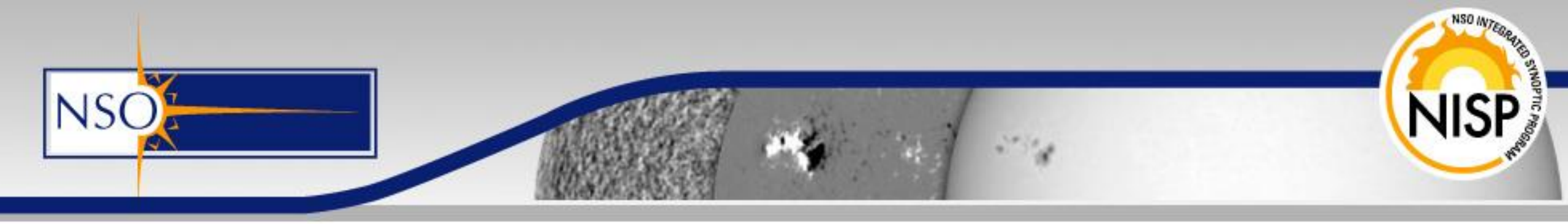


Structure of Solar Magnetic Field in Solar Active Regions:

SOLIS/VSM Observations

Sanjay Gosain, Jack Harvey, Brian Harker, Andy Marble, Alexei Pevtsov, Valentin Martinez Pillet

+ SOLIS Team

National Solar Observatory

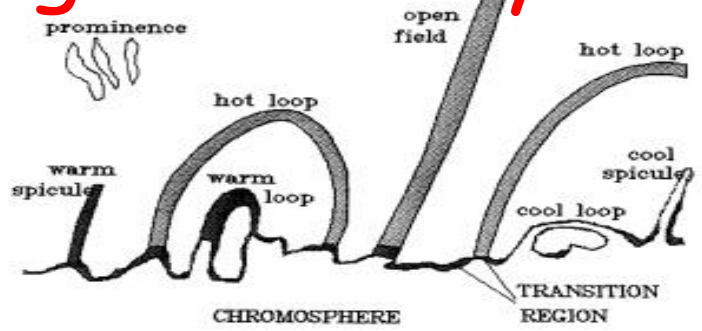
Boulder, CO

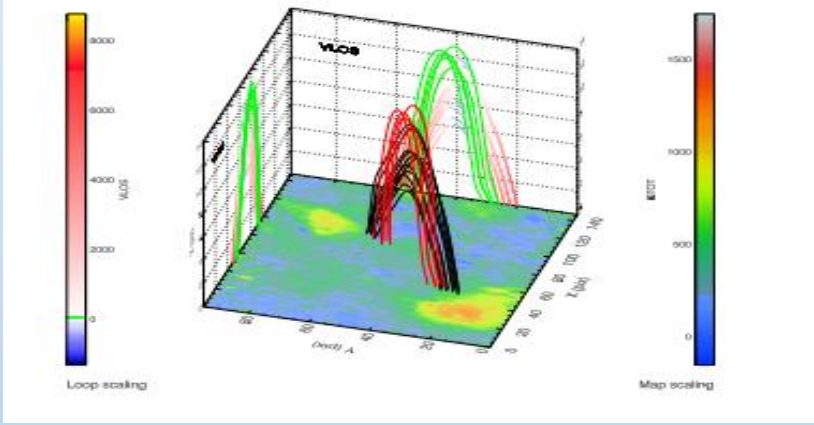
Outline of the presentation

- Brief introduction
- Advantages of Magnetic Field Measurements in the Chromosphere
- Some Results from SOLIS VSM
  -Longitudinal Field Measurements
- Recent Upgrade to Full Stokes Polarimetry
- Initial Full Stokes Results from SOLIS VSM
- NICOLE Inversions and Future plans

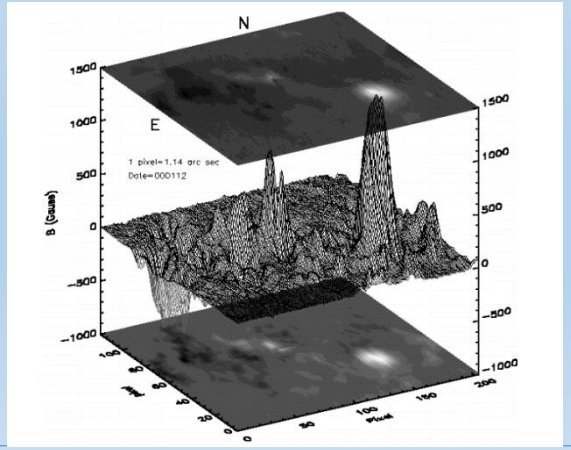
Advantages of Chromospheric Magnetometry

- Very important to understand connection between photosphere, chromosphere, interface region and corona.
- Proves an alternative and better boundary condition for force-free field extrapolations into the corona (Metcalf et al. 1995; Socas-Navarro, 2005).
- Gives us an extra layer to constrain 3-D magnetic structure of the solar magnetic fields from photosphere to corona (Wiegelmann et al. 2012; Choudhary et al. 2001).
- Could also be used to resolve 180 degree azimuth ambiguity (Crouch et al. 2009, 2015).
- Compute free energy and its evolution in solar active regions (Wheatland et al. 2005)





(Lagg, et al. 2005)



(Choudhary, et al. 2001)

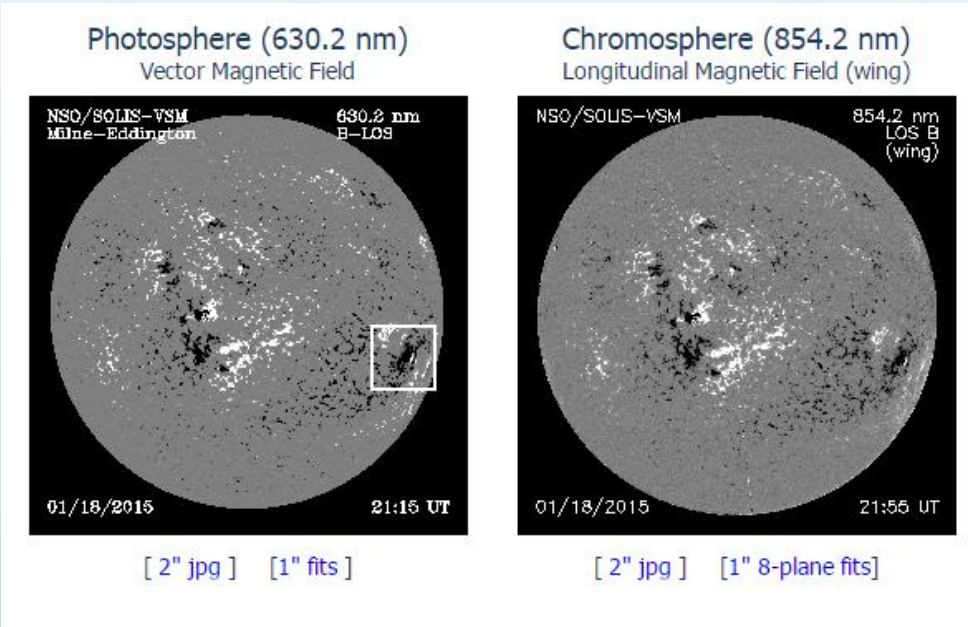
SOLIS-VSM: An Introduction

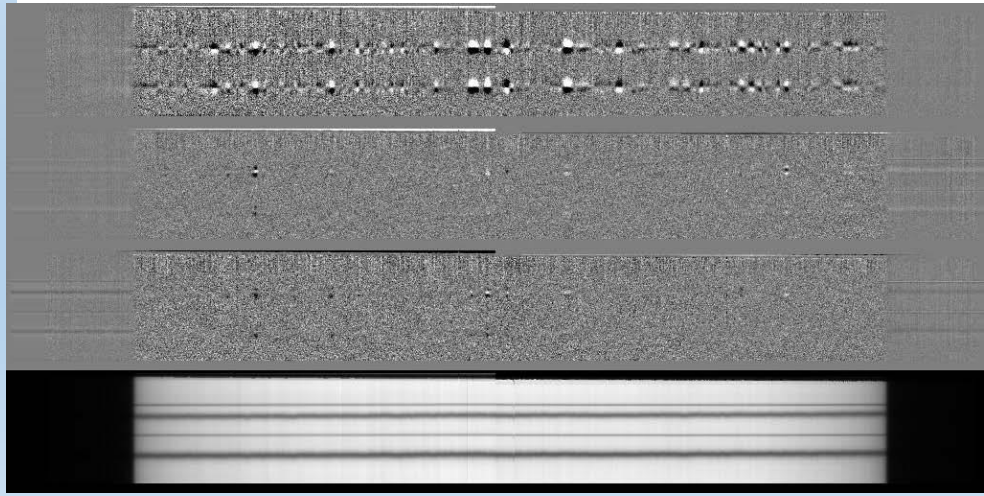
The Vector Spectromagnetograph (VSM) was designed for observing Zeeman-induced polarization signals in the spectral lines of photosphere and the chromosphere.

Keller et al. Proc. SPIE 4853, 194 (2003)

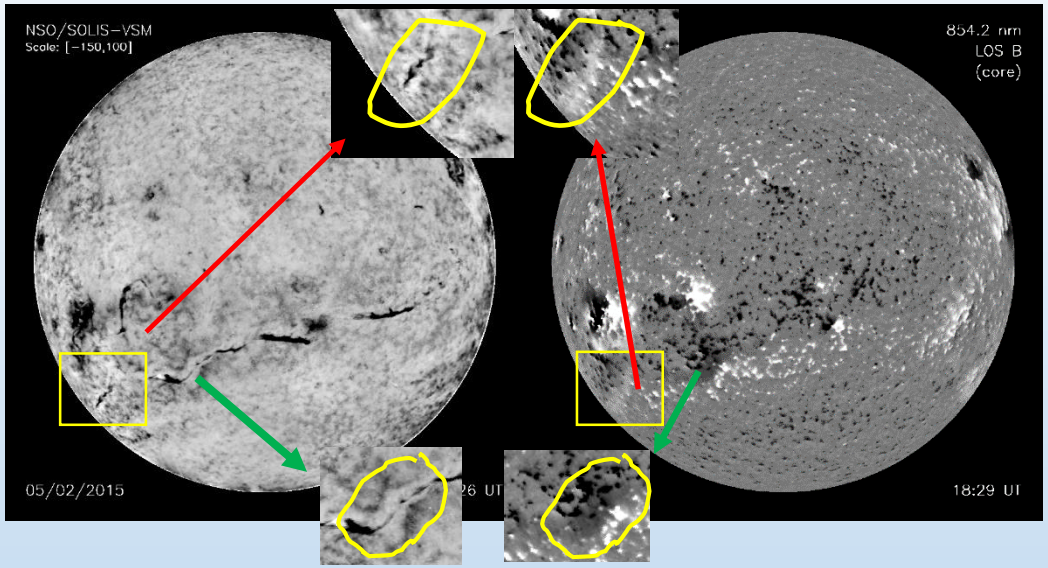
The VSM provides the following data products:

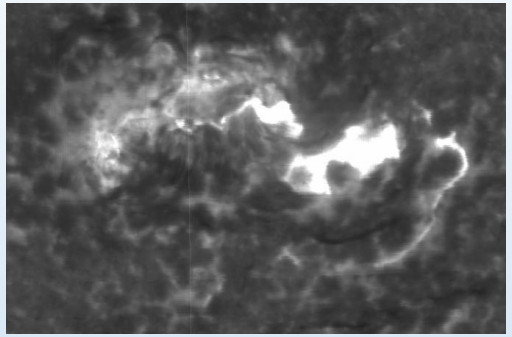
- Photospheric magnetograms :: LOS and Vector Fulldisk
- Chromospheric magnetograms :: LOS Fulldisk
- Chromospheric:: Full Stokes Vector Spectro-Polarimetry Fulldisk

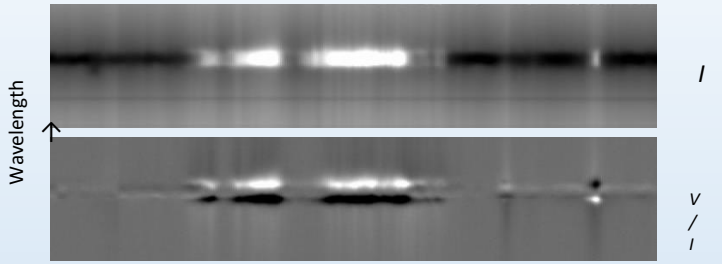




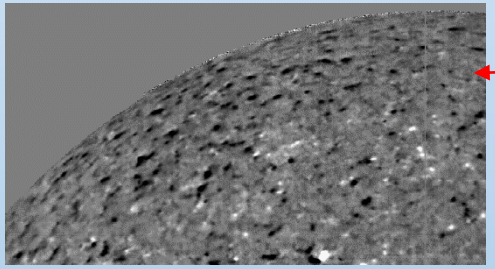
Results from Longitudinal Chromospheric Magnetograms



