

# First Chromospheric (He I 1083 nm) and Photospheric (Fe I 1565 nm) Observations with GREGOR/GRIS

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MAX-PLANCK-GESELLSCHAFT

Indo-German Workshop on Solar Astronomy  
Bangalore, India  
Nov-17 2014



- 1 GREGOR and GRIS
- 2 Data: He I 10830 Å
  - Fine Structure in the Chromosphere
- 3 Data: Fe I 15650 Å
  - Quiet Sun Magnetism
- 4 GRIS - Outlook 2015
  - Instrumental improvements

### GREGOR status

- 2012: first light and inauguration
- 2013: commissioning
- 2014: early science phase

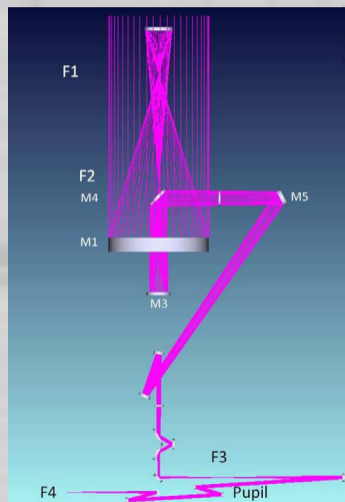
Schmidt et al. (2012)



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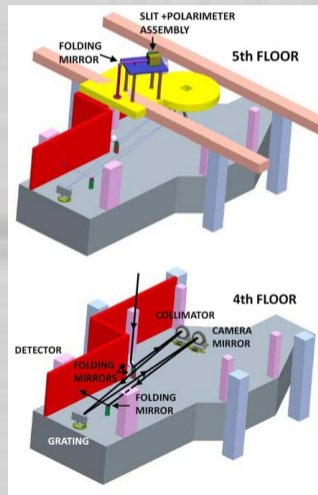
Schmidt et al. (2012)



## GREGOR Infrared Spectrograph (Collados et al., 2012)

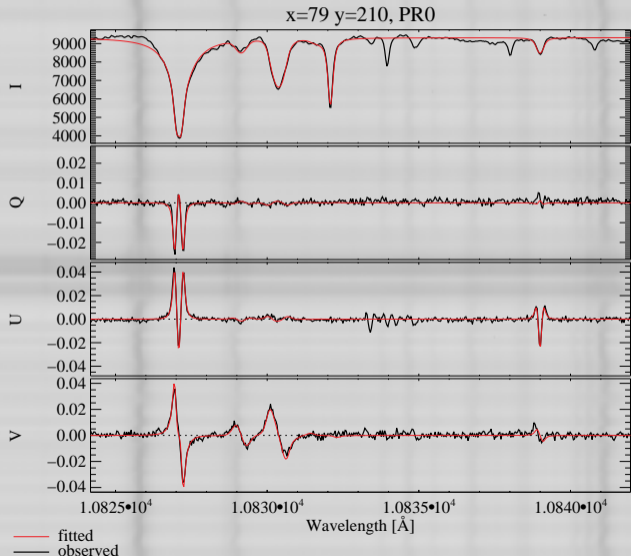
- attached to 1.5 m GREGOR telescope (Tenerife)
- standard Czerny-Turner configuration
- $1x \times 1k$  HgCdTe Rockwell TCM 8600

Wavelength range:	1000–2300 nm
Spectral resolving power:	$\lambda/\Delta\lambda = 1.9 \cdot 10^5$
FOV:	65 arcsec
Spatial sampling:	$0.126 \text{ arcsec/pixel}^{-1}$
Zeeman sensitivity:	$\approx 10^{-4} I_c$
Spectroscopy:	< .1 s cadence
Vector spectro-polarimetry:	< 2 s cadence

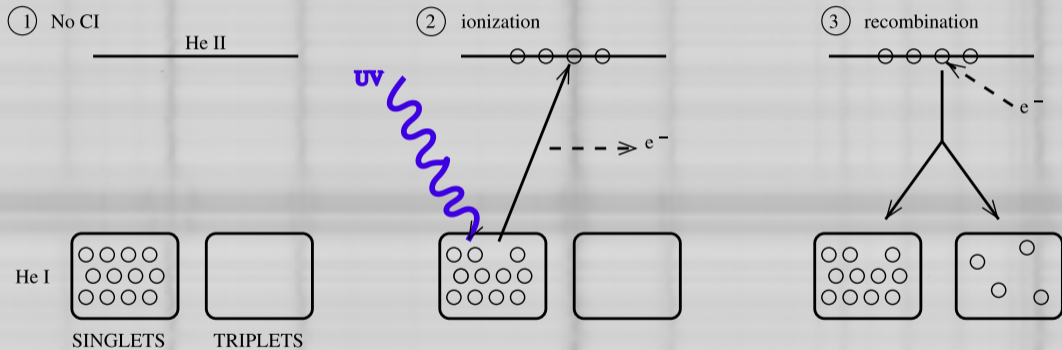


GRIS@1.083 $\mu\text{m}$ : SpecsGRIS@1.083 $\mu\text{m}$ : Specs

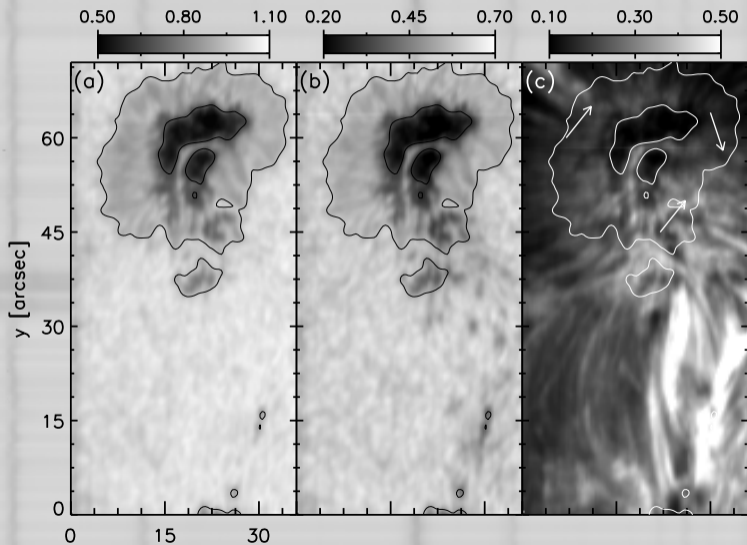
- $\lambda/\Delta\lambda \geq 180000$ ,  
20 mÅ sampling
- spatial resolution: 0".40  
(diff-limit: 0".20),  
sampling: 0".126
- noise level  $6\text{--}8 \cdot 10^{-4}$  at  
1 s/pixel and mod. state



