Observations of the joint action of the Hanle and Zeeman effects in the D_2 line of Ba II

R. Ramelli, M. Bianda, IRSOL

J. Trujillo Bueno, IAC

L. Belluzzi, E. Landi Degl'Innocenti, Univ. Firenze

Goal

- **Spectropolarimetric observations at IRSOL to verify the theoretical modeling of the Stokes profiles of the Ba II D_2 line developed by Belluzzi, Trujillo Bueno & Landi Degl'Innocenti (presented at SPW4 in Boulder and published in ApJ 266, Sep. 2007).**

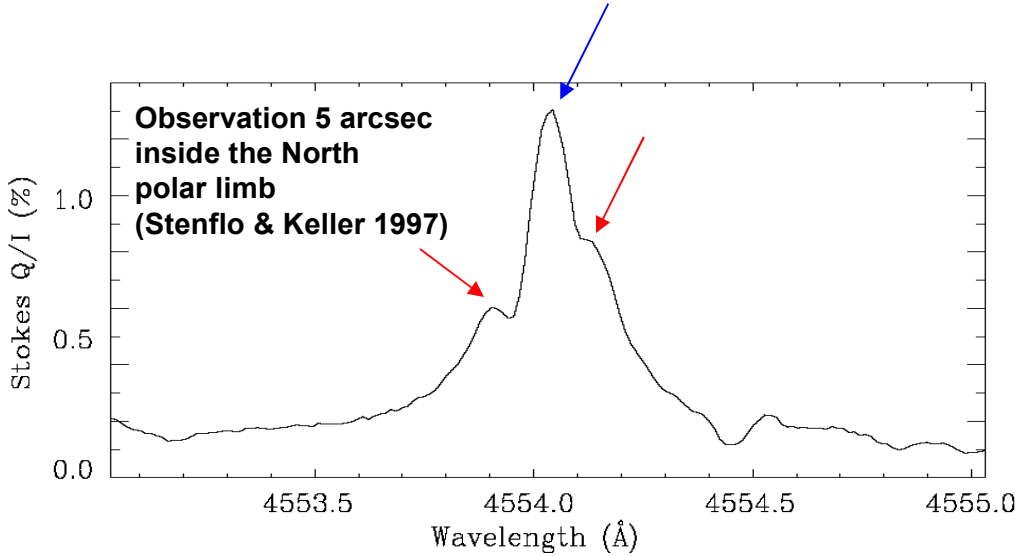
Outline

1. Summary of the theoretical model of Belluzzi et al.
2. The spectropolarimetric observations at IRSOL
3. Compare the theoretical model prediction with the observations
4. Conclusions

1. Summary of the theoretical model

Ba II D_2 Second Solar Spectrum Profile

- **The Ba II D_2 line is one of the most polarized lines of the second solar spectrum.**

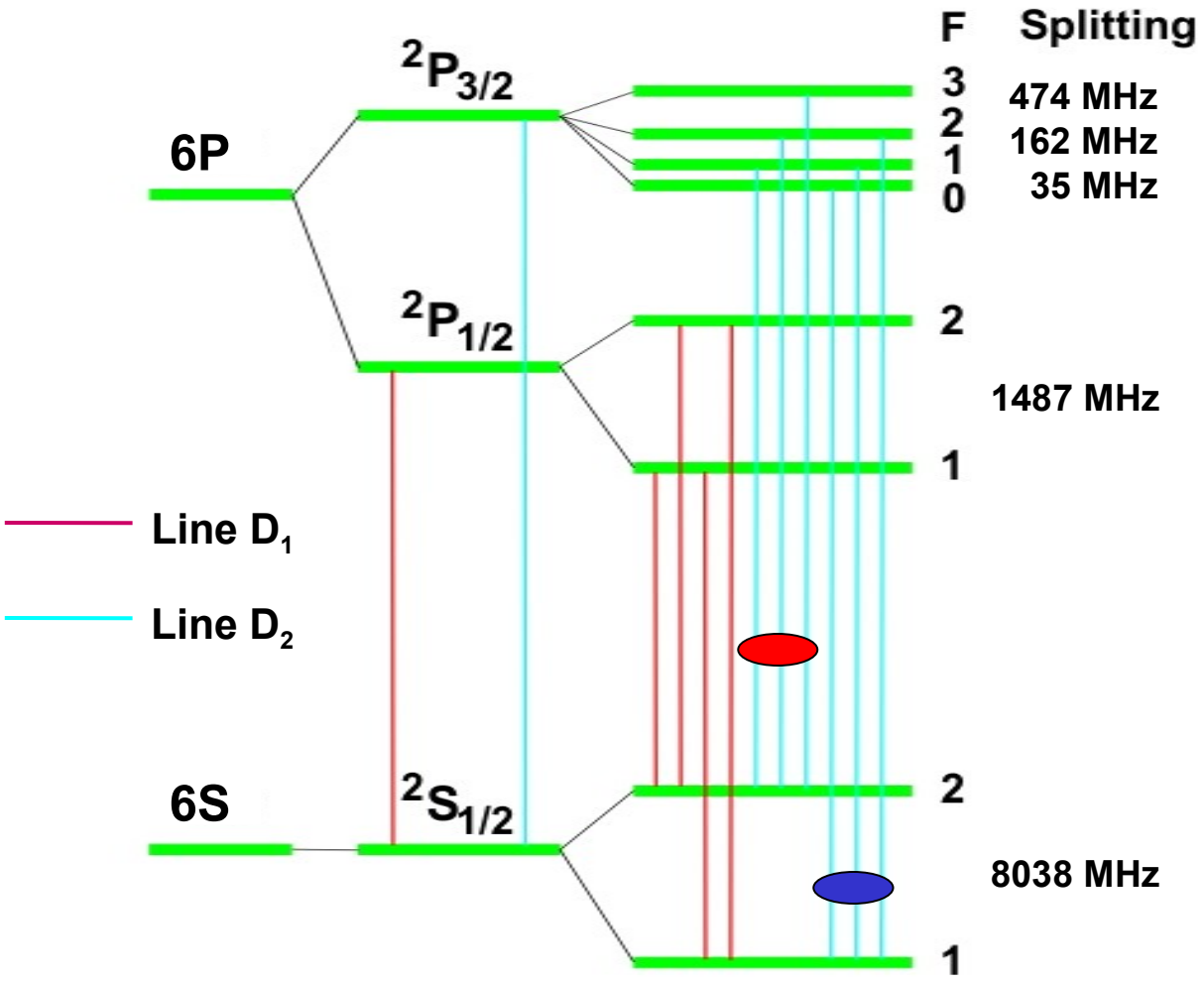


- **The central Q/I peak is due to the isotopes which have no hyperfine-structure. Their relative abundance amounts to 82%. (Ba $_{130,132,134,136,138}$)**

