MODELING OF RESONANCE LINES IN INHOMOGENEOUS HOT STAR WINDS

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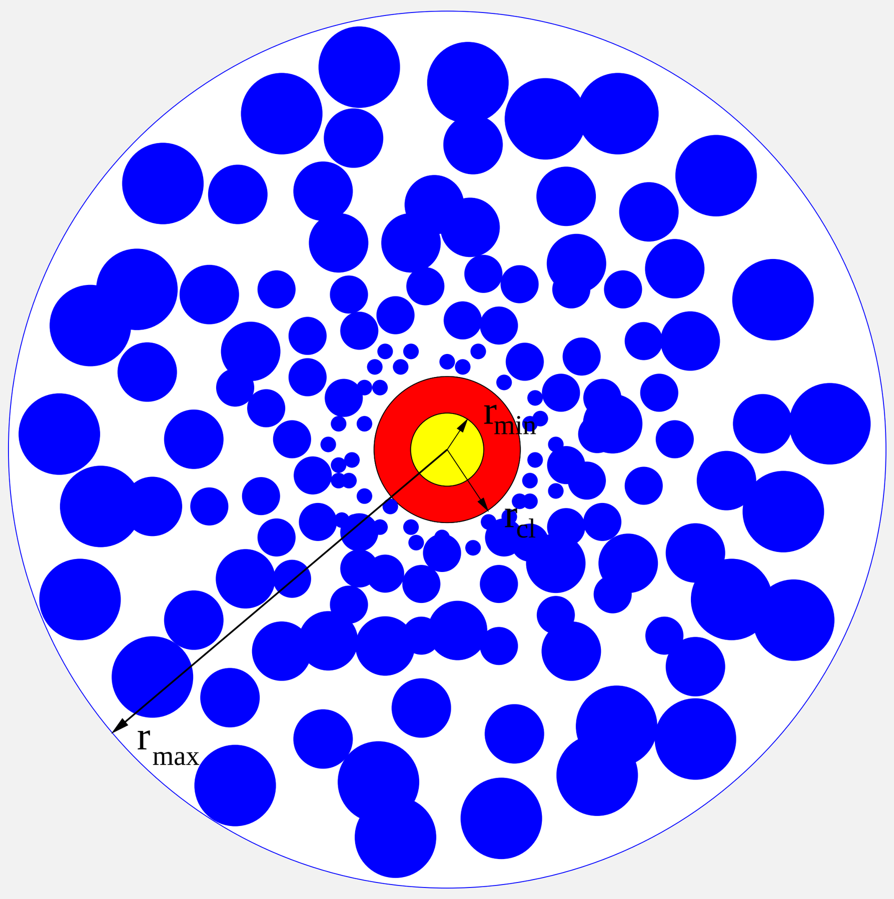
ABSTRACT

The instability of wind radiative driving may cause the occurrence of wind shocks and spatial wind density and velocity structures i.e. clumps. Observational evidence suggests that clumpy structures are a common property and a universal phenomenon of all massive, hot star winds. The structured stellar winds are essentially three-dimensional (3D), and the full description requires the 3D radiative transfer. In this poster a full 3D Monte Carlo radiative transfer code for inhomogeneous expanding stellar winds is presented. We show how different model parameters influence resonance line formation. By modeling UV resonance lines, we demonstrate how wind inhomogeneities may influence line profiles.

WIND MODEL



- **SMOOTH** region
  $r_{\min} < r < r_{\rm cl}$; $r_{\min} = R_*$
- **CLUMPED** region
  $r_{\rm cl} < r < r_{\max}$
  Two density components:
  INTER-CLUMP MEDIUM (ICM) and **CLUMPS**
- Underlying wind velocity

$$v_\beta(r) = v_\infty \left(1 - \frac{b}{r}\right)^\beta$$

- Wind opacity (Hamann, 1980)

$$\chi(r) = \frac{\chi_0}{r^2 v_\beta(r)/v_D}\, q(r)\, \phi_x$$

$$\phi_x = \frac{1}{\sqrt{\pi}} e^{-x^2}$$

χ_0 – opacity parameter; x – dimensioanless frequency; $q(r) \equiv 1$ (constant ionization condition)

DESCRIPTION OF CLUMPING

- Macro-clumping – clumps can be optically thin or thick
- Clumps are statistically distributed with average separation $L = L(r)$
- Clumps are assumed to be spherical with the radius $l = l(r)$
- The density of clumps $\rho_{\rm cl}(r) = D\,\rho_{\rm sw}(r)$; $D \geqslant 1$ – clumping factor
- For the case of dense clumps and void ICM, the volume filing factor is $f_V = 1/D \quad \Rightarrow$

$$D = \frac{L^3(r)}{\frac{4\pi}{3} l^3(r)}$$

- Number density of clumps $n_{\rm cl} \propto \frac{1}{r^2 v_r} \Rightarrow L = n_{\rm cl}^{-1/3}$; L_0 – the clump separation parameter

$$L(r) = L_0 \sqrt[3]{r^2 \frac{v_r}{v_\infty}} \qquad l(r) = l_0 \sqrt[3]{r^2 \frac{v_r}{v_\infty}}$$

