Solar Observations with Gregor

Oskar von der Lühe and the Gregor Team

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Heidelberg, 24. January 2012

Kiepenheuer-Institut für Sonnenphysik

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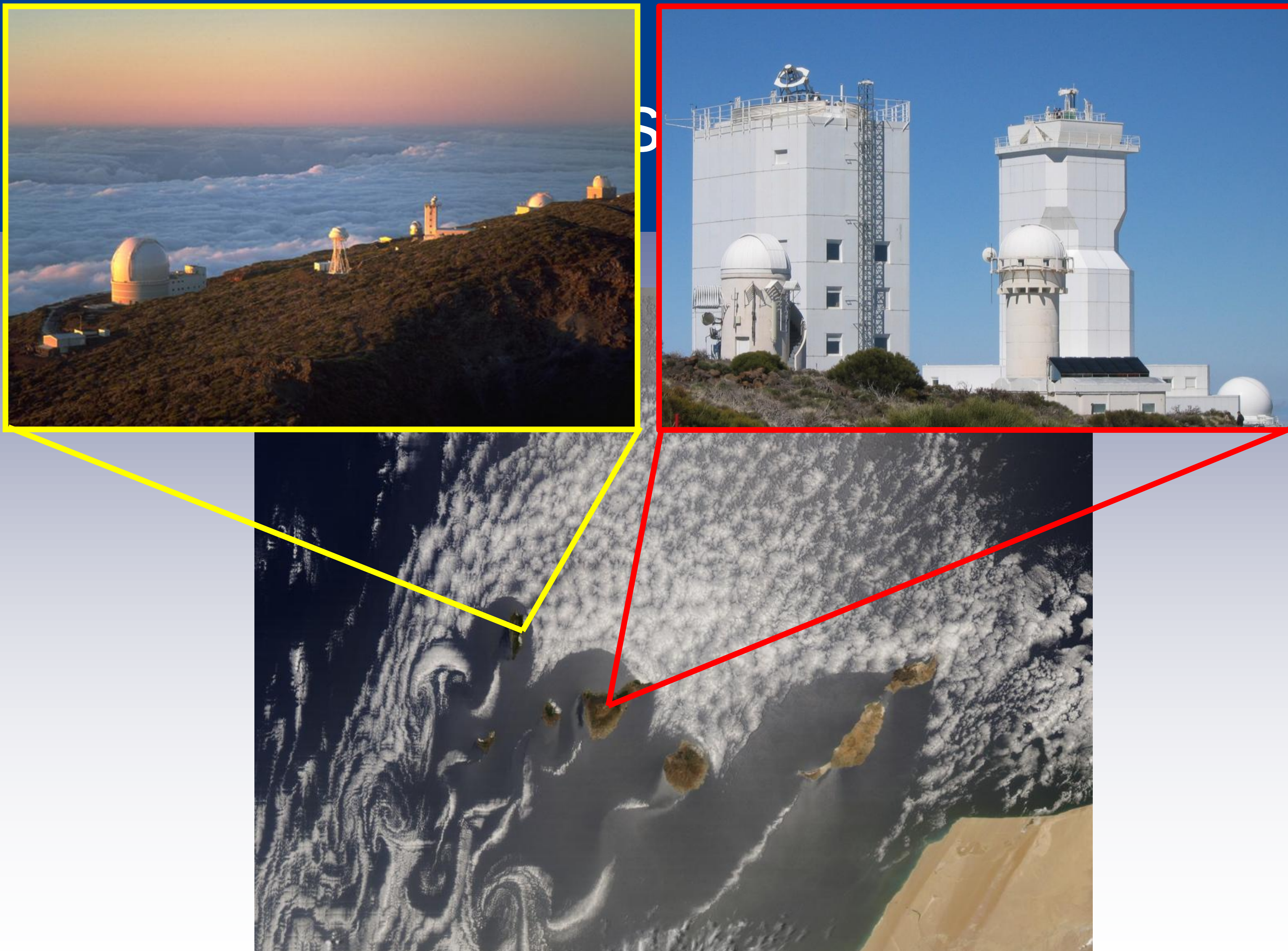


Who is Gregor?

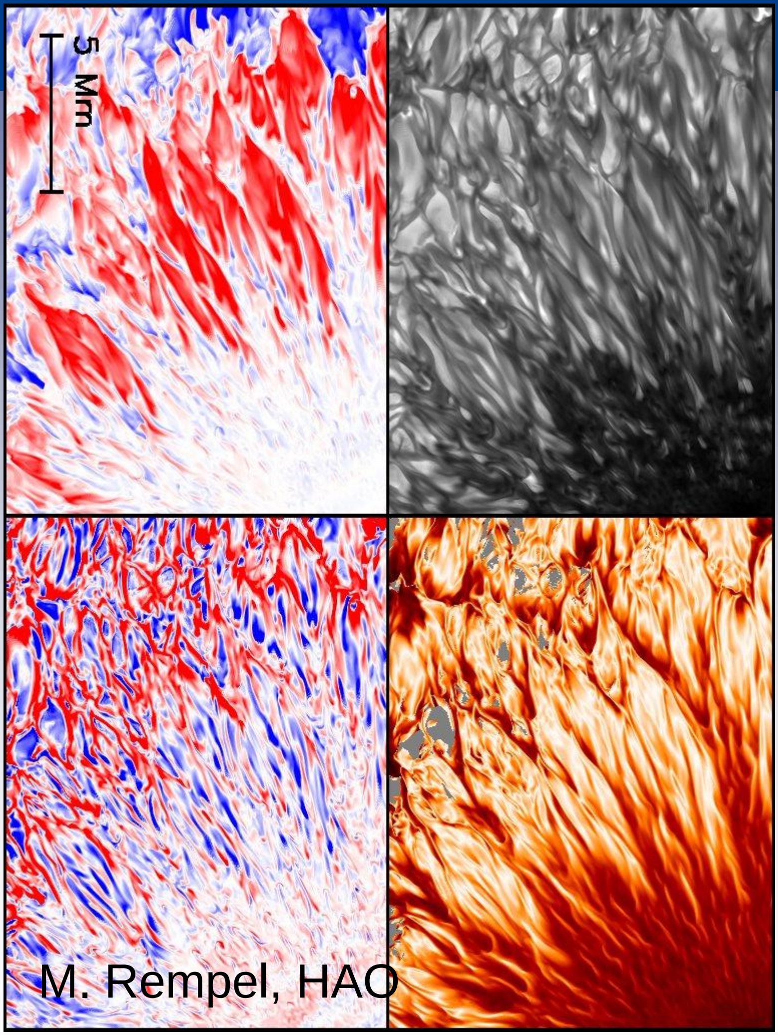
- **GREGOR Consortium**

  Kiepenheuer-Institut für Sonnenphysik (KIS) (chair)
  Max-Planck-Institut für Sonnensystemforschung (MPS)
  Leibniz-Institut für Astrophysik Potsdam (AIP)

- **Partners**

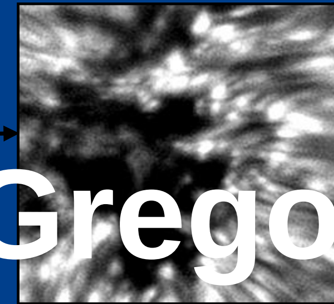
  Instituto de Astrofísica de Canarias (IAC)
  Astronomical Institute (AI), Acad. of Scie. of Czech Republic
  Institut für Astrophysik Göttingen (IAG, until 2008)

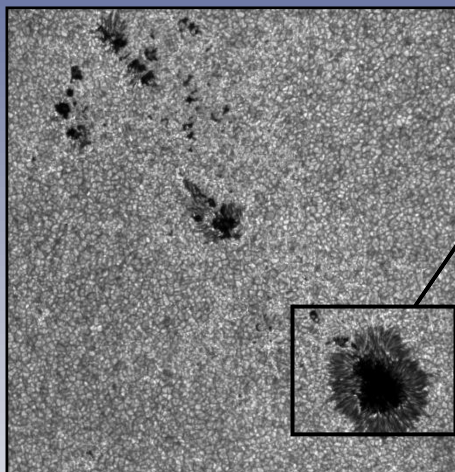
Why large Solar Telescopes?

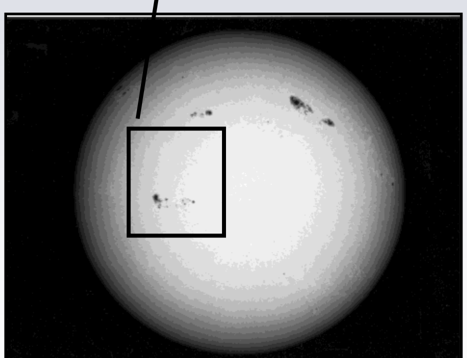


Secci, A., Le Soleil Pt. 1 and 2 (2nd Ed.), Gauthier-Villars, Paris 1877

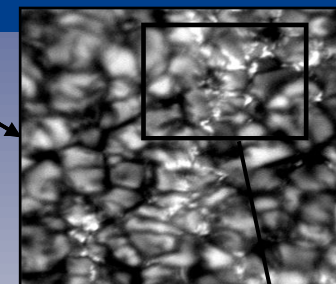
Why do we need Gregor?

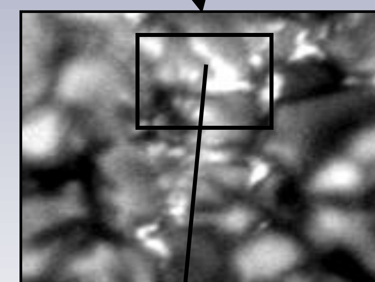


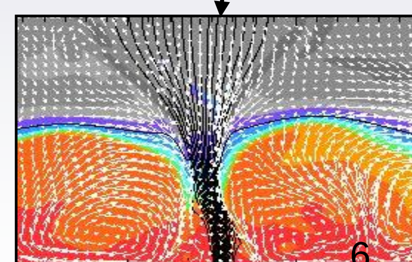




Most small scale solar features are caused by magnetic field and its interaction with the plasma

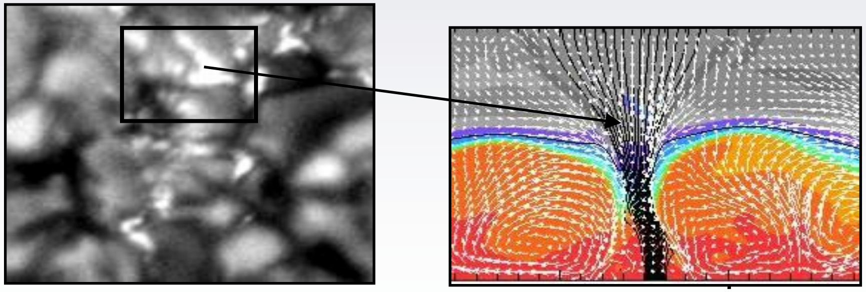


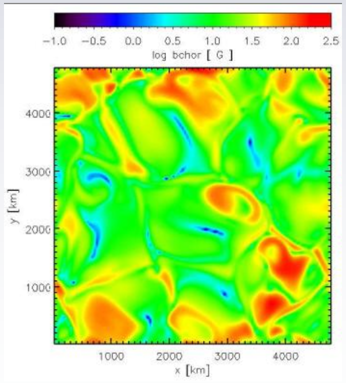


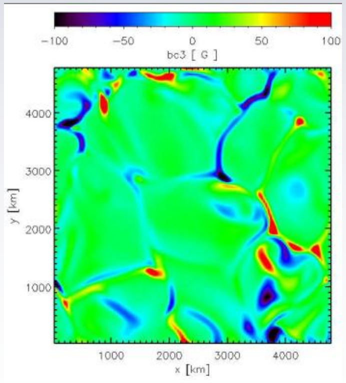


Scientific Goals with Gregor

- Study of the **dynamics and magnetic field** from the **photosphere** into the **chromosphere**
- Investigation of the photosphere/chromosphere as an **integrated system**
- Observations of small scale magnetic structures with **high spectral** and **spatial resolution** and **complete magnetic information** (full Stokes vector)
- Step between current and large solar telescopes like ATST and EST







Project Timeline

- 2001: GI
- 2001: Int
- 2003: De
- 2004: Er
- 2009: MI
- 2009: Int
  tes
- 2011: Int
- 2012: St

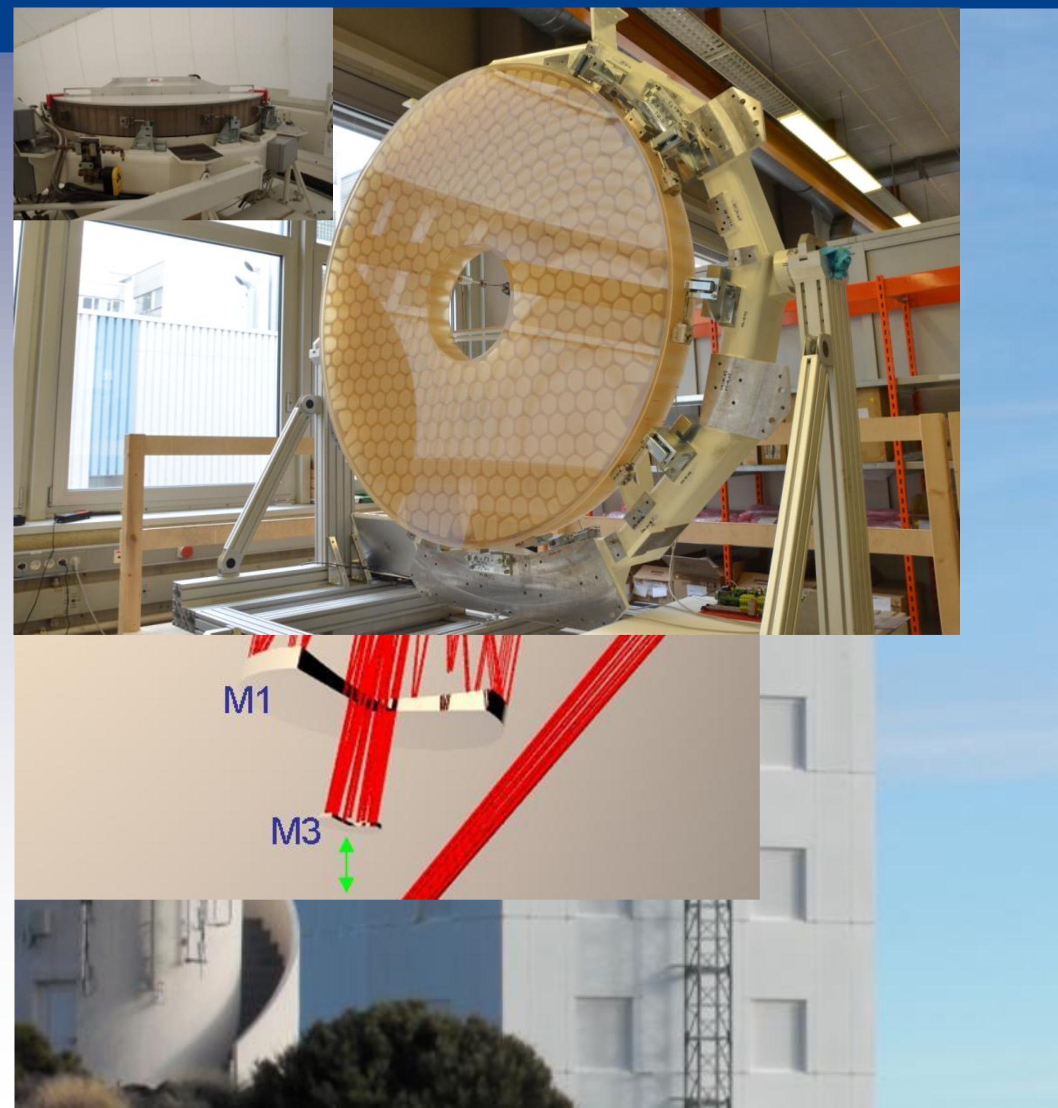
Project Cost Overview

Personnel, all partners	4.5 M€
Non-Personnel and Investments	8.4 M€
(STB Funding	4.5 M€)
(Gregor@Night	0.6 M€)
(HOAO (EU)	0.3 M€)
Total	12.9 M€

