Solar Optical Telescope onboard *HINODE* for Diagnosing the Solar Magnetic Fields

Kiyoshi Ichimoto [1)]
and
HINODE/SOT-team

[1)] Solar-B Project Office
National Astronomical Observatory /NINS

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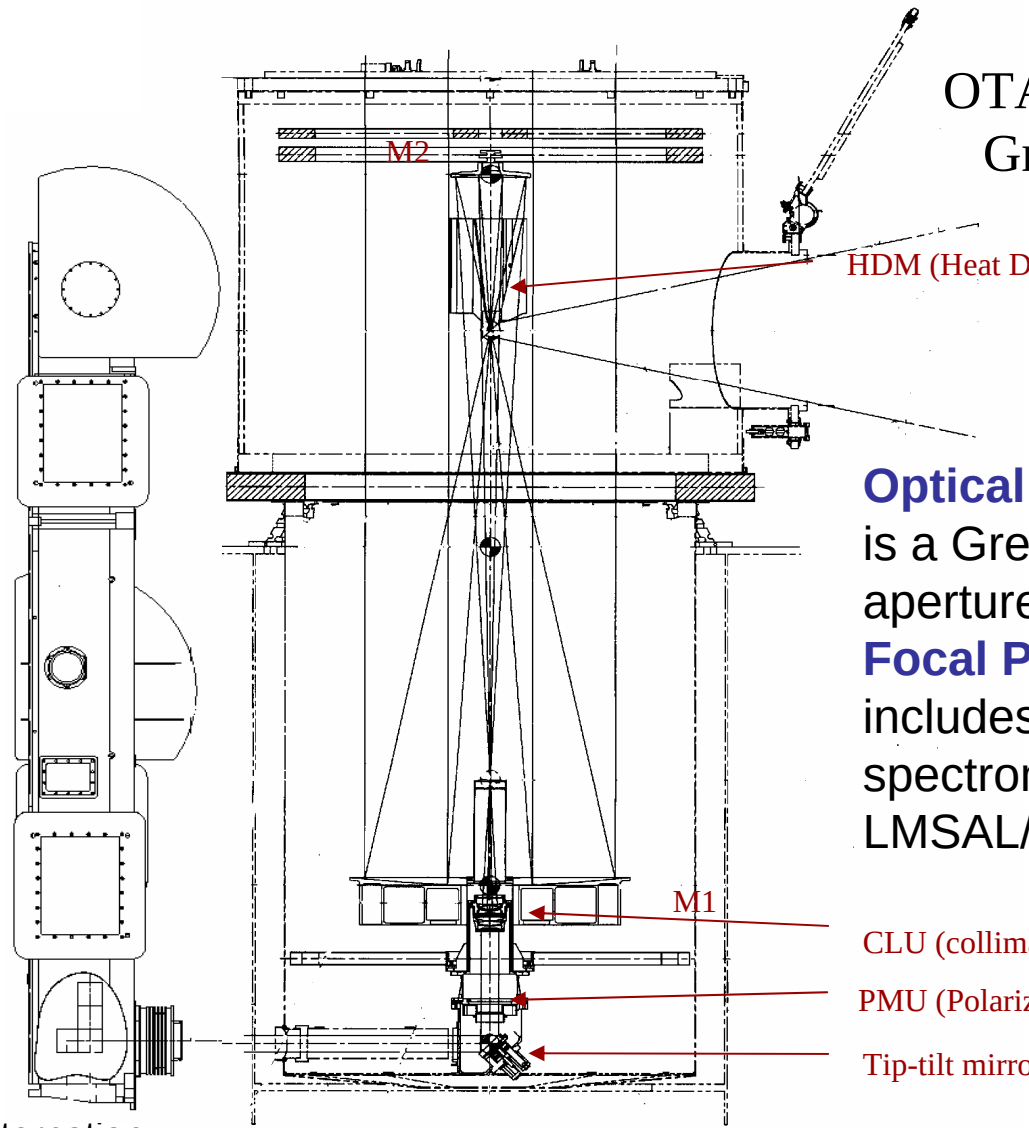
Solar Optical Telescope

SOT = OTA + FPP

FPP:



OTA: ϕ50cm
Gregorian Telescope

HDM (Heat Dump Mirror)

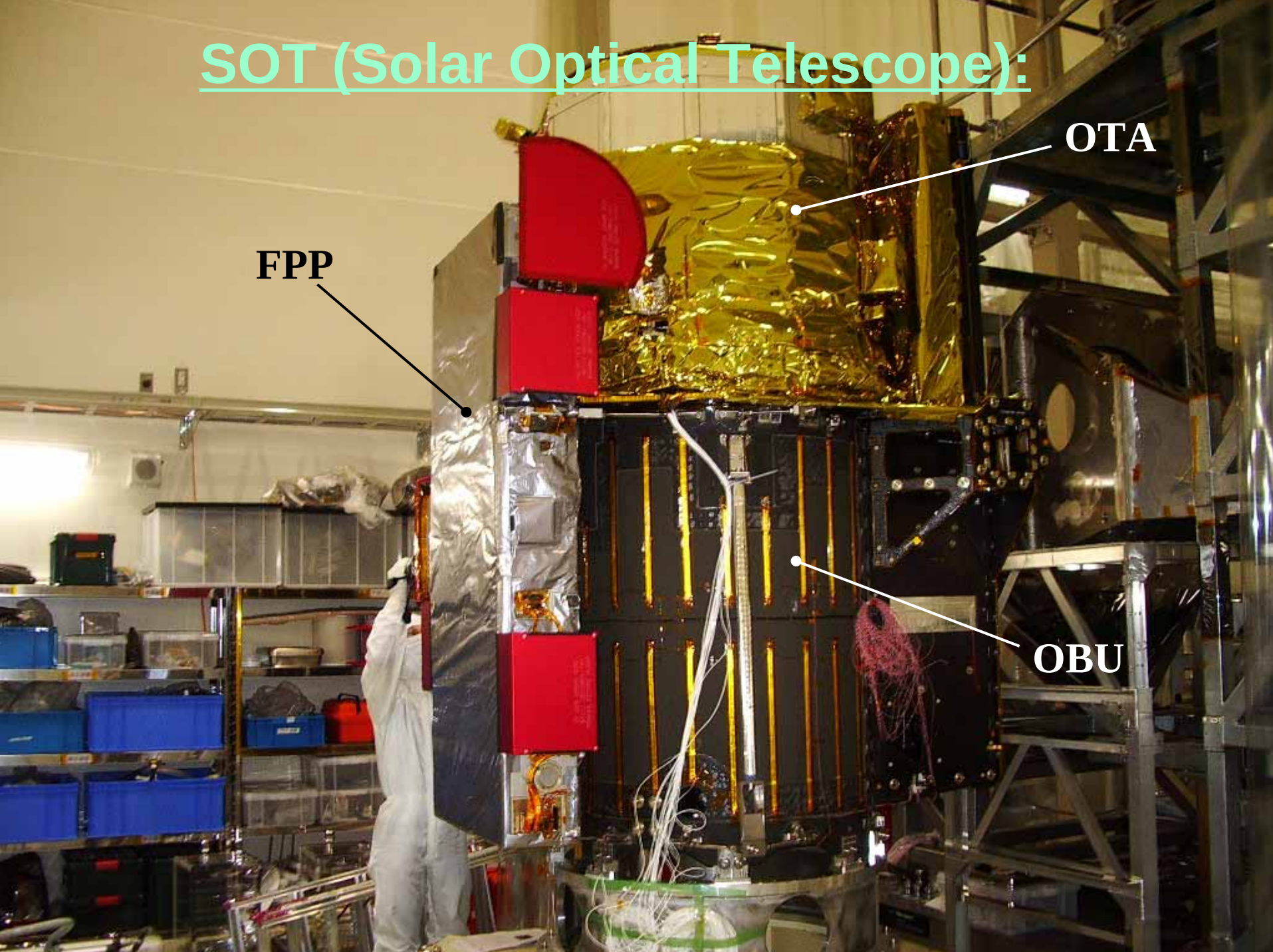
Optical Telescope Assembly (OTA), is a Gregorian telescope with 50 cm aperture, built by NAOJ/ISAS.
Focal Plane Package (FPP), includes observation filters, spectrometer, and cameras , built by LMSAL/HAO/NASA.

CLU (collimator Lens Unit)

PMU (Polarizaiton Modulator Unit)

Tip-tilt mirror

SOT (Solar Optical Telescope):



