Near InfraRed Tunable Filter (NIRTF) for a 2nd generation instrument of DKIST

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Advantage of Near IR Tunable Filter (NIRTF)

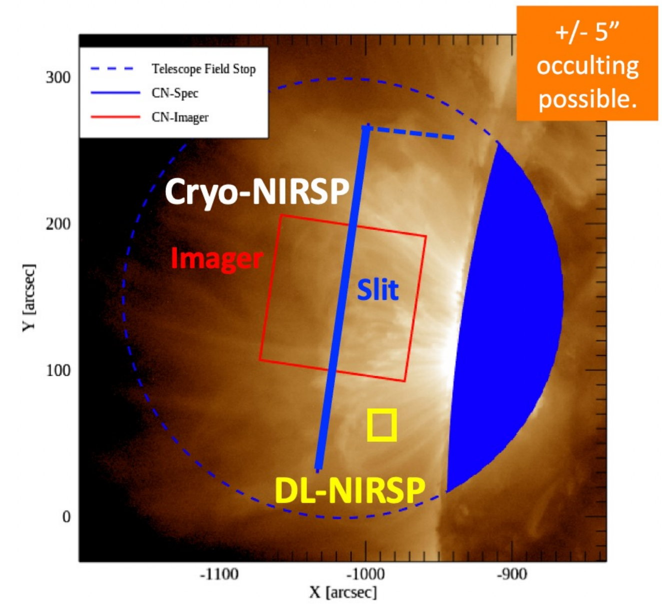
Understand dynamic solar phenomena taking place on the scale of active regions

<u>Spectro-polarimetric observations</u>
in near infrared
with a large field of view
and high temporal cadence

The 1st generation instruments of DKIST do not achieve them at the same time

Filter-based spectro-polarimeter for a near infrared spectral range

Coronal observation (off limb)



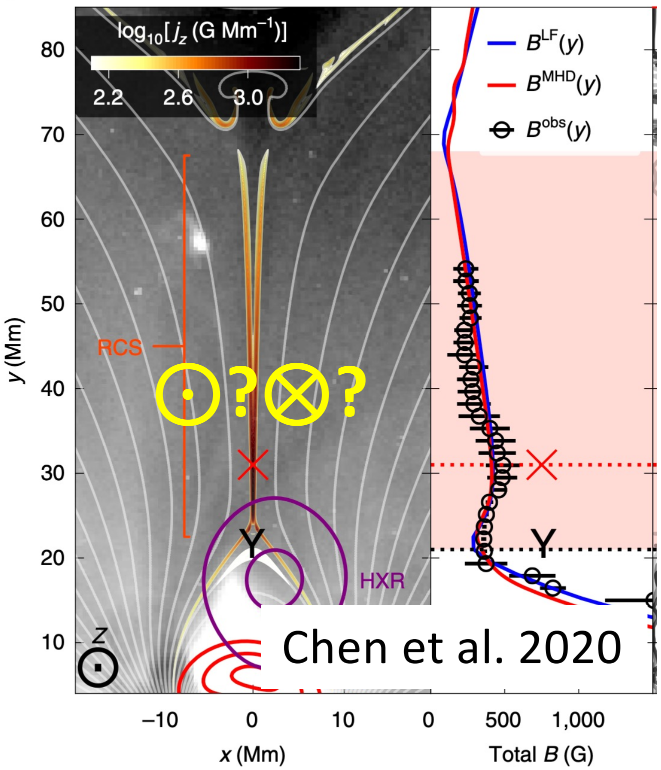
from CSP workshop
Schad and the DKIST team

