Visible Tunable Filter (VTF):

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The VTF is a large-format Fabry-Perot based instrument for imaging spectroscopy and spectropolarimetry. It will take narrow-band images of the Sun at the very high spatial and temporal resolution, allowing rapid imaging spectrometry, Stokes imaging polarimetry, and accurate surface photometry.

At first light of DKIST, the VTF will be available in a

configuration with one hi-res Etalon, while the final instrument will have two matched Etalons to maximize the free spectral range. The parameters for the 1-Etalon configuration are given in parentheses and in red.

Instrument Modes Available:

Narrow-band channel (NBC):

- Polarimetric Imaging (spectro-polarimetry)
- Doppler Imaging (spectroscopy)
- Intensity imaging (monochromatic imaging, i.e. fixed wavelength, 6 pm bandwidth

Broad-band channel (BBC):

In all modes, simultaneous continuum images are taken, using a 1-2 nm prefilter. It is recommended to use wavelengths close to that of the NBC., to avoid differences in the FOV due to differential atmospheric refraction. The BBC images have the same field of view, spatial sampling, exposure time, and cadence as the NBC. Differences in light level are compensated by an internal "dimmer". BBC data are used for registration and image reconstruction of the NBC data, and they are available for scientific analysis.

Spatial Field of View and Resolution:

Optical: 60 arcsec x 60 arcsec (43.000 km x 43.000 km on the Sun, 4096 x 4096 pixels) Fixed spatial sampling: 0.0146 arcsec/pixel

critically samples diffraction limited resolution: 0.028 arcsec @ 520 nm

Longer wavelengths are oversampled.

Spectral Range and Resolution:

Range: 520 - 870 nm (585 - 870 nm)

First-light set of pre-filters: Fe I 525.02 nm (photosphere, Landé factor 3, not for 1-ET configuration), Na D 589.6 nm (Chromosphere), Fe I 630.25 nm (photosphere, Landé factor 2.5), H α 656.3 nm (chromosphere, Landé factor \neq 0), Ca II 854.2 nm (chromosphere, Landé factor 1.1)

Free spectral range: ~1nm (between 0.15 nm and 0.4 nm, from green to red)

Resolution: Between 5 and 10 pm, wavelength-dependent (6 pm (3 pm sampling) at 600 nm (R = 100000))

Ion, Spectral region	Center wavelength [nm]	FWHM [nm]	Peak transmission	FWHM homogeneity
Na D 588.99 nm	589.15	0.14	≥ 60 %	±0.025 nm
Fe I 630.25 nm	630.35	0.16	≥ 60 %	±0.025 nm
H I 656.28 nm	656.40	0.18	≥ 60 %	±0.025 nm

First-light set of pre-filters (specifications):

Ca II 854.21 nm	854.30	0.28	≥ 60 %	±0.025 nm
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Temporal Cadence:

The temporal cadence depends on the instrument mode, the number of spectral lines, and on the target value for the SNR. A single exposure with an exposure time of 25 ms provides an SNR around 190. To reach an SNR of 670, and hence a polarimetric accuracy of 20 G, about 8 measurements with 25 ms are needed (repetitions). The final cadence for one multi-line observing sequence is computed from the VTF timing equation:

$$T = \{\sum_{f=1}^{n_f} n_{r,f} \left[n_{k,f} \cdot (t_e + t_s) \cdot n_j + t_w \right] \cdot n_{l,f} \} + (n_f - 1) \cdot t_f$$

Default values (for spectropolarimetry):

$f \ge 1$	Number of spectral lines
<i>n_{k,f}</i> = 8	(1 - 12 (or more), number of repetitions, depending on desired SNR)
$n_j = 4$	(Fixed, polarization states)
<i>n</i> _{<i>l,f</i>} =11	(wavelength points, 9 - 51, depending on line)
n _{r,f} ≥ 1	Number of repeats for each line
$n_f \ge 1$	(Number of prefilters in observing sequence, $1 \le n_f \le 9$)
<i>t_e</i> = 25 ms	(Exposure time)
<i>t</i> _s = 9.0 ms	(Modulator switch time)
<i>t_w</i> = 34.0 ms	(Etalon tuning time, =0, if n_l =1)
<i>t_f</i> = 2000 ms	(Time to change line, i.e., prefilter change time)

 $t_e+t_s = t_w = 34.0$ ms, to stay in sync with camera readout t_e can be shortened, if needed, cadence will not change. Frame cycle time = 34.0 ms (i.e., frame rate 29.41 Hz)

