The Helioseismic and Magnetic Imager

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Outline

- HMI Overview
- Data Products
- Science Team
- Instrument
- Data Processing
- Status
- Schedule

HMI Overview

- **The primary goal of the Helioseismic and Magnetic Imager (HMI) investigation is to study the origin of solar variability and to characterize and understand the Sun's interior and the various components of magnetic activity.**
- **The HMI investigation is based on measurements obtained with the HMI instrument as part of the Solar Dynamics Observatory (SDO) mission.**
- **HMI makes measurements of several quantities**
  - Doppler Velocity (13m/s rms.).
  - Line-of-sight (10G rms.) and vector magnetic field.
  - Intensity
  - All variables all the time with 0.5" pixels.
  - Most at 50s or better cadence.
  - Variables are made from filtergrams, all of which are downlinked.
- **Higher level products will be made as part of the investigation.**
- **All data available to all.**
- **Launch in April 2008. 5 Year nominal mission.**
- **Education and Public Outreach program included!**

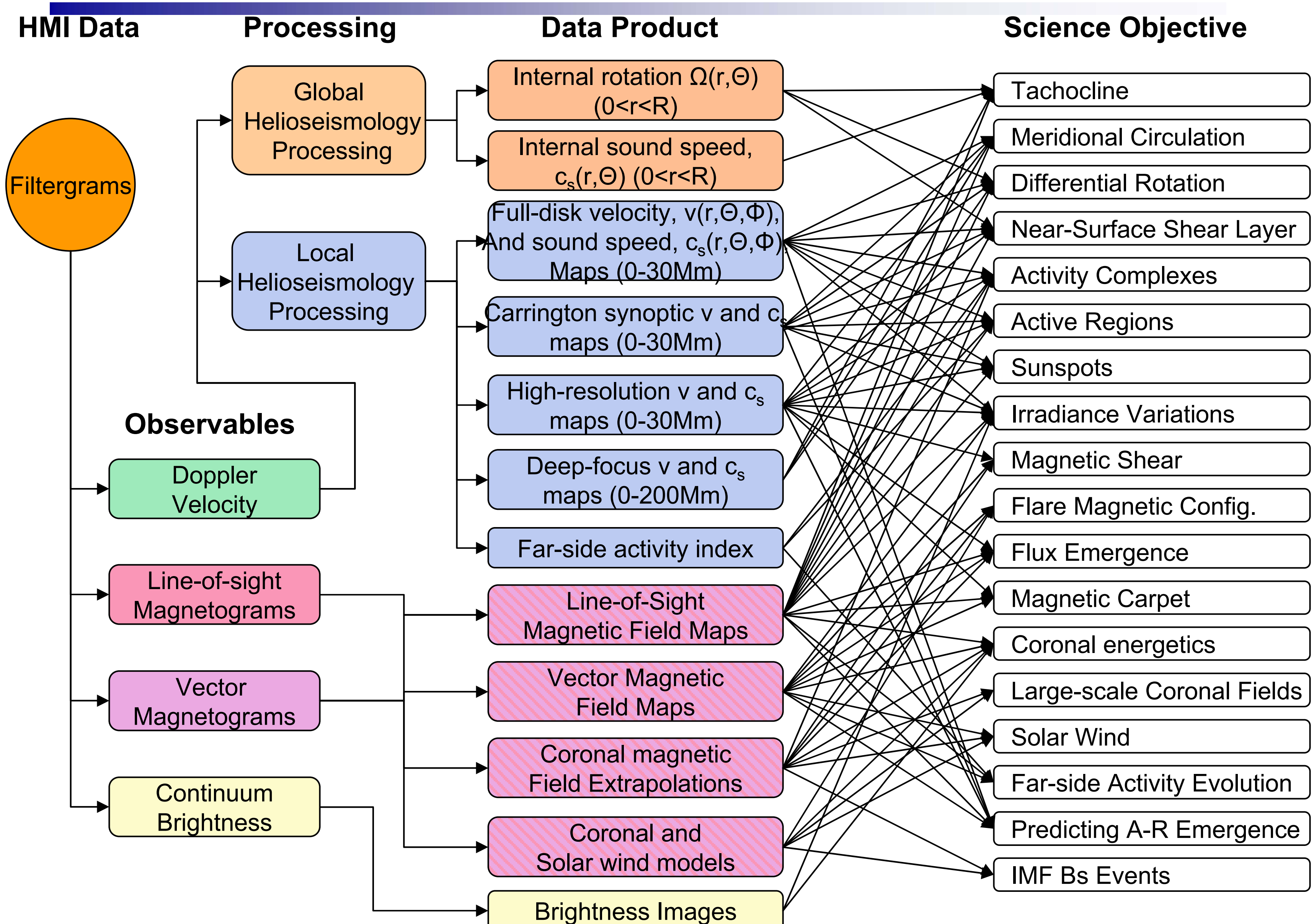
HMI Science Objectives

- **HMI science objectives are grouped into five broad categories:**
  - Convection-zone dynamics
    - How does the solar cycle work?
  - Origin and evolution of sunspots, active regions and complexes of activity
    - What drives the evolution of spots and active regions?
  - Sources and drivers of solar activity and disturbances
    - How and why is magnetic complexity expressed as activity?
  - Links between the internal processes and dynamics of the corona and heliosphere
    - What are the large scale links between the important domains?
  - Precursors of solar disturbances for space-weather forecasts
    - What are the prospects for prediction?
- **These objectives are divided into 18 sub-objectives each of which needs data from multiple HMI data products.**

