Solar Dynamics Observatory
System Concept Review
Helioseismic and Magnetic Imager

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HMI Presentation Outline

- **Science Overview** **- Phil Scherrer**
  - Science Objectives
  - Data Products
  - Requirements Flow
- **Investigation Overview** **- Rock Bush**
  - Configuration
  - Instrument Concept
  - Subsystems
  - Flight Operations
  - Data Operations
- **Instrument Implementation** **- Larry Springer**
  - Trade Studies
  - Resources
  - Heritage
  - Development Flow
  - Schedule
  - Risk & Mitigation

HMI Investigation Plan – 1

The primary scientific objectives of the Helioseismic and Magnetic Imager investigation are to improve understanding of the interior sources and mechanisms of solar variability and the relationship of these internal physical processes to surface magnetic field structure and activity.

The specific scientific objectives of the HMI investigation are to measure and study these interlinked processes:

- **Convection-zone dynamics and the solar dynamo;**
- **Origin and evolution of sunspots, active regions and complexes of activity;**
- **Sources and drivers of solar magnetic activity and disturbances;**
- **Links between the internal processes and dynamics of the corona and heliosphere;**
- **Precursors of solar disturbances for space-weather forecasts.**

HMI Investigation Plan - 2

To accomplish these science goals the HMI instrument makes measurements of:

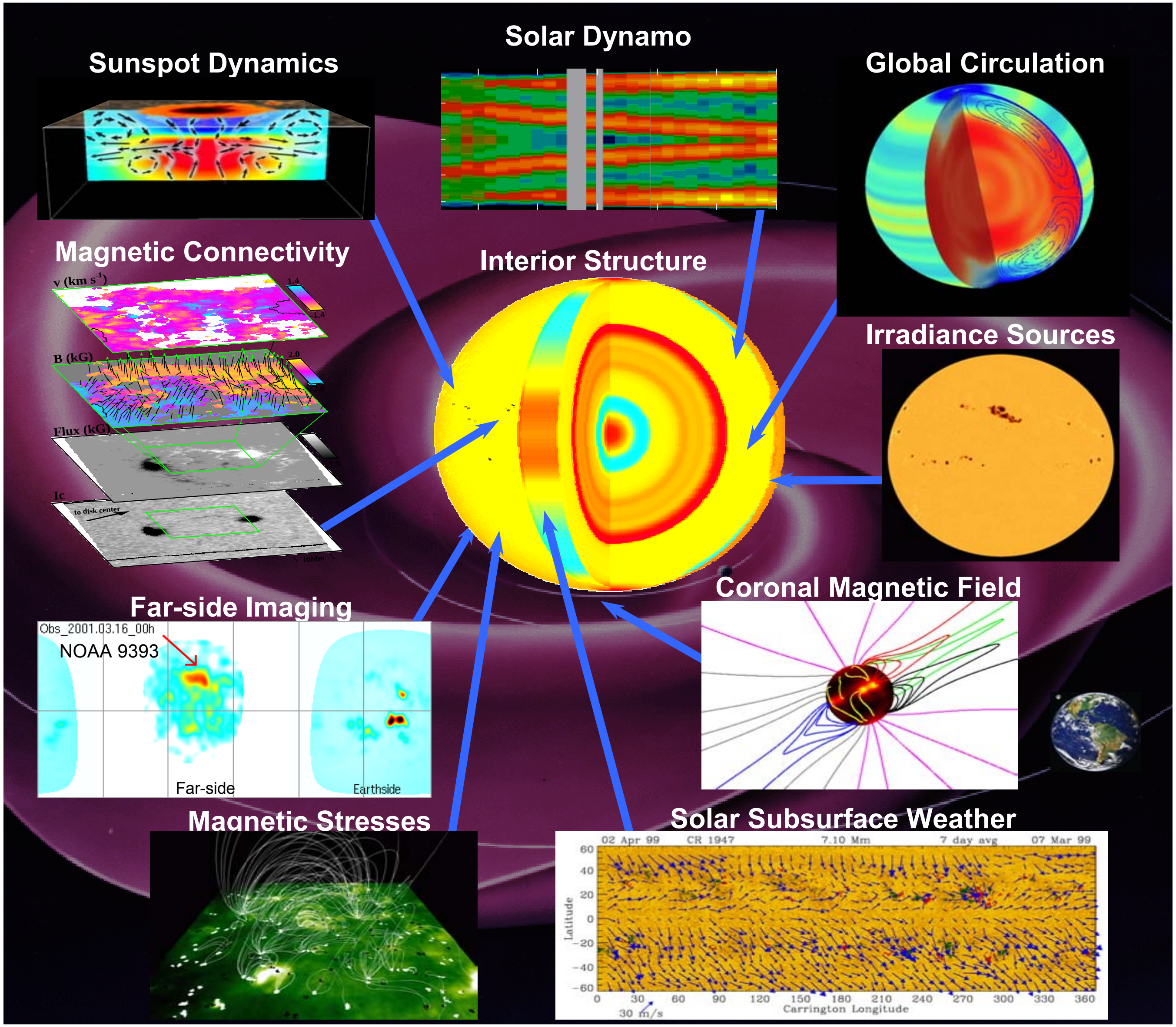
- **Full-disk Doppler velocity, line-of-sight magnetic flux, and continuum images with resolution better than 1.5 arc-sec at least every 50 seconds.**
The Dopplergrams are maps of the motion of the solar photosphere. They are made from a sequence of filtergrams. They are used to make helioseismic inferences of the solar interior structure and dynamics.

- **Full-disk vector magnetic images of the solar magnetic field with resolution better than 1.5 arc-sec at least every 10 minutes.**
The magnetograms are made from a sequence of measurements of the polarization in a spectral line.

- **The sequences of filtergrams must be 99.99% complete 95% of the time**

The **HMI Investigation** includes the HMI **Instrument**, significant data **processing**, data **archiving** and **export**, data **analysis** for the **science** investigation, and **E/PO**.

HMI Science Objectives - examples



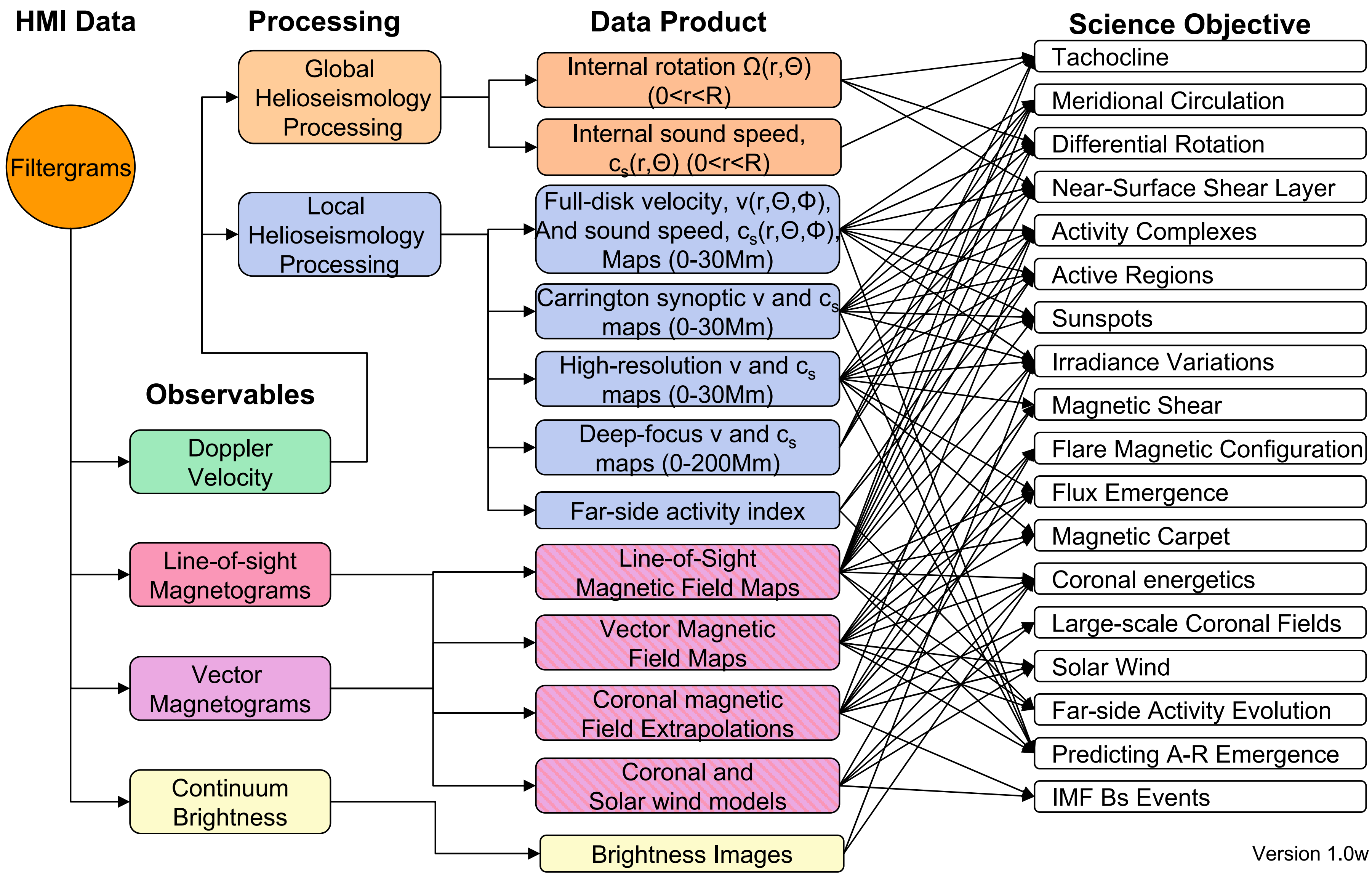
HMI Science Objectives

- **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 Science Data Products

- HMI Science Data Products are high-level data products which are required for input to the science analyses. These are time series of maps of physical quantities in and on the Sun.
  - Internal rotation $\Omega(r,\Theta)$ $(0<r<R)$
  - Internal sound speed, $cs(r,\Theta)$ $(0<r<R)$
  - Full-disk velocity, $v(r,\Theta,\Phi)$ and sound speed, $cs(r,\Theta,\Phi)$ maps (0-30Mm)
  - Carrington synoptic v and cs maps (0-30Mm)
  - High-resolution v and cs maps (0-30Mm)
  - Deep-focus v and cs maps (0-200Mm)
  - Far-side activity index
  - Line-of-sight magnetic field maps
  - Vector magnetic field maps
  - Coronal magnetic field extrapolations
  - Coronal and solar wind models
  - Brightness images
  - Context magnetograms

HMI Science Analysis Plan



Version 1.0w

Top Down View of HMI Science Requirements

•Historically HMI science requirements arose from the societal need to better understand the sources of solar variability and the science community's response to the opportunities demonstrated by SOHO/MDI.

