# SUNRISE

## HIGH RESOLUTION IMAGING AND POLARIMETRY WITH A BALLOON-BORNE STRATOSPHERIC SOLAR OBSERVATORY

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# SUNRISE in Brief

- **Aim:** study magneto-convective processes at a resolution of ≤ 100 km on the Sun
- **Observables:** time series of near diffraction limited UV images and magnetograms in the visible
- **Instrument:** 1-m balloon-borne telescope, with simultaneously observing postfocus instruments
- **Mission:** circumpolar long-duration stratospheric balloon flight(s) at solstice conditions

- **The Team:**


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Max Planck Institute for Solar System Research, Germany

M. Knölker (Co-I) + HAO Team
High Altitude Observatory, USA

V. Martínez-Pillet (Co-I) + IMaX Team
Instituto de Astrofisica de Canarias, Spain and the IMaX consortium

W. Schmidt (Co-I) + KIS Team
Kiepenheuer Institut für Sonnenphysik, Germany

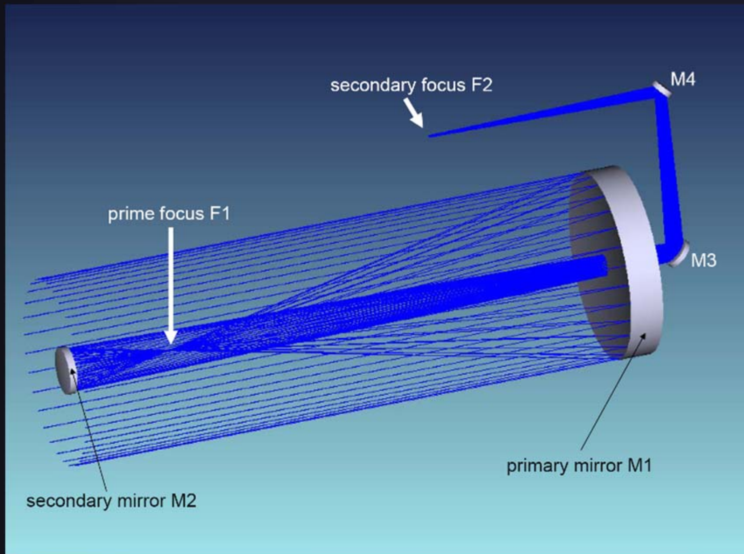
A.M. Title (Co-I)
Lockheed-Martin Solar and Astrophysics Laboratory, USA


# SUNRISE Instrument

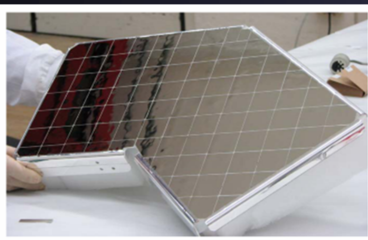
- **Gondola (HAO):**
  - Sun acquisition and tracking (with few tens of arcsec accuracy),
  - Power supply with solar panels and batteries,
  - Carries instrument electronics, telemetry antennas and CSBF electronics
- **Telescope (MPS):**
  - 1 m aperture, 25 m focal length
  - Gregory configuration
  - In-flight alignment of secondary mirror for focus and coma correction
- **Instrumentation (MPS, IMaX, KIS):**
  - CWS: Wavefront sensor and correlation tracker for active telescope control and image stabilization
  - ISLiD: Light distribution unit with beam spliters and reimaging optics, fast piezo-driven tip-/tilt mirror for image stabilization
  - SUFI: UV filter imager with narrow band filters $\lambda$ = 214 nm – 397 nm, phase diversity image reconstruction
  - IMaX: Fabry-Perot based imaging doppler- and magnetograph, $\lambda$ = 525.02nm, $\Delta\lambda$ = 85 mÅ polarization sensitive

