High-performance CMOS Imager Technology for Solar Orbiter Space Mission

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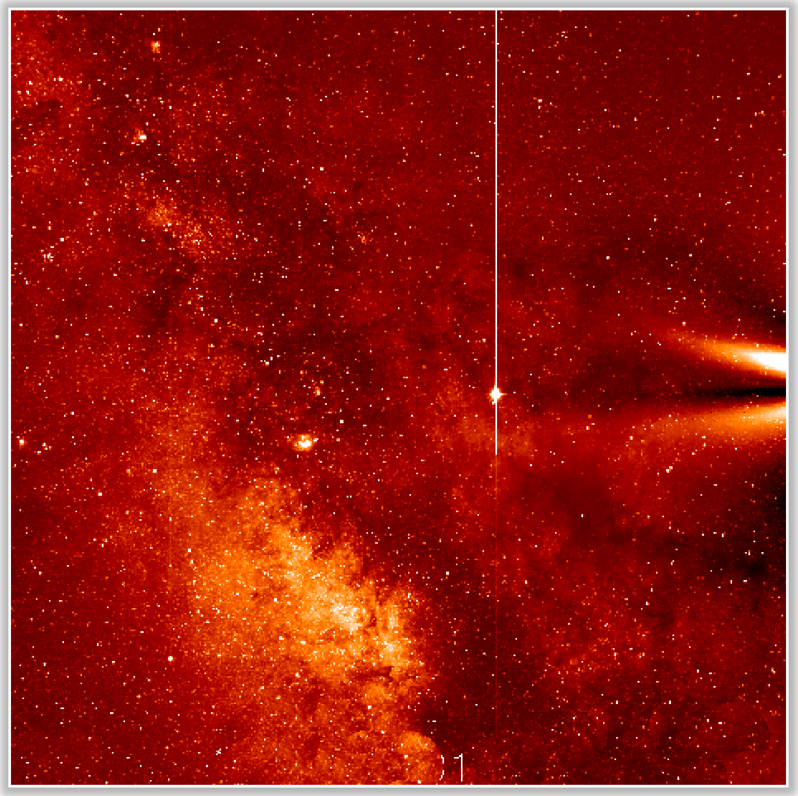
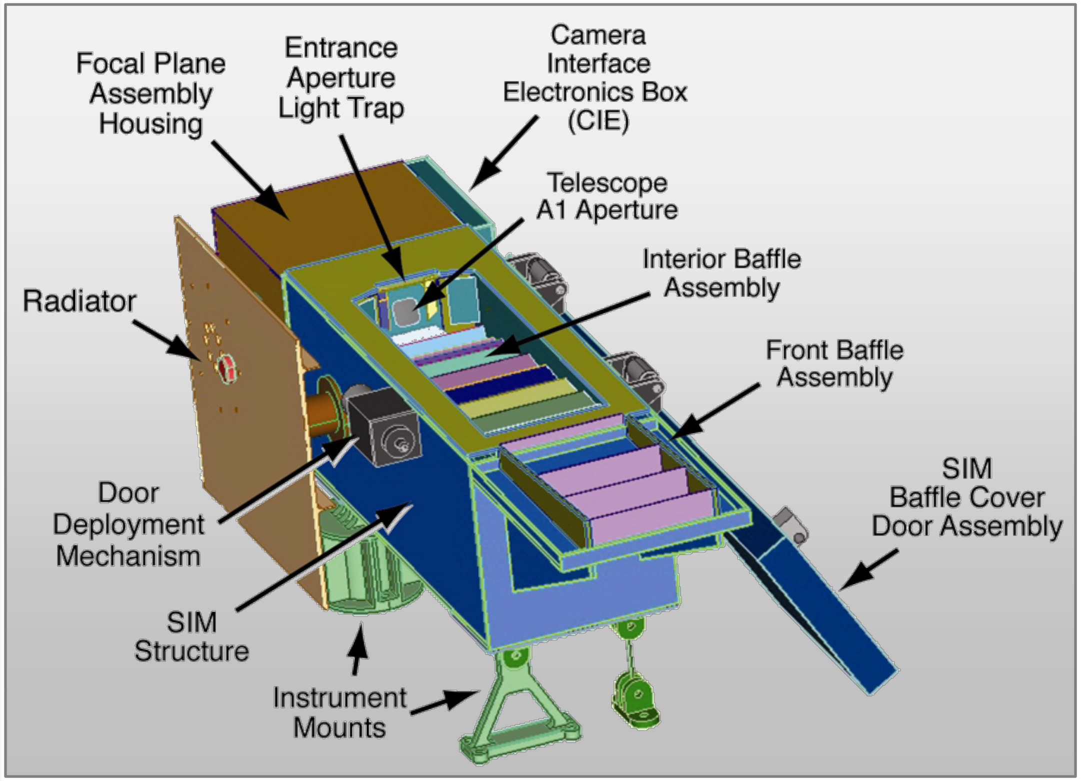
What Is SoloHI?

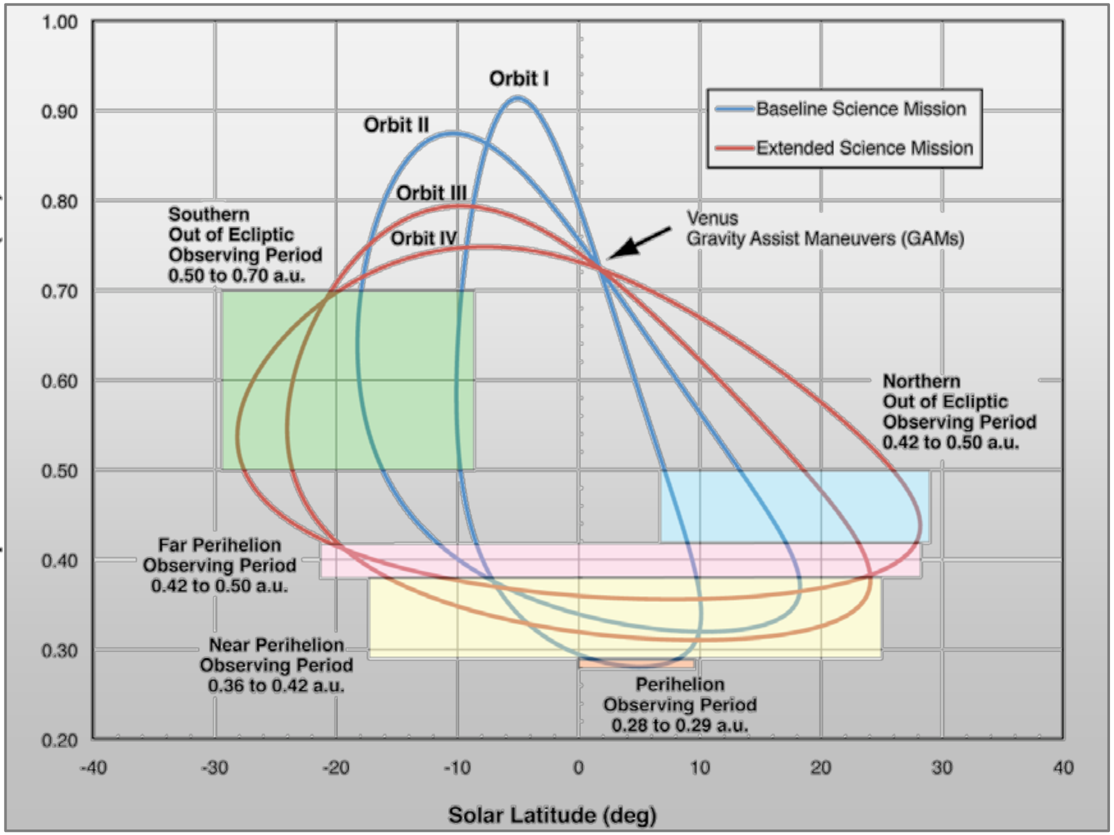
- Wide-Field Imager of the Heliosphere From 5 to 45 deg From the Sun.
- Visible Light Observations.
- Single Telescope: No Mechanisms Other Than One-Shot Door.
- Next-Generation 4Kx4K APS Sensor.





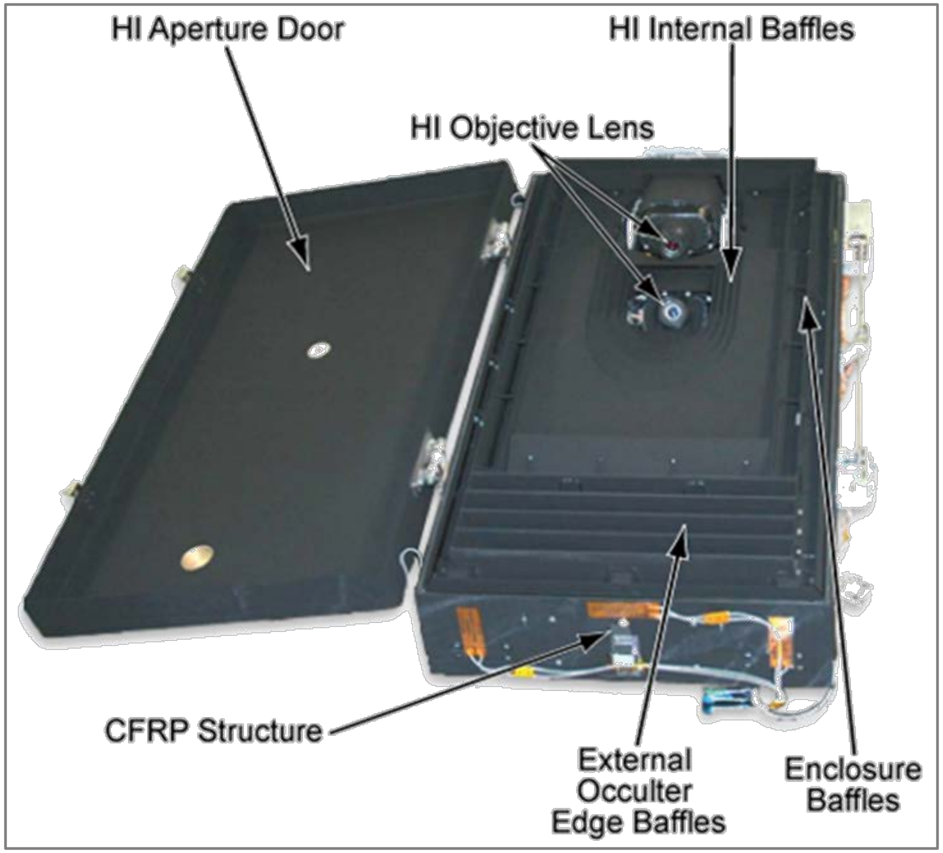
Science Operations Concept
Encounter Mission Mode

- Imaging Instruments Operate **30 days/168-day Orbit.**
- Nominal Partitioning: **3 x 10-Day** Windows.
- Focus on Special Sections of Each Orbit (e.g., **Perihelion**, **Latitudinal Extremes**).
- SoloHI Telemetry Allocation: **52 Gbit/Orbit** (20 kbit/s avg).
- **8 Orbits** in Baseline Mission (Max Latitude <25º).
- **8 Orbits** in Extended Mission (Max Latitude <34º).



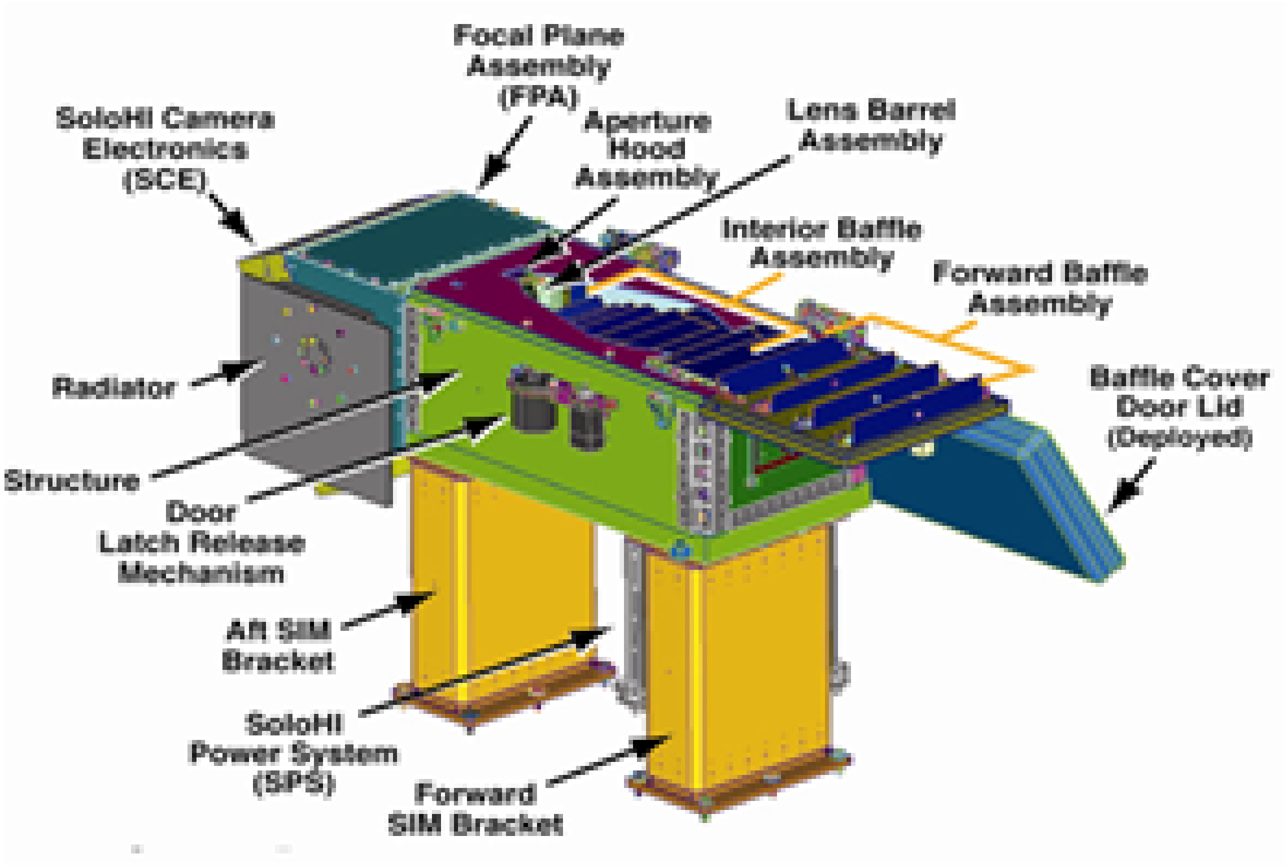
SoloHI relies heavily on heritage from the Secchi/HI proof of concept instrument.

