAMs: Fullerton *et al.* 1997). Detailed investigations and modeling (Kaper *et al.* 1999; de Jong *et al.* 2001) of the DAC behavior allows one to draw a general picture: a typical DAC starts as a relatively wide (up to $0.5\,v_\infty$), low-velocity ($0.2 - 0.4\,v_\infty$) absorption feature and gradually accelerates, while getting narrower, to $\leq v_\infty$. It reaches a maximum column density (smallest for main-sequence stars and largest for supergiants) at $\sim 0.75\,v_\infty$ (up to a factor ~ 2 density enhancement over an unperturbed wind) and gradually disappears while accelerating to v_∞. The slow advancement is frequently accompanied by variability of the absorption edges in the saturated P-Cygni profiles. In general, DACs recur on timescales comparable to (an integer fraction of) the stellar rotational period, while it might not hold true for PAMs. The apparent acceleration of DACs is larger for stars with shorter rotational periods (Kaper *et al.* 1999). In some cases DACs can be traced down to the very base of the wind (Hα), signifying extension over a large volume of the wind (a few stellar radii).

Small-scale, stochastic structures. All *adequately* (good coverage, high S/N and spectral resolution) observed WR stars show outwardly-moving, numerous emission sub peaks on the tops of much broader emission profiles. They were interpreted as arising from overdense, small-scale wind structures (nine stars: see Lépine & Moffat 1999 and references therein). So far (attributable to difficulty in observing the phenomenon in relatively weak emission lines), only one O star was shown to have similar variability patterns in its He II λ4686 emission profile (Eversberg *et al.* 1998). This creates a potential theoretical problem. In OB stars the prominent optical 'wind-sensitive' lines, including He II λ4686, usually form at $r \lesssim 1.5\,R_\star$, *i.e.*, in the region where the instability growth rate was thought to be greatly reduced by the strong diffuse radiation field (Owocki & Rybicki 1985; see, however, Owocki & Puls 1999).

Homogeneous photometric data sets show that presumably single OB and WR stars are fairly stable on a timescale of years, but show complex variability patterns on minutes-to-days timescales (Marchenko *et al.* 1998a,b). Polarimetric/spectrophotometric variability of OB stars (amplitudes up to 0.4% : Hayes 1984 and references therein; Lupie & Nordsieck 1987) is detected in 30-70% (Bjorkman 1994; Schulte-Ladbeck 1994) of the presumably single OB stars. Normal OB main-sequence stars show a lower level of variability compared to OB supergiants. With few exceptions, polarimetric variability does not occur in a preferred plane. Long-term, days-to-months, polarization changes are attributed to electron scattering off the blobs embedded in the stellar winds. Similar variability patterns, though on shorter time scales (note the relatively shorter wind flow time), were registered in ~80% of WR stars, suggesting the same general interpretation for the cause of variability (Robert *et al.* 1989; Drissen *et al.* 1992).

To produce polarimetric variability, dense blobs should originate *directly* from the photospheric inhomogeneities (Brown 1994) unless (*i*) the blobs, being initially very elongated in the radial direction, can rapidly collapse on a wind flow time scale; or (*ii*) the blobs are optically thick. The first suggestion could be confronted by the results of numerical simulations and rough observational estimates. The second assumption obviously deserves further attention, especially considering the phenomenon of dust formation in WR atmospheres (see below). Indeed, recent numerical experiments show that the dilemma of low $\sigma(P)_{net}/\sigma(F)_{net}$ values (~ 0.05, where $\sigma(P)_{net}$ and $\sigma(F)_{net}$ are the net rms amplitudes of the polarimetric and photometric observations: Richardson *et al.* 1996) can be solved assuming a random distribution of optically thick blobs (Rodrigues & Magalhães 2000).

