SUNRISE: High Resolution UV / VIS Observations of the Sun from the Stratosphere

Peter Barthol
Max-Planck-Institut für Sonnensystemforschung
Katlenburg-Lindau, Germany

Who is SUNRISE?

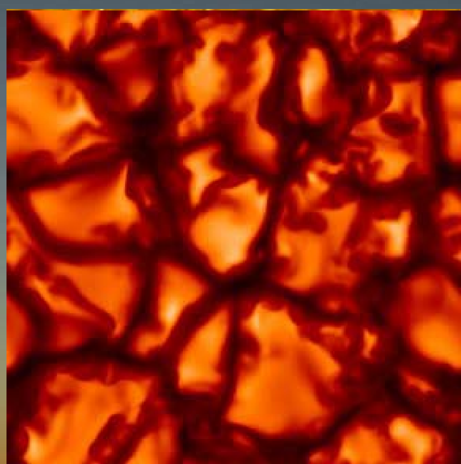
- S.K. Solanki, P.Barthol, A. Gandorfer, R. Meller
  - Max-Planck-Institut für Sonnensystemforschung, Katlenburg-Lindau, Germany
- M. Knölker
  - High Altitude Observatory, Boulder, USA
- V. Martinez-Pillet
  - Instituto de Astrofisica de Canarias, Tenerife, Spain and the IMaX team
- W. Schmidt
  - Kiepenheuer Institut für Sonnenphysik, Freiburg, Germany
- A.M. Title
  - Lockheed-Martin Solar and Astrophysics Laboratory, Palo Alto, USA

SUNRISE Concept

SUNRISE:

- Stratospheric solar observatory
- Balloon-borne telescope with 1 meter aperture
- High resolution imaging and polarimetry of photospheric and chromospheric phenomena
- Spectral domain NIR to UV (≥ 220nm)
- Autonomous operation for ~ 2 weeks
- Inflight alignment capability and image stabilization

SUNRISE Science



- Study of solar magnetic field
- Time dependent characteristics of magneto-convective patterns
- Small scale interaction of convective flows and magnetic field
- Validation of MHD simulations

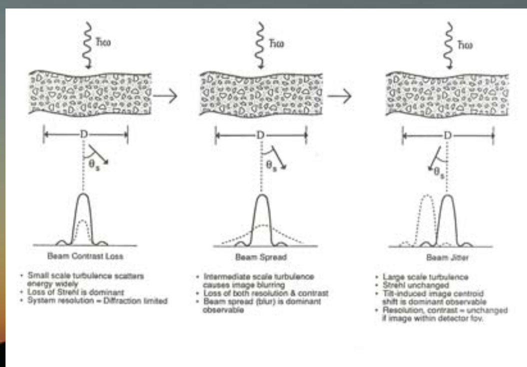
Basic Requirements

- Resolve scale of magnetic elements (<50 km) with sufficient field of view
  → Diffraction limited 1m telescope above atmosphere with high precision pointing + image stabilization
- Resolve (≤5 s) and cover (hours - days) their evolution
  → High cadence + uninterrupted observations
- Measure 3D-distribution of B vector, v, T
  → Polarization sensitive spectroscopy in photospheric/chromospheric line(s)
- High-cadence imaging of different layers
  → Visible + UV filtergrams

Why so far above Ground?

Reduction of “Seeing”:

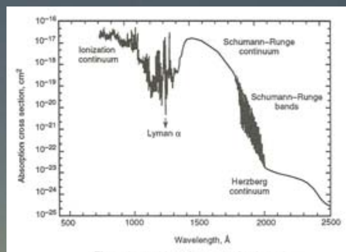
- Ground based observations have limited resolution due to air turbulence
- Angular resolution typically not better than 1 arcsec
- Sometimes (at specific places) resolution is ~ 0.2 arcsec, but you have to be extremely lucky !
- SUNRISE aims at ≤ 0.05 arcsec !!!



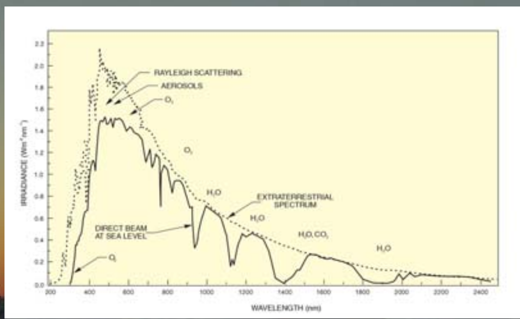
Why so far above Ground?

