The BepiColombo Laser Altimeter BELA and Tx Verification

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Introduction

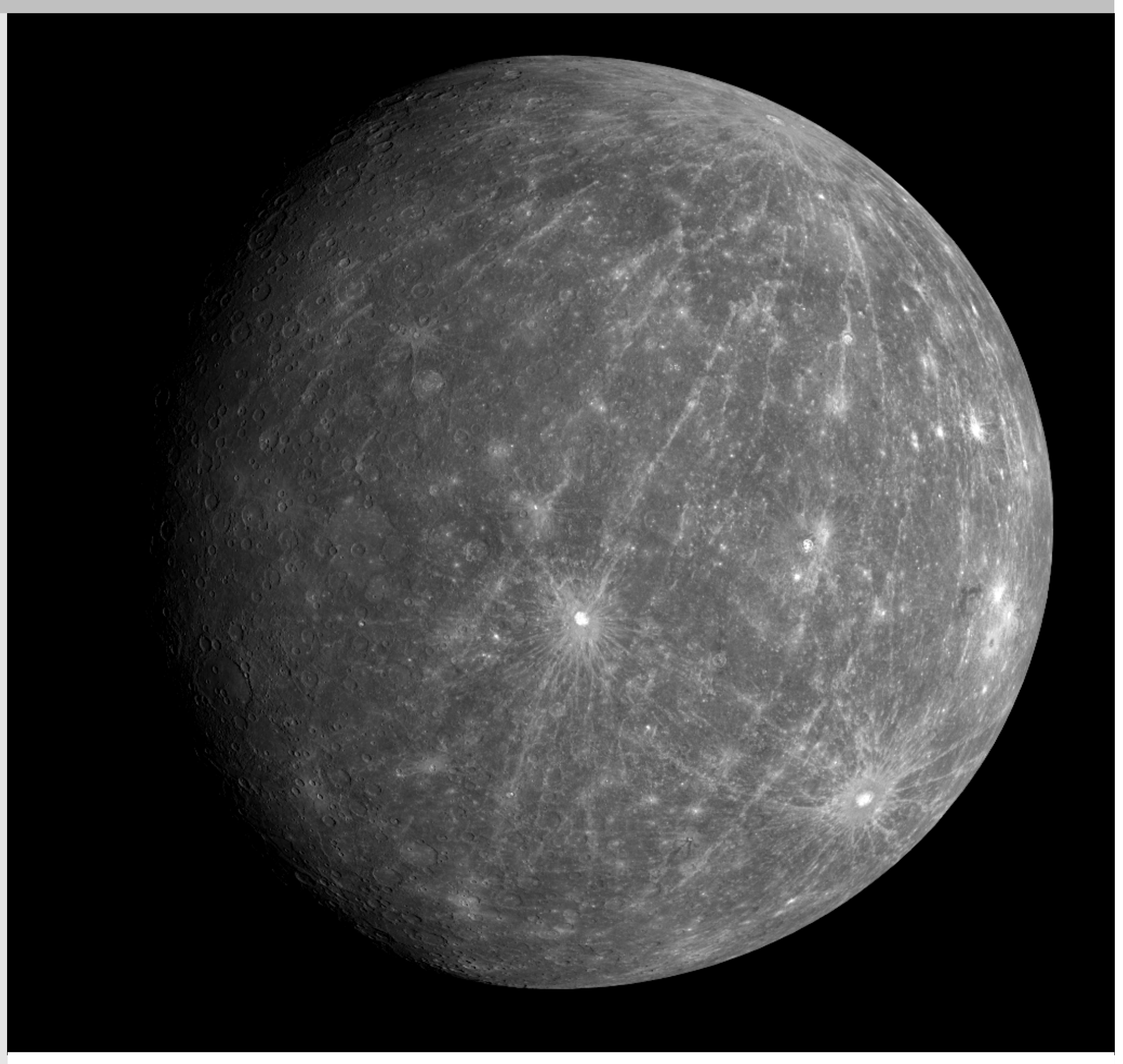


Fig. 1 Planet Mercury as seen during a flyby of NASA's MESSENGER space probe (Picture: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington)

BepiColombo is a mission to the innermost planet Mercury in collaboration of the European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA). The launch is scheduled for 2014 on board an Ariane V rocket.

Integral part will be the BepiColombo Laser Altimeter (BELA) which is being developed and built in collaboration of the University of Bern, Switzerland and the German Aerospace Center (DLR) in Berlin. BELA is the first European laser altimeter for planetary research.

The instrument's mission, which will begin 2020, is the global mapping of the planetary surface from an orbit in up to 1000 km height above the planet. Therefore it uses the “direct detection” approach to laser altimetry. Though the principle is quite simple the technical implementation is not..

Questions about for example the geological evolution of Mercury or about the tidal movements shall be resolved.

