

FIRS: A New Instrument for Multi-Wavelength Spectropolarimetry

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FIRS



Science!

- Sunspot Structure
 - Magnetohydrostatic Equilibrium, Molecule Formation, and the Evolution of Sunspots (my thesis)
 - Canopies
 - Penumbra
- Photospheric-Chromospheric-Coronal Connection
 - Energy Transfer/Heating/Cooling



- Inversion of simultaneous 630/1565 nm observations using TIP, POLIS, and SIR:
 - of a sunspot: Cabrera Solana et al. (2006)
 - of the internetwork: Martinez Gonzalez et al. (2008)



Instrument Requirements



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Multi-Spectral: Multi-Height Diagnostics

Line [\AA]	Species	Landé g	Formation Height
6302	Fe I	1.667, 2.5	mid-photosphere
8542	Ca II	1.1	low chromosphere
10827	Si I	1.5	photosphere
10830	He I	2.0, 1.75, 1.25	high chromosphere
15650	Fe I	3, 1.53	low photosphere



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High Cadence: Dynamics



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High Spectral Resolution: Detailed Physics



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High Spectral Resolution: Detailed Physics

High Spatial Resolution: Structure Detail



Instrument Requirements

with FIRS



FIRS



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Dual-arm spectrograph for simultaneous visible and infrared observations

Beam splitter to share the beam with IBIS

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with IBIS	* * 8542	Ca II	1.1	low chromosphere
	* 10827	Si I	1.5	photosphere
	* 10830	He I	2.0, 1.75, 1.25	upper chromosphere/low corona 500-2000 km
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Instrument Requirements

with FIRS

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High Cadence: Dynamics

Increased throughput with 4 slits



Instrument Requirements

with FIRS

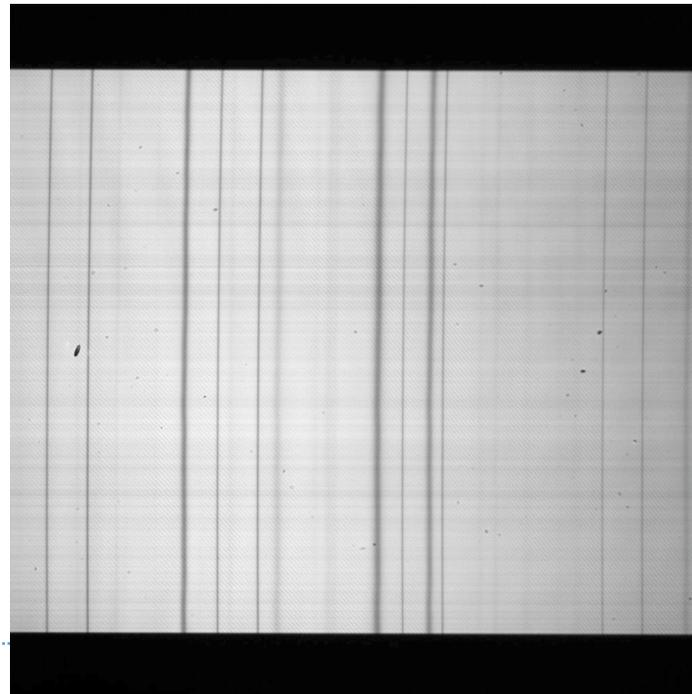
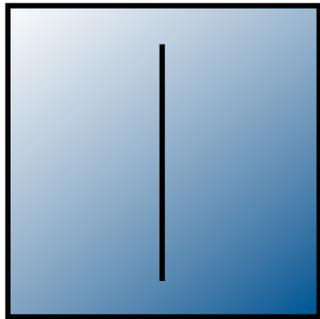
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FIRS



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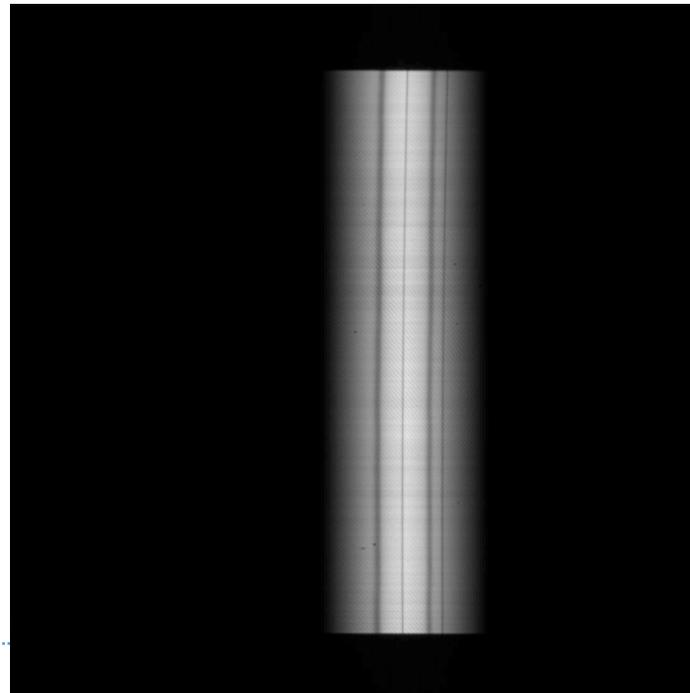
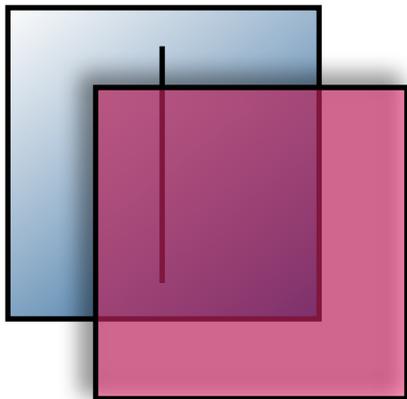
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FIRS



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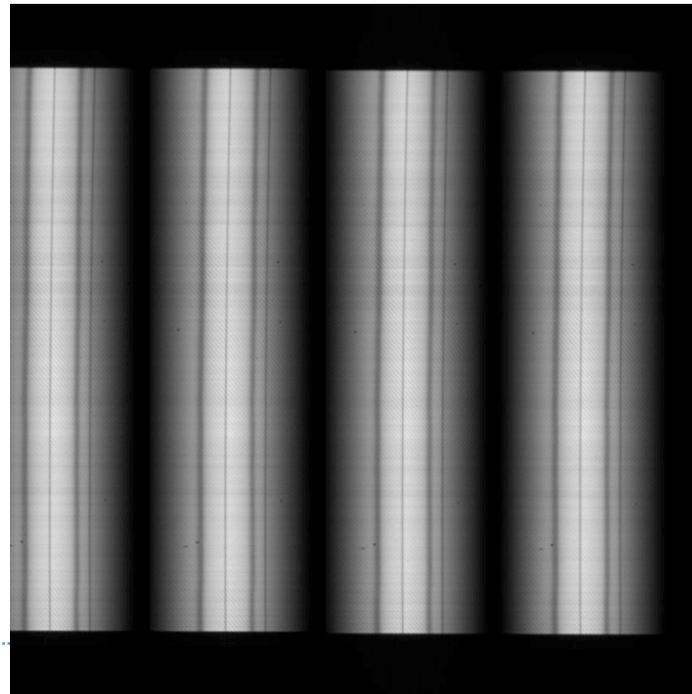
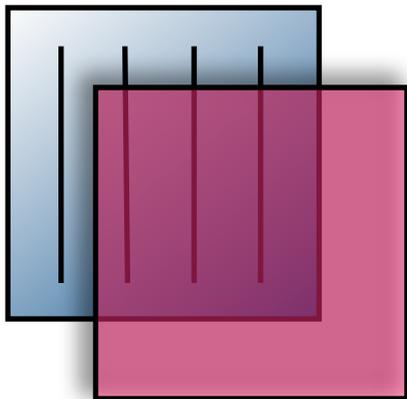
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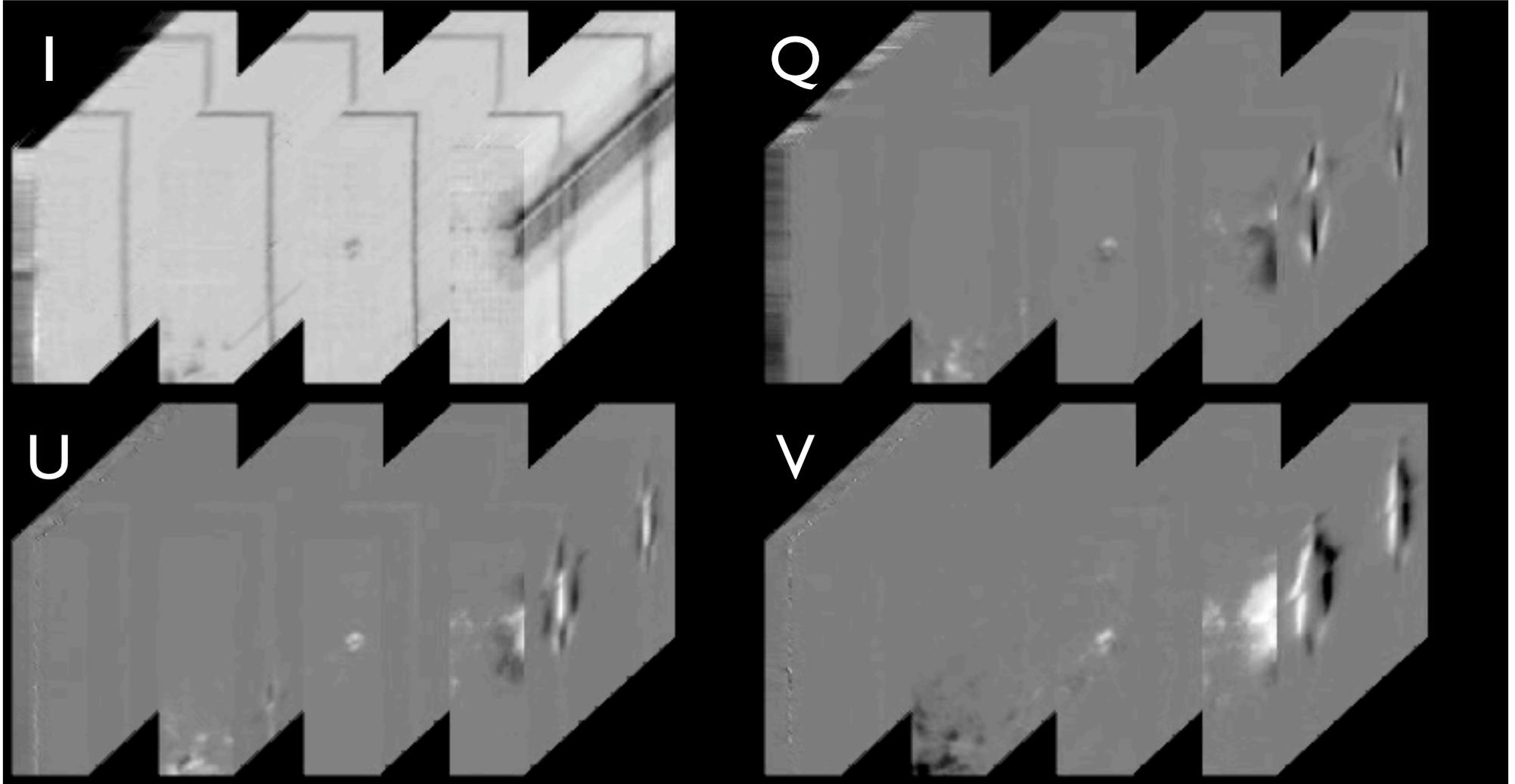
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FIRS



Building a Scan with 4 Slits



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High Spectral Resolution: Detailed Physics

Large IR grating with steep blaze

300,000 for the IR, 600,000 for the visible (3pm measured with HeNe
~200,000)



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High Spatial Resolution: Structure Detail

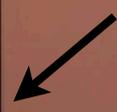
Diffraction-limited with HOAO

f/36 and f/108 feed optics for high and low-res modes

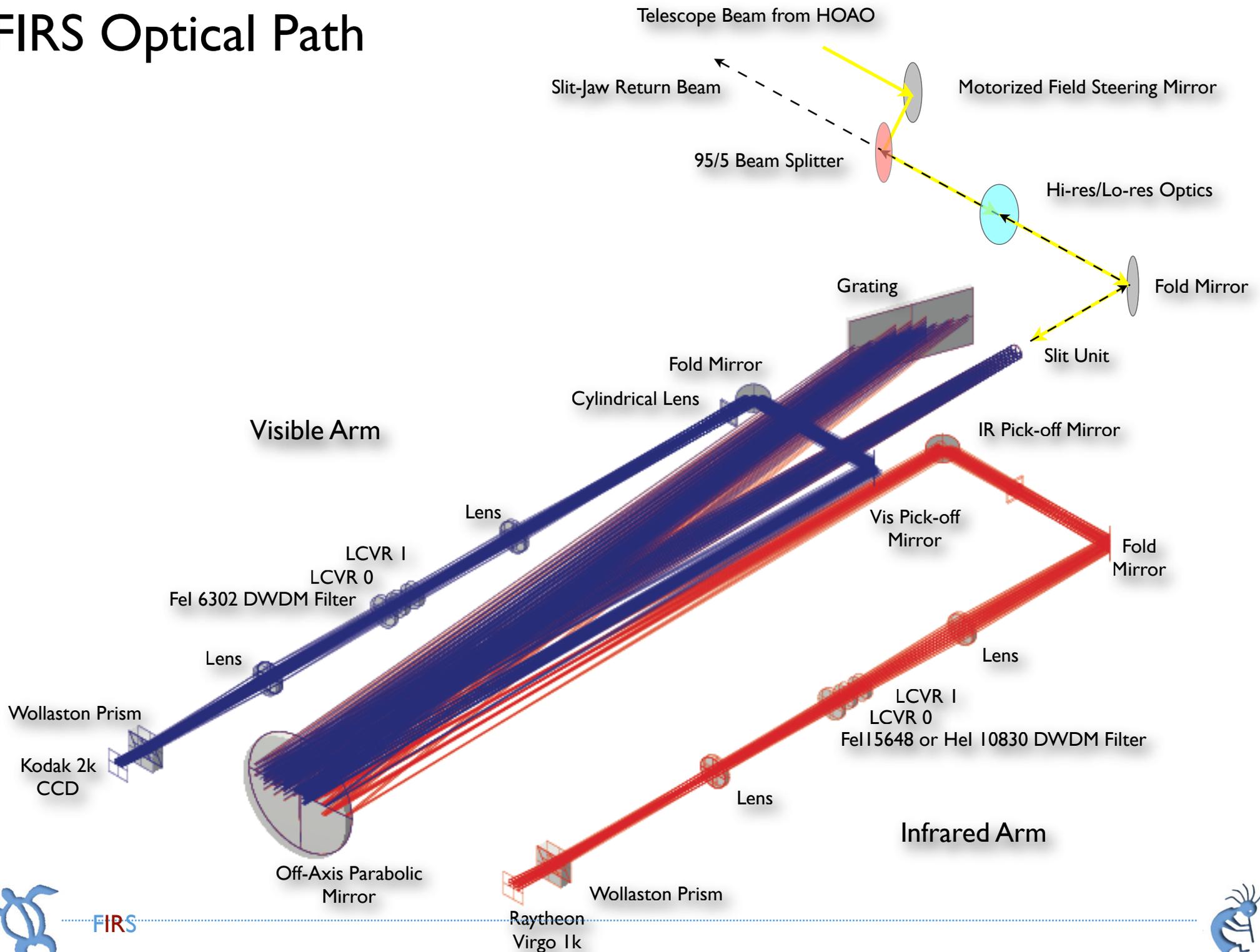




“Tower of Power”
aka f/108 feed optics



FIRS Optical Path



FIRS Properties

* Assuming use of 40 μm slit
 ** S/N $\sim 10^3$

Property	FIRS f/36*	FIRS f/108*	Hinode SOT/SP
Telescope	76.2 cm Solar Tower	...	50 cm Aplanatic Gregorian
Rayleigh limit @ 6302	0.21''	...	0.32''
Rayleigh limit @ 10830	0.36''
Rayleigh limit @ 15648	0.52''
Field	174'' x 75''	58'' x 25''	160'' (320'' max) x 151''
Vis Spatial Sampling	0.30'' x 0.08''/pix	0.10'' x 0.03''/pix	0.15'' x 0.16''/pix
IR Spatial Sampling	0.30'' x 0.15''/pix	0.10'' x 0.05''/pix	...
Nominal Scan Time**	20 min	...	83 min
6302 Spectral Resolution (Sampling)	0.03 (0.01) Å	...	0.03 (0.02) Å
10830 Spectral Resolution (Sampling)	... (0.04) Å
15648 Spectral Resolution (Sampling)	0.17 (0.05) Å

Current Status

FIRS standard configuration is complete!

