Session: Coordinated Heliophysics Science

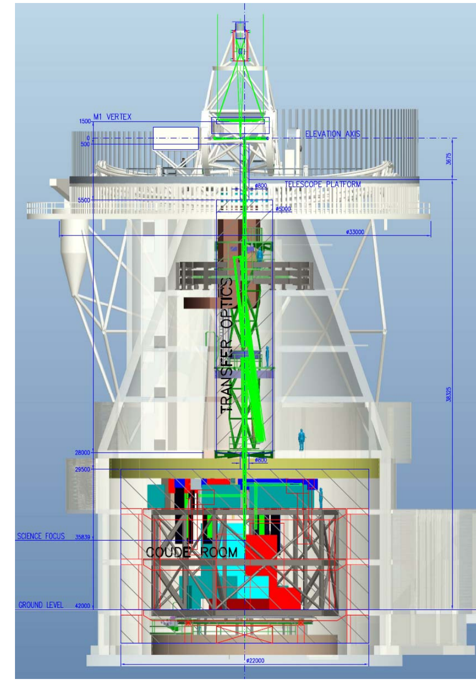
Ground based: EST

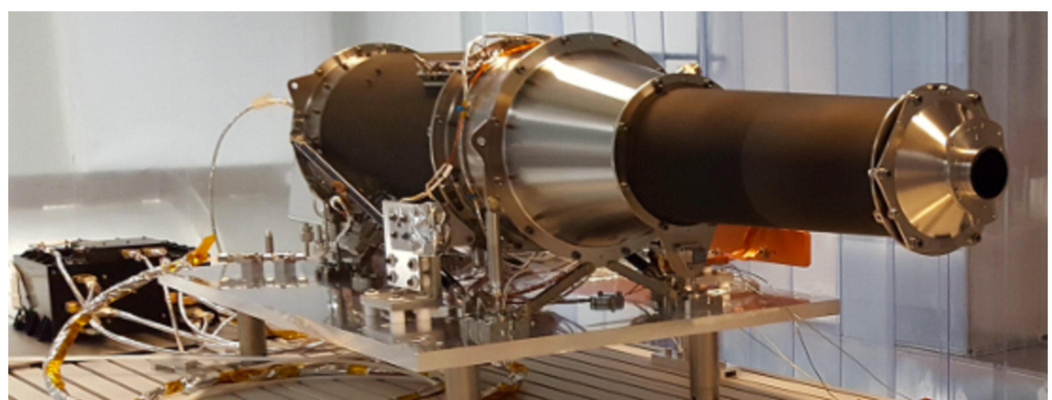
EST Team – SAG
Francesca Zuccarello

METIS Workshop:
21 – 23 November 2018, Goettingen, Germany

Plan of the Talk

- European Solar Telescope (EST)
- EST and Coronal Science
- G-B vs S-B: synergies, advantages and limitations





EST: European Solar Telescope

- **Who:** EAST: European Association for Solar telescopes

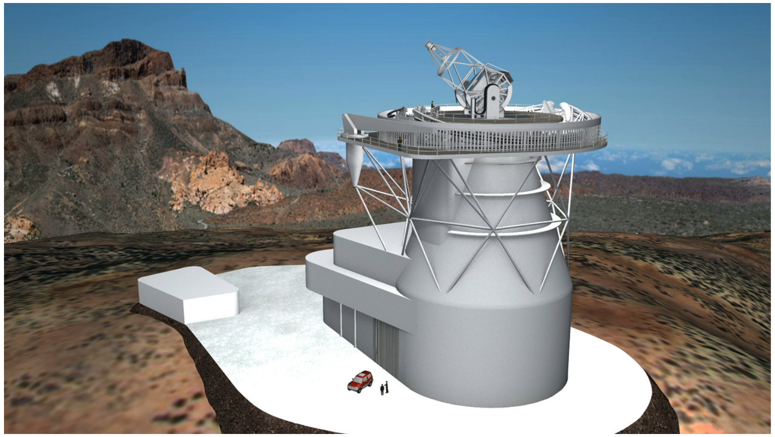
- **Why**: undertaking the development of a ground-based facility: the European Solar Telescope, to keep Europe on the front line of Solar Physics