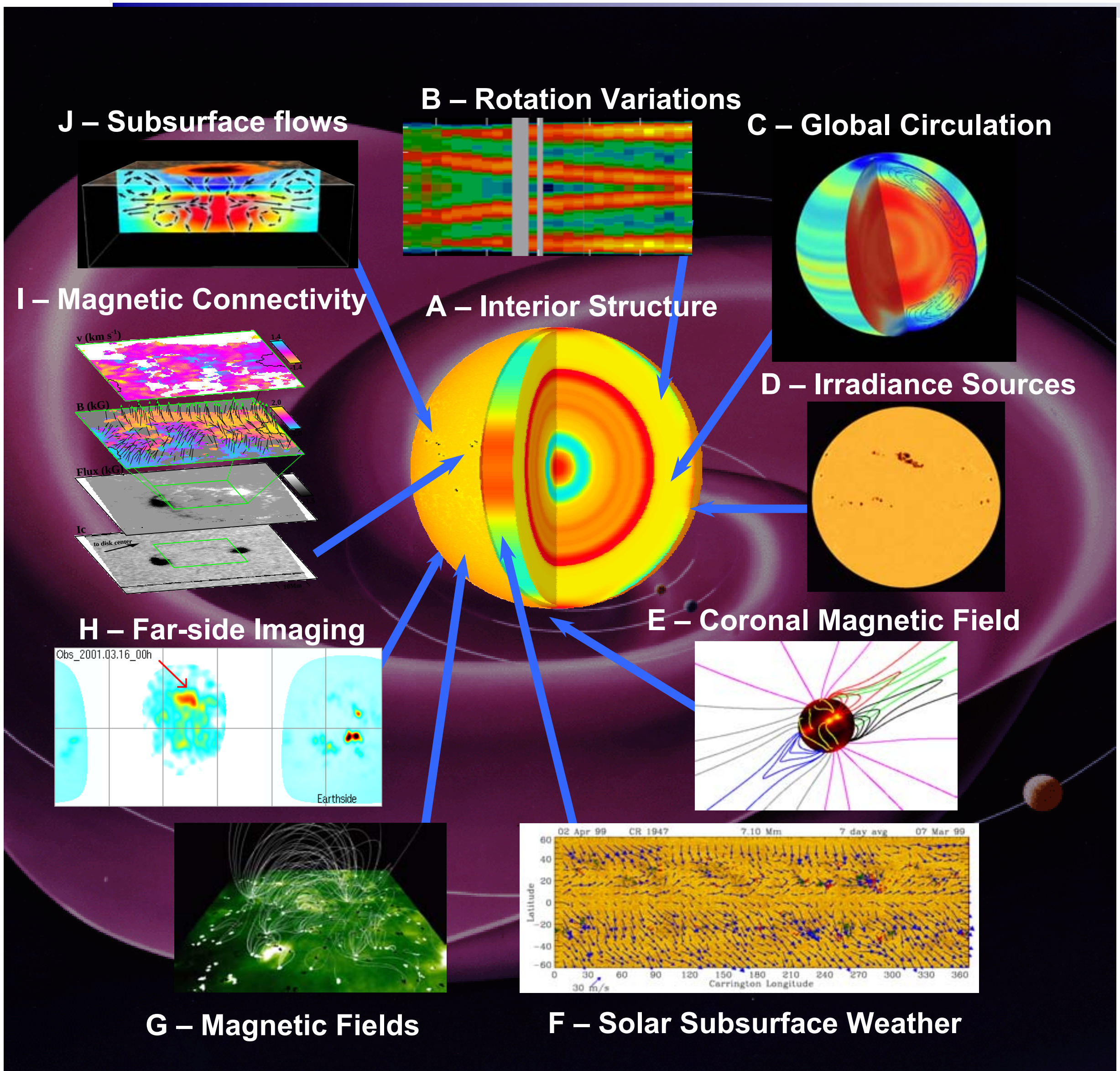
HMI Science Objectives

- **Convection-zone dynamics and the solar dynamo**
  - Structure and dynamics of the tachocline
  - Variations in differential rotation
  - Evolution of meridional circulation
  - Dynamics in the near surface shear layer
- **Origin and evolution of sunspots, active regions and complexes of activity**
  - Formation and deep structure of magnetic complexes of activity
  - Active region source and evolution
  - Magnetic flux concentration in sunspots
  - Sources and mechanisms of solar irradiance variations
- **Sources and drivers of solar activity and disturbances**
  - Origin and dynamics of magnetic sheared structures and d-type sunspots
  - Magnetic configuration and mechanisms of solar flares
  - Emergence of magnetic flux and solar transient events
  - Evolution of small-scale structures and magnetic carpet
- **Links between the internal processes and dynamics of the corona and heliosphere**
  - Complexity and energetics of the solar corona
  - Large-scale coronal field estimates
  - Coronal magnetic structure and solar wind
- **Precursors of solar disturbances for space-weather forecasts**
  - Far-side imaging and activity index
  - Predicting emergence of active regions by helioseismic imaging
  - Determination of magnetic cloud Bs events

HMI Data Products and Objectives



HMI Data Product Examples



A. Sound speed variations relative to a standard solar model.

B. Solar cycle variations in the sub-photospheric rotation rate.

C. Solar meridional circulation and differential rotation.

D. Sunspots and plage contribute to solar irradiance variation.

E. MHD model of the magnetic structure of the corona.

F. Synoptic map of the subsurface flows at a depth of 7 Mm.

G. EIT image and magnetic field lines computed from the photospheric field.

H. Active regions on the far side of the sun detected with helioseismology.

I. Vector field image showing the magnetic connectivity in sunspots.

J. Sound speed variations and flows in an emerging active region.

HMI Co-Investigator Science Team-1

HMI Science Team				
Name	Role	Institution	Phase B,C,D	Phase-E
HMI Lead Institutions				
Philip H. Scherrer	PI	Stanford University	HMI Investigation	Solar Science
John G. Beck	A-I	Stanford University	E/PO Science Liaison	Surface Flows
Richard S. Bogart	Co-I	Stanford University	Data Pipeline and Access	Near Surface Flows
Rock I. Bush	Co-I	Stanford University	Program Manager	Irradiance and Shape
Thomas L. Duvall, Jr.	Co-I	NASA Goddard Space Flight Center	Time-Distance Code	Helioseismology
Alexander G. Kosovichev	Co-I	Stanford University	Inversion Code	Helioseismology
Yang Liu	A-I	Stanford University	Vector Field Observable Code	Active Region Fields
Jesper Schou	Co-I	Stanford University	Instrument Scientist	Helioseismology
Xue Pu Zhao	Co-I	Stanford University	Coronal Code	Coronal Field Models
Alan M. Title	Co-I	LMSAL	HMI Instrument	Solar Science
Thomas Berger	A-I	LMSAL	* Vector Field Calibration	Active Region Science
Thomas R. Metcalf	Co-I	LMSAL	* Vector Field Calibration	Active Region Science
Carolus J. Schrijver	Co-I	LMSAL	* Magnetic Field Assimilation Models	Active Region Science
Theodore D. Tarbell	Co-I	LMSAL	HMI Calibration	Active Region Science
Bruce W. Lites	A-I	High Altitude Observatory	Vector Field Inversions	Active Region Science
Steven Tomczyk	Co-I	High Altitude Observatory	Vector Field Inversions	Active Region Science
				* Phase D only

