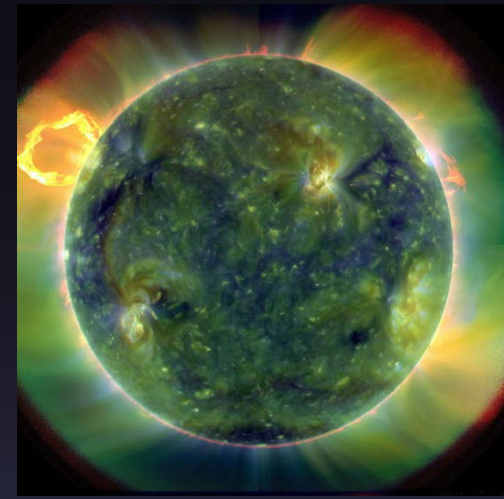


Challenges and Perspectives in Solar Physics



Sami K. Solanki



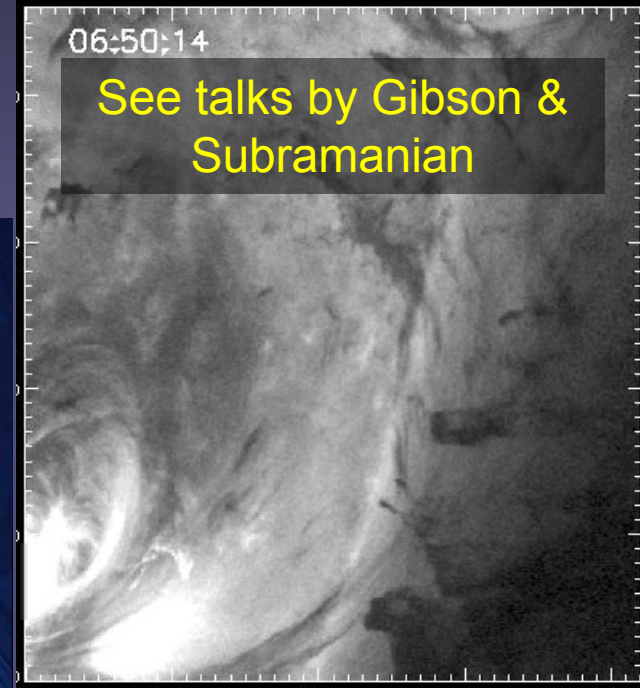
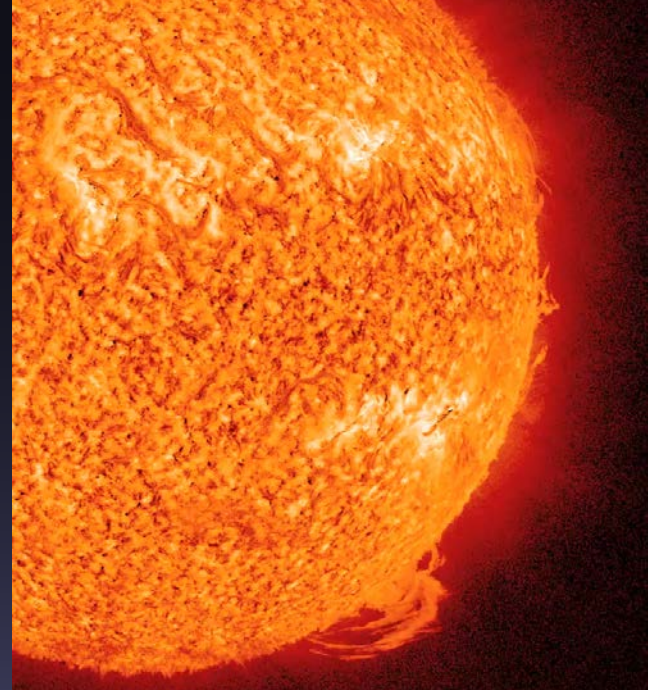
Max Planck Institute for Solar System Research

School for Space Research, Kyung Hee University

Scope of talk

- Solar physics is an active field
- Quite a few recent highlights
- Many of these will be presented by various speakers; I'll try not to overlap
- I'll concentrate on things I know (I make no attempt to be complete)
- Will start more generally than usual for a solar conference

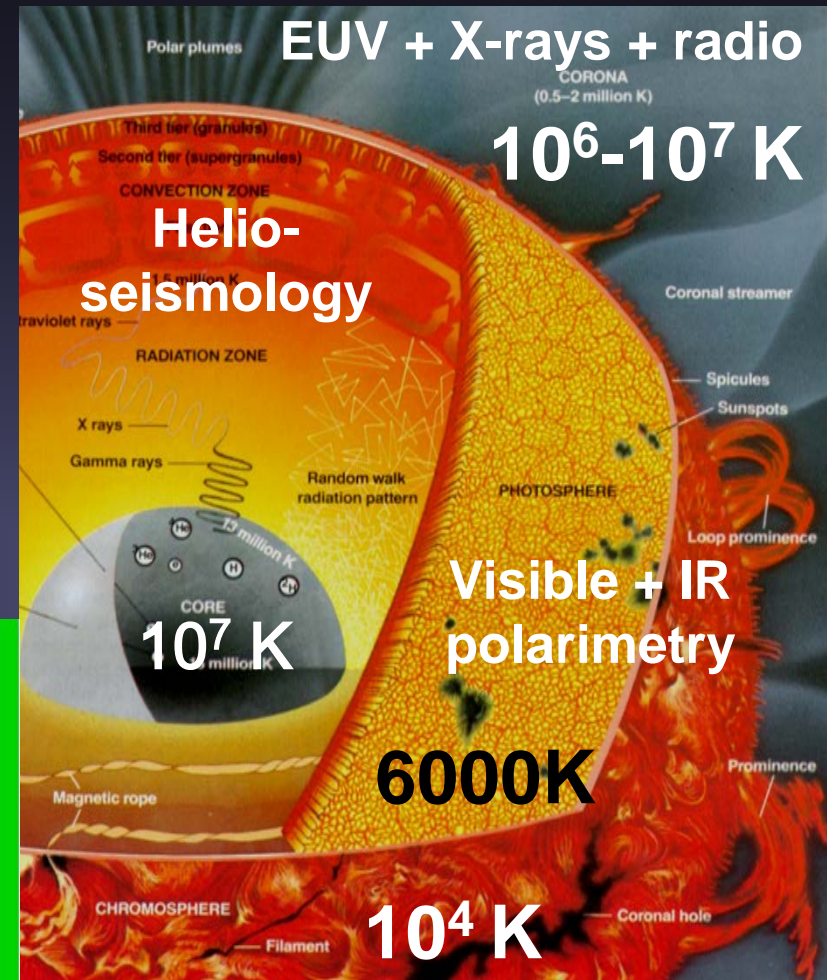
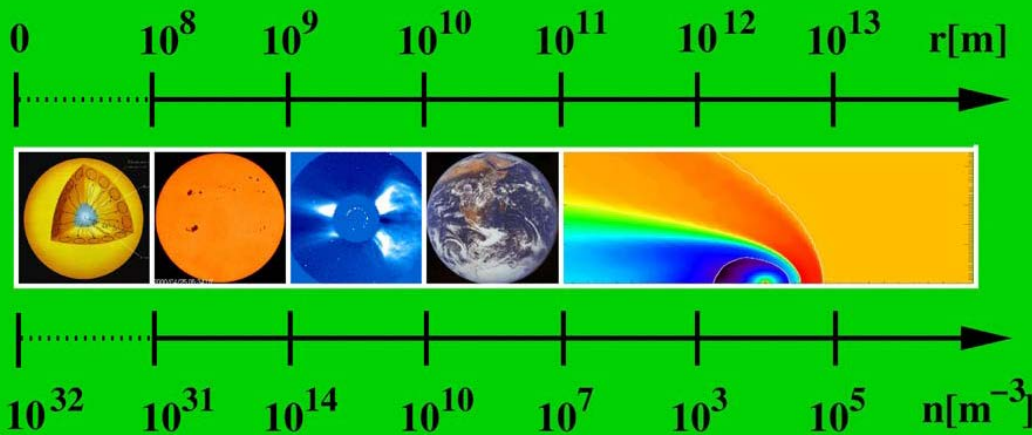
See talks by Karpen & Okamoto



30-Nov-2006
01:10:31 UT

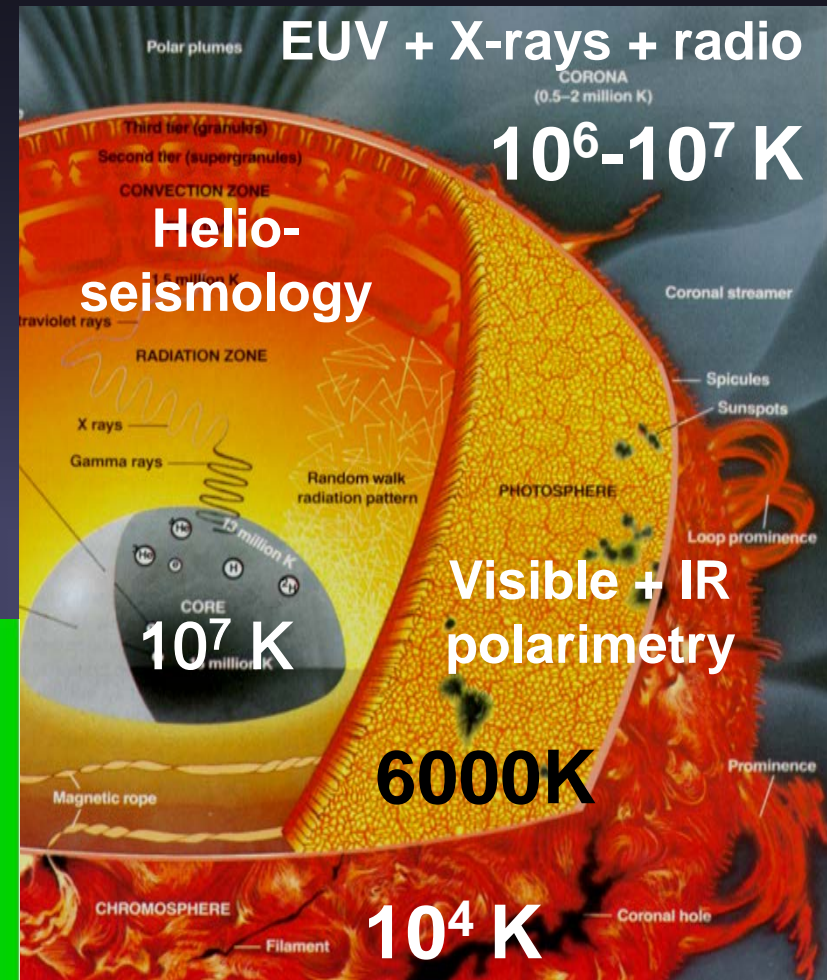
The Sun: a broad field of research

- Broad range of physical parameters. E.g. density changes by $\approx 10^{28}$ from solar core to Heliopause. Temperature varies by $\approx 10^4$
- ➔ Different instruments, different techniques, different communities



The Sun: a broad field of research

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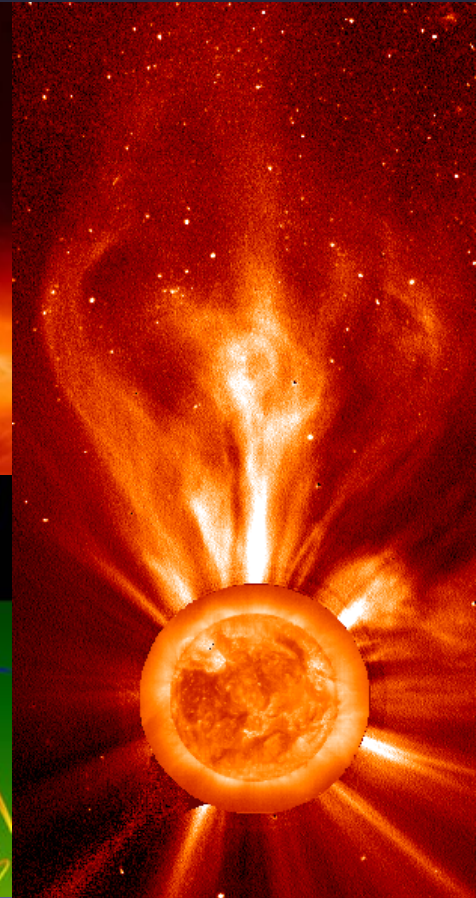
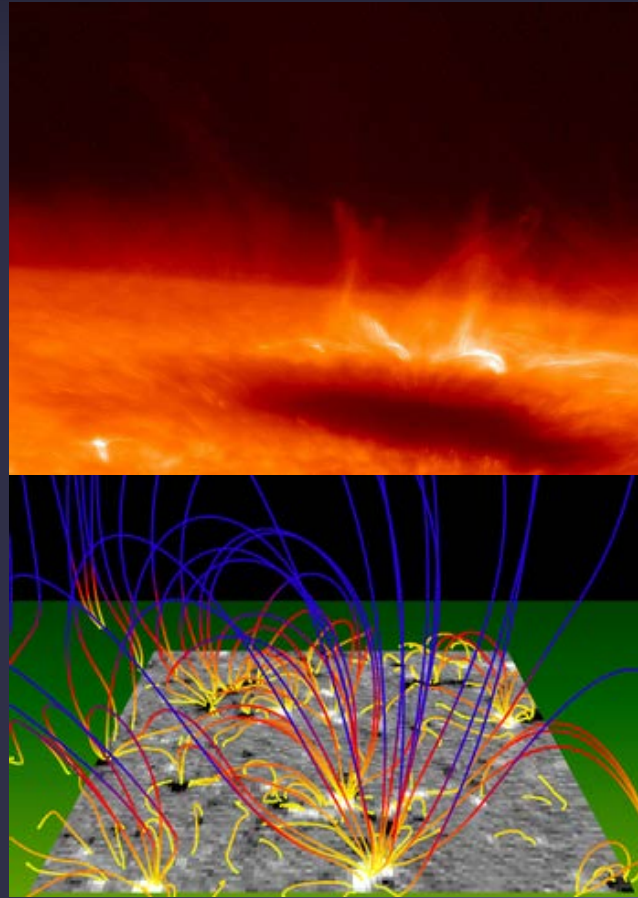


Such divisions pose a major challenge to progress. This conference will help to overcome them



Different solar layers are coupled

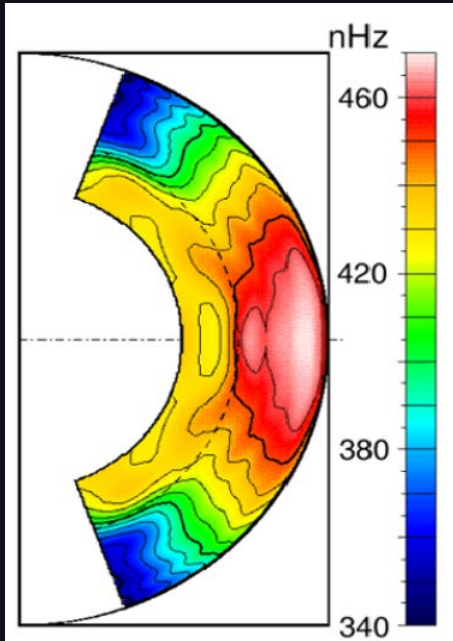
- Sun's layers from convection zone to heliosphere are coupled: lower layers determine structure & energetics of upper layers & sometimes vice versa
- Coupling agents: Radiation, **Magnetic fields**, waves, advection,...
- **Magnetic fields** transport energy from solar interior into upper atmosphere and dissipate it there
- **Magnetic fields** transport material to other regions of the atmosphere (via jets, CMEs, solar wind)
- **Magnetic fields** accelerate energetic particles, e.g. in flares



