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Keynote Lecture

Contribution #: 1**Title:** Polarimetry in astrophysics - a personal selection**Authors:** Sami K. Solanki (1)**Affiliation:** Max Planck Institute for Solar System Research (1)**Type of communication:** Keynote**Abstract**

Polarisation is one of the basic properties of light and contains information on numerous processes acting in the universe. Polarisation measurements have provided unique information on the solar, on stellar and on planetary atmospheres, but also on small bodies in the solar system. It has also given new insights into the interstellar medium and the magnetic field in our Milky Way galaxy and in other galaxies, on the nature of AGNs, and on the intergalactic medium in galaxy clusters. From this vast and rich variety of sources of polarisation, much too varied to cover in a single talk, a small, personally biased selection will be presented and discussed here.

Session 1
Instrumentation
(ground, space, laboratory)

Session 1

Contribution #: 2

Title: Solar polarimetry from space

Authors: Ted Tarbell (1)

Affiliation: LMSAL (1)

Type of communication: Invited review

Session 1

Contribution #: 3

Title: The Large Aperture Solar Optical Telescope (SUVIT) for Solar-C mission

Authors: Kiyoshi Ichimoto (1), Solar-C Working Group

Affiliation: Kyoto University (1)

Type of communication: Oral contribution

Abstract

The Solar-C mission aims at full understanding of the origin of the dynamic solar atmosphere by observing small-scale structures and fundamental plasma processes taking place across different layers of the solar atmosphere with a coordinated suit of complementary observing instruments. We present the science goal and instrument design of one of the major payload planned for the Solar-C: the Solar UV Visible- IR observing Telescope (SUVIT). The role of the SUVIT is to determine the magnetic field structure from the photosphere to the upper chromosphere at ever highest angular resolution with advanced imaging and spectro-polarimetric observations. The system consists of a ~1.4m aperture Gregorian telescope and focal plane instrument packages equipped with narrowband filtergraph imagers (FG), broadband UV imager and spectrometer (UBIS), and a Littrow-type spectro-polarimeter (SP). The basic feature of SUVIT is as follow: - diffraction limited angular resolution; < 0.1" in visible and 0.13" -- 0.4" in near IR, - large field of view that covers typical active regions; > 180"x180", - wide wavelength coverage; include CaII 854nm and HeI 1083nm for chromospheric magnetic field measurements, CaII K 393nm and MgII 280nm for observing chromospheric fine scale dynamics, visible photospheric lines, and continuum, - high precision spectro-polarimetry; SN ~ 3 x 10⁴ achieved for 10"x10" FOV in 10 second with a 2 dimensional spectrograph (IFU). The mission proposal was submitted to JAXA and ESA in this year. Solar-C is a mission led by international collaboration participated by JAXA, ESA and NASA.

Session 1

Contribution #: 4

Title: Solar polarimetry from the ground

Authors: Manuel Collados (1)

Affiliation: Instituto de Astrofisica de Canarias (1)

Type of communication: Invited review

Session 1

Contribution #: 5

Title: Polarimeter for the Multi Application Solar Telescope (MAST) at Udaipur Solar Observatory

Authors: Alok Ranjan Tiwary (1), Shibu K. Mathew (1)

Affiliation: Udaipur Solar Observatory (Physical Research Laboratory) (1)

Type of communication: Oral contribution

Abstract

The Multi-Application Solar Telescope (MAST) is an off-axis Gregorian solar telescope of 50 cm clear aperture installed at the lake site of Udaipur Solar Observatory (USO). A Polarimeter is being developed at USO for measuring the vector magnetic field in solar atmosphere at two different heights, and it will be used with newly installed MAST. Along with a narrow band imager or a spectrograph, spectro-polarimetry, analyses light as a function of its two most important characteristics: wavelength and state of polarization and is a powerful tool for measuring the magnetic field on the Sun. The observational aim of solar spectro-polarimetry is to record the Stokes vector as accurately as possible with highest spectral, spatial and temporal resolution. We use two Liquid Crystal Variable Retarders (LCVRs) and a linear polarizer for the MAST Polarimeter. LCVRs are electro-optically tunable retarders. Characterization of each LCVR is important in order to get the accurate retardance and voltage dependence for a particular wavelength. Here we present the characterizations of the LCVRs for two solar spectral lines at Fe I 617.3 nm, and Ca II 854.2 nm, specifically the temperature and voltage tuning, and the calibration of this Polarimeter to get the response matrix of this Polarimeter. We also present the details of the calibration set-up and the obtained results.

Session 1

Contribution #: 6

Title: Review of the preliminary design of the Brazilian Solar Vector Magnetograph (BVSM)

Authors: Luis Eduardo Antunes Vieira (1), Alicia Clua de Gonzalez (1), Aline de Lucas (1), Alisson Dal Lago (1), Antonio Padilha (1), Bruno Castilho (2), Carlos Braga (1), Cristiano Wrasse (1), Maria Cristina Rabello Soares (3), Daiki Koga (1), Eduardo Burger (1), Ezequiel Echer (1), Flavia Cardoso (4), Fernando Rodrigues (2), Gustavo Guerrero (3), Jenny Rodriguez (1), Jesulino dos Santos (2), Joaquim Costa (1), Jose Vilas Boas (1), Judith Palacios (5)

Affiliation: INPE/Brazil (1), LNA/Brazil (2), UFMG/Brazil (3), USP/Lorena/Brazil (4), Universidad de Alcala (5)

Type of communication: Oral contribution

Abstract

We review here the preliminary design of the solar vector magnetograph and visible-light imager to study solar process through observations of the solar surface magnetic field. The Brazilian's National Institute for Space Research (INPE) is designing the Instrument in collaboration with the University of São Paulo (USP/Lorena), the Federal University of Minas Gerais (UFMG), and the Brazilian's National Laboratory for Astrophysics (LNA). The BSVM is designed to obtain full disk magnetic field and line-of-sight velocity observations in the photosphere. The instrument is composed of the Ritchey-Chrétien telescope with a 500 mm aperture and 4000 mm focal length. LCD polarization modulators will be employed for the polarization analysis and a tuning filter for the wavelength scanning in the Fe I 630.15-630.25 nm wavelength range. Two large field of view, high-resolution 5.5 megapixel sCMOS camera will be employed as sensors. Additionally, we describe in details the system engineering approach employed in this project. As the magnetic field anchored at the solar surface produces most of the structures and energetic events in the upper solar atmosphere and significantly influences the heliosphere, the development of this instrument plays an important role in reaching the scientific goals of The Atmospheric and Space Science Coordination (CEA) at the Brazilian National Institute for Space Research (INPE). In particular, the CEA's space Weather program will benefit most from the development of this technology. We expect that this project will be the starting point to establish a strong research program on Solar Physics in Brazil. Our main aim is acquiring progressively the know-how to build state-of-art solar vector magnetograph and visible-light imagers for space-based platforms to contribute to the efforts of the solar-terrestrial physics community to address the main unanswered questions on how our nearby Star works.

Session 1

Contribution #: 7

Title: Error analysis and optimization of polarization calibration optics in solar telescope

Authors: Junfeng Hou (1), Dongguang Wang (1), Yuanyong Deng (1)

Affiliation: National Astronomical Observatories, Chinese Academy of Science (NAOC) (1)

Type of communication: Oral contribution

Abstract

The solar telescope requires frequent calibration operation to remove the instrumental polarization, then a group of polarization calibration optics (also called instrumental calibration unit (ICU)) is usually needed and placed near Gregorian focus of telescope to realize calibration and reduce instrumental polarization. However, ICU is often designed by assuming that the polarization properties of the optics are nearly ideal. We consider the case where ICU is imperfect. Specifically, we examine the expected performance of ICU as the extinction ratio of the diattenuators degrades, as the azimuth varies with spectra due to dichroism and misalignment of optics, as the retardance varies spatially and with incidence angle, and as the beam deviation induced by the wedge of optics. Besides, we optimized ICU based on the condition number optimization method to improve signal-to-noise ratio (SNR) and reduce calibration time. The work is necessary and important for polarization calibration of solar telescope with high precision.

Session 1

Contribution #: 8

Title: Instruments for Night-Time Polarimetry

Authors: Christoph Keller (1)

Affiliation: Leiden Observatory (1)

Type of communication: Invited review

Abstract

I will review progress in astronomical instruments for polarimetric observations of planets, exoplanets and stars. Technical progress in optical and electro-optical components and detectors, many of them pioneered in solar physics, led to new instrument concepts and a much better understanding of the systems aspects of polarimetric instrumentation and new approaches to understand instrumental effects. I will discuss new instrument concepts and show some of the exciting data produced by night-time polarimeters.

