Istituto Ricerche Solari Locarno

Rapporto 2021

Rapporto alla Fondazione Istituto Ricerche Solari Locarno sulla situazione dell'Istituto alla fine del 2021 e sul piano di lavoro per il 2022

Relatori:	Dr. Michele Bianda Staff dell'IRSOL
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Locarno-Monti, 12 maggio 2022

*) *AIRSOL, Associazione Istituto Ricerche Solari Locarno*

Indice

1 PREMESSA

Da inizio 2021 l'IRSOL è affiliato alla facoltà di informatica dell'USI. Questo importante passo è pure il risultato naturale della profiqua attività scientifica svolta congiuntamente come descritto in questo e nei precedenti rapporti annuali. All'USI è stato costituito nel corso dell'anno l'Istituto Eulero. L'IRSOL è istituto partner, il che permette di incrementare la fattiva collaborazione con l'USI.

L'attività di ricerca scientifica dell'IRSOL, incentrata nel campo della spettropolarimetria solare, nel 2021 ha visto momenti particolarmente importanti.

Il lavoro svolto da Emilia Capozzi duarnte gli ultimi quattro anni all'IRSOL ha portato alla sua brillante difesa della tesi di dottorato all'Università di Ginevra.

Nonostante le dure condizioni di lavoro imposte dalla pandemia, motivo per il quale molti ricercatori hanno lavorato a casa loro per lunghi periodi, la possibilità di rimanere in contatto in modo virtuale ha permesso un lavoro molto proficuo. Tra i risultati ottenuti possiamo citare il lavoro condotto dal Dr. Ernest Alsina i cui risultati sono stati pubblicati su Physical Review Letters. Oltre a questo, molti altri lavori sono stati descritti su articoli pubblicati su riviste referenziate.

Il progetto Sinergia che prevede la collaborazione con USI e l'IAC di Tenerife ah visto rilevanti progressi.

Il gruppo che sviluppa la ricerca nel campo delle simulazioni numeriche ha avuto risposte positive a domande di tempo di calcolo al supercomputer del CSCS.

Nell'ambito del progetto SOLARNET abbiamo verificato la funzionalità di una tecnologia sul telescopio GREGOR a Tenerife che permette di misurare (con ZIMPOL) la polarizzazione con un alto grado di accuratezza. Questa tecnologia è già utilizzata all'IRSOL.

Per la manutenzione e lo sviluppo del polarimetro ZIMPOL abbiamo ora una stretta collaborazione con la SUPSI (Istituto sistemi ed elettronica applicata) definita pure da un accordo. I lavori per rinnovare la parte digitale della camera sono iniziati.

I lavori di infrastruttura cominciati un paio di anni, hanno visto la ristrutturazione dei servizi dell'istituto e lavori di modernizzazione dell'allacciamento idrico. Sistemi di allarme fuoco e anti intrusione sono stati istallati. La modalità di connessione a internet è stata radicalmente rinnovata; ora siamo collegati al sistema informatico dell'USI grazie alle possibilità offerte dal collegamento diretto in fibra ottica. Ciò offre la possibilità di far capo a molti servizi universitari.

L'IRSOL è stato inserito nel testamento della signora Cele Daccò nel quale è previsto un generoso lascito destinato all'istituto. Ciò contribuirà all'ulteriore sviluppo dell' attività di ricerca, di conseguenza, per onorare la memoria dei benefattori, il nome dell'istituto verrà cambiato nel 2022 in: *IRSOL Istituto Ricerche Solari "Aldo e Cele Daccò"*.

Michele Bianda ha raggiunto l'età di pensionamento e si è trovata una soluzione per la continuità alla direzione dell'IRSOL grazie alla disponibilità di Svetlana Berdyugina, ora membro del direttorato, di assumere a tempo parziale la direzione scientifica dell'istituto. Vi è stato un riscontro positivo da parte dell'USI, dove le verrà assegnato il titolo di professore aggregato.

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 al 31 gennaio 2021) *

Dr. Luca Belluzzi (pure affiliato al KIS e all'Istituto Eulero)

Dr. Michele Bianda (pure affiliato all'Istituto Eulero)

Dr. Daniel Gisler

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

Dr. Gioele Janett (dal 1 luglio 2019, part time, pure affiliato all'Istituto Eulero) ***

Dr. Fabio Riva (dal 1 aprile 2020) **

Dr. Oskar Steiner (part time con il KIS)

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

Prof. Dr. Jan Olof Stenflo, emeritus ETHZ, 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_182094
*** 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 al 31 maggio 2021) **

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

Questi progetti di dottorato sono finanziati dal Fondo Nazionale.
* Direttore di tesi: Prof. Dr. Ravit Helled dell'Università di Zurigo
** Direttore di tesi: Prof. Dr. Georges Meynet dell'Università di Ginevra
*** Direttore di tesi: Prof. Dr. Rolf Krause, USI, Lugano

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 sul progetto Visible Tunable Filter (VTF) per il telescopio solare statunitense DKIST.

Collaborazione con la Scuola specializzata superiore di tecnica di Bellinzona, SSST

Abbiamo iniziato con la SSST una collaborazione che permette a studenti della scuola di svolgere all'IRSOL lavori di semestre e di diploma.

Alessio Banfi, stage: dal 16 agosto al 15 ottobre, diploma: dal 18 ottobre al 26 novembre

Simone Beretta, stage: dal 16 agosto al 15 ottobre, diploma: dal 18 ottobre al 26 novembre

Stages scientifici, lavori a tempo determinato

Elisa Gerli (dal 26 luglio al 22 agosto)

Anna Lettieri (dal 30 agosto al 14 settembre): stage nell'ambito del programma Estage

Giairo Mauro (dal 5 al 9 luglio e dal 19 al 30 luglio): stage nell'ambito del programma Estage

Francesco Vitali (dal 2 novembre al 31 dicembre)

Civilisti

Nel corso del 2021 hanno lavorato all'IRSOL:

Michel Basili (dal 12 luglio al 10 settembre)

Giulio Mazzaglia (dal 29 novembre al 31 dicembre)

Michele Moghini (dal 1 marzo al 28 maggio)

Ezio Ranzoni (dal 6 dicembre al 31 dicembre)

Christian Skorski (dal 25 gennaio al 19 febbraio)

Kilian Taddei (dal 19 luglio al 13 agosto)

RINGRAZIAMENTI

- **Ernest Alsina Ballester** Forse si può cominciare dalla conclusione: gli importanti risultati del suo lavoro sono stati pubblicati su *Physical Review Letters*, la prestigiosa rivista scientifica dell'American Physical Society. Ma non solo. L'articolo, infatti, è stato incluso tra gli highlights della rivista. Evidentemente siamo molto grati ad Ernest per quanto ha fatto dal punto di vista scientifico, come riportato in questo e nei passati rapporti annuali. Ciò che non emerge da questi rapporti è però la componente umana, e il significativo contributo che Ernest ha dato nel creare un ambiente collaborativo nel team dell'IRSOL. Ogni volta che gli si chiedeva qualche cosa la sua disponibilità e la sua reazione entusiasta e competente permetteva di risolvere il tema richiesto: da un semplice consiglio linguistico (approfittando del fatto che l'inglese è una delle sue madrelingue), alla richiesta seguire intere parti di un lavoro di dottorato. Il suo carattere riflessivo e buono è stato ampiamente apprezzato. Gli auguriamo una carriera brillante che gli permetta di mettere a frutto i suoi grandi talenti.

- **Emilia Capozzi** Siamo particolarmente lieti di poterci congratulare con Emilia Capozzi per il suo eccellente lavoro. Il 18 giugno, a Ginevra, ha potuto difendere brillantemente la sua tesi e conseguire il titolo di dottore. La sua tesi, basata sul tema generale della misura di segnali di polarizzazione da diffusione, si è sviluppata su due principali temi di ricerca. Il primo faceva parte di un progetto strumentale che necessitava di misure estremamente precise e innovative da svolgersi a Tenerife con il telescopio GREGOR. La seconda parte della tesi si è incentrata sulla ricerca di evidenze osservative di un meccanismo fisico scoperto teoricamente poco tempo prima da Ernest Alsina Ballester nel corso della sua tesi, e sullo studio delle potenzialità diagnostiche di tale meccansimo. Emilia ha saputo districarsi in questo complesso percorso arrivando a ottimi risultati. Durante i quattro anni che ha trascorso all'IRSOL tutti hanno potuto apprezzare il suo buonumore e la sua simpatia, combinati a un'enorme tenacia.

OBITUARIO

- **Cele Daccò, 27 maggio 1919 - 3 agosto 2021†**

  Si è spenta in agosto la signora Cele Daccò. Rimandiamo alla pagina `https://www.usi.ch/it/feeds/16642` per informazioni più precise sulla sua vita e personalità. In questo obituario vorremmo ricordare il suo legame con l'IRSOL. Abbiamo avuto la fortuna di incontrarla nel 2010 all'IRSOL, accompagnata dal vice-presidente della FIRSOL, Dr. Avv. Fulvio Pelli, descrivendo la nostra attività ed intrattenendo una simpatica conversazione. Aveva sviluppato una visione positiva dell'IRSOL e del lavoro ivi sviluppato. Questa impressione si era tradotta in un supporto finanziario in periodi particolarmente difficili per il nostro istituto. L'IRSOL è stato ricordato nel suo testamento ed in segno di ringraziamento la fondazione in accordo con l'istituto ha deciso di ricordare lei ed il marito nel nome dell'istituto.

