UV Wind Line Diagnostics of Clumping

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Abstract

That stellar winds are structured (clumped) in now widely accepted. Further, it is clear that the different spectral diagnostics used to determine mass loss rates are affected by clumping and its associated porosity. Thus, to obtain reliable mass loss rates, the properties of the structure must be understood.

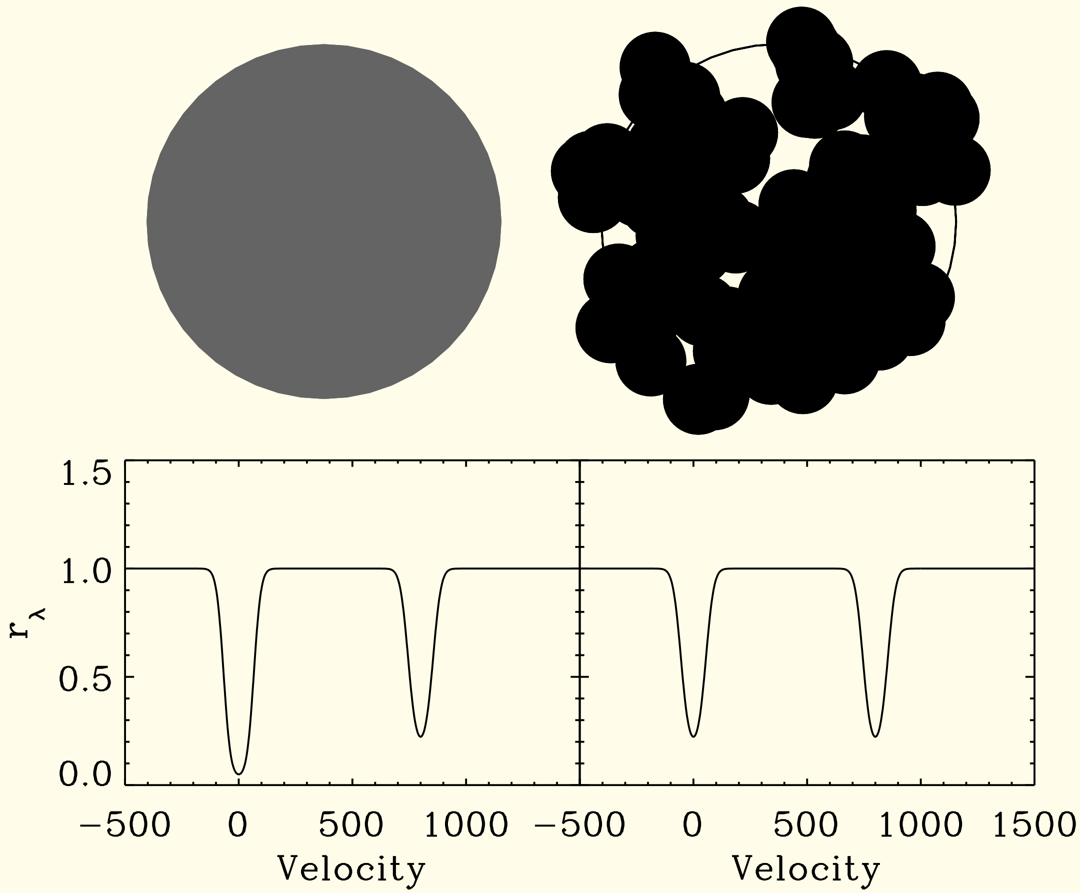
I will talk about how clumping in stellar winds produces distinctive signatures in UV wind lines. I will give examples and discuss how certain characteristics of UV wind lines can be used to infer clump properties.

