Magnetic field diagnostics based on scattering line polarization at the solar limb

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The magnetic solar corona as revealed by polarimetry.

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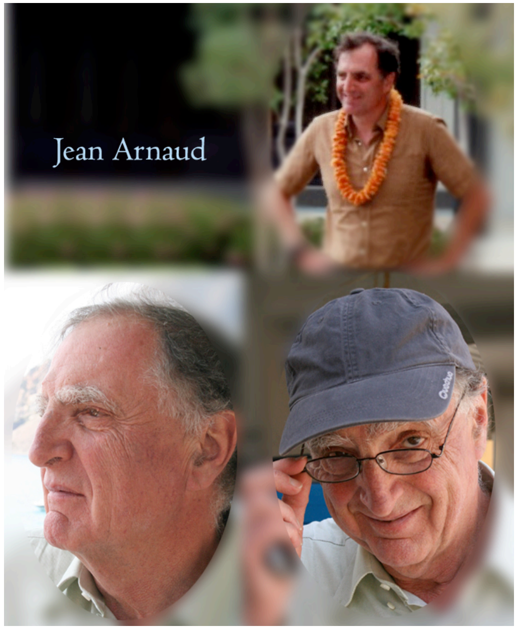
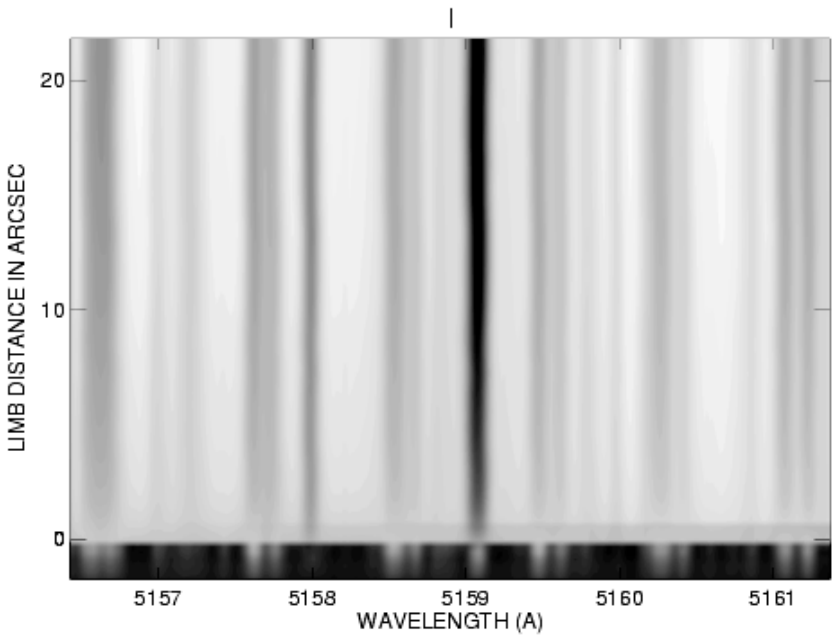
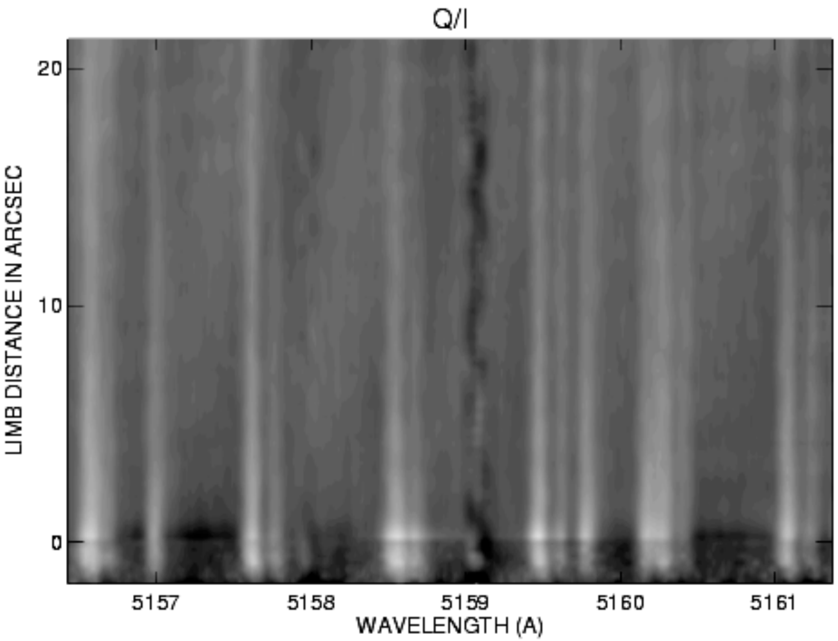
Scattering polarization and Hanle effect observed above the solar limb at Themis

