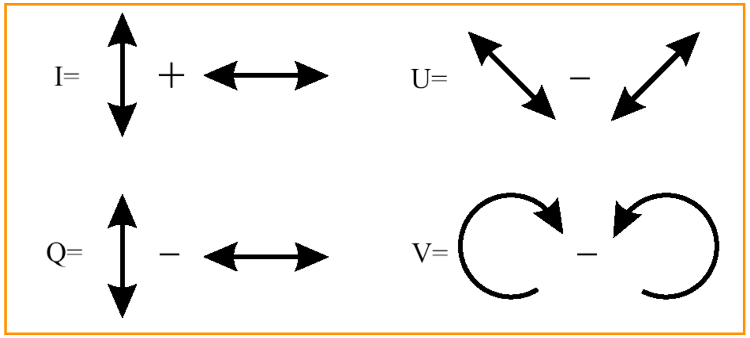
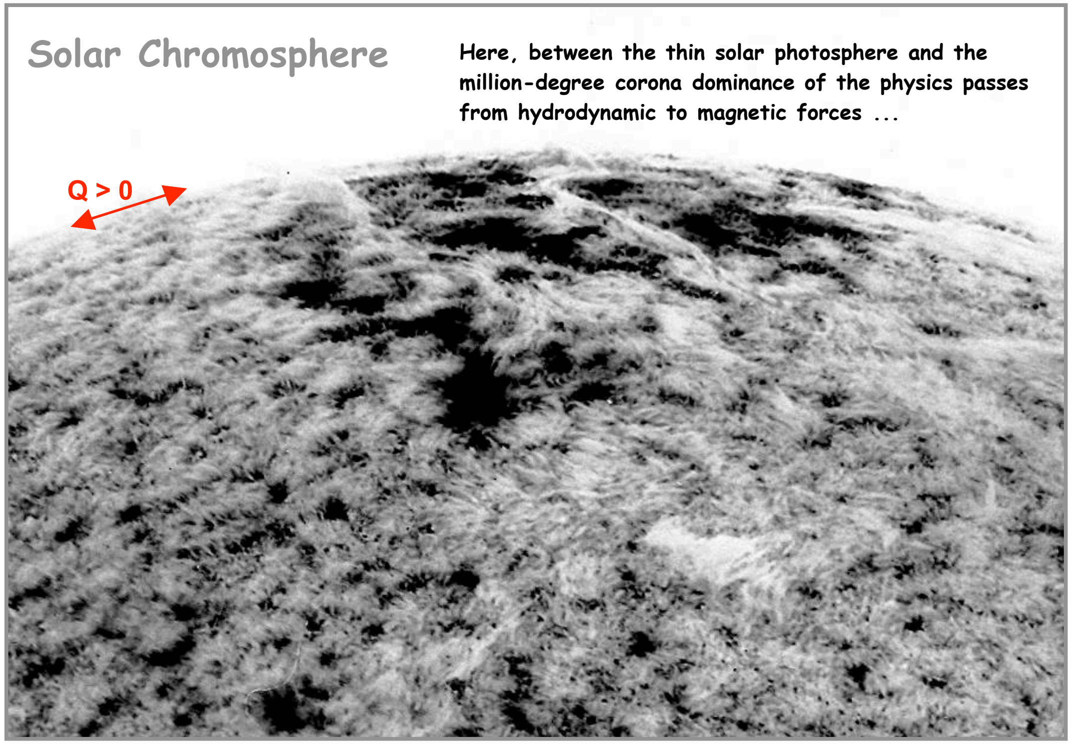
Polarized Radiation Diagnostics Methods for “Measuring” Chromospheric and Coronal Magnetic Fields

Javier Trujillo Bueno
(IAC, Tenerife, Spain)



Courtesy of J. Harvey



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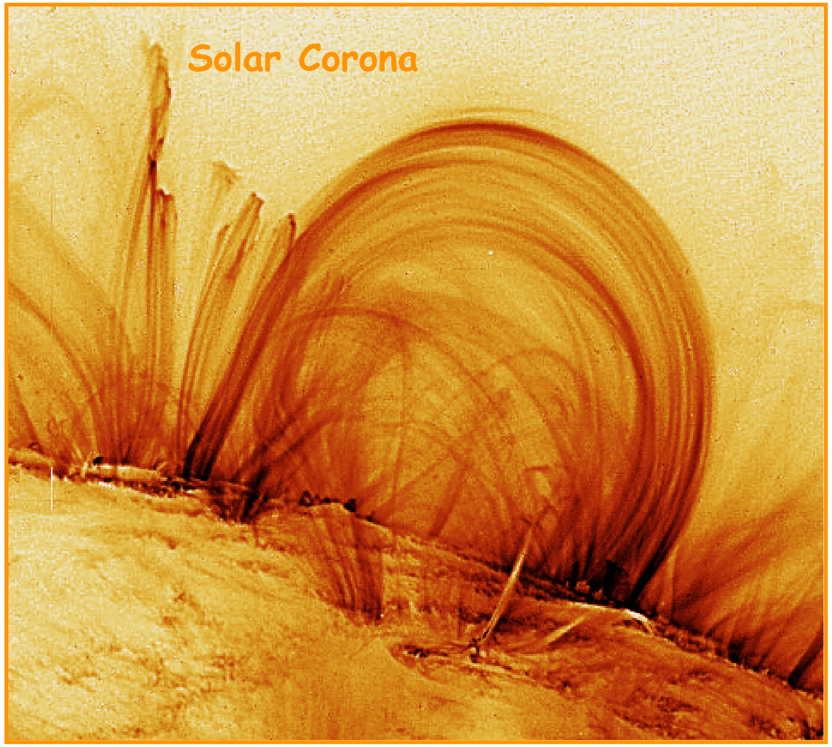

Outline of the talk

- Itroduction
- Physical mechanisms that produce polarization in spectral lines.
- Some diagnostic methods based on them.
- Some suggestions for SOLAR-C
- Concluding comments.

Introduction

- Probably, the greatest future challenge in space astrophysics is the empirical investigation of the **magnetic field vector** in a variety of astrophysical systems:

- **Solar outer atmosphere:** **Chromoshere, TR and Corona**
- Circumstellar envelopes
- Accreting systems
- Etc…

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- To this end we need to carry out

spectropolarimetric observations

from space telescopes,

throughout the whole electromagnetic spectrum, also in the

UV, EUV and X-ray spectral regions.

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- The polarization signals I am going to consider here are produced by the joint action of the Hanle and Zeeman effects, but I will emphasize here the diagnostic potential of the spectral line polarization caused by

atomic level polarization

- Such polarization signals are sensitive to magnetic fields in a parameter domain that goes from at least one microgauss to a few hundreds of gauss (Hanle effect).

- Observations of these polarization effects provide

key information, impossible to obtain via conventional spectropolarimetry.

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Physical mechanisms that control the polarization of the spectral lines that originate in a stellar atmosphere:

- **The Zeeman effect**
- **Atomic level polarization**
- **The Hanle effect**

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What is the Zeeman effect polarization ?

Mr. Zeeman

The spectral line polarization produced by the **wavelength shifts** between the sigma and pi components. (NOTE: such wavelength shifts are due to the Zeeman splitting of the energy levels).

NOTE: Typically, 100 G or more are needed to observe this effect in the linear polarization profiles of solar spectral lines (i.e., in the Q/I and/or U/I profiles).

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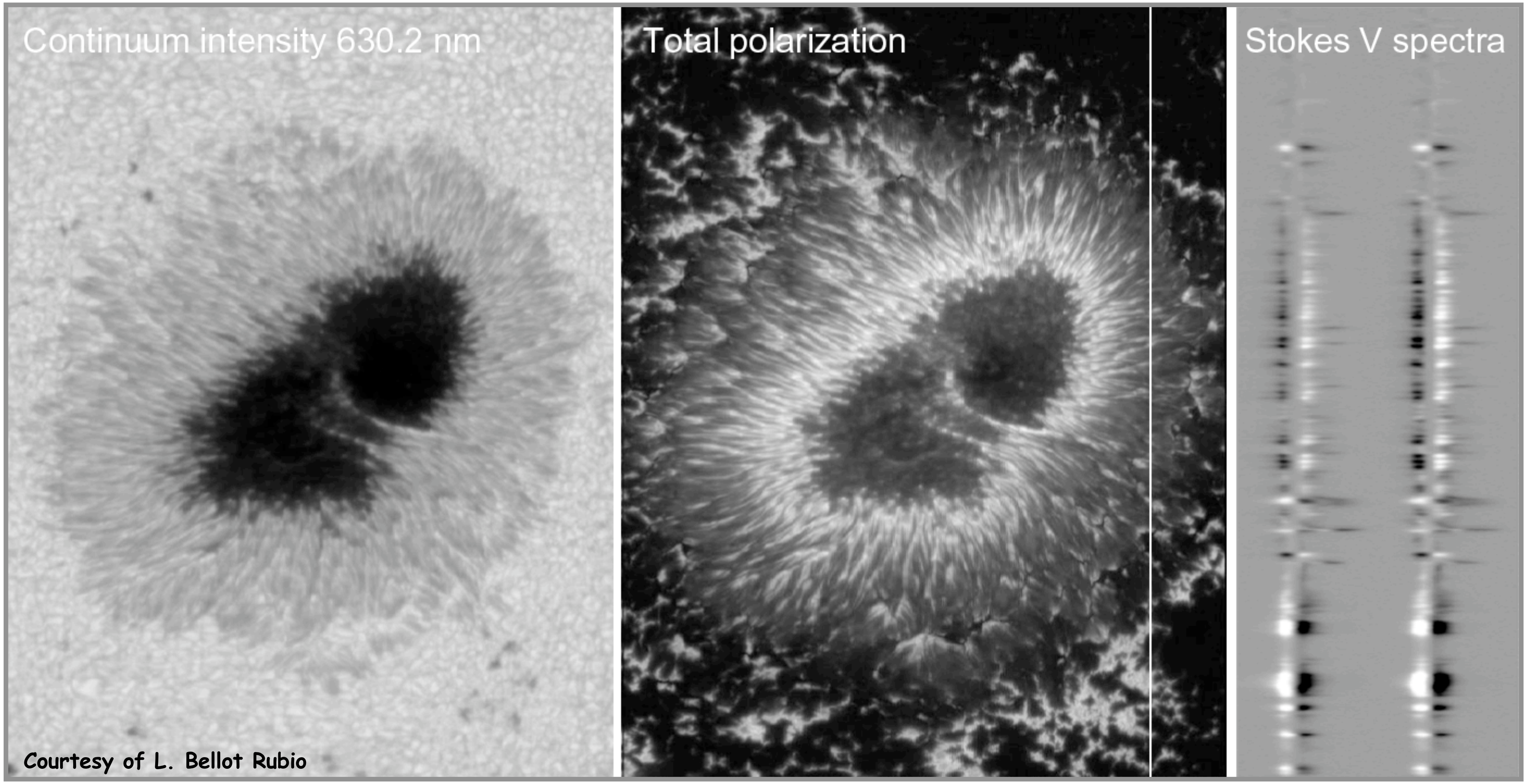
Observation of the polarization of the Zeeman effect in sunspots with HINODE



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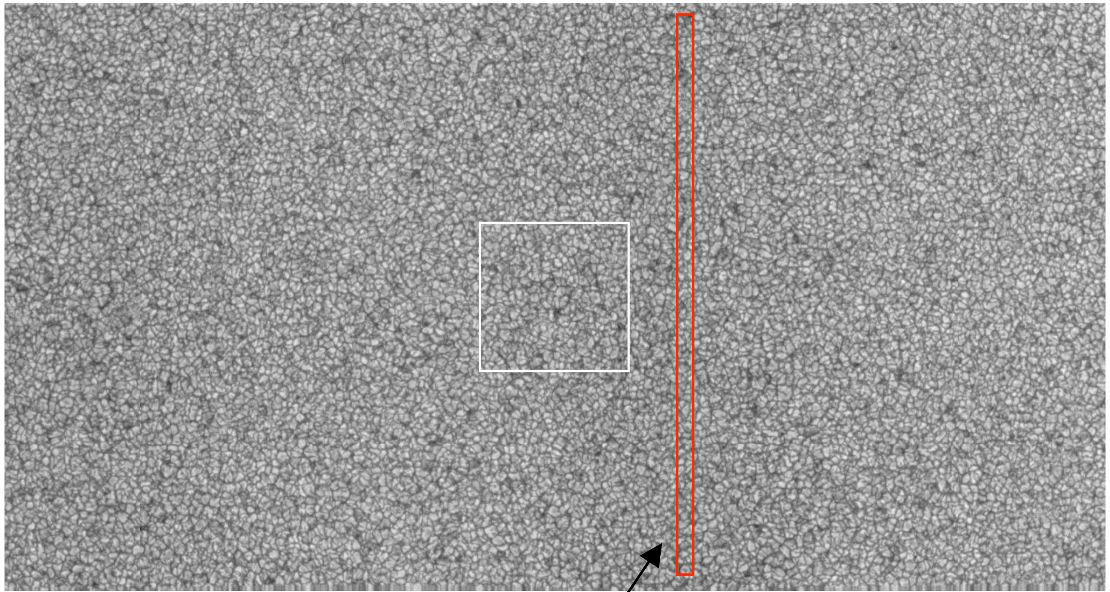
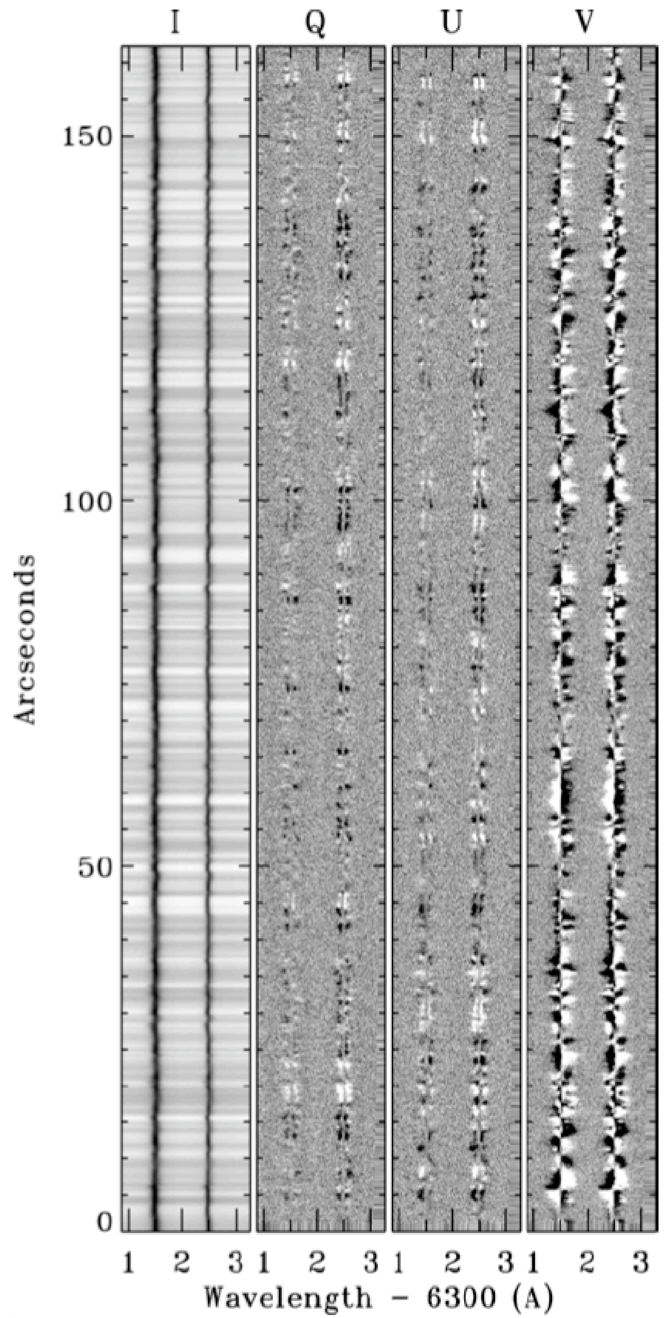
Observation of the magnetic fields of the "quiet" solar photosphere through the "Zeeman eyes" of HINODE
(From Lites et al. 2008)

The "skin" of the Sun: the solar photosphere



Spectrograph's slit



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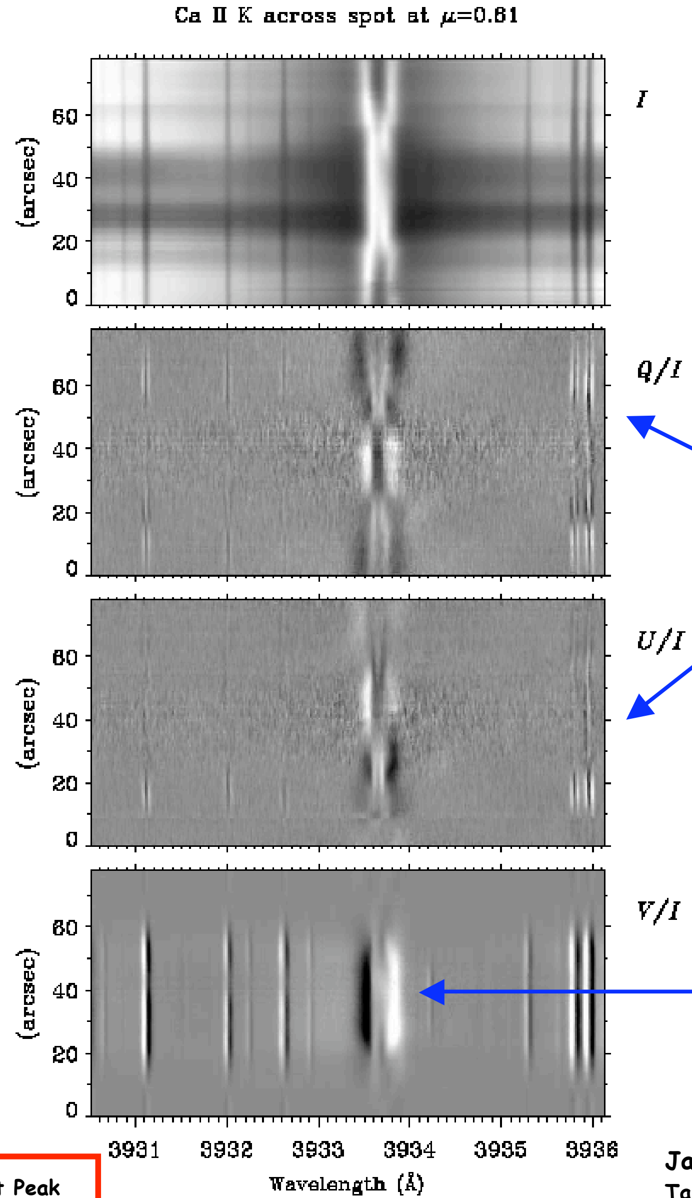
The chromospheric K-line of CA II

OBSERVED IN A SUNSPOT = strongly magnetized region



Linear polarization created by the TRANSVERSE ZEEMAN effect

Circular polarization created by the LONGITUDINAL ZEEMAN effect

Observation by Stenflo (2006) with ZIMPOL @ Kitt Peak

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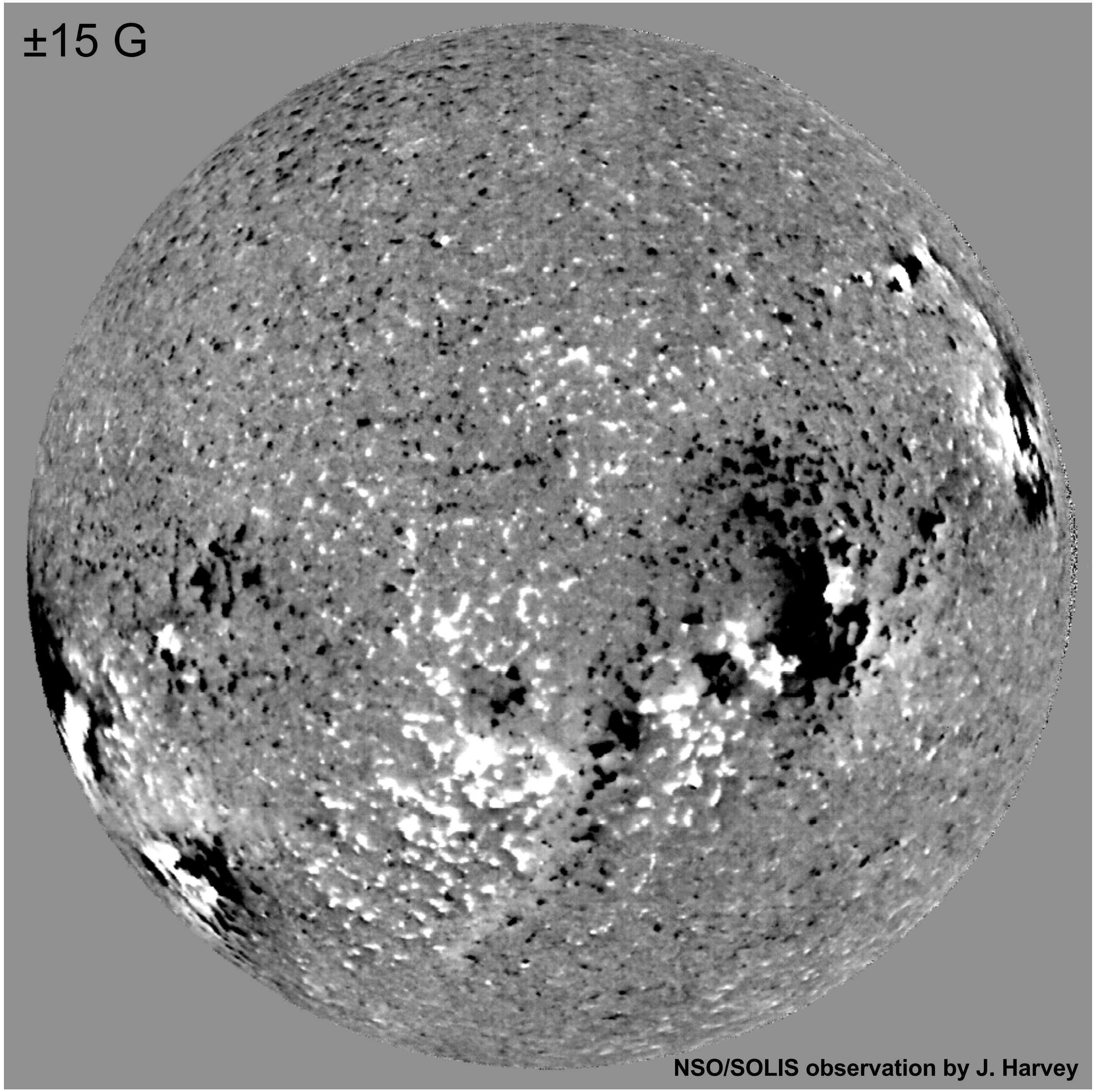
The longitudinal Zeeman effect in the 8542 chromospheric line of Ca II



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GOOD NEWS for the ZEEMAN effect:
The mere detection of polarization implies the presence of a magnetic field B.

BAD NEWS for the ZEEMAN effect:

(1) It is of limited practical interest for the "measurement" of B in chromospheric and coronal plasmas because the Zeeman polarization scales with the ratio between the Zeeman splitting and the Doppler-broadened line width.

(2) The Zeeman effect is BLIND to B that are tangled on scales too small to be resolved.

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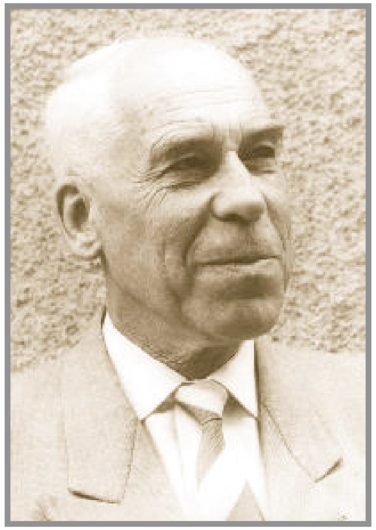
What is the Hanle effect ?



Mr. Hanle

Any modification of the atomic level polarization (population imbalances and coherences) **due to the presence of a magnetic field.**

NOTE: Typically, Q/I and U/I are sensitive to magnetic fields with strengths between at least 1 milligauss and 100 G !

