# TOWARDS HIGH-REVIST; HIGH-RESOLUTION THERMAL MONITORING. LISR – A LAND SURFACE TEMPERATURE MONITORING MISSION ON ISS

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## ABSTRACT

The LisR (Longwave Infrared Sensing demonstratoR) mission will demonstrate the capability to record our planet`s surface temperature from space. The miniaturized payload will be mounted outside the ISS on the Nanoracks Experimental platform NREP. Covering multiple thermal bands, the goal is to derive highly precise land surface temperature (LST) and subsequent insights, including evapotranspiration (the loss of water from plants and soil to the atmosphere) as well as vegetative, in particular water stress. The Information will be used to enable efficient water monitoring practices for farmers by reducing overirrigation and uncertainty in estimating yield. This paper serves as an overview of the LisR mission and the payload, including a cryo-cooled thermal infrared sensor, a free form optic and advanced data processing. With the successful first light of LisR on March 16, 2022, also some first images are presented in this paper.

## 1 Mission and Objectives

The LisR (Longwave Infrared Sensing demonstratoR) records the planet's surface in the thermal infrared part of the electromagnetic spectrum. The payload is mounted outside the ISS on the Nanoracks Experimental Platform (NREP). Covering multiple thermal bands, the goal is to derive highly precise land surface temperature and subsequent insights, including evapotranspiration (the loss of water from plants and soil to the atmosphere) as well as vegetative, in particular water, stress. The information will be used to enable efficient water monitoring practices for farmers by reducing overirrigation and uncertainty in estimating yield. The instrument is the size of a shoebox and is the prototype for a constellation of free-flying satellitesdesigned to deliver such data at even higher spatial and spectral resolution and daily global coverage, the HiVE constellation.

The LisR payload has been launched on board of the Cygnus freighter mission NG-17 "Piers Sellers" on February 19, 2022. The installation on the NREP was on March 9, 2022. LisR has been enabled the first time on March 16, 2022 and is producing image data since then. The commissioning phase will last until end of April, during this period the autonomy of LisR will be steadily increased, the automated data processing will be implemented and the data delivery for customers will be adapted.

With its maximum outer dimension of 40 cm by 10 cm by 10 cm and a mass of 6 kg the LisR instrument comes at the size of a shoebox. With a focal length of 150 mm, an F# of 3 and an aperture size of 50 mm, LisR provides a ground sampling distance of roughly 80 m. The swath width of dual band TIR instrument is around 26 km. The two TIR bands are able to capture images in the electromagnetic spectrum of light between 9 and 11µm. The power consumption in steady state mode sums up to 14 W.

Figure 1. Upper Left: LisR instrument with its black painted cover. Bottom right: LisR instrument without cover. The different subsystems, like the data and power processing unit, the TIR detector and the telescope are visible. Right: Location of LisR on the NanoRacks Experimental Platform NREP.

The thermal infrared region of the electromagnetic is ideal to derive core physical variables, most prominently the surface temperature. Temperature is vital to describe the ecosphere – the sum of all ecosystems ranging from rangeland, grasslands, forests, and wetlands to deserts and even urban areas – of our planet. The ecosphere relies on three interconnected cycles: Energy, Water, and Carbon. With temperature, we can describe the energy cycle: How much (solar) energy is available where for how long? We can also describe the water cycle: How much water is available where, how much water is required by vegetation, and even how much moisture is bound in the soil.

Lastly, this information enables a description of the carbon cycle: When plants have good growing conditions, in particular enough light (energy) and water, they consume carbon from the atmosphere and create carbohydrates (biomass).

Within the LisR mission the following objectives were set:

- demonstrate the capability of small COTS components such as the TIR detector to derive LST
- demonstrate free-form technology for the optics on a CubeSat scale
- validate patented calibration approach for LST data and
- showcase the business case for commercial LST data

## 2 Payload Design

The design requirements were mainly driven by the goal to build an instrument which can provide LST data with a GSD of 100 m or better and ideally with a temperature error with less than 1.5 K. Another important set of design drivers were introduced by the Nano Racks Experimental Platform – NREP. NREP defines all mechanical, electrical and software interfaces to the payload [1]. Moreover, in the context of the LisR mission it was necessary to have a clear nadir facing sight towards the earth to ensure uncomplicate TIR imaging capabilities.

### 2.1 Structural Design

LisR is a comparably small payload, nevertheless it can be divided into different subsystems.