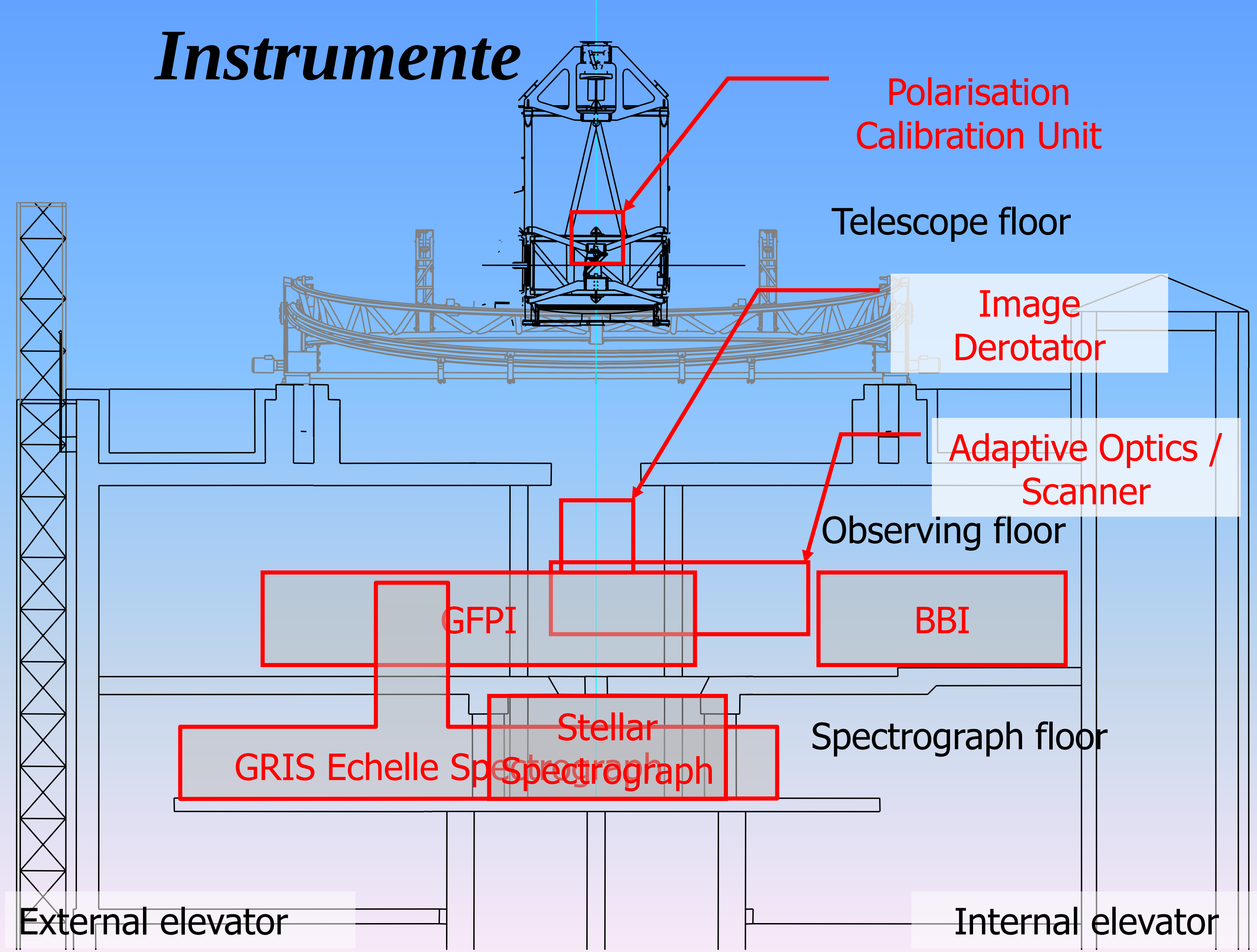
GREGOR Overview

- 1.5-meter aperture
- Primary mirror: f=2.5 m; light-weighted Zerodur, active cooling
- 3-mirror Gregory configuration
- Effective focal length: 55 m (*f/D*=38)
- Nominal field-of-view:

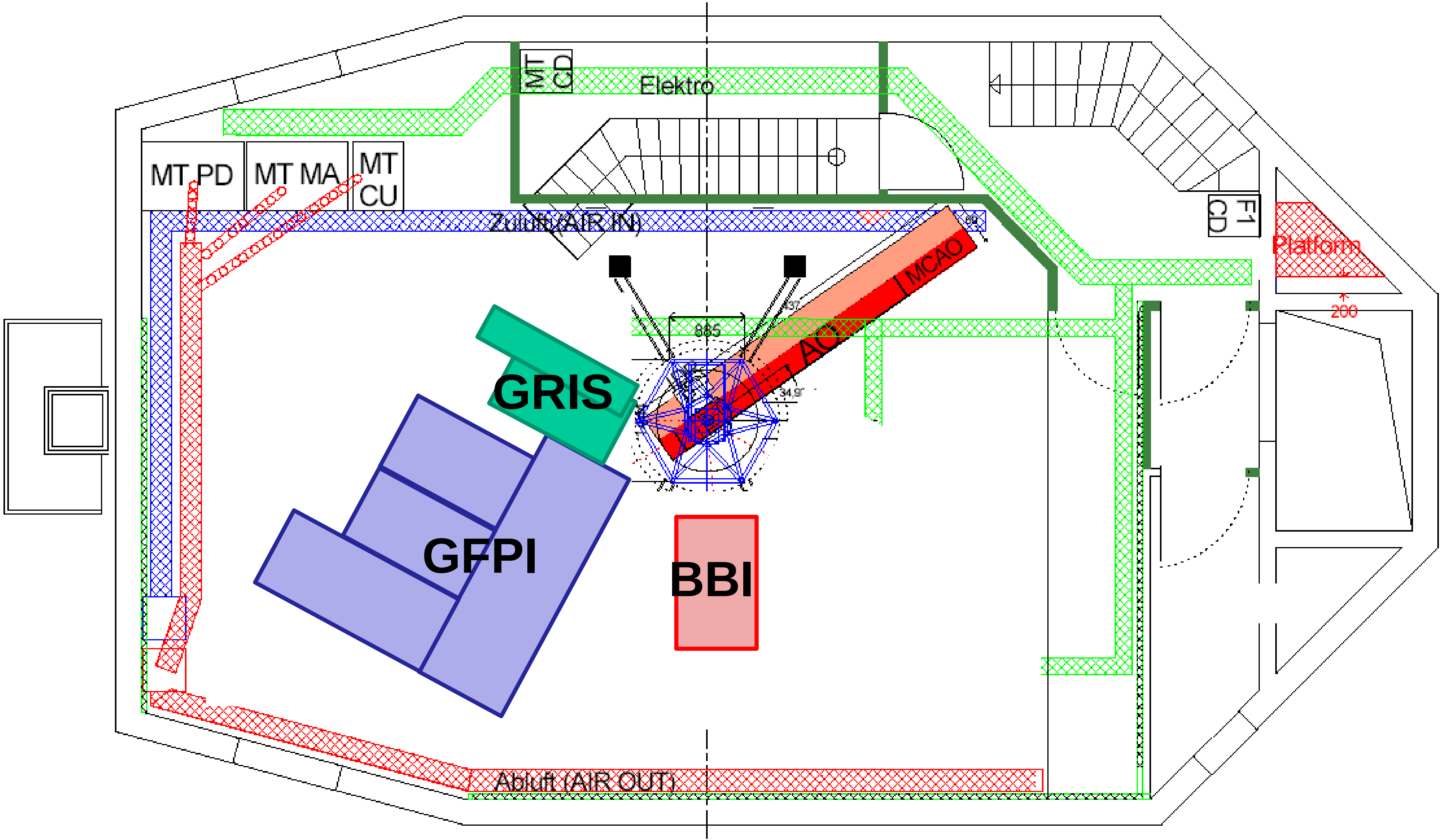
  150″ Ø
- Wavelength coverage: 350 nm – NIR
- Integrated adaptive optics



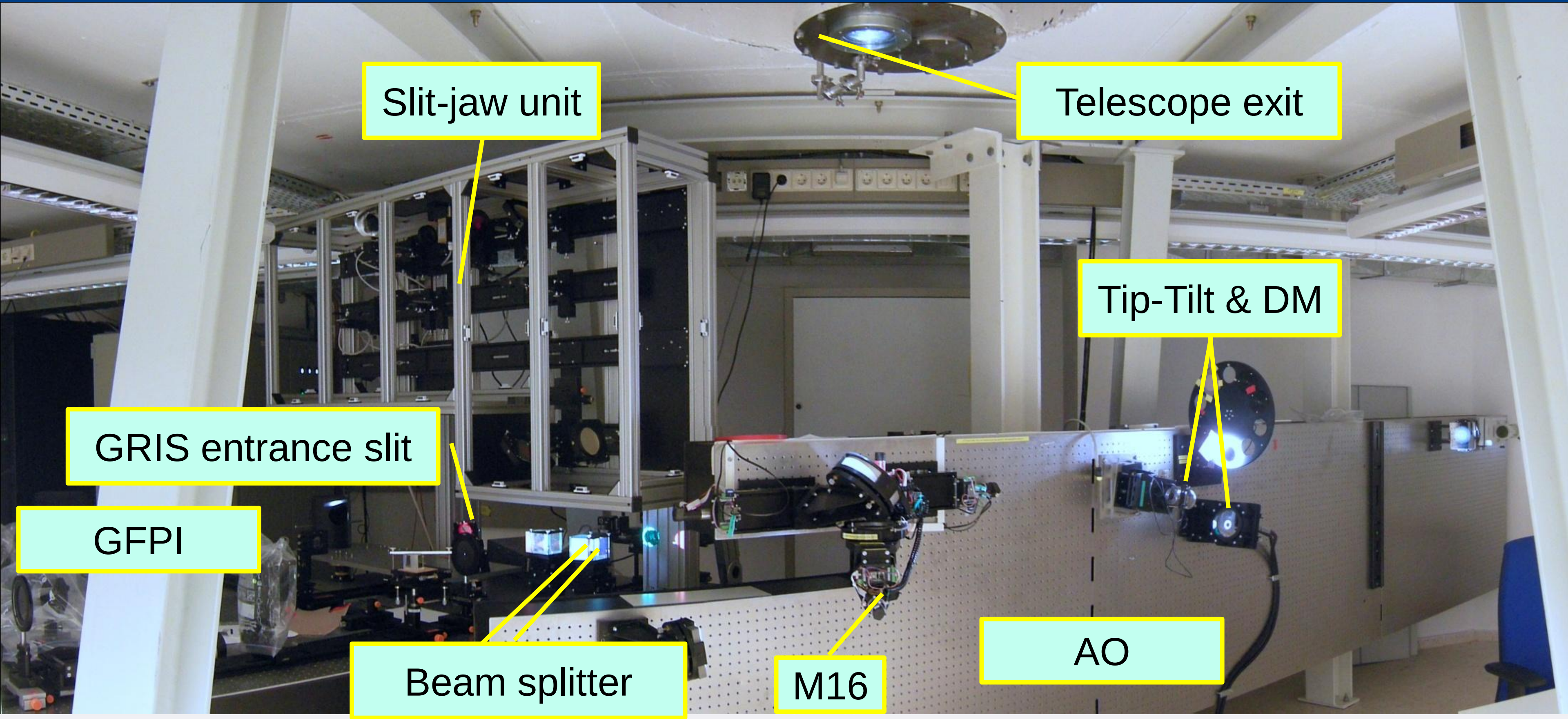
Instrumente



Instrument Floor



Optical laboratory

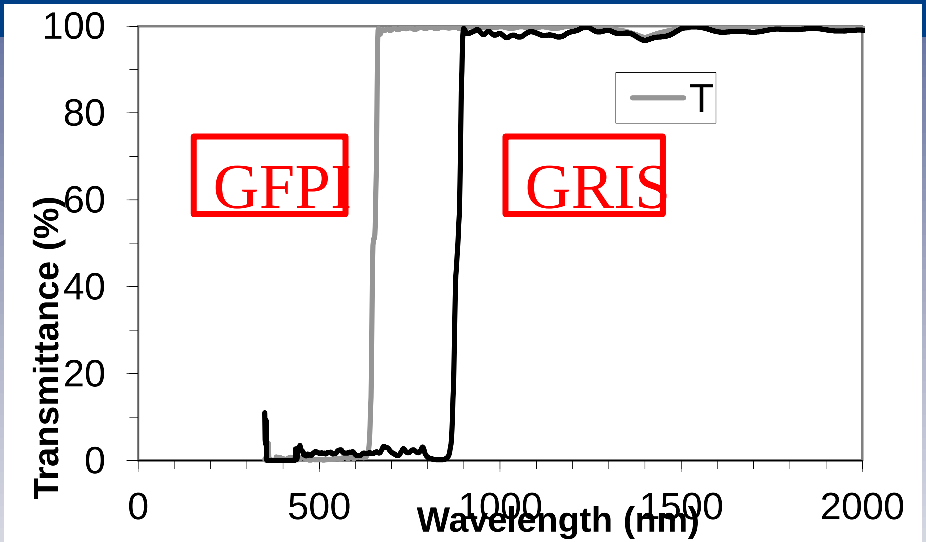


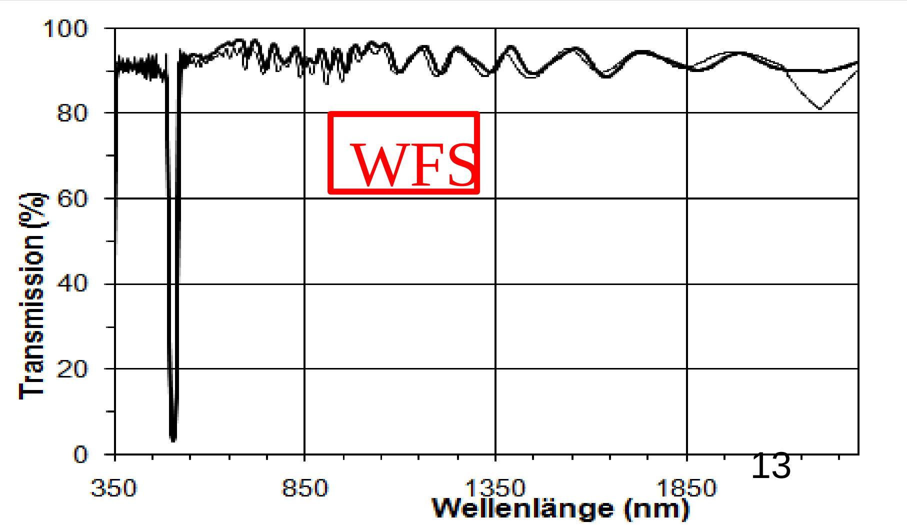
- High order AO, DM with approx 200 actuators (2011).
  First light DM with 80 actuators, MCAO in 2012
- M11 active (slow TipTilt) to compensate pupil image motion
- Image de-rotator in 2011

