The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

International Atomic Energy Agency

310/1749-36

ICTP-COST-USNSWP-CAWSES-INAF-INFN
International Advanced School
on
Space Weather
2-19 May 2006

Solar Activity: Observations and Definition

Henrik LUNDSTEDT
Swedish Institute of Space Physics
Scheelev 17
SE-223 70 Lund
SWEDEN

The Sun: Space Weather Applications

ICTP-COST-CAWSES-INAF-INFN, Trieste, 2006

Henrik Lundstedt
Swedish Institute of Space Physics
Lund, Sweden
www.lund.irf.se

Four talks on Sun: Space weather applications

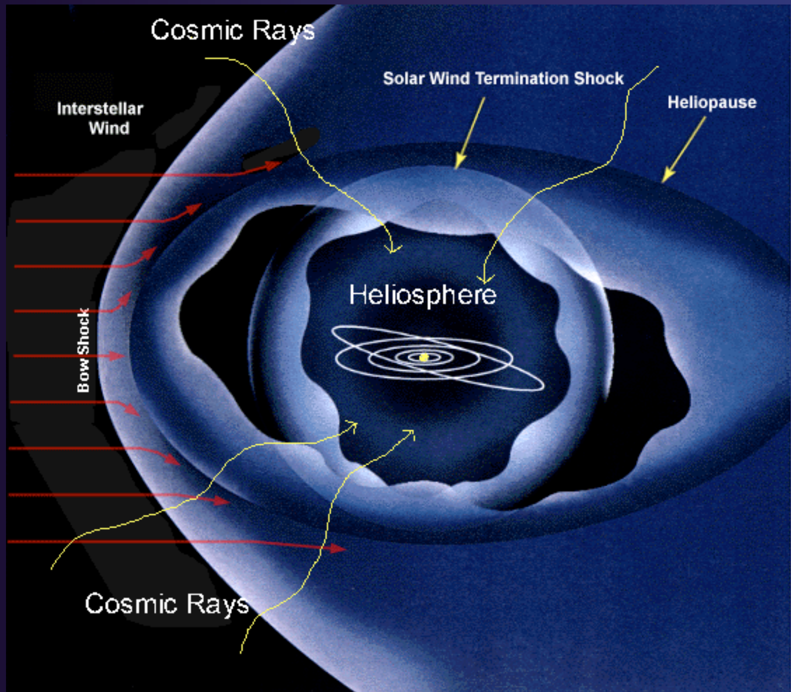
- Solar Activity: Observations and definition
- Solar Activity: Exploration with wavelets
- Solar Activity: Solar drivers of geoeffective phenomena, and their precursors
- Solar Activity: Predictions and real-time forecasts

Outline of my first talk

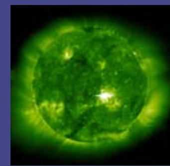
1) Solar Activity: Observations and definition

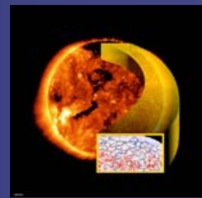
- Space weather - a scientific challenge (use of latest scientific results to produce what a user wants)
- Observations (ground-, space-based)
- Observations of V and B
- Definition

Inside the heliosphere and solar atmosphere cause of space weather effects



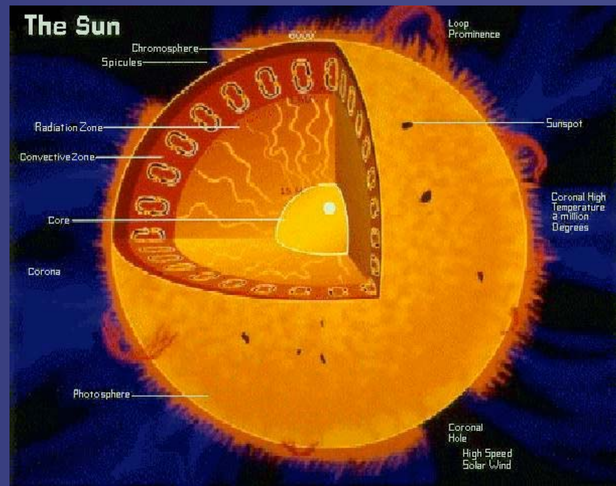
The Heliosphere - The Sun's utmost atmopshere



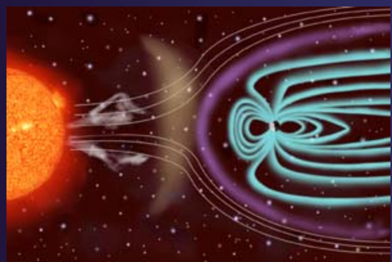


Intensive radiation

Solar wind plasma



The Sun



Earth

The magnetosphere - Earth's utmost atmosphere

The Sun

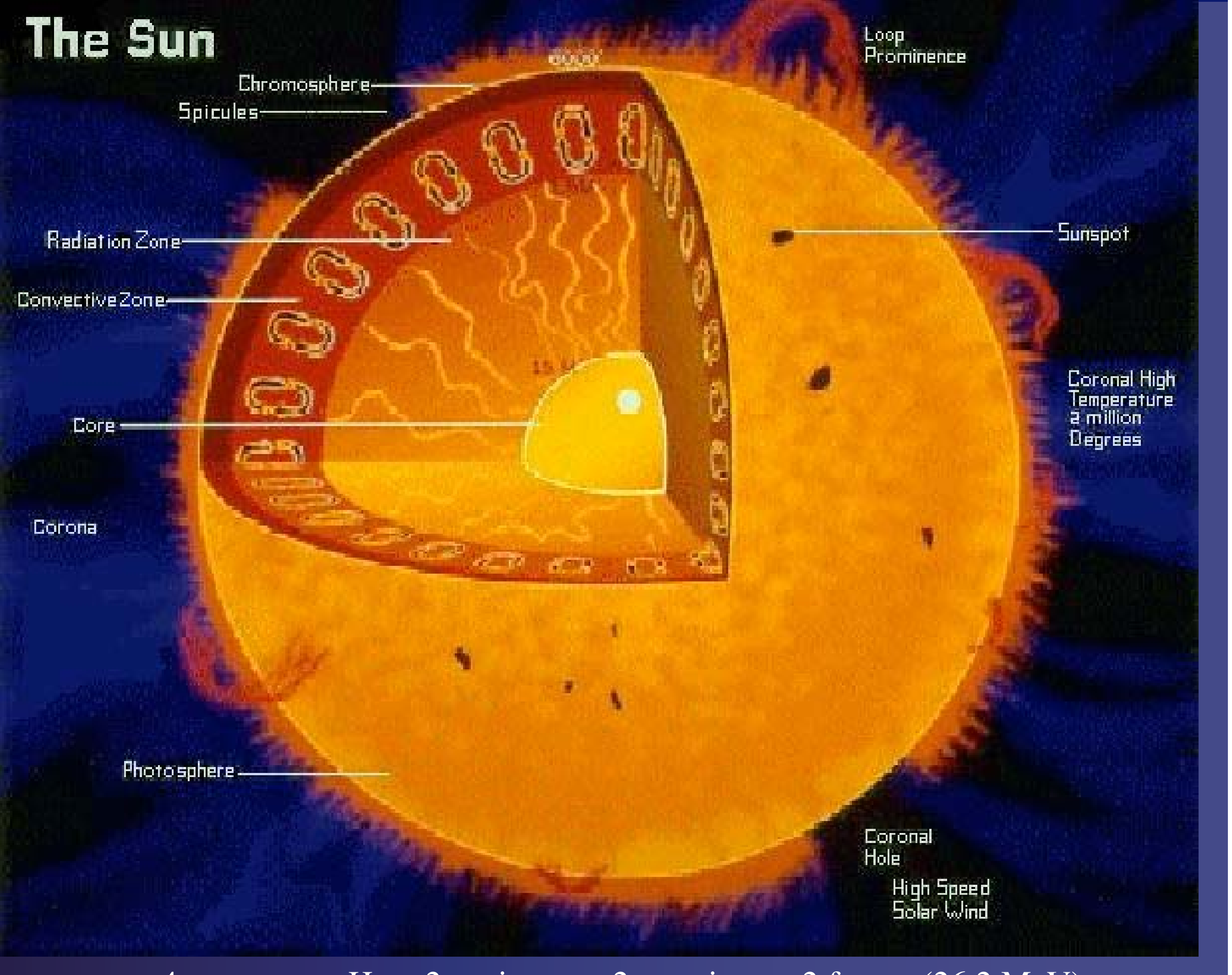
Diameter:
1 390 000 km
(109 x Earth)

Mass:
1.99×10^{30} kg
(330 000 x Earth)

Density:
Core 151×10^{3} kg/m^{-3}
Average 1.41×10^{3} kg/m^{-3}

The Sun consits of:
H (≈ 90%)
Helium (≈ 10%)
C,N,O (≈ 0.1%)

Temperature:
Core 15 million
Photosphere 5800 K
Chromosphere 4300-10^{4}K
Corona 1-30 million K



4 protons --> He + 2 positrons + 2 neutrinos + 2 fotons (26.2 MeV)

Space weather

SPACE WEATHER
The International Journal of Research and Applications

”Rymdväder” was first mentioned in Swedish media in 1991 SDS!

SDS 1991 (cycle 22)

SDS 1991 (cycle 22)

HD 1981 (cykel 21)

Arbetet 1981 (cycle 21)
Forecasts of sw effects

Space weather coined by John Freeman around 1986.

The US National Space Weather Program 1995: ”Space weather refers to conditions on the sun, and in the solar wind, magnetosphere, ionosphere and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and endanger human life or health”. **LWS 2001 and ILWS 2002.**

ESA Space Weather Programme started in April 1999. **ESA Space Weather Pilot projects start in April 2003. SWWT, EU COST 724 Space Weather.**

Meetings in Lund

John Freeman (Rice University, Texas) myntade ordet rymdväder

Workshops on ”Artificial Intelligence Applications in Solar-Terrestrial Physics”, Lund 1993 and 1997.
”Solar Activity: Exploration,Understanding and Prediction” 19-21/9 2005 in Lund.