Numerous direct observations and attempts at their interpretation (Robert *et al.* 1989; Robert 1994; Moffat 1994; Fox & Henrichs 1994; Brown *et al.* 1995; Richardson *et al.* 1996; Lépine & Moffat 1999; Rodrigues & Magalhães 2000) allow one to draw the following 'collective portrait' of the small-scale inhomogeneities in a WR wind. Probably, the same applies to the winds of massive OB stars. Within a given wind volume, $R_{\star} < r \lesssim 10\,R_{\star}$, there might be $\sim 10^2$ relatively large, $r_{\rm cl} \lesssim R_{\star}$, probably optically thick clumps of a total mass of $\lesssim 5\,\%$ of the ambient wind with a density contrast of > 100. Such density fluctuations are common in numerical simulations (Feldmeier 1999). One may assume that roughly the same proportion of large clumps survives to reach much larger distances from the star (see Runacres & Owocki 2002). The large, massive clumps may accelerate at a much slower pace, thus seemingly defying the wind velocity laws traditionally accepted in modeling, though an empirical estimate of the acceleration pace could be model-dependent as well (Koesterke *et al.* 2001). The probable hierarchy of clump sizes results in much more numerous (at least 10^4, Lépine & Moffat 1999), small and optically thin clumps, presumably forming the bulk of the wind. One may only guess about the kinematics of this populace. However, the case of the well-studied binary system V444 Cygni (WR 139, WN5+O6III-V) proves that the traditional β-velocity law or its modification might serve as a good starting assumption (Kurosawa *et al.* 2002). The same applies to the *directly* measured accelerations of the absorption features in the structured winds of early-B hypergiants (Rivinius *et al.* 1997). There is a large anisotropy of the internal velocity dispersions in the observed clumps: the radial dispersion is usually 4× higher than the azimuthal dispersion (Robert 1994; Lépine & Moffat 1999), as expected when the radiatively-driven instabilities (Rybicki *et al.* 1990) 'seed' the observed structures.

Good agreement between the mass-loss rates derived from the optical, radio and IR observations of OB stars is used as an argument in favor of a constant clumping rate in a wind. However, there is growing evidence, both observational

(Lépine *et al.* 2000) and theoretical (Nugis *et al.* 1998; Runacres & Owocki 2002) that this might not hold true, at least for the $r \lesssim 100\,R_\star$ region of the wind.

2.2. IR region: instabilities and dust formation in Wolf-Rayet winds

Some WR stars are known to be prodigious dust formers (Williams *et al.* 1987; Tuthill *et al.* these Proceedings; Williams *et al.* these Proceedings). In such a hostile environment dust can only be formed in a highly structured wind. Optically thick clumps provide vitally important density enhancements and shielding from the UV flux (Cherchneff *et al.* 2000). Dust eclipsing phenomena observed either in presumably single or binary WR stars (Veen *et al.* 1998; Kato *et al.* 2002a,b; Marchenko *et al.* these Proceedings) unequivocally show the presence of relatively dense clumps. Assuming that dust is produced in the optically thick part of the wind (encompassing $\lesssim 0.05\,\dot{M}$), one finds a good correspondence with the overall efficiency of WR dust formation (Zubko 1998).

2.3. Radio emission and X-rays

Nonthermal synchrotron emission in hot stars may serve as an indicator of wind-embedded shocks, thus being ultimately related to the generation of mainly thermal X-rays (White & Chen 1994). As much as 25% of O stars and 40% of WR stars can be classified as non-thermal radio sources (Bieging *et al.* 1989; Chapman *et al.* 1999). However, the question of whether the non-thermal flux originates primarily in zones of colliding winds (van der Hucht *et al.* 1992; Contreras *et al.* 1997; Dougherty & Williams 2000) or is directly related to the shocks generated by wind instabilities in single stars, requires a detailed, case-by-case study. Clear colliding wind binary origin of non-thermal radio emission is found for WR 140 (WC7pd+O4-5, Williams *et al.* 1990, 1994); WR 146 (WC6+O8, Setia Gunawan *et al.* 2000); and WR 147 (WN8(h)+B0.5V, Setia Gunawan *et al.* 2001).

X-rays. Nearly all O and early B stars have detectable soft X-ray fluxes (Berghöfer *et al.* 1997) which are thought to emerge from mutual collisions of the numerous dense clumps, *i.e.*, from a network of wind-distributed shocks (Feldmeier *et al.* 1997). The absolute majority of observed single OB and WR stars is considered to be constant at X-rays. Analysis of X-ray line profile shapes and line ratios, a new powerful diagnostic of wind instabilities, already brought some surprises (see Miller *et al.* 2002 and references therein). Apparently, to reproduce the profiles, one needs to consider a structured wind (*e.g.*, Oskinowa *et al.* 2001) with a reduced $\dot{M}$ (clumping), spatially-variable opacities (Ignace & Gayley 2002) and filling factor, and non-monotonic velocity field.

