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

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

Nazaret Bello González
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Scientist at the Experimental Solar Physics group at KIS
Head of the KIS Science Data Centre

# Space-based vs. ground-based solar observatories

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

**This translates into the use and re-use of data ⇨ high scientific output**

(backed-up by a high number of publications)

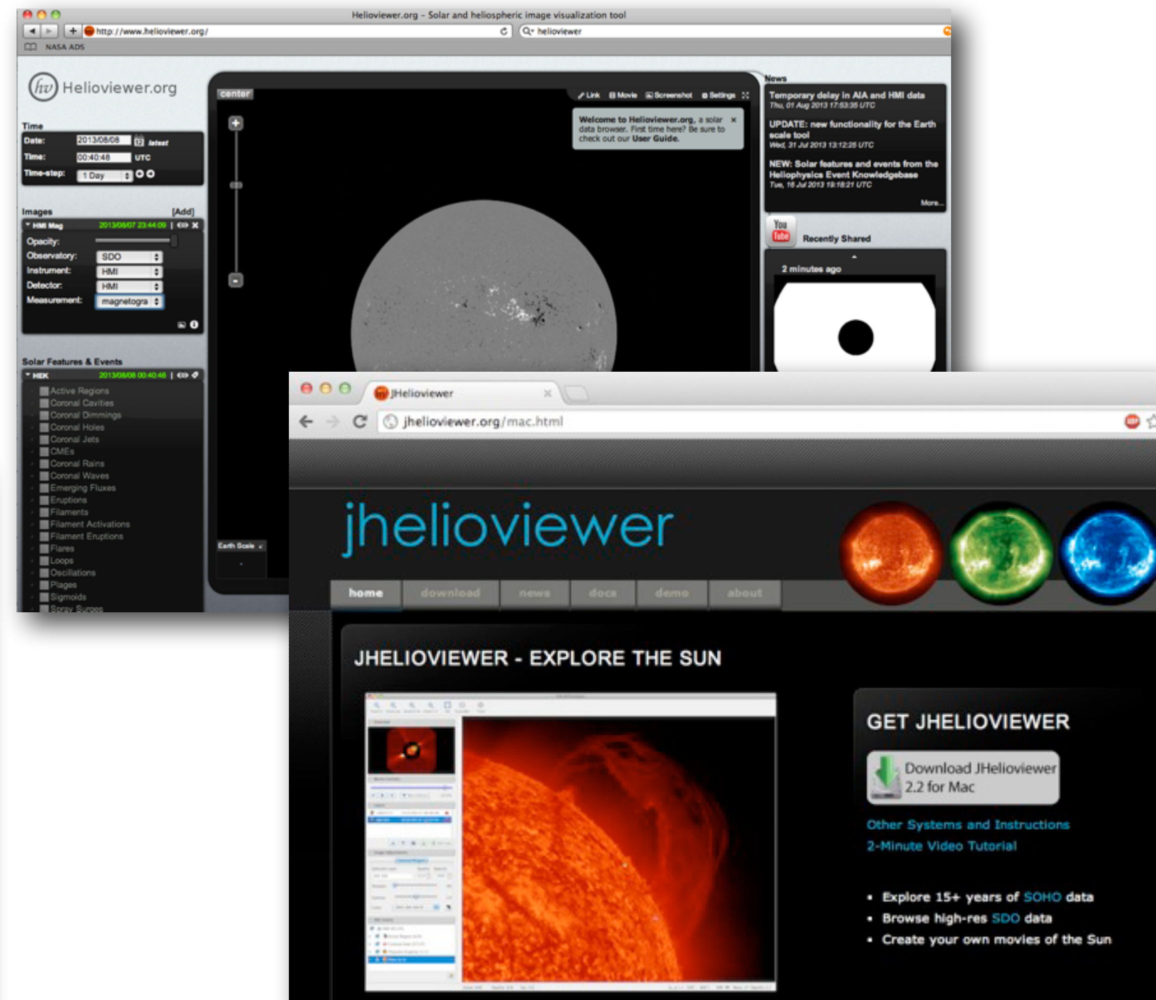
- This is still not the case for ground-based solar observatories.. for which the PI-mode is still in use

# Space-based vs. ground-based solar observatories

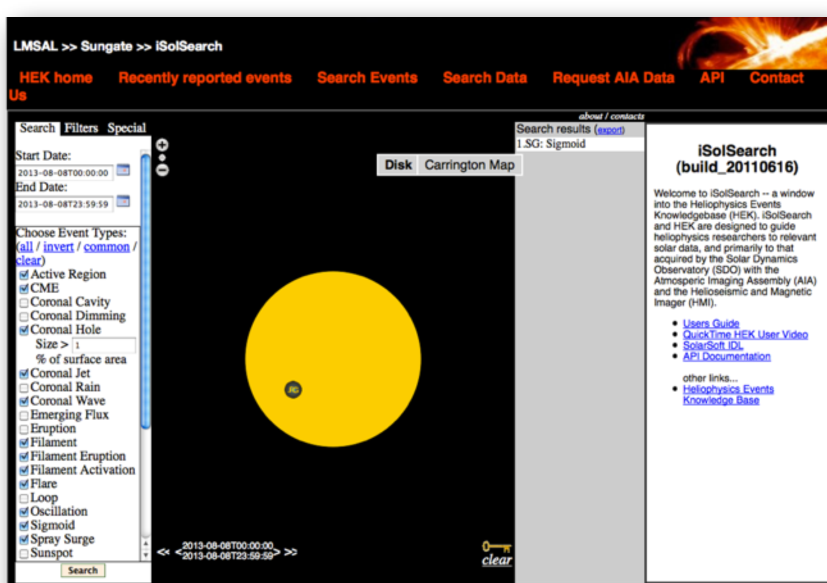
- There is a need to make data discovery easy & to distribute data, especially, for ground-based observations

## Data archives, e.g., VSO


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




## Event searching, e.g., HEK



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

# Next generation large solar telescopes

- Next generation ground-based solar observatories

(US) DKIST & (European) EST 4m-class telescopes

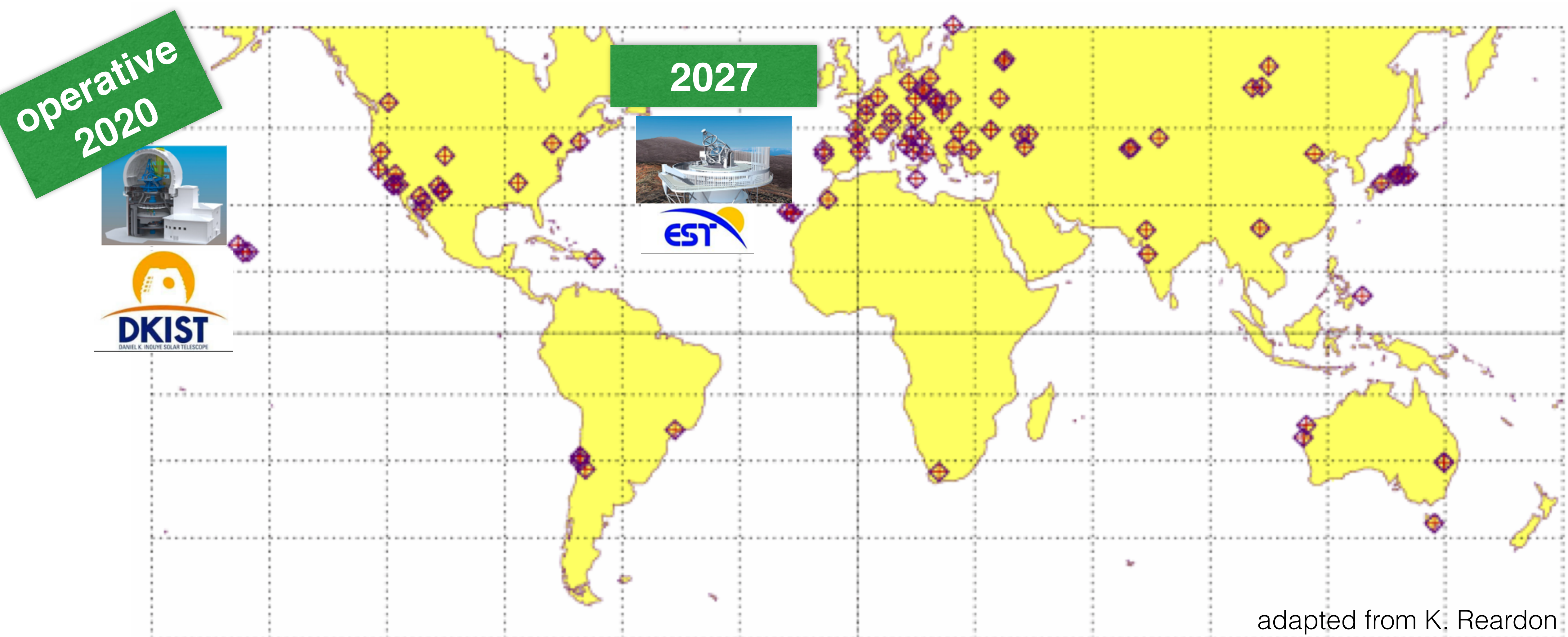
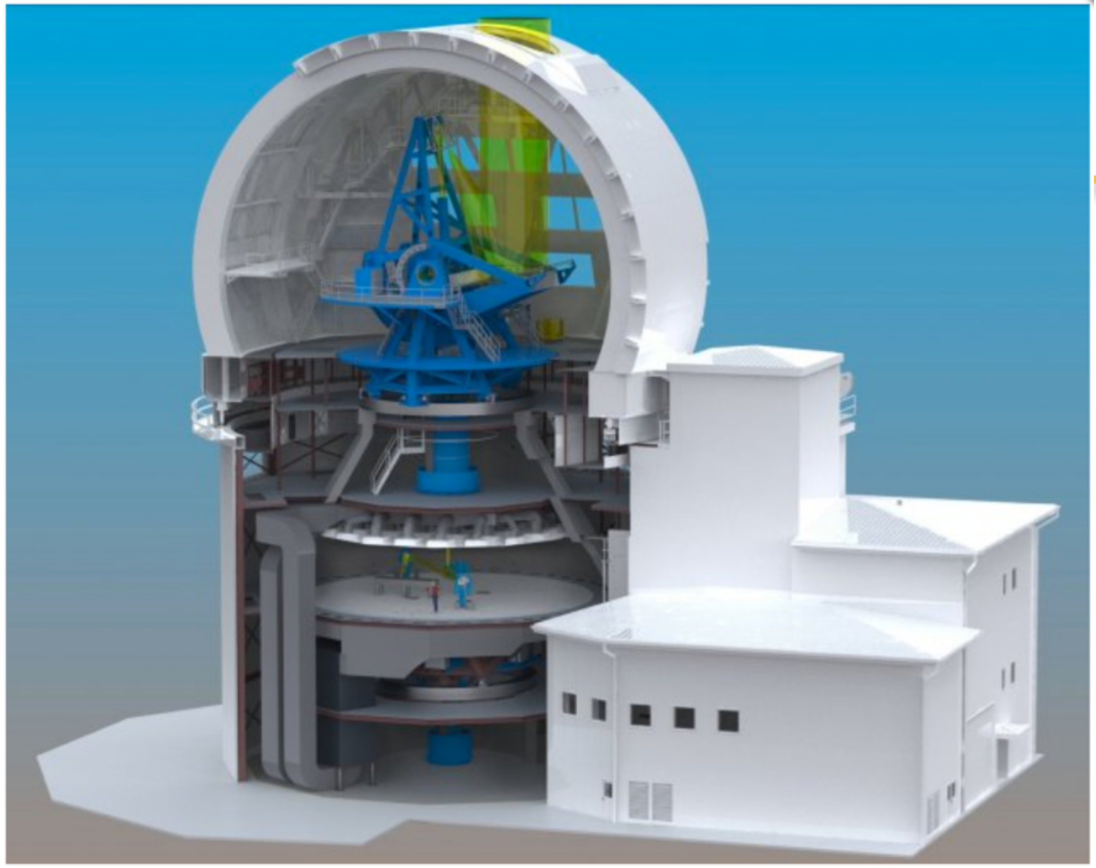



Fig. 1: The distribution of the observatories around the globe.

# Daniel K. Inouye Solar Telescope
# DKIST

# DKIST

Leibniz-Gemeinschaft



Haleakala Obs., Maui

Rendering of proposed ATST facility at the primary Mees site on Haleakalā, Maui, Hawaii by Tom Kekona, K. C. Environmental, Inc. Original aerial photo by Frank Rizzo.

