DKIST INSTRUMENTS

The DKIST team
CSP Workshop – Huntsville
13 November 2017

Science use case experiment design: instruments

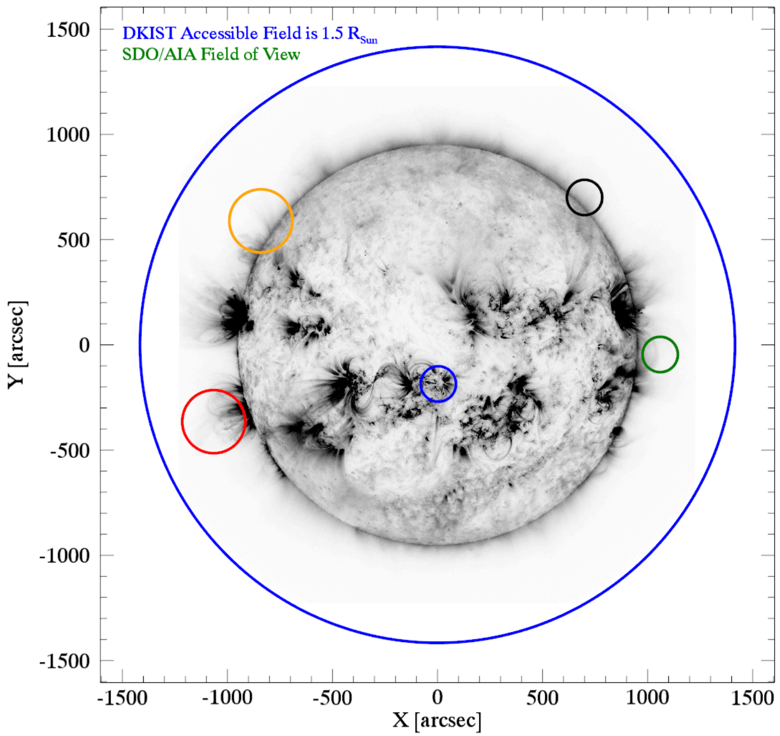
- DKIST instruments are complex, diverse, and rapidly* flexible to support a very broad science portfolio.
- Users must understand and/or make decisions about:
    1. *Telescope field-of-view, targeting (mosaics), coronagraphy, etc.*
    2. *Instrument lab rotation angle ("unrestrained spacecraft roll")*
    3. *Flexible (manually-changed) spectral distribution of light to instruments.*
    4. *Spectral/imaging/polarimetric capabilities of facility instruments*
    5. *Instrument parameters including domain coverage and SNR.*
    6. *Data rate/volume limits.*

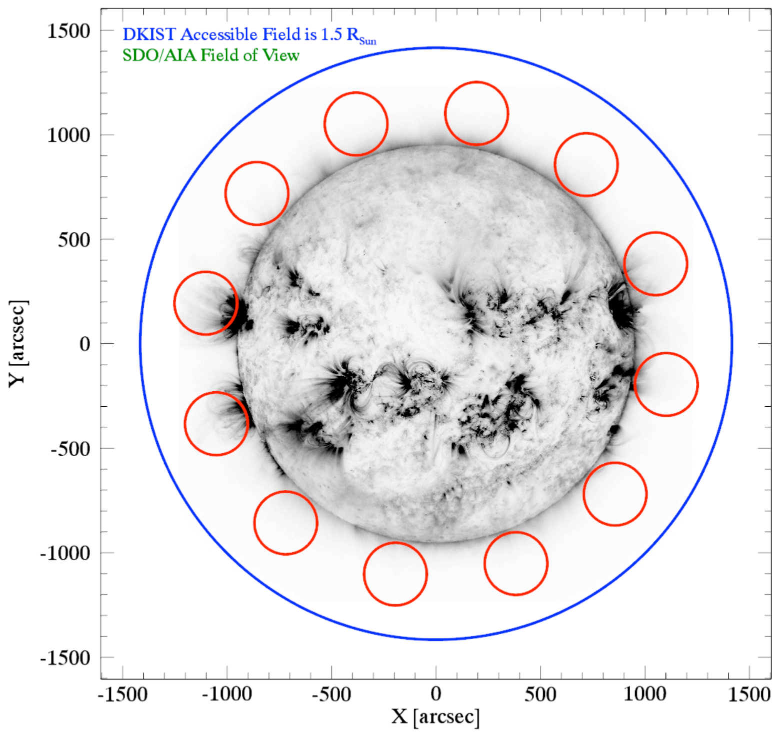
User resources for designing use cases/experiments

- Major systems (telescope/instruments/etc) summary documentation available online: *dkist.nso.edu/CSP*
- Performance Calculators:
  - FIDO Beamsplitter tool (*discussed today*)
    - Verifies spectral distribution and provides data rate estimates.
  - Instrument Performance Calculators *(discussed tomorrow)*
    - Allows exploration of instrument parameters to optimize domain coverage and SNR.
    - Useful for giving details in Use Case description.
- JIRA CSP Use Cases: Input Fields and Repository
  - Detailed questions to help relay your needs to DKIST Ops.
- Instrument design papers (some in print)

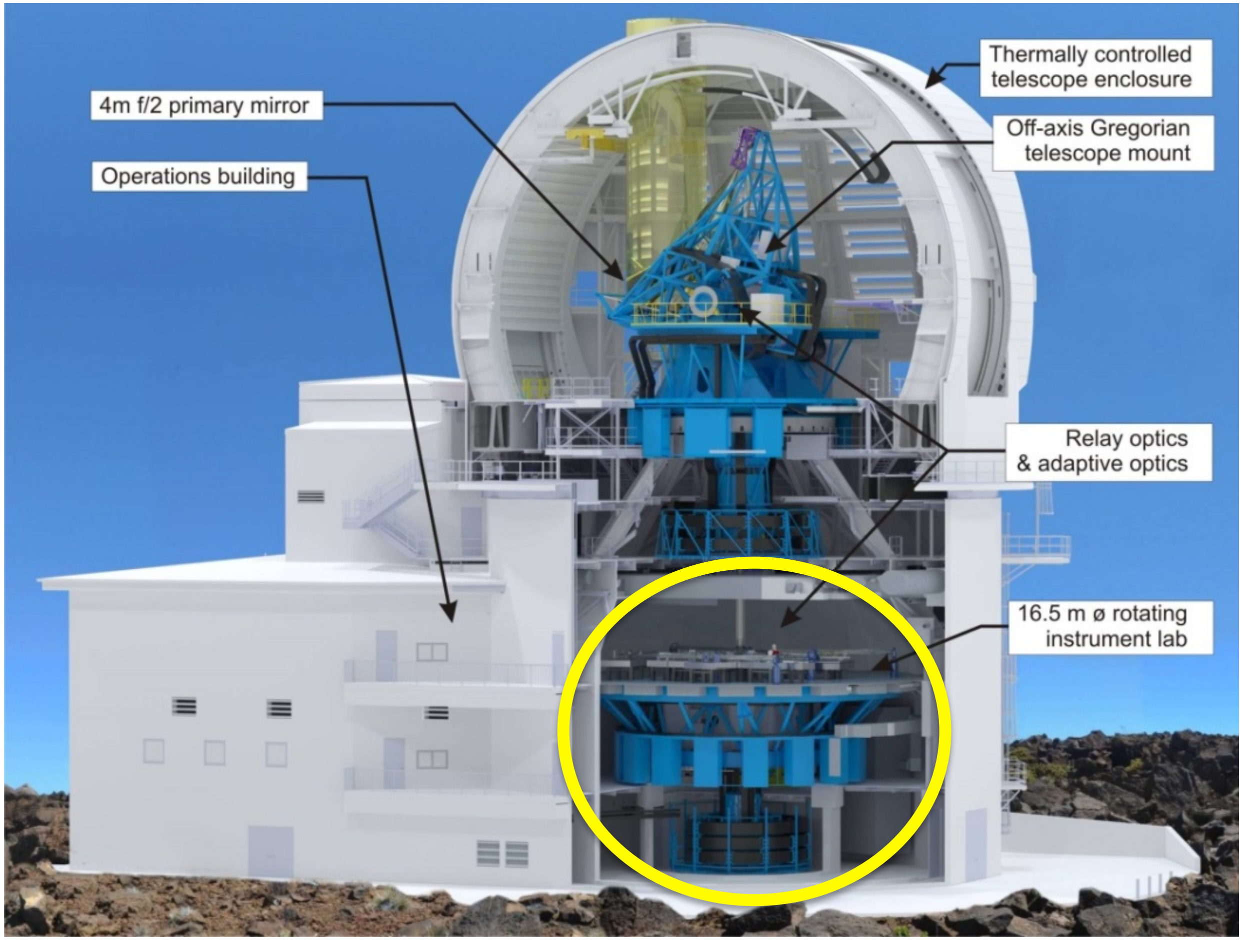
1. Telescope field-of-view, targeting (mosaics), and coronagraphy.

- Telescope prime field stop: 5’ diameter.
- Solar pointing limitations: < 1.5 solar radii
- Gregorian focus field stops: 5’ and 2.8’, each with a limb-occulting mode.
- 5’ for Cryo-NIRSP (offlimb corona). 2.8’ for all other instruments.
- Instruments each have separate instantaneous and scanning accessed field of view.
- The telescope can perform an automated “mosaicing” procedure of discrete targets.





2. The instrument Coudé lab and the field rotation angle



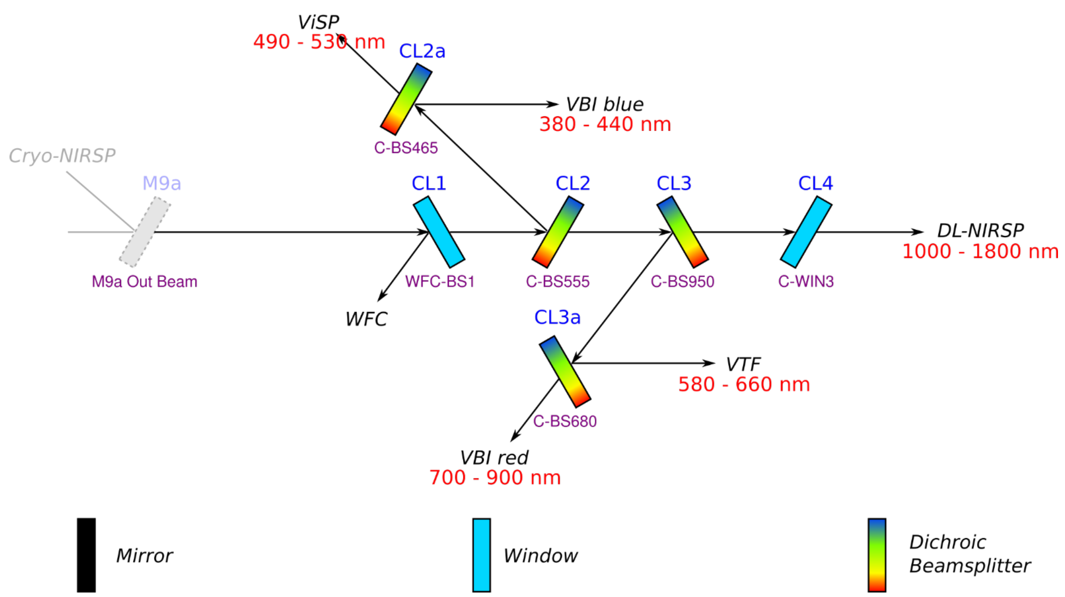
All instruments live in the Coudé instrument Lab and have fixed mountings.

The target's angular orientation with respect to instruments controlled by the Coudé platform rotation.

Coudé Instrument Lab

- 16m rotating instrumental platform
- Clean, environment controlled, externally operated, laboratory.
- Constant rotation compensates mount-induced solar image rotation.
- Can be freely rotated to orient solar image based on science need, e.g.
    - Slits aligned N/S or E/W
    - Slits parallel/perpendicular to limb.
    - Slits freely aligned parallel to filament axis, etc.