- **What**: EST will observe the layers of the solar atmosphere from the base of the photosphere to the high chromosphere

- **Where**: The site will be at the Canary Islands

- **When**: First light in 2027

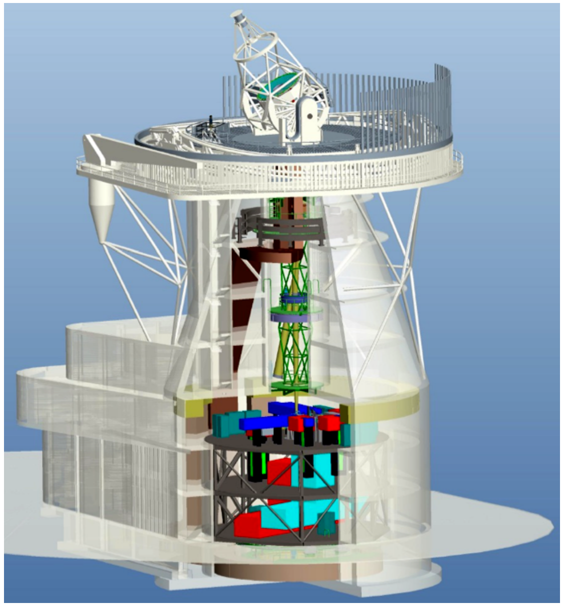
New Strategic European Infrastructure since March 2016 (ESFRI Roadmap)



EST main objectives is to answer to the following questions

- How does the magnetic field evolve and emerge to the solar surface ?
- How is the energy transported from the photosphere to the chromosphere ?
- How is the energy released deposited in the upper atmosphere ?
- Why does the Sun have a hot chromosphere and a hot corona ?
- What causes the explosive events (flares, filament eruptions, CMEs) ?

EST:
European Solar Telescope



- 4-meter diameter
- On-axis Gregorian configuration
- Alt-Az mount
- Simultaneous instrument stations (each with several wavelength channels)
  - Broad-band imager
  - Narrow-band tunable imager
  - Grating spectrograph
- MCAO integrated in the optical path
- Spatial resolution on the solar disk: 30 km (goal 20 km)

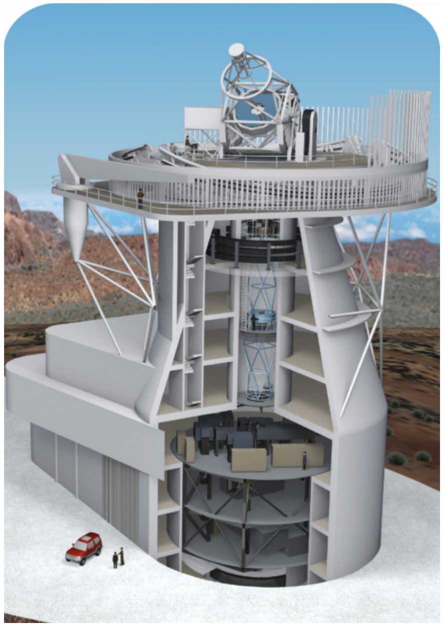
PRE-EST EAST European Association for Solar Telescopes European Commission EST

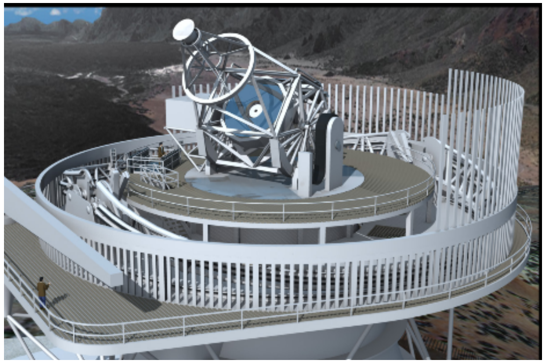
Telescope and instrumentation key capabilities