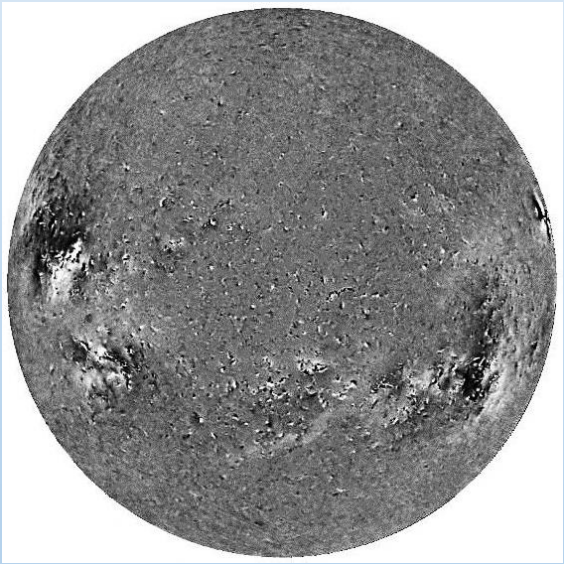




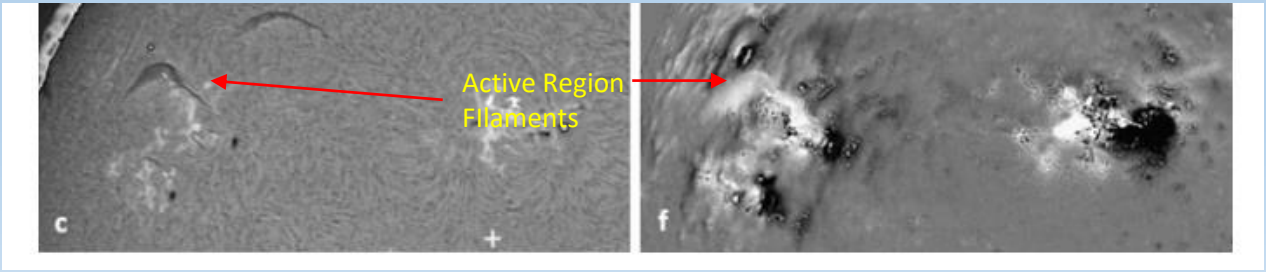
Position along slit
↔



Polar Fields Better seen
in chromosphere

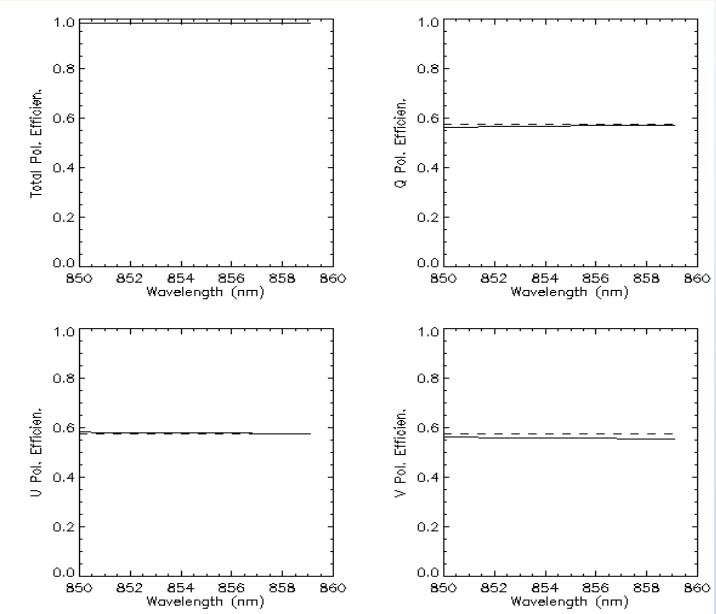


Chromosphere – Photosphere (B_{los})

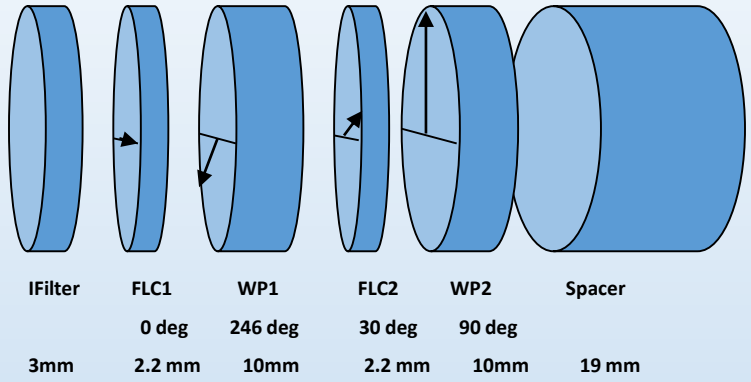


Full Stokes vector measurements in chromospheric line Ca 8542

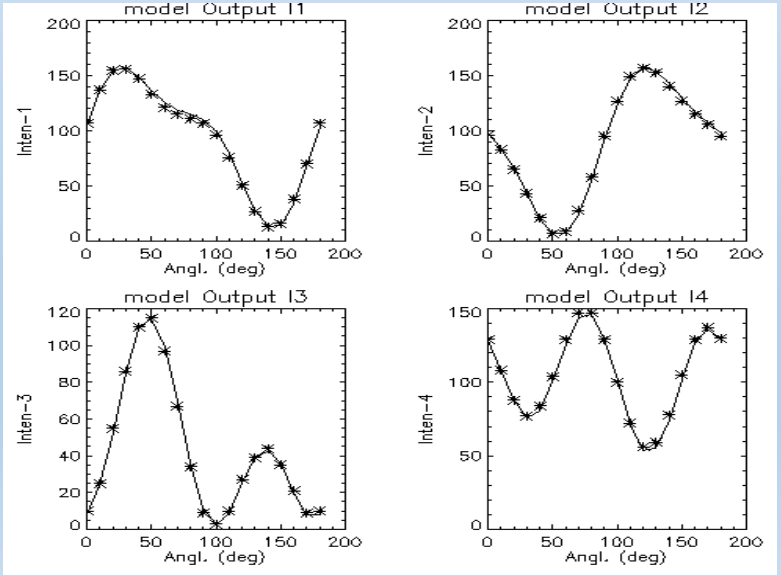
Modulator Design



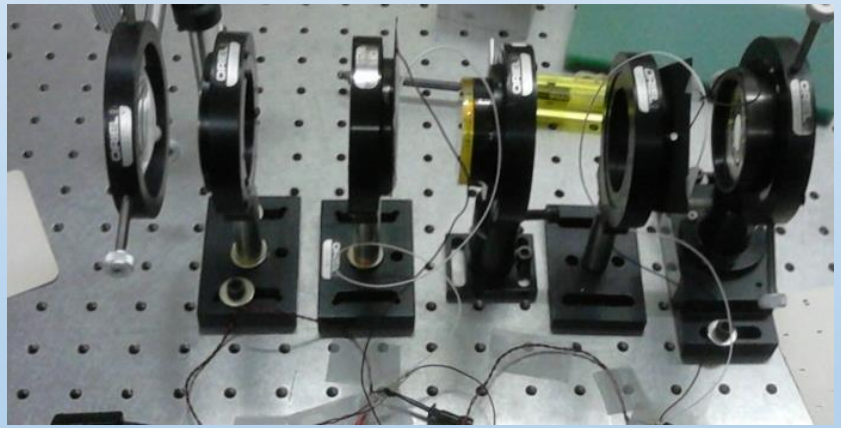
Optimum polarimetric efficiency (~ 0.57 for Q,U,V, as in J. Carlos del Toro Iniesta, 2007) can be achieved from the computed set of angles for FLC modulators and fixed retarders.



8542 Modulator Package Schematic



Measurement of the modulation signal (asterisks) for various known input polarization vectors, and a forward model fit from known angles and retardances (black line).

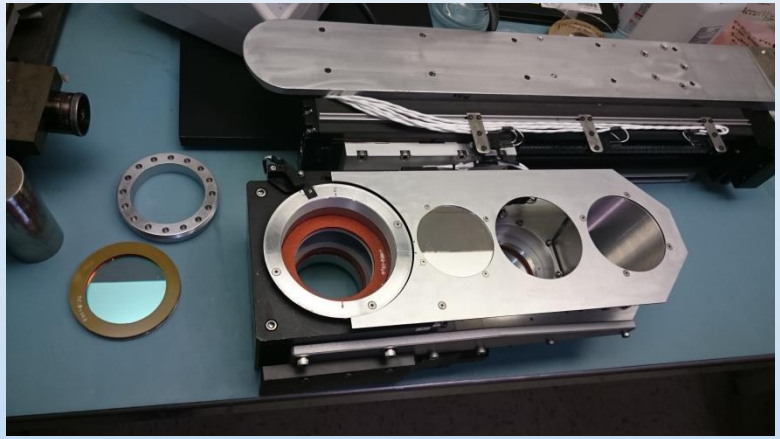


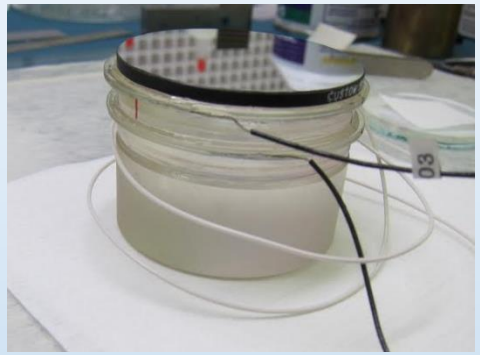
Laboratory testing of Modulator Package

Full Stokes vector measurements in chromospheric line Ca 8542

Modulator Assembly + Installation

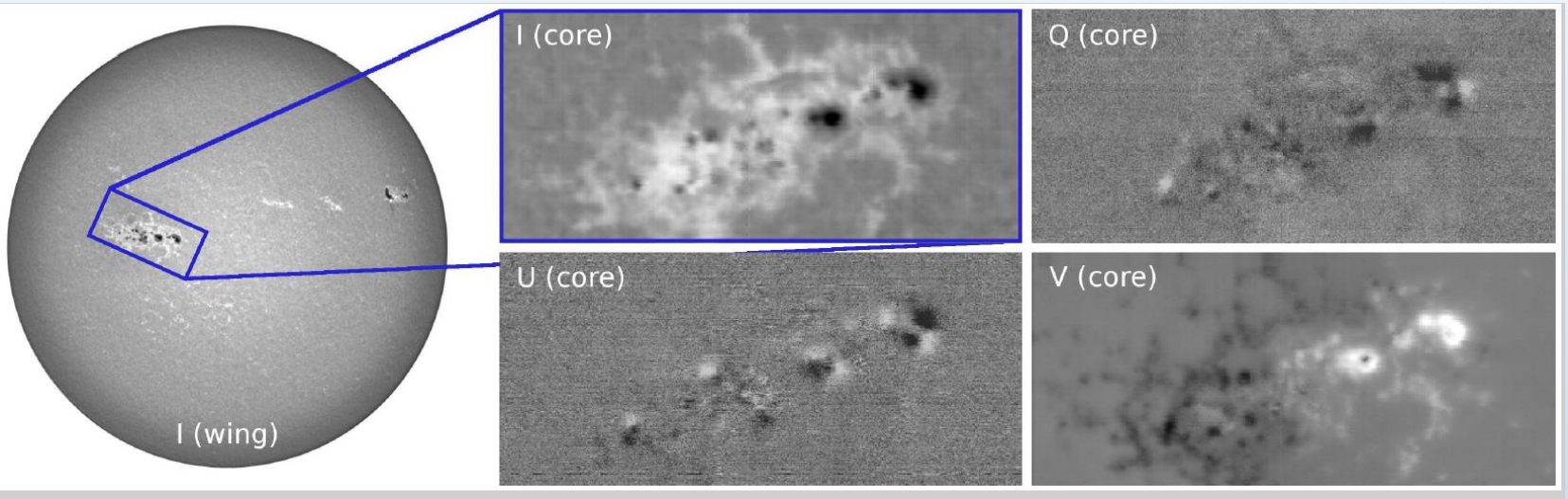
- Modulator package assembled as a stack with index matching compound.
- SOLIS/VSM was brought to lab. for installation of new modulator and calibration optics.
- Polarimeter Calibration unit was upgraded with dual passband prefilter for 8542 and 6302 lines.
- SOLIS/VSM is back to observing site
- Full Stokes Ca 8542 observations began in November 2015.



