Introduction to the RH Radiative Transfer Code

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Two available Non-LTE Radiative transfer codes

**MULTI3D**

- Carlsson, M. 1986, Uppsala Astronomical Report, No. 33
- Leenaarts, J., Carlsson, M. 2009, ASPC 415, 87
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RH

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**RH**
The MULTI3D code

- Well tested
- One- and three-dimensional Cartesian geometry
- Formal solution with short characteristics
- Domain decomposition with MPI parallelization for large clusters
- Partial frequency redistribution with scheme developed for RH transfer code
The RH code

- One-, Two-, Three-dimensional Cartesian, and spherically symmetric geometry
- Short characteristics
- Partial frequency redistribution multi-level atoms
- Polarization, Zeeman effect in atomic and molecular lines, scattering continuum
- Molecular lines, polarization, Non-LTE
- Multiple species in Non-LTE simultaneously
- Parallelization over wavelengths for shared memory machines
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- As densities drop with height, collisions become less frequent, and radiative transitions become relatively more important.

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Directory structure of RH code

- RH_v2
  - librh.a
  - librh_f90.a
- idl
- tools
- atlases
- rhf1d
  - solveray
- rhsc2d
  - solveray
- rhsc3d
  - solveray
- rhsphere
- run1
- run2
- run3
Main Input files for the RH code

- keyword.input
- atoms.input
- molecules.input
Introduction to the RH Radiative Transfer Code

Keyword.input
- atoms.input
  - Atom1.atom
  - Atom2.atom
  - Atom3.atom
- molecules.input
  - Molecule1.molecule
  - Molecule2.molecule
  - Molecule3.molecule
- Atmosphere
- Magnetic field
- abundances
- Kurucz.input
  - List1.gf
  - List2.gf
  - List3.gf
- Magnetic field
  - list1
  - list2
  - list3
Input structure atmospheric data file

example.atmos

example.B

dimensions
boundary conditions
temperature
electron density
hydrogen density
microturbulence
velocity structure
field strength
field inclination
field azimuth
Input structure atomic data file

example.atom

- ID
- bound-bound list
- bound-free list
- collisions

- energy levels
- statistical weight
- level label
- ionization stage
- level IDs
- oscillator strength
- line shape
- wavelength grid parameters
- damping parameters

- cross section
- wavelength shape
- cross section
- temperature dependence
Main Input files for the RH code

- keyword.input
- atoms.input
- molecules.input
RH Analyze

Analyse 1-D
Wavelength and line selection in Non-LTE calculations

- Representative bound–bound and bound–free transitions so that populations are properly calculated with statistical equilibrium.
- Representative wavelength coverage so that radiative rates in every transition are properly estimated.
Wavelength grid for Mg II h&k lines

```
Wavelength [nm] 0 2•10⁻⁹ 4•10⁻⁹ 6•10⁻⁹ 8•10⁻⁹
Flux [J m⁻² s⁻¹ Hz⁻¹] 279.6 279.8 280.0 280.2 280.4
```

Back
# Version: rh1.0, 1-D plane-parallel

# First specify input files for atmosphere and abundances
# (both KEYWORD_REQUIRED).
ATMOS_FILE = ../../Atmos/FALP80.atmos
ABUND_FILE = ../../Atoms/abundance.input

# Set choice of number of rays (KEYWORD_OPTIONAL).
NRAYS = 5

# Input file for all atoms (KEYWORD_REQUIRED).
ATOMS_FILE = atoms.input

# Input file for all molecules (KEYWORD_REQUIRED).
MOLECULES_FILE = molecules.input

## Table of additional wavelengths KEYWORD_OPTIONAL
## WAVETABLE = ../../Atoms/wave_files/Gband_filter.wave

# Maximum number of iterations to initialize scattering radiation
# field in the background (KEYWORD_OPTIONAL).
N_MAX_SCATTER = 2

