Quiet-Sun Photospheric Fields

New insights with GREGOR / GRIS

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MAX-PLANCK-GESELLSCHAFT

2nd International Sino-German Symposium on Solar Physics

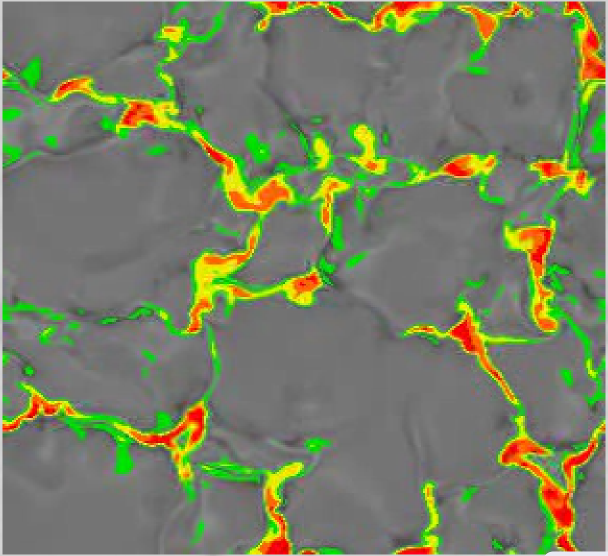
Multi Waveband Observations and Modeling of Solar Activity

Aug 31 – Sep 4 2015, Bad Honnef

MPS

Relevance

- QS magnetism covers >99% of solar surface (even during maxima)
- crucial to understand the solar global magnetism
- local (surface) dynamo or cascade from global dynamo?

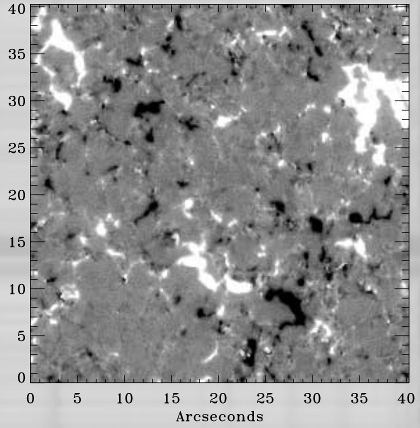


M. Rempel

What is the distribution of field strengths in the QS?

Same instrument: Hinode SOT/SP (Zeeman)

- Orozco Suárez et al. (2007): B_v = 9.5, B_h = 11.3
- Lites et al. (2008): B_v = 11, B_h = 55
- Stenflo (2010): bimodal (B_v = 5-10; 1 kG)
- Asensio Ramos & Martínez González (2014): < 275 G



Deep mode scans Hinode SOT/SP

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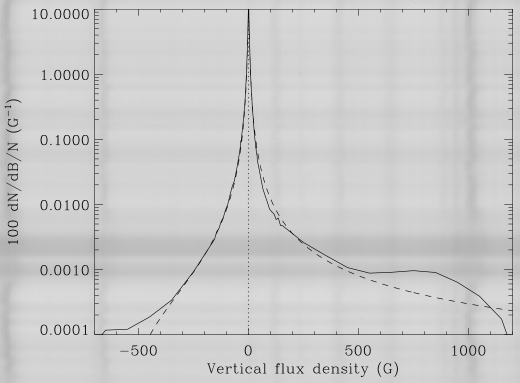

Magnetic dichotomy with two distinct populations

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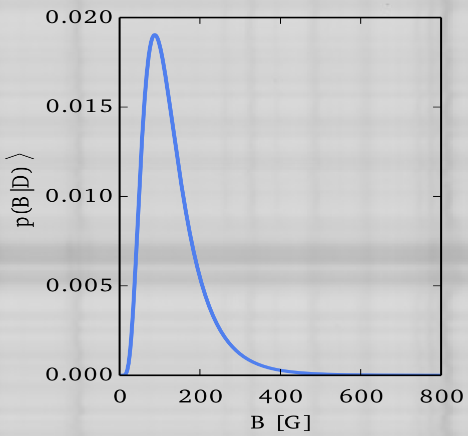
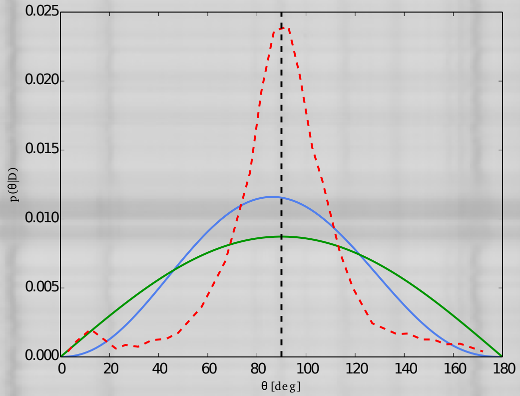


Bayesian analysis of Hinode SOT/SP data

QS fields: Orientation

Measurements

- isotropic + horizontal peak
- isotropic
- mainly horizontal
- isotropic + vertical peak
- bimodal



Martínez González et al. (2008); Asensio Ramos (2009); Asensio Ramos & Martínez González (2014)

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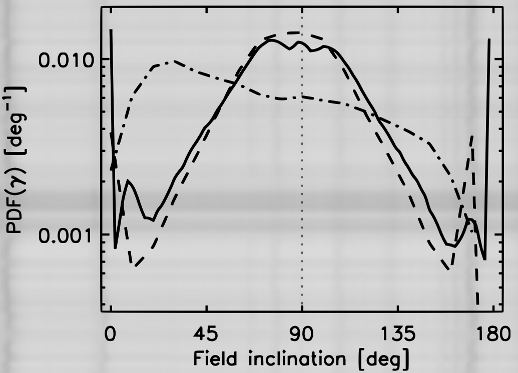