The Integrated Detector-Dewar-Cooler Assembly (IDDCA) by IRnova serves as the thermal detector of LisR. Furthermore, the optical chain entails a free-form optic (FFO) designed by Fraunhofer IOF and manufactured by SpaceOptix GmbH. Another subsystem is the Electronics Stack, which includes a power supply and a data processing unit. For more detailed information about the data processing unit (DPU) please refer to Horch et al. [2]. These three subsystems are fit and safely integrated inside the provided envelope. Additionally, a suitable housing was designed to first, emit the heat of the subsystems and second, protect the payload while being handled inside and outside of the International Space Station (ISS).

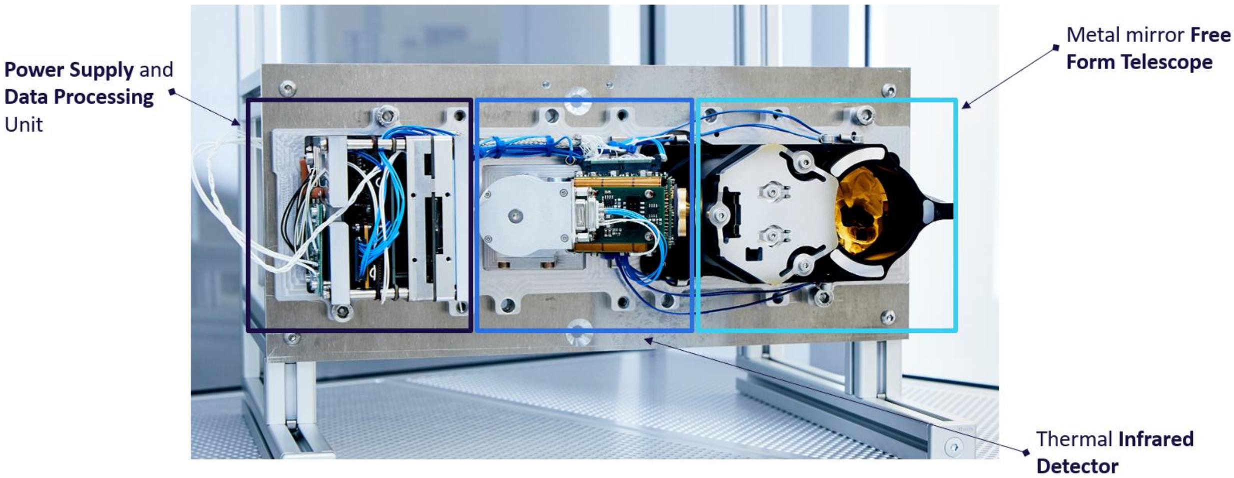


Figure 2. LisR Instrument with the different subsystems. Data and power processing unit, the TIR detector and the free form telescope.

To fit the sizable IDDCA inside the envelope, the direction of line of sight of the camera is, within a certain margin, already set. Its positioning along the long side of the envelope makes a redirection of the line of sight necessary in order to point towards nadir. For this purpose, a new freeform optic telescopewas designed , which is described in detail in Zettlitzer et al. [3]. The telescope achieves the redirection of the line of sight, the focusing of the image onto the detector array as well as minimizing straylight light through a Korsch design while remaining as compact as necessary to fit inside the small envelope. Additionally, the telescope has an athermal design which reduces the influence of instrument temperature to image quality significantly. The optical path of the telescope requires it to be tilted upwards related to the IDDCA.

The electronic components are stacked according to the CubeSat standard. The housing of the DPU as well as the frames of the Electronics Stack act as heatsinks and are connected to the baseplate. The baseplate acts as a supporting structure for the whole payload and therefore at the same time as an optical bench. All structural parts including the IDDCA are manufactured out of the aluminum alloy AW-7075-T6. This alloy provides high strength as well as low thermal stress due to the same coefficient of thermal expansion (CTE) of the structure. The NREP experiment plate consists out of the same material. Only the telescope consists out of AW-6061, nevertheless, the CTEs are similar. The baseplate is one half of the two-part housing of LisR. The other half is a cover milled out of one piece which is fastened to the baseplate.

Due to the high heat load generated mainly by the cryocooler of the IDDCA and the electronics, heat conduction is of great importance. Thermal Gap Pads are added in between contact areas where there is the need of high heat transportation, e.g. between the IDDCA and the baseplate.

