Istituto Ricerche Solari Locarno

Rapporto 2019

Rapporto alla Fondazione Istituto Ricerche Solari Locarno sulla situazione dell'Istituto alla fine del 2019 e sul piano di lavoro per il 2020

Relatori: Dr. Michele Bianda
e lo staff dell'IRSOL

Indirizzo: Istituto Ricerche Solari Locarno
via Patocchi 57
6605 Locarno-Monti
Tel.: (091) 743 42 26
e-mail: info@irsol.ch
sito web: www.irsol.ch

Locarno-Monti, 28 aprile 2020

*) *AIRSOL, Associazione Istituto Ricerche Solari Locarno*

Indice

1 PREMESSA

Per l'Istituto Ricerche Solari Locarno (IRSOL), la cui attività di ricerca scientifica è incentrata nel campo della spettropolarimetria solare, lo scorso anno vi sono stati eventi significativi.

I lavori di ristrutturazione degli edifici (permessi da un lascito ereditario) hanno permesso di rendere agibili nuovi locali con ulteriori posti di lavoro offrendo così un miglioramento delle condizioni di lavoro dei ricercatori e lasciando aperta la possibilità di incrementare il personale.

I lavori hanno percontro avuto un effetto sulla qualità del lavoro all'istituto per i primi mesi dell'anno rendendo difficile la concentrazione e richiedendo ferquenti spostamenti per interventi sugli uffici (sostituzione del pavimento, ritinteggio delle pareti, ecc.).

Importante per il futuro dell'istituto è stato il lavoro di una commissione composta dal presidente della fondazione (P. Jetzer), dalla direttrice del KIS (S. Berdyugina), dal delegato del Rettore per lanalisi della ricerca dell'USI (B. Lepori), dal direttore dell'Istituto di Scienze Computazionali dell'USI (R. Krause) e dal già Capo Divisione della cultura e degli studi universitari e membro del consiglio di fondazione FIRSOL (S. Rusconi). Hanno preparato un documento sul futuro dell'IRSOL che è alla base del processo di affiliazione dell'IRSOL all'USI, passo importante per ulteriormente dare stabilità al nostro istituto (vedi anche il capitolo 6)

Pure con la SUPSI è stato possibile firmare un "Accordo di collaborazione" che mette in evidenza la volontà dei due enti di cooperare su specifici temi di natura strumentale. Un primo obiettivo è la realizzazione di un nuovo polarimetro per il cui finanziamento sono state fatte prime domande che hanno confermato la validità del progetto; i risultati saranno utili nella nuova domanda da sottomettere in primavera. Sono allo studio scenari di cooperazione puntuale per ottimizzare possibili sinergie.

Il lavoro scientifico ha permesso di pubblicare 12 articoli con personale dell'IRSOL come autori su riviste referenziate e 8 articoli su atti di conferenze.

Il Dr. Gioele Janett ha difeso la sua tesi in giugno ed è stato assunto a metà tempo come postdoc per il progetto Sinergia del nostro istituto.

La domanda al Fondo Nazionale per il proseguimento della tesi della MSc E. Capozzi è stato accettato.

Il progetto europeo H2020 SOLARNET che prevede una stretta coordinazione con l'USI è iniziato. Nell'ambito di questo progetto è stata organizzata una scuola estiva all'USI che ha avuto un ottimo successo. Per il progetto che prevede la messa a punto di una tecnologia di misure con estrema precisione polarimetrica, Franziska Zeuner è stata assunta come postdoc.

L'ing. Christian Monstein è il responsabile del "International Network of Solar Radio Spectrometers", una rete di radiotelescopi da lui sviluppati e distribuiti su tutto il mondo che permettono di acquisire importanti informazioni scientifiche sulle eruzioni solari (`http://www.e-callisto.org`). Dopo il suo pensionamento dal ETHZ ha dovuto trovare una nuova affiliazione e siamo stati molto contenti di potergli offrire l'affiliazione all'IRSOL.

AL PMOD/WRC di Davos, istituto che si occupa di climatologia e fisica solare e che è affiliato all'ETHZ, è stata nominata una nuova direttrice che ha anche il titolo di professore ETH. Vi è dunque di nuovo una cattedra in fisica solare in Svizzera. Abbiamo già avviato lavori in cooperazione e intendiamo ulteriormente migliorare i contatti.

2 PERSONALE

Organizzazione generale
L'organizzazione generale è diretta dal presidente della FIRSOL, Prof. Dr. Philippe Jetzer (Istituto di fisica dell'Università di Zurigo).

Direttorato
La direzione dell'IRSOL è affidata ad un direttorio composto da:

Prof. Dr. Svetlana Berdyugina (direttrice del Leibniz-Institut für Sonnenphysik, KIS)

Dr. Michele Bianda

Prof. Dr. Jan Olof Stenflo

La vice-direzione è affidata al Dr. Renzo Ramelli

Staff scientifico: personale fisso e postdoc

Dr. Ernest Alsina Ballester (dal 1 febbraio 2018) *

Dr. Luca Belluzzi (pure affiliato al KIS)

Dr. Michele Bianda

Dr. Daniel Gisler (part time con il KIS)

Dr. Nuno Guereiro (dal 1 maggio 2019) ***

Dr. Gioele Janett (dal 1 luglio 2019, part time) ***

Ing. ETHZ Boris Liver

Dr. Renzo Ramelli (part time)

Dr. Dhara Sajal Kumar (dal 1 maggio 2017 al 31 agosto 2019) **

Dr. Oskar Steiner (part time con il KIS)

MSc. Franziska Zeuner (dal 1 dicembre 2019) ****

Prof. Dr. Jan Olof Stenflo, emeritus ETHZ, affiliato all'IRSOL

Prof. Dr. K. Nagendra, emeritus Indian Institute for Astrophysics, affiliato all'IRSOL

Ing. Christian Monstein, precedentemente all'ETHZ, affiliato all'IRSOL

* Finanziato tramite il progetto del Fondo Nazionale, 200021_175997
** Finanziato tramite il progetto del Fondo Nazionale, 200020_169418. Da settembre lavora alla Airbus a Leiden in Olanda.
*** Finanziato tramite il progetto del Fondo Nazionale, CRSII5_180238
**** Finanziata tramite il progetto H2020 SOLARNET

Staff amministrativo e tecnico

Katya Gobbi (segretaria)

Gianpaolo Mari

Dottorandi

MSc. José Roberto Canivete Cuissa (dal 1 settembre 2019) *

MSc. Emilia Capozzi (dal 1 aprile 2017) **

MSc. Gioele Janett (dal 1 settembre 2015 al 30 giugno 2019) ***

MSc. Simone Riva (dal 1 ottobre 2018) ****

Questi progetti di dottorato sono finanziati dal Fondo Nazionale.
* Direttore di tesi: Prof. Dr. Romain Teyssier dell'Università di Zurigo
** Direttore di tesi: Prof. Dr. Georges Meynet dell'Università di Ginevra
*** Direttore di tesi: Prof. Dr. Mishra Siddhartha, SAM, Politecnico di Zurigo
**** Direttore di tesi: Prof. Dr. Rolf Krause, USI, Lugano

Masterandi

Andrea Battaglia, dal 16 settembre. Lavoro di master ETHZ diretto dalla Prof. Dr. Louise Harra

Collaborazione con la SUPSI

MSc Christian Valles, lavoro di Master seguito dal Prof. Dr. Roberto Gardenghi. Titolo conseguito il 13 settembre 2019

Collaborazione con il Leibniz-Institut für Sonnenphysik, KIS

Regolato da un contratto con il KIS, il Dr. Daniel Gisler lavora a tempo parziale a Freiburg su un progetto dedicato al telescopio solare statunitense DKIST.

Collaborazione con l'Instituto de Astrofísica de Canarias (IAC)

Visita del dottorando MSc. Jaume Bestard dal 26 maggio al 9 giugno per osservazioni

Visita del Dr. Andrii Sukhorukov dal 18 novembre al 19 dicembre, collaborazione progetto Sinergia

Stages scientifici, lavori a tempo determinato

MSc. José Roberto Canivete Cuissa (dal 14 gennaio al 5 aprile) stage

Romain Mercier (dal 20 al 25 maggio) stage

Cédrine Hügli (dal 8 al 20 luglio): stage nell'ambito del programma Estage

Daniel Pallone (dal 2 al 22 agosto): stage nell'ambito del programma Estage

Gala Delparente (dal 5 al 23 agosto): stage nell'ambito del programma Estage

Pietro Lorenzini (dal 15 luglio al 23 agosto): stage nell'ambito del programma Estage

Civilisti

Nel corso del 2019 hanno lavorato all'IRSOL:

Lukas Hochuli (dal 18 marzo al 22 marzo e dal 7 ottobre al 1 novembre)

RINGRAZIAMENTI

- Siamo grati al Dr. Dhara Sajal Kumar per il lavoro che ha svolto dal maggio 2017 fino ad agosto 2019 per l'IRSOL. Grazie al suo lavoro è stato possibile mettere in evidenza le necessità richieste per la realizzazione dello strumento per misure sinottiche da installare sul telescopio americano DKIST.

  Gli auguriamo un produttivo futuro professionale presso l'Airbus a Leiden in Olanda, dove si occupa di un progetto legato alla polarizzazione della luce.

OBITUARIO

Nel corso della stesura di questo rapporto ci è purtroppo giunta la triste notizia del decesso di un nostro stretto collaboratore, membro emerito dello staff dell'IRSOL.

