This project is supported by the European Commission's FP7 Capacities Programme for the period April 2013 - March 2017 under the Grant Agreement number 312495.

www.solarnet-east.eu

SOLARNET
HIGH-RESOLUTION SOLAR PHYSICS NETWORK

FINAL REPORT

May 2017

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1. INTRODUCTION

SOLARNET is a project funded by the European Commission's FP7 Capacities Programme under the Grant Agreement 312495. SOLARNET started on April 1st, 2013 and ended on March 31st, 2017.

This initiative brings together and integrates the major European research infrastructures in the field of high-resolution solar physics, in order to promote their coordinated use and development. This network involves all pertinent European research institutions, infrastructures, and data repositories. Together, these represent first-class facilities. The additional participation by private companies and non-European research institutions maximizes the impact on the worldwide scale.

Project general information:

Grant Agreement number: 312495

Project acronym: SOLARNET

Project title: High-Resolution Solar Physics Network

Funded under: FP7-INFRASTRUCTURES: INFRA-2012-1.1.26 - Research Infrastructures for High-Resolution Solar Physics

Funding scheme: Combination of Collaborative Project and Coordination and Support Action for Integrating Activities

From: 2013-04-01 to 2017-03-31

Date of latest version of Annex I of the Grant Agreement: 25/03/2015

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Networking activities, access to first-class infrastructures and joint research and development activities have been covered under SOLARNET to improve, in quantity and quality, the service provided by European research community forming part of the project.

The total budget of the project was above 8 million € and the EC contribution 6 million €.

SOLARNET has involved 32 partners from 16 countries: 24 EU research institutions, 6 EU private companies and 2 USA research institutions.

SOLARNET has integrated the vast majority of European efforts in the research area of high-resolution solar physics with the objective to significantly enhance the scientific output by fostering a vital collaboration between the research groups active in this scientific area in Europe.

SOLARNET has provided access to leading world-class ground-based research infrastructures, aimed at equipping those with advanced instrumentation, and prepared for the next generation of high-resolution telescopes, which the European Solar Telescope (EST) is the most prominent example.

Within the *Networking Activities,* a number of meetings, workshops and schools were organized for the scientific knowledge transfer. Through these activities, SOLARNET has become a trade-mark among the research community. A successful young researchers Mobility Programme has been accomplished.

The *Access and Service Programme* has attracted a large number of scientists, from student to senior researcher level. The offered amount of access was easily booked out. The number of users, especially those who are new to observational solar physics, is above all expectations that were set at the beginning of the project.

The *Joint Research Activities* have completed their goals successfully. This needs to be estimated high, as the development of prototypes of new instrumentation within the given time was challenging. With the joint effort and dedication of all parties involved, this major accomplishment could be achieved.

The SOLARNET IT-platform provides now the internet-based forum for accessing all material, knowledge, and data that were created and recorded during the project. This platform will be kept operational by IAC over the course of the next years for further disseminating data and information material to the broader community.

The management of SOLARNET has been very efficient in coordinating the activities of the 32 partners working in a diverse set of areas and subjects.

The following actions were carried out under the auspices of SOLARNET:

- Transnational Access to external European users.
- Enhancing and spreading data acquisition and processing expertise to the Europe-wide community.
- Increasing the impact of high-resolution data by offering science-ready data and facilitating their retrieval and usage.
- Encouraging combination of space and ground-based data by providing unified access to pertinent data repositories.
- Fostering synergies between different research communities by organising meetings where each presents state-of-the-art methodologies.
- Training a new generation of solar researchers through setting up schools and an ambitious mobility programme.
- Developing prototypes for new-generation post-focus instruments.
- Studying local and non-local atmospheric turbulence, their impact on image quality, and ways to negate their effects.
- Improving the performance of existing telescopes.
- Improving designs of future large European ground-and space-based solar telescopes.
- Laying foundations for combined use of facilities around the world and in space.
- Reinforcing partnership with industry to promote technology transfer through existing networks.
- Disseminating activities towards society.

The organized events and the European wide availability of information on SOLARNET had an important impact on the European and international scientific community:

- The objectives of SOLARNET were transmitted to the community. SOLARNET is really well known in the respective research community.
- The expected integrative effect of SOLARNET has been fully achieved:
    - The scientific community participated actively in the activities by SOLARNET. This target was clearly met.
    - SOLARNET allowed bringing together an unheard number of European scientists at conferences and workshops.
    - The community is now strongly linked, and ready for the construction of the European Solar Telescope – EST. The technical and instrumental developments are

on their way, several new projects and applications for inclusion on national roadmaps could be initiated.

- The participation of researchers – juniors, PHD, and seniors– from several countries not having facilities as those forming part of the SOLARNET access programme shows the internationalization of the project.
- The latter applies also to the networking activities organized by SOLARNET, especially to the Mobility of Young Researchers Programme. Now a young and talented generation of researchers was trained, which will be able to make full use of the upcoming future opportunities in this growing research area.
- The success of the formation programmes of SOLARNET (through its schools, workshops and mobility programme) has made the project familiar to young students and researchers. The access to telescopes and databases has opened new windows to researchers not affordable before SOLARNET. Even non-solar physics researchers are also aware of the project, thanks to the multidisciplinary meetings organised where the project has been presented.
- Collaborations between the groups of the SOLARNET consortium that have reinforced the global interest by the community on different subjects related to Solar Physics.

2. List of beneficiaries

Name	Short name	Country
INSTITUTO DE ASTROFISICA DE CANARIAS	IAC	Spain
STIFTUNG KIEPENHEUER-INSTITUT FUR SONNENPHYSIK	KIS	Germany
ISTITUTO NAZIONALE DI ASTROFISICA	INAF	Italy
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	CNRS	France
UNIVERSITA DEGLI STUDI DI ROMA TOR VERGATA	UToV	Italy
MAX PLANCK GESELLSCHAFT ZUR FOERDERUNG DER WISSENSCHAFTEN E.V.	MPG	Germany
UNIVERSITETET I OSLO	UiO	Norway
LEIBNIZ-INSTITUT FUR ASTROPHYSIK POTSDAM (AIP)	AIP	Germany
STOCKHOLMS UNIVERSITET	SU	Sweden
UNIVERSITE PAUL SABATIER TOULOUSE III	UPS	France
THE QUEEN'S UNIVERSITY OF BELFAST	QUB	United Kingdom
UNIVERSITY COLLEGE LONDON	UCL-MSSL	United Kingdom
ASTRONOMICAL INSTITUTE OF THE SLOVAK ACADEMY OF SCIENCES	AISAS	Slovakia
ASTRONOMICKY USTAV AVCR VVI	AIASCR	Czech Republic
SVEUCILISTE U ZAGREBU - GEODETSKI FAKULTET	HVAR	Croatia
KONINKLIJKE STERRENWACHT VAN BELGIE	ROB	Belgium
UNIVERSITAET GRAZ	IGAM	Austria
UNIWERSYTET WROCLAWSKI	UWR	Poland
UNIVERSITA DELLA CALABRIA	UCAL	Italy
WAGENINGEN UNIVERSITY	WU	Netherlands
FONDAZIONE ISTITUTO RICERCHE SOLARI LOCARNO	FIRSOL	Switzerland

AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS	IAA-CSIC	Spain
THE UNIVERSITY OF BIRMINGHAM	UoB	United Kingdom
CONSIGLIO NAZIONALE DELLE RICERCHE	CNR-INO	Italy
HANKOM ENGINEERING	HANKOM	Netherlands
CENTRE INTERNACIONAL DE METODES NUMERICS EN ENGINYERIA	CIMNE	Spain
S.R.S. ENGINEERING DESIGN S.R.L.	SRS	Italy
PNSENSOR GMBH	PNSensor	Germany
WINLIGHT OPTICS	WO	France
FUNDACION TECNALIA RESEARCH & INNOVATION	TECNALIA	Spain
ASSOCIATION OF UNIVERSITIES FOR RESEARCH IN ASTRONOMY	NSO	United States
SMITHSONIAN INSTITUTION	CfA-SAO	United States

3. SUMMARY OF WORK AND ACHIEVEMENTS PER WORKPACKAGES

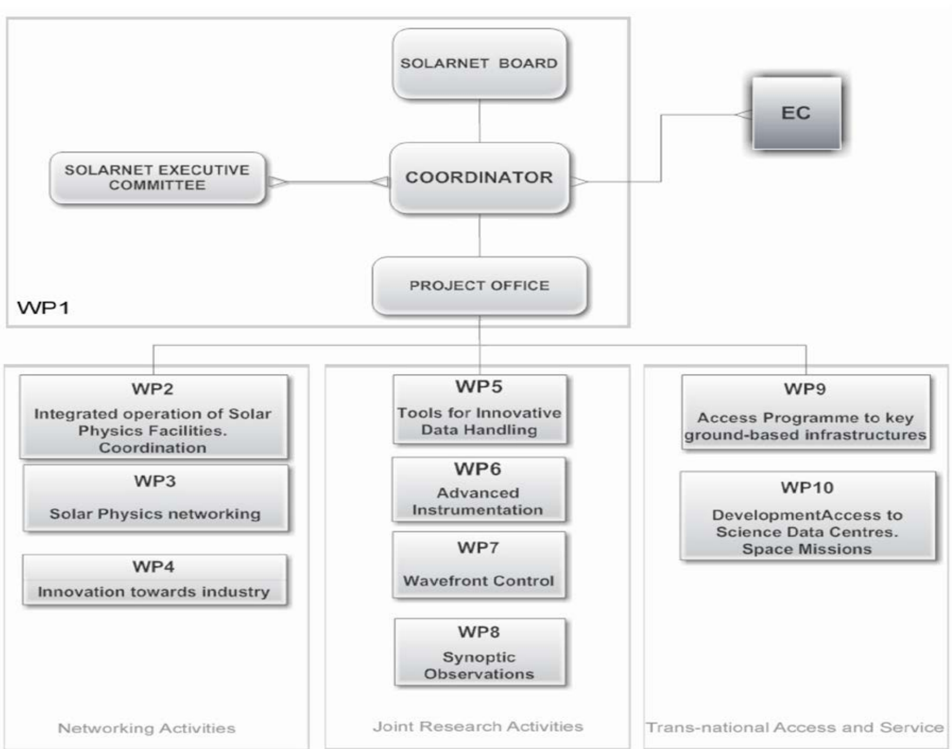
WP10: Project Coordination and Management

Lead Beneficiary: IAC

Main objectives:

- Effective coordination and management of the whole project.
- Implementation of an effective and transparent management of the project, ensuring appropriate control and monitoring: schedule, budget & scope (milestones and deliverables).
- Effective communication among activities and teams.
- Monitoring and reporting of the overall progress and use of the infrastructures for access, assuring the timely delivery of high quality deliverables and milestones.
- Contractual and financial follow-up of the project.
- Coordination of dissemination activities.

In order to guarantee an appropriate management structure and administration of the Project and its tasks and activities, an elaborated management structure was set up:



Summary of activities

1. Board and Executive Committees Meetings.

In accordance with the Grant Agreement the SOLARNET Board has met four times:

- 1st Board Meeting (Kick-off meeting) – Brussels, Belgium, April 10-11, 2013
- 2nd Board Meeting – Madrid, Spain, April 30, 2014
- 3rd Board Meeting – London, UK, October 13, 2015
- 4th Board Meeting (End-of-project meeting) – Tryp Alameda Airport Hotel, Madrid, Spain, March 30-31, 2017

All documents of these meetings are available at the private pages of the SOLARNET webpage.

The Executive Committee has met five times:

- 1st Executive Committee Meeting – Brussels, Belgium, April 11, 2013
- 2nd Executive Committee Meeting – Videoconference, July 22, 2013
- 3rd Executive Committee Meeting – Madrid, Spain, April 29, 2014
- 4th Executive Committee Meeting – London, UK, October 13, 2015
- 5th Executive Committee Meeting – Videoconference, September 21, 2016

2. List of meetings and events organized

An overview of all meetings, workshops, schools, conferences, etc., organized by SOLARNET is provided in the table below:

Date	WP	Title/subject of meeting	Location	Nr of attendees	Website address
30-31 March 2017	10	**4th Board Meeting (End-of-project Meeting)**	Madrid	43	http://www.solarnet-east.eu/bmeeting (after log in)
18 January 2017	10	**EAST General Assembly**	Lanzarote	15	www.astro-east.org
16-21 January 2017	30	**4th SOLARNET Conference (Meeting)**	Lanzarote	145	http://www.iac.es/congreso/solarnet-4meeting/pages/talk-and-poster-download.php
1-2 December 2016	20	**3rd FAS Meeting**	Brussels	21	http://bit.ly/2jm3vTj
21 September 2016	10	**5ve Executive Committee Meeting**	Teleconfe-rence	12	
25-30 August 2016	30	**5ve SOLARNET School**	Belfast	25	https://star.pst.qub.ac.uk/wiki/doku.php/public/solarnet5/start
31 August – 02 September 2016	30	**5ve SOLARNET Workshop**	Belfast	48	https://star.pst.qub.ac.uk/wiki/doku.php/public/solarnet5/start
13-19 April 2016	30	**4th SOLARNET School**	London	25	http://www.ucl.ac.uk/mssl/solar/SOLARNET-4/school-programme

20-22 April 2016	30	**4th SOLARNET Workshop**	London	30	http://www.ucl.ac.uk/mssl/solar/SOLARNET-4/workshop-programme
13 October 2015	10	**3rd Board Meeting**	London	22	http://www.solarnet-east.eu/
13 October 2015	10	**4th Executive Committee Meeting**	London	20	http://www.solarnet-east.eu/
14 October 2015	10	**Mid-Term Review Meeting**	London		http://www.solarnet-east.eu/
2-5 February 2015	30	**2nd SOLARNET Conference**	Palermo	61	http://www.astropa.inaf.it/Solarnet2015/Solarnet2015.html
31 August - 4 September 2015	30	**3rd SOLARNET Conference**	Freiburg	84	http://www.iac.es/congreso/solarnet-3meeting/
5-12 October 2014	30	**2nd SOLARNET School**	Tatranska Lomnica	22	http://www.astro.sk/SOLARNET_2ND_SCHOOL/solarnet
12-16 October 2014	30	**2nd SOLARNET Workshop**	Tatranska Lomnica	28	http://www.astro.sk/SOLARNET_2ND_WORKSHOP/
18-23 May 2015	30	**3rd SOLARNET School**	Granada	26	http://spg.iaa.es/School
25-28 May 2015	30	**3rd SOLARNET Workshop**	Granada	63	http://spg.iaa.es/Workshop
15 October 2015	10	**EAST General Assembly**	London	18	www.astro-east.org
2 October 2014	40	**1st SOLARNET Technology Transfer Workshop**	San Sebastian	23	http://bit.ly/1vYK185
29 September – 3 October 14	40	**1st SOLARNET Technology Transfer Workshop**	San Sebastian,		
30 April 13	10	**2nd Solarnet Board Meeting**	Madrid, Spain	27	http://www.solarnet-east.eu/
29 April 13	10	**3rd Solarnet Executive Committee Meeting**	Madrid, Spain	19	http://www.solarnet-east.eu/
28 April 13	10	**EAST General Assembly**	Madrid, Spain	14	www.astro-east.org
1-2 April 2014	30	**1st Solarnet Workshop**	Wroclaw, Poland	25	http://school.astro.uni.wroc.pl/index.php
24 March – April 4 2014	30	**1st Solarnet School**	Wroclaw, Poland	10 lecturers 20 students	http://school.astro.uni.wroc.pl/index.php
25-28 November 2013	80	**1st Solarnet/SPRING Workshop**	Titisee, Germany	35	http://www3.kis.uni-freiburg.de/~mroth/spring.html
7 November 2013	20	**FAS Meeting**	Stockholm	11	
5-8 August 13	30	**1st Solarnet Conference**	Oslo, Norway	67	http://folk.uio.no/matsc/oslo-13/
22 July 2013	10	**2nd Solarnet Executive Committee Meeting**	Teleconference		http://www.solarnet-east.eu/
22-24 April 2013	80	**Synoptic Network Workshop**	Boulder, USA	36	https://www2.hao.ucar.edu/docs/2013-synoptic-network
11 April 2013	10	**1st Solarnet Executive Committee Meeting**	Brussels, Belgium		http://www.solarnet-east.eu/
10-11 April 2013	10	**Solarnet Kick-Off Meeting**	Brussels, Belgium		http://www.solarnet-east.eu/

3. Distribution of the payments to the partners

All EU funds were readily distributed to the partners after reception at the IAC

4. Milestones.

According to the GA, below is presented the list of milestones achieved during the project:

Milestone number	Milestone name	Work package(s) involved
M1.1	Project kick-off	All
M1.2	Project Web page	WP1
M1.3	Mid-term review meeting	All
M1.4	End-of-project meeting	All
M2.1	TAS Web page	WP2
M2.2	Summary of Access time and service exploitation	WP2
M2.3	Lessons learned from coordinated observations	WP2
M2.4	Specifications for service mode	WP2
M2.5	Data archiving adaptation to VO rules	WP2
M3.1	Scientific meetings	WP3
M3.2	Calls for mobility of young researchers	WP3
M3.3	Training schools and related workshops	WP3
M5.1	Analysis of data compression algorithms	WP5
M5.2	Analysis of MFBD and Speckle image restoration strategies	WP5
M5.3	VO tools prototype	WP5
M6.1	Performance of FPI prototype	WP6
M6.2	Performance of image slicer prototype	WP6
M6.3	Performance of microlens system prototype	WP6
M6.4	Performance of polarimeter prototype	WP6
M7.1	Results of MCAO simulations	WP7
M7.2	Performance of THEMIS AO prototype	WP7
M7.3	OT and ORM site-testing campaign completed	WP7
M7.4	Results of CFD analyses for local seeing optimization	WP7
M7.5	Performance of Heat Rejecter prototype	WP7
M8.1	Final selection of instruments for synoptic observations and operation plan	WP8

5. Interaction with SOLARNET partners and WP and sub-WP leaders. Apart from the standard and official meetings, this interaction was carried out via email, phone, videoconference, etc. with the aim of providing the partners with the required support on management issues and EC guidelines for the fulfilment of the Grant Agreement. In particular, the interaction between the project manager, the technical manager, the project coordinator and the WPs leaders was very systematic by face-to-face meetings, telephone calls, emails, and videoconferences.

6. Activities related to the TAS Programme (WP20 and WP90). The Project Office supported the TAS (Transnational Access and Service Programme). In particular, the management and payment of travel and accommodation grants for astronomers awarded with observing time at the telescopes located at the Canary Islands. A brief TAS summary follows:

Transnational Access and Service Programme	2013 - 2016
Projects awarded with observing time in the telescopes THEMIS*, SST, GREGOR and VTT, and in the instruments IBIS/DST and ROSA/DST *THEMIS provided access only in 2013 and 2014	68
Observing days provided in the above mentioned telescopes and instruments	466
Astronomers benefited with the access provided under the auspicious of SOLARNET	353
Astronomers supported with travel and subsistence grants to carry out observations in situ in the Canary Islands telescopes	59
New users of the infrastructures (supported with travel and subsistence grants)	30

7. Management activities related to the Solar Physics Networking.

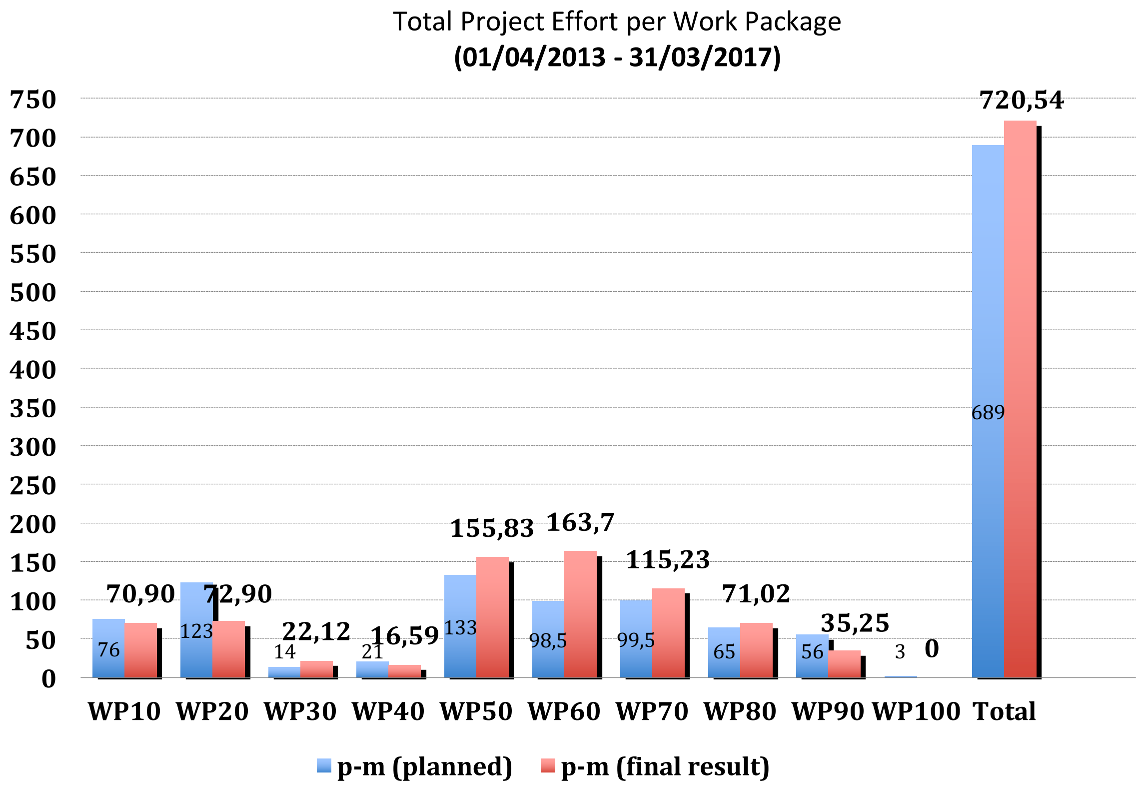
- Support to the five SOLARNET Schools and Workshops held in Wroclaw (March 24 – April 04, 2014), Tatranska Lomnica (October 5-16, 2014), Granada (May 18-28, 2015), London (April 13-22, 2016) and Belfast (August 25 - September 2, 2016), as part of the networking activities of the project (Training of the New Generation of Scientists). All material related to these schools and workshops are available at the public area of the website (http://www.solarnet-east.eu/meetandworksh/solschandwork).

- Support to the SOLARNET Mobility of Young Researchers Programme. Seven announcements of opportunity were published and promoted. 20 young astronomers carried out their stays in the host institutions of 9 countries. The Project Office managed all travel and subsistence requirements of these young researchers. After the stay, reports were sent to the Project Office containing the main results of the work done and acknowledging the support of SOLARNET. The corresponding experienced researchers, acting as tutors of the young astronomers, also prepared and sent a report to the Project Office on behalf of the host institutions.

8. Outreach. The plan prepared on this topic at the beginning of the project – and available at http://www.solarnet-east.eu/downloads – aimed at reaching the goal of promoting joint actions specifically designed to enhance the visibility of the project at international level and getting the targeted audience at large. During the last year it was decided to focus all outreach efforts in promoting and informing all audiences about the European Solar Telescope as a major project to which other related project as SOLARNET and GREST contribute. The preparation of some outreach materials and an intensive usage of the social networks have become of paramount importance for this objective. The traditional way of disseminating and communicating research and development activities by publication in specialized peer reviewed journals was also continued. During the whole project, 67 scientific articles were published in refereed peer-reviewed journals. All these articles are publicly accessible.

9. Use of resources.

The chart below summarizes the human effort of SOLARNET per work package up to March 31, 2017 (48 months after the start of the project). The human effort has reached approximately 104.58 % of the total amount of manpower dedication expected for the four-year contract (689 p-m). This number corresponds to the work performed in all WPs. The project made an optimal use of its resources, reflected by the successful completion of all deliverables. Minor shifts in the usage of person-months were needed. The higher demand on human efforts to complete the technical developments in the WPs 60 and 70, could be compensated by an efficient use of resources in the WPs 20 and 90.



Project effort (number of person-months) broken down per Work-package. In blue, total amount expected for the four-years contract, in red total actual human efforts during the four years

WP20: "Integrated operation and exploitation of solar physics facilities and co-ordination with other research infrastructures"

Leader organization: KIS

Participants: IAC, INAF, CNRS, MPG, UiO, AIP, SU, UPS, QUB, UCLRMSSL, AISAS, AIASCR, HVAR, ROB, IGAM, UWR, IAARCSIC, NSO, CfA-SAO

Work-package summary

The focus of this work package has been to optimize the use of the existing solar facilities and research structures. To achieve this goal, we have worked on a number of objectives: (20.1) coordination and implementation of the Transnational ACCESS and Service program, (20.2) to make available proper data pipelines for existing instruments, (20.3) development of guidelines for metadata, aiming at a standard for archived solar data, (20.4) coordinated observations of our facilities with non-European and/or non-optical infrastructures, (20.5) study new ways of operating our telescopes, in particular, gather experience with performing observations in service mode.

The main body of the work package is the Forum for Access and Services (FAS). At the meetings of the FAS all objectives of this work-package have been monitored and discussed. All telescope and instrument owners have formed part of the FAS, and participated at its meetings. The meetings have been open to all people involved in relevant SOLARNET work-packages.

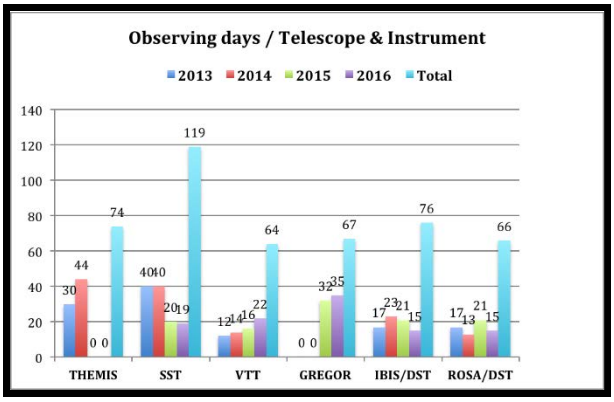
sWP20.1 Common Time Allocation Committee

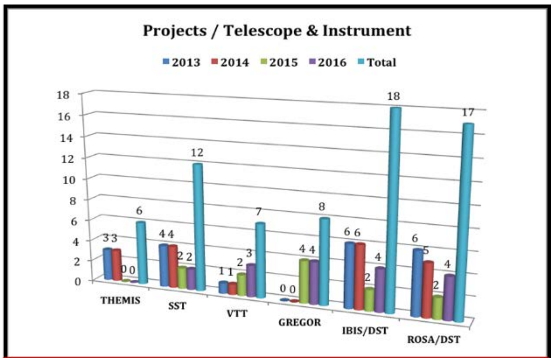
The EAST Time Allocation Committee (TAC) has allocated jointly all SOLARNET ACCESS time to the various telescopes and instruments. In order to adopt the EAST TAC to its new challenges, the FAS decided at its first meeting to assign as EAST TAC members one representative of each institutions that operate the telescopes/instruments handled by SOLARNET (GREGOR, VTT, SST, THEMIS, IBIS@DST and ROSA@DST), plus one representative of IAC and NSO. EAST approved this assignment at its General Assembly 2013.

The EAST TAC granted observing time in PI mode as well as in the 'service' mode. The PI mode is the traditional observing mode, in which the principal investigator and parts of his/her team goes to the telescope and performs the observations. The technical support is typically limited to the telescope and the instruments need to be operated by the observing team. The service mode is a novel observing mode in solar physics. In this mode the proposers describe the scientific objective and give a detailed explanation on what data they need. The data is acquired by a service team at the telescope following the requirements that the proposers have specified.

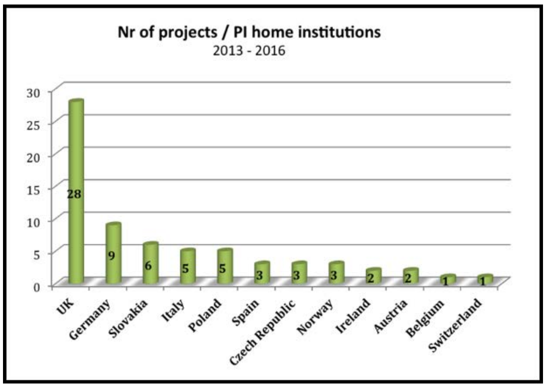
The EAST TAC announced the call for proposals for the observing seasons since 2013 to 2016. The calls were issued in 'SOLAR NEWS', which is subscribed by most Solar Physicists worldwide. Also, the EAST TAC informed all 'known' people that could be interested in the ACCESS program. In addition the Project office implemented a web page within the SOLARNET internet portal to promote the ACCESS program, and distributed a poster on the TAS. The proposal deadlines were in mid-January of each observing season. The number of submitted proposal was higher than expected. The EAST TAC checked the proposals for eligibility and contacted the telescope operators for checking the technical feasibility. The EAST TAC selected two independent referees who rated the proposals according to their scientific merit. Based on the scientific merit, the EAST TAC granted the observing time.

