Ground-Based Coronal Physics in the Next Decade: The DKIST View

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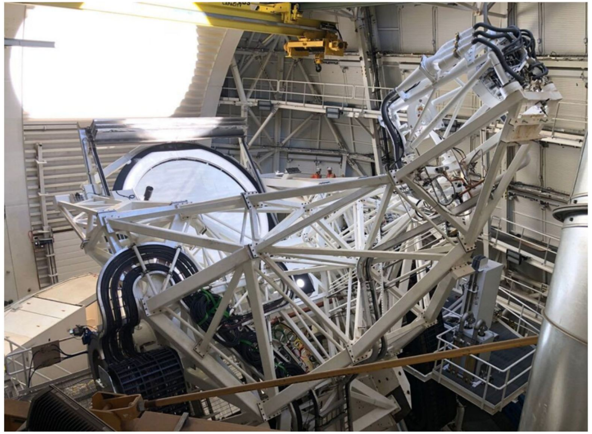
Workshop #2: Next Generation Advances in Ground-Based Solar Physics — A Decadal Preparation



National Science Foundation's
Daniel K Inouye Solar Telescope
4 meter off-axis Gregorian with coronagraphic capabilities
Rimmele et al. Solar Physics 295, 172 (2020)

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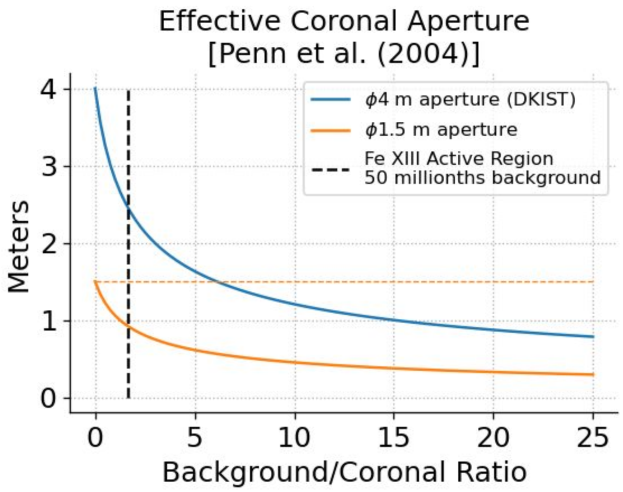
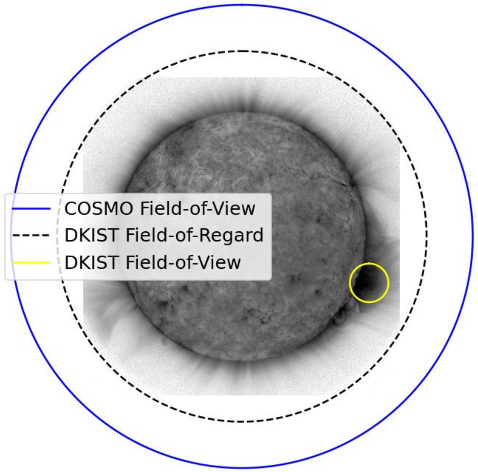
Science Drivers	• *What governs the fundamental structure, composition, and evolution of the corona?* • *How are the corona and solar wind heated and accelerated?* • *How is energy stored, released, and propagated during space weather events?*
Observational needs	Measurements of the **3D distribution of coronal fields** and its embedded plasma – the "*perfect multi-wavelength problem*"
Why ground-based?	1. Magnetic field diagnostics are accessible at VIS/IR and Radio wavelengths. 2. Diffuse multi-scaled corona requires high resolution and large collecting areas.
Proposed ground-based facilities	COSMO: Synoptic coronal polarimetry + waves obs. FASR: *Dynamic* coronal magnetism probed w/ multiple mechanisms ngGONG: Broad network coronal coverage + helioseismology
Other New Synergies	EUV Magnetic Induced Transition (Hinode/EIS) Multi vantage point and in-situ observations (PSP/SO) MUSE → *high-resolution dynamic coronal spectroscopy*
DKIST	1st gen: Coronagraphy with single-slit / IFU multi-wavelength polarimeters. 2nd gen: Needs to be the era of ***highly-multiplexed, high-resolution, dynamic, coronal polarimetry***!

