

# Quiet-sun fields with GRIS 1.56 $\mu\text{m}$

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MAX-PLANCK-GESELLSCHAFT



## Summary

Author	Result	Notes
Orozco Suárez et al. 2007	$P(\gamma) \simeq \delta(\gamma - 90)$	
Orozco Suárez & Bellot Rubio 2012		
Lites et al. 2008	$P(\gamma) \not\approx \delta(\gamma - 90)$	
Borrero & Kobel 2011		
Ishikawa & Tsuneta 2011	$P(\gamma) \simeq \delta(\gamma - 0)$	
Martínez González et al. 2008	$P(\gamma) \simeq \sin \gamma$	
Asensio Ramos 2009		
Borrero & Kobel 2013	$P(\gamma) \not\approx \sin \gamma$	
Asensio Ramos & Martínez González 2014	$P(\gamma) \simeq A\delta(\gamma - 90) + B\sin \gamma$	$A \approx B$
Stenflo 2010	$P(\gamma) \simeq A\delta(\gamma - 0) + B\sin \gamma$	$A \gg B$
Steiner & Rezaei 2012	$P(\gamma) \not\approx A\delta(\gamma - 0) + B\sin \gamma$	

Author	Result
Orozco & Katsukawa 2012	Fields more horizontal at $\mu = 1$ than at $\mu = 0.1$
Borrero & Kobel 2013	Fields more horizontal at $\mu = 1$ than at $\mu = 0.7$
Stenflo 2014	Fields more vertical at $\mu = 0.5$ than at $\mu = 0.1$

*Of torturers and detainees ...*

Juan Manuel Borrero  
borrero@kis.  
uni-freiburg.de

Outline

Disclaimers

Reference frames

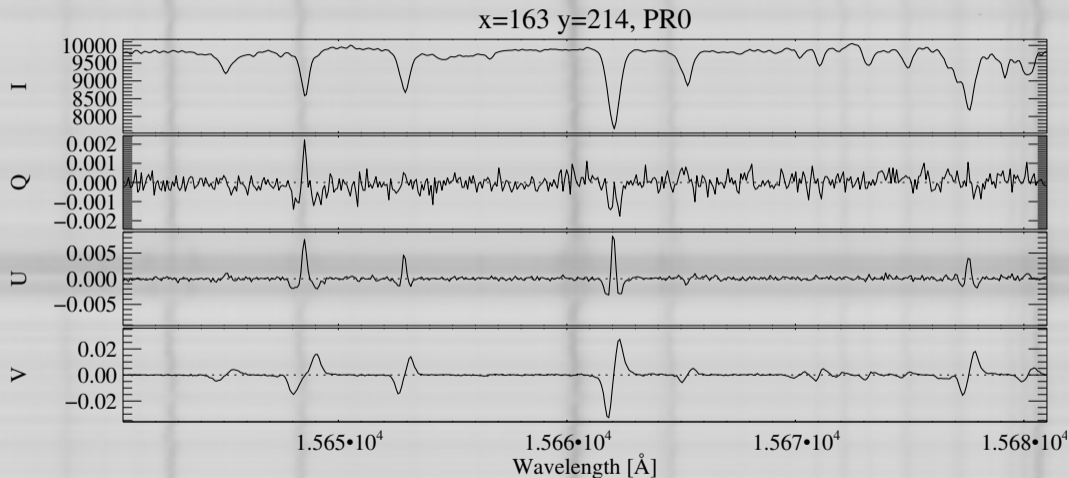
Disclaimers

Studies at  $\mu = 1$

Studies at different  $\mu$ 's

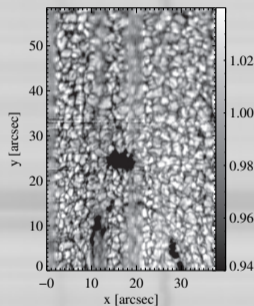
Summary

Conclusions

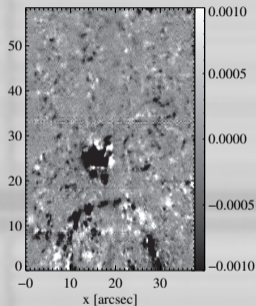
GRIS@1.56 $\mu$ m: Spectral region

— observed

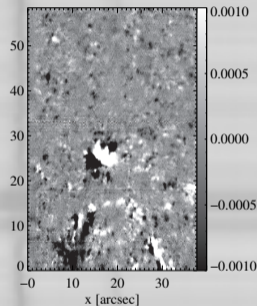
## Scan of pore with quiet sun region (2014-Sep-08)

 $I_C$ 

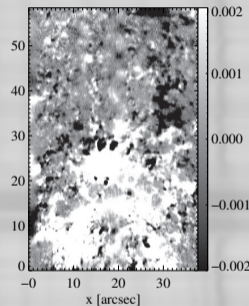
Q



U



V

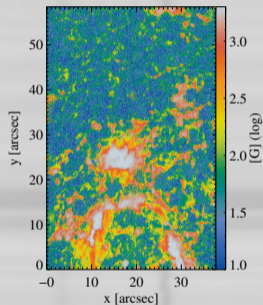


- $x, y = 455'', 247''$  ( $\mu = 0.84$ )
- exp. time: 1 s/pixel and mod. state
- noise level (unbinned):  $4 \cdot 10^{-4} I_C$

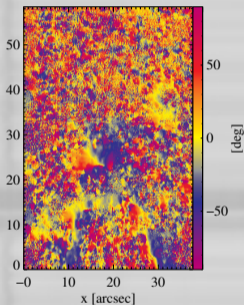
- $\lambda/\Delta\lambda \geq 150000$ , 40 mÅ sampling
- spatial resolution:  $0''.35$  (close to diff. limit), sampling:  $0''.126$

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

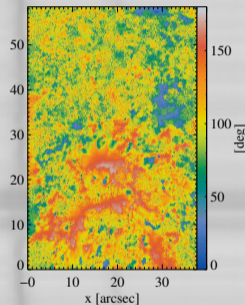
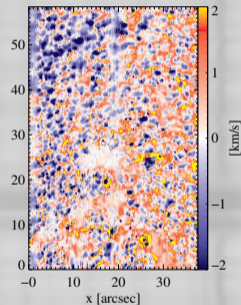
B



AZI



INC

 $v_{\text{LOS}}$ 

## Inversion setup

- Milne Eddington in 6 Fe I lines

15631 – 15665 Å, line strength as free parameter

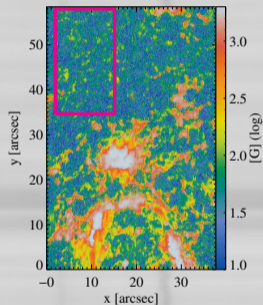
- free parameters

$B$ ,  $\phi$ ,  $\gamma$ ,  $v_{\text{LOS}}$ ,  $v_D$ ,  $a$ ,  $S_1$ ,  $\eta_0$ ,  $\alpha$

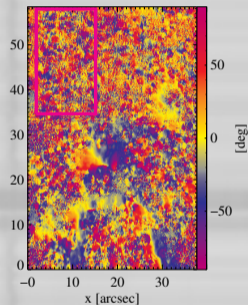
- global straylight (broad PSF wings)

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

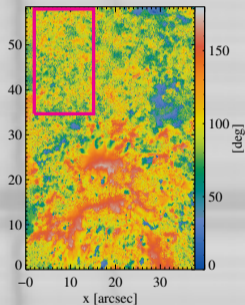
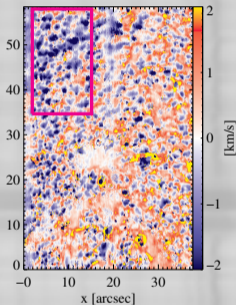
B



AZI



INC

 $v_{\text{LOS}}$ 

## Inversion setup

- Milne Eddington in 6 Fe I lines

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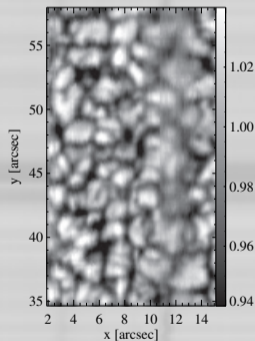
$B, \phi, \gamma, v_{\text{LOS}}, v_D, a, S_1, \eta_0, \alpha$

