The Sunrise III Mission

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SOLARNET IV Meeting, Lanzarote, Spain, 20 January 2017

The Sunrise balloon-borne solar observatory

- 1-m Gregory telescope (Barthol et al. 2011)
  ...rests in protective and stabilizing gondola
- Float altitude of ∼37 km
- Instruments & optical subsystems
  - Imaging Magnetograph eXperiment (IMaX, Martínez Pillet et al. 2011): Vector-Polarimetry in Fe I 5250
  - Ultraviolet Filter Imager (SuFI, Gandorfer et al. 2011): 214, 278, 300, 312, 388, 396 nm
  - Light distribution unit for simultaneous observations (ISLiD)
  - Active image stabilization with correlating wavefront sensor (CWS, Berkefeld et al. 2011)
- Two flights in 2009 and 2013
- Third flight targeted for 2020

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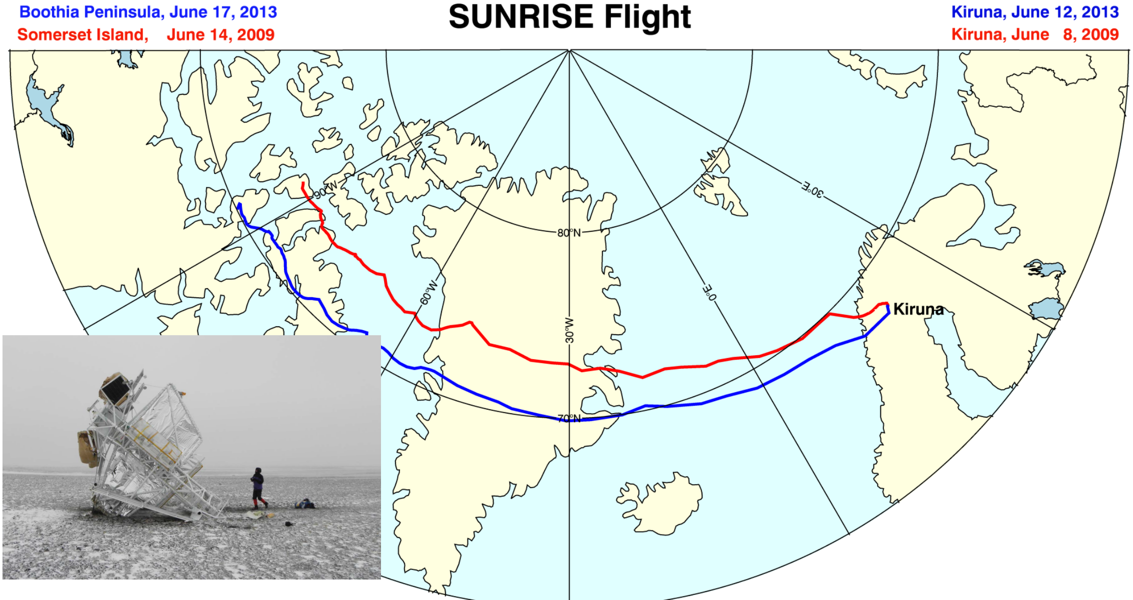
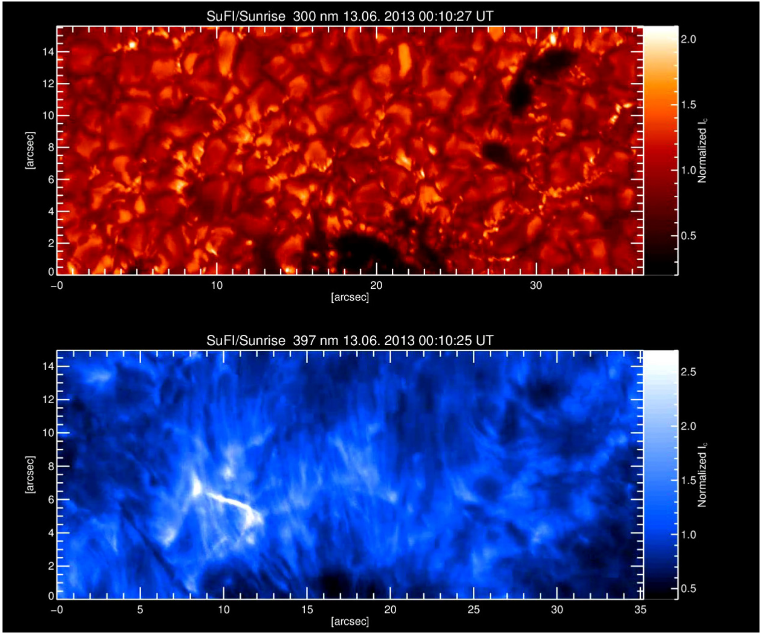


