Earth Observation with the *Flying Laptop* – a small satellite of the University of Stuttgart

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Abstract - The Institute of Space Systems plans to launch the micro-satellite *Flying Laptop* into a sun synchronous orbit at the end of 2006. The satellite will be equipped with a camera payload system operating in the visible and near infrared spectral range as well as in the thermal region. This payload will be used to monitor the Earth surface with a ground sample distance (GSD) of 25 m in the visible and near infrared domain and with a GSD of 50 m in the thermal region. In all spectral regions mentioned above the Bi-directional Reflectance Distribution Function (BRDF) and the Temperature Directional Distribution Function (TDD) respectively will be measured using the target pointing mode. In addition, the transmission of the signal of communication Ka-band can be used to collect a data set describing the attenuation of the Ka-band under different weather conditions in Central Europe. Under rainy conditions, we will test a new method to measure the rain rate exploring the concept of differential absorption of the Ka- and Ku-band signals due to presence of rain in the intervening atmosphere.
Keywords: micro-satellite, BRDF, TDD, rain rate, atmospheric impairment on Ka-band transmission, multispectral data

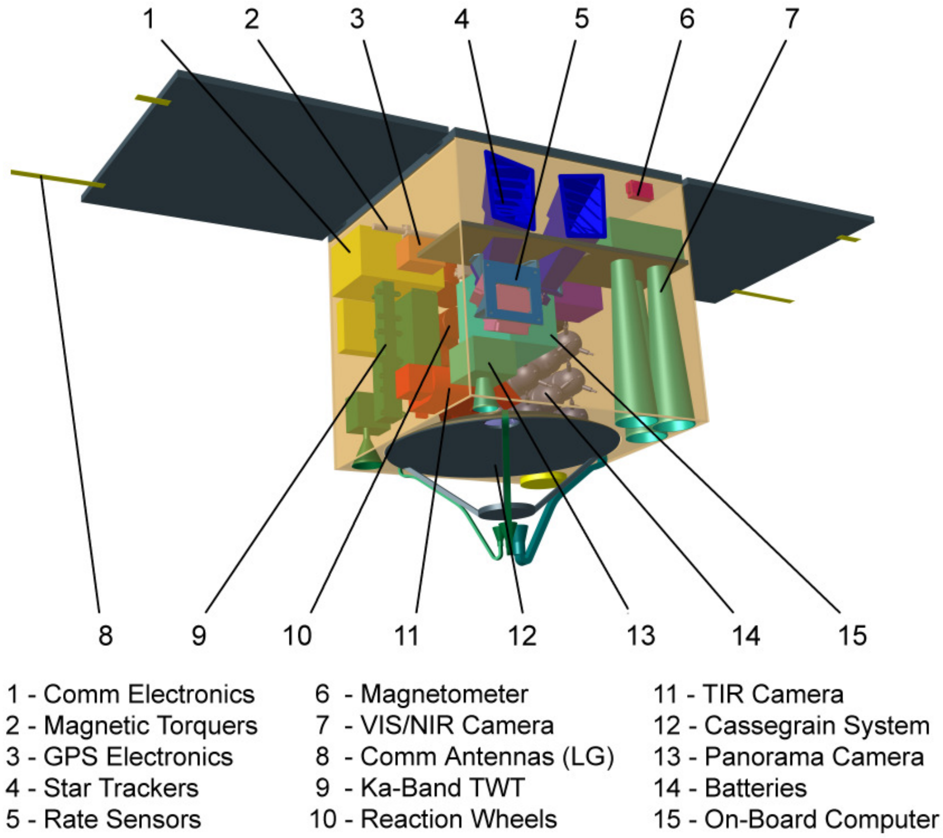
1. INTRODUCTION

Micro-satellites are currently of increasing interest through technical minimization.
An advantage is the fast and cheap development of micro-satellites, which makes them a suitable platform for technology evaluation. Hence, they provide the ideal opportunity to test new systems in space within a short timeframe and low budget. In addition they allow us to test new methods for monitoring the Earth surface and atmosphere.

The *Flying Laptop will be* the first micro-satellite within the Stuttgart Small Satellite Program. The mission objectives are divided into two parts: technology demonstration [1] and scientific observations. This paper discusses the second part.

