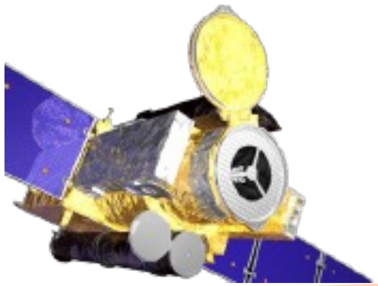
Continuous observations of solar activity

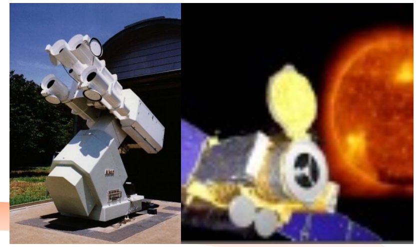
HINODE, Mitaka ground-based telescopes, and build-up for future observations



Yukio KATSUKAWA

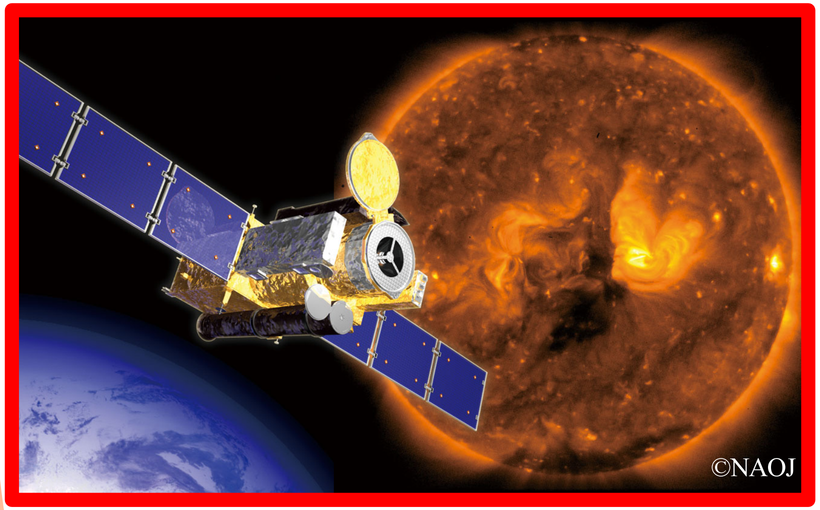
(Solar Science Observatory, NAOJ)

Facilities for solar observations

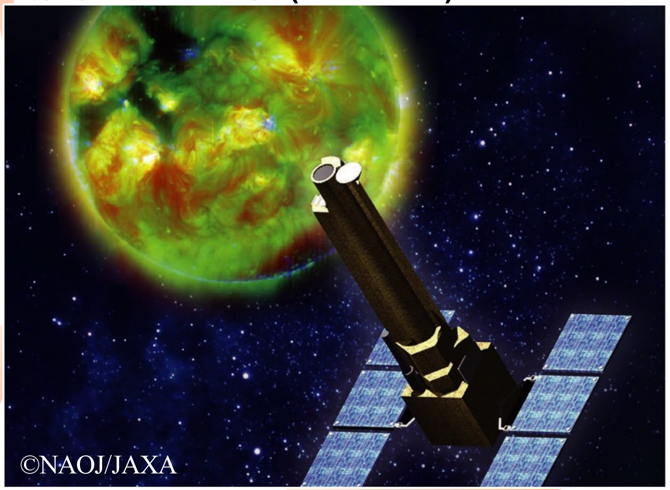


Space-based

HINODE (2006-)



SOLAR-C (2028-)



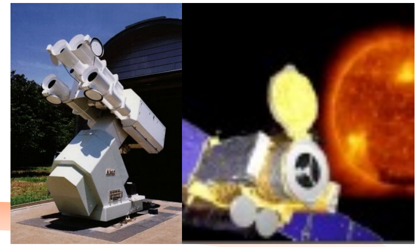
Ground-based

Mitaka GBO (Solar Flare Telescope)

Nobeyama Radio Polarimeter

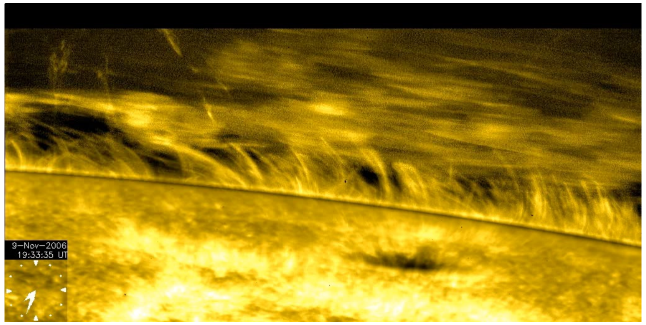
Rocket & balloon

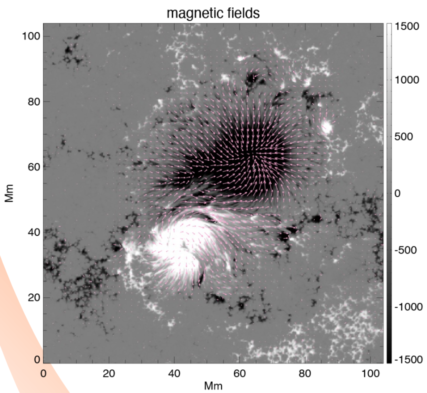
Scientific goals



Understand solar-stellar magnetic activity using the Sun as a template

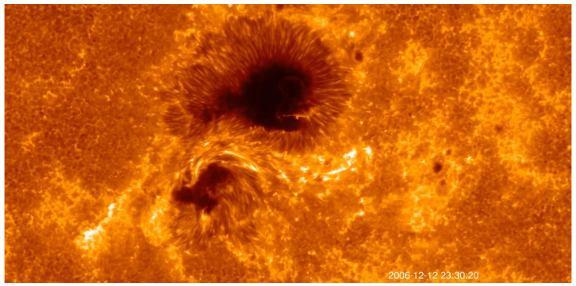
Creation of hot plasma around the Sun



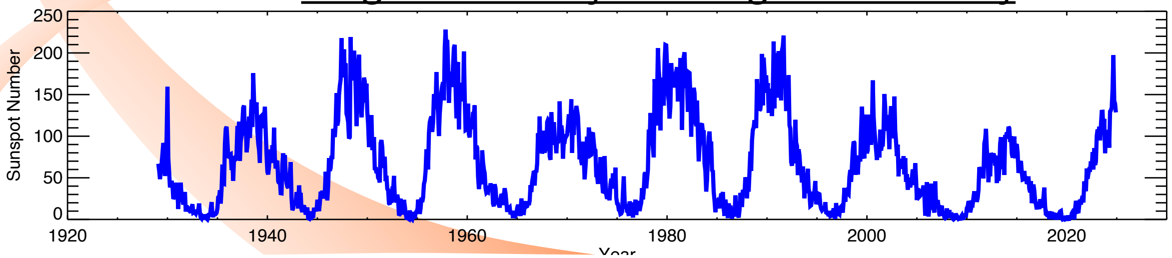


©NAOJ/JAXA

Flare/eruptions driven by magnetic fields

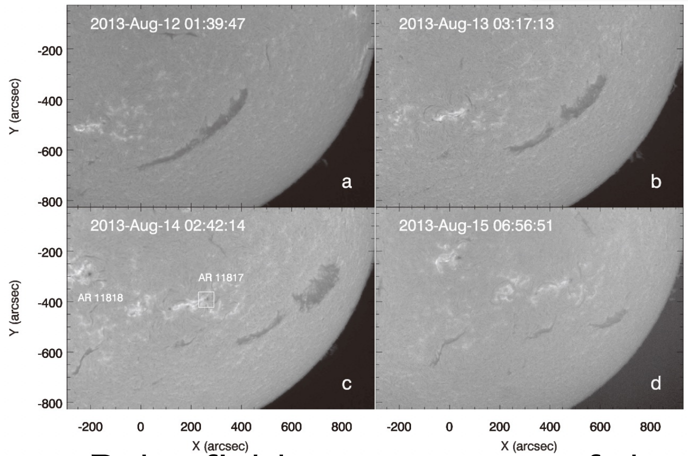


Origin of the cyclic magnetic activity



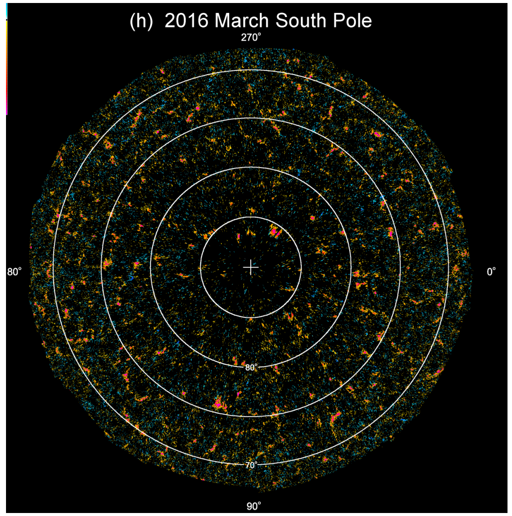
Understanding the solar activity that drives heliospheric and space-weather phenomena

Filament eruption and coronal mass ejection



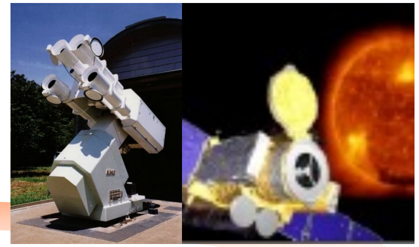
Joshi et al. (2016)

Polar fields as a source of the solar wind



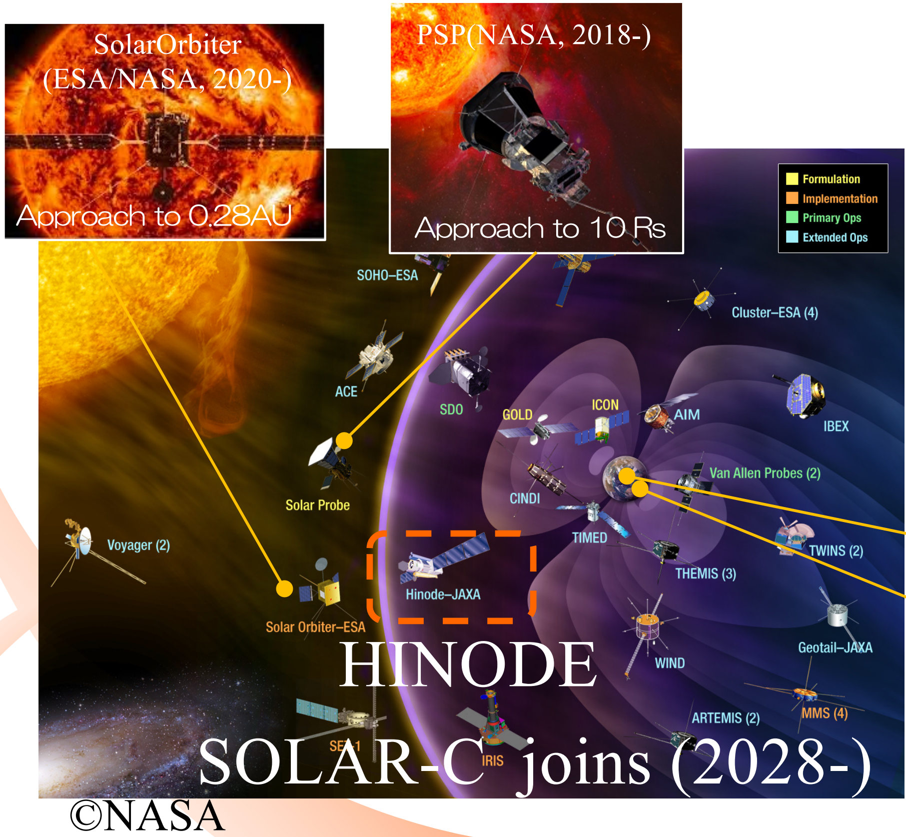
Shiota (2018)

Objectives of HINODE and Mitaka GBO

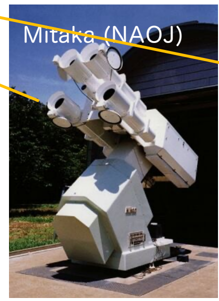


Both the telescopes are not new. But new observations become possible.

