CMFGEN

(Practical notes)

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CMFGEN & Desmond John Hillier

Back to John Hillier's Homepage

CMFGEN:

Probing the Universe through Spectroscopy

A radiative transfer code designed to solve the radiative transfer and statistical equilibrium equations in spherical geometry. It has been designed for applic
Luminous Blue-Variables.

- CMFGEN Flowchart (PDF)
- Documentation for CMFGEN (tar.gz)
  Last updated 28-Jun-2023
- CMFGEN Source Files
  Last updated 26-Jun-2023
- Atomic Data
  Last updated 21-Jun-2023
- Three CMFGEN Models (O , B, WC4)
  Last updated 22-Jun-2023
- A Small Set of CMFGEN Models
  Last updated 18-Apr-2003
- A Grid of O star CMFGEN Models
  Last updated 24-Jun-2009
- A Small Grid of Plane-Parallel Models
  Last updated 26-Apr-2011
- CMFGEN SN models and Spectra
  Last updated 06-Feb-2016

https://sites.pitt.edu/~hillier/web/CMFGEN.htm

MAIN COMMAND

./batch.sh – calculation of atmosphere (structure)

./batobs.sh – calculation of syntetic spectrum (analog of Synspec)

./cpmod.sh – *creating* new directory (./cpmod.sh old_model new_model)

./clean.sh – delete hyperlinks

batch.sh – calculation of atmosphere (structure)
Contains paths to atomic data and main command for the start of calculation

```
#!/bin/tcsh
#
#*****************************************************************
#   Define directories (CAPITAL LETTERS)
#*****************************************************************
#
# HOME is disk
# MODEL is model directory
# ATOMIC is atomic data directory
#
source ~/CMFGEN/cur_cmf1/com/aliases_for_cmfgen.sh


setenv CMFGEN_PROG   $cmfdist/exe/cmfgen_dev.exe

#
#*****************************************************************
#    Atomic data soft links. All other shell commands should be
#    place after these links. These links are model dependent. Ther
#    are required by CMFGEN, CMF_FLUX, and DISPGEN
#
#    When N_F=N_S, no F_TO_S link is needed.
#*****************************************************************

#*************************************************************************
# Generic
# -------
 #************************************************************************

 ln -sf  $ATOMICNEW/misc/two_phot_data.dat                    TWO_PHOT_DATA
 ln -sf  $ATOMIC/misc/xray_phot_fits.dat                     XRAY_PHOT_FITS
 ln -sf  $ATOMICNEW/misc/rs_xray_fluxes_sol.dat                RS_XRAY_FLUXES
 ln -sf  $ATOMICNEW/HYD/I/5dec96/hyd_l_data.dat               HYD_L_DATA
 ln -sf  $ATOMICNEW/HYD/I/5dec96/gbf_n_data.dat               GBF_N_DATA

#*************************************************************************
#    Hydrogen
#   ----------
#*************************************************************************
#
 ln -sf  $ATOMICNEW/HYD/I/5dec96/hiphot.dat                   PHOTHI_A
 ln -sf  $ATOMICNEW/HYD/I/5dec96/hi_osc.dat                   HI_F_OSCDAT
 ln -sf  $ATOMICNEW/HYD/I/5dec96/hi_f_to_s_15.dat             HI_F_TO_S
 ln -sf  $ATOMICNEW/HYD/I/5dec96/hicol.tlusty                 HI_COL_DATA

#*************************************************************************
```

INPUT PARAMETERS

VADAT – file with input parameters (luminosity, temperature, mass loss rate, etc)