- **Prof. Dr. K.N. Nagendra 1955 - 06.03.2020†**

  È lunga la storia che ci ha legati al Prof. Nagendra dell'istituto di astrofisica indiano di Bangalore. È difficile riassumere la sua figura con parole migliori di quelle usate nel necrologio sul sito dell'Unione Astronomica Internazionale:

  `https://www.iau.org/administration/membership/individual/1313/`

  Nel 2004 era iniziata una fruttuosa collaborazione tra il Prof. Nagendra ed il suo gruppo, l'Istituto di astronomia dell'ETHZ guidato dal Prof. Jan Olof Stenflo e l'IRSOL. La collaborazione ha dato dei risultati estremamente importanti, permettendo al gruppo formato da Nagendra di lavorare su dati misurati all'IRSOL e riportando i risultati in decine di pubblicazioni comuni di alto pregio. Dopo il suo pensionamento Nagendra era stato affiliato come professore emerito dell'IRSOL. Attualmente era impegnato nel progetto che ci vede collaborare con l'istituto di fisica di Nizza dell'università Côte d'Azur per studi in laboratorio della polarizzazione da diffusione di righe spettrali del rubidio.

  Ma al di là del dato meramente scientifico, all'IRSOL rimpiangiamo un caro amico, una persona dotata di una estrema sensibilità e umanità.

3 SCIENTIFIC WORK

The overall goal of the scientific activity carried out at IRSOL is to gain a better physical understanding of the magnetic fields present in the solar atmosphere. Solar magnetic fields can be investigated by analyzing the signatures that they leave, through different physical mechanisms, on the spectral and polarization properties of the electromagnetic radiation. In general, the development and application of a given diagnostic method requires:

a) modeling the generation and transfer of polarized radiation in the solar atmosphere, taking the above-mentioned mechanisms into account, in order to identify specific polarization signals encoding information on the magnetic fields;

b) developing instruments capable of observing such signals, and performing precise observations;

c) comparing the observed signals with the results of theoretical calculations performed with realistic simulations of the solar atmosphere.

The research work at IRSOL builds on three pillars: observations and instrument development, theoretical modeling, and numerical simulation, yet they are all focused on the unique topic of polarimetry of the solar atmosphere.
A detailed description of all the scientific works that are presently carried out at IRSOL, together with the result obtained in the past year, is provided below.

3.1 Theoretical and numerical modeling of polarization signals

3.1.1 Investigation of the enigmatic scattering polarization signal of the Na I D_1 line

The detection of linear scattering polarization signals of significant amplitude in the core of the D_1 line of the Na I doublet, first reported by Stenflo & Keller (1997, A&A, 321, 927) and subsequently confirmed by observations carried out with ZIMPOL (both at IRSOL and at GREGOR), has long been regarded as enigmatic because this spectral line originates from a transition whose upper and lower levels both have total angular momentum $J = 1/2$ and, as such, is considered to be intrinisically unpolarizable. A possible theoretical interpretation of this signal was proposed by Landi Degl'Innocenti (1997, Nature, 392, 256), who was able to reproduce the polarization profile observed by Stenflo & Keller (1997) to a remarkable degree by assuming that a substantial amount of atomic polarization (i.e., population imbalances and quantum coherence between pairs of magnetic sublevels) is present in the (long-lived) ground level of sodium. However, this explanation gave rise to a sort of paradox because the required amount of ground level polarization is not compatible with the presence of inclined magnetic fields (whose presence is supported by other works), nor with the depolarizing effect produced by elastic collisions. The theoretical interpretation of such signals thus remained a challenge for theoreticians, and it is one of the central topics of the SNSF project: "The magnetic sensitivity of strong chromospheric lines: from the CLASP experiments to the sodium D_1 paradox" (P.I. Dr. L. Belluzzi), on which Dr. E. Alsina Ballester began working as a postdoctoral researcher in February 2018. This investigation was motivated by the mechanism proposed by Belluzzi & Trujillo Bueno (2013, ApJ, 774, L28) and Belluzzi et al. (2015, ApJ, 814, 116), through which significant linear polarization signals can be produced in the core of the D_1 line without the need for ground-level polarization, by accounting for the joint influence of the hyperfine structure (HFS)

of sodium and partial frequency redistribution (PRD) effects in scattering processes. However, their modeling did not account for two important physical ingredients that can strongly impact scattering polarization: elastic collisions and magnetic fields.

Within the above-mentioned SNSF project, a numerical radiative transfer code has been developed (see Section 3.2.2 for details), making it possible to investigate the combined action of PRD effects (accounting for both Doppler and collisional redistribution), and of magnetic fields of arbitrary strength. An article is now in preparation, in which a very good agreement between observations and the calculated linearly polarized signals of the D_1 and D_2 lines is reported, in particular when including magnetic fields and collisional rates that are consistent with those of previous observational and theoretical investigations. This would represent a possible resolution to the above-mentioned paradox.

On the other hand, an ongoing activity at IRSOL, begun almost a decade ago, is the acquisition of spectropolarimetric measurements of the sodium doublet and their subsequently data reduction. Such a task is especially suited to the capabilities of ZIMPOL, because the amplitudes of the D_1 linear polarization signals taken close to the limb are relatively low, being on the order of 10^{-4} of its intensity. Unfortunately, this also implies that the signal-to-noise ratio of the measured signals is relatively high, motivating the development of statistical techniques to extract the signal from the data, such as non-parametric kernel regression and spline smoothing (work initiated by MSc. Valentin Stradler during his civil service at IRSOL in 2017). The large volume of data accrued throughout this long-term project also puts us in a privileged position to conduct investigations on the D_1 signals based on their shapes, amplitudes, and occurrence rates. Sophisticated statistical approaches (such as clustering, machine learning techniques or model order reduction) are currently being devised to exploit such data both to further investigate the physical origin of the observed D_1 line signal, and to obtain new information on the thermodynamic and magnetic properties of the solar atmophere.

Researchers involved: IRSOL: E. Alsina Ballester, L. Belluzzi, E. Capozzi
External: J. Trujillo Bueno (IAC, Spain)

Publications:

in preparation

3.1.2 The CLASP-II sounding rocket experiment

On April 11, 2019, the Chromospheric LAyer Spectro-Polarimeter (CLASP-II) sounding rocket experiment was successfully carried out from the NASA facility at the White Sands Missile Range in New Mexico (USA). CLASP-II is an international collaboration led by the NASA's Marshall Space Flight Center (USA), the National Astronomical Observatory of Japan (NAOJ, Tokyo, Japan), the Instituto de Astrofísica de Canarias (IAC, Tenerife, Spain) and the Institut d'Astrophysique Spatiale (IAS, Orsay, France). Additional partners are IRSOL (Dr. Belluzzi and Dr. Alsina Ballester are CLASP-II team members), the Astronomical Institute of the Academy of Sciences of the Czech Republic (ASCR), Lockeed Martin Solar & Astrophysics Laboratory (Palo Alto, USA), Stockholm University (Sweden), and the Rosseland Center for Solar Physics Research (Oslo, Norway).

Motivated by a series of theoretical works (e.g., Belluzzi & Trujillo Bueno 2012, ApJL, 750, 11), and strongly supported by the recent success of the Chromospheric Lyman Alpha Spectro-Polarimeter (CLASP-I) experiment (Kano et al. 2017, ApJL, 839, 10), CLASP-II succeeded in

providing unprecedented measurements of the intensity and polarization of the Mg II h and k lines at 280 nm. These unique observations will now be exploited to get new precious information on the thermal, dynamic, and magnetic properties of the upper chromosphere. This complex region of the solar atmosphere is at the core of several key problems, and its investigation is today one of the main priorities in solar physics research.

The experiment was proposed within the framework of the NASA's Sounding Rocket Program. Sounding rockets are simpler and more affordable than satellite missions, and offer a great opportunity to test new ideas and achieve rapid results. CLASP-II was launched at 12:51 pm (local time) aboard a NASA's Black Brandt IX sounding rocket. The rocket reached an altitude of about 273 km, before descending by parachute. The payload was recovered in good condition. The measurement, with a duration of five minutes, was an absolute success. Both the pointing system and the spectropolarimeter worked perfectly. A first analysis of the data has shown a good agreement with the theoretical predictions.

The contribution of IRSOL to both CLASP-I and CLASP-II experiments concerns the theoretical interpretation of the acquired data, through the development and application of novel radiative transfer codes suitable to model the observed polarimetric signals. This is one of the goals of the SNSF project "The magnetic sensitivity of strong chromospheric lines: from the CLASP experiments to the sodium D_1 paradox" (see Sects. 3.1.3 and 3.2.2), and of the SNSF "Sinergia" project "HPC-techniques for 3D modeling of resonance line polarization with PRD" (see Sect. 3.2.3).

Researchers involved:

IRSOL: L. Belluzzi, E. Alsina Ballester
External: the CLASP team

Publications:

in preparation

3.1.3 Analysis of the magnetic sensitivity of the broadband linear polarization signals observed by CLASP

Within the solar chromosphere-corona transition region (TR), the temperature suddenly rises from $\sim 10^4$ K to $\sim 10^6$ K in a space of just a few km. The precise nature of the physical processes causing this phenomenon remains an open question in solar physics research and great efforts are being made to settle it. The hydrogen Lyman–α line is especially valuable in this regard, because the line-core photons of this strong UV emission line mainly originate from the TR, providing a window into its physical properties, whereas the near-wing photons encode information of deeper spatial regions pertaining to the upper solar chromosphere. The apparent diagnostic potential of this line, highlighted by a series of theoretical works, motivated the launch of the Chromospheric Lyman Alpha SpectroPolarimeter (CLASP) sounding rocket. This mission has recently provided highly valuable spectropolarimetric data, including the center-to-limb behavior of both its line-core and wing linear polarization signals. In addition, its slit-jaw system provided broadband measurements within a larger field of view (FOV), not only of the intensity but also of the Stokes Q/I signals. Interestingly, a correlation was found between stronger intensity signals (corresponding to regions with a higher level of activity) and a depolarization in Q/I.