- The SoloHI Instrument Concept Is a Direct Evolution From SECCHI/HI.
  - The SECCHI/HI on the STEREO Mission (Shown Below) Provides the "Proof-of-Principle" That Solar Wind Structures Can Be Well Observed Beyond the Traditional White Light Coronagraph Fields of View.

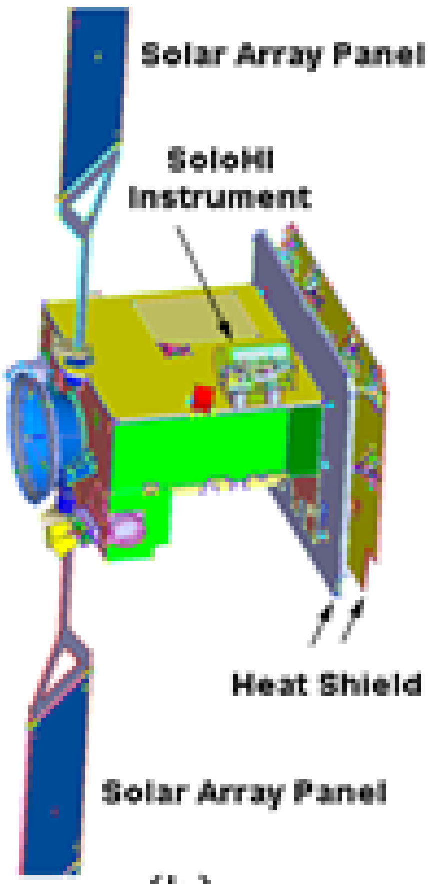


- Modifications for SoloHI.
  - Optical Design Is Tailored for SoloHI and uses the heat shield as the first baffle.
  - SoloHI will require a mass reduction of a factor of 3 from STEREO HI.
  - Next Generation Active Pixel Sensor replaces CCD. Active Pixel Sensor has comparable performance with a built-in shutter capability.
  - APS Drive Electronics is ~1.5kg lighter than the previous version.

SoloHI Instrument and Accommodation on Solar Orbiter Spacecraft

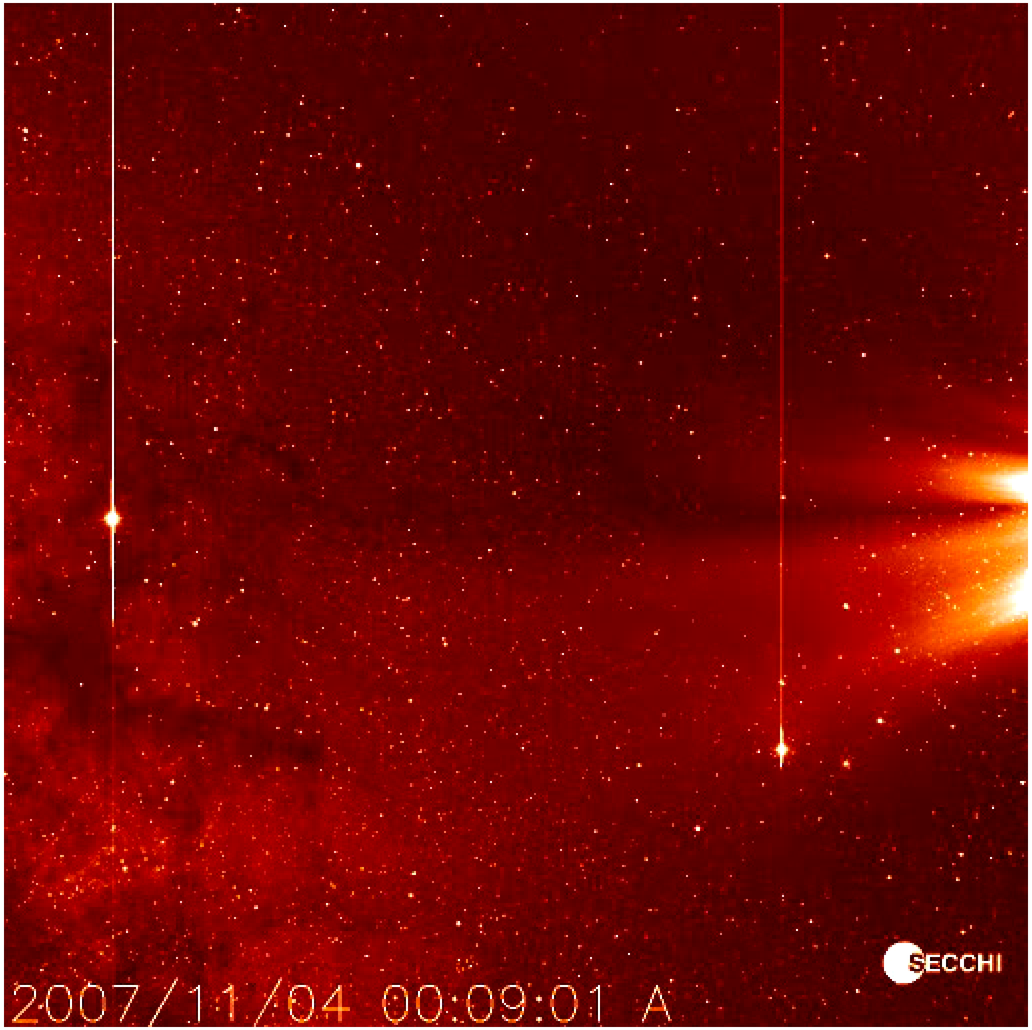


(a)

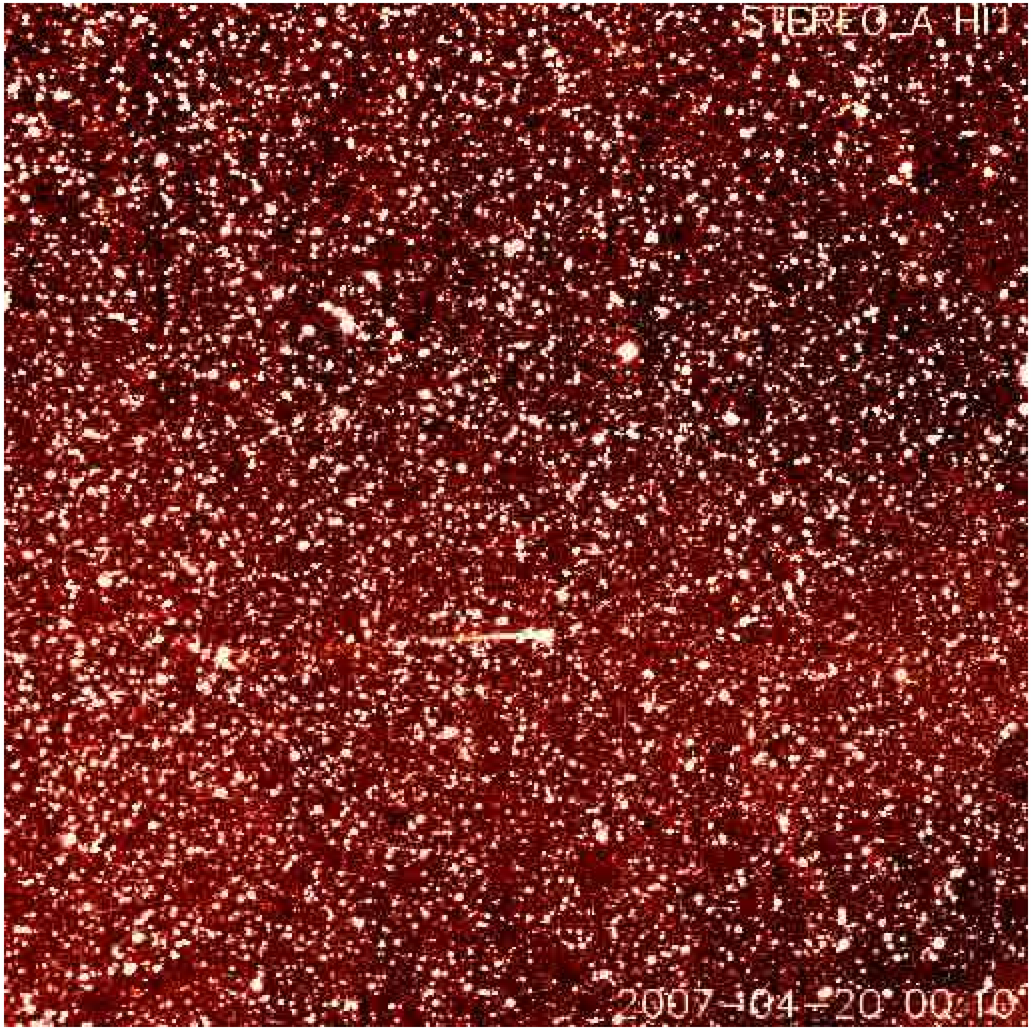


(b)

SoloHI will continue the solar wind observations of STEREO HI from a different perspective.

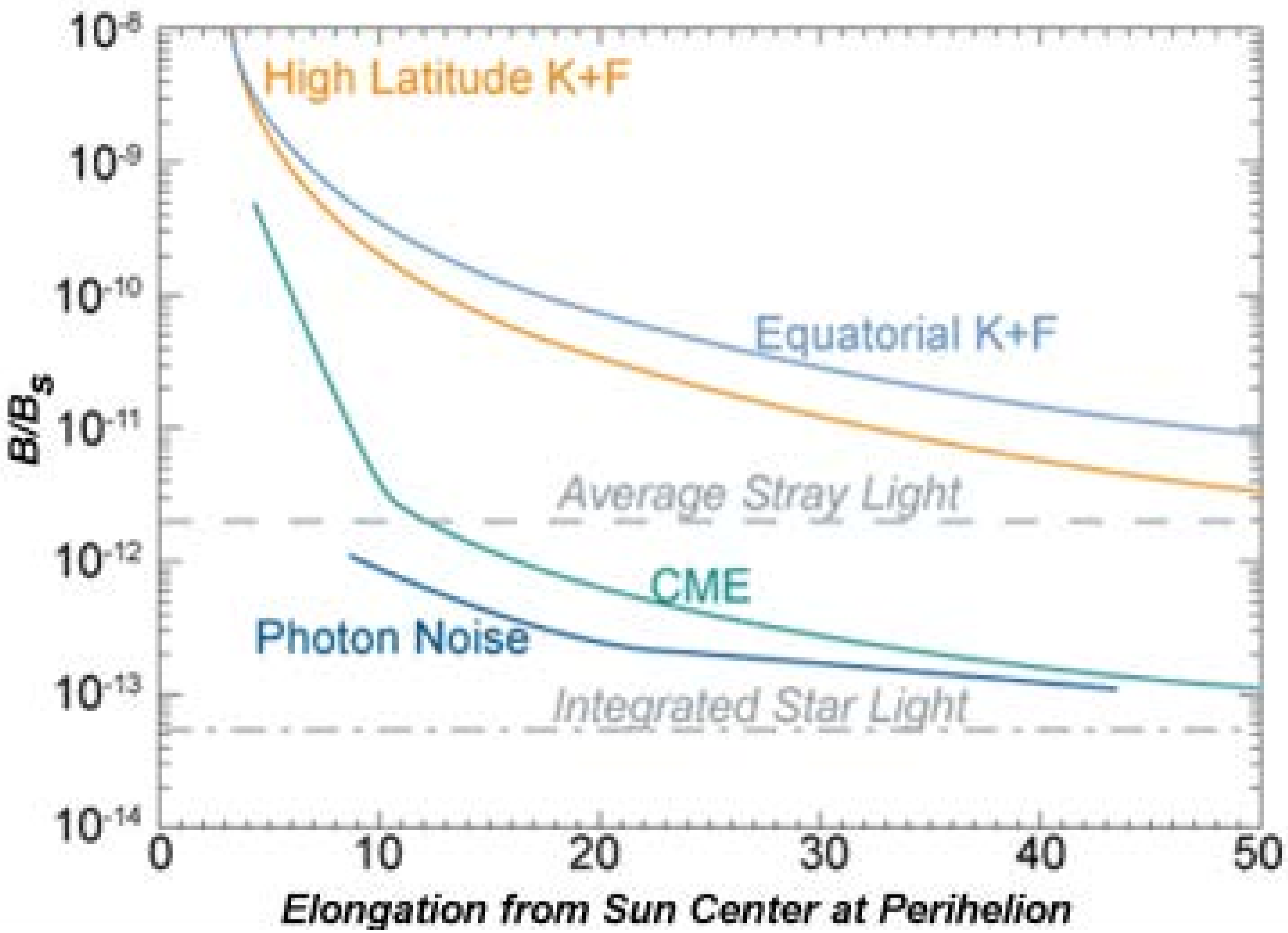


SoloHI will observe dynamic phenomena of the solar wind and other objects in the solar system.