Background

- **Effects of structure on wind diagnostics is now widely accepted.**
  - **Causes Hα and Radio and IR continuum measurements (n_e^2 diagnostics) to *over*-estimate $\dot{M}$.**
  - **Structure, and its accompanying porosity, can cause wind line diagnostics to *under*-estimate $\dot{M}$.**
- **Discuss how UV wind lines contain additional, untapped information that can help characterize the nature of the clumping.**
- **Concentrating on the following diagnostics:**
  1. **Doublet ratios**
  2. **Narrow Absorption Components (NACs) in wind line profiles near v_∞**

Doublet Ratios

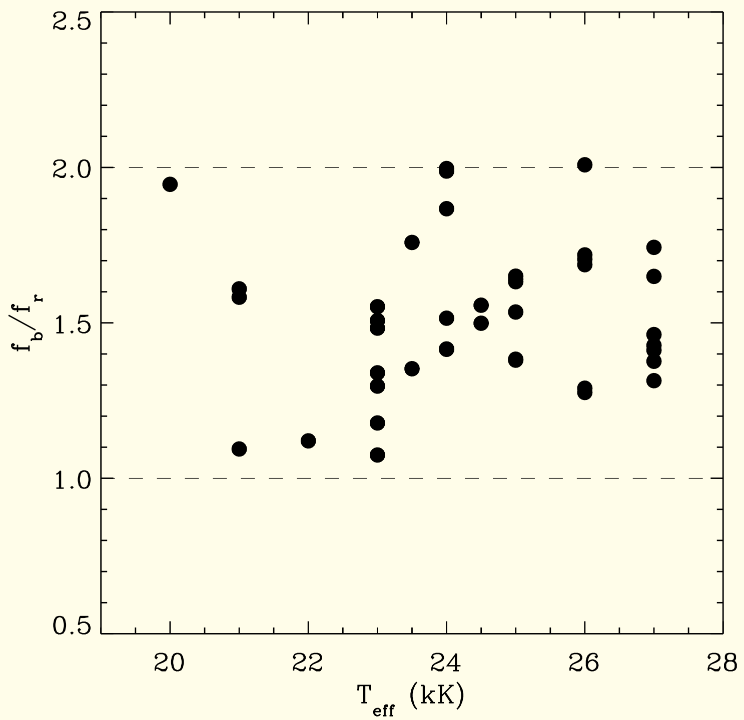
- Known by AGN community as a telltale sign of clumping.
- For a uniform haze, residual intensity is ratio of f-values.
- For partially opaque masking, inferred f-values ratio is 1.



Cartoon showing how, at a specific velocity, a porous wind can cause a doublet to appear unsaturated and the doublet ratio approach unity.

