

論文 / 著書情報
Article / Book Information

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| 題目(和文) | 磁気流体力学シミュレーションを用いた原始惑星系円盤の乱流・熱構造の理解 |
| Title(English) | Understanding the turbulent and thermal structure of protoplanetary disks with magnetohydrodynamic simulations |
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| Category(English) | Doctoral Thesis |
| 種別(和文) | 論文要旨 |
| Type(English) | Summary |

(博士課程)
Doctoral Program

論文要旨

THESIS SUMMARY

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| 系・コース： Department of, Graduate major in | 地球惑星科学 地球惑星科学 | 系 コース | 申請学位 (専攻分野)： Academic Degree Requested | 博士 Doctor of | (理学) |
| 学生氏名： Student's Name | 森 昇志 | | 指導教員 (主)： Academic Supervisor(main) | 奥住 聡 | |
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要旨 (英文 800 語程度)

Thesis Summary (approx.800 English Words)

Studies on protoplanetary disks are essential for understanding the formation process of planets. The disk structure is largely affected by magnetic fields. Therefore, clarifying the influence of the magnetic field on the disk structure allows us to construct the planet formation theory in realistic protoplanetary disks. Especially, turbulence strength is an important parameter because it causes the disk accretion and heats the disk gas. The thermal structure is essential for understanding the planet formation process and verifying the formation theory by comparing with observations. In this thesis, we have investigated the role of magnetohydrodynamics on the turbulent and thermal structures of protoplanetary disks with numerical magnetohydrodynamic (MHD) simulations.

This thesis consists of four chapters below. In Chapter 1, we introduce the general introduction for the previous studies on planet formation and protoplanetary disks. Furthermore, we focus on the effect of magnetic fields on the structures of protoplanetary disks. The disk turbulence is thought to be generated by a magnetorotational instability (MRI). The MRI turbulence largely depends on the ionization fraction which determines the strength of nonideal magnetohydrodynamic (MHD) effects. Because the protoplanetary disks are the low-ionized environment, the understanding of the ionization state and the resulting nonideal MHD effects is important. Therefore, understanding the ionization fraction is necessary to properly understand turbulent strength and for further discussion for the thermal structure. The purpose of this thesis is to understand MRI strength by focusing on the ionization state and to elucidate thermal structure in the magnetized disks.

In Chapter 2, we have investigated the turbulence strength taking into account electron heating by MRI-induced electric fields. The heating decreases the ionization fraction of the gas because the electrons heated by the electric fields quickly stick to dust grains. This effect on the evolution of magnetorotational instability has been neglected. The electron heating is expected to decrease the ionization fraction and enhance the non-ideal MHD effects. We perform three-dimensional MHD simulations including change of the ionization fraction by the electron heating, and investigate the turbulence strength. We confirm that the electron heating suppresses the MRI turbulence. Also, we have found a clear correlation between the magnetic stress and its current density. We propose a formula that successfully predicts the magnetic stress suppressed by the effect of electron heating.

In Chapter 3, we have focused on the thermal structure of protoplanetary disks in the laminar disks. The suppression of magnetic turbulence makes a significant difference from the conventional turbulence-driven accretion disks. When the turbulence is sufficiently weak, the magnetic fields threading the disk remove the angular momentum and energy as magnetohydrodynamic wind, and thereby drives the disk accretion. The energetics of this wind-driven accretion disks can be largely different from the conventional model, but this has not been investigated well. In this Chapter, considering these recent works, we investigate the temperature structure in the wind-driven accretion disk with nonideal MHD simulations. Our simulations have confirmed that the suppression of turbulence around midplane leads to release the heat at disk surface, which is efficiently removed by radiative cooling. As a result, the disk is much colder than the conventional model. Also, removal of accretion energy by disk wind reduce the total energy which used for heating. Therefore, we have concluded that the accretion heating is much inefficient than the conventional model.

In Chapter 4, we summarize the renewed structure of the protoplanetary disks. We also discuss the evolution of the snow line and review the Earth formation process which explains Earth's low-water content on the basis of knowledge of our MHD simulation. The inefficient accretion heating suggests the necessity for the Earth to complete its formation in the early phase of the disk evolution ($\lesssim 0.4$ Myr). To understand rocky planet formation consistent with the water content, requires other heating mechanisms (e.g., hydrodynamic turbulence) and/or formation mechanism that Jupiter can form earlier.

備考：論文要旨は、和文 2000 字と英文 300 語を 1 部ずつ提出するか、もしくは英文 800 語を 1 部提出してください。

Note：Thesis Summary should be submitted in either a copy of 2000 Japanese Characters and 300 Words (English) or 1copy of 800 Words (English).