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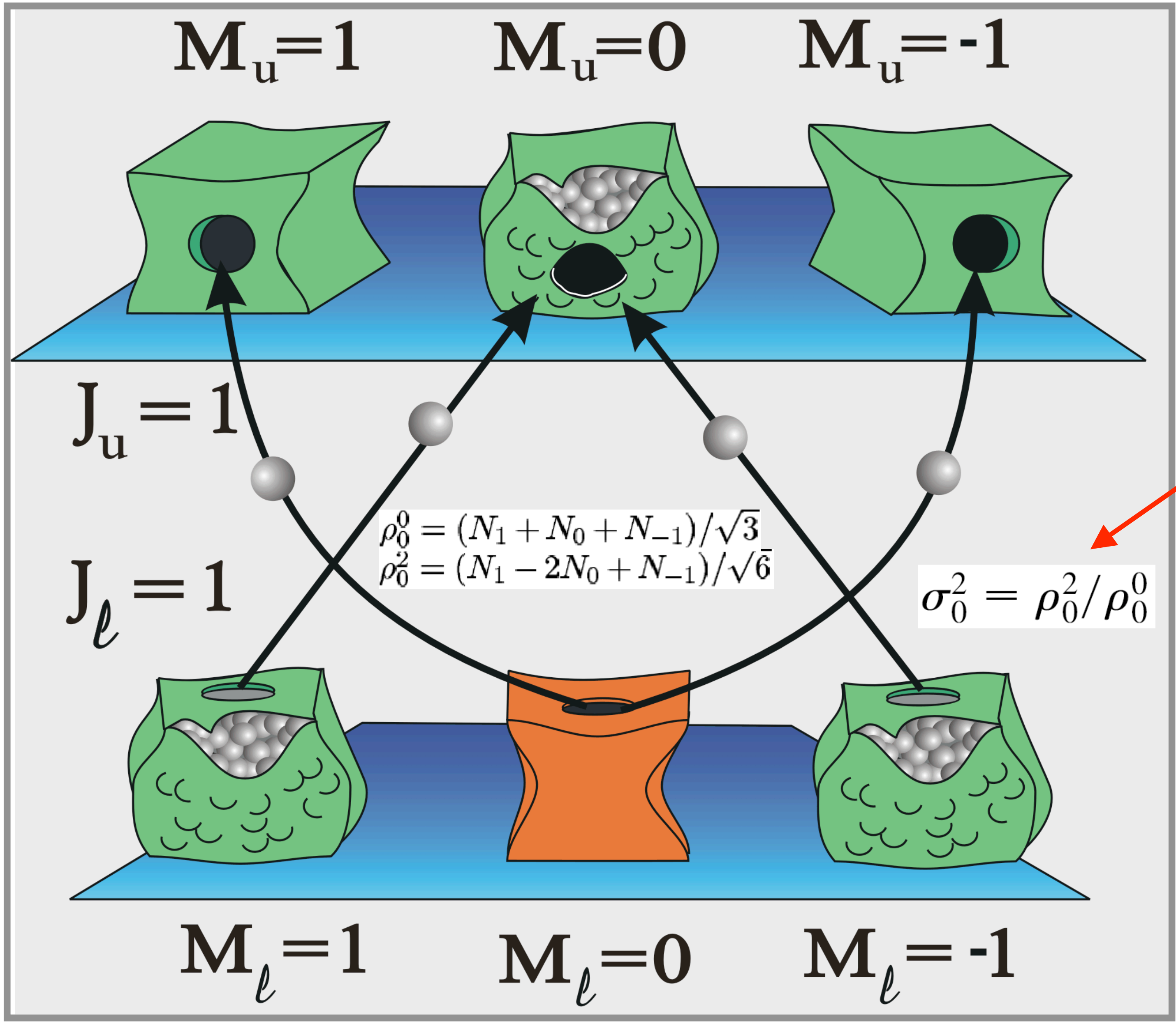
ATOMIC LEVEL POLARIZATION



Fractional atomic polarization of the level under consideration

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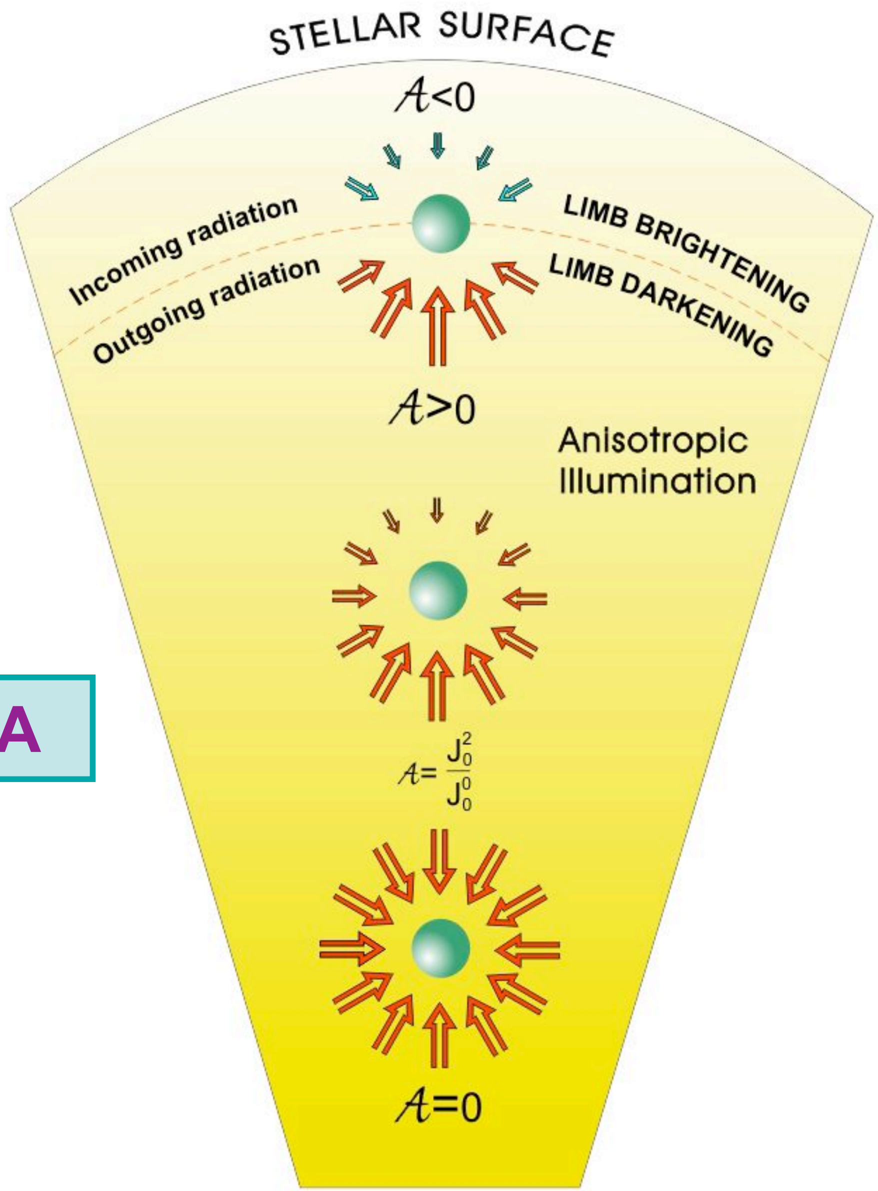
Anisotropy of the radiation field in a spherically symetric atmosphere

How to quantify the "degree of anisotropy" at each point within the medium?

The anisotropy factor $W = \sqrt{2}\,A$

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

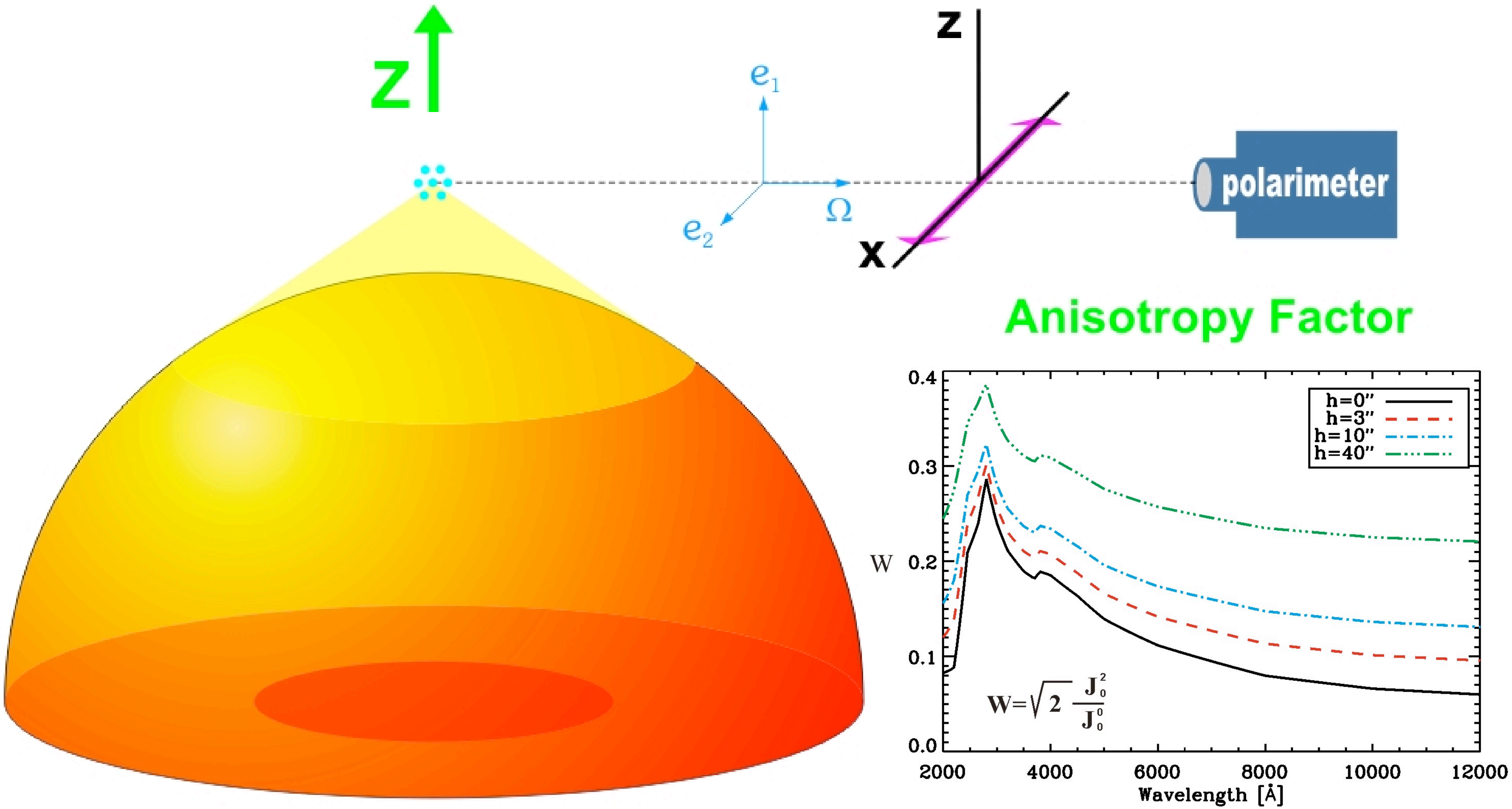


$$J^0_0 = \frac{1}{4\pi}\int d\vec{\Omega}\; I(\vec{\Omega})$$

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

Javier Trujillo Bueno (IAC, Tenerife, Spain).

Anisotropic Illumination



Javier Trujillo Bueno (IAC, Tenerife, Spain).

OPTICAL PUMPING → ATOMIC POLARIZATION

NEVER FORGET !

- POLARIZATION in a spectral line can be produced

  by the mere presence of population imbalances among the sublevels pertaining to the upper and/or lower atomic level of the line transition under consideration.

- Upper-level polarization → selective EMISSION of polarization

- Lower-level polarization → selective ABSORPTION of polarization

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The Hanle effect

- It is especially sensitive to magnetic fields for which the Zeeman splitting is comparable to the natural width of the upper (or lower) level of the spectral line used, regardless of how large the line width due to Doppler broadening is.

- It is therefore sensitive to weaker magnetic fields than the Zeeman effect: from at least 1 milligauss to a few hundreds of gauss.

- It is also sensitive to magnetic fields that are tangled on scales too small to be resolved [e.g., the Hanle-effect investigation by Trujillo Bueno et al. (2004; Nature, 430, 326) showed that the bulk of the "quiet" photosphere is seething with tangled magnetic fields at subresolution scales, with <B>~130 gauss, which may be important for the overall energy balance of the solar atmosphere].

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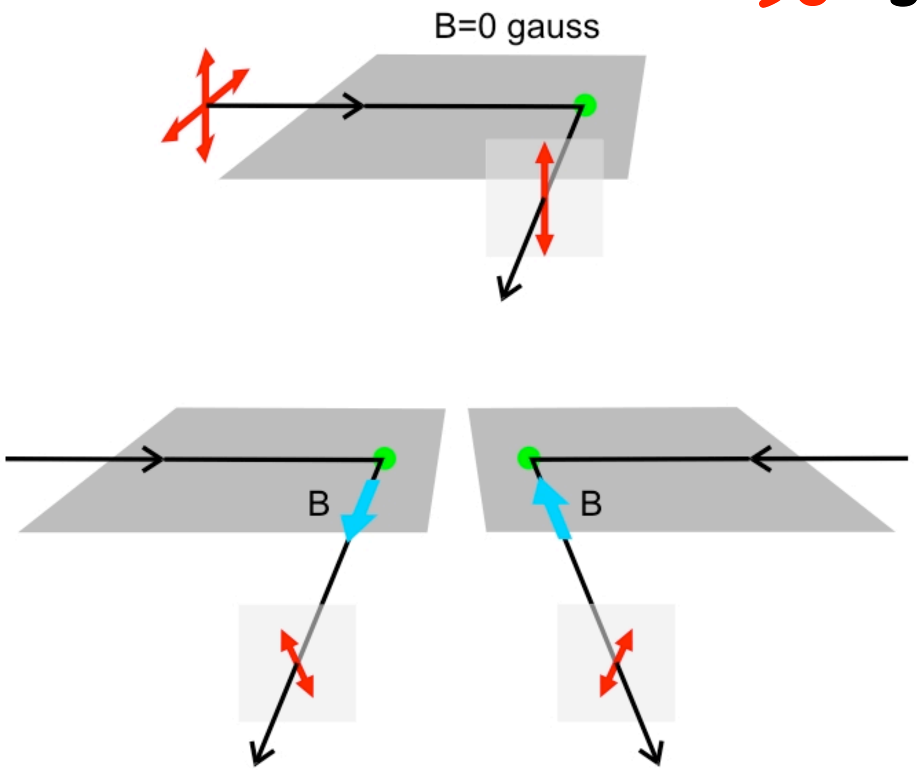
Understanding scattering experiments in the absence and in the presence of a magnetic field → the Hanle effect

90° scattering



The Hanle effect **REDUCES** the line scattering polarization amplitude (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?

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

For example, the critical field is B = 23 G for the Sr I 4607 line.

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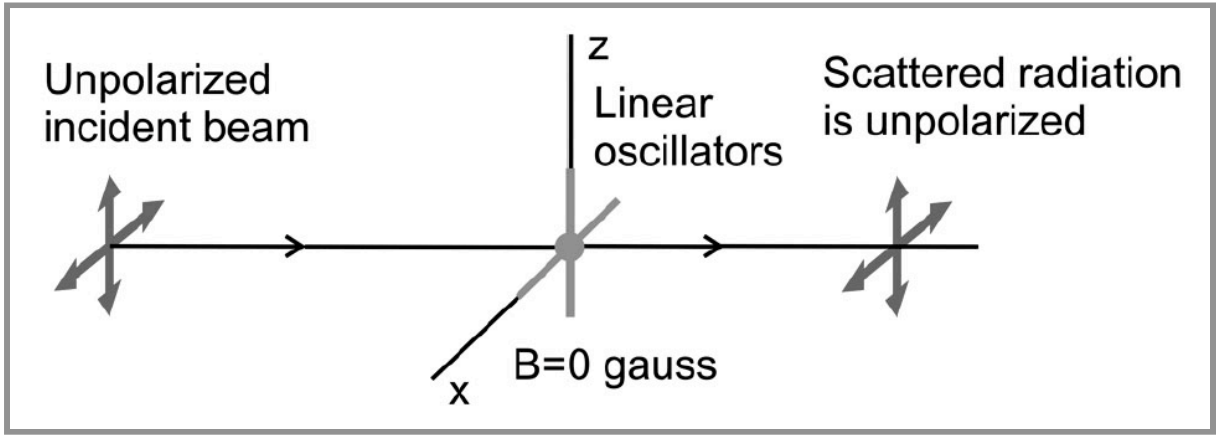
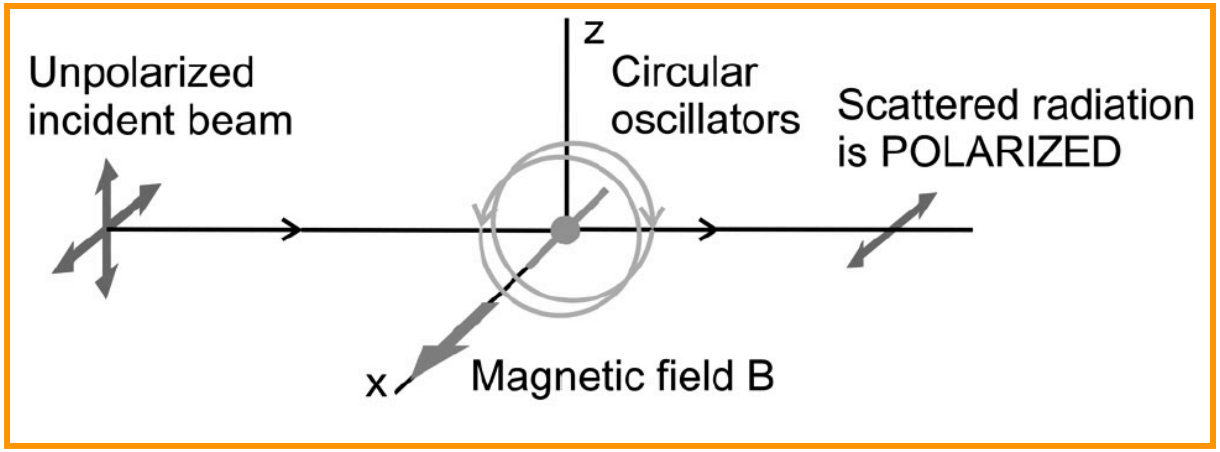
Moreover: in forward scattering, when observing at the solar disk center, the Hanle effect CREATES linear polarization in many spectral lines





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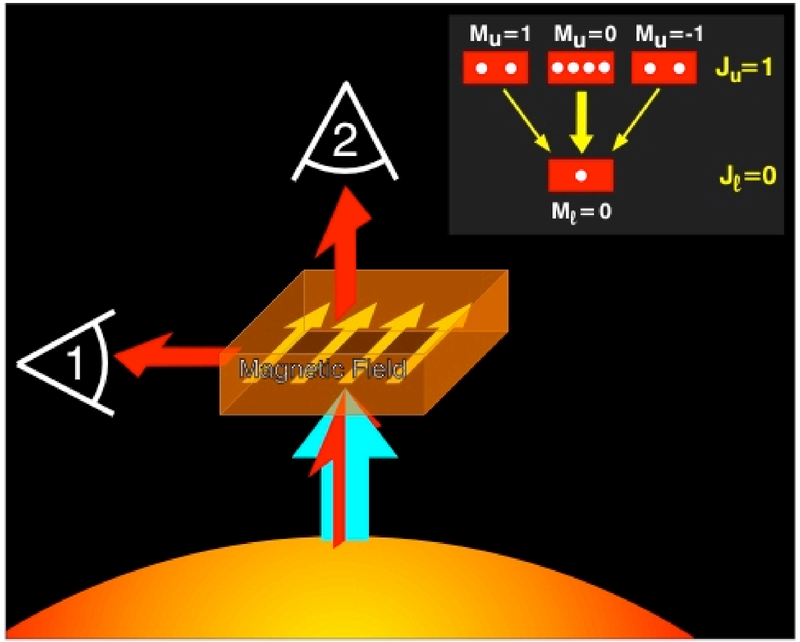
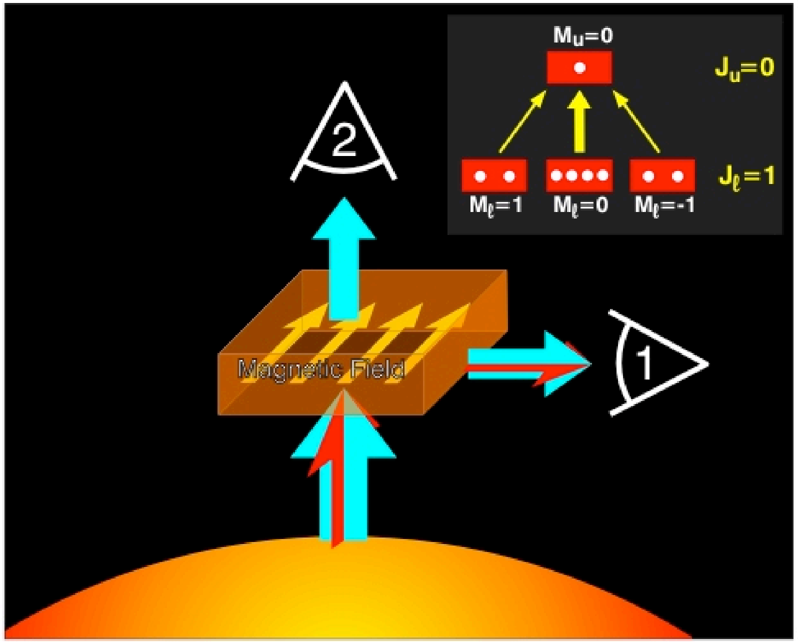
Selective emission versus Selective absorption and the Hanle effect in forward scattering

(Trujillo Bueno et al. 2002; Nature 415, 403)





$\sigma_0^2 = \rho_0^2/\rho_0^0$ quantifies the *fractional atomic alignment*

$$\rho_0^0(J=1) = \frac{1}{\sqrt{3}}\,[N_1 + N_0 + N_{-1}]$$

$$\rho_0^2(J=1) = \frac{1}{\sqrt{6}}\,[N_1 - 2N_0 + N_{-1}]$$

$$Q/I \approx [\mathcal{W}\,\sigma_0^2(\mathrm{up}) - \mathcal{Z}\,\sigma_0^2(\mathrm{low})]$$

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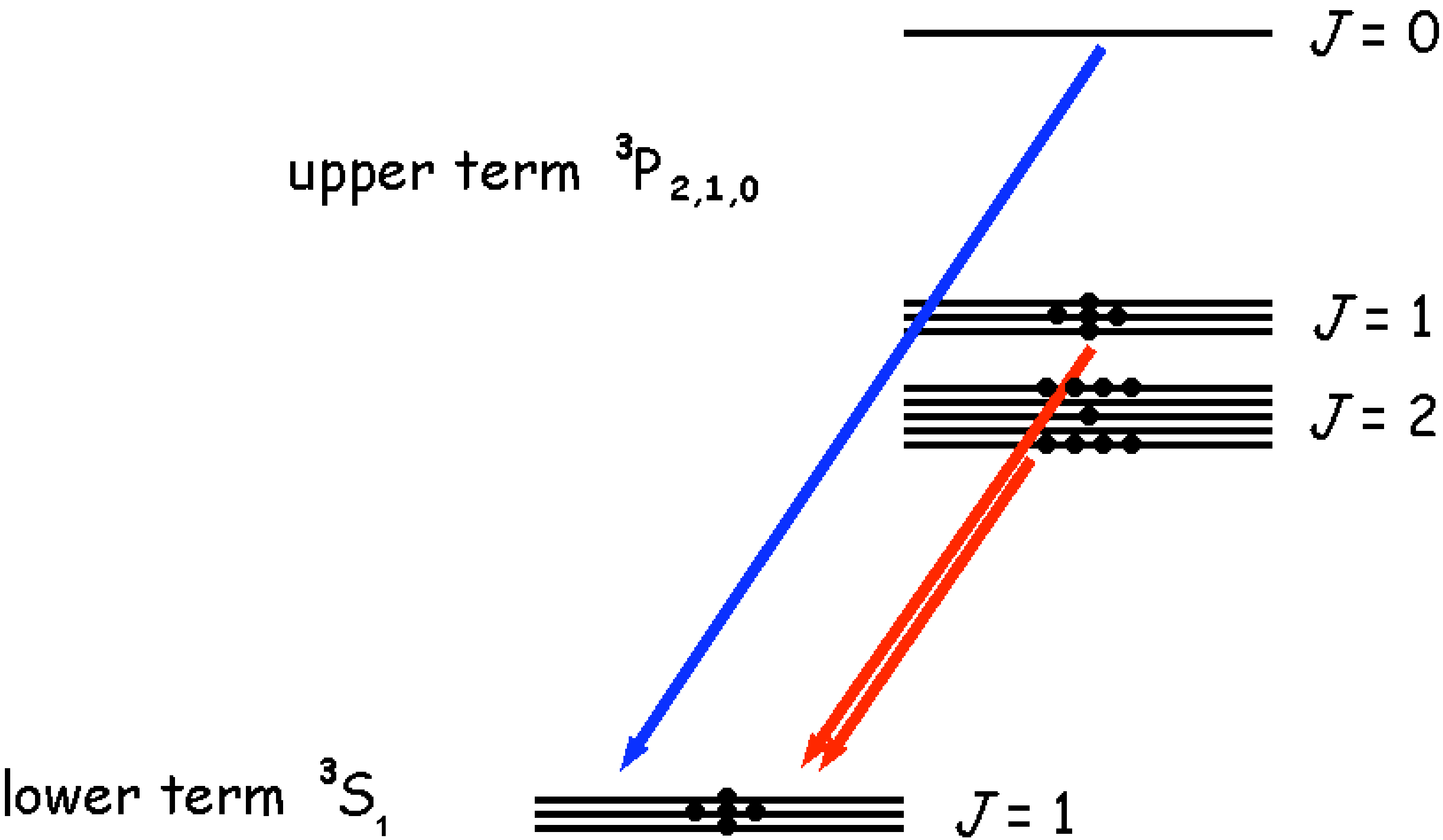
The He I 10830 A multiplet



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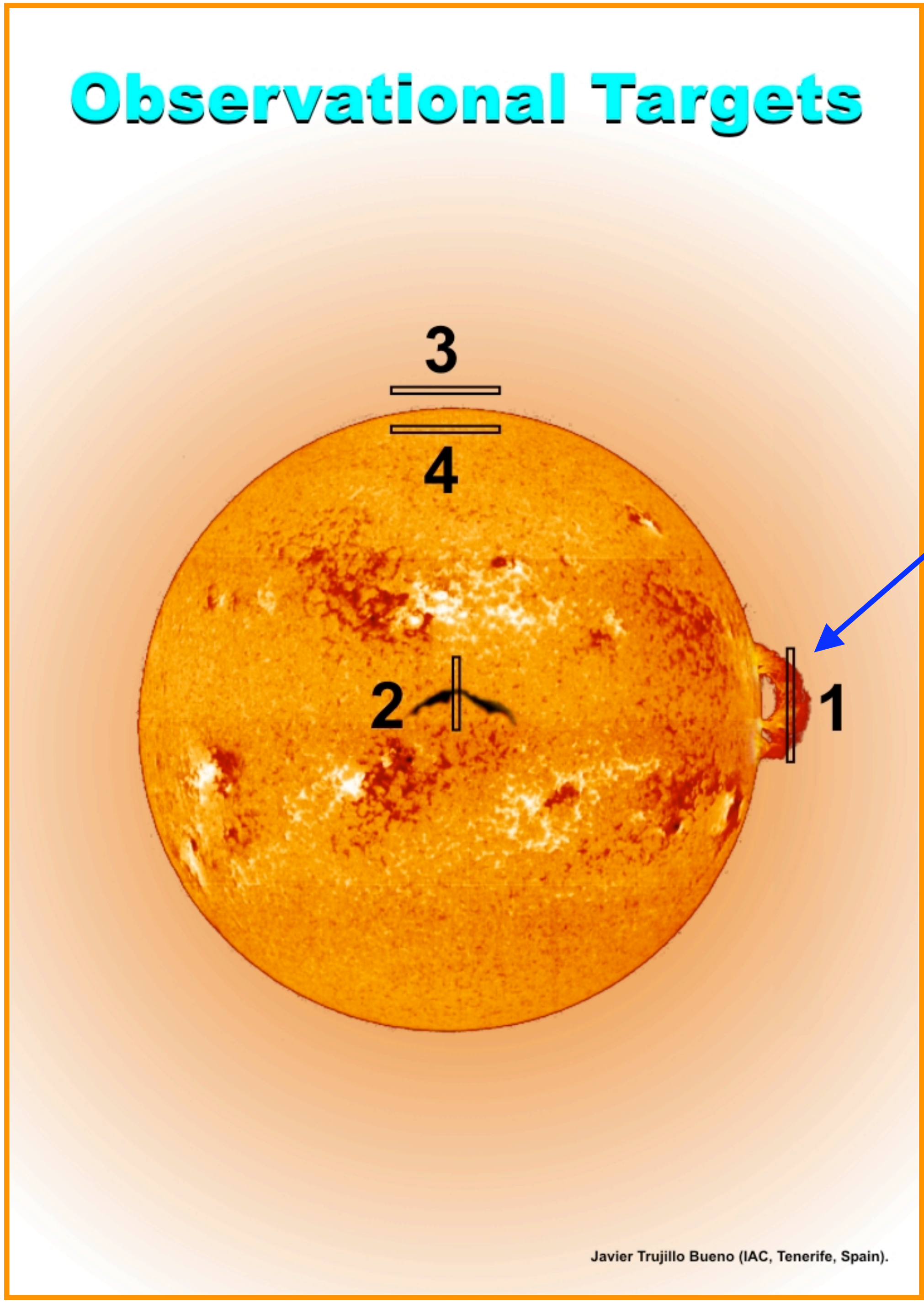