3. Flexible (manually-changed) spectral distribution of light to instruments.



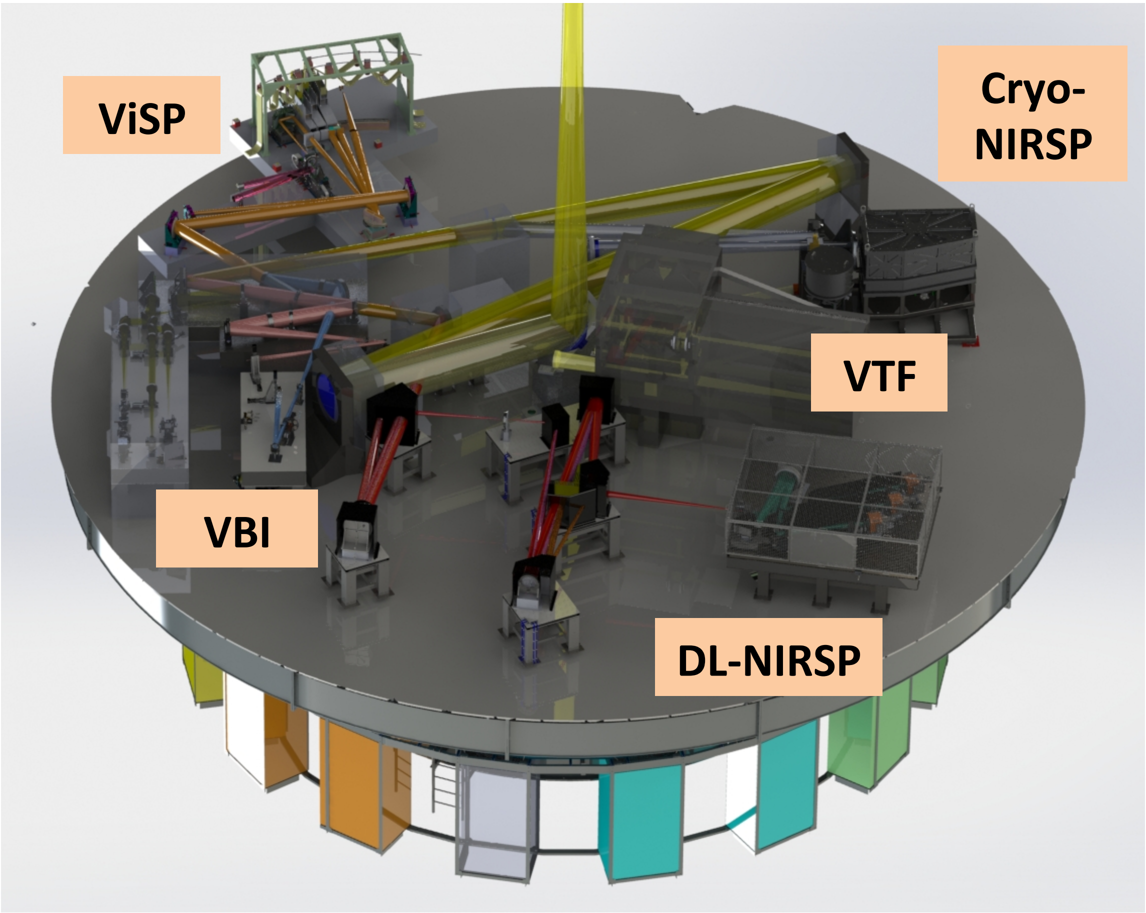
Light entering Coudé is spectrally distributed to instruments with user-configurable (manually-changed) distribution optics (FIDO).

Concept: "All or no light in a wavelength band."

All instruments except one (Cryo-NIRSP) can be operated at same time and with AO.

Detailed discussion to follow below.

4. Spectral/imaging/polarimetric capabilities of facility instruments



First-Light Instrument Suite

Five complementary image-, slit-, and IFU-based instruments.

Diverse spectral coverage with considerable overlap.

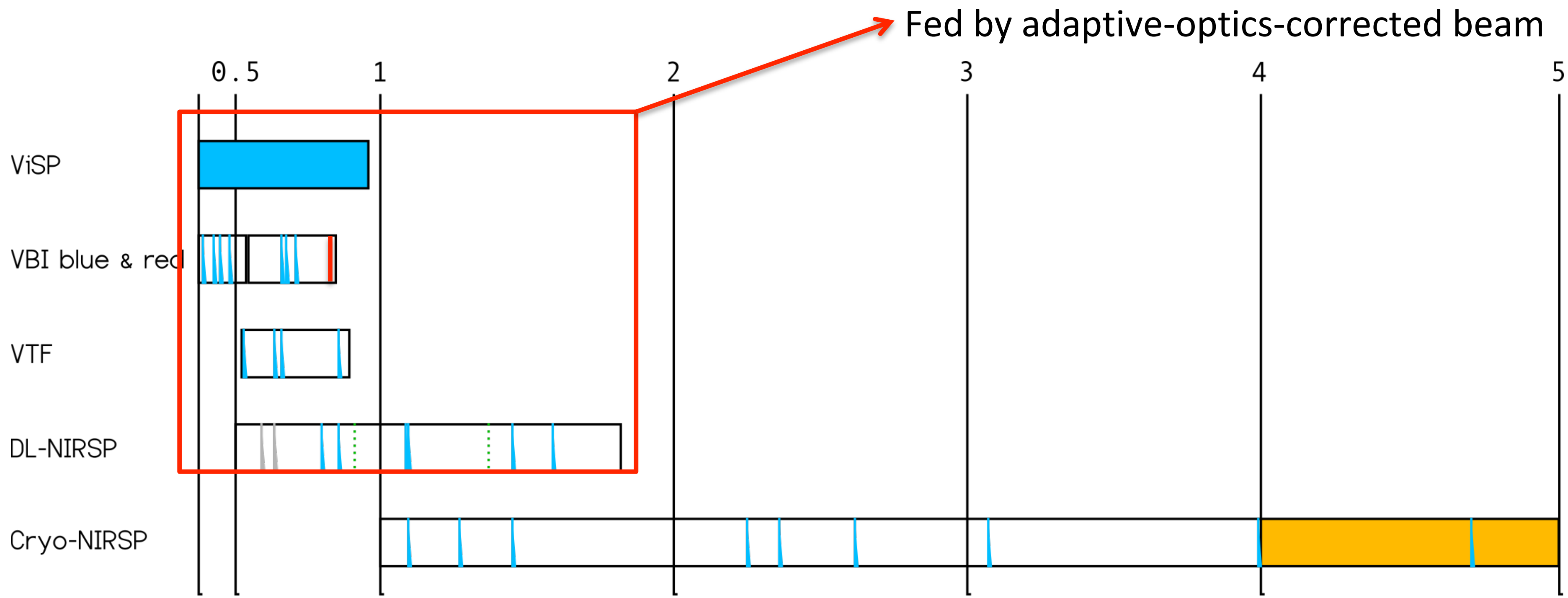
Diagnostics across the entire solar atmosphere.

Spectropolarimetric focus.

DKIST Instrument Suite Overview

Instrument Name	Acronym	Wavelength Range	Analogs
Visible Broadband Imager	VBI (blue, red)	390 – 550 nm 600 – 860 nm	Hinode/BFI; ROSA *High cadence, high spatial res.*
Visible Spectro-Polarimeter	ViSP	380 – 900 nm	SPINOR, Hinode/SP, IRIS *Scanning spectrograph, high spectral fidelity*
Diffraction-Limited Near IR Spectro-Polarimeter	DL-NIRSP	500 – 900 nm 900 – 1350 nm 1350 – 1800 nm	SPIES *True IFU, variable spatial resolution / FOV*
Visible Tunable Filter	VTF	520 – 870 nm	IBIS, CRISP, GFPI, HMI *Imaging spectro-polarimeter*
Cryogenic Near IR Spectro-Polarimeter (with context imager)	Cryo-NIRSP	1000 – 5000 nm	CYRA (BBSO) *Cryogenic, scanning spectrograph, novel IR diagnostics*

Spectral coverage summary



- Instruments – *with the notable exception of the ViSP* – operate at discrete wavelengths, because of the required pre-filters for the instruments.
- Instruments can work alone, or together (Cryo-NIRSP can only work alone)

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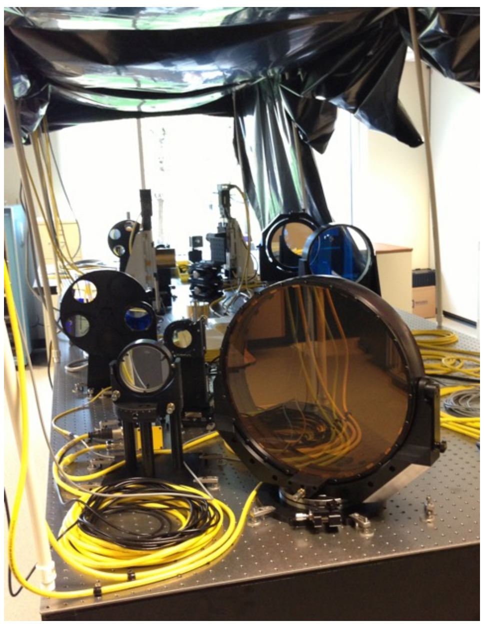
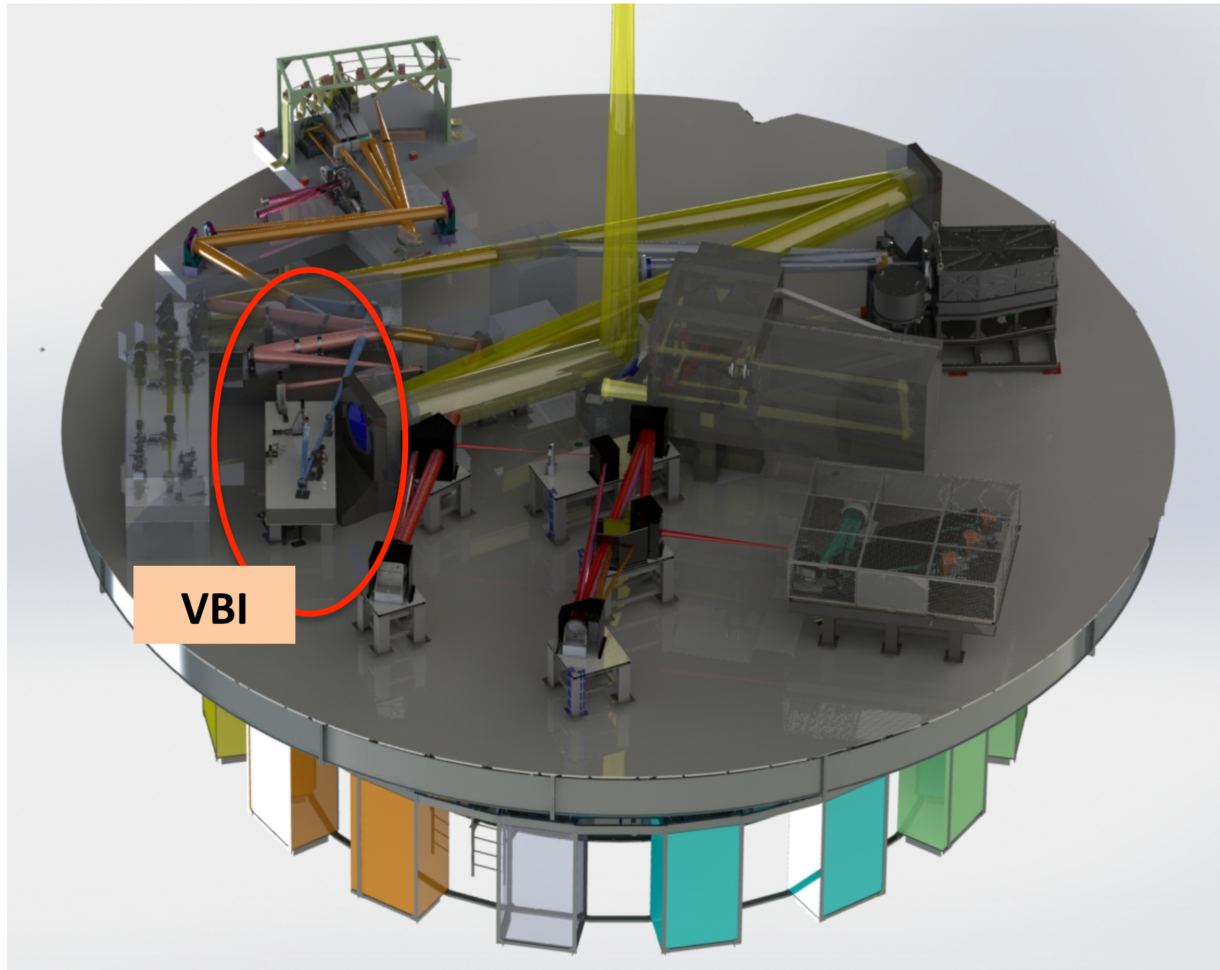
Visible Broadband Imager (VBI)

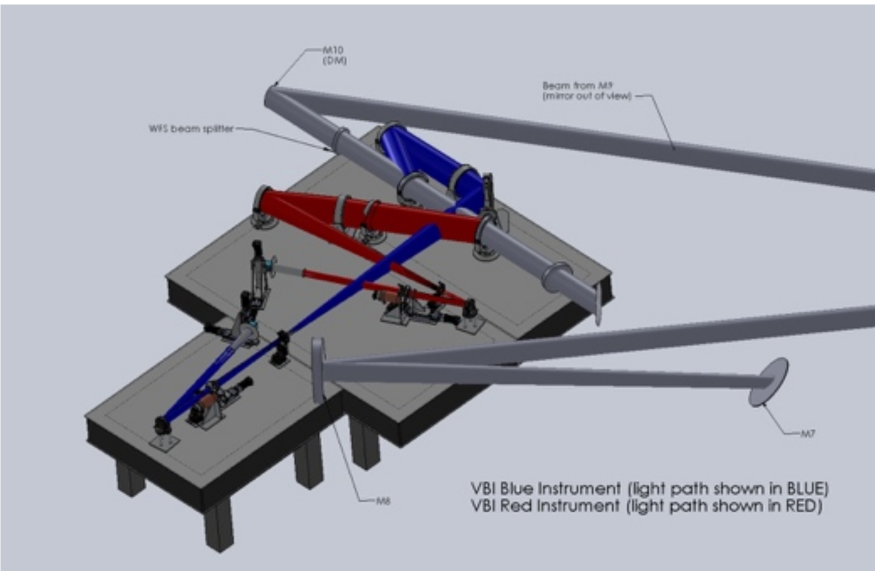
High cadence, high spatial resolution imaging w/ Speckle reconstruction