Especially the work on the laser transmitter part and the (digital) electronics of the instrument is done by the DLR. This includes design, development and integration of the components as well as verification of the units.

Precise alignment of the laser and receiver telescope are mandatory for the functionality of the instrument. Therefore extensive testing will be performed to assure this in the harsh Mercury environment where the solar radiation is up to ten times the value at Earth.

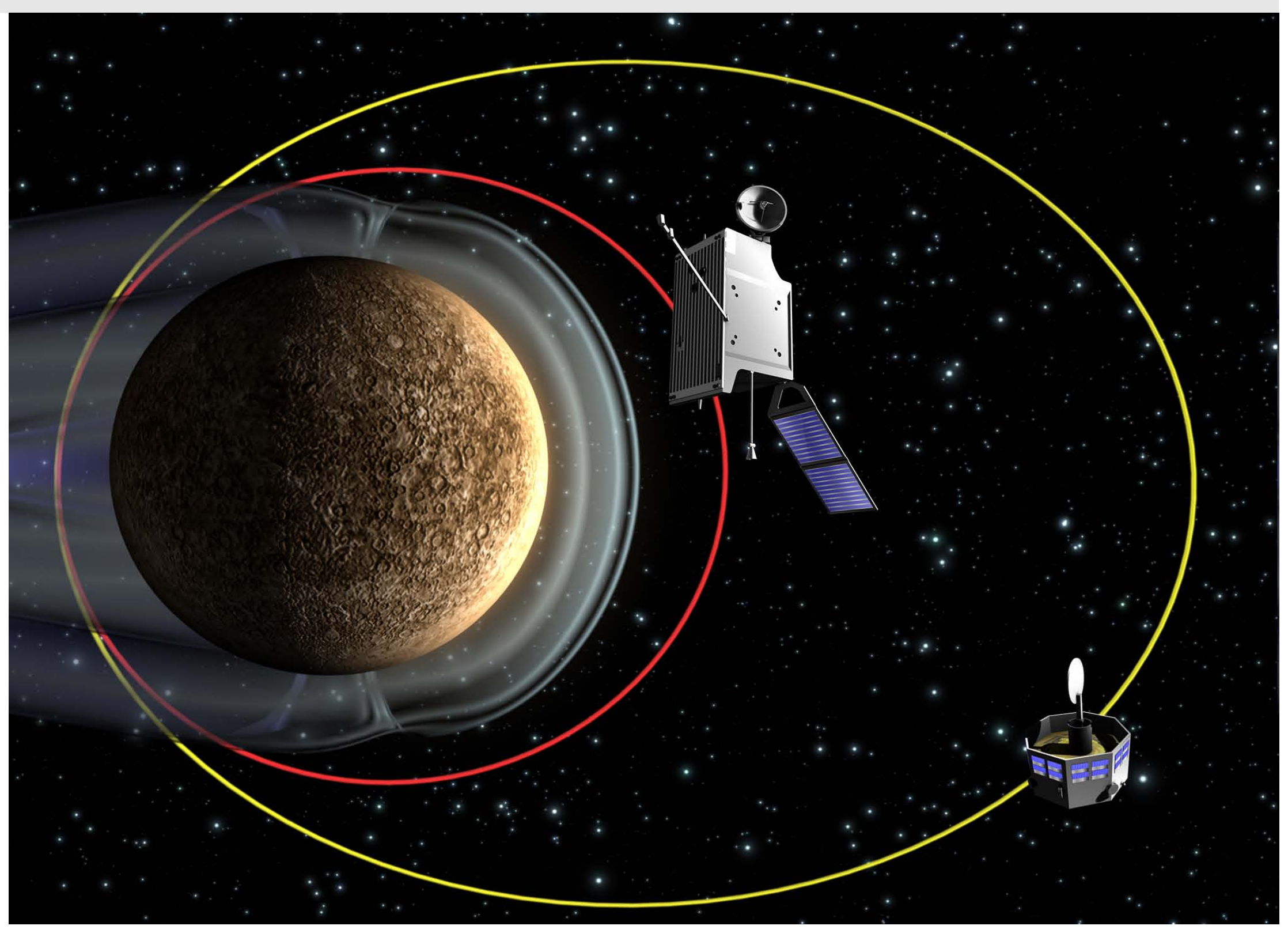


Fig. 2 Illustration of the orbits of the BepiColombo space probes. The Mercury Planetary Orbiter (MPO) (which includes BELA) on the red orbit and the Mercury Magnetospheric Orbiter (MMO) on the yellow orbit.

