(Reports and introductions of experiments using overseas sounding rockets)

Solar sounding rocket experiment CLASP2 & CLASP2.1

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summary

In order to elucidate the most important issues of solar physics, "chromosphere/corona heating" and "solar wind acceleration," it is essential to observe the magnetic field of the chromosphere and transition layer, which are the connection regions between the solar surface and the corona. However, observations are still lacking. Until now, we have been promoting the CLASP series of sounding rocket experiments with the aim of "establishing a method for diagnosing the magnetic field of the chromosphere and transition layers by ultraviolet polarized spectroscopic observation". In this lecture, we will discuss the sounding rocket experiment CLASP2 (conducted in April 2019) and CLASP2.1 (2021), which succeeded in high-precision polarization spectroscopic observation of the ionizing magnesium ray region (wavelength 280 nm) Conducted in October 2010).

Background and Scientific Objectives

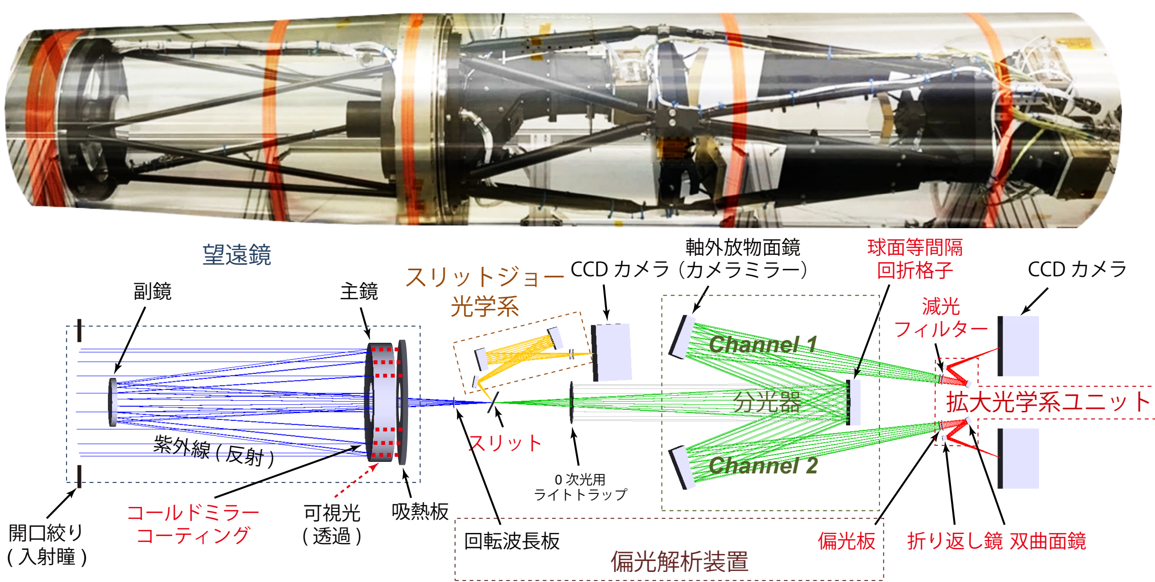
The chromosphere is thin (to 2,000 km) between the 6,000-degree solar surface (photosphere) and the 1 million-degree corona. It is an atmospheric layer. In particular, the middle to upper parts of the chromosphere are gas pressure dominance (photospheres), in which the interaction between the movement of the gas and the magnetic field is essential for plasma phenomena. It is a characteristic region that switches from magnetic pressure to magnetic pressure dominance, and is full of various dynamic phenomena such as magnetofluid waves and jets. These dynamic phenomena are thought to be caused by the magnetic field connecting the photosphere to the chromosphere and the corona, but there has been little observation of the magnetic field above the photosphere so far, and the essential understanding of the amount of energy carried by the magnetofluid wave, the dissipation mechanism, and the generation mechanism of the jet has not been reached.

