

2017 NJIT Alumni Event - BBSO 20th Anniversary Celebration



Wenda Cao

- 10:00 am – Welcome Remarks
- 11:00 am – BBSO Site Tours
- Noon – Lunch & Presentation
- 2:00 pm – Event Conclusion

Big Bear Solar Observatory - Cool Toys for Observing Our Warm Star



Wenda Cao

- BBSO was built by Caltech in 1969.
- Observatory was transferred from Caltech to NJIT in July 1997.
- The dome sits at the end of a 1000 ft. causeway on Big Bear Lake's north shore at 6,750 foot elevation.
- The surrounding waters of Big Bear Lake reduce ground level convection, and predominate winds bring smooth air flows across the flat surface of the lake providing superb conditions for solar observing.
- BBSO is the home of Goode Solar Telescope - the largest solar telescope.

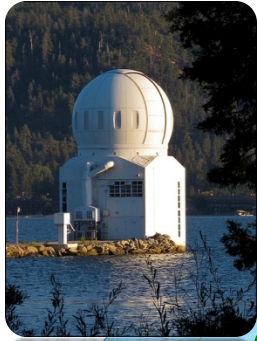


NJIT

New Jersey's Science & Technology University

Big Bear Solar Observatory

THE EDGE IN KNOWLEDGE



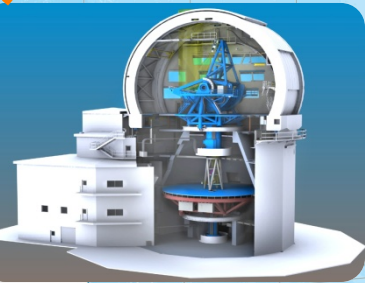
**1.6 m GST
USA 2009**



**1 m SST
Sweden 2002**



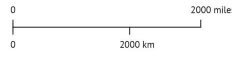
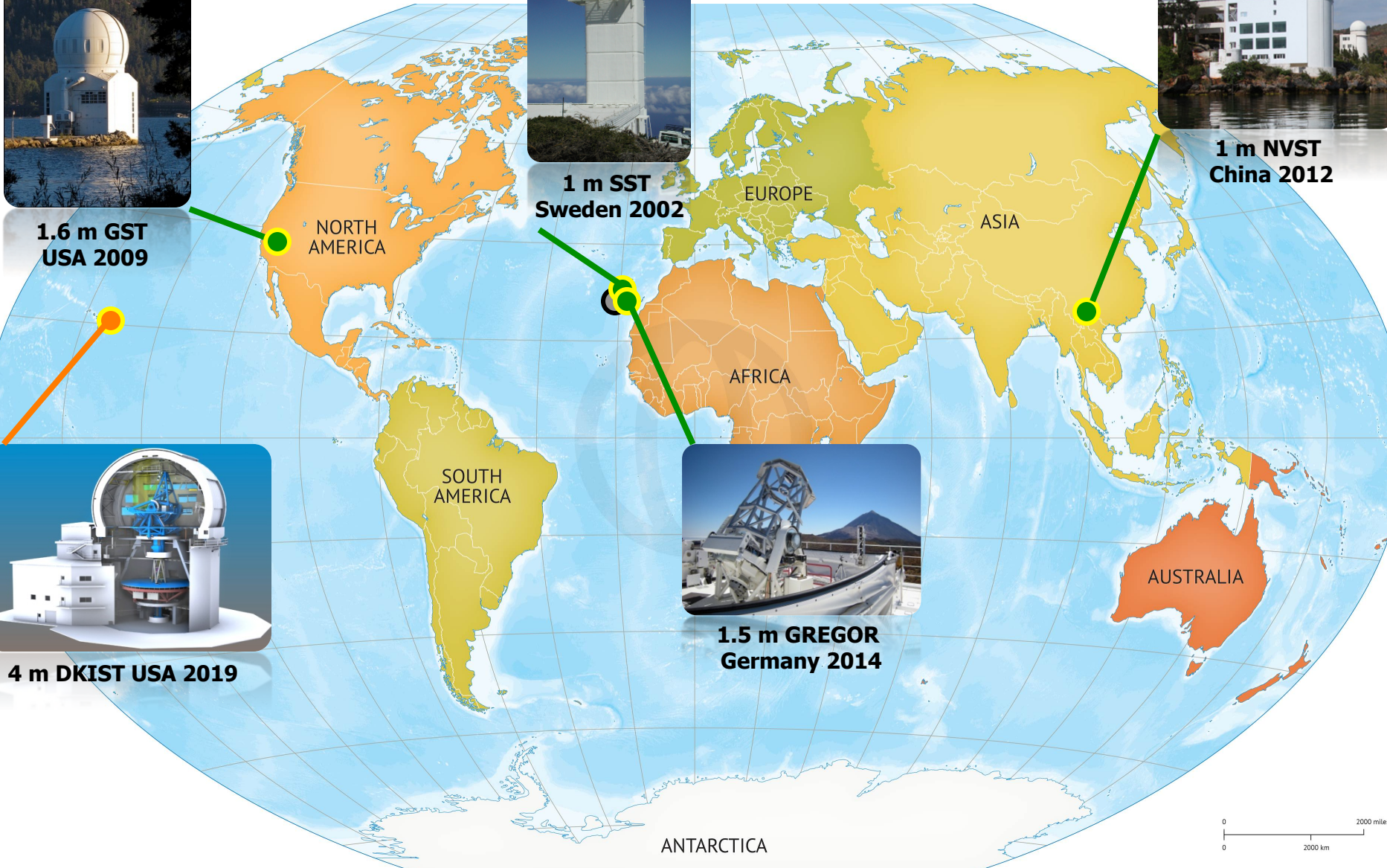
**1 m NVST
China 2012**



4 m DKIST USA 2019



**1.5 m GREGOR
Germany 2014**



NJIT

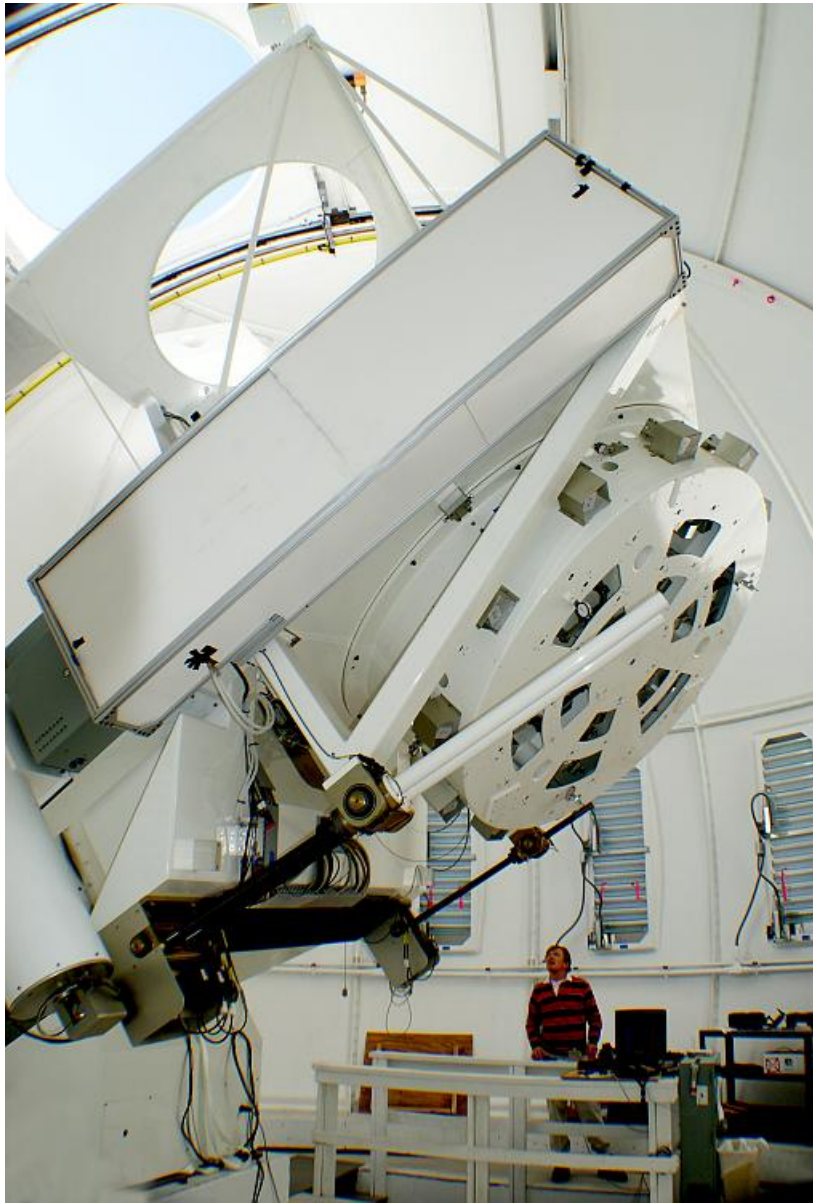
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Big Bear Solar Observatory

THE EDGE IN KNOWLEDGE



Outline



- ❑ Pre-GST Era (1960 - 2002)
- ❑ GST Times (2002 - present)
- ❑ GST Design
- ❑ GST Construction
- ❑ GST Instruments
Development
- ❑ Scientific Results from GST
- ❑ Summary



Pre-GST Era (1960 - 2002)



Prof. Leighton of Caltech

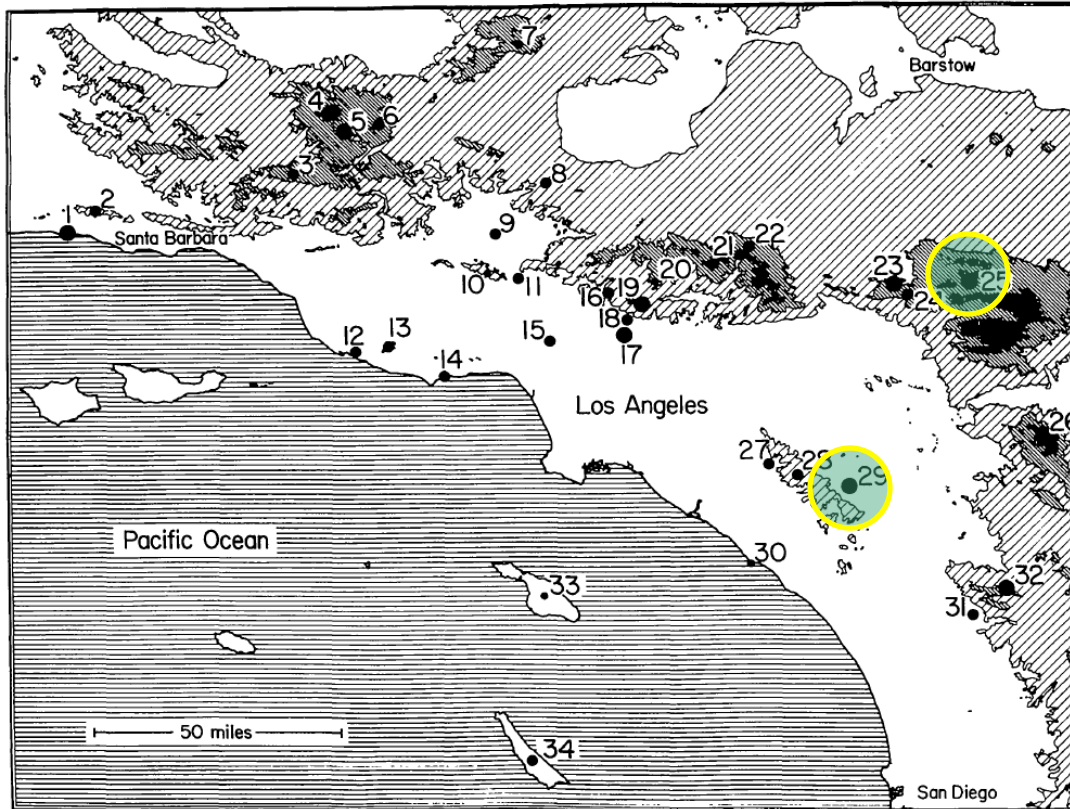


Robert B. Leighton (September 10, 1919 – March 9, 1997)

- ❖ By the 1960s the active nature of the Sun was under intensive study.
- ❖ Narrow-band filters & stop-motion cameras allowed study of the rapidly changing solar features.
- ❖ There was a great need for high-resolution movies of solar activity.
- ❖ Mt. Wilson only had good images for a short time in the morning
- ❖ Caltech needed better observing site, but where?



Site Survey

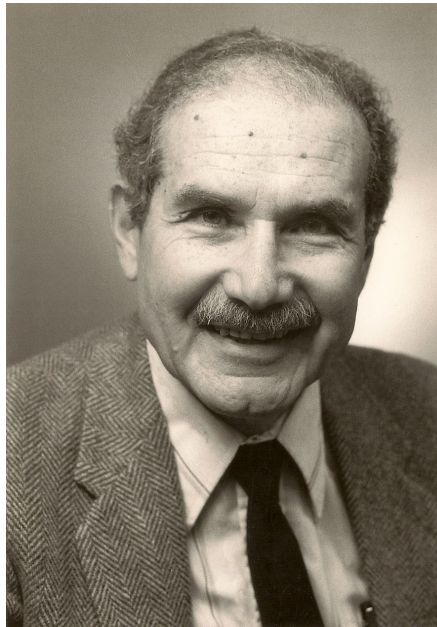


- ❖ Within 125 miles of Pasadena
- ❖ Accessible - don't build a road
- ❖ Land must be obtainable
- ❖ Want long periods of good 'seeing', not spectacular moments
- ❖ Good 'seeing' – freedom from atmospheric distortion
- ❖ Good transparency – freedom from haze, smog, dust, etc.
- ❖ Clarity – freedom from clouds and fog
- ❖ Need all three for a good site

Fig. 1. Locations of the sites studied. The contours are at intervals of 2500 feet (762 m). The numbers refer to Table I and the size of the circles is related to the number of visits to each site.

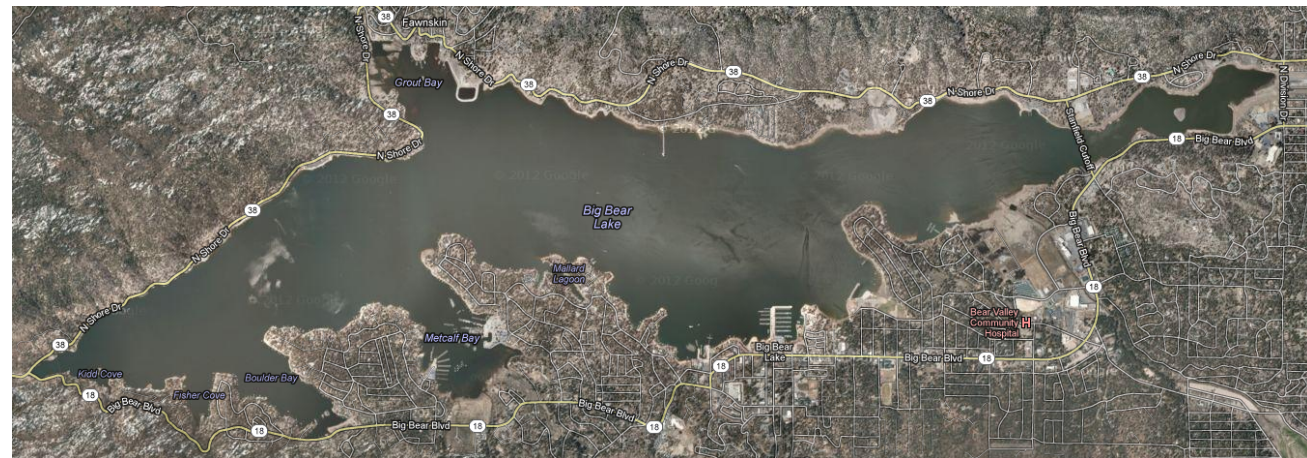


Prof. Harold Zirin



Harold Zirin (Oct 7, 1929 – Jan 3, 2012)

- ❖ Harold Zirin came to Caltech in 1965 and Leighton put him in charge of building the observatory.
- ❖ The surrounding waters of Big Bear Lake reduce ground level convection, and predominate winds bring smooth air flows across the flat surface of the lake providing superb conditions for solar observing.
- ❖ The on-shore land was bought by Caltech and the observatory site itself was leased from Bear Valley Mutual Water Company (MWC).



Construction - 1968



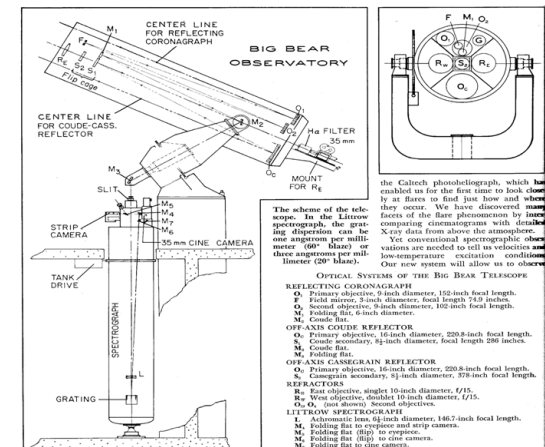
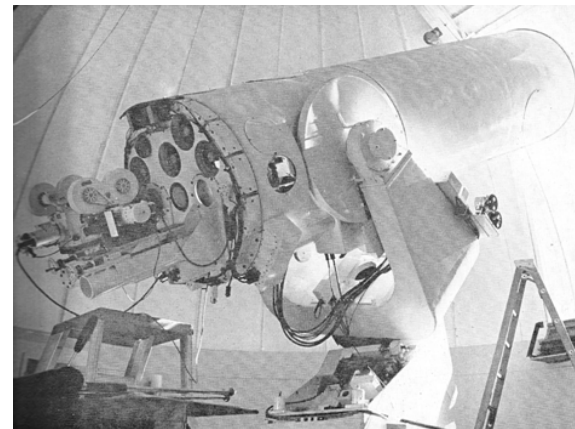
Zirin's Navy





BBSO - 1970

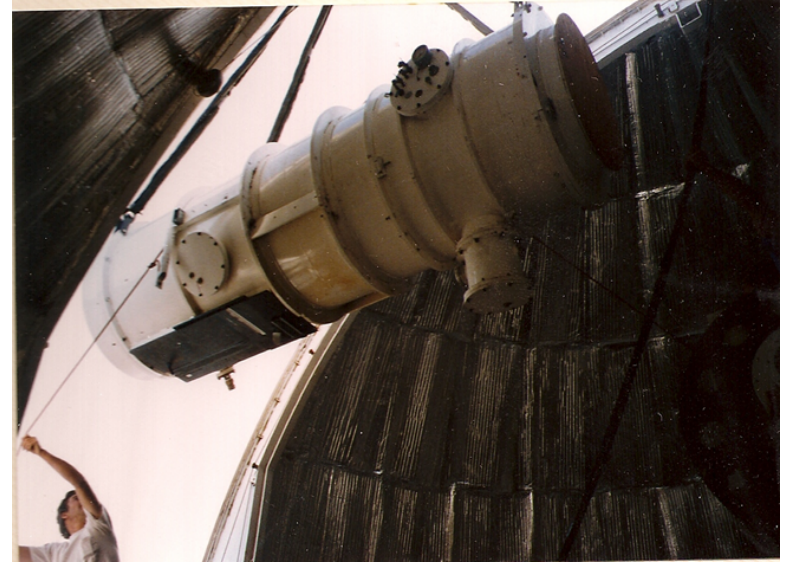
- ❖ Two 10-inch refractors with narrow-band filters
- ❖ A 16-inch off-axis reflector to feed the spectrograph
- ❖ A 9-inch reflecting coronagraph
- ❖ Shortly after the observatory was completed, an 8.5-inch telescope was added. This was an Ha telescope used to train the Skylab astronauts, and was built by the Singer-Link company





BBSO - 1973

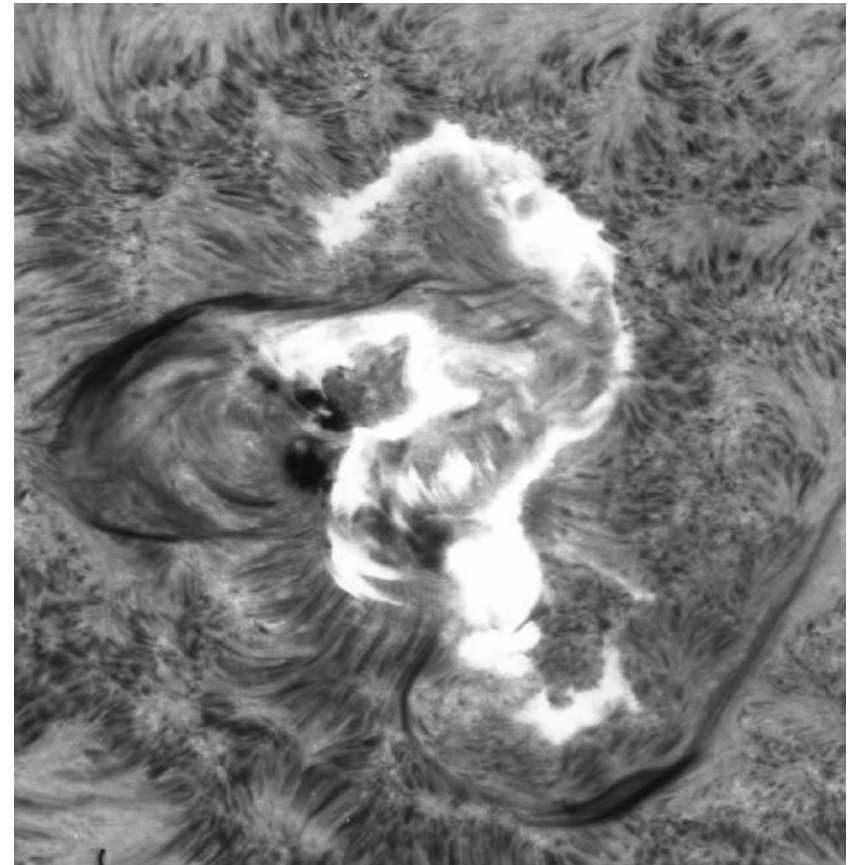
- ❖ In 1973 the telescope assembly was completely remodeled.
- ❖ The new main telescope was a 26-inch vacuum reflector which had been originally built as a test for the second Skylab space station, which never flew.
- ❖ One of the 10-inch refractors was retained, along with the Singer-Link 8-inch telescope
- ❖ The 10-inch was fitted with two automatic flip mirrors to send the light to two side benches.
- ❖ The 26-inch could feed light to three benches and the spectrograph.
- ❖ After the 1992 Big Bear earthquake, the telescope assembly was removed and stored in the garage on shore. The pier was removed and replaced with a new, much stronger one.
- ❖ The observatory was out of action for about four months.