Mercury Science Questions

- What was the **geological development** of Mercury?
- How large are **tidal deformations** and how is the **topography**?
- What are the **characteristics of the surface** (i.e. surface roughness, local slopes and albedo variations)?
- What is Mercury's **inner structure**? Is there a **liquid core**? Why is its **density** so high?
- How is the **magnetic field** generated?
- What is the **chemical composition** of the surface?
- What is the composition of the Mercury **exosphere**?
- Which are the **interactions** between the magnetic field, exosphere and the solar winds?

Principle of Work

The principle of laser altimetry is relatively simple and straightforward. A well collimated laser beam is emitted from the instrument and diffusely reflected on the planetary surface. The reflected photons are then collected by a telescope and focused on a photosensitive detector (see **Fig. 3**).

The signals of outgoing and incoming pulse are analysed and the time between them is determined. As speed of light is very accurately known and constant the distance to the planetary surface can be calculated with the following equation:

$$z = \frac{c \cdot \Delta T}{2}$$

Here $\boldsymbol{c}$ is the speed of light (circa $3 \cdot 10^8$ m · s^{-1}), $\boldsymbol{\Delta T}$ the time delay between the pulses and $\boldsymbol{z}$ the resulting range to the surface.

With state-of-the-art time measurement with nanosecond accuracy a vertical resolution of better than 1 m is feasible.

Besides this data also the shape of the returning pulse and the intensity can be analysed to get information about the albedo at the laser wavelength, about surface slopes and the roughness.

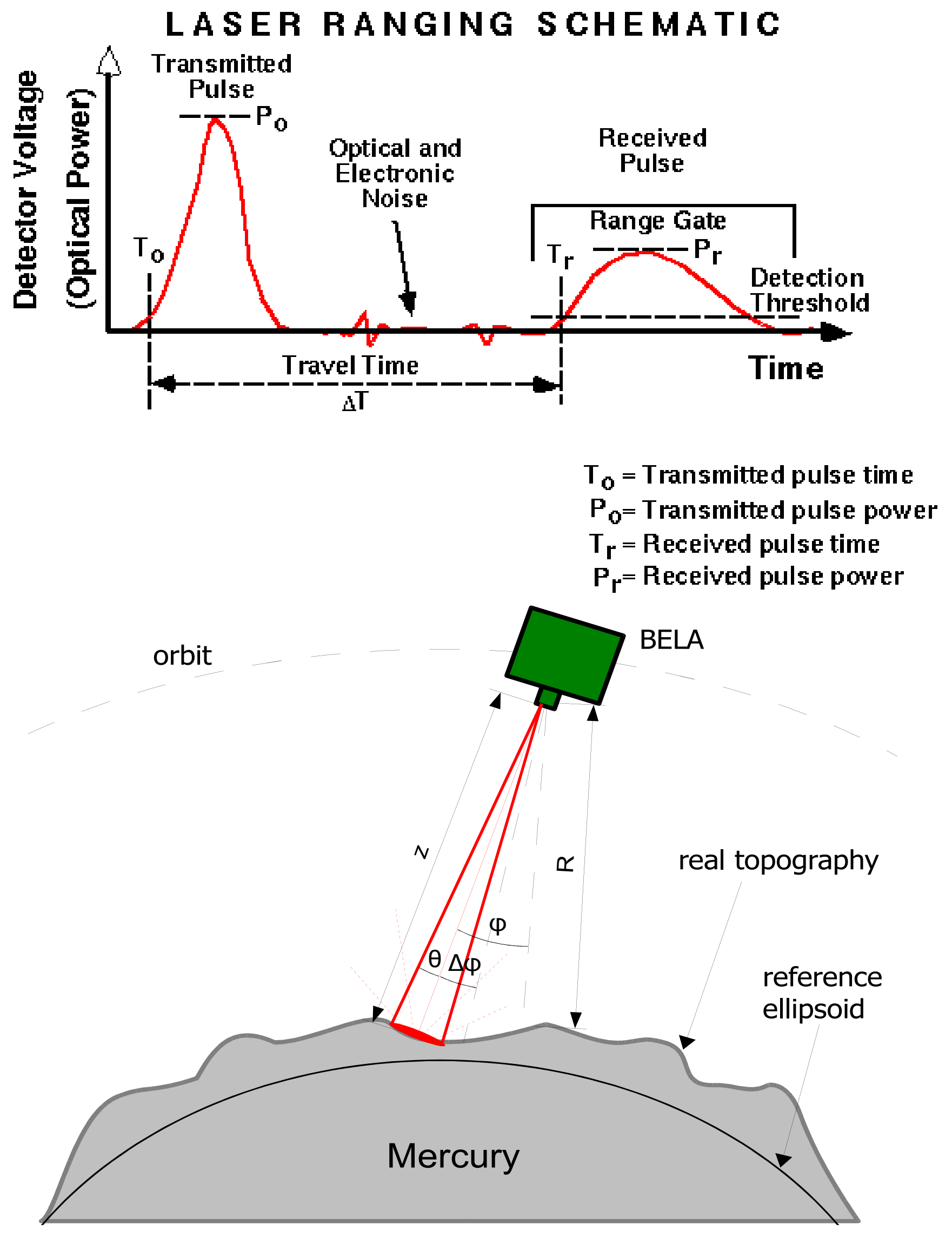


Fig. 3 Temporal resolved emitted and received laser pulse signal at the detector output (top). Principle of an laser altimeter is the time of flight measurement (bottom)

