MSI: a visible multi-spectral imager for 1.6-m telescope of Hokkaido University

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Abstract

We have built a visible multi-spectral imager (MSI) for the 1.6-m Pirka telescope of the Hokkaido University in Hokkaido, Japan. The instrument is equipped with two liquid crystal tunable filters and a 512 x 512 pixel EMCCD camera. One of the major purposes of this instrument is to obtain multi-spectral images (series of narrow-band images at many different wavelengths) of the solar planets rapidly. These tunable filters are a Lyot filter with liquid crystal variable retarders and thus can tune the transmitting wavelength rapidly without moving parts. Their spectral ranges are 400–720 nm and 650–1100 nm and the bandwidth is typically 10 nm on both filters. The EMCCD camera can obtain images at a frame rate of about 32 Hz, which also enables us to improve the spatial resolution with the shift-and-add or the Lucky imaging techniques. The field of view is 3.3 x 3.3 arcmin with a pixel scale of 0.39 pixel/arcsec. The instrument also has UBVRI-band broad-band filters and several narrow-band filters. MSI is mounted at the f/12 Cassegrain focus of the telescope. It had the first light on February 2011, and then have been used for several astronomical and planetary science programs as a major facility instrument at this telescope. We describe the design, construction, integration, and performance of this multi-spectral imager.

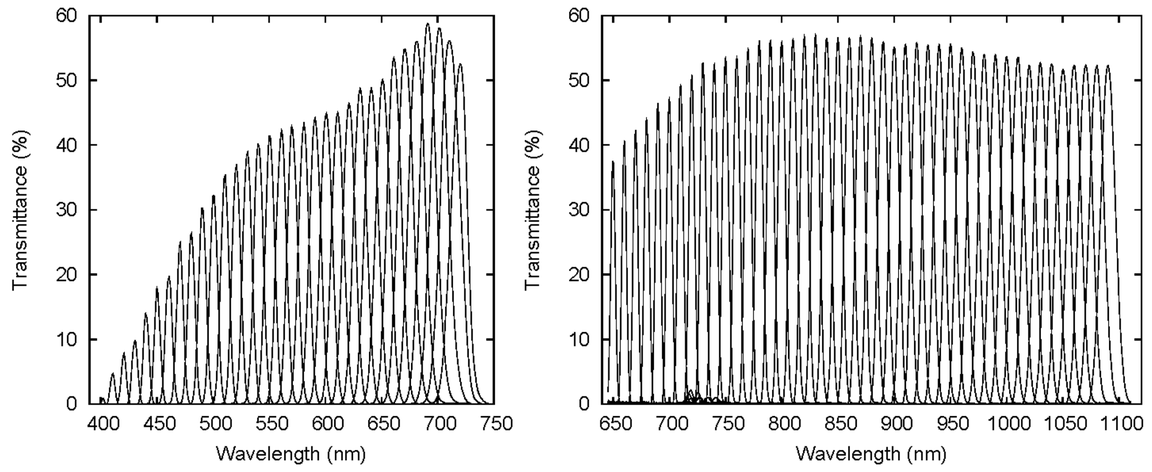
Major Specifications

Spectral coverage	360–1050 nm
Field of view	3.3’ x 3.3’ (0.389”/pixel)
Filters	
Liquid crystal tunable filters	400–720 nm ($\Delta\lambda$ ~ 10 nm) & 650–1100 nm ($\Delta\lambda$ ~ 10 nm)
Narrow-band filters	360, 365, 370, 390 nm ($\Delta\lambda$ = 10nm), Hα ($\Delta\lambda$ = 1 nm)
Broad-band filters	Johnson-Cousins *U, B, V, R, I*
Camera (CCD)	Hamamatsu Photonics C9100-13
	(e2v CCD97 back-illuminated EM CCD)
Array format	512 x 512 pixel (pixel size 16 x 16 μm)
Readout modes	EMCCD mode & Normal CCD mode
Maximum frame rate (full-frame)	31.9 frames/s (EMCCD mode), 2 frames/s (Normal CCD mode)
Minimum exposure time (full-frame)	0.031 s (EMCCD mode), 0.488 s (Normal CCD mode)
Readout noise	33 e- (EMCCD mode, EM gain = 4),12 e- (Normal CCD mode)
EM gain	4-1200
CCD cooling method & temperature	Peltier with forced-air, –65^{o}C
Outer dimensions	995 (W) x 464 (D) x 333 (H) mm
Weight	~50kg