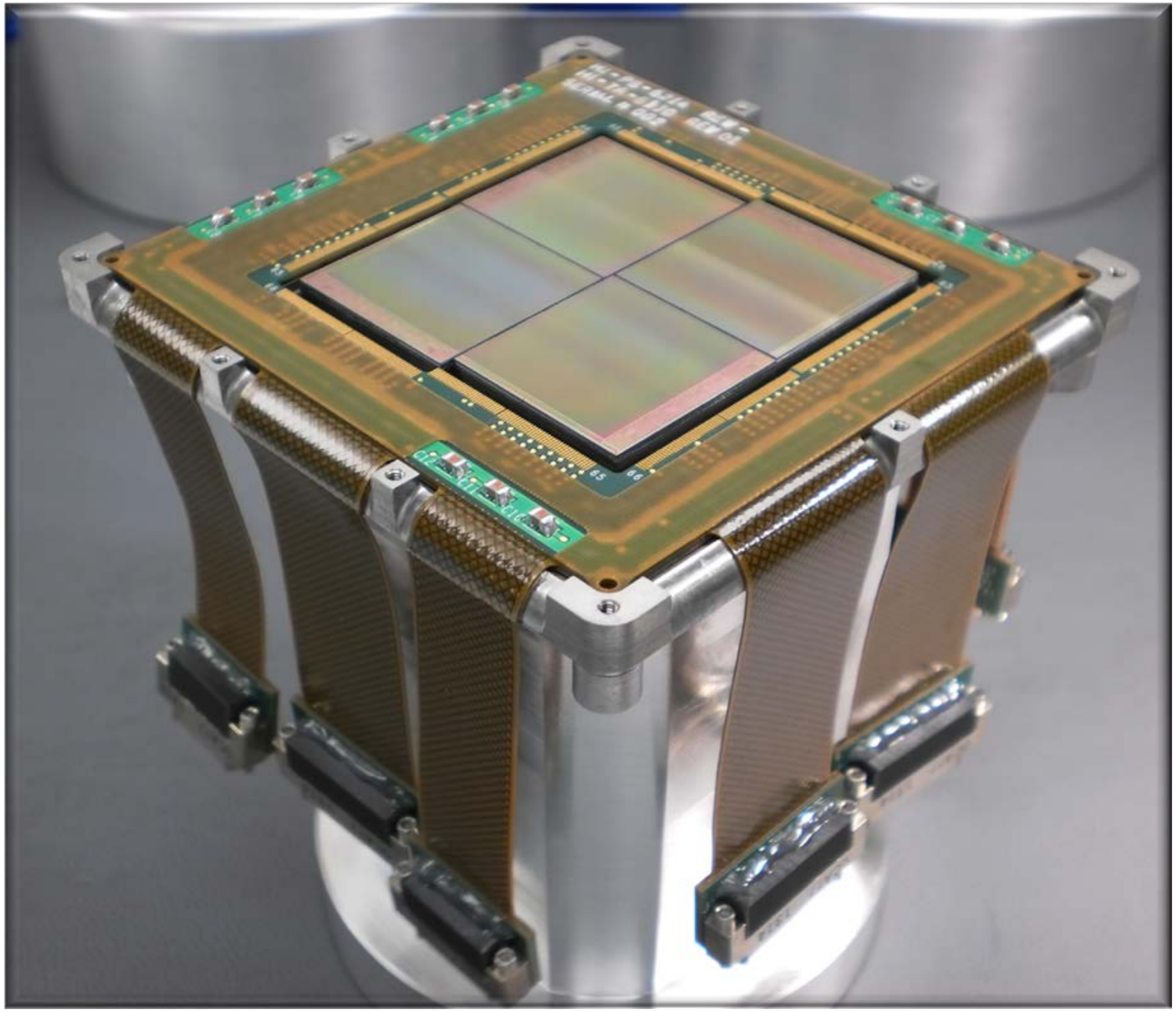


Comet Enke movie

Scene Brightness and Photometric Requirements



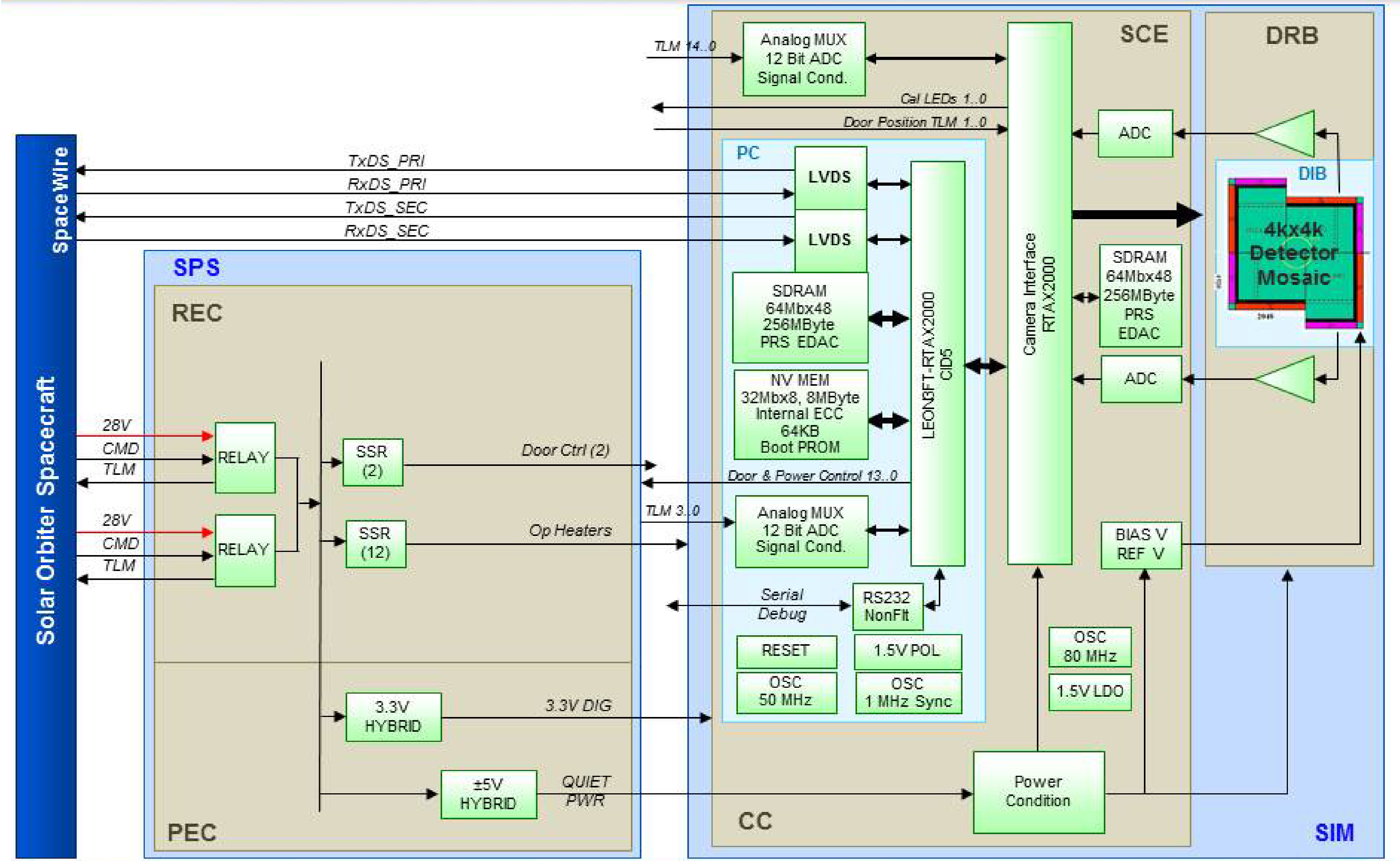
Panoramic images are recorded on a mosaic of four 2Kx2K, 10 micron pixel devices.



Active Pixel Sensor is a critical mission enabling technology:

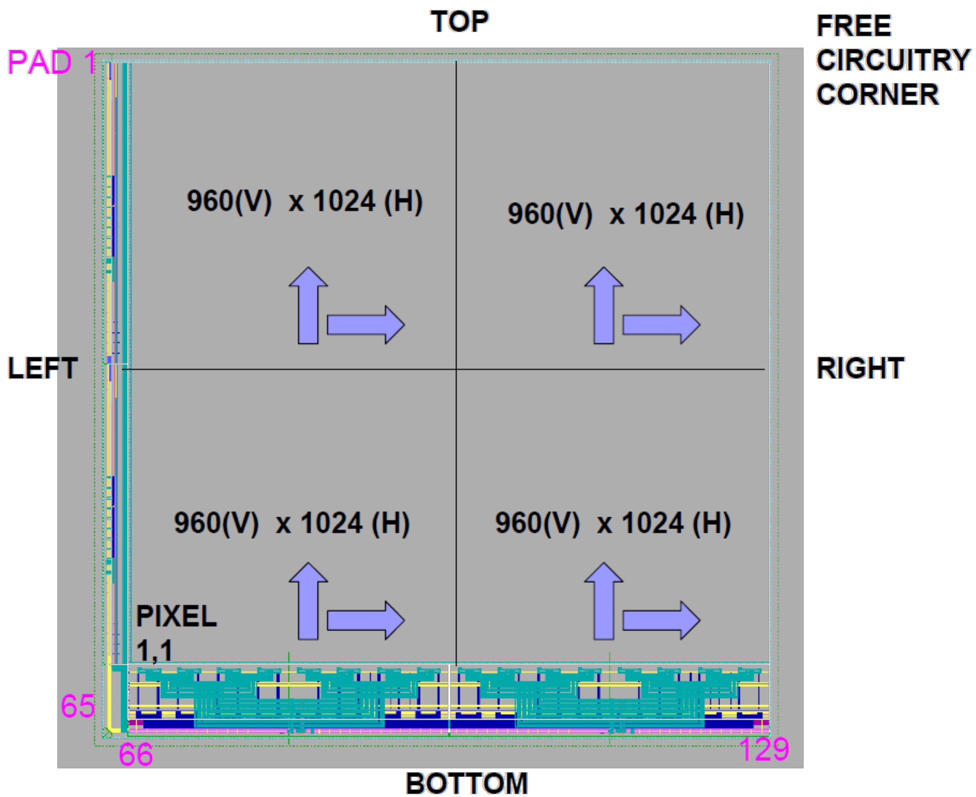
- shutterless readout
- radiation tolerant (100krads)
- on-board CDS simplifies electronics.
- straight forward power and interface requirements.
- CCD like sensor performance.
- tailored low resource camera solution for SoloHI.

Electronics Block Diagram



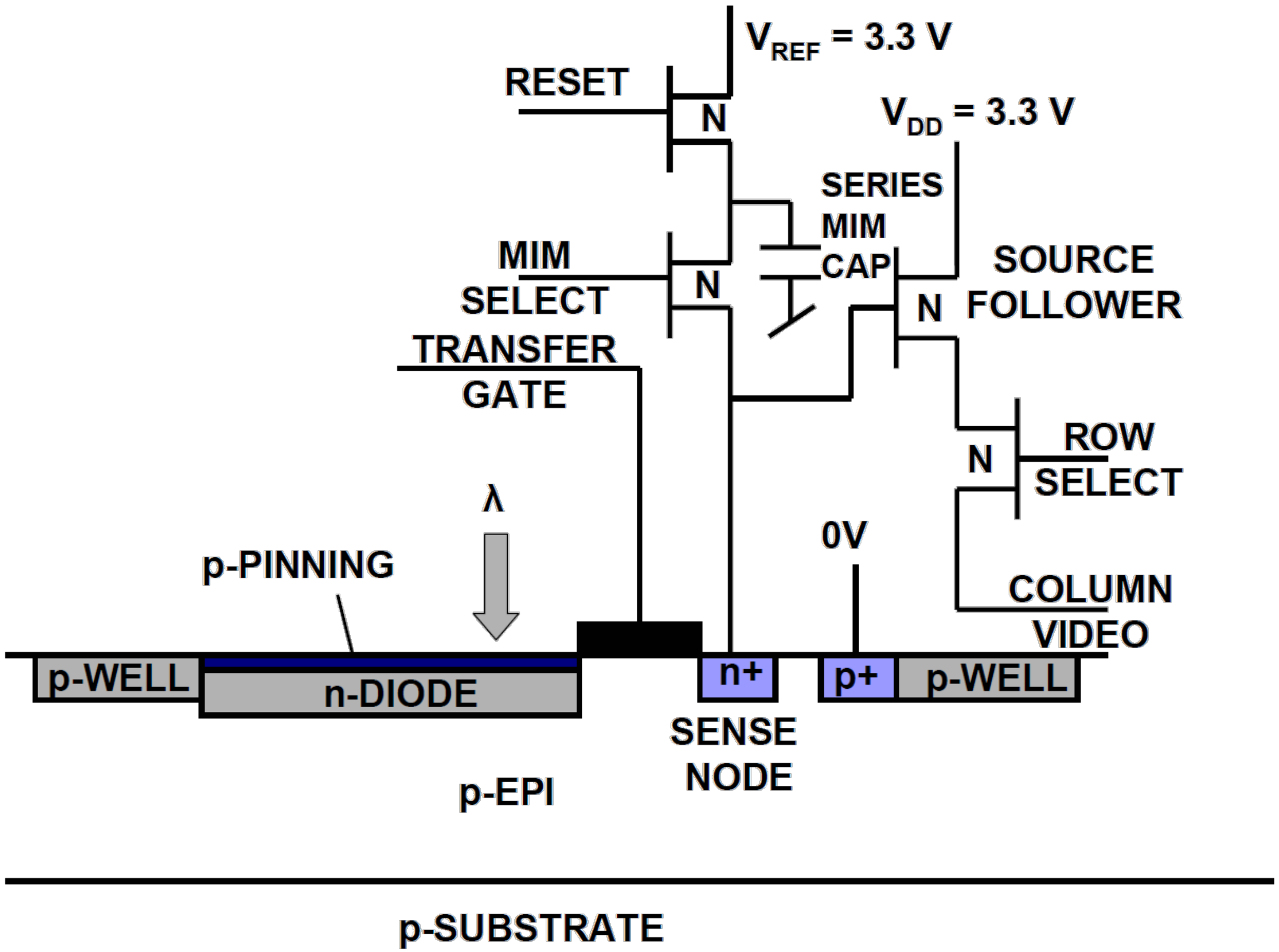
2Kx2K Device Architecture and Readout Well Suited to SoloHI Requirements.

1920(V) x 2048(H) x 10 um



- Format: 1920x2048
- Pixel: 10 Micron With 5 Transistors
- Readout Frame and Interface: Meets Progressive Scan and Interface Requirements
- Left: Row Drivers (Sequence and Control Each Row)
- Bottom: Column Drivers With Corner and Block Video Outputs
- 8 Rows and Columns have Opaque Layer; Used for Dark Current

APS Pixel Design



SoloHI APS has excellent measured performance.

