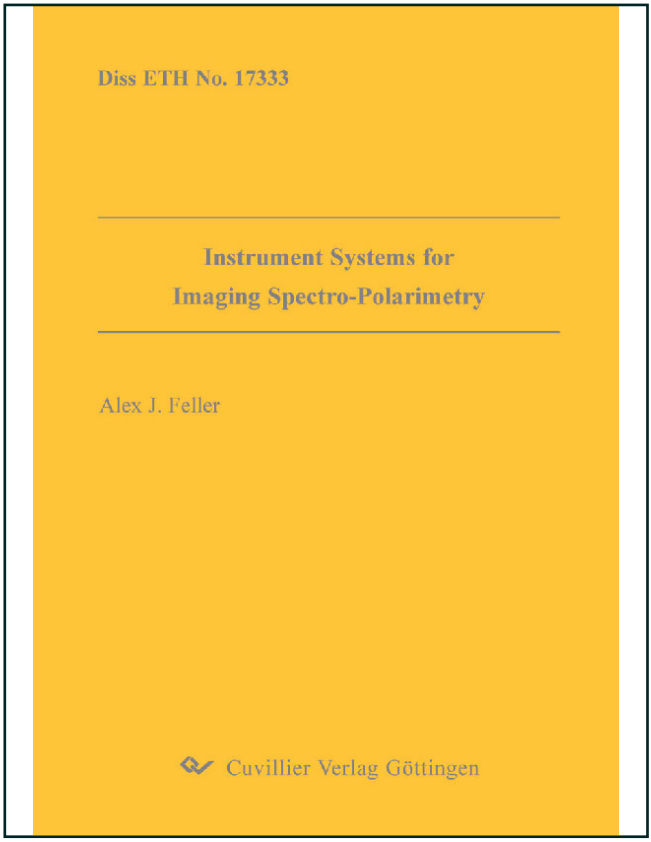
Instrument Systems for Imaging Spectro-Polarimetry



Chapter 1

Introduction

During the the last decade the Institute of Astronomy of ETH Zürich has developed the powerful CCD-based Zurich Imaging Polarimeter (ZIMPOL), described in detail by Povel (1995), Gandorfer et al. (2004) and Gisler (2005).

Until now ZIMPOL has mainly been used in combination with a spectrograph (cf. the review of Stenflo, 2004). Figs. 1.1, 1.2 and 1.3 show some results obtained with the current ZIMPOL II system at the spectrograph of the McMath-Pierce Solar Telescope on Kitt Peak (Arizona, USA).

The new tunable narrow-band filter (TNF) will allow us to combine high-precision polarimetry with monochromatic imaging, thus providing a new scientific dimension to our work with ZIMPOL. Prior to the development of the TNF a first promising exploratory attempt in this direction has been made with the Universal Birefringent Filter at the Richard B. Dunn Solar Telescope on Sacramento Peak (New Mexico, USA). These observations have provided a first glimpse of the type of data that may be obtained with ZIMPOL in monochromatic imaging mode (Stenflo et al., 2002).

The multi-beam interference theory has been derived by the French physicist Charles Fabry in 1890-1892. During the period 1896-1898 Fabry and his colleague Alfred Pérot developed the first type of interferometer which is named after them today. Their most important paper describing the interferometer has been published in 1897 (Pérot & Fabry, 1897) and was followed by many joint publications describing its applications in metrology, spectroscopy and astrophysics (e.g. Pérot & Fabry, 1899). The Fabry-Pérot (FP) interferometer, also frequently called *etalon*[1], exists nowadays in solar physics in two different versions. The *air-spaced* version, the original version of Fabry and Pérot, consists of two separate reflective plates and is tuned by

[1] The expression comes from the French word *étalon* which can be translated with "gauge" or "standard". We adopt here the English spelling *etalon* found in most publications. Sometimes the word etalon is only used for the crystal version of the interferometer. We will however use it for both versions, air-spaced and crystal.

