High-fidelity light curve simulation and validation using empirical data

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Introduction

Light curve assessment and analysis enables the characterization of space objects. Correlations between simulations and measurements allow for the determination of the rotational dynamics, which is essential for in-orbit servicing and active removal missions. In this study we present the validation of our light curve simulation software Raxus Prime, using the Flying Laptop satellite (Fig. 1).

Fig. 1: Picture of the Flying Laptop satellite

Methods

As a foundation for the informative value of our simulations, we characterized the satellite's outer surface materials regarding their surface roughness (see Fig. 2) and reflectivity spectrum (see Fig. 3) .

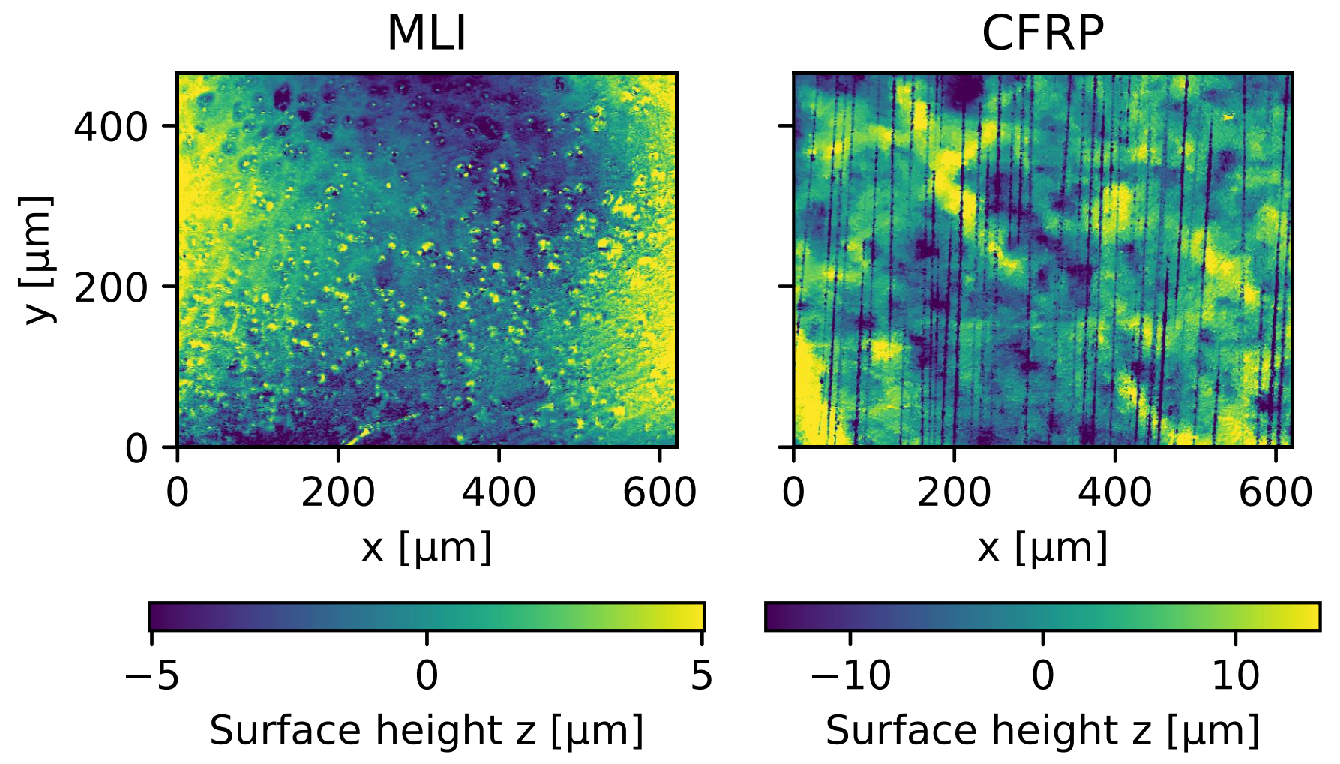

Fig. 2: Roughness maps from a subset of the satellite material samples from measurements with a White Light Interferometer (Bruker Wyko NT9100).