- **Sergio Cortesi, 21 agosto 1932 - 18 dicembre 2021†**

  Non è facile riassumere in poche righe quanto Sergio Cortesi ha fatto per lo sviluppo dell'astronomia a livello regionale ed oltre. Di formazione tecnica, nel 1957 era stato assunto alla Specola Solare a Locarno, stazione dell'Osservatorio federale di Zurigo, grazie alle sue esperienze maturate per interesse nel campo dell'astronomia amatoriale. Ciò che prima era un hobby diventava così la sua professione. L'entusiasmo per la divulgazione non lo lascerà mai. Fu uno dei fondatori della Società Astronomica Ticinese che generò il substrato culturale necessario alla costituzione dell'Associazione Specola Solare Ticinese, impegnatasi a che continuare l'attività della Specola, dopo la rinuncia dell'ETHZ nel 1980 al tipo di ricerca scientifica ivi svolta. Sergio Cortesi fu il ricercatore che permise la continuazione delle osservazioni, spedite da allora all'Osservatorio Reale di Bruxelles. L'importanza di questo lavoro è chiaramente emersa nel corso dell'ultimo decennio dagli studi sulla consistenza della serie delle osservazioni dell'attività solare basata sul conteggio delle macchie. È grazie all'esperienza acquisita nell'iniziativa che portò alla continuità della Specola Solare Ticinese che pochi anni dopo, nel 1984, le persone che si erano impegnate in questa operazione, dunque anche Cortesi, decisero di provare a garantire un futuro pure all'IRSOL. Il grande impegno che Sergio Cortesi ha dedicato alla divulgazione ha avuto un seguito. Difatti ha condiviso il fascino che provava per l'astronomia sia con persone oltre la pensione, sia con giovani alle prime esperienze scolastiche. Quanto abbia influito nel far 'scattare la scintilla' in ragazzi che avrebbero seguito una carriera scientifica non può essere calcolato, ma non si tratta di un fattore irrilevante. La sua dedizione al lavoro può essere riassunta ricordando che l'ultimo disegno da lui fatto è del 4 dicembre, pochi giorni prima di lasciarci. La sua personalità gentile e lucida fino alla fine ci mancherà.

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 work that is presently carried out at IRSOL, together with the results that have been obtained in the past year, is provided below.

3.1 Theoretical and numerical modeling of polarization signals

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

The work on the theoretical modeling of the enigmatic scattering polarization signal of the Na I D_1 line was successfully completed in 2020 and published in August 2021 in the journal *Physical Review Letters* [1]. Thanks to the development of a new radiative transfer (RT) code, which included a series of physical ingredients that were neglected in previous investigations, we could reproduce remarkably well some recent observations of the scattering polarization signal of the Na I D_1 line, finding that the best fit is obtained when a magnetic field of about 15 G is included in the modeling. This result provides a very convincing solution to the solar Na I D_1 paradox introduced in 1998, and opens a new window for exploring the elusive magnetic fields present in the lower chromosphere. A more detailed paper on this investigation is presently in preparation [2]. We recall that this work was one of the key objectives of the SNSF project "The magnetic sensitivity of strong chromospheric lines: from the CLASP experiments to the Na I D_1 paradox" (200021_175997). This project allowed us to offer a three-year post-doc position to Dr. Ernest Alsina Ballester (01.02.2018 – 31.01.2021).

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

Publications:
1. Alsina Ballester, E., Belluzzi, L., & Trujillo Bueno, J. 2021, *Solving the Paradox of the Solar Sodium D1 Line Polarization*, Phys. Rev. Lett., 127, 081101

2. Alsina Ballester, E., Belluzzi, L., & Trujillo Bueno, J. *The physical origin and the diagnostic potential of the scattering polarization signals of the Na I doublet*, ApJ [in prep.]

3.1.2 A new RT code for modeling scattering polarization in complex atomic models accounting for PRD effects

The investigation described in Sect. 3.1.1 required the development of a RT code suitable for modeling scattering polarization in a two-term atom with hyperfine structure (HFS), in the presence of arbitrary magnetic fields, and taking into account partial frequency redistribution (PRD) effects, due to both elastic collisions and the Doppler effect. In addition to enabling the modeling of the scattering polarization signals of various spectral lines of interest (see Sects. 3.1.1 and 3.1.3), this code allowed us to identify suitable approximations for modeling the scattering polarization wings of strong resonance lines, such as the Mg II h and k lines and the HI Ly-α line observed by the CLASP experiments (see Sect. 3.1.5). A paper describing the code in detail, and presenting such approximations was submitted to the journal *Astronomy & Astrophysics* in December 2021 and it was accepted in April 2022 [1].

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

Publications:
1. Alsina Ballester, E., Belluzzi, L., & Trujillo Bueno, J. 2022, *The transfer of polarized radiation in resonance lines with PRD, J-state interference, and arbitrary magnetic fields. A radiative transfer code and useful approximations*, A&A [accepted; https://arxiv.org/pdf/2204.12523.pdf]

3.1.3 Theoretical modeling of the polarization properties of the solar K I D-lines

Using the RT code mentioned in the previous section, we carried out a theoretical investigation aimed at identifying the most relevant physical mechanisms shaping the polarization signals of the K I D-lines, and at analyzing their magnetic sensitivity. Indeed, the modeling of these signals requires taking the HFS of potassium into account. These lines are receiving increasing attention because they will be soon observed through the SUNRISE-3 experiment (scheduled for June 2022). This investigation was carried out between 2020 and 2021. A paper collecting the results will be submitted shortly (possibly before the flight of SUNRISE-3) [1].

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

Publications:
1. Alsina Ballester, E. *The polarization signals of the solar K I D-lines and their magnetic sensitivity*, A&A [in prep.]

3.1.4 The magnetic sensitivity of the scattering polarization wings of Ca I 4227

After acquiring compelling observational evidence for the operation of magneto-optical (MO) effects on the scattering polarization wings of the Ca I 4227 Å line (Capozzi et al. 2020, A&A, 641, A63), we explored the potential of this mechanism for magnetic field diagnostics. It is well known that both the Zeeman and MO effects arise from the longitudinal component of the magnetic field, and that the former is only sensitive to the magnetic flux. This investigation, based on a series of RT calculations, highlighted that, contrary to the Zeeman effect, the impact of MO effects depends also on the fraction of the resolution element occupied by the magnetic field (or its filling factor). This points out the possibility of exploiting this new mechanism, and in particular the rotation of the linear polarization plane that it produces, in order to investigate unresolved magnetic fields. This work was carried out between 2020 and 2021, within the framework of the PhD thesis of Dr. E. Capozzi (thesis successfully defended in June 2021). The results were collected in a paper [1], which was submitted to *Astronomy & Astrophysics* in 2021 and published at the beginning of 2022.

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

Publications:
1. Capozzi, E., Alsina Ballester, E., Belluzzi, L., & Trujillo Bueno, J., 2022 *The polarization angle in the wings of Ca I 4227: A new observable for diagnosing unresolved photospheric magnetic fields*, A&A, 657, 44

3.1.5 The CLASP experiments

On October 8, 2021, the "Chromospheric Layer SpectroPolarimeter" (CLASP2.1) sounding rocket experiment was successfully carried out from the NASA facility at the White Sands Missile Range in New Mexico (USA). This was the third experiment of a series started in 2015. The first two experiments, CLASP (2015) and CLASP2 (2019), provided unprecedented spectropolarimetric observations of the H I Ly-α line at 1215 Å and of the Mg II h and k lines at 2800 Å, respectively. CLASP2.1 was a reflight of CLASP2 aimed at obtaining a map of the polarization across the Mg II h and k lines, by scanning a selected active region. The reduction of the CLASP2.1 data is presently ongoing.

The analysis and interpretation of the data acquired by the CLASP experiments continued during 2021. In 2020, the CLASP2 team exploited part of the CLASP2 data to obtain a map of the magnetic field from the photosphere to the base of the corona. This study was published in 2021 in the journal *Science Advances* [1], and presented in a meeting of the American Astronomical Society [2], receiving attention and appreciation by the community. The same team carried out another investigation in order to verify the polarization accuracy of CLASP2 and estimate the response matrix of the instrument. This was done by combining the pre-flight calibration data with the in-flight calibration (performed pointing the solar disc center). This analysis confirmed that the required polarization accuracy of 0.1% at the 3σ level was in fact achieved by CLASP2. This work was recently submitted to the journal *Solar Physics* [3]. Furthermore, a work focused on the analysis of the center-to-limb variation (CLV) of the scattering polarization signal observed by CLASP2 across the Mg II h and k lines was carried out in 2021. This study showed a very good qualitative agreement between the observational data collected by CLASP2 and the theoretical predictions. A paper collecting the results of this work is presently in preparation [4]. At IRSOL we continued working on the interpretation of the CLASP data with specific focus on the magnetic sensitivity, via MO effects, of the frequency-integrated scattering polarization signal of H I Ly-α, observed by the slit-jaw system of both CLASP and CLASP2. Such broad-band linear polarization signals are dominated by the contribution from the line wings, and are thus strongly sensitive to MO effects. Our preliminary results show that by making reasonable assumptions on the large-scale distribution of magnetic fields in the chromosphere, the two-dimensional (2D) images captured by the slit-jaw system can be satisfactorily reproduced. The results of this work are being collected in a paper [5].