•These and other opportunities led to the formulation of the SDO mission and the HMI investigation.

•The observing requirements for HMI have been incorporated into the concept for SDO from the beginning.

•The details of implementation for HMI as with other observatory sub-systems have evolved to optimize the success of the mission.

•The specific requirements for HMI, as part of SDO, have been captured in the MRD and other SDO documents.

•There is a chain of requirements from SDO mission goals to HMI investigation goals to specific HMI **science objectives** to **observation sequences** to basic **observables** (physical quantities) to raw **instrument data** to the HMI **instrument concept** to HMI **subsystems** and finally to the observatory.

•Specific requirements as captured in the MRD derive from each of these levels.

Basis of Requirements

- **HMI Science Objectives**
  - Duration of mission
  - Completeness of coverage
  - HMI Science Data Products
  - Roll accuracy
  - Time accuracy (months)
- **HMI Observation Sequences**
  - Duration of sequence
  - Cadence
  - Completeness (95% of data sequence)
  - Noise
  - Resolution
  - Time accuracy (days)
- **HMI Observables**
  - Sensitivity
  - Linearity
  - Acceptable measurement noise
  - Image stability
  - Time rate (minutes)
  - Completeness 99%
  - Orbit knowledge
- **HMI Instrument Data**
  - Accuracy
  - Noise levels
  - Completeness (99.99% of data in filtergram)
  - Tuning & shutter repeatability
  - Wavelength knowledge
  - Image registration
  - Image orientation jitter
- **HMI Instrument Concept**
  - Mass
  - Power
  - Telemetry
  - Envelope
- **Subsystem requirements**
  - CCD: Thermal environment
  - ISS: pointing drift rate, jitter
  - Legs: pointing drift range

HMI Key Science Requirements

- Mission duration to allow measuring the Sun from the minimum to maximum activity phases.
- Orbit that allows accurate velocity determination over the combined dynamic range of the Sun and observatory.
- Accurate knowledge of orbit velocity and observatory orientation
- 99.99% capture of the instrument data 95% of the time
- Measurements of solar photospheric velocity with noise levels below solar noise and accuracy to allow helioseismic inferences.
- Measurements of all components of the photospheric magnetic field with noise and accuracy to allow active region and coronal field extrapolation studies.
- Optical performance and field of view sufficient to allow 2 Mm resolution of regions tracked across the solar disk.
- Ground processing capability to produce science data products in a timely manner
- Science team

HMI Observables Requirements - 1

General Requirements			
MRD	**Observable**	**Filtergram**	**Instrument**
1.3.1 **1.3.2** **3.2.1**	Angular resolution: 1.5(1.0)”	Angular resolution: 1.5(1.0)”	Aperture: 14cm
			Jitter: 0.1”
		Square pixels 0.5”	CCD pixels: 4096^2
3.2.2	Full disk	FOV: 2000” x 2000”	CCD pixels: 4096^2
1.2.1 **1.2.2**	99% complete 95% of the time	99.99% complete 95% of the time	Packet loss: 0.01%

Continuum Intensity Requirements			
MRD	**Observable**	**Filtergram**	**Instrument**
	Cadence: 50(45)s	I framelist: 50(45)s	CCD readout speed: 3.4s
	Noise: 0.3%	Intensity noise: 0.3%	Full well: $125ke^-$
2.5.8.5	Pixel to pixel accuracy: 0.1%	Flat field knowledge	Offset pointing

Numbers in () are goals. *indicates TBD. Most numbers are 1σ.

HMI Observables Requirements - 2

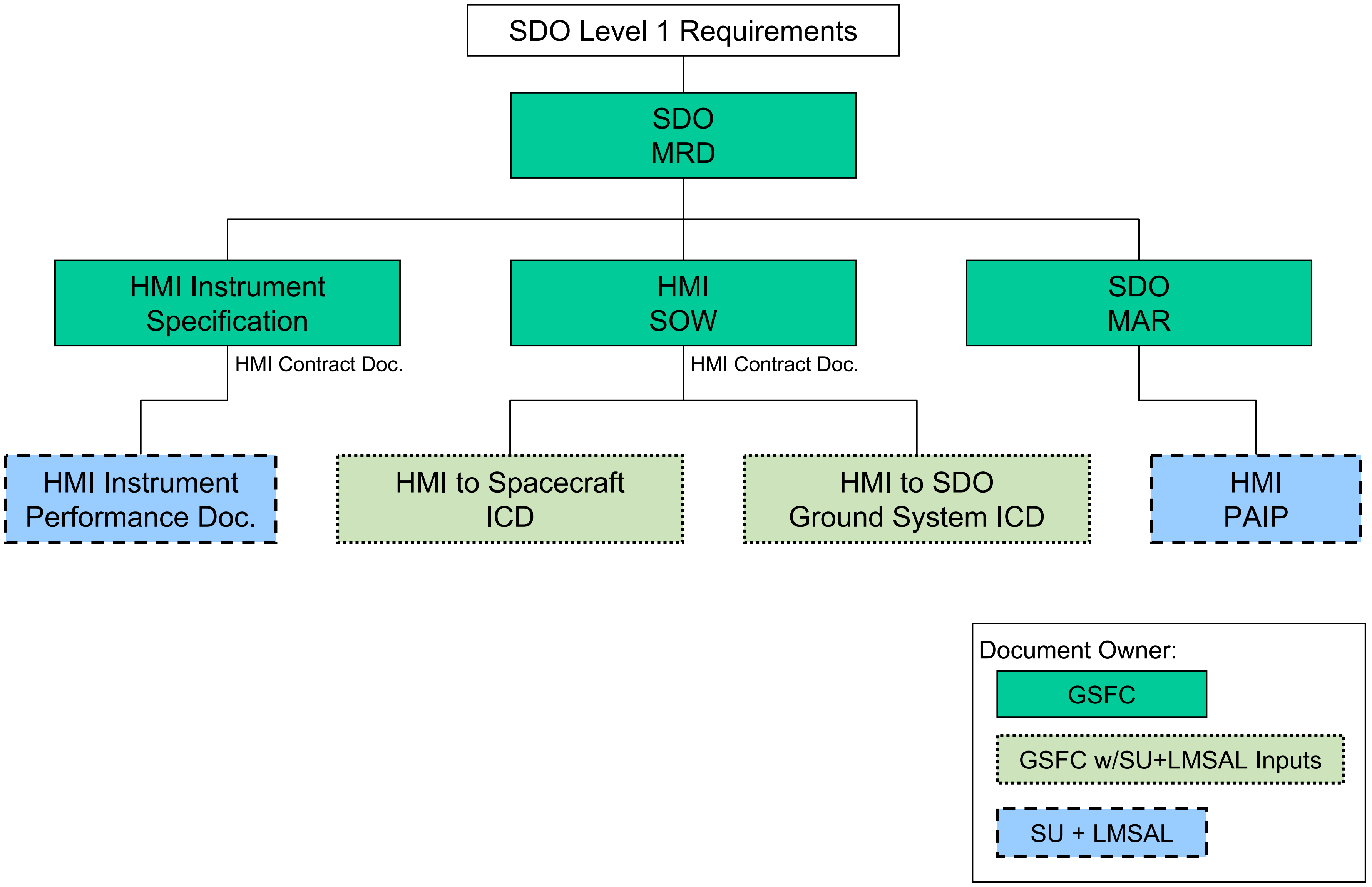
Velocity Requirements			
MRD	**Observable**	**Filtergram**	**Instrument**
1.6.1	Cadence: 50(45)s	V framelist: 50(45)s	CCD readout speed: 3.4s
1.5.1	Noise: 25(13)m/s	Intensity noise: 0.6(0.3)%	Full well: 30(125)ke$^-$
		Filter width: 76 mÅ	Element widths
		Small sidelobes	7 elements
			Element widths
3.2.3 **5.2.5.4**	Disk averaged noise: 1(0.1)* m/s	λ repeatability: 0.3(0.03) mÅ	HCM repeatability: 60(6)”
		Exposure knowledge: 200(20)ppm	Shutter: 50(5)μs
		Each cycle same λ’s	Two cameras
		Effective λ knowledge	Orbit information
2.1	Absolute: 10* m/s	λ accuracy: 3 mÅ	HCM accuracy: 10’
			Filter uniformity, drift
1.5.1	Range: ±6.5km/s	Tuning range: ±250 mÅ	3 tuned elements
	(and ±3kG)	Filtergrams @ 5 or 6 λ	CCD readout speed: 3.4s

HMI Observables Requirements - 3

Line-of-sight Field Requirements			
MRD	**Observable**	**Filtergram**	**Instrument**
1.6.2	Cadence: 50(45)s	LOS framelist: 50(45)s	CCD readout speed: 3.4s
		LCP+RCP each cycle	LCP & RCP available
1.5.3	Noise: 17(10)G	Intensity noise: 0.5(0.3)%	Full well: 40(125)ke$^-$
		High effective Landé g	FeI 6173Å (g=2.5)
1.5.2	Zero point: 0.3(0.2)G	λ repeatability: 0.18(0.12) mÅ	HCM repeatability: 36(24)" or No move LCP↔RCP
		Exposure knowledge: 120(80)ppm	Shutter: 30(20)μs
1.5.4	Range: ± 3(4)kG	Tuning range: ±250mÅ	3 tuned elements
	(and ± 6.5km/s)	Filtergrams @ 5 or 6 λ	CCD readout speed: 3.4s

Vector Field Requirements			
MRD	**Observable**	**Filtergram**	**Instrument**
1.2.4	Cadence: 600(90)s	Vector framelist: 600(90)s	CCD readout speed
1.6.3		4 states each cycle	4 states available
1.5.5	Polarization: 0.3(0.22)%	Intensity noise: 0.4(0.3)%	Full well: 70(125)ke$^-$

HMI Document Tree



HMI Key Instrument Requirements

- **Full sun 1.5 arc-second diffraction limited image**
- **Tunable filter with a 76 mÅ FWHM and a 500 mÅ tunable range**
- **Wavelength selection stability and repeatability of 0.18 mÅ**
- **Mechanism operation cycles over 5 years**
  - 80 million moves for the hollow core motors
  - 40 million moves for the shutters
- **Image stabilization system correction to 0.1 arc-second**
- **Filter temperature stability to 0.01 °C/hour**
- **CCD camera readout time of less than 3.4 seconds**
- **High speed data output of 55 Mbps**

