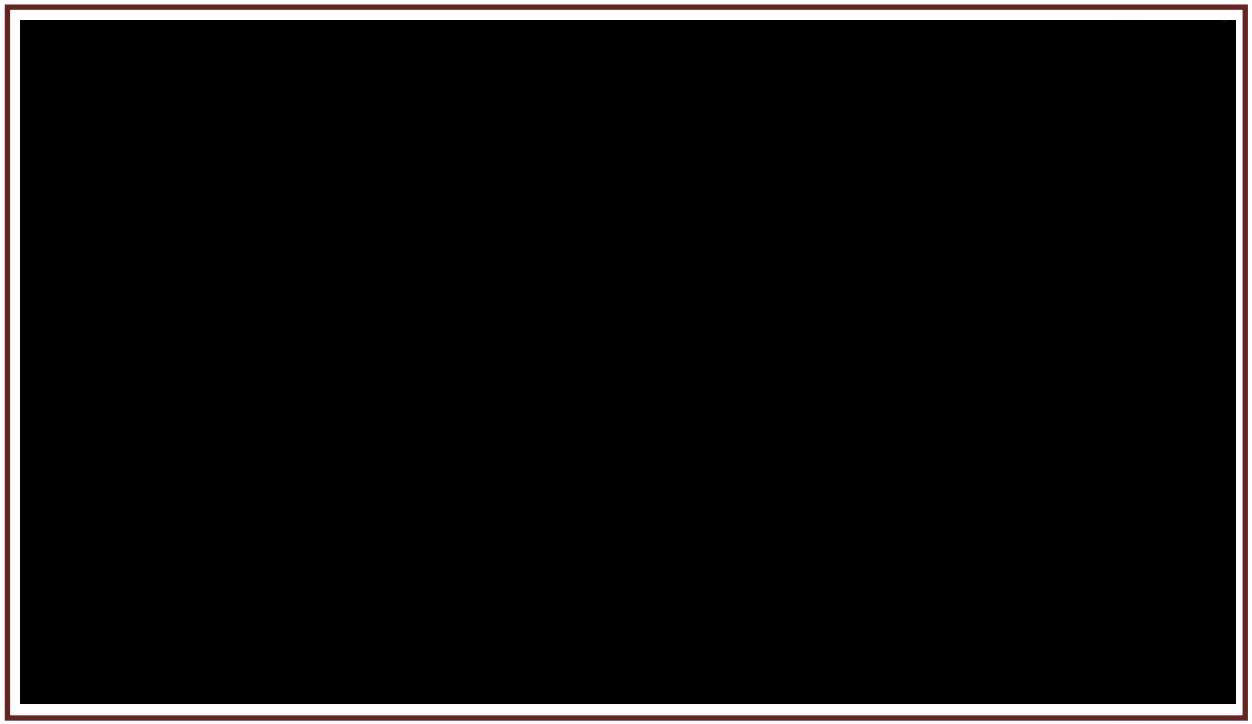
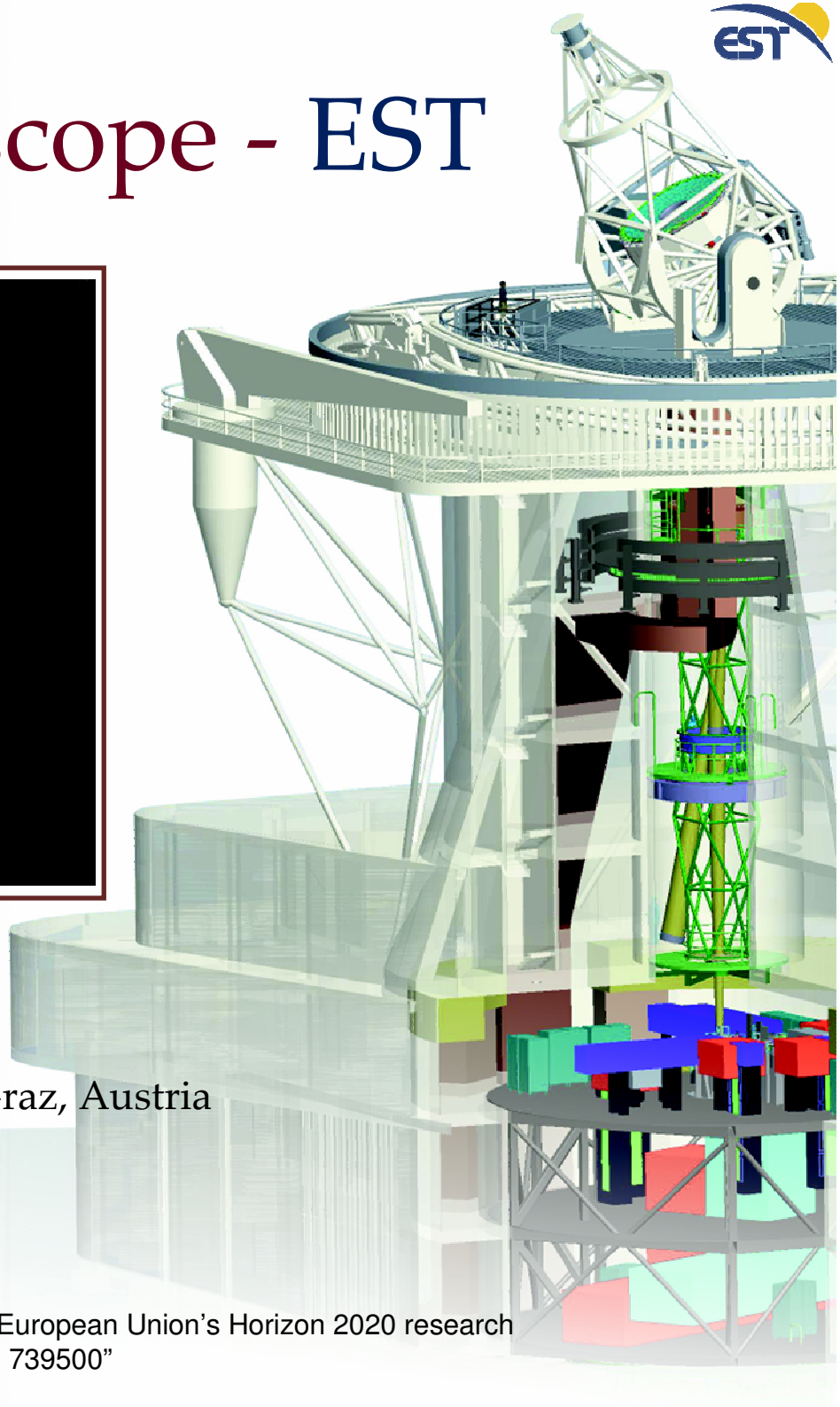
European Solar Telescope - EST





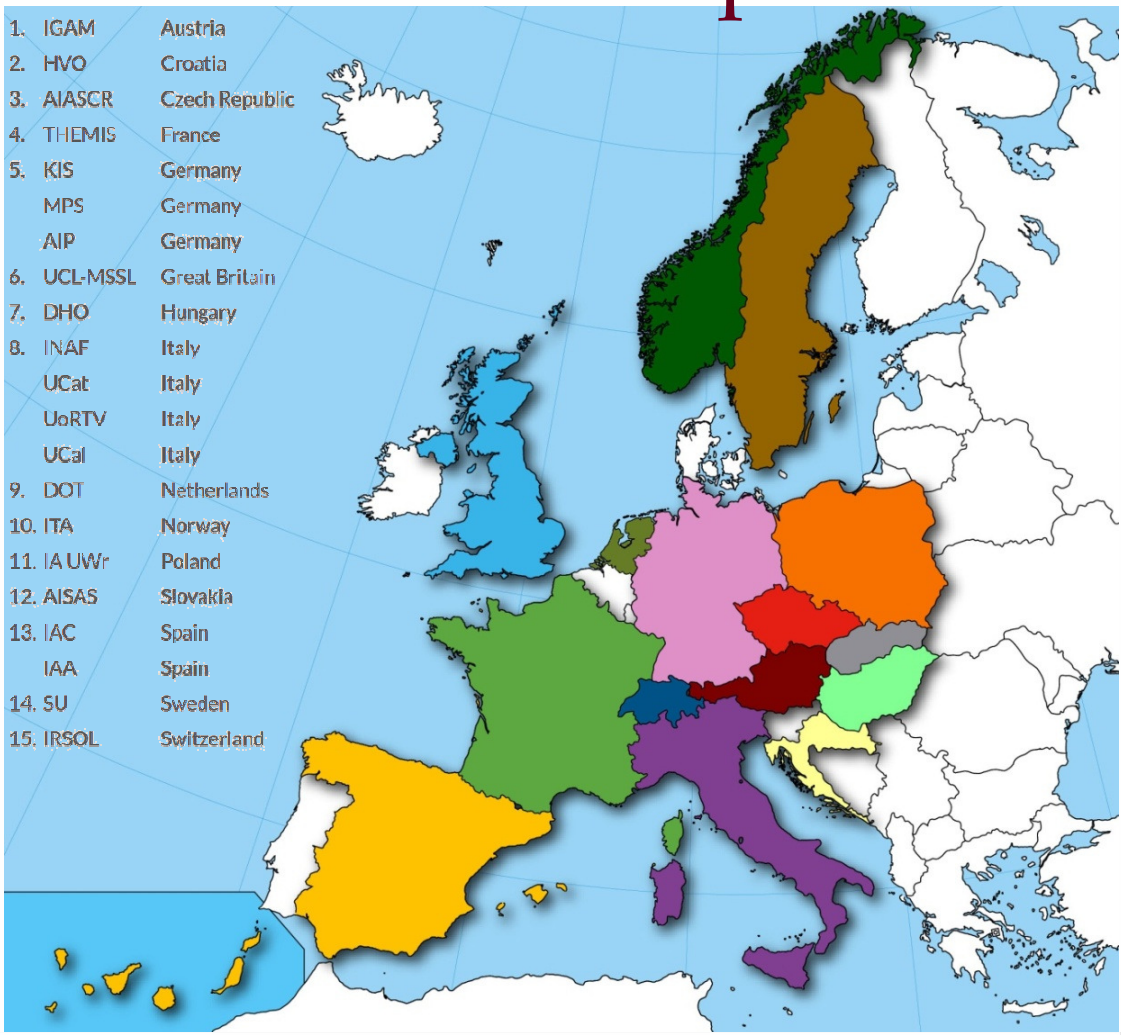
Dominik Utz for the EST team

IGAM/Institute of Physics, Karl-Franzens University Graz, Austria
Presentation mostly prepared by Peter GÖMÖRY;
Astronomical Institute, Tatranska Lomnica, Slovakia

"The PRE-EST project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 739500"

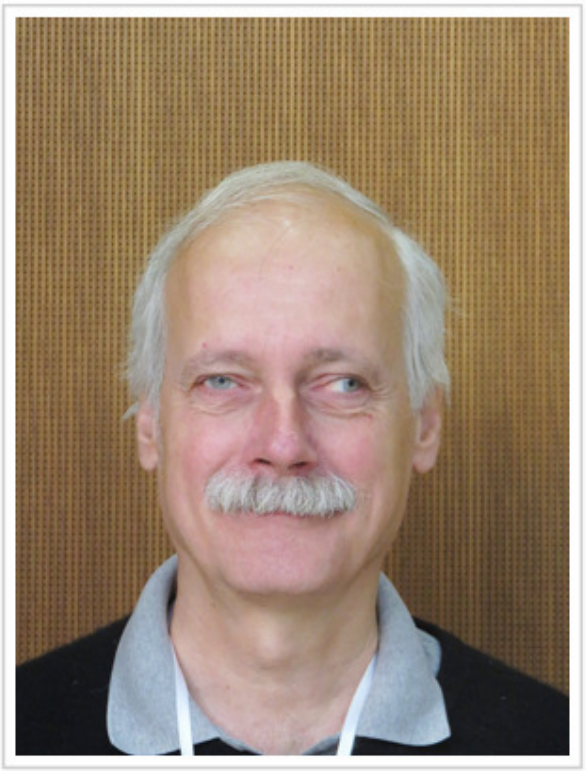
European Association for Solar Telescope EAST

- consortium currently uniting 21 institutes from 15 European countries
- founded in 2006
- with a primary goal to develop, construct, and operate EST to ensure the access of European solar physicists to the world-class observing facility
- negotiations with other potential European (Greece, Ireland) and non-European (Japan, Korea, China) partners to join the EST project are in progress
- Stimulate and coordinate also the usage of existing optical solar telescope infrastructure



Current Directorate of EAST

EAST President



Mats Carlsson

Institute for Theoretical Astrophysics, University of Oslo

Norway

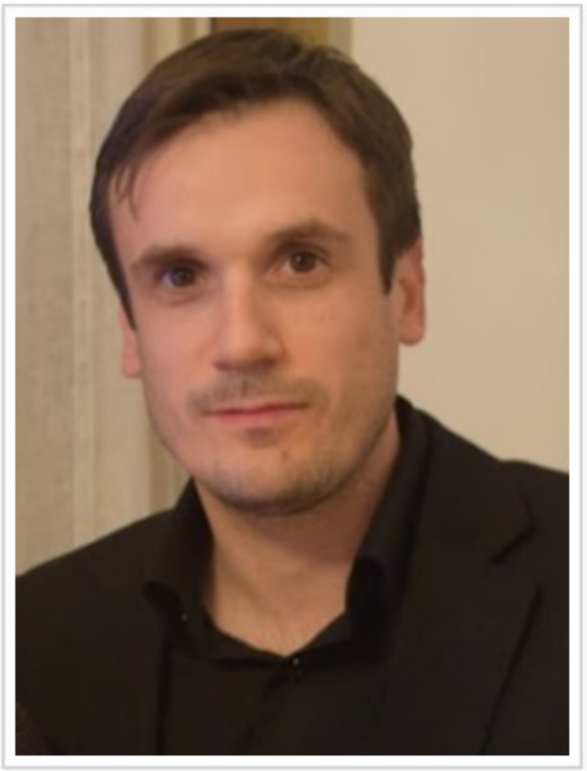
EAST Vice President

Prof. Oskar von der Lühe

Kiepenheuer-Institut für Sonnenphysik, Freiburg

Germany

EAST Executive Director



Marco Stangalini

Astronomical Observatory of Rome-INAF, Rome

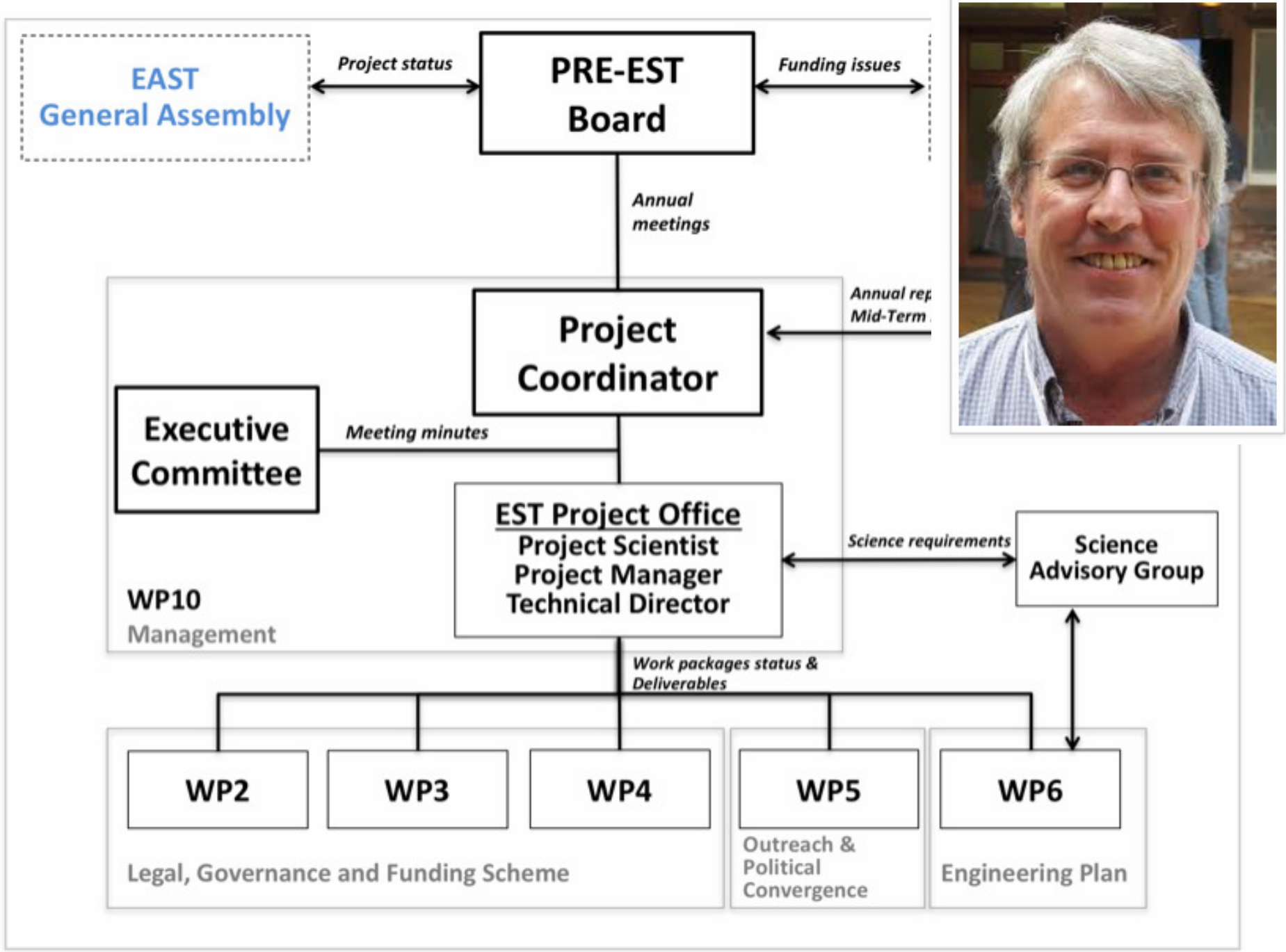
Italy

PRE-EST goals

- To provide the EST international consortium and the national agencies with a detailed plan for the implantation of EST
  - Governance
  - Legal structure
  - Financial issues
  - Strategic actions
  - Technical Works leading to final design