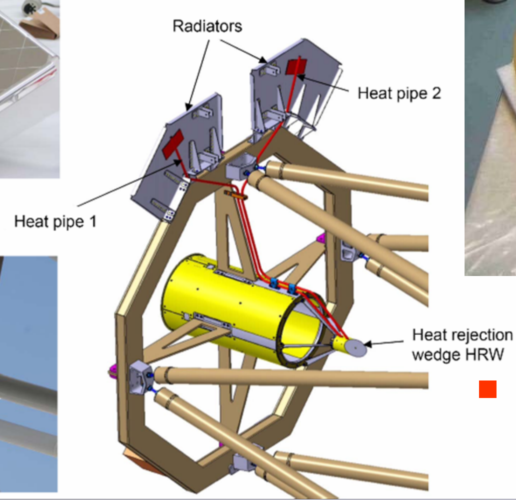
- **Weight/Size:** ~ 2 tons, 5.5 x 6.0 x 6.5 $m^3$ (L x W x H)

# Telescope




- Carbon fiber based telescope structure
- Zerodur lightweighted primary mirror,
  1 meter free aperture, diffraction limited in the visible

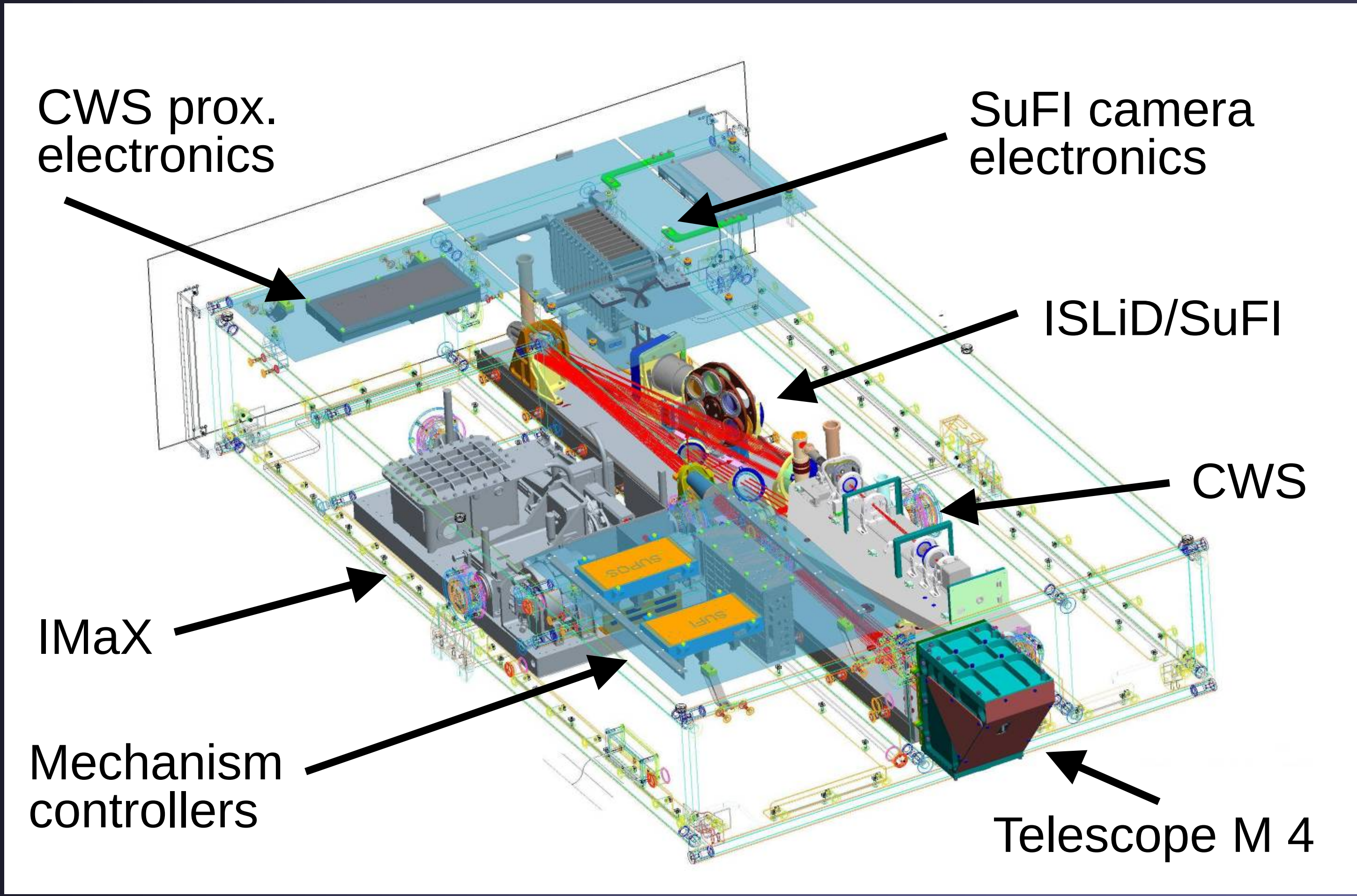




