

# Data archiving for the next generation of solar high-resolution telescopes

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# Data archiving for the next generation of solar high-resolution telescopes

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Scientist at the Experimental Solar Physics group at KIS  
Head of the *Center for Advanced Solar Spectro-polarimetric Data Analysis*  
(CASSDA project)

- Space-based vs. ground-based solar observatories
- Next generation ground-based solar observatories
  - (US) DKIST & (European) EST 4m-class telescopes
- Challenges for data search from ground-based observations
- CASSDA & SOLARNET projects
- The European SVO - A prototype

- Space-based (solar) telescopes provide with science-ready data to the scientific community

⇒ This translates into a high scientific output  
(backed up by a high number of publications)

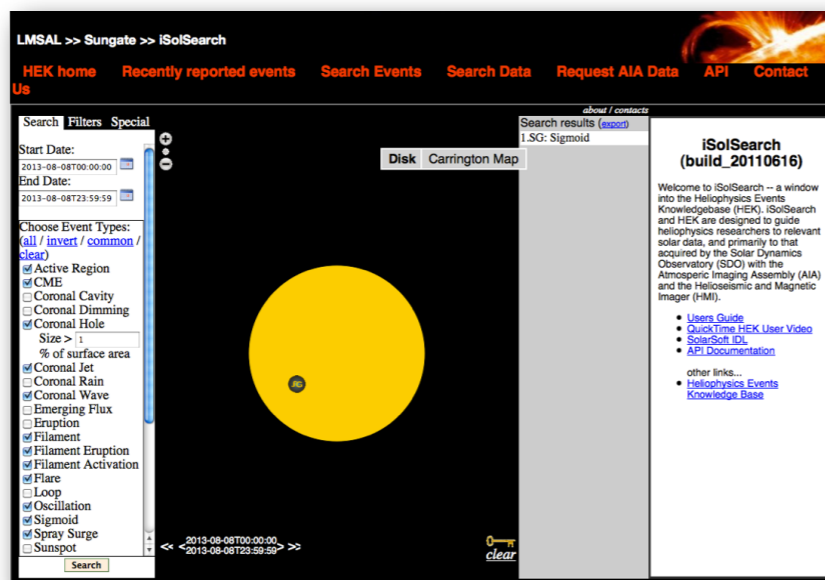
- This is still not the case for ground-based solar observatories..

- There is a need to make data discovery easy & to distribute data, especially for ground-based observations

## Data archives, e.g., VSO



## Event searching, e.g., HEK



LMSAL >> Sungate >> iSolSearch

HEK home Recently reported events Search Events Search Data Request AIA Data API Contact Us

Search Filters Special

Start Date: 2013-08-08T00:00:00  
End Date: 2013-08-08T23:59:59

Choose Event Types:  
all / invert / common / clear

- Active Region
- CME
- Coronal Cavity
- Coronal Dimming
- Coronal Hole
- Size > 1
- % of surface area
- Coronal Jet
- Coronal Rain
- Coronal Wave
- Emerging Flux
- Eruption
- Filament
- Filament Eruption
- Filament Activation
- Flare
- Loop
- Oscillation
- Sigmoid
- Spray Surge
- Sunspot

Search results (aspect)  
1.SG: Sigmoid

iSolSearch (build\_20110616)

Welcome to iSolSearch -- a window into the Helioviewer Events Knowledgebase (HEK). iSolSearch and HEK are designed to guide heliophysics researchers to relevant solar data, and primarily to that acquired by the Solar Dynamics Observatory (SDO) with the Atmospheric Imaging Assembly (AIA) and the Helioseismic and Magnetic Imager (HMI).

- [Users Guide](#)
- [QuickTime HEK User Video](#)
- [SolarSoft IDL](#)
- [API Documentation](#)

other links:

- [Helioviewer Events Knowledge Base](#)

## Browsing tools, e.g., (j)Helioviewer



Helioviewer.org - Solar and heliospheric image visualization tool

Time: 2013-08-08  
Time: 00:40:48 UTC  
Time-step: 1 Day

Images: HMI Mag 20130807 23:44:08

Opacity: SDO  
Instrument: HMI  
Detector: HMI  
Measurement: magnetoga

Solar Features & Events

- HEK: Active Regions, Coronal Cavities, Coronal Dimmings, Coronal Holes, Coronal Jets, CMEs, Coronal Rain, Coronal Waves, Emerging Fluxes, Filaments, Filament Activations, Filament Eruptions, Flares, Loops, Oscillations, Plages, Sigmoids, Spray Surges

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JHELIOVIEWER - EXPLORE THE SUN

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2-Minute Video Tutorial

- Explore 15+ years of SOHO data
- Browse high-res SDO data
- Create your own movies of the Sun

# Next generation 4m-class ground-based solar telescopes

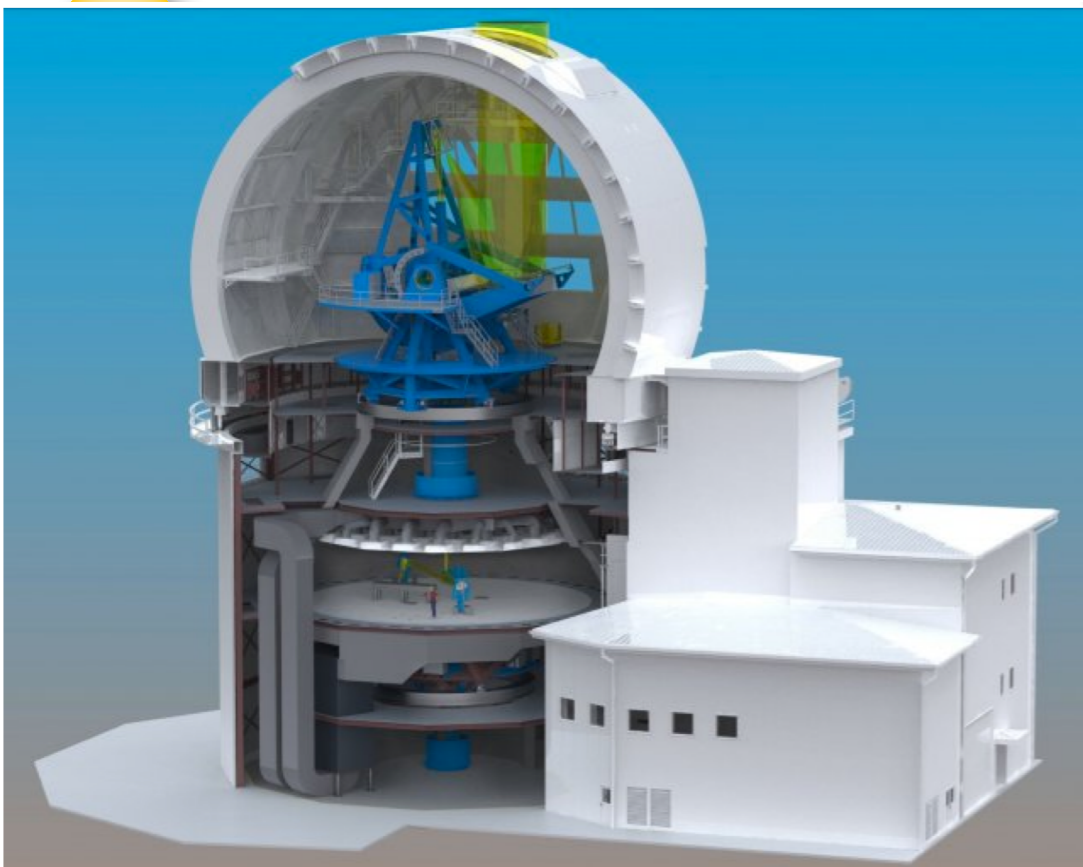
- Next generation ground-based solar observatories
- (US) DKIST & (European) EST 4m-class telescopes



Fig. 1: The distribution of the observatories around the globe.