Session 1

Contribution #: 9

Title: High-accuracy spectropolarimetry with spectral polarization modulation

Authors: Frans Snik (1), Gerard van Harten (2), Christoph Keller (1), Jeroen Rietjens (3), Arturo Lopez-Ariste (4)

Affiliation: Leiden Observatory (1), JPL (2), SRON (3), IRAP (4)

Type of communication: Oral contribution

Abstract

Current astronomical polarimeters modulate polarization information in time (with rotating or variable retarders) and/or in space (with polarizing beam-splitters). We have developed a novel polarimetric concept that is based on spectral modulation: a combination of standard, passive polarimetric optics in front of a spectrograph creates a sinusoidal modulation in the spectrum for which the relative amplitude is equal to the degree of linear polarization and the phase is proportionate to the angle of the linear polarization. We have demonstrated 10^{-4} polarimetric sensitivity and 10^{-3} polarimetric accuracy of this implementation with our SPEX instruments that are dedicated to characterization of atmospheric aerosols. Here, we discuss astronomical applications of this technique. First, it can provide an absolute reference for measuring continuum polarization with a spectrograph, even if it is fiber-fed. We extend this technique to be part of a multidomain polarization modulation approach. We designed and prototyped a quartz-based rotating retarder modulator, that offers optimal full-Stokes polarization modulation at every wavelength from 300 to 2500 nm. This so-called "polychromatic" modulator is highly chromatic and hence also offers instantaneous full-Stokes spectral modulation, which, together with a dual-beam system, offers the ultimate ammunition against degrading systematic effects. Finally, we discuss how such spectral modulation techniques can still be used to measure line polarization, by combining polarization modulation domains to cancel out spectral aliasing, or by employing a multi-line technique.

Session 1

Contribution #: 10

Title: Laboratory studies of light scattered by macroscopic dust particles at visible wavelengths

Authors: Olga Muñoz (1)

Affiliation: Instituto de Astrofísica de Andalucía (1)

Type of communication: Invited review

Abstract

Small dust particles exist in a wide variety of scenarios ranging from the Earth atmosphere to other planetary and cometary atmospheres in the Solar System, interplanetary medium, reflection nebulae, atmospheres of brown dwarfs, etc. Those small particles play an important role in the radiative balance of the body under study. By analyzing the light scattered by those particles we can retrieve valuable information about their physical properties (shape, size, and composition) as well as their location within a certain atmosphere. Light scattering properties of homogeneous spherical particles can be easily computed from Lorenz-Mie theory. However, in the majority of the above mentioned cases, the assumption of spherical particles is highly unrealistic. Limitations in computational resources inhibited reliable computations of light scattering by non-spherical particles covering all range of shapes and sizes we can find in Nature. The main goal of this talk is to show how experimental data of intensity and polarization of the scattered light of different cosmic dust analogs can be used to shed some light on the nature of dust particles. In particular, I will focus on samples relevant for the study of the atmospheres of planets, satellites, and comets in the Solar System.

Session 1

Contribution #: 11

Title: Performance Measurement of Liquid Crystal Variable Retarder

Authors: Dongguang Wang (1), Wenjun Sun (1), Yang Zhang (2), Jiaben Lin (1), Zhen Zeng (1), Yuanyong Deng (1), Junfeng Hou (1)

Affiliation: Key Laboratory of Solar Activity, National Astronomical Observatories of Chinese Academy of Sciences (1), University of Chinese Academy of Sciences (2)

Type of communication: Poster

Abstract

Liquid Crystal Variable Retarder (LCVR) is widely used in modulator and birefringent filter in solar monochromatic observation and magnetic field measurement. For application, the effect of wavelength (λ), temperature (T), and voltage on both of the retardance (δ) and fast axis azimuth requires to be calibrated. Moreover, the inhomogeneity and instability of LCVR also need to be measured for analysis of system errors. We bought several LCVRs from Meadowlark Inc. in America and precisely measured their retardance and axis azimuth as changing test parameters. This paper will present the results of above measurements.

Session 1

Contribution #: 12

Title: Long-Term Variability of the Polarization Response Matrix of the Hinode Spectro-Polarimeter

Authors: Bruce W. Lites (1)

Affiliation: High Altitude Observatory/NCAR (1)

Type of communication: Poster

Abstract

The Spectro-Polarimeter (SP) of the Solar Optical Telescope (SOT) on the Hinode mission has been providing precision polarization measurements at high angular resolution consistently since October 2006. The Hinode team has performed a sequence of annual calibration measurements aimed at determining the flat-field response of this instrument. From these measurements we not only determine the flat-field response of the instrument (detector and optics), but using the average disk-center quiet Sun as a standard candle, we determine the history of overall changes at throughput of the instrument over its active lifetime. These measurements also allow us to examine changes in the intensity-to-polarization elements of the system polarization response matrix. We determine a significant time-variability of the intensity to Q-polarization that appears to be accelerating with time. Implications and consequences of this behavior are discussed.

Session 1

Contribution #: 13

Title: Solar Physics Research Integrated Network Group (SPRING) : A Next Generation Ground-based Synoptic Network

Authors: Sanjay Gosain (1), Markus Roth (1), Frank Hill (2), Michael Thompson (3)

Affiliation: Kiepenheuer Institut für Sonnenphysik (1), National Solar Observatory (2), High Altitude Observatory (3)

Type of communication: Poster

Abstract

SPRING is an evolving concept for next generation solar synoptic observations network. It is envisaged that the new network will cater to the needs of (i) Helioseismology community, by providing improved resolution Doppler observations at multiple heights in solar atmosphere, (ii) Space weather research community, by providing full disk vector magnetograms at a cadence of few minutes and in multiple heights in the solar atmosphere, and (iii) Large solar telescopes, such as DKIST and EAST, by providing high resolution full disk context imaging in multiple wavelengths. We will present the conceptual designs currently being explored for SPRING.

Session 2

Diagnostics and Interpretation

Session 2

Contribution #: 14

Title: Multiple scattering in particulate media

Authors: K. Muinonen (1,2), J. Peltoniemi (1,2), J. Markkanen (1), A. Penttilä (1), G. Videen (3,4)

Affiliation: Department of Physics (University of Helsinki) (1), Finnish Geospatial Research Institute FGI (2), Space Science Institute, Boulder (3), Army Research Laboratory (Adelphi) (4)

Type of communication: Invited review

Abstract

Scattering of light in a macroscopic particulate medium composed of microscopic particles constitutes an open computational problem in planetary astrophysics. There are two ubiquitous phenomena observed at small solar phase angles (the Sun-Object-Observer angle) from, for example, asteroids and transneptunian objects. First, a nonlinear increase of brightness is observed toward the zero phase angle in the magnitude scale that is commonly called the opposition effect. Second, the scattered light is observed to be partially linearly polarized parallel to the Sun-Object-Observer plane that is commonly called the negative polarization surge.

The observations can be interpreted using a radiative-transfer coherent-backscattering Monte Carlo method (RT-CB, Muinonen 2004) that makes use of a so-called phenomenological fundamental single scatterer (Muinonen and Videen 2012). For the validity of RT-CB, see Muinonen et al. (2012). With the help of laboratory experiments (e.g., Munoz et al., present meeting) and exact theoretical methods, the method can allow us to put constraints on the size, shape, and refractive index of the fundamental scatterers.

Acknowledgments. The research is funded by the ERC Advanced Grant No 320773 entitled *Scattering and Absorption of Electromagnetic Waves in Particulate Media* (SAEMPL).

K. Muinonen, *Waves in Random Media* 14, 365 (2004).

K. Muinonen, K., and G. Videen, *JQSRT* 113, 2385 (2012).

K. Muinonen, M. I. Mishchenko, J. M. Dlugach, E. Zubko, A. Penttilä, and G. Videen, *ApJ* 760, 118 (2012).

Session 2

Contribution #: 15

Title: Polarized radiative transfer in solar MHD simulations

Authors: Han Uitenbroek (1)

Affiliation: NSO (1)

Type of communication: Invited review

Session 2

Contribution #: 16

Title: Solar inversion codes

Authors: Jose Carlos del Toro Iniesta (1)

Affiliation: Instituto de Astrofisica de Andalucia (CSIC) (1)

Type of communication: Invited review

Abstract

The last thirty years have witnessed the appearance of a number of techniques that have revolutionized our way to measure solar magnetic fields, namely, the so-called inversions of the radiative transfer equation techniques. Starting from simple models and solutions of the transfer equation and ending with sophisticated processes including full numeric solution of the equation and instrumental effects at the same time, passing through different model approaches and mathematical tools, inversion techniques have become common usage for solar observers. A revision of the ideas, hypotheses, advantages, limitations, and constraints behind inversions is presented, beginning with critical reviews of commonly accepted approximations that are becoming useless as long as new instrumentation is providing better and better observables. The advent of state-of-the-art computing tools increases our capabilities for finer analyses of these new observations.