2. EARTH OBSERVATION

Two different camera systems will be mounted on the satellite. For the green, red and near infrared spectral range, a camera block of three single cameras with array CCD sensors is planned. The cameras operate in the following spectral bands:



- Green: 530 - 580 nm
- Red: 620 - 670 nm
- NIR: 820 - 870 nm

This arrangement simplifies the optical design because the filter can be directly placed in front of the optics. Therefore, a simple double Gaussian optic can be used without the need of chromatic aberration correction. Another advantage is the redundancy of the system. The planned ground sampling distance is 25 m.

The second camera system measures the thermal infrared wavelengths (8 - 12 µm, without the ozone absorption band 9.3 - 9.7 µm), using an uncooled micro-bolometer sensor. The sensor is temperature stabilized and cooled by Peltier elements in order to achieve the desired signal-to-noise ratio. To attain a ground resolution of 50 m, the cassegrain system will be used as shown in Fig.2.

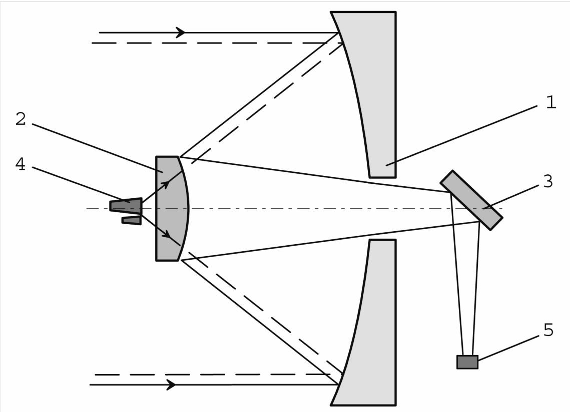


Figure 2. The Ka-band and the thermal infrared camera, use a cassegrain system which is designed as a dual band system: (1 – primary mirror, 2 – secondary mirror, 3 – beamsplitter, 4 – feedhorns, 5 – TIR camera)

The four cameras will take images of interesting areas of the Earth surface. These data sets can be used to continue time series of remote sensing data that were started by using Thematic Mapper of LANDSAT, because the GSD of the sensors will be approximately the same. If successful with the expected high pointing knowledge of 2 arcsec, the determination of the Bi-directional Reflectance Distribution Function in the visible and NIR spectral domain as well as the measurement of the Temperature Directional Distribution in the thermal region will be of scientific interest.

2.1 Bi-directional Reflectance Function and the Directional Brightness Temperature

The reflectance of most surfaces shows anisotropic behavior, which means the reflectance varies with solar and viewing positions. This effect is mathematically described by the bi-directional reflectance distribution function (BRDF) which characterizes how for a scene with given properties, the reflectance observed varies with the angles of observation and illumination:

$$f(\lambda,\theta_s,\varphi_s,\theta_v,\varphi_v) = \frac{L(\lambda,\theta_s,\varphi_s,\theta_v,\varphi_v)}{E(\lambda,\theta_s,\varphi_s)}.$$

L is the radiance reflected into a direction defined by the zenith angle θ_v and azimuth angle φ_v of the view direction V. E is the irradiance from the sun direction (θ_s, φ_s), and λ the wavelength of radiation. The dimension of the BRDF is given in sr^{-1}. Commonly used is the bi-directional reflectance factor BRF $=\pi\ f(\lambda,\theta_s,\varphi_s,\theta_v,\varphi_v)$, which has no dimension.

Soil and vegetation normally show different reflectance characteristics. Generally, natural surfaces are rough. Soil consists of grains which are separated by pores containing water and gas. The reflectance properties of soils are attributed by the coherent scattering of the particles, by the incoherent radiative transfer propagation between the different particles and by the shadow hiding. The latter generates mainly the sharp peak in the bi-directional reflectance at zero phase angle $(\theta_s - \theta_v = 0)$, called hot spot or opposition effect. Vegetation exhibits anisotropic reflectance caused mainly by the very complex volumetric scattering within the leaves canopy and also shadow casting. For vegetated surfaces the composition of shadowed and illuminated components depends highly on the canopy architecture, which is affected by the type of plant species, the growing stage, and the health conditions. Canopy gaps have a strong impact on the BRDF.

The interest of the remote sensing community in the scientific study of the BRDF has greatly accelerated within the last twenty years [2].

A typical application, where knowledge of BRDF is demanded, occurs when images acquired during several orbital overpasses or overflights are to be mosaicked together to form a large one. Due to the BRDF, strong brightness contrasts might appear where the swaths are joined together. A wide field of view sensor observes one margin of a swath under another viewing angle relative to the sun than the other one. Therefore a bidirectional reflectance effect can often be observed as a brightness gradient. For a quantitative analysis in spectral, temporal and spatial domain a correction of the BRDF effect is needed.