Flare and Prominence

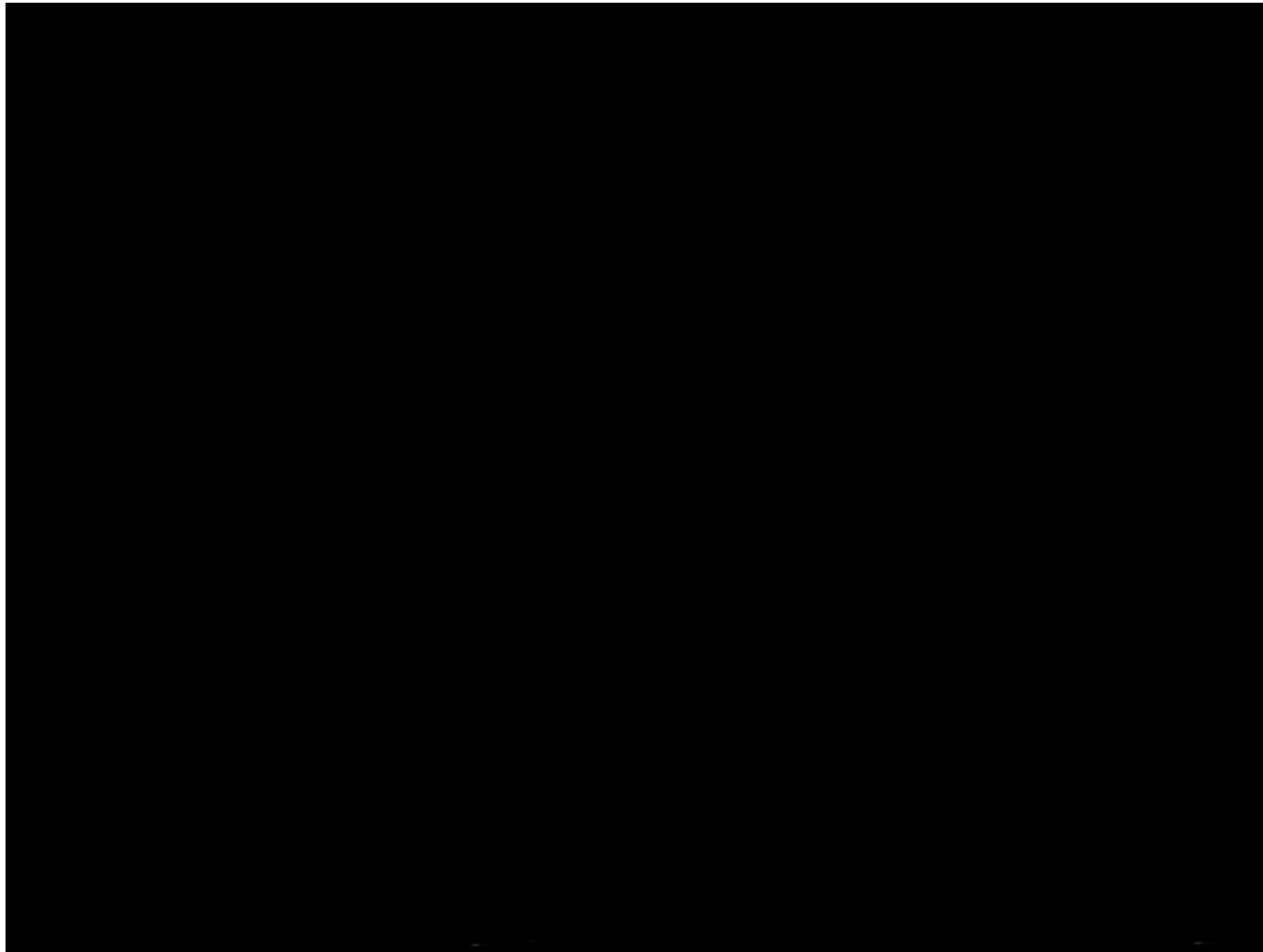


Hedgerow prominence



Sea horse flare on Aug. 7, 1972

Flare Event Recorded in BBSO





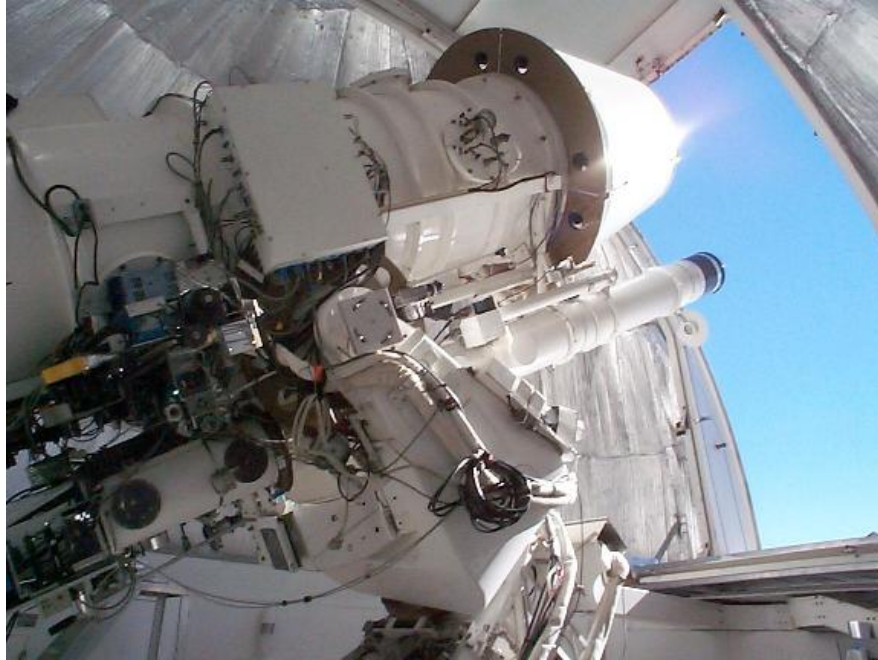
BBSO - 1997



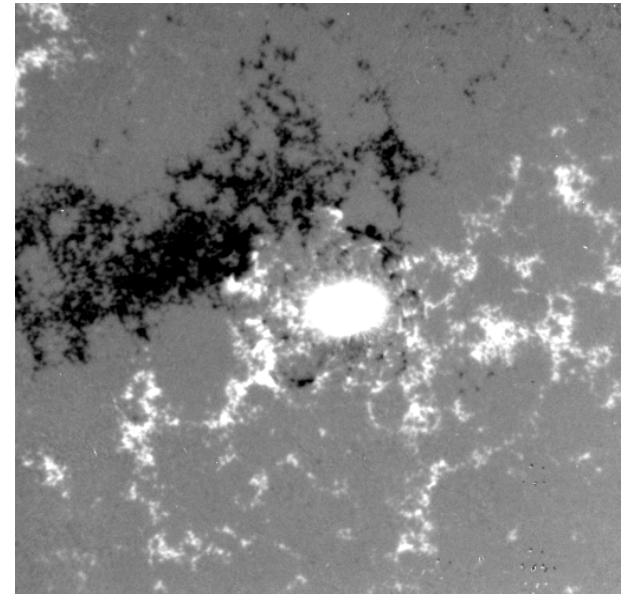
Philips, R. Goode, NJIT Distinguished Professor

- ❖ In 1997, Prof. Zirin retired.
- ❖ Caltech decided to direct their resources to their nighttime astronomy program.
- ❖ Rather than simply closing BBSO down, Caltech accepted bids from other institutes to operate the observatory.
- ❖ New Jersey Institute of Technology (NJIT), in Newark, NJ took over the observatory operation.
- ❖ Prof. Phil Goode became the second director of BBSO.

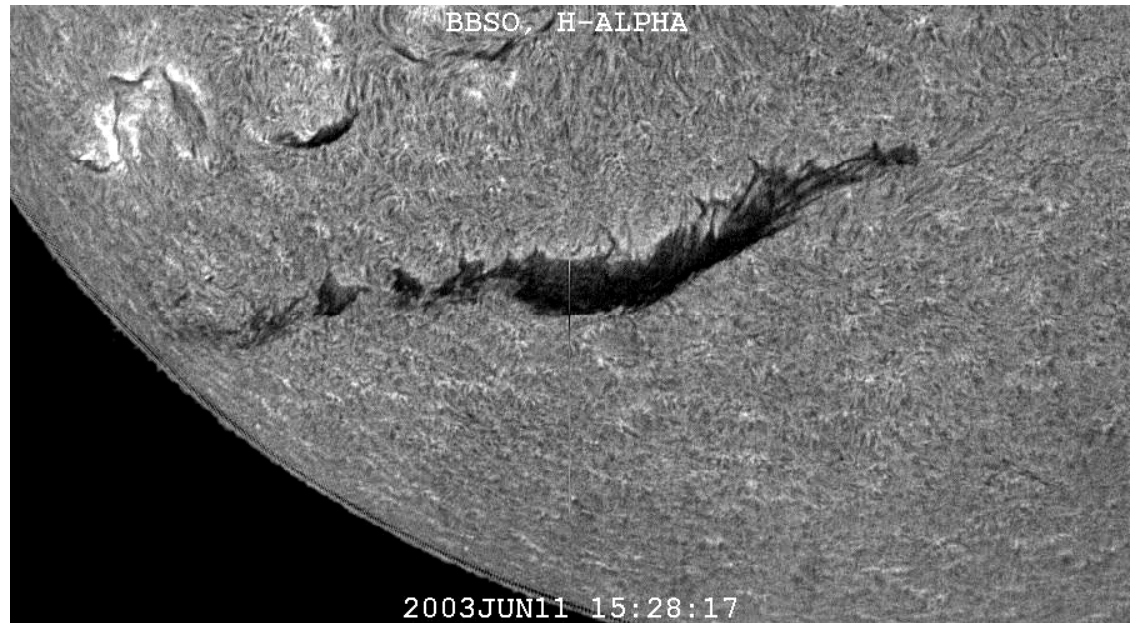
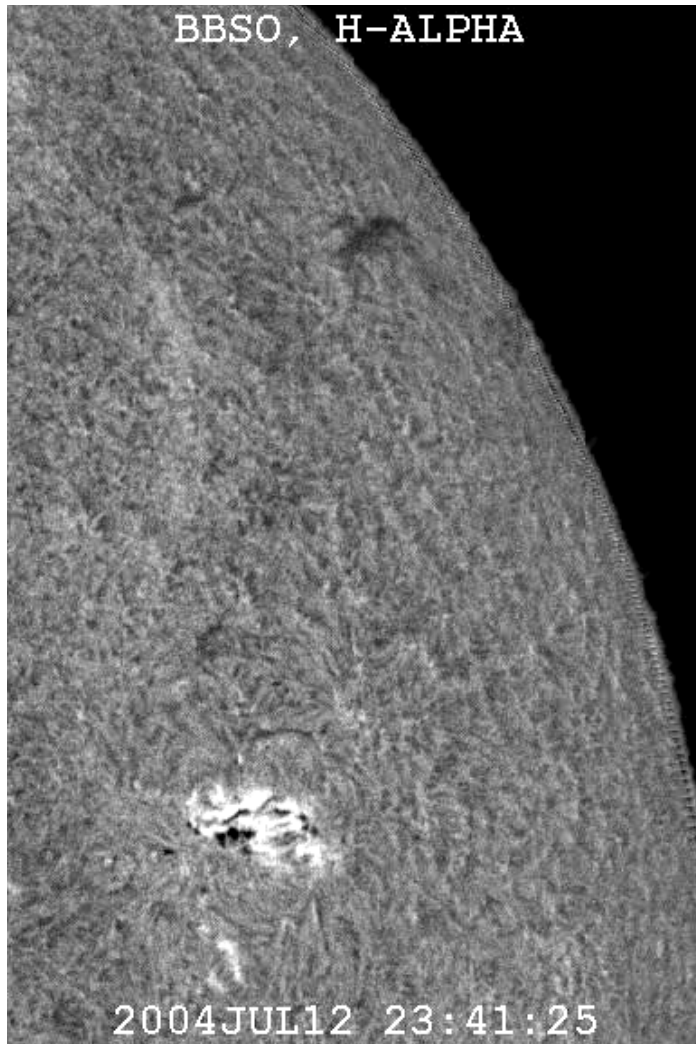
BBSO – 1997 - 2002



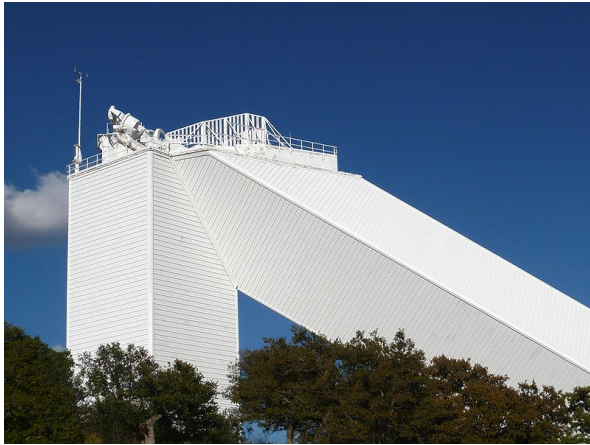
- ❖ Replacement of all of the film and video cameras with digital CCD cameras
- ❖ H α full disk global network
- ❖ Host one of the sites of the Global Oscillation Network Group



Flare and Filament Eruption



BBSO's Place under the Sun



McMath-Pierce , 1962



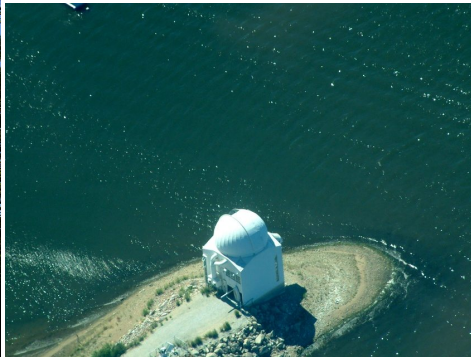
HSOS – 60 cm, 1986



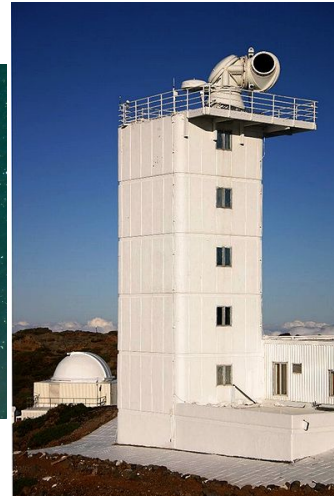
SOHO - 1995



DST - 76 cm, 1969



BBSO - 65 cm, 1973



SST - 1 m, 2002



Hinode - 50 cm, 2006

If BBSO was to remain a viable operation, we would have to change



GST Times

(2002 - 2012)

GST Kickoff in 2002

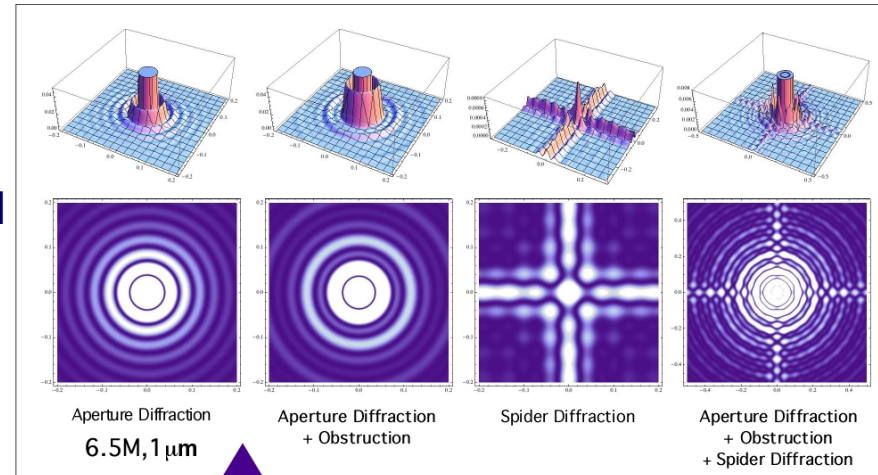


- ❖ In 2002, BBSO/NJIT proposed to build the world's largest aperture solar telescope at 1.6 meters. The GST is optimized for high resolution imaging of the solar surface employing active and adaptive optics technologies.
- ❖ GST Science
 - ❖ High-resolution, high-cadence studies of solar flares
 - ❖ Structure/evolution of magnetic fields in flaring active regions
 - ❖ Dynamics of kGauss flux tubes
 - ❖ Magneto-convection in sunspots
 - ❖ Heating of the upper atmosphere
- ❖ Upgraded instrumentation (2nd generation)
 - ❖ New (imaging) polarimeters (IR + visible)
 - ❖ Real-time image restoration
 - ❖ Adaptive optics
- ❖ By 2010: Ready to solve many space weather problems
 - ❖ SDO, STEREO and Solar-B in space (0.5 m telescope in space)
 - ❖ 1.0–1.5 m telescopes in Europe (THEMIS, SST, GREGOR)
 - ❖ No ATST before 2016



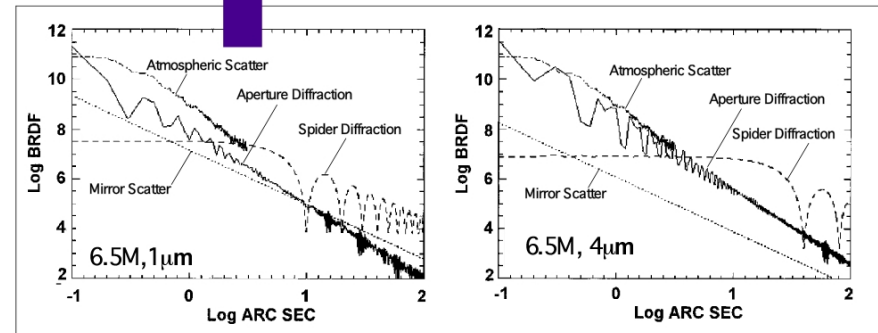
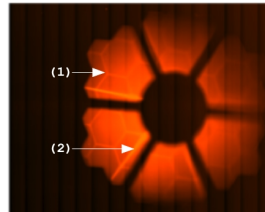
NST Optical Design

- ❖ Off-axis telescope
 - ❖ There is no diffraction from the secondary support structure to degrade coronal images
 - ❖ Stiff secondary support structure – avoid vibrations
 - ❖ Coolant and other services can be delivered to the secondary mirror without crossing the beam
 - ❖ Rotating spiders in the pupil are a real “pain” for Adaptive Optics



(A)

- ❖ On-axis telescope
 - ❖ Symmetric structure
 - ❖ Easy to build and align
 - ❖ Precise polarimetry measurement



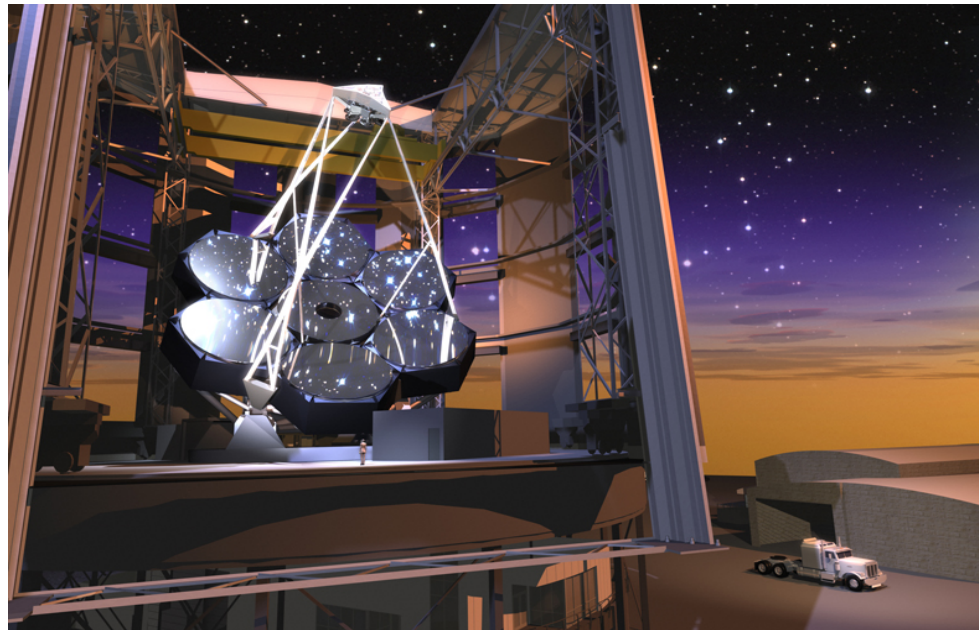
(B)

(C)



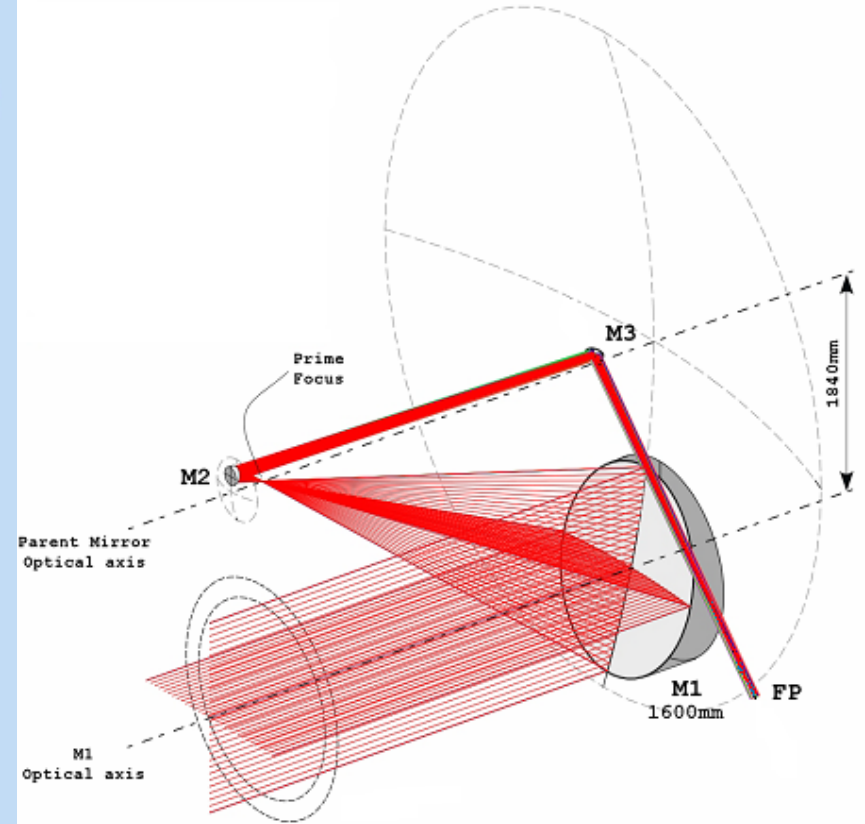
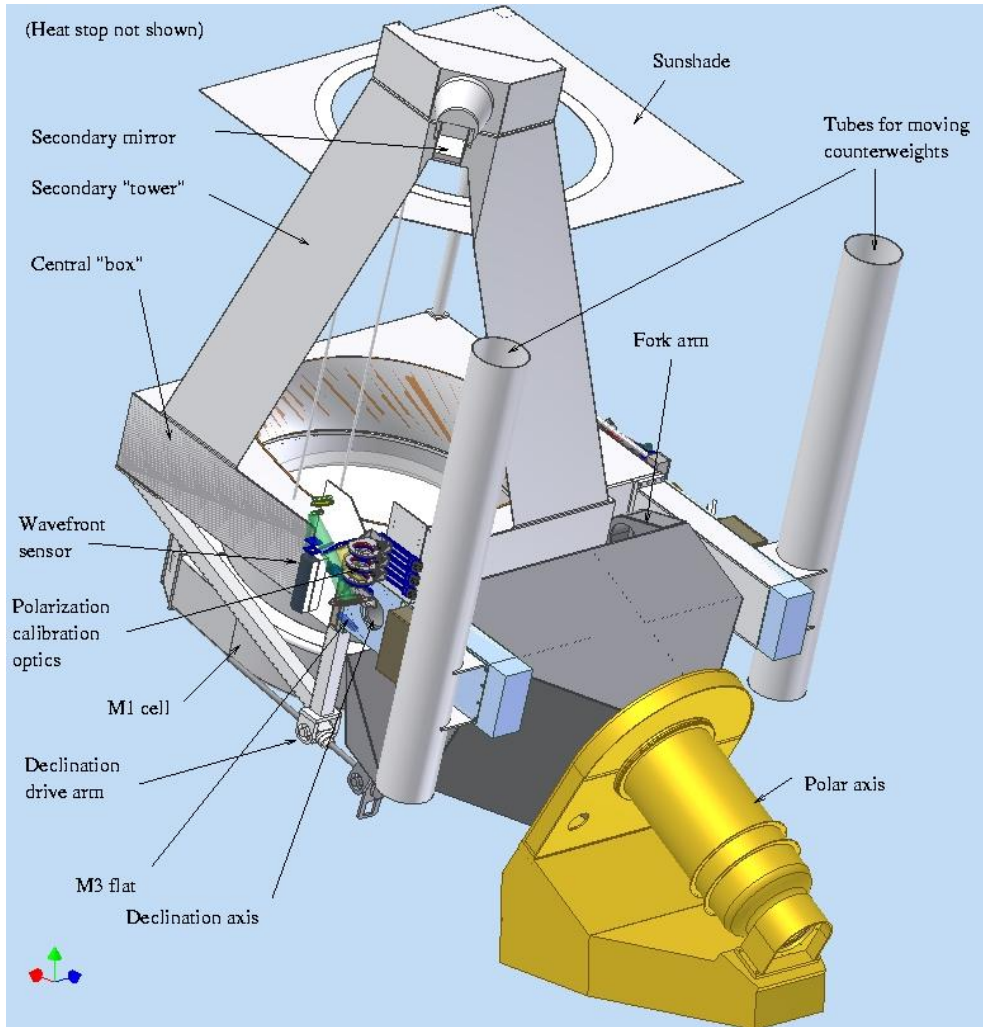
GST and GMT