For scanning/mosaicking φ100"
Near infrared spectro-polarimeters

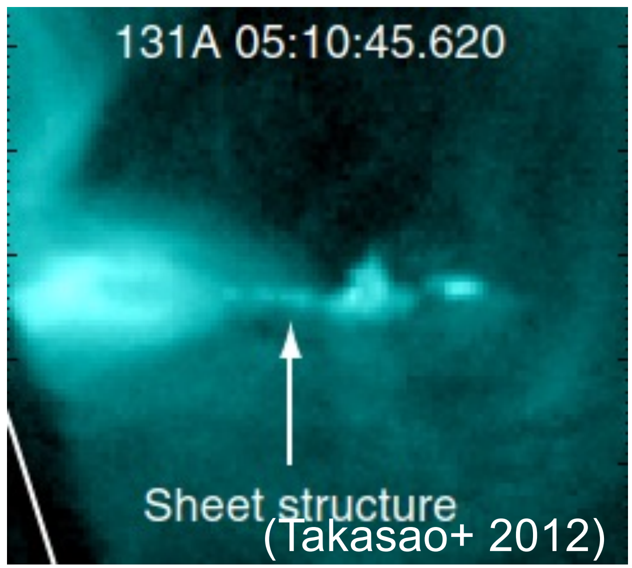
- DL-NIRSP : ~30 minutes
- Cryo-NIRSP: ~30 minutes

NIRTF science objective 1

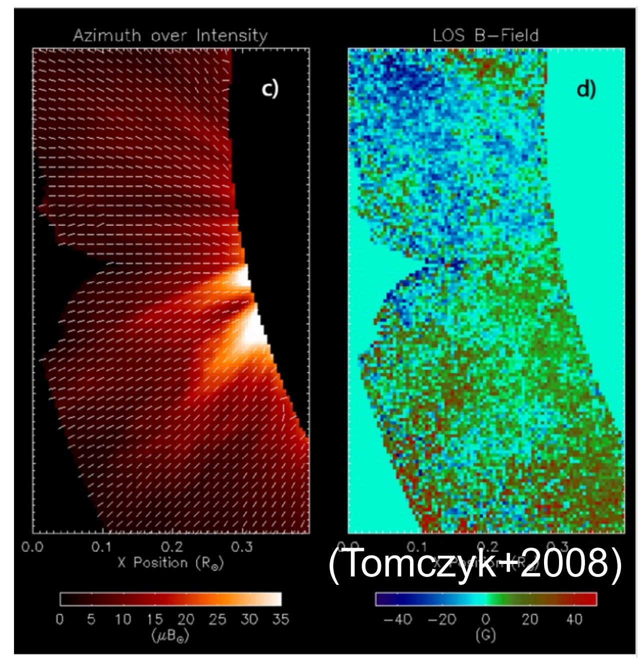
Measurement of coronal magnetic fields related to plasma dynamics



Flares



Waves



This with information of density, temperature, and velocity, allows us to quantify the energy release and transfer without assumptions, and to understand physical plasma processes.

DKIST+NIRTF has 400 times higher light collection capability than that of the CoMP.

NIRTF science objective 2

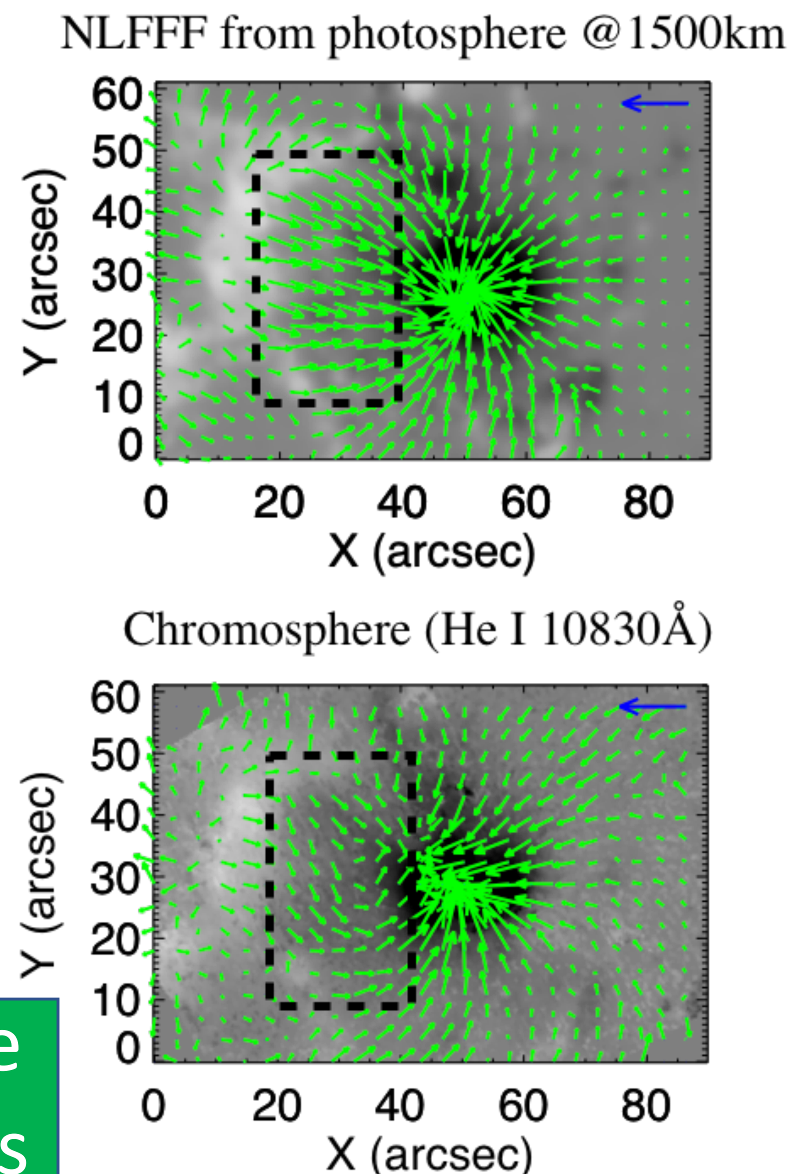
Measurement of chromospheric magnetic fields