Therefore, we focused on the ultraviolet region in which there are many spectral lines derived from plasma of 10,000 to tens of thousands of degrees Celsius, which constitute the middle to upper part of the chromosphere. In recent years, the development of theoretical research combining radiation transport and quantum mechanics has shown that it is possible to measure the magnetic field by observing the polarization of some of the spectral lines of ultraviolet rays with high accuracy (Trujillo Bueno et al. 2011 ApJL, etc.). However, the polarization spectrum of ultraviolet rays, which require observation from space, is unexplored, and the CLASP series of sounding rocket experiments in Japan, the United States, and Europe opened up this gap. In September 2015, we conducted a sounding rocket experiment called Chromospheric Lyman-Alphe Spectro-Polarimeter (CLASP1, Kano et al. 2017 ApJL, Ishikawa et al. 2017 ApJ etc.) was carried out. However, due to the complex atmospheric structure, quantitative measurement of the upper chromosphere magnetic field was not possible, so the observed wavelength was changed from the Lyman α line (122 nm) to the ionizing magnesium ray (wavelength 280 nm), and a new sounding rocket experiment Chromospheric LAyer Spectro-Polarimeter (CLASP2). The greatest advantage of ionizing magnesium rays is that, in addition to the linear polarization caused by scattering and the Hanle effect (the effect of the scattered polarization being modulated by the magnetic field) as in the case of Lyman α lines, a strong line-of-sight magnetic field results in circular polarization detectable by the Zeeman effect (Alsina Ballester et al. 2016 ApJ, etc.).

Development of CLASP2

CLASP2 is a high-precision (0.1%) Make observations. While maintaining a high level of scientific demand, recovered after launch to shorten the development period Development items were minimized by reusing most of the main structure and optical elements of the CLASP1 observation instrument. The CLASP2 observation instrument consists of a Cassegrain telescope with a diameter of 27 cm, a polarization spectrometer (spectrometer + polarization analyzer), and a two-dimensional imaging optical system (hereinafter referred to as "Cassegrain") that observes the solar chromatic layer image around the slit (hereinafter referred to as Slit jaw optics) (Fig. 1). In order to realize a high polarization accuracy requirement of 0.1%, in addition to securing as much light as possible, polarization 2 orthogonal using diffracted ±primary light A new pivoy optics for simultaneous measurement of components were adopted following CLASP1 (Narukage et al. 2015 Applied Optics, Tsuzuki et al. 2019 SPIE).

The development of the observation device, like CLASP1, was promoted through international cooperation. With diffraction gratings and CCD cameras provided by France and the United States, respectively, the NAOJ Advanced Technology Center conducted the design of the observation instrument, the development of the elements, the modification and assembly work to the observation equipment brought back from the United States, and the performance confirmation test. In November 2018, the completed observation equipment was shipped to the United States, and after meshing tests with flight computers and sounding rockets, April 11, 2019 (local time), USA The launch took place at the White Sands Missile Test Site (WSMR) in New Mexico.



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波長	Lya (122nm) フィルター
視野	527 x 527秒角
分解能	2秒角（空間）
時間間隔	0.6秒

偏光分光装置(SP)

波長	Mg II h & k線 (280 nm)
視野	200秒角 (スリット長)
分解能	2秒角（空間）& 0.01 nm (波長)
時間間隔	3.2 秒 (波長板一回転)
偏光精度	0.1% at 3σ

Figure 1: (Top) CLASP2 Observatory. (Medium) CLASP2 optics. Figures in the red indicate new development items in CLASP2. (Bottom) Outline of CLASP2 observation instrument specifications. For more information on optical testing, see Yoshida et al. 2017 SPIE, Song et al. See 2017 SPIE.

Results of CLASP2

CLASP2 was launched and conducted solar observations for about 6 minutes at an altitude of more than 160 km. The following areas were planned before launch: (1) heliocentric (for acquisition of polarization calibration data), (2) active region, (3) quiet region near the solar edge. He observed three regions and succeeded in acquiring polarized spectroscopic spectra of the ionizing magnesium ray region for the first time in the world. In particular, in the observation of the active region, the dominant circular polarization caused by the Zeeman effect was observed over almost the entire area, and the ionizing magnesium rays (in the chromosphere - In addition to radiation from the top), a line-of-sight magnetic field could also be obtained from nearby manganese rays (emitted from the lower part of the chromosphere). By combining these with the photosphere magnetic field observed simultaneously by the Hinode satellite, We succeeded in acquiring continuous magnetic field information from the photosphere to just below the corona, and the figure of the magnetic flux tube that rapidly expands with the chromosphere became clear (Fig. 2, Ishikawa et al. 2021 Science Advances). In the future, it is expected that research on how energy is transferred between different atmospheric layers via magnetic fields will progress.