The solar observations

- Where do we observe the Sun?
- How do we observe the solar rotation and oscillations?
- How do we observe the solar magnetic field?

$$\frac{\partial B}{\partial t} = \nabla \times \left(u \times B \right) - \nabla \times \left[\lambda(r) \nabla \times B \right]$$

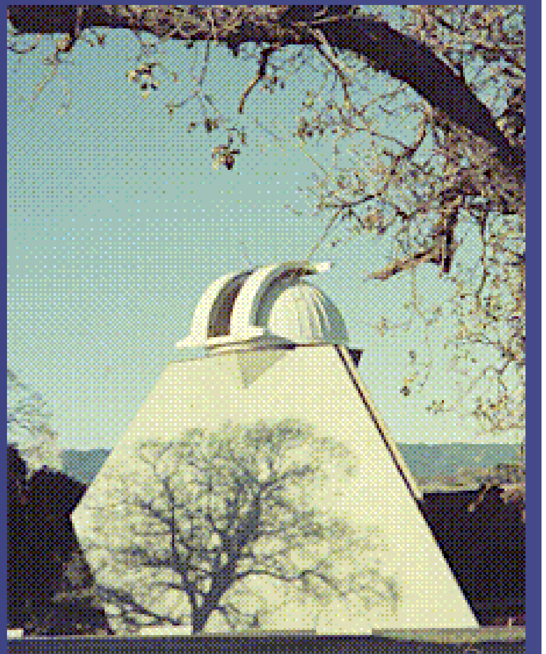
$$\frac{\partial u}{\partial t} + u \cdot \nabla u + 2\Omega \times u = -\frac{1}{\rho_0} \nabla p + \frac{1}{\rho_0 \mu} \left(\nabla \times B \right) \times B + \upsilon \nabla^2 u + f$$

Solar observations in California

Mount Wilson Observatory

Big Bear Solar Observatory

Wilcox Solar Observatory



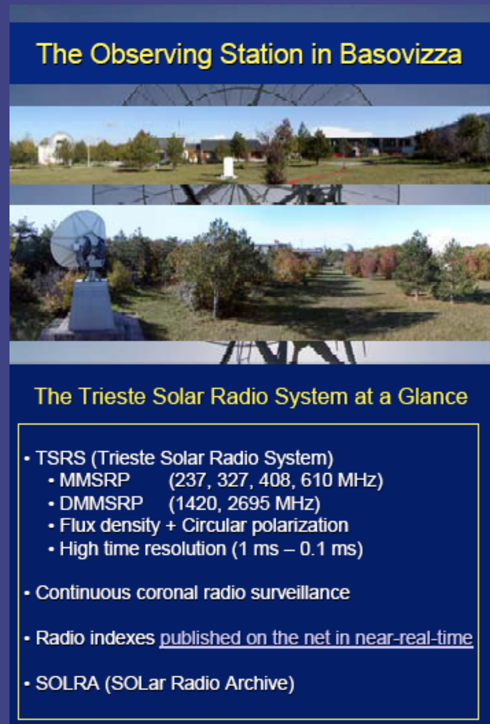
Internet-accessible robotic solar telescope in Livermore

Italian solar observation facilities

Description:_HEMIS is a joint operation from France (CNRS) and Italy (CNR) national research agencies. It is located at Izaña , 2400 m, within the Teide Observatory from the Instituto de Astrofisica de Canarias, on the island of Tenerife (Canary islands, Spain).
THEMIS is a 90 cm solar telescope, currently the third larger in the world. Its specific design, allowing for high-accuracy spectropolarimetry of the solar surface, includes an alt-az mounting, an helium filled telescope tube, a Stokes polarimeter located at the prime focus, and a multi-mode spectrograph. Themis delivers routine vector polarimetry analysis with an accuracy ranging fro
m 10-3 to 10-5 in some configurations. The spectrograph design allows the observation of up to 10 wavelengths simultaneously, giving an opportunity to perform 3D inversion of the magnetic fields structure in the solar atmosphere.

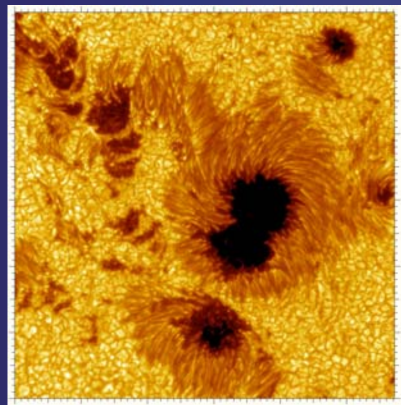
INAF - Catania (Halpha, white light images)

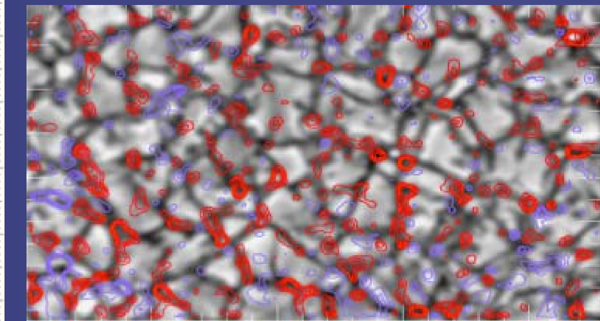
THEMIS on Tenerife (solar magnetic field)

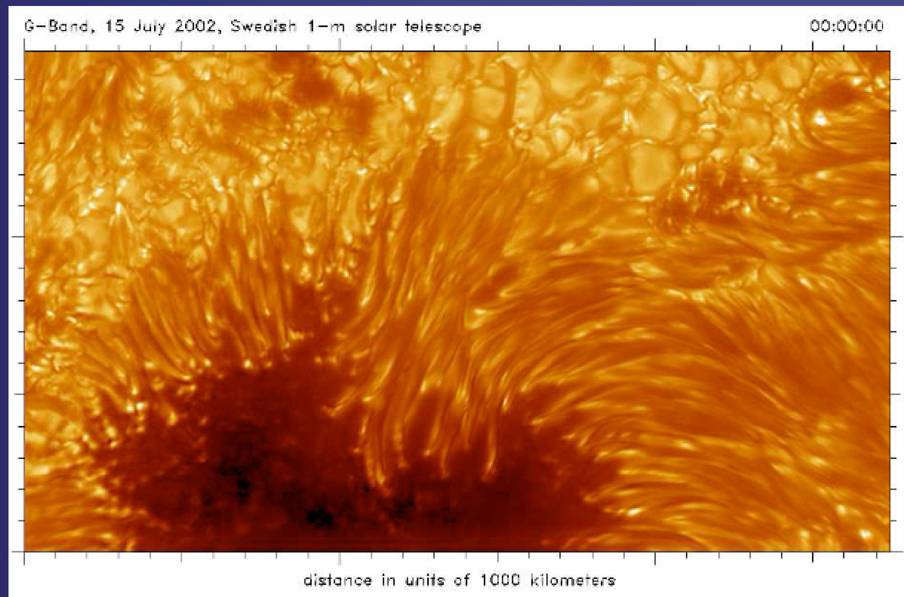


Trieste solar radio telescope

Solar observations with the new Swedish solar telescope on La Palma



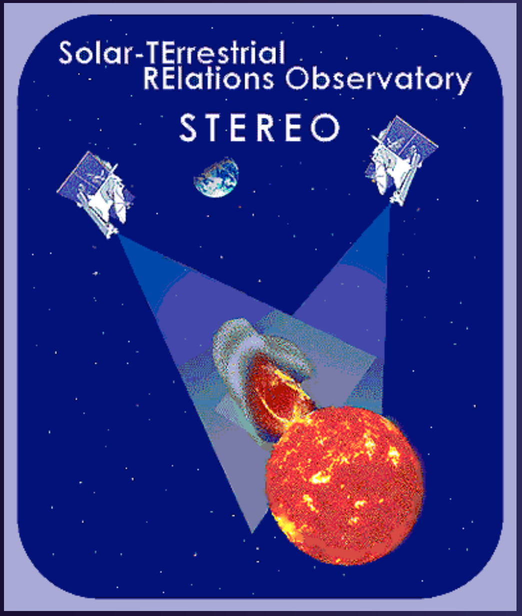




Advanced Technology Solar Telescope

4-m telescope
0.1” resolution
Operational 2009
National Solar Observatory

STEREO - planned launch July 22, 2006



Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI) will have four instruments: an extreme ultraviolet imager, two white-light coronagraphs and a heliospheric imager. These instruments will study the 3-D evolution of CME's from birth at the Sun's surface through the corona and interplanetary medium to its eventual impact at Earth. Principal Investigator: Dr. Russell Howard, Naval Research Laboratory, Washington, D.C.

List of Institutions involved.

STEREO/WAVES (SWAVES) is an interplanetary radio burst tracker that will trace the generation and evolution of traveling radio disturbances from the Sun to the orbit of Earth. Principal Investigator Dr. Jean Louis H. Bougeret, Centre National de la Recherche Scientifique, Observatory of Paris, and Co-Investigator Mr. Michael Kaiser of Goddard, lead the investigation.

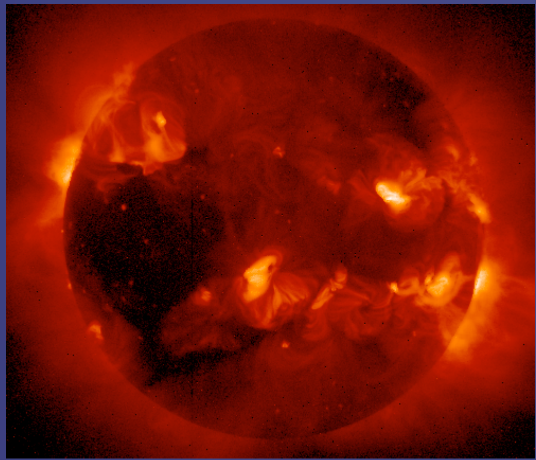
List of Institutions involved.

In-situ Measurements of Particles and CME Transients (IMPACT) will sample the 3-D distribution and provide plasma characteristics of solar energetic particles and the local vector magnetic field. Principal Investigator: Dr. Janet G. Luhmann, University of California, Berkeley.

List of Institutions involved.