# Row of statistical equilibrium equation that is to be eliminated
# to enforce particle conservation (KEYWORD_REQUIRED). If set to -1
# the row with the largest population from the previous iteration will
# be eliminated at each spatial location.
I_SUM = -1

# Set number of maximum iterations and convergence limit
# (both KEYWORD_REQUIRED).
N_MAX_ITER = 25

ITER_LIMIT = 1.0E-2
The keyword.input file

# Parameters for Ng convergence acceleration (all are KEYWORD_OPTIONAL)
# (default for NG.ORDER = 0, no acceleration)
NG_DELAY = 15
NG_ORDER = 2
NG_PERIOD = 3

# PRD specific parameters. PRD_N_MAX_ITER is the maximum number of
# PRD iterations per main iteration. PRD_ITER_LIMIT is the convergence
# limit of PRD iterations in each main iteration. If PRD_ITER_LIMIT is
# negative, the dpropsmax of the current main iteration is taken as the
# PRD convergence limit. Both are KEYWORD_OPTIONAL. If PRD_N_MAX_ITER
# all lines will be treated in CRD.
PRD_N_MAX_ITER = 3
PRD_ITER_LIMIT = 1.0E-2

# PRD.NG._?? are the Ng accelleration parameters for PRD iterations
# (all are KEYWORD_OPTIONAL).

# PRD.NG_DELAY = 0
# PRD.NG_ORDER = 2
# PRD.NG_PERIOD = 3

# If PRD_ANGLE DEP is set to TRUE angle-dependent PRD is used
# (KEYWORD_DEFAULT). The default is FALSE.

### PRD_ANGLE DEP = TRUE
### XRD = FALSE
The keyword.input file

# Temporary files for mean intensities and background opacities
# (KEYWORD_REQUIRED).

J_FILE = J.dat
STARTING_J = NEW_J
BACKGROUND_FILE = background.dat
OLD_BACKGROUND = FALSE

# Apply multiplicative factor to all background metals. METALLICITY
# is specified in terms of dex, ie -1.0 means a tenfold decrease in metals
# Type is KEYWORD_DEFAULT.

# METALLICITY = 0.4
# Data file with lines in Bob Kurucz's format. Type is KEYWORD_OPTIONAL.
# When KURUCZ_DATA is set to "none" (the default value) no data is read.
# Solve for electron density if SOLVE_NE is set to ONCE or ITERATION.
# Type is KEYWORD_DEFAULT. Default value is FALSE.
# KURUCZ_PF_DATA should point to the file with Kurucz partition function
# tables (as function of T) for the first 100 periodic table elements.
# It is needed when either KURUCZ_DATA or SOLVE_NE is set and is of
# type KEYWORD_DEFAULT
KURUCZ_PF_DATA = ../../Atoms/pf.Kurucz.input
# KURUCZ_DATA = kurucz.input
# RLK_SCATTER = TRUE
## SOLVE_NE = NONE

# Set HYDROGEN_LTE = TRUE if hydrogen in the background has to be
# treated with LTE populations (KEYWORD_DEFAULT). Default is FALSE
## HYDROGEN_LTE = TRUE
## HYDROSTATIC = TRUE
The keyword.input file

# Data file for background opacity fudge to compensate for missing
# UV line haze. Type is KEYWORD_OPTIONAL. When set to “none” (the
# default value) no data is read.