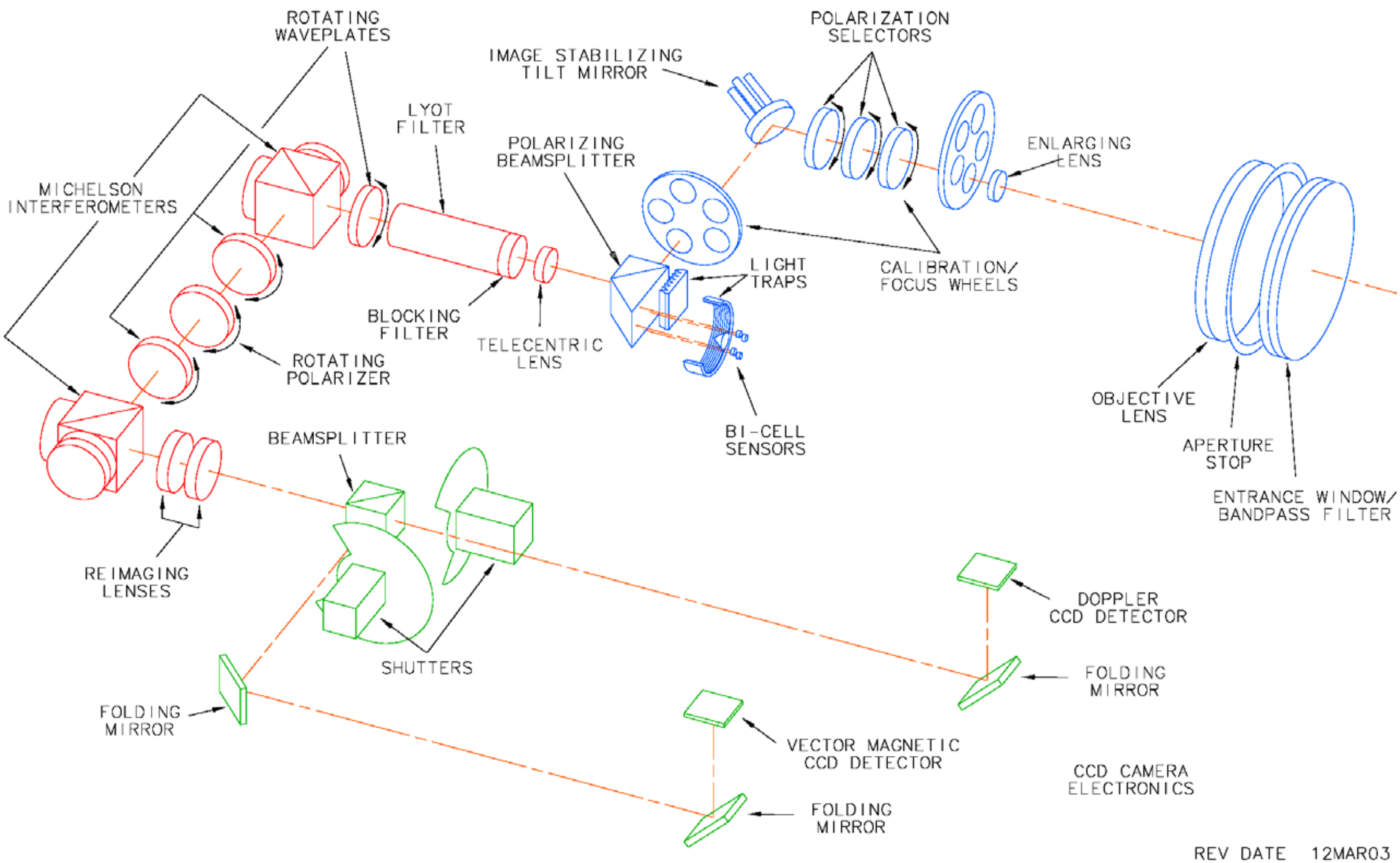
HMI Instrument Concept

- The HMI instrument is an evolution of the successful Michelson Doppler Imager instrument which has been operating on the SOHO spacecraft for over seven years.
- The raw HMI observables are filtergrams of the full solar disk taken with a narrow band (~ 0.1 A bandpass) tunable filter in multiple polarizations.
- The primary science observables are Dopplergrams, line-of-sight magnetograms, vector magnetograms and continuum images computed from a series of filtergrams.
- The vector magnetic field measurements are best decoupled from the helioseismology measurements, and a two camera design results to maintain image cadence and separate the two primary data streams.

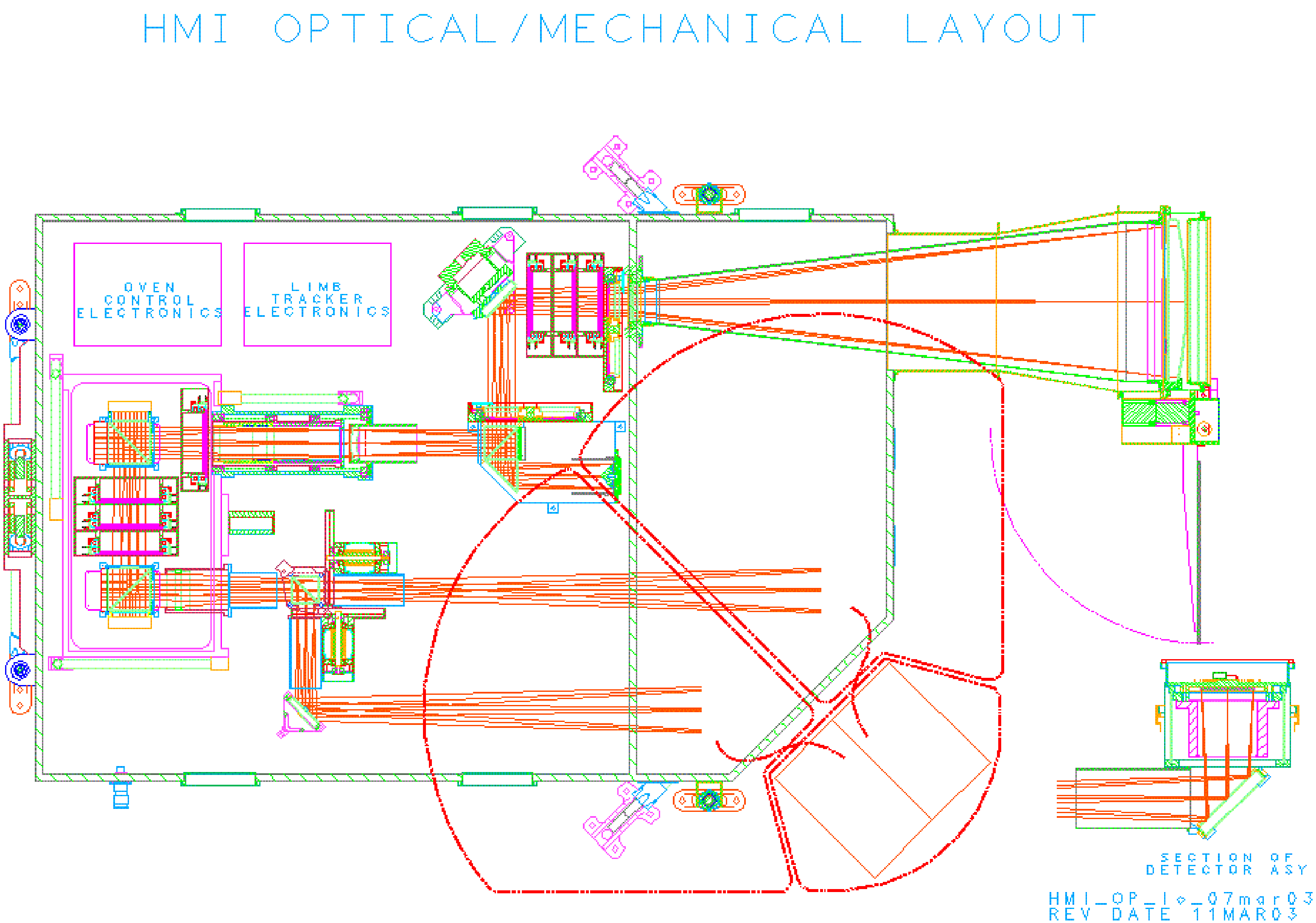
HMI Design Improves on MDI

- **HMI common design features based on MDI:**
  - Front window designed to be the initial filter with widest bandpass.
  - Simple two element refracting telescope.
  - Image Stabilization System with a solar limb sensor and PZT driven tip-tilt mirror.
  - Narrow band tunable filter consisting of a multi-element Lyot filter and two Michelson interferometers.
  - Similar hollow core motors, filterwheel mechanisms and shutters.
- **HMI refinements from MDI:**
  - The observing line is the Fe I 617.3 nm absorption line instead of the Ni I 676.8 nm line. This observing line is used for both Doppler and magnetic measurements.
  - Rotating waveplates are used for polarization selection instead of a set of polarizing optics in a filterwheel mechanism.
  - An additional tunable filter element is included in order to provide the measurement dynamic range required by the SDO orbit.
  - The CCD format will be 4096x4096 pixels instead of 1024x1024 pixels in order to meet the angular resolution requirements.
  - Two CCD cameras are used in parallel in order to make both Doppler and vector magnetic field measurements at the required cadence.
  - The is no image processor – all observable computation is performed on the ground.

