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SOLAR RESEARCH PROGRAMS AT IRSOL, SWITZERLAND

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Abstract. The Zurich IMaging POLarimeter (ZIMPOL) developed at ETH Zurich and installed permanently at the Gregory Coudé Telescope at Istituto Ricerche Solari Locarno (IRSOL) allows a polarimetric precision down to 10^{-5} to be reached. This makes it possible to perform several accurate spectro-polarimetric measurements of scattering polarization and to investigate solar magnetic fields through the signatures of the Hanle and Zeeman effects. The research programs are currently being extended to monochromatic imaging of the Stokes vector with a recently installed Fabry-Perot rapidly tunable filter system with a narrow pass band of about 30 mÅ. The spatial resolution is being improved by the installation of an Adaptive Optics system.

Key words: solar physics, polarimetry, magnetic fields

1. Introduction

The great advances in high precision polarimetry that have been achieved with the introduction of the Zurich IMaging POLarimeter (ZIMPOL) a decade ago opened a new window in solar physics. Polarimetry is in fact a very powerful tool that can be used to study solar magnetic fields as well as the physical processes behind the generation of polarization in atomic and molecular spectral lines. Magnetic field measurements through Zeeman effect signatures, which appear in the presence of strong and oriented magnetic fields, have long been performed at many observatories. With the high polarimetric precision of ZIMPOL it has become possible to extend the magnetic field diagnostics to weak fields and to fields which are tangled on scales below the spatial resolution, which are invisible to the Zeeman effect but get revealed by the Hanle effect (Hanle, 1924) (for details see Trujillo Bueno, 2006).

Spectro-polarimetry is currently the main field of research at the Istituto Ricerche Solari Locarno (IRSOL). Advantage is taken from the circumstance that a ZIMPOL system is permanently installed at IRSOL. In addition the Gregory Coudé Telescope (GCT) of the observatory is very well suited for polarimetric measurements, since the amount of instrumental polarization is low and stays practically constant during the observing day, since it is a function of declination only. Therefore it can easily

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Fig. 1. IRSOL Observatory. In the left part of the building there is the observing room, while the spectrograph room is underground. All is painted white with titanium dioxide. The institute is located 500 m above sea-level, above the city of Locarno, Switzerland.

be accounted for. With a Fabry-Perot filter system and an adaptive optics system recently installed at IRSOL we plan to start several new interesting projects.

2. IRSOL - The Institute

The observatory at the Istituto Ricerche Solari Locarno (IRSOL) (Figure 1), located in southern Switzerland, was constructed in 1960 by the Universitäts-Sternwarte Göttingen (USG), Germany. In 1984, after USG moved its observing activity to the facilities at Observatorio del Teide on Tenerife, a local foundation (FIRSOL) acquired the observatory in Locarno. The partially dismantled instrumentation was rebuilt and improved, in collaboration with USG, University of Applied Sciences of Wiesbaden (Germany), and the Institute of Astronomy at ETH Zurich. The scientific collaboration with ETH Zurich allowed the implementation at IRSOL of an important polarimetry observing program, first with a beam exchange polarimeter and then with ZIMPOL.

3. Instrumentation at IRSOL

The IRSOL telescope (Figure 2 and 3) is a 45 cm aperture Gregory Coudé with 24 m effective focal length. The field stop at the prime focus reduces the field of view to a 200 arcsec diameter circular image. The rest of the solar image is reflected away from the main light beam. This reduces heating and scattered light and is of particular advantage when observing low intensity structures like sunspots, spicules and prominences. The relative orientation of the two folding mirrors M3 and M4 (Coudé) changes only with declination and is orthogonal at the time of the equinoxes. As a consequence the instrumental polarization, originating through oblique reflections, is almost constant during the day and virtually vanishes during the equinoxes (Sánchez *et al.*, 1991). A Gregory Coudé telescope is thus very well suited for polarimetric measurements.

Fig. 2. The 45 cm aperture Gregory Coudé vacuum telescope.

An automatic guiding system developed by the University of Applied Sciences Wiesbaden (Küveler *et al.*, 1998) is also available. Its operation is based on the solar image obtained from the light rejected by the field stop at the primary focus.

The Czerny-Turner spectrograph with 10 m focal length is based on a 180×360 mm grating with 300 lines per mm and 63° Blaze angle. A prism based predisperser allows to select the spectral band entering in the spectrograph without overlap of the grating orders.