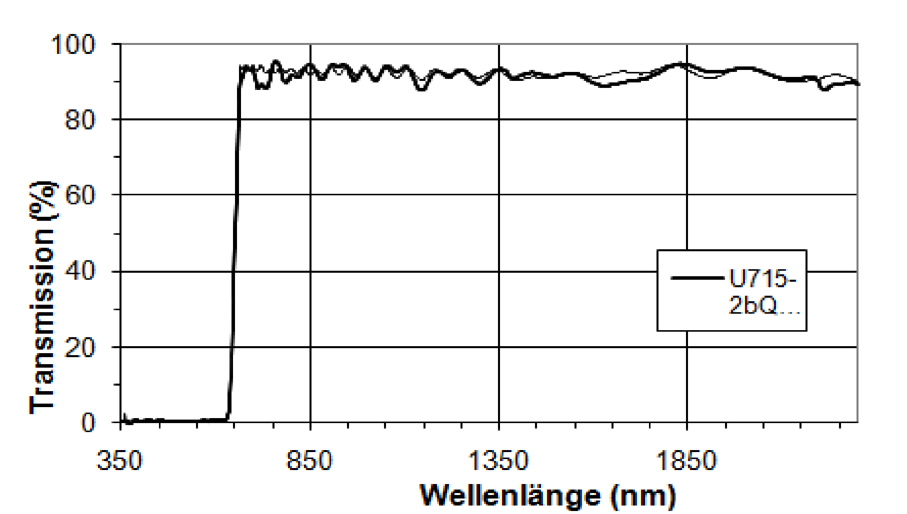
Optical laboratory

Light distribution system

- **M16**
- **Exchangeable dichroic beamsplitter: GFPI, GRIS (650nm; 900nm)**





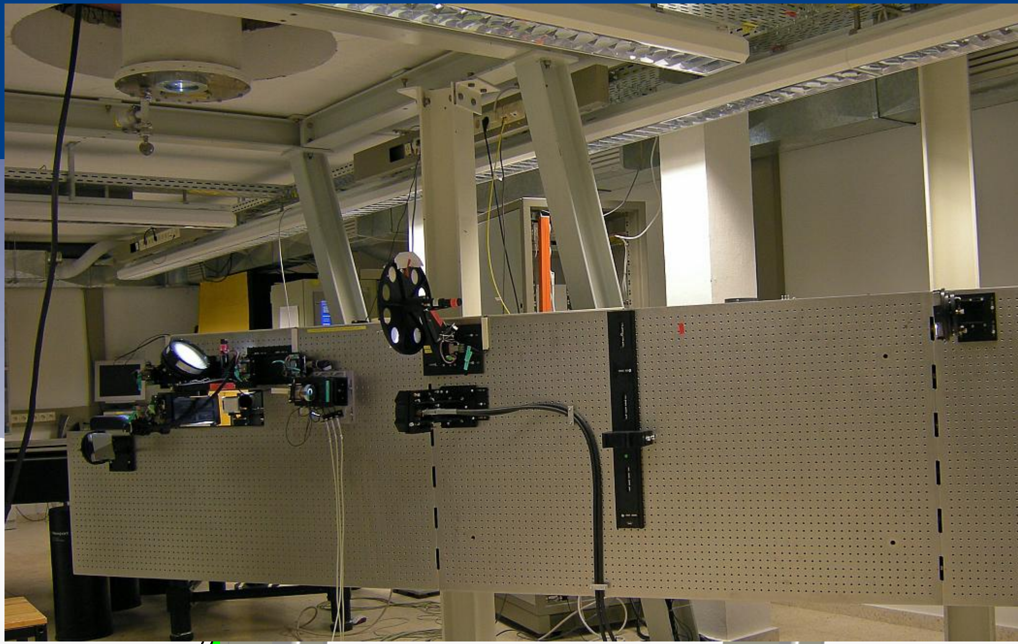


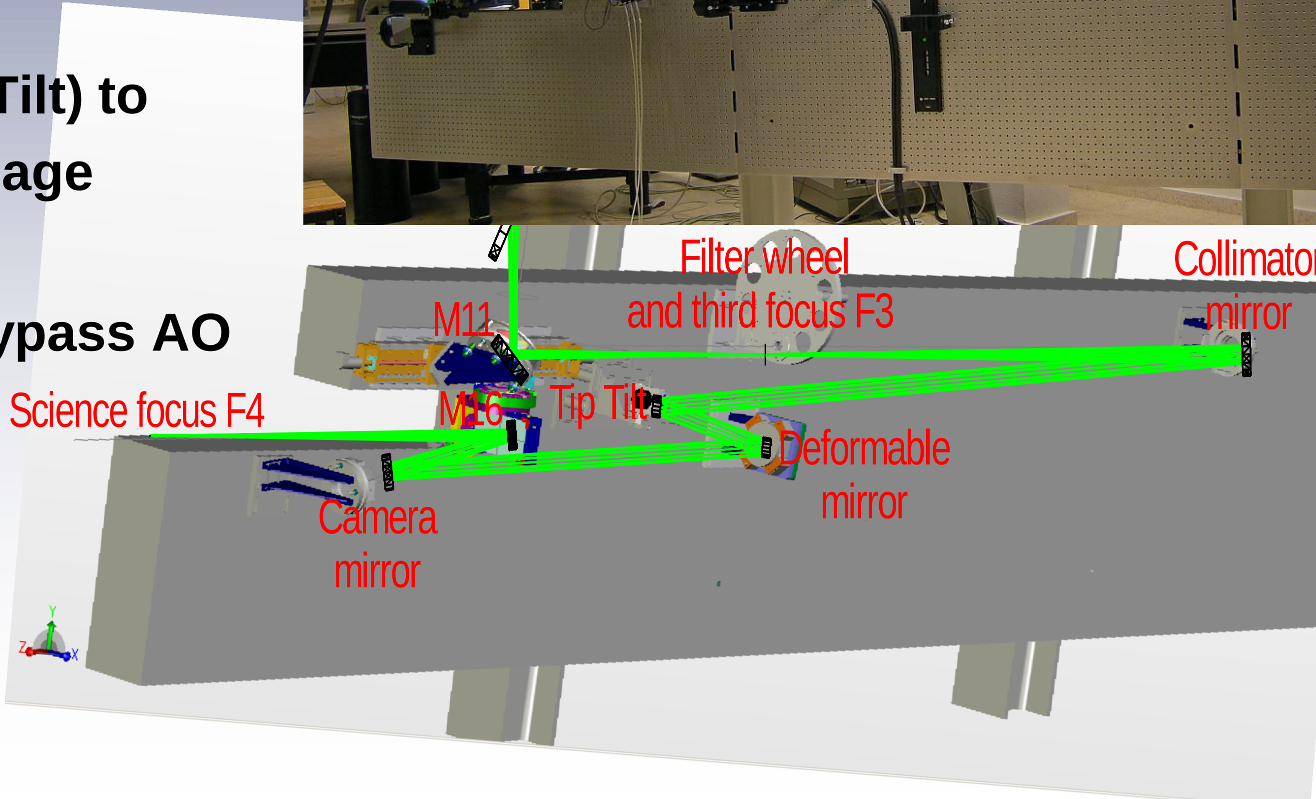
Optical laboratory

AO

- **High order AO, DM with approx 200 actuators (2011). First light DM with 80 actuators**

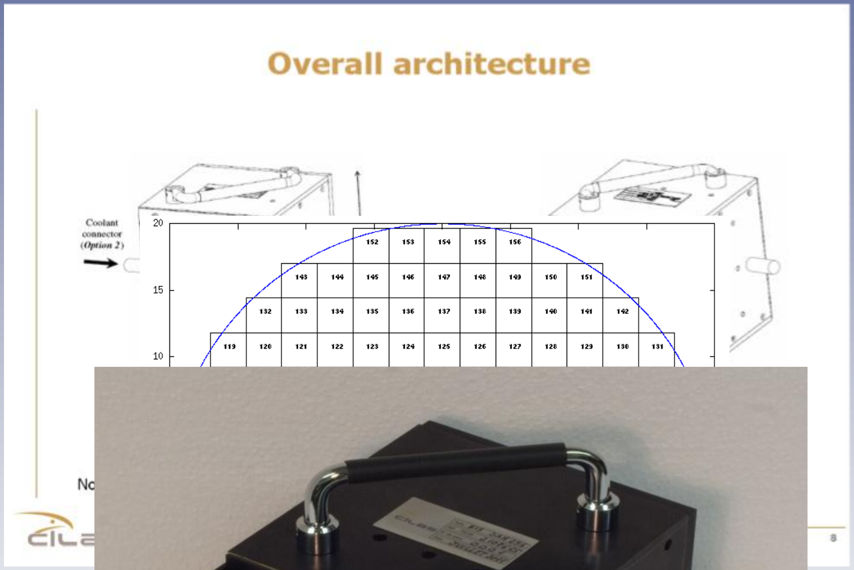
- **M11 active (slow TipTilt) to compensate pupil image motion**
- **removable M11 → bypass AO**





gAOS:
GREGOR (high order) Adaptive Optics System

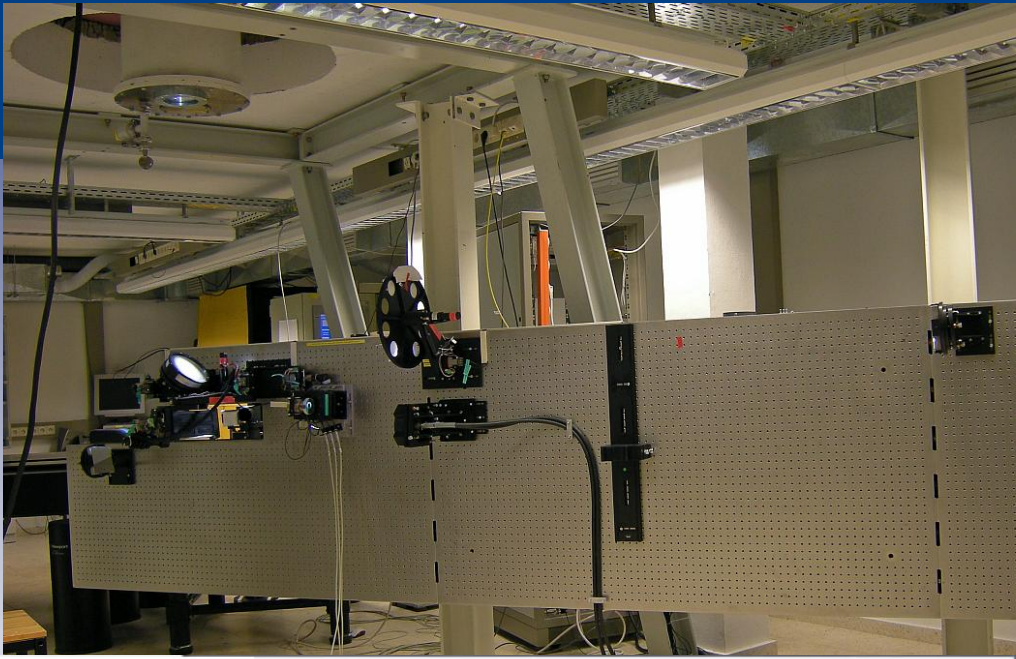
- 50mm TipTilt with ±30´´range
- 50 mm DM, made by CILAS
- 6 µm stroke
- 3.2 mm actuator spacing, 100 mm projected on the pupil
- 196 active actuators
- Mikrotron EOsens camera (400x400pixels, 3.3 kHz frame rate)
- 24x24 pixels per subaperture, 10” FoV
- bandwidth (0db) = 150 Hz
- WFS next to science instrument
- Installation: Jan. 2012

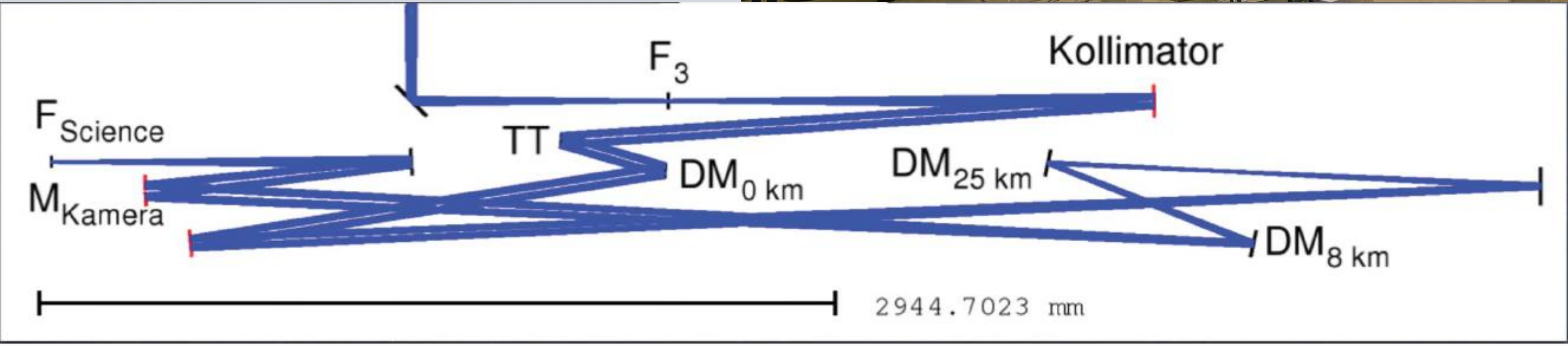


Optical laboratory

MCAO

- **MCAO with two high layer DMs (2012)**
- **FOV 60 arcsec**





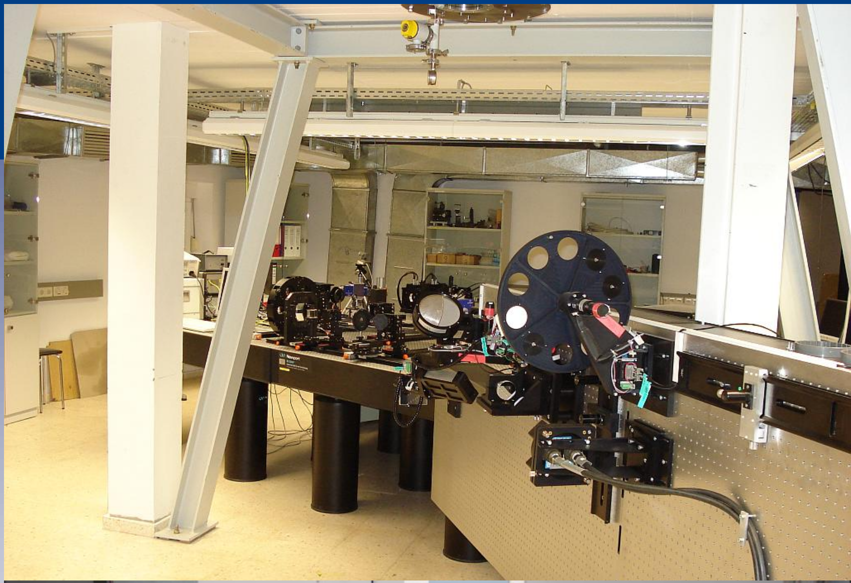
MCAO testbed @ KIS

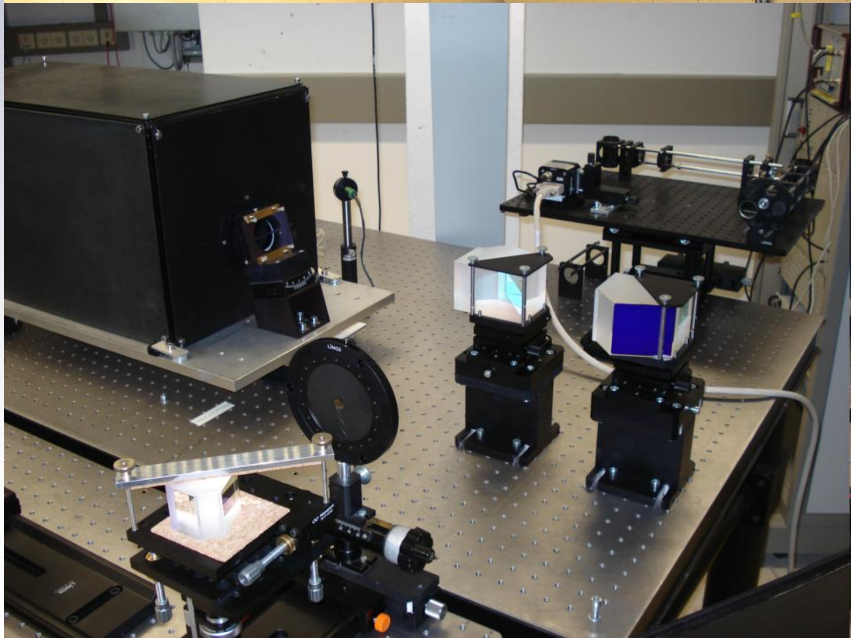
Optical laboratory

- **First light spectro-polarimetry**
  - GFPI: Double FPI filtergraph with full Stokes polarimeter
  - GRIS: Infrared Slit-spectrograph with full stokes vector polarimetry; Slit-jaw unit (H_α; IR_{cont}; 3^{rd} TBD)

- **Simultaneous observation with GFPI and GRIS from the beginning**

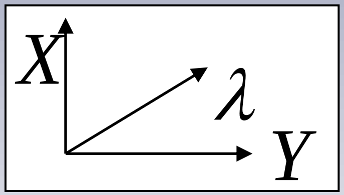
- **Broad Band Imager**
  - Speckle reconstruction

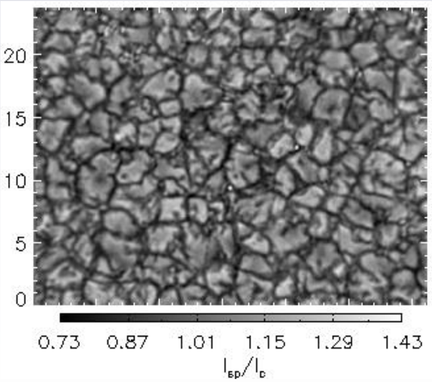


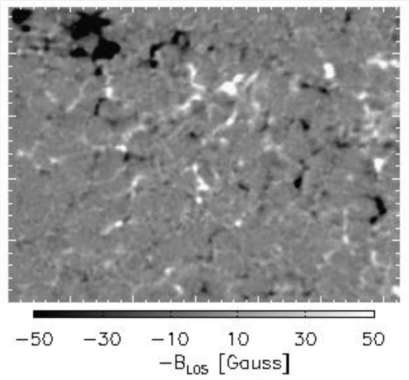


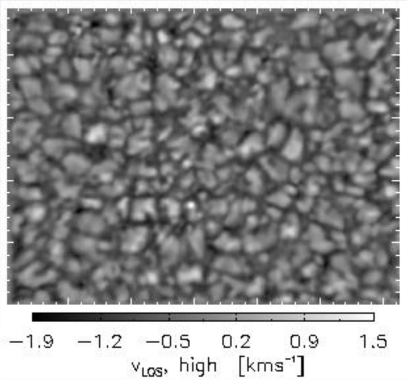
Panoramic Spectropolarimeter (GFPI)

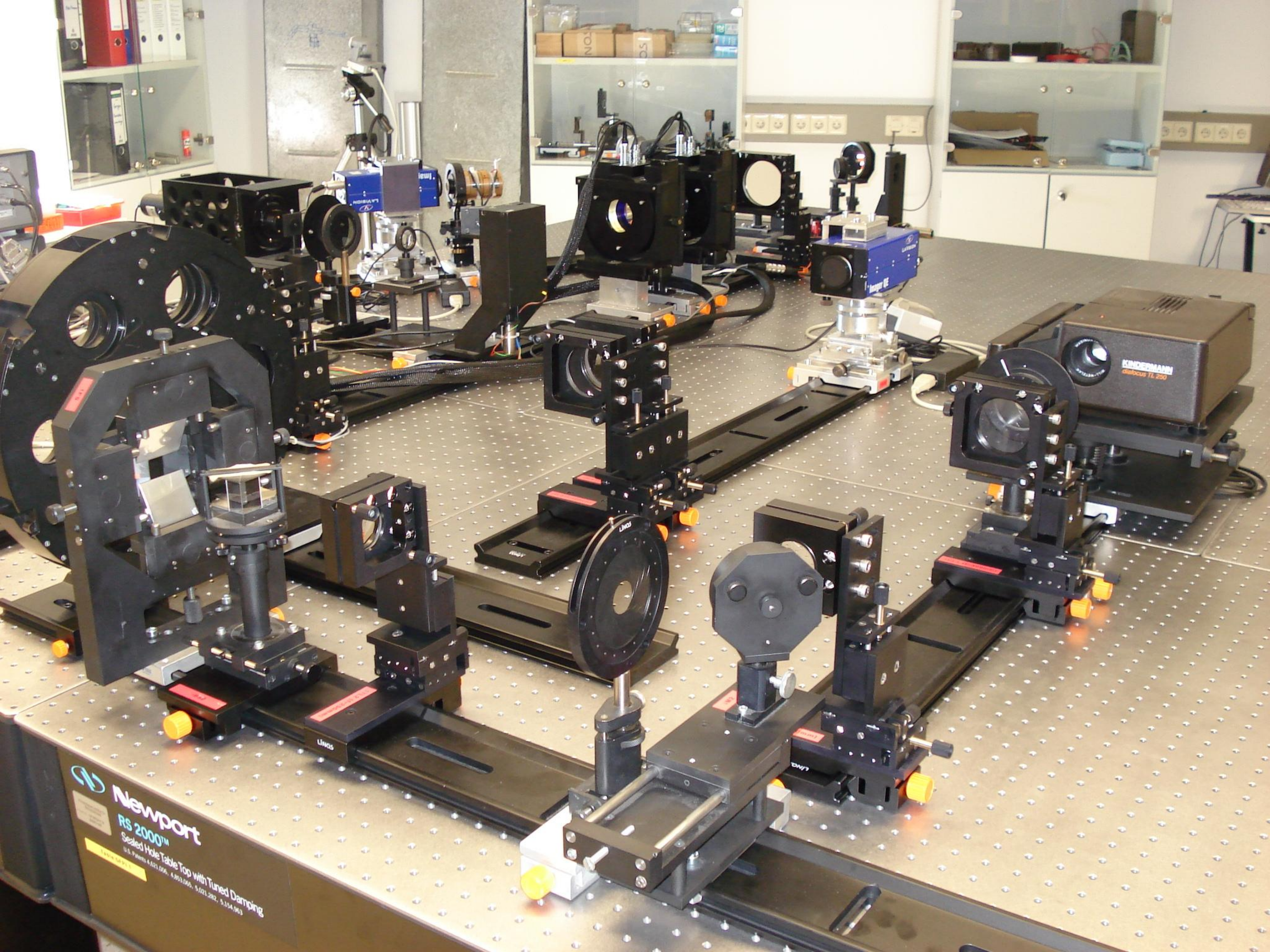
- 2 serial FPI in collimated beam
- 77″ × 58″
- spectral resolution: $\Delta\lambda < 4$ pm → $\lambda / \Delta\lambda \sim 200.000$
- 530 nm – 870 nm
- Full Stokes polarimetry
- Refurbished "Göttinger FPI" / VTT / Tenerife
- Preliminary setup tested at VTT
- Extension with blue channel (below 530 nm) planned