Solar Optical Telescope on *HINODE*

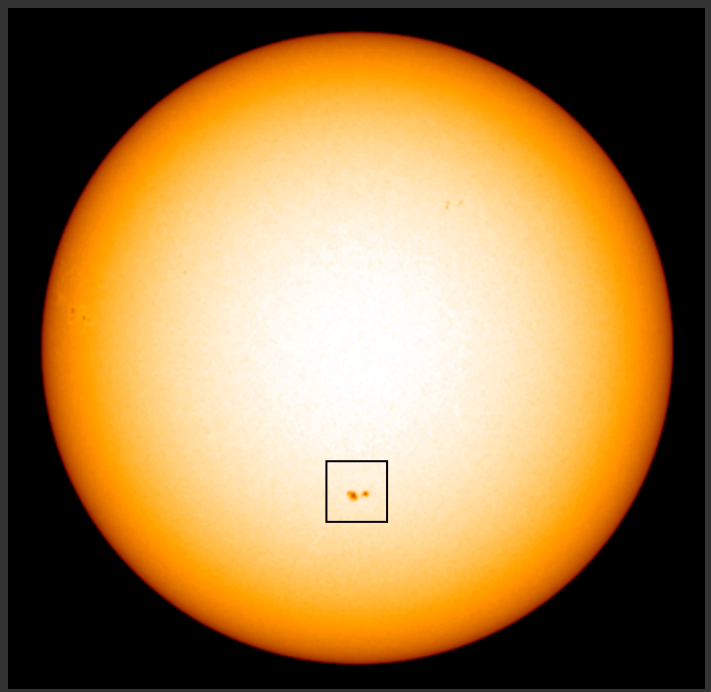
Key Features of SOT

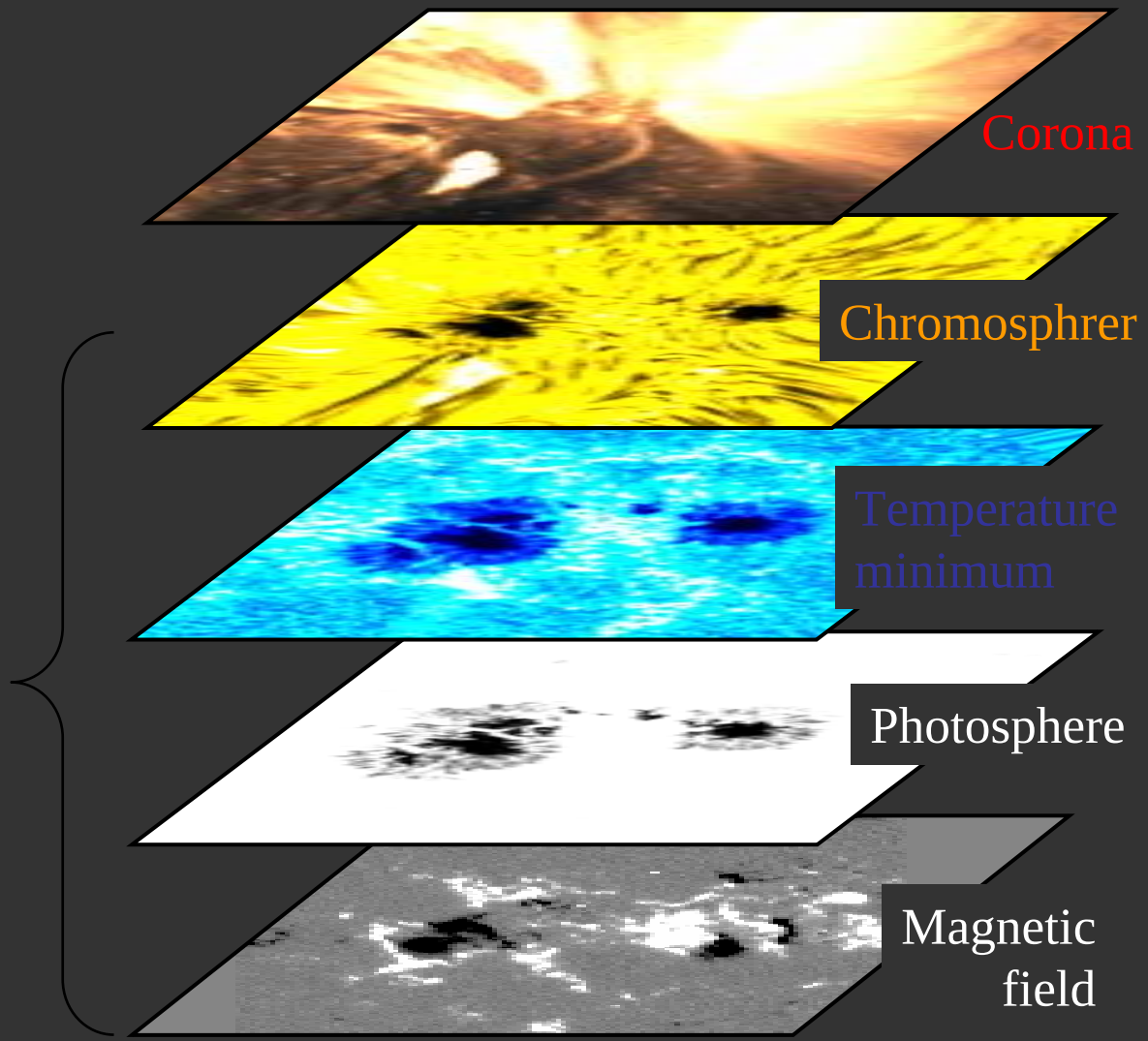
- Largest telescope ever built to observe the Sun from space

- Diffraction-limited images (0.2-0.3arcsec), achieved by 50-cm-diameter aperture
- Observation from space, free from the atmospheric seeing.
- Continuous observation for 24 hours per day in ~8 months per year, thanks to the sun-synchronous orbit of HINODE

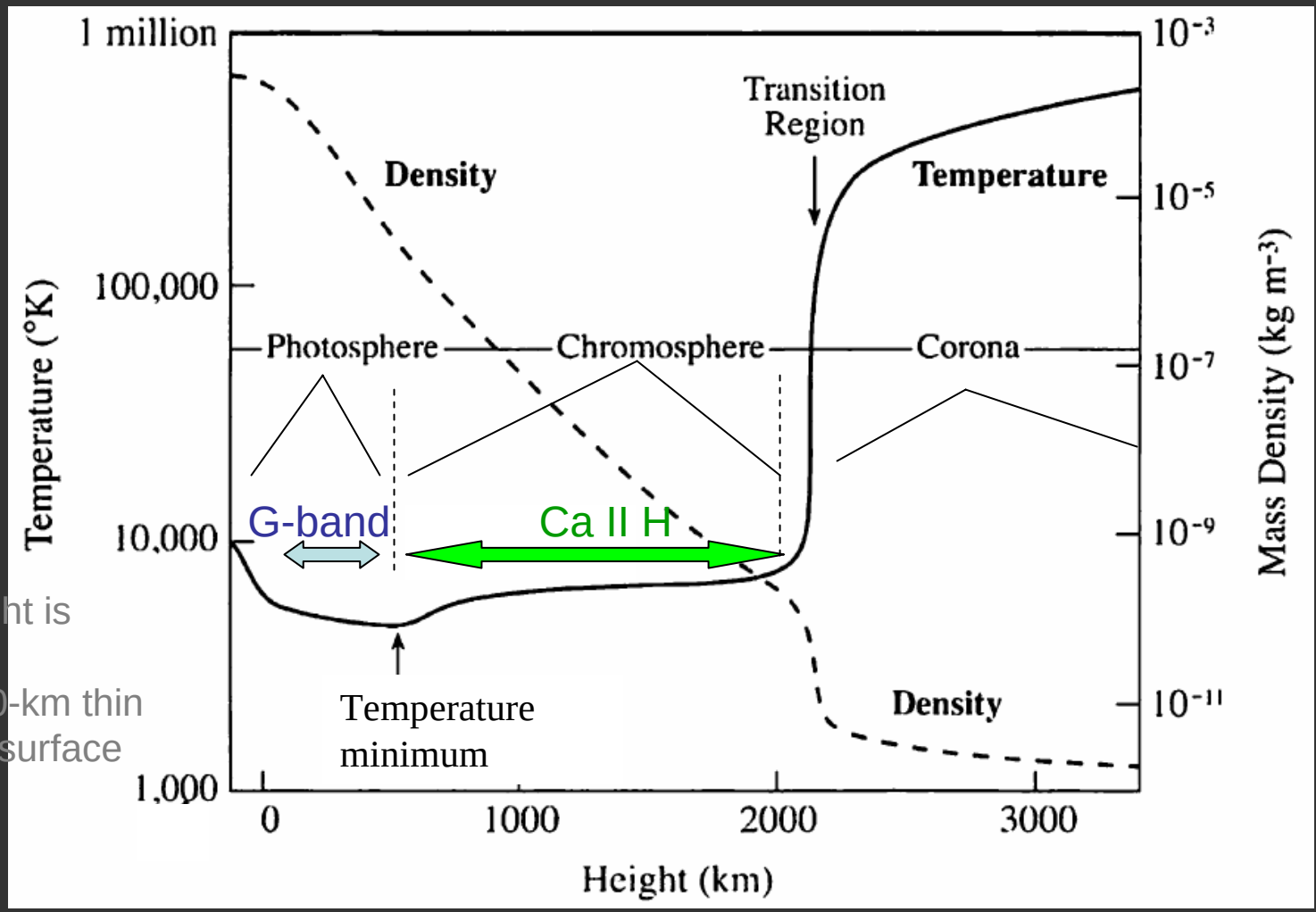
- Stabilized image with the correlation tracker
- 388-668nm range, including spectral lines and continuums useful for studying photosphere and chromosphere
- Optimized for high precession polarization measurements in spectral lines, continuous modulation of Stokes IQUV in every 0.8sec.
- Provides accurate vector magnetic fields in the photosphere.

Stratification of the Solar atmosphere: SOT observes photosphere and chromosphere