MODEL_SPEC – file containing information about super levels and grid

IN_ITS – number of iterations

VADAT

```
237.7754   [RSTAR]          !Rp 125
158.43698685  [RMAX]          !Rmax/Rp
T          [DO_HYDRO]

7          [VEL_LAW]        !Velocity Law
RVSIG_COL  [VEL_OPT]
800.0      [VINF]           !Terminal (km\s)
3.0        [BETA]           !Gamma (i.e. Beta=speed of velocity law)
6.50E-6    [MDOT]           !Mass loss rate
6.500D+5   [LSTAR]          !Luminosity (Lo)
2.750D0    [TEFF]
2.650D0    [LOGG]
47.06587983  [MASS]         !Stars Mass (Mo)

T          [DO_CL]          !Allow for clumping in the model?
REXPO      [CL_LAW]         !Law to evaluate clumping factors.
3          [N_CL_PAR]       !Number of clumping parameters
0.5        [CL_PAR_1]       !1st clumping  parameter (X at Vinf)
5          [CL_PAR_2]
700        [CL_PAR_3]

1.5        [HYD/X]          !H/X abundance (by number)
0.5        [HE/X]           !He/X abundance (by number)
1.250D-4   [CARB/X]         !C/X abundance (by number)
0.80D-3    [NIT/X]          !N/X abundance (by number)
4.00D-4    [OXY/X]          !O/X abundance (by number)
3.500D-5   [SIL/X]          !SIL/X abundance
2.291E-07  [PHOS/X]         !P/X abundance (by number)  = P_sol
1.30D-5    [SUL/X]          !SUL/X abundance
4.160D-5   [IRON/X]         !IRON/X abundance

F          [RD_CF_FILE]     !Read in continuum frequencies from file
3.49897D-3 [MIN_CF]         !Minimum continuum frequency if calculating NU
1000.000D0 [MAX_CF]         !Maximum continuum frequency if calculating NU
```

MODEL_SPEC

```
70          [ND]            !Number of depth points
15          [NC]            !Number of core rays
85          [NP]            !Number of impact parameters [ND+NC]
3           [NUM_BNDS]      !Use 3 for tridiagonal matrix (should be odd)
250000      [NCF_MAX]       !Total number of frequencies
150         [MAX_SIM]       !Maximum # of lines whose Doppler profile overlpas.
150000      [NLINE_MAX]     !Maximum # of bound-bound transitions
21          [NLF]           !For CMF option only

20,20,30    [HI_ISF]
45,45,69    [HeI_ISF]
22,22,30    [He2_ISF]
40,40,92    [C2_ISF]
51,51,84    [CIII_ISF]
64,64,64    [CIV_ISF]
32,32,69    [N2_ISF]
41,41,82    [NIII_ISF]
44,44,76    [NIV_ISF]
41,41,49    [NV_ISF]
54,54,123   [O2_ISF]
88,88,170   [OIII_ISF]
38,38,78    [OIV_ISF]
32,32,56    [OV_ISF]
25,25,31    [OSIX_ISF]
33,33,33    [SkIII_ISF]
22,22,33    [SkIV_ISF]
30,30,90    [PIV_ISF]
16,16,62    [PV_ISF]
24,24,44    [SIII_ISF]
51,51,142   [SIV_ISF]
31,31,98    [SV_ISF]
104,104,1433 [FeIII_ISF]
74,74,540   [FeIV_ISF]
50,50,220   [FeV_ISF]
44,44,433   [FeSIX_ISF]
29,29,153   [FeSEV_ISF]
```

VADAT

```
130.74563885  [RSTAR]            !Rp 125
108.42976734  [RMAX]             !Rmax/Rp
T          [DO_HYDRO]

7           [VEL_LAW]          !Velocity Law
RVSIG_COL   [VEL_OPT]
1820.0      [VINF]             !Terminal (km\s)
1.5         [BETA]             !Gamma (i.e. Beta=speed of velocity law)
1.00E-6     [MDOT]             !Mass loss rate
2.80D+5     [LSTAR]            !Luminosity (Lo)
2.970D0     [TEFF]
3.20D0      [LOGG]
23.07408119 [MASS]             !Stars Mass (Mo)

T           [DO_CL]       !Allow for clumping in the model?
EXPO        [CL_LAW]      !Law to evaluate clumping factors.
2           [N_CL_PAR]    !Number of clumping parameters
0.23        [CL_PAR_1]    !1st clumping  parameter (X at Vinf)
10.0        [CL_PAR_2]

1.0         [HYD/X]            !H/X abundance (by number)
0.11        [HE/X]            !He/X abundance (by number)
1.500D-4    [CARB/X]           !C/X abundance (by number)
1.500D-4    [NIT/X]            !N/X abundance (by number)
1.000D-4    [OXY/X]            !O/X abundance (by number)
-5.81D-04   [MAG/X]            !Mg/X abundance (by mass)
3.300D-5    [SIL/X]            !SIL/X abundance
2.500D-7    [PHOS/X]           !P/X abundance (by number)  = P_sol
2.000D-5    [SUL/X]            !SUL/X abundance
3.600D-5    [IRON/X]           !IRON/X abundance

F           [RD_CF_FILE]       !Read in continuum frequencies from file
3.49897D-3  [MIN_CF]           !Minimum continuum frequency if calculating NU
1000.000D0  [MAX_CF]           !Maximum continuum frequency if calculating NU
1.10D0      [FRAC_SP]          !Fractional spacing for small frequencies
1.05D0      [AMP_FAC]          !Amplification factor for large frequency ranges
0.10D0      [MAX_BF]           !Maximum frequency spacing close to bf edge
```