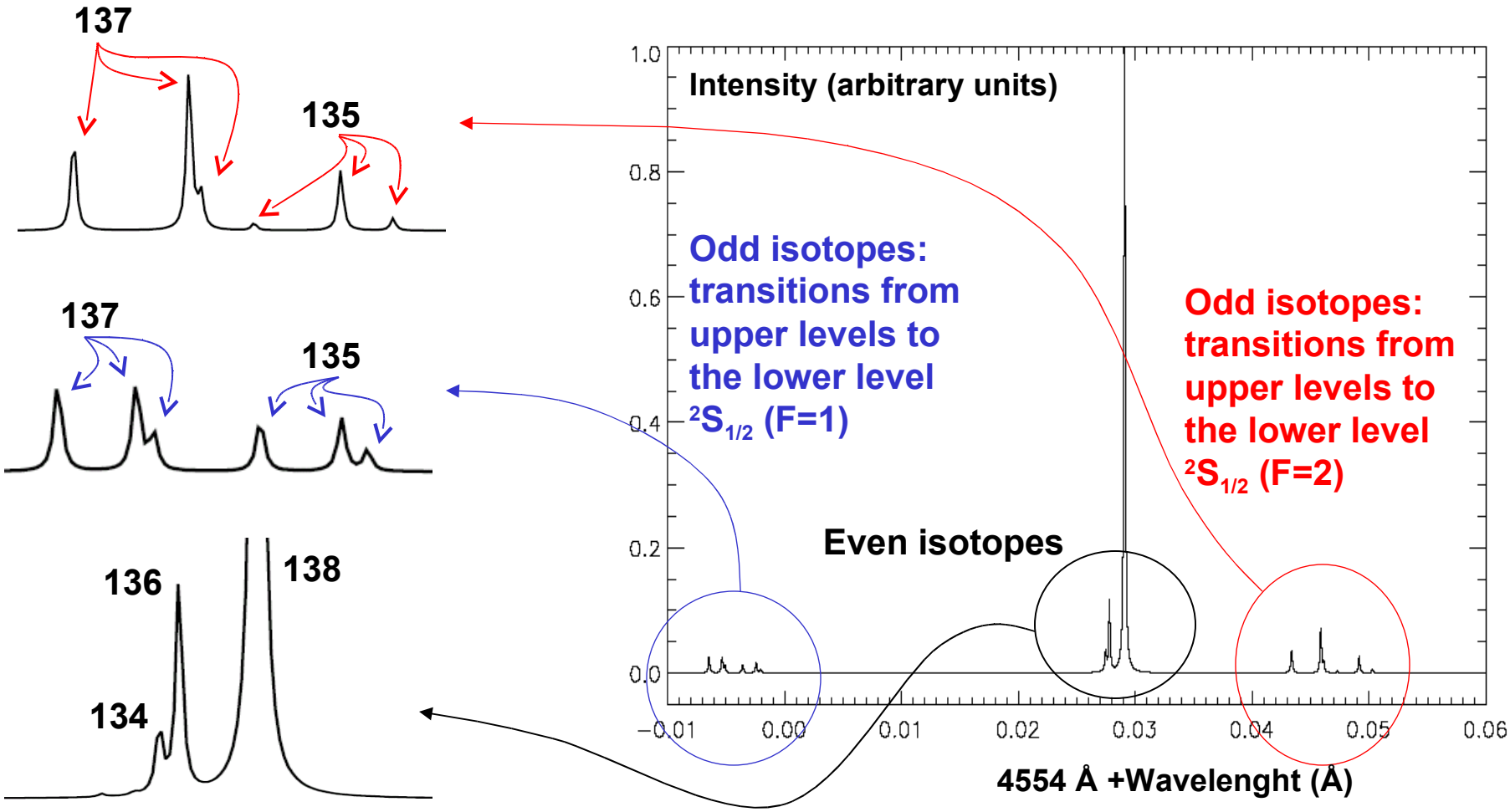
- **The two Q/I peaks in the wings are due to the isotopes which have hyperfine-structure (I=3/2). Their relative abundance amounts to 18%. (Ba $_{135,137}$)**

- **Facts already pointed out by Stenflo&Keller (1997).**

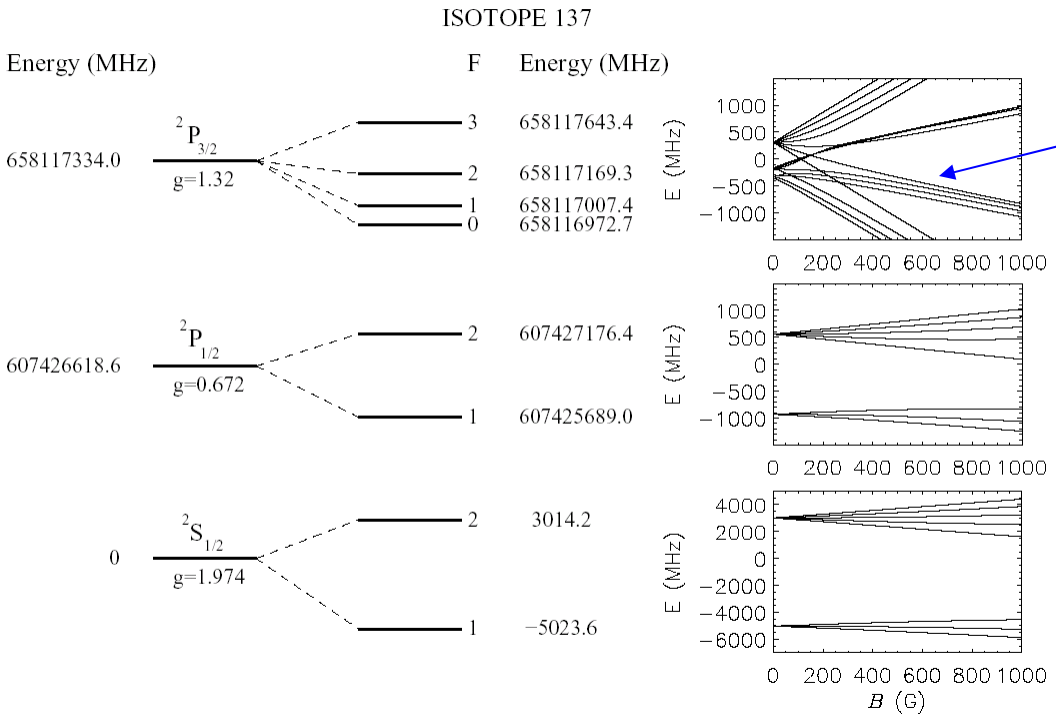
The atomic model



Laboratory positions and intensities of the various components



Splitting of the HFS levels in the presence of a magnetic field



crossings between hfs magnetic sublevels of $^2P_{3/2}$ in the range between 0 and 600 Gauss → important phenomena in resonance scattering (so called level crossing and anti-level crossing effects, Bommier(1980))

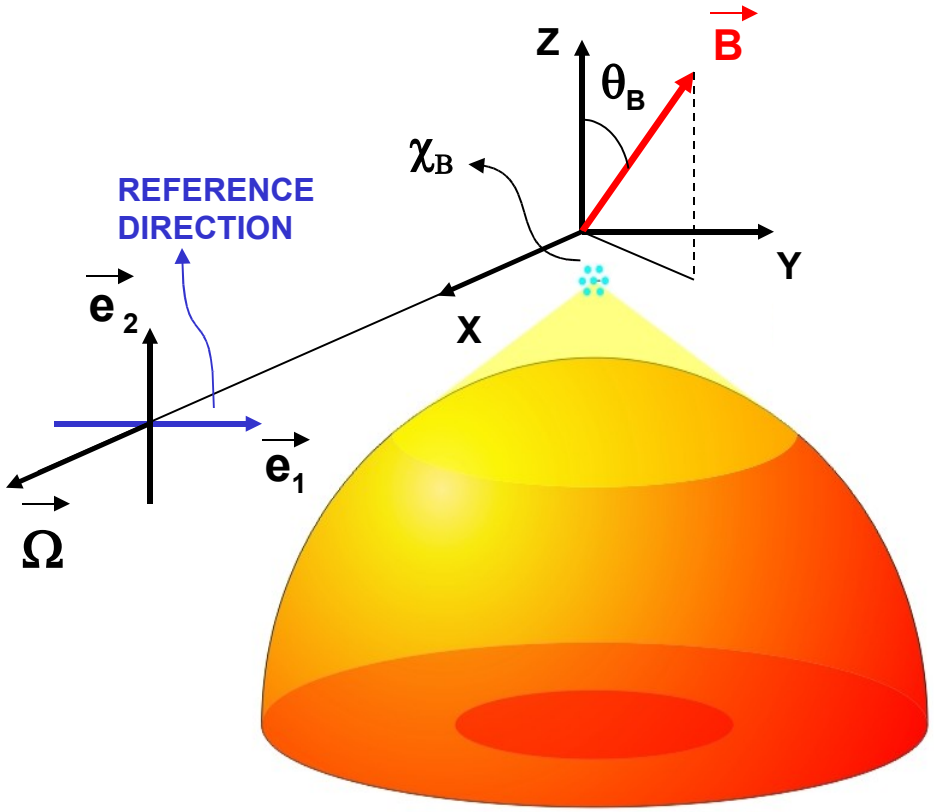
(From Belluzzi et al., ApJ 266, Sep. 2007)

The model

Optically thin slab

An optically thin slab of BaII ions 1000 km above the photospheric level is illuminated by the continuum anisotropic radiation field coming from the underlying solar photosphere.

It is considered the radiation scattered at 90°.