Chromospheric B field with high S/N & a FOV of an active region size

Extrapolation modeling of the coronal B field over the active region

Distinguishing MHD instabilities

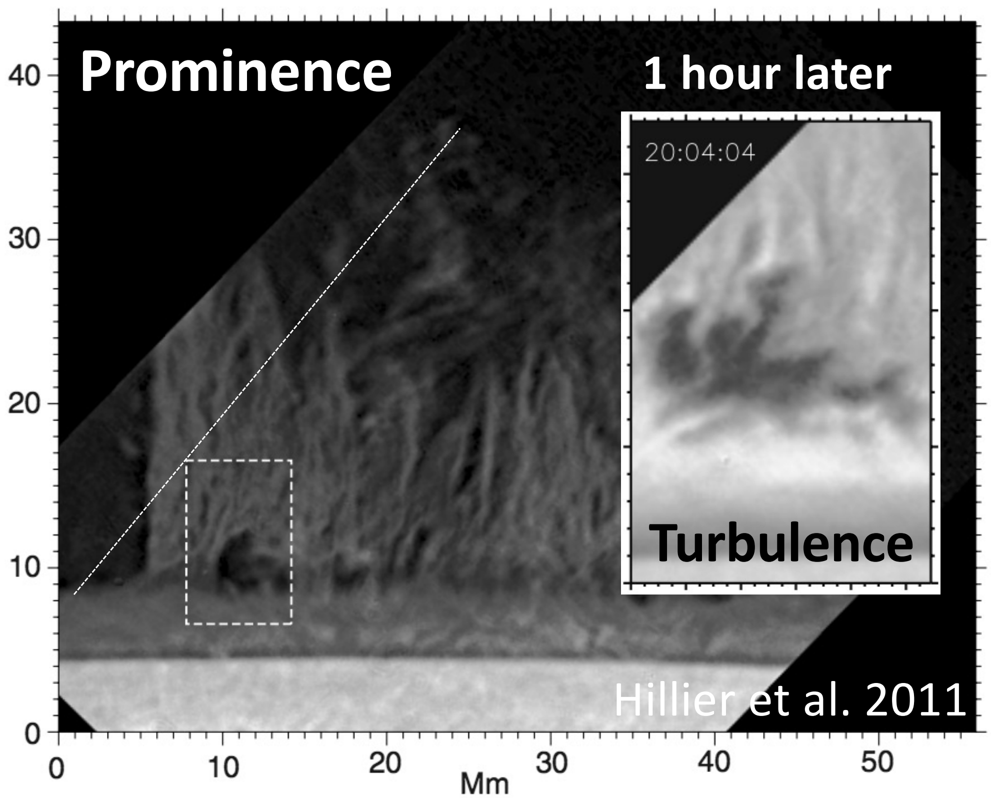
Identifying flare trigger locations

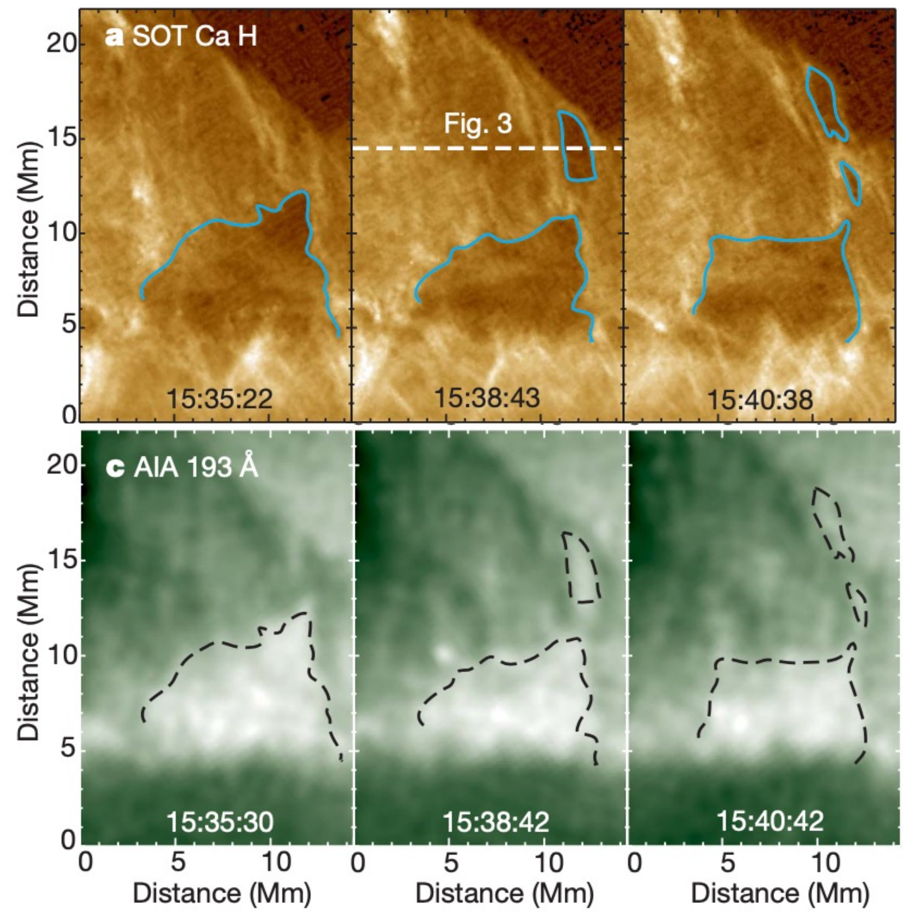


(Kawabata+ 2020)

NIRTF science objective 3

Measurement of prominence magnetic fields





Berger et al. 2011

B & v fields from the entire (～100”)
to micro scale (～0.5”)
=> Energy spectra of the MHD turbulence

Coronal heating associated with the turbulence

NIRTF target performance

Item	Performance
Spectral coverage	1 μm to 1.6 μm • Fe I 1.564 μm (Photosphere V and B [Zeeman]) • He I 1.083 μm (Chromosphere V and B [Zeeman+Hanle]) • H I 1.020 μm (P7) /1.094 μm (P6) (Chromosphere V, B, and E [Zeeman+Stark]) • Fe XIII 1.074 μm (Corona V and B [Zeeman+Hanle])
Spectral resolution	$\lambda/\Delta\lambda_{FWHM}$ > 50,000 for the photosphere and the chromosphere $\lambda/\Delta\lambda_{FWHM}$ > 8,000 for the corona
Spectral scan	Cover spectral line widths • >0.3 nm needed for Fe XIII
Spatial resolution & Field-of-view	For the photosphere and the chromosphere • 0.1" resolution with FOV > 60" (to cover super-granulation and a sunspot) For the off-limb corona and a prominence • 0.2" resolution with FOV > 150" (to trace MHD wave propagation) • Consider an option to switch between narrow and wide FOVs

Need a large-aperture tunable narrow-band filter as well as a large-format IR camera.