## Coronal Illumination - Ionization - Recombination (Centeno et al., 2008)

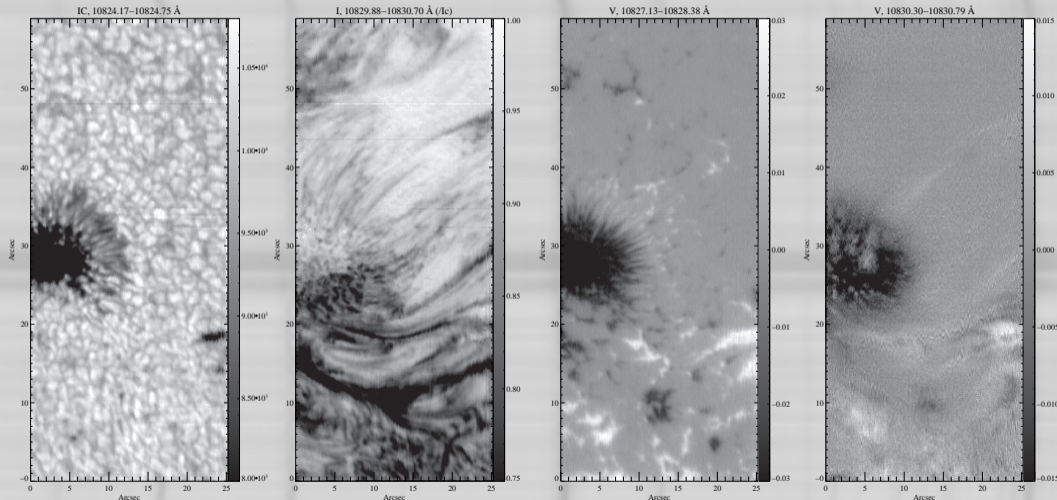


## Comparison: High-res until 2013 (PhD thesis: Joshi, 2014)





# GREGOR/GRIS Data & First Results (June 2014)



Stokes  $I_c$

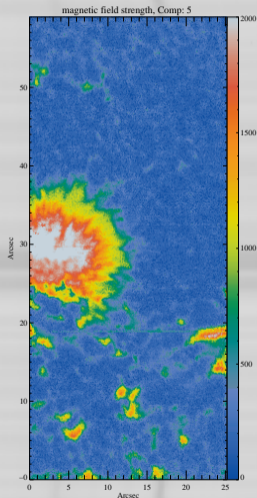
Stokes  $I_{He}$

Stokes  $V_{Si}$

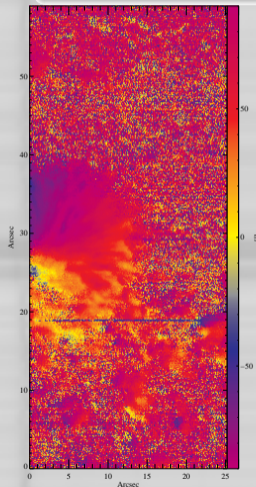
Stokes  $V_{He}$

# GREGOR/GRIS Data & First Results (June 2014)

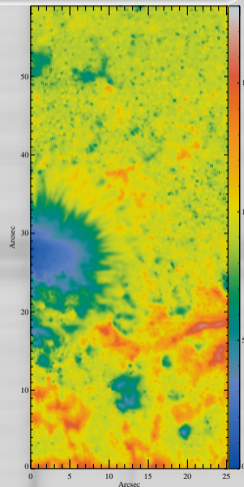
## Ca I – deep photosphere



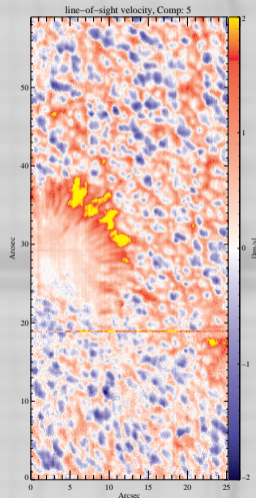
B-strength



Azimuth



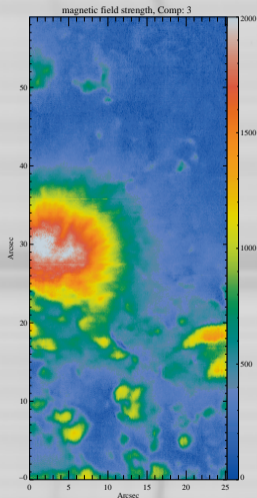
Inclination



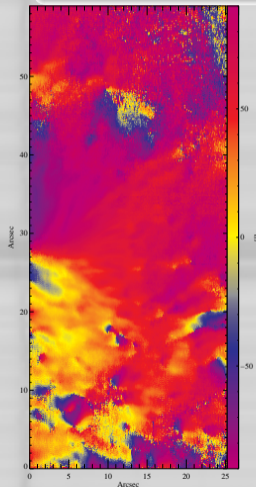
LOS-velocity

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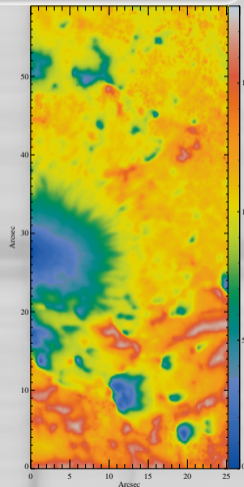
## Si I – mid/upper photosphere