PLAsma and SupraThermal Ion Composition (PLASTIC) will provide plasma characteristics of protons, alpha particles and heavy ions. This experiment will provide key diagnostic measurements of the form of mass and charge state composition of heavy ions and characterize the CME plasma from ambient coronal plasma. Principal Investigator: Dr. Antoinette Galvin, University of New Hampshire.

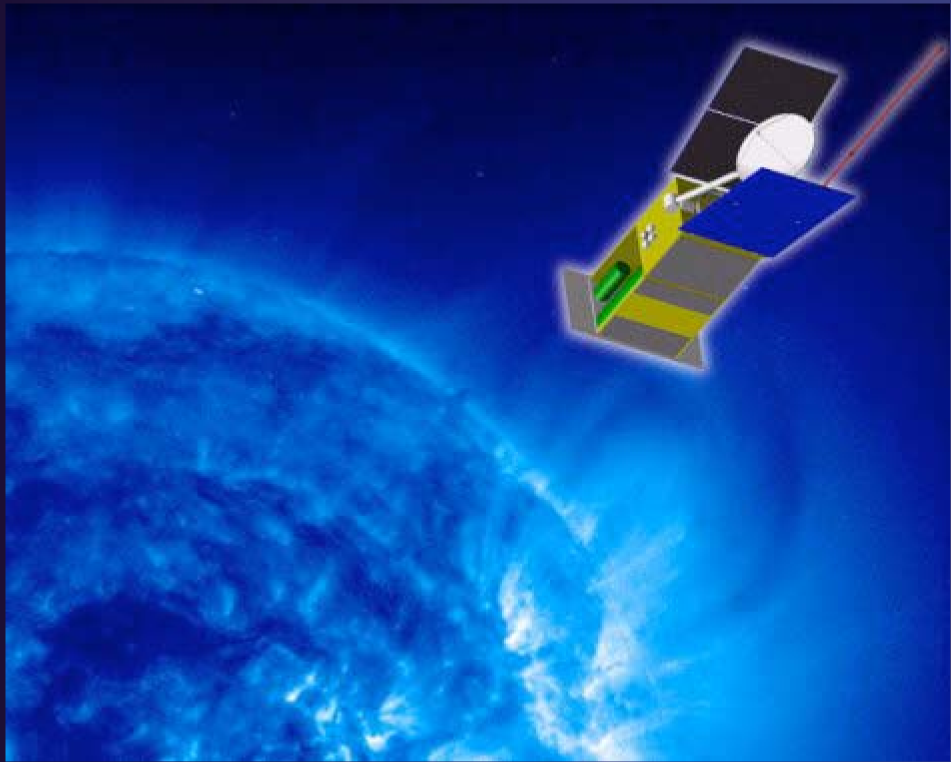
Solar-B planned launch September 2006



Follow-on to Yokoh

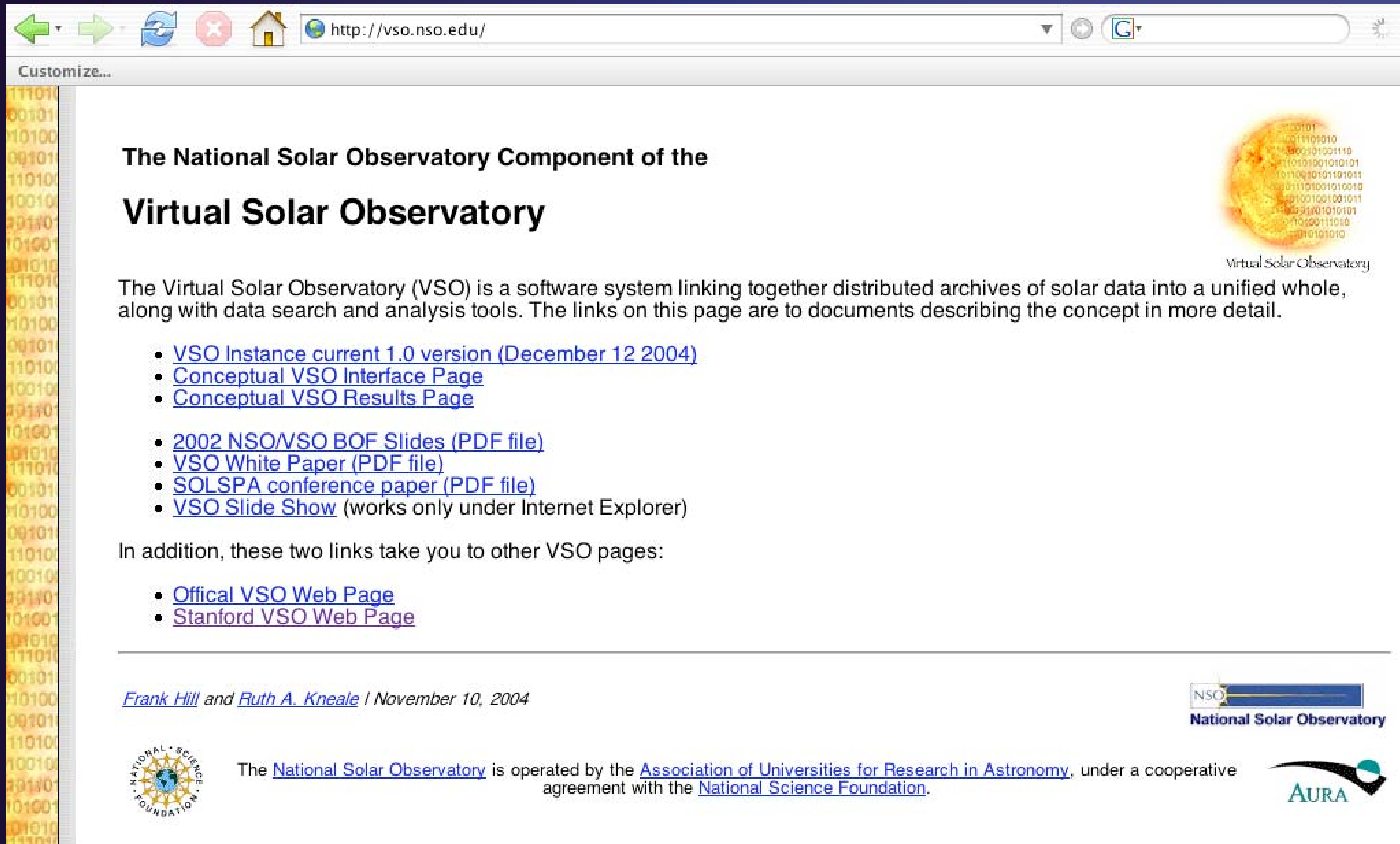
***Solar Optical Telescope (SOT)**:*
Gregorian or Cassegrain, 50cm aperture, light weight glass composite
Angular Resolution: Diffraction limited at 0.25" (175km on the Sun)
Wavelength Range: 480-650nm
Polarimetric Accuracy: 10e-4
Focal Plane Package (FPP) Vector Magnetograph:
Magnetic Lines: 525.0nm FeI; 630.2nm FeI, Continuum: 524.6nm, Velocity: 532.4nm FeI
Field of View: 164x164 arcsec squared
Magnetic Sensitivity: B(longitudinal) = 1-5G, B(transverse) = 30-50G
Temporal Resolution: 5 min., Detectable change in active region magnetic energy: 10e30 erg
Data: Time series of photospheric vector magnetograms, Doppler velocity and photospheric intensity
Focal Plane Package (FPP) Spectrograph:
Littrow type echelle. Spectral resolution 2.0nm
Data: Detailed Stokes line profiles of intensity and polarization
***X-Ray Telescope (XRT)**:*
Wavelength Range: 2,0 to 60.0 Å, Angular Resolution: 1.0 to 2.5 arcsec
Field of View: Full or partial disk, Data: Coronal Images at different temperatures
***EUV Imaging Spectrograph (EIS)**:*
Pixel Size: 1.5 arcsec x 0.002nm, Field of View: 400 arcsec
Wavelength Range: 25-29nm, Temperature Range: 1 x 10e5 - 2 x 10e7 K
Data: Doppler line widths and shifts and monochromatic images

Solar Orbiter - planned launch 2015



Study the Sun from close-up (45 solar radii, .21 au), (0.05 arcsec) latitude as high as 38 degrees

Virtual Solar Observatory



http://vso.nso.edu/

Customize...

The National Solar Observatory Component of the

Virtual Solar Observatory

The Virtual Solar Observatory (VSO) is a software system linking together distributed archives of solar data into a unified whole, along with data search and analysis tools. The links on this page are to documents describing the concept in more detail.

- VSO Instance current 1.0 version (December 12 2004)
- Conceptual VSO Interface Page
- Conceptual VSO Results Page

- 2002 NSO/VSO BOF Slides (PDF file)
- VSO White Paper (PDF file)
- SOLSPA conference paper (PDF file)
- VSO Slide Show (works only under Internet Explorer)

In addition, these two links take you to other VSO pages:

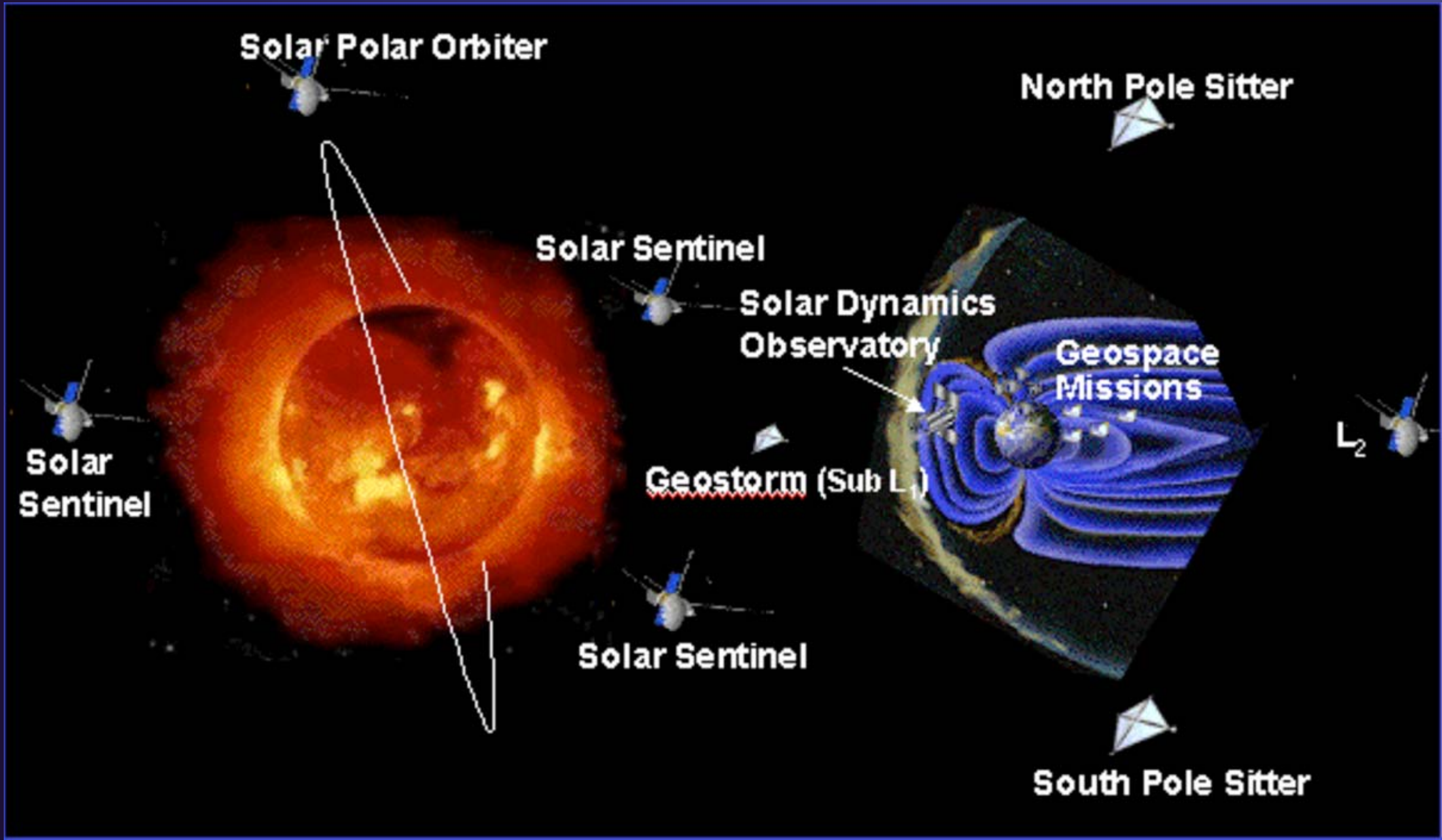
- Offical VSO Web Page
- Stanford VSO Web Page

Frank Hill and Ruth A. Kneale / November 10, 2004

National Solar Observatory

The National Solar Observatory is operated by the Association of Universities for Research in Astronomy, under a cooperative agreement with the National Science Foundation.

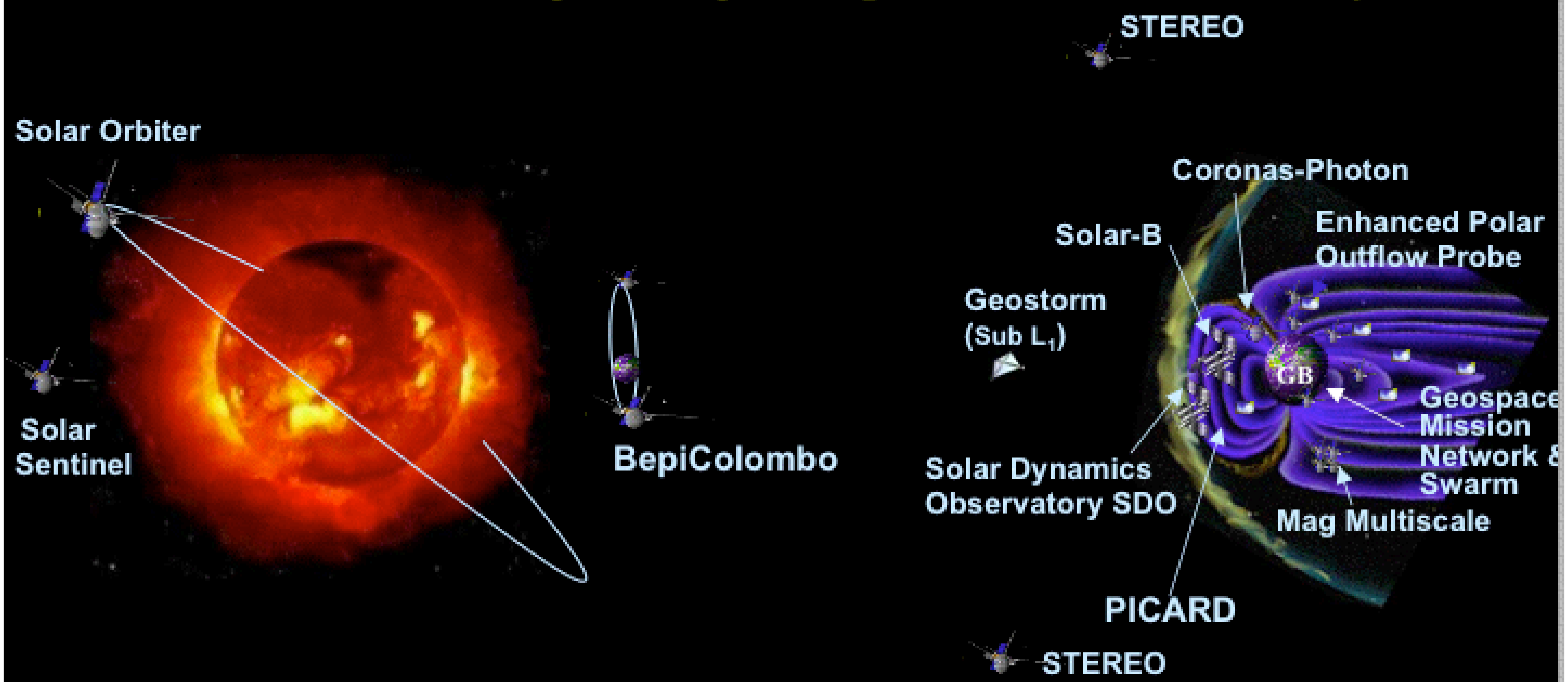
Living with a Star (LWS)



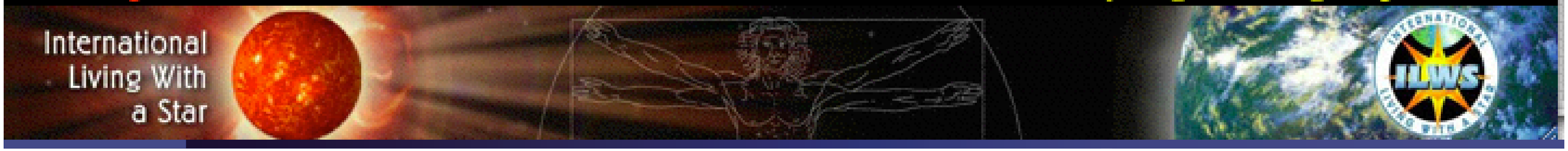
International Living With a Star

Some Candidate Missions

Distributed network of spacecraft providing observations of Sun-Earth system.

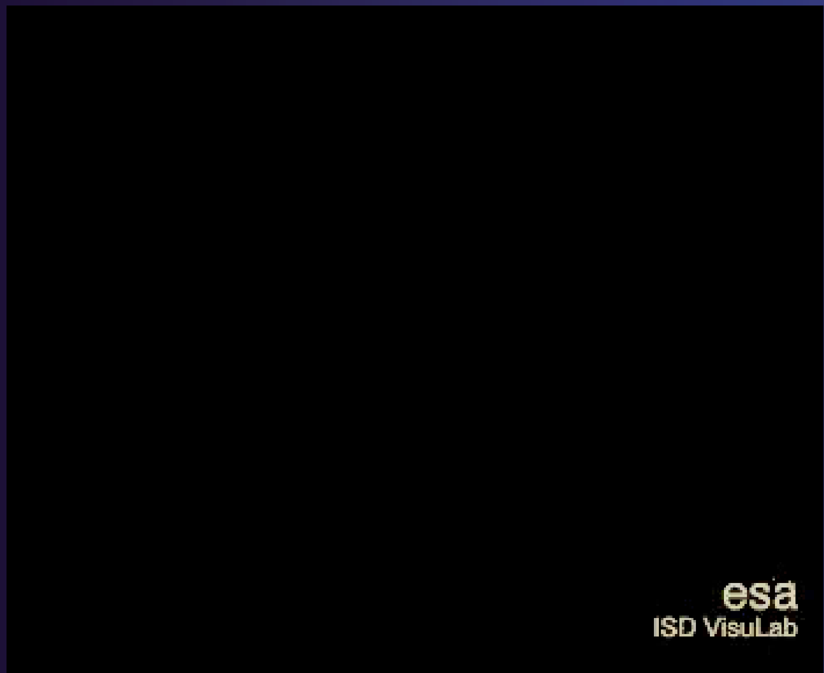


- ***Solar-Heliospheric Network*** **observing Sun & tracking disturbances from Sun to Earth.**
- ***Geospace Mission Network*** **with constellations of smallsats in key regions of geospace.**



SOHO was launched on 2 December 1995

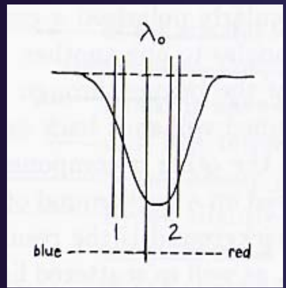
SOHO has given us a new picture of the Sun

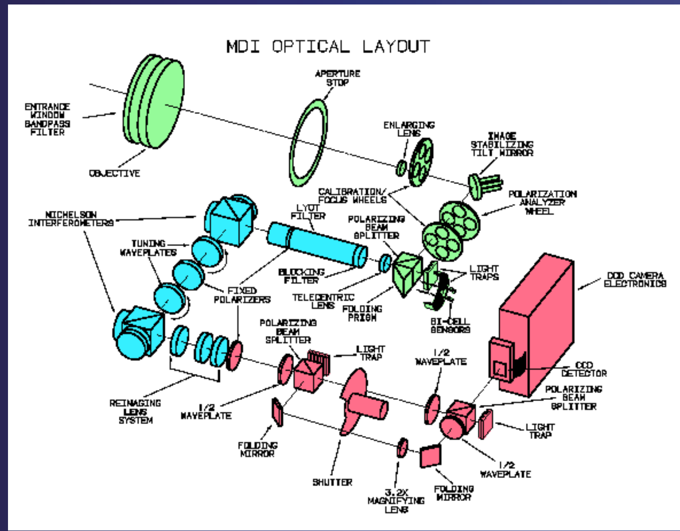


- Prof. P.Scherrer P.I. For the MDI instrument onboard SOHO. The group in Lund collaborates with Stanford.
- Solar Heliospheric Observatory was launched December 2, 1995.
- SOHO has three instruments observing the solar interior, sex the solar corona and three the solar wind.