- High precision polarimetric capabilities, for accurate magnetic field determination

- High angular resolution, with AO and MCAO for atmospheric distortion correction

- Simultaneous observation of different layers of the solar atmosphere





EST WILL COMBINE THE BEST OF PRESENT SOLAR TELESCOPES AND LARGELY IMPROVE THEIR PERFORMANCE

EST and Coronal Science

- EST is **not optimised to carry out Coronal Science** as one of its primary objectives, but it is **well suited to providing complementary observations** of the underlying photosphere and chromosphere that will significantly advance our understanding of coronal physics in a number of areas.

- **"...co-ordination with space-based facilities will be required"**

SRD, July 2018

SRD open to the Scientific Community for contributions till the end of October 2018

EST and Coronal Science

Coronal Science

- Sunspot light-bridges
- Light Walls
- **Origins of the solar wind**
- **Probing pre-flare triggers**
- Macrospicules/spicules and Transition Regions Quakes (TRQs)
- Ellerman bombs

EAST European Association for Solar Telescopes

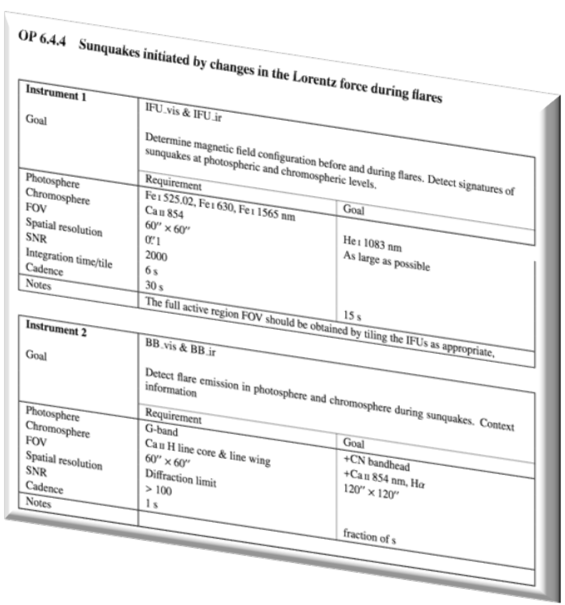
EST european solar telescope

EST: European Solar Telescope
Science Requirement Document (SRD)

Science Advisory Group (SAG)
July 12, 2018

1. Luis Bellot Rubio (IAA, Spain); (Chair of Section II/1)
2. Luca Belluzzi (IRSOL, Suisse);
3. Mats Carlsson (UiO, Norway);
4. Sanja Danilovic (SU, Sweden);
5. Robertus Erdelyi (HSPF, Hungary); (Chair of Section II/2)
6. Alex Feller (MPS, Germany); (Chair of Section II/8)
7. Lyndsay Fletcher (University of Glasgow, UK); (Chair of Section II/6)
8. Peter Gömöry (AISAS, Slovakia);
9. Jan Jurčák (CAS, Czech Republic); (Chair of Section II/4)
10. Elena Khomenko (IAC, Spain); (Chair of Section II/7)
11. Christoph Kuckein (AIP, Germany);
12. Jorrit Leenaarts (SU, Sweden); (Chair of Section II/3)
13. Arturo López Ariste (CNRS, France);
14. María Jesús Martínez González (IAC, Spain);
15. Mihalis Mathioudakis (QUB, UK);
16. Sarah Matthews (UCL, UK);(Chair of Section II/5 & II/9)
17. Ada Ortiz (UiO, Norway);
18. Rolf Schlichenmaier (KIS, Germany, chair of SAG)
19. Javier Trujillo Bueno (IAC, Spain);
20. Dominik Utz (IGAM, Austria);
21. Luc Rouppe van der Voort (UiO, Norway);
22. Francesca Zuccarello (University of Catania & INAF, Italy);

