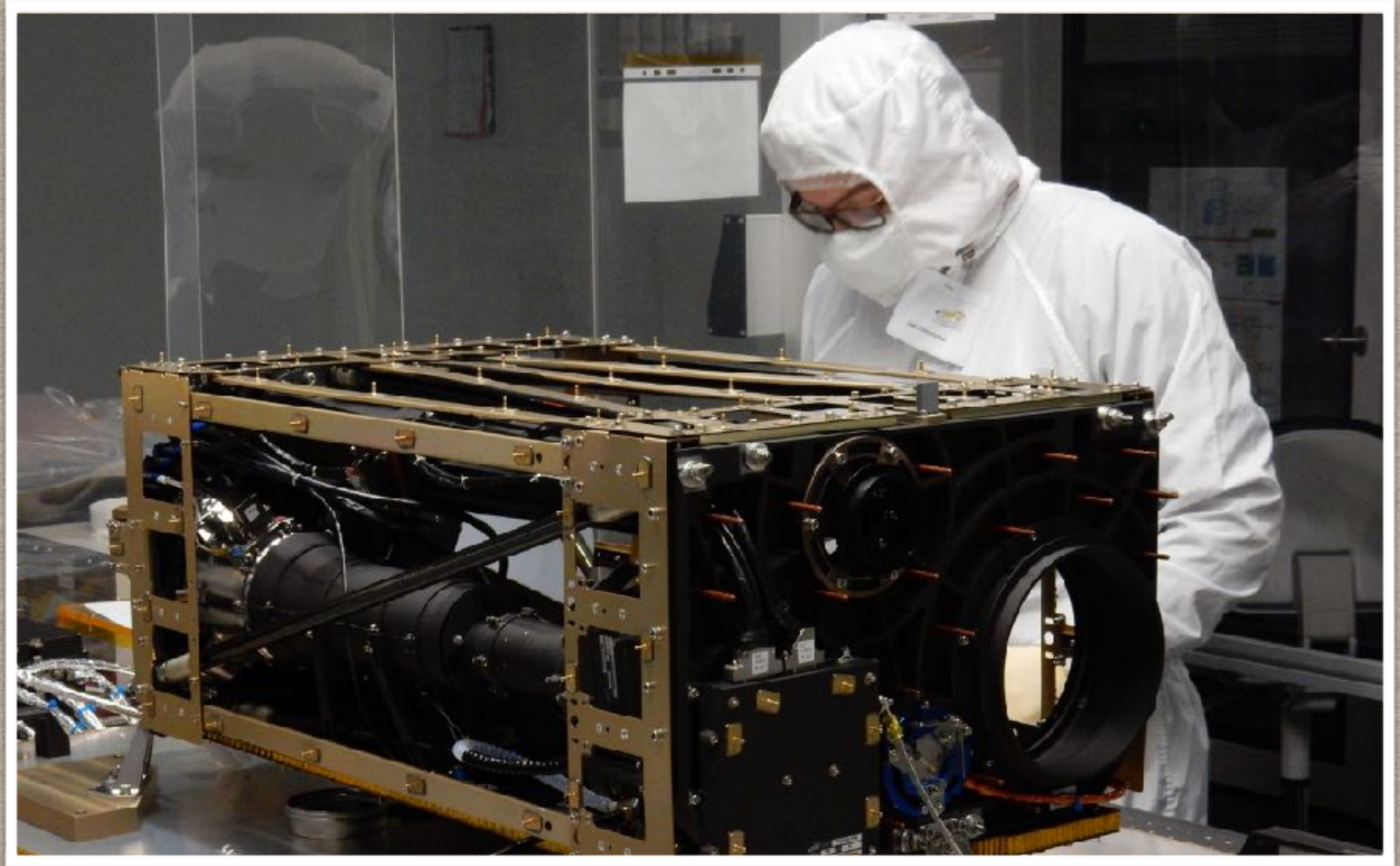
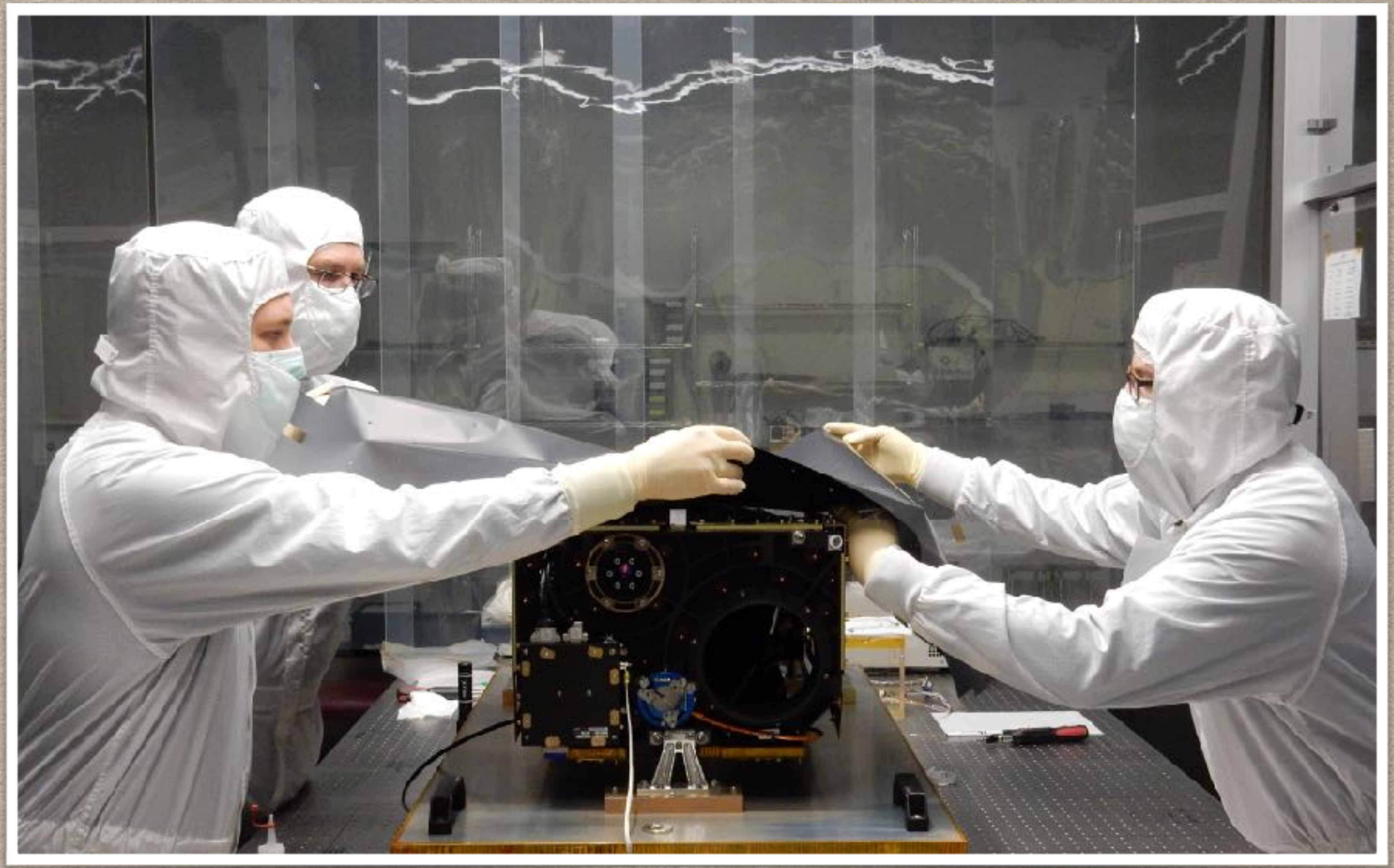


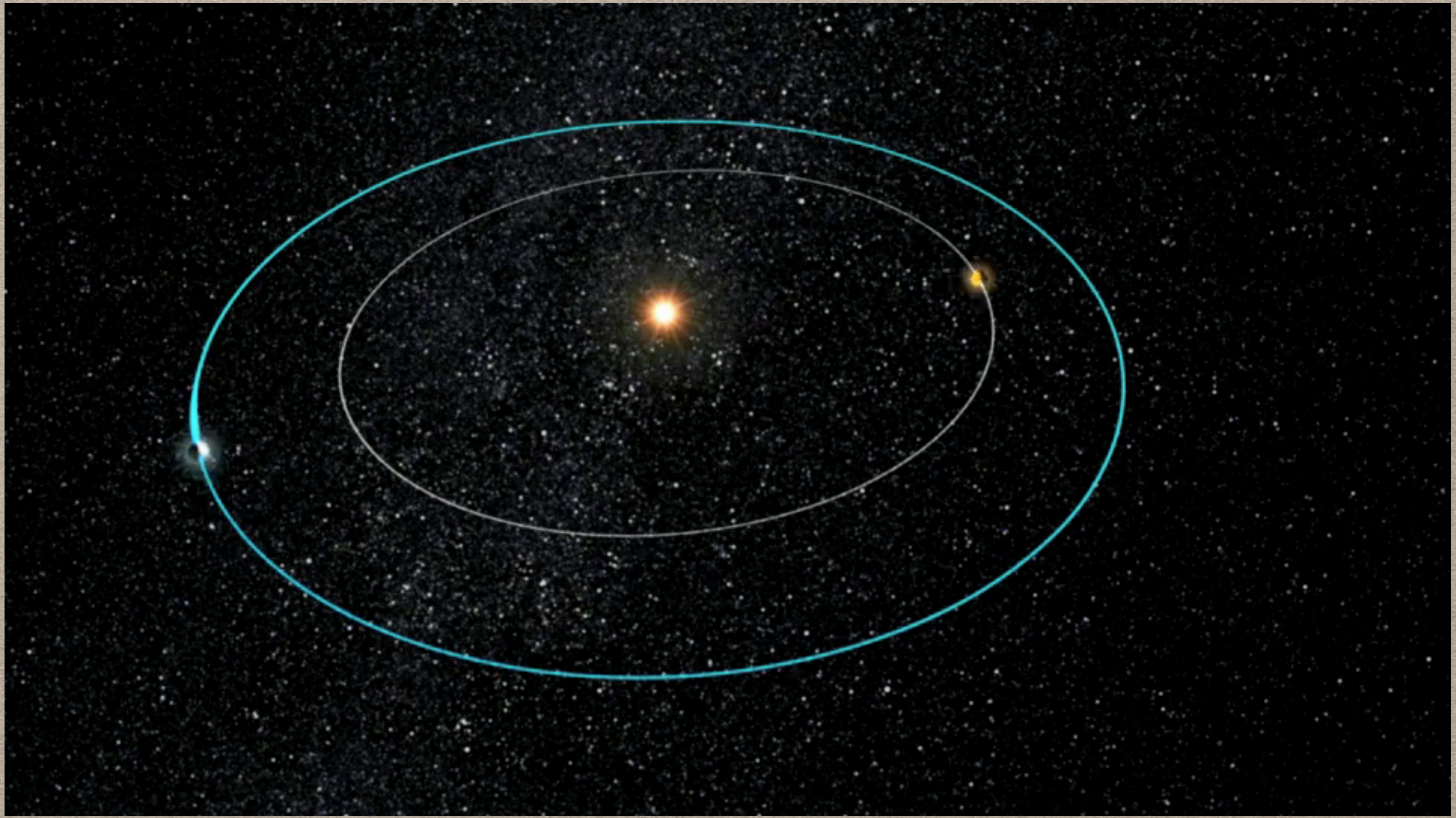


Solar Orbiter Polarimetric and Helioseismic Imager (SO/PHI)

Andreas Lagg and the PHI Team
MPI for Solar System research, Göttingen

The Solar Orbiter Mission

- last 2 days:
  magnetometer has high priority for L5 mission
- 2-viewpoint science:
  many parallels between SolO and L5



- SolO launch:
  October 2018
- 3-year cruise phase
- min. distance: 0.28 AU
- max latitude: 34°

Solar Orbiter Science Cases

1. How and where does the solar wind plasma and magnetic field originate in the corona?
2. How do solar transients drive heliospheric variability?
3. How do solar eruptions produce energetic particle radiation that fills the heliosphere?
4. How does the solar dynamo work and drive connections between the Sun and the heliosphere?