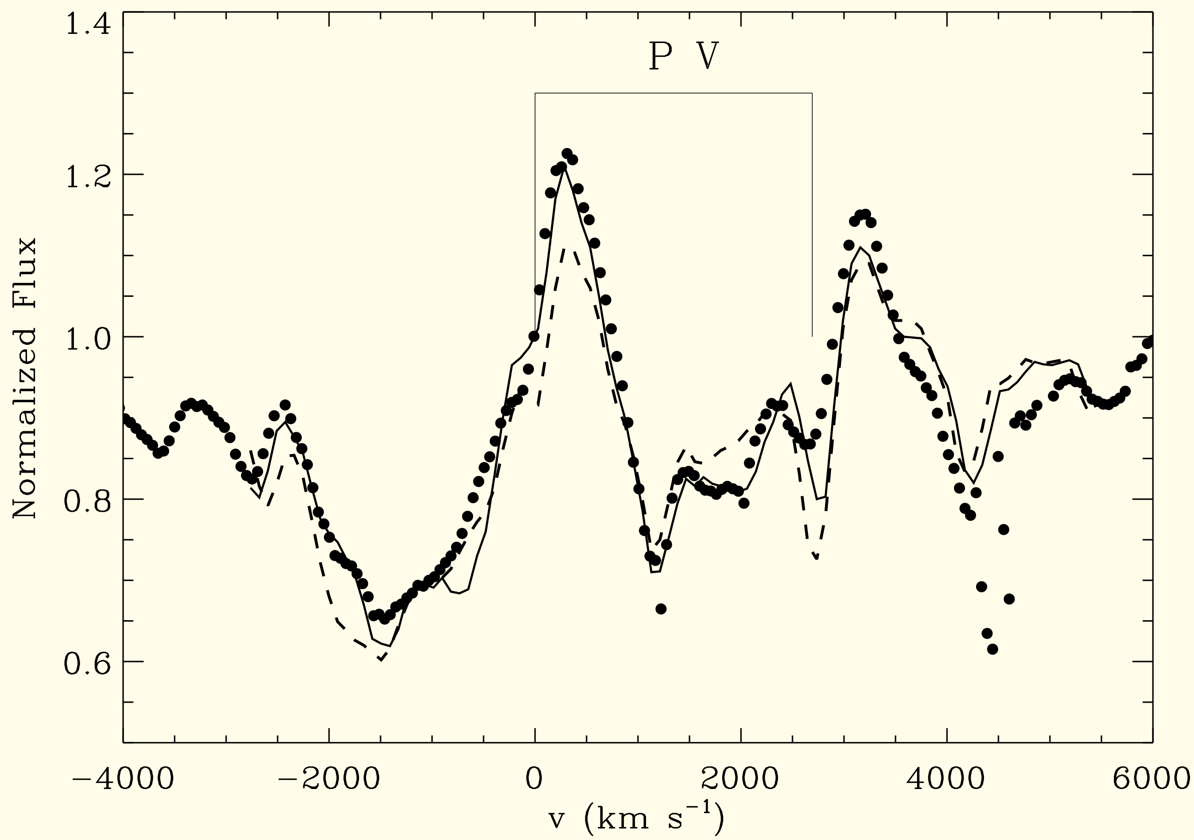
f-value Ratios in B Supergiants

- Allowed ratio to vary and all were between 1 and $f_B/f_R = 2$ – as expected.
- A. possible trend at the lower temperatures.
- Implies lines are strongly affected by clumping.



Derived ratios of oscillator strengths versus $T_{\rm eff}$ for Si IV$\lambda\lambda$1400 in B supergiants with wind lines $0.3 \leq \tau_{rad} \leq 5$ (weaker have inadequate optical depth information and stronger are too saturated).