Monochromatic imaging observations of the solar surface can be performed using the recently installed Fabry-Perot filter system in collimated configuration (Feller *et al.*, 2006) (Figure 4). The system uses two temperature controlled lithium niobate etalons with an aperture of 70 mm. The transmitted wavelength can be selected by electrically tuning the refractive index of the etalon medium, by varying the temperature, or by tilting the etalon. The bandwidth is about 30 mÅ.

An adaptive optics (AO) system based on a tip-tilt mirror and a 37 actuator deformable mirror is currently being installed and tested in collaboration with the University of Applied Sciences of Southern Switzerland, SUPSI, and with ETH Zurich. The system follows the design of the infrared AO system installed at the McMath-Pierce Solar Telescope at Kitt Peak (Keller *et al.*, 2003). The first tests made with the tip-tilt mirror have already given good results (see Figure 5).

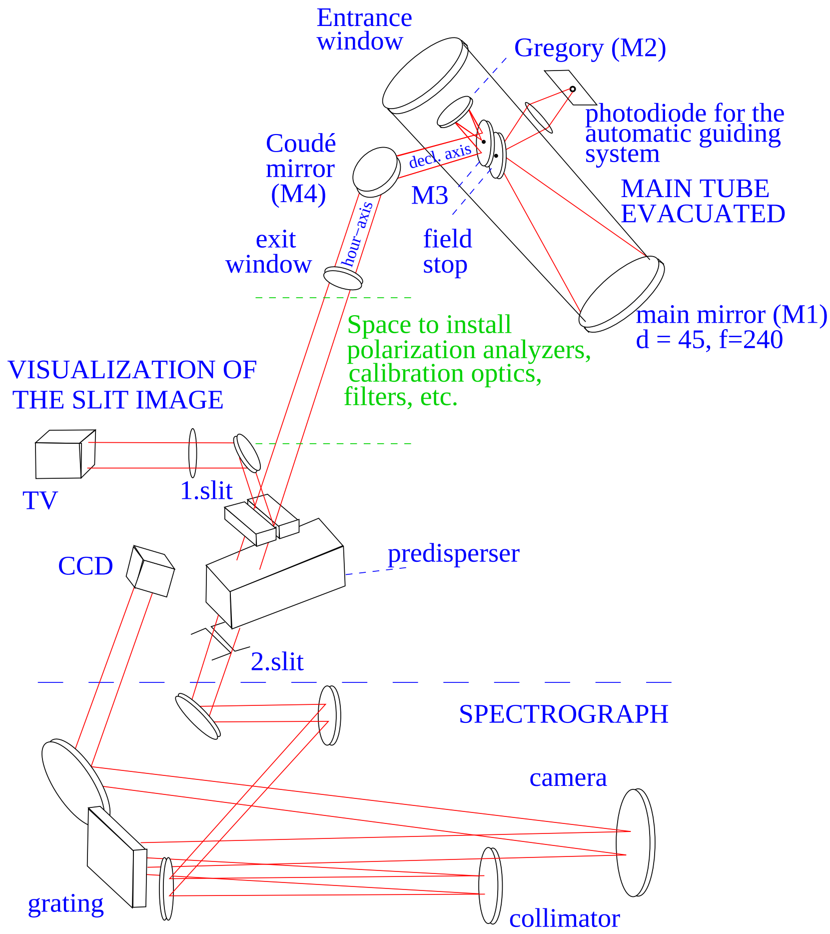

Fig. 3. Optical scheme of the Gregory Coudé Telescope with the spectrograph.

Two polarimeters are available. The oldest one operating at IRSOL is the dual beam exchange device based on a Savart plate and rotating quarter and half wave retarder plates (Bianda *et al.*, 1998). A polarimetric precision of a few 10^{-4} can be reached, but it can be affected by seeing-induced cross-talk, because the technique requires two exposures taken at different times. The second polarimeter is ZIMPOL (Povel, 1995; Gandorfer *et al.*, 2004), which is installed permanently at IRSOL since 1998. Its main advantage is that it is free from seeing-induced effects thanks to its high modulation rate: 42 kHz (obtained with a piezoelastic modulator), or 1 kHz (obtained with ferro-electric liquid crystal modulators). Another advantage is that the same pixels of the CCD ZIMPOL sensor are used to measure all Stokes parameters. Therefore the Stokes Q/I, U/I and V/I images are not influenced by different pixel efficiencies. The ZIMPOL polarimetric accuracy depends mainly on