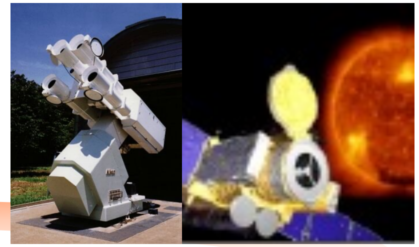
- Contribute to the understanding and prediction of space weather phenomena in the inner-heliosphere
  - Capturing short-term phenomena, such as flare activity, through chromospheric/coronal imaging and spectroscopy, and magnetic field observations.



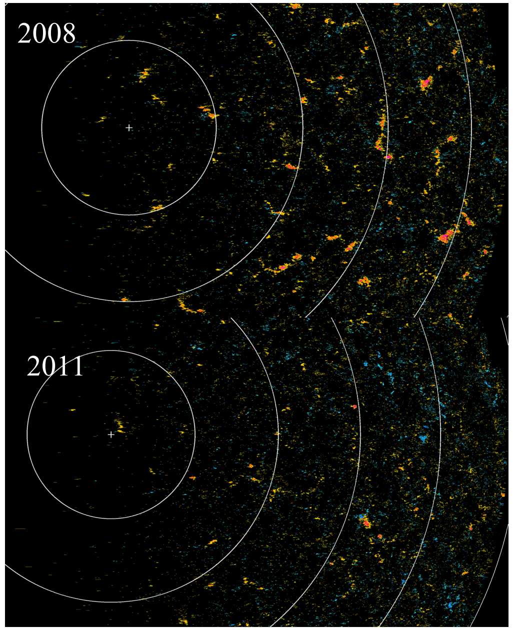
- Stereoscopic observations
- Flares and eruptions as a source of spaceweahter phenomena
- Abundance variation, etc.



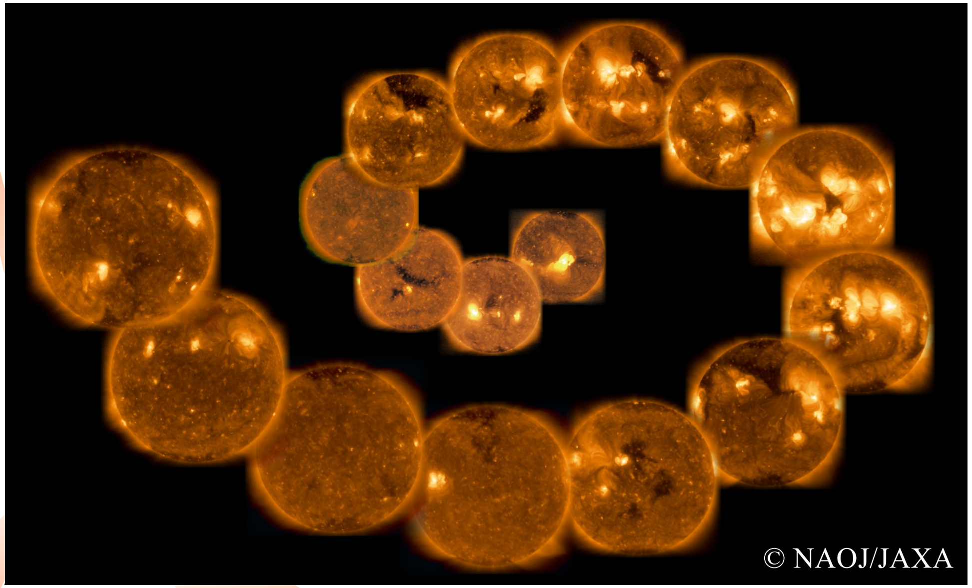
Objectives of HINODE and Mitaka GBO



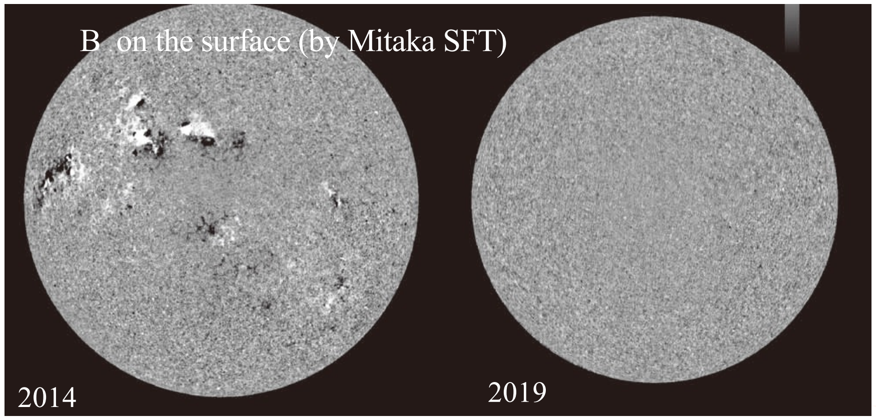
- Record the long-term evolution of solar activity from 10 to more than 100 years
  - Sunspot and surface magnetic field observations
  - Coronal and chromospheric imaging
- Provide essential information for
  - Variation of UV/X-ray irradiance
  - Dynamo mechanism



High res observation of the Sun's polar region
Shiota et al. (2012, 2018)

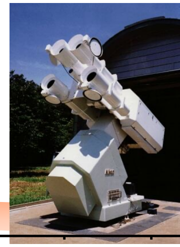


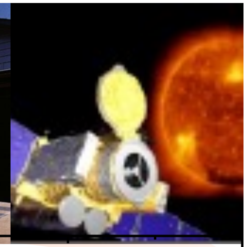
HINODE X-ray observation for 16 years

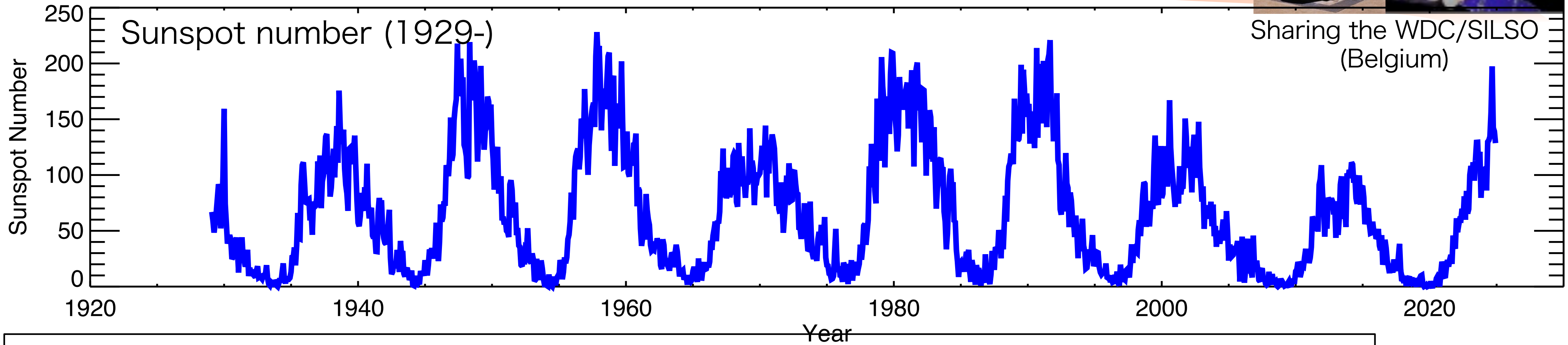


Hanaoka et al. (2020)

Long-term synoptic observation of the solar activity







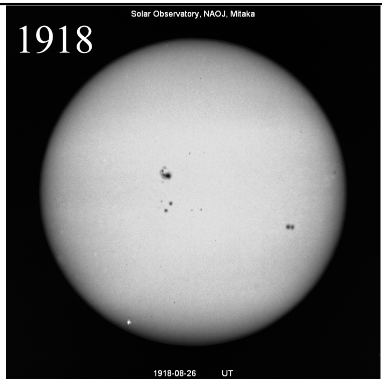
Maintaining unique data for the evolution of the activity cycle

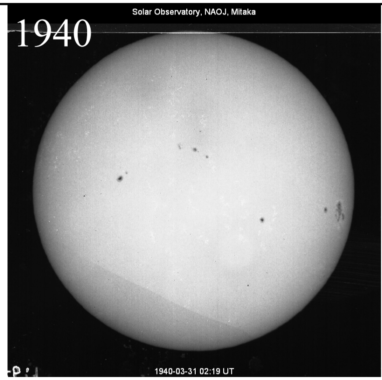
White light (1918-)

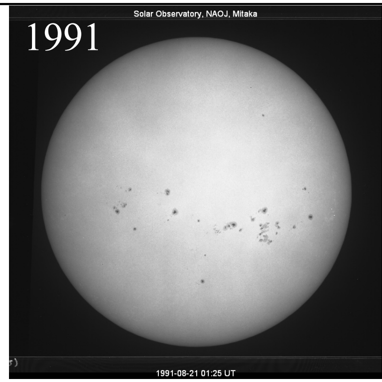
Sunspot sketch (1938-1998)

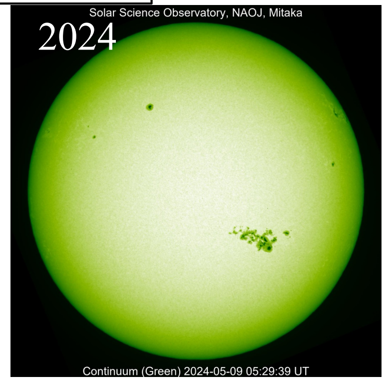
Ca II K line (1917-1974) (2015-)