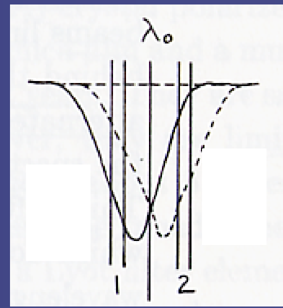
MDI observes the solar rotation, oscillations and the magnetic field
We need to know V and B!

Doppler shift





Zeeman splitting



Photosphere sunspots

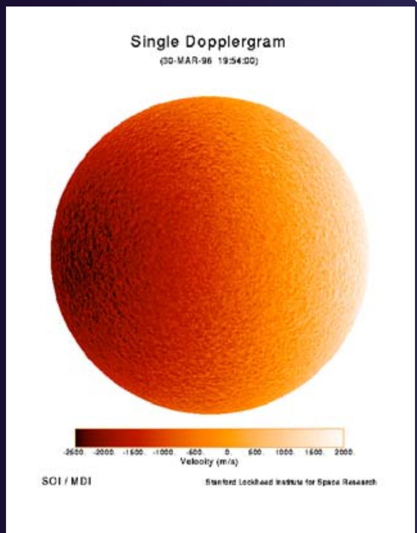
35 days 25 days (27 days seen from Earth)	Differential rotation (ω)	5 min oscillations	Magnetogram	

35 days

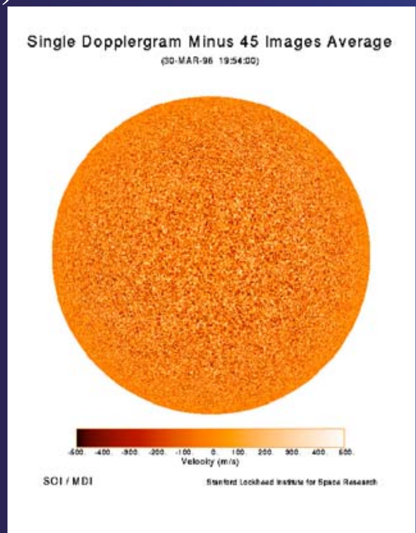
25 days

(27 days
seen
from
Earth)

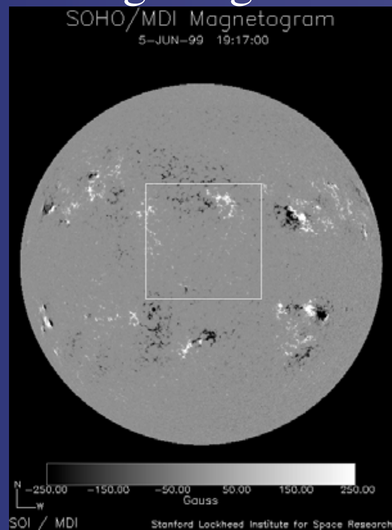
Differential rotation (ω)

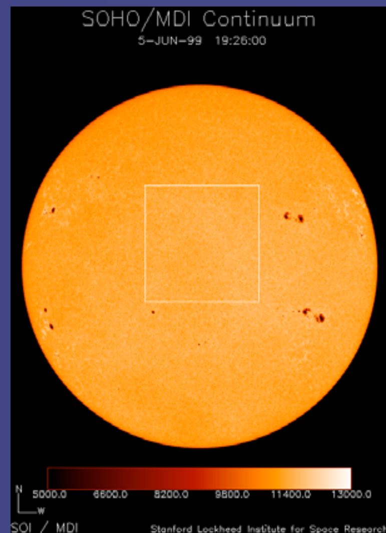


5 min oscillations

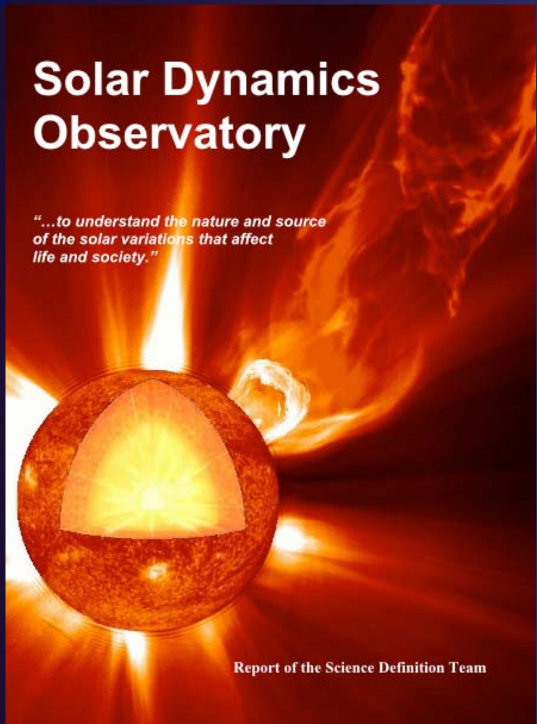


Magnetogram

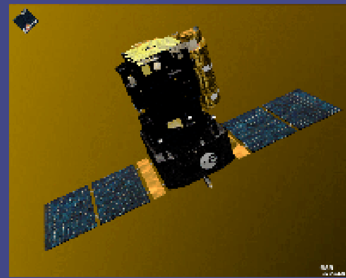




SDO - planned launch August 2008



Follow-on to SOHO



Solar Dynamics Observatory (SDO)

First Space Weather Research Network Mission in the Living With A Star (LWS) Program

http://sdo.gsfc.nasa.gov

Mission Science Objectives

The primary goal of the SDO mission is to understand, driving towards a predictive capability, the solar variations that influence life on Earth and humanity's technological systems by determining

- *How the Sun's magnetic field is generated and structured*
- *How this stored magnetic energy is converted and released into the heliosphere and geospace in the form of solar wind, energetic particles, and variations in the solar irradiance.*

Mission Specs:

- April 2008 launch: GTO to GEO
- Inclined Geosynchronous Orbit (semiannual eclipse seasons)
- 3-axis stabilized spacecraft
- Data transmission: continuous high rate data stream ~150 Mbps compressed data at Ka-Band
- Dedicated ground station
- Mission development and management at GSFC

Key Spacecraft Technologies

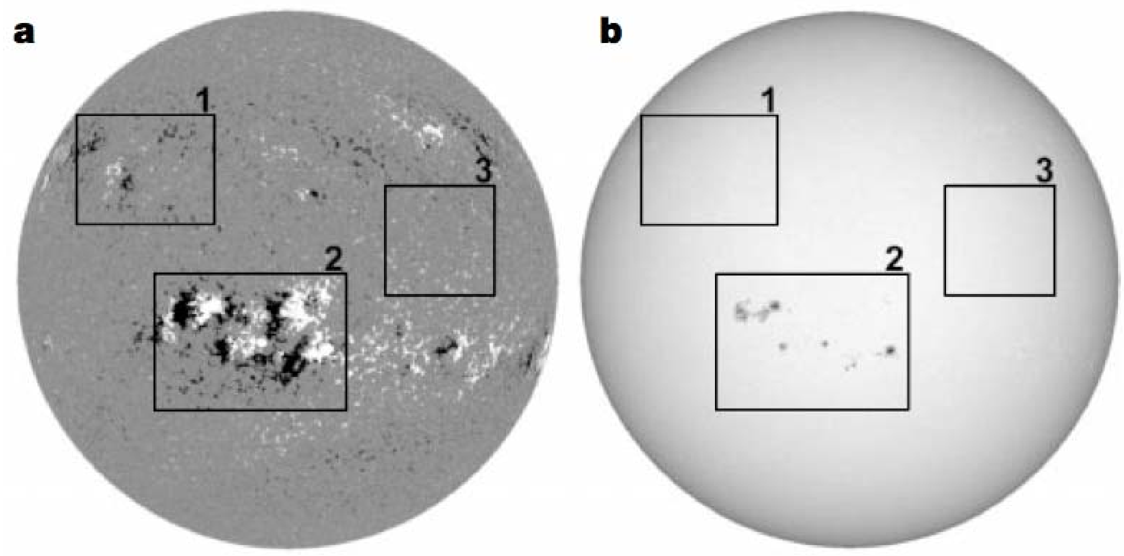
- Ethernet Chipset
- Ka-Band Transmitter
- Active Pixel Star Tracker

Science Investigations

- **Helioseismic and Magnetic Imager (HMI)**
  PI Institution: Stanford University
  - Images the Sun's helioseismic, longitudinal and vector magnetic fields to understand the Sun's interior and magnetic activity
- **EUV Variability Experiment (EVE)**
  PI Institution: University of Colorado
  - Measures the solar extreme ultraviolet (EUV) spectral irradiance to understand variations on the timescales which influence Earth's climate and near-Earth space
- **Atmospheric Imaging Assembly (AIA)**
  PI Institution: Lockheed Martin Missiles & Space Advanced Technology Center
  - Images the solar atmosphere in multiple wavelengths to link changes to surface & interior changes