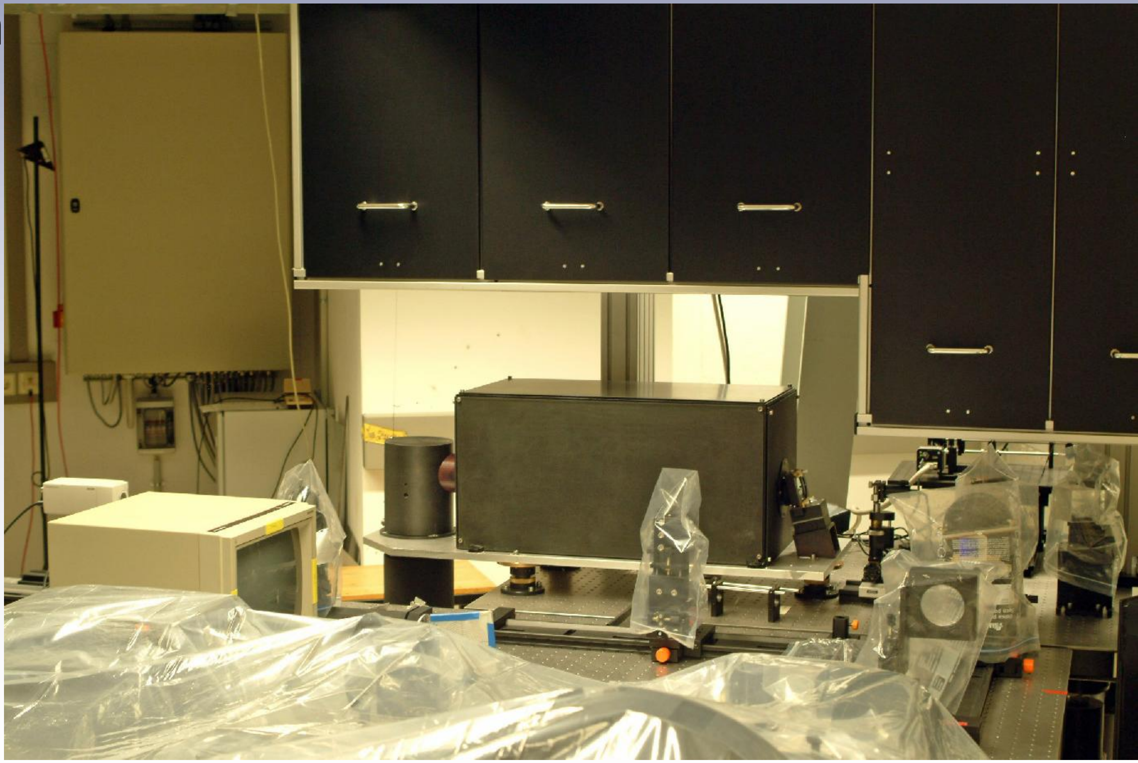





Newport
RS 2000™
Sealed Hole Table Top with Tuned Damping
KINDERMANN
diafocus TL 250
LINOS
LaVision
Imager QE

GRating Infrared Spectrograph (GRIS)

- Long-slit spectrograph including full Stokes polarimetry in IR (similar to TIP / VTT / Tenerife)
- Slit jaw device with high speed cameras (Hα, IR cont. + ?)
- Extension to visible wavelen

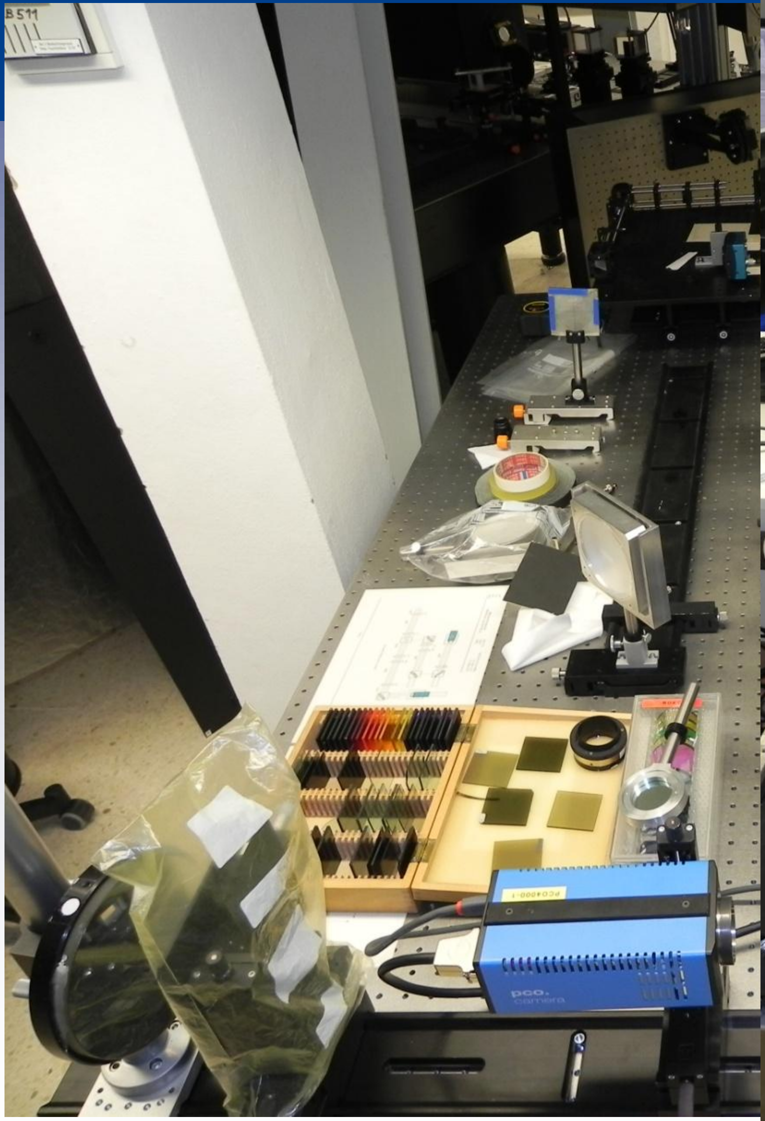


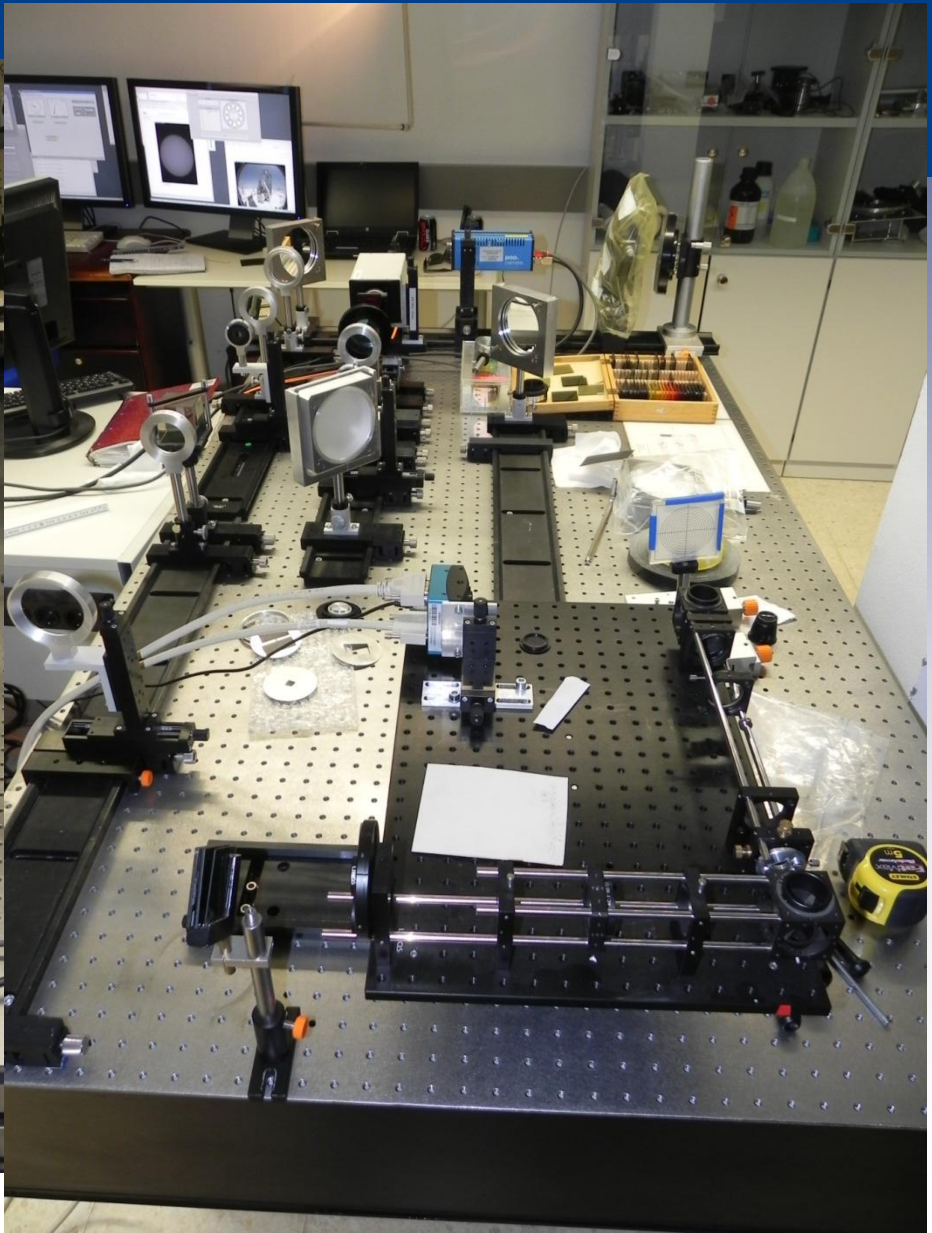
Technical data
Spatial sampling
Spatial coverage

Spectral sampling @ 1083 nm
Spectral coverage @ 1083 nm

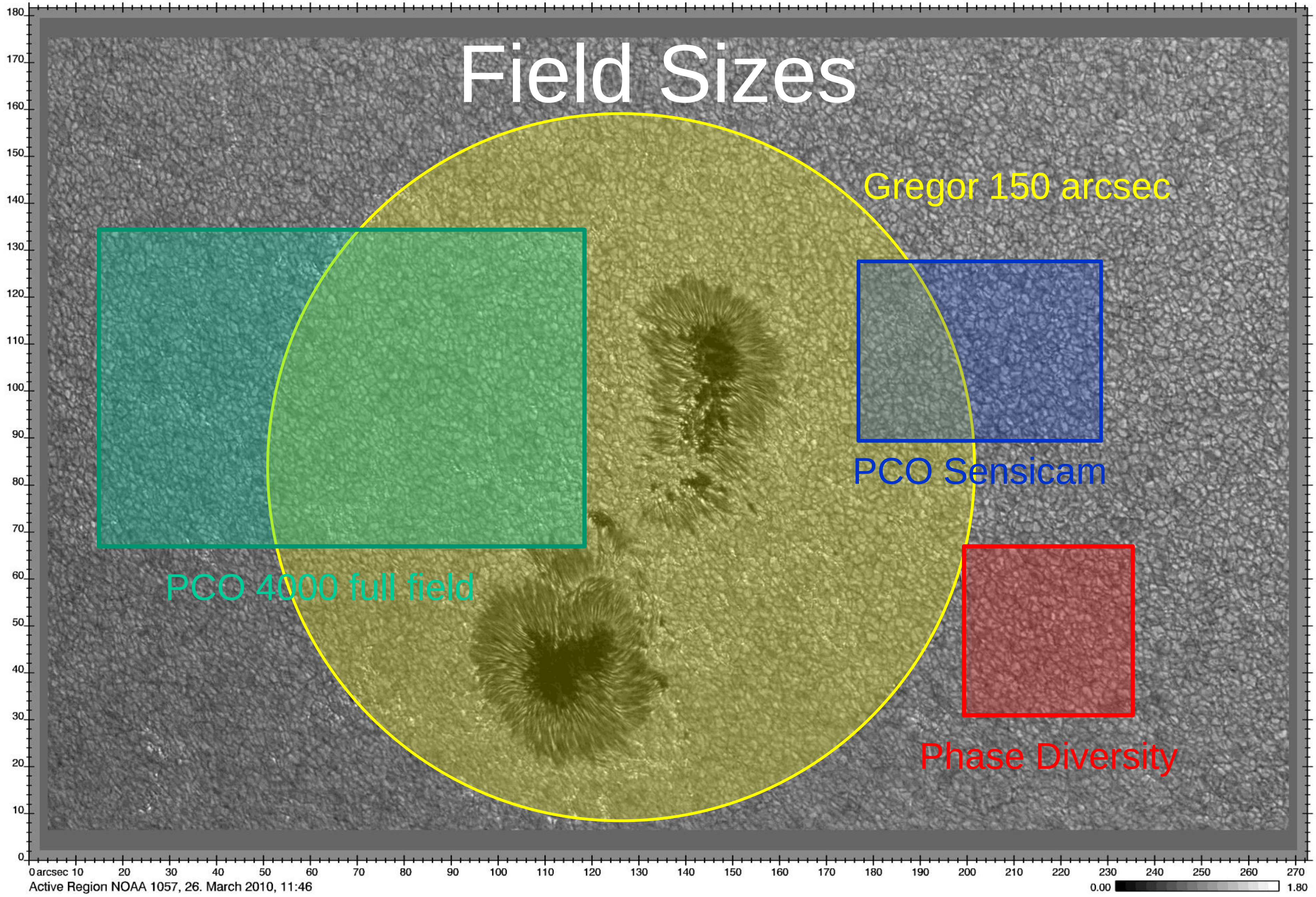
Spectral sampling @ 1565 nm
Spectral coverage @ 1565 nm

Broadband Imager





Field Sizes


Gregor 150 arcsec
PCO Sensicam
PCO 4000 full field
Phase Diversity
0 arcsec 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270
0.00 1.80
Active Region NOAA 1057, 26. March 2010, 11:46

Beyond 2012
GREGOR @ Night

Night-time observations with GREGOR will be used for a large survey to search for solar twins. To this end, a high-resolution stellar spectrograph, *GREGOR@ Night*, will be developed jointly by KIS and the AIP. The spectrograph will be installed in 2013.