- ❖ The GST primary mirror (PM) is also a test article for the off-axis mirrors of the GMT, the Giant Magellan Telescope
- ❖ GMT is a consortium project including Carnegie, MIT, UA, and others
- ❖ GMT includes seven 8.4 m mirrors for an effective aperture of 24.5 m
- ❖ The Steward Observatory Mirror Lab would like to invest \$ 1.5 M for using the GST PM to develop test procedures for these large off-axis mirrors





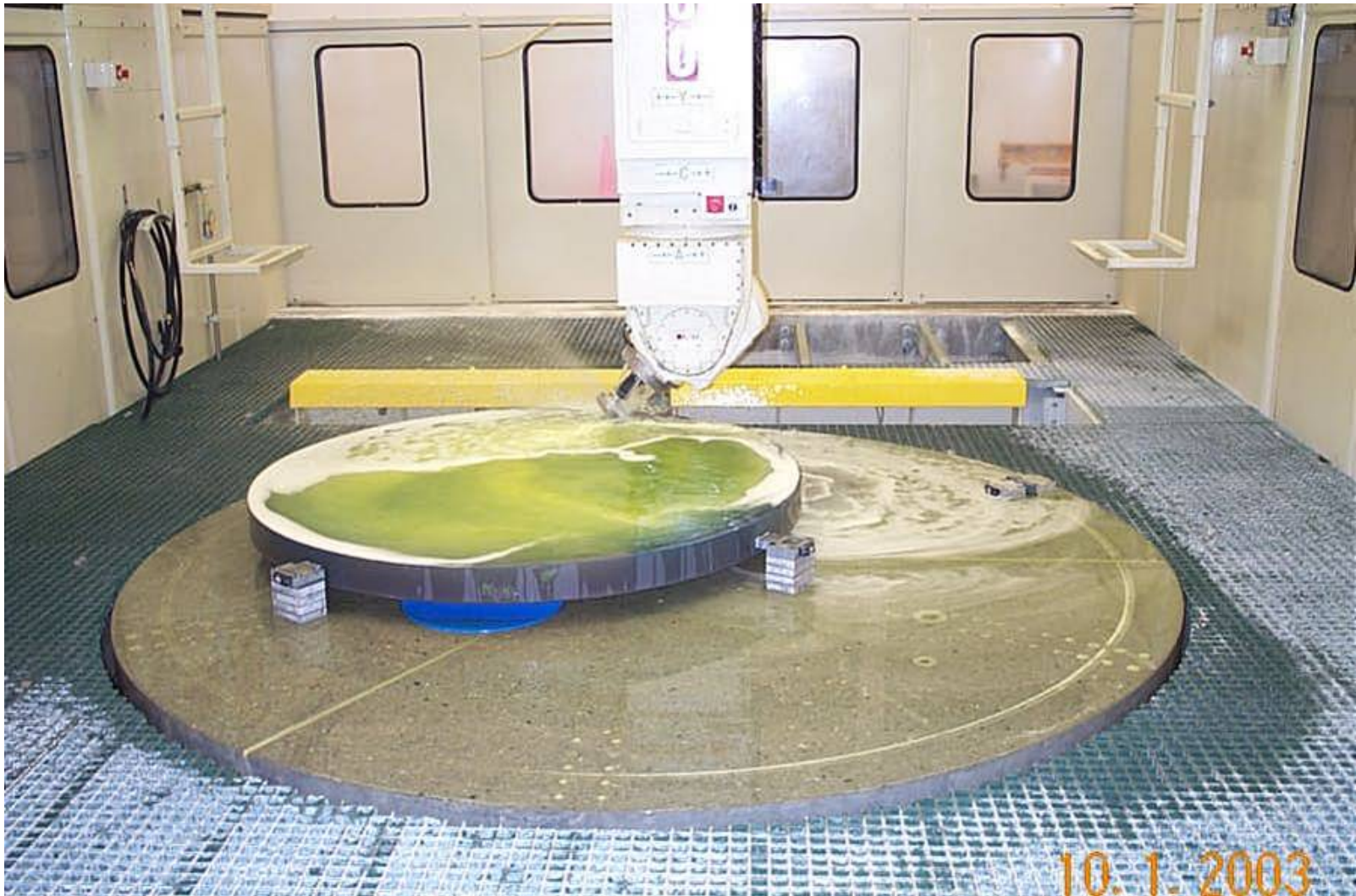
1.6 m Off-axis GST



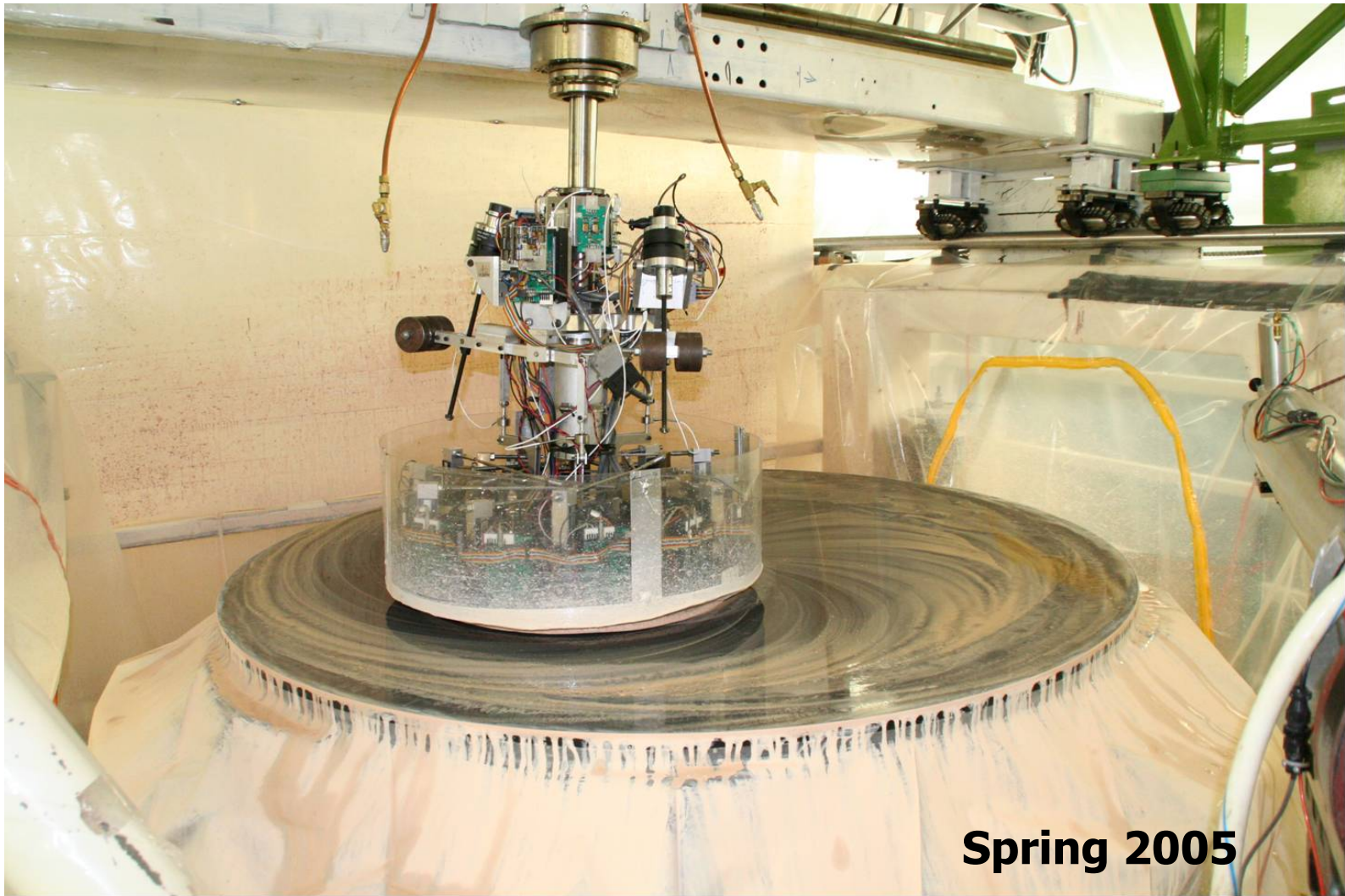
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- GST presentation to NSF December 2002. Construction grants awarded.
 - Fabrication of the primary mirror began 2003.
 - Designs continued into 2005.
 - DFM contracted for telescope structure 2005.
 - Old dome removed October - November 2005.
 - New dome built December 2005 - January 2006.
 - Dome drives installed March - June 2006.
 - Mirror testing in last half of 2006, some problems with test procedures.
 - Figuring and testing of mirror continued to June 2008.
 - Old telescope removed February 2007.
 - New pier built March-April 2007.
 - Work deck (new observing floor) built April 2007.
 - Dome drive rebuilt in 2008.
 - Telescope structure built at DFM Engineering January 2007 to September 2008.
 - Final telescope assembly begins September 29, 2008.
 - First light January 19, 2009.
 - Commissioning from 2009 up to now.

GST Milestones

PM Blank at Kodak: 2003.10



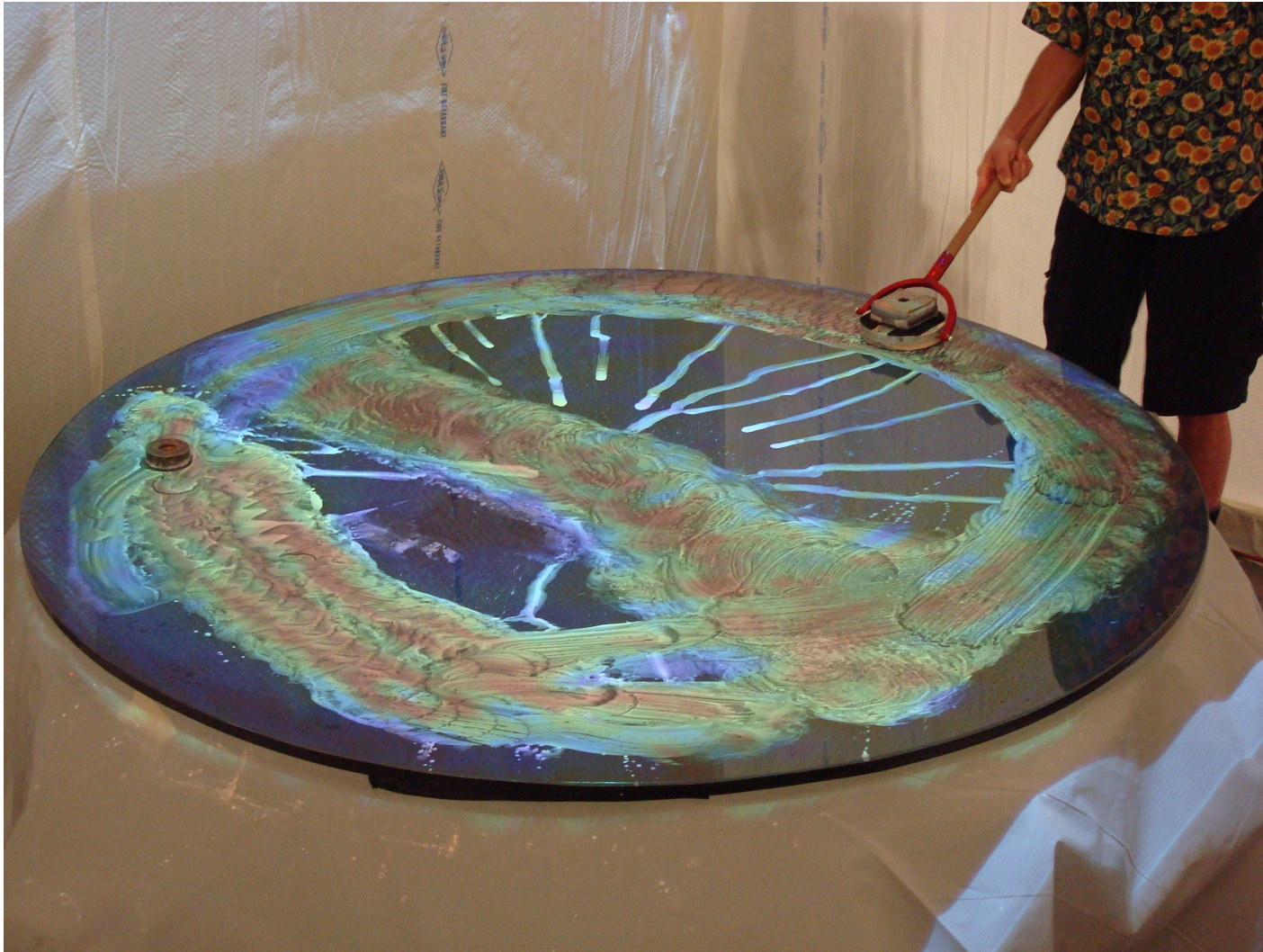
PM in Tucson: 2005. 03



PM: 2005.06



PM Surface





PM Optical Testing

- ❖ Interferometers use light to measure to ~ 1 nm surface errors, for spherical or flat surfaces
- ❖ We need to measure aspheric (non-spherical) surfaces
- ❖ CGH can change spherical wavefronts to aspheric, allowing the use of interferometers for measuring aspheric surfaces

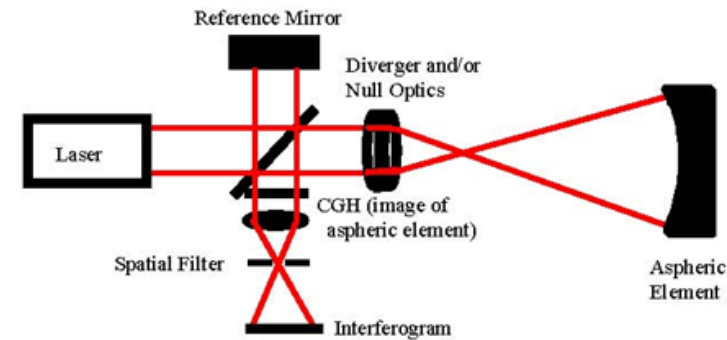


Figure 1. Typical CGH Interferometric Setup.

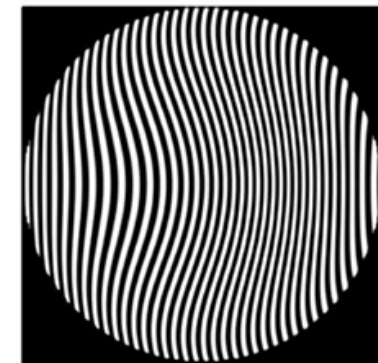
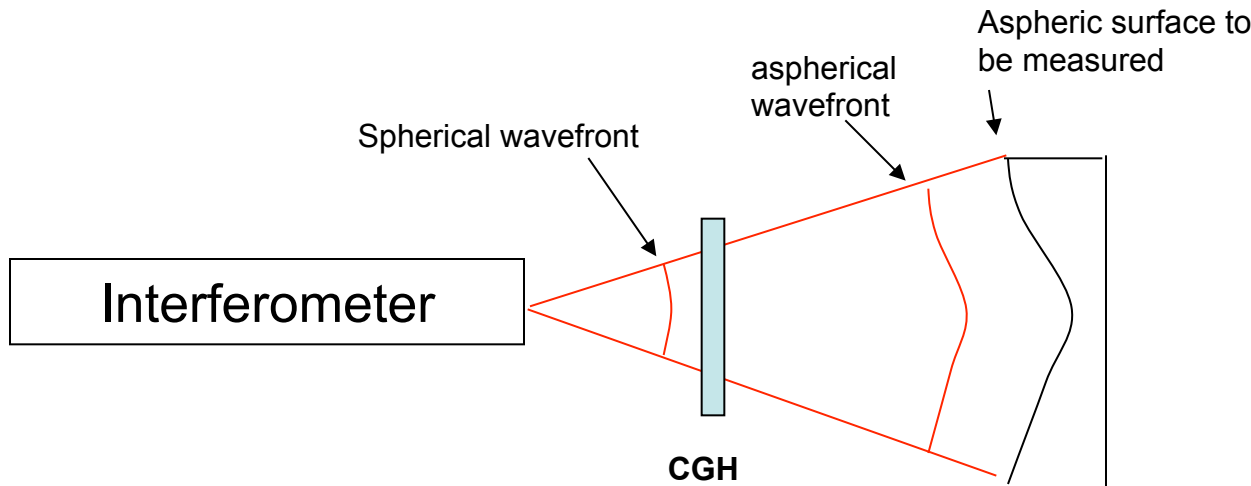
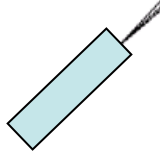
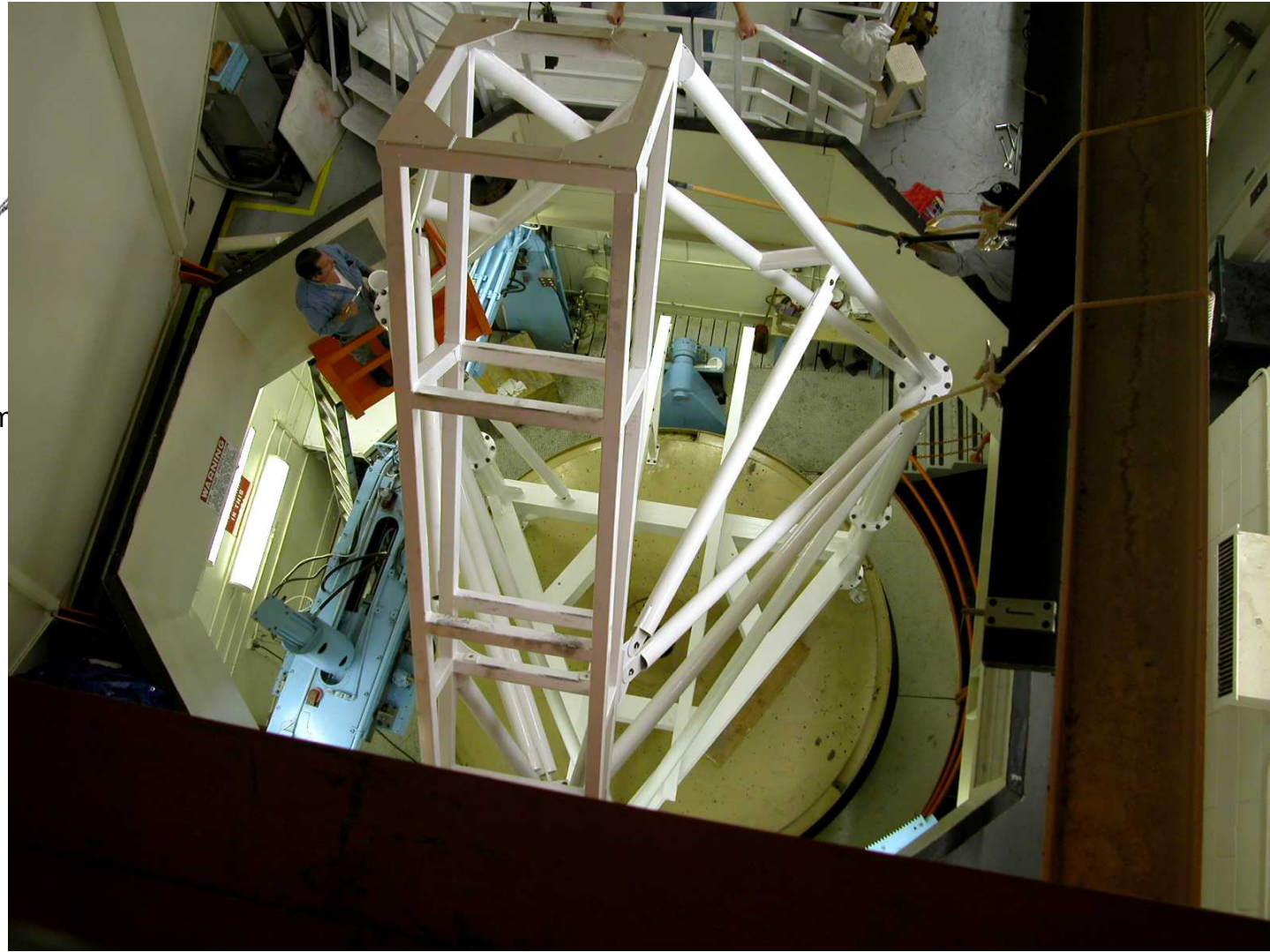


Figure 2. Typical CGH.

PM Testing Setup



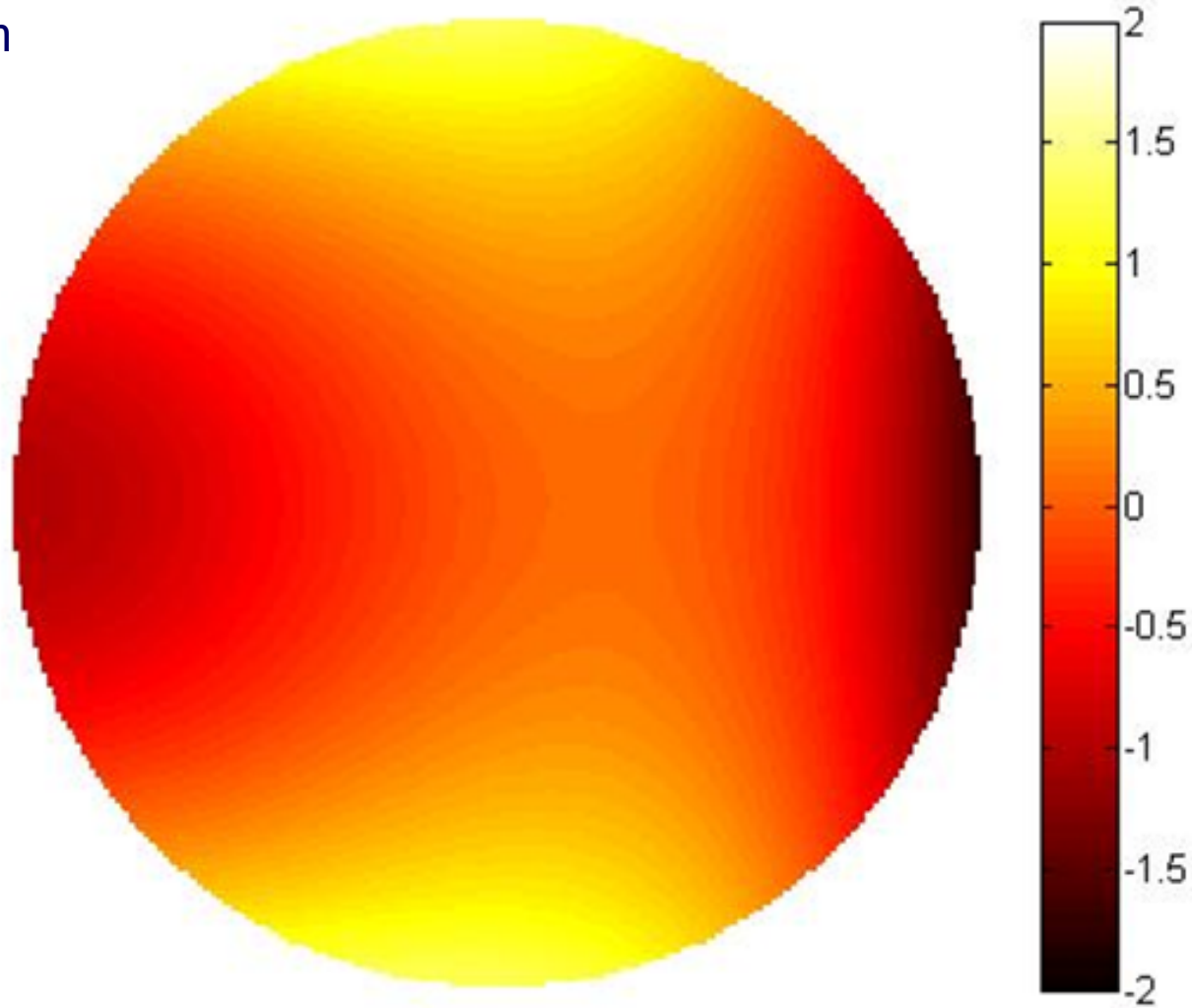
4D interferom



PM Testing: May 2008



- ❖ RMS: 16 nm
- ❖ Done!



