1. FPP Science Goals

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3. FPP Instrument Design Overview
   - Narrowband Filter Imager
   - Broadband Filter Imager
   - Spectropolarimeter

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Primary FPP Science Goals

- **Magnetic Flux Transport**
  - Observe how magnetic flux emerges, disperses, and disappears from the solar surface, including weak internetwork fields (B ~400 G).
  - Determine whether magnetic field is generated in or near the surface: *fast dynamo action*.
- **Convective Energy Scales**
  - Understand the origin of the granulation, mesogranulation, and supergranulation.
- **Sunspots and Active Regions**
  - Determine the vector magnetic field of sunspots and plage.
  - Observe the formation, dynamics, and decay of entire active regions.
- **Upper Atmospheric Connections**
  - Understand the role of the surface magnetic field in the structure and dynamics of the outer atmosphere.
- **Solar Cycle Evolution**
  - Understand the role of active regions in solar cycle modulation.

Level 0 Requirements

- **Vector magnetic field measurement**
  - •Polarmetric precision > 0.01%: measure elemental flux tubes.
- **Spatial Resolution 0.2 arcseconds**
  - • Preserve imaging fidelty of SOT from 3800 - 6800 A.
- **Field of view *O(*100 arcseconds*)***
  - •Capture entire active regions and significant portions of surrounding quiet network.
- **Image stabilization system**
  - •Stabilize SC jitter to < 0.02 arcsec over range of 2 -- 30 Hz.
- **Science Instruments**
  - • Narrowband Tunable Filter: wide FOV, fast cadence magnetograms and dopplergrams.
  - • Broadband Filter Instrument: highest spatial and temporal resolution filtergrams.
  - • Spectropolarimeter: <0.01% precision Stokes vector measurements.

SOT/FPP Design Summary

- **SOT**: **Solar Optical Telescope** aka Optical Telescope Assembly (OTA)
  - 1/2-meter class for 0.2 arcsecond resolution in visible.
  - Axisymmetric design for minimal instrumental polarization.
- **OTU: Optical Transfer Unit**
  - Polarization modulator
  - Tip/Tilt Mirror
- **NFI: Narrowband Filter Imager**
  - Tunable Lyot filter: maximum FOV with uniform bandwidth
- **BFI: Broadband Filter Imager**
  - Interference filters for maximal bandwidth and low optical distortion.
- **SP: Spectropolarimeter**
  - Fe I 6302A line: fixed retardation rotating modulator for high precision Stokes polarimetry.
- **CT: Correlation Tracker**
  - Real-time cross-correlation with updated reference image drives Tip/Tilt mirror.

Optical Bench Unit (OBU)

SOT/OTA System Overview

- **0.5 meter Gregorian Telescope**
  - Primary focal plane allows heat rejection mirror and "field stop" for optimal thermal control.
- **400" X 400" FOV defined by field stop.**
- **Diffraction limited wavelength range: 3968 (3800 goal) to 6700 A**
- **Collimator Lens Unit (CLU)**
  - Passes collimated 30 mm beam to OTU with known pupil location.
- **UV and IR rejection filters at field stop reduce heat load on focal plane.**

OTU System Overview

- **Polarization Modulator**
  - Immediately follows CLU for optimal polarization modulation.
  - Quartz substrate ~0.25 wave retarder and linear polarizer at 6302 .
  - 1.6 second rotation period.
  - DC hollow core motor - continual operation throughout mission lifetime.
  - Multiple wedged optics to minimize beam wobble (POLIS design).
- **Tip/Tilt Mirror System**
  - ISAS design and manufacture.
  - Provides 2-axis image stabilization of 0.02 arcseconds up to 30 Hz bandwidth.

NFI System Overview

- **Tunable Lyot Filter System**
  - 9-calcite wide-field elements in series.
  - Hollow-core DC motor control - fully sealed chamber.
  - Temperature calibrated.
  - 0.2 arcsecond spatial resolution over range from 5100 -- 6600 A.
  - 0.3 - 1 second temporal resolution for filtergrams; 0.1 second for Stokes images.
  - Spectral resolution 60--100 mA.
  - Polarization precision 0.1 - 1 %.
- **FOV selectable via focal plane mask**
  - 320” x 160” wide FOV (some vignetting in corners) for filtergrams, dopplergrams, and longitudinal (Stokes V) magnetograms.
  - 160” x 160” active region FOV.
  - 80” x 160” narrow FOV for full Stokes vector mapping (I,Q,U,V) in 10 seconds.
- **Common Focal plane with BFI**
  - 2048 x 4096 back illuminated frame transfer CCD, 0.08 arcsecond pixels.

