ATMOSPHERIC STRUCTURE DEDUCED FROM DISTURBED LINE PROFILES
APPLICATION TO Ca II LINES

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ABSTRACT

A new method is described in order to derive physical quantities (temperature, pressure, radial velocities) from the observation of disturbed line profiles.

We suggest a method of Fourier analysis with double profiles and a non linear expansion of the coefficient of the Fourier terms. An application to a sequence of H - Ca II line is attempted.

The method seems a powerful tool allowing the determination of at least 4 physical quantities simultaneously.

INTRODUCTION

The study of line profiles with fine structure resolution, in a bидimensional field, with a good time resolution, gives us a large flux of data. If we want to deduce physical quantities, such as temperature, pressure, radial velocities, we need a fast inversion code.

1. BRIEF REVIEW OF INVERSION TECHNIQUES

First we mention the model fitting to reproduce disturbed profiles, which has been used especially for solar granulation and for chromospheric lines. Another way has been the coupling of thermodynamical and NLTE transfer equations (Cram, 1976; Gouttebroze et al., 1980).

The first codes used to invert line profiles were linear ones. They refer to all parameters mixed (contribution functions, Beckers et al., 1969), or to a given parameter such as temperature, velocity or pressure (weighting functions, P. Mein, 1971; or response function for velocities, Beckers et al., 1975). These last methods have been extensively used for wave propagation studies.

But this linear approach cannot account for large amplitude disturbances like those which can be observed in some points of the chromosphere, even for the quiet sun. We need a non-linear approach.
2. NON LINEAR ANALYSIS

Our method consists in a Fourier description of the line profile and a non linear analysis of the disturbances.

2.1. Fourier analysis

Generally the profile is expanded between two wavelengths and repeated periodically (Fig. 1a). In the case of shifted profiles this leads to a discontinuity which increases the amplitude of high order harmonics.

In order to avoid this effect, we introduce a "double profile". In the first interval, we take the profile itself, and in the second one the symmetrical profile (Fig. 1b). With this method, there is no more discontinuity when the line is shifted.

Fig. 1 Single and double profile (respectively (a) and (b)).

2.2 Inversion method

Let $X(z)$ be the disturbance of a given physical quantity. We describe it by a first order expansion with respect to the altitude $z$ (mean value and gradient)
\[ X_i(z) = \sum_{j=1,2} x_{ij} (z - z_0)^{j-1} \]

where \(z_0\) is an arbitrary altitude.

The profile \(f(\lambda)\) is described by a Fourier expansion.

\[ f(\lambda) \approx \alpha_0 + \sum_{1 \leq n \leq N} \left( \alpha_{2n} \cos \frac{2\pi(n-1)(\lambda - \lambda_0)}{4\Delta \lambda_0} + \alpha_{2n+1} \sin \frac{2\pi(n-1)(\lambda - \lambda_0)}{4\Delta \lambda_0} \right) \]

The departure can also be expressed by a similar formula

\[ \Delta f(\lambda) \approx \Delta \alpha_0 + \sum_{1 \leq n \leq N} \left( \Delta a_{2n} \cos \frac{2\pi(n-1)(\lambda - \lambda_0)}{4\Delta \lambda_0} + \Delta a_{2n+1} \sin \frac{2\pi(n-1)(\lambda - \lambda_0)}{4\Delta \lambda_0} \right) \]

where \(N\) is the number of used harmonics.

\(\Delta a_m\) are functions of the coefficients \(x_{ij}\) of the equations (1); we approximate them by a second order expansion.

\[ \Delta a_m = \sum_{1 \leq i \leq p} C_{mij} x_{ij} + \sum_{1 \leq i \leq p} \sum_{1 \leq k < i} C_{mijk} x_{ij} x_{ik} \]

for \(0 \leq m \leq 2N\) \(p\) is the number of physical quantities.

\(\Delta a_m\) are given by the observations and the coefficients \(C_{mij}\) and \(C_{mijk}\) by the NLTE calculations of line profile.

The \(x_{ij}\) will be given by the results of the inversion.

The inversion is carried out in this way:

a) Computation of a theoretical undisturbed profile of the line.

b) Choice of a convenient set of \(x_{ij}\) values to calculate disturbed line profiles and the corresponding fluctuations. Coefficients \(C_{mijk}\) and \(C_{mij}\) are derived from equations (4).

c) For each observed profile we determine \(\Delta a_m\) and derive \(x_{ij}\) by equations (4), the \(C\) coefficients being already known by step (b).

Three frequencies are sufficient to solve the problem for 3 physical quantities, but we use a larger set of equations corresponding to a larger number of harmonics and a least square fit.

We use an iterative process to solve the non linear system (4) in step c.
3. APPLICATION TO Ca II LINE PROFILES

3.1. Theoretical undisturbed profile

We use a NLTE code for the calculation of Ca II with 5 levels and a continuum. This code has been written by S. Dumont, the method has been developed by P. Feautrier (1964), Y. Cuny (1967), and S. Dumont (1967).

We use the VAL. C. model atmosphere (Vernazza et al., 1981). For this first work we use total redistribution for the H-line and velocity distribution included in the source function calculation.

3.2. Theoretical disturbed profiles

We used 13 sets of perturbations. We computed the line profiles for single and crossed perturbations.

Two examples of disturbed profiles are shown on Fig. II.

![Fig. II Theoretical profiles](image)

**Fig. II Theoretical profiles**

- dotted line = mean profile, full line = perturbed profile
- a) velocity gradient = $10^{-2}$ $\text{ms}^{-1}$/100 km and constant temperature fluctuation of 5%
- b) velocity gradient = $10^{-2}$ $\text{ms}^{-1}$/100 km and temperature gradient fluctuation of 1% per 100 km.

3.3. Inversion of a time sequence of profiles of the H-line

We have studies a sequence obtained at Sacramento Peak Observatory by Crum and Damé (1983); we used the H-line of Ca II with a frame each 10 s. We study velocities, gradients of velocities, temperatures and gradients of temperature.

Fig. III shows some typical observed and calculated profiles.
Fig. III Two examples of observed Ca II profiles (full line) the dotted line show the synthetic profile derived from the calculated profile.

The results obtained for the variation of the parameters - velocity and temperature - are summarized on Fig. IV.

Fig. IV Variation of the physical parameters versus time.
Bright points seemed to correspond to downward chromospheric velocities with a negative gradient, and to an increase of temperature.

4. CONCLUSIONS

In this paper, we have described the new method, whereas no emphasis has been put on the results obtained.

First we shall note that some improvements could be performed:
- The accuracy of our results must be discussed, in particular the influence of micro and macro turbulence must be tested.
- The results could be checked with other lines formed at different altitudes.
- NLTE calculations could be improved, in particular partial redistribution could be taken into account.

A better fit should be obtained by using amplitude and phase instead of cosine and sinus expansion. This work is in progress.

Nevertheless this method of Fourier analysis with double profiles and nonlinear expansion seems to be a powerful tool, which allows us to determine at least 4 parameters with H or K line profiles. It could be extended to any kind of disturbed model of atmosphere, like cloud models for example.

REFERENCES

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