The necessity of an angular correction of satellite data and the normalization to standard viewing and illumination conditions was a mainspring for the forcing of the experimental and theoretical investigation of the BRDF. The BRDF correction allows us to compare different images and to improve the classification accuracy.

Furthermore the BRDF is the fundamental quantity for the calculation of the albedo which plays an essential role in the radiation- and energy balance of the planets. The specific use of the angular dependence of the reflectance will also improve the retrieval of biophysical parameters of land surfaces.

Last but not least the BRDF is necessary for the calibration of airborne and spaceborne sensors.

Several empirical, semi-empirical and theoretical models have been developed for the description of typical BRDFs. The normalization to standard viewing geometries, the calculation of the albedo and the multiangular retrieval algorithms are mostly based on the application of appropriate models.

For the completeness of our knowledge about the BRDF and for the understanding of the potential of BRDF for remote sensing we are arranging a mission scenario for BRDF measurements using the *Flying Laptop*.

In order to measure the bi-directional reflectance factors, the *Flying Laptop* will operate in the target pointing mode. That means that the attitude of the satellite is controlled in such a manner, that the same ground pixel is observed from different directions. The goal is to achieve a pointing knowledge of 2 arcseconds. The extension of the area under observation which must be assumed to be homogeneous should be noticeably larger than twice the maximum pixel size resulting from the maximum viewing zenith angle. Hence large forests or desert areas could be chosen for this kind of measurement.

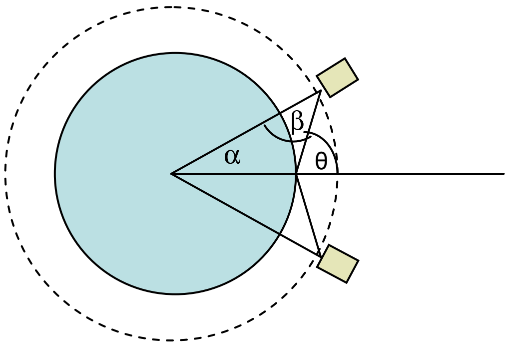


Figure: 3: Demonstration of target pointing

Mixtures of foliages and soil are thermally heterogeneous and the measured angular distribution of the surface brightness temperature depends on the viewing and the sun position.

Our knowledge about the Temperature Directional Distribution (TDD), also called Directional Brightness Temperature (DBT), is still very poor. But this information is essential both for the data use of wide angle sensors and for a correct validation and calibration.

However the atmosphere has an impact on the BRDF as well as on the DBT. Not only does the surface scatter anisotropically but also the atmosphere impacts the traveling radiance in the different directions in an unequal manner because of the angular dependent scattering by air molecules and aerosols. In addition the surface and the atmosphere are coupled by multiple scattering which tends to smooth the directionality of the radiance. Also the transmission and emission of the atmosphere are anisotropic and influence the measured surface temperature.

Therefore, angular and spectral ground based measurements and measurements using airborne and spaceborne instruments have to be combined in order to separate the different contributions. The Institute of Space Systems is going to prepare such multi-level experiments.

2.2 Using the Ka-Band for scientific investigations

The use of higher satellite communication frequency bands is required to implement broad band links. It is therefore necessary to identify and predict the combined effect of different propagation impairments.

Rain attenuation is the dominant propagation impairment at frequencies above about 10 GHz. In addition, gaseous absorption, cloud attenuation, melting layer attenuation, and tropospheric refractive effects become increasingly important with increasing operating frequencies. Some prediction models are available for the estimation of the individual components. But methodologies that attempt to combine them are widely missing. This is partly due to paucity of reliable measured data. This applies especially to Central Europe. The *Flying Laptop* can help to fill this gap. In order to provide a useful database for the identification of the overall impact of every significant attenuation effect along the given paths we invite and ask relevant research institutions and groups of the appropriate operational services to join us and to work with us together in a fruitful partnership.

The inherent potential of spaced based measurements for providing global measurements of rainfall has long been recognized. However, the development of appropriate techniques for a quantitative estimation of rainfall has met limits for a long time. During an experiment monitoring the 12.5 GHz and 19.8 GHz data from the Olympus Satellite [3] it was realized that the attenuation difference could be useful for measuring rainfall. Thus some dual-frequency horizontal microwave links for measuring the path-averaged rainfall were built and tested successfully during some experiments in Europe. It could be shown [4] that a strong relationship between the rain rate and the differential attenuation of the Ku- and Ka-frequency bands exists. The strength of the method analyzed during these campaigns is that it is not necessary to make assumptions about the drop size distribution or other rainfall characteristics [3]. The *Flying Laptop* will - in addition to the Ka-band - be equipped with a Ku-band transmitter, in order to test the findings. The acquisition will be performed in the target-pointing mode using the Ka-band and the Ku-band signal.