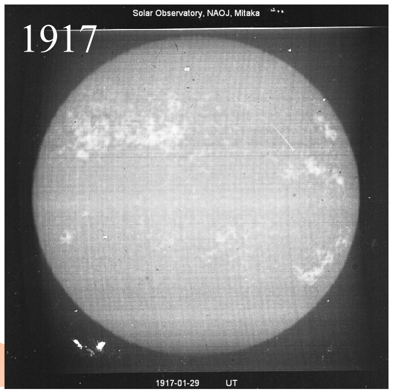
Hα line

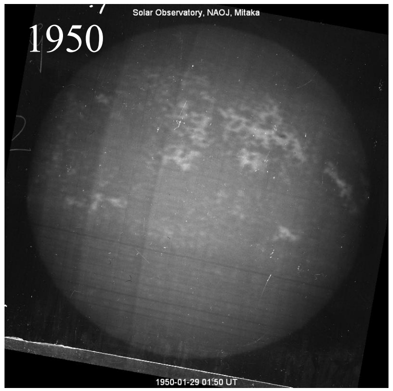


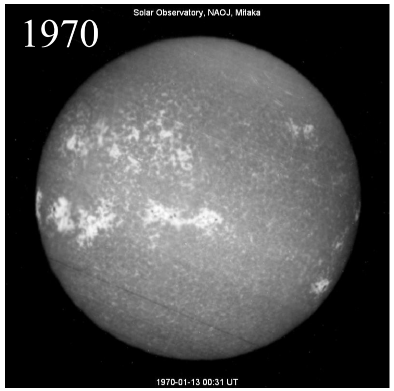


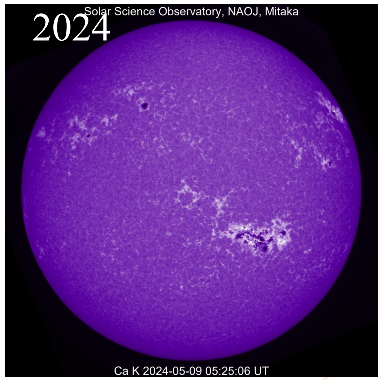




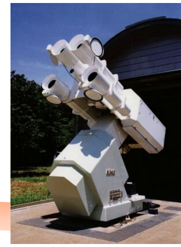


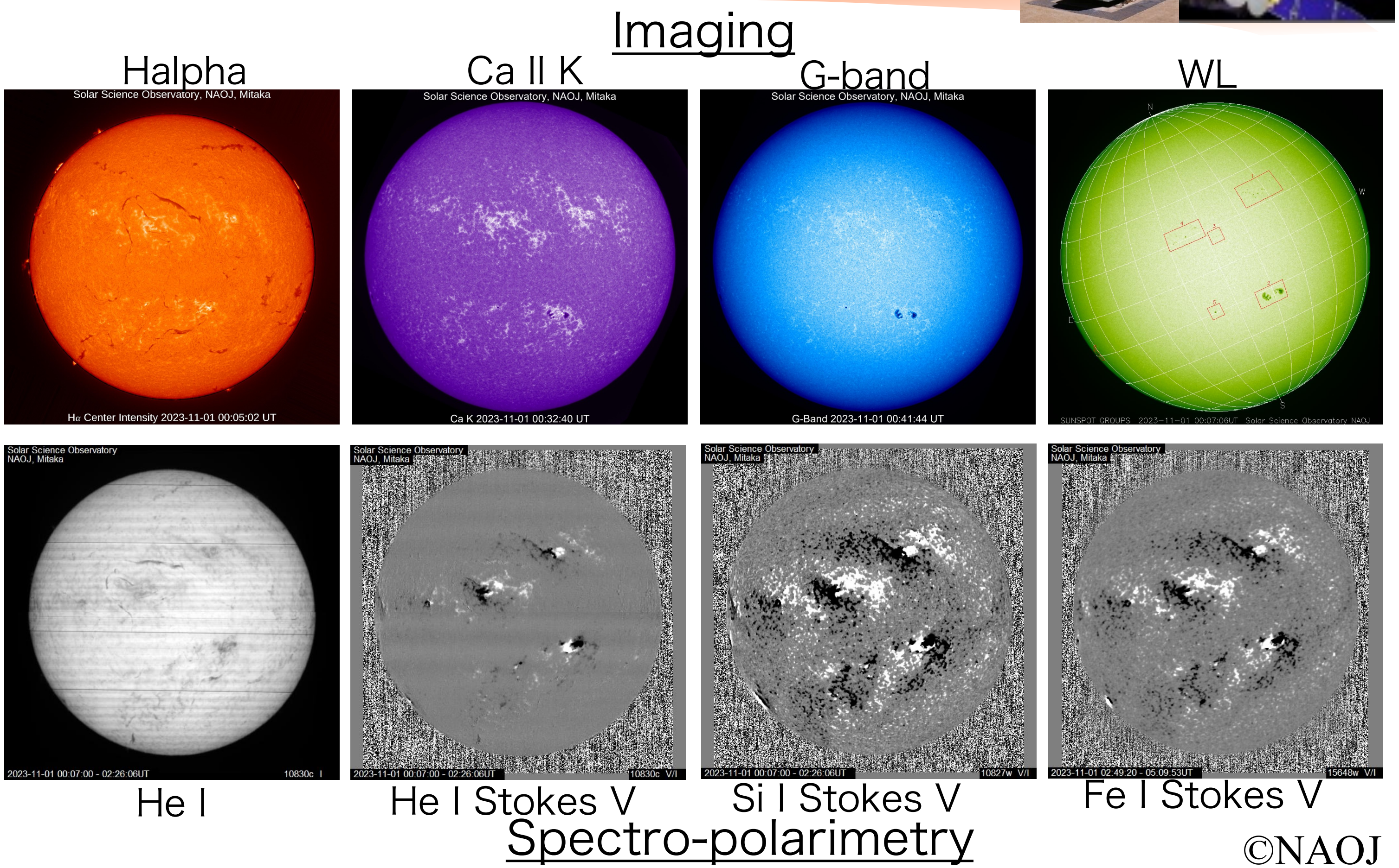






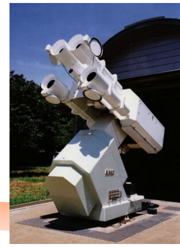
Mitaka ground-based observation



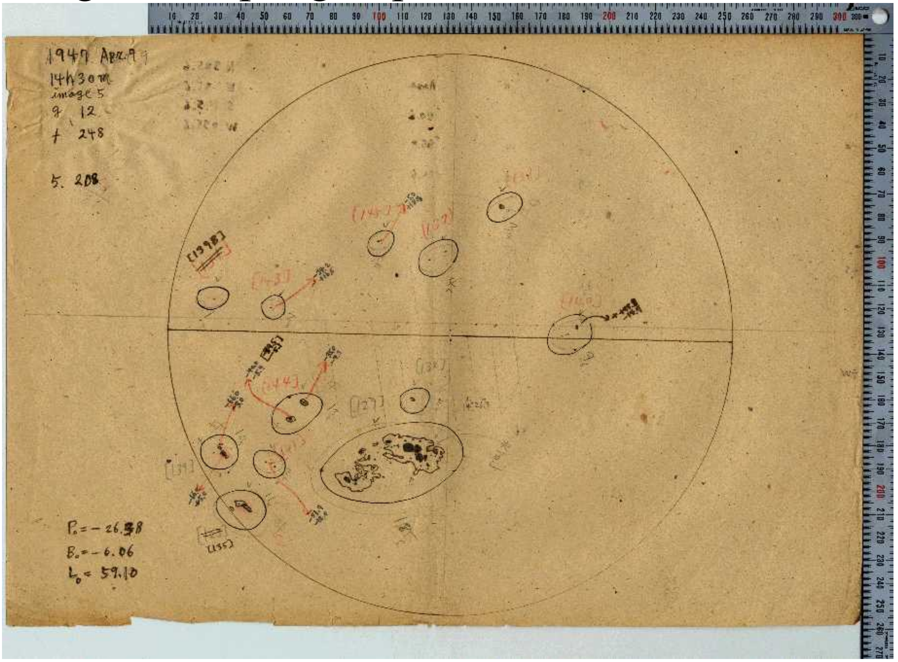


- Capture solar activity phenomena in the photosphere and chromosphere in intensities as well as magnetic and velocity fields via spectro-polarimetry.
  - Make data available to the community at ADC of NAOJ and Virtual Solar Observatory (VSO, maintained in US).
- Keep the current configuration at least until 2026-2027.
  - To cover the current solar maximum