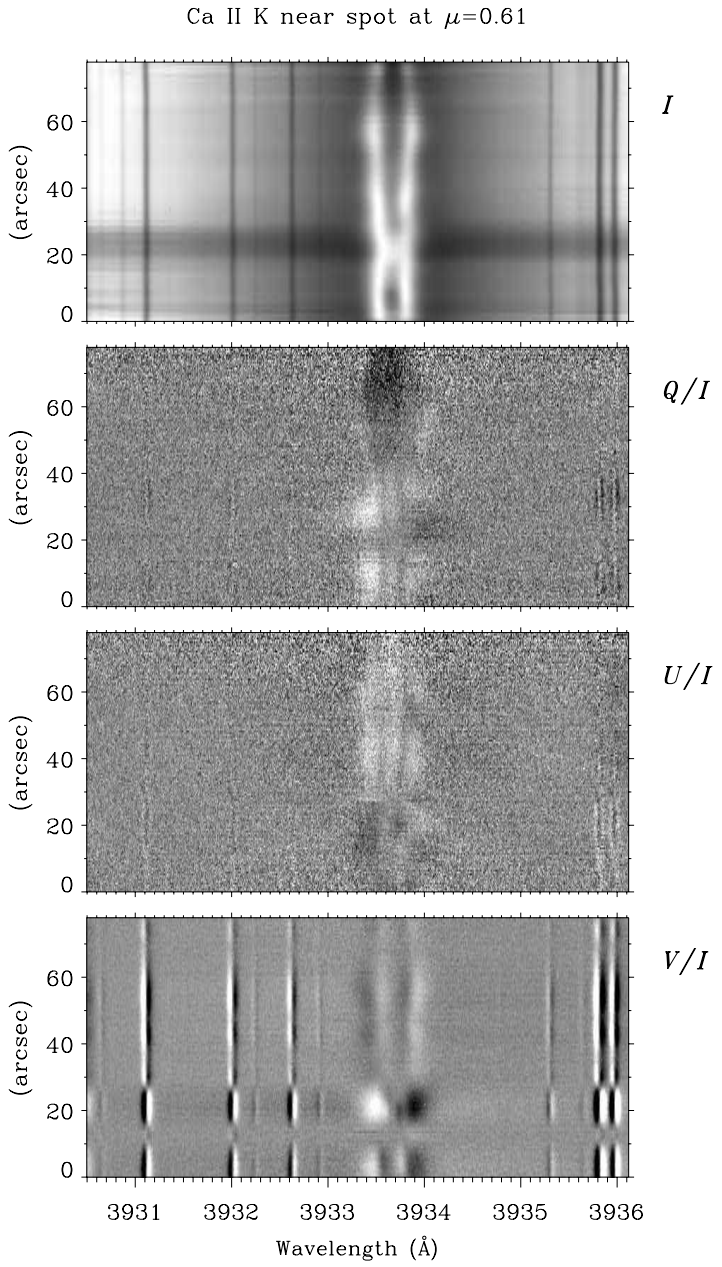


Fig. 1.1: Ca II K near spot (dark band in the I image, NOAA 10743). Limb distance $\mu = 0.61$. ZIMPOL, McMath-Pierce Telescope, March 11, 2005. Grayscales are ± 0.003 for Q/I and U/I, and ± 0.01 for V/I.