NSO



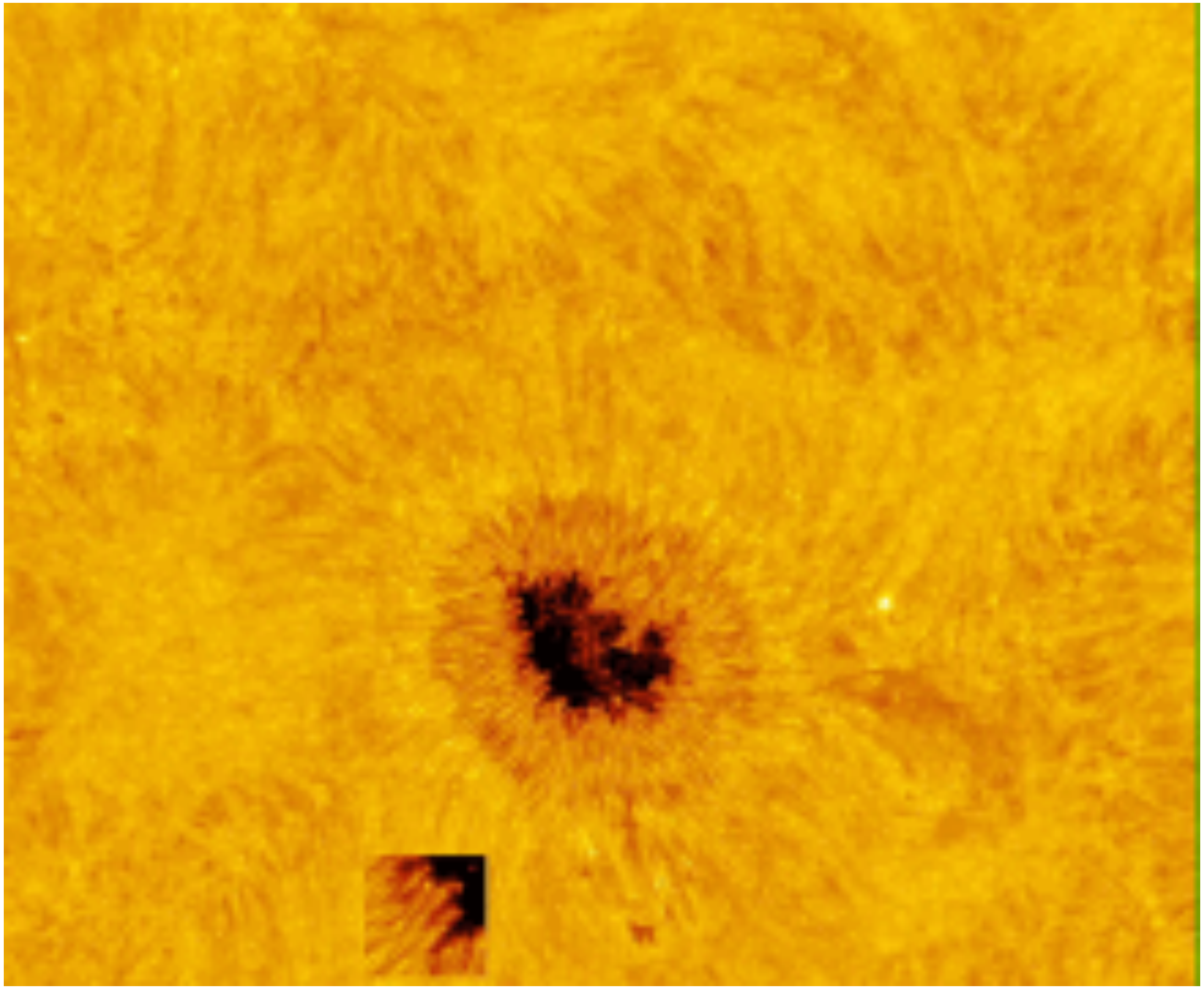


Visible Broadband Imager (VBI)



- 2 detectors (channels)
  4 filters available in each channel
  (0.05 – 0.5 nm FWHM)
- Sequential selection of filters (within each channel)
- Channels fully independent; can work together or alone
- BLUE (390-550 nm):
  CaII K, G-band,
  continuum, H-beta
- RED (600-860 nm):
  Halpha, continuum,
  TiO, Fe XI 789.2 nm (corona)
- NO polarimetry

Visible Broadband Imager (VBI)



Demonstration of the VBI H-beta filter

486.139 nm
FWHM: 0.0464 nm

Visible Broadband Imager (VBI)

Instantaneous Field of View:

45 x 45 arcsec^2 (blue channel)

69 x 69 arcsec^2 (red channel)

Full optical field:

2 x 2 arcmin^2 – by field sampling:

3 x 3 tiles in blue channel.

2 x 2 tiles in red channel

Spatial sampling:

0.011 arcsec (blue)

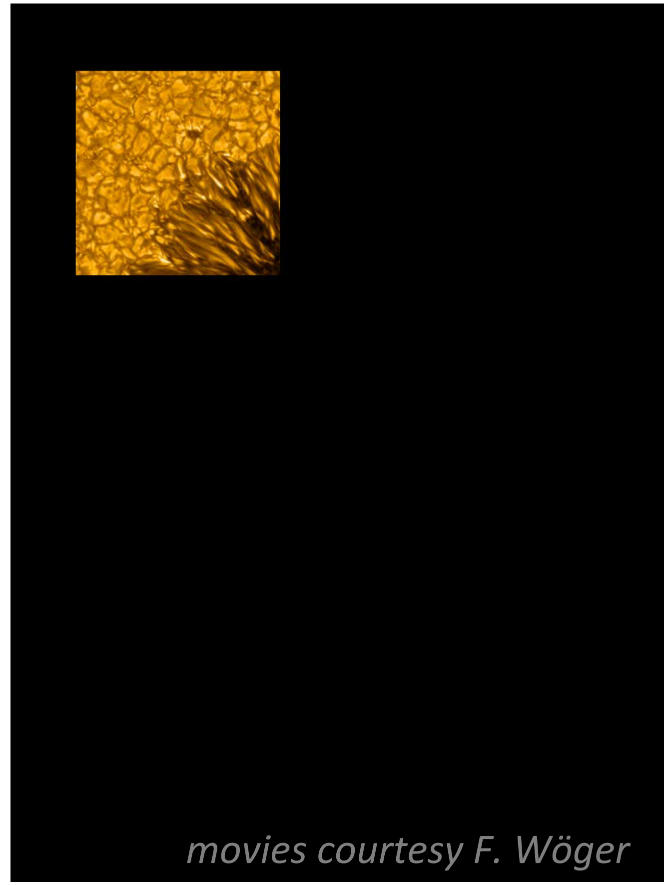
0.017 arcsec (red)

Temporal Sampling:

3.2 s for speckle reconstructed images

0.033 s raw images

0.5 s change of FOV

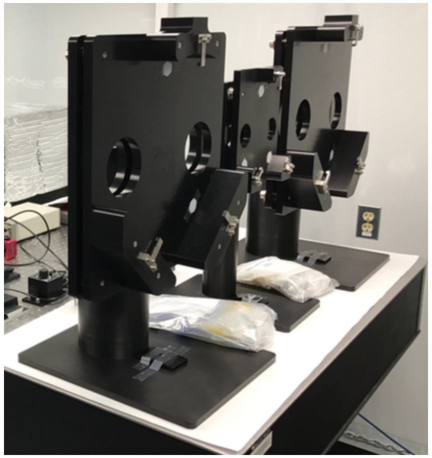


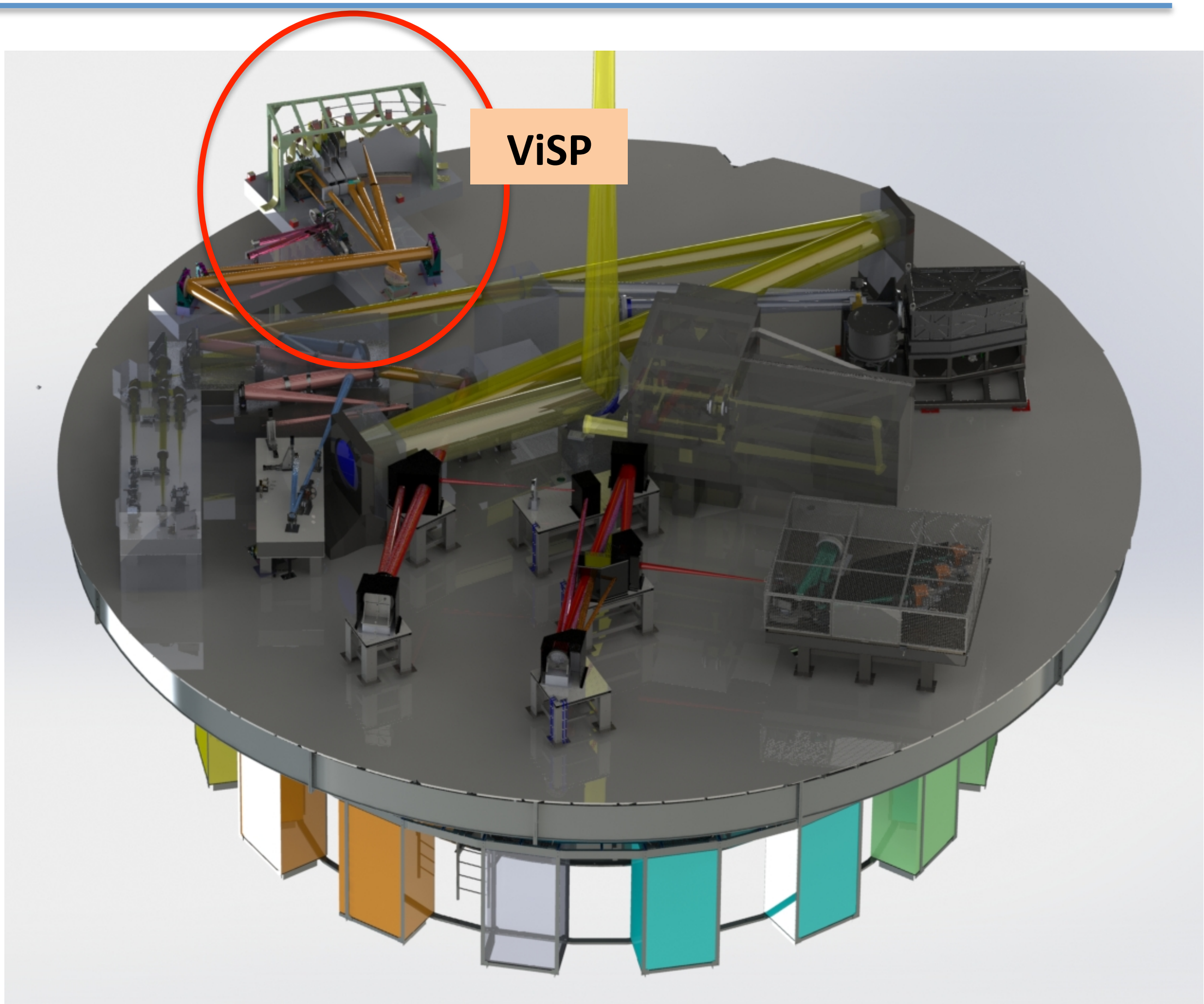
movies courtesy F. Wöger

VBI stresses high cadence and high spatial resolution – will deliver images at the diffraction limit of the telescope

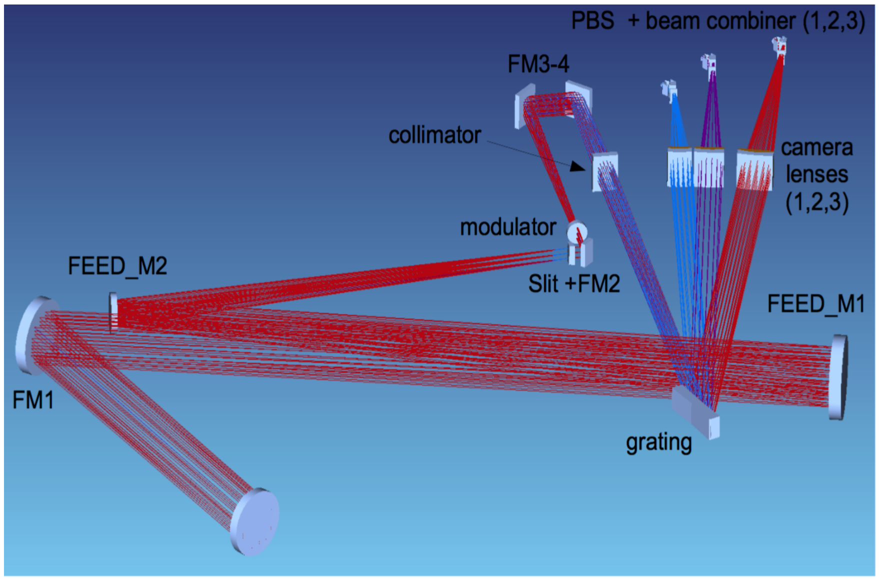
Visible Spectro-Polarimeter (ViSP)

Scanning slit spectropolarimeter, high spectral fidelity, broad assess to well-established and new spectral diagnostics





Visible Spectro-Polarimeter (ViSP)



- Diffraction-grating based spectrograph. Access to full visible spectrum: 380 – 900 nm
- 3 distinct "arms": up to 3 separate spectral bands (~ 1 nm wide) can be observed simultaneously
- ANY portion of the spectrum can be imaged on any spectral arm – depending on combination of desired ranges
- 5 possible slit widths: from 0.028" to 0.214"
- Dual beam full Stokes polarimetry
- Uses VBI blue-channel images for context

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Visible Spectro-Polarimeter (ViSP)

Instantaneous Field of View:

slit width x (75”, 60”, 50”)

Full optical field:

Slit length x 2 arcmin – by slit scanning

Spatial sampling:

0.03”, 0.0236”, 0.0198” (along slit, arms 1-2-3)

Spectral Resolution:

≤ 3.5 pm @ 630 nm or R ≳ 180,000

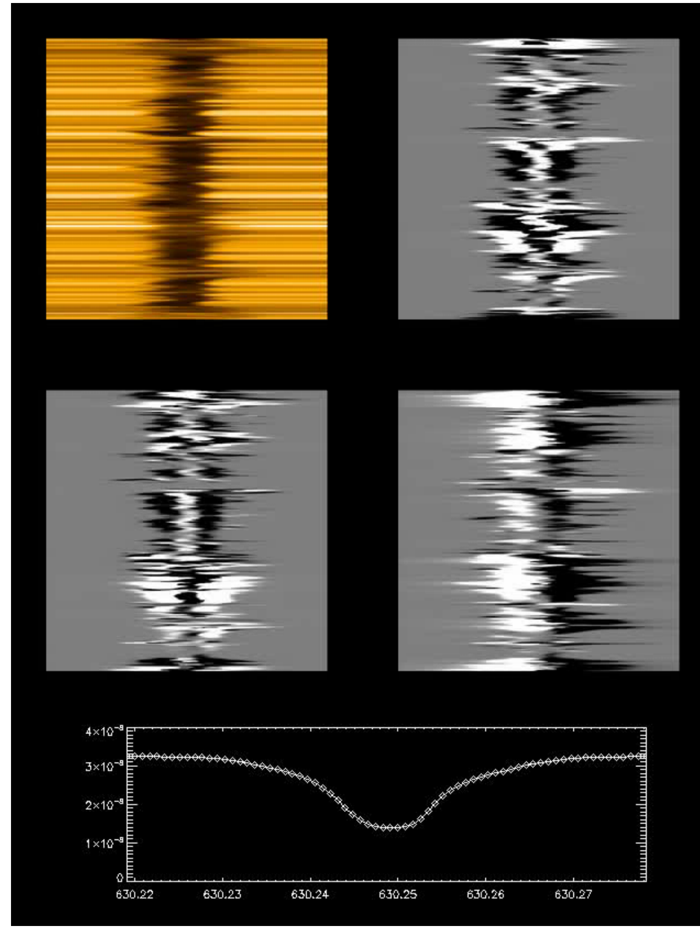
Temporal Sampling:

0.5-10 sec per slit position (polarimetry);

0.02-0.2 sec per slit position (spectroscopy)

Polarimetric Capability:

Target Accuracy: 10^{-3} P/I_{cont} in 10 sec

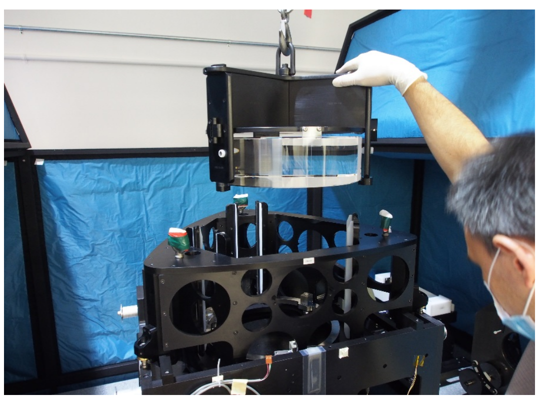


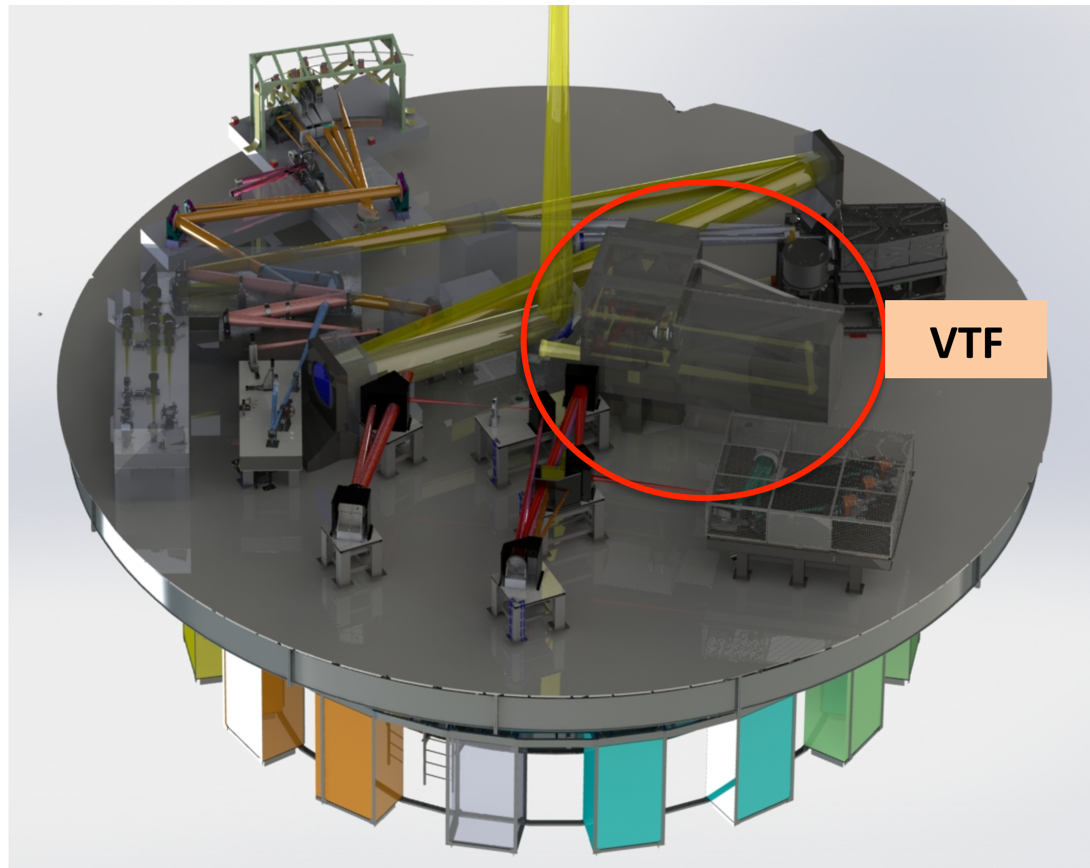
ViSP stresses high spectral fidelity and flexibility–
will deliver high precision spectro-polarimetry

Visible Tunable Filter (VTF)

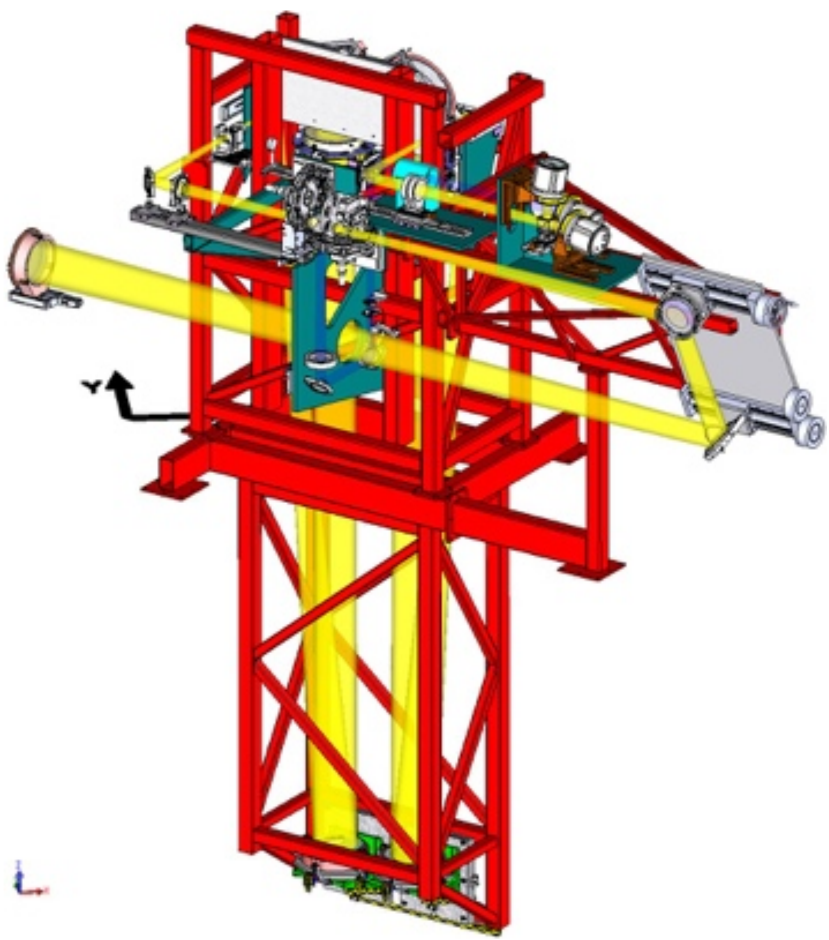
Fast-tuning, narrowband imaging spectro-polarimeter, high fidelity spectro- imaging with great coverage of temporal dynamics.

KIS





Visible Tunable Filter (VTF)



- Dual Fabry-Perot system for imaging spectro-polarimetry (300 mm FP)
- Spectral range: 520 – 870 nm. First light filters: NaD1, FeI 630.2nm, H-alpha, CaII 854.2 nm (~ 1 nm wide)
- Sequential selection of filters/sampling wavelengths
- Simultaneous broad-band images
- Orthogonal polarization states are imaged on two separate detectors
- At first light, only one etalon will be available: limited sampling for broad (chromospheric) lines

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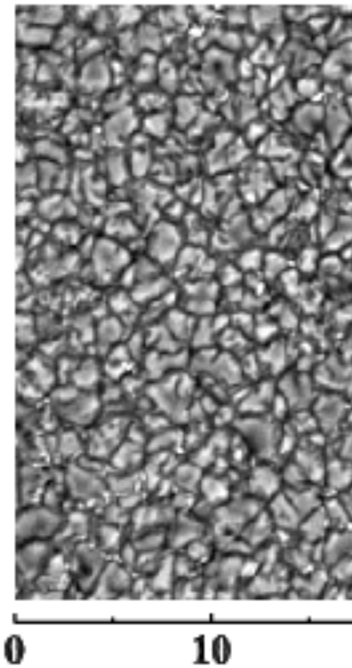
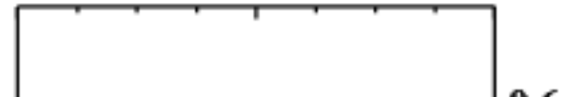
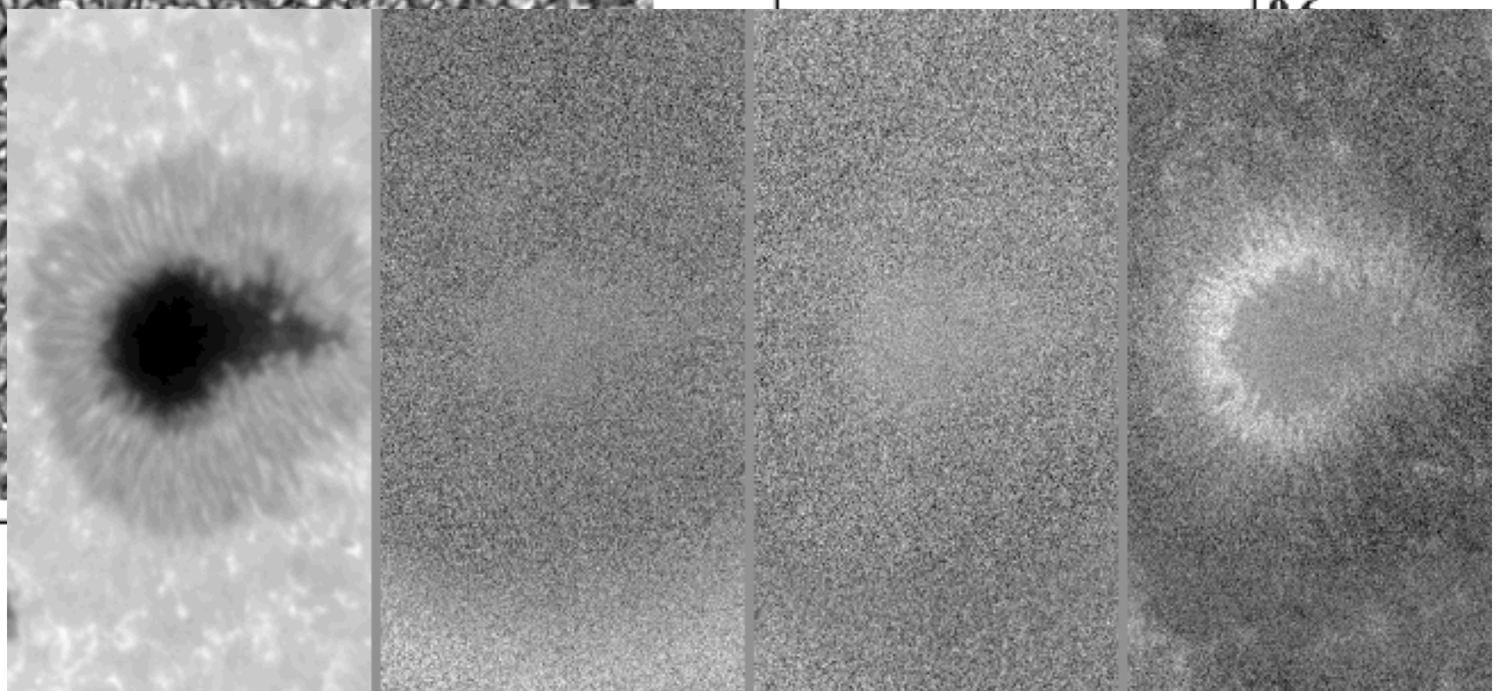
VTF Predecessor Example: IBIS