Key technology 1

Tunable Lyot filter with LCVRs

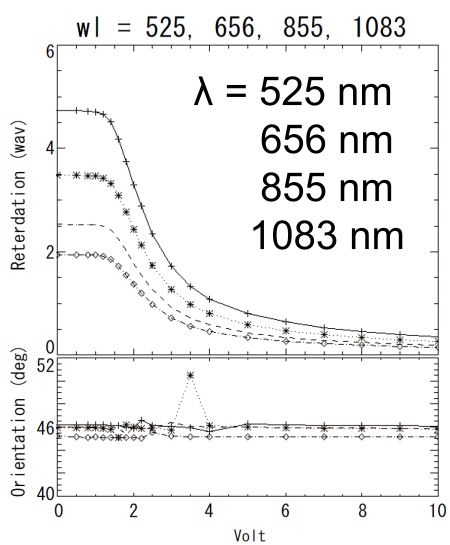
Hagino et al. 2014

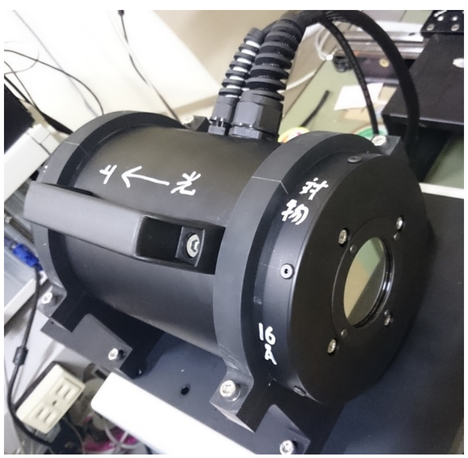
- Two tunable Lyot filters (Φ32 and 40mm) using liquid crystal variable retarder have been developed in Hida observatory since 2014.
  - By using LCVRs and super achromatic half-wave plates those filters work in the wavelength range 500-1100 nm.
  - Design of waveplates and LCVRs for near-infrared observations are in progress.