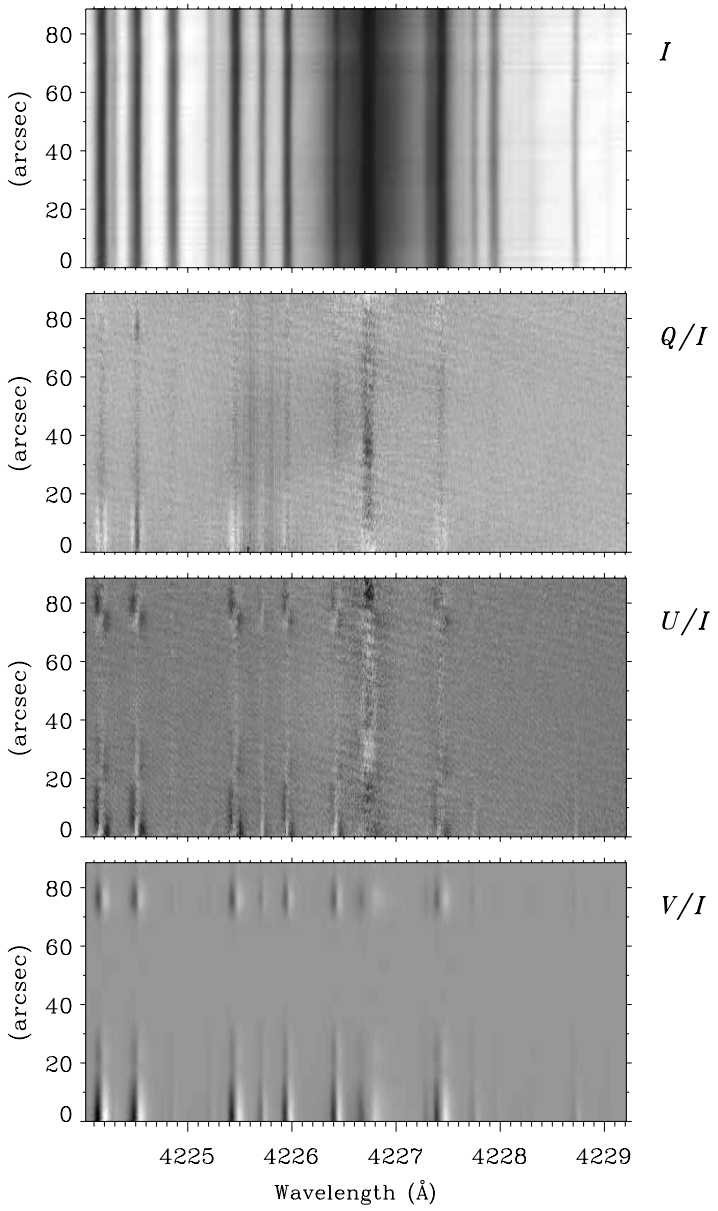


Fig. 1.2: Forward scattering and Hanle effect in Ca I. Measurement just below active region NOAA 10296, about 5 arcmin from disk center. ZIMPOL, McMath-Pierce Telescope, March 7, 2003.