DKIST
DANIEL K. INOUYE SOLAR TELESCOPE

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

In operation on mid 2020, it will be the world's largest solar telescope

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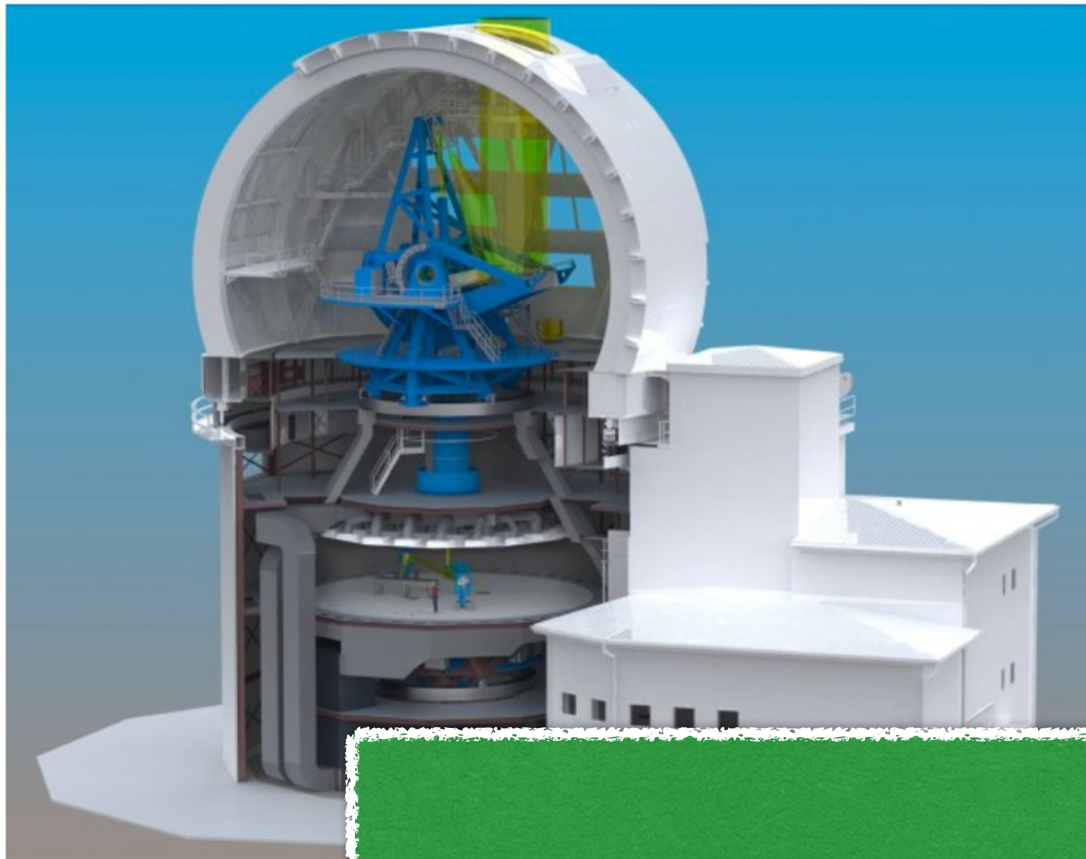
# DKIST



Haleakala


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

→ European contribution

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

In operation on mid 2020, it will be the world's largest solar telescope

DKIST
DANIEL K. INOUYE SOLAR TELESCOPE

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# New generation solar telescopes - Data volume

- 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 |
|---|---|---|
| **VBI** | 1 x 4096 x 4096 detector, 30 fps | **6.5 TB/hour** |
| **ViSP** | 4 x 4096 x 4096 detector, 12.5/6.25 fps | **2.1 TB/hour** |
| **VTF** | 3 x 4096 x 4096 detector, 10 fps | **8.6 TB/hour** |
| **DL-** | | |
| **Cryo** | | |
| | | |

*Adapted fro*

**~ 160 x increased data volume!**

# Next generation large solar telescopes

**The experience with VTF/DKIST data handling will be essential to get ready for EST**

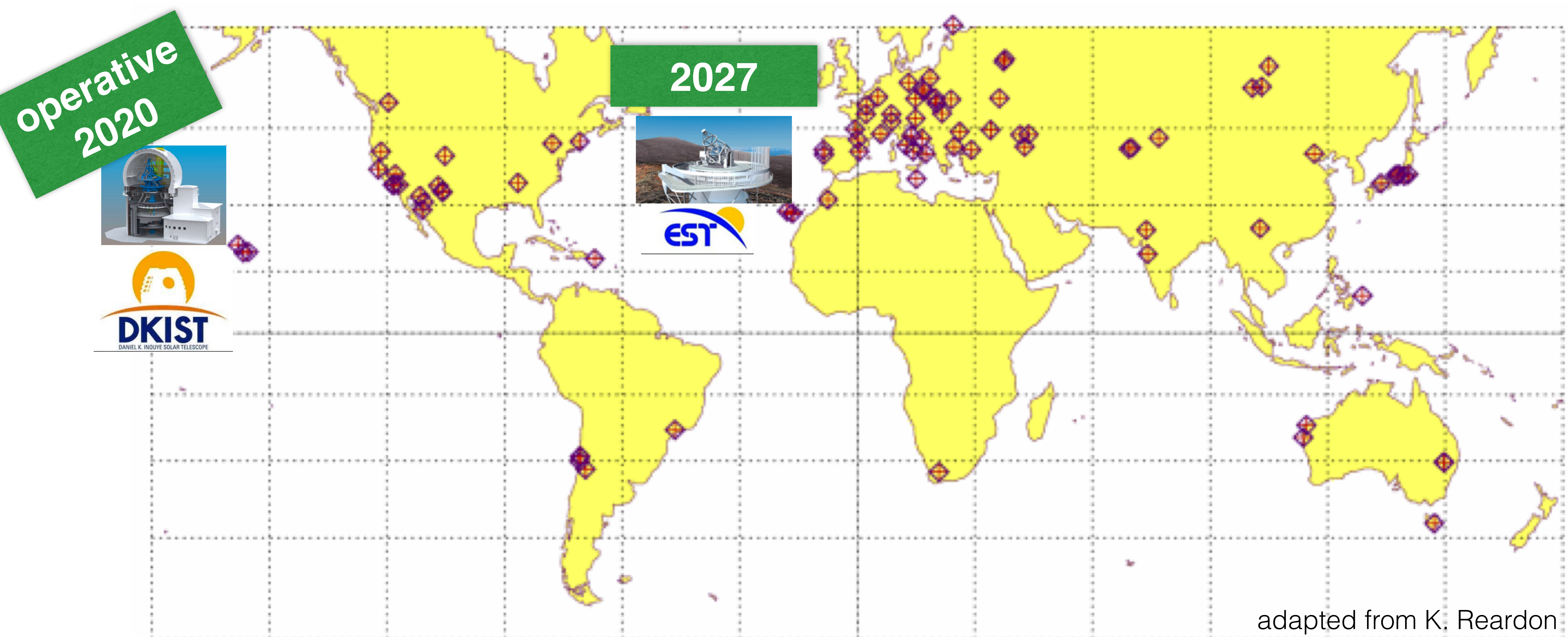
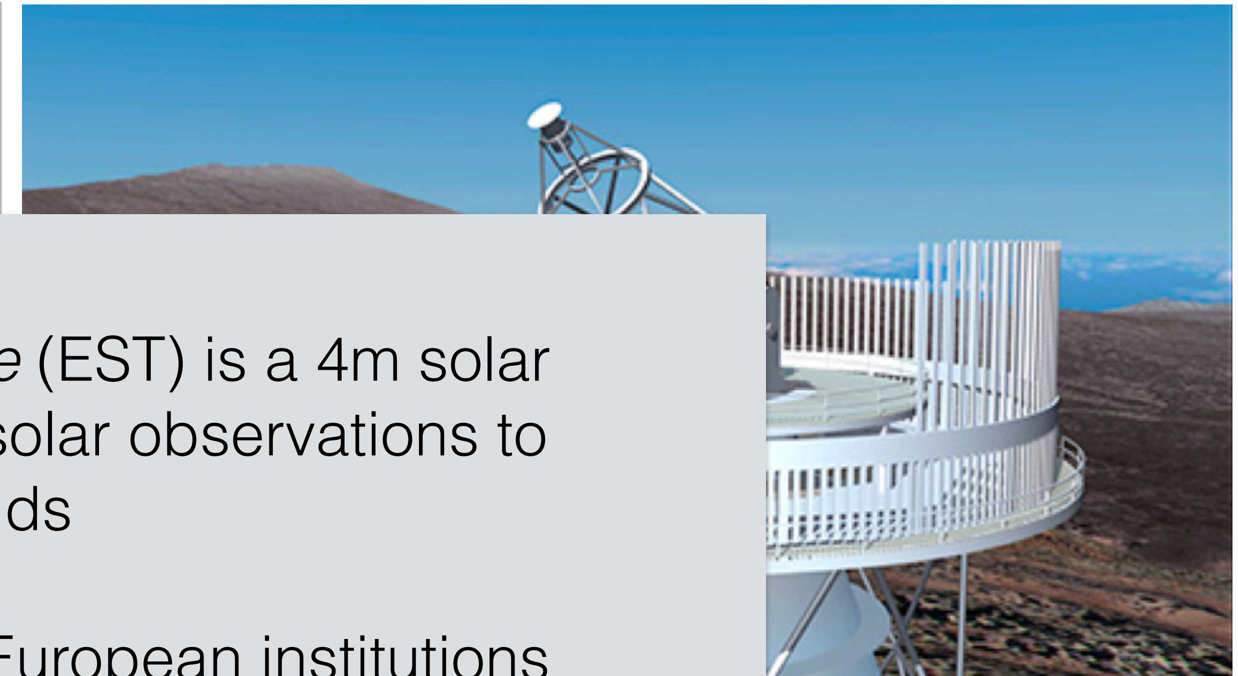



Fig. 1: The distribution of the observatories around the globe.

# European Solar Telescope

# EST

| | Institute | Location |
|---|---|---|
| IGAM | Institutsbereich Geophysik, Astrophysik und Meteorologie | Graz |
| HVO | Hvar Observatory | Hvar |
| AIASCR | Astronomical Institute AS CR | Ondrejov |
| THEMIS | THEMIS S.L.,[n | |
| KIS | Kiepenheuer-In | |
| UniDeb | Heliophysical O | |
| INAF | Istituto Naziona | |
| UU | Ultrecht Univers | |
| ITA | Institute of Theo | |
| IA UWr | 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)

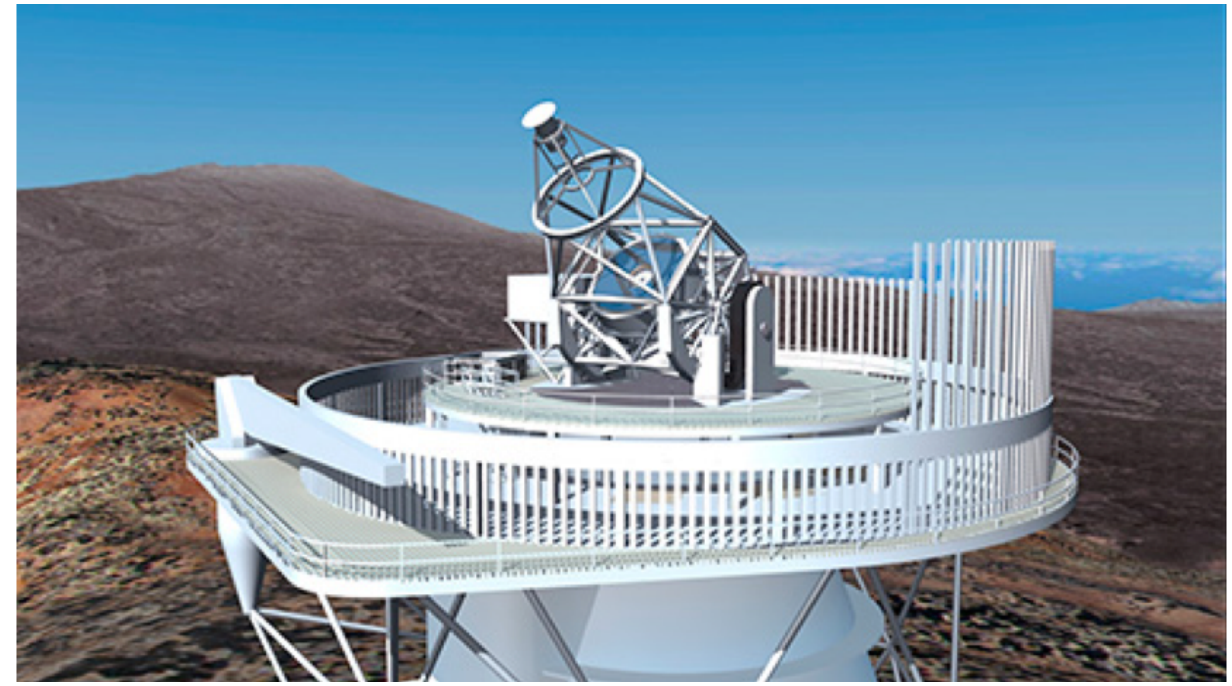
The (3 years) conceptual design study conducted by research institutions and industrial companies was finalised in May 2011