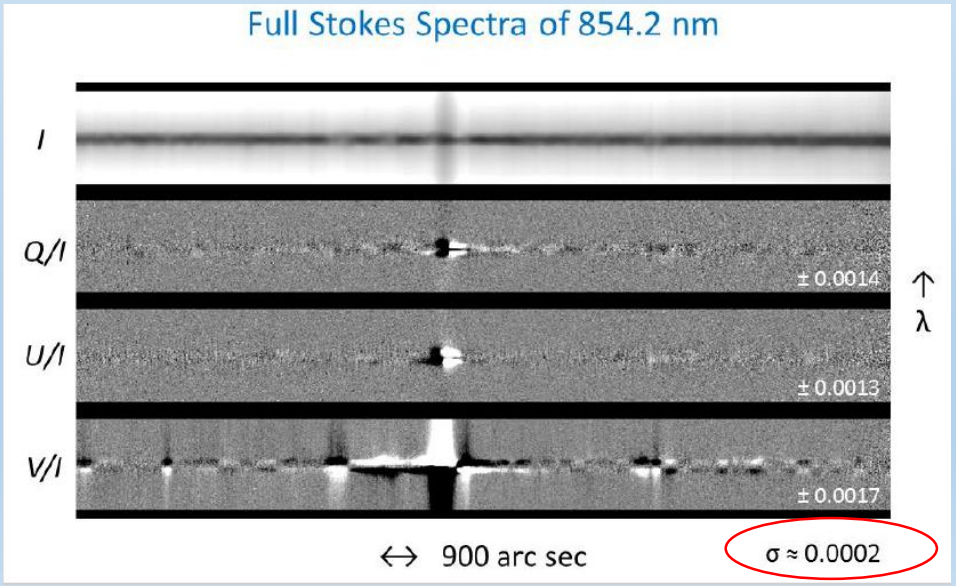


Full Stokes Observations in Ca II 854.2 nm

First Light Results



- Area scans of activity belts with SOLIS VSM
- Typical scan covering an active region , as shown on the left takes 5 minutes.



Solis VSM instrument parameters

Spectral Lines: Fe I 630.2 nm, Ca II 854.2 nm
Polarimetry: Stokes I, Q, U , V
Spatial Sampling: 1 arcsec/pixel
Field-of-view: Full disk
Cadence: 22/45 min. for fulldisk (photo./chromo.)
Active Region Mode: Typical AR scan in 3-5 minutes.
Spectral Dispersion: Ca II (35 mA/pix), Fe I (25 mA/pix)

Inference of Chromospheric Vector Field

An Open Source, Massively Parallel Code for Non-LTE Synthesis and Inversion of Spectral Lines and Zeeman-induced Stokes Profiles

H. Socas-Navarro[1,2], J. de la Cruz Rodríguez[3], A. Asensio Ramos[1,2], J. Trujillo Bueno[1,2,4], B. Ruiz Cobo[1,2]

For full treatment of Stokes profiles we use NLTE inversion code NICOLE.

(Socas-Navarro et al, 2015, A&A)

Spectropolarimetric capabilities of Ca II 8542 Å line

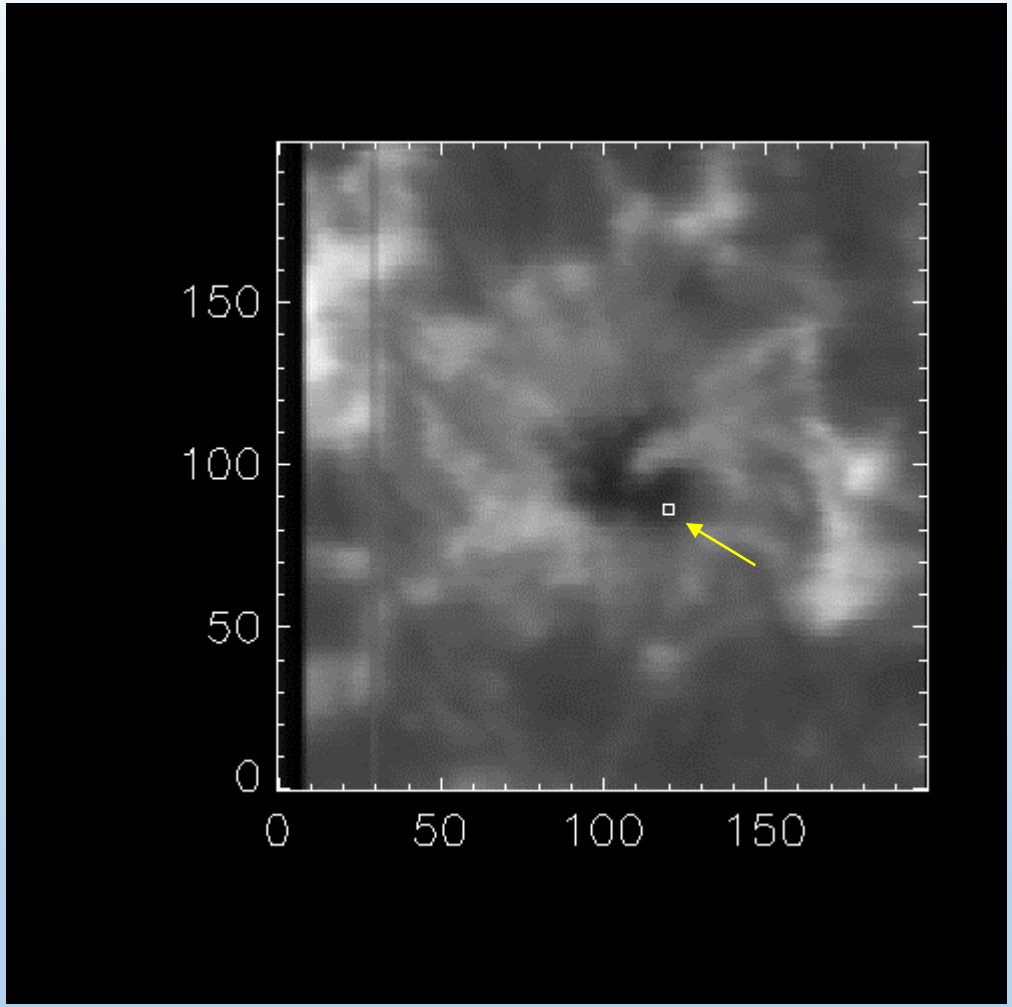
C. Quintero Noda,[1★] T. Shimizu,[1] J. de la Cruz Rodríguez,[2] Y. Katsukawa,[3] K. Ichimoto,[4] T. Anan[4] and Y. Suematsu[3]

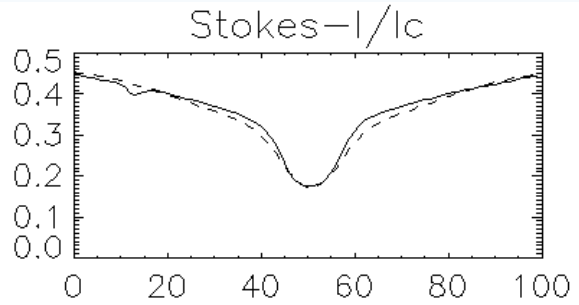
"Our results indicate that the Ca II 8542 Å line is mostly sensitive to the layers enclosed in the range log τ = [0, −5.5], under the physical conditions that are present in our model atmospheres."

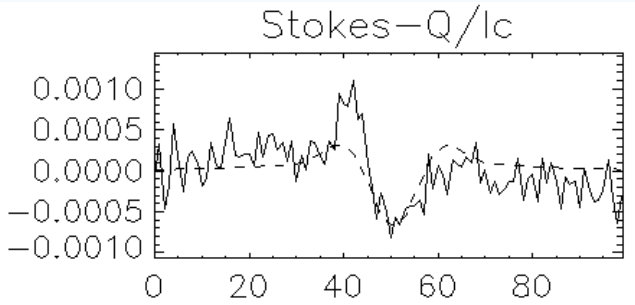
(Quintero Noda et al., 2016, MNRAS)