GOVERNANCE

EST COORDINATION

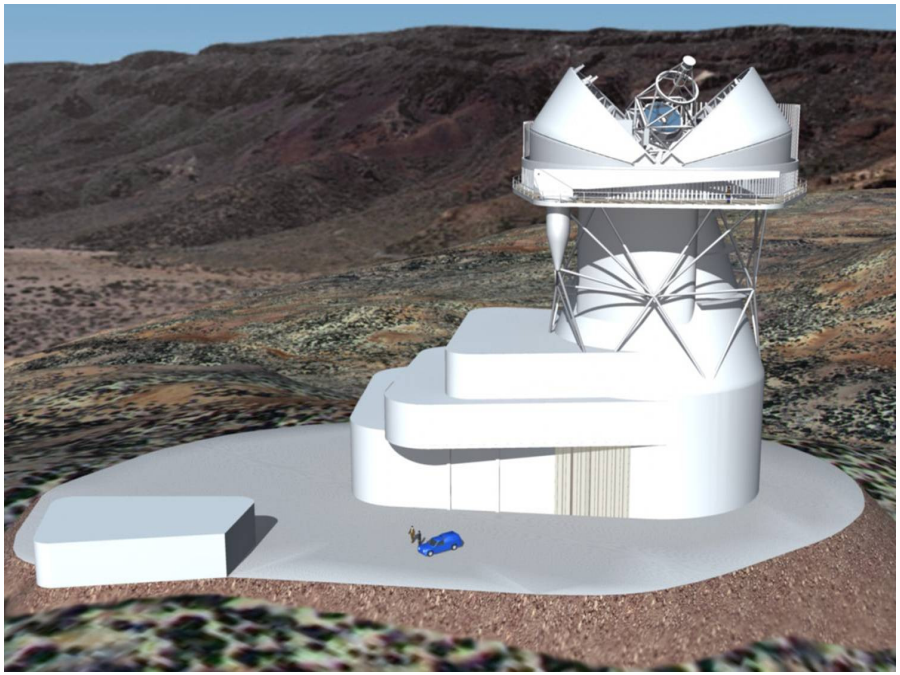


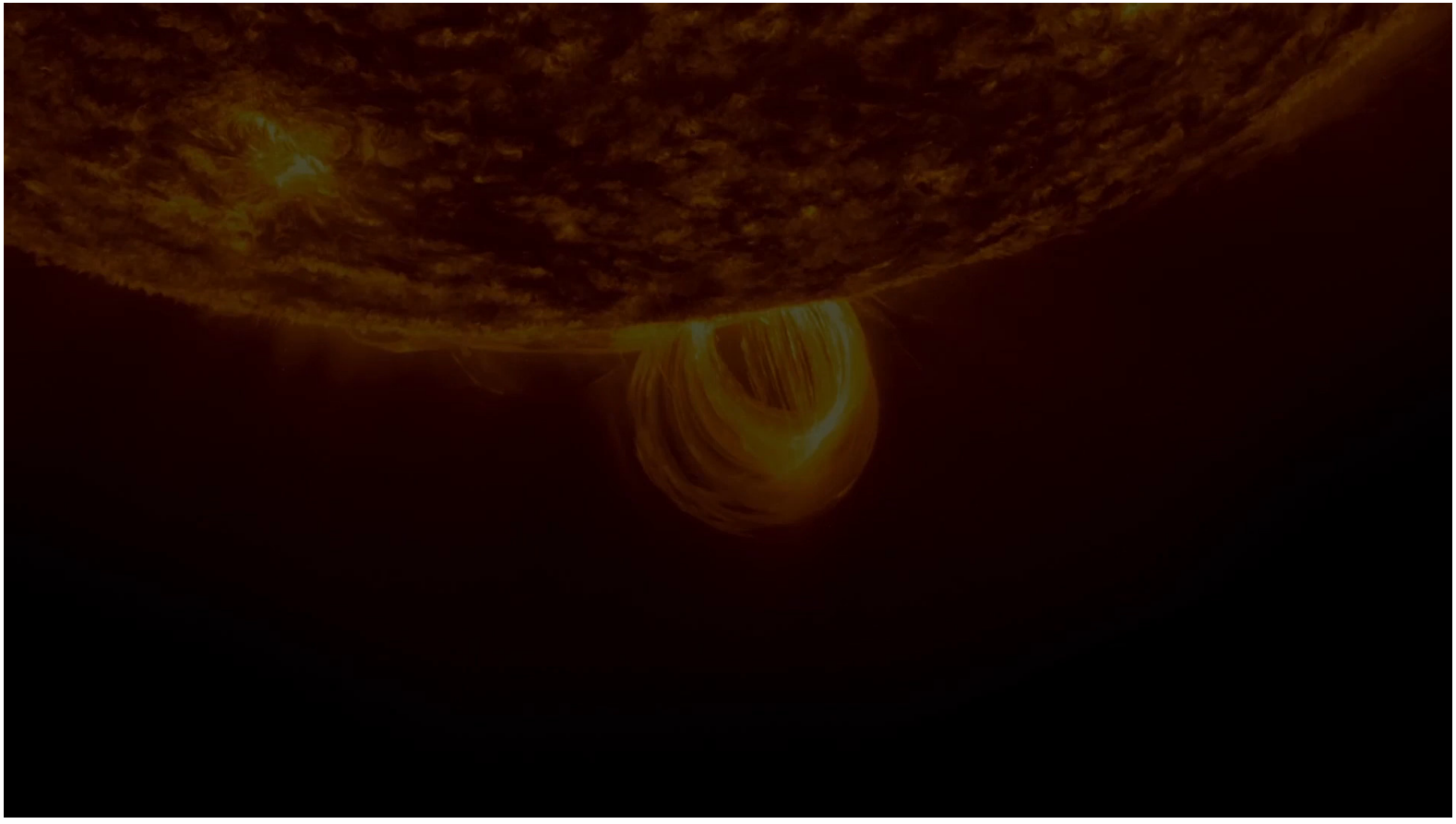
EST: key aspects

- to be built in Canary Islands (Spain): Tenerife or La Palma

EST: key aspects

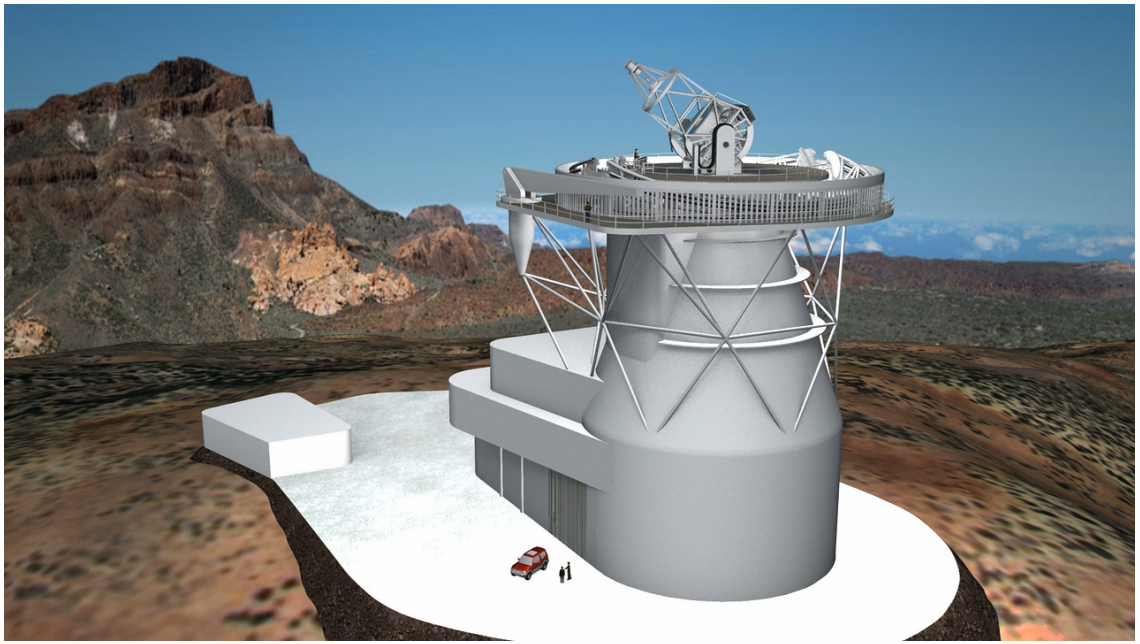
- it will allow us to observe the Sun with superb spatial resolution
- it is optimized to observe the magnetic coupling between the deep photosphere and the upper chromosphere
- it is designed for excellent polarimetric performance

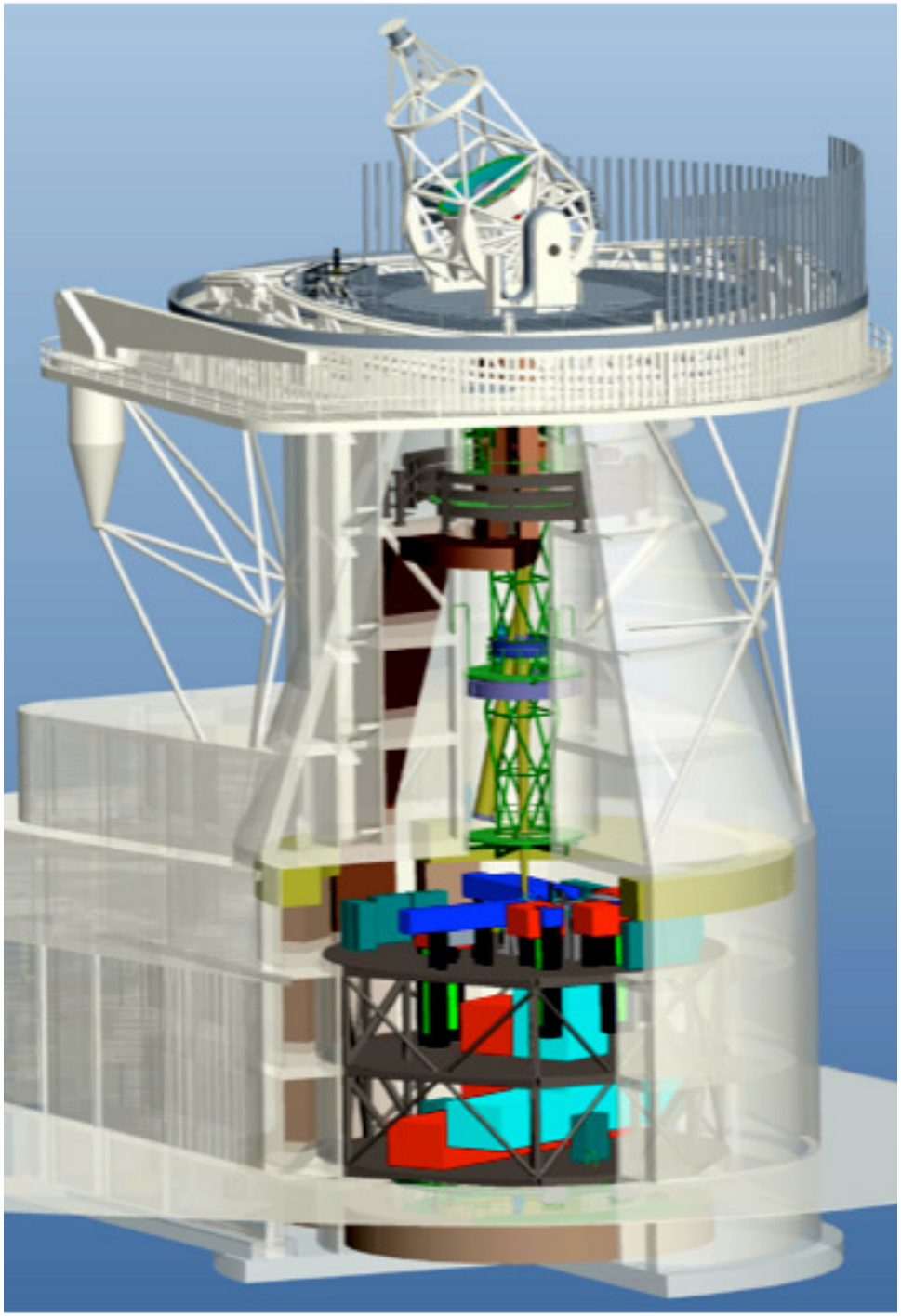




EST: design baseline

- 4-meter diameter
- on-axis Gregorian configuration
- Alt-Az mount
- simultaneous instruments
  - Broad-band imagers
  - Narrow-band tunable imagers
  - Grating spectrographs
- instruments optimized for the simultaneous observation of the photosphere and chromosphere