Data examples



Courtesy of T. Riethmüller & SuFI team

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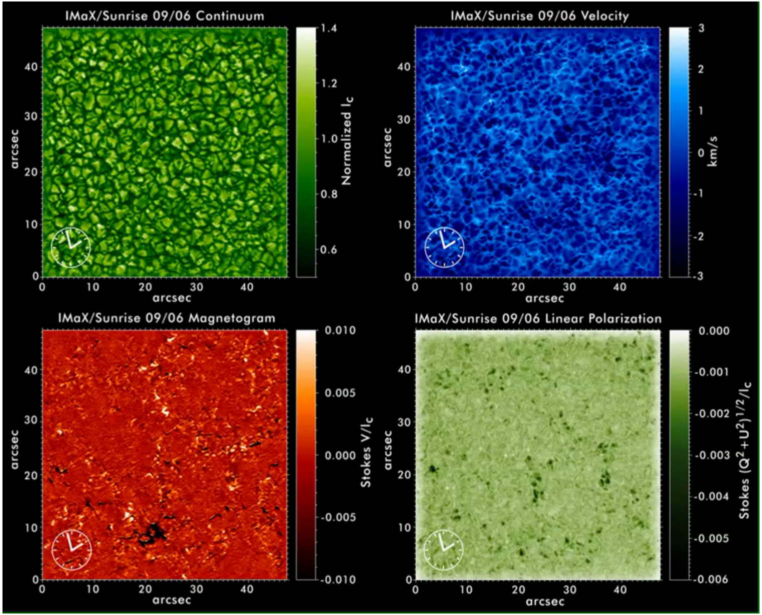


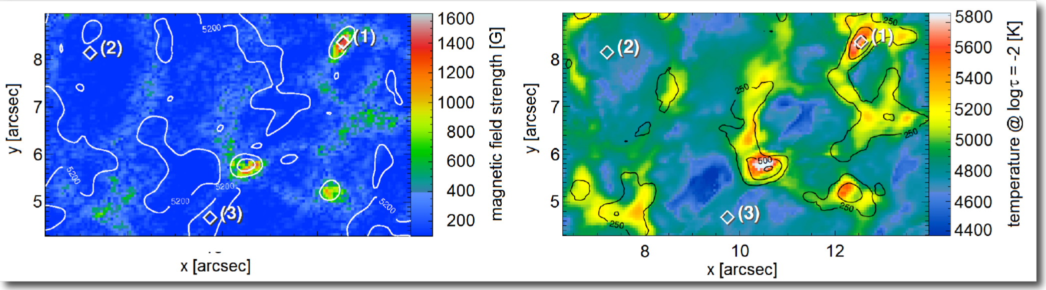
Courtesy of J. Blanco & IMaX team

Scientific results

- 60 refereed publications till now
- APJ special issue with 17 new papers (14 on Sunrise 2) in press

A few out of many highlights

- Kilogauß fields in quiet Sun resolved for the first time (Lagg et al. 2010)



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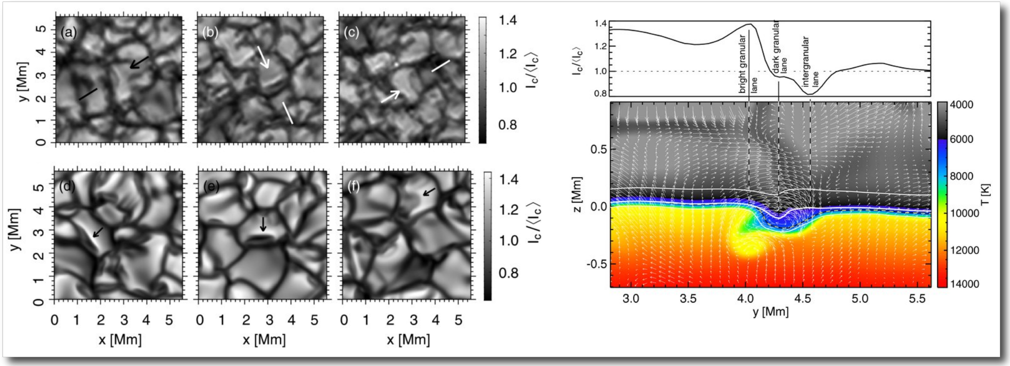