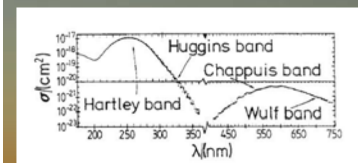
Access to the Ultraviolet Spectral Domain:

- Thermospheric Oxygen and stratospheric Ozone absorbs virtually all UV radiation <300 nm at sea level



Electronic transitions of oxygen in the ultraviolet



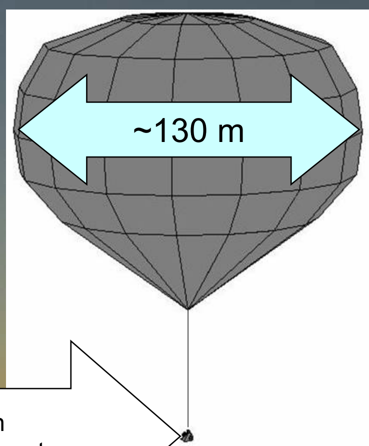


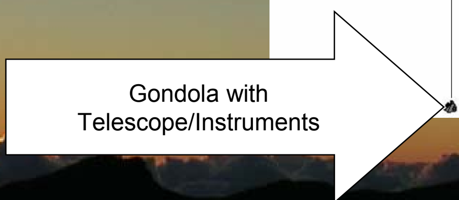
The photo-absorption cross-section of ozone from 180 to 750 nm showing the main absorption bands (Banichevich *et al.* 1993).

SUNRISE Balloon

NASA LDB Flight Program:

- 29.47 MCF, ~ 835000 m^3 Zero pressure balloon
- Science payload weight ~1800 kg
- Float altitude 35 km – 40 km
- Air pressure at float 3 – 7 hPa

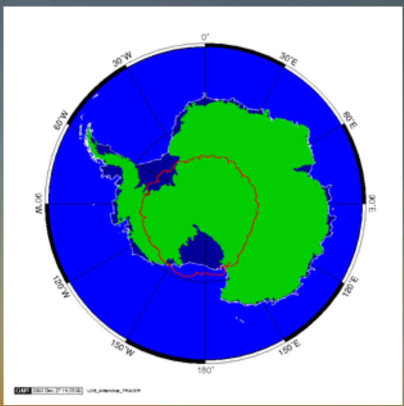




SUNRISE Launch Scenario

SUNRISE Mission Scenarios

Antarctic Flights:



- Launch site: Williams Field, close to McMurdo (77.86°S, 167.13°E)
- Launch window December to January
- Circumpolar trajectories
- Typical latitudinal range 73°S – 82°S
- Flight duration approx. 9-12 days (single loop)
- Sun elevation between 0° - 45° (function of date/time and latitude)

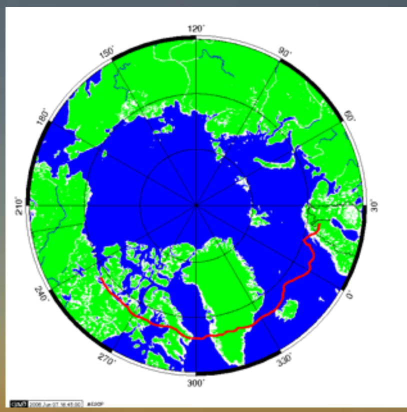
⇒ Uninterrupted solar observation

SUNRISE Mission Scenarios

Arctic Flights:

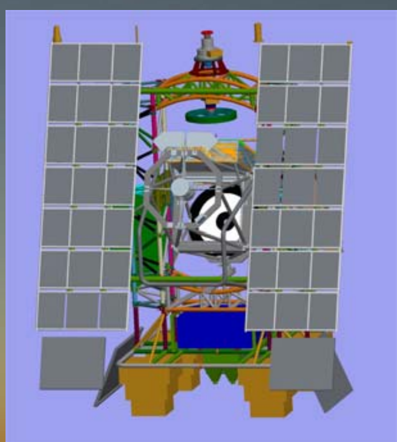
- Launch site: ESRANGE (Sweden), close to Kiruna (67.89°N, 21.10°E)
- Easily accessible by plane, train, truck
- Launch window June to July
- Circumpolar trajectories not yet possible
- Flight duration approx. 5 days (to northern Canada)
- Sun elevation between 0° - 45° (function of date/time and latitude)