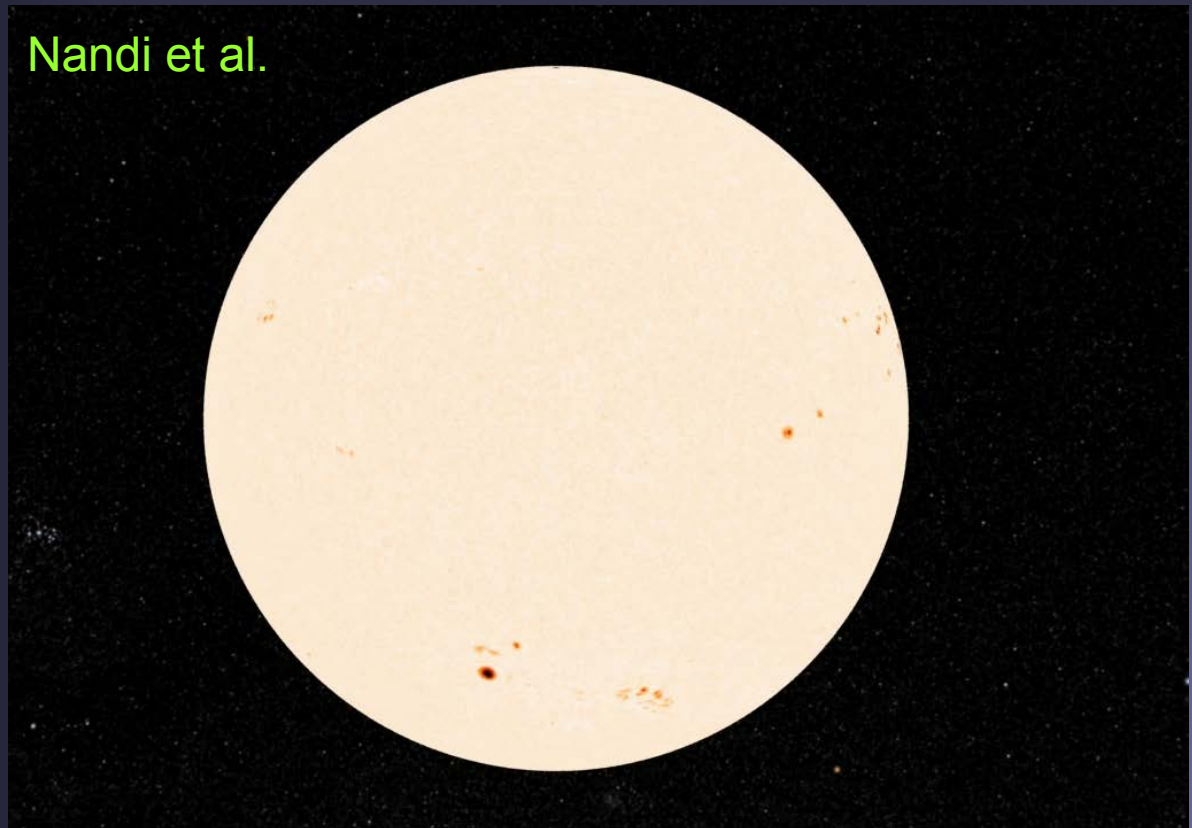
Production of magnetic field

Flows on surface and in interior of the Sun are key to producing the Sun's field: differential rotation, meridional circulation and turbulent convection

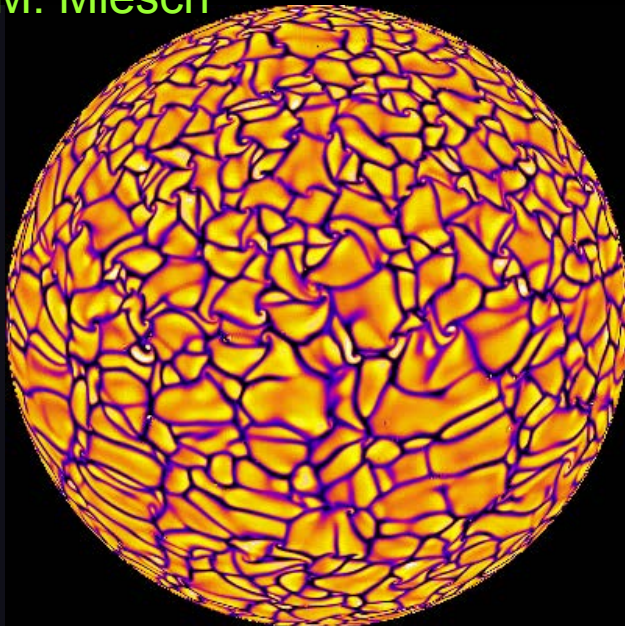
Talks by: Gizon, Hanasoge, Subramanian, Rempel, ...



Nandi et al.



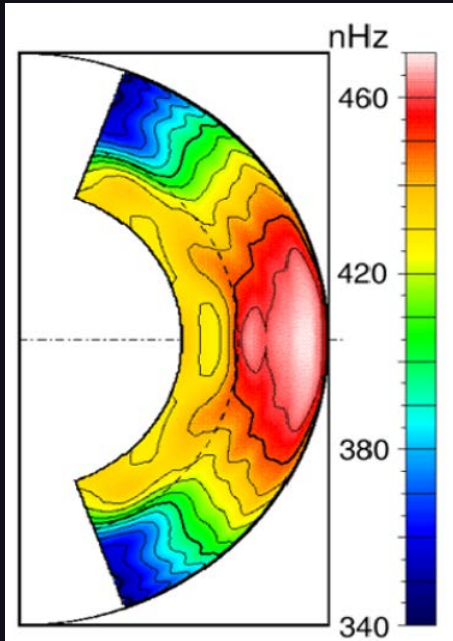
M. Miesch



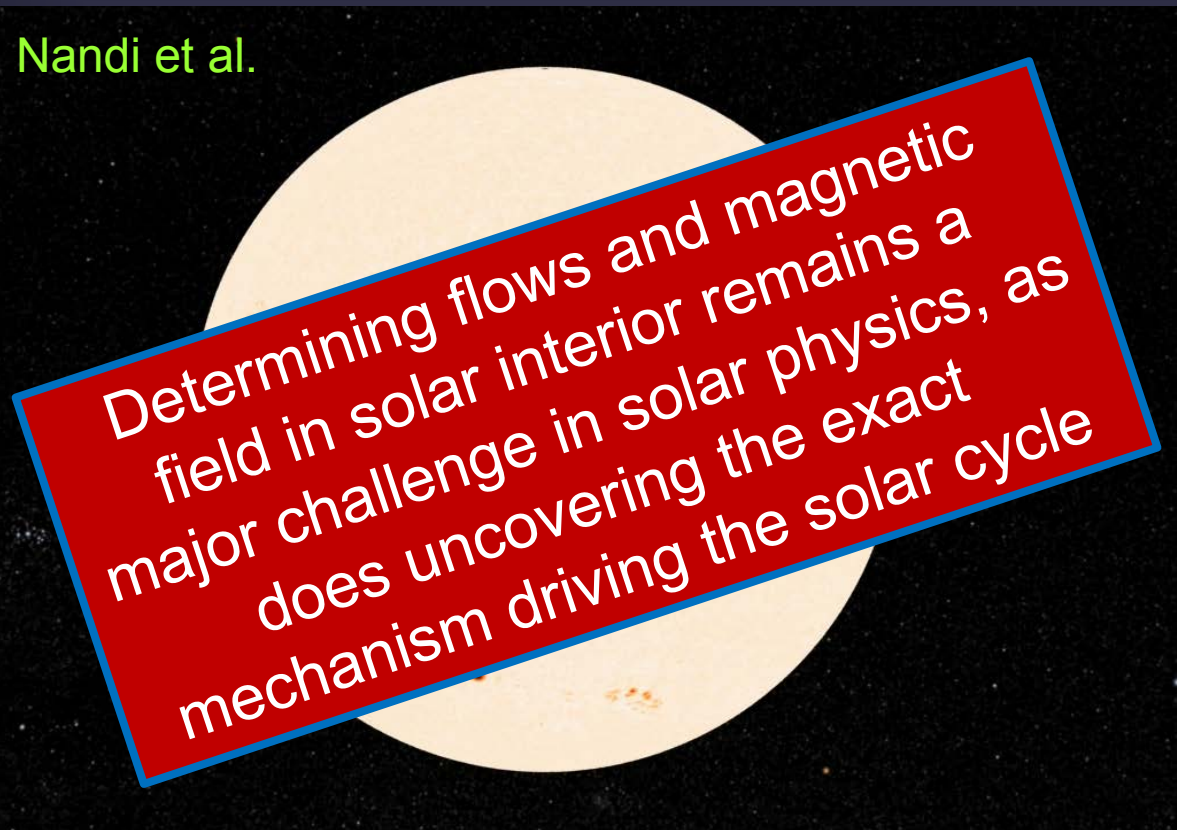
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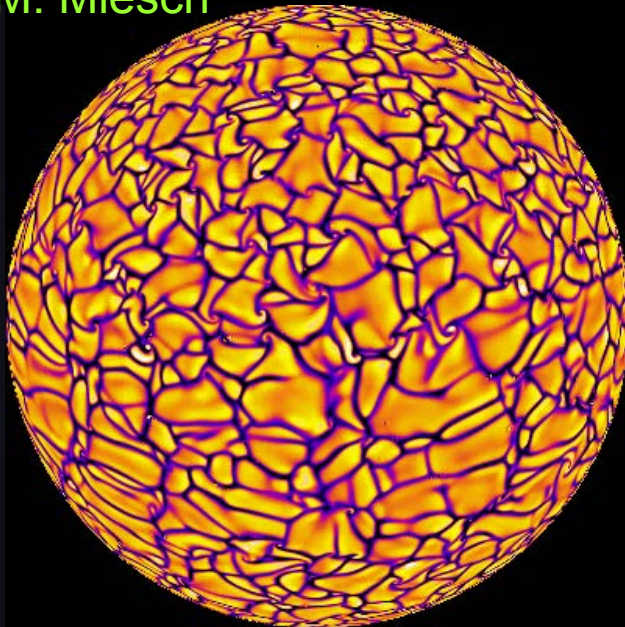
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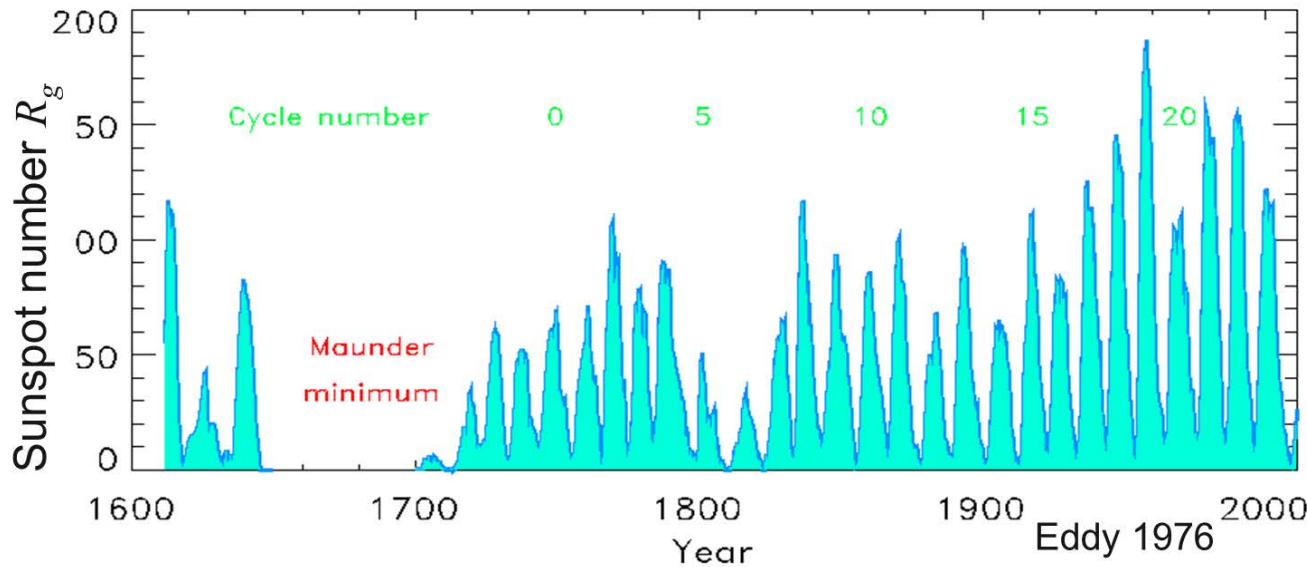
Nandi et al.



M. Miesch



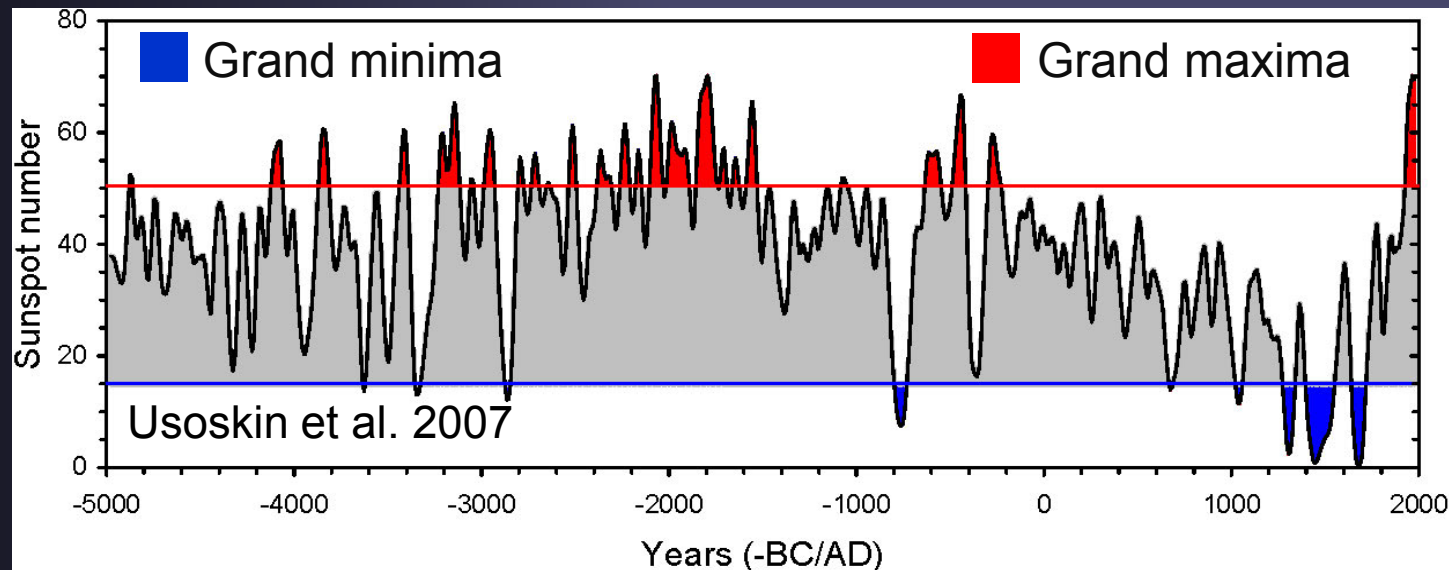
Solar cycle and long-term activity variations



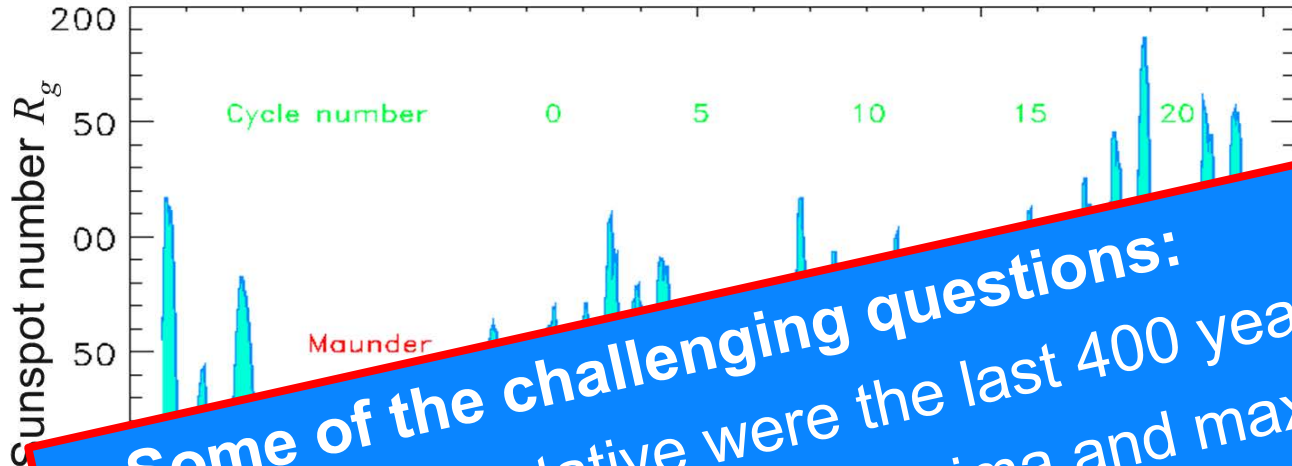
For the last 404 years we have direct records of sunspot number.