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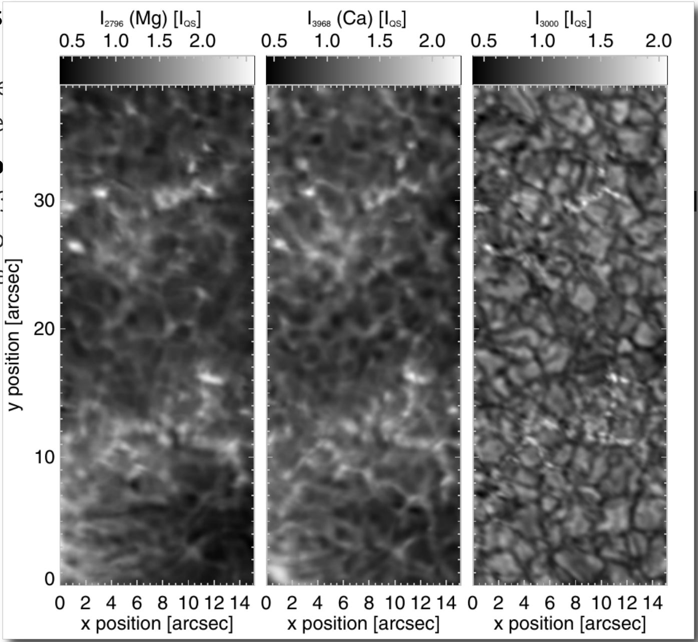

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- New inversion technique: MHD-Assisted Stokes Inversion (MASI, Riethmüller et al. 2017)

In this meeting:

Centeno's talk, Lagg's talk, Gafeira's talk, Chitta's talk, Smitha's poster

One-meter balloon telescopes in the times of DKIST

Ground-based is catching up

- Adaptive optics + image restoration has become mature
- Excellent performance in VIS + NIR (SST, GREGOR)
- Restoration of slit-spectropolarimeter data finally there! (van Noort's talk this afternoon)

→ Competing with DKIST is a real challenge

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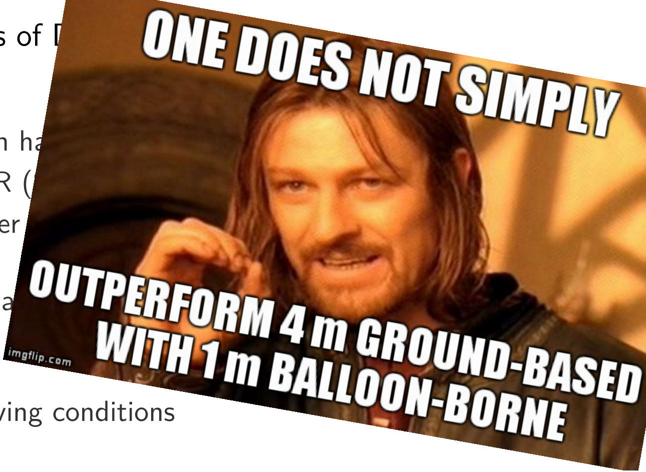

Balloon-borne advantages

- Seeing-free, stable operating/observing conditions
  - → Long time series
  - → "Straylight" advantage
- Co-spatial multi-wavelength (no atmospheric refraction)
- Truly unique: access to near-UV (SuFI: 214-400 nm)

Also: No ≥ 1 m solar space mission in sight

Near-UV: a vast unexplored territory

NUV spectro-polarimetry? From the ground?