Call 854.2: Stokes I only



Call 854.2: I, Q, U, V

Visible Tunable Filter (VTF)

Instantaneous Field of View:

60 x 60 $arcsec^2$

Spatial sampling:

0.014 arcsec/pixel

Spectral Resolution:

6 pm FWHM (@600 nm), R ~ 100000

Temporal Sampling:

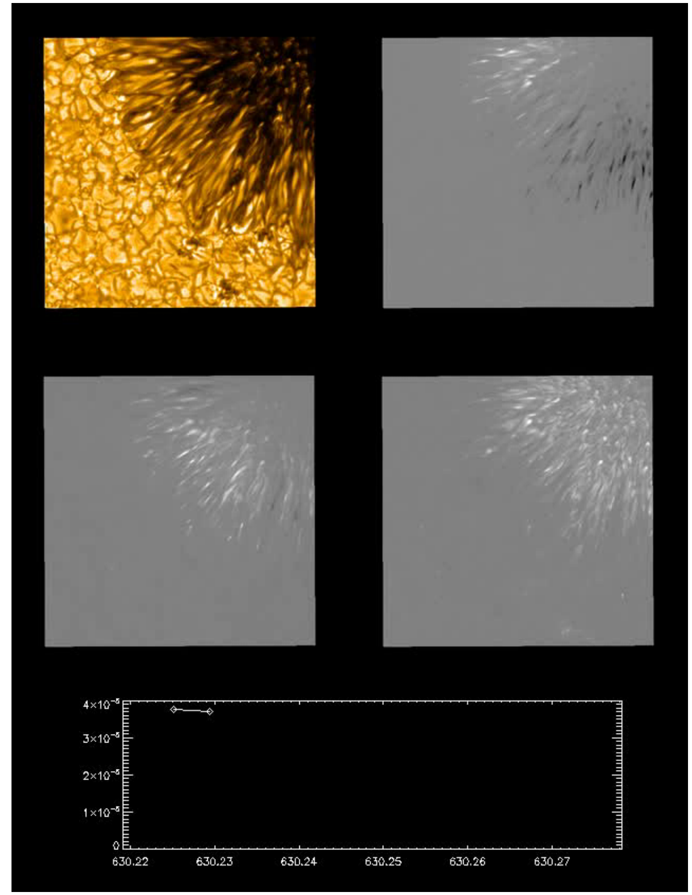
1-2 s per line scan (spectroscopy)

5-10 s per line scan (polarimetry)

Polarimetric Capability:

Full Stokes vector polarimetry

Target Accuracy: $3x10^{-3}$ P/I_{cont}

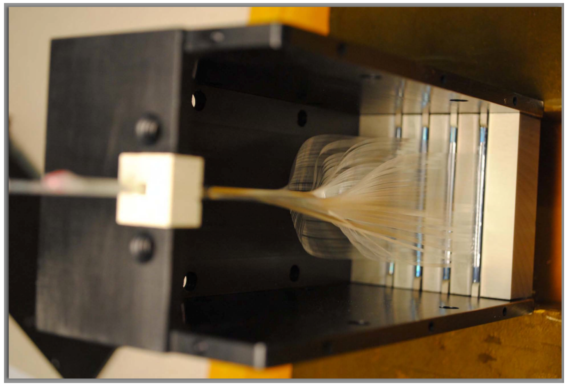


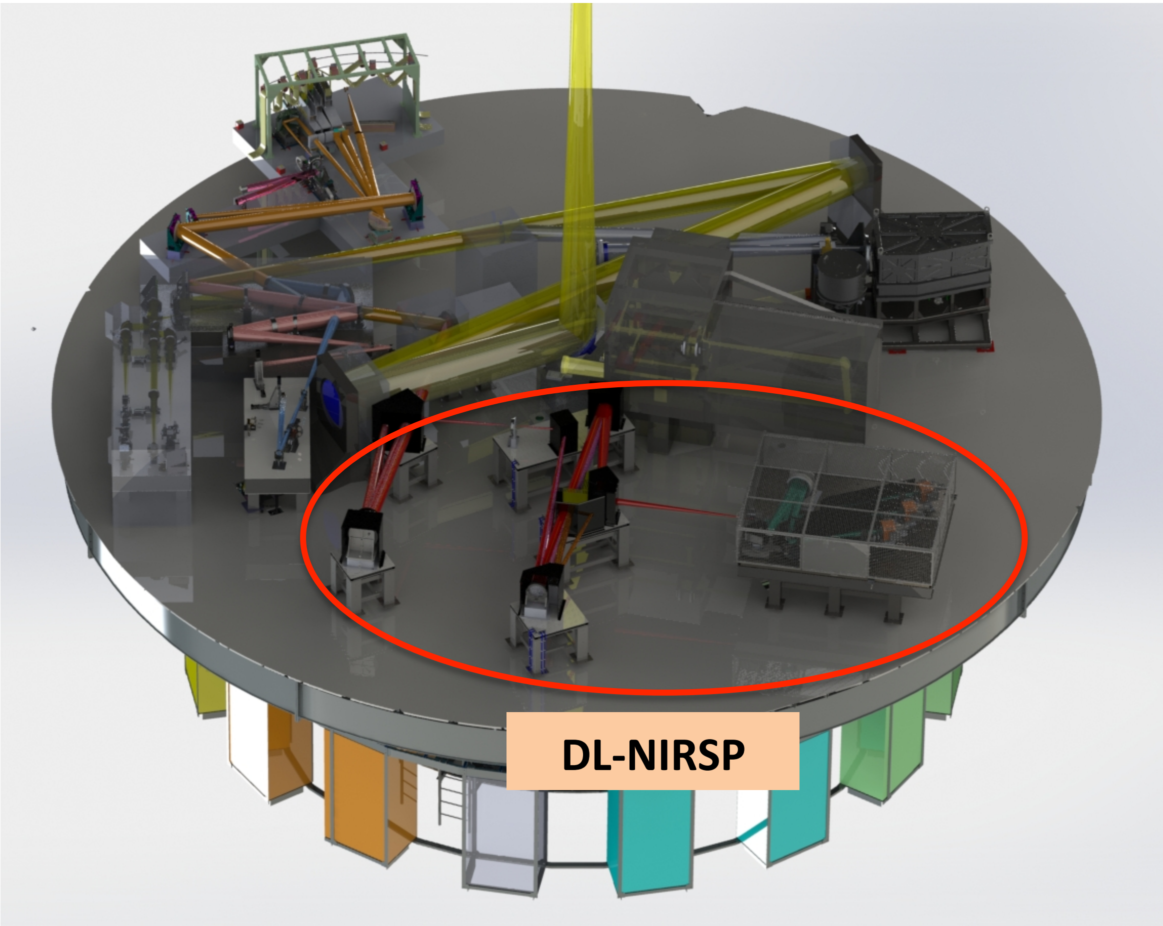
VTF will have very high spatial resolution, and allow rapid imaging spectrometry, Stokes imaging polarimetry, and accurate surface photometry.

Diffraction Limited Near-IR Spectropolarimeter (DL-NIRSP)

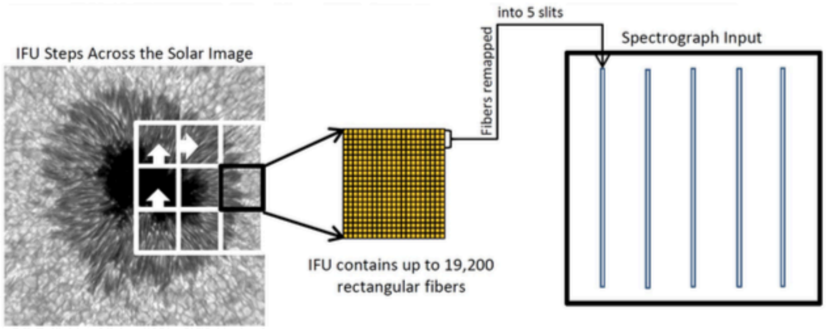
First facility class integral field spectropolarimeter for solar physics. Simultaneous spectral and 2d spatial coverage.

UH/IfA

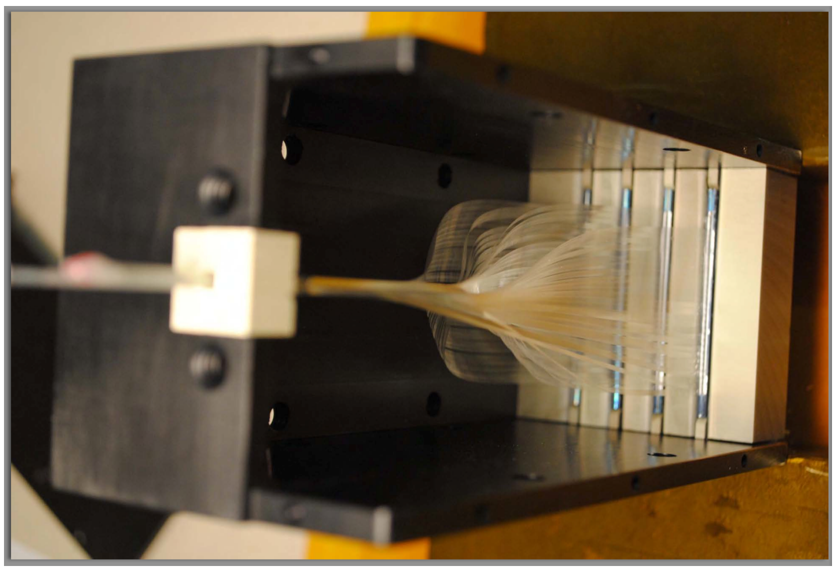




Diffraction Limited Near-IR Spectropolarimeter (DL-NIRSP)



One tile at a time, DL-NIRSP builds spectropolarimetric full data cubes: [X ; Y ; λ ; S [=I,Q,U,V] ; t]

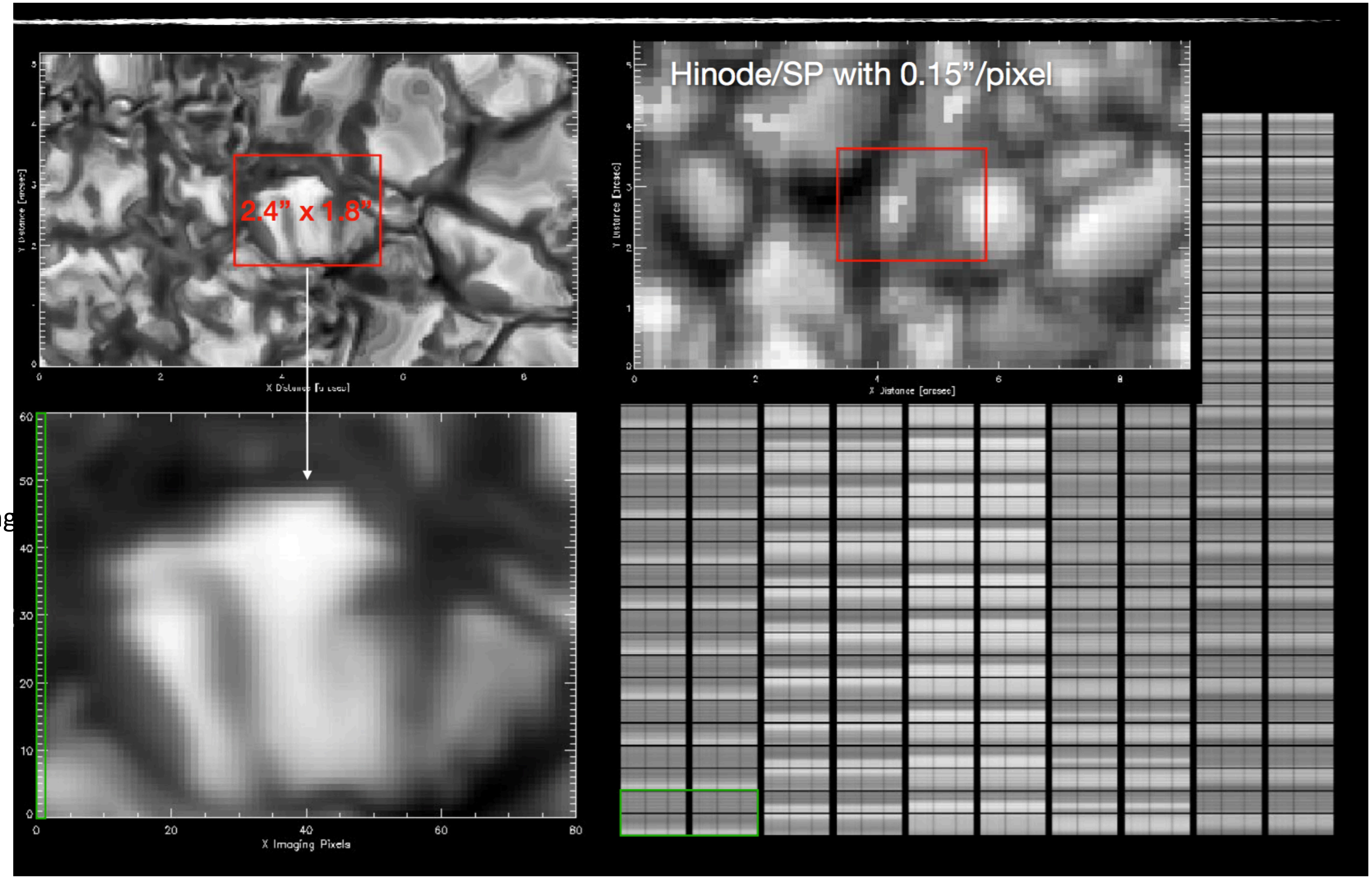


- Diffraction grating based Integral Field Spectrograph
- Spectral range: 500 -1800 nm
- 3 synchronized co-operating channels:
  - 500-900 nm
  - 900-1350 nm
  - 1350-1800 nm
- Only one spectral band (~ 1-2 nm) per channel can be observed. First light filters:
  Fe XI 789.2 ; Ca II 854.2;
  Fe XIII 1074.7 ; He I 1083.0;
  Si X 1430 ; Fe I 1565 nm
- Dual beam polarimetry

DL-NIRSP : what do the data look like?

