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Theory of thermal and ionization effects in colliding winds of WR+O binaries

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Abstract. The colliding winds interaction zone in WR+O binaries is a highly complex environment. In this review we summarize the progress made towards its theoretical understanding during the last years. We review the effect of different physical processes on the interaction zone, among them geometry and orbital motion, radiative forces, thermal conduction, instabilities and turbulence, ionizing radiation, dust formation, clumped winds, magnetic fields, and particle acceleration. Implications with regard to observations are discussed. Subsequently, we proceed to the important question of mutual interaction amongst these processes. Because of the wealth of physical processes involved, numerical simulations are usually mandatory. Finally, we turn to the combined role these processes play for the thermal and ionization properties of the colliding winds interaction zone in WR+O binaries.

1. Why bother? And how?

Theory and observations both strongly suggest that colliding winds do exist in WR+O binaries. This means that for a more complete understanding of the physics of such binaries the collision zone must be taken into account. Also, the presence of a collision zone in wide binaries may allow to learn more about shock physics by comparing theory with direct observations of the collision zone. Finally, the presence of the collision zone is likely to contaminate many observational quantities. Subsequently derived system parameters may be contaminated as well. Seen in a more positive light, such contamination could perhaps be used to detect previously unknown binaries.

There exist various theoretical predictions for the influence of the collision zone on observations, including enhanced X-ray emission (Stevens 1992; Myasnikov & Zhekov 1993; Pittard & Stevens 1997; Walder, Folini, & Motamen 1999) and thermal radio emission (Stevens 1995), variability of line profiles in the UV (Shore & Brown 1988; Stevens 1993; Luehrs 1997), optical (Rauw, Vreux, &

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Bohannan 1999), and IR (Stevens 1999), the heating of the O-star photosphere (Gies, Bagnuolo Jr., & Penny 1997), and dust formation (Usov 1991).

The different models on which these predictions are based may be divided into two groups. Starting from basic physics (e.g. Euler equations) the interaction zone is modeled and some more or less general predictions are made. The emphasis here lies on the development and understanding of a consistent physical picture of the interaction zone. In the following, we shall call them 'type 1' models. Instead, one may start from an observational feature and make some assumptions about the interaction zone (e.g. geometrical shape, ionization state, density) which are then tuned until the modeled emission matches the observations. Here the point is to derive the physical parameters of the interaction zone in accordance with observations but basically without regard for what physics may be responsible for the value of these parameters. Subsequently, we shall call them 'type 2' models. Both approaches have their merits and drawbacks, and increased mutual exchange between them would seem advantageous for both sides. This review, however, will mostly concentrate on 'type 1' models.

2. Physical mechanisms at work: a visit to the zoo

A variety of physical processes are of importance in colliding wind WR+O binaries. In order to achieve a complete picture of the situation, 'type 1' models should include them all, an aim we are still far away from today. In the following, some of the most relevant processes are listed, along with a brief outline of their physical implications and the state of the art with respect to their modeling.

2.1. Geometry, orbital motion

Obviously, reality takes place in three space dimensions. And some observational features seem to require 3D models for their explanation, e.g. the asymmetric X-ray light curve of γ Velorum (Willis, Schild, & Stevens 1995) or the dust spiral in WR 104 observed by Tuthill, Monnier, & Danchi (1999) which apparently even rotates according to their observations. On the modeling side, there are basically two approaches to 3D: by analytical means or through numerical simulations.

Analytical approaches to 3D are often limited to approximate geometrical descriptions of the location of the interaction zone. Tuthill et al. (1999) point out, for example, that the spiral observed in WR 104 follows approximately a rather simple geometrical path, an Archimedian spiral. More elaborate analytical models including orbital motion to some degree and describing the shape, surface density, and velocity of the colliding winds interaction zone have been provided by Cantó, Raga, & Wilkin (1996) and Chen, Bandiera, & Wang (1996). The analytical model of Usov (1995) goes even further and allows, for example, predictions for X-ray emission and particle acceleration.

The strength of such analytical models is that they yield precise results within the frame of their assumptions, there are no artifacts, and that they can be quickly evaluated for a particular set of parameters. Their drawback is that they can take into account only a few physical processes at a time and that they usually have to neglect time dependence. While on geometrical grounds, for example, they support the idea that the dust observed in WR 104 is related to the interaction zone, they give no clue to why there should be dust at all.