Requirement	Value	Compliance
Overall Format	Nominal 4kx4k with 10 micron pixels.	4x 1920x2048, 10 micron pixels
Full Well	≥ 19.2k electrons	>20 K electrons (linear)
Read Noise through image chain (BOL)	≤ 14 electrons	≤ 7 electrons
Dark Current	<2.21 e/pixel-second (BOL) < 4.77 electrons/pixel-second (EOL)	<0.3 e/pix-sec (BOL) for long exposures <4 e/pix-sec (EOL) for long exposures
Average Quantum Efficiency	≥ 25% (490 to 740nm)	32% average
Cosmetics	> 95% pixels meet performance requirements (EOL).	Complies based on initial assessment after proton testing.
Readout Rate	≥ 2M Pixels/sec	Demonstrated performance at 4M Pixels/sec
Operation Mode	Progressive scan.	Complies by design
Redundancy	Independent operation of each device half	Complies by design

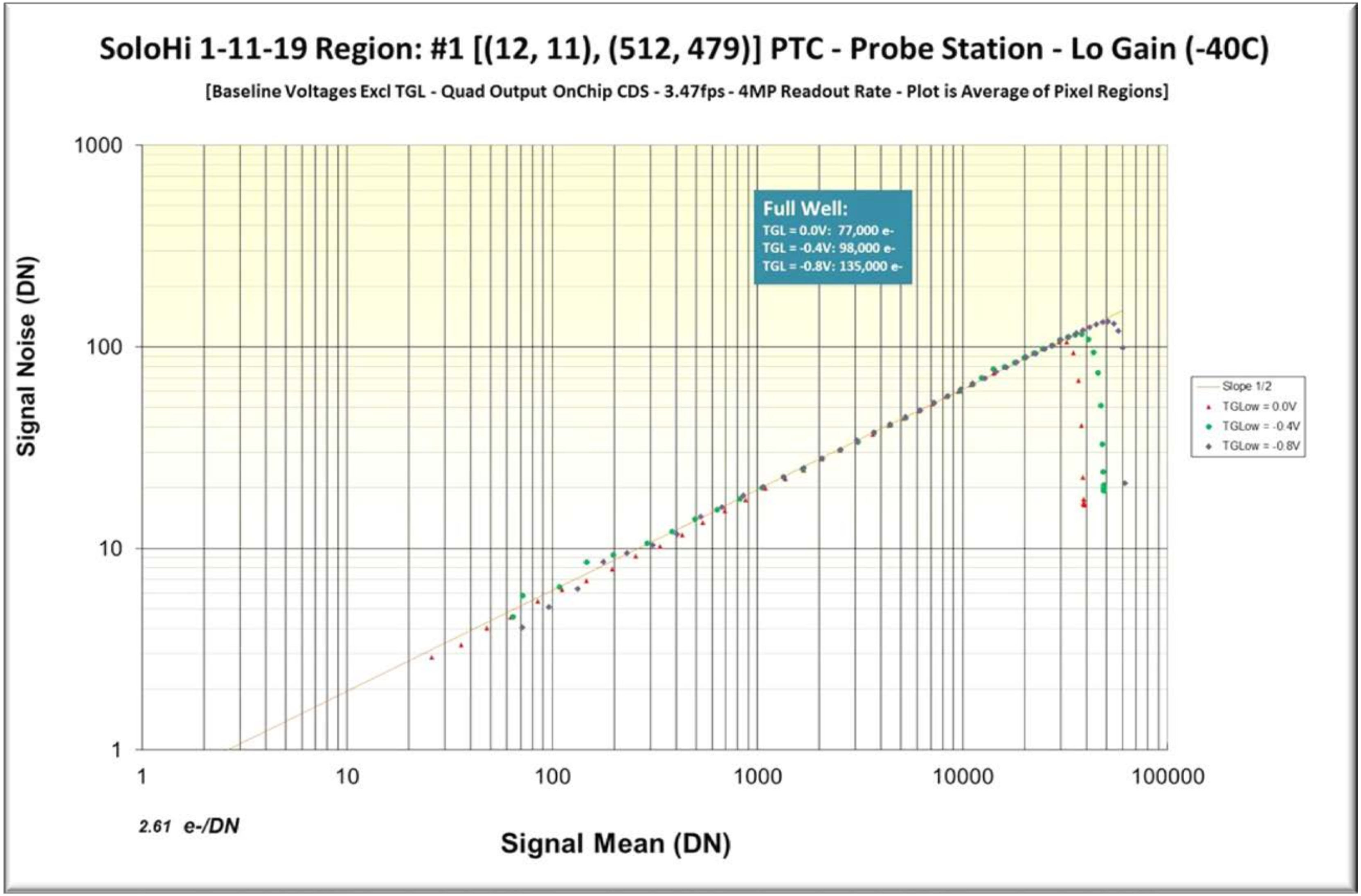
Flight devices processing is well advanced.

- 63 A & B grade die from the three flight wafers probed that as considered candidates for flight devices.

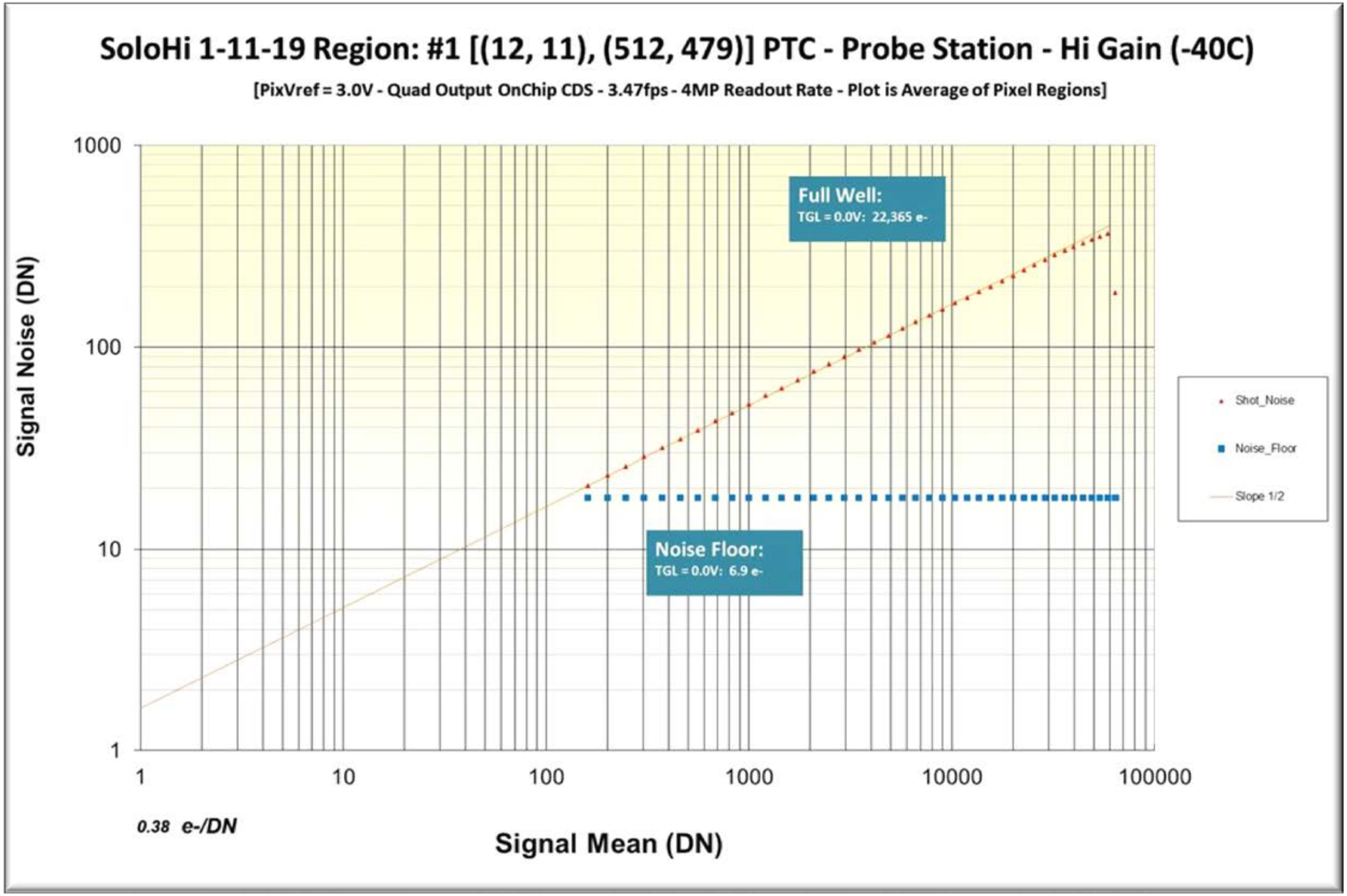
Wafer #	A-Grade	B-Grade	Total
11	7	9	16
13	6	16	22
14	5	20	25
		Grand Total	63

- Grade A devices have 0 bad rows and columns. Grade B devices have up to 2 bad rows/columns.
- Grade A devices will be used for flight and flight spare of SoloHI and WISPR.
- Wafer 15 is in the same family and may used if needed.

