Spectropolarimetry and Stereoscopy of Coronal Rain

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23 - 27 February 2015
ISSI workshop on Coronal Rain
Bern, Switzerland

Remote sensing of the coronal magnetic field.

- Measuring the hot coronal magnetic field is difficult!
  - Gyroresonance iso-Gauss maps from radio observations.
  - Forbidden M1 transitions (Fe Complicates XIII 1074.7 nm, etc.)
  - Coronal seismology (i.e. MHD wave dispersion relation)
- The “newly” quantified abundance of cool “chromospheric-like” material found in the corona offers an new opportunity.
  - Problem 1: Chromospheric magnetic fields are hard too!
  - Problem 2: Rain is dynamic! Large Doppler shifts on disk; fast translation on limb.
  - Problem 3: Weak signals!
- No silver bullet!

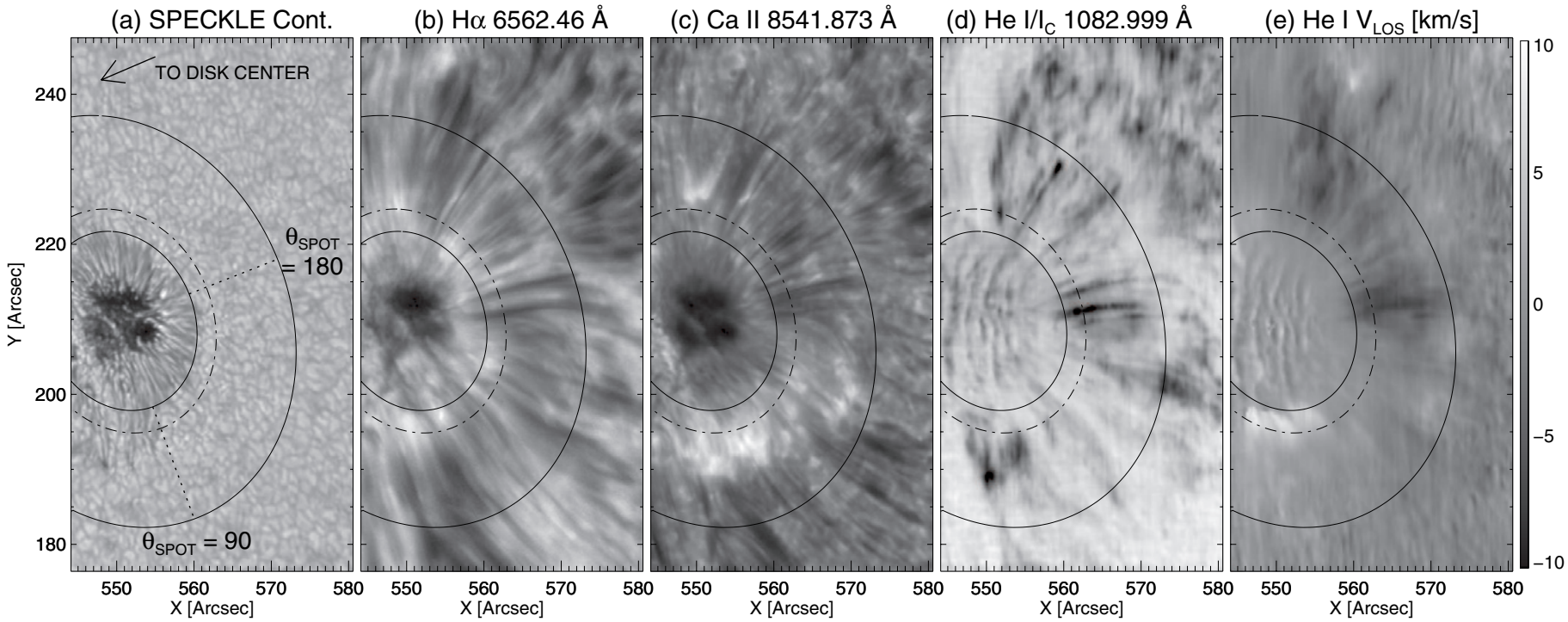
Chromospheric Magnetic Field Diagnostics

- Longitudinal Zeeman Effect – proportional to g*lambda
- Transverse Zeeman Effect – 2nd order (generally weak)
- Hanle Effect – Atomic-level "pumping" + inclined fields; UV lines better due to saturation.

- Ca II IR Triplet (e.g. 854.2 nm)
- Mg h & k
- Na D
- He D3 (orthohelium)
- He I 1083 (orthohelium)
- Lyman Alpha (CLASP)
- H Alpha
- Others: Paschen series. Mid-IR lines?

He I Triplet Advantages:
1. Formation limited to narrow regions
2. Atomic pol. radiatively controlled
3. Spectrally flat triplet system
4. He I 1083 nm brighter in prominence material than Ca II 854.2 and He D3

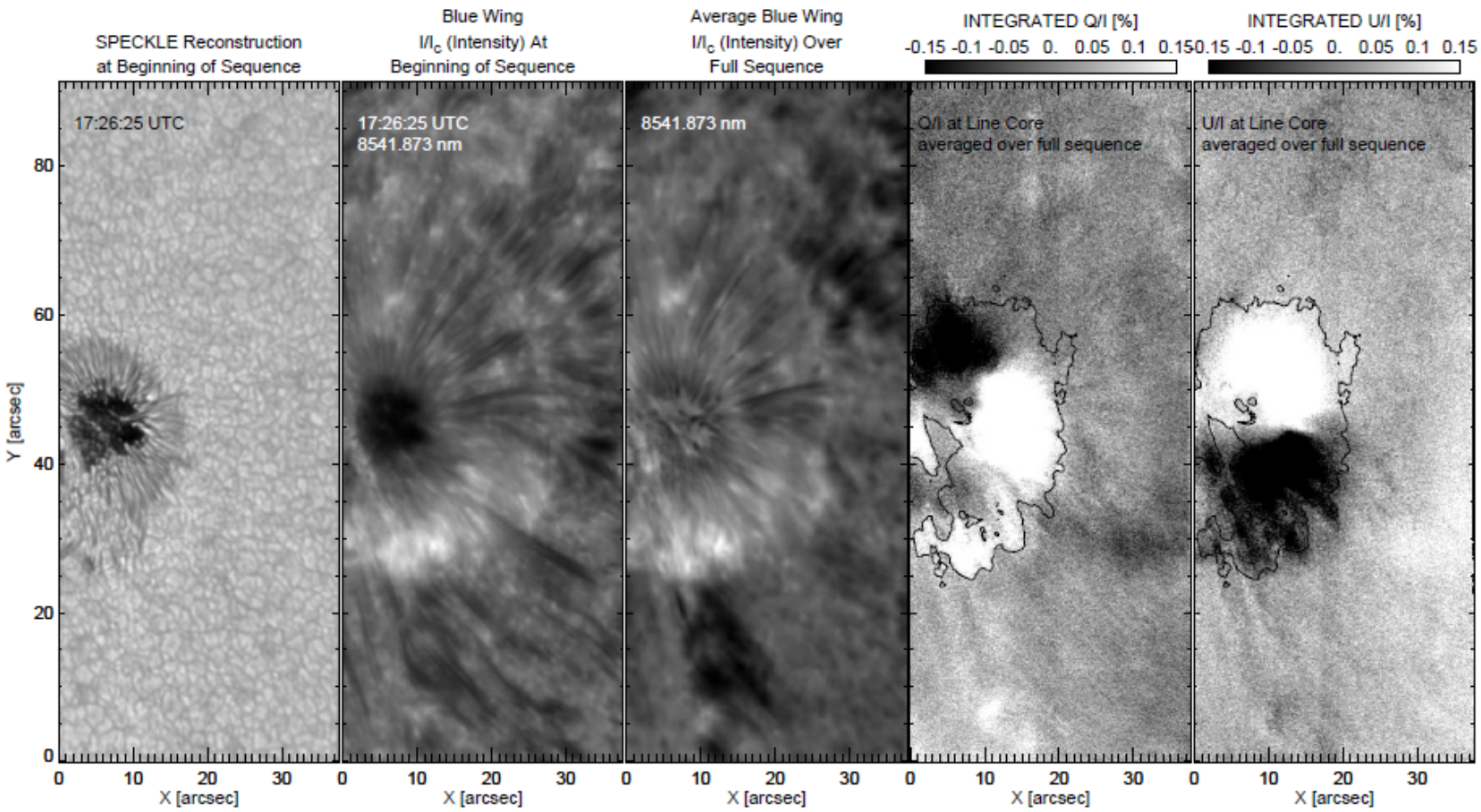
Comparison of Optical/IR Chromospheric Lines



DST/IBIS
(Imaging Fabry-Perot Spectropolarimeter)

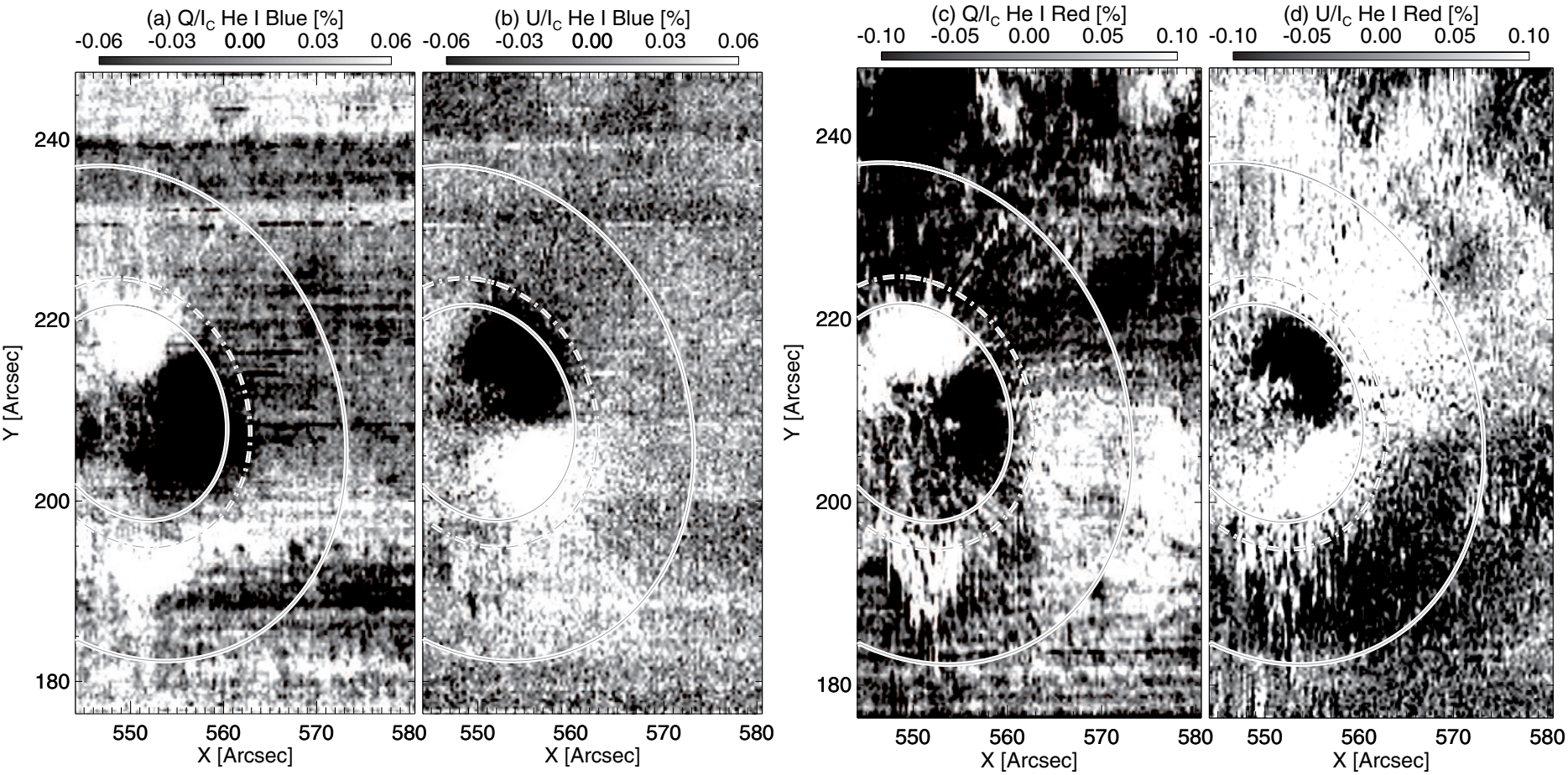
DST/FIRS
Slit-based Spectropolarimeter
0.3” per pixel sampling
Rayleigh Limit: 0.36”