HMI Optical Layout



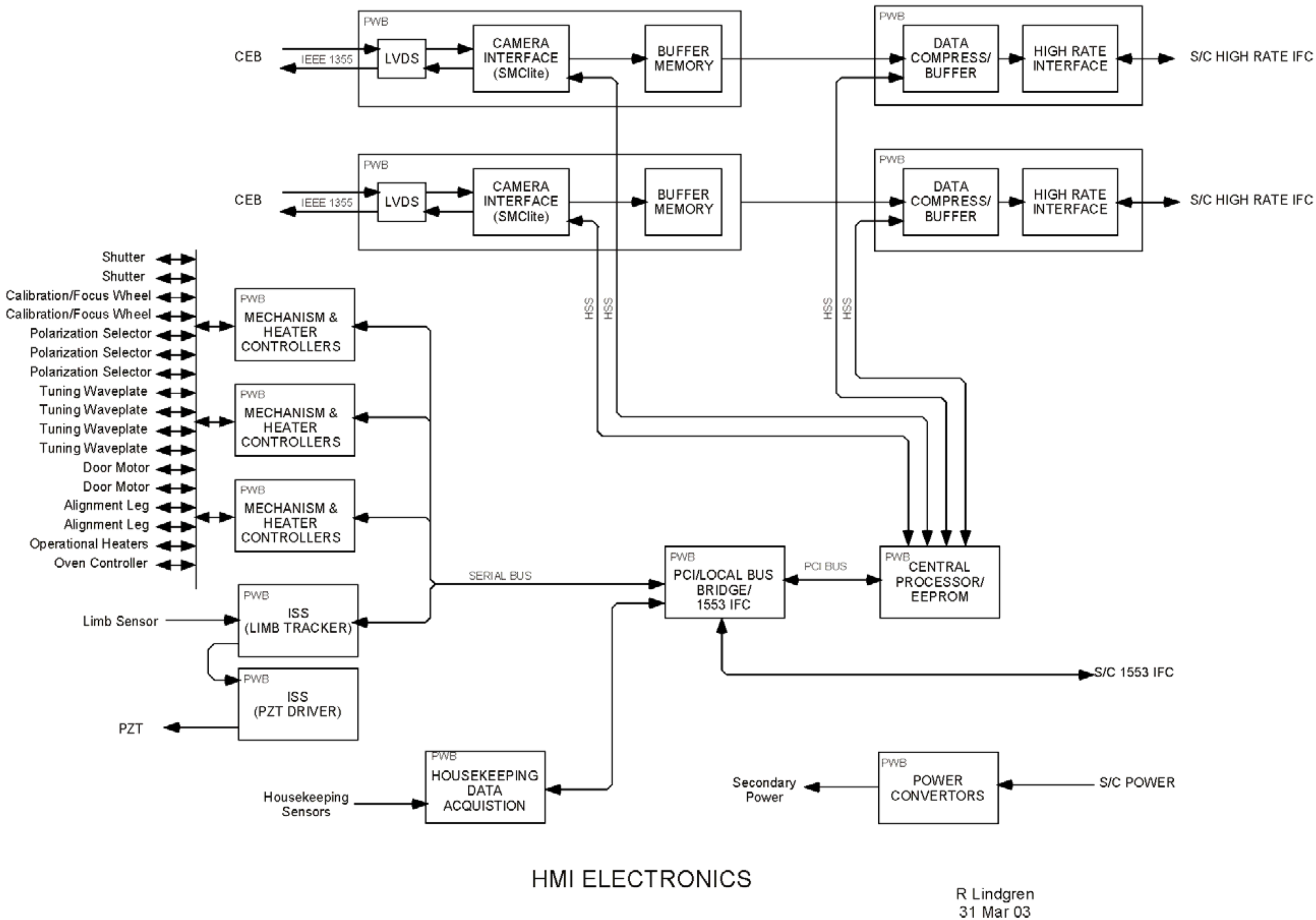
HMI Optics Package Layout



HMI Subsystems

- **Optics Package Structure**
  - The optic package subsystem includes the optics package structure, optical components mounts and legs that attach the optics package to the spacecraft.
- **Optics Subsystem**
  - Includes all the optical elements except the filters.
- **Filter subsystem**
  - The filter subsystem includes the front window, blocking filter, Lyot filter and Michelson interferometers
  - Provides the ability to select the wavelength to image
- **Thermal Subsystem**
  - Controls the temperature of the optics package, the filter oven, CCDs, and the front window.
  - Implements the decontamination heating of the CCD.
- **Image Stabilization Subsystem**
  - Consists of active mirror, limb sensor, precision digital & analog control electronics
  - Actively stabilizes the image reducing the effects of jitter
- **Mechanisms Subsystem**
  - The mechanisms subsystem includes shutters, hollow-core motors, calibration/focus wheels, alignment mechanism, and the aperture door.
- **CCD Camera Subsystem**
  - The CCD camera subsystem includes 4Kx4K CCDs and the camera electronics box(es).
- **HMI Electronics Subsystem**
  - Provides conditioned power and operation of all HMI subsystems as well as HMI C&DH hardware.
- **Software Subsystem**
  - The software subsystem includes the C&DH spacecraft interface and control of HMI subsystems

HMI Electrical Block Diagram



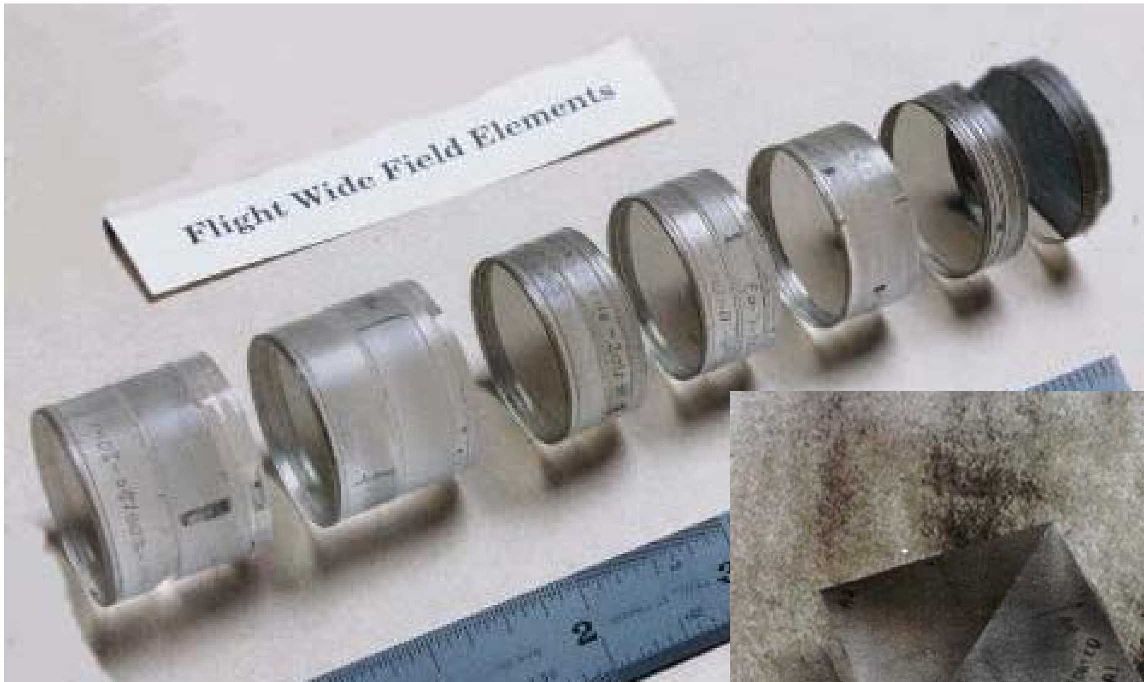
Optics Subsystem

- **1 arc-sec diffraction limited image at the sensor**
  - Requires 14 cm aperture
  - Requires 4096x4096 pixel sensor
- **Solar disk at the sensor 4.9 cm**
  - For sensor with 12 um pixels
- **Focus adjustment system with ±3 (TBC) depth of focus range and 16 steps**
- **Provide calibration mode that images the pupil on the sensor**
- **Provide beam splitter to divide the telescope beam between the filter oven and the limb tracker**
- **Provide telecentric beam through the Lyot filter**
- **Provide beam splitter to feed the output of the filter subsystem to two sensors**
- **Minimize scattered light on the sensor**

Filter subsystem

- **Central wavelength 6173Å Fe I line**
- **Reject 99% of solar heat load from the OP interior**
- **Total bandwidth 76 mÅ FWHM**
- **Tunable range 500 mÅ**
- **Wavelength selection stability and repeatability of 0.18 mÅ**
- **The required bandwidth obtained by cascading filters as follows**
  - Front window 50Å
  - Blocker 8Å
  - Lyot filter (5 element 1:2:4:8:16) 306 mÅ
  - Wide Michelson 172 mÅ
  - Narrow Michelson 86 mÅ
- **Tuning range requires use of three co-tuned elements**
  - Narrowest Lyot element
  - Wide Michelson
  - Narrow Michelson

MDI Lyot Elements and Michelson Interferometers

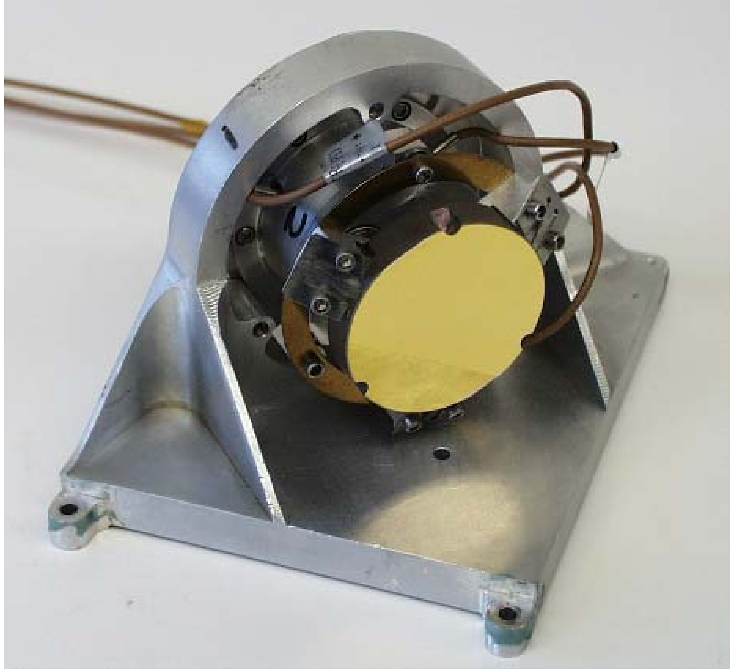


Thermal Subsystem

- **Optics package thermal control**
  - Operating temperature range 15 to 25 °C
  - Active control to ± 0.5 °C
  - Control loop in software
- **Filter oven**
  - Operating temperature range 35 ± 4 °C
  - Temperature accuracy 0.5 °C
  - Temperature stability 0.01 °C /hour
  - Changes in internal temperature gradients as small as possible
  - Dedicated analog control loop in controlled thermal environment
- **Sensor (CCD detector) thermal control**
  - Operating –100 °C to –30 °C
  - Decontamination mode raises CCD to between 20 °C and 40 °C
- **Front window thermal control**
  - Minimize radial gradients
  - Return to normal operating temperature within 60 minutes of eclipse exit

Image Stabilization Subsystem

- Stability is 0.1 arc-sec over periods of 90 seconds (TBC)
- Range ± 14 arc-sec
- Frequency range 0 to 50 Hz
- Continuous operation for life of mission