Performance in Hα

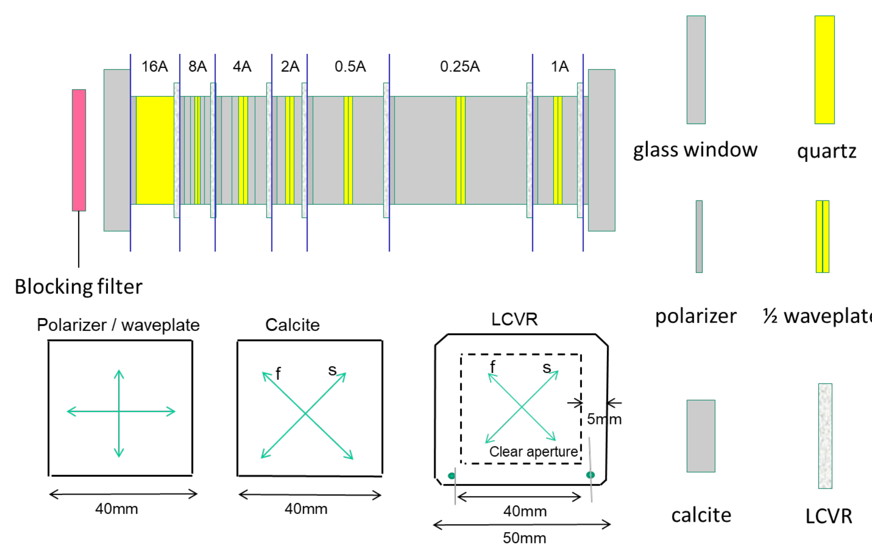
FWHM	FSR	Finesse
0.05 nm	3.2 nm	64

Retardation of LCVR for 32mm filter





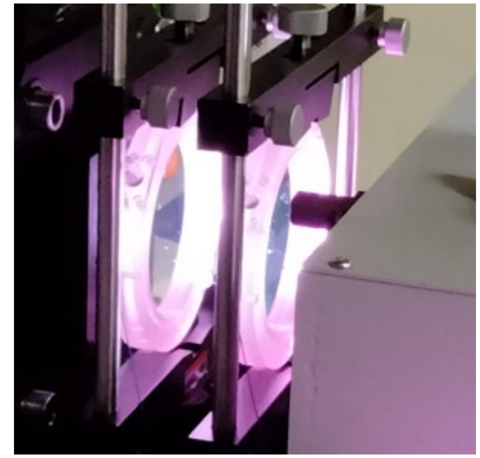
Φ40mm Lyot filter



Key technology 2

Tunable NIR filter using $LiNbO_3$ Fabry-Perot Etalons

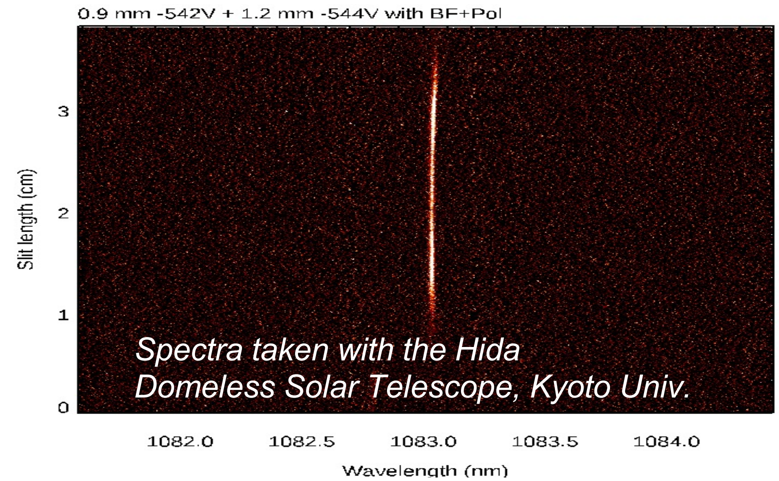
Suematsu et al. 2021

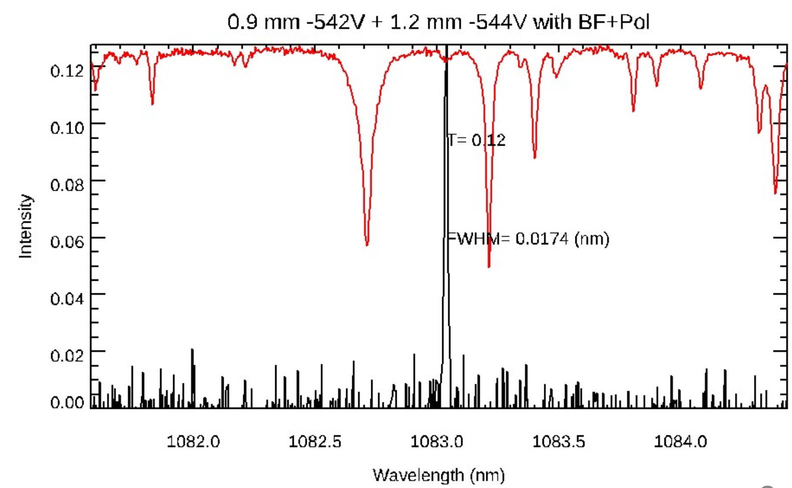


Tandem configuration of the $LiNbO_3$ etalons

- Two $LiNbO_3$ etalons have been newly developed by a Japanese optical company.
  - Φ70 mm clear aperture, t = 0.9 mm and 1.2 mm
  - Optimized in ordinary ray transmission for both He I 1083 nm and Fe I 1564 nm lines when used in tandem configuration.
  - Y-cut $LiNbO_3$ wafers coated with reflective and conductive (ITO) layers which give larger tuning range than Z-cut etalons.

Wavelength (nm)	Thick (mm)	Ray	FWHM (nm)	FSR (nm)	Finesse	Δλ/V (nm/kV)
1083	0.9	n	0.0191	0.292	17.49	0.0348
		e	0.0191	0.303	18.59	0.018
	1.2	n	0.0154	0.219	17.95	0.0281
		e	0.0161	0.228	18.1	0.0175
	Tandem	n	0.0138	0.877	85.98	
1564	0.9	n	0.048	0.618	13.43	0.0513
		e	0.0496	0.642	13.54	0.033
	1.2	n	0.043	0.464	11.37	0.0398
		e	0.0443	0.482	11.53	0.0258
	Tandem	n	0.034	1.851	60.69	