Session 2

Contribution #: 17

Title: Hanle effect diagnostics of the solar atmosphere

Authors: Jiri Stepan (1)

Affiliation: Astronomical Institute ASCR (1)

Type of communication: Invited review

Abstract

The Hanle effect is one of the key mechanisms by which magnetic fields leave their signatures in the polarization state of spectral lines. The Hanle effect diagnostics is most suited for magnetic fields that are not strong enough to produce significant Zeeman splitting. This involves major parts of the solar chromosphere, transition region, and corona. Still, in the regions of strong magnetization, the Hanle and Zeeman effects can interfere in a non-trivial way that requires careful analysis. This talk is intended to give a brief overview of the physics of the Hanle effect and its use for diagnostics of the solar magnetism. I will discuss some simple examples as well as complex simulations involving 3D NLTE radiative transfer and I will address some of the open questions in the field.

Session 2

Contribution #: 18

Title: A Possible Resolution of the Paradox of the Enigmatic D1 Line Polarization

Authors: Javier Trujillo Bueno (1), Luca Belluzzi (2)

Affiliation: Instituto de Astrofísica de Canarias, Istituto Ricerche Solari Locarno

Type of communication: Oral contribution

Abstract

The linearly polarized spectrum of the solar limb radiation produced by scattering processes is of great diagnostic potential for exploring the magnetism of the solar atmosphere. This spectrum shows an impressive richness of spectral details and enigmatic polarization signals, whose physical origin must be clearly understood before they can be exploited for diagnostic purposes. One of the most enduring enigmas is represented by the polarization signals observed in the D1 resonance lines of Na I (5896 Å) and Ba II (4934 Å), which were expected to be intrinsically unpolarizable. The totality of sodium and 18% of barium have hyperfine structure (HFS), and it has been argued that the only way to produce a scattering polarization signal in such lines is through the presence of a substantial amount of atomic polarization in their lower HFS levels. The strong sensitivity of these long-lived levels to depolarizing mechanisms led to the paradoxical conclusion that the observed D1-line polarization is incompatible with the presence in the lower solar chromosphere of inclined magnetic fields sensibly stronger than 0.01 G. Here we show that by properly taking into account the fact that the solar D1-line radiation has a non negligible spectral structure over the short frequency interval spanned by the HFS transitions, it is possible to produce scattering polarization signals in the D1 lines of Na I and Ba II without the need of ground-level polarization. The resulting linear polarization is not so easily destroyed by elastic collisions and/or magnetic fields.

Session 2

Contribution #: 19

Title: Stellar inversion codes

Authors: Thorsten A. Carroll (1), Klaus G. Strassmeier (1)

Affiliation: Leibniz-Institut fuer Astrophysik Potsdam (AIP) (1)

Type of communication: Invited review

Abstract

In contrast to the Sun, stars are point sources and deriving their atmospheric quantities from stellar (Stokes) spectra can only give us surface averaged values. However observing a star while it rotates and taking phase-resolved (Stokes) spectra allows one to achieve a certain surface resolution (depending on the projected rotational velocity). In this talk I give an overview of existing inversion methods aimed at single Stokes profile observations, to retrieve surface averaged magnetic field values, as well as at phase-resolved observations (known as Zeeman-Doppler imaging) that allow one to reconstruct the entire magnetic field distribution on the stellar surface. I will highlight their differences and capabilities, as well as their limitations.

Session 3

Solar Photosphere

Session 3

Contribution #: 20

Title: Polar Fields of the Sun

Authors: Gordon Petrie (1)

Affiliation: National Solar Observatory (1)

Type of communication: Invited review

Abstract

This talk describes observations of the Sun's polar magnetic fields, models for the cyclical formation and decay of these fields, and evidence of their great influence in the solar atmosphere. The polar field distribution dominates the global structure of the corona over most of the solar cycle, supplies the bulk of the interplanetary magnetic field, and is believed to provide the seed for the creation of the activity cycle that follows. A broad observational knowledge and theoretical understanding of the polar fields is therefore an essential step towards a global view of solar and heliospheric magnetic fields. Analyses of both high resolution and long-term synoptic observations of the polar fields are summarized. Models of global flux transport are briefly introduced, from the initial phenomenological and kinematic models of Babcock and Leighton to present-day attempts to explain changes in the behavior of the polar fields. We briefly discuss the observed effects of polar field changes on the corona and heliosphere, and on the ejections that travel through the atmosphere.

Session 3

Contribution #: 21

Title: Quiet Sun Magnetic Fields

Authors: David Orozco Suárez (1)

Affiliation: Instituto de Astrofísica de Canarias (1)

Type of communication: Invited review

Abstract

Most of solar surface is permeated by the so-called quiet sun magnetic fields. They are organized as forming a net of ~ 20 Mm diameter cells that covers the solar surface and outlined by the presence of relatively strong magnetic signals, the network. The interiors of the net (the internetwork) harbor very small-scale and dynamic magnetic structures whose polarization signals are tiny compared to the network. The characterization of these quiet Sun magnetic fields involves a thorough analysis of the latest high spatial and high temporal resolution spectropolarimetric observations. As a result of the latest investigations, the magnetic properties of the network fields are relatively well known, but it is not so true in the case of the solar internetwork. Despite the great advances in current instrumentation and superb observations, little is known about their origin and nature. Most recent investigations have made clear many of the results in dispute about the magnetism of the internetwork but, at the same time, have also created new controversies. Moreover, latest observations have led to new and surprising (re)-discoveries in the quiet Sun at the smallest achievable scales. Here, a review of the main observational properties of the quiet Sun magnetic fields is given, with particular emphasis on those related to the quietest parts of the quiet Sun: the internetwork. Besides, the techniques most often used to infer the magnetic field vector are critically discussed, since they may be responsible for most disagreements found in the literature.

Session 3

Contribution #: 22

Title: Flux appearance and disappearance in the solar internetwork

Authors: Milan Gosic (1), Luis Bellot Rubio (1)

Affiliation: Instituto de Astrofísica de Andalucía (IAA-CSIC) (1)

Type of communication: Oral contribution

Abstract

Internetwork fields are the key to understanding the solar activity at small temporal and spatial scales. It is therefore essential to investigate how they are generated and maintained on the solar surface. In this work, we describe for the first time how internetwork regions gain and lose magnetic flux. We use high-resolution Hinode/NFI magnetograms at disk center to automatically follow quiet Sun magnetic elements from their appearance to disappearance in up to 38 hours of continuous measurements. We determine that magnetic elements appear inside of supergranular cells at a rate of $40 \text{ Mx cm}^{-2} \text{ day}^{-1}$. They disappear through fading, cancellations or by converting into network features. The former mechanism is responsible for half of the flux loss. The removal rate of magnetic flux is twice as large as the appearance rate and we explain this imbalance as the tendency of internetwork elements to grow in flux during their lifetimes. Due to high rates of appearance and their contribution to the network, internetwork elements stand out as the most important contributor to the network and the quiet Sun flux budget.

Session 3

Contribution #: 23

Title: The evolution of individual and groups of flux tubes as seen by IMAx/Sunrise

Authors: Iker S. Requerey (1), Jose Carlos del Toro Iniesta (1), Luis R. Bellot Rubio (1), Valentín Martínez Pillet (2), Sami K. Solanki (3), Wolfgang Schmidt (4)

Affiliation: Instituto de Astrofísica de Andalucía (1), National Solar Observatory (2), Max-Planck Institut für Sonnensystemphysik (3), Kiepenheuer Institut für Sonnenphysik (4)

Type of communication: Oral contribution

Abstract

The formation and subsequent evolution of one isolated solar flux tube has been studied for half an hour with unprecedented spatial resolution and polarimetric accuracy by IMAx/Sunrise. The results tell a nonconventional history where several polarity patches are merged up to equipartition field strength; the magnetic structure is further intensified to kG strengths by convective collapse with bright points and downflow plumes near the edges of the tube; later, the field weakens to be subsequently intensified in what could be the initial stages of an oscillation. The same observations also show bundles of such individual flux tubes evolving as a single entity during the entire half-an-hour long series. The group is seen to share a common canopy in the upper photospheric layers while below the individual tubes continually merge and separate in the same way that chains of bright points in photometric observations have been reported to do. The tube core motions are driven by the evolution of the local granular convection flows, and the continual fragmentation and coalescence of flux results in magnetic field oscillations of the global entity.

Session 3

Contribution #: 24

Title: Small-scale intergranular upflows as seen by Sunrise/IMaX; work in progress

Authors: Dominik Utz (1), Jose Carlos del Toro Iniesta (1), Luis Bellot Rubio (1), Stefan Thonhofer (1)

Affiliation: Instituto de Astrofísica de Andalucía (CSIC) (1)

Type of communication: Oral contribution

Abstract

The quiet solar surface is governed by convective motions leading to the well known granulation pattern. Between the uprising plasma, manifested as granules, the intergranular lanes are situated in which the cooler plasma is downflowing back into the solar interior. Thus it is common that the intergranular lanes are darker and associated with downflows. Often magnetic field gets swept into and accumulated in these downflowing lanes and when a critical magnetic field strength is reached the so-called convective collapse process sets in which is leading to kG strong magnetic field concentrations. Such magnetic fields or parts of it are then normally, at least for some time during the dynamical processes, visible as magnetic bright points (MBPs). Recently, when we were studying such evolutions of MBPs and the involved convective collapse process we identified in a considerable amount of cases next to the triggered downflows spatially and temporally related upflows. In this contribution we would like to present our very preliminary results about such upflows and their interaction with the strong downflows related to the convective collapse process.