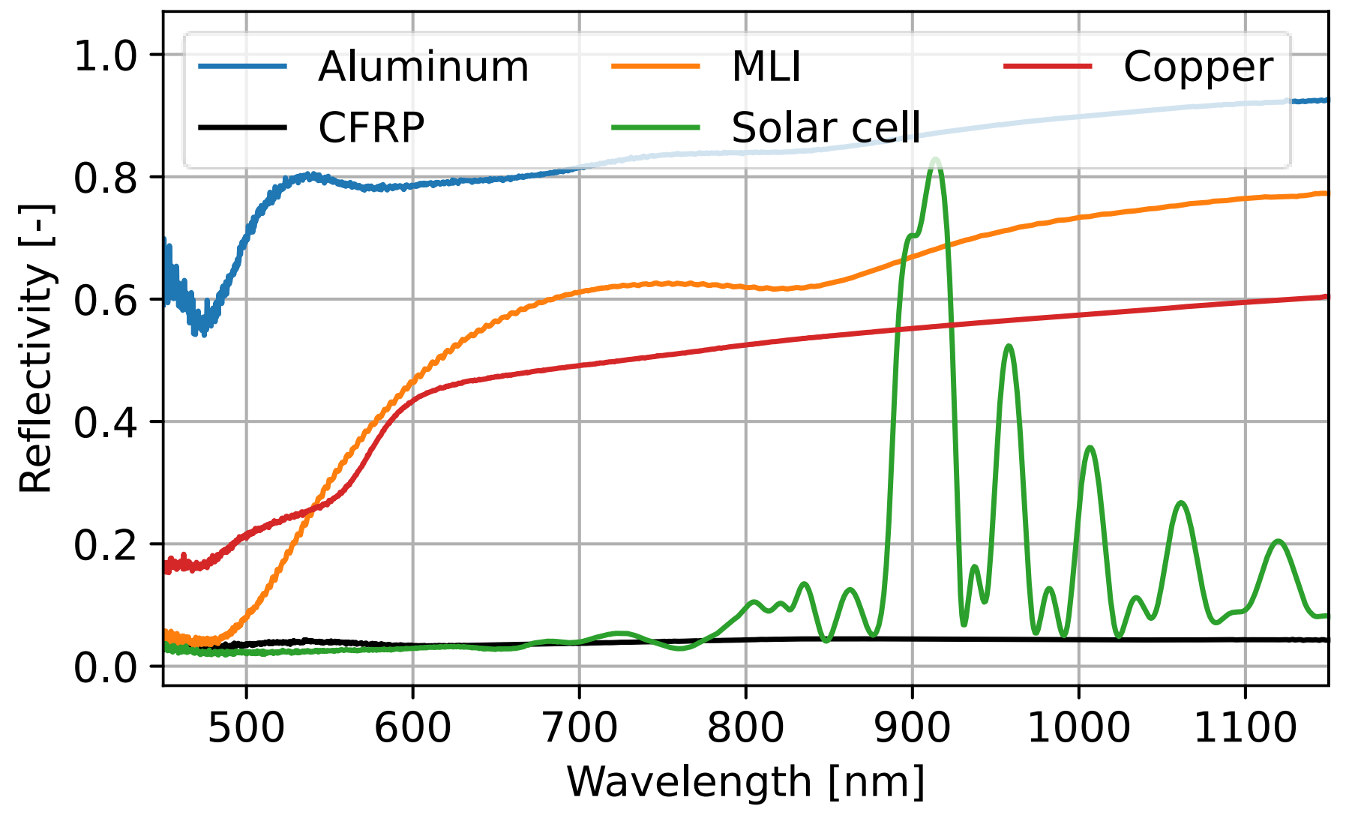

Fig. 3: Specular reflectance spectrum of the satellite materials, measured with a Fourier-Transform Infrared spectrometer (Bruker Vertex 70v).

From this experimental dataset, an analytical Bidirectional Reflectance Distribution Function (BRDF) has been derived for each satellite surface material, which then was attributed to the respective surface elements of our CAD model of the Flying Laptop satellite (see Fig. 4). Using this model, light curve simulations were performed using our raytracing-based code Raxus Prime.