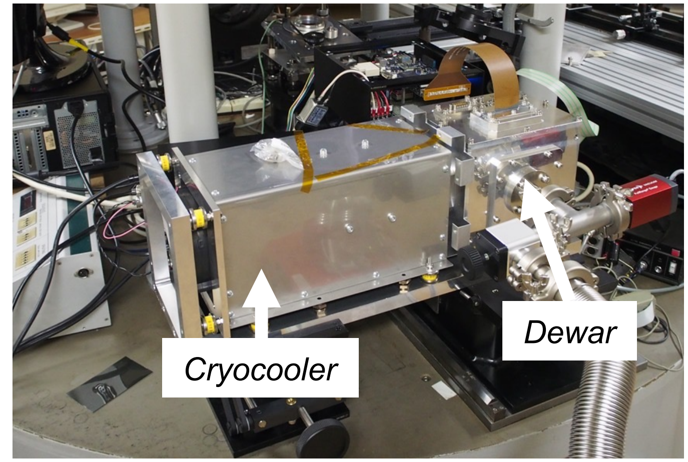


Transmission profile of the etalons at He I 1083 nm

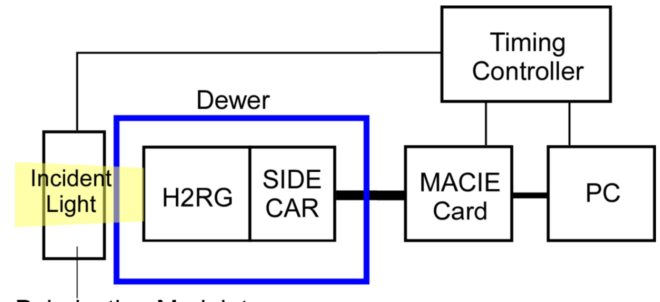
Key technology 3

NIR camera using H2RG detector for solar polarimetry

Hanaoka et al. 2020



- We succeeded to develop an infrared camera using a Hawaii-2RG detector (Teledyne)
  - 2048x2048 pixel format
  - Wavelength range 1.0 - 1.6 μm

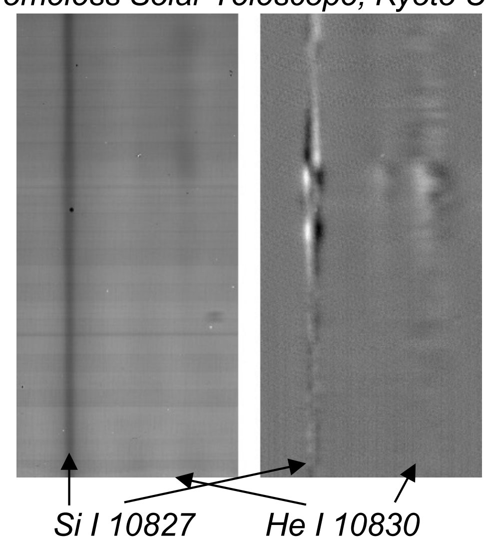


Configuration of the camera system

- Synchronizing polarization modulation and data acquisition
  - MACIE interface board and new assembly codes (Markury Scientific)
  - Typical frame rate: 30 - 120 frames sec^{-1}

Stokes I *Stokes V*

Stokes spectra taken with the Hida Domeless Solar Telescope, Kyoto Univ.



Current status

- Scientific and technical concepts of NIRTF have been studied since 2021.
- We submitted a letter of intent for NIRTF in response to the call for future plans by the subcommittee on Astronomy and Astrophysics in Science Council of Japan.
- NIRTF will be included in a future roadmap compiled by the Japan Solar Physics Community.
- It would be nice if we could discuss future collaboration and partnership between the U.S. and Japan.

Reference

- Rimmele T. R. et al. (2020), Solar Physics, 295, 172
- Chen, B. et al. (2020), Nature Astronomy, 4, 1140
- Takasao, S. et al. (2012), ApJL, 745, L6
- Tomczyk, S. et al. (2007), Science, 317, 1192
- Tomczyk, S. et al. (2008), Solar Physics, 247, 411
- Kawabata, Y. et al. (2020), ApJ, 898, 32
- Berger, T. et al. (2011), Nature, 472, 197
- Hillier, A. S. et al. (2011), ApJL, 736, L1
- Hagino, M. et al. (2014) SPIE, 9151, 91515V
- Suematsu, Y. et al. (2021), Astronomical Society of Japan spring meeting, M04a
- Hanaoka, Y. et al. (2020), Earth, Planets and Space, 72, 181