IBIS Ca II 854.2 nm QU Polarization



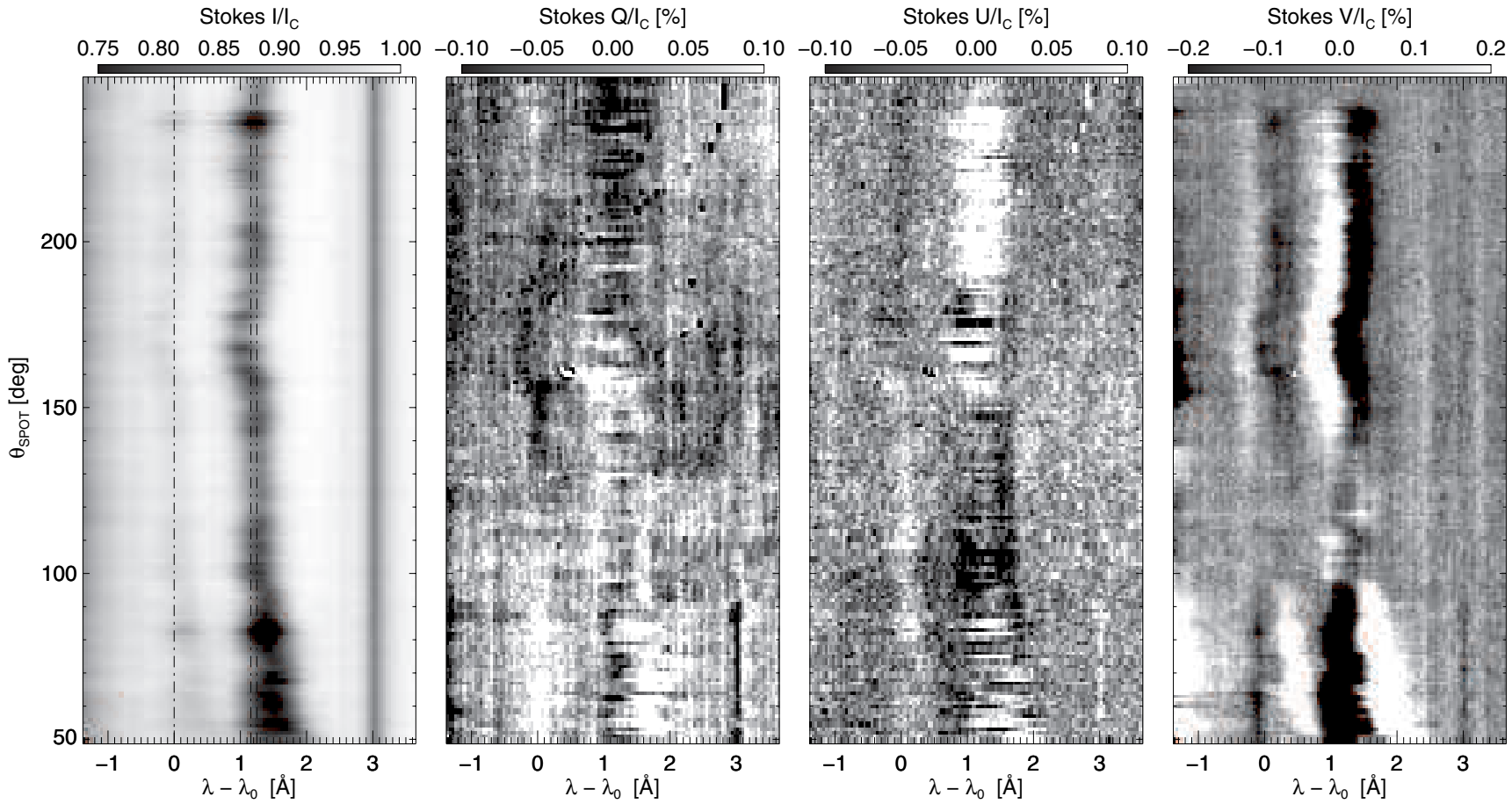
He I 1082.9 ($J_{upper} = 0$; $J_{lower} = 1$)

He I 1083.025 ($J_{upper} = 1$; $J_{lower} = 1$)
He I 1083.033 ($J_{upper} = 2$; $J_{lower} = 1$)



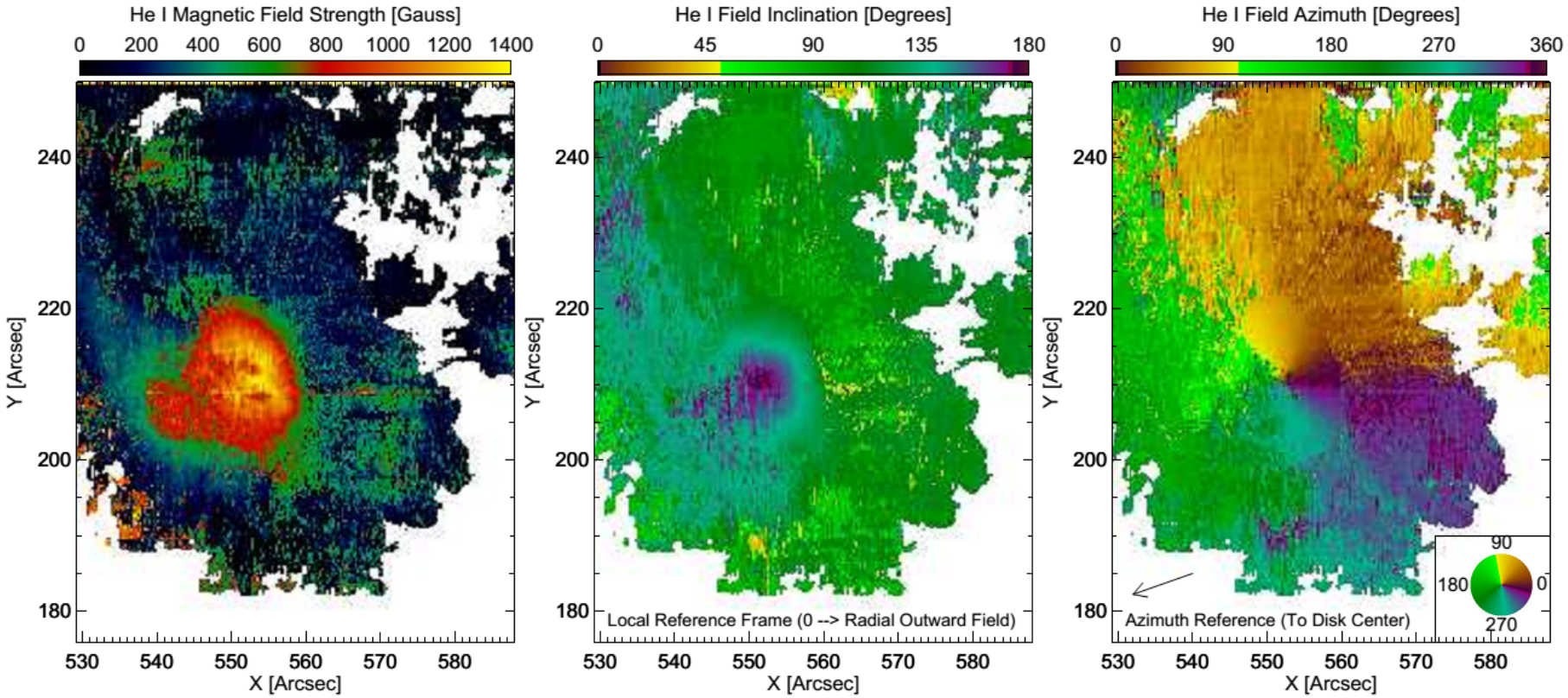
Schad, Penn, & Lin (2013)

He I Atomic Level Polarization Spectra



Schad, Penn, & Lin (2013)

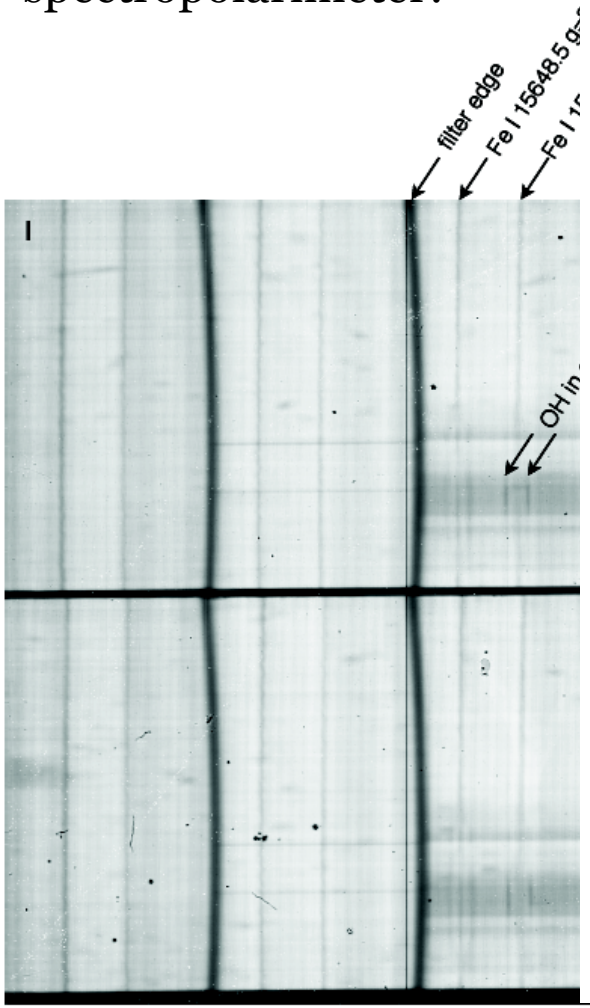
He I Vector Field Maps (Schad et al. 2015, in press.)