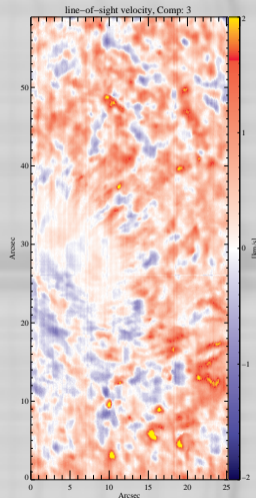
B-strength



Azimuth



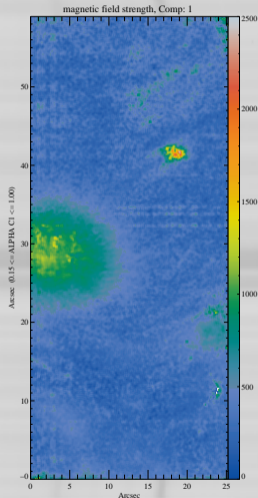
Inclination



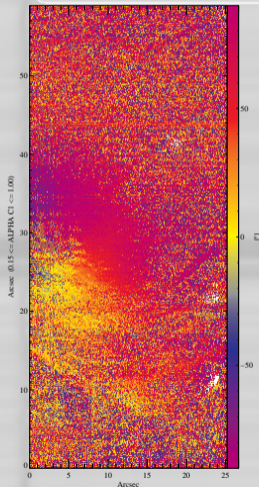
LOS-velocity

# GREGOR/GRIS Data & First Results (June 2014)

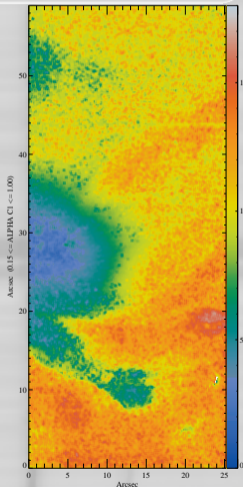
## He I – upper chromosphere



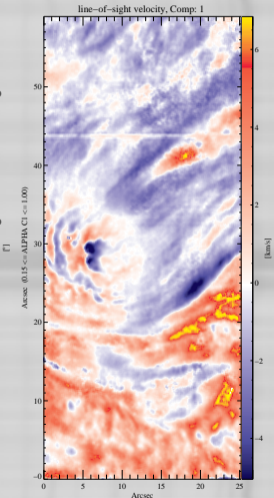
B-strength



Azimuth



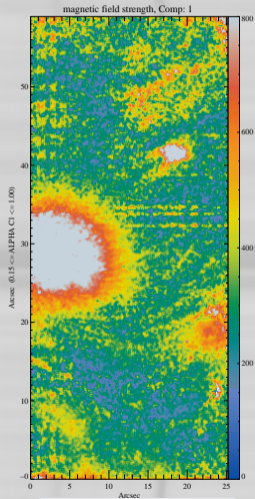
Inclination



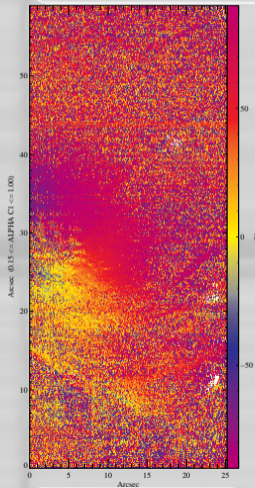
LOS-velocity

# GREGOR/GRIS Data & First Results (June 2014)

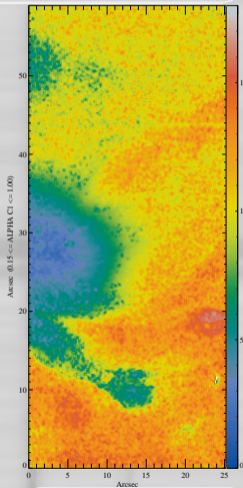
## He I – upper chromosphere



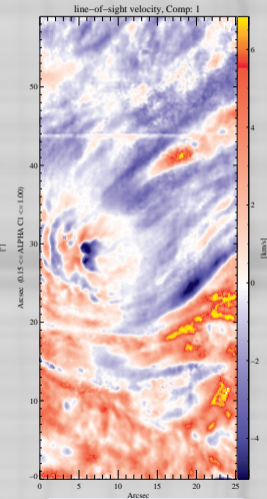
B-strength



Azimuth

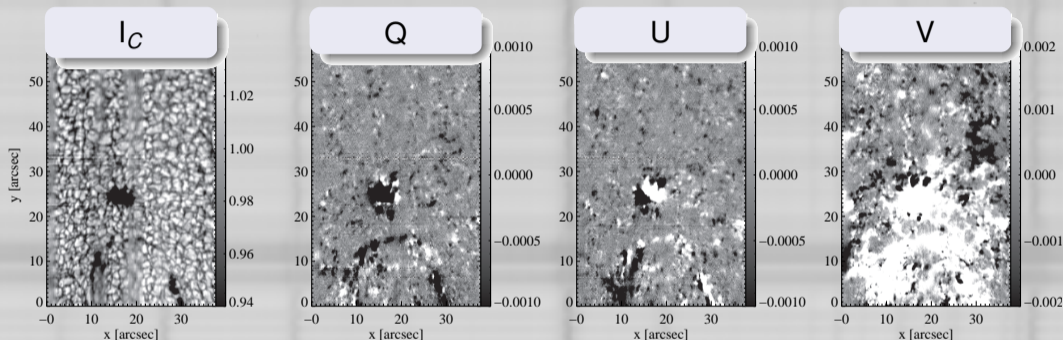


Inclination



LOS-velocity

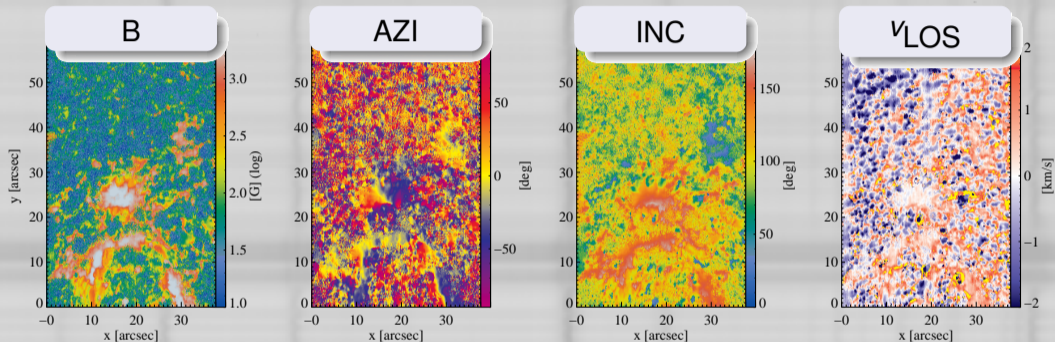
## Scan of pore with quiet sun region (2014-Sep-08)



- $x, y = 455'', 247''$  ( $\mu = 0.84$ )
- exp. time: 1 s/pixel and mod. state
- noise level (unbinned):  $5 \cdot 10^{-4} I_C$

- $\lambda/\Delta\lambda \geq 150000$ , 40 mÅ sampling
- spatial resolution:  $0''.35$  (close to diff. limit), sampling:  $0''.126$

## Scan of pore with quiet sun region (2014-Sep-08)



## Inversion setup

- Milne Eddington in 6 Fe I lines

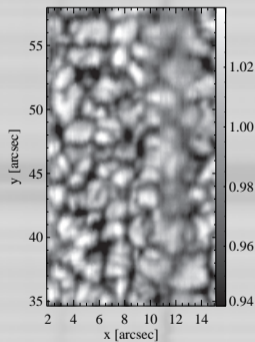
15631 – 15665 Å, line strength as free parameter

- free parameters  
 $B, \phi, \gamma, v_{\text{LOS}}, v_D, a, S_1, \eta_0, \alpha$
- global straylight (broad PSF wings)

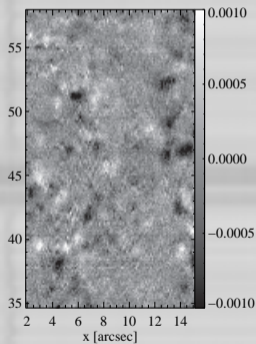
# Very quiet sun region (2014-Sep-08)

All pixels

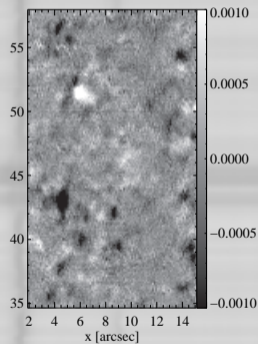
$I_C$



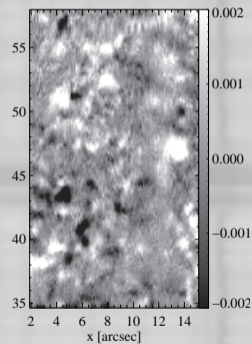
Q



U



V

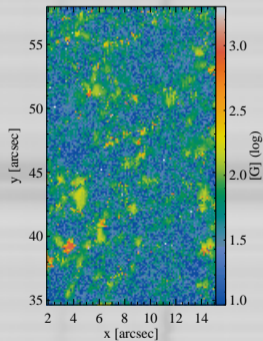




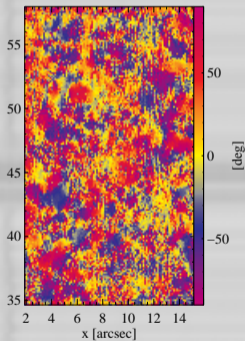
# Very quiet sun region (2014-Sep-08)

All pixels

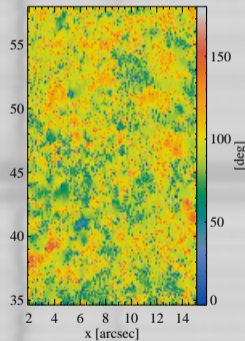
B



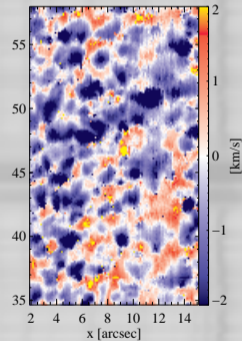
AZI



INC



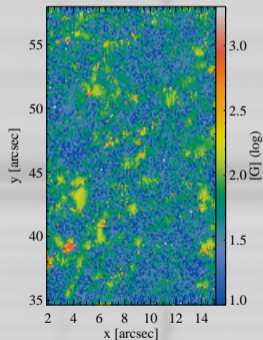
$v_{LOS}$



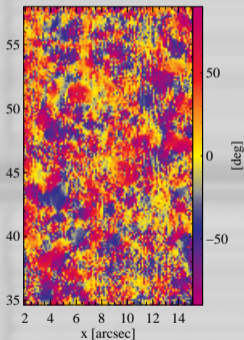
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All pixels

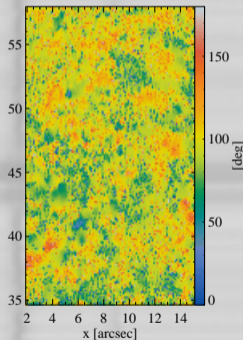
B



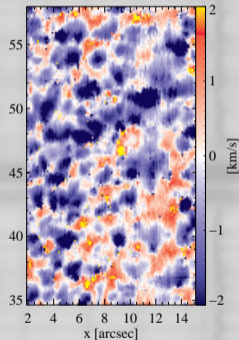
AZI



INC



$v_{LOS}$

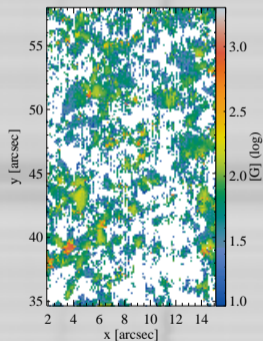


remove all pixels with tot. pol  $\leq 3\sigma$   
Survival of IG lanes or granules?