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


Canaries, Spain

# EST

| | Institute | Location |
|---|---|---|
| **IGAM** | Institutsbereich Geophysik, Astrophysik und Meteorologie | Graz |
| **HVO** | Hvar Observatory | Hvar |
| **AIASCR** | Astronomical Institute AS CR | Ondrejov |
| **THEMIS** | THEMIS S.L.,[note 1] INSU-CNRS, CNR | Paris |
| **KIS** | Kiepenheuer-Institut für Sonnenphysik | Freiburg |
| **UniDeb** | Heliophysical Observatory Debrecen | Debrecen |
| **INAF** | Istituto Nazionale di Astrofisica | Rome |
| **UU** | Ultrecht University, Sterrekundig Instituut | Utrecht |
| **ITA** | Institute of Theoretical Astrophysics | Oslo |
| **IA UWr** | Astronomical Institute of the Wroclaw University | Wroclaw |
| **AISAS** | Astronomical Institute of the Slovak, Academy of Sciencees | 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

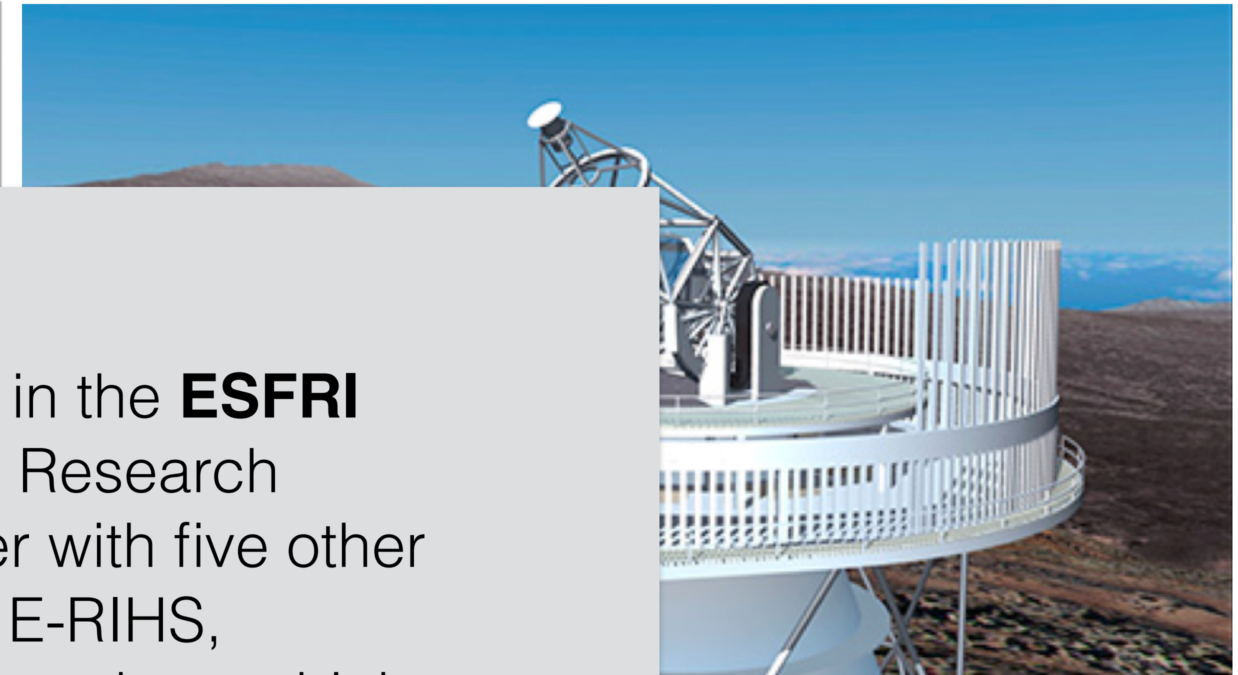
**ESTIMATED COSTS**
- Capital value: Not Available
- Preparation: 10 M€
- Construction: 200 M€
- Operation: 9 M€/year

**HEADQUARTERS**
Instituto de Astrofísica de Canarias
Canary Islands
Spain

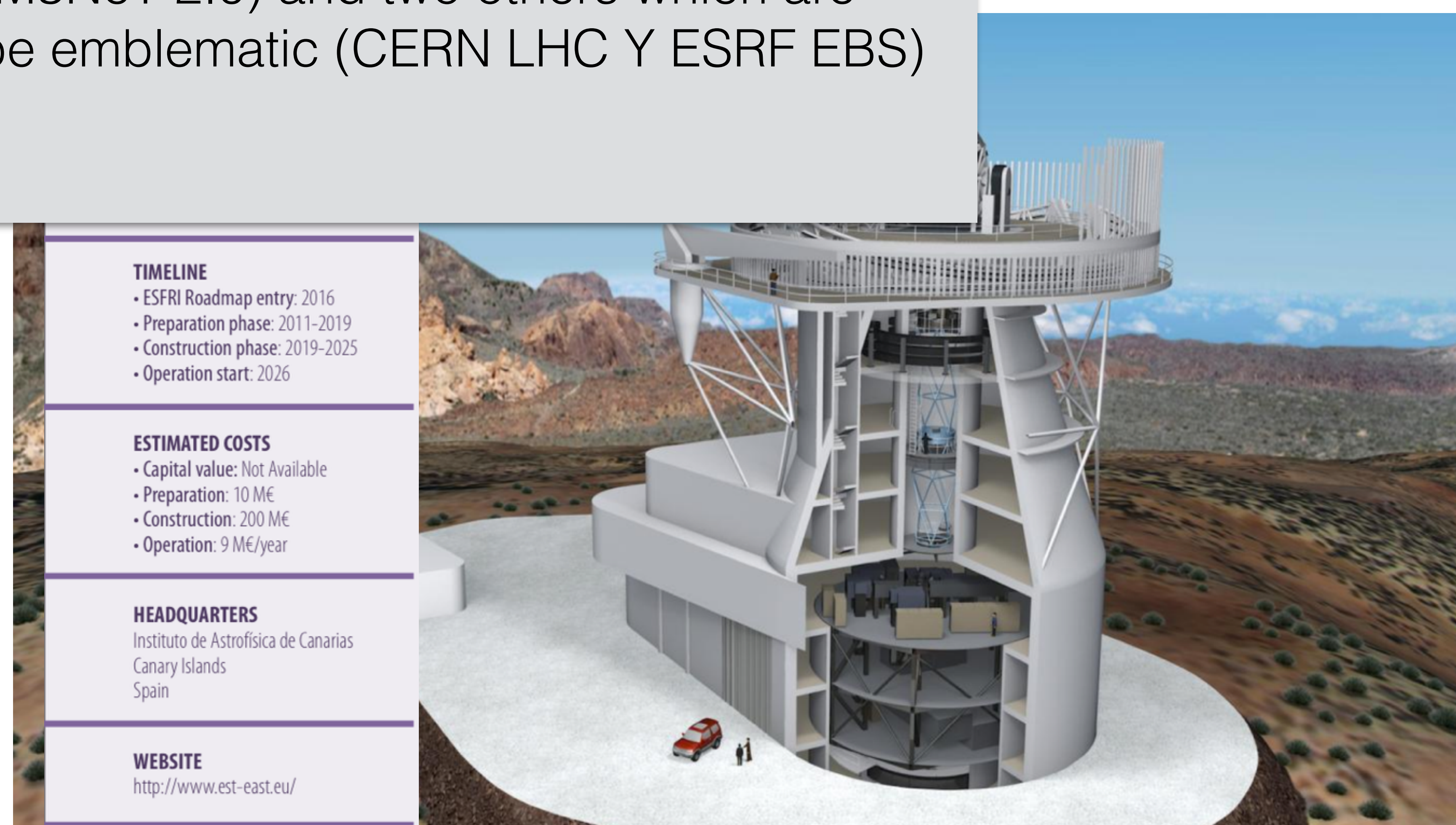
**WEBSITE**
http://www.est-east.eu/

Canaries, Spain

| Institute | | Location |
|---|---|---|
| IGAM | Institutsbereich Geophysik, Astrophysik und Meteorologie | Graz |
| HVO | Hvar Observatory | Hvar |
| AIASCR | Astron | |
| THEMIS | THEMI | |
| KIS | Kiepen | |
| UniDeb | Helioph | |
| INAF | Istituto | |
| UU | Ultrech | |
| ITA | Institute | |
| IA UWr | Astron | |
| AISAS | Astron | |
| IAC | Institut | |
| SU | The Ins | |
| IRSOL | Istituto | |
| UCL-MSSL | Univers | |



In March 2016, EST was included in the **ESFRI** (Forum for a European Strategy in Research Inrastructures) 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)




Canaries, Spain

The EST project is driving other projects..

EAST
European Association for Solar Telescopes

EST

SOLARNET
planned: 01/2019 – 12/22

GREST
GETTING READY FOR EST
(06/2015 – 05/2018)

PRE-EST
(04/2017 – 03/2021)

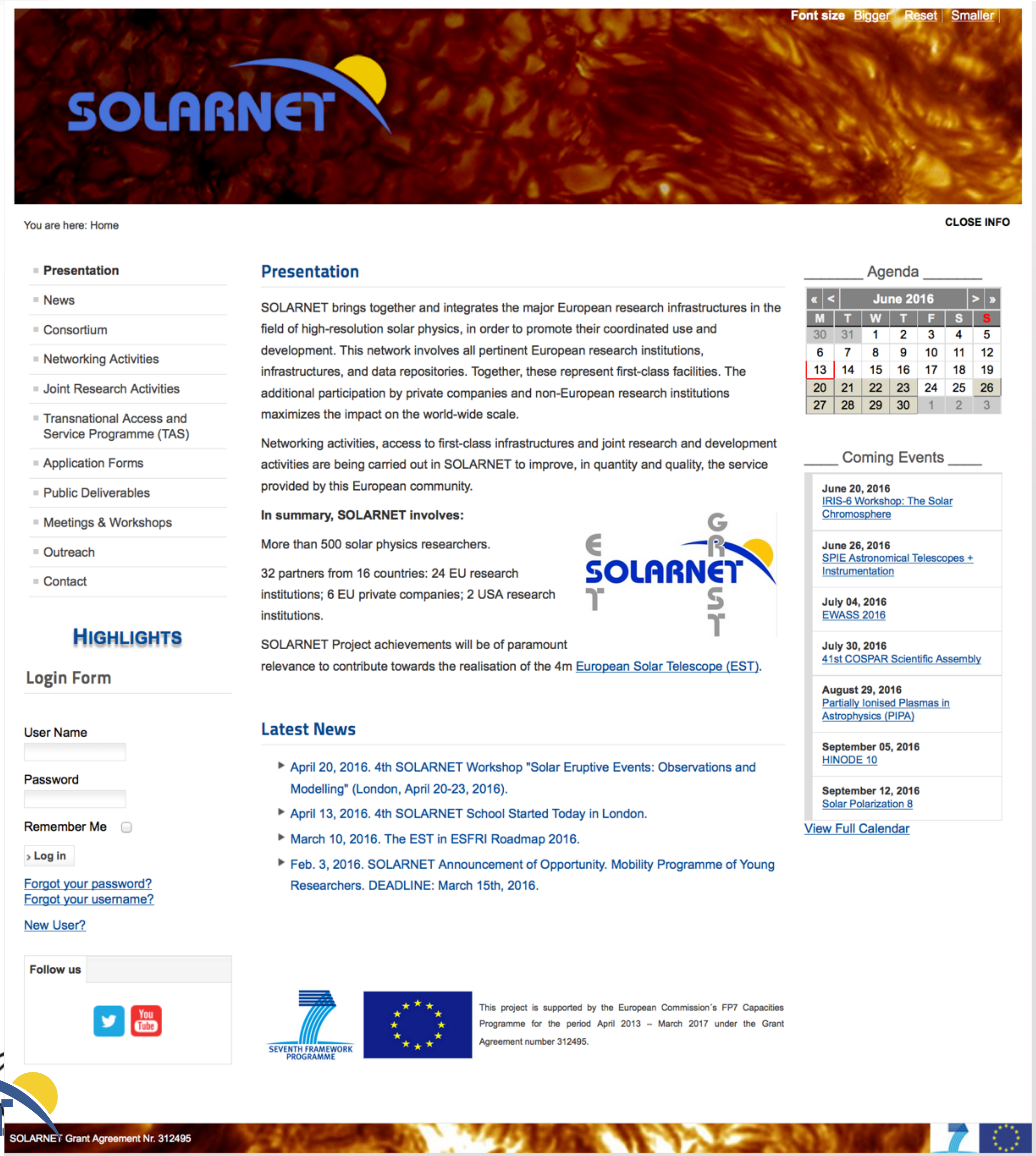
SOLARNET
(04/2013 – 03/2017)

EST Design Study
(2008 - 2011)

ESFRI road map update 2016:
**EST included as ESFRI project**

# SOLARNET Project

http://www.solarnet-east.eu/



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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

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.