We recall that the CLASP experiments are the result of an international cooperation between USA, Japan, and various European institutes. Dr. Belluzzi is team member of the three CLASP experiments, while Dr. Alsina Ballester is team member of CLASP2 and CLASP2.1. The participation of IRSOL to the CLASP experiments was first supported by the SNSF project "The magnetic sensitivity of strong chromospheric lines: from the CLASP experiments to the Na I D1 paradox" (200021_175997) and then by the ongoing SNSF Sinergia project "HPC-techniques for 3D modeling of resonance line polarization with PRD" (CRSII5_180238).

Researchers involved:
IRSOL: L. Belluzzi, E. Alsina Ballester
External: the CLASP team (USA, Japan, Europe)

Publications:
1. Ishikawa, R. et al. (27 co-authors, the CLASP2 team) 2021, *Mapping Solar Magnetic Fields from the Photosphere to the Base of the Corona*, Sci. Adv., 7, 8
2. McKenzie, D. et al. (26 co-authors, the CLASP2 team) 2021, *Mapping of Solar Magnetic Fields from the Photosphere to the Top of the Chromosphere with CLASP2*, Bulletin of the American Astronomical Society, 53, 106
3. Song, D. et al. (27 co-authors, the CLASP2 team), *Polarization Accuracy Verification of Chromospheric LAyer SpectroPolarimeter*, Sol. Phys. [submitted]
4. Rachmeler, L. A. et al. (14 co-authors) *Quiet Sun Center to Limb Variation of the Linear Polarization Observed by CLASP2 Across the Mg* II *h & k Lines*, ApJ [in prep.]
5. Alsina Ballester, E., Belluzzi, L., & Trujillo Bueno, J., *Signatures of magneto-optical effects in the CLASP broadband linear polarization signals*, ApJ [in prep.]

3.1.6 3D modeling of scattering polarization with angle-dependent PRD effects

A series of important results and milestones were achieved in 2021 concerning the development and application of novel numerical methods and computational tools tailored for the modeling of scattering polarization in strong resonance lines, accounting for angle-dependent (AD) partial frequency redistribution (PRD) effects. This activity is carried out within the framework of the SNSF "Sinergia" project "HPC-techniques for 3D modeling of resonance line polarization with PRD" (CRSII5_180238), which is based on a close cooperation between three research groups (from IRSOL, the Euler institute of USI, and IAC) with complementary competences and expertise in solar spectropolarimetry, radiative transfer, and computational sciences. The results obtained during the last year paved the way to the final goal of the project, namely to model scattering polarization with AD-PRD effects in realistic three-dimensional (3D) models of the solar atmosphere. Using a code developed in 2020, we modeled the intensity and polarization profiles of the Ca I 4227 Å line, by solving the full NLTE RT problem for polarized radiation in 1D semi-empirical models of the solar atmosphere, taking AD-PRD effects into account. We considered a two-level atomic model in the presence of magnetic fields of arbitrary intensity and orientation. This work clearly highlighted that the so-called *angle-averaged* approximation, which is commonly considered in order to reduce the computational complexity of describing PRD effects, introduces artifacts in the scattering polarization profiles, especially in the line-core region [1]. Meanwhile, through a close cooperation between the groups at IRSOL and the Euler institute, a new algebraic formulation of the problem, particularly convenient for implementing powerful linear algebra tools and solution methods, was proposed. Exploiting this formulation, it was possible to analyze the stability and convergence properties of the standard stationary iterative methods, in combination with different methods for the solution of the RT equation for polarized radiation (i.e., formal solvers). Moreover, it allowed us to easily implement and analyze Krylov solution methods, which showed to clearly outperform stationary iterative methods. The GMRES method revealed to be particularly efficient for our problem, especially when applied with an innovative preconditioner, developed in a multi-fidelity framework and tailored for the considered AD-PRD problem. These methods are presently implemented in two 1D codes written in C and Matlab, respectively. The results of these investigations were collected in a series of three papers ([2], [3], [4]), two published in 2021 and one submitted in 2021 and accepted in 2022. In parallel, MSc. S. Riva continued his PhD work focusing on the optimization of the algorithm for computing the emission coefficient (his routine is implemented in the aforementioned C code), and carried out an investigation aimed at a quantitative analysis on the accuracy of the approximation of complete frequency redistribution (CRD) in the observer's frame for the treatment of the R_{III} redistribution matrix [5]. During the last part of 2021, we started the following studies, which are presently ongoing: a) by exploiting the aforementioned codes, we are performing a detailed analysis of the impact of bulk velocities on the scattering polarization signal of the Ca I 4227 Å line [6]; b) we are implementing the angle-averaged approximation in the Matlab code (this work is carried out taking advantage of the activity of MSc. G. Mazzaglia, who started in December 2021 a 6-months civil service period at IRSOL/USI); c) we are generalizing the Matlab code in order to consider a two-term atomic model; d) we are extending the C code to the 3D case.

Researchers involved:

IRSOL: L. Belluzzi, N. Guerreiro, G. Janett, S. Riva, E. Alsina Ballester

Sinergia partners: R. Krause (Euler institute, USI, Lugano), P. Benedusi (Euler institute, USI, Lugano), J. Trujillo Bueno (IAC, Spain), A. Sukhorukov (IAC, Spain), J. Štěpán (ASCR, Czech Republic)

Publications:

1. Janett, G., Alsina Ballester, E., Guerreiro, N., Riva, S., Belluzzi, L., del Pino Alemán, T., & Trujillo Bueno, J. 2021, *Modeling the scattering polarization of the solar Ca I 4227 Å line with angle-dependent partial frequency redistribution*, A&A, 655, A13

2. Janett, G., Benedusi, P., Belluzzi, L., & Krause, R. 2021, *Numerical solutions to linear transfer problems of polarized radiation. I. Algebraic formulation and stationary iterative methods*, A&A, 655, A87

3. Benedusi, P., Janett, G., Belluzzi, L., & Krause, R. 2021, *Numerical solutions to linear transfer problems of polarized radiation. II. Krylov methods and matrix-free implementation*, A&A, 655, A88

4. Benedusi, P., Janett, G., Riva, S., Krause, R., & Belluzzi, L. 2022, *Numerical solutions to linear transfer problems of polarized radiation. III. Parallel preconditioned Krylov solver tailored for modeling PRD effects*, A&A [accepted]

5. Guerreiro, N., Janett, G., Riva, S., Benedusi, P., & Belluzzi, L. *The impact of bulk velocity fields on the scattering polarization pattern of the Ca I 4227 Å line* [in prep.]

6. Riva, S., Guerreiro, N., Janett, G., Benedusi, P., Krause, R., & Belluzzi, L. *The impact of angle-dependent*

Doppler redistribution on the R_{III} redistribution matrix [in prep.]

3.2 Magnetohydrodynamic Simulations of the Solar and Stellar Atmospheres

3.2.1 The Alfvénic nature of chromospheric swirls

We finalized the analysis of numerical simulations of the solar atmosphere with regard to vortical motions and their dynamics. For the analysis, we made use of the swirling strength and its dynamical equation, which we previously derived from the fundamental equations of magnetohydrodynamics (Canivete Cuissa & Steiner, 2020).

We could show that swirls propagate upward with the local Alfvén speed as unidirectional pulses driven by magnetic tension forces alone. In the photosphere and low chromosphere, the rotation of the plasma co-occurred with a twist in the upwardly directed magnetic field that was in the opposite direction of the plasma flow. All together, these findings indicated clear characteristics of torsional Alfvén waves. Yet, the Alfvén wave was not oscillatory but took the form of a unidirectional pulse. New in this work was that these Alfvén pulses naturally and self-consistently emerged from realistic numerical simulations of the solar atmosphere and needed not to be artificially excited. At the base of the chromosphere, we found a mean net upwardly directed Poynting flux of $12.8 \pm 6.5\,\mathrm{kW\,m^{-2}}$, which was mainly due to swirling motions. For a comparison, the energy flux needed to compensate the radiative losses in the chromosphere is $4.3\,\mathrm{kW\,m^{-2}}$. We presented these novel results in various scientific online and in person meetings to the interested scientists.