The ACCESS programme was most successful in being oversubscribed and bringing new users to the telescopes. In the course of the 4-year program, the oversubscription rate increased steadily. In 2016 - the fourth year - the ACCESS program was oversubscribed by 200% (26 proposals for 13 allocated projects). If only PI mode campaigns are considered, the oversubscription rate is even higher. It amounts to 250% (22 proposals for 9 allocated projects).





Total: 68 observing proposals / 12 countries



Some statistics of the SOLARNET Access Programme: (top left) number of days allocated at each telescope/instrument; (top right) number of observing campaigns at each telescope/ instrument; (bottom) number of observing campaigns per country.

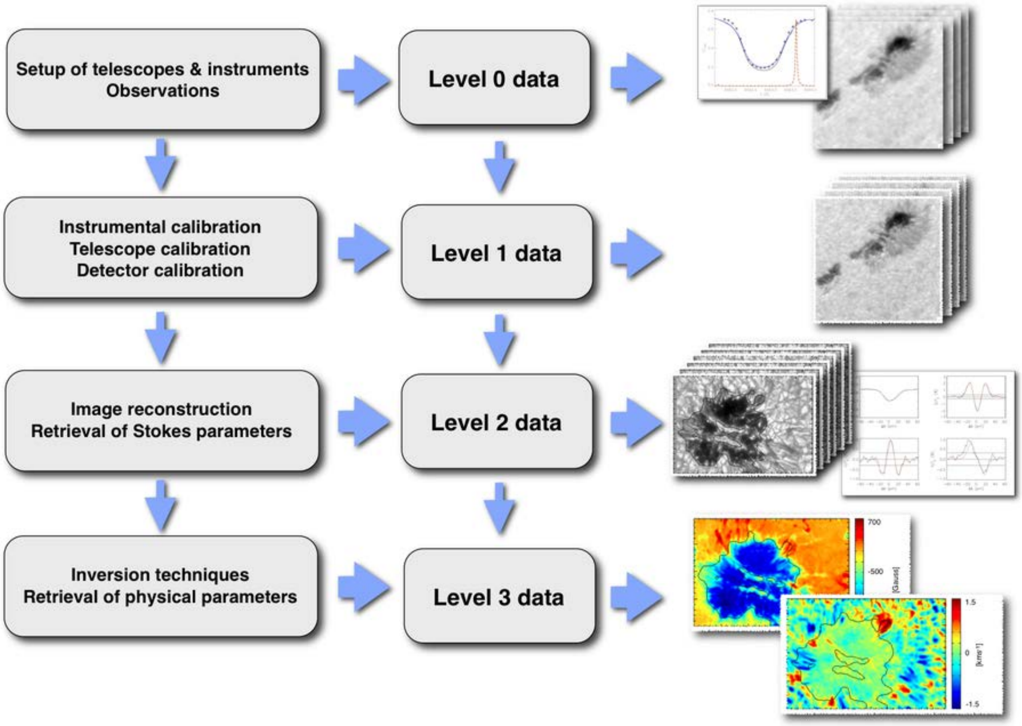
During the whole project, the EAST TAC allocated a total of 68 observing campaigns with 466 observing days. 353 users from 18 countries were awarded with observing time and 59 received a travel & subsistence grant to perform the observations. 30 of 59 of them were new users. The figures above show some statistics of the access programme.

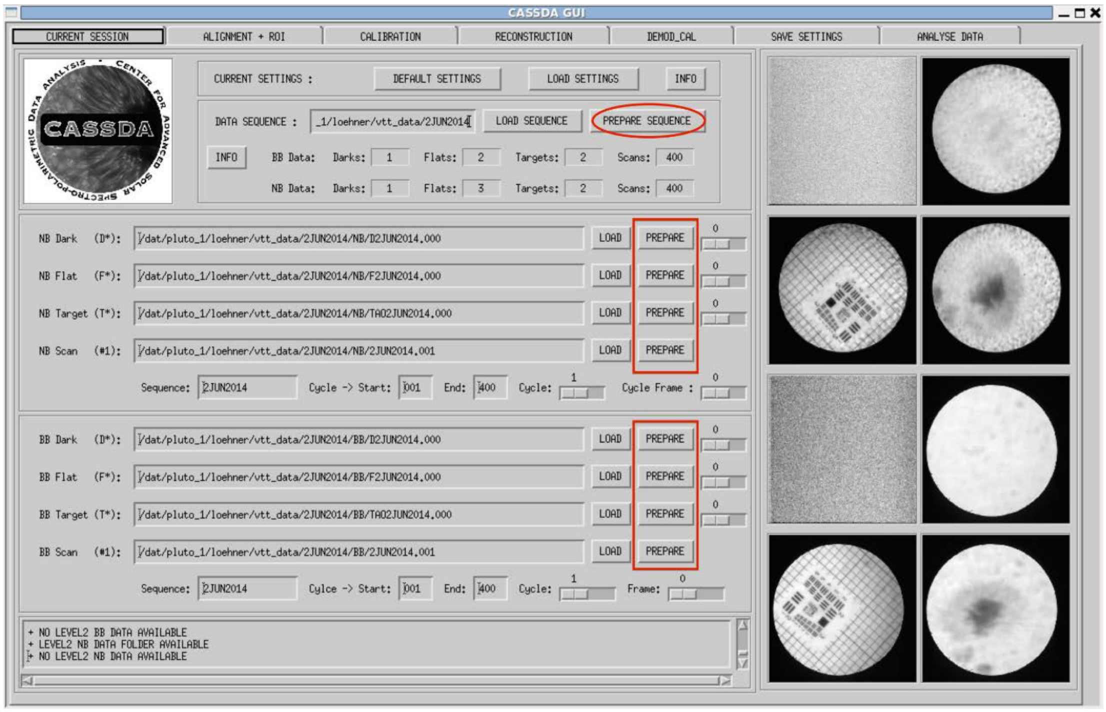
sWP20.2 Guidelines for pipeline development

Presentations and discussions on the four consecutive FAS meetings brought together all the data pipeline experts from the SOLARNET telescopes, as well as US data scientists that are involved in the data pipelines of the upcoming 4m solar telescope DKIST in Hawaii. Having brought together this community is a major success of WP20. The exchange of expertise in the design of data pipelines between the different groups manifests a most valuable result of the WP20 endeavour. Some aspects of this undertaking are summarized in the 'Final report on data pipeline guidelines'. The concept for a data pipeline needs to be distinguished, depending on the type of instrument: each type of instrument needs its own characteristic design. For imaging instruments, standard flat field correction and dark current substraction yield a calibrated image. This standard step would elevate the data into 'Level 1.' Yet, these days, image restoration techniques can be applied to overcome effects of seeing from the Earth atmosphere which degrade the image. For these restoration techniques two methods are typically used: reconstruction by Speckle or blind deconvolution. If, e.g., the speckle technique is used, hundreds of images need to be recorded and calibrated to Level 1, to produce one reconstructed image. This would then be a Level 2 data product of the data pipeline.

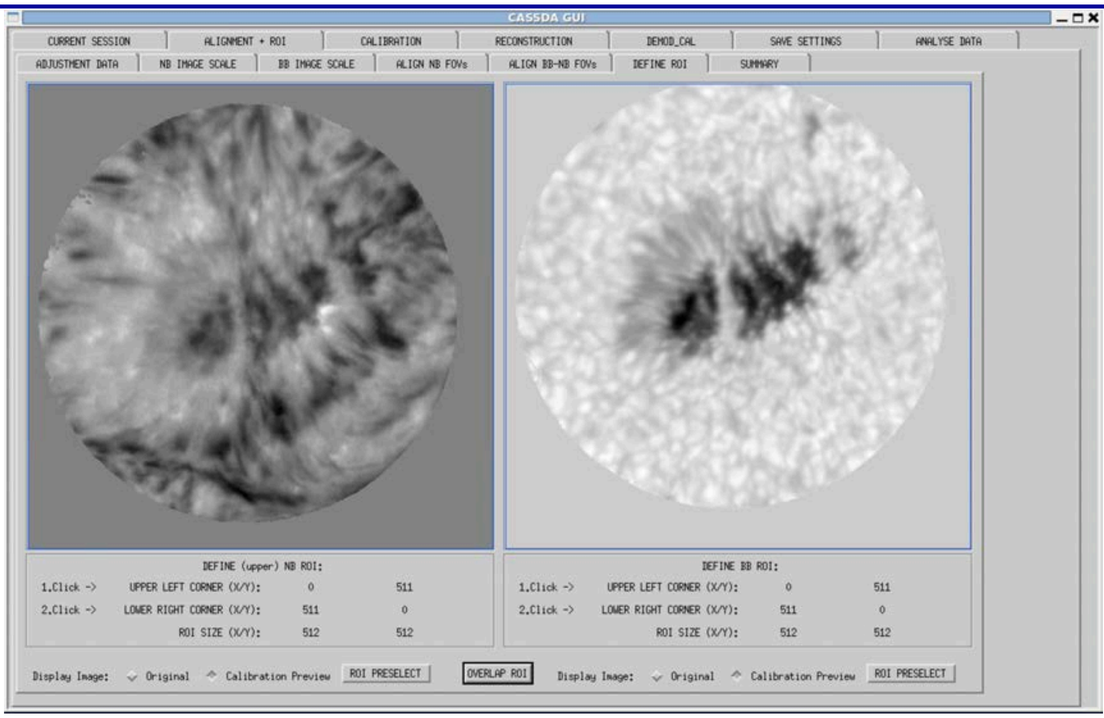
In case of pure imaging data, higher levels do not exist. In case of spectro-polarimetric data, the steps from level 0 to level 2 are more involved. From Level 0 to Level 1, more complex flatfielding precedures are needed and a polarimetric calibration of the telescope and the instrument is to be performed. Then image reconstruction techniques may yield the Level 2 data, i.e. two-dimensional spatial maps of the four Stokes parameters. Each Stokes parameter describing a line profile that depends on wavelength.

Below we show the pipeline structure and two screen snapshots of an example: the Graphical User Interface of the calibration pipeline of TESOS. First the calibration and data file names need to be selected from the menu. The upper row of tabs guide the user through the consecutive steps of the data calibration. If needed, a second row of tabs opens if a particular calibration step is selected. In case of an FPI-system, the broad-band and narrow-band images need to be scaled and co-aligned. The next figure shows these two images. The alignment is typically made using target images that are introduced into the beam in a focus before the instrument.

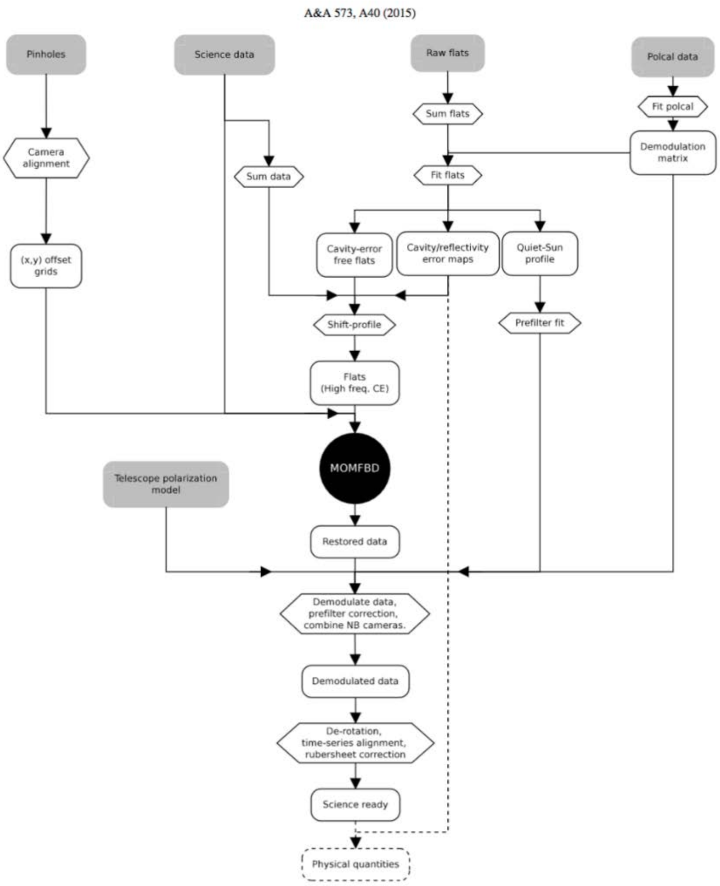

Setup of telescopes & instruments
Observations
Level 0 data
Instrumental calibration
Telescope calibration
Detector calibration
Level 1 data
Image reconstruction
Retrieval of Stokes parameters
Level 2 data
Inversion techniques
Retrieval of physical parameters
Level 3 data


CASSDA GUI
CURRENT SESSION
ALIGNMENT + ROI
CALIBRATION
RECONSTRUCTION
DEMOD_CAL
SAVE SETTINGS
ANALYSE DATA
CASSDA
CURRENT SETTINGS :
DEFAULT SETTINGS
LOAD SETTINGS
INFO
DATA SEQUENCE :
LOAD SEQUENCE
PREPARE SEQUENCE
NB Dark (D*):
NB Flat (F*):
NB Target (T*):
NB Scan (#1):
BB Dark (D*):
BB Flat (F*):
BB Target (T*):
BB Scan (#1):
LOAD
PREPARE
+ NO LEVEL2 BB DATA AVAILABLE
+ LEVEL2 NB DATA FOLDER AVAILABLE
+ NO LEVEL2 NB DATA AVAILABLE

This project is supported by the European Commission's FP7 Capacities Programme for the period April 2013 - March 2017 under the Grant Agreement number 312495.



A flow chart of the data calibration process in the CRISPRED data pipeline of the instrument CRISP@SST is shown in the image to the right. It demonstrates the complexity of calibrating spectropolarimetric data that come from systems using Fabry-Perot Interferometers. Starting points are the rounded boxes with a gray background: the raw data and the telescope polarization model. The diamond boxes indicate fitting and other processing. Products from fitting routines or data processing are represented by rounded, white boxes. The distinct symbol for the MOMFBD processing indicates that it is not done in IDL. Reflectivity and cavity errors must be included in the interpretation of the science data (outside the CRISPRED pipeline, hence



indicated with dashed lines). Omitted in the figure for brevity, all science and calibration images are corrected for dark current.

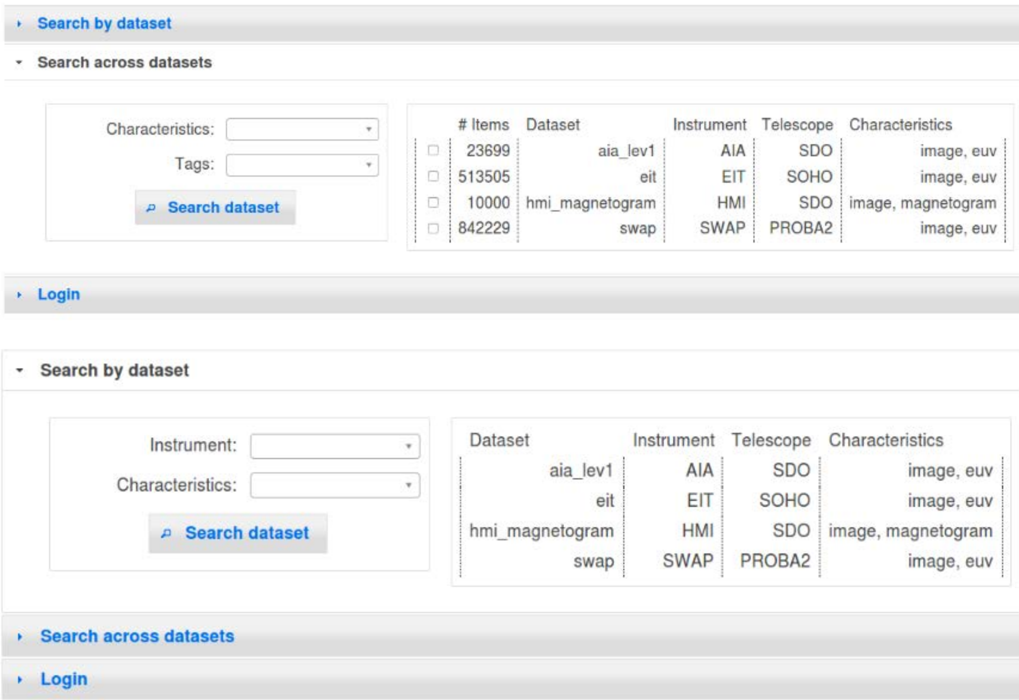
sWP20.3 Data archives and Solar Virtual Observatory

A document to define a standard for the metadata in Solar Physics has been produced. The standard has evolved continuously and the document has been updated whenever considered relevant. The latest version can be downloaded at http://sdc.uio.no/open/solarnet-20.3/. In the community it is known as the SOLARNET standard for metadata and is most relevant to the community world-wide. The team of the US 4m solar telescope DKIST who is designing the concept for their data pipelines is also taking advantage of 'our' European SOLARNET standard.

The SOLARNET metadata standard stresses the necessity to adhere to the 'WCS' coordinates: World Coordinate System. In the updated version the document distinguishes between optional and mandatory keywords. And mandatory keywords are given for distinguished cases. There are mandatory *general* keyword, like e.g., date and time of observation, begin and end, filename, and a name tag for the creator of the data file. Other mandatory keywords are to specify the WCS coordinate for the observation, the positional and velocity keywords of the observing instrument, data descriptive keywords, identifiers for the origin of the observation, instrument specific information. The document defines the usage of Header and Data Units, and the usage of mandatory keywords to define conflicting cases and tabulated keywords.

The document on metadata standard also lists *optional* keywords. The philosophy of optional keywords is that they should be used *if applicable*. E.g., if the data contains a cadence, the keyword 'CADENCE' should be used to quantify the planned time step between two subsequent frames. Note: An important feature of the SOLARNET standard is, that uncertainties and variations for timing and position keywords can be given. For example, with the keyword 'CADENCE', the average, minimum and maximum spacing can be specified with 'CADAVG'. CADMIN, and 'CADMAX'. If the cadence is fluctuating, its variance can be given with 'CADVAR'. This concept of uncertainties and errors is also applied many other keywords. E.g., for a position on the solar disk, a measurement error can be provided.

In this sub-work package we have achieved another major breakthrough: the ingestion of ground-based high-resolution spectro-polarimetric data into the SVO prototype. This was made possible, because during the SOLARNET project, data pipelines and data archives adopted the SOLARNET standard and data archives for various SOLARNET telescopes and instruments were developed. For example, the near-IR spectro-polarimeter GRIS@GREGOR now offers a quick look data archive that provides science-ready data for external users: http://archive.leibniz-kis.de/pub/gris/. The GRIS instrument data pipelines provides the necessary metadata that is ingested into the SVO prototype, such that the GRIS data is fully searchable by external scientists. A similar data archive is provided by BBI@GREGOR, GFPI@GREGOR, and the Italian IBIS@DST data. Their metadata is also ingested into the SVO prototype.



Screenshots from the SVO prototype: http://solarnet.oma.be/

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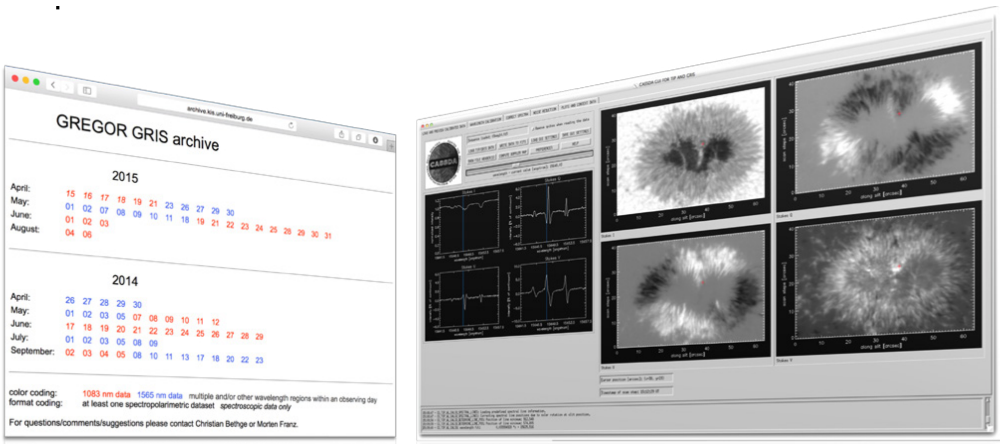
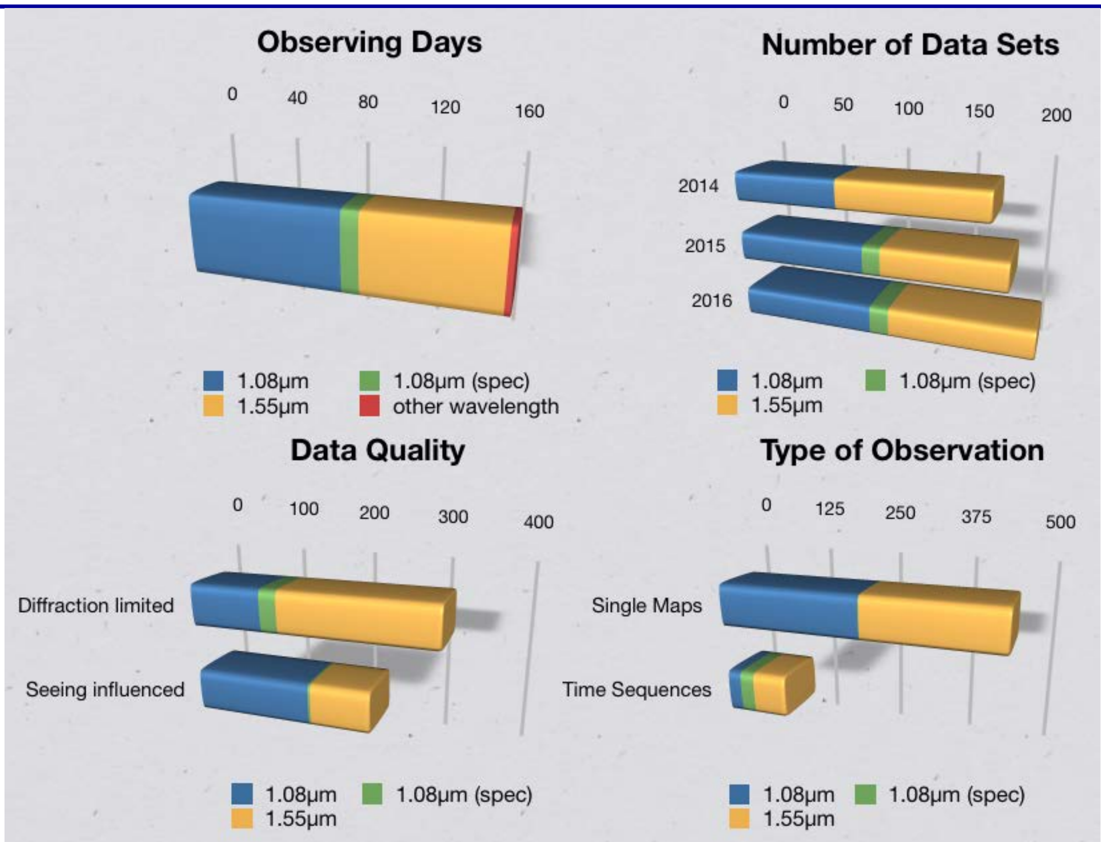
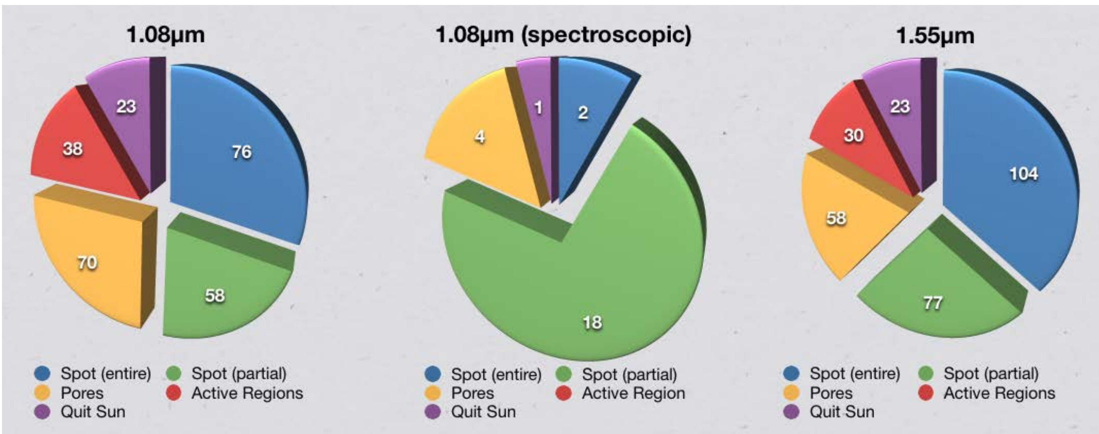






sWP20.4 Coordination with other infrastructures

In dedicated campaigns, facilities world-wide were coordinated to perform a joint scientific observation campaign. Progress in solar science relies on multi-instrument and multi-wavelength observations assisted by spectro-polarimetric observations with large field-of-views and long temporal coverage. Within this task, a number of such campaigns was performed and evaluated, using ground-based high-resolution telescopes in optical, near-IR, and radio wavelengths. Theses campaigns were supplemented by high-resolution and synoptic space-based missions like SDO, IRIS, STEREO, and Hinode.

Synoptic observations

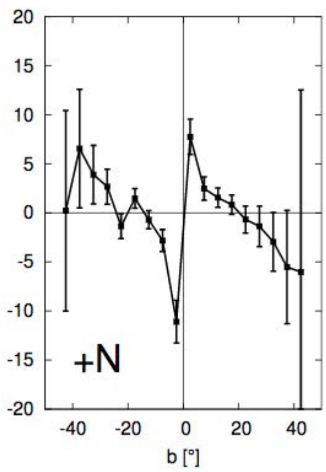
Solar differential rotation for the solar cycles nr. 20 and 22 was analysed using sunspot drawings from Kanzelhöhe Observatory for Solar and Environmental Research, University of Graz, Austria. The positions of sunspot groups were determined using a special software Sungrabber. Temporal, cycle-related variations of the solar rotation were investigated.

Solar differential rotation was measured tracing coronal bright points (CBP) in SDO/AIA full disc solar images. A segmentation algorithm, which uses multiple AIA channels in search for intensity enhancements in EUV and X-ray part of the spectrum compared to the background intensity, was applied to obtain positions of CBPs. After promising results for the test period of 2 days were obtained, the analysis was extended with data from about 6 months. Results on the solar differential rotation parameters for CBPs were compared with those obtained by other tracers and methods including helioseismology. We calculated the height of CBPs to be about 6500 km above the solar photosphere. By an analysis of the solar velocity field determined tracing CBPs, meridional motions, Reynolds stresses and random walk motions were investigated. Meridional motion is predominantly poleward for all latitudes, the horizontal Reynolds stress is consistent with transport of angular momentum towards the equator and the diffusion constant is about 260 km2/s in a good agreement with other measurements and models.

The measured and predicted amplitudes of the 24th solar cycle were compared. The modified minimum–maximum method with the time lag, belonging to the precursor class of methods, was applied to the smoothed monthly sunspot number values (the "old" data set, used before the change introduced on July 1st, 2015). The maximum of the 24th solar cycle occurred in April 2014 with an amplitude of R = 82 and this observed value is very close to our mean predicted value R = 83. The maximum was significantly weaker than in several previous solar cycles.