Significant PHI contribution

Polarimetric and Helioseismic Imager

PHI at a glance:

- Scans over magnetic sensitive photospheric absorption line (FeI 617.3nm)
- Narrow-band filtergrams at 6 spectral positions, 4 polarisation states

- On-board data processing:
  - data reduction (dark, flat, calibration)
  - retrieval of physical parameters (ME inversions)
  - lossless / lossy compression

Intensity | LOS-velocity | B-strength | B-inclination | B-azimuth

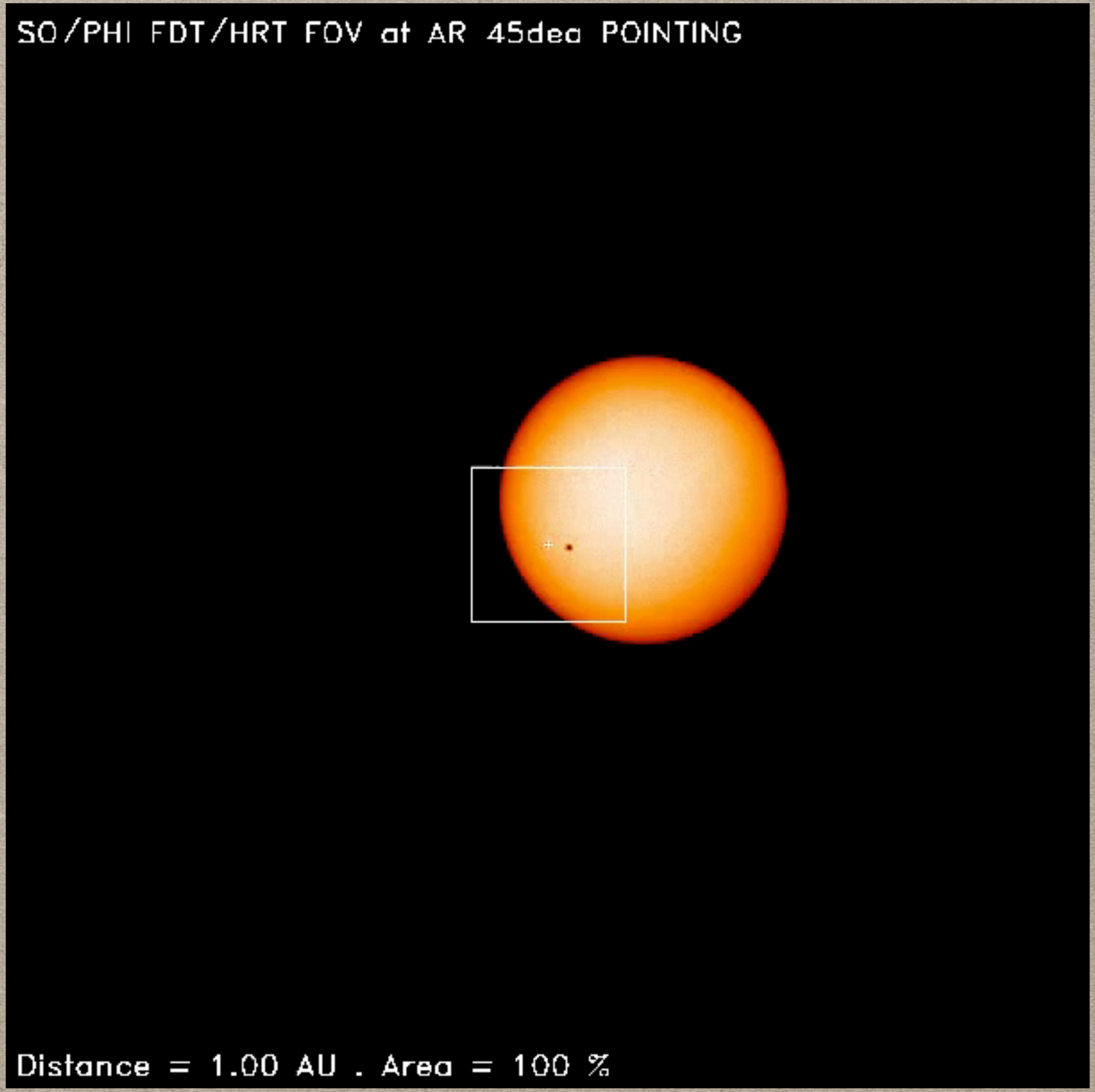
PHI stand-alone science:

- What is the nature of magnetoconvection?
- How do active regions and sunspots evolve?
- What is the global structure of the solar magnetic field?
- How strongly does the solar luminosity vary and what is the source of these variations?

SO/PHI BASIC SPECS

Two Telescopes:

1. Full Disk Telescope:
   - FoV ~ 2°
   - Resolution ~3.5 arcsec/pix
   - Full disk at all orbit positions
   - 17 mm aperture diameter
2. High Resolution Telescope:
   - FoV ~ 16 arcmin
   - Resolution: 0.5 arcsec per pixel (i.e., ~200 km at 0.28 AU)
   - 140 mm aperture diameter



SO/PHI: NEW TECHNOLOGIES

Heat rejection windows:

optical/polarimetric performance between 0.28 and 0.9 AU

Line scanning:

first ever $LiNbO_3$ etalon in space

Science detector:

custom made APS sensor development

Polarization modulation:

space-qualification of LCVRs for SO

Data processing:

use of powerful reconfigurable FPGAs, autonomous onboard calibration and data processing

Telemetry issues:

6.4 GByte per orbit ≈ 100 GByte over entire mission lifetime

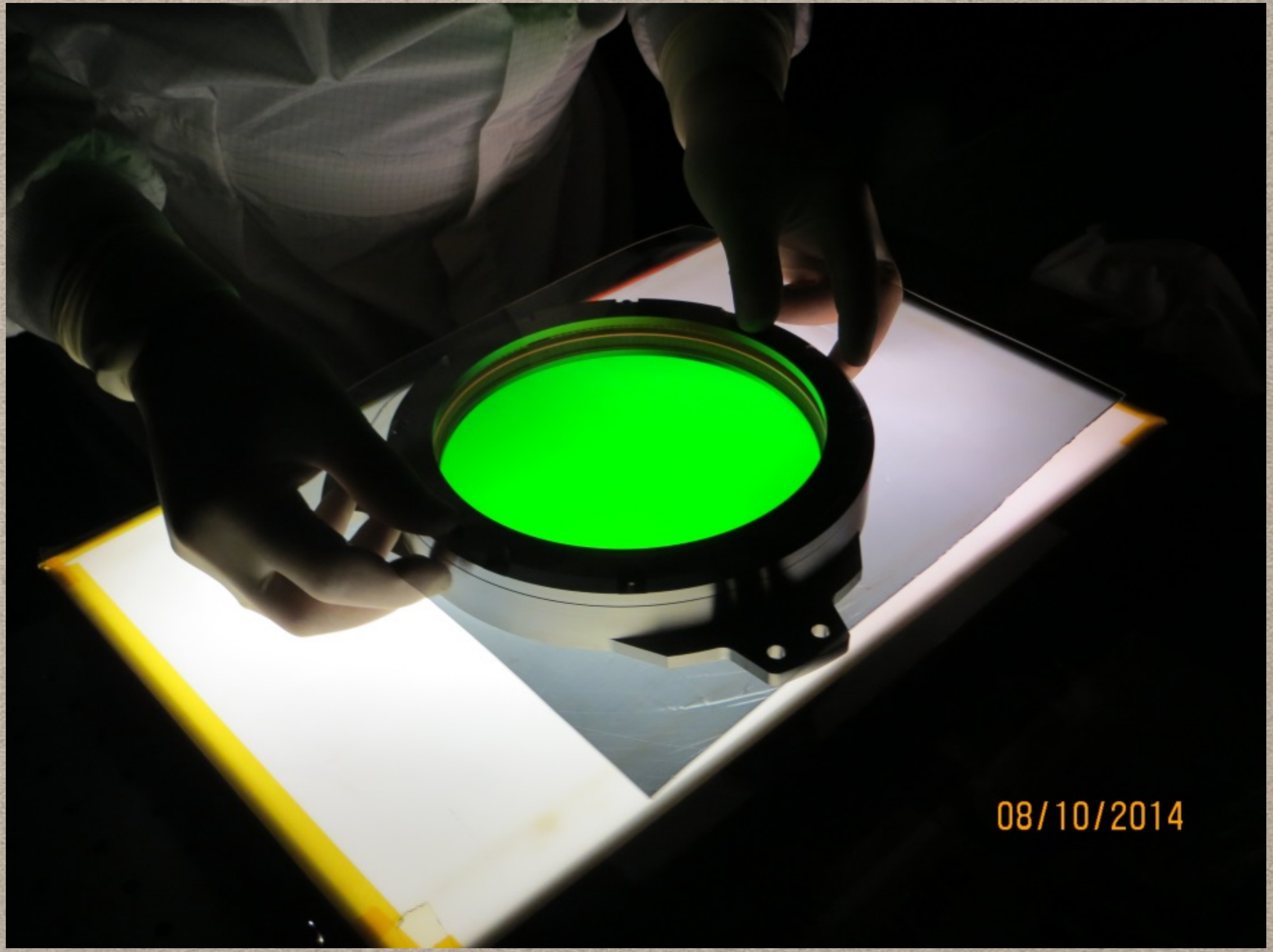
4Tbyte on-board storage

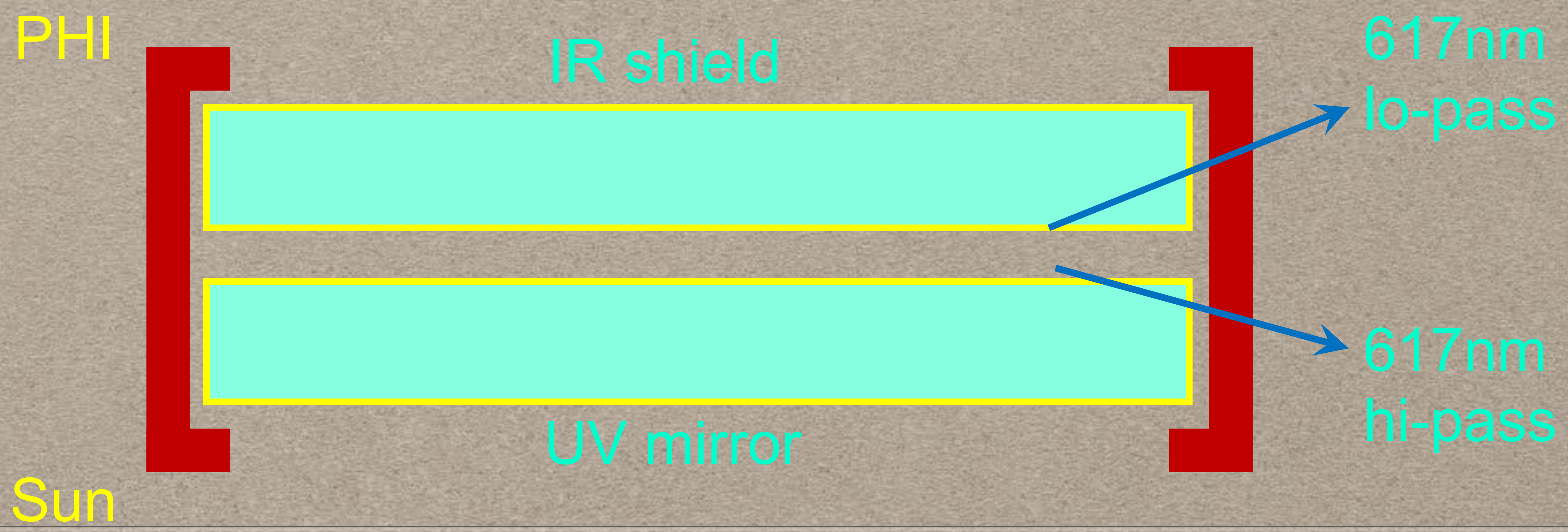
All technologies are developed and ready for launch in 2018

SO/PHI TECHNICAL CHALLENGES

- thermal environment: x10 heat input variation (0.28 vs. 1 AU)
- orbital motion: ±25 km/s
- full disk & high resolution
- autonomous operation (observations without contact)
- image stabilization (0.03″ rms)
- data rate: only ~20 kbps
- power & weight & size

L5: simplification





PHI@L5: SIMPLIFICATION OPTIONS

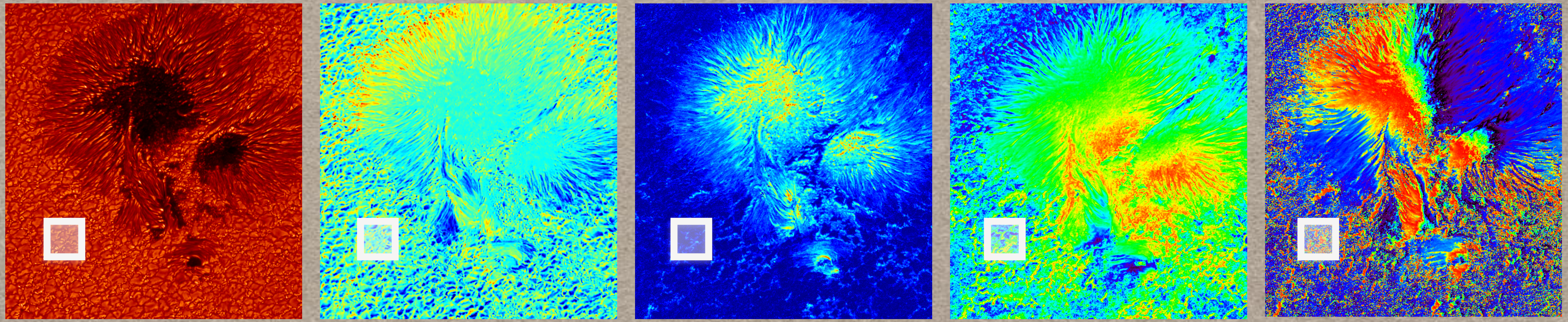
1. Telescope:
   - only 1 telescope
   - no feed selection mechanism
   - 2″ resolution (1″/pixel)
     –> 8cm aperture @6173 Å
     (optional: 4″ –> 4cm)
2. Detector:
   - 2k x 2k (optional: 1k x 1k)
3. Thermal environment:
   - lower heat input
   - stable conditions
4. Observation & operation:
   - constant orbital velocity & image scale (almost)
   - continous contact
5. Cadence:
   - several / day (reduces processing demands, on-board storage)
   - higher cadence for helioseismology (highly compressed)
6. No / less demanding correlation tracker required

- **Hardware ready for launch (Oct. 2018)**
- **On-board processing**
  - most efficient data compression technique available
  - 6x4 Stokes
    –> 1-5 par
  - (comp rati
  - Lossless co
  - Lossy com
    –> total co

PHI delivers highly flexible data products!

