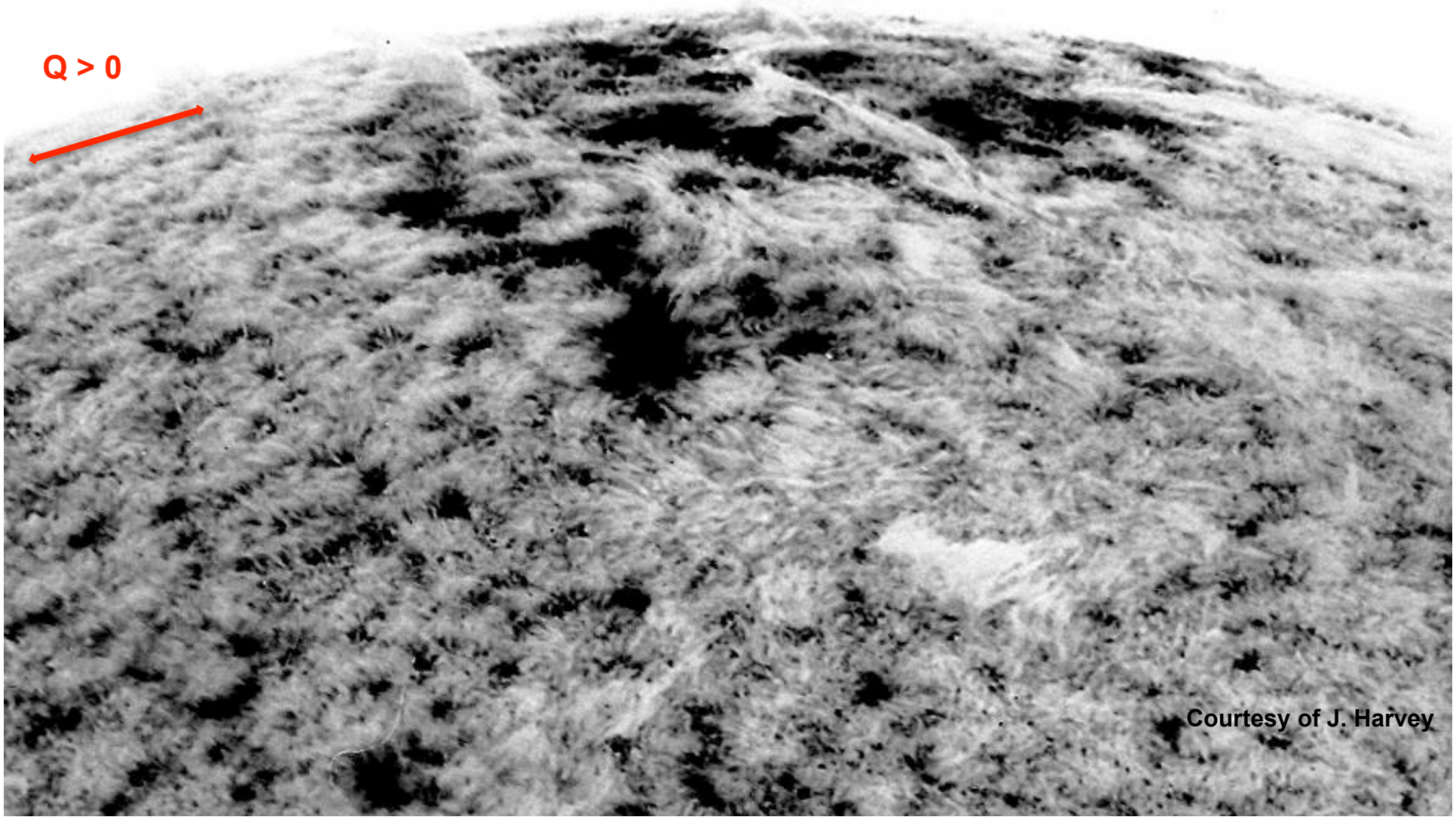
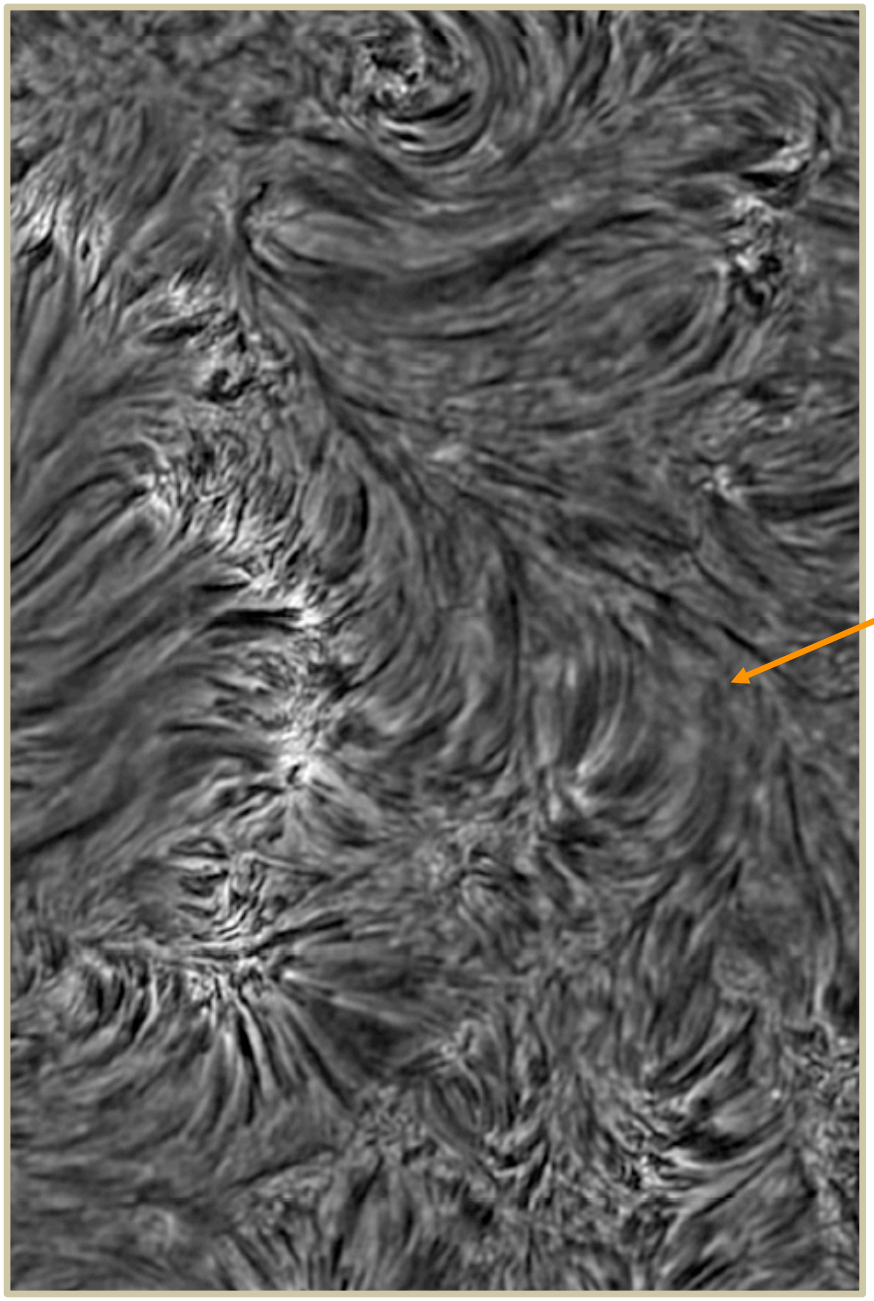
Some polarization diagnostics to explore the magnetism of the upper chromosphere and TR

Javier Trujillo Bueno
(IAC, Tenerife, Spain)



H-alpha intensity image (DOT archive)



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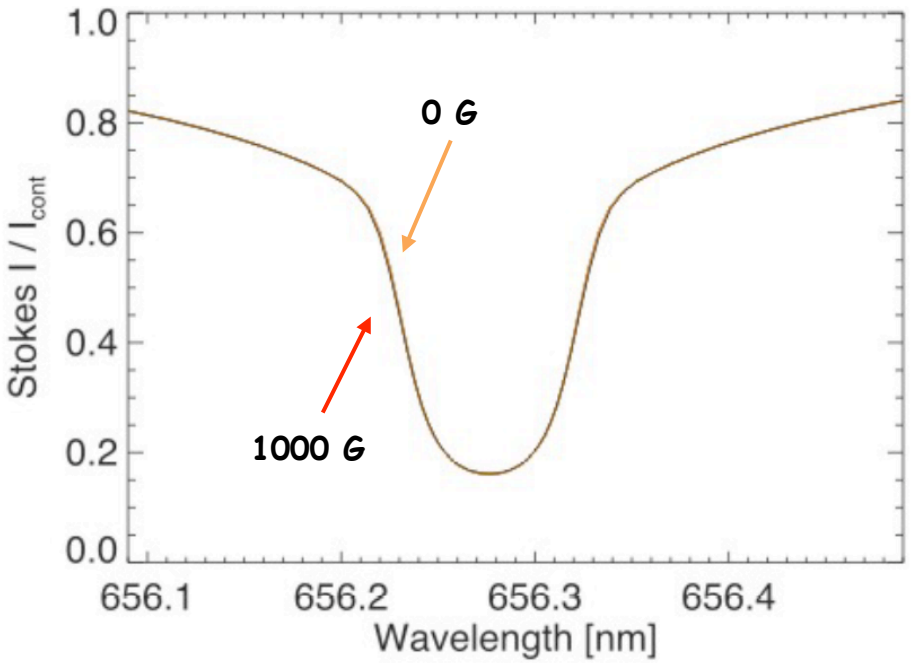
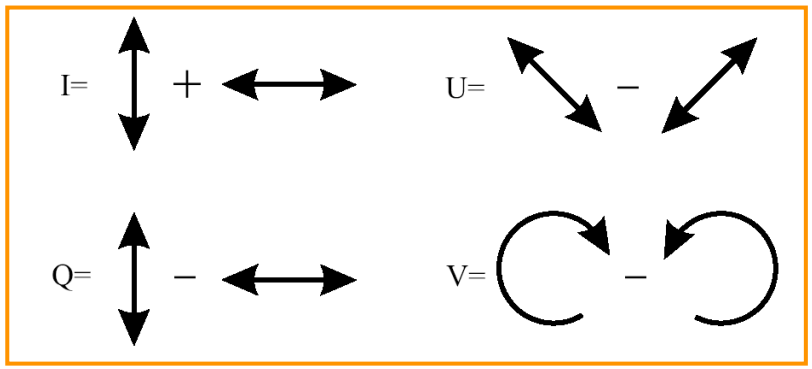
"Quiet" chromosphere

NOTE: Stokes I is insensitive to B



The only way to obtain quantitative empirical information on the magnetic field vector in the solar atmosphere is via the measurement and physical interpretation of the emergent spectral line polarization.