It is this latter kind of question where numerical models are needed and where for some issues nothing less than 3D hydrodynamical simulations will do. However, while obviously being closer to reality, 3D models are expensive in terms of CPU and memory requirements and complicated with regard to data management, visualization, and analysis of the simulations. Consequently, they should be invoked only where required. This point is also reflected in the fact that so far only a handful of 3D hydrodynamical models exist for WR+O binaries. First 3D simulations for three different WR+O binaries, revealing the spiral shape of the interaction zone, were presented by Walder (1995). Based on 3D simulations of γ Velorum Walder, Folini, & Motamen (1999) were able to obtain an asymmetric X-ray light curve similar to the observed one. Pittard (1999) presented the first 3D simulations including radiative forces acting on the winds in the frame of CAK model. While much physics is still missing, these simulations are on the edge of what is feasible today and they provide a wealth of new insight.

2.2. Radiative forces

In close WR+O and O+O binaries the stellar radiation fields are strong enough to affect the dynamics of the colliding winds. For comparable stellar radii of the components, as in O+O binaries, radiative inhibition can occur, as described by Stevens & Pollock (1994). Here the radiation field of one star can inhibit the acceleration of the wind from the companion star. If the two stellar components have largely different radii, as is probably the case in WR+O binaries, Owocki & Gayley (1995) demonstrated that radiative inhibition of the WR-wind by the O-star radiation field is not efficient. Instead, radiative braking of the fully accelerated WR-wind occurs as it approaches the O-star. Whether this braking of a highly supersonic flow can be achieved without the generation of shocks is not yet clear.

In both cases, the stellar winds finally do not collide at the terminal velocities of single star winds, but at lower velocities. Consequently, the X-ray emission is softer and the total X-ray flux is probably diminished as well. Owocki & Gayley (1995) also make the point that the opening angle of the collision zone can be considerably increased due to radiative braking and that radiative braking can prevent photospheric collision.

In both works CAK theory is applied to compute the radiative forces, and within this frame both mechanisms suffer from the same main difficulty: as the ionization state, temperature, and composition of the matter is not exactly known, its response to the stellar radiation fields and, therefore, the CAK coefficients are not well known either. Despite these uncertainties Gayley, Owocki, & Cranmer (1997) have estimated that radiative braking should probably be taken into account in a variety of close WR+O systems.

2.3. Thermal conduction

So far, thermal conduction by electrons and ions has mostly been neglected when modeling WR+O colliding wind binaries. However, because of its strong temperature dependence ($\partial_t T \propto \nabla(T^{5/2}\nabla T)$) and the high post shock temperatures reached in such systems (up to 10^8 K if terminal wind velocities are reached) thermal conduction is likely to play an important role in the physical description of the collision zone.

Quantitatively, not much is known about the influence of heat conduction in WR+O binaries. Myasnikov & Zhekov (1998) have performed 2D numerical simulations using a one temperature model. They neglect radiative cooling and saturation effects, which in particular also means that the entire interaction zone stays hot in their simulations. Their results confirm most expectations: Pre-heating zones, also known as thermal precursors, form upstream of each shock whose temperatures and extensions depend significantly on the flow parameters and the efficiency of thermal conduction. Meanwhile, the temperature of the interaction zone decreases by up to an order of magnitude compared to its adiabatic value. To preserve pressure balance, its density increases by the same amount. The shocks become isothermal. Myasnikov & Zhekov (1998) also note that in the frame of their model the growth of KH instabilities is reduced by strong heat conduction.

The 1D simulations of Motamen, Walder, & Folini (1999) show a drastic change of the picture if radiative cooling is included. A cold, high density region can now form in the interaction zone. The combination of reduced post shock temperature and higher post shock density, both due to thermal conduction, results in enhanced radiative cooling and narrower cooling layers. For WR+O binaries this means that efficient radiative cooling may already set in close to the center of the system. Previous adiabatic cooling of the shocked matter to reach temperatures where strong radiative cooling finally is possible may become obsolete. In summary, the system is likely to become more radiative under the combined influence of thermal conduction and radiative cooling than if thermal conduction were absent. For the case of wind-blown bubbles, 1D simulations by Zhekov & Myasnikov (1998) suggest that the combined influence of radiative cooling and thermal conduction can also cause the formation of additional multiple shocks.