# Daniel K. Inouye Solar Telescope



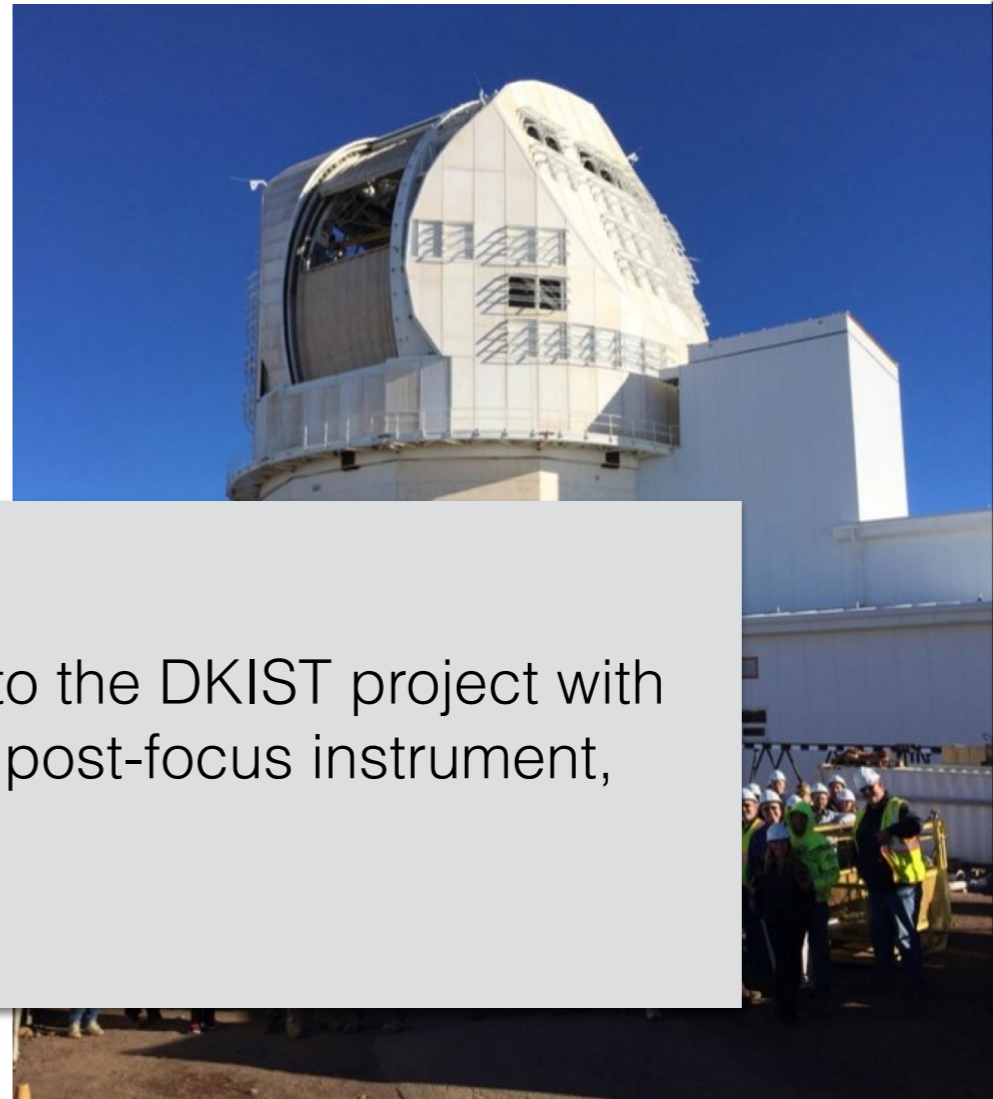
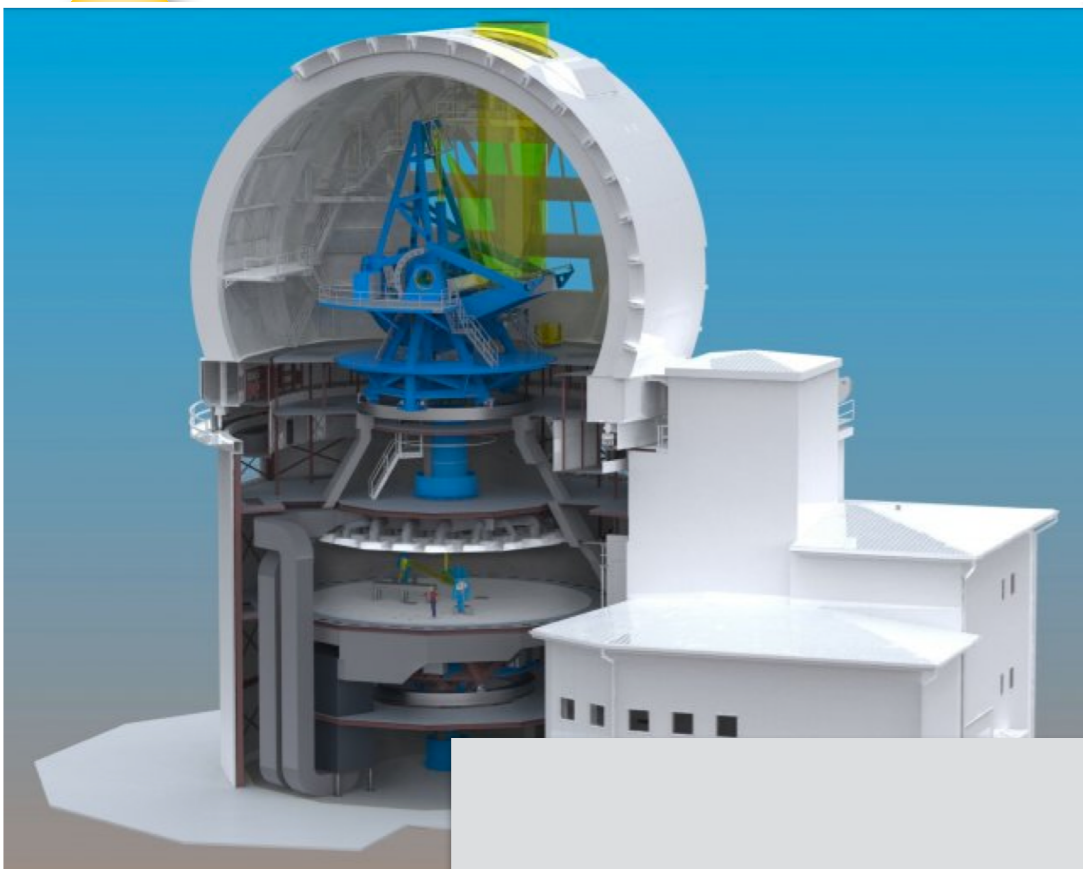


## Haleakala Obs., Maui



DKIST is a 4m solar telescope facility under construction by the (US) National Solar Observatory atop the Haleakala volcano in Maui

On completion around 2018, it will be the world's largest solar telescope



Haleakala Obs

Rendering of proposed ATST facility at the primary Mees S



KIS (Germany) is contributing to the DKIST project with the Visible Tunable Filter (VTF) post-focus instrument, a 2D spectropolarimeter

DKIST is a 4m solar telescope facility under construction by the (US) National Solar Observatory atop the Haleakala volcano in Maui

On completion around 2018, it will be the world's largest solar telescope

Nazaret Bello González, KIS

- The upcoming ground-based large solar telescopes + new post-focus instrumentation (detectors) → vast increase of the data volume




Example: expected DKIST data stream

DKIST Instrument	Detectors	Hourly Data Volume
<b>VBI</b>	1 x 4096 x 4096 detector, 30 fps	<b>6.5 TB/hour</b>
<b>DL</b>		
<b>Cryo</b>		
<b>AO</b>		<b>0.3 TB/hour</b>
		<b>12 TB/hour</b>
		<b>~50 TB/day</b>

~ 20 x increased data volume/hour!

*K. Reardon*

# European Solar Telescope

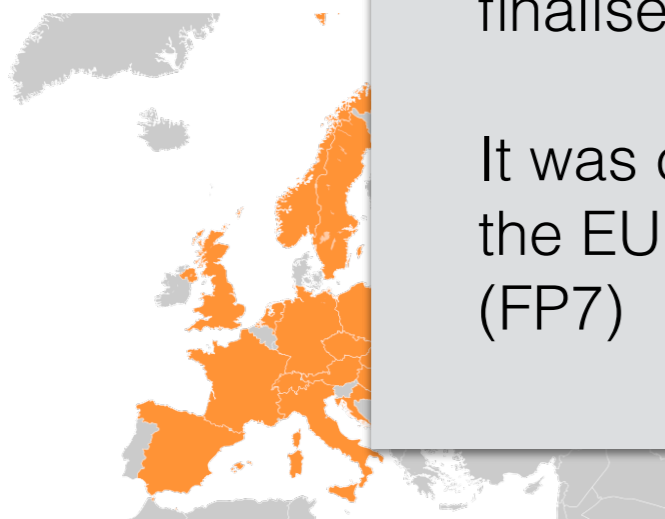
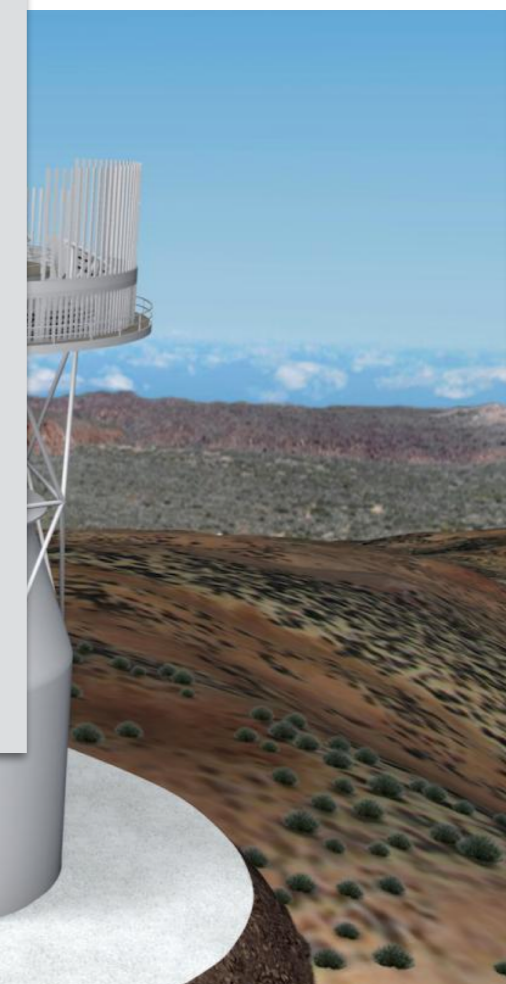
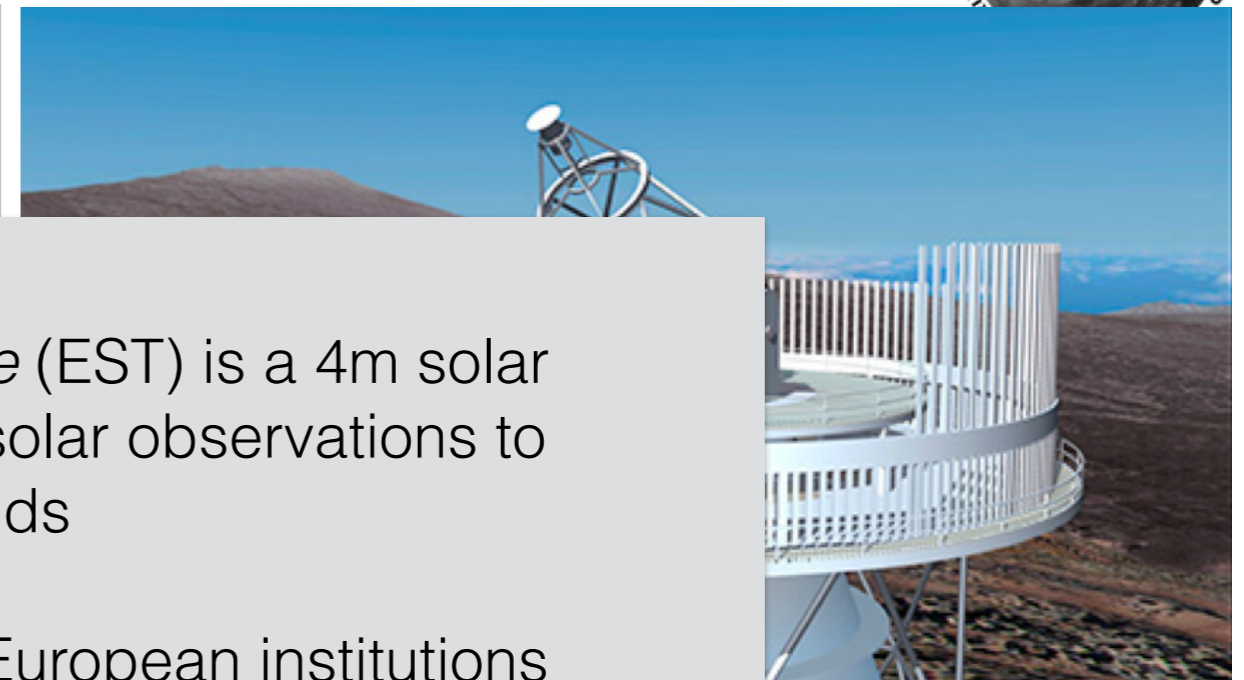
Institute		Location	
IGAM	Institutsbereich Geophysik, Astrophysik und Meteorologie		Graz
HVO	Hvar Observatory		Hvar
AIASCR	Astronomical Institute AS CR		Ondřejov
THEMIS	THEMIS S.L., [In]		
KIS	Kiepenheuer-In		
UniDeb	Heliophysical C		
INAF	Istituto Naziona		
UU	Utrecht Univers		
ITA	Institute of Theor		
IA UW	Astronomical In		
AISAS	Astronomical In		
IAC	Instituto de Astr		
SU	The Institute for		
IRSOL	Istituto Ricerche		
UCL-MSSL	University Colle		