In light of the acquisition of this valuable data, theoretical investigations have been carried

out at IRSOL within the SNSF project "The magnetic sensitivity of strong chromospheric lines: from the CLASP experiments to the sodium D_1 paradox". One such investigation, mimicking the broadband filter used for the CLASP slit-jaw system, has established that the main contribution to the spectrally-integrated Q/I signals arises from the line wings. A prior investigation (Alsina Ballester et al. 2019, ApJ, 880, 85) in the framework of the same project has shown that such wing scattering polarization signals are not insensitive to the influence of magnetic fields, but rather are modified through the action of the magneto-optical (MO) effects that induce a rotation of the plane of linear polarization of the radiation propagating through a magnetized medium (see also Alsina Ballester et al. 2016, ApJ, 831, L15). Interestingly, by accounting for the magnetic sensitivity due to MO effects, the above-mentioned anticorrelation between the broadband intensity and the amplitude of the Q/I signals can be reproduced by considering different atmospheric models depending of the level of activity of each region in the 2D image corresponding to the slit-jaw FOV. Such results were presented by Dr. E. Alsina in the Solar Polarization Workshop 9 and can be found in the proceedings of the workshop. A paper reporting the latter results is currently in preparation. Such findings add further value to observations of CLASP, suggesting that they simultaneously contain information on the magnetic activity in the TR (encoded in the polarization signals of the line core) and in the upper chromosphere (encoded both in the spectropolarimetric data corresponding to the wings and in the broadband images), which may offer clues regarding the energy transfer from deeper layers of the solar atmosphere into the corona.

Researchers involved:

IRSOL: E. Alsina Ballester, L. Belluzzi, E. Capozzi
External: J. Trujillo Bueno (IAC, Spain)

Publications:

Alsina Ballester, E., Belluzzi, L., & Trujillo Bueno, J. 2019, ApJ, 880, 85

Alsina Ballester, E., Belluzzi, L., & Trujillo Bueno, J. 2019, in Proc. Solar Polarization Workshop SPW9, DOI: 0.17617/2.3187774

one more in preparation

3.1.4 Structural links between solar polarization and fundamental physics

All modern treatments of polarized light in astrophysical media are based on a description of light in terms of 4-dimensional vectors, the so-called Stokes vectors. Their transformations when propagating through the medium are described in terms of 4×4 matrices, the Mueller matrices. Independently, in a completely unrelated area of fundamental physics, based on Einstein's discoveries in the beginning of the past century, a 4-dimensional framework for the description of all fundamental physical processes has been established in terms of 4-dimensional Minkowski spacetime. The mathematical formalism to describe particle dynamics and the evolution of quantum fields is in terms of tensors and operators that have representations as 4×4 matrices, e.g. Lorentz transformations and the covariant electromagnetic tensor. Recently it has been shown by J.O. Stenflo that there are astounding structural parallels between the Stokes and Mueller formalism on the one hand, and the Lorentz and electromagnetic tensors in Minkowski spacetime on the other hand. Comparison between the formalisms hints at some deep connections. For instance, the Stokes vector of fully polarized light behaves like the propagation vector of massless particles, while partially polarized light, which in polarization theory is due to the incoherent superposition of wave trains, behaves like massive par-

ticles. Furthermore, Stokes vectors and Mueller matrices behave like spin-2 objects, reminiscent of gravitons in quantum field theory.

Researchers involved:

IRSOL: J.O. Stenflo

Publications:

Stenflo 2019, Proc. 9th Solar Polarization Workshop SPW9, DOI: 10.17617/2.3182802

3.2 Numerical methods and computing techniques for modeling the generation and transfer of polarized radiation

3.2.1 Numerical Methods for the Transfer Equation of Polarized Radiation; PhD work of Gioele Janett

Dr. G. Janett has finished his PhD-thesis "Numerical methods for the transfer equation of polarized radiation", which he submitted to ETH-Zürich on April 16, 2019 and successfully defended it on June 3, 2019. With this thesis ended the SNF-project "Polarized Radiative Transfer in Discontinuous Media" ID 200021_159206, PI: O. Steiner. A series of six journal papers that resulted from this project was completed with an article on a novel fourth-order WENO interpolation technique that was tested and proposed to be particularly suitable for a number of radiative transfer applications such as multidimensional problems, multi-grid methods, and formal solutions.

Researchers involved:

IRSOL: G. Janett, O. Steiner, E. Alsina Ballester, L. Belluzzi

External: S. Mishra (ETHZ)

Publications:

Janett 2019, A&A, 622, 162

Janett, Steiner, Alsina Ballester, Belluzzi, & Mishra: 2019, A&A 624, A104

Janett 2019, Thesis ETHZ

3.2.2 Development of a 1D PRD RT code for a two-term atom with HFS

The theoretical investigations discussed in Sections 3.1.1 and 3.1.3 are focused on the intensity and polarization signals of strong resonance lines. Their modeling required the development of a numerical code capable of solving the radiative transfer problem for polarized radiation in conditions out of local thermodynamic equilibrium (non-LTE), taking into account partial frequency redistribution (PRD) effects in two-term atomic systems. In order to model spectral lines such as those of the sodium doublet, the code also allows for the inclusion of hyperfine structure. The lower term is treated as unpolarized, which is generally regarded as a good approximation for modeling the aforementioned strong resonance lines. In addition, the energy splittings of the magnetic sublevels of the atom, induced by the presence of a magnetic field of arbitrary strength are taken into account in the so-called Paschen-Back regime. The numerical code developed for this purpose, accounting for all the above-mentioned physical mechanisms, is based on the rigorous theory for the generation and transfer of

polarized radiation presented in Bommier (2017, A&A, 607, 50) and it is built upon the redistribution matrix formalism. The numerical complexity of the code has been reduced considerably by making the angle-averaged approximation, thereby avoiding the angle-frequency coupling introduced by the Doppler effect in the observer's reference frame.

An article discussing the numerical details of this radiative transfer (RT) code is currently in preparation. In the interest of further reducing computation time, several routines – particularly those involving the calculation of the line scattering contribution to the emission coefficient – have recently been improved. The debugging of the RT code has been carried out by comparing the resulting synthetic profiles to those obtained with previously developed codes, in particular

- the two-level code of Alsina Ballester et al. (2017, ApJ, 836, 6), applied to the Ca I line at 4227 Å considering a variety of a magnetic field configurations.
- the two-term code of Belluzzi et al. (2014, ApJ, 564, 16), applied to the H I Lyman-α lines as well as the Mg II h & k lines, in the unmagnetized case.
- the multi-term code used in del Pino Alemán (2016, ApJ, 830, L24), applied to the Mg II h & k lines in the presence of inclined and vertical magnetic fields of various strengths.

In addition to the theoretical investigations discussed in previous sections of the present report, the code has been applied to the H I Lyman–α line and to the Mg II h & k lines in order to also test the validity of the approximations of treating scattering processes as purely coherent in the observer's rest frame and neglecting the influence of the magnetic field in the line emission coefficient, both of which may be suitable for modeling the scattering polarization in the wings of these lines and would imply a significant decrease in computational cost.

Researchers involved:

IRSOL: E. Alsina Ballester, L. Belluzzi

Publications:

in preparation

3.2.3 Development of HPC techniques for 3D modeling of scattering polarization with PRD (SNSF Sinergia project).

In 2019, two post-doctoral researchers joined IRSOL within the framework of the SNSF "Sinergia" project "Development of HPC techniques for 3D modeling of scattering polarization with PRD": Dr. N. Guerreiro (three-year position started in May 2019), and Dr. G. Janett (two-year position working at 50%, started in August 2019). We recall that the project involves IRSOL (Dr. L. Belluzzi), the Institute of Computational Sciences (ICS) in Lugano (Prof. R. Krause), the Instituto de Astrofísica de Canarias (IAC) in Tenerife, Spain (Prof. J. Trujillo Bueno), and, as additional partner, the Astronomical Institute of the Czech Academy of Sciences (ASCR) in Ondrejov, Czech Republic (Dr. J. Štěpán). The awarded grant provides funding for post-doctoral positions for a total of four years at each institute (IRSOL, ICS, and IAC), and a PhD position at the Università della Svizzera Italiana (USI). The project officially started in October 2018, with the PhD of MSc. S. Riva (Thesis supervisor Prof. R. Krause). In September 2019, a post-doctoral position was also filled at IAC

(Dr. A. Sukhorukov), while a position at ICS will be filled in June 2020 (the candidate has already been selected).

The overall goal of the project is to develop a three-dimensional (3D) radiative transfer code for polarized radiation, taking partial frequency redistribution (PRD) effects into account. It is well known that this is a very challenging problem, especially from the computational point of view. For this reason, we proposed a "Sinergia" project, which allows combining complementary competences and expertise in theoretical and numerical spectropolarimetry (IRSOL and IAC) and in computational sciences (ICS). The activity carried out at IRSOL during 2019 has been focused on the development of a 1D RT code for polarized radiation, accounting for angle-dependent PRD effects, for the case of a two-level atom with an unpolarized and infinitely-sharp lower level, in the presence of arbitrary magnetic fields and bulk velocities. This code will be a fundamental tool for the whole project for two reasons. On the one hand, it will allow us to develop, test, and optimize new methods and algorithms (in close cooperation with the ICS group), which will be useful for the final 3D code. On the other, it will allow us to carry out novel RT investigations of scientific interest, taking angle-dependent PRD effects into account.

The very first objective was to develop an efficient algorithm for calculating the angle-dependent R_{II} redistribution matrix (i.e., the redistribution matrix describing coherent scattering in the atomic frame with Doppler redistribution in the observer's one), as well as the associated emission coefficient. This goal has been successfully achieved, having reached a substantial speed-up with respect to the previous algorithm. This code was then generalized by implementing the R_{III} redistribution matrix (describing frequency-incoherent scattering processes), the propagation matrix, and suitable formal solvers. At the end of the year, the bulk of a full angle-dependent PRD RT code was ready, and first preliminary tests indicated the possibility to perform a few lambda iterations (considering typical semi-empirical models of the solar atmosphere with about 100 height points) also on a standard laptop.