So far, there exist no 2D simulations for WR+O binaries including both radiative cooling and thermal conduction. However, for other situations such simulations have been performed, for example by Comerón & Kaper (1998) for runaway OB stars.

In reality, however, thermal conduction is likely to be even more complicated. Only two papers shall be mentioned here which illustrate this. One is by Balbus (1986), where the emphasis lies on the effect of magnetic fields and, in particular, on the time scales associated with magnetized conduction fronts. The second is by Borkowski, Shull, & McKee (1989) who show that in many cases one temperature models will not do. Also, they emphasize that the chemical composition and the ionization state can affect the conductive heat flux and, in particular, its saturation. They show that under certain circumstances thermal conduction may be able to reduce the peak temperature only by a factor of three, while for other conditions a reduction by a factor of ten is possible.

With regard to observations, thermal conduction will certainly lead to softer X-ray emission. One may speculate that the X-ray emission could be enhanced as well. Due to higher compression and lower temperatures, the shocked matter may cool radiatively before significantly cooling adiabatically when moving out of the center of the system.

2.4. Instabilities and turbulence

A wealth of analytical estimates and numerical simulations suggest that the interaction zone in colliding wind WR+O binaries is unstable, especially when strong radiative cooling occurs. The interaction zone as a whole gets bent and is possibly torn apart as becomes apparent, for example, in the work of Stevens, Blondin, & Pollock (1992). More recent numerical simulations also suggest the cold interior of the interaction zone to be in supersonically turbulent motion.

A variety of papers are concerned with the physical nature of different kinds of instabilities. The scope covered by these works ranges from the classical Rayleigh-Taylor, Kelvin-Helmholtz, and Richtmyer-Meshkov instabilities, which act on interfaces separating two different physical states (for example the two winds), over various thin shell instabilities, which act on the entire thin layer of high density, cold matter (e.g. Dgani, Walder, & Nussbaumer 1993; Vishniac 1994), to the thermal instability related to radiative cooling (e.g. Walder & Folini 1995). A recent review can be found in Walder & Folini (1998).

Which of the suggested instabilities is important for a certain astrophysical object is often not clear. Also, instabilities usually will not occur isolated but will interact with each other, making it often pointless to speak of one particular instability. Finally, in WR+O binaries advection out of the system center will be superimposed on all instabilities (Belov, & Myasnikov 1999; Ruderman 2000).

The resulting bending of the thin, cold, high density interaction zone probably also affects the interior dynamics of this thin sheet. In a planar, high resolution study Folini & Walder (2000) have focused on the interior structure of the cold part of a colliding winds interaction zone. They find that the cold part of the interaction zone to be subject to driven, supersonic turbulence. The matter distribution within the turbulent interaction zone consist of overcompressed, high density knots and filaments, separated by large voids. The mean density of the interaction zone is considerably reduced compared to the density required to balance the ram pressure of the incoming flows by thermal pressure alone. Its surface becomes billowy due to the turbulent motion inside.

The unstable behaviour of the cold part of the interaction zone should have observable consequences. Spectral lines originating from it should show clearly stronger than thermal line broadening because of turbulent motion. The total extent of the hot post shock zones will be affected by the combined influence of bending and the thermal instability. This may lead to some X-ray variability, as suggested by Pittard & Stevens (1997) for the case of O+O binaries.

Neglecting for a moment the review type character of this article, some speculations may be added. On the basis of observed line profile variations, Luehrs (1997) derived the angular extension of the collision zone in HD 152270. The value he found seems extraordinarily large for a cold, high density interaction zone. Could strong global bending and twisting of a slim interaction zone make it appear to be much more extended? The second speculation is related to the overcompressed knots and filaments observed in numerical simulations of radiatively cooling, unstable collision zones. Could dust formation in close WR+O binaries be linked to such knots? (See also Section 2.6.)

Having argued in favor of an unstable interaction zone in colliding wind WR+O binaries a word of caution seems advisable here as well. Analytical results generally are not directly applicable because their rather restrictive assumptions are usually not fulfilled. Numerical simulations, on the other hand, are more flexible in that respect but it may be difficult to rule out numerical artifacts. Also, instabilities so far have mostly been studied in the frame of rather simple physical models. How additional physical processes will influence the stability properties of the interaction zone has yet to be investigated.