- Observer training July, September 2009
- Released for general use 1st quarter 2010

For the Future

Extended Capabilities:

- Additional visible and IR detectors for simultaneous 6302-8542-10830-15650
- Maybe super-achromatic dual-waveplate modulator for synchronized exposures
- New pair of Wollaston prisms for smaller beam deviation and larger FOV
- More narrow-band filters for extended wavelength coverage



FIRS Data

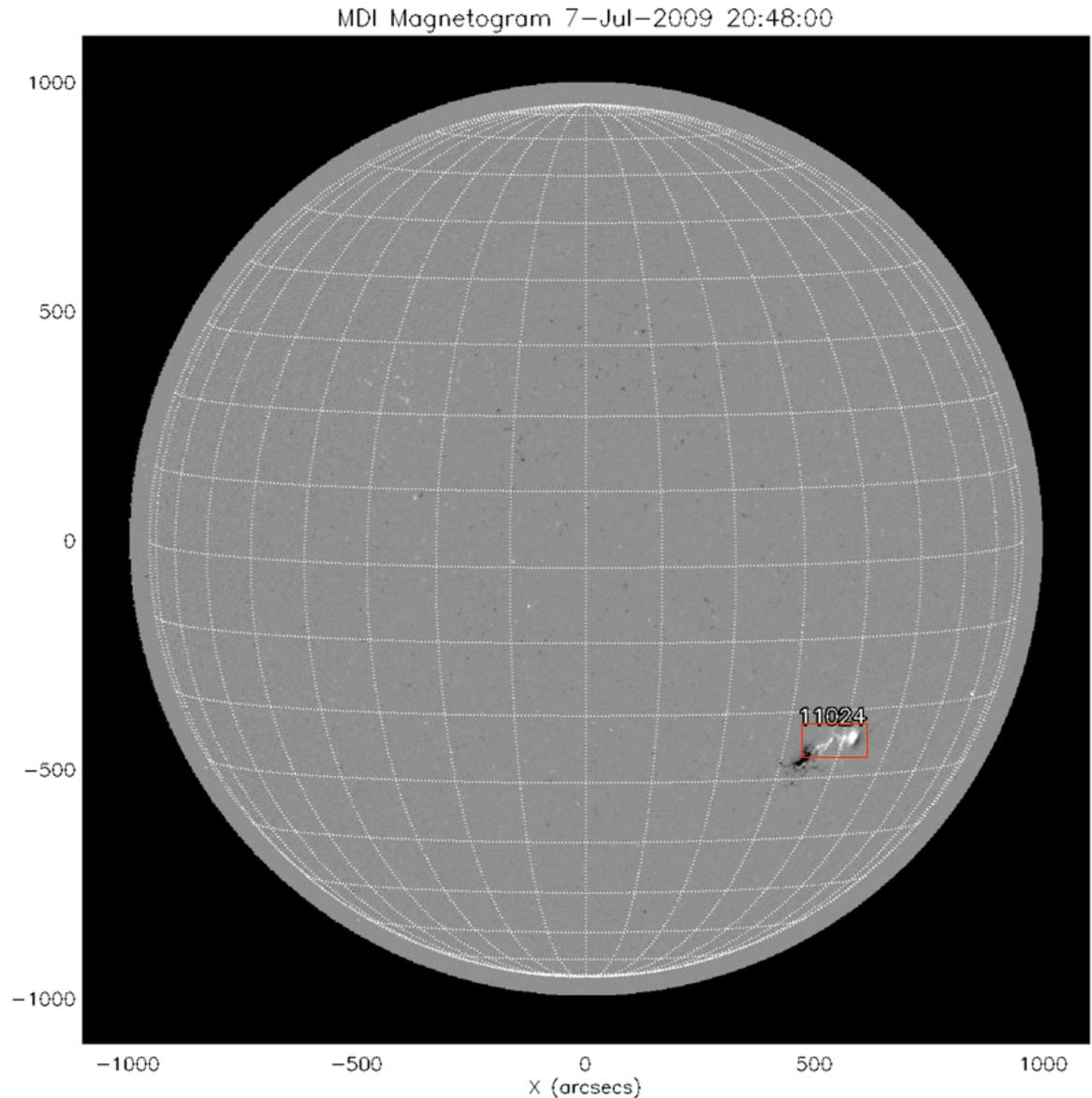
First Light 30 April, 2007

So far: 6 regions, 20 days,
various configurations

NOAA 11024, 7 July, 2009:

Full set of FIRS
wavelengths

Has a coincident
Hinode SOT/SP fast
map, only 4 minutes
apart in the umbra!

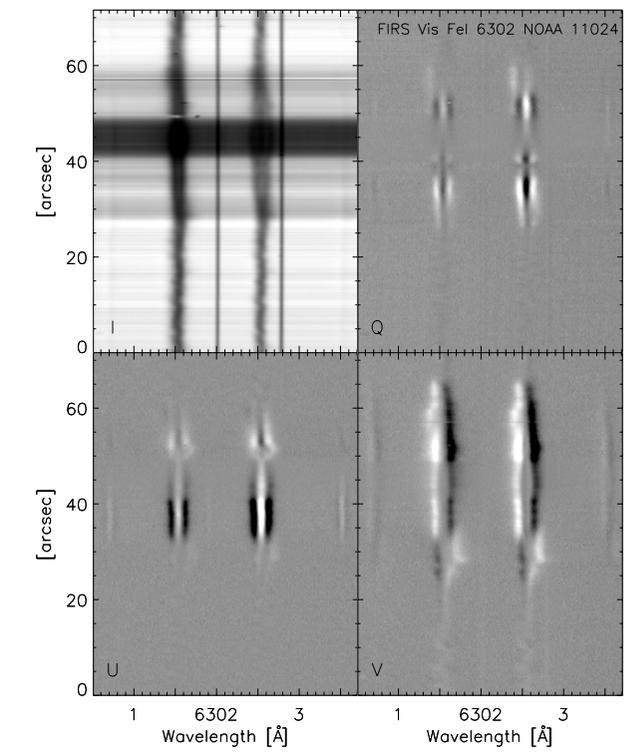
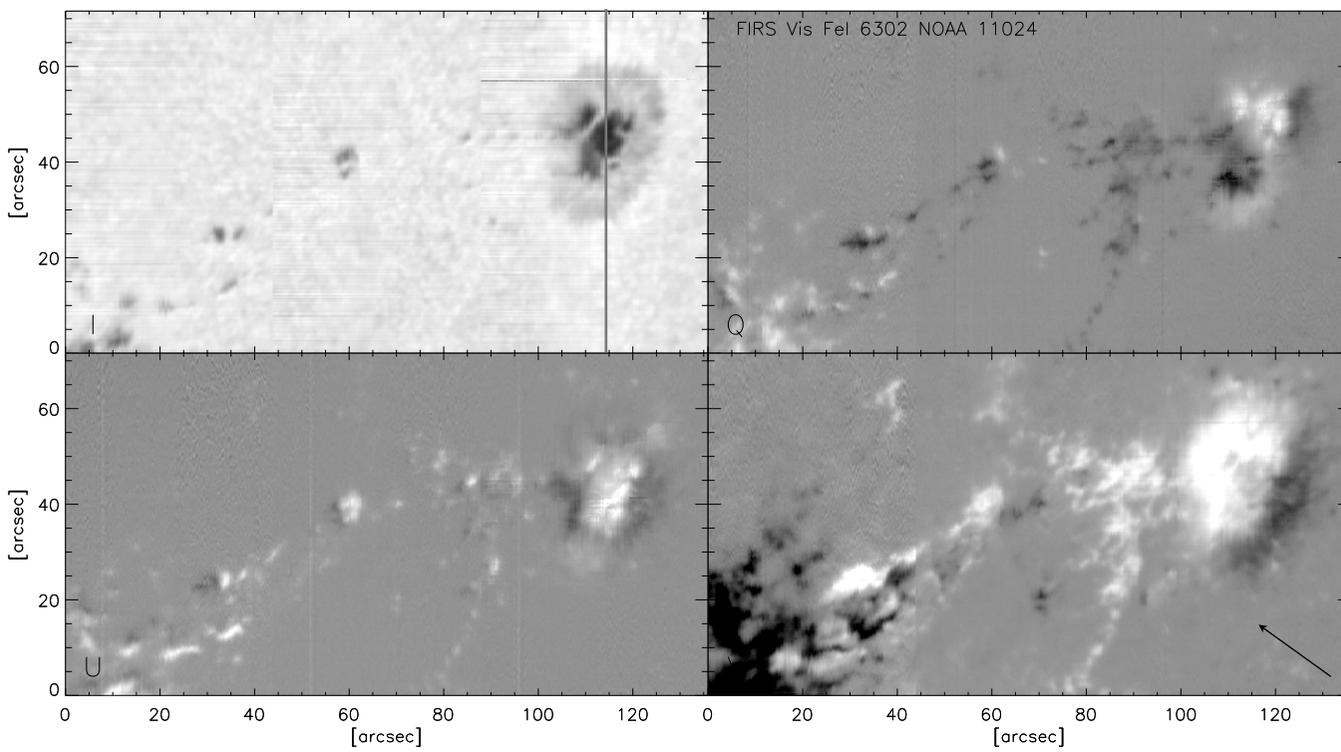
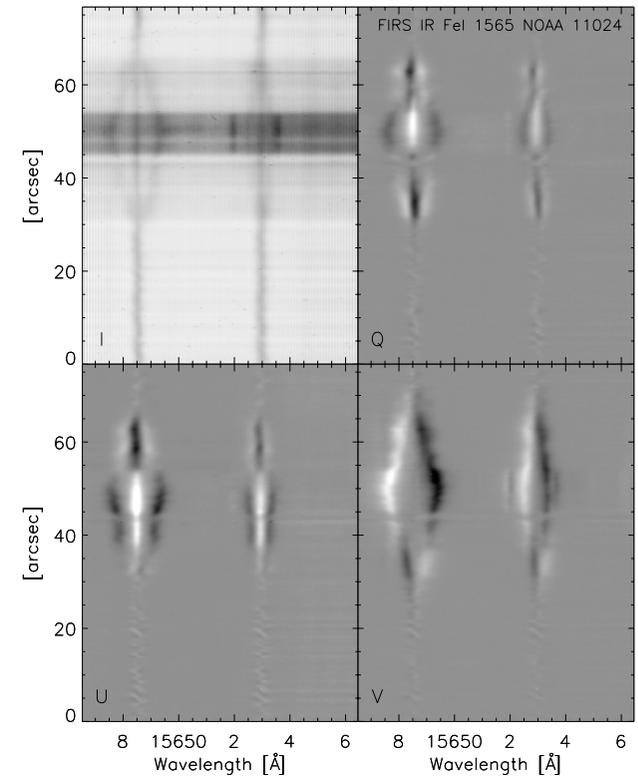
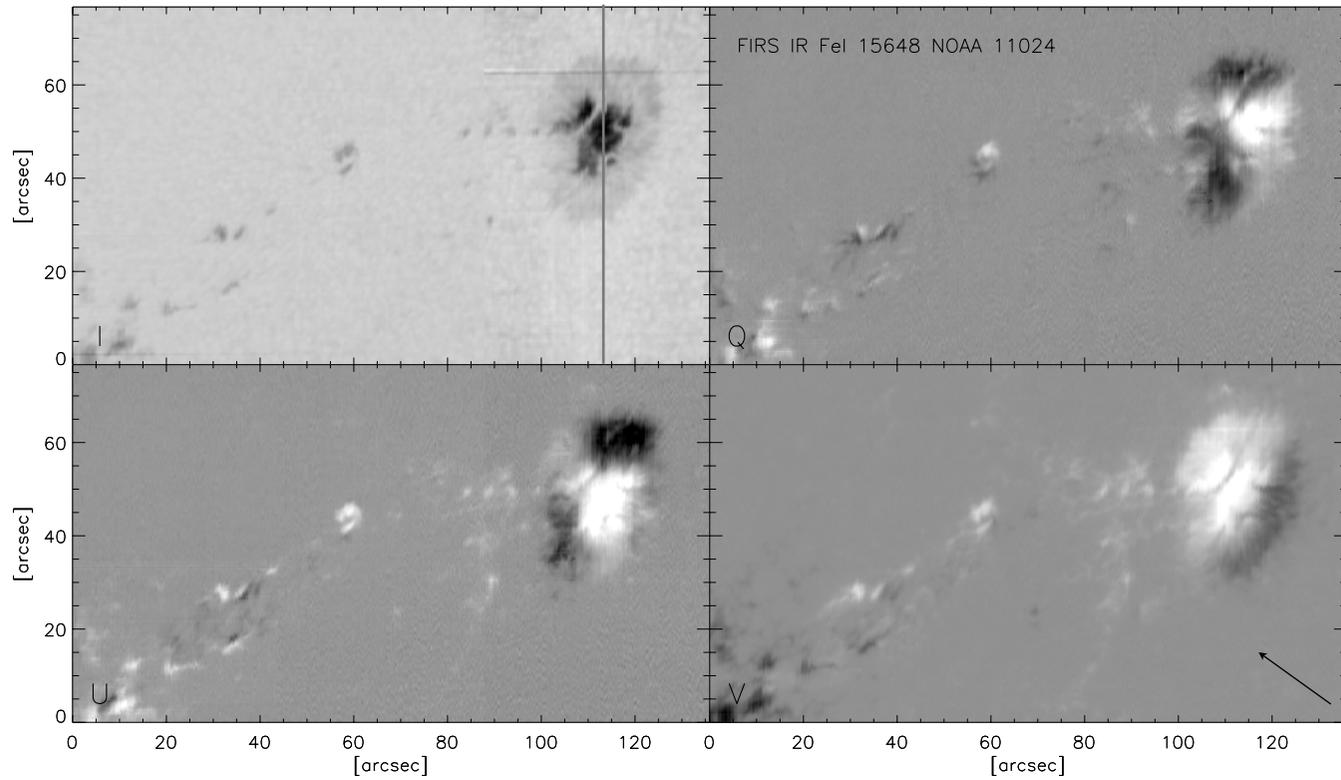


actually, 2009-07-06 would be better, Solis, Hinode, FIRS are close ~13:15 UT

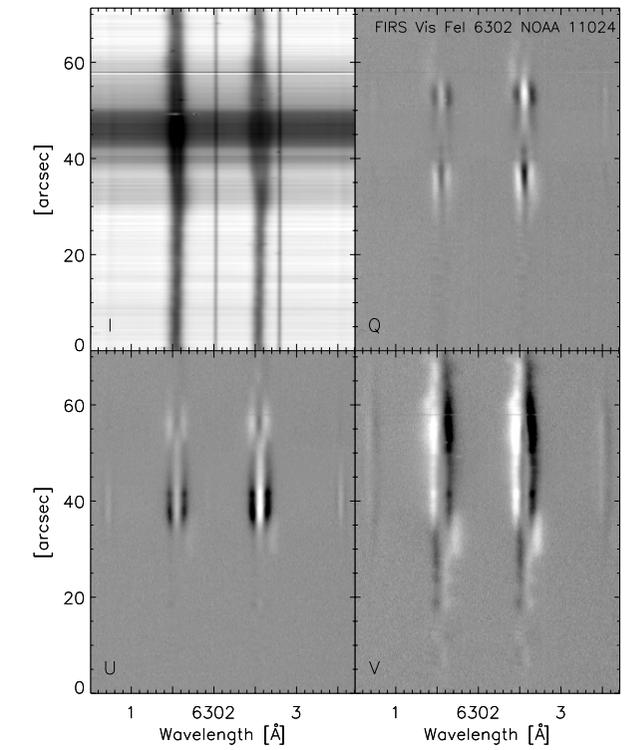
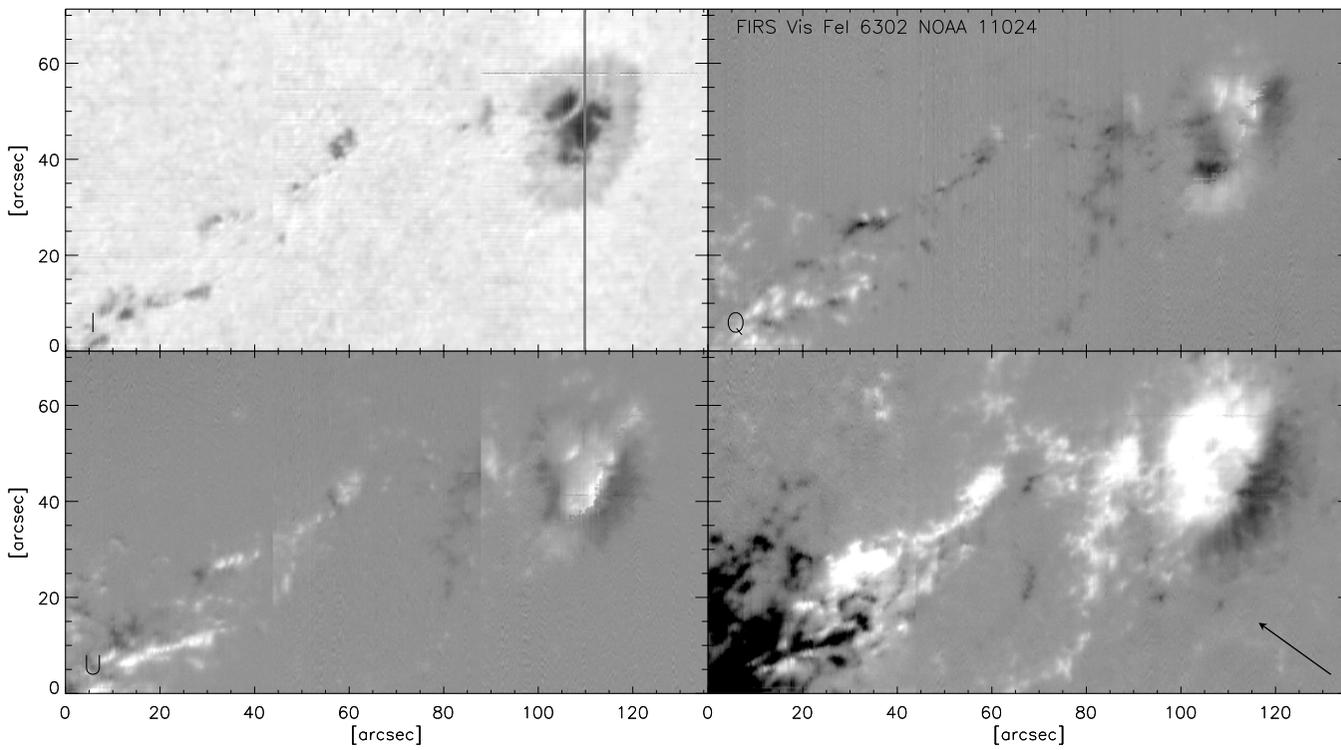
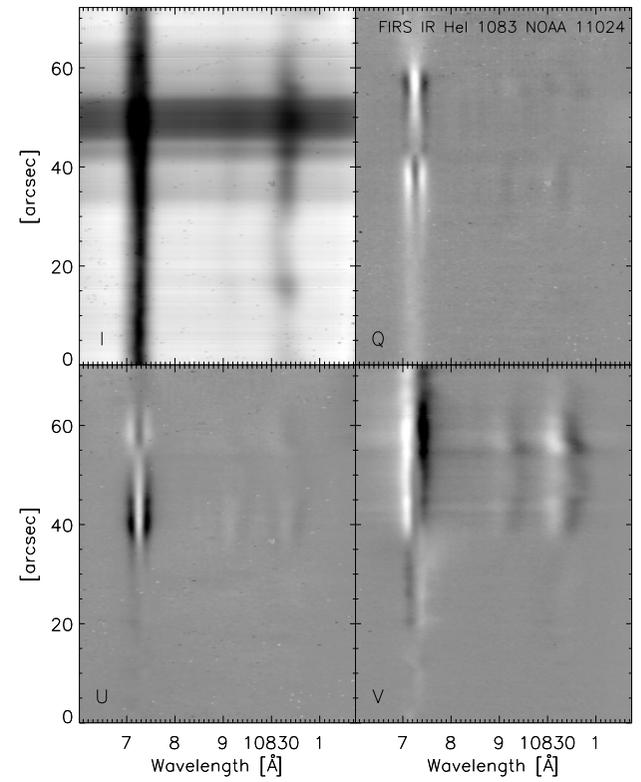
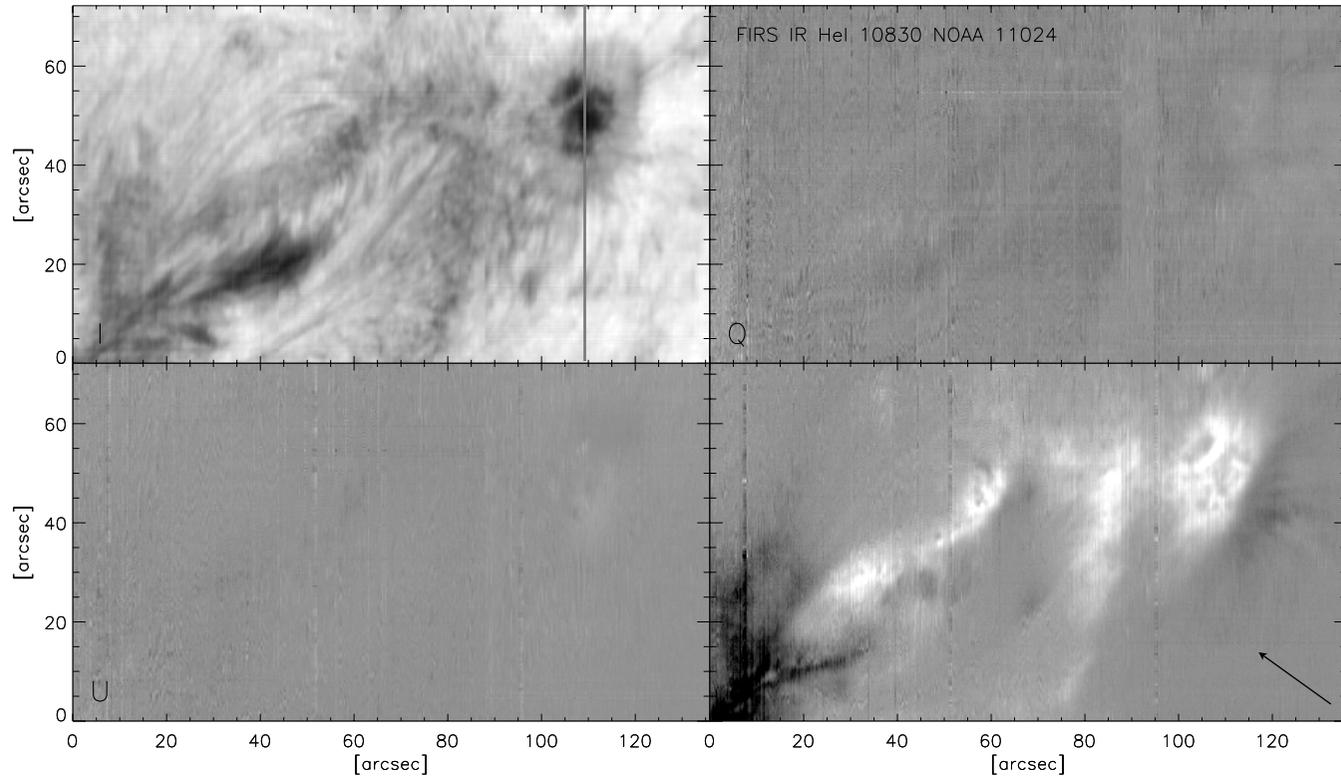
FIRS