The *European Solar Telescope* (EST) is a 4m solar telescope for high-resolution solar observations to be located in the Canary Islands

The EST project engages 15 European institutions lead by the IAC (Spain) and KIS (Germany)

The (3 years) conceptual design study conducted by research institutions and industrial companies was finalised in May 2011
















It was co-financed by the European Commission under the EU's Seventh Framework Programme for Research (FP7)

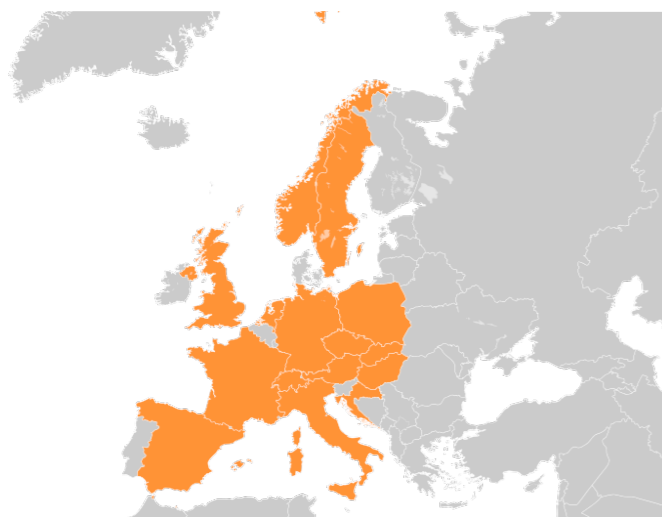
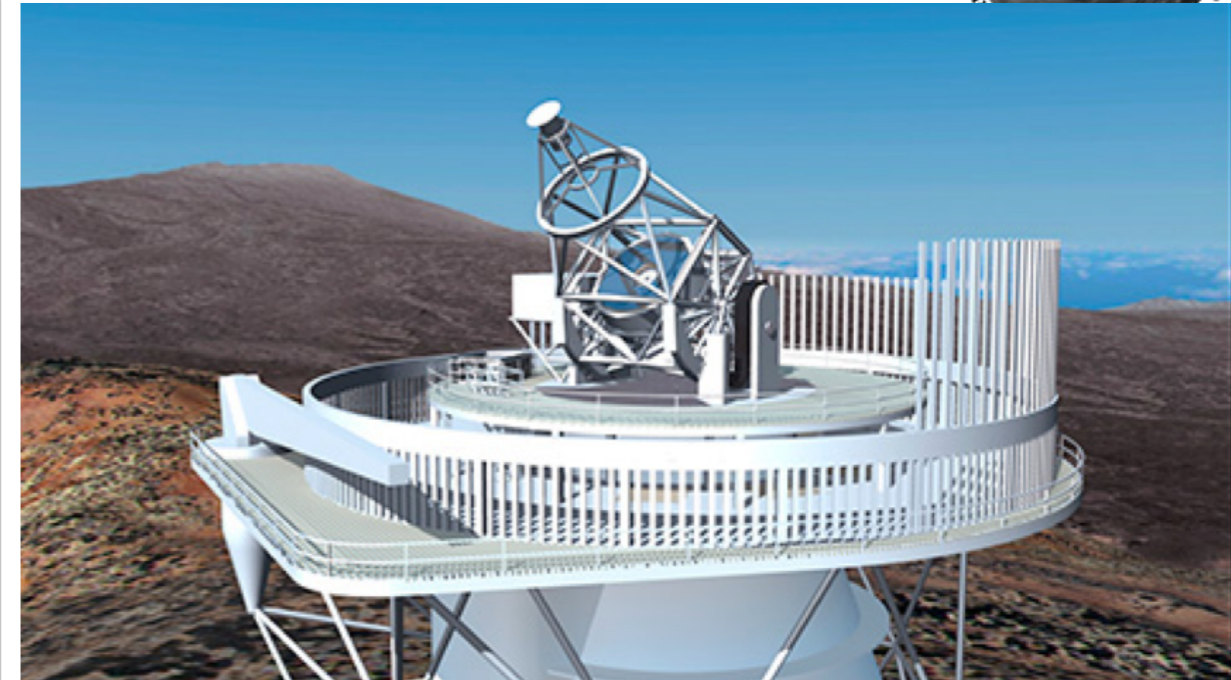


Instituto de Astronómica de Canarias  
Canary Islands  
Spain

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**WEBSITE**  
<http://www.est-east.eu/>

Institute		Location	
IGAM	Institutsbereich Geophysik, Astrophysik und Meteorologie		Graz
HVO	Hvar Observatory		Hvar
AIASCR	Astronomical Institute AS CR		Ondrejov
THEMIS	THEMIS S.L., <sup>[note 1]</sup> INSU-CNRS, CNR		Paris
KIS	Kiepenheuer-Institut für Sonnenphysik		Freiburg
UniDeb	Heliophysical Observatory Debrecen		Debrecen
INAF	Istituto Nazionale di Astrofisica		Rome
UU	Utrecht University, Sterrekundig Instituut		Utrecht
ITA	Institute of Theoretical Astrophysics		Oslo
IA UW	Astronomical Institute of the Wroclaw University		Wroclaw
AISAS	Astronomical Institute of the Slovak, Academy of Sciences		Tatranská Lomnica
IAC	Instituto de Astrofísica de Canarias		La Laguna
SU	The Institute for Solar Physics		Stockholm
IRSOL	Istituto Ricerche Solari		Locarno
UCL-MSSL	University College London - MSSL		London



#### TIMELINE

- ESFRI Roadmap entry: 2016
- Preparation phase: 2011-2019
- Construction phase: 2019-2025
- Operation start: 2026

#### ESTIMATED COSTS



- Capital value: Not Available
- Preparation: 10 M€
- Construction: 200 M€
- Operation: 9 M€/year