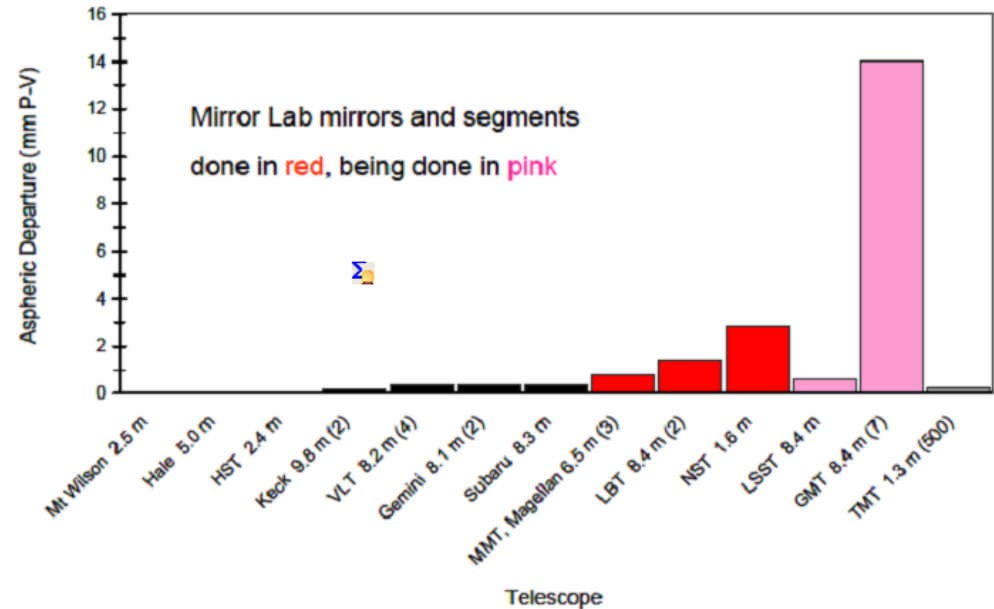


PM Features



- ❖ 1.6 m clear aperture (1.7 m blank) – figured by Steward Mirror Lab to 16 nm rms surface error
- ❖ Primary: f/2.4, 4.4 m telescope length, vertex $R_c = 7.70$ m, OAD = 1.84 m, 13.4° tilt, $< 10 \text{ \AA}$ μ -roughness, and blank of Zerodur with CTE of $(0.0 \pm 1.0) \times 10^{-7} / ^\circ\text{C}$
- ❖ Active optics (36 actuators in PM mirror cell) to control thermally induced variations & air knives, backside “cooling”
- ❖ Real-time telescope alignment
- ❖ High order adaptive optics

Aspheric Departure of Telescope Mirrors or Segments

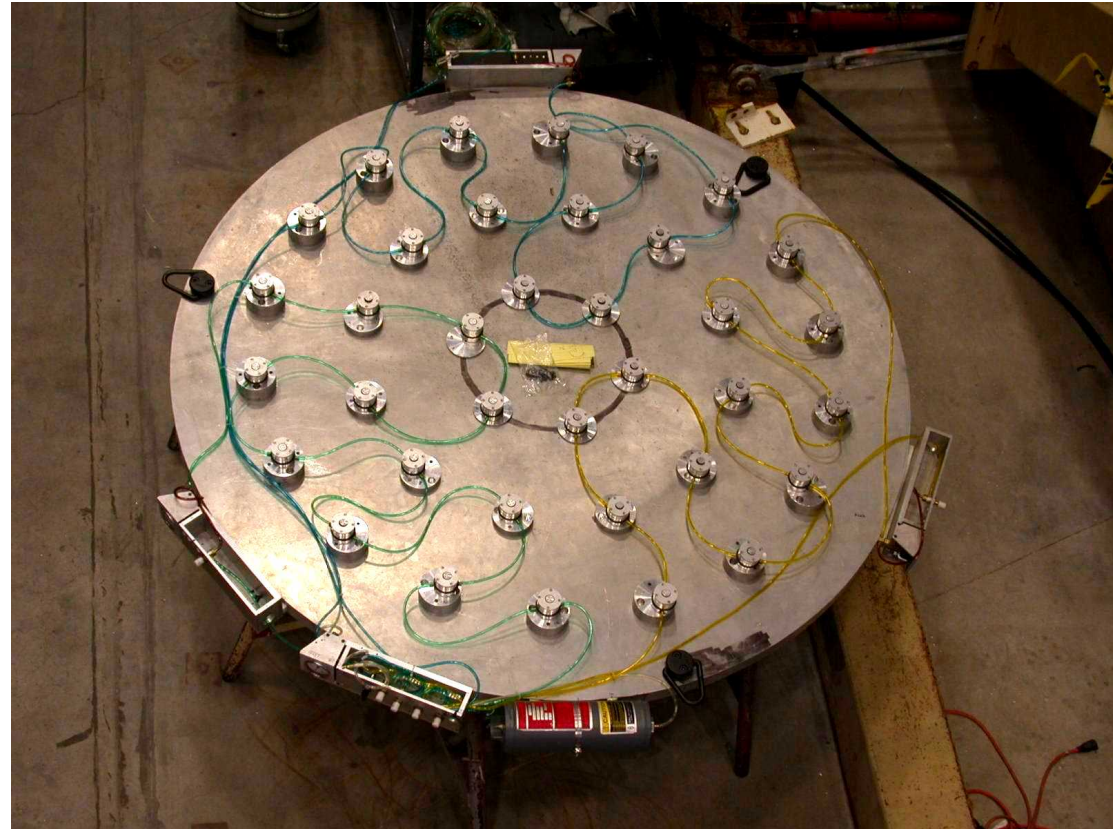


- ❖ **The largest aperture solar telescope**
- ❖ **The largest off-axis astronomical telescope**



Active Optics

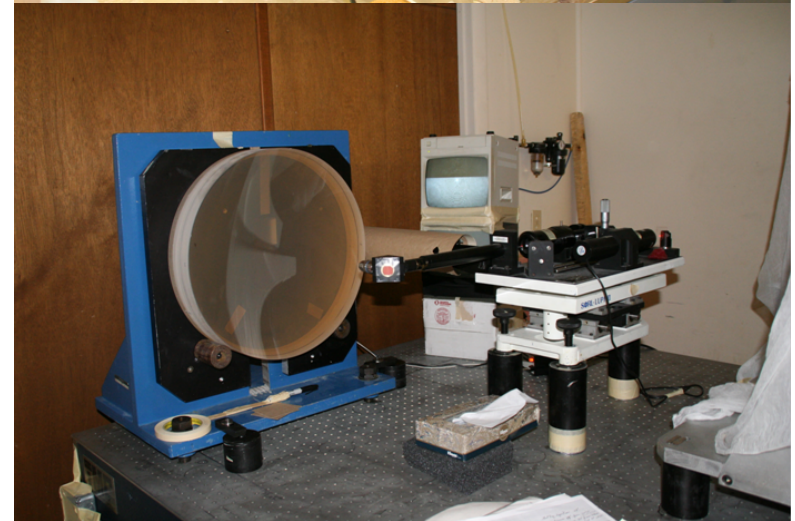
- ❖ The PM is supported by 36 axial and 12 tangential actuators. These force based servos will compensate for gravity and thermally induced errors in the mirror figure
- ❖ A wavefront sensing system is being developed to control the active optics components
- ❖ Real-time telescope alignment, fast T/T and M1 figure control
- ❖ Closed and open loop control are implemented





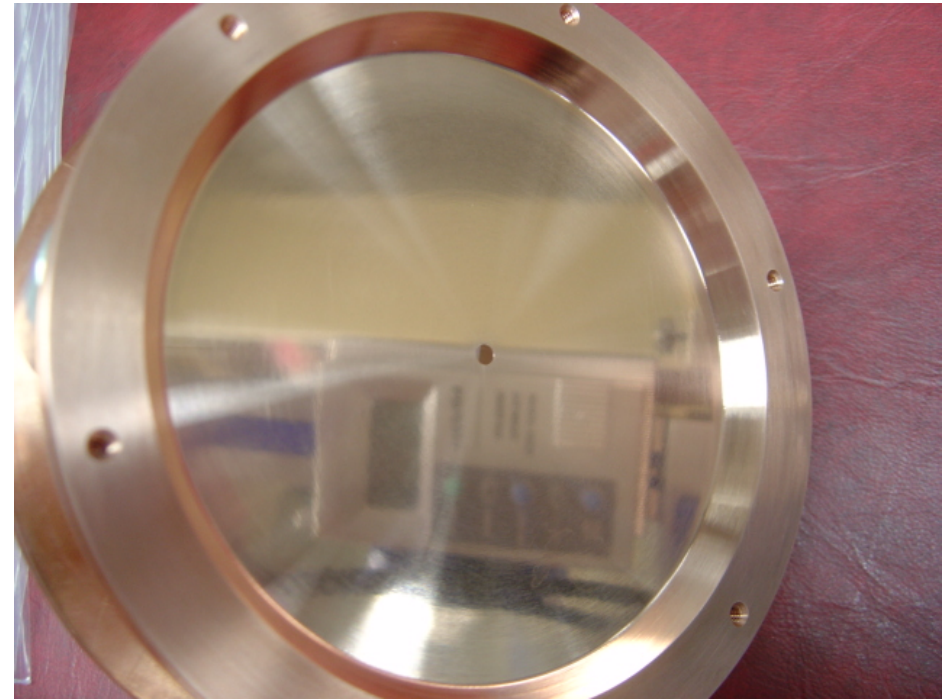
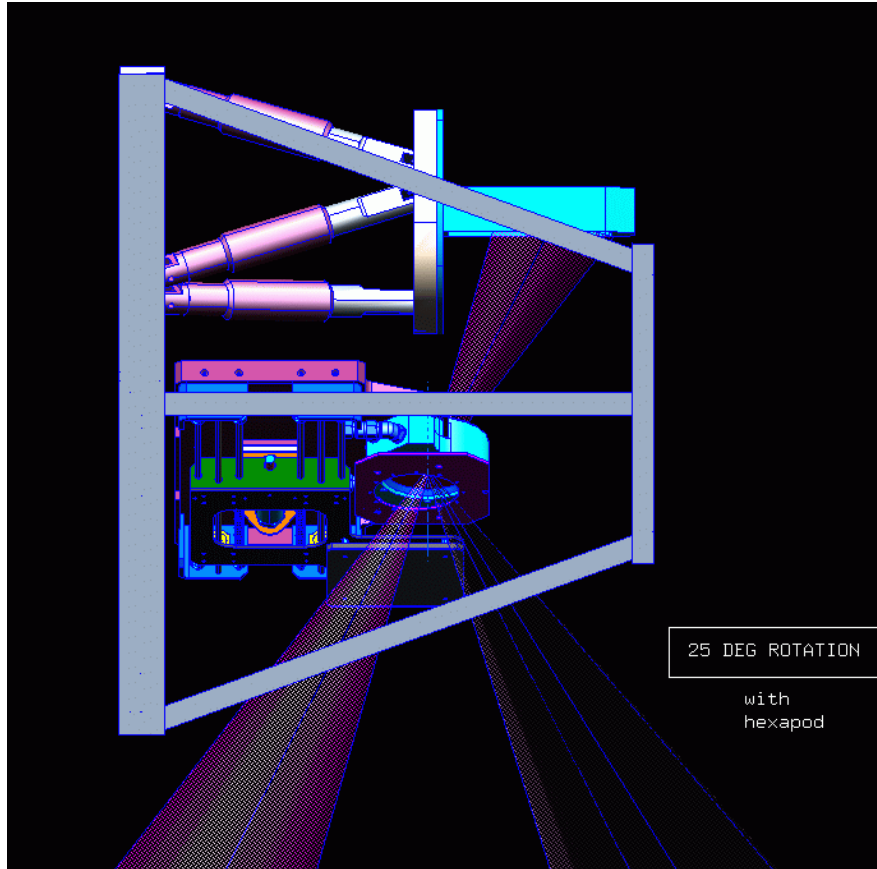
SM: 2006. 10

- ❖ Secondary Mirror (SM) is Zerodur from Schott
- ❖ Space Optics Research Lab (SORL) has figured 0.5 m mirror on axis
- ❖ Cut into two concave elliptical SMs (144.5 mm) < 20 nm surface quality and foci downstream at $f_1 = 300.5$ mm (if measured from on-axis mirror optical center) and $f_2 = 6482.0$ mm
- ❖ Surface accuracy: $\lambda/15$ P-V
- ❖ Surface roughness: $< 15 \text{ \AA}$ (26 \AA)
- ❖ Mirrors protected silver coated
- ❖ SM is mounted on a PI-850 Hexapod
- ❖ Mirrors in BBSO and were tested in UA Mirror Lab in Summer 2007