2009-07-07 14:31:00 UT



2009-07-07 18:02:00 UT



Correction of Polarization Cross-talk

Kuhn et al. (1994) assumes $I \leftrightarrow QU$ and $Q \leftrightarrow U$ are small, and cross-talk is a combination of only linear terms.

Solve first for antisymmetric V through regression:

$$V = V_o - aQ_o - bU_o$$

 we use Matt's routine :)

Then solve for symmetric Q and U :

$$Q = Q_o - cV$$

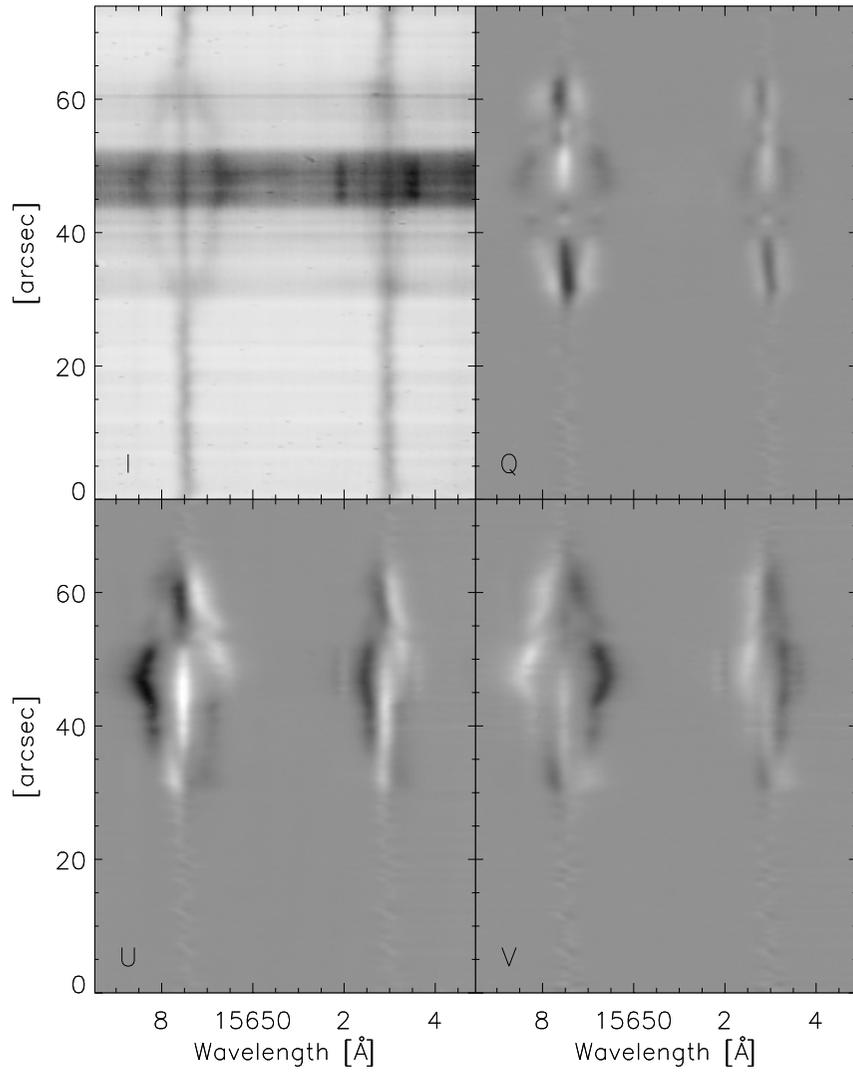
$$U = U_o - dV$$

Resulting coefficients of the inverse Muller matrix:

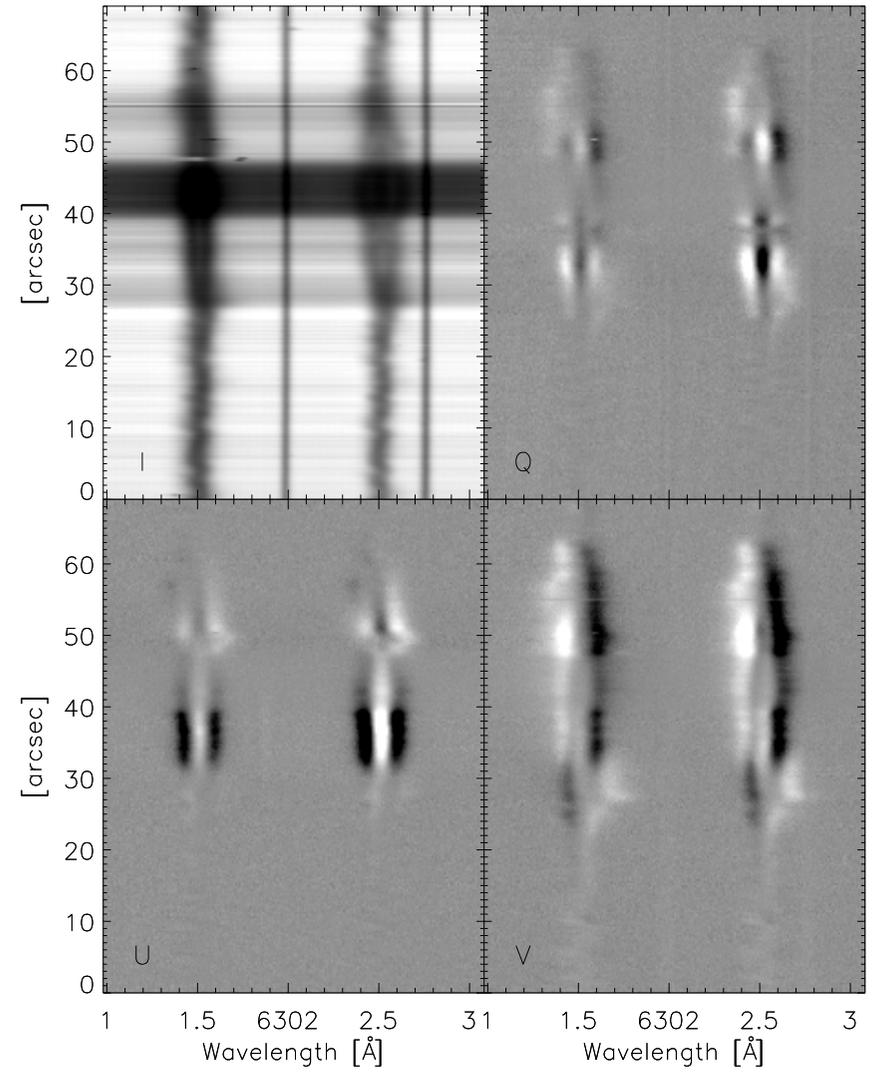
$$M^{-1} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 + ac & ad & -a \\ 0 & bc & 1 + bd & -b \\ 0 & -c & -d & 1 \end{pmatrix}$$



