THE RADIATIVE TRANSFER IN THE AXIAL SYMMETRY

Daniela Korčáková **Viktor Votruba** **Petr Hadrava** **Jiří Kubát** **Petr Škoda**

[1] Astronomical Institute, Academy of Sciences of the Czech Republic, Fričova 298, CZ-251 65 Ondřejov, Czech Republic

email: kor@sunstel.asu.cas.cz, votruba@sunstel.asu.cas.cz, had@sunstel.asu.cas.cz, kubat@sunstel.asu.cas.cz

We present our multidimensional radiative transfer code. The problem is solved in the axial symmetry approximation. The velocity field is included into the radiative transfer equation.

Introduction

We report a numerical multidimensional radiative transfer code for moving media developed by Korčáková (2003). The main assumption of used method is the axial symmetry. The radiative transfer is solved from optically thick to the optically thin regions. The velocity field can be described from static layers up to 2000 $\mathrm{km \cdot s^{-1}}$ (typical values for terminal velocity of stellar wind of hot stars or rotation velocities of disks of cataclysmic variables). The velocity field must be axially symmetrical, but may be accelerating, decelerating, or even oscillating. The radial velocity field ($\equiv$ wind) can be combined with the tangential velocity distribution ($\equiv$ rotation).

The radiative transfer equation is solved using a combination of short (Kunasz & Auer, 1988) and long characteristics method (Cannon, 1970). The detailed description of this method can be found in Korčáková & Kubát (2005a).

The Method Description

code overview

LTE	
NLTE	only the version for parallel computers
S	bound-bound + bound-free + free-free processes + Thomson scattering
elements	Hydrogen
input	$n_e(r,\theta)$, $T(r,\theta)$, $\mathbf{v}(r,\theta)$
output	line profile, intensity map

the solution of the radiative transfer problem

The radiative transfer problem is solved in a set of longitudinal planes (Fig. 1) independently on each other. In every longitudinal plane the polar coordinate system is introduced using the optical depth.

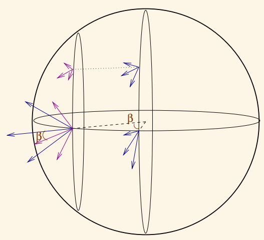


Figure 1: The set of longitudinal planes.

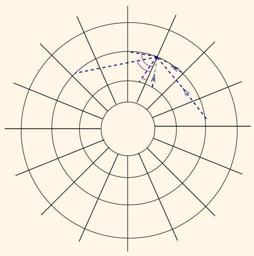


Figure 2: The scheme for solving the radiative transfer in the longitudinal plane.

The radiative transfer equation is solved along the chosen rays from every grid point. These rays does not end at the given cell boundary, but at the next grid circle (Fig. 2). This longer characteristics allow us to better include the global character of the radiation field.

velocity field

Since the radiative transfer equation is Lorentz invariant, we can solve the static radiative transfer equation in every cell assuming constant velocity inside the cell. The change of velocity occurs only at the cell boundaries. This approximation is limited by the value of frequency shift between neighbouring cells. If it is large ($\sim$ 1/4 of Doppler halfwidth), the grid must be finer.

mean intensity integration

The whole radiation field at every grid point is obtained by rotating the longitudinal planes along the axis of symmetry (Fig. 3).

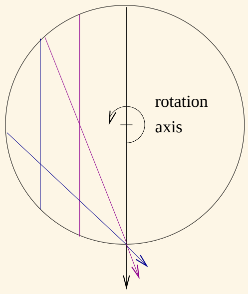


Figure 3: The mean intensity integration.

In this way, the angle description of the specific intensity is defined by global properties of the object. The grid is finer in the outer regions, where the radiation field is strongly anisotropic, while it is coarse in inner parts, where radiation is almost isotropic. This saves memory and computing time. On the other hand, it is impossible to use the commonly used area method without interpolation, which introduces another numerical error. For this reason we use the HEALPix (Hierarchical Equal Area isoLatitude Pixelization, Fig. 4) grid, originally developed for the Virtual observatory (Górski et al., 2005). This technique is more time-consuming, but very accurate.