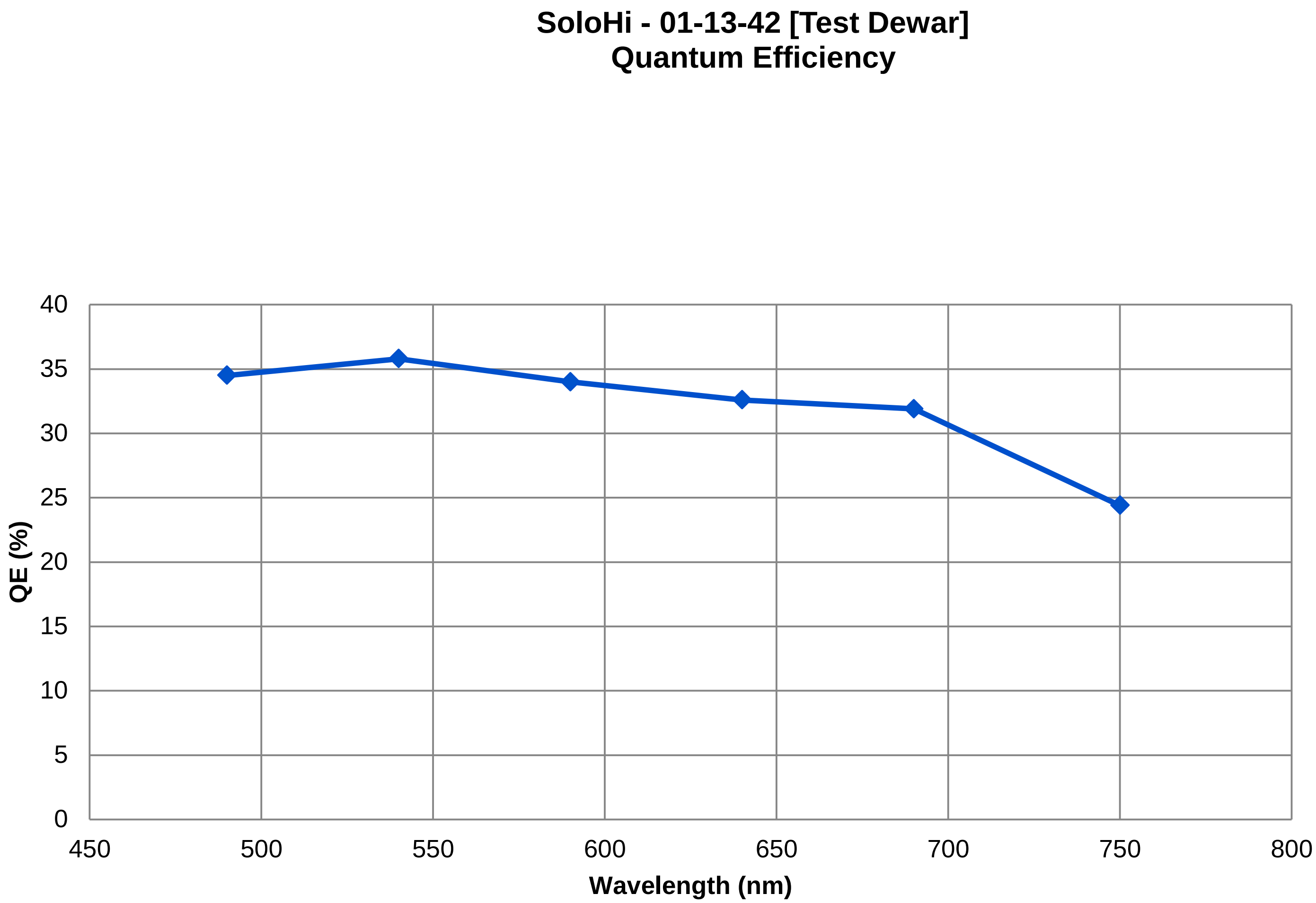
Photon Transfer Curve – Low GAIN



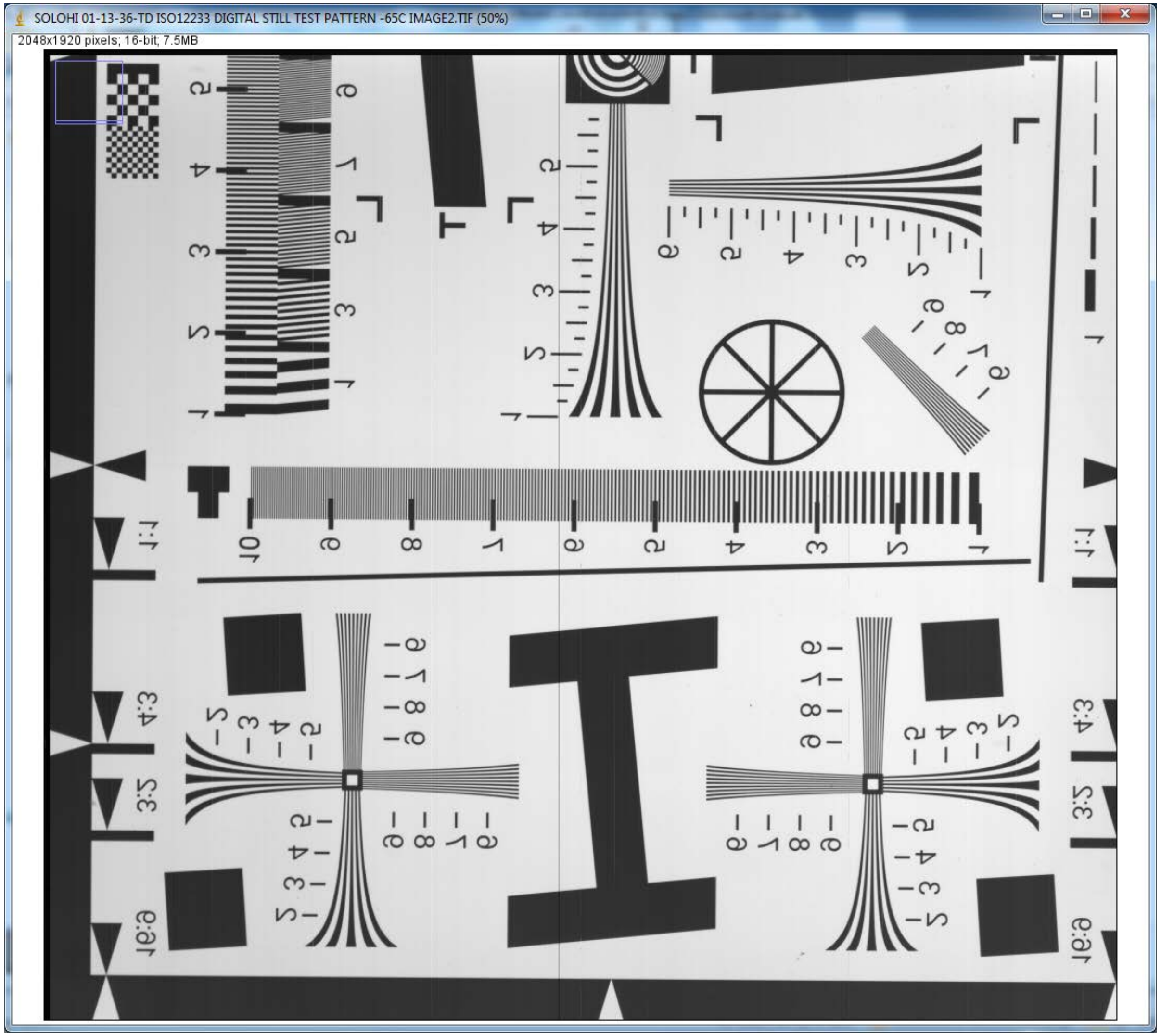
Photon Transfer Curve – High GAIN



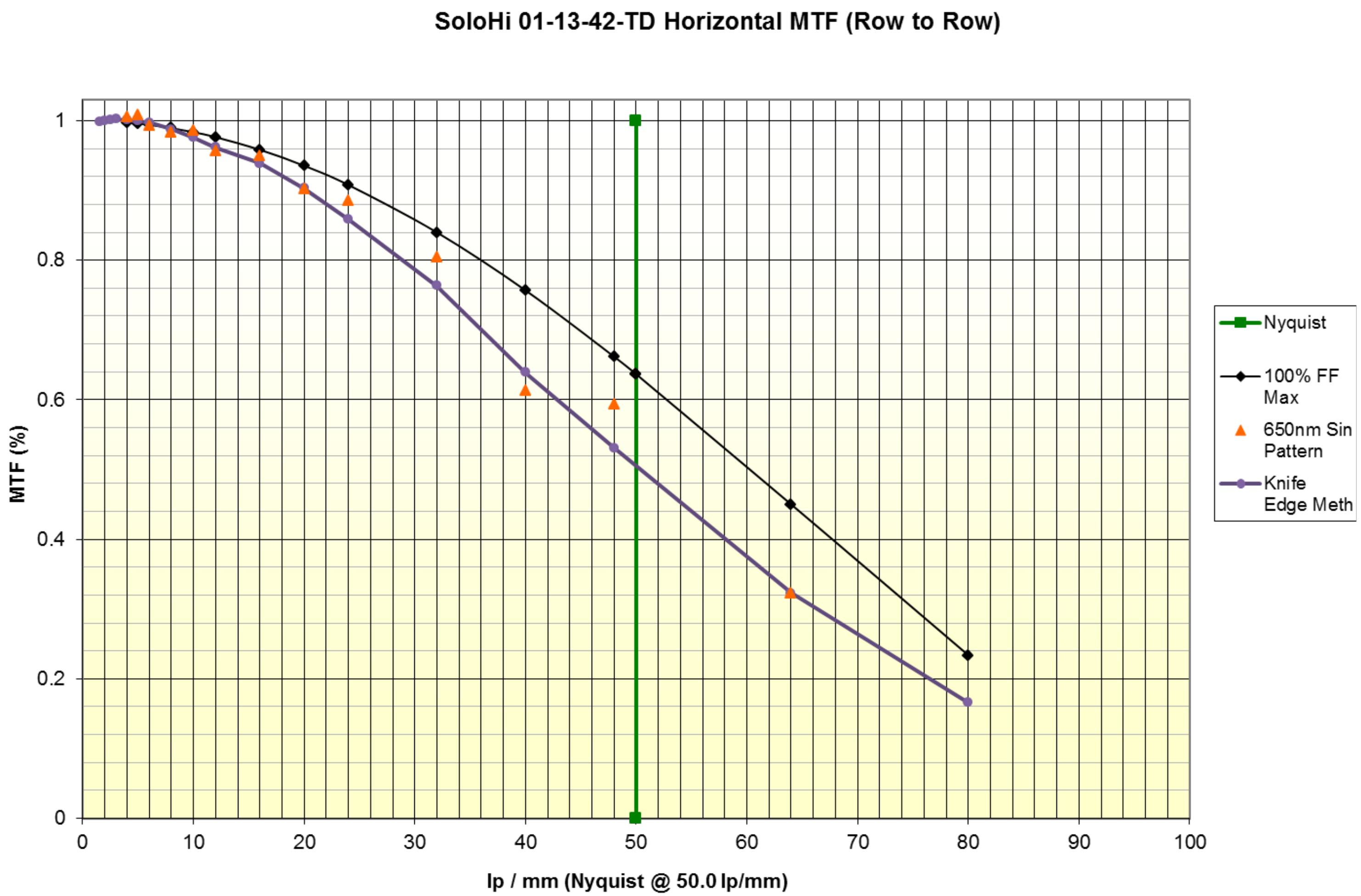
Quantum Efficiency



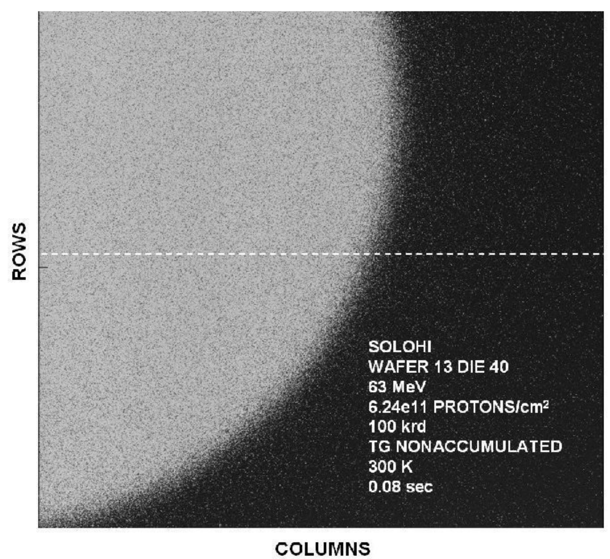
SoloHI device has excellent imaging properties.

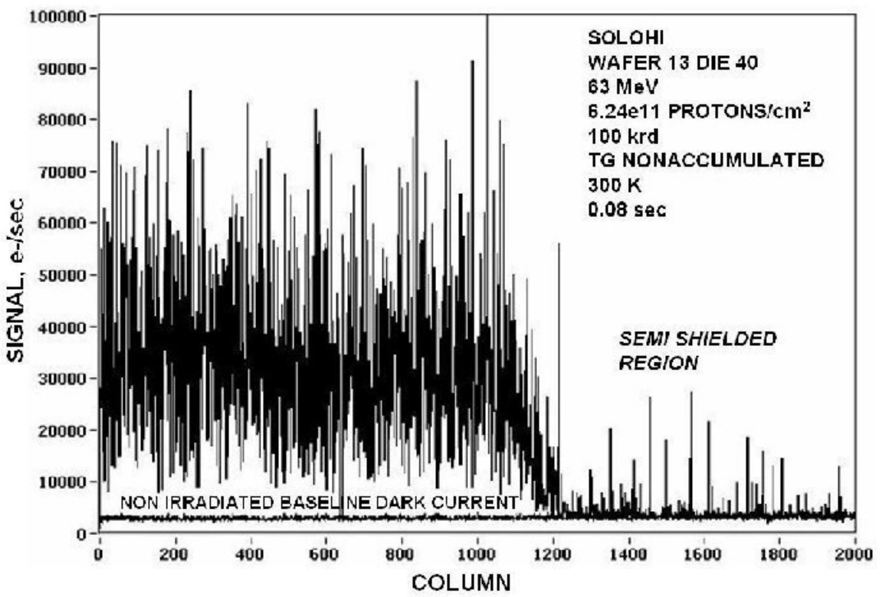


Measured MTF using a projected knife edge and sinusoidal patterns.

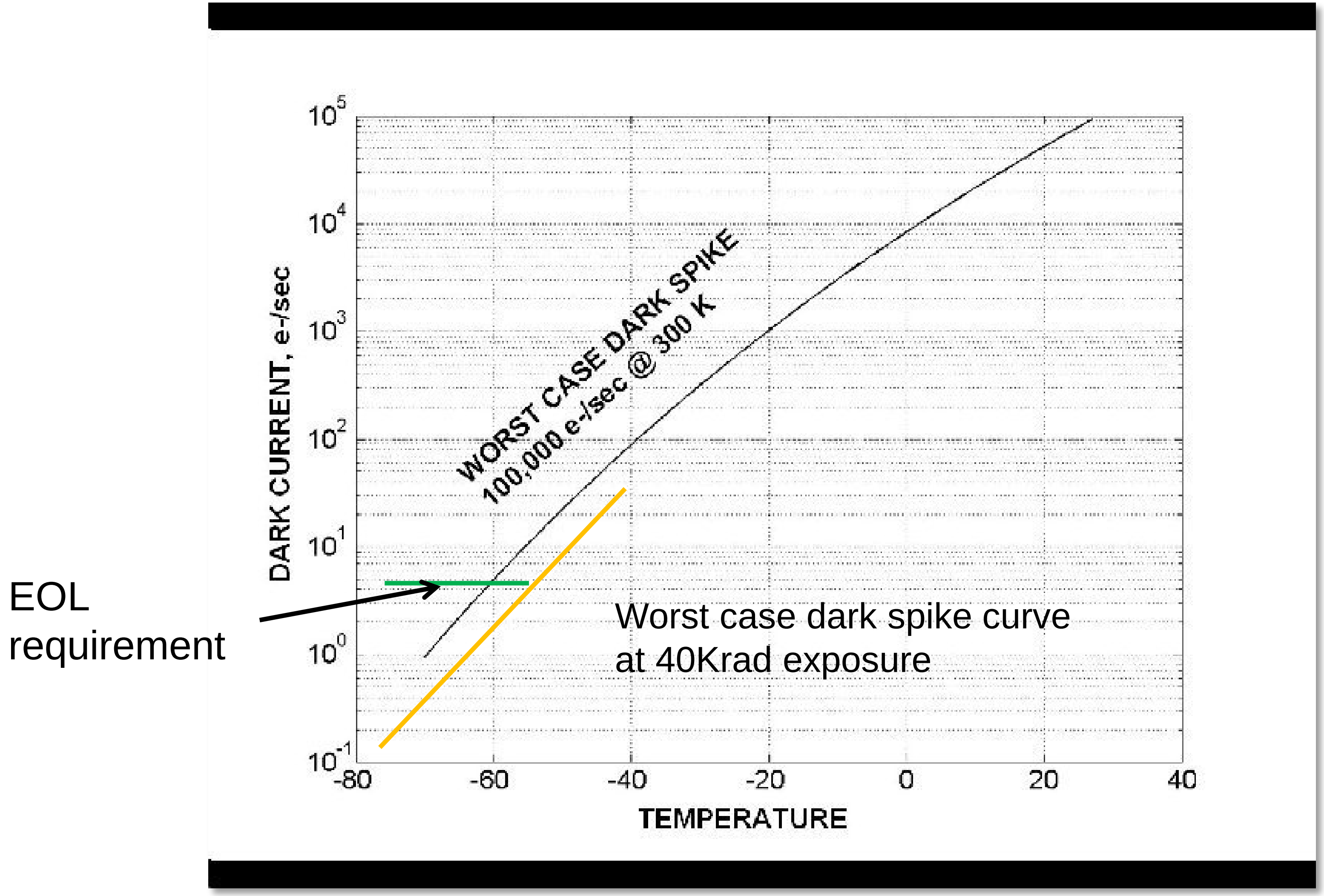


Initial Proton Testing Results
Dark Current Measurements



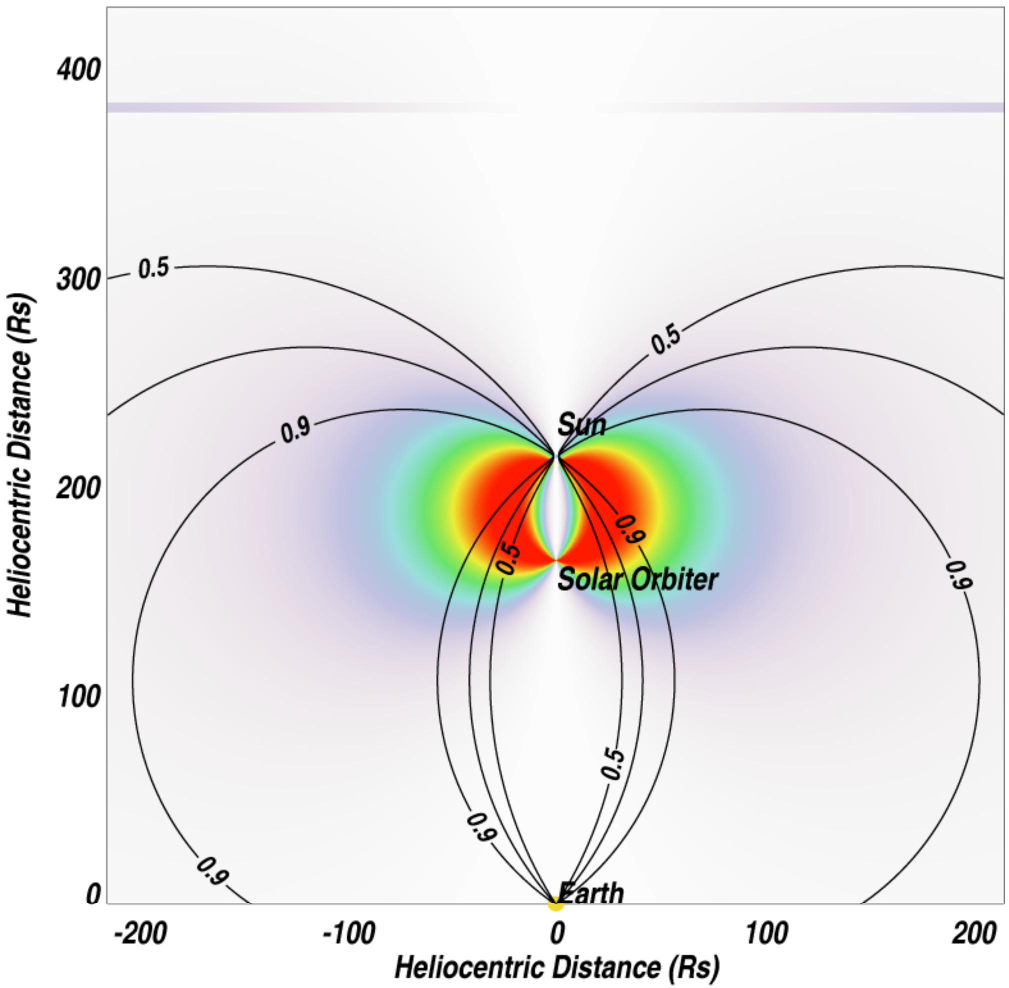


Dark Current Expected Performance



SoloHI Will Lead to Unique Science

- The Varying Heliocentric Distance Transforms SoloHI From a Remote (at Aphelia) to a Local (at Perihelia) Imager
- SoloHI Is the First Imager to Provide Density Power Spectra at Rates Similar to *in-situ* Instruments (~1min) but at Multiple Locations at Once
- SoloHI Is the Only Instrument to Image Shocks and Connect the SEP Sources to the *in-situ* Measurements
- SoloHI Will Provide the First Measurements of the Dust 3D Distribution in the Inner Heliosphere
- SoloHI Only Possibility for Flyby Studies of Sungrazing Comets



