OpticalSpaceLink

High-Efficiency Tunable Laser Guide Star System

Adaptive Optics in Astronomical Telescopes

Ultra-High Resolution for Space Situational Awareness

High-Capacity Optical Space Internet

Resilient Deep Space Communication

Novel Atmospheric Research

TOPTICA PROJECTS GmbH

OpticalSpaceLink

Specification

TOPTICA PROJECTS GmbH

Operational conditions	night, twilight, daylight
Laser output power	≥ 40W med. power version; ≥ 70W high power version
Laser wavelength	589.150 nm (Na D2 line)
Wavelength tunability	Tunable over > ± 1 GHz Na resonance frequency Na D2
Chirp rate	0.8 – 1.7 MHz/µs
Chirp bandwidth	250 – 350 MHz
Chirp frequency	2 – 7 kHz
Frequency stability	< 10 MHz (absolute)
Laser linewidth	single frequency, 2..5MHz (FWHM) adjustable
Power stability (peak-to-peak)	< 10%
Intensity noise (rms)	< 3 % (rms)
Optical beam diameter (4σ, laser output)	(3 +/- 0,1) nm
Beam ellipticity	< 5%
Beam quality (rms wavefront error)	< 50 nm
Beam pointing (rms)	< 160 µrad
Beam shift (rms)	< 100 µm
Polarization extinction ratio	> 100:1
Linear polarization stability	< 2°
Repumper intensity	0 … 20 %, adjustable
Fluorescence reflux	25 Mph/m²/s
supported AO loop bandwidth	Typ. 2 kHz
Cooling system specification	
Coolant temperature	15 °C
Coolant temperature stability	± 0,75 K
Coolant flow rate	approx. 5 l/min.
General specification	
Power consumption	< 1.5 kW
Operating temperature range	-10 … 25 °C
Max operating altitude (above sea level)	< 4300 m
Dimension laser head	440 x 400 x 600 mm
Weight laser head	< 90 kg
Dimension electronic and control cabinet	800 x 800 x 1250 mm
Weight electronic cabinet	400 kg

Key Features

- Daylight and twilight proven optical specification
- Integration into a flexible telescope mounting
- Fully gravity-invariant operation, fast accelerations
- Full performance down to zenith angles of 60°
- High return flux of at least 25 Mph/m²/s
- Enabling AO control loop bandwidths > 2 kHz
- Excellent polarization properties
- Minimized cooling requirements
- State-of-the-art optomechanics
- Active beam control loops
- Fully automated
- Telecom ready
- Remote control interface

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The new Laser Guide Star System

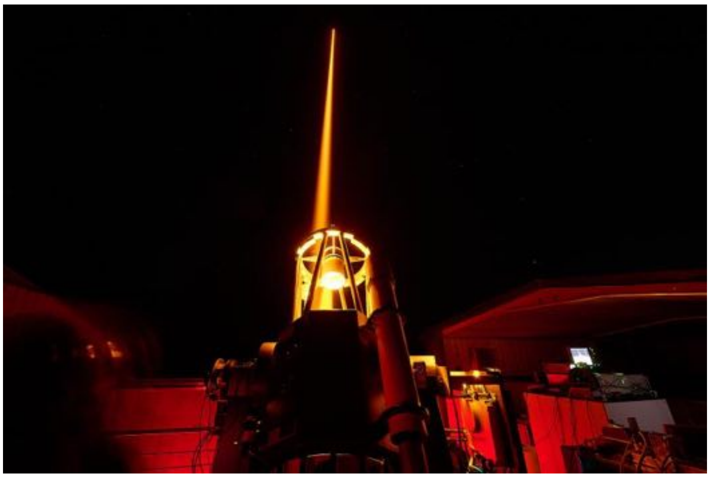
TOPTICA Projects is the world-leading commercial supplier with its "SodiumStar 20/2" laser guide star system. Representing the broadest installed base (e.g., ESO VLT, W. M. Keck Observatory, Gemini Observatories, Subaru Observatory), PRO has also been able to replace older laser solutions. PRO's laser system generates an artificial guide star based on the resonant excitation of sodium atoms in a naturally occurring gas layer within the atmosphere. This sodium layer exists in the upper mesosphere/lower thermosphere at approximately 90…100 km altitude. The laser-excited fluorescence from the sodium atoms travels through the atmosphere while sampling its optical index variations by turbulence and is analyzed on the ground by the wavefront sensors of the adaptive optics control system. The high sensitivity to atmospheric effects in the entire altitude range between the ground and 100 km is the most significant advantage of artificial guide stars generated by sodium resonance fluorescence. Alternatives such as signals generated by Rayleigh scattering of laser beams in the lower atmosphere only sample turbulence in a limited range from ground to about ten kilometers altitude.