HMI Co-Investigator Science Team-2

HMI Science Team – US and International Co-Is				
Name	Role	Institution	Phase B,C,D	Phase-E
HMI US Co-Investigator Institutions				
Sarbani Basu	Co-I	Yale University	* Ring Analysis Code	Helioseismology
Douglas C. Braun	Co I	Colorado Research Associates	* Farside Imaging Code	Helioseismology
Philip R. Goode	Co-I	NJIT, Big Bear Solar Observatory	* Magnetic and Helioseismic Code	Fields and Helioseismology
Frank Hill	Co-I	National Solar Observatory	* Ring Analysis Code	Helioseismology
Rachel Howe	Co-I	National Solar Observatory	* Internal Rotation Inversion Code	Helioseismology
Sylvain Korzennik	A-I	Smithsonian Astrophysical Observatory		Helioseismology
Jeffrey R. Kuhn	Co-I	University of Hawaii	* Limb and Irradiance Code	Irradiance and Shape
Charles A. Lindsey	Co-I	Colorado Research Associates	* Farside Imaging Code	Helioseismology
Jon A. Linker	Co-I	Science Applications Intnl. Corp.	* Coronal MHD Model Code	Coronal Physics
N. Nicolas Mansour	Co-I	NASA Ames Research Center	* Convection Zone MHD Model Code	Convection Physics
Edward J. Rhodes, Jr.	Co-I	University of Southern California	* Helioseismic Analysis Code	Helioseismology
Juri Toomre	Co-I	JILA, Univ. of Colorado	* Sub-Surface-Weather Code	Helioseismology
Roger K. Ulrich	Co-I	University of California, Los Angeles	* Magnetic Field Calibration Code	Solar Cycle
Alan Wray	Co-I	NASA Ames Research Center	* Convection Zone MHD Model Code	Convection Physics
HMI International Co-Investigators				
J. Christensen-Dalsgaard	Co-I	TAC, Aarhus University, DK	* Solar Model Code	Helioseismology
J. Leonard Culhane	Co-I	MSSL, University College London, UK		Active Region Science
Bernhard Fleck	Co-I	European Space Agency	ILWS Coordination	Atmospheric Dynamics
Douglas O. Gough	Co-I	IoA, Cambridge University, UK	* Local HS Inversion Code	Helioseismology
Richard A. Harrison	Co-I	Rutherford Appleton Laboratories, UK		Active Region Science
Takashi Sekii	Co-I	National Astron. Obs. of Japan, JP		Helioseismology
Hiromoto Shibahashi	Co-I	University of Tokyo, JP		Helioseismology
Sami K. Solanki	Co-I	Max-Planck-Institut für Aeronomie, DE		AR Science
Michael J. Thompson	Co-I	Imperial College, UK		Helioseismology
				* Phase D only

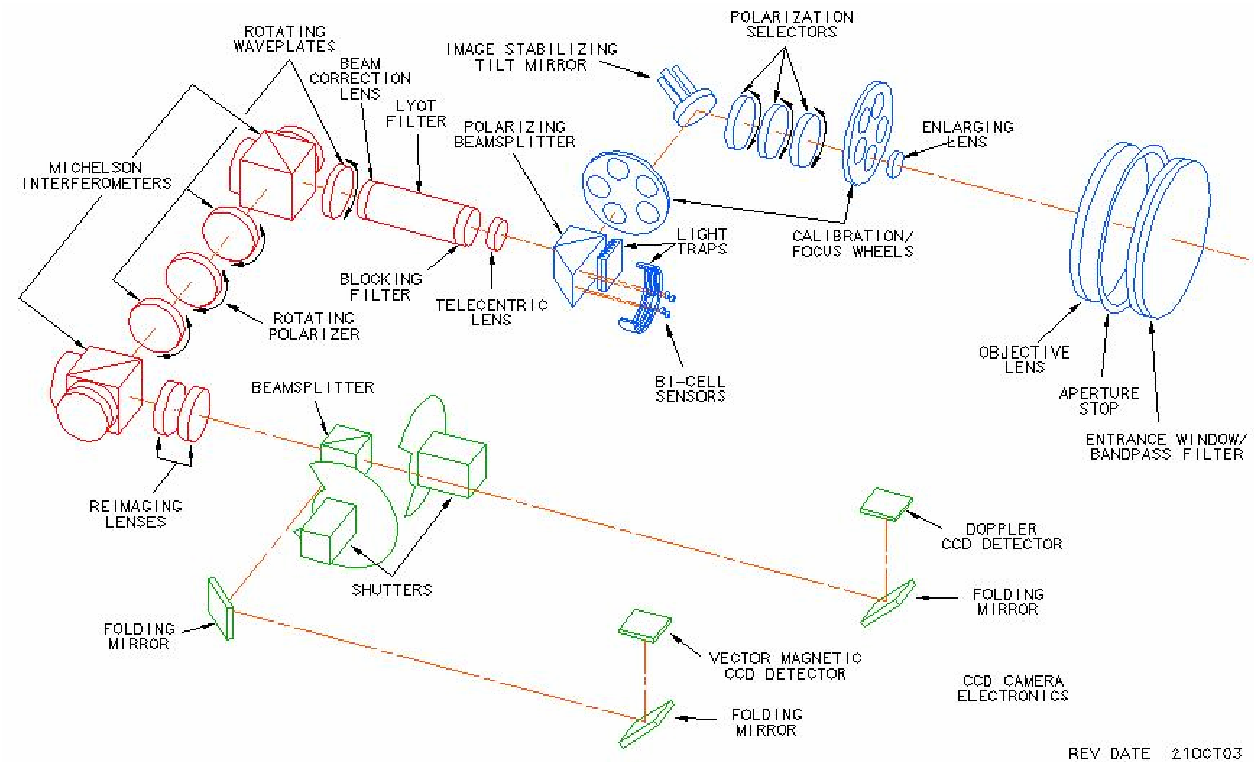
Instrument - Requirements

Parameter	Requirement
Central wavelength	6173.3 Å ± 0.1 Å (Fe I line)
Filter bandwidth	76 mÅ ± 10 mÅ fwhm
Filter tuning range	680 mÅ ± 68 mÅ
Central wavelength drift	< 10 mÅ during any 1 hour period
Field of view	> 2000 arc-seconds
Angular resolution	better than 1.5 arc-seconds
Focus adjustment range	± 4 depths of focus
Pointing jitter reduction factor	> 40db with servo bandwidth > 30 Hz
Image stabilization offset range	> ± 14 arc-seconds in pitch and yaw
Pointing adjustment range	> ± 200 arc-seconds in pitch and yaw
Pointing adjustment step size	< 2 arc-seconds in pitch and yaw
Dopplergram cadence	< 50 seconds
Image cadence for each camera	< 4 seconds
Full image readout rate	< 3.2 seconds
Exposure knowledge	< 5 microseconds
Timing accuracy	< 0.1 seconds of ground reference time
Detector format	> 4000 x 4000 pixels
Detector resolution	0.50 ± 0.01 arc-second / pixel
Science telemetry compression	To fit without loss in allocated telemetry
Eclipse recovery	< 60 minutes after eclipse end
Instrument design lifetime	5 years at geosynchronous orbit

Instrument Overview

- **Optics Package**
  - Telescope section
  - Polarization selectors – 3 rotating waveplates for redundancy
  - Focus blocks
  - Image stabilization system
  - 5 element Lyot filter. One element tuned by rotating waveplate
  - 2 tunable Michelson interferometers. 2 waveplates and 1 polarizer for redundancy
  - Reimaging optics and beam distribution system
  - Shutters
  - 2 functionally identical CCD cameras – “Doppler” and “Magnetic”
- **Electronics package**
- **Cable harness**

