Solar Optical Telescope (SOT)

The Solar-B Solar Optical Telescope (SOT) will be the largest telescope with highest performance ever to observe the sun from space. The telescope itself (the so-called Optical Telescope Assembly, OTA), along with its focal plane package (FPP), is optimized for measurement of the vector magnetic field and associated dynamics in the solar photosphere.

SOT will obtain a continuous series of diffraction-limited images (0.2–0.3 arcsec) in 388–668 nm range, which is achieved by 50-cm-diameter aperture from space while being free from the conditions of atmospheric seeing. The images will be acquired under very stable condition (<0.09 arcsec) archived by the image stabilization system, in which a piezo-driven tip-tilt mirror (CTM) is controlled by using a displacement error estimated from correlation tracking of solar granules (correlation tracker, CT) in order to minimize jitter in solar images on the focal plane CCDs. Thanks to the sun-synchronous orbit of Solar-B, the observations will be possible for 24 hours for about 8 months per year.

The broadband filter imager (BFI) produces photometric images with broad spectral resolution in 6 bands (CN band, Ca II H line, G band, 3 continuum bands) at the highest possible spatial resolution (0.0541 arcsec/pixel) and cadence (<10 sec typical) over the full field of view (218 × 109 arcsec). This will allow accurate measurements be made of the horizontal flows and temperature of the solar surface, and to identify sites of strong magnetic fields.

The narrowband filter imager (NFI) provides intensity, Doppler, and vector-polarimetric imaging with moderate spectral resolution (0.08 arcsec/pixel) in 11 spectral lines (including Fe lines with different Lande g factor, MgIb, NaD lines, and Hα) over the full field of view (328× 164 arcsec). The spectral lines cover the lower photosphere through the chromosphere. Dopplergram and longitudinal magnetogram are obtained in cadence of ~20 sec or less. Shutterless exposure operations provide high cadence (1.6–4.8 sec) of vector magnetogram (Stokes IQUV), although the field of view is restricted; 5.3×164 arcsec with 0.08 arcsec/pixel, 14.7×164 arcsec with 0.16 arcsec/pixel, and 35×164 arcsec with 0.32 arcsec/pixel.

The spectro-polarimter (SP) provides line profiles in all Stokes parameters with high spectral resolution (30 mÅ) in two magnetically sensitive lines of Fe I at 630.15 and 630.25 nm. Normal mapping observation produces polarimetric accuracy of 0.1%. The field of view along the slit is 164 arcsec with 0.16 arcsec resolution. The slit position can be moved step by step (0.16 arcsec), allowing the spatial coverage of ±164 arcsec at maximum. To make a map of 160 arcsec-wide area covering a moderate-sized active region, it takes 83 min in normal mapping mode and 30 min in fast mapping mode. For narrow 1.6 arcsec-wide area, it takes 50 sec and 18 sec, respectively.

Details of the instrument are summarized in the following tables.