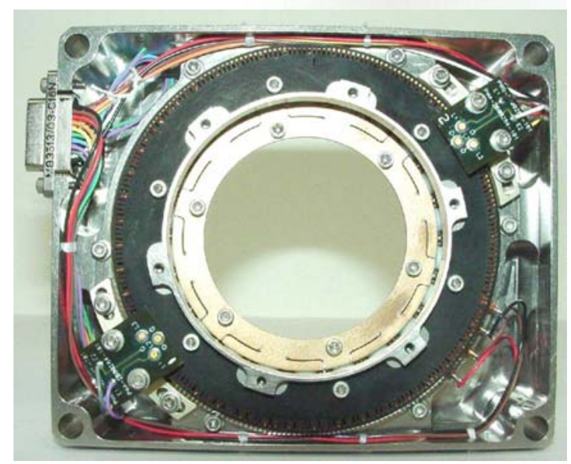
Mechanisms (1 of 2)

Shutters

• Repeatability	100 us
• Exposure range	50 ms to 90 sec
• Knowledge	30 us
• Life (5 year)	40 M exposures

Hollow core motors

• Move time (60 deg)	< 800 ms
• Repeatability	60 arc-sec
• Accuracy	10 arc-min
• Life (5 year)	80 M moves



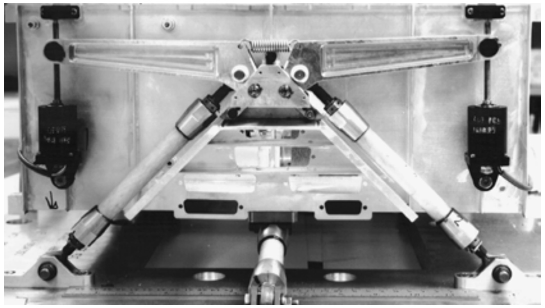
Mechanisms (2 of 2)

Calibration / focus wheels

• Positions	5
• Move time (1 step)	800 ms
• Accuracy	TBD arc-min
• Repeatability	TBD arc-min
• Life (5 Years)	20 K moves

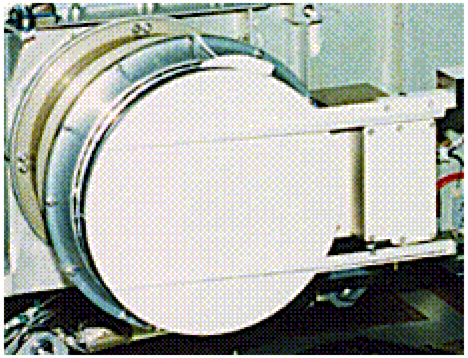
Alignment system

• Movement range	± 200 arc-sec
• Step size	2 arc-sec



Aperture door

- Robust fail open design



CCD Camera Subsystem

• Format	4096 x 4096 pixels
• Pixel size	12 um
• Full well	> 125K electrons
• Readout noise	40 electrons
• Readout time	< 3.4 seconds
• Digitization	12 bits
• Dark current	10 –e/sec/pixel at -60 °C

HMI Electronics Subsystem

- **Provide conditioned power and control for all HMI subsystems**
- **Provide processor for:**
  - Control all of the HMI subsystems
  - Decoding and execution of commands
  - Acquire and format housekeeping telemetry
  - Self-contained operation for extended periods
  - Program modifiable on-orbit
- **Provide stable jitter free timing reference**
- **Provide compression and formatting of science data**
- **Provide dual interface for 55 Mbps of science date**
- **Provide spacecraft 1553 interface**
  - Commands 2.0 kbps
  - Housekeeping telemetry 2.5 kbps
  - Diagnostic telemetry 10 kbps for short periods upon request

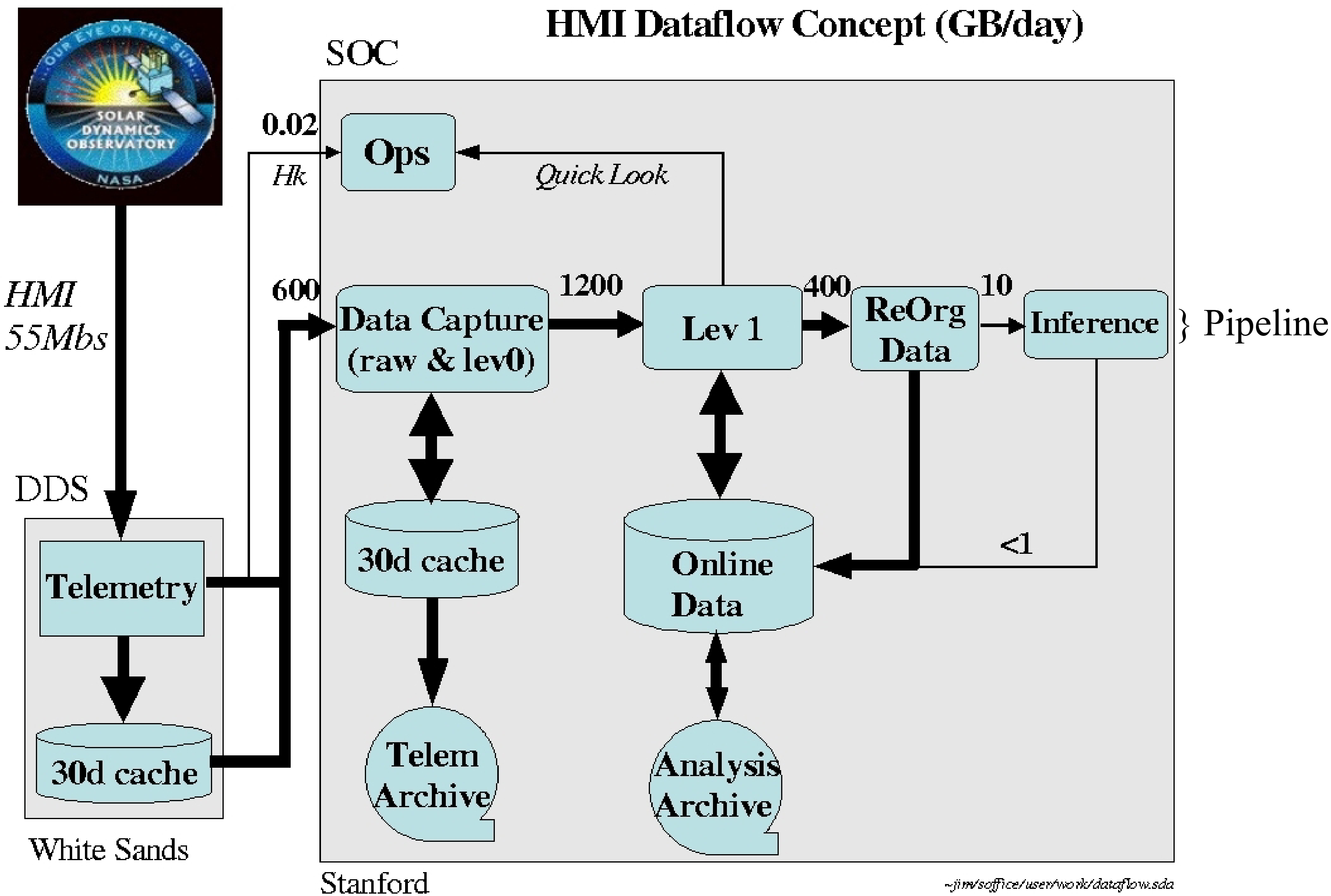
Software Subsystem

- **The HMI flight software will perform the following functions**
  - Process commands from spacecraft
  - Acquire and format housekeeping telemetry
  - Store and execute operational sequences
  - Control all of the HMI subsystems
  - Accept code modifications while in orbit
- **The HMI sequencer is designed to take filtergram images at a uniform cadence with observing wavelengths and polarizations driven by on-board tables**
- **The HMI flight software does not handle any of the CCD camera data, and has no image processing requirements**

HMI Operations Concept

- The goal of HMI operations is to achieve a uniform high quality data set of solar Dopplergrams and magnetograms.
- A single "Prime Observing Sequence" will run continuously taking interleaved images from both cameras. The intent is to maintain this observing sequence for the entire SDO mission.
- Short HMI internal calibration sequences are run on a daily basis in order to monitor instrument performance parameters such as transmission, focus, filter tuning and polarization .
- Every six months, coordinated spacecraft off-point and roll maneuvers are performed to determine the end-to-end instrument flat-field images and measure solar shape variations.
- HMI commanding requirements will be minimal except to update internal timelines for calibration activities and configuration for eclipses.
- After instrument commissioning, it is anticipated that a single command load on weekdays will be sufficient.

HMI Dataflow Concept



Completed Trade Studies

- **Observing Wavelength**
  - To improve magnetic sensitivity of HMI over MDI
  - 6173 Å vs. 6768 Å: 6173 Å selected

- **CPU**
  - To determine the most cost-effective, low-risk solution
  - RAD 6000 vs. RAD 750 vs. Coldfire: RAD 6000 selected (from SXI)