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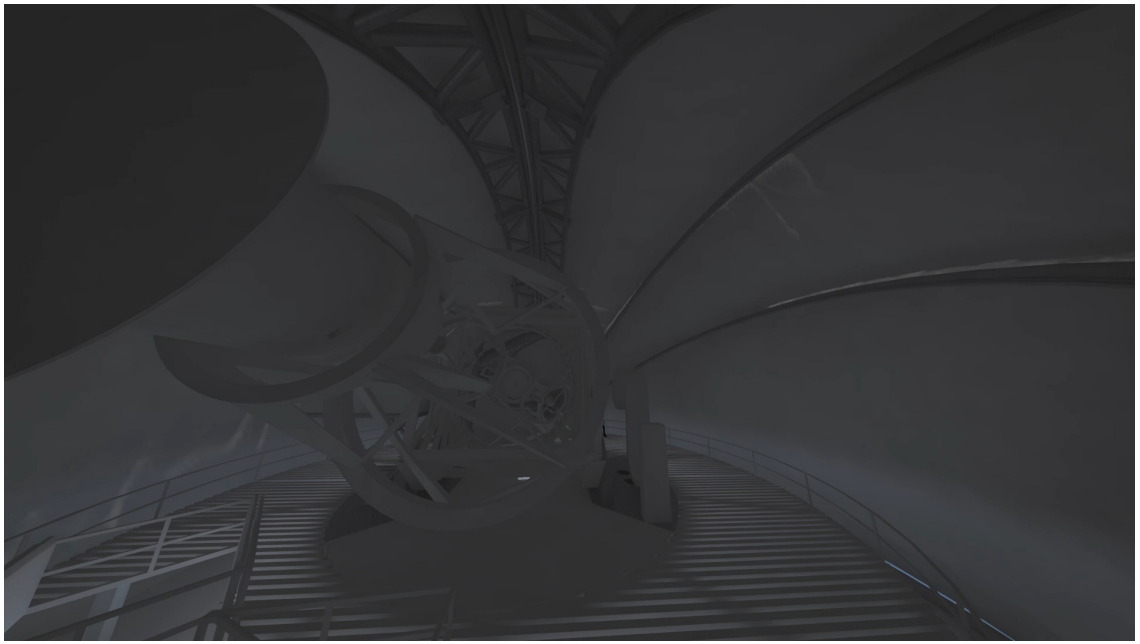
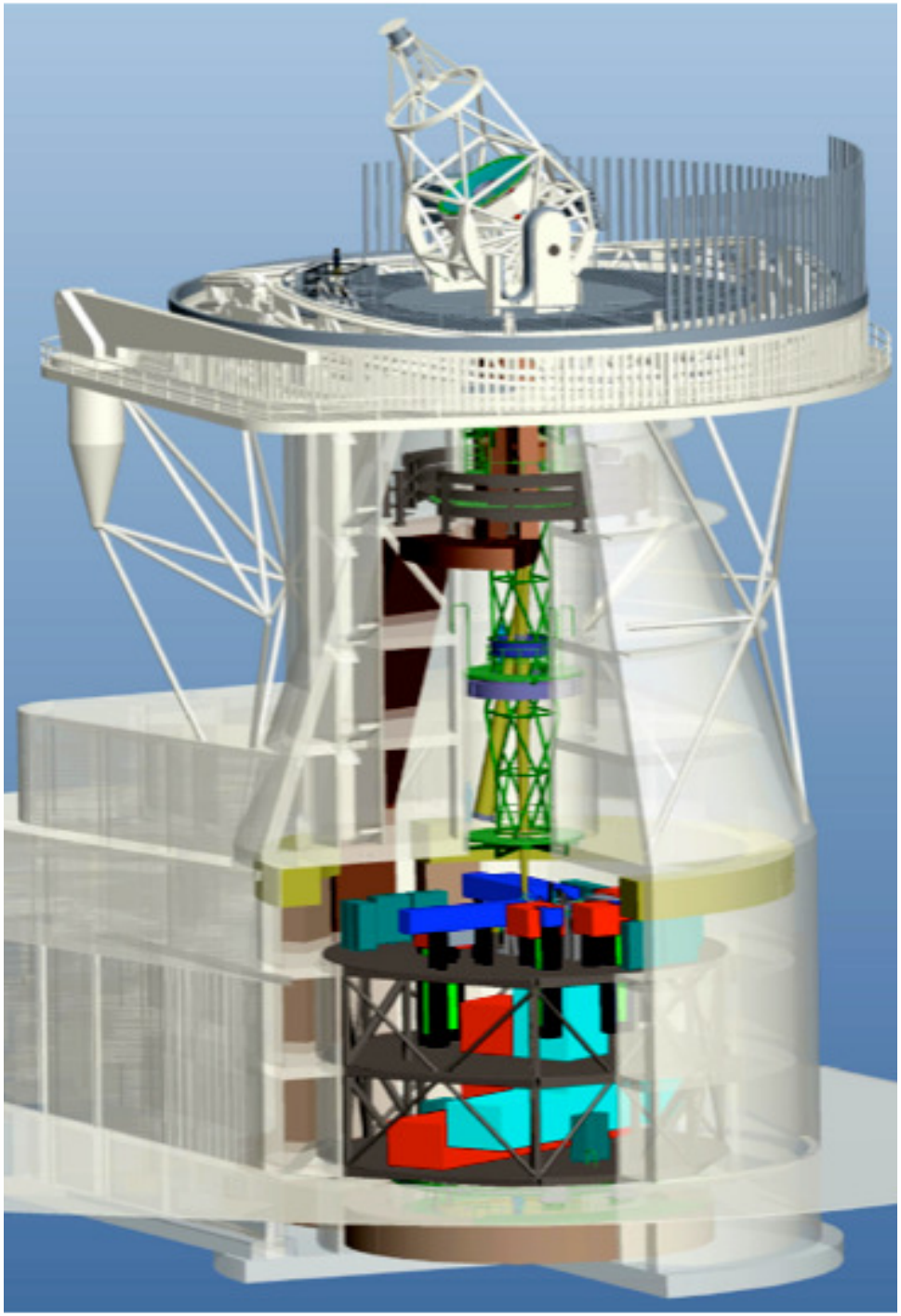
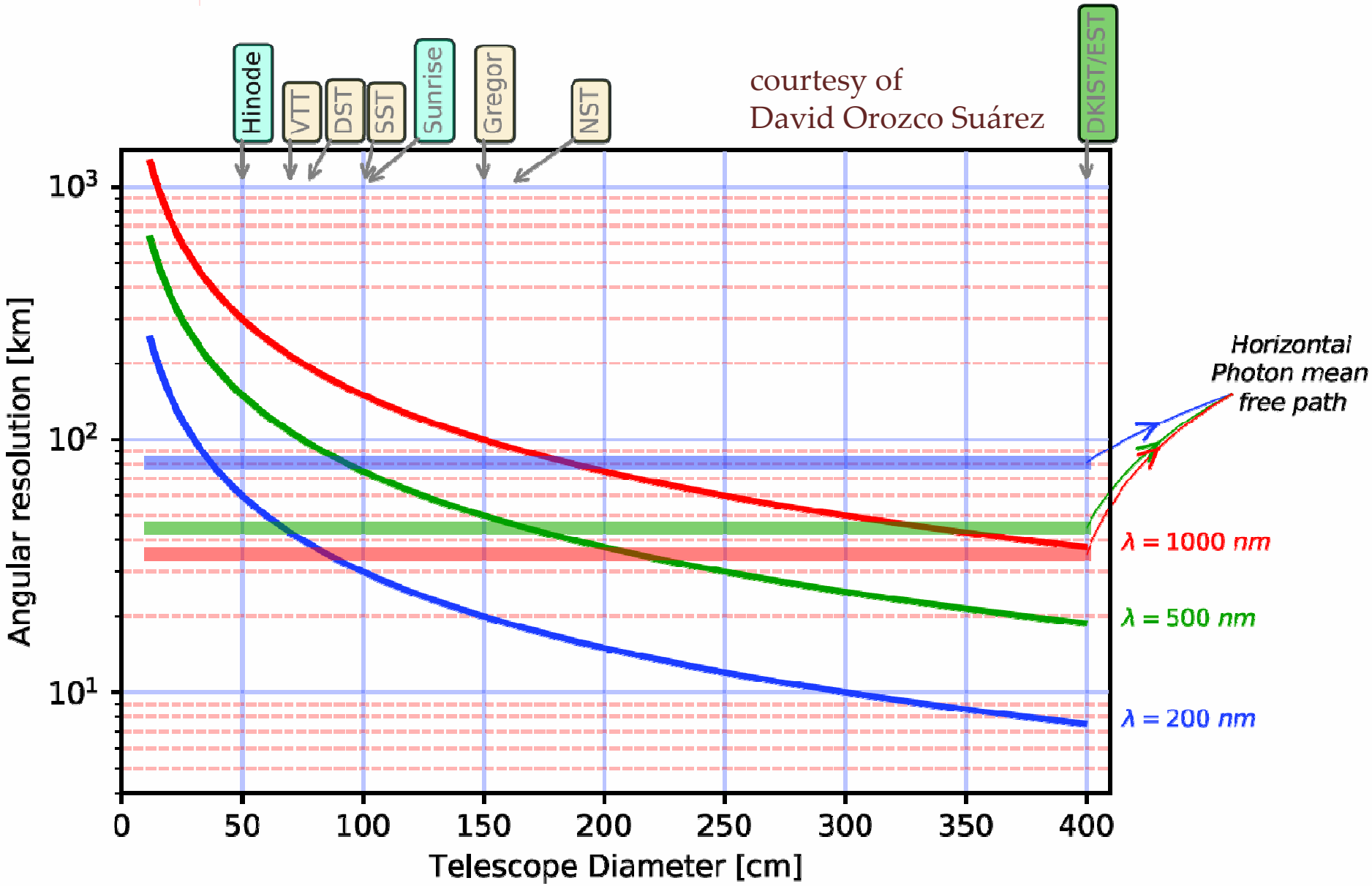




EST: resolution issues?

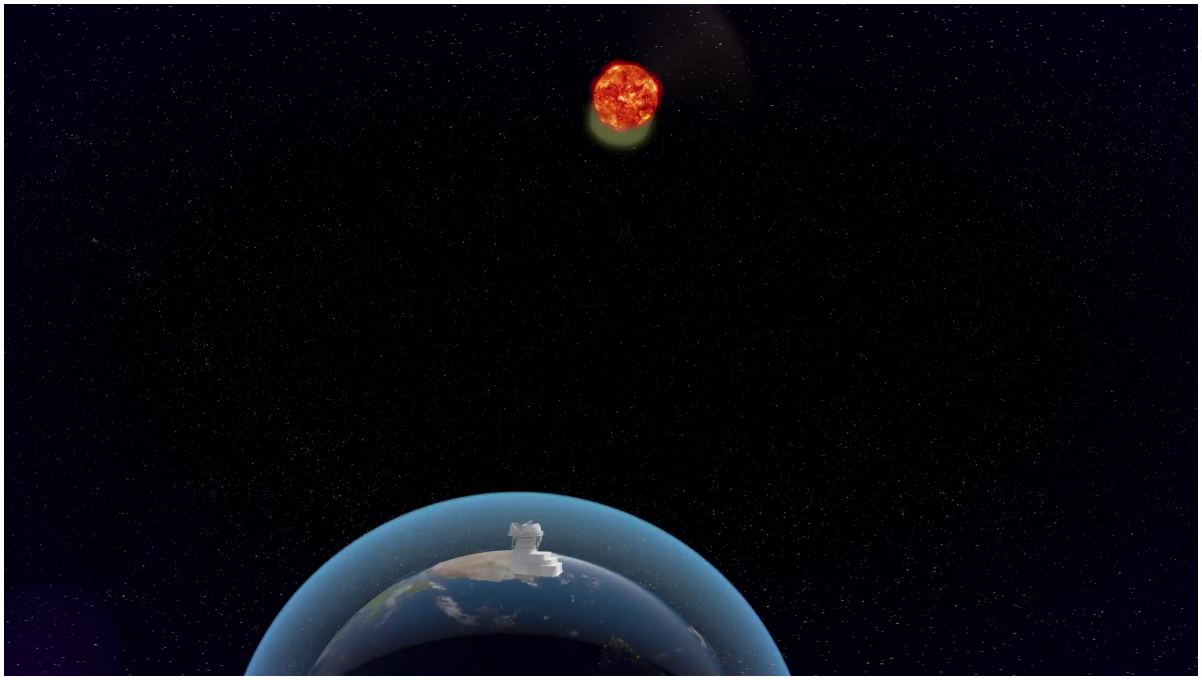


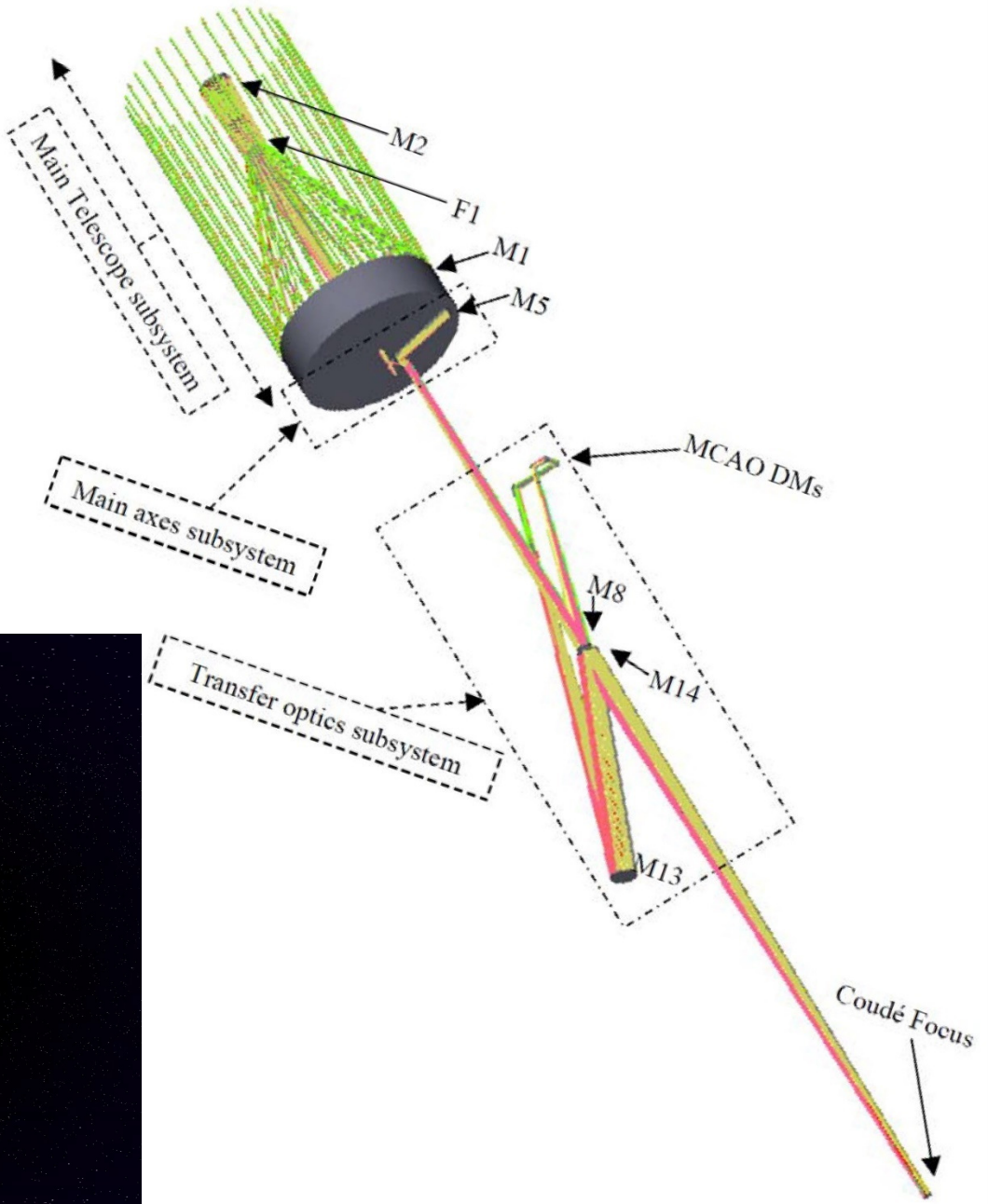
Judge et al. 2014

even in LTE conditions, the source function can be influenced by scattering

EST: telescope design

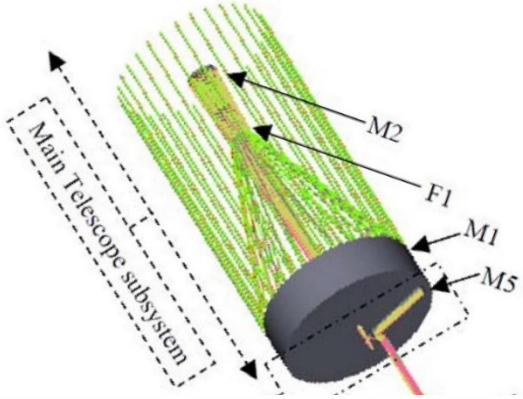
- 14 mirrors to transfer light to the Science Coudé Focus
- rotating transfer optics
- fixed Coudé lab
- AO/MCAO integrated in the optical path
- polarimetrically compensated



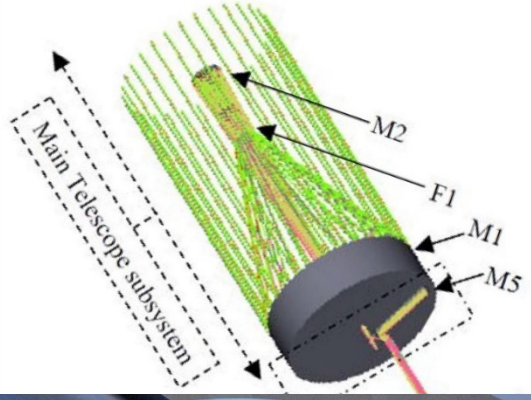


EST: telescope design

- M1 4.1 m aperture mirror with about 640 hexagonal actuated cells



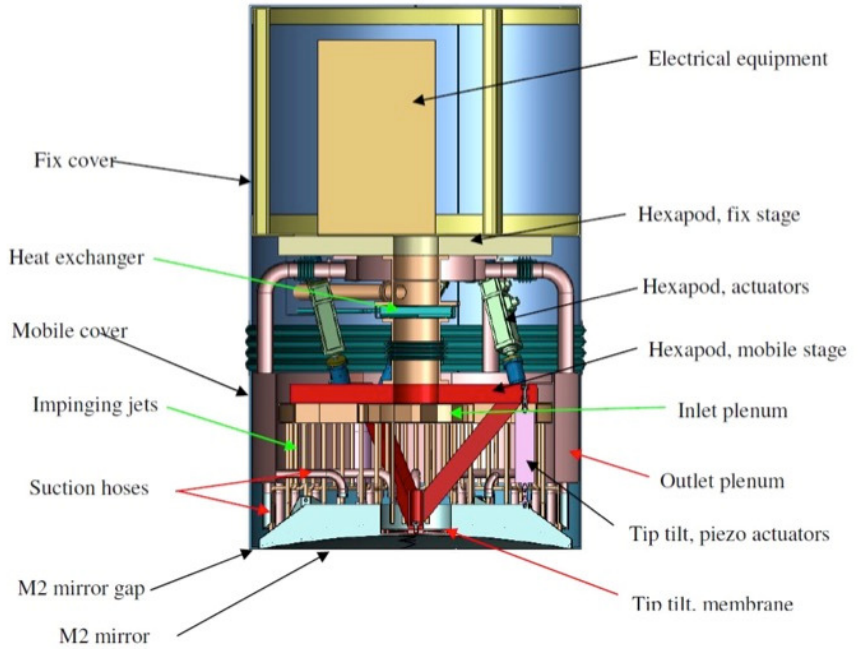
EST: telescope design



- A powerful heat dump/heat rejection unit needed!