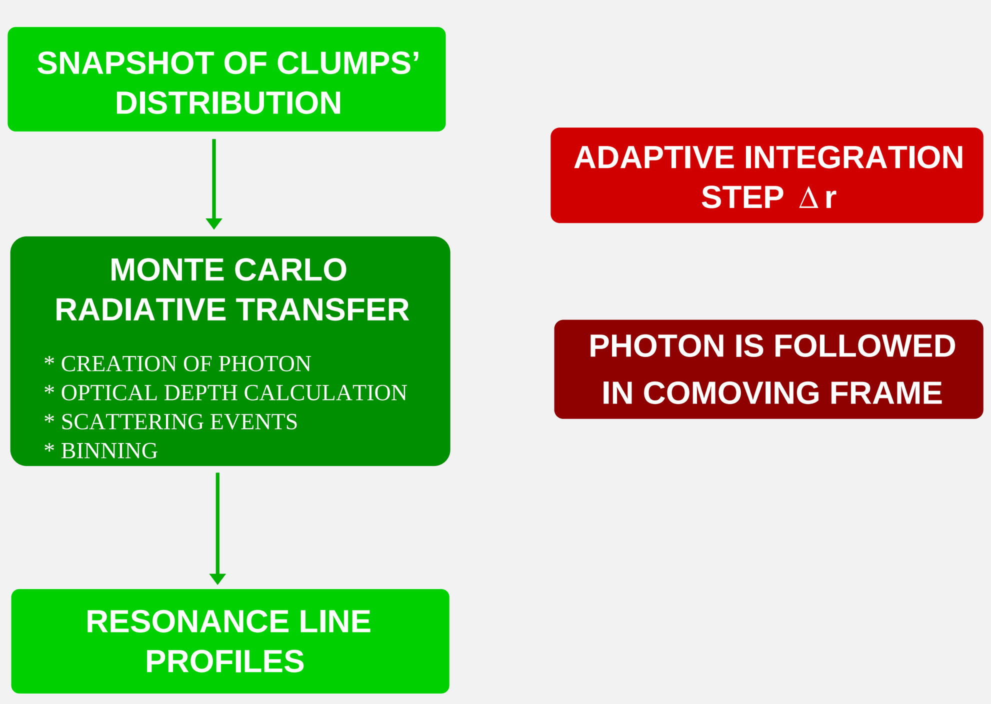
- The density of ICM, $\rho_{\rm ic} = d\,\rho_{\rm sw}$; $\quad 0 \leqslant d < 1$ – ICM density factor
- For the case of dense clumps and non-void ICM $\Rightarrow f_V = (1-d)/(D-d)$
- The distance r_i of the i-th clump from the stellar center $r_i = (r_{\max} - r_{\rm cl})\xi_i + r_{\rm cl}$; $\quad i = 1, N_{\rm cl}$; $\quad 0 < \xi_i \leqslant 1$ – random number; total number of clumps $N_{\rm cl}$
- $1/v_\beta(r)$– probability density distribution function
- Velocity inside clumps ($v_{\rm dis} = m\, v_\beta(r)$, $0 < m \leqslant 1$; r_i^c – position of the i-th clump's ceter)

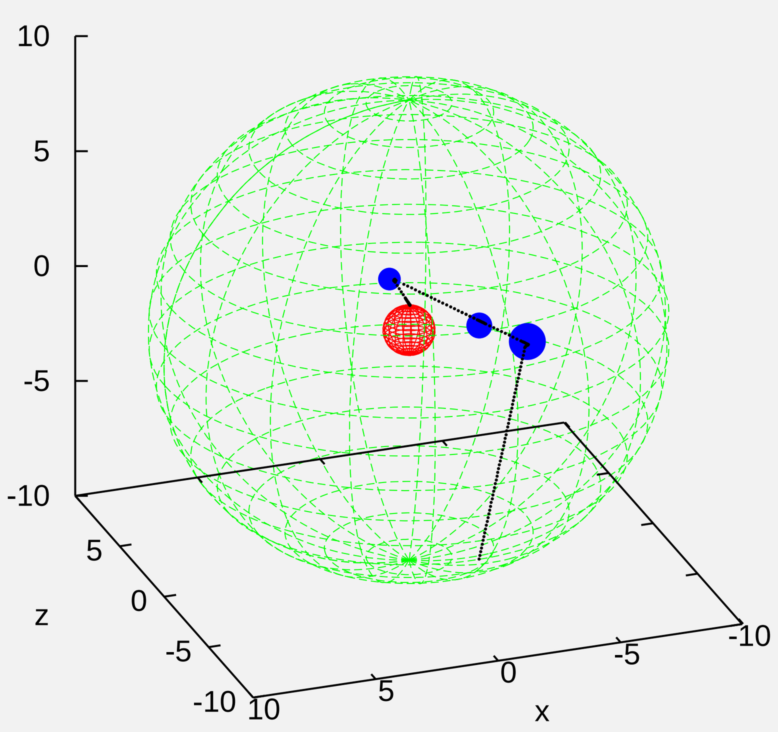
$$v(r) = v_\beta(r) + v_{\rm dis} \frac{r - r_i^c}{l_i}$$