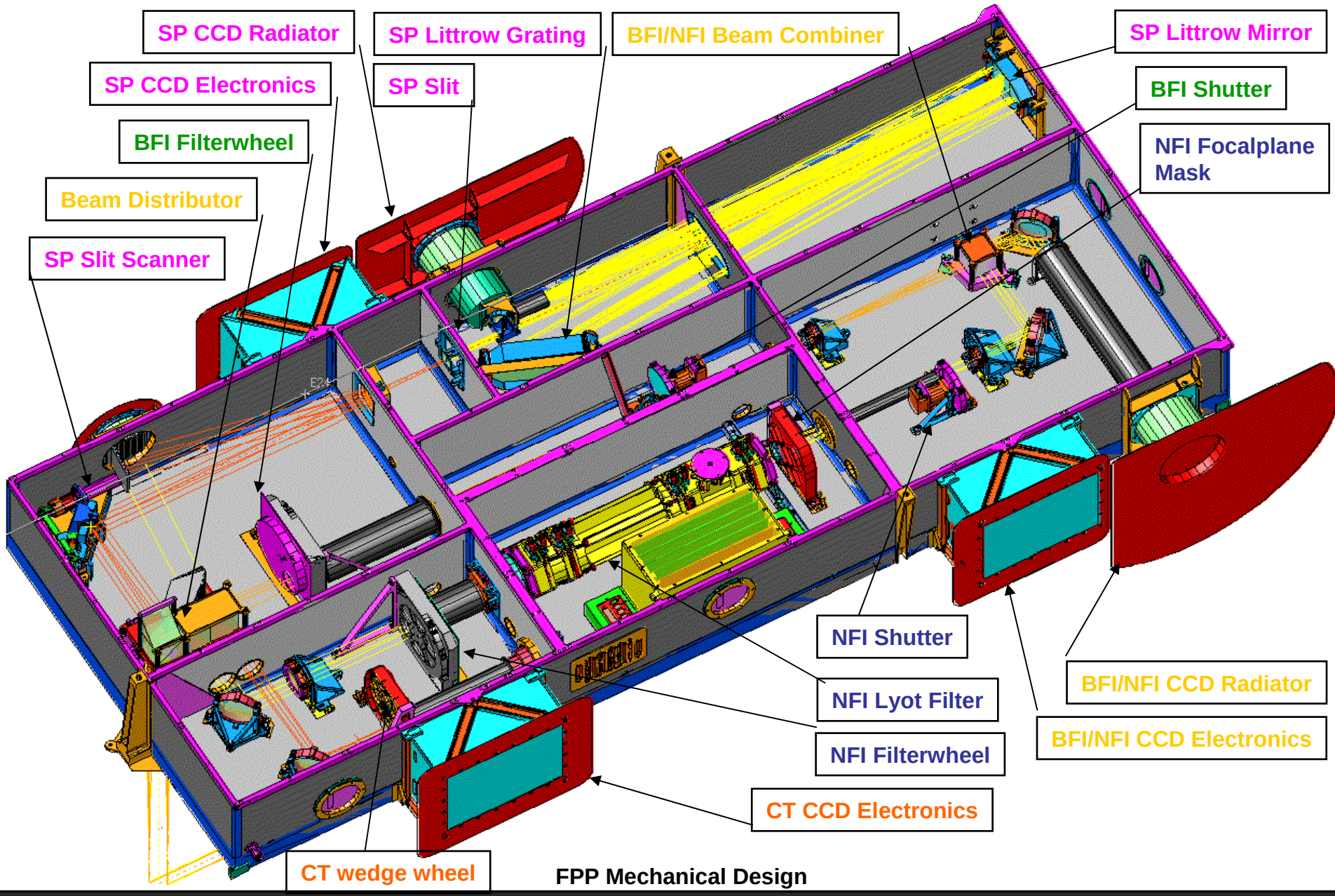


Temperature stratification of solar atmosphere



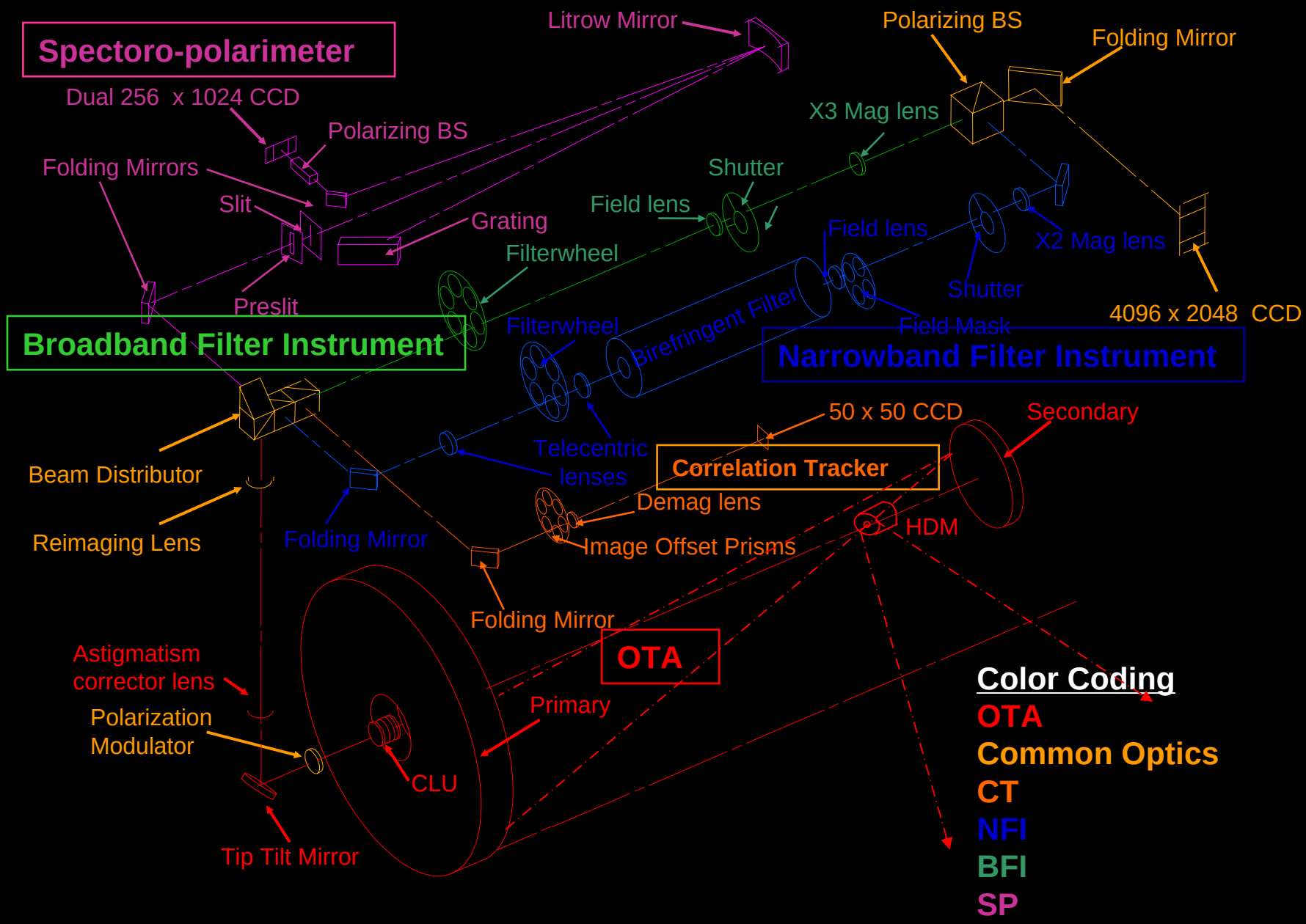
Most of visible light is emitted from the photosphere, 500-km thin layer around the surface of the Sun.

SOT is aimed to resolve fundamental processes taking place on the solar surface and to provide definite boundary conditions that drive the various active phenomena observed in the outer solar atmosphere (corona).



FPP Mechanical Design

Optical layout of SOT



HINODE SOT has four optical paths:

	< aims >
1. Broadband Filter Imager (BFI)	images with highest spatial resolution
2. Narrowband Filter Imager (NFI)	wide FOV, high resol. mag./Dopp., chrom.
3. Spectro-Polarimeter (SP)	precise photospheric magnetic fields
4. Correlation Tracker	image stabilization

Basic parameters of four optical paths:

	BFI	NFI	SP	CT
CCD format	4096 x 2048		112 x 1024 x 2	50 x 50
pixel scale (arcsec/pix)	0.054	0.08	0.16	0.22
maximum FOV (arcsec^2) (EWxNS)	218x109	328x164	328 (scan range) x164 (slit length)	11x11
wavelength resolution (A)	3~10	~0.1	0.02	5
number of wavelength in a data set	1	1~4	244	1
time resolution (typical)	5~30s	10~60s	1min~3hr	580Hz
photometric aquracy (%)	0.5	0.1 ~ 0.5	~ 0.1	~0.5

SOT broadband filters

Field of view	218" × 109" (full FOV)		
CCD	4k × 2k pixel (full FOV), shared with the NFI		
Spatial Sampling	0.0541 arcsec/pixel (full resolution)		
Spectral coverage			
Center (nm)	Width (nm)	Line of interest	Purpose
388.35	0.7	CN I	Magnetic network imaging
396.85	0.3	Ca II H	Chromospheric heating
430.50	0.8	CH I	Magnetic elements
450.45	0.4	Blue continuum	Temperature
555.05	0.4	Green continuum	Temperature
668.40	0.4	Red continuum	Temperature
Exposure time	0.03 - 0.8 sec (typical)		

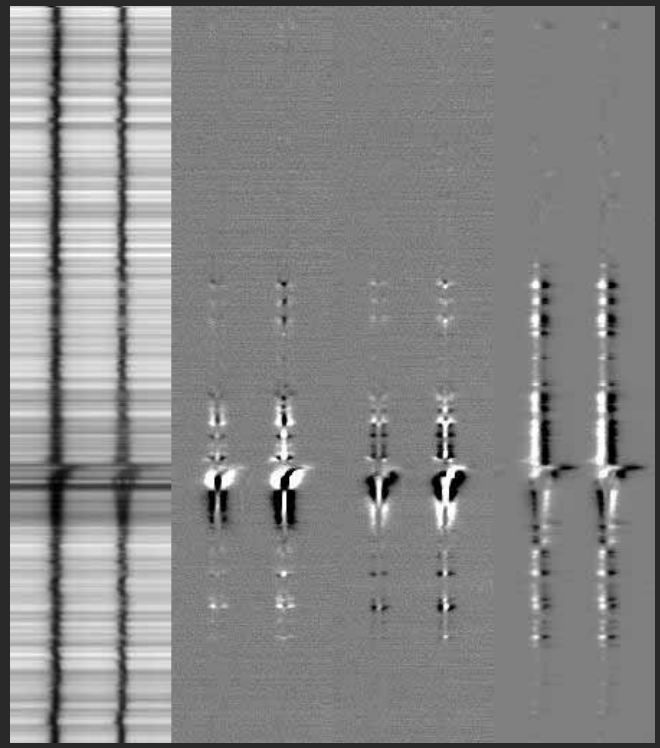
SOT narrowband filter

Field of view		328"×164" (unvignetted 264"×164")		
CCD		4k×2k pixel (full FOV), shared with BFI		
Spatial sampling		0.08 arcsec/pixel (full resolution)		
Spectral resolution		0.009nm (90mÅ) at 630nm		
Spectral windows (nm) and lines of interest				
Center	**λ-range**	**Lines**	**g_{eff}**	**Purpose**
517.2	0.6	Mg I b 517.27	1.75	Dopplergrams and magnetograms
525.0	0.6	Fe 524.71	2.00	Photospheric magnetograms
		Fe I 525.02	3.00	
		Fe I 525.06	1.50	
557.6	0.6	Fe I 557.61	0.00	Photospheric Dopplergrams
589.6	0.6	Na I D 589.6	-	Very weak fields (scattering polarization) Chromospheric fields
630.0	0.6	Fe I 630.15	1.67	Photospheric magnetograms
		Fe I 630.25	2.50	
		Ti I 630.38	0.92	Umbral magnetograms
656.3	0.6	H I 656.28	-	Chromosphreic structure
Exposure time		0.1 - 1.6 sec (typical)		

SOT SP

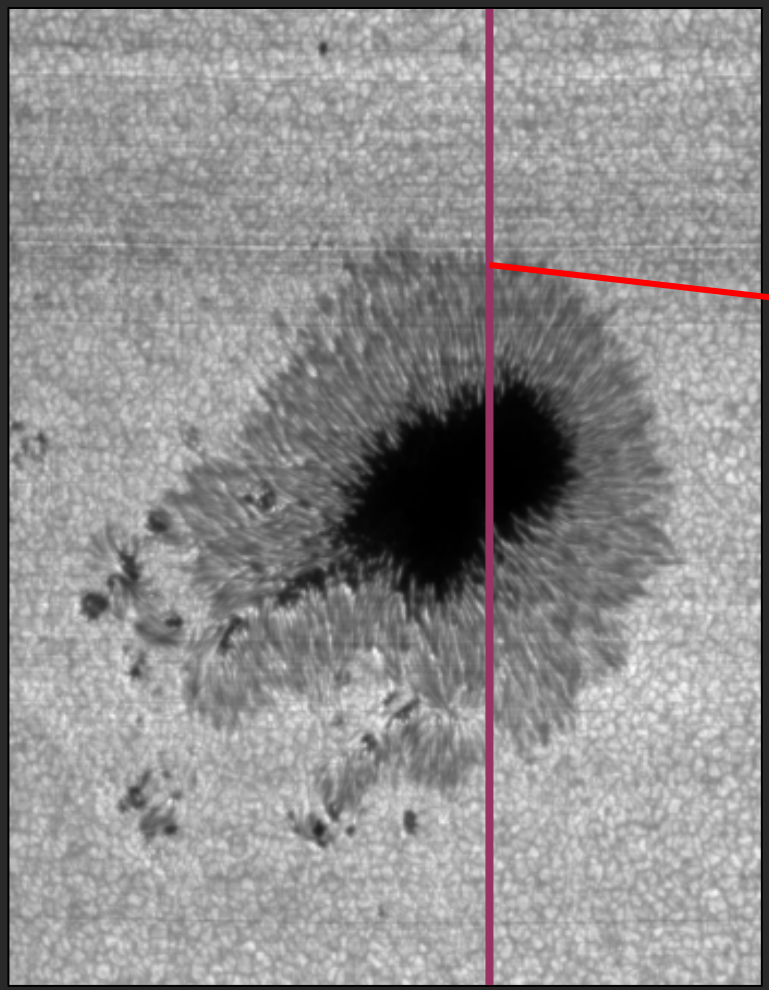
(Spectro-Polarimeter)