SOLARNET Grant Agreement Nr. 312495

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

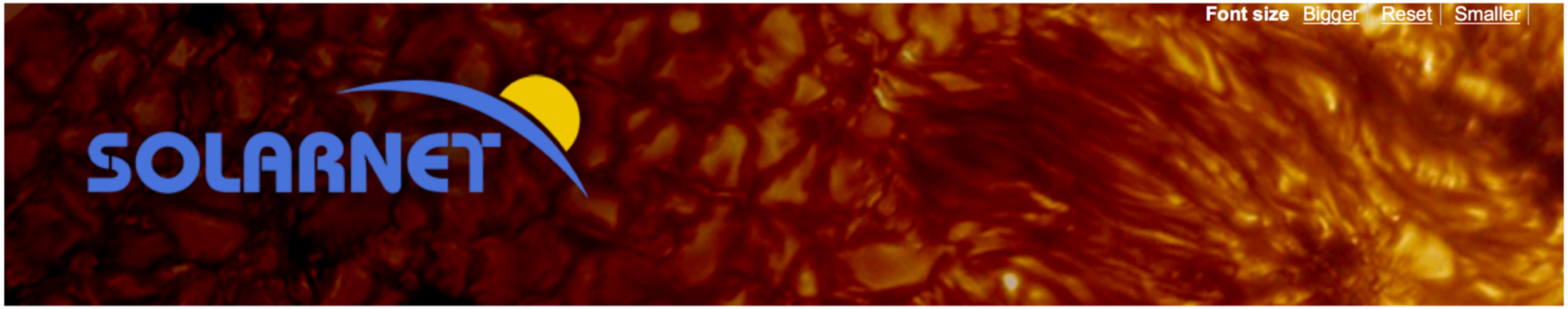
Funded by the FP7 since 2013

# SOLARNET Project

http://www.solarnet-east.eu/

Kiepenheuer-Institut für Sonnenphysik

Leibniz-Gemeinschaft

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- Application Forms
- Public Deliverables
- Meetings & Workshops
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HIGHLIGHTS

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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.

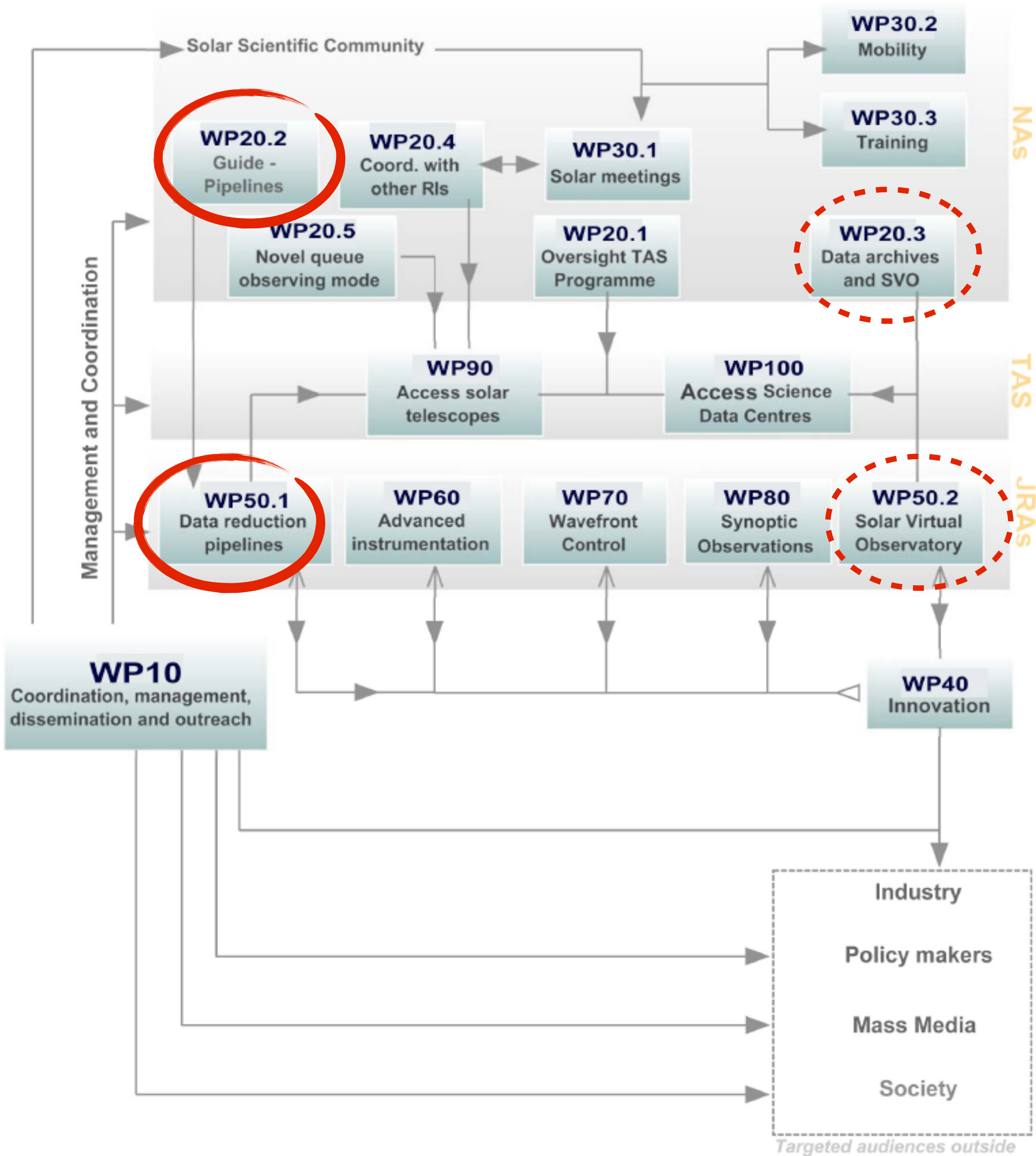
**WP60.2 Image Slicers for 2D spectroscopy**