2.4. General Correlations

Polarization. For WR stars the net polarization scatter, $\sigma(P)_{\rm net}$, rapidly increases toward late spectral subtypes. $\sigma(P)_{\rm net}$ also grows with increasing absolute visual magnitude. However, $\sigma(P)_{\rm net}$ seems to be unrelated to the X-ray luminosity. There is a clear trend for the slower WR winds to display larger $\sigma(P)_{\rm net}$ (Robert *et al.* 1989). The same $\sigma(P)_{\rm net} - v_\infty$ dependence operates for OB stars (Schulte-Ladbeck 1994). This might infer a general dependence of the clumping rate (size distribution?) on the wind density. Note that scaling analysis of the X-ray emission in OB winds gives $L_{\rm X} \propto v_\infty^{-s}$ with $s \le 2$ (Owocki & Cohen 1999). Polarization in OB stars has no relevance to spectral type and

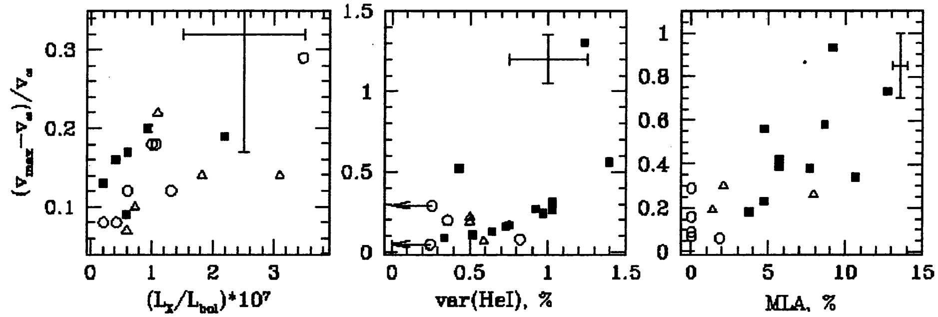

Figure 1. Normalized macro-turbulent velocities, $(v_{\rm max}-v_\infty)/v_\infty$, of presumably single OB stars of the main sequence (open circles), giants (triangles) and bright giants-supergiants (squares) *vs.* (*left panel:*) $L_X/L_{\rm bol}$ (Berghöfer *et al.* 1996); (*central panel:*) index of the He I LPV (Fullerton *et al.* 1996); and (*right panel:*) maximum light amplitude (van Genderen 1989).

does not correlate with Hα changes, as can be expected in a general way (Harries 2000). However, there is a tendency for slowly rotating stars with large Hα emission components to exhibit higher polarization variability (Lupie & Nordsieck 1987).

Photometry. As with polarization, there is a strong tendency for the maximum light amplitudes of OB stars (van Genderen 1988), as well as $\sigma(F)_{\rm net}$ of WR stars (Robert *et al.* 1989; Marchenko *et al.* 1998a) to grow toward higher luminosities and later spectral subtypes. Both in OB and WR stars the amplitudes of variability grow, if modestly, towards shorter wavelengths, suggesting the photosphere as a dominating source of variability (van Genderen *et al.* 1989).

Line profile variations (LPV) in the optical. For WR stars good correlation was found between the indices of LPV and $\sigma(P)_{\rm net}$, $\sigma(F)_{\rm net}$, suggestive of a common origin of the variations seen in different observing modes (Robert 1994). A systematic census of optical absorption LPV of O-type stars showed an increase of LPV with growing stellar radius and luminosity both for the deep photospheric layers and the transition zone between the hydrostatic photosphere and the supersonic wind (Fullerton *et al.* 1996). This conclusion can be extended toward more distant regions of the wind sampled by Hα (Kaper 1999). Both surveys show that $\lesssim 75\,\%$ of OB stars can be considered as variable.

X-ray luminosities of OB stars follow the $10^{-7}\,L_{\rm bol}$ dependence (Berghöfer *et al.* 1997), though with a large scatter, which prompted Kudritzki *et al.* (1996) to obtain an empirical law: $L_X \propto (\dot{M}/v_\infty)^{-0.38} L_{\rm bol}^{1.34}$ and find that the X-ray filling factor scales as $f_X \propto (\dot{M}/v_\infty)^{-1}$. The latter suggests that lower-v_∞ winds should have clumps with higher density contrast, which would lead to higher levels of polarimetric and photometric activity (see above!). On the other hand, there is a notable lack of correlation between L_X and basic stellar parameters in WR stars (Wessolowski 1996) which might stem from the large opacities of the WR winds (Ignace & Oskinova 1999).

