Program & Abstracts

MPS

Solar Polarization Workshop 9

Göttingen, August 26 - 30, 2019

Contents

Conference webpage

https://www.mps.mpg.de/spw9

This booklet contains the detailed program as of August 14th. You will find additional and updated information on the conference website. You can get there by scanning the QR-code on the right.

On behalf of the organizing committees of the Solar Polarization Workshop #9, it is our pleasure to welcome you at the Max-Planck-Institut für Sonnensystemforschung (MPS) in Göttingen, Germany!

Following the concept of the Solar Polarization Workshop (SPW) series, which started in 1995 in St. Petersburg, the 9th edition of this workshop will be dedicated to all aspects of measuring, understanding, and interpreting the polarization of sunlight.

As such, SPW9 is not per se a workshop on solar magnetometry, but rather a platform to discuss the physical, technical, and computational foundations of magnetometry of our star.

In the 9th episode of SPW, which happens right at the dawn of a new era of solar observing facilities on ground and in space, we want to draw a picture of the state-of-the-art of solar polarimetry.

The main emphasis will be the identification of our current limitations and of the necessary intellectual and technical investments, which bring us in line with the enormous challenges in our attempts to measure and interpret polarization in a parameter regime, which so far has been hidden from our views, but which will be accessible with our new infrastructure.

The workshop aims in detecting - and if possible solving – current inconsistencies between modelling and observations. It will set the scene for reviewing the current state and necessary developments in the full chain of solar spectro-polarimetry: physical foundations of light-matter-interaction, 3D-radiative transfer of polarized light, novel technical concepts for measuring polarization, and data analysis in times of “big data” in solar physics.

Synergies between solar polarimetry and the polarimetry of stars will also be assessed during the workshop by a special session on polarimetry of cool stars.

We wish you an inspiring and productive conference and a pleasant stay in Göttingen!

Achim Gandorfer

Andreas Lagg

Sebastián Castellanos Durán

Scientific organizing committee

Achim Gandorfer (MPS, Chair)
Sami K. Solanki (MPS)
Valentin Martinez Pillet (NSO)
Jan O. Stenflo (IRSOL)
Marianne Faurobert (OCA)
Kanakatte Nanjundarao Nagendra (IIA)
Juan Manuel Borrero (KIS)
Manolo Collados (IAC)
Yukio Katsukawa (NAOJ)
Marco Romoli (INAF)
Pascal Petit (OMP)

Local organizing committee

Andreas Lagg (Chair)
Sebastián Castellanos Durán (Co-chair)
Sibylla Siebert-Rust (Secretary)
Björn Löptien
Hans-Peter Doerr
Sowmya Krishnamurthy
Franziska Zeuner
Philipp Löschl

Local support group

Helga Washausen
Birgit Krummheuer
Claudia Rudolph
Ines Dominitzki
Susanne Kaufmann
Grit Kolleck
Tanja Macke
Andrea Vogt
Johanna Wagner-Farssi
MegaGauss Band
Restaurant at the end of the universe
Solar lower atmosphere and magnetism group

Conference venue

Max-Planck-Institut für Sonnensystemforschung
Justus-von-Liebig-Weg 3, 37077, Göttingen

The talks will be held in the Gauss auditorium located in the first floor of the MPS building. The posters will be on display in the ground floor foyer throughout the conference.

WiFi access

Wireless network is available in all rooms of the MPS building. If you do not have access to **eduroam** you may ask for a guest voucher for WiFi at the registration desk.

Guided tours

Guided tours through the facilities at the Max-Planck-Institut für Sonnensystemforschung will be offered on request. There will also be opportunities for short excursions within Göttingen on Wednesday afternoon.

The number of participants for all guided tours will be limited. Please, enscribe in the lists provided at the registration desk.

Food and beverage

Lunch will be provided on all days of the conference. The welcome reception on Monday includes only finger food. On Tuesday we will have an extended poster session with some drinks and more, directly after the afternoon session. The conference dinner takes place on Thursday at the old botanical garden. Coffee breaks are included in the registration fee.

Transport

MPS is within 3 minutes walk from the bus station **Kellnerweg**. From the city, the bus lines **21/22** towards Nikolausberg and **23** towards Faßberg arrive at the bus stop **Kellnerweg**.

The city railway station (Bahnhof) can be reached via the bus lines **21** towards Zietenterrassen and **23** towards Bahnhof. The bus line **22** towards Charlottenburger Straße takes you to the city center (which can also be reached in a few minutes by foot from the railway station).

T-shirts

MPS T-shirts in sizes from S to XXL are available for purchase at the reception.

Emergency contacts

Inside MPS: +49 (551) 384-979-222 (or 222 from any internal phone)

External: 112

Dr. Thomas R. Metcalf was widely respected for his work in the observation, analysis, and interpretation of solar magnetic fields, as well as solar flare hard x-ray imaging and energetics. A patient mentor, Tom helped establish an undergraduate summer research program in Boulder, Colorado, and he expertly advised post-docs and graduate students through the years. He was a prolific researcher who has been described as "one of the nicest guys in science." Dr. Metcalf passed away in July, 2007 at the age of 45. In consultation with Dr. Metcalf's family, the Solar Physics Division (SPD) has established the Thomas Metcalf SPD Travel Fund. The fund helps support newer members' expenses for attending meetings relevant to solar physics. The Scientific Organizing Committee of SPW9 has elected two young scientists as Metcalf lecturers at the workshop: Dr. Francisco Iglesias and Dr. Gabriel Dima. Congratulations! We all are looking forward to your talks!

Francisco A. Iglesias

Gabriel Dima

Monday, 26 August 2019

New infrastructure for solar polarimetry - optical ground based

Chair: Achim Gandorfer

09:00 - 09:15	Welcome address and logistics
09:15 - 10:00	**INVITED REVIEW - Metcalf lecture - Francisco Iglesias: Techniques in solar polarimetry: where are we and what needs to be done**
10:00 - 10:15	Peng Jianguo: Error analysis and system calibration of dual-rotating-retarder Mueller matrix polarimeter
10:15 - 10:30	Horst Balthasar: Polarimetry with the GREGOR Fabry-Pérot Interferometer
10:30 - 11:00	**Coffee & Posters**
11:00 - 11:15	Mikhail Demidov: Solar Synoptic Telescope (SOLSYT): new Russian instrument for solar magnetism research
11:15 - 11:30	Shu Yuan: The simulation of vectorial diffraction imaging of Chinese Giant Solar Telescope
11:30 - 11:45	Rolf Schlichenmaier: EST uniqueness
11:45 - 12:00	Michiel van Noort: MiHI, the Microlensed Hyperspectral Imager

New infrastructure for solar polarimetry – space and non-optical

Chair: Valentin Martinez Pillet

12:00 - 12:30	**HIGHLIGHT - Stacey Sueoka: Polarimetric prospects of DKIST**
12:30 - 14:00	**Lunch & Posters**
14:00 - 14:30	**HIGHLIGHT - Ryohko Ishikawa: The CLASP and CLASP2 Missions**
14:30 - 14:45	Neal Hurlburt: New magnetographs for space-based solar observations
14:45 - 15:00	Andreas Lagg: Sunrise-3: three high-resolution solar spectro-polarimeters in the stratosphere
15:00 - 15:15	Sami Solanki: The Polarimetric and Helioseismic Imager on Solar Orbiter
15:15 - 15:30	Johann Hirzberger: Operating the Polarimetric and Helioseismic Imager on Solar Orbiter (SO/PHI)
15:30 - 16:00	**Coffee & Posters**
16:00 - 16:30	**HIGHLIGHT - Maria Loukitcheva: Radio polarimetry of the Sun in the ALMA era**
16:30 - 16:45	Hemanth Pruthvi: Solar Scanning Polarimeter at Kodaikanal Tower-tunnel Telescope for Ca II 8542 A line
17:00	**Reception**

Tuesday, 27 August 2019

Theory of polarization

Chair: Marianne Faurobert

09:00 - 09:45	**INVITED REVIEW - Luca Belluzzi: Physical processes at the root of solar polarization**
09:45 - 10:00	Svetlana Berdyugina: Preparing for DKIST revolution in solar physics: Think Molecules!
10:00 - 10:15	Helene Frisch: Non-conservative Rayleigh scattering. A perturbation approach
10:15 - 10:30	Kanakatte Nanjundarao Nagendra: Importance of cross-redistribution in scattering polarization of spectral lines
10:30 - 11:00	**Coffee & Posters**
11:00 - 11:15	Jan O. Stenflo: Stokes vectors and Minkowski spacetime: structural parallels
11:15 - 11:30	Megha Anand: Polarized line formation in spherically symmetric expanding atmospheres with weak field Hanle effect
11:30 - 12:00	**HIGHLIGHT - Edgar Carlin: Dichroic variations of Hanle and Zeeman polarization**
12:00 - 12:15	Jose Carlos del Toro Iniesta: Birefringent effects on solid Fabry-Pérot etalons
12:15 - 14:00	**Lunch & Posters**

Theory vs. observations

Chair: Kanakatte Nanjundarao Nagendra

14:00 - 14:45	**INVITED REVIEW - Javier Trujillo Bueno: 95 years after the discovery of the Hanle effect in Göttingen**
14:45 - 15:00	Ernest Alsina Ballester: Magnetic sensitivity in the wings of the linear polarization profiles of the hydrogen Lyman-α line
15:00 - 15:15	Tanausú del Pino Alemán: The polarization of the Mg II h-k doublet and subordinated triplet
15:15 - 15:30	Supriya Hebbur Dayananda: The polarization of the Lyman-α lines of H I and He II in the solar corona
15:30 - 16:00	**Coffee & Posters**

Chair: Jan O. Stenflo

16:00 - 16:15	Masaki Yoshida: Temporal and spatial variation of linear polarization in Lyman-α spicule observed by CLASP
16:15 - 16:30	Rafael Manso Sainz: On the magnetic field observed in the solar transition region
16:30 - 16:45	Michele Bianda: Scattering polarization measurements at GREGOR and IRSOL, some examples and notes
16:45 - 17:00	Emilia Capozzi: Observational hints of magneto-optical effects in the scattering polarization wings of Ca I 4227 A
17:00 - 17:15	Sajal Kumar Dhara: Observations on spatial variations of the Sr I 4607 A scattering polarization signals at different limb distances
17:15 - 17:30	Franziska Zeuner: Evidence for spatially-structured scattering polarization in the photospheric quiet Sun
17:30	**Posters & Drinks / Exhibition**

Wednesday, 28 August 2019

Radiative transfer

Chair: Juan Manuel Borrero

09:00 - 09:45	**INVITED REVIEW - Ivan Milic: NLTE radiative transfer: what did we learn, where are we, and what needs to be done**
09:45 - 10:00	Jaume Bestard: The effects of 3D radiative transfer on the polarization of chromospheric lines
10:00 - 10:15	Gioele Janett: Dealing with discontinuities in numerical radiative transfer
10:15 - 10:30	K. D. Leka: Advances in azimuthal ambiguity resolution for advanced Zeeman spectropolarimetry and inversion
10:30 - 11:00	**Coffee & Posters**
11:00 - 11:45	**INVITED REVIEW - Jaime de la Cruz Rodriguez: Inversions of spectro-polarimetric data: what did we learn, where are we, and what needs to be done**
11:45 - 12:00	Adur Pastor Yabar: Three-dimensional Stokes inversion with magnetohydrostatic constraints
12:00 - 12:15	Tanausú del Pino Alemán: IMP: a multi-D non-LTE radiative transfer inversion code of Stokes profiles
12:15 - 12:30	Juan Carlos Trelles Arjona: 3D quiet Sun multi-line inversions using GRIS at GREGOR infrared spectra
12:30 - 14:00	**Lunch & Posters**

Machine learning & big data

Chair: Michiel van Noort

14:00 - 14:45	**INVITED REVIEW - Andrés Asensio Ramos: Big data in solar polarimetry and the role of machine learning**
14:45 - 15:00	John Armstrong: RADYNVERSION: learning to invert a solar flare atmosphere with invertible neural network
15:00 - 15:15	Ricardo Gafeira: Machine learning initialisation for parallel inversions
15:15	**Excursions**

Thursday, 29 August 2019

Solar phenomena as revealed by polarized light

Chair: Yukio Katsukawa

09:00 - 09:30	**HIGHLIGHT - Tino Riethmüller: The potential of many-line inversions of photospheric spectropolarimetric data in the visible and near UV**
09:30 - 09:45	Azaymi Litzi Siu Tapia: Magnetic properties of short-lived penumbral microjets
09:45 - 10:00	Shahin Jafarzadeh: Magnetic-field topology of fibrillar structures throughout the solar chromosphere
10:00 - 10:15	Véronique Bommier: Would the Sun's photosphere be negatively charged and magnetised?
10:15 - 10:30	María Jesús Martínez Gonzáles: The quiet magnetism as inferred with complex atmospheres
10:30 - 11:15	**Coffee & Posters**
11:15 - 11:30	Alexander Pietrow: Deep polarimetry of a plage region
11:30 - 11:45	Sudarshan Saranathan: Atmospheric stratification in an active region plage
11:45 - 12:00	Christoph Kuckein: A case study of three magnetic bright points observed with GREGOR
12:00 - 12:15	Horst Balthasar: Magnetic field and dynamics of a pore with a lightbridge
12:15 - 12:30	Mariarita Murabito: From the bottom of the photophere to the middle chromophere: penumbral fine structure
12:30 - 14:00	**Lunch & Posters**

Chair: Andreas Lagg

14:00 - 14:30	**HIGHLIGHT - Metcalf lecture - Gabriel Dima: Coronal polarimetry in the DKIST era: old issues and new ideas**
14:30 - 14:45	Maxim Kramar: 3D reconstruction of the coronal magnetic and thermodynamic structures from ground and space based spectropolarimetric observations
14:45 - 15:00	Yusuke Kawabata: Chromospheric magnetic field: A comparison of He I 10830 observations with nonlinear force-free field extrapolation
15:00 - 15:15	Rahul Yadav: Magnetic and dynamic properties of chromospheric loops
15:15 - 15:30	Sowmya Krishnamurthy: Magnetized chromospheric downflows
15:30 - 16:00	**Coffee & Posters**
16:00 - 16:15	Carlos José Diaz Baso: Chromospheric heating driven by cancellation of flux emergence
16:15 - 16:30	Tine Libbrecht: Polarization of the He I D 3 line in a C-flare
16:30 - 16:45	Mikhail Demidov: Large-scale solar magnetic fields observed with IRmag at Mitaka: comparison of measurements made in different spectral lines and observatories
16:45 - 17:00	Juan Sebastián Castellanos Durán: How close are we to observing one Tesla in the Sun?
20:00	**Conference Dinner**

Friday, 30 August 2019

Polarimetry of active regions

Chair: Andreas Lagg

09:00 - 09:15	Philip Lindner: $B_\perp$ at the umbra/penumbra boundary of stable sunspots observed in the near infrared
09:15 - 09:30	Björn Löptien: Relating the magnetic field strength with the umbra-penumbra boundary in sunspots
09:30 - 09:45	Salvo Guglielmino: Spectro-polarimetric analysis of an umbral filament
09:45 - 10:00	Nazaret Bello González: New insights on penumbra formation from observations and STAGGER simulations
10:00 - 10:45	**Coffee & Posters**

Polarimetry of stars & synergies to solar polarimetry

Chair: Alexander Shapiro

10:45 - 11:30	**INVITED REVIEW - Arturo López Ariste: Doing solar physics on other stars**
11:30 - 11:45	Manuele Gangi: The first "Second Solar Spectrum"-like behaviour ever observed in a star different than the Sun: the post-AGB binary 89 Herculis
11:45 - 12:00	María Jesús Martínez González: Measuring magnetic fields in stellar prominences with MIRADAS@GTC
12:00 - 12:15	Mayukh Panja: Spectral synthesis of simulated starspots
12:15 - 13:00	**Jan O. Stenflo: Wrap up / General Discussion**
13:00	**Lunch**

Part I

New infrastructure for solar polarimetry - optical ground based

1 Techniques in solar polarimetry: where are we and what needs to be done

F. A. Iglesias[1], and A. Feller[2]

[1] *Universidad Tecnológica Nacional, CONICET, CEDS, Mendoza, Argentina*
[2] *Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany*

Invited review - Metcalf lecture

Instrumentation for imaging solar polarimetry has continuously improved during the last five decades. Besides the complementary radio and high-energy regimes, the combination of optical spectropolarimetry and numeric Stokes inversion is the dominant technique currently used to probe the solar photosphere and chromosphere, particularly their driving magnetic fields. The ubiquitous but relatively small and weak fields in the quiet Sun are believed today to be crucial for answering many open questions in solar physics. Detecting such fields require measurements with simultaneous high resolution and sensitivity. This is a challenging regime because of the trade-offs that appear due to the high dimensionality of the spectropolarimetric data, and the intrinsic signal-to-noise-ratio limitations when imaging rapidly evolving signals, among others. In this talk we review well-established and upcoming instruments, with an emphasis on those aiming for the above-mentioned regime. It is an exciting time to do so because we are at the verge of the 4-m ground observatories era and there have been important advances in related technologies. Above the atmosphere, space missions are venturing away of 1 AU, and rocket and balloon platforms are aiming to do imaging polarimetry in unexplored spectral ranges. All these are pushing spectropolarimeters towards qualitatively novel designs, some highlights are:

- Even though *spectrographs* and *filtergraphs* are a mature technology, they have limitations, some of which are being tackled by the development of integral field solutions and of novel post-facto image restoration techniques. Moreover, an effort is being put on improving efficiency in the UV and IR regimes, and observing many spectral lines simultaneously with increased spatial resolution.
- Dual beam is still the most used *polarization modulation* technique, with crystal-based devices of spread use and recently space qualified. Dual-frequency liquid crystals are being developed to overcome aperture limitations. Few technologies for *snapshot spectropolarimetry* have been proven in astronomy and are being explored in solar physics with limited results. A full-Stokes *spatial modulator*, if available, could achieve this when combined with an integral field spectrometer.
- CMOS *imaging detectors* have made great improvements in the last decade, pushing back CCDs in many upcoming instruments. However, CMOS calibration has proven difficult when very high sensitivity is aimed. Custom sensor designs, such as the one used in ZIMPOL, have proven useful. Novel approaches based on DePFET or polarization cameras are being considered for solar observations.

2 Error analysis and system calibration of dual-rotating-retarder Mueller matrix polarimeter

Peng Jianguo[1,2], and Yuan Shu[2]

[1] *University of Chinese Academy of Sciences*
[2] *Yunnan Observatories, Chinese Academy of Sciences, Kunming, China*

Contributed talk

The 1 m New Vacuum Solar Telescope (NVST) is the largest ground-based solar telescope in China recently. One of its scientific goal is to diagnose the magnetic field on solar surface accurately by spectro-polarimetry and magnetograph. The main problem of these observations is instrumental polarization of telescope, which should be accurately compensated by the polarization calibration of telescope. For this reason, accurate testing of the polarization elements and devices, used for calibration and polarimetric observation, is required in laboratory, and we developed a Mueller matrix measurement system with dual-rotating-retarder, and the desired polarimetric accuracy of the system is 0.005 or higher.

Based on this requirement, the systematic errors caused by the fluctuation of the light source, retardance deviation, the azimuth error of elements, the interferometric fringe of waveplate, the characteristics by incident angle and spatial nonuniformity of waveplate should be considered. In this work, we discuss the above issues and focus on the effect of retardance deviation, the azimuth error of elements, the spatial nonuniformity of waveplate, and present corresponding solutions for these problems. A method of model fitting of air Mueller matrix, which can obtain the retardance and the azimuth angle accurately, is used to calibrate the system. After system calibration, the measurement accuracy of the Mueller matrix measurement system for air is higher than 0.005, which meets the required accuracy. Meanwhile, we found the additional error caused by the spatial nonuniformity of waveplate when the beam does not pass through the center of rotating retarders or the beam intensity is nonuniform. And we proposed two practical ways, one is to improve the quality of the light beam and the other is to use reference sample for calibration, to reduce the error introduced by nonuniformity.

Finally, we used the Mueller matrix measurement system after calibration to measure a real aluminum mirror and a beam splitter, which are used for solar polarization observation. The deviation between the measurement results and the theoretical model is less than 0.004.

3 Polarimetry with the GREGOR Fabry-Pérot Interferometer

H. Balthasar

Leibniz-Institut für Astrophysik Potsdam (AIP), Germany

Contributed talk

The polarimeter of the GREGOR Fabry-Pérot Interferometer (GFPI) has been upgraded in 2018. In addition to two ferroelectric liquid crystal retarders (FLCR), a fix halfwave plate and a fix quarterwave plate have been inserted to achieve high polarimetric efficiencies for the nominal spectral range of the GFPI (530 - 860 nm).

In this contribution I report how the modified polarimeter interacts with the telescope and the installed polarimetric calibration units. This polarimeter can serve as a prototype for the European Solar Telescope (EST).

4 Solar Synoptic Telescope (SOLSYT): new Russian instrument for solar magnetism research

M. L. Demidov[1], V. M. Grigoryev[1], V. I. Skomorovsky[1], L. B. Retyunsky[1], D. Y. Kolobov[1], S. A. Chuprakov[1], I. V. Russkich[1], A. V. Kiselev[1], V. E. Tomin[1], A. K. Kitov[1], S. A. Denisenko[2], Yu. D. Pimenov[2], and N. A. Lipin[2]

[1] *Institute of Solar-Terrestrial Physics of Siberian Branch of Russian Academy of Sciences (ISTP SB RAS), Lermontov str., 126-a. Irkutsk, 664033, Russia.*
[2] *LOMO JSC, Chugunnaya Str., 20, 194044, Saint Petersburg, Russia.*

Contributed talk

To create a modern telescope capable of performing the full-disk and full-vector measurements with high spatial and temporal resolution, a few years ago at ISTP SB RAS (Irkutsk) in cooperation with LOMO JSC (St.Petersburg) were started works on the development and construction of a new solar instrument in Russia, which, based on its main scientific goals (regular systematic measurements of all four Stokes profiles in several spectral lines in the wide range of wavelengths from visible to infrared with 2 arc sec spatial resolution), was named the SOlar SYnoptic Telescope (SOLSYT). In some aspects SOLSYT can be considered as an analogue of the well-known SOLIS VSM. The similarity is related as to output information and to some design elements such as giving up the coelostat and using the parallactic mounting, and add-on high-dispersion spectrograph. The distinctive feature of SOLSYT is the using for the first time in solar observations in Russia of off-axis optical configuration (Gregory-Mersenne scheme) which differs by some substantial advantages as compared with classic axial-symmetric scheme. In 2017 the main opto-mechanical units of SOLSYT was installed in a specially constructed tower at the Baikal Astrophysical Observatory and in 2019 after assembling all necessary equipment the first observations were made. The talk provides basic information about the optical layout and the structural elements of SOLSYT.