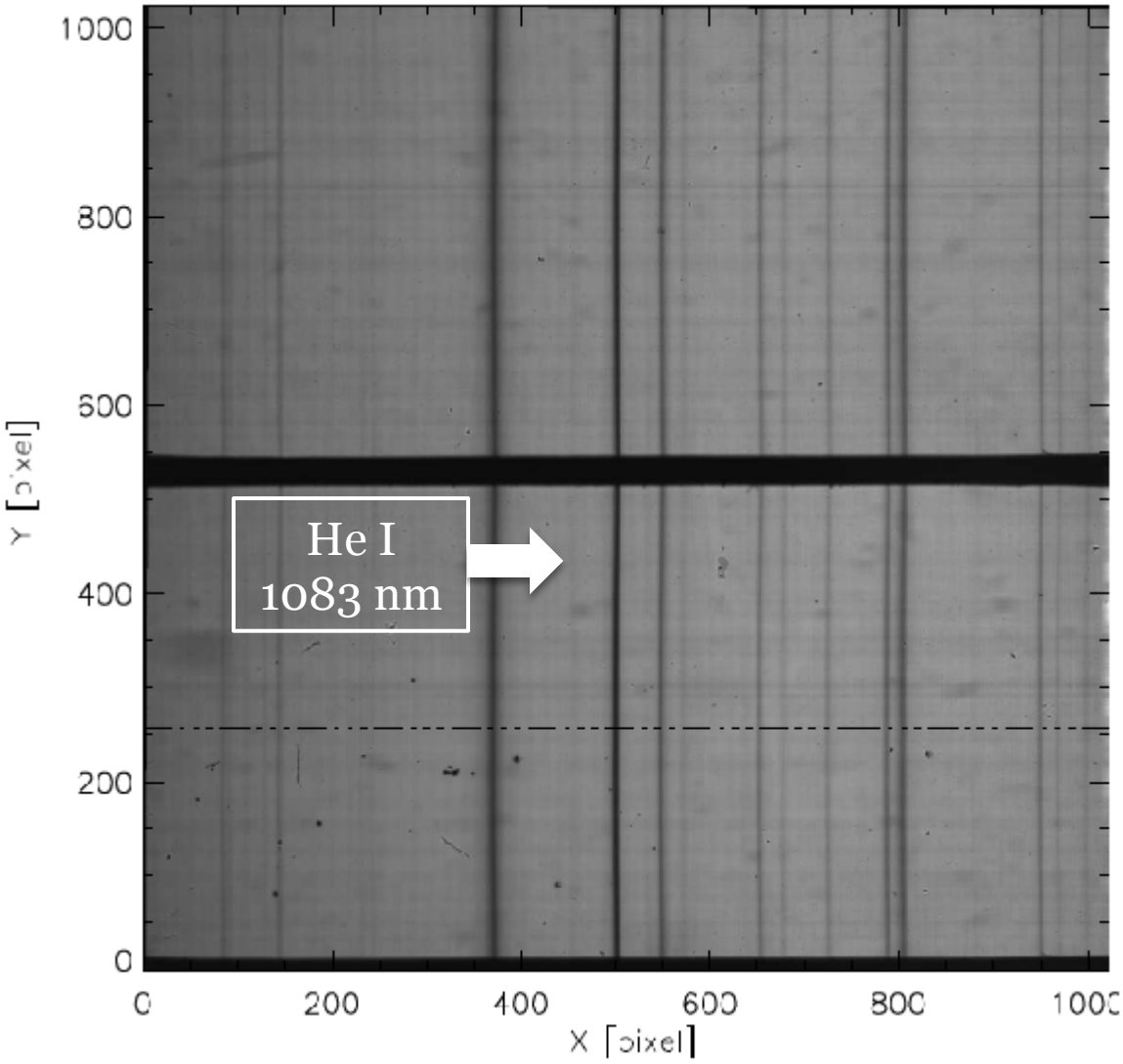


* He I inversions using pHAZEL (Asensio Ramos et al. 2008)
* Simple AZAM-like disambiguation

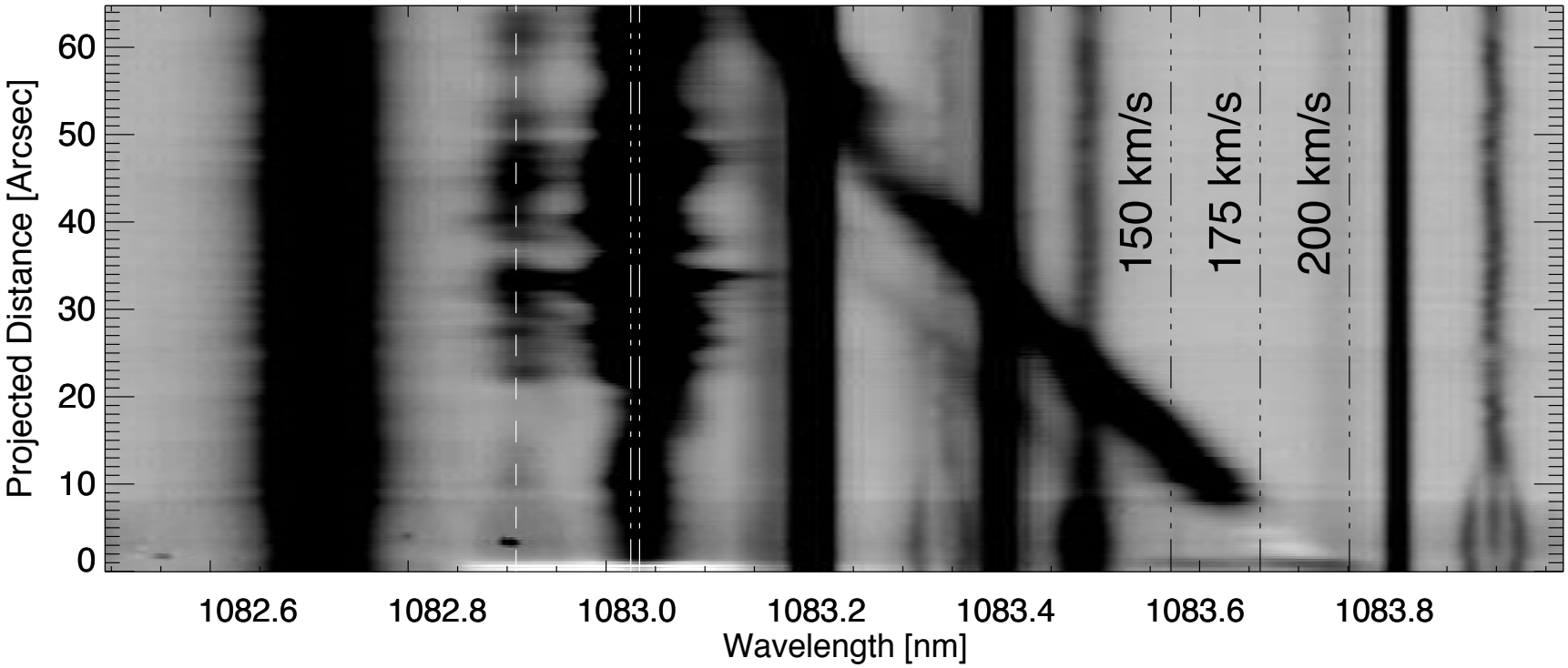
And now, on to coronal rain observations…

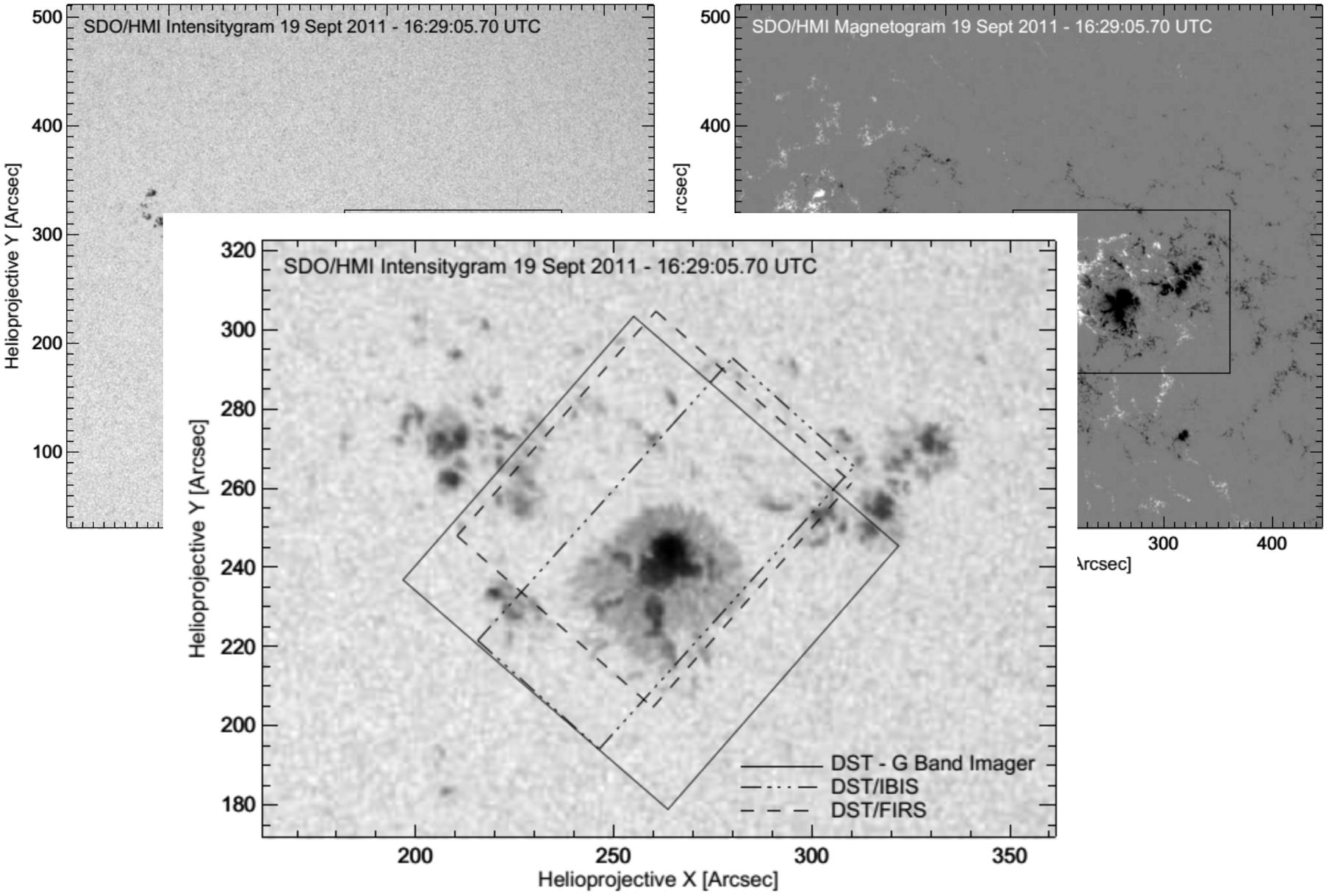
FIRS is a multi-slit spectropolarimeter!