Stokes parameters →



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Physical mechanisms that control the polarization of the spectral lines that originate in the solar atmosphere

The Zeeman effect

Scattering processes and the Hanle effect

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The message of this talk

The Hanle effect is a key physical mechanism that should be increasingly exploited for facilitating the exploration of magnetic fields in the outer solar atmosphere (upper chromosphere, transition region and corona).

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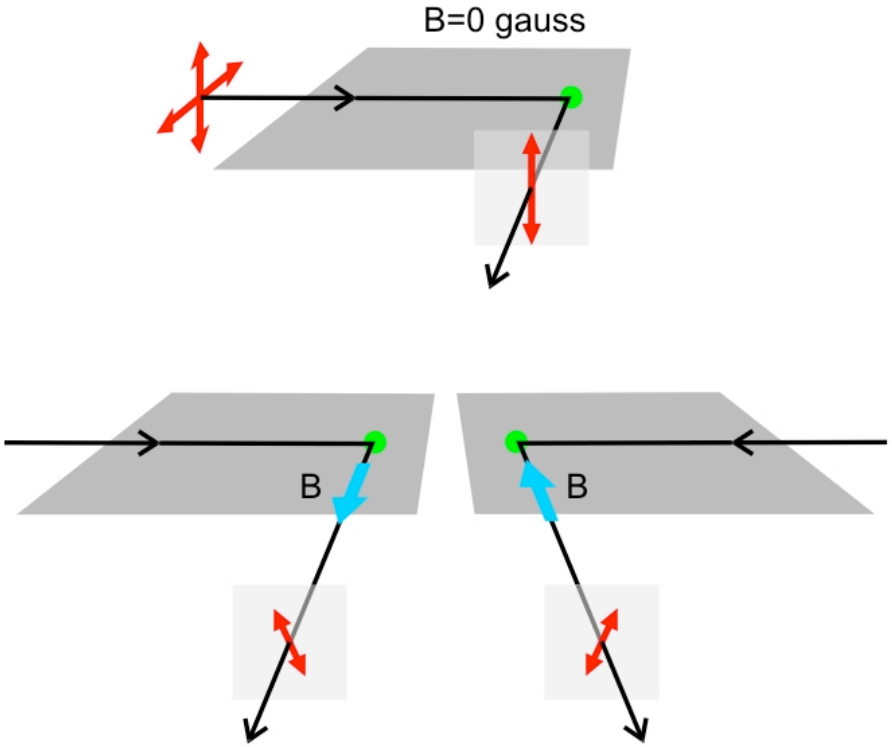
The impact of the Hanle effect on the linear polarization produced by scattering processes

90° scattering geometry



The Hanle effect **REDUCES** the amplitude of the line scattering polarization signal

(i.e.,Stokes Q decreases with respect to the B=0 G case) !

The Hanle effect **ROTATES** the direction of linear polarization

(i.e., Stokes U is NON-ZERO) !

Critical Hanle field?

$8.79 \times 10^6 \; g_L \; B(\text{gauss}) \sim 1/\text{Lifetime}$

Magnetic splitting of the Level = Natural width of the Level

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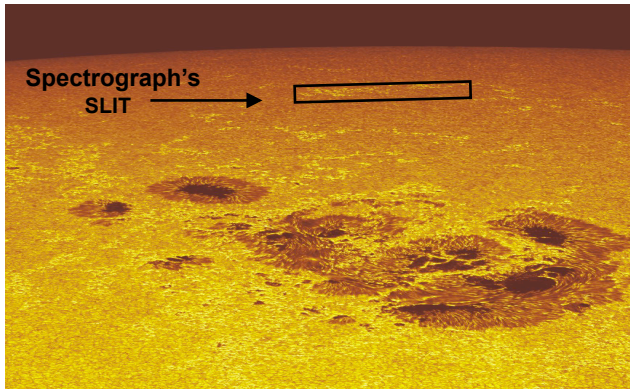
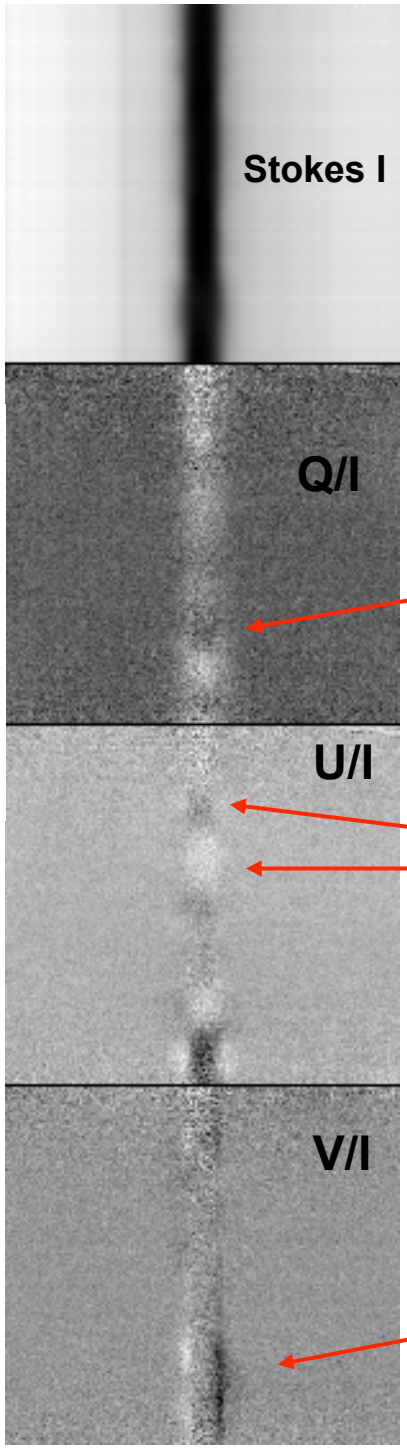
The **Hanle** and **Zeeman effects** in action in the **QUIET solar chromosphere.**

8542 line of Ca II





Observations with ZIMPOL @ THEMIS

of the polarization in the Ca II IR-triplet

(TB, Ramelli, Manso Sainz & Bianda 2010)

Hanle DEPOLARIZATION of the scattering polarization

Hanle ROTATION of the direction of linear polarization

Circular polarization created by the LONGITUDINAL ZEEMAN effect

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New discovery space 1

2D spectropolarimetry of the Ca II IR triplet with SOLAR-C option-B would allow us to map the spatial and temporal variations of the chromospheric magnetic field with unprecented polarimetric sensitivity at high spatial and temporal resolution.

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Two problems (and type of radiative transfer codes) for the interpretation and modelling of the polarization observed in spectral lines

- The diagnostic problem of plasma structures embedded in optically thin regions of the outer solar chromosphere

- The diagnostic problem of the chromospheric and TR plasma itself.

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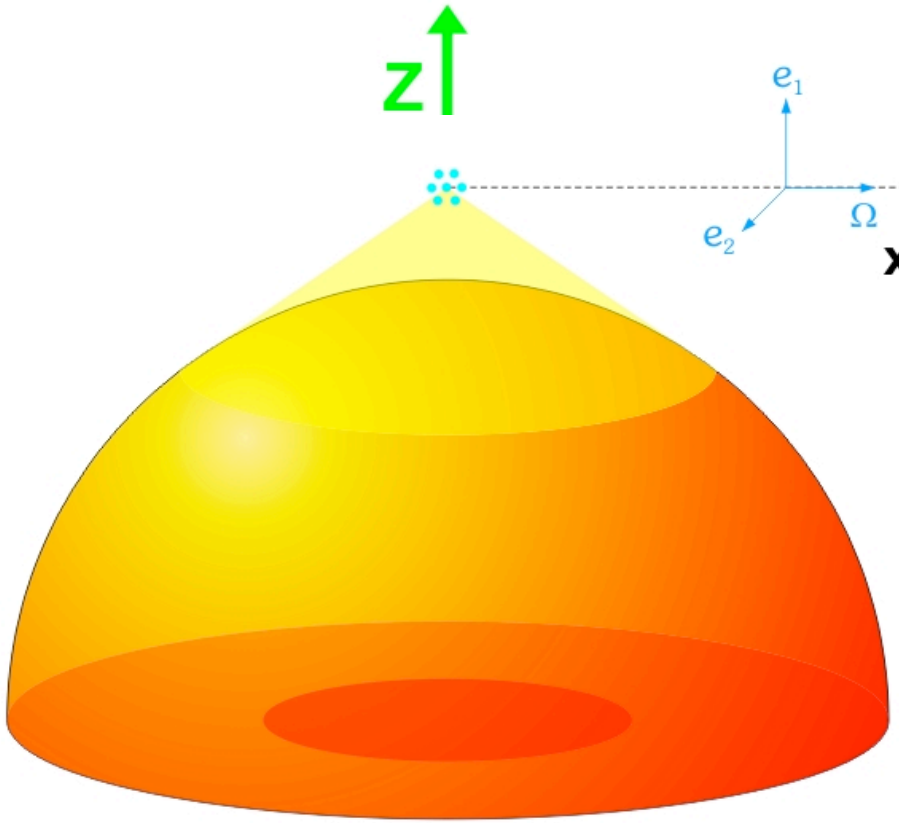
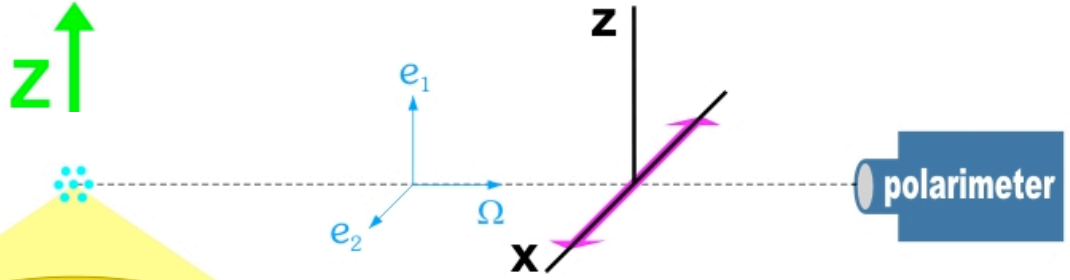
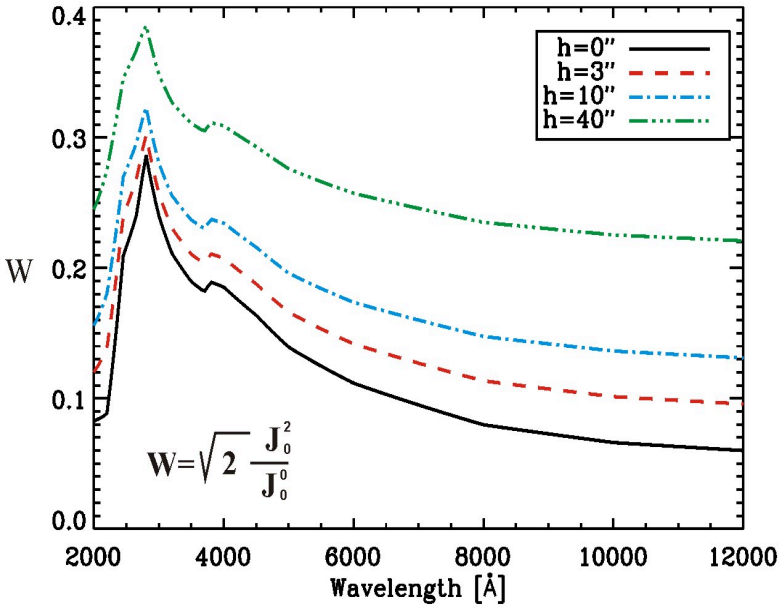
The diagnostic problem of plasma structures embedded in optically thin regions of the solar chromosphere.