## 2.2 Simulations

Several simulations were conducted in the process of the development of LisR. They can be separated into two main categories.

**Thermal analysis**

The first is a thermal management analysis. Using Thermal Desktop, the temperature range of the payload in orbit was simulated. For this purpose, different thermal cases were analyzed. Only the Hot and Cold Case are relevant for the operability and the survival of the payload. Besides the obvious influences of thermal cases like heating power and operational modes of the payload or solar eclipse, additional parameters were considered. Considering Beta-Angle, altitude, solar flux, Albedo-Factor, infrared planet shine and ISS attitude, a hot and cold orbit can be distinguished. Furthermore, different NREP temperatures were considered. The simulation provided the following possible temperature range.

| **Subsystem** | **Operating Temp. Range** | **Temp. Range in Simulation** | **Temperature Margins** | |
|---|---|---|---|---|
| | | | Low Temp. | High Temp. |
| Isolated DC/DC Converter | -55°C to +125°C | +8°C to +69°C | Δ 63°C | Δ 56 °C |
| DPU | -40°C to +85°C | +7°C to +45°C | Δ 47°C | Δ 40°C |
| Electrical Power Supply | -35°C to +85°C | +6°C to +54°C | Δ 41°C | Δ 31°C |
| IDDCA | <+40°C* | +6°C to +52°C (to +34°C if turned off) | N/A | Δ 6°C (in case IDDCA is turned off) |
| Telescope | only gradient important | gradient < 4 K | N/A | N/A |

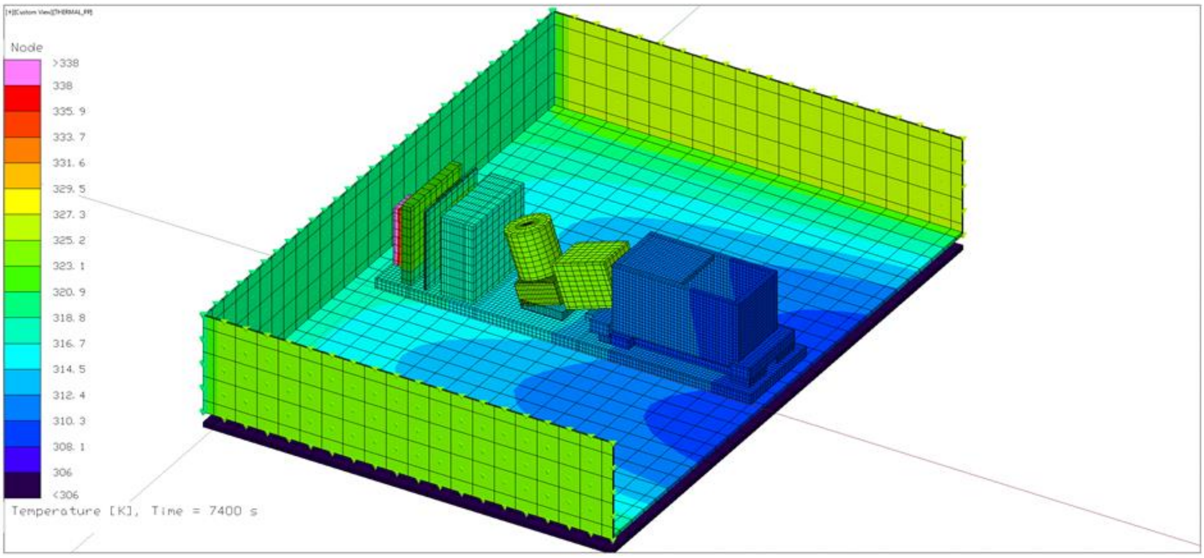


Figure 3. Thermal Simulation of LisR mounted on NREP. Without Housing on NREP - Hot Case, Hottest Orbit Position

During the first four weeks of operations the temperature of the different subsystems was closely monitored. So far the maximum detected DPU temperature was 44°C while the simulation assumed a maximum temperature of 45°C. In this case the simulation and the measured temperatures are well aligned.

**Structural analysis**

The second main category is structural analysis. Those analyses ensure a safe and successful launch and operation of LisR. To assess LisR's behavior under launch loads two simulations were conducted. The first being Static Acceleration and the second a Random Vibration analysis. Both were passed within significant margin to the threshold values. The latter simulation was supported by a physical shaker test later in the development, which was also passed.