Instrument Requirements

The instrument (see **Fig. 4** and **5**) needs to cope with the boundary conditions during the launch, cruise and operation phase. To mention are high structural loads, radiation and high solar flux in the planetary environment. Especially the latter is dealt with sophisticated Stavroudis-type reflecting baffling units and bandpass filters.

A very important requirement of the instrument is that the optical axes of receiver and transmitter are accurately aligned and parallel. The maximal deviation of the laser beam axis w.r.t. the optical bench of the instrument (baseplate) is 50 µrad. This criterion is mandatory to assure that together with other tolerances the laser spot on the surface always fits into the field of view of the instrument.

The resources to achieve all the requirements are thereby very limited. The budget for mass is circa 12 kg and available electrical power is 36 W.

Parameter	Value	Comment
wavelength	1064 nm	Nd:YAG laser
pulse energy	50 mJ	begin of life
divergence	50 µrad	to keep laser spot on surface small
beam alignment stability transmitter	50 µrad	to surely fit in Rx FOV
pulse repetition rate	10 Hz	data points along track 250 m
receiver field of view (FOV)	400 µrad	small to minimise noise
detector	N/A	silicium APD
average data point distance	6 km	global coverage
operational phase	1 yr	

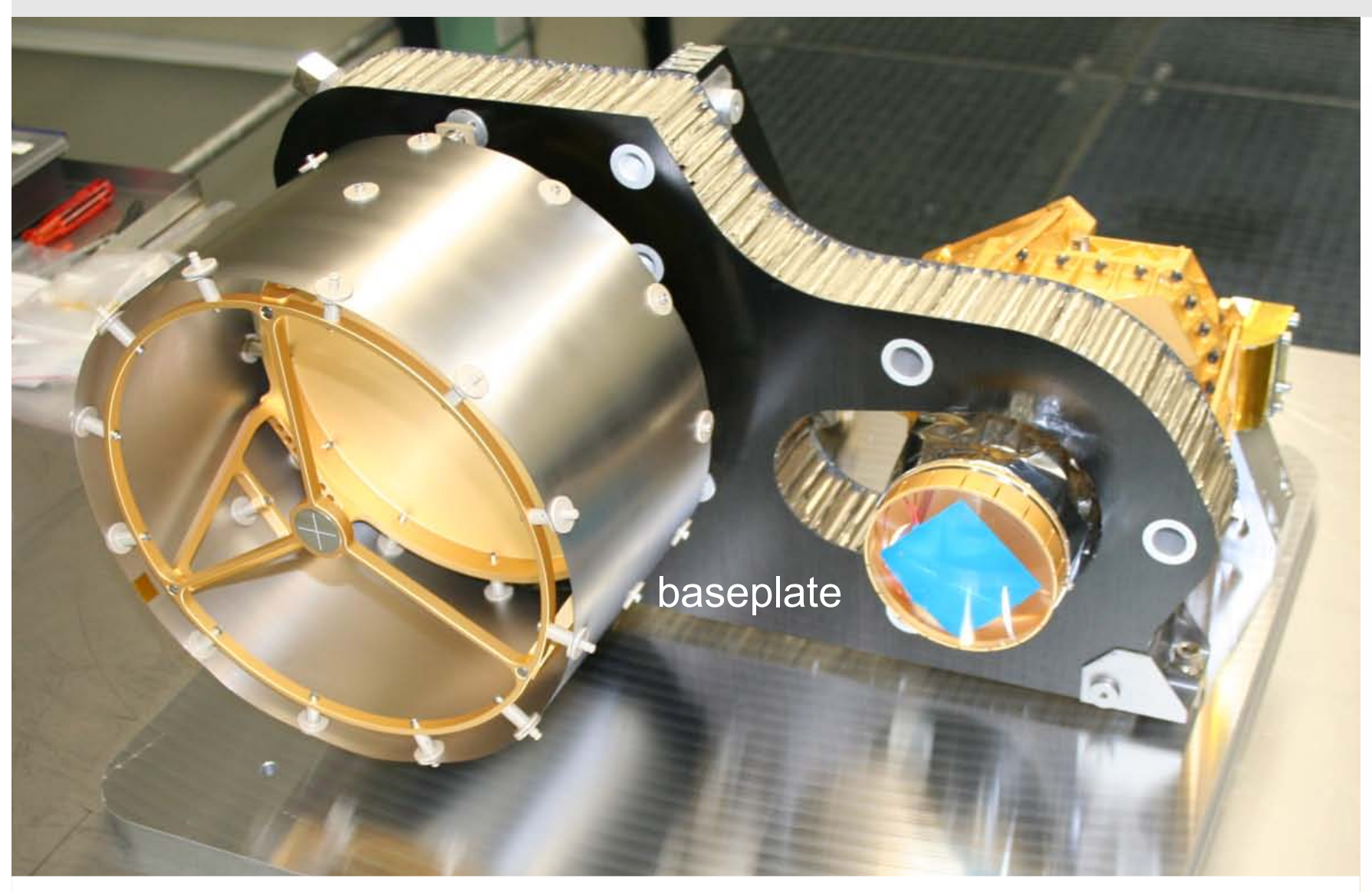


Fig. 4 Baseplate unit structural and thermal model (included are baseplate, transmitter laser, beam expander, receiver telescope and focal plane assembly) (picture University of Bern, Switzerland)

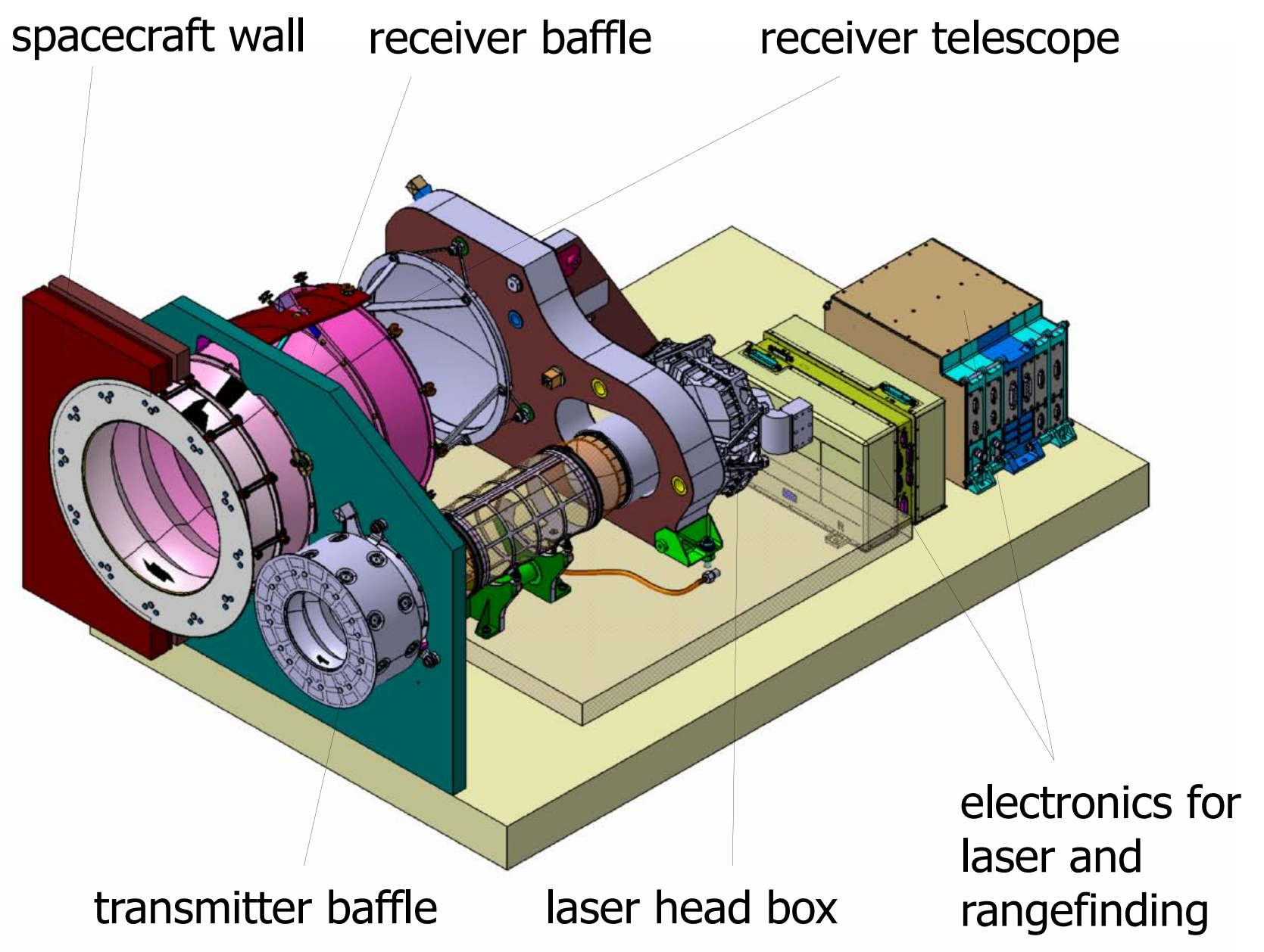


Fig. 5 BELA instrument as 3D CAD model

Verification Setup

To verify the the optical performance and to prove the functionality of the BELA transmitter (Tx) it needs to undergo optical tests in a thermal vacuum chamber setup. A scheme of that setup is depicted in **Fig. 6**.

