Numerical studies of solar chromospheric jets

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論文の内容の要旨

論文題目　Numerical studies of solar chromospheric jets

(太陽彩層ジェットの数値的研究)

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The solar chromospheric jet is one of the most characteristic structures near the solar surface. The quantitative understanding of chromospheric jets is of substantial importance for not only the partially ionized phenomena in the chromosphere but also the energy input and dissipation processes in the corona. In this dissertation, the formation and dynamics of chromospheric jets are investigated using the radiation magnetohydrodynamic simulations.

We newly develop a numerical code for the radiation magnetohydrodynamic simulations of the comprehensive modeling of solar atmosphere. Because the solar chromosphere is highly nonlinear, magnetic pressure dominated, and turbulent, a robust and high-resolution numerical scheme is required. In Chapter 2, we propose a new algorithm for the simulation of magnetohydrodynamics. Through the test problems and accuracy analyses, the proposed scheme is proved to satisfy the

requirements.

In Chapter 3, the effect of the non-local radiation energy transport, Spitzer-type thermal conduction, latent heat of partial ionization and molecule formation, and gravity are implemented to the magnetohydrodynamic code. The numerical schemes for the radiation transport and thermal conduction is carefully chosen in a view of the efficiency and compatibility with the parallel computation.

Based on the developed radiation magnetohydrodynamic code, the formation and dynamics of chromospheric jets are investigated. In Chapter 4, we investigate the dependence of chromospheric jets on the coronal temperature in the two-dimensional simulations. Various scale of chromospheric jets with the parabolic trajectory are found with the maximum height of 2–8 Mm, lifetime of 2–7 min, maximum upward velocity of 10–50 km/s, and deceleration of 100–350 m/s^2. We find that chromospheric jets are more elongated under the cool corona and shorter under the hot corona. We also find that the pressure gradient force caused by the periodic shock waves accelerates some of the short chromospheric jets. The taller jets tend to follow ballistic trajectory. The contribution of the coronal conditions are quantitatively modeled in the form of a power law based on the amplification of shock waves under the density stratified medium.

In Chapter 5, the role of the magnetic field is investigated using the two-dimensional simulations. We distinguish the contribution of the corona and magnetic field using the power law. The average magnetic field strength produces only a small effect on the scale of chromospheric jets. The observed regional difference is mainly explained by the difference of the coronal conditions, which is caused by the different magnetic field structure. We also find shorter chromospheric jets above the strong magnetic flux tube. This is in contrast to the observational studies.

In Chapter 6, a three-dimensional simulation is presented to investigate the effect of three-dimensionality on the scale of chromospheric jets and the dependence on the photospheric magnetic field structure. The tall chromospheric jets with the maximum height of 10–11 Mm and lifetime of 8–10 min are formed. These tall jets are located above the strong magnetic field concentration. This result is different from the two-dimensional study and consistent with the observational reports. The strongly entangled chromospheric magnetic field drives these tall chromospheric jets through the Lorentz force. We also find that the produced chromospheric jets form a cluster with the diameter of several Mm with finer strands.

In Chapter 7, we summarize and discuss our new findings and their implications for the solar chromospheric jets. The regional difference of chromospheric jets is explained through the coronal temperature and density, which is produced by the heating process with the different strength and structure of the magnetic field. The observational relation between the magnetic network and chromospheric jets are interpreted through the magnetic energy release in the complex photospheric magnetic field with mixed-polarity. The formation of the horizontal structure like the multi-threaded nature of solar spicules and the possible driver of observed chromospheric jets are also discussed. The comprehensive numerical model developed in this dissertation allows various future applications for the dynamics on the sun.

The most important new results in this dissertation are (1) the reproduction of tall ($>$ 6 Mm) chromospheric jets using the simulation with realistic physical processes, (2) the quantification of the effect of the coronal condition and magnetic field on the scale of jets, and (3) the reproduction of the cluster of jets with fine-scale internal structure. We conclude that the solar chromospheric jets reflect the information of not only the magnetic field but also the corona and fine-scale motion in the lower atmosphere.