Researchers involved:

IRSOL: A. Battaglia, J.R. Canivete Cuissa, O. Steiner
External: A.A. Bossart (EPFL, Lausanne), F. Calvo (Univ. Stockholm)

Publications:

Battaglia, A.F., Canivete Cuissa, J.R., Calvo, F., Bossart, A.A., and Steiner, O.: 2021, A&A 649, A121

3.2.2 An innovative automated method for vortex identification

An unambiguous and rigorous method for the identification of vortices in fluid flows has not been found yet. Such a method would be necessary to conduct robust statistical studies on vortices in highly dynamical and turbulent systems, such as the solar atmosphere. We now developed an innovative and robust automated method for vortex identification. Local and global characteristics of the flow are taken into account as both are necessary for the realization and detection of coherent vortical structures. This method combines the rigor of mathematical criteria and the global perspective of morphological techniques. The core of the method is the estimation of the center of rotation for every point of the flow that presents some degree of curvature in its neighborhood. For that, we employ the Rortex criterion and the morphology of the local velocity field. We then identify coherent vortical structures by clusters of estimated centers of rotation.

We demonstrated that the Rortex is the most reliable criterion for the extraction of physical information from vortical flows and that the method works perfectly on a simplistic vortex model. We combine the proposed method with a state-of-the-art clustering algorithm to build an automated vortex identification algorithm. The algorithm was applied to artificial velocity fields composed of multiple Lamb-Oseen vortices and a random noisy background. The results demonstrate the reliability and accuracy of the method. The Python implementation of the algorithm was made publicly available at `https://github.com/jcanivete/swirl`.

Our automated vortex identification method can be considered a new tool in the detection and study of vortices in highly dynamical and turbulent flows. By applying the implemented algorithm to numerical simulations and observational data, and by comparing it to existing detection methods, we plan to improve the reliability of the detections and, ultimately, our knowledge on swirling motions in the solar, stellar, and planetary atmospheres.

Researchers involved:

IRSOL: J. R. Canivete Cuissa, O. Steiner

Publications:

Canivete Cuissa, J.R. and Steiner, O.: A&A submitted

3.2.3 Vortex motions in the solar atmosphere

Vortex motions and flows are ubiquitous on the solar surface and in the atmosphere above. Their presence is revealed in high-resolution and high-cadence solar observations from the ground and from space and in state-of-the-art magnetoconvection simulations. They extend over different layers of the solar atmosphere, potentially enabling the channeling and transfer of mass, momentum and energy from the solar surface up to the low corona. As part of an international team of the International Space Science Institute (ISSI) in Bern, we have contributed to a comprehensive review of documented research and new developments in theory, observations, and modelling of vortices over the past couple of decades. This is the first systematic overview of solar vortex flows at granular scales. The review timely addresses the state-of-the-art on vortex flows and outlines both theoretical and observational future research directions.

Researchers involved:

IRSOL: O. Steiner and J.R. Canivete Cuissa
External: K. Tziotziou (NOA Athens), E. Scullion (Northumbria Univ,), S. Shelyag (Australia) and 10 more.

Publications:

Tziotziou, K., Scullion, E., Shelyag, S., Kohomenko, E., Tsiropoula, G., Steiner, O., Wedemeyer, S., Canivete Cuissa, J.R., Kontogiannis, I., Yadav, N., Kitiashvili, I.N., Skirvin, S.J., Dakanalis, I., Kosovichev, A.G., and Fedun, V.: 2022, Space Science Review, submitted

3.2.4 Acoustic-gravity wave propagation characteristics

Over the past several decades, tremendous progress has been achieved in the degree of realism of three-dimensional radiation magneto-hydrodynamic simulations of the solar atmosphere. Four of the most frequently used numerical codes are Bifrost, CO5BOLD, MANCHA3D, and MURaM. We tested and compared the wave propagation characteristics in model runs from these four codes by measuring the dispersion relation of acoustic-gravity waves at various heights. We found considerable differences between the various models and unexpected features in the the phase difference spectra. However, the models computed with the different codes were very different in size and spatial and spectral resolution. To shed light on these discrepancies, we have carried out a new benchmark study, using a common simulation box for the four simulation codes with boundary conditions as similar as possible. The thorough analysis and comparison of these models is still in work.

Researchers involved:

IRSOL: F. Riva, O. Steiner
External: B. Fleck (ESA), M. Carlsson (RoCS, Univ. Oslo), E. Khomenko (IAC, Tenerife), M. Rempel (HAO, Boulder), G. Vigeesh (KIS, Freiburg)

Publications:

Fleck, B., Carlsson, M., Khomenko, E., Rempel, M., Steiner, O., and Vigeesh, G.: 2021, Phil. Trans. R. Soc. A 379:20200170

3.2.5 Towards fully compressible numerical simulations of stellar magneto-convection with the RAMSES code

We conducted a proof-of-concept for the realization of three-dimensional, fully compressible, magneto-hydrodynamical numerical simulations of stellar interiors with the RAMSES code. We adapted the RAMSES code to deal with highly subsonic turbulence, typical of stellar convection, by implementing a well-balanced scheme in the numerical solver. We then ran and analyzed three-dimensional hydrodynamical and magneto-hydrodynamical simulations with different resolutions of a plane-parallel convective envelope on a Cartesian grid. Both hydrodynamical and magneto-hydrodynamical simulations developed a quasi-steady, turbulent convection layer from random density perturbations introduced over the initial profiles. The convective flows were characterized by small-amplitude fluctuations around the hydrodynamical equilibrium of the stellar interior, which was preserved over the whole simulation time. Using our compressible well-balanced scheme we were able to model flows with Mach numbers as low as $\mathcal{M} \sim 10^{-3}$, but even lower Mach number flows are in principle possible. In the magneto-hydrodynamical runs, we observed an exponential growth of magnetic energy consistent with the action of a small-scale dynamo. The weak seed magnetic fields were amplified to mean strengths of 37% relative to the kinetic equipartition value in the highest resolution simulation. Since we have choosen a compressible approach, we saw imprints of pressure and internal gravity waves propagating in the stable regions above and beneath the convection zone. In the magneto-hydrodynamical case, we measured a deficit in acoustic and internal gravity wave power with respect to the purely hydrodynamical counterpart of 16% and 13%, respectively.

The well-balanced scheme implemented in RAMSES allows us to accurately simulate the small-amplitude, turbulent fluctuations of stellar (magneto-)convection. The qualitative properties of the convective flows, magnetic fields, and excited waves are in agreement with previous studies in the literature. The power spectra, profiles and probability density functions of the main quantities converge with resolution. Therefore, we consider the proof-of-concept as successful. The deficit of acoustic power in the magneto-hydrodynamical simulation shows that magnetic fields must be included in the study of pressure waves in stellar interiors. We concluded the publication by discussing future developments.

Researchers involved:

IRSOL: J. R. Canivete Cuissa
External: R. Teyssier (Princeton University)

Publications:

Canivete Cuissa, J.R. and Teyssier, R.: A&A submitted

3.2.6 MPI parallelization of CO^5BOLD and implementation of new I/O routines

High-resolution realistic simulations of the solar and stellar atmospheres require good parallel scalability of the simulation code, typically up to thousands of cores. Therefore, we finalized the MPI parallelization of the LCFrad module, used to solve the radiative transfer equation in CO^5BOLD. We optimized as much as possible the efficiency of the code on a multi-node high performance system such as the supercomputer Piz Daint at CSCS. This task also allowed us to find and correct a few minor bugs present in the code.

While carrying out this parallelization, it emerged the necessity of adapting the I/O routines of CO^5BOLD to enable a parallel access to the model files used to start and save the overall results of a simulation. This should avoid loading all the data on a single core and then communicating them to the other processes. This was particularly important for very large simulations, which otherwise would not fit into the virtual memory of a single processor. To overcome this issue, we implemented a new set of I/O routines based on the HDF5 format.

Thanks to these modifications, we were able to submit a proposal to CSCS for an allocation of 200 000 node hours on Piz Daint, which was accepted with rather enthusiastic comments and without any cut in computational resources. This was a critical task to carry on with our scientific activities of investigating small-scale dynamo action in solar and stellar atmospheres.

Researchers involved:

IRSOL: F. Riva, O. Steiner

3.2.7 Methodology for estimating the magnetic Prandtl number and application to solar surface small-scale dynamo simulations

As the discretisation of an MHD model and its implementation in a simulation code always introduces numerical errors in the system, which in turn add numerical viscosity and magnetic diffusivity to the model equations, a crucial step in the study of small-scale dynamos is a reliable evaluation of the effective magnetic Prandlt number, Pr_{m}, stemming from numerical simulations. In this respect, we developed a methodology, based on the method of Projection on Proper elements of Cartier-Michaud et al. (2016, 2020), to estimate the effective numerical viscosity and magnetic diffusivity that characterize an MHD simulations. This provides us with a way to evaluate Pr_{m} in a post-process step.

First, the numerical error affecting the simulation is estimated using different, higher order accuracy, numerical operators than the ones used in the simulation code to post-process the simulation results. Then, it is assumed that the resulting numerical error can be, at least partially, modeled with a diffusion operator. The numerical diffusivities are finally computed through a least square fit.

The proposed methodology was then applied to a number of small-scale dynamo simulations of the solar atmosphere carried out with the CO^5BOLD code, with the aim of characterising the magnetic energy growth rate and the saturated magnetic field in terms of the Reynolds and magnetic Reynolds numbers of the plasma flow. The results of this study were submitted to the peer reviewed scientific journal Astronomy & Astrophysics, where it recently appeared as publication.