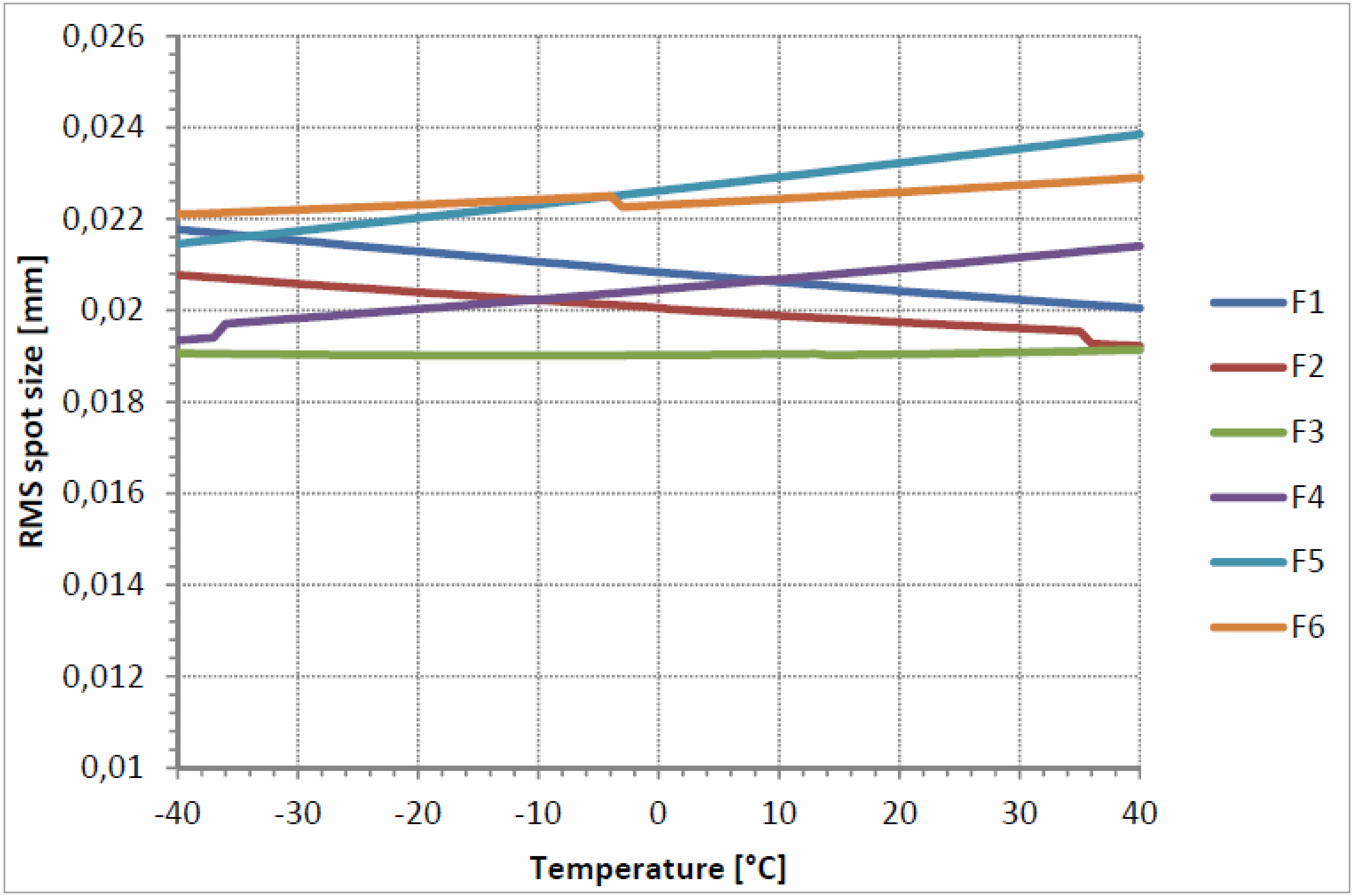
Back Up

SoloHI Team

- Instrument Provider
  - Naval Research Laboratory

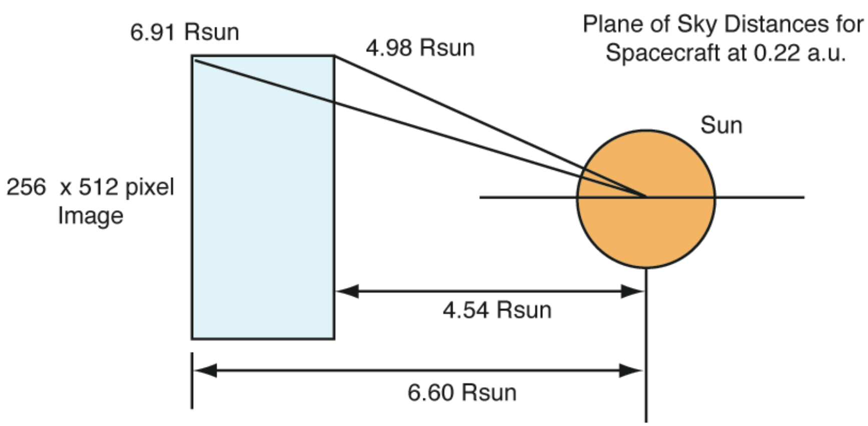
- Co-Investigators
  - US Funded
    - Naval Research Laboratory
    - Jet Propulsion Laboratory
  - Contributed Funding
    - Centre Spatiale de Liege (Belgium)
    - Rutherford Appleton Laboratory (UK)
    - University of Gottingen (Germany)
    - Laboratoire d’Astronomie Marseille (France)
    - Institute d’Astrophysique Spatiale (France)

Spot Size vs Temperature



Wave Turbulence Image Scene for Perihelion 10-Day Period

Wave Turbulence Program Scene at Perihelion

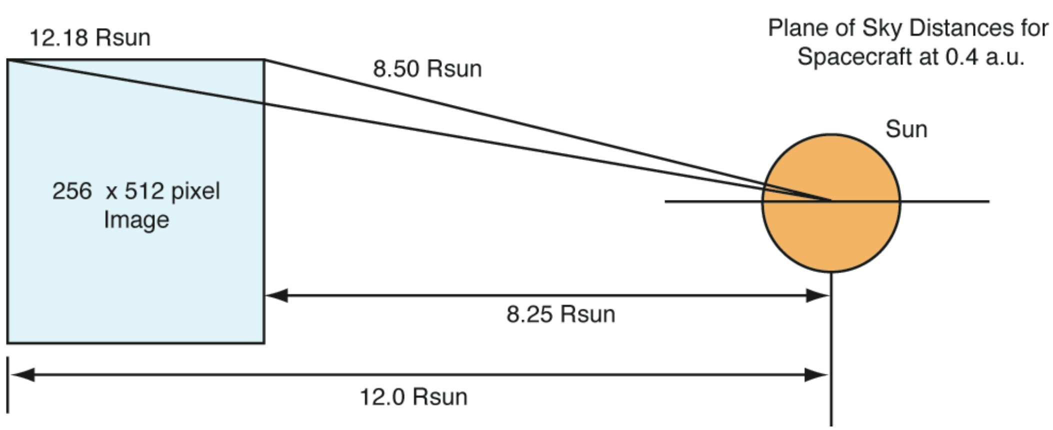


Scene Coverage for Wave Turbulence

- Perihelion: 4.5 – 6.9 R_{sun}
- Perihelion ±5 days: 8.3 – 12.2 R_{sun}

Restricted Radial Extent allows Photometric Accuracy Reqt to be satisfied with Higher Cadence Reqt (< 1 min)

Wave Turbulence Program Scene at Perihelion ± 5 days



SoloHI Science Requirement Traceability Matrix (1 of 3)

Science Objective	2.1 How and where does the solar wind plasma and magnetic field originate in the corona?					2.2 How do solar transients drive heliospheric variability?		
Science Question #	2.1.1	2.1.2	2.1.3			2.2.1		
Science Question	What are the source regions of the solar wind and heliospheric magnetic field?	What mechanisms heat and accelerate the solar wind?	What are the sources of solar wind turbulence and how does it evolve?			How do CMEs evolve through the corona and inner heliosphere?		
Science Product ID	2.1.1a	2.1.2a	2.1.3a			2.2.1a		
Derived Science Products	Global maps of H and He flow velocities and He fractions (METIS, SoloHI)	Velocities and mass density of evolving structures (SoloHI, METIS)	Link evolution of CME properties in the corona to those measured *in-situ* (SoloHI, METIS)			Link evolution of CME properties in the corona to those measured *in-situ* (SoloHI, METIS)		
Science Measurements	Images of coronal and heliospheric solar wind structures in visible	Height-time plot and mass measurements of solar wind features	High cadence images of coronal and heliospheric structures in visible			Height-time plot and mass measurements of CMEs		
Type and Number of Events Captured Over Baseline Science Mission	• Quiescent wind for 3 days • Active wind for 3 days • Pseudo streamers for 3 days	• Quiescent wind for 3 days • Active wind for 3 days • Pseudo streamers for 3 days	Density power spectrum centered at 7 Rsun, 15 Rsun, 20 Rsun at the 0.28 a.u. perihelion			≥ 2 ICMEs		
Type and Number of Events Captured Over Threshold Science Mission	• Quiescent wind for 3 days • Active wind for 3 days	• Quiescent wind for 3 days • Active wind for 3 days	Density power spectrum centered at 7 Rsun at the 0.28 a.u. perihelion			≥ 1 ICME		
Required (R) or Supporting (S) Measurement	S	R	R			R		
Observation Requirements								
Instrument Distance From Sun (a.u.)	0.28 to 0.36	0.28 to 0.36	0.28 to 0.36			0.28 to 0.36	0.36 to 0.5	0.5 to 0.7
Spacecraft Solar Latitude	N/A	N/A	N/A			N/A		
Image Type	Visible broadband	Visible broadband	Visible broadband			Visible broadband		
Scene Radial Coverage	5.5 to 25°	5.5 to 40.5°	5.8 to 7.675°	13.5 to 15.375°	18.5 to 20.375°	5.5 to 44.5°	5.5 to 40.5°	5.5 to 30.5°
Scene Transverse Coverage	26°	5°	5°	5°	5°	26°		
Image Spatial Resolution	≤ 3.0 arcmin	≤ 2.7 arcmin	≤ 2.3 arcmin	≤ 2.6 arcmin	≤ 2.6 arcmin	≤ 3.0 arcmin		
Photometric Accuracy	≥ 20 [1] ≥ 5 [2]	≥ 20 [1] ≥ 5 [2]	≥ 16	≥ 16	≥ 16 [a] ≥ 12 [b]	≥ 20 [1] ≥ 5 [2]	≥ 20 [1] ≥ 5 [2]	≥ 20 [3] ≥ 5 [4]
Cadence	≤ 30 min	≤ 15 min	≤ 10 sec [a] ≤ 15 sec [b]	≤ 1 min	≤ 2 min	≤ 30 min[a, 5b] ≤ 60 min[6b]	≤ 40 min [5] ≤ 80 min [7] ≤ 120 min [8]	≤ 40 min [5] ≤ 80 min [9] ≤ 140 min [10]
Science Observation Period Per Day	24 hrs	24 hrs	≥ 4 hrs	≥ 4 hrs	≥ 4hrs	24 hrs		
Science Observation Days Per Orbit	≥ 14	≥ 6	≥ 4	≥ 4	≥ 4	≥ 14	≥ 12	≥ 1
Science Observation Days for Baseline Science Mission	≥ 98	≥ 42	8 [a], 24 [b]	8 [a], 24 [b]	8 [a], 24 [b]	≥ 98	≥ 92	≥ 16
Science Observation Days for Threshold Science Mission	≥ 14	≥ 6	2 [a], 3 [b]	2 [a], 3 [b]	2 [a], 3 [b]	≥ 14	≥ 14	≥ 1

SoloHI Science Requirement Traceability Matrix (2 of 3)