EST

SOLARNET

# SOLARNET Project

http://www.solarnet-east.eu/



# Challenges in data search & data discovery from solar observations

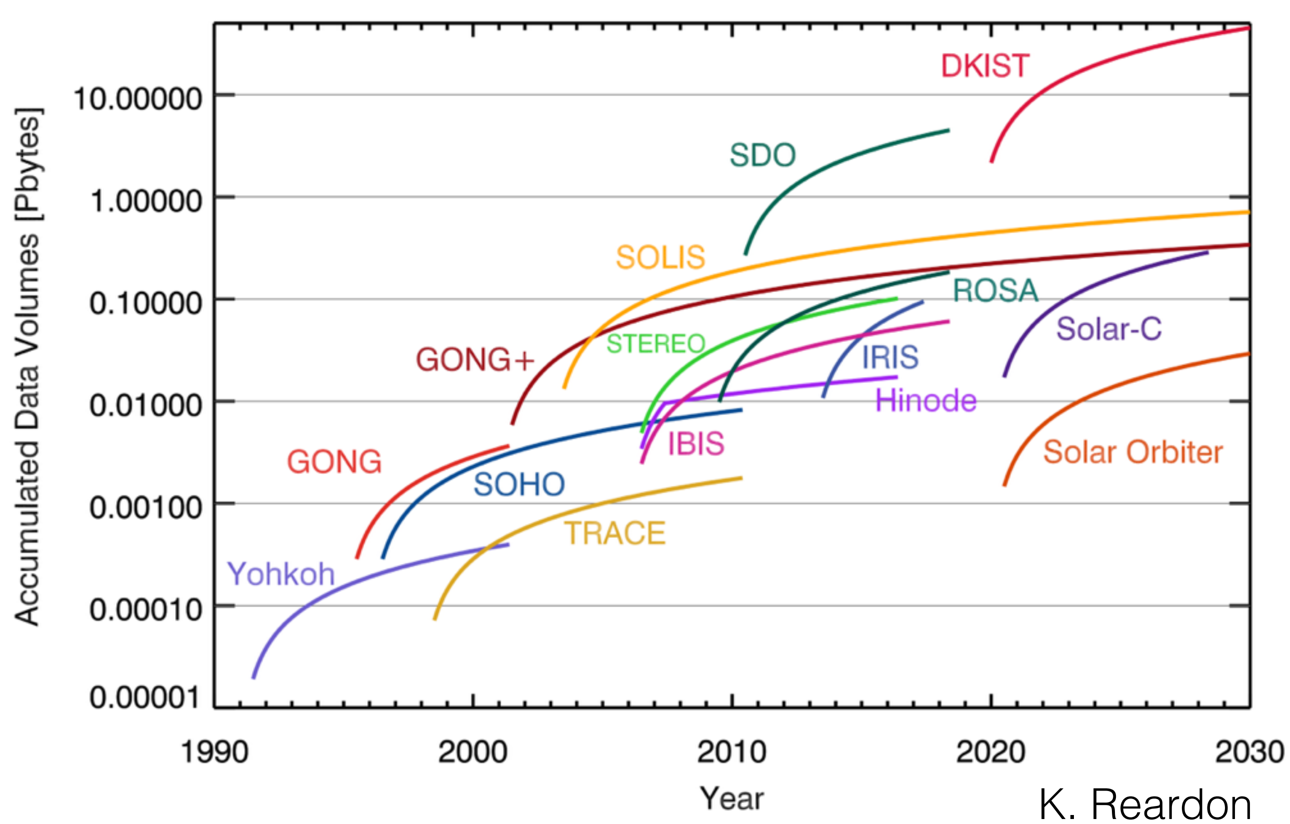
# Ground-based solar observations

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

http://sdc.uio.no/open/solarnet-20.3/WP20.3%20Deliverable%20D20.4_v1.2.pdf

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

http://sdc.uio.no/open/solarnet-20.3/WP20.3%20Deliverable%20D20.4_v1.2.pdf




K. Reardon

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

http://sdc.uio.no/open/solarnet-20.3/WP20.3%20Deliverable%20D20.4_v1.2.pdf

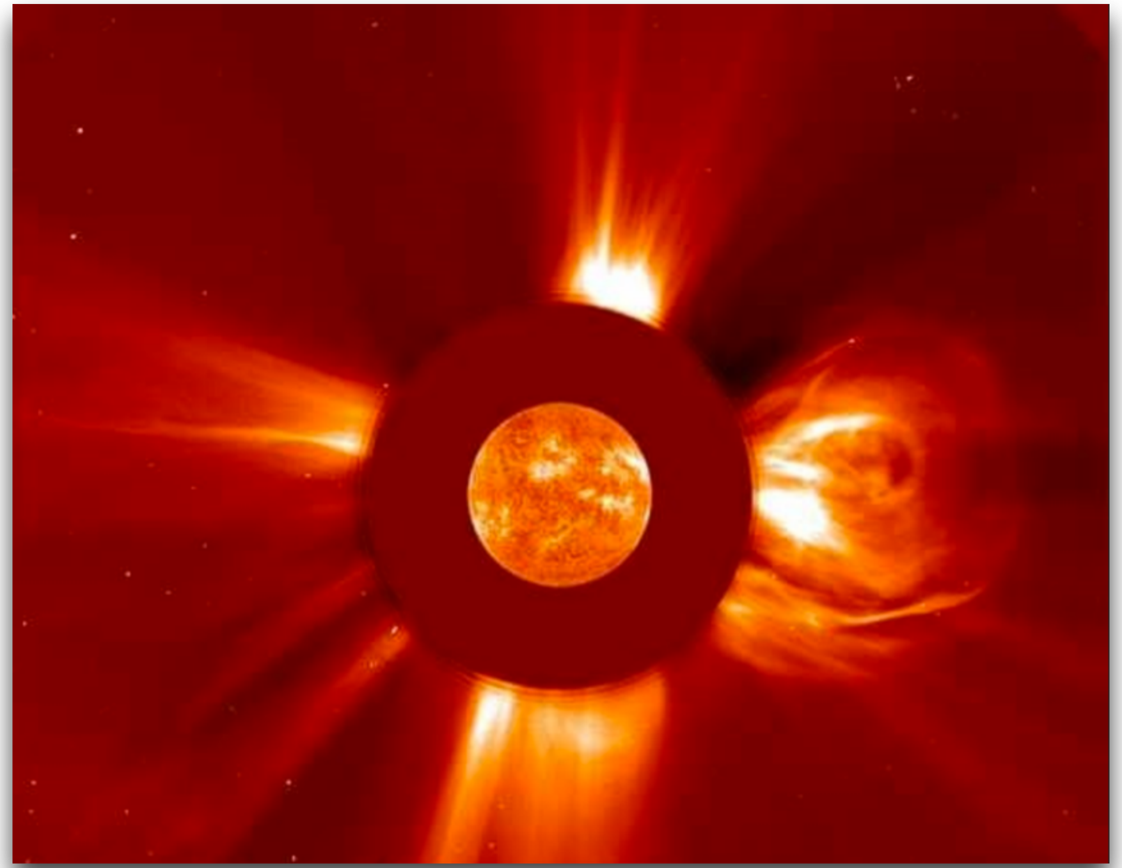
# Ground-based solar observations



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



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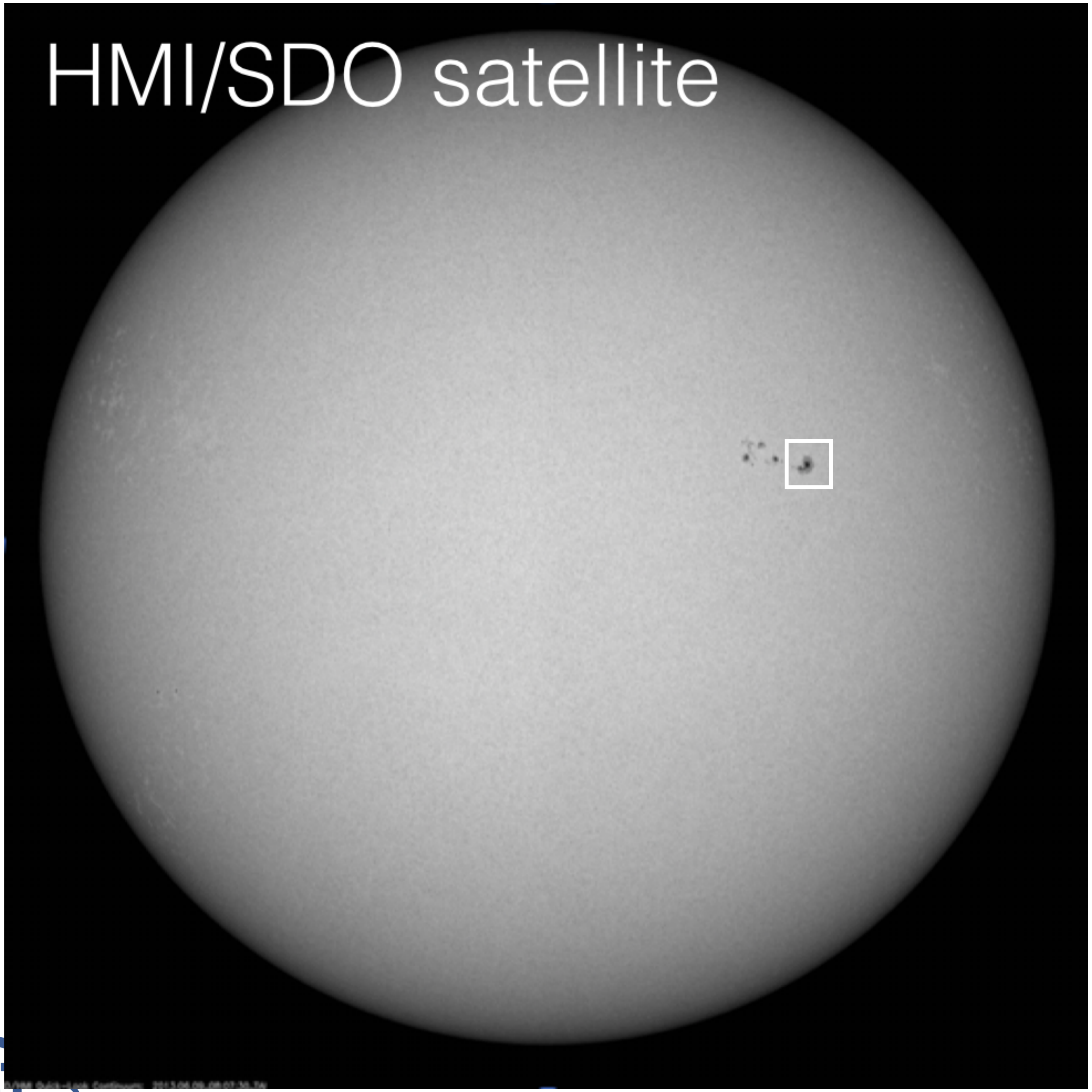
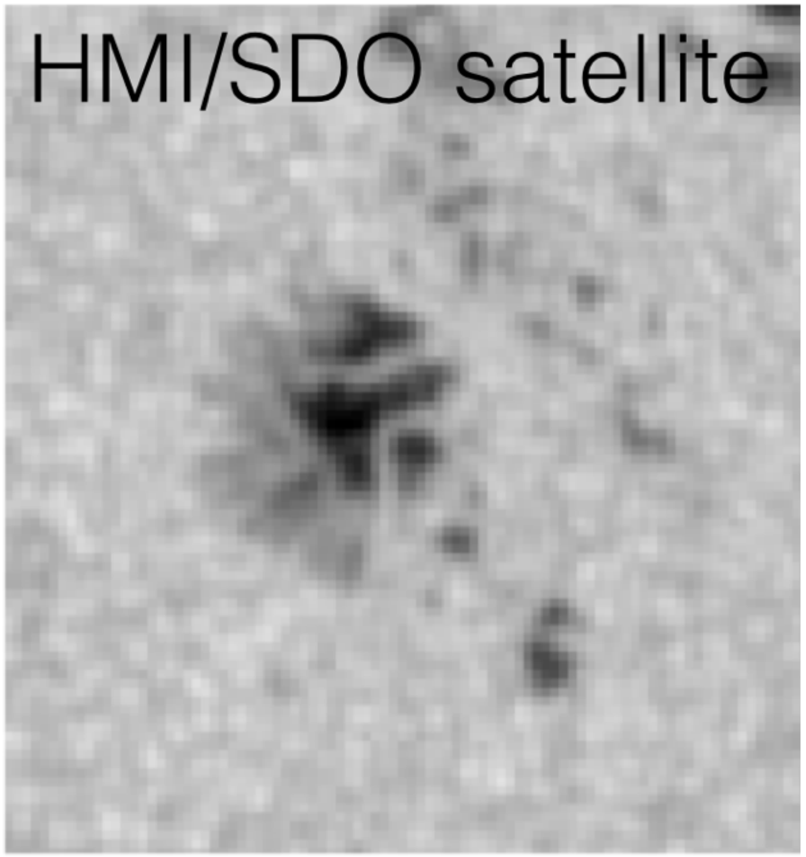
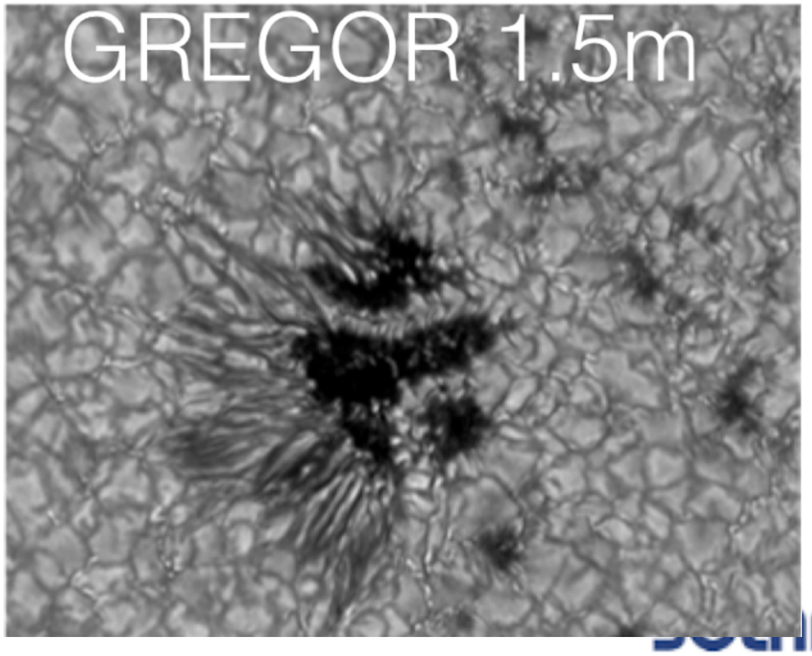
Characteristics of ground-based solar observations:

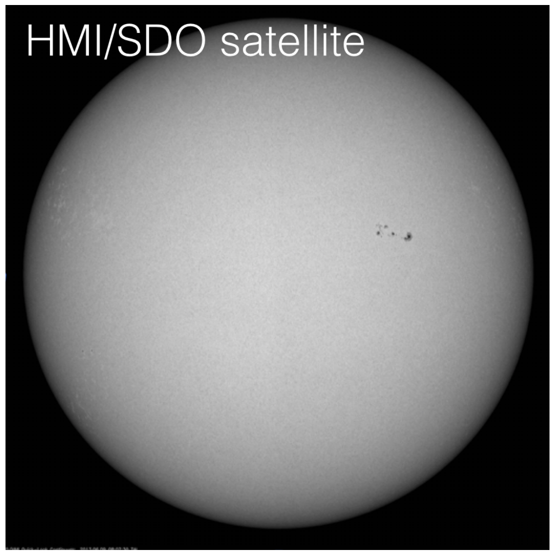


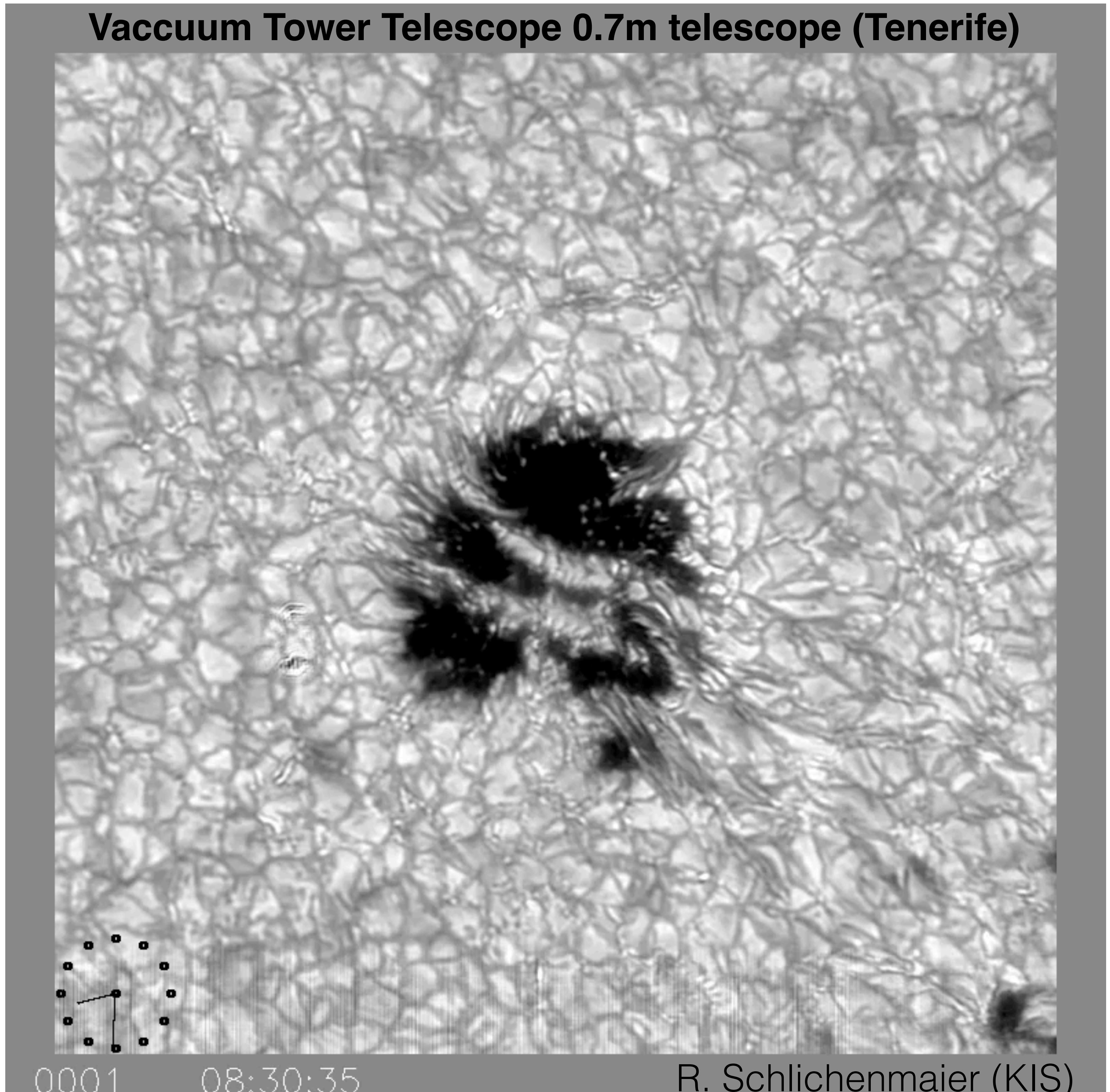



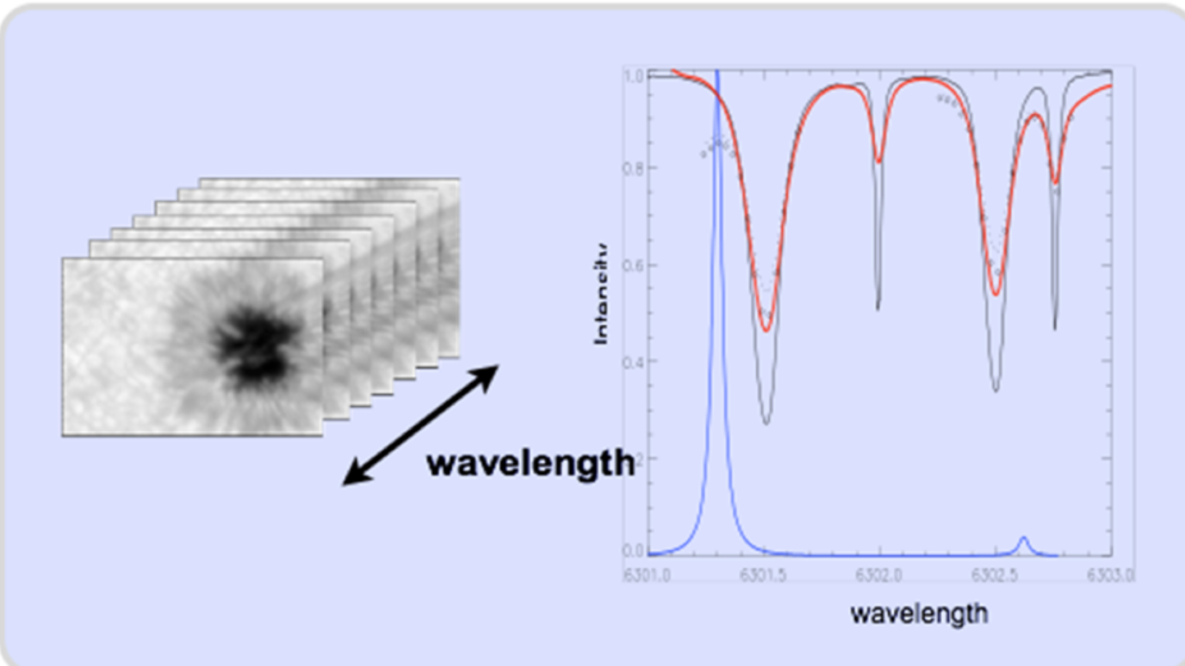

Schlichenmaier et al. (2016)

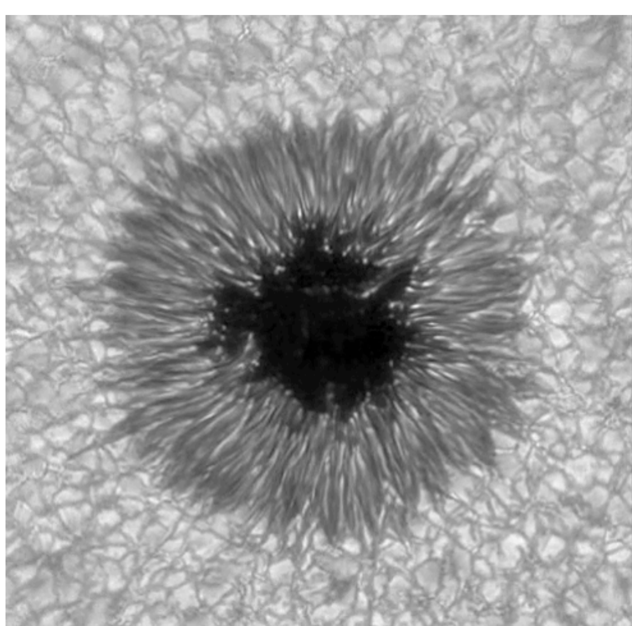
# Characteristics of ground-based solar observations:

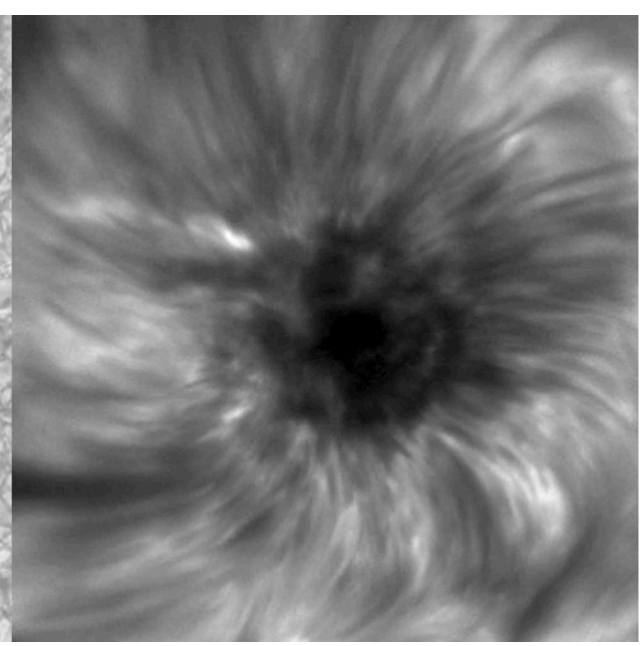


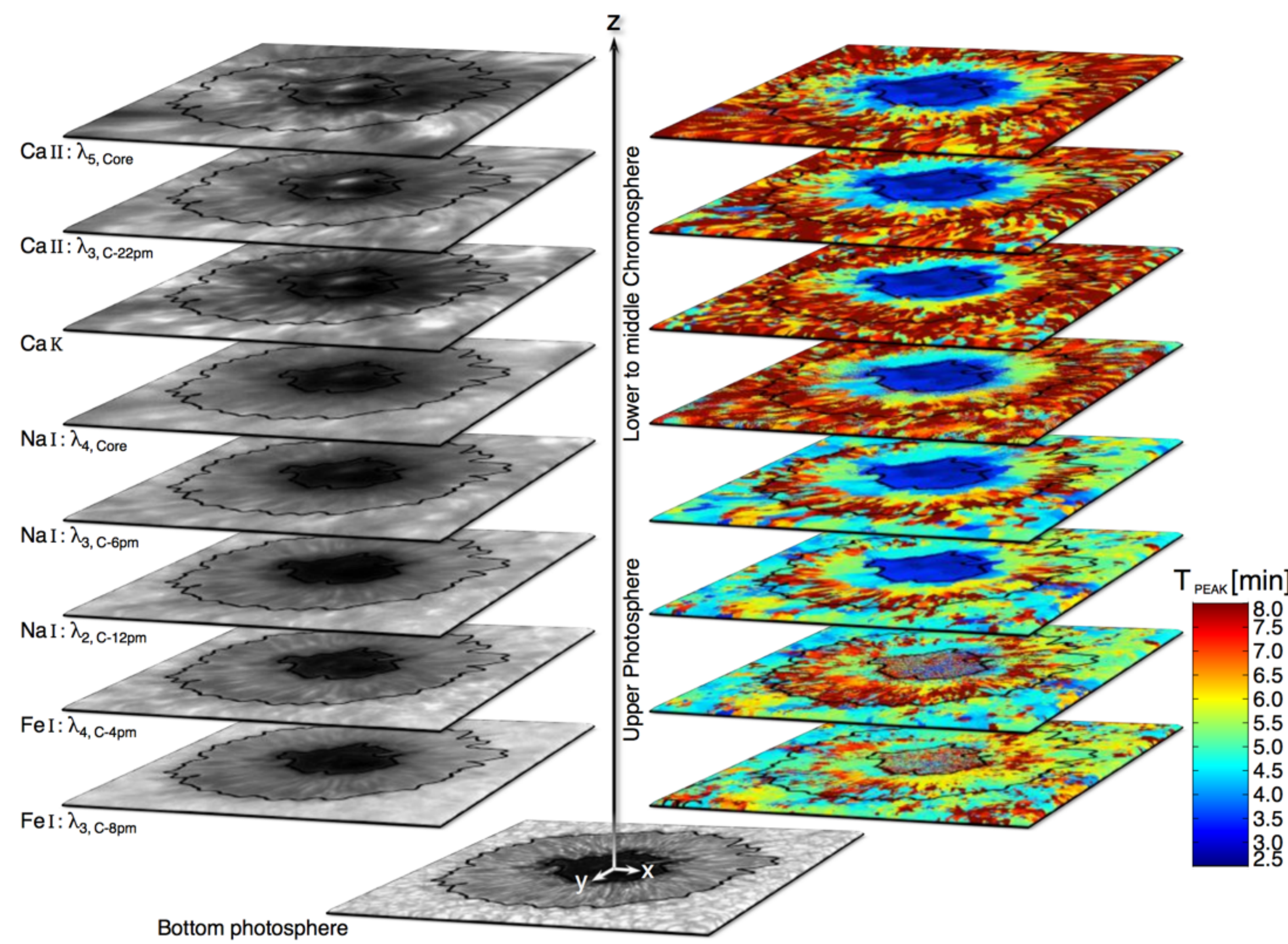



# Characteristics of ground-based solar observations:



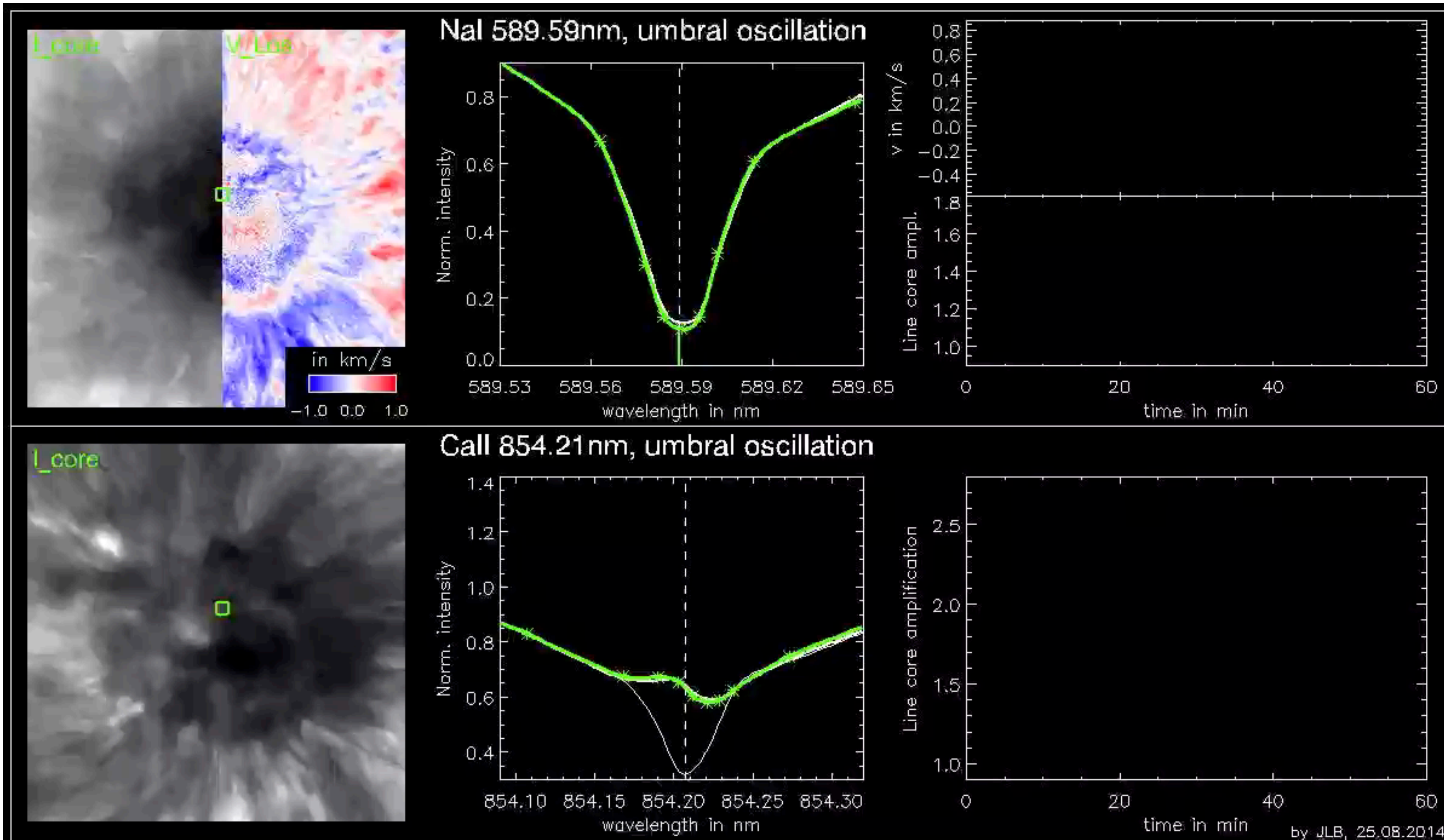








IBIS & ROSA data (J. Löhner-Böttcher, KIS)

