Stokes Profile Inversion and Comparison to Full-Resolution Data

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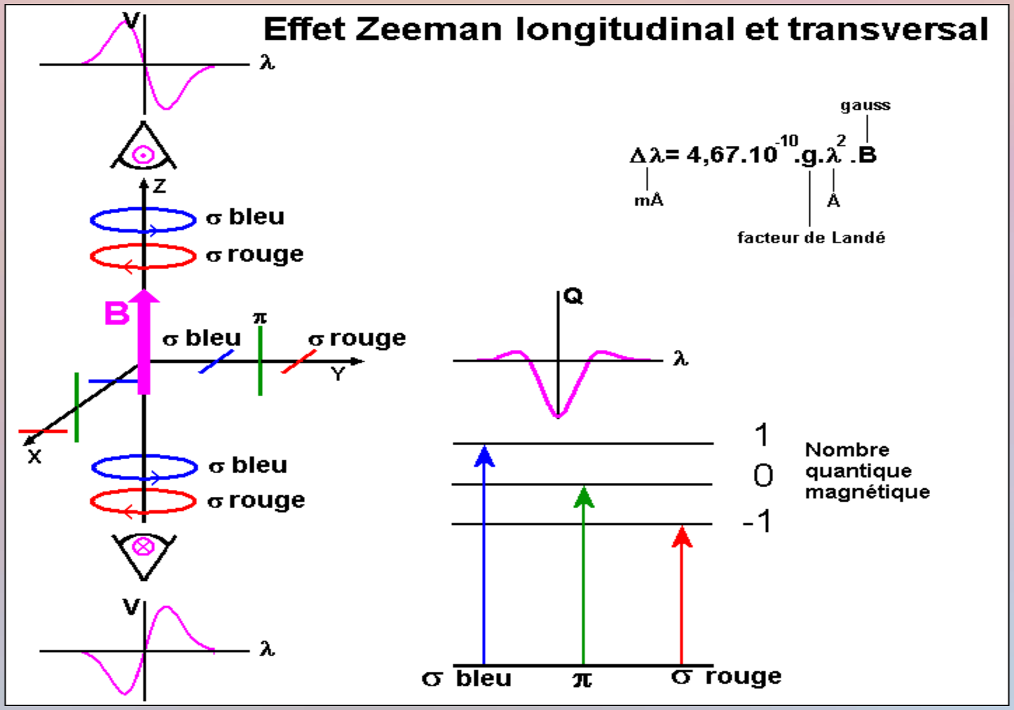
Solar Magnetic Fields

- Magnetic field strength and orientation are great descriptors and predictors of present and future space weather. Magnetism is the cause of most of the currently unpredictable phenomena in the sun.
  - Flares and CME's, for instance, are caused by subsurface magnetic fields escaping the plasma under the photosphere. These then affect our life here on Earth.
- These elements of the magnetic field vector are most readily obtained from what they do to the light emitted from the Sun.

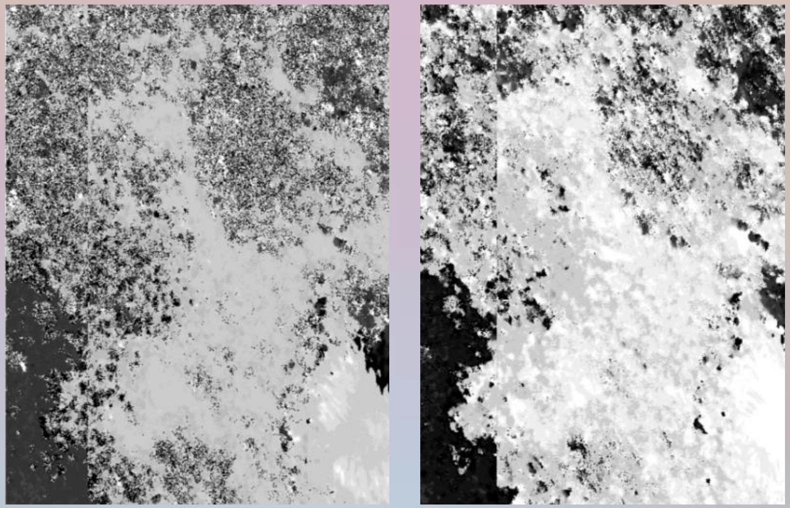
The Zeeman Effect

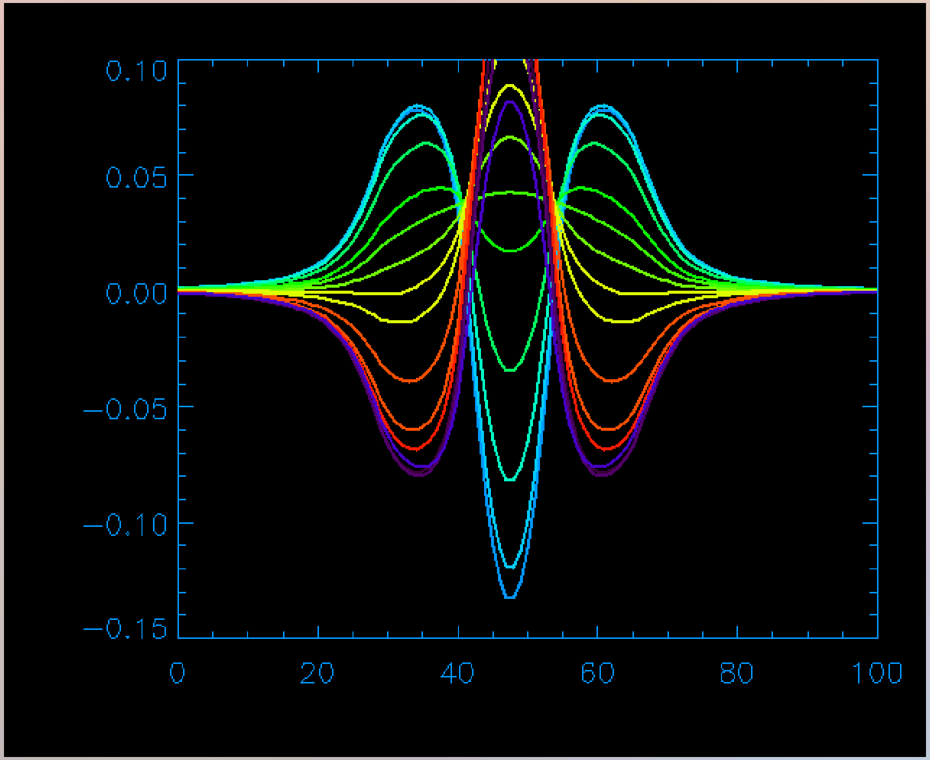
- Magnetic fields affect light most drastically in terms of the Zeeman Effect.
- The Zeeman Effect makes new energy levels to electrons due to the introduction of nonzero magnetic quantum numbers, organizing the light along the way.
- The Zeeman Effect appears most apparently in terms of intensity, but also emerges in terms of polarization.