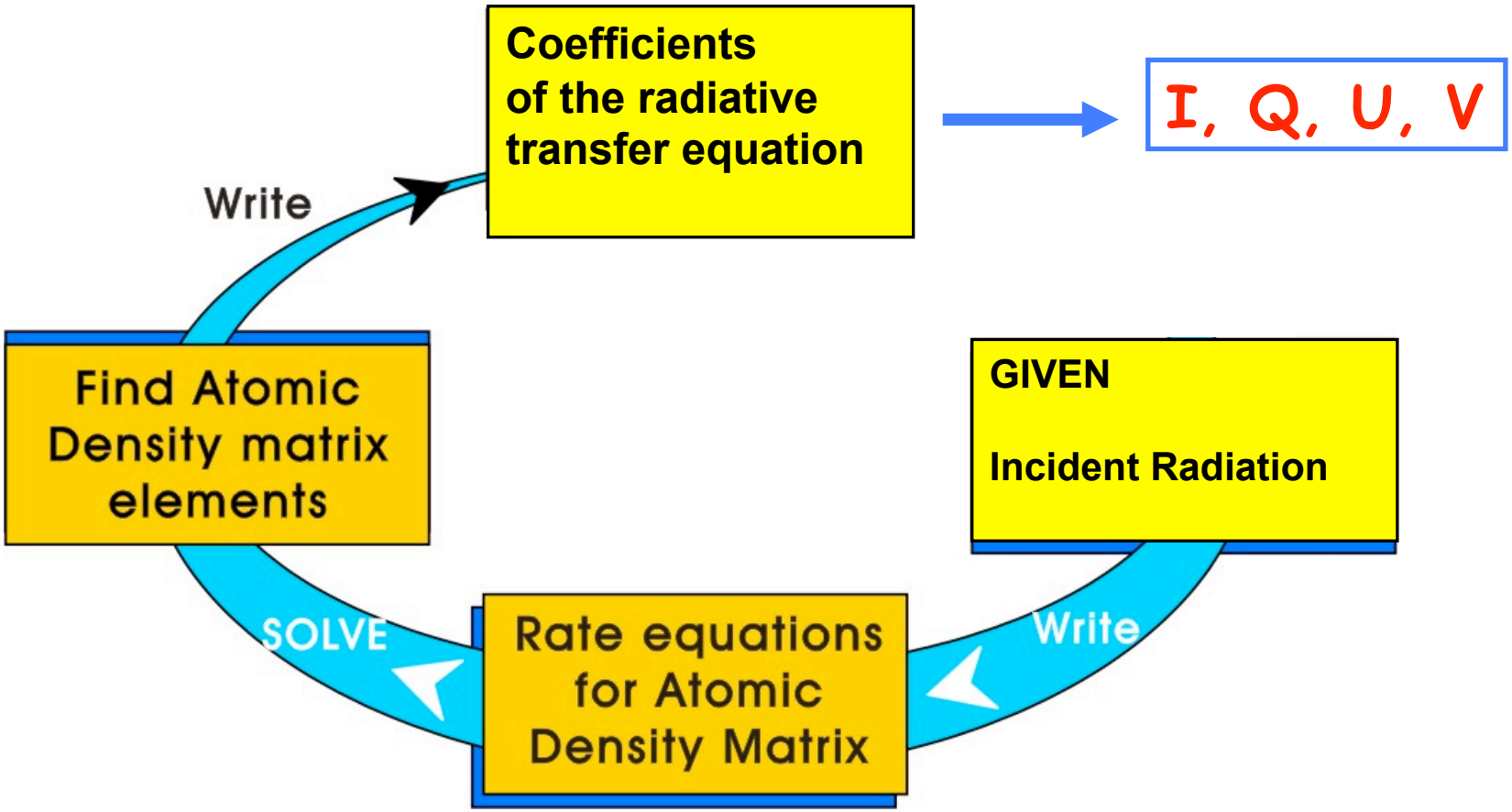


Anisotropy Factor



It requires solving a "simplified" non-LTE problem of the 2nd kind

The "simplified" non-LTE Problem of the Second Kind



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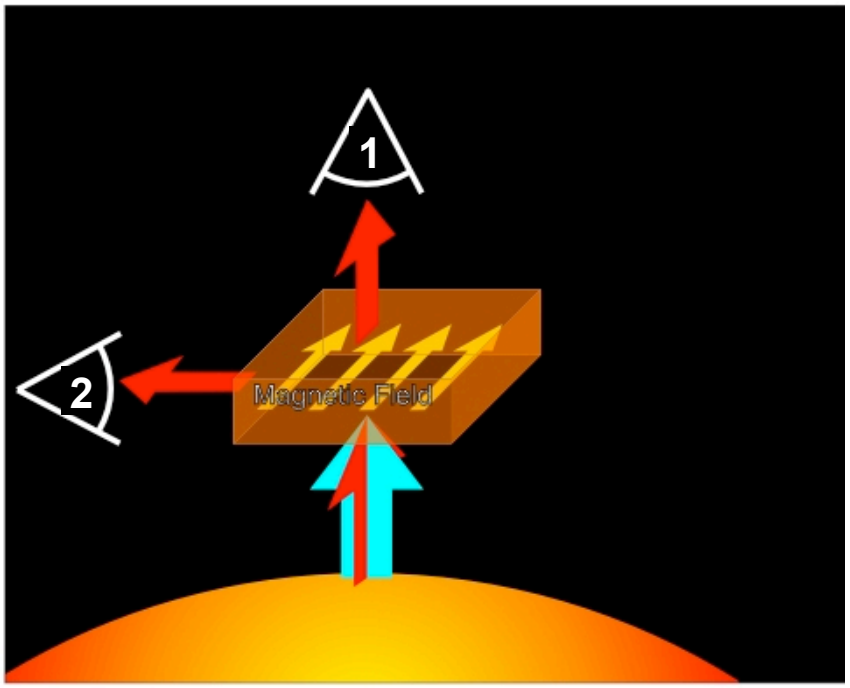
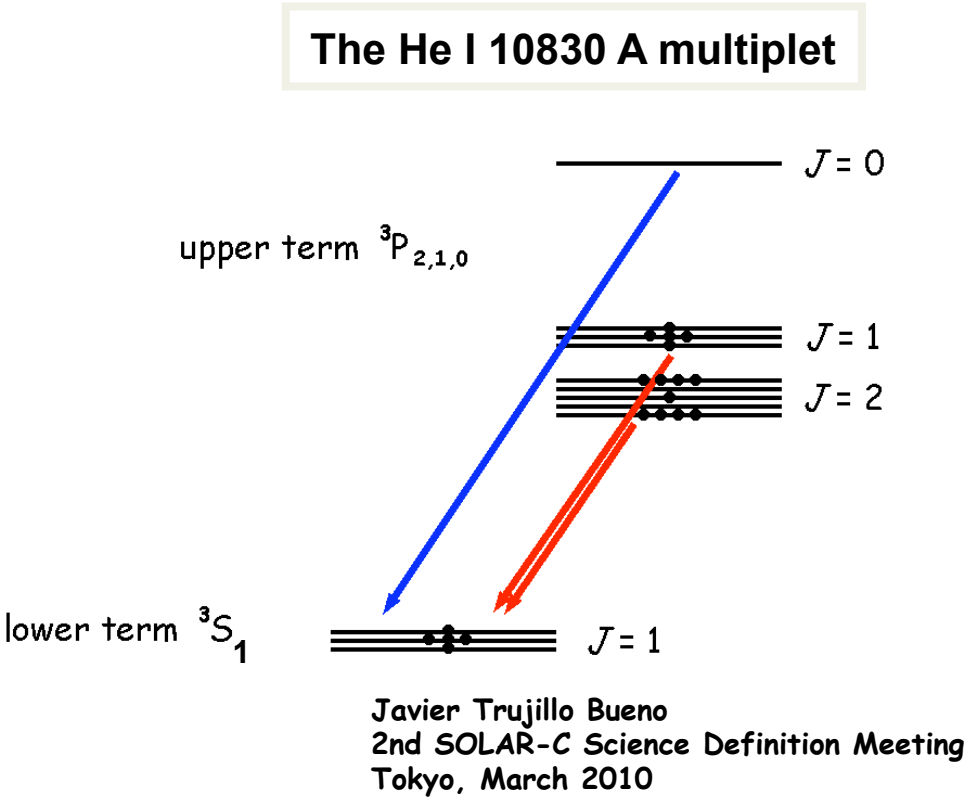
With the computer program HAZEL (HAnle and ZEeman Light; see Asensio Ramos, Trujillo Bueno & Landi Degl'Innocenti 2008; ApJ) **we assume a slab whose optical thickness is chosen to fit the observed Stokes I profile.**

The observed Stokes Q, U and V profiles are then used to infer the magnetic field vector (its strength, its inclination with respect to the solar local vertical, and its azimuth).





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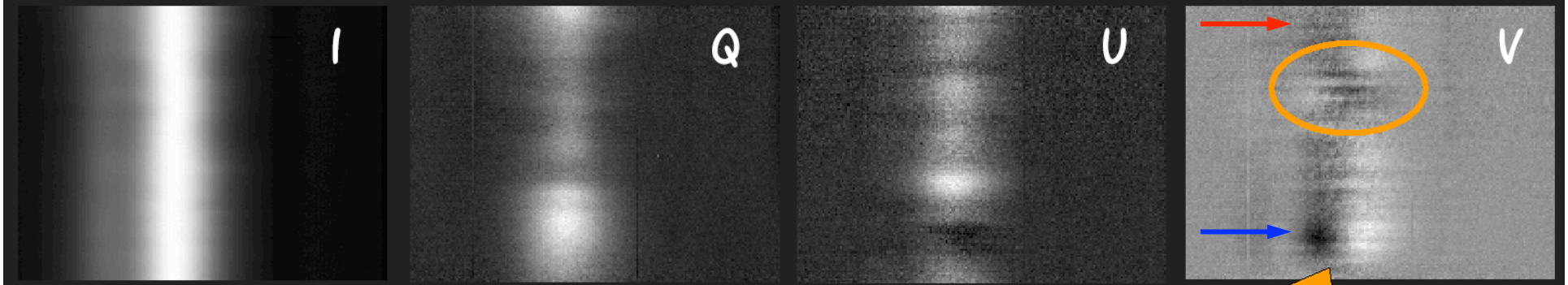
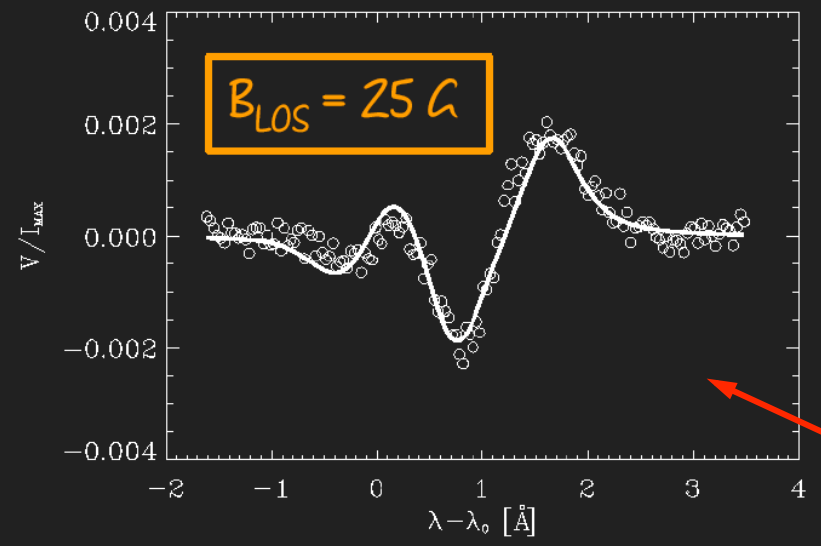
He I 10830 spectropolarimetric observations of off-limb spicules

(From Centeno, Trujillo Bueno & Asensio Ramos 2009; ApJ)

Stokes maps





Detection of a Stokes V Zeeman-induced signal that varies along the slit and even reverses polarity!!