5 The simulation of vectorial diffraction imaging of Chinese Giant Solar Telescope

Shu Yuan[1], Yu Fu[1], Igor DiVarano[2], Zhenyu Kim[1], and Zhong Liu[1]

[1] *Yunnan Observatories, Chinese Academy of Sciences, Kunming, China*
[2] *Leibniz-Institut für Astrophysik Potsdam (AIP), Germany*

Contributed talk

Near-diffraction-limited polarimetry with high accuracy will be pursued by 8m Chinese Giant Solar Telescope (CGST) in future, targeting the finest magneto-hydrodynamic process on the sun. The vectorial diffraction imaging property of telescope is investigated to discuss the contradiction between spatial resolution and polarimetric accuracy for such kind of large solar telescope. The point spread matrix (PSM) is used to characterize this vectorial property of telescope, and a numerical method was developed to simulate the PSM for arbitrary asymmetric optical system. Based on the resulted PSM at the Coudé focus, an observational simulation of small-scale magnetoconvection on the sun is implemented for evaluating the performance of diffraction-limited polarimetry by recent optical design of the telescope. The vectorial imaging property of recent design at the Coudé focus is remarkable, which is resulted by the polarization aberration caused by metal reflection of folding mirrors in the Coudé trains. The anti-symmetric profile in the first column of PSM lead to a non-negligible spurious polarization (SP) in the output images of Stokes Q and U. The pattern of SP is relative to the structure of scalar image and spectral line of the target, which has a feature of high spatial frequency. Theoretically, the maximum of SP define the final polarimetric accuracy of telescope. The largest SP in our observational simulation is 2.3e-3 , which can be suppressed by sacrificing the spatial resolution. According to this research, a techniques of vectorial image reconstruction should be developed for achieving the desired near-diffraction-limited polarimetry in future.

6 EST uniqueness

Rolf Schlichenmaier[1], Oskar von der Lühe[1], and the EST Science Advisory Group[2]

[1] *Leibniz-Institut für Sonnenphysik (KIS), Freiburg, Germany*
[2] *EST SAG members weblink at: WWW.EST-EAST.EU*

Contributed talk

The European Solar Telescope (EST) is a research infrastructure for solar physics and is planned to be an on-axis solar telescope with an aperture of 4 m equipped with an innovative suite of spectro-polarimetric and imaging instrumentation. The EST project was initiated and is driven by EAST, the European Association for Solar Telescopes. EAST was founded in 2006 as an association of 14 European countries. Today, as of April 2019, EAST consists of 26 European research institutes from 18 European countries. The EST Science Advisory Group (SAG) has been installed by EAST and the Board of the PRE-EST EU project in November 2017 and has been charged with the task of analysing the final science requirements for EST. Based on the conceptual design, the SRD update will take into account recent technical and scientific developments, to ensure that EST provides significant advancement beyond the current state-of-the-art.

During the preliminary design study 2008-2011, the request of high polarimetric sensitivity and accuracy led an on-axis design with a beam that is polarimetrically compensated. In this talk I attempt to justify this decision and will review the advantages and disadvantages of on-axis and off-axis designs. The off-axis design has the advantage of a clear aperture, such that spiders and obscurations can be avoided. The latter are a necessity for on-axis telescopes. They cause the point-spread function to have extended 'wings', which I will quantify in my presentation. While this can be corrected for in terms of spatial resolution, it slightly decreases the signal-to-noise ratio. However, off-axis telescopes at a given aperture are larger and more heavy than on-axis telescopes. On-axis telescopes being more compact and having less weight can be integrated into higher towers, i.e., further away from ground-layer turbulence that is dominating the seeing, hereby improving the image quality. In contrast to off-axis telescopes, on-axis telescopes can be constructed such that the optical beam is polarimetrically compensated, thereby facilitating the calibration of polarimetric measurements with a gain in terms of sensitivity.

In a second part of my talk, I will review the new technical developments of deformable secondary mirrors that may affect the EST design substantially. Designs without the rotating transfer optics, saving 7 mirrors and reducing the total number of the telescope mirrors to 7 are discussed. Here, I will summarise advantages, disadvantages, and risks.

7 MiHI, the Microlensed Hyperspectral Imager

Michiel van Noort

Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany

Contributed talk

The Microlensed Hyperspectral Imager (MiHI) is a pathfinder next-generation instrument, that strictly simultaneously records spatial and spectra information, at an arbitrary time resolution. Such instruments are necessary to fully exploit the capabilities of the next generation large aperture solar telescopes, such as DKIST and EST. The MiHI is a true integral field spectrograph, that uses microlenses in combination with a dispersive element (grating) to separate the spatial and spectral information and record it on a large format detector. The relatively small number and simple nature of the optical elements needed to accomplish this, result in an efficient and stable instrument, that is suitable for sensitive polarimetric measurements.

The MiHI was developed as a plug-in module for the TRIPPEL spectrograph at the Swedish Solar Telescope (SST) on La Palma, and it delivers diffraction limited imaging performance over a field of view of 7"x8", covering a spectral range of 4 Å, with a spectral resolution of more than 300000, and with a time resolution limited only by the speed of the cameras that are used.

The current instrument is able to operate in the wavelength range from 5800 Å to 6600 Å, containing the Na-D lines, the H-alpha line, and numerous photospheric lines, including the well-studied line FeI line pair at 6301.5 and 6302.5 Å. The instrument has been used in a number of observing campaigns, yielding several high quality time series, covering a number of interesting spectral lines. These data sets clearly demonstrate that the MiHI gives access to a new and previously unexplored regime of high S/N, high cadence data.

Part II

New infrastructure for solar polarimetry – space and non-optical

8 Polarimetric prospects of DKIST

S. Sueoka, and D. Harrington

National Solar Observatory, 22 Ohi'a Ku Street, Makawao, HI, 96768, USA

Highlight

Integration, testing and commissioning phase for the Daniel K. Inouye Solar Telescope (DKIST) is underway at the summit of Haleakala. This presentation will briefly cover the current progress of facility optics and instrument installation and testing. The main focus will be on the progress of polarization systems engineering. I will discuss what we have learned through the combined effort of modeling and polarimetric metrology, and how it impacts the implementation of the telescope polarization calibration.

9 The CLASP and CLASP2 missions

Ryohko Ishikawa[1], Ryouhei Kano[1], Amy Winebarger[2], David McKenzie[2], Javier Trujillo Bueno[3], Frederic Auchere[4], Noriyuki Narukage[1], Takamasa Bando[1], Ken Kobayashi[2], Laurel Rachmeler[2], Donguk Song[1], Masaki Yoshida[1,5], Takenori J. Okamoto[1], and the CLASP and CLASP2 team

[1] *National Astronomical Observatory of Japan, Tokyo, Japan*
[2] *NASA Marshall Space Flight Center*
[3] *Instituto de Astrofísica de Canarias (IAC); 38205 La Laguna; Tenerife; Spain*
[4] *Institut d'Astrophysique Spatiale*
[5] *SOKENDAI (The Graduate University for Advanced Studies)*

Highlight

To obtain quantitative information on the magnetic field in low-β plasma regions of the solar atmosphere (i.e., in the upper chromosphere and above) it is increasingly important to understand energetic phenomena such as flares, the coronal heating, and the acceleration of the solar wind. In the UV range, there are many spectral lines that originate in the upper chromosphere and transition region and whose polarization signals are sensitive to the presence of magnetic fields via the Hanle, Zeeman and magneto-optical effects.
To investigate the capability of UV spectro-polarimetry, the Chromospheric Lyman-Alpha Spectro-Polarimeter (CLASP) was launched on September 3, 2015 by a NASA sounding rocket from White Sands Missile Range in the US. During its 5 minute ballistic flight, it successfully performed spectropolarimetric observations of the hydrogen Lyman-α line (121.57 nm) and the Si III resonance line (120.6 nm) with an unprecedentedly high polarization sensitivity. For the first time, CLASP observed the linear polarization produced by scattering process in VUV lines and detected polarization signals that indicate the operation of the Hanle effect.
Following the success of CLASP, a second sounding rocket experiment called the Chromospheric LAyer SpectroPolarimeter 2 (CLASP2) was launched on April 11 2019 after refitting the CLASP instrument. CLASP2 carried out spectro-polarimeteric observations in the Mg II h & k lines, which are also UV spectral lines of great interest for exploring the magnetic fields of the upper solar chromosphere. One of the advantages of the Mg II h & k lines is that the circular polarization induced by the Zeeman effect is measurable, in addition to the linear polarization caused by scattering processes. This facilitates the determination of both the strength and direction of the magnetic field.
Here we present the technology that allowed us to achieve high-precision UV spectro-polarimetry with CLASP and CLASP2, as well as the measured intensity and polarization spectra in Lyman-α and the Mg II h & k lines. The observed polarization signals encode information on the magnetic fields and geometry of the upper solar chromosphere and transition region. Finally, we discuss our view concerning the challenges of UV spectro-polarimetry to be addressed in the near future.

10 New magnetographs for space-based solar observations

N. Hurlburt

Lockheed Martin Advanced Technology Center

Contributed talk

We present concepts for a new generation of space-based magnetographs. These include a compact adaptation of the Helioseismic and Magnetic Imager currently flying on the Solar Dynamics Observatory and a novel design that leverages recent developments in photonics. Both magnetographs could be flown on small-sat constellations to provide global coverage of the solar magnetic fields.

11 SUNRISE-3: three high-resolution solar spectro-polarimeters in the stratosphere

A. Lagg[1], S. K. Solanki[1], Y. Katsukawa[2], J. C. del Toro Iniesta[3], T. Berkefeld[4], P. Bernasconi[5], and the SUNRISE-3 Consortium[1,2,3,4,5]

[1] *Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany*
[2] *National Astronomical Observatory of Japan, Tokyo, Japan*
[3] *Institute of Astrophysics of Andalusia, Granada, Spain*
[4] *Leibniz-Institut für Sonnenphysik (KIS), Freiburg, Germany*
[5] *Johns Hopkins University Applied Physics Laboratory, Laurel MD, USA*

Contributed talk

After two highly successful flights the balloon-borne solar observatory SUNRISE is undergoing a major refurbishment for its next scientific flight in 2021: The post-focus instrumentation was upgraded with two completely new slit-based spectro-polarimeters for the near ultra-violet (SUSI/MPS) and the near-infrared (SCIP/NAOJ), while the imaging spectro-polarimeter IMAX$^+$ is now capable of observing not only the photosphere, but also the chromosphere. This new instrument suite will not only allow for detailed measurements of the atmospheric parameters from the deep photosphere up to chromospheric heights at a spatial resolution of 70 km with unprecedented height resolution, but also bear a big discovery potential for solar polarimetry in the largely unexplored spectral region from 300 to 400 nm. In this presentation we will highlight some major results of the previous two SUNRISE flights, present an overview of the new SUNRISE-3 instrumentation and the status of the project, and an outlook to the expected scientific return.

SUNRISE-3 is a joint project of the German Max-Planck-Institut für Sonnensystemforschung together with the Spanish SUNRISE-3 consortium, the Johns Hopkins University Applied Physics Laboratory, USA, the National Astronomical Observatory of Japan and the Japan Aerospace eXploration Agency and the German Leibniz Institut für Sonnenphysik.

12 The Polarimetric and Helioseismic Imager on Solar Orbiter

S. K. Solanki[1], A. Gandorfer[1], J. Hirzberger[1], J. Woch[1], J. C. del Toro Iniesta[2], and the So/PHI team

[1] *Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany*
[2] *Instituto de Astrofísica de Andalucía (IAA - CSIC)*

Contributed talk

The Solar Orbiter is the next solar physics mission of the European Space Agency, ESA, in collaboration with NASA, with a launch planned in 2020. The spacecraft is designed to approach the Sun to within 0.28 AU at perihelion of a highly eccentric orbit. The proximity with the Sun will also allow the Sun to be observed at uniformly high resolution at EUV and visible wavelengths. Such observations are central for learning more about the magnetic coupling of the solar atmosphere. At a later phase in the mission the spacecraft will leave the ecliptic and study the enigmatic poles of the Sun from a heliographic latitude of up to 33.5 degrees.

A central instrument of Solar Orbiter is the Polarimetric and Helioseismic Imager, SO/PHI. It will do full Stokes imaging in the Landé g=2.5 Fe I 617.3 nm line. It is composed of two telescopes, a full-disk telescope and a high-resolution telescope, that will allow observations at a resolution as high as 200 km on the solar surface. SO/PHI will also be the first solar polarimeter to leave the Sun-Earth line, opening up new possibilities, such as stereoscopic polarimetry (besides stereoscopic imaging of the photosphere and stereoscopic helioseismology). Finally, SO/PHI will have a unique view of the solar poles, allowing not just more precise and exact measurements of the polar field than possible so far, but also enabling us to follow the dynamics of individual magnetic features at high latitudes and to determine solar surface and sub-surface flows right up to the poles.

In this presentation a brief introduction to the Solar Orbiter mission will be given, followed by the science goals and the capabilities of SO/PHI, as well as a brief overview of the instrument.

13 Operating the Polarimetric and Helioseismic Imager on Solar Orbiter (SO/PHI)

J. Hirzberger[1], A. Gandorfer[1], D. Orozco Suárez[2], S. K. Solanki[1], J. C. del Toro Iniesta[2], and J. Woch[1]

[1] *Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany*
[2] *Instituto de Astrofísica de Andalucía (IAA - CSIC)*

Contributed talk

The Polarimetric and Helioseismic Imager on-board Solar Orbiter (SO/PHI) will be the first solar spectro-polarimeter on a deep-space mission. Because of the highly variable environment and the long command-response times which goes along with low telemetry and high data latency, SO/PHI requires an operating concept which is novel for space based spectro-polarimeters.

SO/PHI will carry out full on-board data processing, consisting of calibration, demodulation and inversion, in an autonomous manner. The thus established operating concept depends on a thorough ground calibration of the instrument and on re-calibrating on-board for the effects introduced by the variable environment. It has to cope with a severely restricted data access from ground and it has to manage the performance limitations and reliability measures relevant for a deep space mission, e.g. power and pointing stability limits or electromagnetic cleanliness requirements.

In this contribution we present an overview of SO/PHI's operating concept, the scientific operating modes and the on-board calibration scheme. We also present an outlook for the content, the format and the expected accuracy of SO/PHI's data products.

14 Radio polarimetry of the Sun in the ALMA era

M. Loukitcheva

Saint Petersburg branch of Special Astrophysical Observatory, Pulkovskoye chaussee 65/1, St. Petersburg 196140, Russia
Saint Petersburg State University, 7/9 Universitetskaya nab., St. Petersburg 199034, Russia
Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany

Highlight

Radio emission is particularly valuable for diagnostics of chromospheric and coronal magnetic fields as the emission mechanisms, such as thermal bremsstrahlung at millimeter wavelengths and gyroresonance emission in the microwaves, depend on magnetic field. In this contribution I review the basic characteristics of radio emission from the quiet Sun and from solar active regions. I discuss the ideas behind the use of radio observations for measuring the magnetic field in the chromopshere and corona, with special emphasis on the future and present-day capabilities of the instruments, operating at radio wavelengths. This work has been supported by Russian RFBR grant 18-29-21016.

15 Solar Scanning Polarimeter at Kodaikanal Tower-tunnel Telescope for Ca II 8542 Å line

Hemanth Pruthvi[1,2], K. Nagaraju[2], and B. Ravindra[2]

[1] *Leibniz-Institut für Sonnenphysik (KIS), Freiburg, Germany*
[2] *Indian Institute of Astrophysics*

Contributed talk

Solar chromospheric magnetic field measurements are crucial in advancing the understanding of energy transport through solar atmosphere and role of magnetic fields in solar dynamics. We present instrumentation aspects of Solar Scanning Polarimeter that is developed for Kodaikanal Tower-tunnel Telescope of Kodaikanal Solar Observatory. It is a full-Stokes polarimeter aimed to produce magnetic field maps of active regions at Chromospheric heights using Zeeman diagnostics of Ca II 8542 Å line. We developed it to be used with the existing high resolution spectrograph and the detector, at the back-end of the telescope. It has integrated linear scanner and polarimetric calibration unit. Waveplates rotating in steps are used for modulation. We developed custom controls and graphical user interface based software for operating the polarimeter. We present polarimetric calibration, observations, data processing and final data. Polarimetric sensitivity is estimated to be 2×10^{-3} per arcsec, which is mainly limited by the detector. Field-of-view along the slit is about 60 arcsec and it takes 13 minutes to scan 36 arcsec region in 60 steps with one second exposure time. We also revisited instrumental polarization model of the Coelostat to explore ways to reduce polarization cross-talk.

Part III

Theory of polarization

16 Physical processes at the root of solar polarization

L. Belluzzi

Istituto Ricerche Solari Locarno

Invited review

Polarization in the solar radiation can be generated and modified through various physical processes. Starting from the most fundamental ones, such as the Zeeman effect and anisotropic optical pumping (giving rise to scattering polarization), the most relevant mechanisms will be reviewed, highlighting their impact and signatures on both theoretical calculations and observations. Particular emphasis will be placed on the physics of scattering polarization. During this overview, the most important theoretical schemes today available for modeling the various processes will also be discussed, pointing out their strengths and limitations.

17 Preparing for DKIST revolution in solar physics: think molecules!

Svetlana V. Berdyugina

Leibniz-Institut für Sonnenphysik (KIS), Freiburg, Germany

Contributed talk

DKI Solar Telescope (DKIST) has a potential to revolutionize our understanding of the Sun and its magnetism, not only because of DKIST's large aperture but also because it will offer simultaneous multiwavelength spectropolarimetric measurements in a wide spectral range. Such data may allow us to unveil magnetic fields and their evolution on the smallest scale ever achieved in four dimensions (space and time). To prepare for this revolution, we carefully select spectral magnetic diagnostics forming at various atmospheric heights in sunspots, small-scale network fields, and in the quiet Sun. It is clear that traditionally employed atomic magnetic diagnostics cannot provide high enough resolution in height that will match the spatial resolution of DKIST imaging data of 20–30 km. In contrast, molecular lines appearing in bands form at a wide range of heights with spacing in height of 20 km and smaller. To fully exploit this powerful diagnostic, we identify molecular and atomic magnetically sensitive lines which can be observed simultaneously with DKIST instruments in order to achieve the 20 km spatial resolution in 3D. Different sets of lines are employed to probe solar magnetic features in the photosphere, chromosphere and corona using Zeeman, Paschen-Back and Hanle effects.

18 Nonconservative Rayleigh scattering. A perturbation approach

H. Frisch

Université Côte d'Azur, Observatoire de la Côte d'Azur, Laboratoire Lagrange

Contributed talk

The linear polarization of the continuous spectra of stellar and planetary atmospheres is due to Rayleigh and/or Thomson scattering. For a plane-parallel atmosphere, the center-to-limb variation of the emergent polarization rate follows the exact Chandrasekhar's law, if there is no destruction of photons by bound-free or free-free transitions.

It will be shown that this center-to-limb variation can be calculated in the more general situation of nonconservative scattering by performing a perturbation analysis of the polarized radiative transfer equation. The small expansion parameter is the ratio $\epsilon = \kappa_c/(\kappa_c + \sigma_c)$, where κ_c and σ_c are the true absorption and scattering coefficients, respectively. A comparison will be shown between the results of the perturbation analysis and numerical solutions of the 1D polarized radiative transfer equation, for constant values of the expansion parameter ϵ. A simple law is proposed to evaluate the deviations from the Chandrasekhar's law and also tests to evaluate the accuracy of numerical codes for values of the expansion parameter up to 10^{-3}. The possibility to generalize the perturbation method to an arbitrary multidimensional geometry will be discussed.

Reference : H. Frisch Nonconservative Rayleigh scattering. A perturbation approach *Astron. Astrophys. (in press)*

19 Importance of cross-redistribution in scattering polarization of spectral lines

K. N. Nagendra, and M. Sampoorna

Indian Institute of Astrophysics, Koramangala, Bengaluru, India

Contributed talk

Scattering on a multi-level atomic system has dominant contributions from resonance and Raman scattering. While initial and final levels are the same for resonance scattering, they are different for Raman scattering. The frequency change for resonance scattering is described by the conventional partial frequency redistribution (PFR) functions of Hummer, while that for Raman scattering is described by cross-redistribution (XRD) function. Here we briefly present our heuristic approach to the problem of polarized line formation in multi-level atoms taking into account the effects of PFR and XRD. We then present the effects of XRD on linear polarization profiles, taking the examples of Ca II H and K and IR triplet lines, and the ^{3}P–^{3}S triplets of Mg I and Ca I formed in an isothermal one-dimensional atmosphere. We show that XRD produces significant effects on the linear polarization profiles when the wavelength separations between the line components of the multiplet are small, like in the cases of Mg I b and Ca I triplets.

20 Stokes vectors and Minkowski spacetime: structural parallels

J. O. Stenflo

Institute for Particle Physics and Astrophysics, ETH Zurich, CH-8093 Zurich, Switzerland
Istituto Ricerche Solari Locarno (IRSOL), Via Patocchi, CH-6605 Locarno, Switzerland

Contributed talk

The Stokes formalism has astounding structural parallels with the formalism used for relativity theory in Minkowski spacetime. The structure and symmetry properties of the Mueller matrices are the same as those for the matrix representations of the electromagnetic tensor and the Lorentz transformation operator: The absorption terms η_k in the Mueller matrix correspond to the electric field components E_k in the electromagnetic tensor and the Lorentz boost terms γ_k in the Lorentz transformation matrix, while the anomalous dispersion terms ρ_k correspond to the magnetic field components B_k and the spatial rotation angles ϕ_k. In a Minkowski-type space spanned by the Stokes I, Q, U, V parameters, the Stokes vector for 100 % polarized light is a null vector living on the surface of null cones, like the energy-momentum vector of massless particles in ordinary Minkowski space. Stokes vectors for partially polarized light live inside the null cones like the momentum vectors for massive particles. In this description the depolarization of Stokes vectors appears as a "mass" term, which has its origin in a symmetry breaking caused by the incoherent superposition of uncorrelated fields or wave packets, without the need to refer to a ubiquitous Higgs field as is done in particle physics. The rotational symmetry of Stokes vectors and Mueller matrices is that of spin-2 objects, in contrast to the spin-1 nature of the electromagnetic field. The reason for this difference is that the Stokes objects have substructure: they are formed from bilinear tensor products between spin-1 objects, the Jones vectors and Jones matrices. The governing physics takes place at the substructure level.