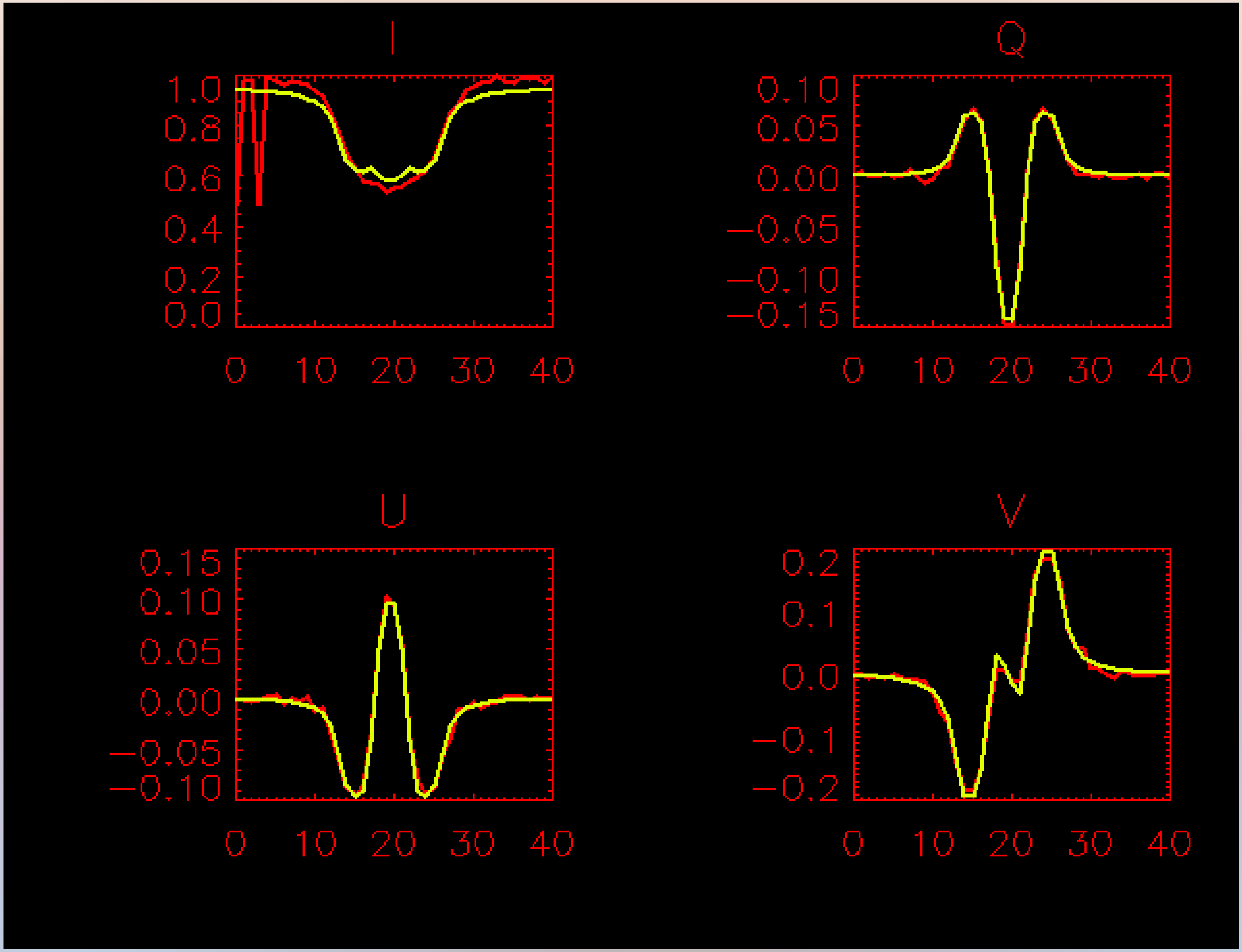
Stokes Profiles

- Depending on the orientation of the magnetic field vector, light is polarized differently in the Stokes profiles, the intensity I, the linear polarizations Q and U, and the circular polarization V.





Stokes Profiles: An Example



Inversion

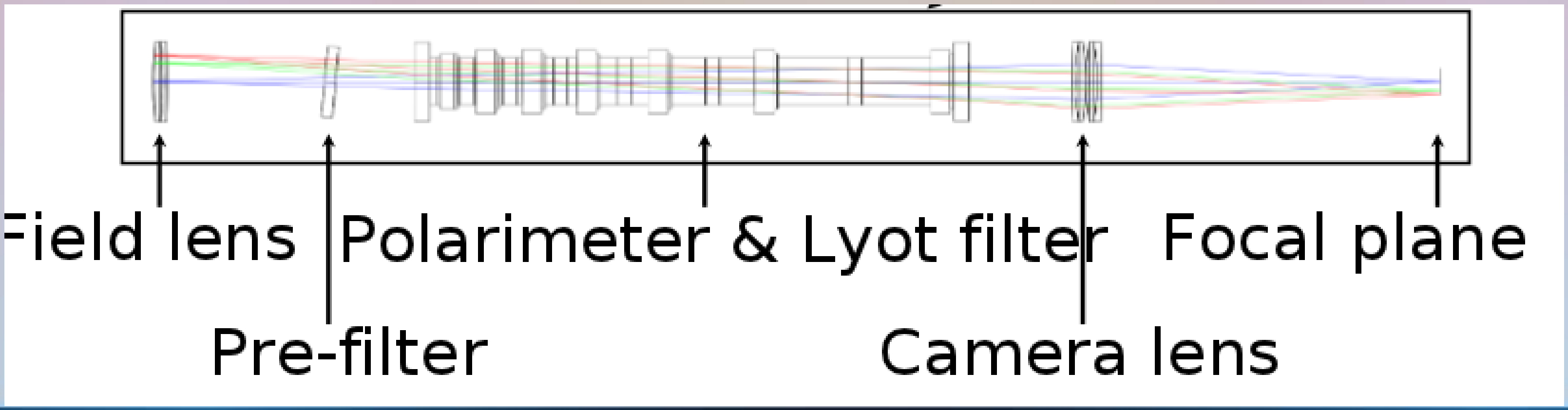
- Stokes profiles are translated into atmospheric parameters through a fitting process called inversion.
  - Milne-Eddington parameters
- The basic premise of inversion is a best-fitting process of a synthesized line to the observed line, called the forward process.
  - This also implies the reverse process of synthesizing lines given Milne-Eddington parameters
  - Constrained by symmetric solutions