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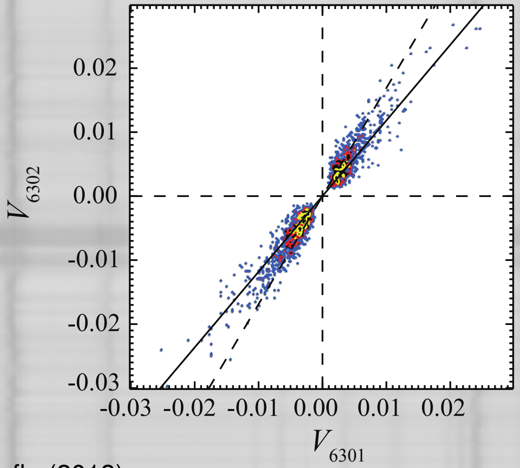


Stenflo (2010); Ishikawa & Tsuneta (2011); Stenflo (2013)

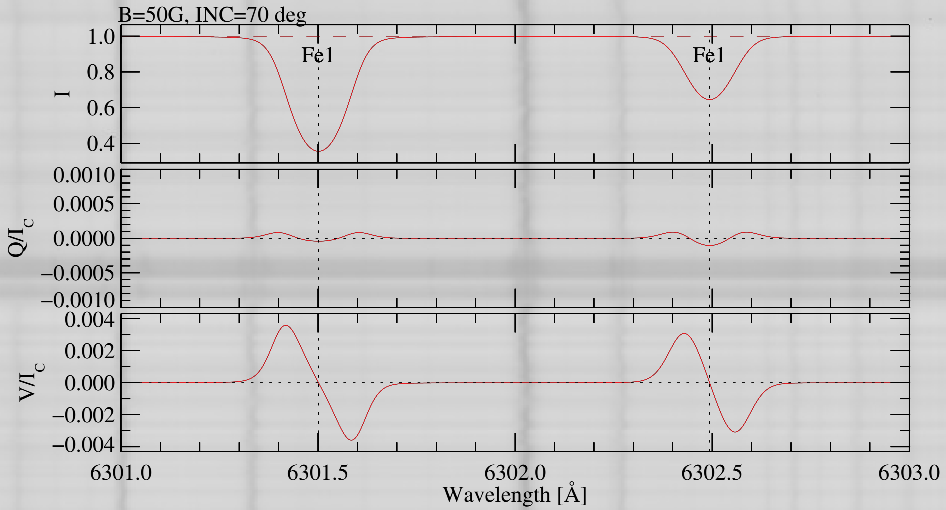
Summary angular distributions (Tab. 2 from Steiner & Rezaei, 2012)

no.	authors	instrument/ simulation	line [nm]	angular distribution	$\langle B^{\mathrm{T}}_{\mathrm{app}} \rangle / \langle B^{\mathrm{L}}_{\mathrm{app}} \rangle$
1	Lites et al. (2007, 2008)	SOT/SP	630	predominantly horizontal	5
2	Orozco Suárez et al. (2007)	SOT/SP	630	predominantly horizontal	2.1
3	Martínez González et al. (2008)	VTT/TIP	1560	isotropic distribution	—
4	Beck & Rezaei (2009)	VTT/TIP	1560	predominantly vertical	0.42
5	Asensio Ramos (2009)	SOT/SP	630	isotropic for weak f elds	—
6	Danilovic et al. (2010)	SOT/SP	630	predominantly horizontal	5.8
7	Stenf o (2010)	SOT/SP	630	predominantly vertical	—
8	Ishikawa & Tsuneta (2011)	SOT/SP	630	predominantly vertical	0.86
9	Borrero & Kobel (2011)	SOT/SP	630	undeterminable	—
10	Borrero & Kobel (2012)	SOT/SP	630	non-isotropic	—
11	Steiner et al. (2008)	h20	630	predominantly hor-	4.3 (2.8)
		v10	630	izontal	1.6 (1.5)
12	Danilovic et al. (2010)	C mf=3	630	predominantly hor-	9.8 (3.5)
		C+B_{ver}	630	izontal	4.2 (2.6)