21 Polarized line formation in spherically symmetric expanding atmospheres with weak field Hanle effect

A. Megha[1], M. Sampoorna[1], K. N. Nagendra[1], L. S. Anusha[2], and K. Sankarasubramanian[1,3,4]

[1] *Indian Institute of Astrophysics, Koramangala, Bengaluru, India*
[2] *Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany*
[3] *Space Astronomy group, ISRO Satellite Centre, Bengaluru, India*
[4] *CESSI, IISER, Kolkata, India*

Contributed talk

It is well-known that extended stellar atmospheres cannot be represented by plane-parallel stratification, but to a first approximation by a spherically symmetric medium. Also, these extended stellar atmospheres are known to be dynamic, with low to high speed stellar winds originating in these layers. Furthermore, the magnetic field is known to be a basic physical quantity which plays a significant role in the formation of polarized line profiles. Therefore here we consider the problem of polarized line formation in the spherically symmetric expanding atmospheres in the presence of weak magnetic fields. We consider the effects of velocity fields and extendedness of the spherically symmetric atmospheres on the emergent linearly polarized profiles. However we restrict ourselves to the non-relativistic regime of velocities wherein mainly Doppler shift effects are significant. Thus only Doppler shift terms are considered in the polarized transfer equation and aberration and advection terms are ignored. For the solution of the concerned polarized transfer equation we use the comoving frame formulation, and apply the Accelerated Lambda Iteration (ALI) method. We present the results by considering the scattering on a two-level atom, including the effects of partial frequency redistribution (PFR). The polarized line profiles would be shown for few velocity laws representative of expanding spherical atmospheres and for different magnetic field configurations.

22 Dichroic variations of Hanle and Zeeman polarization

Edgar S. Carlin

Instituto de Astrofísica de Canarias (IAC); 38205 La Laguna; Tenerife; Spain
Istituto Ricerche Solari Locarno (IRSOL)

Highlight

The morphology of spectral line polarization is the most valuable observable to investigate the magnetic and dynamic solar atmosphere. For this reason, it is fundamental to understand the formation of "anomalous" solar signals that are routinely found in linear and circular polarization, both in simulations and observations. Investigating this, one is faced with the problem of describing the balance between emissivity and dichroism in a dynamic magnetized atmosphere. In this talk I shall show how a suitable theoretical description of such a balance in dynamic scenarios can reproduce several solar polarization fingerprints, some of them considered as anomalous. In particular I shall define several properties of dichroism that have remained hidden until now, introducing the novel dichroic conditions. Thus, I shall expose an unexpected relation between dichroism and radiation field anisotropy, and demonstrate how these realizations improve our understanding about the formation of linear and circular polarization in several physical scenarios with atomic polarization and Hanle and Zeeman effects.

23 Birefringent effects on solid Fabry-Pérot etalons

F. J. Bailén, D. Orozco Suárez, and **J. C. del Toro Iniesta**

IAA-CSIC

Contributed talk

Crystalline etalons present several advantages with respect to other types of filtergraphs when employed in magnetographs, especially that they can be tuned by only applying electric fields. However, anisotropic crystalline etalons can also introduce undesired birefringent effects that corrupt the polarization of the incoming light. In particular, uniaxial Fabry-Pérots, such as LiNbO3 etalons, are birefringent when illuminated with an oblique beam. The farther the incidence from the normal, the larger the induced retardance between the two orthogonal polarization states. The application of high voltages, as well as fabrication defects, can also change the direction of the optical axis of the crystal, introducing birefringence even at normal illumination. Here we obtain analytical expressions for the induced retardance and for the Mueller matrix of uniaxial etalons located in both collimated and telecentric configurations. We also evaluate the polarimetric behavior of Z-cut crystalline etalons with the incident angle, with the orientation of the optical axis, and with the f-number of the incident beam for the telecentric case. We study artificial signals produced in the output Stokes vector in the two configurations. Last, we discuss the polarimetric dependence of the imaging response of the etalon for both collimated and telecentric setups.

Part IV

Theory vs. observations

24 95 years after the discovery of the Hanle effect in Göttingen

J. Trujillo Bueno

Instituto de Astrofísica de Canarias (IAC); 38205 La Laguna; Tenerife; Spain

Invited review

In 1924 a young researcher named Wilhelm Hanle published in *Zeitschrift für Physik* the results of his Ph.D. thesis, which he had elaborated in Jame's Franck laboratory of the University of Göttingen. The topic was *Magnetic Field Influence on the Polarization of the Resonance Fluorescence*. Today the effect that bears his name (the Hanle effect) is considered as one of the classical pioneering works in atomic physics. The Hanle effect played an important role in the development of the new quantum mechanics, since it led to the introduction and understanding of the concept of coherent superposition of degenerate Zeeman sublevels by anisotropic radiation pumping. As the Zeeman sublevels are split by the presence of a magnetic field, the degeneracy is lifted and the radiatively-induced coherence modified. This gives rise to a characteristic magnetic-field dependence of the linear polarization of the scattered spectral line radiation that has found novel applications in many branches of physics including astrophysics. This lecture highlights a personal selection of applications in solar physics, emphasizing what have we learned, where are we and what needs to be done in this new era of large-aperture telescopes.

25 Magnetic sensitivity in the wings of the linear polarization profiles of the hydrogen Lyman-α line

Ernest Alsina Ballester[1], Luca Belluzzi[1,2], and Javier Trujillo Bueno[3,4,5]

[1] *Istituto Ricerche Solari Locarno (IRSOL), Switzerland*
[2] *Leibniz-Institut für Sonnenphysik (KIS), Freiburg, Germany*
[3] *Instituto de Astrofísica de Canarias (IAC); 38205 La Laguna; Tenerife; Spain*
[4] *Universidad de la Laguna (ULL), Spain*
[5] *Consejo Superior de Investigaciones Científicas (CSIC), Spain*

Contributed talk

The linear polarization produced by scattering processes in the hydrogen Lyα line of the solar disk radiation is a key observable for probing the chromosphere-corona transition region (TR) and the underlying chromospheric plasma. While the line-center signal encodes information on the magnetic field and the geometry of the TR, the sizable scattering polarization signals that the joint action of partial frequency redistribution and J-state interference produce in the Lyα wings have generally been thought to be insensitive to the magnetic fields of the solar chromosphere. Here we show that the wings of the Q/I and U/I scattering polarization profiles of this line are actually sensitive to the presence of magnetic fields in the solar chromosphere, with strengths similar to those that produce the Hanle effect in the line core (i.e., between 5 and 100 gauss, approximately). In spite of the fact that the Zeeman splitting induced by such weak fields is very small compared to the total width of the line, the magneto-optical effects that couple the transfer equations for Stokes Q and U are actually able to produce sizable changes in the Q/I and U/I wings. Interestingly, chromospheric magnetic fields with longitudinal components larger than about 100 G produce an almost complete depolarization of the wings of the Lyα Q/I profiles within a ± 5 Å spectral range around line center, while stronger fields are required for the U/I wing signals to be depolarized to a similar extent. The theoretical results presented here further expand the diagnostic content of the unprecedented spectropolarimetric observations provided by the Chromospheric Lyman-Alpha Spectropolarimeter (CLASP).

26 The polarization of the Mg II h-k doublet and subordinated triplet

T. del Pino Alemán[1], J. Trujillo Bueno[1,2], R. Casini[3], and R. Manso Sainz[4]

[1] *Instituto de Astrofísica de Canarias (IAC); 38205 La Laguna; Tenerife; Spain*
[2] *Consejo Superior de Investigaciones Científicas, Spain*
[3] *High Altitude Observatory, National Center for Atmospheric Research, USA*
[4] *Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany*

Contributed talk

In order to exploit the unprecedented spectropolarimetric observations of the solar chromosphere achieved by the CLASP-2 suborbital experiment, we first need to fully understand how the polarized spectrum of the Mg II resonance and subordinated lines is generated within the solar atmospheric plasma. Here we present the results of a theoretical investigation of the generation and transfer of polarized radiation in such ultraviolet Mg II transitions, taking into account the effects of angle-dependent partial frequency redistribution, magnetic fields via the Hanle and Zeeman effects, and the impact of velocity gradients on the excitation of the atomic system. To this end, we use 1D semi-empirical and dynamical models of the solar atmosphere. In addition to the several results obtained, we point out strategies to identify in the CLASP-2 data the impact of chromospheric magnetic fields.

27 The polarization of the Lyman-α lines of H I and He II in the solar corona

Supriya Hebbur Dayananda, Javier Trujillo Bueno, Tanausú del Pino Alemán, and Ángel de Vicente Garrido

Instituto de Astrofísica de Canarias (IAC); 38205 La Laguna; Tenerife; Spain

Contributed talk

The solar corona is the outermost region of the extended solar atmosphere where the quick release of magnetic free energy determines the near-Earth space weather. Probing this extremely hot and rarified plasma requires modeling the polarization of forbidden and permitted coronal lines, and to this end it is crucial to develop efficient codes to compute the Stokes profiles that emerge from given 3D coronal models taking into account the symmetry breaking produced by the presence of magnetic fields and non-radial solar wind velocities. We are developing such a tool with the aim of doing theoretical predictions as well as interpretations of spectropolarimetric observations (e.g., those that DKIST will hopefully provide). In this presentation we show the results of a theoretical investigation of the linear polarization produced by scattering processes in the H I Ly-α at 1216 Å and in the He II Ly-α at 304 Å, using 3D coronal models by "Predictive Science Inc.". This investigation is of especial interest given the large difference in the critical magnetic fields for the onset of the Hanle effect in such spectral lines (53 G and 848 G, respectively for hydrogen and helium lines mentioned above).

28 Temporal and spatial variation of linear polarization in Lyman-α spicule observed by CLASP

M. Yoshida[1,2], Y. Suematsu[2], R. Ishikawa[2], J. Trujillo Bueno[3], Y. Iida[4], M. Goto[5], R. Kano[2], N. Narukage[2], T. Bando[2], A. Winebarger[6], K. Kobayashi[6], and F. Auchère[7]

[1] *SOKENDAI (The Graduate University for Advanced Studies)*
[2] *National Astronomical Observatory of Japan, Tokyo, Japan*
[3] *Instituto de Astrofísica de Canarias (IAC); 38205 La Laguna; Tenerife; Spain*
[4] *Kwansei Gakuin University*
[5] *National Institute for Fusion Science*
[6] *NASA Marshall Space Flight Center*
[7] *Institut d'Astrophysique Spatiale*

Contributed talk

Solar spicules are an interesting target to investigate the coronal heating and the solar wind acceleration problems. In particular, the magnetic field of spicules is a very important quantity that needs to be empirically determined. The CLASP (Chromospheric Lyman-Alpha Spectro-Polarimeter) is a sounding rocket experiment launched in 2015 to obtain spectropolarimetric data in the hydrogen Lyman-α line during an observation time of 5 minutes. CLASP succeeded in obtaining Lyman-α line spectra along spicules. In this talk, we report that we have found temporal and spatial variations in the linear polarization of the Lyman-α line observed in spicules. In order to achieve sufficient signal to noise ratio, we integrated observational data over the wavelength (Lyman-α line core $\pm$0.14 Å), temporal and spatial directions. As a result, we could obtain a significant polarization signal with an accuracy of 0.1–0.3% in a time span of 100 sec. The Q/I signal during the observing time is 0.0–2.0% in off-limb locations. The U/I signal fluctuates in time from +1.0% to -1.0%. In both Q/I and U/I, the highest polarization degree was observed at off-limb heights where we expect almost no line-of-sight superposition of structures, as compared with the lower heights where we have line-of-sight superpositions as seen in the Slit-Jaw filter image. At the lower off-limb heights, Q/I is about +0.2% and U/I is about 0.0% with an accuracy of 0.1%. This is due to the superposition of the spicule structures. The positive Q/I during the observation period indicates that we have scattering polarization caused by the incoming anisotropic radiation. The temporal variation observed in U/I can be considered to be due to the temporal variation of magnetic field vector and the anisotropy of the radiation field. We discuss possible constraints on the magnetic field of the spicules observed by CLASP.

29 On the magnetic field observed in the solar transition region

R. Manso Sainz

Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany

Contributed talk

I will present bounds and values of the magnetic field in active and quiet regions of the solar transition region derived from the analysis of spectropolarimetric observations in three notable $^2S - {}^2P^\circ$ spectral features: Lyman-α, the Mg II h & k lines, and the C IV 155 nm doublet.

30 Scattering polarization measurements at GREGOR and IRSOL, some examples and notes

Michele Bianda[1], Daniel Gisler[1], Renzo Ramelli[1], and Svetlana Berdyugina[2]

[1] *Istituto Ricerche Solari Locarno (IRSOL), CH-6605 Locarno Monti, Switzerland, associated with Università della Svizzera italiana*
[2] *Leibniz-Institut für Sonnenphysik (KIS), Freiburg, Germany*

Contributed talk

Observations with the Zurich IMaging POLarimeter (ZIMPOL) instrument have been carried out in IRSOL for the last two decades and have been additionally made at the GREGOR telescope since 2013. Several observations were also performed installing ZIMPOL at THEMIS. From a technical point of view, we are still often faced with new challenges. Here we present a number of examples of spurious effects encountered in our observations, and we discuss their origin and the solutions devised to minimize them. We also present an overview of how this work has improved the scientific quality of the observations over the years.

31 Observational hints of magneto-optical effects in the scattering polarization wings of Ca I 4227 Å

E. Capozzi[1], E. Alsina Ballester[1], L. Belluzzi[1,2], and M. Bianda[1]

[1] *Istituto Ricerche Solari Locarno (IRSOL), CH-6605 Locarno Monti, Switzerland*
[2] *Leibniz-Institut für Sonnenphysik (KIS), Freiburg, Germany*

Contributed talk

The Ca I resonance line at 4227 Å presents a deep and broad absorption profile with extended wings in the intensity spectrum of the Sun. Its scientific interest is greatly enhanced by its scattering polarization signal, which is among the largest in the so-called Second Solar Spectrum. Its Q/I profile, historically one of the first to be observed, exhibits a peculiar triplet peak structure, with a sharp peak at the line core and extended wing lobes. The physical origin of such wings is rooted in the frequency coherence of scattering processes (i.e. partial frequency redistribution, PRD). It has long been established that the scattering polarization peak at the line center is sensitive to the presence of magnetic fields due to the Hanle effect, which however has a negligible impact in the line wings. On the other hand, recent theoretical studies suggest that the wing linear polarization signals of the Ca I 4227 Å line could also be sensitive to the magnetic field through the so-called Magneto-Optical effects (Alsina Ballester et.al, 2018). The search for observational evidence of this novel physical mechanism has led us to conduct a series of spectropolarimetric observations of this line. We present a selection of them, carried out using the ZIMPOL camera both with the Gregory-Coudè telescope at IRSOL and the GREGOR telescope at Izaña, Tenerife, in which spatial variations in the wing polarization signals are clearly appreciable. We provide a detailed discussion of these results and of our preliminary attempts to get reliable information about the magnetic field, based on the influence of this new physical mechanism in this region of the Second Solar Spectrum.

32 Observations on spatial variations of the Sr I 4607 Å scattering polarization signals at different limb distances

Sajal Kumar Dhara[1], Emilia Capozzi[1], Daniel Gisler[1,2], Michele Bianda[1], Renzo Ramelli[1], Svetlana Berdyugina[2], Ernest Alsina[1], and Luca Belluzzi[1]

[1] *Istituto Ricerche Solari Locarno (IRSOL), 6605 Locarno-Monti, Switzerland*
[2] *Leibniz-Institut für Sonnenphysik (KIS), Freiburg, Germany*

Contributed talk

The Sr I 4607 Å line shows one of the strongest scattering polarization signals in the visible solar spectrum. The amplitude of this signal is expected to vary at granular spatial scales. This variation can be due to changes in the magnetic field intensity and orientation (Hanle effect) as well as due to spatial and temporal variations in the plasma properties. Measuring the spatial variation of such polarization signal would allow us to study the properties of the magnetic fields at subgranular region. But, the observations are challenging since both high spatial resolution and high spectropolarimetric sensitivity are required at the same time. At present only few detections of such spatial variations have been reported. This is due to the difficulty of these measurements, which require to combine high spatial, spectral, and temporal resolution with increased polarimetric sensitivity. To the aim of measuring these spatial variations at granular scale, we carried out a spectro-polarimetric measurement with the Zurich IMaging POLarimeter, ZIMPOL, at the GREGOR solar telescope to obtain the four Stokes parameters at different limb distances, from $\mu = 0.2$ to $\mu = 0.8$ on the solar disk. Our results show a clear spatial variation of scattering linear polarization signals in Sr I 4607 Å line, with a spatial resolution of about 0.6". The spatial scale of these variations is comparable with the granular size. A statistical analysis reveals that the linear scattering polarization amplitude in this Sr I spectral line is positively correlated with the intensity in the continuum, corresponding to the granules, at every μ.

33 Evidence for spatially-structured scattering polarization in the photospheric quiet Sun

Franziska Zeuner[1,2], Rafael Manso Sainz[1], Alex Feller[1], Michiel van Noort[1], Kevin Reardon[3], Francisco A. Iglesias[1,4], Valentín Martínez Pillet[3], and Sami K. Solanki[1,5]

[1] *Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany*
[2] *Georg-August-Universität Göttingen, Institut für Astrophysik, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany*
[3] *National Solar Observatory, Boulder CO 80303, USA*
[4] *Universidad Tecnológica Nacional, CONICET, CEDS, Mendoza, Argentina*
[5] *School of Space Research, Kyung Hee University, Republic of Korea*

Contributed talk

In recent years there has been a race to detect spatial fluctuations in the scattering polarization of the Sr I 4607 Å line. Here, we report on spatially structured scattering polarization in the photosphere, observed in a quiet region at disk centre, which marks the first step towards spatially resolved Hanle observations in Sr I.

Our observation in the spectral region of 4607 Å was carried out with our new high-cadence polarimeter attached to the Dunn Solar Telescope. It provides increased polarimetric sensitivity ($< 0.1\%$) while conserving sufficient spatio-temporal resolution to sample sub-granular scales. Combined with a new pixel-classification method based on a simple model of the local radiation field anisotropy, we statistically detect scattering polarization signals with spatial dimensions of about $0.75''$ emerging from the solar disk centre.

Our new analysis tool is already applicable to current solar telescopes, where a direct measurement of individual scattering signatures on small scales is not possible due to S/N limitations. The results will help to better constrain theoretical models on scattering polarization in the photosphere on sub-granular scales.

Part V

Radiative transfer

34 NLTE radiative transfer: what did we learn, where are we, and what needs to be done

I. Milić

Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder CO 80303, USA
National Solar Observatory, Boulder CO 80303, USA

Invited review

Spectropolarimetric diagnostics of the observations done in spectral lines formed out of local thermodynamic equilibrium is notoriously hard, for multiple reasons. From the modeling point of view, we need to fully understand NLTE line formation and to account for all the relevant transitions and radiative and collisional processes. This also makes the numerical calculation orders of magnitude more demanding. This is especially true in the case of spectral lines where the scattering polarization is important as we need to solve the so called NLTE problem of the second kind. From the inversion point of view, the problems are even more abundant. Numerical methods are very computationally demanding, often requiring minutes or even hours for the inversion of a single polarized spectra. Inversion itself is more ill-posed, due to the non-locality of the NLTE problem, especially so if the lateral radiative transfer effects are present. Finally, we still need to observe some of the more subtle NLTE effects, the most interesting one probably being the spatial variation of scattering polarization.

In this talk we will discuss where we, as a community, stand in solving these scientific problems. The focus will be on the forward modeling and the challenges we face in NLTE inversions. We will also outline the ideas on interpreting the data that is going to be provided by the generation of 4 m class telescopes. Namely, how to deal with large amounts of observations of spectral lines that are non-trivial to model and invert.

35 The effects of 3D radiative transfer on the polarization of chromospheric lines

J. Jaume Bestard[1,2], J. Trujillo Bueno[1,2,3], and J. Štěpán[4]

[1] *Instituto de Astrofísica de Canarias (IAC); 38205 La Laguna; Tenerife; Spain*
[2] *Universidad de La Laguna, Departamento de Astrofísica, Spain*
[3] *Consejo Superior de Investigaciones Científicas, Spain*
[4] *Astronomical Institute ASCR, Czech Republic*

Contributed talk

Several novel telescopes are presently being developed with the main aim of improving our empirical knowledge of the magnetism of the solar chromosphere in active and quiet regions of the solar disk (e.g., DKIST, SUNRISE 3, EST). In order to probe such highly inhomogeneous and dynamic plasma, such telescopes will be equipped with high-sensitivity spectropolarimeters to measure the polarization that the joint action of scattering processes and the Hanle and Zeeman effects introduce in chromospheric lines, such as Hα, the IR triplet of Ca II and the Ca I 422.7 nm resonance line.

A key question related with the modeling of such spectral line polarization is whether or not we have to worry about the effects of 3D radiative transfer (RT). To investigate this challenging problem we have applied the RT code PORTA, which assuming complete frequency redistribution allows us to compute the intensity and polarization of solar spectral lines using state-of-the-art 3D models resulting from magnetohydrodynamic simulations. In this contribution we show the results of our detailed investigations for the hydrogen Hα and the Ca I 422.7 nm lines, taking fully into account the impact of the inhomogeneity and dynamics of the 3D model. An important question we answer is the following: is the 1.5D approximation suitable for modeling the scattering polarization and the Hanle effect in chromospheric spectral lines?

36 Dealing with discontinuities in numerical radiative transfer

Gioele Janett[1], Oskar Steiner[1,2], and Luca Belluzzi[1,2]

[1] *Istituto Ricerche Solari Locarno (IRSOL), Switzerland*
[2] *Leibniz-Institut für Sonnenphysik (KIS), Freiburg, Germany*

Contributed talk

State-of-the-art multidimensional magnetohydrodynamic simulations of solar and stellar atmospheres reveal various types of discontinuities and complex structures in physical parameters such as magnetic field, temperature, and bulk velocities. The numerical solution of the transfer equation of polarized radiation is particularly challenging in the absence of local smoothness and numerical tests revealed that discontinuities in the atmospheric physical parameters effectively reduce the accuracy of the formal solution and thwart high-order convergence.

Moreover, interpolations are ubiquitous in radiative transfer problems. Therefore, we outlined and tested a novel fourth-order weighted essentially non-oscillatory (WENO) interpolation able to guarantee high-order accuracy in smooth regions, while at the same time handling discontinuities in an accurate and non-oscillatory fashion. Numerical tests confirmed that this novel WENO interpolation guarantees fourth-order accuracy in smooth regions of the interpolated functions and it avoids oscillations near discontinuities. Unlike Bézier and monotonic Hermite interpolations, it does not degenerate to a linear interpolation near smooth extrema. For these reasons, this WENO interpolation technique might be particularly suitable for several problems, including a number of radiative transfer applications, such as multidimensional problems, multigrid methods, and formal solutions.