VADAT

```
130.74563885  [RSTAR]            !Rp 125
108.42976734  [RMAX]             !Rmax/Rp
T          [DO_HYDRO]

7             [VEL_LAW]          !Velocity Law
RVSIG_COL     [VEL_OPT]
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1.5           [BETA]             !Gamma (i.e. Beta=speed of velocity law)
1.00E-6       [MDOT]             !Mass loss rate
2.80D+5       [LSTAR]            !Luminosity (Lo)
2.970D0       [TEFF]
3.20D0        [LOGG]
23.07408119   [MASS]             !Stars Mass (Mo)

T             [DO_CL]       !Allow for clumping in the model?
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10.0          [CL_PAR_2]

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0.11          [HE/X]            !He/X abundance (by number)
1.500D-4      [CARB/X]           !C/X abundance (by number)
1.500D-4      [NIT/X]            !N/X abundance (by number)
1.000D-4      [OXY/X]            !O/X abundance (by number)
-5.81D-04     [MAG/X]            !Mg/X abundance (by mass)
3.300D-5      [SIL/X]            !SIL/X abundance
2.500D-7      [PHOS/X]           !P/X abundance (by number)  = P_sol
2.000D-5      [SUL/X]            !SUL/X abundance
3.600D-5      [IRON/X]           !IRON/X abundance

F             [RD_CF_FILE]       !Read in continuum frequencies from file
3.49897D-3    [MIN_CF]           !Minimum continuum frequency if calculating NU
1000.000D0    [MAX_CF]           !Maximum continuum frequency if calculating NU
1.10D0        [FRAC_SP]          !Fractional spacing for small frequencies
1.05D0        [AMP_FAC]          !Amplification factor for large frequency ranges
0.10D0        [MAX_BF]           !Maximum frequency spacing close to bf edge
```

```
T             [INC_XRAYS]
F             [FF_XRAYS]
T             [X_SM_WIND]
1000          [VS_XRAYS]
2.0D-01       [FIL_FAC_1]
200           [T_SHOCK_1]
500           [V_SHOCK_1]
5.6D-03       [FIL_FAC_2]
600.0D0       [T_SHOCK_2]
500           [V_SHOCK_2]
```

VADAT

```
130.74563885  [RSTAR]        !Rp 125
108.42976734  [RMAX]         !Rmax/Rp
T             [DO_HYDRO]

7             [VEL_LAW]      !Velocity Law
RVSIG_COL     [VEL_OPT]
1820.0        [VINF]         !Terminal (km\s)
1.5           [BETA]         !Gamma (i.e. Beta=speed of velocity law)
1.00E-6       [MDOT]         !Mass loss rate
2.80D+5       [LSTAR]        !Luminosity (Lo)
2.970D0       [TEFF]
3.20D0        [LOGG]
23.07408119   [MASS]         !Stars Mass (Mo)
```

VADAT

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EXPO        [CL_LAW]          !Law to evaluate clumping factors.
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0.23        [CL_PAR_1]        !1st clumping  parameter (X at Vinf)
10.0        [CL_PAR_2]

