The GREGOR Solar Telescope

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Organization

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

- GREGOR partners
  - Instituto de Astrofísica de Canarias (IAC)
  - Astronomical Institute (AI), Academy of Sciences of the Czech Republic
  - Institut für Astrophysik Göttingen (IAG, until 2008)

- Total construction costs about €10M and €0.5M operations (w/o FTEs)

- Observing time allocation
  - 250 observing days
  - Day: 20% IAC and 5% CCI upfront, 75% of remaining time ⇒ 60% KIS (incl. OPTICON), 20% MPS, and 20% AIP (incl. AI)
  - Night: 70% AIP and 30% KIS

- Observing season April – mid-December (maintenance in March)
- TAC meets in January to schedule the upcoming observing season
GREGOR Mechanical Design and Cooling System

- Open telescope design with Serrurier struts
- Alt-azimuthal mount
- M2 mounted on a hexapod
- Operates in wind speeds of up to 20 m/s with a relative rms pointing error of 0.5”
- Primary mirror is actively cooled from the backside
- Secondary and tertiary mirror are passively cooled (CeSiC, high heat conductivity, high stiffness)
- Field stop at primary focus
  - Heat load: 5 W / mm²
  - Silver-coated copper body at 45°
  - Water cooling (1 liter per minute)
  - M1 safety cover for emergency shut-down
- Temperature differences to ambient $\Delta T < 1$ K
GREGOR Optical Design

- 1.5-meter free aperture
- Primary mirror M1
  - $D = 150$ cm, $F / 1.7$
  - Light-weighted Zerodur
- Double Gregory configuration
  - M2: $D = 43$ cm, $F / 1.29$
  - M3: $D = 36$ cm, $F / 3.97$
- Effective focal length: 55.6 m ($F / 38$)
- Nominal field-of-view: 150” $\times$ 150” (max. 300” $\times$ 300”)
- Wavelength coverage: 350 nm – NIR
- Integrated (multi-conjugate) adaptive optics
- Polarimetric calibration is carried out in the symmetrical light path.
Polarimetric Calibration Unit

- Linear polarizer
  - Marple Hess prism ⇔ air-spaced double Glan prism
  - 24.5 mm diameter, 45 mm length
  - 0.1° stepping angle
  - $2 \times 10^{-6}$ extinction ratio
- Achromatic $\lambda / 4$ retarder
  - Wavelength range 750–1600 nm
  - 23 mm diameter
  - 0.1° stepping angle
- Superachromatic $\lambda / 4$ retarder
  - Wavelength range 380–800 nm
  - 23 mm diameter
  - Stepping angle 0.1°
- Retarder material
  - Polymethylmethacrylat (PMMA)
- Pinhole and target (grid)
- Power density < 0.5 W / mm²
Manufacturing of the Primary Mirror

- The 1.5-metre, primary mirror was light-weighted at Schott and polished at Zeiss.
- A face sheet of only 12 mm thickness and pockets with a diameter of 68 mm allow a better removal of the absorbed heat load by air-cooling from the backside.
- The final mass of the Zerodur mirror is about 205 kg.
- About 9% of the primary mirror area is obstructed by the secondary mirror.
Optical Quality of the Primary Mirror (w/o Astigmatism)

Empfindlichkeit : 1
Typ : unbekannt
P-V : 546.136 nm
RMS : 19.642 nm
Min : -311.059 nm
The GREGOR solar telescope is protected by a foldable tent dome. The dome material is very smooth so that ice cannot build up. The dome has already sustained wind speeds of more than 250 km/h. The telescope cannot freely move inside the dome and has therefore to be stored in a parking position before closing the dome.
Adaptive Optics (AO) System

- The deformable mirror (DM) of the AO has 250 actuators and was installed in June 2012.
- Each post-focus instrument has a separate Shack-Hartmann wave front sensor (WFS) with 156 sub-apertures.
- WFS camera with an image acquisition rate of 2.5 kHz
- A dichroic pentaprisim (band-stop) directs 5% of the green continuum to the WFS.
- Image scale at science focus $F_4$: 3.7” / mm ($F / 38$)
- A multi-conjugate AO (60” FOV) is already running in an optical laboratory at KIS and will be installed at GREGOR in 2013.
Dichroic pentaprisms are used to distribute light to the AO wavefront sensor, GRIS, and GFPI. These instruments can be operated at the same time. In addition, slit-jaw images can be captured.
Grating Infrared Spectrograph