NOTE: the longitudinal Zeeman effect is of great help here !

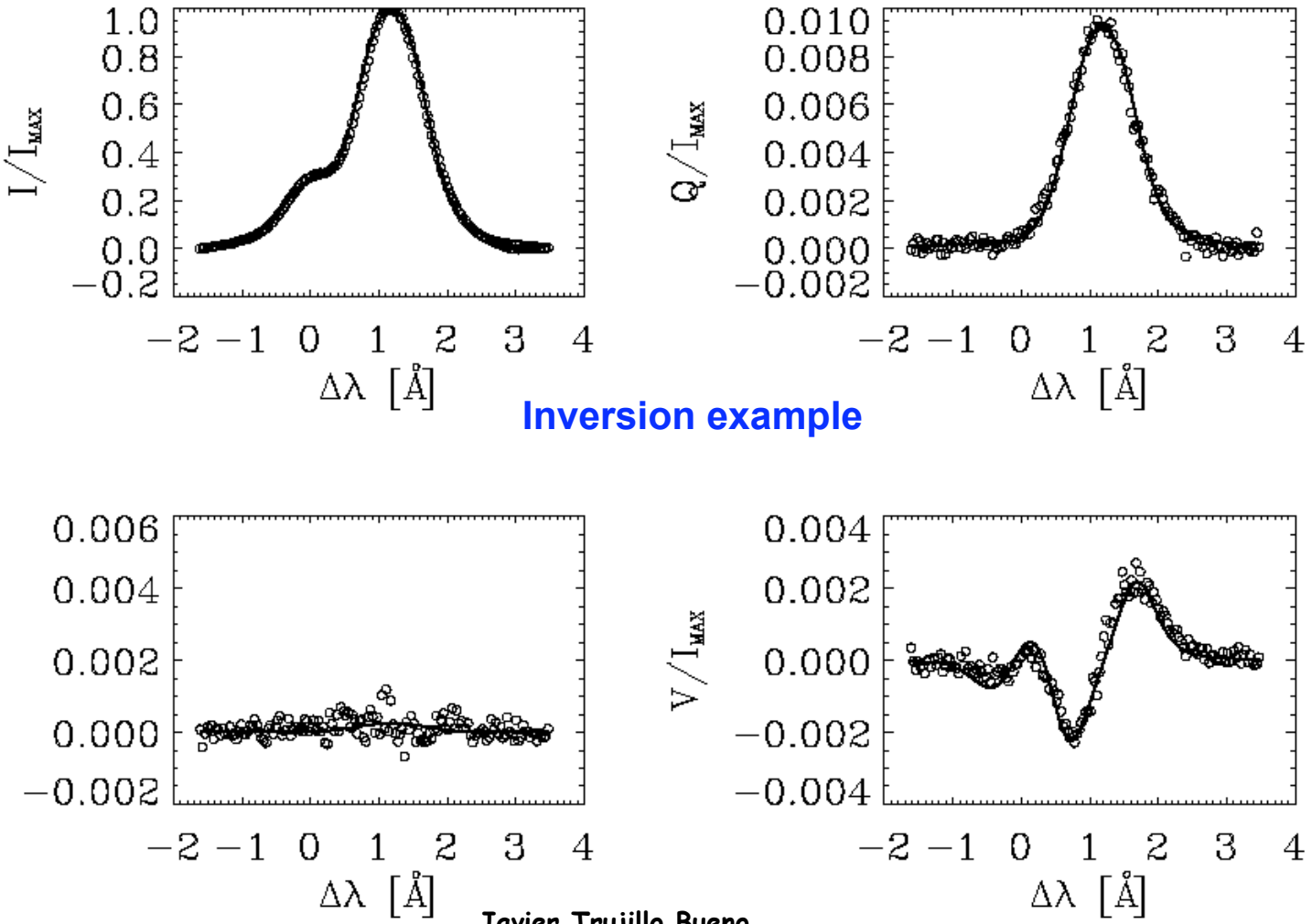
HAZEL inversion of He I 10830 observations of spicules in quiet regions

(From Centeno, Trujillo Bueno & Asensio Ramos 2009; ApJ)

B = 48 G

Inclination = 35º

Azimuth = 0.15º



Inversion example

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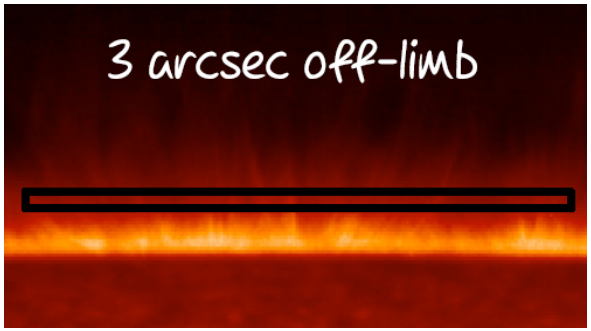
HAZEL inversion of He I 10830 observations of spicules in quiet regions

(From Centeno, Trujillo Bueno & Asensio Ramos 2009; ApJ)



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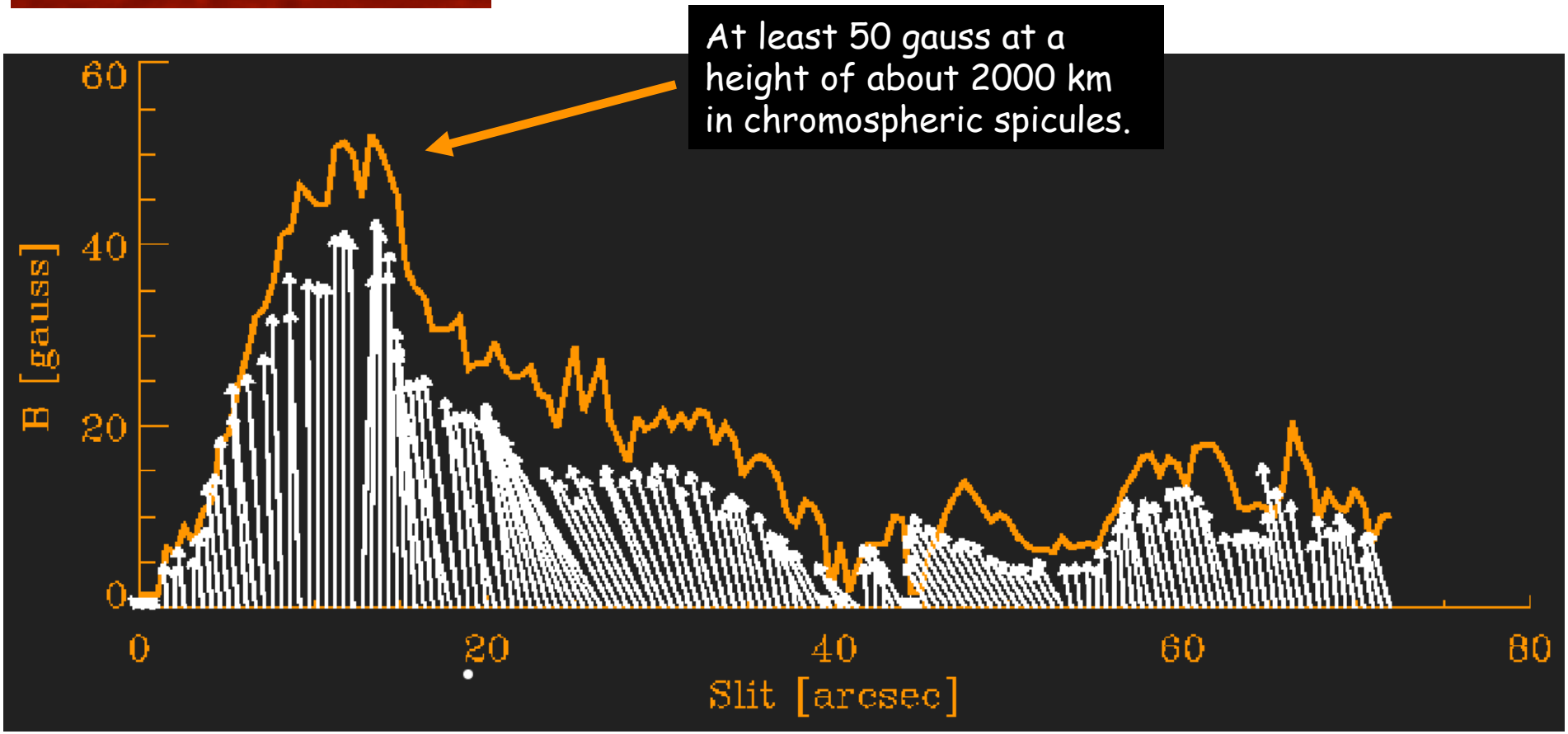

New discovery space 2

- With SOLAR-C option-B we would be able to determine with unprecedented spatial and temporal resolution the strength and geometry of the magnetic field in a variery of chromospheric and coronal plasma structures (e.g., spicules, prominences and active region filaments).