#### HEADQUARTERS

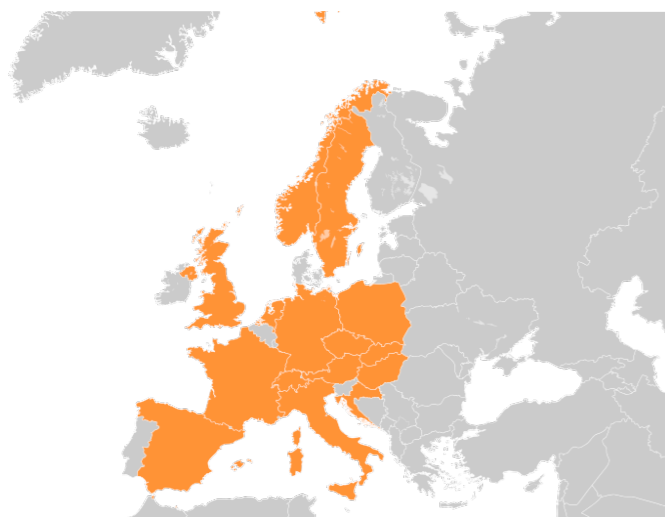
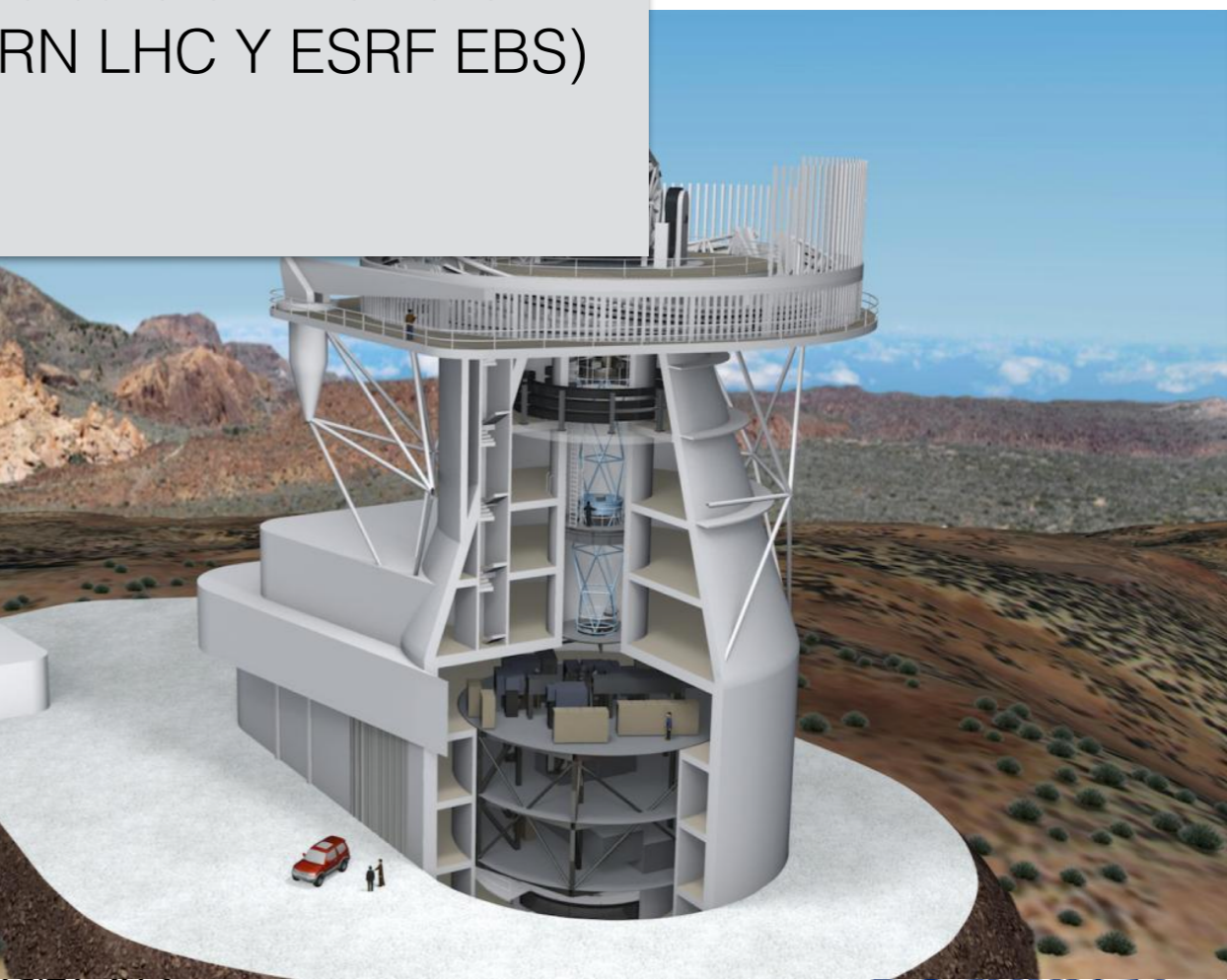
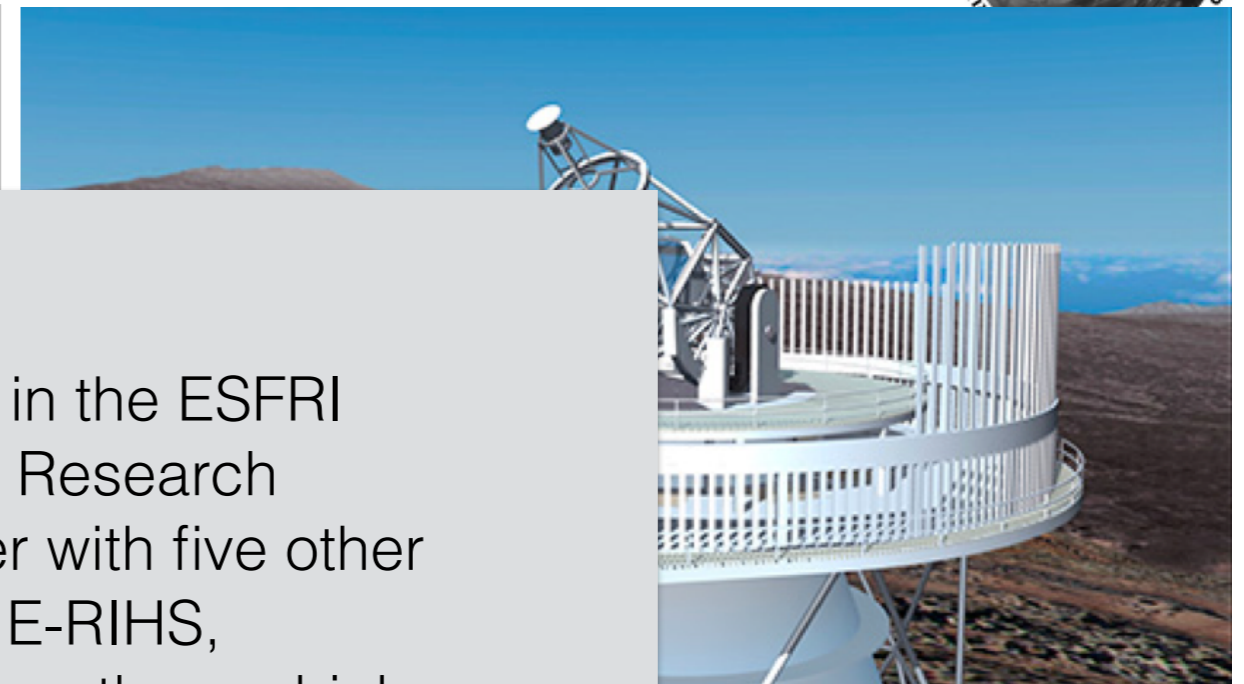
Instituto de Astrofísica de Canarias  
Canary Islands  
Spain

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KIS	Kiepen		
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INAF	Istituto		
UU	Utrecht		
ITA	Institute		
IA UW	Astron		
AISAS	Astron		
IAC	Institute		
SU	The Ins		
IRSOL	Istituto		
UCL-MSSL	Univers		

In March 2016, EST was included in the ESFRI (Forum for a European Strategy in Research Infrastructures) route map, together with five other projects (ACTRIS, DANUBIUS-RI, E-RIHS, EMPHASIS Y KM3NeT 2.0) and two others which are considered to be emblematic (CERN LHC Y ESRF EBS)



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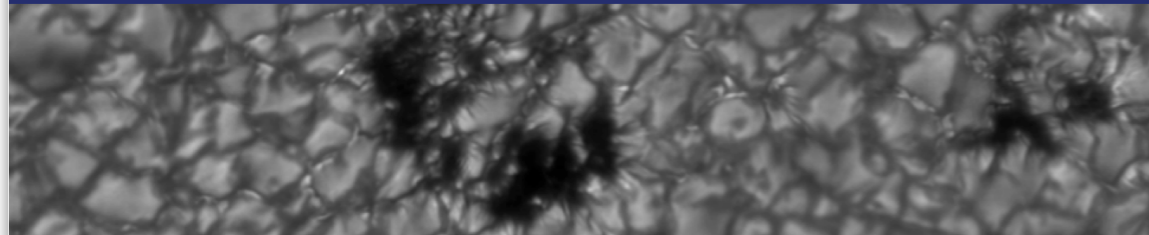
The EST project is driving other projects..

## CASSDA and SOLARNET projects



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Sitemap Imprint 



Institute Research Teaching Observatories **Projects** Organization Public Outreach Contact

## Projects

### CASSDA

1st CASSDA School  
1st CASSDA Workshop

EAST

HotMol

InnoPol

ORIGIN

SOLARNET

SolarOrbiter PHI-ISS

Spaceln

Sunrise

Visible Tunable Filter

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## CASSDA - Centre for Advanced Solar Spectro-polarimetric Data Analysis

The Kiepenheuer-Institut für Sonnenphysik (KIS) is the leading institute operating the German solar telescopes at the Observatorio del Teide (Tenerife):

1. The Vacuum Tower Telescope (VTT), a reference in the international solar physics community, for the observation of the solar photosphere and chromosphere with high spatial resolution, and
2. The 1.5m GREGOR telescope - Europe's largest solar telescope.