Notably, two distinct codes have been developed, one in F90 (developed by Dr. Guerreiro) and one in Matlab (developed by Dr. Janett). Although the latter was initially devised to develop and test specific routines, it was then generalized, thus ending up with a complete RT code. Having two independent codes is presently a great advantage for the final debugging phase (work in progress). The next steps, which will be carried out in close cooperation with our partners, will be the following:

- to exploit our 1D code to investigate and further optimize specific aspects of the calculation (e.g., the angular quadrature, the iterative method, etc.);
- to investigate the possibility to further speed up our calculations by using GPUs and other hardware solutions;
- to carry out first investigations of scientific interest, by focusing on particular spectral lines.

During 2019, the PhD work of MSc. S. Riva has proceeded along two intertwined paths. On the one hand, he continued the development of his own code (written in C++) for calculating the angle-dependent R_{II} redistribution matrix (for the same two-level atom model described above) and the associated emission coefficient. During the last year, he has been able to generalize this code by adding the contribution of R_{III}, including the evaluation of the propagation matrix, and implementing two different formal solvers (DELO-linear and DELO-parabolic, see Janett et al. 2017, ApJ, 840, 107). On the other hand, he has continued and deepened his analysis of the angle-dependent R_{II} redistribution matrix with the final goal of determining the most suitable quadrature schemes

for performing the integrals needed to evaluate the emission coefficient. Such schemes will then be implemented into the above-mentioned code in order to test and compare their accuracy and efficiency in practical applications.

The cooperation with the IAC partners was also initiated both through regular video conferences, and through a working visit of one month of Dr. A. Sukhorukov at IRSOL (November 18 - December 19, 2019).

Our cooperation with Dr. A. Paganini, now working at the University of Leicester (UK), is still ongoing, and it is now focused on particular mathematical aspects related to this project (analysis of suitable methods for performing the angular quadrature). A paper describing a novel numerical method for the evaluation of the angle-averaged R_{II} redistribution matrix, resulting from a work started by Dr. Paganini during his civil service at IRSOL in 2016, has been submitted to A&A at the end of 2019.

Researchers involved:

IRSOL: L. Belluzzi, N. Guerreiro, G. Janett, S. Riva, E. Alsina Ballester
Sinergia partners: R. Krause (ICS, USI), J. Trujillo Bueno (IAC, Spain), J. Štěpán (ASCR), A. Sukhorukov (IAC)
External: A. Paganini (Univ. Leicester)

Publications:

Paganini, A., Hashemi, B., Alsina Ballester, E., & Belluzzi, L., A&A (submitted)

3.3 Magnetohydrodynamic Simulations of the Solar Atmosphere

Based on a high-cadence high-resolution simulation sequence, computed by F. Calvo at IRSOL, we continued to study the formation of vortical flows in the subsurface and atmospheric layers of the solar atmosphere. In particular, we studied differences between simulations with and without magnetic fields and the coupling and propagation of vortical flows between different atmospheric layers. This work was continued by internship student José Roberto Canivete Cuissa, who focussed on the physical meaning of the swirling strength, a quantity derived from an eigenanalysis of the velocity tensor. The dynamical equation of this quantity was derived and differences to the vorticity and vorticity equation investigated. The analysis of the high-cadence high-resolution simulation sequence was further carried out within the scope of the master thesis of Andrea Battaglia submitted at ETH on 23 March 2020. We found evidence of vertically propagating, unidirectional swirls, which propagate at Alfvén speed. We also found that the perturbation is caused by the rotation of the magnetic footpoint, which, in turn, enhances the magnetic tension, causing the rotation on the magnetic field and hence the rotation of the plasma. These works are now continued within the framework of the SNF project "Magnetohydrodynamic Simulations of the Solar Atmosphere" ID 200020_182094, PI O. Steiner. Within this project J.R. Canivete Cuissa started on Sept. 1, 2019 a PhD-thesis at IRSOL in cooperation with Prof. R. Teyssier of the Institute for Computational Sciences of the University of Zürich.

Researchers involved:

IRSOL: O. Steiner, A. Battaglia, A. Bossart, J.R. Canivete Cuissa

External: F. Calvo (Stockholm University)

Publications:

A. Bossart 2019, IRSOL internal report

J.R. Canivete Cuissa 2019, IRSOL internal report

J.R. Canivete Cuissa & O. Steiner 2020, A&A submitted

A. Battaglia 2020, Masters thesis ETH-Zurich, submitted

3.4 Observational projects

3.4.1 SOLARNET project

This project of the Horizon 2020 research framework of the European Union started on January 2019. It aims at integrating the major European infrastructures in the field of high-resolution solar physics in view of the realization of the European Solar Telescope (EST). The project is managed by the European Association for Solar Telescopes (EAST), which was founded in 2006 and now includes members from 18 European nations. Switzerland is represented in the EAST by IRSOL.

The main Swiss participant in SOLARNET is the Università della Svizzera italiana (USI), while IRSOL and Swiss National Supercomputing Center (CSCS) are third parties. The Piz Daint Supercomputer at CSCS will be made available to the solar community to facilitate numerical investigations of the solar atmosphere, including magneto-hydrodynamic and radiative transfer simulations.

IRSOL is working on an innovative technology capable of performing high precision absolute polarimetry with low systematic errors. It is based on devices and measurement methods originally developed to measure the continuum polarization (see 3.4.2). The goal is to further develop the method for all kind of observations where the determination of the absolute polarization value with highest accuracy is important. In December 2019 a new postdoc (Franziska Zeuner) has been employed for this work.

The Haute Ecole d'Ingénierie et de Gestion du Canton de Vaud (HEIG-VD) is also participating to the SOLARNET project and is involved in the work package devoted to the development of a high-performing adaptive optics device.

In September IRSOL and USI successfully organized a summer school which is described later in section 3.7.1.

Researchers involved:

IRSOL: D. Gisler, F. Zeuner, M. Bianda, R. Ramelli

3.4.2 Center-to-limb variation (CLV) of continuum polarization

Precise measurements of the center-to-limb variation of continuum polarization are required by several projects in solar and stellar astrophysics. However, obtaining this kind of measurements is very challenging because of the small amplitude of the signals and various disturbing instrumental effects. In 2013, in collaboration with KIS, we started a measurement project at IRSOL, and since then we have continually worked on improving the method of measurement, so as to increase the precision of the results. A major progress was the construction of the Telescope Calibration Unit (TCU), a rotatable device with a retarder film. It is placed in front of the telescope and therefore allows a first slow polarization modulation before any other disturbing optical element. In Spring and Autumn 2019 extended observations has been performed and high quality data has been obtained for the wavelengths 388, 429, 456, 494, 535, 604, and 667 nm.

Researchers involved:

IRSOL: D. Gisler,

External: S. Berdyugina (KIS)

Publications:

in preparation

3.4.3 Feasibility study for measuring granular scattering polarization in the Sr I 4607 Å line at DKIST

This project was financed by SNF and consists in studying the feasibility of a system to be installed on the 4m aperture solar telescope DKIST installed in Maui, Hawaii. The goal of the system is to perform a synoptic program measuring the evolution of the turbulent magnetic field in the photosphere during a solar cycle.

The measured quantity is the scattering polarization of the strontium line Sr I 4607 Å. The results have shown, that the difficulties are larger than previously estimated, and this project can be done only in collaboration with a larger institute. Discussions in this direction are currently carried out.

Observations at GREGOR in 2018 were reduced and could give information on the behavior of the small scale Sr I 4607 Å depolarization going from the solar limb towards the disk center.

Researchers involved:

IRSOL: S. Dahra Kumar, E. Capozzi, M. Bianda, R. Ramelli

Publications:

Dhara, Capozzi, Gisler, Bianda, Ramelli, Berdyugina, Alsina, Belluzzi 2019, A&A, 630, 67

Dhara, Capozzi, Gisler, Bianda, Ramelli, Berdyugina, Alsina, Belluzzi, 2019, Il Nuovo Cimento C, 42,6

3.4.4 Observational evidences of magneto-optical effects in the wings of the scattering polarization signal of Ca I 4227 Å

Recent theoretical investigations (del Pino Alemán et al. 2016 ApJL, 830, 24; Alsina Ballester et al. 2016 ApJL, 831, 15) have shown that, in contrast to what was previously thought, the conspicuous scattering polarization signals that are produced by effects of partial frequency redistribution (PRD) in the wings of many strong resonance lines (e.g., H I Ly-α, Mg II h and k, Ca I 4227 Å) are sensitive to the presence of magnetic fields. This sensitivity arises from the so-called magneto-optical (MO) effects, induced by the presence of a longitudinal magnetic field. The main impact of these effects is to give rise to a rotation of the plane of linear polarization, resulting in a depolarization of the Q/I wing signal and in the appearance of a wing signal in U/I. During the last years, we have started an observational work aimed at identifying evidences of these theoretically predicted effects in the Ca I line at 4227 Å, carrying out dedicated observational campaigns with ZIMPOL, both at IRSOL and at GREGOR.

After the project described in Sect. 3.4.3 was postponed, this work has become one of the primary objectives of the PhD Thesis of MSc. E. Capozzi. During 2019, MSc. Capozzi has carried out a very detailed analysis of the available data, finding clear indications of the above-mentioned effect. These results are of high scientific interest, and will be described in a publication presently in preparation. At the same time, MSc. Capozzi has started investigating the diagnostic potential of this mechanism, which might offer a new tool, complementary to the Zeeman effect, for investigating particular aspects of the magnetism of the

solar photosphere. To this aim, she is modeling the scattering polarization signal of this line in the presence of magnetic fields of varying strength, for different models of the solar atmosphere. All this activity is closely followed by Dr. Alsina Ballester, who theoretically discovered such effects, and has provided his RT code to carry out the calculations involved in this project. Following this approach, the magnetic sensitivity of several observables and their possible dependence on other atmospheric parameters is presently being analyzed.