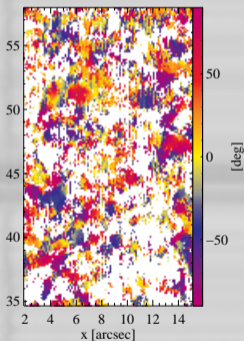
# Very quiet sun region (2014-Sep-08)

Tot. Pol  $> 3\sigma$

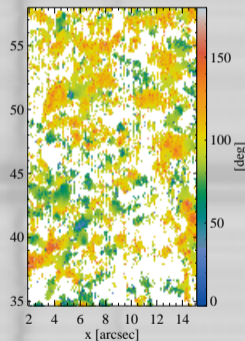
B



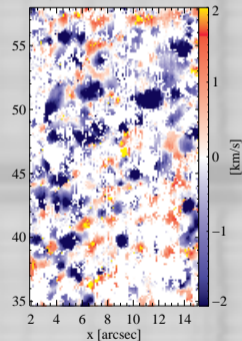
AZI



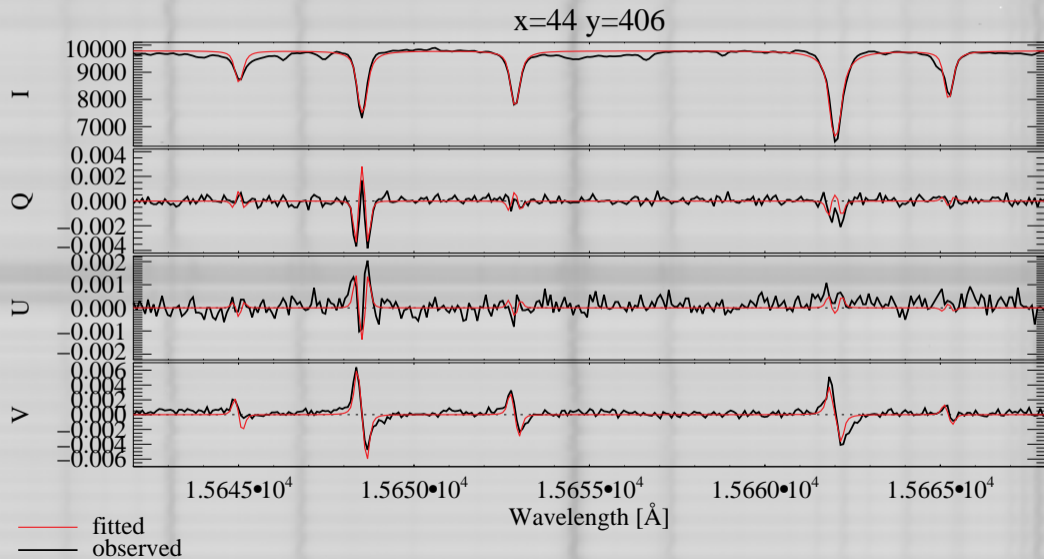
INC

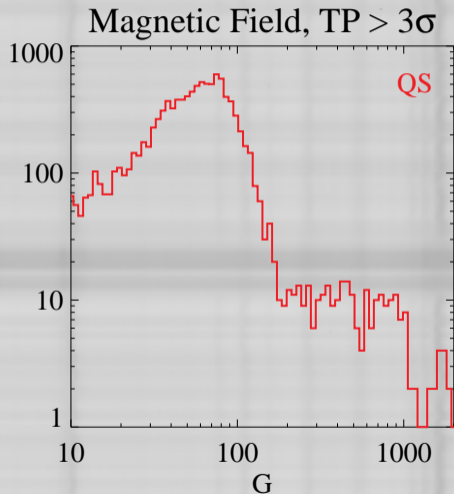
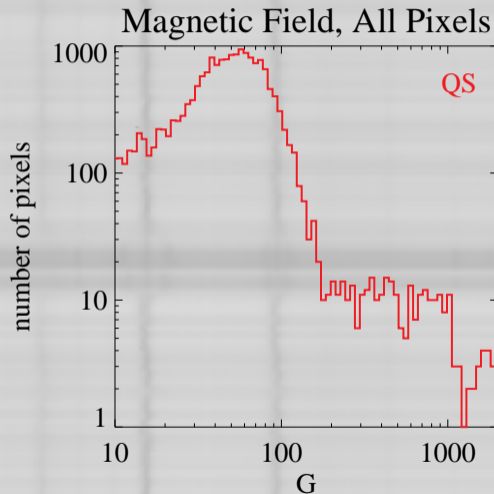


$v_{LOS}$

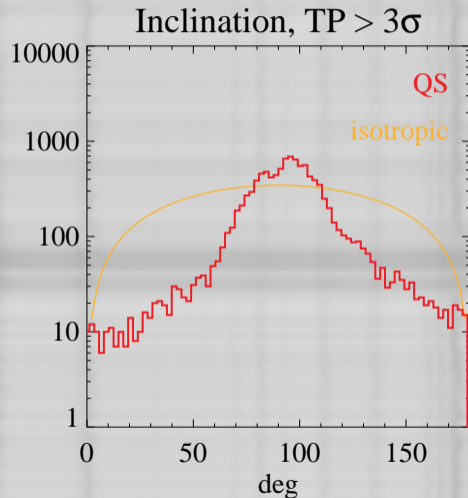
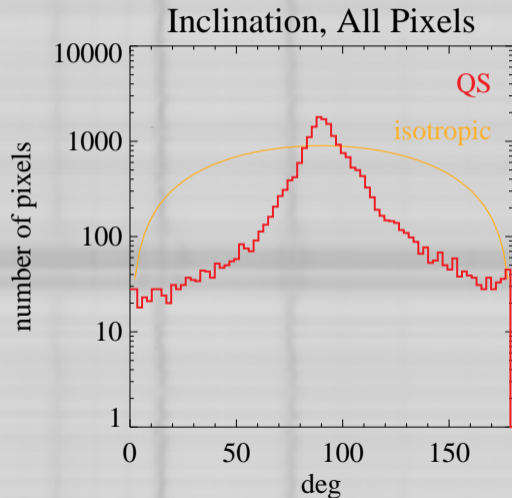


Mainly granules!  
... and some IG lanes

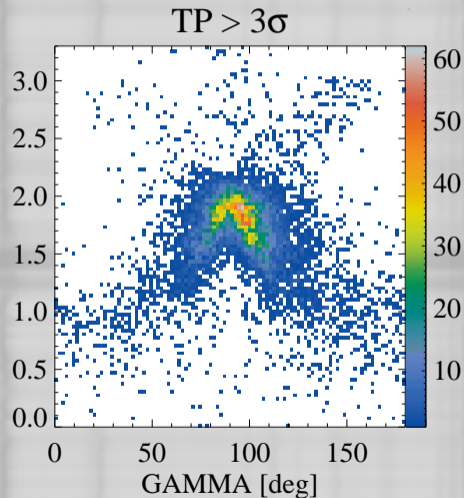
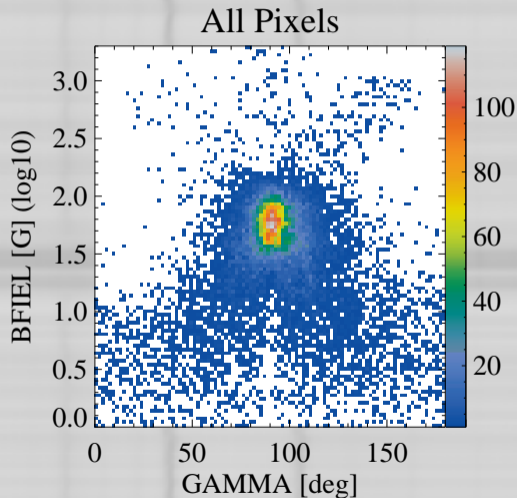
Stokes Profiles: Granule (TP)  $> 3\sigma$ 

