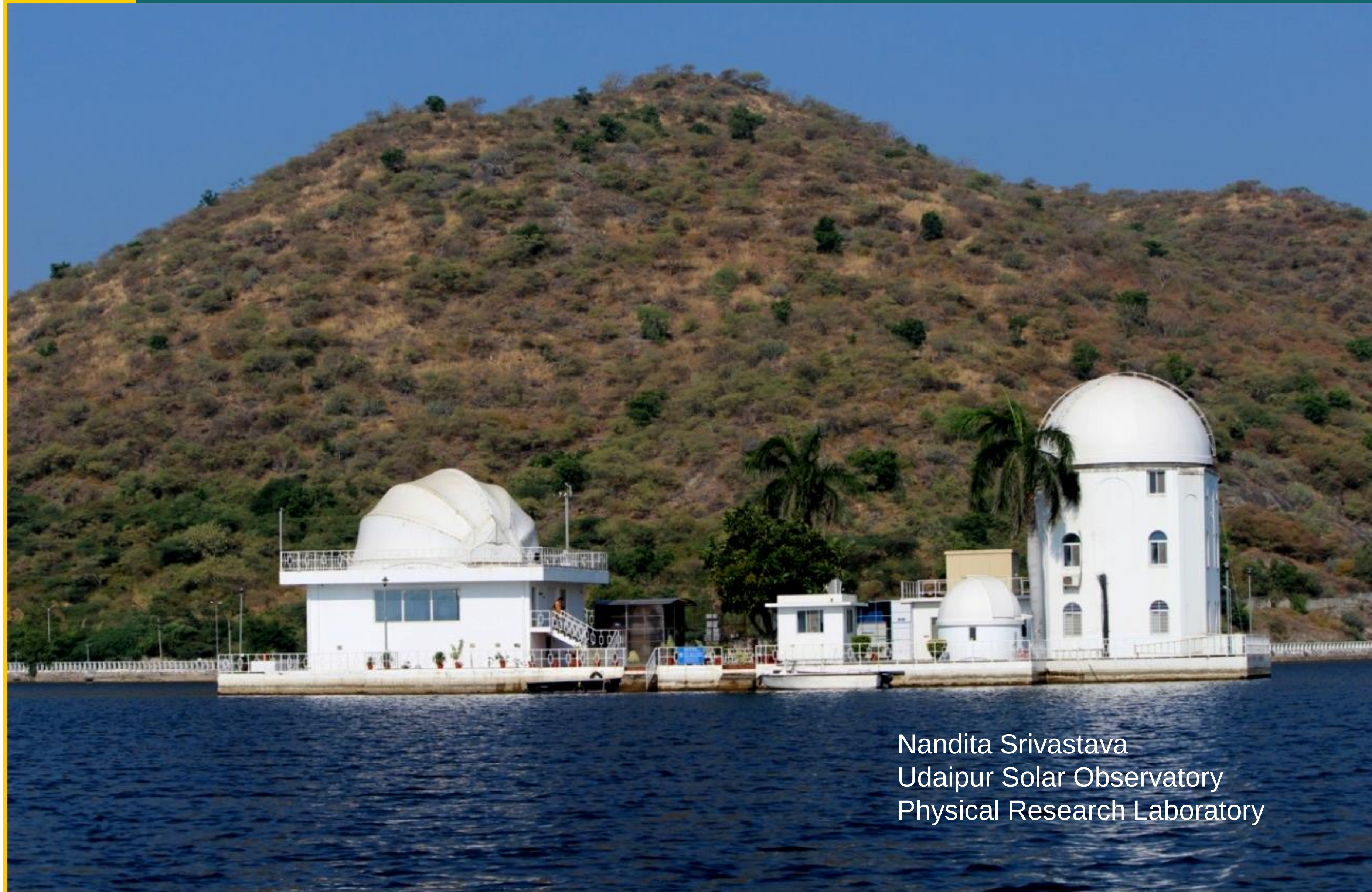
Ground-based Solar Observations



Nandita Srivastava
Udaipur Solar Observatory
Physical Research Laboratory

The New Challenges

"If the Sun had no magnetic field, it would be as uninteresting as most astronomers think it is."

by R. B. Leighton (Moore and Rabin, 1985)

The Grand Questions:

(i) Understanding how solar dynamo generate magnetic field, and

(ii) Improving the predictability of geoeffective space weather

Thompson, (2014), Front. Astron. Space Sci.

Ground-based vs space-based observations

CONS:

• Atmospheric issues: weather and seeing negatively influence the availability of the observations as well as the quality of the images;

• Day-night cycle, *i.e.* at each individual ground-based station the observation time is limited;

• Few wavelength windows are accessible from ground: visible, radio, near IR.

Veronig and Potzi, 2016

Ground-based vs space-based observations

PROS:

- relatively “simple" and inexpensive/low cost observing systems are needed;
- flexibility in changing and upgrading the system (filters, hardware); long life
- Strong Fraunhofer lines are available in the visible range with good diagnostics potential for flares and solar eruptions;
- no telemetry constraints, thus high-cadence observations and analysis can be easily performed;
- no telemetry delays, thus the data are accessible in real-time;
- networks of observatories can overcome the limitations in observing time of individual sites.
- Low vulnerability to space weather effects
- Serve as pathway for developing future space based instruments

Ground-based Observation Network

International Geophysical Year (IGY) 1957–1958.

A world-wide network of ground-based observatories was established to observe solar H-alpha flares.

Since the end of the year 1955, data from a variety of geophysical and solar observatories worldwide were compiled in the Solar-Geophysical Data (SGD) bulletins (until the year 2009).

Current ground-based networks of observatories to monitor solar activity are

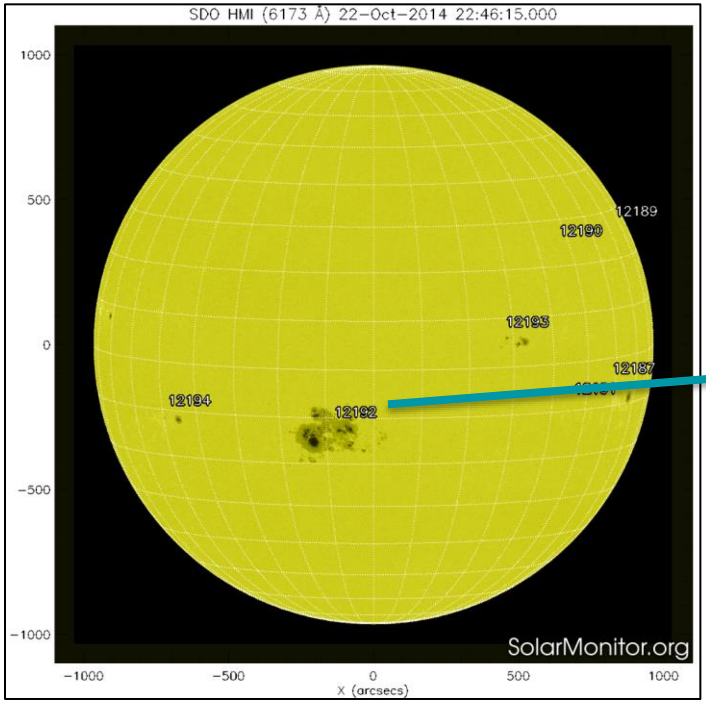
(i) the *Global High-Resolution H-alpha Network* led by the New Jersey Institute of Technology (formerly by Big Bear Observatory; Steinegger et al. 2000) and

(ii) the observations by the NSO *Global Oscillation Network Group* (GONG; Hill et al. 1994).

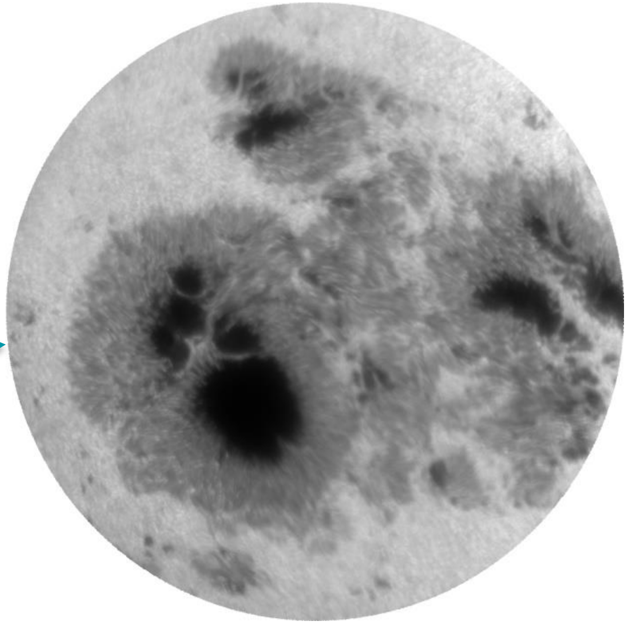
Observations of the Sun

Sun as an active star: Synoptic observations in multi-wavelengths

Mechanisms at work in the active Sun: Need to probe the Sun in High Resolution



SDO/HMI



MAST-USO

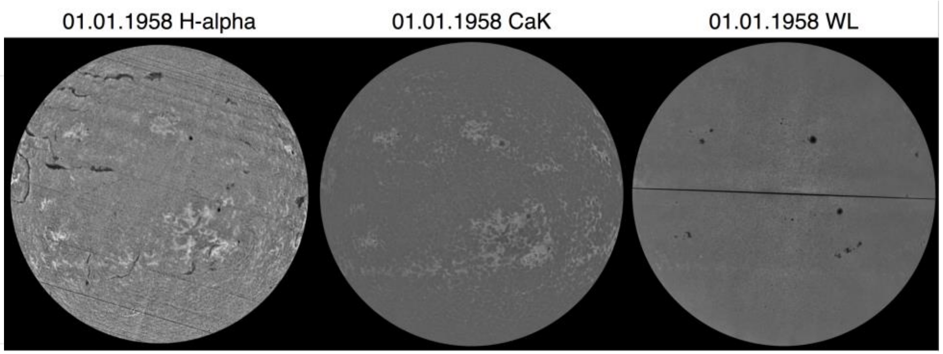
Kodaikanal Solar Observatory

Kodaikanal Solar Observatory
Data Archive

Home | Data | Observatory | Publications | IIA Facilities | People | FAQ | Contact | Track Request

Welcome to the Kodaikanal Solar Observatory Digitized Data Archive!