Stellar Spectrograph

observation of solar-like stars (F–M)

► photospheric lines

► chromospheric emission

resolution ***l***/D***l*** ~ 100.000

long-term observations

► rotation up to 100 d

► cycle up to 20 a or more

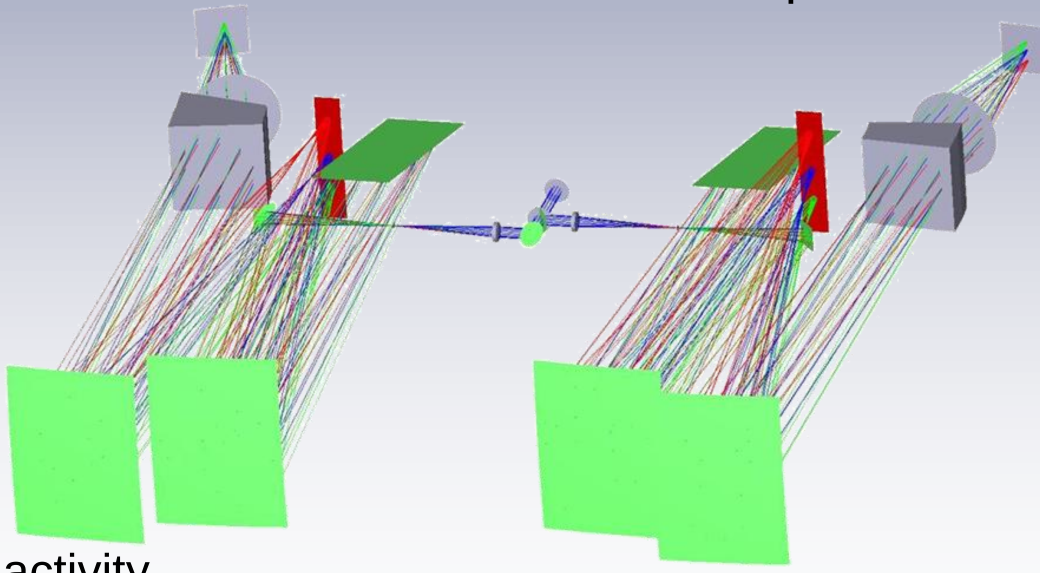
need for dedicated telescopes

fully robotic night-time mode

► fiber-fed double
echelle spectrograph (F2)

► environment sensors for
robotic mode

► use STELLA heritage
(2 x 1.2m in Tenerife)



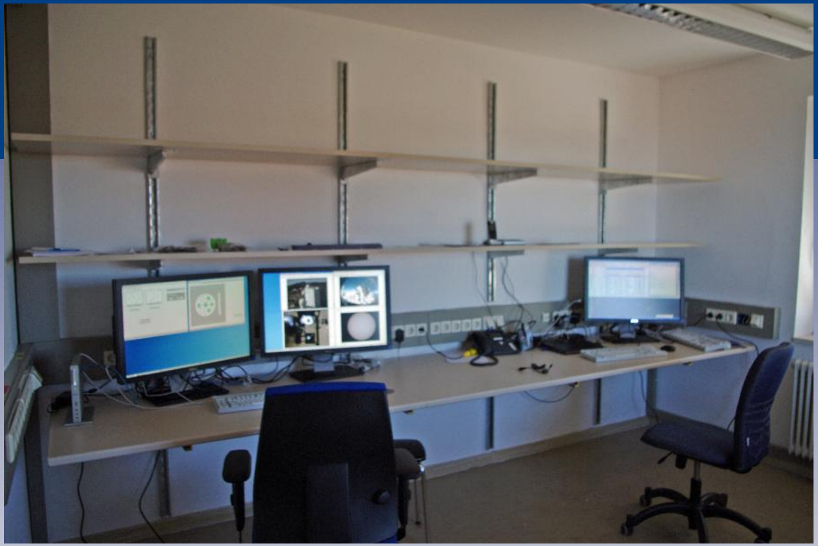
science drivers:

► photospheric & chromopsheric stellar activity

► spectroscopy of candidates for planetary systems
discovered by COROT, EDDINGTON, KEPLER → test e.g. rotational modulation

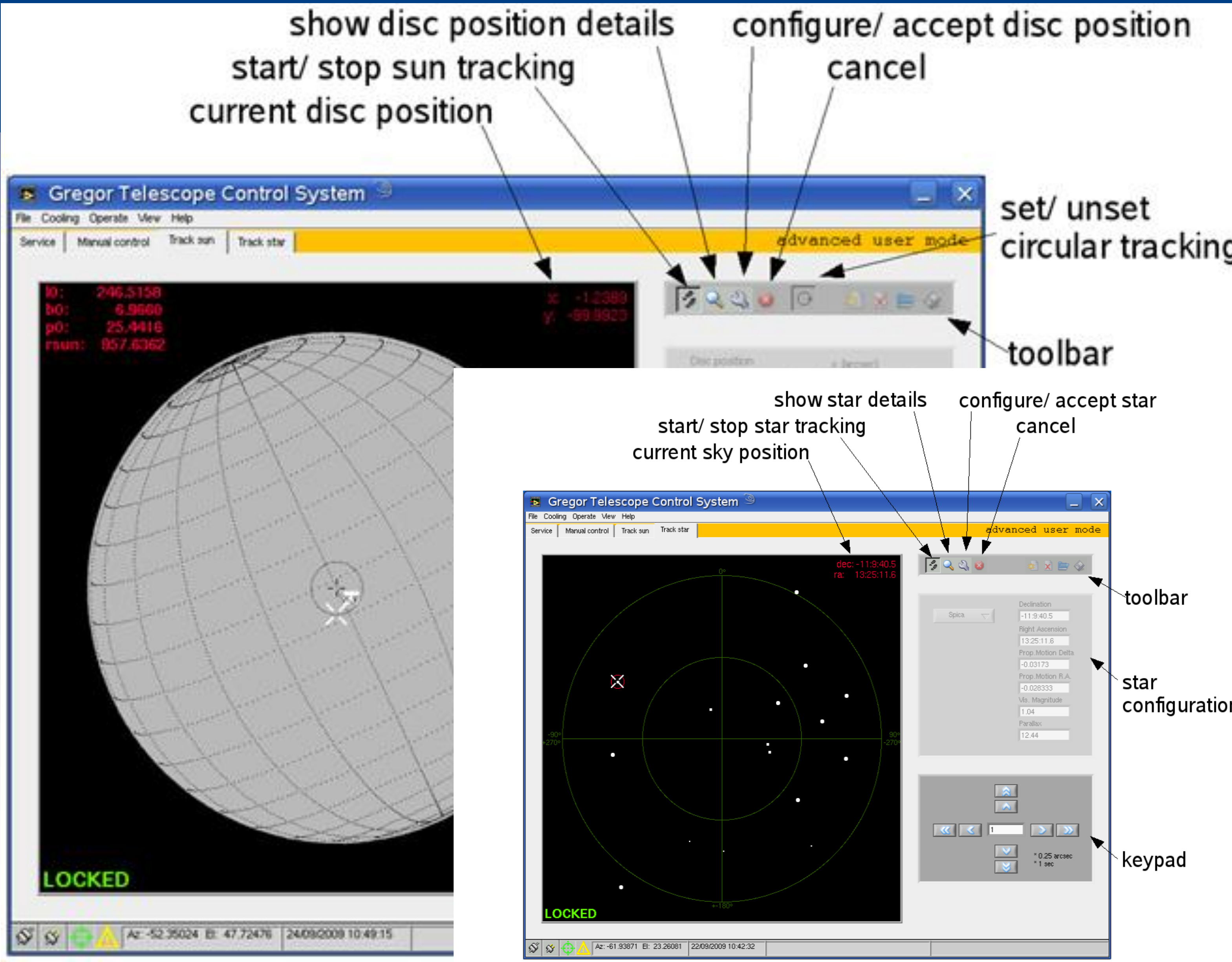
Control system

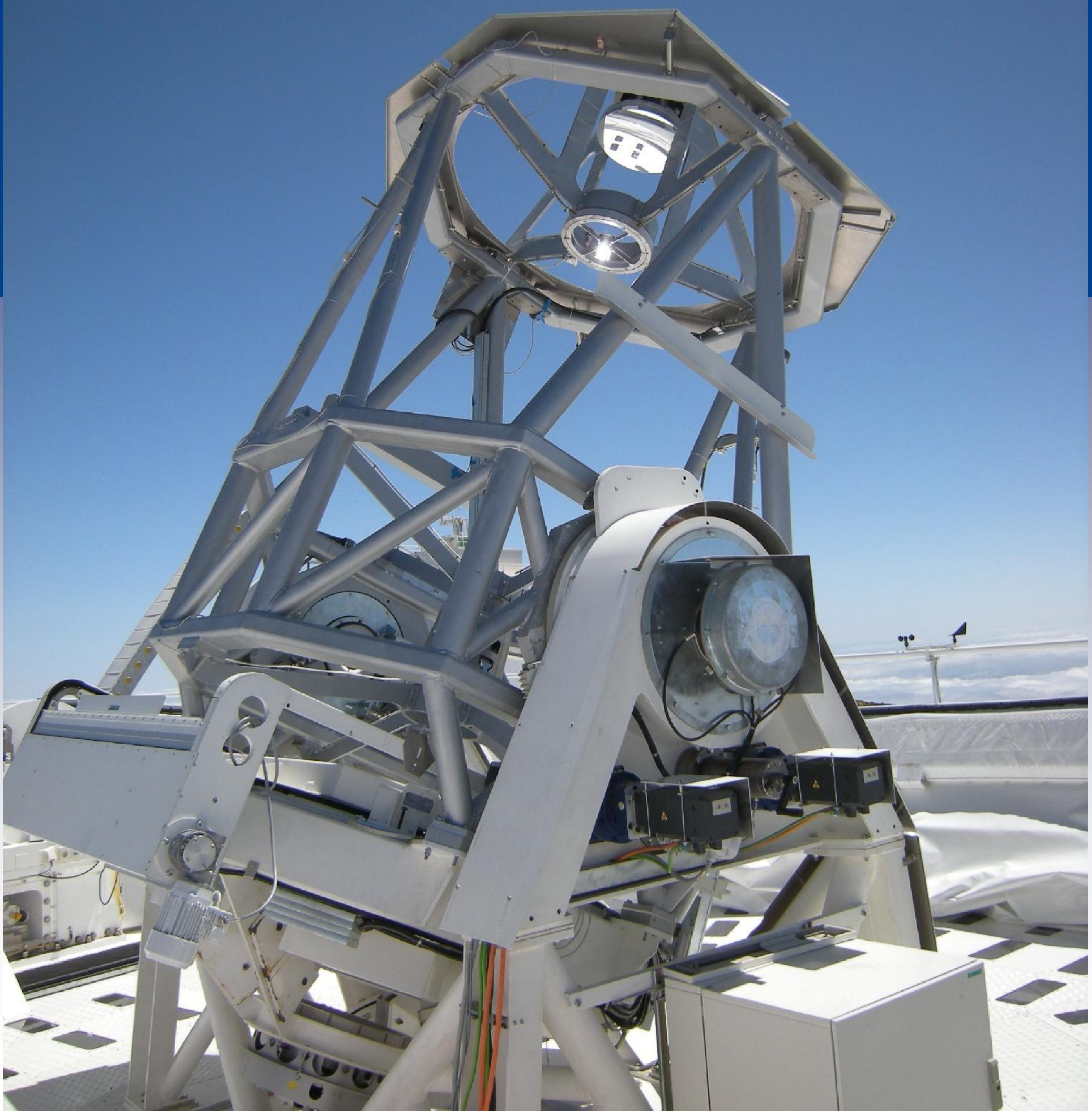
- Complete remote control
- GUI
- DCP commands
  - Between all instruments
  - From shell (e.g. script, command line)
    start track sun: *“dcp gtcs trackmode 1“*
- Trigger bus to synchronize instruments and cameras (incl. at VTT)