Sunspot drawings and full disc white light CCD images from the Kanzelhöhe Observatory for Solar and Environmental Research (KSO) were used to determine the solar differential rotation by tracing sunspot groups during the period 1964 – 2016. The differential rotation parameters derived from the KSO were compared with those collected from other data sets. Also, the north - south rotational asymmetry was investigated. Two procedures for the determination of the heliographic positions were applied: an interactive procedure on the KSO sunspot drawings (1964 - 2008, solar cycles nos. 20 - 23) and an automatic procedure on the KSO white light images (2009 - 2016, solar cycle no. 24). For the determination of the synodic angular rotation velocities two different methods have been used: a daily shift (DS) method and a robust linear least-squares fit (rLSQ) method. Afterwards the rotation velocities had to be converted from synodic to sidereal ones, which were then used in the least-squares fitting for the solar differential rotation law. A comparison of the interactive and automatic procedures was performed for the year 2014. The interactive procedure of position determination is fairly accurate but time consuming. In the case of the much faster automatic procedure for position determination, the rLSQ method for calculating rotational velocities turned out to be more reliable than the DS method. The best fit solar differential rotation profile for the whole time period is w(b) = (14.47 ± 0.01) - (2.66 ± 0.10) sin2b (deg/day) for the DS method and w(b) = (14.50 ± 0.01) - (2.87 ± 0.12) sin2b (deg/day) for the rLSQ method, respectively. A barely noticeable north - south asymmetry was observed for the whole time period 1964 - 2016. Rotation profiles, using different data sets, presented by other authors for the same time periods and the same tracer types, are in good agreement with obtained results. The KSO data set is in good agreement with Debrecen Photoheliographic Data and Greenwich Photoheliographic Results and is suitable for the investigation of the long term variabilities in the solar rotation profile. Also, the quality of the KSO sunspot drawings gradually increased during the last 50 years.

Atmospheric Imaging Assembly (AIA) images from the Solar Dynamics Observatory (SDO) were used to follow the motions of coronal bright points (CBPs) in the period 1 January - 19 May 2011 with a cadence of 10 minutes. This resulted in a data set of 80966 CBPs with measured lifetimes and mean velocities which were used in a random walk model to calculate the diffusion coefficient, D. The results show that D has a value of ≈ 260 km2 s−1 for CBPs with lifetime below 6 hours, decreasing to ≈ 170 km2 s−1 for lifetimes above 12 hours, with a mean value of ≈ 230 km2 s−1.

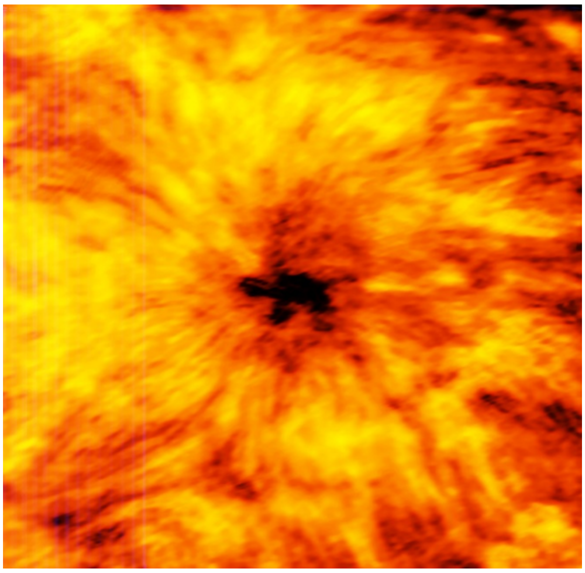


Meridional flow [m/s] versus heliographic latitude [degree] as inferred from Debrecen Photo-heliographic Data. Positive velocities indicate motions

The Debrecen Photoheliographic Data catalogue is a continuation of the Greenwich Photoheliographic Results providing daily positions of sunspots and sunspot groups. The data for sunspot groups focusing on meridional motions and transfer of angular momentum towards the solar equator were analysed. Velocities were calculated with a daily shift method including an automatic iterative process of removing the outliers. Apart from the standard differential rotation profile, we found meridional motion directed towards the zone of solar activity. The difference in measured meridional flow in comparison to Doppler measurements and some other tracer measurements is interpreted as a consequence of different flow patterns inside and outside of active regions. A statistically significant dependence of meridional motion on rotation velocity residuals confirming the transfer of angular momentum towards the equator was found. Analysis of horizontal Reynolds stress revealed that the transfer of angular momentum is stronger with increasing latitude up to about 40 deg where there is a possible maximum in absolute value.

The measured and predicted amplitudes of the 24th solar cycle were compared. The modified minimum–maximum method with the time lag, belonging to the precursor class of methods, was applied to the smoothed monthly sunspot number values (the "new" official data set, introduced on July 1st, 2015, after an extensive effort to recalibrate the data). The maximum of the 24th solar cycle occurred in April 2014 with an amplitude of R = 116 and this observed value is lower than the predicted values ranging between R = 117 and R = 142 (the difference being mostly below the corresponding RMSE). The last maximum was significantly weaker than in several previous solar cycles.

ALMA



New images taken with the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile have revealed otherwise invisible details of our Sun, including a new view of the dark, contorted centre of a sunspot that is nearly twice the diameter of the Earth. The images are the first ever made of the Sun with a facility where ESO is a partner, with a substantial contribution of Dr. Roman Brajsa (HVAR) who acknowledges funding from SOLARNET. The image to the right with a sunspot in the middle is taken at a wavelength of 1.25 mm. The results are an important expansion of the range of observations that can be used to probe the physics of our nearest star. The ALMA antennas had been carefully designed so they could image the Sun without being damaged by the intense heat of the focussed light. The corresponding press release can be found at http://www.eso.org/public/news/eso1703/ .

sWP20.5 Novel queue observing mode in solar physics

Prior to SOLARNET solar observing campaigns were executed in PI mode. A Principal Investigator travels to the telescope and performs the observations with a very limited level of technical assistance. This led to a distinct scientific career of an 'observer', since those PI needed to be acquainted with the optics and the instruments of a telescope, and how to use the sub-systems. As these telescope systems became more and more complex the observing task can no longer be performed by a solar physicist whose expertise focuses on solar physics. Therefore, novel observing modes needed to be developed in which a team of instrument experts carry out the observations and calibrate the data while the solar physicist analyses the data to the benefit of science. In the novel queue observing mode, observing proposals are evaluated and ranked by a time allocation committee, and executed by dedicated telescope staff.

During SOLARNET we gathered experience in operating solar telescopes in queued service mode performing dedicated campaigns at DST, SST, and GREGOR. Observing campaigns were queued according to scientific merit and executed based on several parameters like, e.g., target availability, seeing conditions, and instrumental configuration.

Valuable insights in practical realization issues were gained which will direct the implementation of the queued service mode at the planned European Solar Telescope (EST).

WP30: SOLAR PHYSICS NETWORKING

Leader organization: INAF

Participants: IAC, KIS, INAF, UiO, QUB, UCL-MSSL, AISAS, UWR, IAA-CSIC

Work-package summary

The aim of this work-package has been to foster collaborations among different solar physics groups, promote the interaction and cooperation among researchers of different level of expertise, as well as to encourage and promote synergies with other fields.

Some of the actions foreseen under this work-package have been: exploitation of ground- and space-based data; enhancement of collaborations with other communities and Projects; promotion of collaborations between the new generation of scientists and experienced researchers through short stays and training actions to acquire competences in relevant fields of solar physics.

This work-package is divided in three sub-Workpackages:

- sWP30.1 Meetings
- sWP30.2 Mobility
- sWP30.3 Training (Schools and Thematic Workshops)

sWP30.1: Meetings on solar physics

The objective of this sWP has been to put in contact different solar physics communities and researchers involved in different fields of research. In particular, it was aimed at achieving the following goals:

- Periodic meetings on topics related to solar physics and solar–stellar connections, where the participants could show the results of their research and profit from discussion time slots devoted to exchange of experience and competences.
- The fostering of collaborations aimed at improving the interaction between theoreticians, experts in numerical simulations and observers.
- The sharing of pipelines and software for solar data reduction and analysis.
- The consolidation of high-resolution MHD simulations to analyse the performance of advanced instrumentation for high–resolution solar observations.
- Promotion of seismological studies as a way to understand solar/ stellar interiors

Four meetings were organised by SOLARNET, as reported in the following Table:

Dates	Title	Location	Organiser
5-8 August 2013	Synergies between ground- and space-based solar research	Norway (Oslo)	UiO
2-5 February 2015	Solar and stellar magnetic activity	Italy (Palermo)	INAF
31 August – 4 Sept 2015	The Sun, the stars, and solar-stellar relations	Germany (Freiburg)	KIS
16 – 20 January 2017	The physics of the Sun from the interior to the outer atmosphere	Spain (Lanzarote)	IAC

The 1st SOLARNET Meeting "Synergies between ground- and space-based solar research" was held in Oslo on 5 – 8 August 2013 (http://folk.uio.no/matsc/oslo-13/index.html) together with the 3rd EAST / ATST Meeting. The meeting had 67 participants from both European and non-European countries. The program of the meeting was distributed in 17 Invited talks, 28 Contributed talks, and 15 e-posters. The on-line Proceedings of the Meeting are available at http://folk.uio.no/matsc/oslo-13/program.html. Exemption of the registration fee was given to 26 young participants.

The 2nd SOLARNET Meeting "Solar and stellar magnetic activity" was held in Palermo, Italy, on 2 - 5 February 2015 (http://www.astropa.inaf.it/Solarnet2015/Solarnet2015.html). Specific aims of this meeting were to review the current understanding of magnetic fields in the Sun and similar stars and to discuss future directions of research. The meeting was attended by 61 participants from both European and non-European countries. The program had 15 invited talks, 25 contributed talks, and 13 e-posters. The proceedings of the meeting are available at http://www.astropa.unipa.it/Solarnet2015/Proceedings/Proceedings.html . Exemption of the registration fee was given to 12 young participants.

The 3rd Solarnet Meeting "Solarnet III / HELAS VII / SpaceInn: The Sun, the stars and solar-stellar relations" was held in Freiburg 31 August – 4 September 2015 (http://www.iac.es/congreso/solarnet-3meeting/) together with the 7th International Meeting of the European Helio- and Asteroseismology Network (HELAS) and its project SpaceInn (Exploitation of Space Data for Innovative Helio- and Asteroseismology). The goals of the conference were to review the state of knowledge in helioseismology, which studies the interior of the Sun through observations of the waves observed at the surface, and the application of its tools and techniques to other stars, in the so called asteroseismology. The meeting had 84 participants from European and non-European countries. The meeting was characterized by both oral presentations and posters (13 invited talks, 46 contributed talks, 22 posters). In addition to the plenary sessions, four splinter meetings were held. The meeting was covered in Twitter. All posts related to the conference can be found via #cid_solarnet3_2015. In order to reach out the broad scientific community and the public, all material presented at the conference is made available on the Open Access internet platform www.science-media.org. Financial support, in form of waiver of the registration fee and/or travel support was given to 14 young participants.

The 4th Solarnet Meeting "The physics of the Sun from the interior to the outer atmosphere" was held in Arrecife, Lanzarote (Spain) from 16th to 20th January 2017, during the Third Reporting Period. The purpose of this conference was to provide a coherent picture of the Sun as a single physical system playing all the underlying physical processes measured and observed in the solar atmosphere to date. The meeting had 143 participants from European and non-European countries. Financial support, in form of waiver of the registration fee and/or travel support, was given to 26 young participants. The meeting was covered in Twitter. The posts related to the conference can be found via #solarnet4m. The presentations and the posters can be downloaded at the following link:
http://www.iac.es/congreso/solarnet-4meeting/pages/talk-and-poster-download.php

sWP30.2: Mobility

SOLARNET supported the mobility of young researchers as part of the networking activities in this work-package. The mobility programme has been designed, as an additional aspect of the training program, to reinforce the contacts between different groups and to allow young researchers to begin early to establish international collaborations.

This task was carried out based on the following items:

- Availability of institutions to host young researchers for short stays (up to 2-3 months).
- Periodic calls aimed at selecting a number of candidates preferentially directed at Ph.D. students and young researchers from EC countries.
- The selection of the granted proposals was announced each year on March 31st and Sept 30th.
- The mobility had to start during the 6-month periods starting in July 1st and Jan 1st.

This task was supervised by the Mobility Evaluation Committee (MEC), a group especially created within SOLARNET, which evaluated and selected the submitted applications. The program supported travel, accommodation and subsistence costs up to a given amount per week. The application was always open and a deadline was set every six months. At that moment, the MEC met and decided, based on a combination of curricula and quality of the project, the young students whose visit could be funded. In order to obtain a better distribution of participants in the framework of the gender aspect, the poster advertising the last announcement included a statement inviting explicitely young female scientists to apply (figure below).


This project is supported by the European Commission's FP7 Capacities Programme for the period April 2013 – March 2017 under the Grant Agreement number 312495.

Mobility of Young Researchers Programme
Call for Proposals

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SOLARNET brings together and integrate the major European research infrastructures in the field of high-resolution solar physics, in order to promote their coordinated use and development. Networking activities, access to first-class infrastructures and joint research and development activities will be carried out under this major collaboration, where all pertinent European research institutions are involved, as well as private companies and other non-EU organizartions. SOLARNET achievements will be of paramount relevance to contribute towards the realisation of the European Solar Telescope (EST).

SOLARNET is pleased to announce the seventh call for proposals of its Mobility of Young Researchers Programme.

This Programme aims to contribute to the professional development of researchers at the first steps of their careers, by offering short stays (up to 3 months) preferably at one of the SOLARNET member institutions, public or private entities. Other host institutions from anywhere will be also considered, as far as they are aligned with the scientific interests and objectives of this European initiative. It is expected also that this Programme will promote the integration of this new generation of researchers into the European solar physics community with long-lasting effects.

Applications from young researchers are welcome, and can be submitted at any time until March 15th 2016. Intermediate deadlines are issued to allow the evaluation of applications received until a specific date:

March 15th 2016
SEVENTH DEADLINE
for stays to be carried out within the period
July 1st – December 30th 2016

There are up to 2 grants available for this sixth period of visits.

In order to promote the advancement of equal opportunities for women and men in science and in particular to increase gender equality within the SOLARNET Mobility Programme, we strongly encourage young women astronomers to apply.

EC funds will cover travel and accommodation costs for stays from a minimum of 1 month to a maximum of 3 months. Travel costs will be supported up to 600 €/fellow, and accommodation and subsistence costs up to 200 €/week.

Interested applicants are invited to complete the on-line form available at www.solarnet-east.eu (application forms >> Mobility of Young Researchers).

A motivation letter and a brief summary of the proposed work at the host institution, together with a brief CV, need to be attached to the on-line form. Applicants are encouraged to contact the host institution in advance.

More information
www.solarnet-east.eu

Poster announcing the 7th Call of the Mobility Program

The Mobility program, characterized by 7 Calls during the period March 2013-March 2016, has been a definite success, with a high number of applicants (45). One of the big successes of the program has been to use the available funds to cover more young researchers than initially expected. In the following table we list the number of proposals and the number of funded young researchers:

Call	Received proposals	Initially proposed	Funded proposals	Overpetition factor
July-December 2013	2	4	2	1
January-June 2014	6	2	5	1.2
July-December 2014	4	2	3	1.3
January-June 2015	11	2	3	3.6
July-December 2015	5	2	3	1.7
January-June 2016	2	2	2	1
July-December 2016	5	2	3	1.7

The following table lists the Young Researchers who got the grant to carry on their Mobility Program, together with the Host Institution, the topic of the research and the duration of the stay.

Name	Nationality	University PhD	Host Institution	Topic	Duration
Christopher Nelson	United Kingdom	University of Sheffield	National Solar Observatory	Ellerman bombs	4 weeks
Eamon Scullion	United Kingdom	University of Sheffield	The Queen's University of Belfast	Alignment DST-ROSA	10 weeks
Iker Sánchez Requerey	Spain	Instituto de Astrofísica de Andalucía	Instituto de Astrofísica de Canarias	Inversions with SIR	8 weeks
Ivan Milic	Serbia	Astronomical Observatory	Centre National de la Recherche Scientifique	2D/3D radiative transfer	8 weeks
Petros Syntelis	Greece	Academy of Athens – University of Athens	University of St. Andrews	MHD models of flux emergence	14 weeks

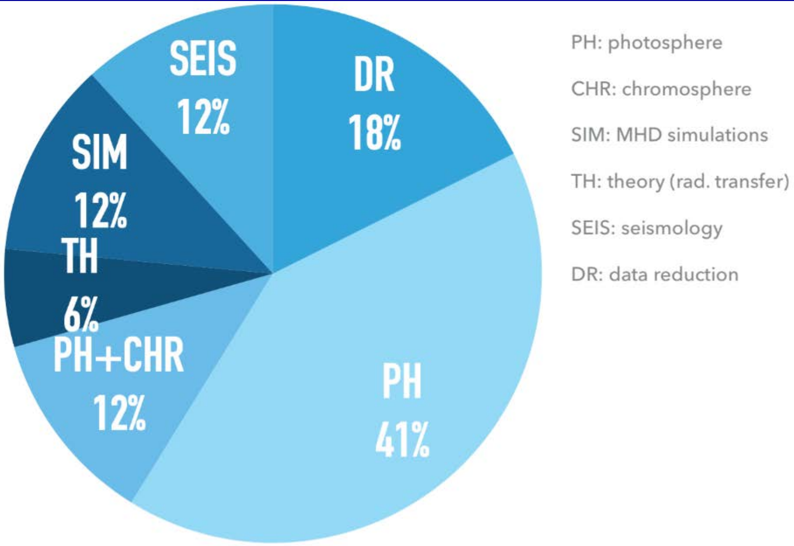
Rebecca Hewitt	United Kingdom	Queen's University Belfast	Università degli Studi di Roma Tor Vergata	Magnetic bright points	8 weeks
Mariachiara Falco	Italy	Università degli Studi di Catania	Kiepenheuer-Institut fuer Sonnenphysik	Magnetoconvection in sunspots	14 weeks
David Mactaggart	United Kingdom	Abertay University	Istituto Nazionale di Astrofisica	Study of ephemeral active regions	9 weeks
Alice Cristaldi	Italy	Università degli Studi di Roma Tor Vergata	Instituto de Astrofísica de Canarias	Inversion of CRISP data	6 weeks
Richard Morton	United Kingdom	Northumbria University	Stockholm University	Modeling of chromospheric fibrils and other small-scale chromospheric structures	4 weeks
Rohan Louis	India	Leibniz Institut fur Astrophysik Potsdam	Instituto de Astrofísica de Andalucía	Spectropolarimetry of small-scale transients in sunspots	7 weeks
René Kiefer	Germany	Kiepenheuer Institute for Solar Physics	NSO	Study of p-modes and their relation to solar activity	12 weeks
Maciej Lucasz Zapior	Poland	University of the Balearic Islands, Spain	Astronomický ústav AV CR v.v.i, Slovakia	Prominence seismology In different optical depths.	6 weeks
Damien Przybylski	Poland	Monash University, Australia	Instituto de Astrofísica de Canarias, Spain	Simulations of torsional oscillations in a flux tube	6 weeks

Luca Giovannelli	Italy	University of Rome Tor Vergata, Italy	Kiepenheuer-Institut fuer Sonnenphysik, Germany	FPI and bidimensional spectroscopy, and the emergence rate of bipolar magnetic elements in the Quiet Sun	6 weeks
Vincent Boning	Germany	Kiepenheuer Institute for Solar Physics	New Mexico State University	Time-distance helioseismology	8 weeks
David Mactaggart	United Kingdom	Abertay University	Istituto Nazionale di Astrofisica	Mechanisms of formation of orphan penumbrae	9 weeks
Mariarita Murabito	Italy	Università degli Studi di Catania, Italy	Instituto de Astrofísica de Andalucía	Spectro-polarimetry of sunspots	11 weeks
Bahar Bidaran	Iran	Alzahra University	University of Oslo	Magnetic bright points	9 weeks
Roberta Forte	Italy	University of Rome Tor Vergata, Italy	Harvard-Smithsonian Center for Astrophysics	Magnetograms pipeline and flare forecasting algorithm	7 weeks

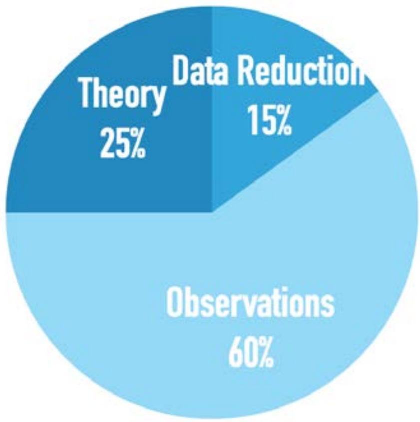
Some statistical figures are:

- ✓ 20 visits in 7 calls (5 women)
- ✓ range of duration: 4 – 14 weeks
- ✓ total weeks: 165
- ✓ average duration: 8.3 weeks
- ✓ average cost per student: 2440 €
- ✓ average cost per week: 251 €
- ✓ total costs 49826,29 € (planned 35200 €)
- ✓ 5 – 6 papers in preparation/submitted/accepted

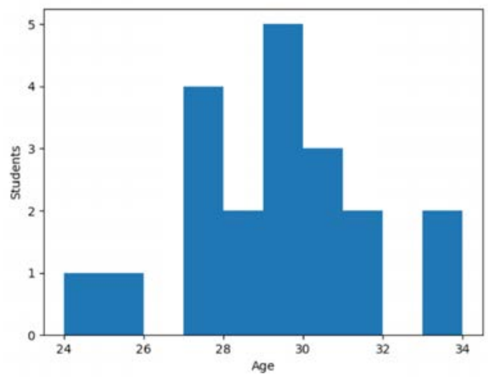
The following figures show the distribution of the subjects investigated by the Young Researchers and the relevant methods of investigations, and some statistics of the Programme.

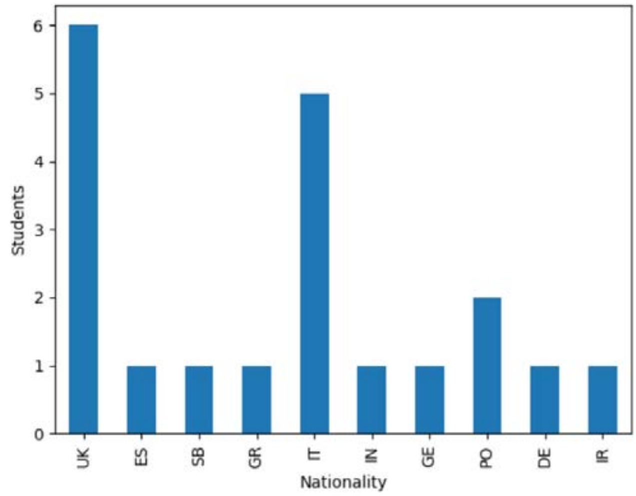


Percentages of distribution of the subjects investigated by the Young Researchers during their visits to the Host Institutions.

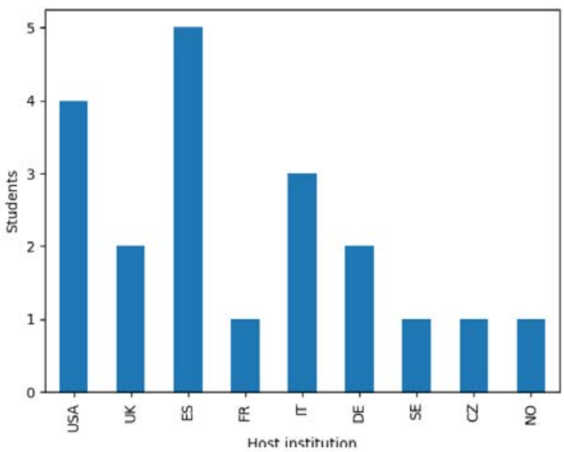


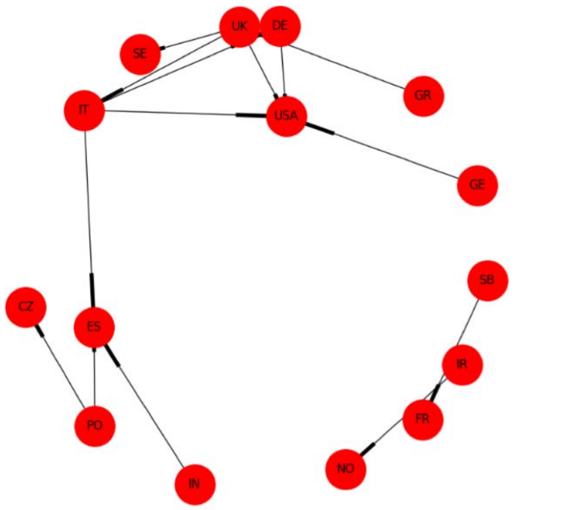
Percentages of distribution of the methods of investigation used by the Young Researchers.





Age (left) and Nationality (right) of the Young Researchers.





Number of Young Researchers in each Host Institutions (left) and schematic representation of the Young Researcher's country of origin wrt Host Institution country (right).

It is also worthwhile to stress that the applicants to the last Call were all young female scientists, ensuring that the gender issue in the end was more balanced than before the last Call.

All funded young researchers and most of the host institutions that they have visited have submitted brief reports summarizing the work carried out during the stay. This was one of the deliverables planned for SOLARNET. The high level of the collaborations clearly demonstrates the success of the program.

sWP30.3: Training (Schools and Thematic Workshops)

The aim of this task was the organization of summer/winter schools for PhD students and novel post-doc researchers on topics related to the development of new instrumentation for solar observations, diagnostic tools, hot solar research topics and fields of mutual interest for solar and stellar physicists.

This task had the goal to organize 5 Schools and Thematic Workshops, as reported in the following Table:

Dates	School	Workshop	Location	Org.
24 March – 4 April 2014	***Introduction to Solar Physics***	Radiative processes in the Sun and the stars	Wroclaw (Poland)	UWRO
5-15 October 2014	Ground- and space- based instruments	Methods in high resolution and synoptic solar physics	Tatranska Lomnica (Slovakia)	AISAS
18 – 28 May 2015	***Solar magnetic fields: modeling and measuring techniques***	Polarization as a tool to study the Sun, the Solar System, and beyond	Granada (Spain)	IAA-CSIC
13 – 22 April 2016	Solar MHD and reconnection	Solar eruptive events: observations and modelling	London (UK)	MSSL/UCL
25 August – 2 September 2016	***MHD waves and oscillations in the solar atmosphere***	Heating mechanisms in the solar atmosphere	Belfast (UK)	QUB

The 1st SOLARNET School was held in Wroclaw (Poland) from March 24 to April 4, 2014 (http://school.astro.uni.wroc.pl) and was dedicated to PhD students and novel post-doc researchers who wanted to broaden their knowledge on solar physics. In addition to the lectures, several "hands-on" sessions were planned, coupled to the appropriate lectures, in order to allow the participants to develop their practical skills. There were 40 applications for the school participation submitted to the Scientific Organizing Committee and 20 young researchers were finally selected. During the School, some lectures on complementary skills were provided, in order to describe the practical aspects in the work of researcher. The presentations and the materials provided by the lecturers are available at the following webpage: http://school.astro.uni.wroc.pl/materials.php . During the School each student gave a short presentation on her/his scientific work (around 15 minutes); all the presentations are available at http://school.astro.uni.wroc.pl/presentations.php . In parallel with the school, the SOLARNET workshop "Radiative processes in the Sun and stars" was also organized in order to allow the young researchers to participate in splinter sessions and to discuss their research with experienced scientists. The main aim of the workshop was to present and discuss the recent scientific results concerning different aspects of solar and stellar phenomena.

The 2nd SOLARNET School "Ground- and space- based solar instruments" (see http://www.astro.sk/SOLARNET_2ND_SCHOOL/solarnet) was held in Tatranska Lomnica (Slovakia), in October 5-16, 2014. The number of applications was 19 and 12 students were selected to attend the School. The lectures, carried out by experienced scientists, were aimed at giving students knowledge on current and future ground- and space- based solar instruments, observational strategies, post-focus instrumentation and data acquisition. The hands-on sessions were carried out also at Lomnický štít Observatory on the Double Solar Coronagraph and Coronal Multi-channel Polarimeter. There was information presented on the European Solar Telescope (EST) project and on the FP7 SOLARNET project, as well as lectures on complementary skills. In parallel with the school, the Workshop: "Methods in high resolution and synoptic solar physics" and 2nd SPRING (Solar Physics Research Integrated Network Group) were also organized in the same place, Slovakia (see the page http://www.astro.sk/SOLARNET_2ND_WORKSHOP/ for a detailed description of the program).

The 3rd SOLARNET School on "Solar Magnetic Fields: Modeling and Measuring Techniques" was held in Granada (Spain) between the 18th and the 23rd of May, 2015. The goal of this school was to provide PhD students and early career potsdocs with a solid background in solar spectropolarimetry, radiative transfer of polarized light and diagnostic techniques. The programme combined both theory and hands-on activities to achieve that goal. Lecture slides, as well as the necessary inversion codes for the hands-on exercises, were provided for downloading at the School's website (http://spg.iaa.es/School). A total of 26 young scientists, comprising PhD candidates and early career postdocs from more than 10 countries, were selected to participate in the school (out of 32 applicants). Students were invited to stay one more week and attend the 3rd SOLARNET Workshop, to be held the following week, with the financial support from SOLARNET. The 3rd SOLARNET Workshop was held in Granada (Spain) between the 25th and 28th of May, 2015. (http://granada-en.congresoseci.com/polarization2015/index).