Prime Focus



Dome Removal: Nov. 2005



New Dome: 12/05 - 02/06



Dome in Operation



Old Telescope Removal: 02/07



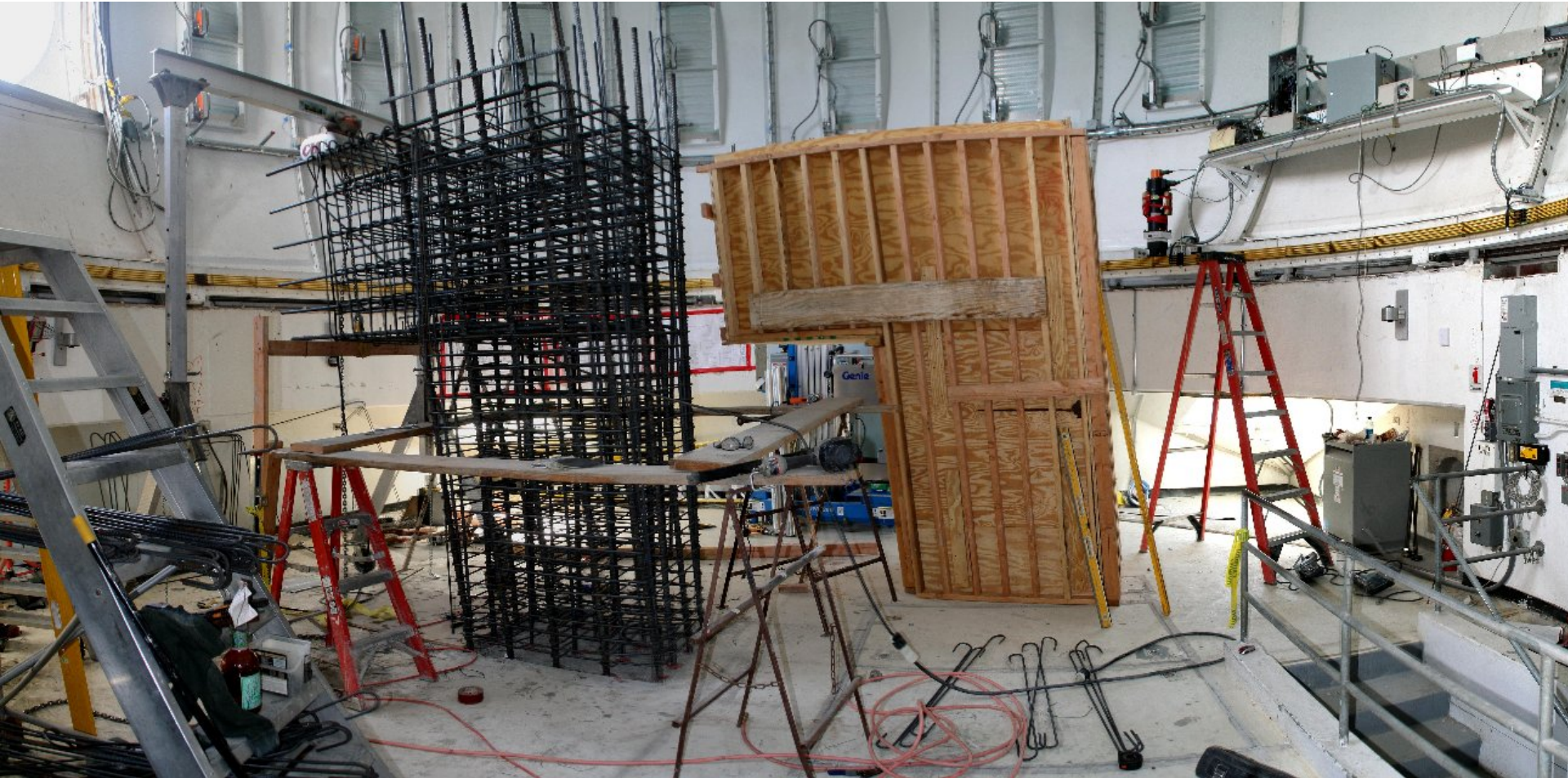
NJIT

New Jersey's Science & Technology University

Big Bear Solar Observatory

THE EDGE IN KNOWLEDGE

New Pier Construction



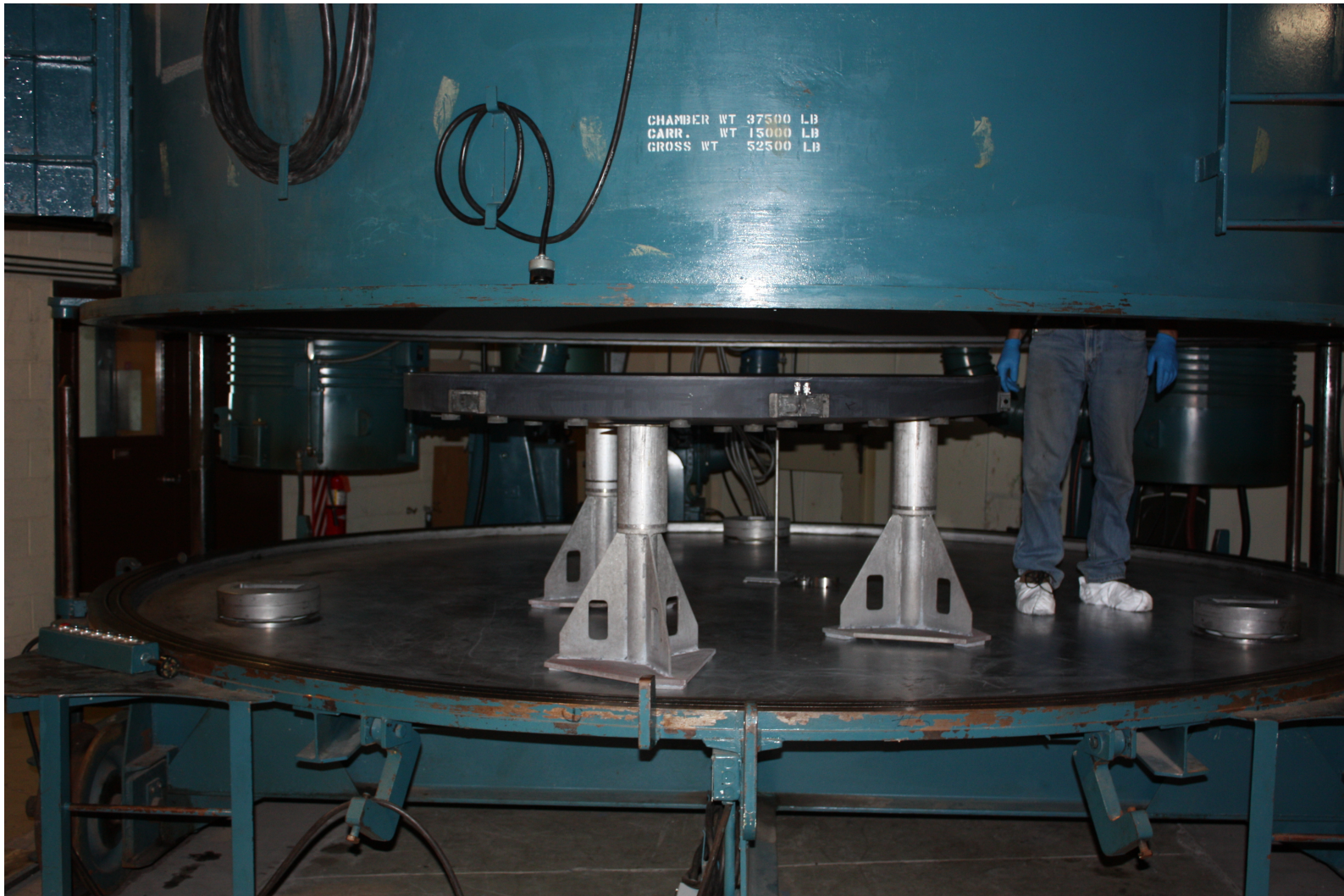
New Pier Construction



PM Pickup: 06/2008



Aluminizing PM



Back to Big Bear



Optical Support Structure: 04-05/2008



DFM Shop: 05/2008



DFM Shop: 05/2008



SM Tower



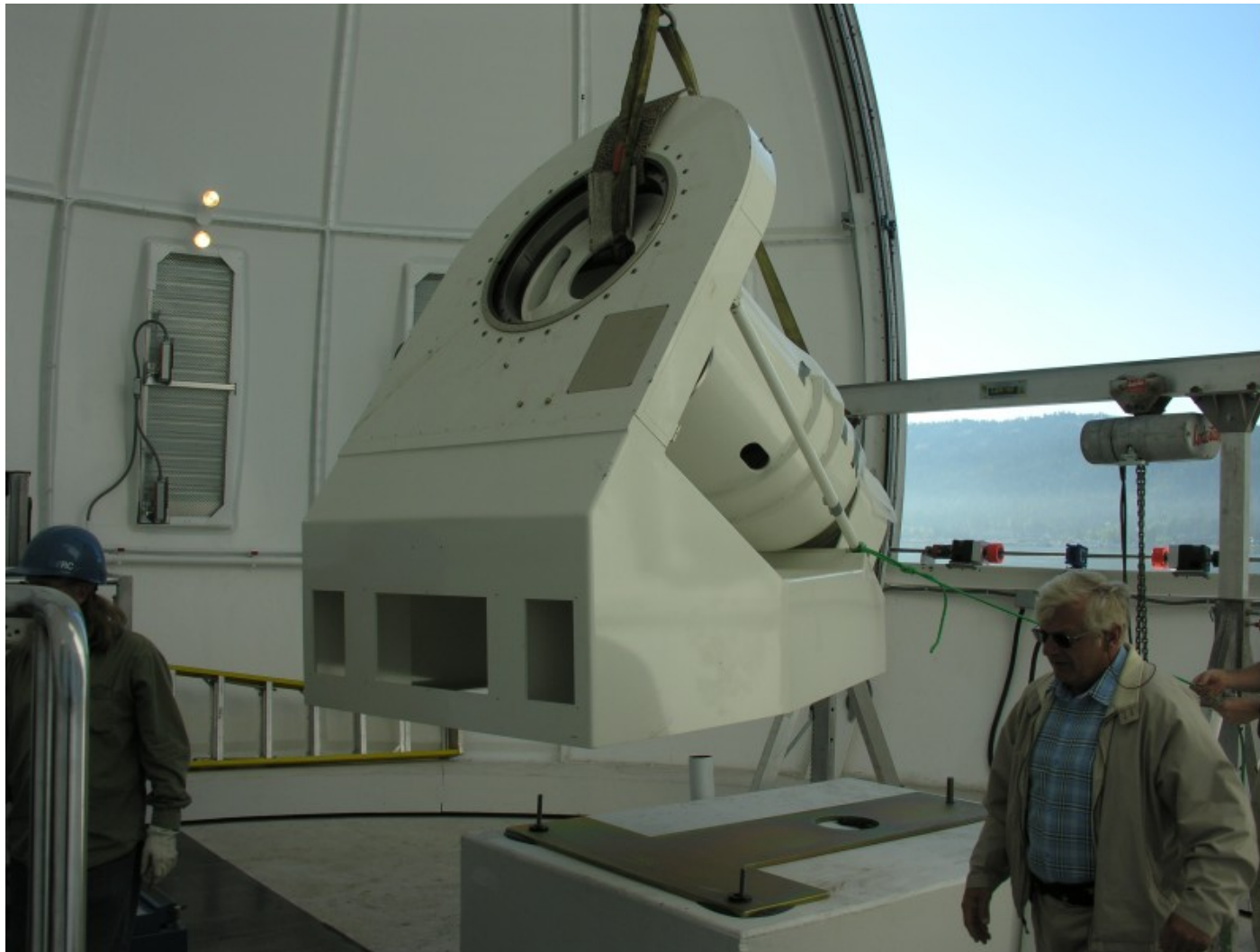
OSS Left for Big Bear: 09/2008



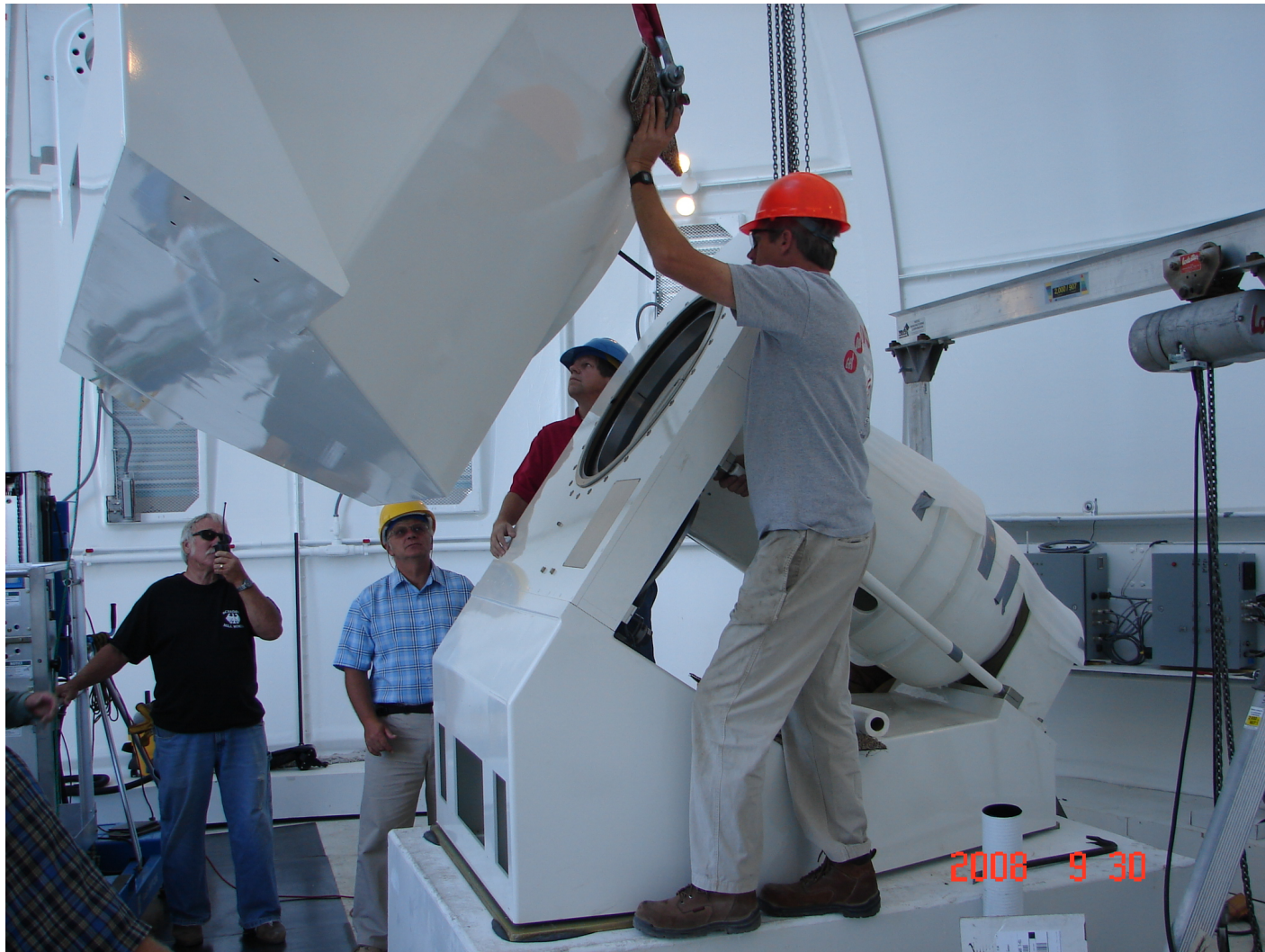
GST Installation: 09/2008



Polar Axis Assembly



Center Section



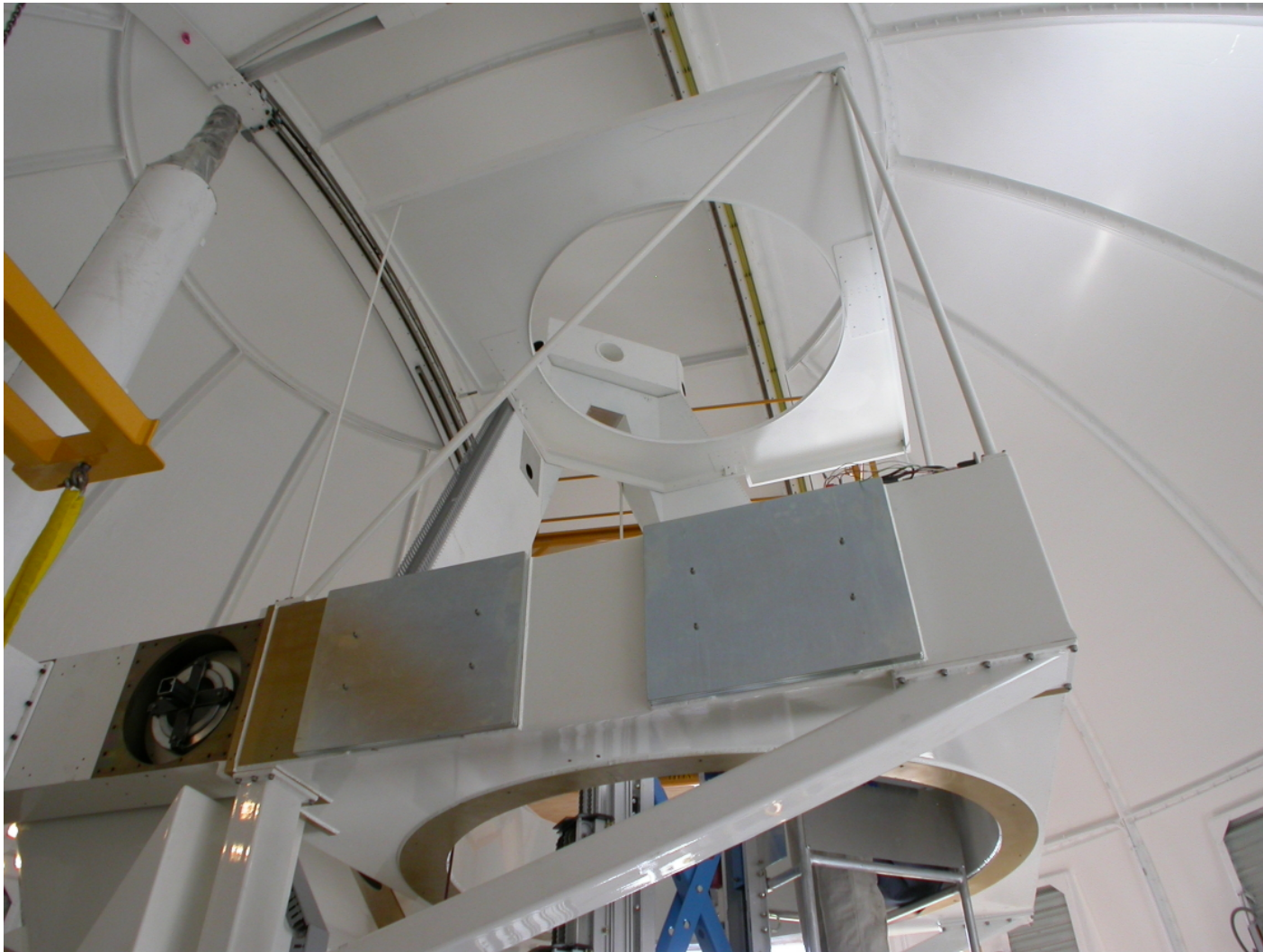
Cell Support



Skeletal Assembly: 10/2008



Sunshade



Mirror Cell on Telescope: 11-12/2008



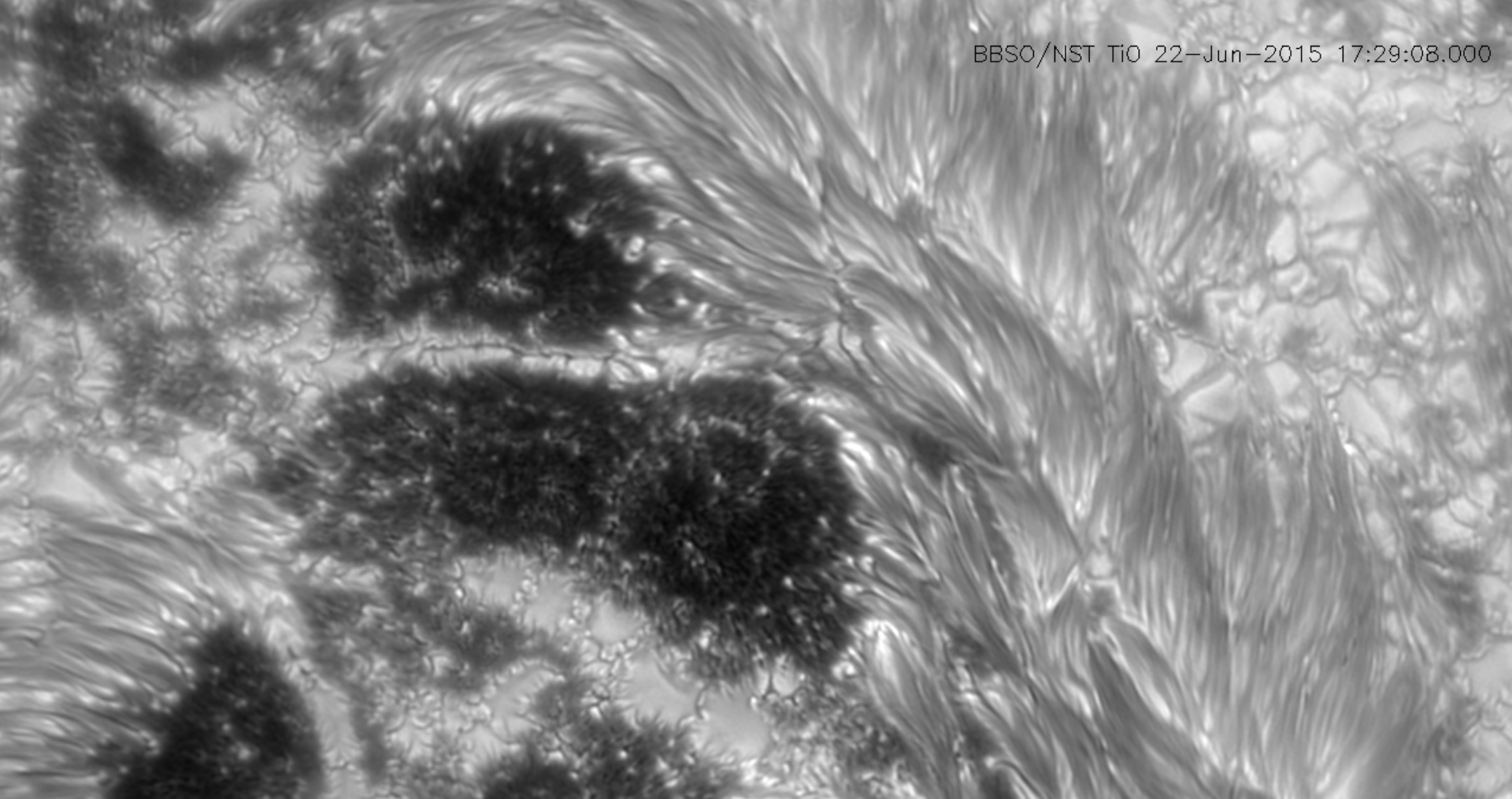
First Light: 01/2009



Does the GST work?



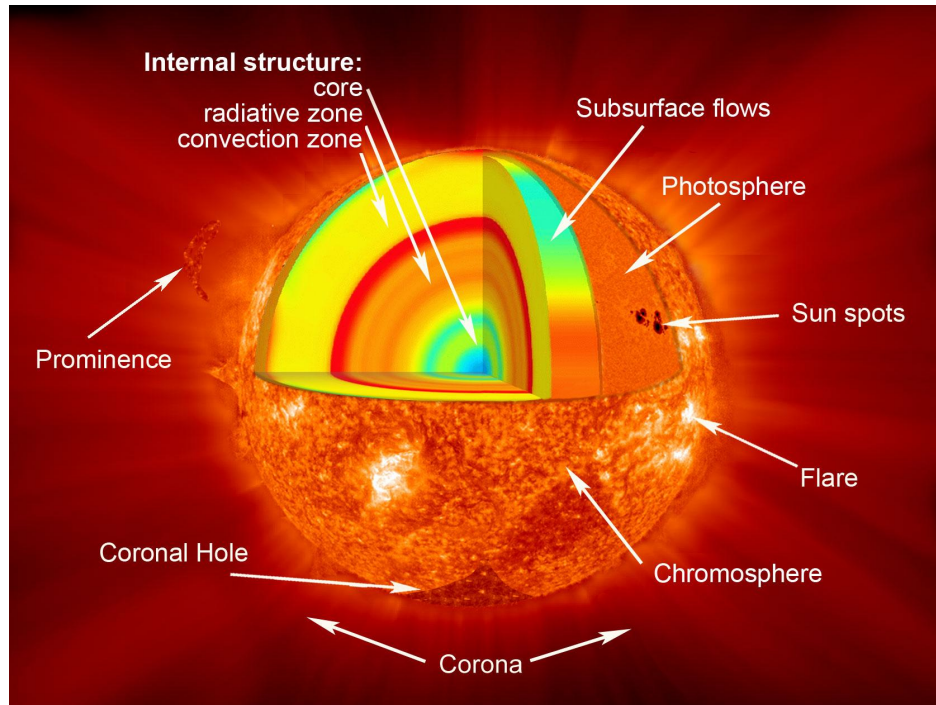
BBSO/NST TIO 22-Jun-2015 17:29:08.000





GST Instruments Development

NST Instruments Requirements

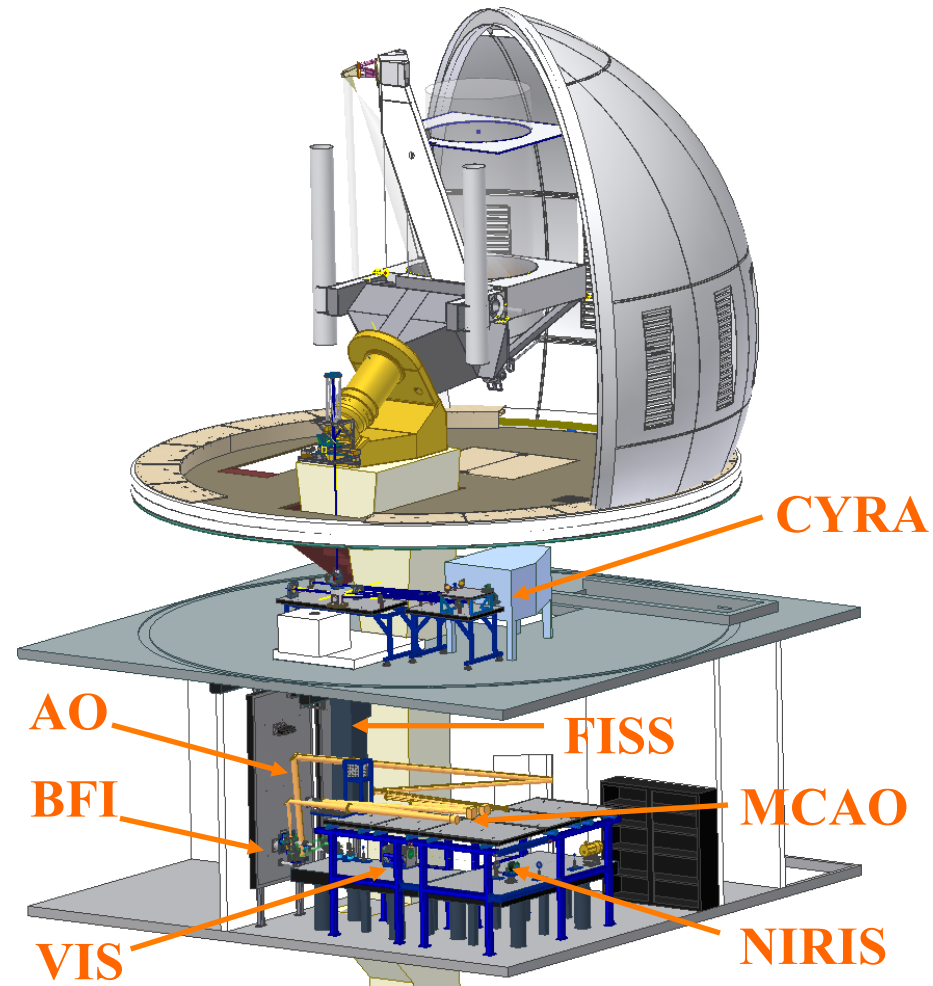


- ❖ High Spatial Resolution
- ❖ High Cadence
- ❖ Wide Wavelength Coverage
- ❖ Large Field of View
- ❖ High Precision Vector Magnetic Field Measurement
- ❖ High Precision Velocity Field Measurement
- ❖ High Spectral Resolution Spectroscopy Diagnosis
- ❖ Simultaneous Observations with NST Multiple Instruments



GST Scientific Instruments

- ❖ Adaptive Optics System (AO:
AO-76, AO-308, MCAO)
– **SPIE.9148.100, SPIE.9148.193**
- ❖ Visible Imaging Spectrometer
(**VIS**) – **SPIE.9147.15**
- ❖ Near InfraRed Imaging Spectro-
polarimeters (**IRIM, NIRIS**)
– **SPIE.9147.127**
- ❖ Cryogenic Infrared Spectrograph
(**CYRA**) – **SPIE.9147.129**
- ❖ Broad-band Filter Imager (**BFI**)
- ❖ Fast Imaging Solar Spectrograph
(**FISS**)





Large Aperture \neq High Spatial Resolution

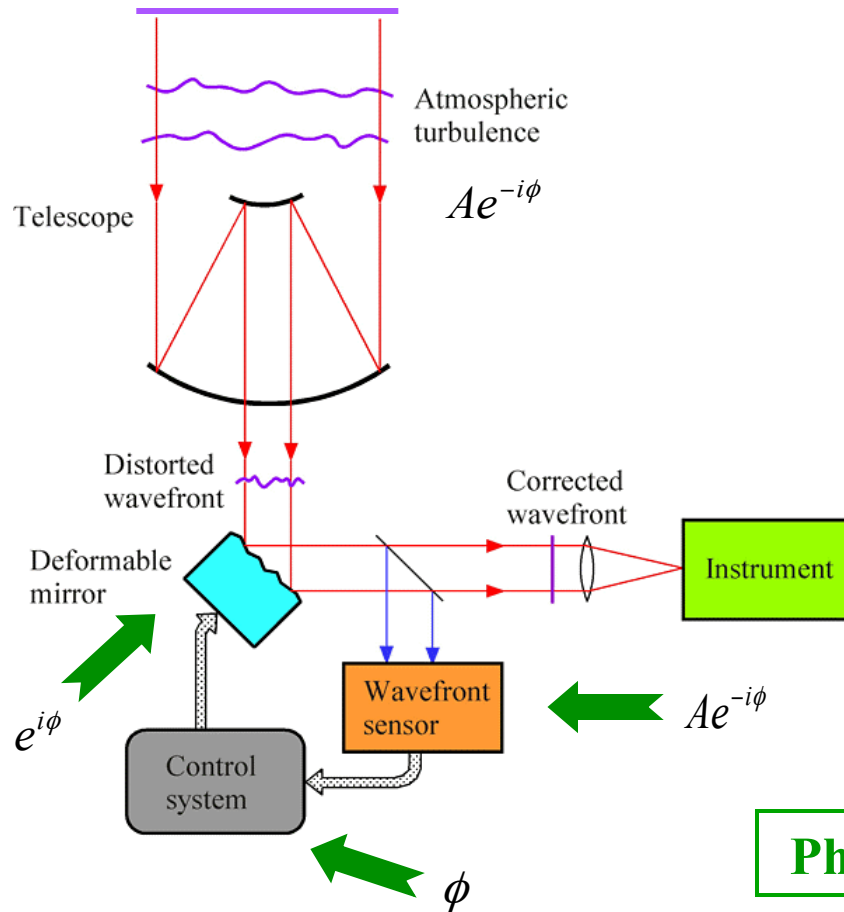


- ❖ Turbulence in earth's atmosphere makes stars twinkle
- ❖ More importantly, turbulence spreads out light; makes it a blob rather than a point
- ❖ Even the largest ground-based telescope have no better resolution than an 8-inch backyard telescope