Session 3

Contribution #: 25

Title: Multi-wavelength observations of magnetic upflows in the solar atmosphere

Authors: Shahin Jafarzadeh (1), Luc Rouppe van der Voort (1), Jaime de la Cruz Rodríguez (2)

Affiliation: Institute of Theoretical Astrophysics (University of Oslo) (1), Institute for Solar Physics (Stockholm University) (2)

Type of communication: Oral contribution

Abstract

We present a thorough observational study of magnetic upflow events (MUEs) from high-quality full Stokes observations of four photospheric magnetically sensitive lines (centered at 5250.21 Å, 6173.34 Å, 6301.51 Å, and 6302.50 Å) acquired at high spatial, temporal, and spectral resolutions with SST/CRISP. Their chromospheric counterparts are investigated in intensity Ca II H and full Stokes time-series of images recorded at Ca II 8542 Å passbands. We propose a new approach to detect the MUEs, from which (and also from advances of the high resolution data) we find a larger number of MUEs at any given time (2.0×10^2 arcsec⁻²), larger by one to two orders of magnitudes, than previously reported. Furthermore, we classify Stokes V profiles associated with the detected MUEs, based on their appearances, and study structure and dynamics of the MUEs in time-series of images. We find them to fall into four classes presenting different shapes of Stokes V profiles with (I) asymmetric double lobes, (II) single lobes, (III) double-humped (two same-polarity lobes), and (IV) three lobes (extra blue-shifted bump in addition to a double-lobes), from which, only less than half of them are single-lobed. We also find about the same fraction of MUEs in network and internetwork areas and they appear in the interior or at the edge of granules in both regions. Distributions of physical properties, except that of horizontal velocity, of the MUEs are almost identical for the different spectral lines in our data with mean values (and standard deviations of the histograms) of $1.3 \pm 0.4 \times 10^{-2} I_c$, $0.06 \pm 0.04 \text{ Mm}^2$, $-0.9 \pm 0.7 \text{ km/s}$, and $113 \pm 136 \text{ s}$ for Stokes V signal, size, line-of-sight velocity, and lifetime, respectively. Their proper motions found to be $2.6 \pm 1.4 \text{ km/s}$ and $1.5 \pm 0.7 \text{ km/s}$ for the MUEs detected in 6173 Å and 6301/2 Å images. We also study properties of the events from both Stokes inversions and MHD simulations. Our findings reveal that, in addition to the detection technique, the number, type (class), and properties of MUEs can strongly depend on signal-to-noise ratio, on resolutions, and on wavelength of the employed datasets.

Session 3

Contribution #: 26

Title: Photospheric Flow Field Related to the Evolution of the Sun's Polar Magnetic Patches Observed by Hinode SOT

Authors: Anjali John Kaithakkal (1), Yoshinori Suematsu (2), Masahito Kubo (2), Yusuke Iida (3), Daikou Shiota (4), Saku Tsuneta (3)

Affiliation: Max Planck Institute for Solar System Research (1), National Astronomical Observatory of Japan (2), Institute of Space and Astronautical Science (ISAS-JAXA) (3), Solar-Terrestrial Environment Laboratory (Nagoya University) (4)

Type of communication: Oral contribution

Abstract

We investigated the role of photospheric plasma motions in the formation and evolution of polar magnetic patches using time-sequence observations with high spatial resolution. The observations were obtained with the spectropolarimeter on board the Hinode satellite. From the statistical analysis using 75 magnetic patches, we found that they are surrounded by strong converging, super granulation associated flows during their apparent lifetime and that the converging flow around the patch boundary is better observed in the Doppler velocity profile in the deeper photosphere. Based on our analysis, we suggest that the likepolarity magnetic fragments in the polar region are advected and clustered by photospheric converging flows, thereby resulting in the formation of polar magnetic patches. Our observations show that, in addition to direct cancellation, magnetic patches decay by fragmentation followed by unipolar disappearance or unipolar disappearance without fragmentation. It is possible that the magnetic patches of existing polarity fragment or diffuse away into smaller elements and eventually cancel out with opposite polarity fragments that reach the polar region around the solar cycle maximum. This could be one of the possible mechanisms by which the existing polarity decays during the reversal of the polar magnetic field.

Session 3

Contribution #: 27

Title: The distinct magnetic property of the penumbra

Authors: Rolf Schlichenmaier (1)

Affiliation: Kiepenheuer-Institut für Sonnenphysik (1)

Type of communication: Oral contribution

Abstract

The various ways of energy transport in radiatively driven magnetoconvection determine the structure of sunspots. At first glance, sunspots are composed of a dark umbra and a brighter penumbra. The darkness of the umbra is readily explained by the tension of the magnetic field lines that suppresses convection. Yet, it is clear that even in the darkest part of the umbra, radiative and conductive heat transport are not sufficient to explain the observed photospheric temperatures. Efficient convection must be present everywhere in sunspots. Indeed, with increasing spatial resolution in the last, say, 30 years the existence of umbral fine structure became apparent. I will present some images obtained with GREGOR that show this fine structure at a spatial resolution of 0.08". These images demonstrate that magneto-convection in the umbra operates at different intensity levels. In contrast, the magnetoconvective mode in the penumbra seems to be more uniform. It always produces filaments that look alike and that lead to the same spatially-averaged brightness. The penumbra is characterized and defined by its brightness relative to the umbra. It also always exhibits the Evershed flow. Yet, the crucial question is: Is there a distinct magnetic property that makes the difference between umbral and penumbral mode of magneto-convection? In this talk we will argue that, yes, there is a canonical value for the vertical component of the magnetic field that makes the difference. The formation of the penumbra is triggered by large inclination, but the penumbra mode of convection can only prevail, if $B(\text{vertical})$ is smaller than a well defined canonical value.

Session 3

Contribution #: 28

Title: Penumbra return flux measured by spectral lines in the visible and infrared

Authors: Morten Franz (1), Manolo Collados (2), Oskar von der Luhe (1), Carsten Denker (3), Sami Solanki (4), Horst Balthasar (3), Thomas Berkefeld (1), Juan Borrero (1), Franz Kneer (5), Andreas Lagg (4), David Orozco (2), Reza Rezaei (1), Rolf Schlichenmaier (1), Wolfgang Schmidt (1), Michael Siegwart (1), Michael Sobotka (6), Dirk Soltan (1), Klaus Strassmeier (3), Reiner Volkmer (1), The Gregor Team

Affiliation: Kiepenheuer-Institut für Sonnenphysik (1), Instituto de Astrofísica de Canarias (2), Leibniz-Institut für Astrophysik Potsdam (3), Max-Planck-Institut für Sonnensystemforschung (4), Institut für Astrophysik (Georg-August-Universität Göttingen) (5), Astronomical Institute of the Academy of Sciences (6)

Type of communication: Oral contribution

Abstract

The exact amount of penumbral return flux is important for our understanding of sunspots. In the past, 3-lobe Stokes V profiles of spectral lines in the visible have been used to detect the signatures of 'hidden' penumbral return flux (Franz 2011, Ruiz Cobo & Asensio Ramos 2013, Scharmer et al. 2013), which was compared to the amount of return flux in sunspot simulations (Rempel 2012). Since this return flux was found to occur in deep photospheric layers (Franz & Schlichenmaier 2013) and since spectral lines in the infrared (IR) sample the atmospheric conditions in a thin layer close to the solar surface, IR lines are suited best to approximate the amount of penumbral return flux. A systematic analysis of a large number of high quality IR data sets from GRIS@Gregor and visible data sets obtained by SP@Hinode yield a different picture. In our contribution we show that the IR data show not only a smaller amount of reversed penumbral Stokes V profiles but also less 3-lobe profiles tracing 'hidden' opposite polarity fields (Franz et al. 2015). There is yet no satisfying explanation for the lack of penumbral return flux detected in IR data, and we discuss a number of effects that could be at its origin. To this end we use forward modeling and investigate the results from sunspot simulation.

Franz, M. (2011) PhDT, Kiepenheuer Institut Freiburg

Rempel, M. (2012) ApJ, 750, 62

Ruiz Cobo, B. & Asensio Ramos, A. (2013), A&A 549L, 4

Scharmer, G. B., de la Cruz Rodriguez, J., Sütterlin, P. & Henriques, V. M. J. (2013), A&A 549L 4R

Franz, M. & Schlichenmaier, R. 2013, A&A, 550, 97

Franz, M., Collados, M., von der Lühe, O. et al. 2015 (in preparation).