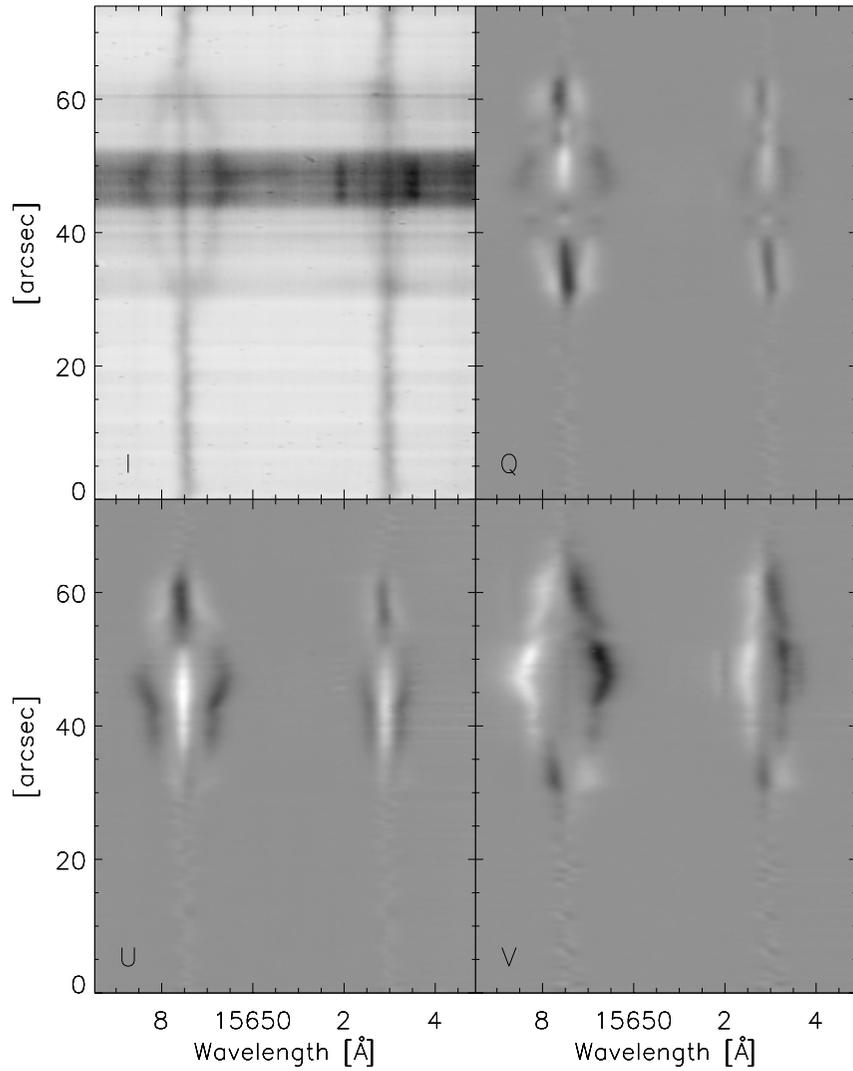
FIRS Fe I 1565 NOAA 11024



FIRS Fe I 6302 NOAA 11024

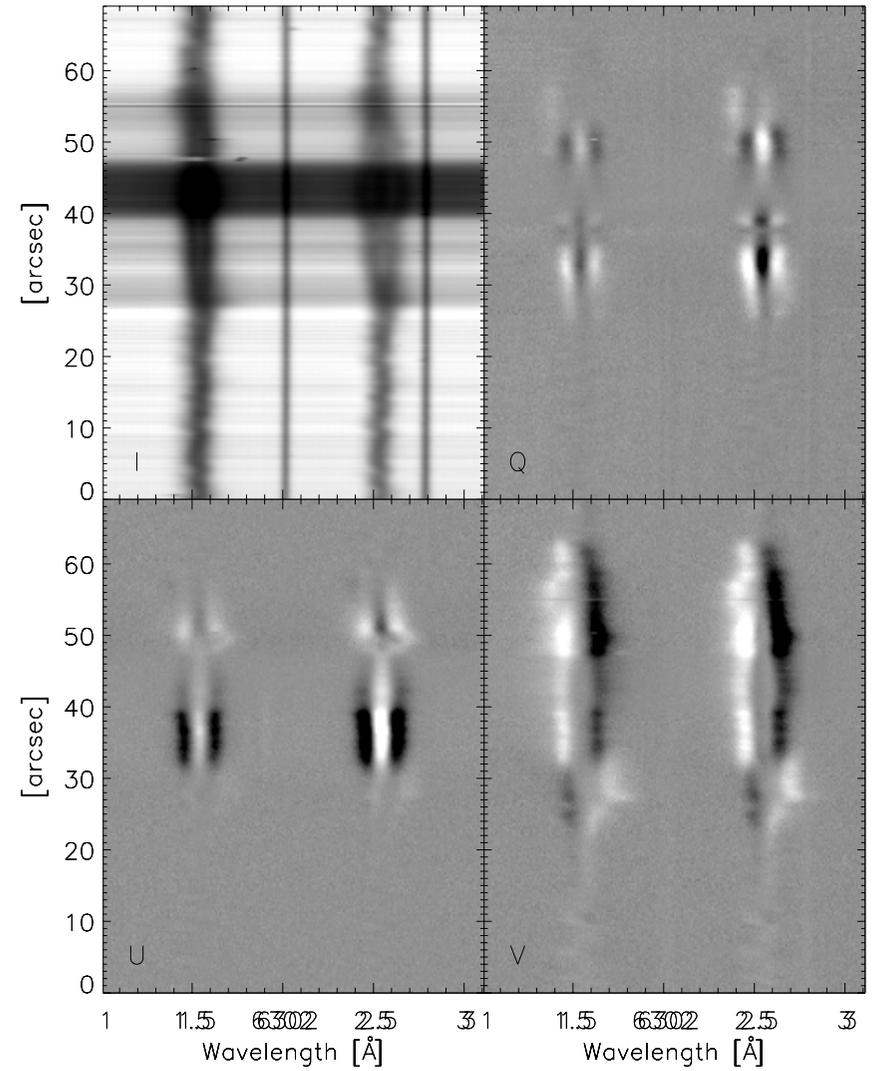


FIRS FeI 1565 NOAA 11024



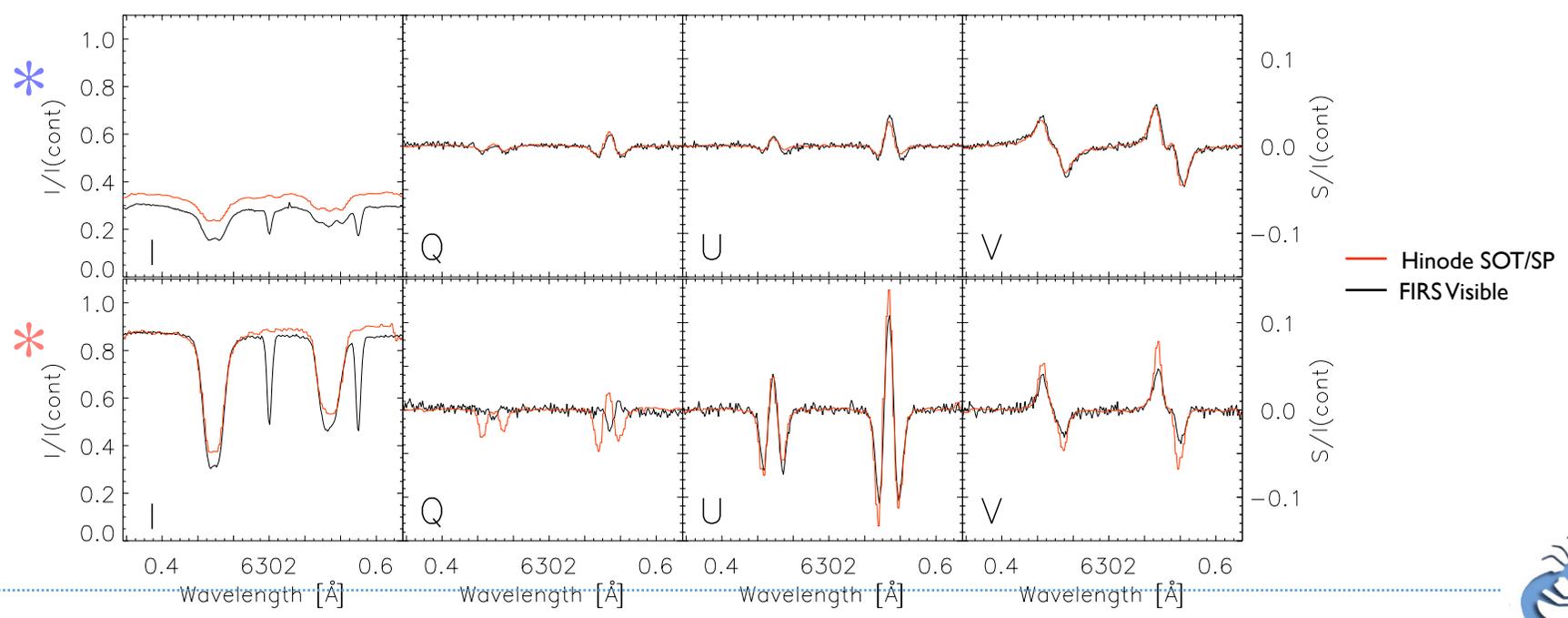
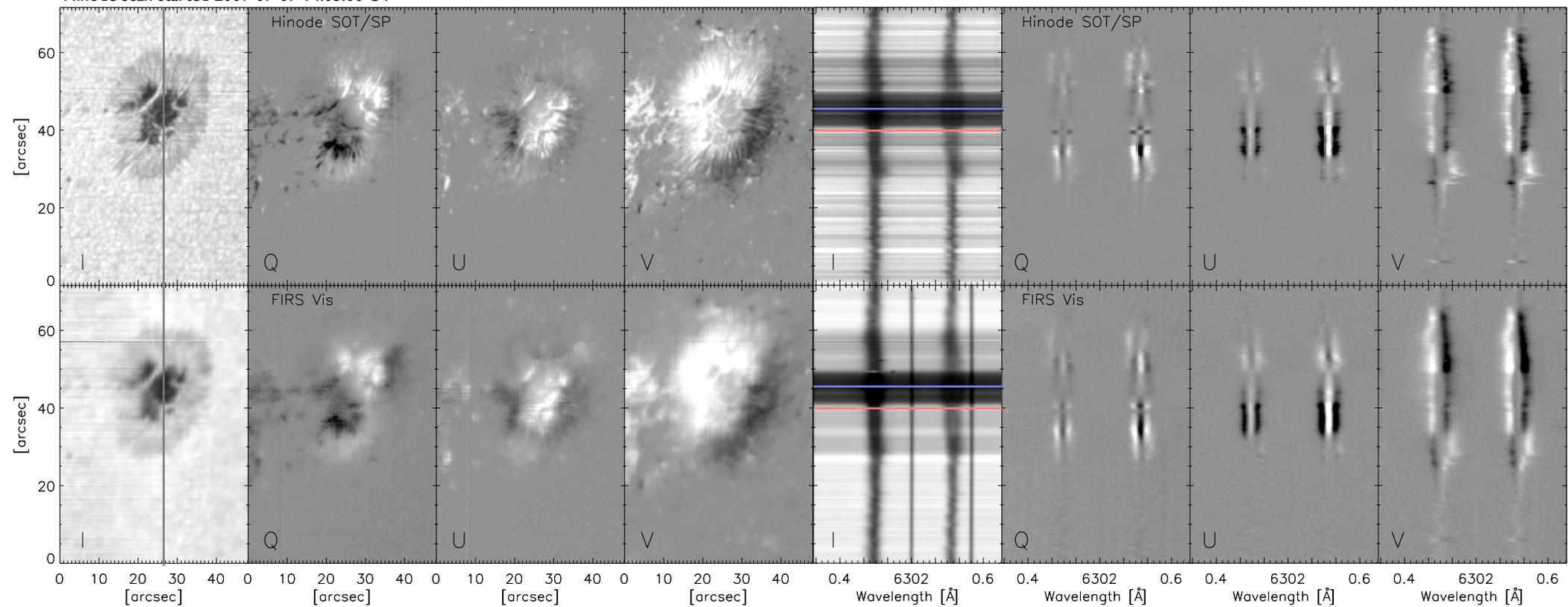
$a=0.114$ $b=0.348$ $c=0.015$ $d=-0.827$

FIRS FeI 6302 NOAA 111024



$a=-0.286$ $b=-0.210$ $c=0.197$ $d=0.109$

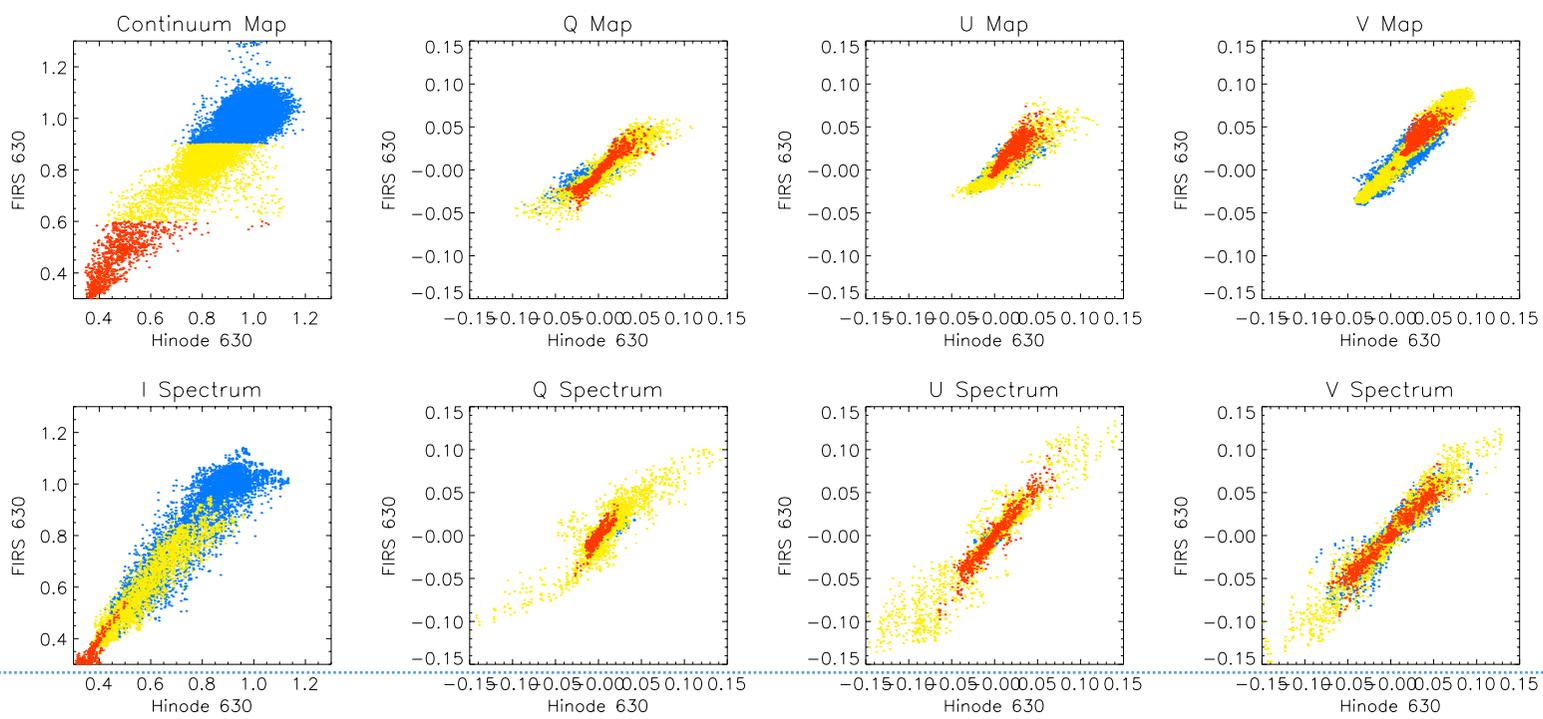
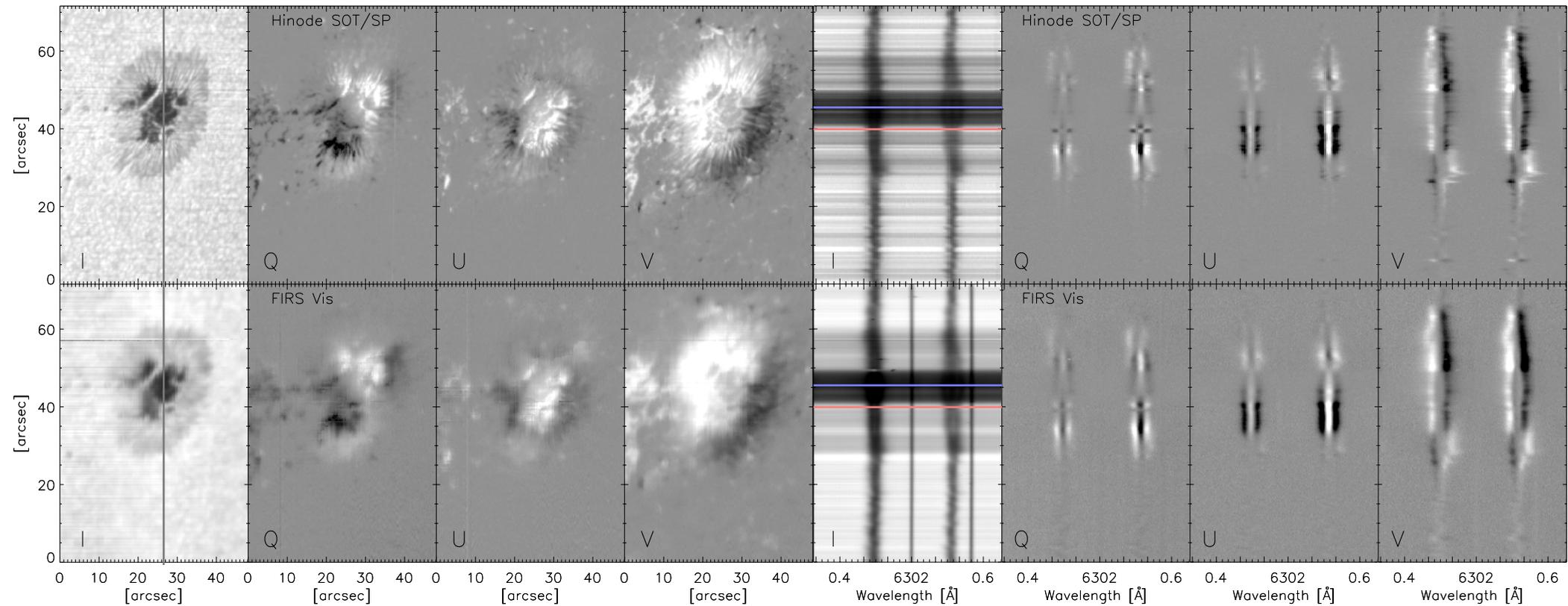




FIRS



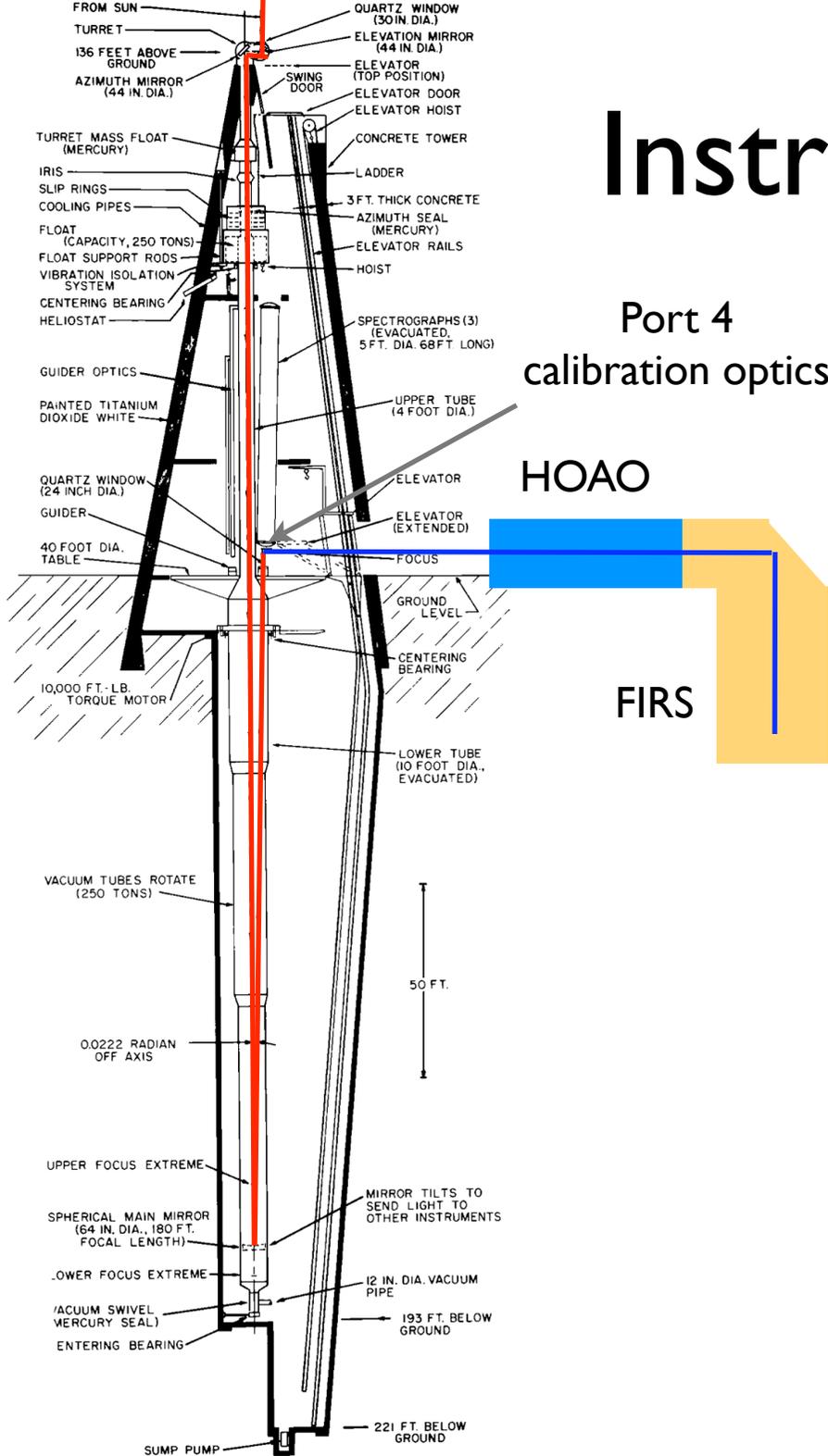
Hinode scan started 2009-07-07 14:03:00 UT



FIRS



Instrumental Polarization (cont.)