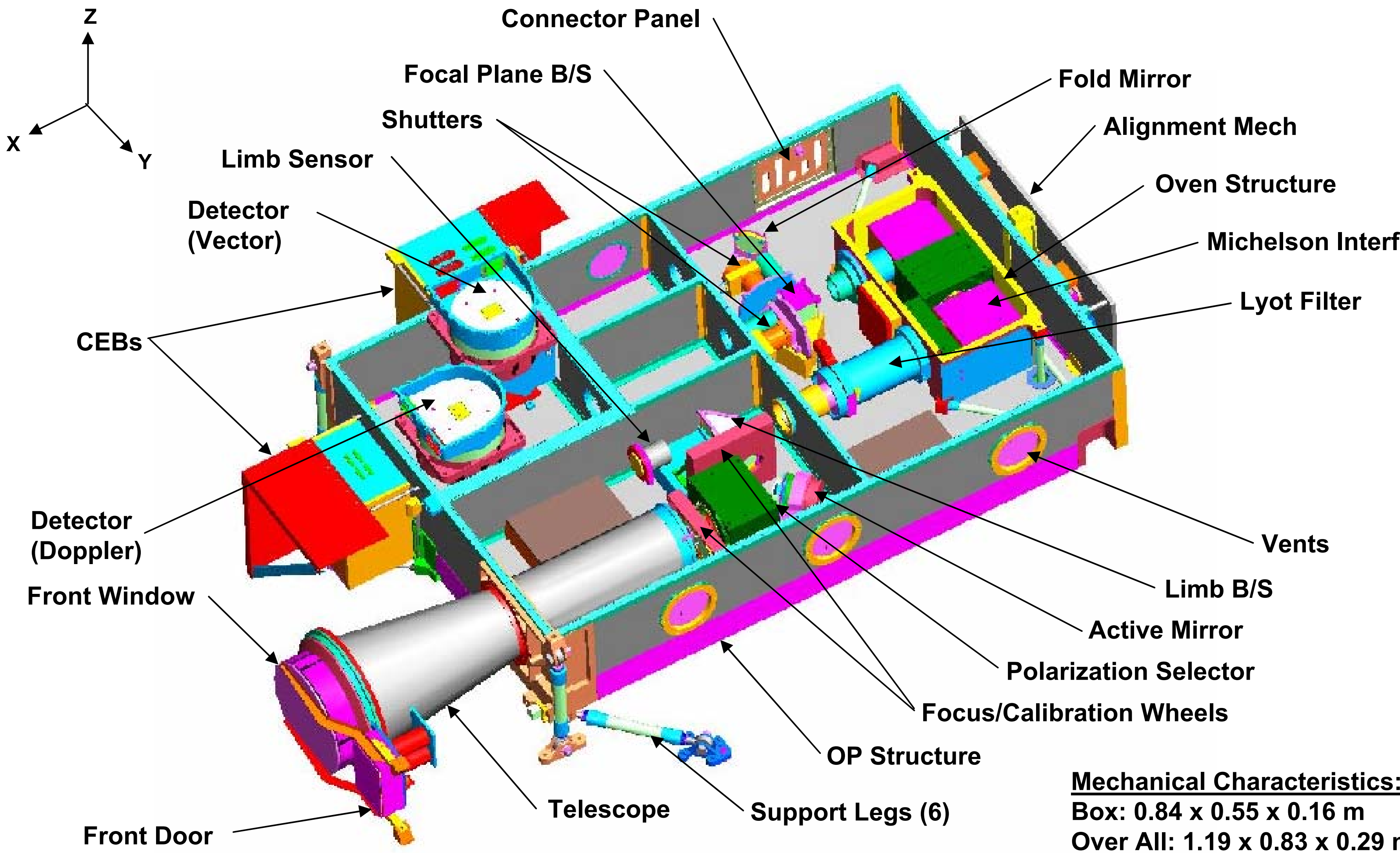
Instrument Overview – Optical Path



<u>Optical Characteristics:</u>
Focal Length: 495 cm
Focal Ration: f/35.2
Final Image Scale: 24μm/arcsec
Re-imaging Lens Magnification: 2
Focus Adjustment Range: 16 steps of 0.4 mm

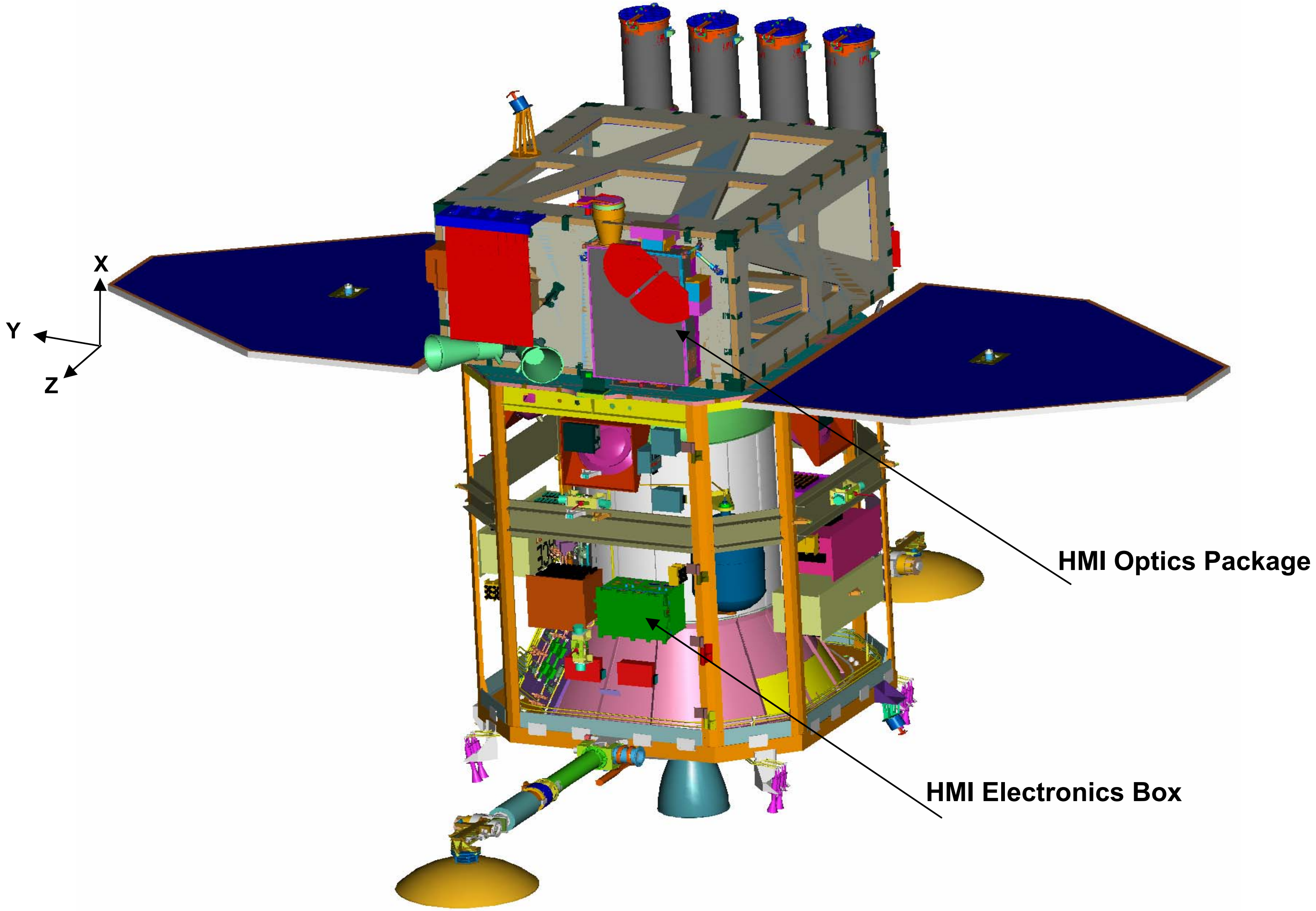
<u>Filter Characteristics:</u>
Central Wave Length: 613.7 nm
Front Window Rejects 99% Solar Heat Load
Bandwidth: 0.0076 nm
Tunable Range: 0.05 nm
Free Spectral Range: 0.0688 nm