The 4th SOLARNET School on "**Solar MHD and Reconnection**" was held at MSSL (Surrey, UK), 13th-19th of April, 2016 (http://www.ucl.ac.uk/mssl/solar/SOLARNET-4). The aim of this school was to provide students and early-career researchers with a solid grounding in Solar MHD and Reconnection using a combination of lectures and hands-on analysis sessions. The School was attended by 41 participants (16 women); further, 39 % of the speakers were women. Lecture slides (https://www.ucl.ac.uk/mssl/solar/SOLARNET-4/school-programme) were provided for downloading from the School's website and are still available at the same link. The associated thematic Workshop on "Solar eruptive events: observations and modeling" (http://www.ucl.ac.uk/mssl/solar/SOLARNET-4/workshop-programme) was held between 20th and 22nd April. During the workshop the students attending the School were invited to present their research.

The 5th SOLARNET School on “Waves and oscillations in the solar atmosphere” and the thematic Workshop on “Heating Mechanisms in the Solar Atmosphere” were held at Queen’s University Belfast from the 25th of August to the 2nd of September 2016 (https://star.pst.qub.ac.uk/wiki/doku.php/public/solarnet5/start). The School was attended by 25 early career researchers from 10 different countries (UK, Germany, Austria, Belgium, Norway, Sweden, Spain, USA, Algeria, Georgia. Among these, 11 attendees were women. Lecture slides, as well as the exercises and the necessary inversion codes for the hands-on activities, were provided for downloading from the School’s website (https://star.pst.qub.ac.uk/wiki/doku.php/public/solarnet5/start) and are still available at the same link. The 5th SOLARNET Workshop was held in Belfast (UK) between the 31st August and the 2nd of September, 2016. The Workshop was attended by 48 researchers from 13 different countries (UK, Germany, Austria, Belgium, Italy, Norway, Sweden, Spain, USA, Algeria, Georgia, India, Bulgaria). Among these, 23 attendees were early career researchers and 15 attendees were women.

WP40: Innovation Towards Industry

Leader Organization: Tecnalia

Participants: TECNALIA, IAC, KIS, INAF, CNRS, UCL-MSSL, AISAS, ROB

Work-package summary

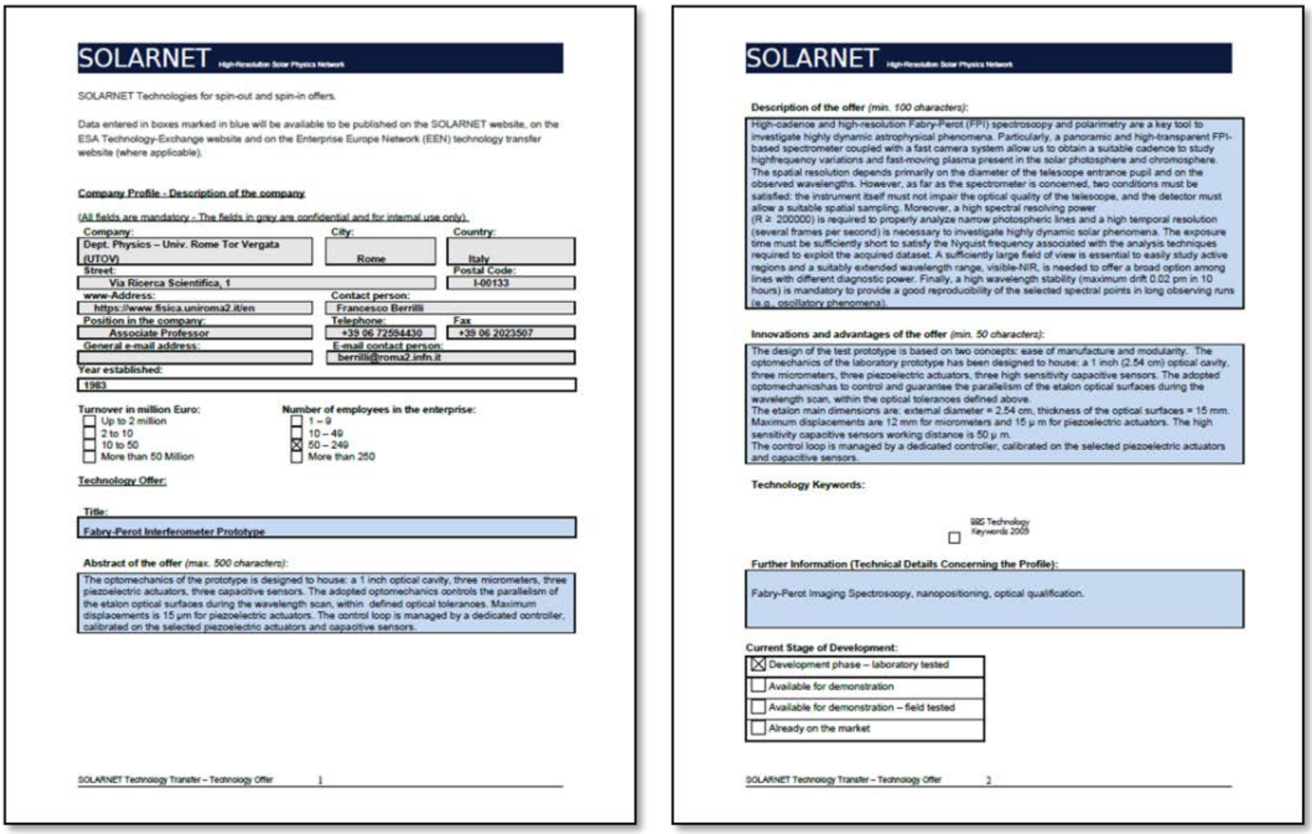
WP40 Overall Objectives

The overall objectives of WP40 can be defined as follows:

- Identification and analysis of technologies, techniques and new concepts already in use at the forefront of solar physics' developments with potential interest for other sectors.
- Dissemination of the innovative aspects and findings of the project towards industry, through the existing and highly successful industrial associations and related high-tech companies at EU level.
- Assessment of space technologies of most interest for solar physics developments, and identification of common needs and opportunities.
- Extension of the effort of collaboration between high-tech companies, universities and public organisations on solar physics and related fields, oriented to the transfer of knowledge using well proven methodologies.
- Increase of the potential for innovation of research infrastructures on solar physics.
- Promotion of synergies with other I3 initiatives on this same topic.

To reach these objectives the following tasks were addressed:

- Identification and analysis of technologies, techniques and new concepts
  - Development of a database for:
    - Technologies Offers
    - Consortium knowledge base
    - Technology Needs identified by the solar astrophysics community
- Dissemination of the innovative aspects and findings of the project towards industry
  - International/European Events
  - SOLARNET workshops
  - European networks
  - Other



SOLARNET High-Resolution Solar Physics Network

SOLARNET Technologies for spin-out and spin-in offers.

Data entered in boxes marked in blue will be available to be published on the SOLARNET website, on the ESA Technology-Exchange website and on the Enterprise Europe Network (EEN) technology transfer website (where applicable).

Company Profile - Description of the company

(All fields are mandatory - The fields in grey are confidential and for internal use only).

Company: Dept. Physics – Univ. Rome Tor Vergata (UTOV)
City: Rome
Country: Italy
Street: Via Ricerca Scientifica, 1
Postal Code: I-00133
www-Address: https://www.fisica.uniroma2.it/en
Contact person: Francesco Berrilli
Position in the company: Associate Professor
Telephone: +39 06 72594430
Fax: +39 06 2023507
General e-mail address:
E-mail contact person: berrilli@roma2.infn.it
Year established: 1983

Turnover in million Euro:
☐ Up to 2 million
☐ 2 to 10
☐ 10 to 50
☐ More than 50 Million

Number of employees in the enterprise:
☐ 1 – 9
☐ 10 – 49
☒ 50 – 249
☐ More than 250

Technology Offer:

Title: Fabry-Perot Interferometer Prototype

Abstract of the offer *(max. 500 characters)*:

The optomechanics of the prototype is designed to house: a 1 inch optical cavity, three micrometers, three piezoelectric actuators, three capacitive sensors. The adopted optomechanics controls the parallelism of the etalon optical surfaces during the wavelength scan, within defined optical tolerances. Maximum displacements is 15 µm for piezoelectric actuators. The control loop is managed by a dedicated controller, calibrated on the selected piezoelectric actuators and capacitive sensors.

SOLARNET Technology Transfer – Technology Offer 1

SOLARNET High-Resolution Solar Physics Network

Description of the offer *(min. 100 characters)*:

High-cadence and high-resolution Fabry-Perot (FPI) spectroscopy and polarimetry are a key tool to investigate highly dynamic astrophysical phenomena. Particularly, a panoramic and high-transparent FPI-based spectrometer coupled with a fast camera system allow us to obtain a suitable cadence to study highfrequency variations and fast-moving plasma present in the solar photosphere and chromosphere. The spatial resolution depends primarily on the diameter of the telescope entrance pupil and on the observed wavelengths. However, as far as the spectrometer is concerned, two conditions must be satisfied: the instrument itself must not impair the optical quality of the telescope, and the detector must allow a suitable spatial sampling. Moreover, a high spectral resolving power ($R \geq 200000$) is required to properly analyze narrow photospheric lines and a high temporal resolution (several frames per second) is necessary to investigate highly dynamic solar phenomena. The exposure time must be sufficiently short to satisfy the Nyquist frequency associated with the analysis techniques required to exploit the acquired dataset. A sufficiently large field of view is essential to easily study active regions and a suitably extended wavelength range, visible-NIR, is needed to offer a broad option among lines with different diagnostic power. Finally, a high wavelength stability (maximum drift 0.02 pm in 10 hours) is mandatory to provide a good reproducibility of the selected spectral points in long observing runs (e.g., oscillatory phenomena).

Innovations and advantages of the offer *(min. 50 characters)*:

The design of the test prototype is based on two concepts: ease of manufacture and modularity. The optomechanics of the laboratory prototype has been designed to house: a 1 inch (2.54 cm) optical cavity, three micrometers, three piezoelectric actuators, three high sensitivity capacitive sensors. The adopted optomechanicshas to control and guarantee the parallelism of the etalon optical surfaces during the wavelength scan, within the optical tolerances defined above.
The etalon main dimensions are: external diameter = 2.54 cm, thickness of the optical surfaces = 15 mm. Maximum displacements are 12 mm for micrometers and 15 µ m for piezoelectric actuators. The high sensitivity capacitive sensors working distance is 50 µ m.
The control loop is managed by a dedicated controller, calibrated on the selected piezoelectric actuators and capacitive sensors.

Technology Keywords:

☐ BBS Technology Keywords 2009

Further Information (Technical Details Concerning the Profile):

Fabry-Perot Imaging Spectroscopy, nanopositioning, optical qualification.

Current Stage of Development:
☒ Development phase – laboratory tested
☐ Available for demonstration
☐ Available for demonstration – field tested
☐ Already on the market

SOLARNET Technology Transfer – Technology Offer 2

Example of technology offer template (Fabry Perot Interferometer)

- Organisation of workshops related to technology transfer
  - 1st Solarnet Technology Transfer Workshop linked with SOFT 2014 Fusion Conference (San Sebastian, Spain). It showed several technologies/needs with potential solutions/ collaborations within the fusion industry.
  - 2nd Solarnet Technology Transfer Workshop was held during this period. Linked with LSW London Space Week, B2B and Summit Conference (London, UK). It showed a significant number of technologies/needs with potential solutions/collaborations within the space industry.
  - 3rd Solarnet Technology Transfer Workshop between SOLARNET and ESA-ESOC (July 2016). Presentation of SOLARNET project and relation to EST. Presentation of EST/SOLARNET Technology Offers/Needs to ESOC. ESOC presented requirements related to future Optical Ground Stations.
- Assessment of space technologies
  - Tecnalia has access to the ESA European Technology Transfer Network database

  - Continuous monitoring of space technologies for potential application in solar astrophysics community
  - Monitoring of opportunities for transfer out from ground based solar telescopes to space based or other sector applications
  - Monitoring of Invitation To Tender (ITT) opportunities through the ESA EMITS portal

- Dissemination of the project and specifically the technology offer and needs listings through:
  - Numerous Spanish space industry meetings
  - Participation at International/European Events
  - Three SOLARNET Industrial workshops
  - Continued interaction with European networks (including ESA)
  - Fact finding mission to EC (Brussels)
  - Continued development of national industrial contacts.

- Organisation of Common Exploitation Booster workshop

  SOLARNET was contacted by EC in Sep 2016 to invite the project to submit a proposal to the Common Exploitation Booster Support Service. The successful proposal was confirmed in late December 2016 and arranged for the end of February 2017 in order to fit within the project timeframe. Common Exploitation Booster Support Services aim to bridge the gap between research results and exploitation by helping the project consortia in:

  - raising awareness on exploitation possibilities and exploitation planning;
  - clarifying issues, exploring solutions and actions, anticipating possible conflicts for successful exploitation;
  - setting up roadmaps for the long-term sustainability of the project results;
  - creating value out of novel knowledge (recognizing exploitable results, creating revenues, improving skills, standardization or patenting, finding pathways for future work).

- Identification of future projects

  Related to 3rd Industrial Workshop, WP40 has identified future potential ESA GSTP projects related to the development of the optical ground station that should be further assessed by members of the SOLARNET community for future funding opportunities:

  - Laser ranger (approx. budget 7-8 M€).
  - Low Cost Meter-Class Adaptive Optics Communications Breadboard (1M€)

- Deep Space Low Cost 4m monolithic Optical Antenna for Day/Night Operations (400k€)
- 4m mirror concept (approx. budget 20M€)

- Promotion of synergies with other I3 initiatives on this same topic.

  The main contact with I3 initiatives has been with ASTERICS (www.asterics2020.eu). The aim of the collaboration was the management and exchange of large volumes of data related to ESFRI projects.

WP50: Innovative data tools

Leader organization: SU

Participants: AIP, IAC, CNRS, KIS, INAF, QUB, NSO, ROB, SU, UCL-MSSL, UiO, UToV

Work-package progress summary

Two were the main goals of this work-package:

- Develop data-reduction pipelines for the most important European ground-based high resolution solar instruments. Enhancement of observational procedures for increased productivity and easier co-observing and combination of data. The pipelines will produce data and meta-data fulfilling the requirements of a Solar Virtual Observatory (SVO).
- Set up a prototype for a SVO archive.

To that aim, the WP50 was divided into 4 tasks grouped within two areas corresponding to the main objectives:

- sWP50.1: Data Reduction Pipelines
    - Task WP50.1.1: General pipeline work
    - Task WP50.1.2: Data compression
    - Task WP50.1.3: Image restoration
- sWP50.2: Solar Virtual Observatory

sWP50.1 Data Reduction Pipelines

Modern astronomical instruments produce data that must be subject to several complicated calibration steps in order to be scientifically useful. The general data pipeline work in task WP50.1.1 and the improvement of image-restoration techniques in task WP50.1.3 were necessary to allow the current major European solar instruments reach their full potential. The study of data-compression techniques in task WP50.1.2 is mainly relevant for future installations.

Task sWP50.1.1 General pipeline work

The goal of sWP50.1 was to produce data pipelines for the major European solar instruments. In this context, a data pipeline is the software that calibrates and administrates raw data so that it can be scientifically analysed. At the start of SOLARNET, some of these instruments were only in a planning state, and for the instruments that did exist, the pipelines were in different stages of development. In general the existing pipelines were not user friendly, their data formats ad hoc, and the output seldom suitable for being ingested in virtual observatories. A virtual observatory is a database where a scientist can search for astronomical data suitable for a certain project, thus making use of archived data instead of spending expensive telescope time on something that already has been observed and/or finding new and valuable uses of data originally recorded for some other purpose.

As input for the pipeline work, SOLARNET sWP20.2 issued guidelines with general recommendations. The most important of these was that output data should be in the FITS format with metadata included as standardised headers. Metadata are data that describe the circumstances of the observations and how the data have been processed. It was the task of SOLARNET sWP20.3 to produce recommendations for the FITS headers and they were issued in the corresponding report and much of the work addressed here was devoted to adapting pipelines to these recommendations. This is no small task. Being fully compliant with the recommendations means introducing 99 new keywords and their values while making sure that no other keyword is used in a conflicting way. At the same time auxiliary data such as wavelength scales would have to be treated and packaged according to new specifications. The SOLARNET recommendations include a self-declaration of its level of compliancy. Thus SOLARNET=1.0 means fully compliant and SOLARNET=0.5 means partially compliant (some fundamental keywords exist and there are no conflicts between other keywords and the SOLARNET recommendations). Perhaps the most important legacy of this effort is that the community has learnt how important these issues are and how they should be tackled.

While the aspect of the pipeline work that has to do with metadata may be what gets the most focus here, it should not be forgotten that the bulk of the effort always goes to solving idiosyncratic technical problems. The following is a summary of work being done.

This table is a brief overview of the pipelines produced in WP50. For a detailed report we refer to deliverable D50.7.

Telescope	Instrument	Responsible partner	Pipeline exists	Pipeline name	Meta-data treatment
GREGOR	GRIS	KIS	Y	GRIS	Y
GREGOR	HiFI	AIP	Y	sTools	SOLARNET=0.5
GREGOR	GFPI	AIP	Y	sTools	(Y)
SST	CRISP	SU	Y	CRISPRED	(Y)
SST	CHROMIS	SU	Y	CHROMISRED	SOLARNET=0.5
SST	TRIPPEL	SU	Y	Specred	(Y)
VTT	LARS	KIS	Y	LDRC	Y
VTT	TESOS	KIS	Y	CASSDA GUI TESOS	SOLARNET=0.5
DST	ROSA	QUB	Y	ROSA data reduction pipeline	SOLARNET=0.5
DST	IBIS	INAF	Y	ibis_lib	SOLARNET=0.5
THEMIS	TUNIS	CNRS	Y	Tunvision	Y
THEMIS	MTR	CNRS	Y	SQUV	(Y)

GRIS (IAC)

This pipeline is almost completely automatic, only demanding a minimum of input from the user. The output data are now very close to being SOLARNET compliant. As GRIS produces spectrograms, there is no image reconstruction technique involved.

BLISS/HiFI (AIP)

When SOLARNET started, BLISS was a planned instrument for the GREGOR telescope. It was later cancelled but replaced by HiFI which is a context imager for blue light that is less ambitious than the projected BLISS. The SOLARNET Executive Committee approved that the software development for HiFI replaces that for BLISS. HiFI is one of the instruments that use the data pipeline **sTools**. HiFI metadata is conforming to the SOLARNET=0.5 level. A technical obstacle for reaching detailed compliancy is that the GREGOR telescope pointing recording has uncertainties, precluding exact automatic recording of the position on the solar disc. Image reconstruction using Speckle.

Publication: C. Kuckein, C. Denker, M. Verma et al., 2017, in: Fine Structure and Dynamics of the Solar Atmosphere. Vargas Domínguez, S., Kosvichev, A.G., Harra, L., Antolin, P. (eds.), Proceedings of the International Astronomical Union, Symposium 327, in press. http://adsabs.harvard.edu/abs/2017arXiv170101670K.

GFPI (AIP)

The pipeline software is sTools which is also used for HiFI. Once the HiFI metadata treatment has been verified to comply with recommendations the procedure will be transferred to GFPI data. The work with GFPI data is more complicated than for HiFI. Image reconstruction using MOMFBD.

Publication: C. Kuckein, C. Denker, M. Verma et al., 2017, in: Fine Structure and Dynamics of the Solar Atmosphere. Vargas Domínguez, S., Kosvichev, A.G., Harra, L., Antolin, P. (eds.), Proceedings of the International Astronomical Union, Symposium 327, in press.
http://adsabs.harvard.edu/abs/2017arXiv170101670K

CRISP, CHROMIS (SU)

CRISPRED, the pipeline for CRISP data, was developed during the first half of the SOLARNET. It has played an important role in solar physics for allowing several researchers to use CRISP. CRISPRED has active users in twelve institutes (as judged from the subscriptions for the mailing list for CRISPRED/CHROMISRED users). CHROMIS was installed at the SST in August 2016 and the first observations were performed during the following two months. This meant that much of the effort during the last months of the SOLARNET project was spent on producing its pipeline: CHROMISRED. This new pipeline was built with similar and partly overlapping software as the existing CRISPRED for CRISP. It has more than 50000 lines of code, not counting the image-reconstruction part. CHROMISRED is close to becoming fully compliant with the SOLARNET metadata standards (SOLARNET=1.0). After it has been found stable, CRISPRED will be taken to that level too as the two pipelines are merged. Both pipelines involve MOMFBD image reconstruction.

Publication: de la Cruz et al. Astronomy & Astrophysics, 573, A40, 2015.

Instrument CHROMIS at the SST. The pipeline is the software that takes care of the data from the instrument.

TRIPPEL (SU)

This instrument is arguably the least standardised in the whole suite since observing campaigns make different choices for detectors and slit-jaw imaging setups. Thus many changes are made between different data sets, so much that it is not enough to set a few input parameters. The goal has been that such changes should be confined to a minimum number subroutines.

LARS (KIS)

The instrument was upgraded in 2016 from a prototype to regular-use instrument. Starting with the 2017 observing season, LARS can be used also by non-expert observers. Metadata treatment is extensive and very close to being SOLARNET compliant though the formal declaration has not been made. Technical limitations of the telescope preclude automatic and precise recording of pointing coordinates on the solar disc.

Publications

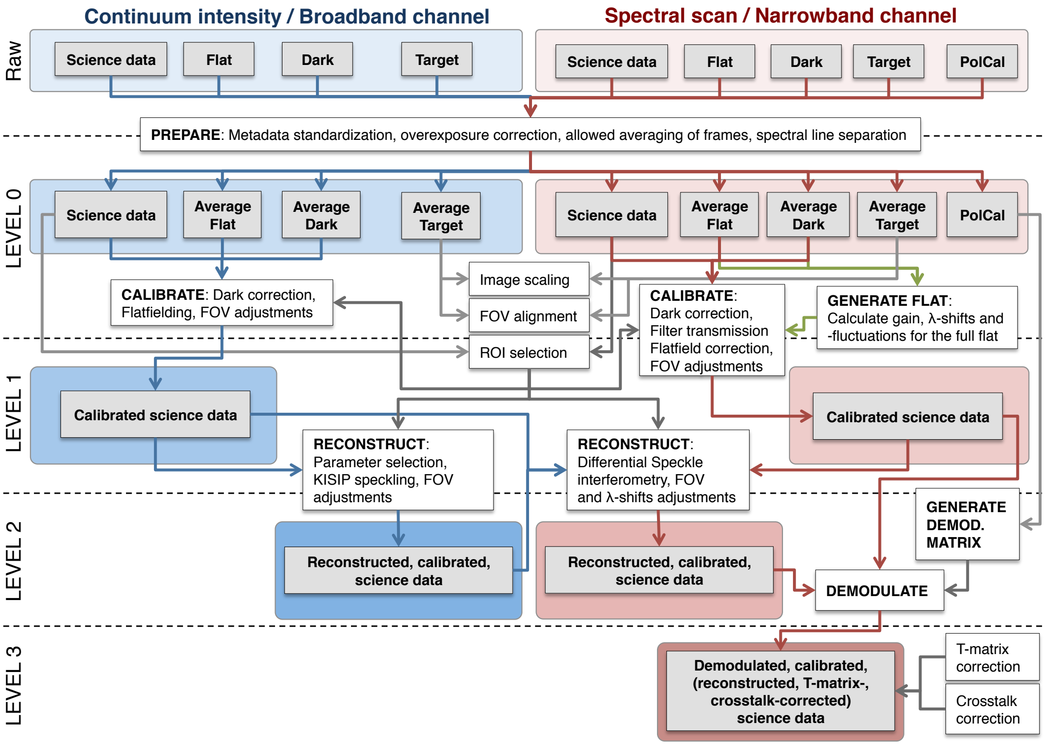
H.-P. Doerr, 2015, Precision spectroscopy with a frequency-comb-calibrated solar spectrograph , PhD thesis

J. Löhner-Böttcher et al., 2017, A&A, submitted

TESOS (KIS)

The metadata treatment was reworked and reached SOLARNET=0.5. Image reconstruction using Speckle.

Publication: J. Löhner-Böttcher, 2016, Wave phenomena in sunspots, PhD thesis



Flow chart illustrating the inner works of CASSDA GUI TESOS.

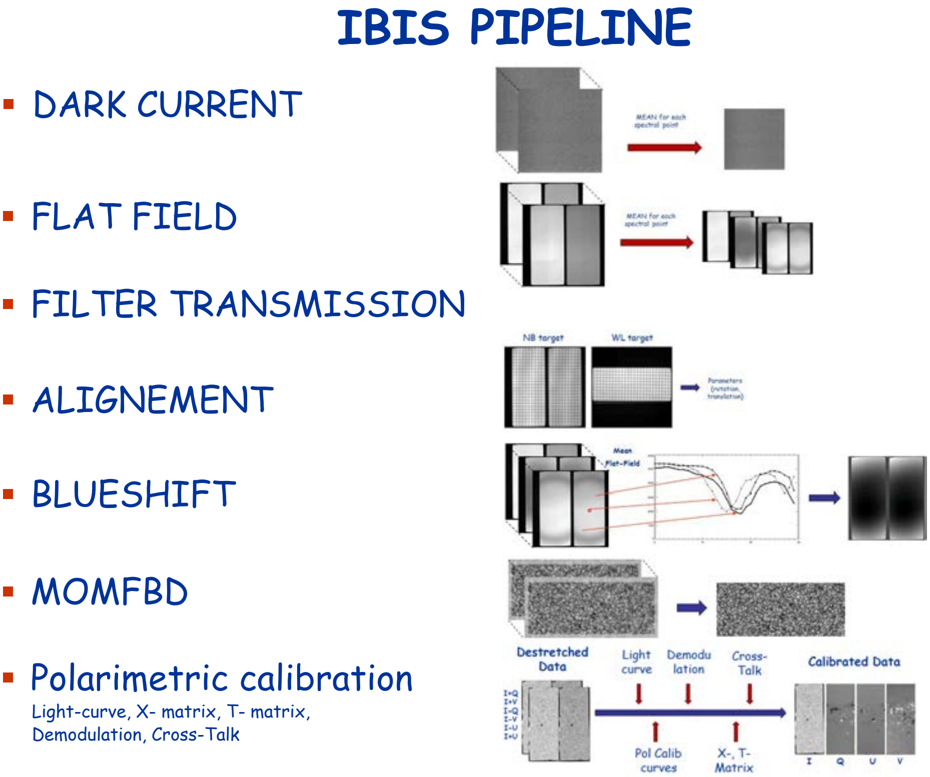
ROSA (QUB)

The work in the ROSA pipeline include introducing metadata treatment to the SOLARNET=0.5 level and writing a manual. The pipeline relies on speckle image reconstruction using KISIP.

IBIS (INAF)

The IBIS pipeline exists in an INAF and an NSO branch. The INAF branch has undergone a metadata-treatment push to reach SOLARNET=0.5. In parallel, an archive for IBIS data has been built: http://ibis.oa-roma.inaf.it/IBISA/ . Apart from making IBIS data available to the community this way, this effort has also driven and motivated the pipeline work. Image reconstruction using MOMFBD.

Publication: Ermolli, et al., IBIS-A: The IBIS solar spectro-polarimetric data Archive. Astronomical Society of the Pacific, Conference Series, in press. (Presentation at the ADASS XXVI Conference held in Trieste on 16-20 Oct 2016)



Schematic illustration of steps in the reduction pipeline for IBIS data.

TUNIS and MTR (CNRS)

Level 0 metadata are almost completely compliant with the recommendations but have yet to be propagated to the fully reduced data.

Conclusion

Thanks to the work in task WP50.1.1, there are now modern pipelines for all major European solar instruments. The pipelines have been raised to a new standard where they are more reliable and easy to use. This has led to higher productivity and more and better science. The work with conforming the pipelines to the needs of virtual observatories will allow the future development of such databases.

Task sWP50.1.2 Data Compression

The goal of this task was to evaluate 3D compression algorithms for solar spectropolarimetric data. The new instrumentation at the foci of the 4-m class solar telescope EST will enable the solar physics community to acquire data at an unprecedented rate – larger than 1 GB/s [1]. This rate and the possible 9-h duration of the observation runs will very probably exceed the storage and the transmission capacity of even the largest science facilities.