1.0         [HYD/X]           !H/X abundance (by number)
0.11        [HE/X]       !He/X abundance (by number)
1.500D-4    [CARB/X]          !C/X abundance (by number)
1.500D-4    [NIT/X]           !N/X abundance (by number)
1.000D-4    [OXY/X]           !O/X abundance (by number)
-5.81D-04   [MAG/X]           !Mg/X abundance (by mass)
3.300D-5    [SIL/X]           !SIL/X abundance
2.500D-7    [PHOS/X]          !P/X abundance (by number)  = P_sol
2.000D-5    [SUL/X]           !SUL/X abundance
3.600D-5    [IRON/X]          !IRON/X abundance
```

MODEL_SPEC

```
70          [ND]          !Number of depth points
15          [NC]          !Number of core rays
85          [NP]          !Number of impact parameters [ND+NC]
3           [NUM_BNDS]          !Use 3 for tridiagonal matrix (should be odd)
250000      [NCF_MAX]     !Total number of frequencies
150         [MAX_SIM]     !Maximum # of lines whose Doppler profile overlpas.
150000      [NLINE_MAX]   !Maximum # of bound-bound transitions
21          [NLF]         !For CMF option only

30,30,30    [HI_ISF]
69,69,69    [HeI_ISF]
30,30,30    [He2_ISF]
49,49,125   [C2_ISF]
68,68,128   [CIII_ISF]
33,33,38    [CIV_ISF]
39,39,85    [N2_ISF]
117,117,177       [NIII_ISF]
69,69,111   [NIV_ISF]
33,33,41    [NV_ISF]
54,54,123   [O2_ISF]
```

Parallel Process !!!!

IN FILE BATCH.SH:

source ~/CMFGEN2023/cur_cmf/com/aliases_for_cmfgen.sh
set local_path = `/usr/bin/lsof +p $$ | \grep -oE /.\*batch.sh`

setenv OMP_NUM_THREADS 5
setenv CMFGEN_PROG $cmfdist/exe/cmfgen_dev.exe

Number parallel processes

```
#!/bin/tcsh
#
#*******************************************************************
#   Define directories (CAPITAL LETTERS)
#*******************************************************************
#
# HOME is disk
# MODEL is model directory
# ATOMIC is atomic data directory
                                    023/cur_cmf/com/aliases_for_cmfgen.sh
                                  ` = `/usr/bin/lsof +p $$ | \grep -oE /.\*batch.sh`
setenv OMP_NUM_THREADS 5
setenv CMFGEN_PROG   $cmfdist/exe/cmfgen_dev.exe

#
#*******************************************************************
                 mic data soft links. All other shell commands should be
#    place after these links. These links are model dependent. Ther
#    are required by CMFGEN, CMF_FLUX, and DISPGEN
#
#    When N_F=N_S, no F_TO_S link is needed.
#*******************************************************************

#*******************************************************************************
# Generic
# -------
 #*******************************************************************************

 ln -sf  $ATOMIC/misc/two_phot_data.dat                    TWO_PHOT_DATA
 ln -sf  $ATOMIC/misc/xray_phot_fits.dat                   XRAY_PHOT_FITS
 ln -sf  $ATOMIC/misc/gal_xray_hr.dat                      RS_XRAY_FLUXES
 ln -sf  $ATOMIC/HYD/I/5dec96/hyd_l_data.dat               HYD_L_DATA
 ln -sf  $ATOMIC/HYD/I/5dec96/gbf_n_data.dat               GBF_N_DATA