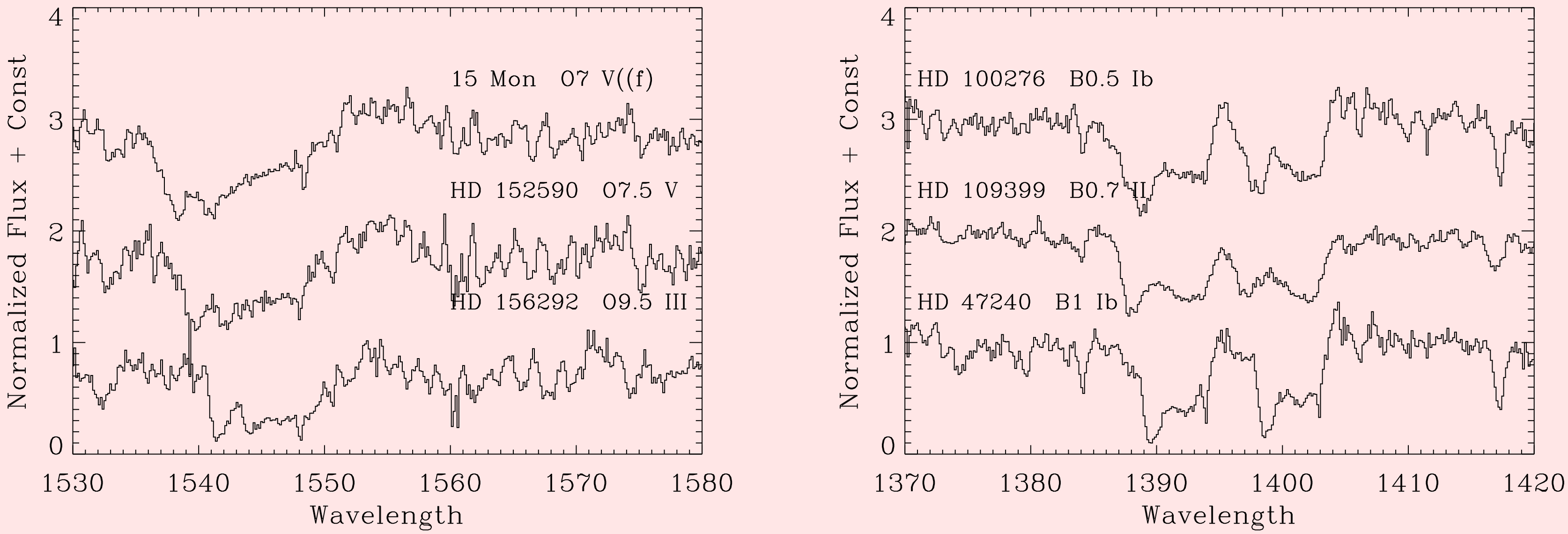
f-value Ratio in ζ Pup



P v$\lambda\lambda$1117, 1128 in ζ Pup from *Copernicus* data. Two least square SEI fits are shown (both use a T_{eff} = 40kK, $\log g$ = 3.5 TLUSTY model photosphere). The dashed fit uses f_B/f_R = 2.02. The solid fit allowed the ratio to vary and determined a value of 1.84. This 10% change clearly improves the fit, making the blue absorption weaker relative to the red.

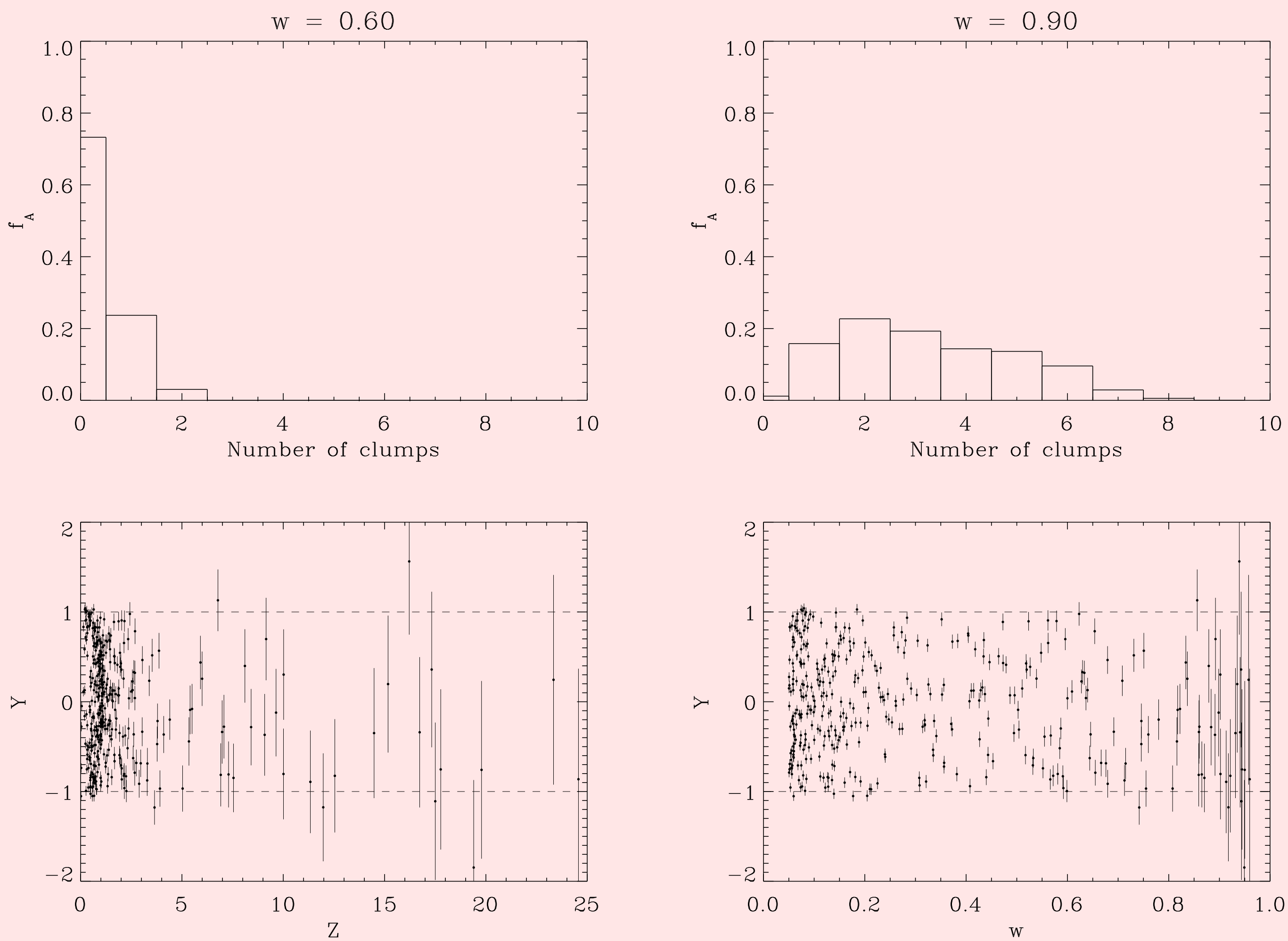
Narrow Absorption Components (NACs)