On-board processing allows selection according to scientific / forecasting requirements:

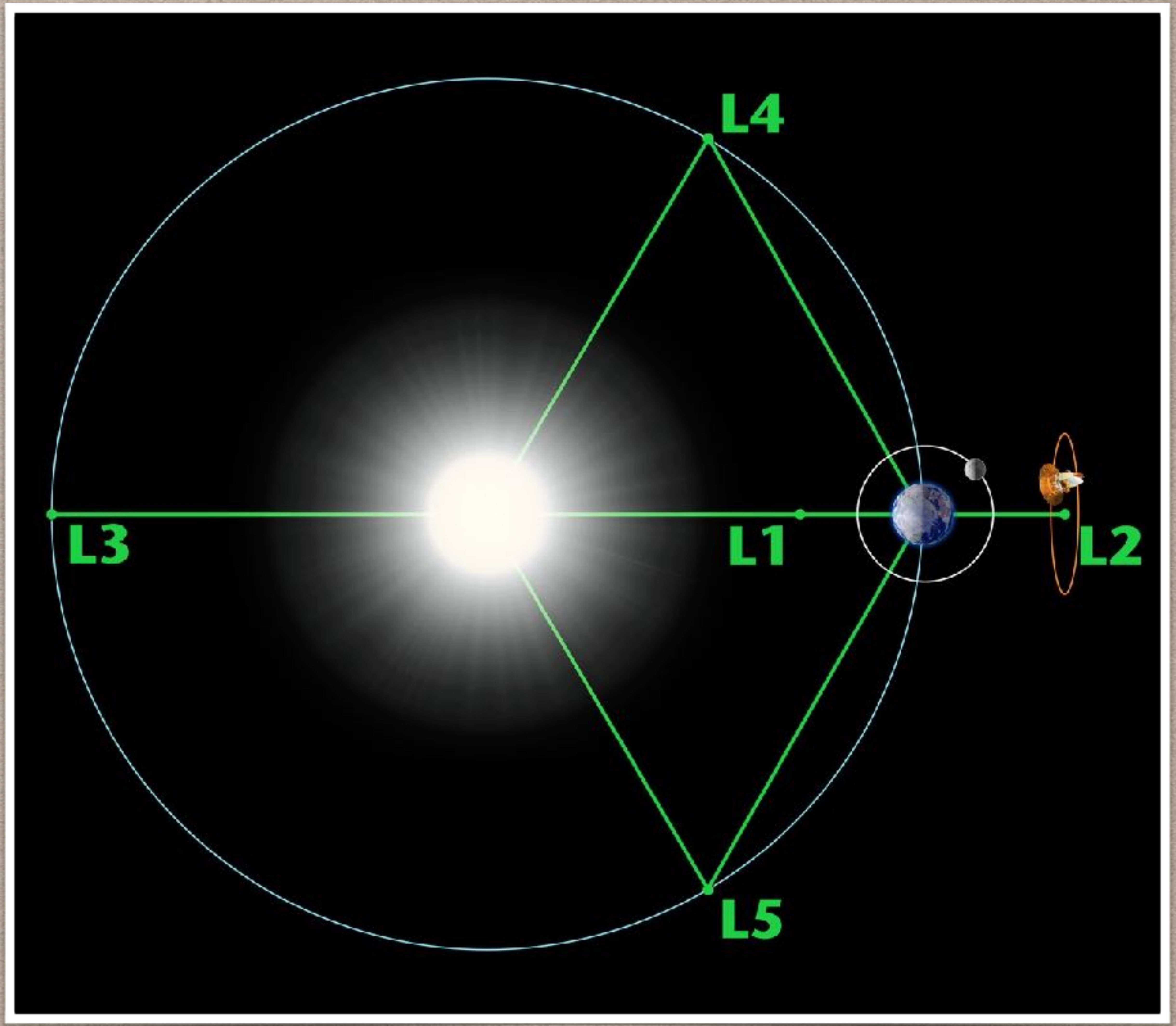
cadence, resolution, binning, FOV-selection, parameter maps selection, compression.



PHI@L5: SPACE WEATHER BENEFITS

Advantages of L5 for space weather application:

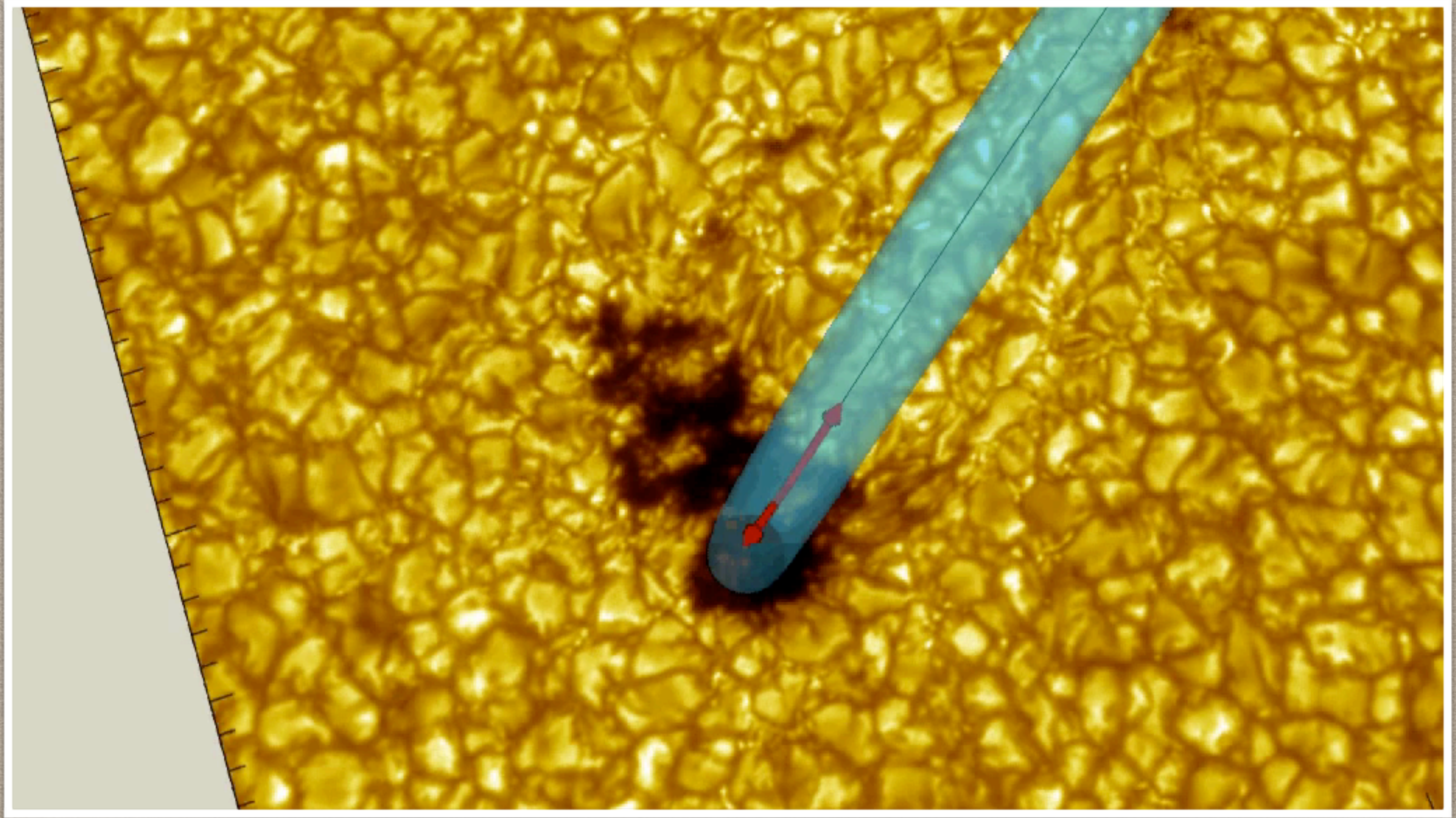
- easier & more reliable LOS-magnetic field measurements (advantageous viewing geometry)
- larger disk coverage improves global field modelling
- –> better prediction of flare probabilities



PHI@L5: SCIENCE BENEFITS

Required are vector field measurements!
(available for only 200g more than LOS magnetograph)

- Continuous stereoscopic B-field measurements possible –>**180° ambiguity removal**
- allows measurement of **currents, build-up of magnetic energy** in ARs
- **Essential to improve understanding of energy release mechanisms**
- **Essential for reliable predictions**