UV LPV at $v \gtrsim v_\infty$. A good fraction of OB (Prinja *et al.* 1990) and WR (St-Louis 1992) stars show LPV at $v \gtrsim v_\infty$, which can be used as a measure of macro-turbulent velocities. The distribution of $v_t = (v_{\max} - v_\infty)/v_\infty$ (for $v_{\max}$ see Prinja *et al.* 1990) *vs.* spectral type for presumably single OB stars shows dramatically increased scatter towards B0-B2 spectral classes, *i.e.*, the bi-stability region (Lamers *et al.* 1999; note that the canonical $L_X - L_{\rm bol}$ relation for OB stars breaks down at B1.5 V: Berghöfer *et al.* 1997). v_t correlates with $L_X/L_{\rm bol}$, LPV(HeI) and photometric activity (Figure 1), highlighting the photosphere-wind connection.

3. Interpretation

Large-scale structures. Both DACs and PAMs are thought, by consensus, to be driven from a photosphere. The widely applicable model explains drifting density enhancements as arising from corotating interacting regions, *i.e.*, regions of interaction of a slow, 'overloaded' wind with a relatively faster 'normal' outflow, gradually being brought into the line of sight by stellar rotation (Cranmer & Owocki 1996; see also Hamann *et al.* 2001). Distinction between the DAC and PAM phenomena, being sometimes elusive, might nevertheless point to different driving mechanisms (Owocki 1999).

There are two conceivable ways to initiate growth of a large-scale structure: surface magnetic fields and non-radial pulsations. 'Seeding' by magnetic field is seemingly preferable, the choice being strengthened by the recent detections of $B \lesssim$ 1kG magnetic fields in OB stars (Donati *et al.* 2001, 2002; Henrichs *et al.* these Proceedings). Magnetic fields (loops?) could be responsible for the relatively long-term (weeks) Hα variability in BA-type supergiants, indicative of non-spherical mass-loss events with complex velocity fields (outflow-inflow: Kaufer *et al.* 1996; Israelian *et al.* 1997). As for 'seeding' by pulsations, the calculated pattern speed of a single mode is usually too high to explain the observed DAC periods. On the other hand, multiple-mode interaction requires too fine a tuning to match the DAC periodicity in each individual case (Henrichs 1999). However, not everything is lost for pulsations, bearing in mind the cases of ζ Pup (O4 I(n)f) and HD 64760 (B0.5 Ib) (see below).

At least in some cases practically all the observed structural changes in OB winds can be attributed to the presence of Co-rotating Interaction Regions (CIRs, Cranmer & Owocki 1996; de Jong *et al.* 2001). However, the CIR model fails to match complex variability at the photospheric level (de Jong *et al.* 2001), thus calling for additional explanation. Variability of photospheric lines is thought to be mediated by pulsations (Henrichs 1999), however direct evidence is still lacking for the most luminous O-type stars (Fullerton *et al.* 1996); moreover, there is a big mismatch between predicted (Glatzel *et al.* 1999) and observed (Fullerton *et al.* 1996; Rivinius *et al.* 1997) RV amplitudes. So far, no conclusive evidence of short-period pulsations was found among WR stars (Balona *et al.* 1989; Marchenko *et al.* 1994; Bratschi & Blecha 1996). It remains to be seen whether deeply seated photospheric variability can trigger and support large-scale wind structures. Additional complication comes from the finding that large-scale structures can be disrupted by the ever present stochastic fluctuations (Owocki 1999). Does this imply that *all* WR stars should be, on