Besides the solar cycle, also large longer term variations are seen

Activity over the Holocene can be reconstructed using cosmogenic isotopes. Many sources of uncertainty



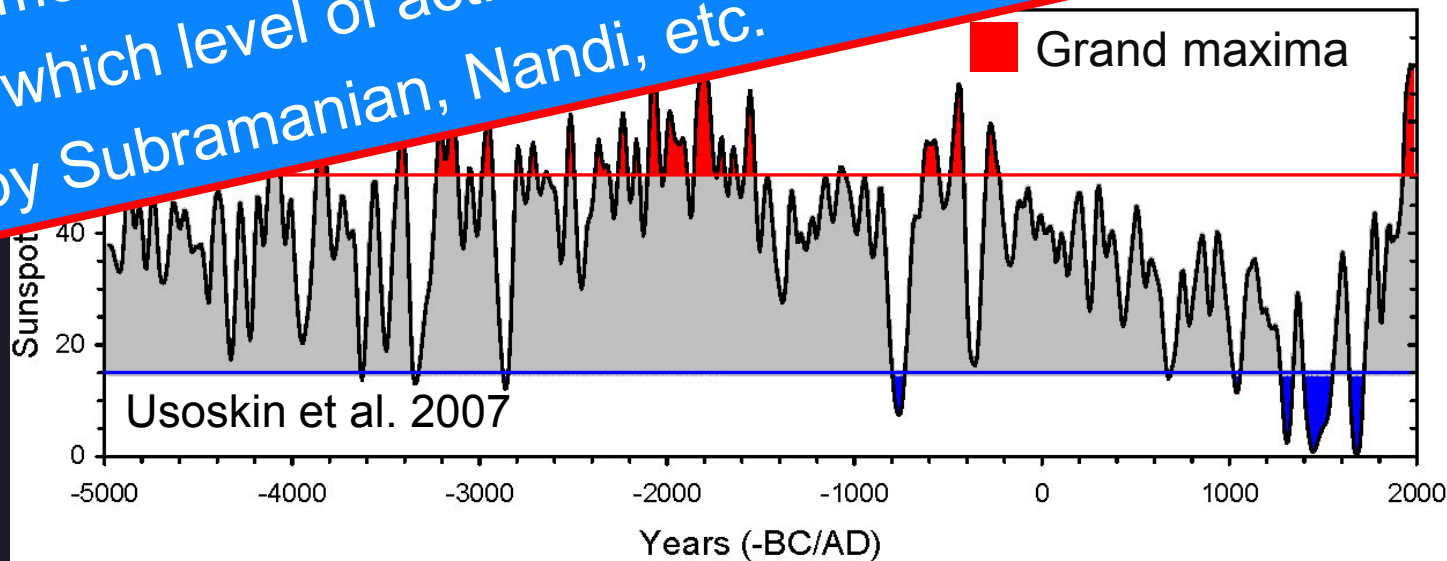
Solar cycle and long-term activity variations



For the last 404 years we have
discovery of

- Some of the challenging questions:**
1. How representative were the last 400 years?
 2. How common are grand minima and maxima?
 3. Towards which level of activity is the Sun heading?
- See talks by Subramanian, Nandi, etc.

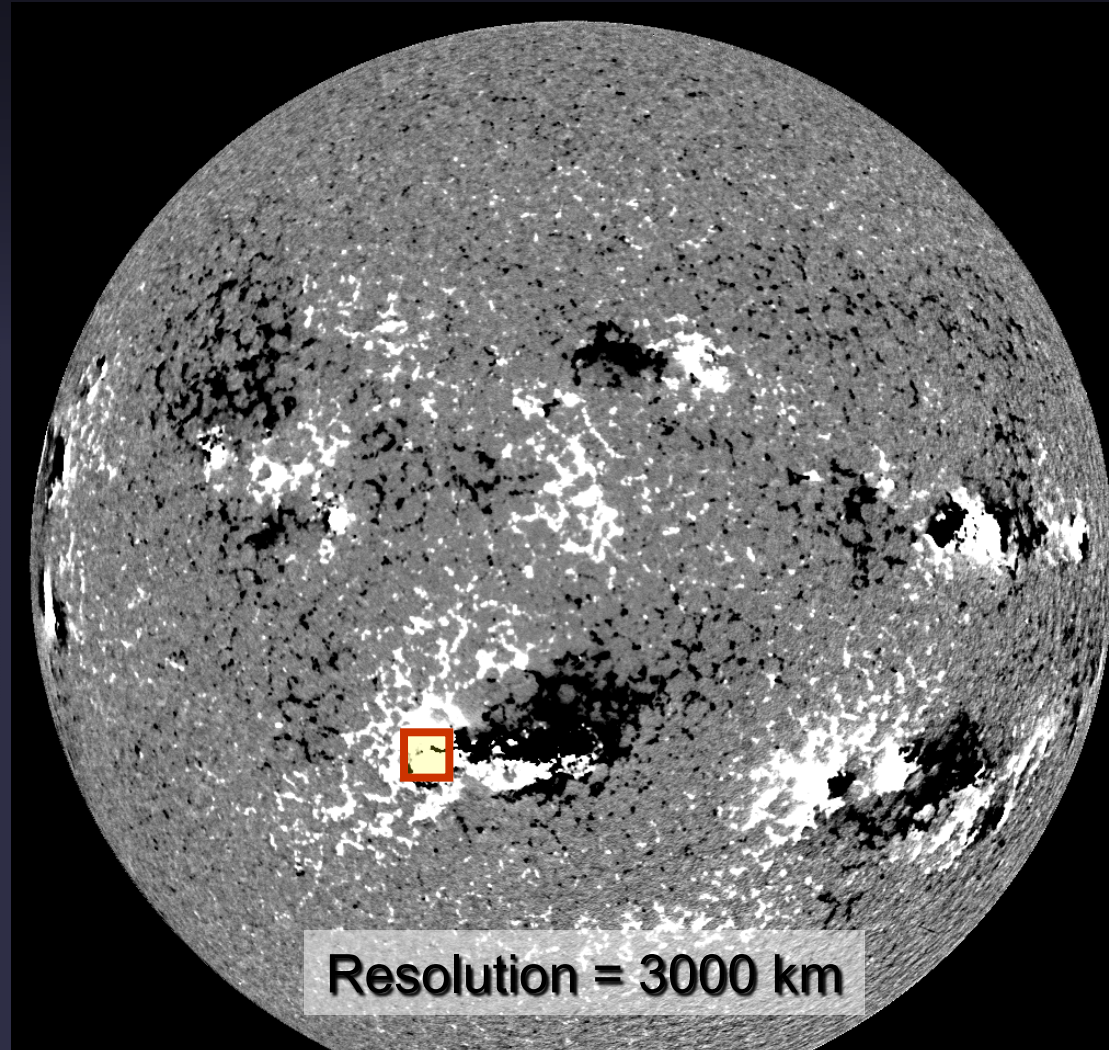
Ad
How
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Measurement of solar magnetic fields

Main Techniques:

- **Zeeman effect:**
spectropolarimetric obs. (most solar B measurements; mainly solar surface); vis - IR
- **Hanle effect:**
spectropolarimetric observations; UV - IR
- **Gyroresonant emission:**
strong field regions in the corona; radio

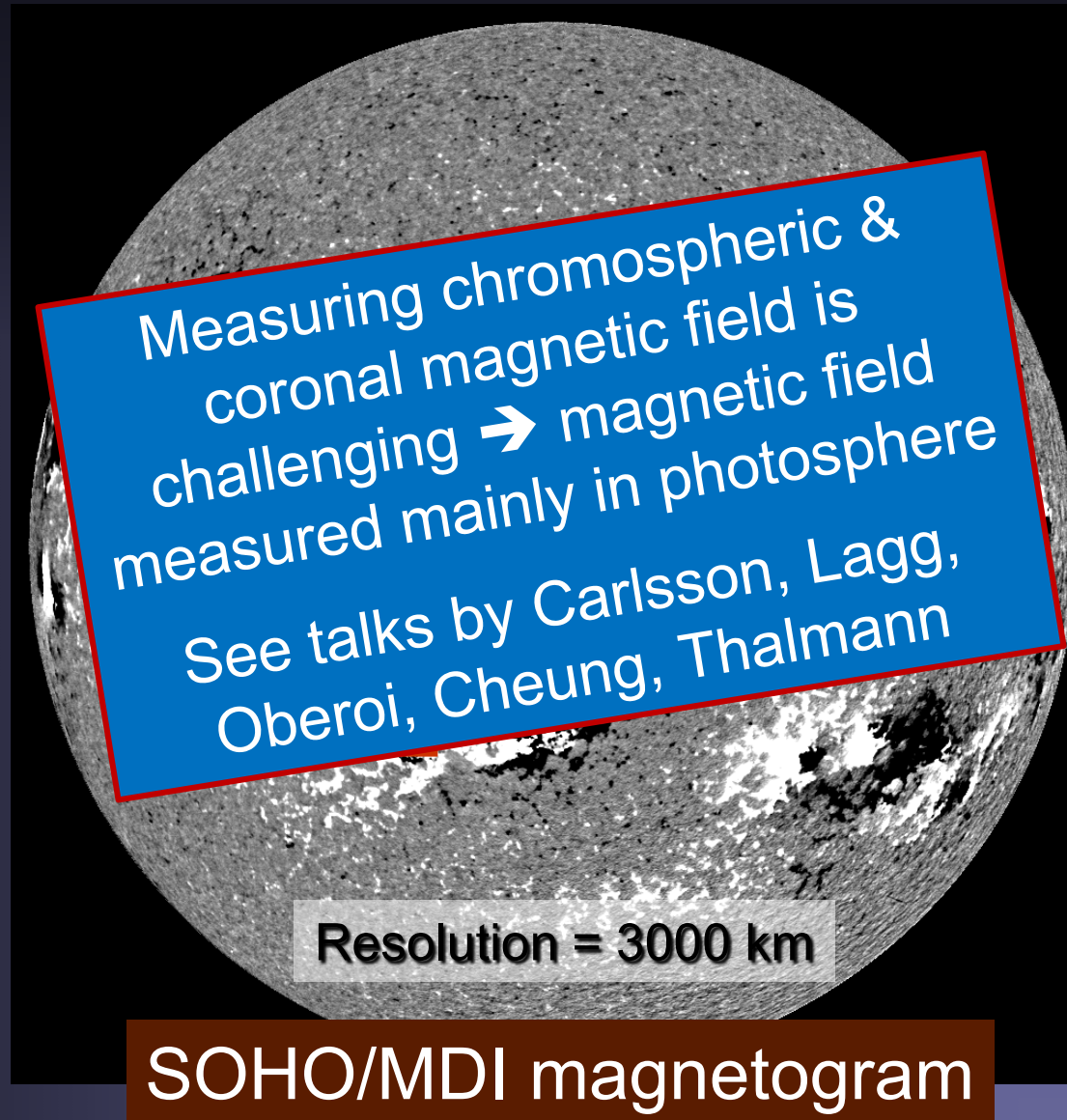


SOHO/MDI magnetogram

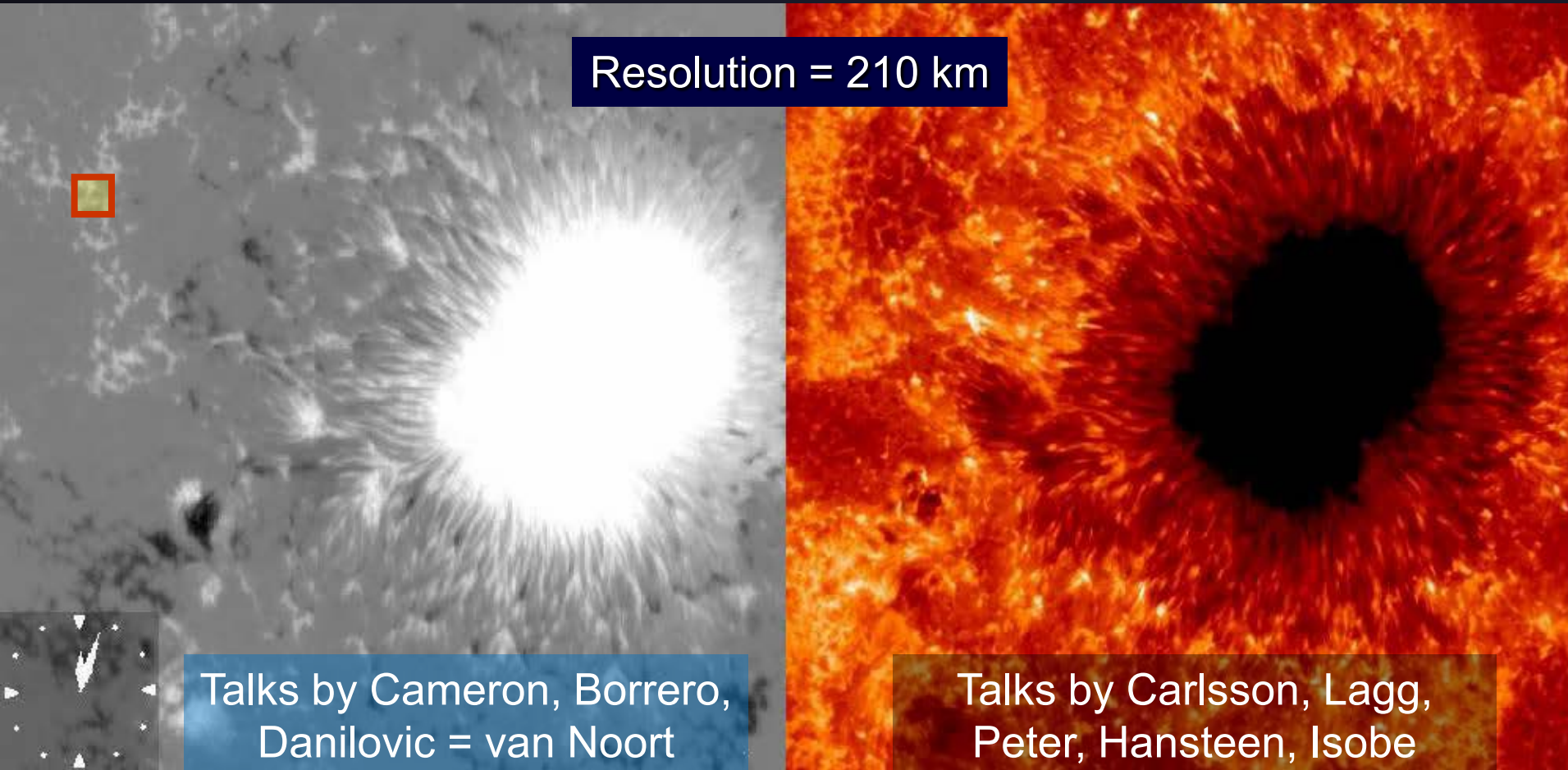
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Fresh structures and patterns appear at higher resolution