Solar prominence case: 90° scattering

In the off-limb case (90° scattering geometry) the main process that contributes to the emergent Q/I is SELECTIVE EMISSION, and

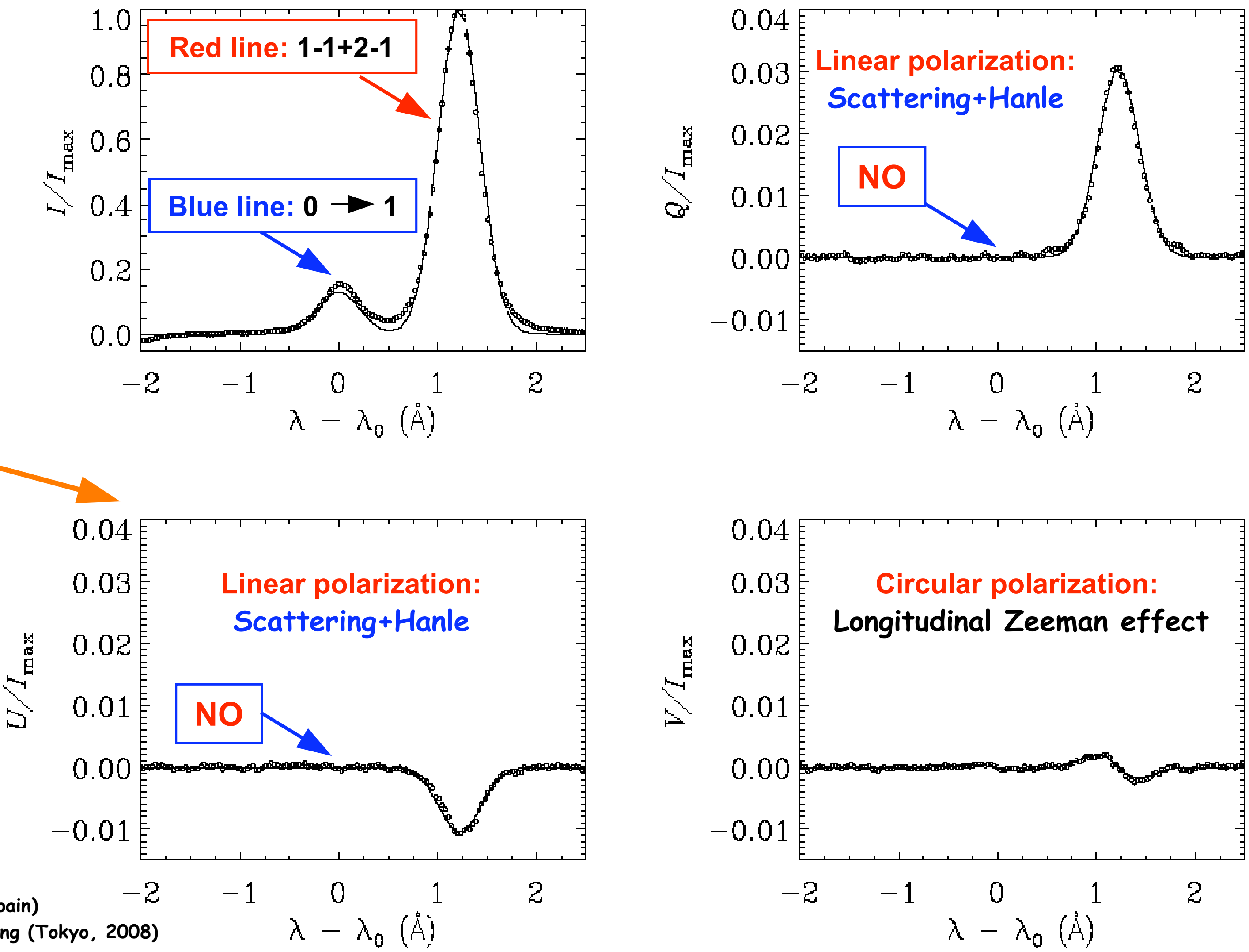
$$\frac{Q}{I} \approx \mathrm{W}\,\sigma^2_0(\mathrm{up})$$

The solar prominence case: spectropolarimetric observation versus quantum theory.

Clear observational signature of the Hanle effect:

rotation of the direction of polarization of the scattered light.

B=26 G
Inclination=25°
Azimuth=160°



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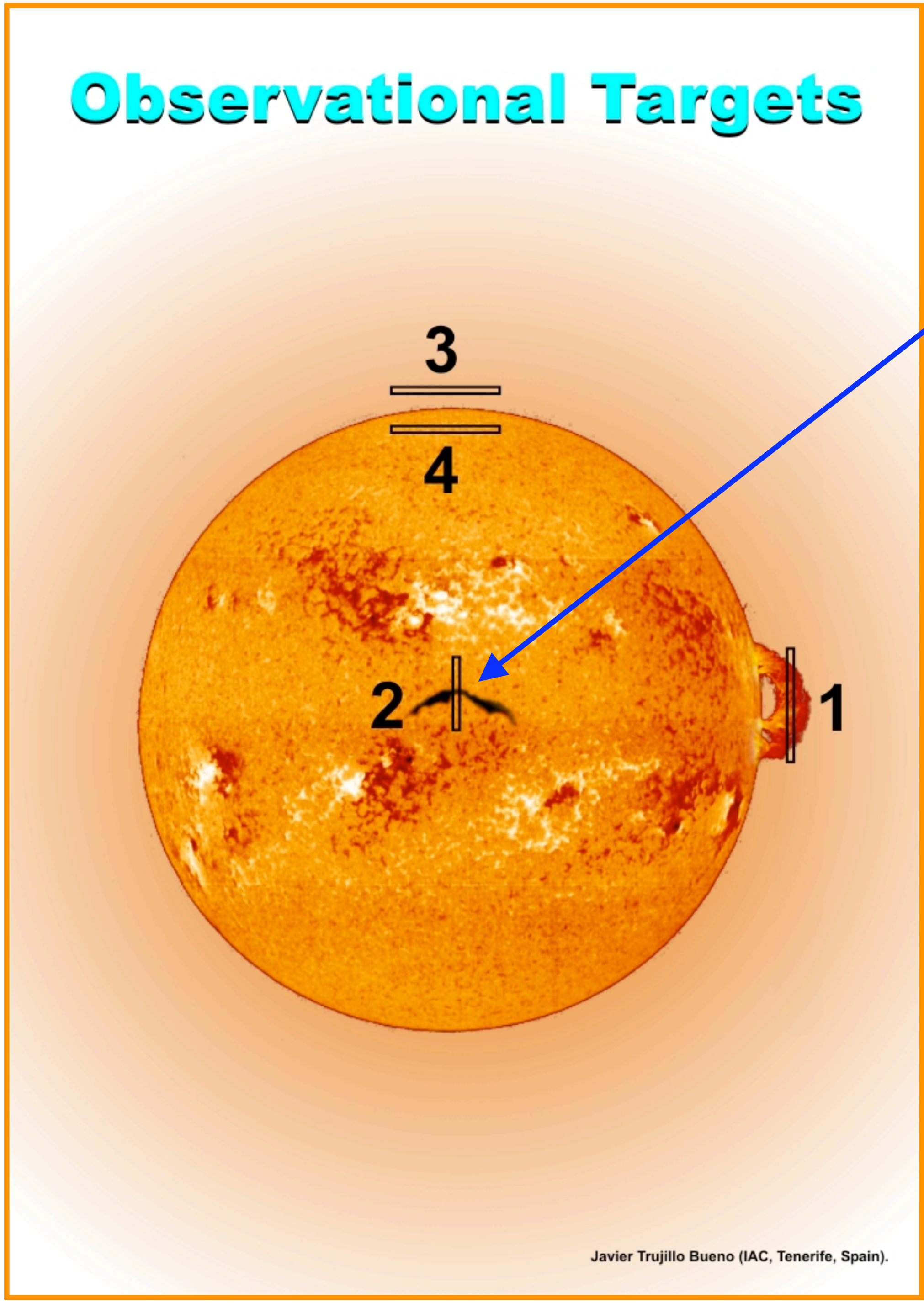


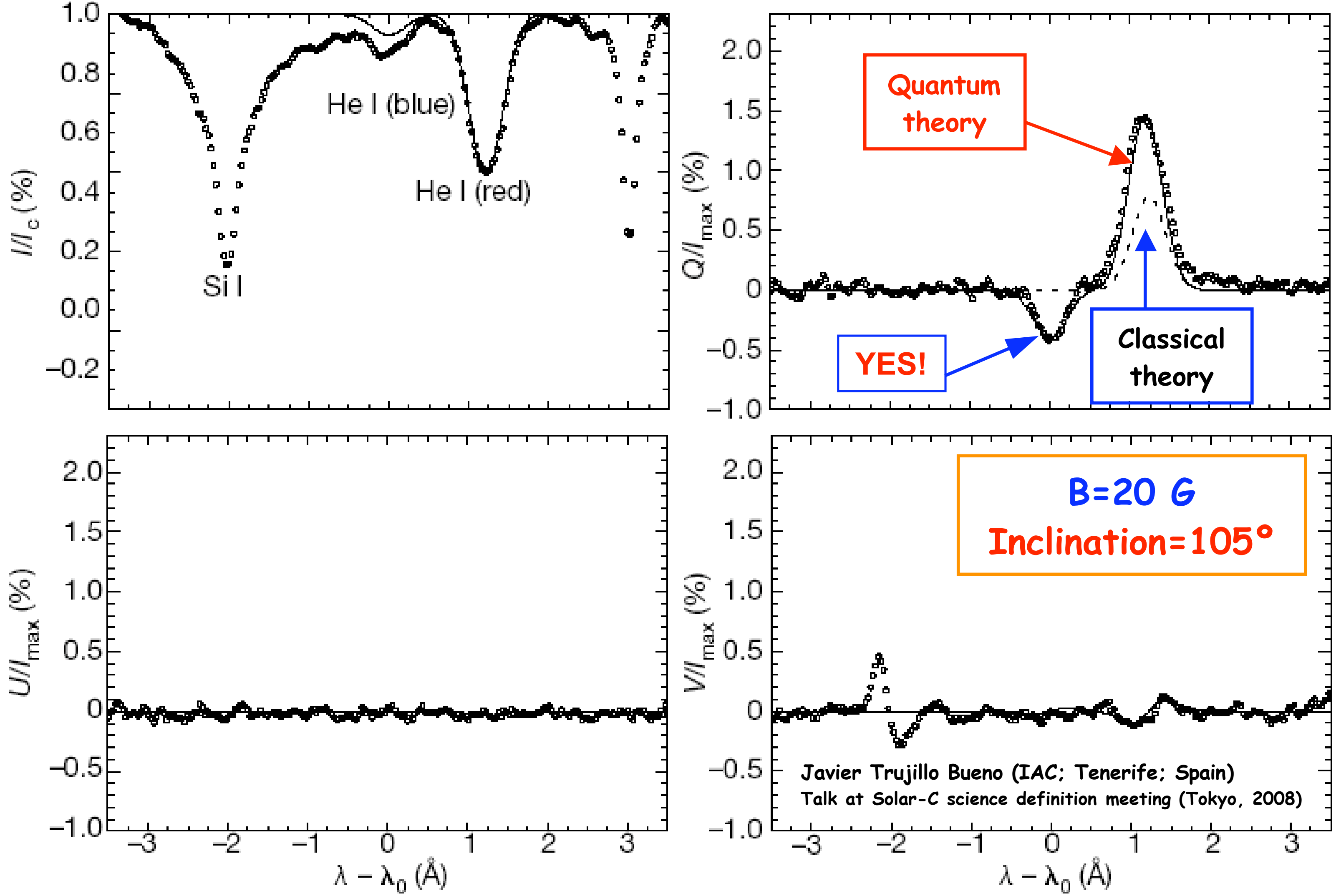
Solar filament case: forward scattering

In the on-disk case (forward scattering geometry)
TWO processes contribute to the emergent Q/I , namely

SELECTIVE EMISSION and SELECTIVE ABSORPTION, and

$$\frac{Q}{I} \approx \mathrm{W}\,\sigma_0^2(\mathrm{up}) \;-\; \mathrm{Z}\,\sigma_0^2(\mathrm{low})$$

The coronal filament case: forward scattering and the Hanle effect at the solar disk center



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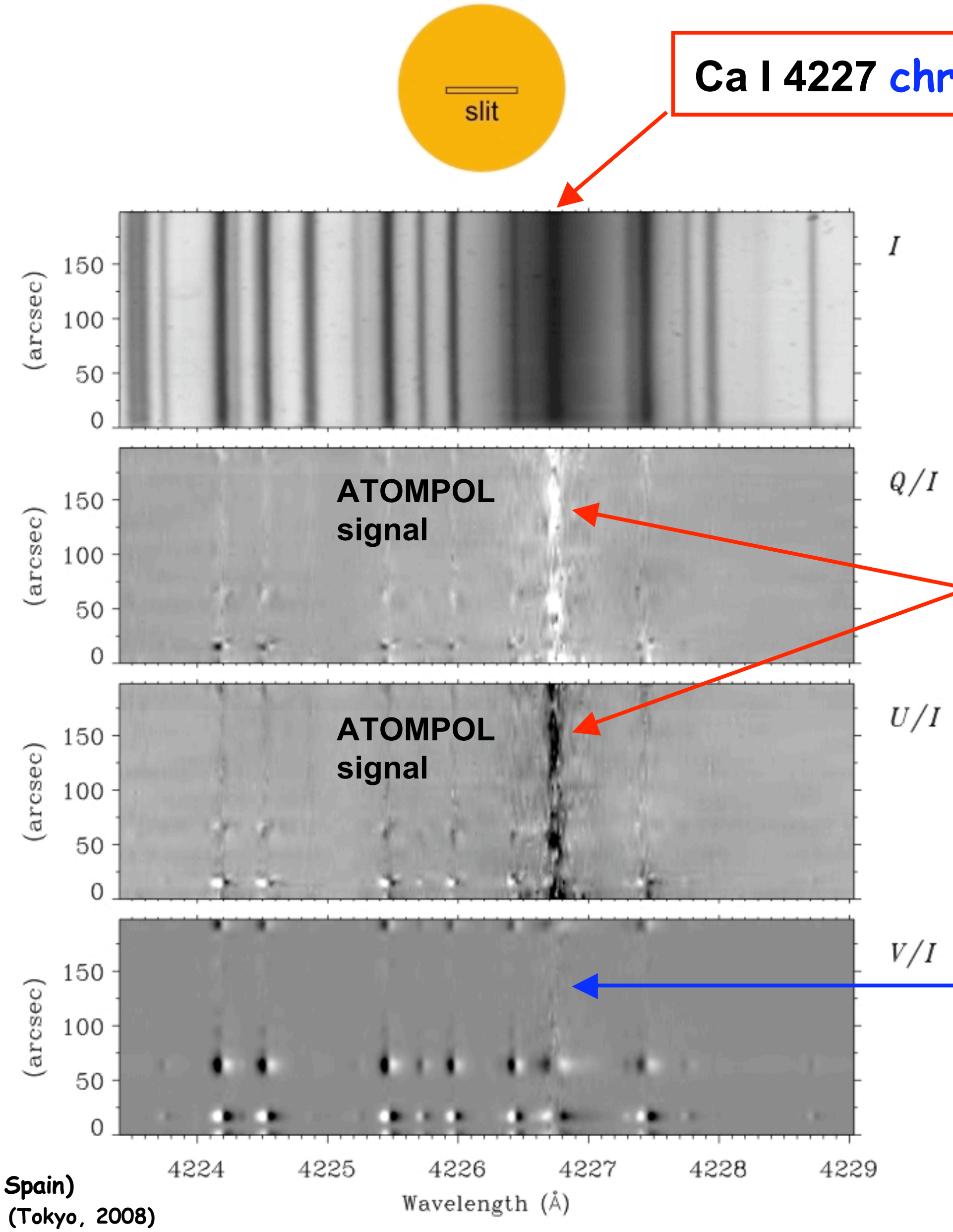
The Hanle effect at the solar disk center

In forward scattering the Hanle effect creates linear polarization in many spectral lines



Linear polarization created by the Hanle effect of an inclined field in forward scattering

Observation taken by Joos using ZIMPOL at IRSOL (Locarno)

Note:
NO Zeeman effect !

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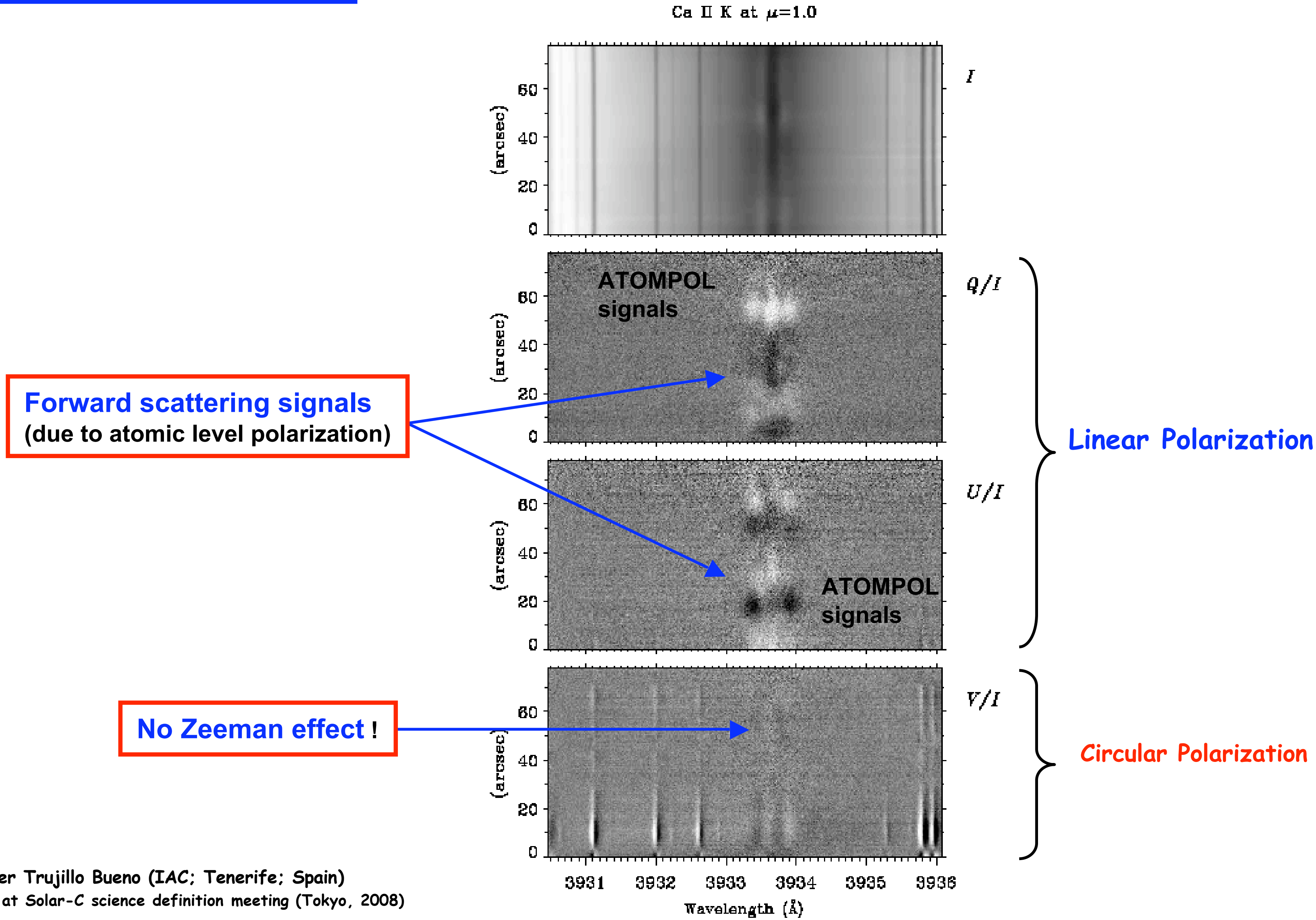
THE K-line of Ca II

"QUIET" CHROMOSPHERE !

OBSERVATION AT THE SOLAR DISK CENTER

(taken by Stenflo et al. 2006 using ZIMPOL at Kitt Peak)



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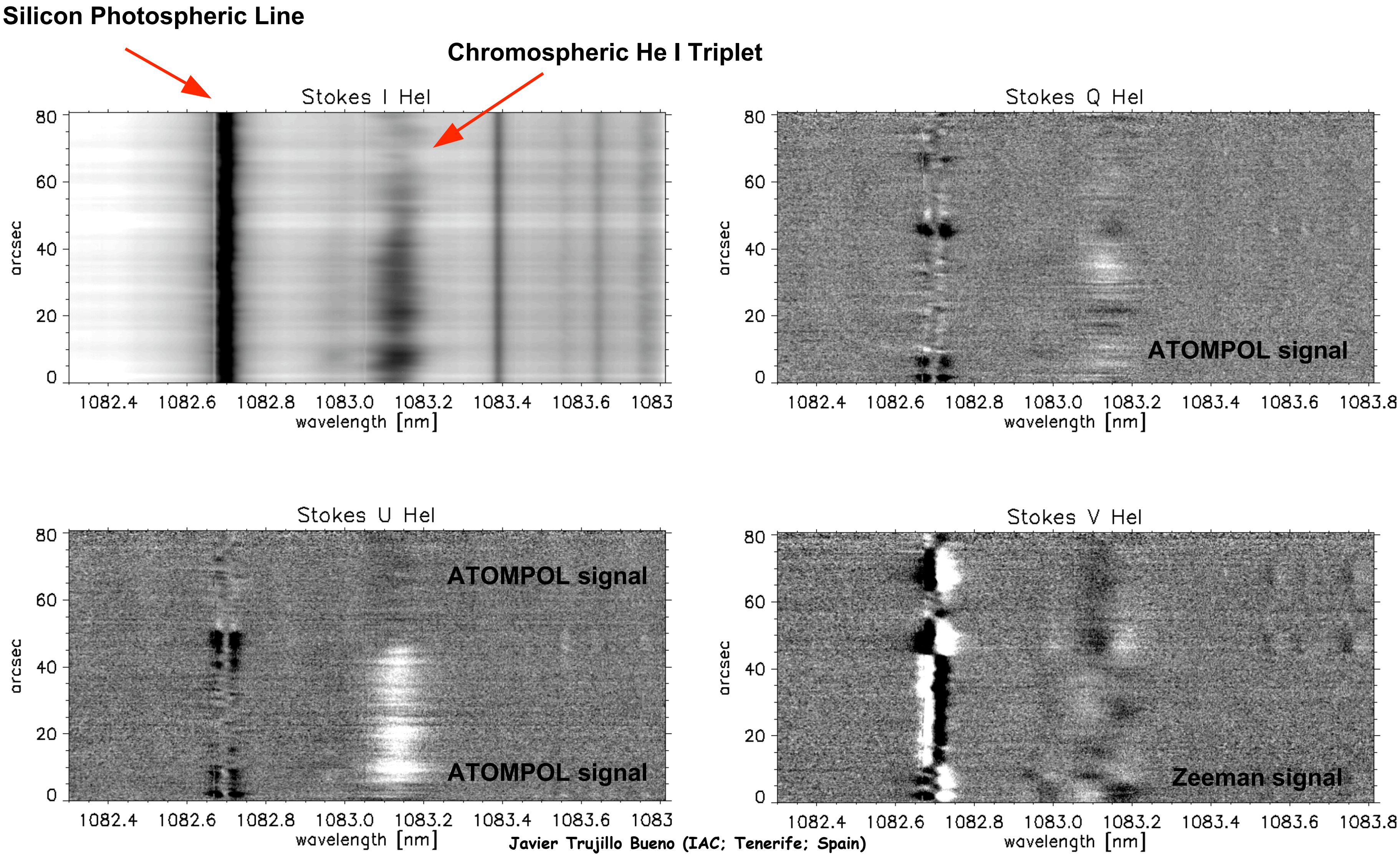
On-disk spectropolarimetric observation of polar faculae in the He I 10830 triplet using TIP

(*Observation with* TIP *taken in collaboration with M. Collados*)



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Magnetic Mappers of the Solar Atmosphere

- How to infer the thermal and magnetic structure of the solar chromosphere and its coupling with the underlying photosphere ?
- How to determine the magnetic fields that confine the plasma of structures embedded in the solar chromosphere and corona ?
- How to explore the magnetic fied topology of coronal loops and arcades ?

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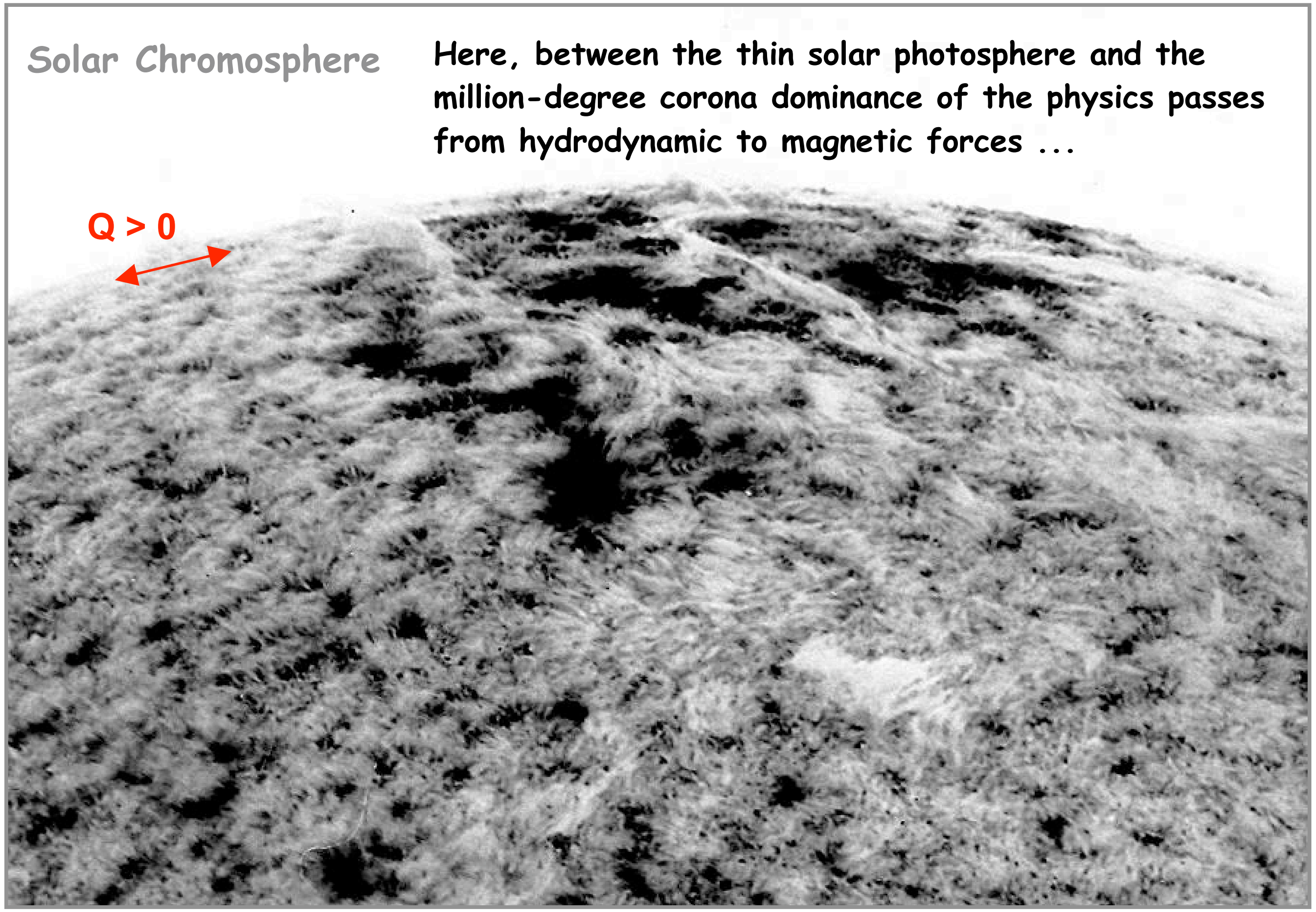
(1) How to explore the magnetism of the solar chromosphere ?