- global straylight (broad PSF wings)

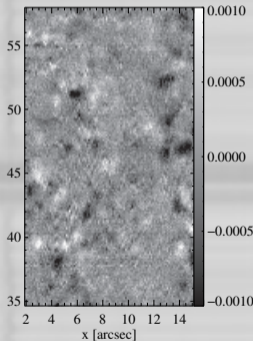
# Very quiet sun region (2014-Sep-08)

All pixels

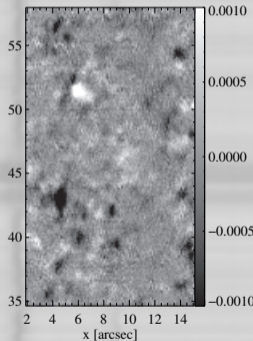
$I_C$



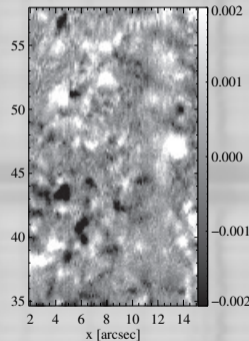
Q



U



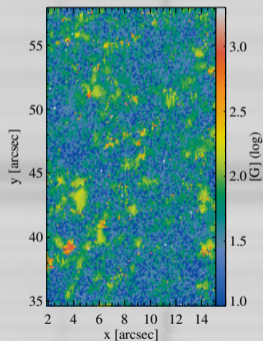
V



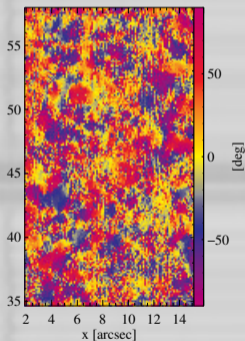
# Very quiet sun region (2014-Sep-08)

All pixels

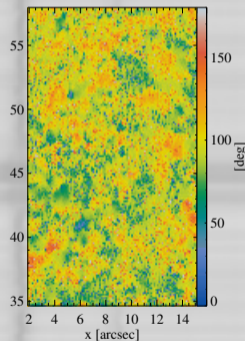
B



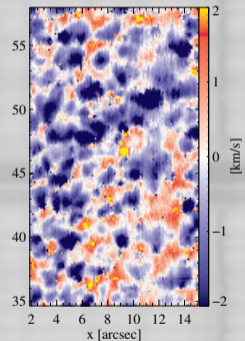
AZI



INC



$v_{LOS}$

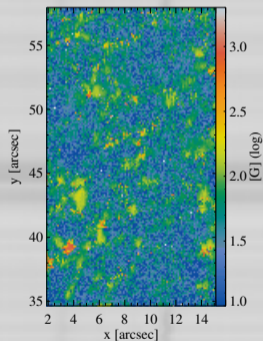




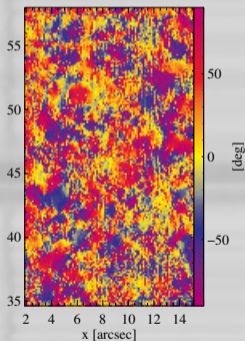
# Very quiet sun region (2014-Sep-08)

All pixels

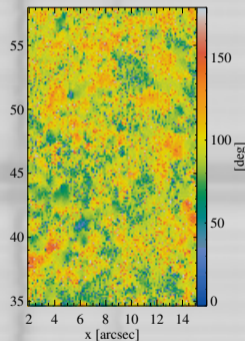
B



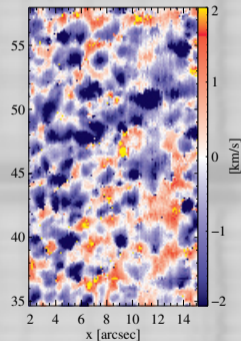
AZI



INC



$v_{\text{LOS}}$

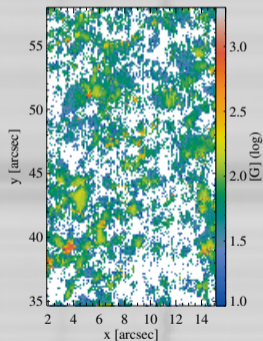


remove all pixels with low signals  
Survival of IG lanes or granules?

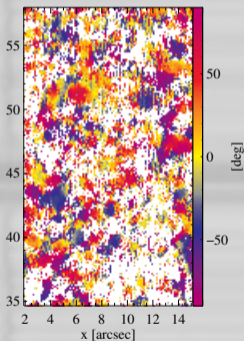
# Very quiet sun region (2014-Sep-08)

$$[(Q \vee U) > 3\sigma] \vee [V > 4.5\sigma]$$

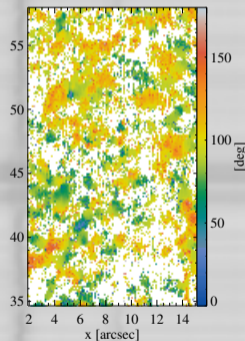
B



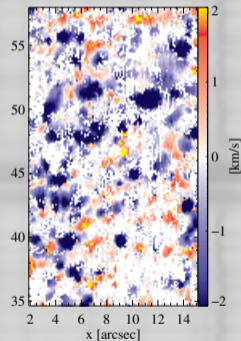
AZI



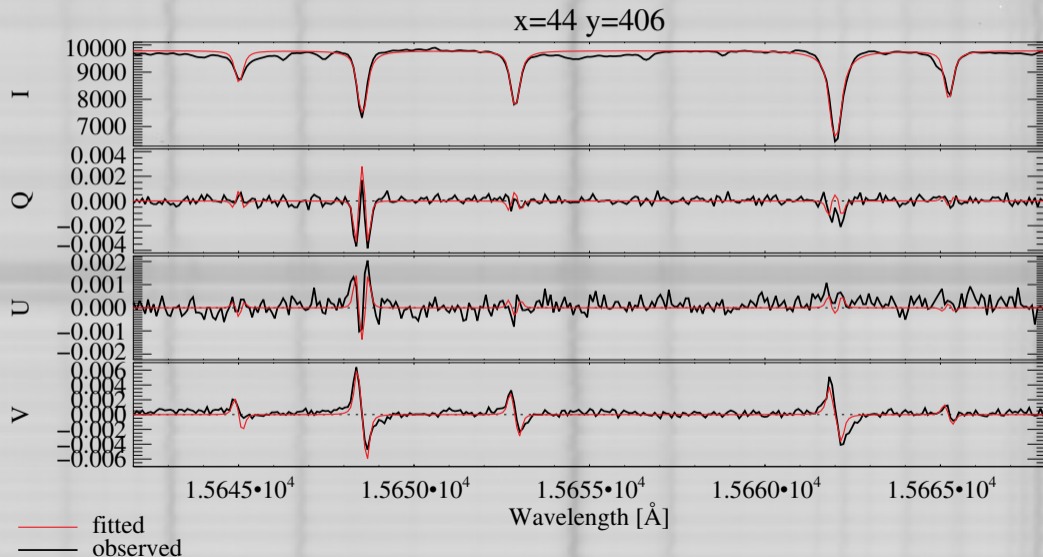
INC



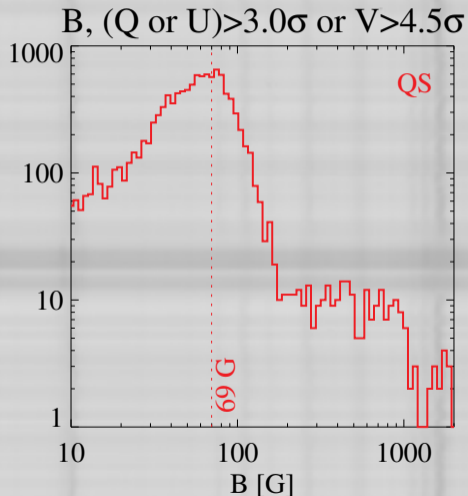
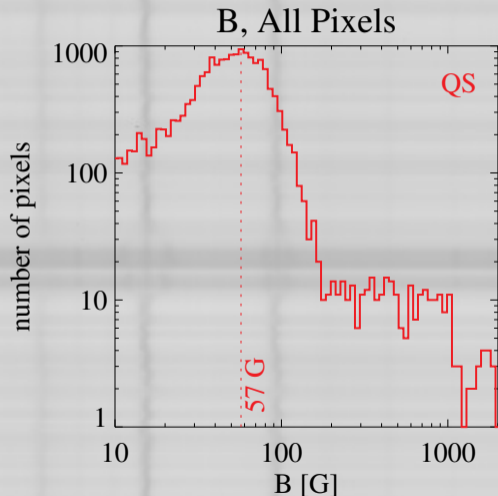
$V_{LOS}$