Magnetograms (left) & Ca II K images by Hinode

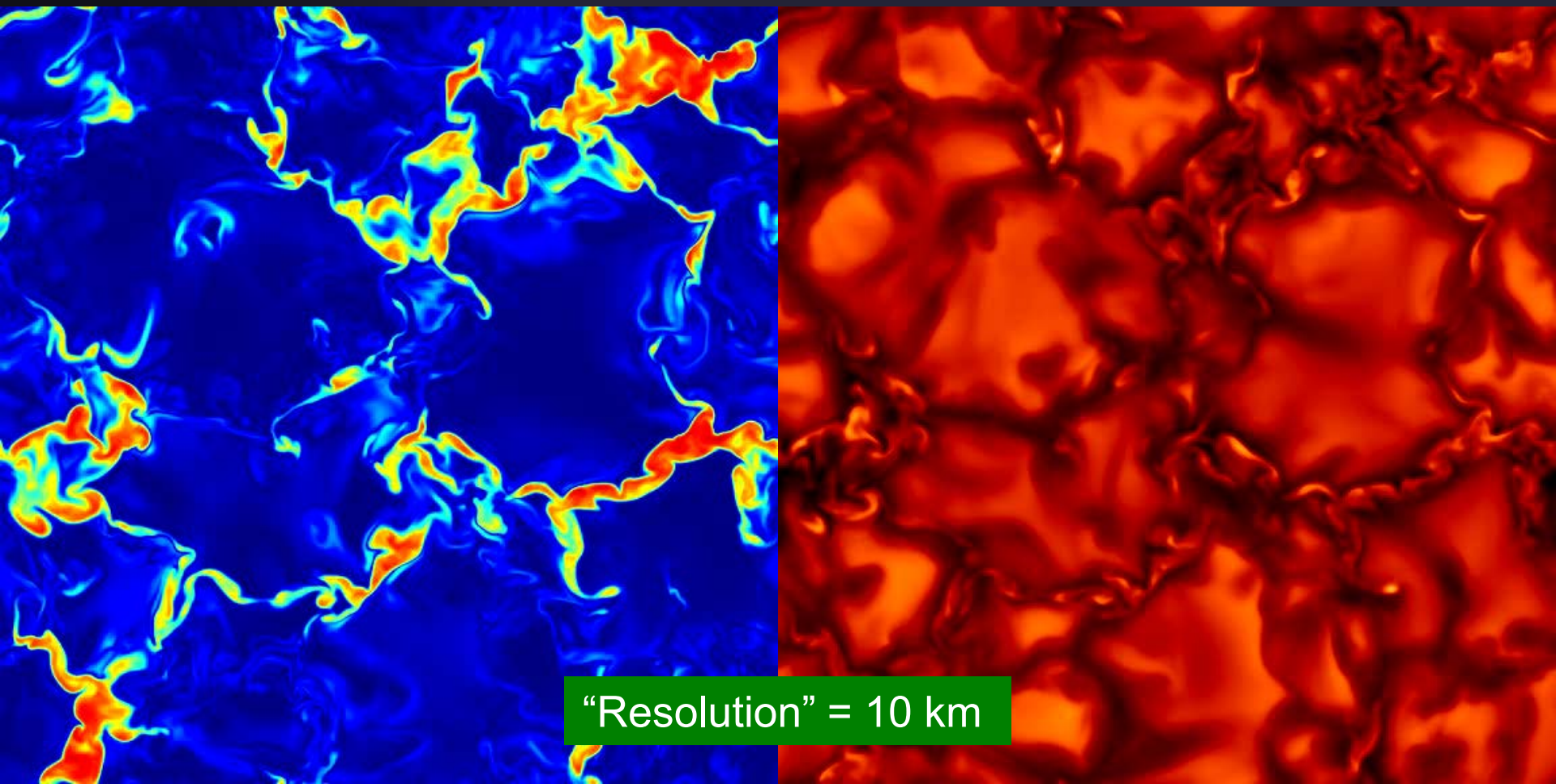
Structure and dynamics at very small spatial scales

Radiation-MHD Simulations of small-scale magnetic fields

Magnetic field

Vögler et al.

Intensity



"Resolution" = 10 km

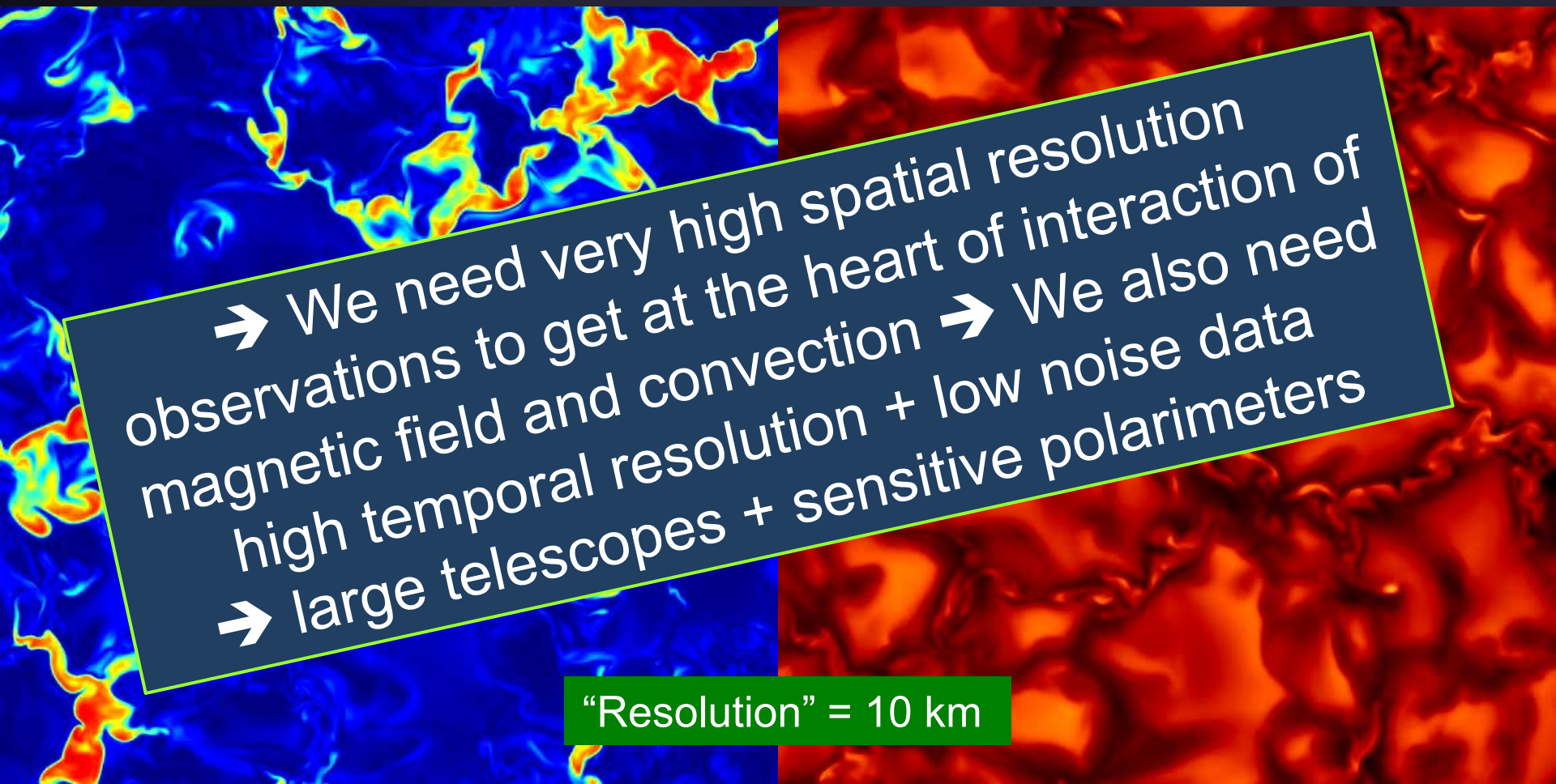
Structure and dynamics at very small spatial scales

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Magnetic field

Vögler et al.

Intensity



→ We need very high spatial resolution observations to get at the heart of interaction of magnetic field and convection → We also need high temporal resolution + low noise data → large telescopes + sensitive polarimeters

“Resolution” = 10 km

Emergence of magnetic field

**Simulation by Mark Cheung (Cheung et al. 2011)
using MURAM code**

Twisted Ω -shaped flux tube with $7.6 \cdot 10^{21}$ Mx rises through bottom

Domain size: $(x, y, z) = (92, 49, 8.2)$ Mm

Grid scale: $(x, y, z) = (48, 48, 32)$ km

Magnetogram: black & white are opposite polarities

Magnetic field seen from the side; top is solar surface

Talks by: Moreno Inertis, Cheung

$t = 0$ hrs 00 mins

The magnetic field produced deep inside the Sun rises to solar surface driven by buoyancy and breaks through to form active regions and sunspots

Emergence of magnetic field

Simulation by Mark Cheung (Cheung et al. 2014)
using MURAM code

Twisted Ω -shaped flux

Domain

C

M

Ma

Talk

Simulations are getting more and more powerful, but we still need to combine local, detailed MHD simulations with global ones (particularly challenging for models including the chromosphere)

t = 0 hrs 00 mins

The magnetic field produced deep inside the Sun rises to solar surface driven by buoyancy and breaks through to form active regions and sunspots

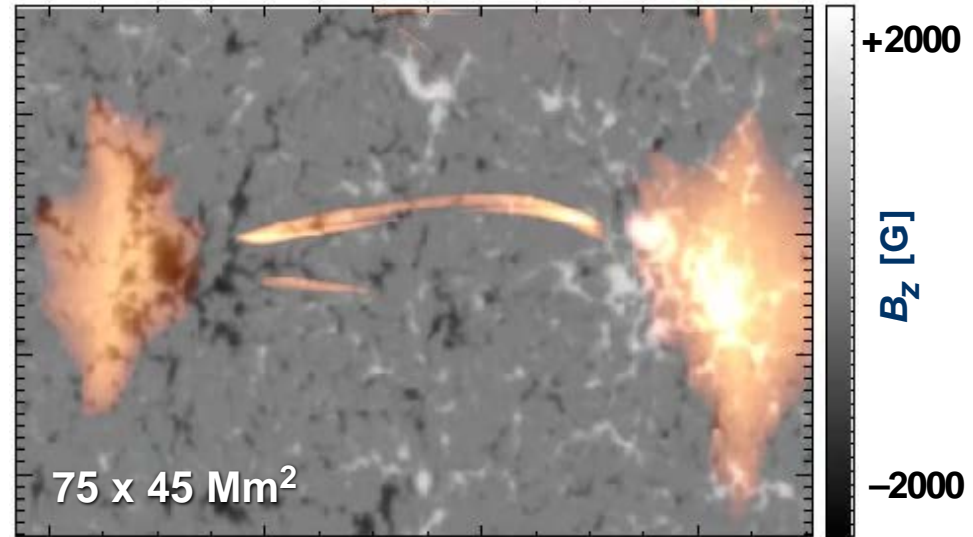
Corona above emerging flux simulation

- ▶ loops form at different places at different times after the sunspots have formed
- ▶ loop footpoints are in sunspot periphery (penumbra)
- ▶ loops form where Poynting flux in the photosphere peaks
→ where / when flux is pushed into sunspot