Researchers involved:

IRSOL: E. Alsina Ballester, E. Capozzi, L. Belluzzi, M. Bianda, R. Ramelli

Publications:

Capozzi, E., Alsina Ballester, E., Belluzzi, L., Bianda, M., & Ramelli, R., A&A (submitted)

one more in preparation

3.4.5 Synoptic program to measure the evolution of the photospheric magnetic field during a solar cycle

Since 2007 we have been carrying out a synoptic program in order to determine if the magnetic flux of the quiet photosphere varies with the solar cycle. With this goal in mind, we apply a differential Hanle effect technique, based on observations of scattering polarization in C_2 molecular lines around 5140 Å, generally taken every month. Our results now span a complete solar cycle, and the program is still being continued.

In 2019, the project was mostly concentrated in the observing program. We are searcing for the financing of a common postdoc IRSOL-KIS to summarize the results on a paper.

Researchers involved:

IRSOL: R. Ramelli, M. Bianda

External: S. Berdyugina (KIS), A. Gorobets (KIS)

3.4.6 Two-fluid scenario in prominences

This project is directed by Dr. Eberhard Wiehr in collaboration with Dr. Götz Stellmacher and with IRSOL personnel. The results obtained in previous observations permitted to identify different dynamical behavior of neutral and ionized species in the atmosphere of solar prominences, as described in Wiehr et al. (2019, ApJ 873, 125). Evidence that ions follow oscillations of the prominence magnetic field more closely than neutrals was confirmed by new observations using the line pair Fe II 5018Å and He I 5015Å instead of the previously used Sr II 4078Å and Na I D lines. The wavelengths distance of only 3Å permits to avoid differential refraction effects. The high recording cadence of about 4s per frame permits to search for short period influences on Doppler shift and line broadening. A publication is in preparation.

Researchers involved:

IRSOL: M. Bianda, R. Ramelli

External: E. Wiehr (Institut für Astrophysik, Göttingen), G. Stellmacher (Institut d'Astrophysique, Paris)

Publications:

Wiehr, Stellmacher, Bianda, 2019, ApJ, 873, 125

one more in preparation

3.4.7 Scattering polarization laboratory experiment

Observations of scattering polarization on the Sun have revealed signals that deviate from theoretical expectations. A particularly striking case is the Na D1 line, which according to standard quantum theory is expected to be unpolarized, but which nevertheless is often found to exhibit a polarization peak in its line core. While sophisticated modeling of the line formation processes in the solar atmosphere may offer a possible explanation (see 3.1.1), the solar atmosphere represents a complex environment that is full of physical parameters over which we have no control. To obtain a definite answer to the question whether some of the observed enigmatic effects could be due to deficiencies in the underlying quantum scattering theory that is used for the interpretation, it is necessary to test the theory under perfectly controlled, well defined conditions in a laboratory environment with known polarization state and direction of the incident radiation. Since none of the laboratory experiments that have been done to date have been able to give any clear answer to the Na D1 enigma, we have established a collaboration with a laboratory in France (at Institut de Physique de Nice), where they have the facilities and know-how for precision measurements of this kind. The aim is to investigate scattering processes in a gas of pure rubidium, focusing on the polarization of spectral lines that have the same quantum-mechanical structure as the sodium D lines. The experiment has been proposed by Jan Stenflo and is supported locally in Nice by William Guerin, Robin Kaiser, and Marianne Faurobert. Theoretical support is being provided by the Nagendra group in Bangalore (now by M. Sampoorna, after Prof. Nagendra unexpectedly passed away in March 2020). The experiment hardware is operative, and initial test measurements have been performed. A skilled PhD student is needed to do the experiment as a PhD thesis project, but at the time of writing, a suitable student and the corresponding funding sources have not yet been found.

Researchers involved:

IRSOL: J.O. Stenflo, K.N. Nagendra, M. Bianda

External: M. Sampoorna (Indian Institute for Astrophysics); W. Guerin, R. Kaiser, M. Faurobert (Nice university)

3.4.8 Hα observations

Within the collaboration with the group of Prof. Javier Trujillo Bueno, an observing campaign at IRSOL was organized in June. MSc Jaume Bestard visited us for a series of high precision polarimetric observations of the scattering polarization in the Hα line. Data will be compared with the results of theoretical work developed by Bestard in his PhD work.

Researchers involved:

IRSOL: M. Bianda, R. Ramelli

External: J. Bestard, J. Trujillo Bueno (IAC, Spain)

Publications:

in preparation

3.5 Miscellaneous, science

Prof. Jan Olof Stenflo besides his solar physics works is exploring new research fields.

3.5.1 Nature of dark energy

Dark energy, which is another name for the so-called "cosmological constant", was introduced two decades ago as a free parameter, without which it was impossible to model the observations of the accelerated expansion of the universe within the standard cosmological framework. The physical nature of this parameter has however remained enigmatic, in spite of intense world-wide efforts in search for some new physical field that could explain it. Recently J.O. Stenflo has published an explanation, according to which dark energy does not represent any new physical field at all, but is an effect that is induced by the boundary conditions of the universe. This explanation leads to a greatly different cosmological framework with a very different expansion history. Besides predicting the observed rate of acceleration of the expansion without the use of free parameters, it resolves the so-called "cosmic coincidence problem" by showing that our present epoch of cosmic history is not special in any way. It also eliminates the need to postulate a violent inflationary phase in the early universe to explain the observed large-scale homogeneity and isotropy of the universe.

Researchers involved:

IRSOL: J.O. Stenflo

Publications:

Stenflo 2019, Astrophysics and Space Science, 364, 143

Stenflo, J. O.: 2020, IntechOpen, DOI: 10.5772/intechopen.91442. Available from:

https://www.intechopen.com/online-first/nature-of-dark-energy

3.6 Specola Solare Ticinese

Scientific work at Specola Solare Ticinese is focused on the determination of the international Sunspot Number (SSN) released by the SILSO World Data Center at the Royal observatory in Brussels, for which Specola is the international reference station. The experience of Sergio Cortesi, who worked under the direction of Max Waldmeier starting in 1957 till 1980, gave continuity to the counting method defined in Zurich by Rudolf Wolf in the mid 1800s. This know-how has been transmitted to Marco Cagnotti.

In 2019, 290 sunspot drawings were made; the drawings and the calculated Wolf number can be seen on the web (`http://www.specola.ch`).

IRSOL staff collaborates with Specola for outreach activities and, when required, for making the solar drawings and performing their reduction. Ramelli acts also as Web Master for the Specola web pages.
The Sunspot Number (SSN) time series is now included in the new implementation plan of the Global Climate Observing System (GCOS).

In particular the Swiss GCOS office at MeteoSwiss finances a project coordinated by Ramelli and done in collaboration with ETH Zurich University Archives for the safe and long term archiving and digitization of the observational data produced by Specola Solare Ticinese.

The main project milestones achieved at Specola in 2019:

1. Preparation of the drawings to be sent for archiving at ETH-Zurich (period 1981-2019), in particular an handwritten signature has been added to the sunspot drawings, according to the instructions given by the ETH Zurich University Archives.

2. Prepared and checked the metadata for the drawings

3. Completed the unweighted counting in collaboration with Mario Gatti and his students at the Istituto Statale Istruzione Superiore Valceresio, Bisuschio.

The SILSO responsible Dr. Frédŕic Clette and Sabrine Bechet, visited Specola Solare and IRSOL twice in 2019 to discuss about this project, to visit the ETHZ Archives, and to install the code Digisun for the processing and analysis of the digitized sunspot drawings.

Researchers involved:

IRSOL-Specola: M. Cagnotti, S. Cortesi, R. Ramelli

External: F. Clette (SILSO, Brussels), S. Bechet (SILSO, Brussels), M. Gatti (Bisuschio, Varese)

3.7 Education

3.7.1 SOLARNET-FoMICS summer school

The SOLARNET-FoMICS summer school *Solar spectropolarimetry: From virtual to real observations* was organized and carried out by IRSOL in cooperation with the Institute of Computational Science (ICS) of the Università della Svizzera italiana (USI). It took place from September 9-14, 2019 on the campus of USI in Lugano. Eight lecturers and twenty-four student participants spent a week developing competence and skills for the computation of synthetic spectropolarimetric data from numerical simulations and comparison to real photospheric and chromospheric observational data. Supplementary lectures treated topics of career development and high-performance computing. Programme, class schedule, list of participants, and class material can be found under

https://solarnet-project.eu/Solar-spectropolarimetry-From-virtual-and-real-observations.

This course was sponsored by SOLARNET under Grant Agreement No 824135 of the European Union's Horizon 2020 research and innovation programme and by the Swiss Graduate Programme Foundations in Mathematics and Informatics for Computer Simulations in Science and Engineering (FoMICS).

3.7.2 Master and bachelor

An ongoing collaboration with University of Applied Sciences and Arts of Southern Switzerland (SUPSI) permitted the conclusion of a master work directed by Prof. Roberto Gardenghi at SUSPI, the work at IRSOL was supervised at IRSOL by Boris Liver.

Using data from numerical simulations produced in the course of the PhD work of Dr. Flavio Calvo that he carried out at IRSOL, we studied magnetic vortical flows, so called solar magnetic tornadoes. Initially, this work was carried out by two internship students (A. Bossart and J.R. Canivete Cuissa) but finally became topic of the masters thesis of Andrea Battaglia submitted to ETHZ. It was supervised by Dr. O. Steiner at IRSOL and directed by Prof. Dr. Louise Harra (ETHZ) (see also 3.3).

3.7.3 Internship and outreach program

At IRSOL we offer young students (secondary and high school) the opportunity to visit a research institute, which can generate interest for a scientific educational path. Every year we give to young secondary school students the opportunity to perform a one day stage before they start the high school. In collaboration with a local company we offered a one day stage at IRSOL to secondary school students of a school in Ascona reporting the best marks in scientific courses. Moreover, we offer support for maturity works dedicated to astronomical topics.