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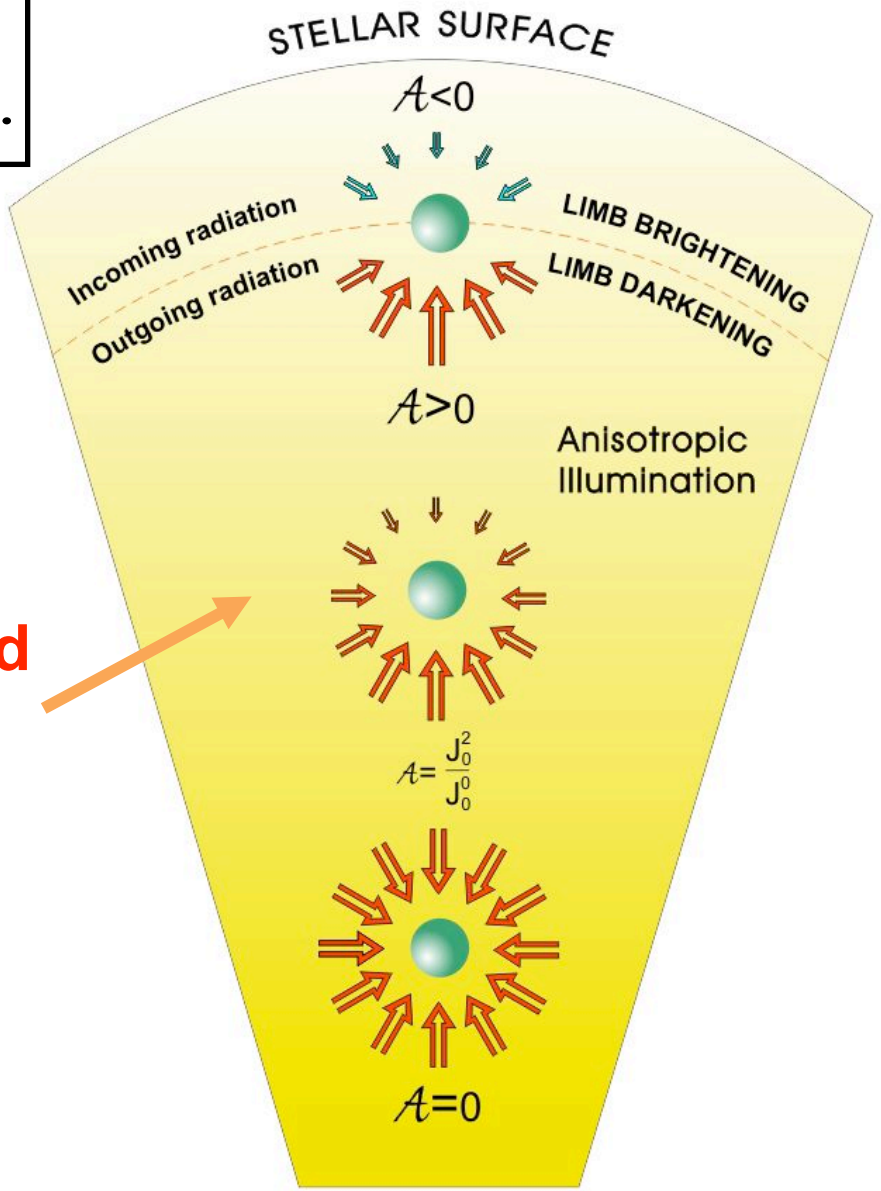
The diagnostic problem of the chromospheric and TR plasma itself.



Anisotropy of the radiation field WITHIN a stellar atmosphere

$$A = \frac{J^2_0}{J^0_0}$$

$$J^0_0 = \frac{1}{4\pi}\int d\vec{\Omega}\, I(\vec{\Omega})$$

$$J^2_0 = \frac{1}{4\pi}\int \frac{d\vec{\Omega}}{2\sqrt{2}}\left(3\mu^2-1\right) I(\vec{\Omega})$$

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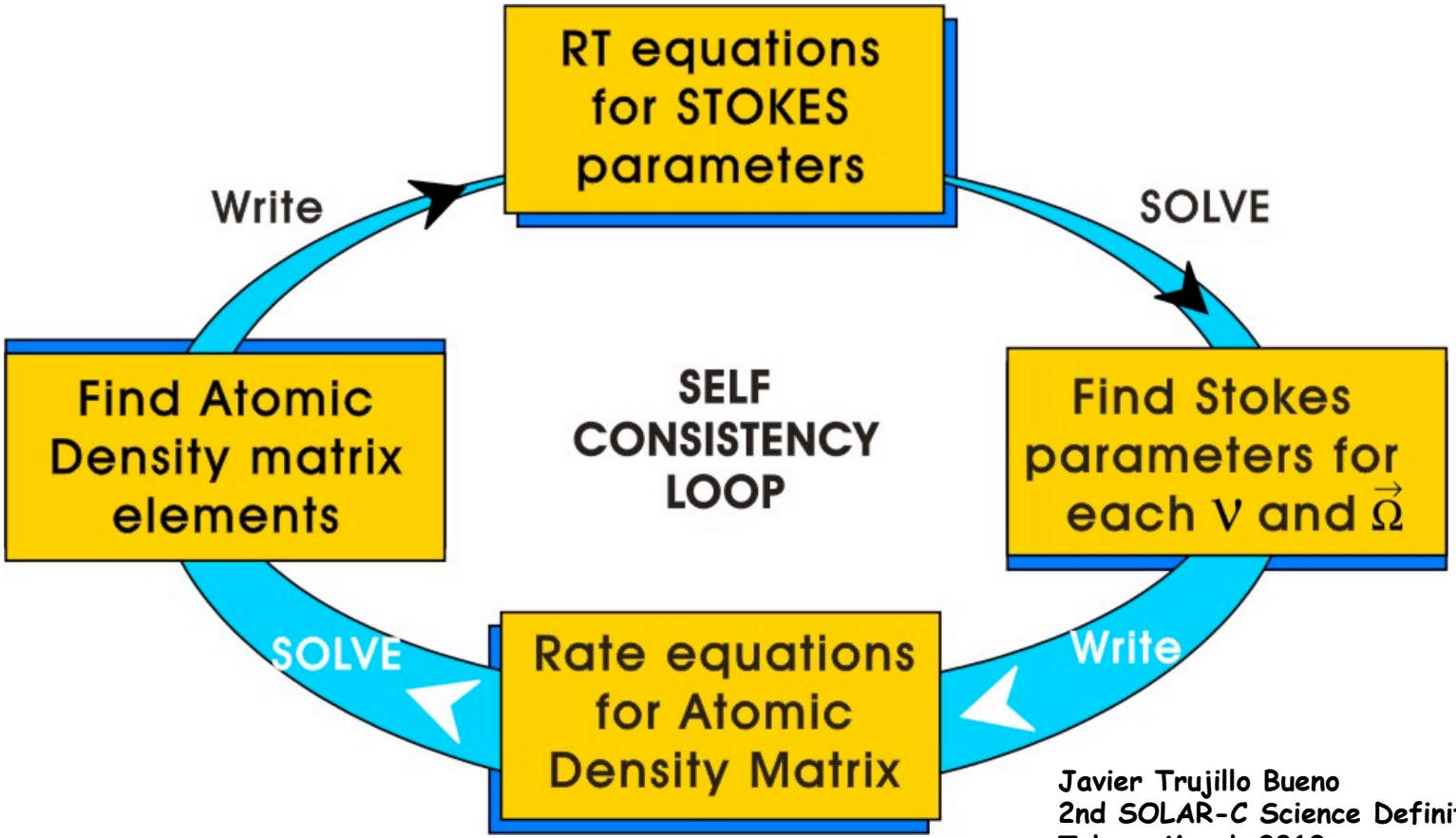
The general non-LTE Problem of the Second Kind

Equations ? → Chapter 7 of Landi Degl'Innocenti & Landolfi (2004)

Numerical methods of solution ? → TB (1999; 2003)

Multilevel RT computer programs ? → Manso Sainz & TB (2003); Stepan (2008; PhD thesis)



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Some interesting spectral line choices :

- The IR triplet of Ca II
- (see Manso Sainz & Trujillo Bueno 2003; Phys. Rev. Letters)

- The H-alpha line
- The Mg II k-line

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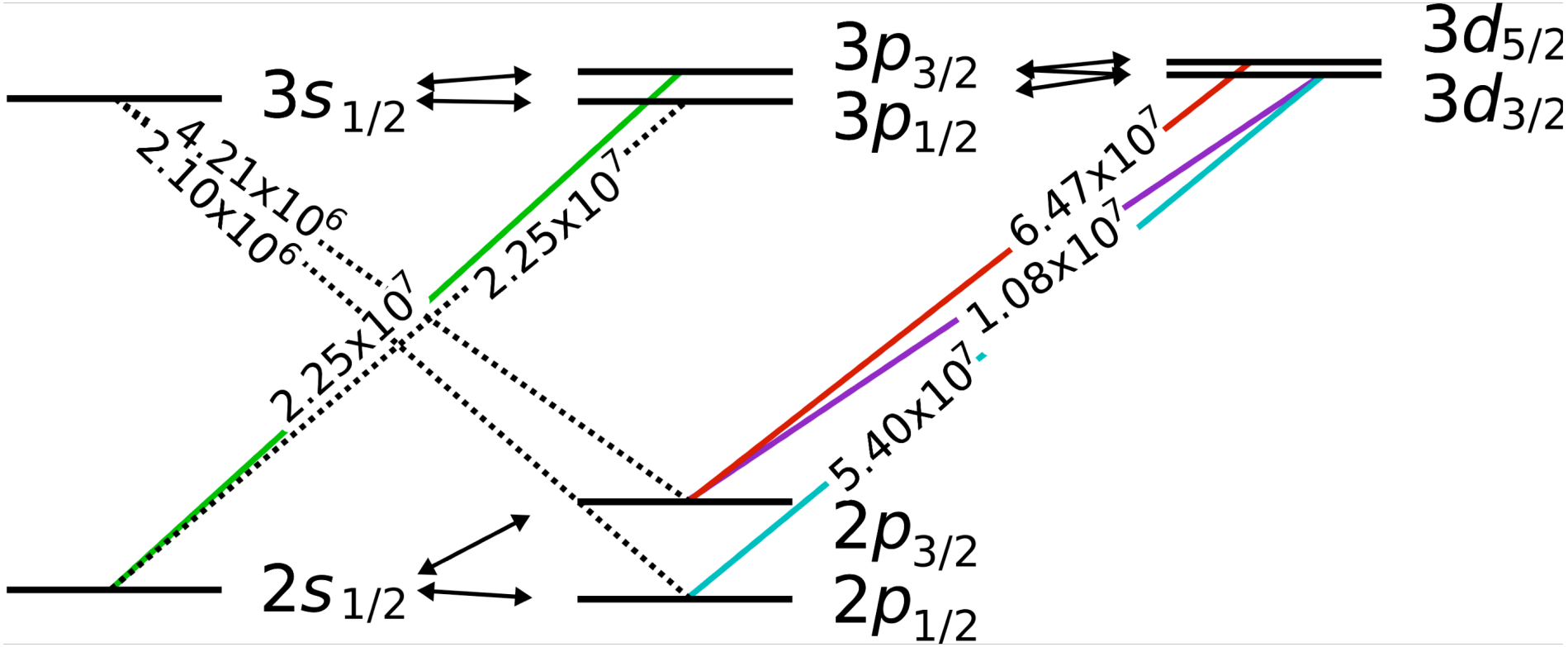
Scattering polarization and the Hanle effect in the H-alpha line

(Stepan & Trujillo Bueno 2010, ApJ)