With regard to possible numerical artifacts the recent publication of Myasnikov, Zhekov, & Belov (1998) must be mentioned. They argue that if not purely numerical in origin anyway, the instabilities observed in numerical simulations of colliding wind binaries at least greatly depend on the applied cooling limit. Their findings certainly require further attention.

Despite these objections, we are firmly convinced that the colliding winds interaction zone in WR+O binaries is unstable. If efficient radiative cooling takes place the interaction zone is most likely subject to strong bending and is possibly torn apart in some locations. We are, however, not sure how violent this instability is and what its exact physical cause is. The cold interior of the interaction zone is probably subject to supersonic turbulence. How exactly this turbulence is driven is not yet clear. Also, the statistical properties of this part of the interaction zone, for example its mean density, have barely been investigated and then only in 2D. This unstable behaviour must cause observable traces.

2.5. Ionizing radiation

There are three sources of ionizing radiation in WR+O binaries: the two stars themselves and the shock heated interaction zone. For the temperature and ionization state of the cold matter within and around the colliding winds interaction zone this radiation is crucial. So far, only a few studies exist, each of which deals with a separate aspect of the problem. Gies, Bagnuolo Jr., & Penny (1997) find that the X-ray radiation emitted by the collision zone in close binaries is capable of significantly heating the O-star photosphere, thereby changing observational quantities used to derive the stellar parameters. Aleksandrova & Bychkov (1998) considered the same radiation source but investigated its influence on the pre-shock material. Investigating wind velocities in the range between 4000 km/s and 15000 km/s they found that the X-rays from the collision zone are capable of ionizing iron nearly completely *before* it gets shocked. While these velocities are clearly above those encountered in WR+O binaries the pre-ionizing effect as such is likely to be present also in these systems. Consequently, emission from highly ionized ions may not solely originate from the shock heated zones themselves, which should be taken into account when using highly ionized elements for diagnostics of the collision zone. Also the temperature of the pre-shock matter is likely to be affected. First attempts to estimate the effect of the stellar radiation field on the cold part of the interaction zone have been made by Rauw et al. (1999) and by Folini & Walder (1999), the latter using 3D optically thick NLTE radiative transfer. Although their results are preliminary, the latter authors find that for their toy example of γ Vel optically thick effects become important within the cold, high density part of the collision zone.

2.6. Dust formation

Observations clearly prove the permanent or episodical dust formation in certain WC+O binaries. The most spectacular example is probably the dust spiral of

WR 104 observed by Tuthill et al. (1999). Recent observational summaries can be found in Williams (1997) and Williams (1999). The observation of dust in such systems is puzzling as conditions there (high temperature, strong UV radiation) seem not especially suited for dust formation.

Theoretically, dust formation in WR+O binaries is not understood so far. Usov (1991) has published density estimates for a homogeneous collision zone. The 2D simulations of V444 first presented by Walder & Folini (1995) have been carried on in the mean time, showing overcompressions of up to a factor of ten in a supersonically turbulent interaction zone, compared to a homogeneous one. In this particular simulation densities of up to about 10^{13} cm^{-3} are observed out to a distance comparable to the separation of the two stars. Considerably more publications exist on dust nucleation and grain growth under laboratory conditions and in WC winds. Cherchneff & Tielens (1995) and Cherchneff (1997), for example, focused on dust nucleation. In particular, they found that high densities, possibly up to 10^{12}cm^{-3}, are required for dust nucleation to take place while the nucleation process is nearly independent of temperature between 1000 K and 4000 K. Although these temperatures seem small for the colliding winds interaction zone in WR+O binaries they might not be out of reach if the densities are high enough. (See also Section 3.) Leaving the question of nucleation aside, Zubko (1992), Zubko, Marchenko, & Nugis (1992), and Zubko (1998) carried out theoretical studies of grain growth via collisions of charged grains with carbon ions in WC winds. A main conclusion from their work is that dust grains may grow even in a highly ionized standard WC atmosphere, provided the condensation nuclei are created somehow.

2.7. Clumped winds, magnetic fields, particle acceleration

The influence of several other physical processes on the collision zone is even less investigated than of those outlined in the previous sections. Three of them, clumped winds, magnetic fields, and particle acceleration, shall be briefly touched in the following.

