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Atomic data requirements for stellar atmospheres: work in Munich on hot star atmospheres and winds

ABSTRACT

Recent work on hot stars in Munich is discussed with particular emphasis on the atomic data requirements necessary.

INTRODUCTION

The great improvements in the quality of spectra in recent years are amply illustrated in fig. 1 where optical observations of two B stars from Gehren et al. (1985) are shown. Although

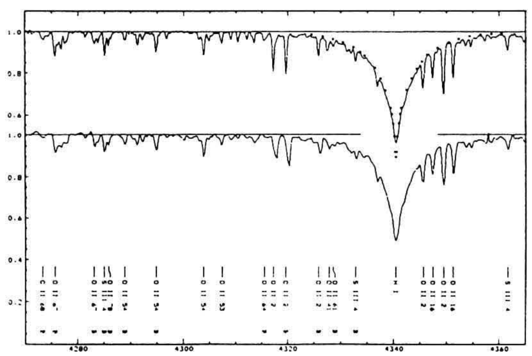

Fig.1 Optical Spectra for two B stars, BS 2928 (upper), S 285-6 (lower). Gehren et al (1985)

the signal to noise ratios are comparable, the object in the lower plot is more than 100 times fainter than that in the upper one. Similar advances have been made in other spectral regions. To make adequate use of such good quality material it has become necessary to construct theoretical models of similar accuracy, firstly to determine astrophysical stellar parameters (temperatures, densities, number fractions) as well as possible and secondly to put tighter constraints on the models themselves. In the case of stellar atmospheres this requires a large amount of atomic data as will be seen from the examples that follow, taken from recent work in Munich.

'STANDARD' MODEL NON-LTE LINE FORMATION CALCULATIONS

'Standard' means that the atmospheres are plane-parallel and are in hydrostatic and radiative equilibrium. While the run of temperature and density with depth is held fixed (line formation), the number densities of the ions in question are allowed to adjust freely to this structure and are not fixed to their thermodynamic values (non-LTE). All of the reported calculations were carried out using the DETAIL, SURFACE, ANALYS suite of programs written by Giddings (1981), the advantage being that the computer time scales linearly with the number of frequency points in the grid so that a large number may be included in the model.

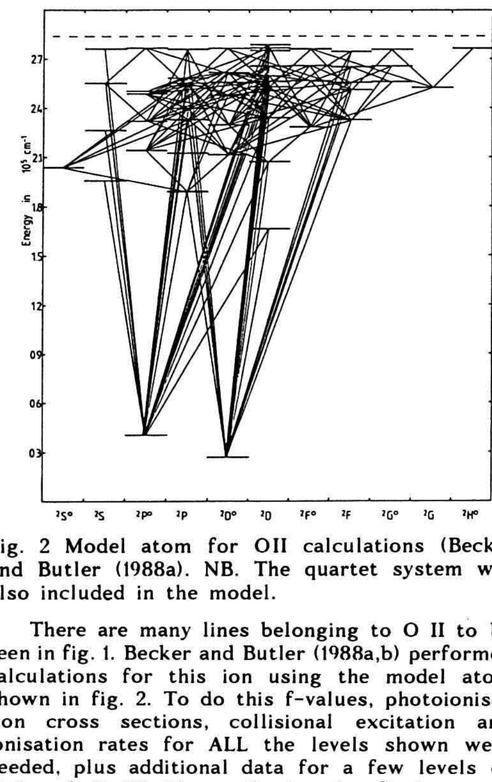

Fig. 2 Model atom for OII calculations (Becker and Butler (1988a). NB. The quartet system was also included in the model.