Session 3

Contribution #: 29

Title: Supersonic Evershed downflows

Authors: Sara Esteban Pozuelo (1), Luis Bellot Rubio (1)

Affiliation: Instituto de Astrofísica de Andalucía (IAA-CSIC) (1)

Type of communication: Oral contribution

Abstract

It is known that the Evershed flow can reach supersonic velocities in the outer penumbra (Westendorp Plaza et al. 1997, 2001; Bellot Rubio et al. 2004). These flows are associated with magnetic field lines dipping down below the solar surface. They were discovered from the inversion of visible and infrared Stokes profiles at moderate spatial resolution ($\sim 1''$), not by direct imaging. With current instruments delivering resolutions of order 0.1 arcsec, it is now possible to attempt to identify them as isolated structures. Van Noort et al. (2013) studied the properties of supersonic Evershed downflows using 0.3'' resolution Hinode data and sophisticated spatially coupled 2D inversions. They found velocities of up to 20 km s⁻¹ and extremely strong magnetic fields of 7 kG, the strongest ever reported in the Sun. The discovery of such fields came as a big surprise, raising doubts that they may be artifacts of the interpolation scheme or the inversion algorithm used by van Noort et al. (2013). Here we present an analysis of supersonic Evershed downflows observed in a temporal sequence of spectropolarimetric scans of the Fe I 6173 Å line taken with the CRISP spectropolarimeter at the Swedish 1m Solar Telescope. The spatial resolution is 0.13 arcsec. Our data show supersonic patches moving toward the outer sunspot boundary and beyond. Interestingly, they sometimes exhibit regular Stokes V profiles with Doppler shifts of more than 9 km s⁻¹. This is the first time that supersonic Evershed downflows are imaged and tracked, which allows us to understand their origin and fate. We study their evolution and derive their properties from a SIR inversion of the observed Stokes profiles.

Session 3

Contribution #: 30

Title: Formation of a solar H α filament from penumbra-like structures

Authors: David Buehler (1), Andreas Lagg (1), Michiel van Noort (1), Sami K. Solanki (1)

Affiliation: Max Planck Institute for Solar System Research (1)

Type of communication: Oral contribution

Abstract

The evolution of a solar H α filament in active region (AR) 10953 is described. Observations from the Solar Optical Telescope aboard the Hinode satellite starting from UT 18:09 27th April 2007 until UT 06:08 1st May 2007 were analysed. 20 scans of the 6302AA Fe I line pair recorded by SOT/SP were inverted using the spatially coupled mode of the SPINOR code. The inversions were analysed together with cospatial SOT/BFI G-band and Ca II H and SOT/NFI H α observations. Following the disappearance of an initial H α filament aligned along the polarity inversion line (PIL) of the AR, a new H α filament formed in its place some 20 hours later, which remained stable for, at least, another 1.5 days. The creation of the new H α filament was driven by the ascend of horizontal magnetic fields from the photosphere into chromosphere at three separate locations along the PIL. The magnetic fields at two of these locations were situated directly underneath the initial H α filament and formed PIL-aligned, penumbra-like structures and Evershed-like flows. The penumbra-like structures were stable and trapped in the photosphere until the disappearance of the initial overlying H α filament, after which they started to ascend into the chromosphere. The ascended penumbra-like structures formed dark seed structures in H α , which elongated to reform the H α filament. The destruction of the initial H α filament was likely caused by the flux emergence at the third location along the PIL, which presumably caused a series of reconnection events. The penumbra-like structures ascended into the chromosphere ~9-24 hours before the H α filament was fully reformed.

Session 3

Contribution #: 31

Title: A new vision of the line ratio method

Authors: Faurobert Marianne (1), Ricort Gilbert (1)

Affiliation: University of Nice-Sophia Antipolis (1)

Type of communication: Oral contribution

Abstract

We have implemented a modified version of the line-ratio method on the Fe I line pair at 630 nm, using Hinode SOT/SP quiet Sun observations to test whether the magnetic field is intrinsically weak or strong. In the weak field limit the unsigned circular polarization integrated over the line profile and normalized with the line central depression is proportional to the absolute value of the line-of-sight component of the magnetic field, so the line ratio is given by the ratio of their Landé factor. However this method is known to be very sensitive to noise artefacts which may affect the weak polarization signals in the quiet Sun. To deal with this problem we go in the Fourier space and compute the Fourier power spectra of the 2D distributions over the solar surface of the normalized unsigned circular polarization in both lines. We correct the spectra from noise by subtracting the noise spectrum obtained in the continuum band, and then we compute their ratio. We applied this method to center-to-limb observations obtained in quiet Sun regions in December 2013. We find that the ratio is very close to the weak field value except at the largest scales of the spectra (from 5 to 20") where it is slightly larger. We conclude that the magnetic structures on scales smaller than 5" are in the weak field regime.

Session 3

Contribution #: 32

Title: Improved magnetogram calibration of Solar Magnetic Field Telescope and its comparison with the Helioseismic and Magnetic Imager

Authors: Xianyong Bai (1), Yuanyong Deng (2), Fei Teng (2), Jiangtao Su (2), Xinjie Mao (3), Guoping Wang (2)

Affiliation: National Space Science Center(Chinese Academy of Sciences) (1), National Astronomical Observatories (Chinese Academy of Sciences) (2), Beijing Normal University (3)

Type of communication: Oral contribution

Abstract

In the presentation, we will introduce a improved calibration method of the Solar Magnetic Field Telescope (SMFT), installed at Huairou Solar Observing Station, National Astronomical Observatories, Chinese Academy of Sciences. The improved calibration process fits the observed full Stokes information, using six points on the profile of Fe I 5324.18 Å line, and the analytical Stokes profiles under the Milne–Eddington atmosphere model, adopting the Levenberg–Marquardt least-squares fitting algorithm. The difference in the calibration of vector magnetic fields between this method and the linear calibration method employing one point are presented. Moreover, we will show its comparison with SDO/HMI.

Session 3

Contribution #: 33

Title: Vector magnetic field changes during flares using SDO/HMI data

Authors: Sebastián Castellanos-Durán (1), Lucia Kleint (2), Benjamín Calvo-Mozo (1)

Affiliation: Observatorio Astronómico Nacional (Universidad Nacional de Colombia) (1), University of Applied Sciences and Arts Northwestern Switzerland (2)

Type of communication: Oral contribution

Abstract

There is a close relation between solar flares and magnetic fields. In the standard model of flares, magnetic field lines reconnect and release very large amounts of energy ($\sim 10^{32}$ ergs). Particles are accelerated in the corona and propagate downward in the solar atmosphere. It is unclear, how deep they reach, or which mechanisms create the signatures observed as low as the photosphere. Observations have found transient and irreversible changes in the photospheric magnetic line-of-sight component. It is probable that these changes also occur in the field inclination, as for example penumbrae suddenly appear or disappear during flares. In this work, we analyze the vector magnetic field observed by SDO/HMI, searching for stepwise changes in a significant sample of flares. Our sample is well distributed in energy ranges and heliographic longitudes. We trace the locations where changes occur and correlate them with the locations of other flare signatures, such as flare ribbons.

Session 3

Contribution #: 34

Title: Can Flux Cancellation Build-Up Magnetic Flux Ropes?

Authors: Stephanie Yardley (1), Lucie Green (1), David Williams (1), Lidia van Driel-Gesztelyi (1)

Affiliation: MSSL (UCL) (1)

Type of communication: Oral contribution

Abstract

Magnetic flux ropes are helical magnetic structures common in the solar corona and capable of supporting cool, dense filament material. A potential formation mechanism is photospheric flux cancellation, where opposite polarity magnetic features converge towards the polarity inversion line and undergo magnetic reconnection to form helical field from a sheared arcade. It is possible to store huge amounts of free magnetic energy along the PIL in the coronal magnetic field leading to spectacular filament eruptions and/ or coronal mass ejections (CMEs) that when Earth-directed can have huge space weather implications. Here we present the analysis of NOAA Active Region (AR) 11226 that produced the spectacular 2011 June 7 filament eruption. We make a comparison between different series available from the Heliospheric Magnetic Imager onboard (HMI) the Solar Dynamics Observatory (SDO) and magnetograms produced by the Narrowband Filter Imager (NFI) on board Hinode. We quantify the amount of flux cancellation that occurs in AR 11226 and the two neighbouring ARs (11227 & 11233) by calculating the reduction in the total magnetic flux of the leading polarity using the automated Solar Tracking the Evolution of photospheric Flux (STEF) algorithm, which detects both small and large scale magnetic features in line of sight (LOS) magnetograms. During the three day period prior to the eruption the total positive flux cancelled at the internal PIL is comparable to an entire medium sized AR available to be built into the flux rope. In comparison, the flux cancellation in the neighbouring ARs 11227 and 11233 was discovered to be weaker.