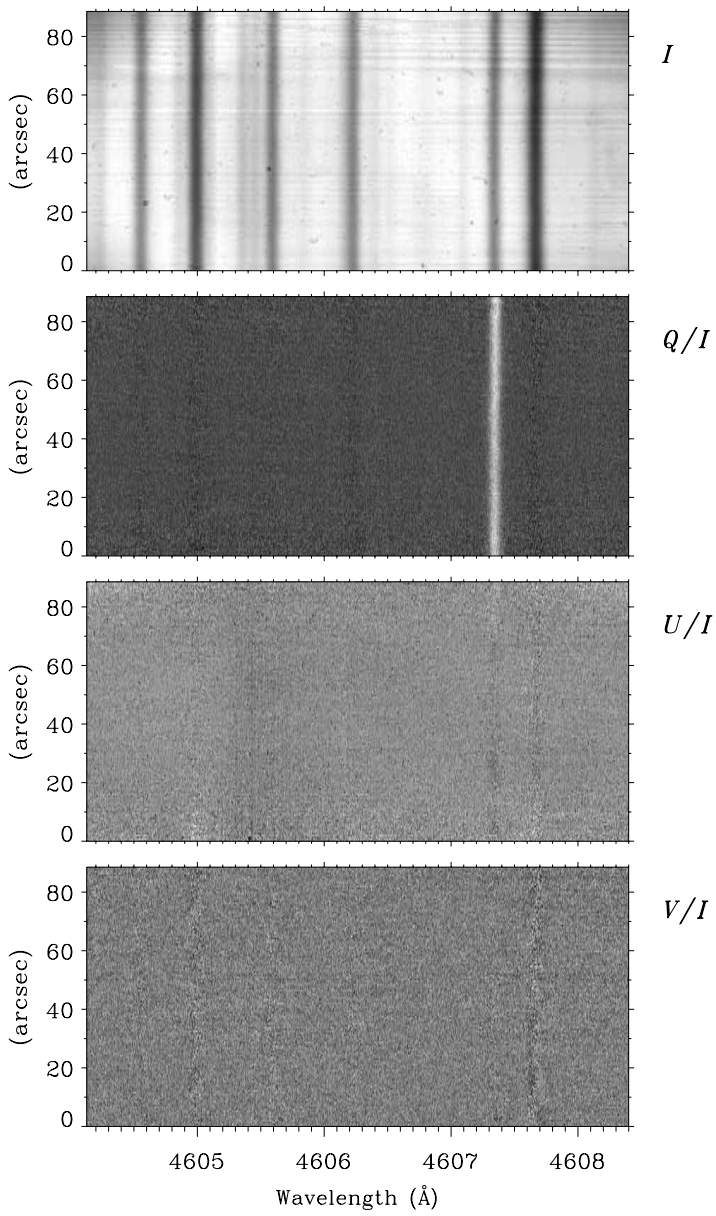


Fig. 1.3: Sr I, limb scattering at $\mu = 0.12$. ZIMPOL, McMath-Pierce Telescope, March 13, 2003. Q/I shows no spatial variations along the slit. One scientific goal for the new imaging polarimeter described in this part is to look for variations at the spatial scale of the granulation (1 arcsec) which is not resolved here.

varying the plate distance with the help of piezoelectric actuators. The *crystal* version consists of one piece of lithium niobate crystal, with polished and coated reflective surfaces. The tuning is done by varying the optical thickness of the crystal, either via thermal expansion or by altering the refractive index via an electrooptic effect.

During the last years, tunable narrow-band filter systems based on air-spaced Fabry-Pérot etalons have come into use at most major ground-based solar telescopes. In the following some references to current systems are given. Since 1998 the Kiepenheuer Institut is operating the TESOS instrument (Triple Etalon SOlar Spectrometer) at the German Vacuum Tower Telescope (VTT) at the Observatorio del Teide, Tenerife (Kentischer et al., 1998; von der Lühe & Kentischer, 2000; Tritschler et al., 2002), composed of three etalons in series in a telecentric optical setup. A two-etalon system in a collimated setup, the IBIS (Interferometric BIdimensional Spectrometer) from the Arcetri group (Cavallini et al., 2000; Cavallini, 2002; Cavallini et al., 2003) is in operation since 2003 at the Richard B. Dunn Solar Telescope on Sacramento Peak. In November 2006 it has been combined with a full-Stokes polarimeter and since then first Stokes images of active regions have been obtained with a spatial resolution close to the telescopic diffraction limit in Fe I, 6302 Å and Ca II, 8542 Å (Kleint, 2007). Another instrument developed by the Arcetri group is the IPM (Italian Panoramic Monochromator, Cavallini, 1998) at the French-Italian solar telescope THEMIS (Téléscope Héliographique pour l'Etude du Magnétisme et des Instabilités de l'atmosphère Solaire) at the Observatorio del Teide. In 2005 the institute of Astrophysics in Göttingen has upgraded (essentially renewed) their Göttingen FPI (Fabry-Pérot Interferometer). This system, based on two etalons in a collimated setup will become a post-focus instrument for the new German 1.5 m GREGOR solar telescope presently under construction at the Observatorio del Teide. Polarimetry with an earlier version of this instrument was performed by Volkmer et al. (1995), among others, using a Stokes V polarimeter.

Apart from ours, the only current system based on a lithium-niobate etalon is the IMaX (Imaging MAgnetograph eXperiment, Martinez Pillet & al., 2004) on-board the balloon-borne SUNRISE solar telescope which is foreseen to fly in 2008. Unlike our etalons the IMaX etalon is z-cut i.e. not birefringent. Moreover, IMaX consists of one single etalon used in double pass, in contrast to the serial combination of different etalons used in all other systems.