RADIATIVE TRANSFER IN AXIAL SYMMETRY

Daniela Korčáková kor@sunstel.asu.cas.cz
Astronomical Institute of the Academy of Sciences, CZ

collaborators:
V. Votruba, J. Krtička, J. Kubát, P. Hadrava, Th. Nagel, K. Werner, D. Semionov, V. Suleymanov, M. Curé, Ph. Stee

picture: http://chandra.harvard.edu/photo

Outline

the description of the method

the method applicability

- the limb darkening
- the stellar rotation
- the stellar wind – Be, B[e] stars
- disks – cataclysmic variables, . . .

the description of the method

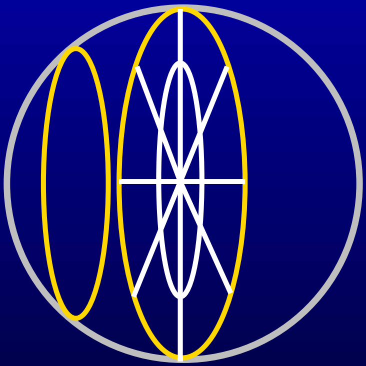
the method preview

- axial symmetry
- LTE
- NLTE – parallel version (in the final test phase)
- hydrogen
- input – $n_e(r,\theta)$, $T(r,\theta)$, $\mathrm{v}(r,\theta)$
- output – line profile, intensity map
- Korčáková & Kubát, 2005, A&A 440, 715

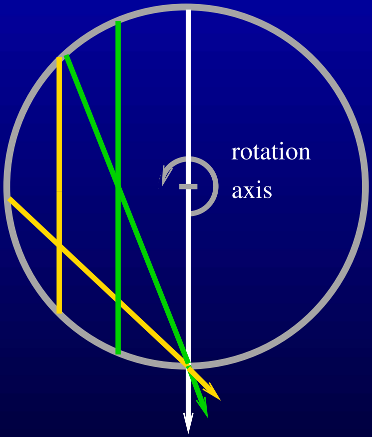
basic idea

- solution of the radiative transfer equation in separated planes
- polar coordinates in every plane
- combination of the short and long characteristics
- velocity field – Lorentz invariant of RTE