⇒ Uninterrupted solar observation as well

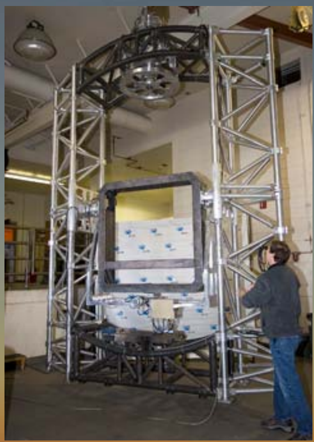


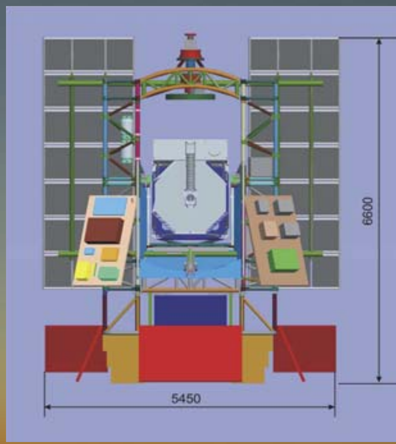
SUNRISE Gondola

- Platform for the telescope and science instruments
- Azimuth/elevation stabilization to few arcsec accuracy
- Power supply (solar panels and batteries)
- Commanding / communication from / to ground via NSBF provided SIP (Science Instrumentation Package)
  - Designed and built by HAO



SUNRISE Gondola

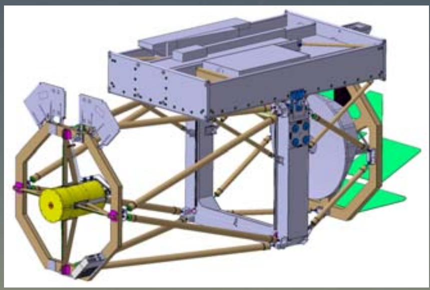
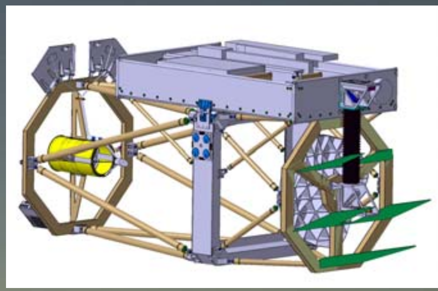


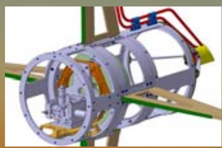
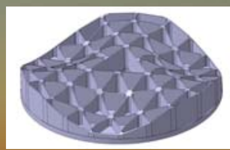


SUNRISE Telescope

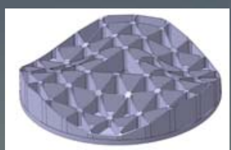
- Carbon fiber based telescope structure with 1m Zerodur lightweighted primary mirror (SAGEM)
- Industrial contract (Kayser-Threde, Munich)
- Gregory configuration (f/25, elliptic secondary)
- Field of view: 3.4 arcmin (150 Mm on the Sun)
- M2: adjustable in 3 degrees of freedom, controlled by a wavefront sensor
- Two plane fold mirrors (M3, M4) to feed postfocus instrumentation (movable for fine focus)

SUNRISE Telescope

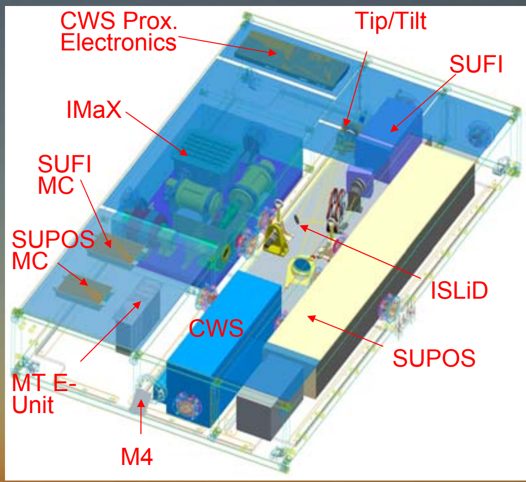

SUNRISE Primary Mirror



- Mirror blank at the end of rear side shaping
- Leightweighting and polishing takes about another year