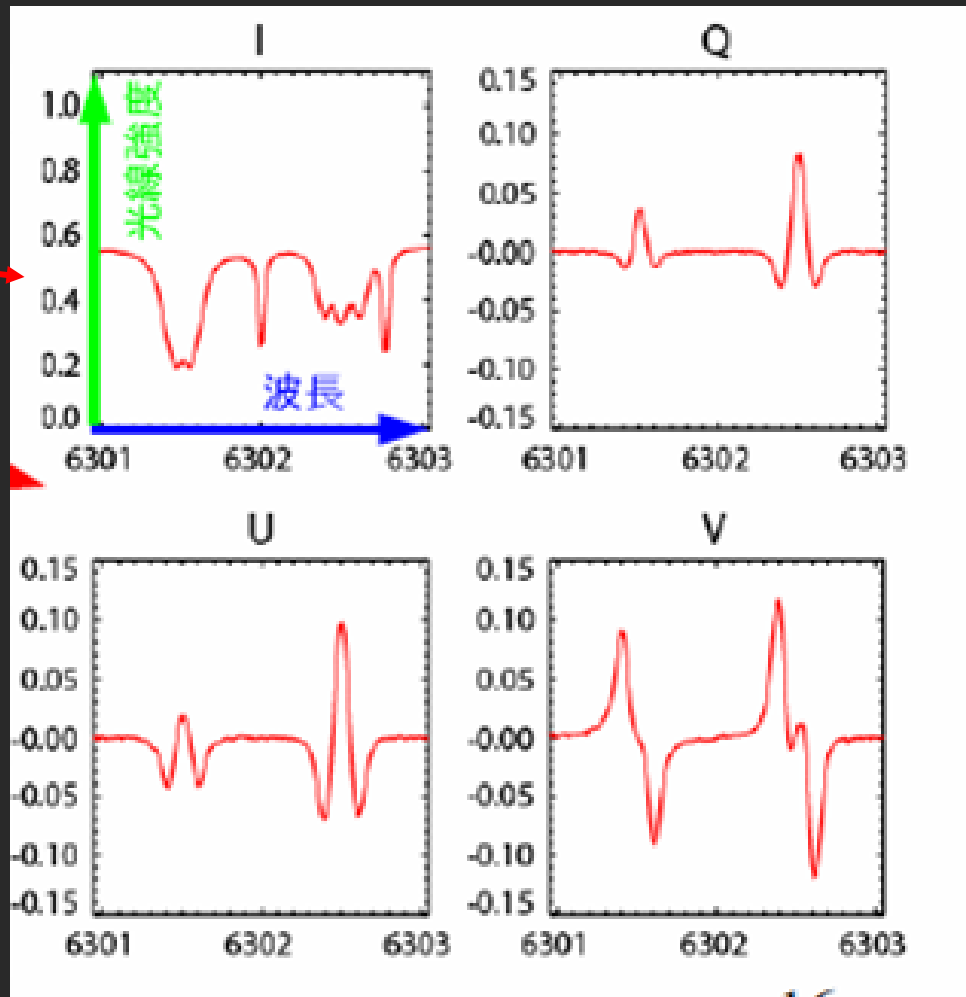
- Fe I 630.15nm and 630.25nm
- Obtain spectra at 16 angular positions of polarization modulator
- 83min for 160" wide scan



Field of view along slit	164" (north-south direction)
Spatial scan range	±164"
Slit width	0.16"
Spectral coverage	630.08nm - 630.32nm
Spectral resolution	27mÅ / 21.53 mÅ sampling
Measurement of polarization	Stokes I,Q,U,V simultaneously with dual beams (orthogonal linear components)
Polarization signal to noise	10^3 (with normal mapping)

Diagnostics using SP data

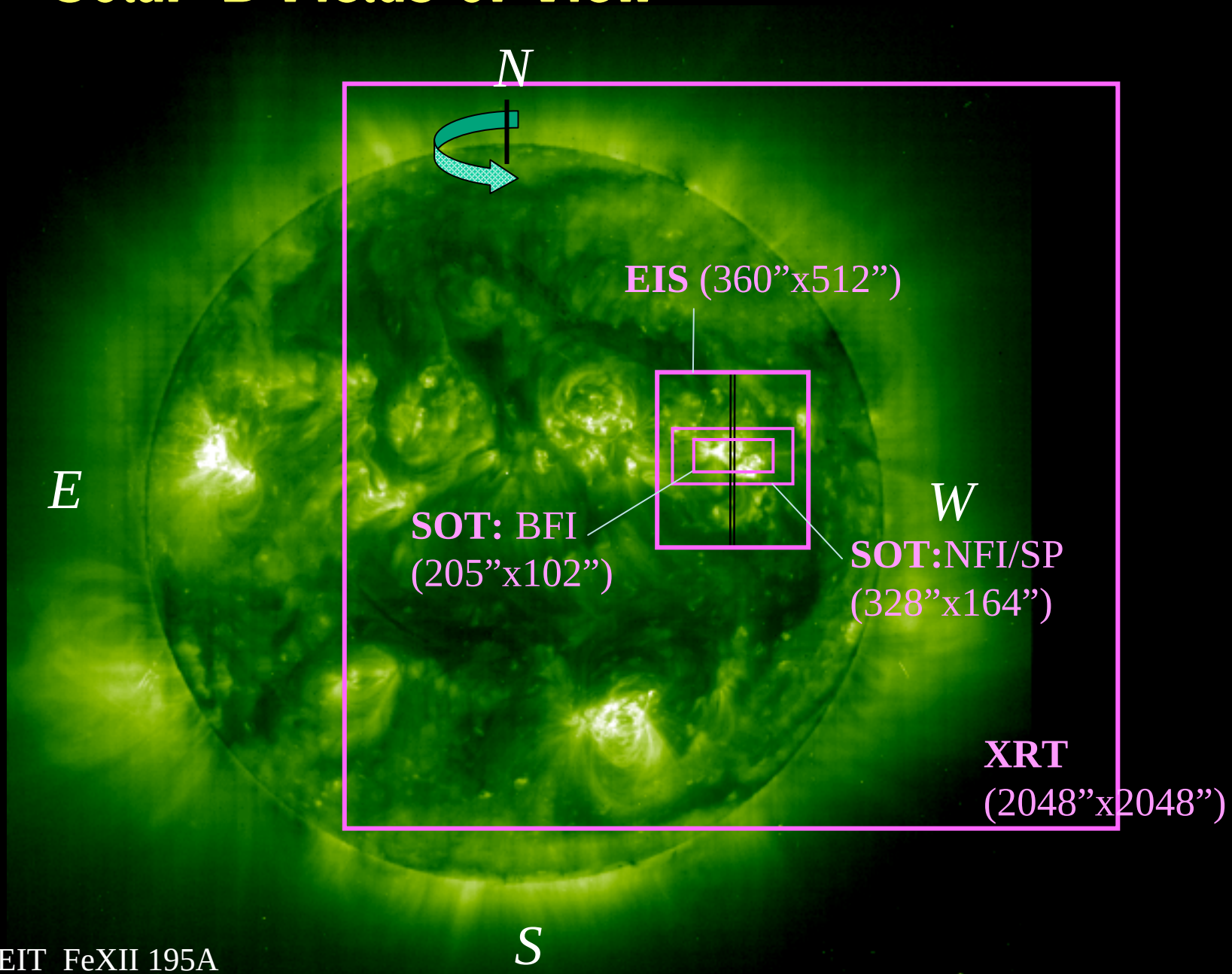




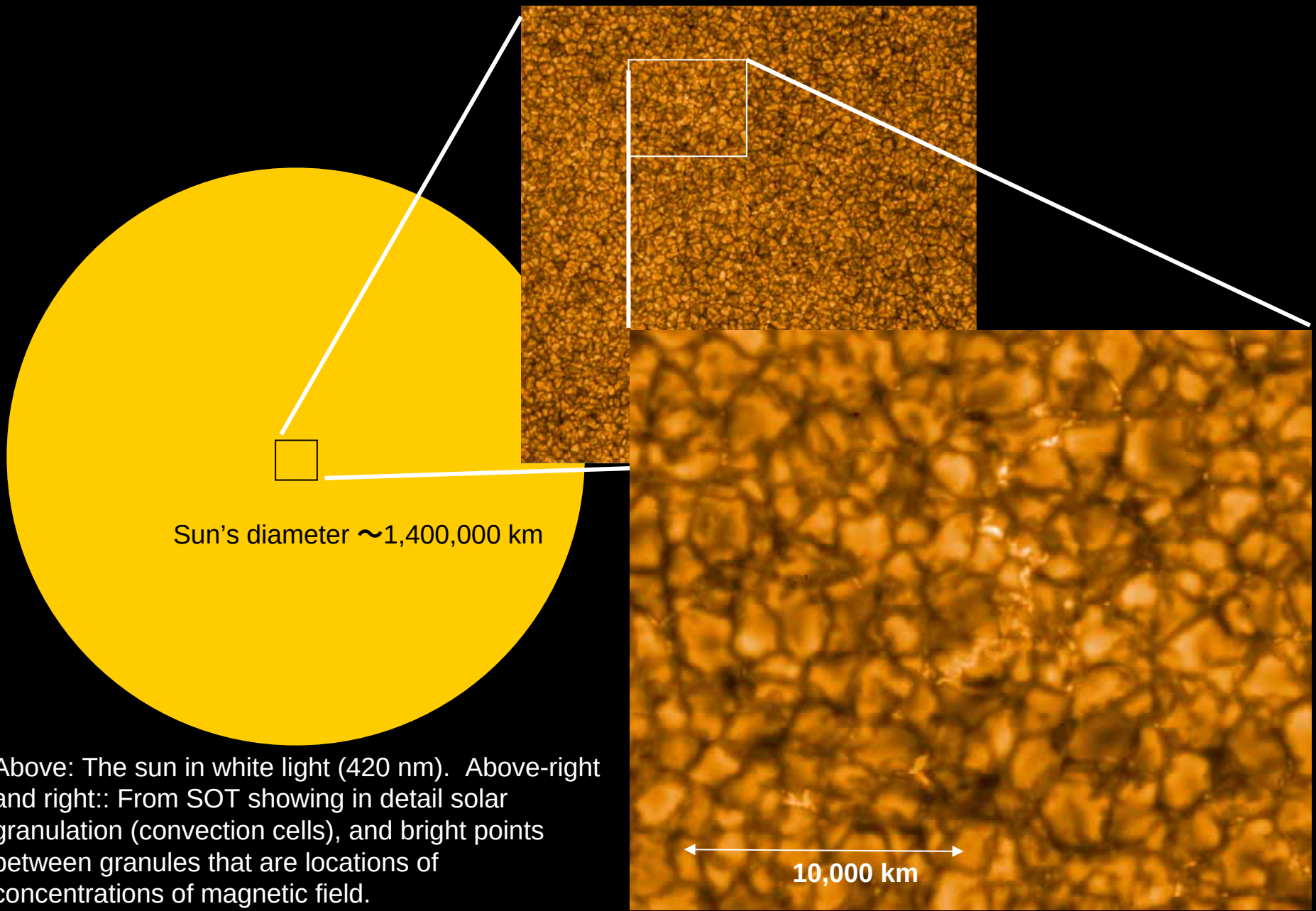
Obtain magnetic field vectors and motions in solar atmosphere.