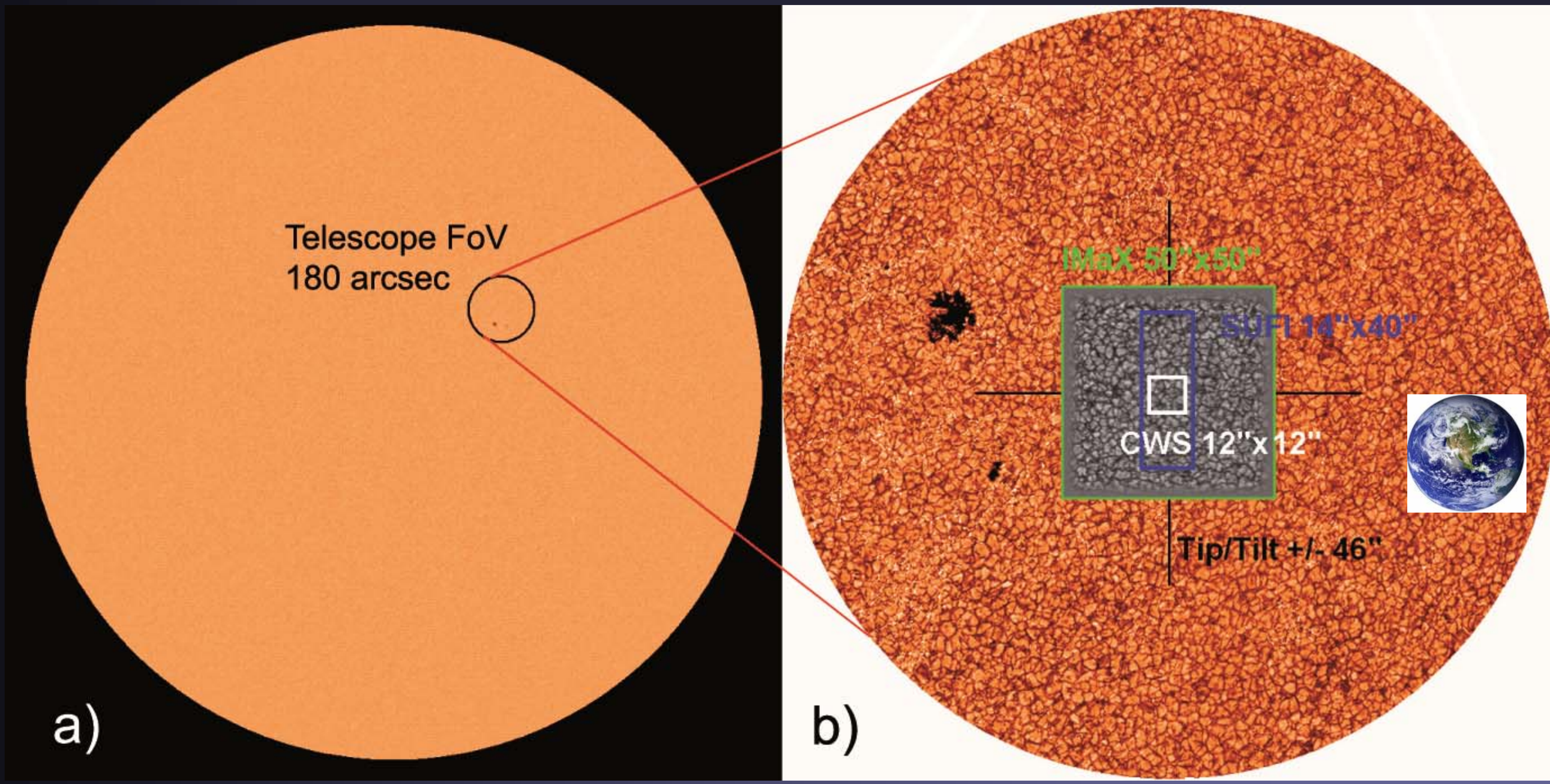

- Heat rejection wedge @ prime focus
  with radiators + heat pipes

# Postfocus Instrumentation

- Carbon-fiber based support structure
- Individual science (IMaX, SuFI) and support instruments (ISLiD, CWS)
- Proximity electronics (mech. controllers, power supplies etc.)