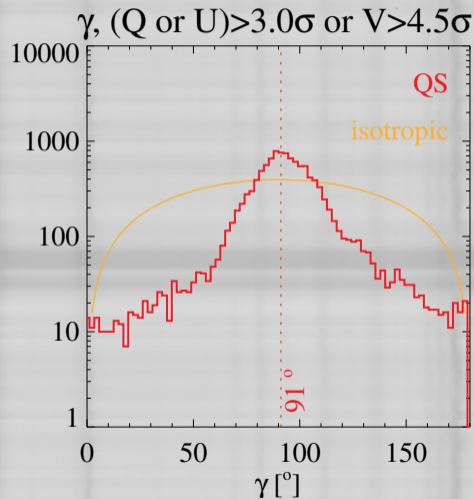
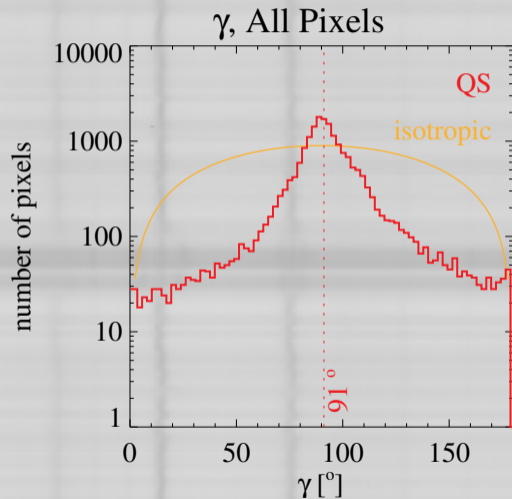
Mainly granules!  
... and some IG lanes

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

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

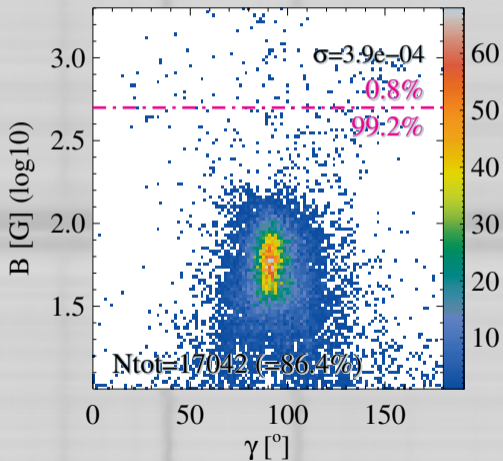


Hinode based studies: 10–50 G

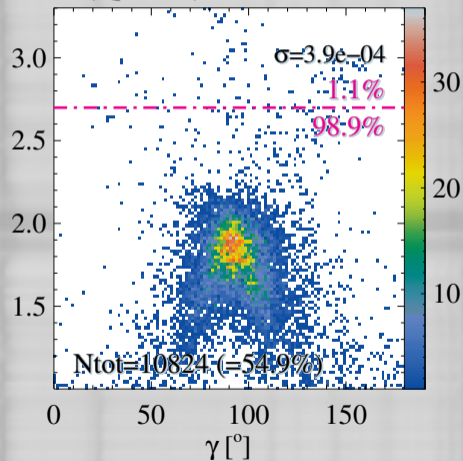
Histogram: Magnetic Field Inclination (Very quiet region, 40–50 Mx cm<sup>-2</sup>)

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

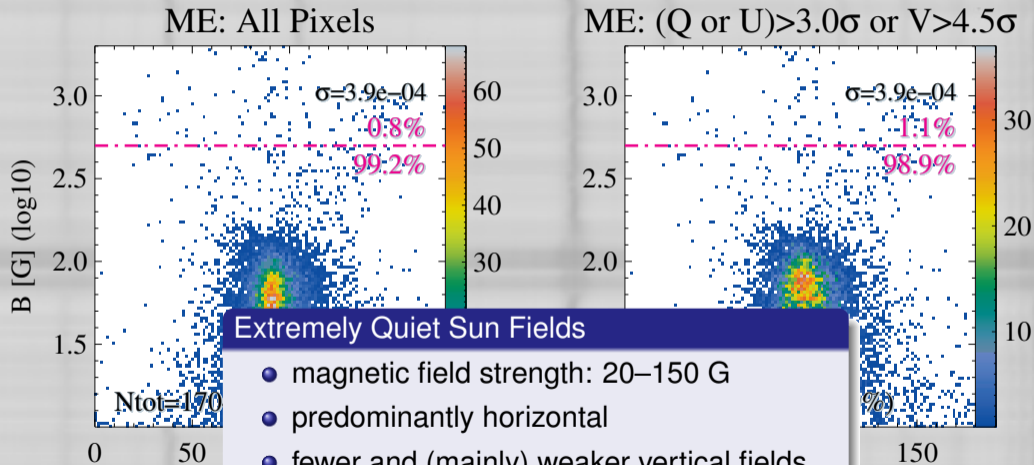
ME: All Pixels



ME: (Q or U) > 3.0 $\sigma$  or V > 4.5 $\sigma$



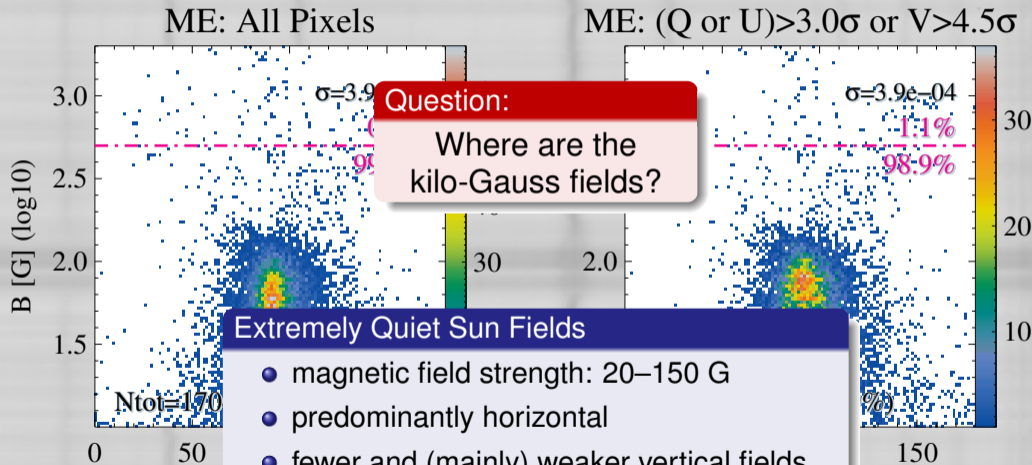
## 2D-Histogram: B vs. $\gamma$ (Very quiet region, 40–50 Mx cm<sup>-2</sup>)



**Extremely Quiet Sun Fields**

- magnetic field strength: 20–150 G
- predominantly horizontal
- fewer and (mainly) weaker vertical fields resulting from tiny Stokes V signals

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



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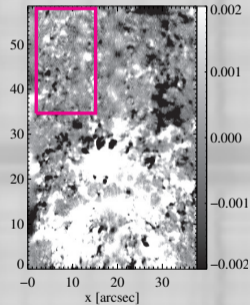
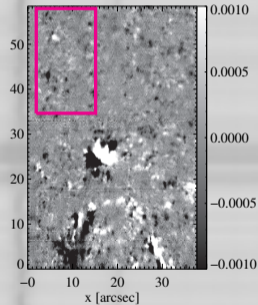
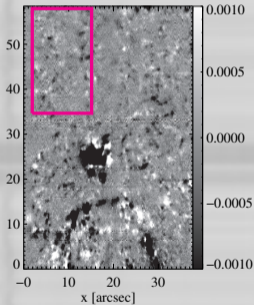
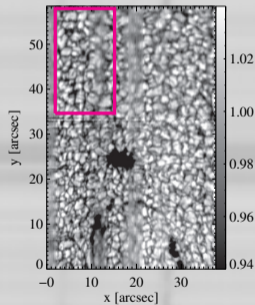
All pixels