SUNRISE Instrumentation

- Postfocus instrumentation sits „piggy-back“ on telescope
- Carbon fiber based honey-comb structure for high stiffness and low thermal expansion
- Pre-aligned instrument „modules“
- Individual radiators for heat dissipators



SUNRISE Instrumentation

Two Service Modules:

- Image stabilization and light distribution unit: ISLiD
- Correlation tracker and wavefront sensor: CWS

Three Science Instruments:

- Filtergraph: SUFI
  - Multi-wavelength phase diversity imager
- Imaging Magnetograph: IMaX
  - Fabry-Perot etalon & liquid crystal modulators
  - 2D maps of the full magnetic vector + Dopplergram
- Polarimetric Spectrograph: SUPOS

ISLiD

Image Stabilisation and Light Distribution system

- Ensures capability of simultaneous observations with all science instruments
- complex panchromatic reimager
- Based on all-dielectric dichroic beam splitters
- Contains fast piezo-driven tip-tilt mirror @ pupil location
- Challenges:
  - Complex coatings
  - High demands on surface quality (UV)
  - Stringent polarisation requirements

CWS

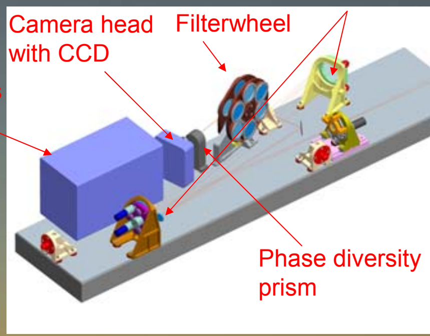
Correlation Tracker and Wavefront Sensor

- Camera system with lenslet array, FoV 25×25 arcsec
- Derives residual image motion and feeds error signals to tip-tilt mirror (correlation tracker): FAST
- Measures low order aberrations and controls active alignment of telescope secondary mirror and M3/M4 refocusing (slow)
  - Designed and built by KIS (Freiburg)

SUFI

SUNRISE Filter Imager

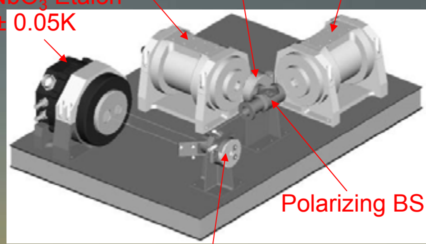
- based on a Schwarzschild configuration
- Highest resolution phase diversity imager
- FoV 17×35 arcsec
- 2k×2k UV enhanced CCD
- Wavelenghts:
  - 225 nm broad band
  - 280 nm continuum
  - 300 nm continuum
  - 313 nm OH band
  - 388 nm CN band



IMaX

Imaging Magnetograph Experiment

- Filter-based imager for high resolution Doppler- and magnetograms
- FoV: 50×50 arcsec
- 525.06 nm, Fe I, g=1.5
- Spectral resolution: 60 mÅ
- Full Stokes vector images every 30s; (I,V) every 5s
- 2 CCDs for phase diversity
  - Built by Spanish IMaX consortium



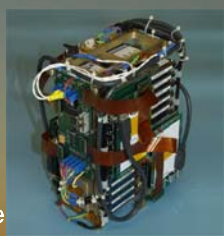
SUPOS

SUNRISE Polarimetric Spectrograph

- Single line spectropolarimeter
- Ca II 854.2 nm line for simultanous photospheric / chromospheric diagnostics
- Littrow configuration with Echelle grating
- Spectral resolution 50 mÅ, spectral range 5 - 10 Å
- Liquid crystal full Stokes modulator
- Scanner with ± 30 arcsec range

Supporting Electronics

- Ethernet based system
- Central on-board computer ICU
- Individual science instrument computers
- Located on rack mounted to gondola structure
- Only proximity electronics close to optical modules