37 Advances in azimuthal ambiguity resolution for advanced Zeeman spectropolarimetry and inversion

K. D. Leka[1,2], Graham Barnes[1], and Eric Wagner[1]

[1] *NorthWest Research Associates*
[2] *Nagoya University*

Contributed talk

We use solar spectropolarimetry to infer the characteristics of the plasma in the solar atmosphere, including the plasma velocity structure, the temperature structure, and the magnetic field. Two of these quantities are vectors. As an example, to infer the vector velocity flows, multiple measurements are required and some level of inversion performed, but the result is then at-hand. In contrast, to infer the vector magnetic field, full Stokes polarimetry data must be used and inverted, but then an additional degeneracy must be removed. In other words, in order to produce physically meaningful results, there is another step post-inversion that must be performed.

Expanding the "Minimum Energy" disambiguation algorithm for photospheric Zeeman polarization (Metcalf 1994; Leka Barnes & Crouch 2009), we present efforts at NorthWest Research Associates (USA) to address two specific advances: temporally-consistent disambiguation (Barnes et al, in prep) and 3-D disambiguation when multiple heights in the atmosphere are provided (Crouch & Barnes 2008, Crouch, Barnes, & Leka 2009). In these cases, the global optimization of a functional based on the field divergence and a local smoothing term (current density) is extended to include the relevant additional dimension. We demonstrate these advances in disambiguation procedures on Hinode/SpectroPolarimeter data. As with the stand-alone Minimum Energy disambiguation algorithm, these codes will be available to the community (or new data analysis pipelines) upon full implementation.

Support for this work is acknowledged from Lockheed-Martin Space Systems contract #410-3056734 for Solar-B FPP Phase E support and NASA Grants #80NSSC18K0055 and #80NSSC18K0180.

38 Inversions of spectro-polarimetric data: what did we learn, where are we, and what needs to be done

J. de la Cruz Rodríguez

Institute for Solar Physics, Stockholm University, Sweden

Invited review

Inversion techniques allow to reconstruct solar observations by assuming a model atmosphere. Nowadays we can include in a single inversion spectral lines that are sensitive to very different regimes of the solar atmosphere, from the photosphere to the upper chromosphere.

During the past years, solar inversion techniques have evolved to include non-LTE partial redistribution effects, a more realistic treatment of instrumental degradation, and, more recently, parameter regularization.

In this talk I will review some of the aforementioned recent improvements and I will present my own views on future developments. Part of these challenges are the inclusion of data from instruments with different spatial resolution, scattering polarization and 3D radiative transfer.

39 Three-dimensional Stokes inversion with magnetohydrostatic constraints

A. Pastor Yabar[1], J. M. Borrero[1], B. Ruiz Cobo[2,3], and M. Rempel[4]

[1] *Leibniz-Institut für Sonnenphysik (KIS), Freiburg, Germany*
[2] *Instituto de Astrofísica de Canarias (IAC); 38205 La Laguna; Tenerife; Spain*
[3] *Universidad de La Laguna (ULL)*
[4] *High Altitude Observatory (NCAR)*

Contributed talk

The inference of the physical parameters for a three-dimensional volume (x,y,z) of the solar atmosphere from spectropolarimetric observations remains a challenging task. It is so because one needs to reliably determine the gas pressure, which is a physical parameter to which Stokes parameters are scarcely sensitive to. Presently this problem is addressed after inferring the various physical parameters in the optical depth scale (x,y,τ) and using additional physical constraints in order to estimate of the gas pressure. By far, the most common approach is to assume hydrostatic equilibrium, in order to get a $\tau \rightarrow z$ conversion and then try to set the whole volume (x,y,z) to a common height reference.

In this contribution we present the first results of the gas pressure calculation taking into account the Lorenz force (magnetic pressure and tension). This is done solving a Poisson-like equation in the three dimensional volume (x,y,z) directly. This way, the calculated gas pressure is consistent with the inferred physical parameters in all the volume and naturally leads to the appearance of the Wilson depression. Here we show the performance of this approach using state-of-the-art magneto hydrodynamic simulations. In a first step we are considering the most ideal case, which allows addressing the accuracy of the approach as compared to the MHD case. After that, we move to more realistic cases in which we decrease the amount of information supplied.

40 IMP: a multi-D non-LTE radiative transfer inversion code of Stokes profiles

Jiří Štěpán[1], **Tanausú del Pino Alemán**[2], and Javier Trujillo Bueno[2]

[1] *Astronomical Institute ASCR, 251 65 Ondřejov, Czech Republic*
[2] *Instituto de Astrofísica de Canarias (IAC); 38205 La Laguna; Tenerife; Spain*

Contributed talk

The inference of the physical parameters that characterize the inhomogeneous and optically thick plasma of solar chromospheric structures is one of the most challenging goals of solar spectropolarimetry. We have developed an efficient multi-D, non-LTE inversion code that takes into account scattering polarization and the Hanle and Zeeman effects. Applying sparsity regularization, domain decomposition, and the massively parallel strategy of the PORTA radiative transfer code, we are able to efficiently infer the self-consistent thermal and magnetic properties of chromospheric plasma structures. In this contribution, we present the logical structure of the IMP code and the first results for a relatively simple chromospheric plasma structure levitating in the solar corona.

41 3D quiet Sun multi-line inversions using GRIS at GREGOR infrared spectra

Trelles, J. C.[1,2], Ruiz Cobo, B.[1,2], and Martínez González, M. J.[1,2]

[1] *Instituto de Astrofísica de Canarias (IAC); 38205 La Laguna; Tenerife; Spain*
[2] *Universidad de La Laguna*

Contributed talk

The strong magnetic activity at the solar surface take place in active regions (ARs) and in Network (the strongest fields of quiet Sun). Outside these regions we have the very quiet Sun (vQS) which is characterized by the unperturbed granulation. The analysis of vQS has revealed a weak, very small-scale, disorganized magnetism that covers the solar surface, from the equator to the poles (see e.g. the review by Sánchez Almeida & Martínez González 2011). Despite of the low magnetic energy as compared to ARs, the role of the vQS in the general energy budget has been already proven (see e.g. Trujillo Bueno, Shchukina & Asensio Ramos 2004).

Though the importance of the vQS for solar studies is clear, still at present, and after more than three decades of research, many questions are still unresolved. In order to shed some light on vQS open questions we have improved the way of getting information about solar atmosphere.
Because at 1.5 microns the solar atmosphere reaches the opacity minimum, using lines at these region allow us to study deep photospheric layers. Moreover, through weak intensity spectral lines and the wings of the high intensity ones we are able to get information about even deeper layers. But, just a few spectral lines of GRIS infrared spectra have accurate atomic parameters.
In order to calculate the unknown (and increase the accuracy of some others) atomic parameters of all useful spectral lines within GRIS infrared spectra we have built a set of quiet Sun reference atmosphere models using the inversion with gradients of two well known spectral lines (15648.52 and 15662.02 $\AA$).

Finally, we have repeated the previous inversion but using the whole spectra in order to get more reliable quiet Sun atmosphere models. Both accurate atomic parameters of different spectral lines and reference atmosphere models let us face some open questions, such as the determination of gas pressure fluctuations out of hydrostatic equilibrium.

To sum up, we present to the community:
-Accurate atomic parameters of all usable spectral lines in GRIS at GREGOR infrared spectra.
-A very reliable set of quiet Sun reference atmosphere models.

Part VI

Machine learning & big data

42 Big data in solar polarimetry and the role of machine learning

A. Asensio Ramos

Instituto de Astrofísica de Canarias (IAC); 38205 La Laguna; Tenerife; Spain

Invited review

Solar spectropolarimetry is entering the realm of big data. Current and future telescopes will produce data at a rate that will make it hard to store in a single machine and even harder to operate on the data. Thankfully, in the last decade, machine learning has experienced an enormous advance, thanks to the possibility of training very deep and complex neural networks. In this contribution I show how deep learning can be used to efficiently solve difficult problems in the field of solar and stellar spectropolarimetry, providing a potential solution to the big data problem. I will focus on how differentiable programming (aka deep learning) is helping us to have access to velocity fields in the solar atmosphere, correct for the atmospheric degradation of spectropolarimetric data, carry out fast 3D inversions of the Stokes parameters to get physical information of the solar atmosphere or map stellar surfaces using Doppler imaging.

43 RADYNVERSION: learning to invert a solar flare atmosphere with invertible neural networks

C. M. J. Osborne[1], **J. A. Armstrong**[1], and L. Fletcher[1,2]

[1] *SUPA School of Physics & Astronomy, University of Glasgow, Glasgow, G12 8QQ, UK*
[2] *Rosseland Centre for Solar Physics, University of Oslo, P.O. Box 1029 Blindern, NO-0315, Norway*

Contributed talk

During a solar flare, it is believed that reconnection takes place in the corona followed by fast energy transport to the chromosphere. The resulting intense heating strongly disturbs the chromospheric structure, and induces complex radiation hydrodynamic effects. Interpreting the physics of the flaring solar atmosphere is one of the most challenging tasks in solar physics. Here we present a novel deep learning approach, an invertible neural network, to understanding the chromospheric physics of a flaring solar atmosphere via the inversion of observed solar line profiles in Hα and CaII λ8542. Our network is trained using flare simulations from the 1D radiation hydrodynamics code RADYN as the expected atmosphere and line profile. This model is then applied to single pixels from an observation of an M1.1 solar flare taken with SST/CRISP instrument just after the flare onset. The inverted atmospheres obtained from observations provide physical information on the electron number density, temperature and bulk velocity flow of the plasma throughout the solar atmosphere ranging from 0-10 Mm in height. The density and temperature profiles appear consistent with the expected atmospheric response, and the bulk plasma velocity provides the gradients needed to produce the broad spectral lines whilst also predicting the expected chromospheric evaporation from flare heating. We conclude that we have taught our novel algorithm the physics of a solar flare according to RADYN and that this can be confidently used for the analysis of flare data taken in these two wavelengths. This algorithm can also be adapted for a menagerie of inverse problems providing extremely fast ($\sim 10\,\mu$s) inversion samples.

44 Machine learning initialisation for parallel inversions

R. Gafeira[1], D. Orozco[1], I. Milić[2], C. Quintero Noda[3], and B. Ruiz Cobo[4]

[1] *Instituto de Astrofísica de Andalucía (CSIC), Apartado de Correos 3004, E-18080 Granada, Spain*
[2] *High Altitude Observatory, National Center for Atmospheric Research, P.O. Box 3000, Boulder, CO 80307-3000, USA*
[3] *Institute of Theoretical Astrophysics, University of Oslo, P.O. Box 1029 Blindern, NO-0315 Oslo, Norway*
[4] *Instituto de Astrofísica de Canarias (IAC); 38205 La Laguna; Tenerife; Spain*

Contributed talk

The new generation of telescopes to come will allow new opportunities to study in detail the solar atmosphere. At the same time, those new observations demand the development of more complex inversion codes to analyse and interpret them.
These new inversion codes will use large computational resources what requires the creation of new tools/approaches to optimise the inversion process.
In this talk, we discuss the advantages and limitations of using machine learning techniques as a tool to estimate optimum initial physical atmospheric models necessary for initializing spectral line inversions based on the full observed Stokes parameters. Tests have been carried out in large maps using SIR and DeSIRe inversion codes both for LTE and NLTE lines.
This approach allows firstly to reduce the number of cycles in the inversion and increase the number of nodes and secondly to automatically cluster pixels which is an important step to invert maps where completely different regimes are present.

Part VII

Solar phenomena as revealed by polarized light

45 The potential of many-line inversions of photospheric spectropolarimetric data in the visible and near UV

Tino Riethmüller

Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany

Highlight

Our knowledge of the lower solar atmosphere is mainly obtained from spectropolarimetric observations, which are often carried out in the red or infrared spectral range and almost always cover only a single or a few spectral lines. Here we compare the quality of Stokes inversions of only a few spectral lines with many-line inversions. In connection with this, we have also investigated the feasibility of spectropolarimetry in the short-wavelength range, 3000 Å − 4300 Å, where the line density but also the photon noise are considerably higher than in the red, so that many-line inversions could be particularly attractive in that wavelength range. This is also timely because this wavelength range will be the focus of a new spectropolarimeter in the third science flight of the balloon-borne solar observatory SUNRISE. For an ensemble of state-of-the-art magneto-hydrodynamical atmospheres we synthesize exemplarily spectral regions around 3140 Å (containing 371 identified spectral lines), around 4080 Å (328 lines), and around 6302 Å (110 lines). The spectral coverage is chosen such that at a spectral resolving power of 150000 the spectra can be recorded by a 2K × 2K detector. The synthetic Stokes profiles are degraded with a typical photon noise and afterwards inverted. The atmospheric parameters of the inversion of noisy profiles are compared with the inversion of noise-free spectra. We find that significantly more information can be obtained from many-line inversions than from a traditionally used inversion of only a few spectral lines. We further find that information on the upper photosphere can be significantly more reliably obtained at short wavelengths. In the mid and lower photosphere, the many-line approach at 4080 Å provides equally good results as the many-line approach at 6302 Å for the magnetic field strength and the line-of-sight (LOS) velocity, while the temperature determination is even more precise by a factor of three. We conclude from our results that many-line spectropolarimetry should be the preferred option in the future, and in particular at short wavelengths it offers a high potential in solar physics.

46 Magnetic properties of short-lived penumbral microjets

A. L. Siu-Tapia, L. R. Bellot Rubio, D. Orozco-Suárez, R. Gafeira, and J. C. del Toro Iniesta

Instituto de Astrofísica de Andaluciía (IAA-CSIC), Apartado de Correos 3004, E-18080 Granada, Spain

Contributed talk

Penumbral microjets (PMJs) are among the first discoveries made with the Solar Optical Telescope from the Hinode spacecraft during the initial phase of the mission. They are small-scale elongated jet-like brightenings that occur intermittently and all over the chromospheric penumbra of sunspots. These transient events can last from a few seconds to several minutes and their origin is presumed to be related to photospheric magnetic reconnection processes. However, the study of this phenomenon remains to be very challenging because it requires measurements with high-spatial, spectral, and temporal resolution along with spectropolarimetric sampling at photospheric and chromospheric heights.

Previous studies have mainly focused on their morphological and spectral characteristics, and more recently on the spectropolarimetric signals of PMJs with lifetimes above 2 minutes during the maximum brightness stage. Thus, the magnetic properties of the shorter-lived PMJs remain unexplored.

Here we discuss the temporal evolution of the polarization signatures produced by short-lived (lifetimes < 2 minutes) PMJs in order to understand how the magnetic field configuration and the gas properties evolve in the upper photosphere and mid-chromosphere and to infer under which conditions the PMJs can occur.

We use fast-cadence spectropolarimetric observations of the Ca II 854.2 nm line taken with the Crisp Imaging Spectrometer at the Swedish 1 m Solar Telescope. The weak field approximation is used to estimate the magnetic field strength and inclination. The properties of the plasma are inferred by inverting the observed Stokes profiles with the DeSIRe inversion code under the NLTE regime.

47 Magnetic-field topology of fibrillar structures throughout the solar chromosphere

Shahin Jafarzadeh[1], Carlos Quientero Noda[1], Thomas Wiegelmann[2], and Luc Rouppe van der Voort[1]

[1] *Rosseland Centre for Solar Physics, University of Oslo, Norway*
[2] *Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany*

Contributed talk

Fibrillar structures of different appearances and/or properties have ubiquitously been observed throughout the solar chromosphere. Here, we present relationships between such elongated structures (in an active region) and the magnetic-field topology at various chromospheric heights. These are done by exploiting high-spatial resolution observations of several spectral scans through Fe I 630.15/630.25 nm and Ca II 854.21 nm lines in full Stokes, as well as through Halpha 656.3 nm, and Ca II K 393.4 nm lines in intensity, acquired (near simultaneously) with the Swedish 1-m Solar Telescope. The magnetic-fields topology is calculated using the recently developed DeSIRe numerical code. The code allows fitting the Stokes profiles for multiple spectral lines in non-local thermodynamic equilibrium and with the option of taking into account partial redistribution effects. Therefore, by adjusting the line profiles, we estimate the height stratification of the atmospheric parameters from the lower photosphere to the middle chromosphere. The results are used later as seeds for the magnetostatic field extrapolations. Thus, the fibrillar structures are compared with the magnetic-field topology derived from the two approaches (i.e., the Stokes inversions as well as the field extrapolations). A comparison between the two methods is also provided. Lastly, properties of magnetohydrodynamic-wave dynamics in the various fibrillar structures (from time-series of images) are compared. These provide us with new insights into the nature of various fibrillar structures in the solar chromosphere as well as their roles in heating these atmospheric layers.

48 Would the Sun's photosphere be negatively charged and magnetised?

V. Bommier,

LESIA, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, Univ. Paris Diderot, Sorbonne Paris Cité, 5, Place Jules Janssen, 92190 Meudon, France; V.Bommier@obspm.fr

Contributed talk

"No satisfactory solution has been found as yet for the unexpectedly small vertical gradients [with respect to the observed ones] obtained by applying the div$\vec{B} = 0$ condition [to the solar photosphere magnetic field measurements]" (S. Solanki, 2003, Astron. Astrophys. Rev. 11, p. 184). This is always true today, when an observation review has just been published (H. Balthasar, 2018, Solar Phys. 293, 120). I propose to build an explanation in the frame of the vector law in magnetised media $\vec{B} = \mu_0 \left(\vec{H} + \vec{M}\right)$, when the magnetisation $\vec{M}$ due to the plasma diamagnetism, itself due to the electrons or free charges spiralling about the magnetic field, is large enough. This requires larger than usual model free charges densities in the solar photosphere. However, it can be remarked that inside the Sun, like in the Solar Corona, the electron thermal velocity clearly surpasses their escape velocity. Their charge-dipole interaction with the neutral Hydrogen atoms in the photosphere slow down their escape. They accumulate there and become thus responsible for the non-negligible magnetisation. The last question is to determine if spectropolarimetry measures $\vec{B}$ or $\vec{H}$: I will show that it is $\vec{H}$, leading thus to the non-zero observed divergence revealing the presence of a non-negligible magnetisation due to the electrons escaping the Sun's interior. Emphasis will be put on the demonstration that the Zeeman hamiltonian for the atom of magnetic momentum $\vec{m}$ and embedded in the magnetised matter is $-\mu_0 \vec{m} \cdot \vec{H}$. Observations of the continuum limb polarisation were performed in the seventies at the Pic-du-Midi, which display a larger than model Thomson scattering due to electrons in the infrared. Electron overdensity with respect to present models would then be inferred. Such observations, able to confirm the present proposed scenario, have to be redone in more details with the future instruments like DKIST or EST.

49 The quiet magnetism as inferred with complex atmospheres

M. J. Martínez González, J. Carlos Trelles Arjona, and B. Ruiz Cobo

Instituto de Astrofísica de Canarias (IAC); 38205 La Laguna; Tenerife; Spain

Contributed talk

Far from the most evident active areas of the Sun, the very quiet Sun is permeated by an intrincated, small-scale, highly dynamic, weak magnetism. Though weak and tangled, it has been shown to provide enough magnetic energy at higher layers to compensate for radiative losses via the emergence of loop structures. The amount of magnetic energy relies on the correct determination of the magnetic field strength, for which we need sensitive spectral lines and high quality observations.

Most studies using very sensitive lines, such as the Fe I pair at 1.5μm, or using high spatial resolution data such as the ones obtained with the Hinode spectropolarimeter, have used simplified atmospheres in their analysis (constant atmospheres or even Milne-Eddington ones). Though Stokes profiles in quiet regions are clearly asymmetric – proving gradients of physical quantities along the atmosphere – these simplistic analysis were assumed to give an "average" value of the physical quantities quantities along the formation region of the spectral line. In this presentation we will show that this is not always the case. If asymmetric profiles are interpreted with a constant atmosphere, the results can be misleading. We perform inversion techniques with more complex models (allowing gradients in the magnetic and dynamic parameters) to infer the physical properties of the quiet solar atmosphere. We revisit the already studied large Hinode map presented in Lites et al. 2008, and we present new observations in the near-infrared obtained with GRIS at GREGOR with an unpredencented spatial resolution below 0.5″.

50 Deep polarimetry of a plage region

A. G. M. Pietrow, J. de la Cruz Rodriguez, and D. Kiselman

Institute for Solar Physics, Stockholm University, Albanova University Centre, SE-106 91 Stockholm, Sweden

Contributed talk

Observationally deriving the connectivity of the magnetic field vector in solar plage regions, has the potential to increase MHD model realism. In order to measure the chromospheric magnetic fields over these regions deep polarimetry is required. To achieve this we have acquired high-cadence observations of a plage region at $\cos(\theta) \sim 0.7$ in Ca II 8542 with the CRISP instrument at the Swedish 1-m Solar Telescope (SST) on La Palma. We explore new ways of reconstructing the Stokes images to maximise the S/N while maintaining a high spatial resolution and, in Stokes I, a high temporal resolution. Using inversion methods we reconstruct the magnetic field vector in the chromosphere and present maps of the field above the plage and its connection to the surrounding regions.

51 Atmospheric stratification in an active region plage

Sudharshan Saranathan[1], Michiel van Noort[1], and Sami Solanki[1,2]

[1] *Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany*
[2] *School of Space Research, Kyung Hee University, Republic of Korea*

Contributed talk

The investigation of small-scale magnetic structures is an important aspect of characterizing the physical processes in the solar atmosphere. Inversions of spectro-polarimetric observations allow us to retrieve physical parameters of the solar atmosphere. We study the atmospheric stratification in an active region plage using slit-spectra obtained with the Swedish Solar Telescope (SST). The observations were restored using a spectral restoration technique based on the Multi-Frame Blind Deconvolution (MFBD) method, followed by a statistical compensation to the effects of seeing-induced high-order aberrations, yielding spectro-polarimetric scans that are among the first from a ground-based telescope to be nearly diffraction limited over the entire scan. We then performed height-stratified inversions using multiple spectral lines with the SPINOR LTE inversion code. We find that the dominant polarity of the plage harbours Kilogauss fields, in agreement with earlier studies. The inversion with multiple spectral lines also reveals the presence of several small-scale patches of opposite magnetic polarity that are concentrated within and around the plage. We study the stratification of physical parameters in these patches, and present the results.