- Zeeman-splitting scales with λ^2
- Less photons $\rightarrow$ longer integration times $\rightarrow$ worse spatial resolution
- Earth ' atmospheric transparency quickly decreasing below 400 nm
- Increased Rayleigh scattering

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Less photons, yes, ...but

- Lines are deeper, narrower $\rightarrow$ Stokes-V amplitudes similar to VIS
- Higher line density $\rightarrow$ higher information density (but blends, atomic data issues)

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NUV spectr

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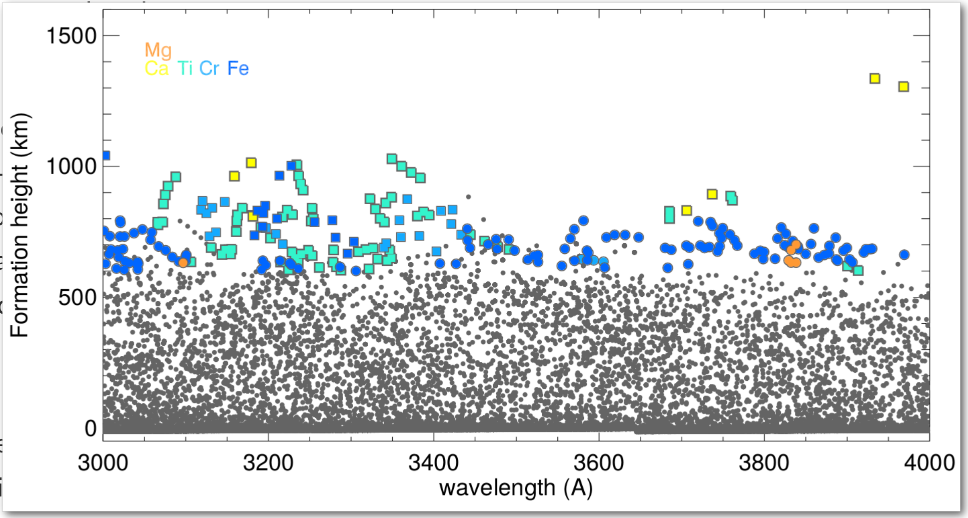


- $\geq$150 out of 15 000 investigated lines in 300-400 nm form at chromspheric height (R. Manso Sainz, LTE with corrections, FAL-C atmosphere, $\tau \sim 1$)

Multi-line inversions vs. lack of photons in near-UV

Case study by Riethmüller & Solanki, in prep.

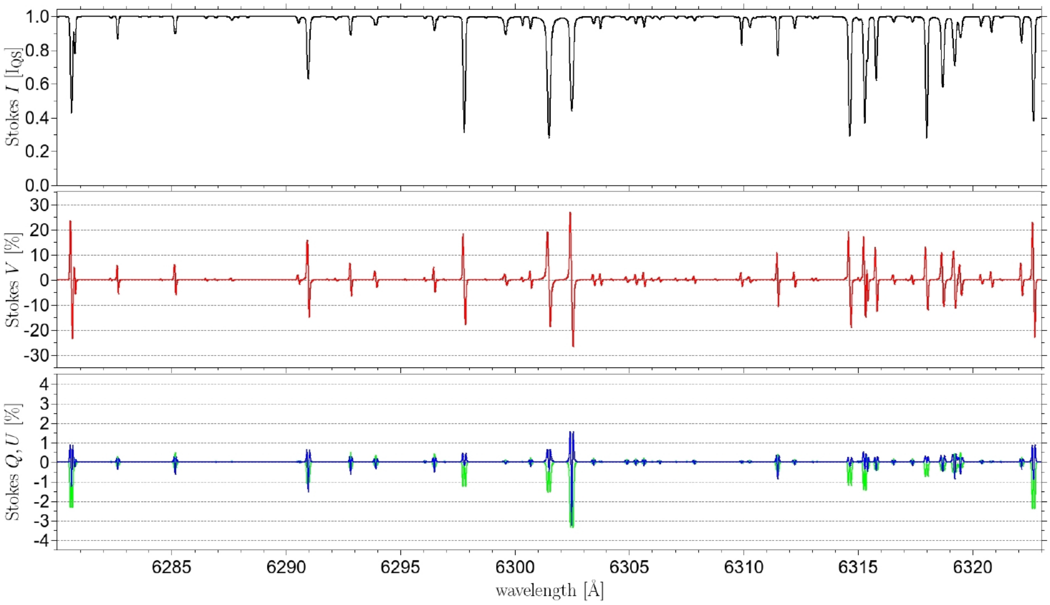
Method

- Promising NUV windows identified from SPINOR synthesis of all known lines (Kurucz, VALD): 314 ± 1.1 nm (352 lines), 412 ± 1.4 nm (265 lines) 630 ± 2.2 nm (80 lines) for comparision
- Synthesized Stokes maps from a MURaM snapshot as test case
- Degraded to a Sunrise 3 scenario: realistic noise level, $\lambda/\Delta\lambda = 150\,000$, *same* spatial sampling at all wavelengths (63 km pix^{-1}; critical at 630 nm)
- Statistical analysis of differences between noise-free and noisy inversions