The data must be compressed and made available for download within the next observation run (i.e.: within 24 h) at the observatory (in Canary Islands). Then the data will be downloaded and decompressed by users around the world. Although the compression is made only once, its speed and efficiency of the have been among the drivers of our analysis.

Comparative tests carried out during the EST Design Study indicated that application of state-of-the-art 2D compression methods to solar spectro-polarimetric data leads to a final data volume that range between 1/2 (lossless compression) to 1/5-1/10 (lossy compression) of the original data volume. However, high-resolution spectroscopic and spectro-polarimetric solar observations consist of time series with small changes from one frame to the next. The correlation present in the spectro-polarimetric data-sets over all dimensions, spatial, temporal and spectral, suggests that the use of 3D compression algorithms applied to either (*x,y*,λ) or (*x,y,t*) data cubes may allow an enhancement of compression efficiency with respect to 2D methods, with no information loss.

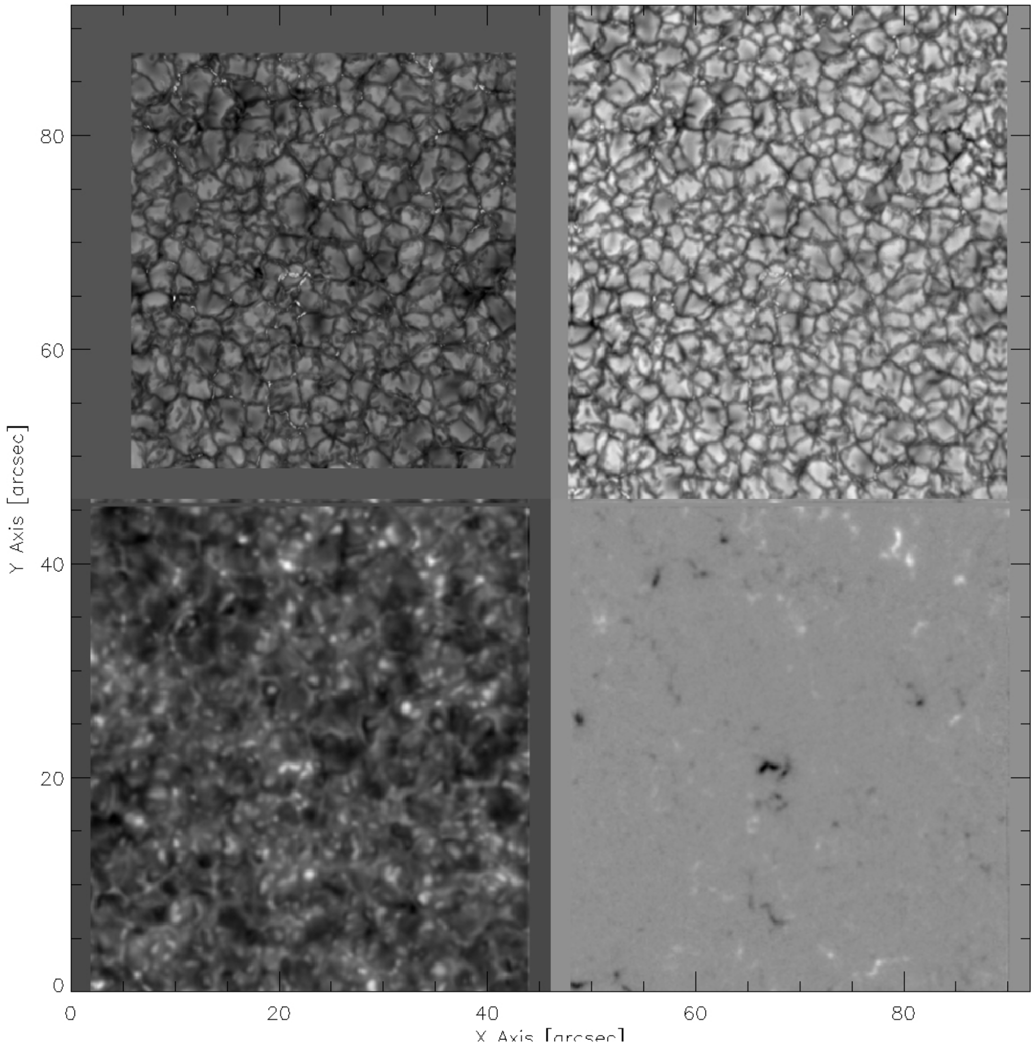
Peculiarities of solar datasets

Solar imaging data have, in general, peculiar characteristics, such as high S/N, continuous data on the FoV, etc., which are not always typical of other hyperspectral data-sets.

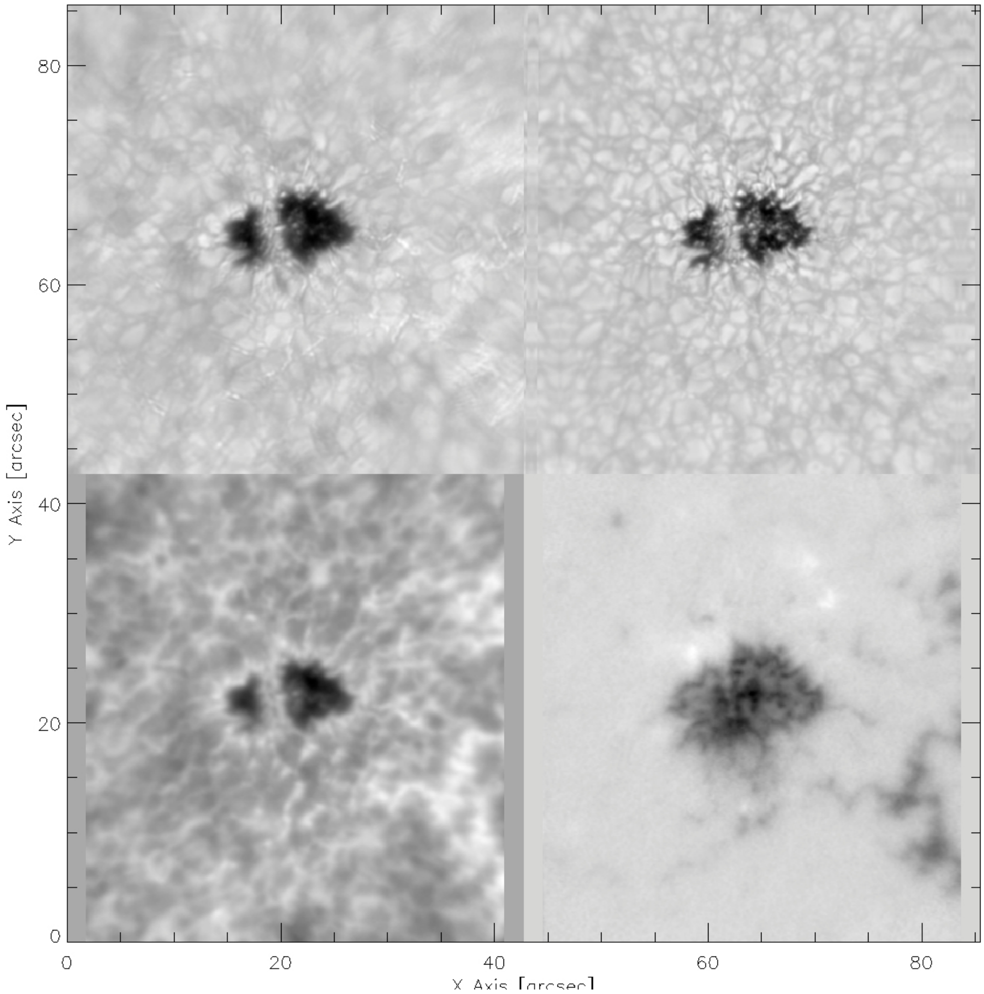
The data-sets used in the *Report on lossless JP3D compression of solar data-cubes* [15] are a partial description of the present variety of high resolution photospheric solar data, which will probably be maintained in the next years. The two data-sets are retrievable from https://www.fisica.uniroma2.it/~solare/en/?p=257 to allow anyone to compare the compression performances of different algorithms on the same data-sets. Sample images of the two data-sets are shown in Figs. 1 and 2. More details on these data-set are in [15].

To extend the analysis on chromospheric solar data, in *Report on lossless JP3D compression of solar chromospheric data-cubes* [16], we compressed and de-compressed a spectroscopic scan of a chromospheric line consisting in 80 repetition of a 21-point imaging scan of the CaII 854.2 nm line of the same Active Region as in [15]. More details on this data-set are in [16]. Sample images of the chromospheric data-set are shown in the figure below.

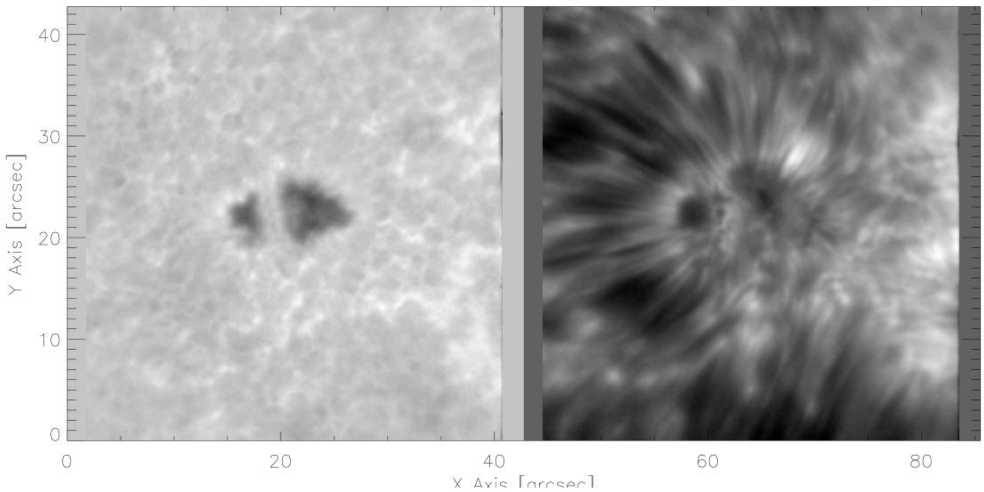
These data-sets include calibrated broad-band, narrow-band and spectropolarimetric observations of the photosphere and chromosphere. They also represent different types of targets: a Quiet Sun region at disk centre and an Active Region at disk centre. Therefore, they allow us to evaluate the performance of the compressing algorithm in different, but 'typical' situations of solar observations: low-contrast images with localized small-scale magnetic fields, high contrast images with concentrated and diffuse magnetic field, highly dynamic chromospheric datasets, etc.



Sample images from the Quiet Sun test data-set. Upper-left: G-band image; Upper-right: Broad-band image; Lower-left: Stokes-I image near the core of the FeI 630.2 nm line; Lower-right: Stokes-V image near the wing of the FeI 630.2 nm line. For the sake of visualization, all images have been rescaled to the same pixel resolution (0.18" pixel^{-1}) and their values have been separately linearly scaled to saturate the greyscale palette.



Some sample images from the Active Region test data-set. Upper-left: G-band image; Upper-right: Broad-band image; Lower-left: Stokes-I image near the core of the FeI 617.3 nm line; Lower-right: Stokes-V image near the wing of the FeI 617.3 nm line. For the sake of visualization, all images have been rescaled to the same pixel resolution (0.167 arcsec pixel^{-1}), their values have been separately linearly scaled to saturate the greyscale palette and we only show the central part of the Broad-band and spectropolarimetric images.



Sample images from the chromospheric data-set data-cubes. Left: Stokes-I image near the wing of the CaII 854.2 nm line; Right: Stokes-I image near the core of the CaII 854.2 nm line. For the sake of visualization, we only show the central part of the images and their values have been separately linearly scaled to saturate the grey-scale palette.

Compression methods tested

The methods studied constitute a selection among the most frequently adopted image compression procedures in a variety of fields of application; they exploit in different ways the properties of the Discrete Wavelet Transforms often coupled with standard entropy coders or similar coding procedures applied to the different bit planes in order to allow a progressive handling of the original image.

- SPECK3D, the Three-Dimensional Set Partitioned Embedded bloCK [2] is an extension of the SPECK algorithm to compress objects of arbitrary shape. After zeroing all the coefficients outside the object sub bands, the original SPECK algorithm is applied just as if the support of the object were rectangular. Essentially, "the whole coding system is a motion prediction coding system. First, the object in inter frame is predicted by the block-based motion estimation and compensation; then the video object (in intra frame) and motion residue (in inter frame) are transformed by the object-based wavelet transform. Finally, the wavelet coefficients are encoded by the algorithm"[3].
- SPIHT3D, The Three-Dimensional Set Partitioning In Hierarchical Trees [4] is based on the subset partitioning algorithm in a 3D hierarchical tree. It is the most usual benchmark for 3D image compression algorithms because of its limited complexity, its transmission ability, the absence of any training phase, and for its low rate-distortion performance.
- JP3D is the implementation of Part 10 of the JPEG2000 standard [5-7] in OpenJPEG, which is an open-source JPEG2000 codec written in C language. Since May 2015, it is officially recognized by ISO/IEC and ITU-T as a JPEG2000 Reference Software. Anyone

can use the code. The only restriction for using the code is that the copyright notice be retained. Thus far, the JP3D standard had been mainly used for the compression of 3D medical imagery [8, 9]. Those and other studies have already evaluated the performances of JP3D on hyperspectral data-sets (e.g.: AVIRIS radiance data-set [10, 11], SAR data [12], etc.), pointing out that its performance is strongly dependent on the characteristics of the compressed data-set.

Results and discussion

From the analysis reported in [13] the tested 2-D lossless compression algorithms were able to reach a compression factor between 1.5 and 3 for the various types of solar images used. Among these algorithms, the one with the best compression ratios was the SPIHT, the one with the shortest compression+decompression times was the JPEG2000. Among the lossy 2D compression algorithms, the JPEG2000 had the best performance overall. The 3D compression algorithms allow us to gain a 2x factor over the 2D methods in the compression ratio with apparently no data degradation. Of course, this comes with a cost, namely the 3D compression is more demanding in hardware and more time consuming. Nevertheless, the evolution of the computing capacity is fast enough to allow us to perform the compression of large data-cubes with relative ease, and, above all, the computing capabilities are evolving faster than the storage or the data-transfer capabilities.

Since the differences in the performances of these 3-D methods were within the errors, we choose JP3D because it is open-source and well documented.

In the analysis detailed in [15] and [16] and partly summarized in in [14], we applied loss-less JP3D compression to calibrated solar data-cubes of different types. The data-sets employed are a partial description of the present variety of solar data, which will probably be maintained in the next years. The performance of the 3D compression varies with the data-type: G-band are the most compressible (~3 BPV), while Stokes I are the less compressible (~7 BPV). The gain against a 2D compression varies from -50% to -30% of the original data volume. The gain in ordering data in [x,y,λ,t] or [x,y,t,λ] is apparently negligible. The JP3D algorithm is efficient in handling the larger files, with little differences in compressing a single large data-cube or several smaller data-cube.

Conclusions

The JP3D compression algorithm applied to either the (x,y,λ) or (x,y,t) allows an approximate doubling of compression efficiency on solar spectro-polarimetric data by 3-D algorithms with respect to 2D methods on same data. The performance of the compression varies with the data-type: G-band images are the most compressible (~3 BPV), while Stokes I are the less compressible (~7 BPV).

We note that this performance is probably not enough to keep data volumes at manageable size (the target compression ratio should be of the order of 25x, i.e., ~1 BPV) therefore, we suggest to explore also the JP3D algorithm performances in lossy compression, for those cases where the preservation of all the information is not critical.

We note also that, even considering an enhancement of the data processing capabilities in the foreseeable future, the compression time will be a crucial factor. In fact, the acquisition rates are likely to increase up to 100 1024×1024 pixel images per second and real time compression of the data-sets may not be feasible. This has to be taken in consideration in the observatory daily schedule.

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15* Del Moro, D., Giovannelli: Report on lossless JP3D compression of solar data-cubes. SOLARNET WP50.1.2 Report D50.2 – 17/03/2016

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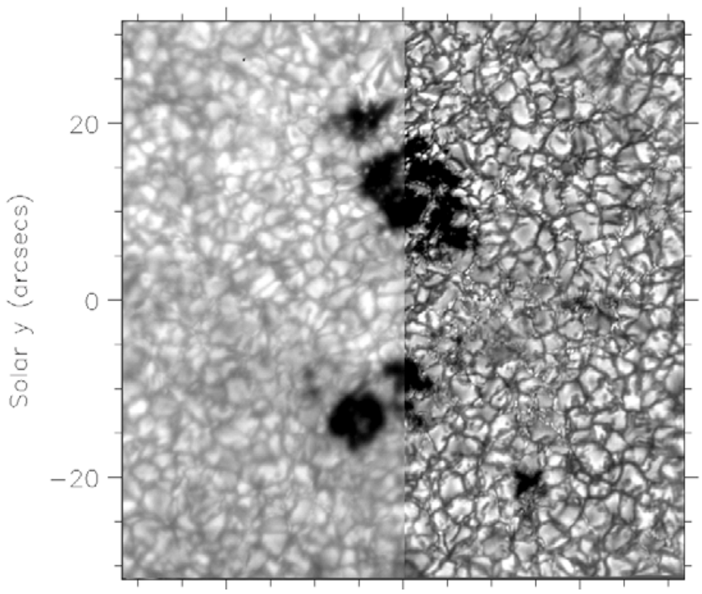
Task sWP50.1.3 Image restoration

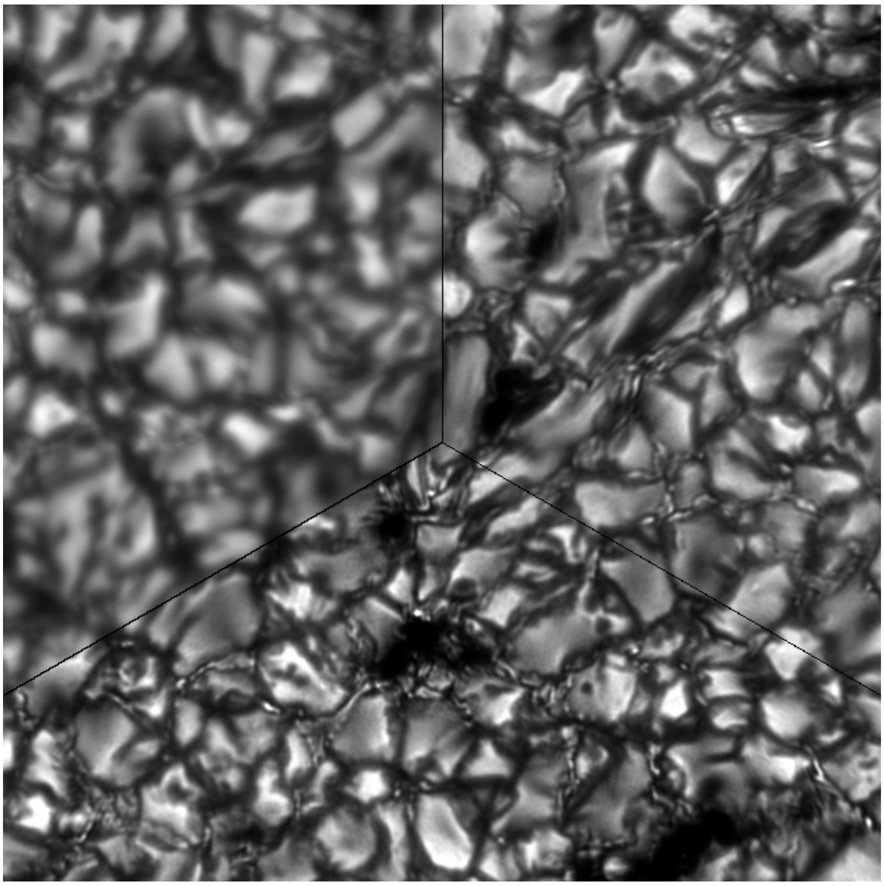
There are two kinds of image restoration methods in regular use for high-resolution solar imaging, particularly data sets with multiple wavelengths and/or polarization states. They are called Multi-object multi-frame blind deconvolution (MOMFBD) and Speckle interferometry with Speckle deconvolution, e.g., with the Kiepenheuer-institute speckle interferometry package (KISIP).

One task of sWP50.1.3 was to improve the accessibility of the codes for both methods. SU has made a fork of the MOMFBD code, and rewritten it extensively to make it easier to maintain (using more standard libraries in place of original code), adapted to the data format of the recently installed SST/CHROMIS instrument, and to implement a number of features that should improve the restorations. The new version, *redux*, is under version control with *git* and available for anybody at git://dubshen.astro.su.se/hillberg/redux. The speckle interferometry code *KISIP* is likewise under *git* version control and available from https://bitbucket.org/fwoeger/kisip.git. Both *momfbd/redux* and *KISIP* are integrated parts of data processing pipelines developed under SOLARNET, where standard parameter settings are provided by the pipeline maintainers. The figures show image restoration results with *KISIP* and *redux*.

Another important task in this sWP was to compare the two methods. While the comparison is interesting in itself, it also spurs everyone involved to understand the codes better. The method-comparison experiment at the 1st CASSDA-SOLARNET Workshop taught us that in order to interpret the results of such a comparison, it is important to have better control over the assumptions imposed by the calibrations and other processing done in different ways in the different data pipelines. Further efforts were needed to isolate image restoration effects from other steps in the pipelines.



A solar image from ROSA. The right half of the image has been reconstructed with the KISIP speckle code.



Three levels of image restoration of CHROMIS narrowband continuum data. Clockwise from upper left: Aligned, co-added, and compensated for the theoretical MTF of the telescope. MFBD-reconstructed. MFBD-reconstructed with phase diversity.

A more carefully designed experiment was started. We installed the *KISIP* code as a drop-in replacement for *MOMFBD* in the CRISPRED pipeline, the data processing pipeline for the CRISP instrument at SST. This ensured that all processing before and after the actual image restoration is done in the same way (and in the best way known for that instrument), thus making the comparison more relevant. Using data from the SST, which is a refractor, removes uncertainties in, e.g., how the central obscuration of reflectors like GREGOR and the elongated pupil of VTT affect the image restoration.

Suitable data for this experiment were collected but we soon realized that the theory for one of the calibrations required for SI with AO compensated data had only been developed for AO systems where the deformable mirror is controlled with Zernike polynomials as modes. The SST AO uses control modes that are designed to take both the statistics of atmospheric turbulence and the mirror electrode pattern into account. We have worked to fill in this gap in the theory and a new paper on the subject will be submitted to Journal of the Optical Society of America A shortly.

sWP50.2 Solar Virtual Observatory

Work was concentrated on the data archive prototype linked to the SVO and the implementation of the recommendations in the pipeline work.

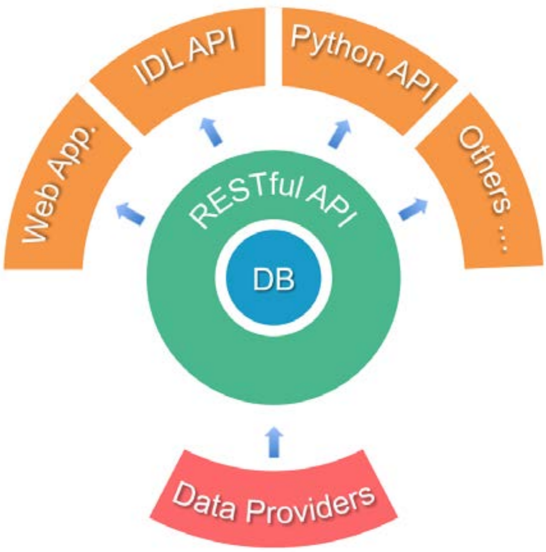
The primary premise for this work is the SOLARNET "Document on standards for data archiving and VO". Substantial work was carried out testing the ideas included in this document and helping pipeline teams with the implementation of the recommendations and modifying the recommendations based on feedback from the pipeline implementations.

Given this background, the design principles for the SVO archive were worked out, and it was determined that a highly normalised data-base structure should be used, in order to minimise the maintenance work and the potential for inconsistencies in the data set. Also, it was decided to implement one database per instrument/data set, and a subset of available metadata for each data set was selected for inclusion in the data base. On top of this structure, it was determined to have a database containing descriptions of each subset. Another design choice was to use a RESTful API to access the data base, upon which it would be easy for other applications to be built (also by third party providers).

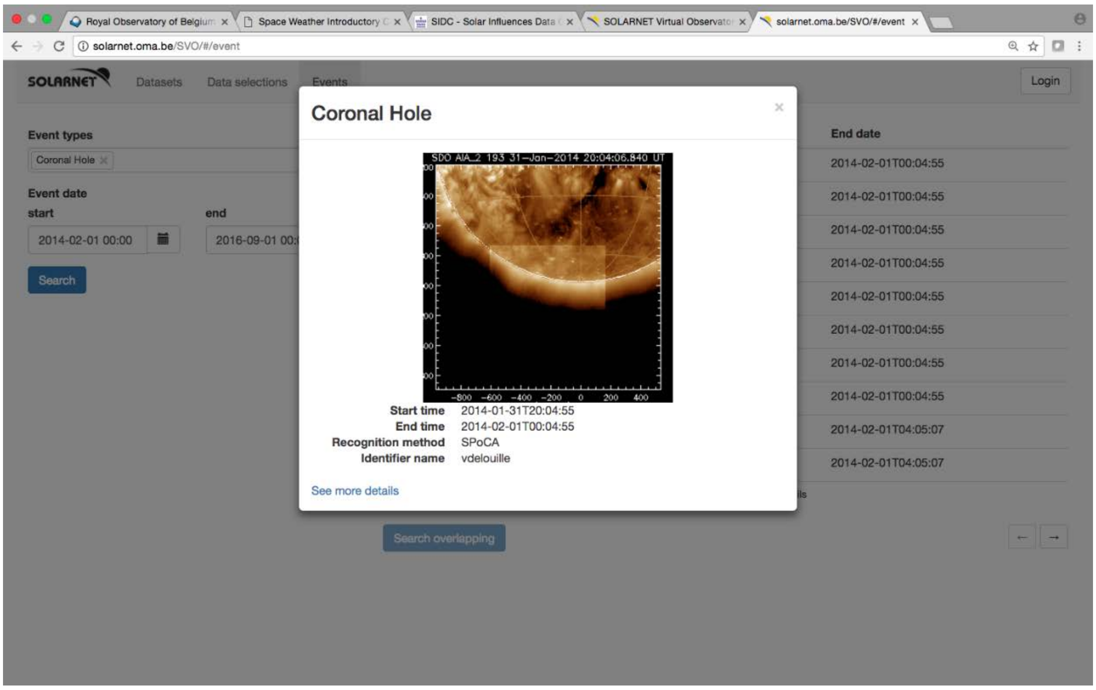
The data base implementation was made in PostgreSQL. On top of that (and the RESTful access layer), three clients to access the contents of the data base were made: One web application, one IDL API, and one python API.

Most of the internal communication was handled by either email or screen-sharing teleconferences, but one important face-to-face meeting was the FAS meeting held at ROB on 1-2 December 2016. The meeting was held to discuss the then-present state of the SVO, and to determine any future development/work.

Subsets of data sets (AIA, EIT, HMI, SWAP, and Themis) were earlier in the database. In this period, further ground-based datasets have been added to the prototype database (Chrotel, GRIS, IBIS, ROSA).



An illustration of the three-layered design of the SVO.



Result page from an event search in the SVO prototype

The prototype Solar Virtual Observatory front page.

The prototype SVO is maintained by ROB and can be studied at http://solarnet.oma.be/.

Another piece of work that was not immediately included in the prototype SVO but will be useful for all coming SVO is the addressing of the problem of listing events. A VO user is likely to search for a specific type of event or features on the Sun, but defining and cataloguing events is not a trivial matter. Based on capabilities developed under another FP7 project, HELIO (Heliophysics Integrated Observatory[1]; Grant No. 238969), we have tried to enhance the criteria used to select data that are based of the occurrence of an event or phenomena, or the presence of a feature. HELIO is based on a service-oriented architecture where the required capabilities[2] are implemented as independent services; there are many instances of most services with a Registry describing their access. This style of architecture means that the SOLARNET SVO can pick and choose which capabilities it wishes to use.

Within the Heliophysics Event Catalogue (HEC[3]) of HELIO, the number of event lists has been expanded from less than 50 to more than 80 with around 20 of these updating on a daily basis. The lists cover many types of events and features in the heliosphere; of particular interest to the SOLARNET SVO are those related to flares at different wavelengths, coronal mass ejections (CMEs), shocks, stream interaction regions (SIR/CIR), and solar energetic particle (SEP) events.