The primary miror of Themis is super polished (thanks to Jean Arnaud). In good seeing conditions off-limb observations are possible together with polarization measurements.



Observations at the solar limb

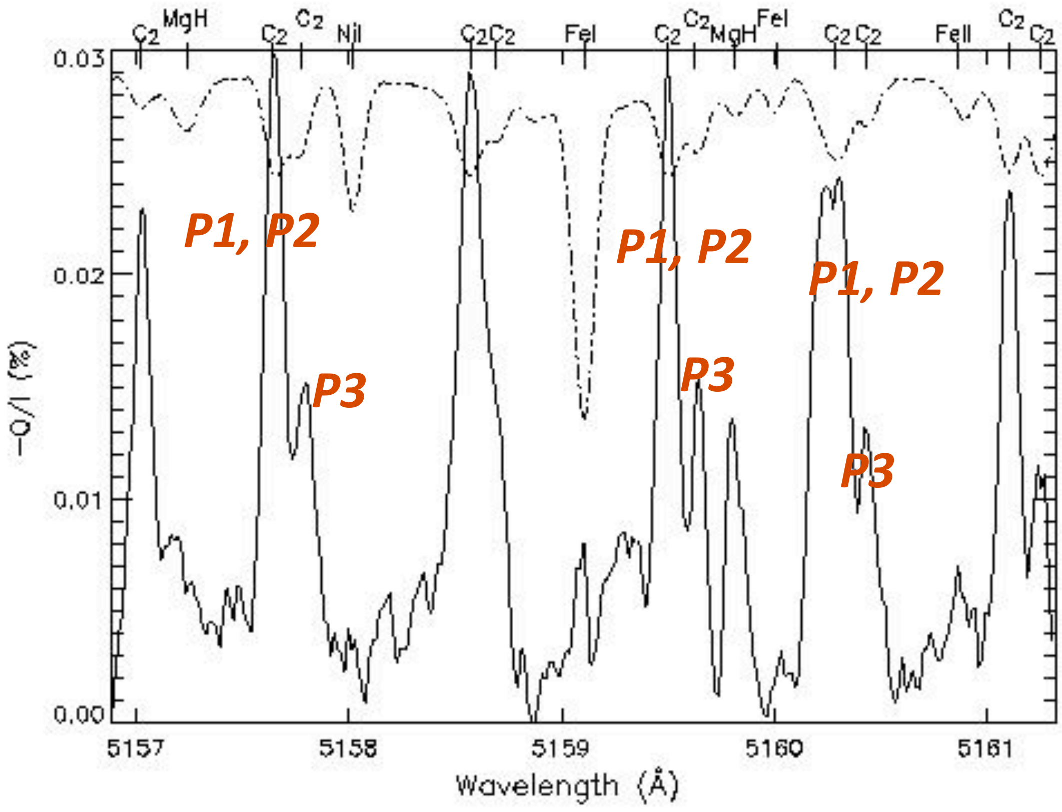




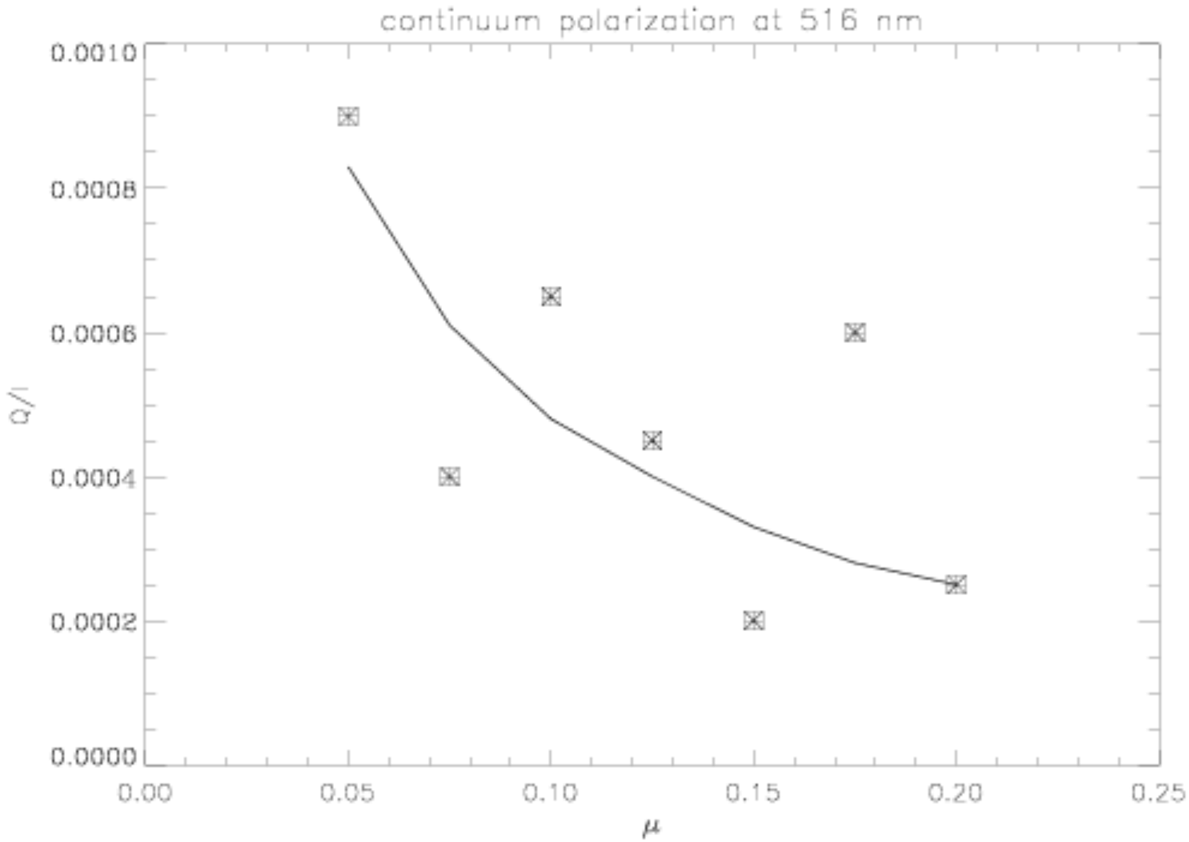
Molecular lines observed at Themis: Faurobert M. & Arnaud J., A&A 2002, 2003

(10 mn exposure time, photometric sensitivity: 10^{-5})