The Kodaikanal Observatory of the Indian Institute of Astrophysics is located in the beautiful Palani range of hills in Southern India. It was established in 1899. Solar observations at this observatory over the last 100+ years provide one of the longest continuous series of solar data. Apart from that, simultaneous observations in different wavelengths make this data a unique one and suitable for multi-wavelength studies.



Quick Links

Interactively Explore The Complete Data Set
Access the Archive Search Interface
Understand the Data
Look at Example Data

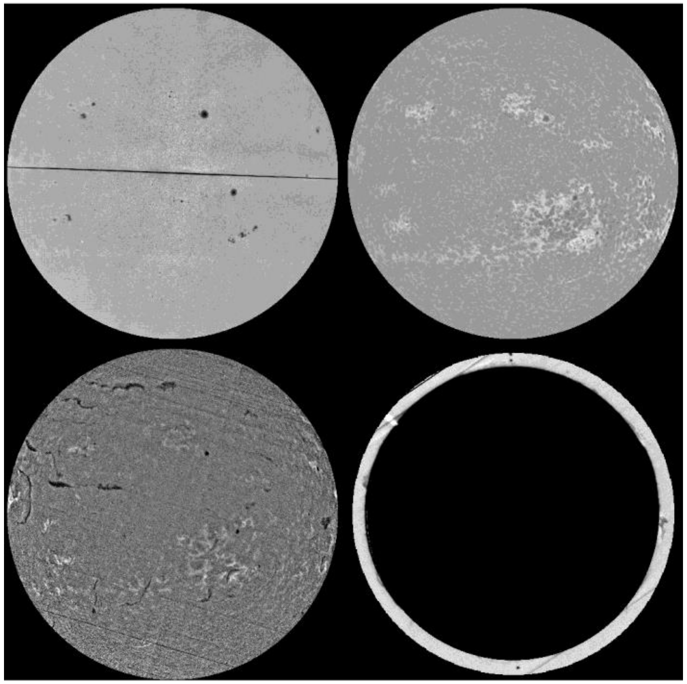
Unique opportunity for Multi wavelength study from historical data

Kodaikanal Solar Observatory Data

Database @ http://kso.iiap.res.in/data

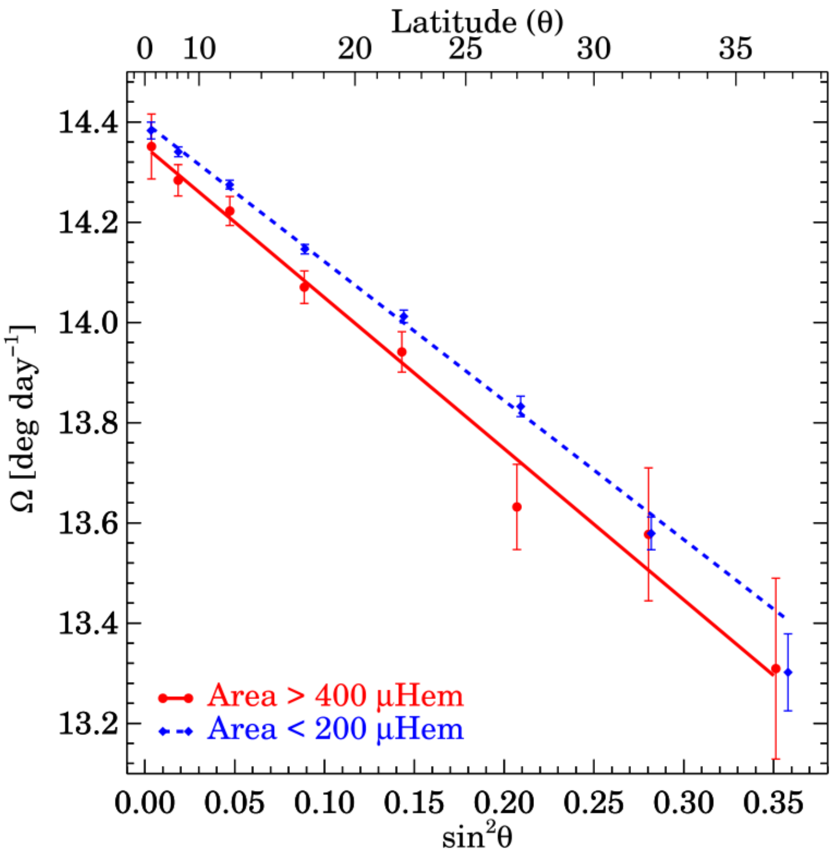
- Ca-K line spectroheliograms – 1904 – 2007
- White light 1904-till date,
- H-alpha spectroheliograms – 1904 – 1999
- Prominence plates – (1904 – 1983) Digitization completed, data archived in IIA website at http://kso.iiap.res.in/data and open to global community **(since April 2016**)

Images of Sun in multiwavelength from Kodaikanal on 01.01.1958



Chatterjee et al. 2016, 2017a,b, 2019, ApJ, Mandal et al. 2017, 2020 A&A, Mandal & Banerjee, ApJL, 2017, Mandal, Chatterjee & Banerjee 2017, Priyal et al., 2014a, Solar Physics, Priyal et al. 2014b, 2019, 2020, Ravindra et al. 2013, A&A, Jha et al. 2019, 2021

Rotation profiles of Sunspots observed from KSO



Period: 1923-2011

Rotation profiles of sunspots with area <200 μHem (blue dashed line) and with area >400 μHem (red solid line).

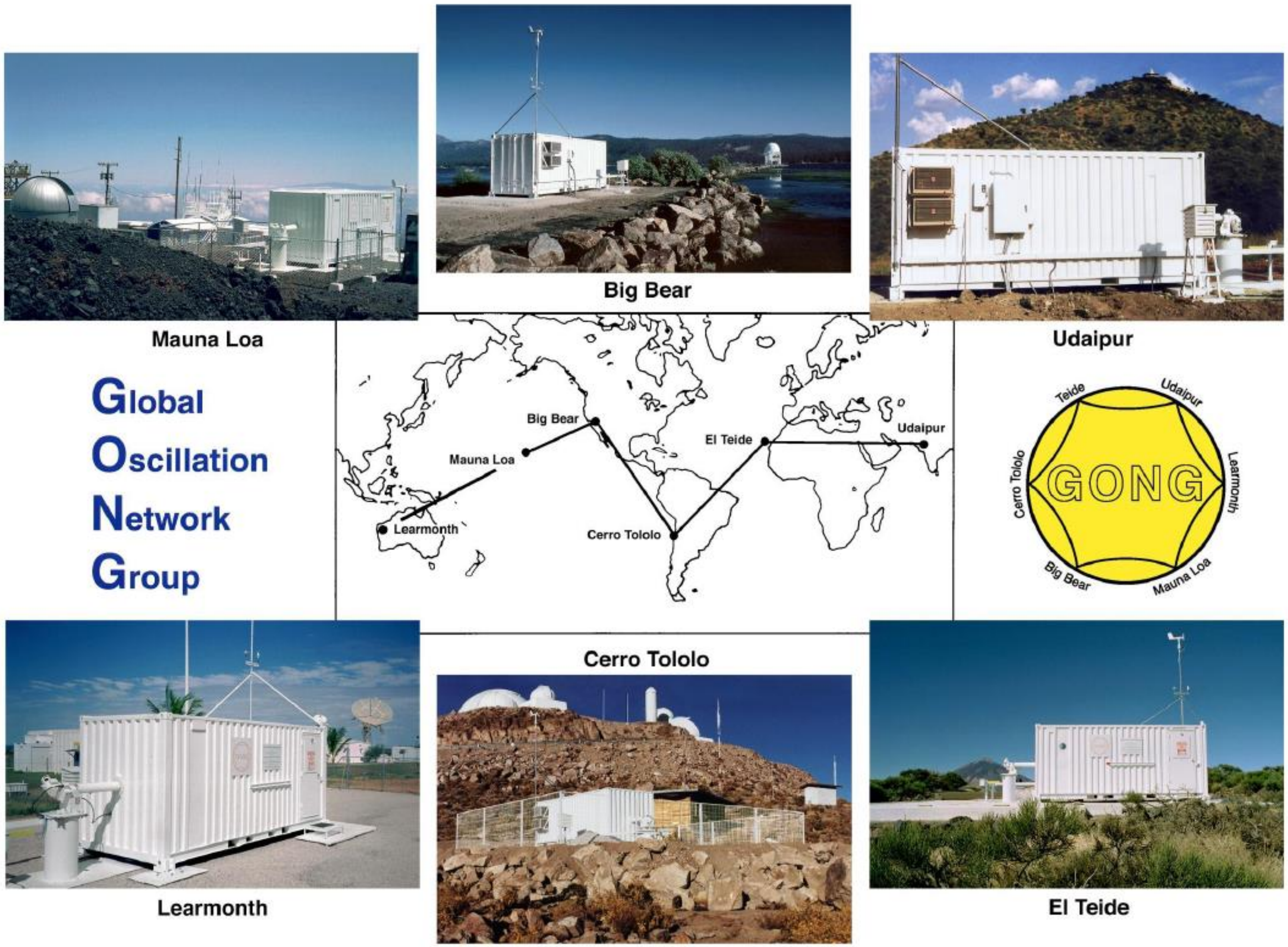
RESULT: The bigger sunspots (with area > 400 μHem) rotate slower than the smaller ones.