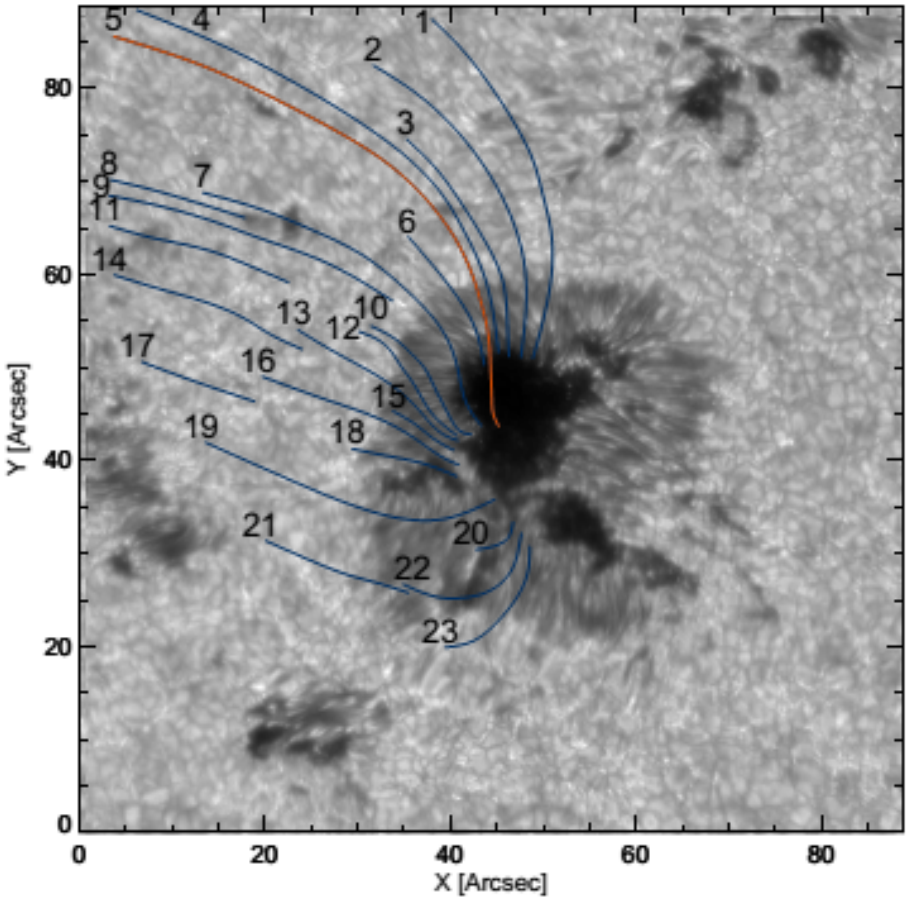


High-speed He I Spectra (DST/FIRS)
19 September 2011



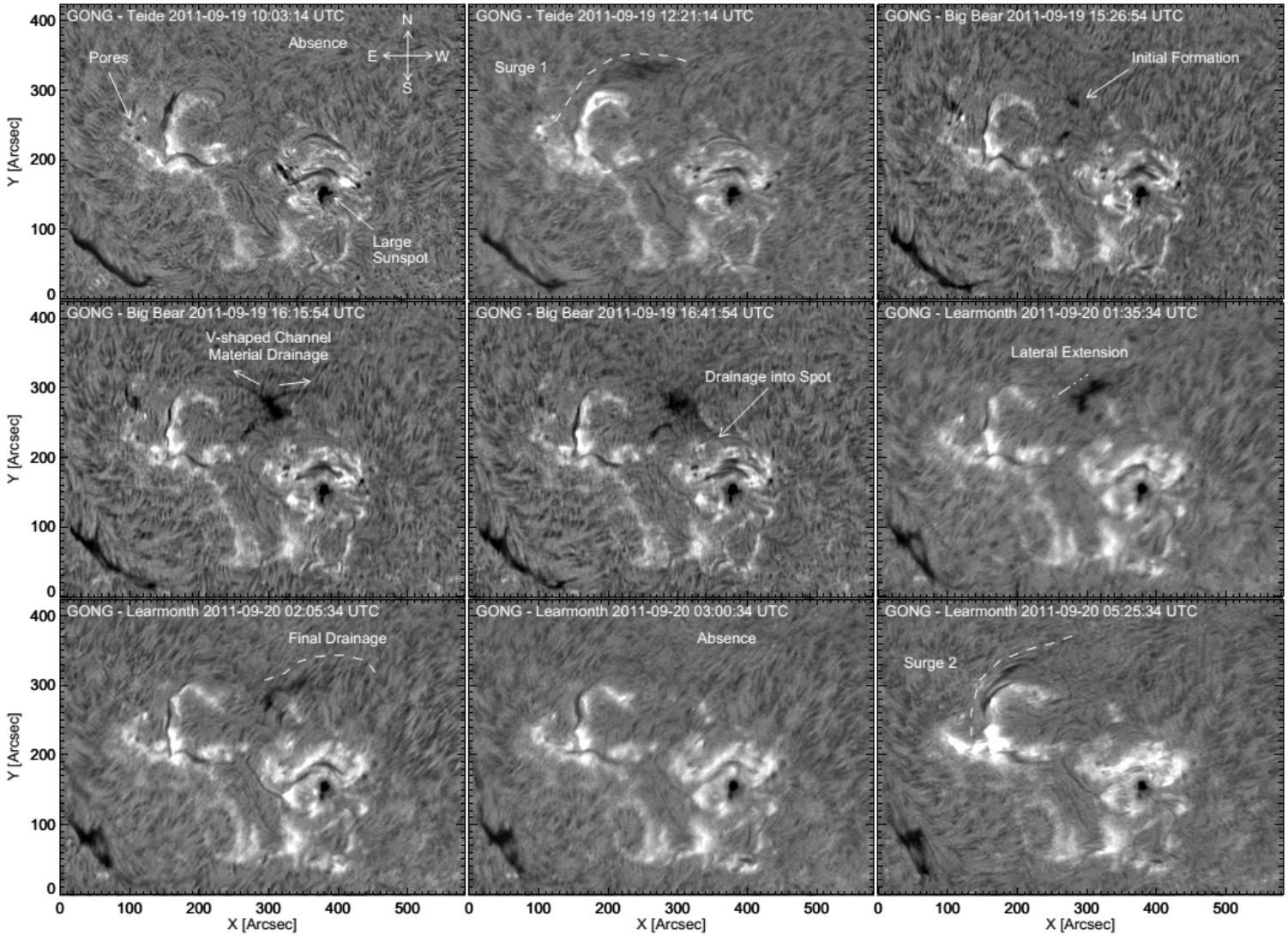

SDO/HMI Intensitygram 19 Sept 2011 - 16:29:05.70 UTC
SDO/HMI Magnetogram 19 Sept 2011 - 16:29:05.70 UTC
SDO/HMI Intensitygram 19 Sept 2011 - 16:29:05.70 UTC
Helioprojective Y [Arcsec]
Helioprojective X [Arcsec]
DST - G Band Imager
DST/IBIS
DST/FIRS

CRISPEX illustration of FIRS data cube….

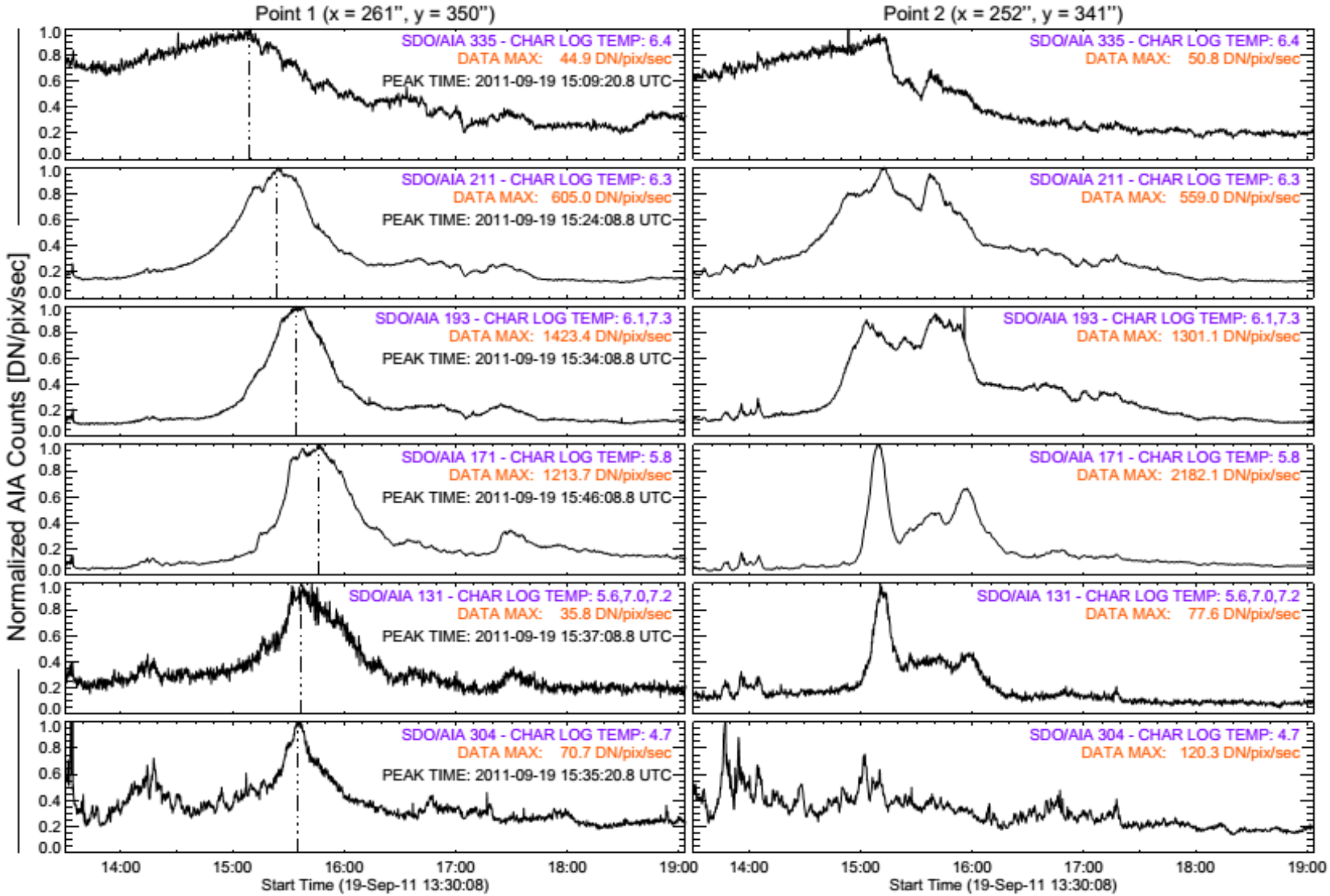


- 23 channels identified in the FIRS data set.
- Thanks CRISPEX!
- Now, what is this flow?

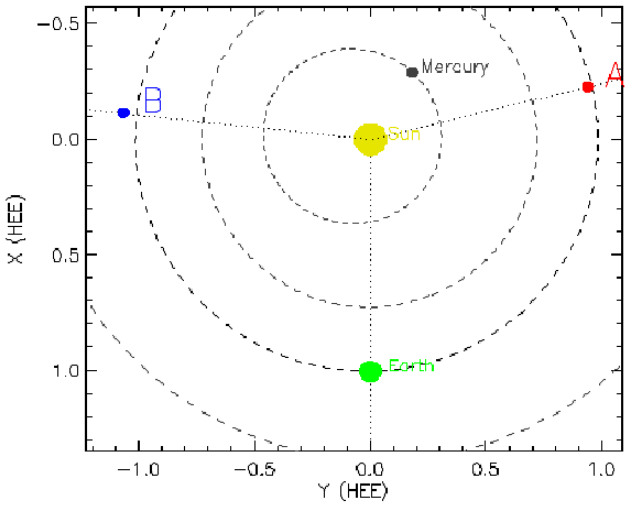
Associated with the formation of a coronal cloud filament…