52 A case study of three magnetic bright points observed with GREGOR

C. Kuckein

Leibniz-Institut für Astrophysik Potsdam (AIP), Germany

Contributed talk

Photospheric bright points (BPs) are the smallest observable manifestations of the magnetic field on the solar surface. However, they remain challenging to observe due to atmospheric seeing and limiting spatial resolution of current telescopes. In this work, we present a data set acquired with the 1.5-meter GREGOR telescope, with multiple instruments, from the visible blue to the near-infrared spectral range at 1 μm. Filtergrams of 450 nm (blue continuum) and Ca II H at 396 nm were used to identify small-scale intergranular BPs. They appear as thin ($\sim$0.30″–0.35″) features which appear in groups or chains and therefore resemble elongated (few seconds of arc), rather than roundish, structures. The analyzed isolated BPs were visible during the 30-minute observations. However, they were very dynamic and their shape often changed. Merging and splitting happened in time scales of minutes. Simultaneous observations with the spectrograph in the 1 μm spectral range allowed for one large scan of spectropolarimetric measurements in the photosphere and chromosphere. To the best of our knowledge, this spectral range has not been explored so far to analyze photospheric (magnetic) BPs. The Si I 1082.7 nm line was analyzed using the Stokes Inversions based on Response functions (SIR) code. Two different optical depths were chosen to show the spatial expansion of the magnetic field with height at the three BPs. A comparison between the Stokes V signals of two photospheric lines (with different sensitivities in optical depth), the Si I 1082.7 and Ca I 1083.9 nm lines, further supported this spatial expansion with height. Moreover, by analyzing the dynamics of the BPs we discovered that the Stokes I and V profiles of the Si I line showed asymmetries which indicate the presence of two components (a fast and a slow one) within the same resolution element. These strong flows seem to be likely at BPs but are sometimes not detected because of instrumental or observational limitations.

53 Magnetic field and dynamics of a pore with a lightbridge

H. Balthasar[1], D. Utz[2], J.I. Campos Rozo[2], C. Denker[1], A. Diercke[1], P. Gömöry[3], S.J. González Manrique[3], S. Hofmeister[2], I. Kontogiannis[1], J. Koza[3], K. Krikova[2], C. Kuckein[1], J. Palacios[4], and M. Verma[1]

[1] *Leibniz-Institut für Astrophysik Potsdam (AIP), Germany*
[2] *IGAM, Karl-Franzens Universität Graz, Austria*
[3] *Astronomical Institute of the Slovak Academy of Sciences, Tatranská Lomnica, Slovakia*
[4] *Leibniz-Institut für Sonnenphysik (KIS), Freiburg, Germany*

Contributed talk

A pore with a lightbridge in active region NOAA 12682 was observed on two subsequent days (September 28 and 29, 2017) with the GREGOR solar telescope. Spectro-polarimetric data were obtained with the GREGOR Infrared Spectrograph (GRIS) in the range 1082.5 – 1084.2 nm covering the helium triplet, a silicon line from the upper photosphere, and a calcium line originating in the lower photosphere. We use the Stokes Inversions based on Response functions (SIR) code to invert the calcium profiles and the HAnle and ZEeman Light (HAZEL) code for the helium and silicon lines. Dynamics are studied with data from the GREGOR Fabry Pérot Interferometer (GFPI), for which we selected the sodium D_2 line. Additional high-resolution images were taken with the High-resolution Fast Imager (HiFI). We also use context images and data from the Solar Dynamics Observatory (SDO).

On the disk-center side of the pore, the magnetic field is almost vertical, while it is inclined on the limb side, where we find also the largest horizontal component of the magnetic field. The highest total magnetic field strength is located in the pore's center. The magnetic field is reduced in the lightbridge close to the center of the pore. At the outer edge of the pore on the disk-center side we encounter downflows in the lower photosphere. Such downflows have been reported in the literature before. The data evaluation is still ongoing.

54 From the bottom of the photophere to the middle chromophere: penumbral fine structure

Murabito M.[1], Ermolli I.[1], Giorgi F.[1], Stangalini M.[1], Guglielmino S.L.[2], Jafarzadeh S.[3,4], Socas-Navarro H.[5,6], Romano P.[7], and Zuccarello F.[2]

[1] *INAF - Osservatorio Astronomico di Roma, I-00078, Italy*
[2] *1Dipartimento di Fisica e Astronomia "Ettore Majorana" – Sezione Astrofisica, Universita' degli Studi di Catania, Catania, I-95123, Italy*
[3] *Rosseland Centre for Solar Physics, University of Oslo, NO-0315 Oslo, Norway*
[4] *Institute of Theoretical Astrophysics, University of Oslo, NO-0315 Oslo, Norway*
[5] *Instituto de Astrofísica de Canarias (IAC); 38205 La Laguna; Tenerife; Spain*
[6] *Departimento de Astrofisica, Universidad de La Laguna, E-38205 La Laguna,Tenerife, Spain*
[7] *INAF - Osservatorio Astrofisico di Catania, Catania, I-95123, Italy*

Contributed talk

The large isolated sunspot (70"× 80") located in the AR 12546, which represent one of the biggest of the last 20 years was observed with spectro-polarimeteric measurements at the Fe I 6173 nm and Ca II 8542 nm lines acquired by the spectropolarimeter IBIS/DST, under excellent seeing conditions lasting more than three hours. Using the Non-LTE inversion code (NICOLE) by processing both line measurements simultaneously, we retrieved the three-dimensional magnetic and thermal structure of the sunspot from the bottom of the photophere to the middle chromophere. We found observational evidences of the spine and intra-spine at chromopheric heights not investigated in previous studies. In particular, a peak-to-peak variation of the magnetic field strength and inclination of about 200 G and 10° are found at chromopheric heights in contrast to the photopheric one of about 300 G and 20°. We also investigated the structure of the magnetic field gradient in the penumbra along the vertical and azimuthal directions confirming previous analysis of data taken in different spectral region (i.e. the region of the He I 1083 nm triplet).

55 Coronal polarimetry in the DKIST era: old issues and new ideas

Gabriel Dima, Tom Schad, and the DKIST Team

National Solar Observatory, Boulder CO 80303, USA

Highlight - Metcalf lecture

Operations of the US National Science Foundation's Daniel K Inouye Solar Telescope (DKIST) near the summit of Haleakala in Hawaii will commence next year, ushering in a new era for solar physics, and in particular, coronal spectropolarimetry. DKIST's large-aperture obscuration-free design provides unprecedented capabilities for measuring optical and infrared coronal emission lines initially with spectral coverage from the 380 nm to the 3.9 micron Si IX line. DKIST and it's first light instrumentation address many observational challenges facing O/IR coronal spectropolarimetry, including scattered light reduction, image stabilization, signal-to-noise, polarimetric accuracy, and spectral coverage, and thereby provides new opportunities to advance old concepts for interpreting coronal polarization and making inferences of the coronal thermal-magnetic conditions. Tomography and forward modeling provide viable approaches to address line-of-sight integration challenges using DKIST observations as well as coordinated observations in the EUV. At seeing-limited spatial resolution in the hot coronal lines, DKIST will probe individuated coronal intensity structures, such as loops, that in principle permit single point analysis using new techniques that exploit multi-wavelength coronal polarimetry. Such new ideas are complemented by the use of lines formed at chromospheric temperatures to probe coronal magnetism during cooling events. Along with photospheric/chromospheric diagnostics of the coronal base, coronal polarimetry at DKIST promises to help advance our understanding of the coronal environment.

56 3D reconstruction of the coronal magnetic and thermodynamic structures from ground and space based spectropolarimetric observations

M. Kramar, and H. Lin

Institute for Astronomy, University of Hawaii at Manoa, Hawaii, USA

Contributed talk

The knowledge of the 3D vector magnetic field, density, and temperature structures of the solar corona is essential to understand the physics of the solar eruptive phenomena, solar wind and their influence on space weather processes. The spectropolarimetric observations of coronal Hanle and Zeeman effects provide information about the magnetic field but their interpretation is not straightforward due to their complex nature and optically thin property of the coronal plasma. With the development of vector and scalar tomographic inversion techniques (Kramar et al., 2013; 2016), it is now possible to directly derive the 3D coronal vector magnetic, electron density and temperature structures using synoptic Fe XIII 1075 nm coronal emission line (CEL) linear polarization (LP) measurements of the Coronal Multichannel Polarimeter (CoMP, Tomczyk et al., 2008) and UV coronal images. Although the vector tomographic inversion based on LP data measured from ecliptic plane is not unique, it can be used to probe certain coronal field configuration (Kramar et al. 2013) and the reconstructed 3D magnetic structures has been validated against UV observations and coronal extrapolation models. Based on the obtained 3D magnetic field, we have calculated the distribution of the magnetic free energy and compared it with the CME kinematic properties.

The inclusion of the circular polarization measurements of the coronal Zeeman effect into the inversion will allow us to better determine the magnetic field (Kramar et al. 2006) and this will become possible with the arrival of DKIST. However, the 3D reconstruction of temporally resolved coronal magnetic field, density, and temperature will require the deployment of a *Space Coronal Magnetometry Mission* (SCMM) with a fleet of spacecraft observing the Sun from many viewing directions simultaneously. We investigate how the use of full Stokes polarization data and multiple observing geometry from and out of the ecliptic plane will improve the accuracy of coronal magnetic field reconstruction.

57 Chromospheric magnetic field: a comparison of He I 10830 Å observations with nonlinear force-free field extrapolation

Y. Kawabata[1,2], A. Asensio Ramos[3], S. Inoue[4], and T. Shimizu[2,1]

[1] *The University of Tokyo*
[2] *Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency*
[3] *Instituto de Astrofísica de Canarias (IAC); 38205 La Laguna; Tenerife; Spain*
[4] *Institute for Space-Earth Environmental Research, Nagoya University*

Contributed talk

Magnetic field structures in the solar corona are essential to understand the dynamical nature of the plasmas responsible for occurrence of flares and coronal mass ejections. The coronal magnetic field, however, is difficult to be directly observed because of the weak polarization signal in thermally broadened spectral lines. To overcome the difficulty, the nonlinear force-free field (NLFFF) modeling has been extensively used to infer the three-dimensional (3D) magnetic field in the solar corona. The assumption in the NLFFF extrapolation is that the plasma beta is low, but this condition is considered to be incorrect in the photosphere. We attempt to reveal the non-potential magnetic field distribution in the chromosphere through spectropolarimetric observations and how significantly the magnetic field at the chromospheric height derived by the current NLFFF modeling with photospheric magnetic field is deviated from the measured chromospheric magnetic field.

We examine the direct measurements of the chromospheric magnetic field in the whole active regions through the spectropolarimetric observations at He I 10830 Å. In addition, the photospheric magnetic field is measured with *Hinode* and *Solar Dynamics Observatory*. The results of NLFFF extrapolation from the photosphere are compared with the direct measurements. Our analysis shows that chromospheric magnetic field may have larger non-potentiality compared to the photospheric magnetic field at some locations. Moreover, the large non-potentiality in the chromospheric height may not be reproduced by the NLFFF extrapolation from the photospheric magnetic field. The magnitude of the underestimation of the non-potentiality at the chromospheric height may reach 30-40 degree in signed shear angle. We conclude that the magnetic field in the upper atmosphere may have higher non-potentiality than previously thought based on the NLFFF.

58 Magnetic and dynamic properties of chromospheric loops

Rahul Yadav

Institutet för solfysik, Department of Astronomy, Stockholm University, Sweden

Contributed talk

The magnetic loops, generated in an emerging magnetic flux region (EFR) at the solar surface, connect the photosphere and the upper solar atmosphere. They are crucial to understanding the coupling of the solar atmosphere. An early-stage EFR was recorded by GRIS/GREGOR in 1083 nm spectral region. We present the magnetic field structure, velocity, and other physical properties of the chromospheric loops seen in EFR, which are inferred from the HAZEL inversion code. The inferred parameters show that the foot-points of loops are having two components of the model atmosphere. We have observed the strong downflows of upto 40 km/sec near the foot-points, whereas the middle part shows upflows (∼-22 km/sec). The magnetic field vectors, ranging from 80 to 400 G, are aligned along the loop and become more horizontal when they reach the apex. We also discuss their counterparts seen in the photosphere and the upper solar atmosphere.

59 Magnetized chromospheric downflows

Sowmya K.[1], Andreas Lagg[1], Sami K. Solanki[1,2], and J. S. Castellanos Durán[1]

[1] *Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany*
[2] *School of Space Research, Kyung Hee University, Korea*

Contributed talk

The chromosphere above active regions (ARs) on the Sun exhibits fast magnetized downflows which are often accompanied by a slow flow component. A comprehensive study of the characteristics of such downflows, however, has so far not been published. We conduct a statistical study of chromospheric downflows and their magnetic properties in a variety of ARs at different stages of evolution. We analyze spectro-polarimetric data obtained in the He I 10830 Å triplet formed in the upper chromosphere to retrieve the line-of-sight velocities and magnetic fields. 14 ARs recorded with the GREGOR Infrared Spectrograph mounted at the GREGOR solar telescope in Tenerife are inverted assuming multi-component Milne-Eddington type atmospheres. Magnetized supersonic downflows coexisting with a slow component are found to be present in all the ARs, especially in He I 10830 Å filaments and arch loop systems, the periphery of pores, loops above light bridges, penumbrae, and umbrae. The velocities of the slow component obey a Maxwellian distribution centered near $0\,\mathrm{km\,s^{-1}}$. The fast downflow component in emerging ARs shows two distinct populations with mean values of about 14 and $27\,\mathrm{km\,s^{-1}}$, respectively. The magnetic field strength shows a normal distribution for both components, with slightly stronger and more inclined fields for the slower component. The fact that supersonic downflows are detected in all datasets suggest that they are rather a common phenomena. Mass flow along filament barbs, draining of loops, coronal mass condensation and umbral oscillations appear to be the plausible mechanisms behind these chromospheric downflows.

60 Chromospheric heating driven by cancellation of flux emergence

C. J. Díaz Baso, and J. de la Cruz Rodríguez

Institute for Solar Physics, Dept. of Astronomy, Stockholm University

Contributed talk

The evolution of the photospheric magnetic field is coupled to the transport of energy into the chromosphere and the corona. In active regions, the emergence of new flux concentrations will interact with the previous configuration, leading to reconnection events that release the magnetic energy heating the solar plasma.

In the present study we analyze how strong reconnection events triggered by magnetic flux cancellation lead to chromospheric heating. We present results from non-LTE/PRD inversions combining spectral lines that sample from the photosphere to the upper chromosphere, such as the Fe I 6302 Å, Ca II 8542 Å and Ca II K lines. We have inferred the temperature, velocity and magnetic field configuration within which these events occur, then providing information on the origin and, how and where this energy is deposited. The spectropolarimetric observations on which we based our study were obtained with the Swedish 1-m Solar Telescope, whose high spatial resolution and high temporal cadence are essential to characterize their properties given their fine dynamic structure.

61 Polarization of the He I D_3 line in a C-flare

T. Libbrecht, J. de la Cruz Rodríguez, J. Leenaarts, et al.

Institute for Solar Physics, Stockholm University, Sweden

Contributed talk

We present the first SST/CRISP spectro-polarimetric observations of He I D_3. We analyzed the data using the inversion code Hazel, and estimate the line-of-sight velocity and the magnetic field vector. We also conducted 3D non-LTE modelling of the He I D_3 and 10830 lines during a reconnection event. During the flare, we detected strong He I D_3 emission at the flare footpoints, as well as strong He I D_3 absorption profiles tracing the flaring loops. The He I D_3 traveling emission kernels at the flare footpoints exhibit strong chromospheric condensations which shock the the deep chromosphere. A strong and rather vertical magnetic field of up to 2500 G is measured in the flare footpoints, confirming that the He I D_3 line is likely formed in the deep chromosphere at those locations. We provide chromospheric line-of-sight velocity and magnetic field maps obtained via He I D_3 inversions. We propose a fan-spine configuration as the flare magnetic field topology. Using an MHD simulation of a small-scale reconnection event, synthetic spectra (intensity only) of the He I D_3 and He I 10830 spectral lines via 3D non-LTE modelling have been obtained. These calculations have given new insights in the line formation mechanism of these lines during a reconnection event.

62 Large-scale solar magnetic fields observed with IRmag at Mitaka: comparison of measurements made in different spectral lines and observatories

M. L. Demidov[1], Y. Hanaoka[2], and T.Sakurai[2]

[1] *Institute of Solar-Terrestrial Physics of Siberian Branch of Russian Academy of Sciences, Lermontov str., 126-a. Irkutsk, 664033, Russia.*
[2] *Solar Science Observatory, National Astronomical Observatory of Japan, Tokyo, Japan.*

Contributed talk

Solar synoptic magnetic flux maps are the fundamental basis of all models for calculations of heliosphere and space weather parameters. Some of the uncertainties in such charts are caused by differences in the full-disk magnetograms, provided by different instruments. Since 2010 observations of such magnetograms are started with infrared spectro-polarimeter (IRmag) at NAOJ/Mitaka, and it is interesting to compare this new data set with measurements made in other observatories. This study presents the results of quantitative analysis of simultaneous IRmag observations in three spectral lines (FeI 1564.8 nm, SiI 1082.7 nm, HeI 1083.0 nm), and between IRmag magnetograms with ones from SDO/HMI, GONG, WSO and STOP SSO (Sayan solar observatory, Russia). It is shown that there is a perfect correlation between observations in FeI 1564.8 nm and SiI 1082.7 nm spectral lines, but not so good with HeI 1083.0 nm. Most probably it is caused by different formation depths of these lines. Correlation of IRmag magnetograms with ones from other observatories as good as 0.70-0.90, depending on combination. But there are significant systematic differences (linear regression coefficients) between different data sets (up to the factor by 3). A possible reasons for that are discussed.

63 How close are we to observing one Tesla in the Sun?

Sebastián Castellanos Durán[1], Andreas Lagg[1], and Sami K. Solanki[1,2]

[1] *Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany*
[2] *School of Space Research, Kyung Hee University, Republic of Korea*

Contributed talk

Our aim is to diagnose the magnetic field structure of a light bridge separating two umbrae of opposite polarity in a delta-sunspot, which shows evidence for extremely strong magnetic fields. We analyze observations from the spectro-polarimeter on board the Hinode spacecraft of the active region AR11967. The thermodynamic and magnetic configurations are obtained by inverting the Stokes profiles under the assumption of local thermodynamic equilibrium. We applied both, the traditional 1D-inversion technique and the so-called 2D coupled inversions, which takes into account the point spread function of the Hinode telescope. We used SDO/HMI to estimate the shear velocity at the light bridge based on the local correlation technique. We report a compact structure with an area of 32.7 arcsec^2 within a bipolar light bridge with field strengths exceeding 5 kG. Two regions associated with downflows of $\sim$5 km/s harbour fields larger than 6.5 kG, covering an area of 2.97 arcsec^2. The maximum field strength is 8.2 kG, which is the largest ever observed field on the surface of the Sun up to now. Based on the induction equation, we explain that the shear acting over $\sim$16.6 h can be the source of the amplification of the field.

Part VIII

Polarimetry of active regions

64 $B_\perp$ at the umbra/penumbra boundary of stable sunspots observed in the near infrared

P. Lindner, R. Schlichenmaier, and N. Bello González

Leibniz-Institut für Sonnenphysik (KIS), Freiburg, Germany

Contributed talk

Aim: Several different magneto-convective modes can be observed in Active Regions with umbrae and penumbrae representing the most apparent modes in sunspots. In observations, the distinction between these two modes has, until recently, mostly been done based on intensity maps. For stable sunspots observed with Hinode/SP, however, Jurčák et al. (2018) showed that the boundary between the penumbra and the umbra can invariantly be defined via a contour in intensity maps or in $B_\perp$ maps (vertical component of the magnetic field strength) at a canonical value $B_{\rm crit}$. In order to generalize this result and to compare different values of $B_{\rm crit}$ for different instruments and spectral lines, we performed a follow-up study for ground-based data acquired in the IR with the GRIS instrument at the GREGOR telescope.
Methods: For 11 spectro-polarimetric datasets from GRIS@GREGOR showing stable sunspots, SIR inversions were performed using the Fe I 1565.8 nm and the Fe I 1566.2 nm lines. Maps of the magnetic field vector were also produced with a computationally fast method based on Auer et al. (1977). A comparison between the performance of this method to SIR inversions was done, however, further analysis were done with the results from the SIR inversions. Averages over $B_\perp$ values at the boundary between the penumbra and umbra found in intensity maps were calculated.
Results: A comparison to $B_\parallel$ values yields a lower variance (standard deviation) of $B_\perp$ between the datasets. The value of the standard deviation of $B_\perp$ values is within the estimated measurement error. Therefore, the existence of a constant value for $B_\perp$ at the boundary between the umbra and the penumbra, as found by Jurčák et al., is supported. Unexpectedly, the calculated value of $B_{\rm crit} = (1843 \pm 100)$G for the GRIS data in the (low photospheric) IR is comparable to the value of $B_{\rm crit} = 1867$ G found by Jurčák et al. (2018) in the (mid photospheric) visible. We ascribe this result to the intrinsic difference in the observing methodology and instrumentation. The implication of this finding on the development and stability of sunspots and pores will be presented.

65 Relating the magnetic field strength with the umbra-penumbra boundary in sunspots

B. Löptien[1], A. Lagg[1], M. van Noort[1], and S. K. Solanki[1,2]

[1] *Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany*
[2] *School of Space Research, Kyung Hee University, Korea*

Contributed Talk

Recently, it was reported that the boundary between the umbra and the penumbra of sunspots occurs at a canonical value of 1867 G for the strength of the vertical magnetic field (B_z), independent of the size of the spot. This so-called Jurčák criterion is interpreted as to be the threshold for the onset of magnetoconvection. However, in case of some spots, the Jurčák criterion does not clearly identify the umbral boundary. This is attributed to be caused by the strong temporal evolution of these spots.

Here we present results which indicate that the Jurčák criterion is not related to the formation of penumbra, based on a statistical analysis of 23 sunspots observed with Hinode/SOT. We find that in some spots in our sample, the decay of the umbra is not connected to a failure of the Jurčák criterion. Moreover, we show that the observed constant value of the averaged Bz reported by Jurčák et al. is not related to the boundary between the umbra and the penumbra. Instead, it is caused by different properties of penumbral filaments between spots of different sizes. In large spots, the penumbral filaments are generally darker than in smaller spots. Hence, our results challenge the interpretation of the canonical value of B_z to be related to the boundary between the umbra and the penumbra and to the onset of magnetoconvection.

66 Spectro-polarimetric analysis of an umbral filament

S. L. Guglielmino[1], P. Romano[2], B. Ruiz Cobo[3,4], F. Zuccarello[1], and M. Murabito[5]

[1] *Dipartimento di Fisica e Astronomia "Ettore Majorana" – Sezione Astrofisica, Università degli Studi di Catania, Catania, I-95123, Italy*
[2] *INAF – Osservatorio Astrofisico di Catania, Catania, I-95123, Italy*
[3] *Instituto de Astrofísica de Canarias (IAC); 38205 La Laguna; Tenerife; Spain*
[4] *Departamento de Astrofísica, Univ. de La Laguna, La Laguna, Tenerife, E-38205, Spain*
[5] *INAF – Osservatorio Astronomico di Roma, Monte Porzio Catone, I-00078, Italy*

Contributed talk

High-resolution observations of the solar photosphere have recently revealed the presence of elongated filamentary bright structures inside sunspot umbrae. These features, which have been called umbral filaments (UFs), differ in morphology, evolution, and magnetic configuration from light bridges that are usually observed to intrude in sunspots.