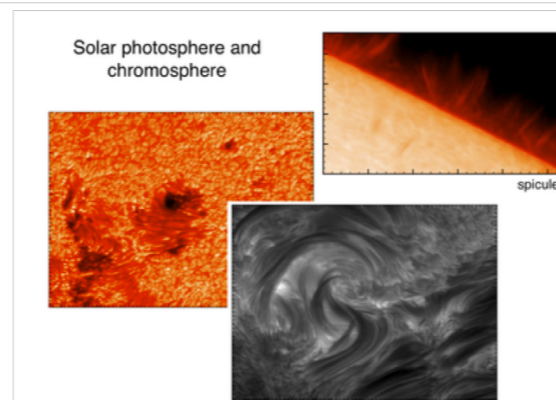
For this reason, the KIS is committed to train students and young scientists in the observing procedure and data handling, to further exploit the observing and data processing facilities. In addition, in order to enlarge the scientific outreach, the data from the solar observatories has to be opened to the international solar physics community. After the standardisation of the data analysis procedure, the processed data should be released in an automated manner to a public data archive, e.g., the Virtual Solar Observatory.

The CASSDA project (*Centre for Advanced Solar Spectro-polarimetric Data Analysis*) is conceived to provide to the solar physics community with accurate spectroscopic and spectro-polarimetric datasets observed at the German telescopes. This project has been awarded by the Joint Initiative for Research and Innovation of the Leibniz Association with funding.

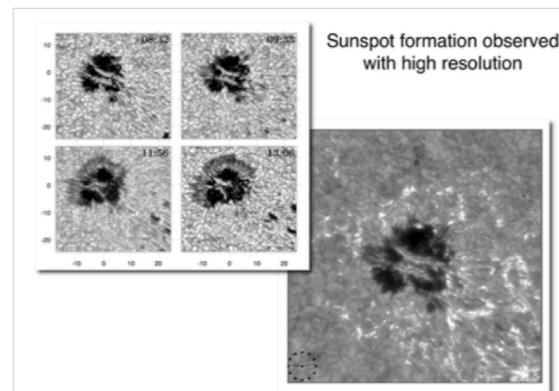
CASSDA is embedded within the Experimental Solar Physics Department of the Kiepenheuer-Institut für Sonnenphysik.

CASSDA started its activities on July 1, 2012, with a starting project duration of three years. The duties of the CASSDA members on data processing and data analysis are driven by a scientific research program on photospheric-chromospheric coupling based on spectro-polarimetric measurements.

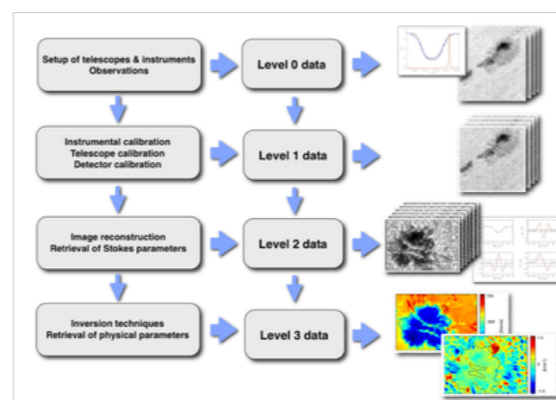
The CASSDA activities include collaborations with AIP (Potsdam, Germany), MPS (Göttingen, Germany), and IAC (La Laguna, Spain).



VTT (B. Sánchez-Andrade Nuño, IAG)



VTT (R. Schlichenmaier, KIS)



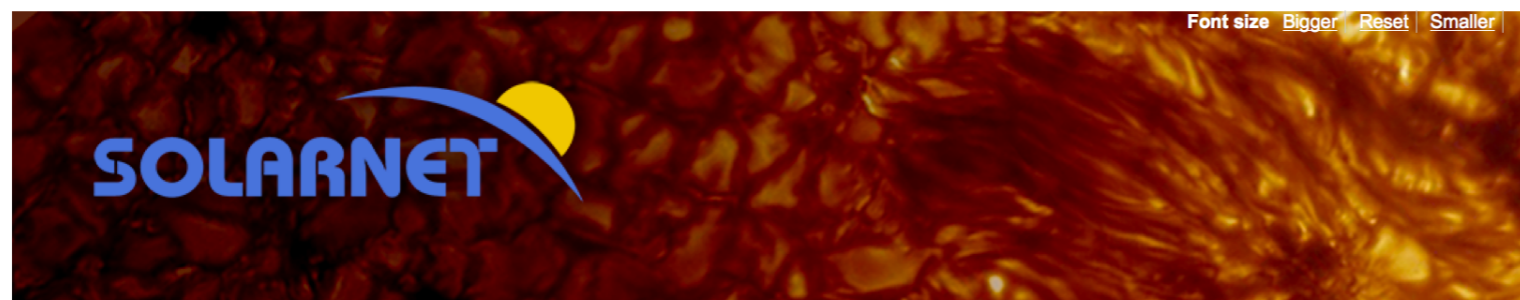
Data Processing Scheme

CASSDA@KIS

Development of data pipelines for the German solar observatories

Startup grant funded by the Leibniz Association

Precursor of the future *European Data Centre* project at KIS



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## HIGHLIGHTS

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## Presentation

SOLARNET 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 world-wide scale.

Networking activities, access to first-class infrastructures and joint research and development activities are being carried out in SOLARNET to improve, in quantity and quality, the service provided by this European community.

### In summary, SOLARNET involves:

More than 500 solar physics researchers.  
32 partners from 16 countries: 24 EU research institutions; 6 EU private companies; 2 USA research institutions.



SOLARNET Project achievements will be of paramount relevance to contribute towards the realisation of the 4m [European Solar Telescope \(EST\)](#).

## Latest News

- ▶ April 20, 2016. 4th SOLARNET Workshop "Solar Eruptive Events: Observations and Modelling" (London, April 20-23, 2016).
- ▶ April 13, 2016. 4th SOLARNET School Started Today in London.
- ▶ March 10, 2016. The EST in ESFRI Roadmap 2016.
- ▶ Feb. 3, 2016. SOLARNET Announcement of Opportunity. Mobility Programme of Young Researchers. DEADLINE: March 15th, 2016.

## Agenda

June 2016						
M	T	W	T	F	S	S
30	31	1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	1	2	3

## Coming Events

- June 20, 2016  
[IRIS-6 Workshop: The Solar Chromosphere](#)
- June 26, 2016  
[SPIE Astronomical Telescopes + Instrumentation](#)
- July 04, 2016  
[EWASS 2016](#)
- July 30, 2016  
[41st COSPAR Scientific Assembly](#)
- August 29, 2016  
[Partially Ionised Plasmas in Astrophysics \(PIPA\)](#)
- September 05, 2016  
[Hinode 10](#)
- September 12, 2016  
[Solar Polarization 8](#)

[View Full Calendar](#)

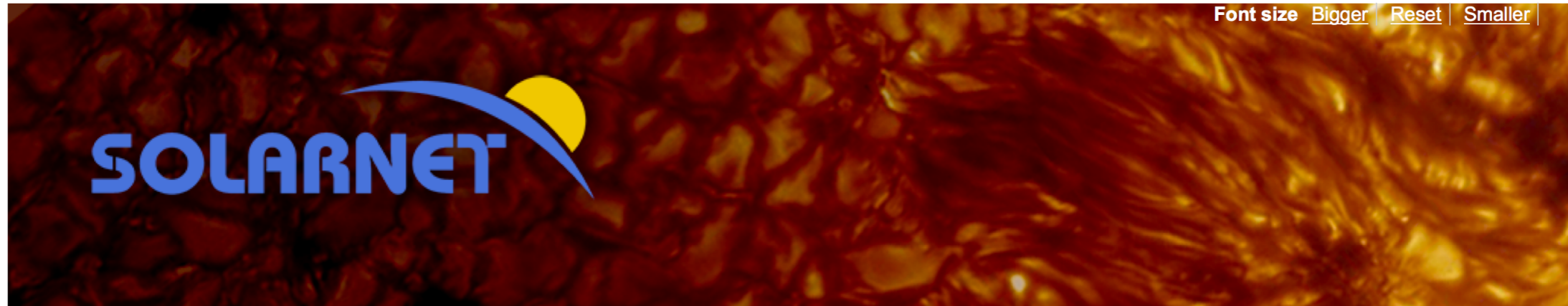
SOLARNET integrates the major research infrastructures in high-res solar physics

Funded by the FP7 since 2013

Getting Ready for EST (GREST) project funded by HORIZON2020



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.