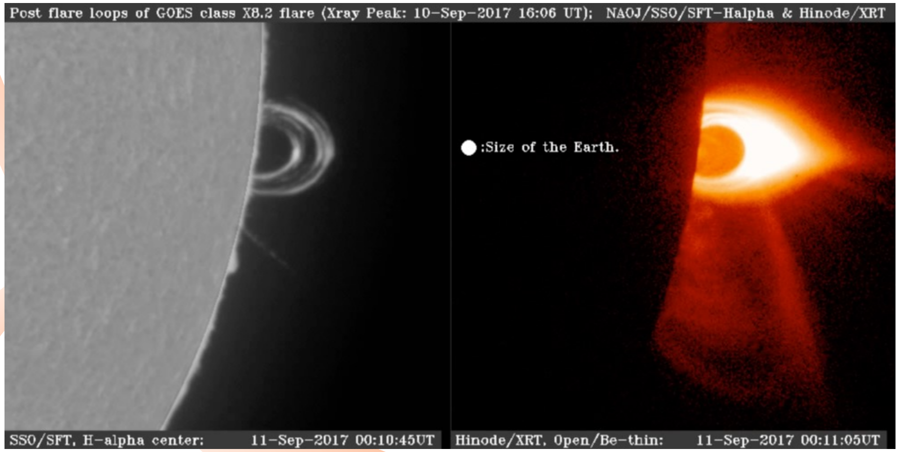
Capturing extreme events



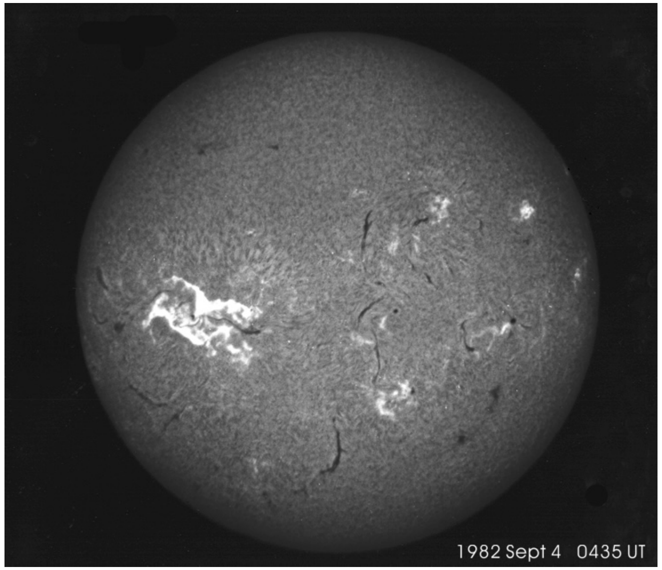

Largest sunspot group 1947/4/8 RGO14886



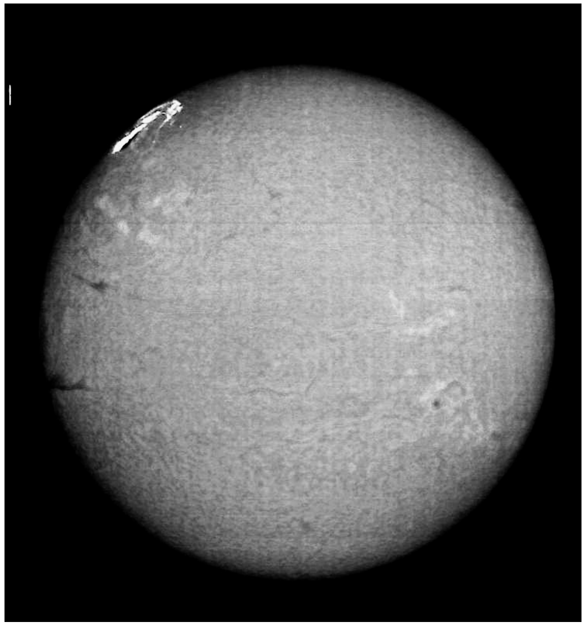
2017/9/10 X8 flare



1982/9/4
M4 flare &
filament eruption



1991/6/4
X12 flare



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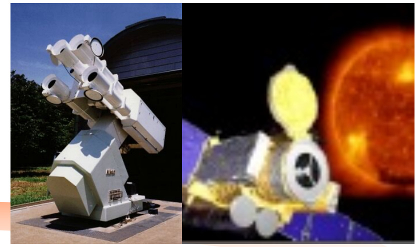
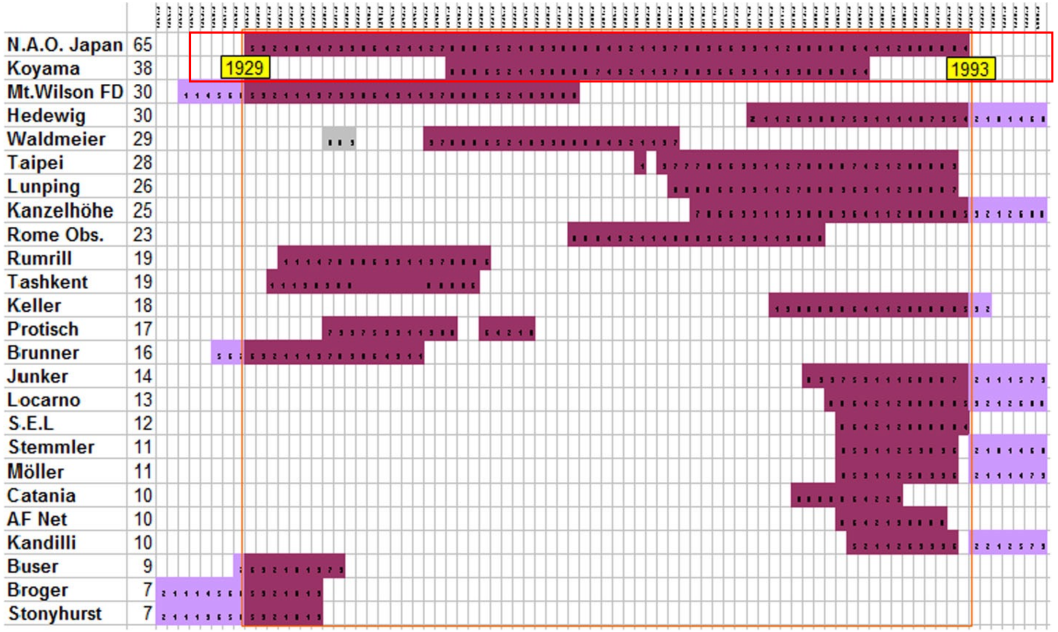
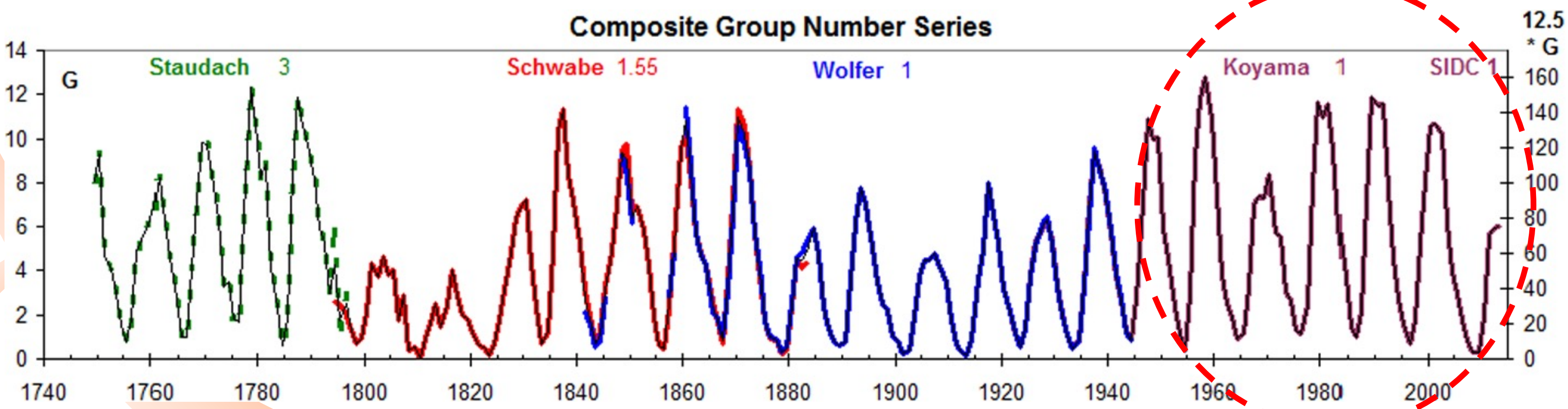
Importance of a long-term consistent observation



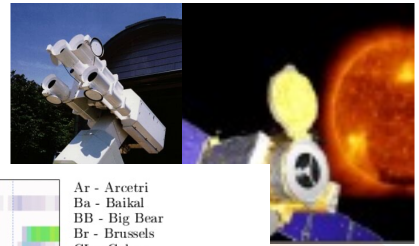
(Clette et al. 2014)



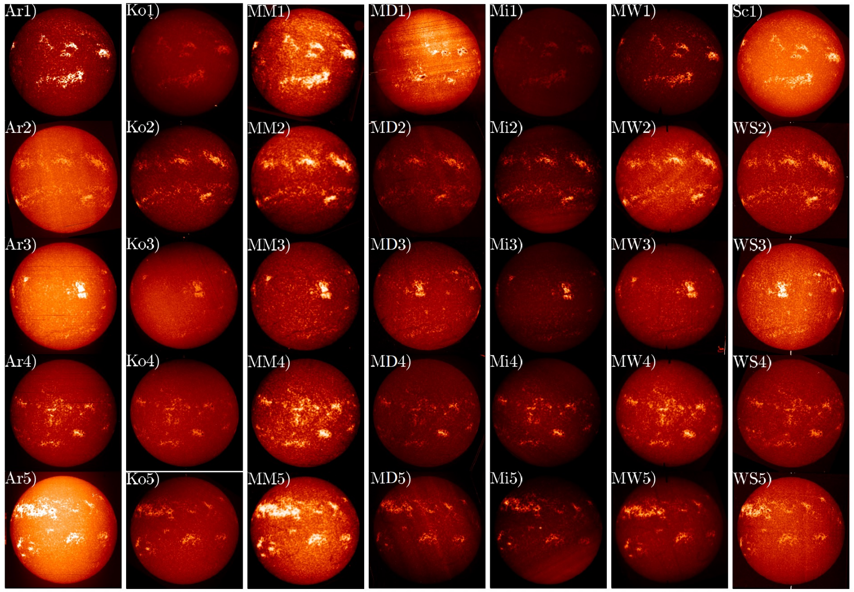
Observations at NAOJ and by Koyama (National Museum of Nature and Science) provided a strong backbone in establishing inter-calibration of the sunspot number in the 20th century.

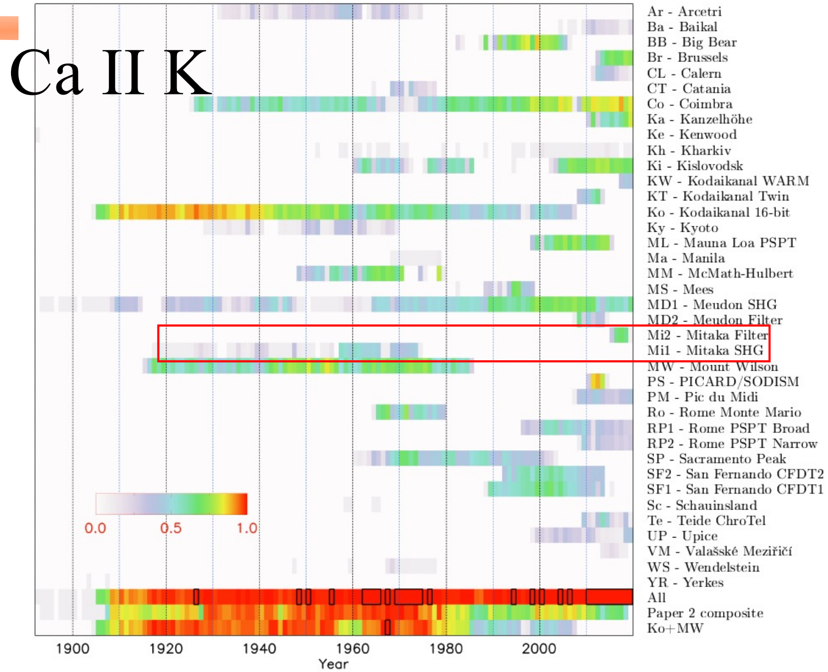


Long-term chromospheric imaging

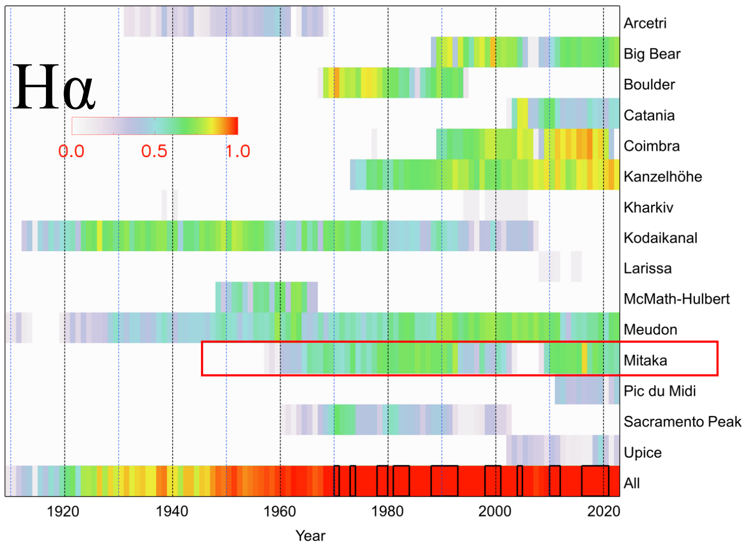


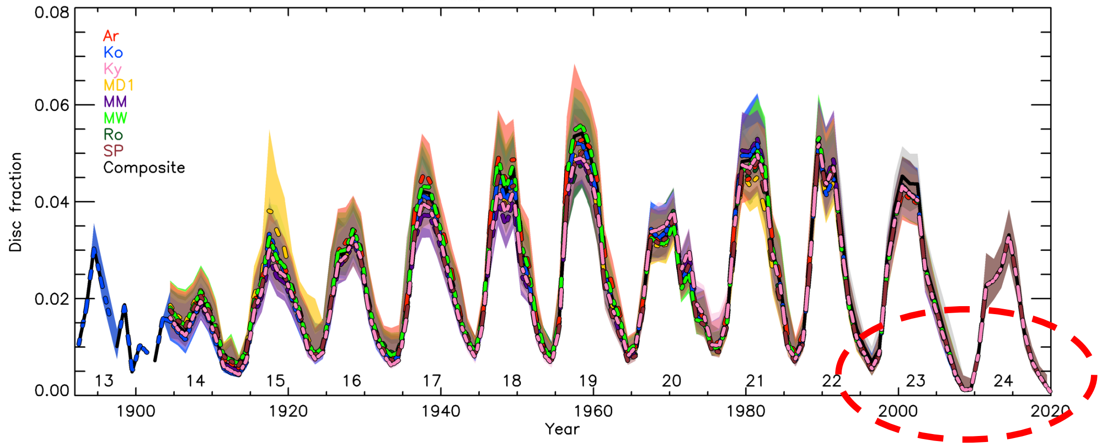
Chatzistergos et al. (2019, 2020)





Chatzistergos et al. (2023)

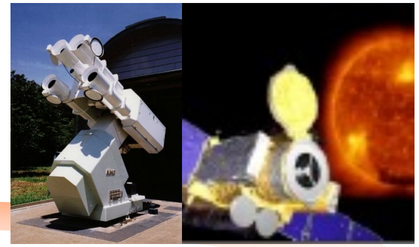




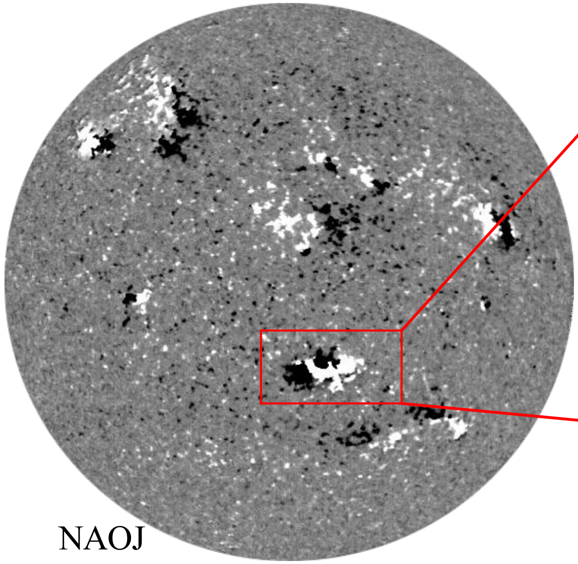
"Plage" area

- The sunspot number is sensitive to only strong magnetic fields
- Indicator of UV radiation

Surface magnetic fields of the Sun are the most fundamental observables by the



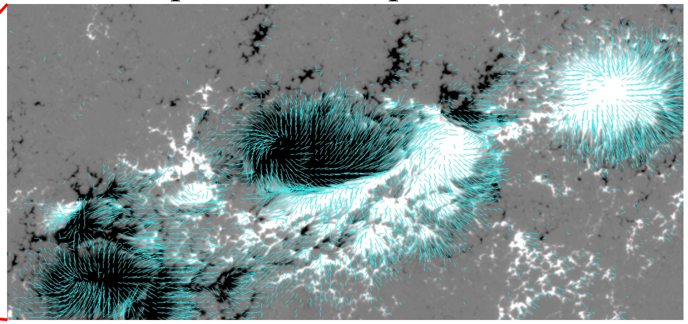
Spectro-polarimetric observation of the surface magnetic fields