To study an UF observed in the leading sunspot of active region NOAA 12529, we have analyzed spectro-polarimetric observations taken in the photosphere with the spectropolarimeter (SP) aboard the *Hinode* satellite. High-resolution observations in the upper chromosphere and transition region taken with the *IRIS* telescope and observations acquired by *SDO*/HMI and *SDO*/AIA have been used to complement the spectro-polarimetric analysis.

The results obtained from the inversion of the *Hinode*/SP measurements allow us to discard the hypothesis that UFs are a kind of light bridge. In fact, we find no field-free or low-field strength region cospatial to the observed UF. In contrast, we detect in the structure Stokes profiles that indicate the presence of strong horizontal fields, larger than 2500 G. Furthermore, a significant portion of the UF has opposite polarity with respect to the hosting umbra. In the upper atmospheric layers, we observe filaments being cospatial to the UF in the photosphere. We interpret these findings as suggesting that the UF could be the photospheric manifestation of a flux rope hanging above the sunspot, which triggers the formation of penumbral-like filaments within the umbra via magneto-convection.

67 New insights on penumbra formation from observations and STAGGER simulations

N. Bello González[1], I. Thaler[2], T. Klinger[3], M. Schmassmann[1], and R. Schlichenmaier[1]

[1] *Leibniz-Institut für Sonnenphysik (KIS), Freiburg, Germany*
[2] *Hebrew University of Jerusalem*
[3] *Albert-Ludwigs-Universität Freiburg*

Contributed talk

High-resolution spectro-polarimetric observations from a developing sunspot show the process of penumbra formation as the protrusion of elongated cells of magneto-convective nature into the umbra. These cells are characterised by inflowing (counter-Evershed) siphon flows that are reverted into Evershed (out-)flows once the actual penumbral filaments form. STAGGER simulations of a sunspot-like slab show similar properties to those found in the observations.Both, observational and numerical results will be presented and the key processes involved in penumbra formation will be discussed.

Part IX

Polarimetry of stars & synergies to solar polarimetry

68 Doing solar physics on other stars

Arturo Lopez Ariste

Recherche en Astrophysique et Planétologie (IRAP)

Invited review

Most stars other than the Sun appear to us as unresolved points. Spectropolarimetry may, however, allow us to resolve the stellar surface if a global velocity field is present.

Zeeman Doppler Imaging has been the traditional technique to resolve magnetic fields in stellar photospheres using Stokes V spectral profiles from rotating stars. Recently linear polarization profiles are also being used to image the stellar photospheres of red supergiants, convection providing the global velocity field. This time it is not the Zeeman effect, but scattering polarization which is observed. Maps of brightness and velocity fields as well as magnetograms are thus being obtained, routinely for some stars like Betelgeuse. With images of velocities, and magnetograms, we are starting to do solar physics in other stars.

I will present this recent technique and illustrate how it makes broad use of what is known of the second solar spectrum to succeed.

69 The first "Second Solar Spectrum"-like behaviour ever observed in a star different than the Sun: the post-AGB binary 89 Herculis

M. Gangi[1], F. Leone[1,2], Heshou Zhang[3,4], and Huirong Yan[3,4]

[1] *INAF - Osservatorio Astrofisico di Catania, Via S. Sofia 78, I-95123 Catania, Italy*
[2] *Universitá di Catania, Dipartimento di Fisica e Astronomia, Sezione Astrofisica, Via S. Sofia 78, I-95123 Catania, Italy*
[3] *Deutsches Elektronen-Synchrotron DESY, Platanenallee 6, D-15738 Zeuthen, Germany*
[4] *Institut für Physik und Astronomie, Universität Potsdam, Haus 28, Karl-Liebknecht-Str. 24/25, D-14476 Potsdam, Germany.*

Contributed talk

We studied the polarized spectrum of the post-AGB binary system 89 Herculis on the basis of data collected with the high-resolution Catania Astrophysical Observatory Spectropolarimeter, HArps-North POlarimeter and Echelle SpectroPolarimetric Device for the Observation of Stars. We find the existence of linear polarization in the strongest metal lines in absorption, with complex Q and U morphologies varying with the orbital period. We rule out Gauss-level magnetic fields, continuum depolarization due to pulsations and hot spots as the possible origin of the observed polarization. In the framework of optical pumping due to the secondary star, we find that the observed periodic properties of the spectral line polarization can be justified by two jets, with a flow velocity of a few tens of $km\ s^{-1}$, at the basis of that hourglass structure characterizing 89 Herculis. With a further analysis we show that the linear polarization of absorption lines from ground state is dominated by the presence of a sub-Gauss magnetic field, attributable to the ground state alignment (GSA) mechanism. We suggest that the study of aspherical envelopes of cool and evolved stars can benefit from high-resolution linear spectropolarimetry and that this technique can also trace the 3D structure of sub-Gauss magnetic fields.

70 Measuring magnetic fields in stellar prominences with MIRADAS@GTC

M. J. Martínez González[1], T. Felipe García[1], A. Asensio Ramos[1], and S. Eickenberry[2]

[1] *Instituto de Astrofísica de Canarias (IAC); 38205 La Laguna; Tenerife; Spain*
[2] *Florida University*

Contributed talk

Prominences (and consequently, filaments too) are known to exist in other late-type stars than the Sun. These structures have been detected as cool overdensities inside the hot coronal gas co-rotating with the star. The most remarkable difference with solar prominences is that stellar ones have been detected at radial distances from 2 to 8 stellar radii, although with a preference for the Keplerian co-rotation radius.

Here we present the theoretical grounds to diagnose the magnetic field of stellar prominences from future spectro-polarimetric observations. We plan to apply these tools to the data that we will acquire with the new MIRADAS instrument attached to the 10-m Gran Telescopio Canarias (our group will have priority access). MIRADAS is a mid resolution, near-IR spectro-polarimeter that, attached to such a large photon collector, will be a unique instrument to explore the magnetism of cool stellar prominences. The commissioning of MIRADAS at GTC is scheduled for the end of 2019.

71 Spectral synthesis of simulated starspots

M. Panja, R. H. Cameron, and S. K. Solanki

Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany

Contributed talk

We have performed the first-ever, realistic ab-initio simulations of the photospheric structure of starspots for a range of cool main-sequence stars, namely the spectral types M, K, and G, using the non-grey radiative MHD code MURaM. Our simulations show that there is an increase in spot contrast with increasing stellar surface temperature, which can explained as an effect of the temperature dependence of H- opacity. We will show synthetic spectral line profiles (Fe I and Ti I) of our simulated spots computed using the radiative transfer code SPINOR. In addition, we have studied the centre to limb variation of starspot intensity contrasts in the continuum near 510.6 nm.

Part X
Posters

72 The Sunrise UV Spectropolarimeter and Imager for SUNRISE 3

A. Feller[1], P. Barthol[1], M. Bayon Laguna[1], M. Bergmann[1], J. Bochmann[1], W. Deutsch[1], H. P. Doerr[1], M. Eberhardt[1], R. Enge[1], G. Fernandez Rico[1], A. Gandorfer[1], S. Goodyear[1], B. Grauf[1], K. Heerlein[1], J. Heinrichs[1], F. A. Iglesias[2], Y. Katsukawa[3], M. Kubo[3], A. Lagg[1], S. Meining[1], S. Meyer[1], M. Monecke[1], R. Müller[1], M. F. Müller[1], D. Oberdorfer[1], I. Papagiannaki[1], S. Ramanath[1], T. Riethmüller[1], K. Sant[1], S. K. Solanki[1], and J. Staub[1]

[1] *Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany*
[2] *Universidad Tecnológica Nacional, CONICET, CEDS, Mendoza, Argentina*
[3] *National Astronomical Observatory of Japan, Tokyo, Japan*

For its third science flight, the balloon-borne solar observatory Sunrise will have extended capabilities to measure magnetic fields, plasma velocities and temperatures with increased sensitivity and over a larger height range from the photosphere up to the chromosphere. One of the scientific instruments foreseen for Sunrise 3 is the Sunrise UV Spectropolarimeter and Imager (SUSI), a grating based spectropolarimeter with slit-scanning and simultaneous context imaging via a slit-jaw camera. SUSI will explore the near-UV range between 300 nm and 410 nm, which is characterized by a high density of spectral lines and to a large extent poorly accessible from the ground. We present the scientific motivation for contributing such an instrument to Sunrise 3 and provide an overview of the SUSI design, expected performance and data products.

73 Non-linearity calibration of CMOS sensors

Kamal Sant, Michiel van Noort, T. L. Riethmüller, and Hans-Peter Doerr

Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany

Although Scientific CMOS sensors have become a standard element in many imaging applications, they are not yet readily available in large formats, and are still relatively slow. To satisfy the requirements for image sensors of the new generation of solar instruments, we are therefore exploring the suitability of industrial CMOS sensors for use in sensitive polarimetric applications. Once thermally stabilized, these cameras are found to have reproducible properties, that can be accurately calibrated. However, many of the fastest industrial cameras appear to suffer from a more difficult to calibrate pixel-to-pixel cross-talk, caused by the parallel design of the sensor readout circuits, resulting in a scene dependent response of the sensor.

To make use of such sensors for the sensitive differential photometry needed for polarimetry, we attempt to characterize this scene dependent response of the sensor. We characterize the response of each pixel to a given irradiance, with respect to the average irradiance of each image line, and the number of other pixels having the same measured response value, in that same image line. These parameters were chosen according to the sensor design, and are the most likely sources of pixel-to-pixel cross-talk.

A setup was developed to carry out this calibration, that should be suitable for the calibration of many of the CMOS sensors available today.

74 Cancelling features in the quiet Sun as observed by Sunrise

S. L. Guglielmino[1], S. K. Solanki[2,3], T. L. Riethmüller[2], L. S. Anusha[2], J. Hirzberger[2], and F. Zuccarello[1]

[1] *Dipartimento di Fisica e Astronomia "Ettore Majorana" – Sezione Astrofisica, Università degli Studi di Catania, Catania, I-95123, Italy*
[2] *Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany*
[3] *School of Space Research, Kyung Hee University, Republic of Korea*

An essential ingredient of the solar magnetism is the evolution of small-scale magnetic features in the quiet Sun. Aiming at understanding their ultimate fate, we have analyzed quiet-Sun cancelling features using high resolution, seeing-free observations acquired by the Imaging Magnetograph eXperiment (*IMaX*) and Sunrise Filter Imager (*SuFi*) instruments aboard the Sunrise Mission. Thanks to the high polarimetric sensitivity and spatial resolution of Sunrise, we are able to follow features with fluxes as low as $\approx 10^{15}$ Mx. We determine their spatial distribution in the photosphere and we study their counterpart in the chromospheric level as seen in Ca II H images.

75 Global dipole moment study using optimized surface flux transport model

M. Talafha, and K. Petrovay

Eötvös Loránd University

The importance of solar polar magnetic fields for the dynamo and for solar cycle forecasting has become increasingly clear in recent years. Polar fields are observed to be built up from active region trailing polarities by meridional flow advection and turbulent diffusion. The surface flux transport (SFT) models describing this process involve a number of free parameters and optional choices such as turbulent diffusivity, meridional flow amplitude or choice of meridional flow profile. In the past these choices were usually optimized to best reproduce the overall time-latitude pattern (butterfly diagram) of the magnetic field distribution. In this approach, mid-latitude features (plumes) are given great weight, while the smaller polar areas, observed less well due to perspective problems, have little influence. As a result, models optimized in this way often show significant disagreements with observations of the polar field, esp. regarding the timing of polar field reversals and maxima or latitudinal extent of the polar field concentration.

We took the alternative approach of constraining SFT model parameters and assumptions by reducing the allowed parameter space to the domain where the phase of polar field variations and the latitudinal extent of the polar magnetic cap agree with observational constraints.

One important application of the result is considering the case when initially there is only a simple bipolar region, placed in some latitude, and run the SFT model with optimized parameters for some time until a dipolar field is formed, one can get the relation between the initial and final field, which can be introduced to the global dipole moment as a further factor as a function of latitude

76 Slow magneto-acoustic waves in numerical simulations of an active plage region

N. Yadav, R. H. Cameron, and S. K. Solanki

Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany

The exact physical mechanism underlying the observed high temperatures of the solar chromosphere remains an unresolved mystery. Wave dissipation is one of the most likely candidates to explain the heating of the solar chromosphere. In order to investigate the wave propagation in a realistic solar environment, we perform numerical simulations of an unipolar plage region using the 'MURaM' code. We analyze the properties of magneto-acoustic waves excited due to the leakage of global p-modes and photospheric turbulent motions, and we investigate their importance in the heating of the solar chromosphere. To study waves that propagate along the magnetic field lines, we track the fluid parcel at the mean solar surface and trace the magnetic field line associated with that fluid parcel at each instant of time. To analyze the magneto-acoustic waves, we calculate the velocity perturbations along the magnetic field line over the course of 25 minutes at a cadence of 1-second. Analyzing the time-distance diagrams, we find that linear magneto-acoustic waves get converted into shocks in the chromosphere. Performing the wavelet analysis of the time series at different heights of the solar atmosphere for 25 different locations in a magnetically concentrated region, we compute the statistically averaged velocity power spectra. Velocity power spectra at various heights reveal the shift of the peak frequency towards the higher frequencies with increasing height. We compare the power spectra calculated with field line tracing method to the power spectra computed at the fixed location. We find that keeping the location fixed can result in large values of power, particularly in the high-frequency domain. We also calculate the spectra for acoustic wave energy flux, revealing the frequency distribution of wave power at various heights. The energy flux carried by these waves is found to be sufficient to compensate for the radiative losses of the lower chromosphere. The simulations are performed on a high spatial resolution of 10km. Moreover, the analysis is also performed on degraded data-sets that can be compared with the future high-resolution observational data obtained with DKIST and/or EST.

77 Convective stability in MURaM simulations of sunspots

Markus Schmassmann[1], Rolf Schlichenmaier[1], Nazaret Bello González[1], Matthias Rempel[2], and Jan Jurčák[3]

[1] *Leibniz-Institut für Sonnenphysik (KIS), Freiburg, Germany*
[2] *High Altitude Observatory, NCAR, Boulder, Colorado, USA*
[3] *Astronomical Institute of the Academy of Sciences, Ondřejov, Czech Republic*

Recent observational results (Jurčák et. al, A&A, 2018, Schmassmann et. al, A&A, 2018) show, that the vertical magnetic field component along the umbral boundary of stable sunspots is independent of size and constant in time. Mullan & MacDonald (ApJ, 2019) relate this result to Gough & Taylor (MNRAS, 1966), who show how the Schwarzschild criterion has to be modified to account for the stabilizing effect of the vertical field component.

We apply the Gough-Tayler stability criterion for instability

$$\frac{{B_{\mathrm{ver}}}^2}{{B_{\mathrm{ver}}}^2 + 4\pi\gamma p} < \nabla - \nabla_{\mathrm{ad}}$$

to sunspot simulations done with MURaM, and compare the region of instability with the boundary of the umbra.

We show that this criterion correctly identifies the peripatopause, i.e. the transition sheet between umbra & penumbra beneath the photosphere. Irrespective of the top boundary condition there is a constant value of the vertical magnetic field component at the umbral boundary in the photosphere. However, only in case of a potential field as the top boundary condition, this value is consistent with Jurčák's observed $B_{\mathrm{ver}} = 1867\,G$, whereas if the magnetic field is forced to be more horizontal at the top boundary, this value is reduced and the field is more inclined.

We conclude tentatively that penumbral and granular type of convection can only occur in regions where the Gough-Tayler instability criterion is fulfilled, and are currently investigating up to what minimal depth it can be evaluated to correctly identify the umbral boundary.

78 Chromospheric observations and magnetic configuration of a supergranular structure

C. Robustini[1], S. Esteban Pozuelo [1,2], J. Leenaarts [1], and J. de la Cruz Rodríguez [1]

[1] *Institute for Solar Physics, Department of Astronomy, Stockholm University, AlbaNova University Centre, SE-106 91 Stockholm*
[2] *Instituto de Astrofísica de Canarias (IAC); 38205 La Laguna; Tenerife; Spain*

We present high spatial resolution narrow-band images in three different chromospheric spectral lines, including Ca II K with the new CHROMospheric Imaging Spectrometer installed at the Swedish 1-m Solar Telescope. These observations feature a unipolar region enclosed in a supergranular cell, and located 68° off the disk-centre. The observed cell exhibits a radial arrangement of the fibrils which recalls of a chromospheric rosette. However, in this case, the convergence point of the fibrils is located at the very centre of the supergranular cell. Our study aims to show how the chromosphere appears in this peculiar region and retrieve its magnetic field and velocity distribution. In the centre of the cell, we measured a significant blue-shift in the Ca II K nominal line core associated to an intensity enhancement. We interpreted it as the product of a strong velocity gradient along the line of sight. We will show the techniques employed to obtain magnetic field maps so close to the limb and suggest a possible configuration that takes into account also the measured velocity within the unipolar region.

79 Physical characteristics of Ca II K bright fibrils

S. Kianfar, J. Leenaarts, J. de la Cruz Rodríguez, and S. Danilovic

Institute for Solar Physics, Department of Astronomy, Stockholm University, Albanova University Center, 10691 Stockholm, Sweden

For a long time the bright fibrils observed in the chromosphere have been believed to have higher temperature compared to the darker background. In this context, we have investigated fibrils belonging to a plage region in multiple chromospheric spectral lines such as Hα and Ca II K transitions. We investigated high spatial resolution observations in the spectral line of Ca II 8542 and Ca II K obtained at the 1–m Swedish solar telescope by using the CRispImaging SpectroPolarimeter (CRISP) and the CHROMospheric Imaging Spectrometer (CHROMIS), respectively. In the datasets, we identified 169 bright fibrils and their dark background counterparts, which have been processed using the multi–line polarimetric inversion code (STiC). The temperature distribution that we retrieved along these structures shows that there is a clear evidence that the bright fibrils are generally hotter that their background in the lower chromosphere. We will present the results of our study which include a statistical analysis of temperature, intensity and line of sight velocity.

80 Admixture of dipole and quadrupole atomic transitions in the presence of external magnetic field

Yee Yee Oo[1], Win Moe Thant[2], K.N. Nagendra[3], and G. Ramachandra[4]

[1] *Taungoo University,Taungoo, Myanmar*
[2] *Department of Physics, Shwebo University, Myanmar*
[3] *Indian Institute of Astrophysics, Bangalore, India*
[4] *GVK Academy, Bangalore, India*

The admixture effect of dipole and quadrupole type atomic transitions on the Stokes parameters characterizing the emitted radiation in the presence of an external magnetic field is studied. The transition from an upper level with angular momentum $J_u = 3/2$ to a lower level with angular momentum $J_l = 1/2$ is considered to take account of the admixture effect. The analytical expressions showing the emitted Stokes parameters for the case of upper and lower levels having same parities are derived. It is shown that the radiative transition probabilities of magnetic dipole ($M1$) and electric quadrupole transition ($E2$) are more intense than those of electric dipole transition ($E1$) and magnetic quadrupole transition ($M2$). The polarization components that are not usually seen in the Stokes I, Q and V profiles appear due to the admixture effect. The interference of the polarization components with opposite signs is responsible for the smaller strength of Stokes I, Q, V in admixture transition compared to those observed in pure transition. In pure dipole transition case, U Stokes profile is always zero for all emitted radiation directions. However, the Stokes U profile arises only due to the admixture effect.

81 Multilevel PRD problem: convergence of the calculation of the Second Solar Spectrum of the Na I D lines

V. Bommier

LESIA, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, Univ. Paris Diderot, Sorbonne Paris Cité, 5, Place Jules Janssen, 92190 Meudon, France; V.Bommier@obspm.fr

The calculation is an application of the multilevel PRD theory built by Bommier (2016, A&A, 591, A59), by applying the atomic density matrix formalism. The application code to the solar Na I D lines was described in Bommier (2016, A&A, 591, A60). However, an error and an imprecision were remaining, which have now been corrected for. The results, theoretical linear polarisation profiles of the Na I D lines observed 4.1 arcsec inside the limb, will be presented. They qualitatively agree with the observed ones, more with the ones of Bommier & Molodij, 2002, A&A, 381, 241, and of Trujillo Bueno et al., 2001, ASP Conf. Ser., 236, 141, who both display purely antisymmetric Na I D1 profiles, rather than with the one by Stenflo & Keller, 1997, A&A, 321, 927, who display a net linear polarisation in Na I D1. A better agreement would be obtained if the dimension number of the atmosphere model was increased. Indeed, the present atmosphere model is 1D, which remains probably highly insufficient for describing these lines, which are formed in the low chromosphere. Emphasis will be put on the convergence of the lambda-iteration in this calculation. It will be shown that although the Stokes parameters I and Q are far from being each converged within the 166 iteration steps of the calculation, simplifications occur by forming their ratio Q/I, which is the emerging linear polarisation rate and the main result of the calculation, leading to sufficient convergence for this ratio in 166 steps. It will be shown that the convergence of the emerging polarisation Q/I is of the Riemann series type for exponent larger than unity (unity is the case of the harmonic series, which does not converge).

82 Polarized line transfer in the incomplete Paschen-Back effect regime

M. Sampoorna[1], **K. N. Nagendra**[1], K. Sowmya[2], J. O. Stenflo[3,4], and L. S. Anusha[2]

[1] *Indian Institute of Astrophysics, Koramangala, Bengaluru, India*
[2] *Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany*
[3] *Institute for Particle Physics and Astrophysics, ETH Zurich, CH-8093 Zurich, Switzerland*
[4] *Istituto Ricerche Solari Locarno, via Patocchi, CH-6605 Locarno-Monti, Switzerland*

Quantum interference between the hyperfine structure states are known to produce a depolarization in the line cores of some of the lines in the linearly polarized spectrum of the Sun (the Second Solar Spectrum). The presence of an external magnetic field in the line forming regions modifies these signatures through the Hanle, Zeeman, and Paschen-Back effects, depending on the strength of the magnetic field. Sowmya et al. (2014, ApJ, 786, 150) derived the relevant partial frequency redistribution (PFR) matrix for scattering on a two-level atom with hyperfine structure splitting, and in the presence of arbitrary strength magnetic fields (including the incomplete and complete Paschen-Back effect regimes). In this paper we solve the problem of polarized line transfer in a magnetized atmosphere, including this PFR matrix. For this purpose, we apply a method which is based on orders of scattering approach. We present the results on the combined effects of incomplete Paschen-Back effect and PFR on the polarized line profiles of D_2 lines of Li I.