- Science data stored on-board
- 2 units with 24 harddisks (100 GByte) each
- 3,6 Terabyte net capacity, RAID functionality

- Communication via TDRS satellite link, low data rate
- LOS communication with E-Link, 2 MByte transparent Ethernet

„Inter gravissimas....“

Challenges for SUNRISE:

- Programatic aspects
- Technological issues
  - Thermal
  - Structural
  - Optical

Programatic aspects

Technological challenges like in a space project

but

Funding comparable to ground based instruments

- Collaboration of groups with different background, ground based experimenters meet space engineers (!)
- Use of COTS products, most parts need qualification, modification or encapsulation in pressure vessels

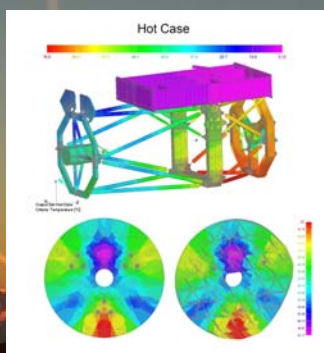
Technological challenge 1: Thermal

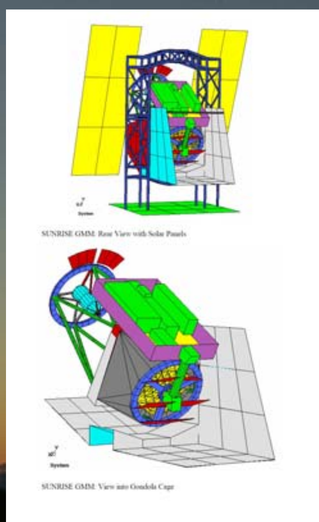
- At 3 hPa no convective energy transport
- System is mainly radiatively controlled
- Variable energy input (Sun, Albedo) and high power dissipating commercial electronics requires detailed thermal modelling
- Tropopause transit gives temperatures below -60°C
- „Off nominal“ conditions need special consideration, i.e. pointing loss or off-pointing

Technological challenge 1: Thermal

Mathematical Modelling of Thermal Scenarios

- to derive component temperatures
- to define surface treatments



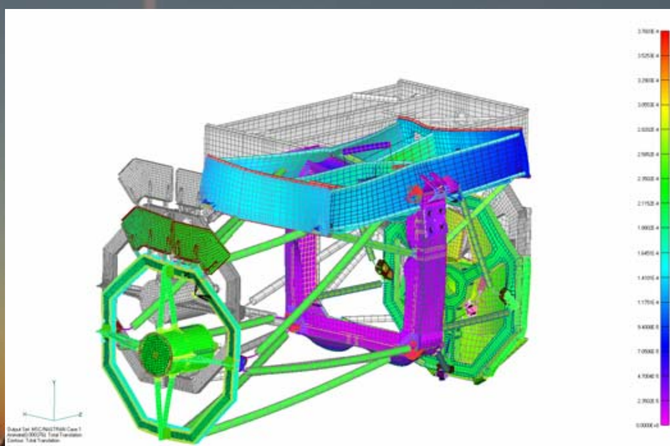


Technological challenge 2: Structural

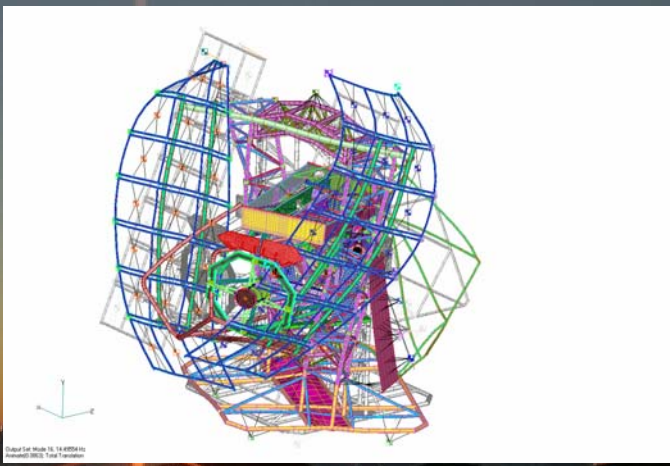
- Telescope in Alt-Az mount: varying gravity vector!
- Large lightweighted primary mirror
- Instruments piggy-back on telescope
- Demanding requirements on pointing stability