Since there is no such thing as a definitive event list – any list represents the opinion of an individual or organization – we have tried to ensure that we have gathered lists of the same or similar events from as many sources as possible, allowing the user to choose how to interpret the information. For some phenomena, this also means from different parts of the Solar System since whether an event is observed depends on the relation of the observer to the source region on the solar surface.

On the data side, we have enhanced the data search capabilities of HELIO to provide access to data sets that complement those that can be addressed through the SOLARNET SVO. HELIO was able to access a wide range of instruments though a number of data sources. In expanding the capability we have concentrated on trying to provide near continuous coverage in observations from ground-based observatories in wavelengths that are not (currently) observed from space.

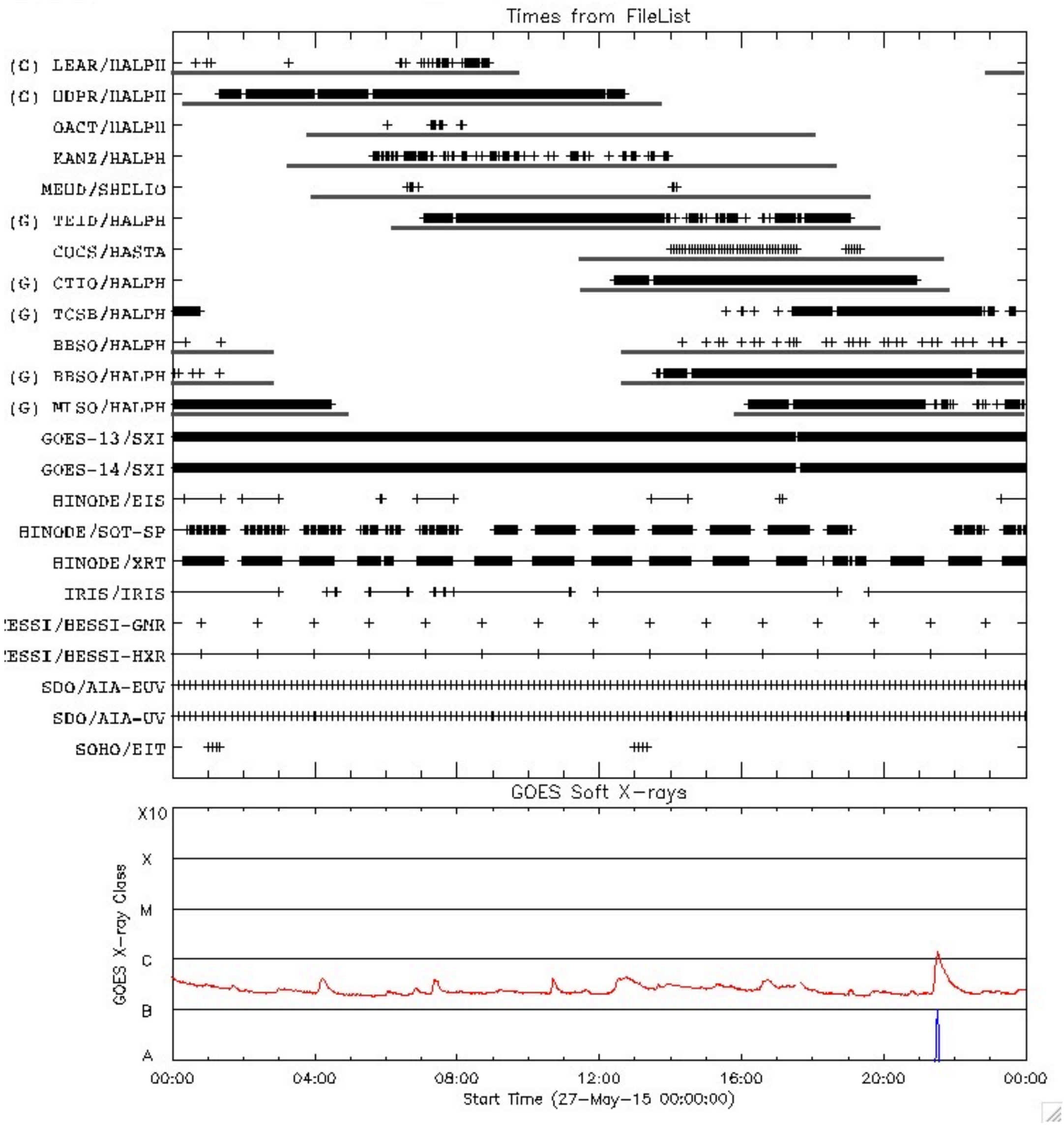
We have provided integrated access to the synoptic networks established as part of the GONG programme: magnetograms and white light images are gathered as part of the helioseismology observations and since 2010 observations have also been made in H-alpha. Since there are six GONG sites spaced around the globe, under good conditions these ought to provide continuous coverage, however, bad weather and scheduled down time can result in gaps. To supplement the coverage in H-alpha provided by GONG, we have added other observatories where the observations are extensive and accessible. Such sites include Kanzelhöhe (Austria), Catania (Italy), HASTA (Argentina) and Big Bear (California, US) and we continue to look for other sites. We have also been trying to improve access to image data made at radio wavelengths. Some progress has been made but coverage is still patchy because

[1] HELIO – http://helio-vo.eu/

[2] Capabilities of HELIO – http://helio-vo.eu/capabilities/

[3] Heliophysics Event Catalogue – http://hec.helio-vo.eu/

there are far fewer observatories in this wavelength range.



Plot showing the times of the observations (marked by "+") that have been found by the search compared to a light-curve from the GOES Soft X-ray Monitor. The ground-based observatories are sorted by the longitude of the site; the space-based observatories are sorted alphabetically.

In the figure above, the plot shows the time of every observation that was found during a search, compared to a light-curve from the GOES Soft X-ray Monitor; the ground-based observatories are sorted by the longitude while the space-based observatories are sorted alphabetically. The overview makes it possible for the user to determine whether all the types of observation that they require are available. They are able to use cursors to select the more precise time interval that is required before retrieving the data; for the GONG H-alpha data, a cadence can be specified and images from the different sites that best match the required times are returned.

WP60: Advanced instrumentation development

Leader organization: IAC

Participants: IAC, KIS, INAF, UToV, MPG, AIP, FIRSOL, CNR-INO, PNSensor, WO

Work-package summary

This work-package aims at the development of new instrumentation for existing solar telescopes, enhancing their capabilities and scientific potential. Some of the novel concepts and designs explored in this WP may be applicable to future large-aperture telescopes, as well.

WP60 is divided into four different sub-WPs, corresponding to different instrumental developments:

- sWP60.1: Large Diameter Etalon development
- sWP60.2: Image Slicer for 2D Spectroscopy
- sWP60.3: Microlens-fed Spectrograph
- sWP60.4: Fast Imaging Polarimeter

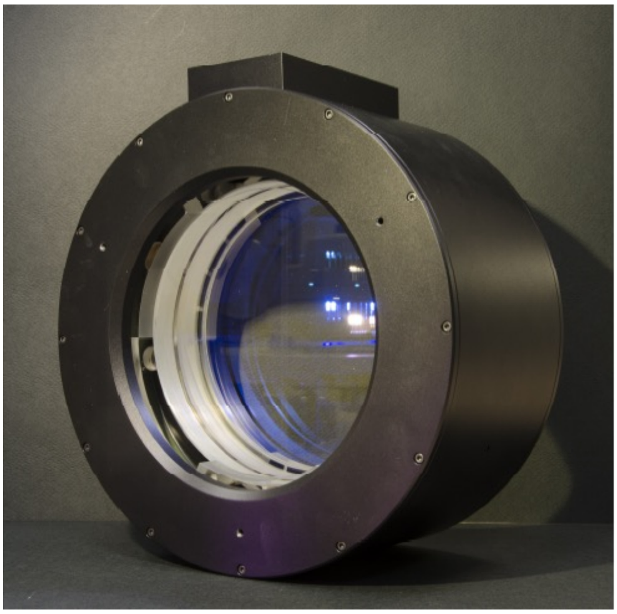
sWP60.1: Large Diameter Etalon development

The purpose of task sWP60.1 is to build a prototype of a large (150 mm in diameter), tunable Fabry-Perot Interferometer (FPI), with minimal cavity defects. A preliminary analysis of the scientific requirements for an FPI-based, imaging spectro-polarimeter, to be used with a 4-meter class solar telescope, identified cavity defects of λ/150 @ 633 nm as a necessary property. The work done in this sWP represents an important step towards the optimization of such devices for use in instrumentation tailored for large solar telescopes like EST.

To date, most of the capacity-controlled, tunable FPIs used in solar physics are produced by IC Optical Systems Ltd (ICOS), with diameters between 50 and 150 mm. After several discussions with the company regarding the possibility to improve their default model and the plausibility of reaching the necessary plate flatness over a large diameter, ICOS was selected for the construction of the SOLARNET prototype. Part of the decision rested also on the fact that the INAF partner of sWP60.1 already owned a CS100 controller (an item of high cost), needed to operate ICOS FPIs.

Besides the intrinsic quality of the optical surfaces, common causes of significant cavity defects for the ICOS etalons include gravity, surface coating, preload stresses, and effects of the piezoelectric actuators used in the capacity-controlled system that regulates the spacing between the two etalon's plates. The final goal of sWP60.1 was to correctly identify and characterize these defects, as well as to propose a path forward to their minimization. After several iterations with ICOS, a modification of the design was agreed upon in the early stages of the SOLARNET project, leading to a fully symmetric design, with two identical plates. A Finite Element Analysis (FEA) of such design was conducted early in the SOLARNET project, and indicated the possibility to further reduce the cavity defects by using the etalon in a horizontal, rather than vertical, configuration.

The prototype was commissioned to ICOS in spring 2015 (see the figure below), with a new and improved design that aims at minimizing pre-operation stresses, due to gravity, pre-load etc. The fabrication of such a large, and delicate piece of equipment is extremely complex, and several issues introduced delays in the expected delivery time. These issues included multiple attempts at optically contacting the wedges, and repeated iterations of the plate polishing, to achieve the required figure. By early September 2016, a conversation with ICOS outlined that the plate figure was still not fully to specification. However, given the imminent closing of the whole SOLARNET project, the delivery of the New Prototype ET150 was concerted "as is", in order to start testing its actual performances, including stability, repeatability, effects of gravity, etc., with the understanding that the cavity would be less than optimal. A procedure for measuring the cavity defects of the etalon had been already developed at the Optical Measurements and Testing Laboratory CNR – INO, and tested on an older ICOS 50 mm etalon (ET50), property of INAF.



Etalon Prototype ET150.

An extensive set of tests and measures of the performance of the ICOS ET150 has been carried out. The tests have been performed at the CNR-INO (Istituto Nazionale di Ottica) Lab in Florence (Italy) using a 6" Zygo GPI XP interferometer and a measuring procedure improved at the same lab. The measurement procedure has characterized the ET150, both as a static and as a dynamic system. The tests were centered on the cavity properties:

- Cavity shape
- Effects of gravity (horizontal vs vertical configuration)
- Cavity shape throughout a full range scan

The setup used to measure these properties and the corresponding results are detailed in the corresponding report, revealing strengths and weaknesses of the prototype. The tests show that changing between horizontal and vertical orientation does not distort the cavity significantly, suggesting that the design is robust. The positioning of the piezoelectric actuators does not seem to have an important effect on the cavity shape, either. Future work should focus on improving the surface flatness and the polishing procedure.

The results point towards the feasibility of a 150 mm, capacity controlled FPI built using "conventional" methods, for use in solar imaging spectroscopy. Remaining sources of concerns are whether the desired flatness (λ/150 at 632.8 nm) can be reached with a more careful polishing procedure, as well as the possibility to effectively reduce or eliminate the residual tilts introduced by the closed capacity-controlled loop. At the end of March 2017, the new ET150 has been returned back to ICOS for final polishing of the etalon plates. Further tests will be performed once the prototype is returned from the manufacturing company.

sWP60.2 Image Slicer for 2D Spectroscopy

Integral Field Spectroscopy (IFS) is a technique that provides the spectra of all the points in a bidimensional field of view at the same time and under the same conditions using an Integral Field Unit (IFU). Its application offers information along three dimensions: X, Y, λ. There exist different alternatives of Integral Field Units (optical fibers, microlenses and image slicers). In this sWP the latter option is explored with a prototype construction and testing. Task sWP60.3 has developed the microlenses alternative (see below).

The objective of sWP60.2 was to develop a prototype of an IFU based on an image slicer optimized for GRIS, the infrared spectrograph of the GREGOR telescope, to make solar observations obtaining the spectra of a 2-D region simultaneously and to validate the concept for the European Solar Telescope instrumentation.

An image slicer is an optical system placed at a focal plane to divide the image into slices which are later distributed generating one or more long-slits. This generated slit feeds a spectrograph as in the case of conventional spectrographs but, since this slit is a reorganization of a bidimensional region, the spectra of all the points of that 2-D field of view are obtained simultaneously.

Image slicers use arrays of mirrors (for pure reflective image slicers) to reflect each part of the image in a different direction using different orientations (tilt X, tilt Y). These orientations are carefully controlled to distribute the images of each 'sliced' part of the field of view into the output slit or slits. Thus, the optical path of each 'sliced' part of the field of view is defined by the reflection using one mirror of each array and generating a piece of the generated output slit, which is known as 'mini-slit'. The design of the image slicer for GREGOR was presented early in the project schedule and later updated, after including modifications required by manufacturing tolerances. The prototype includes not only the image slicer but also the field-of-view scanning system (FoV-SS, see the top right panel of the figure below), optical interface to couple it to GRIS, and the optical bench that holds the system (bottom picture of the figure below). The image slicer was constructed and finally received in October 2016 (top left panel of the figure below).

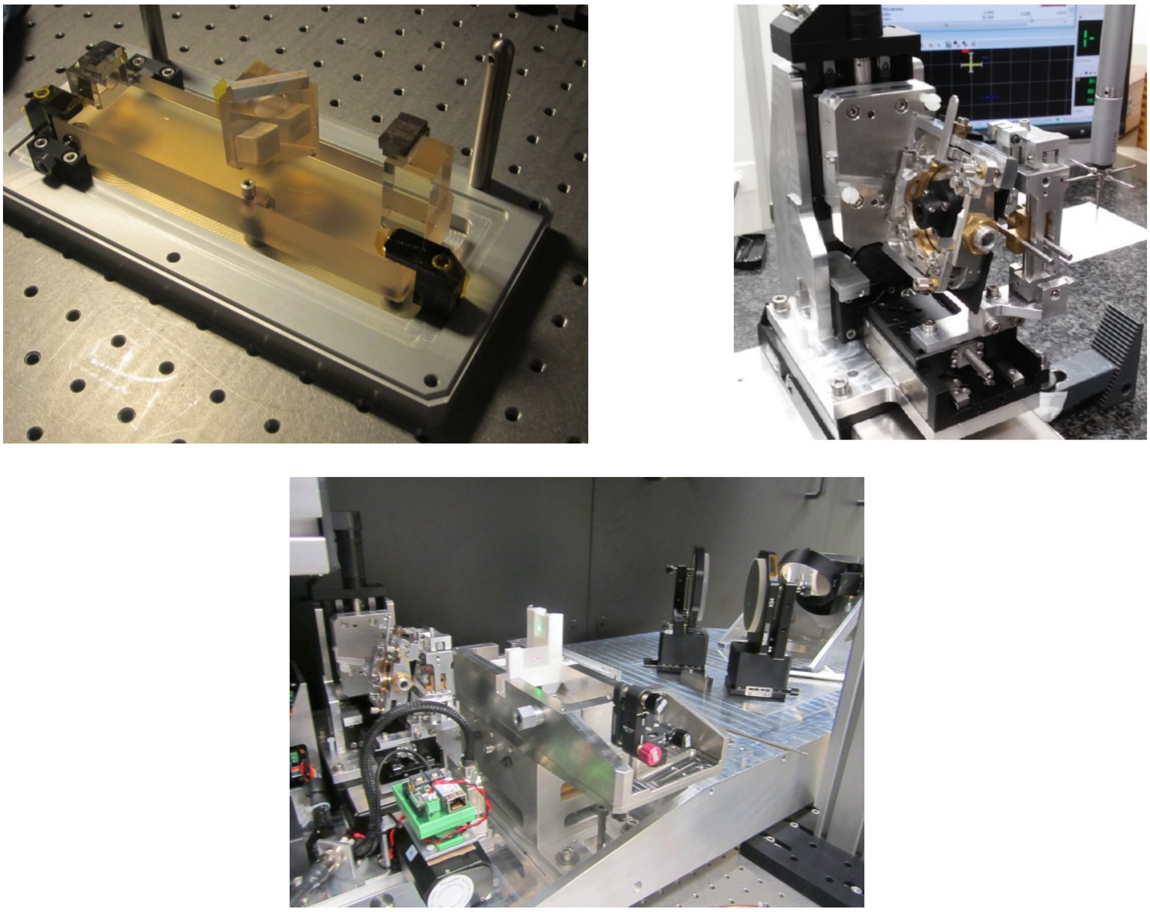


Image slicer (top left), field-of-view scanner (top right) and optical bench especially designed and constructed to host all mechanical and optical elements.

The last period of the project was dedicated to finalize the construction of all opto-mechanical pieces and to test the full unit at the lab and telescope, once the IFU was received. The full system was installed at the telescope in November 2016. The setup used at the lab, the tests at the telescope and the results are described in a SOLARNET document.

The tests were devoted to determine the mechanical and optical performance of the whole system:

- Optical and mechanical alignment of FoV-SS and slicer
- Scanning system accuracy and repeatability
- Image quality of the slicer
- Cross-talk
- Stray-light

After all these tests, the successful performance of the whole system was demonstrated. Some non-crucial problems were identified, though. One of the motors of the FoV-SS did not have the required repeatability and was later substituted. Also, some defects were identified in the image slicer itself, which was sent back to WO for repair after the tests. The unit was received back in March 2017. New tests at GREGOR are scheduled for the end of June 2017, together with scientific observations.

sWP60.3 Microlens-fed Spectrograph

Task sWP60.3 addresses the design and construction of a microlens-fed spectrograph to measure simultaneously all points of a given area on the solar surface a given area, as an alternative to the Integral Field Unit based on image slicers described above. A prototype, called MiHI (Microlensed Hyperspectral Imager), has been designed and constructed.

The MiHI is a prototype of a microlens-fed hyperspectral imager, specifically designed for solar observations, and intended to overcome the limitations of traditional solar instrumentation. It simultaneously resolves the spatial and spectral dimensions, thus promising data with a S/N ratio close to the theoretical maximum. The challenges of developing such an instrument for solar applications differ from those for night-time applications, both in terms of the necessary control of the amount of stray-light produced by the spatial extent of the object, as well as the spectral resolution, that must be high enough to resolve individual atomic lines in the solar spectrum with sufficient spectral and spatial resolution to derive the physical conditions in the solar atmosphere in 3 spatial dimensions, as well as in time.

The MiHI solves these challenges by using a specially designed and manufactured microlens array that allows all resolution targets to be achieved simultaneously, with a minimum of experimental elements, while retaining an acceptable instrument transmission. The design considerations can be found in the corresponding SOLARNET document.

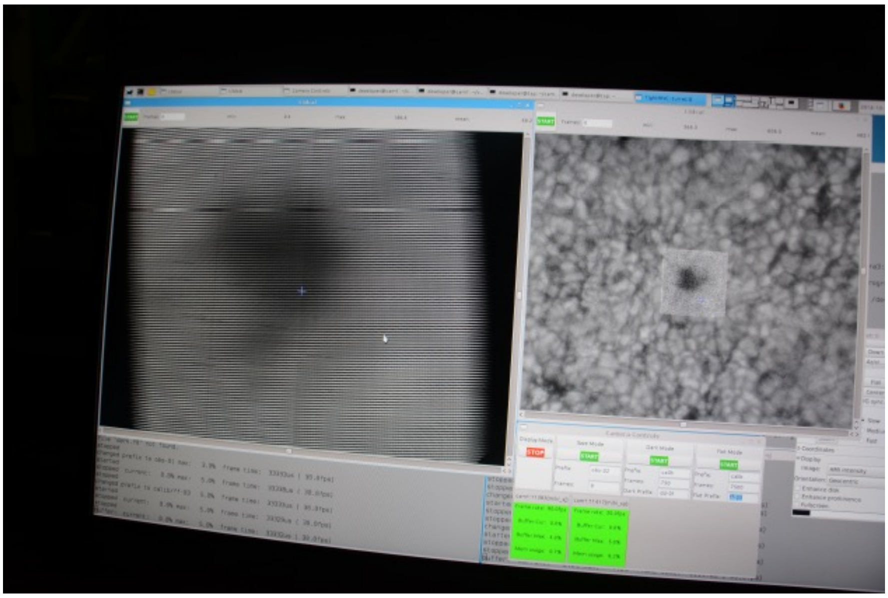
The principle of operation of a hyperspectral imager is typically based around a device that reformats the image plane, thus making space for the spectral dimension. The MiHI uses a double sided microlens array to reduce the size of each of its image elements and accomplish this goal. To avoid overlap of the spectra, an ultra-narrow bandpass filter is required. The filter must be as high-order as possible, to minimize the contamination from one image element to the next, and to optimize the signal level over the maximum possible spectral range. Steepness of the flanks of the filter transmission profile, as well as maximum peak transmission is therefore of the utmost importance.

Assembled MiHI unit in front of the TRIPPEL spectrograph. A, B, C, D are the different sub-assemblies.

To avoid designing and building a spectrograph in addition to designing and building the image formatter, the MiHI prototype was designed as a drop-in replacement for the slit-box of the existing TRIPPEL spectrograph, currently installed at the Swedish Solar Telescope (SST). The figure above shows the plug-in installed on the table, with the remaining part of the spectrograph extending some 2m to the right of the figure.

This project is supported by the European Commission's FP7 Capacities Programme for the period April 2013 - March 2017 under the Grant Agreement number 312495.

A number of tests haven carried during an observing campaign carried out in October 2016 at the Swedish Solar Telescope (SST) with the setup described above. The prototype was installed in front of the TRIPPEL spectrograph, aligned and adjusted, after which some of the basic properties were characterized. All opto-mechanical elements required for the installation of MiHI at the STT were constructed during the third reporting period. Their description and alignment procedures can be found in the corresponding report.

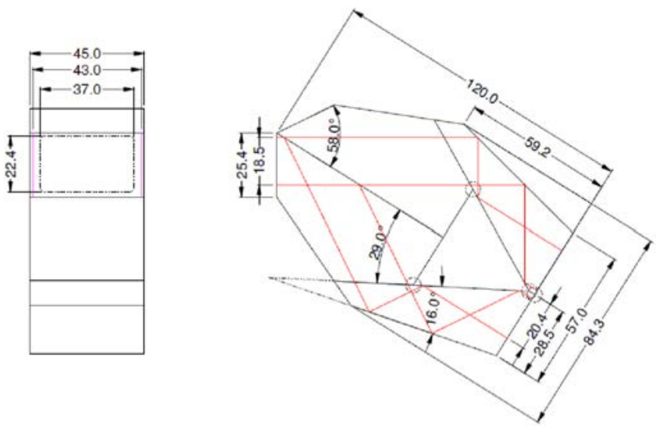


Acquisition software in action at the SST on the 31st of October 2016, during a period of moderately good seeing. On the left, the hyperspectral camera, and on the right, the context image and control interface.

MiHi was then used to observe the Sun in moderate seeing conditions (see image above), thus demonstrating the principle of operation, and resulting in a template dataset that was used to further assess the instrumental properties, and to start learning how to calibrate and reduce datasets of this type. The instrument was found to generously exceed the spectral resolution requirements, and meet the spatial resolution and field-of-view (FOV) requirements, but is somewhat less transparent than intended (25%, where 50% was the target), and shows some signs of minor thermal drifts. The reduction and calibration of the data was found to be challenging, and will require considerable further modelling and observing experience to produce high quality data. All details can be found in the SOLARNET report.

sWP60.4 Fast Imaging Polarimeter

The goal of the Fast Solar Polarimeter (FSP) project was the development of a novel solar imaging polarimeter with an emphasis on significantly increased polarimetric accuracy and high spatial resolution. The instrument is based on a fast polarization modulator synchronized to a high frame-rate and low-noise detector, working at a polarization modulation frequency in the 100 Hz range. This increased modulation frequency suppresses spurious polarization signals induced by external disturbances such as atmospheric turbulence or telescope jitter and avoids crosstalk between polarization states, in particular between linear and circular polarization, which limits the accuracy of today's slower dual-beam polarimeters. In addition, the fast modulation allows to obtain time series of numerically restored Stokes images at a cadence below the typical solar evolution time scale of magnetic structures at the smallest resolved scales (of the order of 100 km on the Sun, corresponding to evolution time scales in the range 1-10s). The higher polarimetric accuracy that can be achieved with FSP will open up new windows for studying solar magnetic fields and is, in particular, expected to advance studies of the enigmatic magnetic field in the quiet Sun and of chromospheric magnetic fields. The instrument is particularly developed in preparation for the next generation of large aperture solar telescopes like the planned European Solar Telescope (EST).



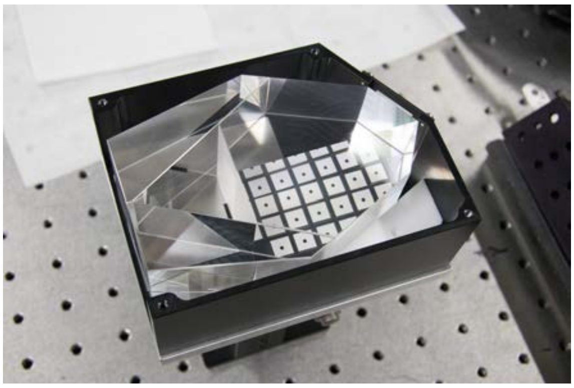
Manufacturing drawing of the polarizing beamsplitter (PBS) for the dual-beam configuration of the FSP modulator; top view onto the beam splitting plane (right) and side view onto the PBS entrance aperture (left).

The FSP modulator and its performance in single-beam configuration have been tested and described in the corresponding report. Another document has been produced in which the polarizing beam splitter (PBS) for the dual-beam configuration is described, together with the test results demonstrating its performance. The figure above shows the layout of the PBS. This high-precision optical device has been invented and designed by MPS, in collaboration with the Canadian optics manufacturer LightMachinery Inc. The ray bundle shown in red enters the fused silica prisms of the PBS at normal incidence, but at an angle of 32° with respect to the sensor plane normal. After splitting at the second face, the orthogonally polarized s and p beams undergo 2 total internal reflections before exiting the PBS normal to the exit face as two parallel beams covering the entire sensor area of about 22.5 x 16.9 mm^2. The paths of both the s and p beams in the PBS are symmetric and the beams travel exactly the same optical distance. This ensures that no differential optical effects are introduced between the beams, and that both beams are exactly in focus on the sensor plane. The normal beam incidence at the entrance and exit faces avoids any wavelength dependent refraction effects. Further the PBS will significantly extend the spectral working range of FSP. The table below compiles the main requirements of the PBS.

Specification	**Value**
Spectral working range	390 – 860 nm
Intensity difference between s and p beams for unpolarised light	< 5%
Extinction ratio	1:20 (req.), 1:100 (goal)
Absolute wavefront error	< λ/4 P-V at 630 nm
Differential wavefront error between s and p beams	< λ/10 RMS at 630 nm
Glass material	Fused silica
AR coatings for entrance and exit faces	< 1% reflectivity within the entire spectral range

Main requirements of the PBS for the FSP dual-beam configuration

The PBS was manufactured by LightMachinery Inc. and delivered to MPS in December 2016. The mount for the beamsplitter was manufactured at MPS (see the figure below).



Photograph of the PBS mounted in an anodized Aluminium housing. To prevent the PBS from changing position relative to the detector, it will be glued after careful alignment to the housing.

The optical and polarimetric performance of the PBS has been tested and compared to the specifications. The following properties were measured:

- Extinction ratio in the wavelength range 400 nm – 850 nm

- Impact of differential residuals in the p- and s-polarized channel of the PBS on polarimetric accuracy following different modulation schemes
- Imaging quality

The setups used to measure these properties and the corresponding results are detailed in the corresponding SOLARNET deliverable. The measurements have shown that the PBS meets the requirements. For the science operation with FSP II, the new dual beam configuration will further increase the achievable polarimetric accuracy due to the increased photon efficiency. The residual differential errors between the 2 PBS channels, in combination with the current non-ideal FSP modulation matrix, will however not allow to further suppress polarization crosstalk, compared to a single-beam configuration. This is not a very critical issue as the high temporal modulation frequency of FSP already suppresses those errors to levels typically below 0.1% in polarization degree.