#*******************************************************************************
```

OUTPUT PARAMETERS

MOD_SUM – summary of model
CORRECTION_SUM – summary of changes at each depth
OUTGEN – summary of changes at each iteration
RVTJ – radius, Velocity, Electron density, Temperature, Atom Density, etc…
HYDRO – look at the errors when velocity = 10 km/s. The errors should be better than 4%
OBSFLUX – check the luminosity (should be consistent within a percent). Convergence (Normalized luminosity check) should typically be better than 2%

obs/ obs_fin – main spectrum. The file contains a list of frequencies (in 10^{15} Hz) and then lists the corresponding fluxes in Janskies (assuming d = 1 kpc). It is a raw data file — no smoothing has been done and no effect of rotation is taken into account. ASCII file !!!

obs/ obs_cont – continuum spectrum (may contain dielectronic lines if they are treated as part of the photoionization cross-sections). ASCII file !!!

Limit number of possible parameters

Temperature – from spectral classification (for OB-type, WR stars)

Luminosity – based on distance and photometric data

$L_{star} = 10^{((4.75 - M_{bol})/2.5)}$

$M_{bol\_star} = M_{v\_star} + BC(T_{star})$

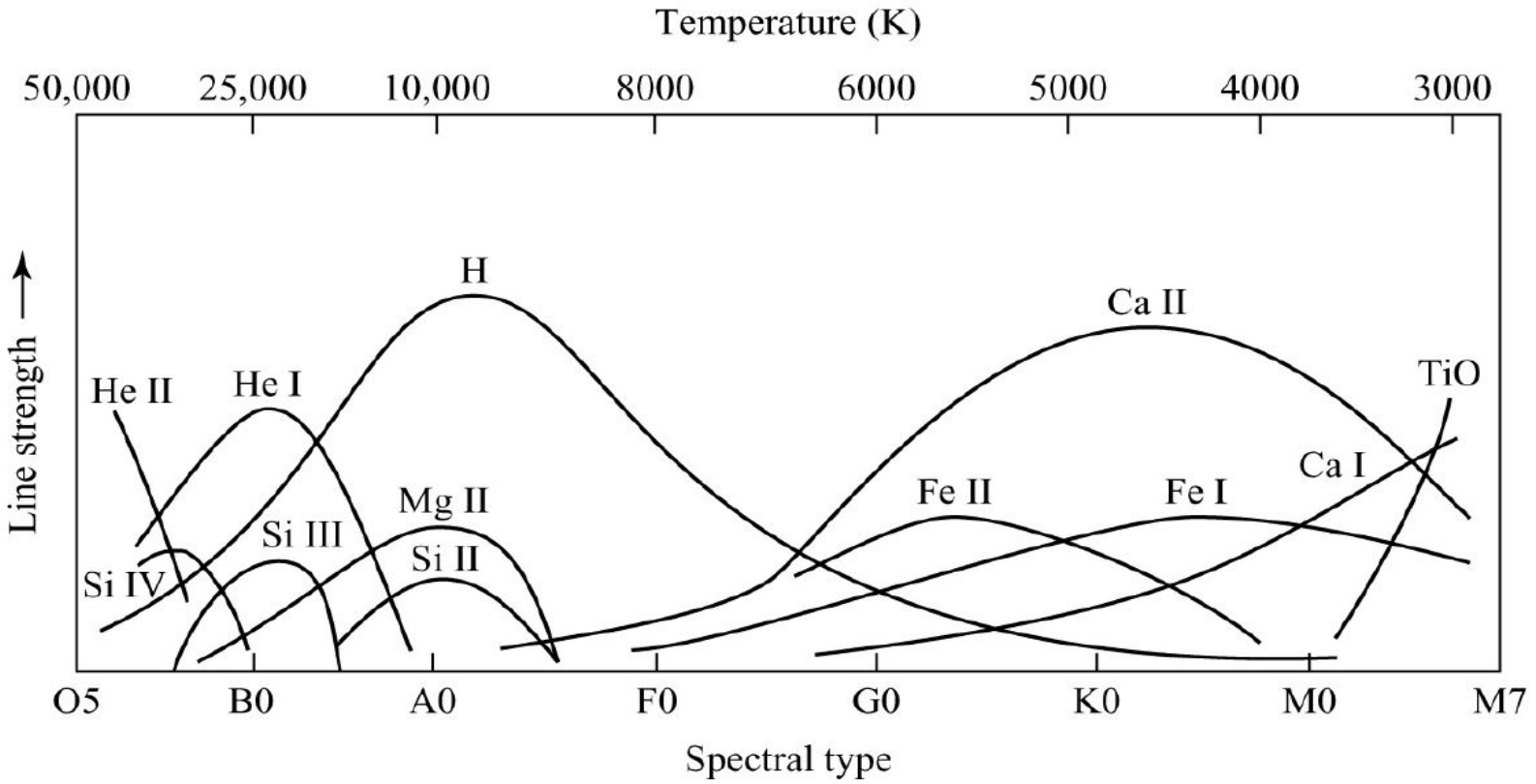
$V\infty = 2.65 * Vesc$