Results

Light curves of the Flying Laptop satellite have been measured during several passes with our institute's observatories at Stuttgart, UFO and miniSLR®, respectively. Subsequently, the corresponding passes were simulated, accounting for the system configuration and atmospheric attenuation, in order to output the light curve signal as radiometric sensor count rate, shown in Fig. 5.

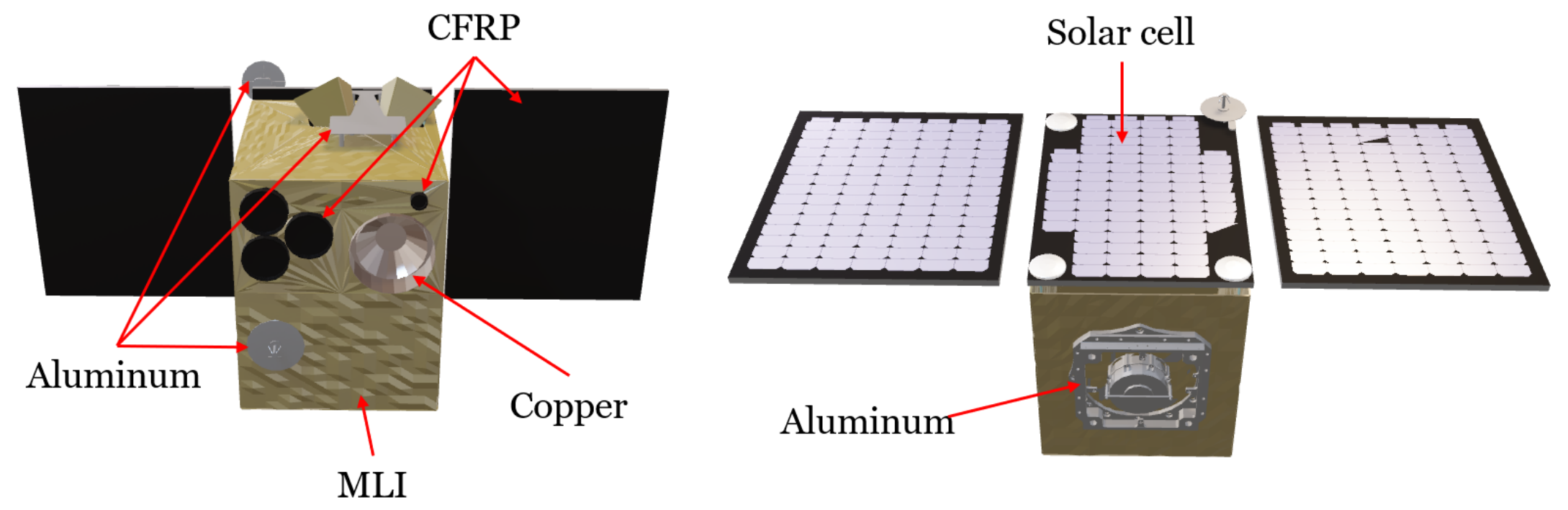

Fig. 4: Model of the Flying Laptop used for simulations.

It shows that the simulations correspond rather well with the measurements. Global offsets may be caused due to environmental conditions, such as unevenly distributed high altitude cirrus clouds. Discrepancy of the transient features on the other hand can be attributed to a non-perfect 3D model and material reflectance. Furthermore, we have extended the method of reflectivity maps [1], by simulating a full map of the Flying Laptop satellite, demonstrating the potential for fast light curve assessment (see Fig. 6).

Conclusion and Outlook

We plan to set up a database containing measured BRDFs of commonly applied space materials and incorporate these into simulations. Furthermore, commanded passes of the satellite are planned. This helps to get a better understanding of the reflectivity maps and enables further validation of this method.

References

[1]: D. Kucharski et al., “Full attitude state reconstruction of tumbling space debris TOPEX/Poseidon via light-curve inversion with Quanta Photogrammetry,” Acta Astronautica, vol. 187, pp. 115–122, 2021.