HEXIC

- Can work for any spectral line, given the quantum numbers.
  - But examines only one spectral line at a time.
- Both spectrograph and filtergraph options
  - Filters with a relatively wide band are used together to create images of the field of view at different wavelengths, which are then used to recreate the spectra.
- An iterative process beginning with a guess, minimizing the chi-squared value.
  - But the question is when should we stop minimizing?

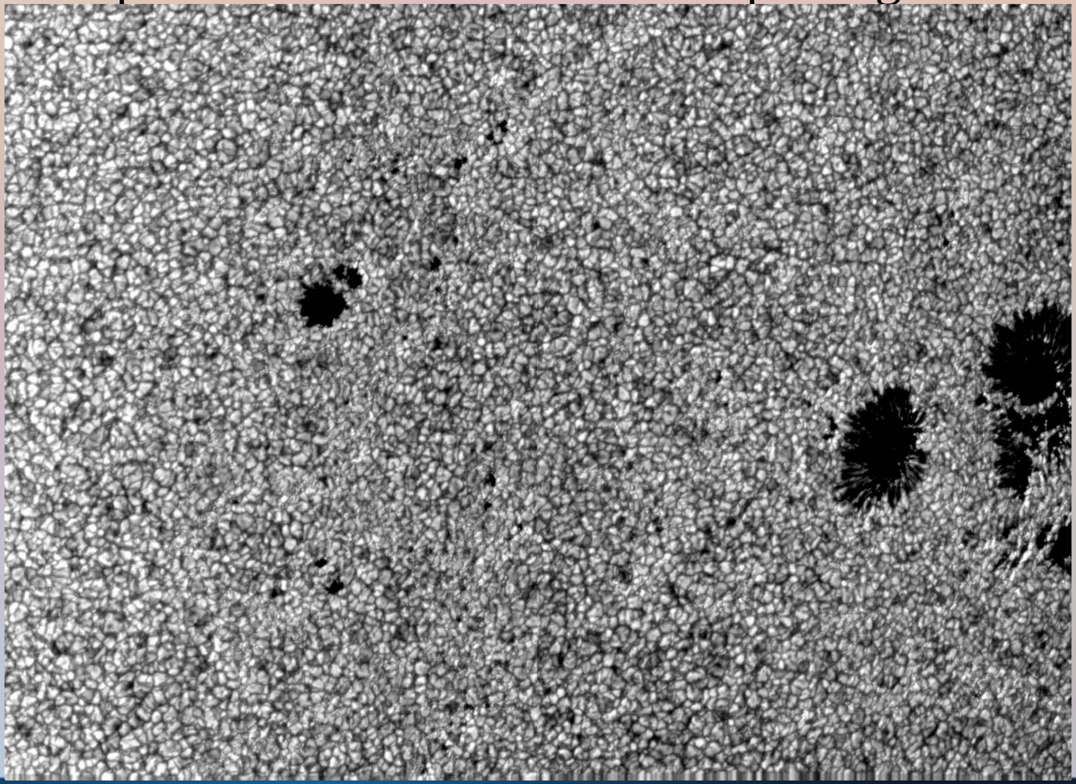
ChroMag

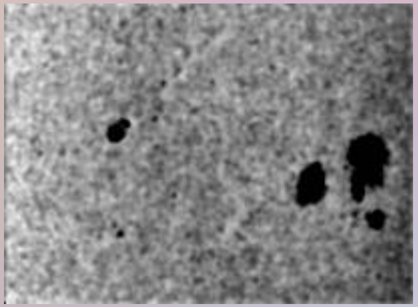
- The Chromosphere and Prominence Magnetometer (ChroMag) is a spectropolarimeter being developed at HAO. It will be able to scan through different levels of the solar atmosphere, examining the magnetic field throughout.
- 2.2” resolution in a full-disk mode
- It will record filter profiles that arise in the chromosphere and the photosphere, but it is not yet operational. This is faster than scanning through all wavelengths, resulting in images created on a shorter time scale.
- It is important to simulate data from ChroMag so that we know what it can detect and what it can't.