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## Joint Research Activities



The following joint research activities will be carried out to improve the service provided by owners/operators of research infrastructures for research on solar physics:

### WP50. Tools for Innovative Data Handling: Pipelines, Databases & SVO

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

### WP60. Advanced Instrumentation Development

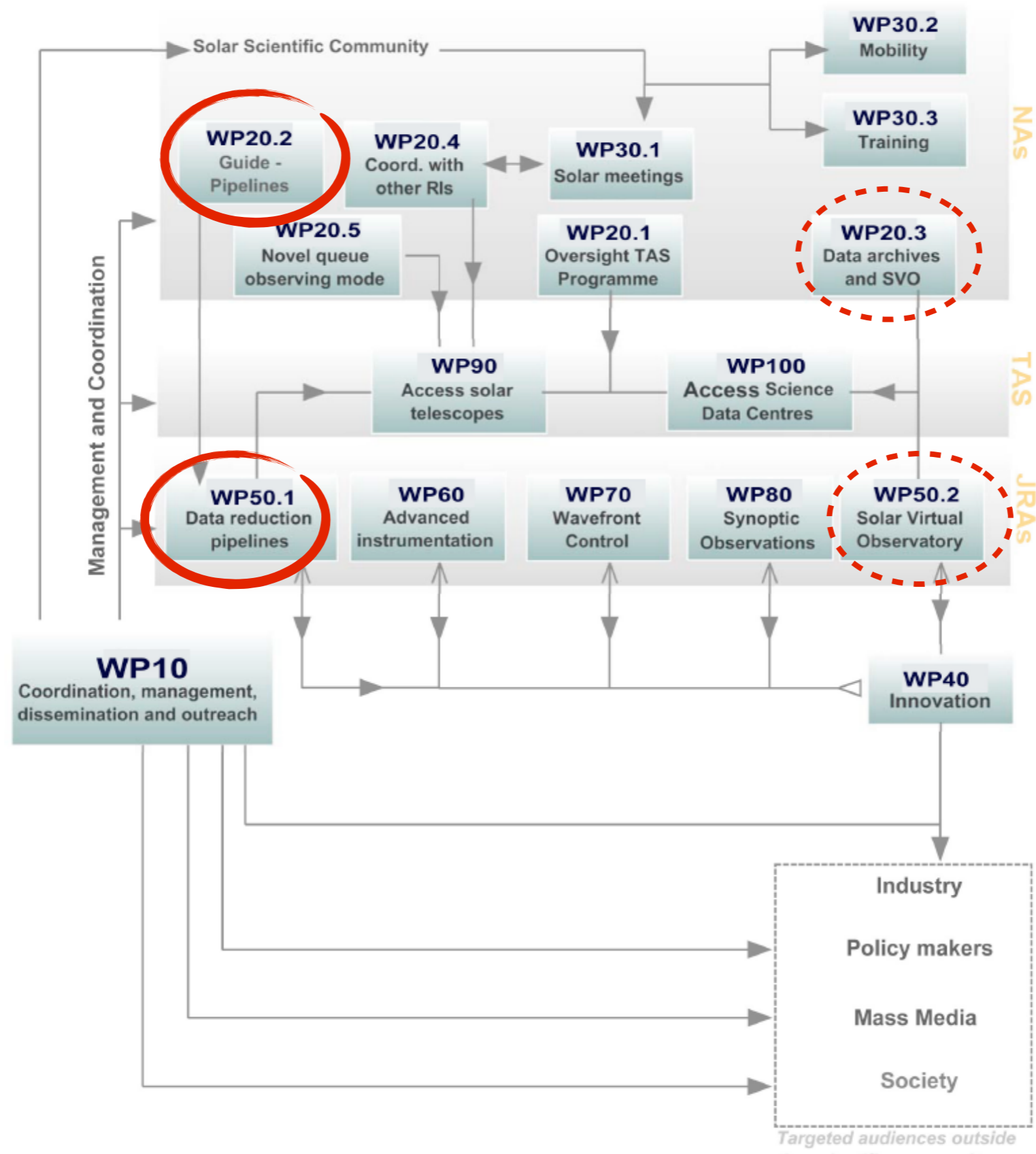
Development of instrumentation to improve the existing solar telescopes and with possible application to the future large aperture solar telescopes. The instrumentation developments included in this WP are the following: large diameter FPIs (100 to 300mm), image slicer for 2D spectroscopy, microlens-fed spectrograph and Fast Imaging Polarimeter.

#### WP60.2 Image Slicers for 2D spectroscopy

## HIGHLIGHTS

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## WP20.3. Data archives and Solar Virtual Observatory.

The object of this task is to establish the rules for an adequate dissemination of data to the community [with a long list of actions]

- To identify the metadata needed in order to determine whether a dataset is relevant to a specific scientific investigation
- To define a subset of the available metadata that should be available to form search criteria in a virtual observatory/archive

A group composed by experienced partners (UiO –chair–, ROB, UCL-MSSL, INAF, IGAM, AISAS, HVAR, AIP, UPS, UWR, NSO and CfA-SAO) has been formed with the above goals

# Challenges in data search from ground-based solar observations

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Based on the

Document on Standards for Data Archiving and VO

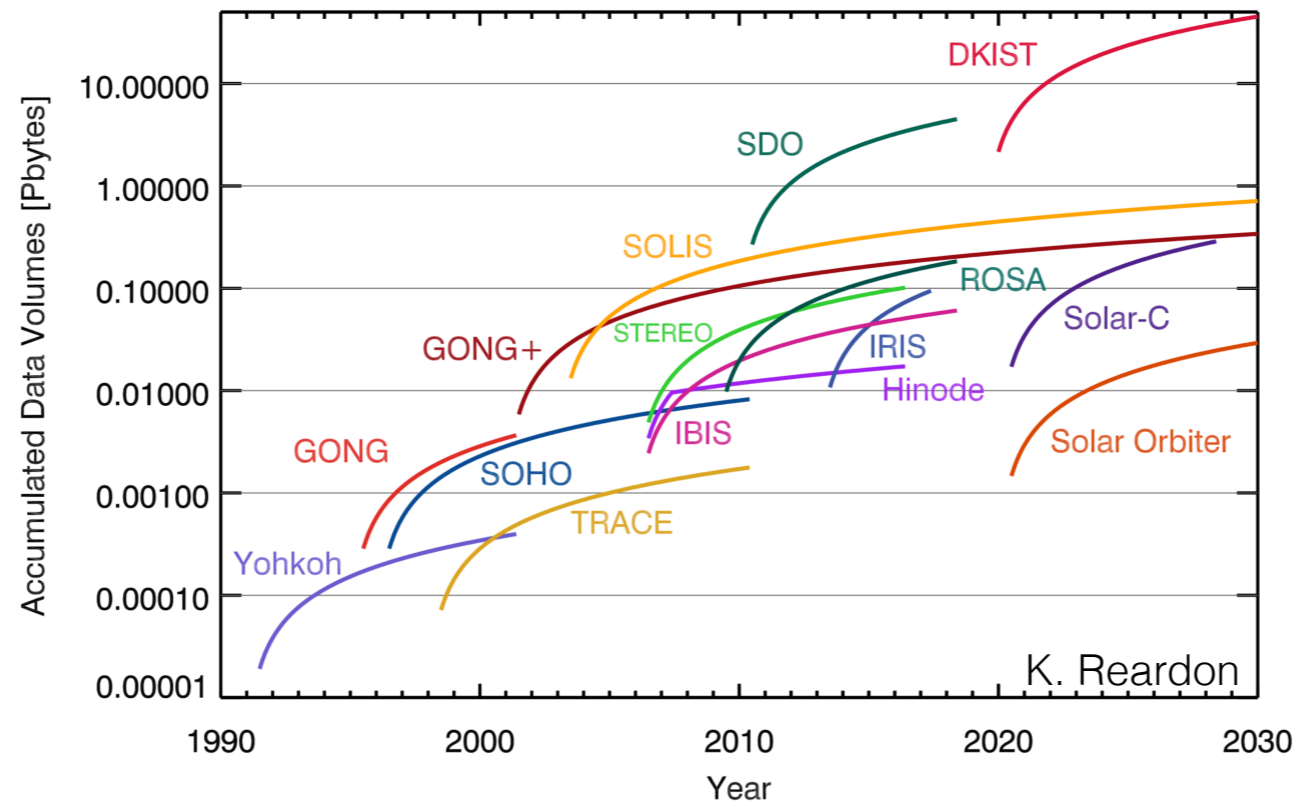
*SOLARNET WP20.3*

<http://sdc.uio.no/open/solarnet-20.3/>

Traditionally, solar observation archives and VOs have been used primarily to locate data from data sets that researchers have already known existed, namely from space-based solar observatories



However, the number of data sets available has grown, and will continue to grow as an increasing amount of data flow from ground-based observations are made and will be available



K. Reardon

The use of multi-instrument analysis of solar phenomena has grown over the last decade, but the ability of SVOs to locate multi-instrument observations has **not** grown with it