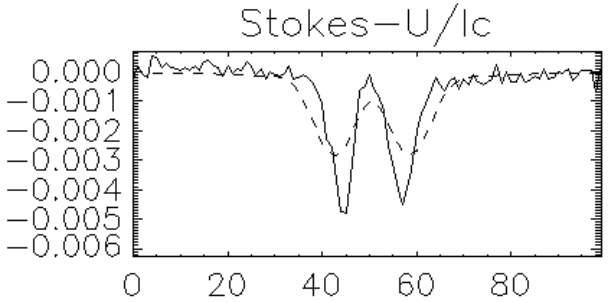
NICOLE Inversions

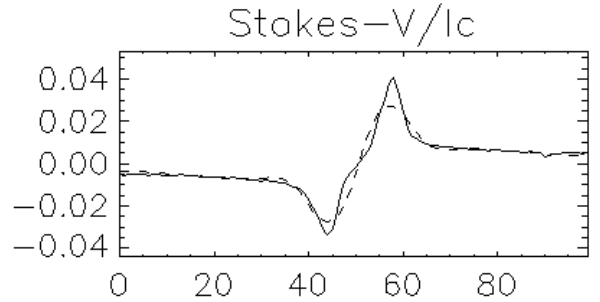
Umbra

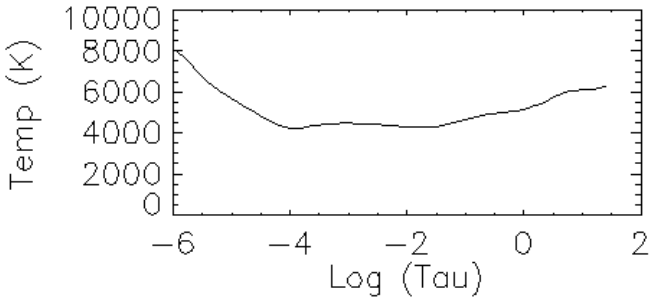


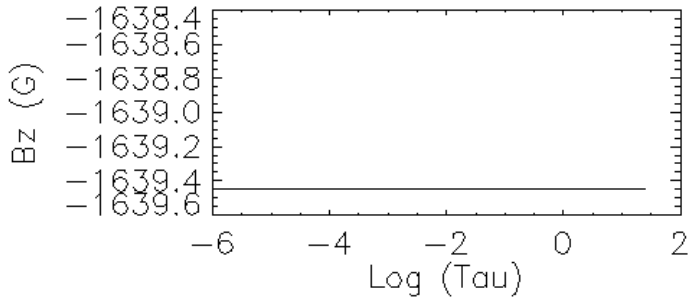


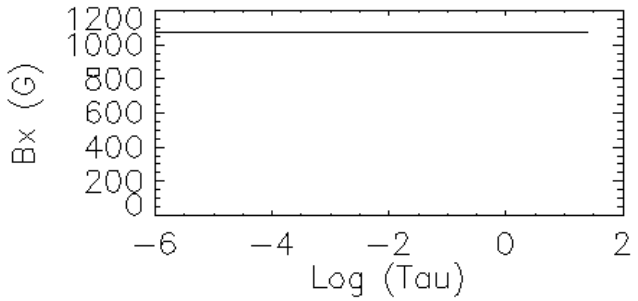


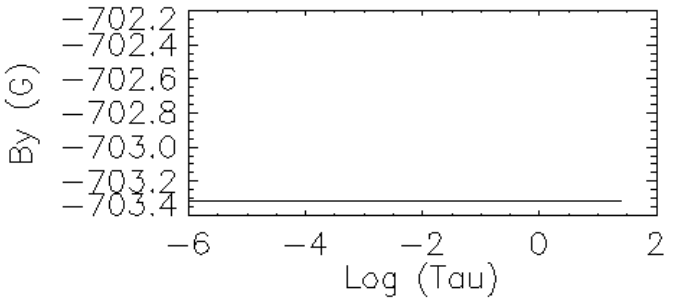






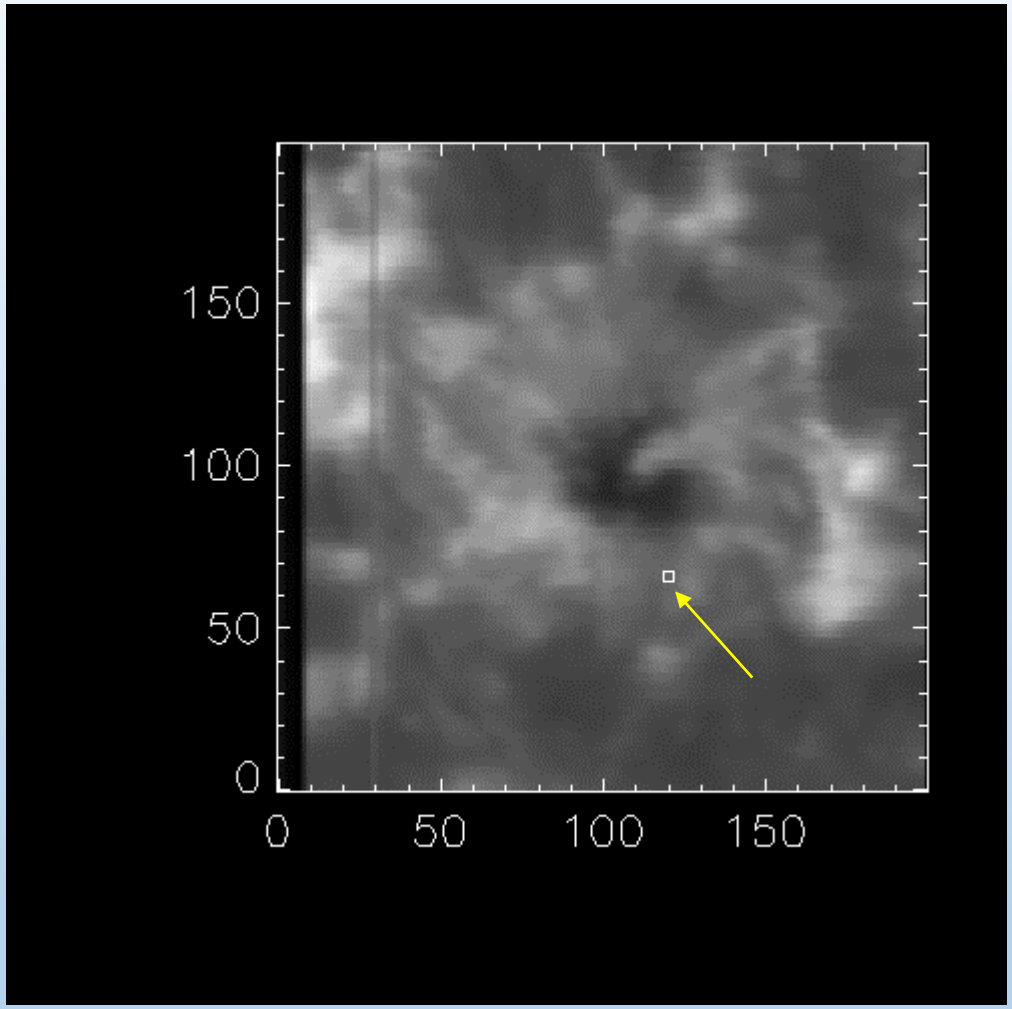


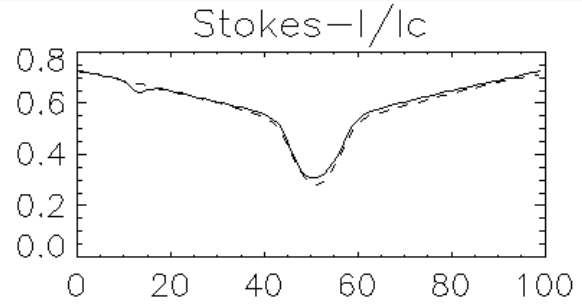


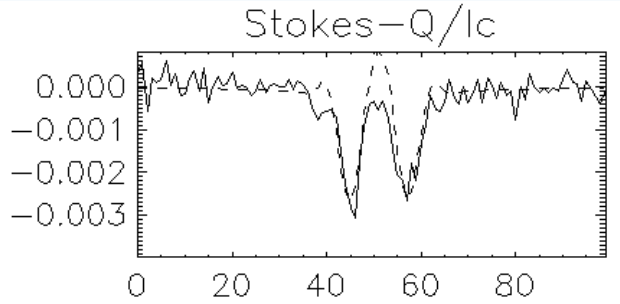


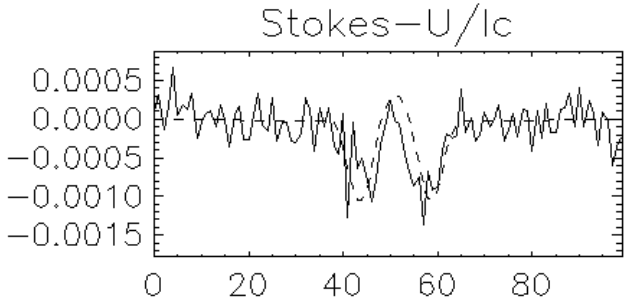
NICOLE Inversions

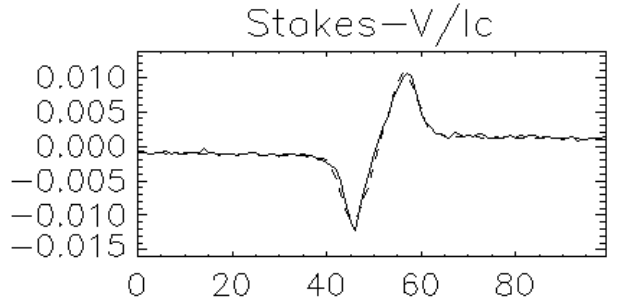
Penumbra

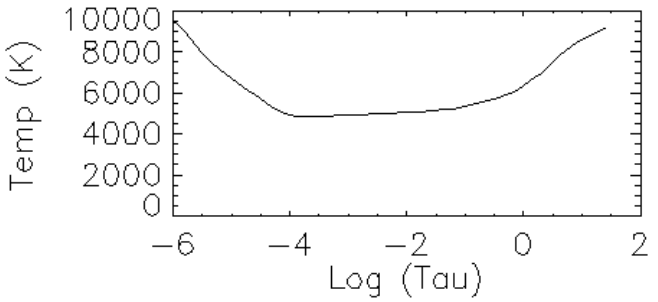


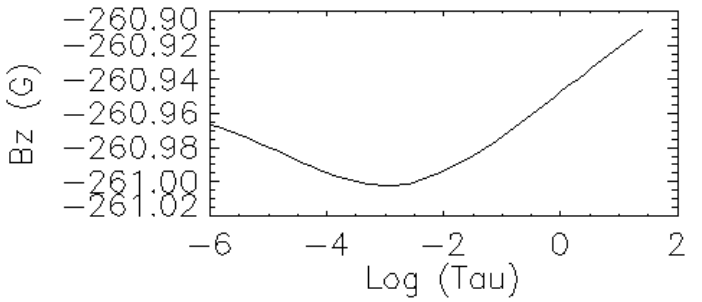


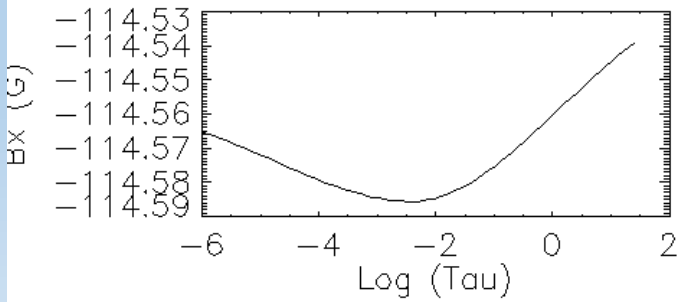


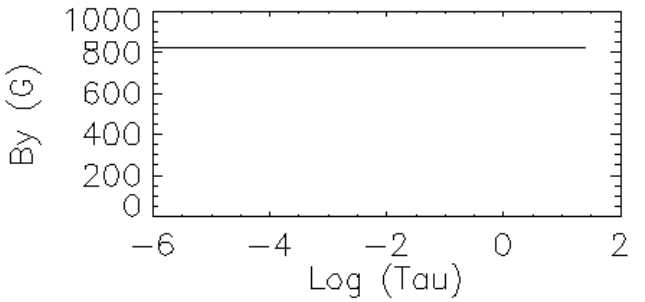






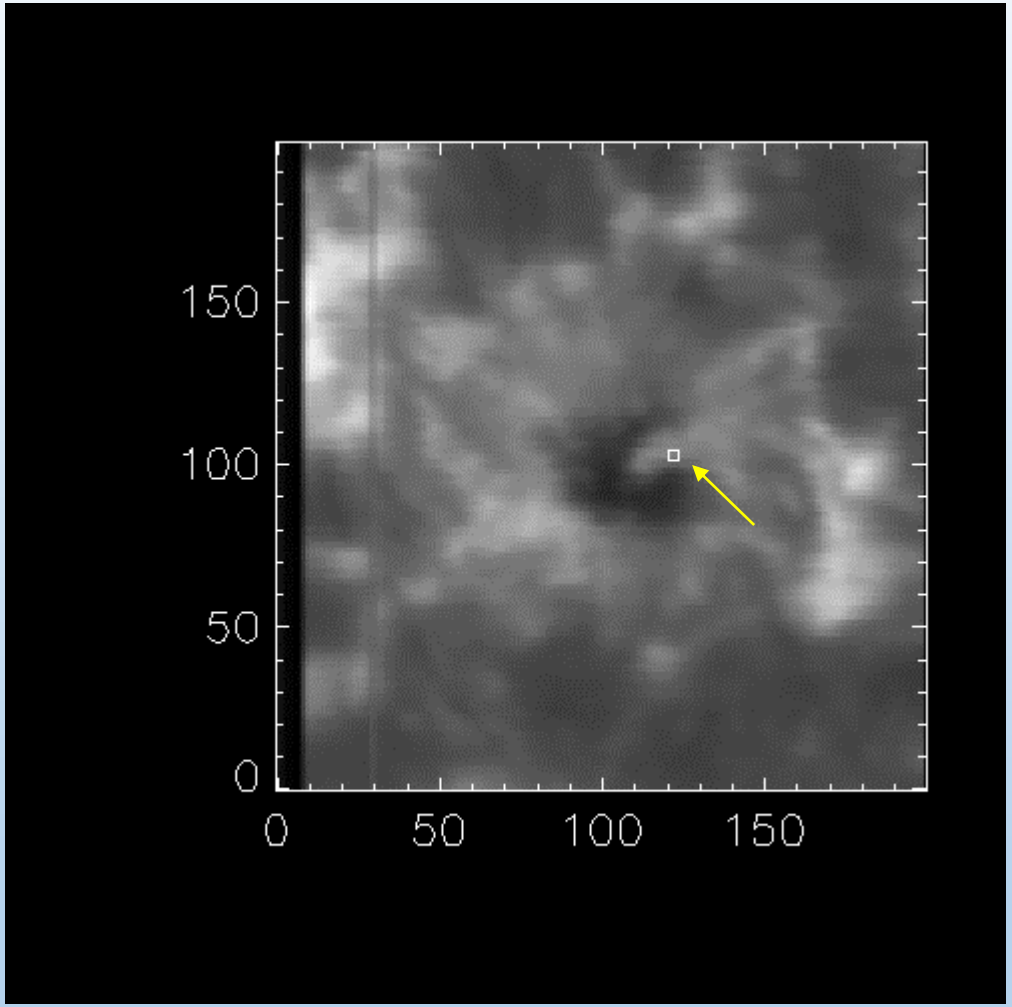


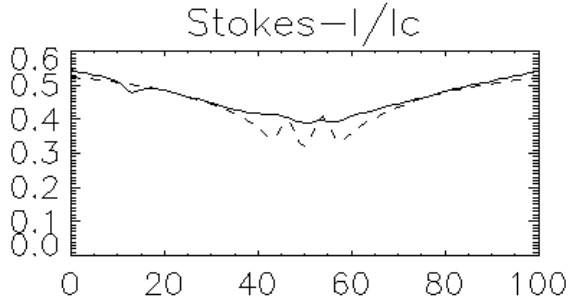


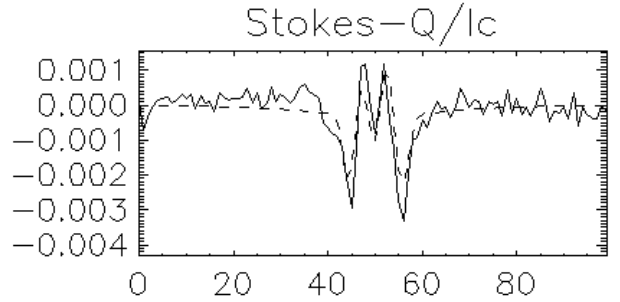


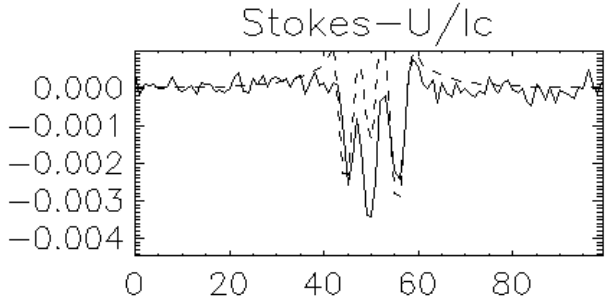
NICOLE Inversions

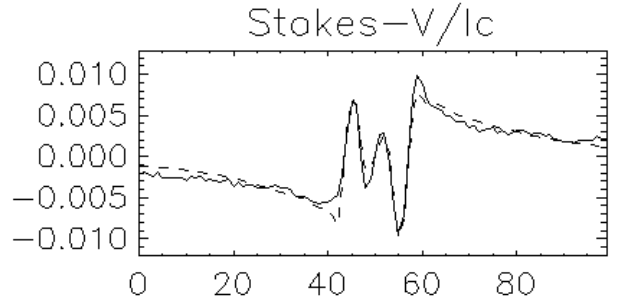
“Light-Bridge”