Instrument Overview – HMI Optics Package (HOP)



Mechanical Characteristics:
Box: 0.84 x 0.55 x 0.16 m
Over All: 1.19 x 0.83 x 0.29 m
Mass: 39.25 kg
First Mode: 63 Hz

S/C Accommodations



Observing Scheme

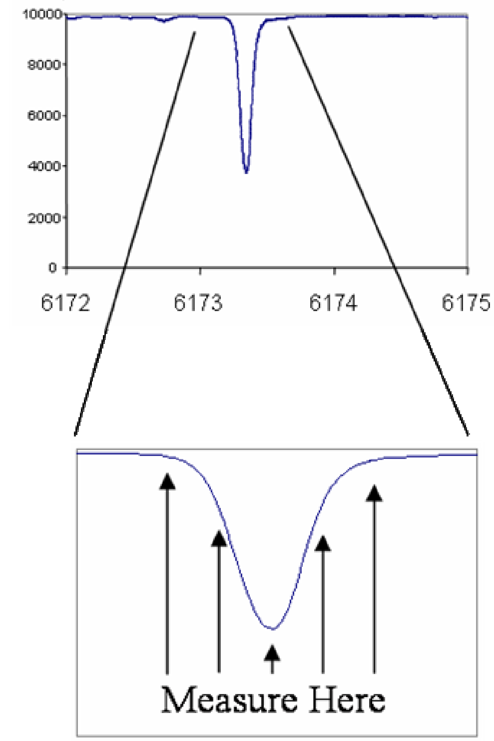
- **Observables**
  - Dopplergrams
  - Magnetograms, vector and line-of-sight
  - Others: Intensity, line depth, etc.
- **Observables made from filtergrams described by framelists**
- **Filtergram properties**
  - Wavelength – selected by rotating waveplates (polarizer for redundancy only)
  - Polarization state – selected by rotating waveplates
  - Exposure time
  - Camera ID
  - Compression parameters, …
  - Determined by subsystem settings
    - E.g. motor positions
- **Framelists**
  - List of filtergrams repeated at fixed cadence during normal operations
  - Entirely specified in software – Highly flexible

Framelist Example

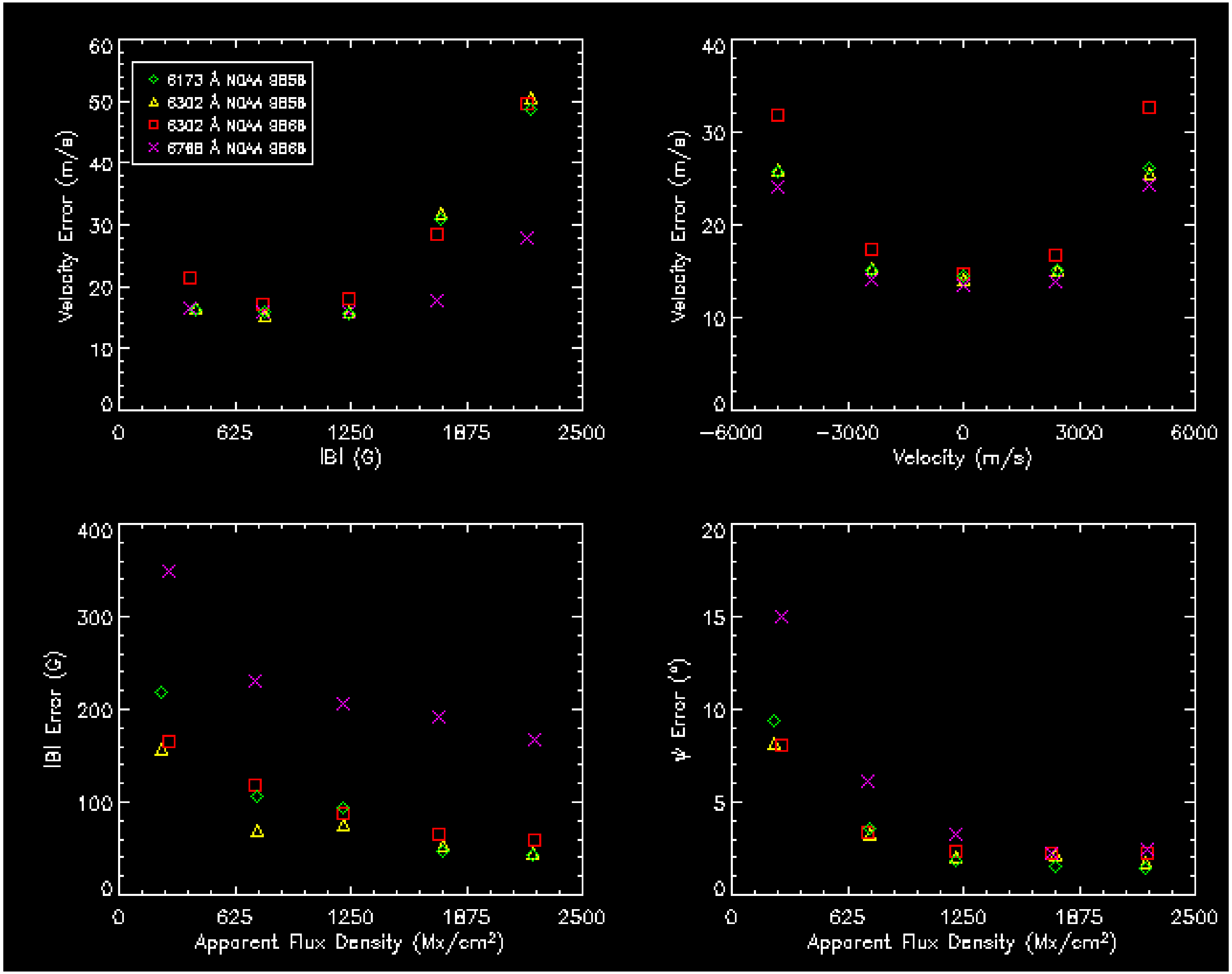
5 Position Framelist

Time(s)	0	8	16	24	32	40	48	56	64	72
Tuning Doppler pol. Vector pol.	I1 L R 1 2	I2 L R 1 2	I3 L R 1 2	I4 L R 1 2	I5 L R 1 2	I1 L R 3 4	I2 L R 3 4	I3 L R 3 4	I4 L R 3 4	I5 L R 3 4