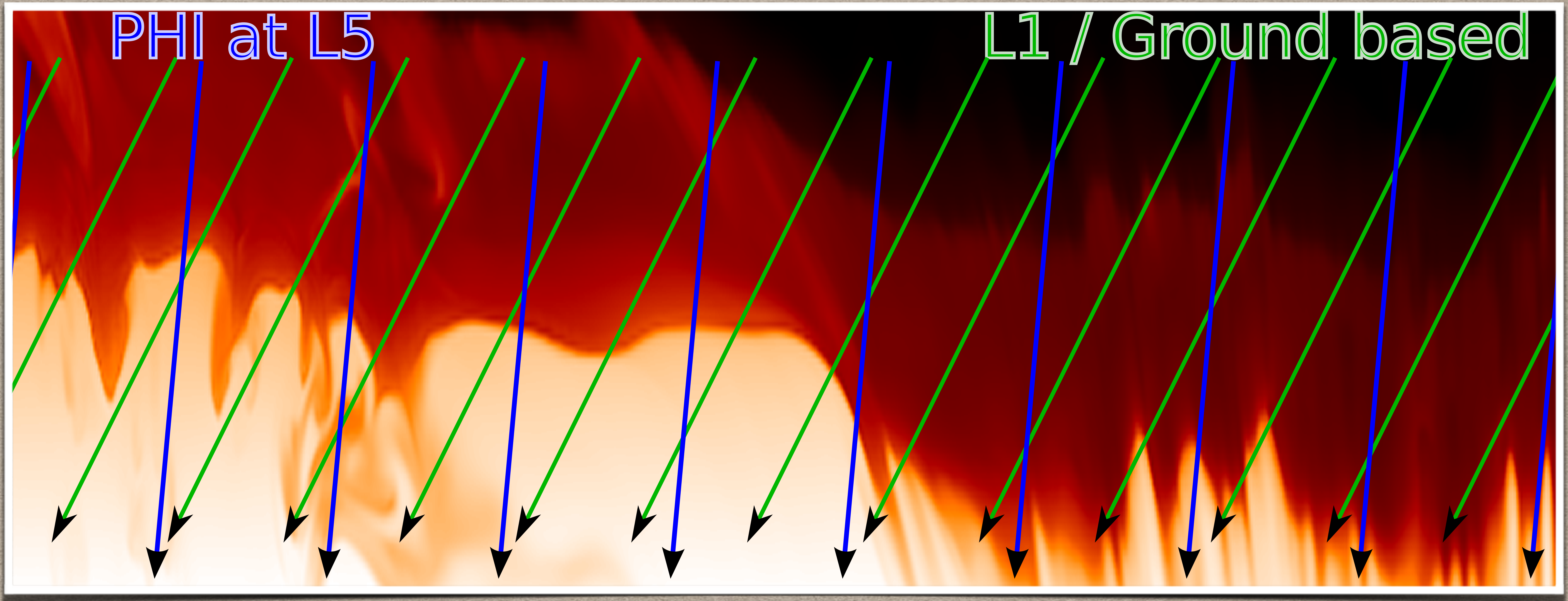


PHI@L5: Science Benefits

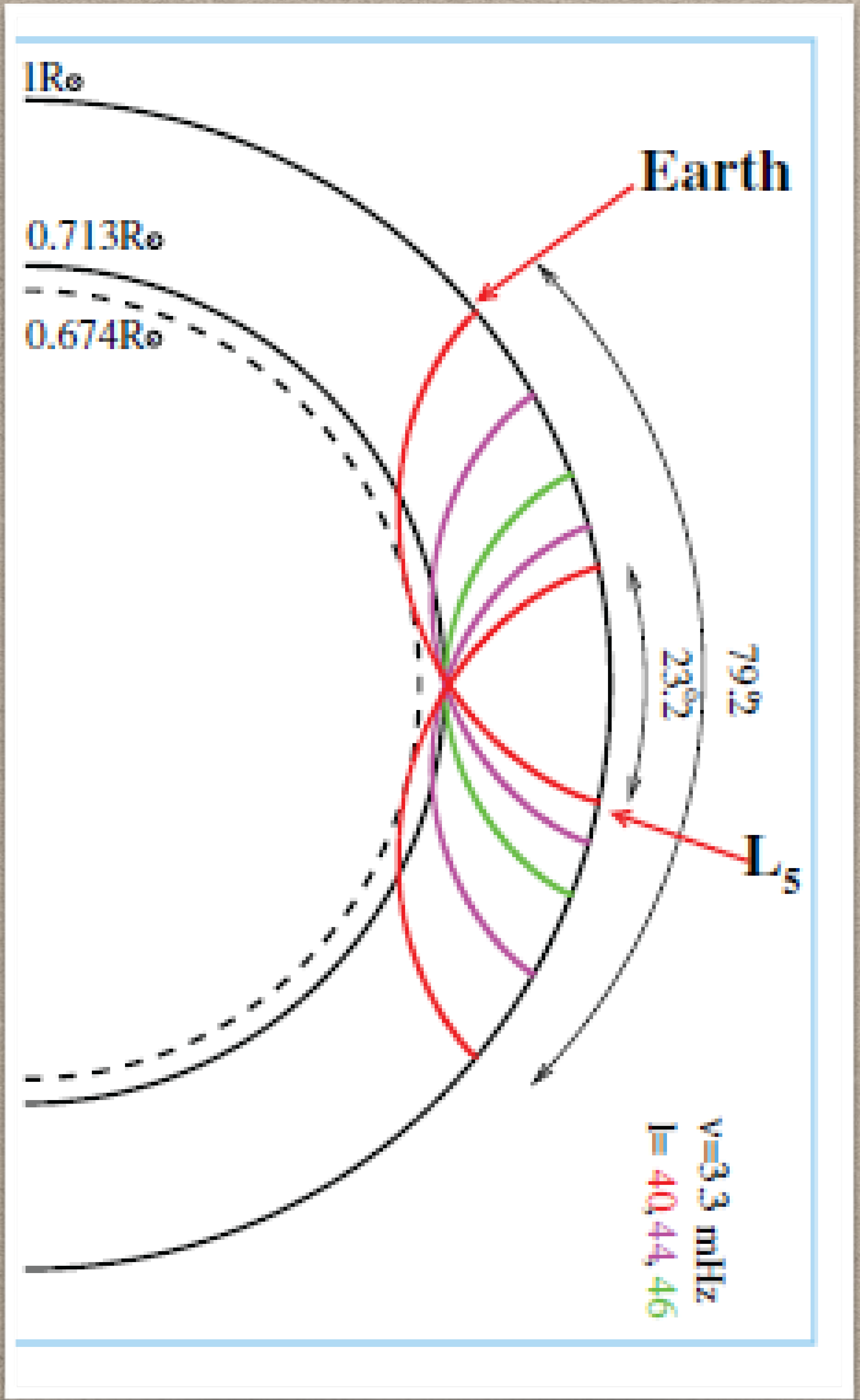
Magnetograms based on inversion of RTE are showing B on surfaces of equal optical depth.

Stereoscopic measurements will allow for inversions on a geometrical heigh scale

–> significant improvement/ simplification for B-field extrapolation



PHI@L5: Benefits for Helioseismology



PHI@L5 would improve

- Better spatial coverage gives better statistics
- Longer observations of each active region
- Longer ray paths available for time-distance
- Vector velocities
- SDO+PHI+L5 offer three viewing angles and/or near complete coverage of the Sun.

Requirements:

- low resolution Dopplergrams
- Cadence: 1 map/minute

L5 Magnetograph Specification

for Global Solar Magnetic Field Maps

based on ADAPT WSA-Enlil and F10.7 & EUV irradiance modeling experience
(Carl Henney, see presentation yesterday afternoon)

Parameter	Baseline	Optimal	Difference	SO/PHI
Observed Area	Active Regions	Full-disk	etalon size	FDT/HRT
Spatial Scale	2"/pixel	1"/pixel 1/3" res (*)	4cm vs. 8cm 50cm (Hinode) (*)	0.5"/pixel
Polarimetry	LOS (I,V)	I,Q,U,V	+200 g	I,Q,U,V
Dynamic Range	+/- 2500 G	+/- 3500 G	operation	+/-4 kG
Sensitivity	< 1 G/pixel	< 1 G/pixel	TBD	S/N 1000
Zero-point error	< 0.1 G	< 0.05 G	TBD	
Cadence	2 hours	15 minutes	data volume	1 minute

(*) L5 modeling matrix, talk by Pete Riley, Tuesday afternoon

SUMMARY

PHI-type instrument essential payload for L5

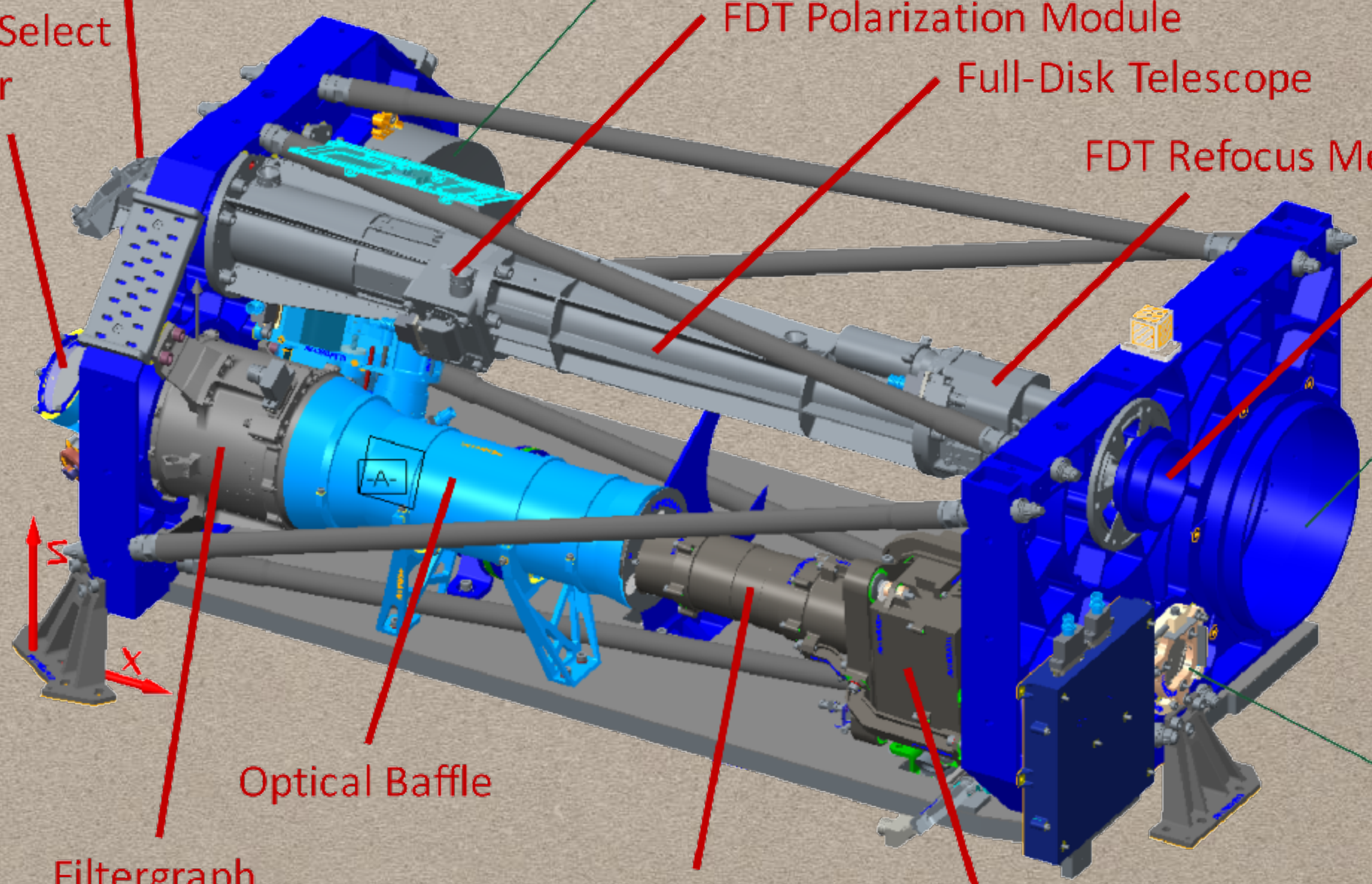
MPS has know-how to build space-qualified magnetograph

MPS has expertise in sophisticated on-board processing

Scientific aspects of PHI@L5 mission are essential!
(stereoscopic helioseismology and vector-B measurements)

SO/PHI DESIGN

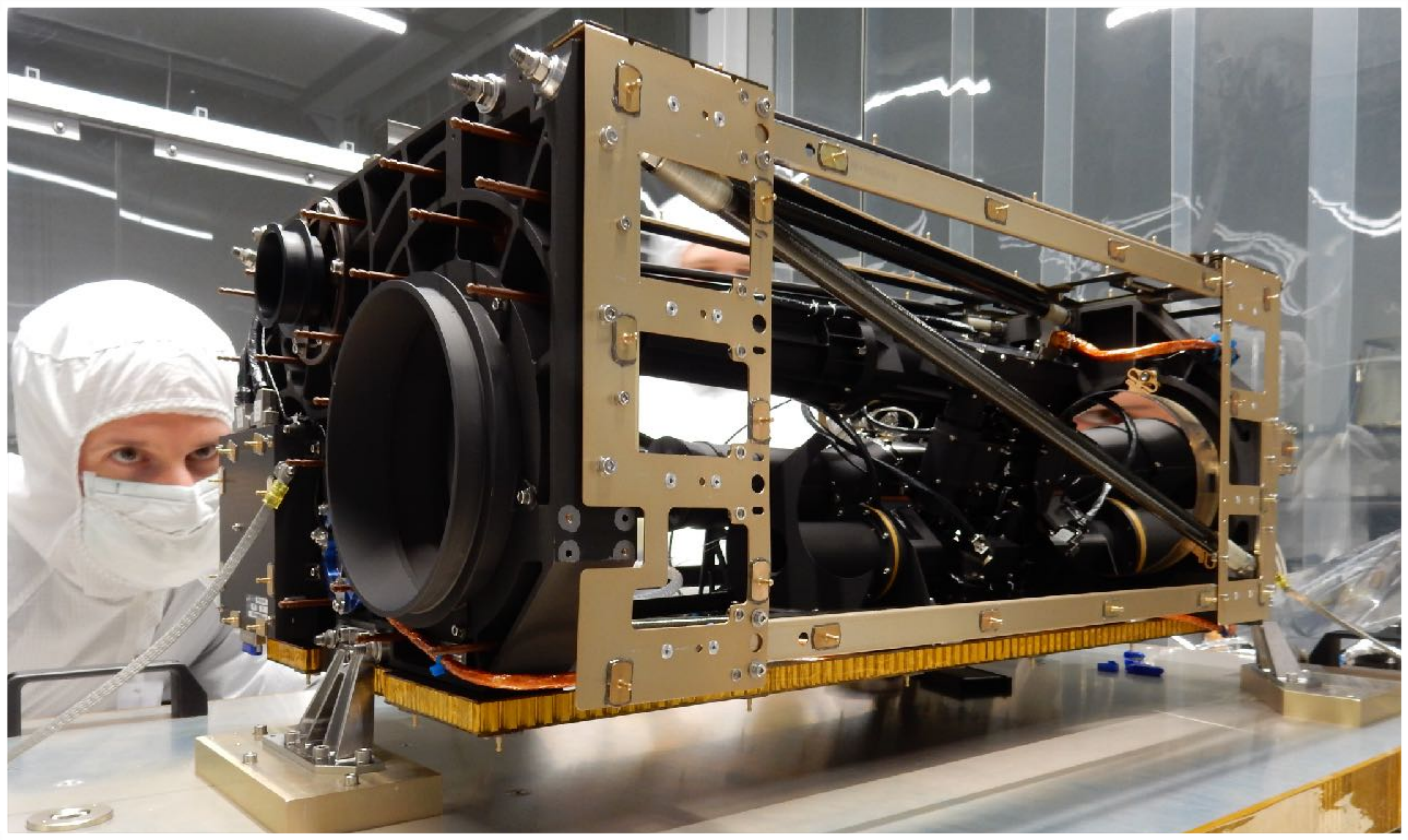
- HRT: off-axis Ritchey-Chrétien telescope
- FDT: off-axis refractor
- Polarization Packages: based on Liquid-Crystal Variable Retarders (LCVRs)
- Filtergraph: transfer-optics with solid state etalon and interference filters
- Image stabilization: 30 Hz Correlation Tracker
- Focal Plane: 2k / >10fps APS detector