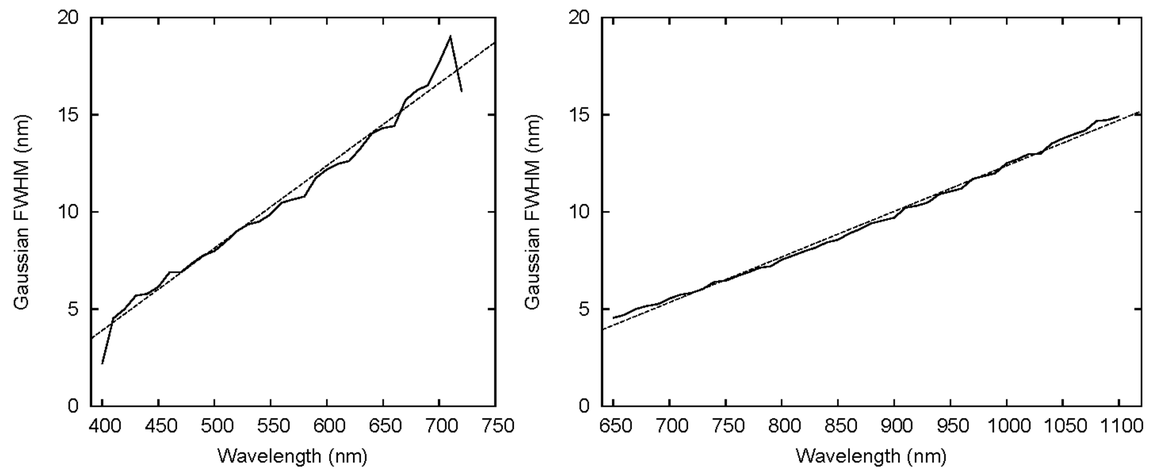
Liquid Crystal Tunable Filters (LCTFs)

The LCTFs of MSI are commercial products, VariSpec VIS-10 & SNIR-10, from Cri, Inc. (currently part of Caliper Life Sciences, Inc.). The response time is typically only 50 ms for VIS and 150 ms for SNIR, at room temperature. The tuning accuracy of wavelength is (bandwidth)/8+0.5 nm (typically 1.8 nm). The out-of-band transmittance is below 0.1%. The bandwidth varies within a range of ~5–19 nm for VIS and ~5–15 nm for SNIR, depending on the setting of center wavelength. The profile of transmittance curve is close to a Gaussian profile.