PRE·EST



OP 6.4.4 Sunquakes initiated by changes in the Lorentz force during flares

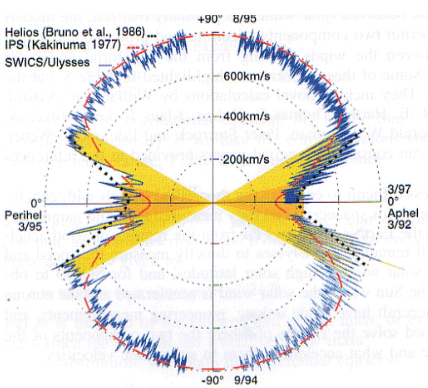
Instrument 1	IFU_vis & IFU_ir	
Goal	Determine magnetic field configuration before and during flares. Detect signatures of sunquakes at photospheric and chromospheric levels.	
	Requirement	Goal
Photosphere	Fe I 525.02, Fe I 630, Fe I 1565 nm	
Chromosphere	Ca II 854	He I 1083 nm
FOV	60″ × 60″	As large as possible
Spatial resolution	0.″1	
SNR	2000	
Integration time/tile	6 s	
Cadence	30 s	15 s
Notes	The full active region FOV should be obtained by tiling the IFUs as appropriate.	
Instrument 2	BB_vis & BB_ir	
Goal	Detect flare emission in photosphere and chromosphere during sunquakes. Context information	
	Requirement	Goal
Photosphere	G-band	+CN bandhead
Chromosphere	Ca II H line core & line wing	+Ca II 854 nm, Hα
FOV	60″ × 60″	120″ × 120″
Spatial resolution	Diffraction limit	
SNR	> 100	
Cadence	1 s	fraction of s
Notes		

Solar Flares and Eruptive Events

- Radiation, structure and evolution of the flare lower atmosphere
- Velocity structure of the flaring atmosphere
- Diagnostics for non thermal particles
- Flare oscillations and Sunquakes
- Large-scale structure and evolution of the magnetic field
- Small-scale structure and evolution of the magnetic field
- Filaments in flaring active regions
- **Coronal Mass Ejections**

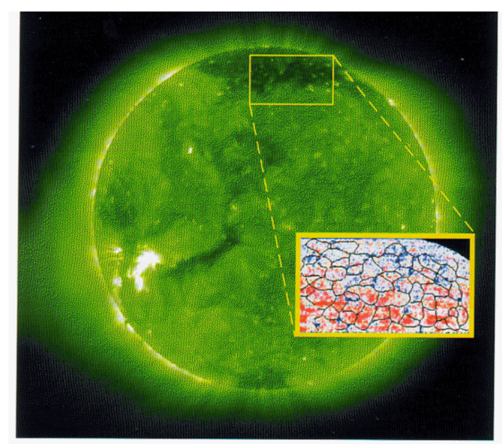
Origins of the solar wind

- Hinode EIS has demonstrated that AR upflows are common, but combined studies with in situ observations have showed clearly that **not all upflows will become outflows** measurable in the solar wind.



Debates continue about **where in the atmosphere the upflows originate**.

Solar Orbiter will provide multi-vantage points measurements of coronal outflows, but need corresponding chromospheric magnetic field measurements in order to determine the processes that produce them, e.g. **low-altitude reconnection**, presence of **small-scale open field at AR boundaries**



Origins of the Solar Wind

Observing plan aims to explore the **role of small-scale** photospheric and chromopsheric **dynamics in driving the solar wind** at the edges of active regions and coronal holes where persistent upflows are observed in coronal lines.