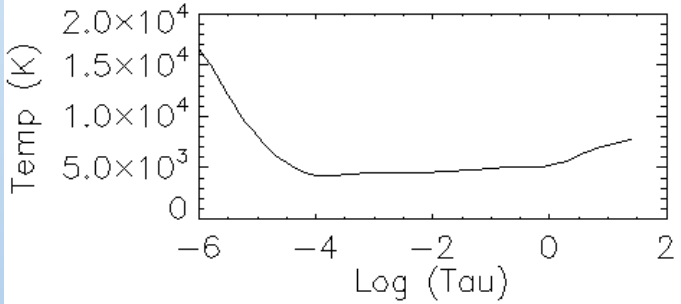


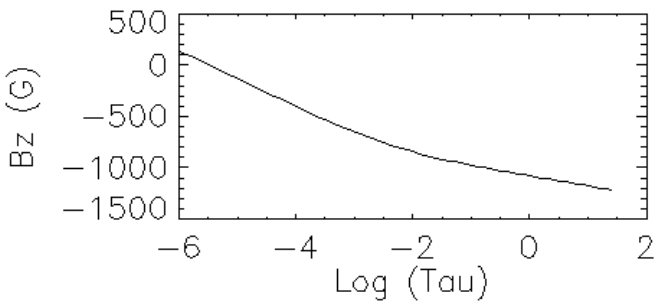


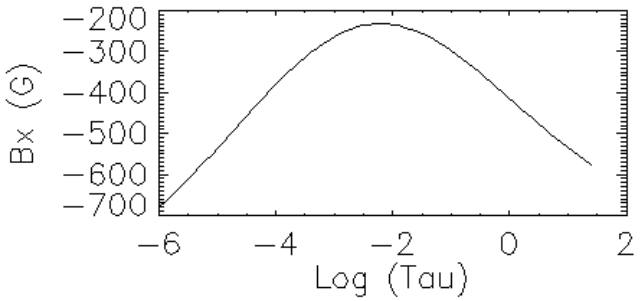


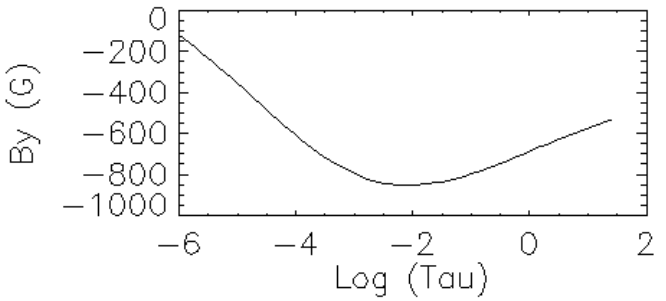






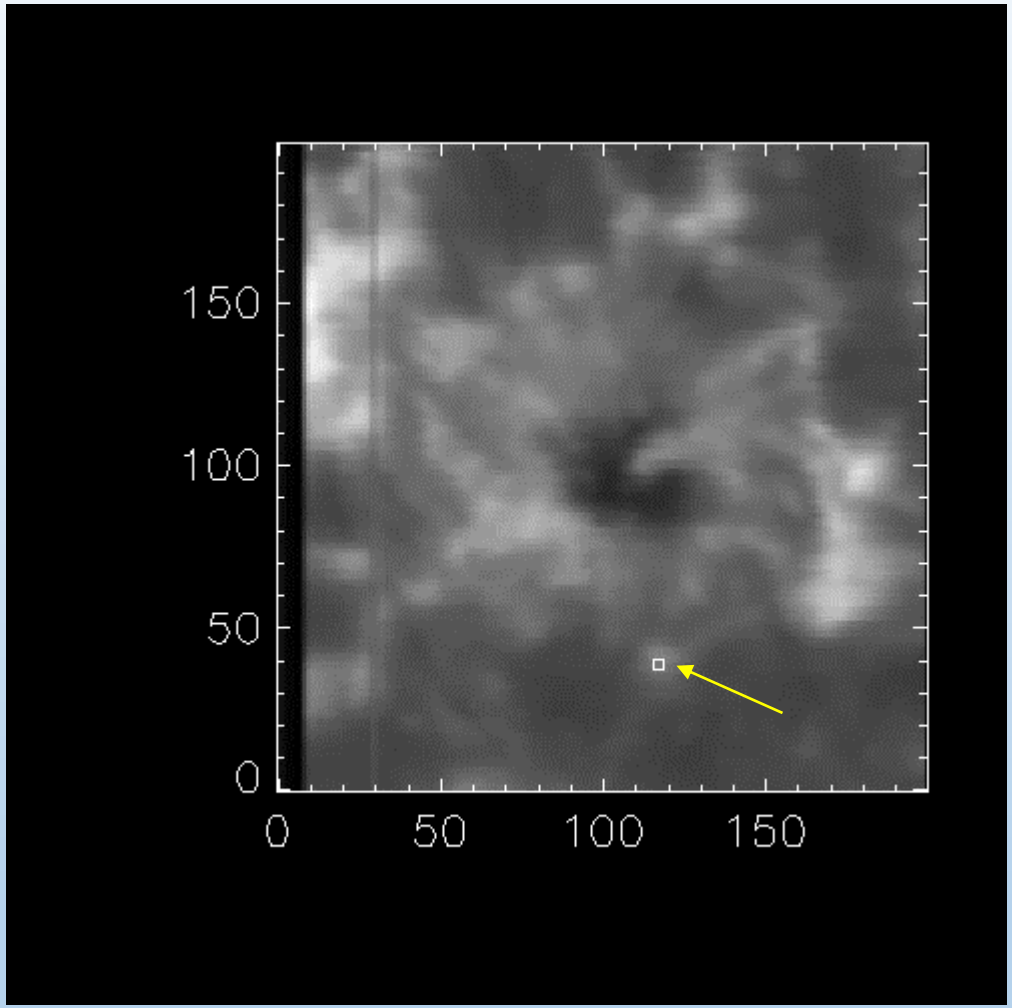


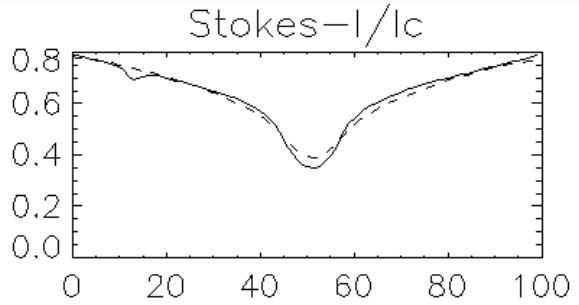


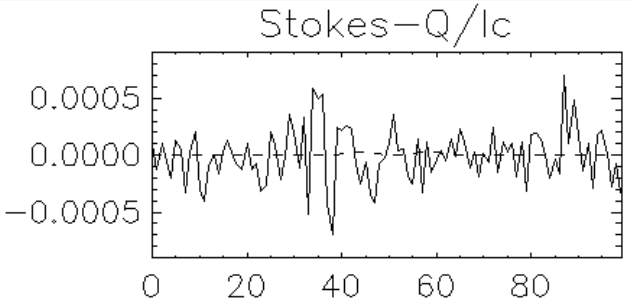


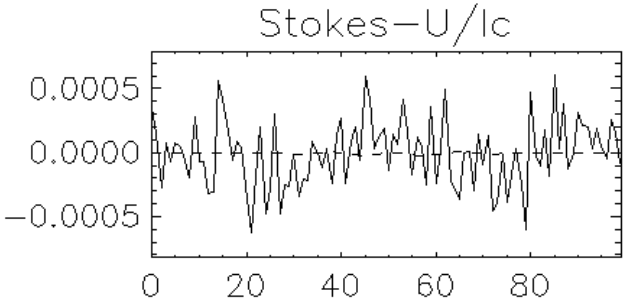
NICOLE Inversions

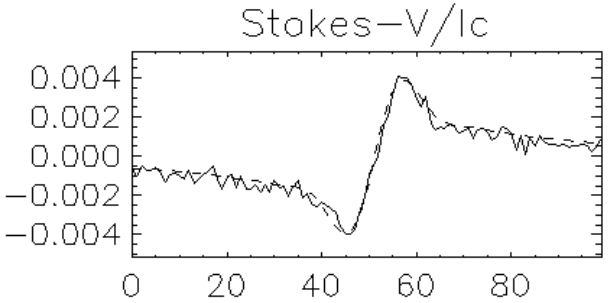
Bright point in Moat Region

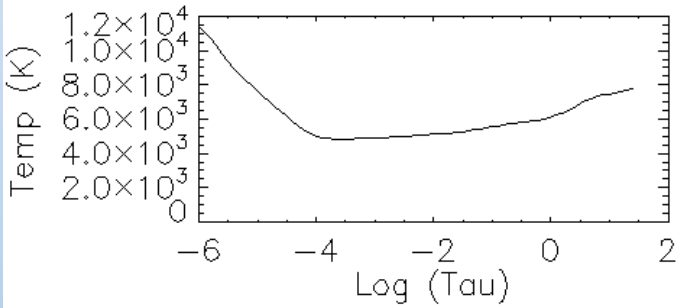


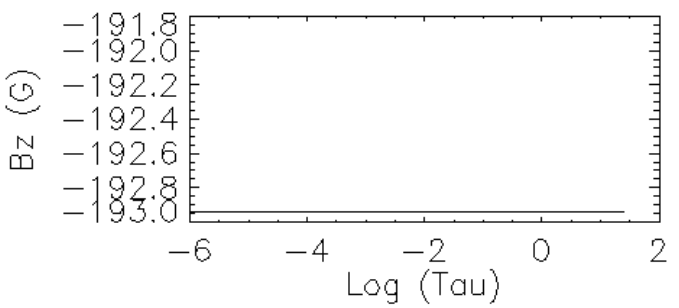


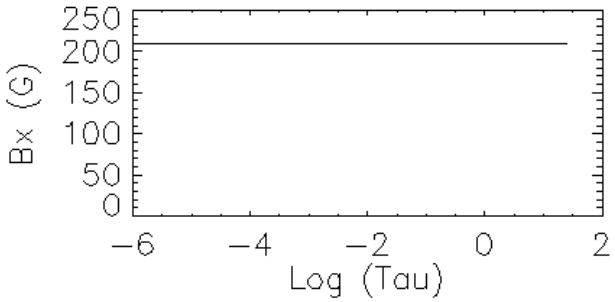