Evidence is growing that the winds of both, WR- and O-stars are indeed clumped rather than smooth. However, the size, compactness and distribution of the clumps is still under debate. Is a clumped wind more like a few massive clumps in a homogeneous flow? Or is more appropriate to talk about the flow in terms of an ensemble of different blobs? As pointed out for example by Lépin (1995), the effect of clumped winds on the interaction zone will depend on which of the two scenarios applies. A fast, compact, high density clump may pass through the entire interaction zone with basically no interaction at all (see e.g. Cherepashchuk 1990). A less dense, not too fast clump, on the other hand, may finally get dissolved in the interaction zone, thereby possibly affecting its stability and emission. But also the theoretical treatment may be different, depending on the nature of the clumped winds. Can they be treated statistically using some mean properties or is it important to treat clumps as 'individuals'?

Concerning magnetic fields, the observation of non-thermal emission suggests the presence of magnetic fields in at least some WR+O binaries. However, their strength and orientation have yet to be determined. On the theoretical side, only a few papers exist on magnetic fields in colliding wind WR+O binaries. Eichler & Usov (1993) and Jardine, Allen, & Pollock (1996) present studies on particle acceleration and related synchrotron emission in the interaction zone in WR+O binaries. Zhekov, Myasnikov, & Barsky (1999) focus on the magnetic field distribution, assuming for the stellar wind magnetic field a simplified Parker model. Depending on their strength, magnetic fields are likely to affect several other physical processes directly or indirectly as well. (See also Section 3.)

3. Open the fences: mutual interactions

The different physical processes addressed in the previous section obviously do not occur as isolated processes. Some processes influence others and vice versa. A few examples of this we have already briefly encountered above. However, there exist hardly any models including more than one or two different physical processes at the same time. It just would be too costly up to now to include more physics in the numerical models. Also, it may be wiser anyway to first improve our understanding of simpler situations before turning to more complicated ones. Nevertheless, one should bear in mind that most likely there will be considerable interaction amongst different physical processes. The remainder of this section is devoted to speculations, rather than results, on a few such interactions. This section may, therefore, be considered to go beyond the frame of a review. However, we deem it necessary to address these questions as they are crucial for the physical understanding of the interaction zone.

Consider first thermal conduction and radiative braking. Especially for close binaries, they are both crucial for the post shock temperature as well as for the location of the interaction zone and its opening angle. The interaction of the pre-shock matter with the radiation field, crucial for radiative braking, will certainly be affected by the increase in temperature due to thermal conduction. It seems plausible to assume that this interaction will be reduced if the matter temperature deviates strongly from the radiation temperature. Let us first start from a radiative braking model. If we now add thermal conduction the pre-shock wind will be heated. According to our assumption this means less interaction between the wind and the radiation field and therefore less radiative braking. The post shock temperature will rise and the pre-heating zones will become even larger. 'Positive back coupling' occurs. Now let us start with a thermal conduction model. Adding radiative braking will slow down the pre-shock wind, the post shock temperature will drop, and the pre-heating zones will become smaller and cooler. Again according to our assumption, radiative braking will become more efficient and the post shock temperature will drop. 'Positive back coupling' again. Both scenarios are speculations. But as each of the two processes alone already has powerful impact on the physics of the interaction zone a common investigation of the two would be highly desirable.

Here it may be added that a radiative precursor instead of a thermal one could have similar effects. A radiative precursor is likely to exist around the wind collision zone in WR+O binaries because of the X-ray and UV emission of the high temperature post shock zones. Its effect would be to heat and ionize the pre-shock matter. However, at least for the case of colliding winds in WR+O binaries radiative precursors on their own are even less investigated up to now than thermal ones.

Another issue is the interplay of thermal conduction, radiative cooling, and ionizing radiation. Together these processes essentially determine how cold the matter can get in the cold, high density part of the interaction zone. While attempts have been made to bring the first two together the isolated problem of the influence of ionizing radiation on the interaction zone has hardly been investigated so far. Its influence is usually taken into account only in the form of heating due to photoionization and then only in the form of a more or less arbitrarily chosen cooling limit of the radiative loss function. Just for arguments sake consider a compact, high density clump in the interaction zone that is opaque to UV radiation. Its outside would be bombarded by UV and X-ray photons, the surface of the clump would be heated. Now, thermal conduction would tend to distribute this energy, received on the surface, over the entire volume of the clump. If the clump then were able to radiate this energy at longer wavelengths, for which the clump were still transparent, the clump may manage to remain cold. Such a mechanism could possibly preserve the cold environment necessary for dust formation.