No variation in the rotation rates between activity extremes, i.e. solar maxima and minima found.

Jha et al 2021

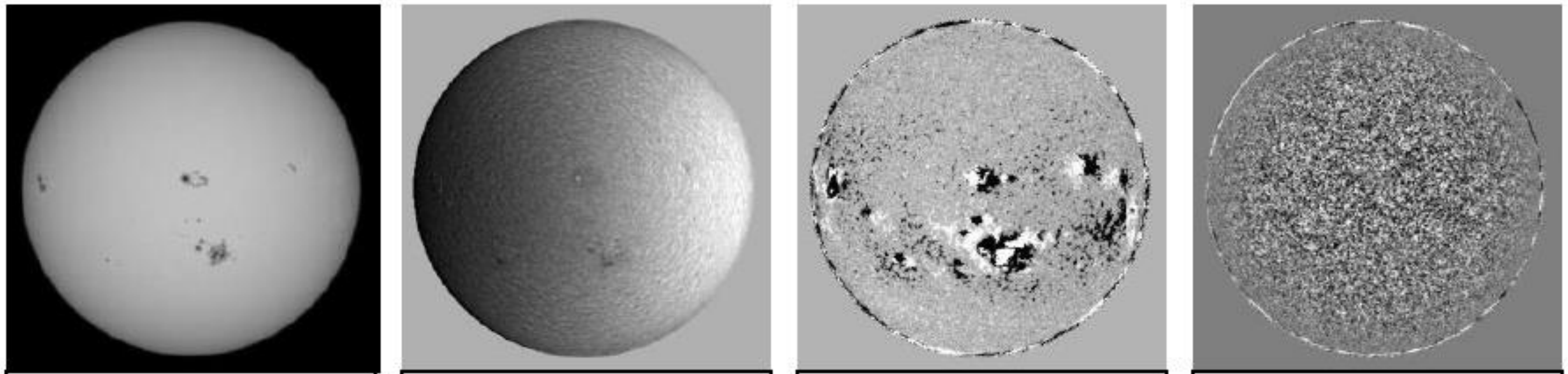
Global Oscillation Network Group (GONG)

GONG: Six –site network, with identical instruments



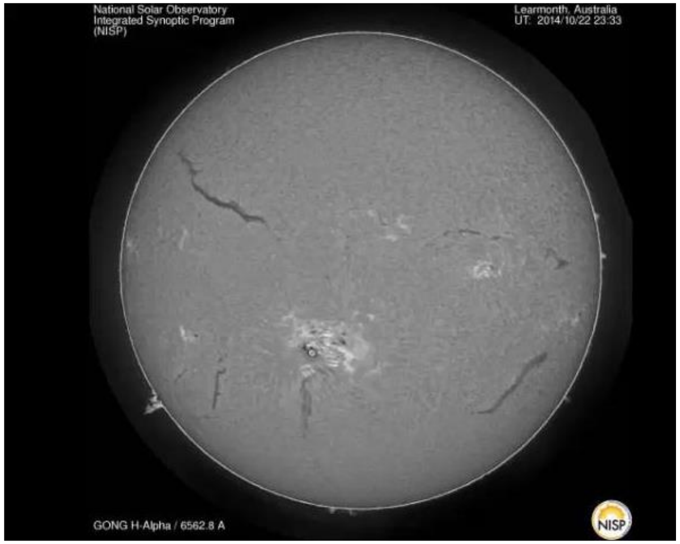
1995-onward

GONG-Datasets



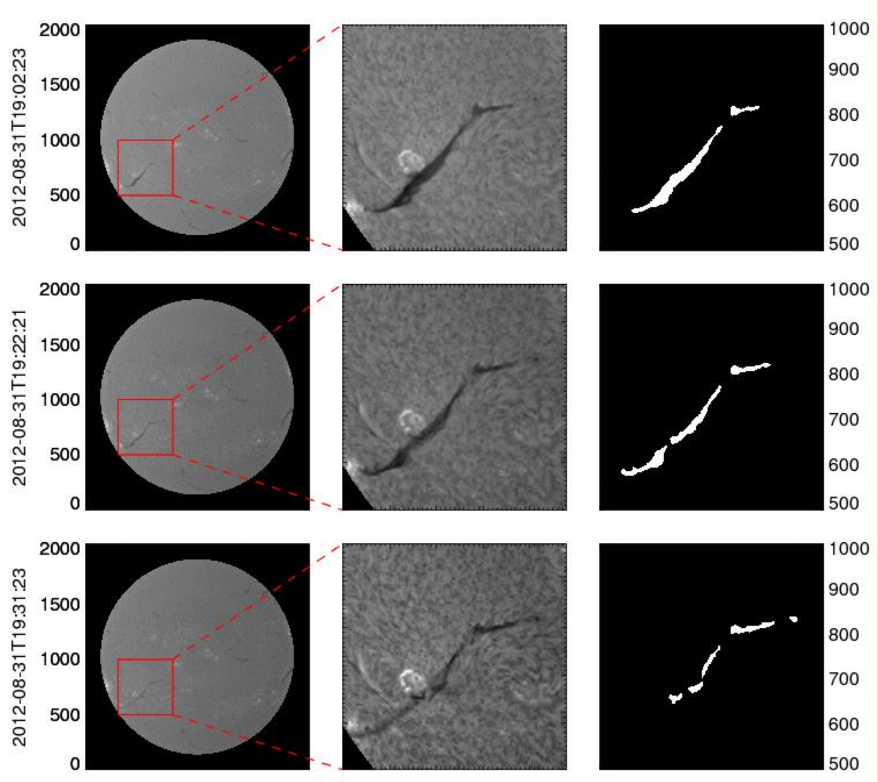
Continuum image (white light) | *Dopplergram (total velocity)* | *Magnetogram (line-of-sight)* | *Dopplergram (p-modes)*

The GONG instrument acquires full-disk Dopplergrams, Magnetograms (line-of-sight), and Continuum images of the Sun using Ni I 6768 Å line at the cadence of one minute with a spatial sampling of 2.5 arcsec per pixel. It also acquires the full-disk chromospheric images of the Sun using H-alpha 6562.8 Å line with a spatial sampling of 1 arcsec per pixel



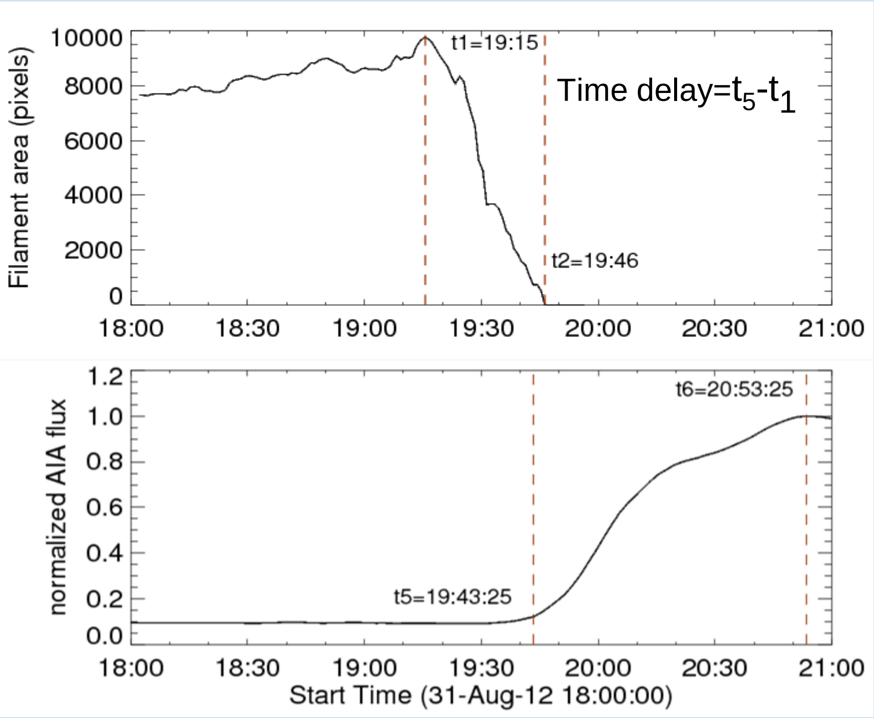
- Global Oscillation Network Group (GONG) H-alpha images (https://gong.nso.edu/).
- GONG-Halpha image the Sun taken with a pixel resolution of 2048 x 2048 with a spatial resolution of 1.06 arcsec and a cadence of 1 minute.