My Process

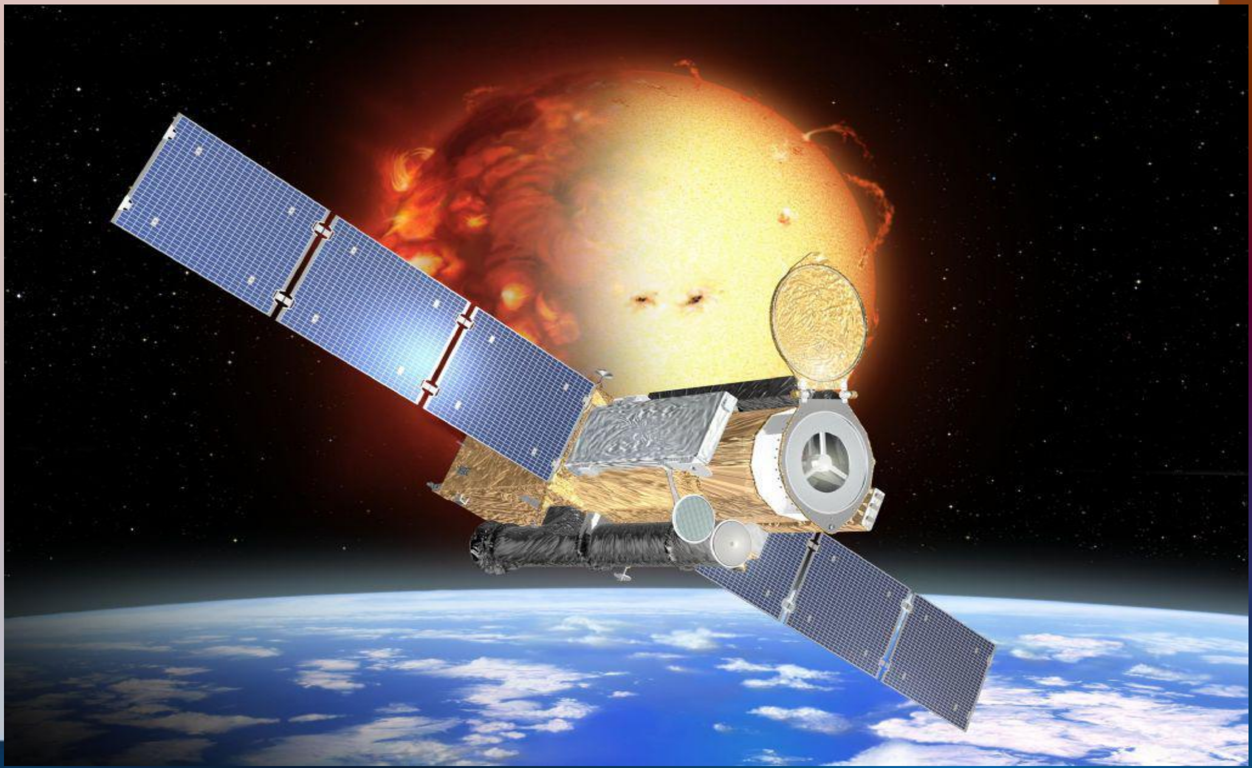
- Step 1: Degrade full-resolution data by smoothing and shrinking it.
- Step 2: Invert degraded data via spectrograph mode
- Step 3: Compare to smoothed, full-resolution inversions
- Step 4: Introduce filters and compare again.





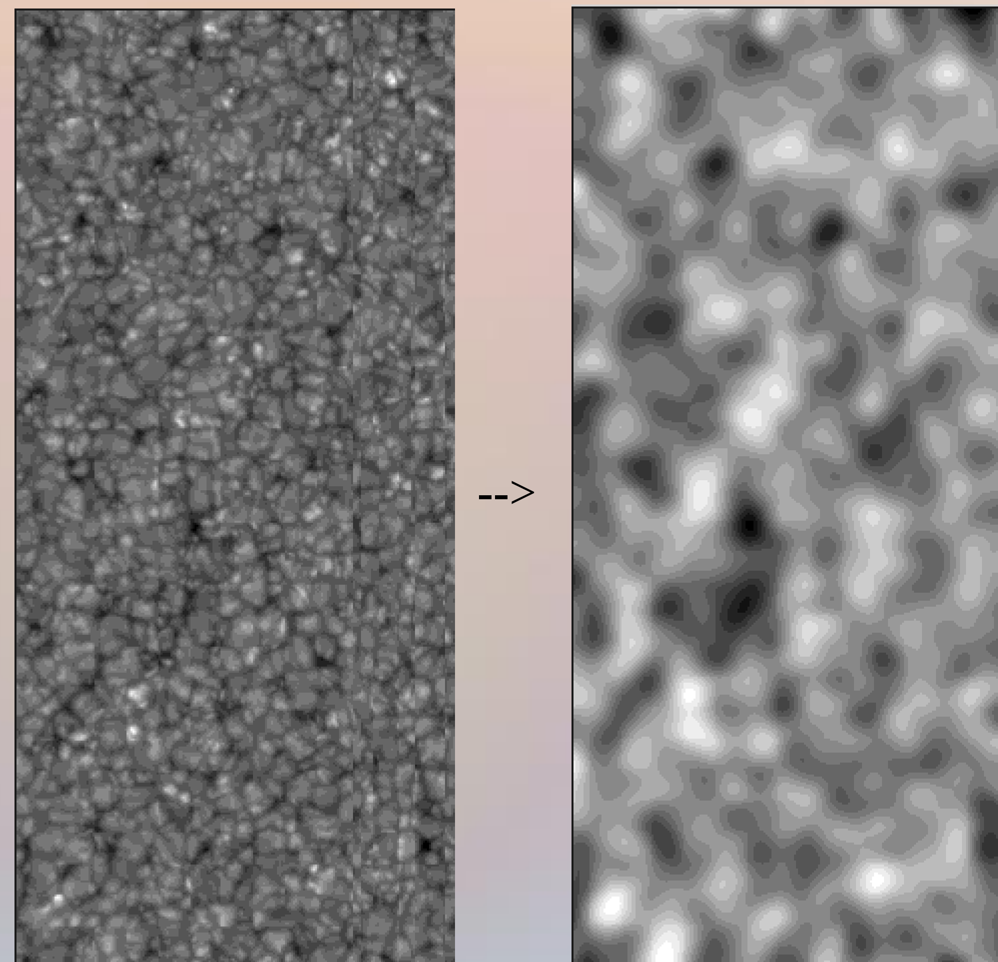
Step 1 : Hinode

- A joint JAXA/NASA mission with the "Solar Optical Telescope, X-ray Telescope and Extreme Ultraviolet Imaging Spectrometer."
  - On the SOT is a .16" pixel size scanning spectrometer, unlike ChroMag, which is an imaging spectrometer with a 1.1" pixel size.
- High-res, intricate, inverted data (Level 2) is readily available, as well as calibrated data (Level 1).
- Produces a full spectrum, unlike the filter system like ChroMag.