In 2017 the cantonal administration of Canton Ticino started the program "Estage", intended to better connect students of the Swiss Italian area with local industries and research institutes promoting stages announced on a web page (`www4.ti.ch/can/oltreconfiniti/dal-1990-a-oggi/estage/`). IRSOL participated to this project and four students could spend several weeks at IRSOL working successfully on specific topics within the framework of the scientific projects 3.2.2.

Romain Mercier, student at Lycée de Jean Perrin in Lyon (F), did an internship measuring the 5 minutes solar oscillation for his high school work.

With "L'ideatorio", Università della Svizzera italiana, we started a cooperation intended to promote an outreach activity. In 2020 we plan to submit a proposal to the SNF Agora program.

IRSOL promotes an outreach program together with Specola Solare Ticinese, organizing observation events supervised by an astronomer.

One of the work packages of the H2020 project PRE-EST is devoted to outreach. We collaborate to this project.

4 INSTRUMENTAL WORK

4.1 ZIMPOL project

4.1.1 Instrument software

The ZIMPOL3 instrument software was originally developed at ETH Zurich. It is based on a distributed server client concept which is very flexible and is used for all kind of instruments at IRSOL. The software is maintained and further developed at IRSOL. However, this is not the case for the core part of the software, the Command Stream Interpreter (CSI) written in Java. For several reasons its implementation turned out to be too complex and cumbersome, with the consequence that it can hardly be maintained with the limited manpower at IRSOL. Up to now we got some support from Peter Steiner the retired ETH engineer who developed the software. To overcome this situation he proposed a new implementation of the CSI in Python. 2018 he showed us the feasibility of the new concept on a first prototype investigation. In 2019 IRSOL got the unique opportunity to realize this protect with the help of Peter Steiner (how did the main part of the work). By end of the year most of the CSI functionality has been implemented and the software was running already very stable.

4.2 Quadropix DePFET sensor

In 2014, the Halbleiterlabor (HLL) of the Max-Plank-Gesellschaft in Munich proposed a new sensor technology based on Depleted P-channel Field Effect Transistors (DePFET) that allows on-sensor demodulation, similarly to the ZIMPOL sensors. In addition it provides several advantages that would overcome certain limitations of the ZIMPOL sensor, e.g. symmetric pixels, much faster read-out rates and high quantum efficiency. After a successful two year feasibility study, IRSOL was offered to be PI in the development of a polarimeter based on the new Quadropix DePFET sensor technology. A working plan was designed by IRSOL, MPS, HLL and SUPSI. In 2019 IRSOL and SUPSI wrote two proposals to get the founding. The first one mainly applied for the development of the camera electronics at SUPSI was submitted to the SNF founding program BRIDGE Discovery. For development and production of scientifically useful sensors a second proposal was submitted to the SNF founding program REquip. The proposals were not accepted, and we are still searching for financing solutions.

4.3 Cooperation with KIS for the VTF

The Visible Tunable Filter (VTF) is a Fabry-Perot based spectro-polarimeter. It will be a first light instrument for DKIST, designed for high spatial resolution 2D imaging spectropolarimetry and spectroscopy. It is currently under development at KIS, and on-site installation and commissioning is planned for 2021. Due to our good expertise in fast polarization modulator technology KIS asked IRSOL for support. IRSOL agreed to a collaboration and provides a certain amount of manpower to this project. In return and according to the amount of work done in the construction phase, IRSOL will be granted observing time with VTF at DKIST. 2019 IRSOL contributed the following tasks to VTF:

- Final alignment of all components of the modulator
- Final assembly of the modulator and performance tests
- Testing of the modulator with the new drive electronics

4.4 The CALLISTO project

The CALLISTO spectrometer is a programmable heterodyne receiver designed 2006 in the framework of IHY2007 and ISWI by Christian Monstein (PI) as member of the former Radio Astronomy Group (RAG) at ETH Zurich, Switzerland. Since 2019 IRSOL is the new host Institute of the CALLISTO project with Christian Monstein as an affiliated staff member. The main applications are observation of solar radio bursts for astronomical science, education, outreach and citizen science as well as rfi-monitoring. Many CALLISTO instruments have already been deployed worldwide and form together the e-Callisto network. CALLISTO is able to continuously observe the solar radio spectrum for 24h per day through all the year. Data from individual instruments are automatically uploaded by FTP to the central server at University of Applied Sciences (FHNW) in Brugg/Windisch.

In 2019 seven new spectrometers as part of the e-Callisto network have been installed at the locations: Arecibo observatory (Puerto Rico), Boumerdes (Algeria), Grotniki, (Poland), Embry-Riddle

Aeronautical University (USA), Rochester Institute of Technology (USA), IRSOL and Landschlacht (Switzerland).

Further work were to upgrade the LINUX central server at FHNW, connected with new PYTHON scripts and upgrade to the latest SSW-IDL version.

Researchers involved:

IRSOL: C. Monstein

Publications:

Koval, Chen, and other 10 including Monstein, C.: 2019, ApJ, 877, 98

Singh, Sasikumar Raja, Subramanian Prasad, Ramesh, Monstein 2019, Solar Physics, 294 112

Morosan, Kilpua, Carley, Monstein 2019, A&A, 623, 63

Peel, Wuensche, C. A. and other 9 including Monstein 2019, Journal of Astronomical Instrumentation, 8, 1940005

5 TECHNICAL WORK

5.1 Computer and networking

To replace some old instruments computers three new ones has been purchased. They have identical hardware and the same Linux OS has been installed to simplify usage and maintenance.

5.2 Infrastructure work

Thanks to the additional funds obtained from an inheritance we could perform renovation works at IRSOL.

The floor around the telescope was renewed permitting a better maintenance of the surface Gianpaolo Mari took the direction ans supervision of the works, and following improvements have been made:

- The renovation of the first floor is concluded. The new guest room with a separate bath already was used for visiting scientists. Three more rooms are available for a total of six more desktops. The coverage of the corridors and of the rooms in the first floor was substituted.
- The floor around the telescope was renewed permitting a better maintenance of the surface. Part of the movable roof was painted. The optical laboratory (former photographic dark room) is now ready.
- The path from the main building to the observatory is now illuminated. The external stairs were repaired and the garage has been better insulated from humidity.
- Within the renovation works it was possible to install the concrete basis for the Callisto radio telescope and to connect it with the observatory trough an underground pipeline.

6 WORKS FORESEEN IN 2020

- **Particular situation**

  During the preparation of this report the COVID-19 pandemic began and it is expected to have very significant consequences on the activities of IRSOL. Work from home is giving results, but what will be the real consequences, also taking into account the general economic situation, is unclear.

- **Collaboration with Università della Svizzera italiana, USI**

  The commission composed by Profs. Philippe Jetzer, Svetlana Beryugina, Benedetto Lepori, Rolf Krause, and Sandro Rusconi prepared a document about the future of IRSOL. On the basis of this document it was possible to start the procedure required for the affiliation of IRSOL to USI. On 27^{th} September 2019 the USI council approved the decision to submit the proposal to the State Council of canton Ticino. The positive decision of the Grant Council (18^{th} February 2020) will be operative on 1^{st} January 2021. The affiliation implies that IRSOL shares the strategic obyectives of USI. That will be reached in a natural way, pursuing the already ongoing work that includes the ongoing Sinergia SNF project and the European H2020 SOLARNET project. IRSOL will keep an open mind attitude searching to develop all initiatives directed to a better interwork with USI. We are also preparing an outreach project with the "L'ideatorio" to be submitted to the AGORA SNF program.

- **Collaboration with SUPSI**

  The strengthening of coordinated works with SUPSI was at the origin of a "Collaboration agreement" signed by SUPSI and IRSOL.

  We will search for funding for the development of the next generation of polarimeters based on a new sensor (see 4.2).

  We will share the participation in the "NTN Innovation Booster" Smart RF Electronics and Advanced Multisource Imaging Systems network.

- **Collaboration with KIS**

  With the Leibnitz Institute of Solar Physics, KIS, we have a long ongoing collaboration that also includes sharing of researchers, and the director of KIS as co-director of IRSOL. The technical cooperations can be summarized in the availability of ZIMPOL at GREGOR, in the cooperation of D. Gisler to the project VTF for DKIST, and in the construction of a telescope calibration unit version for GREGOR, developed in the SOLARNET project (see chapter 3.4.1) We are planing to increase the collaboration searching for a common postdoc working at the the project described in 3.4.5, and exploring the feasibility to cooperate on a polarimeter project together with SUPSI.

- **Development of the scientific program**

  The topics already developed and described in section 3 will be continued.

- **Infrastructure**

  Following the increase in staff and the adaptation of today's needs with regard to connectivity, action was taken at the USI IT service, in order to be able to use a broadband internet connection via fiber. The remote location of IRSOL has made the search for solutions more difficult.

The offer that was considered the most advantageous is that which provides a connection to the USI network via a dedicated fiber connection from IRSOL to the DFA-SUPSI of Locarno offered by Cablecom. In addition to significantly increasing the available bandwidth, the new connection could in the future favor the possibility of using the numerous services offered by the USI IT service. The fiber laying works are coordinated with the canalization and reconstruction works on the access road.

The access road of IRSOL is about 60 years old and requires to be resurfaced. We will take this opportunity also to connect with the Orselina dark water canalization, to prepare the last 100 m pipe for the optical fiber and install a new connection to the electrical power network.