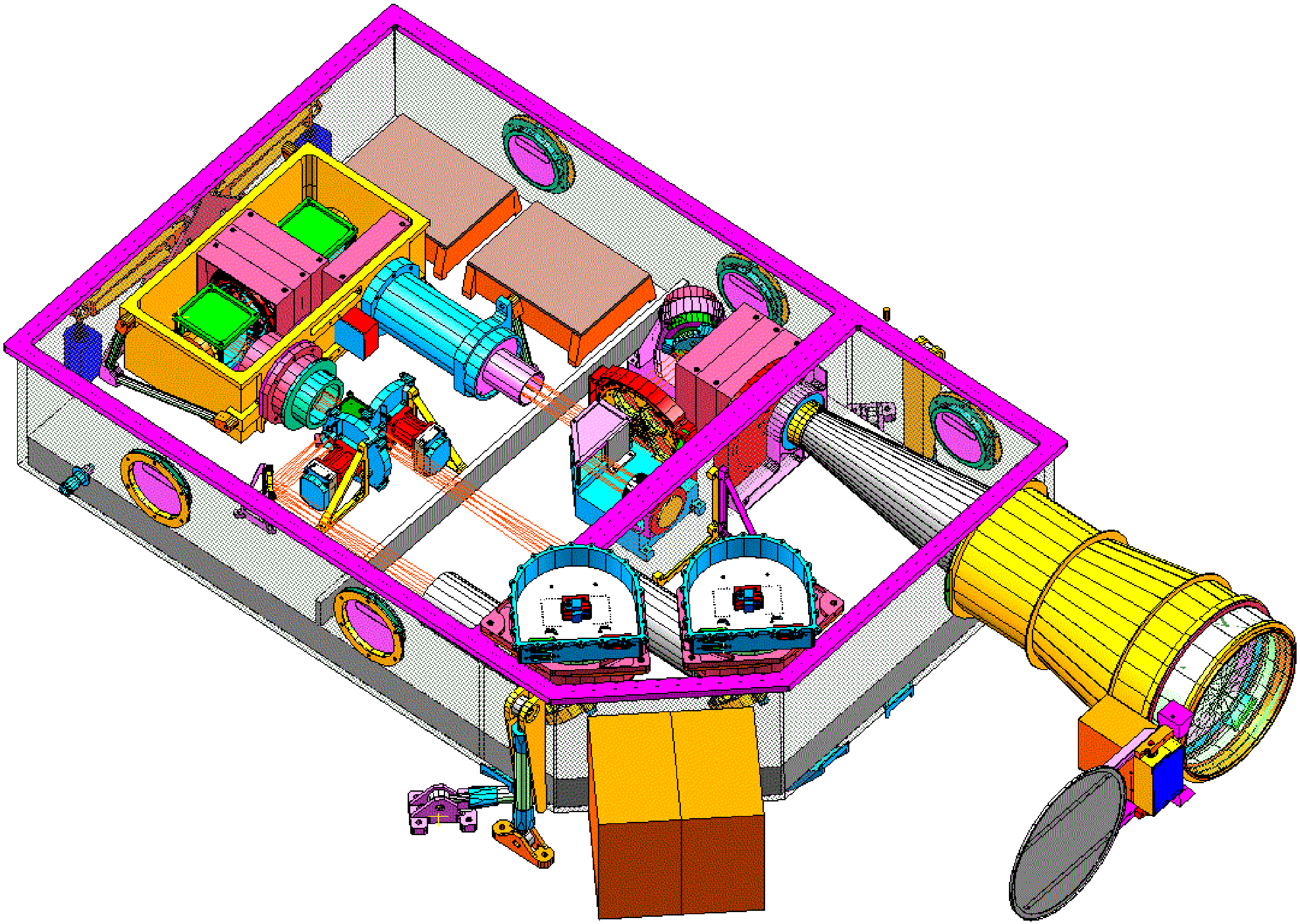
- **High-Rate Telemetry Board**
  - To eliminate a critical single-point failure
  - Single Board or to include a redundant board: Redundant concept selected

- **Sensor Trade**
  - To consider a rad-hard new technology sensor option at a lower cost
  - CMOS vs. CCD Detector: CCD selected, CMOS technology not mature enough

Trade Studies In Progress

- **Inclusion of redundant mechanisms in HMI Optic Package**
  - Increased reliability vs. increased cost & mass
  - Have allocated volume & mass to not preclude additional mechanisms
- **Inclusion of redundant power supply in HMI Electronics Box**
  - Increased reliability versus increased cost and mass
  - Just started this trade
- **Inclusion of redundant processor in HMI Electronics Box**
  - Increased reliability versus increased cost and mass
  - Just started this trade
- **Camera Subsystem - evaluating available options**
  - Build an evolution of a Solar-B FPP camera at LMSAL
  - Procure an evolution of a SECCHI camera from RAL
- **CCD Configuration**
  - Evaluating operation in front side or back side illuminated mode for optimum performance

