RADIATIVE COOLING FUNCTIONS BELOW $2 \times 10^4$ K

PHILIP G. JUDGE and DONALD H. NEFF
Joint Institute for Laboratory Astrophysics, University of Colorado,
Boulder, Colorado 80309-0440

Abstract Radiative cooling functions between $\sim 4500$ K and $2 \times 10^4$ K are examined. IUE spectra are used to estimate cooling rates for UV lines of Fe II. The functions may find important applications in partially ionized non-LTE plasmas where electron temperatures substantially exceed characteristic radiation temperatures, including inactive stellar chromospheres, winds and the broad line regions of active galactic nuclei.

INTRODUCTION

The thermal structure of some astrophysical plasmas is determined by the balance of radiative losses and some unknown and sought-after heating mechanism(s). Under certain conditions (e.g. the solar corona) the radiative losses can be approximated by $\Phi \left[ \text{erg cm}^{-3} \text{ s}^{-1} \right] = N_e N_H f(T_e)$, where $f(T_e)$ is a function of electron temperature ($T_e$) only. $N_e$ and $N_H$, the number densities of electrons and hydrogen, are assumed here to be given (e.g. from the approximation of Hartmann and MacGregor 1980).

We ask if radiation losses below $2 \times 10^4$K can be usefully expressed in these terms, motivated by the need for very fast estimates of radiative losses in ab-initio hydrodynamical calculations of the outer layers of cool stars (Cuntz and Ulmschneider, 1988; Bowen 1988). Present computer resources prohibit traditional methods, even using the most efficient NLTE transfer programs (e.g. Carlsson, 1986). Previous work (e.g. Anderson and Athay 1989) showed that radiative losses in the solar chromosphere depend strongly on radiation transport, and hence that they cannot be represented in this way. However, Judge (1990) demonstrated that for relatively inactive stars the radiative transfer effects disappear and that cooling functions can be usefully applied.

RESULTS

We have examined the major radiative loss channels for $4500 < T_e < 2 \times 10^4$ K. The figures illustrate our results. We have adopted radiative losses from: (i) H$^-$ b-f, f-f (from Ayres 1981); (ii) effectively thin Mg II $h$, $k$, Ca II $H$, $K$, IR triplet;

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(iii) hydrogen from a variety of approximations; (iv) effectively thin losses from Fe II lines; (v) losses from other contributors (ions of C, Si, Al) using the data compiled by Judge (1986).

For hydrogen, we have identified limiting cases which may have useful applications: • the shocked atmospheres of Miras (Bowen 1988) can be modelled assuming that Lyman-α is in detailed balance and the Balmer lines are collisionally excited; • the outer atmospheres of inactive stars (e.g. K, M giants) can be modelled assuming effectively thin losses in the Lyman lines only.

We have estimated Fe II losses from IUE observations of cool giant stars, because: (i) the prominent radiative loss channels of Fe II lie within the wavelength range of IUE; (ii) All the important Fe II lines can be reliably measured owing to very weak photospheric continua; (iii) K and M giants have effectively thin chromospheres in both the Mg II and Fe II lines (Judge 1990). The emergent fluxes can therefore be used directly to estimate the collision cross sections required. Table 1 lists Fe II and Mg II fluxes obtained from high quality, high dispersion IUE spectra. Each star shows that the cooling rate in Fe II transitions is ≤ 1/2 of the Mg II lines.

CONCLUSIONS

Useable cooling functions can be derived which represent approximately radiative losses from the chromospheres of cool stars. The losses include well-determined collisional rates except for Fe II where “astrophysical” estimates of the losses were adopted. The cooling function method is limited in accuracy and applicability because of photo-ionization (mainly of hydrogen) and thermalization. A full report is in preparation.

References

Radiative Cooling Functions

TABLE 1
IUE-HIRES LOSSES IN Fe II and Mg II UV LINES OF M GIANTS

<table>
<thead>
<tr>
<th>Star</th>
<th>Spectrum</th>
<th>Fe II total</th>
<th>Mg II h+k</th>
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<tbody>
<tr>
<td>β Peg</td>
<td>M2 II-III</td>
<td>~ 2.7(-11)</td>
<td>≥ 5.8(-11)</td>
</tr>
<tr>
<td>π Aur</td>
<td>M3 III</td>
<td>~ 5.2(-12)</td>
<td>≥ 1.6(-11)</td>
</tr>
<tr>
<td>γ Cru</td>
<td>M3.4 III</td>
<td>~ 7.6(-11)</td>
<td>1.0(-10)</td>
</tr>
</tbody>
</table>

Figure 1: Cooling functions for individual loss channels excluding hydrogen.

Figure 2: A comparison of cooling rates computed using the approximations described in the text with the approximate calculations of earlier authors. Two approximations for the hydrogen losses are shown. AA = Anderson and Athay (1989), VAL = Vernazza, Avrett and Loeser (1981), MTW = McWhirter et al. (1975), CCJA = Cook et al. (1989), HM = Holzer and MacGregor (1985).