

Spherical opacity sampling model atmospheres for M giants and supergiants

ABSTRACT

The Uppsala MARCS model atmosphere code (Gustafsson et al. 1975) has been modified and extended to make it suitable for the generation of spherically symmetric opacity sampled model atmospheres for cool giants and supergiants. New line lists have been computed for H_2O , TiO and VO based on the best available laboratory data. A grid covering $3000K \leq T_{eff} \leq 4000K$, $-0.5 \leq \log g \leq 1.5$ and $1 \leq M/M_\odot \leq 5$ with the solar composition of Anders and Grevesse (1989) is presented here, together with first comparisons with observations and remarks on radiation pressure and extension effects.

ASSUMPTIONS AND METHODS

Full details will be given in a forthcoming paper (Plez, Brett and Nordlund, 1991). In brief, the assumptions of spherical stratification in homogeneous stationary layers, hydrostatic equilibrium and local thermodynamical equilibrium (LTE) were made. Convection was treated through the mixing length theory and the energy conservation required for radiative and convective flux. The turbulence pressure was neglected. The opacity sampling method (OS) has been used for the treatment of the opacities. New opacities based on the best available data have been calculated for VO , TiO and H_2O .

We have produced a grid covering $3000K \leq T_{eff} \leq 4000K$, $-0.5 \leq \log g \leq 1.5$ and $1 \leq M/M_\odot \leq 5$.

COMPARISONS WITH OBSERVATIONS

As a preliminary test of our models we have

made two particular comparisons to observational data - a comparison of observed and computed fluxes for α Tau and a comparison of our synthetic V-K colours to observations of type III giants.

We have computed a model atmosphere for α Tau with the following parameters: $T_{eff}=3950K$, $M=1.3M_\odot$ and $\log g=1.4$. We used the solar abundances of Anders and Grevesse (1989) except for the CNO abundances which we took from Smith and Lambert (1985). The synthetic spectrum of this model was compared to published observations of α Tau. In general we find the comparison over the wavelength range 5000 \AA to 40000 \AA quite pleasing, in particular a good match to both IR continuum points and the strength of the TiO bands. This has been achieved without recourse to either low Ti abundances or the use of empirical oscillator strengths.

A condensed comparison to observations across the M giant spectral sequence is possible using broad band photometry. We have compared our synthetic V-K colours for the M star model grid to observed V-K colours for class III M stars taken from Ridgway et al. (1980) and find an encouraging agreement. The V-K colour is seen to be a good determinant of T_{eff} for the early M spectral types but becomes increasingly gravity and mass dependent with decreasing T_{eff} . Broad band colours for the complete model grid will be presented in Plez et al. (1991).

THE EFFECT OF ATMOSPHERIC EXTENSION

In order to test if the plane-parallel approximation - which is very often made even in studies of giants and supergiants photospheres - has any significant influence on the derived effective temperatures and chemical compositions, Plez (1990) has carried out a comparison based on spherical models from the present work and plane-parallel ones computed with the same input data. The main results can be summarized as follows: The effect on effective temperatures derived from colours is small (less than $100K$, with the values derived from plane-parallel models being lower). The abundances of C and N, as well as their abundance ratio, derived by using plane-parallel models, may be in error by up to 0.2 dex in a $3500K \log g=0$ model. There are however other sources of systematic errors, like non-LTE or veiling of the continuum by quasi-continuous line spectra (e.g. TiO),

which are likely to be of greater importance. The latter one was found to be extension dependent. Interestingly, the strength of the V-R bands of CO were found to react differentially to extension. This may be used to simultaneously determine the mass and gravity of cool giants and supergiants.

RADIATION PRESSURE IN THE MODELS

Convergence problems encountered during the computation of some models lead to a careful study of the radiation pressure gradient throughout the photosphere. As already discussed by Elitzur et al. (1989) and Plez and Nordlund (1990), radiation pressure on water vapor lines tends to blow out the outer layers of the atmosphere. This effect increases dramatically with decreasing temperature and gravity. Plez and Nordlund found an exaggerated effect due to their inclusion of water opacity as a straight mean. Elitzur et al. used OS but in plane-parallel atmospheres.

The ratio of the radiative acceleration to the gravitational acceleration is found in the spherical case to increase with decreasing mass at given T_{eff} and $\log g$. This is explained by the increasing atmospheric extension causing both a decrease of the local gravitational acceleration and a cooling of the outer layers and thus an enhanced formation of absorbing molecules. The upper limits put by Elitzur et al. on the critical gravity where the radiation pressure gradient balances the gravity at some point in the photosphere are thus lowered in extended atmospheres. There is however a saturation effect and it does not seem that the radiative acceleration continues to increase for effective temperatures below 3000K, as claimed by Elitzur et al. (1989).

The radiation pressure on water vapor lines, if not disrupting the photosphere, leads to an increase of its extension and thus to an increase of the density at height in the atmosphere. This contributes to increase the mass loss rate in cool low gravity stars.

Interestingly, in most of the models the radiative acceleration was found to be largest in the deep layers ($\tau_{\text{ross}}=10$ to 30). By extrapolating the ratio of radiative to gravitational acceleration to a value of 1, (from a series of constant mass and T_{eff} models) an estimate of the 'Eddington luminosity' (or gravity) as a function of T_{eff} was obtained (cf Gustafsson and Plez, this meeting). Due to the low temperature of the

models, convection turns on in the same zone where the opacity has a maximum and diminishes the radiative flux. This has a stabilising effect and thus decreases the critical gravity. The 'Eddington' limit derived here is however not strictly the limit of stability of the atmosphere, as the effective gravity becomes positive again higher up in the photosphere until possibly radiation pressure on molecular lines takes over. The interesting fact is that, at least for effective temperatures larger than about 3200K, the atmosphere becomes unstable in the deep layers before the radiation pressure on water vapor lines can disrupt the equilibrium in the outer layers.

A more general discussion of these effects, based on a broader temperature range, is given in Gustafsson and Plez (this meeting).

REFERENCES

- Anders, E., Grevesse, N., 1989 - Abundance of the elements: Meteoritic and solar, in *Geochim. et Cosmochim. Acta* **53**,197
- Elitzur, M., Brown, J.A., Johnson, H.R., 1989 - On the onset of mass loss in late-type stars, in *Astrophys. J. Letters* **341**,95
- Gustafsson, B., Bell, R.A., Eriksson, K., Nordlund, Å., 1975 - A grid of model atmospheres for metal-deficient giant stars. I., in *Astron. Astrophys.* **42**,407
- Plez, B., 1990 - The importance of sphericity and opacity sources for abundance determinations in cool giants and supergiants, in *High-resolution spectroscopy in astrophysics, Mem. S.A.It.* **61**,765.
- Plez, B., Nordlund, Å., 1990 - Model atmospheres for M-giants, in *from miras to planetary nebulae, which path for stellar evolution?*, ed. M.-O. Mennessier, and A. Omont, Editions frontières, p. 88
- Ridgway, S.T., Joyce, R.R., White, N.W., Wing, R.F., 1980 - Effective temperatures of Late-Type stars: the field giants from K0 to M6, in *Astrophys. J.* **235**,126
- Smith, V.V., Lambert, D.L. 1985 - The chemical composition of red giants I, in *Astrophys. J.* **294**,326

AUTHORS' ADRESSES

- B. Plez and J.M. Brett: Astronomiska Observatoriet, Box 515, S-75120 Uppsala, Sweden
- Å. Nordlund: Astronomisk Observatorium, Østervolgade 3, 1350 København, Denmark