NFI Observables

- **Filtergrams**
  - Arbitrary wavelength within in any line and nearby continuum.
- **Dopplergrams**
  - Made on-board by FPP computer from 4 or more filtergrams in a line
- **Longitudinal Magnetograms**
  - Made on-board by FPP computer from filtergrams converted to Stokes I & V.
- **Stokes Vector Elements**
  - I, Q, U, and V made on-board from filtergrams taken at 6--8 phases of the polarization modulator.
  - Shutterless mode for higher time resolution or sensitivity but with smaller FOV.
  - On-board processing in FPGA smart memory similar to SP algorithm.

NFI Spectral Lines

Ion	Wavelength	g,eff	Purpose
Mg Ib	5172.7 A	1.75	Low chromosphere magnetograms, dopplergrams, Stokes vectors
Fe I	5247.1	2.00	Secondary photospheric magnetic line.
Fe I	5250.2	3.00	Used with 5247 line for ratio analyses.
Fe I	5250.6	1.50	"
Fe I	5576.1	0.00	Photospheric dopplergrams
Fe I	6301.5	1.67	Secondary photospheric magnetic line
Fe I	6302.5	2.50	Primary photospheric magnetic line Stokes comparisons with SP
Ti I	6303.8	0.92	Sunspot umbral magnetogram line
HeNe	6328.1		Laser alignment and testing line
H I	6563		H-alpha chromospheric filtergram and dopplergram line.

BFI System Overview

- **Provides filtergrams with highest possible spatial and temporal resolution over largest FOV: maximize telescope useage.**
- **FOV: shutter selectable**
  - 160” x 160” CCD center area (2048 x 2048 0.08 arcsecond pixels)
  - 320” x 160” CCD full array exposure (4096 x 2048 0.08 arcsecond pixels)
- **Spectral range 3880 -- 6800 A**
- **Temporal resolution < 5 sec for 160 x 160 arcsec FOV**
- **Photometric Accuracy < 2% for continuum irradiance measurement.**
- **Common Focal Plane with NFI**
  - 2048 x 4096 back illuminated frame transfer CCD, 0.08 arcsecond pixels.

BFI Interference Filters

Center	FWHM	Purpose	
3883.5 A	10	CN molecular bandhead: chromospheric network	
3968.5 A	3	Ca II H-line: magnetic elements in low chromosphere	
4305.0 A	10	CH G-band molecular bandhead: magnetic elements in photosphere; convection flowmapping.	
4505.5 A	5	Blue continuum window	Measure continuum irradiance
5550.5 A	5	Green continuum window	
6684.0 A	5	Red continuum window	

SP System Overview

- **F/31 Littrow design**
  - Off-axis paraboloid mirror avoids Littrow lens radiation damage issues.
- **Slit: 160” x 0.16”**
  - Maximum map FOV = 320” x 160” (2000 raster steps of 0.16” each).
- **Dual-beam polarization analysis**
  - Calcite prism gives +(Q,U,V) and -(Q,U,V) beams simultaneously on detector.
- **Fe I 6301.5 A (g=1.67) and 6302.5 A (g=2.5) lines**
- **Spectral resolution < 35 mA**
- **Spectral range > 2 A**
- **Polarization precision ~ 0.01 %**
- **Polarization S/N for map > 10^3**

SP Observing Modes

- **Normal Mapping Mode**
  - Expose/read/demodulate for 3 modulator rotations (4.8 seconds).
  - Optionally, move the slit one step of 0.16 arcsec (takes 0.1--0.2 sec).
  - Reduce I/Q/U/V spectra to 12 bits by shifting or look-up table.
  - Send to MDP for compression and downlink.
  - Raw data rate = 218 kPixels/sec.
  - 160” raster takes ~80 minutes, 320” raster takes ~160 minutes.
- **Fast Map Mode**
  - Expose/read/demodulate for 1 modulator rotation, step the slit 0.16 arcsec, Expose/read/demodulate for 2nd rotation and add results: 0.32” raster sample.
  - On-chip sum 2 pixels in spatial direction (along slit): effective pixel size is 0.32” x 0.32”.
  - Convert to 12 bits, send to MDP.
  - Raw data rate = 146 kPixels/sec.
  - 1” raster takes ~10.9 seconds, 160” arcsecond raster takes ~29 minutes.

Command & Data Handling Overview

- **MDP Interface**
  - Science data: 16 bit serial interface (nominal 512 KHz).
  - Command and housekeeping data (64 KHz).
  - Filtergraph Ready/Busy status line.
  - Spectropolarimeter Ready/Busy status line.
- **Macro-commands initiate complex observables**
  - Spectrograph maps.
  - Filtergraph Stokes maps.
  - Longitudinal magnetograms.
  - Dopplergrams.
  - CT reference image acquisition.