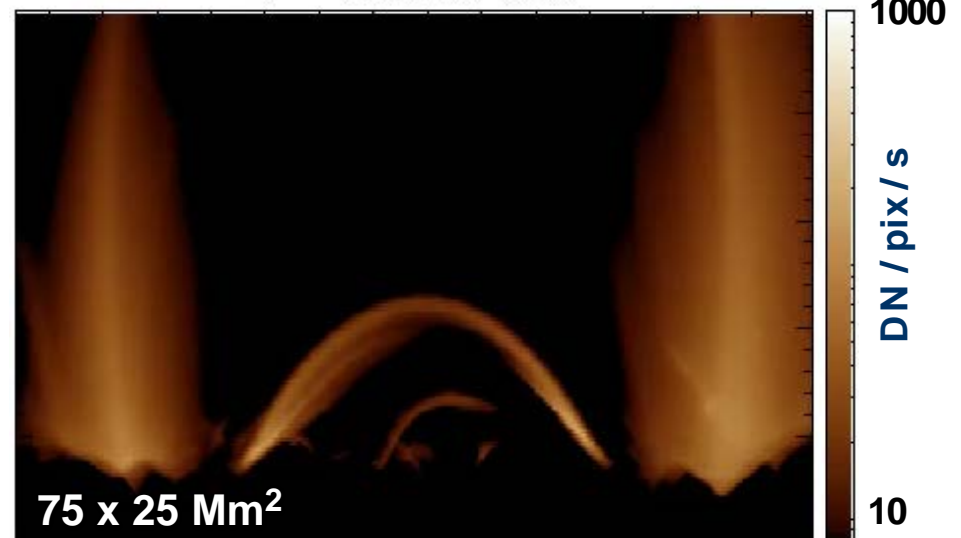
Chen et al. (2014) A&A

See talks by Klimchuk, Mason, Peter, Cheung, Isobe, Oberoi, Thalmann

view from top: B_{vert} @surface + AIA 193 Å



from side $t = 60.000$ min



Corona above emerging flux simulation

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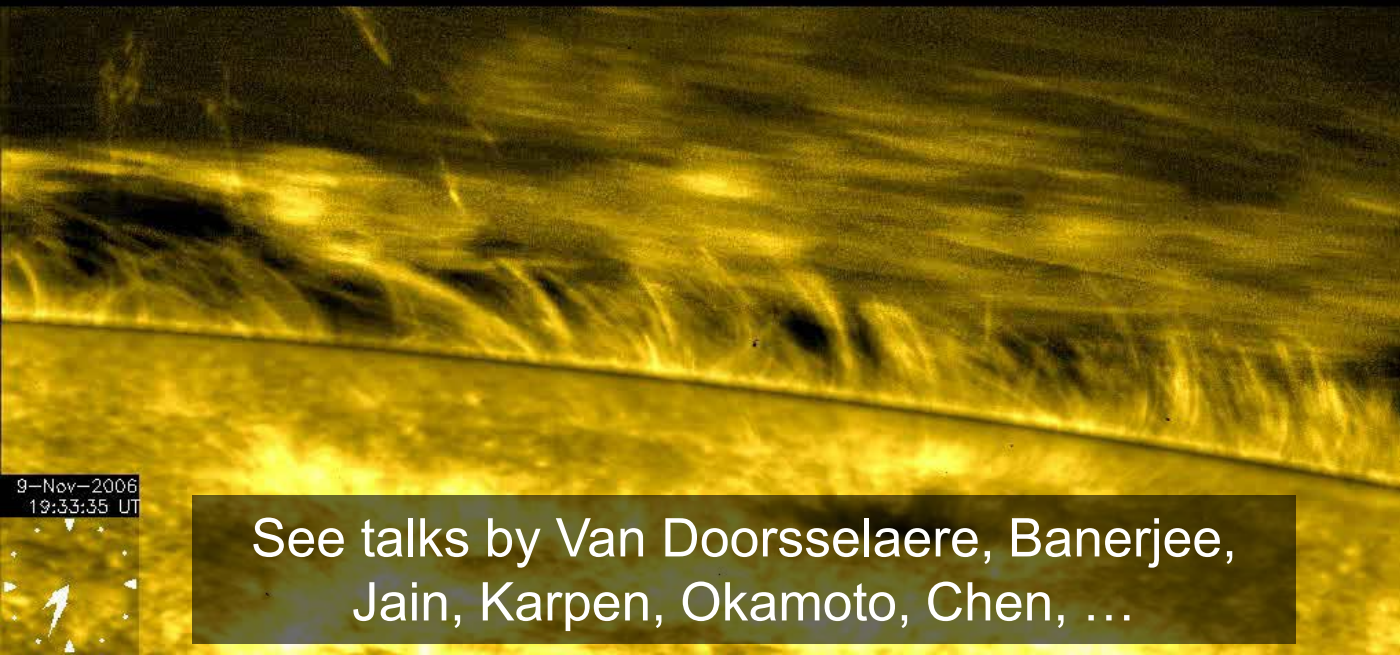
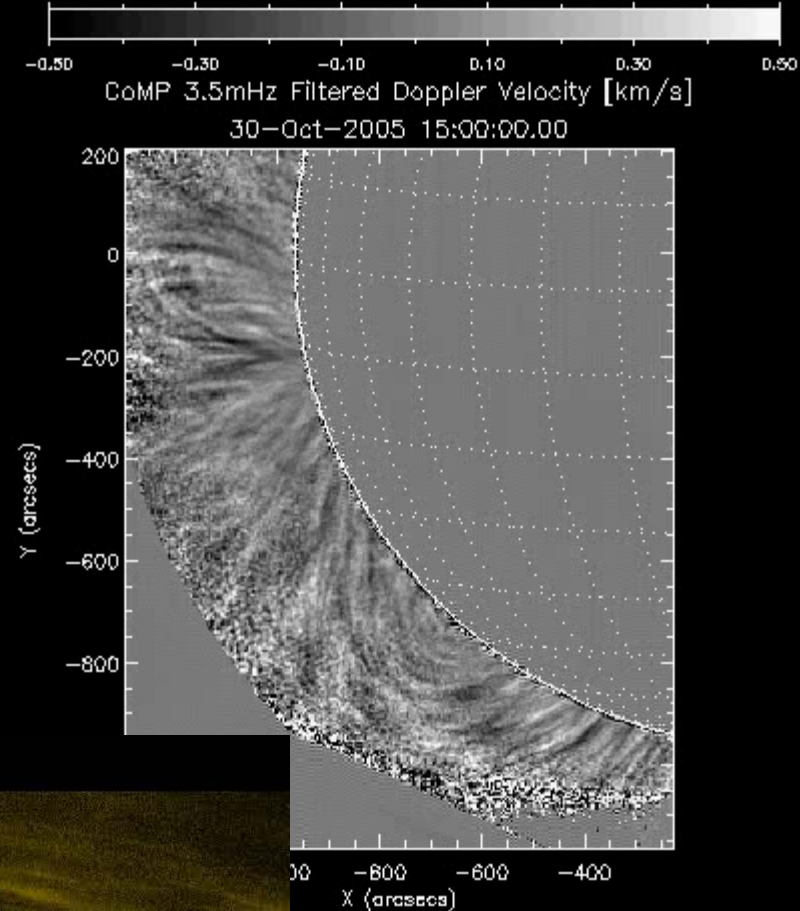
Chen et al. (2014) A&A

See talks by Klimchuk, Mason, Peter, Cheung, Isobe, Oberoi, Thalmann



Swaying spicules and waving loops

Alternative mechanism for transporting energy into corona is by waves: many types of waves detected in recent years. Dissipation of the energy is often the problem: either too quick or too slow



See talks by Van Doorselaere, Banerjee, Jain, Karpen, Okamoto, Chen, ...

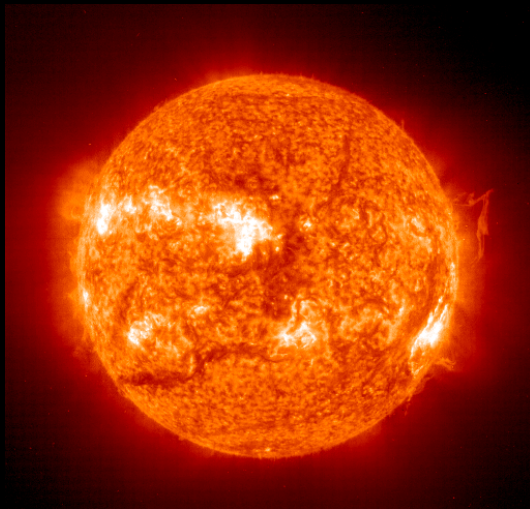
Tomczyk et al.
2007

Okamoto et al.
2007

De Pontieu et al.
2007

Global strategy to study Sun: Goals

High latitude (polar processes and dynamo, 3-D star/CMEs)



Close up / co-rotation (link Sun and inner heliosphere)

Out of Sun-Earth line/multi-point observations



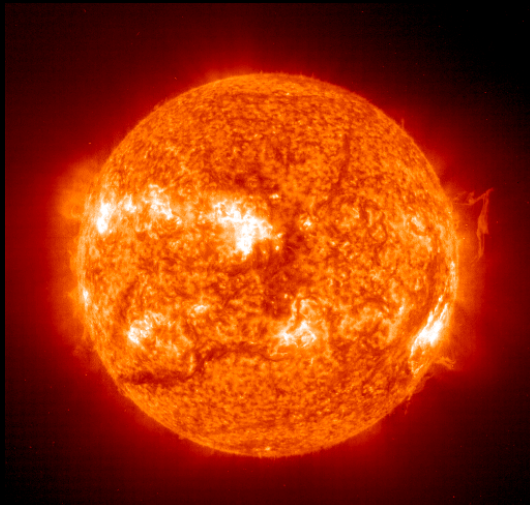
Outer heliosphere

Out of Sun-Earth line/multi-point observations (3-D star, Earth-directed ejecta)

High resolution, high cadence ground-based, Earth Orbit or L1 (fundamental processes)

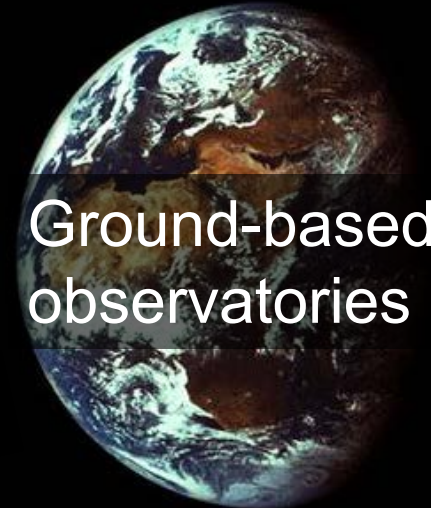
Global strategy to study Sun: Missions

Solar Orbiter [2017]



Solar Orbiter

Solar Probe
[2018]



Ground-based
observatories

STEREO
[2006]

Voyagers
1 + 2

STEREO [2006]
RIP?

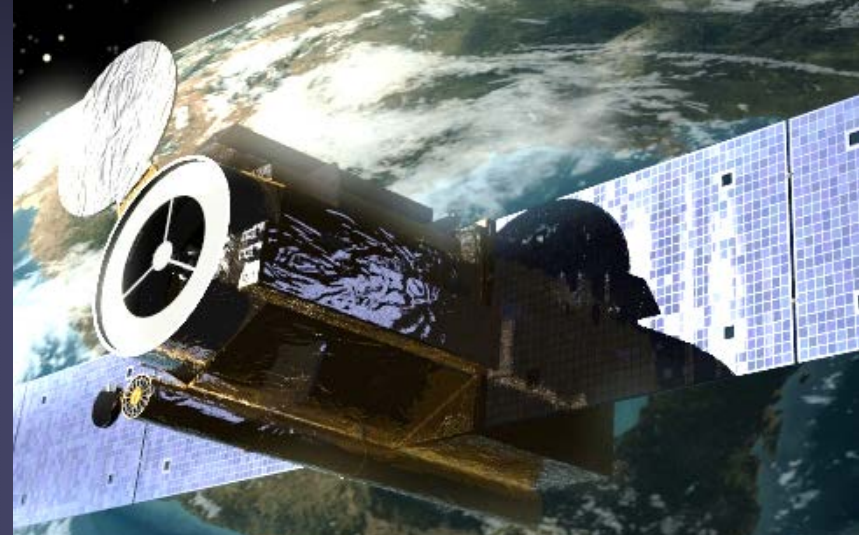
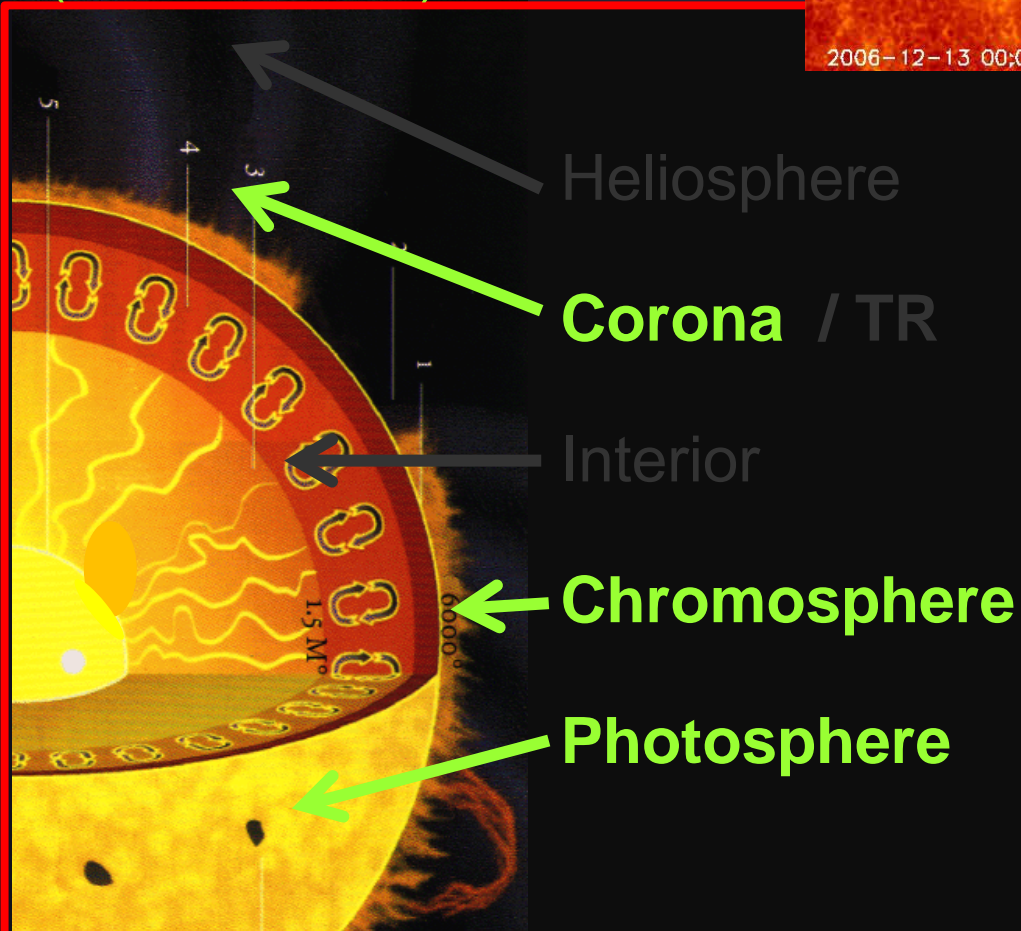
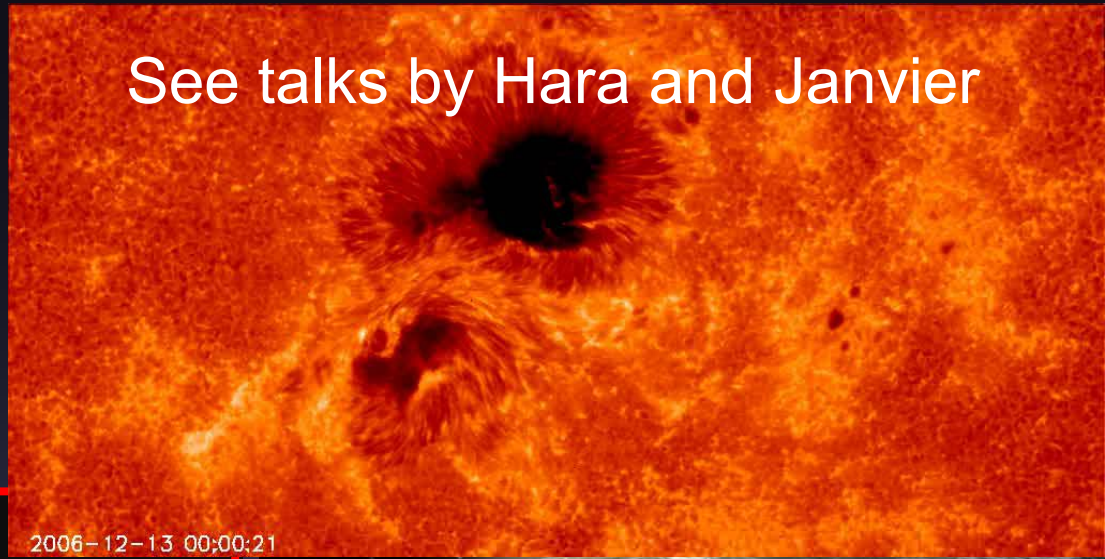
SOHO [1995] Rhesi [2001] Hinode
[2006] Sunrise [2009] SDO [2010]
Proba2+3 [2009,2018] Iris [2013]
Solar-C [2022] Aditya [2018]