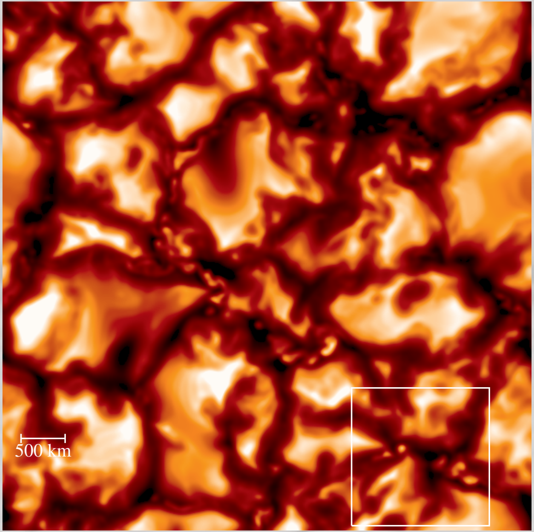
Summary of observations

Summary of observations

Reason 1: Sensitivity of polarimeters



Reason 2: Unresolved Stokes signals – signal cancellation



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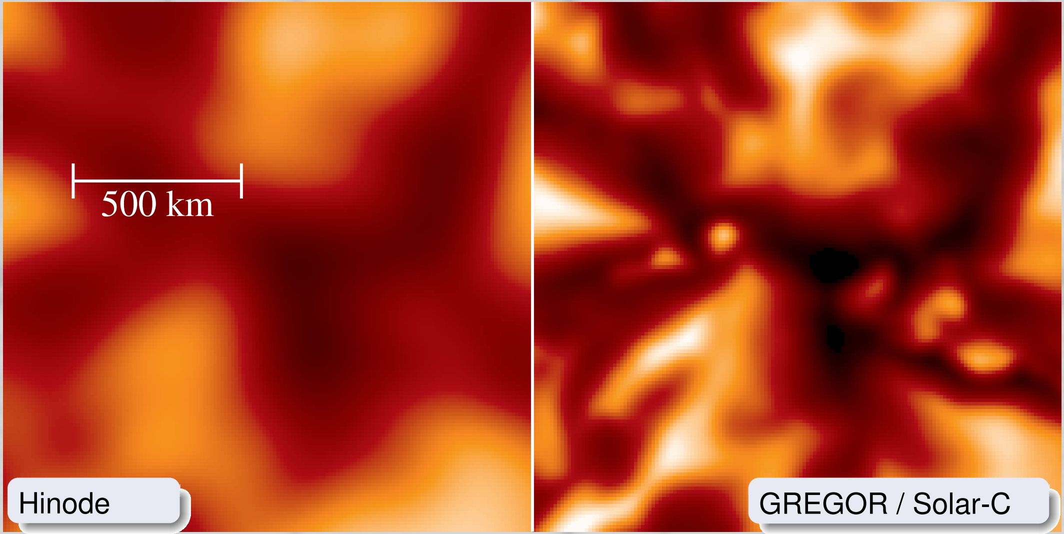

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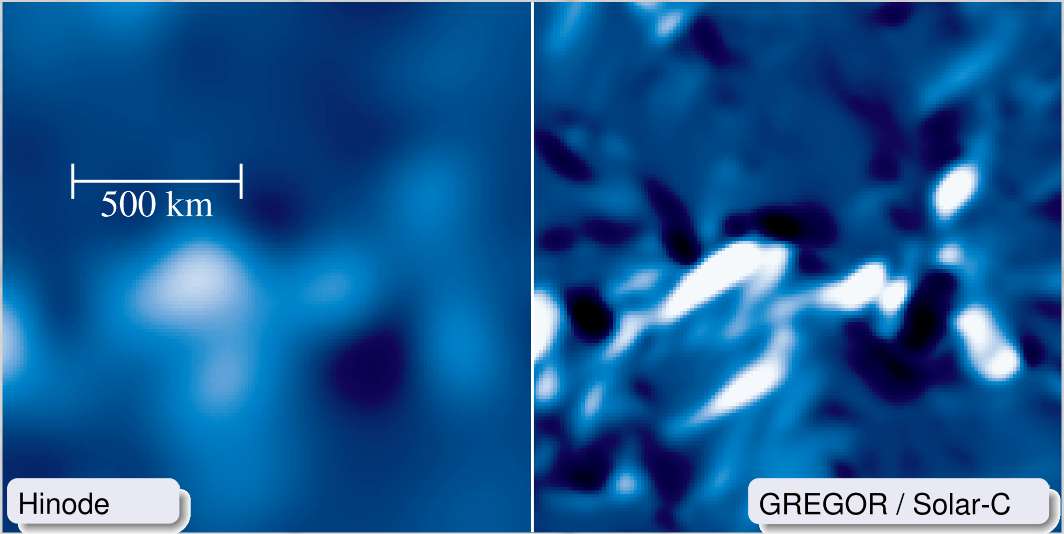


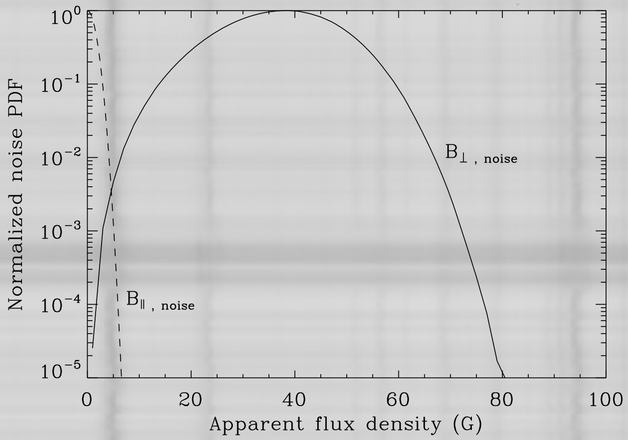
Reason 3: Bias introduced by Zeeman effect

weak-field limit

$$B_{||} \propto V$$
$$B_{\perp} \propto [Q^2 + U^2]^{1/4}$$

Stenflo (2013)

- ⇒ noise leads to more horizontal fields (disk center)
- ⇒ apparent flux: 25× higher in $B_{\perp}$ non-Gaussian