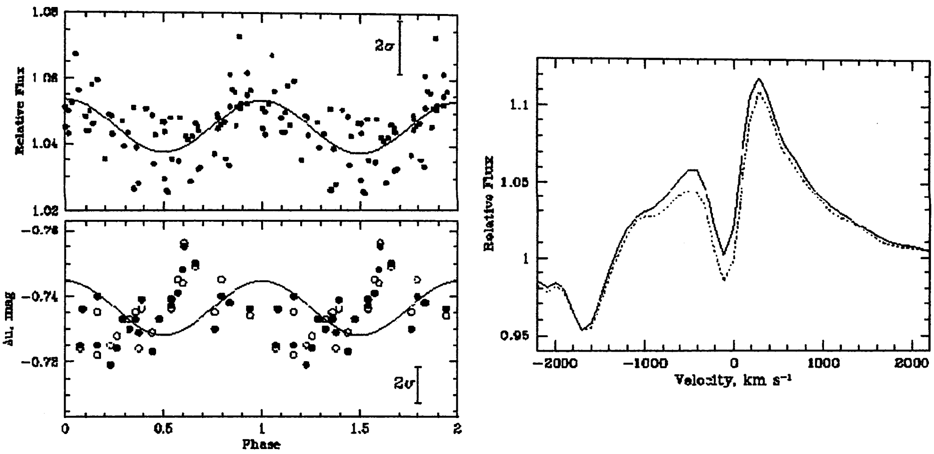

Figure 2. *Upper left panel:* flux in the P-Cygni absorption part of the Hα profile of ζ Pup phased with $P = 19.7 \pm 1$ h (Marchenko *et al.* 2002, in preparation). A sine-wave fit is superposed on the data along with a typical 2σ error bar. *Lower left panel:* simultaneous narrow band continuum photometry at ~3 600 Å (filled circles) and ~5200 Å (open circles). The same sine-wave is repeated for comparison. *Right panel:* average Hα profiles taken at $\phi = 0.0 \pm 0.1$ (full line) and $\phi = 0.5 \pm 0.1$ (dotted line).

average, more active than OB stars, judging by the lack of DAC phenomenon in WR stars?

Small-scale structures. Line-driven instability is regarded as being self-sufficient to generate small-scale stochastic structures (Owocki & Puls 1999). On the other hand, there is an undeniable link between the wind and photospheric activity for the large-scale structures. Can it operate on a smaller scale as well, presumably creating clumps with different characteristics (sizes, density contrasts)?

3.1. Wind-photosphere (-‘exosphere’) connection

The best, unequivocal examples of links between photospheric (OB stars) or ‘exospheric’ (at the $\tau \simeq 1$ level in the UV-optical WR continuum) activity and the wind structures comprise only few cases. Here we mention:

(*i*) In the *presumably* single star EZ CMa (WR 6, WN4) the strong modulation in the continuum flux is followed by the practically coherent varibility of lines of different ionization potential (*i.e.*, formed in different parts of the wind), from UV to the optical (St-Louis *et al.* 1995; Duijsens *et al.* 1996; Morel *et al.* 1997). One should note that higher-flux, hotter regions of the WR exosphere cause a dramatic boost of v_∞, implying substantial change in the ionization structure of the wind. More complicated is the enigmatig object WR 46 (HD 104994, WN3p+OB?), discussed by Marchenko *et al.* (2000) and Veen *et al.* (2002a,b,c).
(*ii*) ζ Pup (O4 I(n)f) shows a set of distinct periods (Massa *et al.* 1995; Reid & Howarth 1996): $P = 5.1 - 5.2$ d is the rotational period, seen both in photometry and spectroscopy; $P = 16 - 19$ h is the recurrence time-scale of the DACs registered in X-rays, UV, optical lines and *simultaneous optical photometry* (Figure 2); $P = 8.5$ h is detectable in photospheric absorption lines and attributed to

non-radial pulsations.

(*iii*) In HD 64760 (B0.5 Ib) the 1.2 - 2.4 d modulation can be traced in photospheric lines and followed through wind-formed UV resonance lines, with non-radial pulsations favored as a driving agent (Kaufer *et al.* 2002).

(*iv*) θ^1 Ori C (O4-6) is, so far, the only O star with a detected magnetic field. Strong rotational modulation is detected in B, X-ray, emission and absorption UV and optical lines, pointing to magnetic confinement of the wind (Donati *et al.* 2002).

In many more cases the variability can be traced practically to the photospheric level (de Jong *et al.* 2001). However, in general the relationship between wind and photospheric activity remains elusive (*e.g.*, Massa *et al.* 1998).