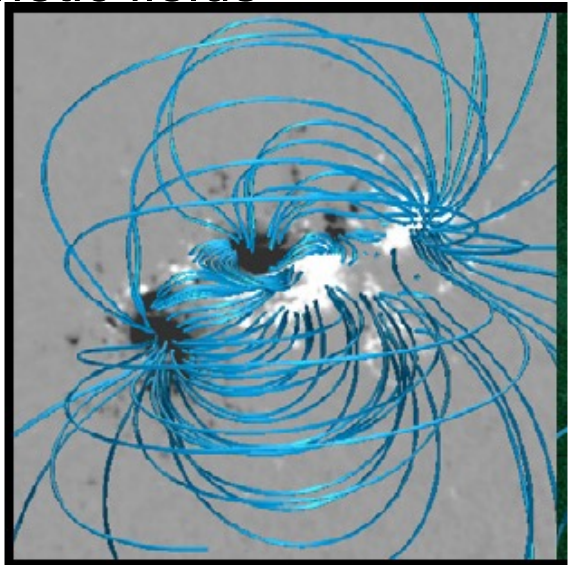
NAOJ
Solar Flare Telescope

HINODE satellite
Solar Optical Telescope

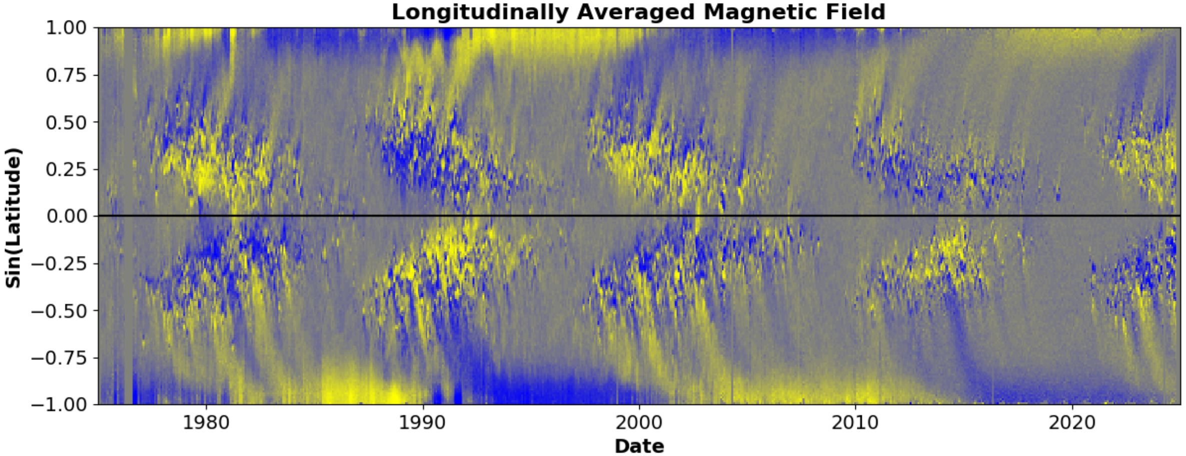
(C)NAOJ/JAXA



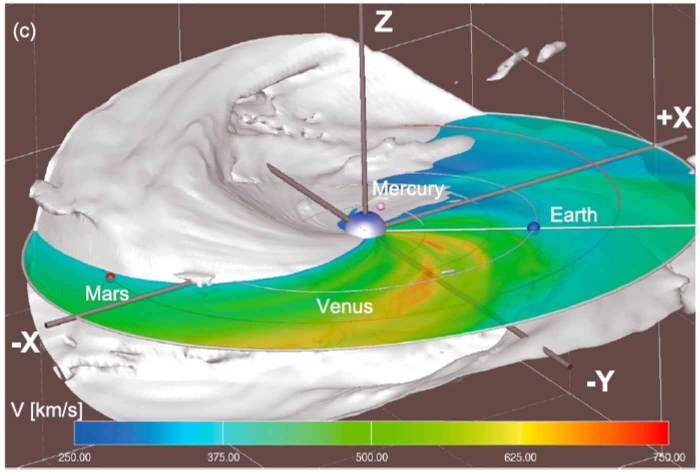
Polarizatiion angles and amplitudes (Stokes IQUV) provide magnetic field vector of the surface fields.



Coronal field estimation by non-Linear Force-Free Field (Inoue et al. 2014)

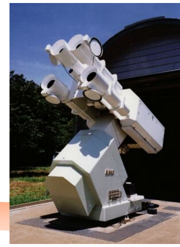


Magnetic field variation through the solar cycle (Hathaway et al.)



Solar wind model (Shiota et al. 2014)

Next generation international network observation: ngGONG



- In a single station observation, it is impossible to cover 24hrs and 365 days.
  - *60-70% operation duty in Mitaka, ~20% coverage*
- Synoptics observation is planned to be continued by an international network observation (ngGONG).

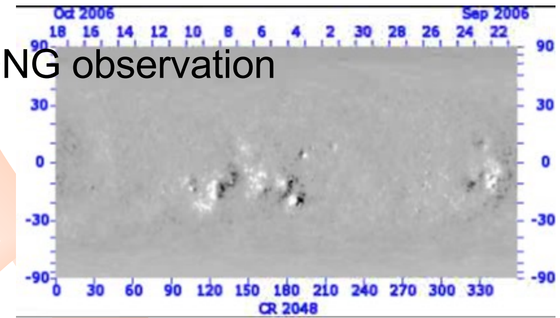
<ins>Key features</ins>

- Larger aperture (~50 cm):
  - Enhancing polarimetric sensitivity
- Multiple spectrum lines
  - Photosphere: Fe I 1.56 μm(g=3)
  - Chromosphere: He I 1.08 μm
  - Magnetic and velocity observations
  - Helioseismic observation of the internal structure

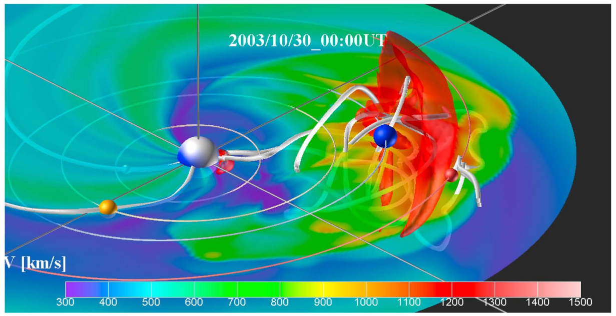
Mitaka SFT is a proto-type

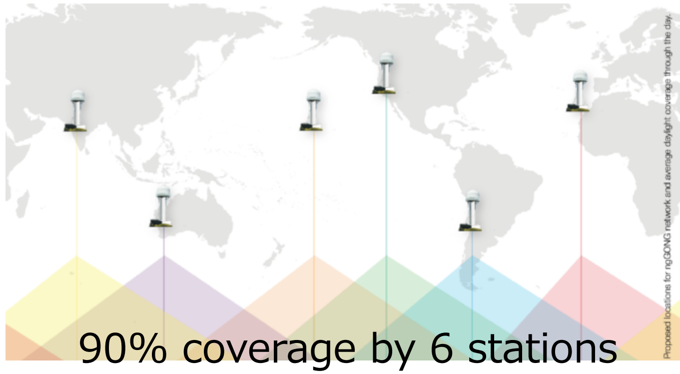
©NSO

ngGONG concept



GONG observation



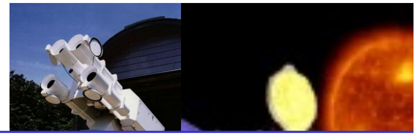


90% coverage by 6 stations

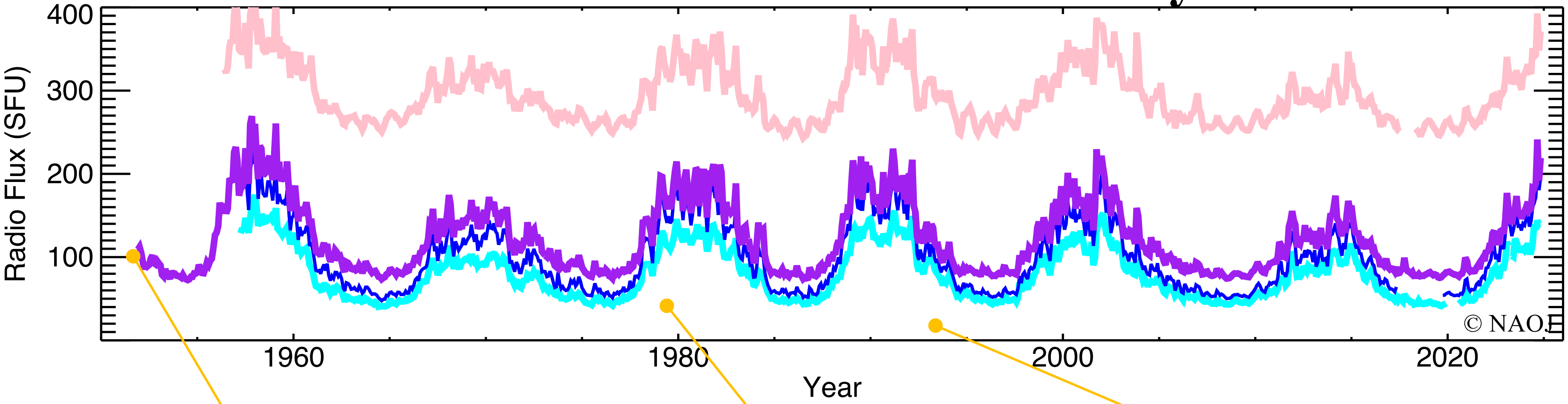
Contributed a WP for the Heliophysics Decadal Survey 2024.

- Way of contribution is under discussion.

Nobeyama Radio Polarimeters: NoRP



End of FY2027: Plan to terminate NoRP



1951: Started obs of radio flux at 3.75GHz in Toyokawa (Nagoya Univ.)

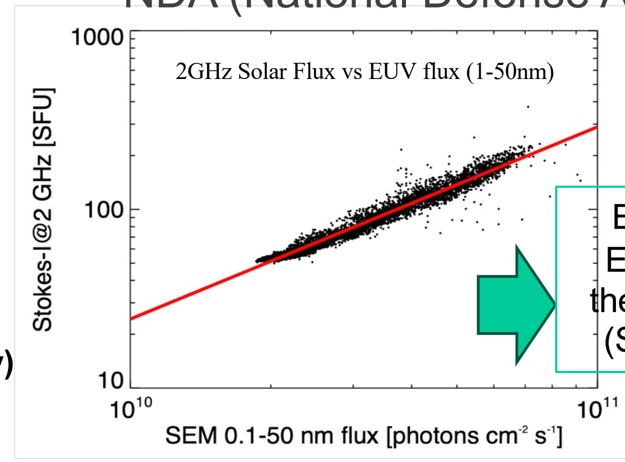
1978-1984: Started 17, 35, 80GHz in Nobeyama

1994: The antennas in Toyokawa were relocated to Nobeyama.

NoRP

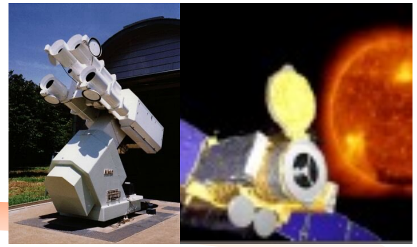
NDA(National Defense Academy) 1-10GHz Radio Flux Telescope
Constructed in FY2022-2023
Starting test observation in 2024

We plan to continue the radio flux obs at NDA (National Defense Academy).