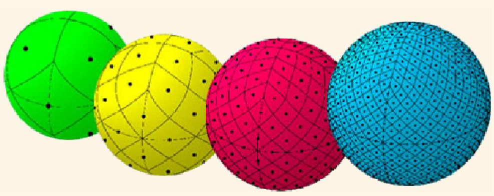


Figure 4: HEALPix grid. http://healpix.jpl.nasa.gov/

The Method Applicability

static stellar atmospheres

- **limb darkening**
- the applicability: spectra analysis, interferometry, gravitational microlensing . . .

rapidly rotating stars

- **gravity darkening** and **differential rotation** are naturally included
- Korčáková & Kubát (2004), Korčáková & Kubát (2005b)

stellar wind

- the consistent solution: deep **optically thick** photosphere layers + **optically thin** wind region
- **different properties of the stellar wind** in the equatorial and polar regions are included
- description of the velocity field influence **from the static atmosphere to the terminal velocity**
- radiatively driven stellar wind
- Korčáková et al. (2004), Korčáková & Kubát (2006), Krtička et al. (2008)

disks

- the consistent solution: **the central object** + **the disk** + **the hot corona** + **the polar wind**
- the applicability: Be, B[e], cataclysmic variables
- Korčáková et al. (2005)

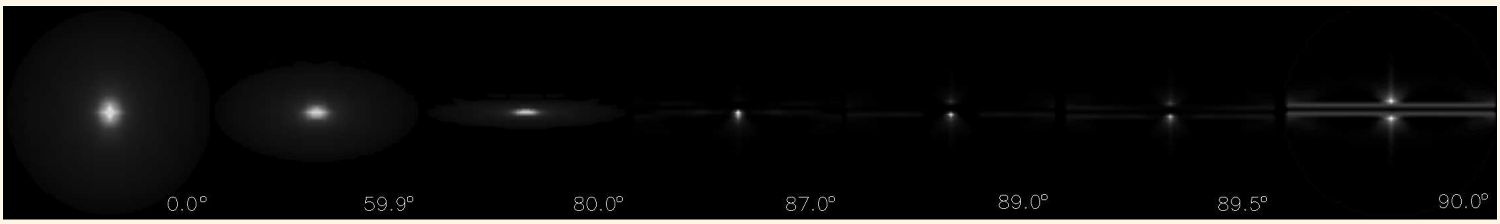
Conclusion

The method was originally developed for the study of stellar wind. Since it consistently solves the radiative transfer from optically thick to the optically thin regions as well as from zero velocity to relatively high velocity, it is applicable for a lot of celestial objects. It is very useful for the description of extended stellar atmospheres, rapidly rotating stars, disks around Be or B[e] stars as well as for the accretion disks around white dwarfs. It can be also used for the study of protoplanetary nebulae. In this case, the nebula is too close to the central star, that it is necessary to take into account star and nebula together.

This research was supported by grants 228398 (the European Commission), 205/09/P476 (GA ČR), 205/08/0003 (GA ČR) and LC06041 (MŠMT ČR). The Astronomical Institute Ondřejov is supported by a project AV0Z10030501.

References

Cannon, C. J. 1970, ApJ 161, p. 255 – 264
Górski, K. M., Hivon, E., Banday, A. J., Wandelt, B. D., Hansen, F. K., Reinecke, M., Bartelmann, M., 2005, ApJ 622, p. 759 – 771
Korčáková, D., 2003, PhD thesis, Masaryk University Brno, Czech Republic
Korčáková, D., Kubát, J., 2004, IAUS 215, p. 25 - 26
Korčáková, D., Kubát, J., Krtička, J., Šlechta, M., 2004, IAUS 224, p. 533 - 538
Korčáková, D., Kubát, J., 2005a, A&A 440, p. 715 - 725
Korčáková, D., Kubát, J., Kawka, A., 2005, ASPC 334, p. 403 - 406
Korčáková, D., Kubát, J., 2005b, MSAIS 7, p. 130 - 131
Korčáková, D., Kubát, J., 2006, ASPC 355, p. 75 - 78
Krtička, J., Korčáková, D., Kubát, J., 2008, ASPC 388, p. 191
Kunasz, P., Auer, L. H. 1988, JQSRT 39, p. 67 – 79



Poster presented at Recent Directions in Astrophysical Quantitative Spectroscopy and Radiation Hydrodynamics, Boulder, Colorado, March 30 – April 3, 2009