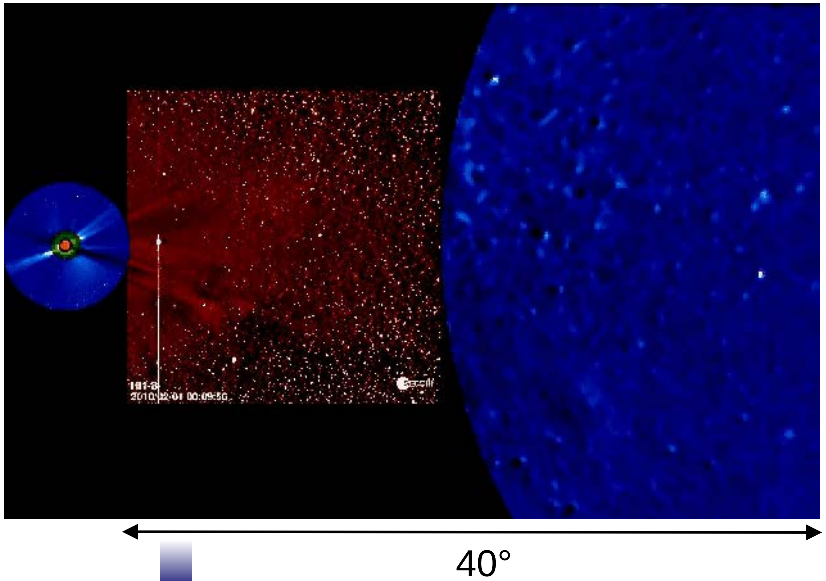
Science Objective	2.2 How do solar transients drive heliospheric variability?								
Science Question #	2.2.2			2.2.3					
Science Question	How do CMEs contribute to solar magnetic flux and helicity balance?			How and where do shocks form in the corona?					
Science Product ID	2.2.2a			2.2.3a		2.2.3b		2.2.3c	
Derived Science Products	Map source regions to *in-situ* properties: magnetic connectivity, polarity and helicity (EUI, METIS, SPICE, SoloHI, SWA, MAG, EPD)			Timing of eruptions and coronal manifestations (EUI, SoloHI)		Location, intensity, thermal/non-thermal distribution of erupting regions (SoloHI, RPW)		Position and speed of shocks (SPICE, METIS, SoloHI, RPW, EUI)	
Science Measurements	Height-time plot and mass measurements of CMEs			High cadence height-time plots and mass measurements of CME fronts					
Type and Number of Events Captured Over Baseline Science Mission	≥ 2 ICMEs			≥ 2 ICMEs with an accompanying shock		≥ 2 ICMEs		≥ 2 ICMEs with an accompanying shock	
Type and Number of Events Captured Over Threshold Science Mission	≥ 1 ICME			≥ 1 ICME		≥ 1 ICME		≥ 1 ICME	
Required (R) or Supporting (S) Measurement	S			R		S		R	
Observation Requirements									
Instrument Distance From Sun (a.u.)	0.28 to 0.36	0.36 to 0.5	0.5 to 0.7	0.28 to 0.36	0.36 to 0.5	0.28 to 0.36	0.36 to 0.5	0.28 to 0.36	0.36 to 0.5
Spacecraft Solar Latitude	N/A			N/A					
Image Type	Visible broadband			Visible broadband					
Scene Radial Coverage	5.5 to 44.5º	5.5 to 40.5º	5.5 to 30.5º	5.5 to 40.5º	5.5 to 30.5º	5.5 to 40.5º	5.5 to 30.5º	5.5 to 40.5º	5.5 to 30.5º
Scene Transverse Coverage	26º			5º					
Image Spatial Resolution	≤ 3.0 arcmin			≤ 2.7 arcmin					
Photometric Accuracy	≥ 20 [1] ≥ 5 [2]	≥ 20 [1] ≥ 5 [2]	≥ 20 [3] ≥ 5 [4]	≥ 20 [1] ≥ 5 [2]	≥ 20 [1] ≥ 5 [2]	≥ 20 [1] ≥ 5 [2]	≥ 20 [1] ≥ 5 [2]	≥ 20 [1] ≥ 5 [2]	≥ 20 [1] ≥ 5 [2]
Cadence	≤ 30 min[a, 5b] ≤ 60 min[6b]	≤ 40 min [5] ≤ 80 min [7] ≤ 120 min [8]	≤ 40 min [5] ≤ 80 min [9] ≤ 140 min [10]	≤ 6 min[a, 5b] ≤ 15 min[6b]	≤ 6 min [5] ≤ 15 min [12c] ≤ 18 min [11d]	≤ 6 min[a, 5b] ≤ 15 min[6b]	≤ 6 min [5] ≤ 15 min [12c] ≤ 18 min [11d]	≤ 6 min[a, 5b] ≤ 15 min[6b]	≤ 6 min [5] ≤ 15 min [12c] ≤ 18 min [11d]
Science Observation Period Per Day	24 hrs			24 hrs	≥ 16 hrs	24 hrs	≥ 16 hrs	24 hrs	≥ 16 hrs
Science Observation Days Per Orbit	≥ 14	≥ 12	≥ 1	≥ 6	≥ 1	≥ 6	≥ 1	≥ 6	≥ 1
Science Observation Days for Baseline Science Mission	≥ 98	≥ 92	≥ 16	≥ 42	≥ 13	≥ 42	≥ 13	≥ 42	≥ 13
Science Observation Days for Threshold Science Mission	≥ 14	≥ 14	≥ 1	≥ 6	≥ 1	≥ 6	≥ 1	≥ 6	≥ 1

SoloHI Science Requirement Traceability Matrix (3 of 3)

Science Objective	2.3 How do solar eruptions produce energetic particle radiation that fills the heliosphere?						2.4 How does the solar dynamo work and drive connections between the Sun and the heliosphere?					
Science Question #	2.3.1						2.4.1		2.4.2		2.4.3	
Science Question	How and where are energetic particles accelerated at the Sun?						What is the three-dimensional structure and extent of streamers and CMEs?		How are variations in the solar wind linked to the Sun at all latitudes?		What are the sources and properties of dust in the inner heliosphere, and do Sun-grazing comets contribute to this dust?	
Science Product ID	2.3.1a		2.3.1b		2.3.1c		2.4.G1a		2.4.G2a		2.4.G3a	
Derived Science Products	UV and X-ray imaging of loops, flares, and CMEs (EUI, SPICE, STIX, METIS, SoloHI)		Location, timing, and motion of CMEs and shocks (EUI, SoloHI)		Images of longitudinal extent of CMEs in visible, UV, and hard X-rays (SoloHI, METIS, EUI, SPICE, STIX)		Measure the dynamic three-dimensional structures of streamers and CMEs at all latitudes (SoloHI, METIS*)		Observe morphology and dynamics of boundaries between streamers and coronal holes (SoloHI, EUI*, METIS*)		Measure F-corona brightness, morphology, and variability as a function of ecliptic latitude (SoloHI)	
Science Measurements	High cadence height-time plots and mass measurements of CME fronts						Images of coronal and heliopheric solar wind structures in visible		Images of coronal and heliospheric solar wind structures in visible		Images of coronal dust in visible	
Type and Number of Events Captured Over Baseline Science Mission	≥ 2 ICMEs		≥ 2 ICMEs		≥ 2 ICMEs		• Quiescent, active wind and pseudo streamers for 2 days • ≥ 1 CME at each latitudinal extreme		Quiescent, active wind and pseudo streamers for 2 days at each latitudinal extreme		≥ 1 Sun-grazing comet with a tail	
Type and Number of Events Captured Over Threshold Science Mission	≥ 1 ICME		≥ 1 ICME		≥ 1 ICME		N/A		N/A		N/A	
Required (R) or Supporting (S) Measurement	S		R		R		R		R		R	
Observation Requirements												
Instrument Distance From Sun (a.u.)	0.28 to 0.36	0.36 to 0.5	0.28 to 0.36	0.36 to 0.5	0.28 to 0.36	0.36 to 0.5	0.36 to 0.50	0.5 to 0.70	0.36 to 0.50	0.5 to 0.70	0.36 to 0.50	0.5 to 0.70
Spacecraft Solar Latitude	N/A						≥ 15°	≤ -15°	≥ 15°	≤ -15°	≥ 15°	≤ -15°
Image Type	Visible broadband						Visible broadband		Visible broadband		Visible broadband	
Scene Radial Coverage	5.5 to 40.5°	5.5 to 30.5°	5.5 to 40.5°	5.5 to 30.5°	5.5 to 40.5°	5.5 to 30.5°	5.5 to 40.5°	5.5 to 30.5°	5.5 to 40.5°	5.5 to 30.5°	5.5 to 40.5°	5.5 to 30.5°
Scene Transverse Coverage	5°						26°		26°		26°	
Image Spatial Resolution	≤ 2.7 arcmin						≤ 3.0 arcmin		≤ 3.0 arcmin		≤ 6.0 arcmin	
Photometric Accuracy	≥ 20 [1] ≥ 5 [2]	≥ 20 [1] ≥ 5 [2]	≥ 20 [1] ≥ 5 [2]	≥ 20 [1] ≥ 5 [2]	≥ 20 [1] ≥ 5 [2]	≥ 20 [1] ≥ 5 [2]	≥ 20 [1] ≥ 5 [2]	≥ 20 [3] ≥ 5 [4]	≥ 20 [1] ≥ 5 [2]	≥ 20 [3] ≥ 5 [4]	≥ 20	
Cadence	≤ 30 min		≤ 6 min [a, 5b] ≤ 15 min [6b]	≤ 6 min [5] ≤ 15 min [12c] ≤ 18 min [11d]	≤ 30 min		≤ 40 min [5] ≤ 80 min [7] ≤ 120 min [8]	≤ 40 min [5] ≤ 80 min [9] ≤ 140 min [10]	≤ 120 min	≤ 120 min [5,9] ≤ 150 min [10]	≤ 120 min	
Science Observation Period Per Day	24 hrs	≥ 16 hrs	24 hrs	≥ 16 hrs	24 hrs	≥ 16 hrs	24 hrs		24 hrs		24 hrs	
Science Observation Days Per Orbit	≥ 6	≥ 1	≥ 6	≥ 1	≥ 6	≥ 1	≥ 4	≥ 4	≥ 4	≥ 4	≥ 4	≥ 4
Science Observation Days for Baseline Science Mission	≥ 42	≥ 13	≥ 42	≥ 13	≥ 42	≥ 13	≥ 12	≥ 12	≥ 12	≥ 12	≥ 12	≥ 12
Science Observation Days for Threshold Science Mission	≥ 6	≥ 1	≥ 6	≥ 1	≥ 6	≥ 1	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2

* Science data products from other Solar Orbiter instruments will address the science question better, but is not required

Deriving Science/Instrument Requirements



Solar Wind Turbulence

→ High Cadence Imaging

- FOV: 5.8° - 7.7°
- Cadence: < 10 sec
- Resolution: <2.3 arcmin

Solar Wind Acceleration

→ Height-Time Plots of Features

- FOV: 5.5° – 40.5°
- Cadence: < 15 min
- Resolution: <2.7 arcmin

Science Measurement Requirements for Baseline/Threshold Investigation

Science Product ID	Measured Parameters	Cadence (Temporal Resolution)	Spatial Range (FoV)	Spatial Resolution	Duration/Events/Features /Orbital Location?	Baseline Criteria Impact	Threshold Criteria Impact
2.1.1a	Images of coronal and heliospheric solar wind structures in visible	30 min	35° x 35°	5 arc min	Three different types, each for 3 days: quiescent, active, pseudo streamers	Green	Green
2.1.2a	Height-time plot and mass measurements of solar wind features	15 min	35° x 5°	5 arc min	Three different types, each for 3 days: quiescent, active, pseudo streamers	Green	Yellow
2.1.3a	High cadence images of coronal and heliospheric structures in visible	at least 2 min	3° x 5°	2.5 arc min	Density power spectra at three distances (7,15,20 Rs) for 4-hrs/day	Green	Red
2.2.1a	Height-time plot and mass measurements of CMEs	30 min	40° x 40°	5 arc min	≥ 2 CMEs	Green	Green
2.2.2a	Height-time plots and forward modeling of CMEs	30 min	40° x 40°	5 arc min	≥ 2 CMEs	Green	Green
2.2.3a	High cadence Height-time plots & mass measurements of CME fronts	6 min	35° x 5°	2.5 arc min	≥ 2 CMEs with shocks	Green	Red
2.2.3b	High cadence Height-time plots & mass measurements of CME fronts	5 min	35° x 5°	2.5 arc min	≥ 2 CMEs	Green	Red
2.2.3c	High cadence Height-time plots & mass measurements of CME fronts	6 min	35° x 5°	2.5 arc min	≥ 2 CMEs with shocks	Green	Red
2.3.1a	High cadence Height-time plots & mass measurements of CME fronts	30 min	40° x 5°	5 arc min	≥ 2 CMEs	Green	Green
2.3.1b	High cadence Height-time plots & mass measurements of CME fronts	6 min	40° x 5°	2.5 arc min	≥ 2 CMEs	Green	Red
2.3.1c	High cadence Height-time plots & mass measurements of CME fronts	30 min	40° x 5°	5 arc min	≥ 2 CMEs	Green	Green
2.4. 1	Images of coronal and heliospheric solar wind structures in visible	60 min	40° x 40°	5 arc min	Three different types, each for 3 days: quiescent, active, pseudo streamers	Green	Green

Variable Scene and Resolution

The Continuously Changing Scene and Resolution

- Lead to Different Science Targets for Each Orbit
- Require Flexible Observing Plans

	Scene Radial Coverage (deg)											
	0.28 a.u.		0.29 a.u.		0.36 a.u.		0.42 a.u.		0.50 a.u.		0.70 a.u.	
	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer
Full Frame Image	5.5	44.5	5.5	44.5	5.5	44.5	5.5	44.5	5.5	44.5	5.5	30.5
Inner FOV Subframe Image centered at 7 Rsun	5.8	7.675	5.8	7.675	5.8	7.675	5.8	7.675				
Inner FOV Subframe Image centered at 15 Rsun	13.5	15.375	13.5	15.375	13.5	15.375	13.5	15.375				
Inner FOV Subframe Image centered at 20 Rsun	18.5	20.375	18.5	20.375	18.5	20.375	18.5	20.375				
Radial Swath Subframe Image	5.5	40.5	5.5	40.5	5.5	40.5	5.5	30.5	5.5	30.5	5.5	23.5

	Scene Radial Coverage on Thompson Surface (Rsun)											
	0.28 a.u.		0.29 a.u.		0.36 a.u.		0.42 a.u.		0.50 a.u.		0.70 a.u.	
	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer
Full Frame Image	5.8	42.2	6.0	43.7	7.4	54.3	8.7	63.3	10.3	75.4	14.4	76.4
Inner FOV Subframe Image centered at 7 Rsun	6.1	8.0	6.3	8.3	7.8	10.3	9.1	12.1				
Inner FOV Subframe Image centered at 15 Rsun	14.1	16.0	14.6	16.5	18.1	20.5	21.1	24.0				
Inner FOV Subframe Image centered at 20 Rsun	19.1	21.0	19.8	21.7	24.6	27.0	28.7	31.5				
Radial Swath Subframe Image	5.8	39.1	6.0	40.5	7.4	50.3	8.7	45.9	10.3	54.6	14.4	60.0

Baseline Observing Programs for Perihelion Period

	Perihelion Region						
Observing Program ID	**A1.1**	**A1.2**	**B1.1**	**B1.2**	**B1.3**	**C1.1**	**C1.2**
Program Description	Synoptic		Wave Turbulence			Shock Formation	
Image Type	Full Frame		Inner FOV Subframe			Radial Swath Subframe	
Radial FOV	[5°, 25°]	[25°, 45°]	[5.80°, 7.68°]	[13.5°, 15.375°]	[18.5°, 20.375°]	[5°, 25°]	[25°, 45°]
Transverse FOV	40°		5°			5°	
Binning	2 x 2		1 x 1	2 x 2	2 x 2	2 x 2	
Image Size w/Binning	1024 x 2048	1024 x 2048	192 x 512	96 x 256	96 x 256	1024 x 256	1024 x 256
Maximum # of Images in Summed Image	4	32	8	12	16	4	32
Compression Type	H-Compress	Rice	H-Compress	Rice	Rice	H-Compress	Rice
Compressed Image Size (MB)	1.3	3.0	0.06	0.03	0.03	0.16	0.37
Image Cadence	30.0 min		0.13 min	0.77 min	1.54 min	5.54 min	
Images per Day	**48**		**1872**	**312**	**156**	**260**	
Observing Period per Day	24 hrs		4 hrs each			24 hrs	
Observing Days per Orbit	4		2			2	