Filament Eruptions as Precursors to Flare-CME Events



Evolution of filament as tracked in our code using GONG H-alpha data

Time evolution of filament area decay and aia flux rise



Sinha, Srivastava and Nandy, 2019

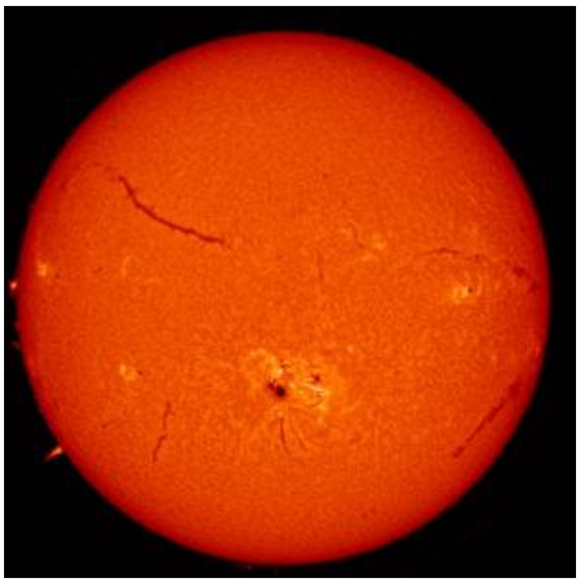
- A good correlation between area decay rate of the quiescent filaments and the speed of the associated CMEs with a correlation coefficient of 0.75.
- By analyzing the time delay of the EUV brightening of solar flares relative to the start time of associated filament eruption, we show that in 83% of cases, filament eruption precedes the flare brightening, which indicates that eruptive filaments can be considered as one of the precursors for the occurrence of a solar flare.

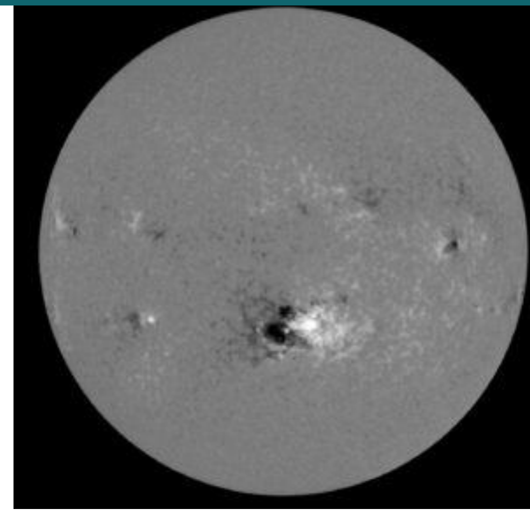
GONG Inputs for Real Time Space Weather Forecast

Since 1995

Duty Cycle -91%

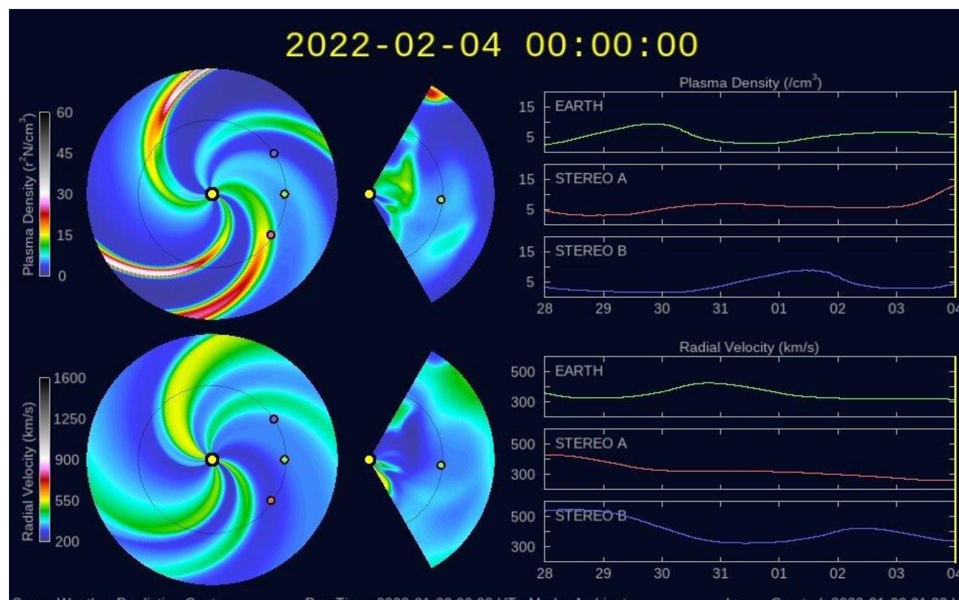
Space Weather Studies





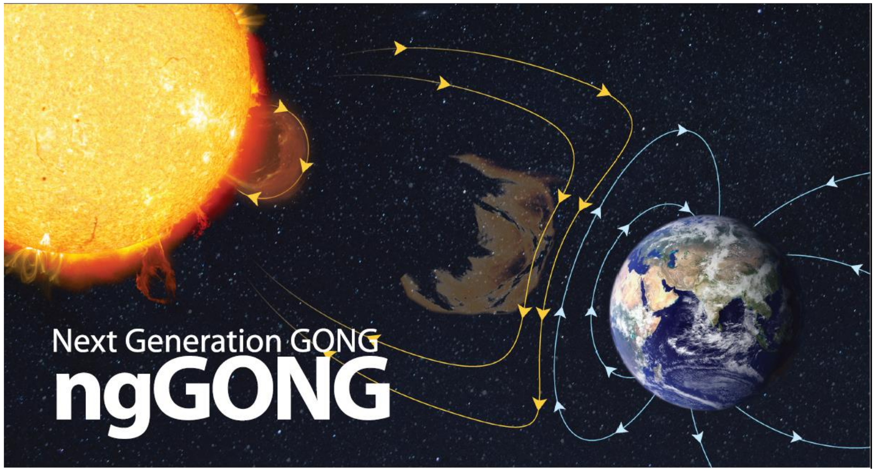
GONG Magnetogram used as input for NOAA-SWPC for WSA-ENLIL model

ENLIL model : Solar Wind forecast from 0.2- 2 AU



New Generation GONG

25 + years of GONG



Next Generation GONG Network driven by Space Weather Forecasting

The National Solar Observatory (NSO) is promoting the definition and design of the **Next Generation Global Oscillations Network Group (ngGONG)**. This network will replace NSO's existing facilities, GONG and SOLIS as both are more than 20 years old and new requirements for synoptic solar observations have arisen since their construction. There is strong interest for a new solar synoptic network within the space weather research and forecasting agencies in the US, but also within the broader international solar community.

NSO proposes to develop **ngGONG** to provide solar data on a continual basis. Once operational, ng GONG will:

- Measure the magnetic polarity of boundary data that propagate the magnetic connectivity from the solar surface into the heliosphere.
- Map the 3-D magnetic topology of solar erupting structures in the chromosphere and corona, increasing advanced warning of space weather events from hours to days.
- Anticipate processes in the solar interior and on the Sun's far-side that impact heliospheric conditions.
- Provide context for high-resolution observations of the Sun as well as for in situ single-point measurements throughout the heliosphere.

ngGONG is an international effort that builds on our experience with GONG, and incorporates the US expertise with that of other countries that operate synoptic programs.

The instruments that currently feed Space Weather operational models were not initially designed for that purpose. **ngGONG will be the first ground based network that includes operational Space Weather requirements from its conception**. We anticipate the breadth of knowledge that ngGONG will provide about the magnetic linkages in the solar system to transfer into the developing field of exo space-weather and its impact on the habitability of other worlds.

www.nso.edu/nisp

NSF

The National Solar Observatory is operated by AURA under a cooperative agreement with the National Science Foundation.

AURA

The Association of Universities for Research in Astronomy

NSO

Financials

Construction of the ngGONG is estimated at $100 million.

Operations costs for ngGONG are expected to be $1 million per site annually, totaling $6 million per year.

Why do we need ngGONG?

Next Generation GONG will be a ground-based network of Space Weather driven observatories that will provide continuous, robust coverage of solar variability over timescales of decades.

Artist's impression of ngGONG shelter.

Benefits of a ground-based space weather network

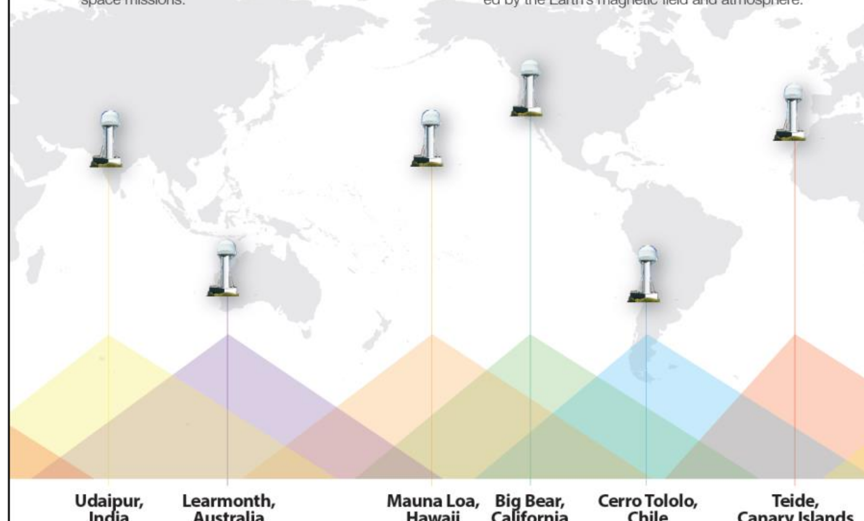
Lifetime – Space missions have limited lifetimes due to the harsh environment at their location, and due to the difficulty in repairing them when they malfunction. In principle, ground-based systems can be operated indefinitely.

Upgrades and Maintenance – Once a space mission is launched it is virtually impossible to access for upgrades or repairs. Ground-based systems can be continually maintained and improved.

Cost – The costs of constructing and operating ground-based systems are typically less than 20% of the costs for space missions.