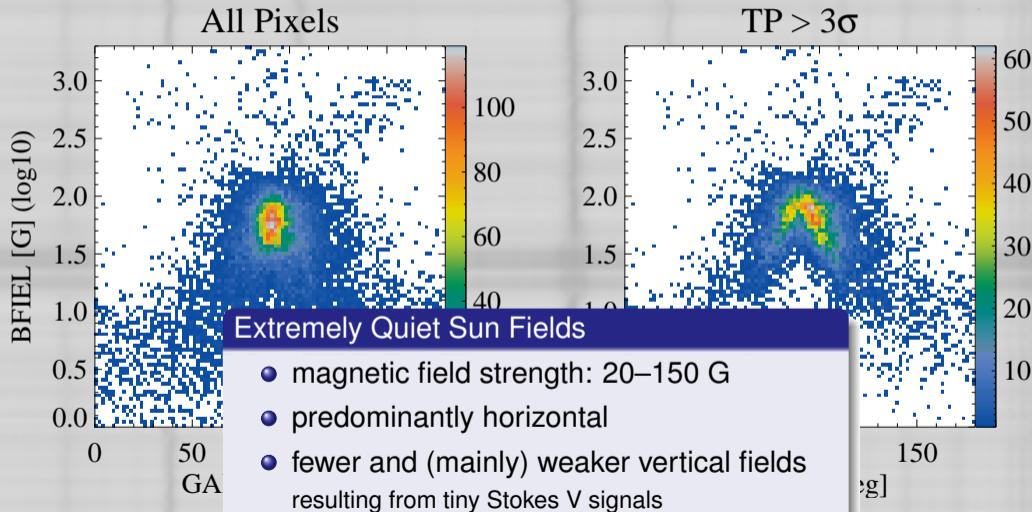
Histogram: Magnetic Field Strength (Very quiet region, 40–50 Mx cm<sup>-2</sup>)

Hinode based studies: 10–50 G

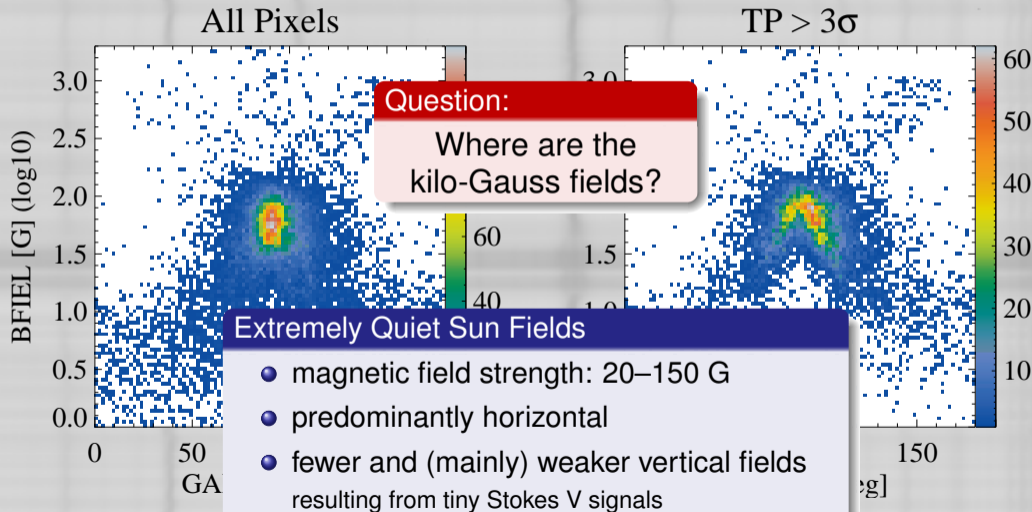
Histogram: Magnetic Field Inclination (Very quiet region, 40–50 Mx cm<sup>-2</sup>)

## 2D-Histogram: B vs. $\gamma$ (Very quiet region, 40–50 Mx cm<sup>-2</sup>)



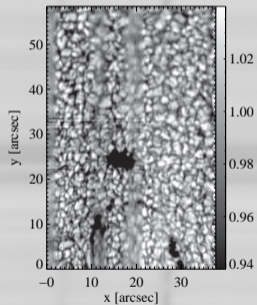
2D-Histogram: B vs.  $\gamma$  (Very quiet region, 40–50 Mx cm<sup>-2</sup>)



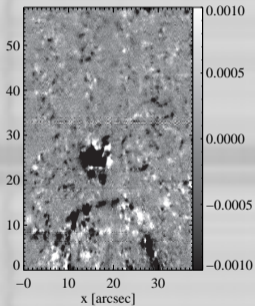
2D-Histogram: B vs.  $\gamma$  (Very quiet region, 40–50 Mx cm<sup>-2</sup>)