Show SDO/AIA 171 and 211 movies…

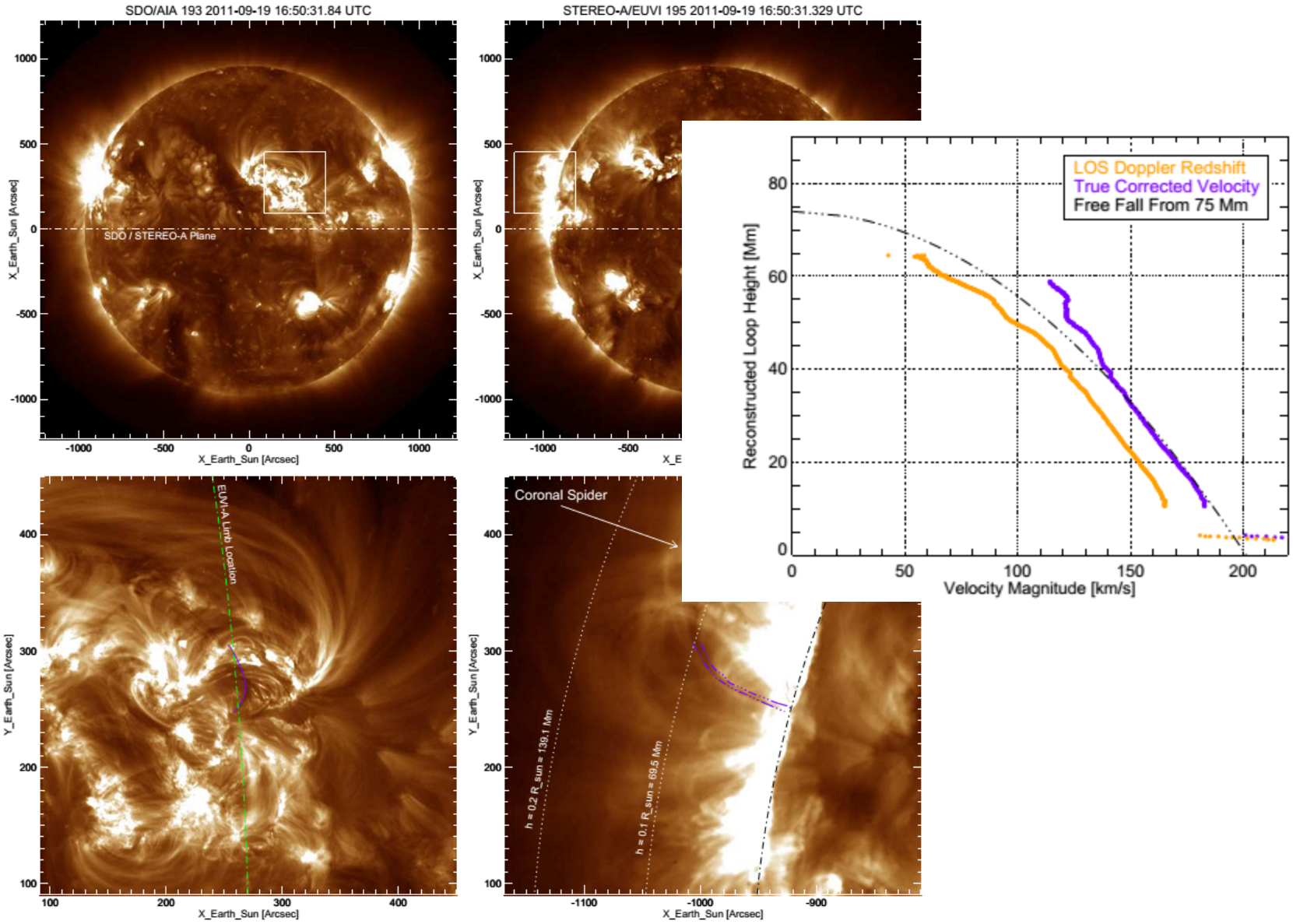

Point 1 (x = 261", y = 350")
Point 2 (x = 252", y = 341")
Normalized AIA Counts [DN/pix/sec]
SDO/AIA 335 - CHAR LOG TEMP: 6.4
DATA MAX: 44.9 DN/pix/sec
PEAK TIME: 2011-09-19 15:09:20.8 UTC
SDO/AIA 335 - CHAR LOG TEMP: 6.4
DATA MAX: 50.8 DN/pix/sec
SDO/AIA 211 - CHAR LOG TEMP: 6.3
DATA MAX: 605.0 DN/pix/sec
PEAK TIME: 2011-09-19 15:24:08.8 UTC
SDO/AIA 211 - CHAR LOG TEMP: 6.3
DATA MAX: 559.0 DN/pix/sec
SDO/AIA 193 - CHAR LOG TEMP: 6.1,7.3
DATA MAX: 1423.4 DN/pix/sec
PEAK TIME: 2011-09-19 15:34:08.8 UTC
SDO/AIA 193 - CHAR LOG TEMP: 6.1,7.3
DATA MAX: 1301.1 DN/pix/sec
SDO/AIA 171 - CHAR LOG TEMP: 5.8
DATA MAX: 1213.7 DN/pix/sec
PEAK TIME: 2011-09-19 15:46:08.8 UTC
SDO/AIA 171 - CHAR LOG TEMP: 5.8
DATA MAX: 2182.1 DN/pix/sec
SDO/AIA 131 - CHAR LOG TEMP: 5.6,7.0,7.2
DATA MAX: 35.8 DN/pix/sec
PEAK TIME: 2011-09-19 15:37:08.8 UTC
SDO/AIA 131 - CHAR LOG TEMP: 5.6,7.0,7.2
DATA MAX: 77.6 DN/pix/sec
SDO/AIA 304 - CHAR LOG TEMP: 4.7
DATA MAX: 70.7 DN/pix/sec
PEAK TIME: 2011-09-19 15:35:20.8 UTC
SDO/AIA 304 - CHAR LOG TEMP: 4.7
DATA MAX: 120.3 DN/pix/sec
0.0
0.2
0.4
0.6
0.8
1.0
14:00
15:00
16:00
17:00
18:00
19:00
Start Time (19-Sep-11 13:30:08)

What about a stereoscopic view?

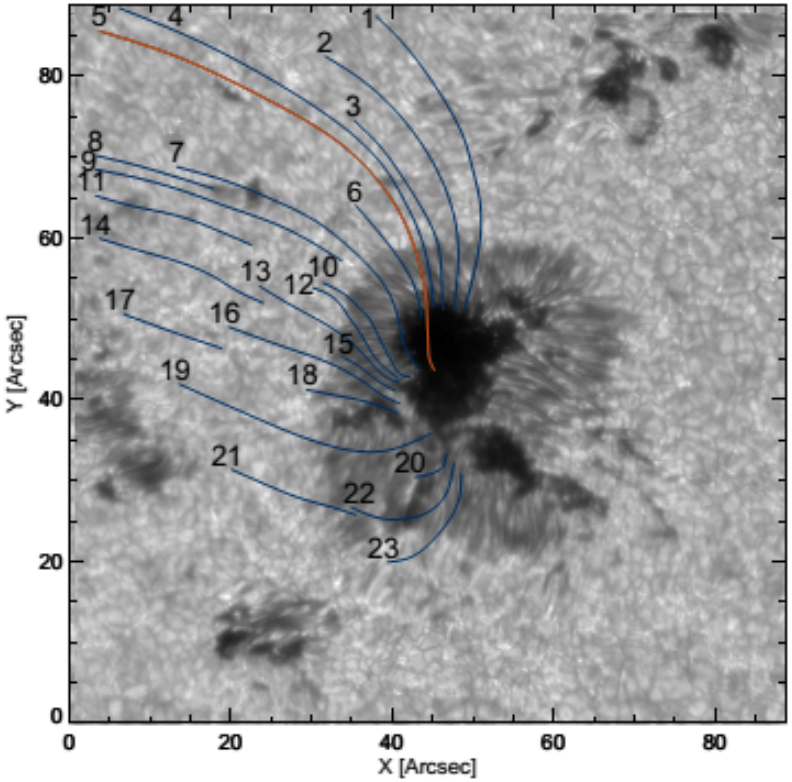


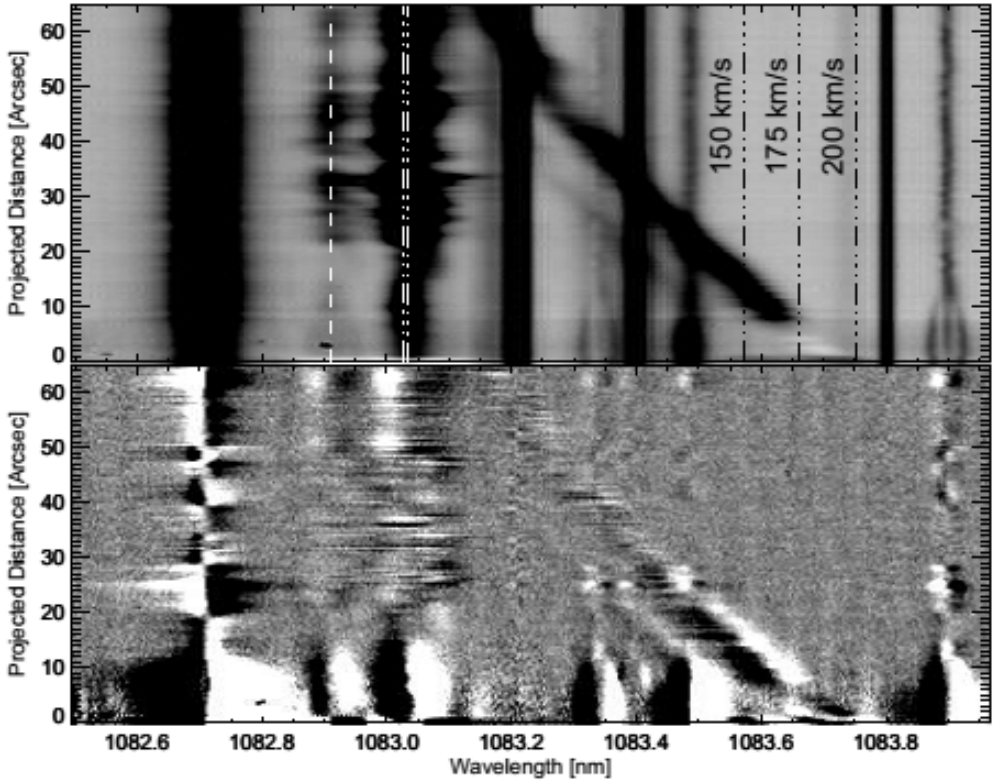
	STEREO-B	Earth	STEREO-A
Heliocentric distance (AU)	1.073496	1.004564	0.966648
Semidiameter (arcsec)	893.927	955.267	992.738
Heliographic (HEEQ) longitude	-96.294	-0.000	103.402
Heliographic (HEEQ) latitude	0.254	7.130	-3.074
Roll from ecliptic north	0.031		-0.028
Roll from solar north	-7.201		6.596
Light travel time to Earth (min)	12.872		12.892
Separation angle with Earth	96.213		103.669
Separation angle A with B		160.114	

Show SDO/AIA 171 and STEREO/A 171 movie…


SDO/AIA 193 2011-09-19 16:50:31.84 UTC
SDO / STEREO-A Plane
X_Earth_Sun [Arcsec]
Y_Earth_Sun [Arcsec]
STEREO-A/EUVI 195 2011-09-19 16:50:31.329 UTC
EUVI-A Limb Location
Coronal Spider
h = 0.2 R_sun = 139.1 Mm
h = 0.1 R_sun = 69.5 Mm
LOS Doppler Redshift
True Corrected Velocity
Free Fall From 75 Mm
Reconstructed Loop Height [Mm]
Velocity Magnitude [km/s]