PRO's SodiumStar 20/2 is field-proven and commercially available (TRL 9 for astronomy). However, it has been designed for astronomical applications at nighttime only. In this project, PRO will migrate this existing system into compliance with SST and telecommunications applications' unique needs, particularly much higher AO control bandwidths and **day- or twilight operation**.

Any AO control loop's crucial parameter is the signal-to-noise ratio (SNR) at the wavefront sensor. At night in the large astronomical observatories' locations, the background light is as low as possible. Therefore, the signal-to-noise ratio is mainly determined by the signal light ("return flux") of the artificially generated guide star. During twilight or even daylight, the background signal (sunlight) has to be suppressed significantly, or the artificial guide star's intensity needs to be increased. Also, for tracking fast-moving objects in space, the sensor's available integration time is much shorter than in typical astronomical applications, where the pointing direction of the telescope is almost static. These considerations led to the development of an optimized laser guide star system called **OpticalSpaceLink**.

The artificial guide star's return flux will be increased by higher optical laser power and well-understood advanced quantum excitation schemes (e.g., frequency chirping of the excitation laser).

Twilight operation of the OSL Sodium Guide Star Laser system



OSL test setup at the Allgäuer Volkssternwarte in Ottobeuren

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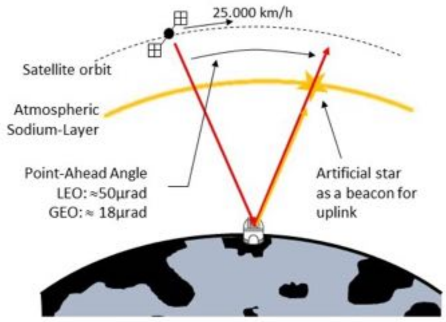
Application

Free space optical communication (FSOC)

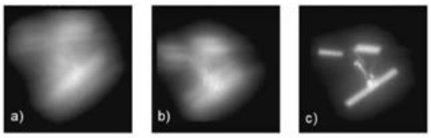
Mega-constellations of several thousand interlinked satellites that span the globe will deliver broadband internet connectivity to every location on Earth. Free-space optical communications provide ultra-high-speed, license-free, and secure interconnection links. **OpticalSpaceLink** assisted adaptive optics enables the multi-terabit optical laser up- and downlinks between ground stations and satellites. It secures realizable low communication link power budgets, low terminal energy consumption, and highly precise satellite tracking by optical ground stations as the only available technology to compensate for any atmospheric link disturbances.



Schematic of interworking between satellite communication up- and downlink and the guide star laser. Due to the high velocity of the satellite, the uplink (together with the required guide star laser) points in a different direction than the downlink (point-ahead angle).

Space situational awareness
Ultra-High Resolution space mapping

Highest-resolution imaging capabilities for observation of near-earth-space objects (up to geostationary orbits, with altitudes of 36.000 km) are of enormous relevance not only for managing and controlling space debris but also for space missions in general (e.g. Launch and Early Orbit Phases). **OpticalSpaceLink** assisted adaptive optics enables optical telescopes of the medium-size-class to track and image any sun-lit object of centimeter rages up to highest geostationary orbits by compensation of any kind of atmospheric imaging aberrations. By twilight and daylight operational capabilities, **OpticalSpaceLink** expands the possible observation time many times over.



Optical image of the satellite ('SeaSat-1') in earth orbit: a) without adaptive optics, b) with optical pointing/tracking only, c) with adaptive optics using an artificial guide star; 3.5 m telescope, source: USAF-SOR, credit: D. Montera.