AO Principle

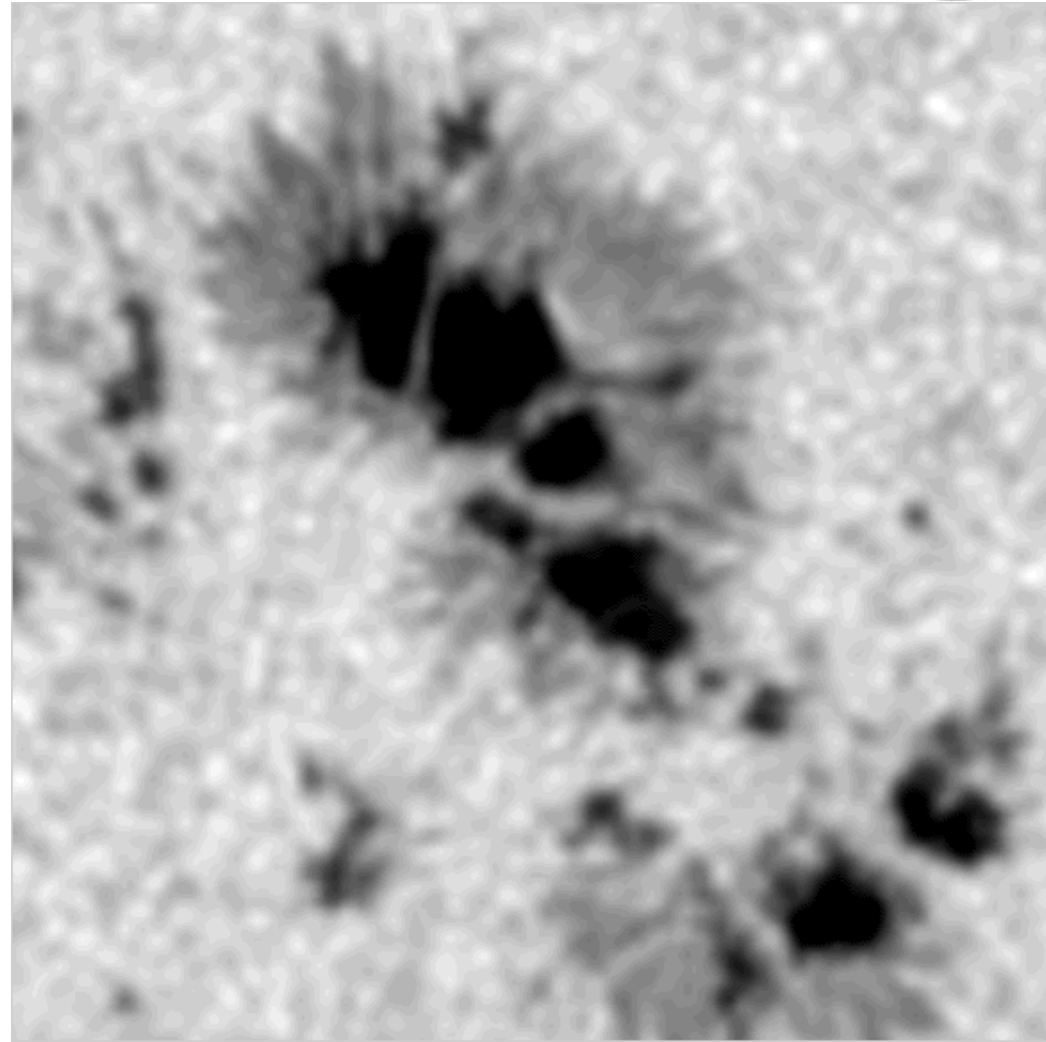


Phase Conjugation: $A \exp(-i\phi) \cdot \exp(+i\phi)$

GST AO and MCAO



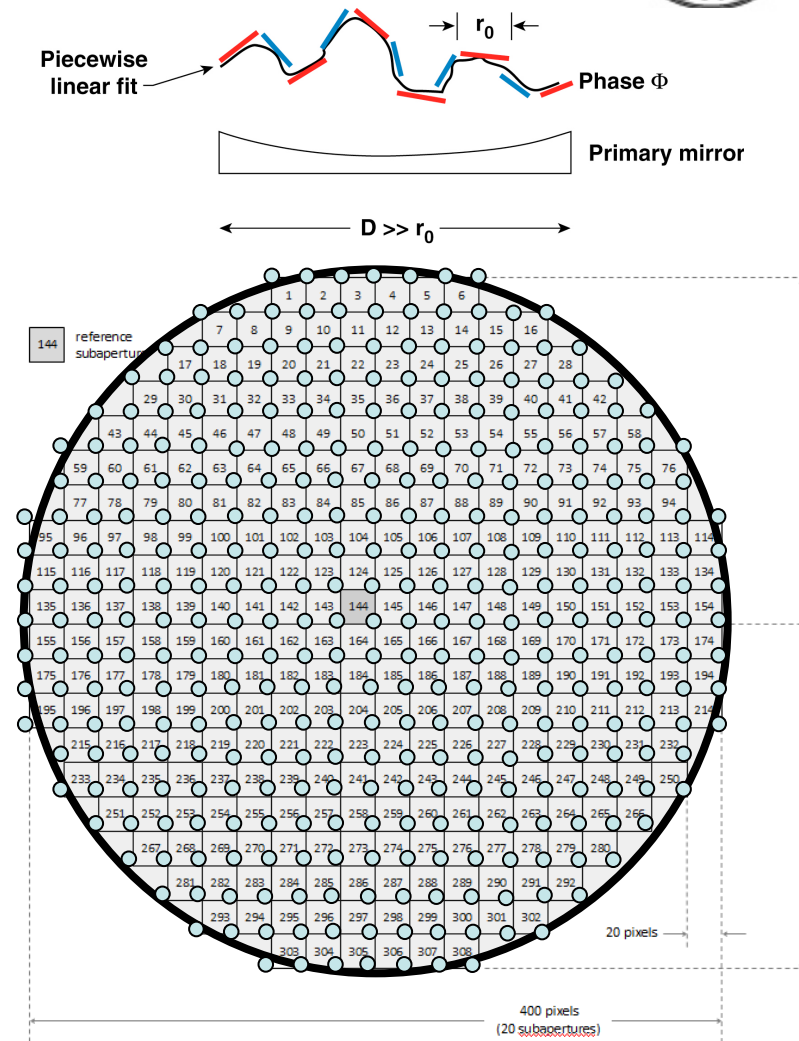
- ❖ 1st Generation AO-76
 - ❖ Strehl ratio: 0.7 in the NIR under median BBSO seeing
- ❖ 2nd Generation AO-308
 - ❖ Acquire diffraction limited imaging over the telescope's full range of operation
- ❖ 3rd Generation GLAS & MCAO
 - ❖ Expand field of view of diffraction limited observations to $\sim 1'$ in the visible
- ❖ AO-76, AO-308 and MCAO represent a successful collaboration between BBSO/ NJIT, KIS and NSO



2nd Generation AO: AO-308



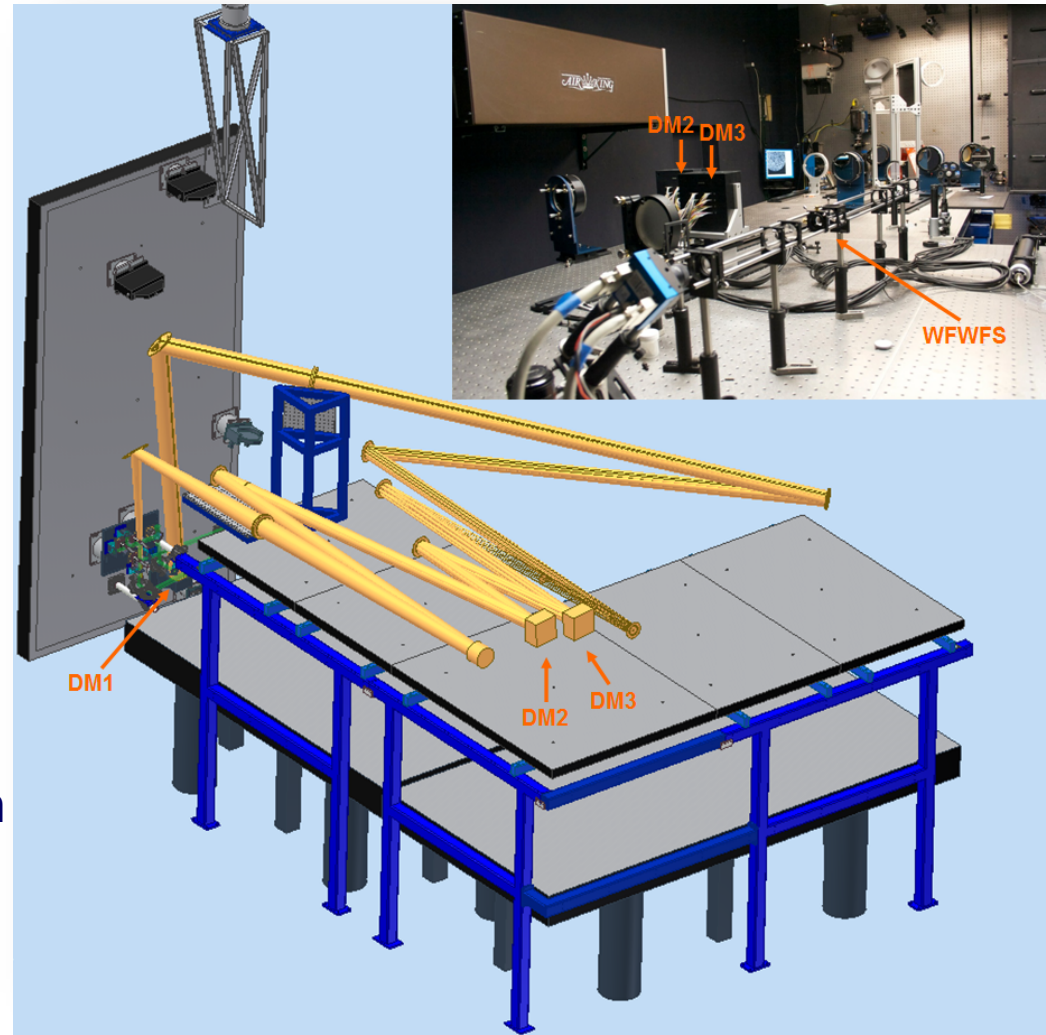
- ❖ AO-308 is operational, AO-308 is a collaboration between BBSO and NSO
- ❖ Shack Hartmann WFS with 308 sub-apertures (AO-308): 20 sub-apertures across the NST primary mirror
- ❖ Xinetics Deformable Mirror with 357 actuators and 5 mm spacing
- ❖ Phantom V.7.3 camera with a frame rate of 2000 Hz for 400 by 400 pixel sub-array
- ❖ Bitware TigerSHARC Boards with 16 digital signal processors (DSPs)
- ❖ Closed-loop Bandwidth: 120 Hz
- ❖ Acquire diffraction limited imaging over the telescope's full range of operation





3rd Generation AO: GMCAO

- ❖ Multi-Conjugate AO (MCAO) is a collaboration with KIS & NSO
- ❖ MD SH WFS with 208 sub-apertures and 9 guide regions
- ❖ Three DMs with 357 actuators conjugated to pupil (1km), 3 km (2km), and 8 km (3km)
- ❖ Multi-CPU parallel computation
- ❖ High speed camera with frame rate of 2000 Hz
- ❖ Closed-loop Bandwidth: 120 Hz
- ❖ Expand field of view of diffraction limited observations to $\sim 1'$ in the visible



Clear: MCAO Pathfinder for Observations of the Sun



CAO/MCAO 27 July 2016
(53" by 53") TiO (705.7 nm)



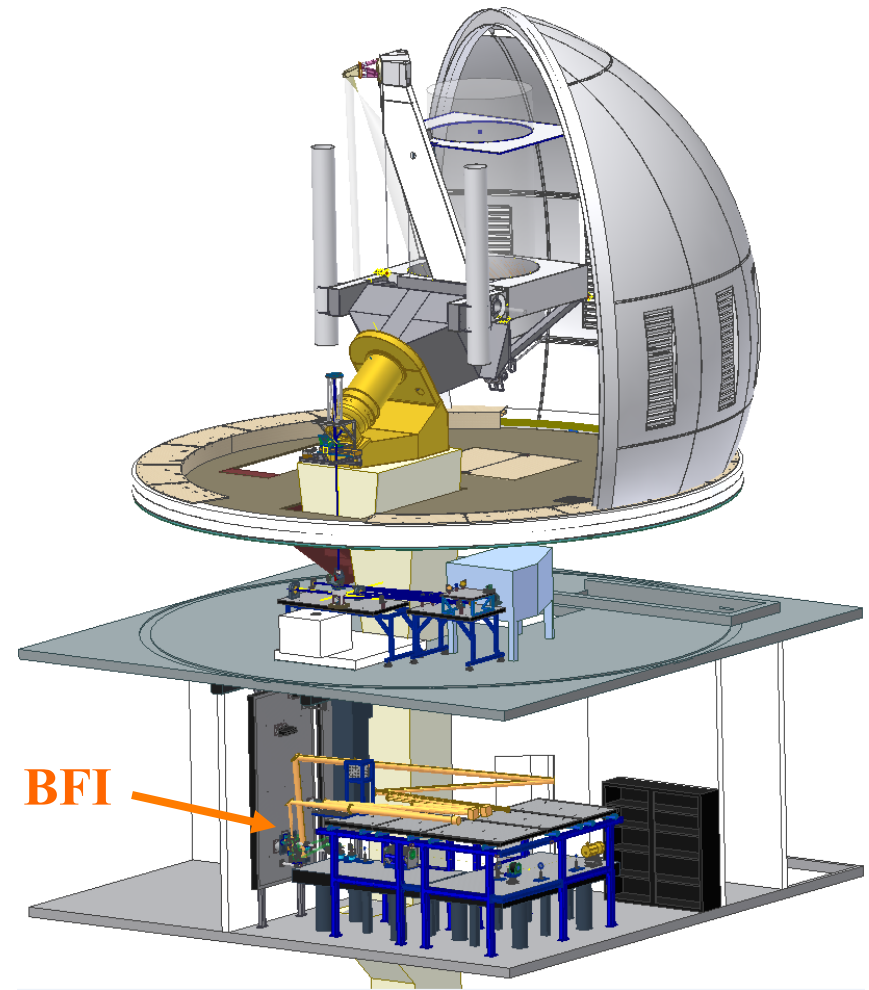


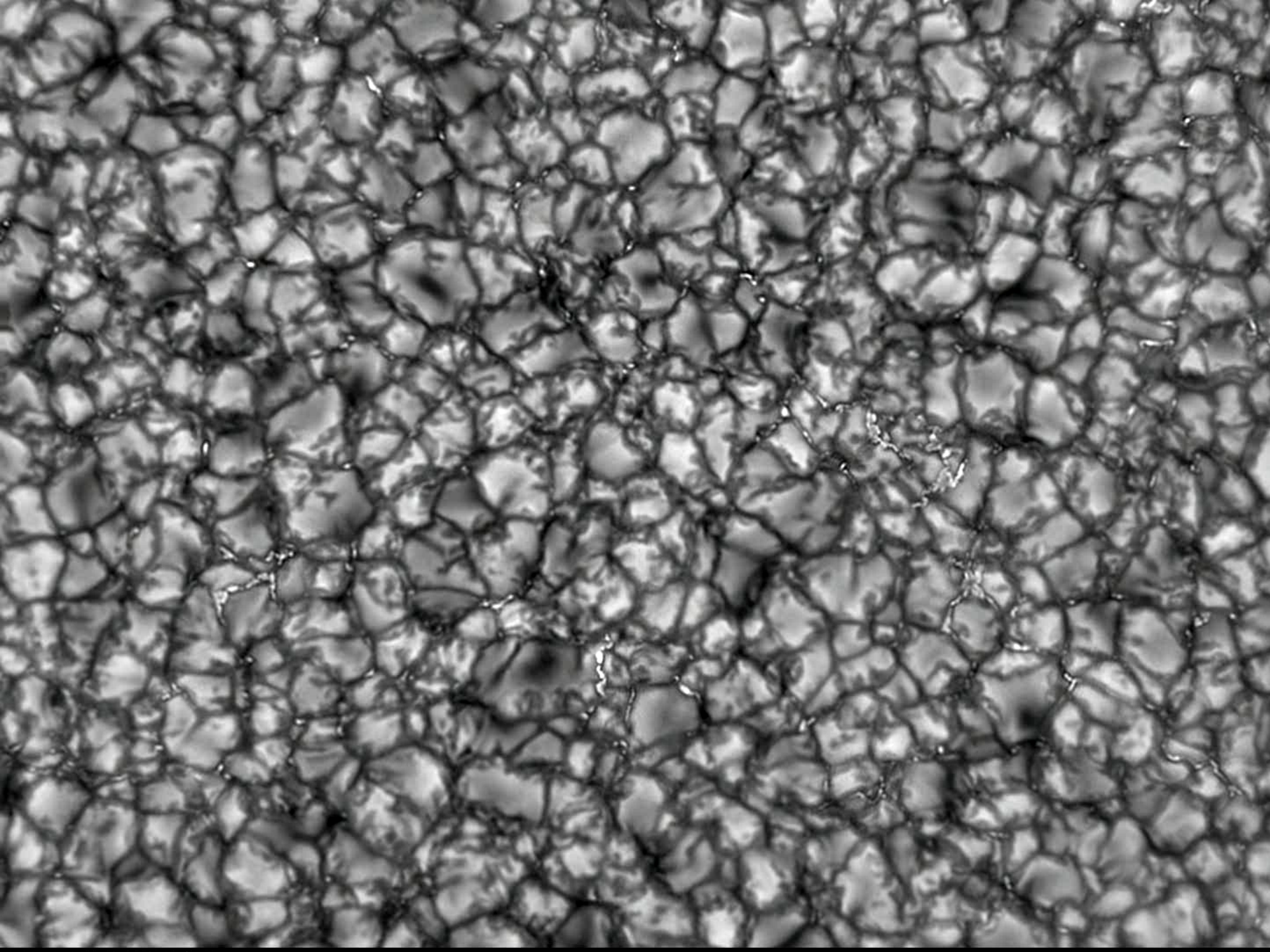
Broad-band Filter Imager

- ❖ Highest possible spatial and temporal resolution photometric observation
- ❖ Serves as scientific analysis and engineering feedback
- ❖ Reference images for alignment with space instruments
- ❖ Typical exposure: 0.8 – 1.5 ms
- ❖ Typical burst cadence: 10 – 15 s
- ❖ Available channels:

	Central Wavelength	Height above $\tau_{500}=1$	Filter Bandpass	Field of View	Image Scale	Minimum Cadence
G-band	430.5 nm	~ 50 km	5 Å	55"	0.027"/pix	7-10 secs
TiO	705.7 nm	~ 150 km	10 Å	70"	0.034"/pix	7-10 secs

- ❖ Speckle reconstruction post-processing with parallel computers

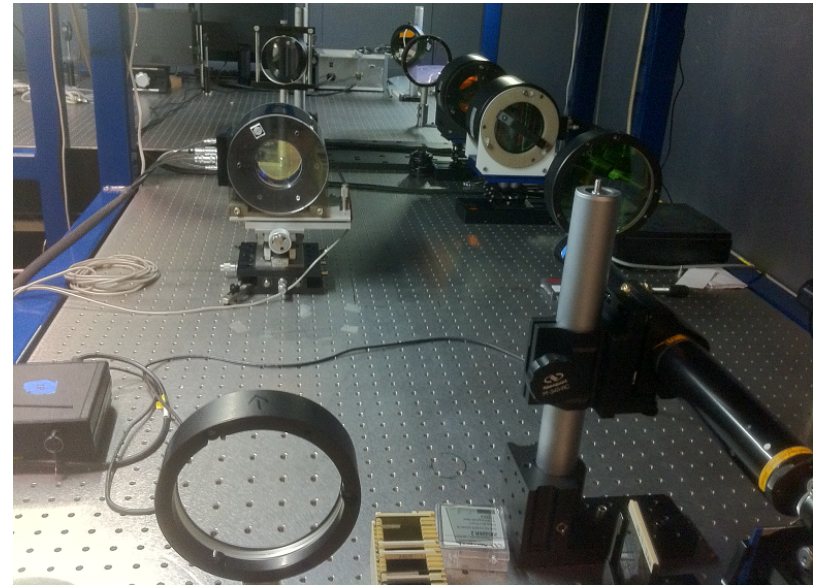
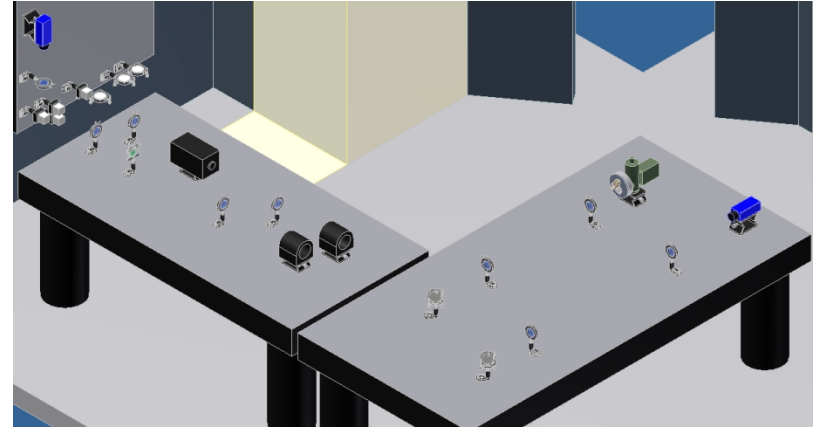




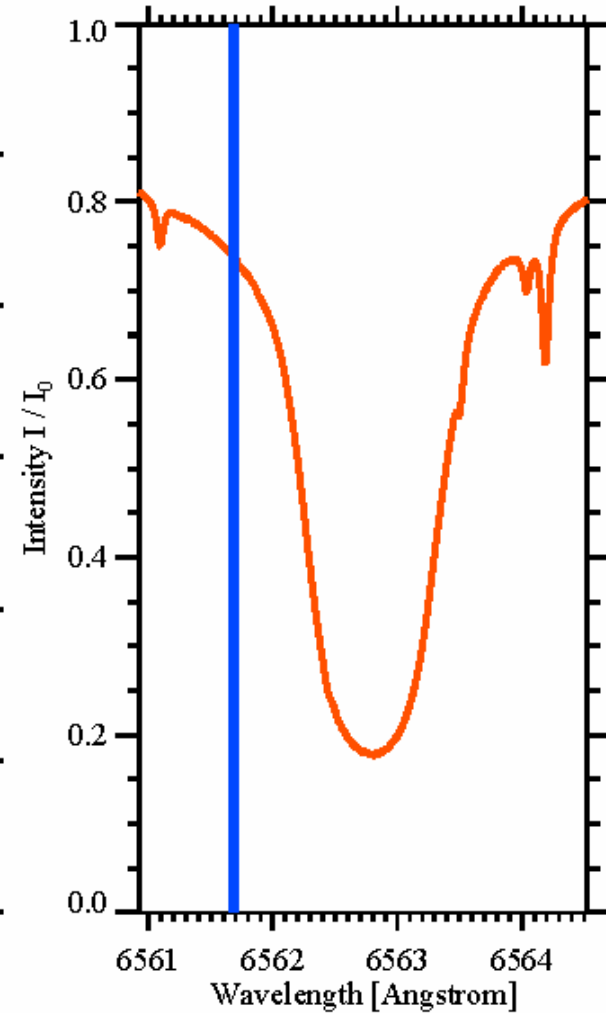
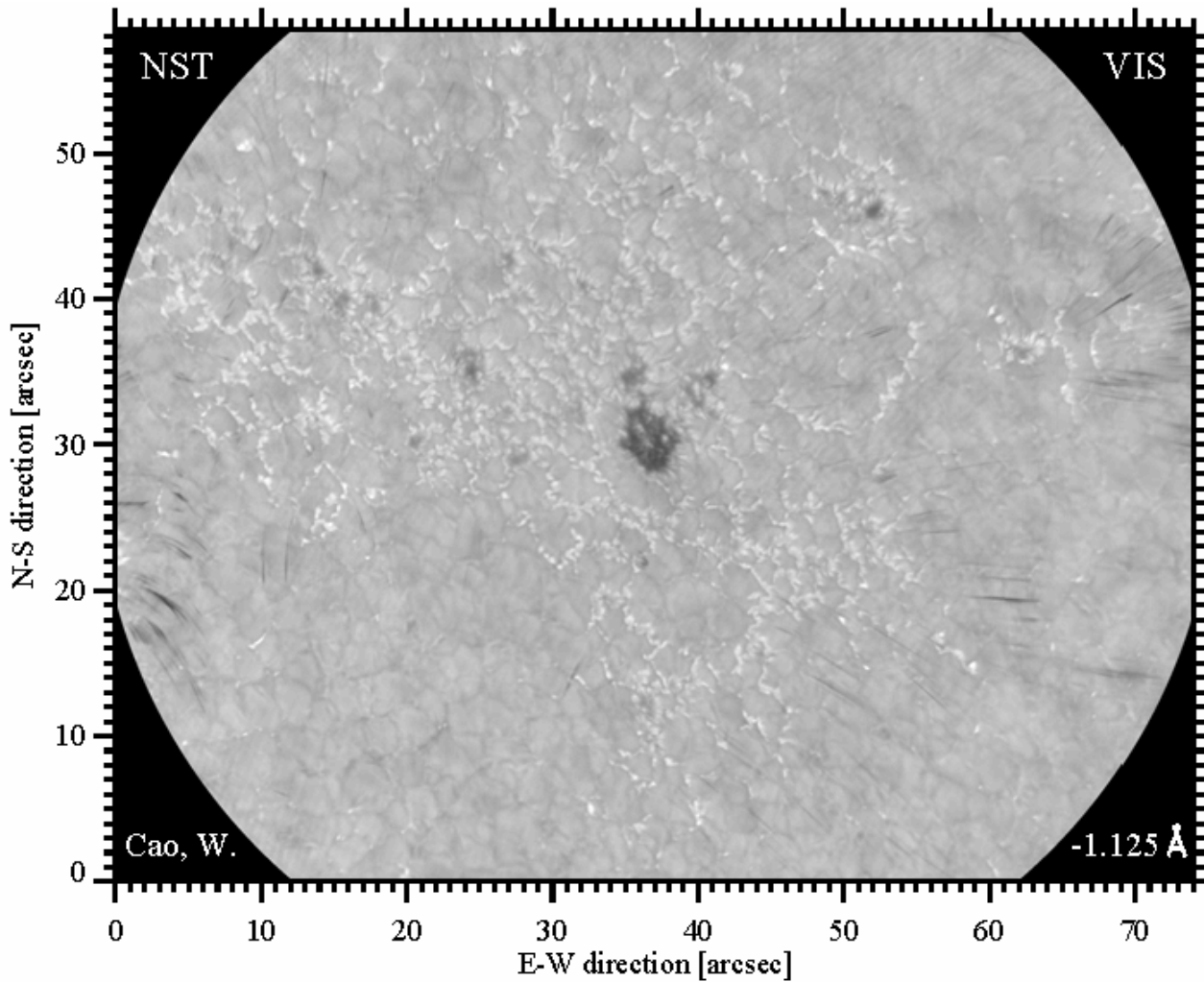
Visible Imaging Spectrometer



