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“Radiation in stellar winds.  
Resonance line formation in inhomogeneous hot star winds”

doctoral thesis by Mgr. Brankica Šurlan

Referee report

Thesis by Ms. B. Šurlan concerns very interesting and still fully not solved issue i.e.: radiative transfer through the moving gas. The problem is extremely difficult, not only because it requires to solve huge set of differential equations (energy, momentum, continuity) together with differentially-integral radiative transfer equation, but also because numerically it is still very time consuming problem even for presently working computers. Therefore, most often in the case of moving astrophysical objects, like accretion disks, winds, jets, people compute either better hydrodynamic with extremely simplified (often neglected) radiation cooling term, or better radiative transfer assuming stationary situation. Any attempt to combine radiation with gas dynamic is very important step forwards.

Ms. B. Šurlan has solved a problem of resonant line formation in the 3-D spherical clumpy wind often met in case of O, B type stars. Ms. B. Šurlan has designed and written Monte Carlo code to follow photon packages while escaping from the media with strong inhomogeneity and vorosity (i.e. non-monotonic velocity field). As author has pointed out, and I fully agree with her, all wind models are very strongly parametrized. But in this Thesis Ms. B. Šurlan shows that she understands very well how those parameters influence final results.

The Thesis contains eight chapters, where three of them are describing present statement of hot stellar winds, their spectral diagnostic, hydrodynamic and clumping. Fourth chapter
describes most popular methods of radiative transfer treatment in moving media including Sobolev’s approximation and Monte Carlo approach. Chapter fifth is devoted to describe all parameters used to solve Monte Carlo resonance line formation in clumpy winds with velocity distribution along inter-clump medium. Results of numerical simulations are presented in sixth chapter, while comparison with observations and conclusions are in seventh and eight chapter respectively.

Introduction is written very generally, which is very good on one side, since it shows broad knowledge of the author. But on the other side, some sentences are very general, and many questions arise in the reader’s mind. For instance: i) what is the value of typical wind temperature? - for Sun it is given on page 6 but no information for winds in O or B stars, ii) why incoherent scattering (Compton) is not important? - see p. 9.

Since this work has scientific meaning, many interesting sentences should be more precised:

- p.5 “wind reaches its maximum far from the stellar surface” - typically how far?
- “free-free and bound-free processes can be neglected in the wind of O and B” - why?, they are so important in “classical” radiative transfer calculations.
- p.17 “high spatial resolution and instrumental sensitivity are required” - but how high, order of magnitude ?
- p. 14 “physical properties cannot be directly inferred from observations” - many people are fitting models of atmospheres to find star parameters i.e effective temperature and gravity.
- p.16 “line absorption scales linearly with $\rho$” - only for unsaturated lines - linear part of the curve of growth (CoG), for saturated lines this is not true, second part of CoG which depends on velocity parameter.

Sec. 2.2 presents “spectral diagnostic of stellar winds”, I miss at least one example how do we see those winds and their inhomogeneities, for instance simple look at “black troughs” or DACs will be useful.

In discussion of clumping (Sec. 3) several mechanisms are presented: for instance Shaviv (2001) proposed that interaction of clumps with radiation pressure can modify the clump behavior. But what about thermal instability proposed by Field in 1965. He found, that clouds can condense and evaporate due to illumination by UV or X-ray radiation. Their formation is caused by thermal instability, where cloud can be formed if there is a perturbation of the order of the Field length, which depends on colling and heating mechanisms in a cloud (p.31 and macro-clumping).

Sec.4.4.2 first and second paragraph. The author forgot to say that “classical” solution methods are able to compute temperature, density, ionization structure for hydrogen and heavy elements and all frequency dependent opacities and emissivities together with Compton scattering in optically thick media. Therefore, “classical” Feautrier method allows to follow continuum and
lines creation and passing through an atmosphere in all directions (limb-darkening or brightening). This is what the code presented in this Thesis is not doing. 3-D Monte Carlo simulations allow photons to travel in the constant ionization \((q(r)=1)\) plasma, which is clumpy and has assumed velocity gradient. Only one opacity is taken into account - resonant line scattering. Continuum opacity is ignored. So, in my opinion, Monte Carlo codes cannot be compared to the “classical” solution method at all. People working with “classical” methods may say that Monte Carlo simulations without proper treatment of ionization and scattering are unphysical.

Mgr. B. Šurlan has mentioned that she is not using Sobolev approximation (Eq. 2.22), but she solves Sobolev equation of transfer (4.8), which is a simplification of full radiative transfer equation. In Sobolev equation, the matter structure differential of the true intensity is replaces by the frequency differential equaled to the velocity differential of the true intensity. This procedure is not done in “classical” calculations of plane-parallel atmospheres. In such case, I don’t feel like Monte Carlo method can compute full radiative transfer. It just show how line is modified due to velocity distribution (vortexity) and strong inhomogeneity (porosity). Thermal broadening usually computed in “classical” atmospheric calculations from the gas temperature is fully assumed here. Of course, turbulent line broadening is assumed in both cases. Sobolev theory is based on calculation of radiation escape probability which is \(e^{-\tau}\). This type of treatment does not compute a source function depending on the temperature, density and ionization state of matter. Finally, Sobolev approximation is valid for large velocity gradient - how large? Some numbers will be useful.

Mgr. B Šurlan understands that her model is very much based on strong parametrization, and she has shown nicely how those parameters influence the wind structure. She has doing all calculations in adaptive integration step, which is very good for substantial parameter gradients.

The most interesting result achieved by Mgr. B. Šurlan is strong absorption deep in the line profile due to wind clumping. Particularly, I'm interested in multi absorption line structure presented in Fig. 5.9, since similar profile is observed in UV lines of distant quasars. My question is, why this multi absorption structure is never repeated in other calculations, i.e. following figures. It will be nice to see in Fig. 4.2, what was the input line profile. I would expect it was Gaussian, but how broad?

The Thesis are well organized from editorial point of view. I found some mistakes which make this work harder to read and it may help the author in the future work:

- explanation what “a” means in Eq. 2.6 will be nice,
- p 10 - source function is “independent of frequency”, but it is in Eq. 2.21, below,
- “values” - typo p. 35,
- p. 56 i 57 - Sec. 5.2.2 quoted in two places doesn’t exist. Should be 5.5 ?
- p. 62 in titles of subsection should be inter-clump factor, since small “d” is the one.
- Fig. 5.2 - it will be nice to write in the figure label how Right panel differs from Left.
• the same parameter has two names: $\kappa_0$ and $\chi_0$. As I have noticed it means the same: reference opacity used in 5.7. On the page 72 it is $\kappa_0$, while in many figures is $\chi_0$.

• Fig. 6.5 again uses $\kappa_0$, but additional problem is orange dash-dotted line which is not on the figure, but is listed in the label below figure. Additionally full red line represents $m=0.1$ on the figure, but $m=0.2$ in the figure label.

• p. 86 “is not observed disappears” - one verb is enough.

Summarizing, the scientific result contained in the Thesis is original and very important step forward to tred transfer of radiation in moving media. The Thesis are written clearly, with all necessary background, and understanding of all parameters, those assumed and randomly chosen in Monte Carlo process. The presented work fully proves Ms. Brankica Šurlan deserves to be awarded a doctoral degree.

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