$\dot{M} \sim L^*$ (Vink et al. 2000, 2001, Krticka & Kubat, 2017)

CNO – from stellar evolution tracks
Other elements ~ Solar abundances

$$\log \dot{M} = -6.697(\pm 0.061) + 2.194(\pm 0.021) \log(L_*/10^5)$$
$$-1.313(\pm 0.046) \log(M_*/30) - 1.226(\pm 0.037) \log\left(\frac{v_\infty/v_{\rm esc}}{2}\right)$$
$$+0.933(\pm 0.064) \log(T_{\rm eff}/40000) - 10.92(\pm 0.90)\{\log(T_{\rm eff}/40000)\}^2$$

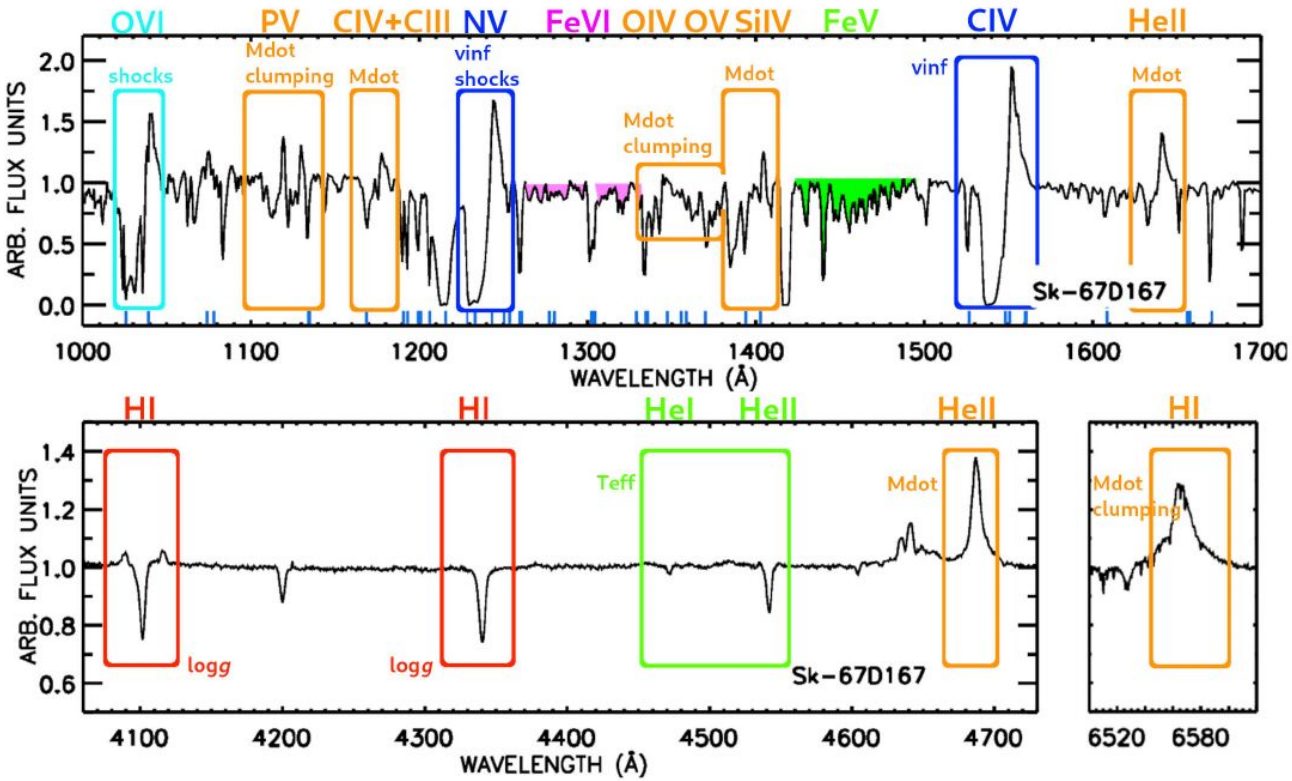
Line Strengths as a Function of Spectral Type



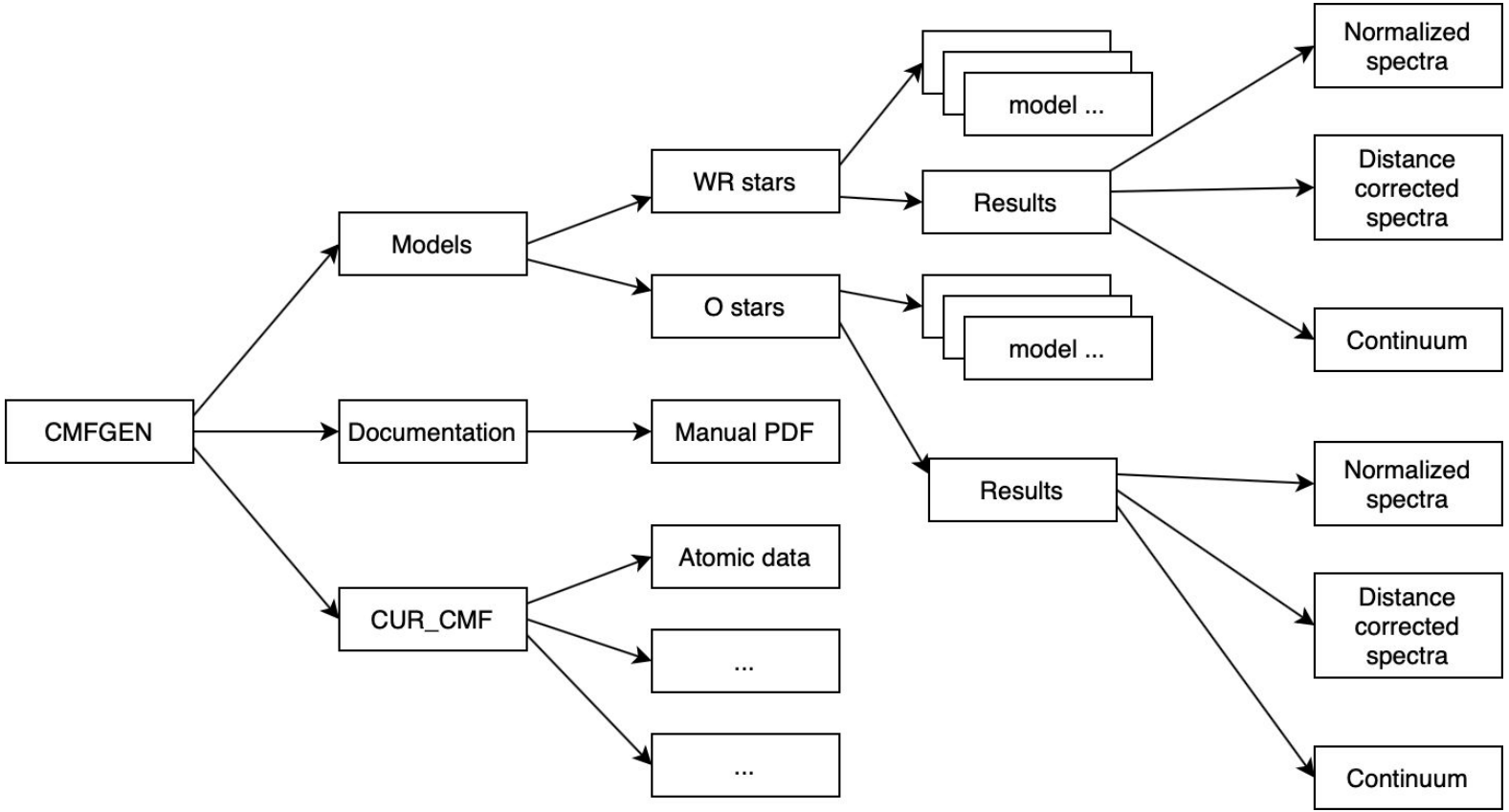
Estimation of Parameters

Rotational broadening

V sin i
sensitive lines:
HeI 4713
OIII 5592



My experience



CMFGEN: Installation

Make the folder where CMFGEN will live:
> mkdir ~/CMFGEN2023
> cd ~/CMFGEN2023/
Download USBstick /Maryeva/CMFGEN/ !!!
Now, download CMFGEN sources and atomic data from https://sites.pitt.edu/~hillier/web/CMFGEN.htm here.

Unpack it:
> tar xzvf atomic_data_21jun23.tar.gz
> tar xzvf cur_cmf_26jun23.tar.gz
Also, get the patch (.diff file) and place it here.

Now, go to the sources folder and apply the patch:
> cd cur_cmf
> patch -p1 < ../fix_cmfgen.diff

Finally, build it:
> make

It should finish without errors, and create a lot of .exe files in exe/ folder, including cmfgen_dev.exe and cmf_flux.exe.

If the code crashes - type **ulimit -s unlimited** to increase allowed stack size for the process

Model Computation

The spectrum of an O star primarily depends on log g and Teff, while for a WR star L, R_* and $\dot{M}$ can be considered to be fundamental. In CMFGEN models, the parameters that define a model are determined by the type of model.

- If the density structure is assumed to be fixed, L and Rcore are used to define the model. log g, Teff , and M_* are not used, and the values in VADAT are ignored, and may be totally inconsistent with L and R_* (case WR stars)
- Hydrostatic models. When the model is initialized L and Rcore are considered to be the fundamental parameters, and log g, Teff , and M_* are ignored. However, before running the model, you should make sure L, R_* and Teff are consistent. When the hydrostatic iteration is performed, log g and Teff are regarded as fundamental. L, Rcore and M_* will be updated in VADAT to be consistent the values of log g and Teff in VADAT (O star case)

Start new model (example)

Select a starting model and set up the directory

- Create a new directory for the star's model

- Determine the ogrid model that most closely matches- Mdot, Teff, log g

> cpmod oldModel newModel
> cd newModel

edit VADAT

> ./batch.sh

Start new model (example)