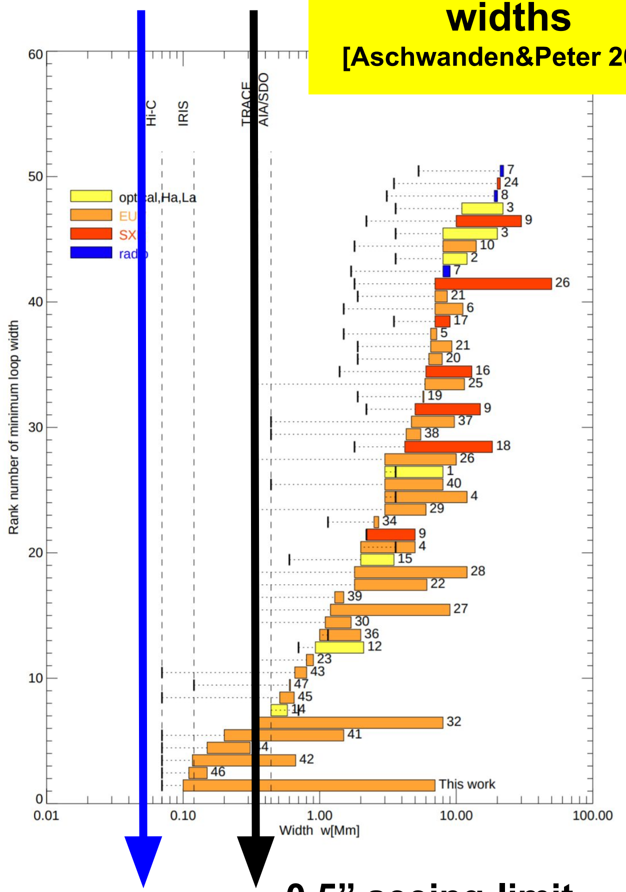
The Strengths of DKIST in the Corona

- Largest aperture solar coronagraph for the next decade
- Broad wavelength/thermal coverage: ~0.38 to 28 µm
- Large of field of regard (<1.5 Rsun) with targeted field-of-view comparable to active region sizes (5 arcmin).
- Highest spatial resolution with AO-corrected diagnostics (on-disk / near limb). Seeing-limited in corona.