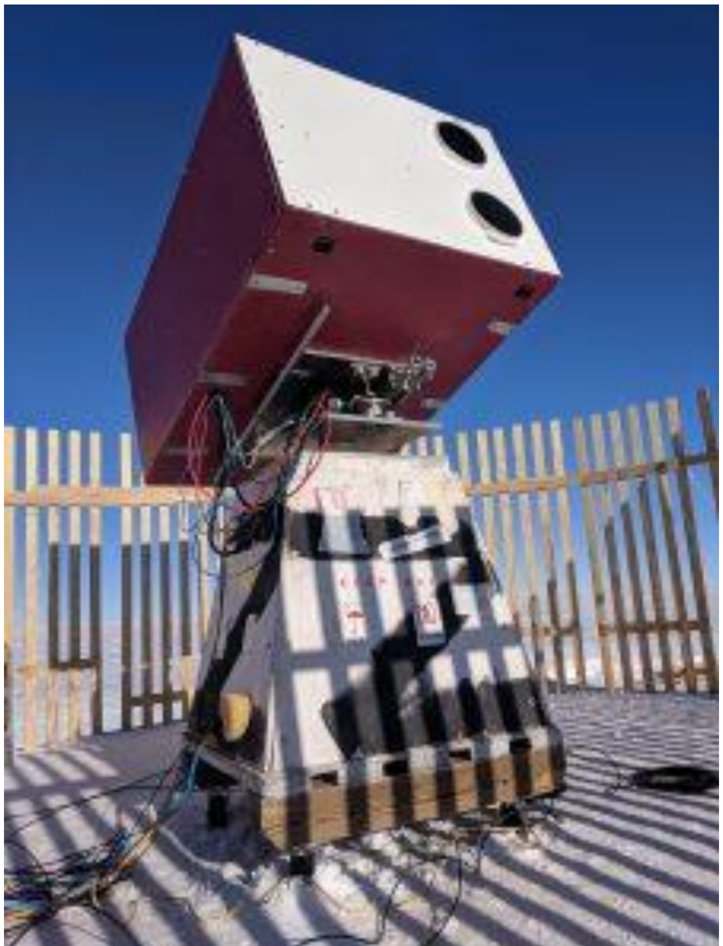
Data Delivery – The rate at which data can be returned from a space mission is highly constrained by the distance to the spacecraft, the power of the spacecraft telemetry system, and the sensitivity of the receiving antennas on the ground. None of these restrictions exist for ground-based systems that can also take advantage of the continual improvements in internet technology.

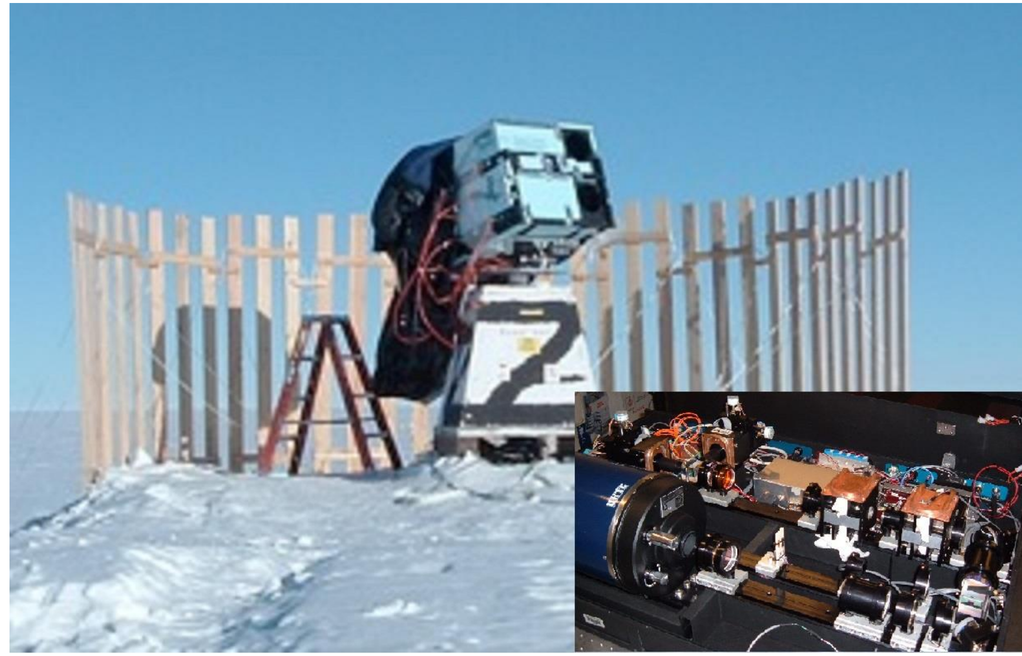
Space Weather Vulnerability – Space systems are embedded in the very environment that causes space weather and are thus at risk for damage from that source. Ground-based systems are much less vulnerable as they are shielded by the Earth's magnetic field and atmosphere.



Proposed locations for ngGONG network and average daylight coverage through the day.

Observing the Sun from Antarctica





- Magnetic and velocity fields maps (magnetograms and dopplergrams) at different heights of the solar atmosphere, by MOTH (Principal Investigator: Prof. Stuart M. Jefferies).

- The current configuration of MOTH II instrument consists in two parallel telescopes, one for observations in the D1 line of Potassium (K) at 770 nm and one for observations in the Sodium (Na) I D2 line at 589 nm, which allows to obtain magnetograms and dopplergrams at two heights of the solar atmosphere.

High-Resolution Observations of the Sun

Recent Projects:

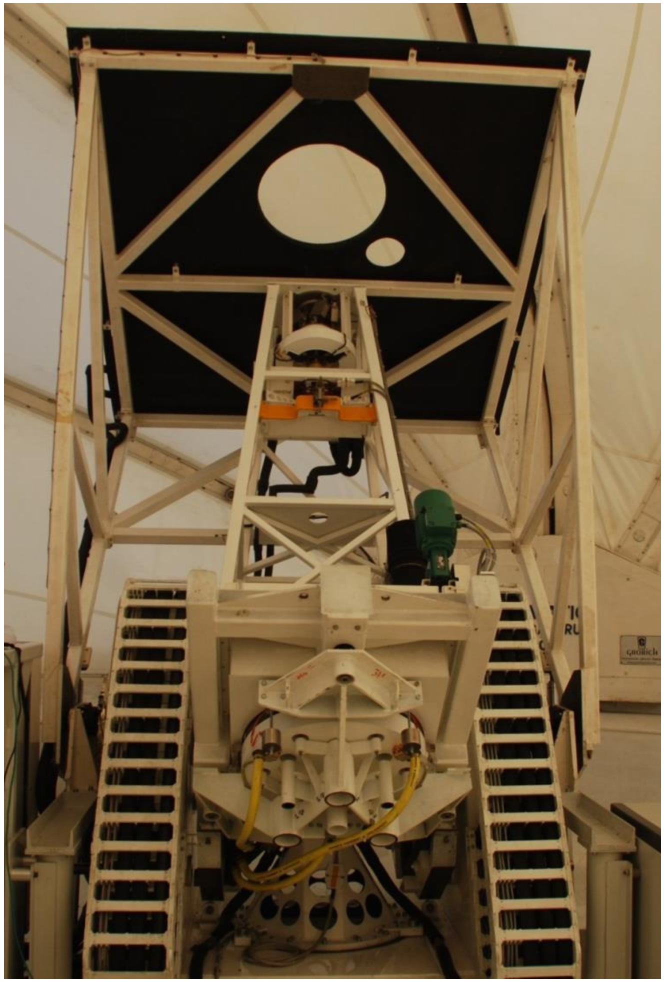
Multi-Application Solar Telescope (MAST), USO-PRL

National Large Solar Telescope (NLST), IIA (Proposed)

Daniel K. Inouye Solar Telescope (DKIST), Hawaii, USA

Multi-Application Solar Telescope at USO, Udaipur

State-of-the art instrument: 50 cm primary mirror



MAST became operational in June 2015.
Science instruments built by USO team

Telescope built by AMOS, Belgium

MAST Back-end instruments

Narrow band Imagers

Narrow band imaging in photospheric and chromospheric spectral lines for understanding the coupling, G-Band (430.5 nm) and H$\propto$ (656.3 nm)

Tuneable narrow band imager and polarimeter

Spectral line profile scanning, Stokes parameter measurement. Zeeman effect for magnetic field measurement and Doppler shifts of the lines for los velocity

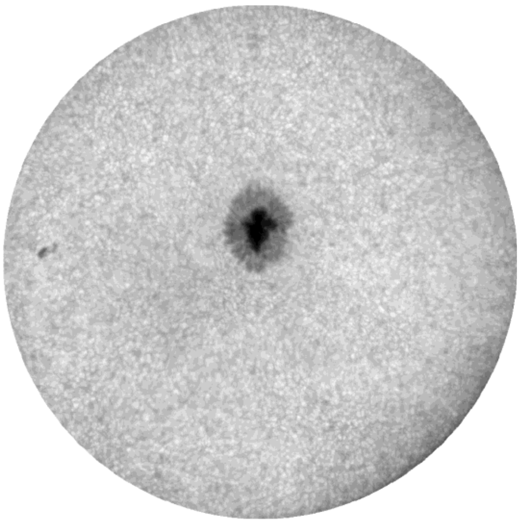
Adaptive optics for seeing correction

Deformable mirrors used for the wave front correction introduced by the atmospheric seeing