Transmittance curves of LCTFs for linearly polarized light

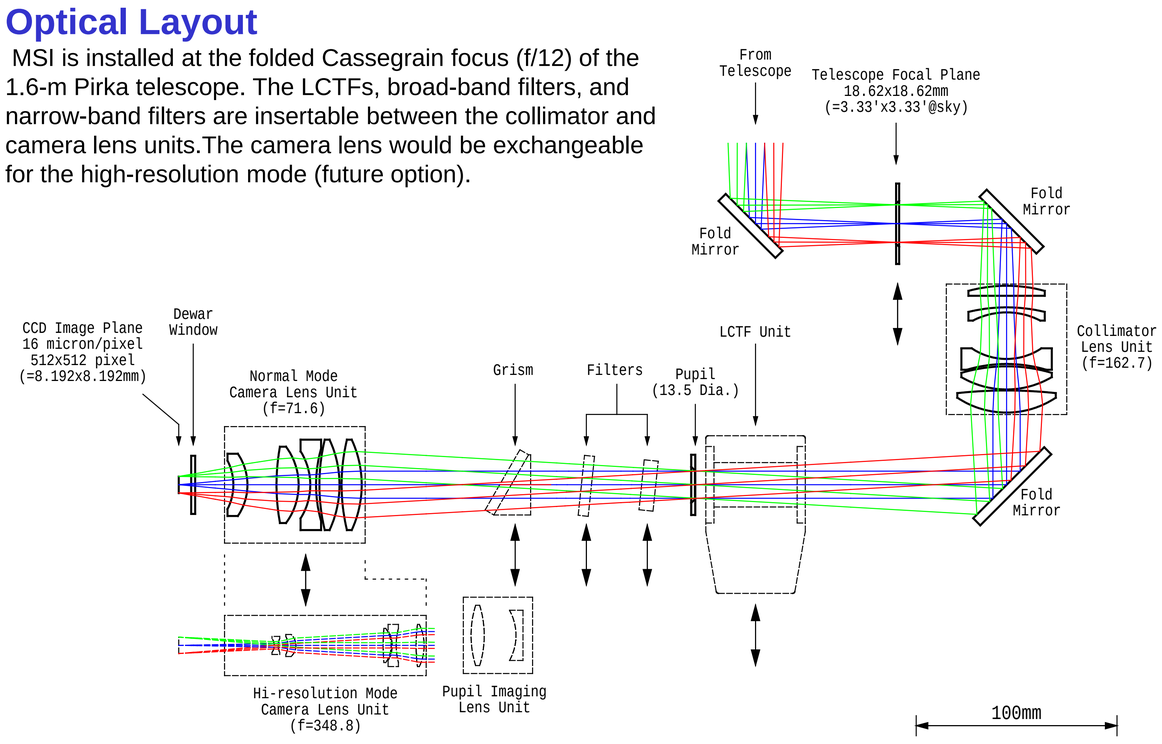


Bandwidth dependency on center wavelength setting



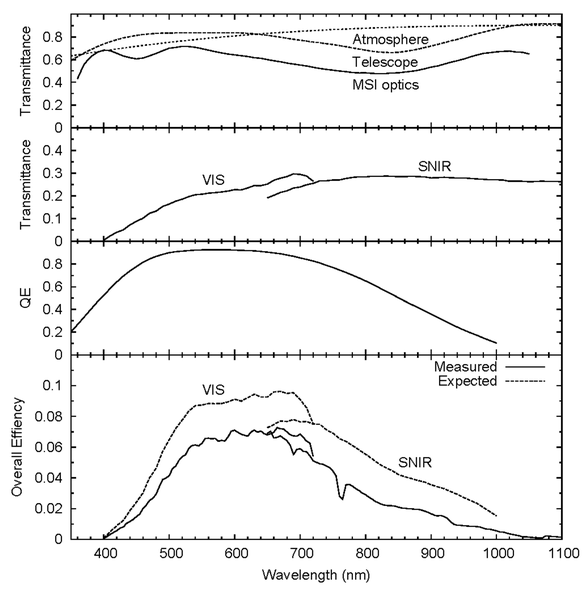
Optical Layout

MSI is installed at the folded Cassegrain focus (f/12) of the 1.6-m Pirka telescope. The LCTFs, broad-band filters, and narrow-band filters are insertable between the collimator and camera lens units.The camera lens would be exchangeable for the high-resolution mode (future option).

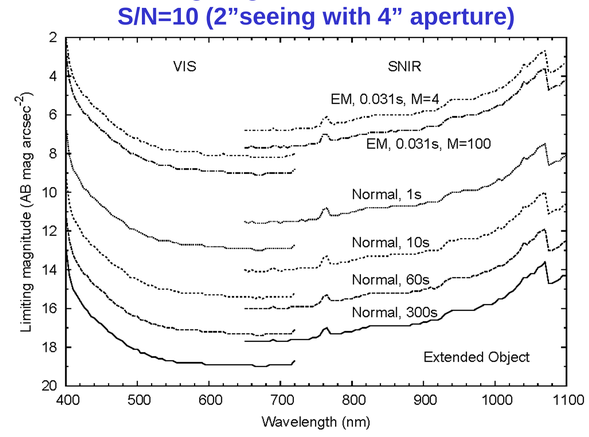


Optical Efficiency & Limiting Magnitudes

Optical efficiency



Limiting magnitudes with LCTFs for S/N=10 (2”seeing with 4” aperture)



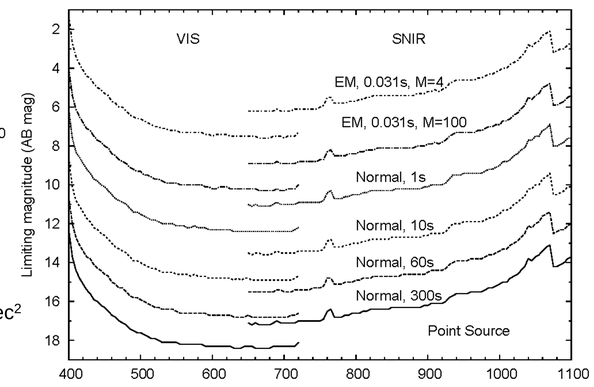
Limiting magnitudes with broad-band filters for S/N=10 with 60s exposure time