$I_C$

Q

U

V



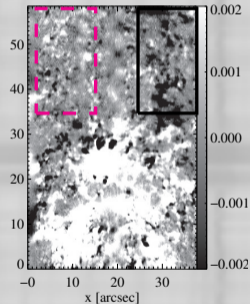
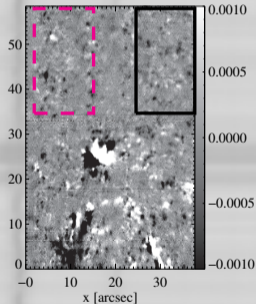
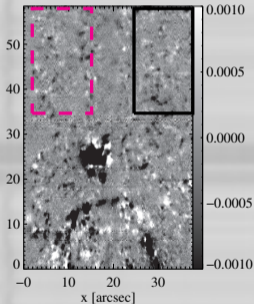
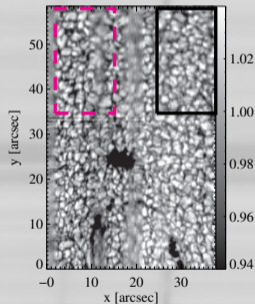
All pixels

$I_C$

Q

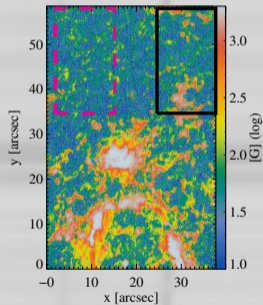
U

V

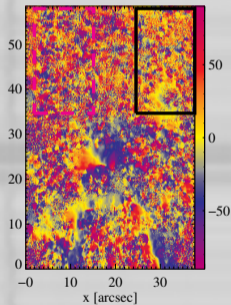


All pixels

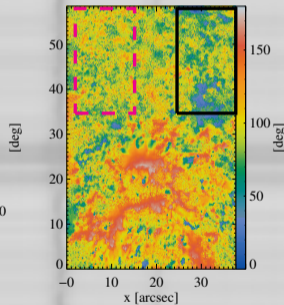
B



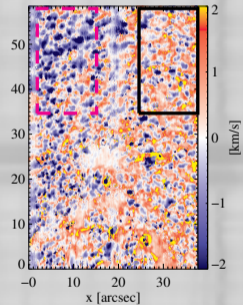
AZI



INC



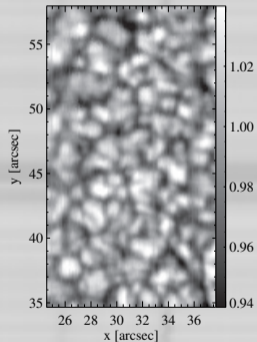
$v_{\text{LOS}}$



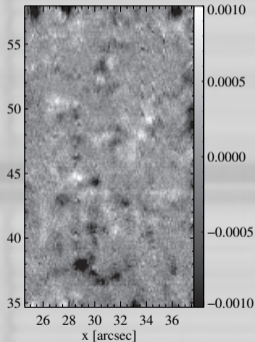
# Search for kilo-Gauss fields

All pixels

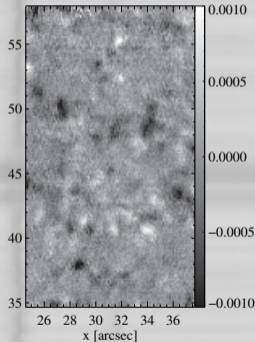
$I_C$



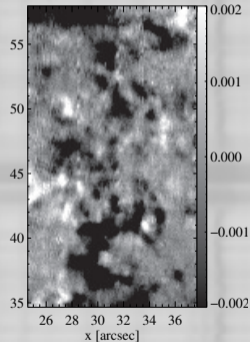
Q



U

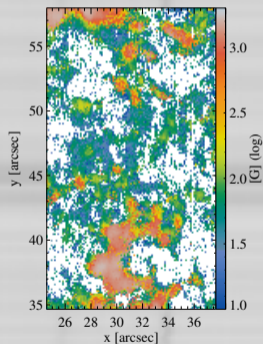


V

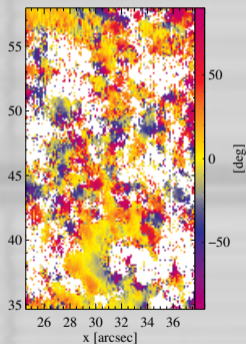


$$[(Q \vee U) > 3\sigma] \vee [V > 4.5\sigma]$$

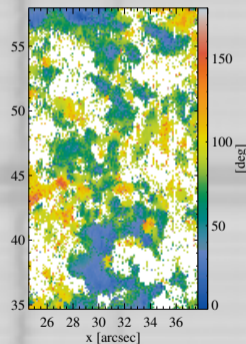
B



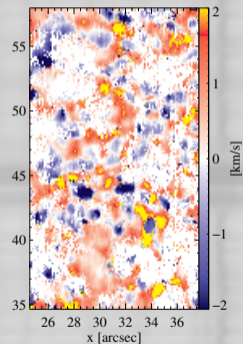
AZI

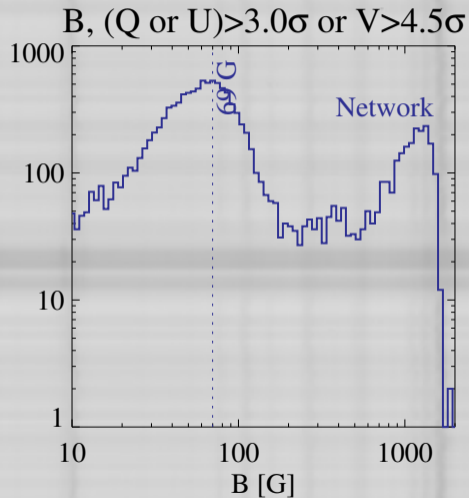
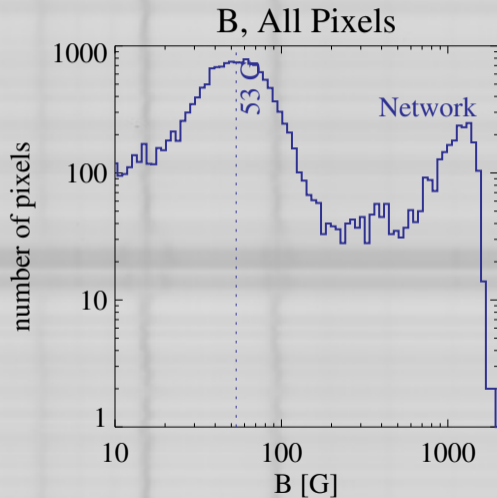


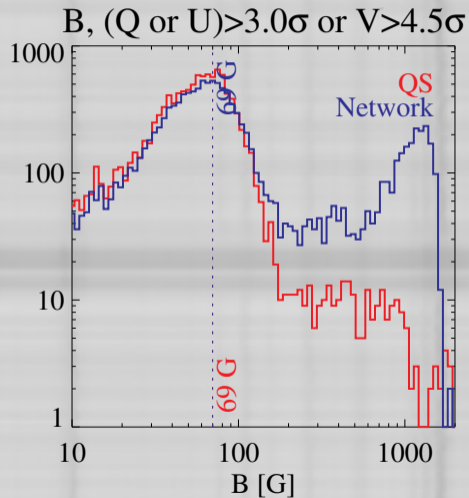
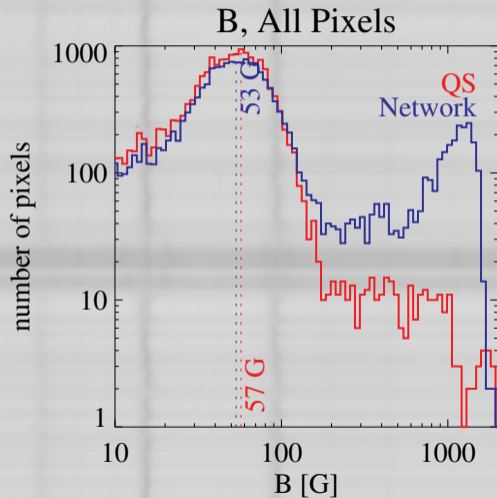
INC