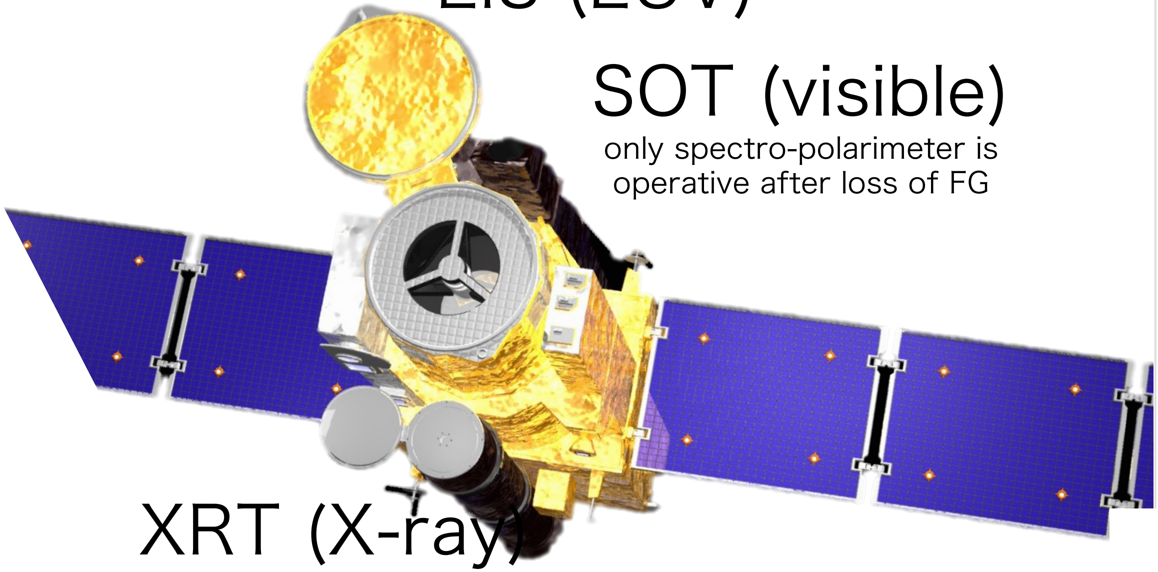


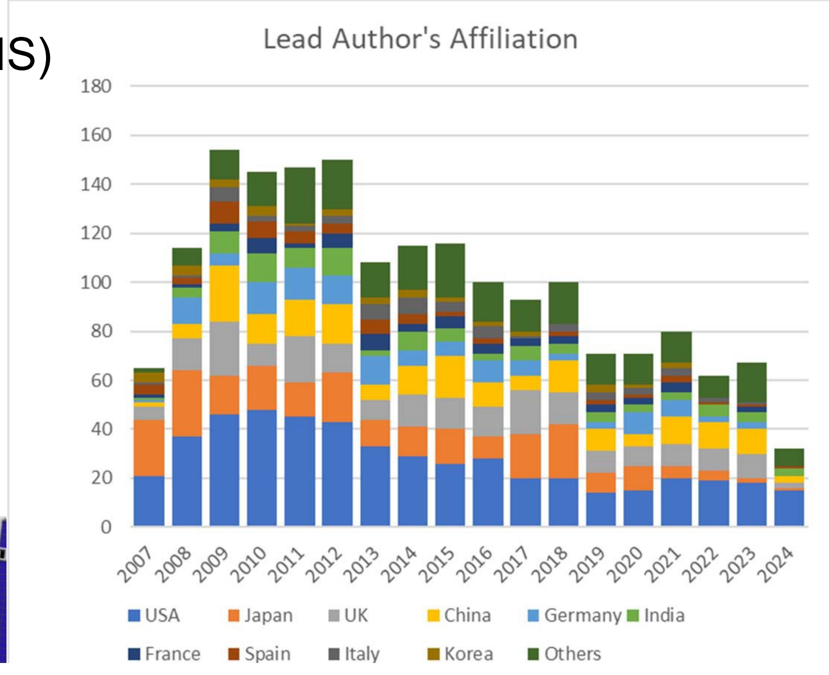
Estimation of stellar EUV flux from stellar thermal radio emission (Shimojo et al. 2024)

HINODE



- Operation since 2006.
- Equipped with the three telescopes (SOT, XRT, and EIS)





Number of refereed publications (2007-2024/7)

- By coordinating these observations by the 3 telescopes, we will obtain data that can be used for research connecting the solar photosphere and the corona.
- NAOJ's role
  - Contribution to the science operation, including maintenance of the HINODE website)
    - 60~80% contribution of chief observers and chief planners in Japan.
  - Joint op of the HINODE science center and collaborative research w/ ISEE, Nagoya U.
    - Publication of higher-order scientific data (polar magnetic fields, coronal magnetic fields, flare catalogue)
    - Matching Fund Project Assistant Professor for numerical modeling studies

HINODE Science Center @ISEE, Nagoya U.

Flare catalogue

Last updated: 2023-08-31

Hinode Flare Catalogue

Hinode is a Japanese misson developed and launched by ISAS/JAXA, with NAOJ as domestic partner and NASA and STFC (UK) as international partners.

Show 20 entries   Filter entries... (e.g. "x 2015")   « ‹ 1 2 3 4 5 … 1219 › »

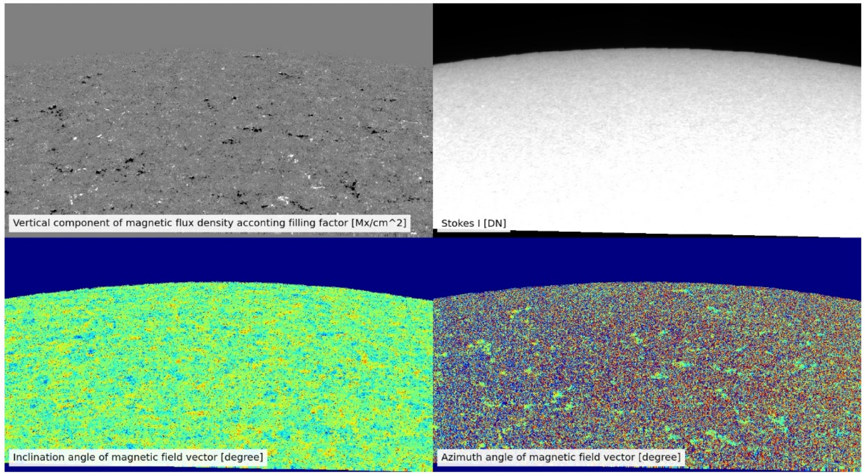
Event number	GOES			AR location	X-ray class	SOT		XRT	EIS	DARTS	RHESSI	Suzaku/WAM	NoRH
	start	peak	end			FG	SP						
243740	2023/07/31 22:52	2023/07/31 23:01	2023/07/31 23:13	S08W38	C5.7	0	0	55	0		no		
243730	2023/07/31 22:35	2023/07/31 22:47	2023/07/31 22:52	S09W38	C5.4	0	0	46	0		no		
243720	2023/07/31 15:04	2023/07/31 15:13	2023/07/31 15:22	N10W01	C2.7	0	0	26	0		no		
243710	2023/07/31 11:36	2023/07/31 11:41	2023/07/31 11:47	N10W00	C3.0	0	1	23	0		no		
243700	2023/07/31 08:42	2023/07/31 09:00	2023/07/31 09:13	S20E44	M1.6	0	0	4	0		no		
243690	2023/07/31 07:15	2023/07/31 07:23	2023/07/31 07:28	S10W26	C4.6	0	0	0	1		no		
243680	2023/07/31 04:34	2023/07/31 04:47	2023/07/31 05:00	S18E45	C6.8	0	0	70	0		no		
243670	2023/07/31 03:12	2023/07/31 03:17	2023/07/31 03:22	S20E48	C1.8	0	0	22	0		no		
243660	2023/07/30 22:17	2023/07/30 22:21	2023/07/30 22:30	S09W26	C1.7	0	0	49	0		no		
243650	2023/07/30 13:07	2023/07/30 13:16	2023/07/30 13:20	S11W20	C4.0	0	4	0	0		no		
243640	2023/07/30 08:18	2023/07/30 08:22	2023/07/30 08:26	S20E58	M1.8	0	0	0	0		no		
243630	2023/07/30 08:01	2023/07/30 08:14	2023/07/30 08:18	S16E55	M1.8	0	0	0	0		no		
243620	2023/07/30 04:53	2023/07/30 04:56	2023/07/30 05:00	N16W55	C6.4	0	0	0	0		no		
243610	2023/07/30 04:32	2023/07/30 04:46	2023/07/30 04:53	N16W56	C5.6	0	0	8	0		no		
243600	2023/07/29 23:23	2023/07/29 23:40	2023/07/29 23:56	N14W58	C4.9	0	0	68	0		no		
243590	2023/07/29 20:02	2023/07/29 20:10	2023/07/29 20:16	N09E21	C2.8	0	0	30	0		no		
243580	2023/07/29 16:11	2023/07/29 16:24	2023/07/29 16:37	S11W08	M1.4	0	6	76	0		no		
243570	2023/07/29 13:10	2023/07/29 13:20	2023/07/29 13:25	S09W08	C5.5	0	0	75	0		no		
243560	2023/07/29 10:18	2023/07/29 10:36	2023/07/29 10:52	S18E68	C9.2	0	0	116	0		no		
243550	2023/07/29 06:55	2023/07/29 07:34	2023/07/29 08:12	N14E88	C6.7	0	0	64	0		no		

Showing 1 - 20 of 24,373 entries

- The DOI of this catalogue is '10.34515/CATALOG.HINODE-00000'.
- This catalogue is developed and maintained by S. Masuda, K. Watanabe, T. Minoshima, H. Tonooka, Y. Miyamoto and T. Segawa.
  Reference:Watanabe, K., S. Masuda, and T. Segawa, Hinode Flare Catalogue, Solar Physics, 279, 317-322, 2012.

The scheme will continue for SOLAR-C.

Database for Hinode SOT Polar Magnetic Field



Data description

This database is a collection of vector magnetic field maps of the solar polar regions based on the Stokes spectral profiles of Fe I 630.15 nm and 630.25 nm observed by the Solar Optical Telescope onboard the Hinode satellite. The Stokes inversion was processed by the Milne-Eddington inversion code MILOS (Orozco Suárez & del Toro Iniesta, 2007), and the 180° ambiguity was resolved by the method of Ito et al. (2010). The drift of the slit position was carefully removed (Shiota et al. in prep.). For more details and analysis, please refer to Shiota et al. (2012).

Terms of Use

When you publish a work using this database, please acknowledge the publisher and cite the related articles as follows.

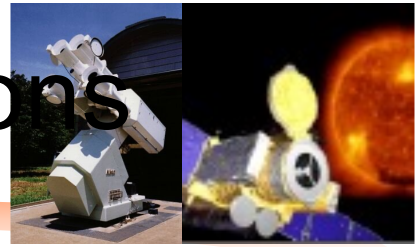
Example of acknowledgments

Hinode is a Japanese mission developed and launched by ISAS/JAXA, with NAOJ as domestic partner and NASA and STFC (UK) as international partners. It is operated by these agencies in co-operation with ESA and NSC (Norway). ISEE Database for Hinode SOT Polar Magnetic Field (doi: 10.34515/DATA_HSC-00001) was developed by the Hinode Science Center, Institute for Space-Earth Environmental Research (ISEE), Nagoya University.