SO/PHI DESIGN

- 2 AlBeMet main blocks
- 6 low CTE CFRP struts
- Al honeycomb baseplate
- Total volume: 30 x 40 x 80 cm^3
- Total mass: 35 kg (c.f. HMI: 73kg, MDI: 56.5kg)

- current status: FM polarimetric calibration
- delivery to ESA in a couple of weeks

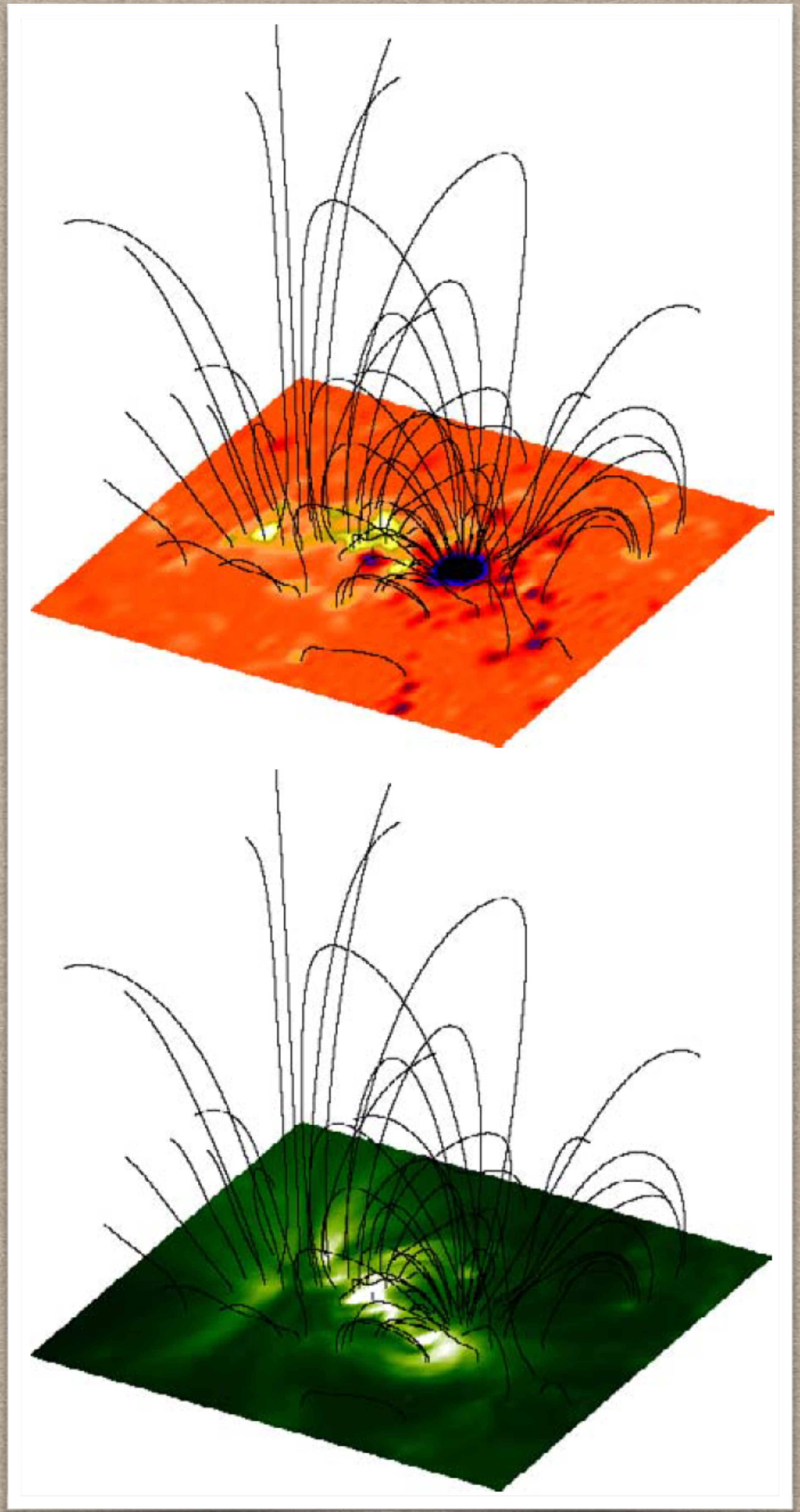


PHI FM, Jan 21 2017

SO is designed to probe all solar layers from its interior up to the heliosphere. The most prominent questions concern the magnetic coupling between the different atmospheric layers.

SO with both remote sensing and in-situ measurements aims to address the largely unsolved problems of chromospheric and coronal heating as well as the transport phenomena into the interplanetary space

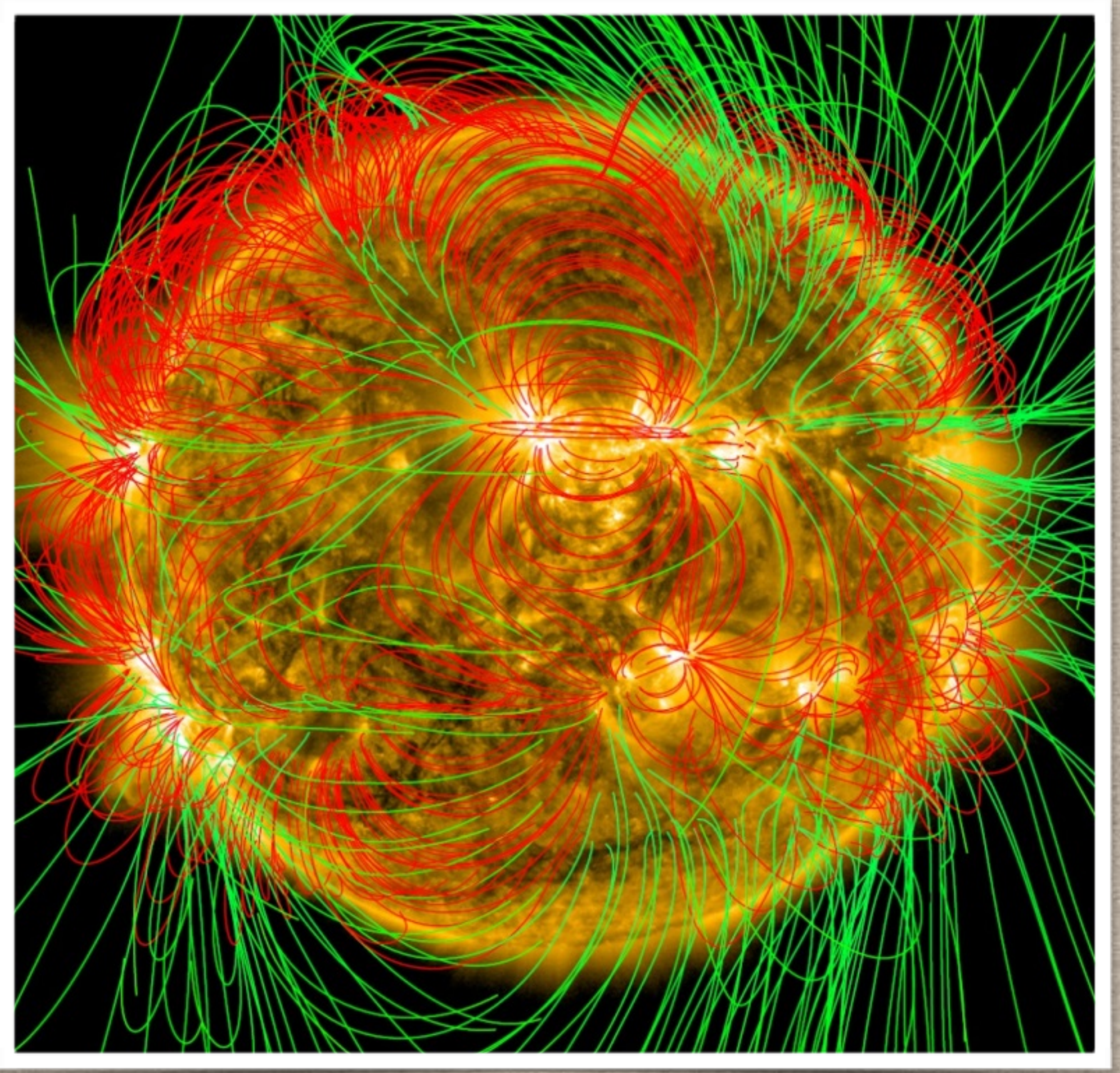
SO/PHI will provide the photospheric magnetic field structure which represents essential boundary conditions to achieve these goals.