```
> mkdir model_poems1008
> mkdir model_poems1008/obs
> cp obs2/* model_poems1008/obs
> cp clean.sh model_poems1008/obs
> cp clean.sh model_poems1008/
> ./cpmod.sh model_poems1005 model_poems1008
> cp IN_ITS model_poems1008/
> cd model_poems1008
> chmod 755 *
> chmod 755 */*
> cp RVSIG_COL RVSIG_COL_OLD
> cp ../HYDRO_DEFAULTS HYDRO_DEFAULTS
```

change some parameters in VADAT

```
> ./batch.sh
```

Start new model (example)

```
> mkdir model_poems1008
> mkdir model_poems1008/obs
> cp obs2/* model_poems1008/obs
> cp clean.sh model_poems1008/obs
> cp clean.sh model_poems1008/
> cpmod.sh model_poems1005 model_poems1008
> cp IN_ITS model_poems1008/
> cd model_poems1008
> chmod 755 *
> chmod 755 */*
> cp RVSIG_COL RVSIG_COL_OLD
> cp ../HYDRO_DEFAULTS HYDRO_DEFAULTS
> mkdir lte ; cp VADAT ./lte ; cp batch.sh ./lte/ ; cp MODEL_SPEC ./lte ; cp ../ltebat.sh ./lte/ ; cp ../clean.sh ./lte

 From another model / lte
> cp GRID_PARAMS lte
> cp ltebat.sh lte
>cd lte
```

Start new model (example)

edit MODEL_SPEC
- ND = 925
- NP = 940 (ND + 15)
> ltebat.sh
> wind_hyd.exe
edit VADAT
> cp RVSIG_COL_NEW ../RVSIG_COL
> cp ROSSELAND_LTE_TAB ../
> cp VADAT ../
> cd ..
>./batch.sh

Lowell_CMFGENGuide.pdf in Documentation CMFGEN

CMFGEN

CMFGEN computes the hydrostatic structure using an iterative procedure which is undertaken during the general CMFGEN procedure. For O stars, only a few hydrostatic iterations are needed to obtain a well converged hydrostatic structure. The initial hydrostatic structure is generally taken from an earlier model (but can be generated), although in earlier versions of CMFGEN we often utilized the density structure from a Tlusty (Lanz & Hubeny 2003) model.