EST: telescope design

- M2 with tip tilt capabilities on a hexapod for image alignment



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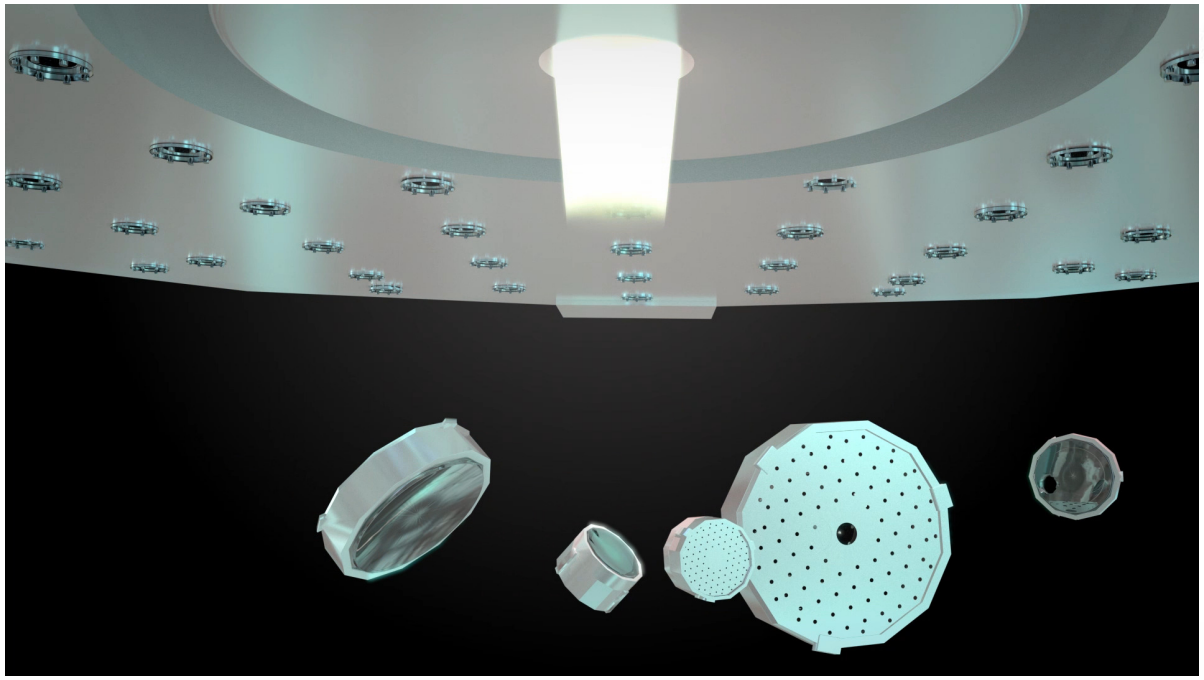
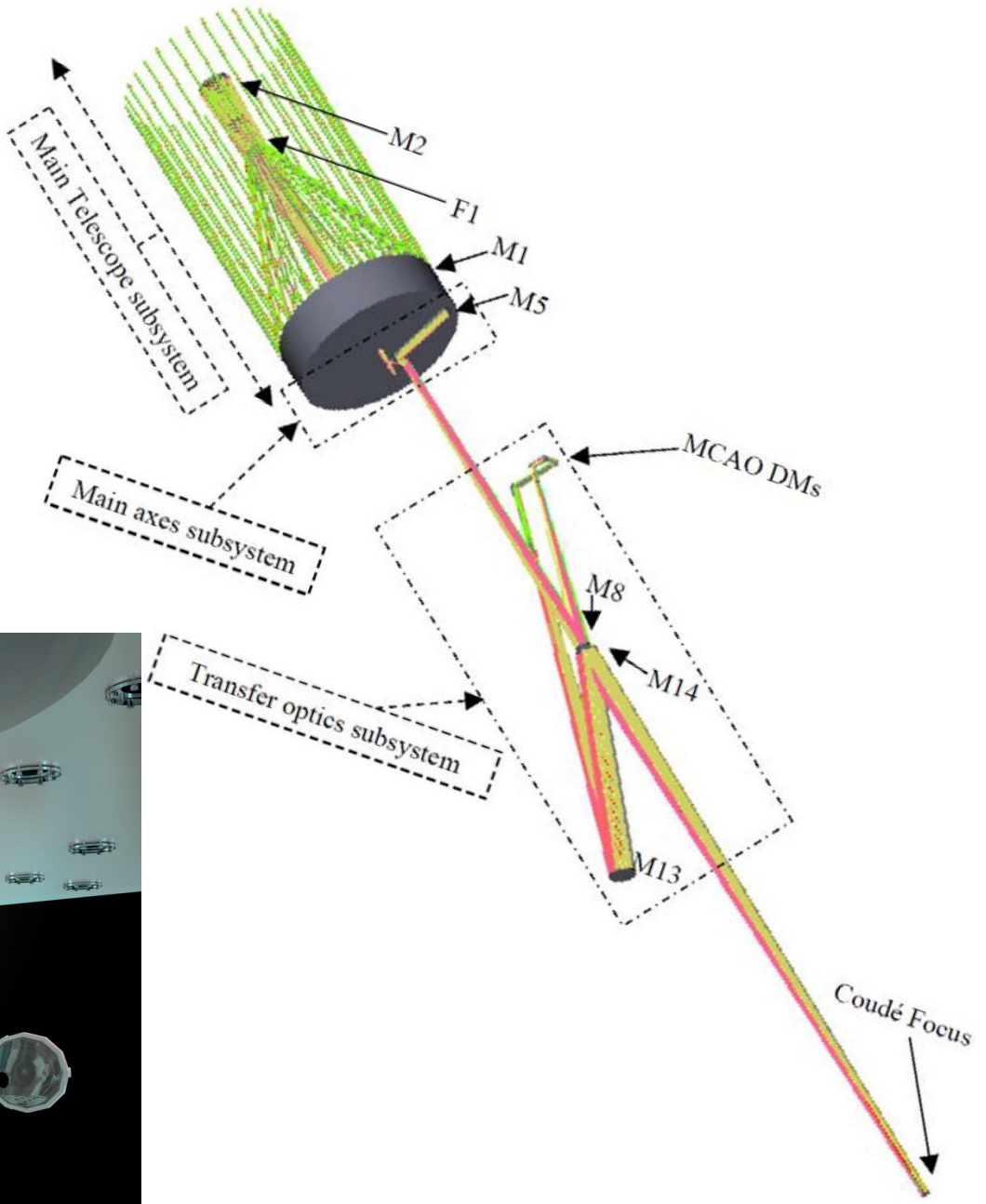


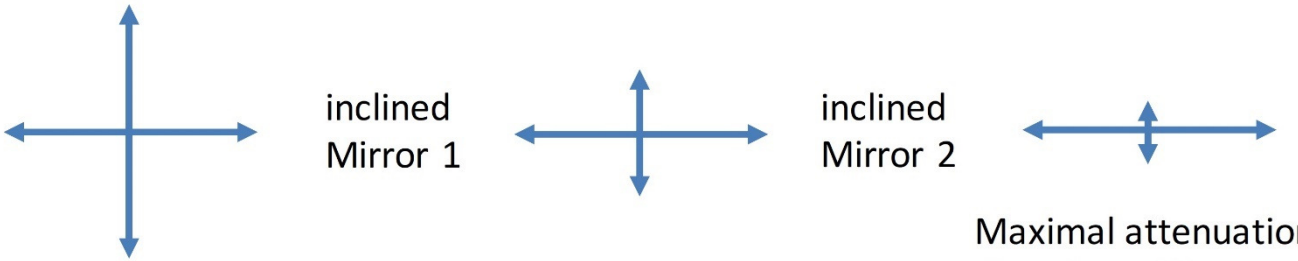


EST: telescope design

- EST – polarimetrically compensated telescope
- Muller matrix, M_{est}, independent of time (= unity) and independent on wavelength
  - M(M1) = M(M2) = unity matrix, since axially symmetric

$$\begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix}_{\text{obs}} = \underbrace{\begin{pmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{pmatrix}_{\text{Muller}}}_{M_{\text{telescope}}(t) = M_{\text{M1}}(t) * M_{\text{M2}}(t) * \ldots * M_{\text{Mn}}(t)} * \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix}_{\text{sun}}$$

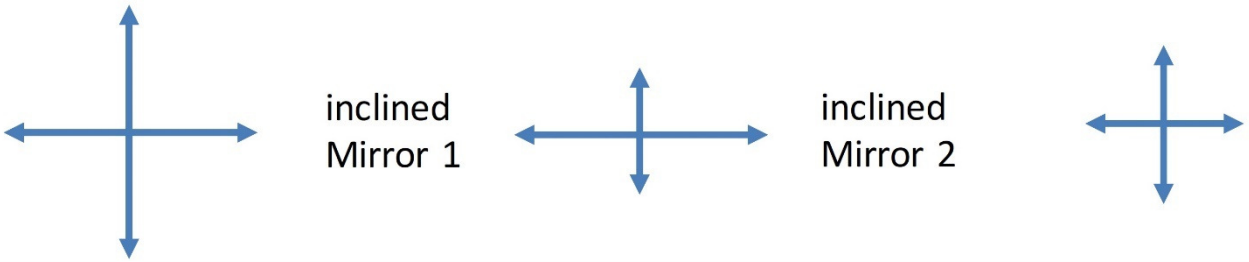
Careless configuration of two subsequent mirrors:

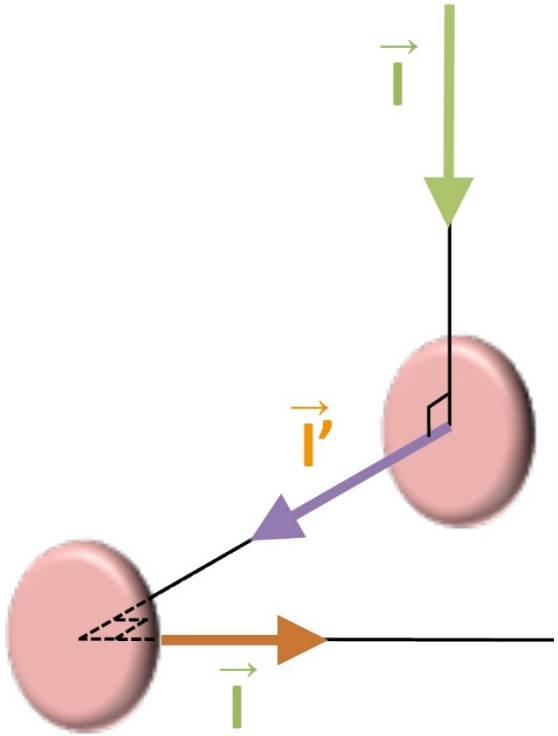


Maximal attenuation of one direction of linear polarisation:

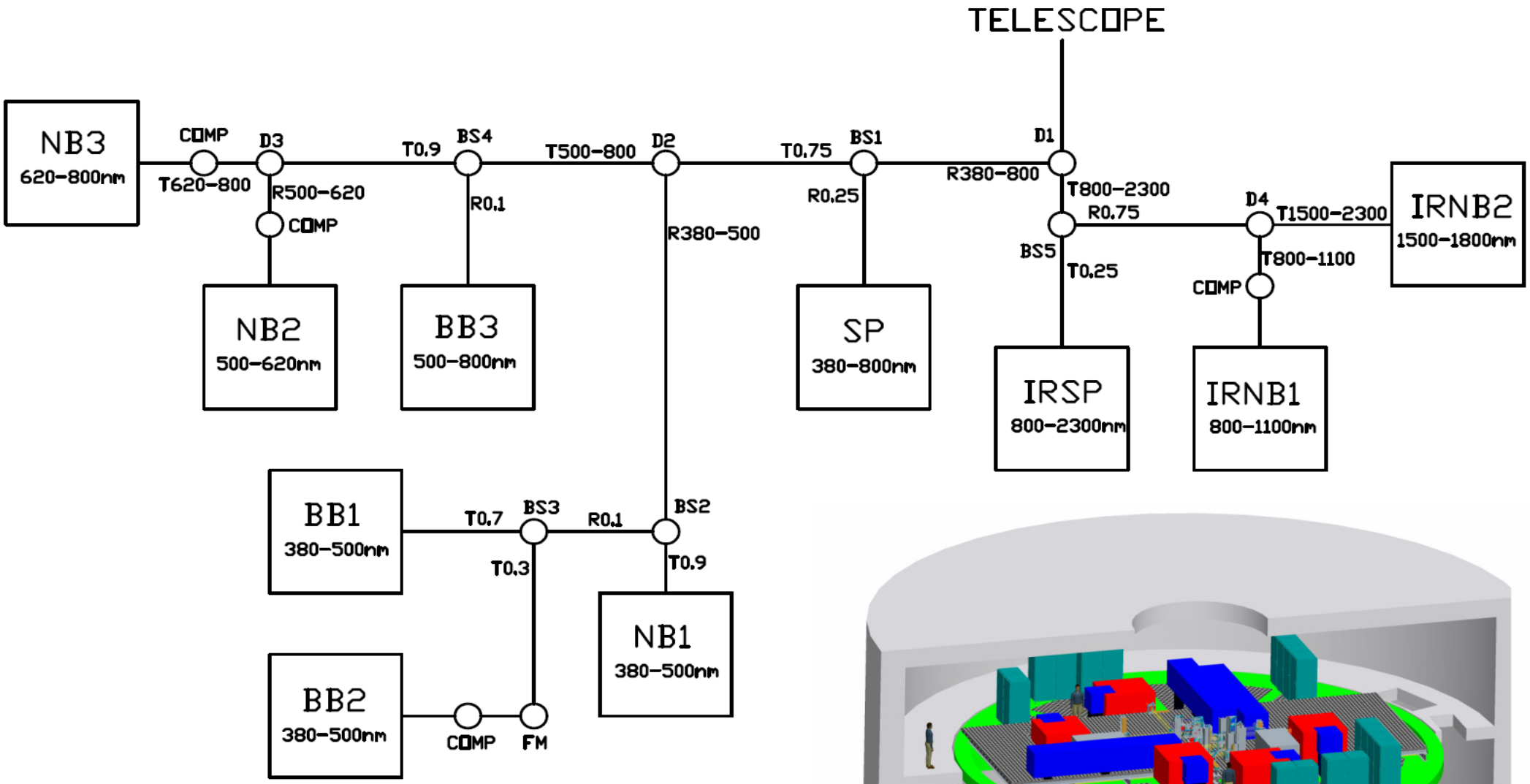
- increase of noise!
- loss of sensitivity!