Researchers involved:

IRSOL: F. Riva, O. Steiner

Publications:

Riva, F. and Steiner, O.: 2022, A&A, 660, A115

3.2.8 Small-scale dynamo action in the atmosphere of cool main-sequence stars

The origin of the ubiquitous small-scale magnetic field observed on the solar surface is generally linked to the presence of a small-scale dynamo (SSD) operating in the sub-surface layers of the Sun. To shed light on the functioning of this SSD, a number of numerical studies of a realistic solar atmosphere have been carried out in the past two decades, greatly improving our knowledge on how an SSD operates. Nevertheless, virtually no studies exist on SSD action on the surface of other main-sequence stars.

Therefore, starting from the model sequence of Salhab et al. (2018), we are currently carrying out a set of hydro and magneto-hydrodynamics simulations of a small partial volume encompassing the surface layers of F5V, G2V, K2V, and K8V main-sequence stars with CO^5BOLD, investigating how SSD action can amplify a tiny seed magnetic field. In particular, we plan to characterize the growth rate of the magnetic to kinetic energy ratio in terms of the Reynolds and magnetic Reynolds numbers of the simulations, and of the effective temperature and surface gravity of each star. Ultimately, we would like to investigate the spatial structure of the magnetic field resulting from SSD action and how it interacts with the plasma in the stellar atmospheres.

Researchers involved:

IRSOL: F. Riva, O. Steiner

3.3 Observational projects

3.3.1 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. 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 that has been previously applied successfully to measure the continuum polarization (Berdyugina, Gisler et al., in prep.). The goal of the project is to further develop the method for all kinds of observations where the determination of the absolute polarization value with highest accuracy is important, also for large aperture solar telescopes.

In the first phase of this project, the 45 cm Gregory telescope in Locarno at IRSOL was used as a test environment for the device performing the slow modulation necessary to correct for most systematic errors and allowing for enhanced accuracy in spectropolarimetric measurements (called TCU). For these results a paper will be published in summer 2022 in SPIE Astronomical Telescopes and Instrumentation.

The second phase focuses on the application of the measurement technique to the 1.5 m GREGOR solar telescope on Tenerife, Spain. For this aim, IRSOL in co-operation with KIS build a new measurement instrument, the GREGOR Slow Polarization Modulator (GSPM). Its position within the optical train was determined by the requirement to be placed before any inclined mirror and its size to allow the optical components to be purchased from stock. Unlike in the case of the IRSOL telescope, where the TCU could be placed in front of the telescope aperture, it is not possible to place any optical element in front of the GREGOR telescope aperture. This resulted in a position of the GSPM close to the second focus of the GREGOR telescope, before the polarization calibration unit. This allowed a smaller aperture of the GSPM than the TCU, which in turn allowed us to use optical components with better quality compared to the film used for the almost ten times more larger TCU. At the same time, a sufficient distance to the focal plane is required to avoid thermal damage of the optical components. Like the TCU, we also used here a zero-order retarder to perform the slow modulation.

In a technical campaign of ten days from 22nd of September to 1st of October, the GSPM was successfully tested at the GREGOR telescope. We tested two types of retarders: crystal and polymer based. We find that both are very efficient in correcting the spectropolarimetric measurements, and at the end of the campaign none of them showed signs of thermal destruction. We especially demonstrated that measurements in selected scientifically important spectral lines in the visible (i.e. 450 - 650 nm) show significantly reduced fringes by the FLC modulator and reduced polarimetric offsets. These main errors complicated the analysis of previous measurements at the GREGOR telescope with the ZIMPOL system. Additionally, we were able to demonstrate the functionality of the GSPM in combination with the adaptive optics system of GREGOR, which is crucial if future scientific measurements where high spatial resolution is required. The results of this campaign will be used in the last report for the SOLARNET project, due at the end of 2022, as well as a technical paper which will be prepared.

For 2022, we plan scientific observations with ZIMPOL using the technique at GREGOR.

Researchers involved:

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

Publications:

[1] Zeuner, F., Gisler, D., Ramelli, R. & Bianda, M. , SPIE [in prep.]

3.3.2 Hanle rotation signatures in scattering polarization

On the 11th of August in 2021 IRSOL performed an observation of Hanle rotation signatures in the Sr I line at 4607 Å using the ZIMPOL system. The observation was made possible by using the novel measurement technique based on slow modulation developed within the SOLARNET project (see Sect. 3.3.1), and clearly shows the great potential of this technique. The Hanle rotation signatures substantiated in a linear polarization signal whose direction differs from the solar limb tangent. The signals are found to be very small and with negative and positive sign, thereby requiring high sensitivity spectropolarimetric observations as well as a well determined absolute polarization level. Both was achieved by combining the fast modulation of ZIMPOL combined with the novel slow modulation technique, and a long integration time needed to achieve the required signal-to-noise ratio for the detection.

A publication of this finding is accepted for publication in A&A.

In a future work, a close collaboration with the theoretical group of IRSOL aims to interpret the observations through detailed radiative transfer calculations. In the modeling process it will be necessary to simultaneously include a turbulent magnetic field and a deterministic field, needed to interpret the signatures of Hanle rotation. At the same time, the model is supposed to have the lowest number of free parameters possible, in order to allow for some kind of a fitting process of the model to the data. The numerical codes for this problem are available, but need to be adjusted and tested for this particular problem.

Researchers involved:

IRSOL: F. Zeuner, L. Belluzzi, N. Guerreiro, M. Bianda, R. Ramelli

Publications:

[1] Zeuner, F., Belluzzi, L., Guerreiro, N., Ramelli, R. & Bianda, M. *Hanle rotation signatures in the Sr* I *4607 Å line*, A&A [accepted]

3.3.3 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 C2 molecular lines around 514.0 nm, generally taken every month. Our results now span more than a complete solar cycle. In 2021 observations have been mainly done with the TCU device (see Sect. 3.3.1), to strongly reduce the systematic errors in the absolute measurement of the polarization signals. Since November 2021 F. Vitali analysed the new data since 2017, and applied a consistent data reduction pipeline to the full data set. He was able to complete the first version of the reduction and to calculate the peak ratios time evolution (data ranging from 2010 to 2021). F. Vitali summarized the results of his work in a report provided to IRSOL in February 2022.

Researchers involved:

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

External: S. Berdyugina (KIS)

Internship: F. Vitali

3.4 Miscellaneous, science

3.4.1 Exoplanet science with intensity interferometry

José Roberto Canivete Cuissa worked on a project on intensity interferometric techniques lead by Prof. Dr. P. Saha at the Institute for Computational Science (UZH) and that already lead to a publication.

While the transit method has been a fruitful technique for detecting exoplanets, it is not suited for spatially resolving their features. The largest exoplanets detected have angular sizes of < 0.1 mas, far below the spatial resolution limits of modern telescopes. Some transiting hot Jupiters show evidence of lopsided structures on scales of order 10 μas: asymmetric atmospheric molecular abundances and very strong zonal winds reaching up to orders of $\sim 10\,\mathrm{km/s}$. Imaging such features is beyond the limits of conventional imaging techniques. However, intensity interferometry, a technique that involves spatially cross-correlating the photons from pairs of telescopes, offers the prospect of angular resolution on such scales at optical wavelengths. In the optical band around wavelengths of 350 nm, it can achieve resolutions of < 10 μas, in the near-infrared band around wavelengths of 1050 nm, it can achieve resolutions of < 30 μas, with a telescope baseline of 5 km. Suggestively, the former range overlaps with the iron absorption lines in WASP-76b, a hot-Jupiter that has an asymmetric atmospheric iron abundance. The latter overlaps with the He I triplet line in HD 189733b, a hot-Jupiter that has an evaporating atmosphere. We explore the prospects of detecting such hot-Jupiter features using various telescope combinations like the next-generation atmospheric Cherenkov telescopes, the Very Large Telescope (VLT) and the Extremely Large Telescope (ELT). We calculate the interferometric signal from the above exoplanets and their asymmetric atmospheric features using these setups.

Researchers involved:

IRSOL: J. R. Canivete Cuissa

External: S. Baumgartner, M. Bernardini, H. de Laroussilhe, A. M. W. Mitchell, B. A. Neuenschwander, P. Saha, T. Schaeffer, D. Soyuer, L. Zwick (University of Zürich)

Publications:

L. Zwick, D. Soyuer, T. Schaeffer, P. Saha, B. A. Neuenschwander, A. M. W. Mitchell, H. de Laroussilhe, J. R. Canivete Cuissa, M. Bernardini, and S. Baumgartner, A&A, in prep.

3.4.2 The Effect of Stellar Contamination on Space-based Transmission Spectroscopy

O. Steiner participated in the Study Analysis Group 21 (SAG21) of the Exoplanet Exploration Program Analysis Group (Exo-PAG) of NASA's Exoplanet Exploration Program. It has been organized to study the effect of stellar contamination on space-based transmission spectroscopy, a method for identifying the atmospheric composition of an exoplanet by measuring a wavelength-dependent radius of a planet as it transits its star.