Step 1: Shrinking Method

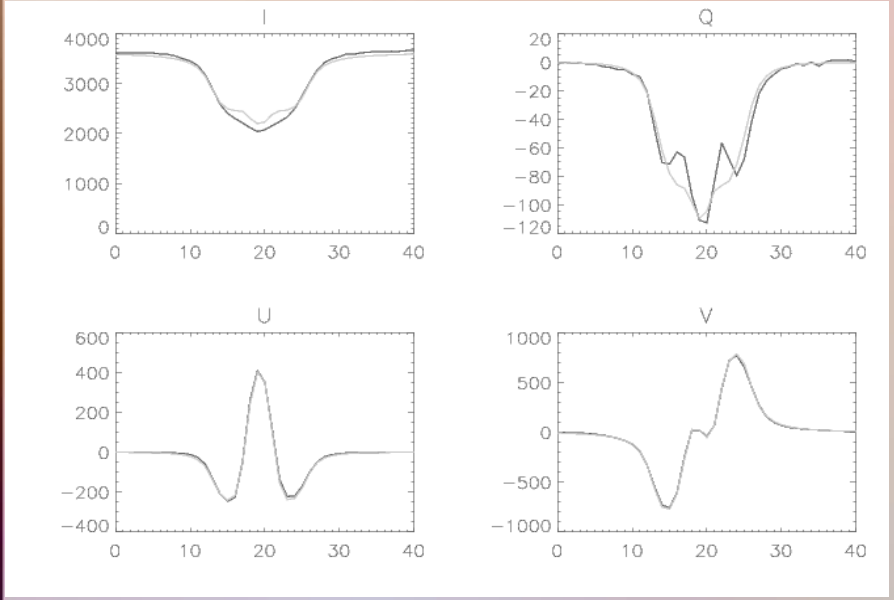
- Convolution with a Gaussian
- Nearest neighbor congrid



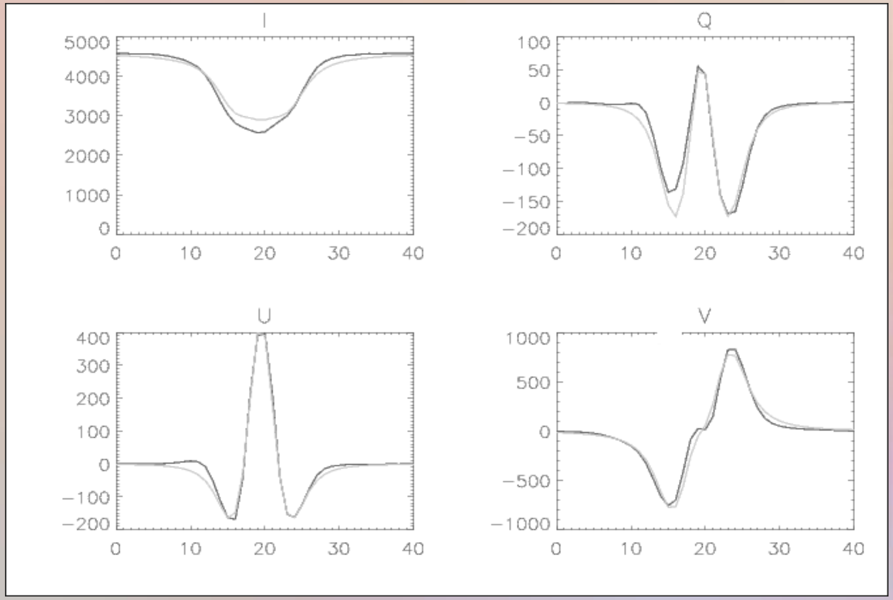
Step 2: Hinode Comparisons

- This is not a simple average. The smoothing operation includes information from outside the pixel area. The difference is most present in the azimuth.