- ❖ Single Fabry-Pérot etalon ($D = 70 \text{ mm}$) plus narrow band interference filter
- ❖ Wavelength coverage: 550 – 700 nm
- ❖ Band pass: 5.8 – 8.2 pm
- ❖ Telecentric configuration with F/120
- ❖ Available spectral lines:
 - ❖ $\text{H}\alpha$ ($656.3 \pm 0.15 \text{ nm}$)
 - ❖ Fe I ($630.2 \pm 0.15 \text{ nm}$)
 - ❖ NaD_2 ($588.9 \pm 0.15 \text{ nm}$)
 - ❖ more lines are coming as needed ...
- ❖ Field of view: 75"(H) by 64"(V)
- ❖ High speed computer with SSD HDs
- ❖ Spectroscopy cadence: a 11 points scan with multi-frames selection: < 15 secs



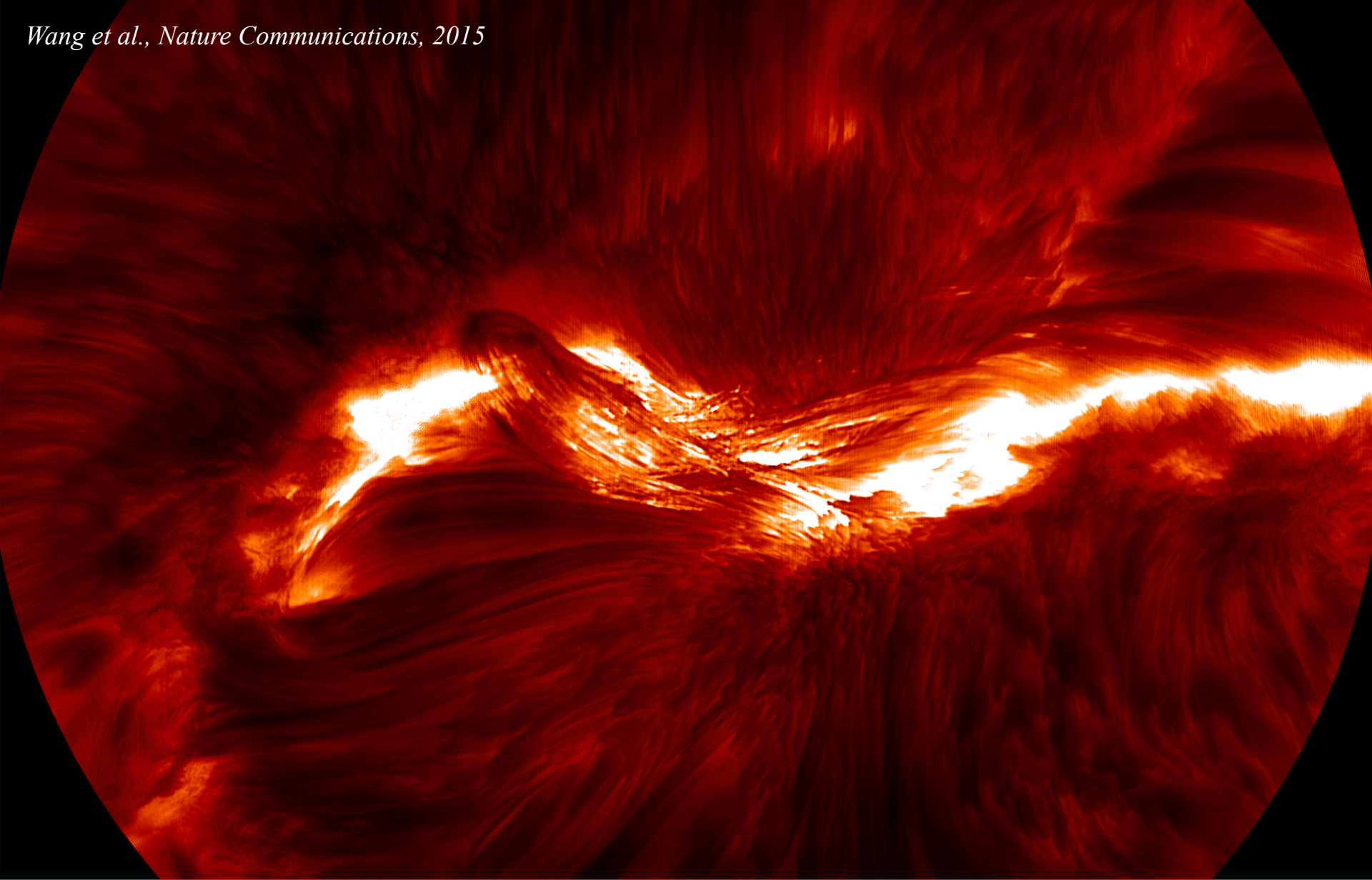
VIS Spectroscopy Observation

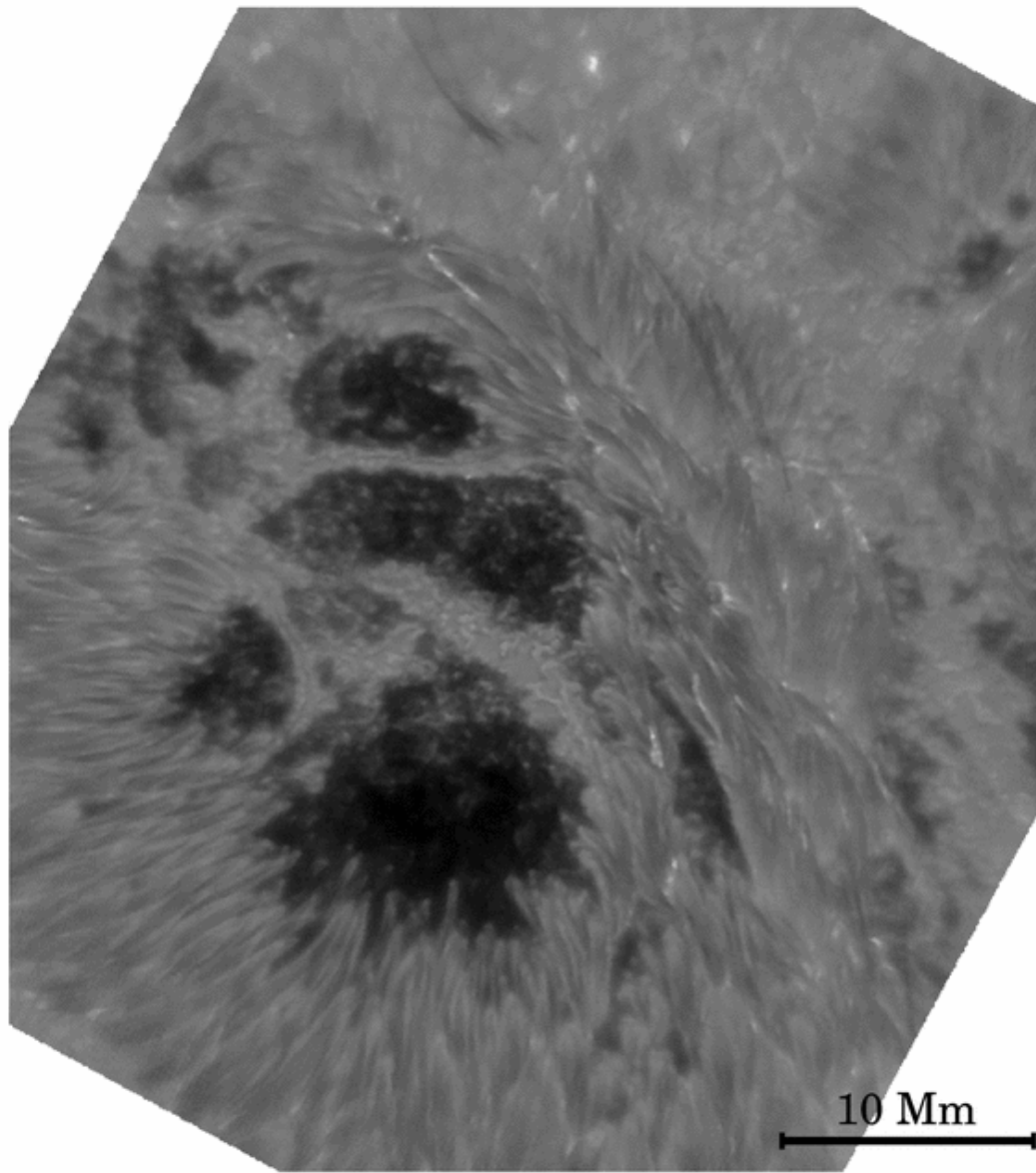


VIS Spectroscopy Observation

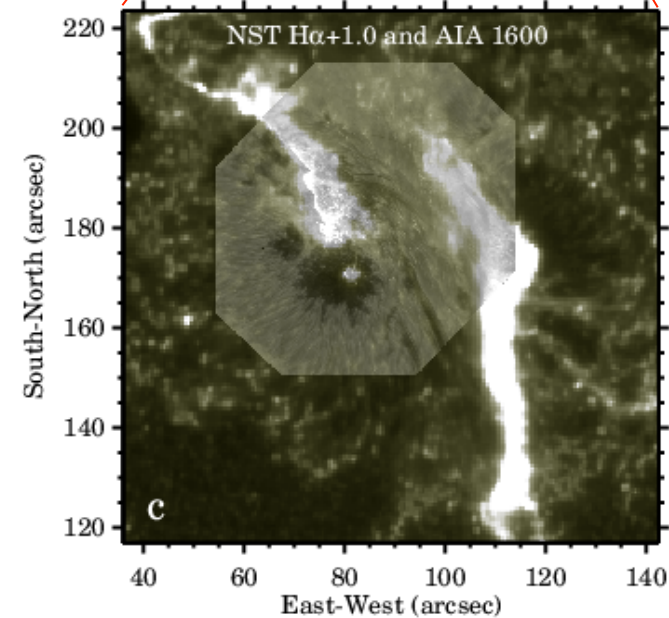
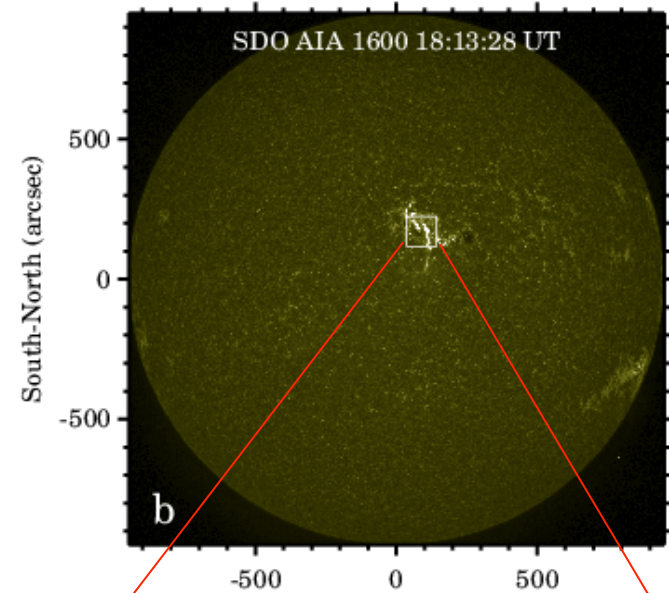


Wang et al., Nature Communications, 2015



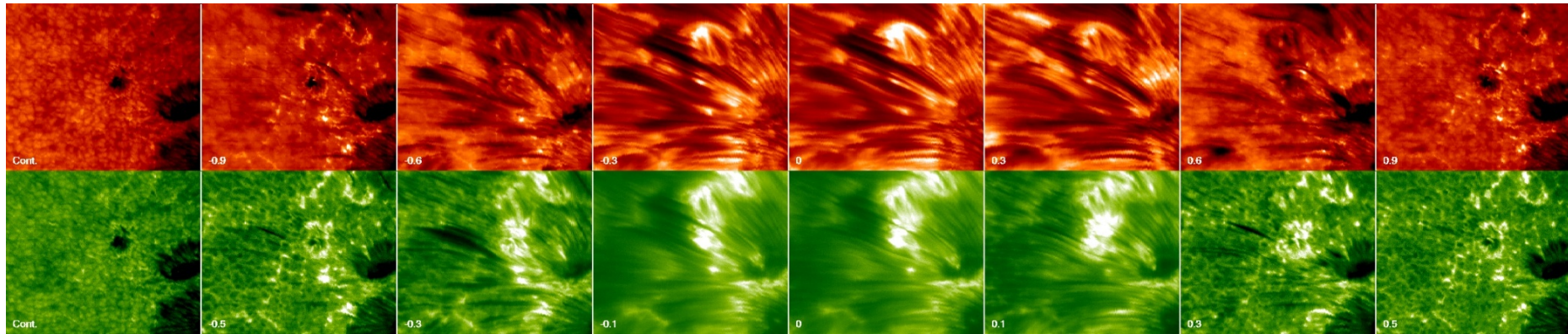


A M-class flare on 06/22/15 captured with NST-VIS $H\alpha + 1.0 \text{ \AA}$



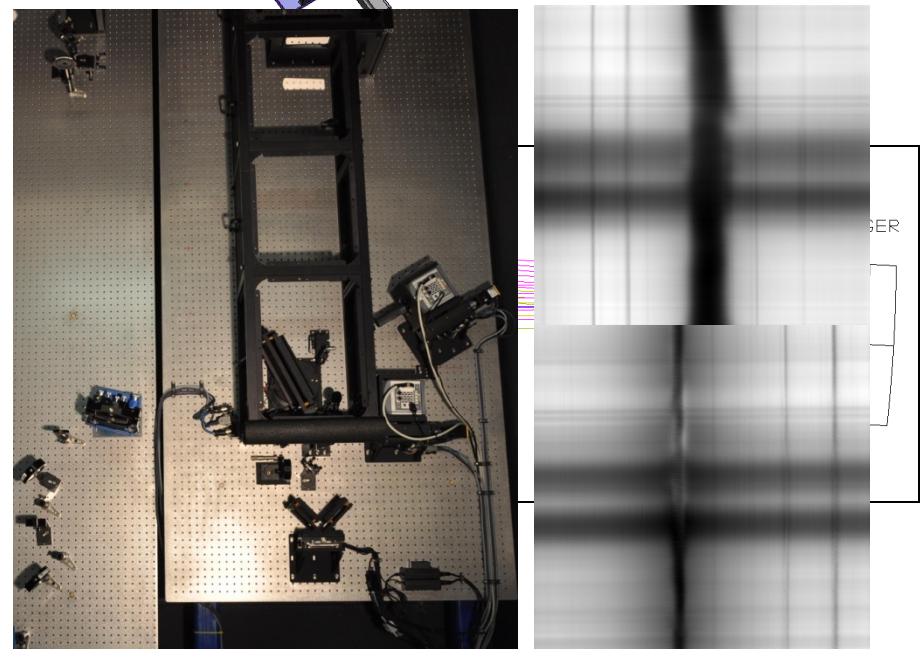
Jing, et al., Nature Reports, 2016

FISS



mottles, jets microflares ...

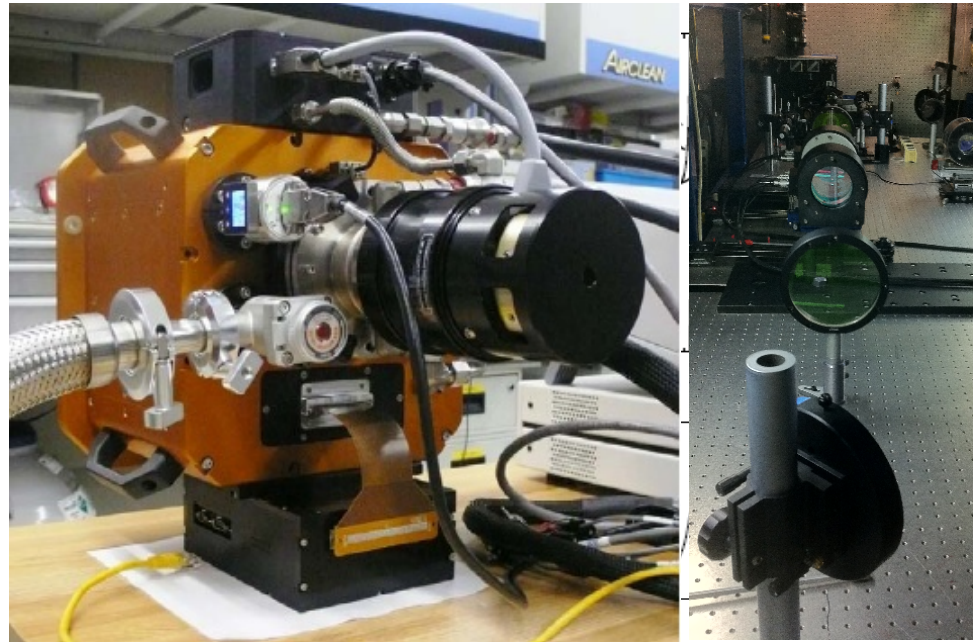
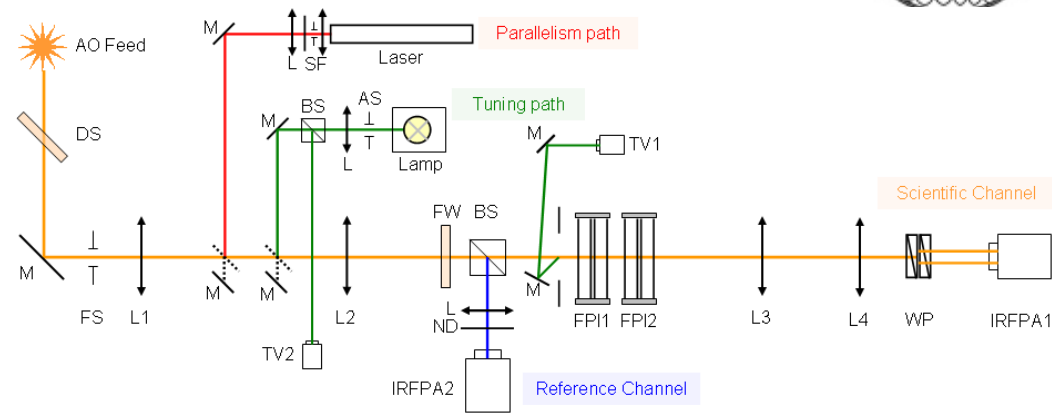
- ❖ Slit-scan imaging spectrograph
- ❖ Quasi-Littrow configuration
- ❖ Spectral resolution : 1.4×10^5
- ❖ 60" scanning cadence : 60 sec.
- ❖ Dual-band spectra at H_{α} and Ca II 854 nm using dual CCD cameras
- ❖ Echelle grating with order-selecting filters



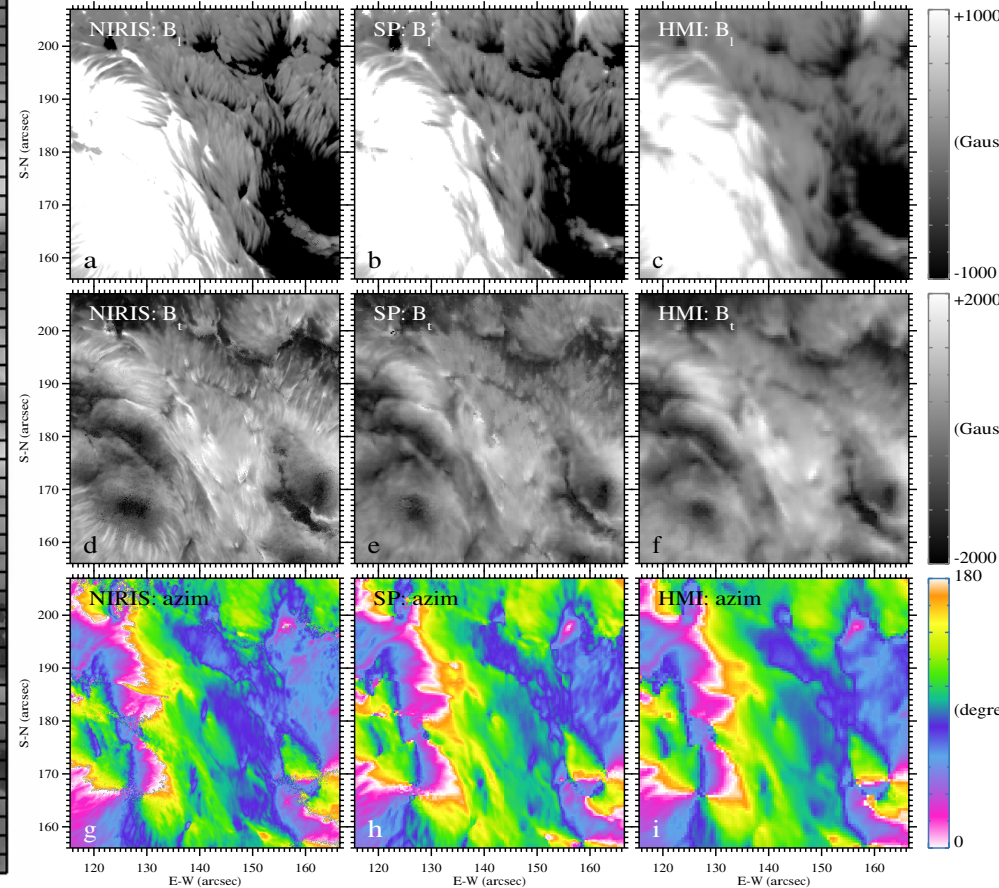
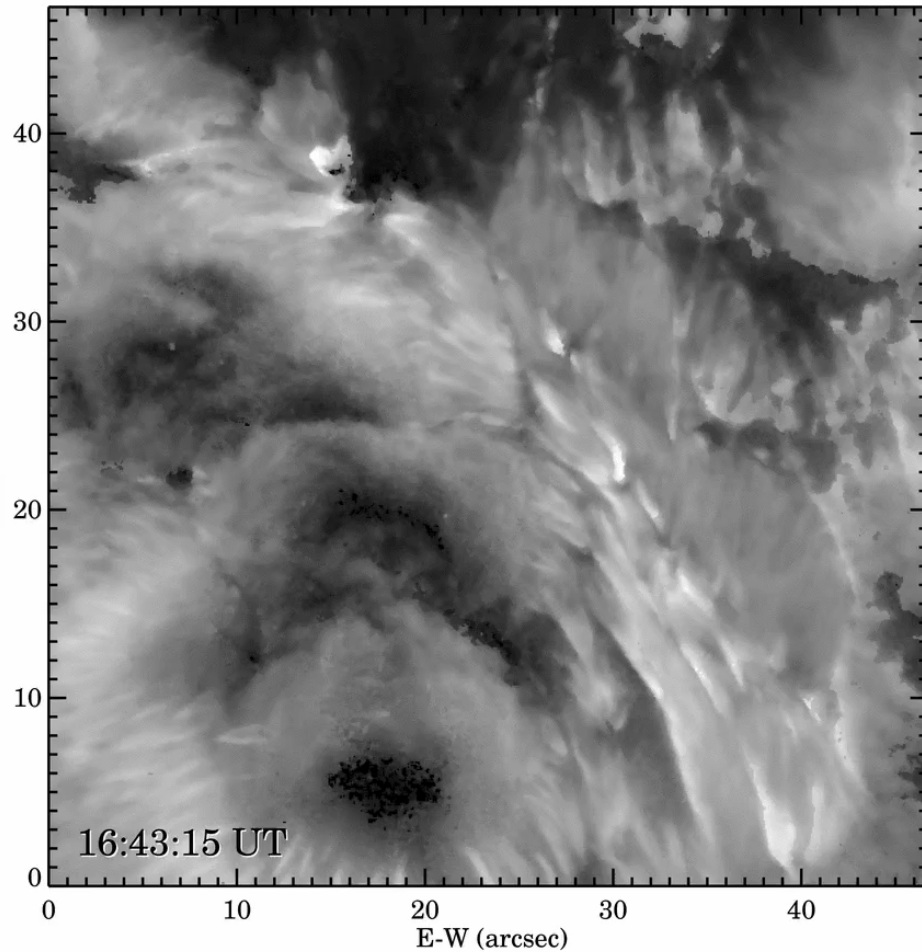


2nd Generation -- NIRIS

- ❖ Dual Fabry-Pérot etalons with apertures of 100 mm
- ❖ Wavelength coverage: 1000–1750 nm (He I 1083 and Fe I 1565 nm)
- ❖ New HgCdTe 2K by 2K camera with a frame rate up to 65 Hz
- ❖ Field of view: 85" round
- ❖ Dual beam polarimetry
- ❖ Achromatic rotating waveplate
- ❖ Spectral resolving power: $> 10^5$
- ❖ Telecentric optical configuration
- ❖ Polarimetry sensitivity: $10^{-4} I_c$
- ❖ Vector spectro-polarimetry cadence: < 30 secs



