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Extrapolating the solar magnetic field as a magnetohydrostatic equilibrium

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Modeling the three-dimensional (3D) magnetic fields of the solar active region in multiple layers is very important in studies of solar activities. Since only the magnetic field in the photosphere can be measured accurately and routinely, the main approach of the magnetic field modeling is to extrapolate the magnetic field from photospheric magnetograms. A basic assumption of the modeling in the past several decades was to completely neglect all plasma effects and to perform the so-called force-free field (FFF) extrapolations. The FFF extrapolation has been proved to be a great success in recovering 3D magnetic field in the solar corona. While the force-free assumption is well justified in the corona where plasma is very sparse so the magnetic field dominates the corona, it is not the case in the photosphere and chromosphere. In these lower atmosphere, a magnetohydrostatic (MHS) equilibrium which takes into account plasma forces, such as pressure gradient and gravitational force, is considered to be more appropriate. The corresponding MHS extrapolation has been developing rapidly during the past several years.

Both analytical and numerical methods have been developed to model the MHS equilibrium. In an analytical approach, one has to assume a horizontal electric current which is perpendicular with gravitational force [1]. To model twisted magnetic configuration, Low [2] further introduced a linear-force-free electric current component. In the general MHS case, three kinds of methods have been proposed to solve the MHS equations. They are: MHD relaxation method [3,4], Grad-Rubin method [5], and optimization method [6]. Each of them has been tested with either analytical or numerical reference solution (Figure 1). Furthermore, the MHD relaxation method and the optimization method have been used to study solar activities by extrapolating the observed magnetograms.

Recently, an MHS version of preprocessing of the vector magnetogam has been proposed to make the magnetogram consistent with the MHS assumption. The MHS preprocessing is an extension of the widely applied FFF preprocessing. Moreover, by recognizing that the non-force-free layer is very thin in the solar atmosphere, the MHS extrapolation is combined with the nonlinear FFF extrapolation to improve the computational efficiency dramatically.

The MHS extrapolations require high spatial resolution boundary conditions as input to resolve the fine structures in the solar lower atmosphere. Such hig-resolutin measurements (e.g., with SST, DKIST) are improving rapidly, which offer great opportunities to further develop the MHS modeling.

References

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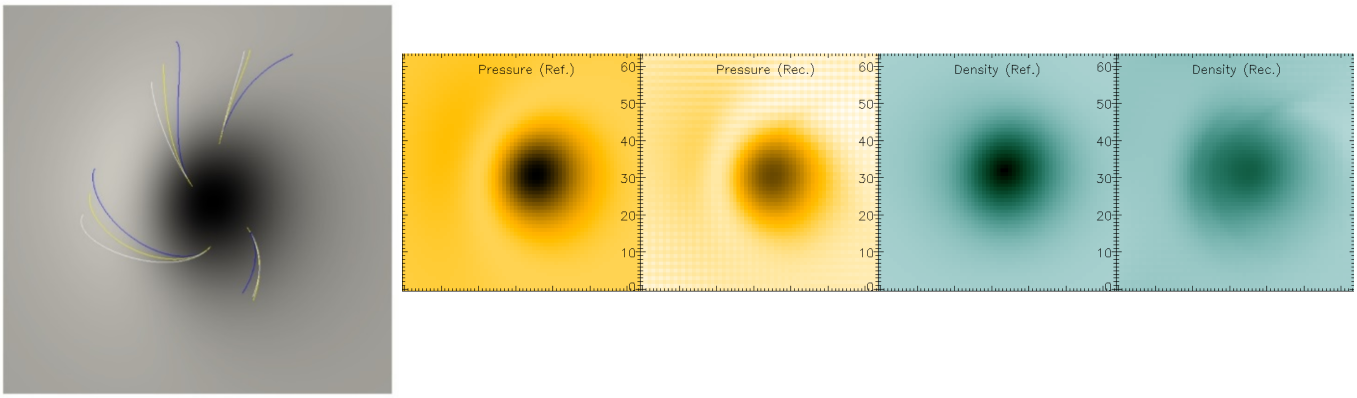

Figure 1 Left: Comparison of the reference (white), MHS (yellow), and NLFFF (blue) field lines. Right: Comparison of reference and MHS pressure (density).