Hinode SOT/SP example

Reason 4: Height dependent B⊥ & B||

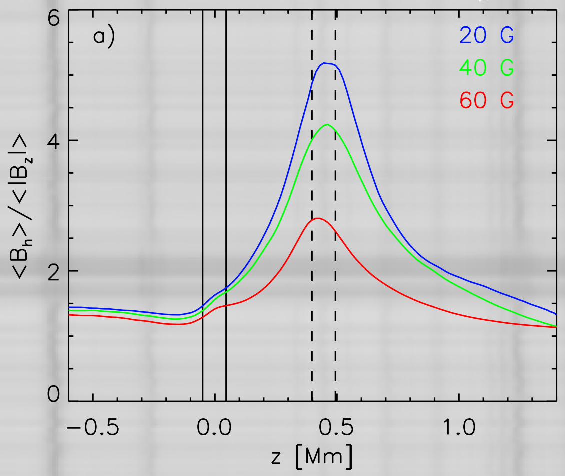
$B_\perp$ vs. $B_{||}$

depends strongly on

- spectral line selection
- analysis method (height dependent inversion vs. ME)
- heliocentric angle (higher opacity at limb)

Local turbulent dynamo

- MHD: $P(\gamma) \propto \sin\gamma$ (e.g. Vögler & Schüssler, 2007)
- height dependent (Rempel, 2014)



Rempel (2014)

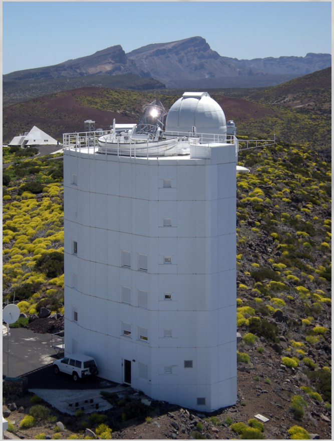
Reason 5: Methods for QS diagnostics

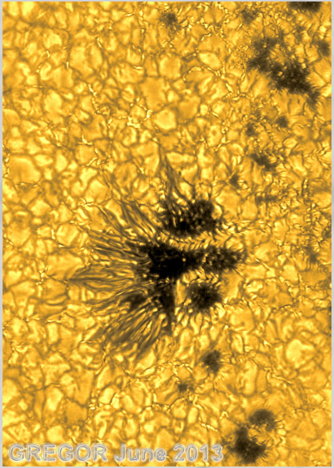
Analysis methods

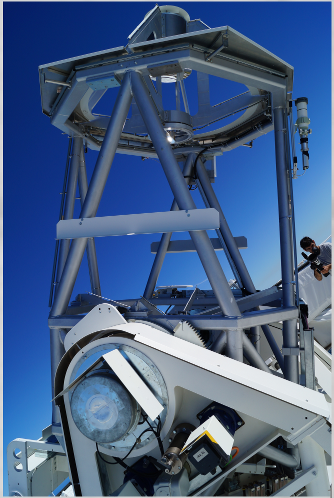
- Zeeman vs. Hanle
- selection of profiles (σ-level)
- inversions
  - ME vs. height dependent
  - filling factor
- direct techniques (e.g. line ratio)

Solution: Improved instrumentation?