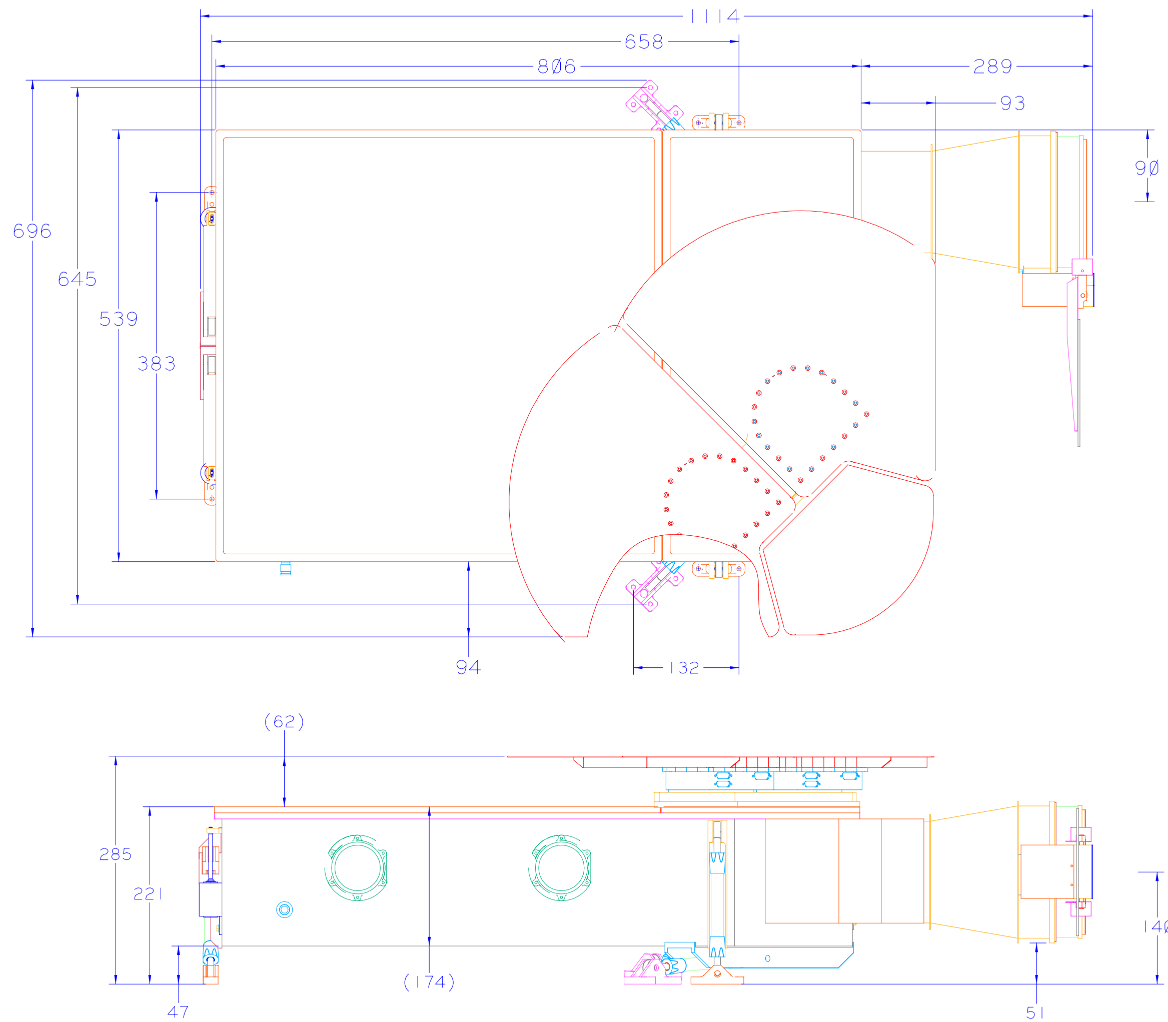
Current Optics Package – 3D view

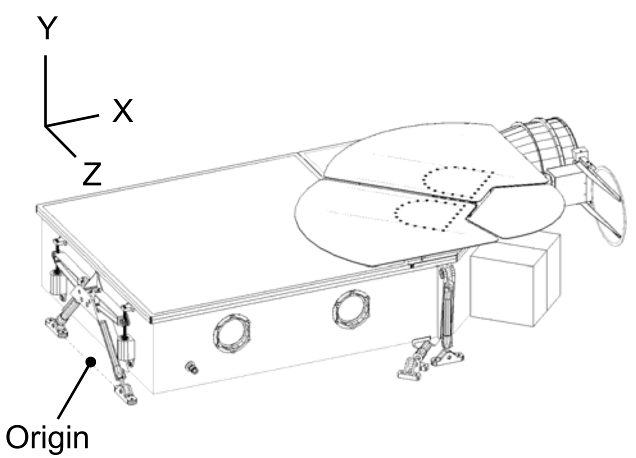


HMI Optics Package Layout

Current OP envelope
(20 Mar 2003)
X = 1114 mm
Y = 285 mm
Z = 696 mm

Current OP mass = 35.3 kg
Current total mass = 53.3 kg
Mass allocation = 53.3 kg

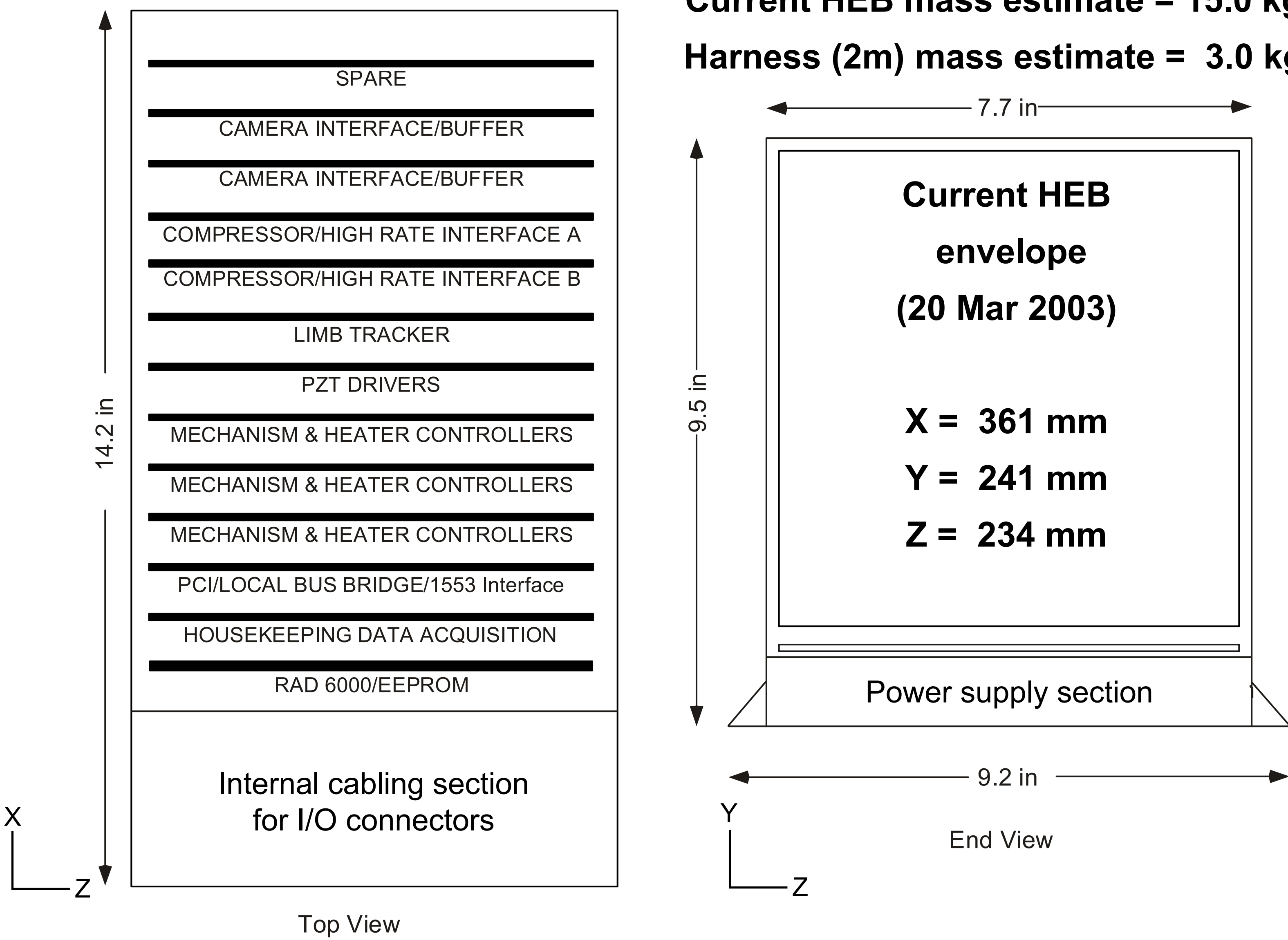




HMI Electronics Box Layout

Current HEB mass estimate = 15.0 kg

Harness (2m) mass estimate = 3.0 kg



HMI Resources - Average Power

20 Mar 2003	**Operational Mode (W)**	**Eclipse Mode (W)**	**Survival Mode (W)**	**Early Ops (W)**
EB Electronics	30.5	30.5	0.0	0.0
OP Oven Control	1.0	1.0	0.0	0.0
OP Filter Oven	3.0	3.0	0.0	0.0
subtotal	34.5	34.5	0.0	0.0
PC Inefficiency	14.8	14.8	0.0	0.0
subtotal	49.3	49.3	0.0	0.0
Survival Heaters	0.0	0.0	45.0	45.0
CCD Decontam Heaters	0.0	0.0	0.0	22.0
Operational Heaters	13.0	23.0	0.0	0.0
subtotal	62.3	72.3	45.0	67.0
CEB (LMSAL)	30.0	30.0	0.0	0.0
Current Estimate	92.3	102.3	45.0	67.0
Current Allocation	94.0	TBD	TBD	TBD

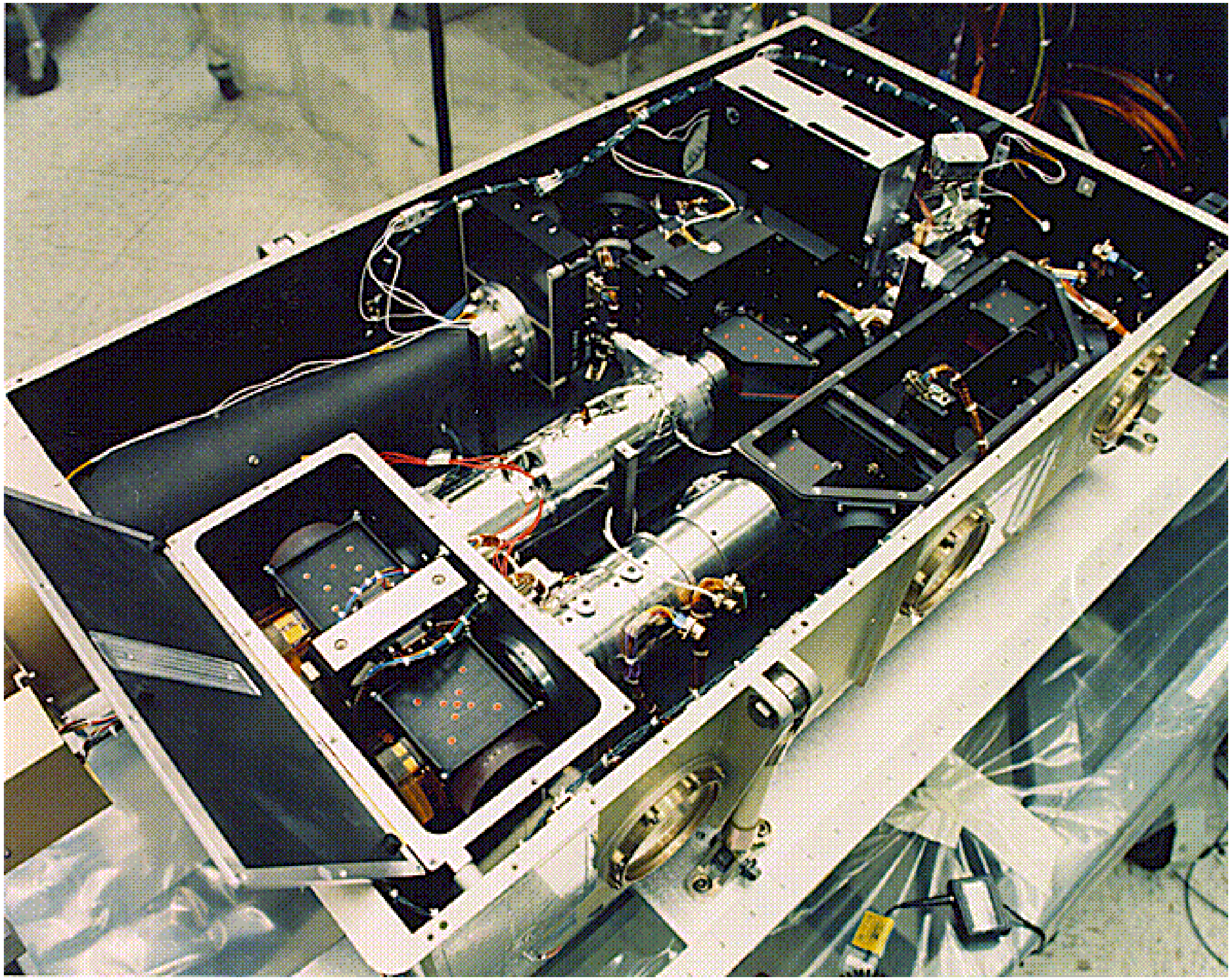
Spacecraft Resource Drivers

- **Science Data Rate**
  - 55 Mbits/sec
- **Data Continuity & Completeness**
  - Capture 99.99% of the HMI data (during 10-minute observing periods)
  - 95% of all 10-minute observations are required to be 99.9% complete
- **Spacecraft Pointing & Stability**
  - The spacecraft shall maintain the HMI reference boresight to within 200 arcsec of sun center
  - The spacecraft shall maintain the HMI roll reference to within TBD arcsec of solar North
  - The spacecraft shall maintain drift of the spacecraft reference boresight relative to the HMI reference boresight to within 14 arcsec in the Y and Z axes over a period not less than one week.
  - The spacecraft jitter at the HMI mounting interface to the optical bench shall be less than 5 arcsec (3 sigma) over frequencies of 0.02 Hz to 50 Hz in the X, Y and Z axes.
- **Reference Time**
  - Spacecraft on-board time shall be accurate to 100 ms with respect to ground time (goal of 10 ms)

HMI Heritage

- **Primary HMI heritage is the Michelson Doppler Imager instrument which has been successfully operating in space for over 7 years. Between launch in December 1995 and March 2003, almost 70 million exposures have been taken.**
- **Basically all HMI subsystems are based on designs developed for MDI and other space instruments developed at LMSAL.**
  - Lyot filter has heritage from the SOHO/MDI, Spacelab-2/SOUP, Solar-B/FPP instruments.
  - HMI Michelson interferometers will be very similar to the MDI Michelsons.
  - Hollow-core motors, filter-wheel mechanisms, shutters and their controllers have been used in SOHO/MDI, TRACE, SXI, EPIC/Triana, Solar-B/FPP, Solar-B/XRT and STEREO/SECCHI.
  - The Image Stabilization System is very similar to the MDI design, and aspects of the ISS have been used in TRACE and STEREO/SECCHI.
  - The telescope and other optics have heritage from MDI, Spacelab-2/SOUP and Solar-B/FPP.
  - The Optics Package structure has heritage from MDI and Solar-B/FPP.
  - The alignment/pointing system and the front door will be near copies of those on MDI.
  - The CCD Camera Electronics will be an evolution of cameras on MDI, TRACE, SXI, and Solar-B/FPP; or an evolution of the STEREO/SECCHI camera.
  - The main control processor for HMI is being used on the SXI and Solar-B/FPP instruments.
  - Flight software has heritage from SXI and Solar-B/FPP.

HMI Design Heritage



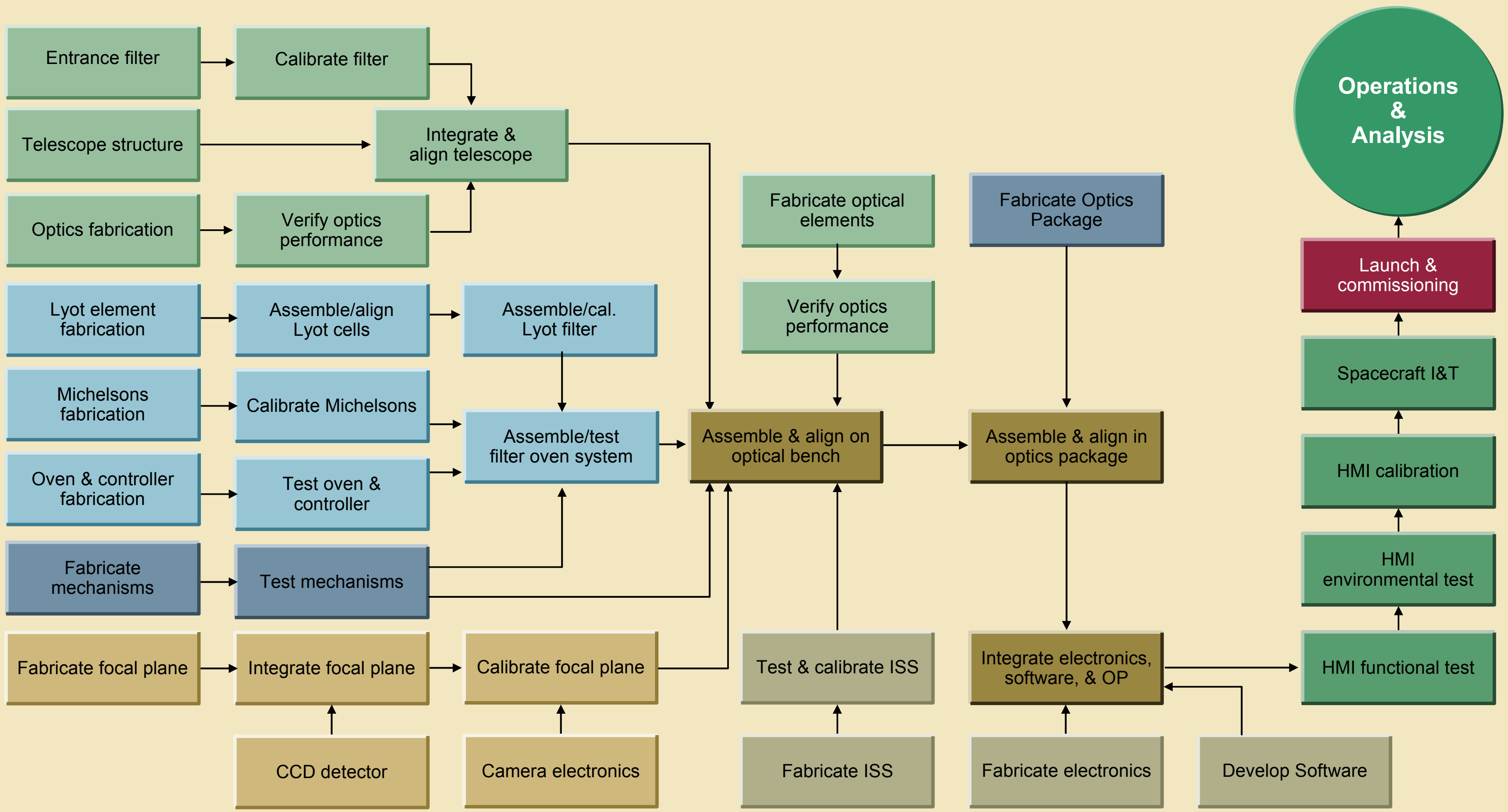
The HMI design is based on the successful Michelson Doppler Imager instrument.