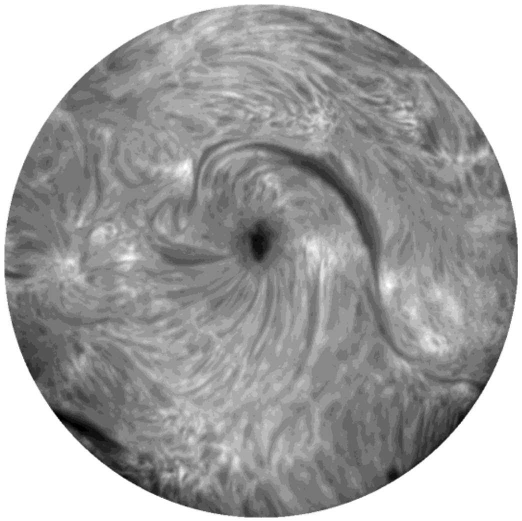
Fine Structure of an isolated sunspot

MAST-USO high resolution images *Mathew et al. 2017*

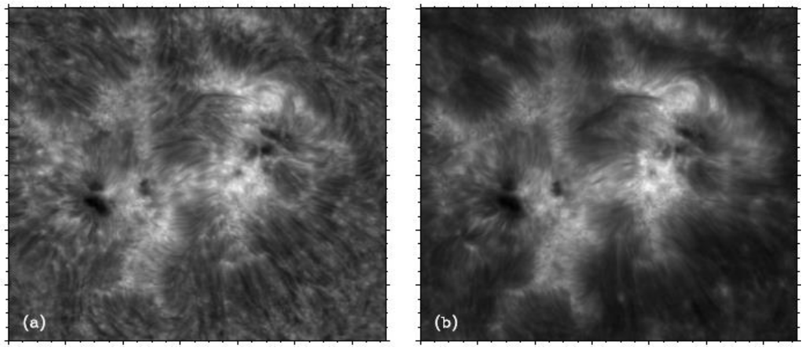
G-band (Photosphere)



H-alpha (chromosphere)

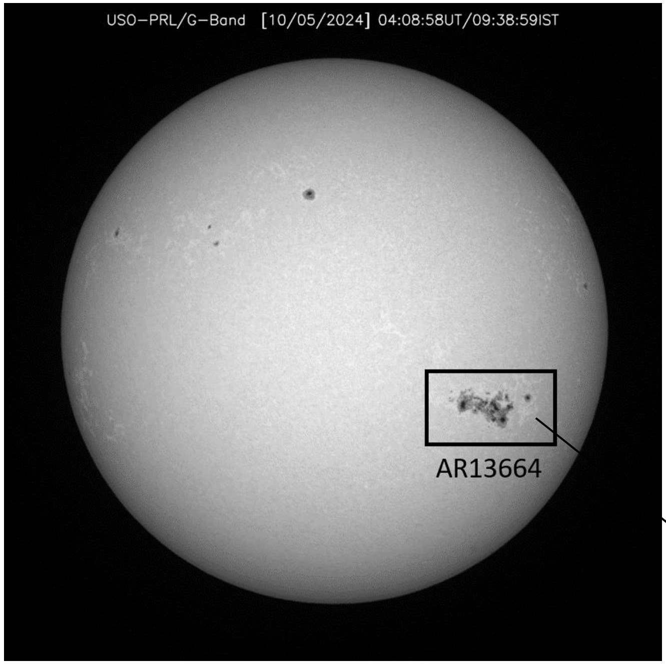


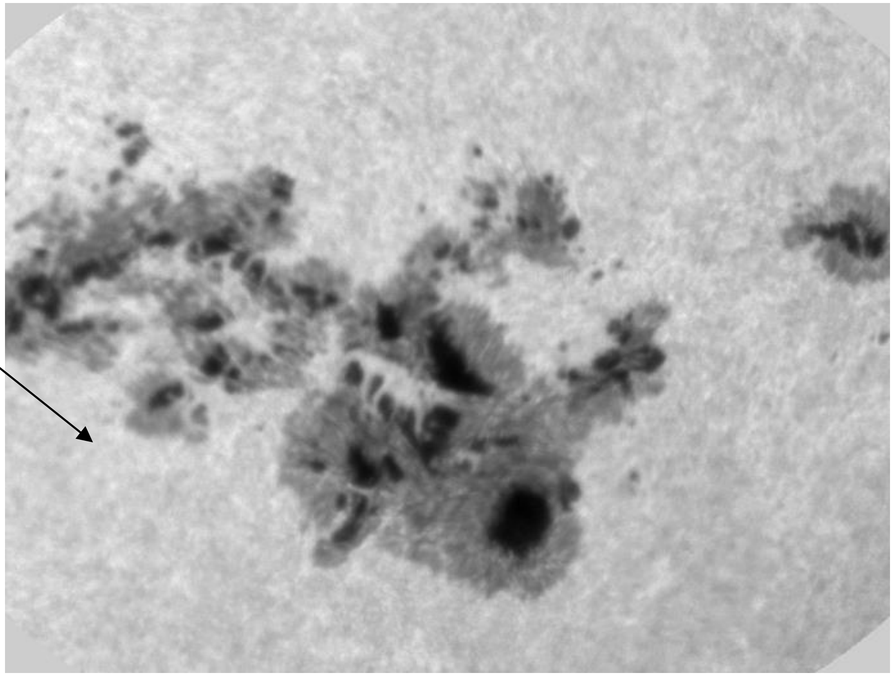
Images taken by MAST on 04 June 2015, at 05:13 UT for the AR 12356 with 3 arc-min fov



- **Dual FP-based Narrowband Imaging Spectropolarimeter ,** **Fe I 6173 Å and Ca II 8542 Å**

May 2024 Solar Eruption





THE NATIONAL LARGE SOLAR TELESCOPE (NLST)

NLST is a 2-m aperture 3-mirror Gregorian on-axis telescope with an innovative design and low number of optical elements that will yield a high throughput with low polarization and high spatial and spectral resolution.

WHY 2-m?

- Scientific objectives:
  - ✓ High spatial resolution to resolve sub-arc sec magnetic elements;
  - ✓ High optical throughput (i.e. the number of photons per time on the detector and thus the signal to noise ratio which can be achieved);
- Use a tested design and technology (based on GREGOR);
- Realize project on a short time scale (3-4 years);
- Keep costs down.

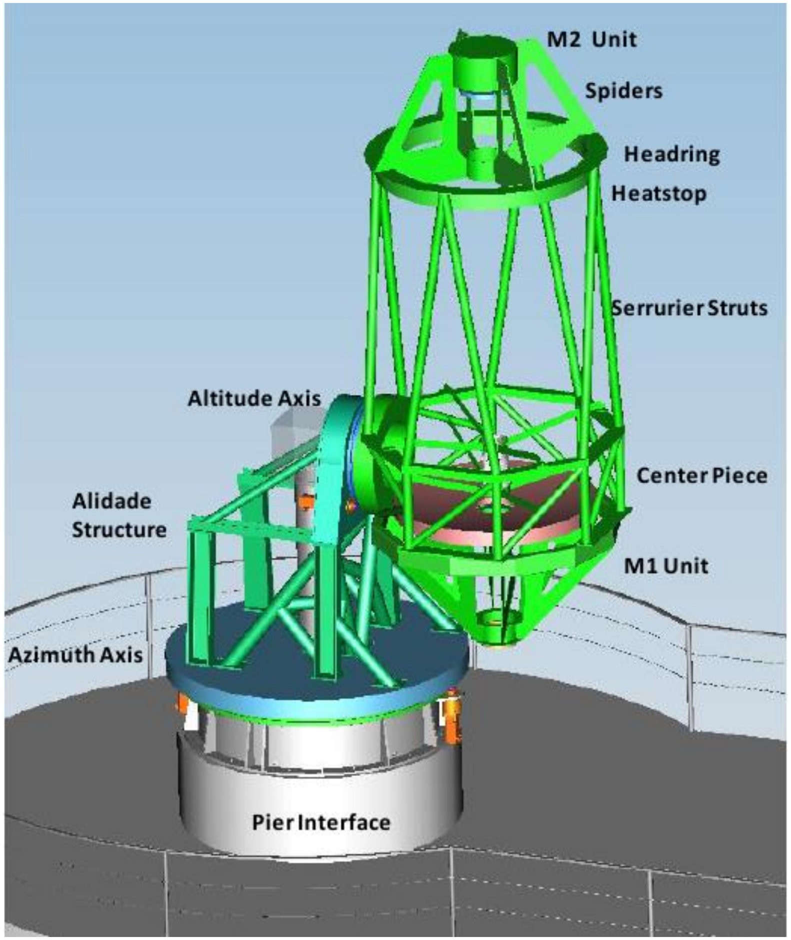
MAIN SCIENTIFIC AIMS

- Magnetic field generation and the solar cycle (understanding the dynamo, origin and nature of the solar cycle);
- Magnetic coupling between the interior and outer solar atmosphere (dynamical processes and heating; magnetic network; sunspots);
- Local helioseismology;
- Measuring weak magnetic fields (e.g. internetwork, quiescent prominences);
- Thermal structure of the chromosphere;
- Energetic phenomena & Activity (e.g. active prominences, loops, flares & CMEs).