➢ Detailed structural analyses and high structural stiffness

Structural Deformations under 1g Load

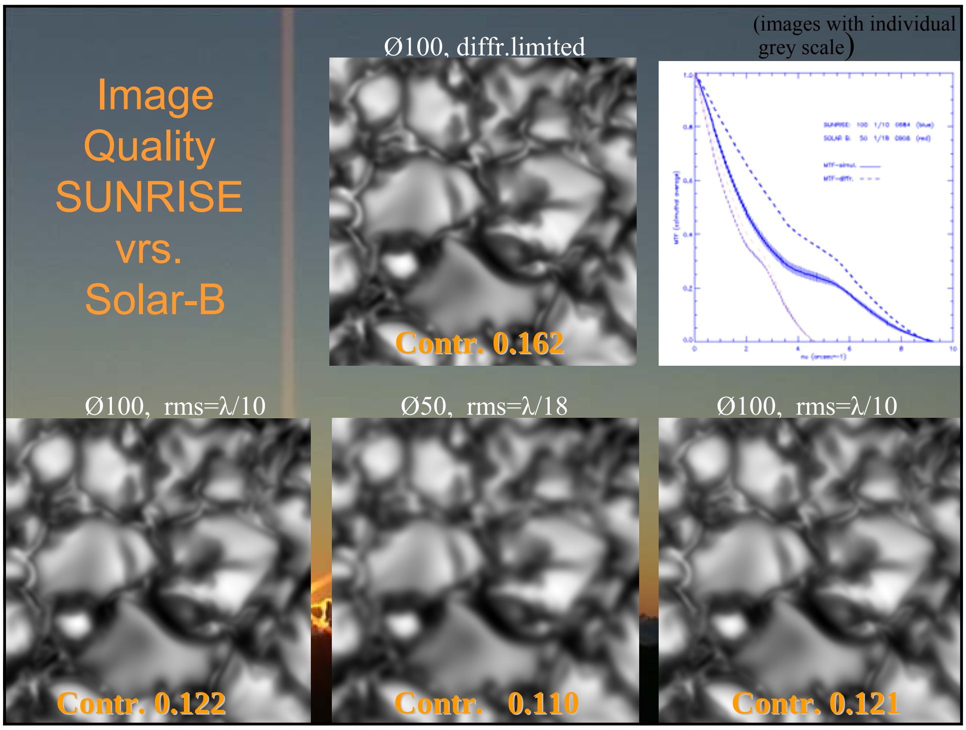


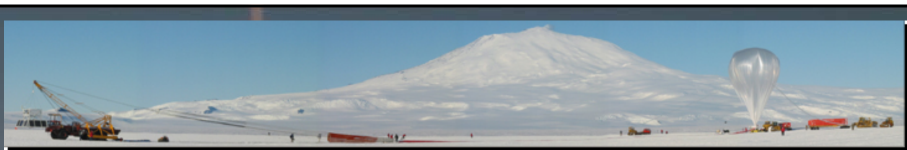
Eigenfrequency Assessment



Technological challenge 3: Optical

- 1 meter primary mirror with diffraction limited performance is a challenge of its own
- UV is not a problem of a dedicated instrument, but for main telescope and ISLiD
- Coatings, polarization sensitivity and stability
- How can we compete with instruments like Solar-B?
- ➢ Overall WFE has to be better than λ/10rms, otherwise we loose advantage of larger aperture





Schedule Milestones (ESRANGE):

• Gondola test flight continental U.S.	Fall 2007
• Primary mirror shipment to KT (contractual date):	Dec 2007
• PFI structure / module integration, should start:	Feb 2008
• Telescope delivery to MPS:	Apr/May 2007
• Telescope / PFI integration, alignment, calibration, finished:	Oct 2008
• Gondola shipment from HAO to MPS:	Oct 2008
• Gondola / Telescope / PFI integration, system testing until:	Feb 2009
• Mission Readiness Review (MRR)	Feb 2009
• Arrival at ESRANGE/Sweden	Apr 2009
• Launch	Jun 2009

Some animated Impressions…

Launch of BLAST Payload, ESRANGE 2005

View from Float Altitude

Cut-Down and Free Fall

Parachute Opening and Drift Down

Successful Landing…