## Search for kilo-Gauss fields

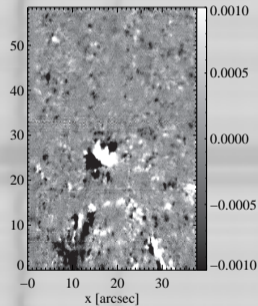
All pixels

 $I_C$ 

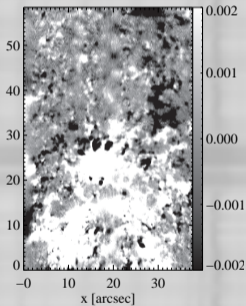
Q



U



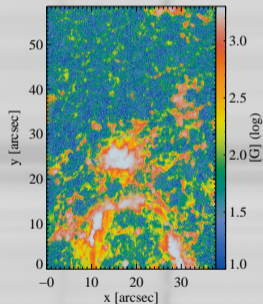
V



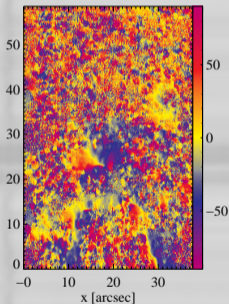
# Search for kilo-Gauss fields

All pixels

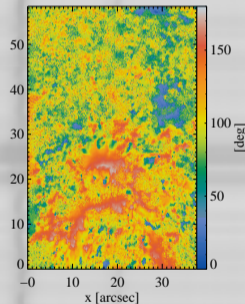
B



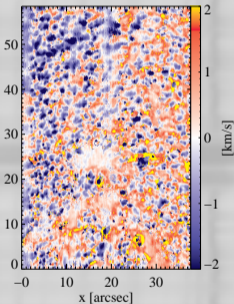
AZI



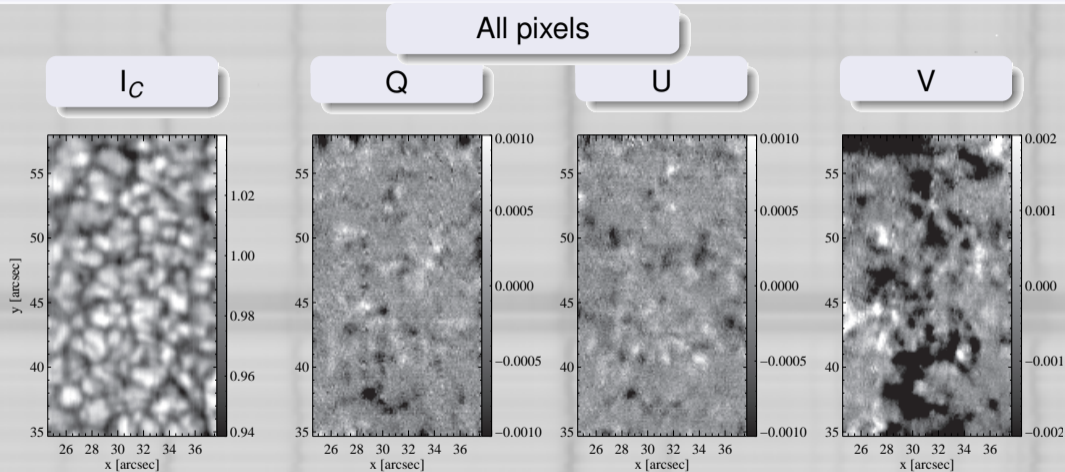
INC



$v_{LOS}$



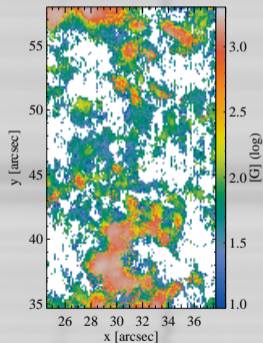
## Search for kilo-Gauss fields



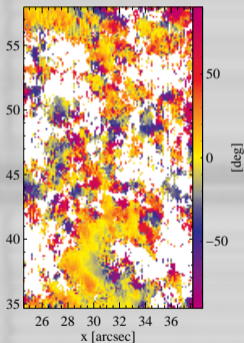
## Search for kilo-Gauss fields

Tot. Pol  $> 3\sigma$ 

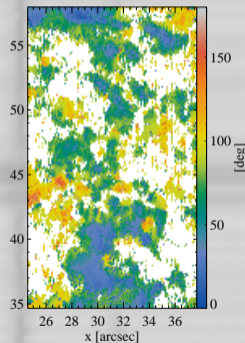
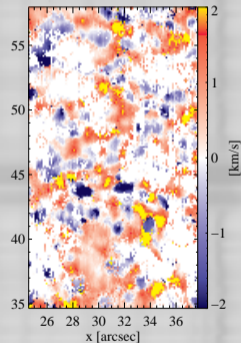
B

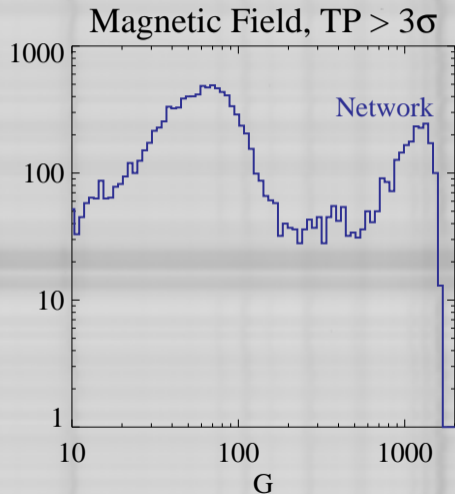
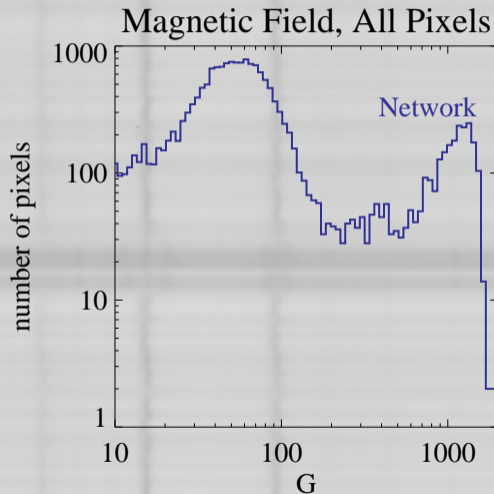


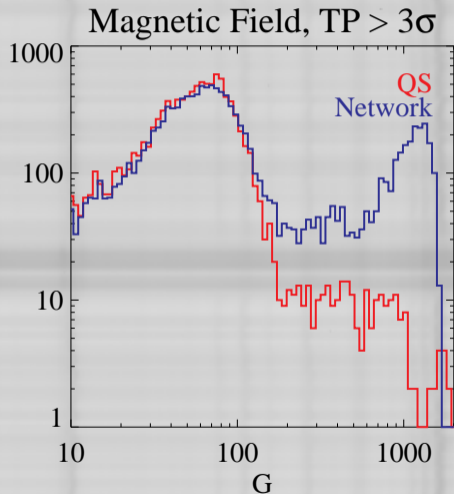
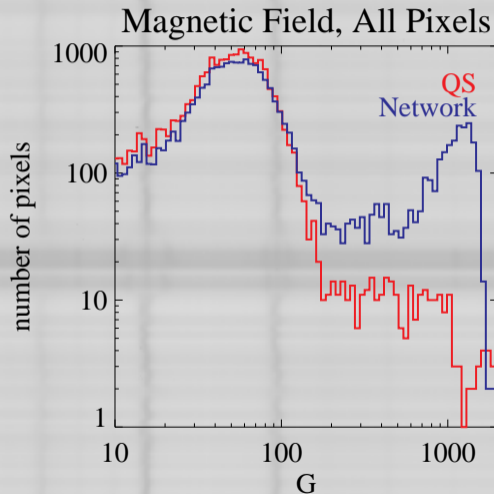
AZI

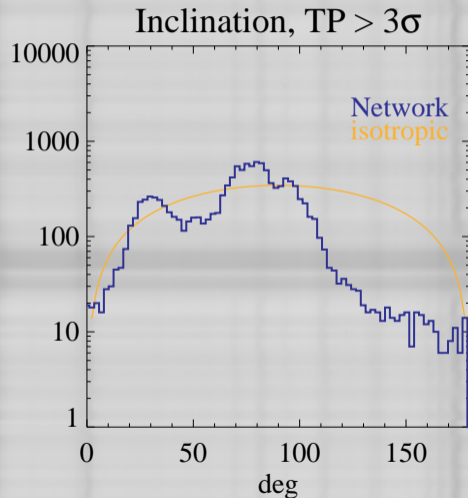
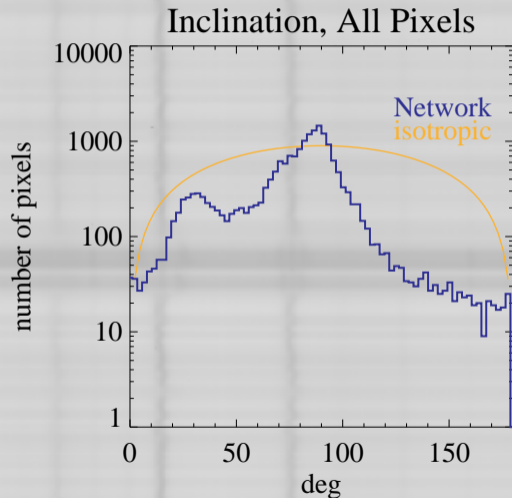


INC

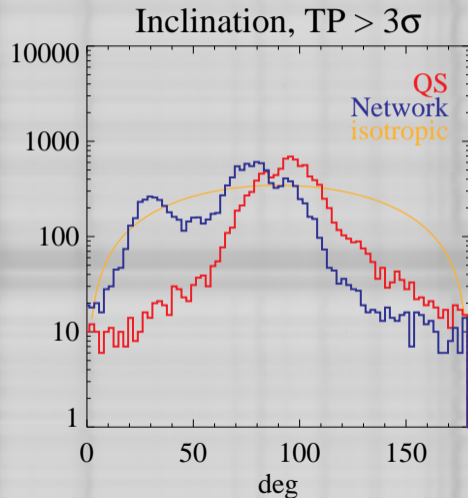
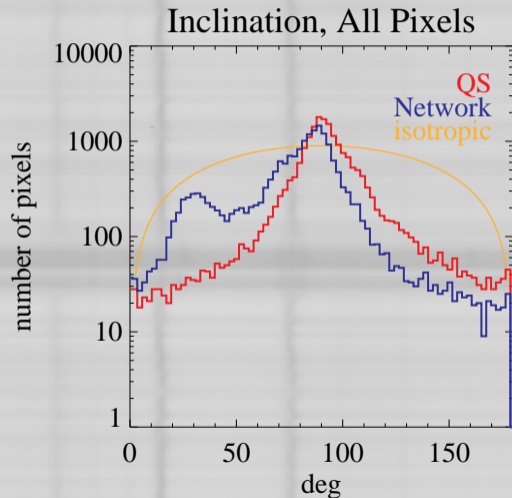
 $v_{LOS}$ 