Session 3

Contribution #: 35

Title: GUI for LCT analysis

Authors: Jose Iván Campos Rozo (1), Santiago Vargas Domínguez (1)

Affiliation: Universidad Nacional de Colombia (1)

Type of communication: Oral contribution

Abstract

The Local Correlation Tracking (LCT, November & Simon, 1988) technique is a robust method used to study the dynamics of structures in a time series of images. By tracking pixel displacements, using a correlation window, LCT can determine proper motions and generate flow maps of horizontal velocities. This procedure is used to study the dynamics of plasma in the solar photosphere at different spatial scales, e.g the analysis of granular and supergranular convective cells, meridional flows, etc. SunPy is a joint effort of, using the advantages of Python, developing tools to be applied for processing and analysis of solar data. A widget implemented in Python and Sunpy was developed. It generates a user-friendly graphical user interface (GUI) to control various parameters for the process of calculating flow maps of proper motions for a series of filtergrams (data cube).

Session 3

Contribution #: 36

Title: Blue shifted Stokes V profiles in the quiet Sun

Authors: Christoph Kiess (1)

Affiliation: Kierpenheurinstitut für Sonnenphysik (1)

Type of communication: Poster

Abstract

Borrero et al. (2010) discovered blue shifted Stokes V profiles in quiet Sun IMAX data from the first SUNRISE flight. Those events are connected to strong, possibly supersonic magnetic upflows. They have been subject to further investigations by several authors (e.g. Quintero Noda et al. 2014; Rubio da Costa et al. 2015). Method. I will show quiet Sun data, observed with the IBIS instrument at the Dunn Solar Telescope. I have two time series, each covering the FeI 6173 Å line A for 30 minutes at two different heliocentric angles. The spectral line was sampled at nine wavelength positions, all four components of the Stokes vector were observed. Spatial sampling is about 0.1"/pixel. Possible candidates for supersonic flows were selected using a threshold in the continuum measurement of the Stokes V signal. Those profiles are strongly asymmetric. The Stokes profiles of those events were inverted using the SIR (Stokes Inversion based on Response Function) code. Results. A statistical analysis of life times, sizes and probability density for the events will be presented. Further I will discuss SIR inversion results for the magnetic upflow events, i.e. a possible underlying atmospheric structure. Gradients in both line of sight velocity and magnetic field strength are needed to invert the observed profiles.

Session 4
Solar Chromosphere, Transition Region,
and Corona

Session 4

Contribution #: 37

Title: Spectropolarimetry of the solar chromosphere

Authors: Andreas Lagg (1), GREGOR GRIS Team

Affiliation: Max Planck Institute for Solar System Research (1)

Type of communication: Invited review

Abstract

Only a few spectral lines are currently used to probe the magnetic field in the solar chromosphere. Among those lines the He I triplet at 1083 nm takes an exceptional position: It's special formation process, requiring coronal ultra-violet radiation to populate the ground-state of ortho-Helium, removes any photospheric contamination in this line. The absorption is limited to a narrow slab in the chromosphere, allowing the usage of rather simple models for the radiative transfer. The combined action of Zeeman and Hanle effect permits magnetic field measurements over a wide range of magnetic field strengths, from several Gauss up to the kilo-Gauss regime. The instrumental development for observations in this line allow to exploit the potential of the He I triplet with unprecedented detail. A resolution down to 200 km can be achieved with the spectrographs at the largest solar telescopes currently available (GREGOR and NST). In this talk I will present a selection of high-quality spectropolarimetric observations in the He 1083 nm triplet.

Session 4

Contribution #: 38

Title: Magnetic Fields in Solar Prominences

Authors: Arturo López Ariste (1)

Affiliation: IRAP – CNRS (1)

Type of communication: Invited review

Abstract

Magnetic fields have been reliably measured in prominences for about 20 years. While it is common to associate magnetic field measurements in the Sun to the Zeeman effect, prominences stand out as the only place where the Hanle effect is reliably used to measure magnetic fields. I will give a brief Abstract of how this is done and review recent results of measurements in active region filaments, of high resolution images and of the permanent discussion on the actual inclination of the magnetic field in different prominence parts: body, feet, tornados and other plasma formations.

Session 4

Contribution #: 39

Title: non-LTE chromospheric diagnostics and inversions in flux-emerging regions

Authors: Jaime de la Cruz Rodríguez (1), Viggo Hansteen (2), Luis Bellot Rubio (3), Ada Ortiz (3)

Affiliation: Institute for Solar Physics (Stockholm University) (1), Institute for Theoretical Astrophysics (University of Oslo) (2), Instituto de Astrofísica de Andalucía (3)

Type of communication: Oral contribution

Abstract

Magnetic flux emergence into the outer layers of the Sun is a fundamental mechanism for releasing energy into the chromosphere and the corona. In this paper, we study the emergence of granular-sized flux concentrations and the structuring of the corresponding physical parameters and atmospheric diagnostics in the upper photosphere and in the chromosphere. We make use of a realistic 3D MHD simulation of the outer layers of the Sun to study the formation of the Ca II 8542 line. We also derive semi-empirical 3D models from non-LTE inversions of our observations. These models contain depth dependent information of the temperature and line-of-sight stratification. Our analysis explains the peculiar Ca II 8542 Å profiles observed in the flux-emerging region. We report hints of heating when the field reaches the chromosphere.

Session 4

Contribution #: 40

Title: Design and Status Updates of a Polarimeter for Chromospheric Measurements with SOLIS/VSM

Authors: Sanjay Gosain (1), Jack Harvey (1)

Affiliation: National Solar Observatory (1)

Type of communication: Poster

Abstract

We present design, calibration and test results of the new polarimeter for chromospheric measurements with SOLIS/VSM. The instrument is being developed at National Solar Observatory, Tucson for the upgrade of SOLIS/VSM for full disk chromospheric vector magnetometry. The new modulator unit is based on two ferroelectric liquid crystals (FLCs) and a fast camera for minimizing seeing effects. We will present laboratory test results and simulation of the performance of the polarimeter.

Session 4

Contribution #: 41

Title: Polarimetry of the X1 flare on March 29, 2014

Authors: Lucia Kleint (1), Phil Judge (2)

Affiliation: University of Applied Sciences Northwestern Switzerland (1), HAO/NCAR (2)

Type of communication: Oral contribution

Abstract

Flares occur due to a restructuring of the magnetic field. Studying their polarization signatures in the lower solar atmosphere is therefore a crucial step in their understanding. We analyze the very rich data set of the X1 flare on March 29, 2014, which includes polarimetric data from SDO/HMI (photospheric Fe I 6173 Å line), IBIS (chromospheric Ca II 8542 Å line), and FIRS (chromospheric He I 10830 Å line). The photospheric magnetic field shows step-wise changes in several locations, similar to previous observations of other large flares. The chromospheric data allow us to investigate the presence of anisotropy (particle beams), through their linear polarization signatures and thus to probe models of particle acceleration. We clearly detect atomic polarization in He 10830, in addition to the regular Zeeman pattern, and explore the origins of this polarization, both through radiation and particle collisions. For the Ca 8542 data, we employ simple methods to estimate the yet unknown chromospheric magnetic field during flares.

Session 4

Contribution #: 42

Title: Chromospheric Dichroism in Oxygen Photospheric Lines

Authors: Tanausú del Pino Alemán (1), Javier Trujillo Bueno (1), Rafael Manso Sainz (1)

Affiliation: Instituto de Astrofísica de Canarias

Type of communication: Oral contribution

Abstract

To probe the magnetism of the quiet solar chromosphere we need to observe and model spectral lines whose intensity and polarization are sensitive to the physical properties within such an important atmospheric region. It is commonly believed that to this end we can use only chromospheric lines, like the K line of Ca II. Here we show that the scattering polarization of some photospheric lines encodes information on the chromospheric physical properties. We present spectropolarimetric observations and detailed radiative transfer modeling of the polarization produced by scattering processes and the Hanle and Zeeman effects in the IR triplet of O I around 777 nm. The intensity profiles of these lines originate within the lower photosphere, approximately between 200 km and 300 km in standard semi-empirical models. The same applies to the circular polarization signals produced by the Zeeman effect. Interestingly, the scattering polarization signals observed in the same lines are generated above the photosphere, where elastic collisions with neutral hydrogen atoms are unable to destroy the atomic polarization that anisotropic radiation pumping processes induce in the oxygen levels. The physical origin of the observed scattering polarization signals is the ensuing selective emission and selective absorption (dichroism) of polarization components, which take place entirely within the quiet solar chromosphere (i.e., without any significant photospheric contribution). In particular, the scattering polarization of the longer wavelength line of the oxygen IR triplet is dominated by chromospheric dichroism. The response function of the emergent scattering polarization to magnetic field perturbations peaks around 1000 km above the visible solar surface. All these results are important for developing new diagnostic windows on the magnetism of the quiet solar chromosphere.