This is a NEGATIVE of a spectroheliogram at the line center of the Ca II K-line taken by J. Harvey many years ago at Kitt Peak.

One has the strong impression of HEIGHT in these cloud and fibril features !

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Another reason to investigate the magnetism of the "*quiet*" solar chromosphere

The ubiquitous presence of small-scale magnetic fields in the "*quiet*" solar photosphere might have several important consequences for the overlying solar atmosphere, such as ubiquity of reconnecting current sheets and heating processes.

Therefore, it is now even more important to carry out detailed investigations on the thermal and magnetic structure of the solar chromosphere.

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Which spectral lines should we use for "mapping" the magnetic field of the solar chromosphere ?

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Suggestion 1:

The Hanle and Zeeman effects in the IR triplet of Ca II

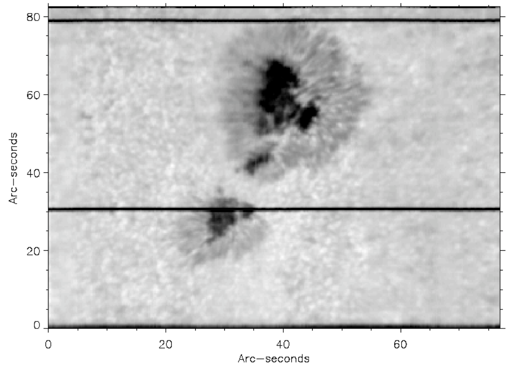
Javier Trujillo Bueno (IAC; Tenerife; Spain)
Talk at Solar-C science definition meeting (Tokyo, 2008)

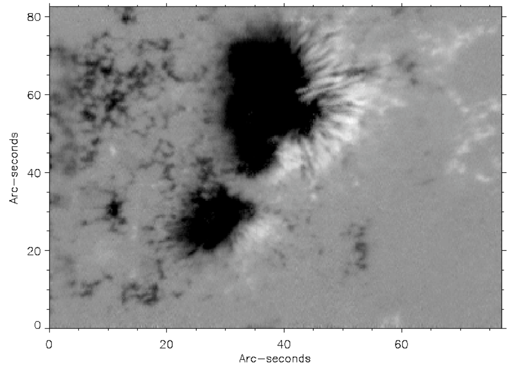
In sunspots the polarization of the Ca II IR triplet is dominated by the Zeeman effect

Suitable tool for determining the 3D structure of sunspot magnetic fields (see, e.g., Socas Navarro 2005)

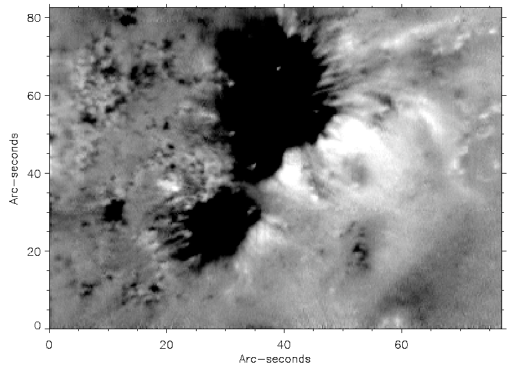
Intensity image | **Circular polarization images**

Photospheric line close to the IR triplet of Ca II

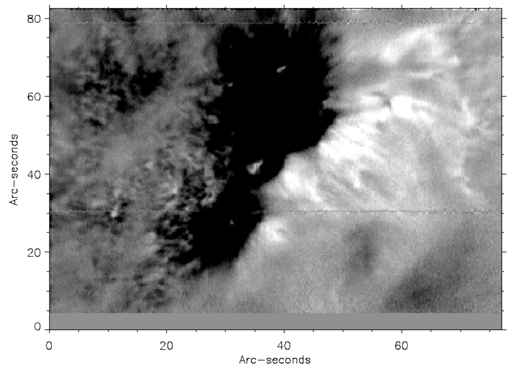




Chromospheric 8498 line of the Ca II IR triplet

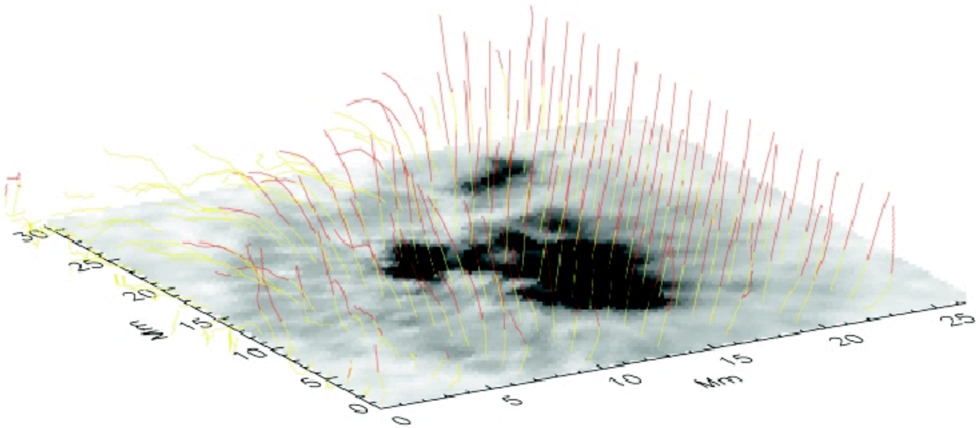


Chromospheric 8542 line of the Ca II IR triplet

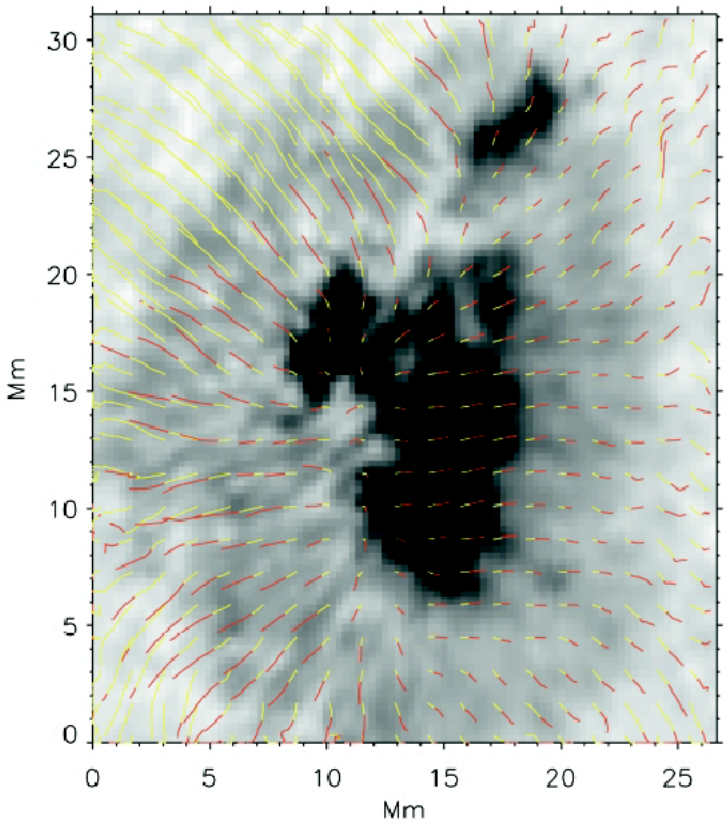


In sunspots the polarization of the Ca II IR triplet is dominated by the Zeeman effect

The determination of the 3D structure of sunspot magnetic fields can be done by interpreting the observed Stokes profiles of the Ca II IR triplet through the application of the non-LTE inversion code of Stokes profiles induced by the Zeeman effect of Socas-Navarro, Trujillo bueno and Ruiz Cobo (2000; ApJ).



The model resulting from the application of our non-LTE inversion code of Stokes profiles induced by the Zeeman effect reveals a complex topology with areas of opposite-sign torsion, suggesting that flux-ropes of opposite helicities may coexist together in the same spot. (see Socas-Navarro 2005).



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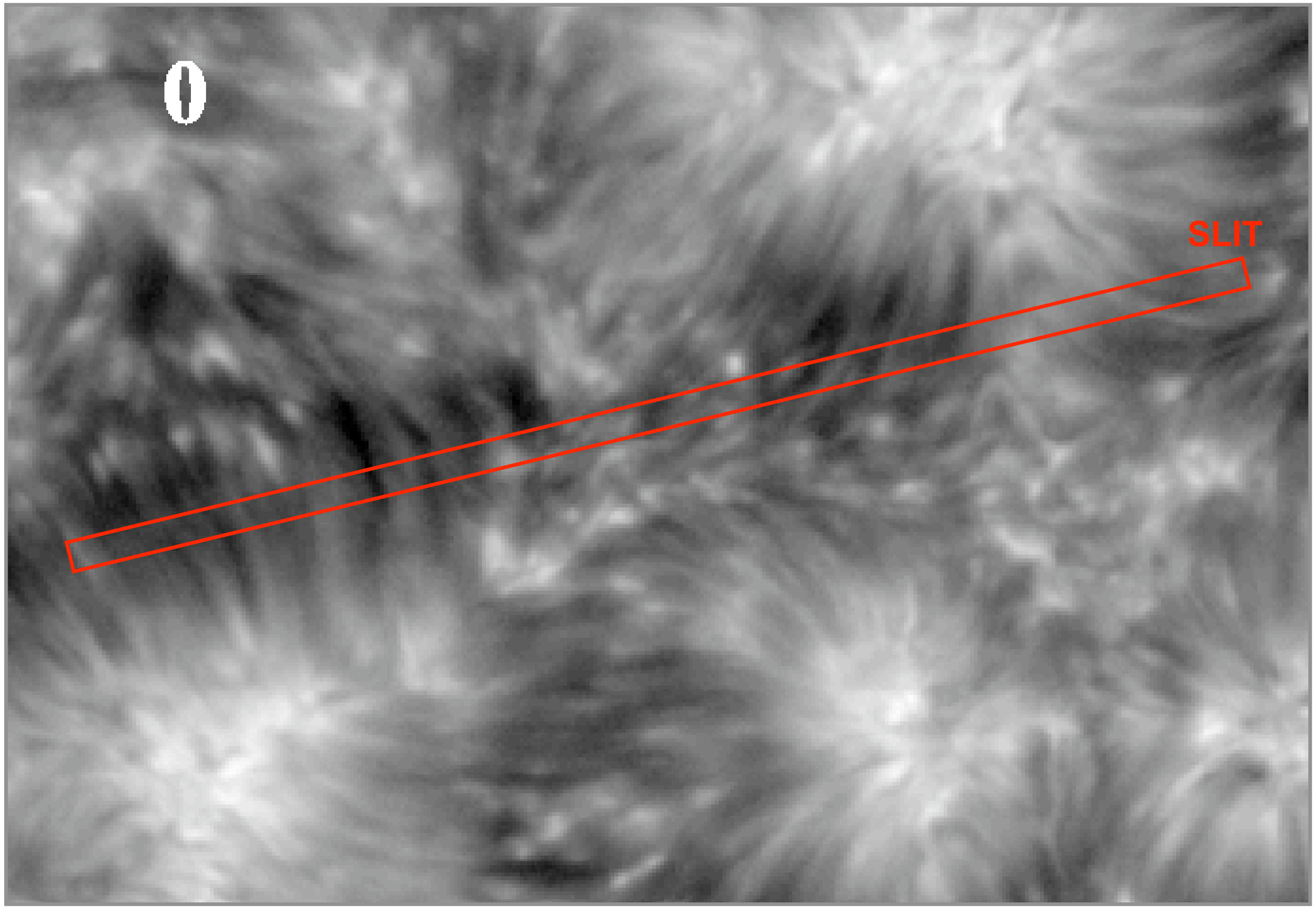
The Hanle and Zeeman effects in the Ca II IR triplet as a thermometer and magnetometer of the ("quiet") solar chromosphere

(a fibrilar dominated-magnetism medium !)

(Manso Sainz & Trujillo Bueno 2007; 2009; Trujillo Bueno et al. 2009)

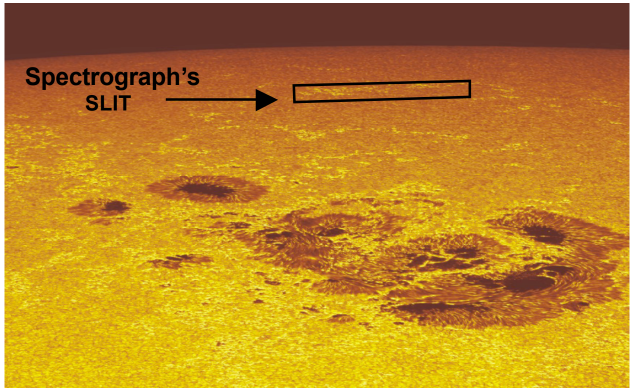
Intensity image of A QUIET REGION at the line center of the 8542 line of ionized calcium



(From Cauzzi et al. 2008)

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

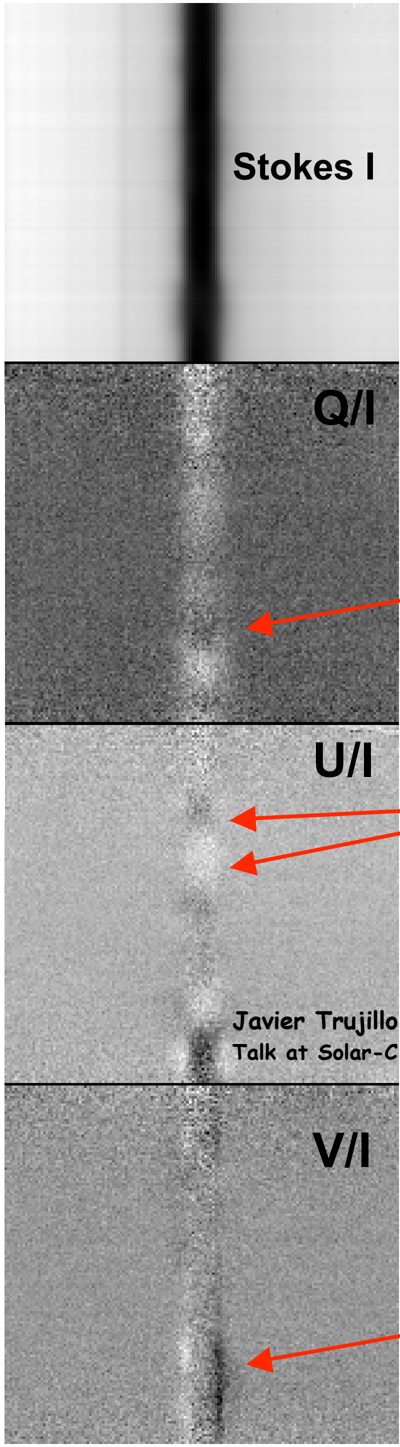
8542 line of Ca II



Observations with ZIMPOL @ THEMIS

of the polarization in the Ca II IR-triplet

(Trujillo Bueno, Ramelli, Manso Sainz & Bianda 2009)



Stokes Q changes its amplitude, but it remains positive

Stokes U changes its sign !

Circular polarization created by the LONGITUDINAL ZEEMAN effect

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In the "quiet" chromosphere the polarization of the Ca II IR triplet is such that:

- Stokes V (the circular polarization) is dominated by Mr. Zeeman.

- Stokes Q and U (the linear polarization) are dominated by atomic level polarization and by Mr. Hanle.

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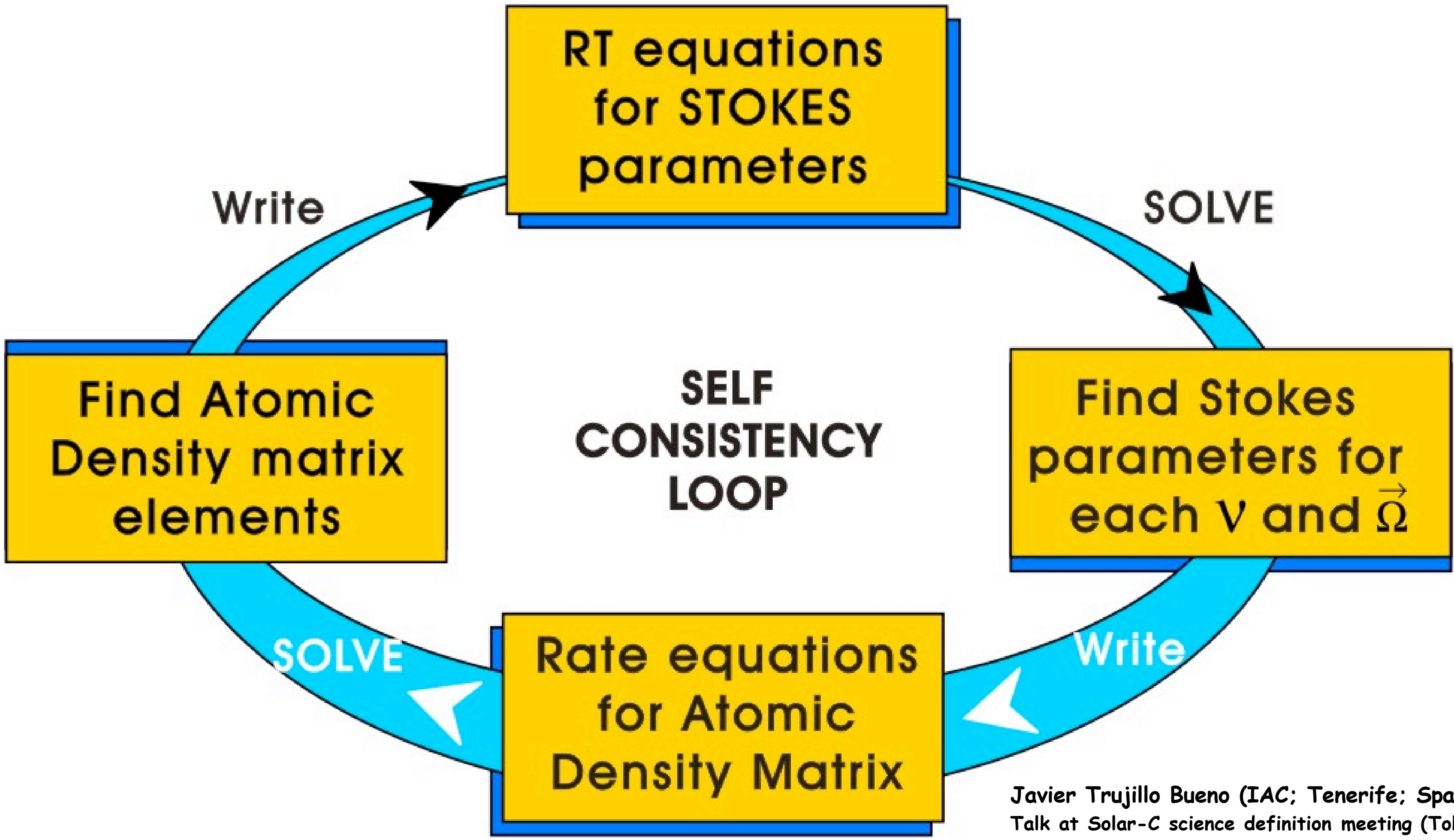
The generation and transfer of polarized radiation

Equations ? → see the monograph by Landi Degl'Innocenti & Landolfi (2004)

Numerical method of solution ? → Trujillo Bueno (1999; 2003)

Multilevel Hanle-effect RT computer program ? → Manso Sainz & Trujillo Bueno (2003)



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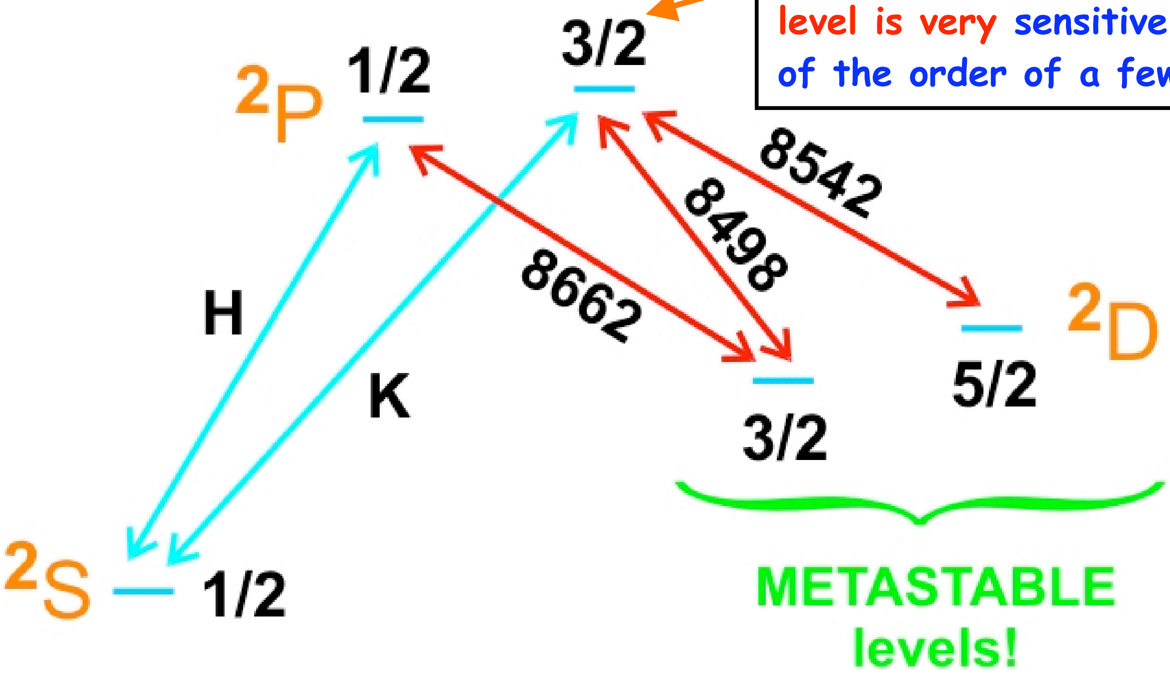
A 5-level atomic model for Ca II

The atomic polarization of this upper level is very sensitive to magnetic fields of the order of a few gauss.



Critical Hanle field (in gauss)

$$B_c \approx \frac{1.137 \times 10^{-7}}{t_{\mathrm{life}}\, g_{\mathrm{L}}}$$

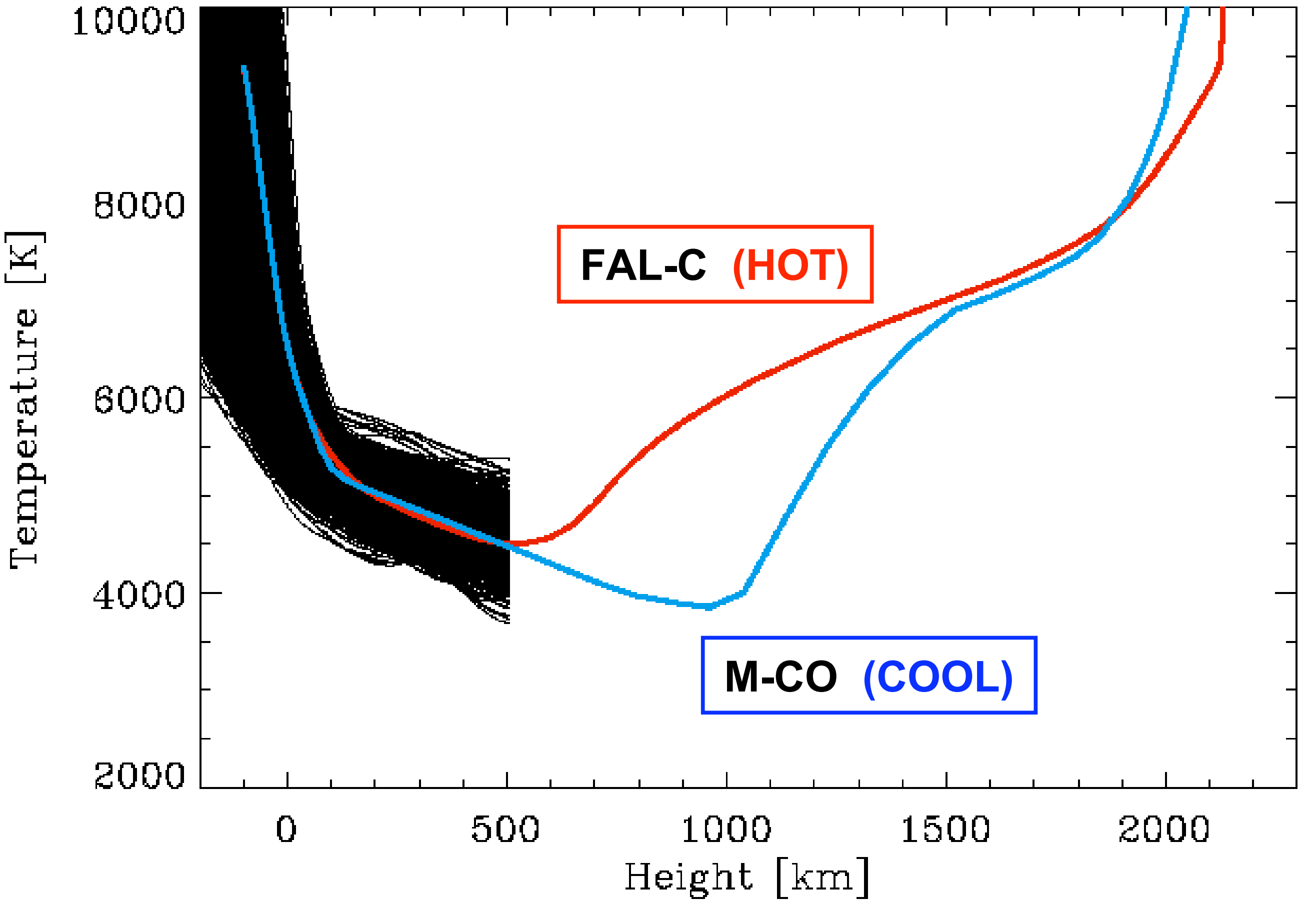
Level's lifetime (in seconds)

Level's Landé factor

Their atomic polarization (population imbalances and quantum coherences) are sensitive to magnetic fields between 0.001 and 0.1 G.