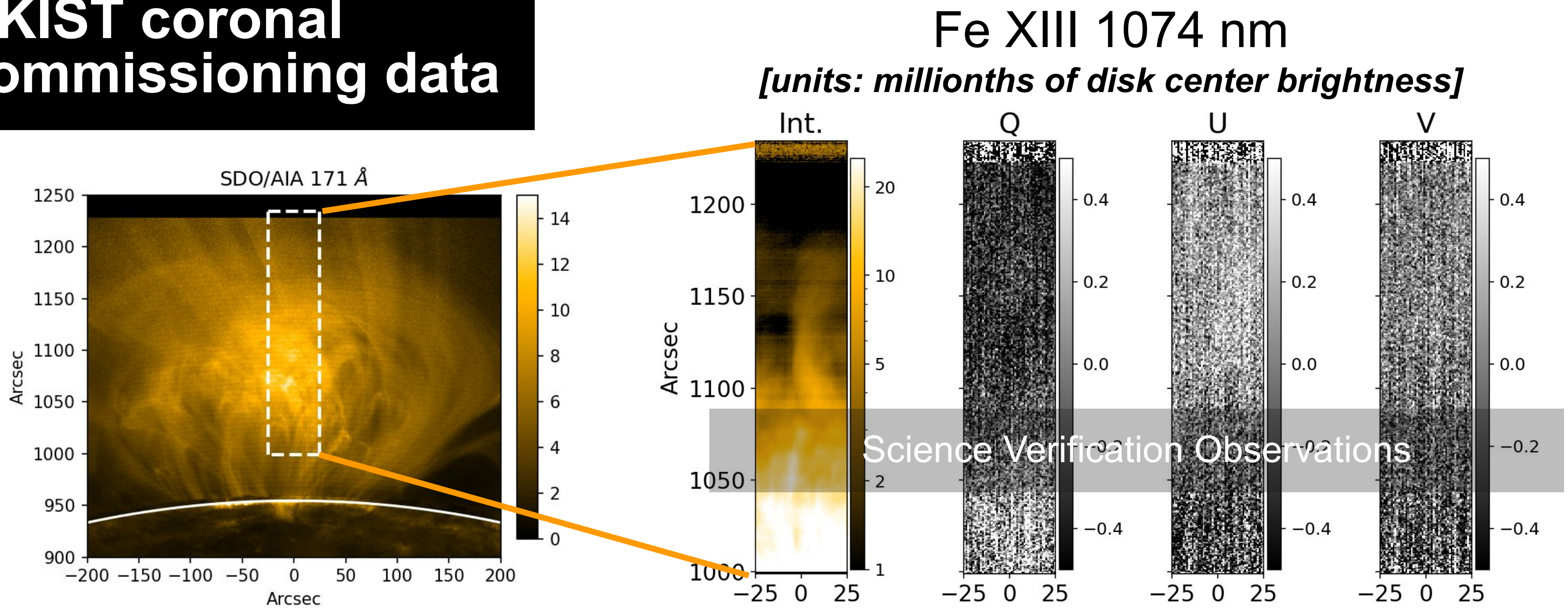
Coronal loop widths
[Aschwanden&Peter 2017]



DKIST 1um Diff.Limit

~ 0.5" seeing-limit

DKIST coronal commissioning data



First maps of coronal line polarization from Cryo-NIRSP

*** Preliminary Verification Data ** [~10 min single-slit raster]*

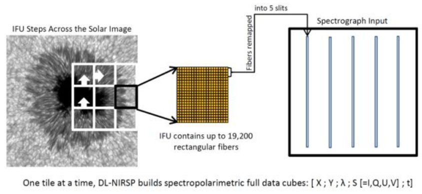
J. Kuhn, A. Fehlman, T.Schad, I.Scholl and the Cryo-NIRSP team

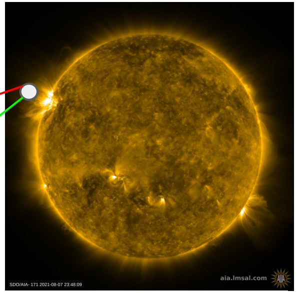
Other coronal lines measured to date by Cryo-NIRSP: Fe XIII 1079 nm, Si X 1430 nm, **Si IX 3934 nm**

First multi-wavelength IFU coronal line measurements from DL-NIRSP

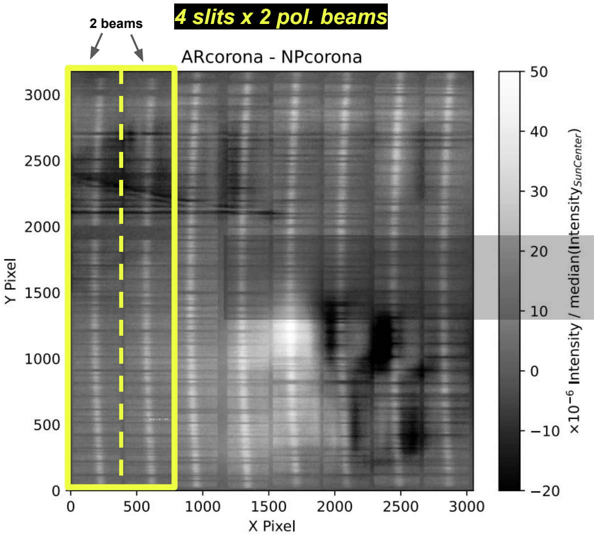
*<u>** Preliminary Verification Data **</u>*