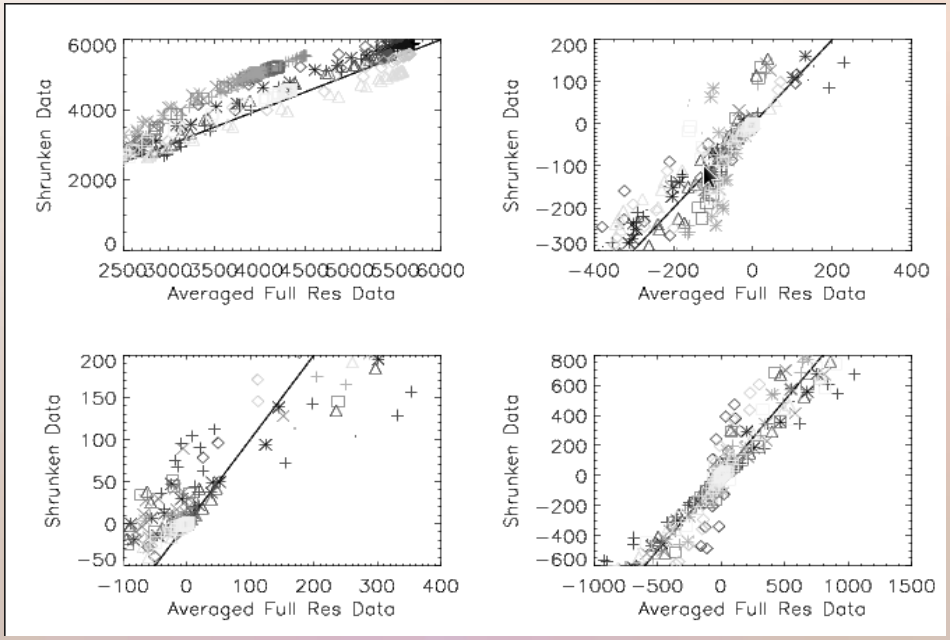
Averaged Level 1 Profiles



Degraded Profiles

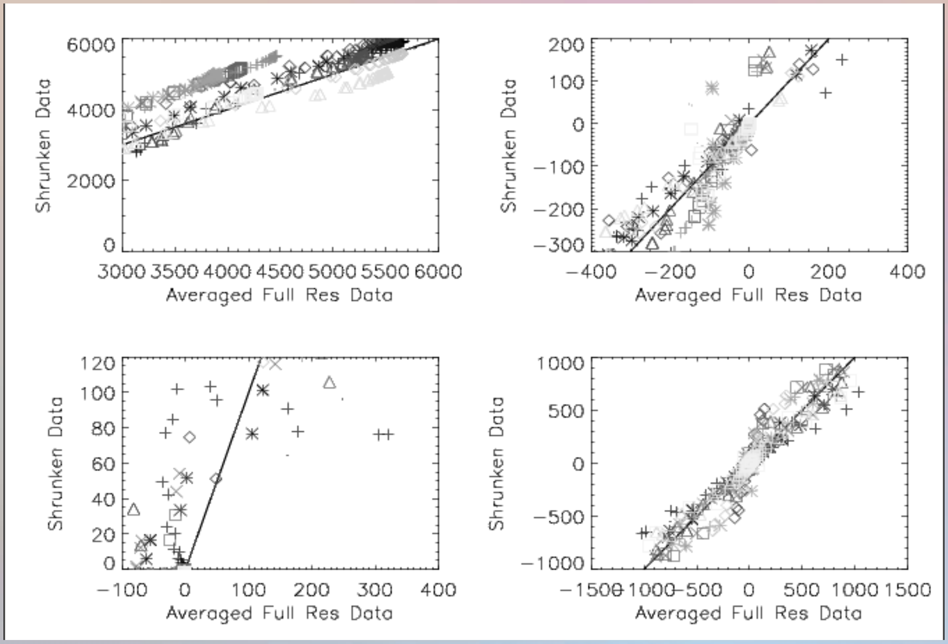


Step 2: More Hinode Comparisons



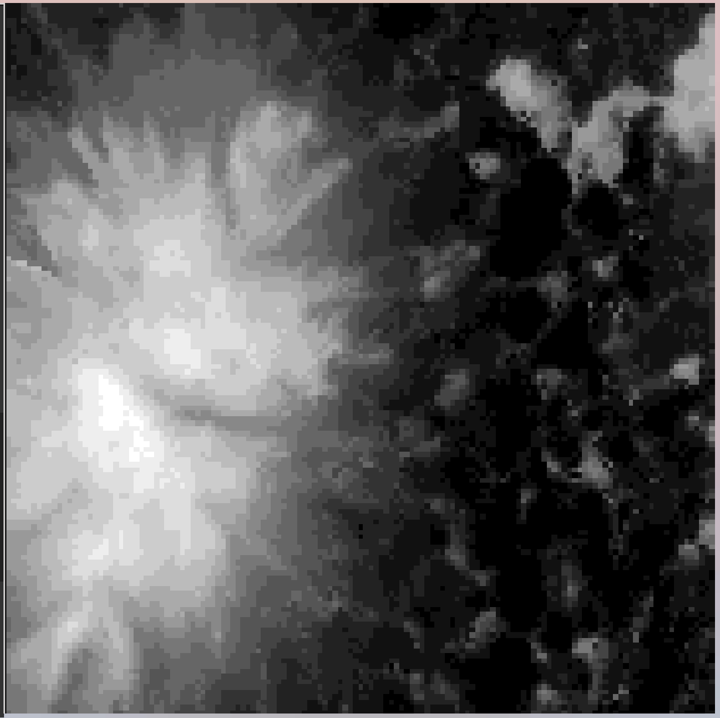
Synthesized Stokes Profiles

Observed Stokes Profiles

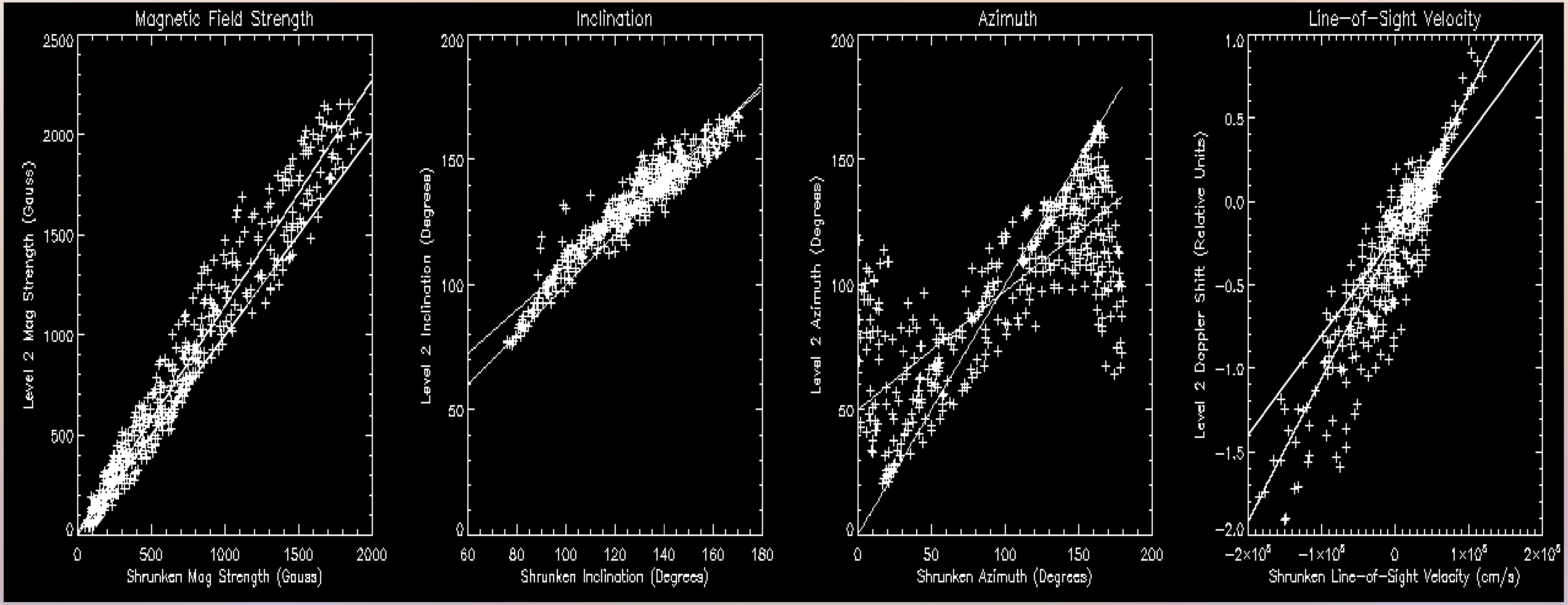


Step 3: Level 2 Hinode Data

- Hinode Level 2 data has already been inverted by examining both Fe I lines 6301.5 A and 6302.5 A.
  - Much more detailed than my inversion
- I smoothed and shrunk them to the same dimensions as the degraded data.