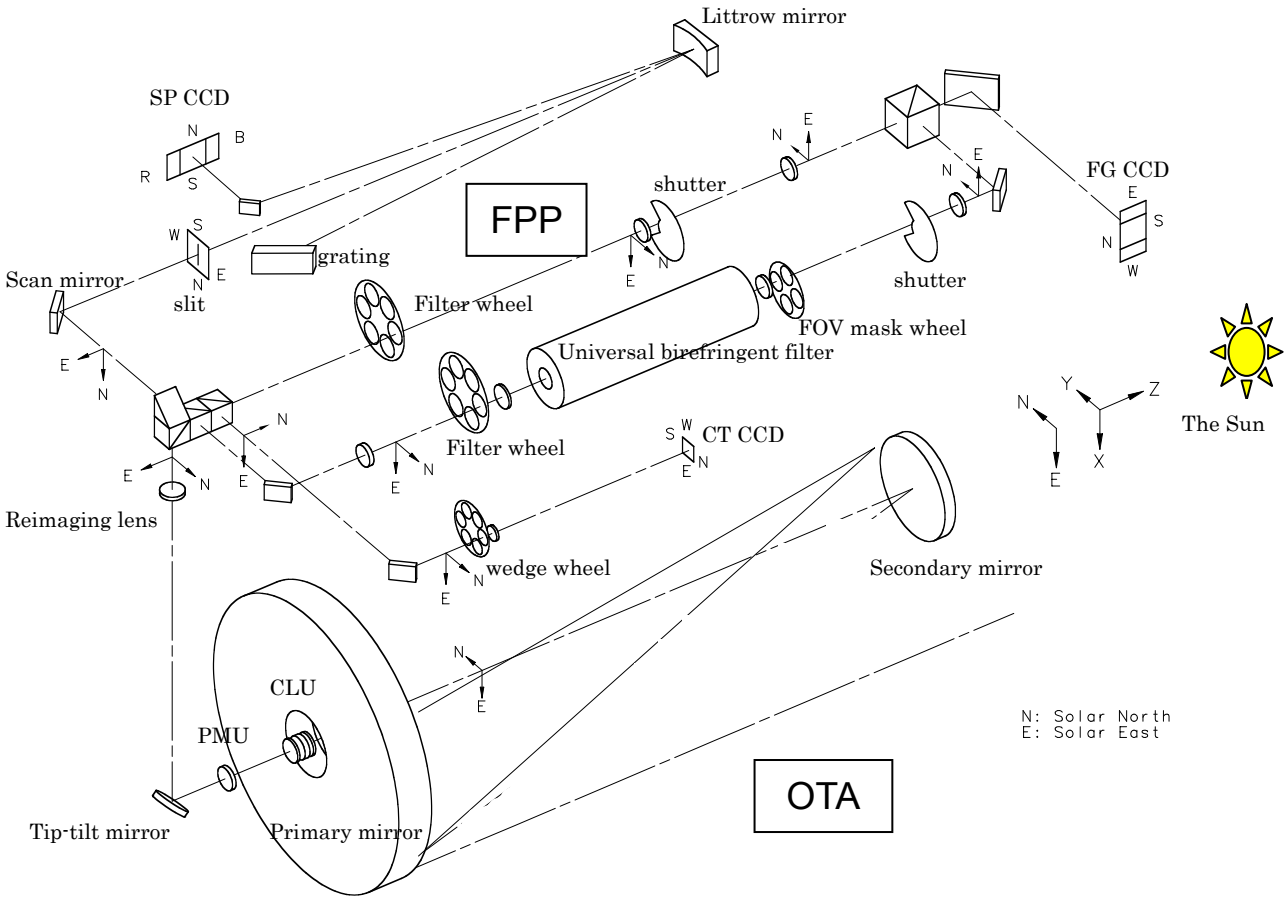

Figure. 1 SOT Optical Layout

Table. 1 Optical Telescope Assembly (OTA) Overview

Telescope		
	Optics type	Aplanatic Gregorian with heat dump mirror
	Primary mirror	50cmϕ aperture, light-weighted ULE
	Primary-secondary mirror length	1.5 m
	Central obscuration ratio	0.344 in radius
	Effective F ratio	9.055 at secondary focus
Collimator Lens (CLU)		
	Exit pupil size	3 cmϕ, collimated in air
Polarization Modulator (PMU)		
	Rotation speed	Continuous, 1.6 sec/rotation
Tip-tilt mirror for image stabilizer (CTM)		
	Signal used for closed loop control	Residual signal from correlation tracker
	Actuator	3 Piezo actuators
	Tilt range	10.5 arcsec in radius on the sky
	Control crossover frequency	14 Hz (nominal gain)
	Stability	<0.02 arcsec (in laboratory environment)

Table. 2(a) Focal Plane Package (FPP) Overview I: Filter Observations.

Broadband Filter Imager (BFI)				
Field of view	218 × 109 arcsec (full FOV)			
CCD	4K × 2K pixel (full FOV), shared with NFI			
Spatial sampling	0.0541 arcsec/pixel (full resolution)			
Spectral coverage				
	Center (nm)	Width (nm)	Line of interest	Purpose
	388.35	0.7	CN I	Magnetic network imaging
	396.85	0.3	Ca II H	Chromospheric heating
	430.50	0.8	CH I	Magnetic elements
	450.45	0.4		Blue continuum, temperature
	555.05	0.4		Green continuum, temperature
	668.40	0.4		Red continuum, temperature
Exposure time	0.03–0.8 sec (typical)			
Narrowband Filter Imager (NFI)				
Field of view	328 × 164 arcsec (unvignetted 264 × 164 arcsec)			
CCD	4K × 2K pixel (full FOV), shared with BFI			
Spatial sampling	0.08 arcsec/pixel (full resolution)			
Spectral resolution	0.009 nm (90 mÅ) at 630 nm			
Spectral band (tunable filter)				
	Center (nm)	Width (nm)	Lines of interest	Purpose
	517.2	0.6	Mg I b 517.27	Chromospheric dopplergrams and magnetograms
	525.0	0.6	Fe I 524.71 Fe I 525.02 Fe I 525.06	Photospheric magnetograms
	557.6	0.6	Fe I 557.61	Photospheric dopplergrams
	589.6	0.6	Na D 589.6	Very weak fields (scattering polarization), Chromospheric fields.
	630.2	0.6	Fe I 630.15 Fe I 630.25 Ti I 630.38	Photospheric magnetograms Umbral magnetograms
	656.3	0.6	H I 656.28	Chromospheric structure
Exposure time	0.1–1.6 sec (typical)			
Standard observable examples for filter observations				
Filtergram	A signal exposure for each spectral coverage			
	Frame size	4K×2K, 2K×2K, 1K×1K, or 0.5K×0.5K		
	Summing	1×1, 2×2, or 4×4 pixel		
	Readout time	3.4sec (1×1 summing), 1.7sec (2×2), 0.9sec (4×4) Partial readout for faster cadence		
	Reconfigure time	<2.5 sec (for changing filter wheels etc)		
Dopplergram	Image of the Doppler shift of a spectral line derived from narrowband filtergrams at several wavelengths			
	Frame size	2K×1K, 1K×1K, or 0.5K×0.5K		
	Summing	1×1, 2×2, or 4×4 pixel		
	Duration	12.8sec (4 images, 2×2 summing, 0.8sec exposure)		
Longitudinal magnetogram	Stokes V/I images converted onboard from narrowband filtergrams			
	Frame size	2K×1K, 1K×1K, or 0.5K×0.5K		
	Summing	1×1, 2×2, or 4×4 pixel		
	Duration	8 images (4 wavelengths) are taken. 12.8 sec for 1K×1K and ~21 sec for 2K×1K		