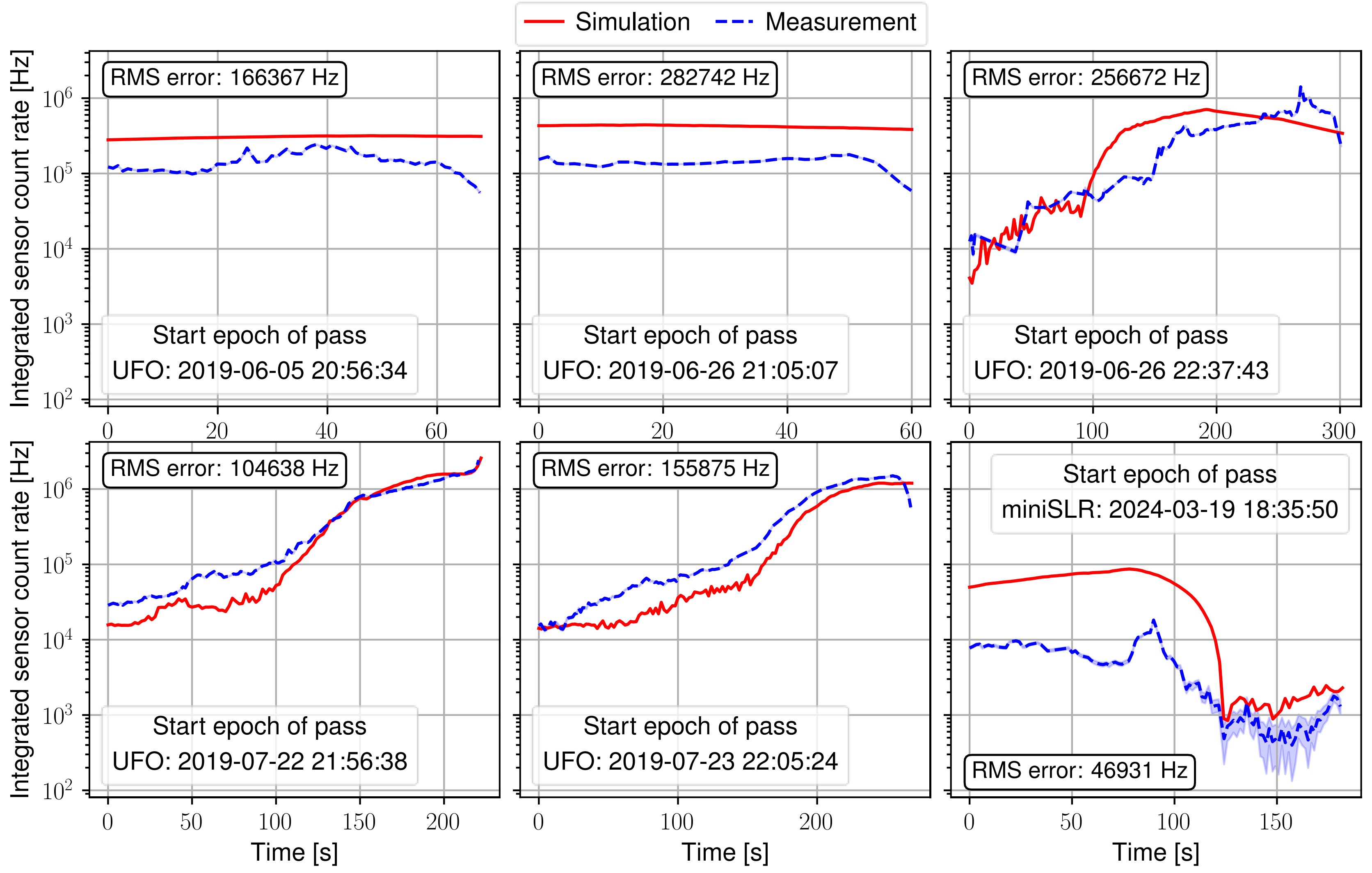

Fig. 5: Measured and simulated light curves of the Flying Laptop for the UFO and miniSLR ground station.