# Telescope and Instrument Fields-of-View

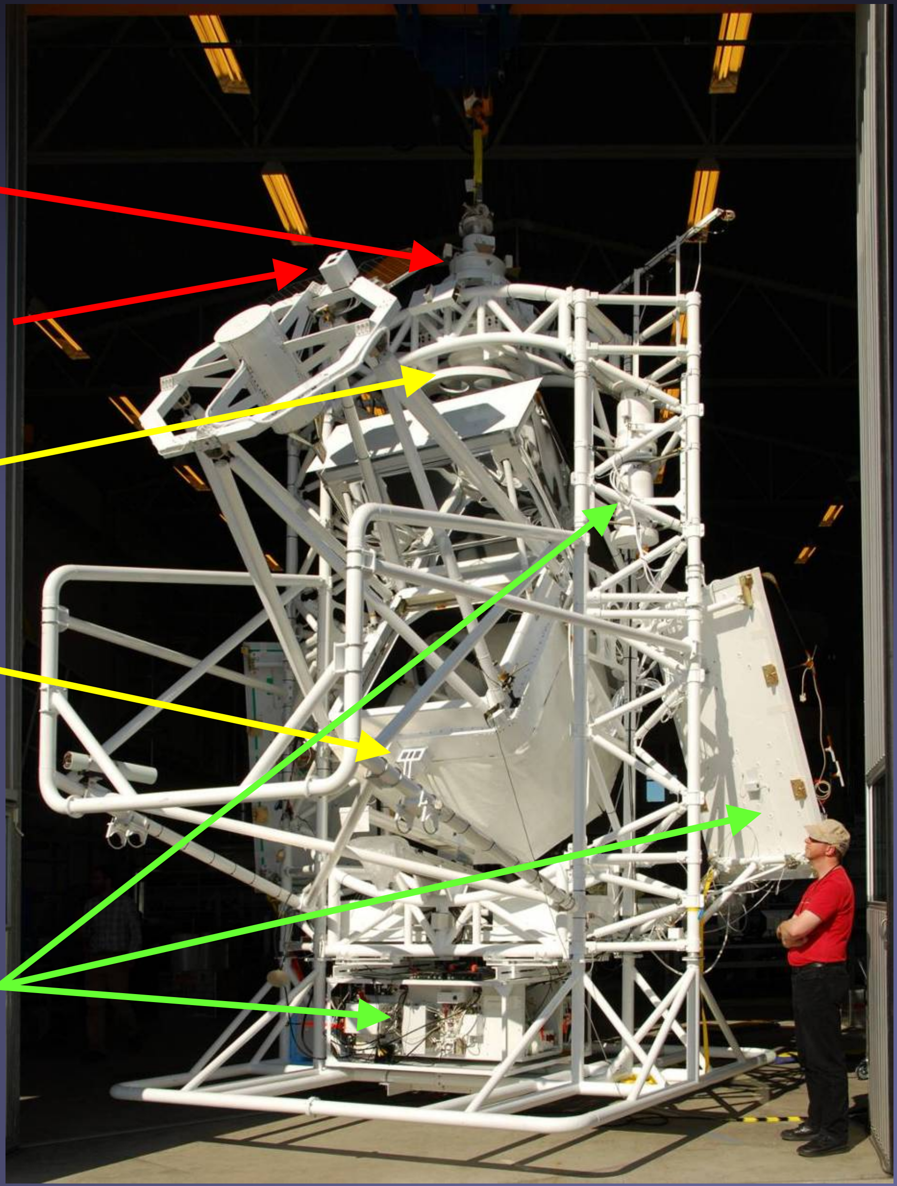



a) Full solar disk with circular telescope FoV

b) science instruments FoV and free range of image stabilization

# Gondola

- Sun acquisition and tracking with 3 stage sensor concept:
  - corner cells indicating right quadrant
  - medium accuracy 1 dim sensors for azimuth and elevatipn (PASS, FRED), both mounted to gondola frame top end
  - High resolution Lockheed Intermediate Sun Sensor (LISS) on telescope front ring
- Two-stage azimuth drive for decoupling gondola from flight train (coarse) and azimuthal position control with momentum wheel (fine)
- Elevation is controlled via linear translation stage coupling telescope central frame with gondola
- Aluminum/steel core framework structure with high stiffness, additional roll cages protecting telescope and instrumentation during launch and landing
- Gondola carries instrument and gondola electronics on racks mounted to the rear side, as well as on-board data storage containers and CSBF commanding/telemetry equipment



Launch on June 8, 2009, 08:27 LT, ESRANGE, Kiruna, Sweden

Landing on Somerset Island, Northern Canada
June 13, 2009, 23:44 UT

NASA LDB Flight Program:
34 MCF, ~ 1.000.000 $m^3$, Zero pressure balloon


SUNRISE trajectory, ~134 hours (~6d) at 34-37 km float altitude

# SUNRISE Technical Performance 1st Flight

Positives:

- Telescope and instrumentation worked flawlessly