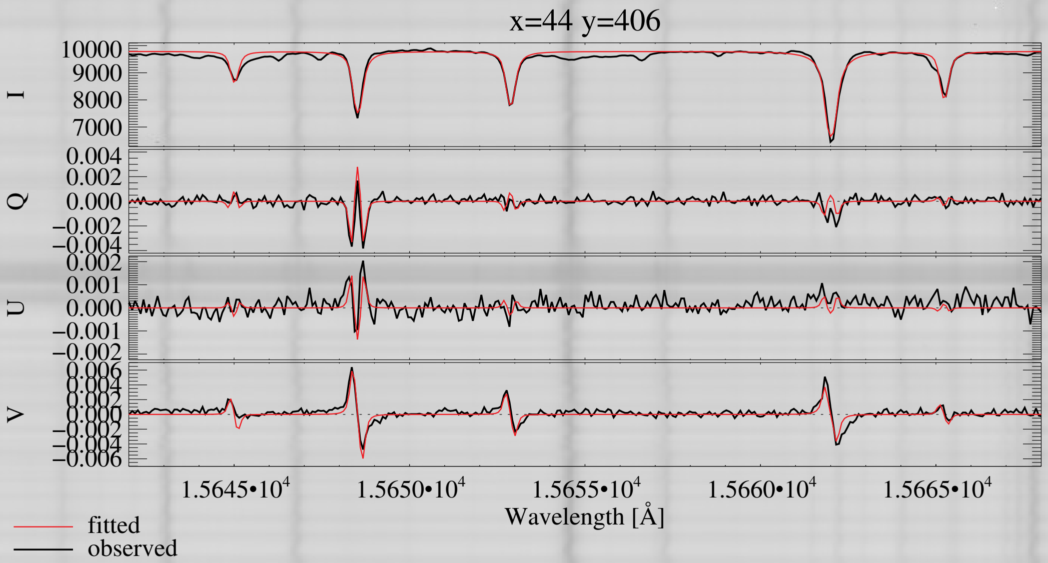
Recent results from GREGOR / GRIS



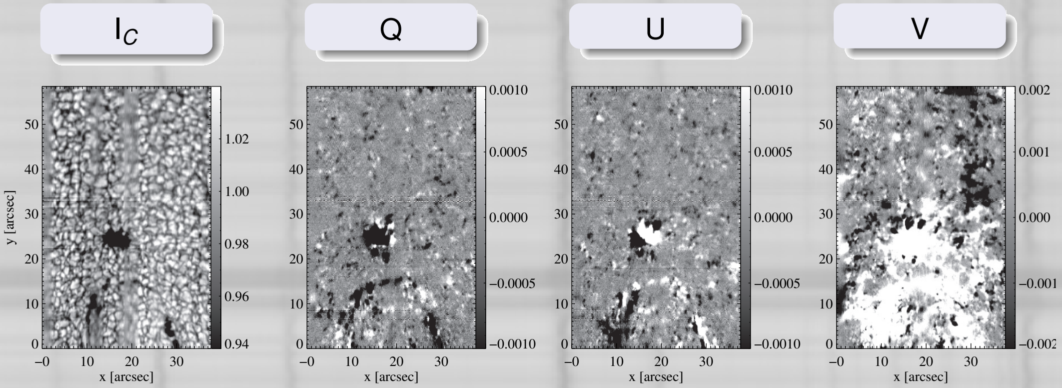




Stokes Profiles: Granule (TP) $> 3\sigma$



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): $4 \cdot 10^{-4}$ I_C

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

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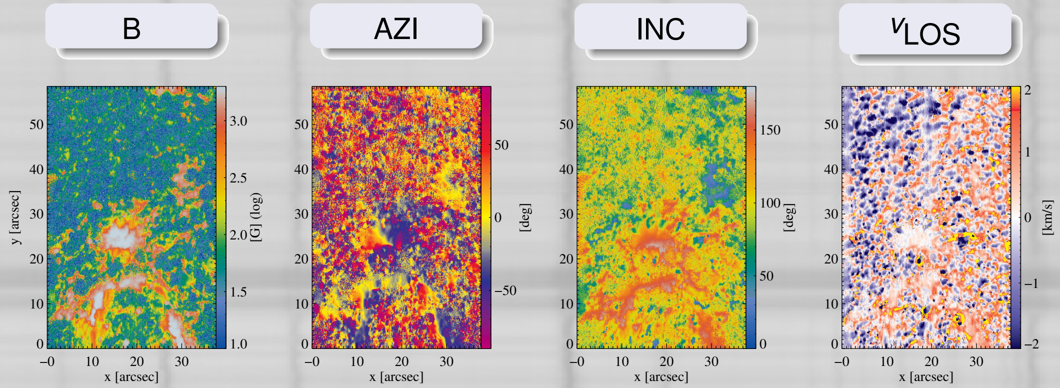

Inversion setup

- Milne Eddington in 6 Fe I lines

  15631 – 15665 Å, line strength as free parameter

- free parameters

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

- global straylight (broad PSF wings)

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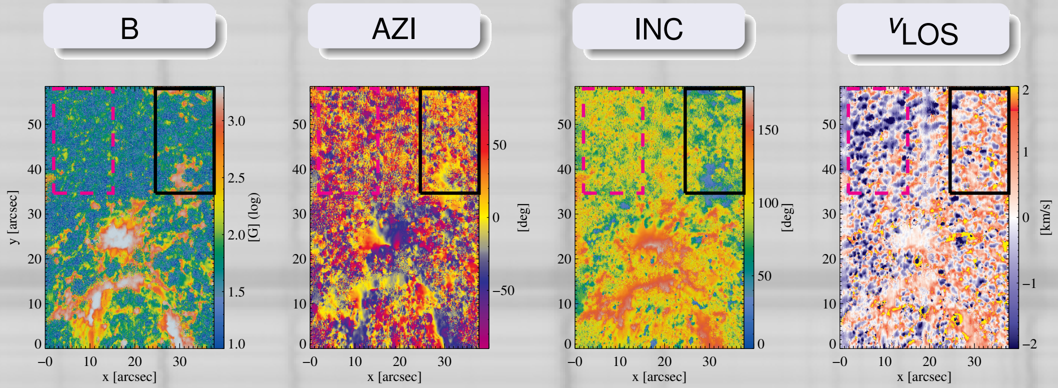

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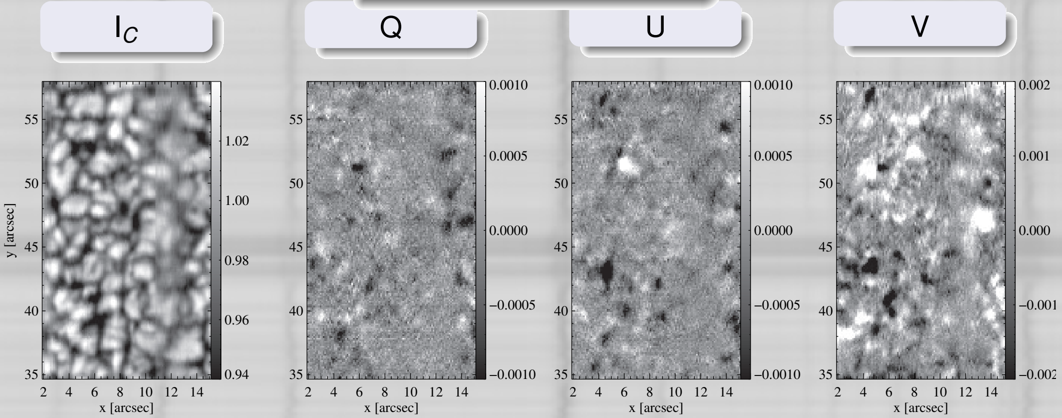
Very quiet sun region (2014-Sep-08)