Linear polarization spectrum 50'' inside the limbe



Measurement of the continuum polarization



X: measurements at Themis at various limb distances

____: 1D radiative transfer calculations with VALC quiet sun model

Molecular lines seen in emission above the limb

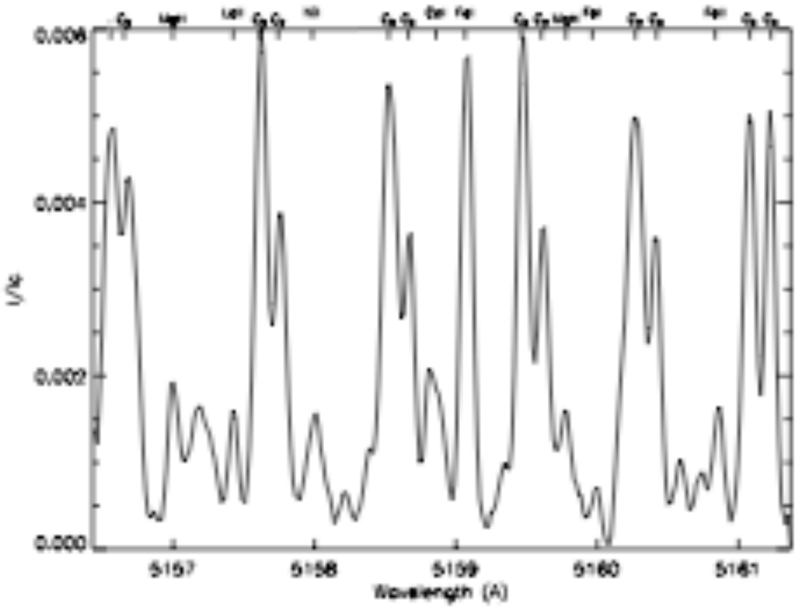