1D radiative transfer calculation @ 500 nm; simulation with 32 km resolution (Rempel, 2012)

Telescope PSF + IFU sampling
In High-Res Mode
0.03” ≈ 20 km sampling



Dual-beam spectra from each “pixel” in the FOV

Diffraction Limited Near-IR Spectropolarimeter (DL-NIRSP)

<u>Instantaneous Field of View:</u>

2.4 x 1.8 arcsec^2 (high-res.)

6.16 x 4.62 arcsec^2 (med-res.)

27.84 x 18.56 arcsec^2 (wide field)

<u>Full optical field:</u>

2 x 2 arcmin – by field sampling

<u>Spatial sampling:</u>

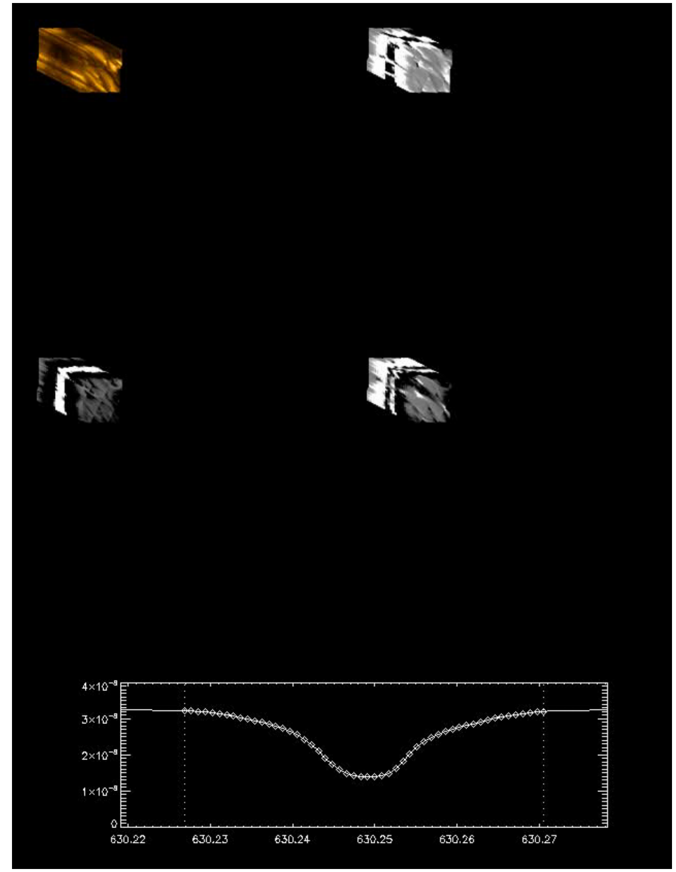
0.03, 0.077, 0.464 arcsec

<u>Spectral Resolution:</u>

R =125000

<u>Temporal Sampling:</u>

0.03 – 10 seconds / tile

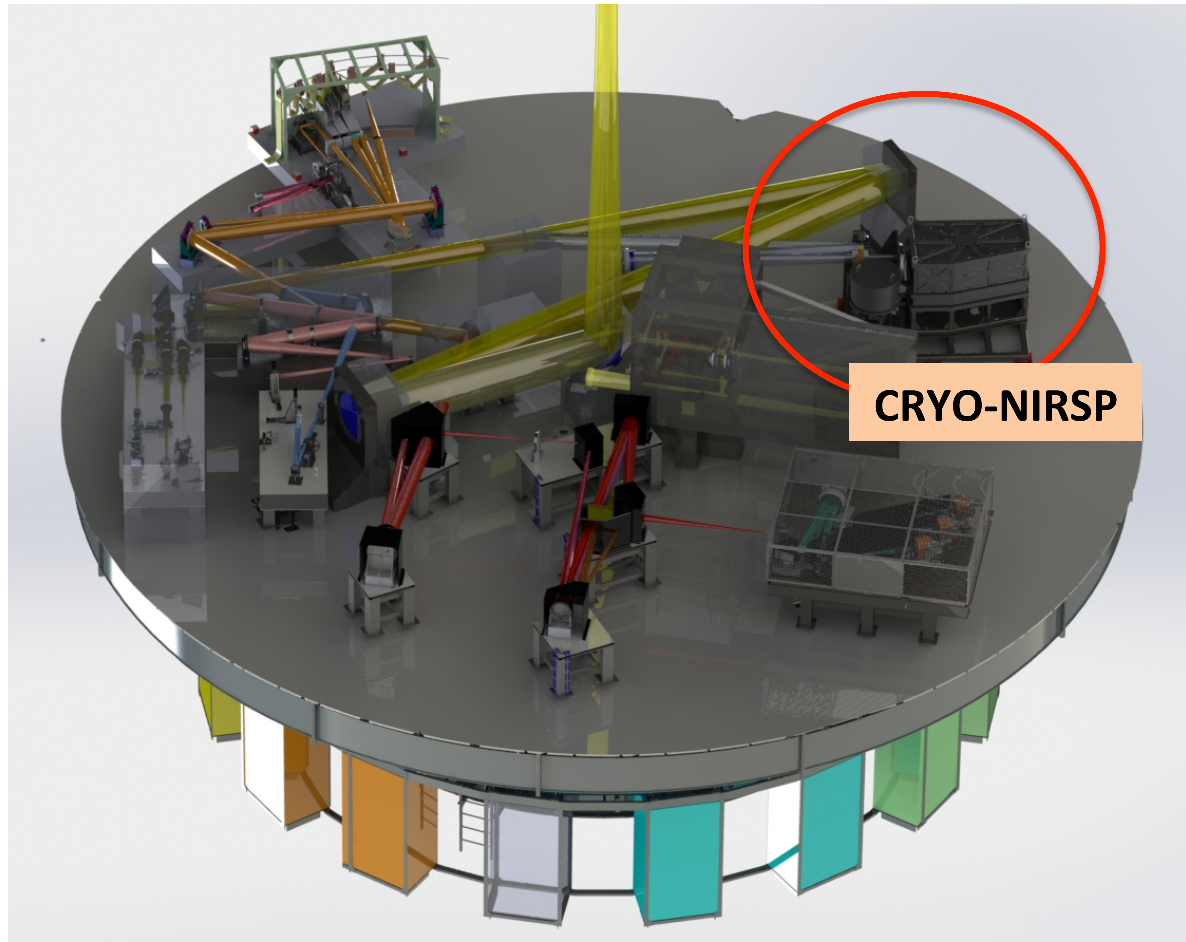


DL-NIRSP provides *simultaneous* spatial and spectral coverage over small-moderate FOVs, while maintaining high spatial resolution, spectral resolution, and polarimetric accuracy

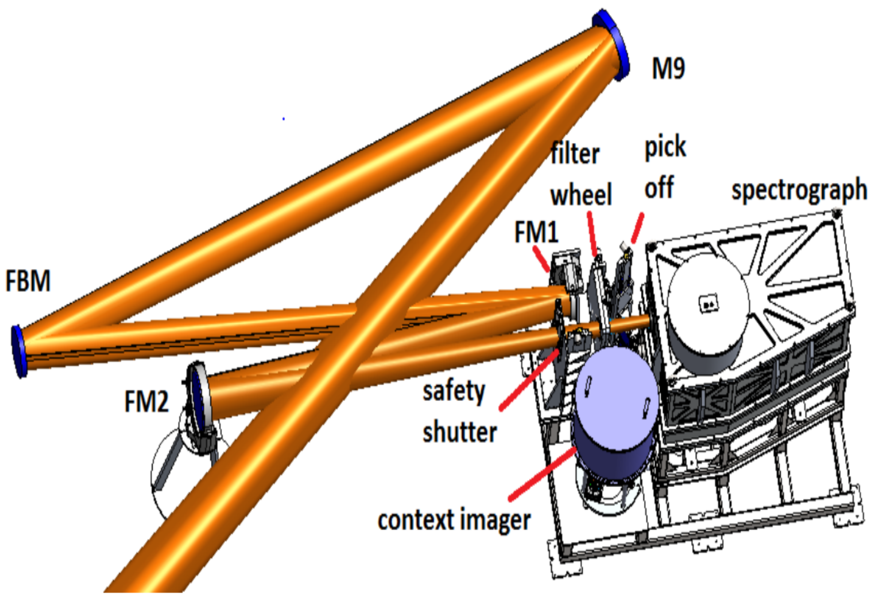
Cryogenic Near-IR Spectropolarimeter (Cryo-NIRSP)

Facility-class near-IR cryogenic slit-based spectrograph optimized for background-limited coronal and near-IR observations.

UH/IfA



Cryogenic Near-IR Spectropolarimeter (Cryo-NIRSP)



- Cryogenic: optimized for coronal observations (low background)
- Diffraction grating based spectrograph. Near IR range: 1000 – 5000 nm.
- Need order sorting filters (20-100 nm wide, λ-dependent). Six are currently available: diagnostics from 5,000 to 2MK
- 2 slit widths: 0.15" and 0.5" (nominal: on disk and off-limb)
- Dual beam polarimetry
- Context imager (100"x100")

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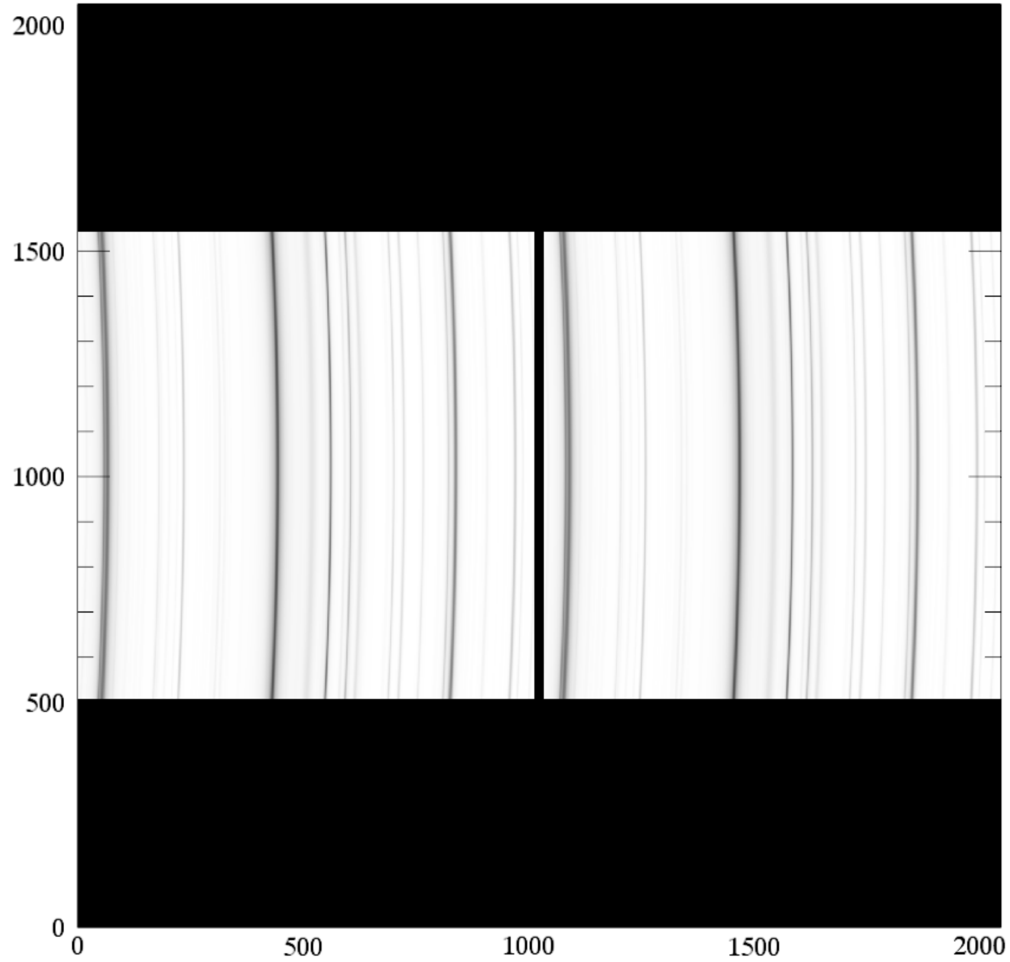
Cryo-NIRSP: dual beam polarimetry

Synthetic HeI 1083 spectra
On-disk 2’ Mode
2’ slit length

Coronal mode has 4’ long slit and covers full array.

Context imager is 2k x 2k detector covering 100” x 100”.



