The Solar Coronal Magnetic Field Measurements With SOLARC

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ABSTRACT
Direct solar coronal magnetic field measurements have become possible since recent development of high-sensitivity infrared detection technology. The SOLARC instrument installed on Mt. Haleakala is such a polarimetric coronagraph that was designed for routinely observing Stokes parameter profiles in near infrared (NIR) wavelengths. The Fe\textsuperscript{+12} 1075 nm forbidden coronal emission line (CEL) is potential for weak coronal magnetic field detection. As a first step the potential field model has been used to compare with the SOLARC observation in the Fe\textsuperscript{+12} 1075 nm line (Liu & Lin 2008). It’s found that the potential fields can be a zeroth-order proxy for approaching the observed coronal field above a simple stable sunspot. In this paper we further discuss several nodi that are hampering the progress for reconstructing the real coronal magnetic field structures. They include the well-known Van Vleck effect in linear polarization signals, ignorance of the information of the NIR emission sources (i.e., inversion problem of coronal magnetic fields), a fat lot of global non-linear force-free field tools available for better modeling coronal magnetic fields, and so on.

Key words: SUN: corona, SUN: magnetic field

1 INTRODUCTION
Successful coronal magnetic field measurements by IR polarimetry method have been reported recently (Lin et al. 2000; Lin et al. 2004). These first coronal magnetic field maps offer the valuable opportunity to test the various popular theoretical models for coronal magnetic field structures.

Currently we have completed the study on the comparison between the observation by SOLARC and the potential field model (Liu and Lin 2008; hereafter, paper I). We found that the observed linear and circular polarization signals are well consistent with the simulated results from the layers located just above the strong photospheric field of a sunspot near the plane of the sky containing the solar center. This conclusion is significant for both theoretic and observational researches. First, the corona should be no longer optically thin if large optical density of the coronal plasma dominating somewhere in the path along the sight line, resulting the use of a more reasonable integration function that is heavily weighted toward particular layers close to sunspot than the traditional uniform integration one. Second, since the coronal NIR emission may be mainly contributed by a local coronal region, then it is feasible to reveal its magnetic field structures from the polarization signals observed. In another word, the polarization signals are meaningful for tracing local coronal magnetic field configurations. Obviously the coronal CEL polarization data will provide rich new information and help improve our understanding of the solar coronal physics. Third, it demonstrates the possibility for the quantitative comparison between coronal magnetic field measurements and coronal models since many early studies counted on the comparison only based on extrapolated magnetic field configurations, i.e., House (1974). The two-dimensional magnetic flux map by SOLARC is an array of 16 × 8 by 128 optical fibers covering a rectangle coronal region of about 0.30 × 0.15 solar radii\textsuperscript{2} near the limb (Fig. 1). Furthermore, if each pixel of the spatially resolved coronal magnetogram carries the emergent polarization information for a single coronal emission source, then, fourth, such a two-dimensional coronal magnetogram should be mapping a real three-dimensional coronal fields and the single-source inversion method to infer the magnetic field directly from the polarimetric observation such as that proposed by Judge (2007) can be confirmed. Fifth, following the the first comparison between coronal magnetic field observation and global potential magnetic field model (paper I), linear and non-linear force-free field methods will be used as the subsequent to study their respective advantage and validity for modeling the non-potential coronal magnetic fields.

Before using the coronal polarization signal measurements by the promising IR CELs to clearly convey the information of the coronal magnetic field structure in the near
future, several difficulties, briefly presented in the following sections, must be figured out or partly improved.

2 THE VAN VLECT EFFECT

Different from the transverse magnetic field observations for the photosphere in which the judgement of the direction of the transverse field vectors are subject to uncertainties due to the famous 180° ambiguity in Zeeman effect, the transverse magnetic field directions inferred from the linear polarization data of the corona sustain not only the Zeeman effect ambiguity but the 90° ambiguity due to the Van Vleck effect (Fig. 2, top frame). House (1974) had explained this phenomenon from the point of the classical theory of electrodynamics. Fig. 2 demonstrates a simulation for the linear polarizations along a coronal loop rooting at the solar limb. It is shown that both the linear polarization amplitudes and directions are sensitive to the location on the loop. However, the amplitude evolution is smooth (Fig. 2, bottom frame), while the direction can change abruptly from parallel to perpendicular relatively to the local tangent direction of the loop. Thus the vector magnetic field directions (projected on the plane of the sky) can not be resolved from one coronal magnetogram. Theoretically, the reliability of three-dimensional coronal vector tomographic techniques can be tested by synthesized coronal Hanle and Zeeman effect observations to bring this issue to a close (Kramar & Inhester 2006). However, obtaining long time-sequence spectropolarimetric coronal observations with high quality is not easy for ground-based instruments.