Port 4
calibration optics

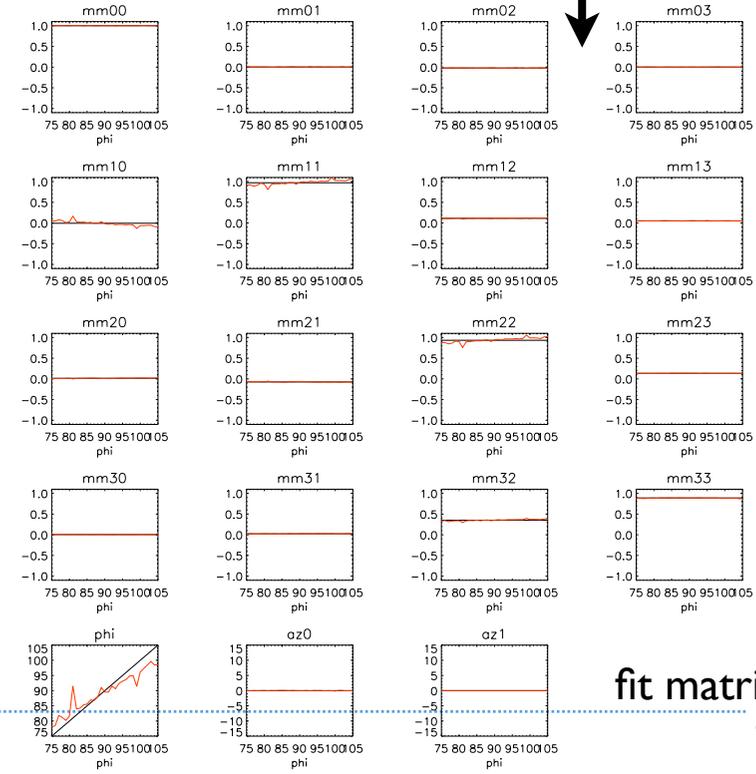
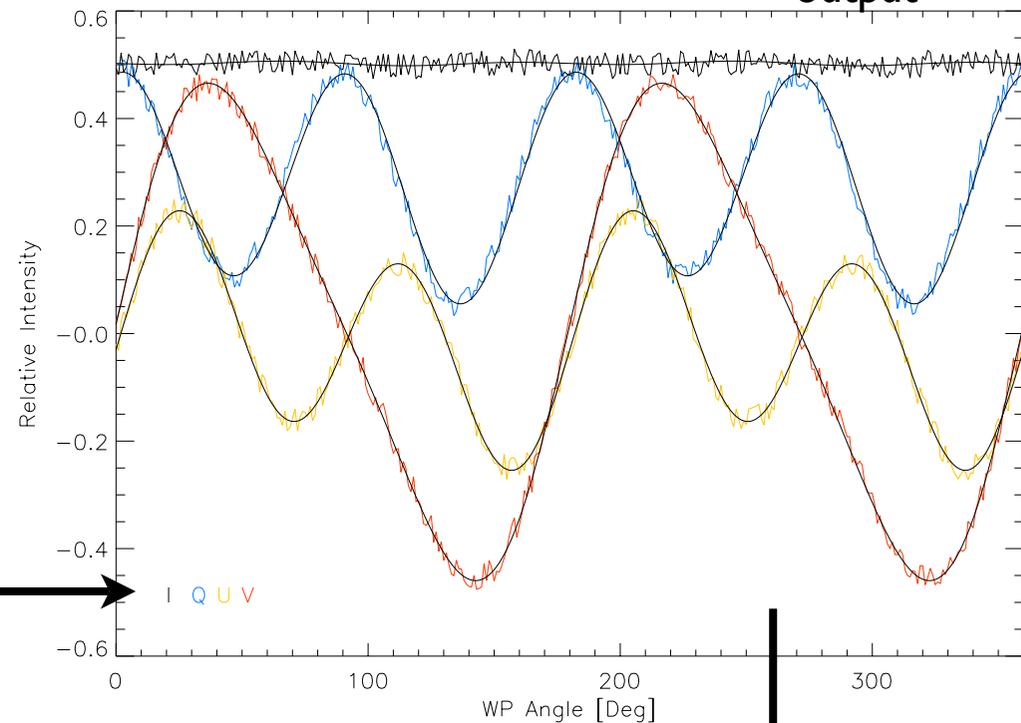
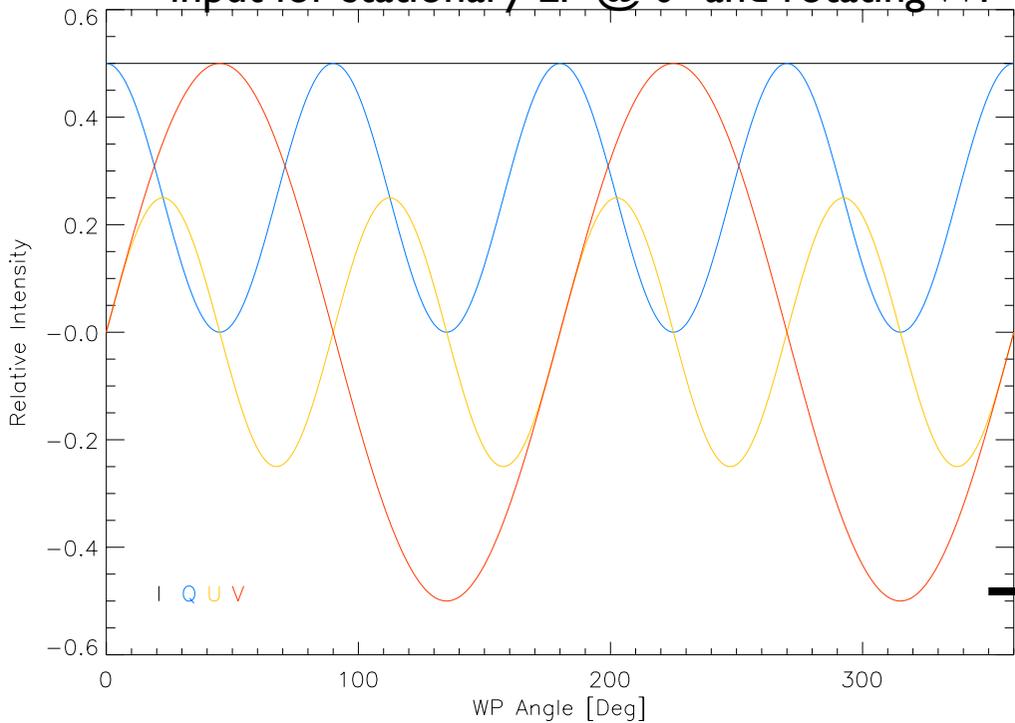
HOAO

FIRS

- Obtain independent polarization calibration data with the Port 4 LP and WP for our observations
- Can remove everything downstream from port 4 to get the pointing-dependent telescope model

input for stationary LP @ 0° and rotating WP

output



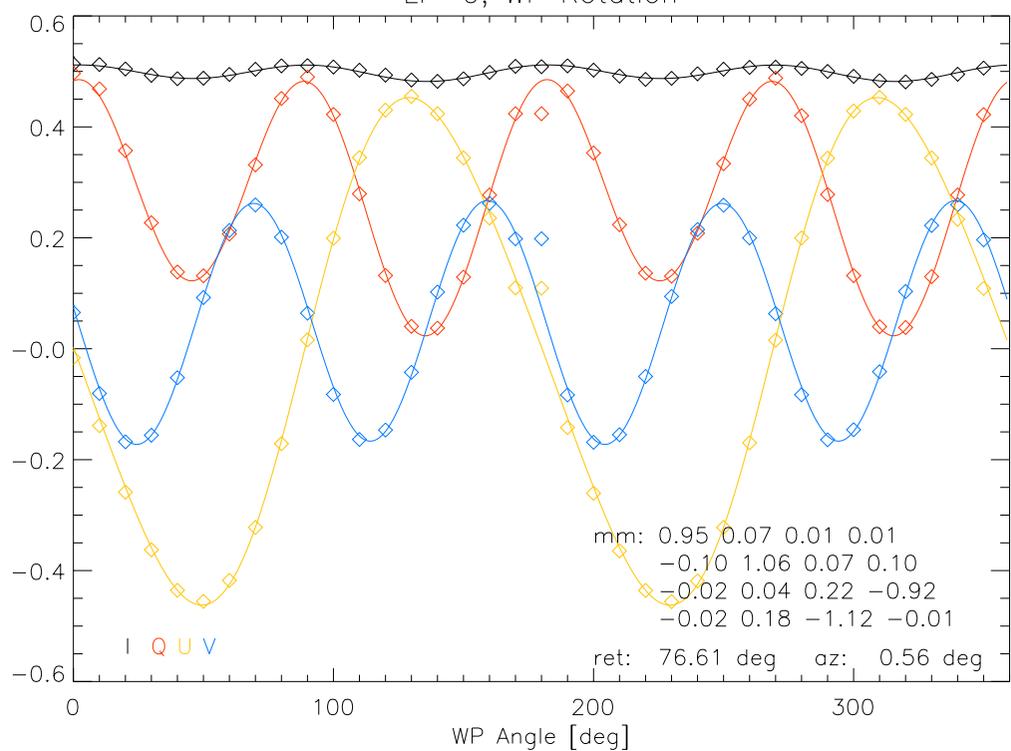
FIRS

fit matrix



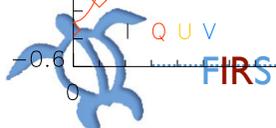
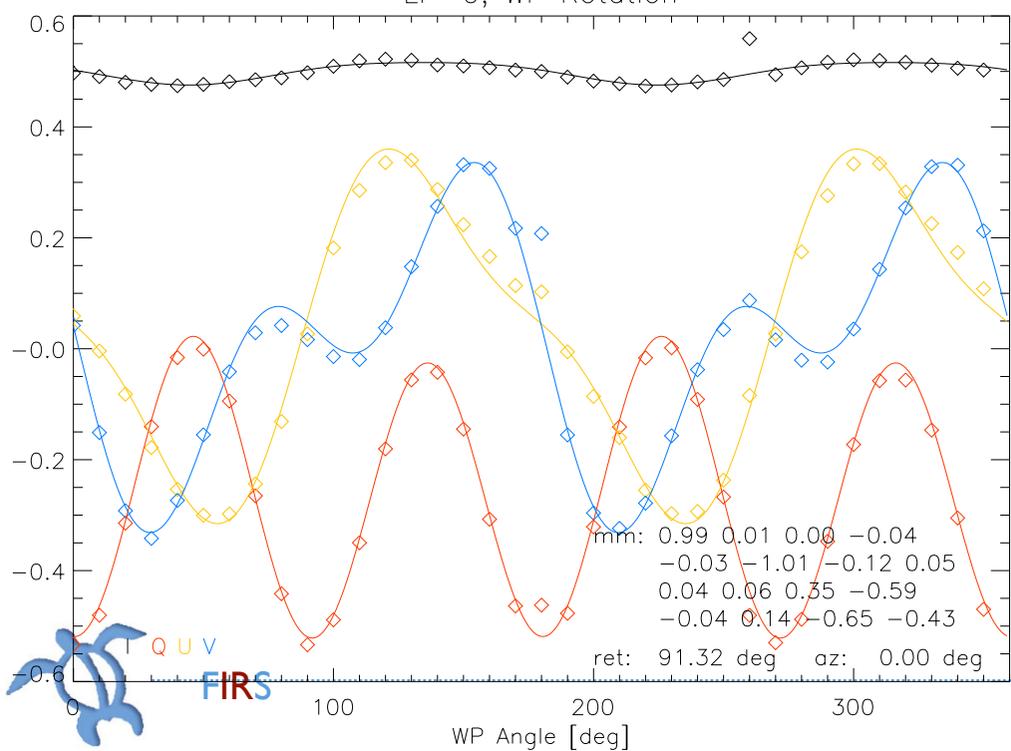
LP=0, WP Rotation