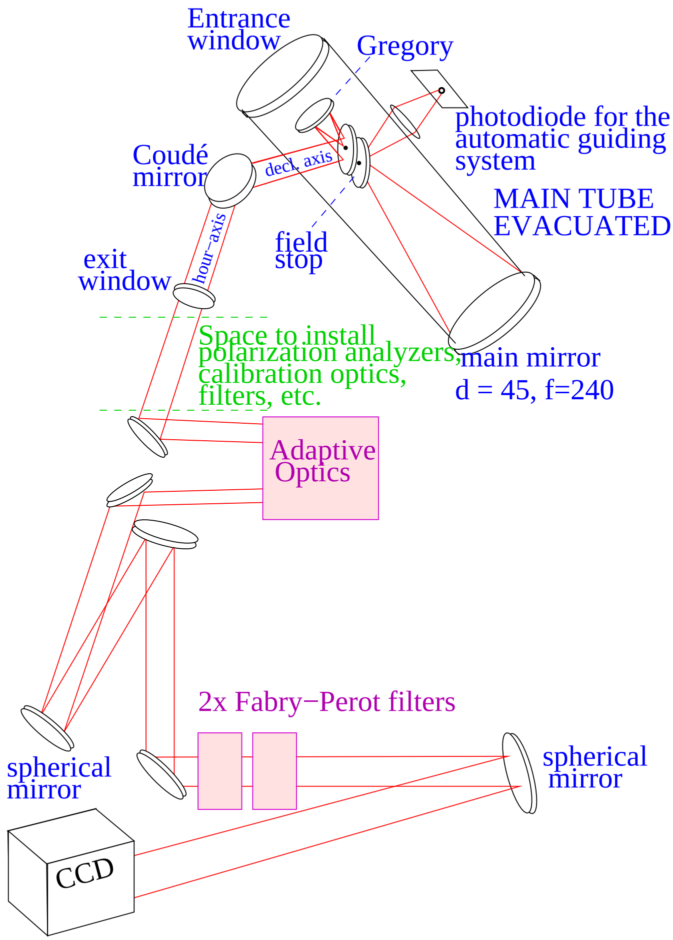

Fig. 4. Optical scheme of the Gregory Coudé Telescope for measurements with the Fabry-Perot filter system.

the photon statistics. With long exposure times it has already been possible at IRSOL to reach an accuracy of about 10^{-5}.

4. Scientific research projects at IRSOL

The research projects at IRSOL take advantage of the very good polarimetric and spectral accuracy of the instrumentation. A large amount of observing time is available to carry out monitoring measurements or for projects requiring long observing times (which cannot easily be done at large telescope facilities, where the observing time is shared by different research groups according to a predefined program). In addition it is possible to be very flexible with the programs to allow fast reaction to

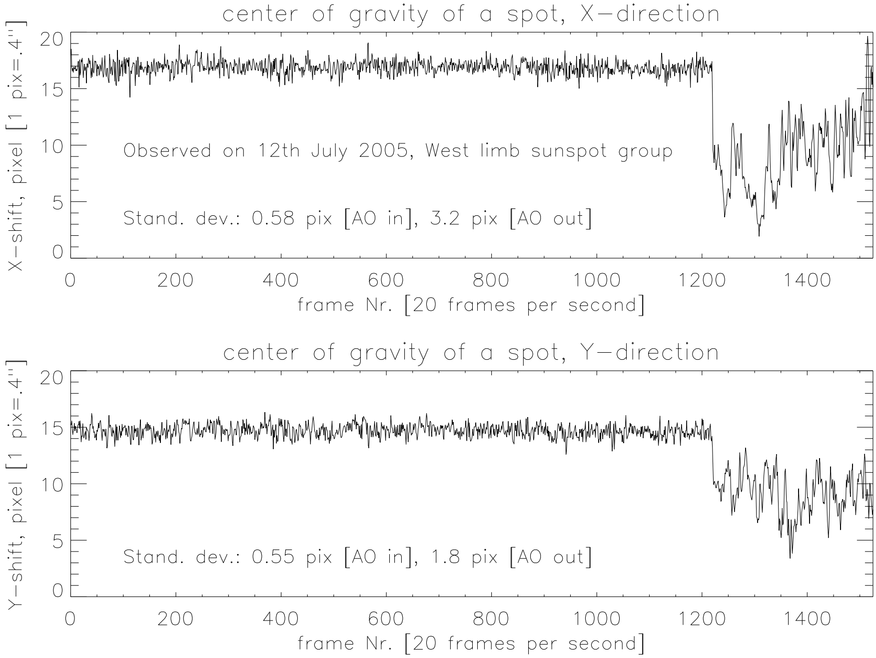

Fig. 5. First tests with the tip-tilt correction of the AO system. The two plots show the displacement of the barycentre of a sunspot in the x resp. y direction with and without tip-tilt correction. The tip-tilt mirror was switched off around frame number 1200.