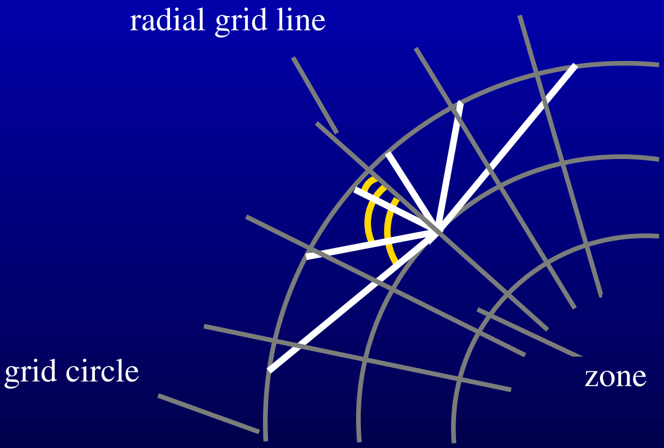
longitudinal planes



whole radiation field



upper boundary condition

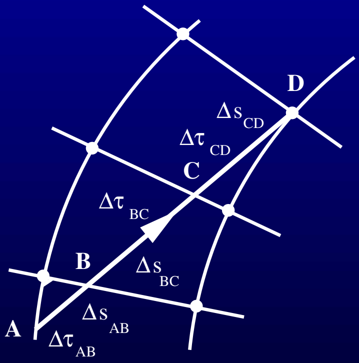


integration

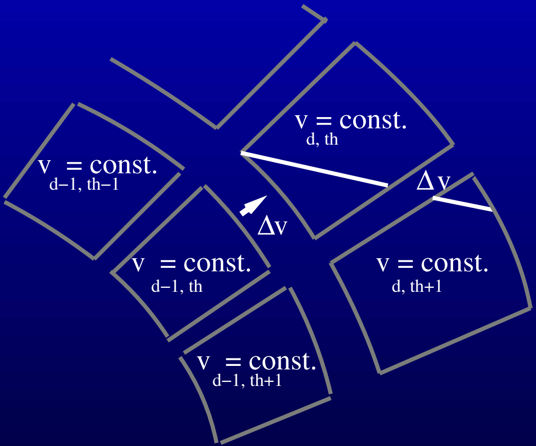
$$I_{(B)} = I_{(A)} e^{-\Delta\tau_{(AB)}} + \int_0^{\Delta\tau_{(AB)}} S(t) e^{[-(\Delta\tau_{(AB)}-t)]} dt$$

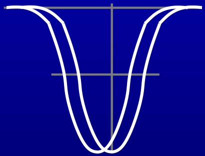
S(t):

- bound-bound
- bound-free
- free-free
- Thomson scattering

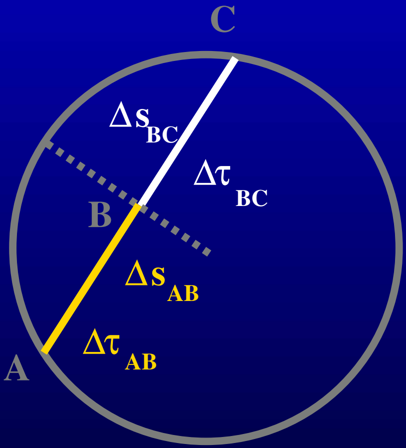


velocity field

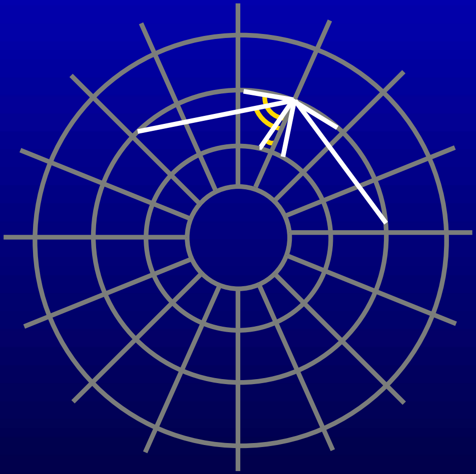




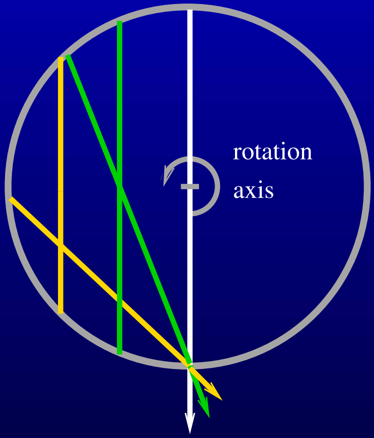
the solution in the central region



the lower boundary condition



mean intensity

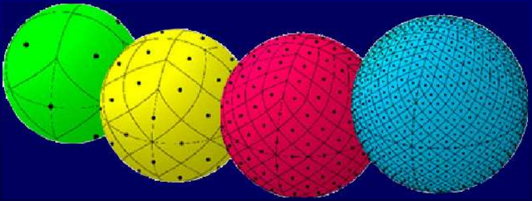


- the grid is defined by global properties
- advantage – better description in outer regions, where the radiation field is strongly anisotropic

- disadvantage – not possible to use an area method
- HEALPix (Hierarchical Equal Area isoLatitude Pixelization)

  Gorski, Hivon, Banday, Wandelt, Hansen, Reinecke, Bartelmann, 2005, ApJ 622, 759

  http://healpix.jpl.nasa.gov/



parallelisation

- mpi
- memory × computational time × communication
- the formal solution of the radiative transfer equation is splitted into the nodes by lines
- the solution of the NLTE rate equations is distributed to the nodes by frequencies at the given point
- in the final test phase

advantages

- better description of the global character of the radiation field than by the short characteristic method
- not so time consuming as the long characteristic method
- arbitrary velocity field