Instrument 2	Broad-band Imagers	
Goal	Detect small-scale photospheric and chromospheric activity. Provide context information on the surrounding AR/CH.	
	Requirement	Goal
Photosphere	G-band	
Chromosphere	Ca II H line core & line wing	+Ca II 854 nm, $H\alpha$
FOV	$60'' \times 60''$	$120'' \times 120''$
Spatial resolution	Diffraction limit	
SNR	> 100	
Cadence	5 s	1 s
Notes	See above for co-ordination requirements.	

Instrument 1	IFU spectropolarimeters	
Goal	Determine magnetic field topology and dynamics of the photosphere and chromosphere at active region and coronal hole boundaries as a function of height. Combine with UV/EUV imaging and spectroscopic observations of TR and coronal response using Solar Orbiter EUI/SPICE and/or Solar C EUVST.	
	Requirement	Goal
Photosphere	Fe I 525.02, Fe I 630, Fe I 1565 nm	+Si I 1082.7 nm
Chromosphere	Ca II H_2 396.8, Ca II 854, He I 1083 nm	+Na I D_2
FOV	$10'' \times 10''$	As large as possible
Spatial resolution	$0.05''$	
SNR	2000	
Integration time/tile	5 s	
Cadence	60 s	30 s
Notes	These observations need to be co-ordinated with space platforms to enable the connection to the TR and corona to be made. For Solar Orbiter this should be done at conjunction. This OP links to OP 3.3.1 on spicule acceleration on disk, so could potentially be merged, and is very similar to DKIST SUC-61 created by Louise Harra. Appropriate Solar Orbiter SOOPs, as listed in SUC-61 are L_BOTH_HIRES+LCAD_CH_Boundary_Expansion; L_SMALL_HIRES_HCAD_SlowWindConnection; L_SMALL_HRES_HCAD_Fast_Wind; L_SMALL_HRES_HCAD_SlowWindConenction; R_SMALL_HRES_MCAD_PolarObservations. EST can potetially provide greater multi-height coverage.	

It will measure the **magnetic field strength and direction** from the photosphere to the upper chromosphere using **spectropolarimetry**, and the **plasma dynamics using 2D spectroscopy** to determine intensity, line widths, and line of sight velocities.

Measurements should be coordinated with space platforms to provide the link to coronal spectroscopy, and ideally with in-situ measurements of plasma composition.

Erderly, Mathiudakis, Matthews, SRD

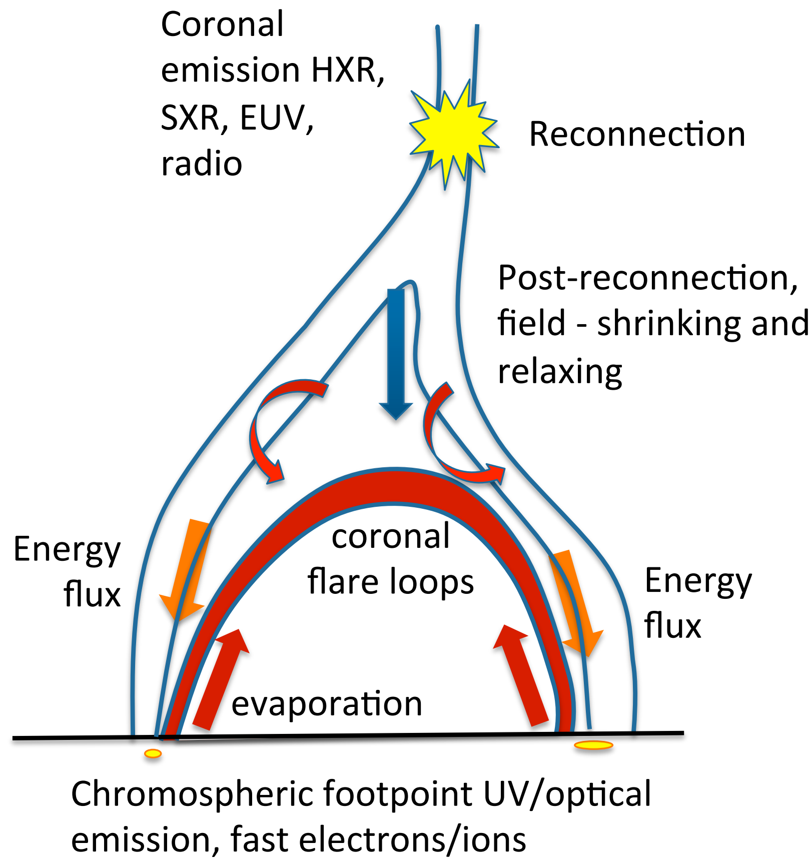
Flares:
The paradigm of the magnetic coupling of the solar atmosphere