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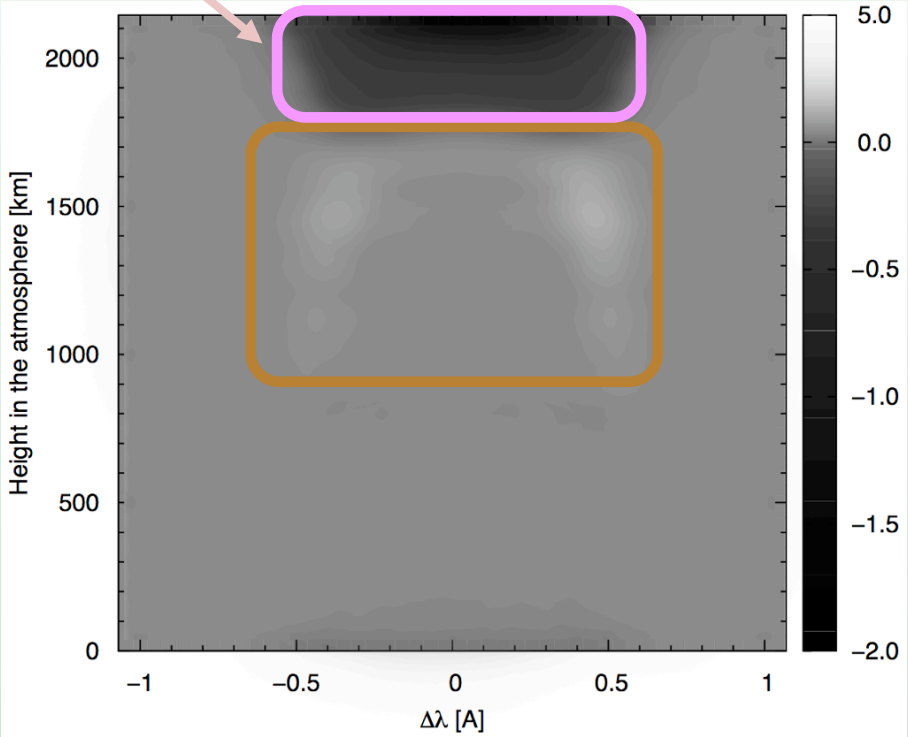
Response of the emergent Q profile of H-alpha to the Hanle effect of an inclined field

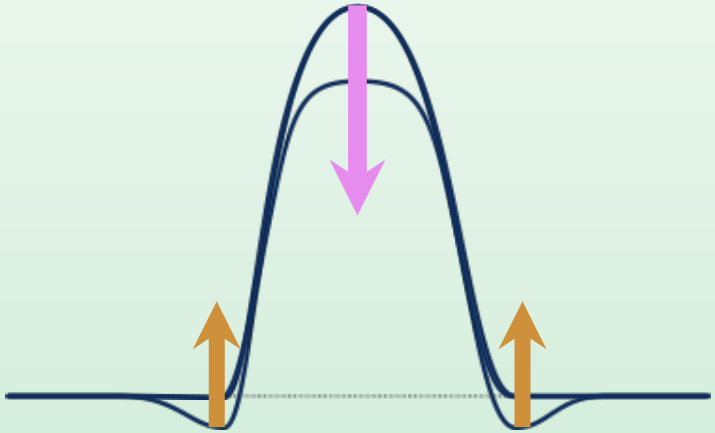
(Stepan & TB 2010)

Upper chromosphere

Q/I response function



Response of the Q/I profile



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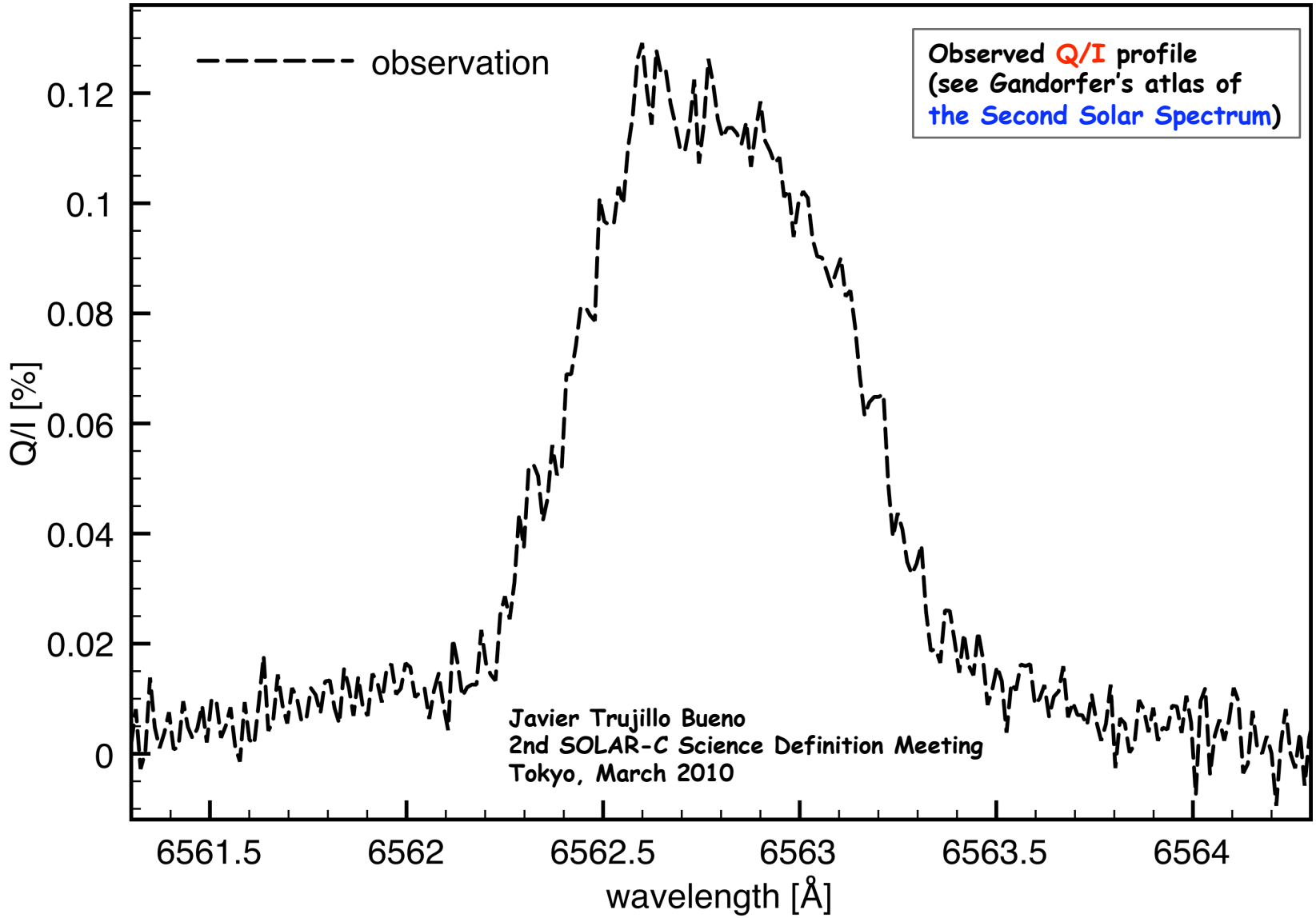
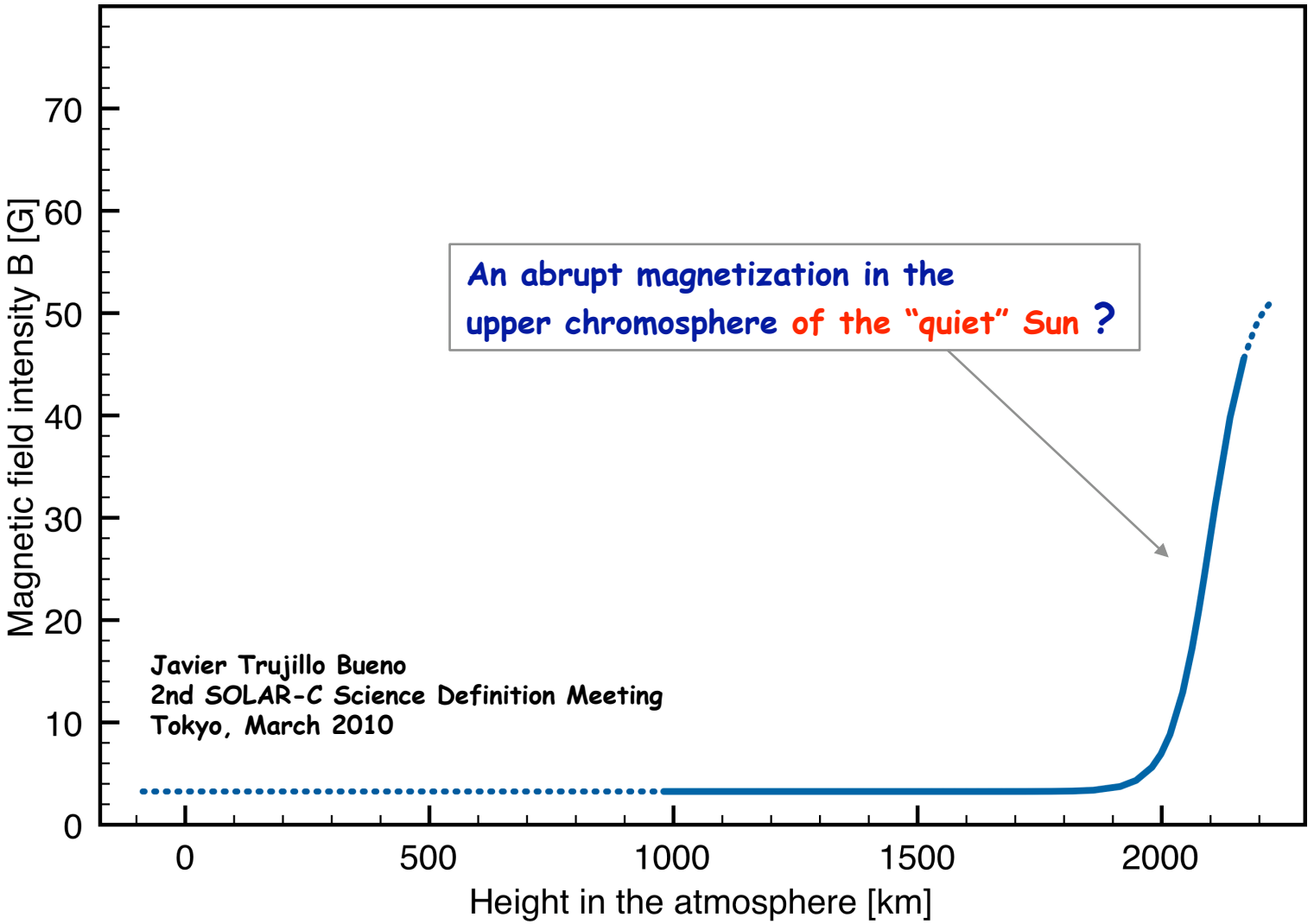
Observed Q/I in the H-alpha line