With the above values for t_s , t_e , and t_w , and for a single spectral line, the timing equation simplifies to

$$T = n_r \cdot 34.0(n_k \cdot n_j + 1) \cdot n_l [ms]$$

Example results:

1. Intensity Imaging, burst of 50 images(t_w=0): T= 1.67 s

2. Doppler Imaging:
 a) Chromosphere: 51 wavelength points, 1 exposure per wavelength: 3.47 s
 b) Photosphere: 12 wavelength points, 4 exposures per wavelength: 2.04 s

 Spectropolarimetric imaging: 11 wavelength points, 4 pol. states, 8 repetitions (->3 x 10⁻³ P/I_{cont}): 12.34 s Single Etalon configuration: 11 wavelength points, 4 pol. states, 10 repetitions (->3 x 10⁻³ P/I_{cont}): 15.33 s

Polarimetric Capabilities and Accuracy:

Full Stokes vector polarimetry (dual beam)

 3×10^{-3} P/I_{cont} polarimetric signal based on 12.3 second (15.3 s) single line scan above.

Photometric Capabilities (Precision):

Detected Photons and SNR for selected wavelength (values for 1-Etalon configuration in red)

Ion (Wavelength)	Detected photons per pixel per 25	SNR
	ms exposure (continuum)	
Fe I 525.00 nm	25000	160
Fe l 630.25 nm	37000 <mark>(33500)</mark>	190 <mark>(180)</mark>
H I 656.28 nm	40000 (36000)	200 (190)
Ca II 854.21 nm	28000 (25500)	165 <mark>(160)</mark>

Instrument modes & parameter settings:

Parameter	Default mode	Supported modes	Expert modes (not
	(P-C1-M2-S8)		available in service mode)
Instrument	Polarimetric imaging	Doppler imaging Intensity imaging	-
camera, pixel binning	1x1 binning (C1)	2x2, 4x4 binning	2x2, 4x4 binning

camera, ROI	Full field	2048 x 2048, 1024 x 1024,	whatever the camera
		centered subfields	allows
spectral sampling	critical (2 points per	- equidistant 2-fold	non-equidistant scan
	spectral res. element)	undersampling	steps
scanning direction	sequential (red to blue)	nested (starting at red end	scan scheme defined by
	(M2)	of scan range),	scan steps given above
Repetitions (-> SNR)	8 repetitions (S8)	n _r >1 repetitions	any reasonable number

Data Structure & Volume:

One full image: 4096 x 4096 pix x 2 bytes/pix = 33.55 MB per image (1 MB =1,000,000 Byte) **Narrowband channel (NBC), 1 or 2 cameras:**

Intensity imaging: One camera is used. Typically, 12 (identical) images = 0.4 GB; image reconstruction may need more images, depending on method used.

Doppler imaging: One camera is used. Strong line: up to 51 wavelength steps = 1.7 GB; weak line: 12 images: 0.4 GB. **Spectropolarimetric imaging:** 2 cameras are used. Example: photospheric line, 11 wavelength points, 4 states, 8 repetitions = 352 images, thus: 352 img*33.55 MB/img=11.8 GB/camera x 2 cameras = 23.6 GB

Broadband channel (BBC): Takes the same number of images, in sync with the NBC, i.e. data volume is identical to that of one NBC camera.

Example Modes of Operation:

(A) Purpose: Waves in the solar atmosphere, coupling between photo- and chromosphere.
Instrument Mode: Polarimetric imaging in two lines, 630.25 nm (photosphere, 11 wavelength points), 854.1 nm (chromosphere, 21 wavelength points).
Parameter settings: default, (P-C1-M2-S8) for 630.25 and for 854.1
Cadence: 37.9 s, according to VTF timing equation
Duration: 60 min (95 2D Stokes spectra)
Data volume: 95 data sets * 11.8 GB/cam * 3 cam = 3.36 TB

(Options: use 2x2 binning for 854.1 nm, to increase SNR; use non-equidistant line scanning or equidistant undersampling to get more line wing information.)

(B) Purpose: Magneto-convection in the photosphere
Instrument Mode: Polarimetric imaging in one, 630.25 nm (photosphere)
Parameter settings: default, i.e., P-C1-M2-S8 for 630.25
Cadence: 12.3 s, according to VTF timing equation
Duration: 60 min (295 2D Stokes spectra)
Data volume: 295 data sets * 11.8 GB/cam * 3 cam = 10.44 TB

(Options: use fewer wavelength points, either to decrease data volume or to increase cadence; use 2x2 pixel binning to increase SNR and decrease data volume; observe smaller ROI, to decrease data volume.)