Cryogenic Near-IR Spectropolarimeter (Cryo-NIRSP)

Instantaneous Field of View:

0.15” x 2’ (on-disk)

0.5” x 4’ (corona)

Full optical field (by slit scanning):

2 x 2 $arcmin^2$ – on disk

4 x 3 $arcmin^2$ – coronal mode

Spatial sampling:

0.12” along slit; 0.052” Context imager

(No AO: stability better than 1”)

Spectral Resolution:

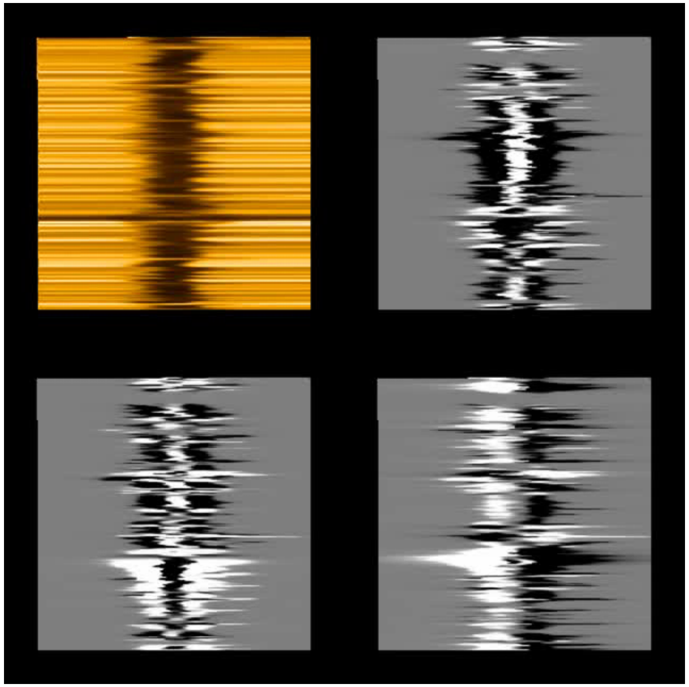
R = 100,000 (Disk);
R = 30,000 Coronal Mode:

Polarimetric Capabilities:

Full Stokes Polarimetry (Dual Beam)

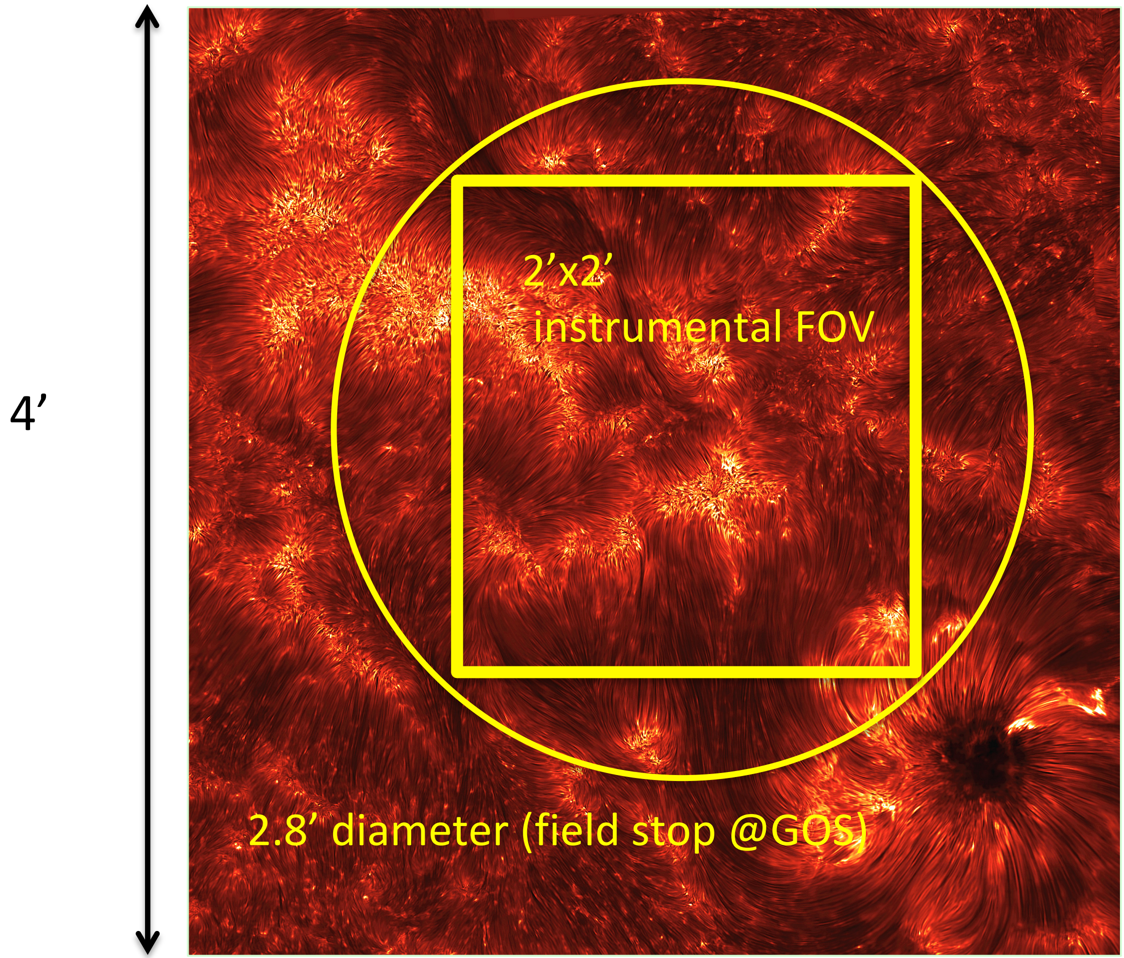
Target Accuracy: $5x10^{-4}$ P/I_{cont})

Context imager (100’’ x 100’’) centered on slit.

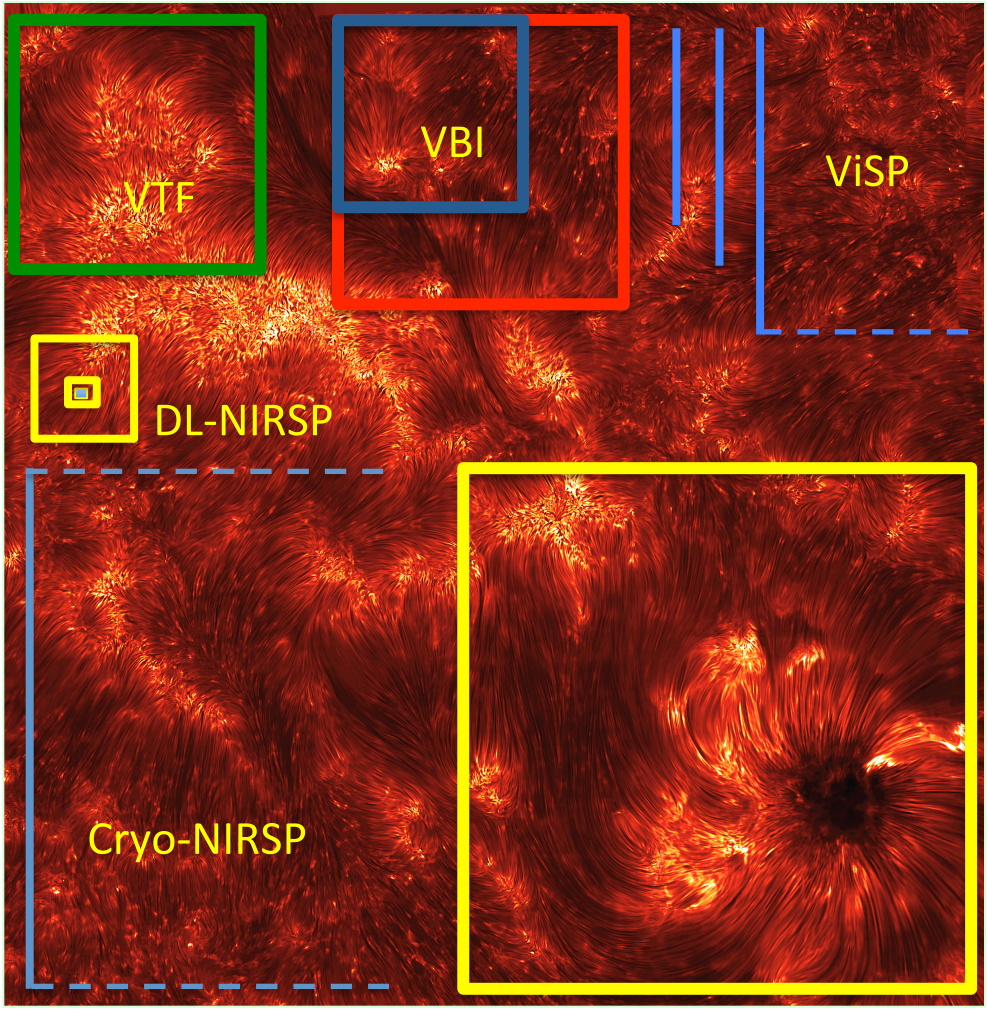


Cryo-NIRSP is optimized for coronal observations in novel, IR diagnostics. Operation flexibility serves wide range of exploratory science

Instruments' FOV - on disk example



Instruments' FOV

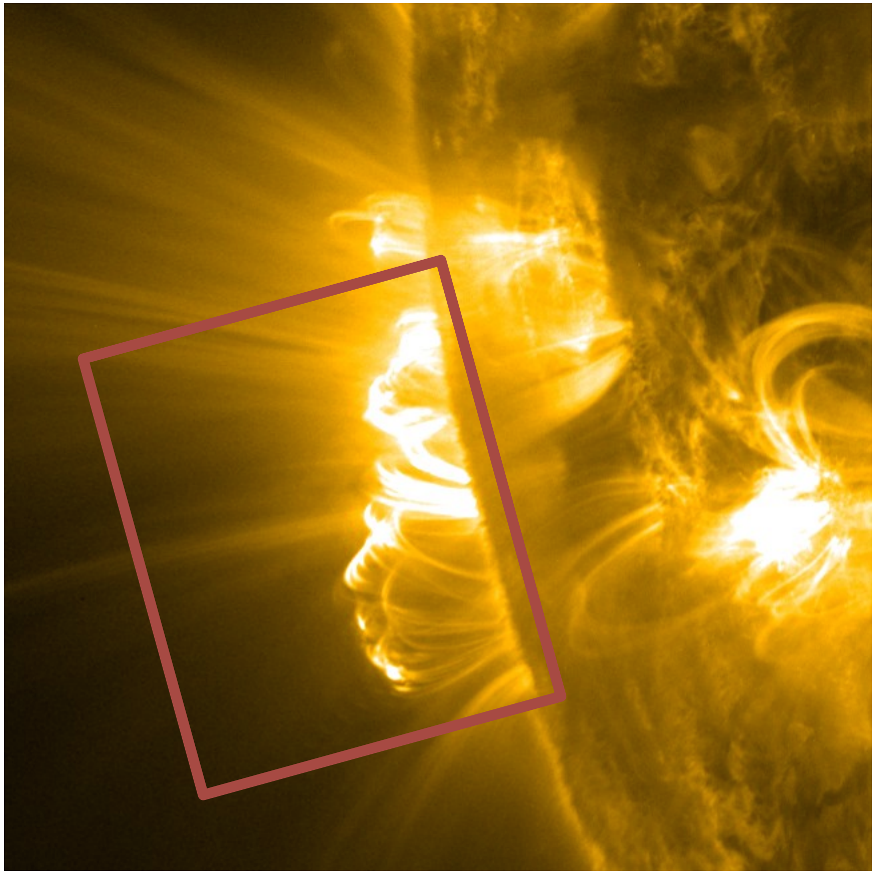


Note: ALL instruments co-point on Sun !