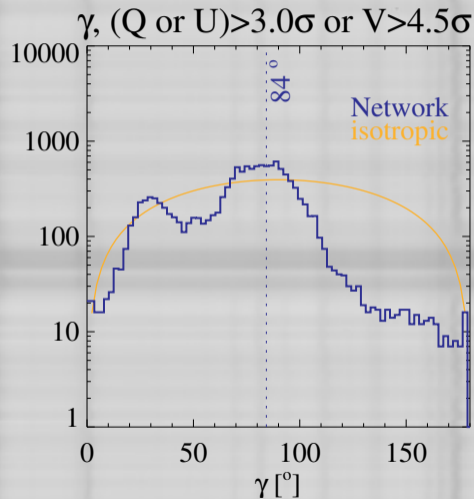
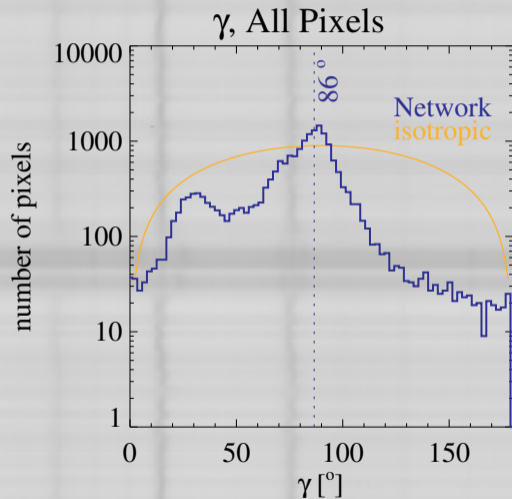


$v_{LOS}$

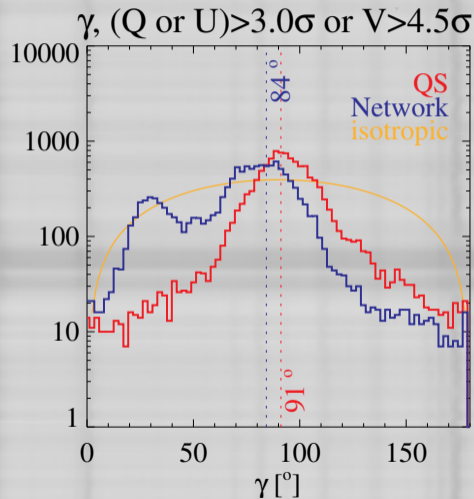
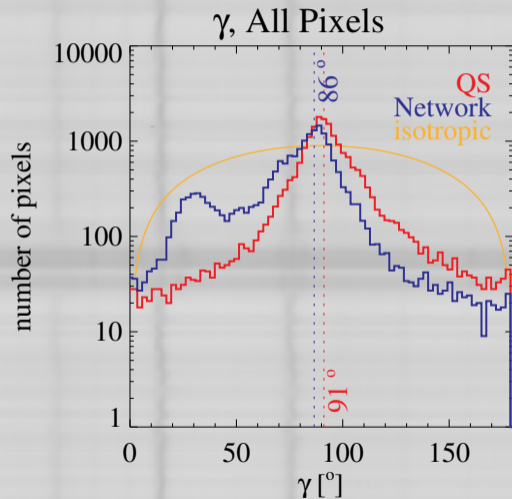


Histogram: Magnetic Field Strength (QS + network fields,  $\approx 150 \text{ Mx cm}^{-2}$ )

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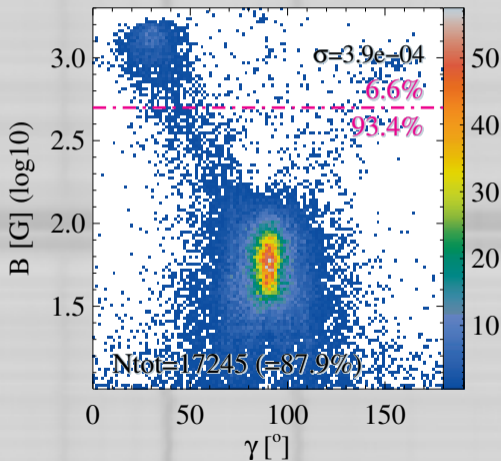
Histogram: Magnetic Field Inclination (QS + network fields,  $\approx 150 \text{ Mx cm}^{-2}$ )



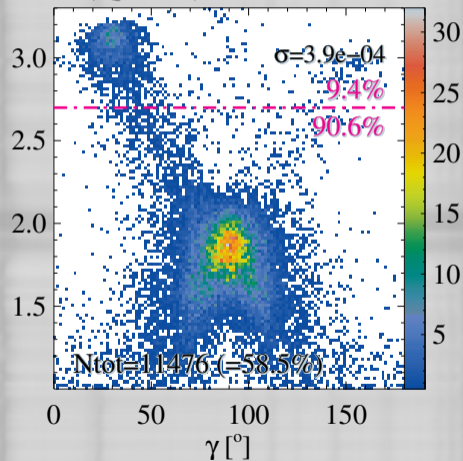
Histogram: Magnetic Field Inclination (QS + network fields,  $\approx 150 \text{ Mx cm}^{-2}$ )

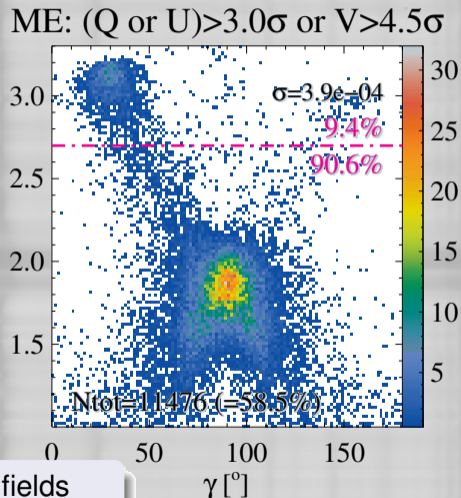
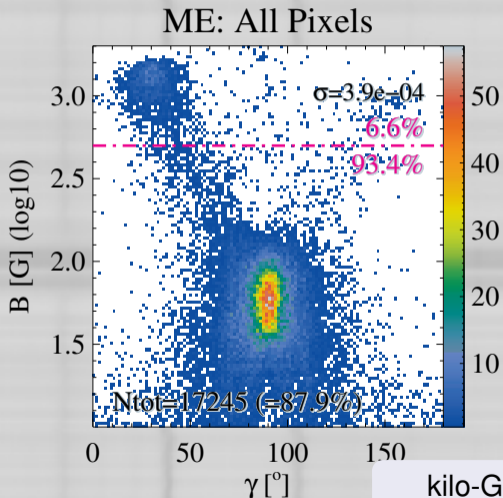
2D-Histogram: B vs.  $\gamma$  (QS + network fields,  $\approx 150 \text{ Mx cm}^{-2}$ )