- More than 1.8 TByte science data, IMaX ~480.000 img, SuFI ~150.000 img
- About 33 hours of observation at various positions on the Solar disk, including limb
- Several continous time series of more than 30 min length
- Achieved spatial resolution: ~0.1 arcsec, ~100 km @ solar surface
- No indication for ‘seeing’, static aberrations negligable, image reconstruction can handle this
- All temperatures well within design limits

On the down side:

- Integrated system testing is essential, SUNRISE was mated for the first time at the launch site!
- Complex instrument needs extended inflight commissioning before science operation starts (thermal equilibrium, verification of LISS/telescope relative alignment, exposure time corrections etc.), high commanding and telemetry bandwidth is crucial. SUNRISE did not get any science image down to ground during the whole mission!
- Observation time series frequently interrupted due to wind gusts beyond control of gondola, mainly in azimuth
- Instrument spatial resolution limited by excited structure resonances (10 Hz) and high frequency noise, could only be damped but not fully eliminated by tip-/tilt image stabilization

# Outlook

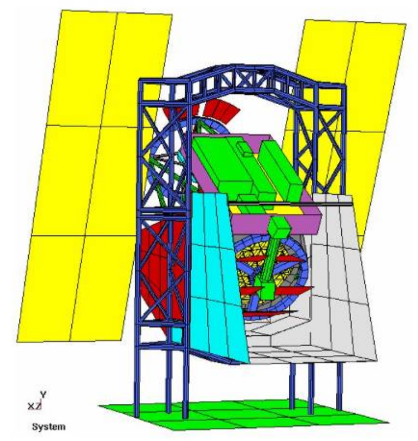
- We plan for a second flight, target 2012 (higher solar activity)
- Improvements shall be implemented for
  - 'over-the-horizon' telemetry and
  - stability of telescope pointing

- Details about SUNRISE can be found in:

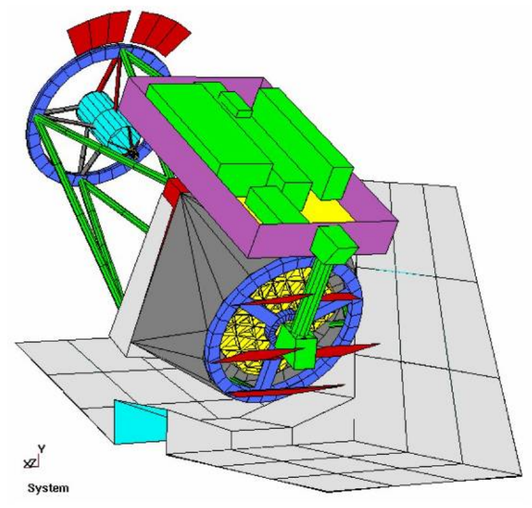

- The Sunrise Mission, P. Barthol, A. Gandorfer, S.K. Solanki, et al.,
  Solar Physics, 2011, Vol. 268, No. 1, p. 1-34, DOI: 10.1007/s11207-010-9662-9
- The Imaging Magnetograph eXperiment (IMaX) for the Sunrise balloon-borne solar observatory, V. Martinez Pillet, J.C. del Toro Iniesta, A. Alvarez-Herrero, et al., Solar Physics, 2011, Vol. 268, No. 1, p. 57-102
- The Filter Imager SuFI and the Image Stabilisation and Light Distribution system ISLiD of the Sunrise balloon borne Observatory, A. Gandorfer, B. Grauf, P. Barthol, et al.,
  Solar Physics, 2011, Vol. 268, No. 1, p. 35-55.
- The Wave-front correction system for the Sunrise balloon borne solar observatory, T. Berkefeld, W. Schmidt, D. Soltau, et al., Solar Physics, 2011, Vol. 268, No. 1, p. 103-123
- SUNRISE: Instrument, Mission, Data And First Results, S. K. Solanki, P. Barthol , S. Danilovic, et al, 2010 Astrophysical Journal, 2010, ApJ 723 L127, doi: 10.1088/2041-8205/723/2/L127

# Technological challenge 1: Thermal

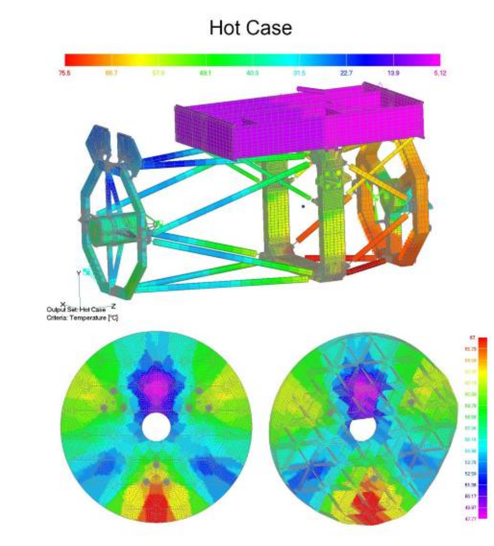
- At 3 hPa no convective energy transport
- System is mainly radiatively controlled
- Surface treatments (paints, tapes, foils etc.) are important to control solar absorption ($\alpha$) and infrared emission ($\varepsilon$)
- Variable energy input (Sun, Albedo) and high power dissipating commercial electronics requires detailed thermal modelling
- Tropopause transit gives temperatures below -60°C
- „Off nominal“ conditions need special consideration, i.e. pointing loss or off-pointing