Parameter tuning

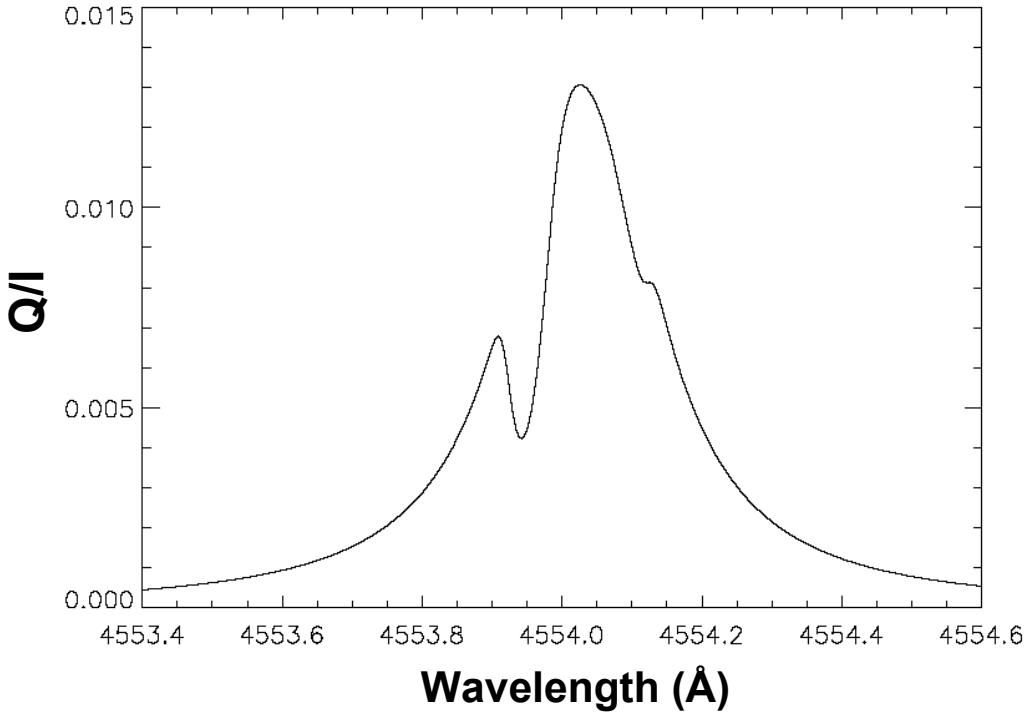
No magnetic field

Assuming that no magnetic field is present, the values of the Doppler width, of the anisotropy factor, and of the continuum contribution are set in order to reproduce the profile of Stenflo& Keller (1997) with the best agreement.

$\Delta\lambda_D$ = 30 mÅ W = 0.037

$\varepsilon_I^{cont} / \varepsilon_I^{line}(max) = 9 \cdot 10^{-5}$

Q/I profile obtained with the model in absence of magnetic field (very similar to the theoretical profile obtained by Stenflo&Keller in 1997)



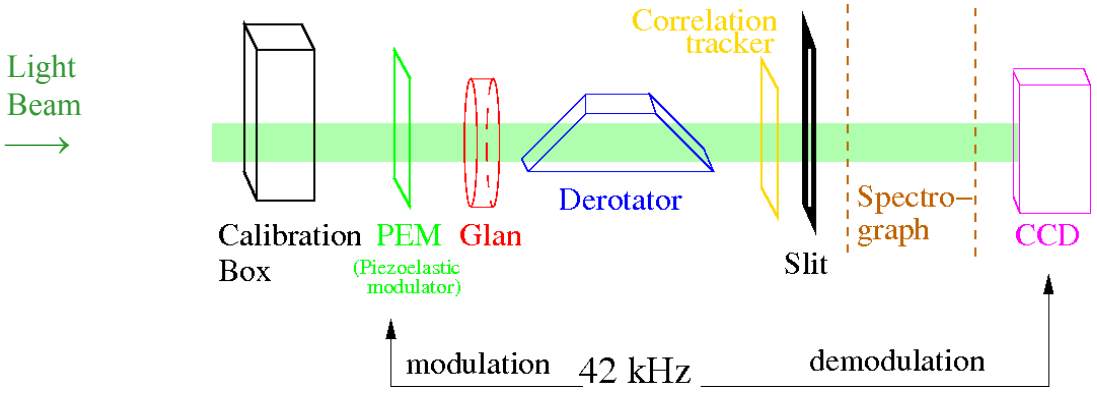
2. The observations

- Several spectropolarimetric observations were obtained near the solar limb in both quiet and active regions (slit parallel to the limb)
- at IRSOL, Locarno
- during 8 days
- in the period 31 Mar 2006 – 13 Mar 2007
- with ZIMPOL

- **Telescope:** Gregory - Coudé, evacuated
  - Diameter of primary mirror: 45 cm
  - Total focal length: 25 m
- **Spectrograph:** Czerny - Turner
  - focal length: 10 m
  - grating 18 cm × 36 cm
  - 300 lines / mm
  - blaze 63°

ZIMPOL polarimeter

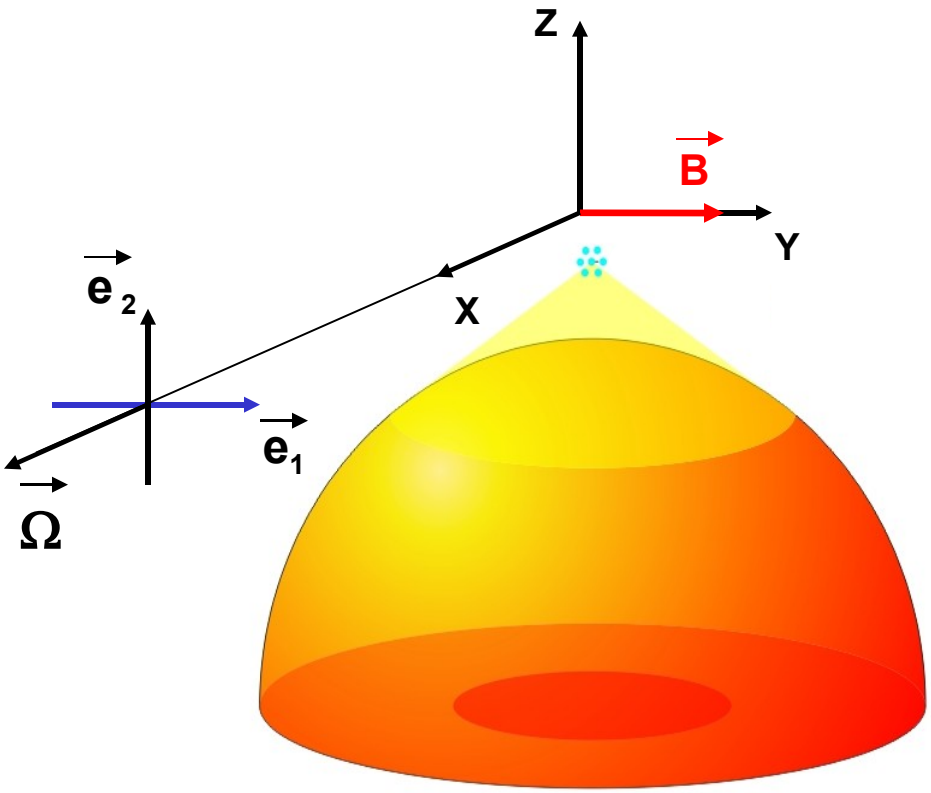
- ZIMPOL2-polarimeter ***(Zurich Imaging Polarimeter,*** developed at ETH-Zurich) allows precise full Stokes measurements free form seeing induced spurious effects (modulation 42 kHz).
- Polarimetric accuracy depends primarily on photon statistics. 10^{-5} level can be reached with long exposure time.