Researchers involved:

IRSOL: O. Steiner

External: SAG21 team

Publications:

Rackham, B.V., Espinoza, N., Berdyugina, S.V. and 58 more including O. Steiner: 2022, *The Effect of Stellar Contamination on Space-based Transmission Spectroscopy*, https://arxiv.org/abs/2201.09905

3.5 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 2021, 284 sunspot drawings were made; the drawings and the calculated Wolf number can be found 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.

In the framework of this project a sunspot group database has been published online in 2021 on https://sunspots.irsol.usi.ch and covers the period 1981 to now. The needed works on the WEB interface have been completed by the civilist Christian Skorski.

In the meantime Marco Cagnotti is completing the database with the data available on the sunspot drawings made at Specola from 1957 to 1980 and recently digitized at the ETH Zurich library. In the year 2021, the database was filled with the data from 1963 to 1972. The publication of these data is foreseen in 2022 when the database will be completed.

Researchers involved:

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

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

3.6 Education

3.6.1 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 (see 8.4).

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 (https://www4.ti.ch/can/oltreconfiniti/dal-1990-a-oggi/estage/). This year two students participated to the project.

Support for observations was provided for the matura-work of Birgitta Zahner at Kantonsschule Wattwil. The work was awarded between the best final works at the Wattwill school.

With “L’ideatorio”, Università della Svizzera italiana, we re-submitted an Agorà proposal to SNF under the title ”the Sun: our star” for a communication project to be carried out from September 2022 to August 2024. The project has been accepted and will be funded.

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 ZIMPOL camera redesign at SUPSI

The ZIMPOL system is mainly used for measurements with a high polarimetric resolution. The current ZIMPOL3 camera has some limitations in collecting photos per time that finally limits the polarimetric resolution for all measurements. Therefore to further improve the polarimetric resolution it is required to overcome this limitation.

In 2021 we started again a collaboration with SUPSI for the ZIMPOL3 camera development. SUPSI studied the current status of the camera. Their conclusion was that with the current old electronics a significant improvement will not be possible. Therefore we decided to redesign a part of the camera which will be done in two steps. The first step is a redesign of the digital electronics in the camera with state of the art devices and development methodologies. The current camera logic and software will then be migrated to the new electronics. This work has started in September 2021 and should be finished by end of 2022. In the second step all the camera logic and software will be redesigned too and should finally increase the camera performance.

4.1.2 Instrument software

The instrument software 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 continuously improved and optimized for the actual research topics.

In 2021 the automatic positioning system for measurement close to the solar limb has been improved. The system is now faster and more precise but also allows automatic measurement with the spectrograph slit perpendicular to the limb. These improvements are important for current and future synoptic programs (see 3.3.3).

4.2 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 construction at KIS, and on-site installation and commissioning is planned for 2023. 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.

4.3 Preparing the instrumental upgrade of the telescope

Several improvements are needed, but before to proceed a clear work plan has to be prepared. In 2021 this work was started including the contribution of ing. Michele Moghini.

4.4 Collaboration with SSST, Bellinzona

We stsrted a collaboration with the technical school SSST - Scuola Specializzata Superiore di Tecnica - Bellinzona. The aim is offering to students of the school the opportunity of performing practice and diploma works at IRSOL.

Two students took this opportunity, one realized a mechanical device for the Fabry Perot system that is combined with the spectrograph. At the entrance of the spectrograph a slit has to be alternated with a variable aperture, and the device was constructed by Simone Beretta. The second student, Alessio Banfi, researched a solution to construct a basic controller for controlling the spectrograph and the adjustment devices correlated with it. He could also start with the hardware. The continuation of this work was given to Ezio Ranzoni, who will conclude it in 2022.

4.5 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 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 to the central server at University of Applied Sciences (FHNW) in Brugg/Windisch.

In 2021 sixteen new spectrometers as part of the e-Callisto network have been delivered commissioned to the following locations: Indian Institute of Astrophysics (Bangalore/India), Malaysian Space Agency (Kebangsaan/Malaysia), Boscha Observatory (Jakarta/Indonesia), Deutsche Luft- und

Raumfahrt DLR (Neustrelitz/Germany), Egypt Space Agency (Cairo/Egypt), Udaipur Solar Observatory (Udaipur/India), University of Alcalá (Alcalá/Spain) and Istituto Nazionale Di Astrofisica INAF (Triest/Italy). Currently, the network is hosting 192 instruments worldwide whereas on average 70 instruments provide real-time data to the central server. In 2021 the network reported a total of 1024 dynamic solar radio bursts, based on 4666 host-observations. These and previous observations finally led to 9 publications as given below.

Researchers involved:

IRSOL: C. Monstein

Publications:

Marassi, Alessandro; Monstein, Christian Advances in Space Research, 2021, ISSN: 0273-1177.

Ndacyayisenga, T.; Umuhire, A. C.; Uwamahoro, J.; Monstein, C. Annales Geophysicae, vol. 39, no. 5, pp. 945–959, 2021.

Kharayat, Hema; Joshi, Bhuwan; Mitra, Prabir K; Manoharan, P K; Monstein, Christian Solar Physics, vol. 296, pp. 99, 2021.

Joshi, Bhuwan; Mitra, Prabir K; Bhattacharyya, R; Upadhyay, Kushagra; Oberoi, Divya; Raja, K Sasikumar; Monstein, Christian Solar Physics, vol. 296, no. 6, pp. 85, 2021.

Kouloumvakos, Athanasios; Rouillard, Alexis; Warmuth, Alexander; Magdalenic, Jasmina; Jebaraj, Immanuel. C; Mann, Gottfried; Vainio, Rami; Monstein, Christian Astrophysical Journal, vol. 913, no. 2, pp. 99, 2021.

Ndacyayisenga, Theogene; Uwamahoro, Jean; Raja, K Sasikumar; Monstein, Christian Advances in Space Research, vol. 67, no. 4, pp. 1425-1435, 2021.

AC Umuhire, J Uwamahoro, KS Raja, A Kumari, C Monstein Advances in Space Research 68 (8), 3464-3477

WZA Wan Mokhtar, ZS Hamidi, ZZ Abidin, ZA Ibrahim, C Monstein Indian Journal of Physics 95 (6), 1051-1060

M Lv, Y Chen, V Vasanth, MS Radzi, ZZ Abidin, C Monstein Solar Physics 296 (2), 1-24

Note: detailed information about publications can be found here:

https://scholar.google.com/citations?hl=en&user=tng5MV8AAAAJ&view_op=list_works&sortby=pubdate

5 TECHNICAL WORK

5.1 IT

5.1.1 New IT organization

With the affiliation to USI the high level support and network services are provided by USI. Local support is provided by the outreach company HSI Zeta SA (former Ticimatica SA).

5.1.2 Network

IRSOL has been integrated in the USI network. This has been possible thanks to the new dedicated optical fiber installed by Cablecom that connects IRSOL to the access to the regional network at

SUPSI/DFA. This required the installation of new swtiches, WLAN access points and a new network cabling following the topology suggested by the USI IT staff. All these works allowed to have a more reliable and faster internet connection, but also to benefit of several IT services provided by USI (e.g. VPN, e-mail server, WEB server, Eduroam, ...) and by Switch.

5.1.3 Servers

A new powerful server has been installed in summer 2021 by HSI Zeta, where some virtual machines (VM) with automatic backup have been installed or are foreseen:

- VM dedicated to the data storage and data analysis.
- VM dedicated to the WIKI server, the documentation local WEB server and IDL license server.
- VM dedicated to the 3CX server for the telephone (to be installed in 2022)
- VM dedicated to local DHCP and DNS server (foreseen)

The server core4 used mainly for computation had a disc failure. The disc has been replaced, the OS newly installed.

5.1.4 Observation database

During his civil service, Michel Basili set up a database to store the metadata of the solar observations and developed the related software.

It is foreseen that in 2022 he will further develop the system and in particular he will prepare a user friendly WEB interface to access to the content of the database.

5.1.5 Software

Through USI we made a subscription to the MS-Office 365 package.
In addition we started a subscription to the Overleaf license for 10 users.

5.2 Infrastructure work

The infrastructure works started in 2020 were successfully continued.

- The access road to IRSOL was opened in 2020 to install a canalization, the new electric power connection, and an optical fiber connection cable. In 2021 the road was asphalted, and the electric cables connected and tested. The garage has now a new power supply line.
- A fire and intrusion alarm system has been installed.
- The lavatories in the main building needed to be updated and that was performed in 2021 (apart the one already realized in the guest room).

6 WORKS FORESEEN IN 2022

- **New direction of the institute**

  In May 2022 Prof. Dr. Svetlana Berdyugina, already member of the IRSOL directorate, will assume the role of director. She will work part time, maintaining her role as managing director of the Leibniz-Institut für Sonnenphysik (KIS) in Freiburg in Breisgau. That will be a benefit strengthening the collaboration we have with KIS. Michele Bianda (already retired) will continue working at IRSOL part time on topics related to observations and instrumentation.

  The following points are thus just a general overview.