There are many lines belonging to O II to be seen in fig. 1. Becker and Butler (1988a,b) performed calculations for this ion using the model atom shown in fig. 2. To do this f-values, photoionisation cross sections, collisional excitation and ionisation rates for ALL the levels shown were needed, plus additional data for a few levels of O I and O III. To synthesise the final spectra radiative and collisional damping parameters were also required. The success of the calculation is shown by the fact that the new results show (almost) no sensitivity to the value of the 'microturbulence' adopted. 'Microturbulence' is an ad hoc additional broadening usually necessary to make LTE calculations match the observations. Further details may be found in the cited papers. A similar picture was found for N II (see Becker and Butler 1988c,1989) where again a large amount of atomic data was input.

There has long been a problem with the abundance derived in LTE from the C II 4267 A line, it was consistently much below solar. Our new calculations (Eber and Butler 1988) removed this discrepancy. The atomic model was once more on the same scale as shown previously but in addition it was found that dielectronic recombination also plays a significant role. This was incorporated in the models in the manner suggested by Mihalas and Hummer (1973) whereby the resonances are treated as pseudo-bound states. Oscillator strengths were therefore required in this approximation. The solid curve in fig 3. shows the good agreement obtained with the observed points when solar abundance is assumed.

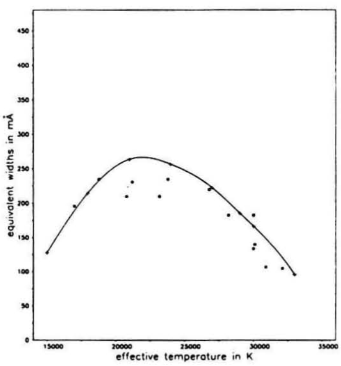

Fig. 3 Comparison of CII calculations (full curve) with observations (points). (Eber and Butler (1988)

These calculations were all designed to allow the abundances in hot stars to be determined with some accuracy. Of course before this can be done it is essential that the other stellar parameters, temperature and density (gravity) also be known accurately. The gravity is usually determined from the shape of the wings of the hydrogen lines which are density sensitive as they are Stark- broadened. On the other hand, the temperature in the range of interest (15000- 35000K) is usually found from the ratios of strengths of the lines of ions of Si. Unfortunately, these lines also depart from the LTE predictions. Becker and Butler (1990) have managed to obtain a consistent picture through similarly extensive calculations to those described above except that this time Si II/III and IV are all treated simultaneously in the same thorough fashion. This consistency is demonstrated in fig. 4. where all the curves cross in a small region. The smallness of this region determines how good a fit may be obtained.

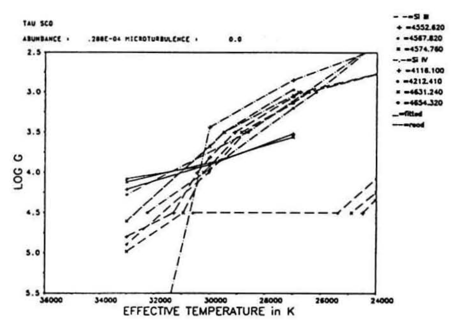

Fig. 4 Fit for various Si (broken) and H (full) lines for Tau Sco (Becker and Butler 1990)

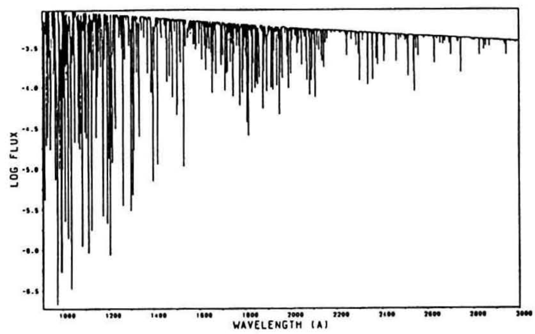

Fig. 5 LTE line blanketing for the B star BS 2928

Admittedly not all the problems have been solved. Some lines are still troublesome. One idea as to where improvements might still be made was the observation that the ionisation thresholds of the levels involved all lie between 1000 and 3000 A. There are many spectral lines in this range that might be expected to affect the lines of interest (see fig. 5). Tests so far indicated that this is not the case but the atomic data (f-values, damping parameters) are of dubious quality.