Note: Cryo is a standalone instrument

Cryo-NIRSP 5’ FOV – off limb

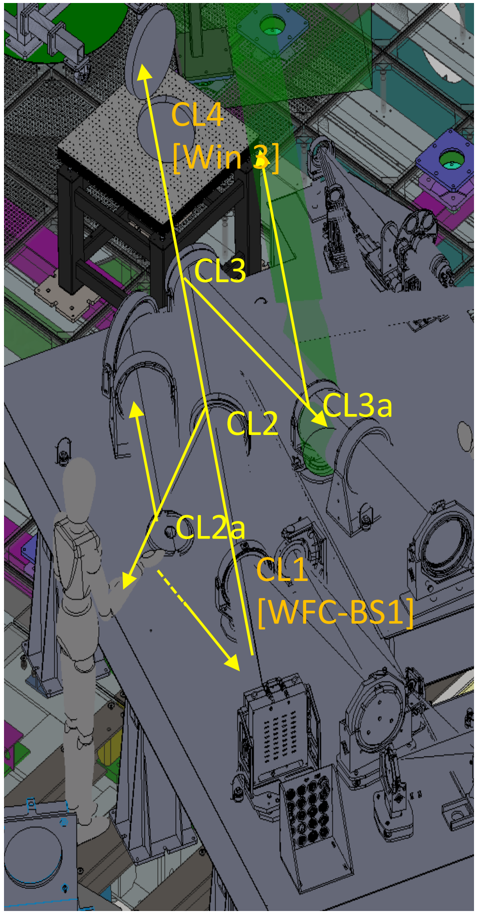
Cryo-NIRSP



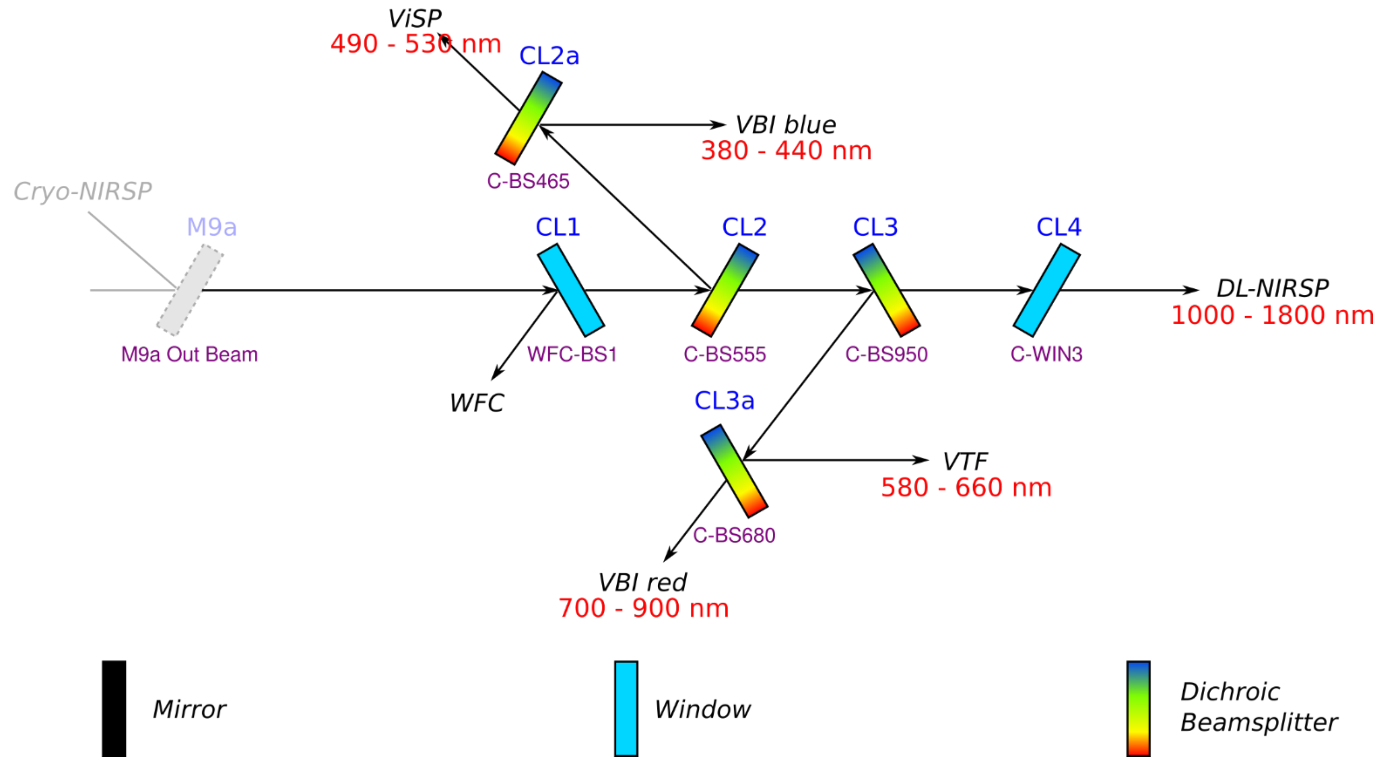
Back to #3. Flexible (manually-changed) spectral distribution of light to instruments.

Facility Instrument Distribution Optics (FIDO)

- FIDO consists of dichroic beamsplitters downstream of the adaptive optics deformable mirror.
- A mirror feeding the Cryo-NIRSP can be inserted ahead of AO within some *20-30 minutes* for fast switch-over
- "*All* or *No* Light in a wavelength band"
- The dichroics are *interchangeable* for maximum flexibility
- Each individual instrument can also be fed *all* of the light using a mirror and windows
- Changing a dichroic configuration can take up to *one day*
  - Changing of configurations will likely be minimized during DKIST operations
  - Aim is to establish a list of configurations that are often requested



FIDO Layout



Dichroics are long-pass filters (transmit longer wavelengths)

FIDO: Many different ways to combine instruments ⟹ flexibility(diagnostic power) = data (calibration) challenges

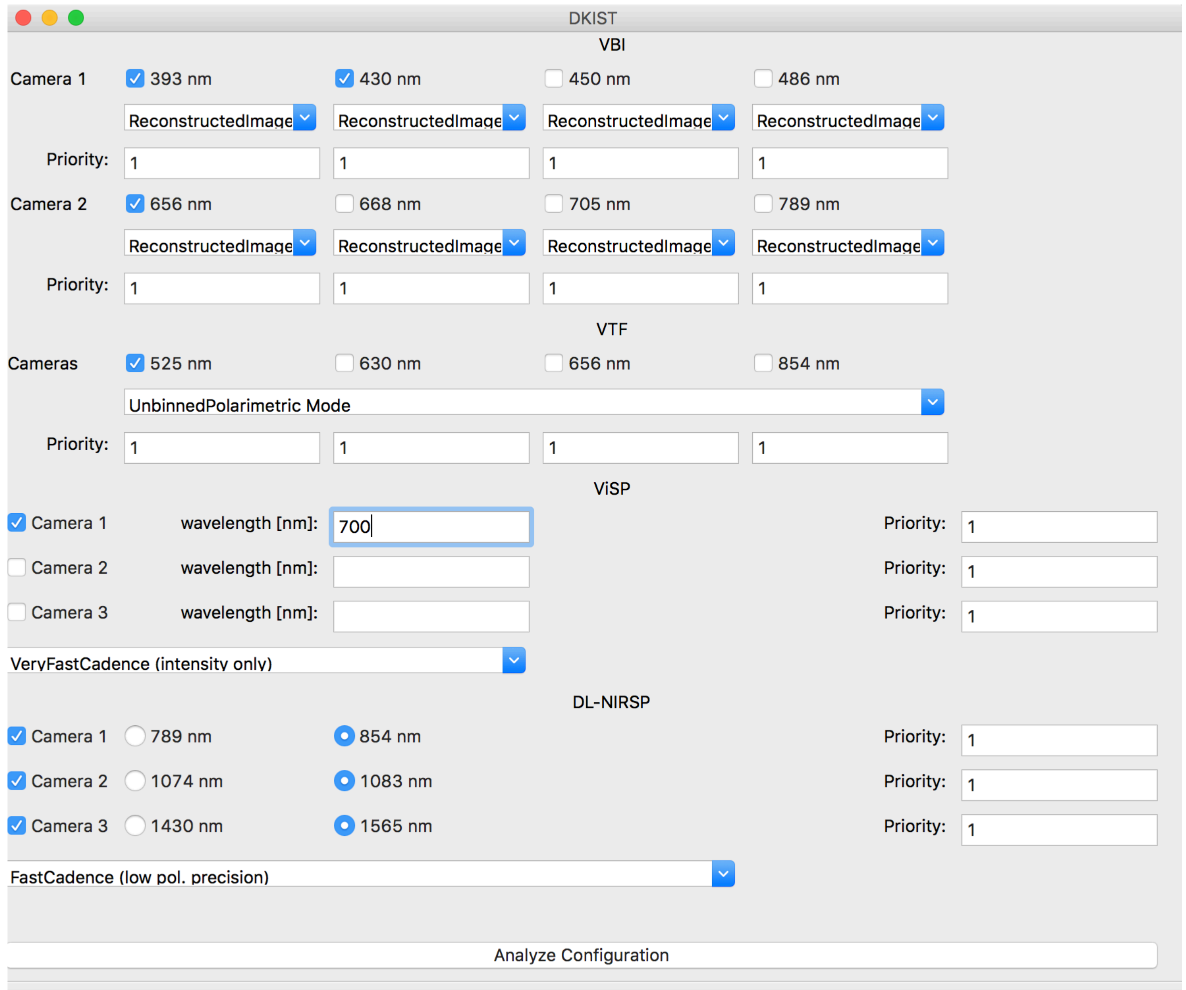
Available beamsplitters/windows

Name	Reflected Band	Transmitted Band	Comment
C-BS465	380 – 440 nm	490 – 1800 nm	Standard Location: CL2A
C-BS555	380 – 530 nm	580 – 1800 nm	Standard Location: CL2
C-BS680	380 – 660 nm	700 – 1800 nm	Standard Location: CL3A
C-BS643	*380 – 630 nm*	*656 – 1800 nm*	*Procurement is a GOAL*
C-BS950	380 – 900 nm	1000 – 1800 nm	Standard Location: CL3
C-WIN1		380 – 900 nm	Transmission band AR coat
C-WIN2		380 – 1800 nm	Uncoated front surface
C-WIN3		500 – 1800 nm	Transmission band AR coat Standard Location: CL4
C-MIR1	380 – 1800 nm		Protected Silver coat

How to chose the beamsplitters:
Beamsplitter Configuration Tool

INPUTS:
Wavelengths and modes for each desired instrument

Priorities can also be used for optimization



Beamsplitter Configuration Tool

Configuration Outputs

```
====================================================================
The following Coude Optics configurations [CL2, CL2a, CL3, CL3a]
deliver the highest ranking:
====================================================================
[BS_465,BS_950,BS_680,BS_555]; [BS_465,MI_001,BS_680,BS_555];
[BS_465,MI_002,BS_680,BS_555];

::VBI1:: waverange [nm]: [380,440]
-----> Max. Data Rate (successful diagnostics): 960 MB/s
     success: 393; 430;
     fail:
::VBI2:: waverange [nm]: [580,660]
-----> Max. Data Rate (successful diagnostics): 960 MB/s
     success: 656;
     fail:
::VTF:: waverange [nm]: [490,530]
-----> Max. Data Rate (successful diagnostics): 2880 MB/s
     success: 525;
     fail:
::ViSP1:: Channel receives no light!
     success:
     fail:    700;
::DLN1:: waverange [nm]: [700,1800]
-----> Max. Data Rate (successful diagnostics): 67 MB/s
     success: 854;
     fail:
::DLN2:: waverange [nm]: [700,1800]
-----> Max. Data Rate (successful diagnostics): 67 MB/s
     success: 1083;
     fail:
::DLN3:: waverange [nm]: [700,1800]
-----> Max. Data Rate (successful diagnostics): 67 MB/s
     success: 1565;
     fail:

Aggregate Bandwidth (max. 3500-4000 MB/s): 5001 MB/s
====================================================================
```

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5. Instrument parameters including domain coverage and SNR>

- In most cases, must be calculated using the Instrument Performance Calculators. Some examples given in summary docs.
- IPCs available online (dkist.nso.edu/CSP) and will be discussed tomorrow.

6. Data rate/volume limits

- DKIST is built for very high data rates, but still has limits on rate and volume.
- Rates/volumes are calculated by Instrument Performance Calculators for your detailed use case.
- First-order estimates of rate/volume provided the FIDO beam splitter calculator.

Capabilities of the Data Handling System (DHS)

- The DHS provides **five** dedicated "camera lines" of 960 MiB/s bandwidth each.
- Camera lines can be **shared** among multiple cameras within 960 MiB/s limit (e.g. when binned, windowed, or not running at the highest framerate)
- Max cumulative bandwidth is 4800 MiB/s; however, depending on sharing, practical max is 3500 to 4000 MiB/s
- Data acquisition at the max possible rate might have to be limited in duration due to data volume issues − typically daily data volumes of 5-30 TB

Maximum Instrument Detector Rates

VBI: 2x (4096 x 4096) [Andor Balor].
Max rates: 2 x 960 MiB/s

VTF: 3x (4096 x 4096) [Andor Balor].
Max rates: 3 x 960 MiB/s

ViSP: 3x (2560 x 2160) [Andor Zyla 5.5].
Max rates: 3 x 433 MiB/s

DL-NIRSP: 1 x (4096 x 4096) [Andor Balor] + 2 x (2048 x 2048) [H2RG]
Max rates: 1 x 960 MiB/s; 2 x 240 MiB/S

Cryo-NISRP: 2 x (2048x2048) [H2RG]
Max rates: 2 x 80 MiB/s

Beamsplitter Configuration Tool

Data Rate Outputs

```
==================================================================
The following Coude Optics configurations [CL2, CL2a, CL3, CL3a] deliver the hig
ranking:
==================================================================
[BS_465,BS_950,BS_680,BS_555]; [BS_465,MI_001,BS_680,BS_555];
[BS_465,MI_002,BS_680,BS_555];

::VBI1:: waverange [nm]: [380,440]
-----> Max. Data Rate (successful diagnostics): 960 MB/s
     success: 393; 430;
     fail:
::VBI2:: waverange [nm]: [580,660]
-----> Max. Data Rate (successful diagnostics): 960 MB/s
     success: 656;
     fail:
::VTF:: waverange [nm]: [490,530]
-----> Max. Data Rate (successful diagnostics): 2880 MB/s
     success: 525;
     fail:
::ViSP1:: Channel receives no light!
     success:
     fail:    700;
::DLN1:: waverange [nm]: [700,1800]
-----> Max. Data Rate (successful diagnostics): 67 MB/s
     success: 854;
     fail:
::DLN2:: waverange [nm]: [700,1800]
-----> Max. Data Rate (successful diagnostics): 67 MB/s
     success: 1083;
     fail:
::DLN3:: waverange [nm]: [700,1800]
-----> Max. Data Rate (successful diagnostics): 67 MB/s
     success: 1565;
     fail:

Aggregate Bandwidth (max. 3500-4000 MB/s): 5001 MB/s
==================================================================
```

Summary

DKIST provides diverse and powerful instrumentation for broad science.

We have discussed some aspects of experiment design:

1. *Telescope field-of-view, targeting (mosaics), coronagraphy, etc.*
2. *Instrument lab rotation angle ("unrestrained spacecraft roll")*
3. *Flexible (manually-changed) spectral distribution of light to instruments.*
4. *Spectral/imaging/polarimetric capabilities of facility instruments*
5. ***Instrument parameters including domain coverage and SNR.***
6. *Data rate/volume limits.*

Instrument Performance Calculators will be discussed in further detail tomorrow.