Control system

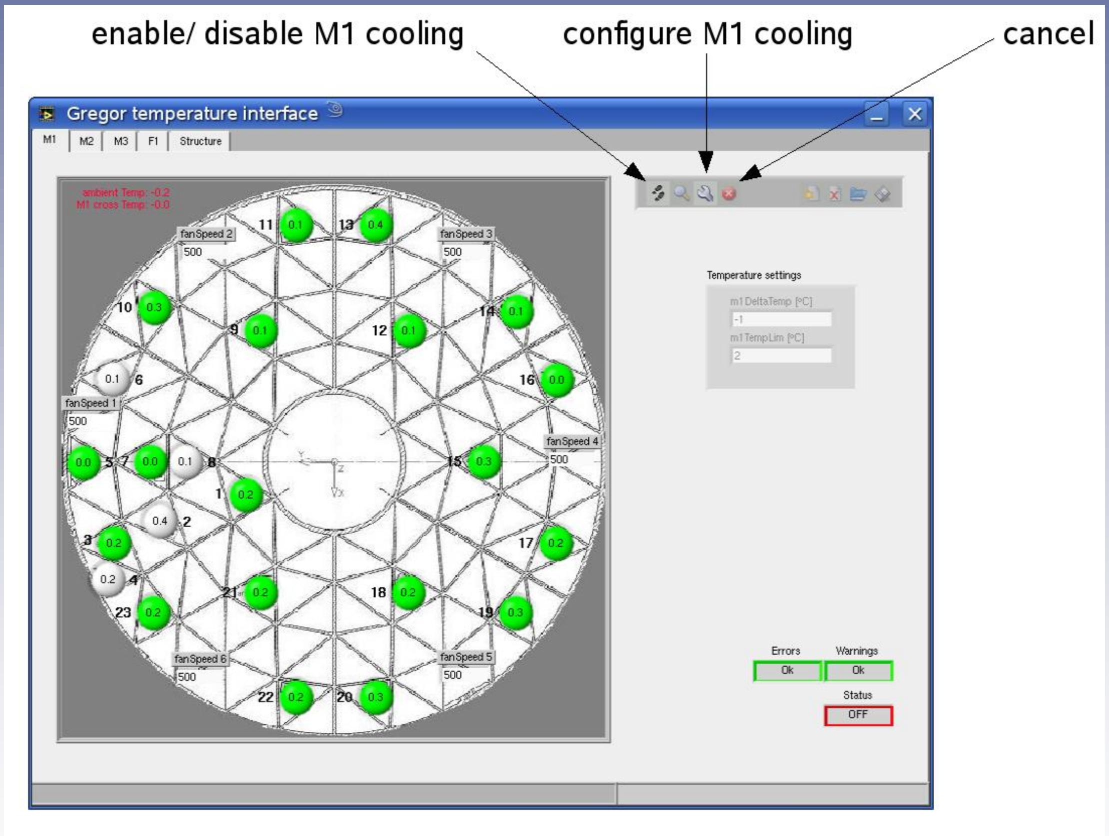
GUI





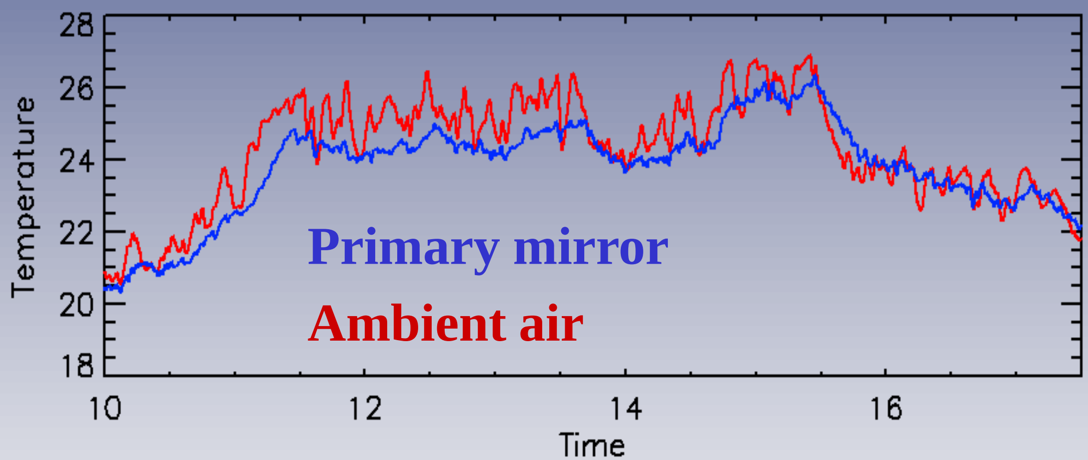
Primary mirror, field

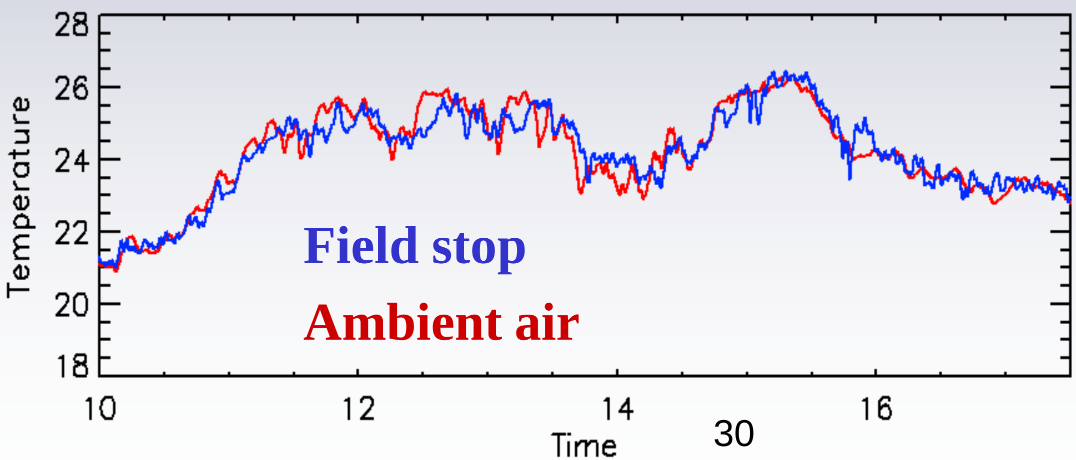
Cooling



Cooling system tests

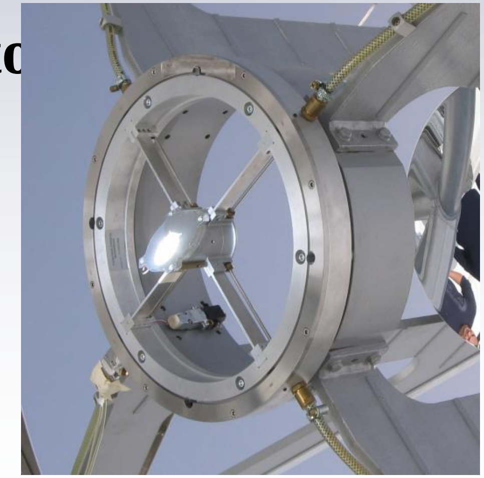
Primary 1m mirror and field stop



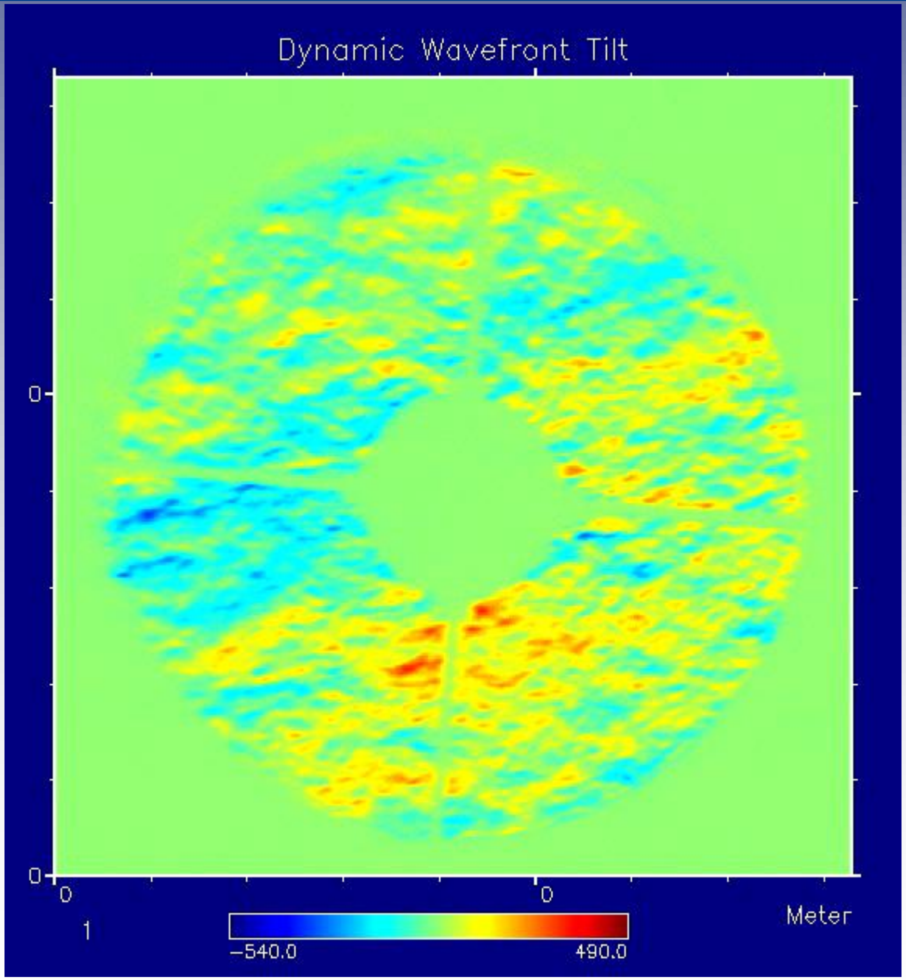


Primary mirror was slightly overcooled, to avoid large positive temperature differences to ambient temperature
→ 1.5m M1 needs more powerful cooling system!

Fail safe tests of field sto



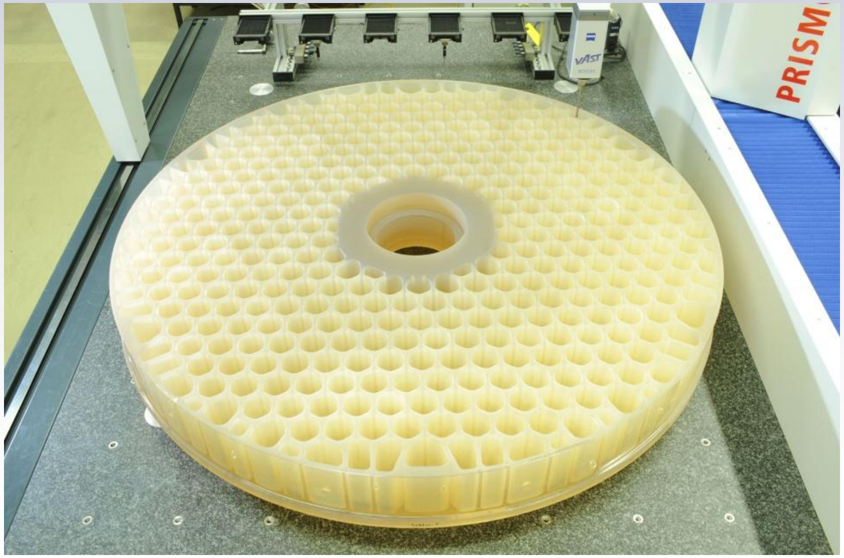
Dynamic wavefront tilt in pupil

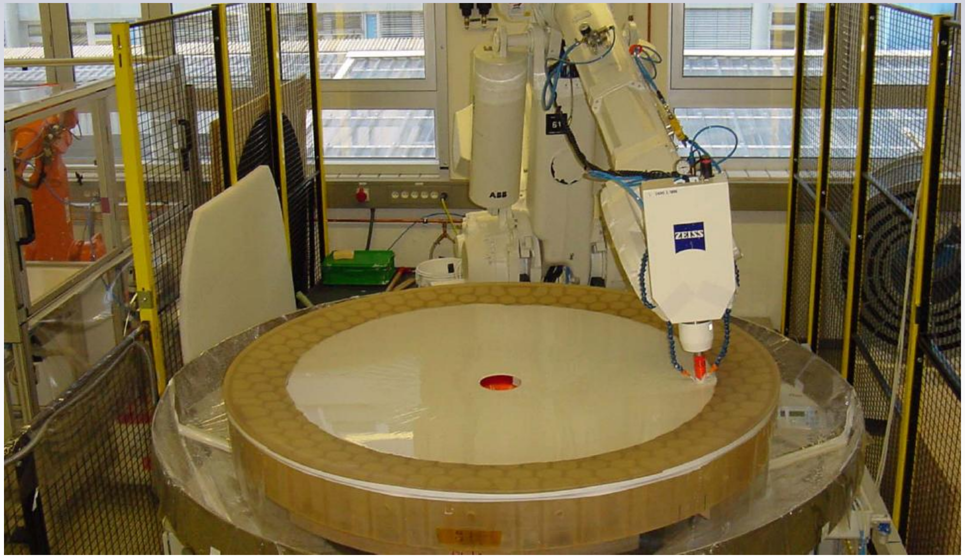


Primary mirror

Overview

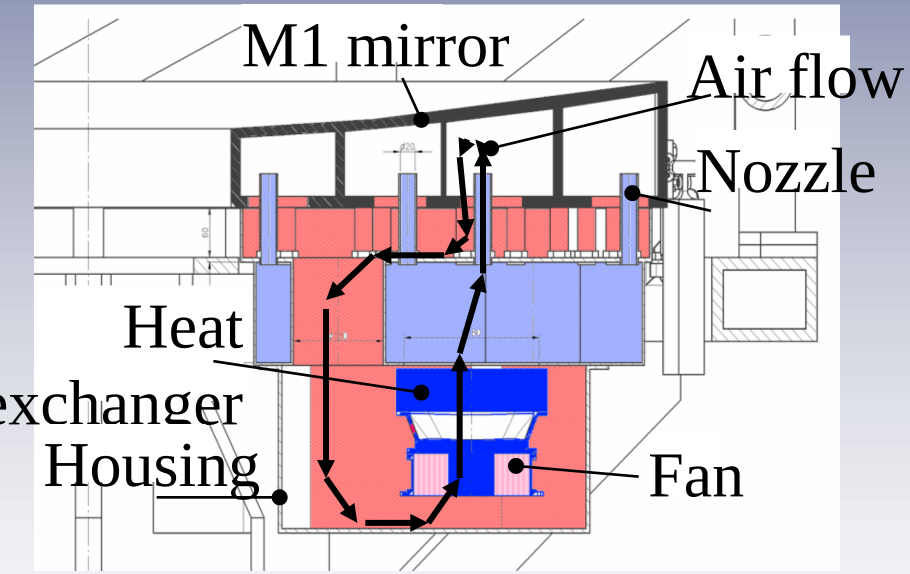
- **Originally planned Cesic mirror replaced by light weighted Zerodur mirror (~205kg)**
- **Summer 2009: Start of polishing @ Zeiss**
- **Zerodur mirror requires redesign of mirror cell und cooling system (Zerodur less stiff, less thermal conductivity than Cesic)**

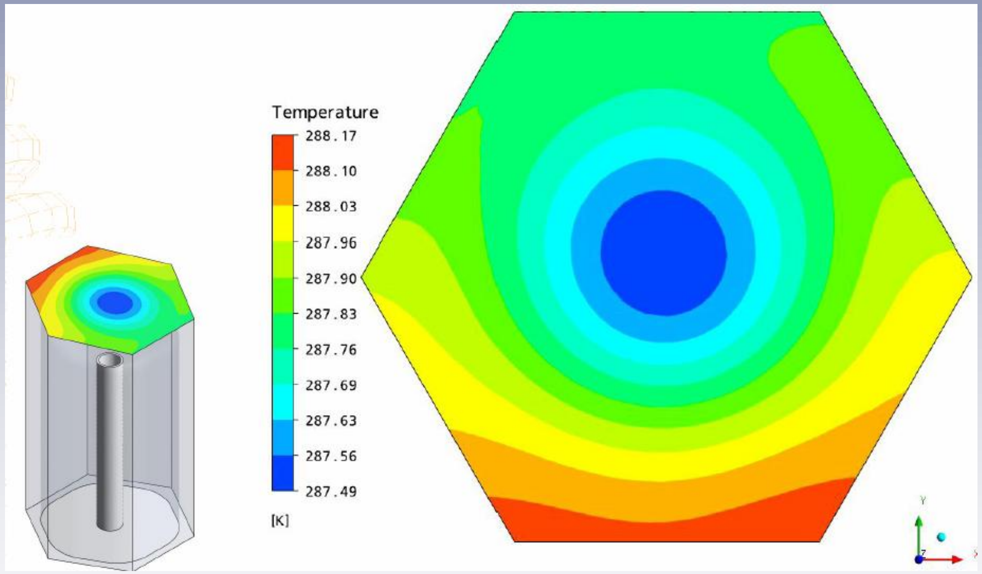




Primary mirror

Cooling principle

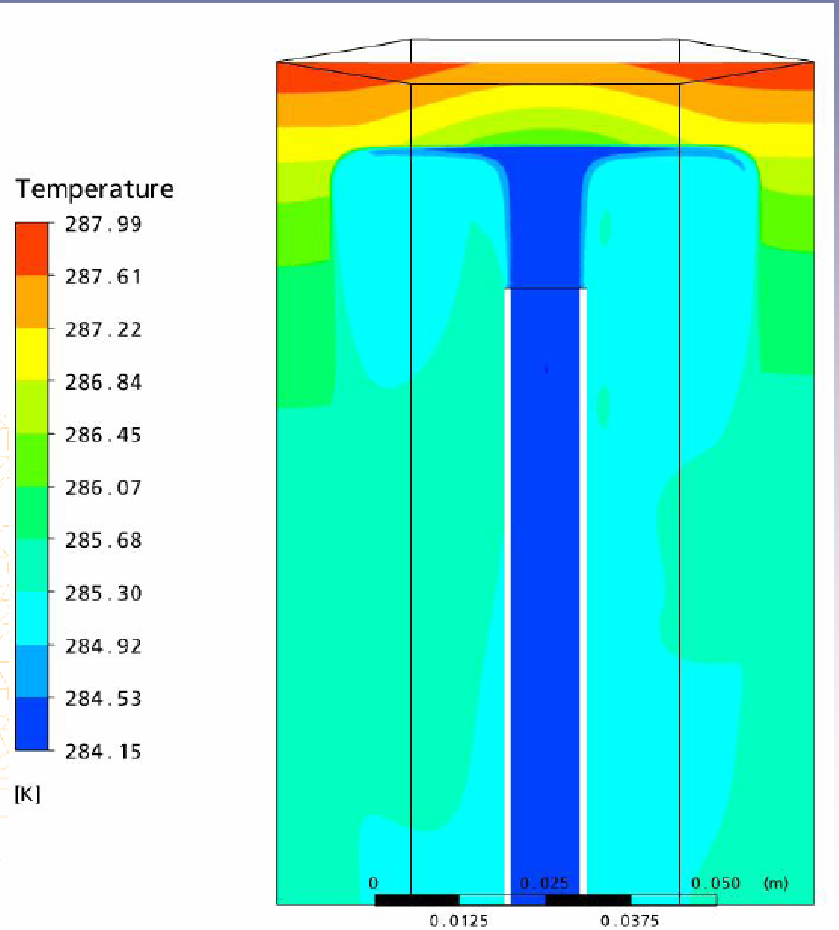




- ≈ 0.4 - 0.6 °C gradient across one cooling cell

Study of Zerodur primary mirror

Temperature gradient: face sheet → back side

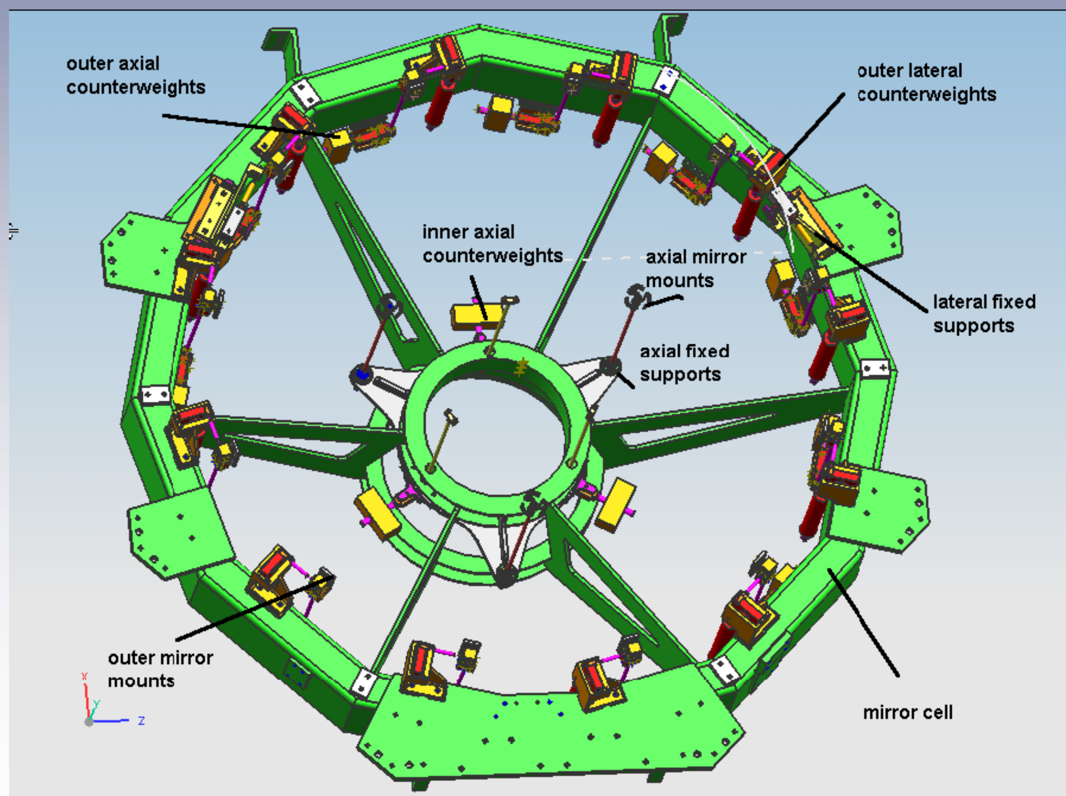


- **≈ 2 °C gradient from top to bottom**
- **≈ 0.4 - 0.6 °C gradient across one cooling cell**

Primary mirror

Support system (mirror cell)

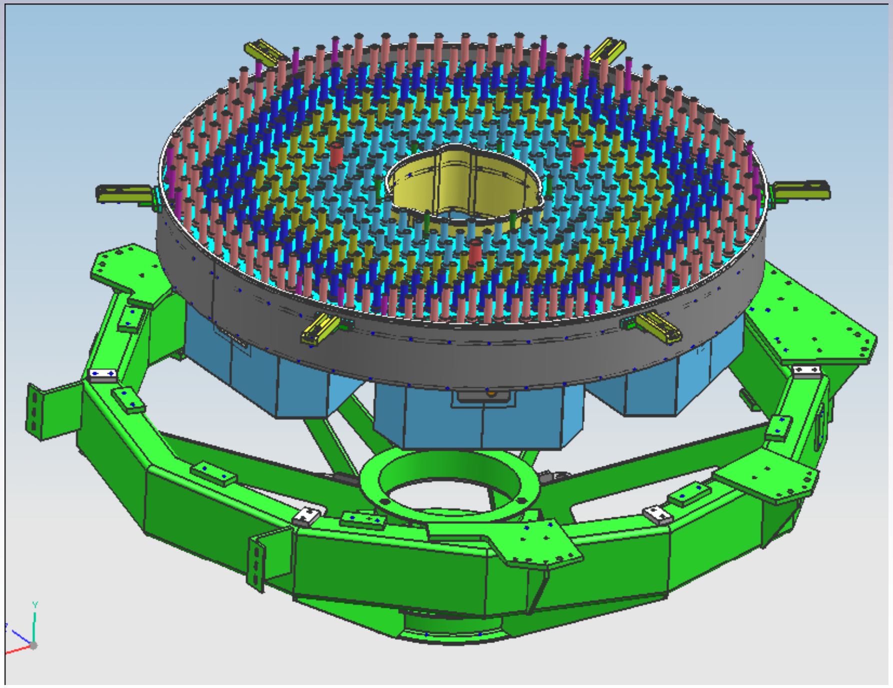
- **12 lateral and 12 axial astatic mounts (with counterweights)**
- **3 lateral and 3 axial static mounts**