Outcome

- Both NUV-ML inversions similar or better compared to Fe I 6302 double-line
- 413 nm ML much better than red double-line, similar to red ML

Multi-line inversions vs. lack of photons in near-UV



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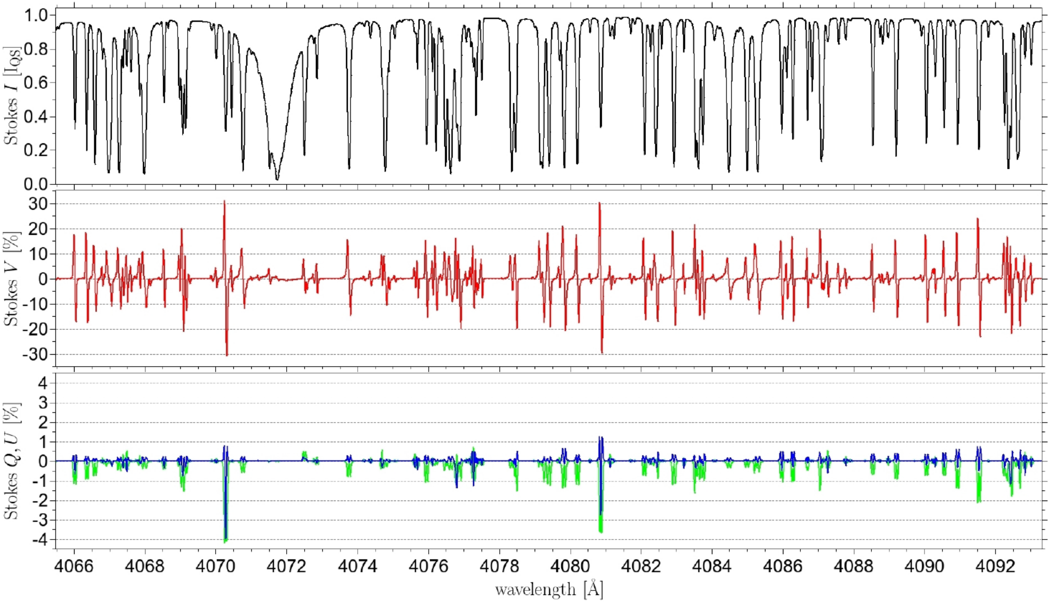

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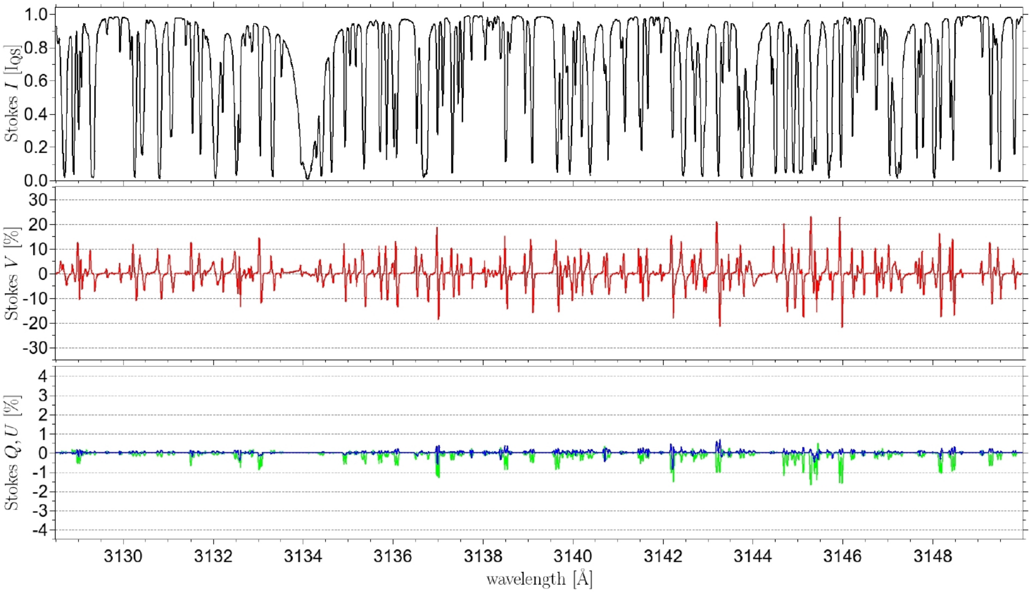