THE NATIONAL LARGE SOLAR TELESCOPE (NLST)

Proposed by IIA-Bangalore
TELESCOPE FEATURES

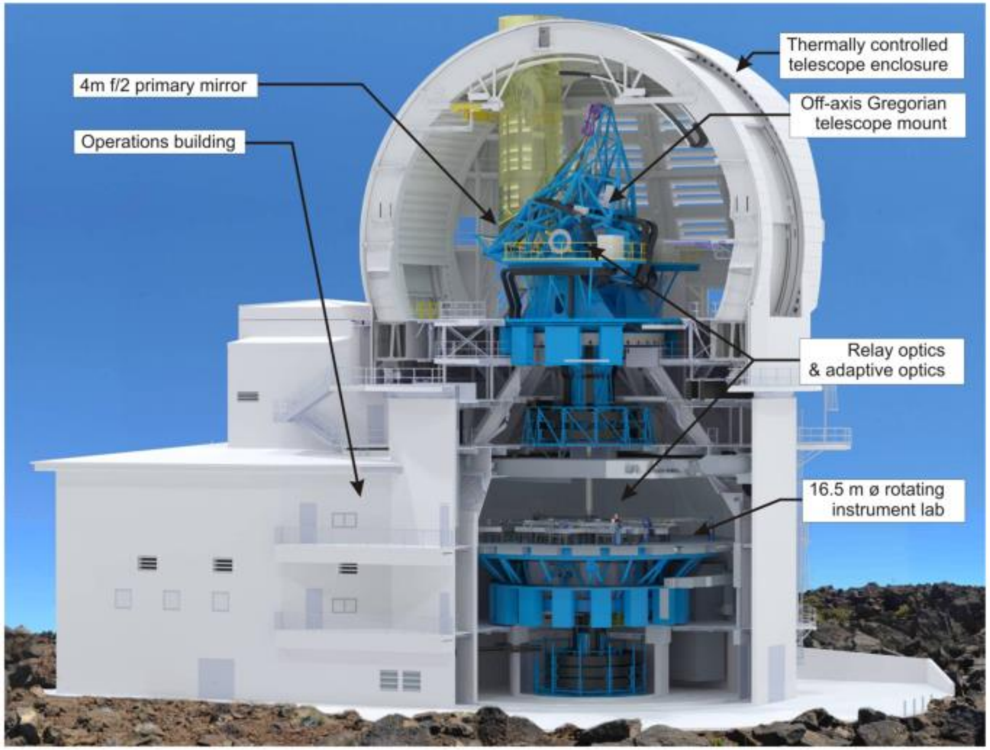
- Aperture (primary mirror M1) : 2 metre with f/1.75
- Optical configuration : 3 mirror , Gregorian on axis
- Field of view : 300 arcsec (200 arcsec AO corrected)
- Final focal ratio of the system : f/40
- Wavelength of operation : 380 nm to 2.5 microns
- Polarization accuracy : > 1 part in 10,000
- Adaptive optics : Close to diffraction limited performance
- Spatial resolution : < 0.1 arcsec at 500 nm



Focal plane instruments

- *Broad Band Imaging System* in Hα (656.3 nm), Ca II K (393.4 nm), CN band (383.3), G band (430.5 nm) and the continuum;
- *Tunable Fabry-Perot Narrow Band Imager* (500 – 900 nm);
- *High Resolution Spectropolarimeter* (380 – 1600 nm).

Daniel K. Inouye Telescope (DKIST), Hawaii



- DKIST; Target AR follow-up observations
- Instrument setup @DKIST
- Visible Imaging Spectropolarimeter (ViSP)

2’ x 2’ FOV, 0.07” resolution @630 nm

Spectral Coverage 380-900 nm

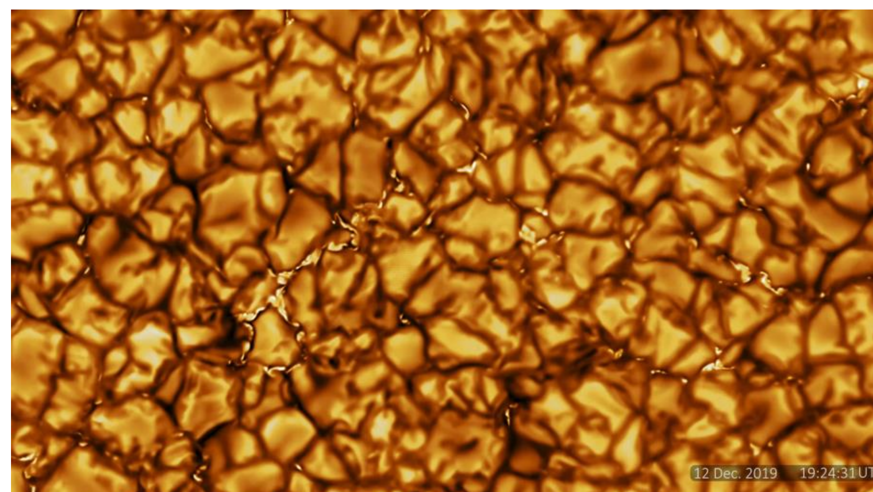
- Visible Tunable Filter (VTF)
- 1’ FOV, 0.014”/pixel
- Spectral Region 520-870 nm
- All instruments fed by MCAO

Aperture -4 m

25 Km, SNR 10^4
Simultaneous Multi-line diagnostic

Sensitive Spectropolarimetry

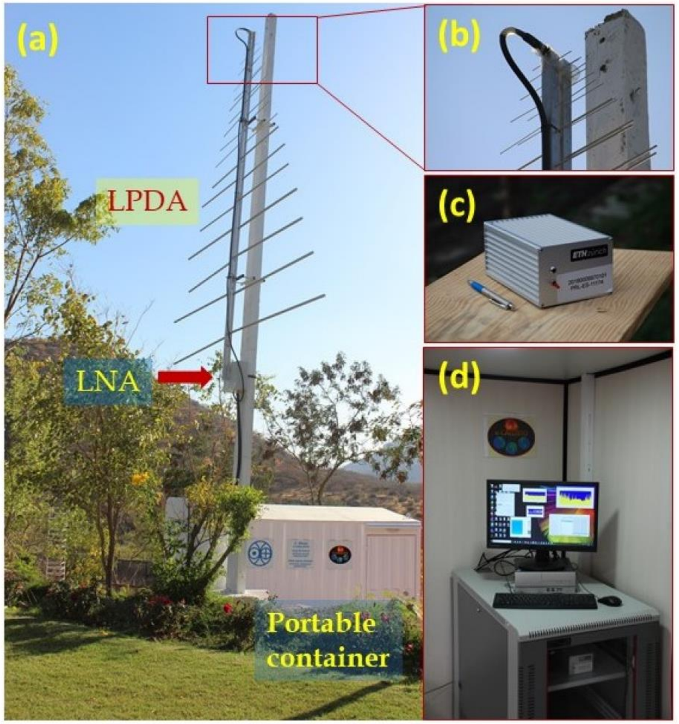
Coronal off –limb observations



E-CALLISTO at USO-PRL, Udaipur

Compound Astronomical Low cost Low frequency Instrument for Spectroscopy and Transportable Observatory

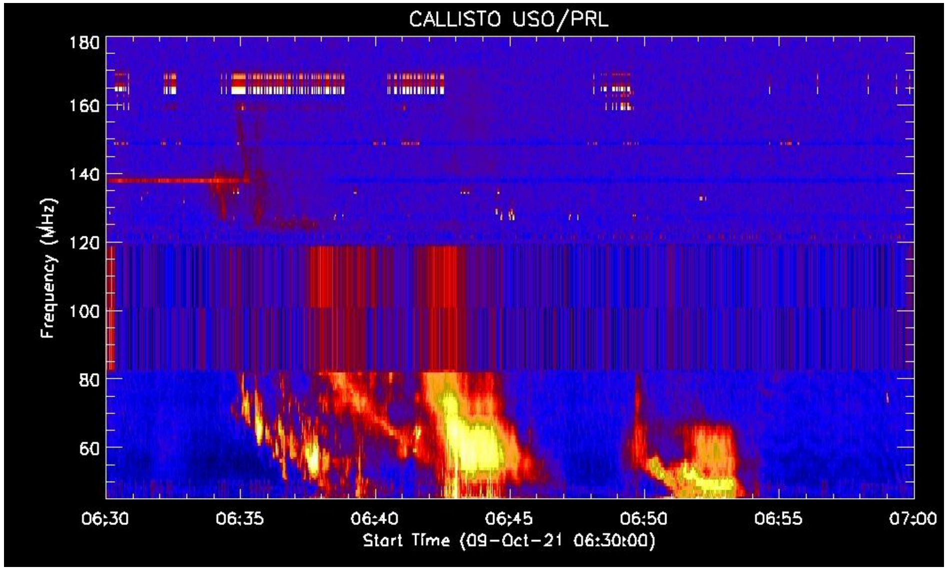
Frequency range: 45.0 MHz to 870.0 MHz



https://www.prl.res.in/~ecallisto/

Further upgradation: Multiple antenna system and FFT based spectrometer for wide band observations

- ✓ Real-time monitoring of solar storms (flares and CMEs)
- ✓ Kinematic parameters of CMEs
- ✓ Detection of flare-accelerated electrons



Detection of a solar storm of 2021 October 09 (M-class flare), producing multiple shock waves.