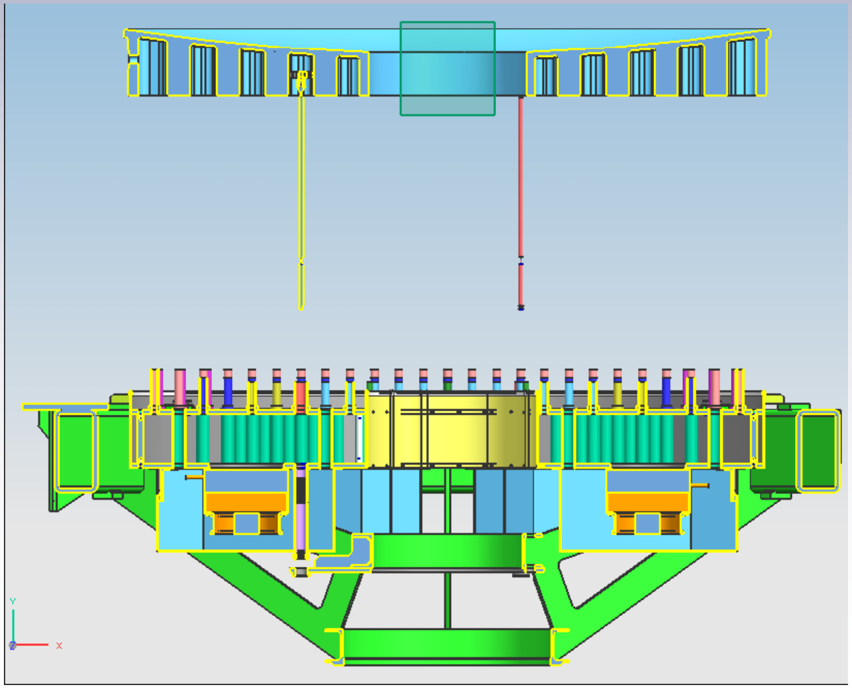


Primary mirror

Assembly

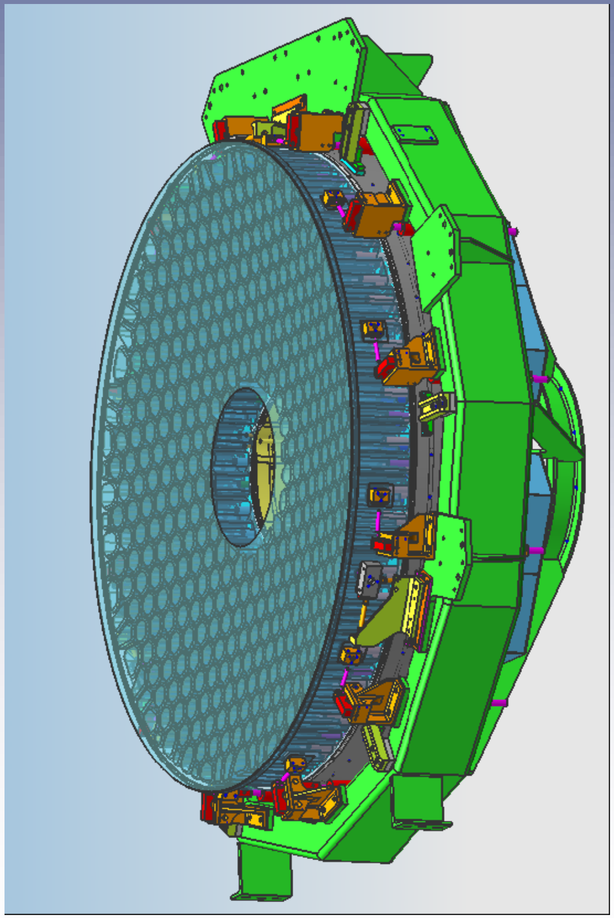
- Assembly of the cooling system to the M1 cell (beside the telescope)
- Assembly of the primary mirror to the M1 cell (beside the telescope)
- Attaching the mirror cell to telescope structure

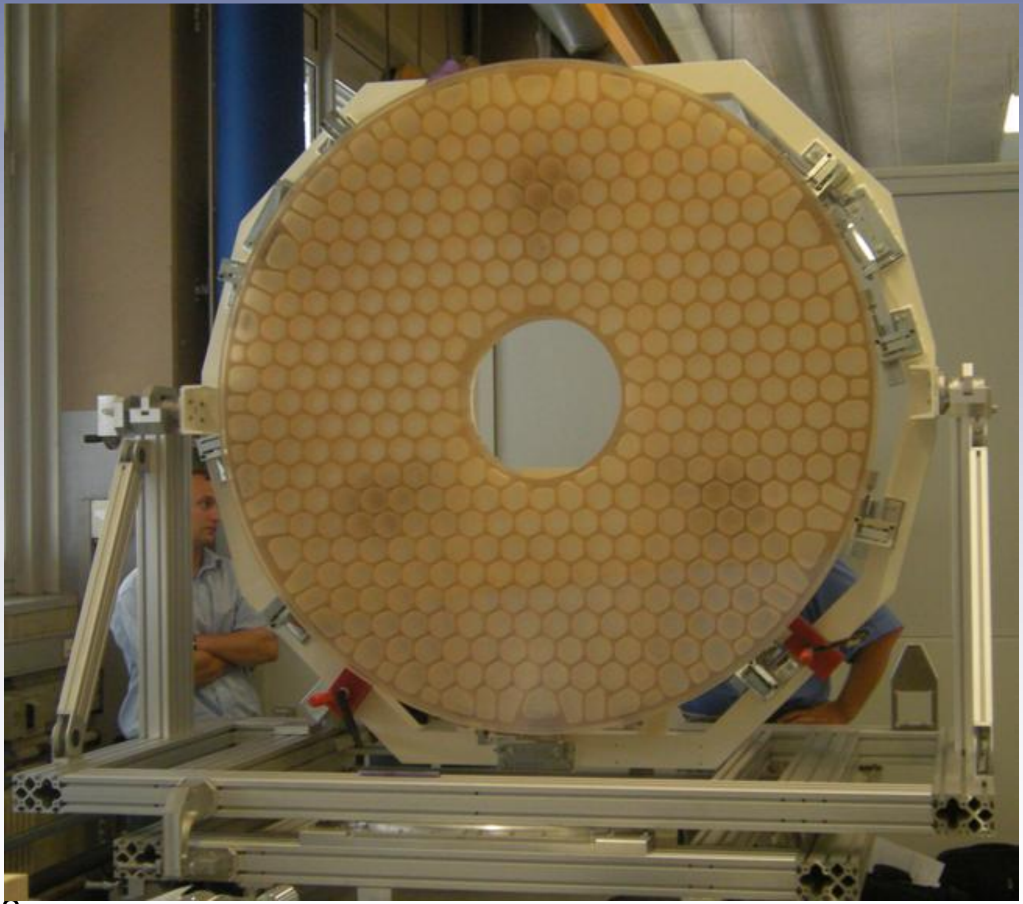




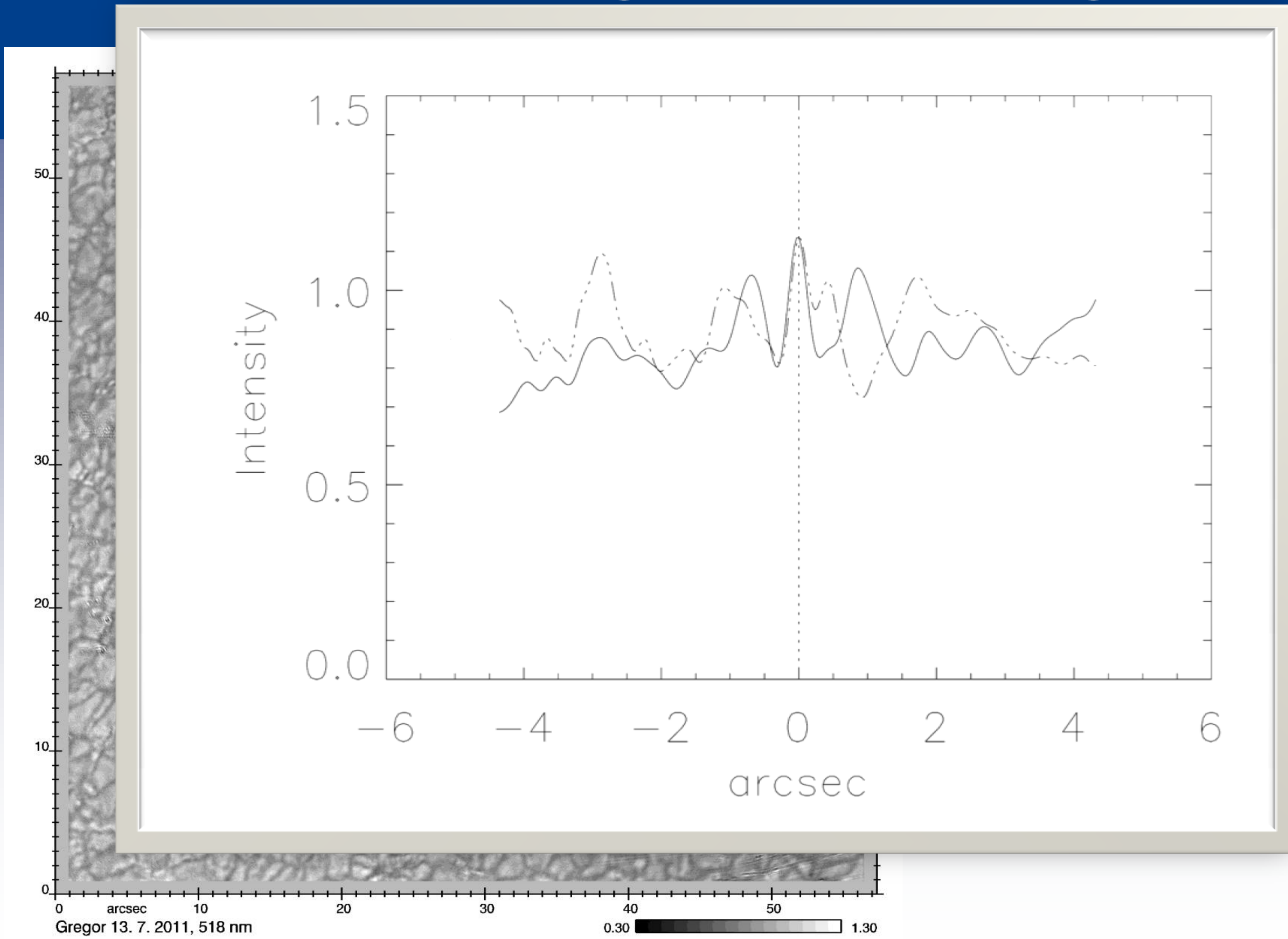
Primary mirror

Support system and testing





First image with Gregor



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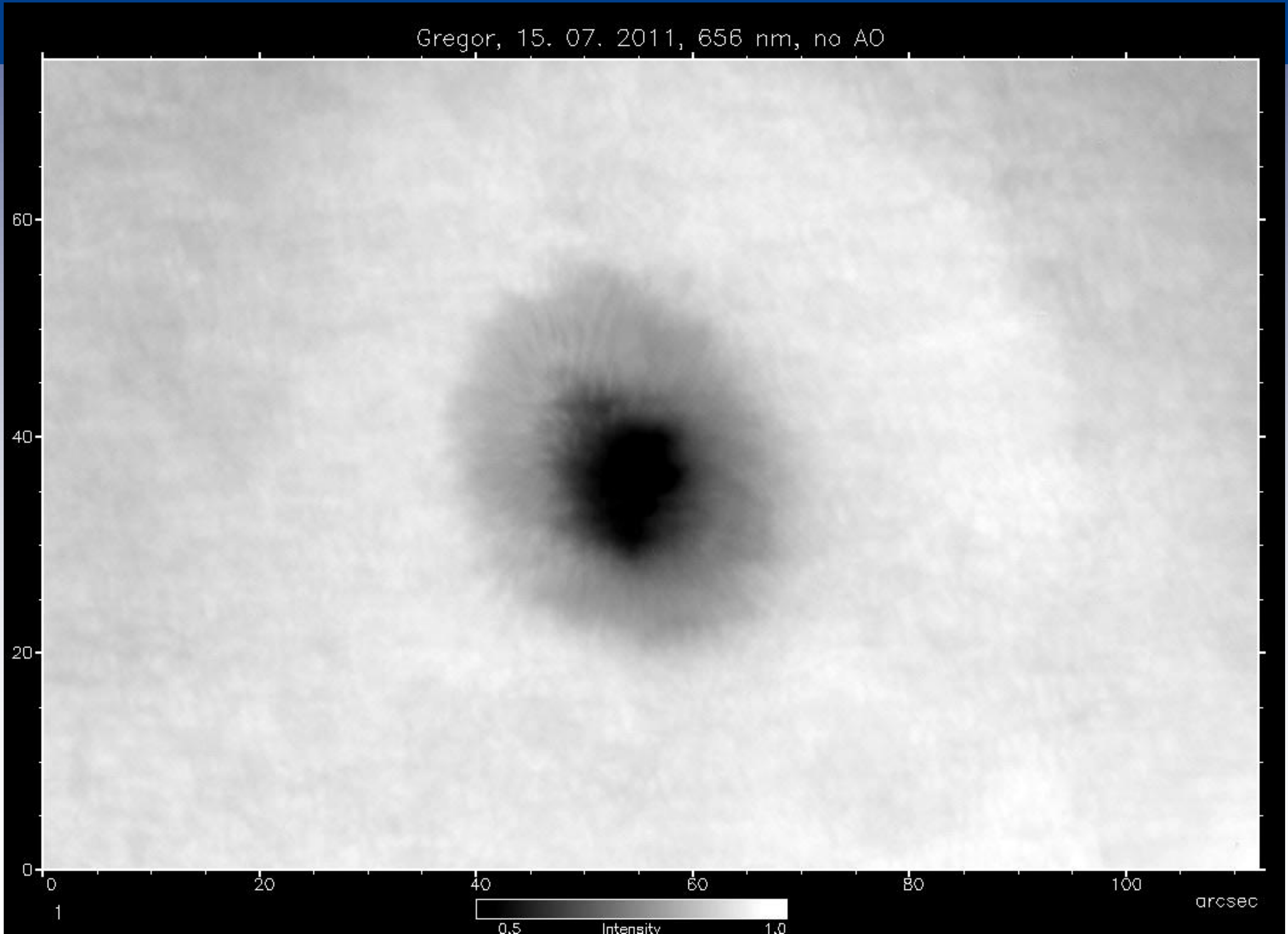
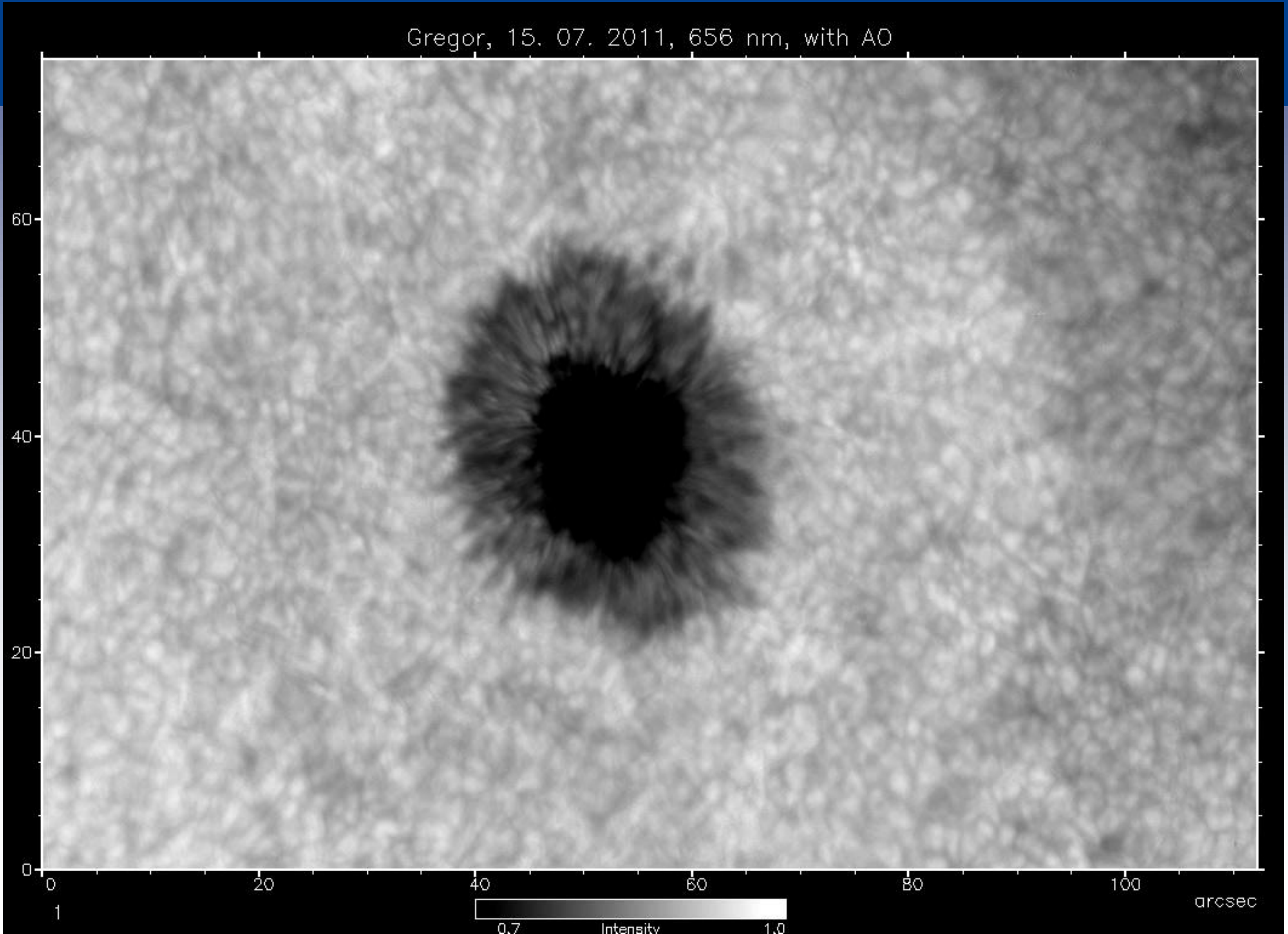
Pictures – Sonne …