This setup must provide a high optomechanical stability as the angular movements of the beam are in the order of maximal 50 µrad. The difficulty is to distinguish between intrinsic movements of the beam and influence of the optical components, vibrations of the chamber and air turbulences. For this reason a second very stable laser beam is used as a reference. This reference laser shares the same optical path as the transmitter laser beam and thus includes the same errors due the optics. But it does not contain the intrinsic errors of the Tx laser. Thus by measuring the relative distance of these two beams the alignment stability of the BELA laser can be determined. **Fig. 7** shows a stability measurement of a test laser. These data have already been corrected by the reference laser signal. It can be seen that the used setup is at least an order of magnitude more stable than the expected value to be measured of the BELA laser.

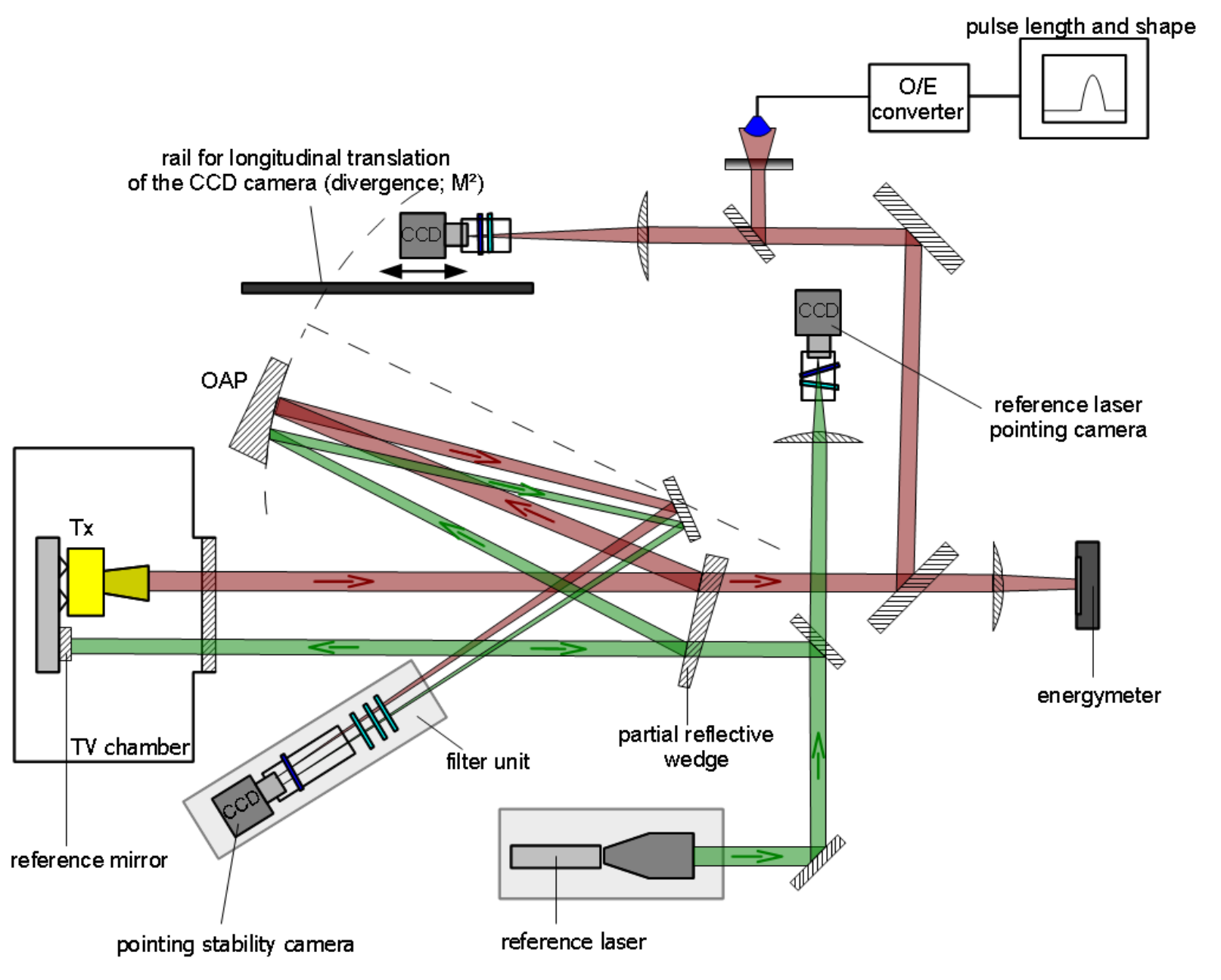


Fig. 6 The optical verification setup to measure the alignment stability of the BELA transmitter laser and other parameters (transmitter laser in red and reference laser in green)