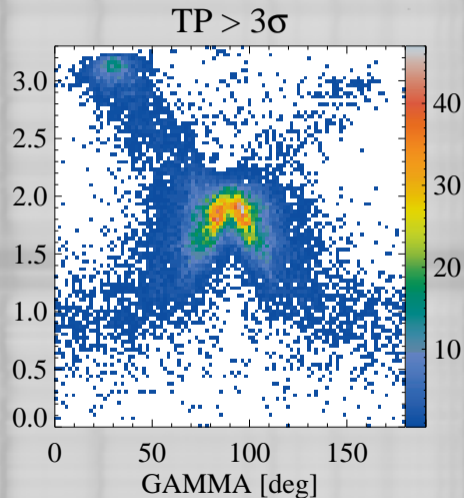
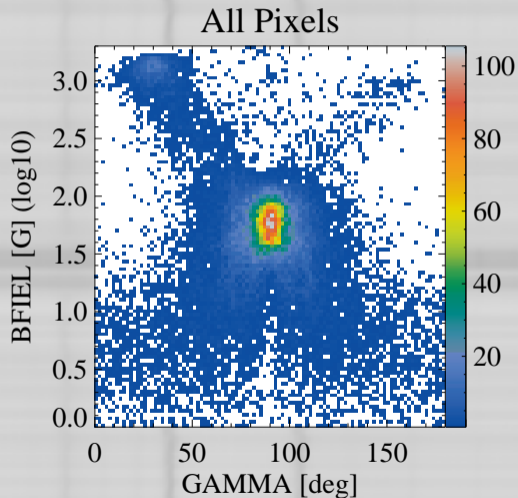
Histogram: Magnetic Field Strength (QS + network fields,  $\approx 150 \text{ Mx cm}^{-2}$ )

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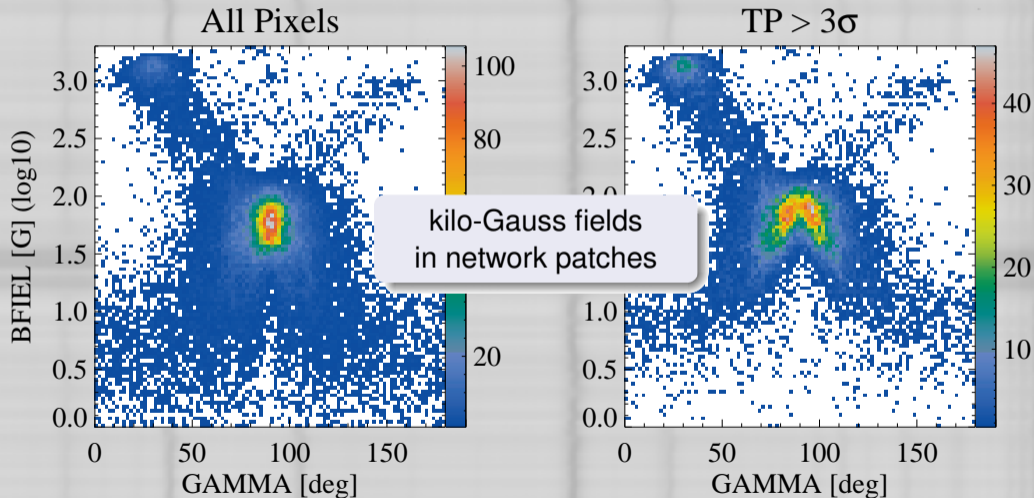
Histogram: Magnetic Field Inclination (QS + network fields,  $\approx 150 \text{ Mx cm}^{-2}$ )

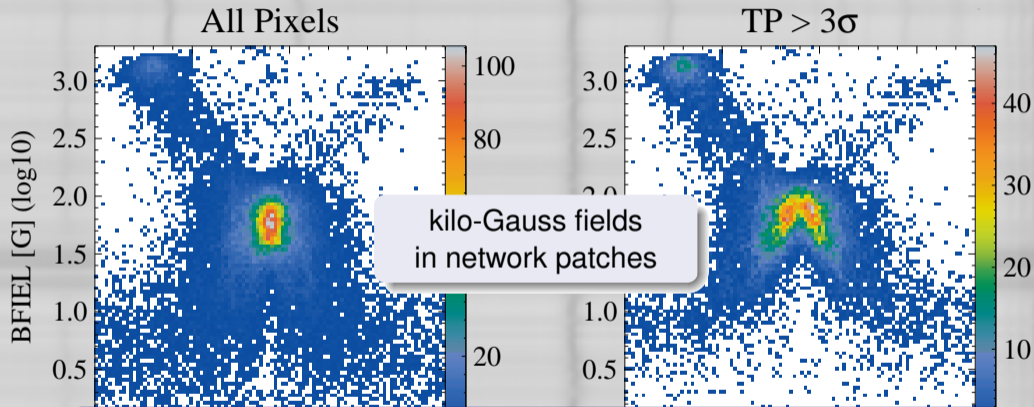


Histogram: Magnetic Field Inclination (QS + network fields,  $\approx 150 \text{ Mx cm}^{-2}$ )

2D-Histogram: B vs.  $\gamma$  (QS + network fields,  $\approx 150 \text{ Mx cm}^{-2}$ )

# 2D-Histogram: B vs. $\gamma$ (QS + network fields, $\approx 150 \text{ Mx cm}^{-2}$ )

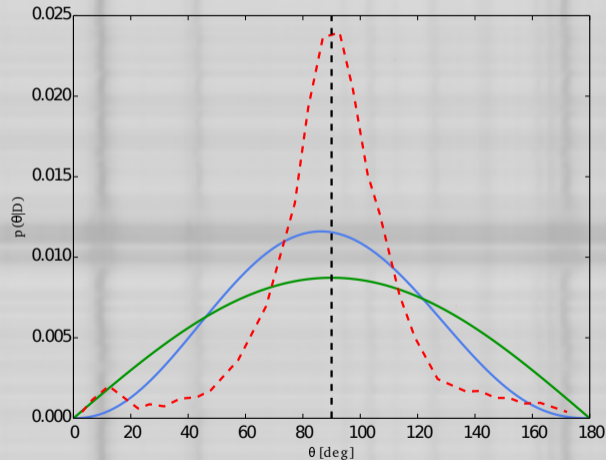
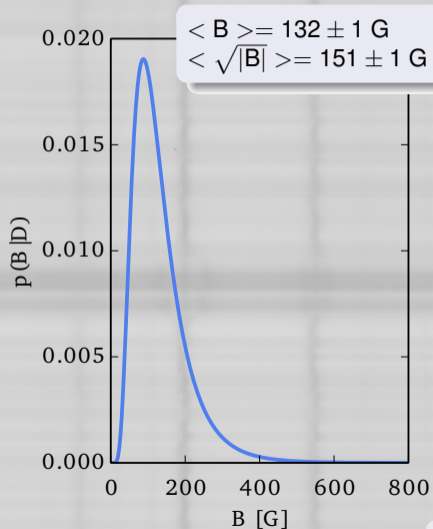


2D-Histogram: B vs.  $\gamma$  (QS + network fields,  $\approx 150 \text{ Mx cm}^{-2}$ )

Stenflo (2010)    “... magnetic dichotomy with two distinct populations”