Visible FeI 6302



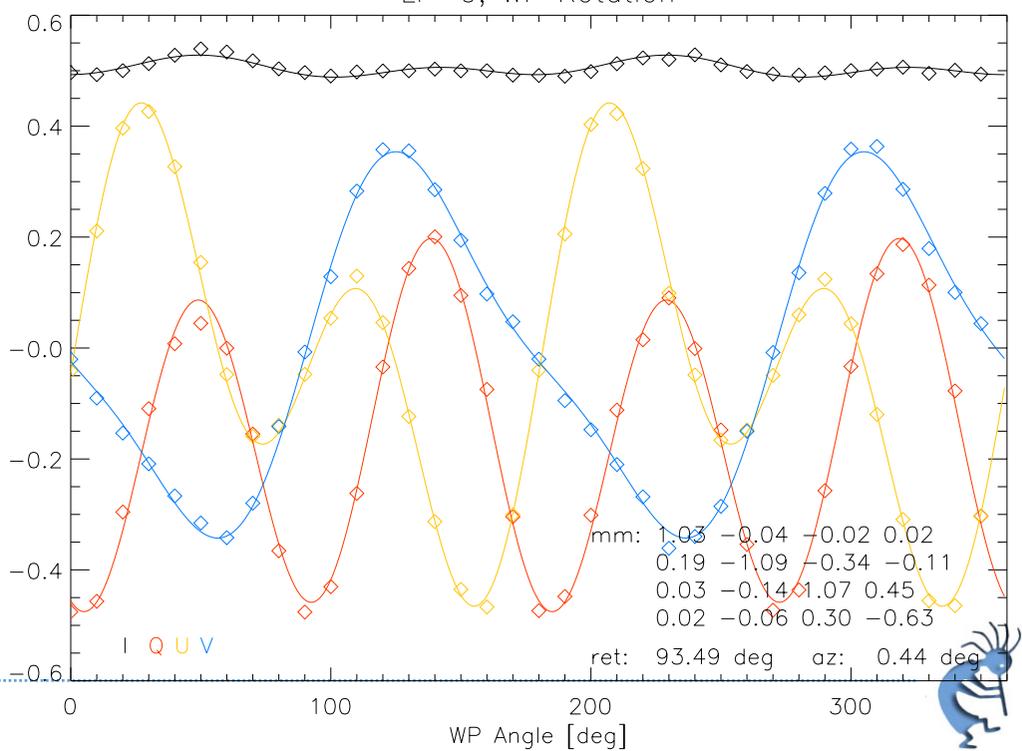
LP=0, WP Rotation

IR HeI 10830



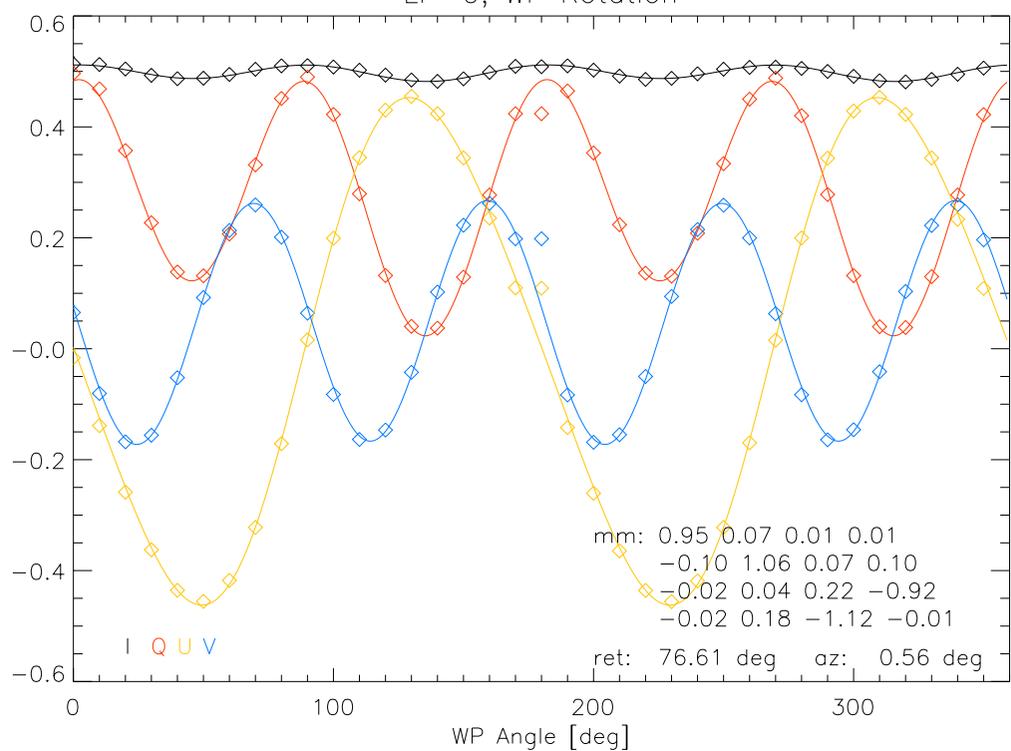
LP=0, WP Rotation

IR FeI 15648



LP=0, WP Rotation

Visible FeI 6302

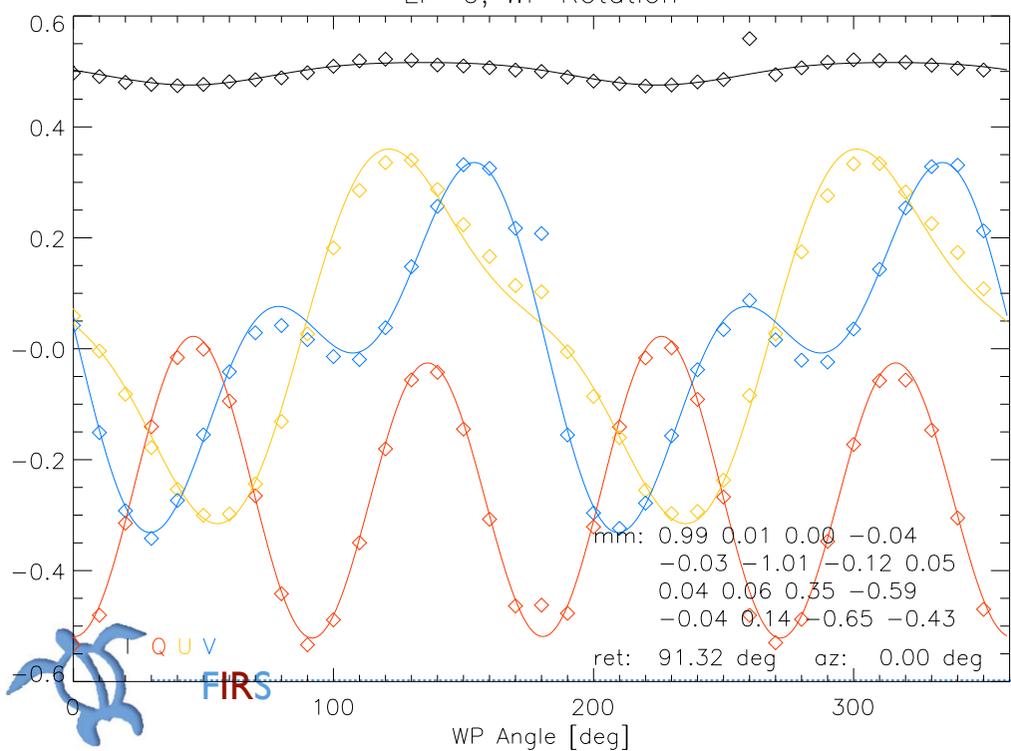


Now we can compare with a pointing and wavelength dependent telescope model



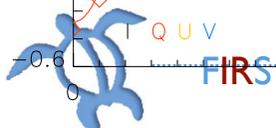
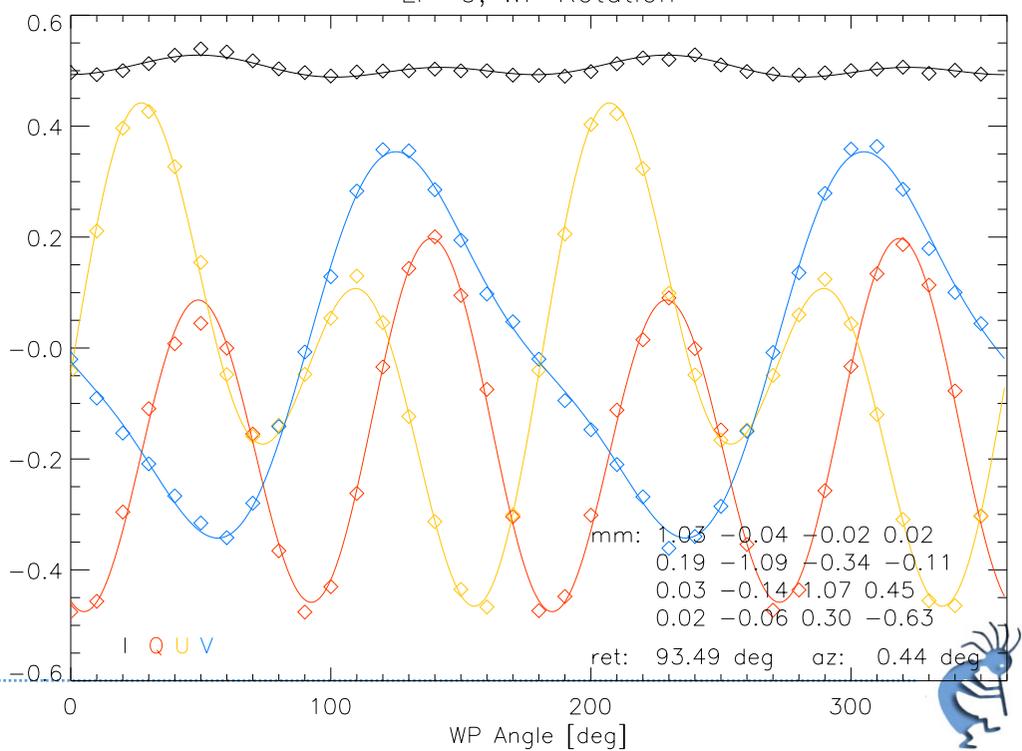
LP=0, WP Rotation

IR HeI 10830



LP=0, WP Rotation

IR FeI 15648

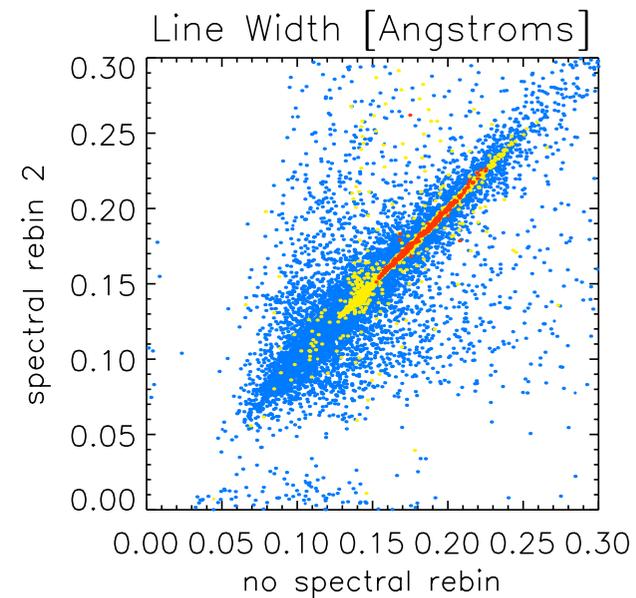
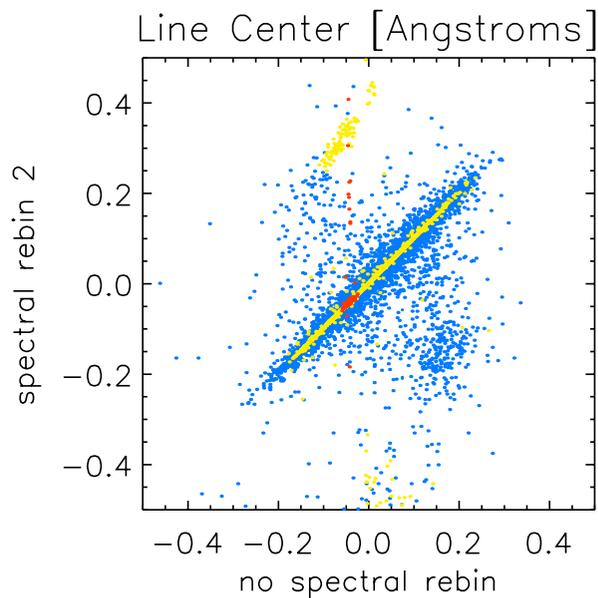
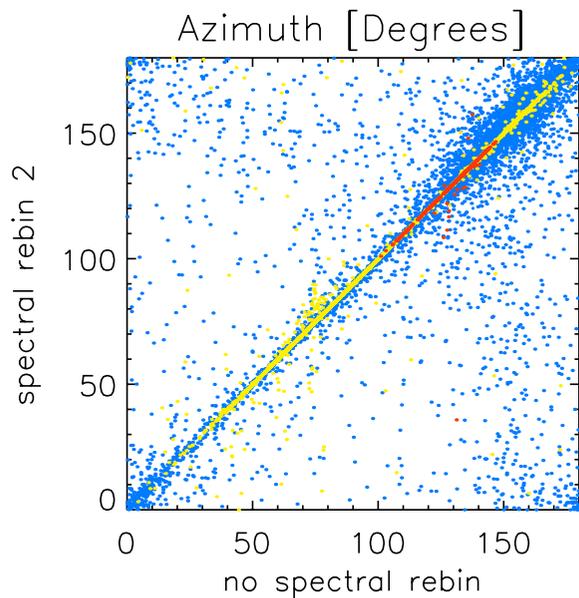
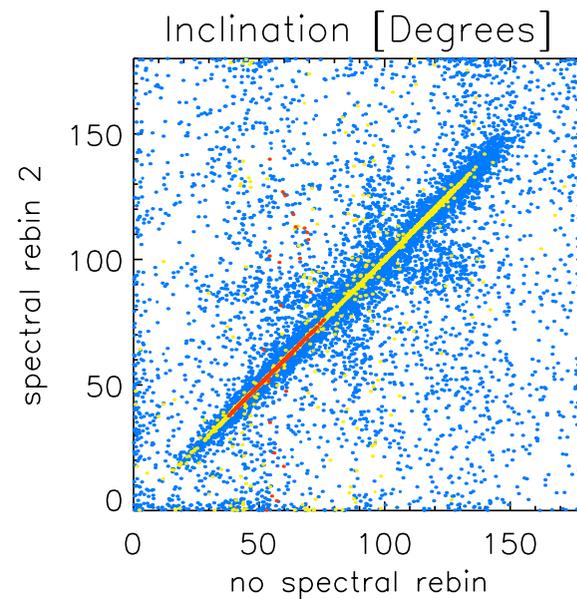
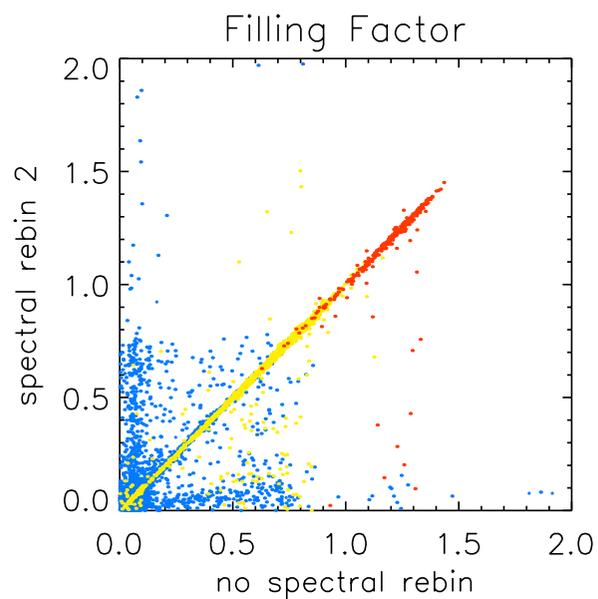
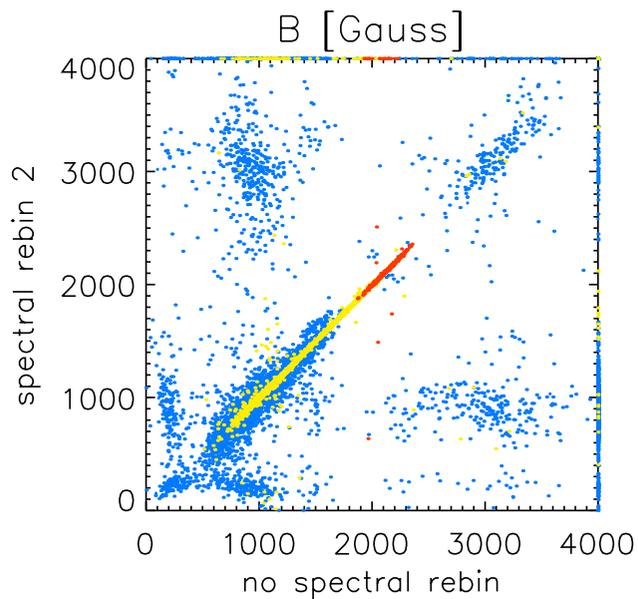


Inversion of Data

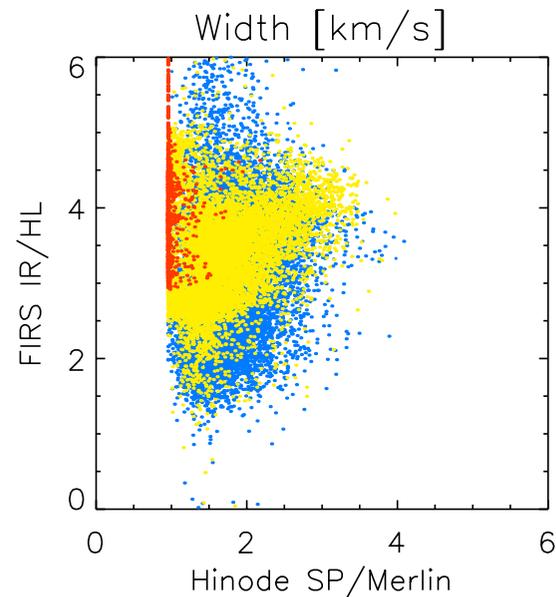
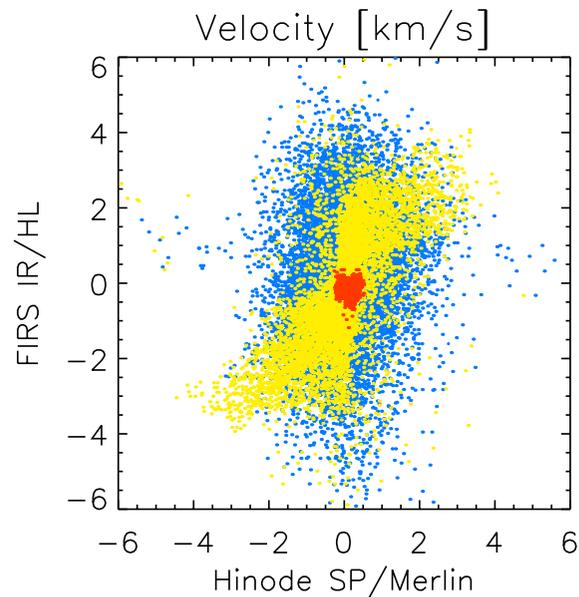
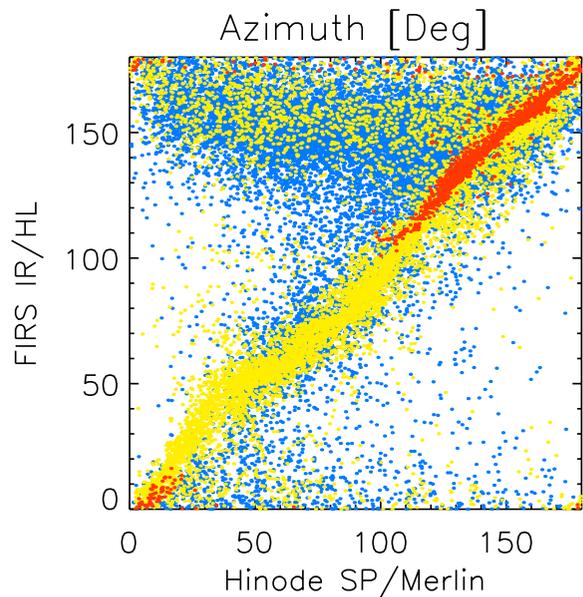
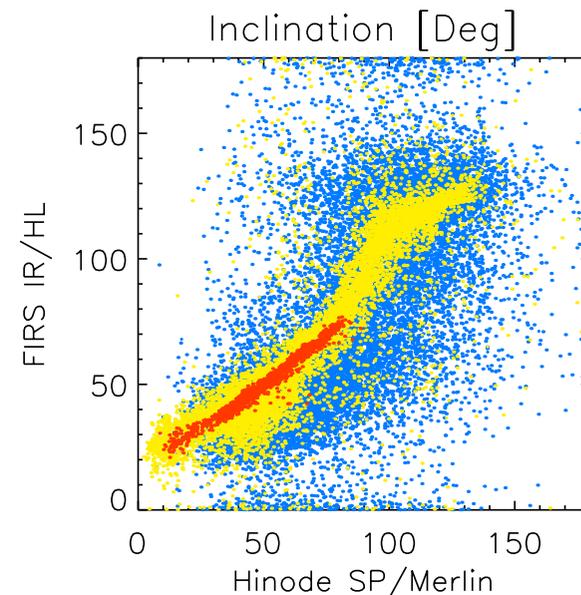
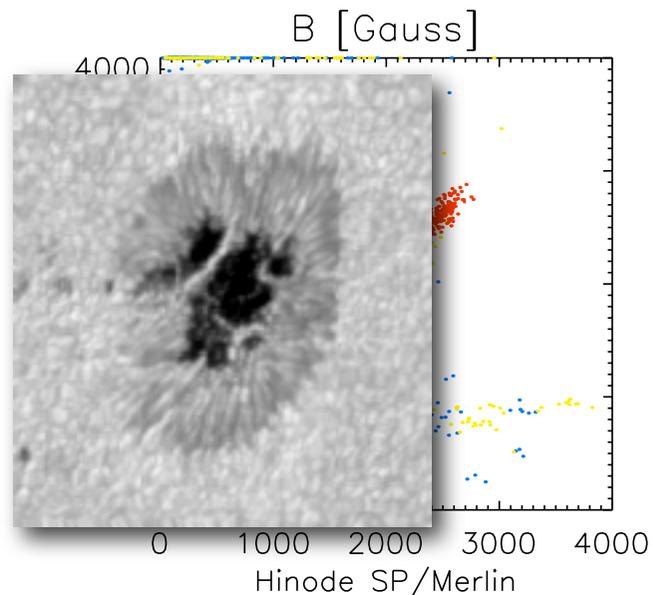
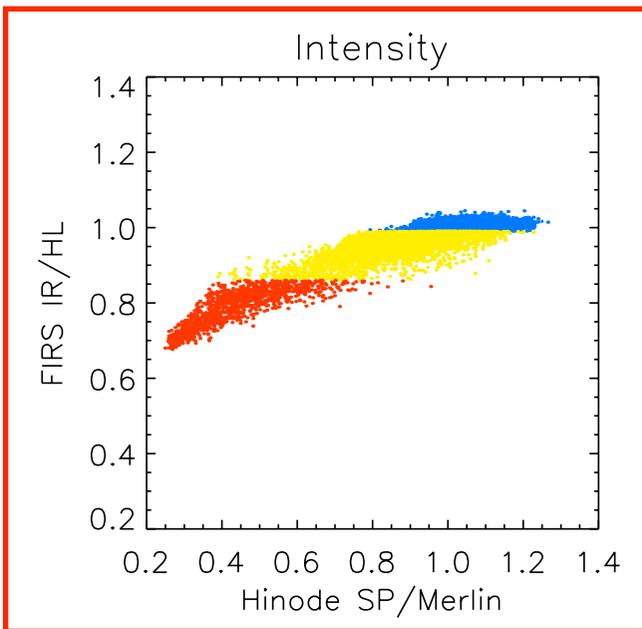
- Haosheng's gaussian fitting routine
 - Originally written for simple inversion of Fe I 1565
 - Does not (yet) account for the magneto-optical effect, 630 nm version for FIRS and Hinode data is forthcoming
- Merlin
 - Used on Hinode data at CASC/HAO
 - Not yet working with FIRS 630, needs some work (help?)
 - Hoping for improvements in new software version