ASSUMPTIONS

- Lower boundary: line-free continuum and no limb darkening
- Scattering lines;
- Complete redistribution
- Pure Doppler-broadening

MONTE CARLO RADIATIVE TRANSFER





UV RESONANCE LINE PROFILES

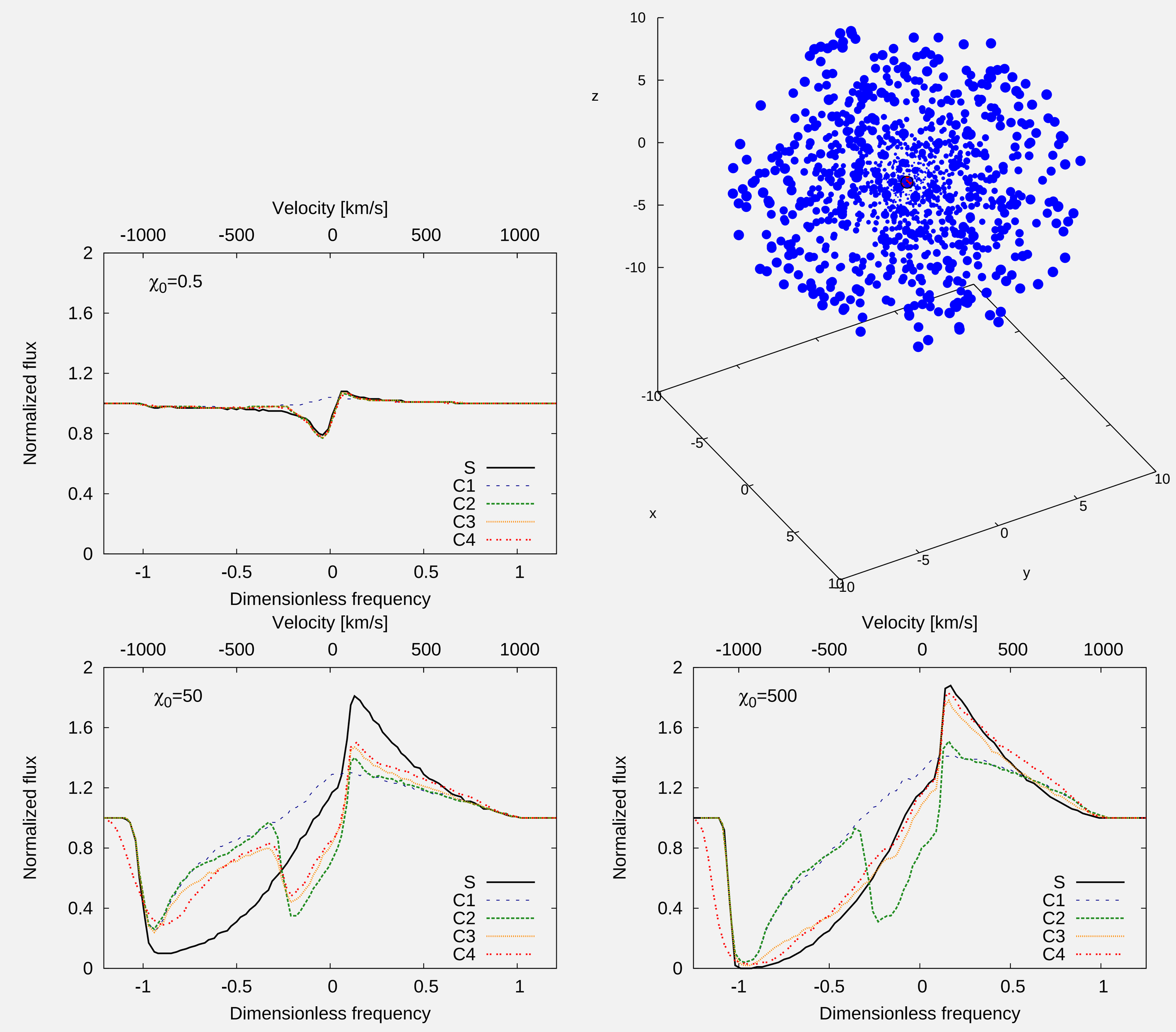


Figure: Line profiles for weak (upper left panel), medium (lower left panel), and strong (lower right panel) lines for the clump distribution in the upper right panel. S – the smooth model; Cn denotes the clumped models – C1 ($r_{\rm cl} = 1$), C2 ($r_{\rm cl} = 1.3$), C3 ($r_{\rm cl} = 1.3$, $d = 0.05$), C4 ($r_{\rm cl} = 1.3$, $d = 0.05$, $v_{\rm dis} = 0.2\, v_\beta$).

COMPARISON WITH OBSERVATION

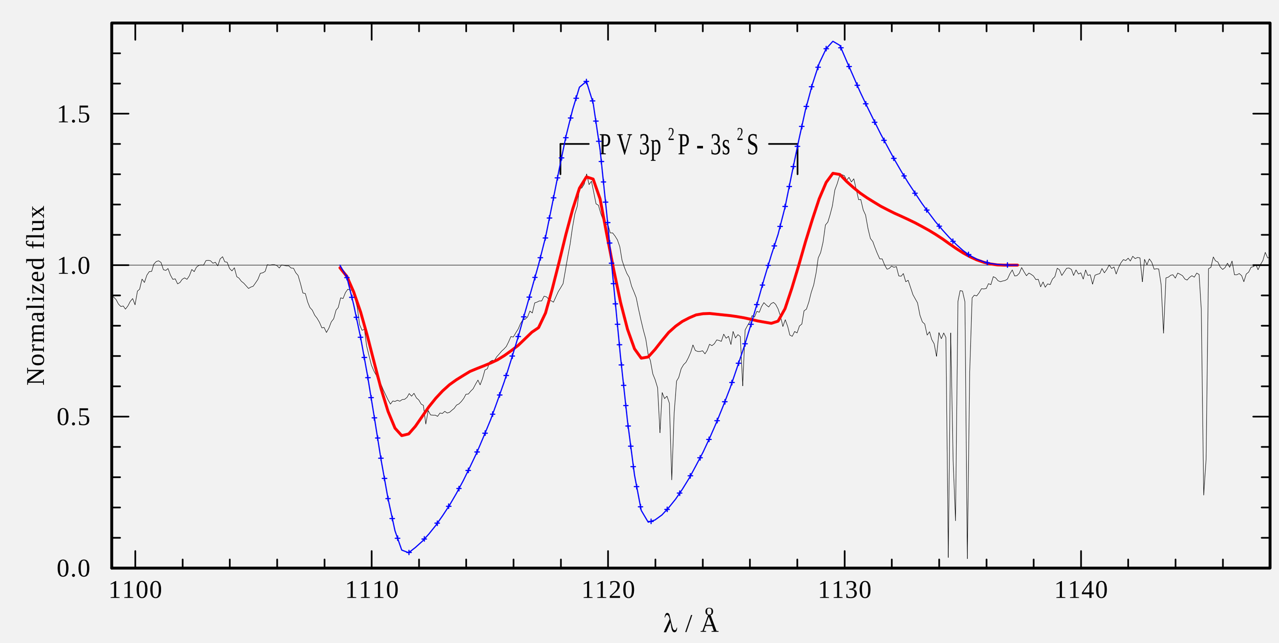


Figure: Comparison of line profiles calculated using different wind models with the observed spectrum of ζ Pup by COPERNICUS (thin full black line).The unclumped wind model is shown by the blue full line with crosses, while clumped model is shown by the red thick full line ($\chi_0 = 350$,$v_\infty = 2250\,km\,s^{-1}$, $v_D = 60\,km\,s^{-1}$, L_0=0.5R_*, D=10, d=0.03, $v_{\rm dis}/v_\beta$=0.05.

CONCLUSIONS

- When macroclumping is taken into account line strength becomes significantly weaker.
- For given D, the key model parameter L_0 affecting the effective opacity $\Rightarrow \dot{M}$.
- Onset of clumping $r_{\rm cl}$ affects the line shape; absorption dip near the line center may provide an effective diagnostic tool for the onset of clumping.
- The line saturation is strongly affected by the ICM.
- Increasing the velocity dispersion inside clumps $\Rightarrow$ the absorption extends to higher velocities than v_∞.
- In case of resonance doublets, clumping effects are analogous to the case of single lines.
- Our 3D model confirms that any mass-loss diagnostics which do not account for wind clumping must underestimate the actual $\dot{M}$.

ACKNOWLEDGEMENTS

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