Characteristics of ground-based solar observations:




IBIS data (J. Löhner-Bötcher, KIS)

# Ground-based solar observations

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 **quality/success** parameters
- Versatile observing modes: non-standarised 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

http://sdc.uio.no/open/solarnet-20.3/WP20.3%20Deliverable%20D20.4_v1.2.pdf

# Defining the output of data-pipelines

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

http://sdc.uio.no/open/solarnet-20.3/WP20.3%20Deliverable%20D20.4_v1.2.pdf

This is our current challenge!

# Ground-based solar data archive — An example: GREGOR data

Nazaret Bello González, KIS

# Data archive for the GREGOR Infrared Spectrograph

## 2017

| | |
|---|---|
| March: | 28 29 |
| April: | 02 03 04 |
| May: | 05 |
| June: | 12 13 14 16 17 18 19 20 |
| September: | 01 02 03 07 08 09 11 12 13 22 28 29 |
| October: | 02 03 30 31 |
| November: | 01 |

## 2016

| | |
|---|---|
| May: | 09 13 14 15 18 19 20 21 22 23 26 27 29 30 |
| June: | 02 04 05 06 07 08 09 10 11 *12* *13* *14* *15* *16* 19 20 21 22 28 |
| July: | 02 03 19 27 |
| August: | 08 10 13 14 15 16 17 19 22 23 24 25 26 29 30 |
| September: | 02 21 22 23 24 26 28 29 |
| November: | 25 28 |

## 2015

| | |
|---|---|
| April: | *15* *16* *17* *18* 19 21 23 26 27 29 30 |
| May: | 01 02 07 08 09 10 11 18 19 21 22 23 24 25 28 29 30 31 |
| June: | 01 02 03 |
| August: | 04 06 19 |
| September: | 08 09 10 12 13 14 15 16 17 19 20 |

## 2014

| | |
|---|---|
| April: | 26 27 28 29 30 |
| May: | 01 02 03 05 07 08 09 10 11 12 |
| June: | 17 18 19 20 21 22 23 24 25 26 27 28 29 |
| July: | 01 02 03 05 08 09 |
| September: | 02 03 04 05 08 10 11 13 17 18 20 22 23 |

M. Franz, KIS

# Data archive for the GREGOR Infrared Spectrograph

## 2017

March: 28 29
April: 02 03 04
May: 05
June: 12 13 14 16
September: 01 02 03 07
October: 02 03 30 31
November: 01

May: 09 13 14 15
June: 02 04 05 06
July: 02 03 19 27
August: 08 10 13 14
September: 02 21 22 23
November: 25 28

April: *15* *16* *17* *18*
May: 01 02 07 08
June: 01 02 03
August: 04 06 19
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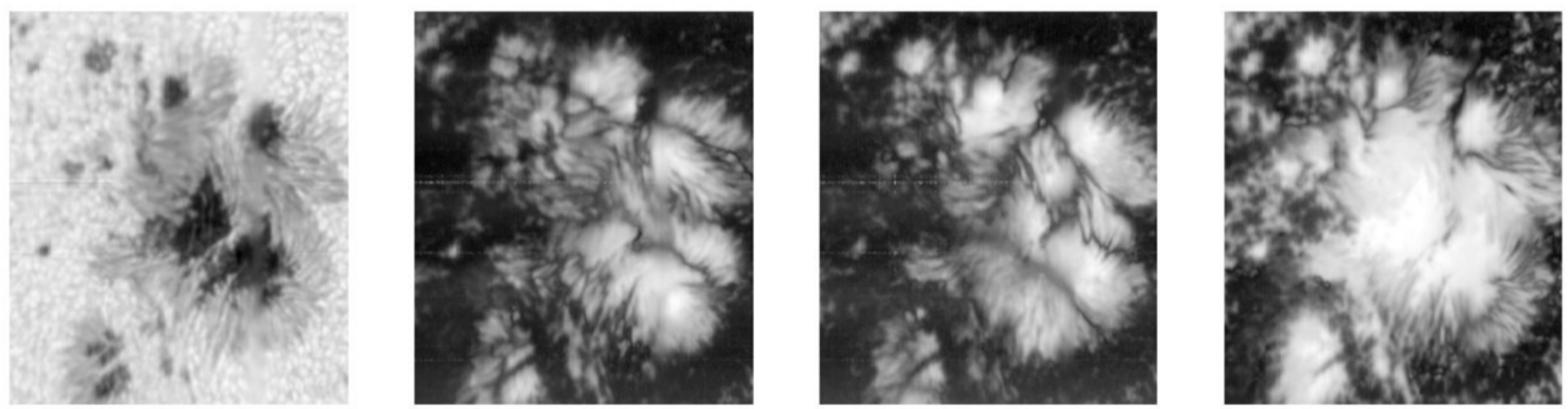
April: 26 27 28 29
May: 01 02 03 05 07 08 09 10 11 12
June: 17 18 19 20 21 22 23 24 25 26 27 28 29
July: 01 02 03 05 08 09
September: 02 03 04 05 08 10 11 13 17 18 20 22 23

Back to main page Go to archive folder

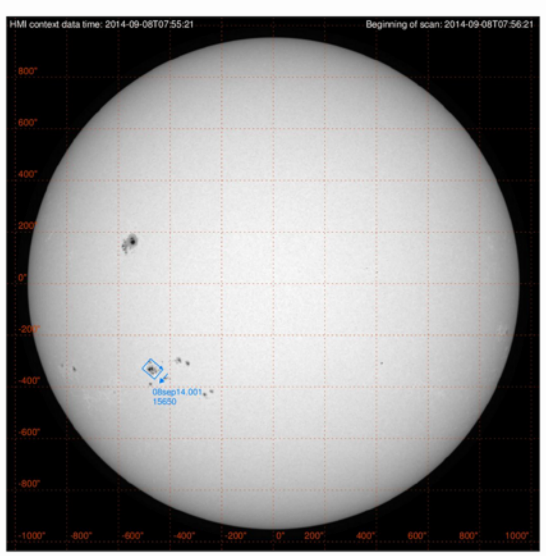
HMI context data: The arrow in the box indicates the 'slit direction', the arrow outside the box the scanning direction.
Blue (red) color of the box indicates that the GRIS scan is flipped in the scanning direction with respect to HMI (or not).

Please note that the coordinates ('x/y-pos') given in the GRIS preview images are those from the fits headers, so they are not necessarily correct.

08sep14.001




08sep14.001
1564 nm
07:56:21-08:32:07 UT
30.0 ms / 20 accum.
# of steps: 400
x/y-pos: -205'' / -444''



M. Franz, KIS

# The SOLARNET VO — A prototype

# The SOLARNET VO — A prototype

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

For explanations on how to search and download the data, please see our detailed User Manual

## Access data via a web application

The purpose of the web application is to give a very simple access to search and download solar data. For more complex search, you are invited to use the Python or IDL clients.

The web application presents the following features:

- Cross dataset search by date of observation, wavelength, tags and telescope
- Specific dataset search that is dependant on the dataset
- Search by solar events date and type
- Co-observation searches i.e. the date of observation overlap
- Quick-look with thumbnail (if available) and FITS header
- Data selection download by FTP and ZIP (if not too large)

N.B. : This is the version 2 of the application. The version 1 corresponding to the deliverable of March 2106 is not online anymore, but the code can be found at https://github.com/bmampaey/SDA/tree/1.1

## 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

## Access data via RESTful API

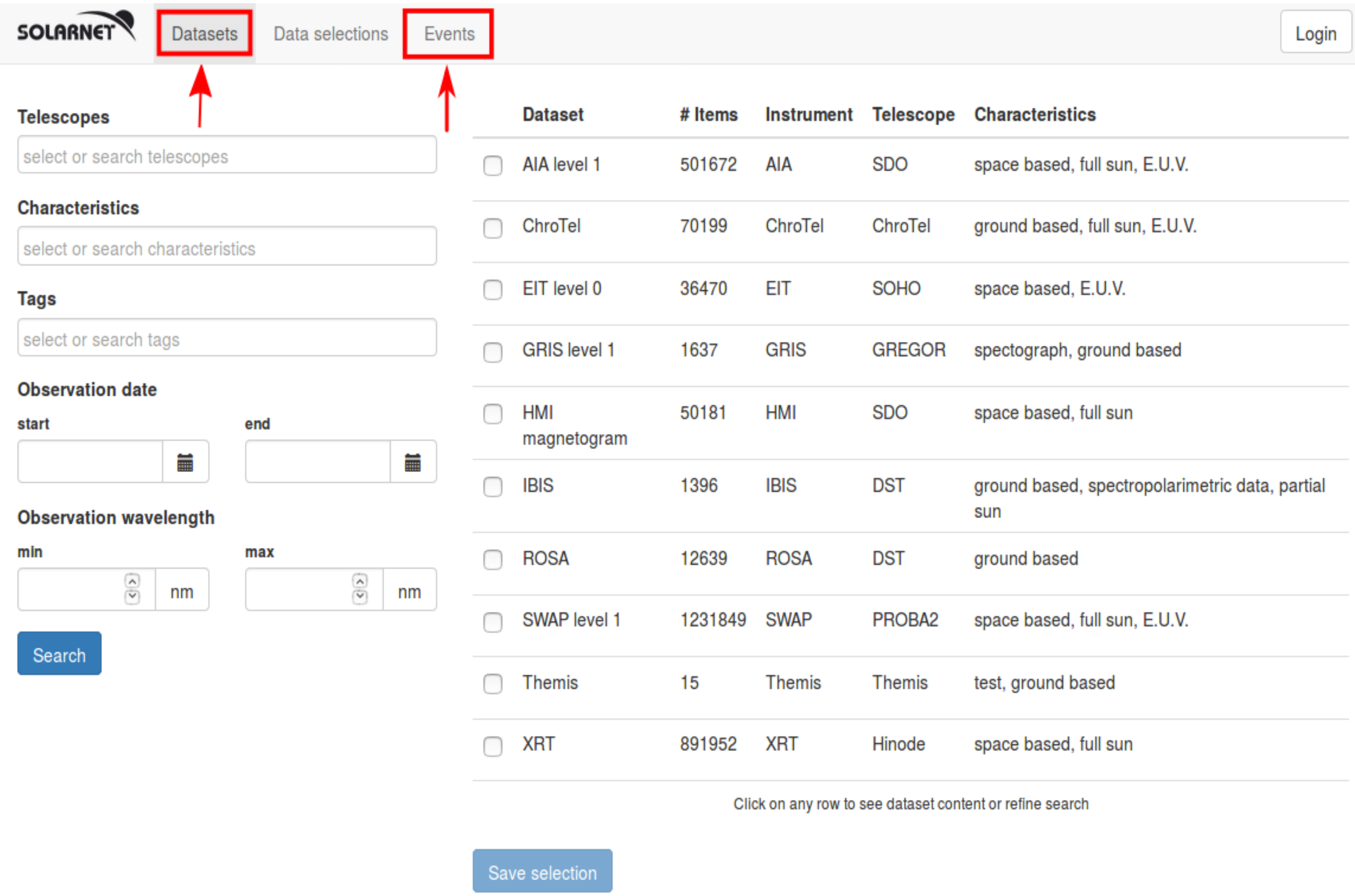
All metadata and data locations are available through a RESTful API. The documentation is accessible at http://solarnet.oma.be/SDA/api/doc If you develop tools using the API, please let us know.