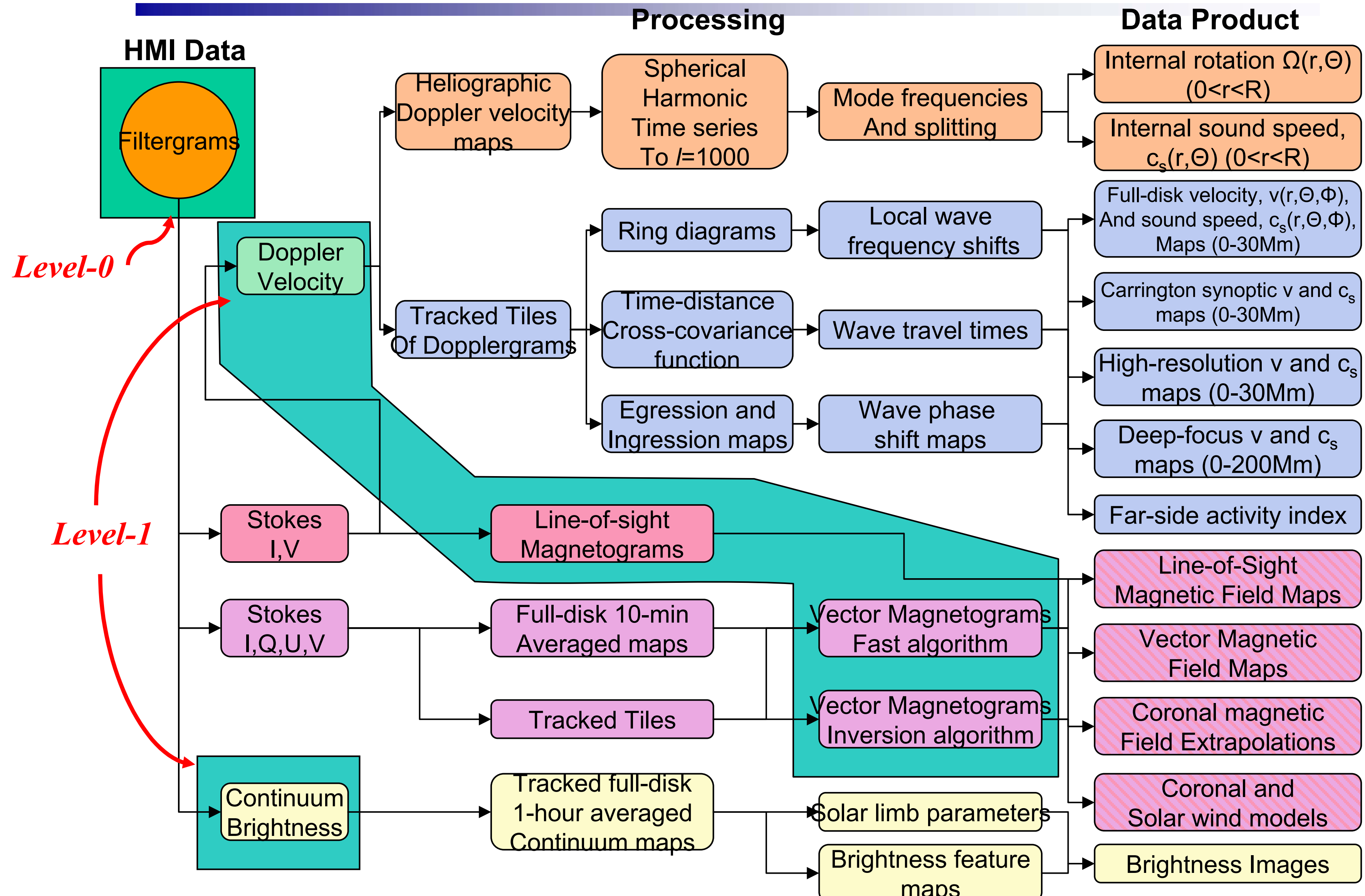
- **Time: Time of first exposure at given wavelength since start of framelist execution**
- **Tuning: I1, I2, … specify the tuning position**
- **Doppler pol.: Polarization of image taken with Doppler camera**
  - L and R indicate left and right circular polarization
  - Used for Doppler and line of sight field
- **Vector pol.: Polarization of image taken with vector camera**
  - 1, 2, 3, 4: Mixed polarizations needed to make vector magnetograms
  - Used for vector field reconstruction