7 SCIENTIFIC ACTIVITY

7.1 Visits

04/02 Sandeep Ramanath, Indian Institute of Astrophysics, Bangalore

17-20/03 Ondrej Procházka, Astrophysics Research Centre Queens University Belfast Northern Ireland, UK

02-17/04 Freédéric Clette and Sabrine Bechet, Royal Observatory Belgium

16-30/06 Eberhardt Wiehr, Astro Physik Göttingen

18-26/06 Gotz Stellmacher, Paris

26/05-09/06 Jaume Bestard, IAC, Tenerife, Spain

04/06 Michel Hübner, EPFL

03-10/07 Edgar Carlin, IAC, Tenerife, Spain

08-10/07 Franziska Zeuner, MPS, Göttingen, Germany

14/08 D. Soltau, Germany

02-04/10 Damian Fabbian, MPS, Göttingen, Germany

18/11-19/12 Andrii Sukhorukov, IAC, Tenerife, Spain

21-25/11 E. Wiehr, Astro Physik Göttingen

13/11 A. Nuzzo, B. Colbois, Swiss Science Council

26/11 Thomas Zenger, ETH-Library (Explora)

7.2 Visits to other institutes

23-24/09 Andrea Battaglia, KIS, Freiburg

03-05/12 Andrea Battaglia, KIS, Freiburg

11-17/11 Ernest Alsina Ballester, IAC, Tenerife

29/05-01/05 José Roberto Canivete Cuissa, KIS, Freiburg

03-05/12 José Roberto Canivete Cuissa, KIS, Freiburg

7.3 Participation to workshops, meetings, schools and talks

21-25/01 M. Bianda, (and R. Krause, USI) Brussels, EAST General Assembly, PRE-EST rewiew meeting, PRE-EST Board meeting, SOLARNET Kick-Off Meeting;

04-08/02 O. Steiner: ISSI International team "The nature and physics of vortex flows in solar plasmas", ISSI Bern. Talks via telecon: *Horizontal vortex tubes at the edges of solar granulation* and *Non-magnetic bright points as a manifestation of vortex flows*;

5-6/03 E. Alsina Ballester, M. Bianda, E. Capozzi, S. Dhara, D. Gisler, G. Janett, C. Monstein, R. Ramelli "3^{rd} Swiss SCOSTEP Workshop"
Talks:

- E. Capozzi: *High-precision spectropolarimetric investigations to study the magnetic field in the solar granulation*
- E. Alsina Ballester: *The magnetic sensitivity of the scattering polarization signal in the wings of the Ca I resonance line at 422.7 nm*
- R. Ramelli, *The digitization of the swiss historical sunspot observations and its relevance for the Sunspot Number data series.*
- M. Bianda, *The European Solar Telescope, Swiss participation*
- S. K. Dhara, *Feasibility study of a filter polarimeter dedicated to the measurement of the scattering polarization at the Sr I 4607 A for DKIST*

7/03 R. Ramelli, Swiss SCOSTEP committee meeting, Davos;

12-14/06 O. Steiner: Platform for Advanced Scientific Computing Conference, PASC18, ETH Zürich, Minisymposium Multidimensional Stellar Evolution: Bridging the Modeling and Computational Challenges. Invited talk: *Aspects of multi-dimensional radiation transfer in stellar atmospheres*;

30/06-6/07 R. Ramelli: IAU Symposium 354, Copiapo (Chile), Poster: *IRSOL spectropolarimetric observing programs and magnetic field diagnostics: recent advances.*

12-16/08 O. Steiner: RoCS International Team "WaLSA on Waves in the Lower Solar Atmosphere at High Resolution", Rosseland Center for Solar Physics, Oslo. Talk: *Waves and swirls*;

26-30/08 E. Alsina Ballester, L. Belluzzi, M. Bianda,N. Guerreiro, R. Ramelli, S. K. Dhara, E. Capozzi, , G. Janett, J. O. Stenflo "Solar Polarization Workshop 9 (SPW9)", Max Planck Institut für Sonnensystemforschung (MPS), Göttingen, Germany.
Talks:

- E. Alsina Ballester: *Magnetic sensitivity in the wings of the linear polarization profiles of the hydrogen Lyman-α line*
- E. Capozzi: *Observational hints of magneto-optical effects in the scattering polarization wings of Ca* I *4227 Å*
- L. Belluzzi: *Physical processes at the root of solar polarization*
- J. O. Stenflo: *Stokes vectors and Minkowski spacetime: structural parallels*
- M. Bianda: *Scattering polarization measurements at GREGOR and IRSOL, some examples and notes*
- S. K. Dhara: *Observations on spatial variations of the Sr i 4607 A scattering polarization signals at different limb distances*
- G. Janett: *Dealing with discontinuities in numerical radiative transfer*

Poster:

- R. Ramelli: *2D imaging spectropolarimetry of solar prominences with ZIMPOL and a Fabry-Pérot filter system*

09-14/09 E. Capozzi, S. K. Dhara, M. Bianda, R. Ramelli, O. Steiner, l. Belluzzi, E. Alsina Ballester, A. Battaglia, R. Cuissa, SOLARNET-FoMICS Summer School on Solar Spectropolarimetry: from virtual to real observations, Università della Svizzera italiana (USI), Lugano, Switzerland.
Lectures:

- O. Steiner: "Solar spectropolarimetry: From virtual to real observations", Lugano. Three lectures on *Aspects of magnetohydrodynamic simulations of stellar atmospheres*;
- R. Ramelli: *High precision polarimetry*

9/10 R. Ramelli, Swiss SCOSTEP committee meeting, Brugg;

11/10 M. Bianda, O. Steiner: general assembly of the Swiss Society for Astrophysics and Astronomy, Basel;

15/11 M. Bianda, ESO Information Day 2019, Olten

11-13/11 E. Capozzi, CSCS School on High Performance Computing with Python, Centro Svizzero di Calcolo Scientifico (CSCS), Lugano, Switzerland.

12-14/11 E. Alsina Ballester, CLASP-2 Science Meeting, Instituto de Astrofísica de Canarias (IAC), La Laguna, Tenerife, Spain.
Talks: *Magneto-optical effects in the H* I *Lyman-α wings* by E. Alsina Ballester

28-29/11 O. Steiner RoCS science gathering, Rosseland Center for Solar Physics, Oslo, Talk: *Phase shift diagrams as a tool for code validation?*

03-04/12 M. Bianda, J.O. Stenflo, "Symposium in honor of Prof. Dr. Werner Schmutz, and Prof. Dr. Louise Harra", PMOD/WRC Davos

7.4 Organization of schools

9-14/09 SOLARNET-FoMICS Summer School at USI in Lugano: "Solar spectropolarimetry: from virtual to real observation"

7.5 Talks at IRSOL

04/02 K. Sandeep, Indian Institute of Astrophysics, Bangalore, "The impact of bulges on bar formation in Milky Way type galaxies"

18/03 O. Procházka Title: "Type II White-light Solar Flares Instrumentation and Data Analysis"

25/06 Eberhard Wiehr, Institut fur Astrophysik, Göttingen, "Velocity and Line-Width Excess of Emission Lines from Ions over Neutrals"

03/10 Damian Fabbian, MPS

28/11 Andrii Sukhorukov, IAC, "Coherent Scattering in the Observer's Frame, no magnetic field"

7.6 Participation in exam boards

03/06 O. Steiner: Member of the jury for the defense of the PhD-thesis of G. Janett and principal author of the report on the thesis. ETH-Zürich;

01/02 O. Steiner: Opponent for the PhD-thesis defense of Johan Pires Bjørgen (Largely impeded because of illness). Stockholm University.

13/09 M. Bianda, B. Liver, exam board members for the Master thesis of Christian Valles at SUSPI

7.7 Participation in scientific committees

- *L. Belluzzi:* Member of the Science Advisory Group (SAG), appointed to update the Science Requirement Document (SRD) for the European Solar Telescope (EST). This document will be the scientific base for the Technical Requirement Document (TRD), which will set the constraints and specification for the final design of EST. Belluzzi worked together with Dr. Alex Feller and Prof. Javier Trujillo Bueno (sub-group 8), on the chapter "Scattering Physics and Hanle-Zeeman diagnostics".

- *L. Belluzzi*, member of the scientific team that prepared the proposal "Magnetic Imaging of the Outer Solar Atmosphere (MImOSA)" in response to the call for White Papers for the "Voyage 2050" long-term plan in the ESA science programme. First author and coordinator:

Dr. Hardi Peter (MPS, Germany). The proposal was selected for an oral presentation at the ESA workshop in Madrid in October 2019. The proposals are presently under evaluation.

- *O. Steiner:* Member scientific advisory committee of the Rosseland Center for Solar Physics (RoCS) of the University of Oslo.
  Member Time Allocation Committee (TAC) for the SOLARNET trans-national access programme for observing and high performance computing time.
- *M. Bianda* Organizing Committee Member of Commission E1 Solar Radiation and Structure
- *R. Ramelli*: member of the Swiss SCOSTEP committee
- *R. Ramelli*, jury member in "Schweizer Jugend Forscht" competition: Liceo Lugano 2, Savosa, 12 January 2019 & Rapperswil, 2-4 May 2019
- *C. Monstein*, Member of steering committee of International Space Weather Initiative (ISWI) at United Nations Office of Outer Space Affairs (UNOOSA) in Vienna, Austria
- *C. Monstein*, Member of Committee on Radio Astronomy Frequencies (CRAF)
- *C. Monstein*, Member of Committee on Space Research (COSPAR)

8 ATTIVITÀ DIVULGATIVA

8.1 Visite guidate, visite di cortesia

09/04 Allievi del Liceo di Bellinzona nell'ambito dei lavori di maturitá, G. Pogliesi e R. Ramelli

03/06 1 classe (1E) del Liceo di Bellinzona, R. Ramelli

11/09 Partecipanti SOLARNET-FOMIX Summer School

28/09 Societá Ticinese di Scienze biomediche e chimiche

30/09 2 classi (4FAM) del Liceo di Bellinzona, F. Lucchinetti, R. Boldini e R. Ramelli

12/11 1 classe del Liceo di Mendrisio, L. Ortelli

8.2 Stages informativi

20/08 stage premio per le migliori note in scienze in 4^a media al Collegio Papio (DFD Solutions SA Tecnologia e sistemi di Sicurezza - IRSOL): Mara Ceschi, Alina Morello, Julian Spiess

8.3 Organizzazione di eventi

Il lavoro di divulgazione è coordinato con la Specola Solare Ticinese e fa capo ad un gruppo di animatori composto dal personale scientifico di IRSOL e Specola, nonché da collaboratori volontari. Ci si presenta al pubblico sotto il nome di Centro Astronomico del Locarnese (CAL). Sono state organizzate osservazioni solari e notturne seguite da una presentazione alla Specola Solare Ticinese.