All pixels



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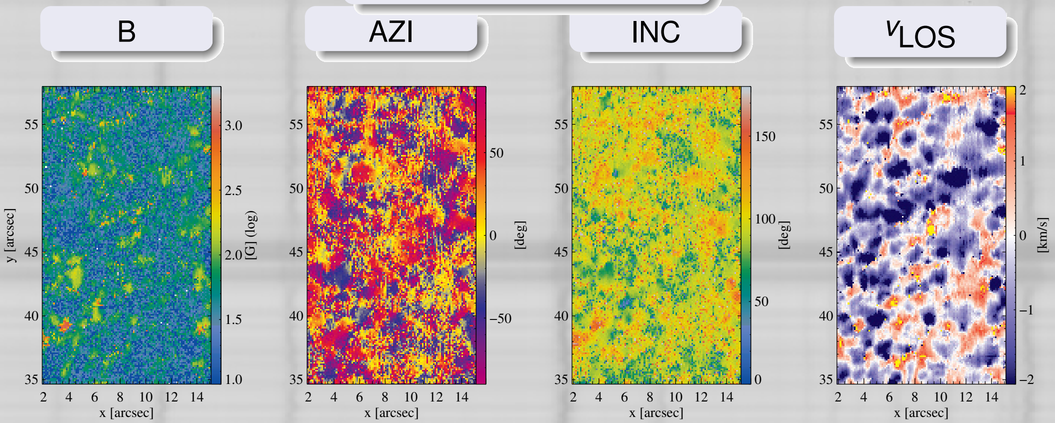

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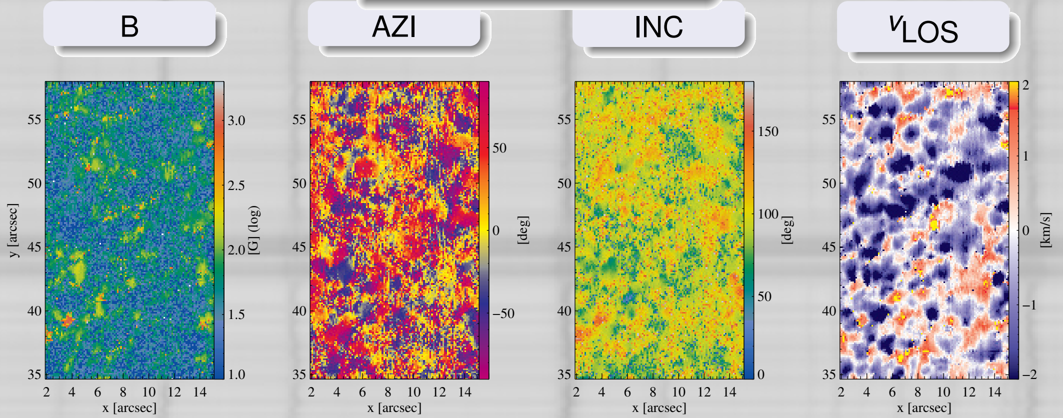
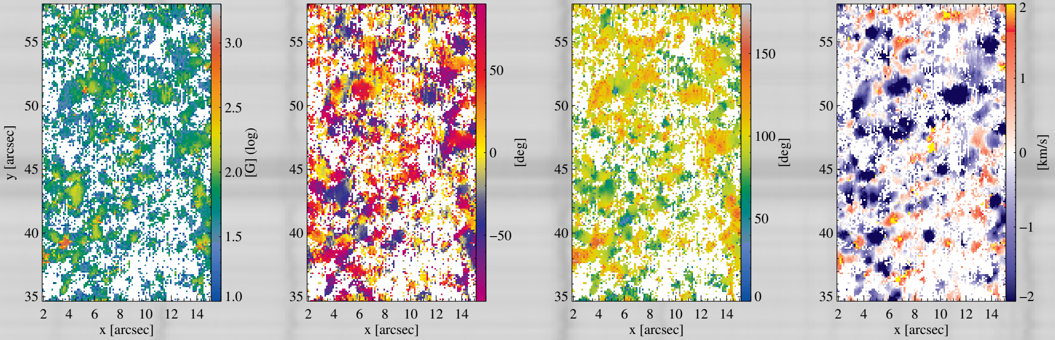


remove all pixels with low signals
Survival of IG lanes or granules?

Very quiet sun region (2014-Sep-08)

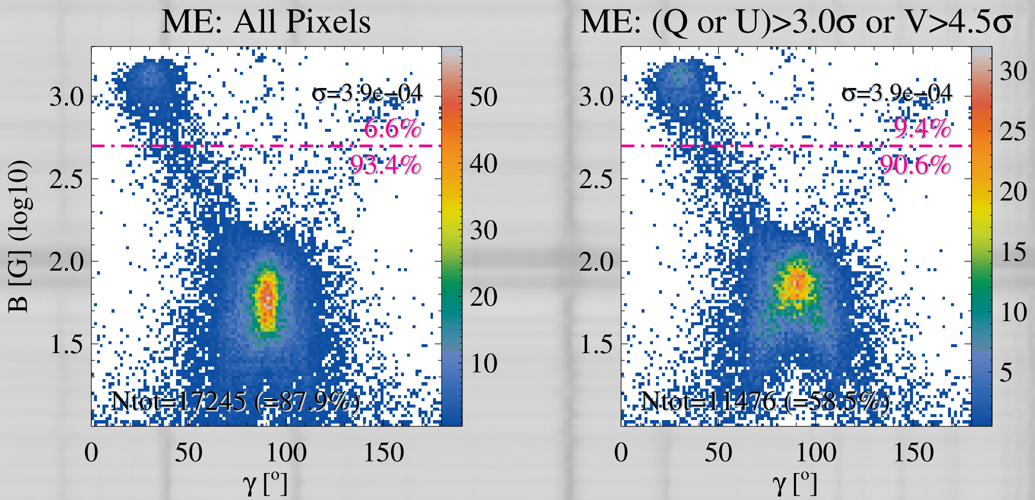
$$[(Q \vee U) > 3\sigma] \vee [V > 4.5\sigma]$$