This configuration will be used in combination with a fast CMOS camera. The first scientific application will be at an observing campaign in August 2017 at the IBIS filtergraph instrument of the Dunn Solar Telescope (DST) in New Mexico, USA.

WP70: Wavefront control: turbulence characterization and correction

Leader organization: IAC

Participants: IAC, KIS, INAF, CNRS, UToV, SU, UCAL, WU, HANKOM, CIMNE, SRS

Work-package summary

WP70 is divided into 3 sWPs, with a total of 5 tasks, two related with adaptive optics issues (sWP70.1), one related to seeing measurements (sWP70.2), and the other two related to seeing effects minimization (sWP70.3):

- sWP70.1. Adaptive Optics (AO)
  - Task sWP70.1.1 Multiconjugate Adaptive Optics (MCAO) Simulations and Tests
  - Task sWP70.1.2 Implementation of an AO prototype for THEMIS telescope
- sWP70.2. Atmospheric Seeing Characterization
- sWP70.3. Local Seeing
  - Task sWP70.3.1 Application of CFD techniques for local seeing optimization
  - Task sWP70.3.2 Development of an innovative heat rejecter prototype for GREGOR telescope

sWP70.1.1 Multiconjugate Adaptive Optics (MCAO) Simulations and Tests

The European Solar Telescope is a 4-m planned facility designed to have high spatial resolution capabilities to understand the mechanisms of magnetic coupling in the chromosphere and the photosphere. It will feature both a conventional and a multi-conjugate adaptive optics (AO) of similar complexity than the systems for night-time Extremely Large Telescopes. A particularity of solar AO is that it uses the solar granulation as a reference; therefore the wavefront sensing is performed using correlations on images with a field of view of about 10”. A sensor collecting such a wide field of view averages wavefront information from different sky directions, affecting the sensing of high altitude turbulence, the sampling of which does not depend anymore on the size of the subapertures only, but rather on the size of the projection of the extended field of view.
Understanding this effect is crucial for the design of future solar facilities, i.e. to choose the adequate height of the DMs on MCAO systems, and also to predict the quality of the reconstruction that such system would be able to achieve. For that reason, we have studied

wide field sensing and explain the analytical equations that describe the process. The equations have been validated with the results of the numerical simulations run with the code FrIM. A complete error budget has been evaluated, including the generalized fitting error.

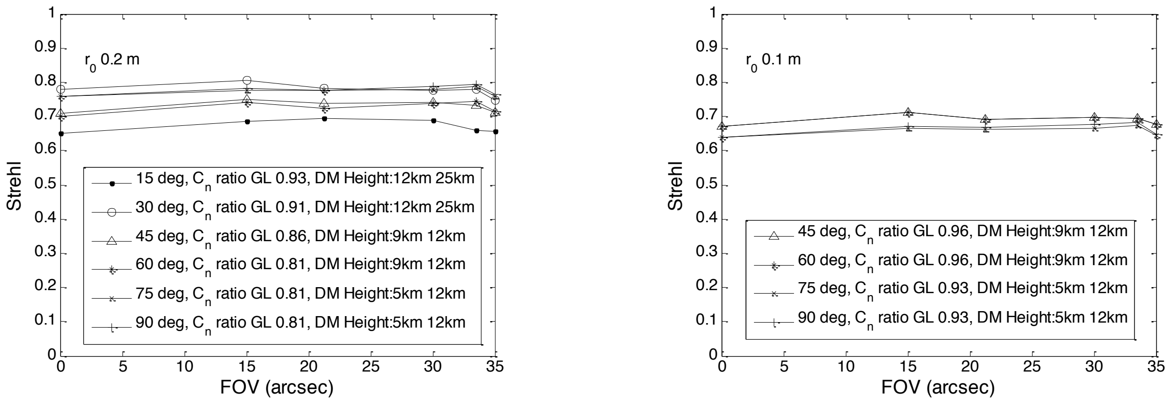
The influence of the correction order of turbulent layers in an MCAO system in the visible has been simulaed using the physical propagation approach. For this purpose we have used the code PROPER. This is a code written in IDL which simulates the change in the electromagnetic field of the wavefront along a given trajectory. Static phase screens have been generated following a Kolmogorov statistics. The outcome of this study is that amplitude propagation errors can be neglected, while phase propagation errors due to non-linear effects have to be considered. A perfect cancellation of phase errors is achieved if the MCAO correction is done in the inverse order of turbulence occurrence. Nevertheless, the degradation of the performance is not critical if high turbulent layers are corrected in the order of occurrence.

Specific simulations have been performed under different turbulent conditions to determine the optimum height for the MCAO DMs. With the results of the numerical simulations run in FrIM, using real atmospheric profiles from ORM and OT, we show that, after correction, a homogeneous Strehl higher than 40% can be achieved over a 1 arcmin FoV for all elevations. These numerical results are validated with the analytical equations and the complete error budget commented above. The main result of this analysis is presented in the table below, where the number of DMs and their optimum conjugated heights is listed.

Parameter	AO	MCAO
DM heights (km)	0	0, 5, 9, 12, 25
Spatial sampling (cm)	8	8, 30, 30, 30, 30
Sensing field points	1	19
FOV (arcsec)	10	60
Wavelength (nm)	550	550

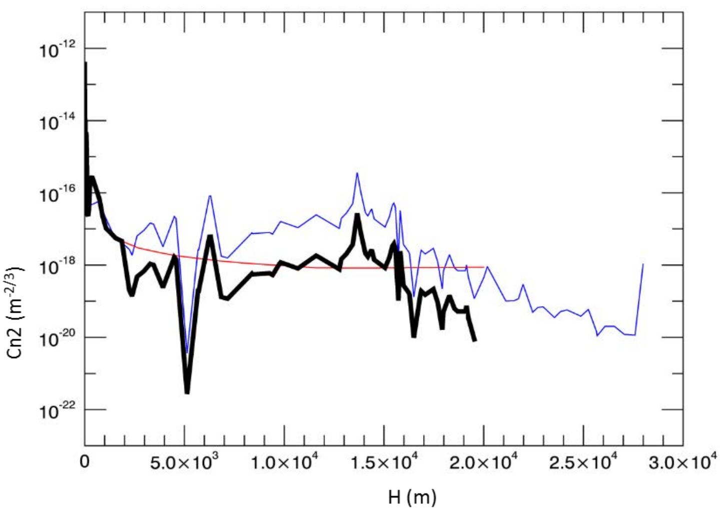
EST MCAO system parameters

An example of the performance of the MCAO system in terms of Strehl ratio achieved for diverse points in the field-of-view is presented in the figure below. There, the curves for different seeing conditions (namely, r0 equal to 10 and 20 cm) and different elevations are plotted. The legend of the figures mentions the DMs that are used for the correction (only two high-altitude DMs are used simultaneously, together with the pupil DM) and the contribution percentage of the ground layer to the turbulence profile. The details of this analysis are presented in the corresponding report.



Strehl ratio of the MCAO-corrected image as a function of the field of view (FOV) size. Under the worst atmospheric conditions that have been simulated, the system can work and reach a total Strehl (~65% Strehl fitting error only) of 40%. For each elevation the minimum required ground layer C_n^2 fractional contribution to the wavefront distortion is presented, as well as the DMs that are actuated.

For the determination of the optimum conjugated heights of the MCAO DMs, a method to characterize the day time turbulence up to several tens of km is derived. The SHABAR instrument used to determine the diurnal seeing conditions (see sWP70.2) is only sensitive up to a distance of 2-3 km to the turbulent layer. The contribution to the seeing of higher layers is crucial to understand the image degradation and, consequently, other means are required to explore the behavior of these high-altitude layers. To complement the results obtained with the SHABAR, we make use of the instrument SCIDAR, installed at the Observatorio del Teide (OT) and which can derive turbulence profiles during the night. We have also used data taken by regular radiosondes that are launched in Tenerife (twice per day). The three data sets



Vertical Cn2 profiles for SHABAR(red), radiosonde(blue), combination SHABAR-Rdiosonde (Black)

(SHABAR, SCIDAR and radiosonde) have been adequately compared and merged to produce a single turbulence profile which may be considered as typical of the atmospheric conditions at the OT (see the plot below). This profile has been used for the optimization of the MCAO system and presented in a report.

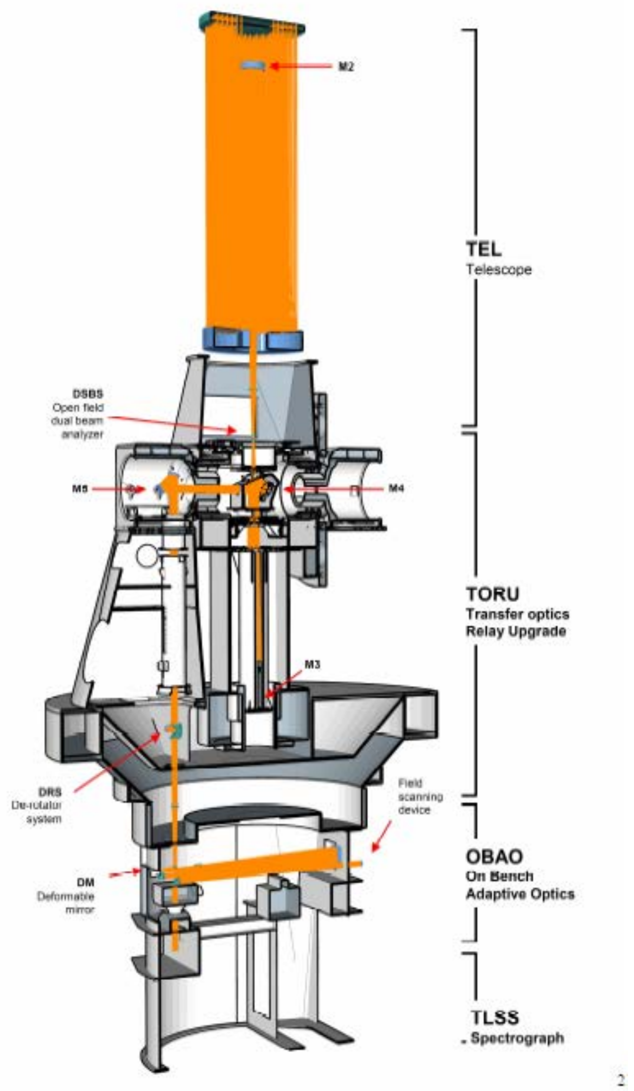
Efforts were also dedicated to forecast the MCAO correction. To that aim, a hardware demonstrator was constructed to test our forecasting algorithm FORS (closed loop FORcasting System). We studied the outcomes of introducing both a simple periodic defocus aberration and a real open loop defocus time sequence acquired at the VTT solar telescope. In both cases, FORS grants a significant performance increase, improving the stability of the system in closed loop conditions, and decreasing the amplitude of the residual uncorrected wavefront aberrations.

sWP70.1.2 Implementation of an AO prototype for THEMIS telescope

AO systems are installed at most existing solar telescopes to improve their image quality, with excellent results in imaging observing modes, but the combination of polarimetric measurements with adaptive optics is extremely challenging and it is not usually fully addressed. Being THEMIS a solar telescope which provides high polarimetric performance, the implementation of an AO prototype to improve its image quality retaining its unique spectropolarimetric capabilities, would open the possibility to specialize this telescope in high resolution in polarimetry. The possibility of performing very high quality polarimetric measurements using AO is one of the challenges of the future large aperture European Solar Telescope (EST) and the implementation of an AO system at THEMIS will provide an excellent bench to test these observing techniques for EST. This sWP includes the following tasks:

- Design of the AO system (CNRS-THEMIS, CNRS)
- Construction and installation of the AO system (CNRS)
- Tests of the AO system (CNRS)

A full study has been conducted to implement an adaptive optics system for the THEMIS telescope, taking into account the current technical state of the telescope and the scientific goals derived from the polarimetric usage of the long slit spectrograph attached to the telescope. It shall be clear from the beginning that THEMIS has been specifically designed to be a "calibration-free" polarimetric telescope and that the AO design has been done keeping this important specification valid. The adaptive optics (AO) prototype for THEMIS is composed of two separate and complementary branches. On the one hand, there is the design and construction of the AO optical bench itself, including the wavefront sensor, the pupil deformable mirror and all the accompanying mechanical and optical parts. On the other hand, some changes in the mechanics and optics of the telescope are required to accommodate the adaptive optics system.



Sketch of the THEMIS telescope showing the points where changes related to SOLARNET WP 70.1.2 are taking place

During the initial phases of the project, the design of the AO prototype was accomplished and the corresponding reports and deliverables were produced. Later, the detailed design of all changes required at telescope level was produced and providers of all new optical and mechanical elements were contacted and purchase orders submitted. Finally, all these elements have been received and tested at the laboratory during the third reporting period. The design is such that the same optical bench can be moved from the lab to the telescope as it is. New mirrors M2 to M5 of the telescope have been acquired, tested and installed at the telescope with their corresponding mounts. The performance of these new optomechanical parts has proved to be within specifications. Global on-sky testing of the whole system is planned for fall 2017. The adequate reports have been generated where all these achievements are presented.

The figure presented above is a sketch of the THEMIS telescope in which all the changes required to implement a successful prototype are shown.

sWP70.2 Atmospheric Seeing Characterization

Two long-baseline SHadow BAnd Rangers (SHABAR) instruments were deployed by the IAC in the Canary Islands during 2010, one at Observatorio del Teide (OT), in Tenerife island, and another at Observatorio del Roque de los Muchachos (ORM), in La Palma island. The instruments acquire sunlight signal data that can be reduced to produce C_n^2 and r_0 profiles for the lower atmosphere layers up to some 2-3 Km height. The mission of these instruments, together with other daytime turbulence measurement instruments, is the characterization of the daytime sky in both sites, OT and ORM, in order to select the best location for the European Solar Telescope.

Reports have been presented in which the data acquisition and analysis is described, as well as the main results of the data analysis performed showing the statistics and seeing properties at different heights from the ground and the daily variation for the different seasons of the year. These results are presented for both Canarian observatories: OT and ORM. In the figure below, the variation of the median r_0 with height at both observatories is presented. More details can be found in the corresponding document, including the diurnal and seasonal variation. In particular, the following statistics has been generated:

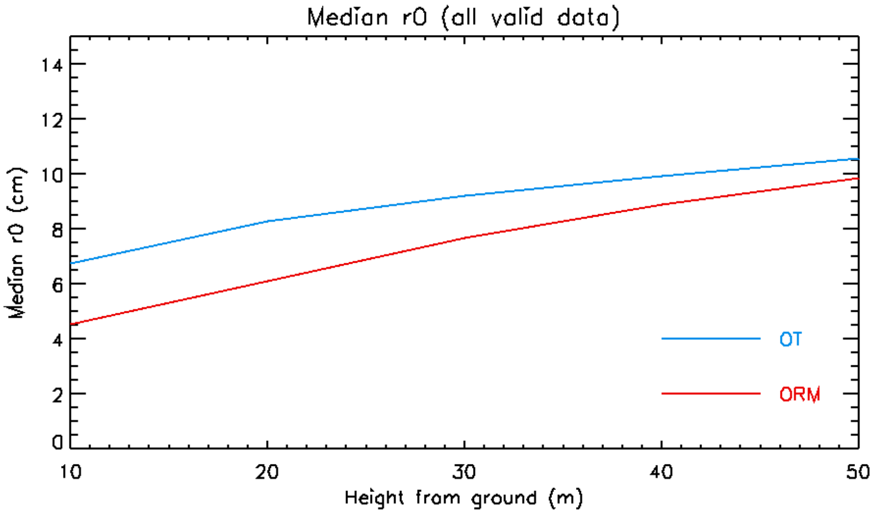
a. Median r_0 variation with height (from 10 to 50m)
   - a1. Global, using all data
   - a2. By season (spring, summer, autumn)

b. Median r_0 variation with hour angle, season and height

c. Monthly variation of median r_0

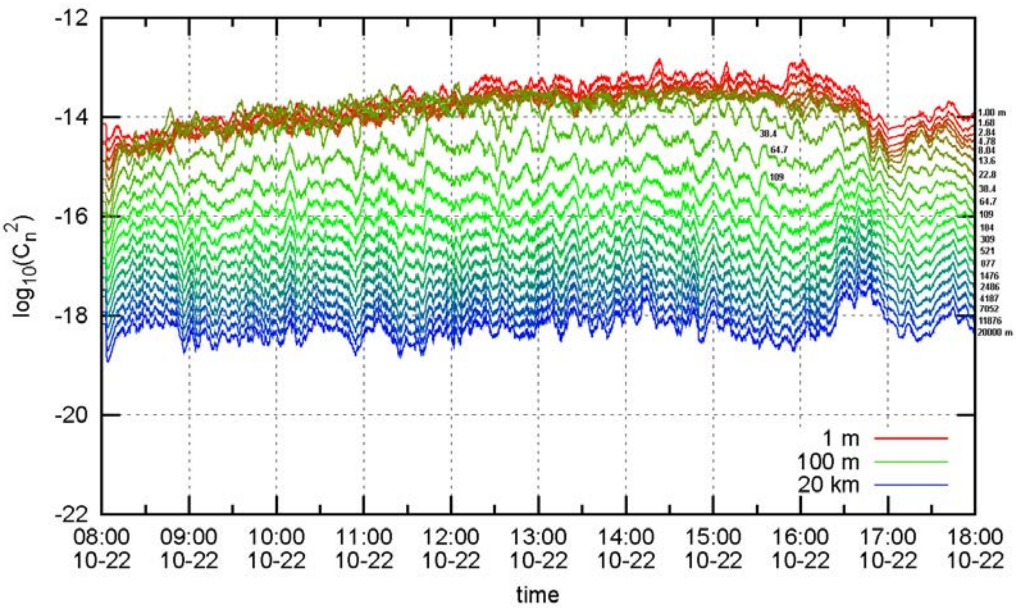
d. Probability estimates of r_0 larger tan 7, 12 and 25 cm

This project is supported by the European Commission's FP7 Capacities Programme for the period April 2013 - March 2017 under the Grant Agreement number 312495.



Median variation with height of the Fried parameter, r_0, during the whole period of operation of the long SHABAR instruments at the OT and ORM observatories.

In addition, several short-baseline SHABARs have been also constructed to measure daytime seeing at existing and prospective telescope sites on La Palma and Tenerife. The structure parameter $C_n^2(h)$ obtained with one the short SHABARs, plotted for many heights during one day, is shown in the figure below.



Structure parameter plotted for many heights during one day. At the right side are the heights in meter of the individual curves. These curves from the measurements with a SHABAR with 424 mm maximum scintillometer distance are significant up to a height of about 1 km. Longer SHABARs are needed for reliable information about the higher atmospheric layers. However, these short SHABARs show already clearly that the lowest air layers nearby the instrument give the most important contribution to the scintillation.

sWP70.3.1 Application of CFD techniques to the local seeing optimization

This task addresses a number of related issues.

We have addressed the task of developing numerical methods to estimate the atmospheric seeing and simulate some test cases of certain configurations of the EST. The resulting method has been described in a paper entitled paper "Variational multiscale based dissipation models for the estimation of atmospheric seeing", by J. Baiges and R. Codina, and that has been published in the journal Computers & Fluids.

In this work we have presented a numerical model for the estimation of atmospheric seeing in observation sites. The main feature of the proposed model is that it is based on the numerical dissipations which arise from a particular version of the Variational Multiscale Method, the Orthogonal Subgrid Scale method. It is a finite element method where one assumes that the solution can be split into large and small scales. The former are considered those captured by the finite element mesh, whereas the latter are considered L2-orthogonal to the former and modeled approximately.

The advantage of using this kind of models lies on the fact that, by decomposing the fields of interest into coarse and fine scales, they are able to deal simultaneously with the sources of numerical instabilities and the modeling of turbulent effects. In the present work we have summarized the properties of our variational multiscale method, which is based on modeling the numerical subscales in an as complete as possible manner: the subscales are considered to be transient in time, non-linear, and orthogonal to the finite element space. This leads not only to the resolution of numerical stability issues (advection and the use of arbitrary interpolations for velocity and pressure), but also to a rich representation of turbulent phenomena. Based on this turbulence model, we have developed the expressions for the viscous and thermal dissipations, which have been used for evaluating the constant of structure of the refraction index Cn2 following classical models.

We have tested the performance of the method in three practical cases, namely a convective boundary layer, the flow inside a transfer optics room, and the flow around a telescope enclosure. In all three cases we have compared our model with the results obtained by using a Smagorinsky and WALE models for evaluating the viscous and thermal dissipations, and, in the convective boundary layer case, with the results presented in the literature. The numerical examples show that the method is capable of doing an accurate estimation of the Cn2 coefficients. This fact does not only provide us with a new numerical tool for the evaluation of the atmospheric seeing but it also adds arguments in favor of the viability of implicit LES methods which rely on the numerical stabilization mechanisms for the modeling of turbulence.

In a second stage, efforts were concentrated on completing the set of CFD simulations to evaluate the seeing conditions in several configurations of the telescope facilities for the EST telescope and help the SOLARNET consortium to decide the optimum design of the EST facilities. To that aim, different configurations were analysed for the telescope facilities with a conventional dome (closed configuration) and facilities with windshield (open configuration), in summer, for North wind of 5 m/s, in order to select the optimal configuration. The analysis include different moments of the day, since the ambient temperature, the ground temperature and the temperature of the facilities changes along the day and, hence, the seeing degradation is different. Also, several conditions on thermal control have been taken into account to obtain an estimate of the convenience and effect of the thermal control mechanism. The final objective of the analysis was to keep the temperature of the surfaces of the facility as close as possible to the ambient temperature so as to minimize the local seeing effect.

Once the temperature maps were obtained for the selected configurations, the CFD analyses were performed to evaluate the local seeing degradation. A connection method between thermal analysis and CFD analysis has been successfully implemented, providing a useful and robust tool to optimize the future thermal analyses. Other capabilities have also been implemented, such as sensitivity analysis, or a simplified method to optimize some aspects of thermal behaviour of the telescope. The main results of this study can be summarised as:

- If a dome without thermal control is considered, it is not clear that the effect of the dome in the seeing conditions is positive: the presence of the dome causes turbulent vortexes to appear, and if the temperature gradients at the surface of the dome are large these are transported to the interior of the dome and the seeing conditions are degradated.
- If thermal control is considered, then the effect of the dome is very positive (cases 33 and 35). For case 34, even with thermal control the light beams have to traverse the external turbulent vortex recirculation at the entry of the dome, which causes large temperature gradients *outside the dome*, but still in the path of the light beam. This causes the dome to be less effective in improving the quality of seeing.
- The effect of internal heating in the dome can have varying effect on the seeing conditions. The case with high HR shows a good enough performance (although the dome with thermal control is still better). On the other hand, the case with low HR shows a very bad performance, maybe the worst performance observed in the cases with the dome.

Finally, an analysis of different alternatives for the EST telescope structure has been performed. The analyses have been centred on the Rocking-Chair, Gantry and Yoke models. The performance of each structural model has been evaluated according to their dynamic behaviour, as well as to the errors induced by gravity and the wind loads acting on the structure. An alternative configuration for the upper section of the telescope tube has also been considered, as well as the possibility of changing the current Nasmyth platform position from the right side of the telescope to the rear side.

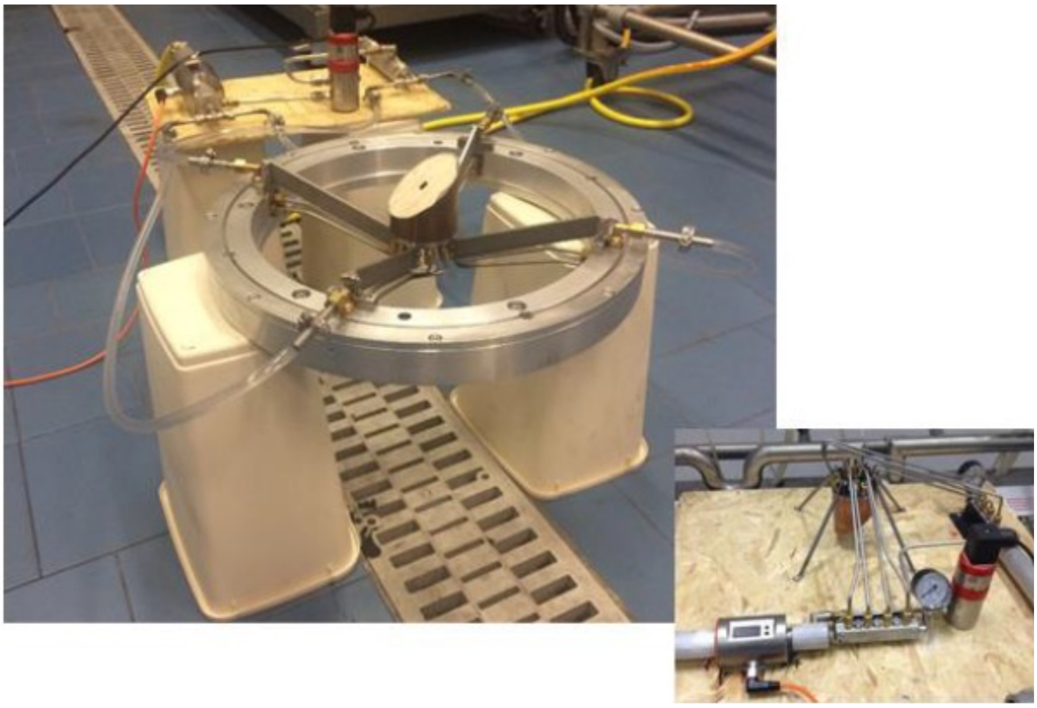
All the analyses, simulations and the results are described in the corresponding reports.

sWP70.3.2 Development of an innovative heat rejecter prototype for GREGOR telescope

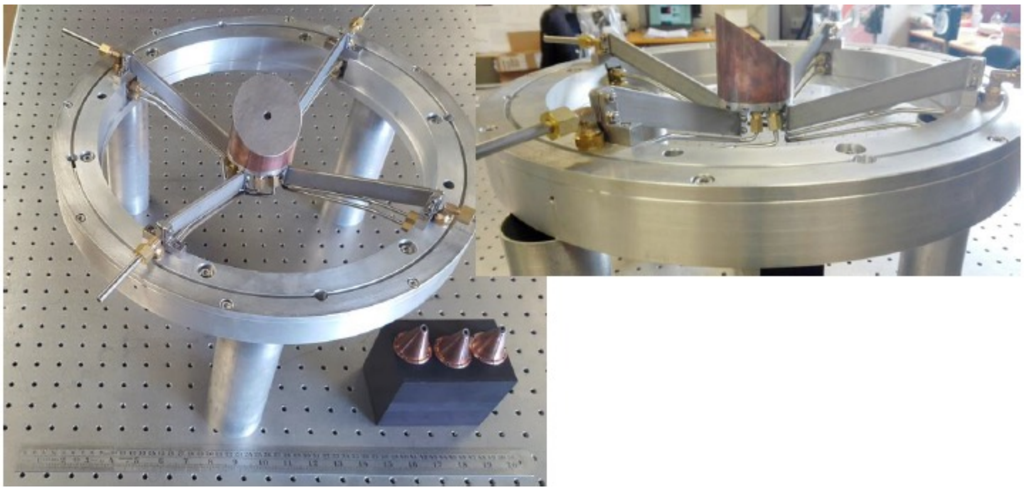
Task 70.3.2 is devoted to the design and construction of a heat rejecter (HR) prototype for the GREGOR telescope. This HR follows the concept of the design proposed for EST, and, consequently, represents a proof of concept for the technical solution.

A thermal analysis was done to study the current contact sensors layout, evaluate the thermal environment at GREGOR F1 and estimate the possible improvement in the reduction of local seeing effects. A "cold" prototype was constructed to check the leakage, and the hydraulic and thermal performance. The Heat Rejecter (HR) final prototype has been produced and is ready for delivery to the GREGOR telescope. The HR front surface has been polished and coated. The device includes three interchangeable field diaphragms. Laboratory tests have demonstrated the good performance of the system. The final prototype has been realized after modifications deduced from the experience achieved with the first "cold" prototype to reduce the hydraulic friction resistance inside the HR body and pipes. A number of hydraulic tests have been performed on the final prototype. The heat rejecter will be integrated and tested at the telescope during the next maintenance period of the GREGOR telescope (foreseen for summer 2017).

All these aspects are described in the corresponding documents. The figures below show some images of the Heat Rejecter prototype for the GREGOR telescope.



Heat Rejecter setup during hydraulic tests.



HR assembled with the Inner ring. Left: front view of the HR assembly and the three different field stops with a ruler to compare the dimensions. Right: side view of the HR assembly.