particular solar events. The modular layout of the instrumentation inside the observing room is very convenient for installation and testing of new instrumentation.

Examples of the scientific results obtained at IRSOL in recent years are:

- Investigations of the Hanle effect in the quiet chromosphere (Bianda *et al.*, 1999).
- Publication of the first two volumes of the “Atlas of the Second Solar Spectrum” (Gandorfer, 2000; Gandorfer, 2002).
- Discovery of vast amounts of hidden magnetism in the solar photosphere (Trujillo Bueno *et al.*, 2004; Stenflo, 2004).
- Determination of novel constraints on impact polarization in solar flares (Bianda *et al.*, 2005).
- Measurements of full Stokes profiles in prominences in H_α (Figure 6), He D_3, H_β, and in spicules in He D_3 (Ramelli and Bianda, 2005; Ramelli *et al.*, 2005).
- First polarimetric measurements of the molecular Zeeman effect in several CH lines in the G band (Asensio Ramos *et al.*, 2004) and of the Paschen-Back effect in CaH transitions (Berdyugina *et al.*, 2006).

Different other observing programs are also foreseen in the future. They will focus on solar magnetism and polarimetry with the Fabry-Perot filter system or with the spectrograph. They also include synoptic type programs (eg. variations of the Hanle-effect signatures with heliographic latitude and solar cycle). Furthermore IRSOL is open to coordinated type programs with other observatories: simultaneous

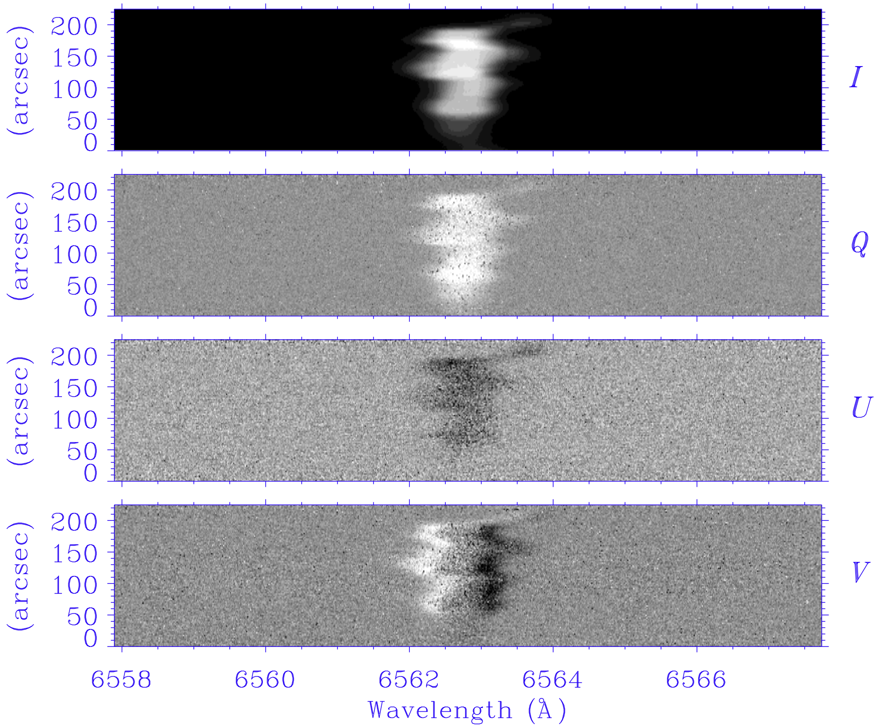

Fig. 6. Example of full Stokes spectro-polarimetric recording of an erupting prominence in H_α. The measurement was taken on 27th August 2004 at about 50 arcseconds form the limb.

observations of solar features with complementary sets of instruments or supporting type observations that complement the science of another project.

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