Session 4

Contribution #: 43

Title: Spectra of Helium D₃ observed with SST/TRIPPEL

Authors: Tine Libbrecht (1), Dan Kiselman (1), Jaime de la Cruz Rodriguez (1)

Affiliation: Stockholm University

Type of communication: Oral contribution

Abstract

We present high-resolution spectra of the chromospheric He I D₃ line at 5876 Å, observed with SST/TRIPPEL. The lower triplet level of D₃ gets populated via a photoionization-recombination mechanism. Therefore, the line intensity is sensitive to EUV-radiation from the corona and transition region. We investigate the He I D₃ line behaviour for different targets on the sun: flares, active regions, plages, off-limb, etc, and interpret the spectra in context of space-borne co-observations with IRIS and SDO. Moreover, He I D₃ is magnetically sensitive and will be used for high-resolution polarimetric observations with SST/CRISP in the near future.

Contribution #: 44

Title: Modeling the polarization of strong resonance lines in the general Hanle-Zeeman regime

Authors: Ernest Alsina Ballester (1), Luca Belluzzi (2), Javier Trujillo Bueno (1)

Affiliation: Instituto de Astrofísica de Canarias (1), Istituto Ricerche Solari Locarno (IRSOL) (2)

Type of communication: Poster

Abstract

The intensity and polarization of strong resonance lines, like Sr II 4077 Å and Ba II 4554 Å, encode precious information on the physical properties of the solar atmosphere, including its magnetic field. Their radiative transfer modeling is, however, rather complicated because of the key role played by several mechanisms, such as partial frequency redistribution (PRD), atomic level polarization, and the combined action of the Hanle and Zeeman effects. Typically, the PRD problem is solved either in the weak field limit of the Hanle effect regime or neglecting atomic level polarization in the strong field limit of the Zeeman effect. Here we outline the first steps of a research project whose goal is to develop and apply a non-LTE radiative transfer code capable of computing the PRD Stokes profiles of strong resonance lines in the general Hanle-Zeeman regime. A preliminary application to the Sr II 4077 Å line is presented.

Session 4

Contribution #: 45

Title: Peacock jets above a light bridge of a sunspot

Authors: Carolina Robustini (1), Jorrit Leenaarts (1), Jaime De La Cruz Rodriguez (1)

Affiliation: Stockholm University (1)

Type of communication: Poster

Abstract

In this poster will be presented a research about long-scale jets observed above the light bridge of a sunspot. These jets are visible in the H-alpha line and appear as a series of contiguous jets (Peacock jets), reminiscent of a peacock tail. The dynamics of these jets is studied by means of geometric argumentations applied to H-alpha images obtained with CRisp Imaging SpectroPolarimeter at the Swedish 1-m Solar Telescope. The temperature in the regions of interest is investigated through the method of the differential emission measure applied to images from seven non-photospheric channels of the Atmospheric Imaging Assembly from the Solar Dynamics Observatory.

Session 5
Polarization in the Solar System and
Exoplanetary Systems

Contribution #: 46

Title: Polarization of the jovian planets

Authors: Robert West (1)

Affiliation: Jet Propulsion Lab, Caltech (1)

Type of communication: Invited review

Abstract

Interest in measurement of the polarization of the jovian planets (including Saturn's rings and satellite Titan) has a decades-long history and continues to this day. Polarization information from an instrument near the earth is limited by a small range of scattering angles near the back scattering direction. Nevertheless some information at intermediate scattering angles can be gained by examining the angle of linear polarization near the planetary limb. Ground-based observations also have the potential to reveal temporal variations in atmospheric properties (polarizing properties of aerosols and their distribution with latitude and altitude). Spacecraft observations provide access to a greater range of scattering angles and wavelengths, but over a more limited time span. Spacecraft observations at intermediate scattering angles show mostly negative polarization in the 'ammonia ice' cloud layer near the top of the troposphere, and strong positive polarization in the polar stratospheric haze. The strong positive polarization, coupled with strong forward scattering implies that the polar stratospheric particles are fractal aggregates or small monomers. Their association with auroral regions implicates auroral energy deposition and confinement by the circumpolar zonal jets. In mid and low latitudes the particles show no signatures of spherical shape, consistent with expectation of their crystalline nature. Spatially-resolved center-to-limb observations are also helpful in constraining pressure levels where the clouds reside. Titan's extensive atmospheric haze is highly polarized and strongly forward scattering and these features are key to identification of aggregates of many (~4000) small (40 nm radius) primary particles. Saturn's rings have weak polarization features similar to those for solid surfaces (asteroids) but with a mixture of finer grains. This work was performed by the Jet Propulsion Laboratory, California Institute of Technology.

Session 5

Contribution #: 47

Title: Optical linear polarimetric observations of Jupiter and Saturn using a Wedged Double Wollaston

Authors: Javier Gorosabel (1), Ricardo Hueso (2), Antonio García-Muñoz (3), Agustín Sánchez-Lavega (2), Santiago Pérez-Hoyos (2), Alberto García-Prieto (2)

Affiliation: IAA-CSIC (1), UPV/EHU (2), ESTEC-ESA (3)

Type of communication: Oral contribution

Abstract

The solar radiation on a planetary atmosphere is scattered and polarized by gases and suspended particles. Jupiter and Saturn are fully covered by complex systems of clouds and hazes with a vertical structure that is a function of time and atmospheric dynamics. In polarimetric observations of Jupiter and Saturn the degree of polarization depends on wavelength, viewing geometry (phase angle and distance to the planets central meridian) and location on the planetary disk (longitude and latitude and structure of the clouds and hazes at that location). In both planets the polar and equatorial regions are covered by high hazes which are formed by auroral and photochemical processes. Observations in the ultraviolet (380-410 nm) and at the strong methane absorption band of 890 nm are sensitive to the upper hazes formed by small size particles while at red wavelengths (600-950 nm), solar radiation reaches the upper cloud layer. Therefore, a combination of observations at the range of wavelengths from the uv to 890 nm allows to characterize the upper aerosols and lower clouds. We report on polarimetric observations of Jupiter and Saturn that we have carried out over 2014 with a Wedged Double Wollaston (WeDoWo) prism [1] attached to the ALFOSC instrument, currently mounted at the 2.5m Nordic Optical Telescope (NOT) [2]. Observations were obtained under a variety of filters and attain a spatial resolution limited by the atmospheric seeing. Maximum degree of linear polarization is of the order of a few percent well above the expected accuracy of the WeDoWo (<0.7%). We present full maps of linear polarization in Jupiter and partial strips of 10 arc sec wide covering Saturn from one pole to the other. On the long-term, polarization observations combined with photometric reflectivity data, on different dates allow to follow the changes in particles optical properties as a function of atmospheric dynamics. Additionally, the observations are compared to models of the multiply scattered radiation from the planet atmospheres. For that purpose, we are using a Pre-conditioned Backward Monte Carlo (PBMC) algorithm [3] that computes the full Stokes vector for multiple scattering. Finally, the WeDoWo prism is well suited for polarimetric observations of other Solar System objects and a variety of astrophysical objects.

[1] Oliva, E. Wedged double Wollaston, a device for single shot polarimetric measurement. *A&AS* 123, 589–592 (1997).

[2] Gorosabel et al. Optical linear polarimetric observations of Solar System bodies using a Wedged Double Wollaston, EPSC Conference (2014).

[3] García Muñoz, A. & Mills, F.P. Pre-conditioned Backward Monte Carlo solutions to radiative transport in planetary atmospheres. *A&A* 573, A72, (2015)

Session 5

Contribution #: 48

Title: Towards measuring the magnetic field of Mercury with spectropolarimetry

Authors: Arturo Lopez Ariste (1)

Affiliation: IRAP – CNRS (1)

Type of communication: Oral contribution

Abstract

Mercury is shrouded in a tenuous exosphere, mostly the result of sputtering from the solar wind. With THEMIS we have been observing this exosphere for the last 10 years and described its seasons and its interaction with solar magnetic storms. We have also measured the resonance scattering polarization of the Na D lines emitted by this exosphere. I will present these measurements in the path towards measuring the magnetic field of Mercury by the detection of the Hanle effect on those polarization signatures

Session 5

Contribution #: 49

Title: Polarimetry of the small bodies of the solar system

Authors: S. Bagnulo (1), I. Belskaya, Alberto Cellino (2), Ludmilla Kolokolova (3), Gian Paolo Tozzi (4)

Affiliation: Armagh Observatory (1), INAF - Osservatorio Astrofisico di Torino (2), University of Maryland (3), INAF - Osservatorio Astrofisico di Arcetri (4)

Type of communication: Invited review

Abstract

Polarimetric techniques are routinely used to characterise the surface properties and atmospheric features of the objects of the solar system. By studying the variation of polarization as a function of phase angle (the angle between the Sun, the object and the observer) one can for instance estimate the albedo of the asteroids, and infer some information on the properties of the surface regolith. During the last decade, the scope of polarimetric measurements of the objects of our solar system has substantially expanded. Faint objects such as cometary nuclei and transneptunian objects -- that in the pre-VLT era were out of reach of our telescopes -- are now commonly included in the target list of the observing programmes. At the same time, it is also understood that polarimetry of atmosphere-less bodies offers stronger constraints than simple albedo estimates, providing information on the properties of the surfaces which are useful for both mineralogical interpretation and taxonomic classification. New spectropolarimetric investigations promise to produce some important developments. Studies of cometary dust require spatially resolved observations, e.g., CCD images, as cometary dust has different characteristics at different distances from the nucleus and in different morphological features (e.g. jets, fans, shells, etc). In this talk we will summarise what we have learnt from polarimetric observations so far, and which problems future observations should address.