Based on the previously mentioned Thermal Management Analysis a Thermal Expansion Analysis was conducted. However, the thermally induced stress is low due to the fact that the same material is used for most parts.

The ISS Program requires payloads to withstand certain static loads. The IVA (Intra-vehicular Activity) Crew Applied Load is applicable for payloads within the ISS. Although LisR is installed on the outside it is still handled by crew inside the ISS prior to installation. This load of 125 lbf (556.4N) distributed over a 4-inch by 4-inch area (10.16 cm x 10.16 cm) at most unsupported locations was simulated on LisR. All necessary safety margins were kept.

The EVA (Extra-vehicular Activity) Kick Load applies to outside payloads and represents small impacts. The load of 125 lbf (556.4N) distributed over an area of 0.5" (1.27cm) diameter (1.36e-3ft2) (1.3e-4m2) at most unsupported locations is more critical than the IVA load above because of its much smaller surface area. LisR passed this simulation with sufficient margin as well.

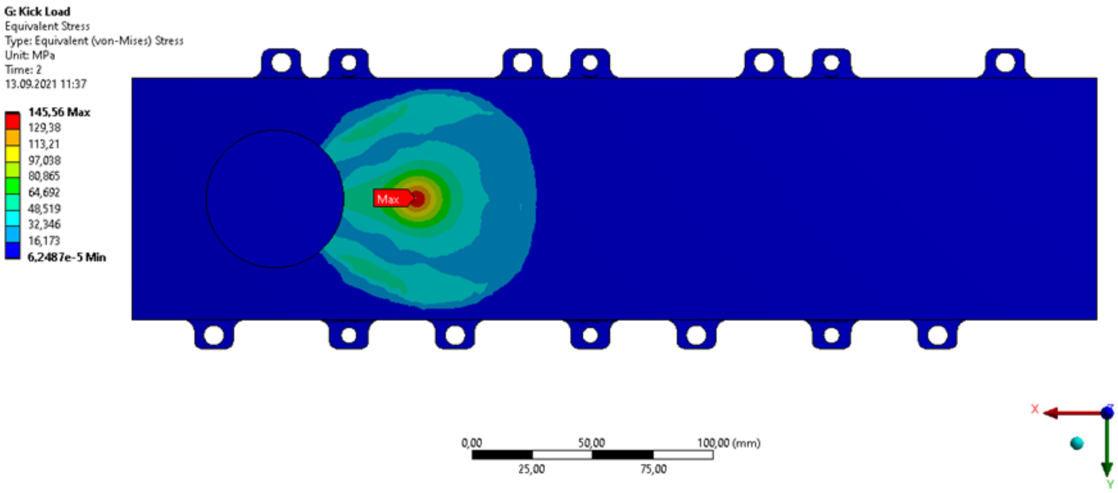


Figure 4. Equivalent stress for shown area under Ultimate (2.0x) Load, EVA Kick Load

## 2.3 Electrical Design

The electronics for LisR has five subsystems namely

1. Power Front End
2. Electronics Power Supply (EPS)
3. Data Processing Unit (DPU)
4. Focal Plane Array (FPA)
5. Cooler

The block diagram below shows the placement of subsystems inside LisR

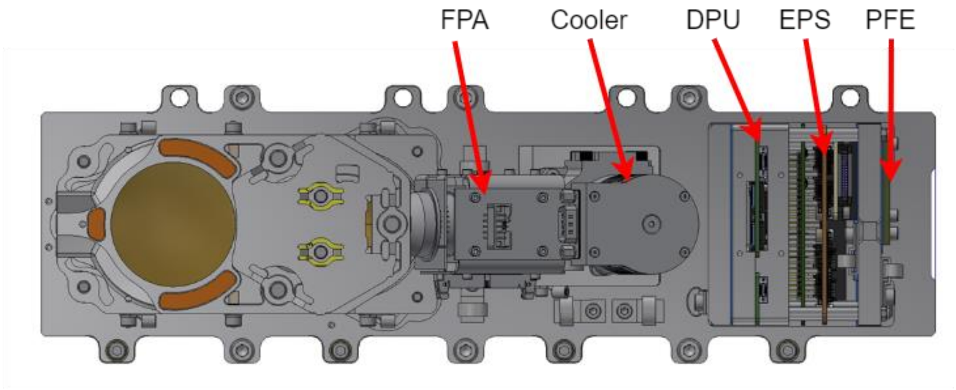


Figure 5. Block diagram of LisR electronic components.