Instrument – Expected Performance

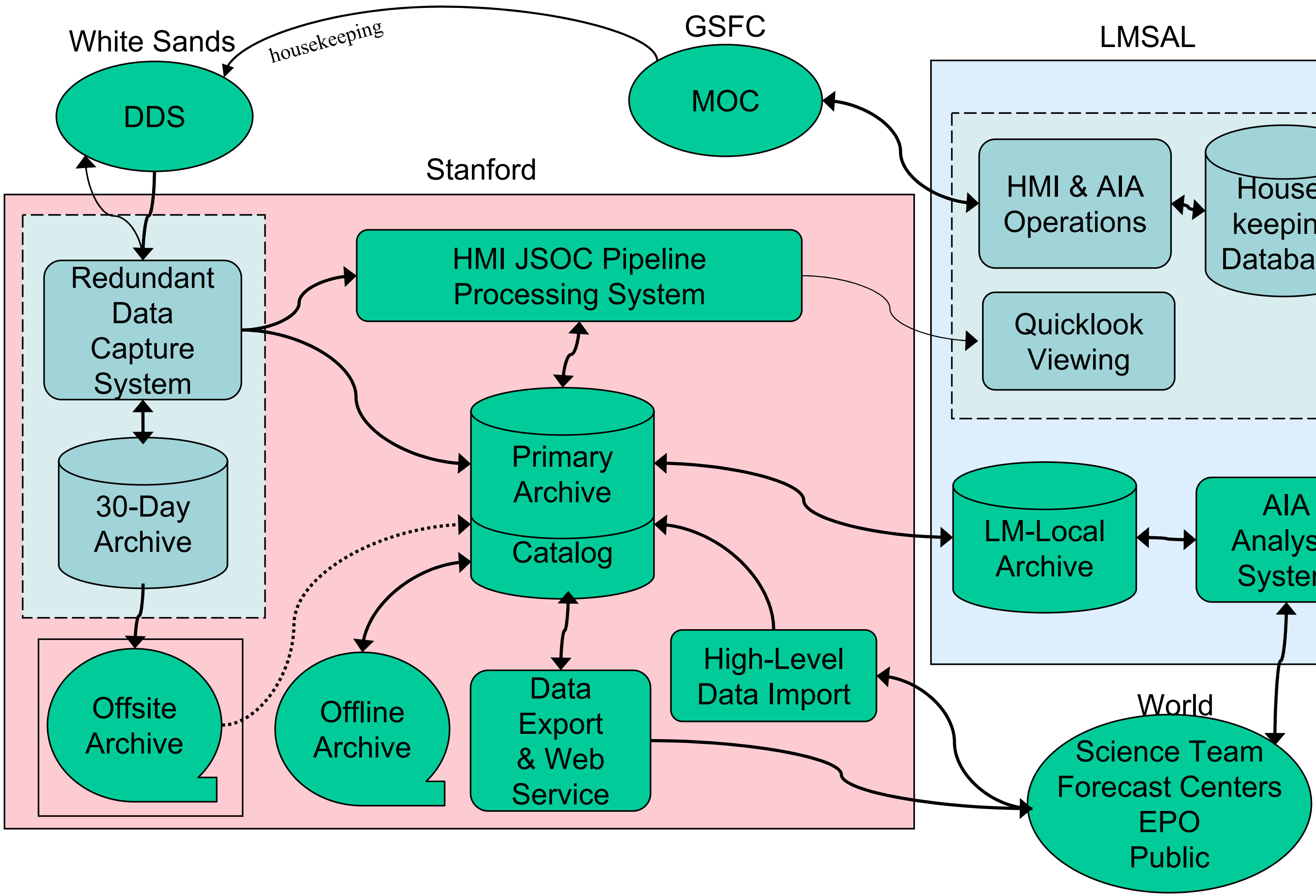


HMI Data Processing and Products



HMI Data Analysis Pipeline

HMI & AIA JSOC Architecture



Status

- **HMI and SDO PDRs completed**
- **Michelson CDR completed**
- **Most of optics and filters on order or close**
  - Low on Calcite. Top $$$ paid…
- **First 4096x4096 CCD's manufactured**
- **Structure at various stages**
- **Mechanisms**
  - Shutters undergoing life test
  - Others still not started
- **Electronics at various stages**
  - Have engineering CPU and Bridge Board
  - Others under development
- **Instrument software at various stages**
  - Have SUROM
- **Ground software at various stages**

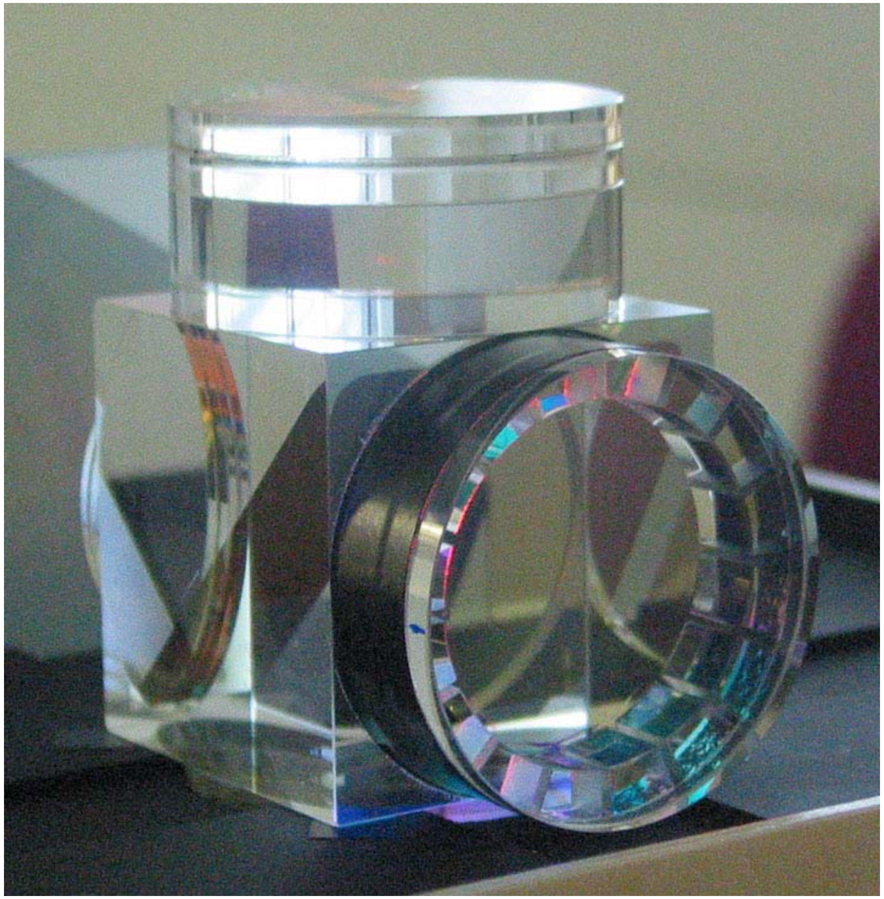
Status - Logo

Cover "Borg Cube"

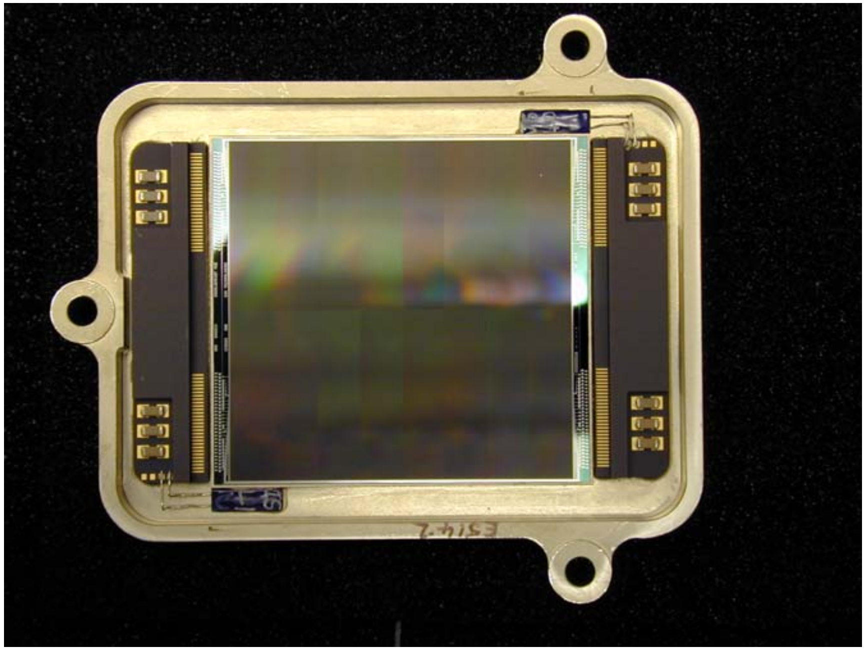
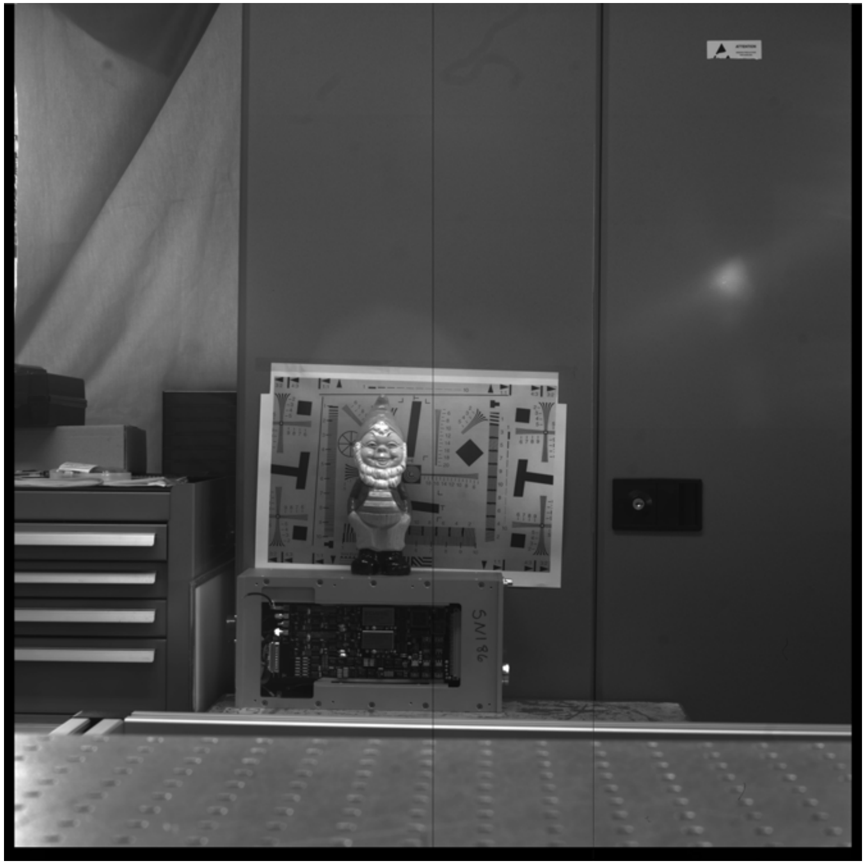
LMSAL contest winner "Aztec"

