Modelling of line-profile variability in WC stars

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Suppose that the atmosphere of a WC star is formed by clumps embedded in the homogeneous spherically symmetric stellar wind. A single clump may be modeled as a part of the spherical layer restricted with a surface of a cone. Present the gas density in the cone as a sum of gas density in homogeneous atmosphere and gas density in a clump:

\[ n_k^{\text{cl}}(r) = D_k n_k(r) e^{-\left(\frac{r-r_{cl}}{\delta_{cl}}\right)^2} + n_k(r). \]  

(1)

Here \( n_k(r) \) is the gas density in the homogeneous atmosphere, \( D_k \) is the ratio of gas densities at a point \( r = r_{cl} \), and \( \delta \) is the size of the clumps in units \( r_{cl} \).

For the law of gas motion in the clump we assume (Kholtygin & Kostenko 1998):

\[ v_{cl}(r) = v(r) + \sqrt{2y} e^{0.5-y^2} \Delta v_{cl}, \quad y = \frac{r - r_{cl}}{\delta_{cl}}. \]  

(2)

Here \( \Delta v_{cl} \) is a free parameter, and \( v(r) \) is the \( \beta \)-velocity law. The profiles of the subordinate C\textsc{iii} \( \lambda5696 \) is calculated in seii-like approximation. Let \( F_i \) be the clump flux. Then the total contribution of the clumps to the line profile is:

\[ F_\nu = 2\pi \int_0^\infty \int_{M_{\text{min}}}^{M_{\text{max}}} \int_{R_*}^{R_{\text{atm}}} N(M, r_{cl}, \theta) F_i(\nu) dM_{cl} dr_{cl} \sin \theta d\theta. \]  

(3)

Here \( M \) is the mass of a clump, which ranges between \( M_{\text{min}} \) and \( M_{\text{max}} \); \( F_i \) is the energy emitted by a clump in the frequency interval \( d\nu \), and \( N \) is the mass spectrum of the clump ensemble. For the outer edge of the atmosphere we adopt \( R_{\text{atm}} = 50R_* \) supposing that the contribution of the remaining part of the wind in the total line profile is negligible. The shape and variability of the profiles of the C\textsc{iii} lines reflect the properties of the whole clump ensemble.

If we assume a power law for \( F_i \):

\[ N(F_i) = A F_i^{-\alpha}, \]  

(4)

where \( A \) is the normalizing coefficient, and \( \alpha \approx 2.0 \pm 0.4 \), then the total flux in the line emitted by a clump is

\[ f_i = \int_{-\infty}^{+\infty} I_i(\nu) d\nu = \int_{-\infty}^{+\infty} I_i^0 e^{-\frac{1}{2} \left( \frac{\nu - \nu_i^0}{\sigma_i^0} \right)^2} d\nu = I_i^0 \sigma_i^0 \sqrt{2\pi}, \]  

(5)
Figure 1. The difference spectra of the CIIIλ5696 line. \( \alpha = 1.8, \)
\( F_{\text{max}}/F_{\text{min}} = 2 \times 10^4, v_\infty = 2400 \text{ km s}^{-1}, \beta = 0.5. \) The time interval between
the sequential spectra \( \Delta t = 5^m. \)

which gives
\[
I_i^0 = \frac{f_i}{\sigma_i \sqrt{2\pi}},
\]
where \( \nu_i^0 \) is the central frequency of the subpeak \( i \), and \( \sigma_i \) is the width of line.
Here \( f_i = F_i/F_{\text{max}} \) is the flux normalized to the maximal flux of clumps supposing
that each clump form the subpeak with the gaussian profile.

To simulate of the line profile variation we model the whole ensemble of
the clumps at the time \( t = 0 \) and suppose that clumps are randomly distributed
in cone angle and starting radius and then move independently. The clump
parameters are recalculated in the time interval \( \Delta t \). The total line profiles \( I^n(x) \)
are evaluated for the moments \( t_n = n \cdot \Delta t. \) We average the different sets of
calculated profiles \( I^n(x) \) \( (n = 1-M) \), where \( M \) is the total number of the profiles
and calculate the mean and difference spectra. Resulting difference spectra are
given in Figure 1. One can see that the separate scraps of shells produce rapidly
moving subpeaks on the emission part of the line profiles which are similar to
the observational results \( \text{e.g., Moffat et ale 1994}. \) Our modelling revealed that
the location of the moving bumps depends strongly on the angle and distance
distribution of the clump ensemble, which might be properly adapted for a closer
comparison with the observational data. The flux in the individual subpeak
depends mainly on the mass of the corresponding clump.

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References