The main question of flare physics is to understand:

How the energy, previously stored in a stressed coronal magnetic field →

- is released so rapidly,
- transported through the atmosphere of the Sun,
- converted into the kinetic energy of the non-thermal particles and into the flare's radiation output.

Their relation to CMEs (yes/no, before/after).



Fletcher, 2014

Probing pre-flare triggers

- This observing plan aims to explore the **role of small-scale photospheric and chromopsheric dynamics** in the period **before flare/CME** onset and its relationship to TR and coronal dynamics.

Instrument 2	Broad-band Imagers	
Goal	Detect small-scale photospheric and chromospheric activity around the neutral line, including flux emegernce, cancellation. Provide context information on the surrounding AR.	
	Requirement	Goal
Photosphere	G-band	
Chromosphere	Ca II H line core & line wing	+Ca II 854 nm, Hα
FOV	$60'' \times 60''$	$120'' \times 120''$
Spatial resolution	Diffraction limit	
SNR	> 100	
Cadence	5 s	1 s
Notes	See above for co-ordination requirements.	

Instrument 1	IFU spectropolarimeters	
Goal	Determine magnetic field topology and dynamics of the photosphere and chromosphere within the vicinity of the neutral line in an active region as a function of height. Combine with UV/EUV imaging and spectroscopic observations of TR and coronal response using Solar Orbiter EUI/SPICE and/or Solar C EUVST.	
	Requirement	Goal
Photosphere	Fe I 525.02, Fe I 630, Fe I 1565 nm	+SiI 1082.7 nm
Chromosphere	Ca II H 396.8, Ca II 854, He I 1083 nm	+Na I D_2
FOV	$30'' \times 30''$	As large as possible
Spatial resolution	$0.05''$	
SNR	2000	
Integration time/tile	10 s	
Cadence	100 s	30 s
Notes	These observations would have to be a TOO but need to be co-ordinated with space platforms to enable the connection to the TR and corona to be made. For Solar Orbiter this could be done either at conjunction or quadrature, with quadrature providing a 3D view of the overlying corona, particularly if combined with Solar C EUVST. Relevant SOOPs: L_FULL_HRES_HCAD_Coronal_Dynamics; R_SMALL_HRES_HCAD_AR_Dynamics; R_SMALL_HRES_HCAD_RSburst; L_FULL_HRES_HCAD_Eruption_Watch	

It will measure the **magnetic field** strength and direction from the photosphere to the upper chromosphere using **spectropolarimetry**, and the **plasma dynamics using 2D spectroscopy** to determine intensity, line widths, and line of sight velocities.

Measurements should be coordinated with space platforms to provide the link to coronal spectroscopy.

Erderly, Mathioudakis, Matthews, SRD

CMEs sources and temporal relations with flares

- There are still some difficulties in determining the relationship between flares and CMEs, due to the use of different instruments needed to observe phenomena on the disk and in the outer corona.