SUNRISE GMM: Rear View with Solar Panels



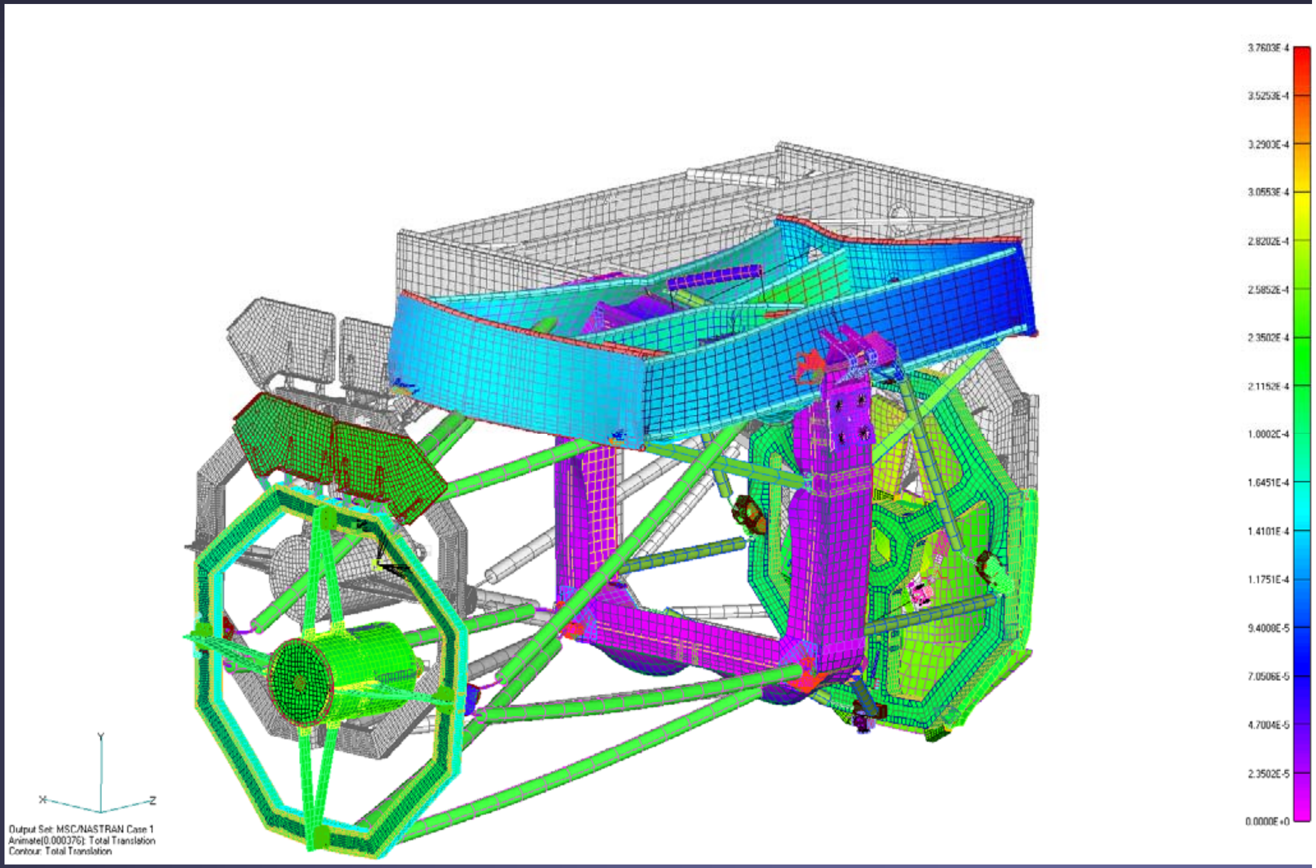
SUNRISE GMM: View into Gondola Cage



# Technological challenge 2: Mechanical

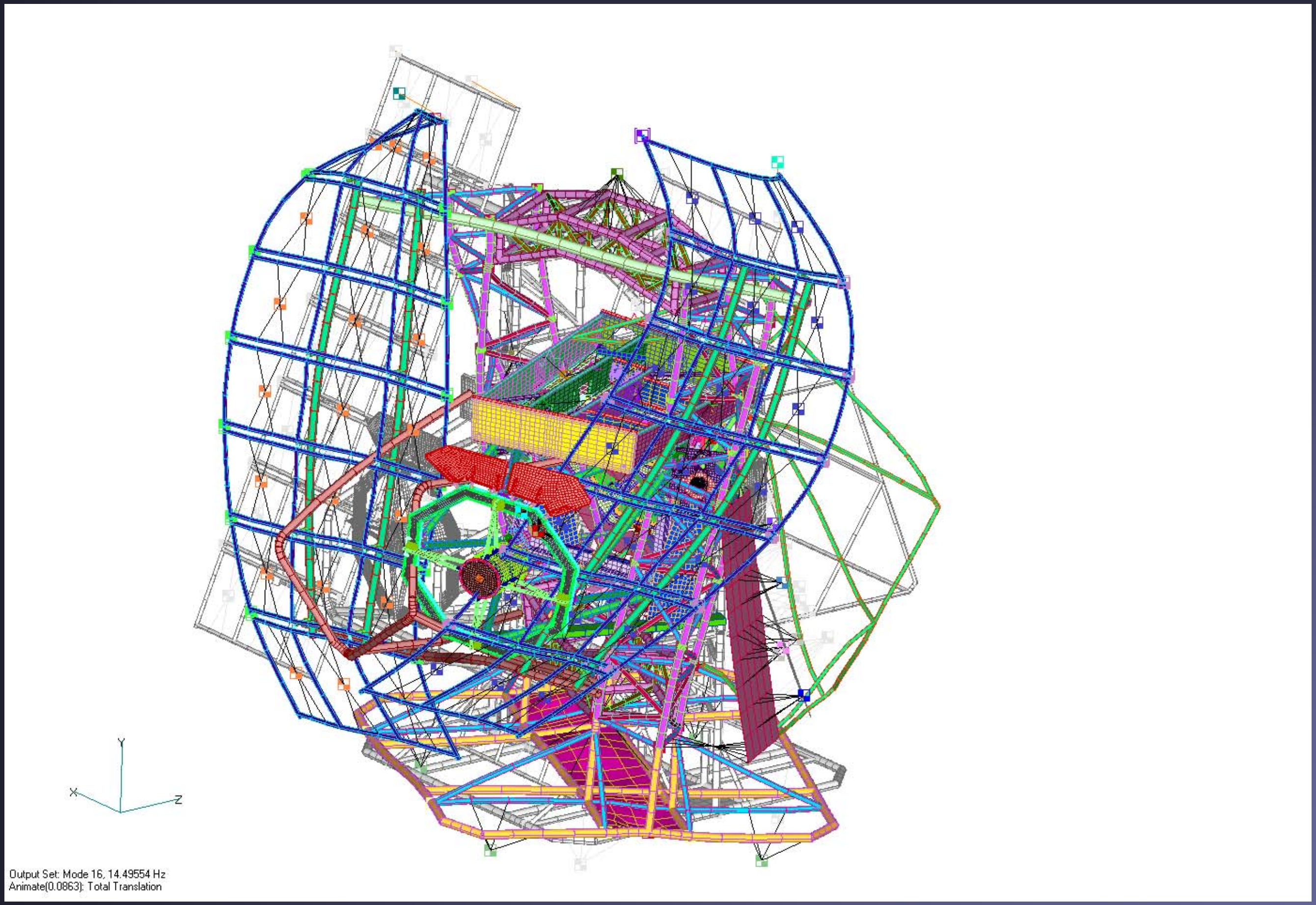
- Telescope in Alt-Az mount: varying gravity vector!
- Instruments piggy-back on telescope
- Demanding requirements on pointing stability

➢ Detailed structural analyses and high structural stiffness




Structural Deformations under 1g Load

# Technological challenge 2: Mechanical




Eigenfrequency assessment, decoupling important for pointing control loops

# Technological challenge 3: Optical

- Lightweighted 1 meter primary mirror with diffraction limited performance is a challenge of its own, long lead item (2.5 y)
- UV optics asks for contamination control (particles and molecular)
- Polarization optics requires careful design of coatings, mechanical mounts (bi-refringence) and temperature stability
- Telescope in-flight alignment stable to 1 µm (actively controlled)
- High spectral resolution requires calibration with real sunlight On-ground system tests after assembly/integration

Thank you for your attention