**Power Front End**

The Power Front End (PFE) is the first component that receives power from the NREP. Therefore, this sub-system is responsible for regulating the in-rush current and soft start. PFE also monitors the steady state current and cuts-off the current in case the payload is drawing current beyond a certain threshold. And when the current has dropped down, it restarts supplying the current.

**Electronics Power Supply**

Electronics Power Supply (EPS) is responsible for supplying power to all the subsystems. EPS has several channels which can be configured individually and have filtered outputs. This is to ensure that noise from any channel isn't induced on any other channel. The EPS also has individually configurable current limits for all channels. This provides similar protection as the PFE but at a much more granular level. It also allows to control the supply of power to individual channels.

**Data Processing Unit**

The Data Processing Unit (DPU) stears the core of operations on LisR. It not only processes the data but also acts as the on-board computer. Every operation on LisR is controlled through the DPU. DPU commands the image acquisition using the thermal imager, converts/processes the imagery and sends them to the Nanode interface on ISS. In addition to the imagery, DPU also records all the housekeeping, position and attitude telemetry and processes it for transmission. DPU is controlled through scripts written in LUA. It also monitors the health of EPS and can facilitate control of power to the different subsystems.

**Focal Plane Array (FPA) and Cooler form the thermal imager**

The FPA holds the IR sensor and the electronics required to capture, process and transmit the images to the DPU. The IR sensor has two filters superimposed on it. This enables LisR to see two very different sets of information for the same area of interest. Since LisR uses Quantum Well Infrared PhotodetectorS (QWIPS) a cryocooler is required to keep the detector array to a constant temperature of ~55K for high signal to noise ration and optimum sensitivity.

## 3 Command and data handling

The commanding of the LisR payload is realized via LUA scripts. This approach brings the advantage to keep the operational overhead low and also enables to operate the LisR payload as autonomously as possible. The commanding scripts do not only include simple command lines e.g. to start the image capturing process but also include a logic to react in critical scenarios like the potential overheating of subsystems. Inside LisR payload the commanding scripts are executed by the DPU.

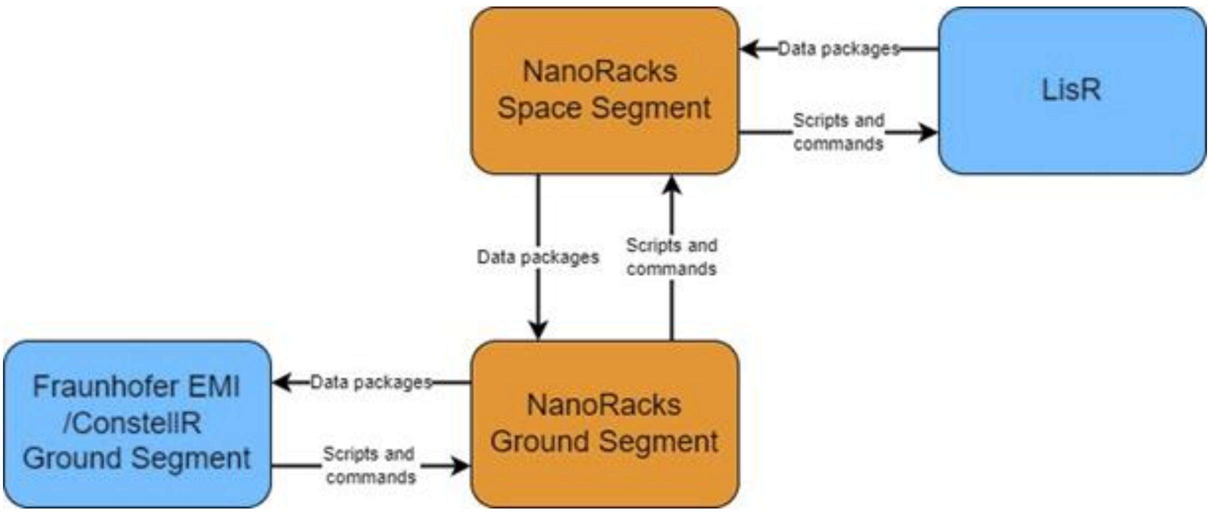


Figure 6. Command and data handling concept for the LisR mission.