Status - Michelsons

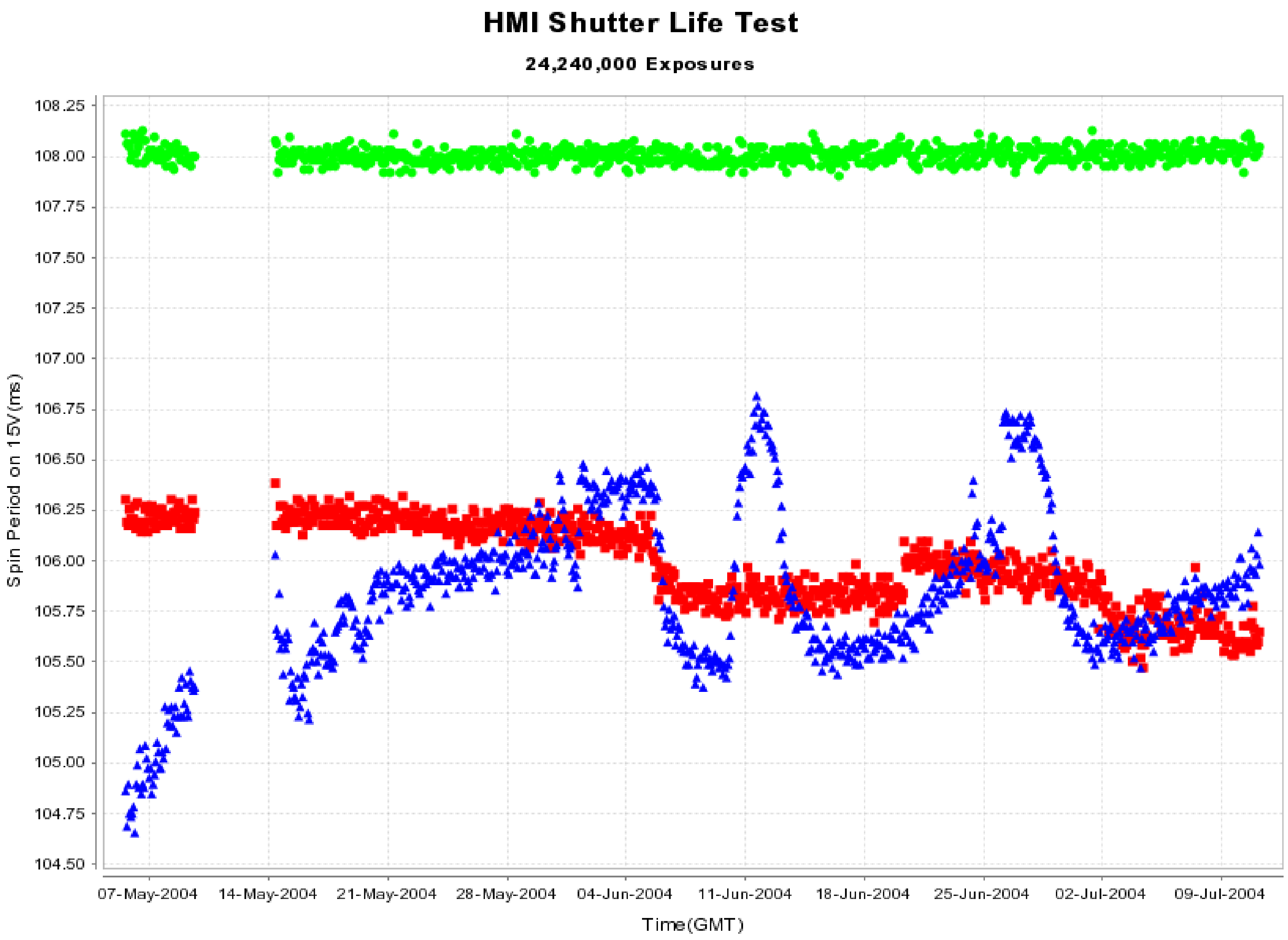
Michelson ETU



Status - Cameras

Image of CCD	Image with CCD
	

Status - Mechanisms



Schedule

- Nov 2004: MDI CDR
- Feb 2005: Mission CDR
- Jan 2006: Start system integration
- Apr 2006: Start system tests
- Nov 2006: Deliver instrument
- Apr 2008: Launch
- May 2008: Begin science observations
- May 2013: End of science observations
- May 2014: End of mission

Research Position in Observational Solar Physics

- The Solar Physics Group at Stanford University invites applications for a research position to participate in the development of the Helioseismic and Magnetic Imager instrument for the NASA Solar Dynamics Observatory.
- The project includes the development of tools for calibration of the HMI instrument in ground testing and on orbit, as well as participating in the actual ground testing. Research in helioseismology, photospheric magnetic fields, and/or other HMI science objectives will be concurrent with instrument development support.
- A PhD in physics, astrophysics, geophysics or related subject is required. Experience with optics, Unix/linux, C, and IDL is desired.
- The successful candidate will be appointed for initial two-year term to a research scientist position; extension of the initial appointment is possible. Start date is fall 2004 or earlier.
- Stanford University is committed to equal opportunity through affirmative action in employment and we are especially eager to identify minority persons and women with appropriate qualifications.
- U.S citizenship or permanent residency status is required.
- Please send a current resume, publications list, a brief statement of research interests and three letters of recommendation to: Professor Philip Scherrer, Hansen Experimental Physics Laboratory, 455 Via Palou, Stanford, CA 94305-4085,FAX: 650.725.2333, PScherrer@solar.stanford.edu