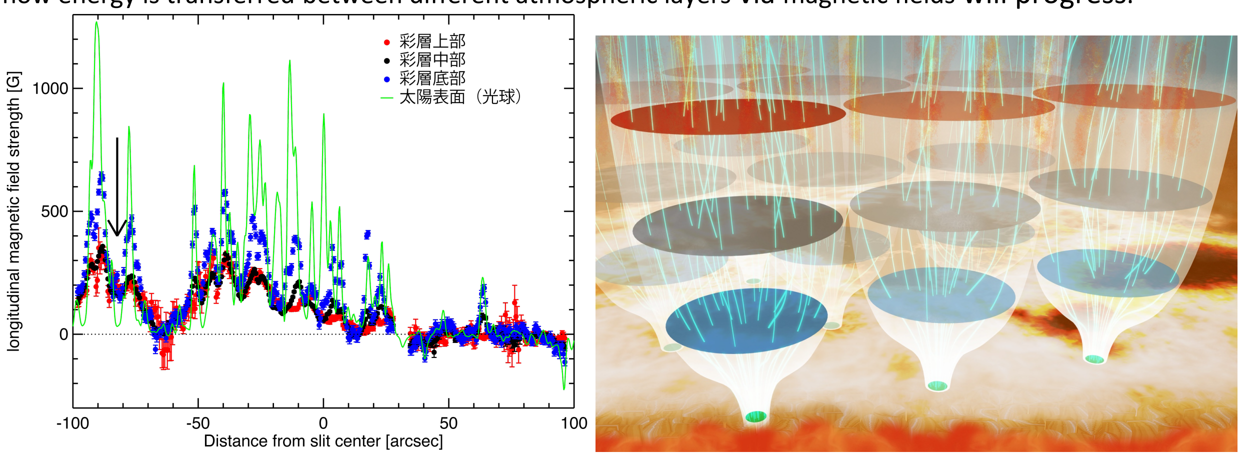


Figure 2: (Left) Magnetic field distribution from the surface of the Sun to just below the corona. CLASP2 observed three layers: the bottom of the chromosphere (blue), the middle (black), and the top (red). The magnetic field (green) on the surface of the Sun was obtained by observation by the Hinode satellite. (right) An imaginary diagram of a magnetic flux tube revealed by joint observations by CLASP2 and the Hinode Satellite (NAOJ).

CLASP2.1 filed

CLASP2 revealed that the circular polarization of ionizing magnesium lines due to the Zeeman effect can be sufficiently detected, and that the radial magnetic field strength in the middle and upper layers of the chromosphere can be derived from it. Furthermore, together with the discovery of manganese rays that can simultaneously acquire the line-of-sight magnetic field at the bottom of the chromosphere, the usefulness of the ionizing magnesium ray wavelength range has further increased. The CLASP2 instrument returned unscathed to the desert by parachute after launch. So we decided to develop the CLASP2 Reflight Plan (CLASP2.1). In CLASP 2.1, slit scans are performed with the same observation device. As a result, a two-dimensional map of the radial magnetic field and height information by multiple spectral lines reveal the three-dimensional structure of the magnetic field responsible for energy propagation to the corona.