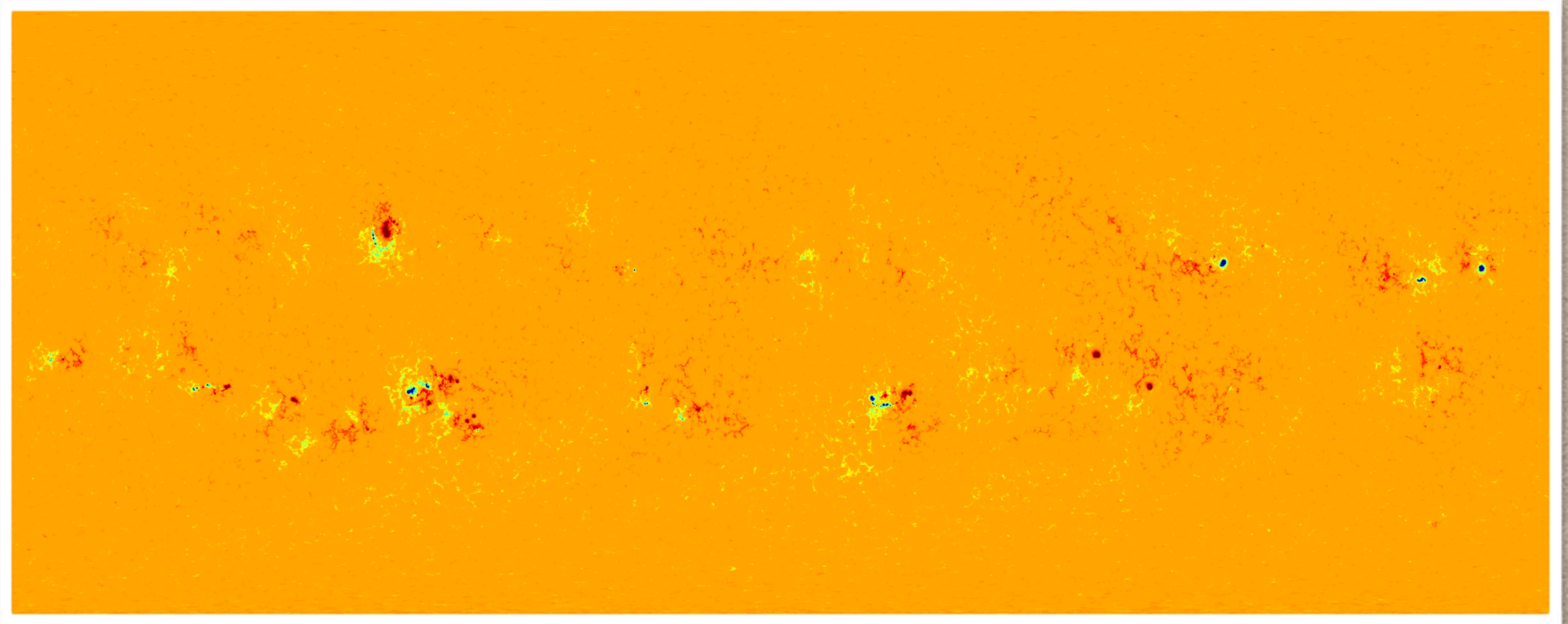


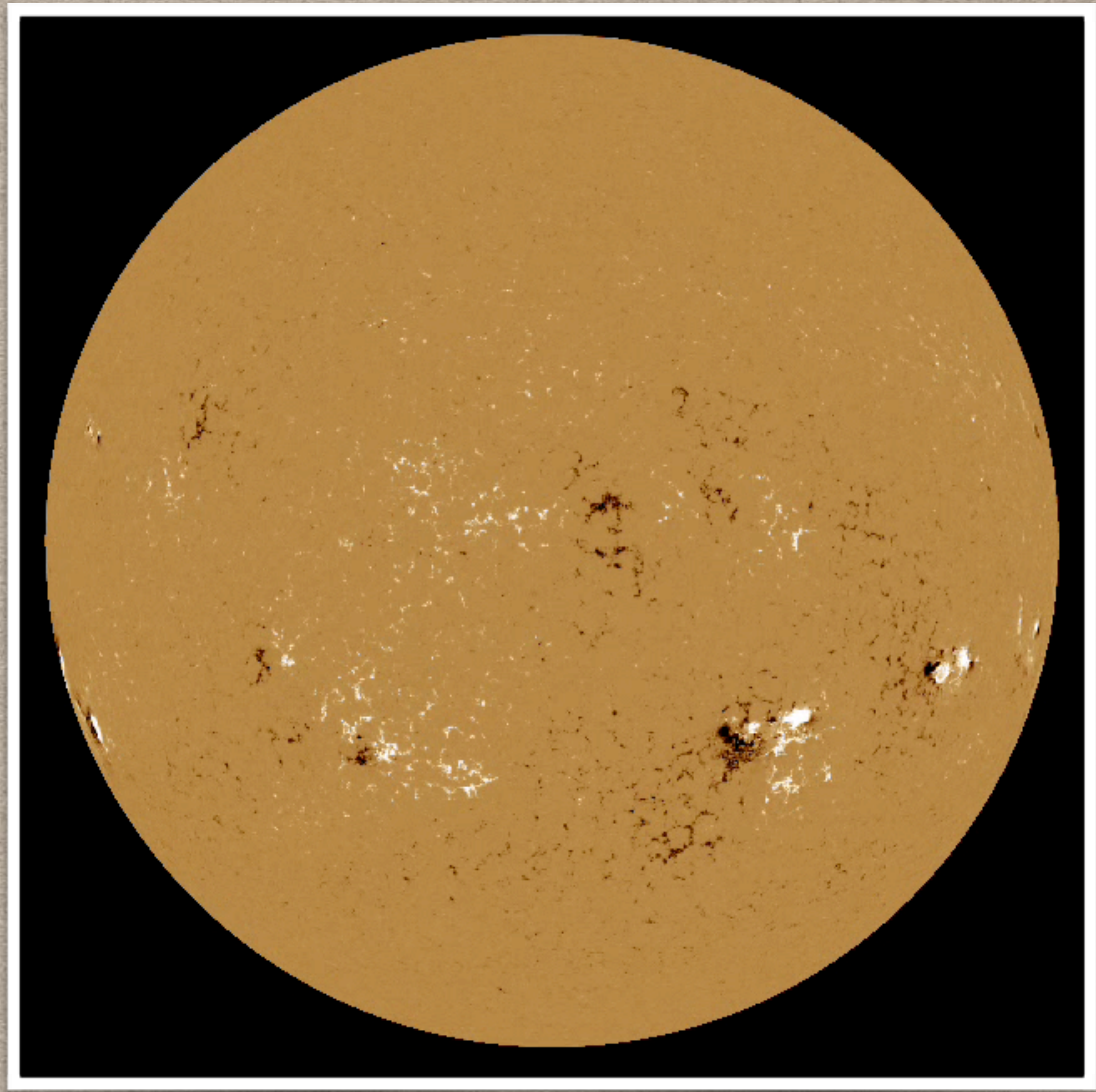
Marsch et. al (2004)

SO's close perihelion transits enables to follow surface structures for more than half of a rotation period, i.e. up to 23 days.

Vantage points far from Earth allow for instantaneous 4π magnetic maps

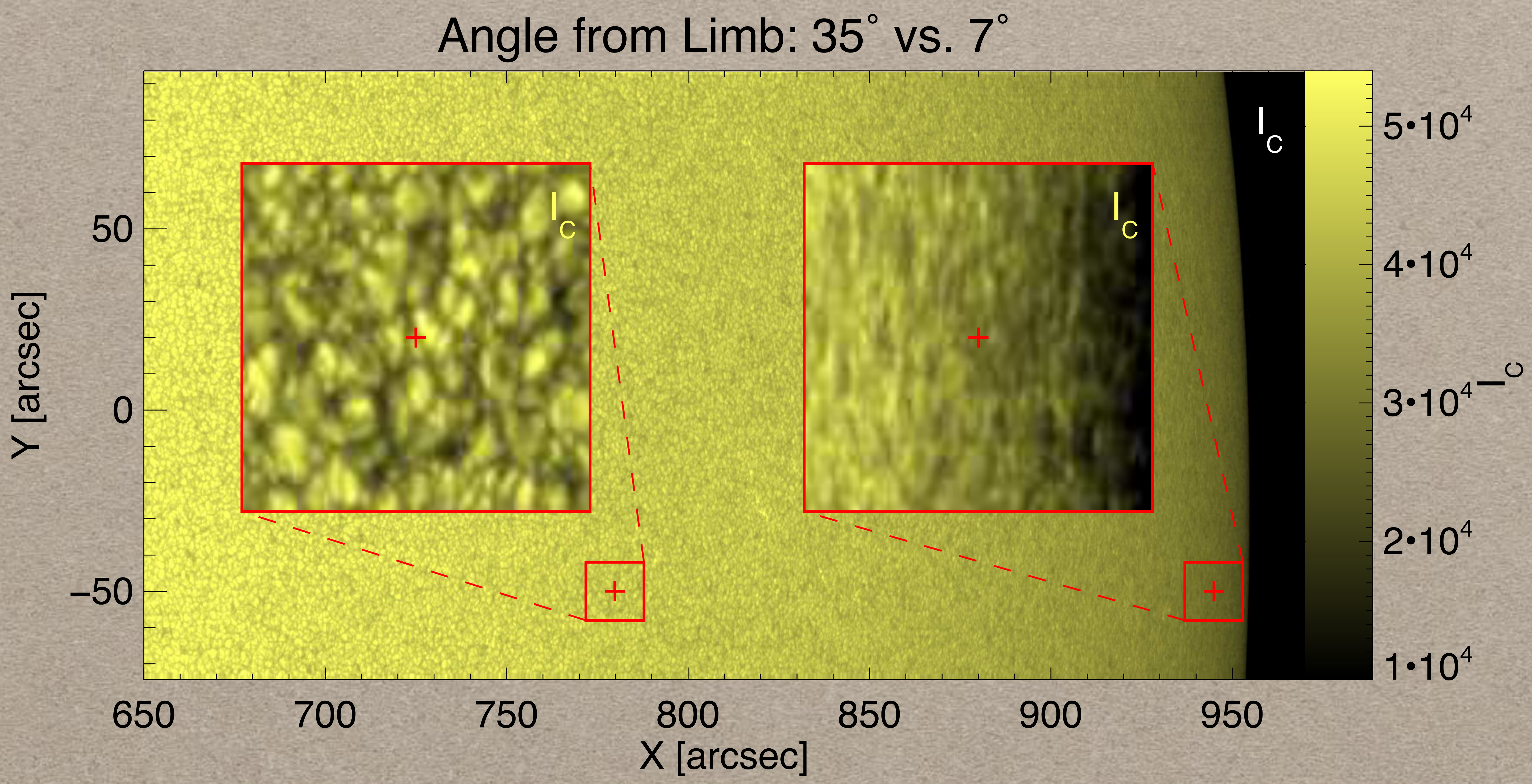


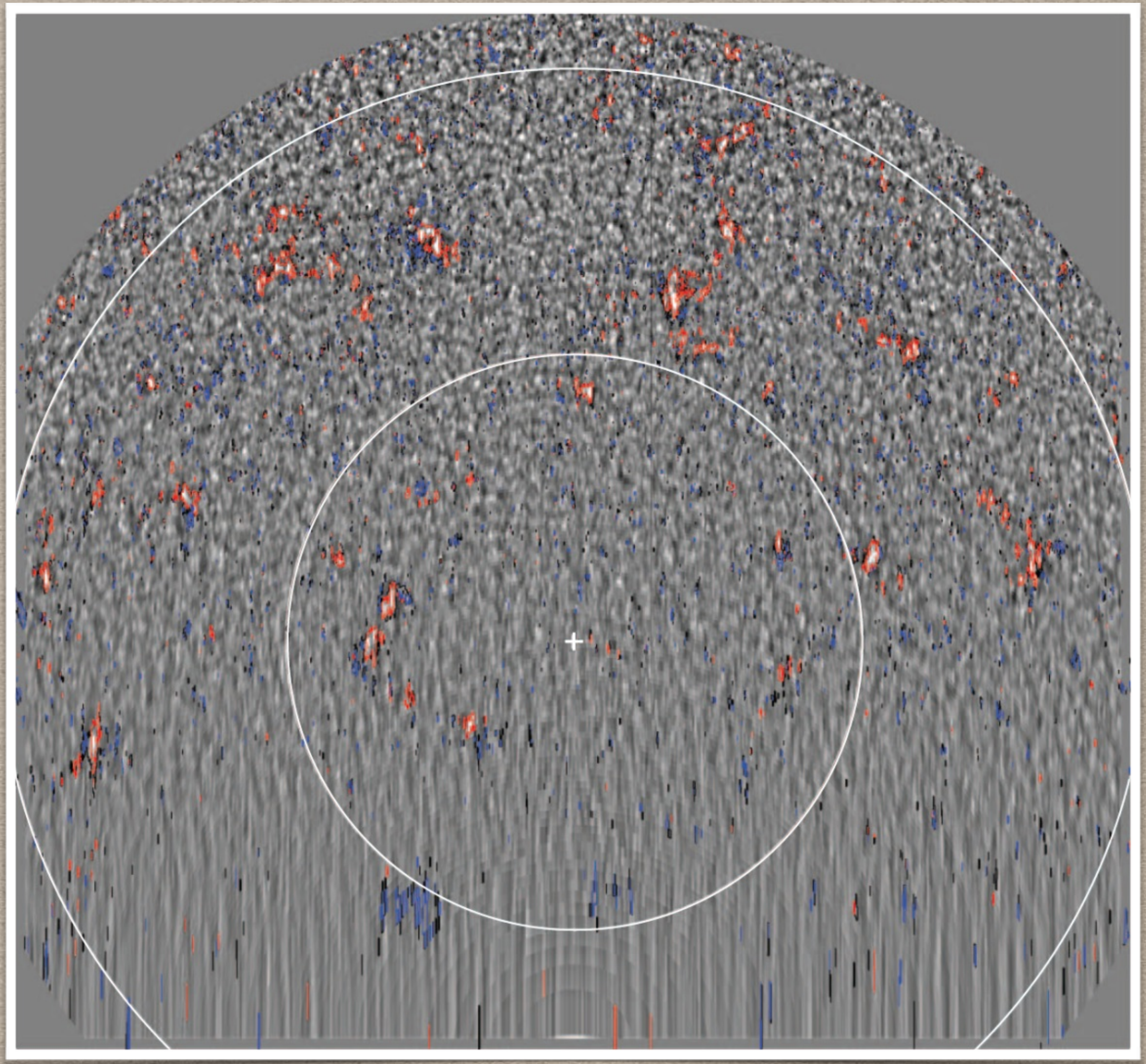




SO/PHI POLAR SCIENCE

Polarimetric and dynamic studies of the solar polar regions from the ecliptic plane suffer from geometric foreshortening. SO/PHI will be the first polarimeter looking at the poles from an inclination <83 deg