Extended source

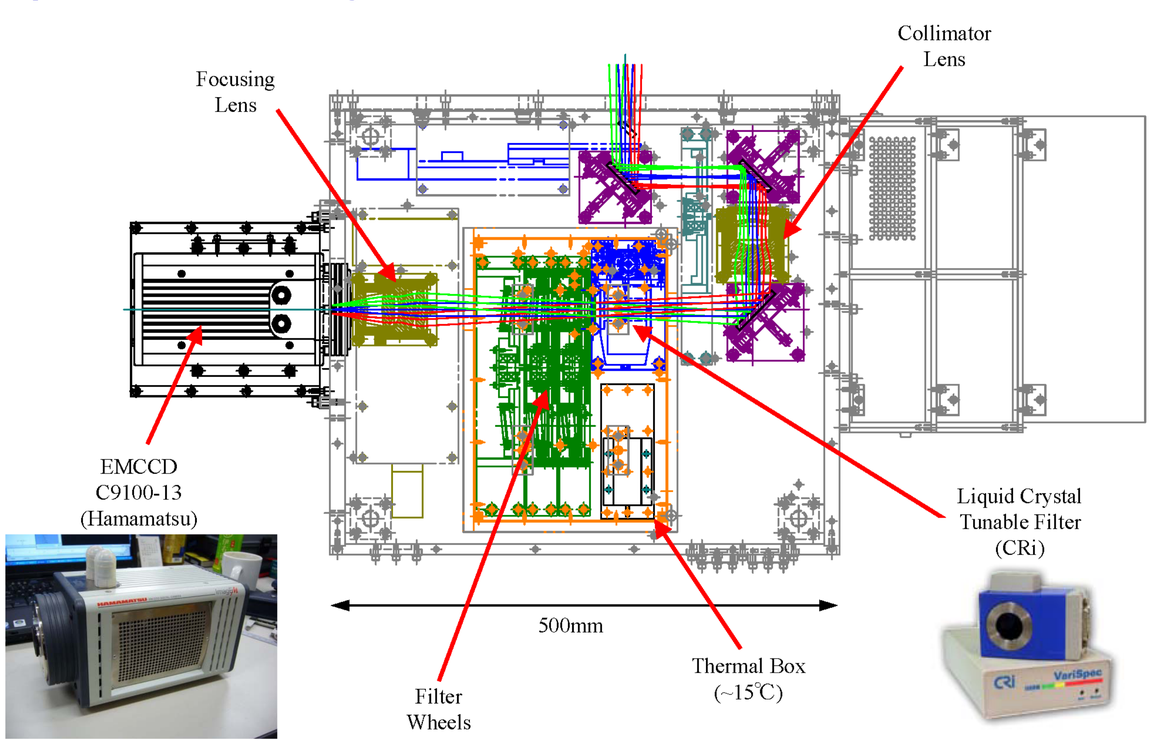
U=17.8, *B*=20.6, *V*=20.7, *R*=20.5, *I*=19.4 mag/arcsec^2

Point source (2” seeing with 4” aperture)

U=17.3, *B*=20.0, *V*=19.9, *R*=19.8, *I*=18.7 mag

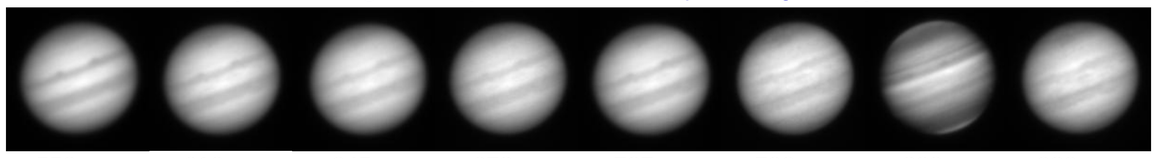


Opto-Mechanical Layout



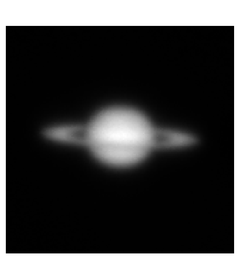
Examples of Multi-Spectral Imaging

Multi-spectral images of Jupiter at several CH_4 and NH_3 absorption bands



552 nm (NH_3) | 619 nm (CH_4) | 645 nm (NH_3) | 678 nm (continuum) | 727 nm (CH_4) | 790 nm (NH_3) | 889 nm (CH_4) | 930 nm (NH_3)

Multi-spectral image and spectra of Saturn



677nm