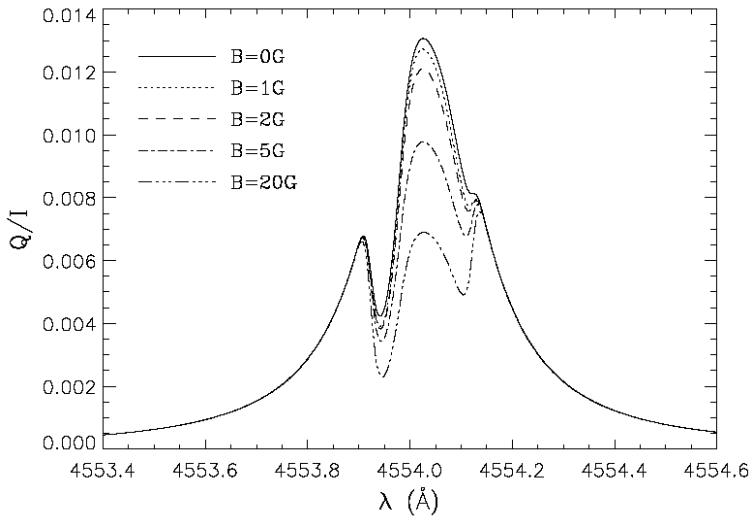
ZIMPOL 2 - setup

3. Theoretical model versus observations

Horizontal magnetic field perpendicular to the line of sight

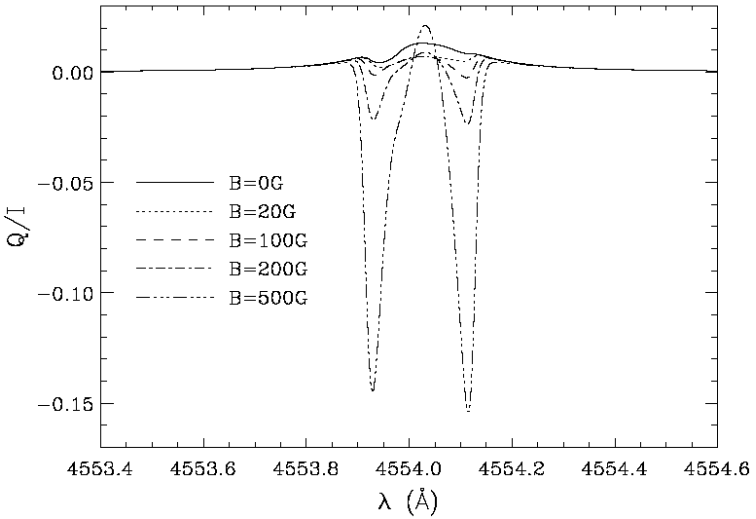


Theoretical model



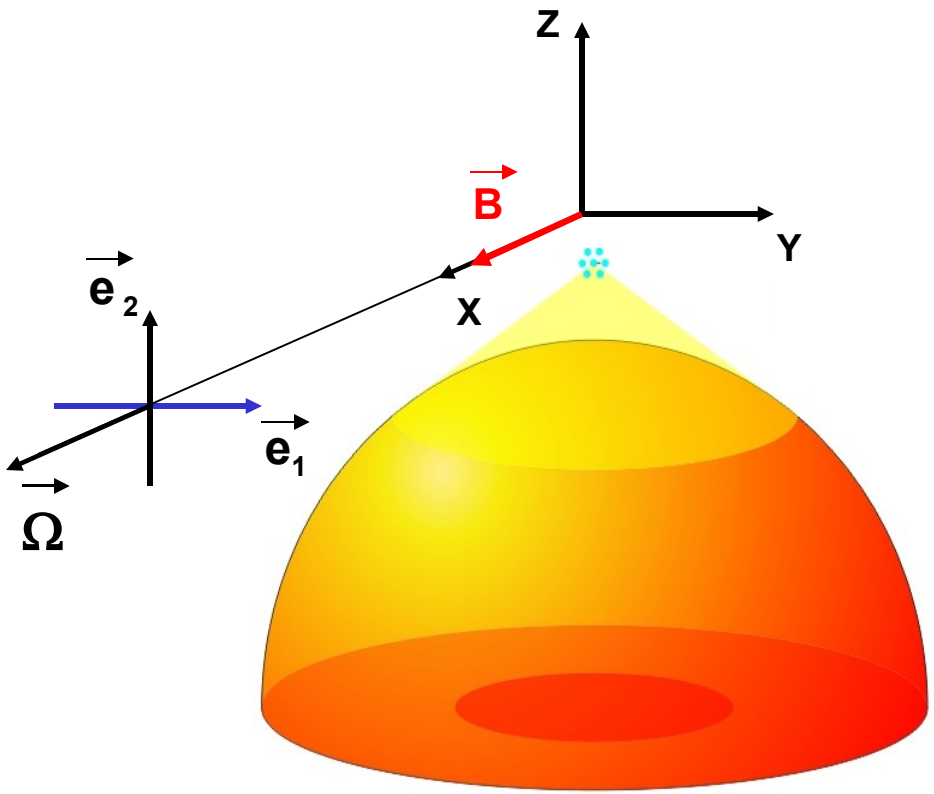
Horizontal field, perpendicular to the line of sight

0 < B < 20 Gauss
→ line core: the linear polarization of the scattered radiation decreases with the magnetic field in the line core (Hanle effect)
→ peaks of the wings unaffected



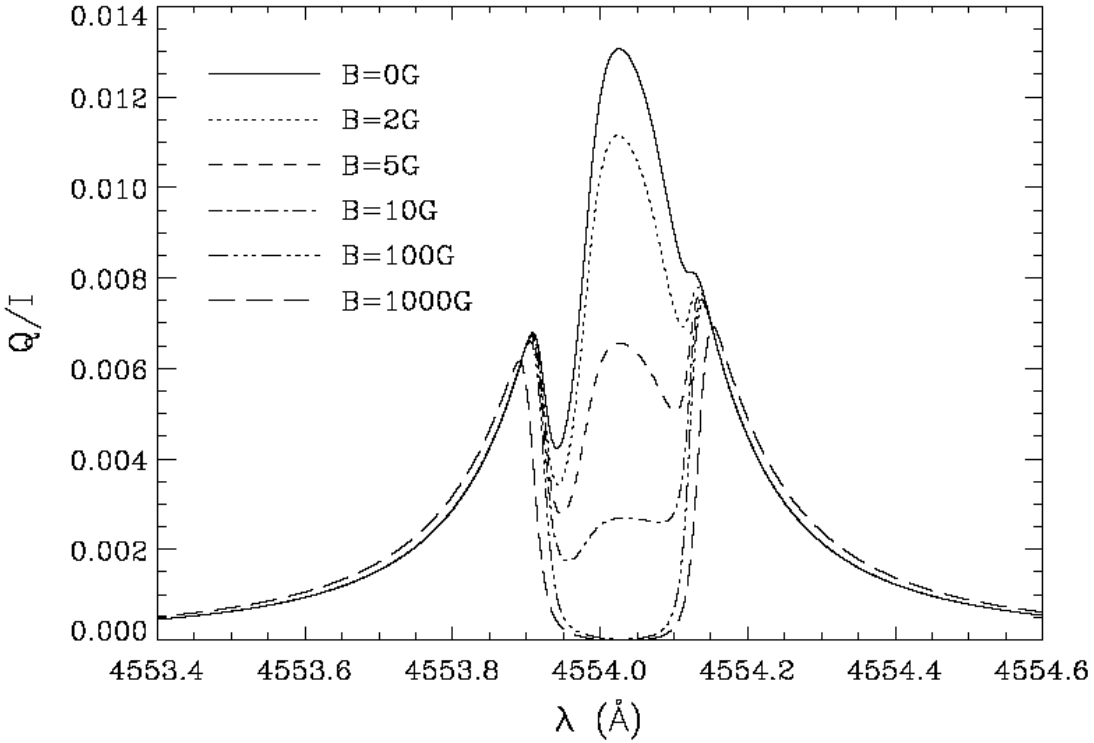
B>100 Gauss → the polarization is dominated by the tranverse Zeeman effect.

Horizontal magnetic field directed along the line of sight



Horizontal field, directed along the line of sight

Theoretical model



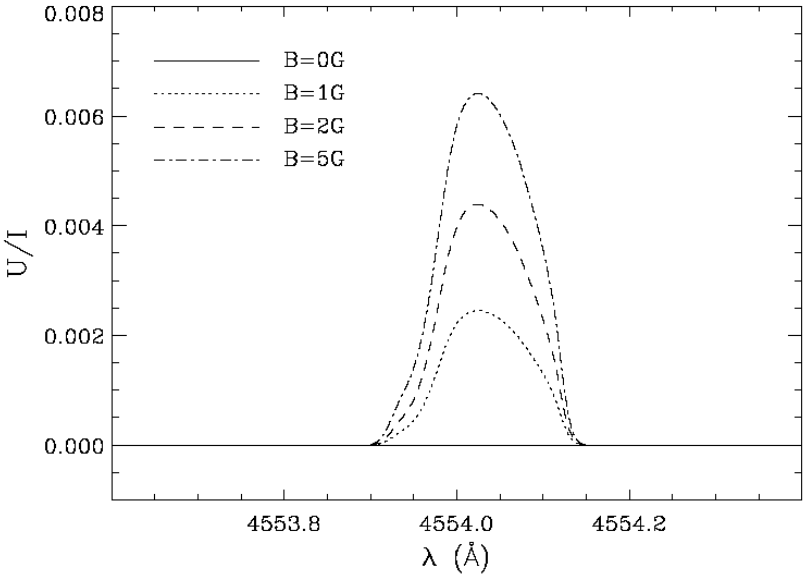
1<B< 100 Gauss
decrease of the linear polarization in the line-core due to the Hanle effect (no contribution to the linear polarization comes from the Zeeman effect).