Compensated design in EST:





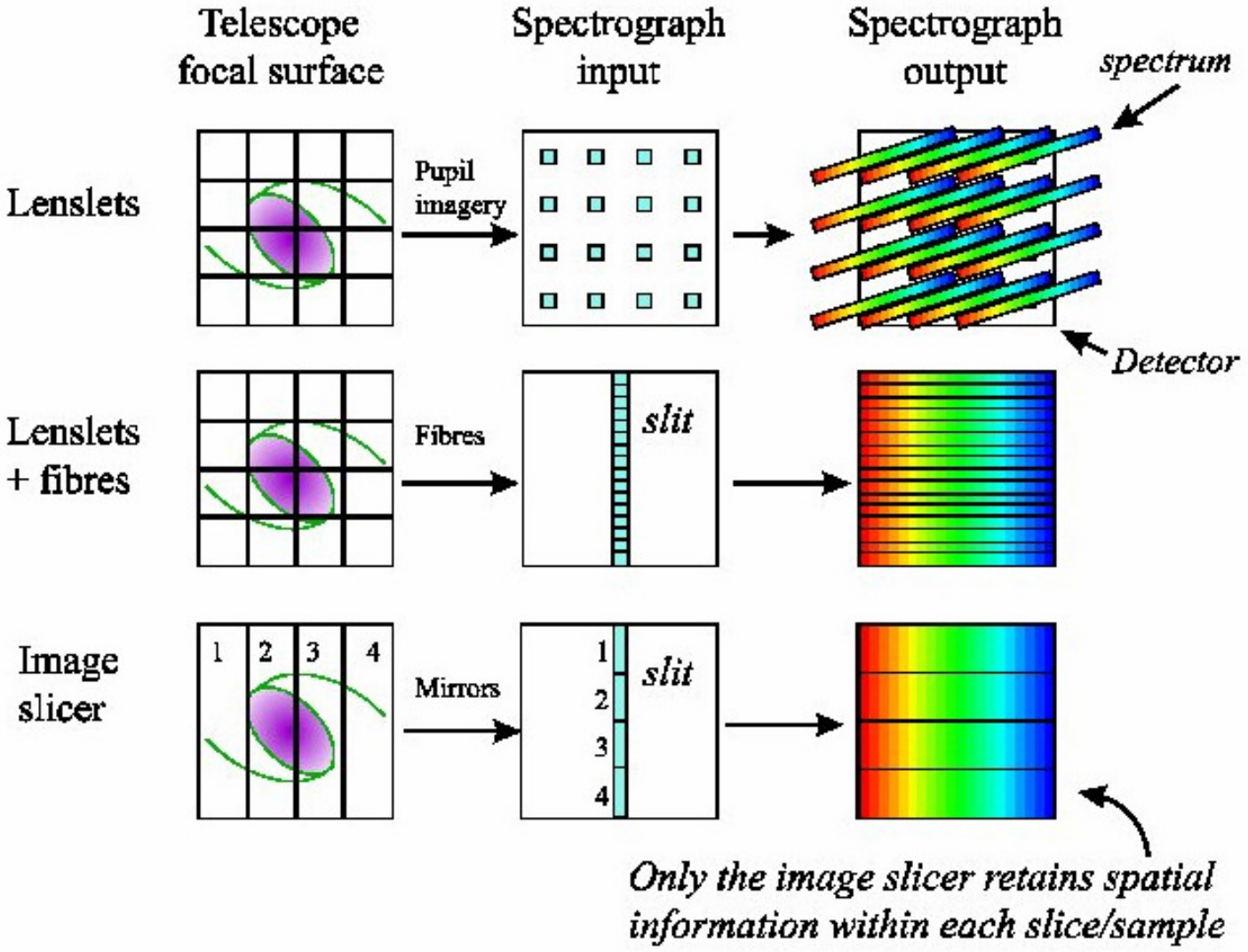
EST: instruments and light distribution



- broad band imagers
- narrow-band tunable imagers
- grating spectropolarimeters

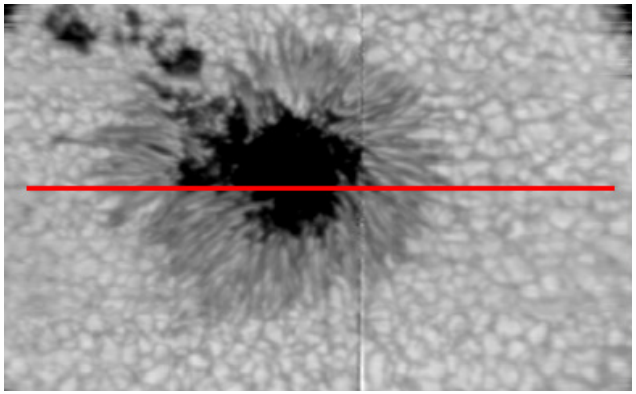
EST: integral field spectroscopy

- image slicer (Calcines et al. 2014), IAC
- microlenses (van Noort et al., in prep.), MPS
- fibers (Schad et al., 2014), NSO (for DKIST, DL-NIRSP)

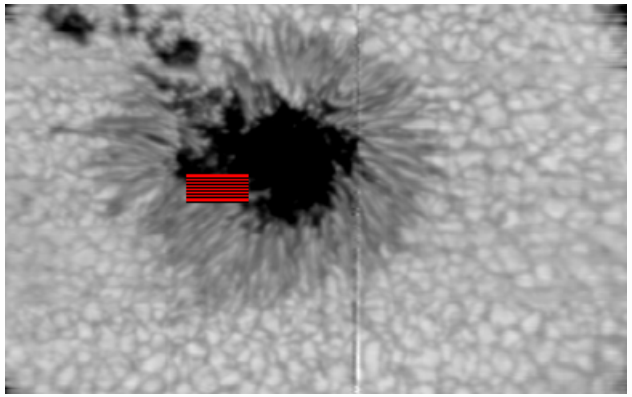


EST: image slicer

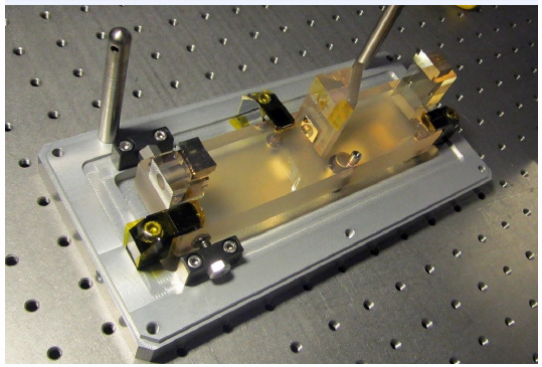
- prototype image slicer developed for GREGOR

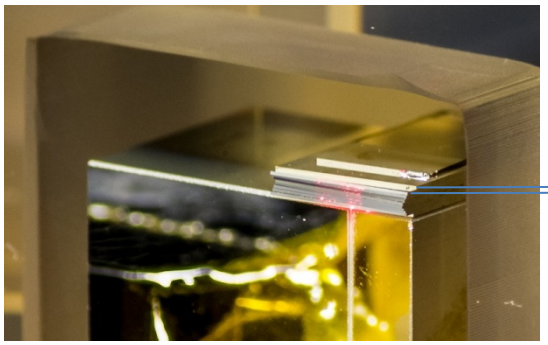


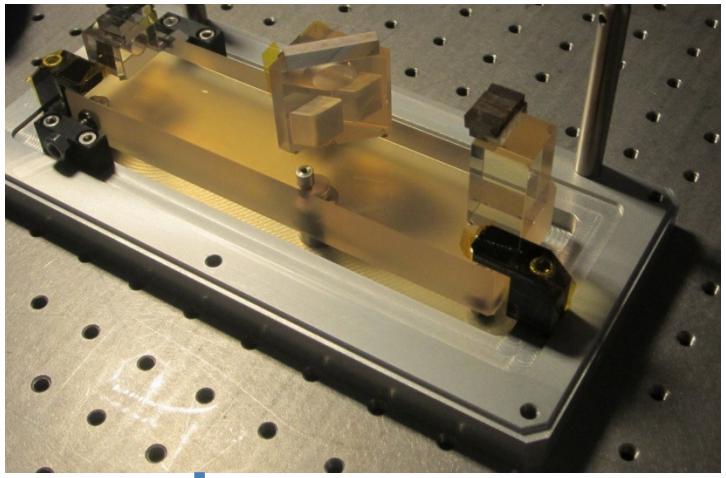
64” × 0.27”

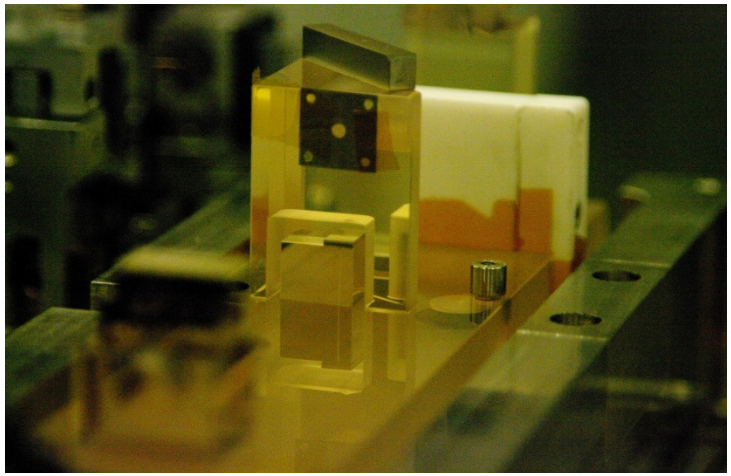


6” × 3”