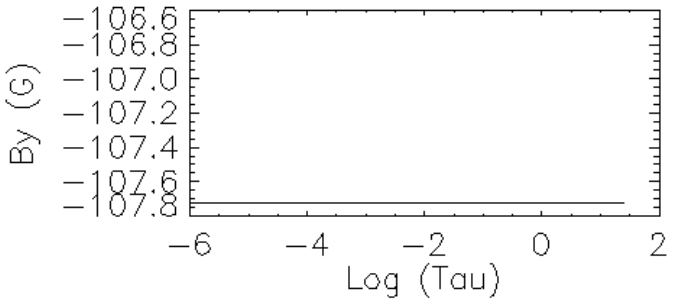






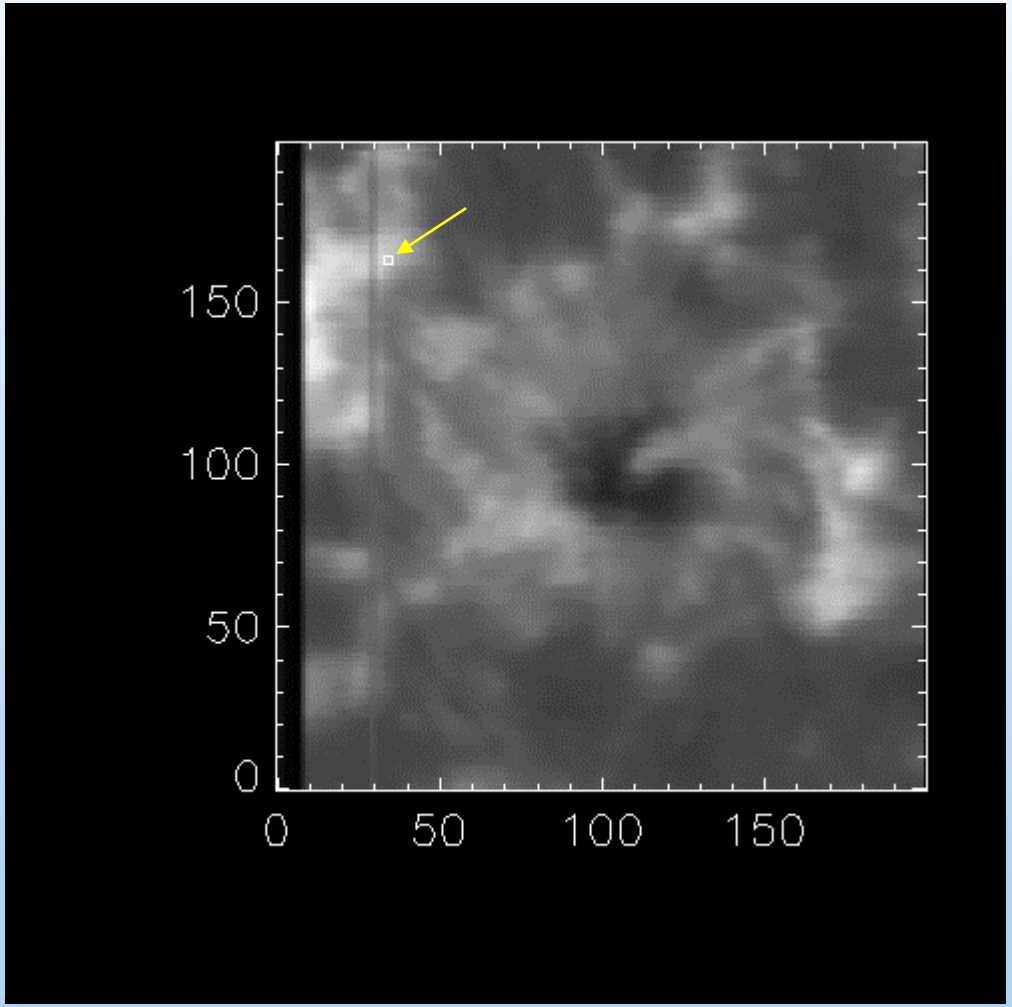


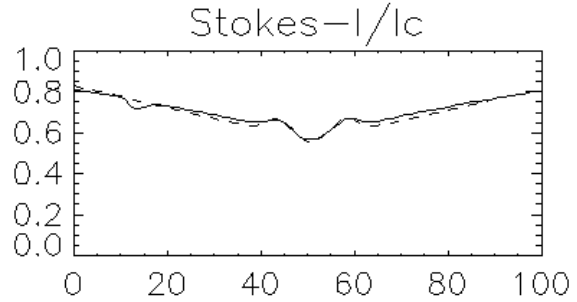


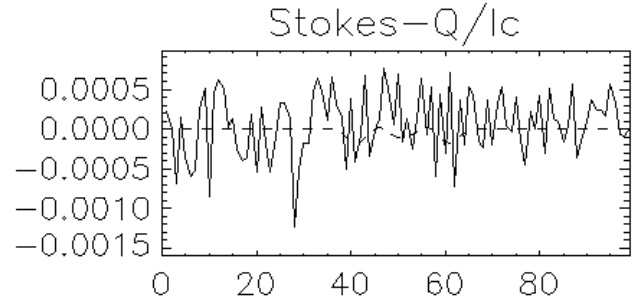


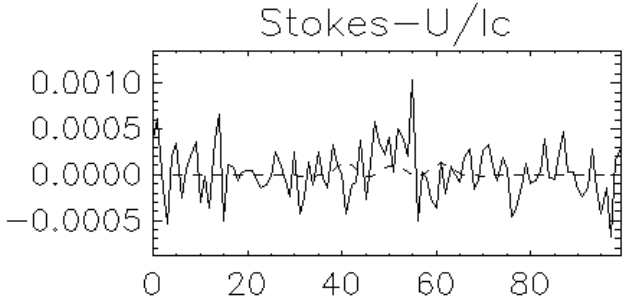
NICOLE Inversions

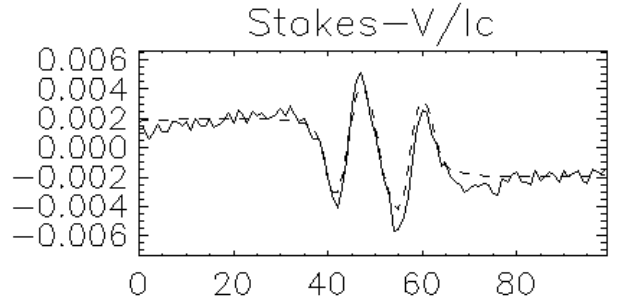
Plage

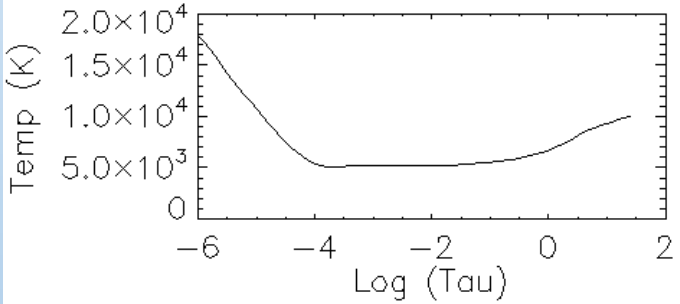


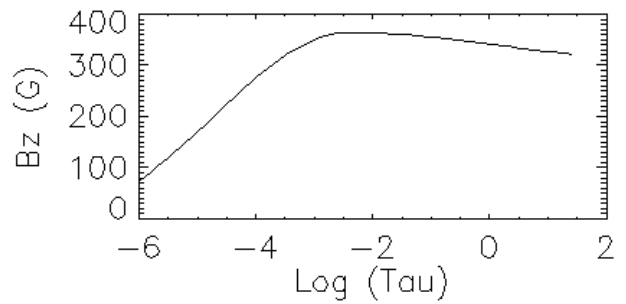


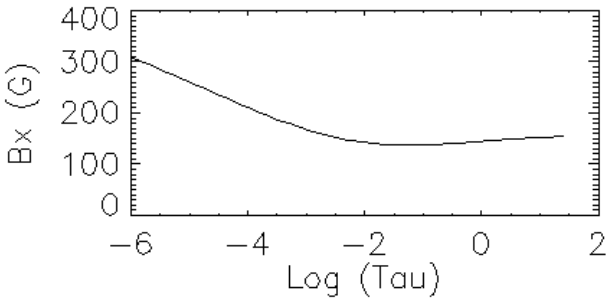


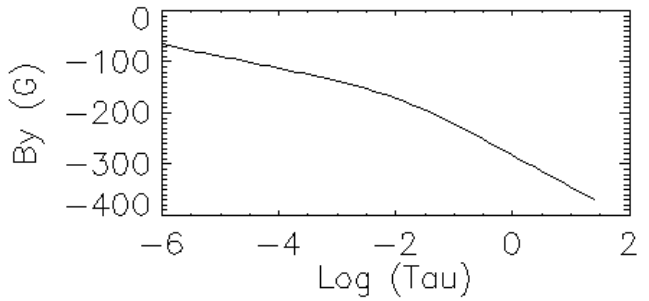




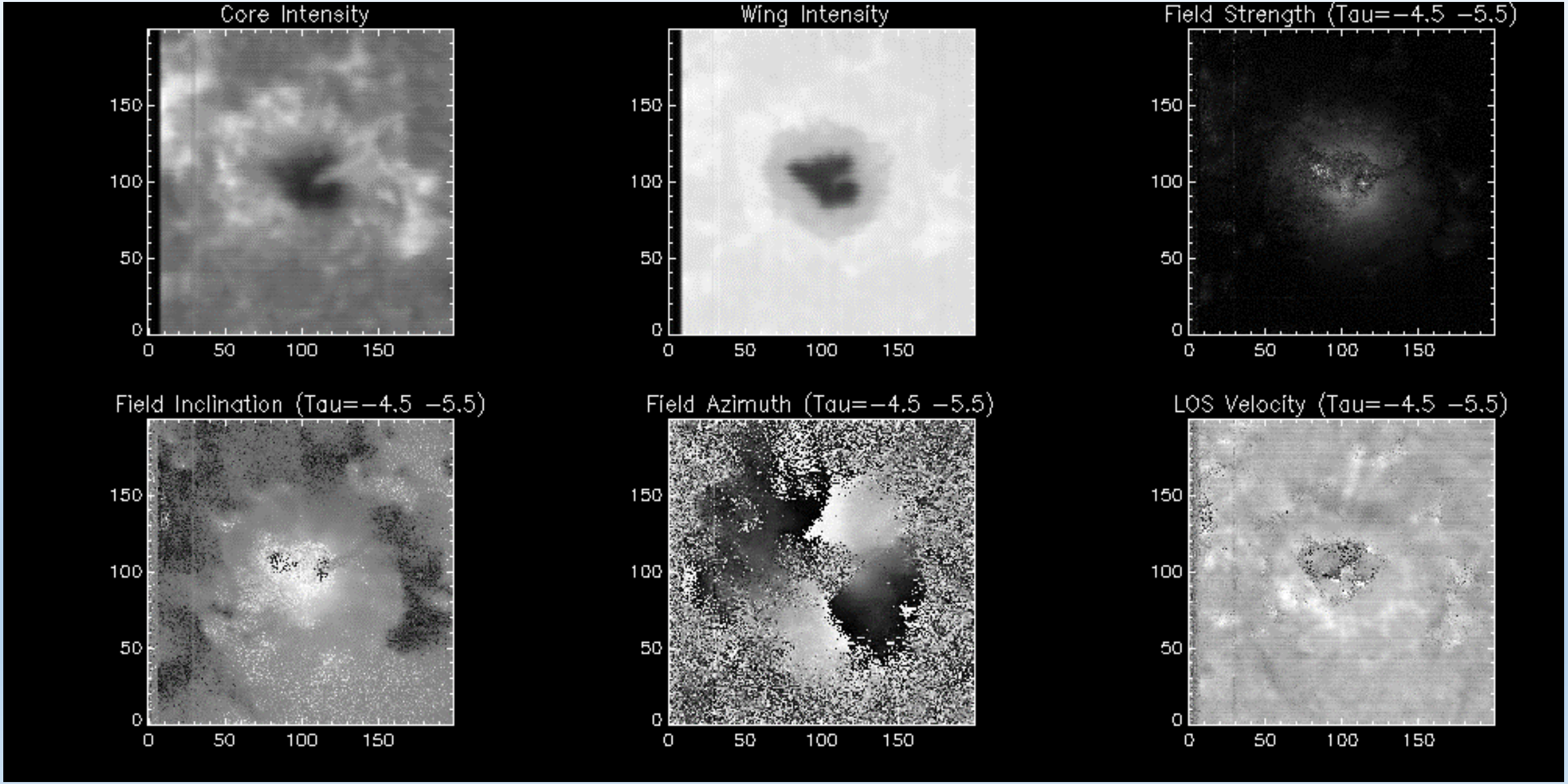




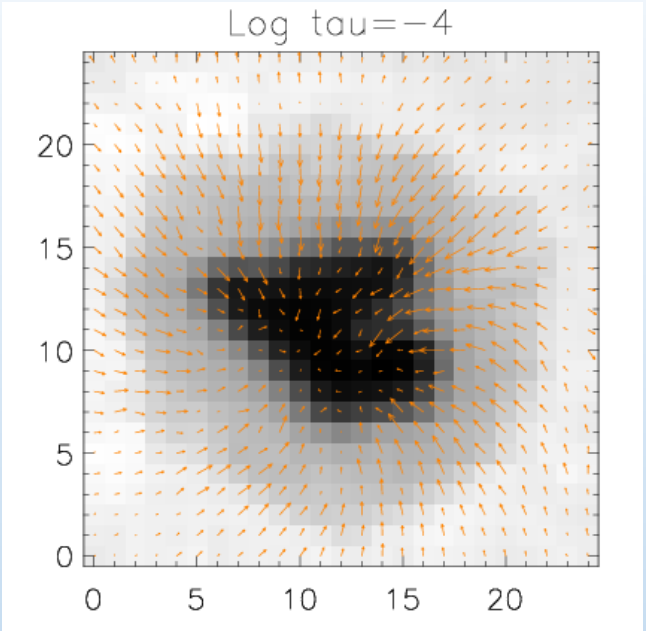