Fig. 1. I/I_c recorded at one arcsec above the solar limb, I_c the intensity of the continuum at disk center. Molecular lin of C_2 and MgH appear as emission lines, together with atom lines of Fe II, Fe I, Co I, Ni I and La II.

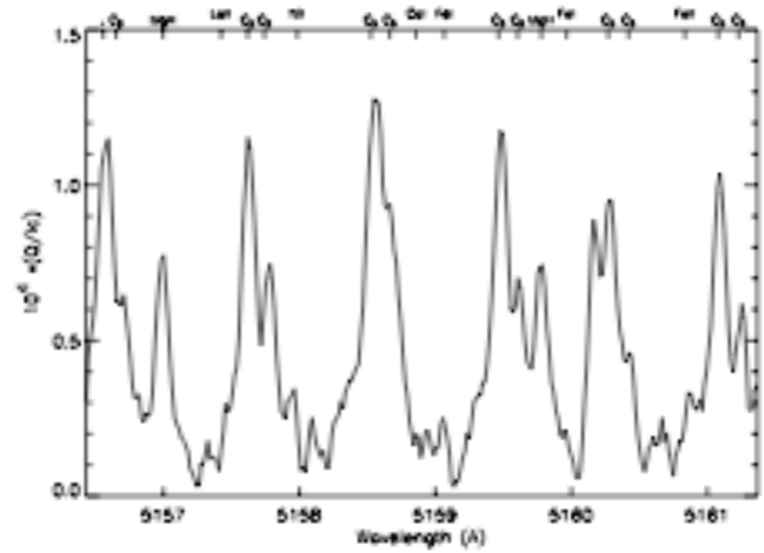
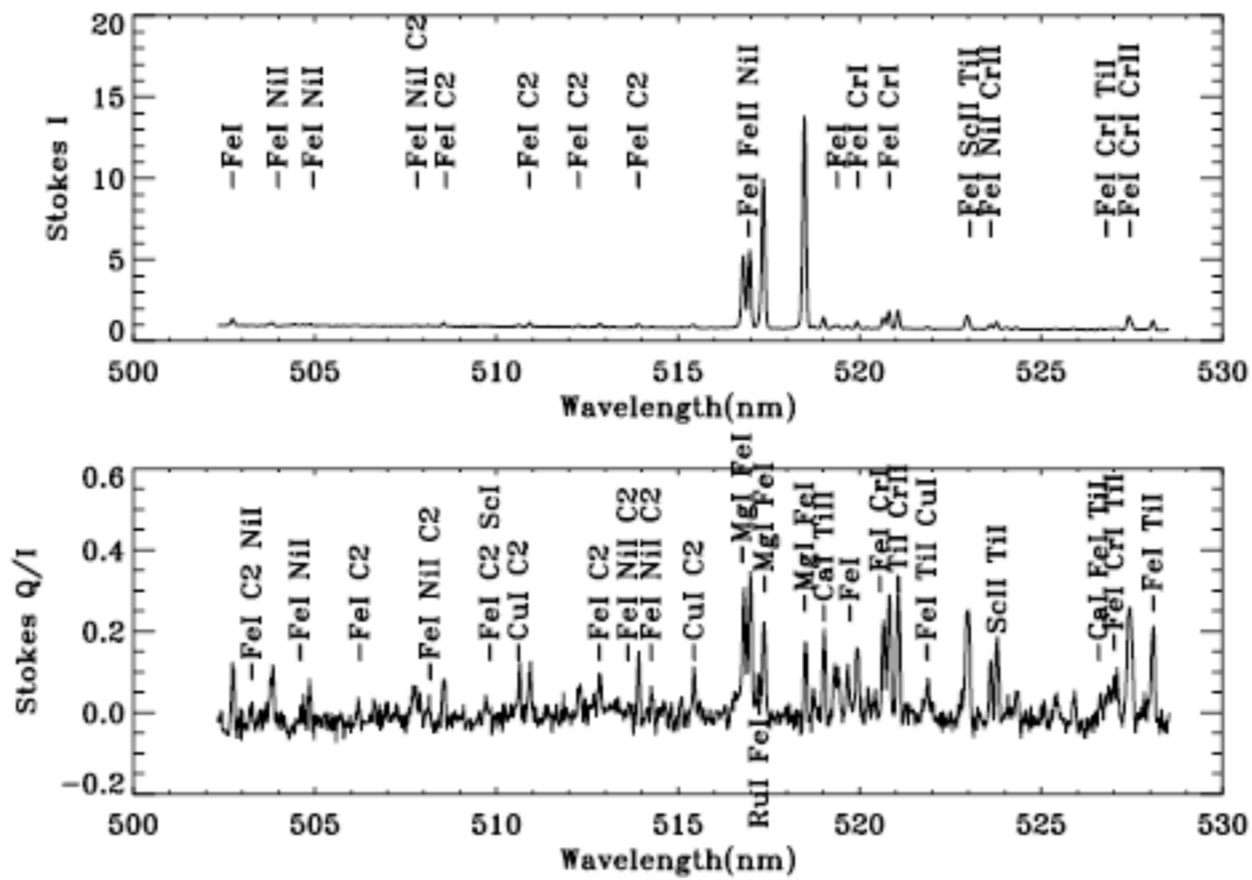