Zeeman effect produces polarization in spectral lines

Solar-B Fields of View

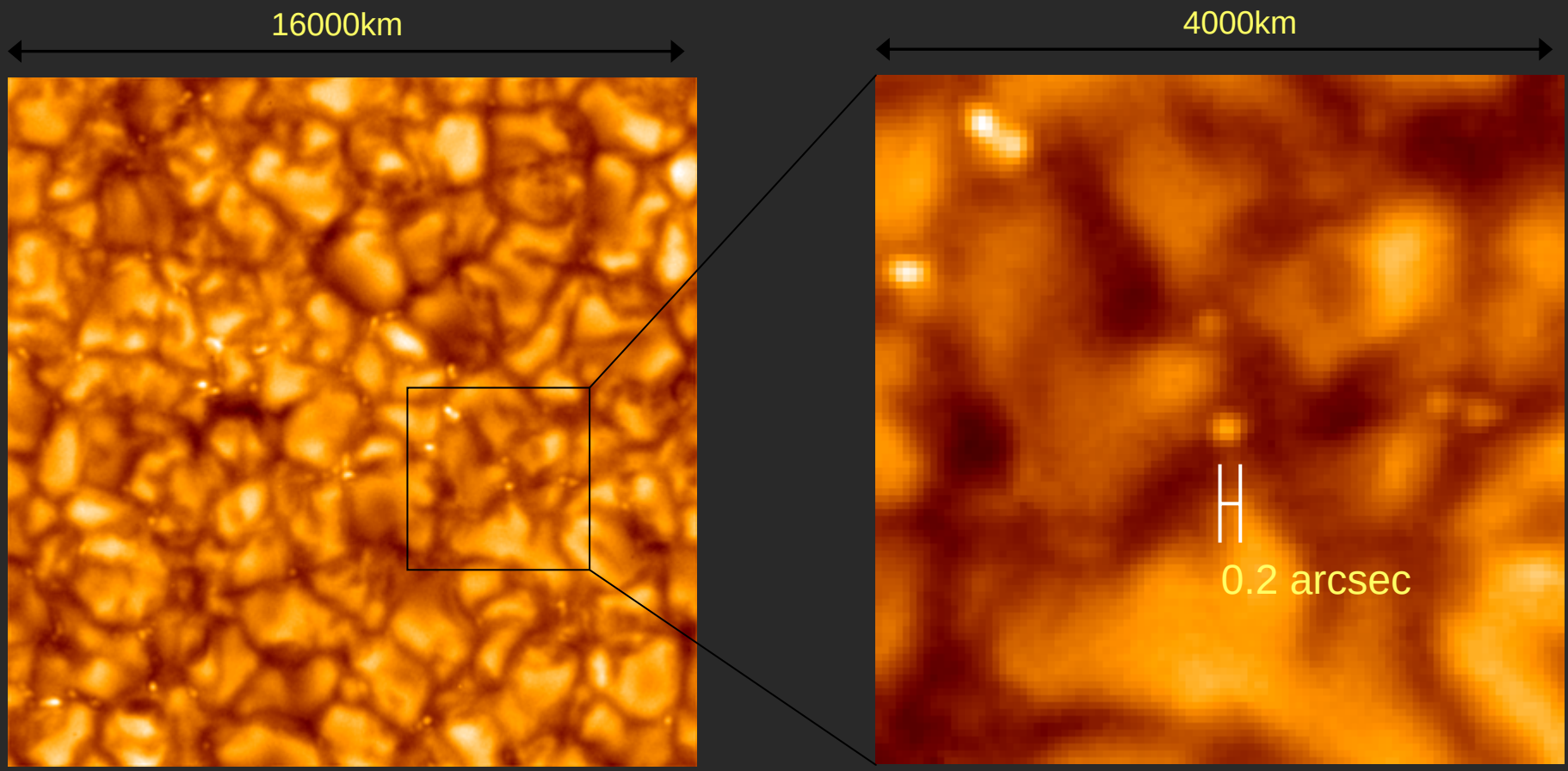


Hinode SOT First Light image, 2006.10.25



Above: The sun in white light (420 nm). Above-right and right:: From SOT showing in detail solar granulation (convection cells), and bright points between granules that are locations of concentrations of magnetic field.

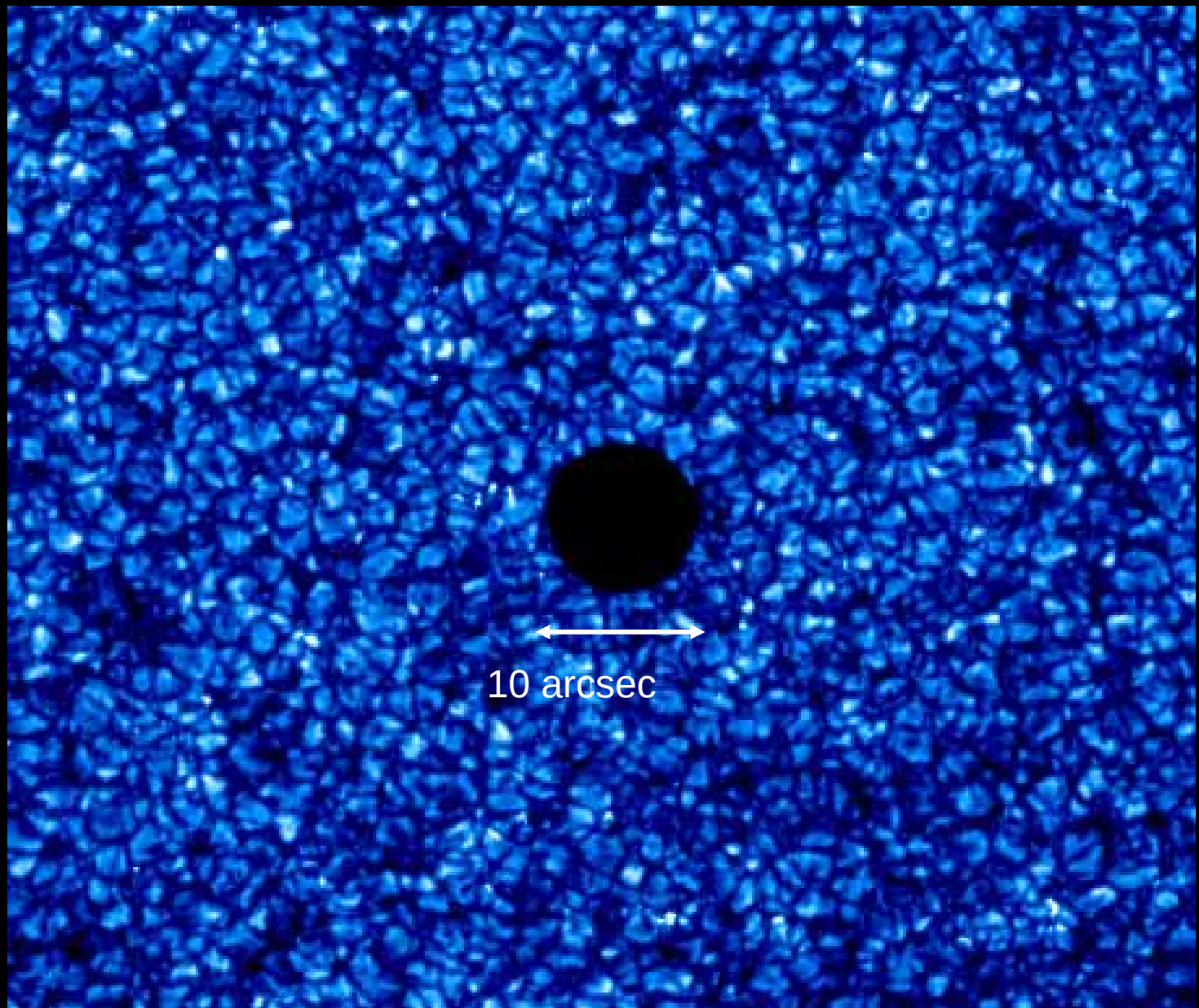
Close-up of granules



Granules and bright points corresponding to tiny magnetic features are clearly seen in the movie.

Obtained data proves that SOT achieves the diffraction limit resolution of 50cm-aperture telescope, 0.2 arcsec in the wavelength of 430 nm.

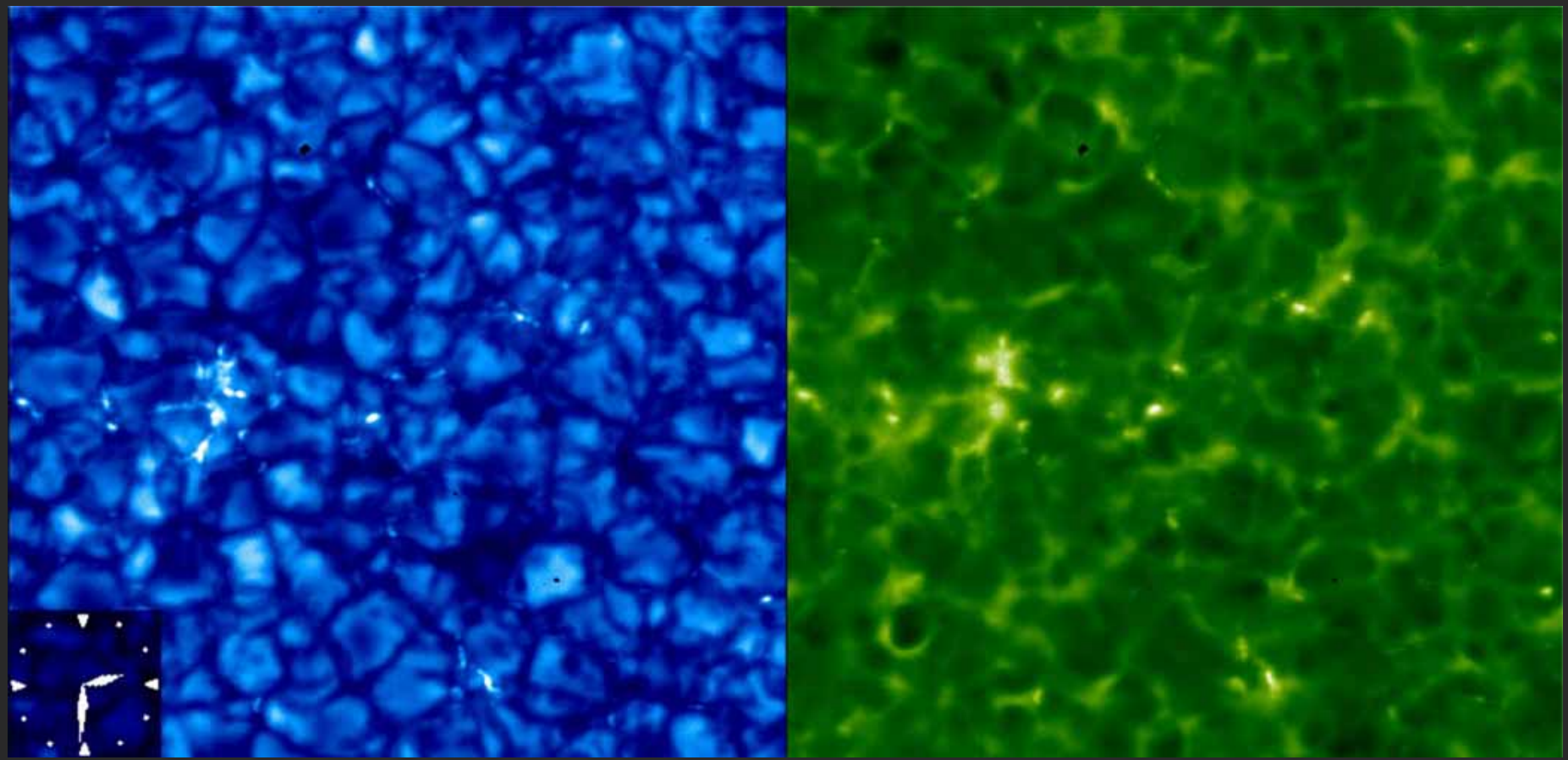
BFI: G-Band image of Mercury Transit and Quiet Sun on Nov 9th