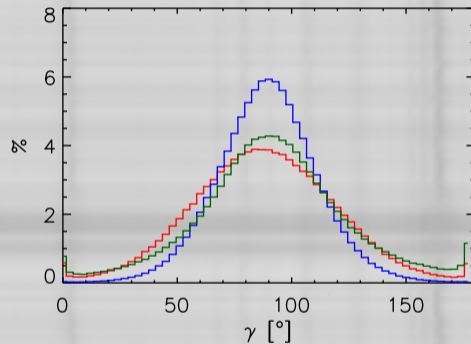
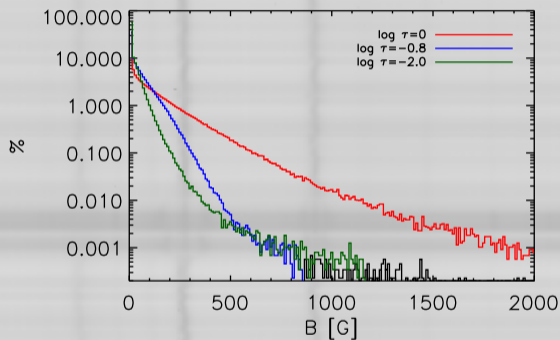
- 1 collapsed: kG, extremely vertical
- 2 uncollapsed: weak fields, asymptotically isotropic at zero flux

## Comparison: Asensio Ramos &amp; Martínez González (2014)



data; isotropic; Bellot Rubio & Orozco Suárez (2012) (dashed)

## Comparison: Danilovic et al. (in preparation)



2D inversions of Hinode data:  $\log \tau = 0$ ;  $\log \tau = -0.8$ ;  $\log \tau = -2.0$

## Quiet Sun & Network: Summary

### Quiet Sun & Network Fields: two distinct populations

- 1 very quiet-Sun region
  - dominated by 10–150 G fields
  - prevalent horizontal
  - previous studies (Hinode): 10–50 G
- 2 quiet-Sun regions with network
  - same distribution as very quiet Sun
  - + mainly vertical,  $> 1$  kG fields

In-between bins sparsely populated (few hG fields and intermediate inclinations)

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## Future work

- improve inversion technique (HeI $\lambda$  10830 → SPINOR)
- investigate Fe I 1.56  $\mu$ m line properties
- observations:  $\mu = 1$ , larger FOV (statistics, both network polarities)



## GREGOR/GRIS improvements planned for 2015

### 2015 improvements @ GREGOR

- derotator  
→ allows for longer scans
- Ag recoating  
→ increases photon flux  $\times 2$
- alignment  
→ decreases beam wobble

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## Goal

- diffraction limited performance 1–2.2  $\mu\text{m}$
- scans with high S/N at all activity levels
- off-limb prominence / spicule observations
- wave studies: fixed-slit time series

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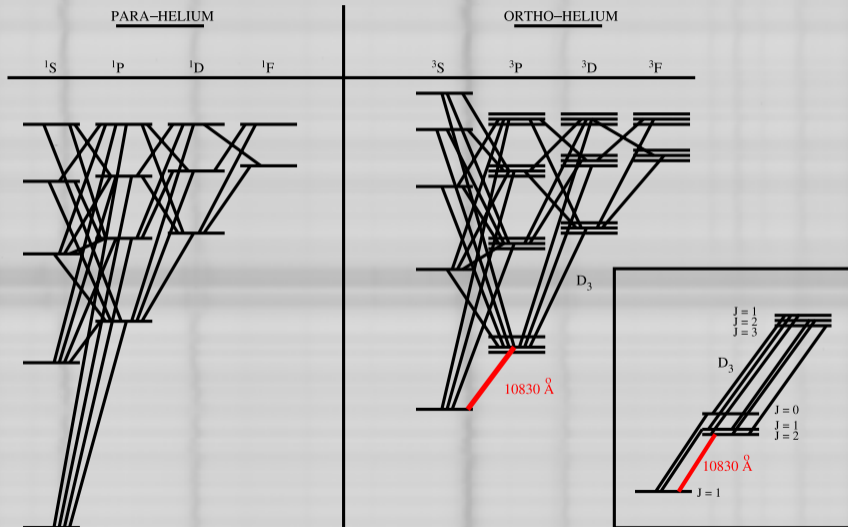
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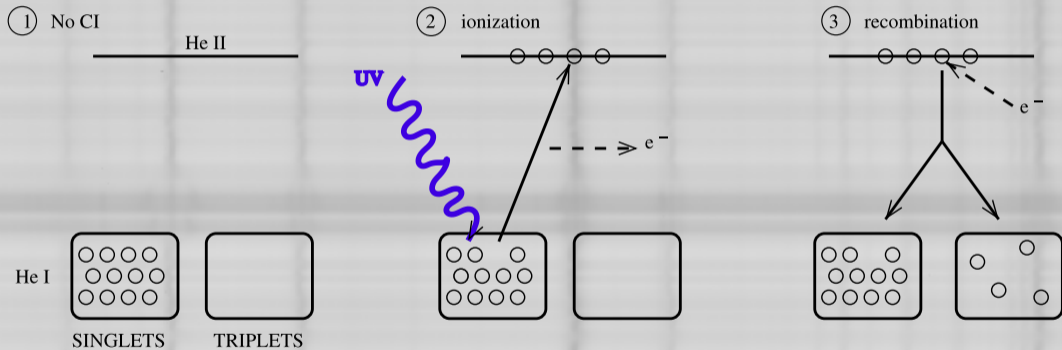
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## The He I atom (Centeno et al., 2008)



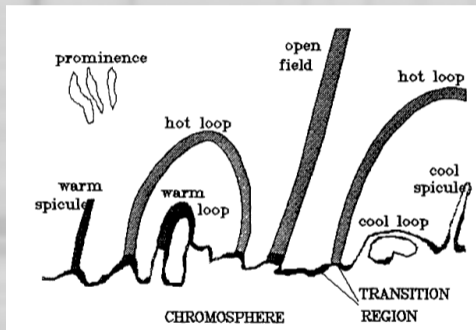
## Coronal Illumination - Ionization - Recombination (Centeno et al., 2008)



He I – What can be observed?

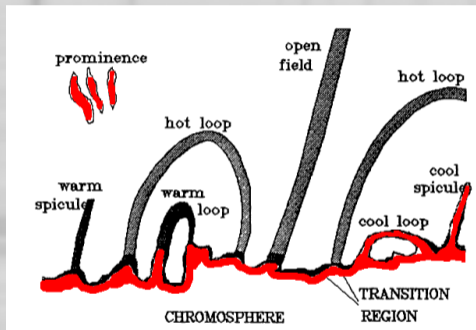


# He I – Formation Height



Avrett et al. (1994)

# He I – Formation Height

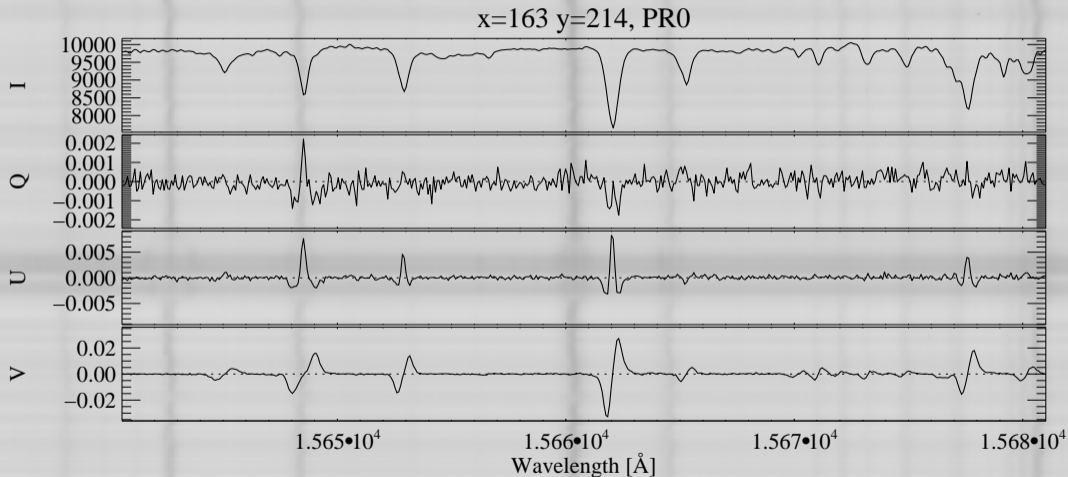


Avrett et al. (1994)







GRIS@1.56 $\mu\text{m}$ : Spectral region

— observed