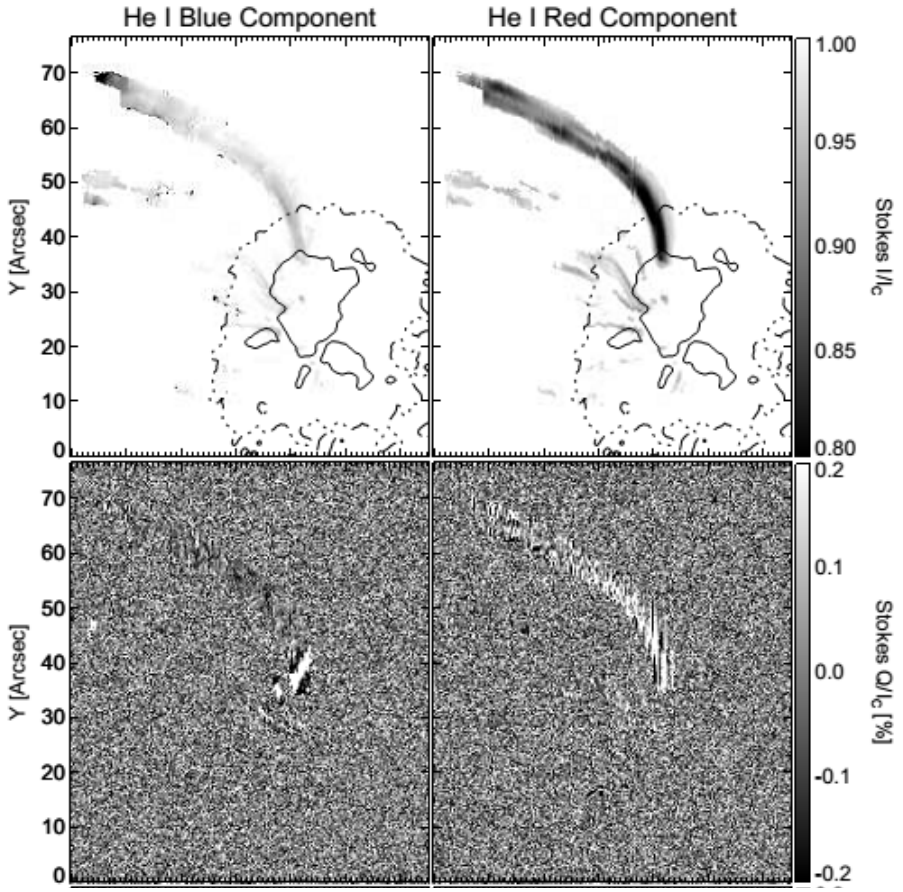
He I Polarimetry…

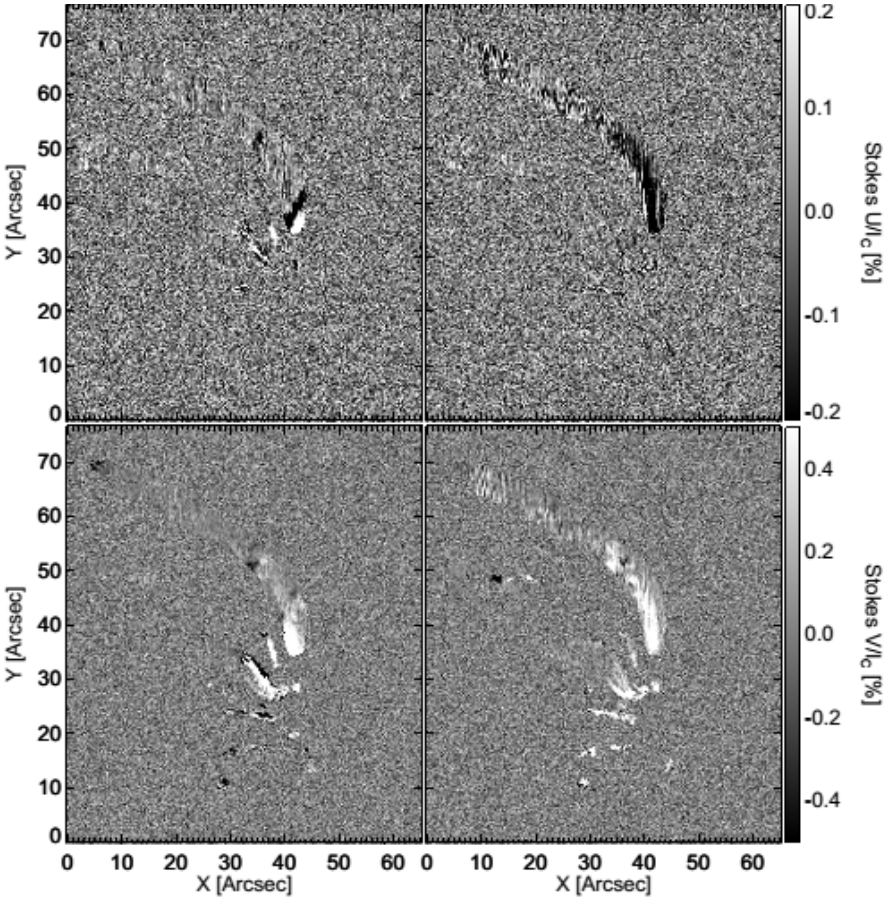

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
Y [Arcsec]
X [Arcsec]
0
20
40
60
80

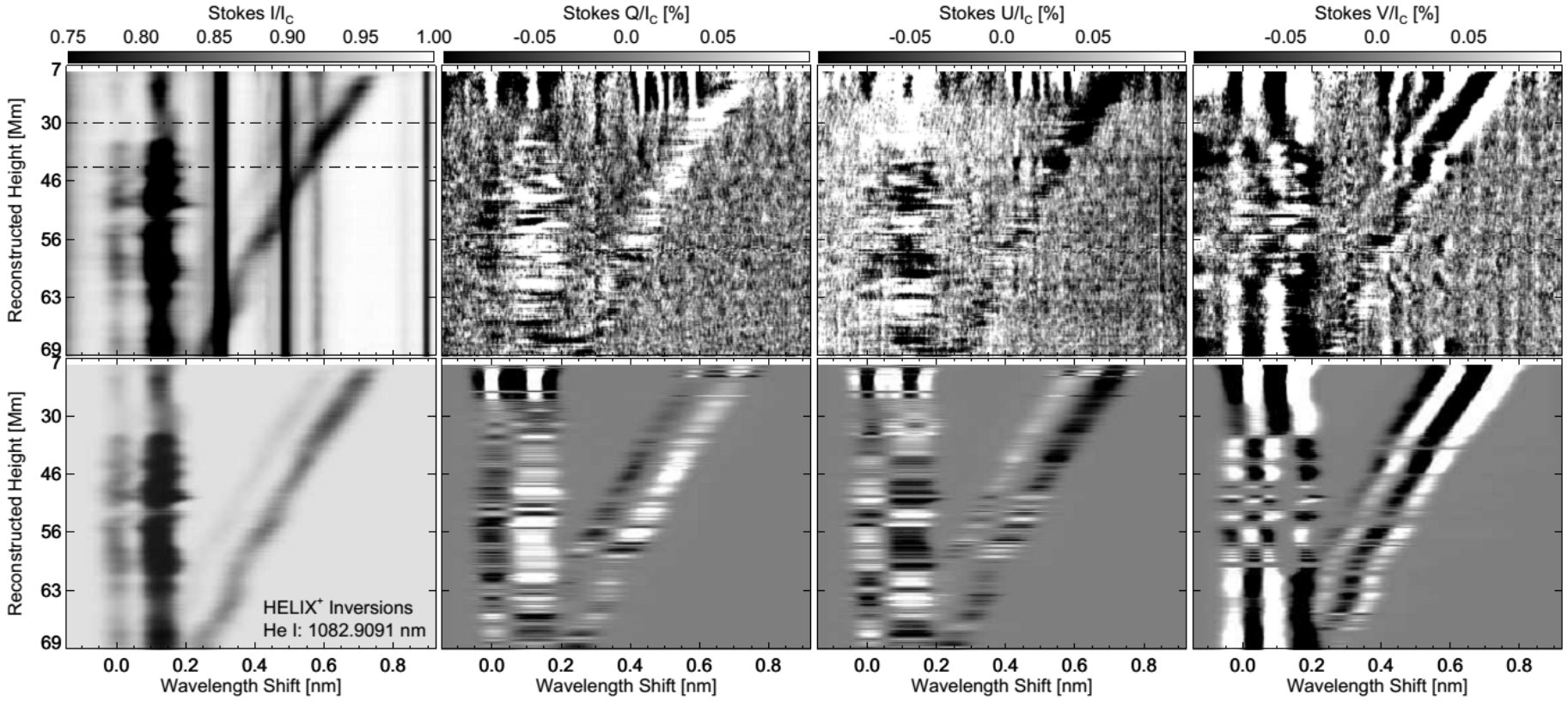

150 km/s
175 km/s
200 km/s
Projected Distance [Arcsec]
Projected Distance [Arcsec]
Wavelength [nm]
1082.6
1082.8
1083.0
1083.2
1083.4
1083.6
1083.8
0
10
20
30
40
50
60

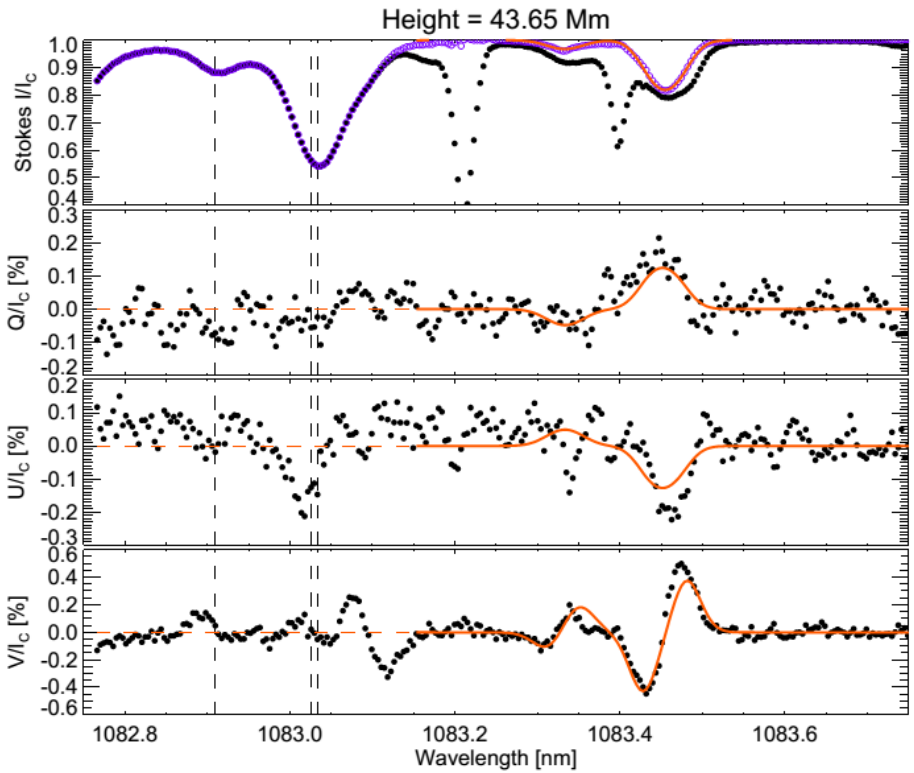
Observation notes..

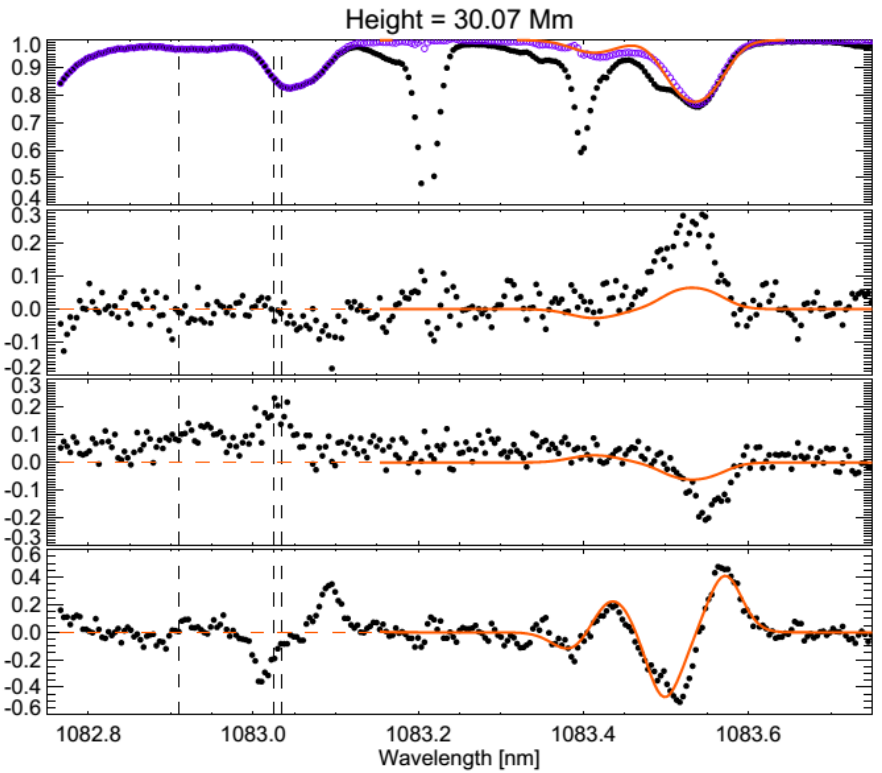
- 0.3” sampling by FIRS, 218 slit positions
- $\lambda/\delta\lambda \sim 280000$; $\delta\lambda = 38.4$ milliAngstrom
- 1 sec total integration time
- Scan time of the full region ~ 32 minutes
- [Q,U,V] noise level → [1, 0.92, 1.3] x 10^-3 I_c


He I Blue Component
He I Red Component
Y [Arcsec]
Stokes I/I$_c$
1.00
0.95
0.90
0.85
0.80
Stokes Q/I$_c$ [%]
0.2
0.1
0.0
-0.1
-0.2