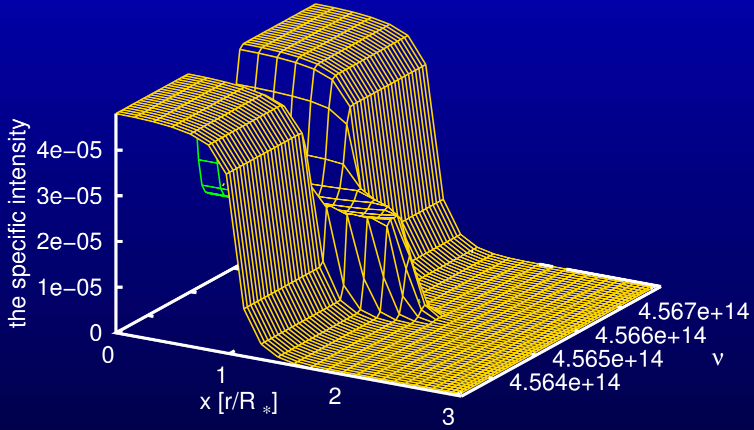
disadvantages

- high velocity gradients $\Longrightarrow$ a finer grid
- computing time $= f$ (number of frequency points) $\sim$ parabolic

the method applicability

- the limb darkening
- the stellar rotation
  - gravity darkening, differential rotation
- the stellar wind
  - optically thin + optically thick regions
  - polar + equatorial regions
  - Be, B[e] stars, . . .
- disks
  - cataclysmic variables, protostellar disks
- object + surrounding media
  - protoplanetary nebulae

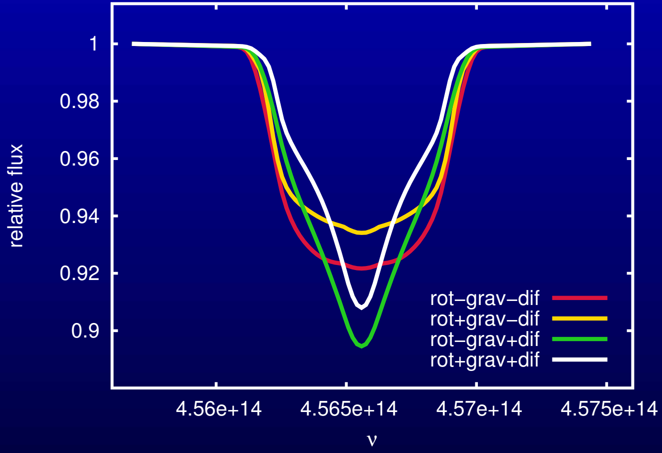
the limb darkening



the stellar rotation

- rapidly rotating stars
- the gravity darkening
- the differential rotation

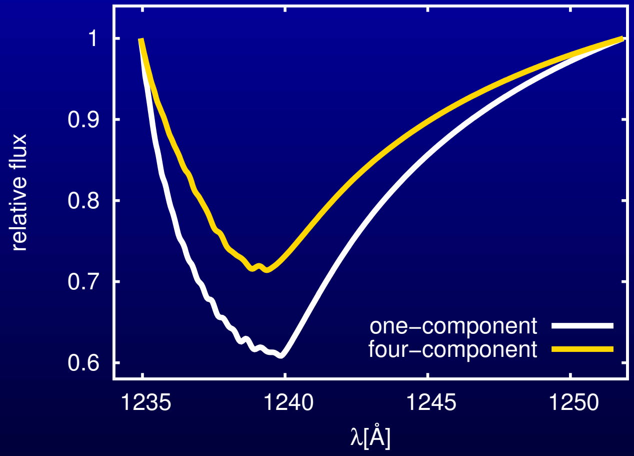
an extended rapidly rotating atmosphere



the stellar wind

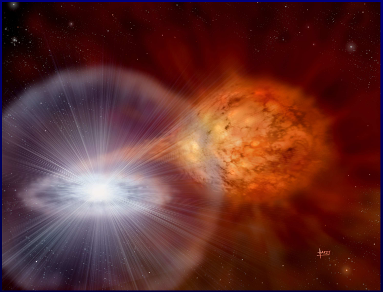
– optically thick atmospheric regions + wind
– polar + equatorial region
– static layers + fast outer region
– stellar wind + rotation
– Be, B[e] stars