H. Lin, S. Jaeggli, T. Anan, and the DL-NIRSP Team

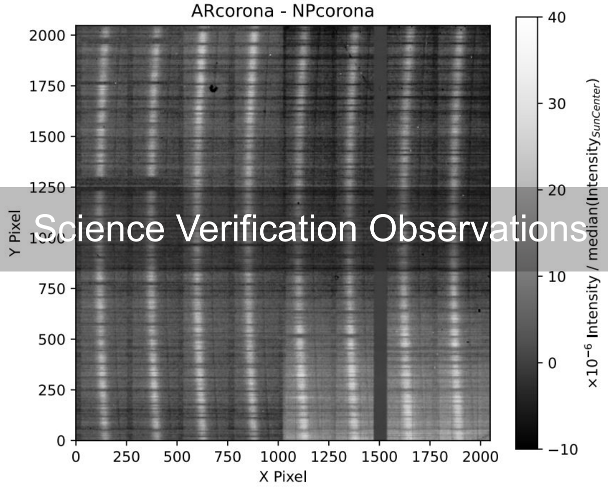




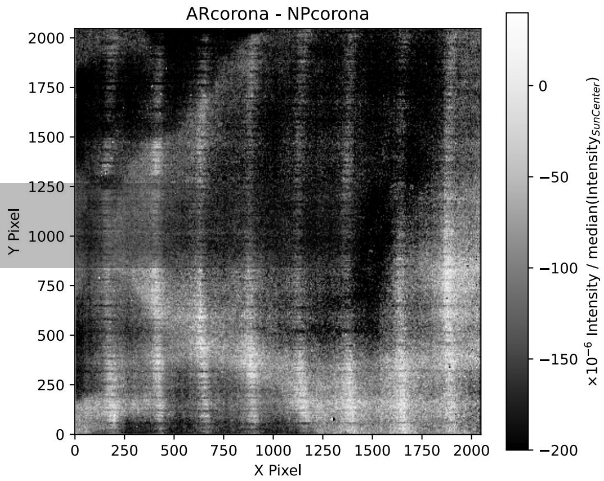
Science Verification Observations



Fe XI 789.2 nm



Fe XIII 1074.6 nm



Si X 1430 nm

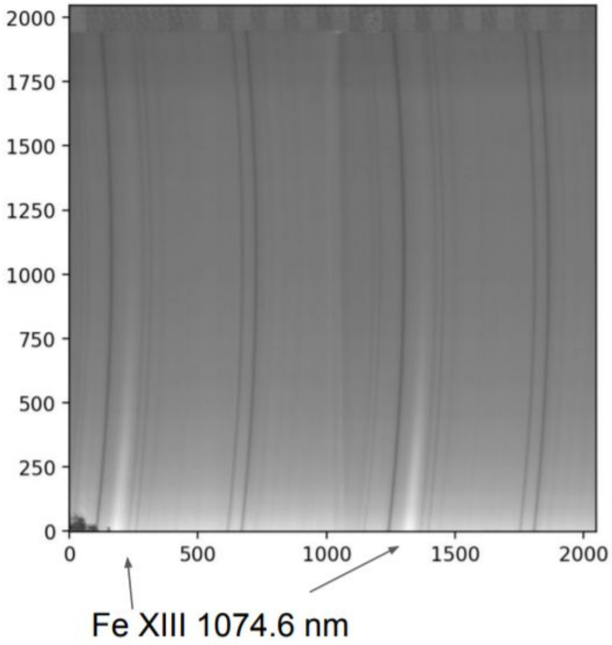
DKIST enhancements under development

Objectives: Increase observing efficiency, cadence, and simultaneous coverage of dynamic multi-thermal corona.