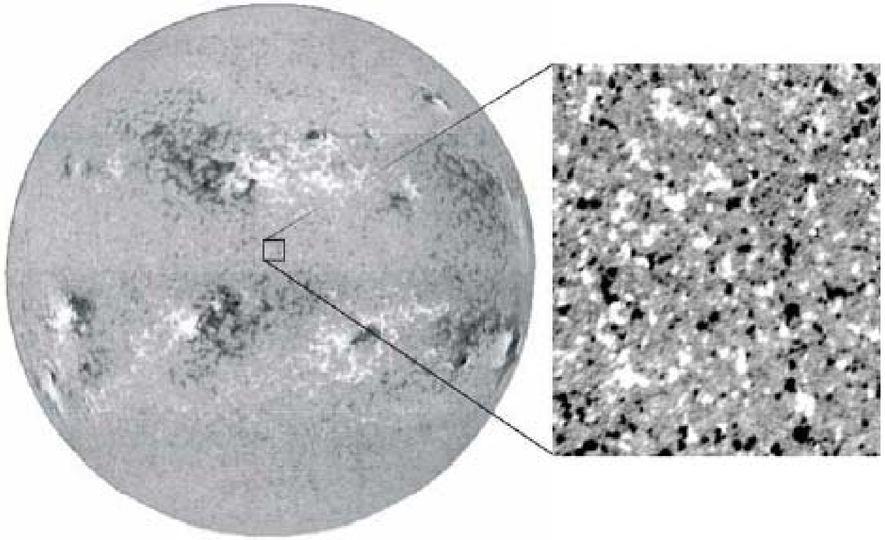
03/11/05

Magnetograms

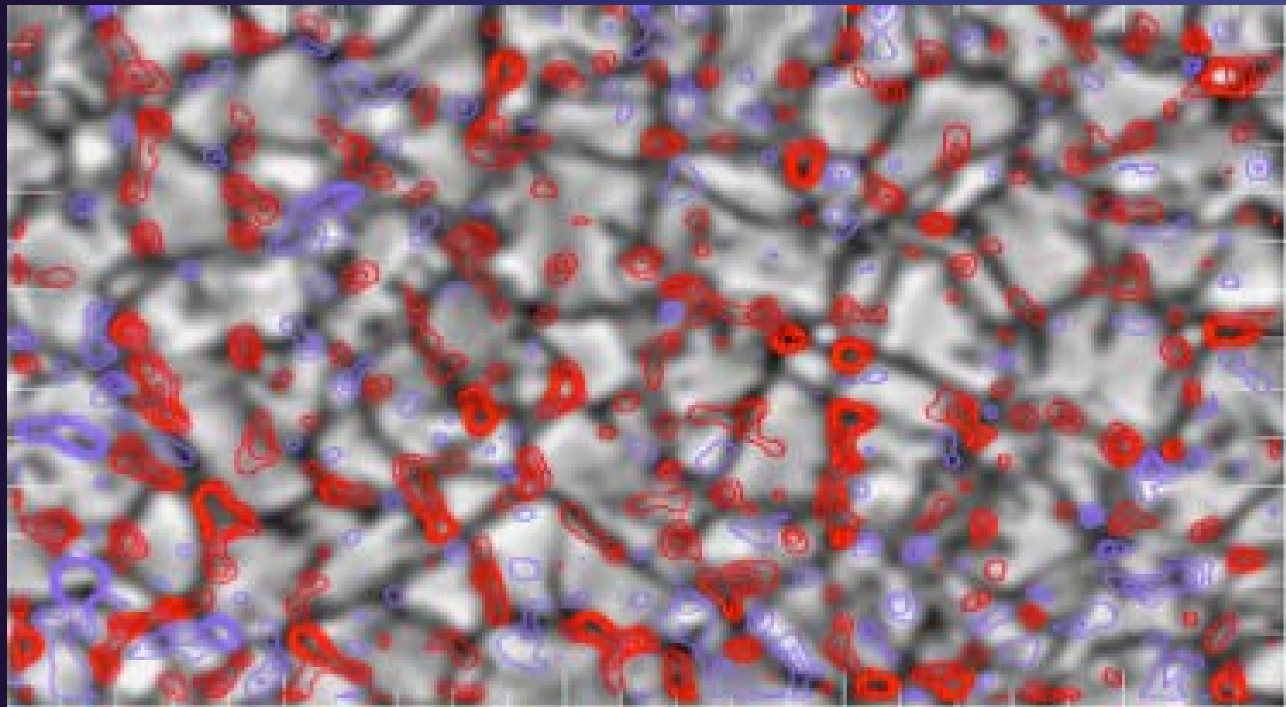


1. Enhanced magnetic network
2. Bipolar magnetic regions
3. Magnetic network ("salt and pepper")

Mixed-polarity network field

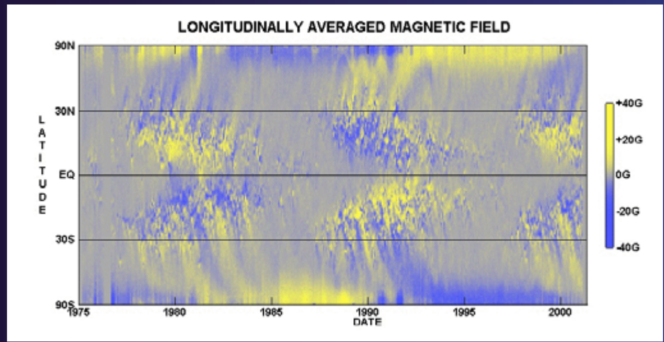


High-resolution magnetograms



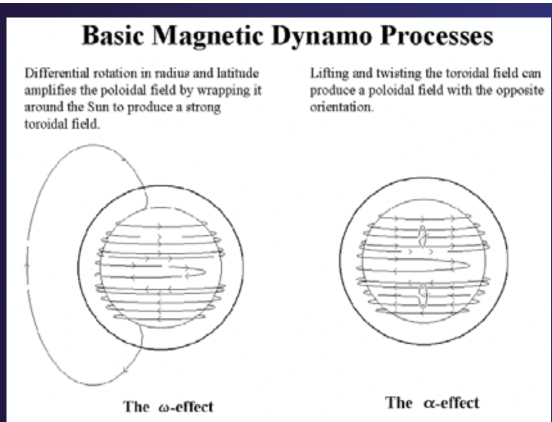
La Palma

Solar climate - MHD theory
α–ω–flux transport dynamo



Dikpati. M. and P. Gilman, Aston. J, 559, 2001

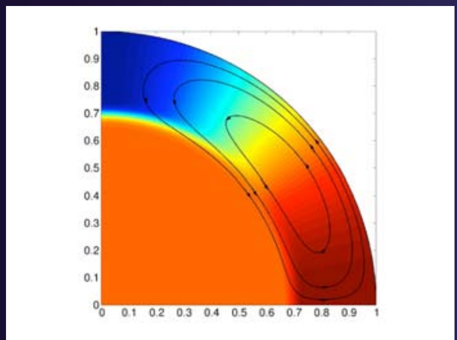
$$B = B_P + B_T = \nabla \times \left[A(r,\theta)\hat{\phi}\right] + B_\phi(r,\theta)\hat{\phi}$$

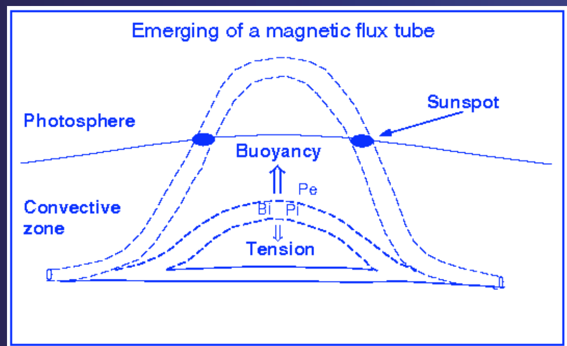


$$\frac{\partial B}{\partial t} = \nabla \times (u \times B) - \nabla \times \left[\lambda(r)\nabla \times B\right]$$

u = diff rotation,
meridional flow and a turbulent flow

$$-(r\sin\theta)B_P \cdot \nabla|\Omega(\theta)| = \lambda(\nabla^2 - \frac{1}{r\sin^2\theta})B_\phi$$

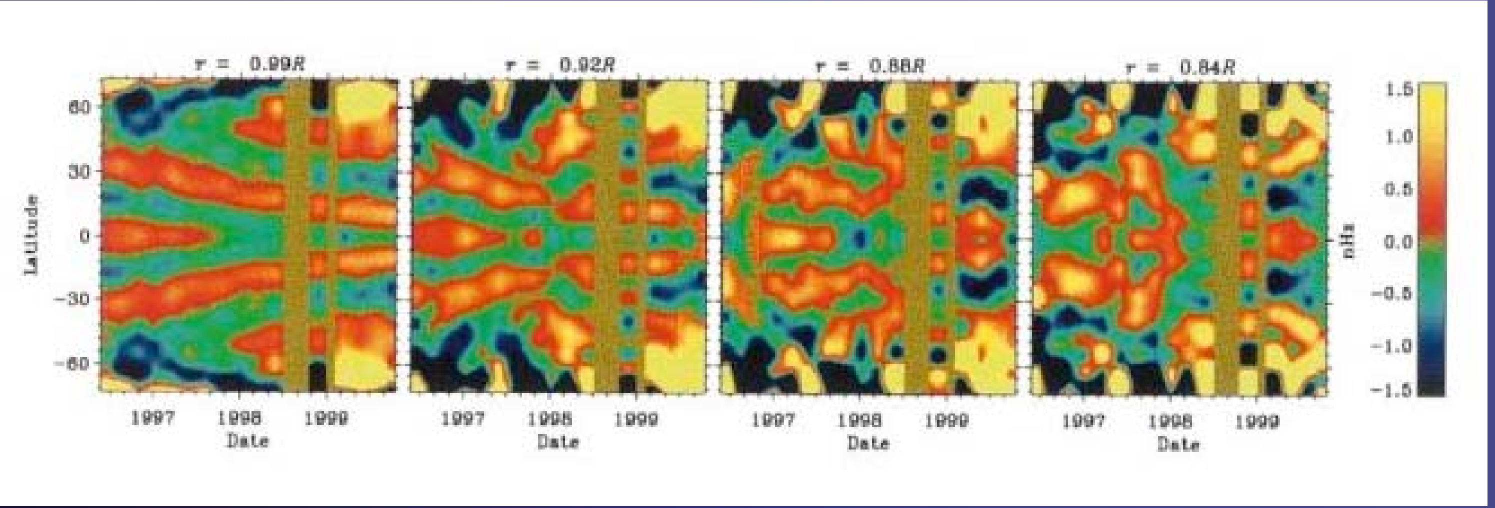




$$P_{out} = P_{in} + B^2/2\mu$$

$$\int_0^{2\pi} (\hat{u} \times \hat{B})d\phi = \alpha_{ij}B_{0j} + \beta_{ijk}\frac{\partial B_{0j}}{\partial x_k} + \ldots$$

