

論文 / 著書情報
Article / Book Information

題目(和文)	原始惑星系円盤中の固体粒子の運動に関する理論的研究：太陽系内側天体の炭素枯渇問題及び木星大気中の貴ガス濃縮問題への応用
Title(English)	Theoretical Study on the Motion of Solid Particles in Protoplanetary Disks: Implications for Carbon Depletion in the Inner Solar System and Uniform Noble Gas Enrichment in Jupiter ' s Atmosphere
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出典(和文)	学位:博士(理学), 学位授与機関:東京科学大学, 報告番号:甲第218号, 授与年月日:2025年3月26日, 学位の種別:課程博士, 審査員:井田 茂,奥住 聡,尾崎 和海,中本 泰史,横山 哲也
Citation(English)	Degree:Doctor (Science), Conferring organization: Institute of Science Tokyo, Report number:甲第218号, Conferred date:2025/3/26, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

論文要旨

THESIS SUMMARY

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)
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要旨 (英文 800 語程度)

Thesis Summary (approx.800 English Words)

The Solar System formation is unclear. Although solids' motion in the protosolar disk is important for understanding the planetesimal formation, it still has a lot of uncertainty. Some cosmochemical data implies the solids' motion in the disk. Previous studies suggested that both carbon abundance of the rocky bodies and noble gas enrichment in the Jovian atmosphere are related to the solids' motion in the disk. In this thesis, we aim to get the information of the solids' motion from the carbon abundance of the rocky bodies and noble gas enrichment in the Jovian atmosphere.

The bulk Earth is depleted in carbon by 2–3 orders of magnitude compared to the Sun, interstellar medium (ISM) dust, and comets, while 1–2 orders of magnitude deplete chondrites. This creates a three-step carbon abundance distribution in the Solar System: bulk Earth, chondrites, and comets. Refractory carbon, abundant in ISM and comets, must have been destroyed in the protosolar disk through mechanisms like photolysis, oxidation, or pyrolysis of complex organics. However, previous studies indicated that radial transport suppresses carbon depletion via photolysis and oxidation, and efficient pyrolysis is necessary in chondrites' parent body formation region. This study aims to explore the conditions for carbon depletion, incorporating factors like the varying stickiness of icy and silicate particles and the high-temperature region in the FUV-exposed layer, which were previously unexamined. We performed a 3D Monte Carlo simulation of radial drift, vertical settling, and radial and vertical turbulent diffusion of the solid particles in a steady accretion disk. We set the composition of the refractory carbon as the amorphous hydrocarbon and complex organics. We considered that all refractory carbons can be destroyed by photolysis and oxidation, while pyrolysis only destroys the complex organics. We evaluated the radial distribution of the carbon abundance by the simulation.

As a result, we found that the carbon abundance drops off inside the snow line by 1-2 orders of magnitude compared to the solar value under the following conditions: i) when silicate particles are much less sticky than icy particles and ii) when there are high-temperature regions in the disk upper layer. The former leads to fast decay of the icy pebble flux while the silicate particles are still piling up inside the snow line. The latter contributes to the efficient turbulent stirring up of silicate particles to the upper FUV-exposed layer. The drop-off at the snow line is slight when the photolysis and oxidation do not operate. We also found that the carbon abundance can drop off inside the 'pyrolysis line'. Our result suggests that the condition of the complex organics enrichment in the refractory carbons is required in addition to the above two conditions to replicate the three-step distribution of carbon in the Solar System.

Galileo probe revealed that noble gas abundances (Ar, Kr, Xe) in the Jovian atmosphere are 2--3 times higher than the solar value. As the composition of the Jovian atmosphere should be the same as the solar value, it is a mystery. A previous study suggested that disk photoevaporation can explain the enrichment. However, they did not incorporate sublimation and condensation for noble gases. We aim to explain the noble gas enrichment in the Jovian atmosphere, considering the sublimation and re-condensation of each noble gas, disk photoevaporation, and the radial transport of dust. We solve a one-dimensional diffusion equation for the disk gas from the infall stage, incorporating internal and external photoevaporation. We also solve advection and diffusion equations for the dust and noble gases. We focus on models able to reproduce the global characteristics of the early solar system, i.e., a disappearance of the disk after 4 to 6 Myr and the formation of planetesimals at two locations. When the noble gases are trapped only on the surface of amorphous ice, argon, krypton, and xenon are thought to be released from cold dust grains in the protosolar disk between 19 and 35 K. Our models then generally lead to inefficient trapping and near-solar abundances in Jupiter, incompatible with the constraints. However, recent laboratory experiments using amorphous ice trapping the noble gases inside yield significantly higher desorption energies, translating into releasing noble gases between 40 and 50 K. We then find that the lower mass-loss rate due to disk photoevaporation can reproduce the noble gas enrichment.

Through this thesis, the carbon fraction requires the higher fragmentation velocity for icy particles than silicates in the entire region outside the snow line while the noble gas enrichment requires the comparable fragmentation velocity to the silicates in the outer disk region. However, if the most solid particles infall inside the snow line, they can pass through the snow line before spreading to the colder disk regions be pushed back to the inside the snow line. It can result in the ignorance of the icy pebbles coming from outside the snow line and the drop-off of the carbon fraction. Therefore, future work investigating the effect of gas disk evolution on the carbon depletion problem is important for constructing a consistent model of solid motion in the protosolar disk.

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).

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