3 GLOBAL NON-LINEAR FORCE-FREE MAGNETIC FIELD MODELS

We need model coronal magnetic fields in spherical geometry for the purpose of direct comparison with the large-scale SOLARC observations covering coronal regions close to the solar limb. Although there are some non-linear force-free field methods that do not depend on the use of a specific coordinate system, most of the codes available are implemented in Cartesian geometry, ignoring the more general application in the case of the spherical coordinate system. A recent practical tool using simple reference functions, formally similar to the Green’s function, has been developed and improved (Yan & Li 2006; He & Wang 2008), which will be utilized for the force-free models testing in our future work. This method is convenient in the direct photospheric boundary integration for the magnetic field component calculations for any interested coronal point. It is noted that Wiegelmann (2007) presented a new code for the extrapolation of non-linear force-free field in spherical coordinates, but this method is not applied and still under development.
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Figure 3. Demonstration for SOLARC observation and synthesized result. The coordinate system is the same as in Figure 2 and in the paper (Liu and Lin 2008). The two frames in the top two rows illustrate the assumed emission sources and Stokes parameter integration Gaussian functions, in which the line in blue represents the Gaussian function profile centered at layer 120, while the one in red, centered at layer 130 just above the sunspot of AR 10582. The two frames in the third row for the line-of-sight magnetic flux map at layer 130 (note, negative/positive fluxes are shown with white/black ) and the transverse magnetic field vectors at layer 120, respectively. Bottom row: comparison between observed and synthesized linear polarizations for layer 120 that are overlaid on an EUV image.

4 SINGLE-SOURCE INVERSION

The lack of knowledge of source regions of the IR coronal radiation, including the coronal density and temperature distributions, is the greatest uncertainty in our study with the SOLARC measurements. Nevertheless, based on decades of observations, it is well known that strong coronal emissions are always associated with active regions. This experience was confirmed by the study of the careful quantitative comparison between SOLARC data and potential field extrapolation (paper I). Both circular and linear polarization signals simulated with designed weighting functions (in red and blue, respectively) are shown in Fig. 3. The vectors of the transverse magnetic fields, synthesized within the SOLARC field of view for the layer close to the sunspot AR 10582, are not parallel to the directions of the linear polarization for most pixels! The linear polarization directions seem keep open at the height ranging from 0.1 to 0.4 solar radii, while the magnetic fields are closed. The main reason for the close of the magnetic field lines is due to the direct magnetic field connection between the sunspot AR 10582 and 10581 that form a large bright EUV coronal loops system in the north-south direction obviously above the west limb (Fig. 2 in Lin et al. 2004). It’s suggested that CEL radiation may originate from a region close to the strongest photospheric magnetic feature in the active region with a small spatial scale comparable to the characteristic size of the coronal loops seen in the intensity images (Paper I). Triggered by this thought, we make a tentative examination for all the five coronal regions observed by SOLARC. The result is shown in Fig. 4. Note that the parameters used in the calculation are the same as in paper I. Unexpectedly, one-valley feature in the $\sigma_{LP}$ profiles is evident for most pixels in the five coronal regions. However, this feature may be ruined by the Van Vleck effect as seen in the first five or six columns in the first two rows. At the higher heigh, the $\sigma_{LP}$ profiles are more obviously featured by one valley. Does the one-valley feature indicate the strongest radiation CEL source location? It is a critical question related to the coronal magnetic field inversion.

5 CONCLUSION

We list and discuss some key problems in the probing of coronal magnetic field in the short review. The difficulties are expected to be improved in virtue of the recent launched STEREO mission and the proposed vector coronal tomography techniques.

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