Torsional oscillation Modulation



Lorentz force acting on differential rotation - possible explanation of modulation of dynamo

$$\frac{\partial u}{\partial t} + u \cdot \nabla u + 2\Omega \times u = -\frac{1}{\rho_0}\nabla p + \frac{1}{\rho_0 \mu}(\nabla \times B) \times B + \upsilon \nabla^2 u + f$$

Non-linear chaotic solar dynamo
(N. Weiss)

$$\frac{\partial B}{\partial t} = \nabla \times (v \times B) + \eta \nabla^2 B$$

$$\dot{A} = 2DB - A,$$

$$\dot{B} = iA - \frac{1}{2} i\Omega A^* - B,$$

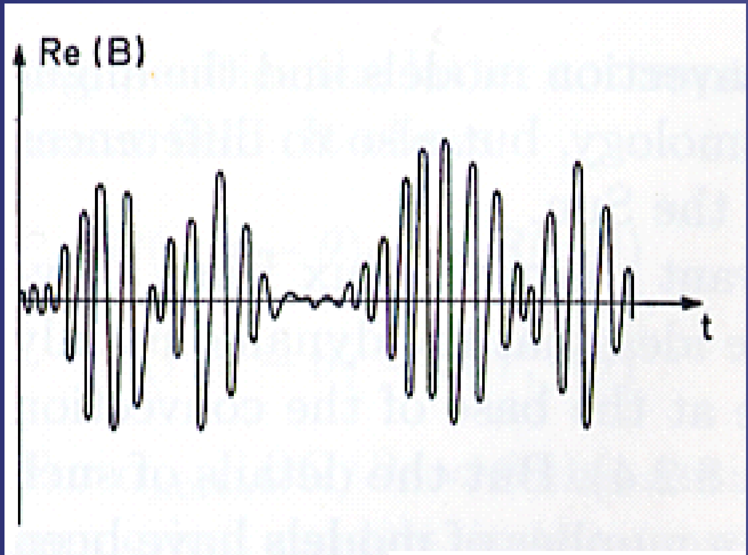
$$\dot{\Omega} = -iAB - \nu\Omega$$

A complex generalization of the three ordinary Lorenz diff equations.

$$D = \alpha_0 \Delta\Omega_0 r_s^3 / \eta_t^2$$

The toroidal magnetic field for a $\alpha\Omega$ dynamo.

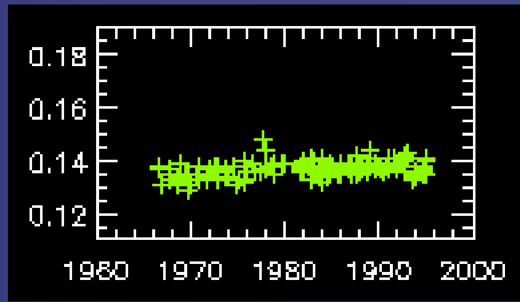
As the dynamo number D increases
D1 (no activity) ->
D2 (cycle activity) ->
D3 (chaotic activity)



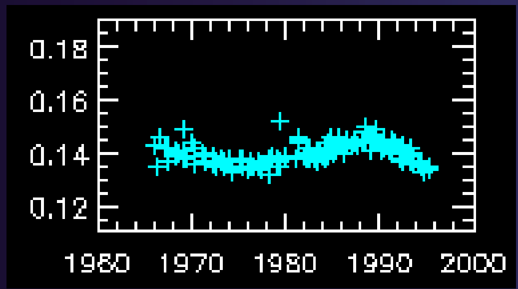
Rapid changes for other solar type stars

For a solar type star the luminosity decreased with 0.4%på in just a few years. Similar rapid changes happened during the Maunder minimum! (compare 1640-1645!)

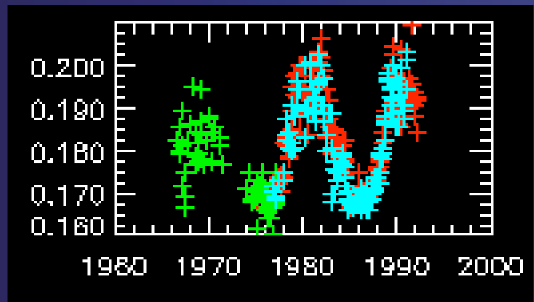
Mount Wilson studies



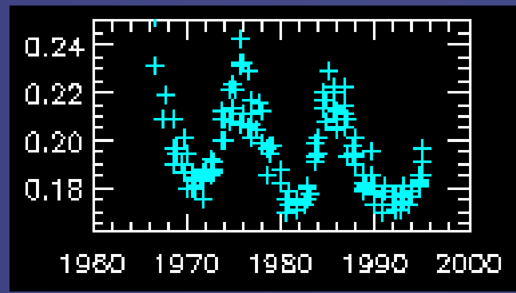
HD 9562 (G2V) Maunder minimum state



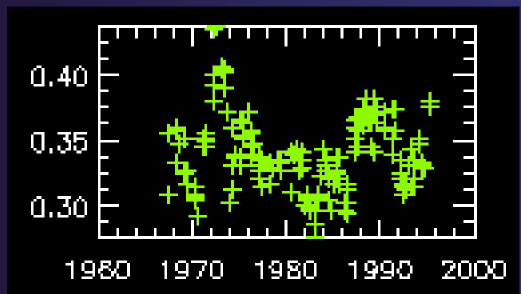
HD 136202 (F8IV) 23 years



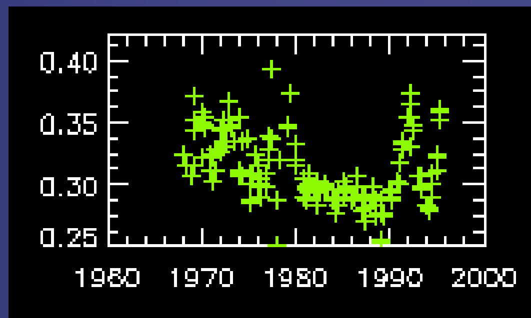
Sun (G2V) 10.0 years



HD 10476 (K1V) 9.6 years

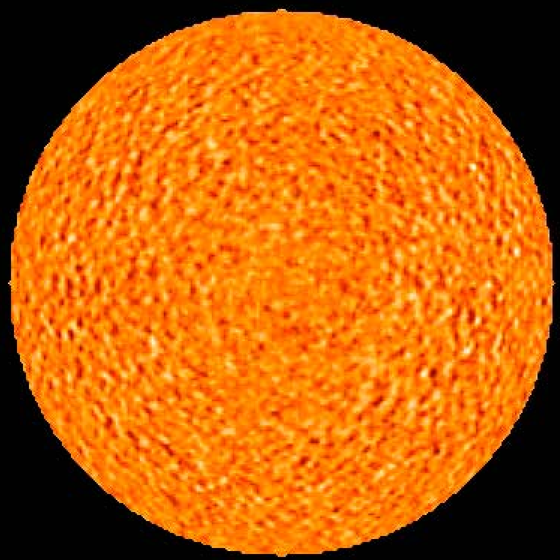


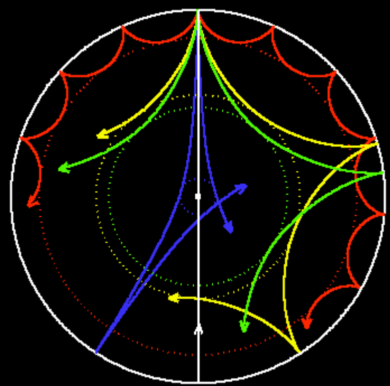
HD 149661 (K0V 17.4 +4.0 years) multiple cycles