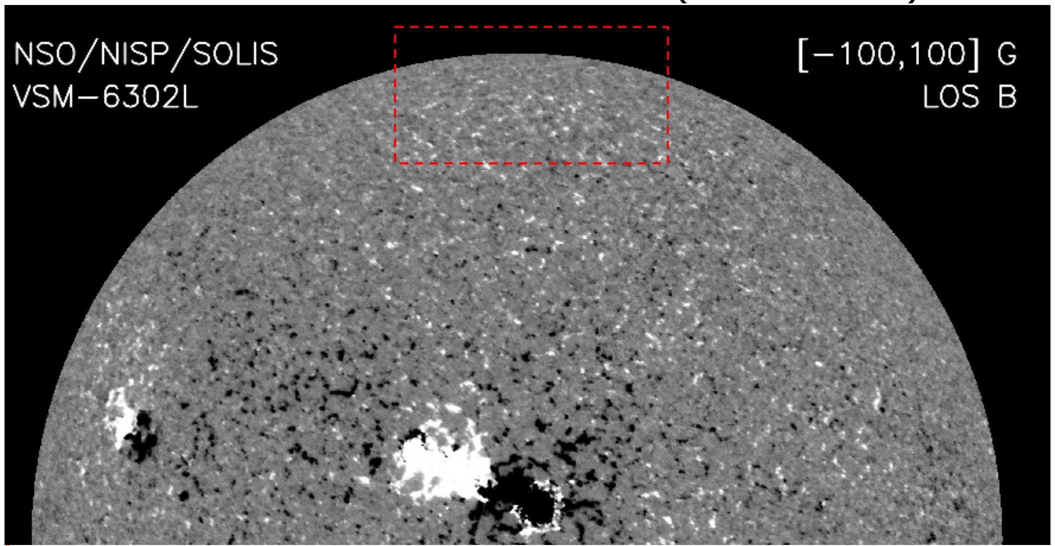
Data DOI

- D. Shiota, M. Shimojo, M. Kubo, Y. Katsukawa, H. Iijima, S. Imada, and S. Masuda, "ISEE Database for Hinode SOT Polar Magnetic Field," Hinode Science Center, Institute for Space-Earth Environmental Research, Nagoya University, 2021.
  doi: 10.34515/DATA.HSC-00001

HINODE SP polar field observations

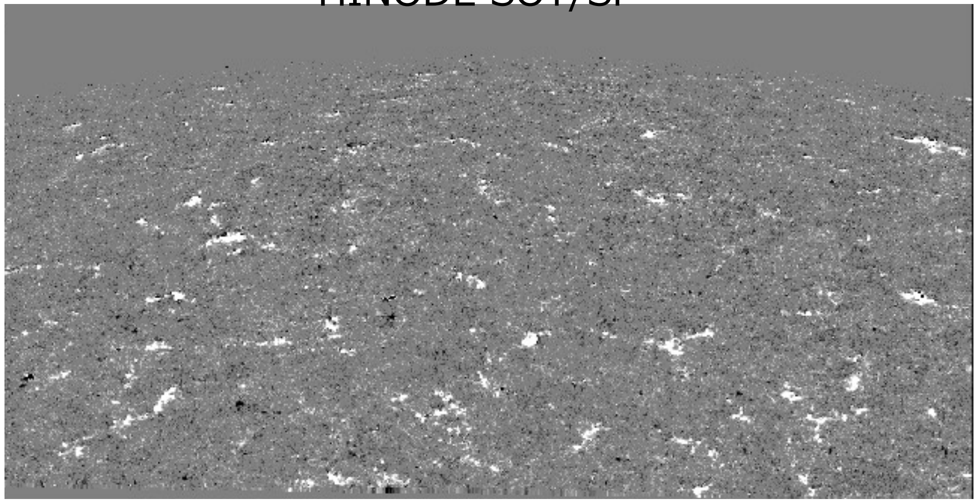


Ground-based observation (SOLIS VSM)

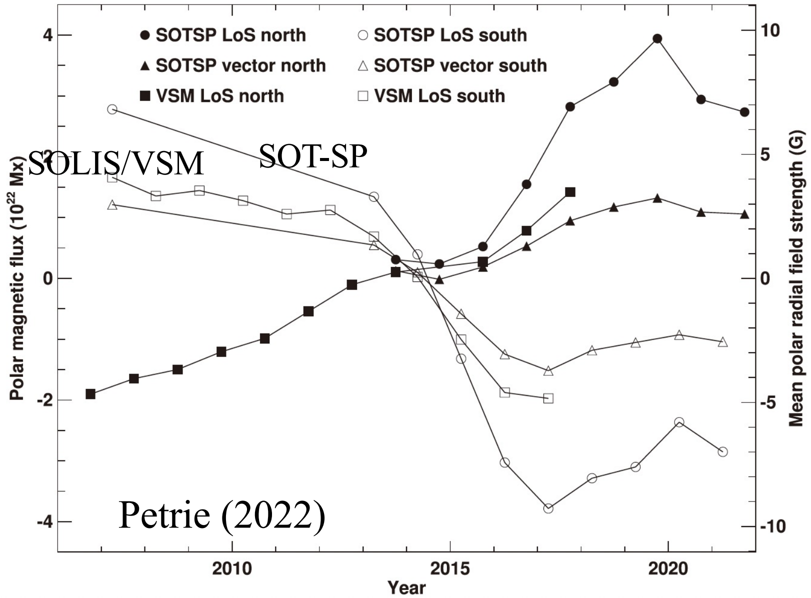


HINODE SOT/SP

©NAOJ/JAXA



Unique capability of high resolution and stable polarimetric accuracy.

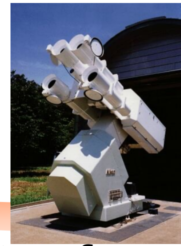


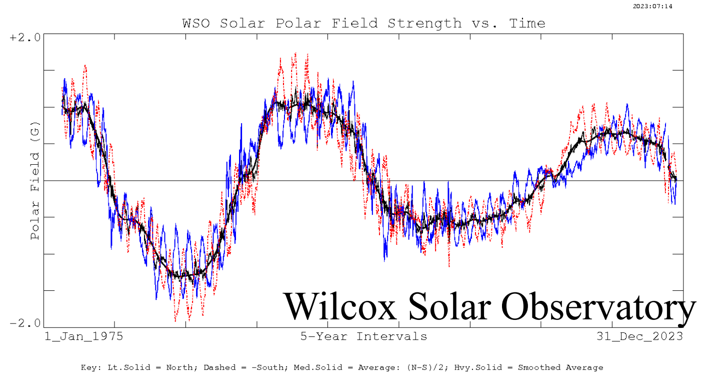
There are still debates on the determination of the polar flux.

"Open flux problem"

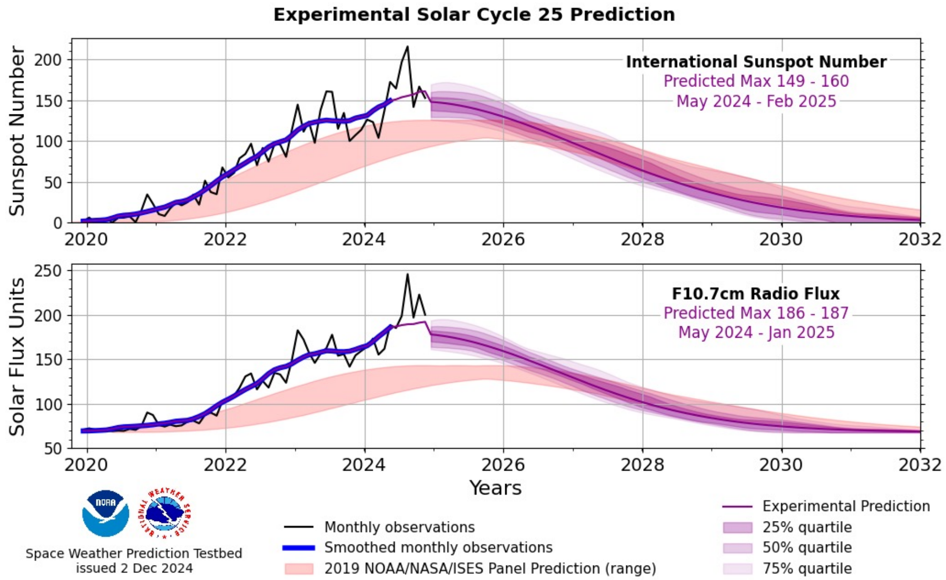
The measured magnetic flux at 1AU is smaller than the extrapolated field from the solar surface (factor of 2 or more).

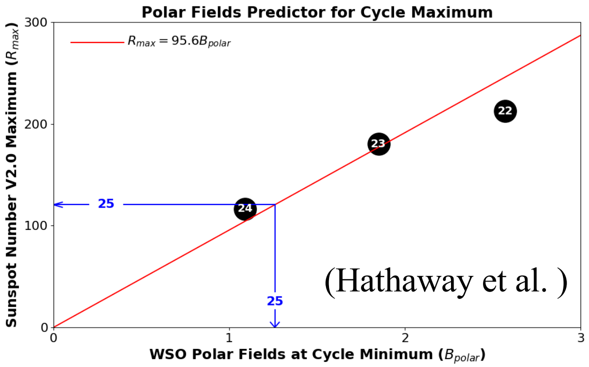
Importance of the polar fields





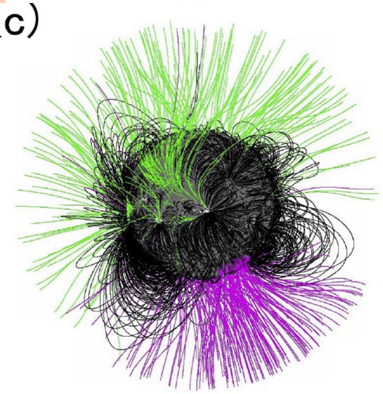
Thought to be a good indicator for predicting the next cycle, but….



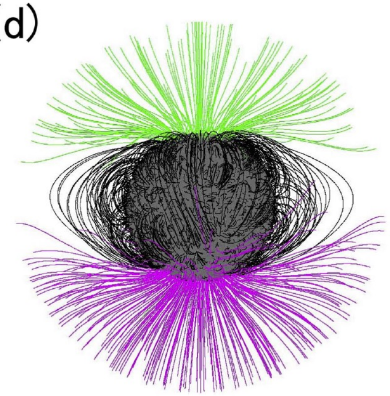


The polar coronal hole is a source of the fast solar wind.

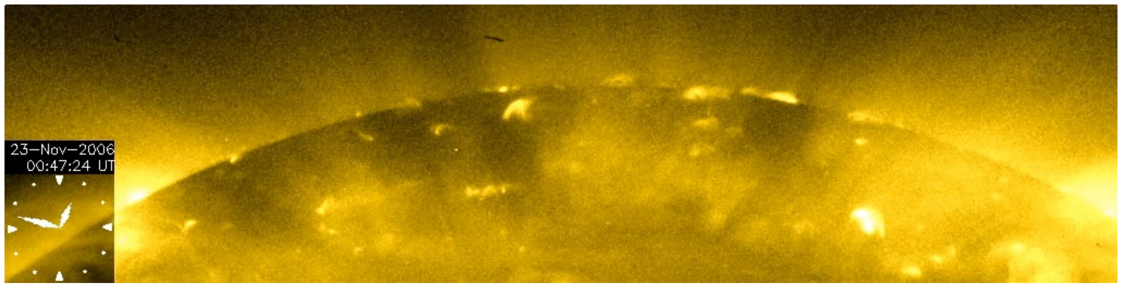
(c)



(d)



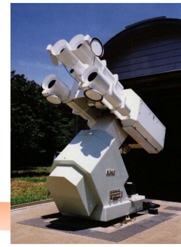
(Yoshida et al. 2023)



(Shimojo et al. 2007)

Coordination with the Solar Orbiter for tracing jets from the coronal hole to the inner heliosphere.