As a final example, we have just started gathering data for a non-LTE calculation of Fe in order to determine the iron abundance in stars with temperatures of 40000K and upwards. As a first step we have used relatively inaccurate data to generate the spectrum shown in fig. 6. This might give some indication of the magnitude of the problem.

While only line formation calculations have been described here, progress in radiative transfer techniques (Anderson 1989, Werner 1986) makes it likely that models of similar complexity (with the same demanding use of atomic data) will soon be

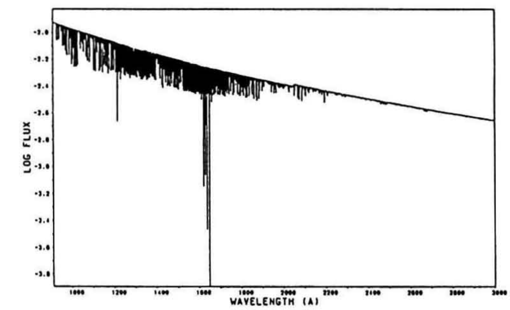

Fig. 6 A synthesised Fe IV/V/VI spectrum for a 60000 K, log g = 6 star

made in which the temperature and density are also allowed to react to this additional opacity (non-LTE line blanketing).

APPLICATIONS

The main goal of the calculations just described was to provide tools to determine accurate stellar parameters. These tools have been put into action in a number of cases. For example, Schoenberner et al. (1988) analysed a number of hot stars which had been designated as being strong in nitrogen. The analysis showed this to be correct, quantified the overabundance and showed helium and carbon to be also overabundant, thus demonstrating that nuclear processed material has been brought to the surface of these stars in conflict with current stellar evolution theories. This point is fully discussed in the paper.

The supernova in the Large Magellanic Cloud in 1987 caused a great deal of excitement. In particular, the spectral type of the pre-cursor was not at all what had been expected. The group in Munich had been studying similar objects (though unfortunately not the SN itself) as part of a program to look at abundances in the LMC (and SMC) and since the tools were at hand, were able to obtain the abundances shown in Table 1 (Kudritzki et al. 1987). Again there is clear evidence for the presence of nuclear processed material, once more showing some disagreement with stellar evolution time scales.

Table 1 Log abundances relative to the sun for two B supergiants and H II regions in the LMC. (Kudritzki et al 1987)

element	Sk 21-65	Sk 41-68	LMC/HII
He	+0.41±0.05	+0.28±0.05	-0.07
C	≤ -0.9	≤ -0.7	-0.77±0.15
N	+0.5±0.2	+0.2±0.1	-1.02±0.1
O	-0.7±0.2	0.0±0.2	-0.49±0.08
CNO	≤ -0.4	≤ -0.2	-0.59
Si	-0.6±0.2	+0.1±0.2	
Mg	-1.1±0.2	-0.9±0.2	
Al	≤ -0.7	≤ -0.6	

In fact, all of the models had been developed to re-analyse the spectra obtained by Gehren et al. (1985) an example of which is shown in fig. 1. Their LTE analysis showed no evidence for a galactic abundance gradient as can be seen for nitrogen and oxygen in fig. 7. This disagrees with results for H II regions (Shaver et al 1985) where an abundance gradient is observed. If confirmed by the proposed non-LTE investigation this means that theoreticians considering galactic evolutionary models must reconsider their results.