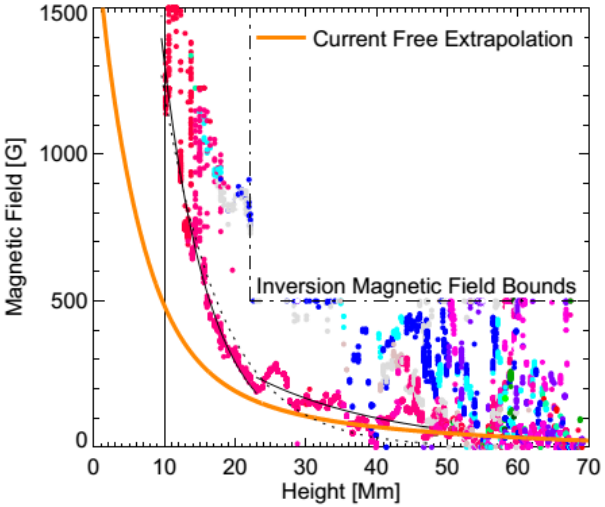

Y [Arcsec]
X [Arcsec]
Stokes U/I$_c$ [%]
0.2
0.1
0.0
-0.1
-0.2
Stokes V/I$_c$ [%]
0.4
0.2
0.0
-0.2
-0.4

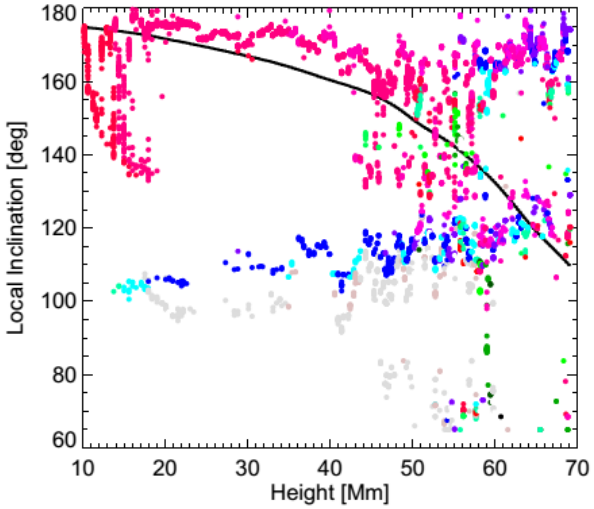

Stokes I/I$_C$
0.75 0.80 0.85 0.90 0.95 1.00
Stokes Q/I$_C$ [%]
-0.05 0.0 0.05
Stokes U/I$_C$ [%]
-0.05 0.0 0.05
Stokes V/I$_C$ [%]
-0.05 0.0 0.05
Reconstructed Height [Mm]
7 30 46 56 63 69
HELIX$^+$ Inversions
He I: 1082.9091 nm
0.0 0.2 0.4 0.6 0.8
Wavelength Shift [nm]

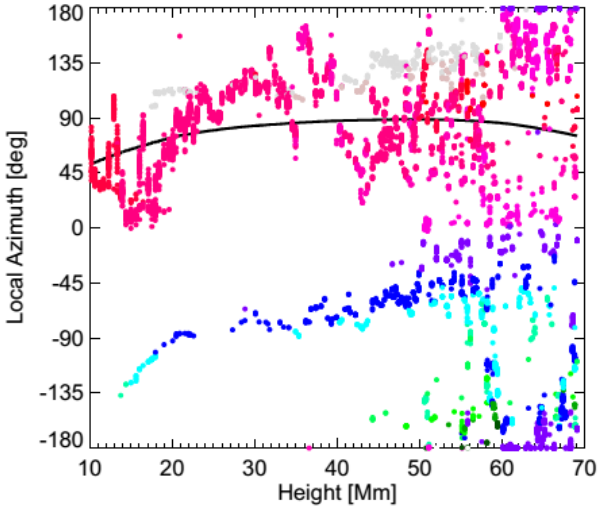

Height = 43.65 Mm
Stokes I/I$_C$
Q/I$_C$ [%]
U/I$_C$ [%]
V/I$_C$ [%]
1082.8
1083.0
1083.2
1083.4
1083.6
Wavelength [nm]

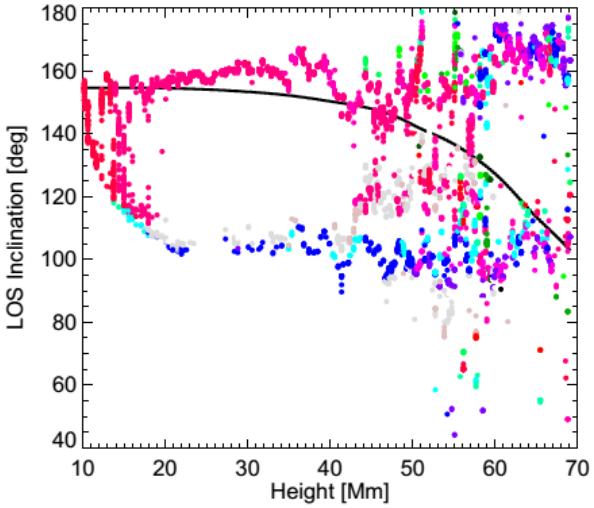

Height = 30.07 Mm
1082.8
1083.0
1083.2
1083.4
1083.6
Wavelength [nm]

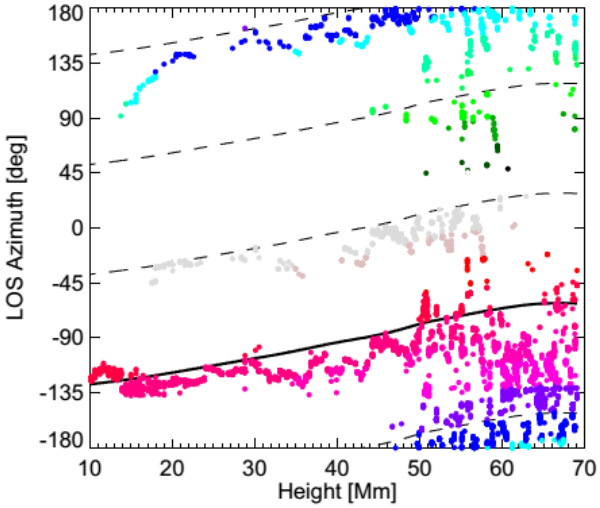
Every He I spectra inverted 50 times by Helix + (Lagg et al. 2007; Trujillo Bueno & Asensio Ramos 2007)