NIRIS, Hinode-SP and HMI

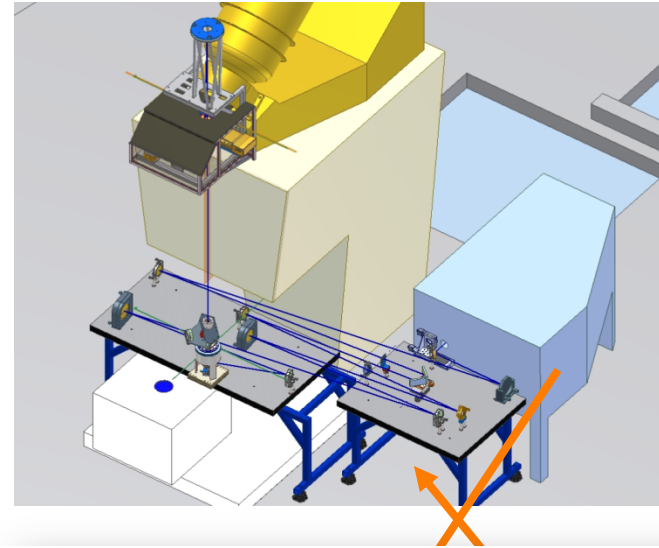


Liu, et al., Nature Communications, 2016



Cryogenic IR Spectrograph

- ❖ CYRA is in its construction phase, a collaboration with NSO, HAO & UH
- ❖ Fully cryogenic IR solar spectrograph
- ❖ Scientific motivation
 - ❖ *Dynamics of weak photospheric field*
 - ❖ *Chromospheric field variation with altitude*
 - ❖ *Characterize cool regions in chromosphere*
 - ❖ *Dimmer targets: umbra, off-limb ...*
- ❖ High Zeeman Sensitivity: $\delta\lambda \sim \lambda^2 g_{eff} B$
- ❖ NIR Bands of Interest for CYRA
 - ❖ *TiI 2.231 μm , $\lambda g_{eff} = 5578$, photosphere*
 - ❖ *FeI 4.064 μm , $\lambda g_{eff} = 5080$, photosphere*
 - ❖ *SiI 4.143 μm , $\lambda g_{eff} = 9321$, photosphere*
 - ❖ *CaI 3.697 μm , $\lambda g_{eff} = 4067$, chromosphere*
 - ❖ *MgI 3.682 μm , $\lambda g_{eff} = 4307$, chromosphere*
 - ❖ *CO 4.6 molecular band, chromosphere*
- ❖ High spatial resolution, high cadence spectrometry and polarimetry

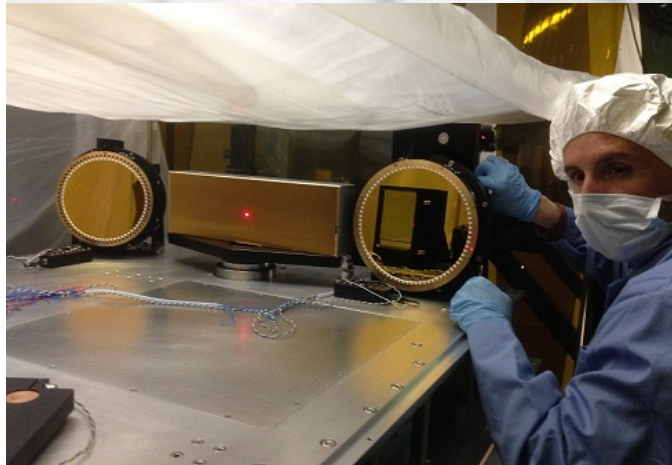
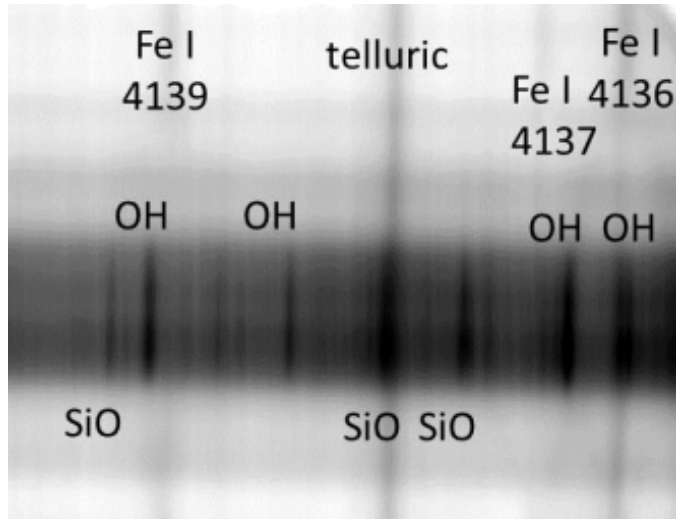


CYRA

Table 1: Spectrograph Coverage of CYRA for Its Current Configuration

Region	Species	λ [nm]	g_{eff}	Mag Sensitivity λg_{eff} [nm]	Note
Photosphere	Fe I	1565	3	4695	Sunspot only
	Ti I	2231	2.5	5578	
	Fe I	4063.7	1.25	5080	
	Si I	4236.5	1.625 or 2.25	6732 or 9321	
Chromosphere	Ca I	3697.4	1.1	4067	Spectroscopic Spectroscopic
	Mg I	3681.6	1.17	4307	
	Fe I	4132	n/a	n/a	
	CO	4666	n/a	n/a	
Corona	Si X	3934	1.5	5901	

Cryogenic IR Spectrograph



- ❖ Operating Temperature of 77 K to minimize background thermal emission
- ❖ Spectral range 1.0 to 5.0 μm
- ❖ Spectral resolving power $> 10^5$
- ❖ Spatial resolution: diffraction-limited for wavelengths $> 2 \mu\text{m}$
- ❖ Temporal modulation 10 Hz with dual beam differential polarimetry
- ❖ Field of view: 75"
- ❖ Image stabilization: Tip/tilt
- ❖ Image rotation compensator
- ❖ image scanner, context imaging and guiding
- ❖ HAWAII 2RG 2K \times 2K HgCdTe camera with a frame rate up to 65 Hz



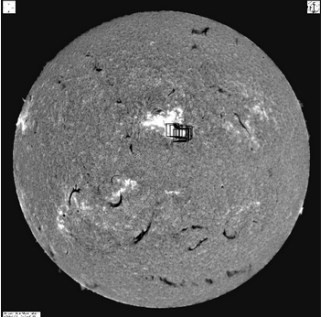
GST Scientific Results

Data Opening to Community



Previous Day **BBSO NST Data Finder - 2012-05-11T22:34:49** Next Day

NST Data Coverage
16:25:32 - 22:34:49 UT



Data Samples

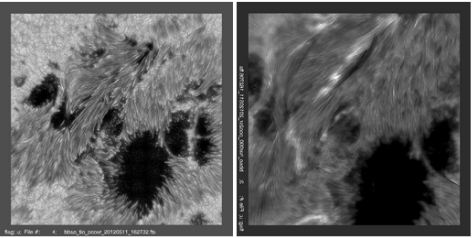
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- bbso_tio_pcoi_20120511_181956z12.fits | [thumb](#) | [header](#)
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- bbso_tio_pcoi_20120511_204157z73.fits | [thumb](#) | [header](#)
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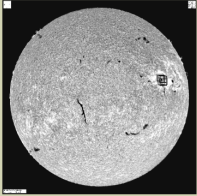
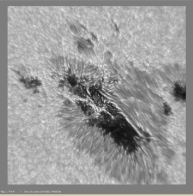
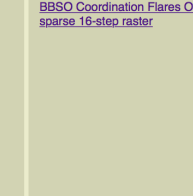
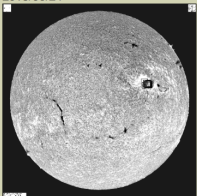
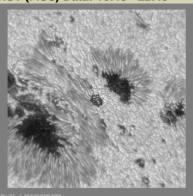

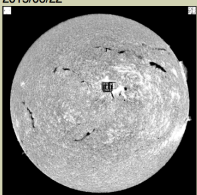
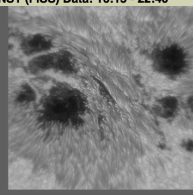

DATE: 2012/05/11
FILTER: TIO; Ha
OBS TIME: 16:25 - 22:34UT
TARGET: NOAA 11476; joint obs. w/ Hinode
SEEING, DATA QUALITY: fair
OBSERVER: cp
OBS COMMENTS: FITS (Flexible Image Transport System) format is defined in 'Astronom
OBS COMMENTS: and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
OBS COMMENTS: NOAA 11476 leading spot

Comments by Scientist:
See [Obs Logs](#) for more info...

After Reconstruction Info:
Quick Look Low Resolution [TIO](#) and [Ha](#) Movies

Reconstructed Images Samples:



 <p>2015/06/25</p>	 <p>NST Data: 16:40 - 21:50</p>	 <p>IRIS Data: 17:22 - 22:00 BBSO Coordination Flares OBS 3660100039: Large sparse 16-step raster</p>
 <p>2015/06/24</p>	 <p>NST (FISS) Data: 16:40 - 22:45</p>	 <p>IRIS Data: 17:00 - 22:30 BBSO Coordination Flarewatch OBS 3660100039: Large sparse 16-step raster</p>
 <p>2015/06/22</p>	 <p>NST (FISS) Data: 16:15 - 22:40</p>	 <p>IRIS Data: 17:00 - 21:14 BBSO coordination flares AR 12371 OBS 3660100039: Large sparse 16-step raster IRIS Data: 21:25 - 23:06 BBSO coordination flares AR 12371 OBS 3620104038: Medium sparse 16-step raster</p>

NST observing proposal submission: <http://www.bbso.njit.edu/cgi-bin/NSTObsForm>

NST-IRIS joint observations: http://www.bbso.njit.edu/NST-IRIS_Catalog.html

NST data quick look movies: http://www.bbso.njit.edu/~vayur/NST_catalog

NST data download request: http://www.bbso.njit.edu/~vayur/nst_requests/

GST Users and Collaborators



- ❖ *Stanford University - SU*
- ❖ *Harvard-Smithsonian Center for Astrophysics-- CFA*
- ❖ *Montana State University - MSU*
- ❖ *California State University, Northridge - CSUN*
- ❖ *University of Colorado Boulder - CU*
- ❖ *University of Hawaii - UH*
- ❖ *New Jersey Institute of Technology - NJIT*
- ❖ *National Solar Observatory - NSO*
- ❖ *Naval Research Lab - NRL*
- ❖ *Kiepenheuer-Institut für Sonnenphysik - KIS, Germany*
- ❖ *Nagoya University - STEL, Japan*
- ❖ *Nanjing University - NJU, China*
- ❖ *Peking University - PKU, China*
- ❖ *Seoul National University - SNU, Korea*
- ❖ *Korea Astronomy and Space Science Institute - KASI, Korea*
- ❖ *National Astronomical Observatory of China - NAOC, China*
- ❖ *Astronomical Institute of Czech Academy of Sciences - ASU, Czech*
- ❖ *Purple Mountain Observatory - PMO, China*
- ❖ *Crimean Astrophysical Observatory - CAO, Republic of Crimea*
- ❖ *Northumbria University - NU, UK*
- ❖ *Yunnan Astronomical Observatory - YNAO, China*
- ❖ *Shandong University - SDU, China*
- ❖ *Akdeniz University - AU, Turkey*
- ❖ *National Central University - TCU, Taiwan*



<http://www.nasa.gov/feature/goddard/2016/tracking-waves-from-sunspots-gives-new-solar-insight>



GST Supporting Projects

- ❖ *DKIST – Daniel K. Inouye Solar Telescope*
- ❖ *ALMA – Atacama Large Millimeter/submillimeter Array*
- ❖ *GONG – Global Oscillation Network Group*
- ❖ *SOLIS – Synoptic Optical Long-term Investigation of the Sun*
- ❖ *IRIS – Interface Region Imaging Spectrograph*
- ❖ *SDO – Solar Dynamics Observatory*
- ❖ *Hinode – Solar B*
- ❖ *Hi-C II Rocket Mission*
- ❖ *GREGOR – 1.5 m Solar Telescope built by Germany Consortium*
- ❖ *NVST – 1 m New Vacuum Solar Telescope built by YNAO*



National Science Foundation
WHERE DISCOVERIES BEGIN



NJIT

New Jersey's Science & Technology University

Big Bear Solar Observatory

THE EDGE IN KNOWLEDGE

Science and Education



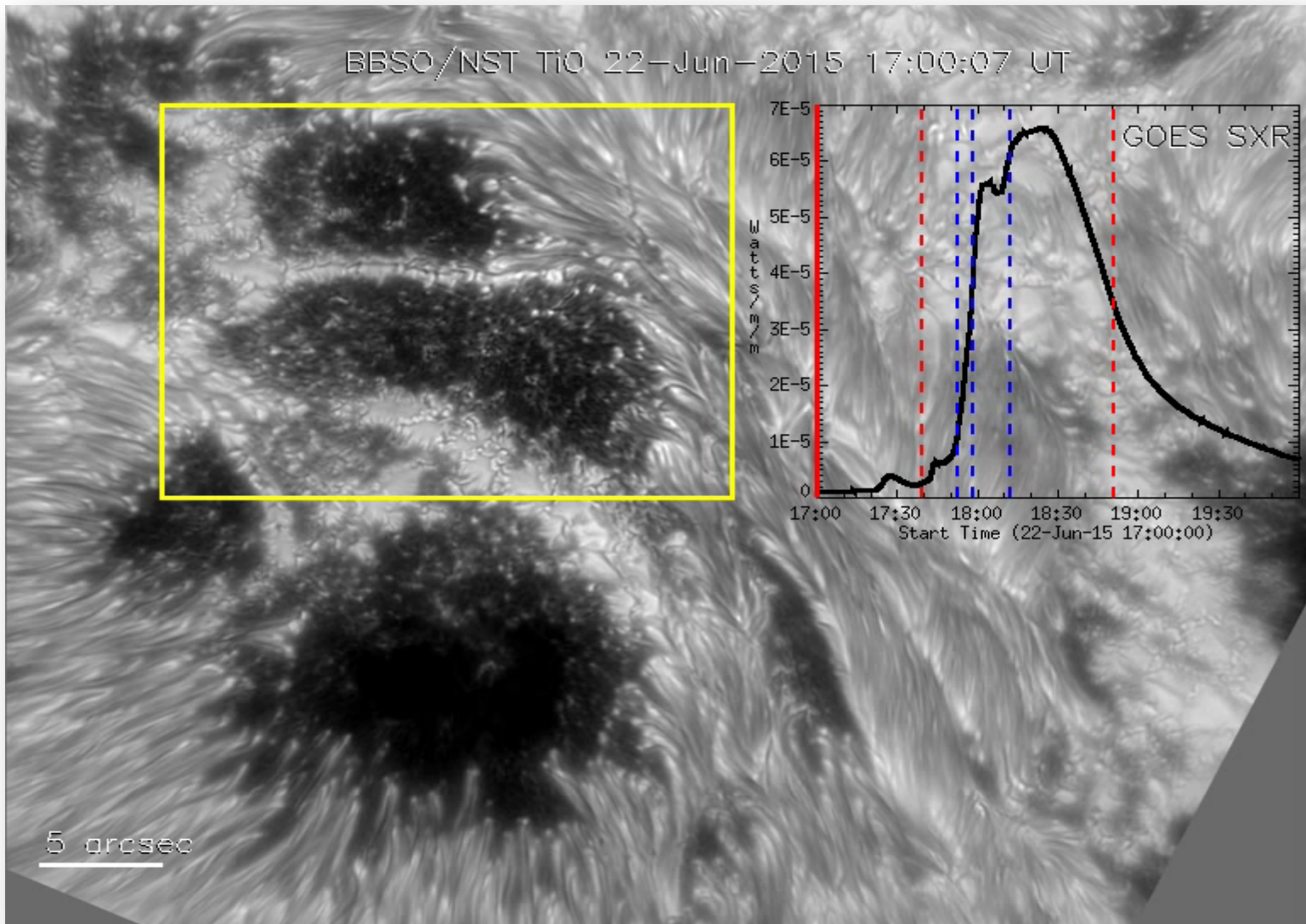
- ❖ 70+ Publications from GST Observations since 2010
- ❖ 5 Nature/Science Papers
- ❖ 30+ Publications on Instrumentation Development
- ❖ 15+ PhD Students working on their Thesis with GST data
- ❖ 5 of our post-docs have advanced to tenure-track faculty positions in the U.S.
- ❖ 10 other former post-docs have earned professorships in their home countries.

BBSO
Big Bear Solar Observatory

Home Projects People Operations Data Partners About BBSO

Publications from NST Observations

1. Flare differentially rotates sunspot on Sun's surface, 2016, Chang Liu, Yan Xu, Wenda Cao, Na Deng, Jeongwoo Lee, Hugh S. Hudson, Dale E. Gary, Jiasheng Wang, Ju Jing & Haimin Wang, *Nature Comm.* 7, 13104, doi: 10.1038/ncomms13104 .
2. Resolving the Fan-spine Reconnection Geometry of a Small-scale Chromospheric Jet Event with the New Solar Telescope, 2016, Zeng, Zhicheng; Chen, Bin; Ji, Haisheng; Goode, Phillip R.; Cao, Wenda, *Astrophys. J. Lett.*, 819/1, article id. L3 (ADS)
3. Observations of Oppositely Directed Umbral Wavefronts Rotating in Sunspots Obtained from the New Solar Telescope of BBSO, 2016, Su, J. T.; Ji, K. F.; Cao, W.; Banerjee, D.; Priya, T. G.; Zhao, J. S.; Bai, X. Y.; Chen, J.; Zhang, M.; Ji, H. S., *Astrophys. J.*, 817/2, article id. 117 (ADS)
4. Interference of the Running Waves at Light Bridges of a Sunspot, 2016, Su, J. T.; Ji, K. F.; Banerjee, D.; Cao, W. D.; Priya, T. G.; Zhao, J. S.; Yu, S. J.; Ji, H. S.; Zhang, M., *Astrophys. J.*, 816/1, article id. 30 (ADS)
5. Unprecedented Fine Structure of a Solar Flare Revealed by the 1.6-m New Solar Telescope, 2016, Ju Jing, Yan Xu, Wenda Cao, Chang Liu, Dale Gary & Haimin Wang, *Scientific Reports* 6, Article number: 24319 (Nature)
6. Ultra-narrow Negative Flare Front Observed in Helium-10830 Å Using the 1.6 m New Solar Telescope, 2016, Xu, Yan; Cao, Wenda; Ding, Mingde; Kleint, Lucia; Su, Jiangtao; Liu, Chang; Ji, Haisheng; Chae, Jongchul; Jing, Ju; Cho, Kyuhyoun; Cho, Kyungsuk; Gary, Dale; Wang, Haimin, *Astrophys. J.*, 819/2, article id. 89 (ADS)
7. Observations of a Series of Flares and Associated Jet-like Eruptions Driven by the Emergence of Twisted Magnetic Fields, 2016, Lim, Eun-Kyung; Yurchyshyn, Vasyil; Park, Sung-Hong; Kim, Sujin; Cho, Kyung-Suk; Kumar, Pankaj; Chae, Jongchul; Yang, Heesu; Cho, Kyuhyoun; Song, Donguk; Kim, Yeon-Han, *Astrophys. J.*, 817/1, article id. 39 (ADS)
8. Multiwavelength Observations of a Slow-rise, Multistep X1.6 Flare and the Associated Eruption, 2015, Yurchyshyn, V., Kumar, P., Cho, K.-S., Lim, E.-K., Abramenko, V. I., *Astrophys. J.*, 812/2, article id. 172 (ADS)
9. Simultaneous observation of a hot explosion by NST and IRIS 2015, Kim, Yeon-Han; Yurchyshyn, Vasyil; Bong, Su-Chan; Cho, Il-Hyun; Cho, Kyung-Suk; Lee, Jaemin; Lim, Eun-Kyung; Park, Young-Deuk; Yang, Heesu; Ahn, Kwangsu; Goode, Phillip R.; Jang, Bi-Ho I., *Astrophys. J.*, 810/1, article id. 38 (ADS)
10. Formation and Eruption of a Small Flux Rope in the Chromosphere Observed by NST, IRIS, and SDO, 2015, P. Kumar, V. Yurchyshyn, H. Wang, & K.S. Cho, , *Astrophys. J.*, 809/1, article id. 83 (ADS)
11. Witnessing magnetic twist with high-resolution observation from the 1.6-m New Solar Telescope, Haimin Wang, Wenda Cao, Chang Liu, Yan Xu, Rui Liu, Zhicheng Zeng, Jongchul Chae, & Haisheng Ji, *Nature Communications* 6, Article number: 7008, doi:10.1038/ncomms8008
12. Intensity and Doppler Velocity Oscillations in Pore Atmospheres, 2015, Cho, K.-S., Bong, S.-C., Nakariakov, V. M., Lim, E.-K., Park, Y.-D., Chae, J. C., Yang, H.-S., Park, H.-M., and Yurchyshyn, V., *Astrophys. J.*, 802, article id 45. (ADS)
13. Dynamics in Sunspot Umbra as Seen in New Solar Telescope and Interface Region Imaging Spectrograph Data, 2015, Yurchyshyn, V., Abramenko, V., and Kilcik, A., *Astrophys. J.*, 798, article id. 136. (ADS | Arxiv.org)
14. Active Region Coronal Rain Event Observed by the Fast Imaging Solar Spectrograph on the NST, 2014, Ahn, Kwangsu; Chae, Jongchul; Cho, Kyung-Suk; Song, Donguk; Yang, Heesu; Goode, Phillip R.; Cao, Wenda; Park, Hyungmin; Nah, Jakyung; Jang, Bi-Ho; Park, Young-

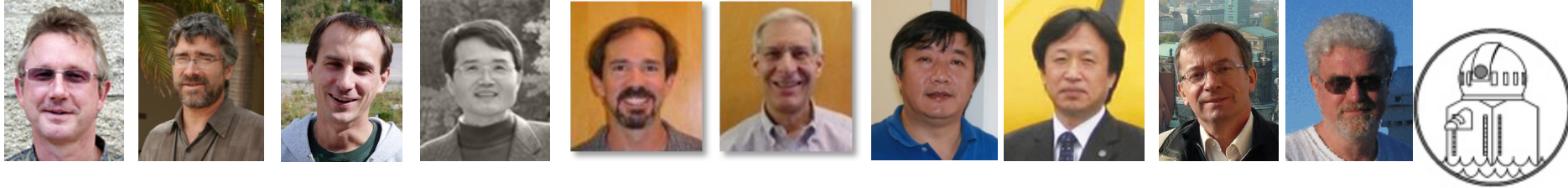


NST Witnesses a Sunspot Differentially Rotated by a Flare
Liu, et al. 2016, Nature Communications

Summary

- ❖ The 1.6 m GST is fully operational, which is the largest aperture and the highest resolution solar telescope over the world.
- ❖ GST scientific instruments provide the solar community with unprecedented high resolution photometric, spectroscopic and polarimetric data covering from the spectral range from 400 nm to 5 μm , to probe the solar atmosphere from the deepest photosphere to the base of the corona, and from the quietest to the most active Sun.
- ❖ BBSO has become not only a benchmark of NJIT, but also a center of solar high-resolution researches and observations.





Acknowledgement

NST Project is supported by NJIT, US NSF, NASA, AirForce, NOAC, KASI

NST Team: Philip R Goode, Roy Coulter, Wenda Cao, Nicolas Gorceix, John Vasik, Sergiy Shumko, Jeff Nenow, Kwangsu Ahn, Vasyl Yurchyshyn, Volodymyr Abramenko, Algae Kellerer, Dirk Schmidt, Claude Playmate, Seonghwan Choi, Randy Fear, Xianyu Zhang

NST Collaborators: Thomas Rimmele, Jeff Kuhn, Gil Moretto, Fredrich Woger, Haisheng Ji, Jongchul Chae, Matt Penn, David Elmore, Young-Deuk Park, Wolfgang Schmidt, Oscar van de Luhe, Jose Marino