Key:
NASA, ESA, JAXA, others

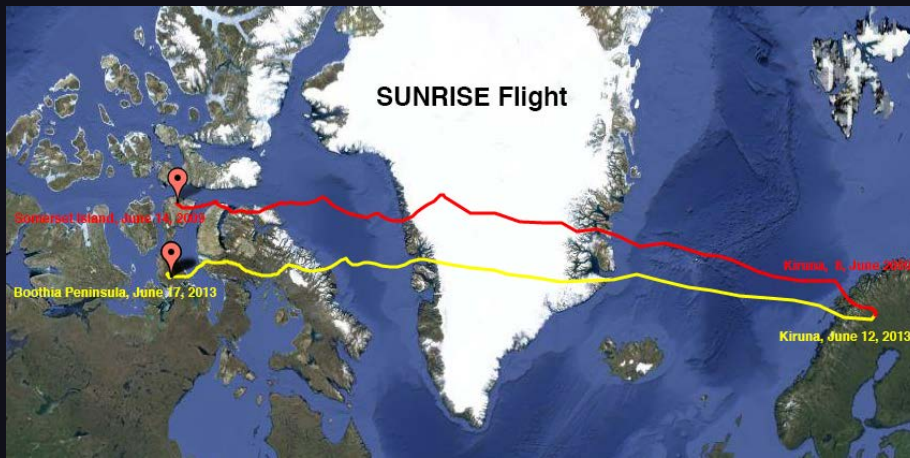
Hinode

JAXA, ESA, NASA mission to study photosphere and corona at high resolution (3 instruments)

See talks by Hara and Janvier



One highlight: discovery of huge amounts of “hidden” magnetic flux in the photosphere



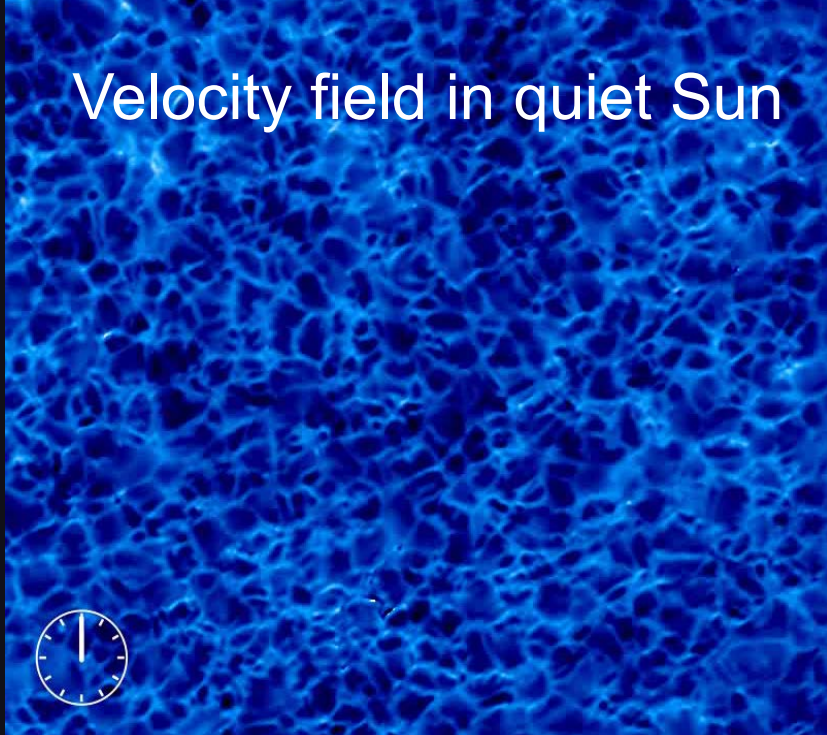
Sunrise

A mission aiming to resolve the structure and dynamics of the Sun's magnetic field

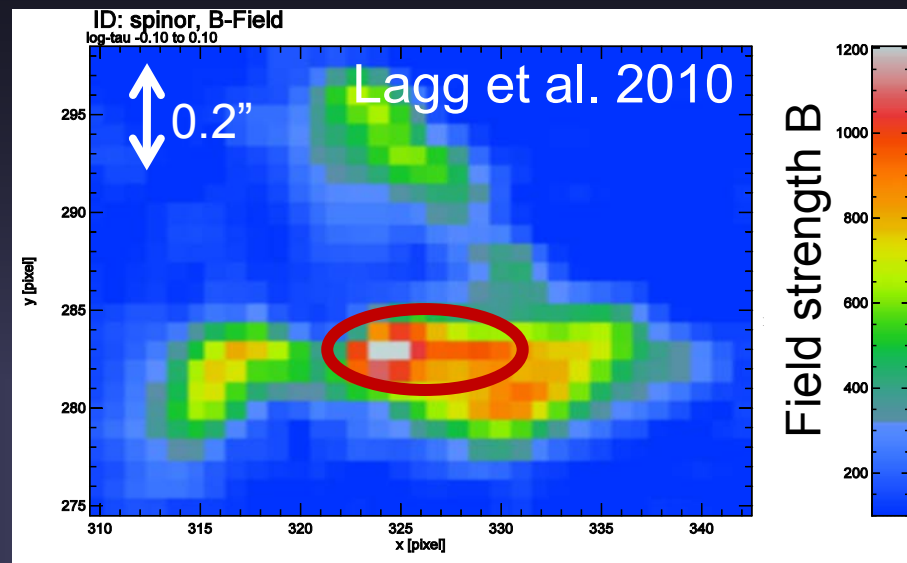


Balloon-borne observatory with 1-m telescope to observe magneto-convection at small spatial scales on Sun (largest solar telescope to leave ground)

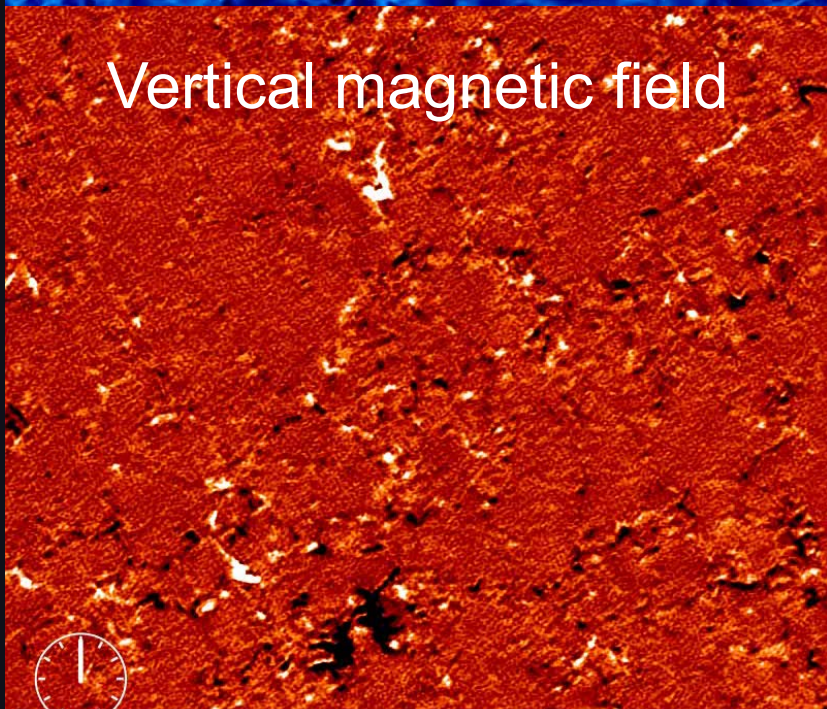
Velocity field in quiet Sun



Magnetic elements resolved



Vertical magnetic field



Measurements directly give $B > 1000$ G, even in quiet Sun → for the first time solar magnetic elements are spatially resolved

See talk by Danilovic → van Noort

Interface Region Imaging Spectrometer

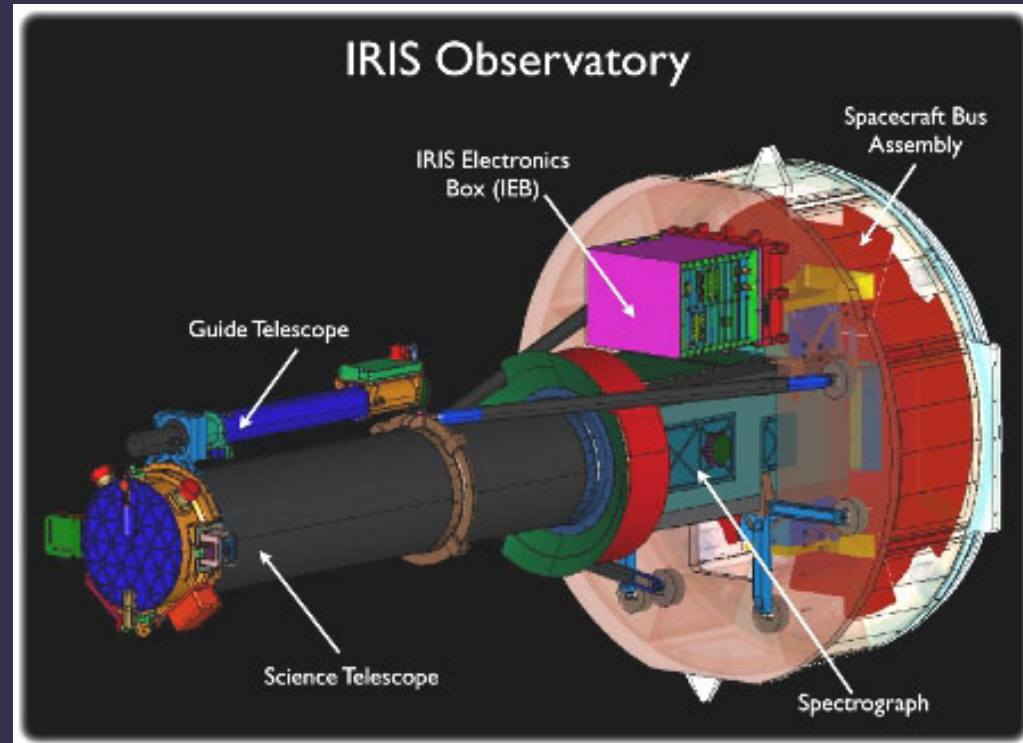
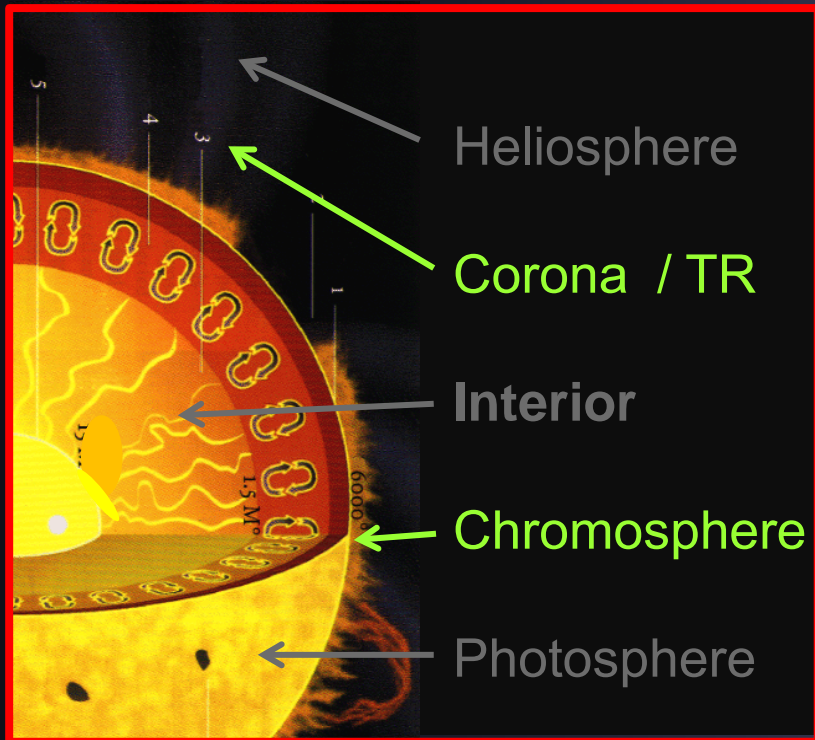
FUV spectrometer (similar to SUMER)

Covers chromosphere, transition region and partly corona

Observes with 0.3 arc s pixels

Takes slit jaw images

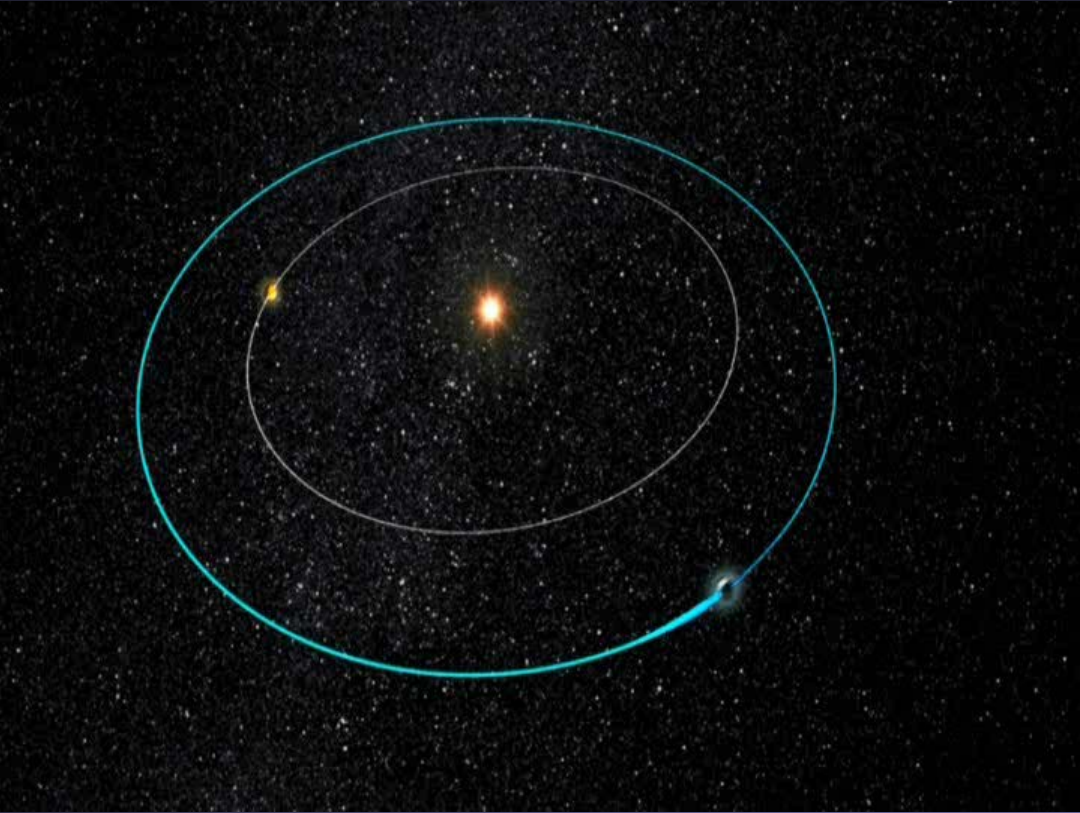
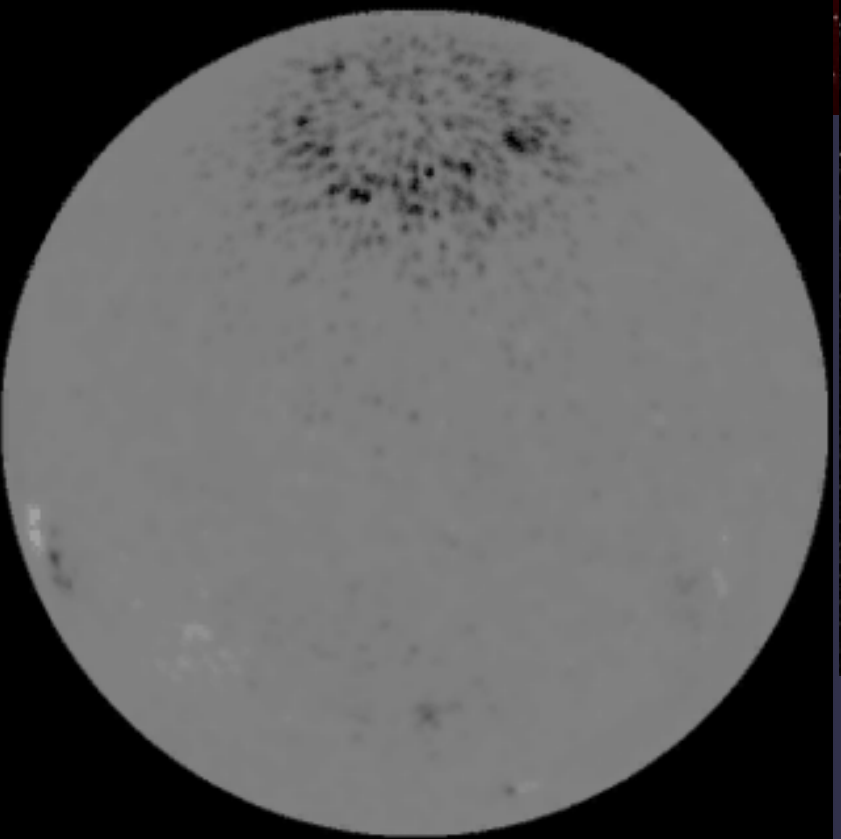
See talk by Tian → Peter