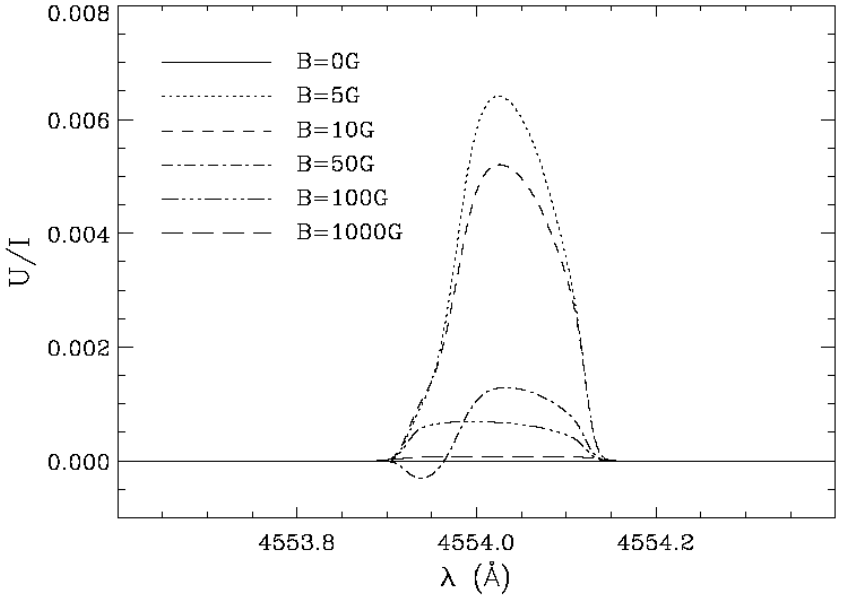
B>100 Gauss
regime of saturation.

Wings unaffected by the magnetic field.

Horizontal field, directed along the line of sight

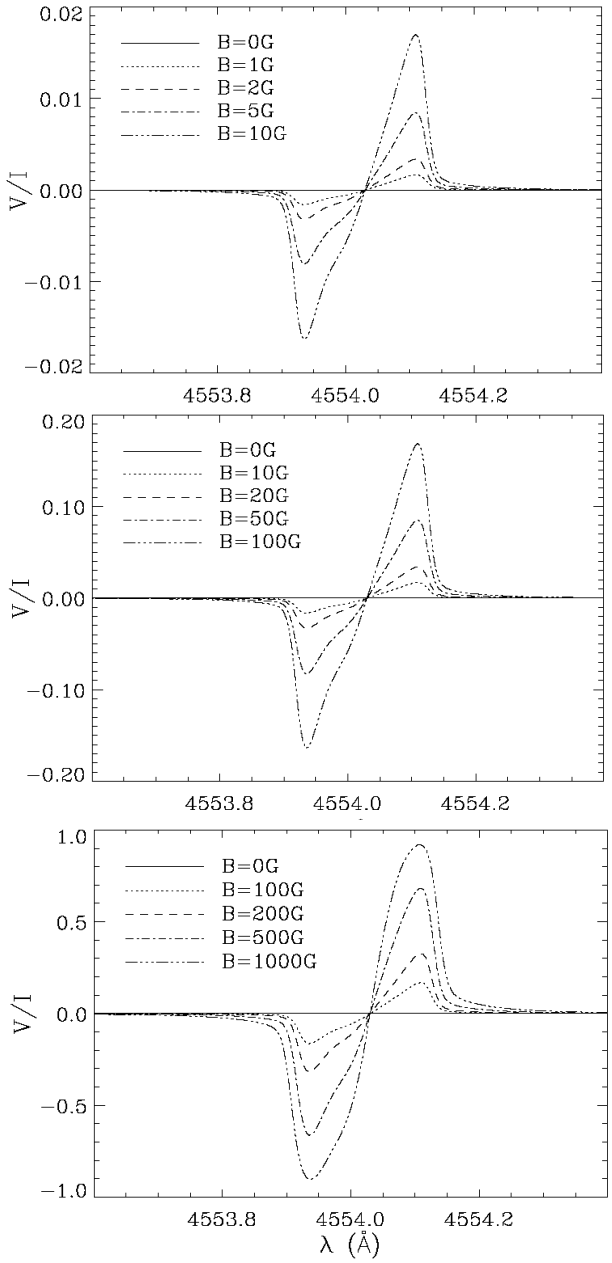
Stokes U





Maximum at B ~ 5 Gauss

Horizontal field, directed along the line of sight



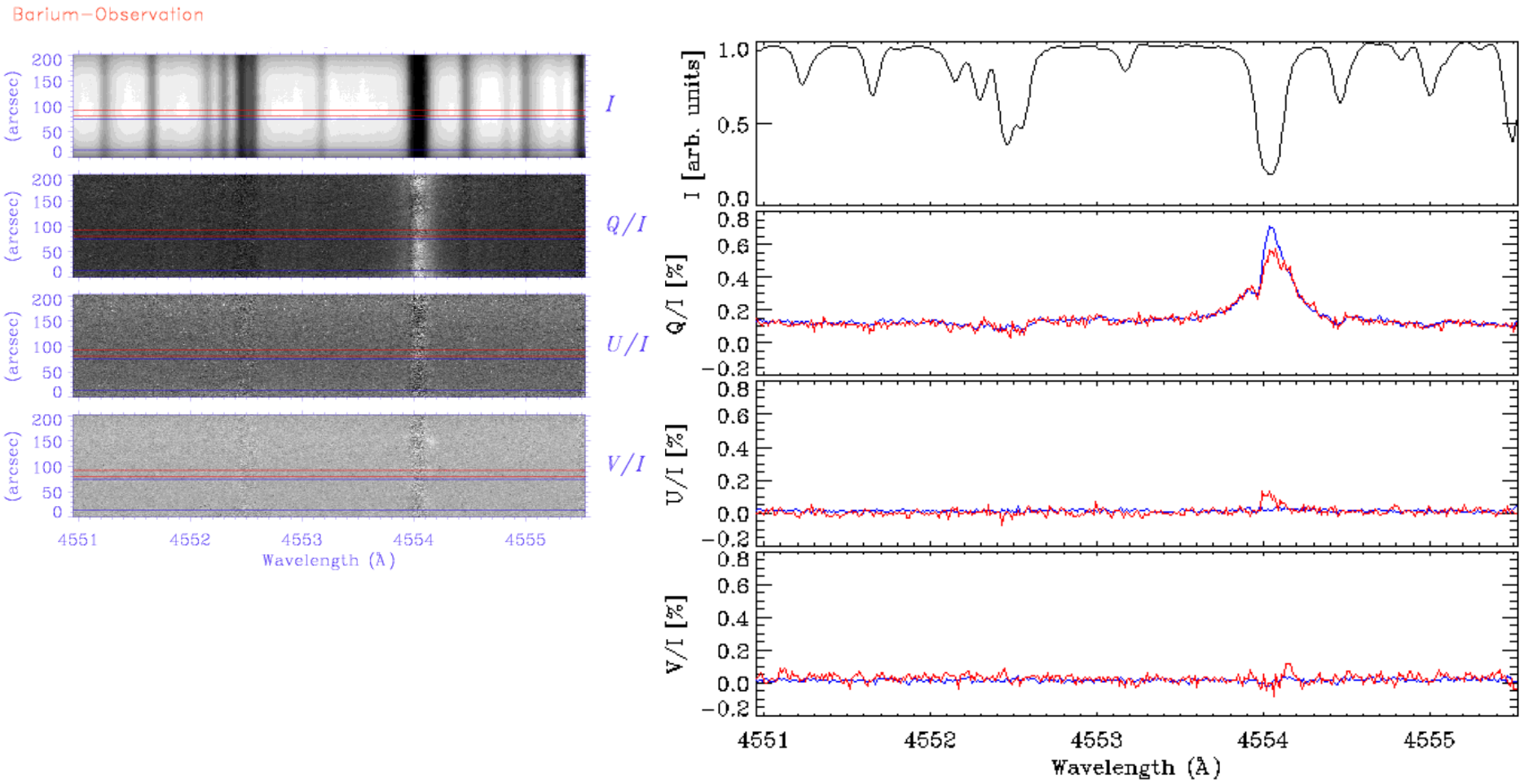
An antisymmetric V/I profile appears in the presence of a horizontal magnetic field directed along the line of sight (longitudinal Zeeman effect).

