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Variations of the Position of Perturbation Layer of Solar Frequency Shifts[†] [⋆]

CHINTARUNGRUANGCHAI Pattana[1] YANG Wu-ming[1,2△]
BI Shao-lan[1] TAN Xiao-yan[2]

[1] *Department of Astronomy, Beijing Normal University, Beijing 100875*

[2] *School of Physics and Chemistry, Henan Polytechnic University, Jiaozuo 454000*

Abstract The variation of solar p-mode oscillation frequency with the solar magnetic activity is called the frequency shift, which is considered to be caused by a perturbation in a thin layer near the solar surface. A method for predicting the frequency shift by the magnetic activity index and the solar model had been developed previously. In this method, the frequency shift depends on the intensity of magnetic activity and the position of the perturbing source. The intensity of magnetic activity is considered to be proportional to the magnetic activity index. And the position of the perturbing source was assumed to be fixed previously. This paper has studied the variation of the position of perturbing source. By using the observed p-mode oscillation frequency and Ca II index of the Sun, it is found that the position of perturbing source may be varied with the solar magnetic activity. In the solar maximum year, the position of perturbing source is deeper, but it is shallower in the solar minimum year.

Key words Sun: oscillations—Sun: magnetic fields—Sun: activity—Sun: interior

1. INTRODUCTION

Helioseismology has been developed for decades, which makes it possible to study the solar interior structure that can not be observed directly by through studying the solar acoustic wave modes. Besides the p-mode oscillations, there are also periodic magnetic activities

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△ yangwuming@bnu.edu.cn

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occurred in the Sun. The solar magnetic activities are originated from a loop strong magnetic field, which is produced by a dynamo mechanism in the bottom of solar convective region[1,2]. Woodard et al.[3] first found that the solar p-mode frequency varies with the magnetic activity. Afterwards, using the observed data of the Big Bear Solar Observatory, Libbrecht et al.[4] confirmed this variation, and called it the frequency shift.

Solar p-mode oscillations depend on the solar interior stricture[5−8]. Hence, the solar frequency shift just means that some variations of solar interior structure take place, which will affect the solar acoustic waves propagating in this region. The effect of solar periodic activities on the p-mode frequency has been studied by many authors[9−12]. Libbrecht et al.[4] suggested that the variation of solar interior structure in the period of solar activity mainly happens in a thin layer near the solar surface, and the radial structure of this variational layer (perturbation layer) does not vary with the time and latitude.

Metcalfe et al.[13] and Dziembowski[14] have introduced a method to calculate the frequency shift by using a stellar model, in which there are two important parameters: the intensity of magnetic activity and the position of the perturbation layer. Many authors have proven that the frequency shift is correlated with the intensity of magnetic activity[15−17]. Chaplin et al.[17] compared the frequency shifts and various magnetic activity indices observed by the Birmingham solar observational network in three solar activity cycles, and obtained that the Mg II and Ca II indices can be used for calculating the frequency shifts. Under the assumptions that the ratio between the magnetic activity intensity and the Mg II index is a constant, and the position of perturbation layer is fixed, Metcalfe et al.[18] calculated the frequency shifts, and obtained that the perturbation layer is located at the place 0.3 Mm below the solar photosphere. In addition, this method has been used as well in the studies on the magnetic activities of other stars[18−20].

Observations show that the averaged magnetic field strength of the Sun varies with the solar activity[21]. In this paper, based on the method of Metcalfe et al.[13], and using the data of GONG (Global Oscillation Network Group)[22] etc., we have studied the problem that whether the position of perturbation layer varies with the solar magnetic activity.

2. P-MODE FREQUENCIES AND FREQUENCY SHIFTS OBSERVED BY GONG

In this paper, we use the p-mode frequencies observed by GONG, which are given for the every observational period of 36 d, the so-called one GONG's month. The observation of GONG divides the solar disk into many observational regions, thus to observe the oscillation frequencies ν_{nlm} of different n, m, and l modes. Here we only need to consider the central frequency ν_{nl}, which is defined as:

$$\nu_{nl} = \sum_{m=-l}^{l} \frac{\nu_{nlm}}{2l+1} \ . \tag{1}$$