Solar Orbiter

A high-resolution mission to the Sun and inner Heliosphere
(launch scheduled 2017)



Combines in situ & remote sensing instruments



Solar Orbiter

A high-resolution mission to the Sun and inner Heliosphere
(launch scheduled 2017)

Find out how the Sun controls the Heliosphere
→ Fly in the challenging environment close to the Sun
→ See talks by Subramanian, Gibson, Karpen
Also SO will explore the Sun's polar regions

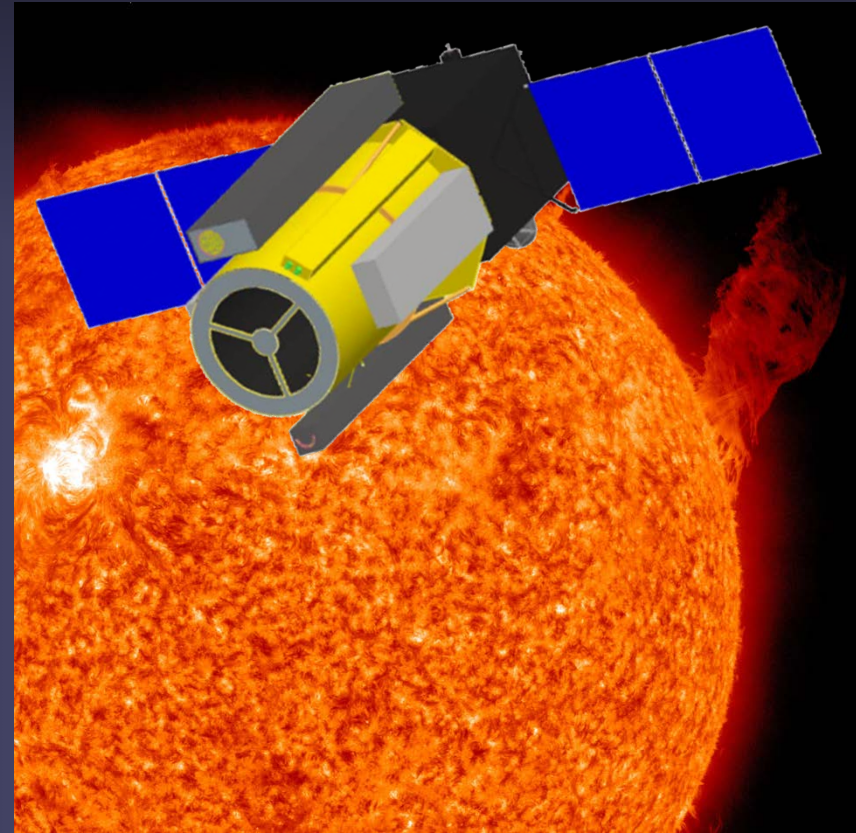
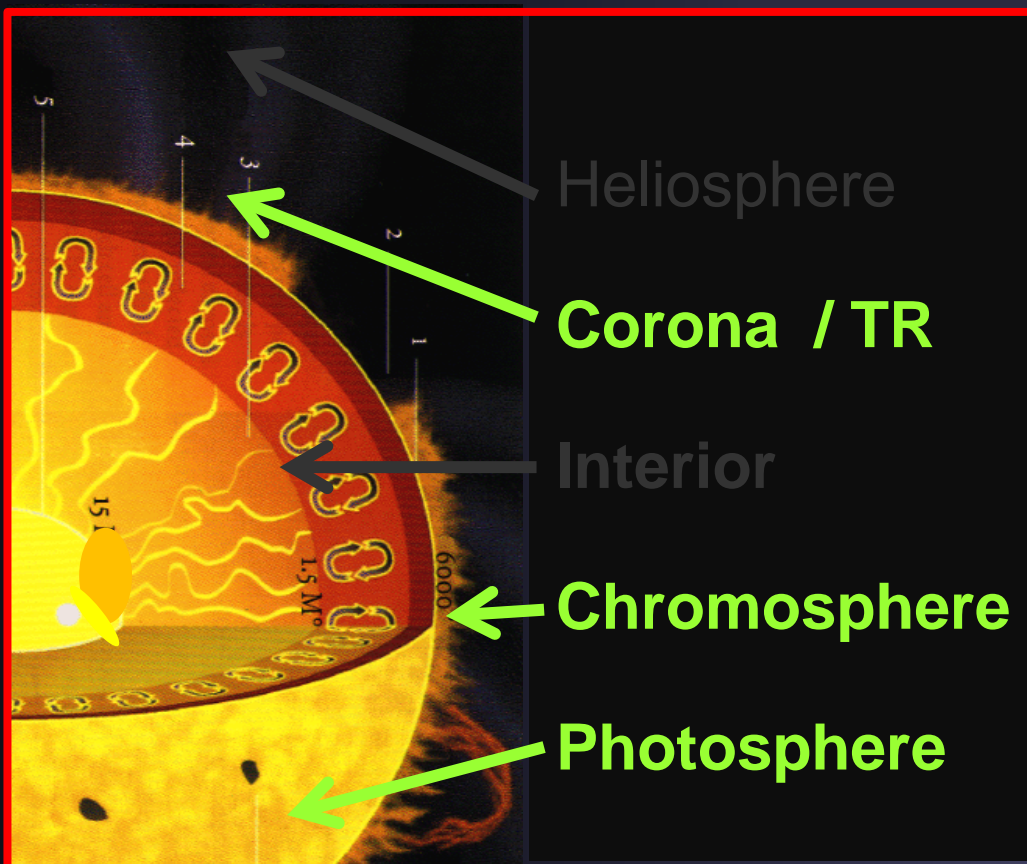
Combines in situ & remote sensing instruments

Solar-C

Mission being proposed to JAXA, ESA and NASA.
Launch expected around 2021-2023

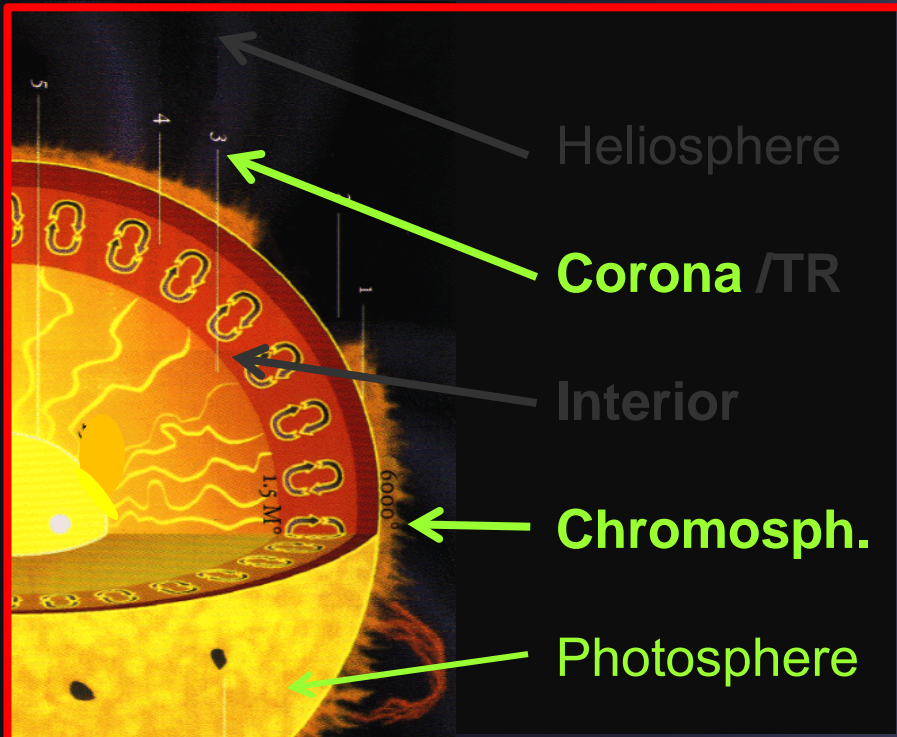
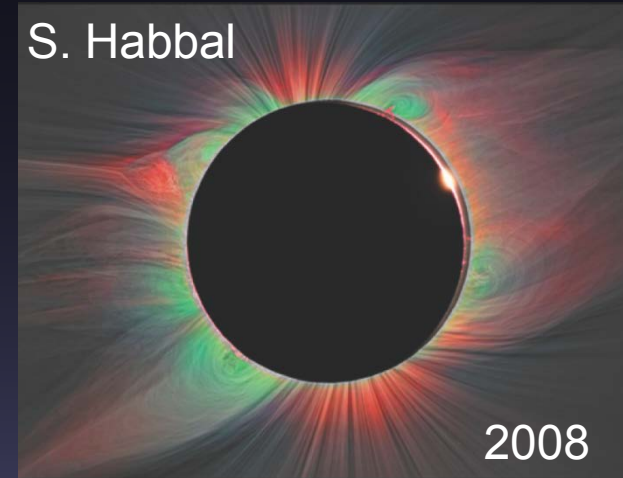
Aim: very high resolution

3 telescopes (it will be a “super Hinode” + “super IRIS”)



Aditya: proposed Indian space mission

- Provide new insights into:
 - Coupling & Dynamics of Solar Atmosphere
 - Solar variability (of relevance to climate)
 - Solar flares
 - Prominences



- Observe from L1 vantage point
- 6 Instruments:
 - Visible Emission-Line Coronagraph (VELC)
 - Solar UV Imaging Telescope (SUIT)
 - Soft and hard X-ray telescopes
 - Plasma and solar wind packages
- See talk by S. Seetha