	Stokes IQUV (for vector magnetogram)	I/Q/U/V images made onboard from narrowband filtergrams at different polarization modulator positions		
		Shuttered exposures	Frame size	2K×1K,1K×1K, or 0.5K×0.5K
			Summing	1×1, 2×2, or 4×4 pixel
		Shutterless exposures	Frame size	144×1K, or 64×1K
			Summing	1×1, 2×2, or 4×4 pixel
			Duration	1.6–4.8 sec (1–3 waveplate rotations)

Table. 2(b) Focal Plane Package (FPP) Overview II: Spectro-Polarimeter Observations.

Spectro-Polarimeter (SP)			
	- Spectra of two Fe lines at 630.15 and 630.25 nm and nearby continuum - Raw spectra are added and subtracted onboard to demodulate, forming Stokes parameters I, Q, U, and V.		
	Field of view along slit	164 arcsec (NS direction)	
	Spatial scan range	± 164 arcsec (transverse to slit)	
	Spatial sampling (slit)	0.16 arcsec	
	Spectral coverage	630.08 nm to 630.32 nm	
	Spectral resolution/sampling	30 mÅ / 21.5 mÅ	
	Measurement of polarization	Stokes I, Q, U, V simultaneously with dual beam (orthogonal linear components)	
	Polarization signal to noise	10^3 (normal map)	
Standard observable (mapping mode) examples for SP			
	Normal mapping	Time per position	4.8 sec (3 rotations of waveplate)
		Polarimetric accuracy	0.001
		FOV along slit	164 arcsec
		Sampling along slit	0.16 arcsec
		Data size	918K pixels in 4.8 sec or 191K pixel/s
		Slit-scan sampling	0.16 arcsec
		Time for map area	50 sec for 1.6 arcsec wide 83 min for 160 arcsec wide
	Fast mapping	Time per position	One rotation for the 1st slit position and another rotation for the 2nd slit position
		FOV along slit	164 arcsec
		Sampling along slit	0.32 arcsec
		Data size	459K pixels in 3.6 sec or 127K pixel/s
		Slit-scan sampling	0.32 arcsec
		Time for map area	18 sec for 1.6 arcsec wide 30 min for 160 arcsec wide
	Dynamics	Time per position	1.6 sec (One rotation)
		FOV along slit	32 arcsec (to reduce data size)
		Sampling along slit	0.16 arcsec
		Data size	179K pixels in 1.6sec or 120K pixel/s
		Slit-scan sampling	0.16 arcsec
		Time for map area	18 sec for 1.6 arcsec wide

Table. 2(c) Focal Plane Package (FPP) Overview III: Correlation Tracker

Correlation Tracker (CT)		
	- Producing displacement error for feeding back to CTM tip-tilt mirror control	
	CCD	50×50 pixels, 0.22 arcsec/pixel
	Frame rate	580Hz
	Spectral range	629–634nm
	Displacement Range	+/− 5 pixels
	Error signal accuracy	~ 0.01 arcsec

Table. 3 SOT observation controls and data handling

Observation controls			
	- Managed by observing tables in Mission Data Processor (MDP) - An observing table exists for filter observation and SP observation, respectively. - Macro-commands for taking observables and instrument commands is listed with interval in the table.		
Data handling			
	Effective process speed in MDP	832K pixels/sec (maximum, for FPP data)	
	Bit compression in MDP	16bit data compressed to 12 bit, 8 lookup tables	
	Image compression in MDP (expected compression ratio)	12bit DPCM (lossless)	6–8bits/pixel
		12bit JPEG(DCT) (lossy)	<~3bits/pixel for filters ~1.5bits/pixel for SP
	# Compression rate depends on images and required image quality		
	Allocated telemetry rate (max) for SOT	~1.3Mbps (nominal) ~1.8Mbps (SOT dominant)	
	Data rate (after compression) averaged per day	~300Kbps, assuming 15 downlink stations in a day	