Quiet Sun: Granules and Magnetic Elements

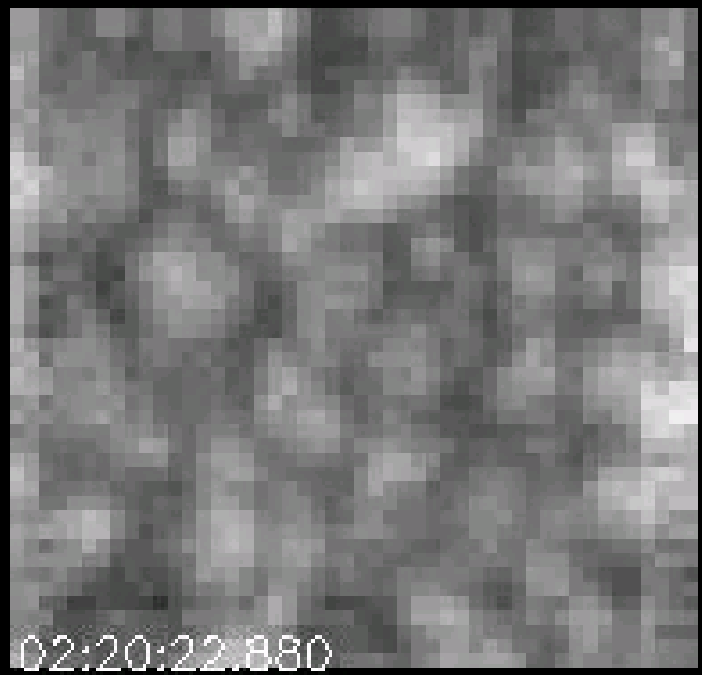
G-band (photosphere)

CaII H (chromosphere)



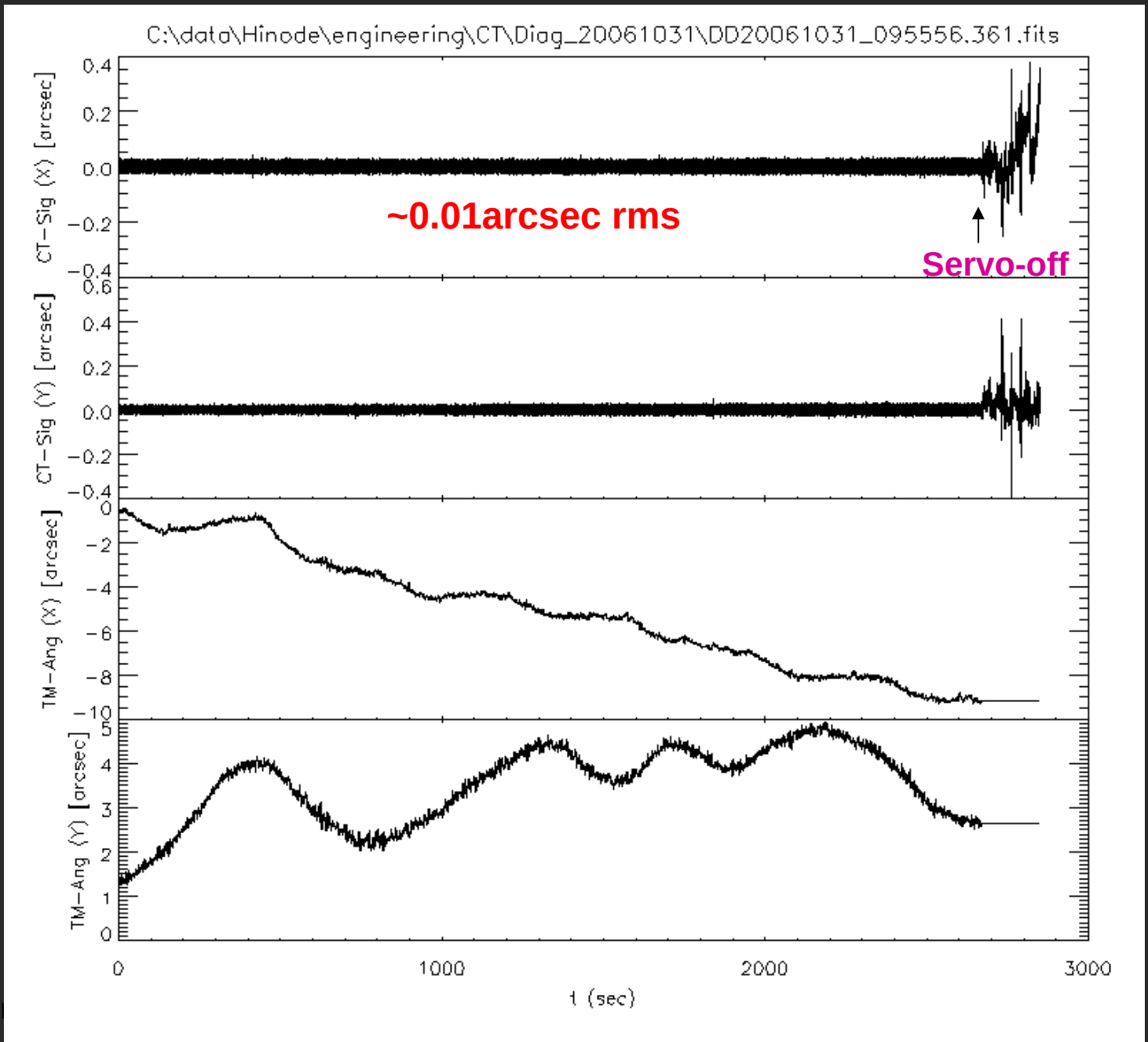
SOT CORRELATION TRACKER (CT)

- HINODE spacecraft tracking is excellent, drifting by typically ±0.1-0.2 arcseconds in ~10 seconds
- CT generates residual pointing error signal using the correlation between sun's granular pattern at 580Hz
- CT image : 50x50 pixels (11x11")
- CT&TTM freezes residual motion to the ~0.01 arcsecond level