4. Perspectives

Theoretically, it would be interesting to find a clue to the statistical trends, namely: the growth of activity, both for OB and WR stars, towards later spectral subtypes and higher luminosities, as well as in the winds with progressively lower v_∞; practical absence of DAC-like phenomena in WR stars along with the lack of any correlation between main stellar parameters and the X-ray flux.

Observationally, the challenge is to distinguish between the light variability caused by wind-embedded clumps and the 'genuine' photospheric flux variations. Judgment could be based on the wavelength dependence of the amplitudes of variability along with the temporal behavior of the continuum flux. Initially, this program should target the most luminous stars of the latest WR or O subtypes. Another relevant program may seek a relation between the activity of the OB star continuum and the axial rotation rate.

Other potentially rewarding programs could concentrate on: (*i*) establishing any relations between instabilities and chemical composition. Though the preliminary theoretical results imply that one should not expect anything peculiar (Puls *et al.* 1998), the relevant observations are indicative but fragmentary at the best (Walborn *et al.* 1995). However, the situation is rapidly improving (Fullerton *et al.* these Proceedings); (*ii*) investigation of the radial dependence of the clumping rate, with emphasis on the $r \lesssim 1.5\,R_\star$ and $r > 100\,R_\star$ regions of winds; (*iii*) finding more examples of stochastic clump generation in the winds of OB stars; (*iv*) observing in the UV with S/N matching the optical — there might be surprises waiting (*e.g.*, Heap 1994); (*iv*) widening the search for the 'seeding' agents responsible for recurrent or periodic large-scale structures in OB winds; and (*v*) obtaining more high-resolution X-ray profiles, especially important for single and binary WR stars.

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Discussion

KUDRITZKI: I was intrigued by your plot of $(v_{\rm black} - v_\infty)$ *vs.* $\log L_{\rm X}/L_{\rm bol}$. This correlation is very interesting. But you have already a few data points. I suggest that you take the wind turbulent velocity $v_{\rm turb}$ derived from the fits of the blue edges of the P-Cygni profile and correlate them with X-ray luminosity. They have been determined for many OB-stars and they might reflect the shock jump velocities in the stellar wind.

MARCHENKO: This a good suggestion, thank you! The only concern would be that there might be not as many stars with the calculated turbulent velocities as the number of stars with the directly measured $v_{\rm turb}$. However, any additional data points may be quite helpful.

KAPER: (*i*) Broadband photometry of WR stars is complicated by strong WR emission lines. Can you exclude that the photometric variability is due to emission-line variations? (*ii*) Can you put a constraint on the size of the structures causing the emission-line variability in WR stars?

MARCHENKO: (*i*) Yes, in the mentioned case of late-WN stars the emission-line variability was isolated by simultaneously observing some of the stars. (*ii*) Unfortunately, there are no direct constraints. Numerical modeling of the observed photometric and polarimetric variability indicates that a typical size could be a good fraction of the stellar radius. If one has to interpret the X-ray scintillations in the high-mass binary systems (OB stars) as due to occultation by a clumpy wind, then the clump's size turns out to be roughly the same.

OWOCKI: A comment to Marchenko's answer to Kaper's question: I think the size of structures giving rise to the WR emission like variability must be much smaller than a stellar radius. In recent work with Dessart applying instability models, we estimate that a lateral 'pitch angle' of about 3° gives best fit to the emission variability.

MARCHENKO: Yes, your simulations point to the small-scale structures. However, I believe that the question is not settled yet. To resolve the issue of the large photometric / polarimetric variability ratios, one has to introduce a certain number (corresponding to $\sim 1 - 5\%$ of $\dot{M}$) of optically thick clumps. For a reasonable density contrast, the clumps should have sizes $\sim R_\star$ to be optically thick in the continuum.

KOENIGSBERGER: You showed a plot of variability in WR 140 (WC7+O4-5). Why is this variability assigned to instabilities and not oscillations in the stars themselves?

MARCHENKO: By the amplitudes of the variability, one may expect to see some changes in the optical spectra of the components. Our (preliminary) conclusions are negative, *i.e.*, there are no detectable spectral variations at phases 0.02 - 0.05. Additional point: the star is reddening during the oscillations. It is tempting to suggest that the pattern is introduced by dust clumps formed in the zone of wind collision, somewhere at $r > 300\,R_\odot$.

Another coffee break: Dave Strickland and Mark Kidger, at ease