HMI Technology Readiness Level

- **CCDs**
  - Early mask development to be done in Phase A
  - Engineering development devices being produced early in the program

- **All other components are TRL 6 or above**

HMI Assembly & Integration Flow



HMI Developmental Tests

- **HMI Structural Model (SM)**
  - Will have high fidelity structure and mounting legs
  - Will be filled with mass simulators
  - Will be vibration tested to verify the structural design prior to delivery to the spacecraft
- **Hollow-Core Motors and Shutters**
  - Will life test prototype units in vacuum
- **Filter Oven**
  - Will have a development model oven and controller that are loaded with simulated optical elements and extensively instrumented for thermal performance
  - It will be characterized in vacuum to verify thermal-stability performance
- **Michelson**
  - The polarizing beam splitters, that are the heart of the Michelsons, will be carefully tested and characterized prior to being used to build the Michelsons
  - Will have the first unit built early in the program
  - This unit will be characterized prior to fabrication of the remaining Michelsons

Environmental Test Approach

- **HMI is a proto-flight instrument**
  - To be tested at appropriate proto-flight levels and durations
  - There will be no component qualification
- **Preferred order of testing:**
  - LFFT
  - SPT for Calibration
  - SPT for Sunlight Performance
  - EMI/EMC
  - LFFT
  - Sine & Random Vibration
    - Electronics & Optics Package separately
    - Powered off
  - LFFT
  - Thermal Vacuum / Thermal Balance
  - LFFT
  - SPT for Calibration
  - SPT for Sunlight Performance in vacuum
  - Mass Properties
  - Delivery

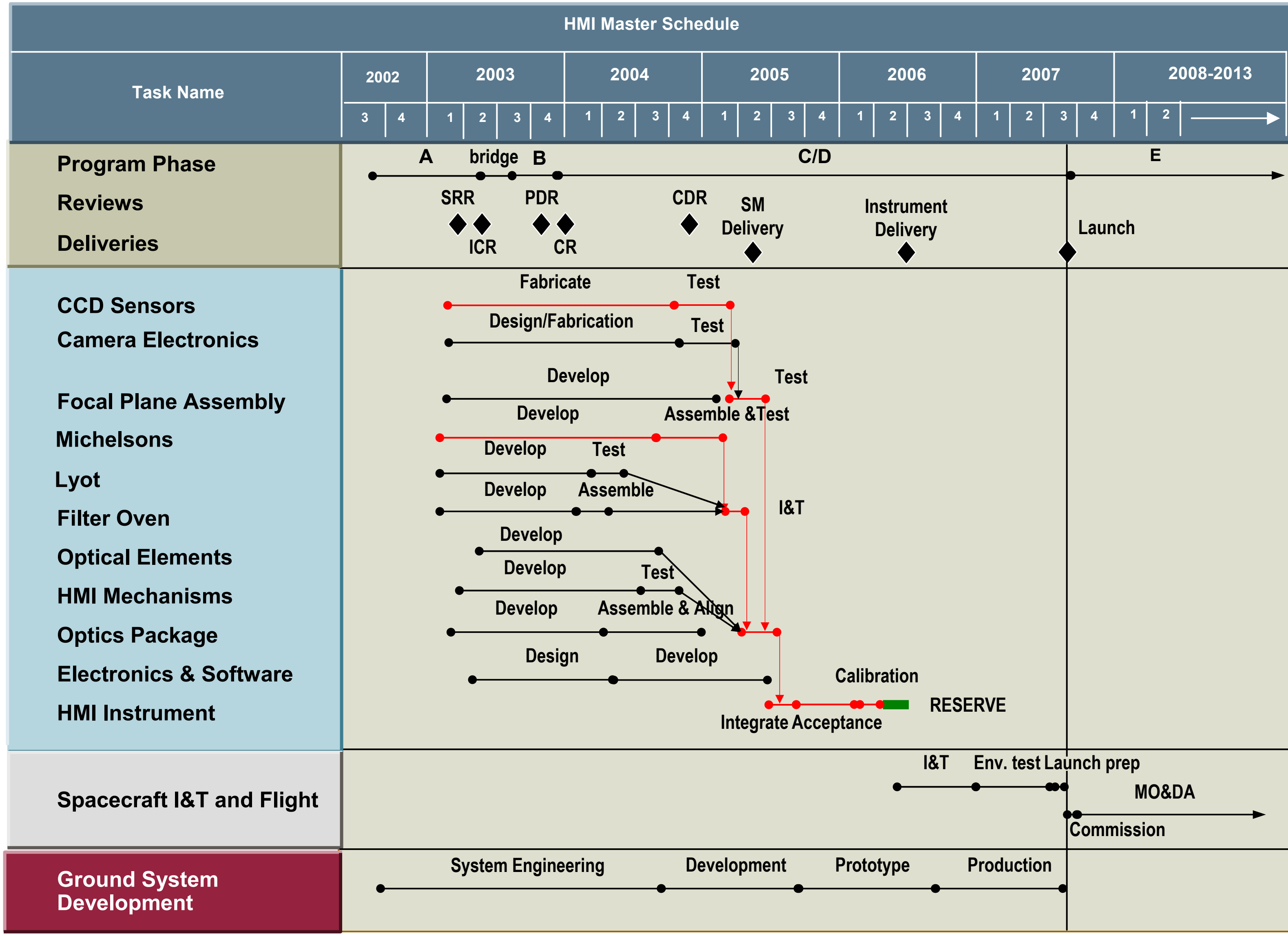
Instrument Calibration Approach

- **Critical subsystems that will be calibrated at LMSAL prior to integration include:**
  - CCD cameras
  - Michelsons
  - Lyot filter
  - Mechanisms
  - Other optical elements
- **The completed HMI will be calibrated at LMSAL both in ambient and in vacuum using lasers, the stimulus telescope, and the Sun**
- **Observatory-level calibration checks will be performed as part of the special performance tests with lasers and the stimulus telescope**

Functional Test Approach

- **HMI will use a structured test approach**
- **The tests will be controlled by released STOL procedures**
- **The aliveness test will require <30 minutes and will test the major subsystems**
- **The Short Form Functional Test (SFFT) will require a few hours and will test all subsystems but not all paths**
  - It will not require the stimulus telescope
- **The Long Form Functional Test (LFFT) will require ~8 hours and will attempt to test all paths and major modes**
  - The SFFT is a subset of the LFFT
  - Will require the use of the stimulus telescope and the laser
- **Special Performance Tests (SPT) are tests that measure a specific aspect of the HMI performance**
  - These are detailed tests that require the stimulus telescope or other special setups
  - They are used only a few times in the program

Schedule & Critical Path



HMI Risk

Risk Description	Risk Level	Mitigation Strategy
CCD Development. If E2V vendor has 4Kx4K CCD development issues, then Instrument schedules could be delayed.	**High**	With retraction of UK contribution, Project initiate engineering feasibility effort with E2V by end of April 2003; form GSFC/SHARPP/HMI Board to track E2V effort.

HMI Summary

- **The HMI instrument is well understood based on experience with the development and orbital operation of the MDI instrument.**
- **We have identified areas that might impact the instrument development schedule, and are working aggressively on the following items.**
  - A common HMI and SHARPP specification for CCD sensors has been developed, and the procurement for the initial design work and evaluation unit fabrication will be in place shortly.
  - The procurement process for the Michelson interferometers has been started, including site visits to potential vendors and the development of final specifications.
  - In addition to significant flight heritage, life-tests of the hollow core motors and shutters are planned to validate their performance for the planned SDO mission duration.
  - Detailed thermal modeling and extensive testing of an engineering test unit will be used to optimize the thermal design.
- **Many of the Stanford University and Lockheed Martin Solar and Astrophysics Lab personnel that collaborated on the MDI project are participating in the HMI development, and we are confident that HMI will be as successful as MDI.**

Backup Slide

HMI CCD and Camera Electronics

- **Baseline CCD vendor is E2V**
  - Specification drafted - includes capabilities that allow more optimal camera electronics design and requires less power
  - SHARP and HMI to use identical CCDs
  - E2V to be given a design phase contract ASAP
- **Two principal paths for development of camera electronics**
  - Develop cameras in-house => evolution of the Solar-B FPP FG camera
  - Procure cameras from RAL => evolution of the SECCHI camera
- **Key Considerations for decision on approach**
  - Schedule => very critical
  - Cost => RAL approach less expensive if already doing SHARPP cameras
  - Performance => both "good enough" but RAL better
- **Approach if camera electronics are procured from RAL**
  - Baseline same camera for SHARPP and HMI
  - Have separate RAL subcontracts from LMSAL and NRL
  - Continue to study FPP-option through Phase A
- **Approach if camera electronics are developed at LMSAL**
  - Do not provide cameras for SHARPP
  - Keep informed on RAL-for SHARPP camera status and vice versa