- **NACs near v_∞ are common in unsaturated wind lines (Prinja & Howarth 1986).**
- **NACs MAY result from clumping.**
- **Consider cylindrical clumps that are:**
  1. **Conserved**
  2. **Maintain a constant solid angle and**
  3. **Have column densities that decrease as x^{-2}**



Spectra of stars with unsaturated wind lines that show NACs near the terminal velocity. For C IV this occurs in late O stars near the main sequence (left), and for Si IV it occurs in early B stars of moderate luminosity (right).

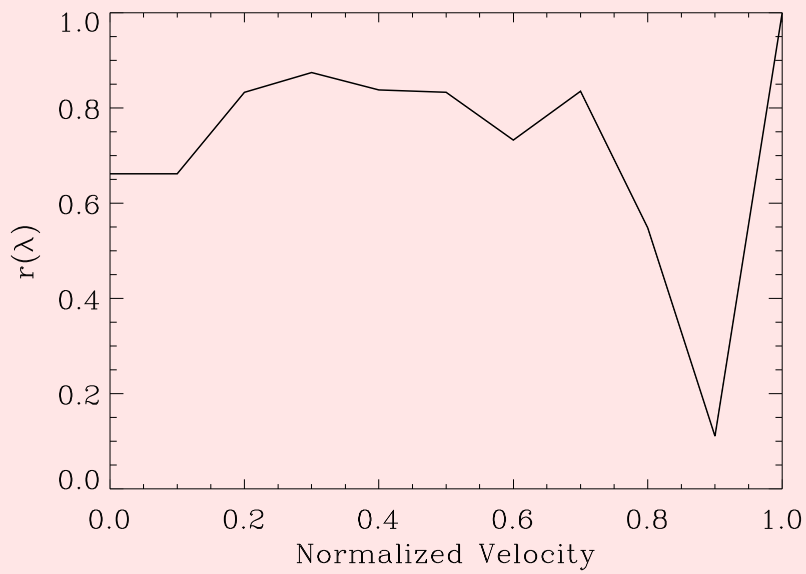
Simulation of 10000 clumps in $1 \le x \le 25$, and $R_{clump} = 0.05 R_\star$ at $x = 1$



Top: Distribution of clumps at $w = 0.6$ (left), and $w = 0.9$ (right). At 0.6, the star is mostly uncovered, so optically thick clumps produce weak absorption. At $w = 0.9$, nearly the entire star is covered, so the absorption can be quite strong.

Bottom: Clump centers and sizes plotted against distance (left) and velocity (right). Clumps are sparse at large distances, but bunched at high velocity.

$$r(w) = \sum_{N=0}^{N_T} f_A(w, N) \exp\left[-\frac{\tau_0 N}{x(w)^2}\right] \quad (1)$$