B | AZI | INC | v_{LOS}



Mainly granules!
... and some IG lanes

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



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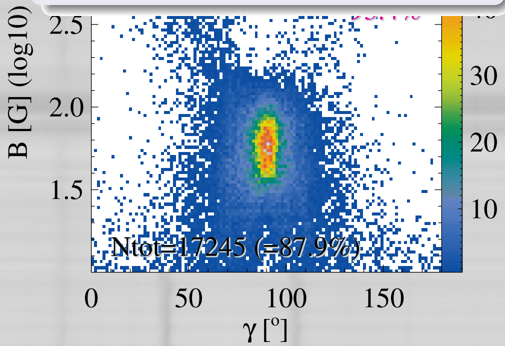
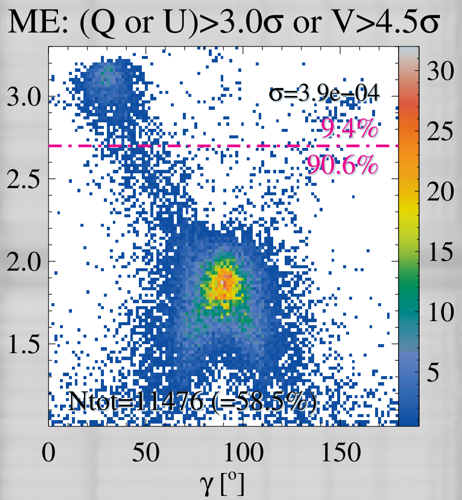
Extremely Quiet Sun Fields

- strength: 20–150 G
- mainly horizontal
- few and weak vertical fields





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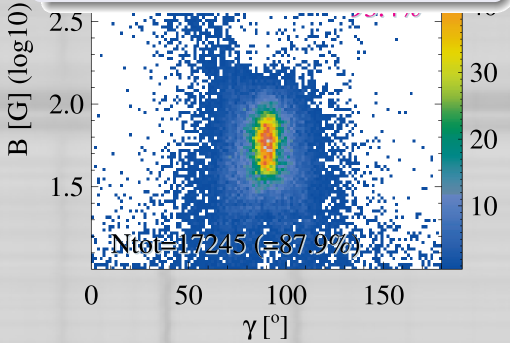

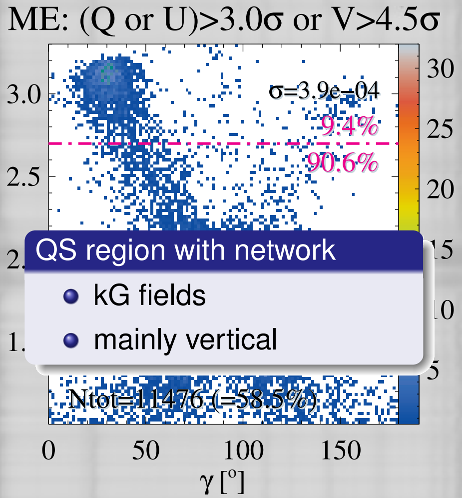

QS region with network

- kG fields
- mainly vertical

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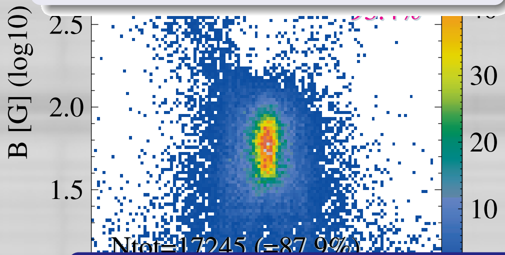

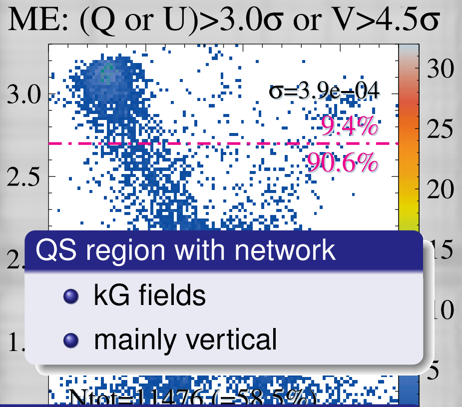

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Stenflo (2010) *"... magnetic dichotomy with two distinct populations"*

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

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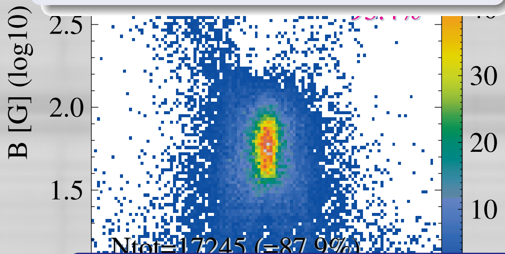

