【Grant-in-Aid for Scientific Research (S)】

Prediction of Solar Storm Arrival by Innovative Radio Observation

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Purpose and Background of the Research

●Outline of the Research

In recent years, many social infrastructures have been operated in space. Solar eruptive phenomena, such as flares, eject part of solar atmosphere that causes solar storms. These solar storms can arrive at the Earth and cause major disturbances to the environment around the Earth, resulting in extensive damage to social infrastructures. Predicting the arrival of solar storms in advance is an urgent problem. The purpose of this study is to elucidate the propagation process of solar storms. The method is to detect solar storms from ground-based radio observations by using radio scattering phenomena caused by the solar storms. In particular, we will develop a new radio observation system using digital phased array technology and observe eight different locations of a solar storm simultaneously. From data assimilation simulations using this observation data, the prediction error of 24 hours before the arrival time will be dramatically improved to 1 hour, contributing to safe space activities for human beings.

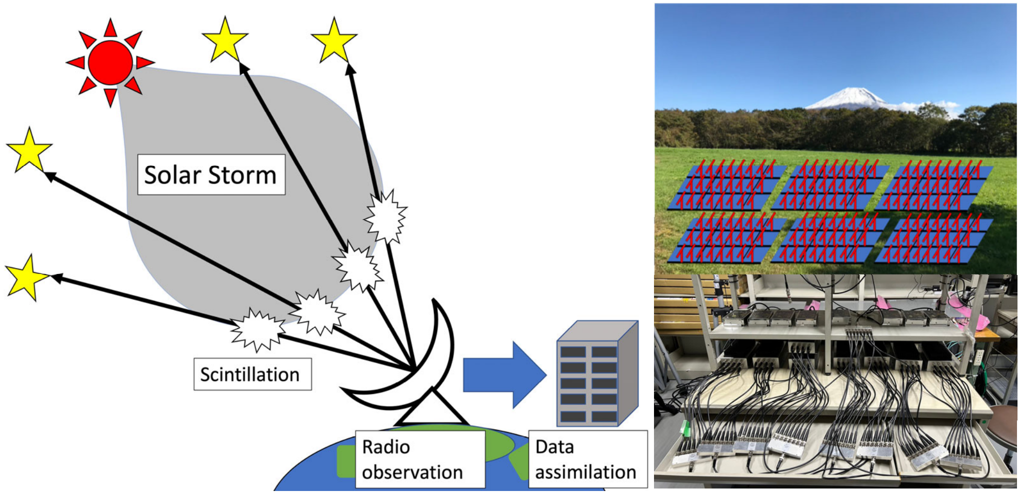

Figure 1. Image of radio observation of a solar storm approaching the Earth (left), image of the radio observation system to be developed in this project, and photo of the prototype digital signal processors (right) .

●Radio observation of solar storms

A solar storm is an ionized atmosphere (plasma), which can scatter radio waves. When a solar storm passes between the Earth and a radio source during a radio observation of a celestial body outside the solar system, the radio waves from the celestial body are scattered and their intensity fluctuates rapidly. From this interplanetary scintillation phenomenon, it is possible to extract the density and velocity of the medium (in this case, a solar storm).

●Innovative Radio Observation

Existing large telescopes could only observe in one direction at a time and could not obtain the structure of a solar storm over a wide area. In this research, digital phased array devices will be mounted on a radio telescope with a wide field of view to observe multiple directions simultaneously. This system will dramatically improve the observation efficiency of solar storms.

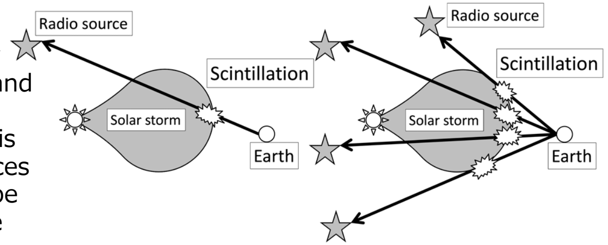

Figure 2. Image of solar storm observation in only one direction using conventional telescopes (left) and simultaneous multi-directional observation using the telescope to be developed in this research (right)

Expected Research Achievements

●Three-dimensional structure of solar storms

We will develop a two-dimensional phased array antenna with a wide field of view. The signals from these array antennas will be digitized, and eight objects included in the field of view of the antennas will be simultaneously tracked and observed. When a solar storm passes through the line-of-sight of the observations, eight different cross sections can be observed along the travel direction of the solar storm. The density of the solar storm can be derived from the amplitude of the scintillation, and the velocity of the solar storm can be derived from the spectrum of the scintillation. Although the derived physical parameters are integral quantity along the line-of-sight, the three-dimensional structure of the solar storm can be reconstructed using multiple different cross-sections, which is the same principle as a CT scan used in medical equipment.

●Space weather forecasting by real-time data assimilation simulation

The solar storm observations obtained in this study are included into a magnetohydrodynamic simulation. In this simulation, a number of solar storm simulations with different initial parameters are driven by the observed data near the solar surface. The results of these simulations are compared with radio scintillation observations using data assimilation techniques to find the solar storm parameters that best reproduce the observations. Thus, the best fit simulation should provide a real picture of the propagation process. Furthermore, the best fit simulation results can be used to accurately predict the future propagation of solar storms. Since the ground-based radio observation data in this study are immediately available, real-time arrival-time forecasts of solar storms can be made using this data assimilation simulations.

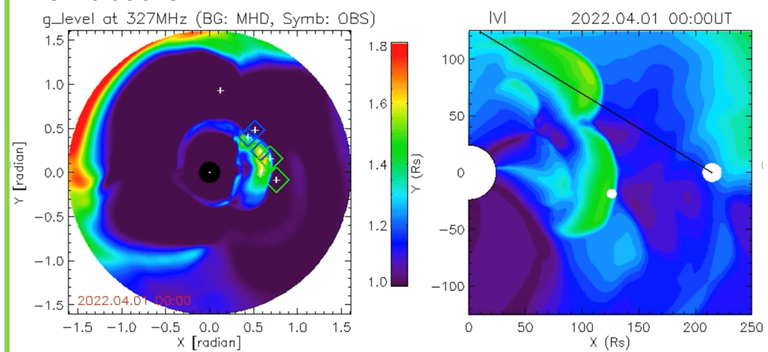

Figure 3. Example of real-time space weather forecast simulation using solar storm observation data. (left) Mapping of the distribution of scattering by solar storms. (right) Relationship between a solar storm (green arc) propagating between the Sun (leftmost large circle) and the Earth (right circle) and the line-of-sight (black line) of a radio observation.

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