Proposed research work :

Title : Magnetic energy density of the quiet solar photosphere : what can we learn from the SrI 460.7 nm line ?

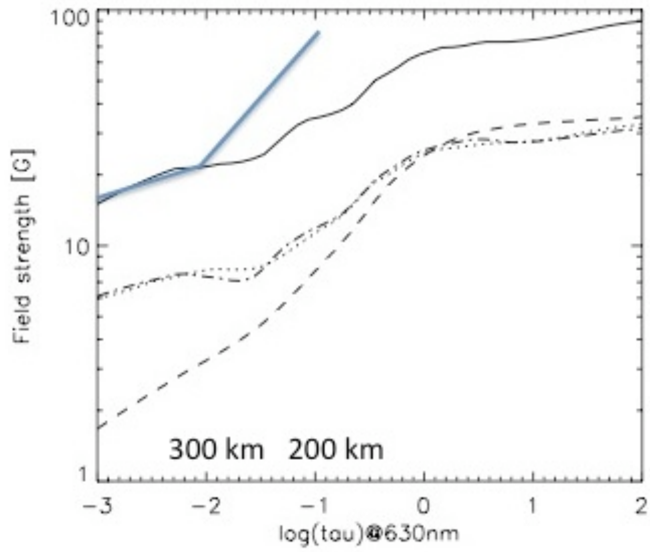
1- Context

This proposal is part of a broader project related to the investigation of magnetic fields in the quiet solar photosphere and chromosphere by means of their Hanle effect. Here we shall focus on the magnetic energy content of the quiet solar photosphere which is a crucial quantity, presently badly constrained by the observations.

More than 95% of the volume of the quiet photosphere is probably filled with turbulent magnetic fields with mixed polarity at small scale (i.e . on a scale that is smaller than a typical photon mean free path). But magnetograms based on the Zeeman effect are blind to such small scale fields because the Zeeman polarization is cancelled out. However, the Hanle effect does not vanish, it is thus a unique diagnostic tool in such cases. Spectral lines formed by scattering of photons in dilute layers of the solar atmosphere show a linear polarization in the absence of magnetic field . But in the presence of weak fields, if the magnetic splitting of the magnetic sub-levels remains on the order or smaller than their natural width, scattering polarization is modified by the so-called Hanle effect. If the weak fields have mixed polarity at small scale, their Hanle effect is detected as a line depolarization, depending on the quadratic mean of the magnetic strength, thus related to the magnetic energy density.

In Milic & Faurobert (2012b, PaperI) we have performed an inversion of the linear polarization observed at 9 different limb-distances in 2 lines of C2 and one MgH line, in quiet regions of the solar disk, to put constraints on the depth-dependence of the magnetic energy density. We used observations obtained at Themis in 2000 (Faurobert & Arnaud, A&A 2002, 2003). We developped a new way of interpreting « old » data, by combining observations in lines of different molecules with different sensitivity to the Hanle effect, and by introducing directly in the atmospheric model a depth-dependent turbulent magnetic field. This had never been done before. We found that the quadratic mean magnetic strength decreases strongly from 90 Gauss at 200 km to 10 Gauss at 400 km above the base of the photosphere. This is a quite new result which is indeed very important.

Presently, 3D MHD simulations of the magneto-convection in the quiet sun (Voegler & Schuessler 2008) show a decrease of the magnetic energy density with height but with a much smaller gradient. Our results then seem to indicate that some important physical mechanisms are missing in the present simulations.



Mean magnetic strength in the photosphere
____: MHD simulations (Voegler & Schuessler, 2008)
Blue line: inversion results (Milic & Faurobert, 2012b)

2- Proposed work

In this proposal, we wish both to confirm and to extend the investigations on the behaviour of the turbulent mean magnetic strength in the quiet solar photosphere. We propose to extend the inversion method developped in PaperI to the interpretation of the center-to-limb variations of the linear polarization in the SrI line at 460.7 nm. This line shows a nice linear polarization peak when observed in the quiet Sun. As it is stronger than the molecular lines that were used in Paper I, it is formed in relatively deeper layers and its polarization may be measured at larger limb-distances. It will thus provide us with constraints on the behaviour of the mean strength of turbulent magnetic fields below and above 200 km.

2-1 Observations

This line has been extensively observed at Themis, and on different solar telescopes. We shall use Themis observations obtained in 2000 (Faurobert et al. 2001), and in June 2012. In June 2012, the instrument had been significantly improved, with better detectors and a better polarimeter, furthermore a tip-tilt mirror stabilizes the images at the solar limb.

The new observations are reduced with an IDL package provided by A. Lopez-Ariste (DeepStokes, Themis). The student will get familiar with the reduction procedure.

2-2 Polarized line formation in a 1D quiet sun model

We need to solve consistently the statistical equilibrium equations of the atomic levels and the radiative transfer equations in the lines of interest. As the polarization remains on the order or smaller than a few percents, the line intensity and the population of the atomic levels may be first computed neglecting the polarization as in a standard non-LTE problem. We shall use the code MULTI (Carlsson,) for this firts step.

Then we shall compute the linear polarization in the line, in the presence of the Hanle effect, with the Scattering Expansion Method introduced in Frisch et al. (2009). In these computations we will take into account the depolarizing effect of a depth-dependent turbulent magnetic field.

2-3 Inversion method

The values of the quadratic mean of the turbulent magnetic field strength at 3 or 4 height points in the photosphere will be considered as free parameters, and we shall assume that the quadratic mean varies linearly between these points.

A simplex minimization procedure can be used as in PaperI, in order to find the best values of the parameters according to the observed polarization rates in the SrI line.

3- Perspectives

A full investigation of the depth-dependence of the magnetic energy in the solar atmosphere, from the photosphere up to the chromosphere can, in principle, be carried out by using different lines formed at various altitudes. At Themis we also observed the center-to-limb variations of the linear polarization in the NaD2 line at 589 nm and in the BaII D2 line at 455.4 nm. These lines can give access to the upper photosphere and to the low chromosphere, respectively.

The non-LTE line formation processes, however, are more complexe, as far as polarization effects are concerned, because of fine levels interferences in the NaD2 line and hyperfine structure effects in the BaII one. This is, of course, out of the scope of a short-term project, but could be proposed as a PhD work.