- Krtička, Korčáková, Kubát, 2008, ASPC 388, 191
- N V line 1242 Å

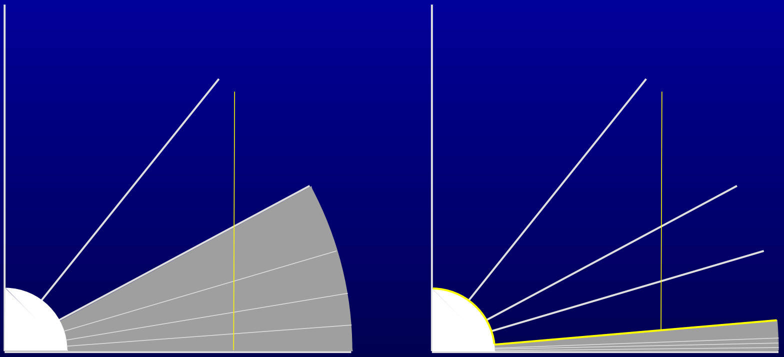


disks

- protostellar disks
- cataclysmic variables =
  central white dwarf + transition region +
  disk + hot corona
  - disk – optically thick or thin
  - impossible to include a hot spot



cataclysmic variable

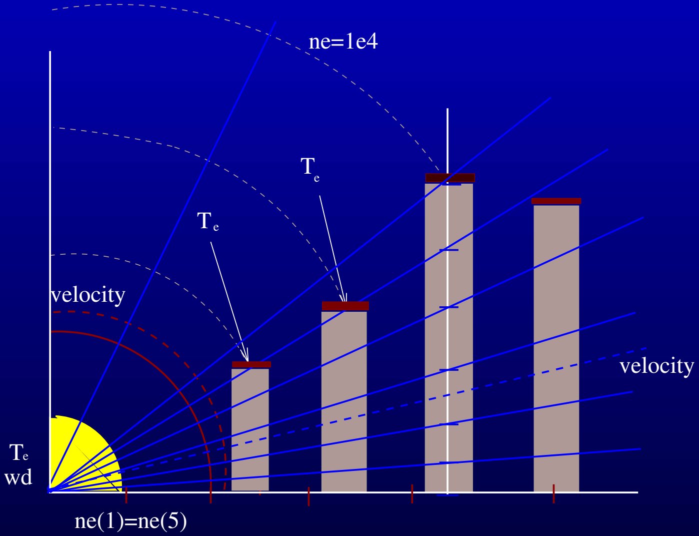


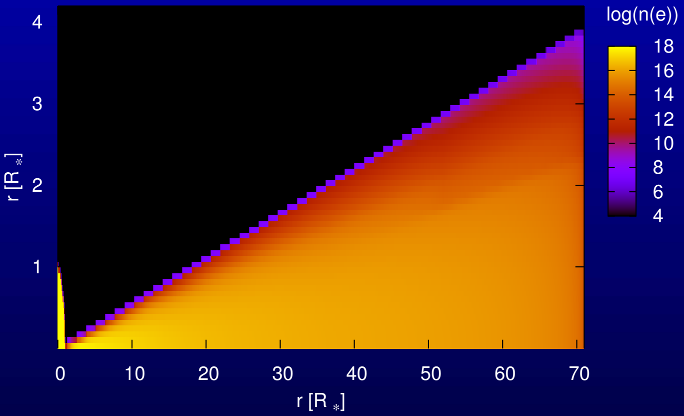
SS Cyg

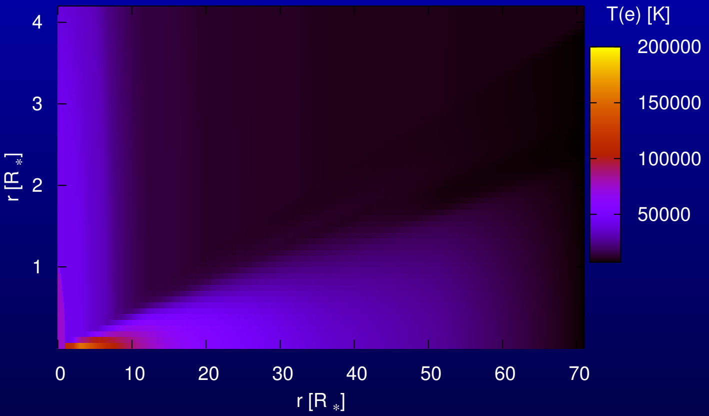
M_{wd}	$1.19\ M_{\odot}$
R_{wd}	$0.006\ R_{\odot}$