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)

# The SOLARNET Solar Virtual Observatory

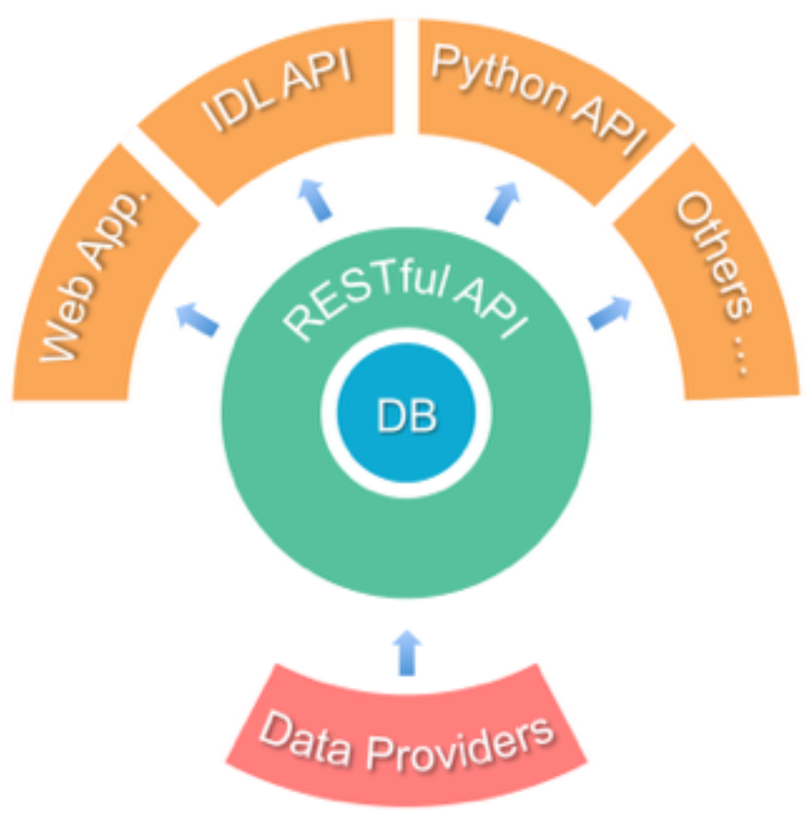
- In SOLARNET-1 a SVO prototype was developed.
- The goal of the SVO is to increase awareness of available datasets
- It's possible to search on <u>datasets</u>, <u>events</u> and then <u>cross search</u> your search results with other Datasets
- Some data is viewable as quick-look.
- URL: solarnet.oma.be




| Dataset | # Items | Instrument | Telescope | Characteristics |
|---|---|---|---|---|
| AIA level 1 | 501672 | AIA | SDO | space based, full sun, E.U.V. |
| ChroTel | 70199 | ChroTel | ChroTel | ground based, full sun, E.U.V. |
| EIT level 0 | 36470 | EIT | SOHO | space based, E.U.V. |
| GRIS level 1 | 1637 | GRIS | GREGOR | spectograph, ground based |
| HMI magnetogram | 50181 | HMI | SDO | space based, full sun |
| IBIS | 1396 | IBIS | DST | ground based, spectropolarimetric data, partial sun |
| ROSA | 12639 | ROSA | DST | ground based |
| SWAP level 1 | 1231849 | SWAP | PROBA2 | space based, full sun, E.U.V. |
| Themis | 15 | Themis | Themis | test, ground based |
| XRT | 891952 | XRT | Hinode | space based, full sun |

# The SOLARNET Solar Virtual Observatory

- At the core of the SVO is a database containing meta-data from all datasets.
- The meta-data can be searched with the web App and IDL and Python API
- Through the RESTful API other developers can interface with the meta-database.
- The data can be downloaded from the providers server.

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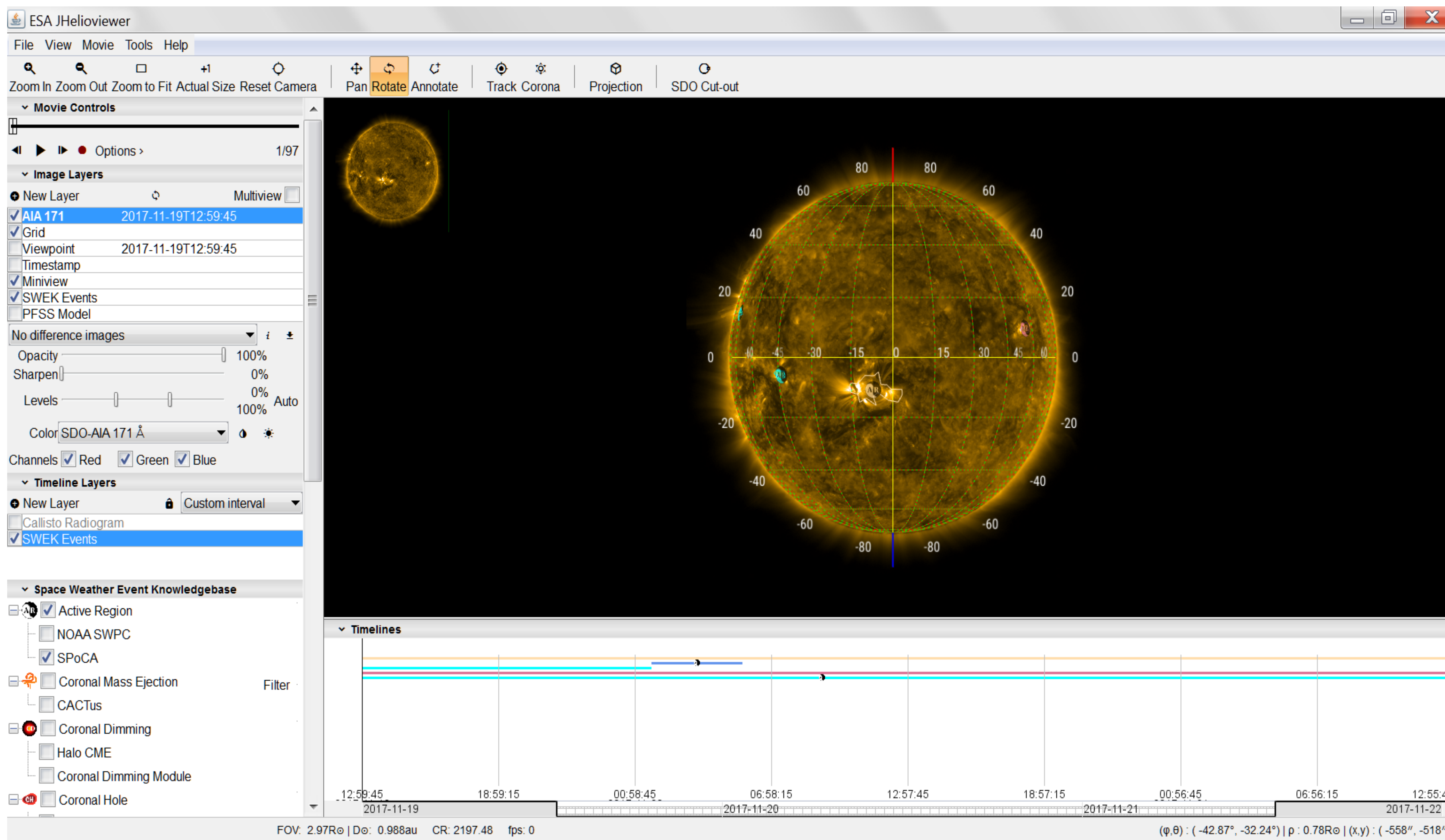
# Visualisation tools
# — Another way of data discovery

# jHelioviewer a quicklook viewer for Solar data

- Access to jpeg2000 quicklook data from different dataset.
- Several viewing options like running, base difference and multiview mode
- Several Image projection
- Time line synchronized with image time series
- Showing feature events from Heliophysics Events knowledge base (HEK)
- URL: www.jhelioviewer.org

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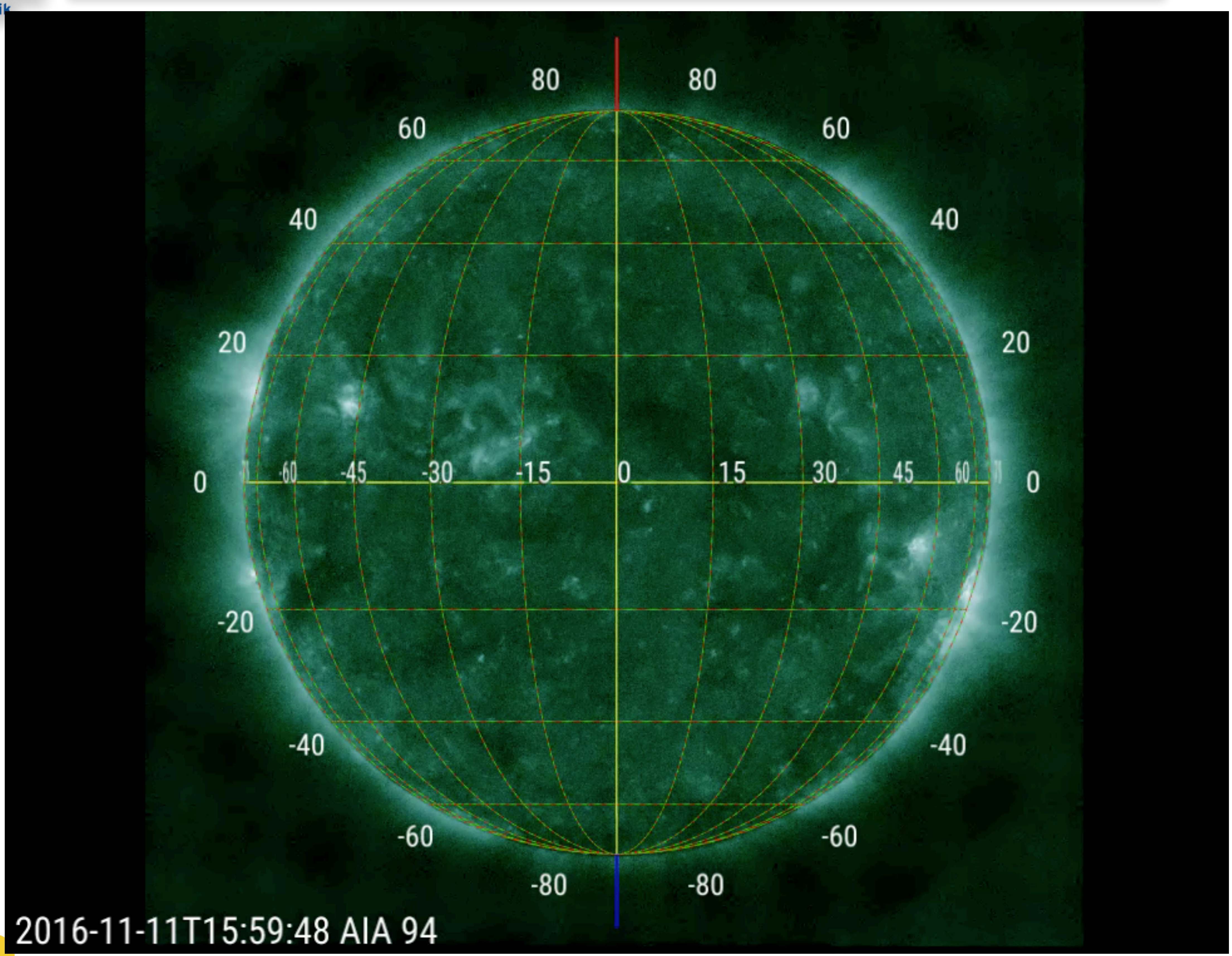
# JHelioviewer — Discovering data

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# Summary

## The ground-based solar physics community is

1. Experimenting a change of paradigm on data handling, data archiving and data dissemination driven by the steady development of the observing capabilities and upcoming of large observing facilities (EST)

2. Aware of the need/the challenge on:
   - Standarising the observation procedure
   - Developing efficient data-pipelines
   - Storing the necessary metadata (time, WCS coordinates, event, wavelength..) to build a comprehensive database

3. Aware there is no need of 're-inventing the wheel' — Joint efforts with
   - The space-based solar community on data catalogue
   - The astronomical community — ASTERICS (OBELICS & DADI)