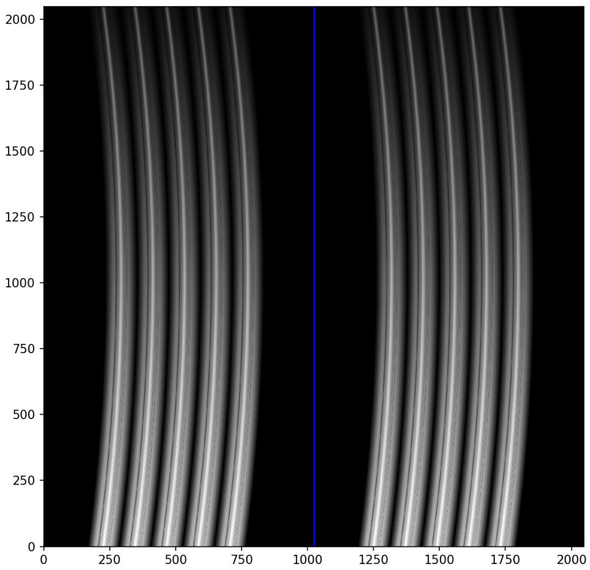
- **M9b short-pass beam-splitter split near 1 micron**
  - Allows simultaneous operation of Cryo-NIRSP and post-AO instruments
  - One example configuration:
    - Cryo-NIRSP spectropolarimetry at Si IX 3.9 um (or Si X 1430) + Context Imager
    - DL-NIRSP IFU spectropolarimetry at Fe XI 789, Fe XIII 1074/1079 nm
- **New coronal spectral diagnostics**
  - First light filter set emphasizes coronal magnetic field measurements.
  - Baseline new filters for FIP diagnostics: Ar^{+12} lines at λ8339Å and λ10143Å
  - Continuously varying order sorting filters for IR coronal spectrum exploration.
- **Multiplexing the Cryo-NIRSP: low dispersion multi-slit configuration**
  - Low dispersion single-slit provides simultaneous multi-spectral diagnostics
  - Multiple slit increase field scanning cadence (baseline: 5 slits separated by ~12'')
    - With additional throughput, configuration offers > ~10x efficiency boost.

Proposed low dispersion multi-slit Cryo-NIRSP

Current CryoNIRSP image
Science Verification Data

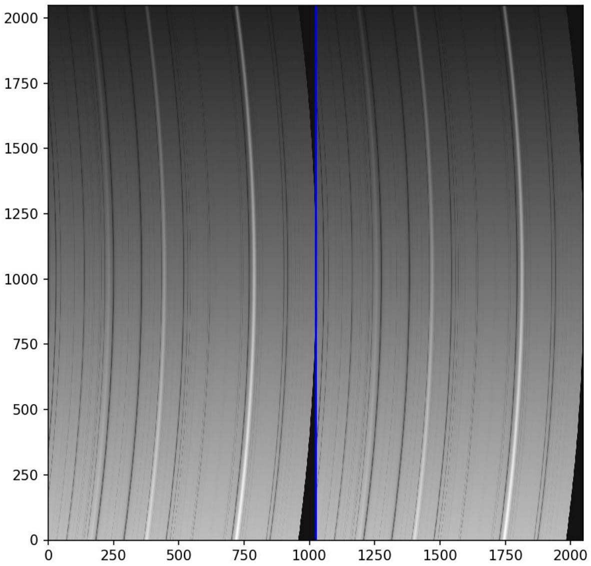


5 slits (+/- 250 km/s)
Resolving up to ~35,000



56 ln/mm, 33 deg blaze
Fe XIII 1074 nm (above)
Si IX 3934 nm works as well.
**Potentially 8 slits

1 slit wide-bandpass



Simultaneous coverage of
He I 1083 nm and density
sensitive Fe XIII lines
1074/1079 nm

