STEellar PHOTOSpheric CONVECTION

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ABSTRACT Using a combination of three fields of astrophysics (stellar structure and evolution, hydrodynamics, and spectral line synthesis), a “C”-shaped spectral line bisector for the Sun and a reversed “C” shaped line bisector for an A5 star can be reproduced.

Keywords: Sun; convection; granulation; spectral line asymmetry; stellar structure

INTRODUCTION

A systematic study of the asymmetry of spectral lines provides an important probe of convective motions in stellar photospheres. For the Sun, the surface convection, called granulation, has broader regions of hot rising convective elements, and narrower areas of cooler sinking elements. The net effect of the unresolved granulation is a depressed red shoulder of the solar absorption lines. As a result, the line bisector, which connects the midpoints of horizontal line segments bounded by the spectral line profile, has a “C” shape. An important discovery was that there are stars whose characteristic bisectors are a reversed-C shape as well. It is now known observationally that stars with different line bisector shapes (which, therefore, have different characteristic convective motions), are located in different regions on the H-R diagram. The boundary between these two regions is called the “granulation boundary” (Gray and Nagel 1989). The stars on the cooler side of the boundary have “C” shaped bisectors, the others have the reversed “C” shape.

In this paper we explore the possibility that the accuracy of detailed stellar convection simulations can be tested using the observed line asymmetry. An ultimate goal of this project is to reproduce the granulation boundary as well as the asymmetric spectral lines of individual stars. After these tests, the information in our detailed simulations of stellar photospheric convection can provide a deeper understanding of convective energy transportation in stars. As a consequence, certain theoretical approximations for convection, i.e., the mixing length theory, can be evaluated using our hydrodynamic simulations.

OVERVIEW OF THE PROJECT

First, the detailed structure of a whole star is constructed. The stellar model is constructed using Yale Rotating Evolution Code (YREC) with the non-rotating configuration. For the equation of state, Mihalas, Hummer, and Däppen’s (M-H-D equation of state) table was used for the Sun. For stars, the built-in equation of state in YREC has been used. This is basically the solution of the Saha
equation taking into account only the single ionization of the elements, except He whose single and double ionization are considered. For the opacity, Los Alamos opacities are used. Then, a part of the model structure is used as an initial condition for the detailed convection simulation. This way, the convective region of the star we analyze is consistent with the interior. This ensures that the simulation is not of a convection zone in an artificial environment. For these calculations, the Anders-Grevesse mixture (1989) was used.

**TABLE 1  STELLAR MODELS**

<table>
<thead>
<tr>
<th></th>
<th>M/M(_\odot)</th>
<th>logL/L(_\odot)</th>
<th>logR/R(_\odot)</th>
<th>log T(_{\text{eff}}) Age(Gyr)</th>
<th>(\alpha)</th>
<th>X</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
<td>3.76</td>
<td>4.5</td>
<td>1.230</td>
<td>0.7071</td>
</tr>
<tr>
<td>A5</td>
<td>1.86</td>
<td>1.15</td>
<td>0.24</td>
<td>3.93</td>
<td>0.45</td>
<td>1.230</td>
<td>0.7071</td>
</tr>
</tbody>
</table>

The next step is to solve the hydrodynamic equations to simulate stellar convection zones, which is one of the most challenging tasks. Since the convection is turbulent, simulation with any kind of approximation may easily fail to depict the detailed characteristics of the convection to the degree that we want. Furthermore, the effect we want to see, likely occurs at the region where the radiative energy transfer is not totally negligible. Therefore, the fully compressible, radiation-coupled hydrodynamic equations (Chan and Sofia 1986) with realistic equation of state and opacity have to be solved.

**Fig. 1:** The temperature and the radial velocity fluctuation.

**Fig. 2:** The line bisector calculated using the fluctuating quantities shown in Fig. 1.
The present results are for the two dimensional case using spherical coordinates. The numerical technique is the alternate direction implicit on staggered mesh (Chan and Wolff 1982). The equation of state and opacity is consistent with that for the initial stellar models. Since in the present models, the energy transfer by radiation was treated using the radiative diffusion approximation, regions with small optical depth were avoided.

Finally, using the characteristics of the convection from the simulation (Fig. 1 shows the fluctuating quantities at a horizontal level), disk integrated synthetic spectral lines are calculated and then compared with an observed spectrum. The velocity and temperature fluctuations from the simulation cause the characteristic spectral line asymmetry. The asymmetry depends on the convection, which depends, again, on the condition of the stellar convection zone.

SUMMARY

The simulation for convection in an A5 star shows that the temperature fluctuations are larger than that of the Sun (Fig. 1). Therefore, the reversed-C shaped bisector can be understood in terms of the large intensity contrast between the hot rising elements and the cool sinking elements. When the contribution from sinking element on the integrated intensity is much smaller, the effect of the rising elements is dominant on spectral lines. Therefore, the unresolved convective motion in the disk integrated image may look like only upflows on the whole visible sphere. This expanding star effect may be responsible for the reversed C shaped bisector (Fig. 2).

This simulation reveals that there are several characteristics of the convective flow on A5 stars which are different from that of the Sun. First, the mean radial velocity is larger that that of the Sun. Second, velocity of sinking elements is comparable to that of rising element. And, finally, the radial velocity fluctuation is comparable to that of the horizontal velocity fluctuation.

A more rigorous analysis of this simulation will provide interesting and important information on the stellar photospheric convection of A5 stars.

The qualitative agreement with observation in the present two simulations can be further quantified by a detailed comparison of an observed stellar spectrum at a given wavelength.

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REFERENCES