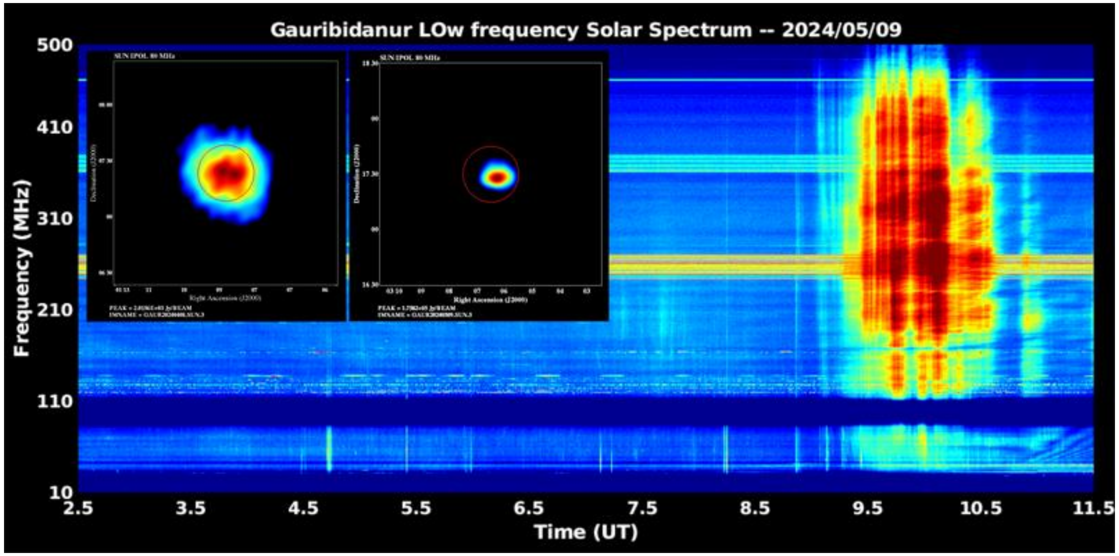
Joshi et al. Solar Physics, 2021, 296, 85

Radio Observations at IIA

(i) ***Gauribidanur RadioheliograPH (GRAPH)*** *– 2D images of the solar corona in the heliocentric distance range ~1.1 – 2.0 solar radii every 250 msec.*

(ii) ***Gauribidanur LOw-frequency Solar Spectrograph (GLOSS)*** *– Dynamic spectrum of radio signatures of the transient activities in the solar corona in the height range ~1.1 – 2.0 solar radii every 250 msec.*

(iii) ***Gauribidanur Radio SpectroPolarimeter (GRASP)*** *– Spectropolarimetry of radio signatures of the transient activities in the solar corona in the height range ~1.1 – 2.0 solar radii every 250 msec.*



A composite of the low-frequency radio imaging (80 MHz) and spectral observations (10 - 500 MHz) of the solar corona from the Gauribidanur observatory.
The radio signatures of the powerful X2.2 class flare that occurred in the solar atmosphere on 9 May 2024 around 09:10 UT can be clearly noticed in the spectrum

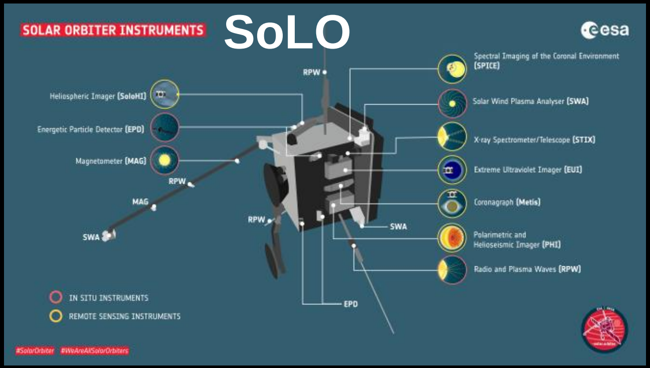
These unique ground-based radio observations were associated with the strongest geomagnetic storm activity during 10 - 12 May 2024.

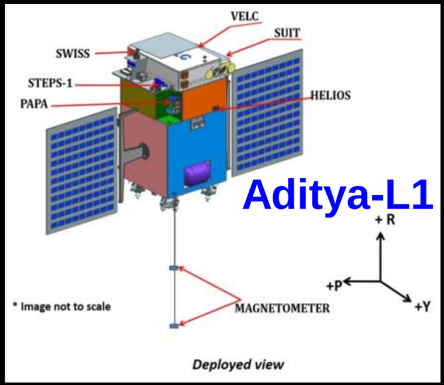
Table I: Summary of solar data available from ground observatories

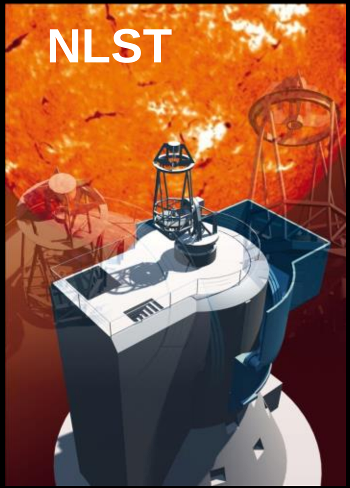
Type of data	Source of data from Indian Observatories	Data Availability
Solar images in various optical wavelengths	1. Udaipur Solar Observatory, PRL, Udaipur **GONG (full disk) (part of 6 site global network)** H-alpha (656.3 nm) https://gong2.nso.edu/dsds 2. Udaipur Solar Observatory, PRL, Udaipur **MAST (limited fov),** H – alpha (656.3 nm) G – band (430.5 nm) https://www.prl.res.in/~usodataarchive/ 3. Indian Institute of Astrophysics (IIA), Merak **DFM (G-band full disk), H-alpha (limited fov)** **Website not available** 4. Indian Institute of Astrophysics (IIA), Kodaikanal **WARM telescope (G-band & H-alpha fulldisk)** https://www.iiap.res.in/solar_images/?q=DISPLAY_HOME 5. ARIES, Manora Peak, Nainital **H-alpha (limited fov)** https://www.aries.res.in/	**In JOP mode** Level 1 data can be made available within few hrs Delay of 10 min Delay of 10 min Delay of 1 day
Solar Dopplergram images	1. Udaipur Solar Observatory, PRL, Udaipur GONG Full disk line-of-sight magnetogram https://gong2.nso.edu/dsds	Delay of few days
Solar spectral and magnetogram images	1.Udaipur Solar Observatory, PRL, Udaipur GONG Full disk line-of-sight magnetogram https://gong2.nso.edu/dsds 2. **MAST** Fe I (617.3 nm) Ca II 8542 A Multi-slit spectrograph for spectral imaging and magnetic field measurements https://www.prl.res.in/~usodataarchive/	Delay of 1 hour **In JOP mode** Level 1 data can be made available within few hrs
Solar Radio Imaging & Solar radio bursts	1. Indian Institute of Astrophysics (IIA), Gauribidanur GRAPH, Gauribidanur RadioheliograPH https://www.iiap.res.in/centers/radio#hrrs 2. **GLOSS** Gauribidanur LOw-frequency Solar Spectrograph https://www.iiap.res.in/centers/radio#hrrs 3. **GRASP** Gauribidanur Radio SpectroPolarimeter https://www.iiap.res.in/centers/radio#hrrs 4. **E-Callisto (USO, Udaipur, IIA, Gauribidanur)** https://www.prl.res.in/~ecallisto/	
Solar Radio Observations (80-1750 MHz)	1. Pune (NCRA-TIFR) uGMRT Other worldwide observatories in Collaboration with GMRT/NCRA 2. **MWA (Australia)** 3. **ASKAP (Australia)** 4. MeerKAT (South Africa)	Data not available on quick turn around time. Available on

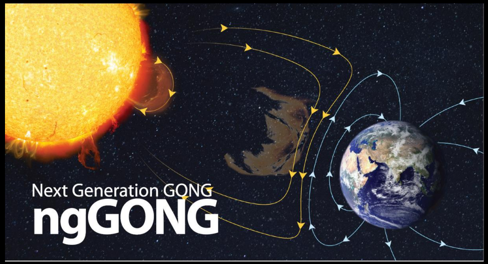
Indian ground based solar observations

Multi-messenger Era for Solar Physics







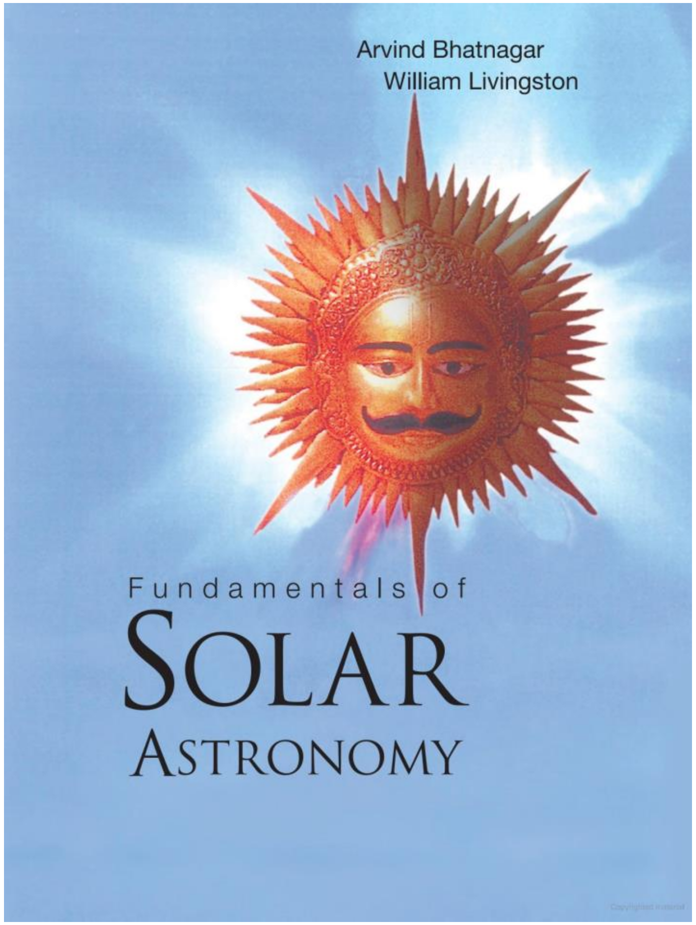


Summary

- This is an exciting time for Solar Astronomy, to observe the Sun both from the ground and space.

- There are challenging questions to answer and need observation from ground and space.

- Exploiting the potential of these observations, combined with models and their validation, are crucial for better understanding of the Sun and also Space Weather.


Arvind Bhatnagar
William Livingston
Fundamentals of
SOLAR
ASTRONOMY

Thanks