Javier Trujillo Bueno (IAC; Tenerife; Spain)
Talk at Solar-C science definition meeting (Tokyo, 2008)

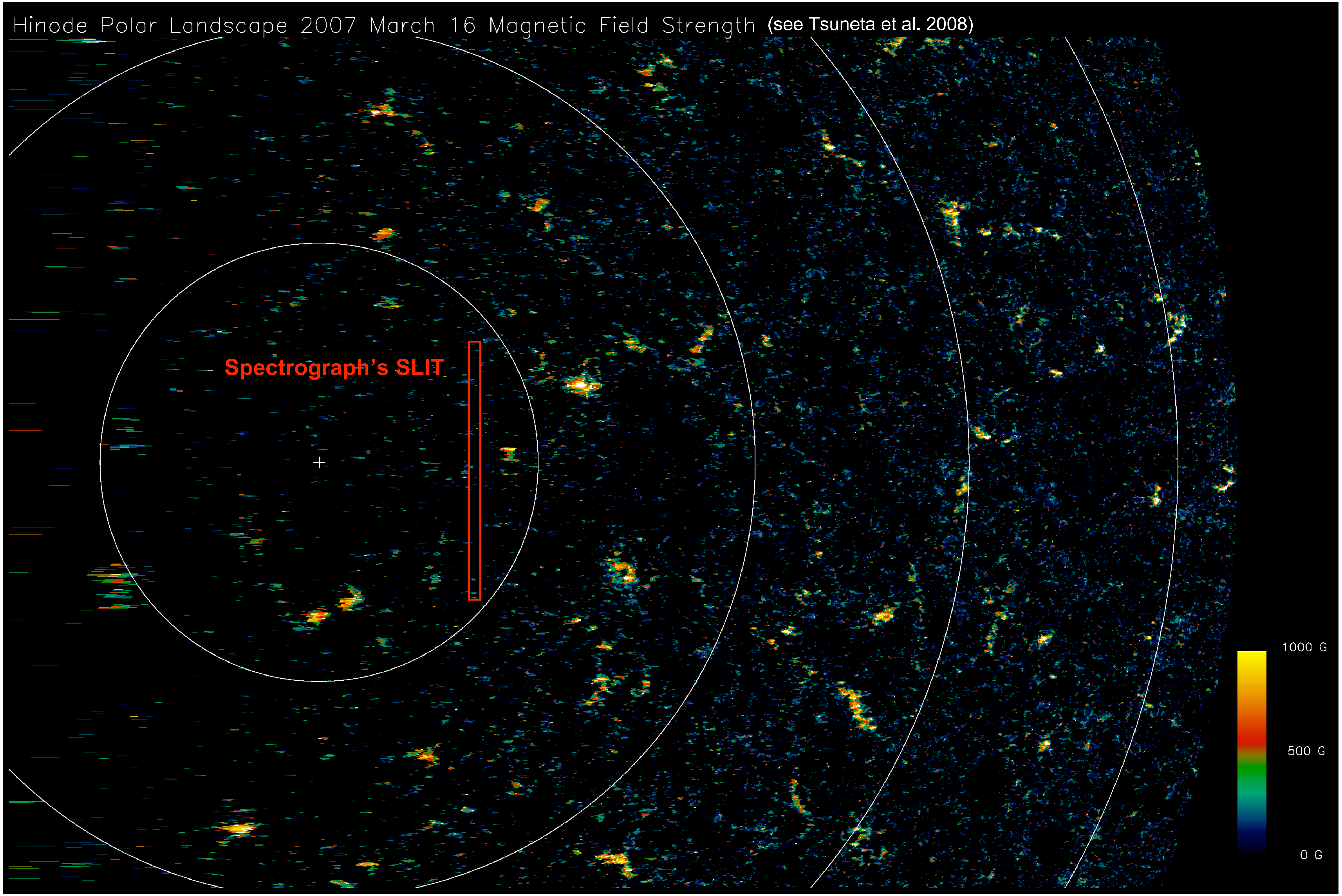
1D models of the solar atmosphere



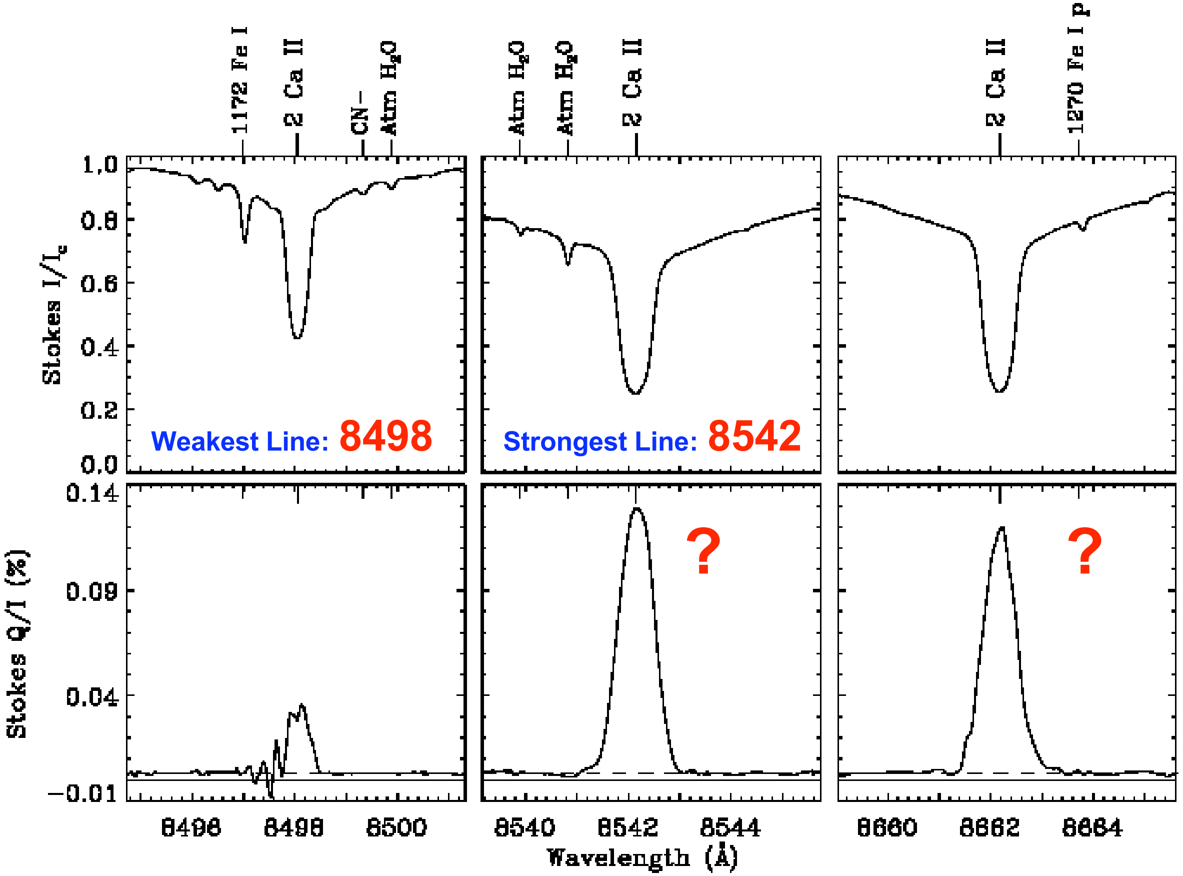
Javier Trujillo Bueno (IAC; Tenerife; Spain)

Talk at Solar-C science definition meeting (Tokyo, 2008)

Spectropolarimetric observations close to the polar regions



First observation of scattering polarization in the IR triplet of Ca II in the "quiet" Sun

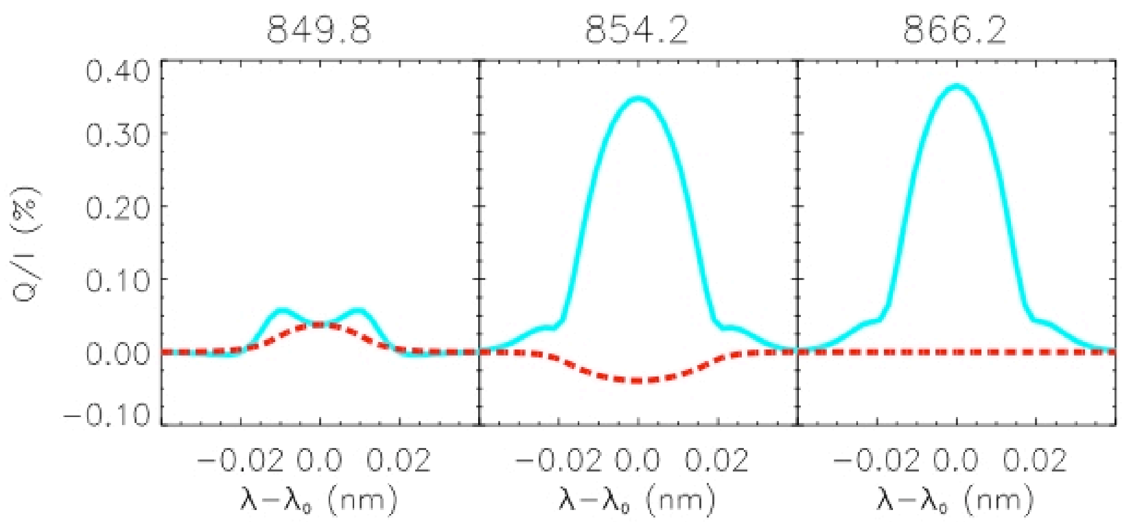


The Ca II 8662 and 8542 lines were expected to show negligible linear polarization. However, the Q/I observations of Stenflo et al. (2000) showed well defined polarization peaks (see the figure).

"This observational result further underscores that we are dealing with a fundamental problem, for which we lack a physical explanation" (Stenflo et al. 2000).

The calculated Q/I linear polarization of the Ca II IR-triplet in a (HOT) semi-empirical model of the solar atmosphere

(From Manso Sainz & Trujillo Bueno 2003; Phys. Rev. Letters 91, 111102)

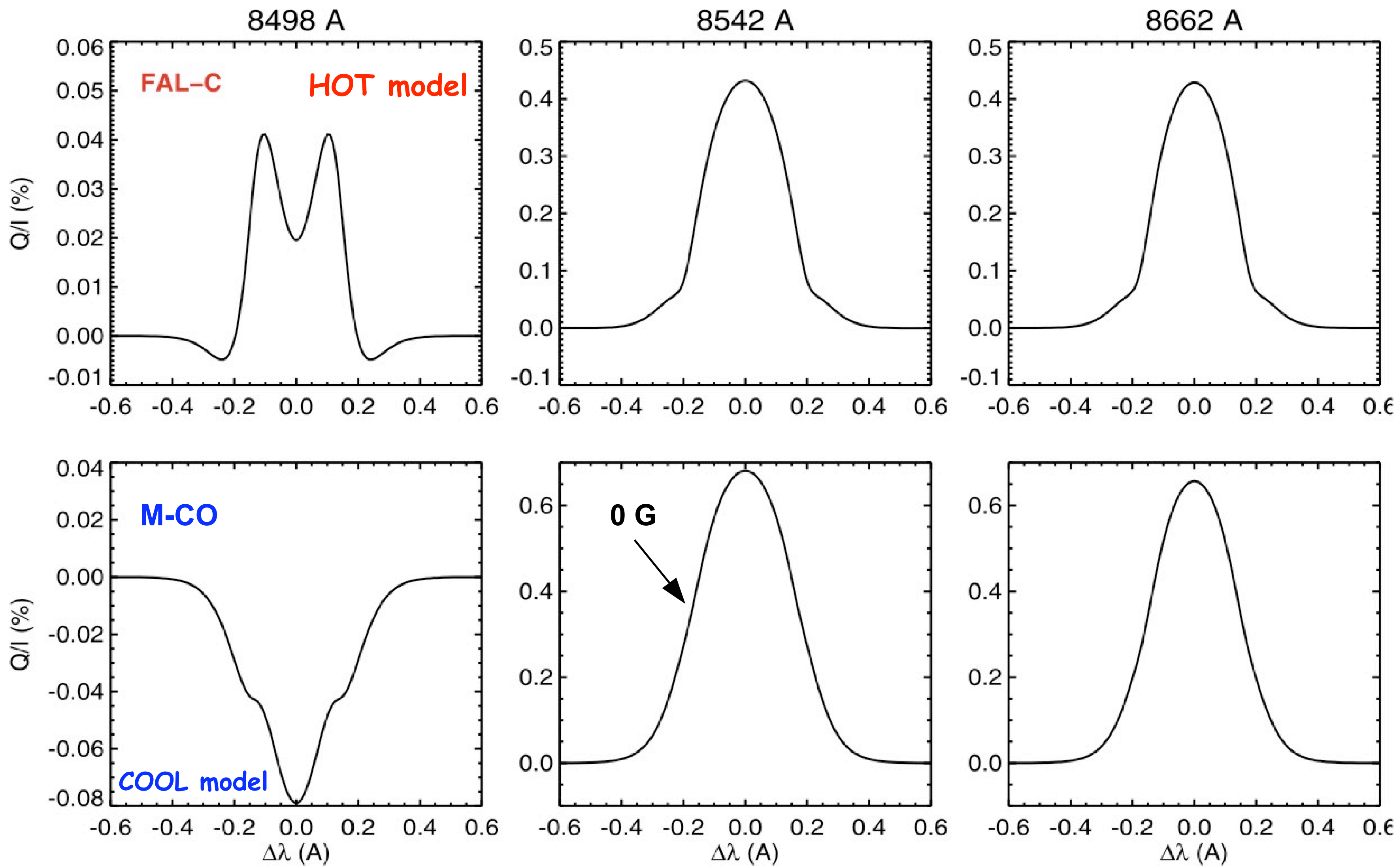


Javier Trujillo Bueno (IAC; Tenerife; Spain)
Talk at Solar-C science definition meeting (Tokyo, 2008)

Scattering Polarization in the Ca II IR triplet

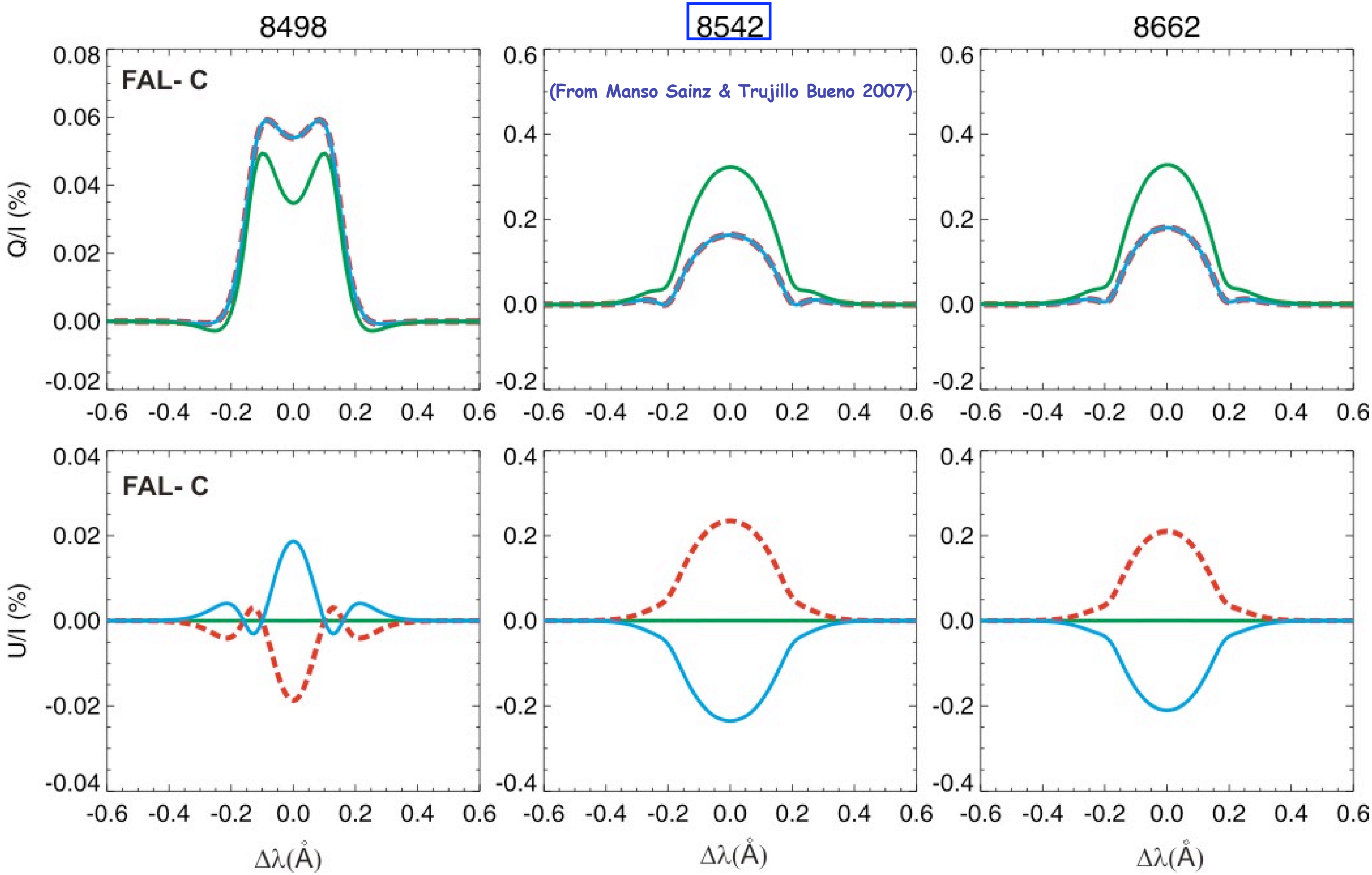
Results for the FAL-C (HOT) and M-CO (COOL) models for B=0 G

(From Manso Sainz & Trujillo Bueno 2001; 2007)



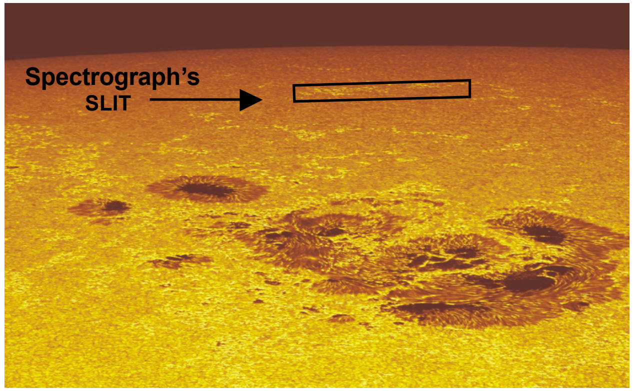
The Hanle effect in the Ca II IR triplet

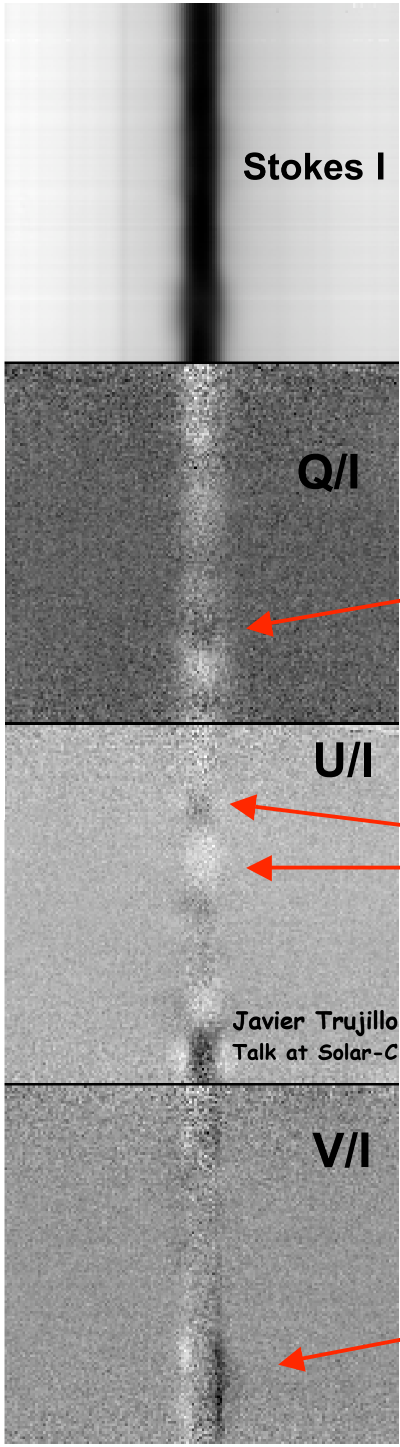
Results for the FAL-C (HOT) model for a horizontal field with B=5 mG pointing to you (red), perpendicular to you (green) and away from you (blue)



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

(Trujillo Bueno, Ramelli, Manso Sainz & Bianda 2009)

Hanle DEPOLARIZATION of the scattering polarization

Hanle ROTATION of the direction of linear polarization

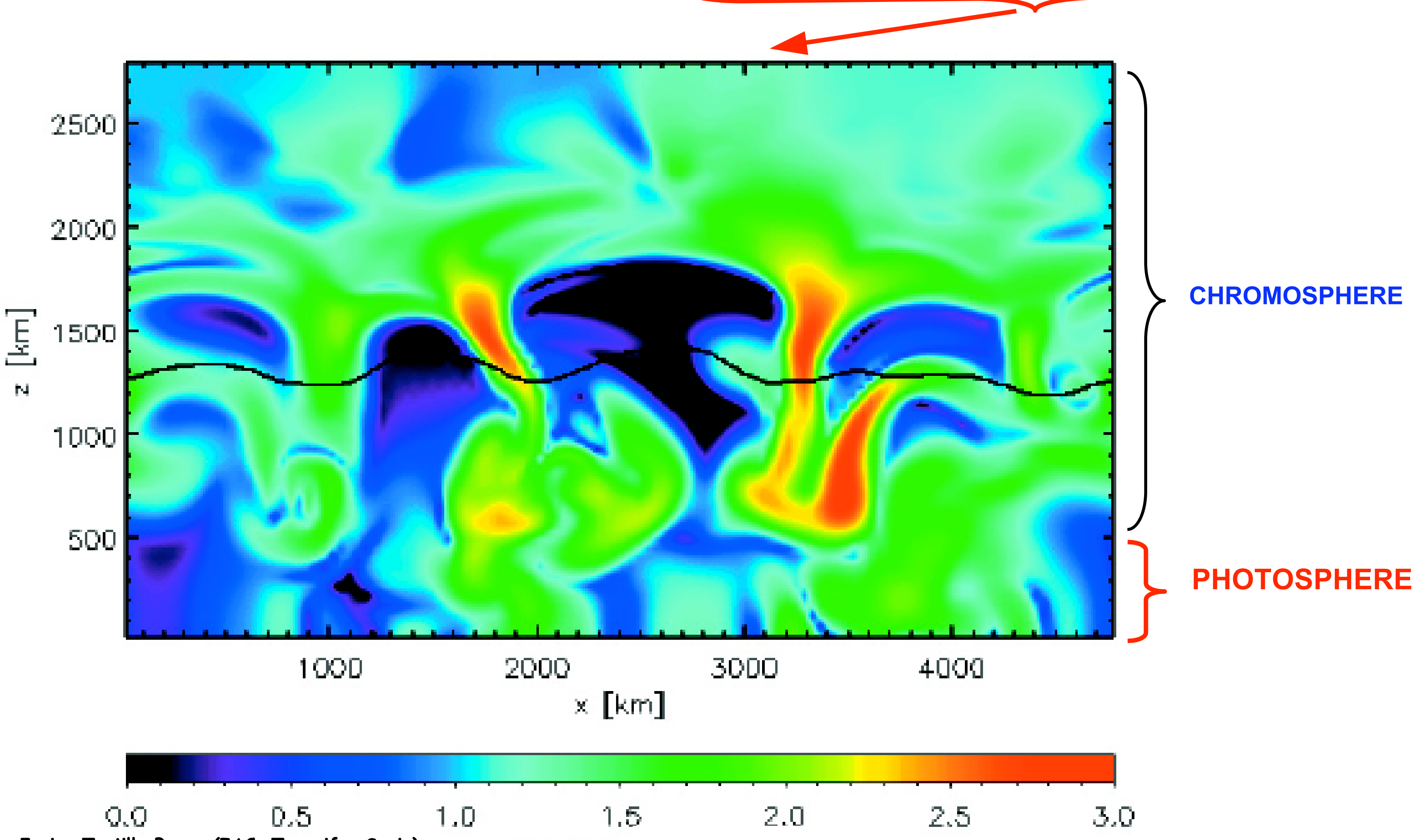
Javier Trujillo Bueno (IAC; Tenerife; Spain)
Talk at Solar-C science definition meeting (Tokyo, 2008)

Circular polarization created by the LONGITUDINAL ZEEMAN effect

This type of polarization signals produced by ATOMIC LEVEL POLARIZATION and the HANLE effect in the solar atmosphere should be exploited to:

(1) explore the thermal and magnetic structure of the solar chromosphere

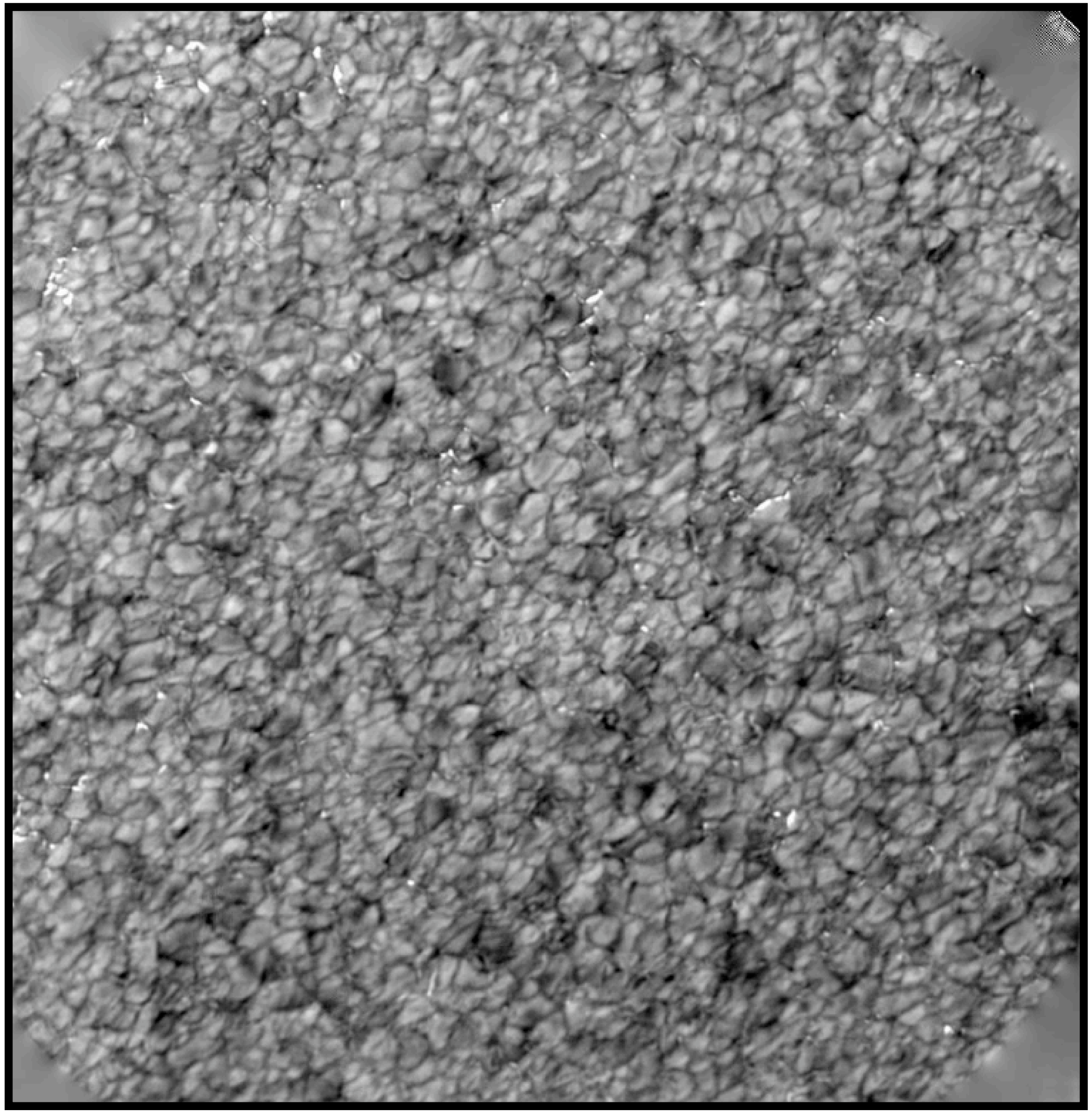
(2) evaluate the degree of realism of MHD simulations of the chromosphere



Javier Trujillo Bueno (IAC; Tenerife; Spain)
Talk at Solar-C science definition meeting (Tokyo, 2008)

(Snapshot taken from Wedemeyer-Bohm et al. 2005)

(B) How to infer the magnetic fields that confine the plasma of structures embedded in the solar chromosphere and corona ?