- **Università della Svizzera italiana, USI**

  The already ongoing and fruitful scientific collaboration will be continued.

- **Collaboration with SUPSI**

  The work started in 2021 for the improvement of the ZIMPOL system will be continued.

- **Collaboration with KIS**

  With the Leibnitz Institute of Solar Physics, KIS, we have a long ongoing collaboration that also includes sharing of researchers. The role Prof. Berdyugina will assume will also favor this collaboration.

- **Development of the scientific program**

  The topics already developed and described in section 3 will be continued. New topics will be introduced by the new direction.

- **Updating of the instrumentation**

  Studies about an important update of the telescope control and some infrastructure works at the observatory building are foreseen.

7 SCIENTIFIC ACTIVITY

7.1 Visits

17/11 Carin Rae Lightner, Stefan A. Meyer, ETHZ

7.2 Visits to other institutes

23/06 O. Steiner, Uni-ZH, PhD Committee Meeting

10/09 M. Bianda, D. Gisler, R. Ramelli, F. Zeuner, SUPSI, Kick-off meeting: ZIMPOL upgrade project

09-12/11 F. Riva, Leibniz-Institut für Sonnenphysik (KIS), Freiburg (D)

17/11 M. Bianda, D. Gisler, R. Ramelli, F. Zeuner, SUPSI, ZIMPOL project

26/11 O. Steiner, Uni-ZH, PhD Jamboree

7.3 Participation to workshops, meetings, schools and talks

18-21/01 O. Steiner: *The Alfvénic nature of chromospheric swirls*, Virtual meeting of the Rosseland Center for Solar Physics (RoCS) (online)

12/02 F. Zeuner & D. Gisler: *GREGOR Slow Polarization Modulator*, OTTM (online)

01-04/03 O. Steiner: *MHD Simulations of Small-scale Magnetism and Vortical Flows*, Advances in Observations and Modelling of Solar Magnetism and Variability, Golden Jubilee of the Indian Institute of Astrophysics (invited, online)

15-19/03 J. R. Canivete Cuissa, F. Riva, and O. Steiner: Astronomy in the Era of Big Data, 50th Saas-Fee Course of the Swiss Society for Astrophysics & Astronomy (online)

26/04 J. R. Canivete Cuissa & O. Steiner: *Vortices evolution in ideal (M)HD*, European Geosciences Union (EGU) General Assembly 2021 (online)

28/06 O. Steiner: *Selected Questions of Solar Magnetoconvection*, Solar Orbiter Working Group Magnetoconvection (invited, online)

05-09/07 J. R. Canivete Cuissa, F. Riva, and O. Steiner: Platform for Advanced Scientific Computing (PASC) Conference (online)

07/07 F. Riva: *Estimating the magnetic Prandtl number: application to solar dynamo simulations*, public seminar series organised by the Euler Institute (online)

06-10/09 J. R. Canivete Cuissa & O. Steiner: *On the dynamics of vortices in the solar atmosphere*, 16th European Solar Physics Meeting (online)

06-10/09 F. Riva & O. Steiner: *Methodology for estimating the magnetic Prandtl number and application to solar surface small-scale dynamo simulations*, 16th European Solar Physics Meeting (online)

13-14/09 R. Ramelli: *Archiving and Digitization of the Sunspot observations* Swiss National GAW/GCOS Symposium (online)

27/09 J. R. Canivete Cuissa & R. Teyssier: *Stellar magneto-convection with RAMSES*, Ramses User Meeting 2021 (online)

28-30/09 O. Steiner: Solar Orbiter/Polarimetric and Helioseismic Imager (SO/PHI) Science Meeting at MPS in Göttingen (in person)

08/10 M. Bianda, O. Steiner: General Assembly of the Swiss Society for Astrophysics and Astronomy (online)

25-28/10 J. R. Canivete Cuissa & O. Steiner: *The Alfvénic nature of chromospheric swirls*, Hinode-14 / IRIS-11 Joint Science Meeting (online)

15/11 O. Steiner: *SOLARNET & Piz Daint*, 3rd SOLARNET Forum for telescopes and databases (online)

24/11 F. Zeuner: *How a "simple" spectral line continues to challenge paradigms in solar physics*, IAC Solar Physics Group Seminar (online)

21/12 F. Zeuner: *Progress on high precision absolute polarization measurements*, EST-SOLARNET technical workshop (online)

7.4 Participation in exam boards

18/06 Alsina Ballester Bianda: Member of the jury for the defense of the PhD-thesis of E. Capozzi. ETH-Zürich;

7.5 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).
- *O. Steiner:* Member scientific advisory committee of the Rosseland Center for Solar Physics (RoCS) of the University of Oslo.
- *O. Steiner:* Member Time Allocation Committee (TAC) for the SOLARNET trans-national access programme for observing and high performance computing time.
- *R. Ramelli*: member of the Swiss SCOSTEP committee (treasurer)
- *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)

7.6 Awards

- We congratulate Carin Rae Lightner working at the Optical Materials Engineering Laboratory, Dept. of Mechanical and Process Engineering, ETH Zurich. For her work she is using a ZIMPOL system borrowed from IRSOL.

  In March, 2021 in March she winned a poster prize at the 2021 Chiral Materials Conference for her poster "Measurement of Raman Optical Activity using High Frequency Polarization Modulation". The work presented was done in collaboration with: Daniel Giesler (IRSOL), Stefan A. Meyer, Hannah Niese and Robert C. Keitel.

8 ATTIVITÀ DIVULGATIVA

8.1 Visite guidate, visite di cortesia

La situazione particolare ha drasticamente ridotto questa attività.

17/06 Visita della classe 2E del Liceo di Bellinzona.

31/07 Visita di studenti dell'USI alla Specola e all'IRSOL (Michele Bianda, Franziska Zeuner, Renzo Ramelli).

8.2 Stages informativi

17.05 Samuele Gerometta (stage 4^a media)

31/07 stage premio per le migliori note in scienze in 4^a media al Collegio Papio (DFD Solutions SA Tecnologia e sistemi di Sicurezza - IRSOL): Federico Fusetti, Gregor Margni, Samuel Jakimovsky

18/08 Simone Lazzarino (stage 4^a media)

8.3 Partecipazione ad eventi e conferenze divulgative

03/12 R. Ramelli, "Cosa ci svela la luce delle Stelle", Tecday, Liceo di Lugano 2

8.4 Lavori di Maturità seguiti all'IRSOL

Alexia Buloncelli , Liceo di Bellinzona, "Le macchie solari e il conteggio ponderato"

Birgitta Zahner , Kanzonshule Wattwill, Sonnenspektrometrie"

8.5 Presenza nei media

8.5.1 Radio

26.04 RSI Rete 1: Luna, non solo magia, R. Ramelli

21.06 RSI Rete 1: Il solstizio d'estate: cosa conosciamo e studiamo del Sole, R. Ramelli e L. Belluzzi

28.08 RSI Rete 1: Il Sole ha un mistero in meno, L. Belluzzi

05.11 RSI Rete 2: La via alta: un'alba boreale sulle alpi?, R. Ramelli

8.5.2 Articoli apparsi sulla stampa

24.02 La Regione, "Locarno, accordo tra l'Istituto ricerche solari e la Supsi"

21.12 La Regione, "L'Irsol con l'Usi... illumina il Locarnese universitario"

8.5.3 Articoli apparsi online

24.02 Ticinonews, “Ricerca solare, SUPSI e IRSOL uniscono le forze”

21.04 Ticino Scienza: *Da una missione spaziale lampo la mappa dettagliata dei campi magnetici del Sole*, L. Belluzzi, M. Bianda, R. Ramelli
`www.ticinoscienza.ch/news.php?da-una-missione-spaziale-lampo-la-mappa-dettagliata-de`

19.08 USI - Notizie ed Eventi: *Researchers from IRSOL and IAC solve twenty-year-old paradox in solar physics*, L. Belluzzi
`https://www.usi.ch/en/feeds/16643`

12.10 SUPSI Eventi e comunicazioni: “La collaborazione tra SUPSI e IRSOL si rafforza: avviato un nuovo progetto di ricerca” `www.supsi.ch/isea/eventi-comunicazioni/news/2021/2021-07-15.html`

17.10 Ticino Scienza: *IRSOL, missione spaziale bis per catturare nuovi dati sui campi magnetici del sole*, L. Belluzzi
`https://www.ticinoscienza.ch/it/news.php?irsol-missione-spaziale-bis-per-catturare-n`

8.5.4 Podcast

15.11 Co.Scienza: *Studiare il Sole*, L. Belluzzi
`https://open.spotify.com/episode/6WhN58H7stTPtFzWbFm6cC?si=M1NkOHzcSy-vX5B_Z67zaA&utm_source=copy-link&nd=1`

9 PUBLICATIONS

9.1 Appeared in 2021

9.1.1 Appeared in peer reviewed journals

Alsina Ballester, E., Belluzzi, L., and Trujillo Bueno, J. 2021, *Solving the Paradox of the Solar Sodium D1 Line Polarization*, Physical Review Letters, **127**, 081101