Some results of theoretical investigations, recently carried out for the Ka- and Ku-band frequencies of the *Flying Laptop*, are demonstrated in Fig. 4 [5]. However the impact of melting layers on the attenuation difference cannot be neglected. In order to study this impact for real situations in central Europe we are working in cooperation with institutions dealing with weather radars (for instance the professorship for High Frequency and Photonics of the Technical University at Chemnitz, Germany, and the Institute of Meteorology of the University of Karlsruhe, Germany). In addition to ground based weather radars we will also use thermal measurements to study the impact of melting layers on the attenuation difference of the Ka- and Ku-band.

3. CONCLUSION

The *Flying Laptop* will be the first micro-satellite built at the University of Stuttgart within a Stuttgart Small Satellite Program. In this paper the scientific objectives of the *Flying Laptop* have been described.

One goal of the mission is the collection of scientific data for the determination of the BRDF and the TDD which are essential for a more effective use of remote sensing data.

A new measurement method for determining the rain rate will be practically demonstrated by using the target pointing mode of the *Flying Laptop*. The expected results will be useful for future global measurements of the rain rate using satellites and will be helpful for the preparation of the Global Precipitation Mission (GPM) panned for 2010 by NASA and JAXA.

In addition the *Flying Laptop* can identify the combined effect of different propagation impairments on the Ka-band frequencies for the future use of higher satellite communication frequency bands which is required to implement broad band links.

The international community is invited to take part in the data analysis of the *Flying Laptop*.

4. REFERENCES

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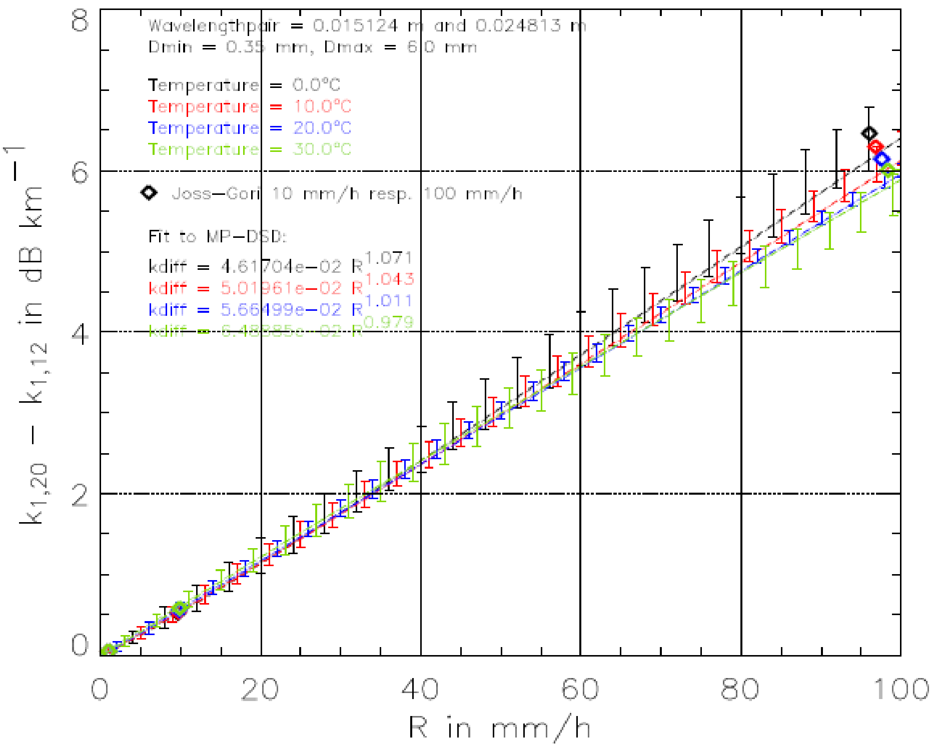

Figure: 4 [4]: Attenuation Δk_1 (20GHz - 12GHz) [dB/km] versus rain rate [mm/h] calculated for different drop size distributions (error bar) and temperatures (color). The rain rate refers to the speed of drop fall at sea level.