83 On-board data reduction pipeline for SO/PHI

K. Albert[1], J. Hirzberger[1], N. Albelo Jorge[1], D. Busse[1], J. Blanco Rodríguez[2], J. S. Castellanos Durán[1], J. P. Cobos Carrascosa[3], B. Fiethe[4], A. Gandorfer[1], Y. Guan[4], L. Guerrero[1], P. Gutierrez-Marques[1], M. Kolleck[1], T. Lange[4], H. Michalik[4], S. K. Solanki[1], J. C. del Toro Iniesta[3], and J. Woch[1]

[1] *Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany*
[2] *Universidad de Valencia*
[3] *Instituto de Astrofísica de Andalucía (IAA - CSIC)*
[4] *Institute of Computer and Network Engineering, TU Braunschweig*

The Polarimetric and Helioseismic Imager (PHI) is the first solar spectropolarimeter to fly on a deep space probe, the Solar Orbiter (SO). SO/PHI is a state-of-the art instrument, with the required polarimetric accuracy of 10^{-3}. The main technical challenges that the instrument is facing are the dynamic environment, highly limited telemetry, and long command-response times. To overcome these problems and meet the requirements, SO/PHI implements on-board data processing including: processing of calibration data, and applying it directly during the processing of the science data. The final downlinked data products are the results from the inversion of the radiative transfer equation: magnetic field vector map, line-of-sight velocity and temperature map.

Such an on-board data reduction system must be reliable, execute the image processing operations on the limited on-board hardware, run on the instrument processing unit in non-real time, offer information in the data products that enable error detection without additional communication with the instrument, and last but not least offer possibility for improvements or necessary changes. This represents a sharp contrast from the systems in use until today.

We developed a software framework in which all the data processing functionalities are implemented. We build the processing logic by combining basic operations running on Field Programmable Gate Arrays (FPGAs) with dedicated firmware to accelerate the processing. We define processing blocks that can be combined with few restrictions to build pipelines, ensuring flexibility. We increase reliability by providing two parallel implementations, one using the FPGAs, another using only the microprocessor. We log metadata on several software levels to ensure reproducibility of results, possibility of error detection, as well as the logging of all information relevant for the scientists analysing the data.

This contribution highlights aspects of the SO/PHI on-board data reduction that are different from traditional on ground data processing pipelines.

84 Geomagnetically induction effects related to impulsive space weather events at low latitudes

N'guessan Kouassi, Vafi Doumbia, Kouadio Boka, and Zie Tuo

Laboratoire de Physique de lAtmosphère, Université Félix Houphoüet Boigny, Abidjan, Côte d'Ivoire

During the International Equatorial Electrojet Year (IEEY), from 1992 to 1994, variations of the North-South (Ex) and East-West (Ey) components of the geoelectric field and the horizontal northward (H), eastward (D) and vertical downward (Z) components of the geomagnetic field were recorded along a meridian chain of ten stations across the geomagnetic dip-equator in West Africa (about 5W longitude).The Geomagnetically Induced Current (GIC) in response to impulsive space weather events was estimated based on two different approaches. The first approach consisted of using the observed geoelectric field variations associated with the February 17, 1993 geomagnetic storm and the April 4, 1993 solar flare to calculate the related GICs. In the second approach, the components of the geoelectric field (Exc and Eyc) were estimated from the geomagnetic field variations during the February 17, 1993 geomagnetic storm, from which an estimate of the potential GICs was inferred. The estimated geoelectric field (Exc and Eyc) and GICs in the second approach were compared with the results of the first approach.

85 A spectropolarimetric survey of F-G-K stars

M. Gangi[1], and F. Leone[1,2]

[1] *INAF - Osservatorio Astrofisico di Catania, Via S. Sofia 78, I-95123 Catania, Italy*
[2] *Universitá di Catania, Dipartimento di Fisica e Astronomia, Sezione Astrofisica, Via S. Sofia 78, I-95123 Catania, Italy*

In recent years it has emerged how linear spectropolarimetry can be a powerful diagnostic tool for stellar atmospheres. We present the preliminary results of a spectropolarimetric observational campaign conducted on a sample of F-G-K stars to investigate the possible presence of intrinsic linear polarization. The observations were made with the high resolution *Catania Astrophysical Observatory Spectropolarimeter* (CAOS) and cover a sample of 21 stars with spectral classes between F and K.

We have found linear polarization across the absorption LSD profiles for about 71% of stars of our sample, often variable in time.

Our preliminary results confirm the idea that the presence of linear polarization is widespread among stars and that a broad and in-depth spectropolarimetric study is recommended.

86 2D imaging spectropolarimetry of solar prominences with ZIMPOL and a Fabry-Pérot filter system

R. Di Campli[1,2], **R. Ramelli**[1], M. Bianda[1], I. Furno[2], and L. Belluzzi[1,3]

[1] *Istituto Ricerche Solari Locarno, Switzerland*
[2] *École Polytechnique Fédérale de Lausanne, Switzerland*
[2] *Leibniz-Institut für Sonnenphysik (KIS), Freiburg, Germany*

We report about first 2D-observations of solar prominences with the ZIMPOL polarimeter in combination with a tunable narrow band Fabry-Pérot filter system coupled with the spectrograph at the Gregory Coudé telescope in Locarno. This work required to carefully take care of many instrumental aspects like instrumental polarisation, image rotations and stray-light subtraction. The full Stokes images of one prominence have been used to obtain two dimensional maps of the magnetic field, the macroscopic drifts and the plasma temperature, applying the HAZEL inversion code.

87 Brief introduction of a New Tower Solar Telescope

Yingzi Sun

National Astronomical Observatories, Chinese Academy of Sciences

In 2016, the Huairou Solar Observatory Station of the National Astronomical Observatory of the Chinese Academy of Sciences undertook the renovation project of the solar tower of Beijing Normal University. Based on the original tower site and the celestial mirror, a new imaging system, a grating spectrometer system and an observation terminal system were designed and constructed to realize all-visible spectral observation of the sun. The solar tower is 20 meters high. The imaging system has an off-axis parabolic mirror with 400 mm aperture and a focal length of 7 meters. The spectral resolution is 0.002 nm at 532.4 nm.

88 SCIP: Near-IR Spectro-Polarimeter for the SUNRISE-3 balloon telescope

Y. Katsukawa[1], J. C. del Toro Iniesta[2], S. Solanki[3], M. Kubo[1], H. Hara[1], T. Shimizu[4], T. Oba[4], C. Quintero Noda[5], T. Tsuzuki[1], F. Uraguchi[1], T. Tamura[1], Y. Nodomi[1], Y. Suematsu[1], R. Ishikawa[1], R. Kano[1], Y. Kawabata[4], K. Ichimoto[6], S. Nagata[6], T. Anan[7], D. Orozco Suárez[2], A. C. López Jiménez[2], J. P. Cobos Carrascosa[2], M. Balaguer Jiménez[2], A. Feller[3], T. Riethmueller[3], and A. Lagg[3]

[1] *National Astronomical Observatory of Japan, Tokyo, Japan*
[2] *IAA-CSIC*
[3] *Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany*
[4] *ISAS/JAXA*
[5] *Univ. of Oslo*
[6] *Kyoto Univ.*
[7] *NSO*

SCIP (Sunrise Chromospheric Infrared spectroPolarimter) is a new instrument for the third flight of the SUNRISE balloon-borne solar mission planned for 2021. SCIP aims to conduct spectro-polarimetric observations of near-infrared spectral lines in the two wavelength ranges from 765.5 to 771.6 nm and from 846.6 to 854.7 nm simultaneously. The wavelength ranges include spectrum lines sensitive to magnetic fields in the photosphere and chromosphere, such as Fe I 846.8 nm, K I 766.5 and 769.9 nm, Ca II 849.8 and 854.2 nm etc. The instrument is designed to obtain 3D magnetic and velocity structures of the solar atmosphere by combining the above spectrum lines with spatial and spectral resolution of 0.2" and 2×10^5, respectively, and with 0.03% polarimetric sensitivity in 10 sec integration. By making coordinated observations with the UV spectro-polarimeter SUSI and the visible light imaging polarimeter IMaX+ aboard the same platform, it is expected to obtain unprecedented spectral coverage in the spectro-polarimetric observation. The SCIP instrument is designed to achieve good polarimetric accuracy by optimizing performance of the optics at the observing wavelengths and by considering temperature variation during the flight. Key techniques for them are developed through international collaboration among Japan, Spain, and Germany.

89 Development of an infrared camera using a Hawaii-2RG detector for solar polarimetry

Y. Hanaoka, Y. Katsukawa, S. Morita, Y. Kamata, and N. Ishizuka

National Astronomical Observatory of Japan, Tokyo, Japan

Solar polarimetry in near infrared wavelengths is promising because the magnetic field information of the chromosphere can be obtained in addition to that of the photosphere. To realize the infrared polarimetry with a large format detector, we developed an infrared camera with a H2RG array of Teledyne, which has 2048x2048 pixels, focusing on the wavelengths 1.0 – 1.6 μ. It is required to synchronize the polarization modulation and data acquisition by the camera for the polarimetry. However, it had been impossible under the fast read-out mode of H2RGs. We introduced a MACIE interface board and new assembly codes (Markury Scientific) to realize the synchronization, and now it is possible to carry out the polarimetry with high frame rates such as 30 – 120 frames $\sec^{-1}$. In the workshop, we will present the operation scheme of the camera with a polarization modulator, and show some results of an experimental observation.

90 Polarization model for the Multi-Application Solar Telescope at the Udaipur Solar Observatory

Ramya M. Anche[1], Shibu K. Mathew[2], Mohana Krishna[3], K. Sankarasubramanian[4], G. C. Anupama[1], Ramya Bireddy[2], Rahul Yadav[5], and Avijeet Prasad[6]

[1] *Indian Institute of Astrophysics, Koramangala, Bangalore, India*
[2] *Udaipur Solar Observatory, Udaipur, India*
[3] *University of California San Diego, 9500 Gilman Dr, La Jolla, CA 92093, USA*
[4] *U R Rao Space Center, Bangalore, India*
[5] *The Institute for Solar Physics, Stockholm, Sweden*
[6] *University of Huntsville, Alabama, USA*

Solar polarimetry aims at measuring the full set of Stokes vectors (I, Q, U, V) to extract the magnetic field information of the solar atmosphere. During the spectro-polarimetric observations, the oblique reflections in the telescope mirrors modify (crosstalk) or even produce polarization (instrumental polarization). For accurate polarimetric measurements of the source, it is important to correctly model the instrumental polarization and crosstalk introduced by the telescope.

The Multi-Application Solar Telescope (MAST) at the Udaipur Solar Observatory is a 50 cm off-axis Gregorian telescope with an imaging spectro-polarimeter operating at 6173 and 8542Å wavelengths for simultaneous observations of photosphere and chromosphere of the Sun. The MAST optical configuration consists of nine mirrors (most of them inclined) where the instrumental polarization effects introduced are expected to be considerably high.

Here, we present a formalism for an analytical estimation of the Mueller matrix of the telescope using a polarization ray tracing algorithm that also incorporates the effect of variation in the refractive index of the mirror coatings. The model was experimentally verified using observations taken in the 6173 Å channel during the months of January and May 2018. The instrumental polarization was found to vary between 3.91 % to 14.29 % over the course of the observation from 9 AM to 4 PM and the crosstalks from Q to U and V estimated at maximum solar elevation (12 PM) were found to be 52.84 % and 73.93 % respectively. We obtained a reasonable match between the model and the observations with some offsets. We also discuss the possible reasons for these deviations and their effects.

91 Polarization calibration of the Solar Magnetic Activity Research Telescope (SMART)

D. Yamasaki[1], S. Nagata[2], and K. Ichimoto[2]

[1] *Department of Astronomy, Kyoto University*
[2] *Astronomical Observatory, Graduate School of Science, Kyoto University*

One of the four telescopes of the Solar Magnetic Activity Research Telescope (SMART: UeNo et al. 2004) is a partial disk ($320'' \times 240''$) filter magnetograph SMART-T4(Nagata et al. 2014). SMART-T4 consists of a rotating wave plate, tunable tandem Fabry-Perot filters which scan four wavelength points around the Fe I 6302.5Å ($\pm$0.16Å and $\pm$0.08Å) with $\sim$ 130mÅ bandwidth, a polarizing beam splitter, and two CCD cameras simultaneously take orthogonally polarized light with a frame rate of 30 frames per second. SMART-T4's polarization optical system is expressed by a simple combination of a polarization modulator and a polarization analyzer. The system collects 10^4 photons at each pixel and exposure, by integrating as many as 700 images, SMART-T4 achieves the polarimetric sensitivity of $\sim 5 \times 10^{-4}$, with maximum temporal resolution of $\sim$ 20 seconds. We have carried out the polarization calibration of the SMART-T4 with linear and circular sheet polarizers placed in front of the polarization modulator. Based on the measurement, we have evaluated the polarimeter response matrix of the SMART-T4. As a result of this analysis, we found the following things. First, the most dominant modulation component in each Stokes Q, U, or V input was consistent to the polarization optical system model. Second, we found the significant spacial variation of the polarimeter response matrix, which means that the deduced matrix cannot be regarded as uniform through the SMART-T4 field of view. For crosstalk from the linear to circular polarizations, the spacial variation was two order larger in magnitude than the required uncertainty of < 0.007, and for circular to linear polarization, it was one order larger than that of < 0.005. Thus, we need to calibrate the SMART-T4 stokes profiles pixel by pixel. We then have examined the vector magnetic field derived from the calibrated stokes profiles. In this presentation, we explain the development of the polarization demodulation code to deduce Stokes vectors from the observed data, and the Stokes inversion code to derive the vector magnetic field from Stokes vector as well as the comparison of the vector magnetic field obtained with SMART-T4, Helioseismic and Magnetic Imager (HMI) aboard Solar Dynamics Observatory (SDO), and Hinode Solar Optical Telescope (SOT).

92 Restoring process in a sunspot penumbra

P. Romano[1], **S. L. Guglielmino**[2], M. Murabito[3], and F. Zuccarello[2]

[1] *INAF – Osservatorio Astrofisico di Catania, Catania, I-95123, Italy*
[2] *Dipartimento di Fisica e Astronomia "Ettore Majorana" – Sezione Astrofisica, Università degli Studi di Catania, Catania, I-95123, Italy*
[3] *INAF – Osservatorio Astronomico di Roma, Monte Porzio Catone, I-00078, Italy*

The formation of the sunspot penumbra is a physical process which is not yet clear in all its aspects and implications. This question is mainly due to the fact that there are only few observations of this process carried out with high spatial, spectral, and temporal resolution. Therefore, many open questions about the penumbra and its formation are still pending. In this poster, we describe the preliminary results obtained from the observations of the decay and subsequent restoring of a sector of penumbra in the preceding sunspot of the active region NOAA 12348. We analyzed data acquired along two photospheric lines (Fe I 630.25 nm and Fe I 617.3 nm lines) sampled in full polarimetric mode and two chromospheric lines (Ca II 854.2 nm and Hα 656.28 nm lines) without polarimetric measurements, taken on May 18 and 19, 2015, by the IBIS instrument operating at the NSO/Dunn Solar Telescope. Our results show evidence that the restoring process of the penumbra is due to the resettlement at photospheric level of the field lines overlying the pore. This confirms the interpretation of the penumbra formation as a result of the change in the inclination of the field lines belonging to the magnetic canopy.

93 COCOPLOTs displaying 3D data using 2D colour images

A. G. M. Pietrow, M. Druett, and C. Robustini

Institute for Solar Physics, Stockholm University, Albanova University Centre, SE-106 91 Stockholm, Sweden

COlor COllapsed PLOTting software (COCOPLOT, Druett et al. 2019, in prep) generates quick-look and context images. The aim is to convey spectral profile information from all of the spatial pixels in a 3D datacube via a single 2D image, using color. Filters for red, green, and blue channels are convolved with the datacube to produce an RGB a color image. This process avoids the user needing to scan through many different wavelengths when searching for regions in the datacube that satisfy multiple criteria.

Although applicable to any 3D datacube, this software was inspired by a single thought: what would the Sun look like if we could only see light from one spectral line? In an absorption line, with low emission in the central wavelengths, and high wings on either side, the blue and red cone receptors of our thought experiment would be triggered, making the Sun appear purple. For a strong, narrow emission line the converse is true, and so the line would appear green. A red or blue Doppler-shifted emission would appear in those colours respectively.

We present examples of how COCOPLOT works on the intensity profiles of high-spatial resolution images from the Swedish 1-m Solar Telescope, and which kind of information these context images can provide. Moreover, we show how the COCOPLOT method can be applied to a large variety of profiles, such as Stokes profiles. COlor COllapsed polarization maps can be useful to quickly vizualize asymmetries and circumscribe regions of interest. We make the code publicly available, currently in IDL and PYTHON.

94 Solar-cycle variations of the magnetic flux in the internetwork

M. Faurobert, and G. Ricort

University Cote d'Azur (UCA) Lagrange Laboratory

We use spectro-polarimetric observations obtained onboard the Hinode satellite with SOT/SP in the FeI lines at 630 nm in quiet Sun regions at a mimimum (December 2007) and a maximum (December 2013) of the solar cycle. The circular polarization maps and the granulation images are corrected for defocus and for the effect of the Point Spread Function by means of a Richardson-Lucy algorithm. Then we derive the unsigned magnetic flux and the power spectrum of its spatial fluctuations in 10" x10" internetwork regions at various heliocentric angles. The Stokes parameter inversion is performed under the assumption of weak magnetic field strengths.We find that both the shape and the amplitude of the power spectrum of the unsigned magnetic-flux vary between the minimum and the maximum of the cycle whereas the unsigned-flux mean value over the selected internetwork regions does not vary significantly. At disk center the magnetic fluctuations are stronger at solar maximum whereas closer to the pole they are stronger at the minimum of the cycle.

95 Polarization calibration of the Chromospheric LAyer Spectro-Polarimeter (CLASP2)

Donguk Song[1], **Ryohko Ishikawa**[1], Ryouhei Kano[1], Hirohisa Hara[1], Kazuya Shinoda[1], Masaki Yoshida[1,5], David McKenzie[2], Javier Trujillo Bueno[3], Frédéric Auchére[4], Laurel Rachmeler[2], Ken Kobayashi[2], Takenori J. Okamoto[1], and CLASP2 team

[1] *National Astronomical Observatory of Japan, Tokyo, Japan*
[2] *NASA Marshall Space Flight Center*
[3] *Instituto de Astrofísica de Canarias (IAC); 38205 La Laguna; Tenerife; Spain*
[4] *Institut d'Astrophysique Spatiale*
[5] *SOKENDAI (The Graduate University for Advanced Studies)*

The Chromospheric LAyer Spectro-Polarimeter (CLASP2) is a NASA sounding rocket experiment designed at achieving high precision measurements (< 0.1 %) of the linear and circular polarizations in the Mg II h & k lines (near the 280 nm), whose line cores originate in the upper chromosphere of the Sun. The CLASP2 was successfully launched on April 11, 2019, and observed three targets: the solar disk center, a plage region and the quiet Sun near the limb. A unique polarization calibration is required to ensure that the CLASP2 provides 0.1 % polarization accuracy as respresented by the theoretical prediction of Stokes profiles. The CLASP2 consists of a Cassegrain telescope and a spectro-polarimeter (SP) composed of two channels that measure the two orthogonal polarization states simultaneously. The instrumental polarization of the telescope due to the coating non-uniformity and off-axis incidence is estimated to be negligibly small. Therefore, our polarization calibration was only carried out for the SP. For this, we performed the polarization calibration in two steps as follows. First, we derived the response matrix of the SP by using the pre-flight polarization calibration data. For this, we developed a custom-made light source whose F-number is the same as the telescope, and attached it directly to the SP. The light source is designed to inject polarized light into the the SP: linearly polarized light was obtained by rotating a polarizer installed in the light source at intervals of 45° and we got circularly polarized light by a polarizer and a quarter-waveplate installed just after the polarizer. To derive the response matrix element, we assumed the spurious polarization term to be zero based on un-polarized light measurements, and determined other elements of the response matrix, such as scale factor and crosstalk between Stokes vectors. After the launch of the CLASP2, we confirmed the level of spurious polarization by using the in-flight data taken at the solar disk center. The final derived response matrix is used to correct the demodulated polarization signal from the plage and the limb observations. Here, we present the methodology used for calibrating the SP and describe the final response matrix of the instrument. We also discuss the achieved accuracy of the response matrix elements based on our tolerance requirements.

96 Stochastic entropy production in the quiet Sun magnetic fields

A. Gorobets, and S. Berdyugina

Leibniz-Institut für Sonnenphysik (KIS), Freiburg, Germany

The second law of thermodynamics imposes an increase of macroscopic entropy with time in an isolated system. Microscopically, however, the entropy production can be negative for a single, microscopic realization of a thermodynamic process. The so-called fluctuation theorems provide exact relations between the stochastic entropy consumption and generation. Here, we analyse pixel-to-pixel fluctuations in time of small-scale magnetic fields (SSMF) in the quiet Sun observed with various instruments. We demonstrate that entropy generated by SSMF obeys the fluctuation theorems. In particular, the SSMF entropy consumption probability is *exactly* exponentially smaller than the SSMF entropy generation probability. This may have fundamental implications for the magnetic energy budget of the Sun.

97 Testing polarimetric science use cases with the SO/PHI instrument simulator

P. Loeschl, J. Hirzberger, J. Schou, S. K. Solanki, and M. Kolleck

Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany

With the launch of Solar Orbiter (SO) on the horizon, it will soon be possible to simultaneously observe the Sun from additional vantage points off the Earth-Sun line. One of its instruments, the Polarimetric and Heliospheric Imager (PHI) will thereby be the first spectropolarimeter to operate outside of this line of sight. This will enable stereoscopic observations to the solar magnetic field and opens up the possibility for novel observational techniques in solar physics, which we explore in this work. Therefore, we extended the SO/PHI instrument simulator SOPHISM (Blanco et al., 2018) with the real SO/PHI science processing pipeline and added capabilities to represent the Helioseismic and Magnetic Imager (HMI) on SDO. Combined with synthesised spectra from photospheric MHD simulations, we produce realistic synthetic observations of a sunspot from several vantage points around the orbit of Solar Orbiter. These are used to test and develop novel methods such as geometric disambiguation of the magnetic field azimuth, multi-view synoptic maps for significantly decreased observation time and other general stereoscopic applications.