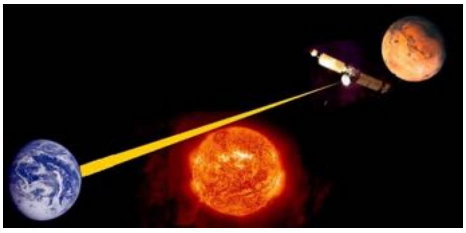
Space debris maneuvering

Collision avoidance and the control of space debris have become of outstanding importance for near-Earth astronautics. The massive number of small and tiny debris particles in orbit is a real hazard for satellites and human-crewed space missions. Laser beam based particle maneuvering displays one promising technology to control and remove debris particles. OpticalSpaceLink assisted adaptive optics enables laser launch telescopes to focus the maneuvering laser very precisely onto the debris target even at high orbital angular speeds. It contributes to keep the laser output power considerably low by compensating the optical aberration of Earth's atmosphere and providing a diffraction-limited beam focus onto the target. Daylight operational capabilities enable long time windows for maneuvering actions.

"Cerise" collision event in 1996 (Artist's view, ESA).

Deep Space Communications

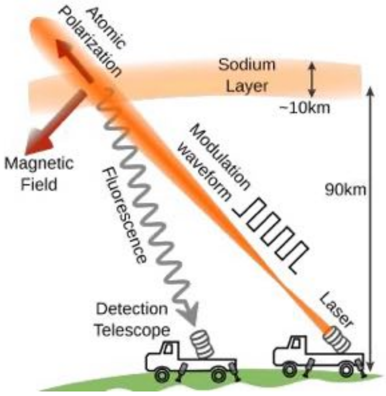
Deep space optical ultra-high-speed communications bridge vast distances between Transmitter and Receiver in interplanetary or interstellar space and require highly precise spacecraft tracking by earth-based optical ground stations. OpticalSpaceLink assisted adaptive optics enables uplink spacecraft tracking even at very high spacecraft speeds in deep space and compensates for any atmospheric-induced downlink signal disturbances.



Deep space optical free space laser communication. (artist's view, Source: NASA)

Atmospheric Research
Earth magnetometry research

Ultra-high-resolution spectroscopy of sodium atoms of Earth's mesosphere can help to investigate changes in Earth's magnetic field, air mass movements in the upper atmosphere and solar winds. Investigations of air mass movements let expect new insights into mechanisms of climatic changes. **OpticalSpaceLink** excites the sodium atoms with a single frequency laser line width of less than 5 MHz. The laser is tunable over the entire range of sodium atoms' velocity classes. Intensity-modulated, the laser can be used to excite Larmor oscillations to make the sodium atoms a sensor for the magnetic field strength.



Schematic of the spectroscopy of atoms in the sodium layer of the mesosphere using the intensity modulated Guide Star Laser in order to measure the spatial and temporal distribution of the strength of the earth magnetic field (from J.M. Higbie, 2009, not to scale)

Astronomy

The sodium guide star technology generates artificial guide stars at nearly any point in the sky down to elevation angles of less than 30°. Fast slewing of guide stars is possible to follow the direction of view of the astronomical telescope. The highest wavefront measurement accuracy indicates more than one guide star laser per telescope. The compliance with the highest requirements on equipment's weight, footprint, thermal stability, and environmental conditions allows deployment in any kind of high-end astronomical telescopes. Simple installation, operational and maintenance procedures keep operational efforts, outage time, and costs low.

Images of the planet Neptune obtained with MUSE/GALACSI instrument on ESO's VLT (left hand side: Adaptive Optics control in loop, right hand side: no adaptive optics correction, source: ESO)

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Typical Data and System Architecture