To upload new commanding scripts to LisR the LUA scripts are sent to the NanoRacks Ground Segment first. This also includes information about when the old script should be stopped and the new one is scheduled to start.

The LisR payload generates three different kinds of data. Thermal-infrared-images (along with the metadata), telemetry data and a status-livestream. While the images and telemetry data are only downlinked once a day the status livestream data shows certain parameters to monitor the health of LisR in real time.

**TIR images and telemetry**

The images and telemetry data are packed in TAR-files and sent to the Nanoracks space segment via SFTP. Nanoracks uploads the received data packets daily to the Fraunhofer EMI/ ConstellR Ground Segment, where the data is then processed in a cloud environment up to Level 2 LST data. Furthermore, the telemetry data is processed and analyzed in a dashboard to closely monitor the health of the LisR payload.

**Status-livestream**

The status-livestream consists of information of different temperature sensors, current consumption of individual components and the mode of the payload. Especially during the commissioning phase where the commanding scripts are kept simple and do not include complex logics to react in critical situations like overheating of subsystems, the live stream enables the operators to closely study the behavior of the different subsystems while operating the payload for several hours.

## 4 First Light

After processing steps like radiometric and geometric correction the first LisR images demonstrate the capability to detect features like streets, fields, rivers and housing areas with an unprecedented sharpness for a detector in its class. The data and even more the demonstrated technology will improve applications like crop yield or water monitoring on agricultural fields. After evaluating the sharpness of the images, the next step is to evaluate the accuracy of the temperature data. The detailed processing chain as well as the next steps are described in detail in Brunn et al. [4].

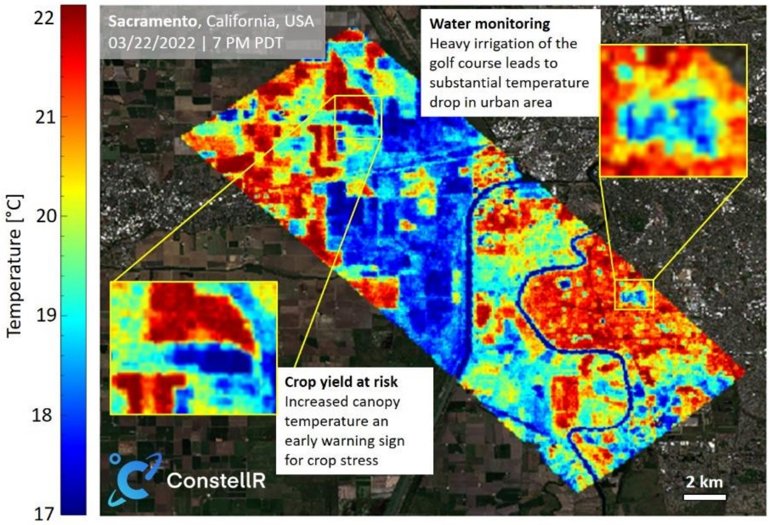


Figure 7. First light images of LisR with potential use cases enabled by the daily and highly precise LST data.

## 5 SUMMARY AND OUTLOOK

This paper described the goals and the design of the LisR mission and payload respectively. The payload design phase included a series of different analyses like the thermal analysis simulating expected temperatures of the different subsystems while operating LisR outside the ISS. But also, structural simulations like Kick-Load or EVA loads were presented as these loads are mandatory for payloads handled by the ISS crew. After the successful launch of LisR on February 19, 2022, the commissioning phase of LisR has begun. During the commissioning which is still ongoing at the time writing this paperfirst data of LisR was processed. The received meta data showed that all subsystems are working flawlessly within the expected and simulated temperature ranges. Moreover, first LST data has shown sharp images which allow for detailed feature detection. The next step in the evaluation process of the LisR data will include an analysis of the temperature accuracy. The LisR mission clearly demonstrated the capability to monitor LST data even with small COTS components and newly applied free-form methods for the optics. As LisR only serves as a technology demonstrator, the follow-up mission HiVE is already under development. The first HiVE Satellite will be launched in October 2023. This will mark the moment in time where ConstellR will provide a daily and global LST monitoring service for the agriculture industry and beyond.

## 6 ACKNOWLEDGEMENT

The project for realizing the LisR mission was funded by the German ministry of economics in the context of the technology transfer project EXIST.

## 7 REFERENCES

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