Attività divulgativa

Visite a carattere divulgativo sono organizzate all'IRSOL solamente su esplicita domanda. Una lista di eventi é riassunta al punto 8.1.

8.4 Partecipazione ad eventi e conferenze divulgative

20/02 R. Ramelli, "La meteo spaziale e le aurore Boreali", sala conferenze, CdT Muzzano.

29/10 M. Bianda, "Osservazioni solari: spettropolarimetria. Uno sguardo al futuro", Osservatorio Galilei, Suno

03/12 R. Ramelli, Tecday al Liceo di Locarno, 3 presentazioni: "Cosa ci svela la luce delle stelle"

8.5 Lavori di Maturità seguiti all'IRSOL

Loris Jorio Liceo di Bellinzona, "Determinazione dell'età di ammassi stellari attraverso la fotometria"

Daniel Panero Liceo di Bellinzona, "Alla ricerca del campo magnetico nelle protuberanze solari" (visits and measurements: 24/06, 9/08)

Luca Riva Liceo di Bellinzona, "Misura della rotazione differenziale del Sole" (visit and measurements: 23/07)

8.6 Presenza nei media

8.6.1 Radio

23/01 Renzo Ramelli su Rete 1, Millevoci, "Anche il Sole dell'IRSOL brilla nei computer del Centro Svizzero di Calcolo Scientifico" (con Michele De Lorenzi e Maria Grazia Giuffreda)

8.6.2 Televisione

28/04 RSI, "Giardino di Albert", puntata: "Il Sole inferno in cielo". Intervista a Michele Bianda nell'introduzione e nella parte conclusiva

8.6.3 Articoli apparsi sulla stampa

"Per l'IRSOL l'affiliazione all'USI", La Regione, 18 ottobre

8.6.4 Articoli apparsi online

"Esito positivo per l'esperimento di fisica solare CLASP-II cui partecipa l'IRSOL" , USI, Notizie ed eventi, `https://www.usi.ch/it/feeds/10404`, 29 aprile

"Faculae, spots, flares", https://www.explora.ethz.ch/en/s/fackeln-flecken-flares/ con intervista di R. Ramelli e C. Monstein, Dicembre

9 PUBLICATIONS

9.1 Appeared in 2019

9.1.1 Appeared in peer reviewed journals

Alsina Ballester, E., **Belluzzi, L.**, Trujillo Bueno, J.: 2019, *Magnetic sensitivity in the wing scattering polarization signals of the hydrogen Lyman-alpha line of the solar disk radiation*, ApJ, **880**, 85

Dhara, Sajal K., **Capozzi, E.**, **Gisler, D.**, **Bianda, M.**, **Ramelli, R.**, Berdyugina, S., **Alsina, E.**, **Belluzzi, L.**: 2019, *Observations on spatial variations of the Sr I 4607 Åscattering polarization signals at different limb distances with ZIMPOL*, A&A, **630**, 67

Janett, G.: 2019, *Discontinuities in numerical radiative transfer*, A&A, **622**, 162

Janett, G., **Steiner, O.**, **Alsina Ballester, E.**, **Belluzzi, L.**, Mishra, S.: 2019, *A novel fourth-order WENO interpolation technique. A possible new tool designed for radiative transfer*, A&A, **624**, 104

Koval, A., Chen, Y, Tsugawa, T., *and other 9 including* **Monstein, C.**: 2019, *Direct Observations of Traveling Ionospheric Disturbances as Focusers of Solar Radiation: Spectral Caustics*, ApJ, **877**, 98

Morosan, D. E., Kilpua, E. K. J., Carley, E. P., **Monstein, C.**: 2019, *Variable emission mechanism of a Type IV radio burst*, A&A, **623**, 63 3

Peel, M. W., Wuensche, C. A., Abdalla, E., *and other 8 including* **Monstein, C.**: 2019, *Baryon Acoustic Oscillations from Integrated Neutral Gas Observations: Radio Frequency Interference Measurements and Telescope Site Selection*, Journal of Astronomical Instrumentation, **8**, 1940005

Sampoorna, M., **Nagendra, K. N.**, Sowmya, K., **Stenflo, J. O.**, Anusha, L. S.: 2019, *Polarized Line Formation in Arbitrary Strength Magnetic Fields: The Case of a Two-level Atom with Hyperfine Structure Splitting*, ApJ, **883**, 188

Singh, D., Sasikumar Raja, K., Subramanian, Prasad, Ramesh, R., **Monstein, C.**: 2019, *Automated Detection of Solar Radio Bursts Using a Statistical Method*, Solar Physics, 294 112

Stenflo, J. O.: 2019, *Origin of the cosmological constant*,Astrophysics and Space Science, **364**, 143

Vigeesh, G., Roth, M., **Steiner, O.**, and Jackiewicz, J.: 2019, *Internal gravity waves in the magnetized solar atmosphere. II. Energy transport*, ApJ, **872**, 166

Wiehr, E.; Stellmacher, G.; **Bianda, M.**: 2019, *Evidence for the Two-fluid Scenario in Solar Prominences*, ApJ, **873**, 125

9.1.2 Appeared in proceeedings or ArXiv

Alsina Ballester, E., **Belluzzi, L.**, Trujillo Bueno, J.: 2019, *Magnetic Sensitivity in the Wings of the Linear Polarization Profiles of the Hydrogen Lyman-α Line.* In: A. Gandorfer, A. Lagg, K. Raab (eds.), *Proc. 9th Solar Polarization Workshop SPW9*, Max-Planck-Institut für Sonnensystemforschung, Göttingen 2019, DOI: 10.17617/2.3187774

Dhara, Sajal K., **Capozzi**, E., **Gisler, D.**, **Bianda, M.**, **Ramelli, R.**, Berdyugina, S., **Alsina, E.**, **Belluzzi, L.**: 2019, *Spatial variations of the Sr I 4607 Å scattering polarization signals at subgranular scale observed with ZIMPOL at the GREGOR telescope*, Il Nuovo Cimento C, **42**, Issue 1, 6

Nagendra, K. N., Sowmya, K., Sampoorna, M., **Stenflo, J. O.**, Anusha, L.S.: 2019, *Polarized Line Transfer in the Incomplete Paschen-Back Effect Regime with Angle-dependent Partial Frequency Redistribution.* In: A. Gandorfer, A. Lagg, K. Raab (eds.), *Proc. 9th Solar Polarization Workshop SPW9*, Max-Planck-Institut für Sonnensystemforschung, Göttingen 2019, DOI: 10.17617/2.318665

Sampoorna, M., **Nagendra**, K. N., Sowmya, K., **Stenflo, J. O.**, Anusha, L. S.: 2019, *Polarized Line Formation with Incomplete Paschen-Back Effect and Partial Frequency Redistribution*, ASP Conference Series, **519**, 113

Sampoorna, M., **Nagendra**, Frisch, H.; **Stenflo, J. O.**: 2019, *Effects of Angle-Dependent Partial Frequency Redistribution on Polarized Line Profiles*, ASP Conference Series, **519**, 109

Schlichenmaier, R.; Bellot Rubio, L. R.; Collados, M.; and 23 more including, **Belluzzi, L.**: 2019, *Science Requirement Document (SRD) for the European Solar Telescope (EST) (2nd edition, December 2019)*, arXiv:1912.08650

Stenflo, J. O.: 2019, *Dark energy as an emergent phenomenon*, ArXiv e-prints: 1901.01317

Stenflo, J. O.: 2019, *Stokes vectors and Minkowski spacetime: structural parallels.* In: A. Gandorfer, A. Lagg, K. Raab (eds.), *Proc. 9th Solar Polarization Workshop SPW9*, Max-Planck-Institut für Sonnensystemforschung, Göttingen 2019, DOI: 10.17617/2.3182802

9.2 In press or already published in 2020

Prieto, M., Gordo, J.B., Rodríguez-Pacheco, J., Martínez, A., Sánchez, S., Russu, A., Monstein, C., Fernández, R.: 2019, *Increase in Interference Levels in the 45 - 870 MHz Band at the Spanish e-CALLISTO Sites over the Years 2012 and 2019* , Solar Physics, **295**, 11

Canivete Cuissa, J.R., Steiner, O.: 2020, Vortices evolution in the solar atmosphere: A dynamical equation for the swirling strength, A&A, submitted

Battaglia, A.: 2020, Origin and evolution of the magnetic swirls in numerical simulations of the solar atmosphere, Masters thesis, ETHZ

Paganini, A., Hashemi, B., Alsina Ballester, E., & Belluzzi, L.: 2020, A&A (submitted)

Stenflo, J. O.: 2020, *Nature of dark energy*, IntechOpen, DOI: 10.5772/intechopen.91442. Available from:

`https://www.intechopen.com/online-first/nature-of-dark-energy`

9.3 Theses

Gioele Janett.: 2019, *Numerical methods for the transfer equation of polarized radiation*, Ph.D. thesis, ETHZ, 10.3929/ethz-b-000348946

`https://www.research-collection.ethz.ch/handle/20.500.11850/348946`

9.4 Other publications

Bossart A.: 2019, *Chromospheric Swirls and Sub-photospheric Magnetic Field Concentrations*, IRSOL internal report;

Canivete Cuissa, J.R.: 2019, *Vortices detection and evolution in solar simulations: a dynamical equation for the swirling strength*, IRSOL internal report.

9.5 Atlas and scientific data on our website

On the page `http://www.irsol.ch/data-archive` one can find several atlas in digital form.