SoloHI Observing Program Telemetry Estimate

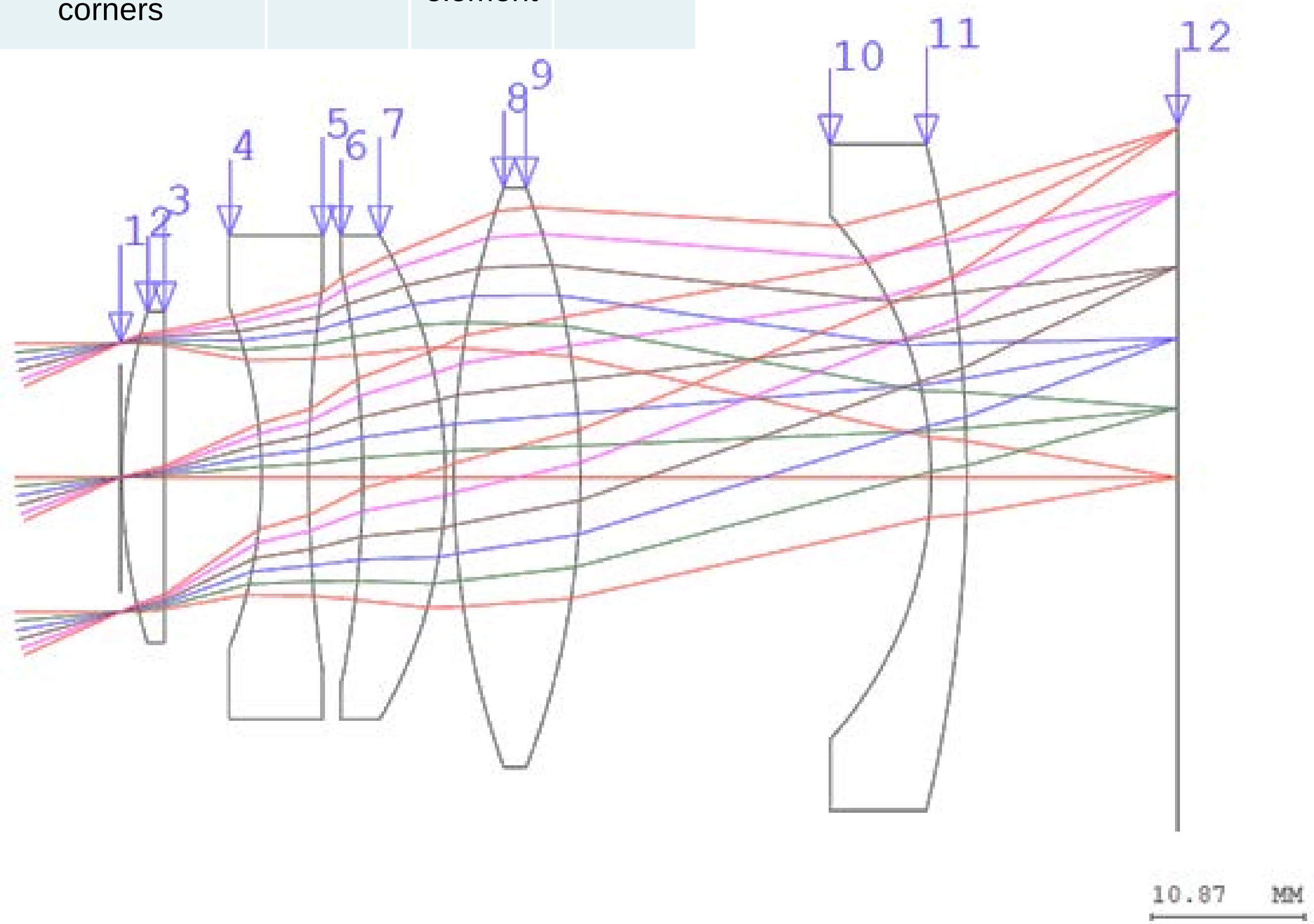
	Observing Duration in Single Orbit (days)	Daily Science Data Estimate (Gbits)	Daily Data Volume Estimate (Gbits)	SoloHI Data Rate (kbps)	Orbit Science Data Estimate (Gbits)	Orbit Data Volume Estimate (Gbits)
Perihelion Observing Programs						
Solar Wind Turbulence Program	2	2.78	2.95	34.2	5.56	5.91
Shock Formation Program	2	2.90	3.08	35.6	5.79	6.15
Near Perihelion Observing Programs						
Synoptic Observing Program	10	1.12	1.21	14.0	3.36	3.62
Solar Wind Turbulence Program	3	1.73	1.85	21.4	5.20	5.55
Shock Formation Program	4	1.88	2.01	23.2	7.52	8.03
Far Perihelion Observing Programs						
Synoptic Observing Program	12	1.27	1.36	15.7	13.93	14.97
Shock Formation Program	1	2.10	2.24	25.9	2.10	2.24
Northern Latitude Observing Programs						
Synoptic Observing Program	2	1.17	1.24	14.3	2.35	2.47
Southern Latitude Observing Programs						
Synoptic Observing Program	2	1.13	1.22	14.1	1.13	1.22
Shock Formation Program	1	1.58	1.69	19.6	1.58	1.69
Observing Program Totals for:						
Perihelion (4 days)			**3.02**	**34.90**	11.4	12.1
Near Perihelion (10 days)			**1.72**	**19.91**	16.1	17.2
Far Perihelion (12 days)			**1.43**	**16.59**	16.0	17.2
Northern (2 days)			**1.24**	**14.30**	2.3	2.5
Southern (2 days)			**1.46**	**16.84**	2.7	2.9
Orbit (30 days)				**20.00**	**48.5**	**51.9**

Baseline Observing Programs Satisfy the 20 kbps Telemetry Data Rate Requirement

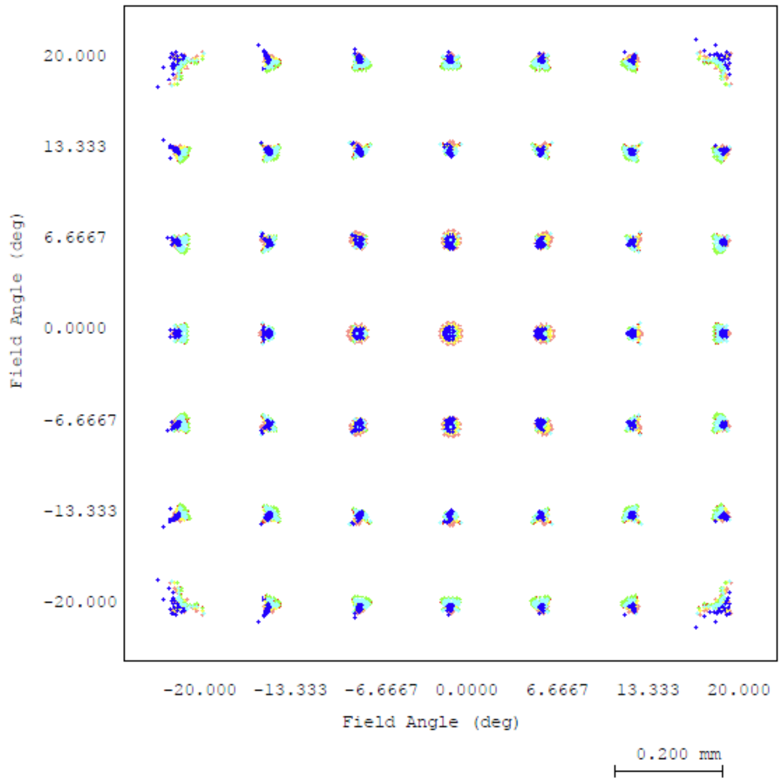
Optical Design

Telescope FOV	Detector FOV	Spectral Range (nm)	Entrance Pupil (mm)	F#	# of lenses	RMS Spot Size (µm)
M 48º	40º x 40º	500-700	16 x 16 llimited to 19 mm diameter in the corners	3.4	5-element	19-23

Low Pass Filter S9
High Pass Filter S7

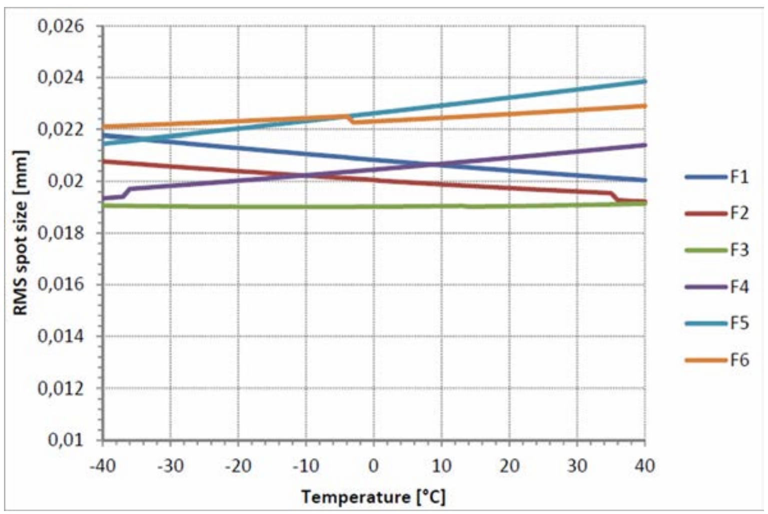


Spot Diagram



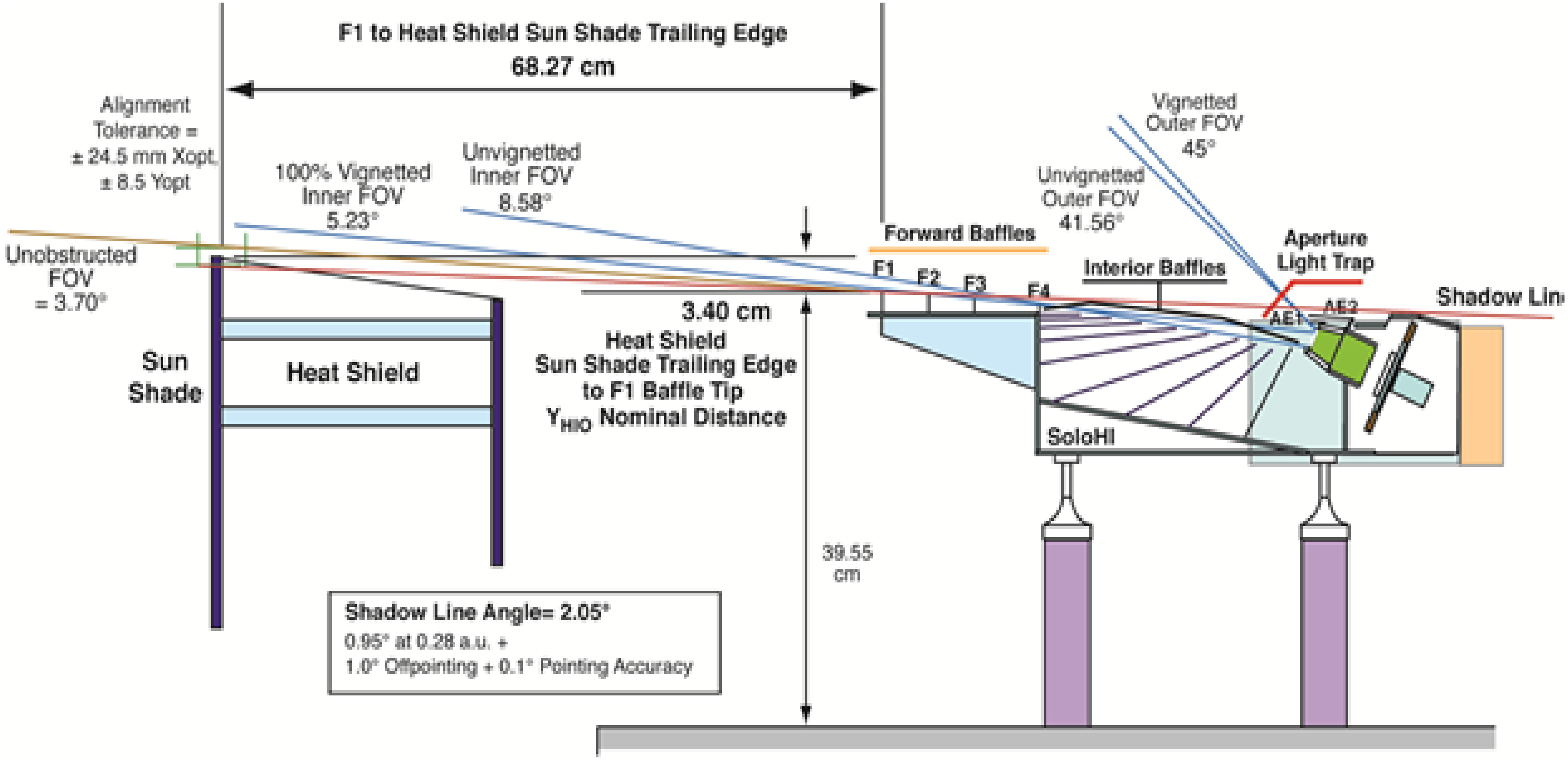
#	RMS spot [mm]
1	0.0213
2	0.0204
3	0.0189
4	0.0196
5	0.0214
6	0.0225

RMS spot diameter in nominal conditions.



Spot Size vs Temperature

Cross Section of SoloHI



- The instrument is designed to reduce stray light to acceptable levels by a series of baffles – the sun shade/heat shield on the spacecraft is the first “baffle”.

Solar Orbiter Level-1 Science Objectives/Questions

- How and Where Do the Solar Wind Plasma and Magnetic Field Originate in the Corona?
  - What Are the Source Regions of the Solar Wind and Heliospheric Magnetic Field?
  - What Mechanisms Heat and Accelerate the Solar Wind?
  - What Are the Sources of Solar Wind Turbulence and How Does It Evolve?
- How Do Solar Transients Drive Heliospheric Variability?
  - How Do CMEs Evolve Through the Corona and Inner Heliosphere?
  - How Do CMEs Contribute to Solar Magnetic Flux and Helicity Balance?
  - How and Where Do Shocks Form in the Corona?
- How Do Solar Eruptions Produce Energetic Particle Radiation?
  - How and Where Are Energetic Particles Accelerated at the Sun?
- How Does the Solar Dynamo Work and Drive Connections Between the Sun and the Heliosphere?
  - How Are Variations in the Solar Wind Linked to the Sun at All Latitudes?
  - What Is the 3-Dimensional Structure and Extent of Streamers and CMEs?
- Additional SoloHI Goals/Questions
  - What Are the Sources and Properties of Dust in the Inner Heliosphere, and Do Sun-Grazing Comets Contribute to the Dust?

The Role of SoloHI on Solar Orbiter

- SoloHI Will Image
  - The Solar Wind Structures and Fluctuations Directly.
  - The Solar Wind Environment Around Planets and Other Missions.
  - CME and Shock Propagation and Evolution and Their Connection to the Site of Production of SEPs.

- SoloHI Will Measure Electron Density Turbulence
  - Fast Cadence Readout Mode To Generate Power Spectral Density to Compare to In-Situ Observations of Density and Magnetic Field Spectral Density.

- SoloHI Provides The Links Between the
  - Solar Orbiter Remote Sensing and *in-situ* Instruments.
  - Solar Orbiter and Solar Probe+ Missions.