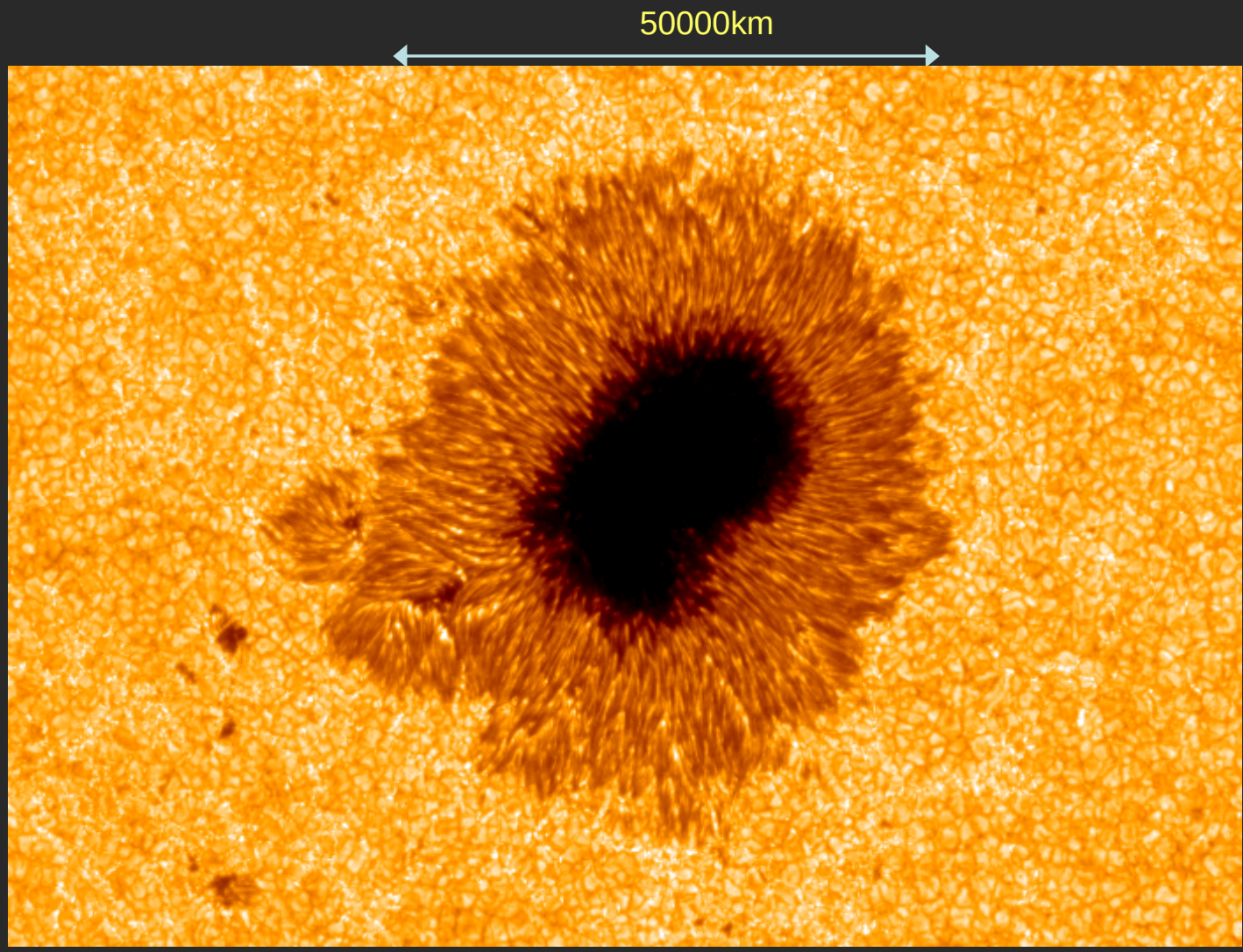


21-Hour Time Series of images from the CT

2006.10.31 CT servo-On, error signal/TM angle time profiles

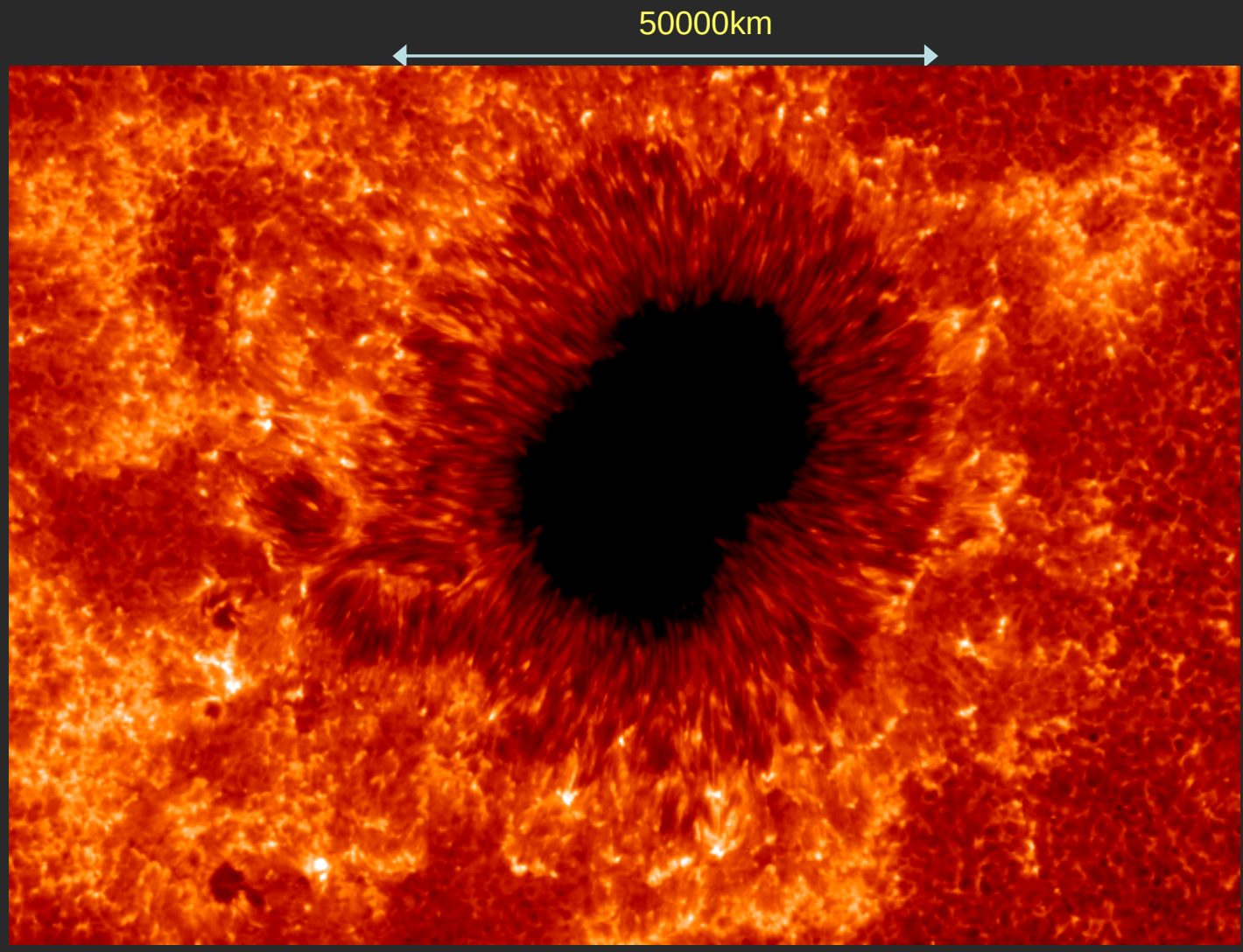


G-band
(430nm)



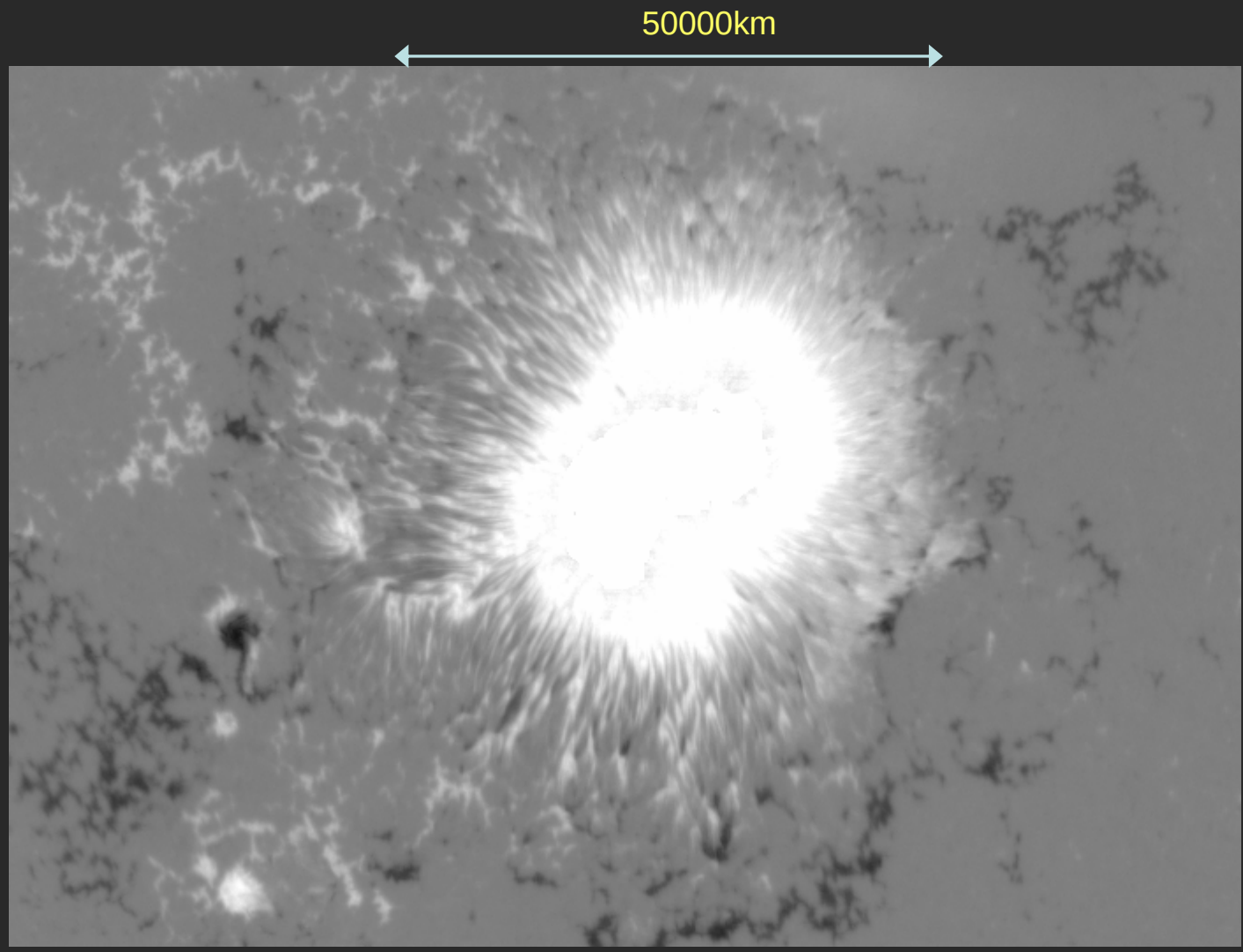
SOT/*Hinode* can measure magnetic field photosphere and observe the chromosphere above by selecting filters. This function allows us study dynamic phenomena such as the heating around Sun spot, flares, and jets.

Ca II H
(397nm)



Spectral line of Ca II H mainly represents the chromosphere above the photoshere. Brightness indicates the strength of heating in the chromosphere, which coincide with magnetic field concentration on the photosphere.

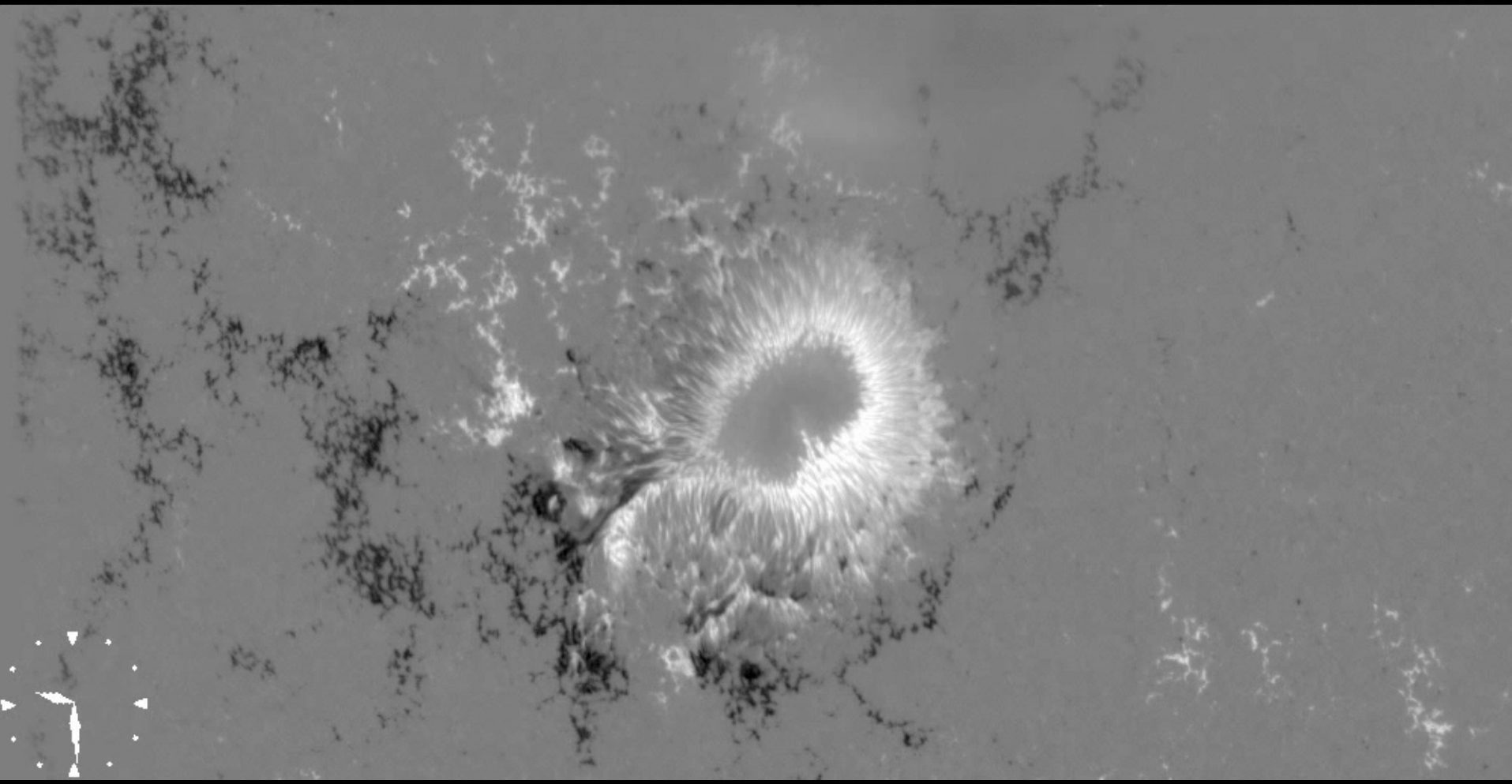
Longitudinal magnetic field (Fe I 630nm)



White and black of the magnetogram shows N and S polarities, respectively. Strength of magnetic field reaches 3000 Gauss in the Sun spot. Localized magnetic fluxes up to 1000 Gauss are observed outside the Sun spot.