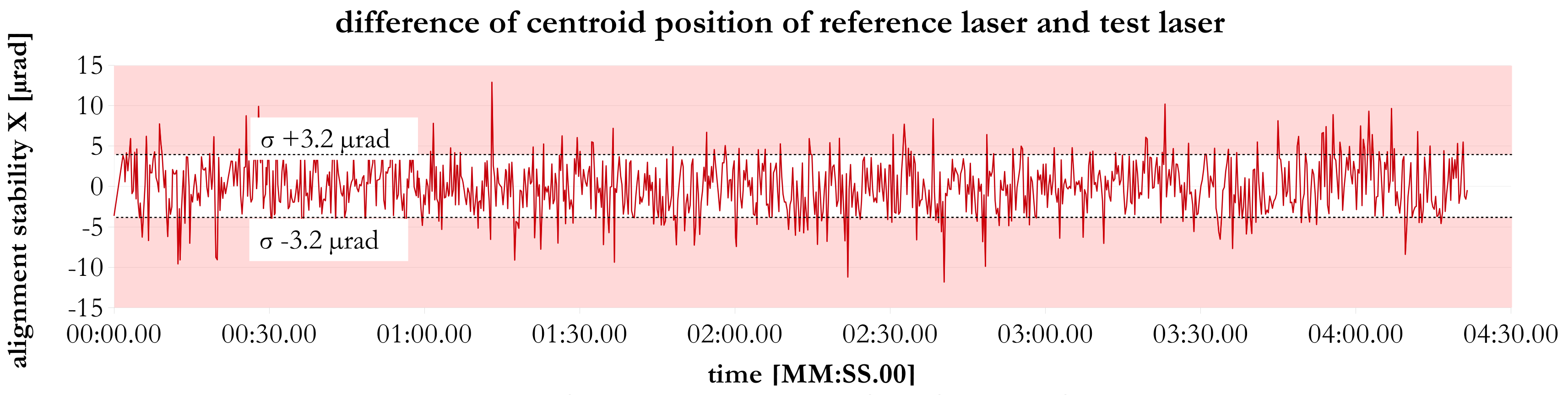


Fig. 7 The alignment stability of the test laser used to verify the feasibility of the measurement setup