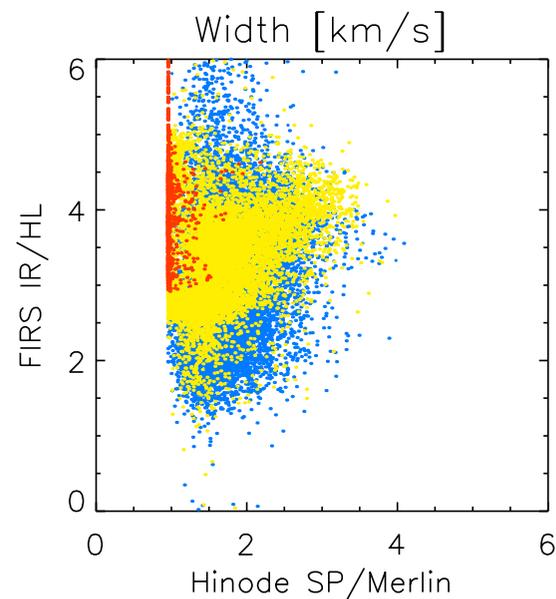
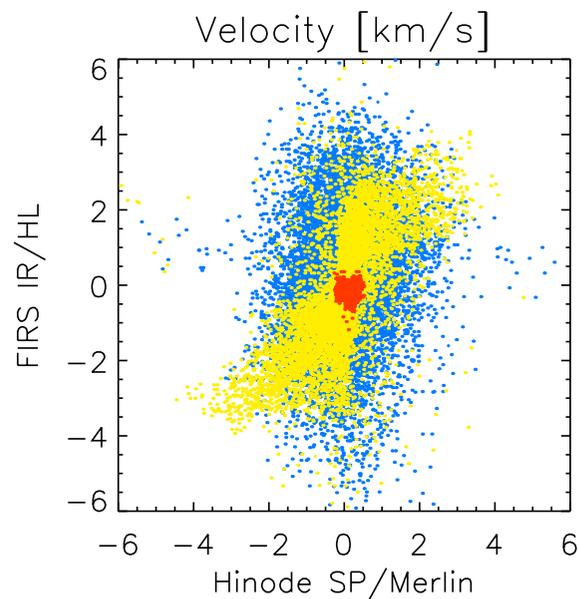
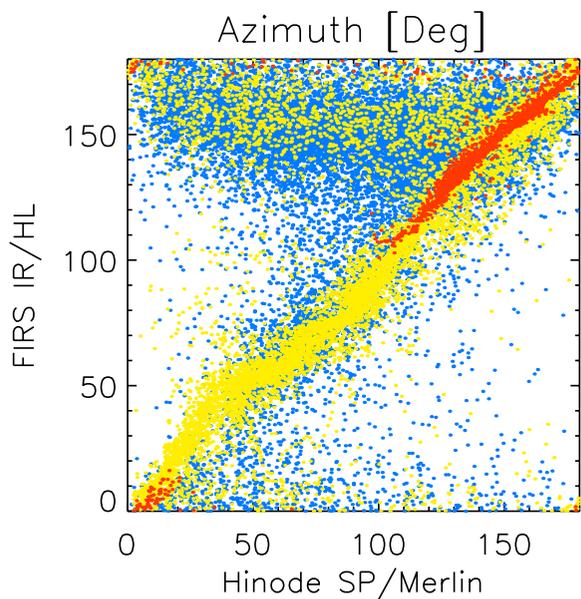
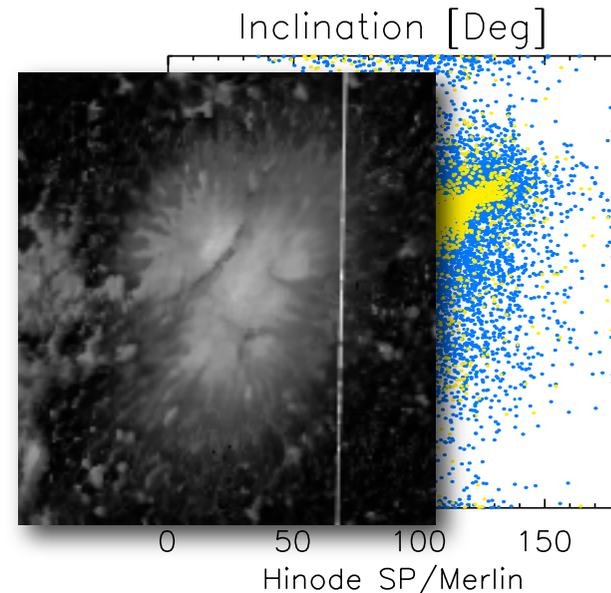
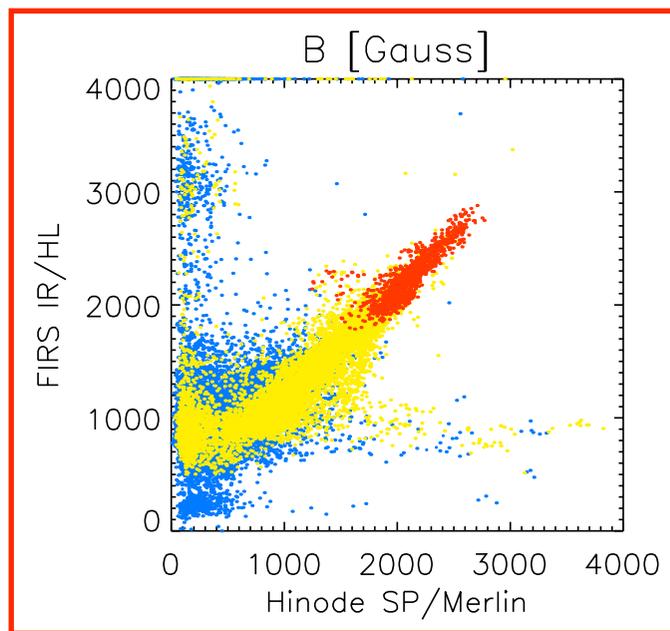
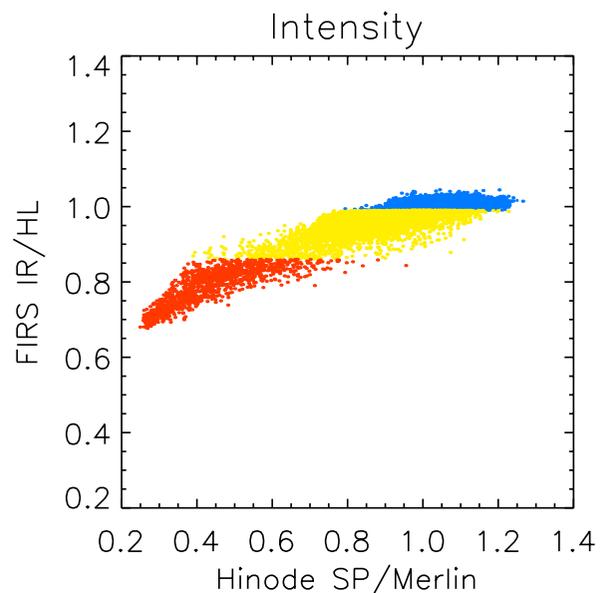
Test: FIRS I565/HL vs. Same Spectrally Rebinned x2



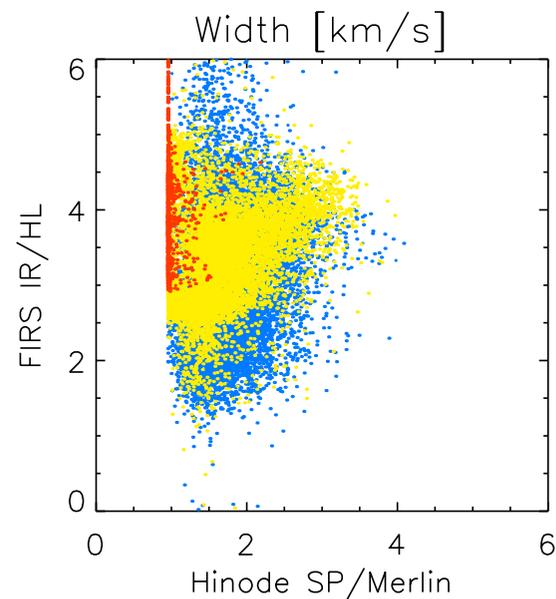
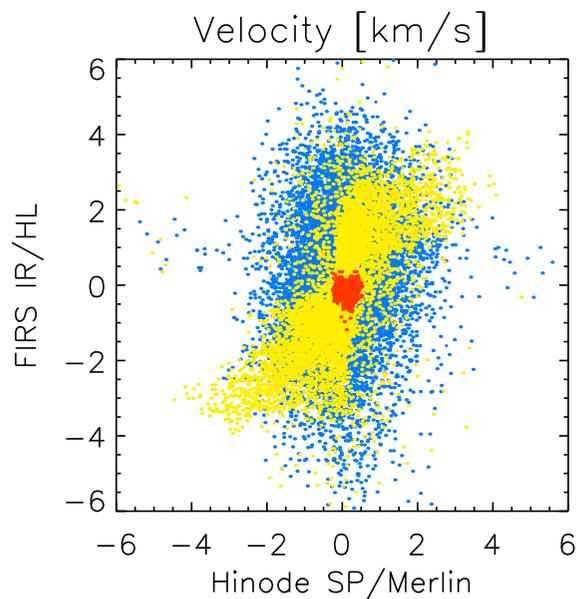
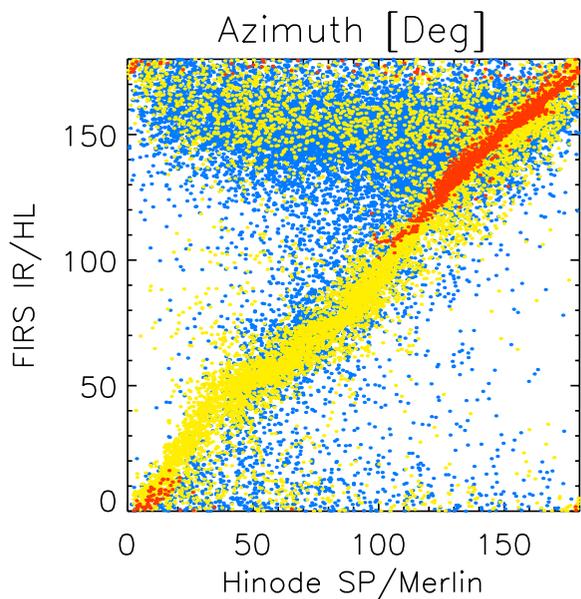
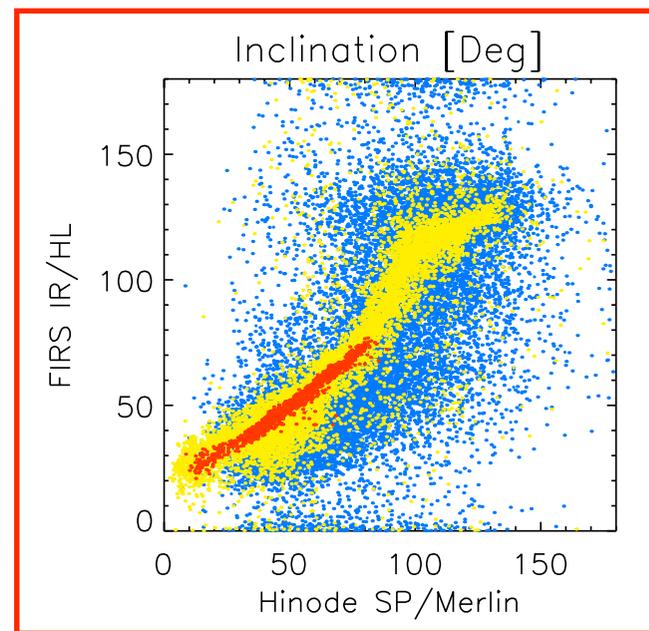
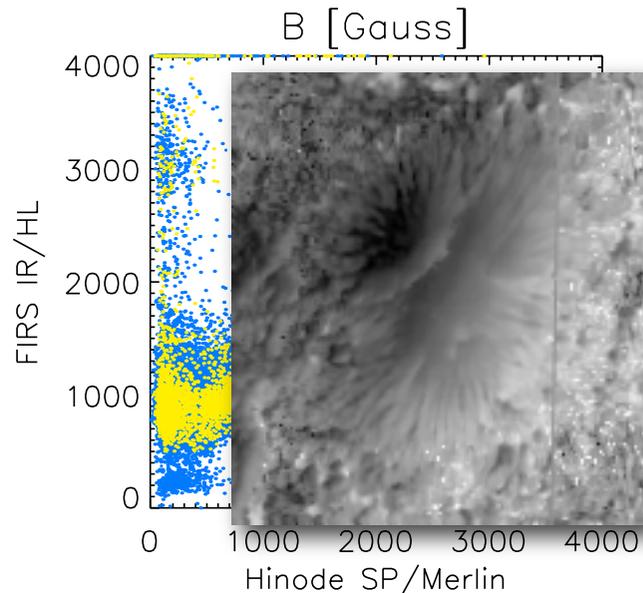
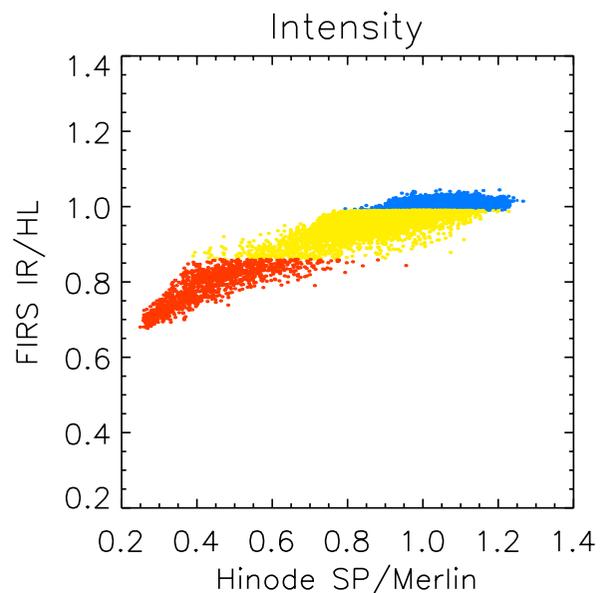
Results: FIRS 1565/HL vs. Hinode 630/Merlin