Fig. 2. $|Q|/I_c$ recorded at one arcsec above the solar limb, I_c is the intensity of the continuum at disk center. We observe the scattering polarization of C_2 and MgH lines. The polarization of the atomic lines of Fe II, Fe I, Co I and La II is also marginaly detected.

Linear polarization Q/I measured in the molecular lines in emission 1'' above the limb

Molecular line	Branch (J)	$\|Q\|/I(\%)$
(MgH) 515.70 nm	Q (17)	3.96
(C_2) 515.76 nm	P1 (30) + P2 (29)	1.90
(C_2) 515.77 nm	P3 (28)	1.91
(C_2) 515.85 nm	P1 (29) + P2 (28)	2.40
(C_2) 515.87 nm	P3 (27)	2.55
(C_2) 515.95 nm	P1 (28) + P2 (27)	1.99
(C_2) 515.96 nm	P3 (26)	1.87
(MgH) 515.98 nm	Q (16)	4.54
(C_2) 516.02 nm	P1 (27) + P3 (1)	
(C_2) 516.03 nm	P2 (26)	1.90
(C_2) 516.04 nm	P3 (25)	1.26
(C_2) 516.10 nm	P1(26) + P2 (25)	2.06

Eclipse observation. Flash spectrum
Qu et al., 2009



Modeling

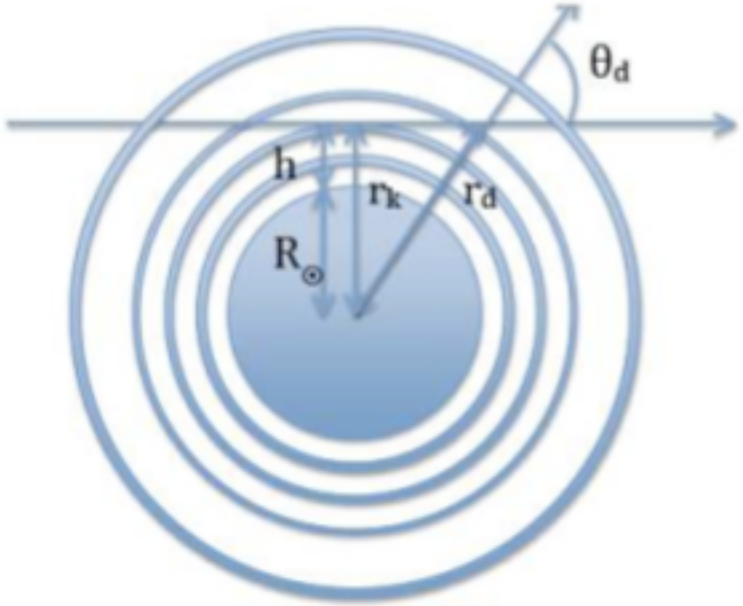


Figure: Illustration of along-the-ray approach in spherical geometry

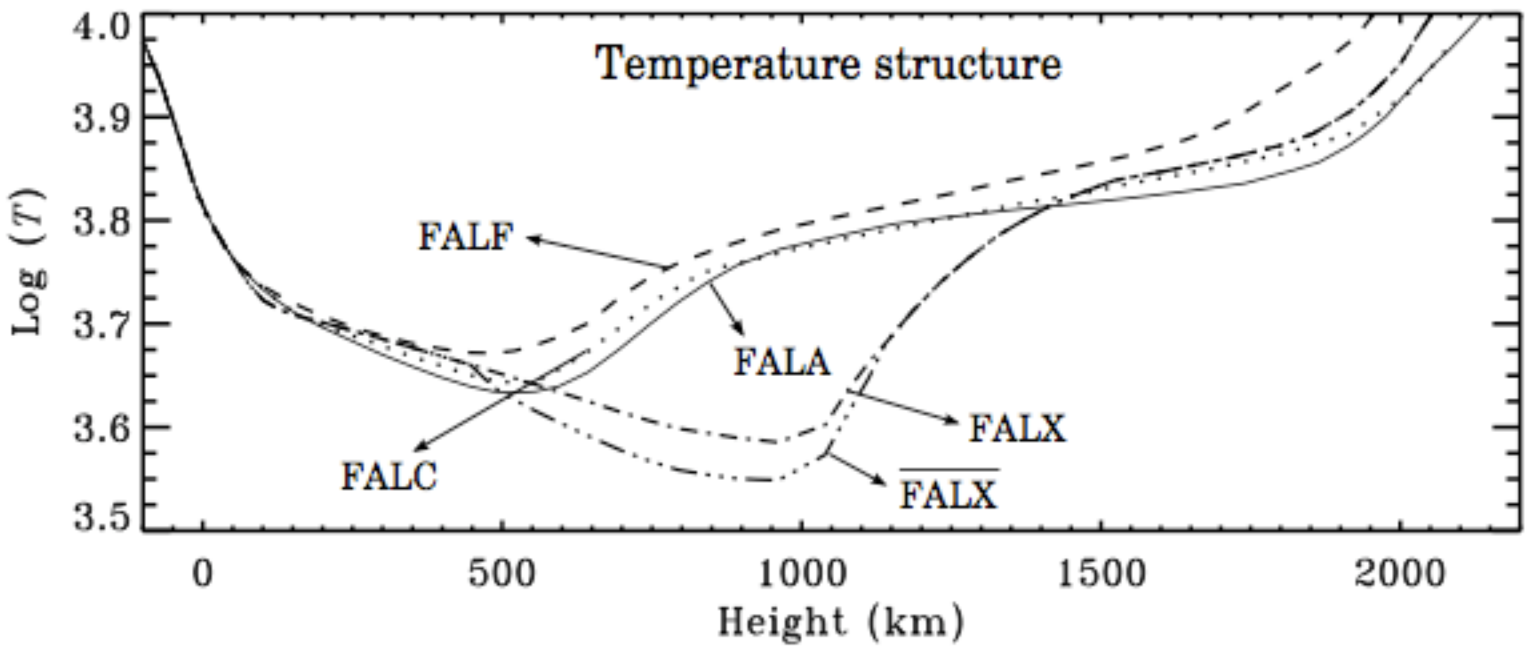
NLTE line formation

We want to model Stokes vector with consistent NLTE radiative transfer formalism:

- We modeled MgH and $\mathrm{C_2}$ lines at 515.98 nm and 515.96 nm respectively.
- We use FALC and FALX quiet Sun models (Fontenla, Avrett & Loeser, 1990)
- 2 level atom formalism with presence of background continuum opacity

Milic & Faurobert, 2012

Quiet sun 1D semi-empirical models



Line scattering/collisions

Visible solar limb

Number density of the MgH line lower level population

collisional depolarization decreases with height

Probability of collisional deexcitation decreases with height → line scattering probability increases with height