Battaglia, A., **Canivete Cuissa, J.R.**, Calvo, F., Bossart, A.A., and **Steiner, O.** 2021, *The Alfvénic nature of chromospheric swirls*, A&A **649**, A121

Benedusi, P., **Janett, G., Belluzzi, L.**, and Krause, R. 2021, *Numerical solutions to linear transfer problems of polarized radiation. II. Krylov methods and matrix-free implementation*, A&A, **655**, 88

Fleck, B., Carlsson, M., Khomenko, E., Rempel, M., **Steiner, O.**, and Vigeesh G. 2021, *Acoustic-gravity wave propagation characteristics in three-dimensional radiation hydrodynamic simulations of the solar atmosphere*, Phil. Trans. R. Soc. A **379**:20200170

Ishikawa, R. et al. (27 co-authors, including **Belluzzi, L.** and **Alsina Ballester, E.**) 2021, *Mapping Solar Magnetic Fields from the Photosphere to the Base of the Corona*, Science Advances **7**, eabe840

Hudson, H., Briggs, M., Chitta, L., Fletcher, L., Gary, D., **Monstein, C.**, Nimmo, K., Saint-Hilaire, P., White, S. 2021, *Characterizing a "Solar FRB"*, American Astronomical Society Meeting Abstracts, **53**, 127

Janett, G., Alsina Ballester, E., Guerreiro, N., Riva, S., Belluzzi, L., del Pino Alemán, T., and Trujillo Bueno, J. 2021, *Modeling the scattering polarization of the solar Ca I 4227 Å line with angle-dependent partial frequency redistribution*, A&A, **655**, 13

Janett, G., Benedusi, P., **Belluzzi, L.**, and Krause, R. 2021, *Numerical solutions to linear transfer problems of polarized radiation. I. Algebraic formulation and stationary iterative methods*, A&A, **655**, A87

Joshi, B., Mitra, P.K., Bhattacharyya, R., Upadhyay, K., Oberoi, D., Raja, K.S., **Monstein, C.** 2021, *Two-Stage Evolution of an Extended C-Class Eruptive Flaring Activity from Sigmoid Active Region NOAA 12734: SDO and Udaipur-CALLISTO Observations* , Solar Physics, **296**, 85

Keys, P.H., **Steiner, O.**, and Vigeesh, G. 2021, *On the effect of oscillatory phenomena on Stokes inversion results*, Phil. Trans. R. Soc. A **379**:20200182

Kharayat, H., Joshi, B., Mitra, P.K., Manoharan, P.K., Monstein, C. 2021, *A Transient Coronal Sigmoid in Active Region NOAA 11909: Build-up Phase, M-class Eruptive Flare, and Associated Fast Coronal Mass Ejection*, Solar Physics, **296**, 99

Kouloumvakos, A., Rouillard, A., Warmuth, A., Magdalenic, J., Jebaraj, I.C., Mann, G., Vainio, R., **Monstein, C.** 2021, *Coronal Conditions for the Occurrence of Type II Radio Bursts*, Astrophysical Journal, **913**, 99

Lv, M., Chen, Y., Vasanth, V., Radzi, M.S., Abidin, Z.Z., **Monstein, C.** 2021, *An Observational Revisit of Stationary Type IV Solar Radio Bursts*, Solar Physics, **296**, 1

Ndacyayisenga, T., Uwamahoro, J., Sasikumar Raja, K., **Monstein, C.** 2021, *A statistical study of solar radio Type III bursts and space weather implication*, Advances in Space Research, **67**, issue 4, 1425

Paganini, A., Hashemi, B., **Alsina Ballester, E.**, and **Belluzzi, L.** 2021, *Fast and accurate approximation of the angle-averaged redistribution function for polarized radiation*, A&A, **645**, 4

Peter, H., **Alsina Ballester, E.**, Andretta, V., Auchère, F., **Belluzzi, L.**, et al. (18 co-authors) 2021, *Magnetic imaging of the outer solar atmosphere (MImOSA)*, Experimental Astronomy, Online First, `https://doi.org/10.1007/s10686-021-09774-0`

Vigeesh, G., Roth, M., **Steiner, O.**, and Fleck, B. 2021, *On the influence of magnetic topology on the propagation of internal gravity waves in the solar atmosphere*, Phil. Trans. R. Soc. A **379**:20200177

Wan Mokhtar, W.Z.A., Hamidi, Z.S., Abidin, Z.Z., Ibrahim, Z.A., and **Monstein, C.** 2021, *Data background levels of the metre and decimetre wavelength observations by E-CALLISTO network: the Gauribidanur and Greenland sites*, Indian Journal of Physics **95**, 1051

Wiehr, E., Stellmacher, G., Balthasar, H., and **Bianda, M.** 2021, *Velocity Difference of Ions and Neutrals in Solar Prominences*, ApJ, **920**, 52

9.1.2 Appeared in proceedings or ArXiv

Canivete Cuissa, J.R. and **Steiner, O.**: 2021, *Vortices evolution in ideal (M)HD*, EGU General Assembly 2021, online EGU21-4713, `https://doi.org/10.5194/egusphere-egu21-4713`

McKenzie, D. et al. (26 co-authors including **Alsina Ballester, E.** and **Belluzzi, L.**) 2021, *Mapping of Solar Magnetic Fields from the Photosphere to the Top of the Chromosphere with CLASP2*, Bulletin of the American Astronomical Society, **53**, 106

9.2 In press or already published in 2022

Alsina Ballester, E., Belluzzi, L., and Trujillo Bueno, J. 2022, *The transfer of polarized radiation in resonance lines with PRD, J-state interference, and arbitrary magnetic fields. A radiative transfer code and useful approximations*, A&A [in press] `https://arxiv.org/pdf/2204.12523.pdf`

Benedusi, P., **Janett, G., Riva, S.**, Krause, R., and **Belluzzi, L.** 2022, *Numerical solutions to linear transfer problems of polarized radiation. III. Parallel preconditioned Krylov solver tailored for modeling PRD effects*, A&A [in press]

Canivete Cuissa, J.R. and **Steiner, O.**: 2022, *An innovative and automated method for vortex identification - I. Description of the SWIRL algorithm*, A&A, submitted

Canivete Cuissa, J.R. and Teyssier, R.: 2022, *Towards fully compressible numerical simulations of stellar magneto-convection with the RAMSES code*, A&A, submitted

Capozzi, E., Alsina Ballester, E., Belluzzi, L., and Trujillo Bueno, J. 2022, *The polarization angle in the wings of Ca* I *4227: A new observable for diagnosing unresolved photospheric magnetic fields*, A&A, **657**, A44

Clette, F., Lefèvre, L., Bechet, S., **Ramelli, R.**, Cagnotti, M. "Reconstruction of the Sunspot Number Source Database and the 1947 Zurich Discontinuity", 2021,Solar Physics,296,137

Jaume Bestard, J., Trujillo Bueno, J., **Bianda, M.**, Štěpán, J., **Ramelli, R.** "Spectropolarimetric observations of the solar atmosphere in the Hα 6563 Å line", 2022, Astronomy and Astrophysics, 659, A179

Rackham, B.V., Espinoza, N., Berdyugina, S.V. and 58 more including **O. Steiner**: 2022, *The Effect of Stellar Contamination on Space-based Transmission Spectroscopy*, `https://arxiv.org/abs/2201.09905`

Riva, F. and **Steiner, O.**: 2022, *Methodology for estimating the magnetic Prandtl number and application to solar surface small-scale dynamo simulations*, A&A, **660**, A115

Riva, F. and **Steiner, O.**: 2022, *Estimating the magnetic Prandtl number of small-scale dynamo simulations*, in: H.-G. Ludwig (ed.), The CO5BOLD Quarterly Companion **23**

Tziotziou, K., Scullion, E., Shelyag, S., Kohomenko, E., Tsiropoula, G., **Steiner, O.**, Wedemeyer, S., **Canivete Cuissa**, J.R., Kontogiannis, I., Yadav, N., Kitiashvili, I.N., Skirvin, S.J., Dakanalis, I., Kosovichev, A.G., and Fedun, V.: 2022, *Vortex motions in the Solar atmosphere: Definitions, theory, observations, and modelling*, Space Science Review, submitted

Zeuner, F., Belluzzi, L., Guerreiro, N., Ramelli, R., and Bianda, M.: 2022, *Hanle rotation signatures in Sr I 4607 Å*, A&A, in press

9.3 Theses

Capozzi, E.: 2022, *Observation and modeling of scattering polarization signals sensitive to unresolved photospheric magnetic fields via Hanle and magneto-optical effects*, DOI: 10.13097/archive-ouverte/unige:154699, `https://archive-ouverte.unige.ch/unige:154699`

9.4 Other publications

Battaglia, A., **Canivete Cuissa, J.R.**, Calvo, F., Bossart, A.A., and **Steiner, O.**: 2021, *The Alfvénic nature of chromospheric swirls*, in: H.-G. Ludwig (ed.), The CO5BOLD Quarterly Companion **21**

9.5 Atlas and scientific data on our website

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

On the web page `https://sunspots.irsol.usi.ch/` there is a sunspot group database, published in collaboration with Specola Solare Ticinese