QUANTITATIVE SPECTROSCOPY OF MASSIVE HOT STARS
Lecture IV: PoWR - NLTE model atmosphere code

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Selected chapters on astrophysics

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Specificication of the PoWR code

The main purpose

- To simulate the emergent spectrum of a hot star with given stellar parameters
- The models have been successfully applied so far for:
  - OB stars (luminosity class 0-V), early A
  - Wolf-Rayet stars
  - Central stars of planetary nebulae (massive and low-mass)
  - Subdwarfs
  - Extreme helium stars
- The code has been developed since the late 1970s under the guidance of prof. Wolf-Rainer Hamann
- Developers: Werner Schmutz, Ulf Wessolowski,Gerhard Dünnebeil, Uwe Leuenhagen, Lars Koesterke, Helge Todt, Götz Gräfener, Wolfgang Leindecker, Sonja Burgemeister, Martin Steinke, Tomer Shenar, Andreas Sander

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Specificicication of the PoWR code

Basic assumptions

- Spherically-symmetric expansion
- Stationarity
- Pre-specified wind velocity law and mass-loss rate

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

$$b = R_* \left\{1 - \left(\frac{v(R_*)}{v_\infty}\right)^{1/\beta}\right\}$$

$$\dot{M} = 4\pi r^2 \rho(r) v(r)$$

Specificication of the PoWR code

Physics that is taken into account

- non-LTE radiative transfer
- Detailed model atoms with up to $\sim$ 1000 explicit non-LTE levels
- Iron-group elements with millions of lines in a superlevel approach
- Inhomogeneities on small scales (”microclumping“)
- Embedded X-ray sources

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Computation of the emergent spectrum

Can optionally account for:

- pressure broadening of spectral lines
- inhomogeneities on large scales ("macroclumping", "porosity")
- wind rotation

Specificication of the PoWR code

Limitations

- Spherically-symmetric expansion $\rightarrow$ not optimal for Be/Oe stars
- Pressure broadening only for emergent spectrum $\rightarrow$ not good for high $\log g$ objects, e.g., WD or NS
- An expanding atmosphere with strict monotonic increasing $v(r)$ assumed for treatement of CMF radiative transfer $\rightarrow$ no static atmospheres/stars completely without wind
- No molecular data in PoWR $\rightarrow$ not optimal for stars cooler than B stars
- Not for cool stars, e.g., Sun

Accessing the PoWR models

Grid of models

- PoWR homepage:
  `http://www.astro.physik.uni-potsdam.de/~PoWR`
- Grids of Wolf-Rayet stars of the nitrogen subclass WN (WNE and WNL) and OB star models at different metallicities
- WR models are organized in grids in the $T_* - R_t$
- An approximate scaling invariance of WR atmospheres, the same model spectrum can be applied to stars with different luminosities, but same T_* and R_t.
- For OB star grids, reduction done by choosing combinations of T_{eff}, $\log g \rightarrow L_*$ from stellar evolution models, $\dot{M}$ fixed

$$R_{\mathrm{t}} = R_* \left[\frac{v_\infty}{2500\,\mathrm{km}\,s^{-1}} \bigg/ \frac{\dot{M}\sqrt{D}}{10^{-4} M_\odot \mathrm{yr}^{-1}} \right]^{2/3}$$

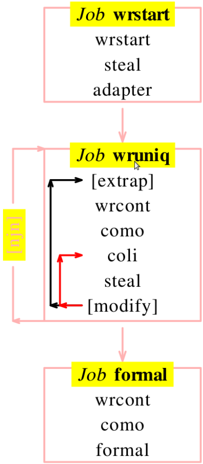
Accessing the PoWR models

Available data for each model

- Spectral Energy Distribution
    - Emergent flux received at 10pc distance, low spectral resolution.
- Line spectrum in high resolution for different wavelength bands.
    - Optionally normalized or flux-calibrated
- Atmosphere stratification
    - Electron temperature, density, optical depth, etc.
- Colors and ionizing photons

Structure of the PoWR code

Structure



wrstart: setup model, 1st approx. for J_ν
steal: statistical equations with approximate lambda operator → population numbers
adapter: [adapt pop.numbers from previous model]

extrap: speed up convergence by extrapolation
wrcont: angle-dependent rad transfer (static, cont.)
como: moment eqns. (static, continuum)
coli: comoving rad. transfer (continuum & lines)
steal: statistical eqns. → popnums, [temp. corr.]
modify: automatic interpolation for bad depth points

wrcont: (see above)
como: (see above)
formal: Formal integral (observer's frame) → emergent spectrum

Structure of the PoWR code

Directories I

Can optionally account for: each PoWR user has a $POWR_WORK directory, containing at least:

- wrdata$n for currently calculated model No. n
- output containing human-readable output files (log files, numbers,spectra to plot) for each model n
- scratch with temporary data, status information, organized as subdirectories per job and model, e.g., wrstart$n
- wrjobs comprises all PoWR scripts (wrstart, wruniq, etc.; bash scripts) to run PoWR models, usually one per mode

Structure of the PoWR code

Directories II

For individual installations (not in cluster) additional directories:

- proc.dir with scripts to check and start PoWR scripts / status
- wrdata-archive contains the atomic database, files per ion, broadening data, iron files (pre-calculated super levels and lines)
- exe.dir, exe_vd20.dir, exe_xxl.dir executable binaries in different dimensions (depending on iron files)
- intellibs the necessary dynamic libraries

→ in a cluster installation these directories are not per user Moreover:

- tmp_data similar to scratch
- tmp_2day contains assisting data files: DMFILE, EDDI

→ in a cluster installation these directories are per HOST for faster access (local data vs. NFS access to $POWR_WORK)

Structure of the PoWR code

Input files I

- CARDS
  - user-edited ASCII file with all model specifications, numerical parameters, and output options
  - each program picks out the appropriate lines
  - some options can be changed while model is running (stat break wruniq$n)
- DATOM
  - ASCII file with the atomic data
  - read by (almost) all programs
  - data (ions) must fit to model/input in CARDS
  - iron: only request of ion stages (lowest-highest)

Structure of the PoWR code

Input files II

- FEDAT, FEDAT_FORMAL
  - 10^7 lines and 10^4 levels approximated by superlines and superlevels
  - created (prepared) by special program package Blanket
  - large files, usually symbolic link from wrdata$n to wrdata-archive
  - different versions: number and grouping of levels, included ion, Doppler broadening for superlines (VDOP, fixed)
  - SMALL version: FEDAT_FORMAL only with lab-confirmed λ
- FGRID
  - ASCII file: frequency grid (λ (Å) table) for continuum/coarse grid
  - usually only giving the bluemost point (e.g., 5 Å, 20 Å) $\rightarrow$ replaced bys
  - CARDS option BLUEMOST-WAVELENGTH
  - completely ignored if taken from previous model (CARDS option OLD FGRID)

THANK YOU FOR YOUR ATTENTION!

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