ME: All Pixels

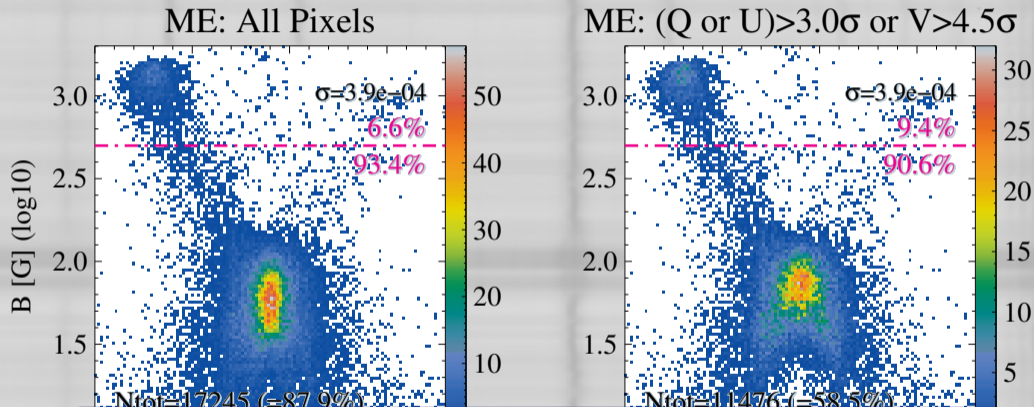


ME: (Q or U)  $> 3.0\sigma$  or V  $> 4.5\sigma$



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

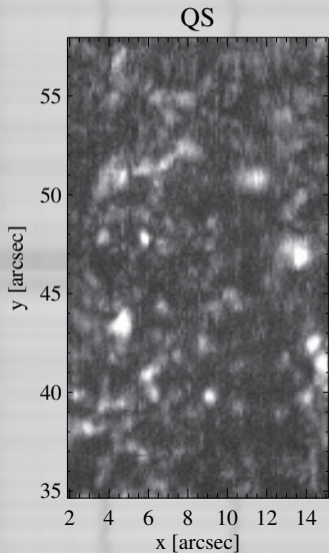
kilo-Gauss fields  
in network patches

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

# S/N Study: Stokes maps: QUV flags

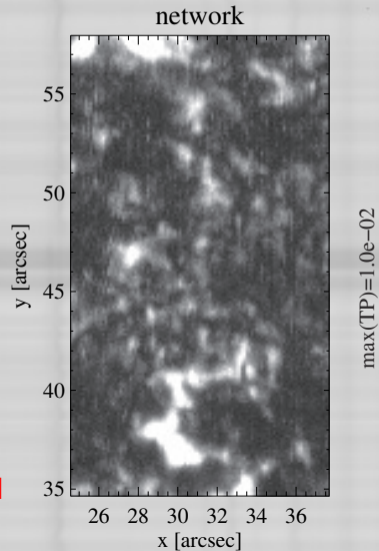


max(TP)=1.0e-02

inter-  
mediate  
incl.

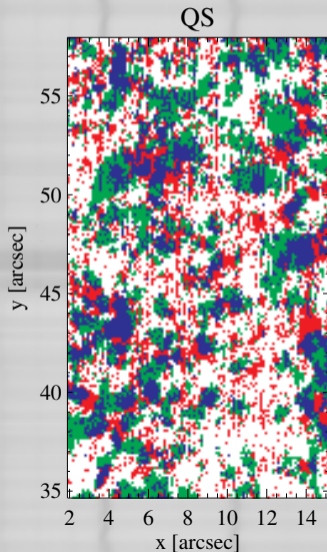
mainly  
vertical

mainly  
horizontal



max(TP)=1.0e-02

## S/N Study: Stokes maps: QUV flags



(Q or U) > 3.0 $\sigma$   
V > 4.5 $\sigma$   
(18.4%)

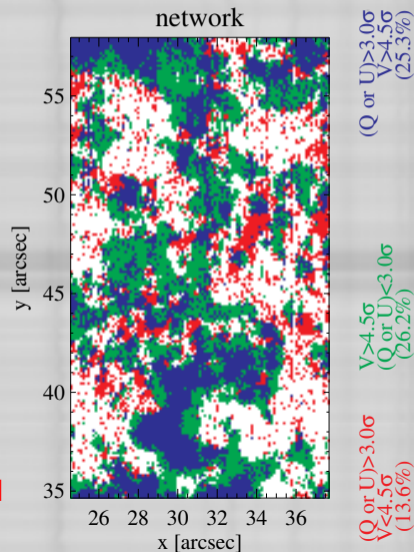
inter-  
mediate  
incl.

V > 4.5 $\sigma$   
(Q or U) < 3.0 $\sigma$   
(21.3%)

mainly  
vertical

(Q or U) > 3.0 $\sigma$   
V < 4.5 $\sigma$   
(18.9%)

mainly  
horizontal



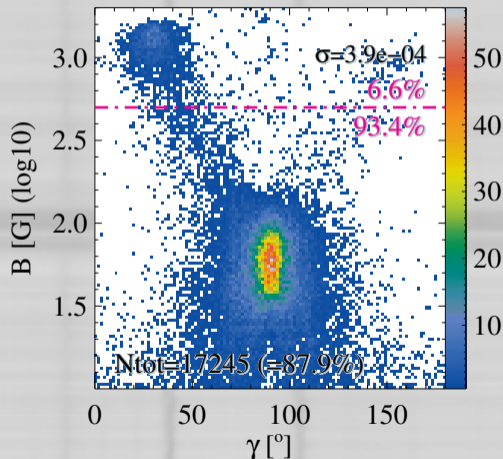
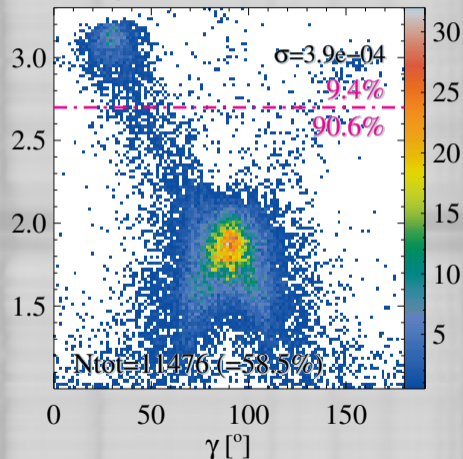
(Q or U) > 3.0 $\sigma$   
V > 4.5 $\sigma$   
(25.3%)

V > 4.5 $\sigma$   
(Q or U) < 3.0 $\sigma$   
(26.2%)

(Q or U) > 3.0 $\sigma$   
V < 4.5 $\sigma$   
(13.6%)

## S/N Study: Histograms

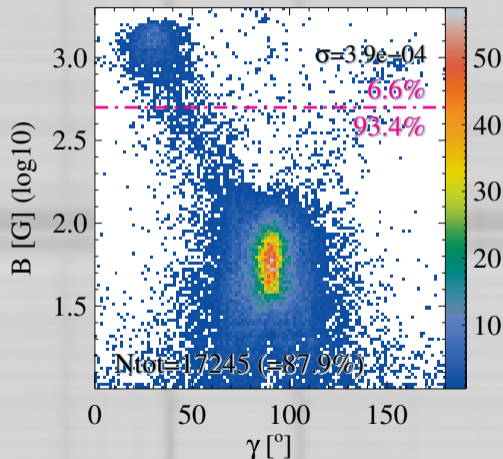
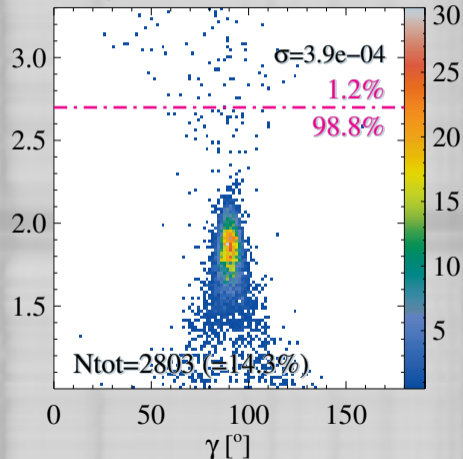
ME: All Pixels