Step 3: Comparison to Level 2

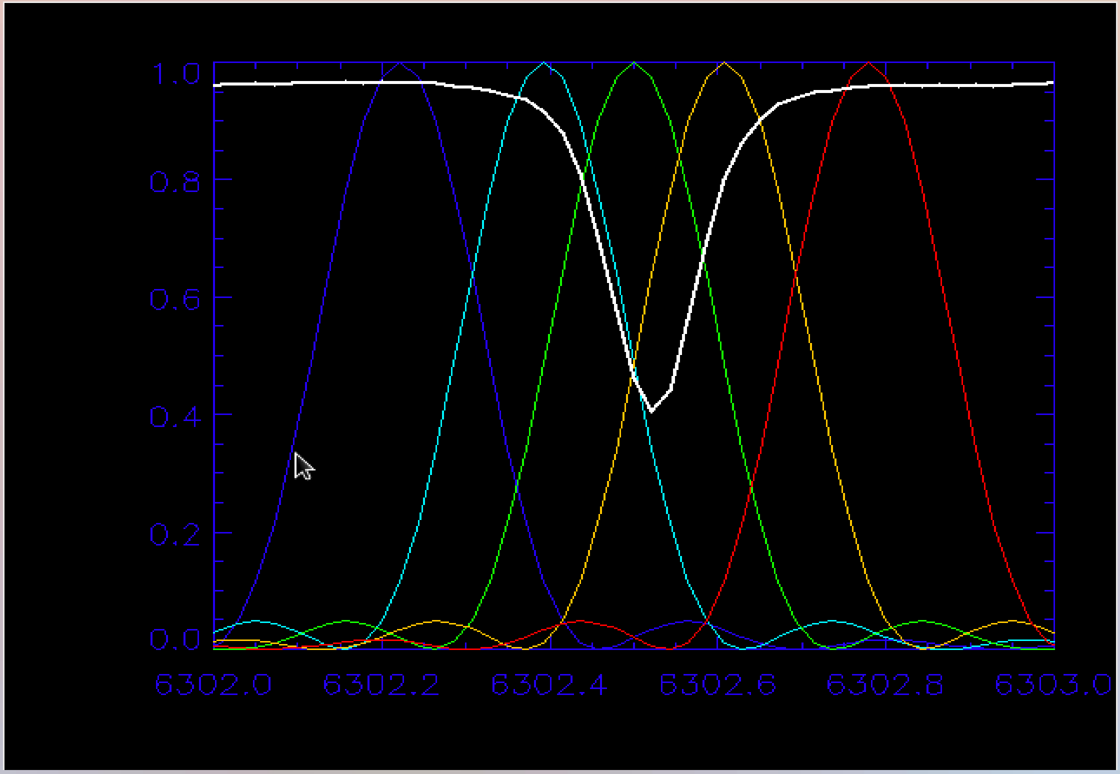


Pearson Coefficients

.9772 .9496 .7584 .9057

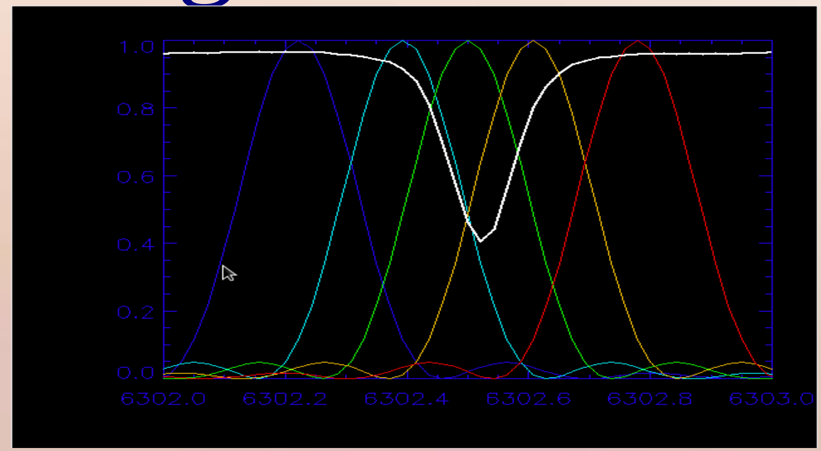
Step 4: Filtergraph

- The Lyot filter transmission is modeled five times and multiplied by the spectral line profile, similar to how it would be in ChroMag.
- At least three filter profiles are needed to find a solution for the eleven Milne-Eddington parameters.