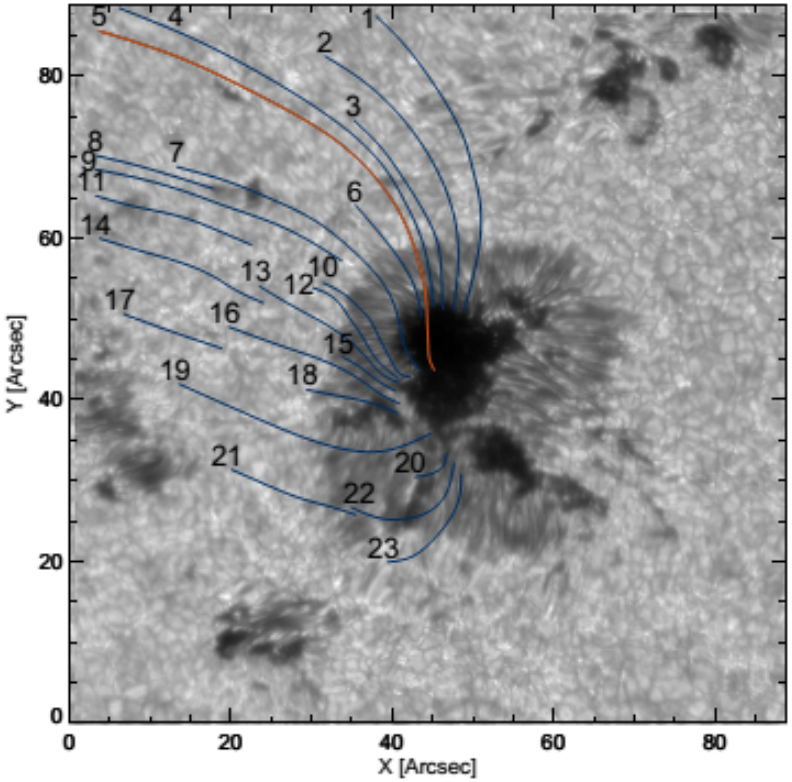








Impacting the lower atmosphere…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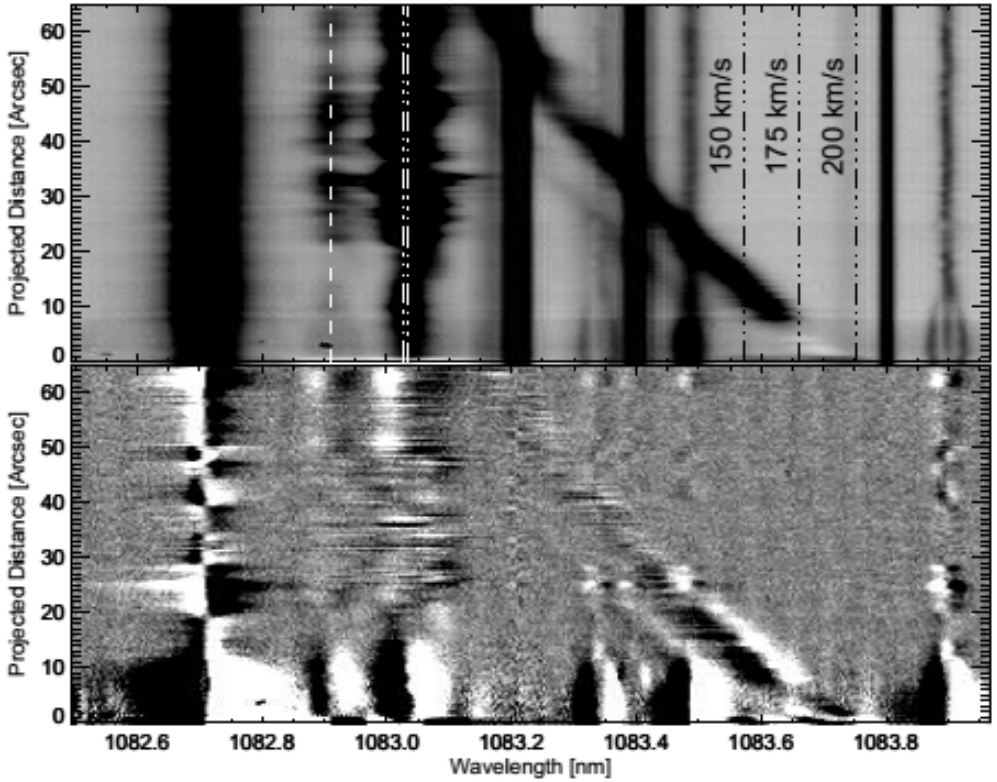
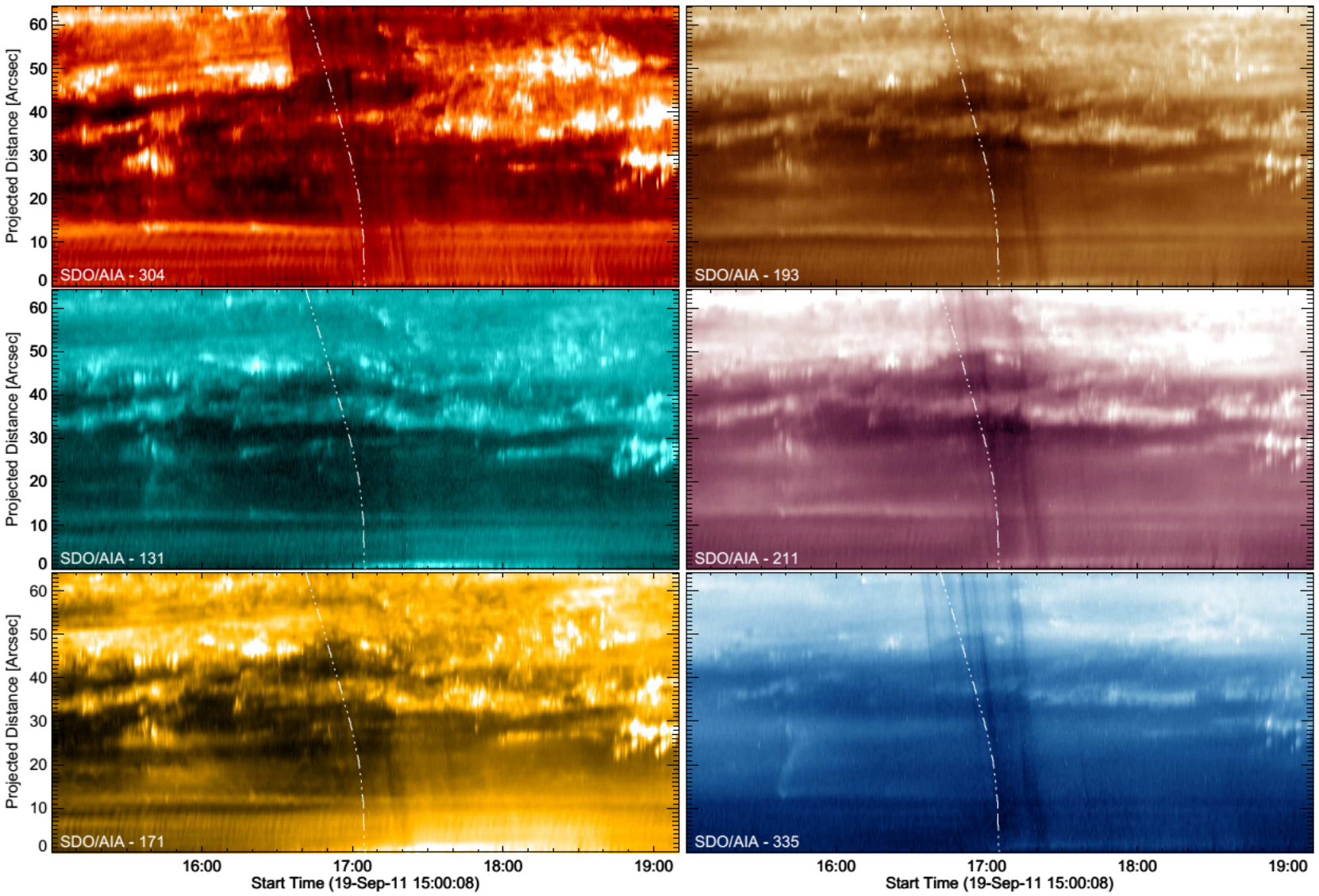
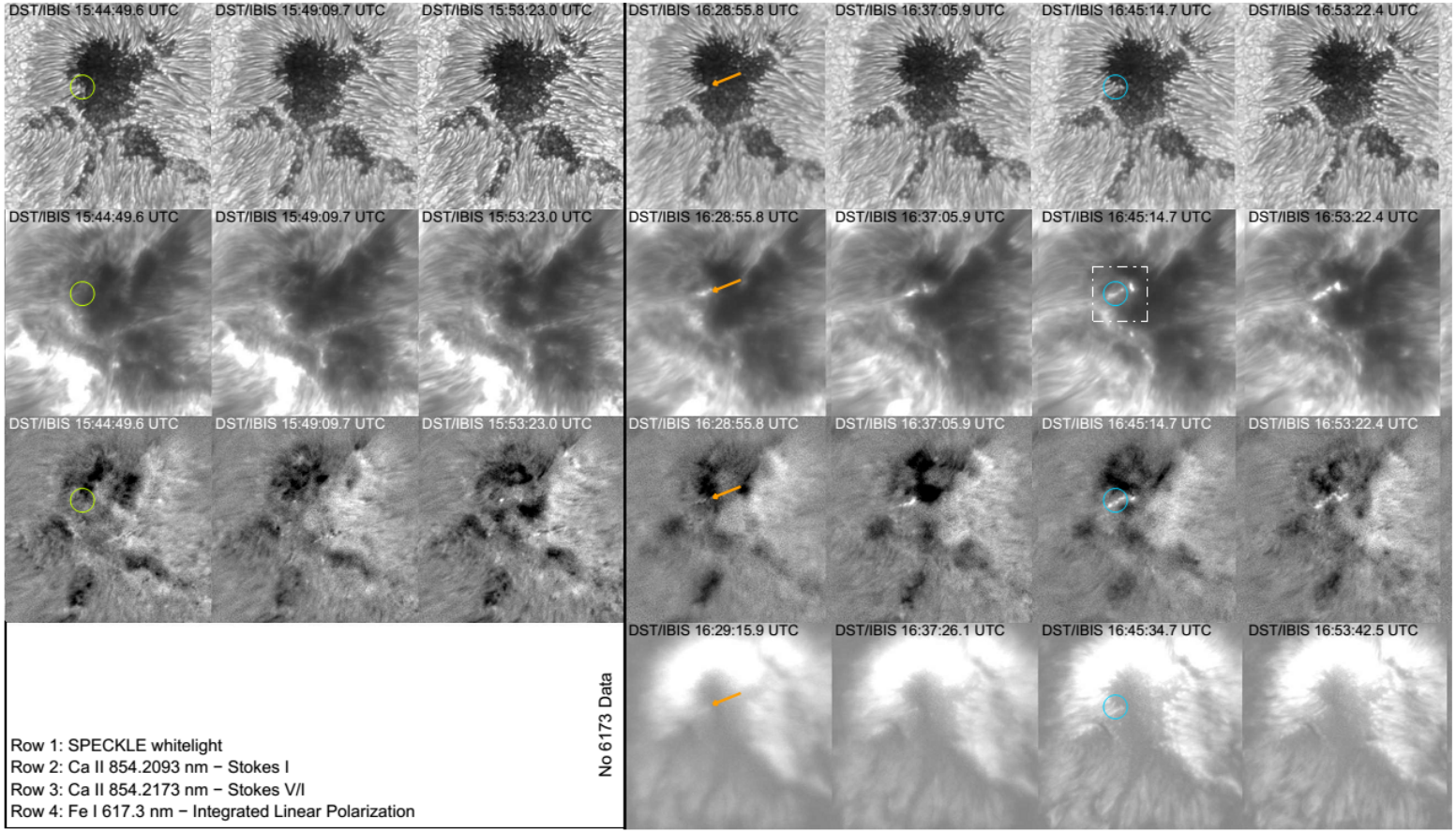
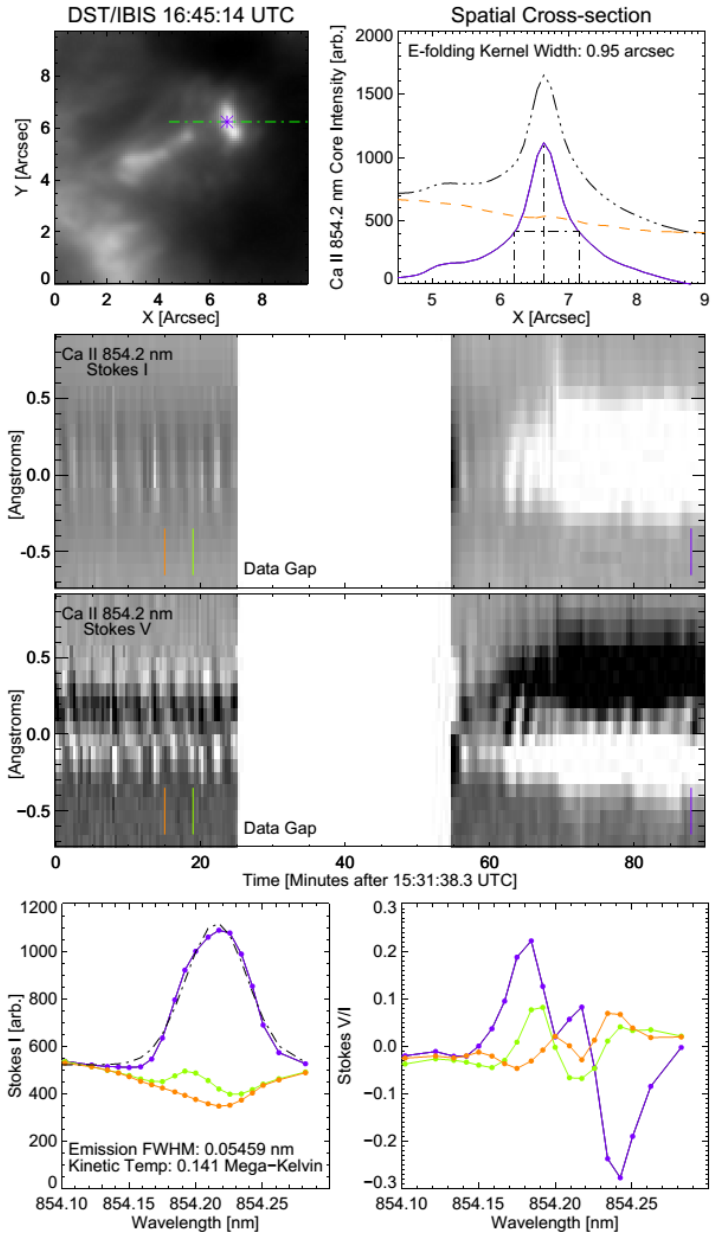
22
23
Y [Arcsec]
X [Arcsec]
0
20
40
60
80


150 km/s
175 km/s
200 km/s
Projected Distance [Arcsec]
Projected Distance [Arcsec]
Wavelength [nm]
1082.6
1082.8
1083.0
1083.2
1083.4
1083.6
1083.8
0
10
20
30
40
50
60


Projected Distance [Arcsec]
0
10
20
30
40
50
60
SDO/AIA - 304
SDO/AIA - 193
SDO/AIA - 131
SDO/AIA - 211
SDO/AIA - 171
SDO/AIA - 335
16:00
17:00
18:00
19:00
Start Time (19-Sep-11 15:00:08)


DST/IBIS 15:44:49.6 UTC
DST/IBIS 15:49:09.7 UTC
DST/IBIS 15:53:23.0 UTC
DST/IBIS 16:28:55.8 UTC
DST/IBIS 16:37:05.9 UTC
DST/IBIS 16:45:14.7 UTC
DST/IBIS 16:53:22.4 UTC
DST/IBIS 16:29:15.9 UTC
DST/IBIS 16:37:26.1 UTC
DST/IBIS 16:45:34.7 UTC
DST/IBIS 16:53:42.5 UTC
Row 1: SPECKLE whitelight
Row 2: Ca II 854.2093 nm − Stokes I
Row 3: Ca II 854.2173 nm − Stokes V/I
Row 4: Fe I 617.3 nm − Integrated Linear Polarization
No 6173 Data


DST/IBIS 16:45:14 UTC
Y [Arcsec]
X [Arcsec]
Spatial Cross-section
E-folding Kernel Width: 0.95 arcsec
Ca II 854.2 nm Core Intensity [arb.]
X [Arcsec]
Ca II 854.2 nm
Stokes I
[Angstroms]
Data Gap
Ca II 854.2 nm
Stokes V
[Angstroms]
Data Gap
Time [Minutes after 15:31:38.3 UTC]
Stokes I [arb.]
Emission FWHM: 0.05459 nm
Kinetic Temp: 0.141 Mega-Kelvin
Wavelength [nm]
Stokes V/I
Wavelength [nm]

Summary

- Cooled coronal material may be our best means to probe the fine-scaling of the coronal magnetic field in the near future.
- He I 1083 is a good tool, but signal is going to be challenging for small scale coronal blobs.
- What diagnostics do we need? Any prediction for the magnitude of electric fields?