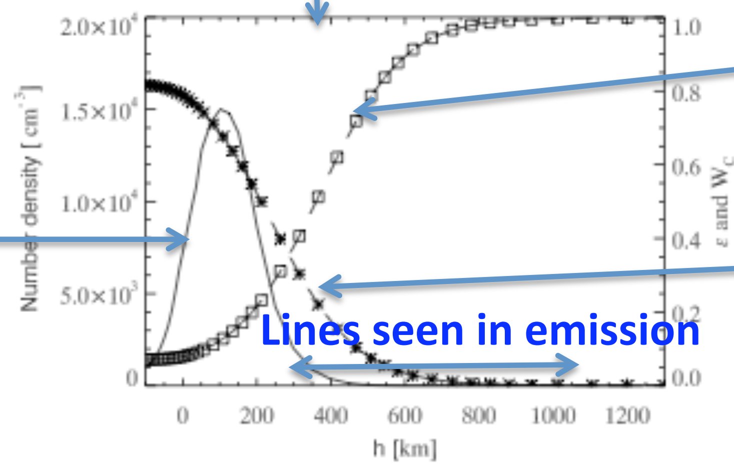


Figure: Height dependence of lower population of MgH transition, ε (asterisks) and W_C (squares) parameters.

Line center intensity FALC/FALX

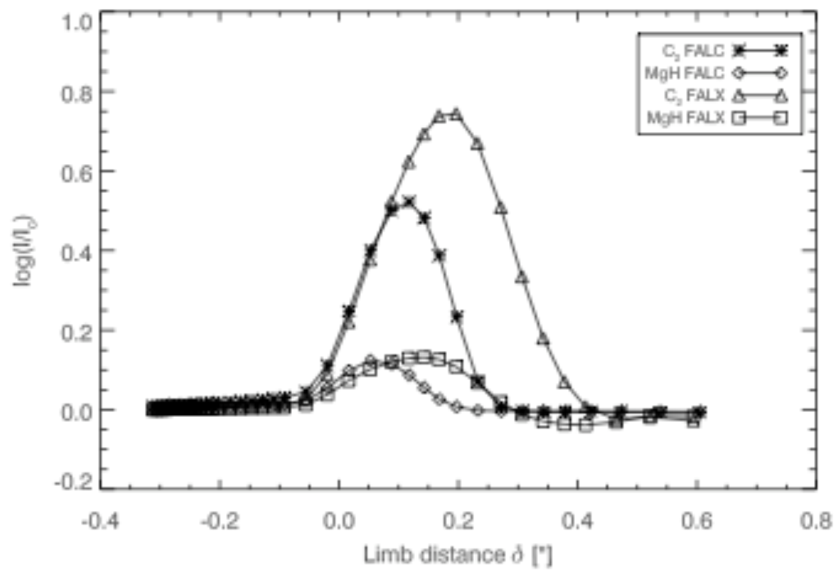


Figure: Line center-to-continuum intensity ratio vs limb distance.

FALX model is cooler than FALC in the low chromosphere: more molecular emission

Polarization at line center
FALC Model/FALX model

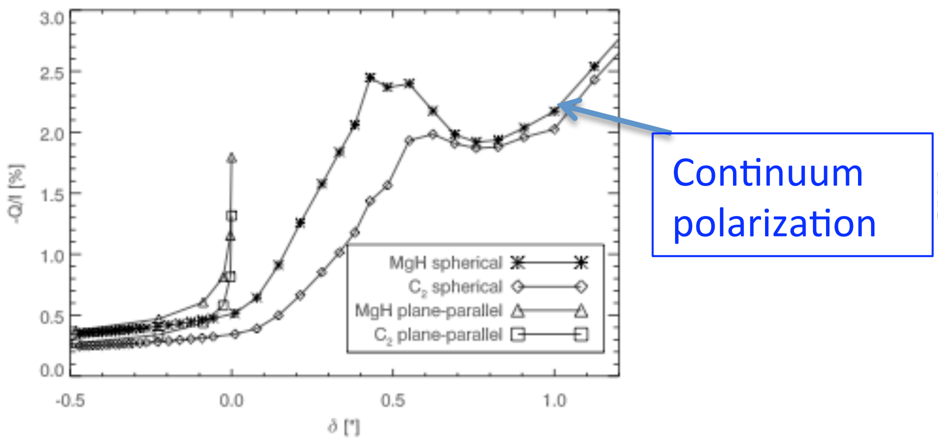


Figure: Comparison of line center polarization between spherical and plane-parallel geometry for FALC solar model.