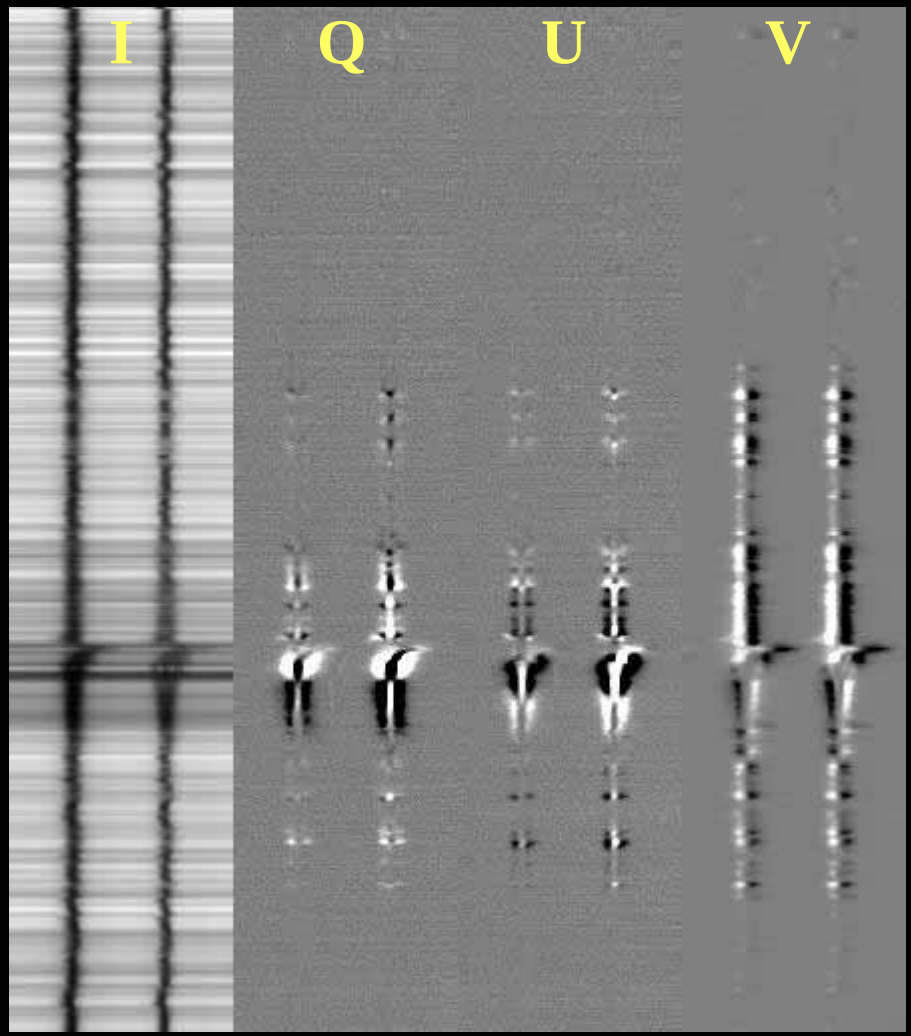
Evolution around a Sunspot

Longitudinal magnetogram of AR 10923 by NFI 6302A

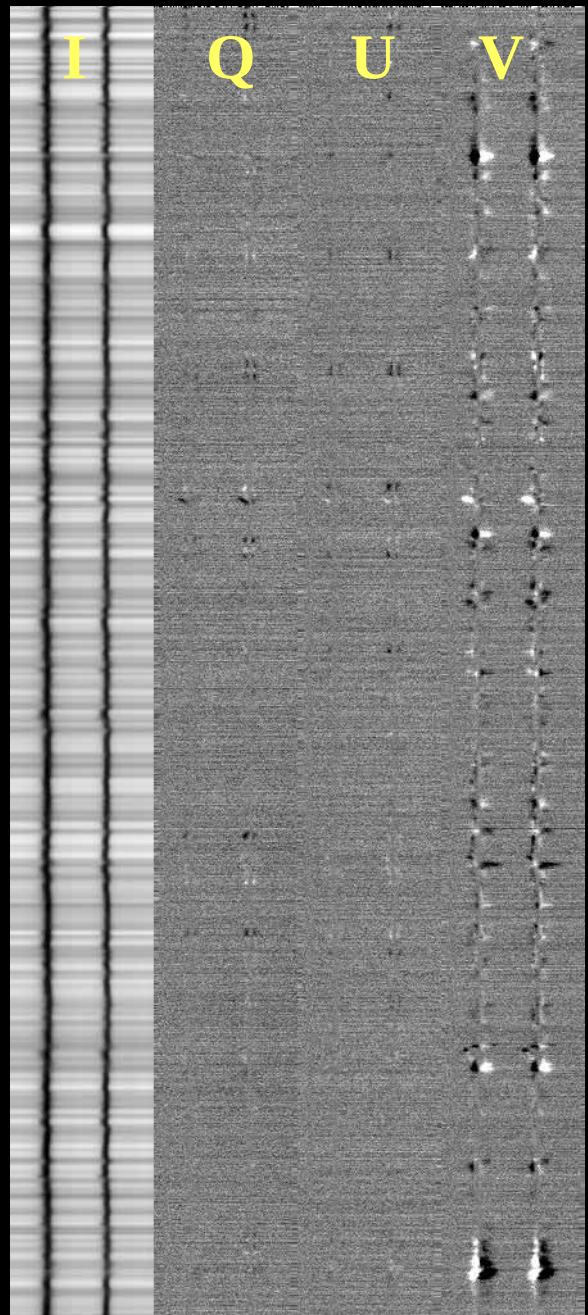


SOT Spectro-Polarimeter

Active Region, Half Resolution

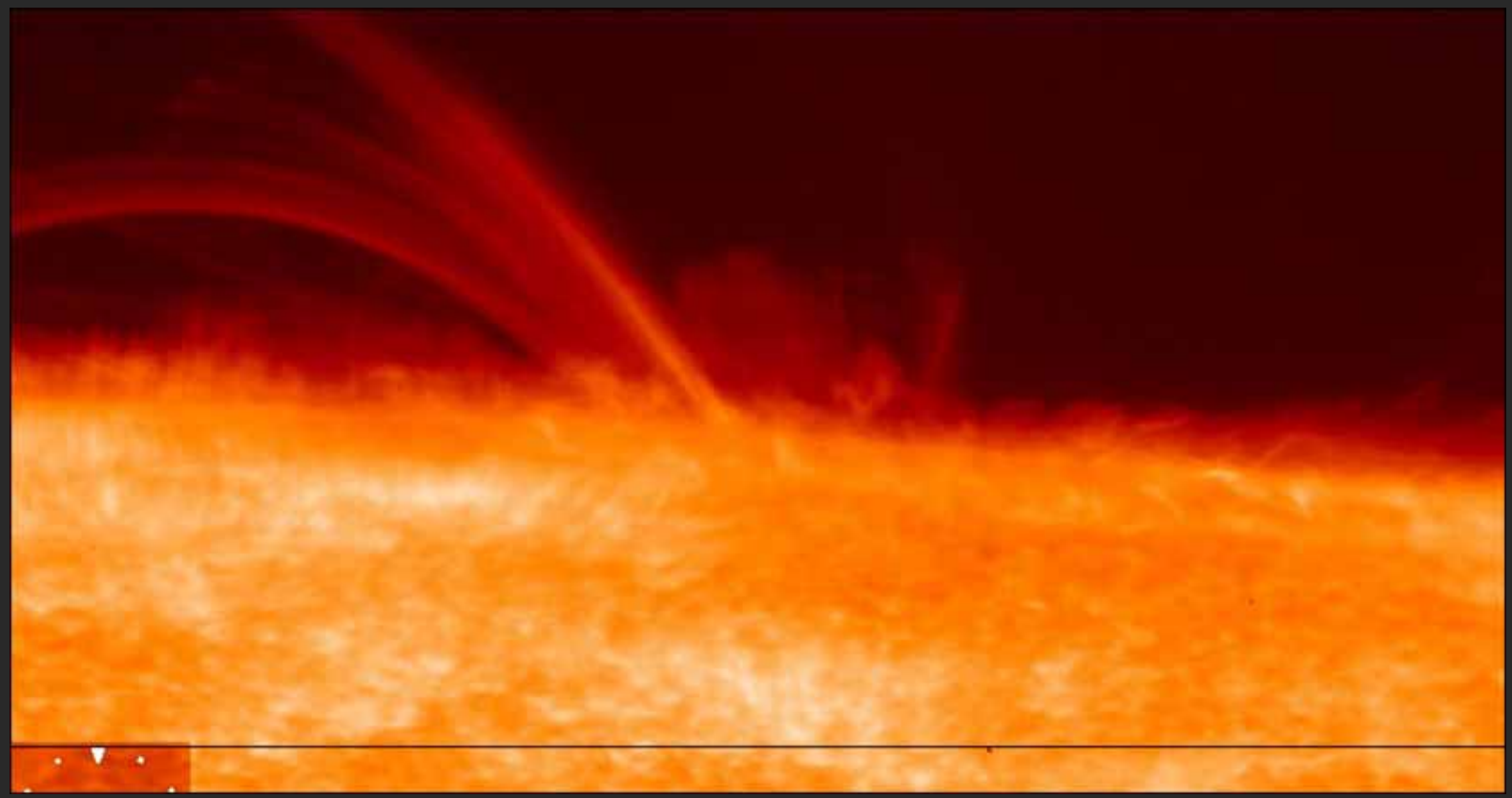


Quiet Region, Full Resolution



Dynamic eruption above Sun spot

82000km



This movie in Ca II H shows an active region near the limb of the Sun. It highlights brightenings and dynamic eruption around the Sunspot. Thanks to its low stray-light and distortion-free observation, SOT/*Hinode* has captured this dynamic phenomena for the first time.

Summary

- HINODE/SOT is now providing excellent images of solar photosphere and chromosphere (~10GB/day); the BFI and SP are in operation with their full performance, NFI is in operation but with limited wavelength tuning; engineering checkout is still ongoing.
- It is promising that HINODE/SOT will provide over the next 3-10 years unprecidented observations of the magnetic field evolution in the photosphere, and, together with the XRT/EIS observations, HINODE will open the new world in the plasma physics of the solar atmosphere.
- The basic calibration software is under development, and the data will be available on web from spring of 2007.

- Latest information
  http://hinode.nao.ac.jp/index_e.shtml

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