Session 5

Contribution #: 50

Title: Some interesting features of light scattering from grains to regolith

Authors: Gordon Videen (1), Karri Muinonen (2), Evgenij Zubko (3), Yuriy Shkuratov (3)

Affiliation: Space Science Institute (1), Helsinki University (2), Kharkov University (3)

Type of communication: Oral contribution

Abstract

Over the past several years, we have considered light scattering from several types of irregularly systems that approximate what we might expect to see in the solar system. We have considered highly irregular particles and irregular regolith. These studies have not only shown us that the light scattered from these systems is vastly different, but also has led to a number of conclusions relevant to acquiring information about these systems.

Session 5

Contribution #: 51

Title: Experimental scattering matrices of lunar dust simulant at 488nm and 520nm

Authors: Jesús Escobar (1), Olga Muñoz (1), Daniel Guirado (1), Fernando Moreno (1), José Luis Ramos (1), Edward J. Garboczi (2), Jay D. Goguen (3)

Affiliation: Instituto de Astrofísica de Andalucía (1), Material Measurement Laboratory (National Institute of Standards and Technology) (2), Jet Propulsion Laboratory (California Institute of Technology)(3)

Type of communication: Oral contribution

Abstract

The Moon has been observed using polarimetric surveys during years. A good example are the polarimetric maps taken by Shkuratov et al. (2008) [1], Opanasenko et al. (2008) [2], or the study of the light-scattering properties of the lunar mare areas with AMIE camera on board the SMART-1 spacecraft [3]. Recently, disk-integrated linear polarization spectra of Earthshine, (sunlight that has been first reflected by Earth and then reflected back to Earth by the Moon) has been proposed as a powerful diagnostic tool for detecting biosignatures in exoplanets atmospheres [4]. In spite of being observed for many years, an accurate characterization of the wavelength dependence of the lunar depolarization factor is still missing. In this work we will present measurements of the 4x4 full scattering matrix as a function of the scattering angle of the so-called JSC-1A lunar dust simulant, where JSC stands for the Johnson Space Center. Sample JSC-1A is a lunar stimulant of low-Ti mare regolith soil produced to support NASA's future exploration of the lunar surface [5]. Its lunar analog is Lunar Soil 14163 that was collected at the end of the first EVA (extra vehicular activity) on Apollo 14 (January 31, 1971 – February 9, 1971) [6]. JSC- 1A has been developed from a volcanic basaltic ash deposit located at Merriam Crater (San Francisco). The particle shape of this simulant has been studied by E.J. Garboczi[7]. The experimental scattering matrices of the JSC-1A sample has been performed at the Cosmic Dust Laboratory (CoDuLab) [8] at two different wavelengths (488 and 520 nm) covering the scattering angle range from 3 to 177 degrees. We conduct special tests to check that our measurements refer only to single scattering conditions.

[1] Yu. Shkuratov, N. Opanasenko, A. Opanasenko, E. Zubko, S. Bondarenko, V. Kaydash, G. Videen, Yu. Velikodsky, V. Korokhin, *Icarus*, 198, 1–6, (2008)

[2] N. V. Opanasenko, A. N. Opanasenko, Yu. G. Shkuratov, V. G. Kaydash, Yu. I. Velikodsky, V. V. Korokhin, *Solar System Research*, 43, 3, 210–214, (2009)

[3] O. Wilkman, K. Muinonen, G. Videen, J.-L. Josset, A. Souchon, SMART-1/AMIE team, *Journal of Quantitative Spectroscopy & Radiative Transfer*, 146, 529- 539, (2014)

[4] M. F. Sterzik, S. Bagnulo, E. Palle, *Nature*, 483, 64-66, (2012)

[5] www.orbitec.com/store/JSC1A_Bulk_Data_Characterization.pdf

[6] <http://curator.jsc.nasa.gov/lunar/lsc/14163.pdf>

[7] E.J. Garboczi, *Powder Technology*, 207, 96–103, (2011)

[8] O. Muñoz, F. Moreno, D. Guirado, J. L. Ramos, A. López, F. Girela, J. M. Jerónimo, L. P. Costillo, I. Bustamante, *Journal of Quantitative Spectroscopy & Radiative Transfer*, 111, 187-196, (2010)

Session 5

Contribution #: 52

Title: Characterizing exoplanets through polarimetry

Authors: D. Stam

Affiliation:

Type of communication: Invited review

Session 5

Contribution #: 53

Title: Polarization in exoplanetary systems caused by transit, grazing transit and starspot

Authors: Nadiia M. Kostogryz (1), Taras M. Yakobchuk (2), Svetlana V. Berdyugina (3)

Affiliation: Kiepenheuer-Institut fuer Sonnenphysik (1), Main Astronomical Observatory of NAS of Ukraine (2), Kiepenheuer-Institut fuer Sonnenphysik (3)

Type of communication: Oral contribution

Abstract

We present results of numerical simulations of flux and linear polarization variations in transiting exoplanetary systems, caused by the host star disk symmetry breaking. Different configurations of planetary transits depending on orbital parameters were considered. Starspot contribution to the polarized signal is also estimated. Applying the method to known systems and simulating observational conditions, a number of targets are selected where transit polarization effects could be detected. We investigate several principal benefits of the transit polarimetry, particularly, determining orbital spatial orientation and distinguishing between the grazing and near-grazing planets. Simulations show that polarization parameters are also sensitive to starspots, and they can be used to determine spot positions and sizes.

Session 6

Stellar Magnetic Fields

Session 6

Contribution #: 54

Title: Stellar surface magnetic fields across the HR diagram

Authors: Oleg Kochukhov (1)

Affiliation: Uppsala University (1)

Type of communication: Invited review

Abstract

Magnetic fields are believed to play an important role at many stages of stellar evolution. However, direct diagnostic of stellar surface magnetic fields is a challenging task due to a weakness of typical magnetic field signatures in stellar spectra and the necessity to use highly specialised observational techniques to detect and characterise the fields. Thanks to recent development of several high-resolution spectropolarimeters, systematic observations of Zeeman effect in stellar spectra have been become possible for many types of stars across the HR diagram. In this review talk I summarise this recent progress and discuss implications of these studies for our understanding of stellar magnetism.

Session 6

Contribution #: 55

Title: Magnetic fields of massive stars

Authors: Gregg Wade (1)

Affiliation: RMC (1)

Type of communication: Invited review

Abstract

In this talk we summarize the known magnetic properties of hot, massive B and O stars. We review the methods used to detect and measure their magnetic fields, and the limitations of those methods. We discuss outstanding questions related to the interaction of magnetic fields with radiatively-driven stellar winds, scenarios explaining the origin of the magnetic fields, and the broader impacts of fields on the evolution of massive stars and their remnants.

Session 6

Contribution #: 56

Title: New insights into the origin and strength of magnetic fields in OB-type stars

Authors: Svetlana Hubrig (1), Markus Schoeller (2), Alexander Kholtygin (3), Lidia Oskinova (4), Thorsten Carroll (1)

Affiliation: Leibniz-Institut fuer Astrophysik Potsdam (AIP)(1), ESO (2), Astronomical Institute (St Petersburg State University) (3), Universität Potsdam, Institut für Physik und Astronomie (4)

Type of communication: Invited review

Abstract

Substantial progress has been achieved over the last decade in the methods of stellar magnetic field measurements. I will review these methods applied in different magnetic surveys of early B- and O-type stars. The results on the magnetic field characteristics of massive stars obtained by various surveys will be compared. Studies of the presence of magnetic fields in both cluster and field stars suggest further directions of investigations to be followed in view of answering the question of the field origin in this type of stars.

Session 6

Contribution #: 57

Title: The origin and role of magnetic fields in Herbig Ae/Be stars – a key to understand intermediate-mass star formation.

Authors: Markus Schoeller (1)

Affiliation: European Southern Observatory (1)

Type of communication: Oral contribution

Abstract

Magnetic fields are important ingredients of intermediate-mass star formation and accretion-ejection processes. Models of magnetically driven accretion and outflows successfully reproduce many observational properties of low-mass pre-main sequence stars, the classical T Tauri stars, but the picture is completely unclear for higher-mass stars, the Herbig Ae/Be stars, due to the poor knowledge of their magnetic field topology. Obviously, magnetic field configurations are of utmost importance to understand the magnetospheres of Herbig Ae/Be stars. We present our recent results of magnetic field measurements using largely improved sensitivity of our methods indispensable for the detection of the rather weak magnetic fields in this type of stars.