$T_{eff\,(wd)}$	$74912\ K$

Kepler rotation law:

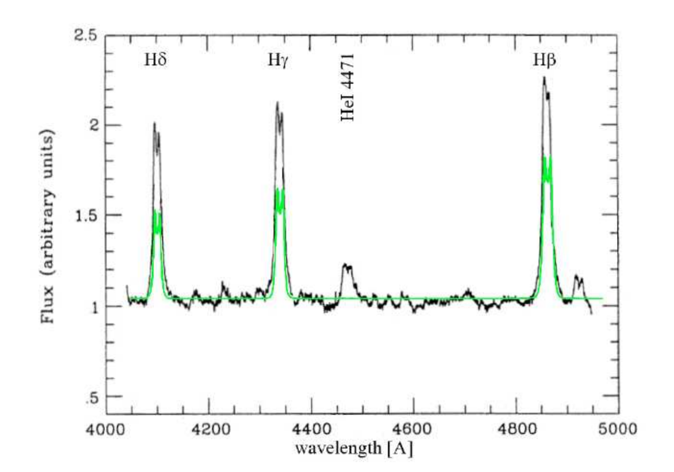
$$v(r, \theta = \pi/2) = (gM_{wd}/r)^{1/2}$$
$$v(r, \theta) = v(r, \theta = \pi/2) sin(\theta)$$


ne=1e4
T e
T e
velocity
velocity
Te
wd
ne(1)=ne(5)

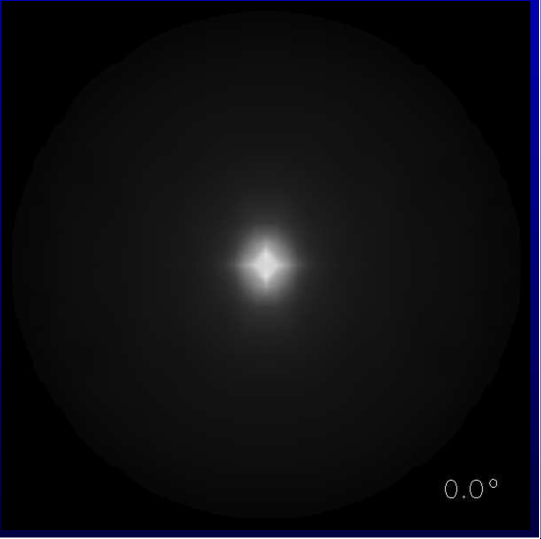

log(n(e))
18
16
14
12
10
8
6
4
r [R *]
4
3
2
1
0
10
20
30
40
50
60
70
r [R *]



T(e) [K]
200000
150000
100000
50000
4
3
2
1
r [R *]
0
10
20
30
40
50
60
70
r [R *]



Kromer, M., Nagel, T., Werner, K., 2007, A&A 475, 301


0.0°