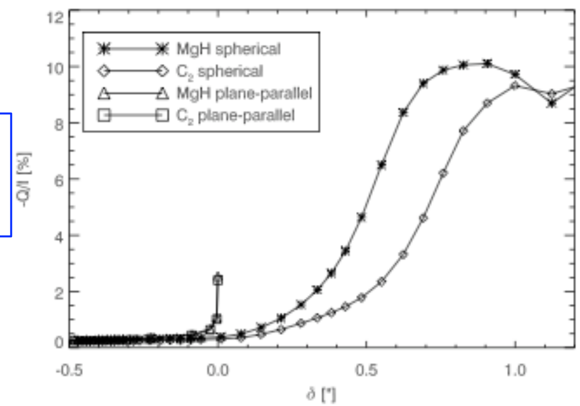


Figure: Comparison of line center polarization between spherical and plane-parallel geometry for FALX solar model.

Significantly higher polarization rates are expected in the « cool » chromosphere model

The observations by Faurobert& Arnaud (2002) are in better agreement with the cool model

Same for the eclipse observation by Qu et al. (2009)

Hanle effect in the presence of magnetic fields with mixed polarities at small scales

No net rotation but depolarization
Depolarization factor W_H

Isotropic magnetic field

$$W_H = 1 - 0.4\left(\frac{\Gamma_H^2}{1+\Gamma_H^2} + \frac{4\Gamma_H^2}{1+4\Gamma_H^2}\right)$$

Horizontal field with random azimuth

$$W_H = 1 - 0.75\left(\frac{4\Gamma_H^2}{1+4\Gamma_H^2}\right)$$

$$\Gamma_H = \frac{B}{B_c}$$

Hanle parameter, W_H
saturation when $\Gamma_H \to \infty$

$$\langle W_H \rangle = \int_0^\infty W_H(B) f(B) dB$$

is the observable quantity

Spatial average on the resolution element

PDF of magnetic strength

Hanle effect of unresolved weak magnetic fields C_2 lines

Sensitivity domain of C2 lines to the Hanle effect: $B \approx \frac{\Gamma_r}{0.88 g_L} \approx 25G$

MgH lines are sensitive to stronger fields on the order of 60 G (differential Hanle effect)

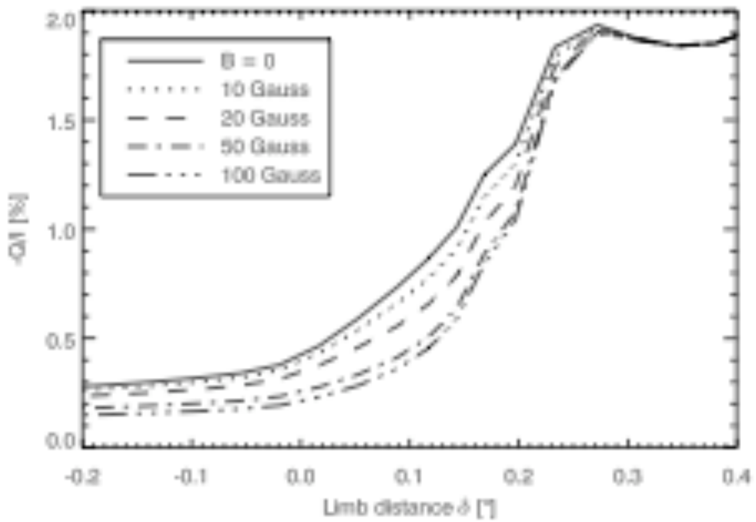


Fig. 8. Limb polarization at the C_2 line center versus limb distance plotted for different values of a depth-independent turbulent magnetic field.

Conclusion?

- It seems that many lines show scattering linear polarization at the solar limb.
- Forward modeling may be used to test MHD models of the chromosphere (we need 3D models).
- Differential Hanle effect for different lines
- But the observational task is probably very difficult : we want to go very close to the limb (good seeing and good coronal sky)
- Are there instruments able to make a survey of the linear polarization of the flash spectrum from the UV to the IR?