### OPACITY_FUDGE = ../../Atmos/opacity_fudge.input

# Output files for atomic data, spectrum, populations, and geometry
# (all KEYWORD_DEFAULT).
# DEFAULT = SPECTRUM_OUTPUT = spectrum.out
# OPACITY_OUTPUT, RADRATE_OUTPUT, COLLRATE_OUTPUT, and DAMPING_OUTPUT # are all
# KEYWORD_OPTIONAL

# When set to “none” (which is the default) no output is produced.
# For keyword OPACITY_OUTPUT and emissivity of active transitions of
# the solution is written to the specified file.
# For keyword RADRATE_OUTPUT radiative rates for active transitions are
# written to the specified file.
# For keyword COLLRATE_OUTPUT collisional rates for active transitions are
# written to the specified file.
# For keyword DAMPING_OUTPUT damping parameters for active transitions are
# written to the specified file, as well as the broadening velocity
# for the specific atom.
OPACITY_OUTPUT = opacity.out
RADRATE_OUTPUT = radrate.out
COLLRATE_OUTPUT = collrate.out
DAMPING_OUTPUT = damping.out

# Typical value of “micro-turbulence” in [km/s]. Used in getlambda.c
# to convert doppler units to real wavelengths.

VMICRO_CHAR = 3.0
The keyword.input file

# Treshold value of macroscopic velocity in [km/s] above which line
# absorption coefficients are calculated seperately for the different mu
# values (KEYWORD_OPTIONAL).
## VMACRO_TRESH = 1.0E-1
# Reference wavelength in [nm] (KEYWORD_DEFAULT). When not specified
# or set to 0.0 no additional wavelength point will be added.
# DEFAULT – LAMBDA_REF = 500.0
# If VACUUM_TO_AIR (KEYWORD_OPTIONAL) is set to TRUE wavelengths at and above
# VACUUM_TO_AIR_LIMIT (see spectrum.h) will be converted to air wavelength
# in the output files.

VACUUM_TO_AIR = TRUE
The keyword.input file

# Input file for the magnetic field (KEYWORD_OPTIONAL). Default is "none".
# STOKES_INPUT = ../../Atmos/FALC_82.2000G_45.B
# Input Stokes mode (KEYWORD_OPTIONAL).
# Options are: NO_STOKES, FIELD_FREE, POLARIZATION_FREE, and FULL_STOKES.
STOKES_MODE = FULL_STOKES
# Include magneto-optical effects (KEYWORD_DEFAULT). Default is TRUE.
# MAGNETO_OPTICAL = FALSE
# Typical value of magnetic field in Tesla (1 T = 1.0E+4 Gauss)
# (KEYWORD_DEFAULT).
## B_STRENGTH_CHAR = 0.20
# Include scattering polarization in the background (KEYWORD_DEFAULT).
# Default is FALSE.
BACKGROUND_POLARIZATION = TRUE
## LIMIT_MEMORY = TRUE
# ALLOW_PASSIVE_BB = FALSE
# Set this value to TRUE to get printout on CPU usage (may take some
# extra CPU usage though!).
PRINT_CPU = TRUE
# Enable program to do the formal solution for N_THREADS wavelengths
# concurrently (KEYWORD_OPTIONAL). Maximum number of threads is limited
# by the value of N_THREAD_LIMIT in routine setThreadValue in file
# readvalue.c. Typically, N_THREADS should be equal to the number of
# processors in a multi-processor machine, or zero (the default) otherwise.
N_THREADS = 4
# End
# Natom
4
#
#
# Atoms
# model file ACTIVE/PASSIVE INITIAL_SOLUTION population file
../../Atoms/H.6.atom ACTIVE ZERO_RADIATION pops.H.out
../../Atoms/C.atom PASSIVE LTE_POPULATIONS
../../Atoms/O.atom ACTIVE OLD_POPULATIONS pops.O.out
../../Atoms/Si.atom PASSIVE ZERO_RADIATION
#

Back
The molecules.input file

# Nmolecule
#
5
#
# molecules

..../Molecules/H2.molecule PASSIVE LTE_POPULATIONS
..../Molecules/CH.molecule PASSIVE LTE_POPULATIONS
..../Molecules/CO.molecule ACTIVE LTE_POPULATIONS
..../Molecules/CN.molecule PASSIVE LTE_POPULATIONS

..../Molecules/H2O.molecule PASSIVE LTE_POPULATIONS