ME: (Q or U) > 3.0 $\sigma$  or V > 4.5 $\sigma$ 

Selection: "robust" results

## S/N Study: Histograms

ME: All Pixels

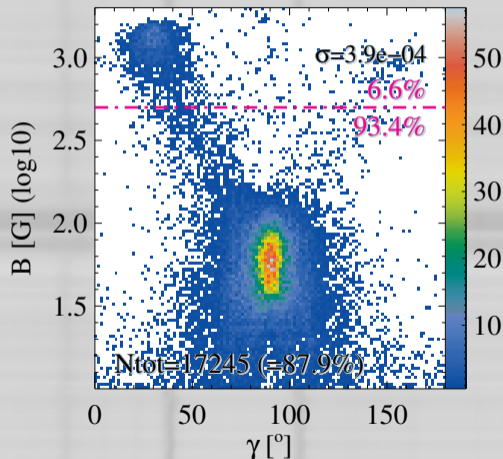
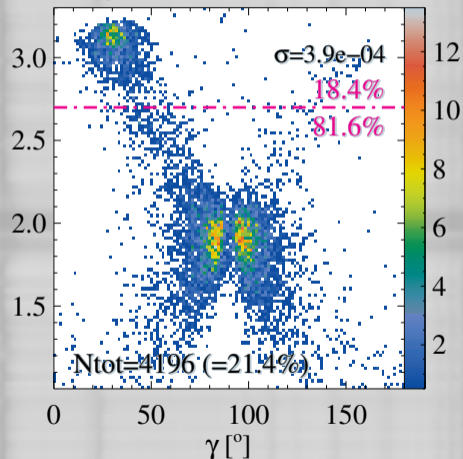
ME: (Q or U) > 3.0 $\sigma$  and V < 4.5 $\sigma$ 

Selection: "only horizontal"



## S/N Study: Histograms

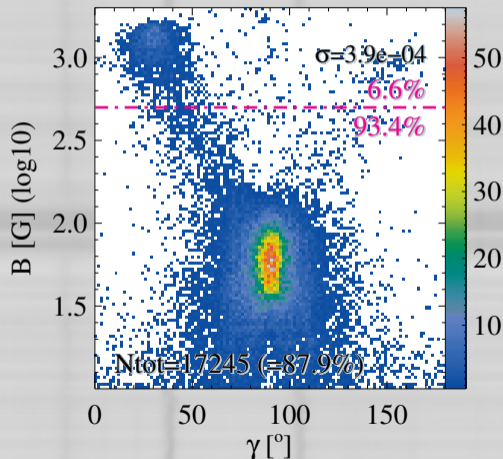
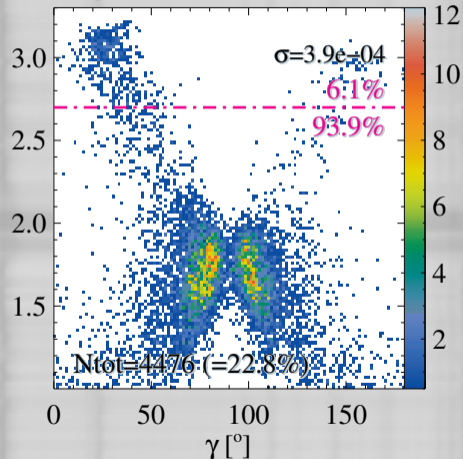
ME: All Pixels

ME: (Q or U) > 3.0 $\sigma$  and V > 4.5 $\sigma$ 

Selection: "intermediate inclinations"

## S/N Study: Histograms

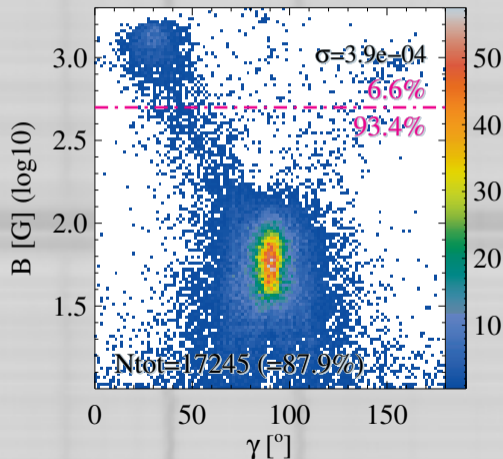
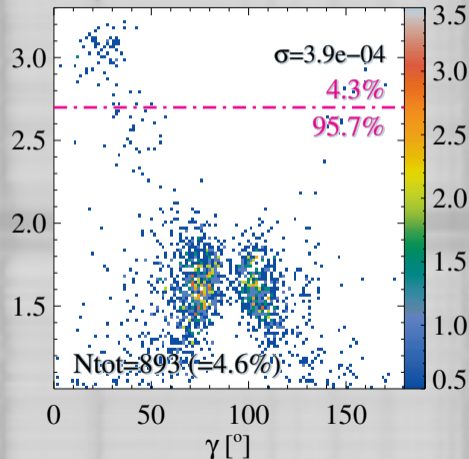
ME: All Pixels

ME: (Q and U) < 3.0 $\sigma$  and V > 4.5 $\sigma$ 

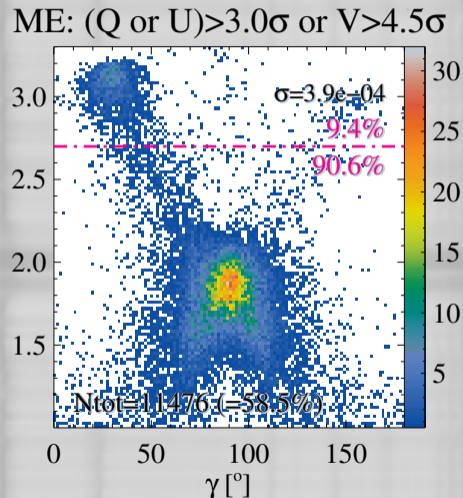
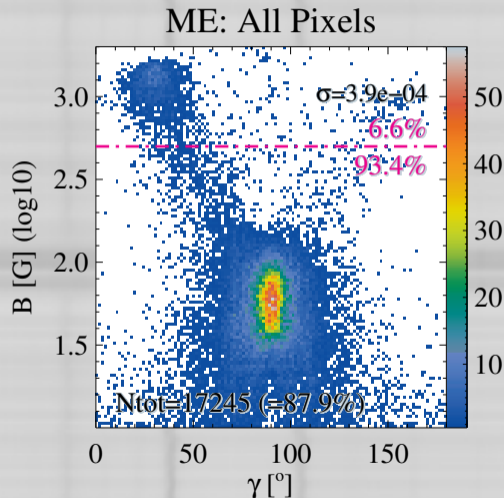
Selection: "vertical"

## S/N Study: Histograms

ME: All Pixels

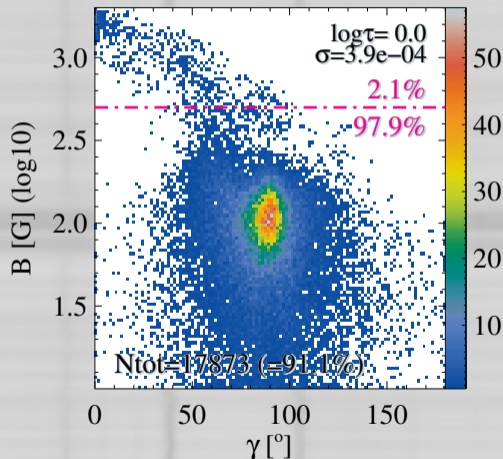
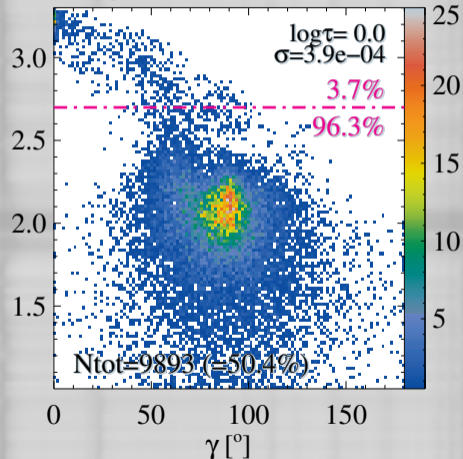
ME: (Q and U) < 2.0 $\sigma$  and V > 4.5 $\sigma$ 

Selection: "strictly vertical"

Comparison ME to SPINOR inversions:  $\log \tau = 0.0$ 

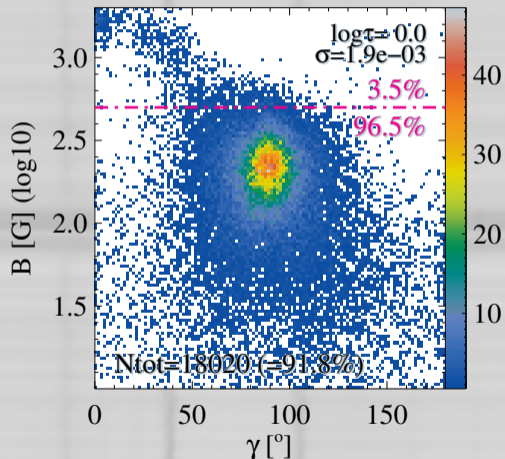
SPINOR inversions: simple 1D,  $\log \tau = 0.0$ 