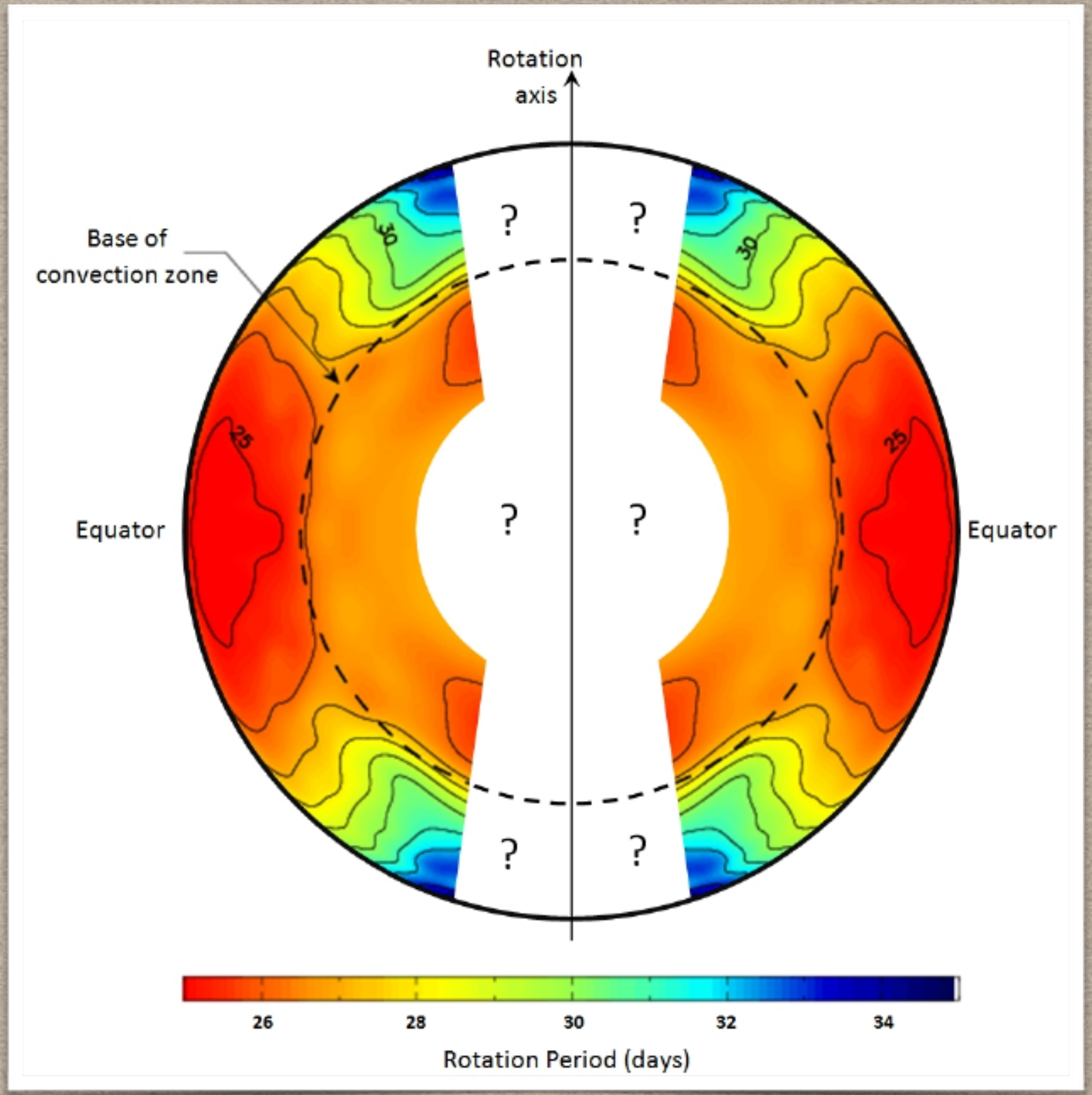


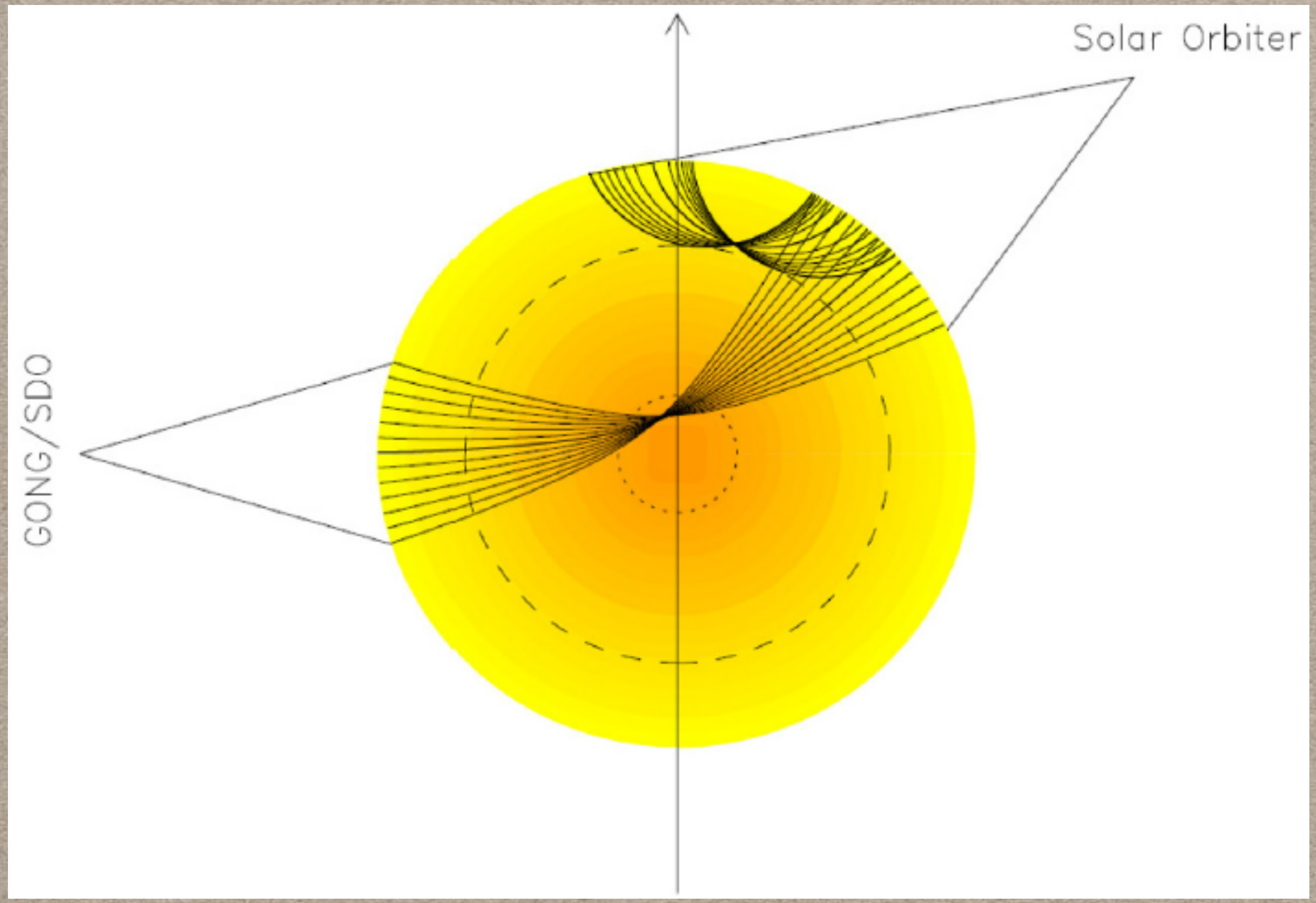
Tsuneta et. al (2008)

SO/PHI SCIENCE: HELIOSEISMOLOGY

Observations from a vantage point in the ecliptic does not allow probing solar latitudes higher than ~70°.

SO/PHI observations from out of the ecliptic will help to address problems of, e.g., the solar dynamo.





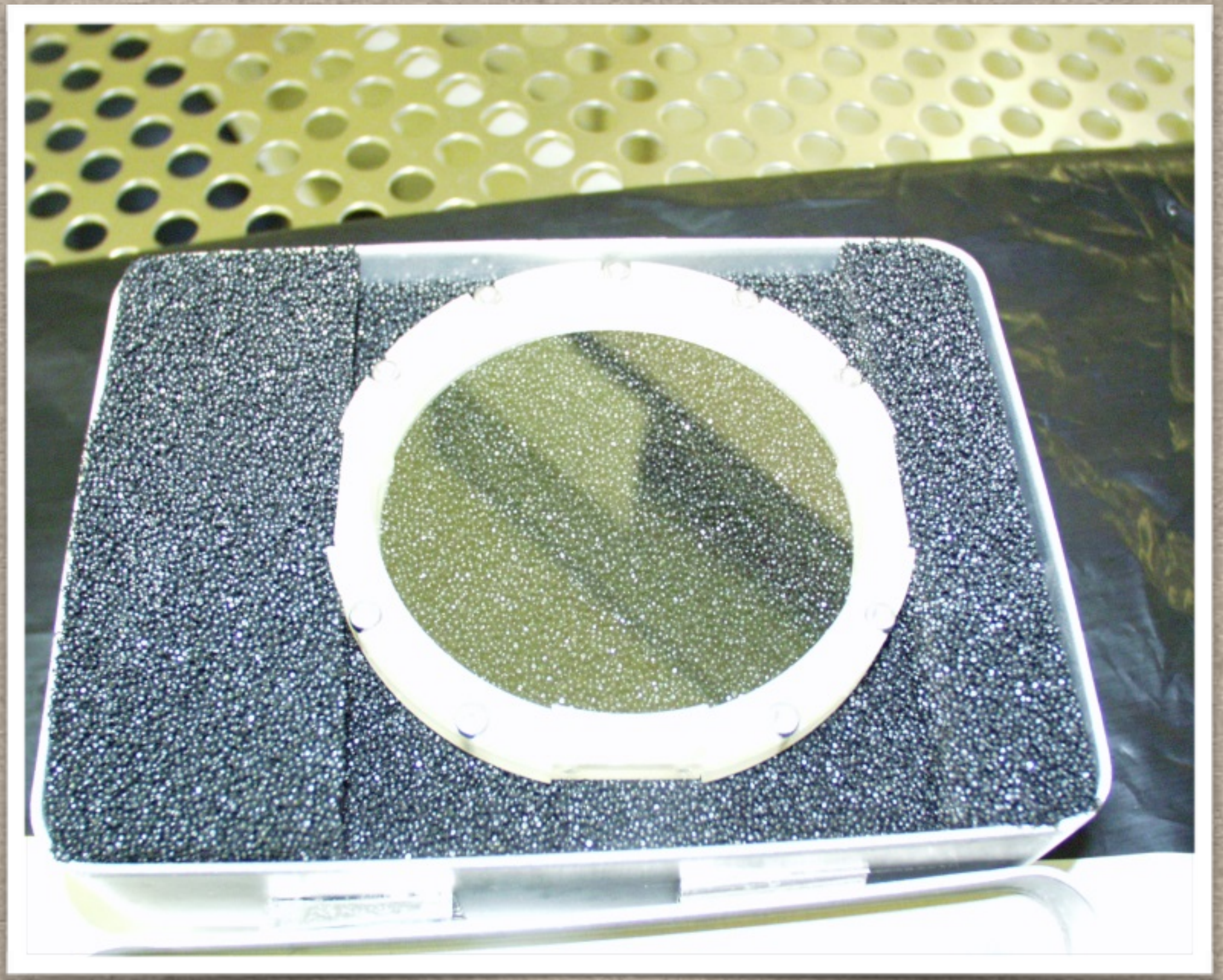
Stereoscopic Helioseismology

Probing the Sun from different vantage points may allow for probing deeper layers than what is possible with only one instrument.

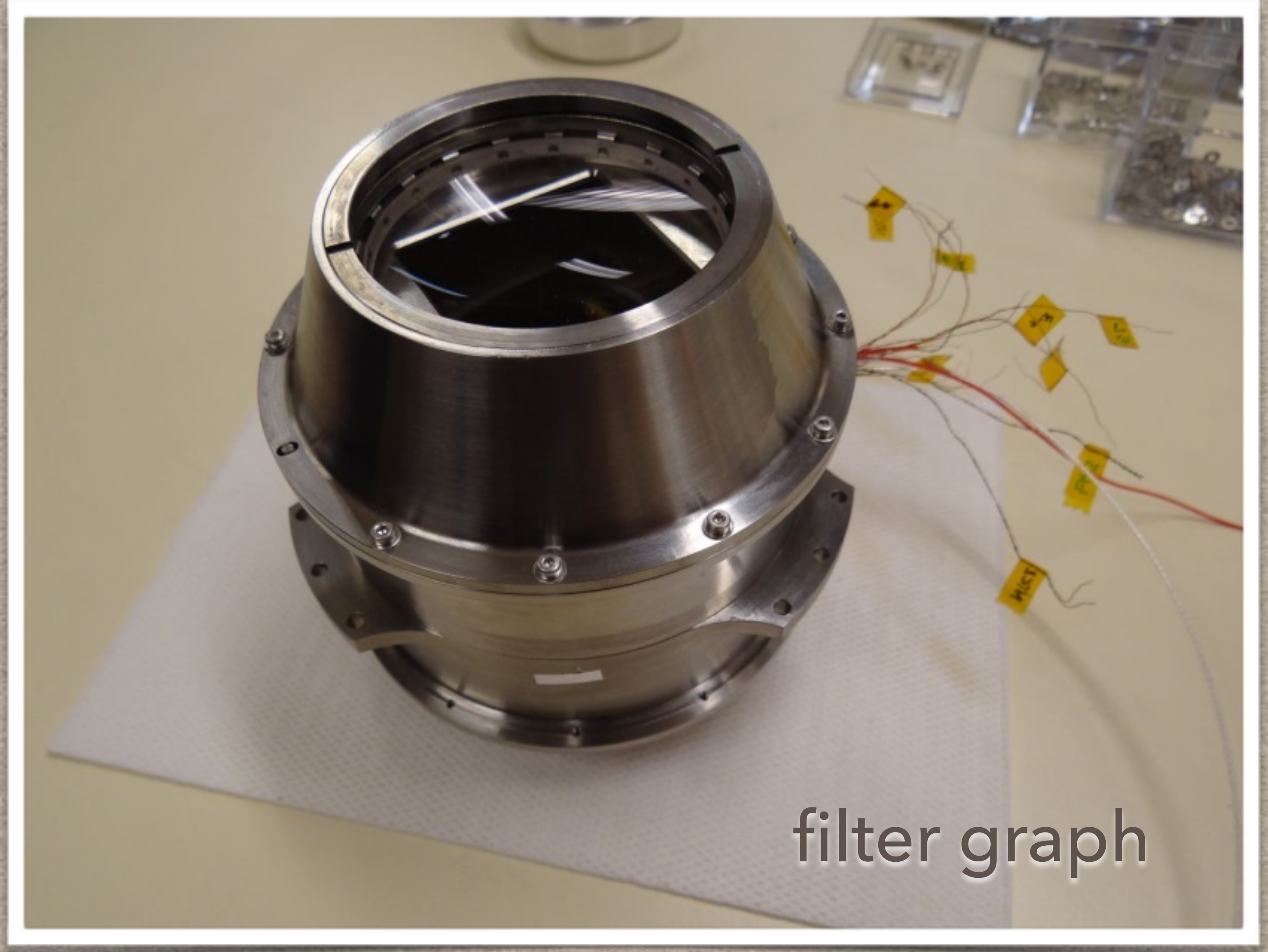
SO/PHI FILTERGRAPH

Line scanning device based on a solid state Fabry-Pérot etalon:

- FWHM = 90mÅ, free spectral range = 3.0Å
- ~ 1nm surface roughness, ~10nm abs thickness tolerance
- T-stability: <0.1K on etalon
- 66°C operating temperature
- 1.5 W heater power



250µm $LiNbO_3$ etalon

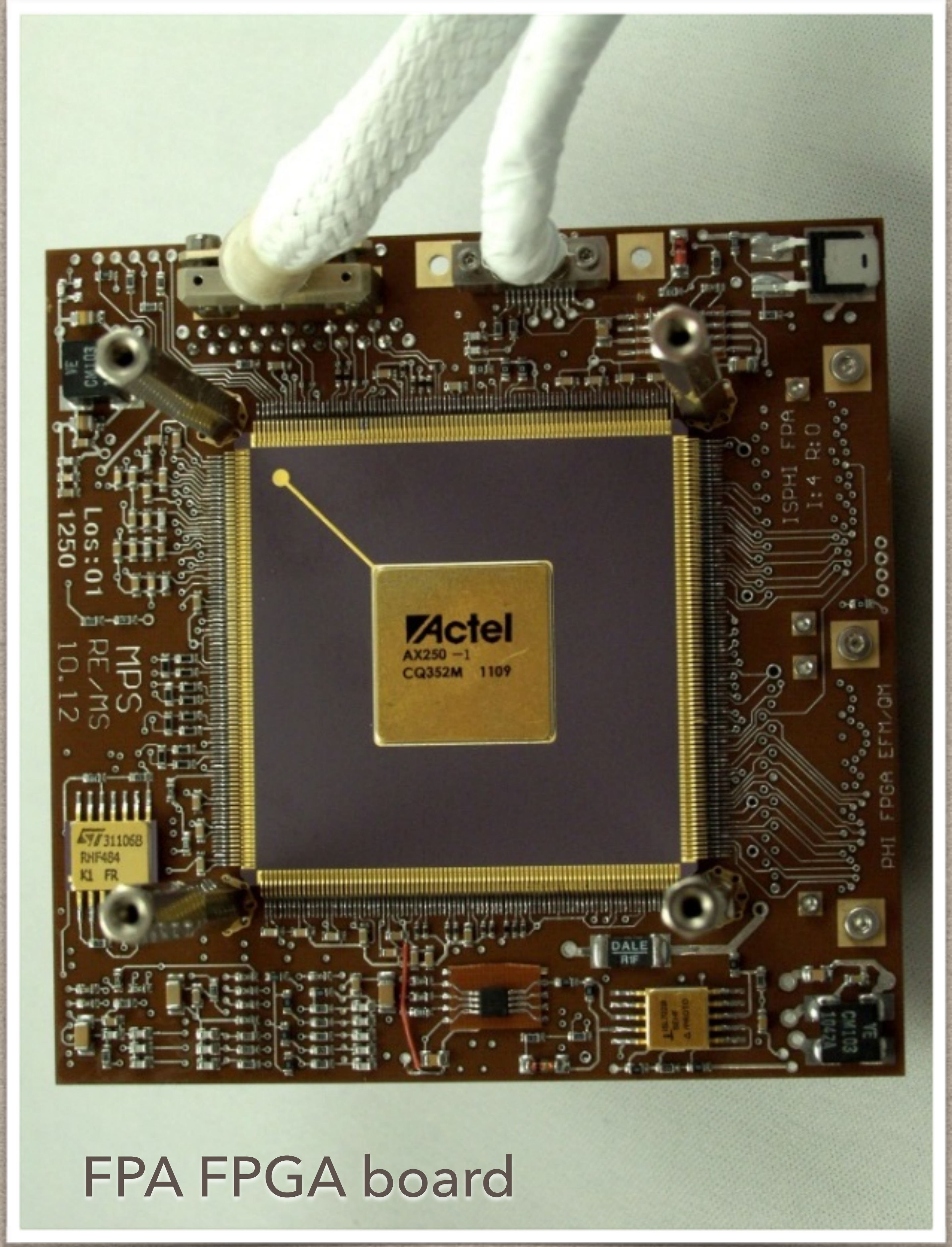


filter graph

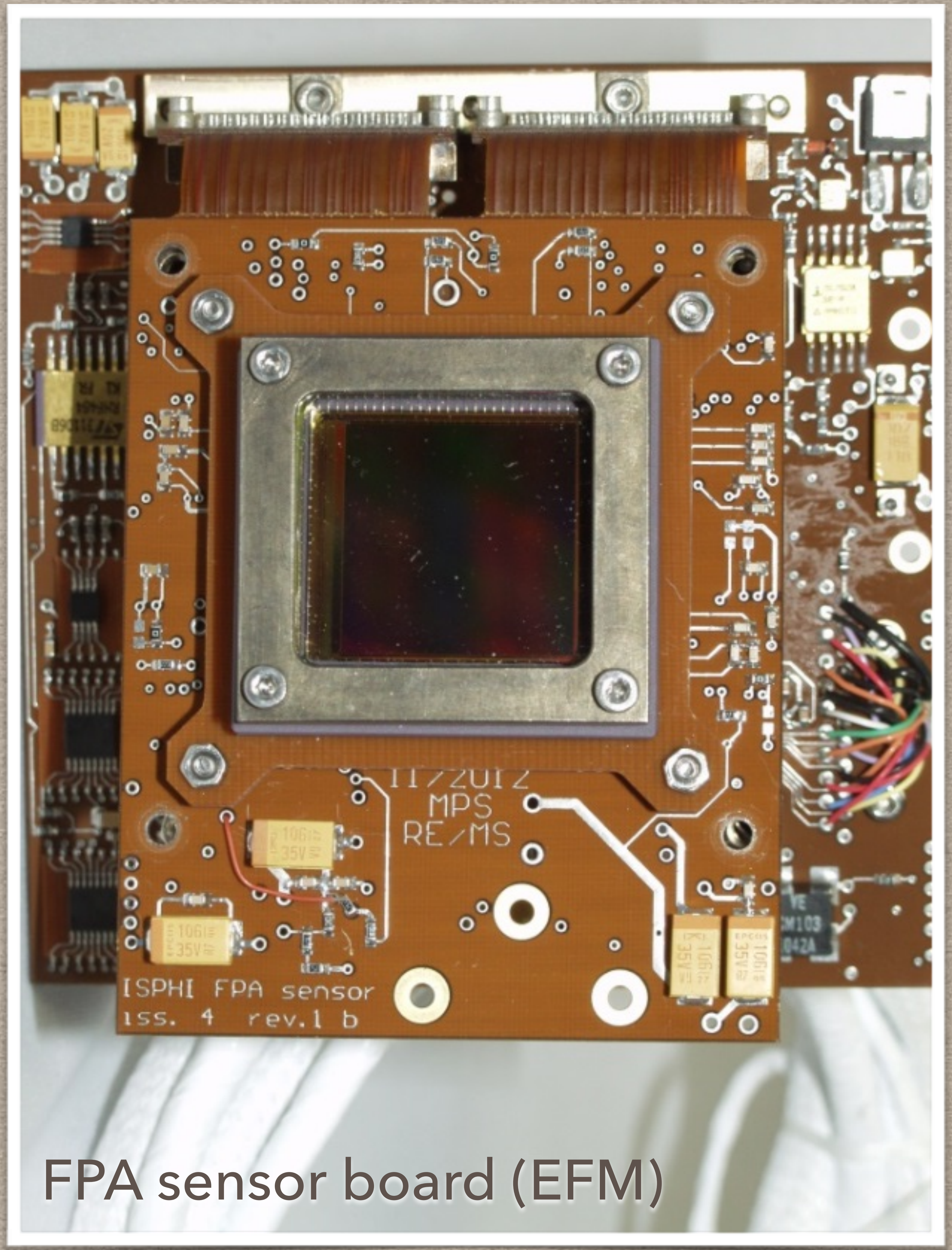
- 2 optical windows (lenses, ITO coated)
- 2 interference filters (order sorter, IR blocker)
- 1 $LiNbO_3$ etalon
- Oven (active thermal control)
- HV connection

SO/PHI FOCAL PLANE ASSEMBLY

- 2k x 2k read-out at > 10fps
- FWC: 100ke$^-$ (<1% linearity)
- Actively cooled sensor (cold element) => dark noise: ~100 e$^-$/s per pixel
- Automatic Single Event Upset (SEU) recovery
- Automatic sensor Single Event Latch-up (SEL) detection and recovery (sensor power cycle)



FPA FPGA board

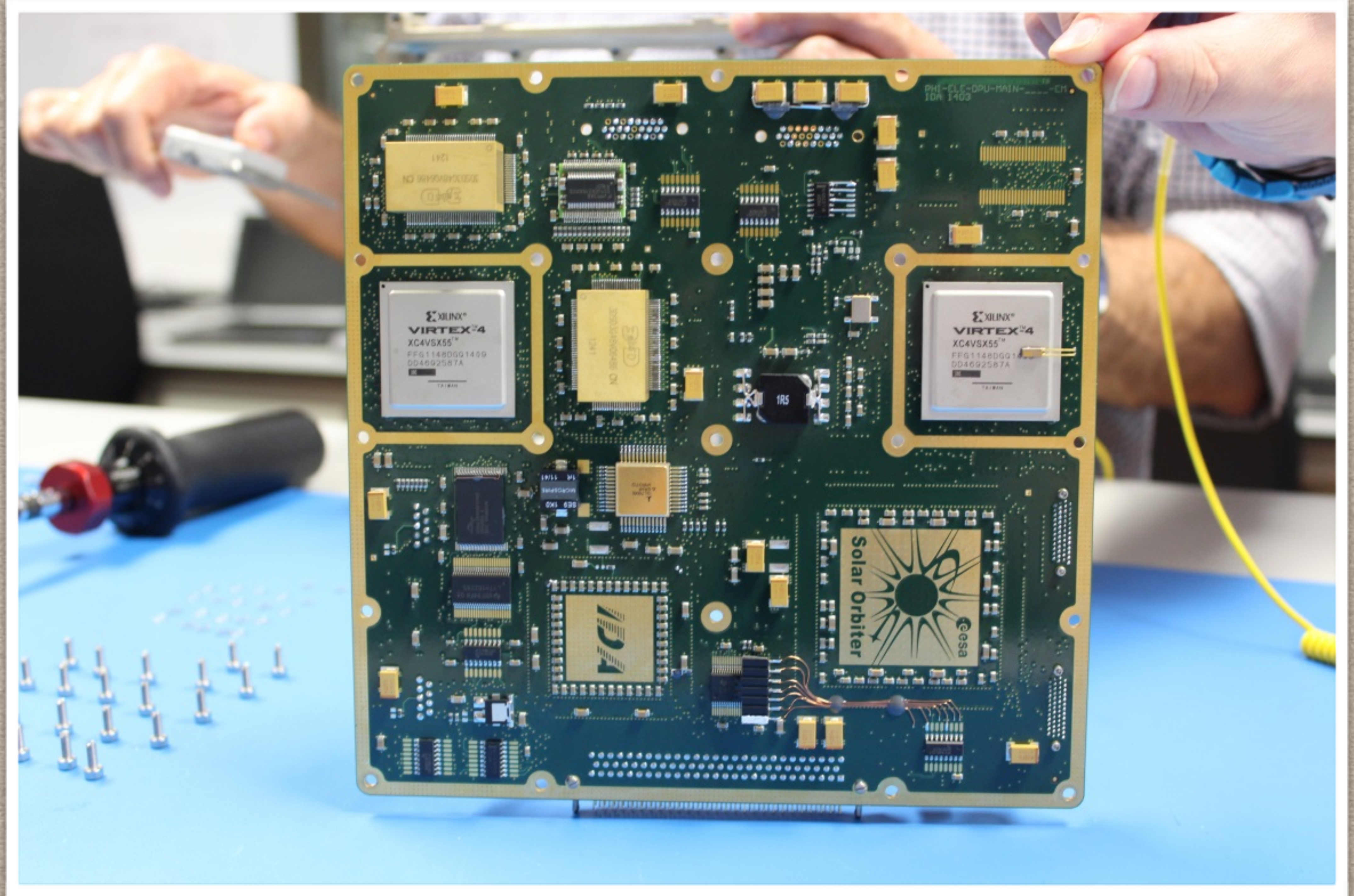


FPA sensor board (EFM)

SO/PHI DIGITAL PROCESSING UNIT

Tasks:

- Instrument control
- Science data Acquisition with >10 fps
- Correlation Tracker control
- Onboard data calibration
- Onboard data inversion
- 4 Tbits flash memory control
- Commanding/Telemetry



Most critical items:

2 reconfigurable FPGAs for onboard data analysis, image acquisition and CT control