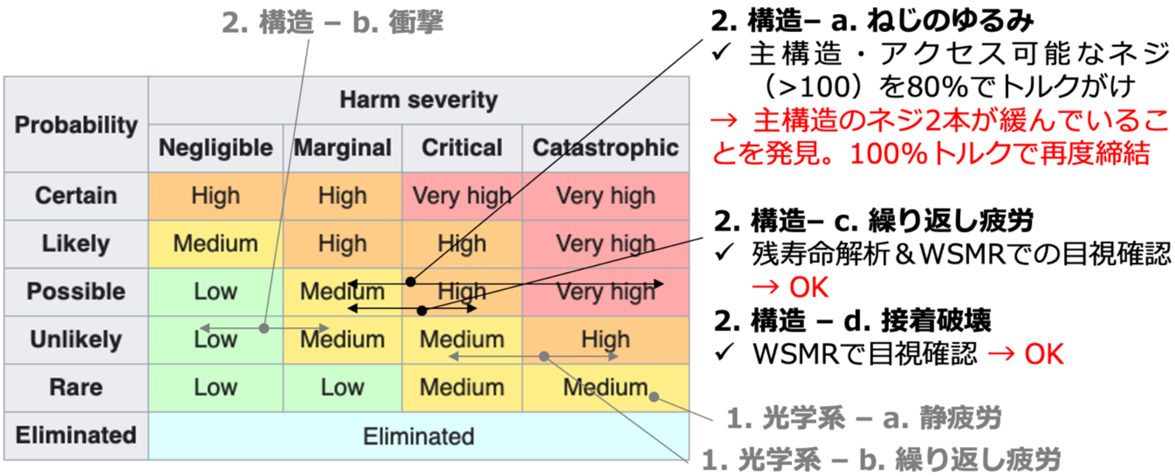
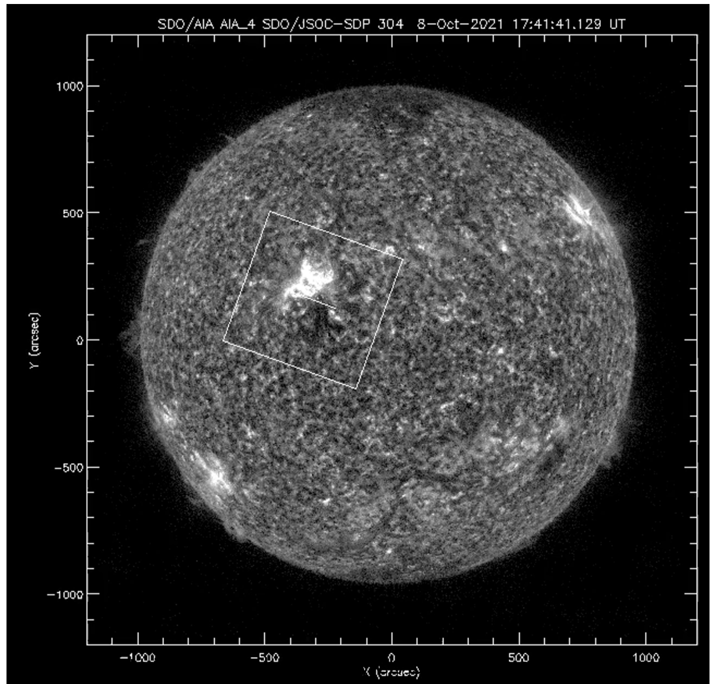


Figure 3: Risk analysis and countermeasures for re-flight. It was decided to respond to the items indicated in the black.

We, Japan, the United States, and Europe CLASP2 team submitted the proposal to NASA in October 2020 and the proposal was accepted in February 2021 with the 'Excellent'. Due to the corona disaster Although there were concerns about the situation where the outlook was uncertain, the launch in the autumn of this year has been decided,CLASP2.1The plan has started in earnest. When writing a proposal, we planned the activity at NASA/MSFC to install the rotating wave plate (In the case of long-term storage, it was desired to make the rotating surface horizontal.CLASP2After LaunchRemove it and store it separatelyhad to) and telescope alignmentdoMeasure thatDrawing、2Times to the U.S.Travel toI was thinking。 However, at that time, the corona vaccine was not widespread and quarantine was required in the U.S. and Japan, respectively, and there were concerns about the risk of infection while traveling, so it was decided to carry out all work in WSMR to reduce the number of trips, and travelers were also required to use the Ishikawa (Japanese side P rincipal Investigator) and Song (Japanese Instrument Scientist).

CLASP2Observation equipmentFly againLetOnFirstconcernand becomes.Tanoga,In a limited timeHow can we ensure the soundness of the structure? De Ah る。For thatallriskIdentifying FactorsEvaluated its likelihood and impact (図 3)。 And、occurrence の possibility が Undeniable、[1]Loosening the screws,2]Repeated fatigue (Especially the hinge part)、[3] Adhesive breakdown of optical elements,の 3About the pointWe decided to take measures。In addition,CLASP2Also during development, C to be reusedLASP1structure や About optical elements,Torque to confirm screw fastening, gluingVisualConfirmConducted at NAOJ,No problems were identified. nowCLASP2.1Preparing for Launch、WSMR で[1], [3]When I did the correspondence, there was no problem with the adhesion,The screws that support the main structure are2It was confirmed that it was loose as the book.Problem points before vibration test,を discoveryCould。Loose screws areRe in Flight TorqueFastening and vibration testlaunchI faced it. See also、 Before and after the vibration test, after launch,Each timeConduct optical testingBy doing so,Observation instrument alignmentand throughputMake sure it is kept.