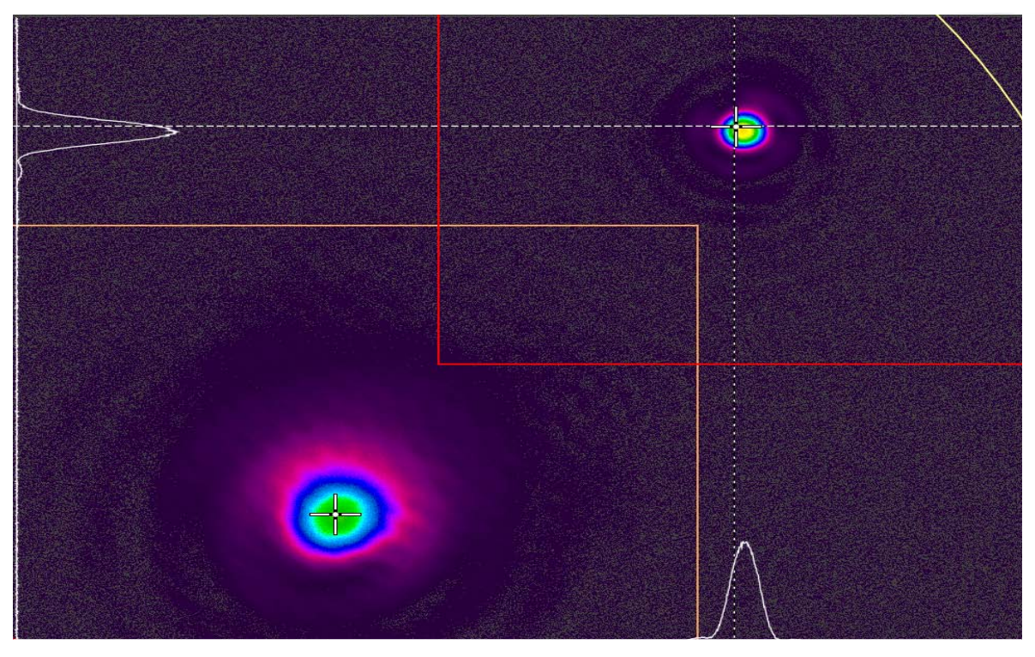
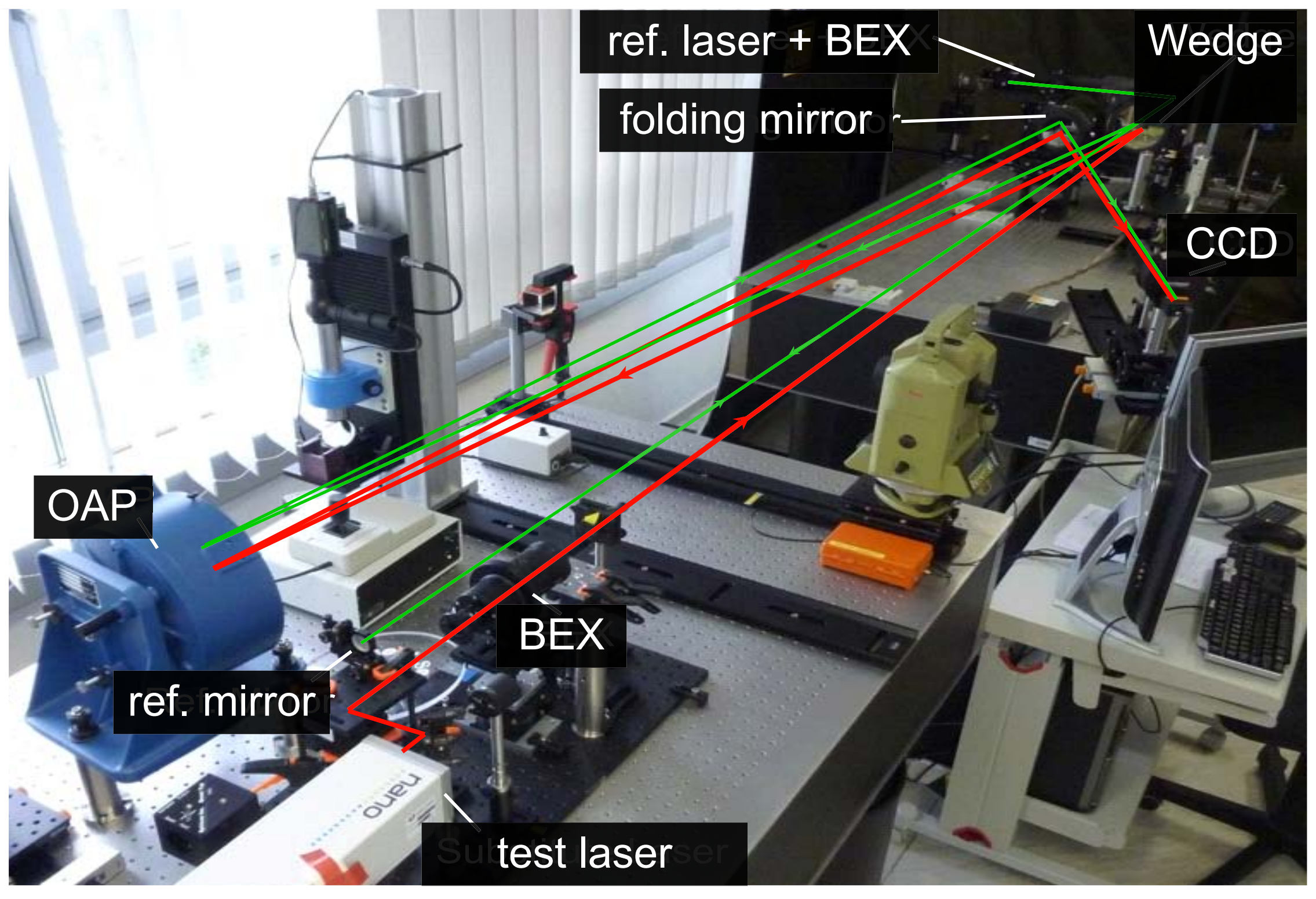


Fig. 8 Depicted is a screenshot of the beam analysis software. The bigger spot is generated by the test/BELA laser and the smaller by the reference laser. The relative distance between the centroids is measured.

Fig. 9 (on the right) The optical setup to measure the alignment stability of the BELA Tx laser. The red line illustrates the BELA laser beam path and the green line the reference laser. Both beams are focused on the detector and the data are captured and processed on a PC.



Conclusion

BELA is a very complex instrument which needs a lot of high technology components to be developed and designed for its operation. Despite the integration and the testing must be performed with great care as the instrument will have to survive and work in space environment for about 7 years without mechanical maintenance. Moreover the alignment stability must be verified as it is a mandatory criterion for the scientific success of the instrument. The optical test setup outlined here, which has been designed and built up at the Institute of Planetary Research can perform this part (see **Fig. 9**).