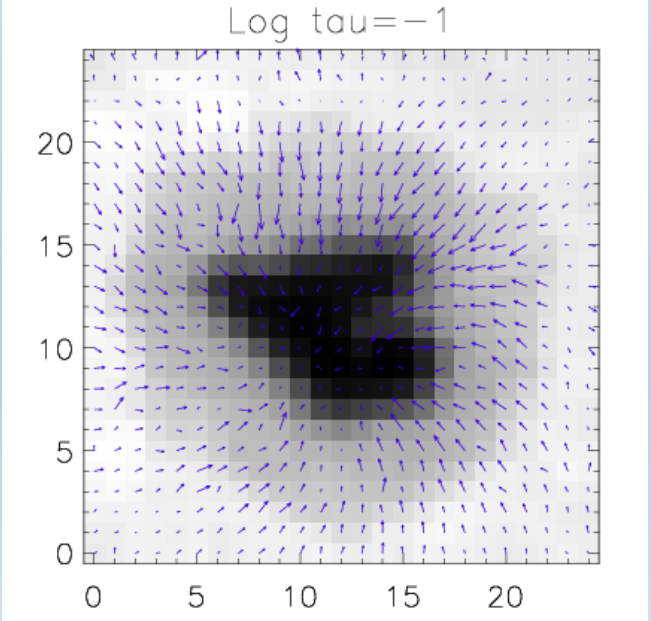


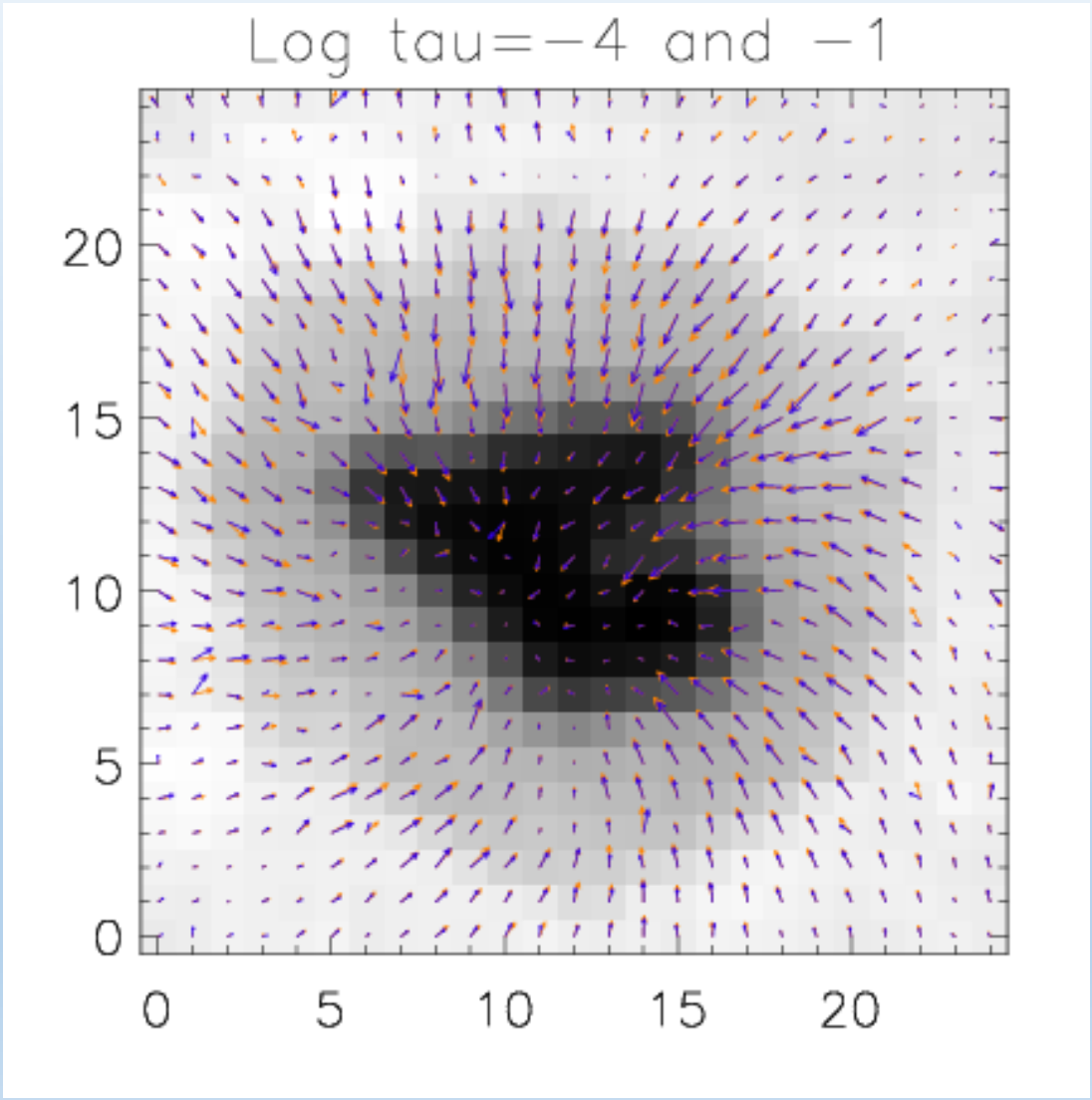
Maps of Magnetic and Velocity Field



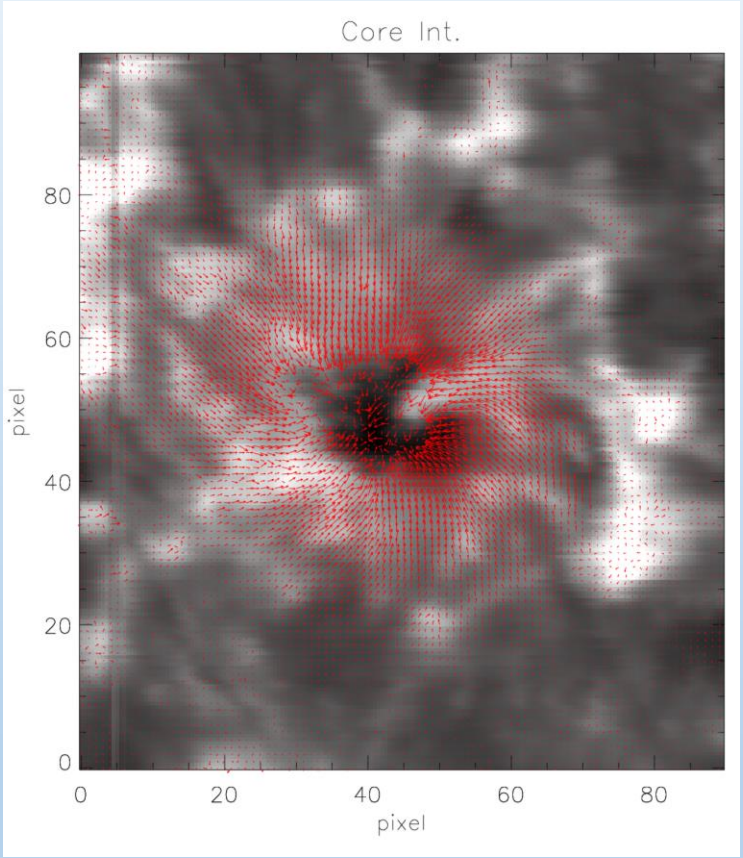
Sample NICOLE Inversions for a Sunspot

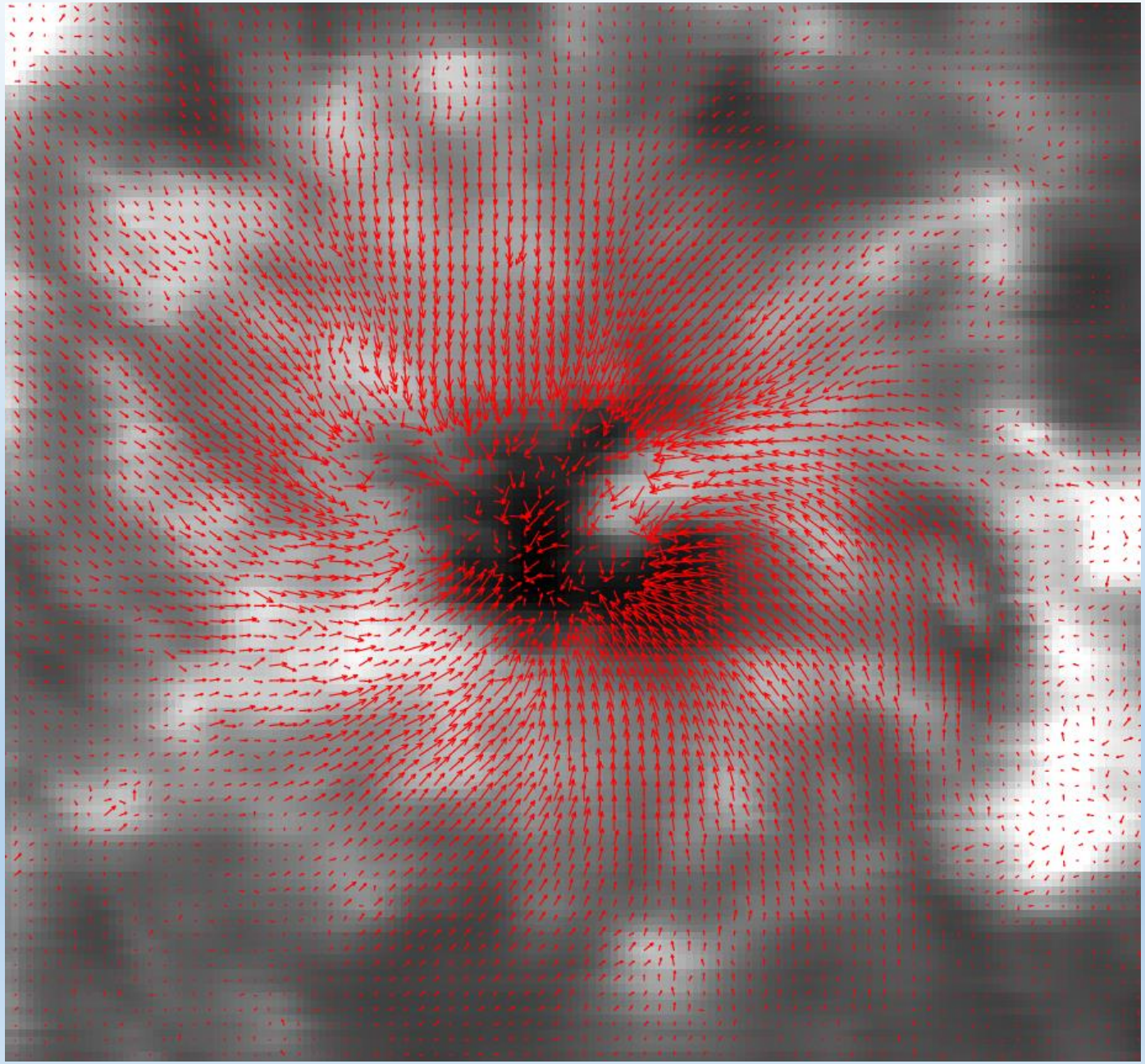




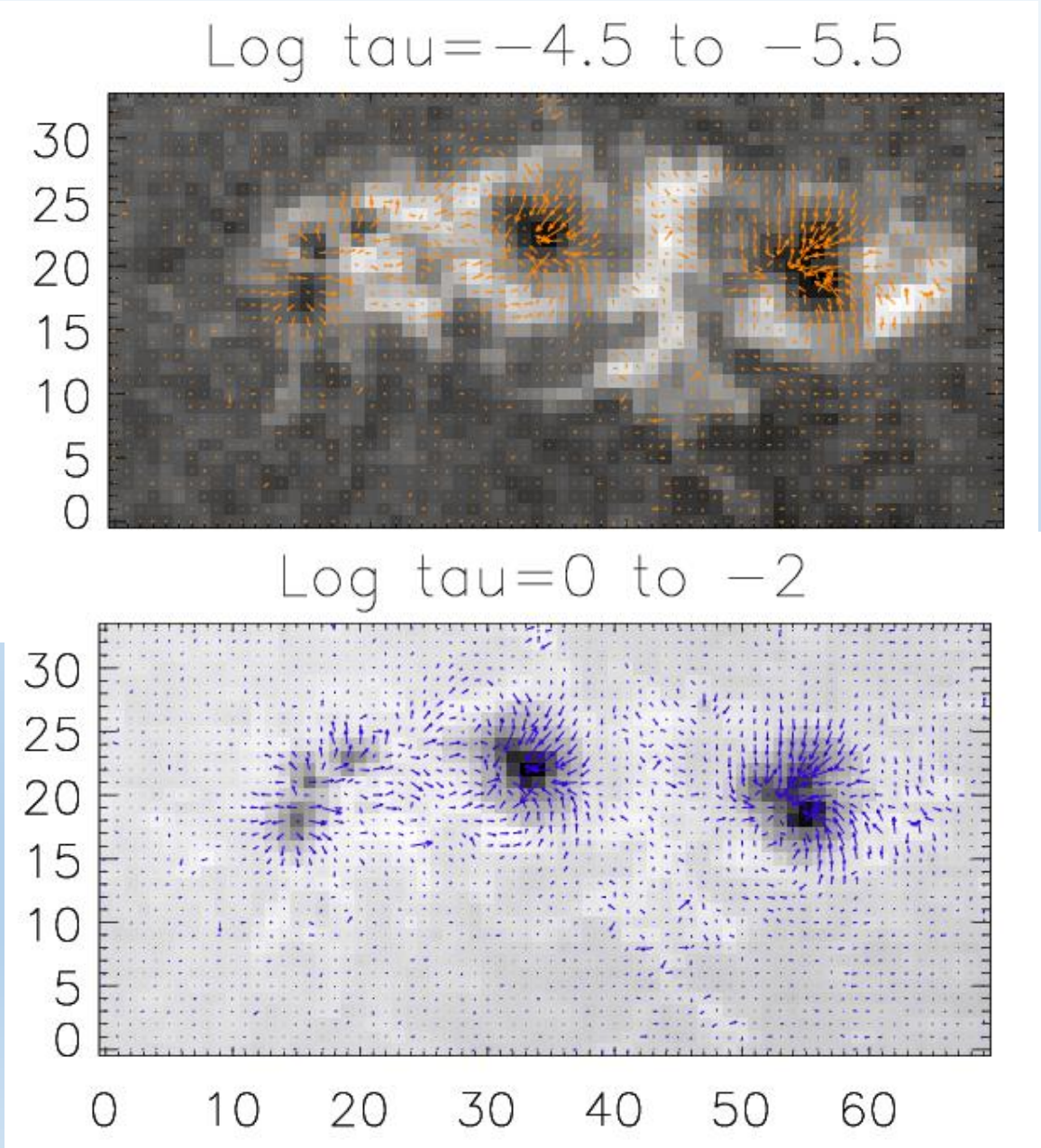


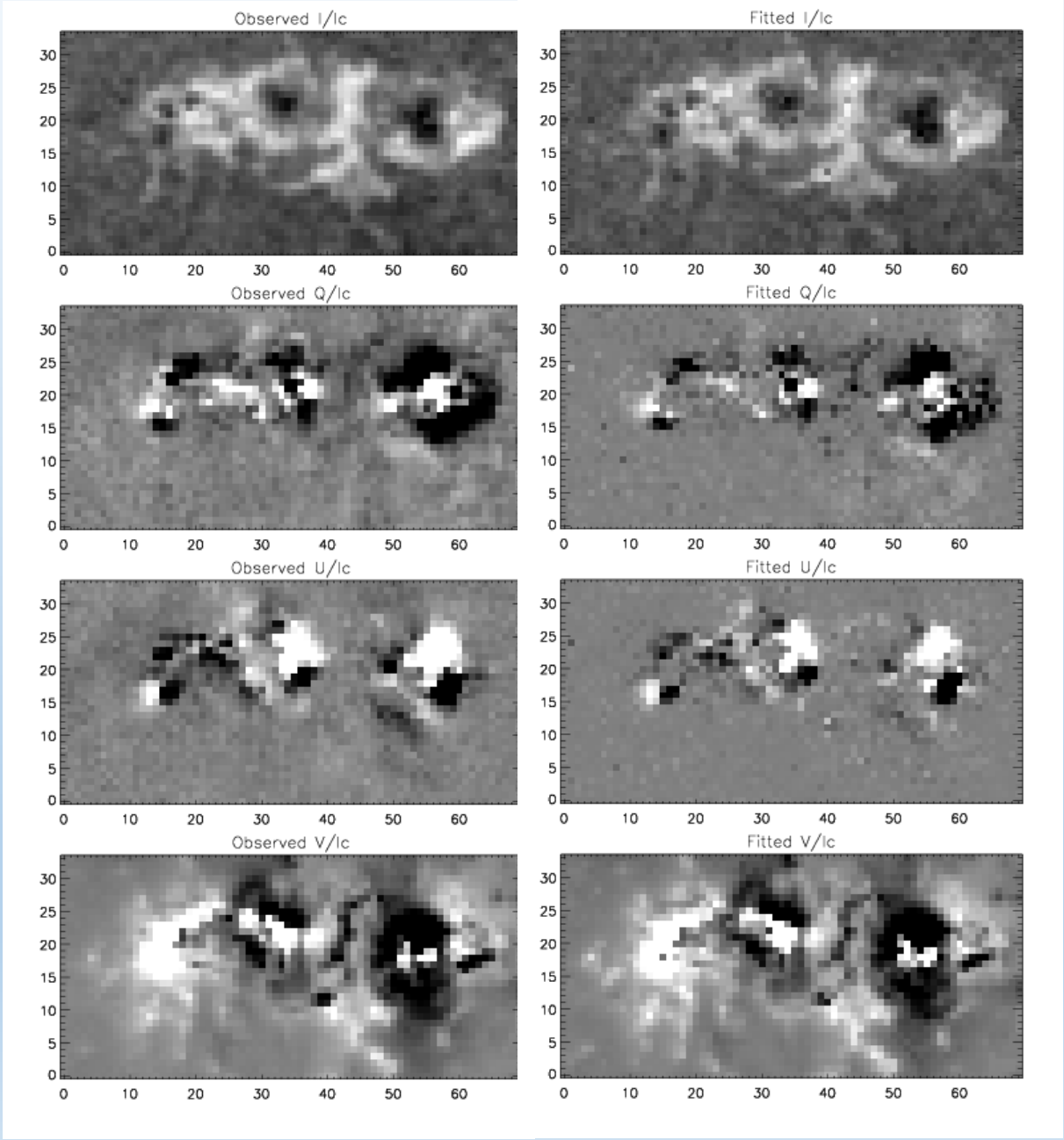
Sample NICOLE Inversions for a Sunspot



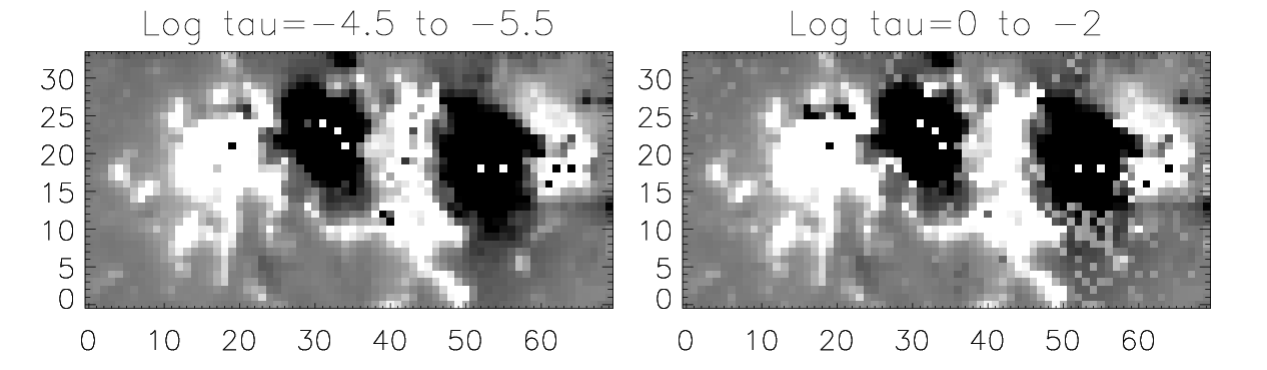


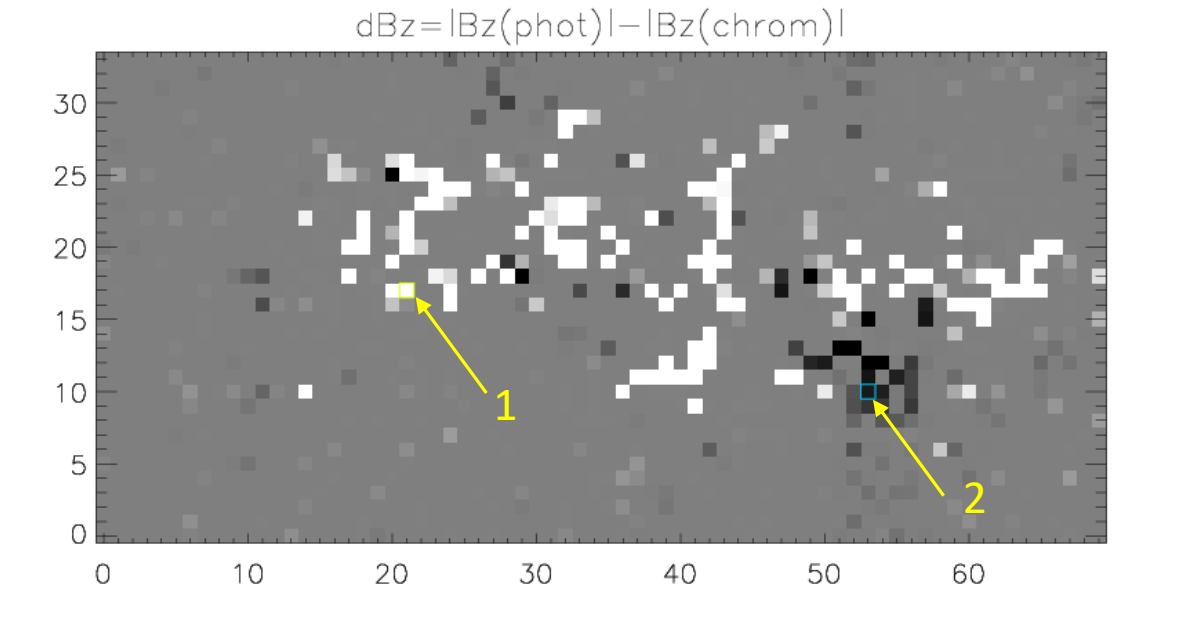
Sample NICOLE Inversions for an Active Region

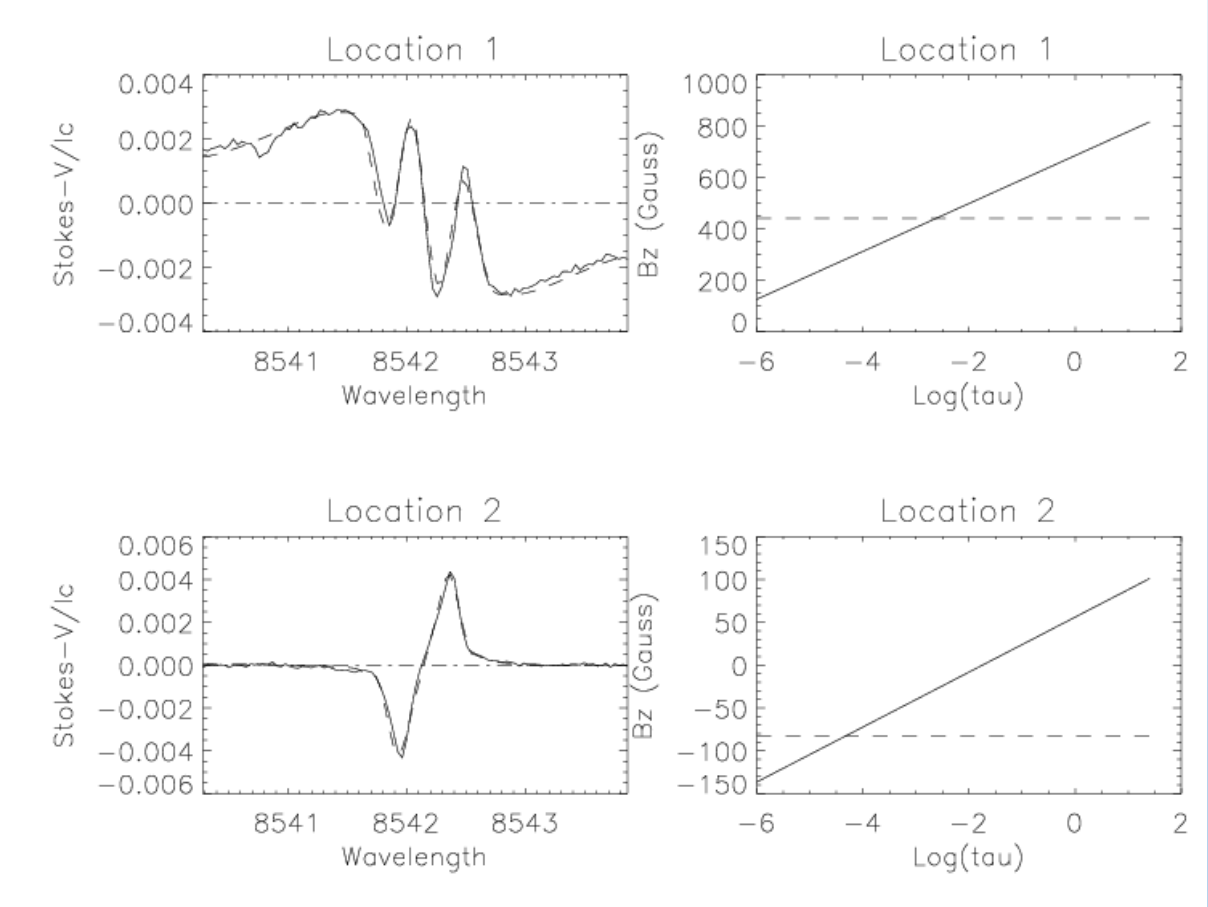




Can we recover Bz-gradient in solar atmosphere?







Future plans

Better Initialization:

- Weak Field Approx. can be used to initialize B-field.
- Inversions with binned set can be used as guess for full resolution

Faster Speed:

- More processors, GPUs ?
- Binning in spectral dimension.

Test Force-freeness:

- Test force-freeness compared to Photosphere
- Use as lower boundary condition for force-free extrapolations.

Multi-line Inversion:

Invert together with Fe I 630 nm lines to infer field gradients in stable sunspots.

(Fe and Ca lines are not observed simultaneously.)

Thanks!!