Future concepts for DKIST coronal science instrumentation

- **Techniques for boosting spectropolarimetric observing efficiency need to be advanced**
    - Additional slit multiplexing for simultaneous spectral coverage.
    - Image slicers and/or IFUs for coronal use cases
    - Infrared Fabry Perot or Lyot Filter instrument

Comment: *It can be difficult to optimize an instrument for both high-resolution and wide-field high dynamic range science.* ***Needs well-founded science requirements!***

- **Potential in coronal linear polarization imaging**
    - Multi-temperature linear polarization imaging for dynamic field topology constraints
    - Ultra high bandpass filters + large format micro-polarizer cameras
- **Facility maintenance optimization and improvements**
    - In-situ washing operations will continually be improved with experience gained.
    - Alternative cleaning methods/infrastructure TBD?
- **Other related science areas and technologies**
    - Mid-infrared imaging of flare continua [> 5 um]. TIDES [Penn et al.]
    - Low spectral resolution broad-band IFU spectroscopy for flares
- **Advance frontier in coronal spatial resolution**
    - Daytime laser guide stars for adaptive optics [Beckers 2002] / ORCAS

Summary and synergies: Ground-based coronal science

How do we plan in this decadal to be successful with ground-based coronal physics in the next decade?

1. Reaffirm what success entails to understand the complex corona / inner heliosphere system.

2. <u>Advance instrumentation to claim more of DKIST's frontier for coronal science</u>

   a. Strengths: large-aperture, high-dynamic range, broad wavelength, high spatial resolution.
   b. Multi-wavelength polarimetry of the extended magnetized corona / solar wind.
   c. Other frontiers (FIP effect, flare science, etc.)

3. Understand the complementary aspects of DKIST, FASR, COSMO, ngGONG and space-based missions (e.g. MUSE)

   a. We must continue to develop models that demonstrate complementarity.

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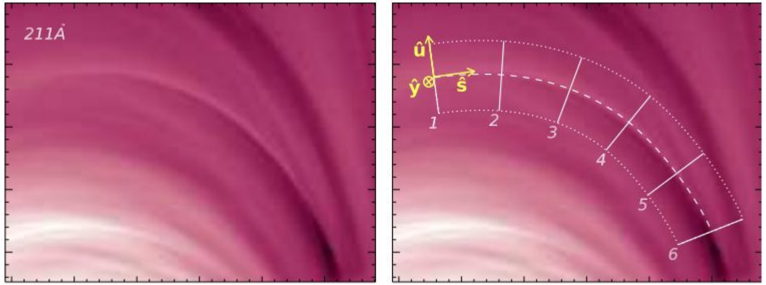
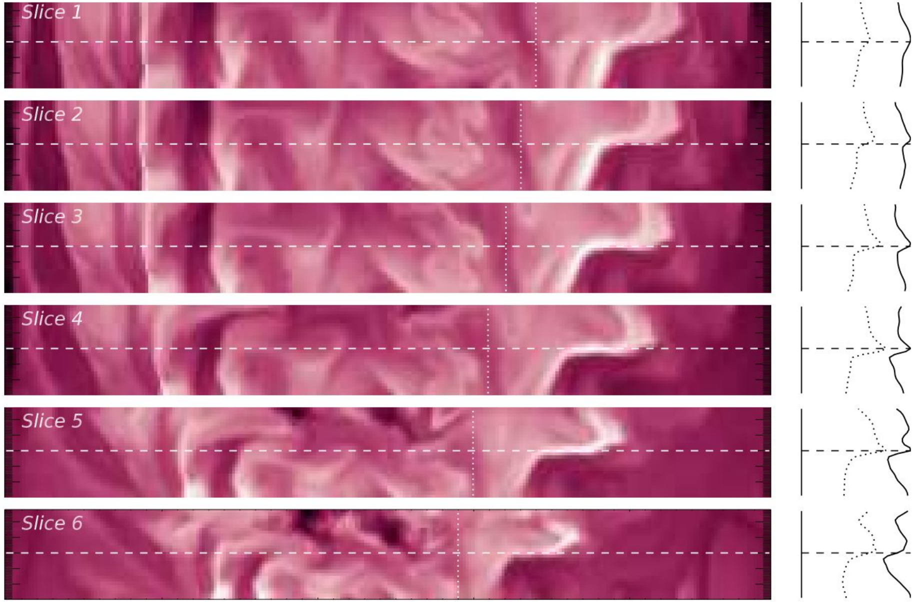
Extra slides

Science highlight: coronal Loops or Veils?