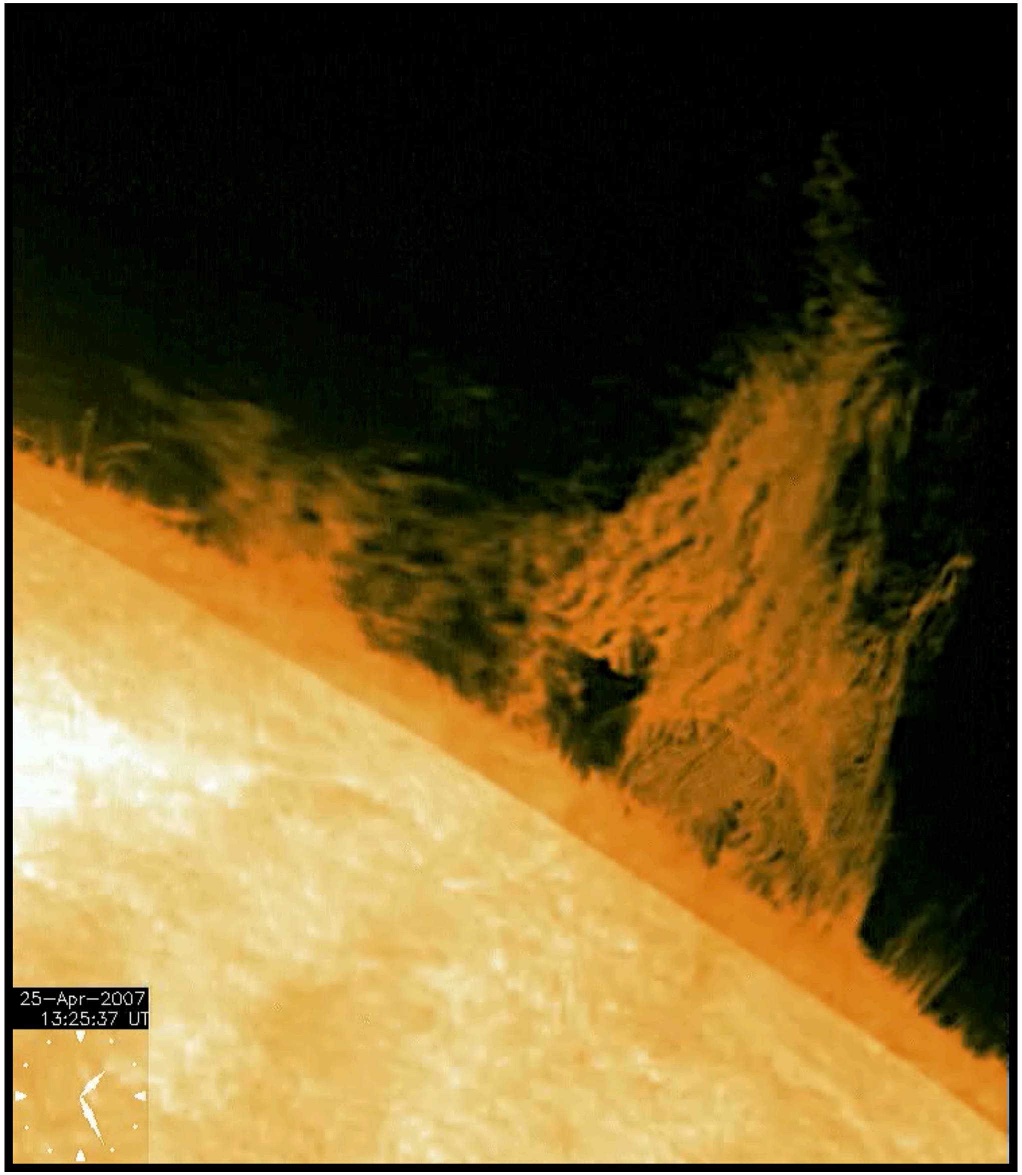


Coronal Filament
(seen against the bright solar disk)

This movie shows intensity images of the solar atmosphere at consecutive wavelengths going from the continuum to the line center of the H-alpha line.

Courtesy of L. Rouppe van der Voort
(SSVT @ Canary Islands observatories)

How to infer the magnetic fields that confine the plasma of structures embedded in the solar chromosphere and corona ?



Solar Prominences

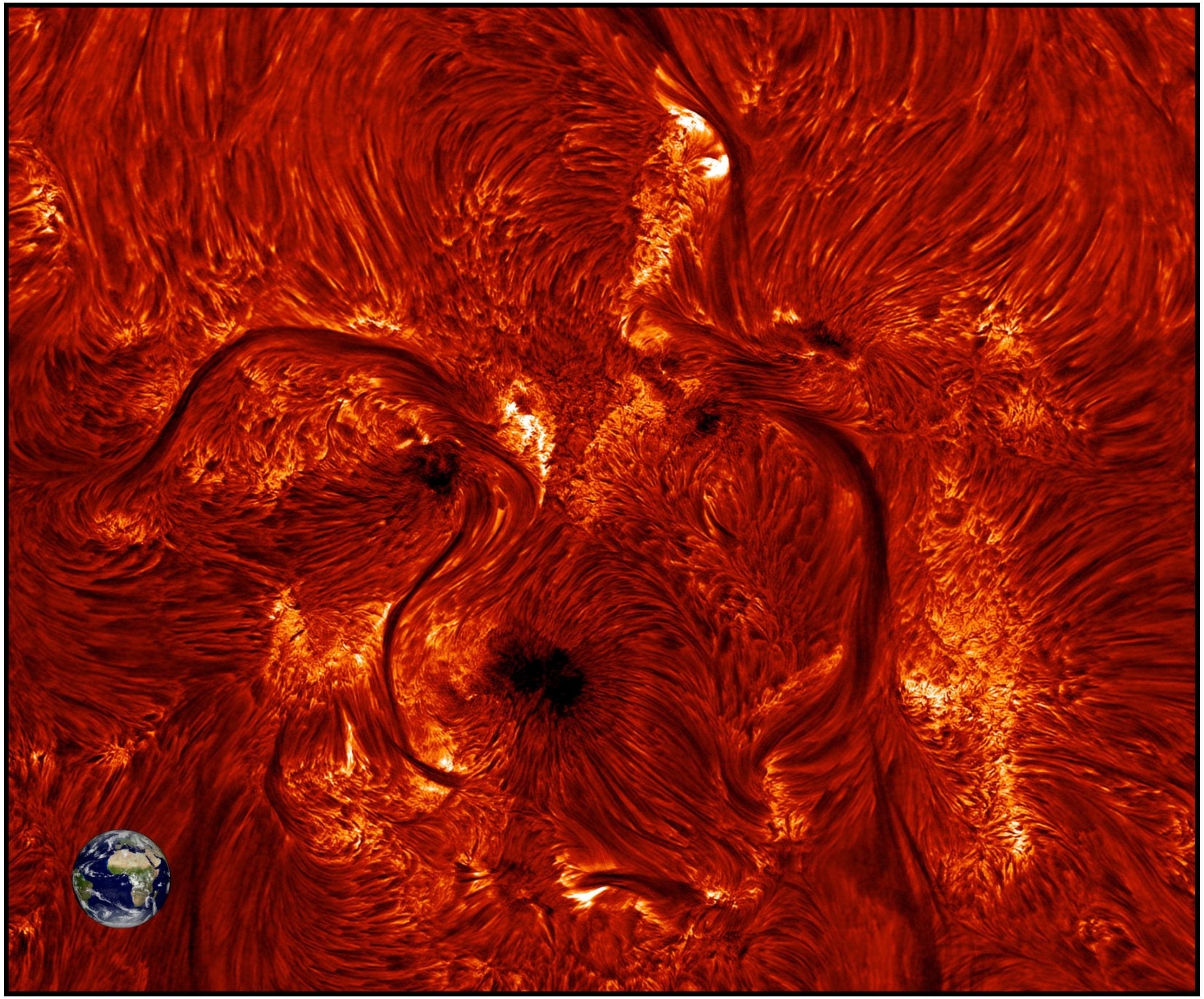
(seen against the dark background of the sky)

Courtesy of T. Berger

How to infer the strength and topology of the magnetic field in more active regions (e.g., emerging flux regions, active region filaments, flaring regions, etc.)

Active Regions

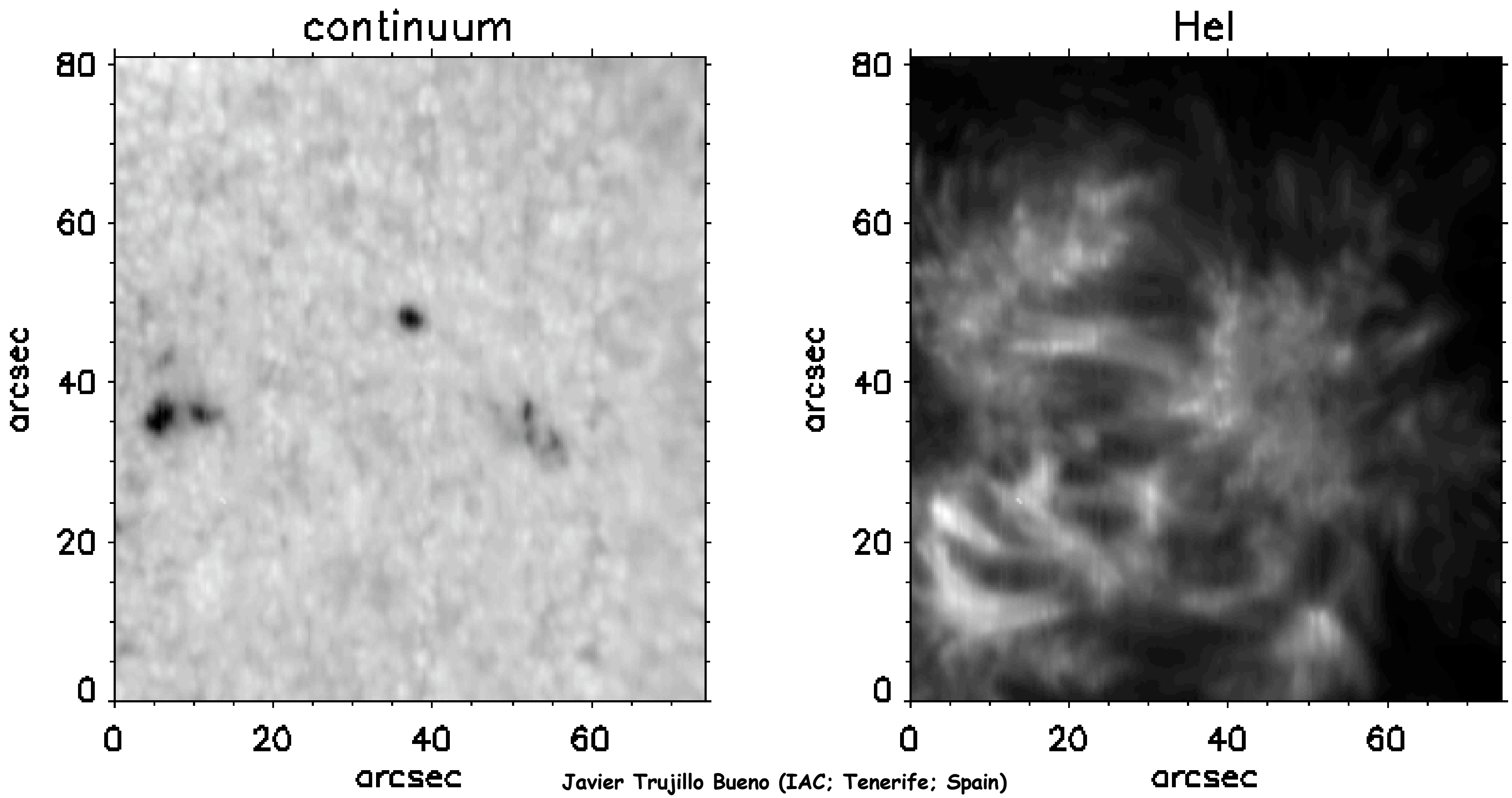
(seen on-disk)



DOT archive

SUGGESTION 2: By observing and interpreting the polarization signals produced by the joint action of atomic level polarization and the Hanle and Zeeman effects in the He I 10830 triplet.

Images of A SMALL ACTIVE REGION in the IR continuum and in the He I 10830 line

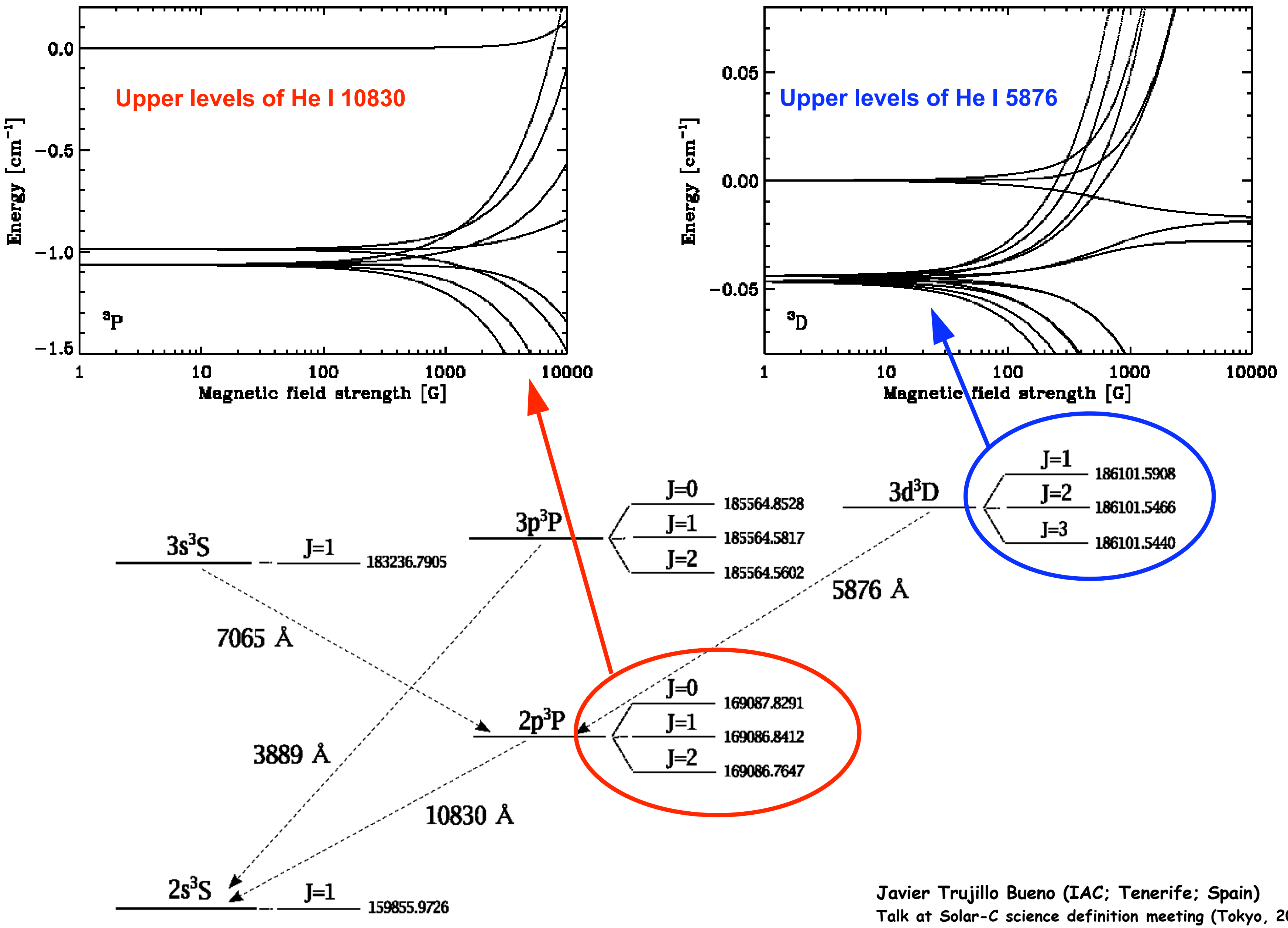


Javier Trujillo Bueno (IAC; Tenerife; Spain)
Talk at Solar-C science definition meeting (Tokyo, 2008)

The He I 10830 triplet shows clear (Hanle+Zeeman) polarization signals in plasma structures of the solar chromosphere and corona, such as:

- Filaments and prominences (e.g., Lin et al. 1998; Trujillo Bueno et al. 2002; Merenda et al.2006)
- Active region filaments (e.g., Kuckein et al. 2009; Merenda 2008: PhD thesis)
- Regions of emerging flux (e.g., Solanki et al. 2003)
- Active regions (e.g., Lagg et al. 2006)
- Polar faculae (e.g., see one of previous images)
- Flaring regions (e.g., Sasso et al. 2007)
- Chromospheric spicules (e.g., Trujillo Bueno et al. 2005)

NOTE: it is crucial to carry out the calculations taking into account the Paschen-Back effect and the impact of level crossings and repulsions on the atomic level polarization.



Javier Trujillo Bueno (IAC; Tenerife; Spain)
Talk at Solar-C science definition meeting (Tokyo, 2008)

The polarization of the He I 10830 triplet is such that:

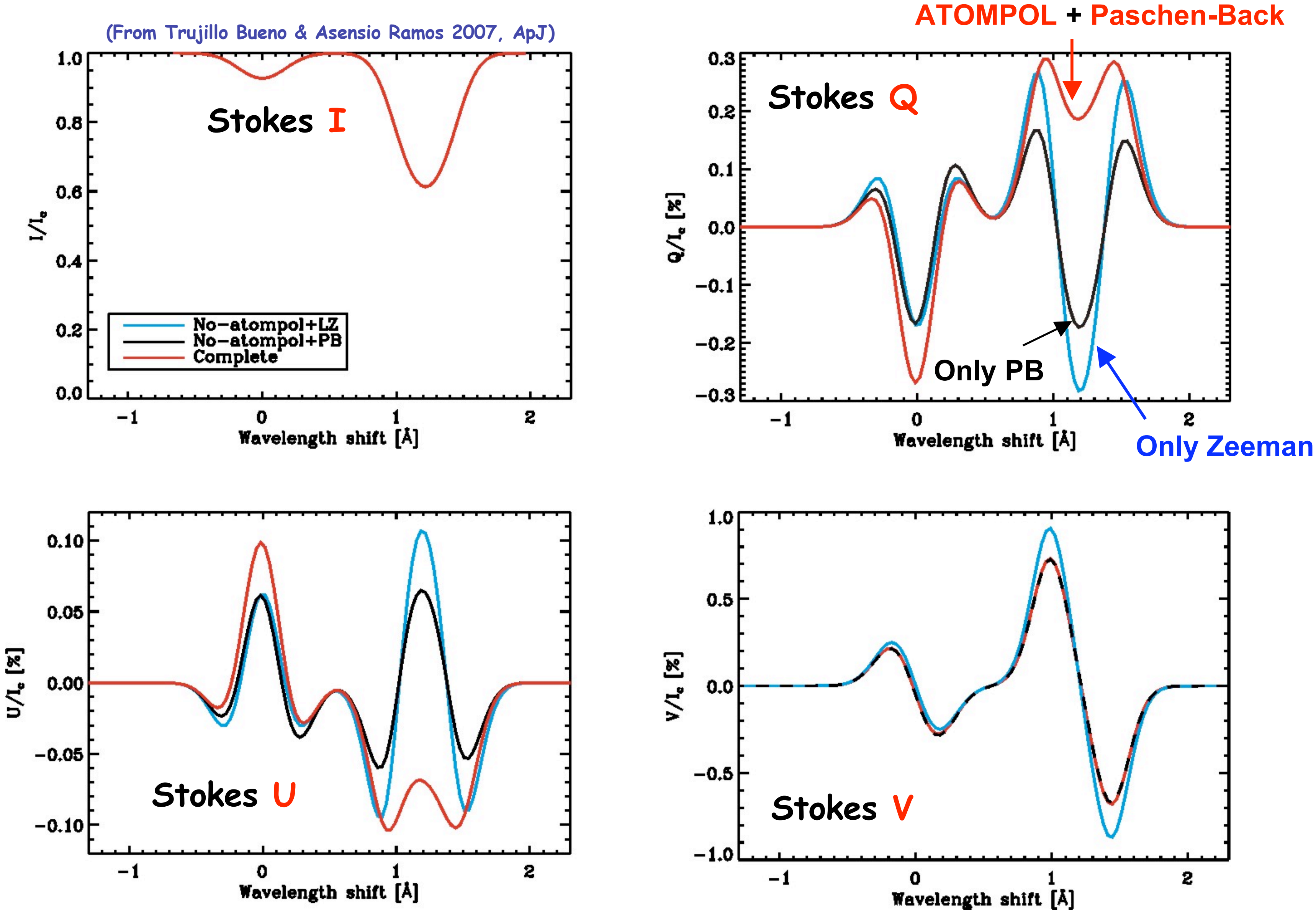
- Stokes V (the circular polarization) is dominated by Mr. Zeeman (longitudinal).

- Stokes Q and U (the linear polarization) is caused by the joint action of ATOMPOL, Mr. Hanle and Mr. Zeeman (transversal).

Javier Trujillo Bueno (IAC; Tenerife; Spain)
Talk at Solar-C science definition meeting (Tokyo, 2008)

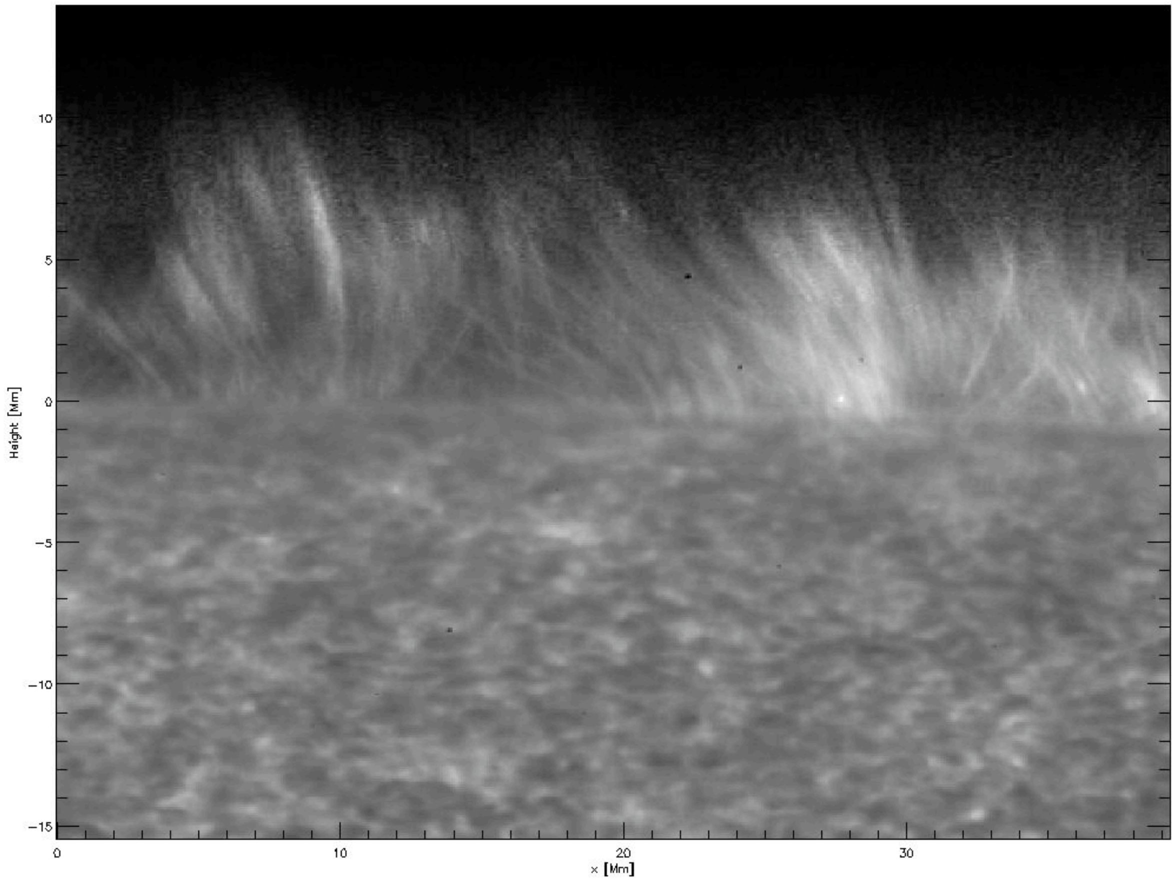
Simulated disk-center observation of the intensity and polarization of the He I 10830 triplet for a magnetic field vector with B=500 G, inclined by 80 degrees with respect to the local vertical.