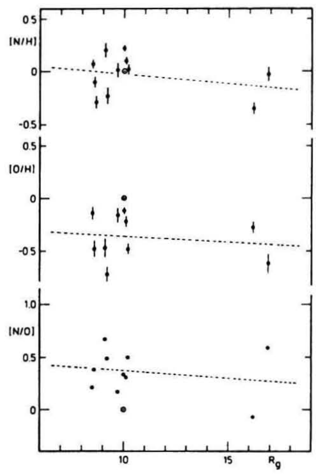

Fig. 7 Log abundances for O and N as a function of galactocentric distance. Note the lack of a gradient. (Gehren et al 1985)

STELLAR WINDS AND UNIFIED MODELS

In the previous section only successful calculations were described. Butler (1984) made calculations for N III which were also in agreement with observation for stars of high gravity (see fig. 8). However, Butler and Simon (1985) using the identical model found a nitrogen overabundance of a factor of six in rough agreement with theoretical estimates but this result must be treated with some scepticism. In particular the value of the microturbulence used is supersonic for a star of this temperature and gravity. This, together with the pattern of the deviations in the line strengths shows the need for stellar wind calculations, in fact for 'unified' models in which the wind and photosphere are treated simultaneously.

The success of the stellar wind calculations alone may be seen from fig. 9 taken from Puls (1987). The fit is almost perfect but there are no adjustable parameters involved. Another beautiful

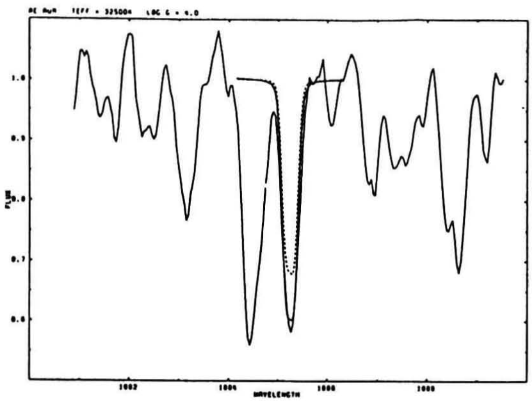

Fig. 8 Fit for the N III 1885 line in AE Aur. Full curve - three times solar abundance, broken - solar. (Butler 1984)

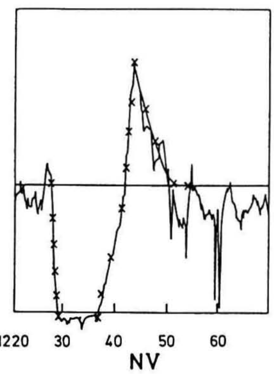

Fig. 9 Fit for the N V resonance line in Zeta Pup (Puls 1987)

example is to be seen in the work of Pauldrach et al. (1989). Walborn and Panek (1984a,b,1985) had observed strong trends in the strengths of the Si IV UV resonance lines with gravity while lines of other ions showed no similar effects. The calculations show exactly the same trends as observed. The reader is referred to the cited papers for details.

Gabler et al (1989) have recently obtained 'unified' photospheric and wind models in which the change in H alpha from a strong absorption line to a very strong emission line can be clearly seen and understood as a consequence of the velocity field. The models may also be able to explain the 'Zanstra discrepancy' in Planetary Nebula as they produce orders of magnitude more flux shortward of the He II Lyman edge than do plane-parallel models.

In making these wind models, non-LTE calculations have been made for a very large number of ions (see Pauldrach 1987 for details) the data for which have been begged, borrowed and generally acquired by every means possible. In addition the winds are assumed to be radiatively driven, i.e. ions absorb photons thereby gaining momentum with a net component away from the star thus forming the wind. To derive the force given to the matter by the radiation integrations over spectra similar in complexity to that shown in fig 6. are necessary throughout the wind. For this once more a huge number of f-values and damping parameters are needed. The current data have been taken from the work of Abbott (1982) but this was intended for temperatures less than 50000K. To extend the wind calculations to higher temperatures f-values and energy levels in particular are needed for Fe, Mn, Ni, Ti, Cr, Cu, Zn for all ionisation stages but especially for those with more than four electrons removed. The data need only have statistically good accuracy but should not be in LS-coupling.

SUMMARY

I hope that it is clear from these few examples that any atomic data you may calculate will always find a good (and useful) home in Munich. There is relatively urgent need for the oscillator strength data described in the last paragraph and all data on iron, preferably not in LS-coupling, would be greatly appreciated.

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