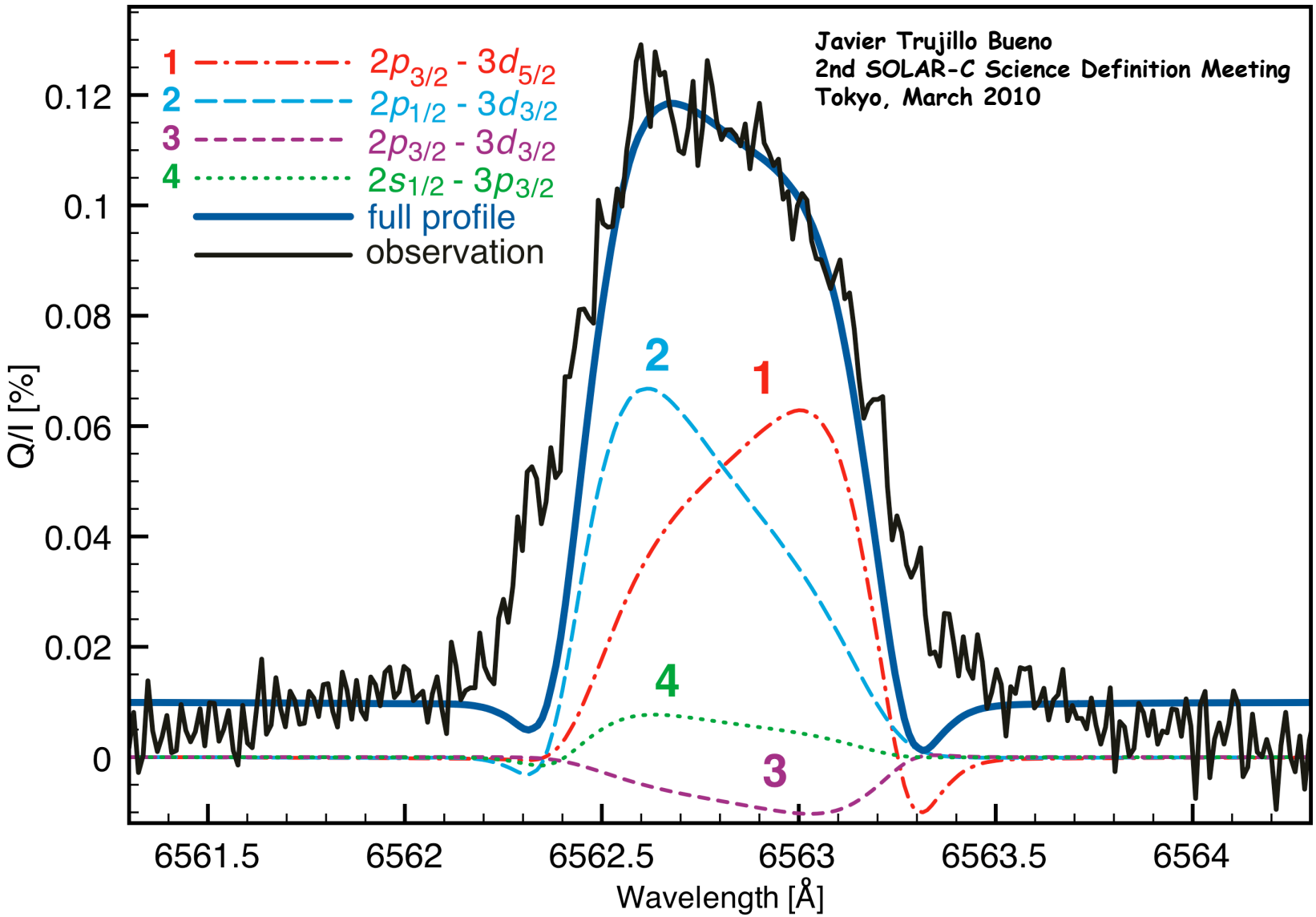
The Hanle effect in the H-alpha line is very sensitive to the presence of gradients of the magnetic field strength in the upper chromosphere (see Stepan & TB 2010; ApJ)

Height-variation of the magnetic field strength needed to produce the observed Q/I ?



The Hanle effect in the H-alpha line

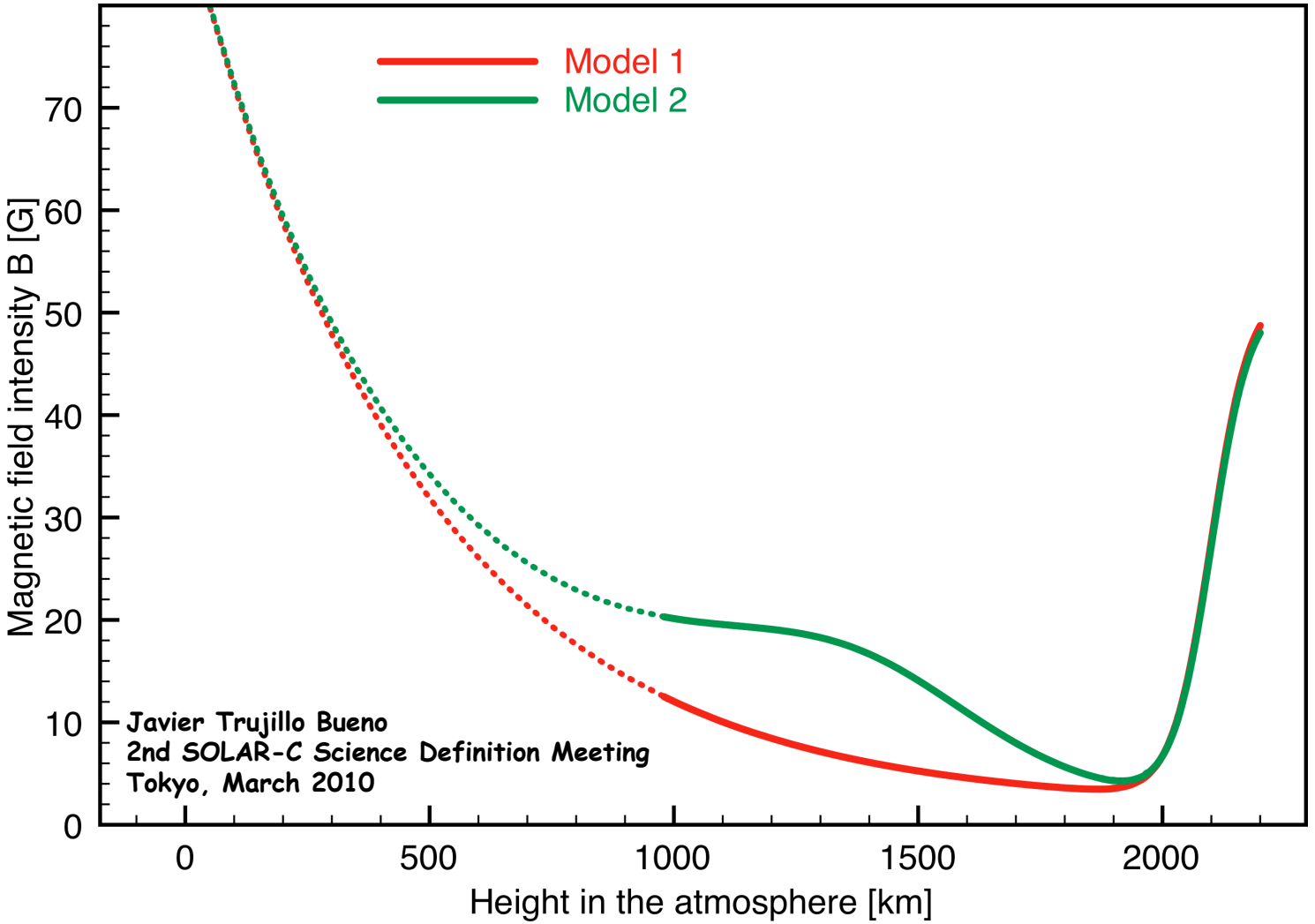
(Stepan & TB 2010; ApJ)



On the probable existence of an abrupt magnetization in the upper chromosphere of the "quiet" Sun

(Stepan & TB 2010; ApJ)

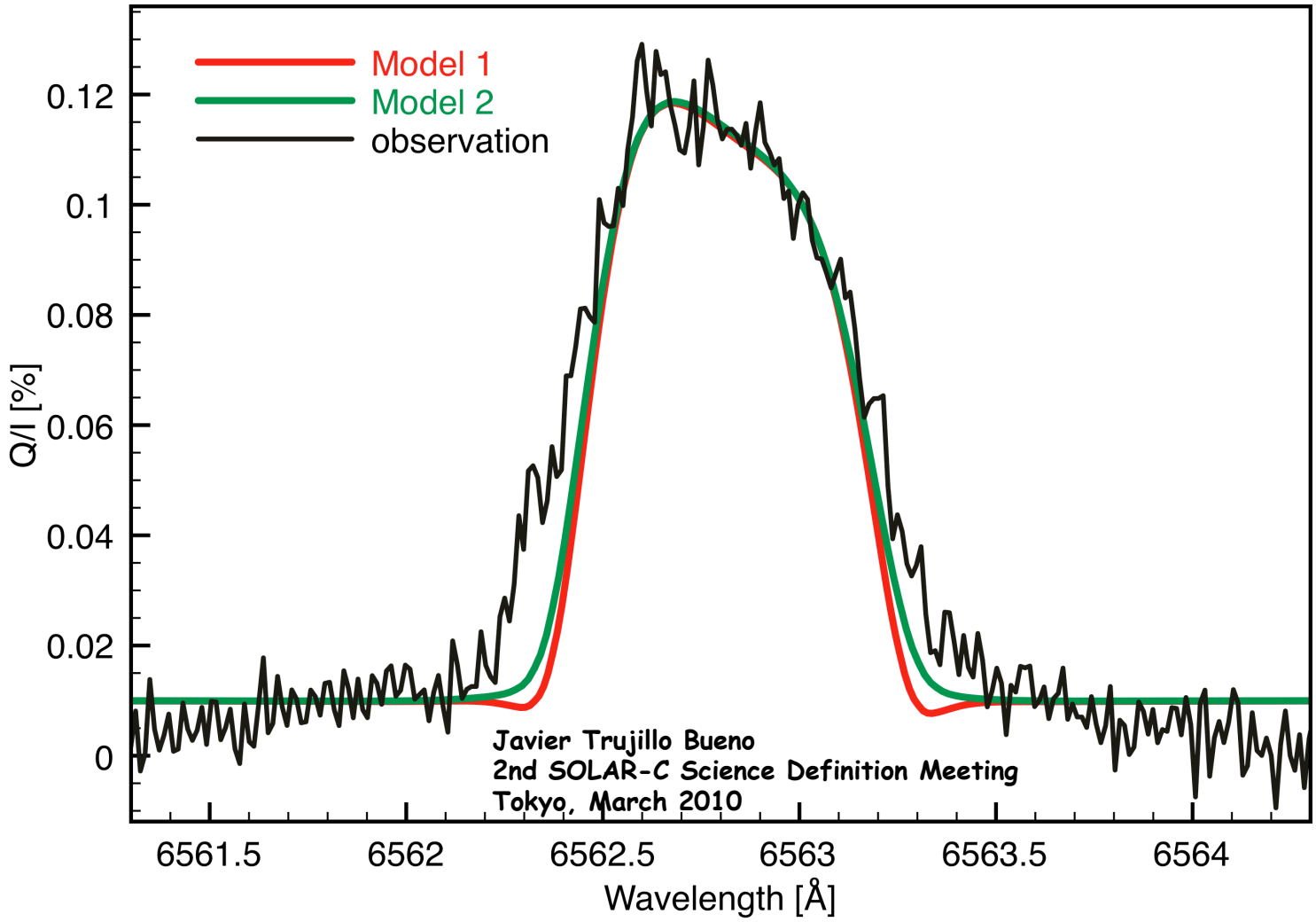
Height-variation of the magnetic field strength needed to produce the observed Q/I



On the probable existence of an abrupt magnetization in the upper chromosphere of the "quiet" Sun

(Stepan & TB 2010; ApJ)

The resulting theoretical Q/I profile of the H-alpha line



New discovery space 3

H-alpha spectropolarimetry with SOLAR-C option-B would allow us to explore with high angular and temporal resolution the spatial structure of the magnetic field in the upper chromosphere of the Sun.