Instrument 1	SP_vis & SP_ir	
Goal	Search for any brightening or flaring emission which could be spatially and temporally correlated with a CME. Infer the magnetic field configuration of the flux rope involved in the eruption leading to the coronal mass ejection.	
	Requirement	Goal
Photosphere	Fe I 1565	+Si I 1082.7 nm
Chromosphere	Ca II 854 nm, Hα, Ba II 455	+He I 1083 nm
Wavelength samples	15	20 for chromospheric lines
FOV	60″ × 60″	120″ × 120″
Spatial resolution	0.″05	
SNR	200	
Cadence	5 s	
Notes	Raster scans with slit parallel to the magnetic flux rope axis to look for plasma motions and for brightenings in the surroundings.	

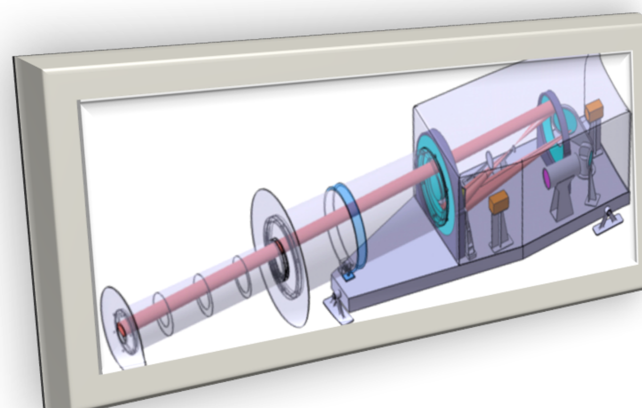
Instrument 2	BB_vis & BB_ir	
Goal	Detect flare signatures at photospheric and chromospheric heights. Context information on the active region morphology before, during and after the flare - CME occurrence.	
	Requirement	Goal
Photosphere	G-band	+CN bandhead
Chromosphere	Ca II H line core & line wing	Hα
Wavelength samples		
FOV	120″ × 120″	As large as possible
Spatial resolution	0.″1	
SNR	> 100	
Cadence	10 s	5 s
Notes	These observations should be complemented with data acquired by coronagraphs.	

This circumstance can have different implications, like for instance the fact that there can be a loss of information during the time when the plasma is travelling within the region covered by the occulting disk of the coronagraph.

Fletcher, Zuccarello, Kuckein, Danilovic, SRD

EST and METIS:
Synergies and complementarities:

- How energy is deposited in the polar regions where the fast solar wind is generated and accelerated ?
- Which are the sources of the slow solar wind at lower latitudes ?
- How does the global corona evolve and how does give birth to the huge coronal mass ejections characteristic of solar activity ?



Previous experience, advantages and limitations

Ground-based telescopes:

🙂 Higher angular resolution
🙂 Possibility to repair, upgrade instruments
🙂 Change of the target in real time
🙂 Unique observations in the Hα line (often patrol observations, but low spatial resolution)

😡 Wavelength range limited by Earth atmosphere
😡 Data Acquisition strongly dependent on seeing conditions
😡 Day/night constraints

Previous experience, advantages and limitations

Satellite Instruments:

- 🙂 No seeing problems
- 🙂 Public release data
- 🙂 Pipelines (for instance, Solar Software, almost immediately available
- 🙂 Data archives and repository well organized

- 😡 Telemetry and data transfer limitation
- 😡 Effects of energetic particles during solar explosive events
- 😡 Difficulty to upgrade or repair
- 😡 Lost of satellite control (see, e.g. SOHO)
- 😡 Limited time interval of satellite observations (10 y ?)

Conclusions

- EST: a ground-based 4-m solar telescope optimized for spectropolarimetric observations of the photosphere and chromosphere
- EST is **not optimised to carry out Coronal Science** as one of its primary objectives, but it is **well suited to providing complementary observations** of the underlying photosphere and chromosphere
- Several Science Cases (and relevant OPs) concerning Coronal Science and the main objectives of METIS are already present in the Science Requirement Document
- SRD: need of complementary observations.

Thanks for your attention

The research leading to these results has received funding from the European Union's Horizon 2020 research and innovation programme under GA no. 739500 (PRE-EST project).

PRE-EST

European Commission