0 < B < 100 Gauss
the signal increases almost linearly with the magnetic field

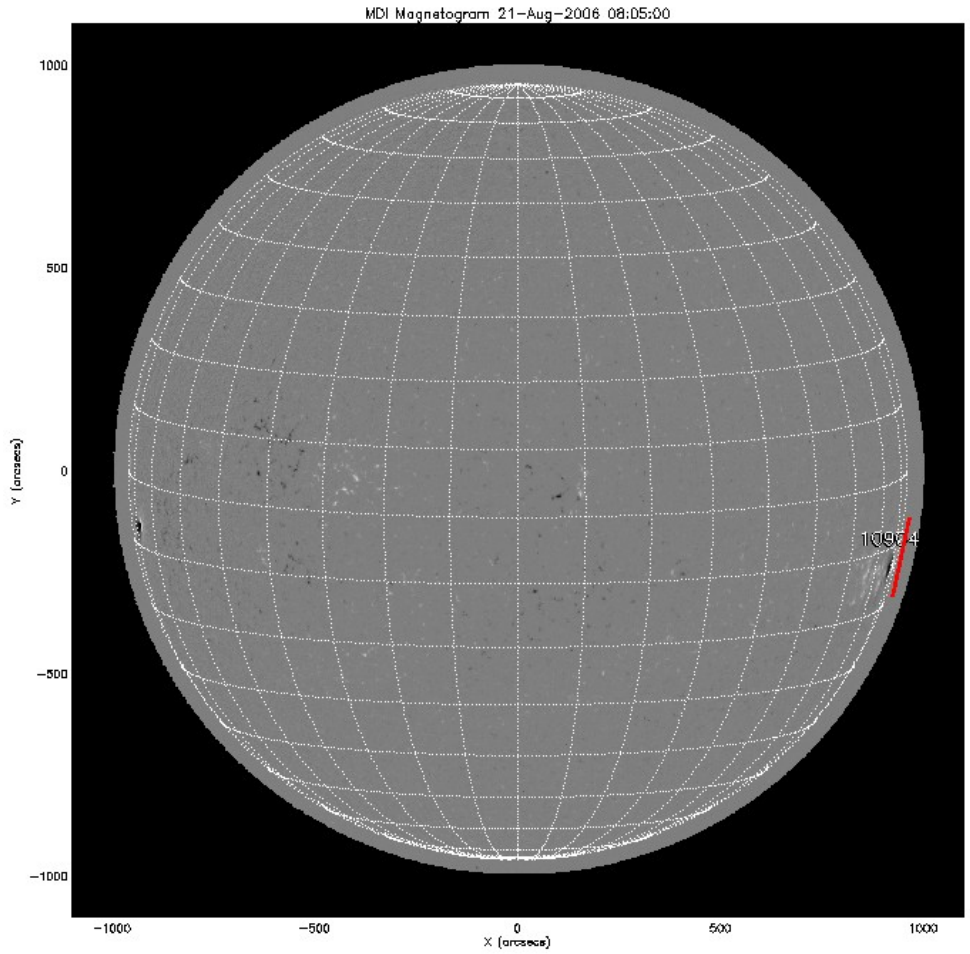
Note that, besides the longitudinal Zeeman effect, there is also a small contribution to V due to the alignment to orientation conversion mechanism (presence of orientation in the upper levels of the transition).

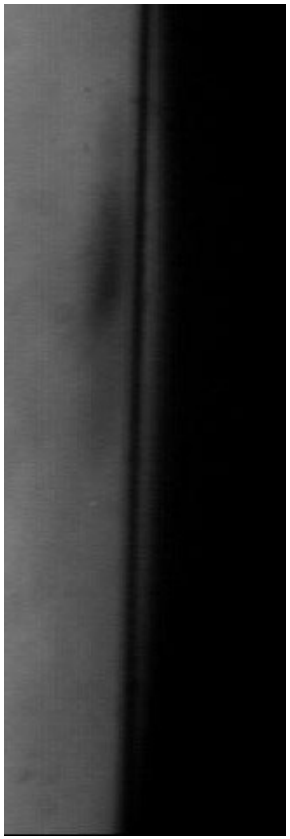
Observation at the North Pole limb

(15 August 2006)



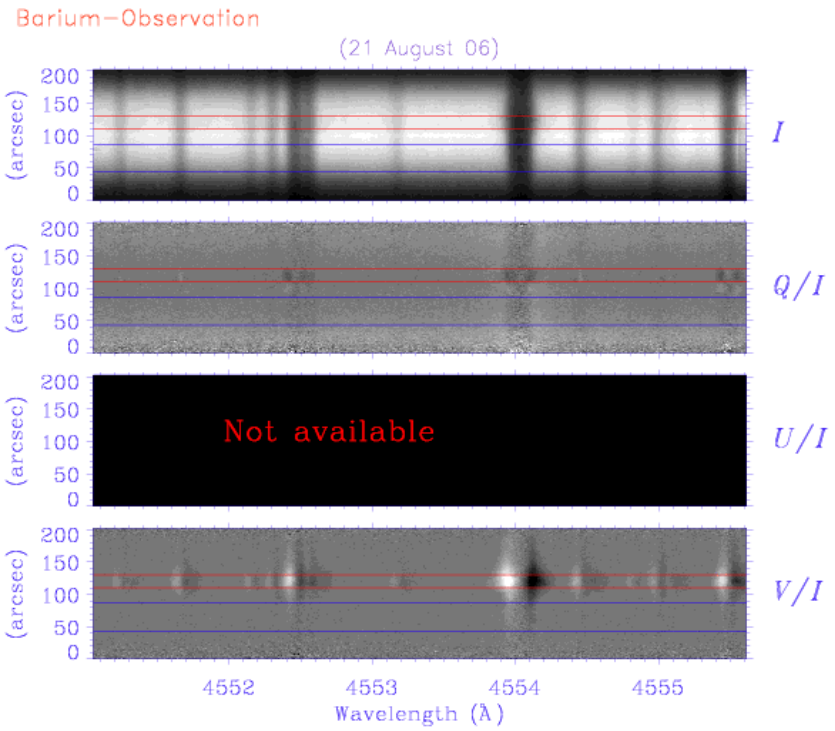
Observation at the limb above a Sunspot (21 August 2006)