Operation strategies of HINODE



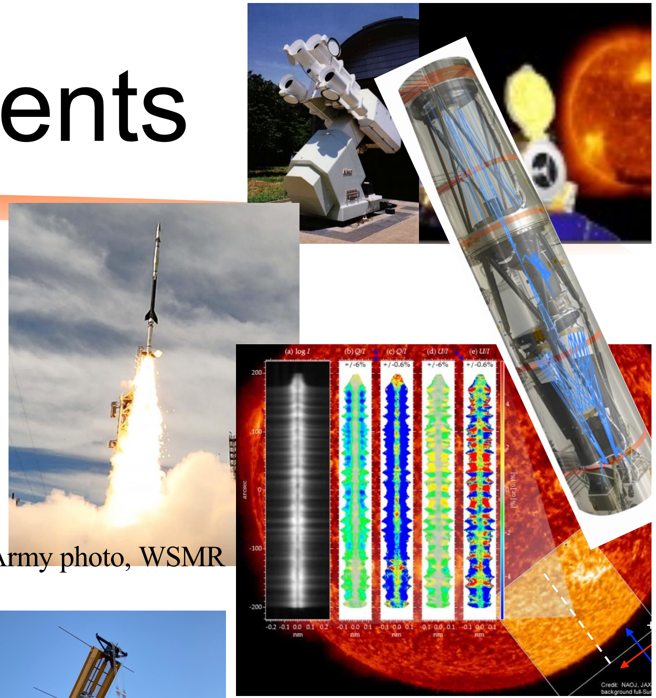

- HINODE (SOLAR-B) Project Team has been moved to extended operation team at ISAS level.
  - SOLAR-C Project Team at JAXA level.

<u>Extension until FY2033</u>

- Until SOLAR-C (~2028)
  - Highly active Study photosphere-chromosphere-corona coupling by conducting high-resolution joint observations with ALMA (radio observations) and ground-based telescope DKIST etc. (visible-infrared observations).
  - Cooperative observation studies with instruments in the inner heliosphere and the Earth's magnetosphere (PSP, Solar Orbiter, Mio, AKATSUKI, Arase, PUNCH, etc.)
- 1 yr after SOLAR-C
  - Cross-calibration between HINODE/EIS and SOLAR-C
- Until FY2033
  - Polar magnetic field obs. with SOT/SP, especially to cover the next solar minimum
  - Full-Sun imaging (CME watch etc.) with XRT

Rocket and balloon experiments

- CLASP (2015), 2(2019), 2.1 (2021) rocket
  - US spectro-polarimetry (w/ NASA)
  - CLASP1: Lyα (121 nm), CLASP2/2.1: Mg II (280nm)
  - Obtained height dependent magnetic fields

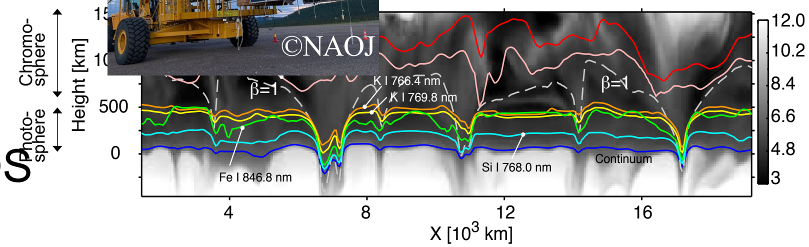


©US Army photo, WSMR

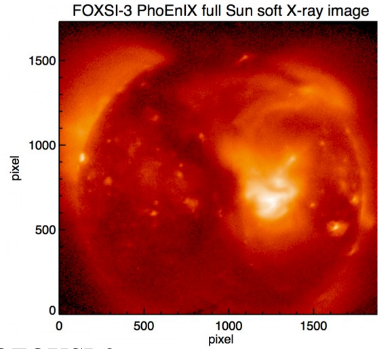
©NAOJ/JAXA, NASA/MSFC

- SUNRISE-3 (2022->2024) balloon
  - UV-Vis-NIR high resolution spectro-polarimetry (w/ MPS, Spain, APL, NASA)
  - Flight in July 2022, reflight in June 2024!!

©NAOJ



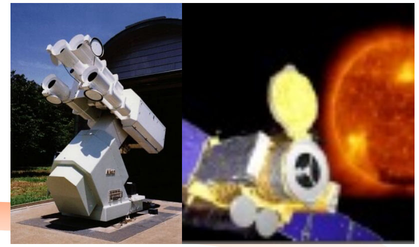
- FOXSI-3 (2018) / 4 (2024) / 5 (2025-) rocket
  - X-ray imaging spectroscopy by the high-speed CMOS camera
  - Launched in 2024, successfully captured a flare!!



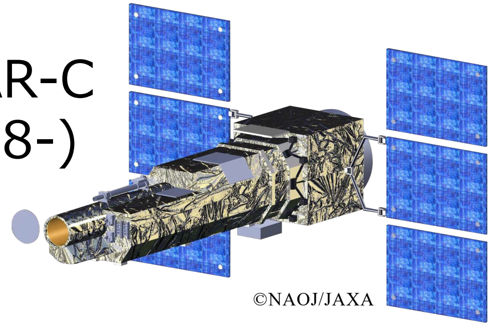
©FOXSI-3 team

External funding (KAKENHI + ISAS/JAXA)

Knowledge transfer for development of space instruments



SOLAR-C
(2028-)



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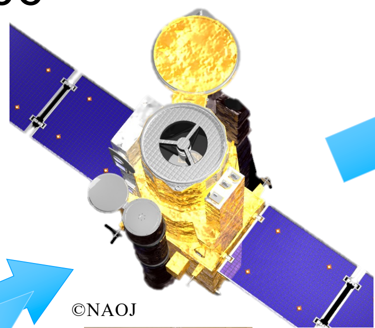
HINODE (SOLAR-B)
2006-



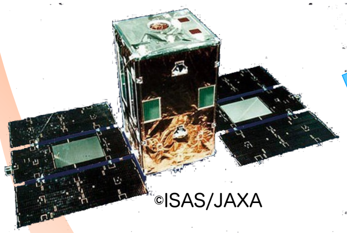
©NAOJ

Balloon (NASA)

©MPS

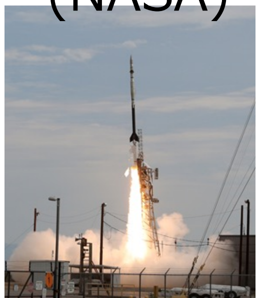
Sunrise III (2022->2024)
UV-Vis-IR polarimetry

Yohkoh (SOLAR-A)
1991-



©ISAS/JAXA

Sounding rocket
(NASA)



©NASA/MSFC

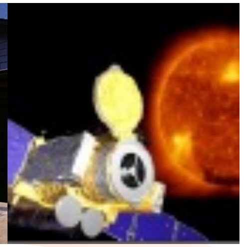
XUV Doppler Telescope
(ISAS/JAXA rocket, 1998)
(Sakao et al. 1999)

HXR spectrum
(ISAS/JAXA balloon, 2002)
(Kobayashi et al. 2008)

CLASP (2015/2019/2021): UV polarimetry
FOXSI (2018/2024): X-ray imaging-spectroscopy

3

Rocket and balloon experiments at NAOJ ATC

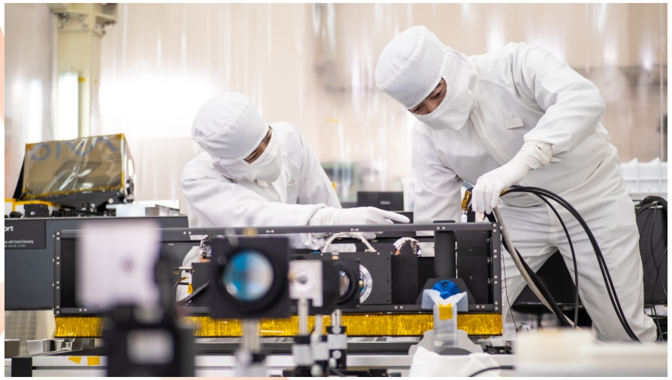


Development of advanced technology and human resources (young researchers and engineers) for next-generation space-based observations

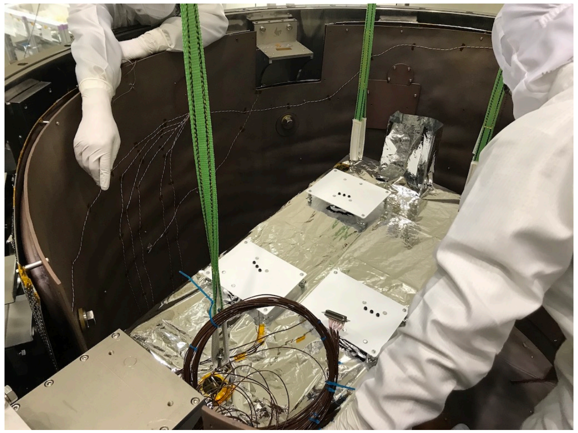
Assembly of the optical components

Optical alignment of the telescope

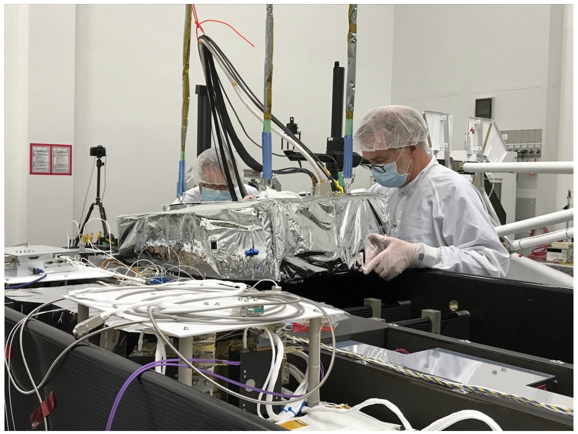
Vibration test @ ISAS



Integration of the focal plane instrument

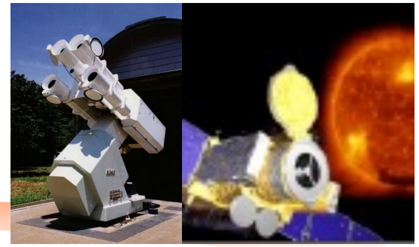


Thermal vacuum test



International development of the instruments

Project organization



NAOJ DG

NAOJ SOLAR-C Project
Chief: Hara

Strategic development for SOLAR-C and beyond

Kubo, Okamoto
Kawabata, Shinoda,
Mitsutake
Suzuki
Katsukawa, Ishikawa,
Narukage, Tei

ATC
Narukage

ADC
Shimojo, Nishida

SOL project

Rocket and balloon

CLASP2/2.1
Ishikawa, Okamoto

SUNRISE-3
Katsukawa, Kubo, Hara,
Kawabata, Matsumoto
2022->2024

FOXSI-3/4/5
Narukage
2024, 2025(TBD)

HINODE

management
Katsukawa

Operation

SOT
Katsukawa, Sekii,
Ishikawa, Kubo, Okamoto
Kawabata, Oba

XRT
Narukage, Shimojo

EIS
Hara, Itami, Tei

Management
Katsukawa

Admin
Hara (Y)

PO
Yonetani

Mitaka GBO
Hanaoka
Shinoda
Nishida, Yonetani

NoRP
Shimojo,
Shinohara

Support by NRO

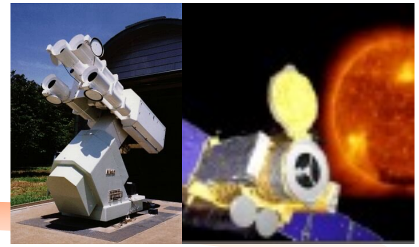
data verification
w/ community

Collaboration

Hinode Scienece Center
@Nagoya ISEE
(database, simulation)
Matsumoto

Blue: SOLAR-C pro
Green: Grad. Education Office
Orange: ALMA
Purple: Nagoya U.

Why Japan and NAOJ?



NAOJ's role

- Acquire observational data and provide them for space weather modeling and forecast (w/ Nagoya U., NICT)
  - Less cost because of the existing telescopes
  - Knowledge for long-term observation and maintenance of consistent data
- Make data public at ADC and new developments at ATC
- Central role in involving the community in Japan, as an inter-university research institute.
  - NoRP data verification, HINODE operation

Why in Japan?

- The Sun is a unique and varying object.
  - Large major events have to be observed when it happens. The Carrington-class flare may happen for a few decades.
  - Grand Minimum (e.g. Maunder minimum) may come in the future.
- Problematic when satellite observations are lost.
  - It happened last week in SDO, because of flooding of the data center.
- Geographically distant from the US and Europe
  - Flare capture rate by the Mitaka telescope is ~20%. (clear days~70%, 1/3 per day)
- Cross-calibration is important for activity indices.

Solar projects timeline