Step 4: Filtergrams

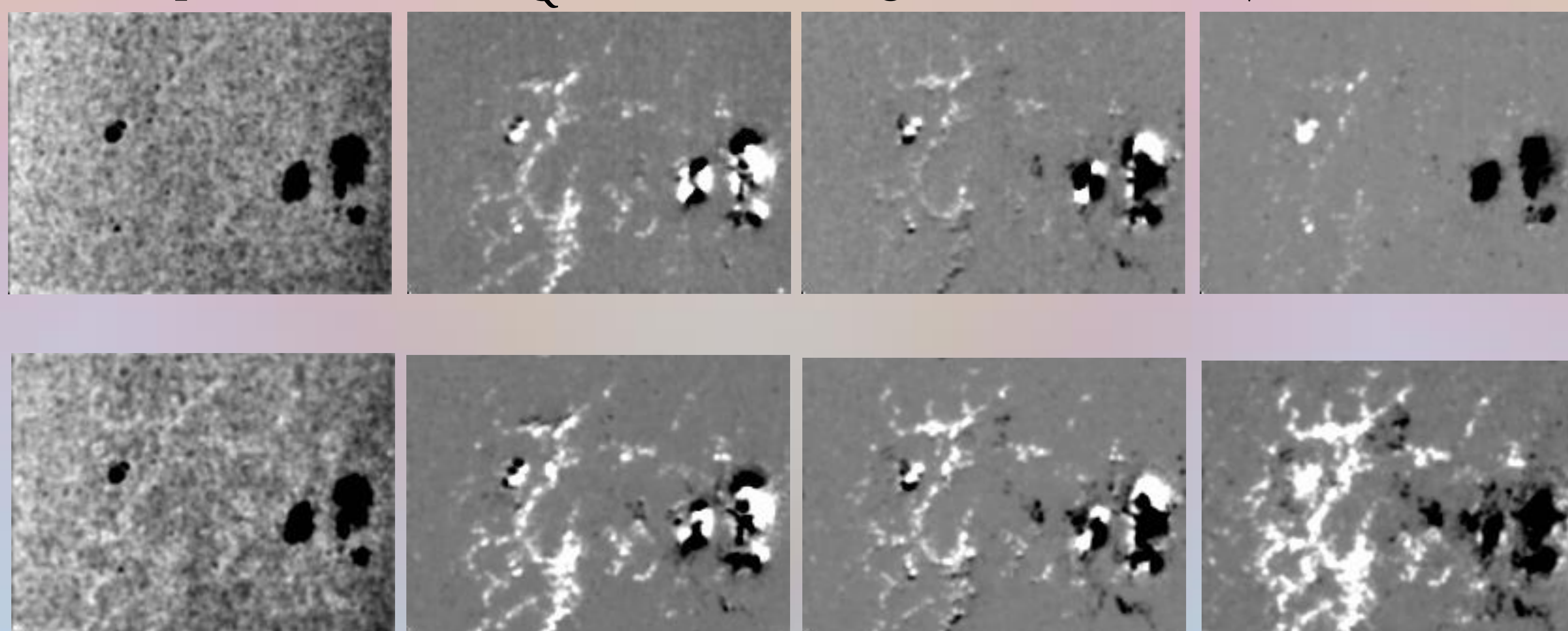
- Wing filters compared to core filters



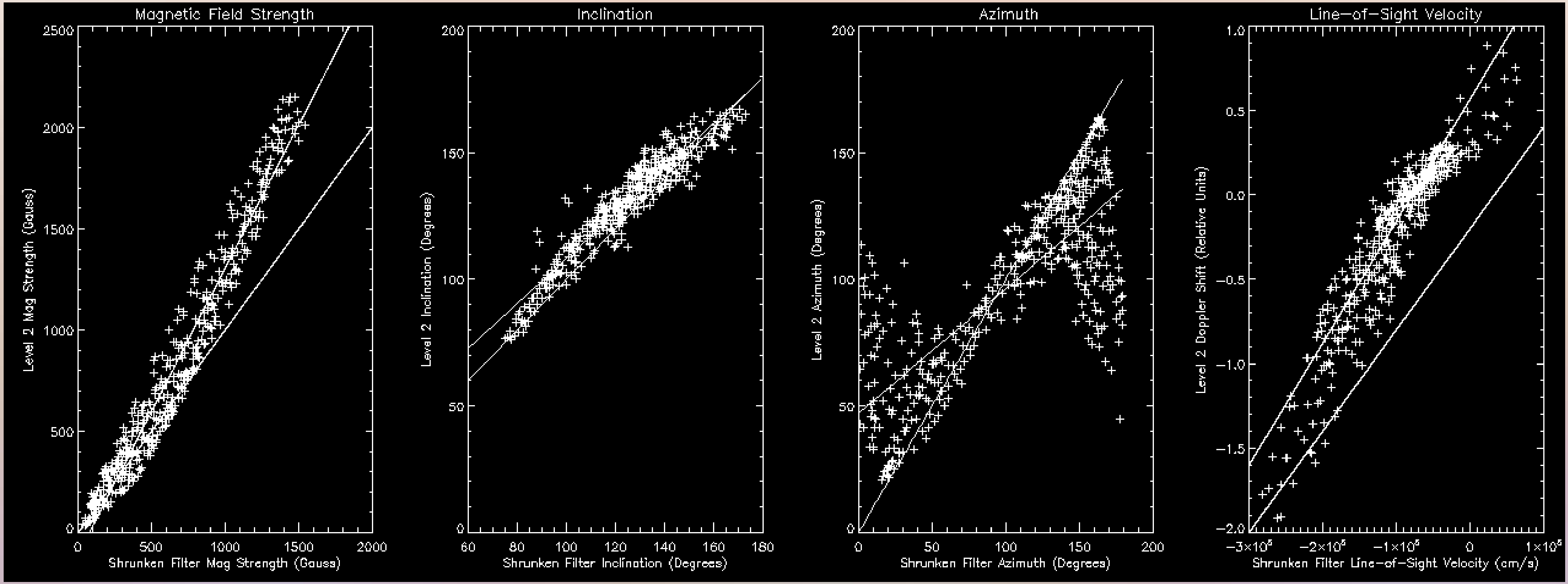
I Q U V

Wing

Core



Step 4: Comparison to Level 2



Pearson Coefficients

.9759	.9465	.7742	.9297

Results

- We have good linear correlation between the higher resolution, fully inverted Hinode data and our simulated, smoothed ChroMag data in terms of field strength, inclination, and line-of-sight velocity.
- The method of smoothing to create low-res data mixes the line profiles in areas larger than the pixel. In areas of low magnetic field strength, the Q and U profiles are difficult to resolve, resulting in a lack of correspondence between the degraded data and the smoothed Level 2 data. This results in the badly correlating azimuth values.
- Of course, granular features cannot be recognized with ChroMag's 2.2” resolution, but trends of magnetic field and Stokes profiles on a ~3 grain scale can be seen.

Conclusion

ChroMag will not be able to detect much on the scale of granulation, but magnetic field vectors are well reproduced on a 1.1” pixel scale. ChroMag will create a weighted average of those subresolution phenomena.

HEXIC works as an accurate inversion code, even if some scaling factors need to be considered. In the future, stray light components need to be added into the calculation of the magnetic field strength. Overall, though, the only important Milne-Eddington parameter that is distorted beyond use is the azimuth, though areas with strong, coherent magnetic fields like sunspots could yield valuable azimuth data. Otherwise, Q and U are indistinguishable from noise and therefore yield random azimuth values.

THE FUTURE!

- We weren't able to include all factors that we wanted to in the degradation.
  - What we have done is a best case scenario.
- We will add noise to the degradation in the future.
- We will also add uncertainty in the filter profiles.

Acknowledgements

- Alfred de Wijn, Rebeca Centeno Elliott, Codie Gladney, Marty Snow, Erin Wood, HAO, LASP, CU Boulder