the field of view of the slit jaw optical system, and the straight line

CLASP2.1 Launch

1Months and a halfWSMRThe exams went largely smoothly.2021 年 10 月 8Day (local time)CLASP2.1 を Launched. Both the rocket and the sounding equipment work perfectly and about6Over the MinuteWhatSuccessful acquisition of observation data.The first thing we did wasTo obtain data for polarization calibration の Observations at the heliocentrumbe。 ThisIn Observations ofThe obtained data is analyzed after launch and the polarization characteristics of the observation equipment are は CLASP2fromchangeWouldn't have done thatconfirmed. Then wentAreas of activityObservations inAnd now(Figure)4）,

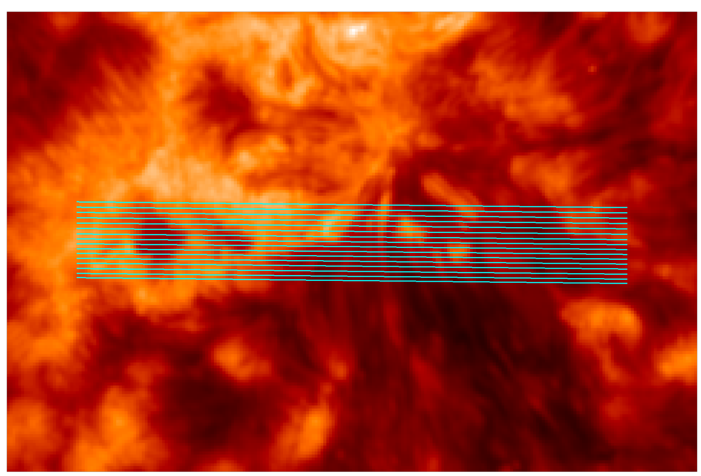


Fig. 5: Chromosphere observed with CLASP2.1 slit jaw optics. Polarization spectra were obtained at 16

Rocket'sPoint1.7”In the stepBy moving (nudge capability)plan16Places、200”×26”の In the regionscanSuccessful observation た (Figure)5)。 At each slit positionThe17.6Perform accumulation of more than a second,VariousDerived from the Zeeman effect with shapeIonizing magnesium wire, manganese wireCircular polarization spectrumConfirming the detection of。

from now on

Currently, the entire team is working together to calibrate the data. CLASP2.1 has also succeeded in joint observations with the Hinode satellite, and we will work on the creation of scientific results, such as derivation of a three-dimensional magnetic field directly under the photosphere and corona. In addition, as the next project of the next solar observation satellite Solar-C EUVST, which is being developed in cooperation with Europe and the United States (White Paper "Scientific Research Strategy of the 1930s" Solar Researchers Liaison Committee (Solar Researchers Liaison Committee "Scientific Research Strategy in the 2030s" White Paper Ishikawa et al., Kawahata et al., Oba et al.) and as a future mission outside the sea (Peter et al. 2021 Experimental Astronomy, Orozco Suarez et al. 2022 Experimental Astronomy), a solar mission to measure magnetic fields from space using polarized spectroscopic observations is being considered. In these future plans, ionizing magnesium rays and lyman α lines are expected to be influential spectral lines, and the measurement technology, observation data, and scientific results obtained from our sounding rocket experiments will be used to produce these technologies. It is expected that these studies will make significant progress. In addition, relatively young researchers, engineers, and students are involved in these sounding rocket experiments, and it can be said that they have made a great contribution from the viewpoint of human resource development.

Thanks

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- 2016-2018 JSPS Grant-in-Aid for Scientific Research 16H03963 Grant-in-Aid for Scientific Research (B)
- 2016 NAOJ Joint Development Research
- FY2015 ISAS International Joint Mission Promotion Expenses
- 2013-2017 JSPS Grants-in-Aid for Scientific Research JP25220703 Grant-in-Aid for Scientific Research (S)
- 2021-2023 JSPS Grant-in-Aid for Scientific Research 21H01138 Grant-in-Aid for Scientific Research (B)
- FY2020-2021 JAXA Small Project (No budget allocation due to acquisition of Grants-in-Aid for Scientific Research)
- 2019-2021 JSPS Grant-in-Aid for Scientific Research 19K03935 Grant-in-Aid for Scientific Research (C)