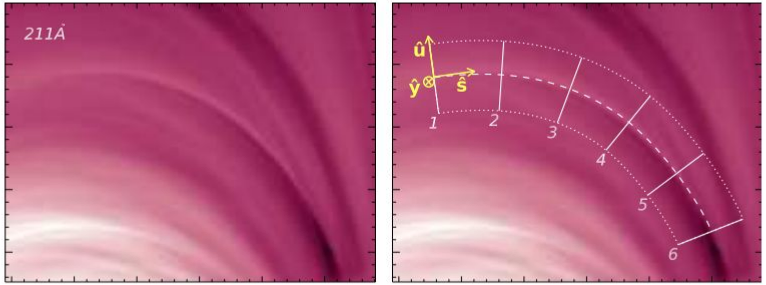
Malenshenko+ (2021)

- Synthetic loops can be traced to wrinkled sheet-like structures in MURAM.
- Loops may not be the circular or elliptical structures we idealize.
- Can be tricky to distinguish observationally.



Perpendicular slices of the LOS distribution of the contribution

Science highlight: coronal Loops or Veils?



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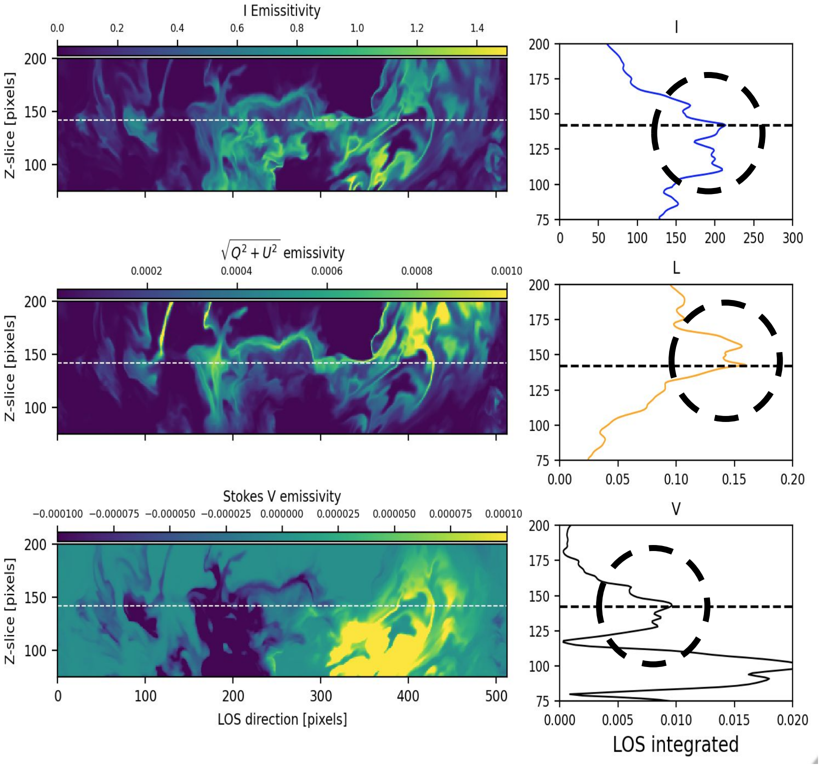

Synthetic polarized contribution functions at right using techniques of Schad & Dima (2020.
High dynamic range polarimetry at near diffraction limited-scales helps constrain simple vs complex structuring.