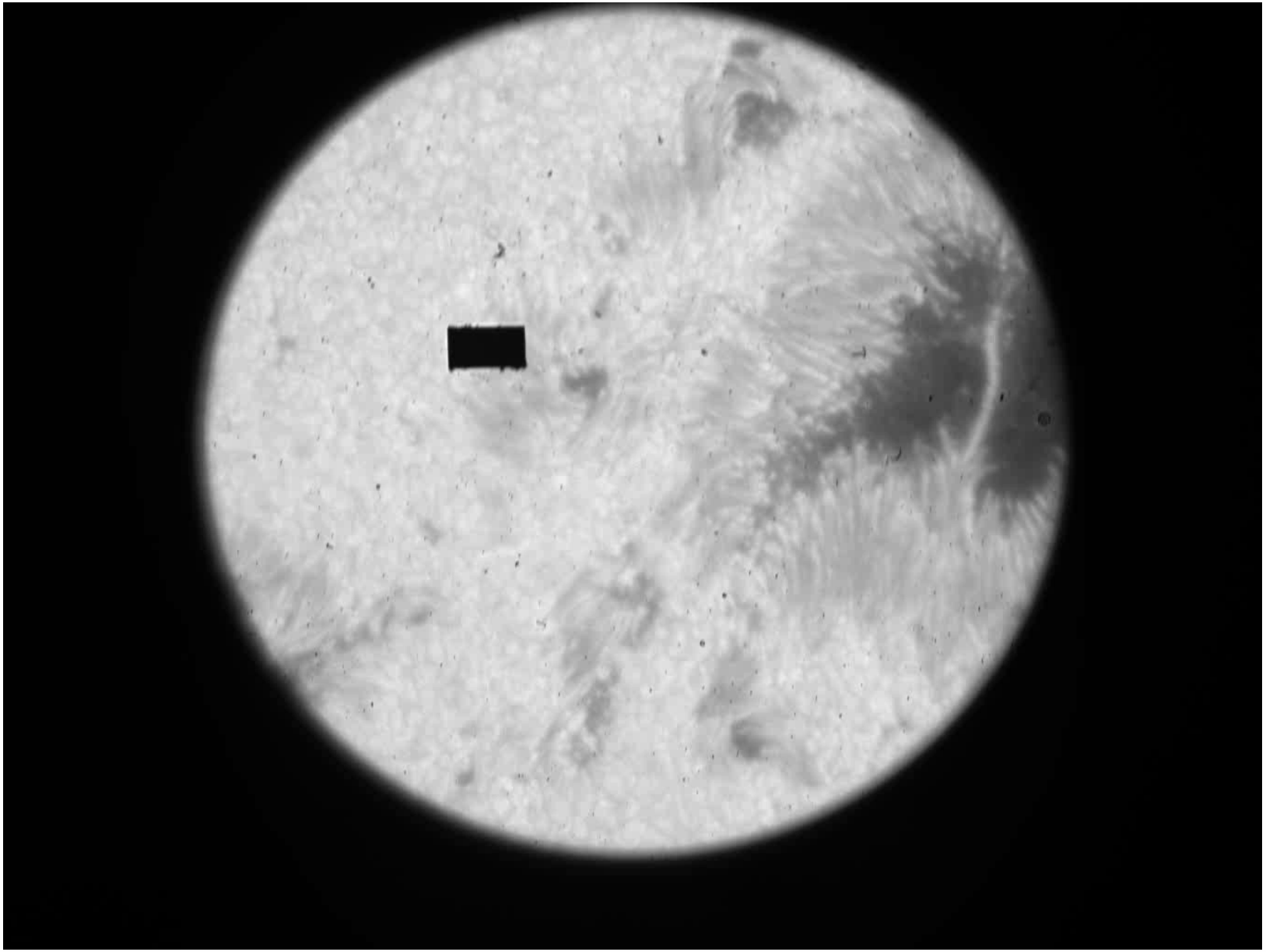




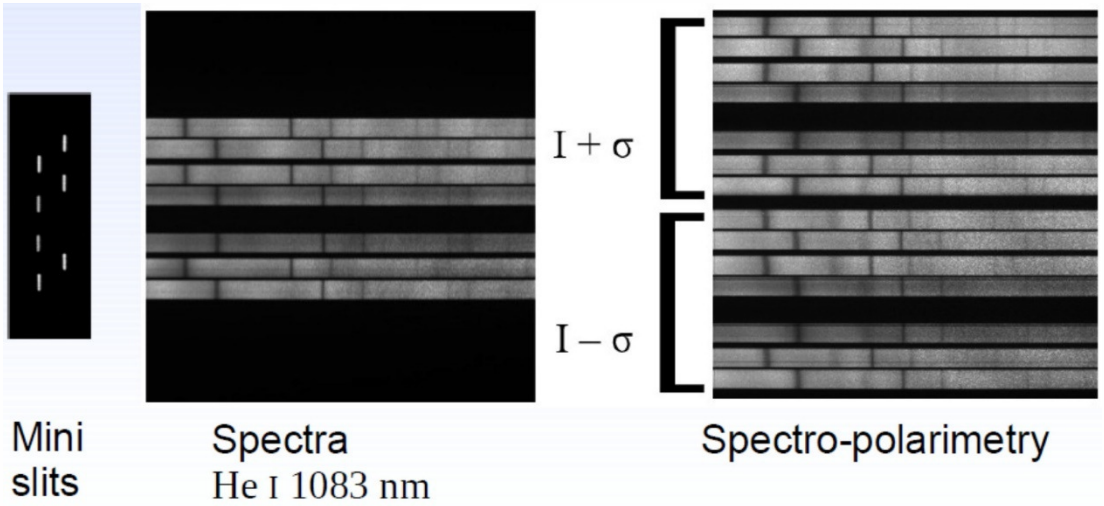


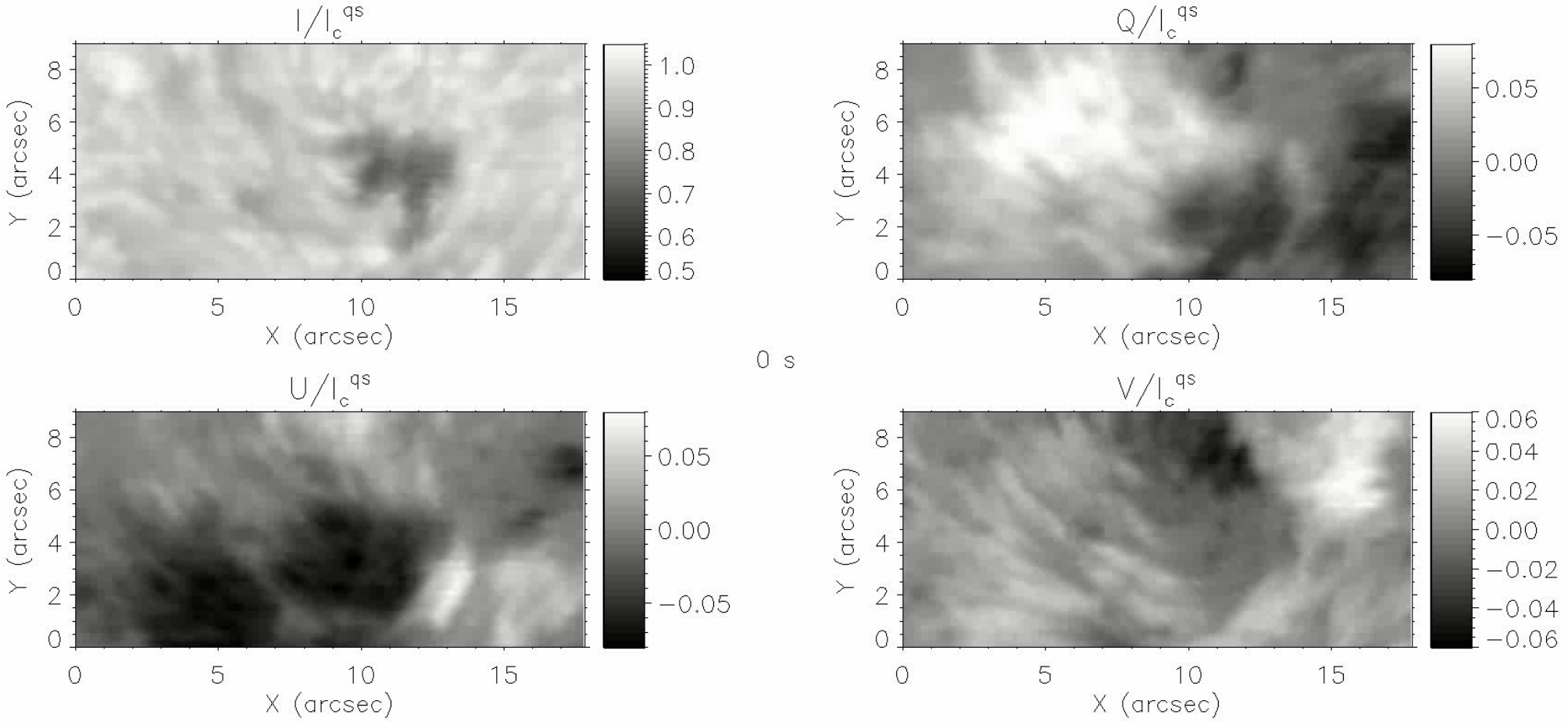
100 µm

EST: image slicer

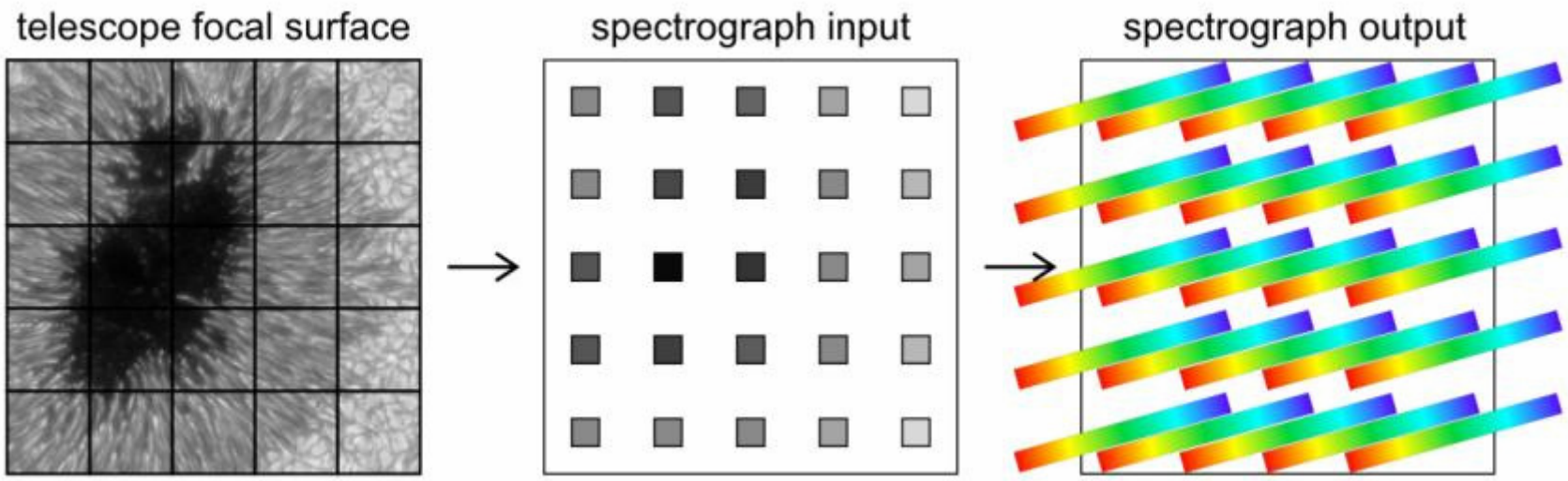


EST: image slicer



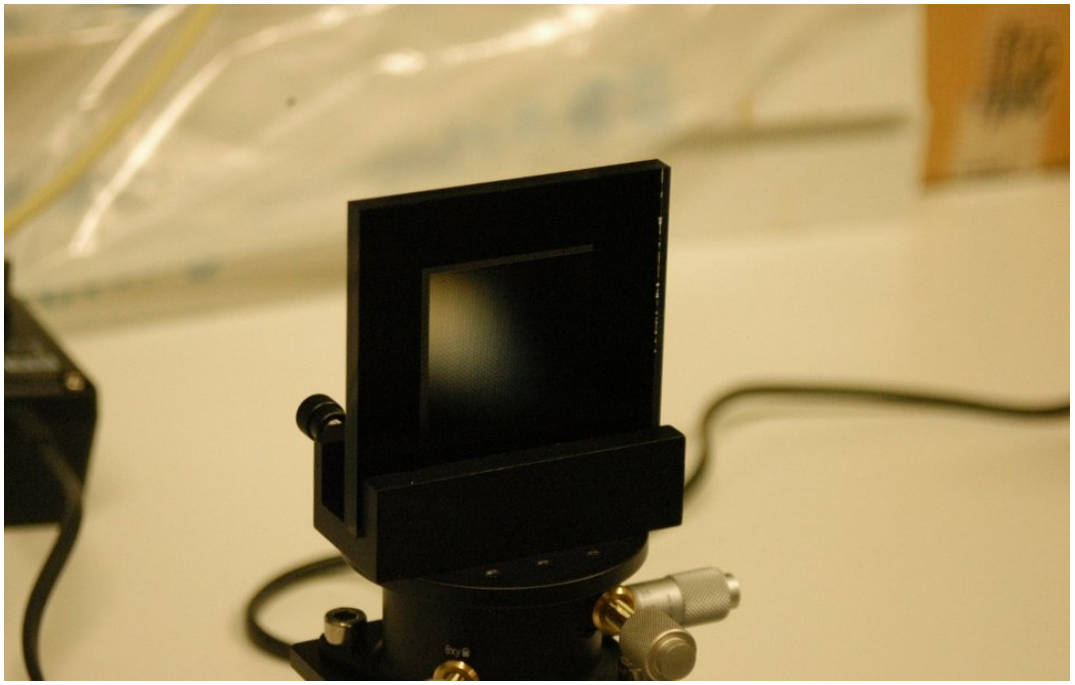


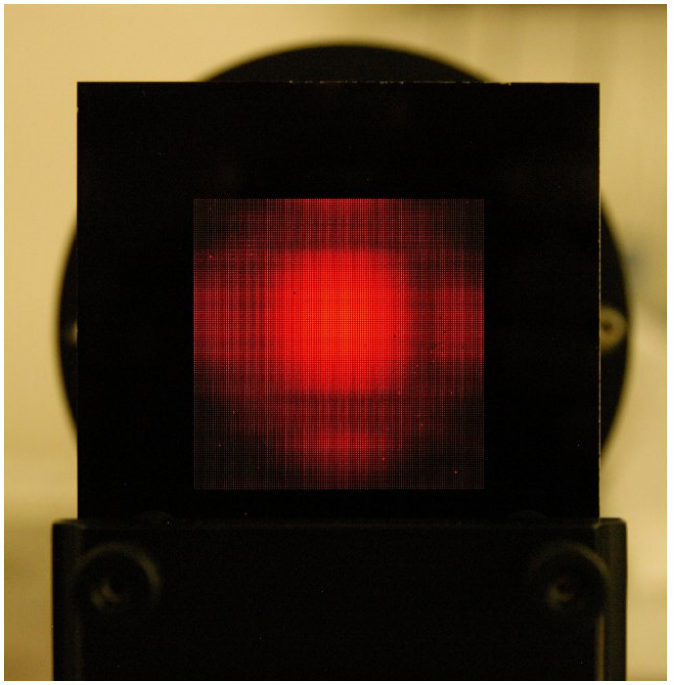
EST: microlenses



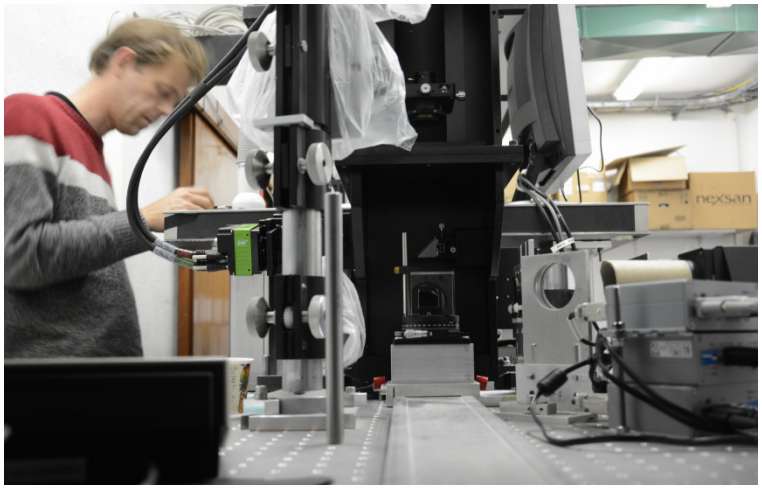
- make space for spectral dimension by “shrinking” pixels
- disperse at a small rotation angle to the pixel grid
- truncate using a narrow prefilter to avoid overlap
- 3D cube recorded in a single exposure
- single microlens array does not work (Suematsu@DST, stray-light issues)
- second microlens array needed to image pupil on grating
- straylight mask on second array
- two sides of single substrate to keep alignment

EST: microlenses



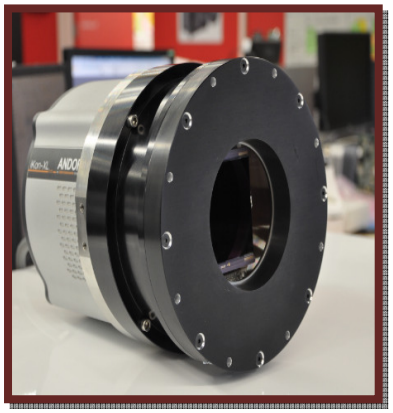


- made by Fraunhofer Inst. for Applied Optics in Jena
- 6.35 mm plate of SiO 2 (maintains alignment very well)
- 128x128 elements (42x42mm)
- front to backside alignment ≤ 1µm
- □20 outliers (□0.1%)
- tested at TRIPPEL@SST

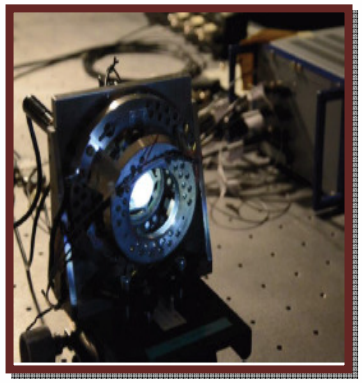


EST: instrumental developments

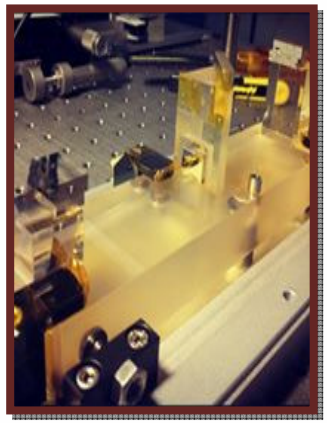
Boosting **new generation of detectors**:
large format
high precision
low noise.

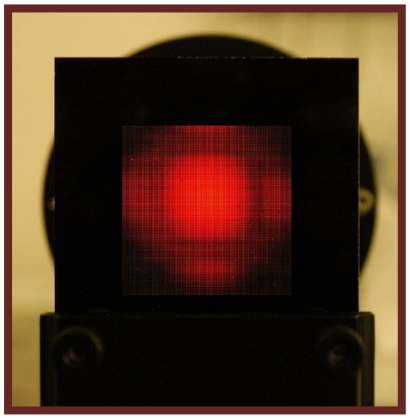


Development of **large format liquid-crystal modulators (LCVR)**



Development of a large **Fabry-Perot prototype** for a high mechanical stability and high quality control of the parallelism of the etalon plates.





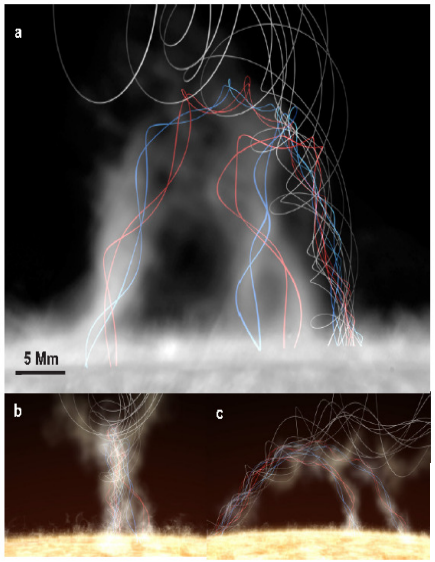
New techniques for **2D solar spectro-polarimetry**:
image slicers
microlens arrays

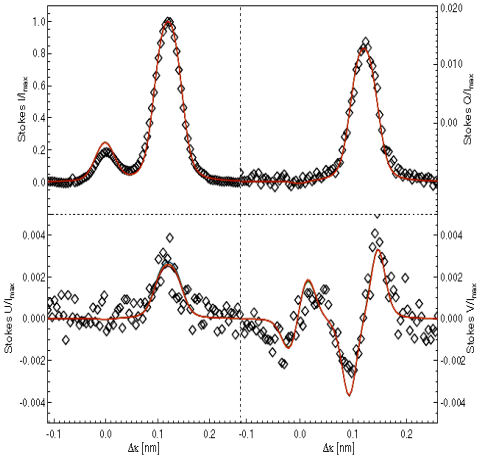
EST main science questions

- How do magnetic fields emerge into the surface and evolve?
- How is the energy transported form photosphere to chromosphere?
- How is the energy released in the upper atmosphere?
- Why does the Sun have a hot chromosphere?
- Wave propagation from the photosphere to chromosphere
- Dynamics of large-scale magnetic structures (sunspots, ARs)
- Polar magnetic fields
- Magnetic fields in the chromosphere (spicules, prominences)
- Energy disipation in the chromosphere

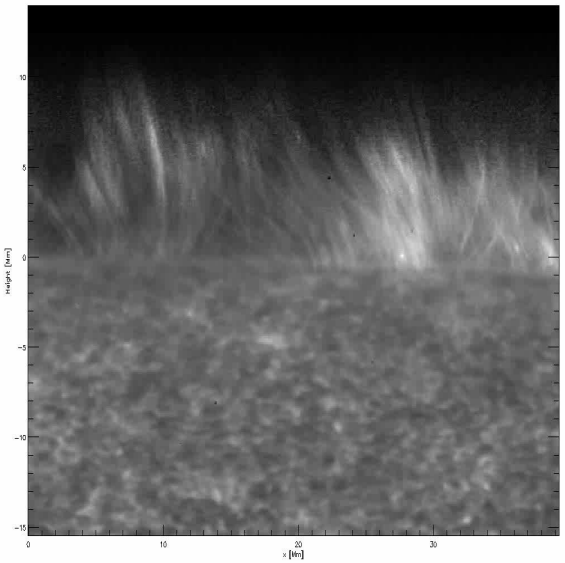
- Main science goal: unveil the magnetic coupling of the solar atmosphere from the deep photosphere up to the upper chromosphere

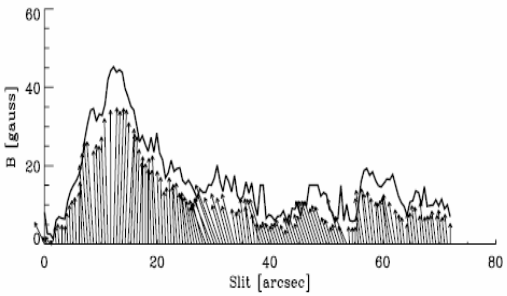
→ instruments optimized for chromosphere and photosphere





Martínez González et al. (2015, 2016)