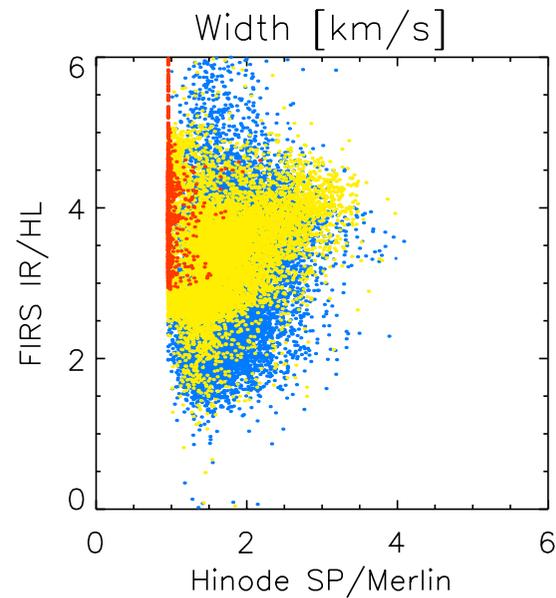
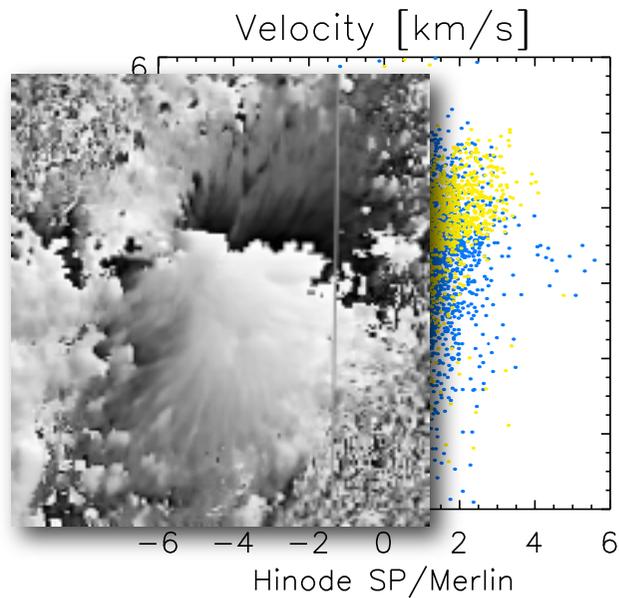
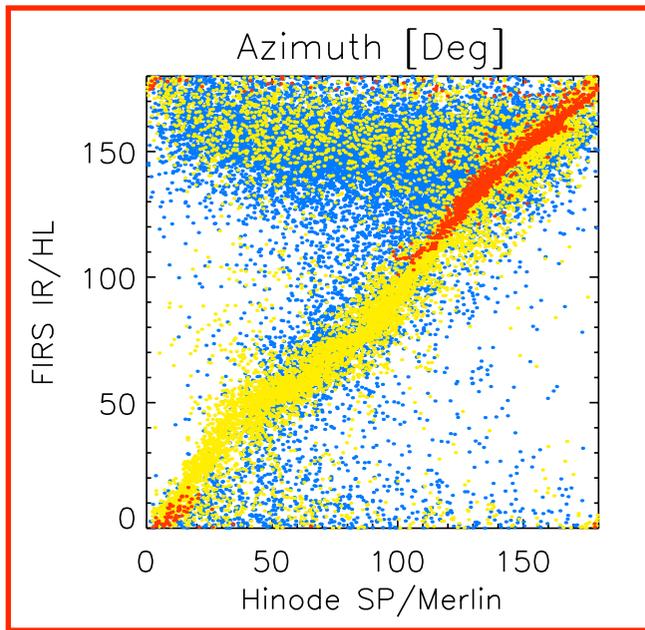
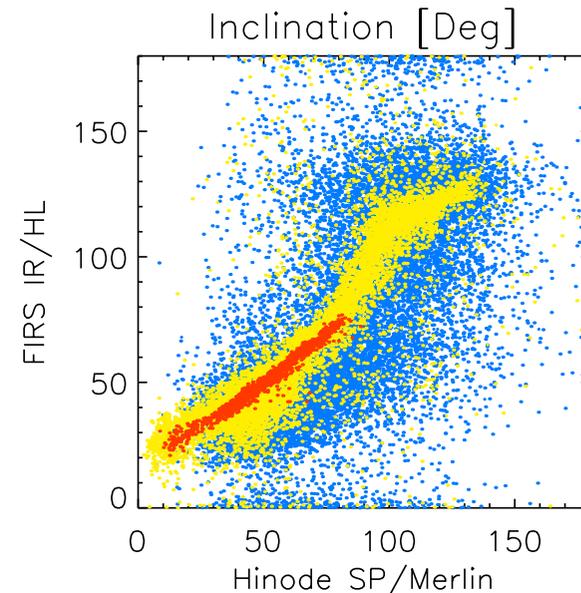
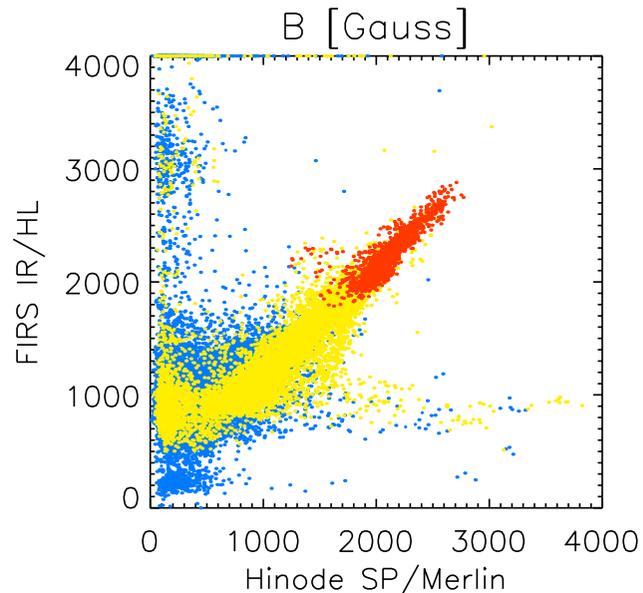
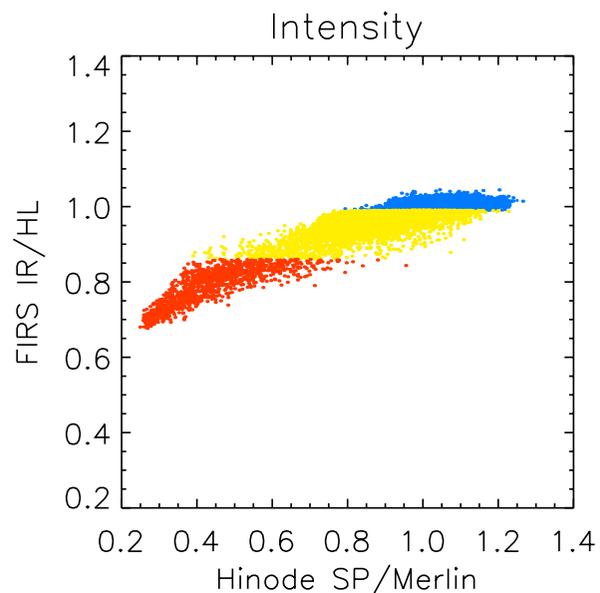
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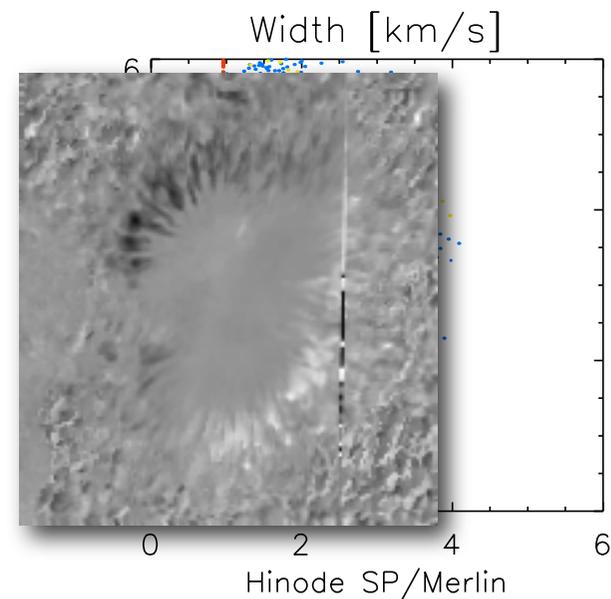
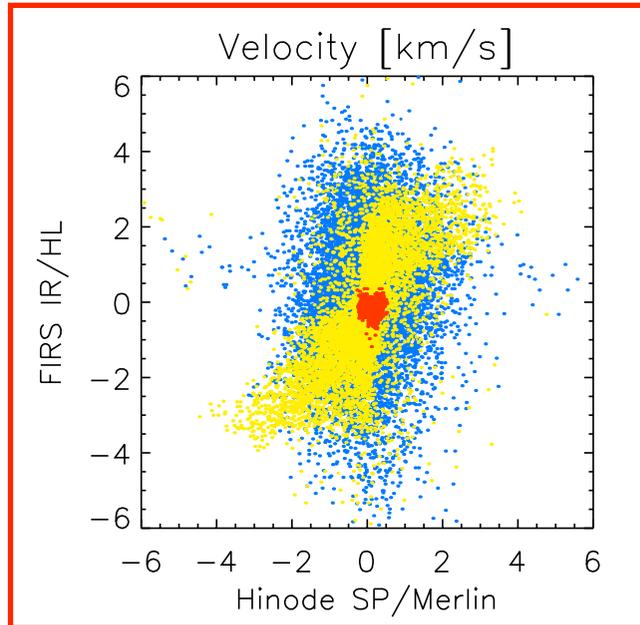
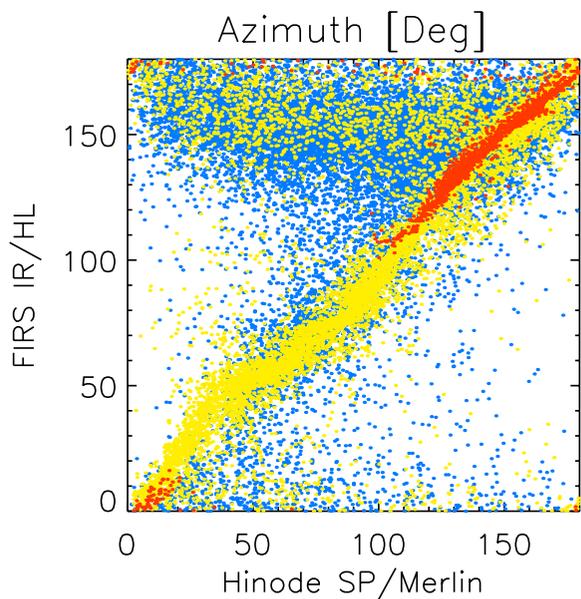
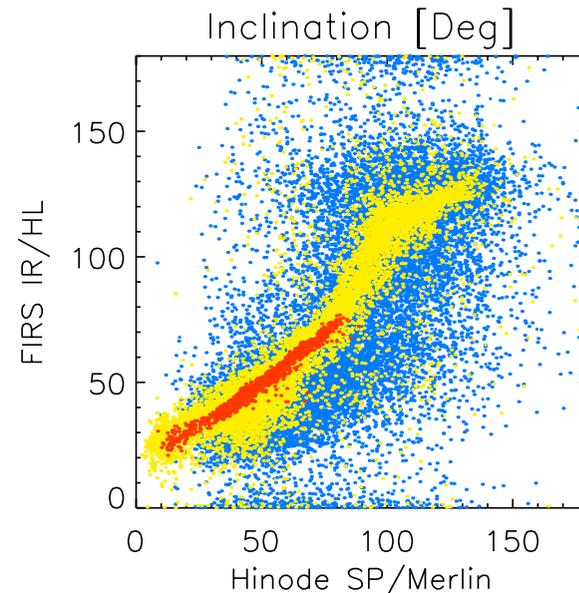
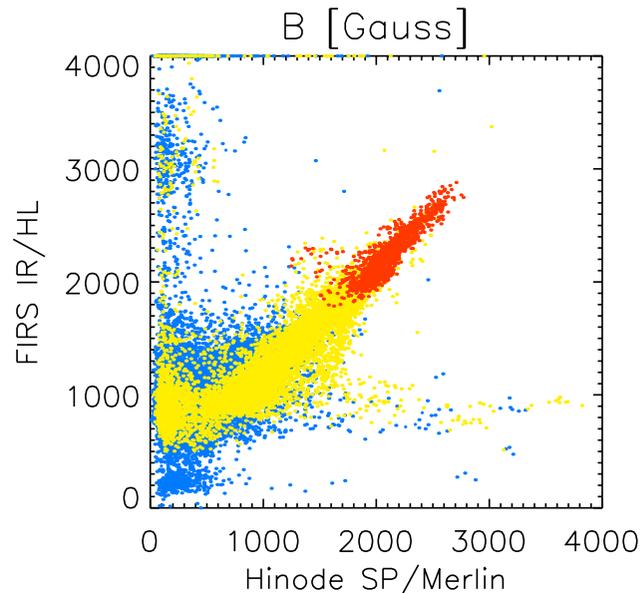
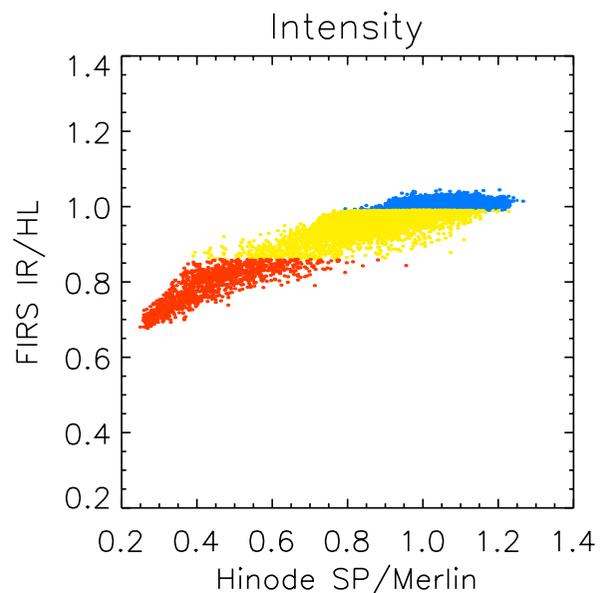
Results: FIRS 1565/HL vs. Hinode 630/Merlin



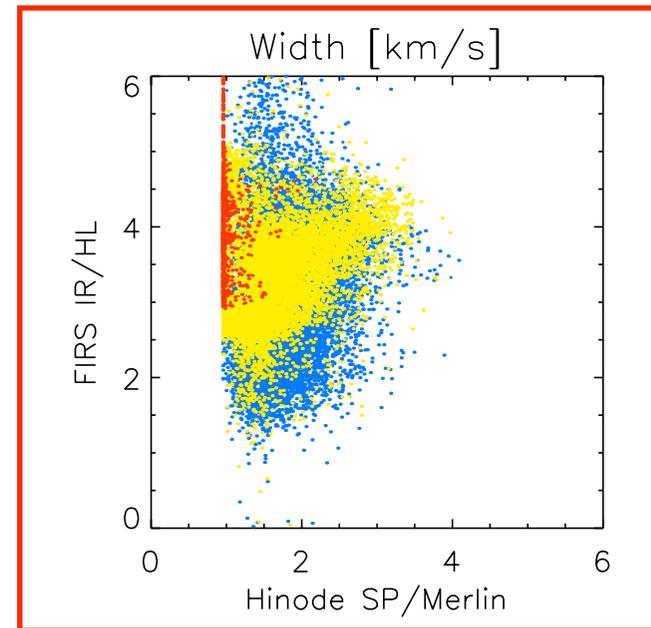
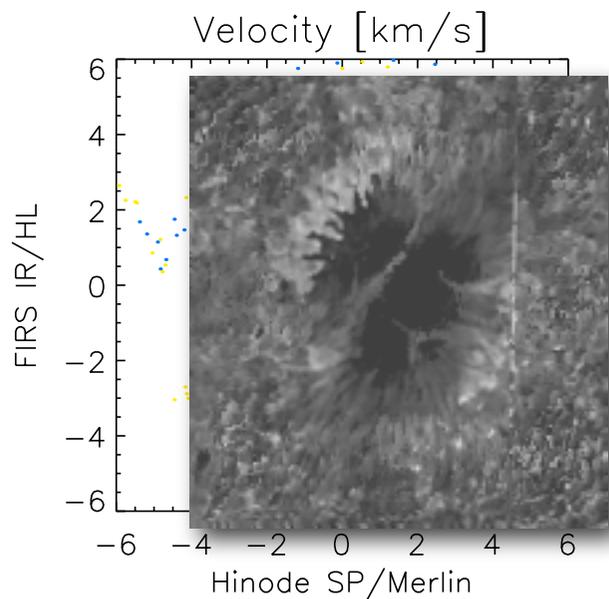
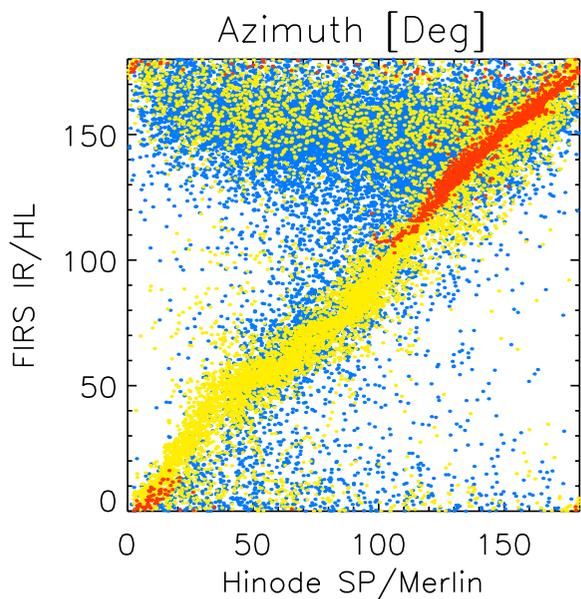
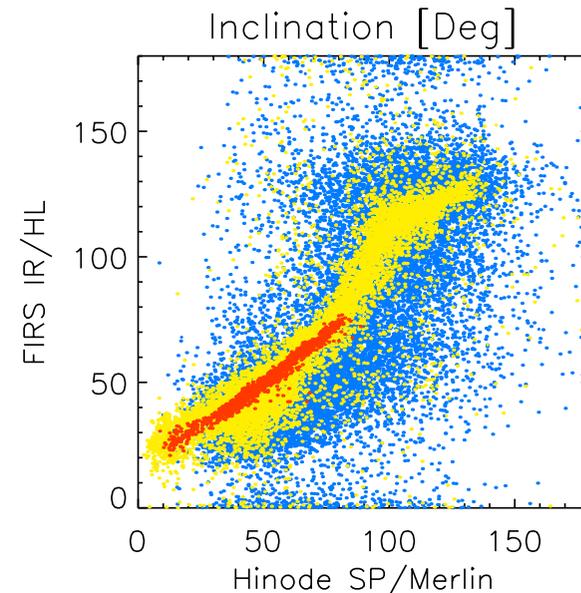
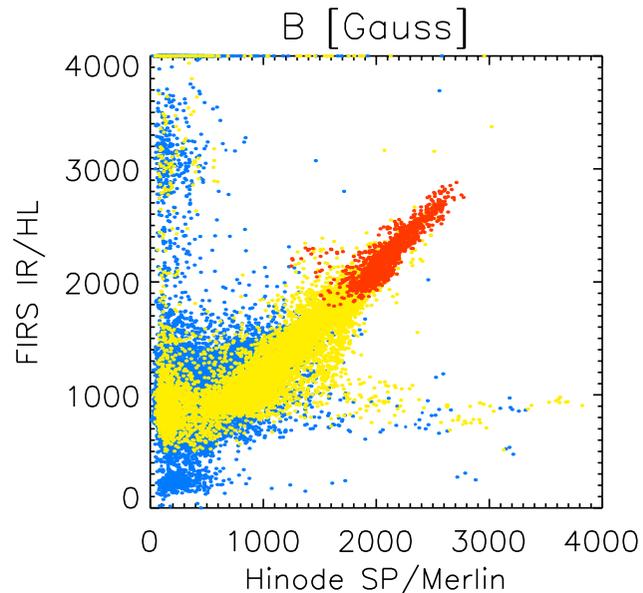
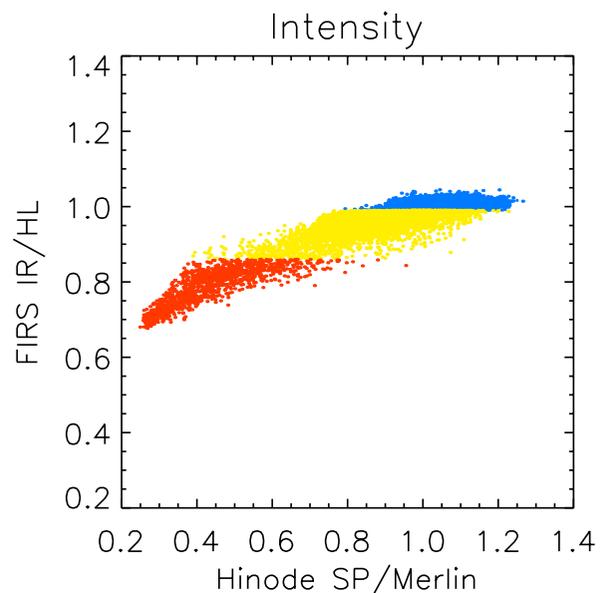
Results: FIRS 1565/HL vs. Hinode 630/Merlin



Results: FIRS 1565/HL vs. Hinode 630/Merlin



Results: FIRS 1565/HL vs. Hinode 630/Merlin



Summary

FIRS works! Let's use it!

What to do next:

- Quantify data quality differences between FIRS and Hinode Fe I 630
- Resolve inversion technique differences between Merlin and HL's code