(From Trujillo Bueno & Asensio Ramos 2007, ApJ)



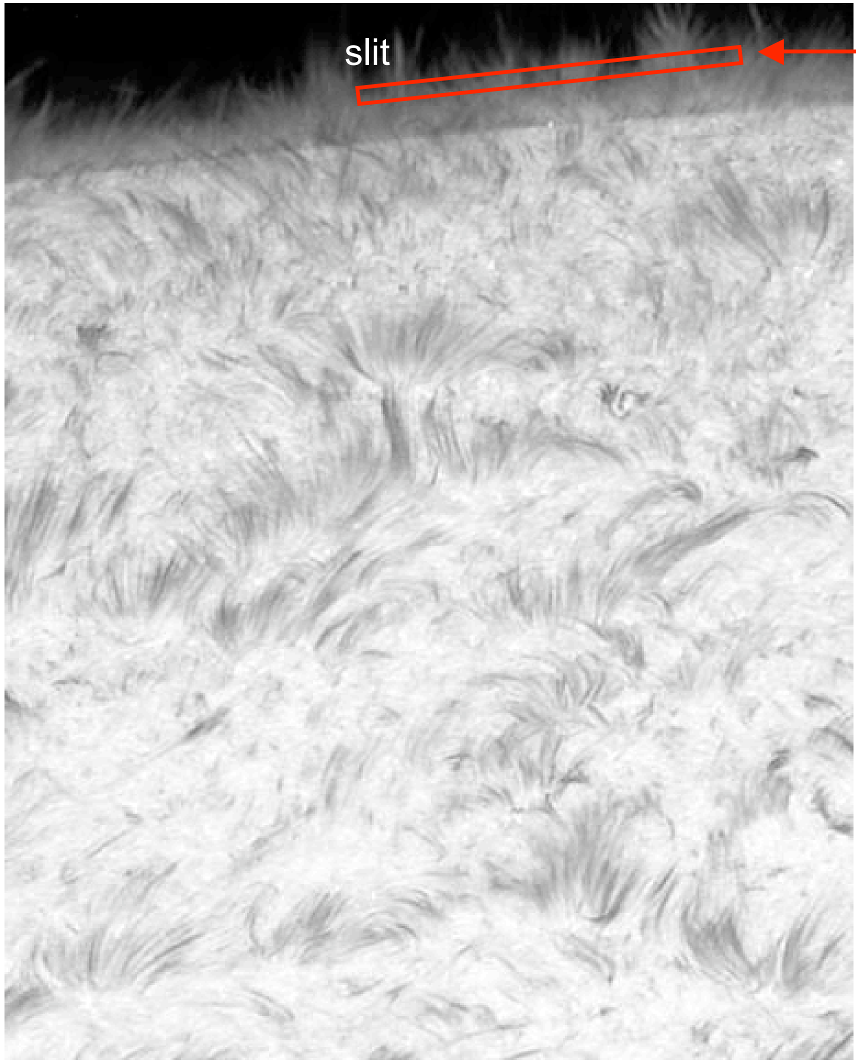
Applications in Solar Physics

The magnetic field that channels the dynamic jets that we call SPICULES



Hinode solar space telecope archive

How to infer the magnetic field vector of solar chromospheric spicules?



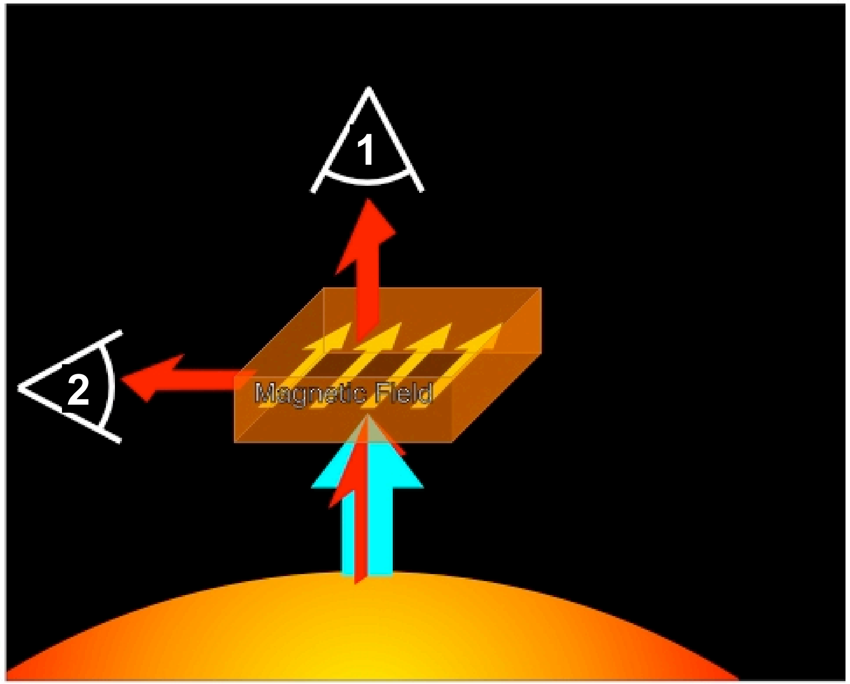
DOT H-alpha wing image showing spicules emanating from network magnetic concentrations.

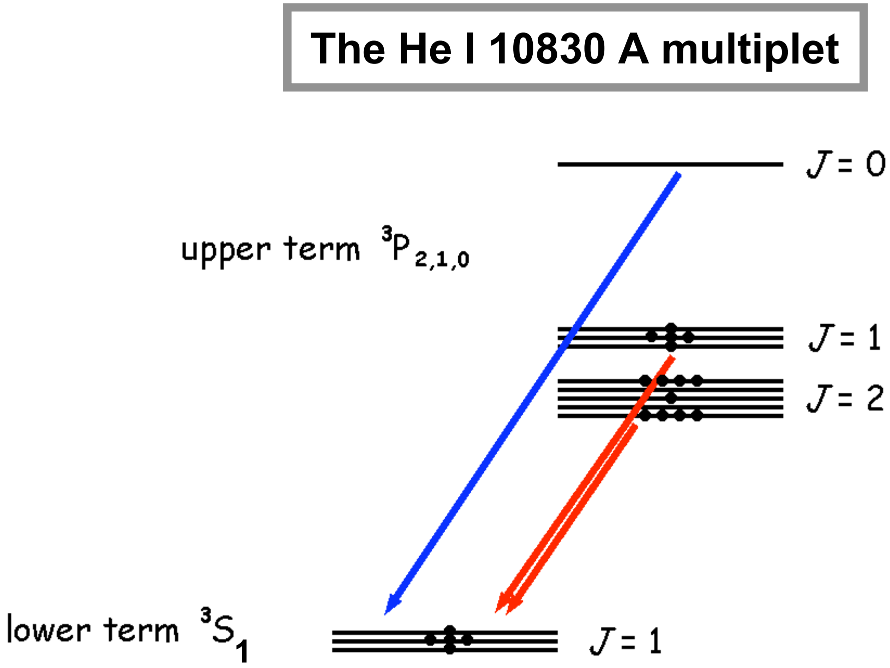
Difficult to measure but “easy” to interpret

Javier Trujillo Bueno (IAC; Tenerife; Spain)
Talk at Solar-C science definition meeting (Tokyo, 2008)

We take into account radiative transfer in 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).

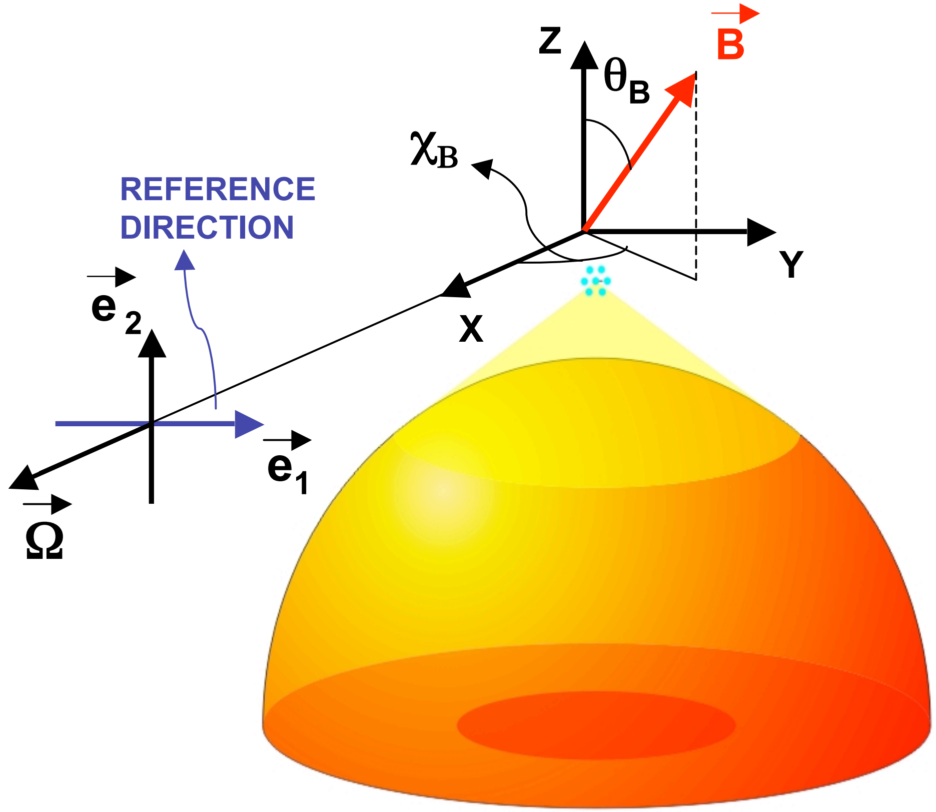




Javier Trujillo Bueno (IAC; Tenerife; Spain)
Talk at Solar-C science definition meeting (Tokyo, 2008)

Geometry of the problem

We assume that a slab of neutral Helium atoms is illuminated by the continuum anisotropic radiation field coming from the underlying solar photosphere.

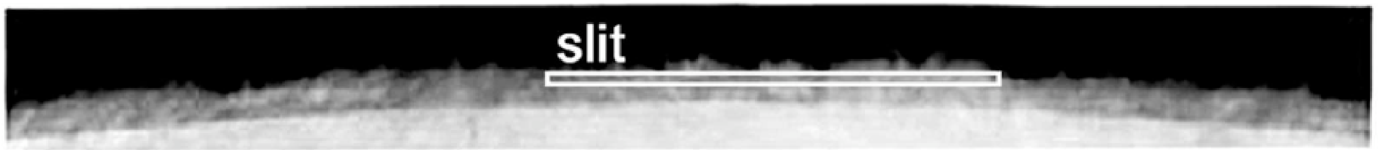


Javier Trujillo Bueno (IAC; Tenerife; Spain)
Talk at Solar-C science definition meeting (Tokyo, 2008)

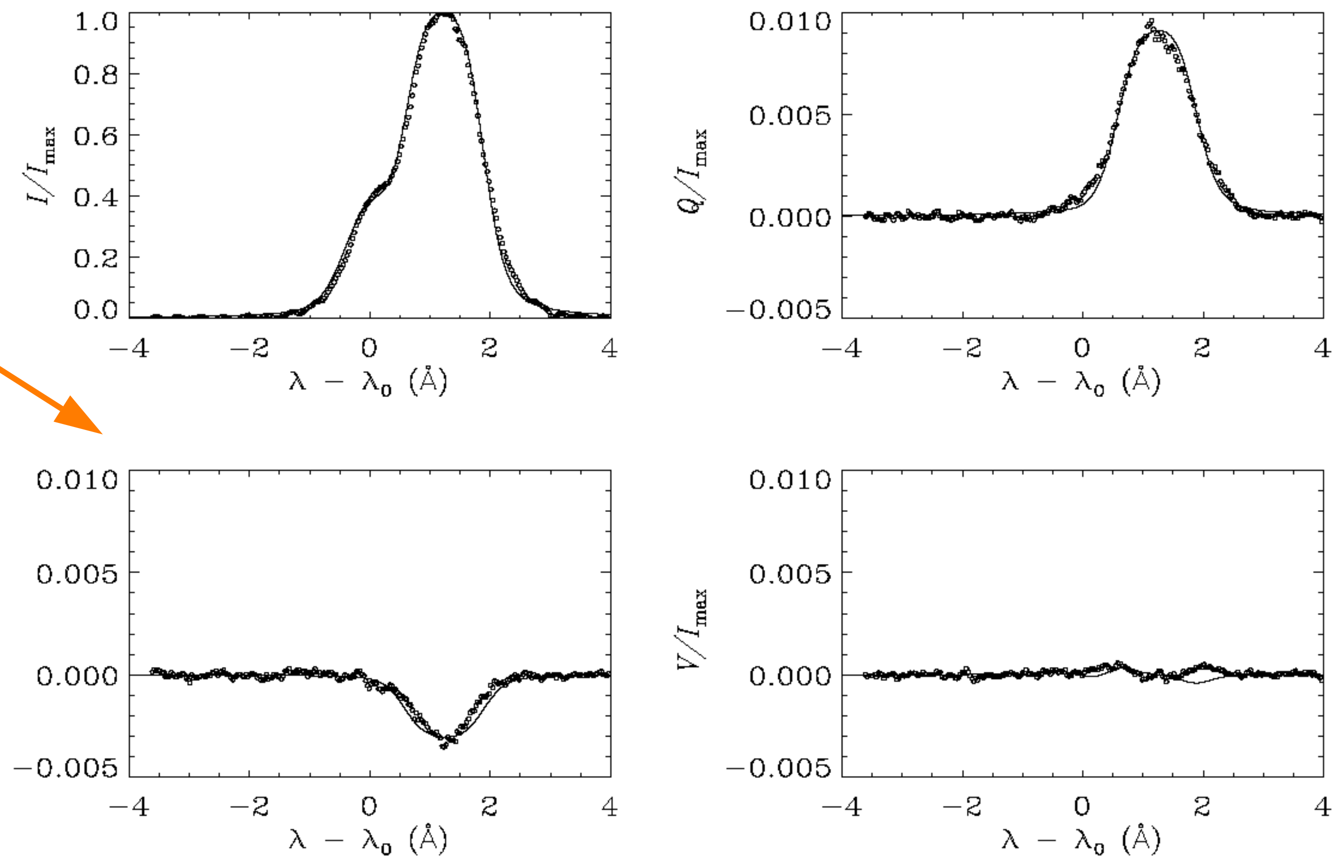
Spectropolarimetric observations in the He I 10830 line vs. RT modeling of the Hanle and Zeeman effects.

(Trujillo Bueno et al. 2005; ApJ Letters, 619, L191)

SPICULES
QUIET REGIONS



Observational signature of the Hanle effect:
rotation of the direction of polarization of the scattered light.

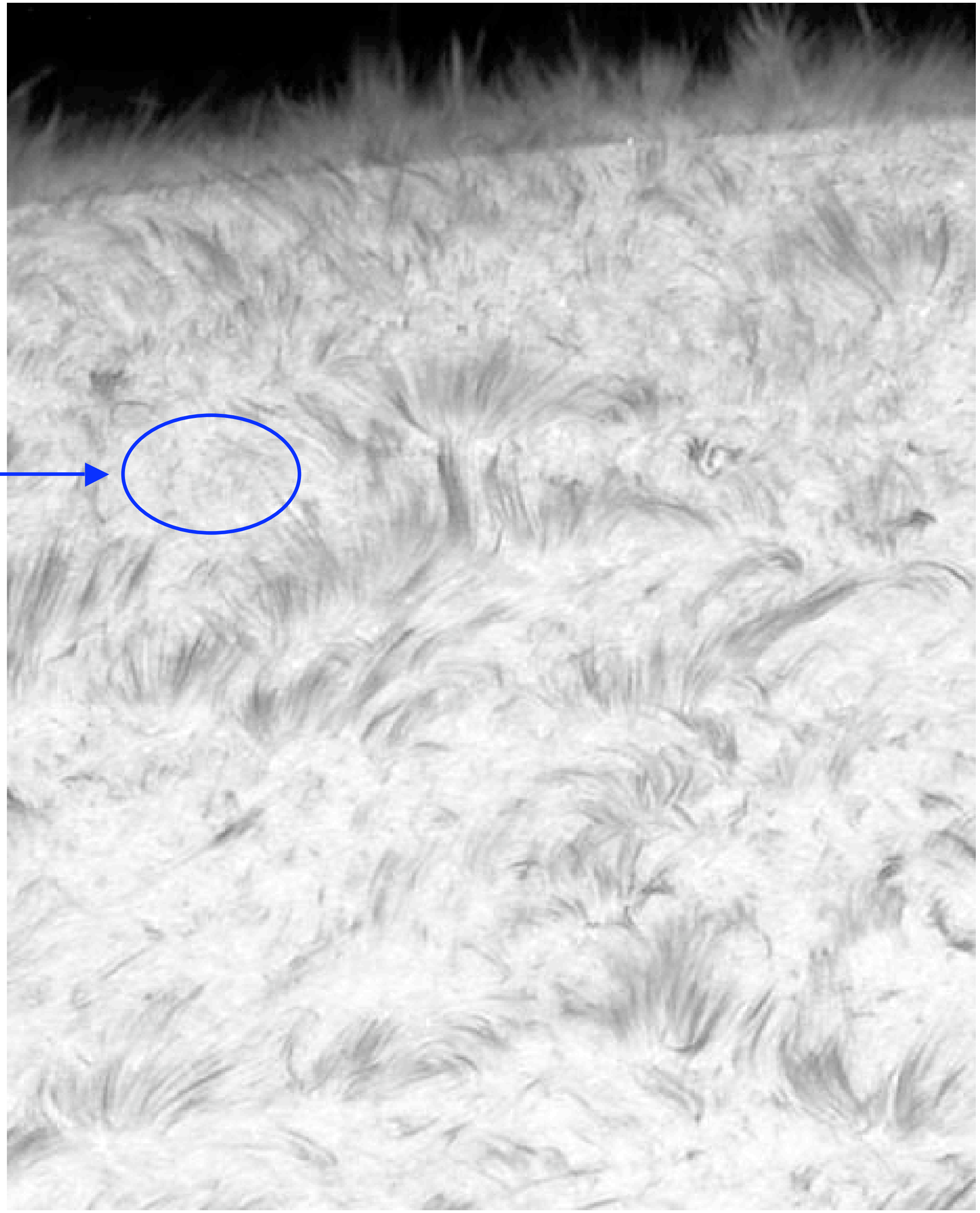


B=10 G
Inclination=37°
Azimuth = 173°
V=13 km/s
$\tau = 3$

Do we have magnetic canopies in the most "quiet" regions of the solar chromosphere ?

QUESTION

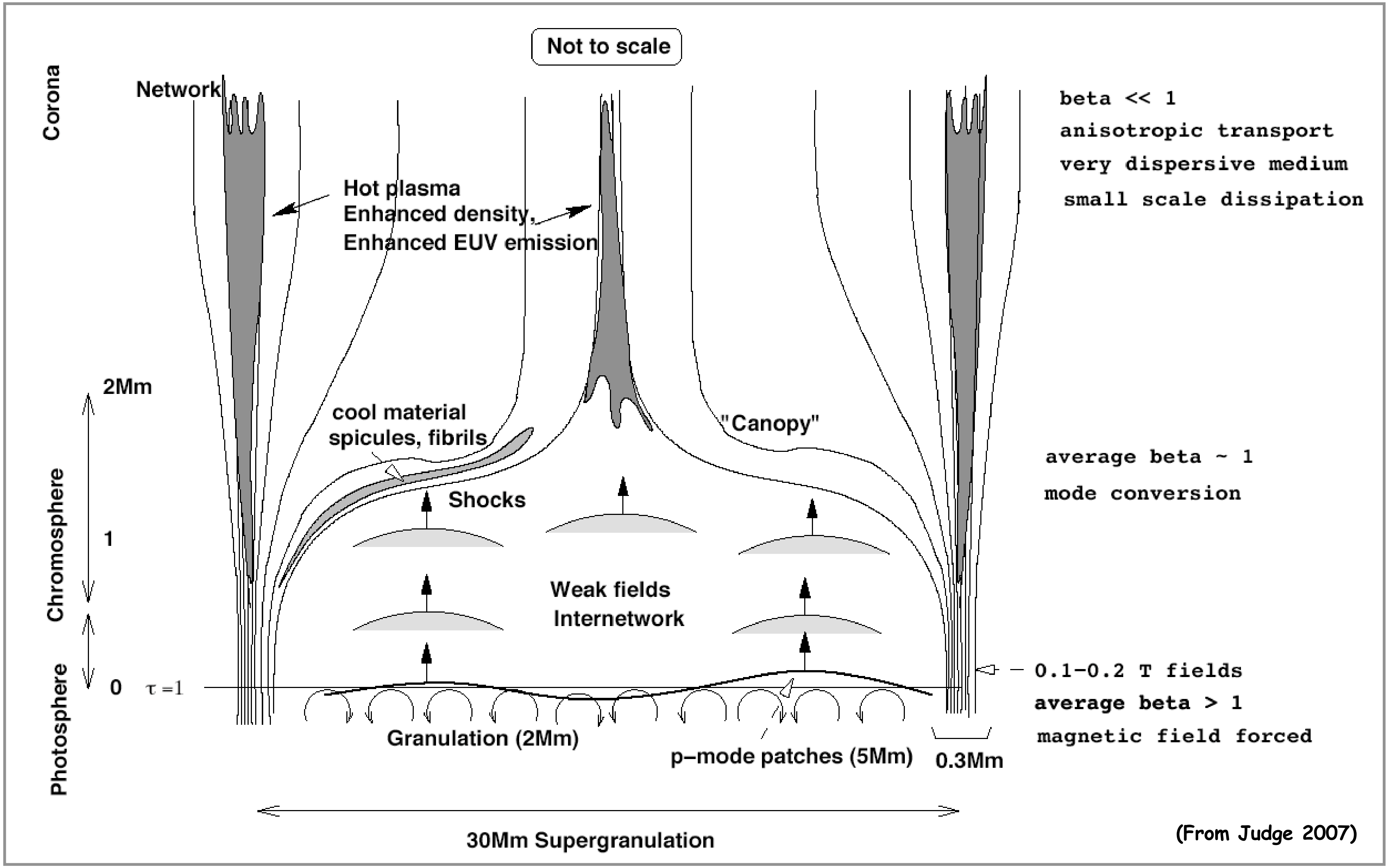
Can we explore via spectro-polarimetry in the He I 10830 triplet the structure of the magnetic field in "quiet" regions like this one, where there seems to be insufficient chromospheric material to trace it ?



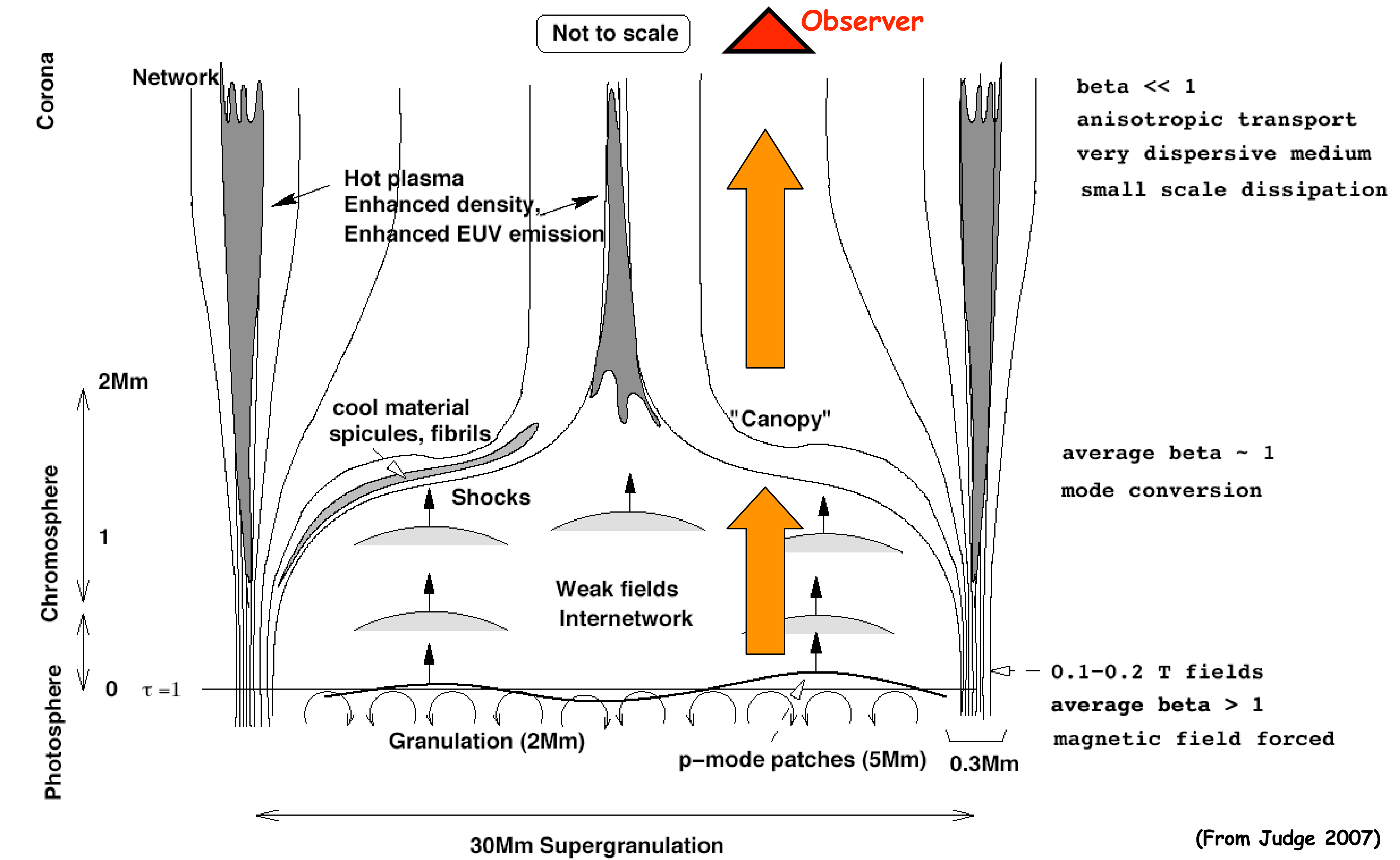
DOT H-alpha wing image showing spicules emanating from network magnetic concentrations.