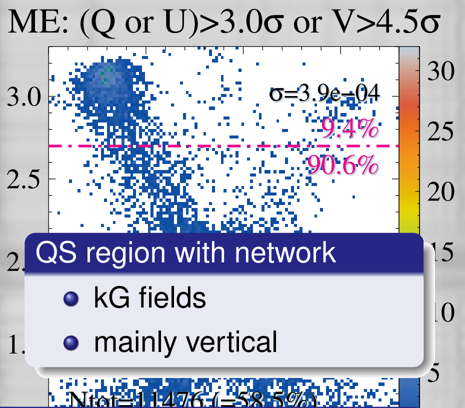

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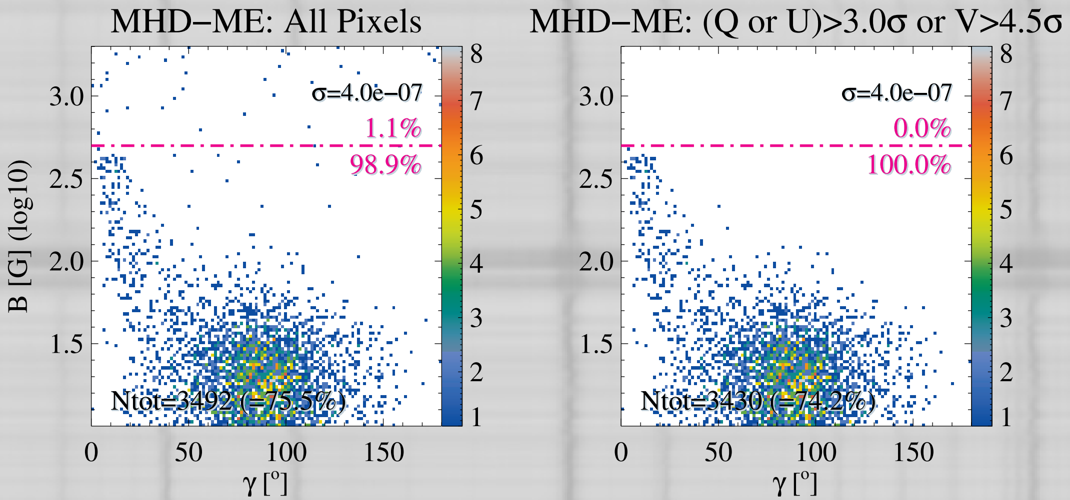
2D-Histogram: B vs. γ MHD-data



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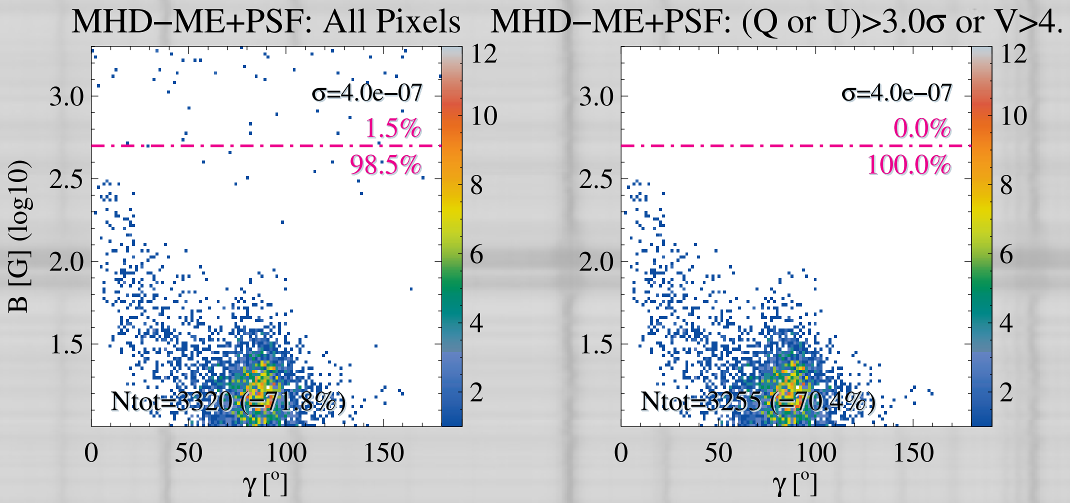
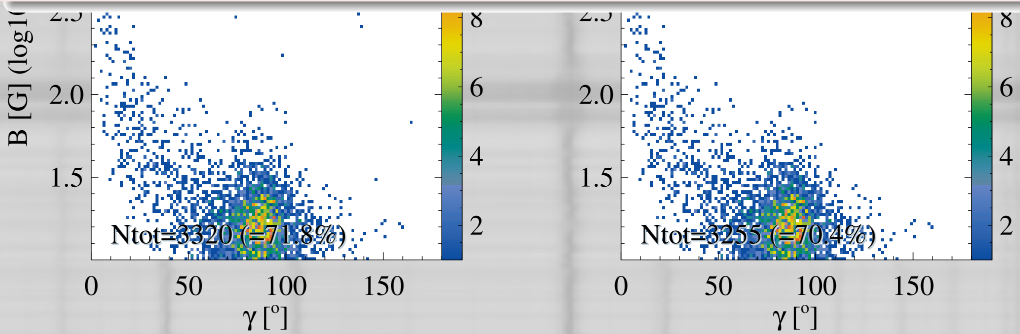


2D-Histogram: B vs. γ MHD-data

Increase of B_h:B_v from decrease in spatial res!

- $B_h \propto \sqrt{Q, U}$, $B_v \propto V$ $\Rightarrow$ $B_h^{PSF} = \sqrt{\alpha} B_h$
- PSF-convolution: reduces Q, U, V signal by same factor $\alpha < 1$ $\Rightarrow$ $B_v^{PSF} = \alpha B_v$ $\Rightarrow$ recovered field is more horizontal!



Summary: Quiet Sun Magnetism

Agreement:

- crucial to understand solar magnetism

Disagreement

- dependency with level of solar activity
- strength, direction, μ-dependence

Steps toward a solution

Advances in instrumentation:

- Hi-res & pol. sensitivity (10^{-4})

$\rightarrow$ GREGOR, NVST, NST, DKIST, EST, Solar-C

Advances in analysis:

- inversions: proper treatment of straylight ("filling-factor" discussion, 2D-inversions)
- proper treatment of height-dependence
- improved modelling (Hanle)

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