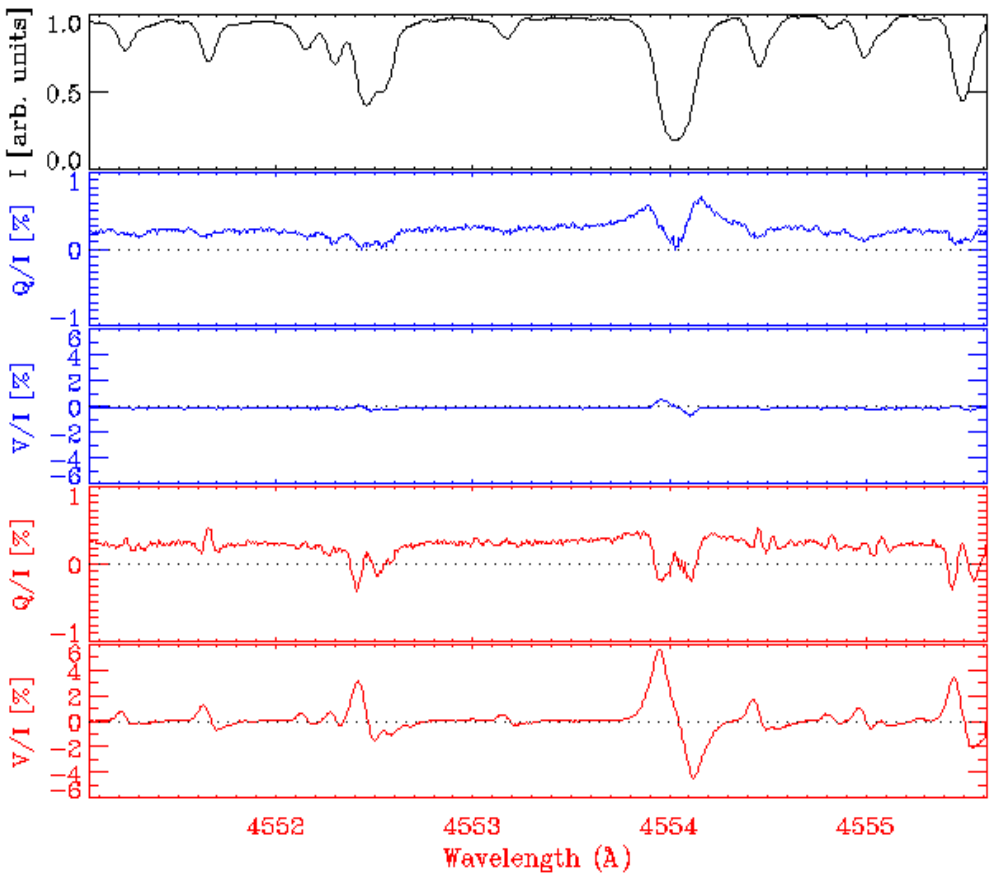




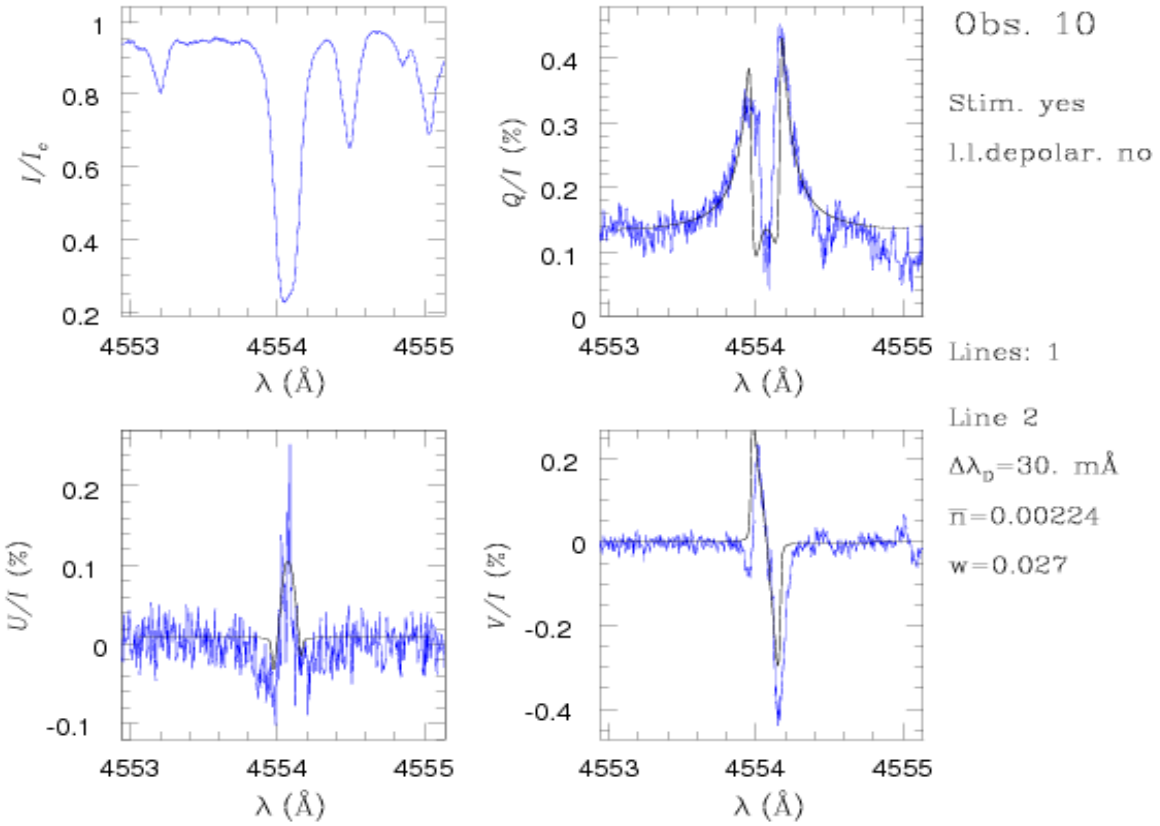
Slit jaw image

Observation at the limb above a Sunspot
(21 August 2006)





Fit with the theoretical profile



Scatter direct.
θ=82.15°
χ=0.°
γ=90.°

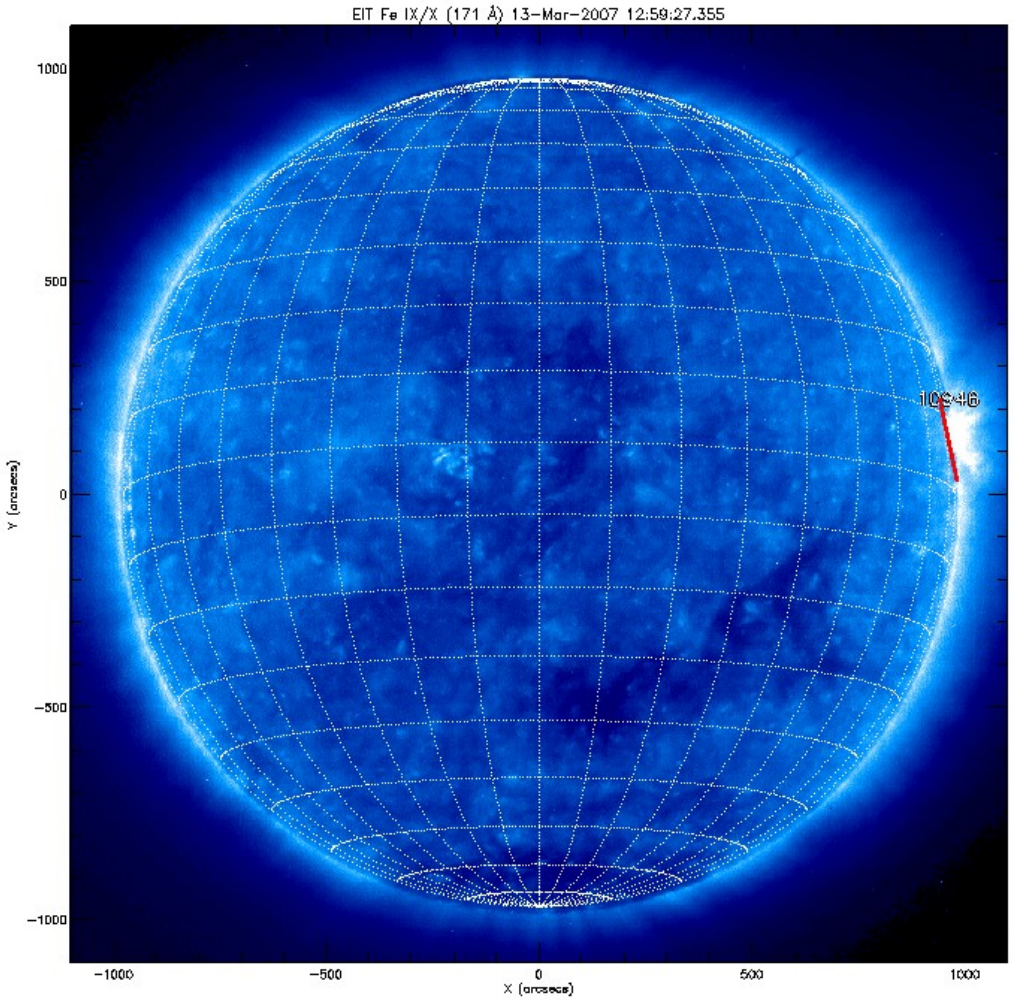
Determ.m.f.
B=28.24 G
θ_B=63.42°
χ_B=98.1°

B_x=−1.8 G
B_y=25. G
B_z=13. G

$\varepsilon_I^c/\varepsilon_I^{max}$=0.0002
$\varepsilon_Q^c/\varepsilon_I^{max}$=2.6E−07
$\varepsilon_U^c/\varepsilon_I^{max}$=2.E−08
$\varepsilon_V^c/\varepsilon_I^{max}$=0.

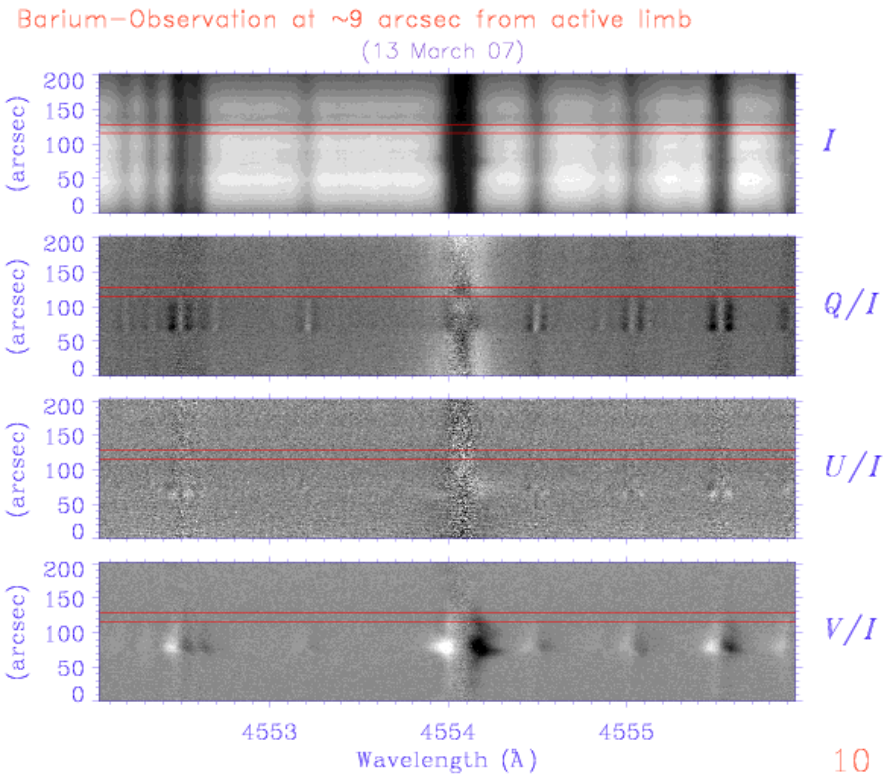
R.Ramelli et al., SPW5 Ascona, 17 September 2007