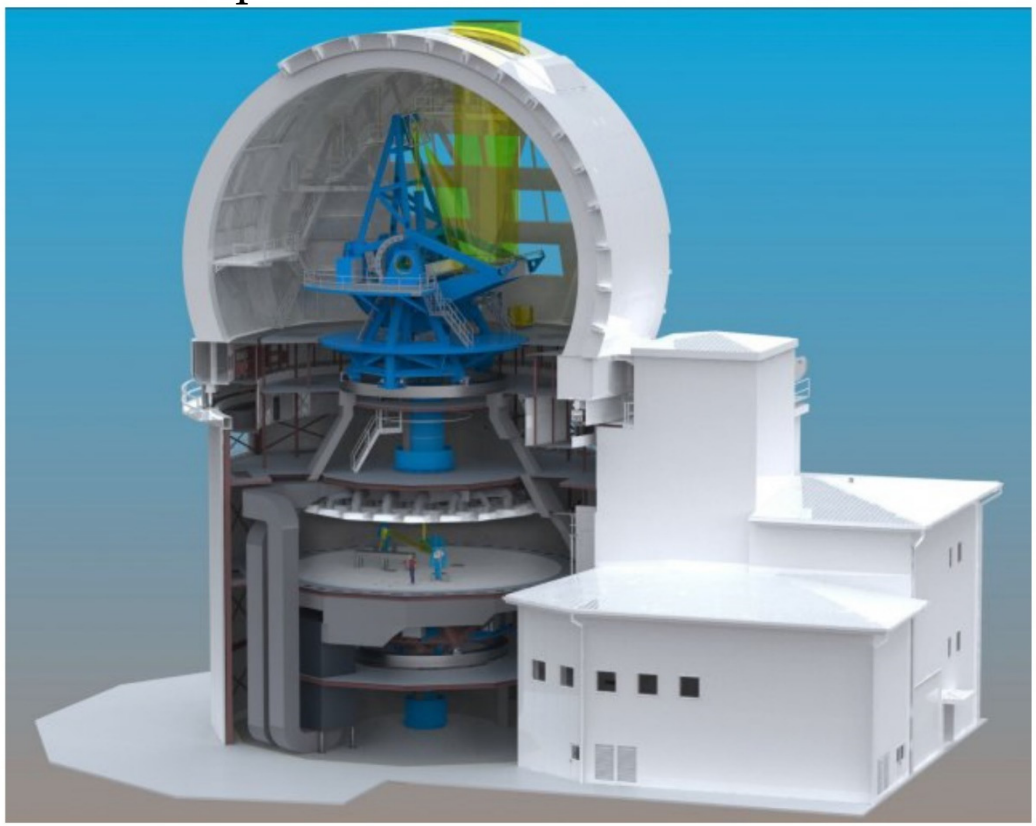


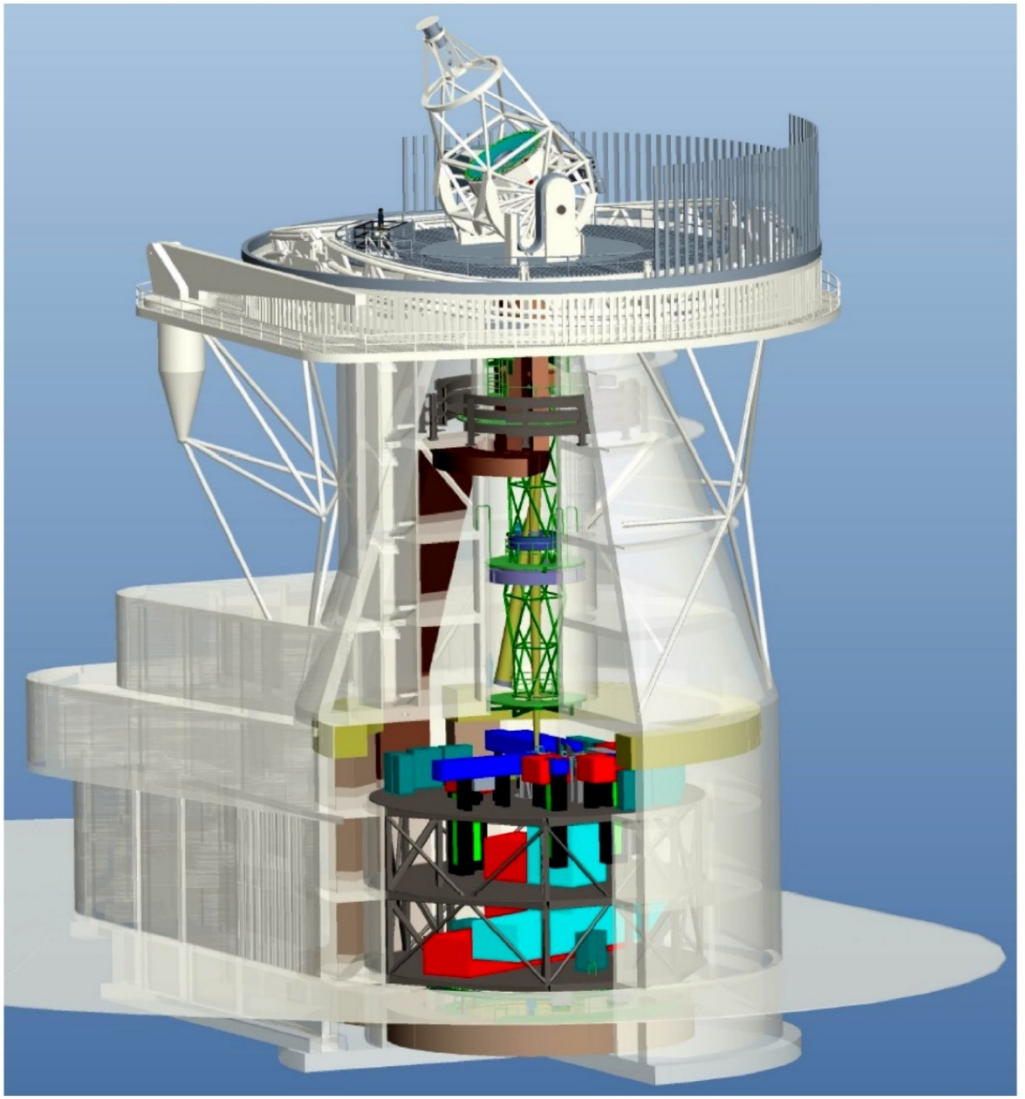


Centeno et al. (2010)

EST and DKIST

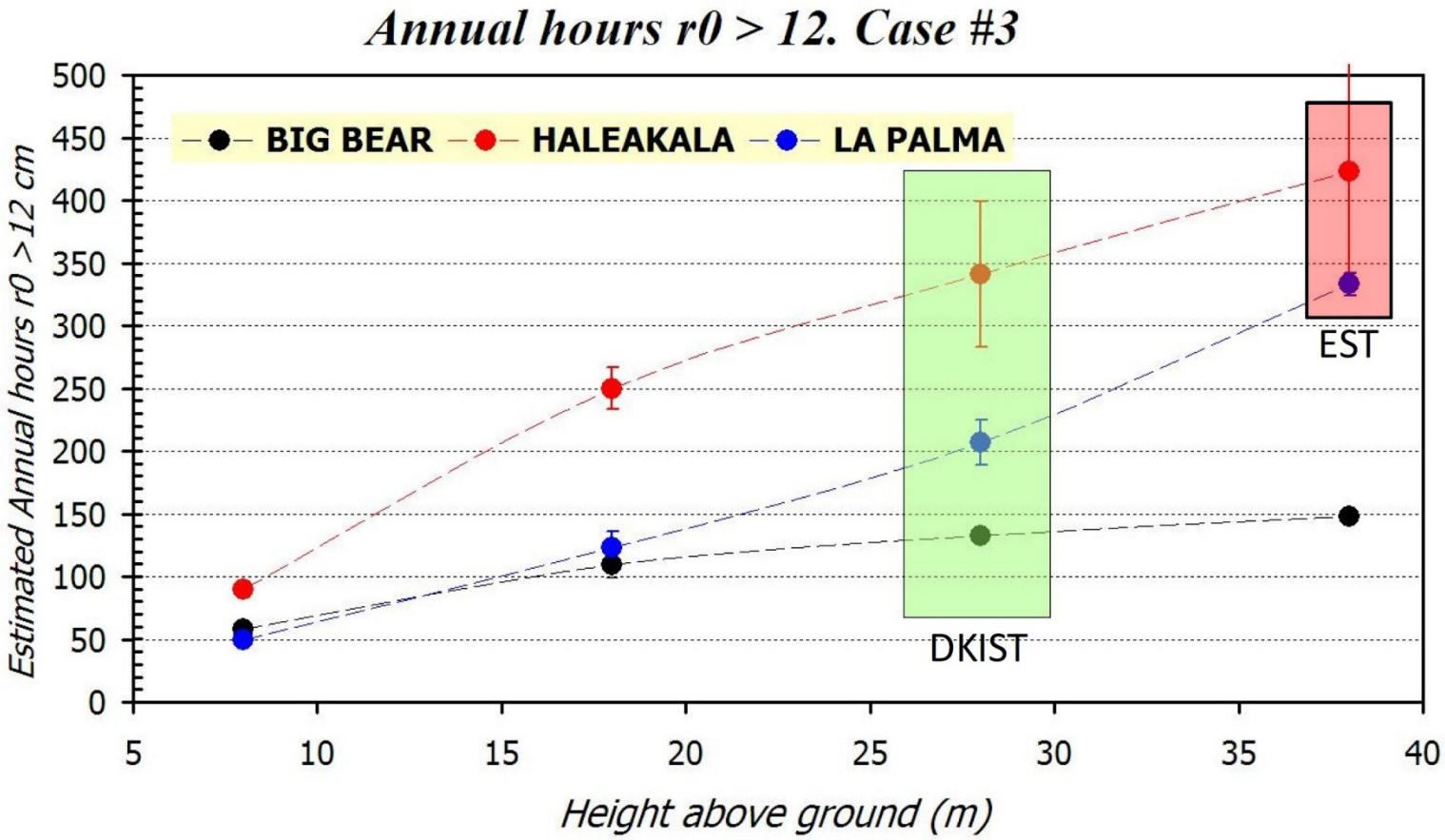
- dome size of 4m off-axis corresponds to 8m on axis
  - EST can be built higher above ground
  - seeing dominated by ground layer, improvement with height
- DKIST Muller matrix is time dependent
  - M1 and M2 are difficult to calibrate and their Muller matrices are time dependent
  - accuracy and sensitivity
    - Muller matrix determines accuracy
    - sensitivity is ability to measure polarisation
    - EST is potentially more accurate than DKIST
  - DKIST polarimetric calibration is much more involved, but in principle possible!





EST and DKIST

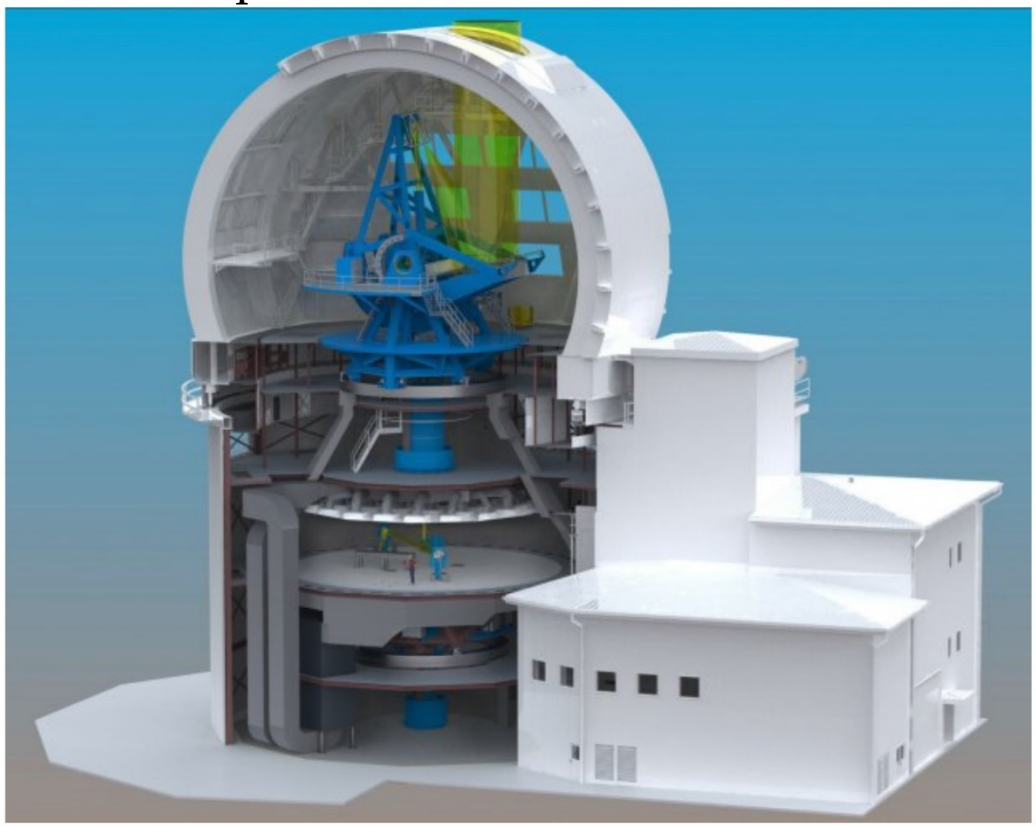
- dome size of 4m off-axis corresponds to 8m on axis
  - EST can be built higher above ground

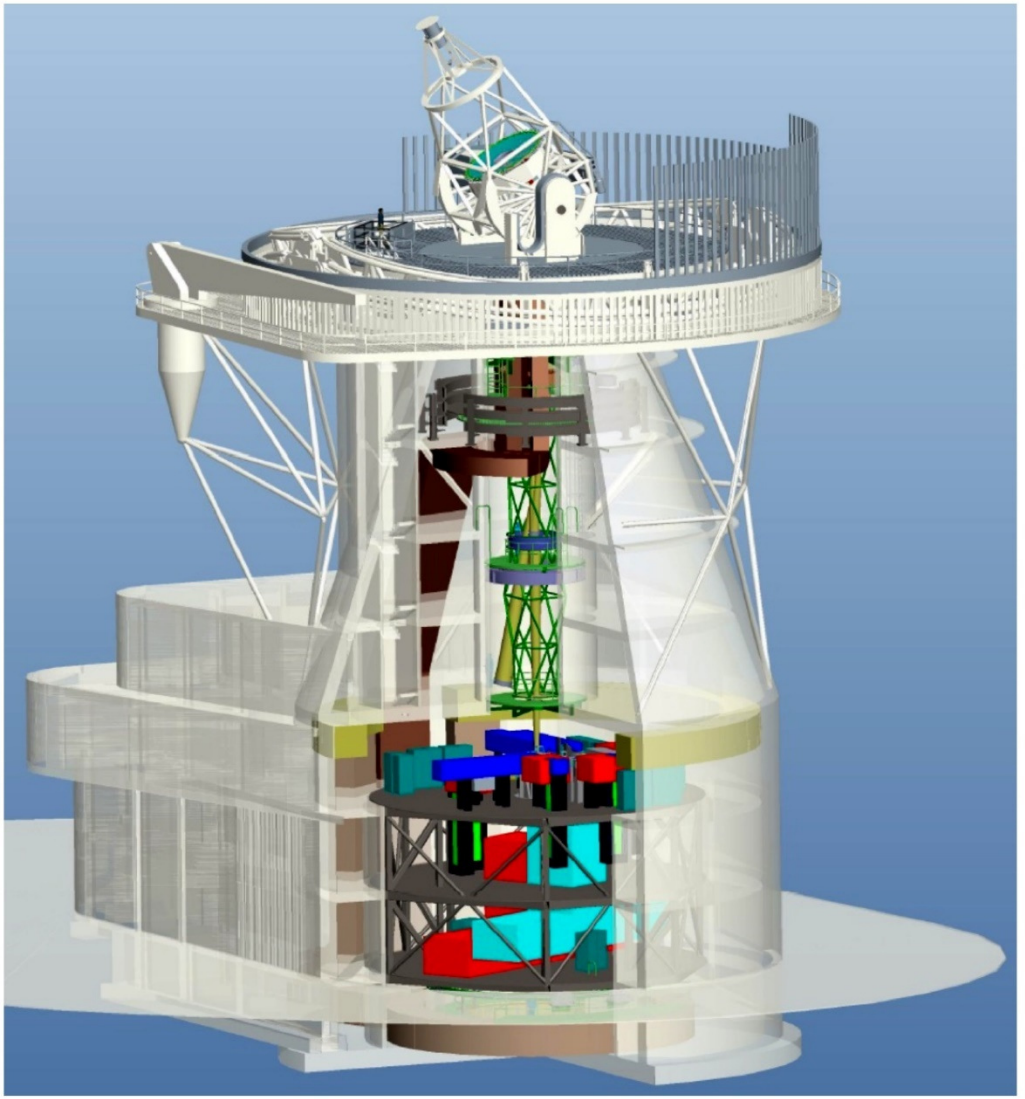


Annual hours with the Fried parameter r0 being larger than 12cm versus height above ground for Big Bear (black), Haleakala (red), and La Palma (blue). DKIST will be 28m above ground (green box), and EST will be at 38m (red box). (from ATST site survey working group final report)

EST and DKIST

- dome size of 4m off-axis corresponds to 8m on axis
  - EST can be built higher above ground
  - seeing dominated by ground layer, improvement with height
- DKIST Muller matrix is time dependent
  - M1 and M2 are difficult to calibrate and their Muller matrices are time dependent
  - accuracy and sensitivity
    - Muller matrix determines accuracy
    - sensitivity is ability to measure polarisation
    - EST is potentially more accurate than DKIST
  - DKIST polarimetric calibration is much more involved, but in principle possible!