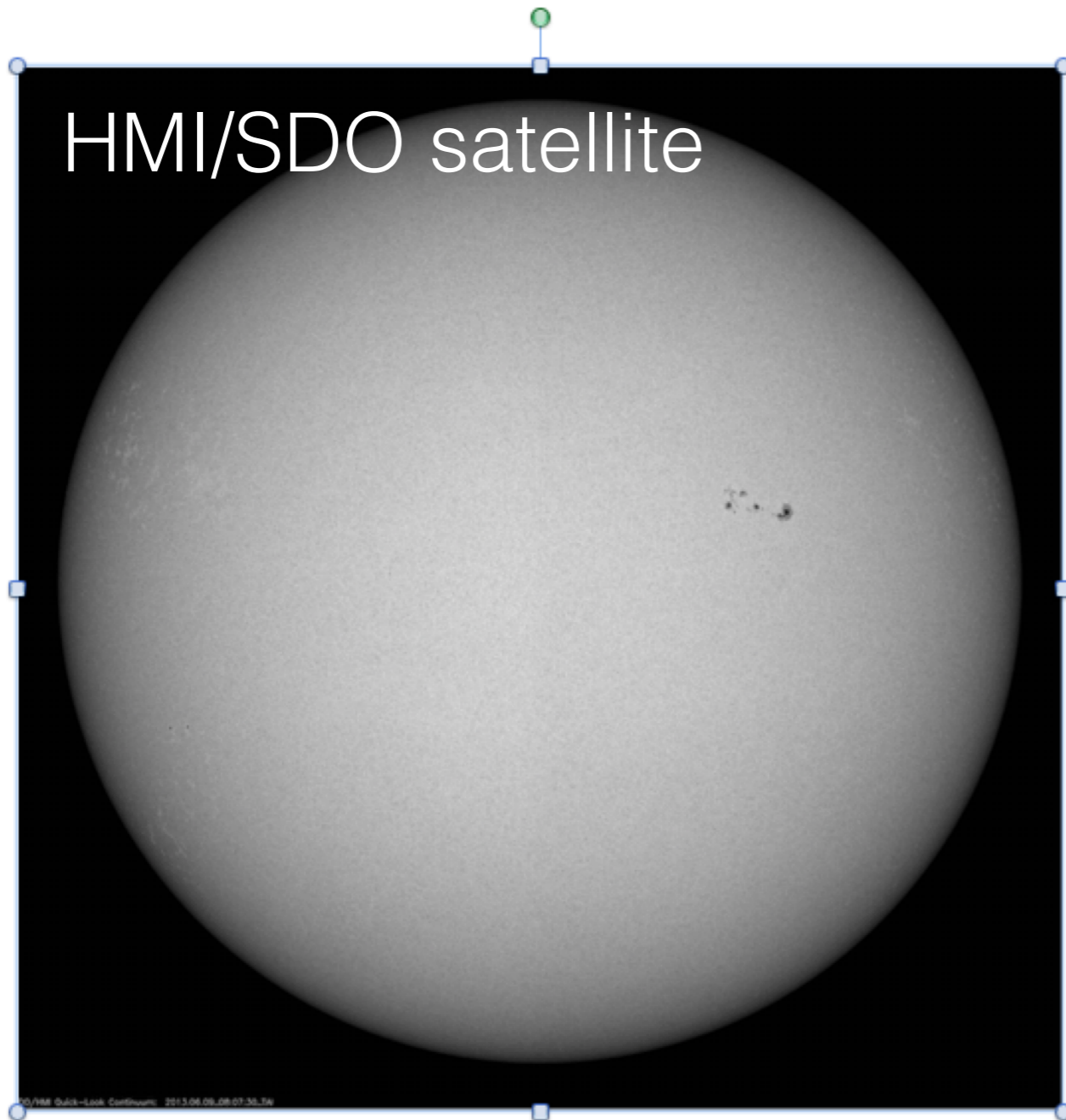
An ideal Solar Virtual Observatory (SVO) should be able to find sets of successful observations matching a hypothetical ideal observation

proposal:

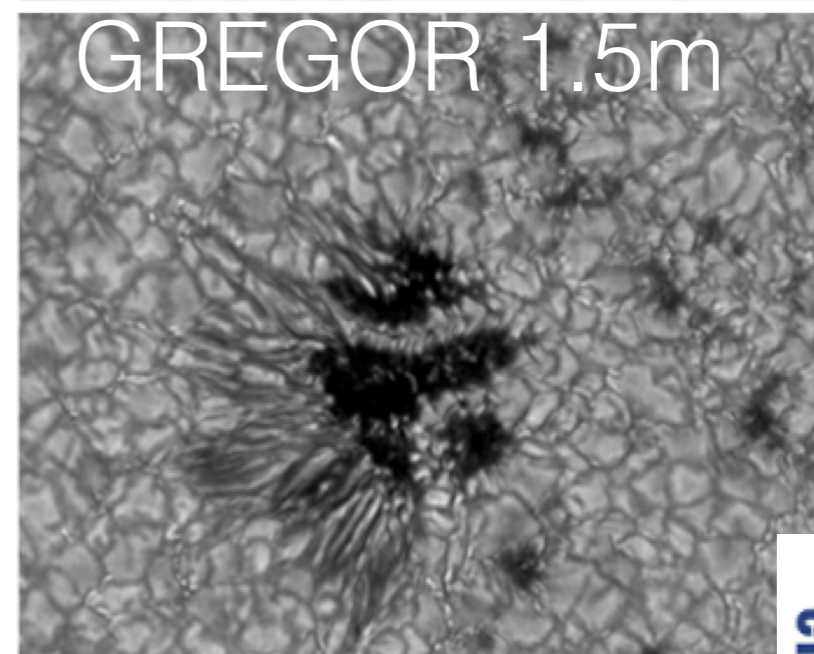
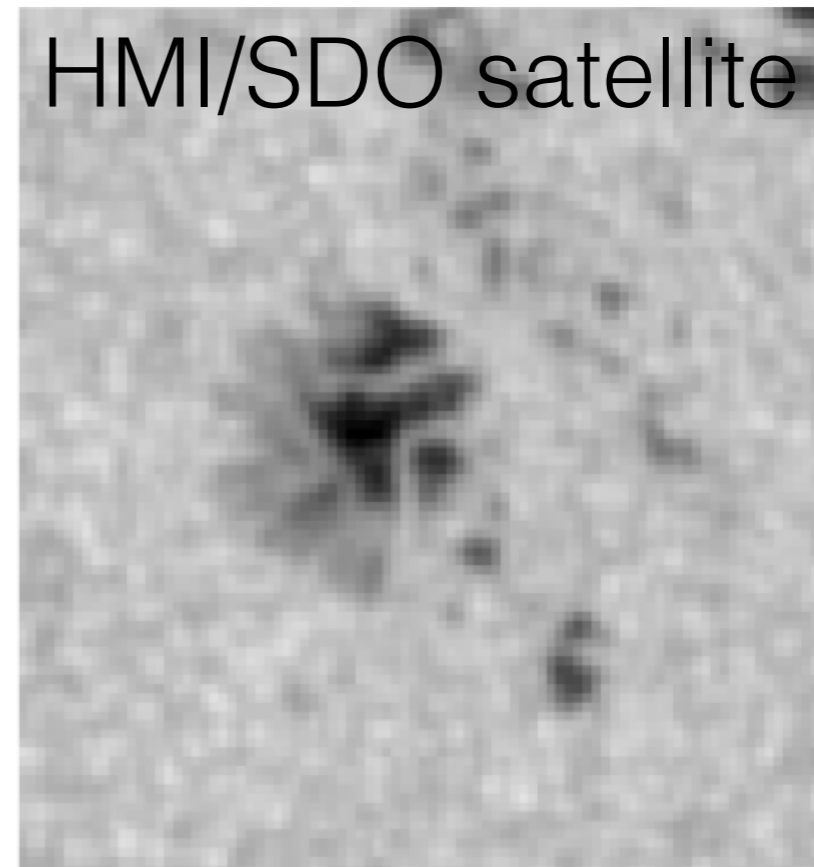
joint observations of specific targets/events from multiple instruments

Such a scenario may even involve observations that do not overlap in time, e.g. solar disc observations of events vs. *in situ* observations of particles/shocks/interactions at a later time

Characteristics of ground-based solar observations:



R. Schlichenmaier (KIS)



## Characteristics of ground-based solar observations:

Limited  
Sun, s

Seeing  
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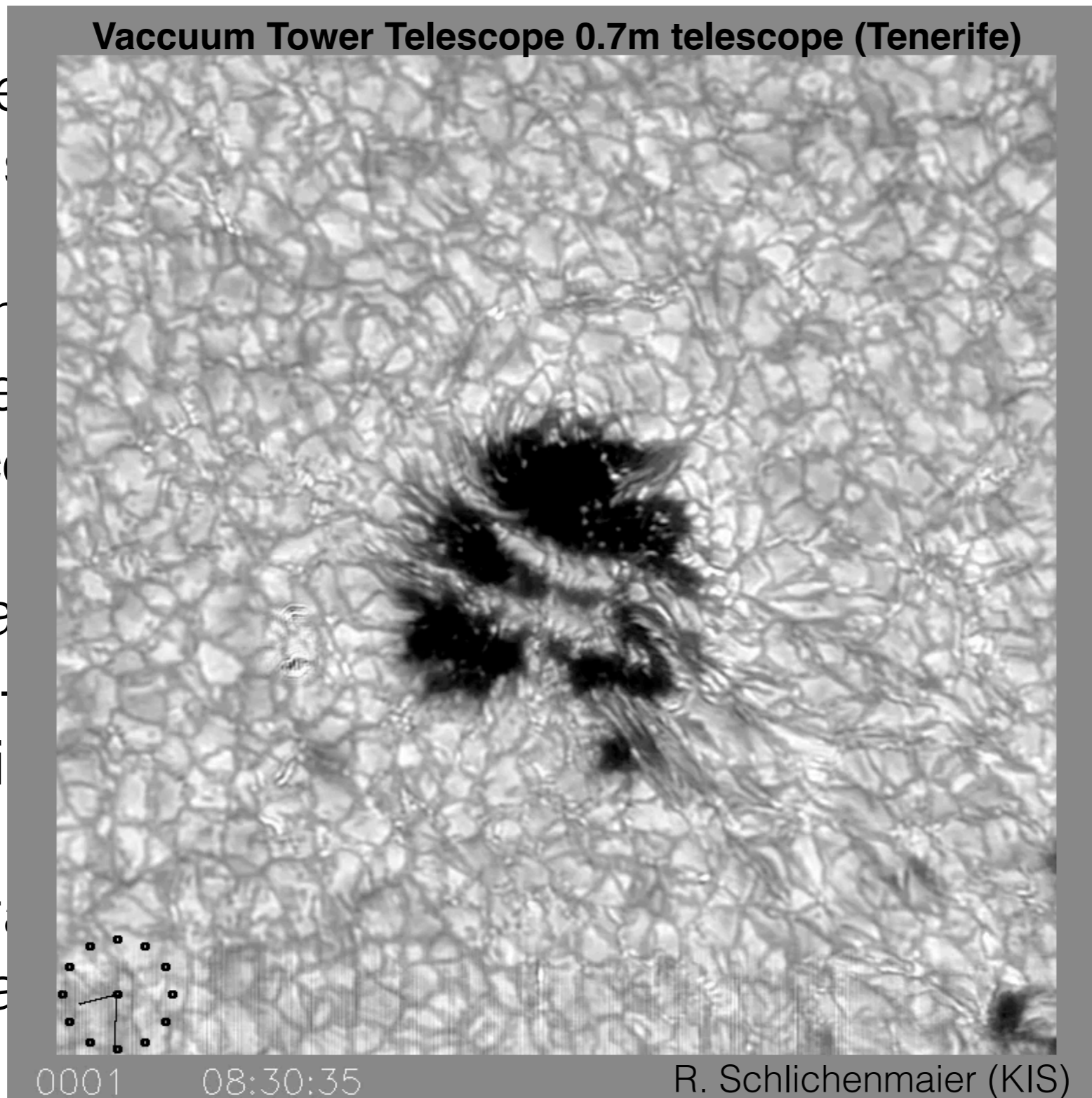
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Characteristics of ground-based solar observations:

- Limited FoV (non-full disc) - Target dependent: quiet Sun, sunspots, pores, plages, faculae, prominences,...
- *Seeing* conditions, cadence variations, # dropped frames, polarimetric accuracy, etc. as a **quality/success** parameters
- Versatile observing modes: non-standardised observing runs - novel science (multi wavelength,..) - difficulty in unifying data pipelines
- Upgrade of instrumentation - changes in data characteristics for a given (upgraded) instrument

The ideal SVO should address:

1. Efficient presentation of search results
2. Visualisation: quick-look and movies, using external existing websites
3. Type of observations, targets and events must be identified
4. Instrument specific criteria: ideally, the archive should extract generic parameters matching specific criteria

In order to fulfil the “vision” of an ideal SVO, it is necessary to ensure that the data to be served contains the necessary metadata



# Standards for data archiving and SVO for ground-based observations

## GOAL:

Establish standards for adequate data dissemination

## DIFFICULTIES:

(1) The standards should include clear descriptions of **data quality/success** criteria that may be used to select data

(2) It should be possible to develop **generic tools** for data visualisation and analysis

There are numerous projects with SVO-like characteristics and goals (e.g. VSO, HELIO, Heliviewer, and the Hinode archive)

SOLARNET tries to take advantage of the lessons learned by these

In addition, we also try to maximise the ability of a future SVO to take advantage of existing utilities

However, inherent differences and inconsistencies between existing pipeline outputs, services, and SVOs make this very hard through a simple merging of the existing practices

Instead, we concentrate on using the most generally accepted FITS standards (e.g. the World Coordinate System) to describe the physical aspects of the data as accurately and exhaustively as possible

There must be translation routines that make legacy data compatible with SVOs that depend on SOLARNET recommendations

This would be done *without* modifying the original files, but rather by “synthesising” a set of metadata compatible with the SOLARNET recommendations, in order to ingest the data in an SVO

For new pipelines, there must be a convergence towards:

1. Including as much as possible of the metadata of SOLARNET recommendations
2. Excluding superfluous and sometimes ill-defined keywords
3. Using only the SOLARNET definitions of all SOLARNET keywords

## SOLARNET recommendations on File Format:

Based on common practice in the solar community, SOLARNET highly recommends using the **FITS** file format for data dissemination

SOLARNET addresses how to include the metadata content through keywords inside FITS files, but *that does not preclude the use of other file formats*

As long as the requirements for the metadata information content are met, an automated translation between the representations in different formats is achievable

## SOLARNET recommendations on *File Format:*

1. File name recommendations
2. FITS File Header and Data Units (HDUs)
3. Storing data in a single file or in separate files



SOLARNET recommendations on the  
*physical description of observational data:*

1. Use of World Coordinate System (WCS) and related keyword
2. WCS positional keywords and relative radial velocity
3. Exposure time, binning
4. Instrument/data characteristics etc. (wavelength band, resolution power, use of adaptive optics,..)
5. Quality aspects
6. Data statistics
7. Missing and saturated pixels, spikes/cosmic rays

## Quality aspects:

Many quality aspects of ground-based observations change rapidly, even from one exposure to the next

Until now, there has been little effort in order to characterise quality aspects of ground-based observations in a manner that is *consistent* between different telescopes, and even between different setups at the same telescope

Example: In FITS files from ESO (European Southern Observatory), the keyword **PSF\_FWHM** is used to give the full width at half maximum in arc seconds for the point spread function. However, this quantity is generally not available for solar observations. Some adaptive optics systems, however, may record parameters like the atmospheric coherence length  $r_0$ . If available, the value of  $r_0$  should be stored in the keyword **ATMOS\_R0**

## SOLARNET recommendations on metadata on *the origin of the observations*

1. From where to how, PROJECT to SETTINGS/OBS\_MODE
2. Who and why? (“free text”)
  - OBSERVER
  - PLANNER
  - CAMPAIGN

## SOLARNET recommendations on

- Grouping
- Pipeline processing information applied to the data
- Integrity and administrative information
- Reporting of events detected by the pipeline/  
spacecraft
- Other keywords/rules

# The European SVO - A prototype

The SOLARNET VO needs to, from a user point of view, enable optimal data retrieval to enable scientific exploration. It should interface with the (US) VSO and offer data from ground-based and space-based observatories

<http://solarnet.oma.be/>

SOLARNET Virtual Observatory Prototype



This web server is a prototype for the [SOLARNET](#) Virtual Observatory, and is hosted currently at the Royal Observatory of Belgium

## Access data via a web application - Wizard

The wizard is a simple web application to search and download solar data.

Search and create selection of the data you want. The selection will be available for download through FTP.

It's purpose is to give a very simple access to data. For more complex ways of selecting data, please see the IDL and python API below.

## Access data via IDL

To search and download solar data from IDL, you will need IDL version 8.0 or higher and to download the following library on your computer [SOLARNET.pro](#)

You can then compile it and use it as in the examples in the [README](#)

## Access data via Python

To search and download data from python, install the SOLARNET python library. If you have pip install, it is as simple as doing

```
pip install solarnet
```

You can then import it and use it as in the examples in the [Readme](#)




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.

SOLARNET WP lead by the Royal Observatory of Belgium (Brussels)

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## Access data via a web application - Wizard

▼ Search by dataset

Instrument:


Characteristics:

[Search](#)


Dataset	Instrument	Telescope	Characteristics
AIA Level 1	AIA	SDO	image, euv
Chrotel	ChroTel	ChroTel	VSO
EIT	EIT	SOHO	image, euv
HMI Magnetogram	HMI	SDO	image, magnetogram
<b>SWAP Level 1</b>	<b>SWAP</b>	<b>PROBA2</b>	<b>image, euv</b>
Themis	Themis	Themis	spectrum
XRT	XRT	Hinode	VSO

▶ [Search across datasets](#)

▶ [nbello's data selections](#)



SEVENTH FRAMEWORK PROGRAMME




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.

So far contains data from space-based and full-disc ground-based observatories



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SOLARNET Virtual Observatory Prototype



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## Access data via a web application - Wizard

Search by dataset

Instrument:

Characteristics:

- Select all
- image
- euV
- magnetogram
- spectrum
- VSO


Dataset	Instrument	Telescope	Characteristics
AIA Level 1	AIA	SDO	image, euV
ChroTel	ChroTel	ChroTel	VSO
EIT	EIT	SOHO	image, euV
HMI Magnetogram	HMI	SDO	image, magnetogram
SWAP Level 1	SWAP	PROBA2	image, euV
Themis	Themis	Themis	spectrum
XRT	XRT	Hinode	VSO

Search across datasets

nbello's data selections

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## Access data via a web application - Wizard

▼ Search by dataset

▼ Search by dataset

- ▶ Search by dataset
- ▶ Search across datasets
- ▶ nbello's data selections

▼ Search data Chrotel ?

Start date:

End date:


Wavelengths:

Tags:

[Search data](#)


	Date Observation	Wavelength	Tags
<input type="checkbox"/>	2014-02-07 16:12:00	393.4	
<input type="checkbox"/>	2014-02-11 18:09:20	1083.0	
<input type="checkbox"/>	2014-02-07 16:15:00	393.4	
<input type="checkbox"/>	2014-02-07 16:18:00	393.4	
<input type="checkbox"/>	2014-02-11 18:15:20	1083.0	
<input type="checkbox"/>	2014-02-07 16:33:00	393.4	
<input type="checkbox"/>	2014-02-07 16:48:00	393.4	
<input type="checkbox"/>	2014-02-11 18:21:20	1083.0	
<input type="checkbox"/>	2014-02-07 16:21:00	393.4	
<input type="checkbox"/>	2014-02-07 16:24:00	393.4	
<input type="checkbox"/>	2014-02-07 16:27:00	393.4	
<input type="checkbox"/>	2014-02-11 18:30:40	1083.0	
<input type="checkbox"/>	2014-02-07 16:36:00	393.4	
<input type="checkbox"/>	2014-02-07 16:39:00	393.4	
<input type="checkbox"/>	2014-02-07 16:45:00	393.4	
<input type="checkbox"/>	2014-02-12 11:51:40	1083.0	
<input type="checkbox"/>	2014-02-07 16:51:00	393.4	
<input type="checkbox"/>	2014-02-07 16:57:00	393.4	
<input type="checkbox"/>	2014-02-07 17:00:00	393.4	
<input type="checkbox"/>	2014-02-07 17:03:00	393.4	

	Characteristics
scope	
SDO	image, evu
ProTel	VSO
SOHO	image, evu
SDO	image, magnetogram
OBA2	image, evu
hemis	spectrum
inode	VSO



Leibniz  
Leibniz-Gemeinschaft

Nazaret Bello Gonzalez, KIS



**SOLARNET**

How can EST be integrated in and profit from ASTERICS?