98 Conceptual design of multispectral filtration and processing techniques based on opticals components for application in solar imaging

Felipe Oliveira Tavares, and Luis Eduardo Antunes Vieira

National Institute for Space Research (INPE)

The usual way of remotely collecting information about the magnetic field in the Sun is by studying the changes in its radioactive spectrum, driven by the Zeeman effect in terms of displacement and polarization of the absorption lines. In the solar surface, this effect is detected in absorption lines of the Iron. With the imaging of the Sun at different wavelengths and polarization, it is possible to describe the Zeeman effect of origin and thus to identify the configuration of the magnetic field in the region of interest. Usually, filters are used to select these characteristics for then acquisition, with CCD cameras for example. It is extremely important that the information is analyzed corresponds to equivalent temporal states. The use of conventional electronic components takes a certain technical difficulty in meeting this requirement. By simultaneously acquiring dozens or more images with extremely high resolution and processing complex calculations for each acquired pixel the response time becomes high, in the order of minutes. This limitation impedes the study of magnetic evolution in fast solar events, besides being more vulnerable to noise conditions, such as the refraction bias of the atmosphere in terrestrial telescopes. In this work, a conceptual solution is suggested to reduce the response time of a solar imager with the use of optical components for filtering and processing instead of classical electronics. The proposed concept consists of the use of a crystal of photorefractive material with the initial filter function to select short regions of interest of the solar spectrum. With the use of holographic techniques in the crystal, it is possible to produce interference patterns that act as mirrors for certain wavelengths defined in the previous recording of the crystal. Mirrors redirect incident light into different paths. Each of the deviated light lines is analyzed for their polarization configuration through a retarder. In this way, we have the necessary variables to estimate stoke parameters. It proposes that the concept presented that this calculation is made with optical components. Optical processing has gained prominence as an alternative to high processing power and low consumption in relation to electronic/digital methodologies. One of the pioneering techniques in optical processing that allows for extreme parallel calculations is the printing of tiny optical cells, in the micron scale, in silicon crystals to create complex artificial neural networks. To demonstrate the proposed concept, the filtering system will be developed to the calculation of stoke parameters using artificial neural networks printed in a semiconductor crystal, in the case of a single pixel. With the results obtained, if it proves viable, the concept will be updated to analyze information from more pixels. Functional prototypes with these components will be developed for both laboratory-controlled and ground-based solar telescopes.

99 Attempting to estimate the Lorentz force vector at the photosphere

Graham Barnes[1], and K. D. Leka[1,2]

[1] *NorthWest Research Associates*
[2] *Nagoya University*

The Lorentz force at the photosphere signals the transfer of information across the $\tau = 1$ boundary and traces the drivers for sunspot evolution. It has been invoked to both form the strongly sheared polarity inversion lines commonly associated with major flares, and to initiate seismic emission associated with the impulsive phase of some flares.

We report on efforts to produce photospheric maps of the Lorentz force vectors through the inversion and processing of Hinode/SpectroPolarimeter data. With full-region SIR inversions we retrieve estimates of the magnetic field gradients both horizontally and with optical depth. Using these gradients, the full electric current density vector can be inferred and used to compute the Lorentz force directly. In particular we discuss the assumptions which must be invoked using this approach, in contrast to prior studies that use SDO/HMI vector magnetograms and invoke strong assumptions regarding the horizontal scale of the magnetic field.

The material presented herein is based upon work supported by NASA under grant #80NSSC18K0067.

100 Optical components characterization of the GSST's proof of concept

A. R. Barbosa, L. E. A. Vieira, F. Carlesso, and F. O. Tavares

National Institute for Space Research (INPE)

The Sun's magnetic field has great influence in the solar phenomena, with a better understanding of the solar magnetic field, it will be possible to understand how the sun influences the Earth. Thus, methods to estimate the magnetic field of the sun, from the Earth or the space near the Earth, were developed. Spectropolarimetry is one of the most used techniques. A spectropolarimeter is being developed by the INPE's solar physics group through the Galileo Solar Space Telescope (GSST) Project. The proof of concept consists of a Ritchey-Chrétiende telescope, a polarization modulation package, a Fabry-Pérot Etalon interferometer, sCMOS cameras, narrow band filters and adaptive optics. To guarantee a good calibration of the instrument and to be aware of its uncertainties is extremely important, since the noise level in the images of the Stokes parameters has a strong influence on the quality and the final performance of the instrument. In this project, a study on CMOS sensor will be presented, estimating the noises of greater influence. The next steps for the master project is estimate the Stokes parameters from the GSST's proof of concept as well as the uncertainties of this instrument. For this, the other components will be calibrated, the Mueller matrix will be estimated and the data obtained will be compared with data from another instrument. The results of this study will contribute to the GSST project as a whole and is an greatly important step for the next phase of the project.

101 IMaX+: a brand-new magnetograph and tachograph

J. C. del Toro Iniesta[1], D. Orozco Suárez[1], A. Álvarez Herrero[2], Isabel Pérez Grande[3], Esteban Sanchis Kilders[4], B. Ruiz Cobo[5], M. Balaguer Jiménez[1], A. C. López Jiménez[1], A.B. Fernández Medina-Maeso[2], L. R. Bellot Rubio[1], J. P. Cobos Carrascosa[1], D. Álvarez García[1], J. L. Ramos Más[1], P. Labrousse[1], D. Hernández Expósito[1], A. Moreno Mantas[1], A. Sánchez Gómez[1], B. Aparicio del Moral[1], F.J. Bailén[1], F. Girela Rejón[1], M. Herranz de la Revilla[1], M. Cebollero[2], A. Núñez Peral[2], A. Gonzalo[2], A. Sánchez[2], R. San Julián[2], D. Garranzo-García[2], H. Laguna[2], P. García Parejo[2], M. Silva-López[2], M.J. Rivas[2], P. Manzano[2], M. Álvarez[2], J. Villanueva[2], I. Martínez Herranz[3], A. P. Sanz Andrés[3], E. Roibás Millán[3], M. Chimeno Manguán[3], F. Meseguer Garrido[3], I. Torralbo Gimeno[3], J. Piqueras[3], J. Blanco Rodríguez[4], J.L. Gasent-Blesa[4], A. Ferreres Sabater[4], P. Rodríguez-Martínez[4], D. Gilabert[4], A. Navarro Antón[4], S. Casans Berga[4], J. Jordán Martínez[4], V. Esteve Gómez[4], E. Marco Soler[4], E. Páez[5], E. Magdaleno Castelló[5], and M. Rodríguez Valido[5].

[1] *IAA-CSIC,* [2] *INTA,* [3] *UPM,* [4] *UV,* [5] *IAC*

Building upon the successful technologies of the IMaX instrument, which already flew as a scientific payload in the two first editions of the SUNRISE mission, IMaX+ is a new magnetograph and tachograph aimed at inferring the vector magnetic field and the line-of-sight velocity of the photosphere and the low chromosphere (high photosphere) by measuring in 60 s all four Stokes parameters in the (alternate) spectral lines at 525.02 or 525.06 nm (Fe I), and at 517.3 nm (Mg I_{b2}). The polarimetric sensitivity goal is 10^{-3} in the Fe I lines and beyond in the Mg I_{b2} line. Line tunability is possible with a double filter wheel which hosts a field stop (for AIV purposes), a phase diversity plate, the sorting pre-filters for the three lines, and, probably, some polarization and calibration optics. Two new, home-made scientific cameras are based on 2048 x 2048, 11 μ^2 pixel GSENSE400BSI sensors. These sensors and the new ISLiD system enable IMaX+ to have a FOV of 60×60 arcsec^2 and to oversample the image so that three pixels lie within the Airy disk. This must improve the knowledge of the PSF and hence increase our capabilities for image restoration.

102 Measurement of magnetic field and plasma diagnostics of solar active regions by spectral-polarization microwave observations

T. Kaltman[1], V. Bogod[1], L. Yasnov[2], and A. Stupishin[2]

[1] *Special Astrophysical Observatory, Russia*
[2] *Radio Physics Research Institute, St. Petersburg State University, Russia*

Solar active regions (AR) comprise the totality of magnetic phenomena: from complex photospheric configurations of sunspots to magnetic structures extending through the chromosphere into the corona including open and closed magnetic field lines. Different types of emission mechanisms are responsible for the radiation of various parts of AR in the range of centimeter and decimeter waves. Radiation over sunspots is due to cyclotron emission on the lower harmonics of the gyro frequency. Free-free emission of thermal plasma is responsible for radiation over floccules and coronal holes, and non-thermal emission – for inter-spot radiation of halo and micro-bursts at the tops of arch structures. Methods of magnetic field and plasma parameters diagnostics were developed based on astrophysical interpretation of radiation associated with all of the above emission mechanisms.

Observations with the radio telescope RATAN-600 probe physical conditions in the solar atmosphere measuring its intensity and polarization spectra. In this contribution we present updated practical methods of diagnostics of plasma parameters in ARs and methods for measurements of coronal magnetic field by bremsstrahlung and cyclotron radiation. We also report a newly developed iterative fitting method to estimate electron density and temperature above AR based on the observations of polarized radio emission with the RATAN-600 radio telescope and on the extrapolations of the photospheric magnetic field to the corona.For rigorous diagnostics of non-thermal radiation, methods of separation of radio sources with different radiation mechanisms are developed.

Solar radio zebras belong to the most important radio fine structures used in diagnostics of solar flare plasmas. Assuming the double plasma-resonance model of zebras, we study the relation between zebra-stripe frequencies and gyro-harmonic numbers. A model is developed that allows to correlate the surfaces of the double plasma resonance with the surfaces along the axis of the plasma channels. This makes it possible to determine sufficiently detailed conditions for the propagation of plasma jets in such channels.

This work is supported by Grant 18-29-21016 and by Grant 18-02-00045 of the Russian Foundation for Basic Research.

103 Polarity reversal on the young superactive dwarf LQ Hya

J. J. Lehtinen[1,2], T. Hackman[3], O. Kochukhov[4], T. Willamo[3], M. J. Käpylä[1,2]

[1] *Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany*
[2] *ReSoLVE Centre of Excellence, Aalto University*
[3] *University of Helsinki*
[4] *Uppsala University*

We present four recent magnetic inversions of the young superactive K0V type dwarf star LQ Hya using the Zeeman Doppler imaging method. These magnetic field maps are based on high resolution spectropolarimetry obtained with HARPSpol@ESO3.6m and ESPaDOnS@CFHT between January 2010 and December 2017. The maps reveal a polarity reversal in the radial field component between 2016 and 2017. Simultaneous long term photometry shows that at the same time the star has experienced an activity minimum and a return towards increasing spot activity. Hence, we connect the observed polarity reversal with LQ Hya reaching the minimum phase of its 20 year activity cycle. The maximum field strengths of the magnetic inversions vary widely between the observing epochs. This is unlikely to be representative of actual variations in the field strenth and rather be a consequence of changing field geometry, as the more complex field structures hide a larger amount of field strength in length scales below the acheavable resolution.

104 Why do penumbral filaments form?

M. Panja, R. H. Cameron, and S. K. Solanki

Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany

MHD simulations have been quite successful in reproducing observed features of penumbral filaments. They have revealed that the Evershed flow is very similar to the horizontal component of the overturning convection seen in quiet sun granulation . However the reasons for the origin of penumbral filaments are still unclear and simulations require ad-hoc boundary conditions to produce penumbrae that have radial extents similar to what is observed. The filamentary nature of the penumbra, and the inward migration of the filament heads towards the umbra suggest that penumbral filaments could infact be surface manifestations of flux tubes that are highly fluted. Here we use the MURaM radiative MHD code, to vary the initial subsurface structure of magnetic flux tubes, with the intent of studying the effect of the fluting instability on the radial extent of penumbral filaments.

Zeuner, Franziska, Max-Planck-Institut für Sonnensystemforschung
Yuan, Shu, Yunnan Observatories - Chinese Acad. of Sci.
Yoshida, Masaki, National Astronomical Observatory of Japan / SOKENDAI
Yee Yee, Oo, Taungoo University
Yanamandra-Fisher, Padma, Space Science Institute
Yamasaki, Daiki, Kyoto University
Yadav, Rahul, Institutet för solfysik - Stockholm University
Yadav, Nitin, Max-Planck-Institut für Sonnensystemforschung
Wang, Dongguang, National Astronomical Observatories - Chinese Acad. of Sci.
van Noort, Michiel, Max-Planck-Institut für Sonnensystemforschung
Trujillo Bueno, Javier, Instituto de Astrofísica de Canarias
Trelles Arjona, Juan Carlos, Instituto de Astrofísica de Canarias
Talafha, Mohammed, Eötvös Loránd University
Sun, Yingzi, National Astronomical Observatories - Chinese Acad. of Sci.
Sueoka, Stacey, National Solar Observatory
Stenflo, Jan, ETH Zürich
Song, Donguk, National Astronomical Observatory of Japan
Solanki, Sami, Max-Planck-Institut für Sonnensystemforschung
Siu Tapia, Azaymi Litzi, Instituto de Astrofísica de Andalucía
Schmassmann, Markus, Leibniz-Institut für Sonnenphysik
Schlichenmaier, Rolf, Leibniz-Institut für Sonnenphysik
Saranathan, Sudharshan, Max-Planck-Institut für Sonnensystemforschung
Sant, Kamal, Max-Planck-Institut für Sonnensystemforschung
Rodrigues Barbosa, Adriany, National Institute for Space Research
Robustini, Carolina, Institutet för solfysik - Stockolm University
Riethmüller, Tino L., Max-Planck-Institut für Sonnensystemforschung
Ranganathan, Mohanakrishna, California State University Northridge
Ramelli, Renzo, Istituto Ricerche Solari Locarno
Pruthvi, Hemanth, Leibniz-Institut für Sonnenphysik
Prabhakar, Maya, Indian Institute of Astrophysics
Pietrow, Alexander, Stockholm University
Peng, Jianguo, Yunnan Observatories - Chinese Acad. of Sci.
Pastor Yabar, Adur, Leibniz-Institut für Sonnenphysik
Panja, Mayukh, Max-Planck-Institut für Sonnensystemforschung
Oliveira Tavares, Felipe, National Institute for Space Research
Murabito, Mariarita, INAF-Rome
Milic, Ivan, CU Boulder / NSO
Martinez Pillet, Valentin, National Solar Observatory
Martínez González, María Jesús, Instituto de Astrofísica de Canarias
Manso Sainz, Rafael, Max-Planck-Institut für Sonnensystemforschung
Loukitcheva, Maria, Saint Petersburg branch of Special Astrophysical Observatory
Löschl, Philipp, Max-Planck-Institut für Sonnensystemforschung
Löptien, Björn, Max-Planck-Institut für Sonnensystemforschung
Lopez Ariste, Arturo, CNRS

Lindner, Philip, Leibniz-Institut für Sonnenphysik
Libbrecht, Tine, Institutet för solfysik - Stockholm University
Leka, K. D., NorthWest Research Associates
Lehtinen, Jyri, Max-Planck-Institut für Sonnensystemforschung
Lagg, Andreas, Max-Planck-Institut für Sonnensystemforschung
Kuckein, Christoph, Leibniz-Institut für Astrophysik Potsdam
Krishnamurthy, Sowmya, Max-Planck-Institut für Sonnensystemforschung
Kramar, Maxim, University of Hawaii
Kouassi, N'Guessan, Université Félix Houphouet Boigny - Cote d'Ivoire
Kianfar, Sepideh, Institutet för solfysik - Stockholm University
Kawabata, Yusuke, The University of Tokyo
Katsukawa, Yukio, National Astronomical Observatory of Japan
Kanakatte Nanjundarao, Nagendra, Indian Institute of Astrophysics
Kaltman, Tatiana, Special Astrophysical observatory
Jaume Bestard, Jaume, Instituto de Astrofísica de Canarias
Janett, Gioele, Istituto Ricerche Solari Locarno
Jafarzadeh, Shahin, University of Oslo
Ishikawa, Ryohko, National Astronomical Observatory of Japan
Iglesias, Francisco A., National Research Council - CONICET
Hurlburt, Neal, Lockheed Martin Advanced Technology Center
Hirzberger, Johann, Max-Planck-Institut für Sonnensystemforschung
Hebbur Dayananda, Supriya, Instituto de Astrofísica de Canarias
Hanaoka, Yoichiro, National Astronomical Observatory of Japan
Guglielmino, Salvo, Università degli Studi di Catania
Guerreiro, Nuno, Istituto Ricerche Solari Locarno
Gorobets, Andrei, Leibniz-Institut für Sonnenphysik
Gangi, Manuele, INAF - Catania Astrophysical Observatory
Gandorfer, Achim, Max-Planck-Institut für Sonnensystemforschung
Gafeira, Ricardo, Instituto Astrofísica Andalucía
Frisch, Helene, Universite Cote d'Azur
Feller, Alex, Max-Planck-Institut für Sonnensystemforschung
Faurobert, Marianne, University of Cote d'Azur
Dominguez, Carlos, Instituto de Astrofísica de Canarias
Doerr, Hans-Peter, Max-Planck-Institut für Sonnensystemforschung
Dima, Gabriel, National Solar Observatory
Díaz Baso, Carlos José, Institutet för solfysik - Stockholm University
Dhara, Sajal Kumar, Istituto Ricerche Solari Locarno
Demidov, Mikhail, Institute of Solar-Terrestrial Physics of Siberian
del Toro Iniesta, Jose Carlos, IAA-CSIC
del Pino Alemán, Tanausú, Instituto de Astrofísica de Canarias
de la Cruz Rodriguez, Jaime, Institutet för solfysik - Stockholm University
Danilovic, Sanja, Institutet för solfysik - Stockholm University
Castellanos Durán, Sebastián, Max-Planck-Institut für Sonnensystemforschung
Carlin Ramirez, Edgar S., Instituto de Astrofísica de Canarias

Capozzi, Emilia, Istituto Ricerche Solari Locarno
Calvo, Flavio, Institutet för solfysik - Stockholm University
Borrero, Juan Manuel, Leibniz-Institut für Sonnenphysik
Bommier, Véronique, Observatoire de Paris
Bianda, Michele, IRSOL / USI
Berdyugina, Svetlana, Leibniz-Institut für Sonnenphysik
Belluzzi, Luca, Istituto Ricerche Solari Locarno
Bello González, Nazaret, Leibniz-Institut für Sonnenphysik
Barnes, Graham, NorthWest Research Associates
Balthasar, Horst, Leibniz-Institut für Astrophysik Potsdam
Asensio Ramos, Andrés, Instituto de Astrofísica de Canarias
Armstrong, John, University of Glasgow
Antunes Vieira, Luis Eduardo, National Institute for Space Research
Anche, Ramya M., Indian Institute of Astrophysics
Anand, Megha, Indian Institute of Astrophysics
Alsina Ballester, Ernest, Istituto Ricerche Solari Locarno
Albert, Kinga, Max-Planck-Institut für Sonnensystemforschung
Afonso Delgado, David, Instituto de Astrofísica de Canarias

	Monday	Tuesday	Wednesday	Thursday	Friday
09:00	Welcome address and logistics	Belluzzi: The physics of polarization (invited review)	Milic: NLTE radiative transfer (invited review)	Riethmüller: Multiline inversions (highlight)	Lindner: Pro umbra/penumbra
	Iglesias: Techniques in solar polarimetry (invited review - Metcalf lecture)	Berdyugina: DKIST & Molecules	Bestard: 3D RT effects of chromos	Siu Tapia: Properties of penumbral microjets	Löptien: Con umbra/penumbra
10:00	Peng: Error analysis & calibration	Frisch: Non-conservative Rayleigh scatter	Janett: Discontinuities in numerical RT	Jafarzadeh: B topology of fibrillar structures	Guglielmino: Pol of an umbral
	Balthasar: Polarimetry with GFPI	Nagendra: Redistribution scattering pol	Leka: Azimuthal ambiguity Resolution	Bommier: Photospheric negative charge	Bello: Insights on penumbra formation
	Coffee & Posters	**Coffee & Posters**	**Coffee & Posters**	Martinez: Quiet magnetism complex atm	**Coffee & Posters**
11:00	Demidov: Russian solar synoptic	Stenflo: Stokes & Minkowski spacetime	de la Cruz Rodriguez: Inversions of spectro-polarimetric data (invited review)	**Coffee & Posters**	Lopez Ariste: Doing solar physics on other stars (invited review)
	Yuan: Chinese giant solar telescope	Megha: Spherically symmetry Hanle		Pietrow: Polarimetry of a plage region	
	Schlichenmaier: EST uniqueness	Carlin: Dichroic variations of Hanle and Zeeman polarization (highlight)	Pastor: 3D magnetohydrostatic inv	Saranathan: Atm stratification of plage	Gangi: Second spectrum in a star
	van Noort: Microlensed hyperspectral	del Toro: Birefringence in FP Etalons	del Pino Aleman: Multi-D NLTE RT	Kuckein: Three magnetic bright points	Martinez: B fields in stellar
12:00	Sueoka: DKIST (highlight)		Trelles: 3D quiet Sun multi-line inv	Balthasar: Dynamics of a pore with a LB	Panja: Spectral synthesis of starspots
	Lunch & Posters	**Lunch & Posters**	**Lunch & Posters**	Murabito: Penumbral fine structure	Stenflo: Wrap up
				Lunch & Posters	**Lunch**
14:00	Ishikawa: CLASP missions (highlight)	Trujillo Bueno: 95 years of the Hanle effect: where are we? (invited review)	Asensio Ramos: Big data in solar polarimetry and the role of machine learning (invited review)	Dima: Coronal polarimetry: old issues and new ideas (highlight - Metcalf lecture)	
	Hurlburt: New magnetographs in space			Kramar: 3D reconstruction coronal structure	
	Lagg: Polarimetry on Sunrise-3	Ballester: Magnetic sensitivity Lyman-α	Armstrong: RADYNVERSION for flares	Kawabata: Chromospheric magnetic field	
15:00	Solanki: Polarimetry on Solar Orbiter	del Pino Aleman: Polarization of the Mg II	Gafeira: AI initialisation for inversions	Yadav: Properties of chromospheric loops	
	Hirzberger: SOPHI instrument	Supriya: Polarization of the solar corona		Sowmya: Magnetized chromos downflows	
	Coffee & Posters	**Coffee & Posters**		**Coffee & Posters**	
16:00	Loukitcheva: Radio polarimetry of the Sun in the ALMA era (highlight)	Yoshida: Polarization Lyman-α in spicules		Diaz: Chromospheric heating by cancellation	
	Pruthvi: Polarimeter at Kodaikanal	Manso Sainz: B field in the transition reg.		Libbrecht: Pol of the He I D 3 in a C-flare	
		Bianda: Scattering polarization obser.		Demidov: Large-scale solar magnetic fields	
		Capozzi: magneto-optical effect scat pol		Castellanos: Super-strong magnetic fields	
17:00	**Reception**	Kumar: Sr I scattering pol at different μ	**Excursions**	**Conference Dinner 20 h**	
		Zeuner: Spatially-structured scattering			
		Posters and Drinks / Exhibition			

Latest program can be found here:

www.mps.mpg.de/spw9-program