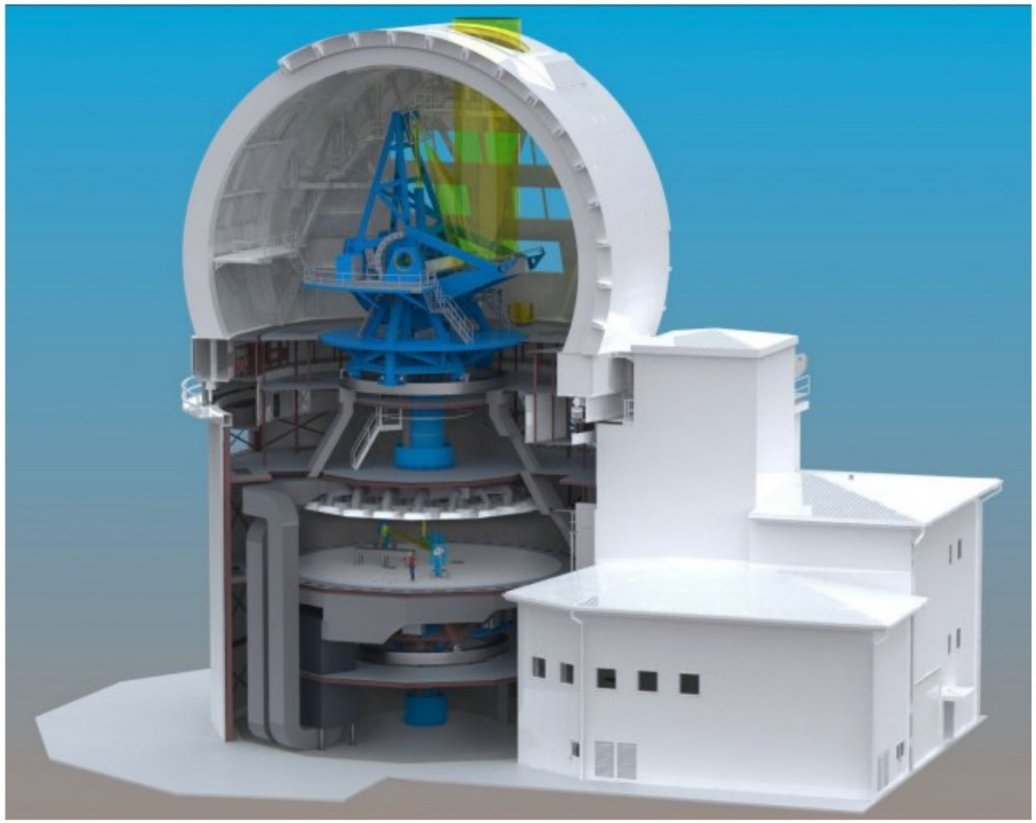


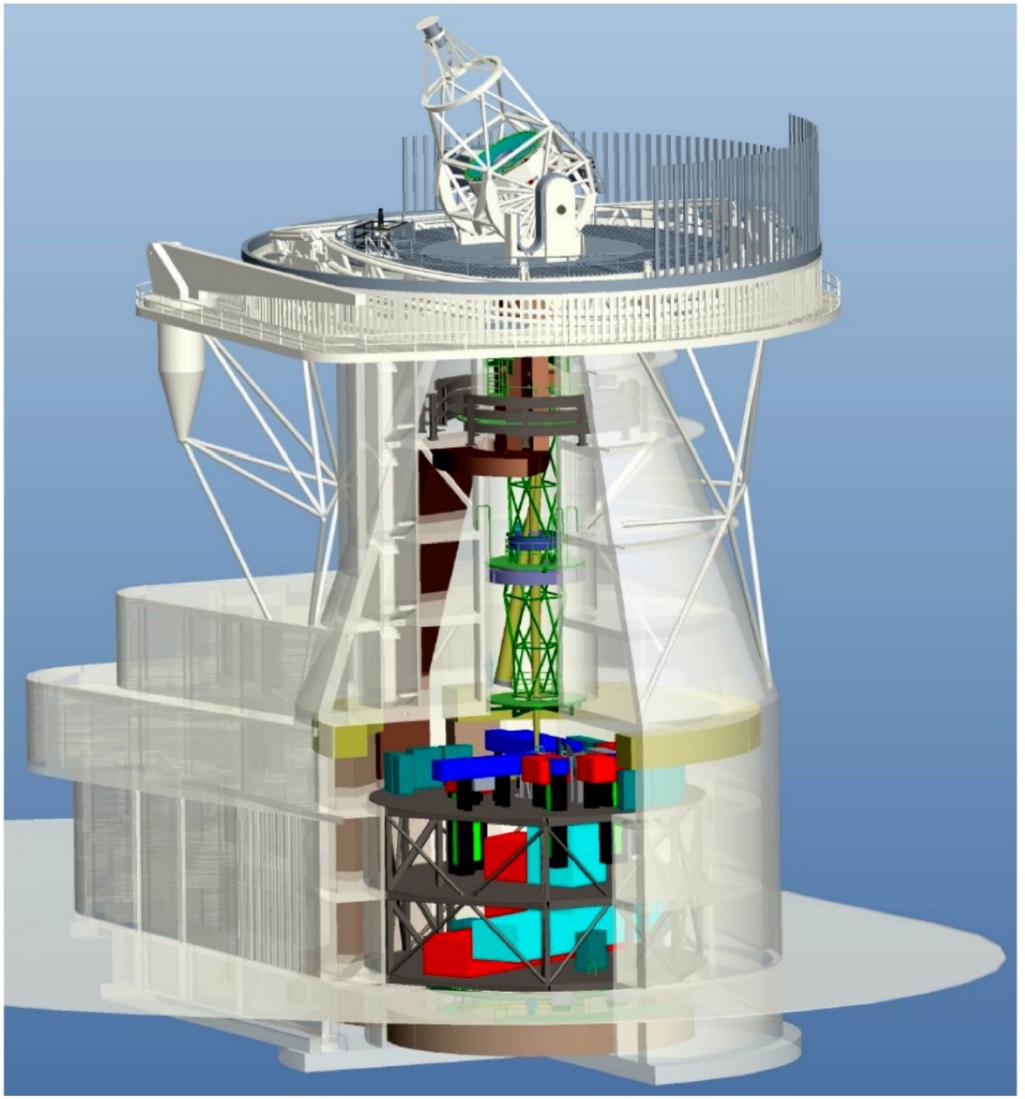


EST and DKIST

- Europe has a large young community of solar researchers
- European expertise is crucial for success of DKIST
  - many DKIST experts were educated in Europe

- **Europe needs a next generation solar telecope → the EST**





EST complementarity with DKIST and Solar Orbiter

- high resolution, long-term studies become a reality → DKIST + EST (weather permitting!)
- imaging/spectroscopy of the TR and corona to constrain energy transport to the outer atmosphere (SO)
- out of ecliptic vantage points to constrain 3D structures; solar wind/energetic particle origin (SO)

Solar Orbiter (ESA/NASA)

DKIST (credit: NSO/AURA/NSF)

EST - European Solar Telescope

EAST
European Association for Solar Telescopes

- founded in 2007
- 17 member states

EST Design Study
(2008 - 2011)

SOLARNET
(04/2013 – 03/2017)

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

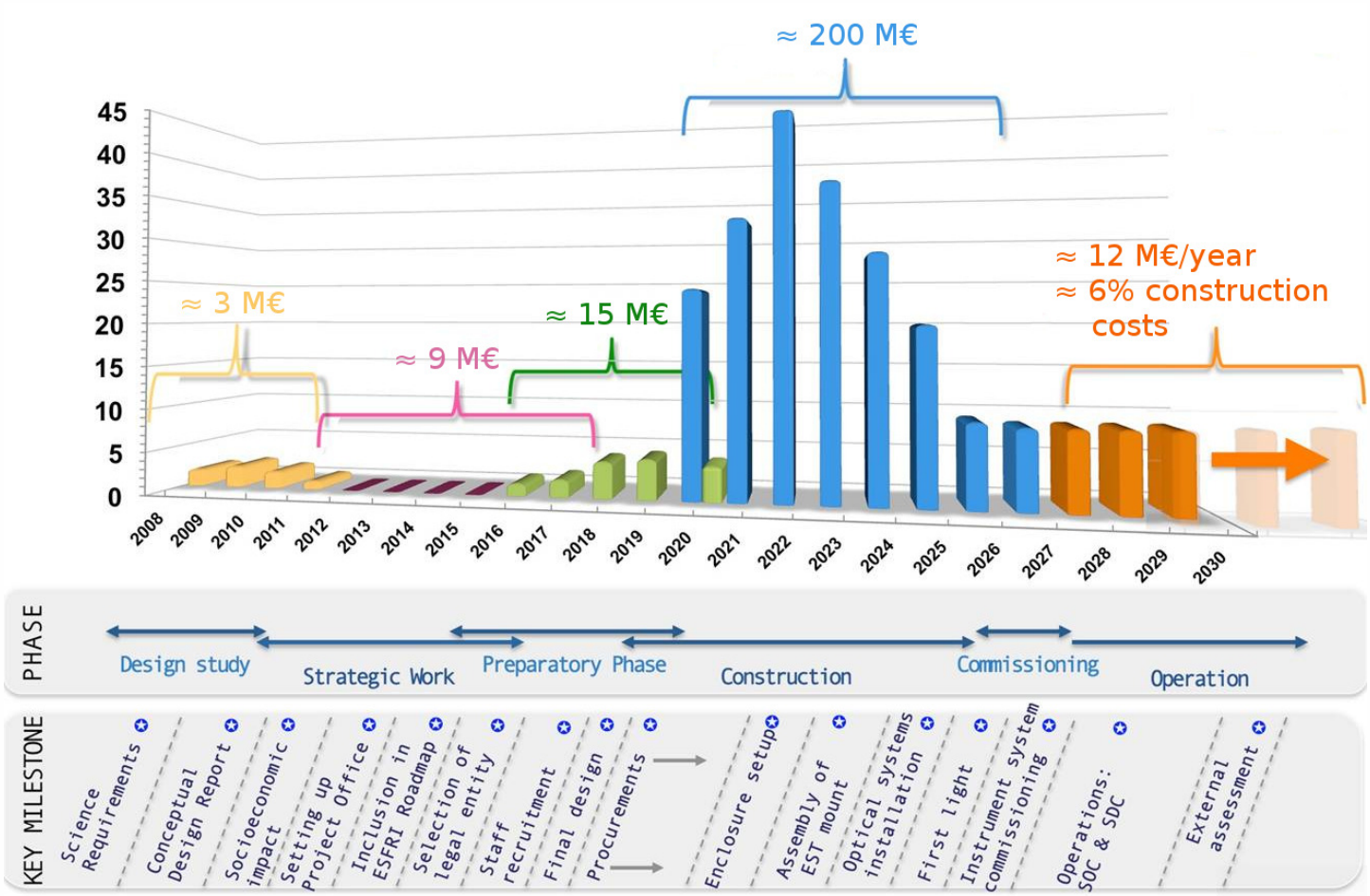
SOLARNET
applied: 2019 – 2022

PRE-EST
(04/2017 – 03/2021)

EST

ESFRI road map update 2016:
EST included as ESFRI project

EST - history and schedule

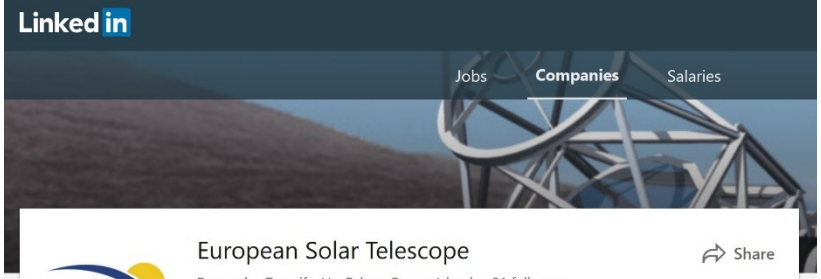


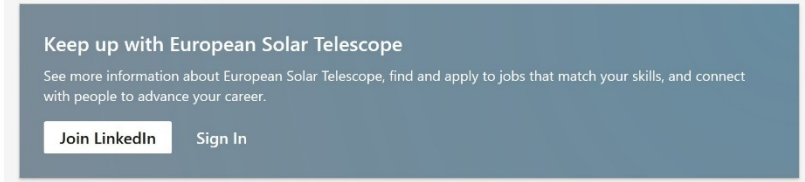
- EAST coordinated all the projects related to the advancement of the EST
- these projects were co-financed by EU with 16 M€
- addition of EST to the active project list of the ESFRI roadmap 03/2016

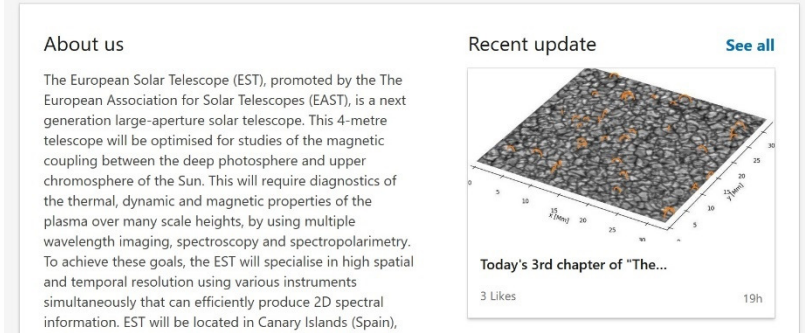
- Conceptual design study of EST, EC FP7 project, 02/2008 - 07/2011
- SOLARNET, EC I3 project, 04/2013 - 03/2017
- GREST, EC H2020 project, 06/2015 - 06/2018
- PRE-EST, EC H2020 project, 04/2017 - 03/2021

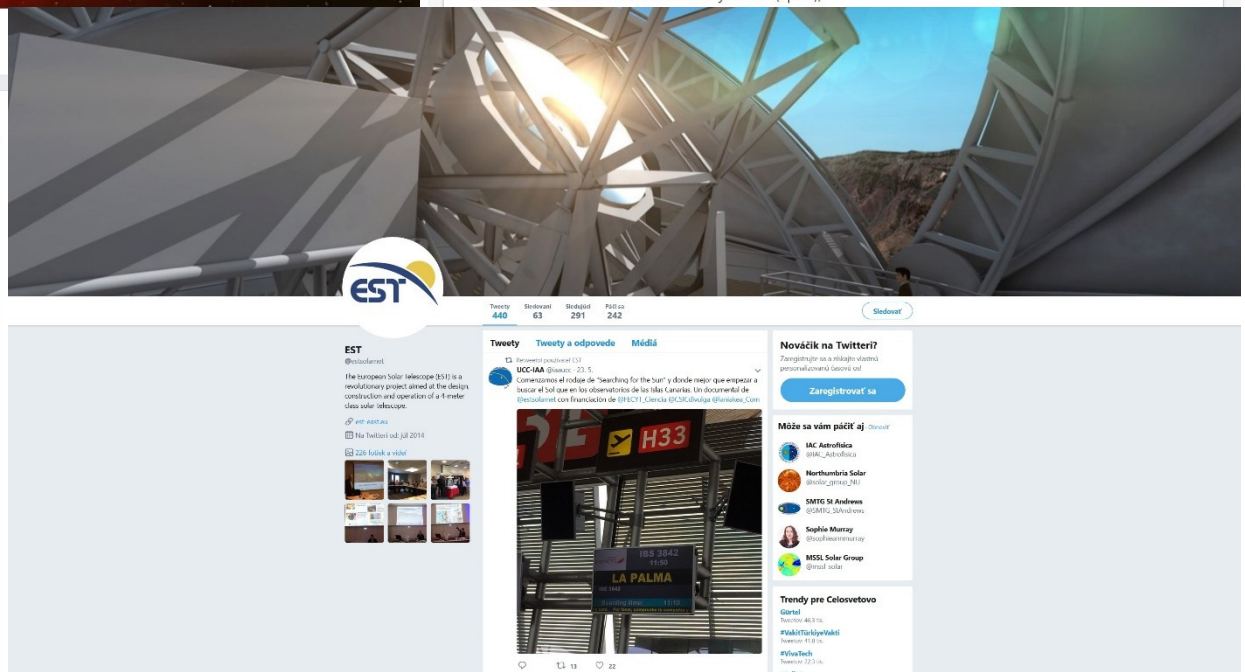
EST - community

- EAST for more info → follow the EST at social media
  - facebook: https://www.facebook.com/EuropeanSolarTelescope
  - twitter: https://twitter.com/estsolarnet
  - linkedin: https://www.linkedin.com/company/european-solar-telescope









Thank you for your attention