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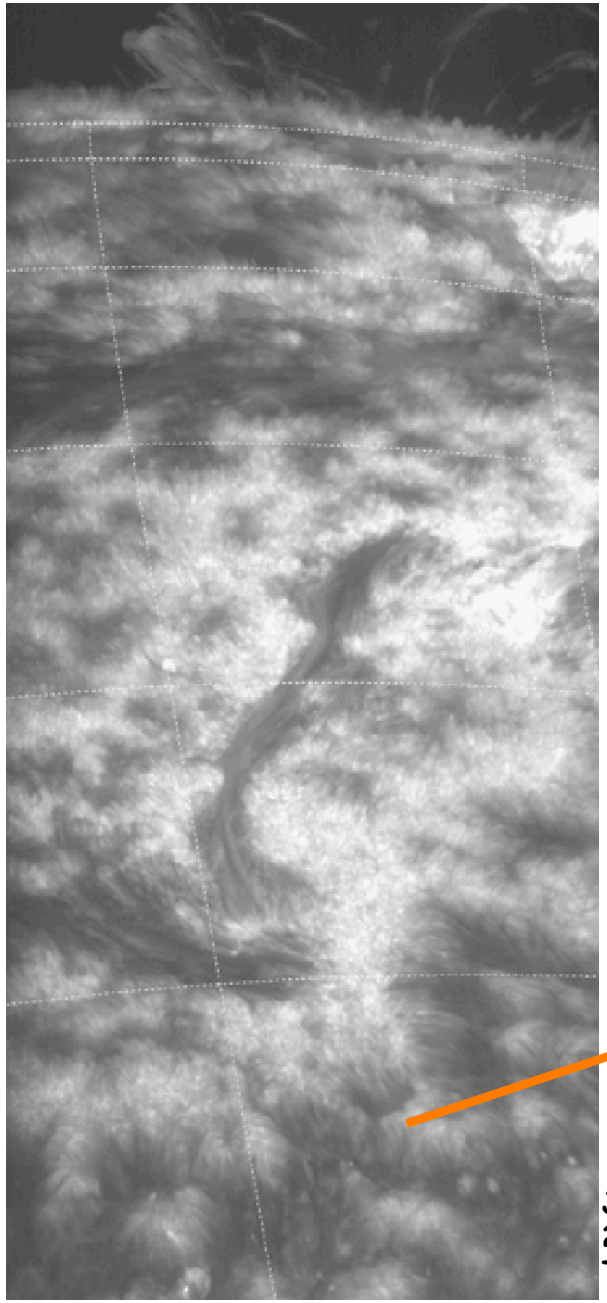
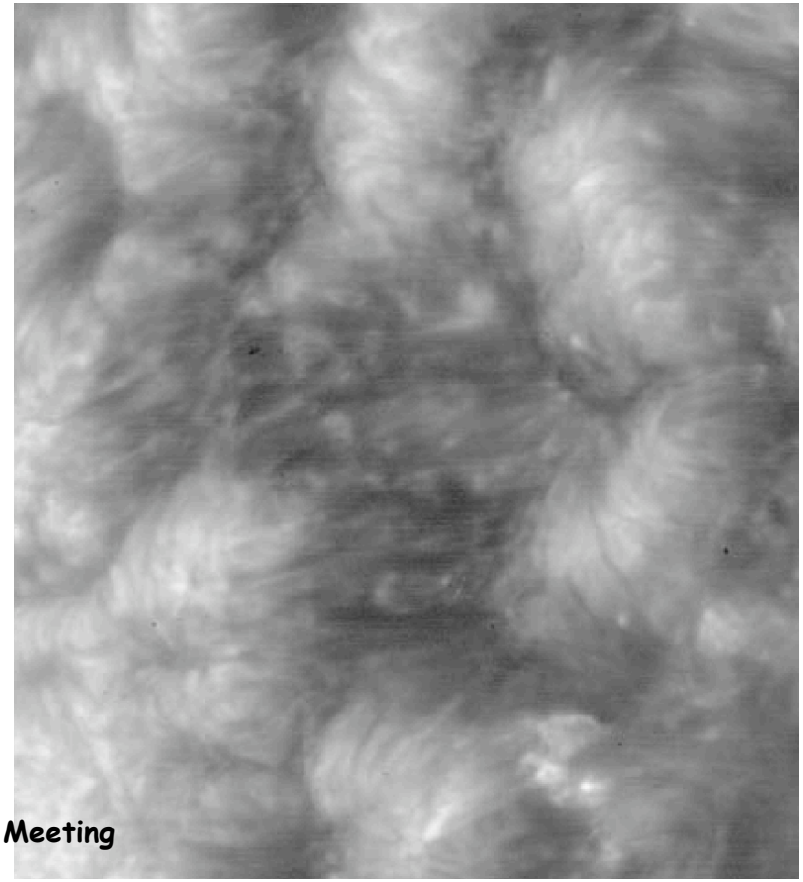
Ly-alpha intensity image
of the TR (see Vourlidas et al. 2010)



How to explore the magnetism of the transition region ?

Quiet Transition Region
(detail of a supergranular cell)



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Radiative transfer modeling of the intensity and scattering polarization of the Mg II k-line and of its sensitivity to the Hanle effect in the solar TR

(Results from an ongoing work in collaboration with M. Sampoorna & J. Stepan)

- Radiative transfer code with Partial Frequency Redistribution (PRD) and polarization (see Sampoorna & Trujillo Bueno 2010; ApJ).

- Model atmospheres used: for the moment semi-empirical models like FAL-C, but we can do the RT calculations with PRD + scattering polarization in MHD models also.

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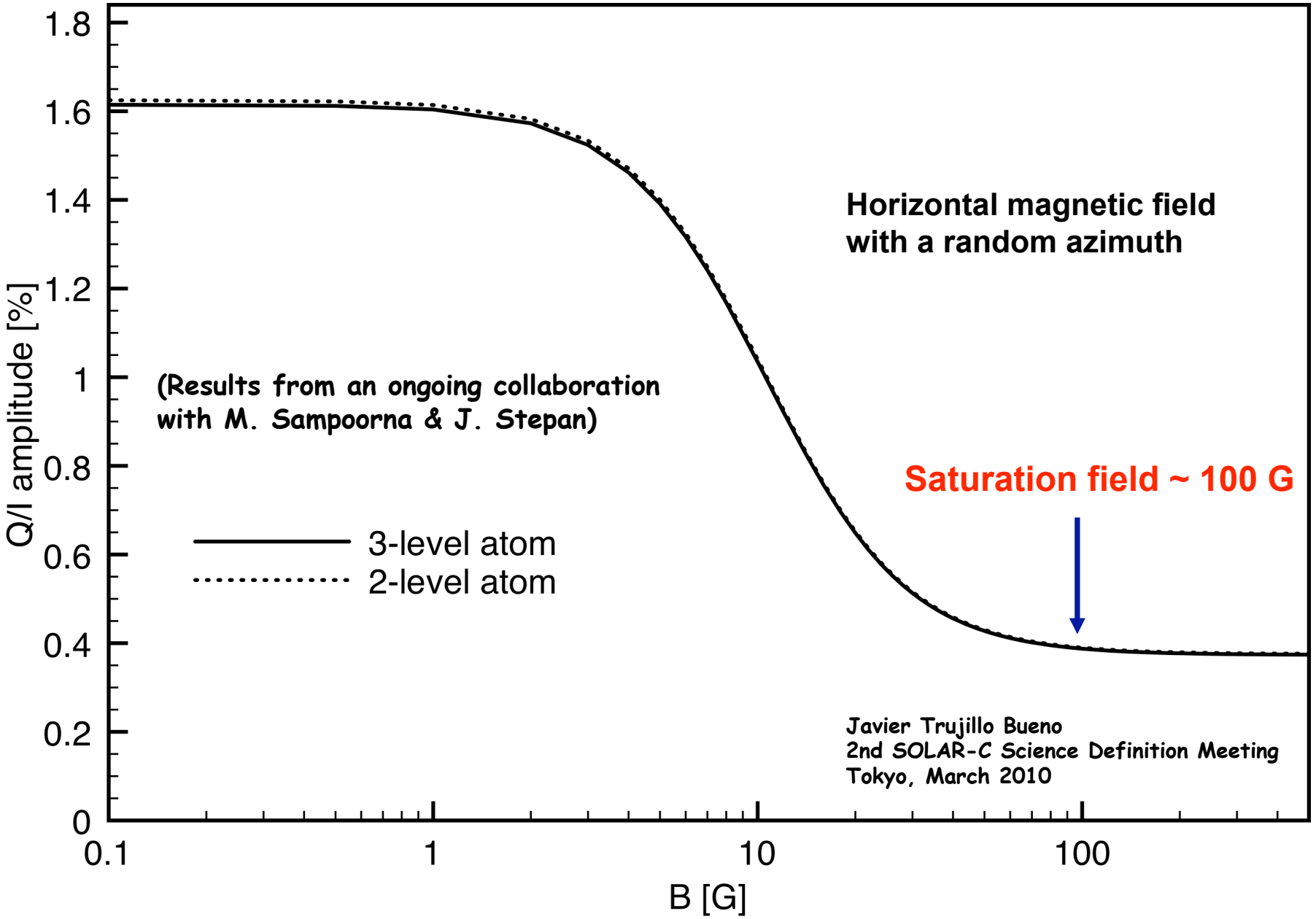
The Hanle effect at the Mg II k-line center



New discovery space 4

- With SOLAR-C option-B we could discover and explore for the first time scattering polarization in a Transition Region line, opening thus a novel diagnostic window on the physical conditions of the outer solar atmosphere.

Concluding comment

With SOLAR-C option-B

JAXA + NASA + ESA

would make feasible a new revolution in our empirical understanding of solar magnetism.

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