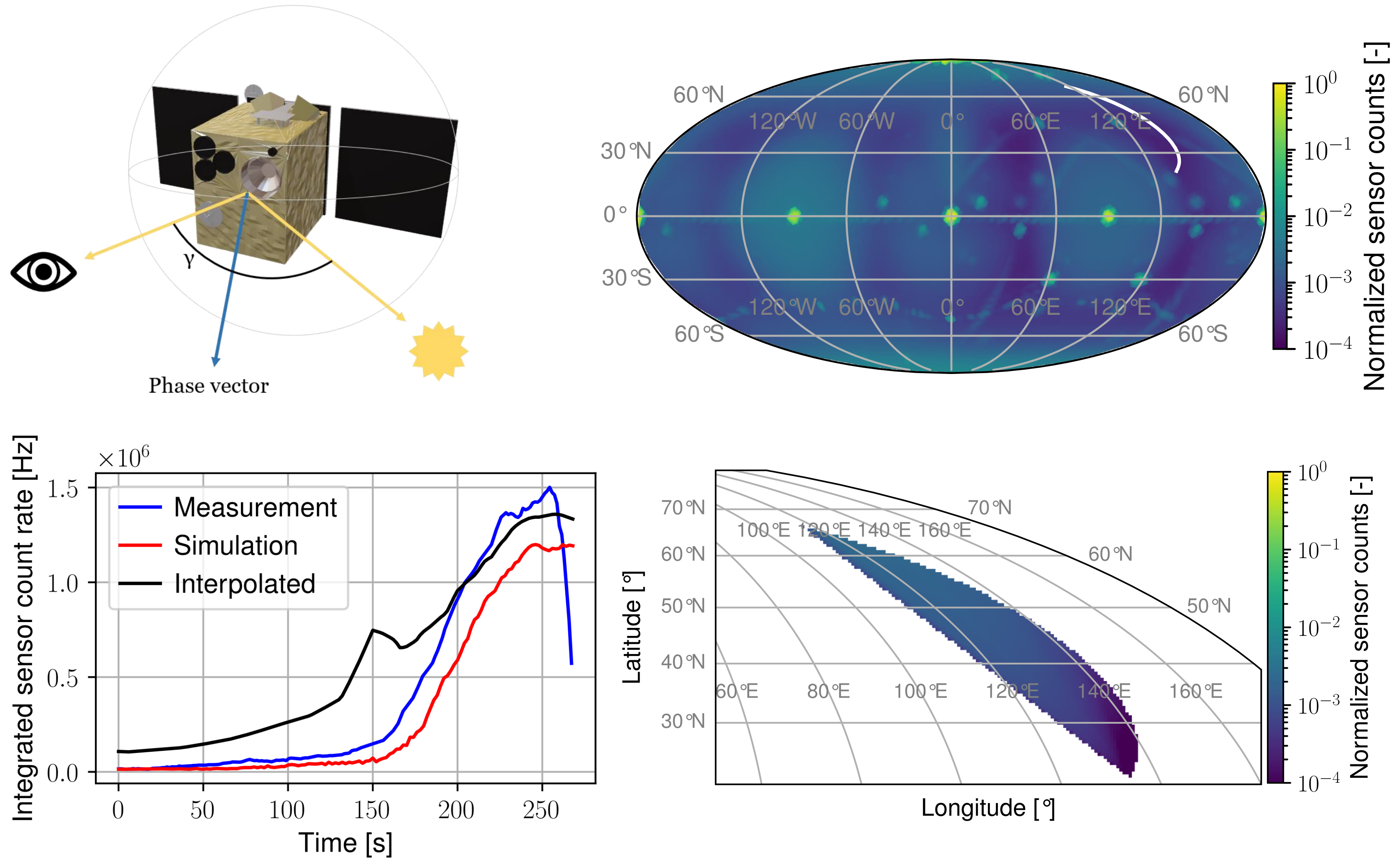

*Fig. 6: **Top left:** Phase vector projection in the body-fixed frame. **Top right:** Simulated reflectivity map, including phase vector (white) trajectory of a pass in the body-fixed frame. **Bottom left:** Comparison of light curves for one UFO pass. **Bottom right:** Measurement data projection.*

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