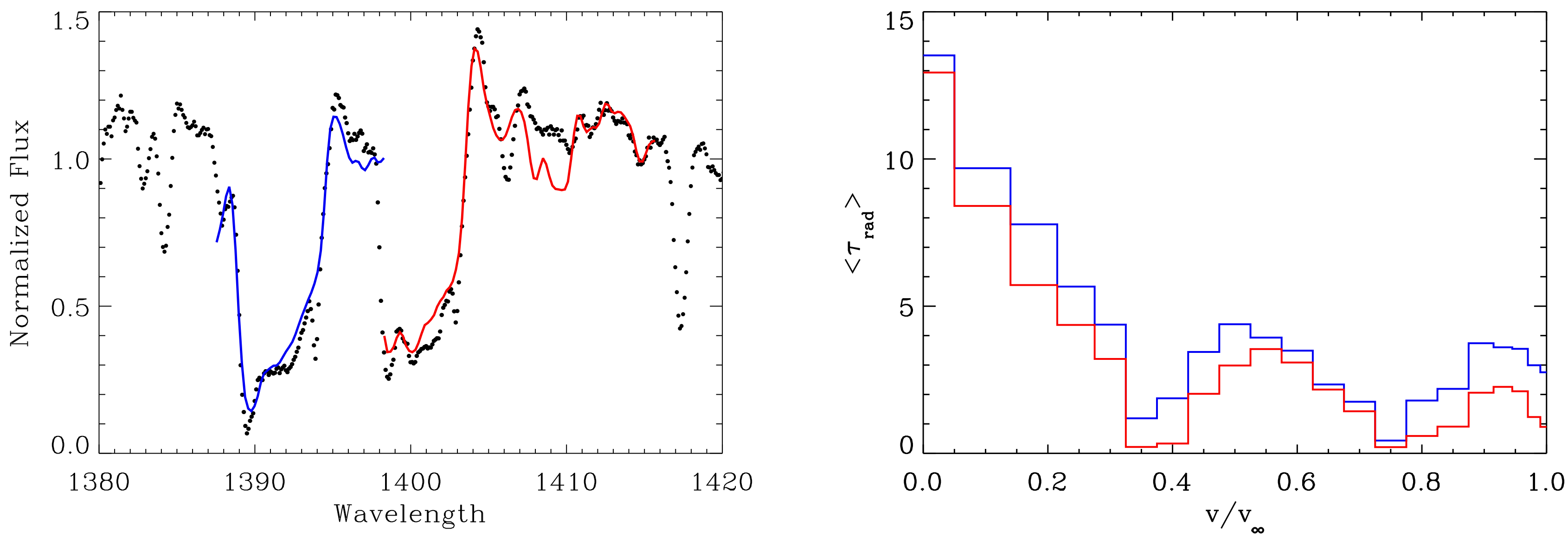
Residual intensity for the clump simulation where clumps have optical depths of 100 at $x = 1$. A strong NAC is clearly present.

- **The model produces NACs because the clumps are optically very thick and relatively sparse.**
- **The sparseness gives small covering factors at low velocity so that $r(\lambda) \sim 1$.**
- **The thickness at $w = 1$ ensures that τ is still large as $w \to 1$, where the covering factor is ~ 1.**

The model provides real constraints on the nature of the clumps.

A Special Case: Decoupled Si IV $\lambda\lambda$1393, 1402

- **In intermediate luminosity early B stars, Si IV $\lambda\lambda$1393, 1402 is often well developed but unsaturated.**
- **These stars often have $v_\infty \lesssim 870$ km s^{-1} – half the doublet separation. Thus the components are decoupled and can be analyzed separately.**
- **Each component acts as a singlet, making the SEI approximation in a clumped wind far less questionable.**



Left: **Fits to the Si IV components in HD 47240 (B1 Ib, $v_\infty = 980$ km^{-1}).**
Right: **Derived τ_{rad}'s. The signs of clumping vary throughout the wind, with $\tau_B/\tau_B \sim$ 2:1 near the NACs, suggesting this is the best region to measure $\dot{M}$.**

Conclusions

- **UV wind lines contain additional diagnostics which convey useful information about how the wind is clumped. Specific lines in particular temperature and luminosity ranges are especially informative.**
- **The information from the wind lines (which effectively provide a core sample of the wind) can supplement other diagnostics to help constrain the nature of wind structure.**
- **To interpret the wind lines diagnostics, a reasonably simple, self-consistent model of radiative transfer in clumped winds is needed.**