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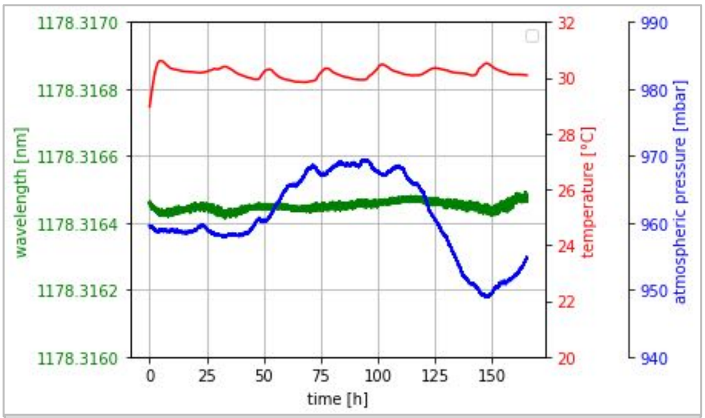
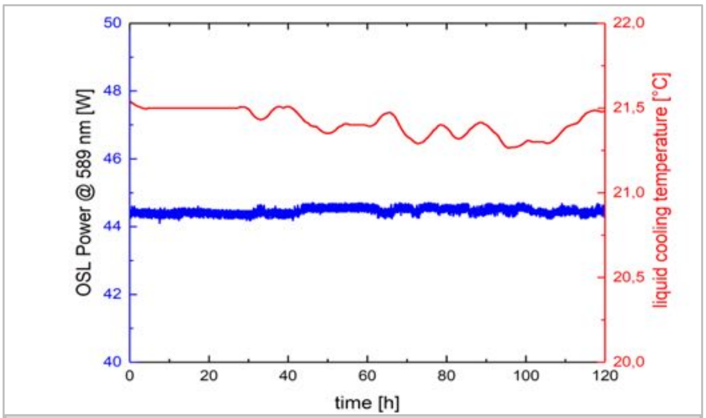
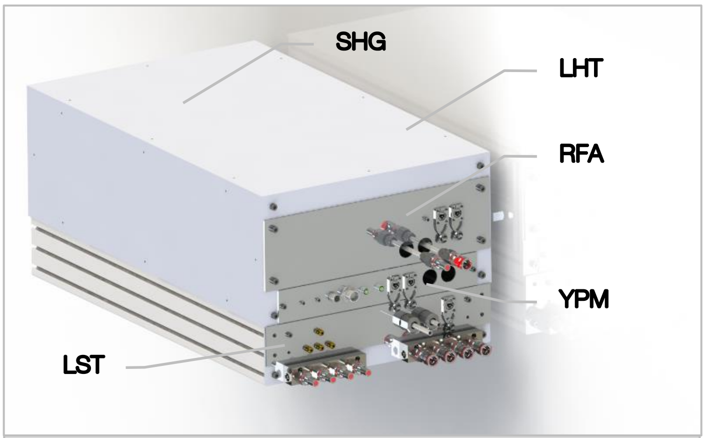


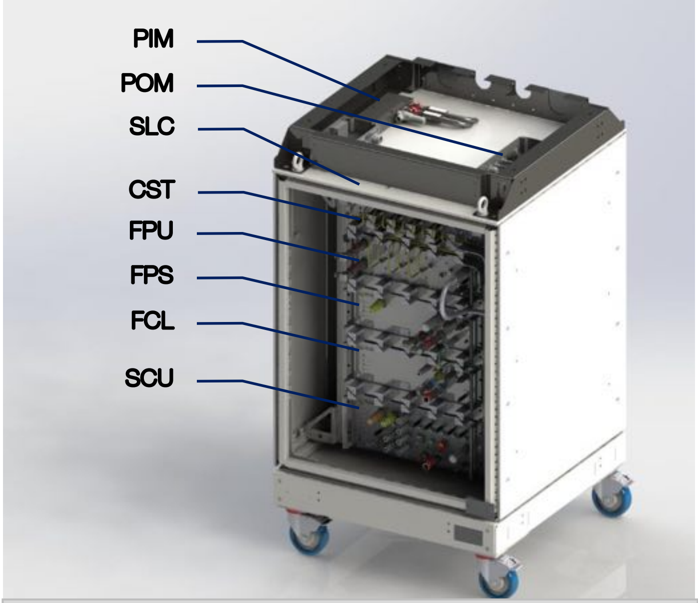
Long-term wavelength stability of the OSL seed laser over 175 hours, locked to the spectroscopy stabilized reference laser. The standard deviation is 2.6 MHz and the peak-to-peak deviation is 17 MHz



Long-term power measurement showing a mean value of 36 W The standard deviation is 0.1 W and the peak-to-peak variation of 1.3 %.



The Laser head tray is compatible with the existing design of the SodiumStar 20/2 making an upgrade to telescopes for existing customers straight forward.



The SpaceLinkCabinet can be placed several ten meters from the Laser Head, making the integration to smaller telescopes (optical ground stations) easier.