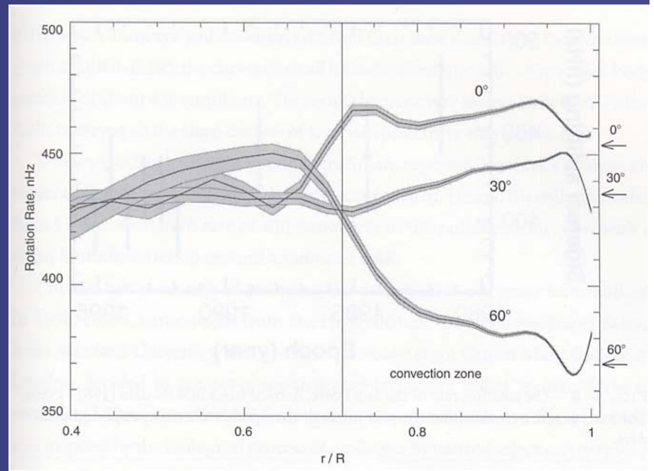


HD101501 (G8V) chaotic

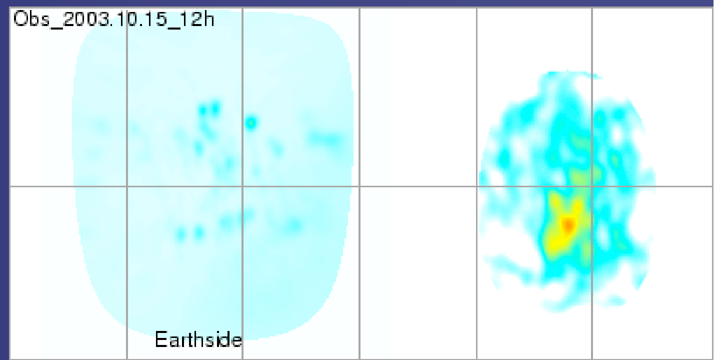
Oscillations reveal solar interior







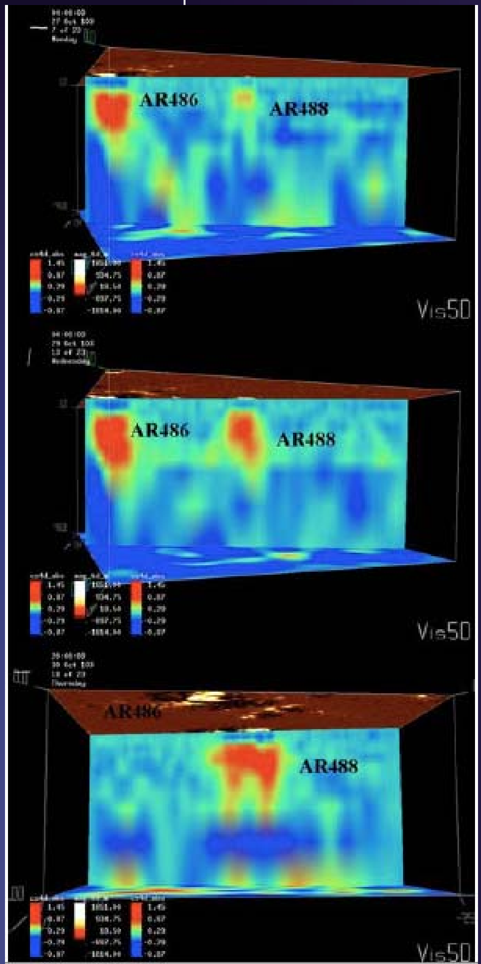
Rotation inside the Sun

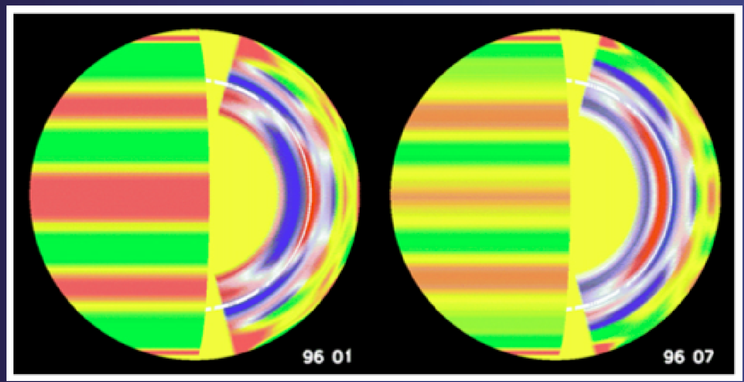


Sunspots on far side of the Sun

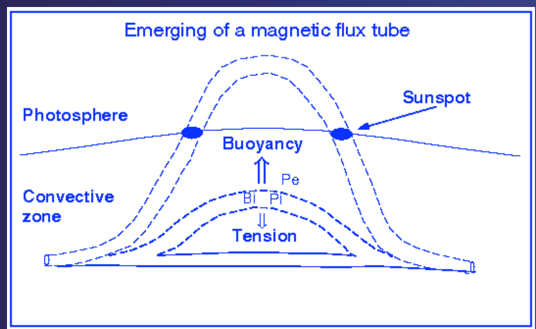
Helioseismic observations have shown:
Tachocline, flow below a sunspot and flux emerging

Tachochline - site of dynamo where B is produced

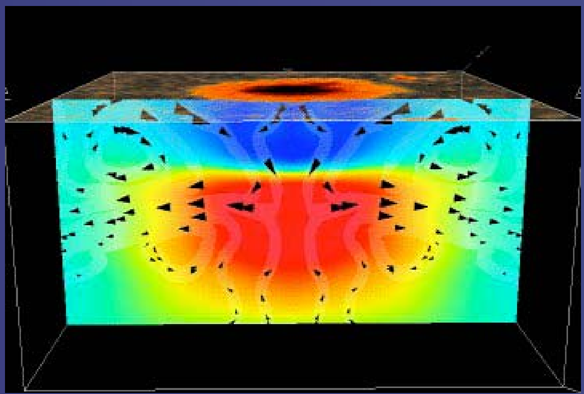




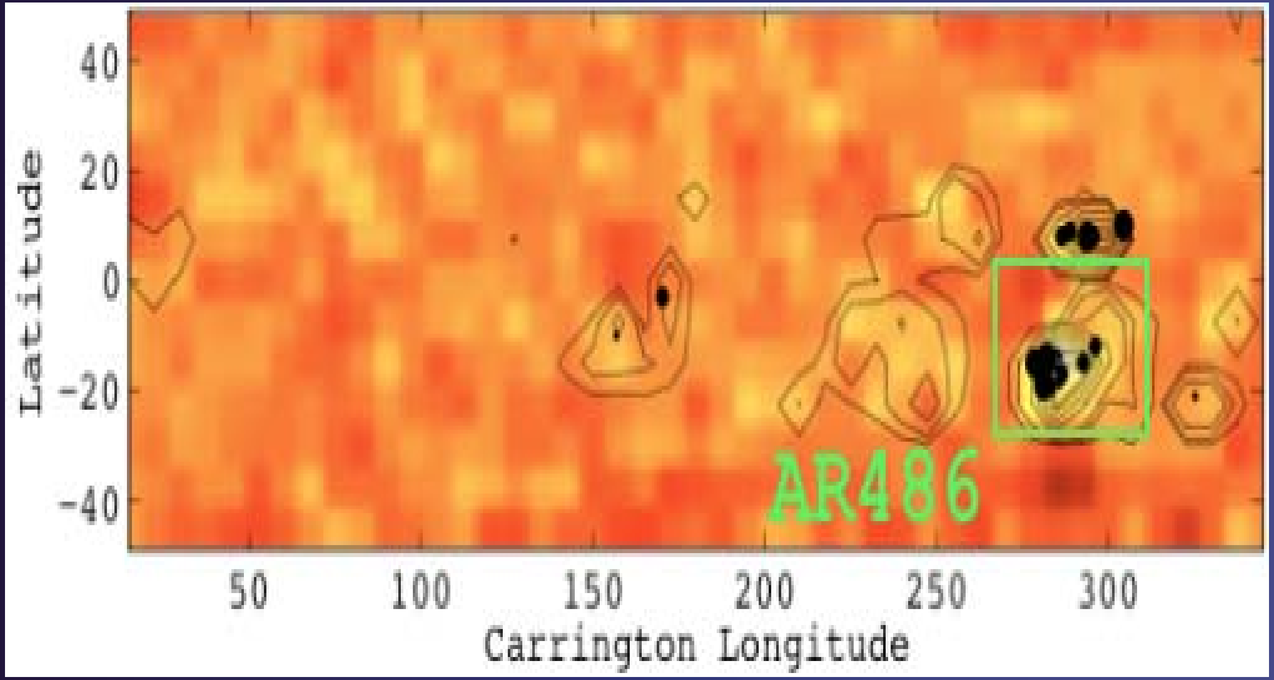
Magnetic flux is emerging



Flow below a sunspot



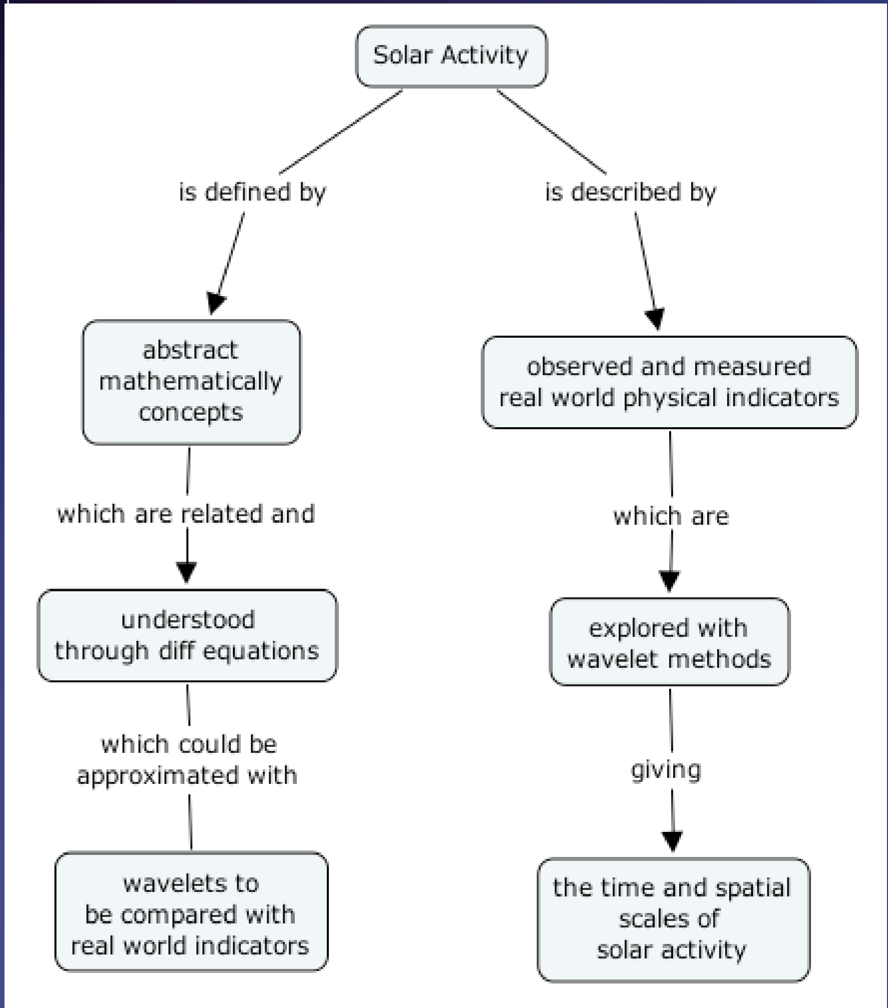
Helioseismic observations give a new picture: of correlated activity below, on surface in corona



Jensen, J. M., Lundstedt, H., Thompson, M. J., Pijpers, F. P., and Rajaguru, S. P .: Application of Local-Area Helioseismic Methods as Predicters of Space Weather, in Helio- and Asteroseismology: Towards a Golden Future, ed. D. Danesy, Proc. SOHO 14/GONG+ 2004 Meeting, ESA SP-559, 497-500, 2004

Solar activity
Definition vs description
A new approach

Mathematics **Physics**



Topical Forum
Fundamental research
(www.lund.irf.se/HeliosHome/fundamentalresearch.html)

COST 724 WG1
Monitoring and predicting solar activity for space weather
(ca724wg1.ts.astro.it)

Lund Workshop
Solar Activity: Exploration, Understanding and Predictions
(www.lund.irf.se/workshop)

THE END

of

First Talk