1D: All Pixels

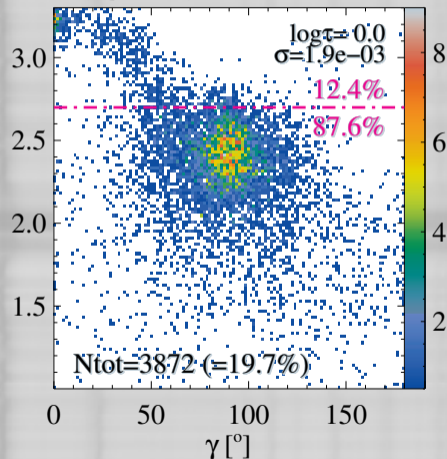
1D:  $(Q \text{ or } U) > 3.0\sigma$  or  $V > 4.5\sigma$ 

SPINOR inversions: local straylight removed,  $\log \tau = 0.0$

LS: All Pixels

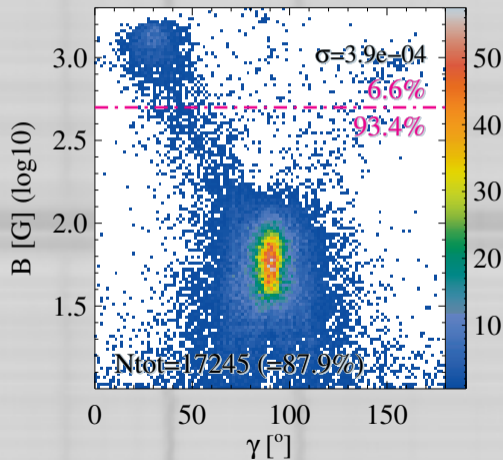
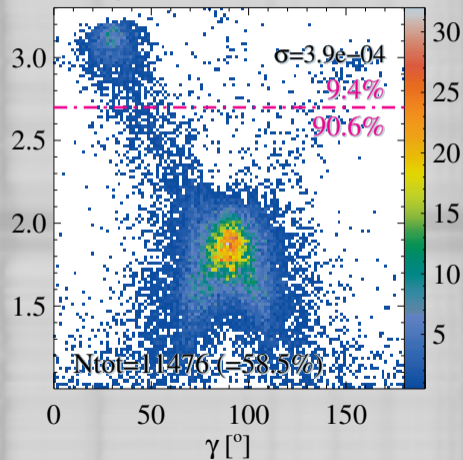


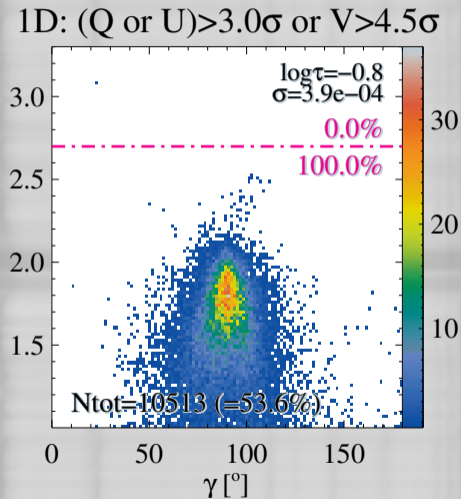
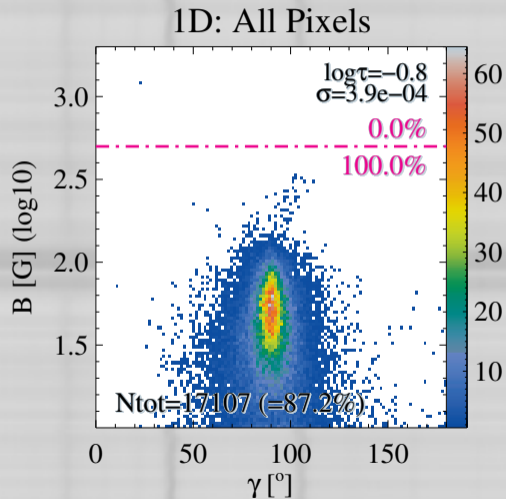
LS:  $(Q \text{ or } U) > 3.0\sigma$  or  $V > 4.5\sigma$



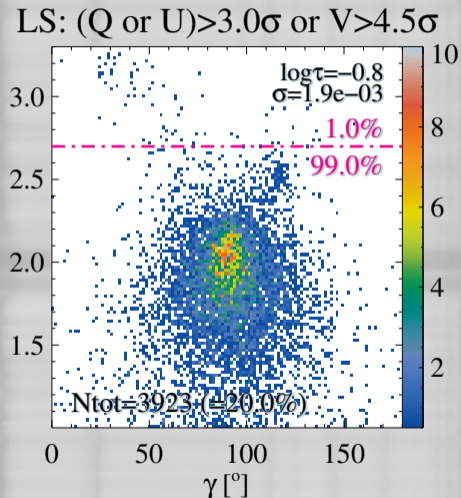
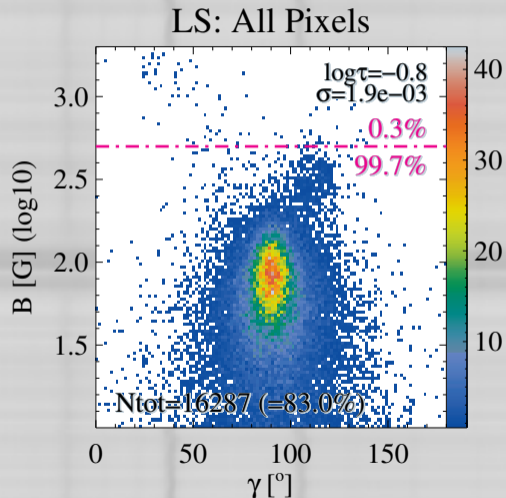
Comparison ME to SPINOR inversions:  $\log \tau = -0.8$ 

ME: All Pixels

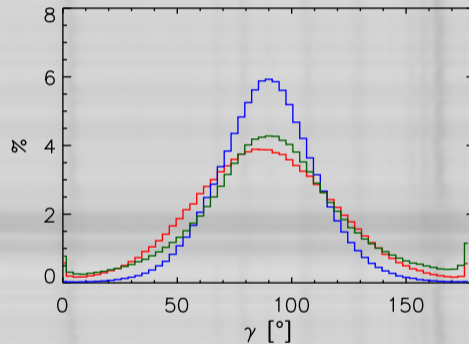
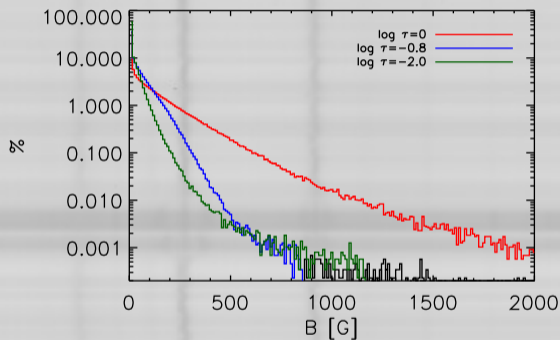
ME: (Q or U) > 3.0 $\sigma$  or V > 4.5 $\sigma$ 

SPINOR inversions: simple 1D,  $\log \tau = -0.8$ 



SPINOR inversions: local straylight removed,  $\log \tau = -0.8$ 

## 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 Fields: two distinct populations

### 1 very quiet-Sun region

- prevalent horizontal
- dominated by weak fields:

inversion	$\log \tau = -0.8$	$\log \tau = 0$
ME	50–150 G	
1D	30–100 G	50–200 G
LS removed	30–100 G	80–400 G

- no kG fields
- ### 2 quiet-Sun regions with network
- same distribution as very quiet Sun
  - + mainly vertical,  $> 1$  kG fields
  - kG fields only in deepest layer

In-between bins are sparsely populated:  
few hG fields & intervening inclinations

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