Javier Trujillo Bueno (IAC; Tenerife; Spain)
Talk at Solar-C science definition meeting (Tokyo, 2008)

Cartoon Model of the “Quiet” Solar Chromosphere



Cartoon Model of the "Quiet" Solar Chromosphere



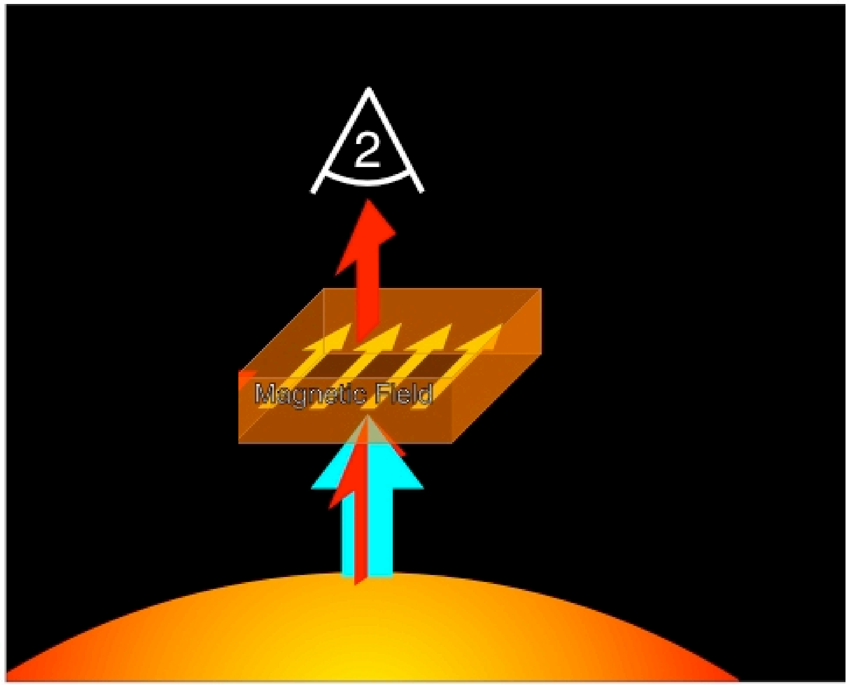
(From Judge 2007)

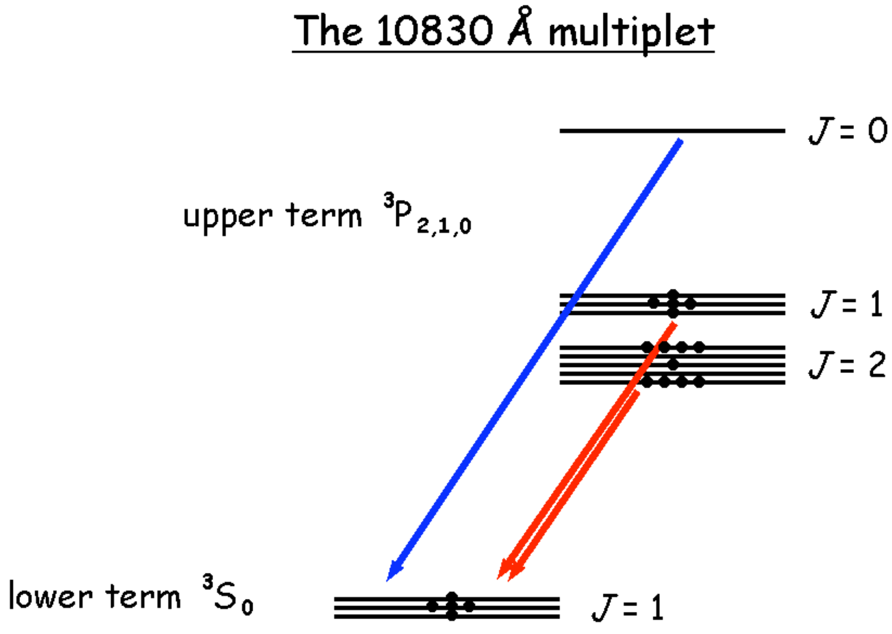
The amplitude of the emergent polarization must depend on the **optical thickness** of the absorbing layer.

Let us see how it varies assuming:

(1) a horizontal field between 10 and 100 gauss.

(2) disk-center observation (forward-scattering geometry).

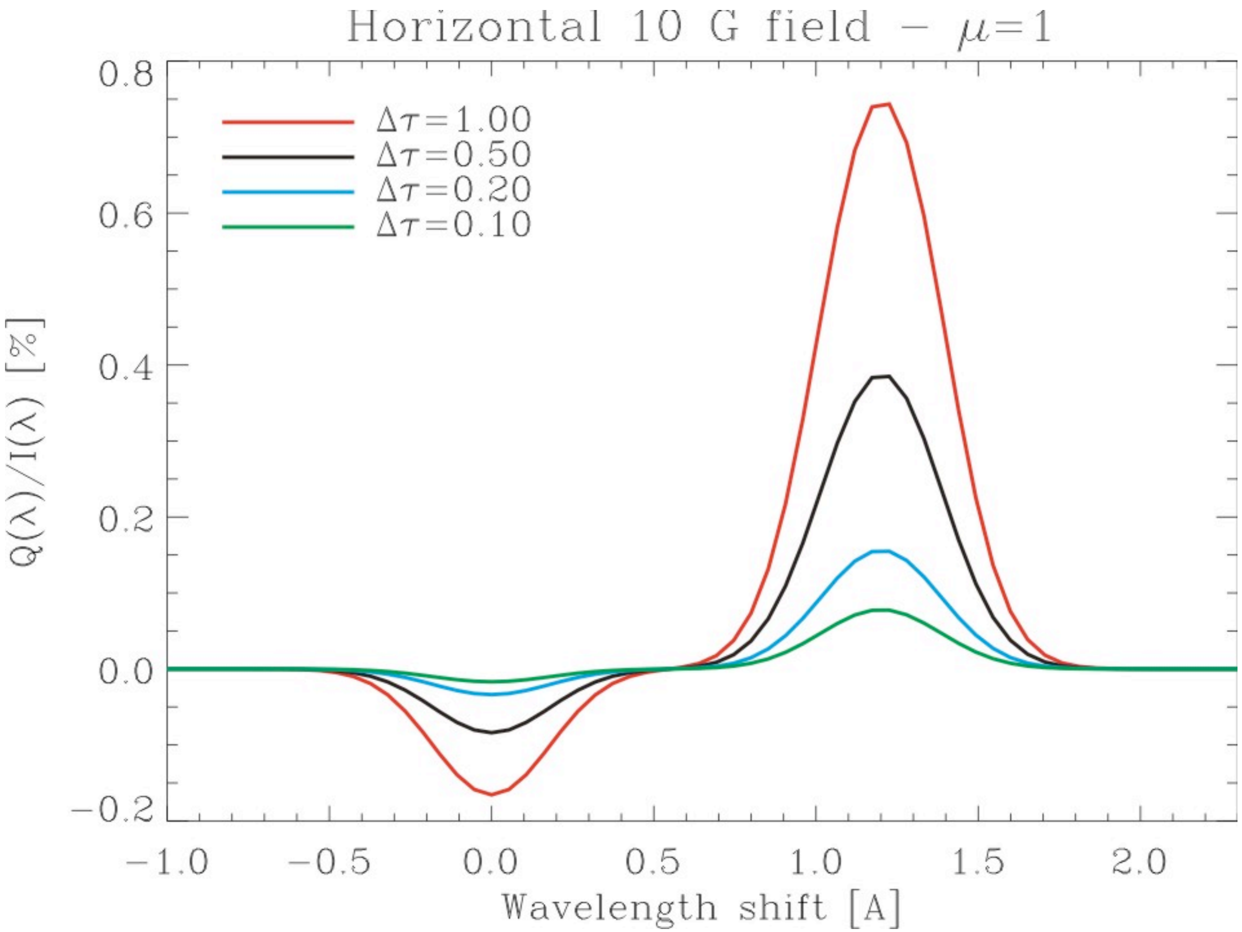




Javier Trujillo Bueno (IAC; Tenerife; Spain)
Talk at Solar-C science definition meeting (Tokyo, 2008)

The He I 10830 linear polarization signal created by the Hanle effect of an inclined field when observing at the solar disk center (forward scattering geometry)

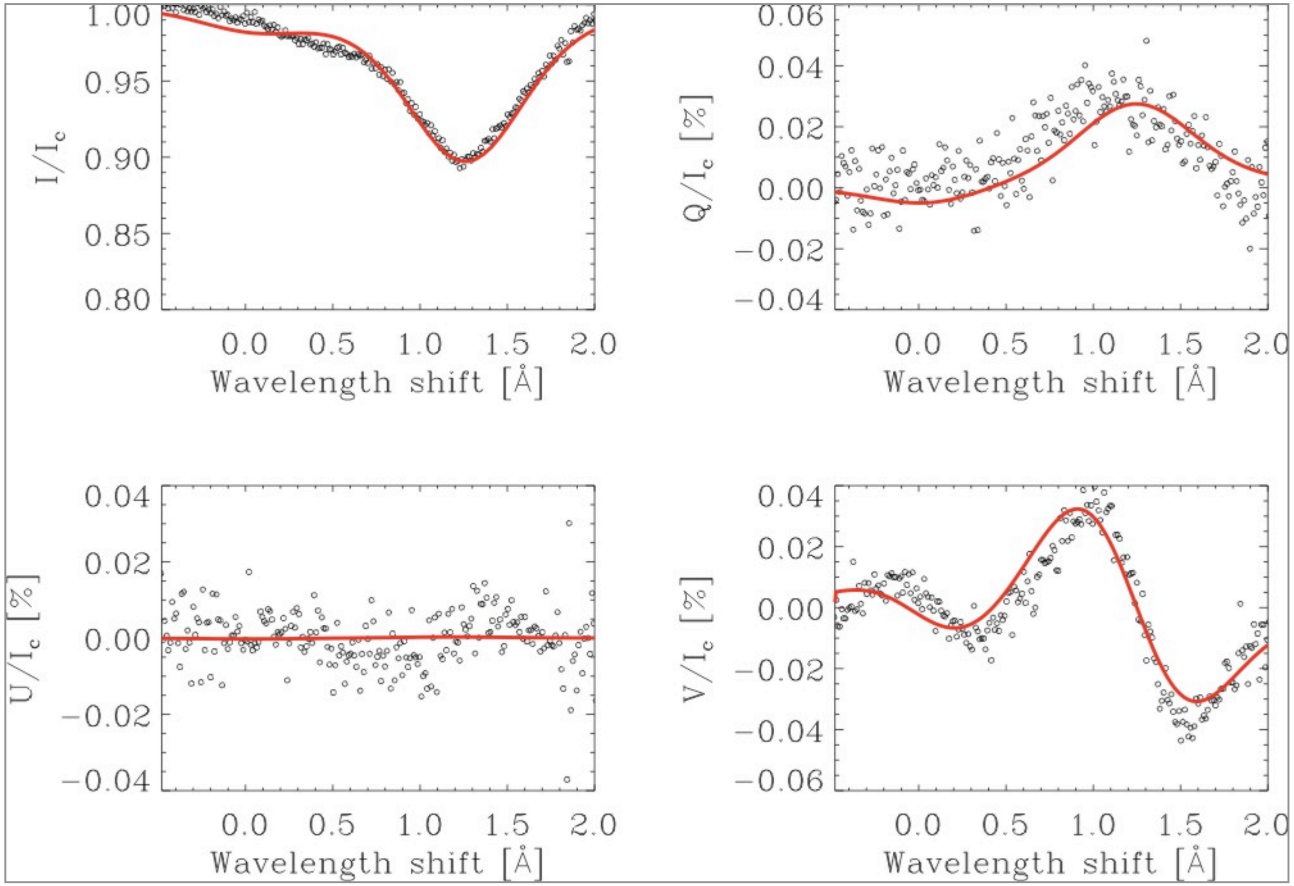
NOTE that the smaller the optical thickness of the plasma structure the smaller the Q/I amplitude !



Javier Trujillo Bueno (IAC; Tenerife; Spain)
Talk at Solar-C science definition meeting (Tokyo, 2008)

Can we detect with the Tenerife IR Polarimeter He I 10830 linear polarization signals when observing "QUIET" inter-network regions at the solar disk center?

If detected, such a Hanle-effect signal would be due to the presence of an inclined magnetic field in the "QUIET" chromosphere !



Hanle signal !

Result of our **HAZEL** inversion:

B=47 G

Inclination=47º

$\Delta\tau_{\rm red} \approx 0.2$

Zeeman signal !

(From Asensio Ramos & Trujillo Bueno 2009; SPW5)

The Astrophysical Journal, 683, 565, 2008

ADVANCED FORWARD MODELING AND INVERSION OF STOKES PROFILES RESULTING FROM THE JOINT ACTION OF THE HANLE AND ZEEMAN EFFECTS

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Received 2007 December 11; accepted 2008 April 15

ABSTRACT

A big challenge in solar and stellar physics in the coming years will be to decipher the magnetism of the solar outer atmosphere (chromosphere and corona) along with its dynamic coupling with the magnetic fields of the underlying photosphere. To this end, it is important to develop rigorous diagnostic tools for the physical interpretation of spectro-polarimetric observations in suitably chosen spectral lines. Here we present a computer program for the synthesis and inversion of Stokes profiles caused by the joint action of atomic level polarization and the Hanle and Zeeman effects in some spectral lines of diagnostic interest, such as those of the He I 10830 Å and 5876 Å (or D_3) multiplets. It is based on the quantum theory of spectral line polarization, which takes into account in a rigorous way all the relevant physical mechanisms and ingredients (optical pumping, atomic level polarization, level crossings and repulsions, Zeeman, Paschen-Back, and Hanle effects). The influence of radiative transfer on the emergent spectral line radiation is taken into account through a suitable slab model. The user can either calculate the emergent intensity and polarization for any given magnetic field vector or infer the dynamical and magnetic properties from the observed Stokes profiles via an efficient inversion algorithm based on global optimization methods. The reliability of the forward modeling and inversion code presented here is demonstrated through several applications, which range from the inference of the magnetic field vector in solar active regions to determining whether or not it is canopy-like in quiet chromospheric regions. This user-friendly diagnostic tool called "HAZEL" (from HAnle and ZEeman Light) is offered to the astrophysical community, with the hope that it will facilitate new advances in solar and stellar physics.

Exposure times (T) needed for detecting X/I signals with the indicated polarimetric sensitivity (PS), with 0.5" and a spectral resolution of 0.05 Angstroms, and assuming a 1m space telescope having an overall throughput of 5% .

• **Ca II IR-triplet lines**	• **He I 10830 triplet**
• PS=0.1% T=0.32 sec	• PS=0.1% T=0.16 sec
• PS=0.01% T=32 sec	• PS=0.01% T=16 sec

Javier Trujillo Bueno (IAC; Tenerife; Spain)
Talk at Solar-C science definition meeting (Tokyo, 2008)

The polarization of the IR triplet of Ca II

Good news

- Good choice to study both, the "quiet" and the active Sun magnetism.
- Provides information on the thermal and the magnetic structure, all the way up from the photosphere to the bulk of the chromosphere.
- The polarization signals are sensitive to magnetic strengths from milligauss to kG fields.
- Ideal choice to evaluate the reliability of MHD models of the photosphere+chromosphere via spectral synthesis and comparison with spectropolarimetric observations.

Not so good news

- Not the ideal choice for studying the magnetic field that confines the plasma of structures embedded in the solar chromosphere and corona (e.g., prominences, filaments, spicules, …).
- The forward scattering signals are rather small, but nevertheless measurable through longer integration times.
- Stokes inversion of the magnetic field vector is possible, but requires to infer first a model for the thermal+density stratification.

The polarization of the He I 10830 triplet

Good news

- Ideal choice for studying the magnetic field that confines the plasma of structures embedded in the solar chromosphere and corona (e.g., prominences, filaments, spicules).
- It is also suitable for obtainig some information on the magnetic field vector in regions of emerging flux, flaring regions, sunspots, etc.
- Photospheric lines present in the same spectral region, so information on the photospheric-chromospheric coupling can also be obtained.
- Stokes inversion of the magnetic field vector is already possible (with the Hanle+Zeeman code HAZEL).

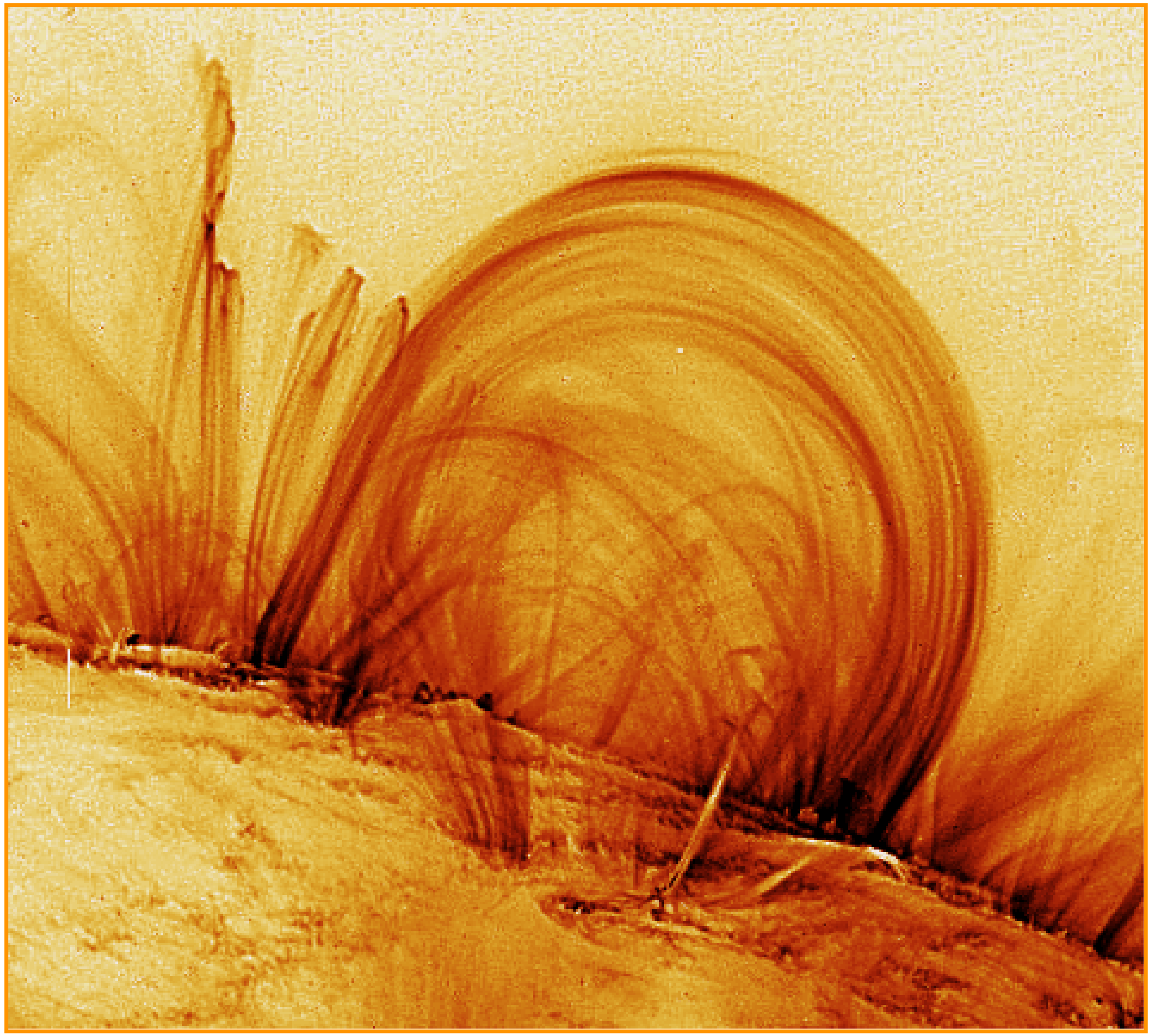
Not so good news

- Not the best choice to study the magnetism of the "quiet" chromosphere.
- Difficult to obtain information on the thermal and/or density structure.
- Difficult to obtain information on the height corresponding to the inferred magnetic field vector.
- Not an ideal choice to evaluate the reliability of MHD models of the solar atmosphere.

Javier Trujillo Bueno (IAC; Tenerife; Spain)
Talk at Solar-C science definition meeting (Tokyo, 2008)

How to explore the magnetic fied topology of coronal loops and arcades ?

SUGGESTION 3: Build a **EUV imaging polarimeter** in order to map the magnetic fieds of coronal loops and arcades



Javier Trujillo Bueno (IAC; Tenerife; Spain)
Talk at Solar-C science definition meeting (Tokyo, 2008)

Can we expect scattering polarization signals in spectral lines at EUV wavelengths for which the underlying quiet solar disk is seen completely dark ?

- **For many EUV lines their lower level is the upper or lower level of a forbidden line at visible wavelengths, which are polarized due to the anisotropic illumination in the forbidden line.**

- **This lower-level polarization is transferred to the upper level of the EUV line by collisional excitation.**

- **Therefore, since the upper level of the EUV line is polarized, we will have measurable scattering polarization signals caused by the ensuing selective emission processes.**

- **Contrary to the case of forbidden line polarimetry, such linear polarization signals can be observed also in forward scattering at the solar disk center → coronal magnetic mapper.**

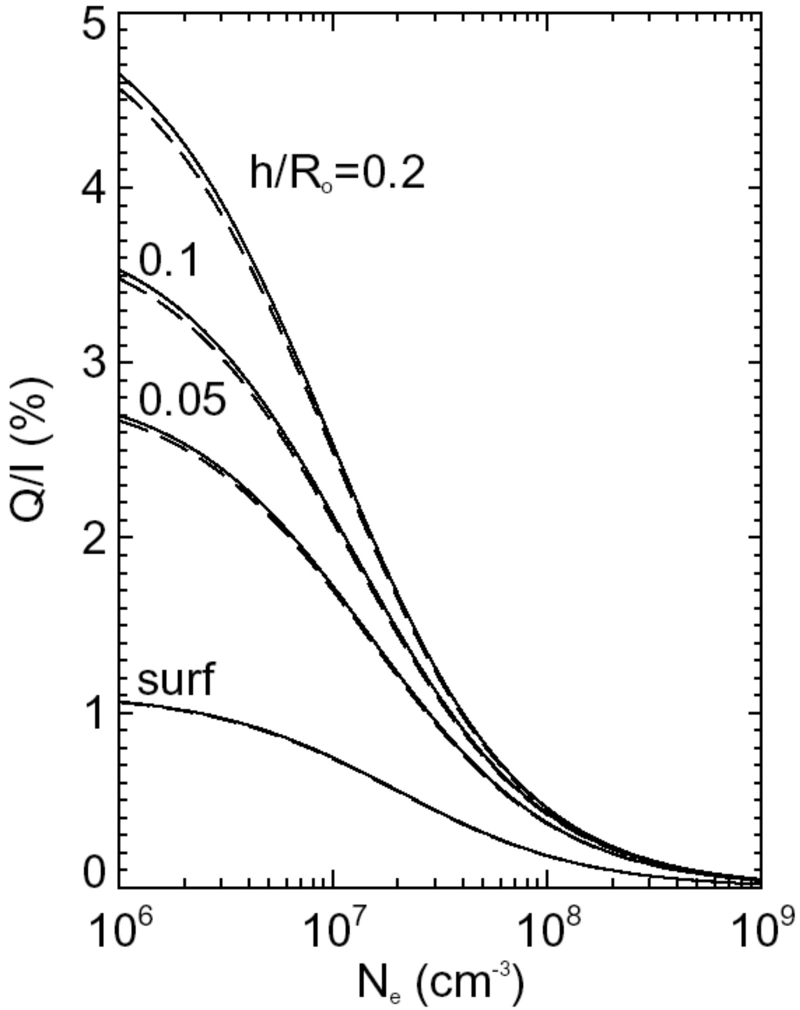
See the paper by Manso Sainz & TB (2009) in the proceedings of the Solar Polarization Workshop 5 (SPW5)

Theoretical prediction of the linear polarization produced by coronal loops in the EUV Fe X line at 174.5 Angstroms

From Manso Sainz & TB (2009) (see SPW5 paper)

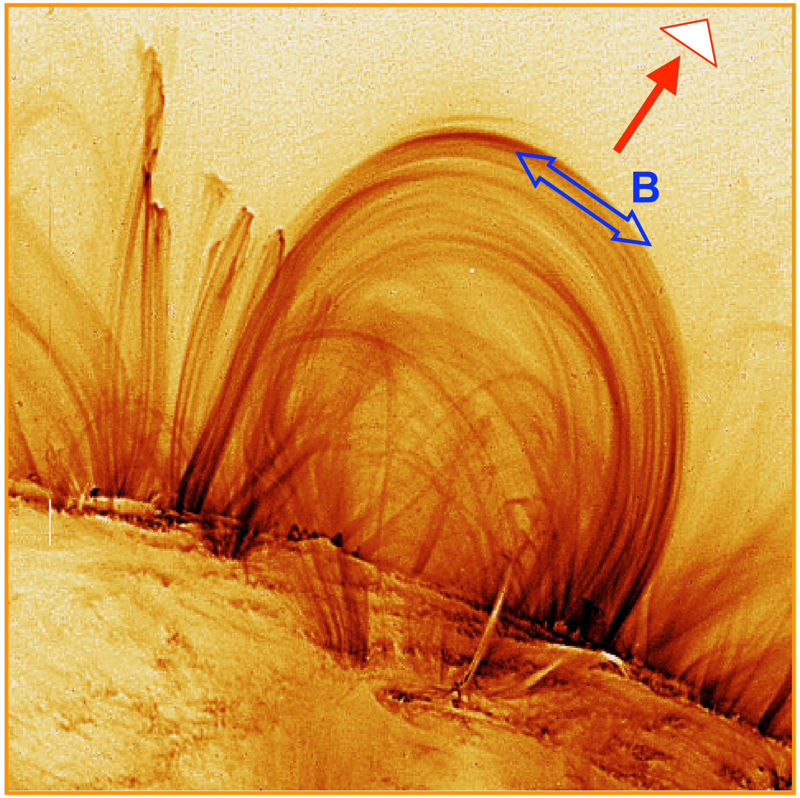
Horizontal Magnetic Field Case

Top of the loop as seen at the disk-center



FORWARD scattering geometry

TOP of the loop as seen at disk center



Concluding comments

- If you want to do something scientifically challenging put in SOLAR-C a spectropolarimeter for measuring simultaneously the polarization in photospheric and chromospheric lines (e.g., for the spectral region of the IR triplet of Ca II and/or for that of the He I 10830 triplet).

- If, in addition, you want to do something technologically challenging put in SOLAR-C a EUV imaging polarimeter (i.e., a TRACE-like instrument BUT capable of obtaining also linear polarization images of coronal loops).

Concluding Comments

- I bear no doubt that (Hanle + Zeeman) spectropolarimetry will be a revolutionary technique in 21st century astrophysics.

- JAXA + ESA + NASA should take advantage of our joint knowledge in this field to open this NEW diagnostic window to the Universe.

Javier Trujillo Bueno (IAC; Tenerife; Spain)
Talk at Solar-C science definition meeting (Tokyo, 2008)