So far, we have again neglected magnetic fields in this section. Their presence, however, will have a direct influence on thermal conduction or the stability and density of the cold part of the interaction zone. The altered thermal conduction then in turn may affect, for example, radiative braking or dust formation. So indirectly magnetic fields may influence physical processes or quantities, like radiative braking, which at first glance one may believe to be unaffected.

4. End of the visit: collecting the pieces

Theoretical predictions for the thermal and ionization state of the colliding winds interaction zone in WR+O star binaries require the inclusion of a variety of physical processes. Which processes are indeed important for which system is, however, often a difficult question. A brief summary of where we stand today is attempted in the following.

How hot can it get? Being one of the key questions it has been examined quite carefully. The only process leading to a temperature increase in the high temperature part of the interaction zone is shock heating. The temperature reached depends on the relative velocity of the colliding flows which, in turn, can be affected by radiative braking. Thermal conduction, on the other hand, causes a decrease of the peak temperature. This peak temperature may be higher than the temperature we observe, depending on when radiative cooling becomes important. If the density is too low or the peak temperature too high the matter will undergo significant adiabatic cooling as it moves out of the center of the system, before it starts to cool radiatively and thus becomes observable. The peak temperature may also affect the maximum densities which can be reached within the cold part of the collision zone. A lower peak temperature, due to thermal conduction for example, allows for faster cooling, closer to the center of the system, and consequently for higher densities of the cooled matter. Presently, studies exist on the influence of each single processes and on the combined influence of thermal conduction and radiative cooling in 1D. The combined influence of all these processes has, however, yet to be investigated, finally in 2D or 3D. The question is certainly important with regard to X-ray emission.

Comparison with observation shows that for close binaries the predicted X-ray emission is still too high and too hard, whereas for wider systems theory and observation agree much better. The combined influence of the above processes probably will help to bring theory and observation closer together in this point.

How cold can it get? Another key question which, despite its importance with regard to ionization states, compression, and dust formation, especially for close binaries, has barely been attacked so far. Basically, thermal conduction and photoionization tend to heat the cold part of the interaction zone, whereas radiative cooling reduces its temperature. From these processes, heating of the interaction zone by photoionization is by far the least investigated. Here the stellar radiation fields as well as the radiation from the shock heated zones must be taken into account and their interaction with the matter has to be determined. At least for some systems, this probably requires detailed multidimensional radiative transfer computations. The difficulty with radiative cooling, crucial in this context, is that it strongly depends on the temperature and ionization state of the matter. The cooling history, and therefore time dependence, may also be important. Finally, the properties of the hot post shock zones, the source of thermal electrons and ionizing photons, are not well known either. In the future, the question should be clarified whether detailed radiative transfer is indeed needed. Then, the heating of the cold part of the interaction zone by photoionization should be investigated more quantitatively.

Towards observations. Traces of the interaction zone seem to be present in all spectral ranges. Observational predictions from what we called 'type 1' models in this review exist, to our knowledge, for X-rays (many) and radio (one). As far as we know, there are no predictions form 'type 1' models for UV, optical, and IR. The reason is that predictions for these latter spectral ranges depend essentially on the cold part of the interaction zone which, as mentioned before, is not yet well understood. All models reproducing line profile variations in the UV, optical, or IR are of what we called 'type 2'. Starting from a more or less simple geometrical description of the interaction zone these models then assume a certain ionization state and level population. They are valuable as they show us what certain parameters of the interaction zone should be like in order to reproduce observations. However, these models themselves give no physical explanation of why the parameters should have their particular values.

The 'grand unified model'. Looking at 'type 1' models, some physical processes are included in one model but not in the other (for example thermal conduction or radiative braking) and some physical ingredients are barely considered at all so far (for example clumped winds or magnetic fields). 'Type 2' models may be improved by considering other than just the most simple, analytical matter distributions. It may also be worthwhile trying to find out how unique a certain observed signature is. Is there only one way to reproduce it or allow several different, equally plausible models for the same observational feature? Enhanced combination of 'type 1' and 'type 2' approaches could help to decide such questions. Although a 'grand unified model' for WR+O colliding wind binaries will remain out of reach for several years to come, considerable progress has been made with regard to the modeling and understanding of single physical processes such a model must comprise. This should also help us to decide which physical processes are indeed needed in order to explain a particular system. Also in future modeling will be expensive and models, therefore, should comprise only the essential physics.

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