Acronym	Description
PIM	Power Entry and Interface Module
POM	Power Outlet and Interface Module
SLC	Space Link Cabinet
CST	Cabinet Splice Tray
FPU	Fiber Laser Pump Unit
FPS	Fiber Laser Power Supply
FCL	Frequency Controlled Laser
SCU	Surveillance and Control Unit

Acronym	Description
SHG	Second Harmonic Generation
LHT	Laser Head Tray
RFA	Raman Fiber Amplifier
YPM	Ytterbium Pump Laser MOPA
LST	Laser Head Splice Tray

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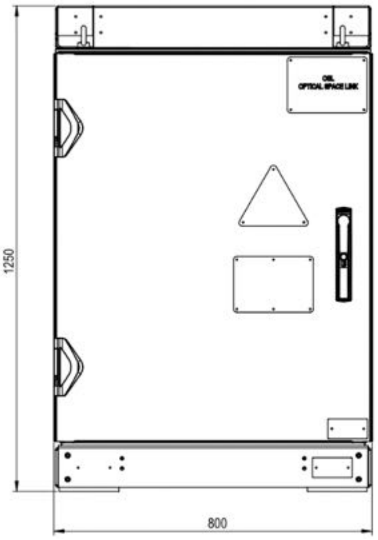
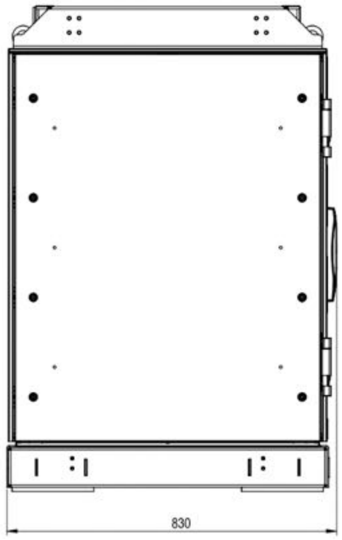
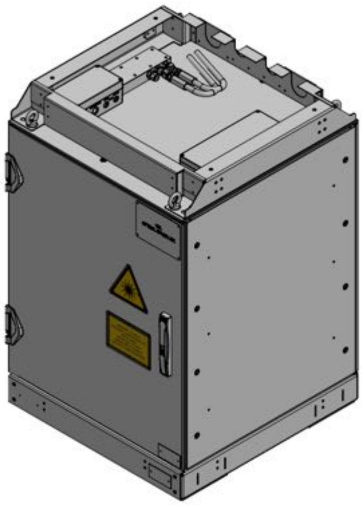
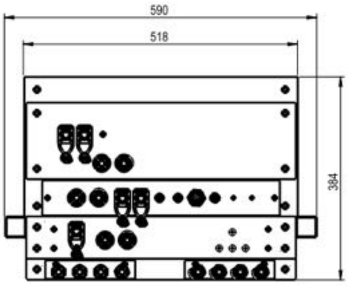
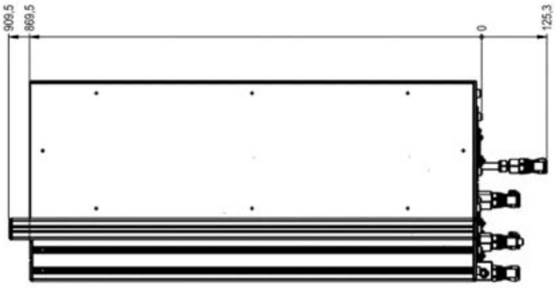
Mechanical Dimensions

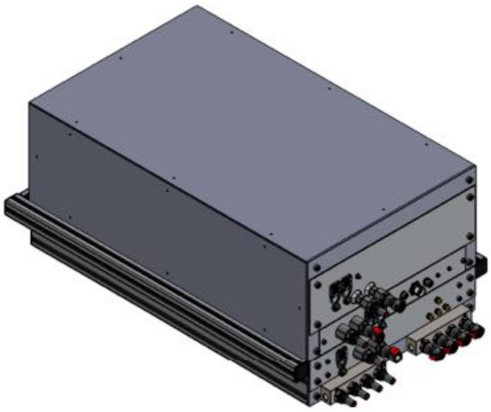












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