- GRIS is a slit spectrograph for observations in the near infrared
- Slit-jaw imaging system for Hα, TiO, Ca II IR, and continuum observations
- Future extension for spectroscopy at visible wavelengths

**Technical Data**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image scale</td>
<td>0.135&quot; / pixel</td>
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<tr>
<td>Scanning range</td>
<td>138&quot; (69&quot; polarimetry)</td>
</tr>
<tr>
<td>Dispersion @ 1083 nm</td>
<td>2.12 nm / pixel</td>
</tr>
<tr>
<td>Spectral coverage</td>
<td>2.16 nm</td>
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<tr>
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First results \( \Rightarrow \) GRIS
First results ⇒ GRIS

Fe 15650

Fe 15650
First results ⇒ GRIS
- BBI consists of two broad-band (1–10 nm) imagers with a large field-of-view (110” × 70”) for image restoration.
- Alternative Foucault set-up for evaluating the telescope performance.
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Broad-band imager (BBI)
First results ⇒ BBI
First results → BBI
GREGOR Fabry-Pérot Interferometer

- GFPI is an imaging spectro-polarimeter for high spatial, temporal and spectral resolution observations of the photosphere and chromosphere.
- Two etalons are mounted in the collimated beam. Their coatings have been optimized for the wavelength range of 530–870 nm.
- Vector polarimetry is possible in the range of 580–660 nm.
- Two wavelength ranges can be observed sequentially (interference filters are mounted on motorized, precision translation stages).
- A second FPI for observation below 530 nm will be installed in 2013.

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</thead>
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<tr>
<td>CCD camera</td>
<td>LaVision Imager QE</td>
</tr>
<tr>
<td>Detector</td>
<td>Sony ICX285AL Chip</td>
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<tr>
<td>Full well capacity</td>
<td>18,000 e−</td>
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<tr>
<td>Read-out noise</td>
<td>4.5 e−</td>
</tr>
<tr>
<td>A/D conversion</td>
<td>12-bit</td>
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<tr>
<td>Quantum efficiency</td>
<td>60% @ 550 nm</td>
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<tr>
<td>Chip size</td>
<td>8.8 mm × 6.7 mm</td>
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<tr>
<td>Pixel size</td>
<td>1376 × 1040 pixel</td>
</tr>
<tr>
<td>Etalons</td>
<td>6.45 μm × 6.45 μm</td>
</tr>
<tr>
<td>Clear Aperture</td>
<td>IC Optical Systems</td>
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<tr>
<td>Reflectivity</td>
<td>70 mm</td>
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<tr>
<td>Wavelength range</td>
<td>95±2%</td>
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<tr>
<td>Effective Finesse</td>
<td>530–860 nm</td>
</tr>
<tr>
<td>FSR</td>
<td>50–60</td>
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<tr>
<td>FWHM</td>
<td>0.15 nm</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>2.5 pm</td>
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<tr>
<td>FOV</td>
<td>~250,000</td>
</tr>
<tr>
<td>Image scale</td>
<td>52.2” × 39.5”</td>
</tr>
<tr>
<td></td>
<td>0.038” / pixel</td>
</tr>
</tbody>
</table>
First results ⇒ GFPI

- Continuum intensity
- Line core intensity
- Doppler velocity
- Line width
GREGOR @ Night

- Automated operation of spectrograph and telescope
- Adapt the SOFIN spectrograph of the Nordic Optical Telescope to GREGOR
- $R = 87,000$ in 45 echelle orders (350–1130 nm) with three grating settings
- CCD (390–900 nm)
- Iodine cell for high-precision radial velocity work (500–630 nm)
- Future upgrades
  - Stokes-V polarimeter
  - link to the VTT laser-frequency comb
Thank you very much!

The November 2012 issue of *Astronomische Nachrichten/AN* is dedicated to the GREGOR solar telescope, its subsystems, and post-focus instruments.