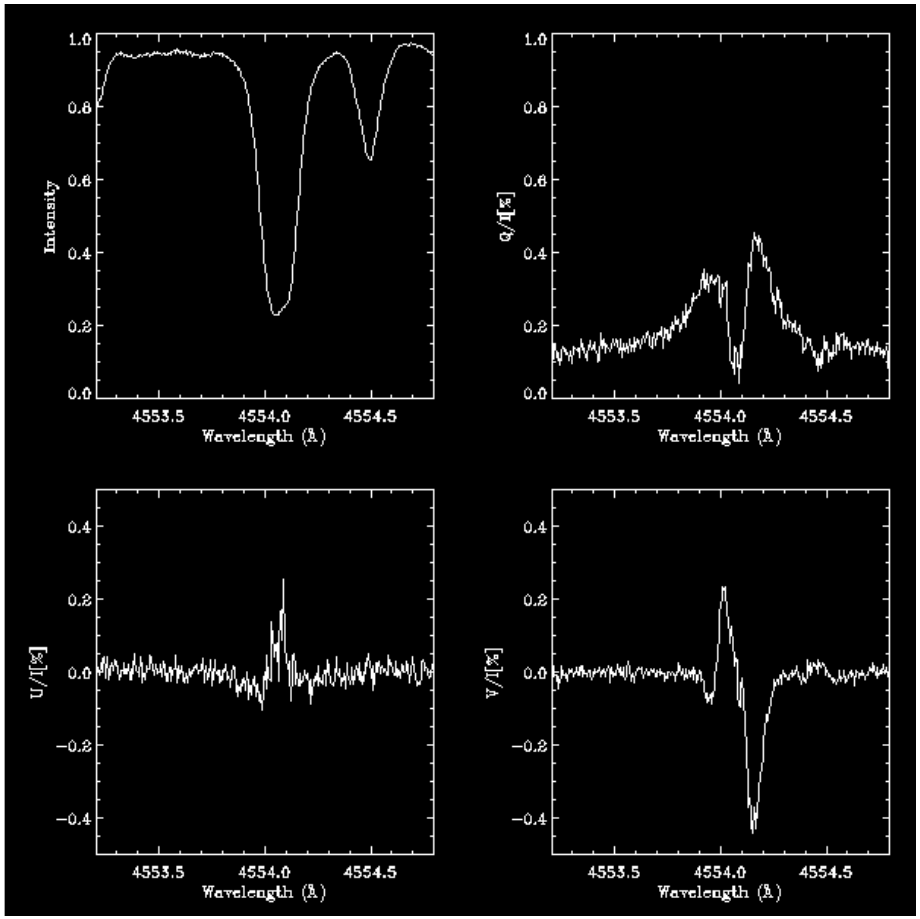
Observation at active limb (13 Mar 2007)



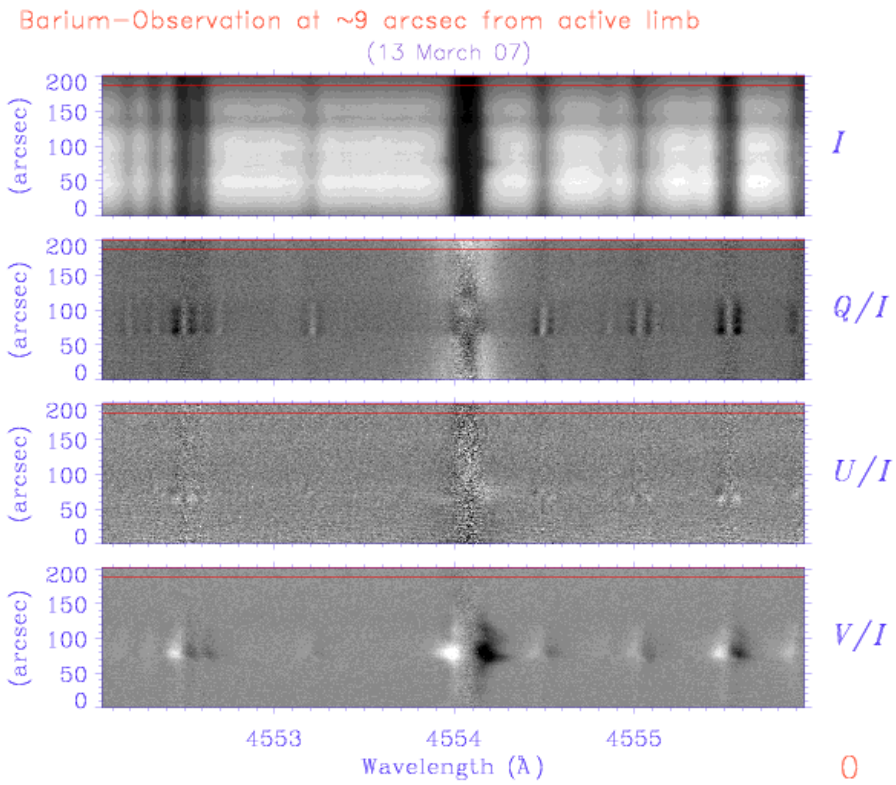
(Measurement of ~ 3 hours)

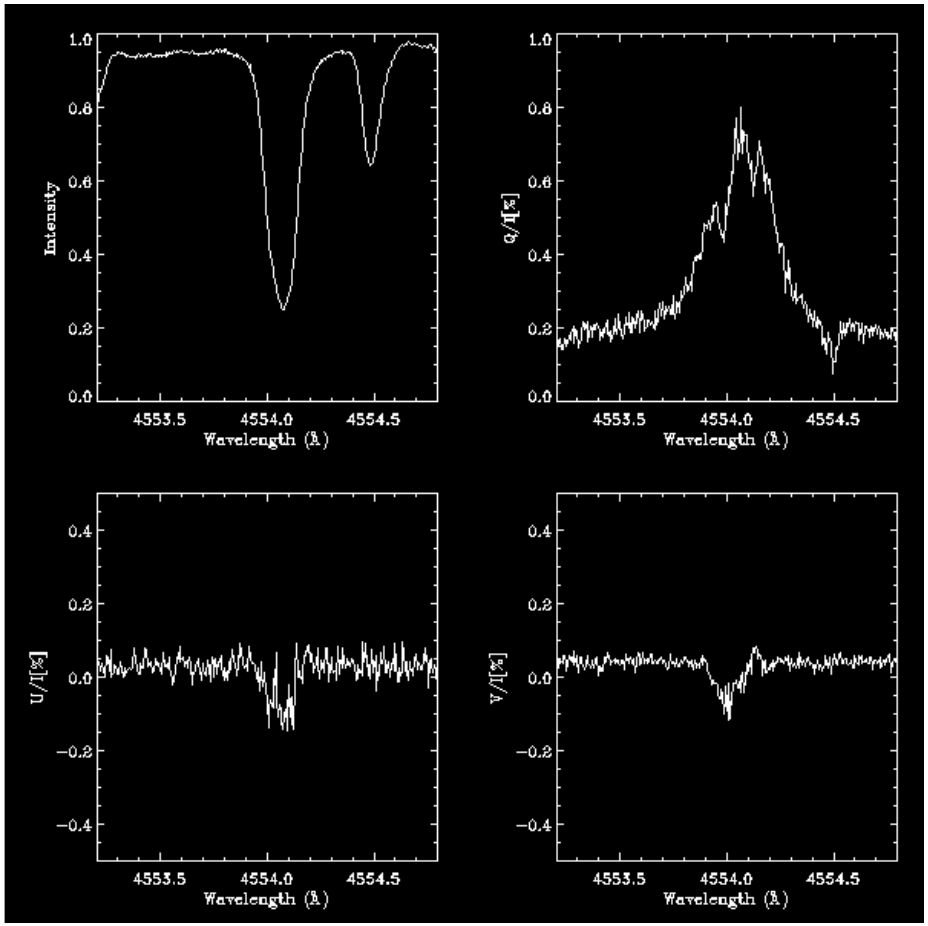
Observation at active limb (13 Mar 2007)





Observation at active limb (13 Mar 2007)





4. Conclusion

- Our observations of the Ba II D_2 line can be well described by the theoretical model of Belluzzi et al.
- The Ba II D_2 spectropolarimetric observations open a new window for magnetic field diagnostics in the solar photosphere and chromosphere (different behaviour of the central and the wing components)
- Future: 2D spatial polarimetric imaginig (with Fabry-Perot)