- Images of the Sun with a field of ca. 110 x 70 arcsec
- Continuum in ca. 10 nm wide spectral bands (Filterbox C) between 396 nm und 709 nm, plus G-Band (1 nm)
- Demonstration of state of the teleseope in July

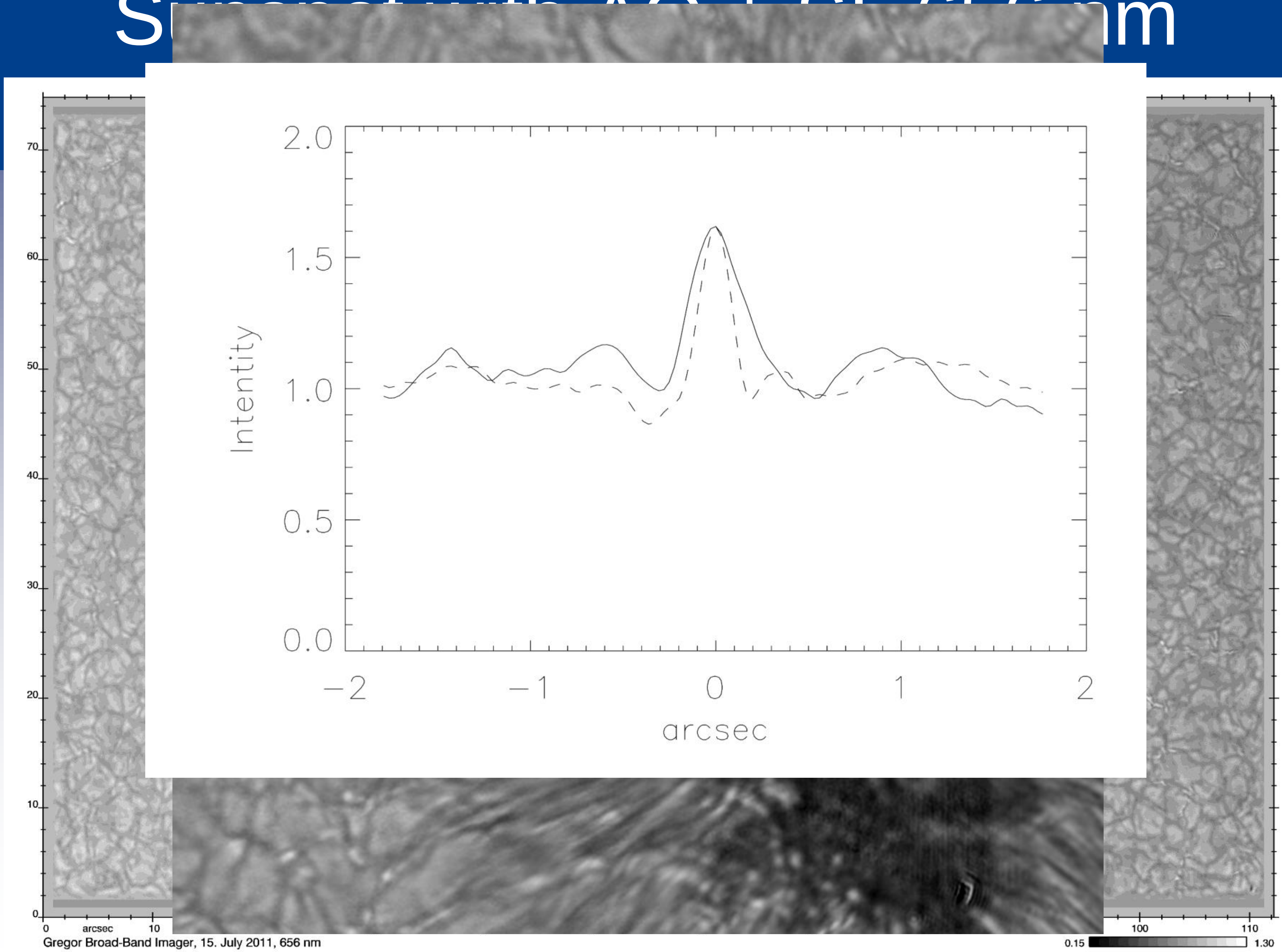
Sunspot without Adaptive Optics



Sunspot with Adaptive Optics

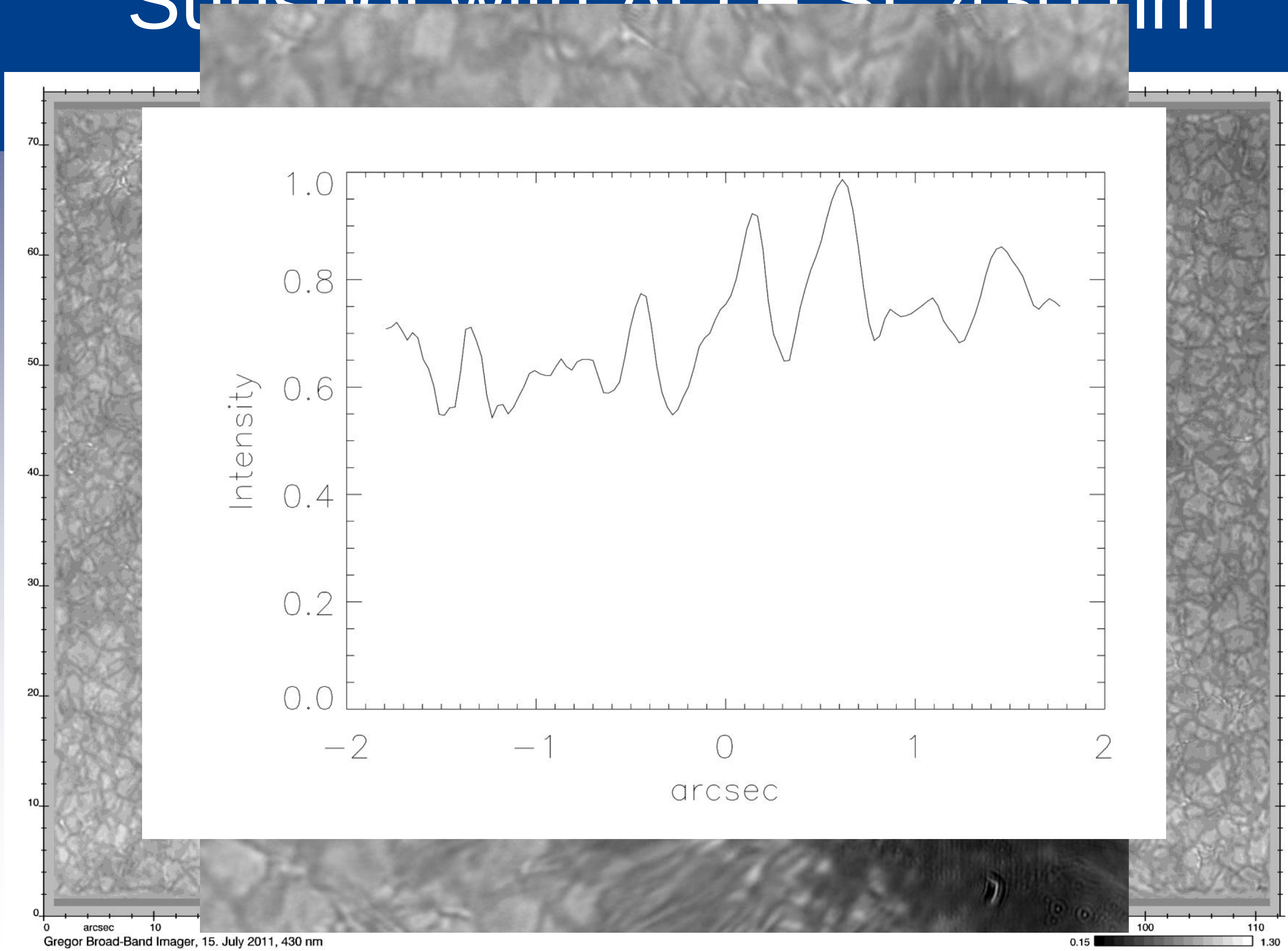


Sunspot with AO + SI 656 nm

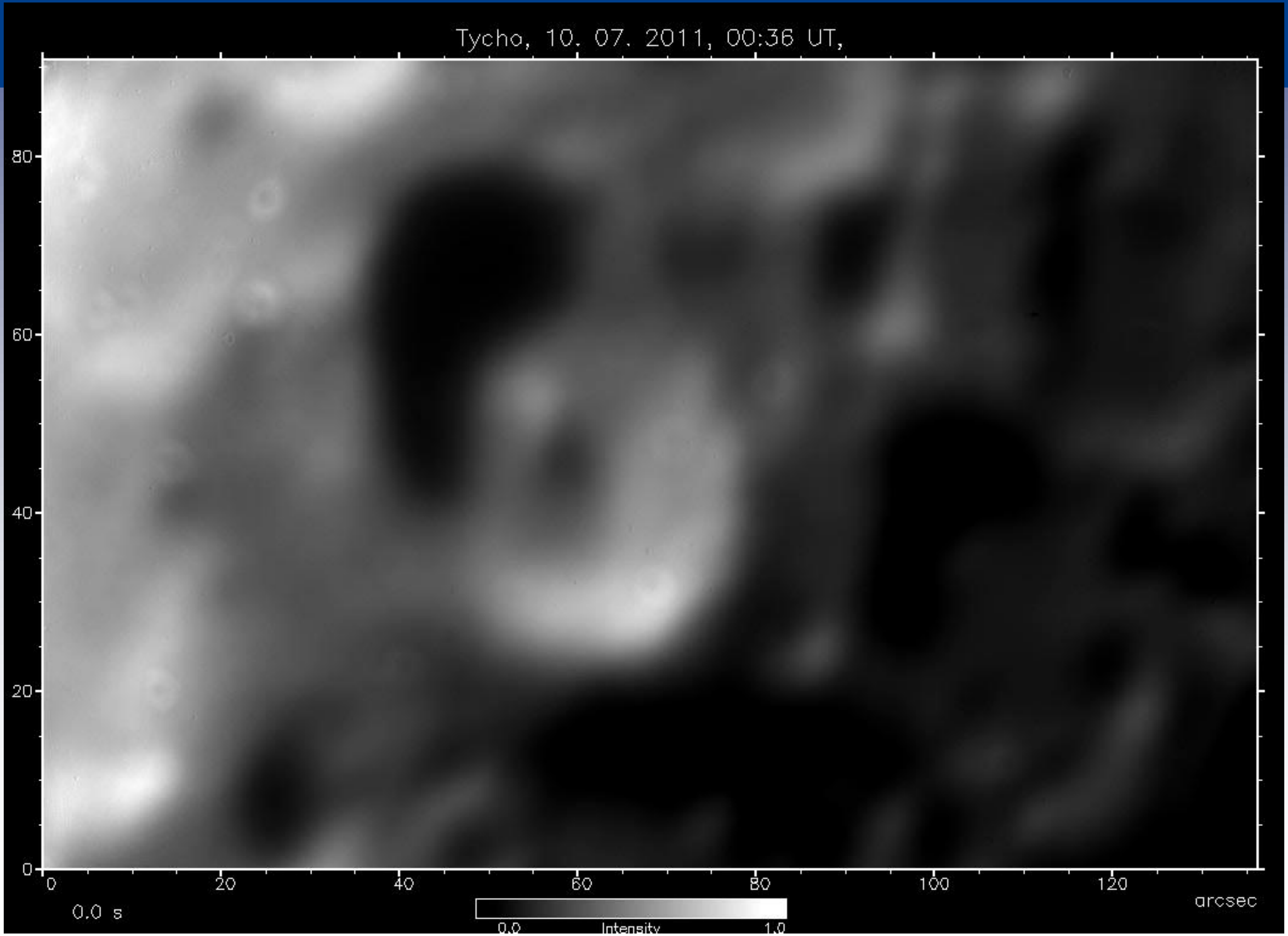


Gregor Broad-Band Imager, 15. July 2011, 656 nm

Sunspot with AO + SL 430 nm

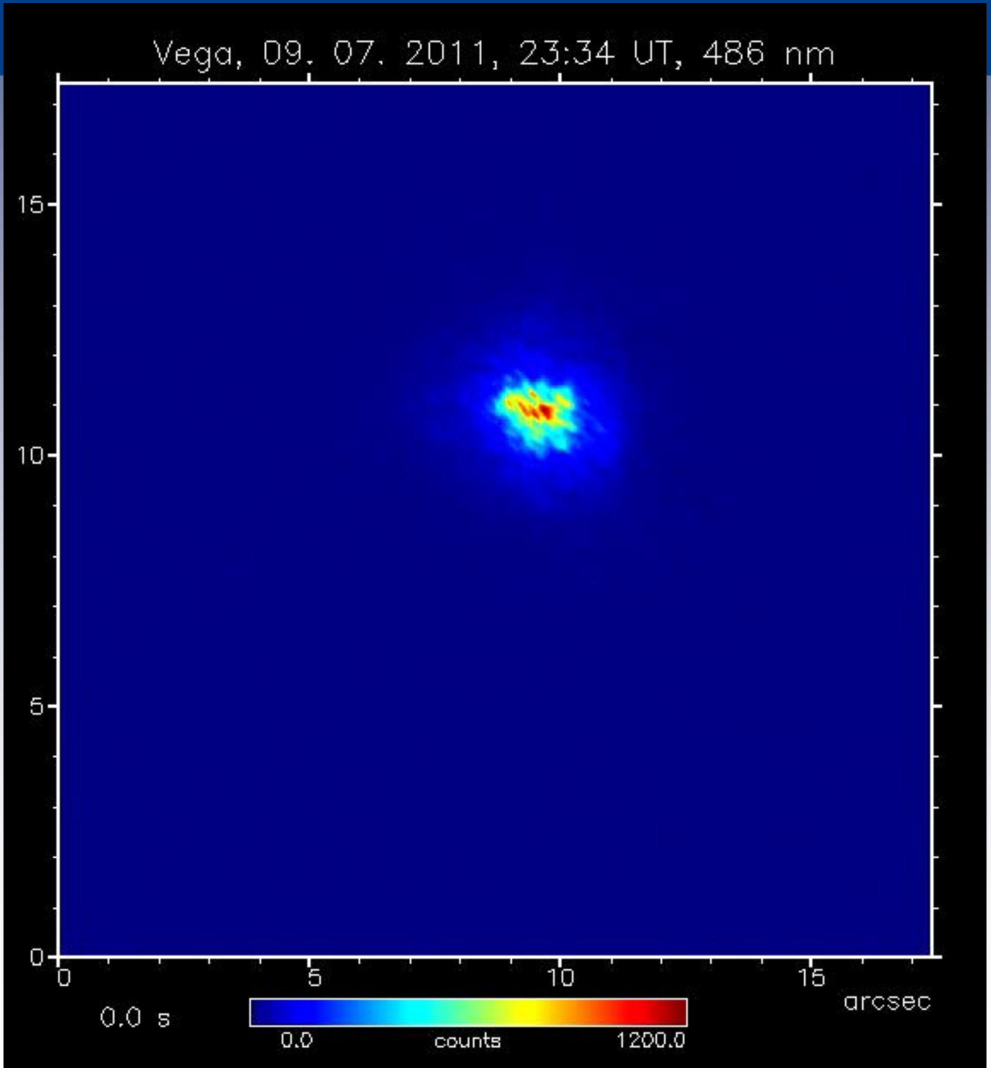


… Mond, …



Tycho, 10. 07. 2011, 00:36 UT,
80
60
40
20
0
0
20
40
60
80
100
120
arcsec
0.0 s
0.0
Intensity
1.0

… und Sterne!



Vega, 09. 07. 2011, 23:34 UT, 486 nm
15
10
5
0
0
5
10
15
arcsec
0.0 s
0.0
counts
1200.0

Which observing capabilities are needed

Several large aperture telescopes on the ground and in space

- ATST
- NLST
- EST
- Chinese Large Telescope?
- Solar C

- **Det... ...ocesses in the**
  - ... ...ion
  - ...
  - ...

- **Comprehensive studies of large to medium scale processes in the sola...**
  - ... ...and/or ...
  - ...
  - ...

Small to medium aperture ground based networks and space facilities

New High Resolution Observatories

BBSO New Solar Telescope

1.6m USA

Yunnan Obs. Solar Telescope

1m China

Advanced Technology Solar Telescope

4m USA

European Solar Telescope

4m EUR

Gregor

1.5m D/ES

National Large Solar Telescope

2m India

Design **Construction** **Commissioning**

Conclusions

- Gregor had a resolution of ca. 2 arcsec in July, 4 weeks after M1 installation
  - M1 position alignment not completed
- No indication for high order optical errors
  - ripple appears enhanced in Foucaultgrams, but contributes little
- No noticeable negative impact of cooling on image quality
- Gregor has the potential to become an excellent telescope!