New High Resolution Observatories



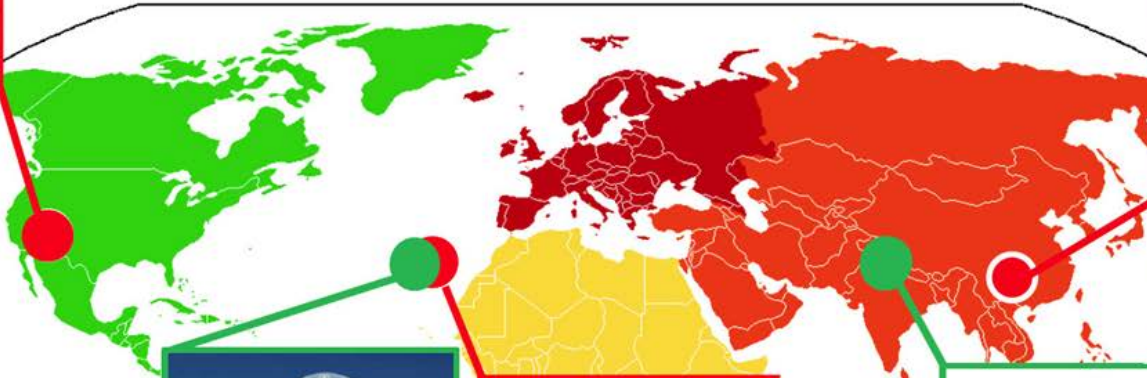
BBSO New Solar Telescope

1.6m USA



Yunnan Obs. Solar Telescope

1m China



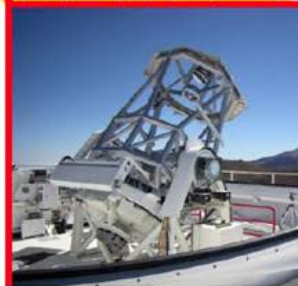
Advanced Technology Solar Telescope

4m USA



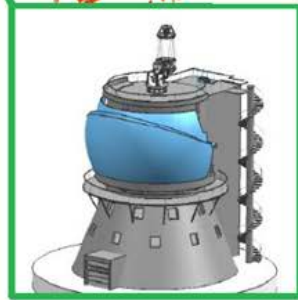
European Solar Telescope

4m EUR



Gregor

1.5m D/ES



National Large Solar Telescope

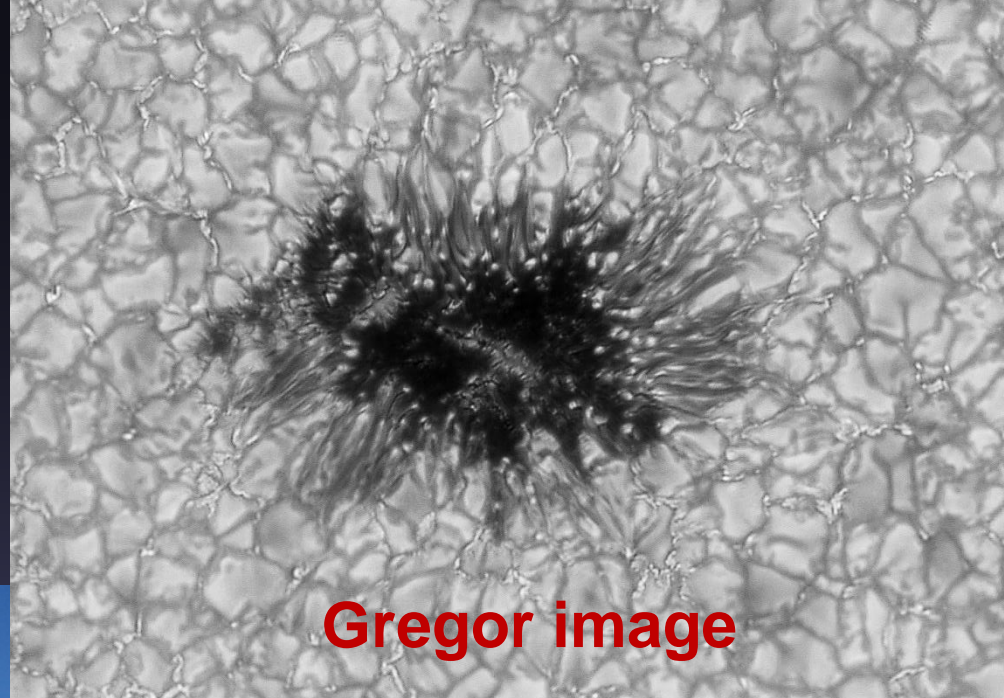
2m India

Design Construction Commissioning

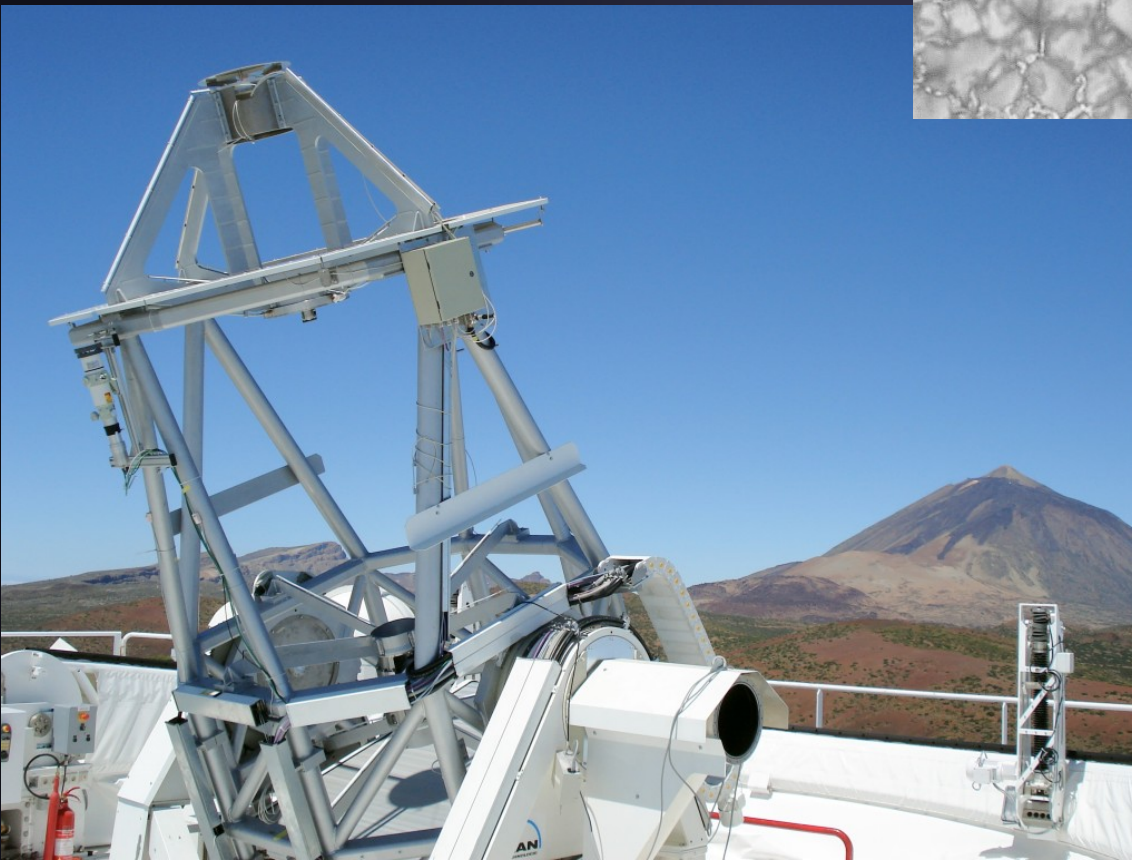
Fig. kindly provided by Siraj Hasan

Ground-based solar telescopes

A new generation of large solar telescopes is now providing outstanding data



Gregor image



Gregor, with 1.5m mirror and NST with 1.6m are, along with the 1m telescope in Yunnan, the new large telescopes

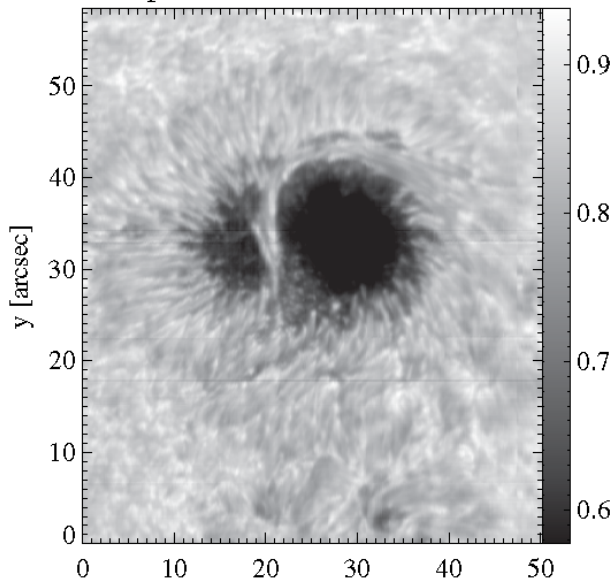
The SST at 1m is still providing outstanding science

Ground-based solar

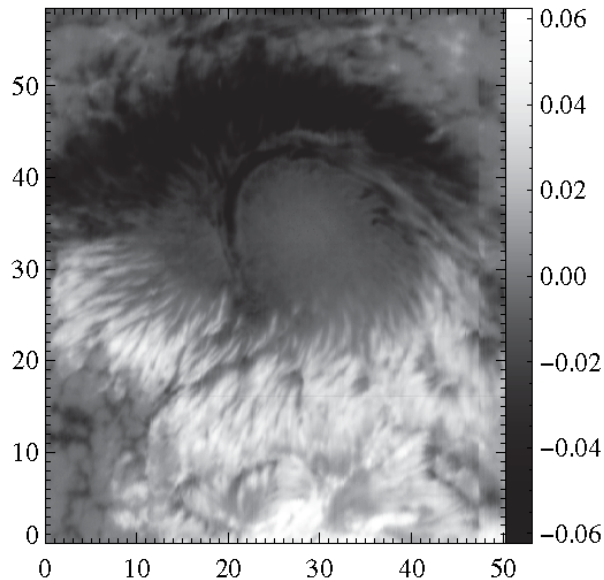
A new solar providing



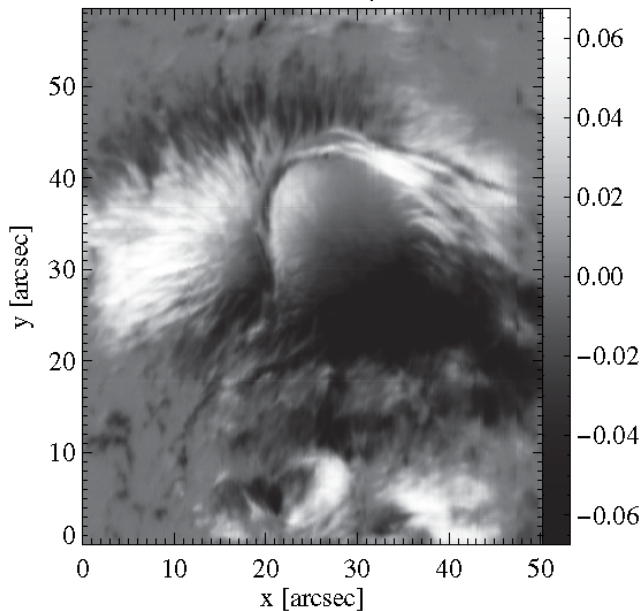
08sep14.009: Fe 15648.5 Stokes I



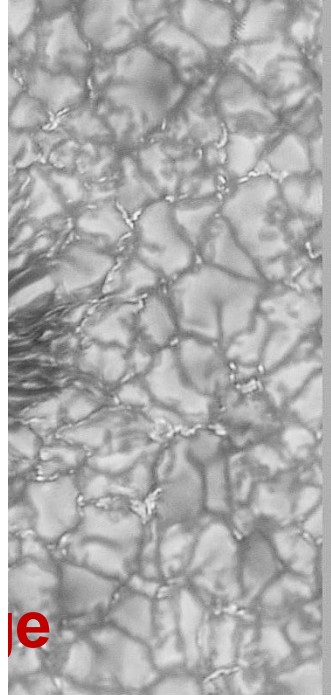
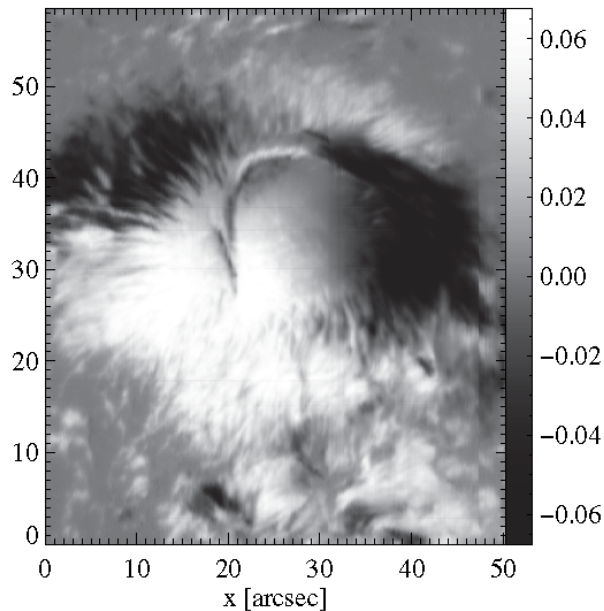
Stokes V



Stokes Q



Stokes U



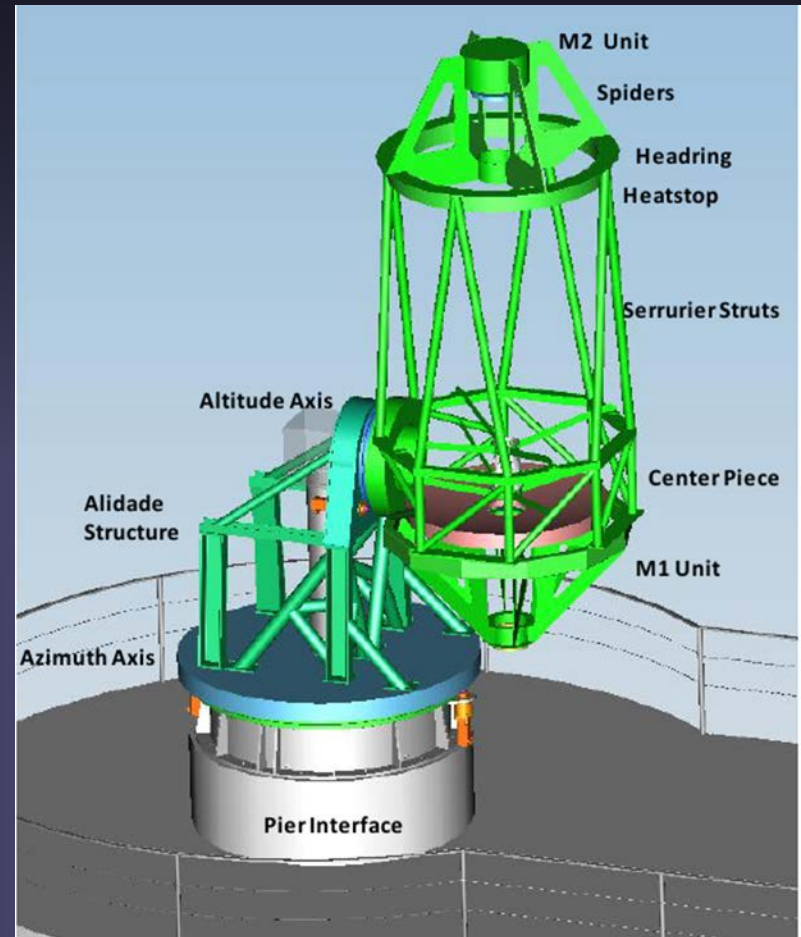
e

5m mirror
1.6m are,
m
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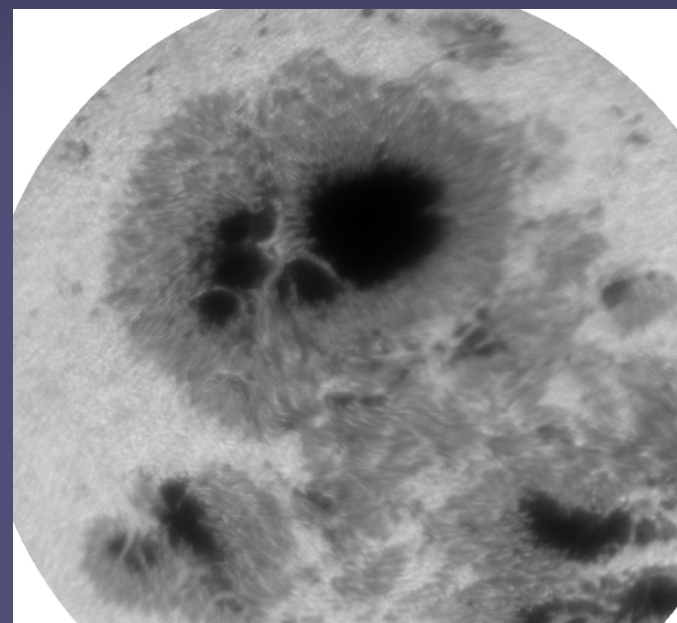
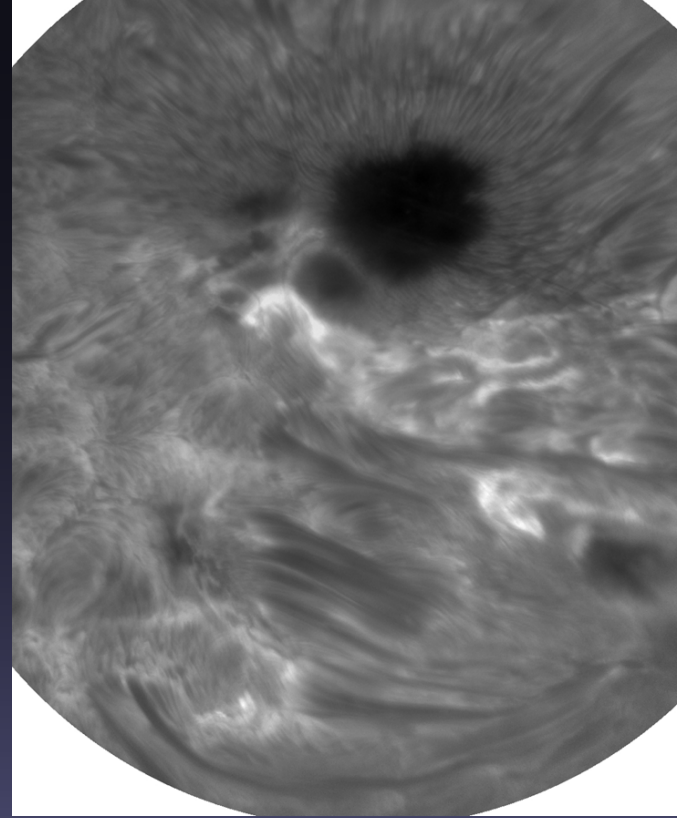
NLST = National Large Solar Telescope

- 2m aperture, high resolution telescope for imaging and polarimetry
- To be located in Hanle, North India; first light expected 2019
- Instruments:
 - Broad-band filter imager
 - Tunable Fabry-Perot narrow-band imager (500-900 nm)
 - Spectropolarimeter 0.38 – 1.6 μm
- Talk by Rangarajan



MAST: Multi Application Solar Telescope

- 50 cm off-axis design (for reduced scattered light)
- Collapsible dome
- Thermally stabilized mirrors
- Test observations in g-band and H- α look very promising
- Talk by Shibu Mathew



Thank you for your attention