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Sunrise III: more than a reflight

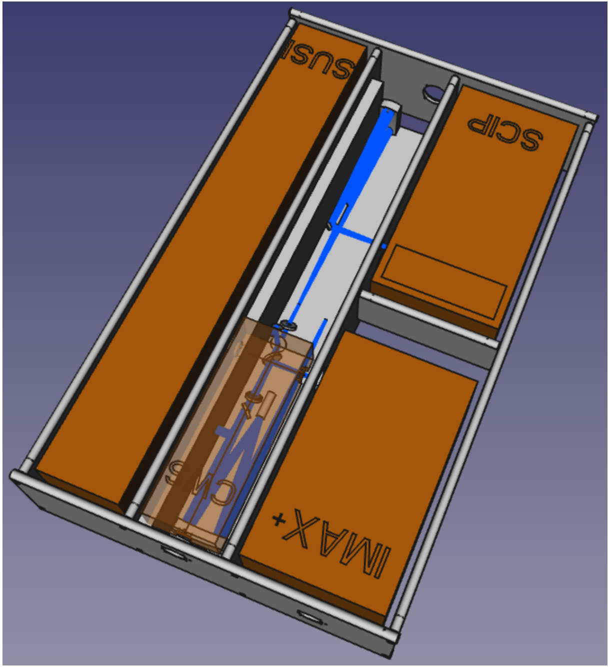
- New Gondola with three-axis stabilization (APL)
- Enhanced Correlating Wavefront Sensor for image stabilization (KIS)

Scientific payload suite with unique diagnostic capabilities

- SCIP: Sunrise Chromospheric Infrared spectroPolarimeter (NAOJ/JAXA + MPS/IAA)
  - Two-channel, dual-beam slit-S/P at 770 and 850 nm
- SUSI: Sunrise Ultraviolet Spectropolarimeter and Imager (MPS)
  - Multi-line slit-S/P + imaging in 300-430 nm range
- IMaX: Imaging Magnetograph eXperiment (IMaX consortium, lead by IAA)
  - Fabry-Pérot-based imaging S/P in Fe I 524.70, 525.02, and Mg I 517.3 nm
- CoMag: Compact Magnetograph (APL)
  - Full-disk Stokes-V magnetograph at 630 nm, fed by dedicated 6 cm telescope

Post-Focus Instrument package

- Feed optics upstream of F2 unchanged
- Re-design & simplification of light distribution unit



Courtesy of A. Feller

SCIP

- Two wavelength bands at 770 nm (K I, Mg I, Ni I) and 850 nm (Ca II, Fe I) chromospheric and photospheric lines
- Multi-line approach (Quintero Noda et al. 2016, MNRAS)
- FOV: 58" slit, 58" scan range
- Sampling: 0.094" pixel^{-1}
- $\lambda/\Delta\lambda > 10^5$
- Polarimetric sensitivity: 3×10^{-4} in 5-10 seconds

SUSI

- Diffraction-limited multi-line S/P + imaging at 300-430 nm
- Spectral field of view $\sim 2 - 4$ nm; $\lambda/\Delta\lambda = 150\,000$
- 60" slit, 60" scan range
- Polarimetric sensitivity: $\sim 3 \times 10^{-4}$
- Dealing with residual image jitter is critical to meet requirements

  $\rightarrow$ Fast (50 Hz) image acquisition suitable for image/spectrum restoration

Summary

- Great science output from Sunrise I, Sunrise II ramping up
- Telescope + optics still intact after two crashes into Canadian mud
- Third flight planned for 2020 with greatly enhanced instrument suite

Key aspects

- Simultaneous multi-wavelength, multi-line S/P in chromosphere and photosphere between 300 and 850 nm
  - Unique capabilities for Zeeman and Hanle diagnostics
  - Much improved height sampling, more robust inversions
- New instruments: Slit S/P for NUV and NIR, full-disk magnetograph
- Enhanced IMaX and image stabilization
- New Gondola with three-axis pointing stabilization