WP80: Synoptic observations: Solar Physics Research Integrated Network Group (SPRING)

Leader organization: KIS

Participants: IAC, INAF, MPG, QUB, AISAS, AIASCR, IGAM, UoB, NSO

Work-package summary

High-resolution telescopes (such as SST, GREGOR and the future EST and DKIST) allow observations of only a small fraction of the solar surface. Real-time context data showing the large-scale dynamics and magnetism at different layers of the solar atmosphere are crucial to understand the global behavior of solar phenomena. However, despite the amount of information coming from space and ground-based full-Sun telescopes, real-time information about the variation of important parameters such as velocities, magnetic field and intensity at different solar layers is still lacking. To this aim, a network of telescopes with a small aperture but a large field-of-view can provide useful data to prepare observing campaigns with large-aperture high-resolution telescopes and complement the data taken with them. Distributed in a world-wide network, these small apertures can represent an invaluable supporting tool for coordinated observations with the major infrastructures. The goal of this work-package has been to define the scientific requirements of such a network and to analyse the technical alternatives that can deliver the required data products of interest.

This WP is divided into three phases:

- Phase 1: Science Requirement Study
- Phase 2: Feasibility Study
- Phase 3: Development and Operation Study

Observational and technical requirements

During the first period of the project, the scientific requirements were defined, from which the observational requirements were derived and translated into technical requirements.

The derived observational requirements are listed in the table below for the four main scientific target areas of SPRING:

GOAL	Obs. Params	Cadence	Spectral/Spatial
Long-term behavior of solar magnetism	Accurate vector Magnetic Field measurements Senstivity Goal: B-los <1G, B-trans <50G	Few per day (long-term statistics only, not for short term evolution)	High spectral resolution (spectrograph), Fulldisk, seeing limited spatial resolution, Sensitive polarimetry.
Long-term behavior of solar internal flows	Accurate velocity field Measurements Sensitivity Goal: vel <10m/s	For photosphere: ~1 min, chromosphere ~30 sec	Moderate spectral resolution (filtergraph), fulldisk, seeing limited, Sensitive Doppler measurements
Space weather	High-cadence vector magnetic fields Sensitivity Goal: <10G for B-los, <150G for B-trans	Photo & Chromosphere: ~5-10 minute	Moderate spectral (filtergraph), fulldisk, seeing limited
High Resolution Contextual Imaging	High-resolution images of the sun in various wavelengths	Broad and Narrow band images at a cadence of 1 per minute	High spatial resolution (~1 arcsec; 4kx4k), fulldisk acquisition, Tip-tilt system for image stabilization **Image reconstruction only for desired FOV

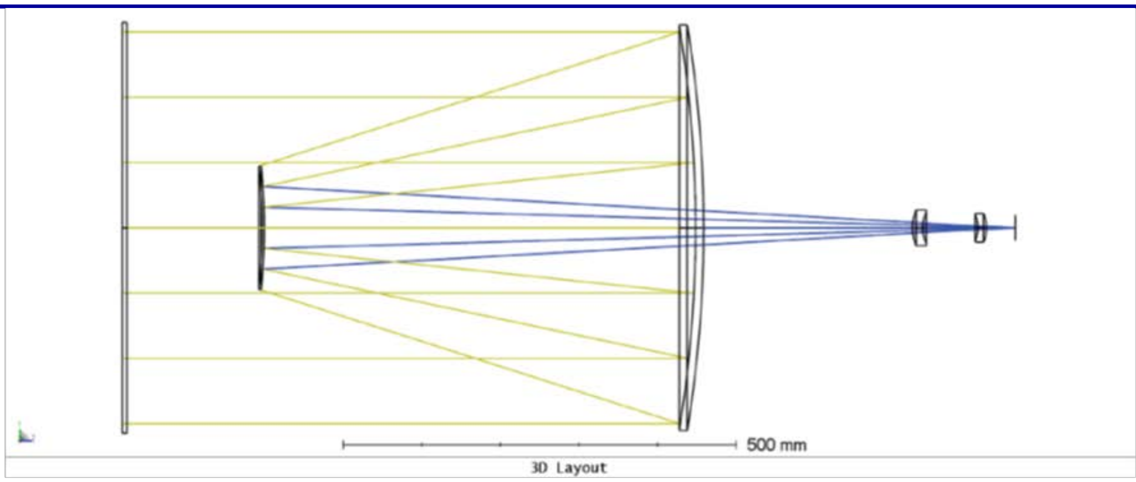
The translation into technical requirements followed the key idea to obtain a simple observatory, which is easy to operate and most cost effective. From the list of the observational requirements it is clear that a single instrument is not capable of fulfilling all those needs. Even if it can, its technical complexity would be too high, which finally would lead to high costs and low mean time between failures. For a network that should provide the data without interruption, this is not acceptable. Therefore the development had to follow the concept of a single platform that host several instruments.

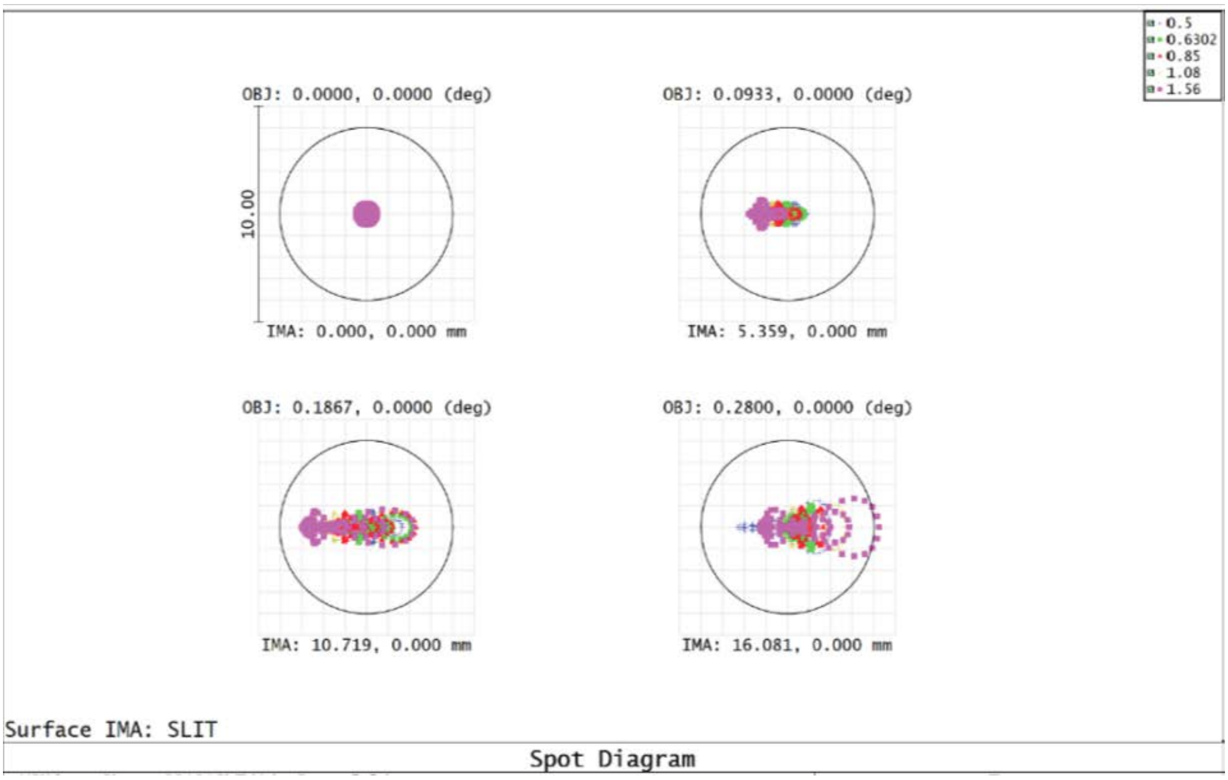
Starting from the requirements for the spatial resolution, the detectors, instruments and front-end telescopes were defined. For magnetometry a high-end spectrograph is needed. The light-collecting power is provided by a 50cm telescope. To obtain magnetograms sufficiently quick a multiplexed slit is considered, which feed light into the spectrograp (mxSpec).

For Doppler measurements in different spectral lines one only needs moderate sized aperture. Our calculations showed that a sensitivity of 10 m/s can be reached with a fulldisk telescope (FDISK) with an aperture size of 20 cm for most of the photospheric lines. For chromospheric lines one needs to integrate more photons.

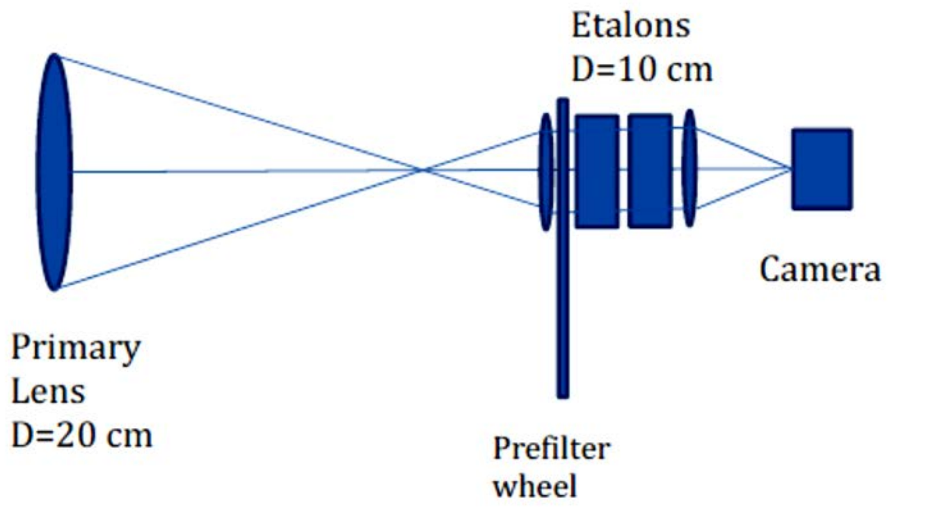
The temporal cadence requirement dictates that a tunable filter with high throughput, such as Fabry-Perot interferometer, must be used.

To achieve the requirements of multiple lines, velocity sensitivity, and SNR results in the fact that different cameras and etalons will be needed for infrared measurements. To achieve the required temporal cadence, one needs to split the instruments into three. Those have identical setups, but cover different wavelength range, where two are in the visible (500-750nm) and another for infrared (800-1500nm).





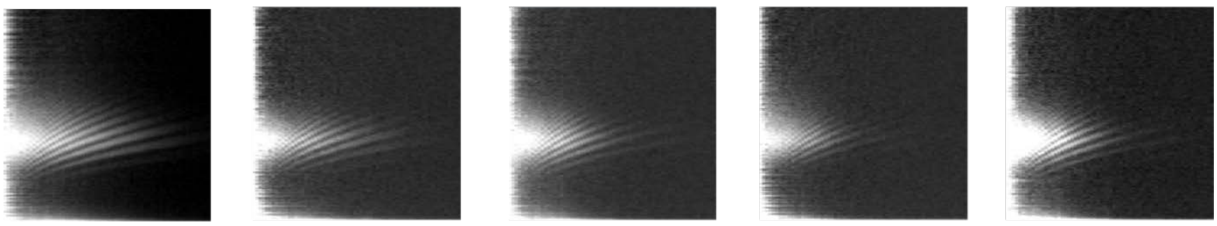
Top design of the telescope for magnetometry. Bottom: Spot diagram indicating the diffraction limited operation over the full wavelength range.



Optical setup for the Doppler measurements.

For the Doppler measurements one employs an achromatic Doublet with an opening of D=20-25 cm and an an ratio of f/D=10. Relay optics make sure that one obtains an achromatic wide field (see the figure above).

The technical feasibility of this concept was extensively tested using the guiding telescope of the Vacuum Tower Telescope (VTT). Instead of a prefilter wheel a fast matrix filter shifter was used to obtain full-disk Dopplergrams in various wavelengths. Dual Fabry-Perot interferometers were operated in a collimated mount. The etalon air gap is piezo tuned and servo stabilized for parallelism. A polychromatic polarimeter could successfully be tested to obtain LOS/vector magnetic and velocity maps in various lines.



Diagnostic diagrams for full-disk Doppler observations as to be obtained continuously with SPRING. The examples show these diagrams in five different spectral lines (labels in Angstrom). The diagrams are used for helioseismology and give a good indication for the successful optical setup of the full-disk telescope (working drift monitoring and sufficient spatial coverage).

The decision on the choice of the spectral lines was supported by numerical simulations. The structure and dynamics of the solar photosphere was studied based on the high-resolution, state of the art RHD code ANTARES that simulates near solar surface convection and the solar atmosphere. The vertical stratification of the inhomogeneous atmosphere was analyzed by a correlation analysis and evaluation of the vertical run of relative fluctuations of thermodynamic state variables for up- and down flows to identify characteristic height levels that separate the thermal convection zone from a convectively stable region where the hot granular gas overshoots into the atmosphere, to a transition region and the upper oscillatory layers in the high photosphere.

The overall technical concept is described in the corresponding document, including a study on the seeing conditions at the six possible sites Teide Observatory, Big Bear Observatory, Cero Tololo, Mauna Loa, Learmonth and Udaipur, estimates for data rates, and a description of the cloud monitoring.

In order to obtain a cost estimate, the combination of cameras, instruments and telescopes needed to be combined. Furthermore the cost for the building and the telescope tower were taken into consideration. The two concepts one with the fulldisk telescope (FDIS) and one with the multiplexed spectrograph (mxSPEC) result in a cost of up to 51.3 Mio. Euro for setting up a network with six nodes around the world (see the table below).

Overall, the study was successfully completed. SPRING has gained large attention by the scientific community. The need for synoptic observations of the Sun is expressed by the world-wide research community. Now, plans for setting up a ground-based network of observatories can now be built on this technical and feasibility study. This network may also represent the pointing platform to allow further interested parties to provide further instruments besides the measurements taken for magnetometry, full-disk intensity and velocity maps.

Instrument	Cost (€M)	Nsites	total (€M)
Cost estimates for FDIS (all three channels)			
Fabry-Perot Etalons for FDIS-B,R, IR	2,0	6	12,0
Pre-filters for FDIS	0,4	6	2,4
Cameras for FDIS B,R, IR	0,6	6	3,6
Polarimter costs	0,10	6	0,60
Optomechanical	0,05	6	0,3
Cost estimates for mxSPEC (all channels)			
Gratings for mxSPEC-B,R,IR	0,15	6	1,0
other items same as FDIS			
High-Res. Context Imager	0,5	6	3
	Total FDIS		**21,9**
	Total mXSPEC		**10,90**
Telescope, Mount etc.			
Mount	0,5	6	3,0
25cm telescope (3 per site)	1,0	6	6,0
Tip-tilt (3 per site)	1,0	6	6,0
		Total	**15,0**
Software			
Data Transfer+Reduction	0,2	6	1,2
Instrument control	0,5	6	3,0
Data storage	0,5	6	3
Computing center	0,5	6	3
		Total	**10,2**
Infrastructure			
Shelter	0,2	6	1,2
Concrete	0,3	6	1,8
Utility upgrades	0,2	6	1,2
Installation labor travel ship	0,25	6	1,5
		Total	**4,2**
OPTION-1	Grand Total	With FDIS	**51,3**
OPTION-2	Grand Total	with mxSPEC	**40,30**

WP90: Transnational ACCESS programme

Leader organization: KIS

Participants: : IAC, KIS, INAF, CNRS, SU, QUB

Work-package summary

The oversight of the TAS programme is described in the report on WP20. The ACCESS time at the SOLARNET telescopes and instruments was allocated and delivered successfully. The ACCESS programme enabled a large number of users to take advantage of state-of-the-art facilities. In particular it brought a large number of new users to the telescopes. It helped to foster small national European communities which cannot afford such large facilities.

All relevant number on the ACCESS programme are given in the document "Report on the TAS programme 2013 - 2016".

A total of 466 observing days were allocated and executed. These are 15 days more than planned, but since the real unit costs turned to be slightly smaller than the initial estimated costs, the used budget amounts to almost the same amount.

Both PI and service mode campaigns have delivered valuable state-of-the-art data sets that led to scientific publications in refereed scientific journals.

WP100: Access to Science Data Centres. Space missions.

Leader organization: UiO

Participants: MPG, UiO, ROB

Workpackage sumary

The description of Work for SOLARNET specifies the following for this work-package:

"Access to the most demanded European Science Data Centre, providing data gathered by the solar satellite HINODE, and the Solar Dynamics Observatory (SDO), will be offered. As previously mentioned, this access to space-based data for solar research, offered for the first time under an I3 supported by the EC, will expand significantly the content of the Programmes for the high-resolution solar physics community supported in the past.

The Hinode Science Data Centre Europe, the Belgian Web Incessant Screening and the German Science Center for the Solar Dynamics Observatory, are the three facilities offering access and services under this WP101, WP102 and WP103.

The main efforts, concerning these web-based databases, will be to widely advertise these resources, to increase the number of EU researchers accessing to them.

Modality of Access

The previously mentioned project web-page will include also reference and full information about these WP10 activities. Some specific information about the modality of access, support offered and periodical assessment is provided under the facilities' description.

Outreach of new users

As a complement of the publicity made through the project website, a set of publicity actions will be undertaken to attract users, specially targeted groups (new users):

– Participation in conferences, info days and meetings. Brochures, talks, etc.

– General advertisements. A special effort will be made to inform about the new facilities and instruments offering access for the first time under an EC programme: HINODE-UiO, BEWISSDOM and GSC-SDO (and the same applies for the access offered (WP9.2, WP9.5 and WP9.6) to GREGOR, IBIS/DST and ROSA/DST)."

The centers have all streamlined the access to the facilities and have significantly added new resources to the databases through the SOLARNET project.

The three centers have increased awareness of the existence of the space-based data to the solar physics community in Europe. This has been accomplished through participation in conferences and meetings.

More details about the individual centers are given below.

SubWorkpackage 101: HINODE/IRIS. Access to Science Data Centres

Detailed monthly reports on the activity in the Science Data Centre have been produced followed by detailed usage statistics (complete data available from http://sdc.uio.no/sdc/webstats).

Access to the Hinode Science Data Centre was provided throughout the whole project. The most significant improvement through the SOLARNET project was the addition of all data from the Interface Region Imaging Spectrograph (IRIS). The data was made available from the first day of open data policy, October 31st 2013. During the reporting period, all data from Hinode and IRIS have been continuously ingested into the Data Centre. Additional search possibilities have been added and the data presentation has been further improved through improved thumbnail pictures.

At the start of the SOLARNET Project the average number of distinct hosts accessing the data centre was around 600-700 per month. This increased in the beginning of the Project period and stabilized around 1100-1400. The last year, the numbers have gone down again – which is typical for missions after some time. The same increase is evident in the number of page-views from Europe where the average monthly numbers have increased from 590 (January-March 2013) to 1655 (July-September 2014).

SubWorkpackage 102: BE-WISSDOM. Access to Science Data Centres

The Solar Dynamics Observatory (SDO) was launched in January 2010 carrying three primary instruments the Atmospheric Imaging Assembly (AIA), the Helioseismic and Magnetic Imager (HMI) and the Extreme ultraviolet Variability Experiment (EVE). These instruments produce between 1 and 2 TB of data per day.

The goal of the European SDO data centre is to be a powerful cache for the data produced by SDO. By doing this we diminish the load on the USA SDO data centre at the Joint Science Operations Center (JSOC) at Stanford university and provide the Solar community with a quick and reliable access to SDO data.

The SDO datacenter

The hardware of the SDO data centre was updated in 2015. The SDO datacenter now has the following hardware: The storage array is made up of a SuperMicro storage server and a JBOD (just a bunch of disks) storage extension. These are equipped with 45 4TB harddisks and two 80 GB solid state drives, providing about 120 TB of usable storage after formatting.

The database server was purchased with 80 GB and 800 GB SSD hard disks to store the indices of the databases, maximum of 12 SATA/SAS hot-swap hard disks, a redundant power supply and 256 GB double data rate type SDRAM.

The SDO data centre provides access to the following SDO data sets.

- Near real time (15 min) 1k by 1k AIA quicklook data. A movie of the last 24 hours can be found on our website http://sdodata.oma.be/latest/
- Full resolution 4k by 4k AIA/HMI (HMI continuum and magnetogram) Level 1 fits files at a cadence of 1h for all wavelengths.
- Synoptic 1k by 1k AIA data at a 2-minute cadence for 94 Ångström and 211 Ångström wavelength.
- Magnetic HMI Active Region Patches (MHARP) data at 720 second cadence
- For high cadence data, we have a buffer system where data is kept by user request. With an alert service for when your data is available. This data is accessible through the following ways
    - Directly from ROB through the ftp and http protocol
    - In IDL trough the Virtual solar observatory.
    - In Python through the Virtual solar observatory.
    - Through a web application named the SDO wizard. http://sdodata.oma.be/sdo_wizard/

Interpretation of the web statistics

In order to collect and analyse the web data we use the server log file analysis method. This works by reading the logfiles in which the web server records file requests by browsers. We use two web log analysis software namely awstats and webalyzer.

There are two caveats that need to be kept in mind when dealing with web data from log file analysis. Log file analysis software doesn't always distinguish between a browser operated by a human and a web crawler collecting data for a search engine this can lead to an overestimation of the number of visitors. Secondly due to web cache a person revisiting a page may not be counted towards the number of visits causing an underestimation of the number of visitors.

Both these problems can be solved by excluding known web crawlers and stopping browser caching but this hampers visibility in search engines and result in degraded performance for the visitor and bigger load on the servers. An option for the future to deal with this is to start using the page tagging method.

SubWorkpackage 103: GSC-SDO. Access to Science Data Centres

The German Science Center for the Solar Dynamics Observatory (GSC-SDO) is dedicated to the acquisition and distribution of data from the Helioseismic and Magnetic Imager (HMI) instrument that is onboard the Solar Dynamics Observatory (SDO). The GSC-SDO is hosted by the Max Planck Institute for Solar System Research (MPS) in Goettingen, Germany.

The ultimate goal of sWP103 is to make HMI data (and other relevant data) available to the European solar physics community through the Data Record Management System, NetDRMS. NetDRMS is a software suite developed by Stanford University specifically for managing SDO observations and sharing the data worldwide: http://jsoc.stanford.edu/netdrms . NetDRMS is fully operational at the GSC-SDO and data are automatically transferred directly from Stanford University as soon as they are available. The GSC-SDO has an online raw storage capacity of 888 TB dedicated to SDO/HMI data and other related data products.

The GSC-SDO is "subscribed" to the several data series from the HMI instrument. When a NetDRMS site subscribes to a particular data series, that site by default receives all the meta-data, i.e. keyword, value pairs, directly from Stanford University. There is a separate mechanism that must be triggered in order to also receive the images. Furthermore, this can be done selectively so you can choose which images you want in your local NetDRMS system. This latter feature is particularly useful if local storage resources are not sufficient to store all the images, allowing a site to only transfer the images of interest.

The GSC-SDO currently makes available the following HMI images:

- All line-of-sight Dopplergrams (45s cadence), 4927619 images, 82 TB
- All line-of-sight Dopplergrams (720s cadence), 308316 images, 5 TB
- All line-of-sight Magnetograms (45s cadence), 4927619 images, 74 TB
- All line-of-sight Magnetograms (720s cadence), 308316 images, 4 TB
- All continuum intensities (45s cadence), 4927619 images, 73 TB
- All continuum intensities (720s cadence), 308316images, 4 TB
- Subset of Milne-Eddington inversions, 44515 images, 19 TB

The GSC-SDO continues to make available HMI images to the Kiepenheuer-Institut für Sonnenphysik (KIS) in Germany.

The MPS strongly promotes the GSC-SDO whenever possible. In particular, it is described in many posters from the MPS that are prepared for meetings/conferences worldwide. Many MPS publications also acknowledge and/or describe the GSC-SDO. This is a consequence of the GSC-SDO being a local facility for MPS scientists, and hence many of the scientific results coming from the MPS made use of data from the GSC-SDO.

4. List of SOLARNET deliverables

Deliverable Number	Deliverable Title	WP number	Lead beneficiary number
D10.1	Minutes of Board Meetings	10	IAC
D10.2	Report on public outreach	10	IAC
D10.3	Minutes of Board Meetings	10	IAC
D10.4	Report on public outreach	10	IAC
D10.5	Minutes of Board Meetings	10	IAC
D10.6	Report on public outreach	10	IAC
D20.1	Reports on the TAC tasks and the TAS Programme	20	KIS
D20.2	Survey document – State of the art of existing pipelines and procedures - Preliminary report on pipeline guidelines	20	CNRS
D20.3	Final report on pipeline guidelines	20	CNRS
D20.4	Document on standards for data archiving and VO	20	UiO
D20.5	Report on the VO tools prototype	20	UiO
D20.6	Report on the facilities for coordination	20	KIS
D20.7	Report on coordinated observations	20	KIS
D20.8	Specification of observing service mode on selected telescopes	20	SU
D20.9	Reports on the TAC tasks and the TAS Programme	20	KIS

D20.10	Reports on the TAC tasks and the TAS Programme	20	KIS
D30.1	On-line meeting proceedings	30	INAF
D30.2	Progress and final reports issued by host institutions concerning short stays	30	IAC
D30.3	Training schools material	30	INAF
D30.4	On-line meeting proceedings	30	INAF
D30.5	Progress and final reports issued by host institutions concerning short stays	30	IAC
D30.6	Training schools material	30	INAF
D30.7	On-line meeting proceedings	30	INAF
D30.8	Progress and final reports issued by host institutions concerning short stays	30	IAC
D30.9	Training schools material	30	INAF
D40.1	Report on workshops	40	TECNALIA
D40.2	Pilot projects plan for common R&D activities	40	TECNALIA
D40.3	Report on workshops	40	TECNALIA
D40.4	Report on workshops	40	TECNALIS
D50.1	Status, requirements and development of the instrument pipelines	50	SU
D50.2	Report on data compression methods	50	INAF
D50.3	Strategies to improve MFBD and speckle techniques	50	SU

D50.4	Standardised and improved MFBD and speckle codes	50	SU
D50.5	Data archive prototype linked to the SVO	50	UiO
D50.6	Status, requirements and development of the instrument pipelines	50	SU
D50.7	Status, requirements and development of the instrument pipelines	50	SU
D50.8	Data archive prototype linked to the SVO	50	UiO
D60.1	Preliminary report of FEA of large FPI	60	CNR-INO
D60.2	Image slicer design	60	IAC
D60.3	Microlens-des system design	60	MPG
D60.4	1k x 1k pnCCD conceptual design	60	PNSensor
D60.5	Dual-beam polarization modulator	60	MPG
D60.6	Dual-beam polarization modulator: test report	60	MPG
D60.7	FPI prototype	60	CNR-INO
D60.8	FPI prototype: tests report	60	CNR-INO
D60.9	Image slicer prototype	60	IAC
D60.10	Image slicer prototype: tests report	60	IAC
D60.11	Microlens-fed system prototype	60	MPG
D60.12	Microles-fed system prototype: tests report	60	MPG

D70.1	Results of MCAO correction Simulations	70	IAC
D70.2	AO prototype for THEMIS and tests report	70	CNRS
D70.3	Results of site-testing campaign at ORM and OT	70	IAC
D70.4	Results of the optimization of EST design based on CFD analysis	70	IAC
D70.5	GREGOR Heat Rejecter prototype and tests report	70	INAF
D70.6	Results of MCAO correction simulations	70	IAC
D70.7	AO prototype for THEMIS and tests report	70	CNRS
D70.8	Results of site-testing campaign at ORM and OT	70	IAC
D70.9	Results of the optimization of EST design based on CFD analysis	70	IAC
D70.10	GREGOR Heat Rejecter prototype and tests report	70	UToV
D70.11	Results of MCAO correction simulations	70	IAC
D70.12	AO prototype for THEMIS and tests report	70	CNRS
D70.13	Results of site-testing campaign at ORM and OT	70	IAC
D70.14	Results of the optimization of EST design based on CFD analysis	70	IAC
D70.15	GREGOR Heat Rejecter prototype and tests report	70	UToV

D80.1	Science and technical requirements for synoptic observations instrument.	80	KIS
D80.2	Final proposed instrument concepts and operation plan	80	KIS
D90.1	Access to ground-based telescopes. Amount of Access	90	KIS
D90.2	Access to ground-based telescopes. Amount of Access	90	KIS
D90.3	Access to ground-based telescopes. Amount of Access	90	KIS
D100.1	Assessment on access to databases.	100	UiO
D100.2	Assessment on access to databases.	100	UiO
D100.3	Assessment on access to databases.	100	UiO