Space Debris: Extraction of the Rotational State from Multistatic Light Curves

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Abstract

With the rapid increase of space debris in the last decades, the risk for collisions of objects in orbit grows significantly. To avoid collisions, it is important to catalog the objects and determine their orbits. In order to propagate accurate orbits, it is necessary, to know the orientation of the object, so that the perturbation forces acting on it, can be taken into account in the orbit determination. Due to the changing observation geometry and orientation of the object during a pass, an observed object reflects sunlight with different intensities. This change in brightness over time can provide information about rotation parameters such as rotation speed and axis. These data can be used to propagate future orbits with higher accuracy. The goal is to quantify the information content of multistatic light curves, trying to investigate the sensitivity to the rotation parameters. Analyses are planned with respect to the initial orientation, the geometry change due to the motion in orbit, as well as the optical parameters and the size of the object. The information obtained can also be used to simplify a time- and computationally intensive simulation if the maximum resolvable step size is determined for each rotation axis. In a forward simulation, the findings from the theoretical analyses will then be used and analyzed in the context of multistatic images. Furthermore, a database is to be built up which, in addition to the light curves, also contains further information about the objects and the stations involved. Not only information about the sensitivity of the individual measuring instruments, but also about the measuring conditions will be available. This will allow a quantification of the quality of the measurements. The multistatic measurements will be performed by a local measurement network, which includes the observatories in Munich, Wettzell, Graz and Zimmerwald.

1. Introduction - Motivation

The rapid growth of debris in space is creating an increasing risk of collisions in the various orbits. The risk of collision between active and inactive satellites as well as with other bodies in space grows exponentially with increasing space flight and the number of collisions. To avoid these collisions, it is necessary to know the attitude of the debris to be able to deflect it to another orbit or to bring it back to earth. To determine the attitude in orbit, one approach is to observe the change in brightness of the reflected sunlight to the observer over time. Due to the changing observation geometry, during a pass, between observer, sun and object, the sunlight is reflected to the observer with different intensities. In addition, the intensity of the backscattered light changes due to the change in orientation of the object. Depending on which side of the satellite or the debris is illuminated by the sun, the object reflects brighter or darker. From this temporal change of the brightness, which can be represented as a light curve, some rotation parameters can be derived from the observation.

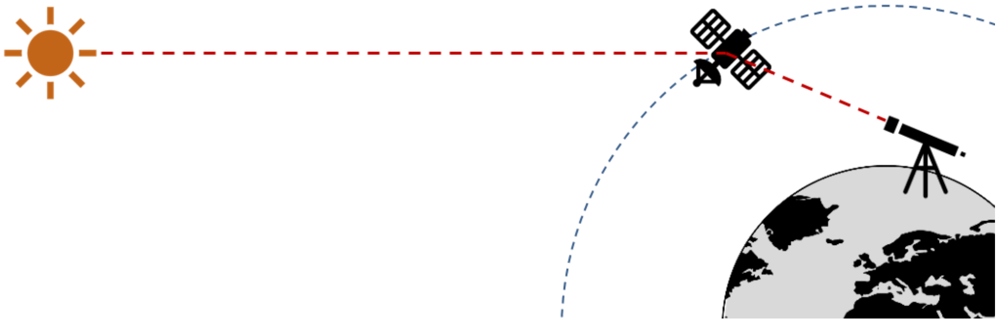

Figure1: Observation geometry of the sun, the measured object and the observer during a light curve measurement. The movement in the orbit changes the whole observation geometry and consequently, in addition to the attitude, the intensity of the backscattered light. This change over time can then be extracted as a light curve.

2. Previously Realized Activities

The common method for the recording and analysis of space debris, which was also performed at the Technical University of Munich in the past, is as follows:

- Starting with the object selection, only objects with known geometry are observed. In addition, the change in backscattered brightness is only observed from a single station.
- The next step is a spectral analysis of the light curve to find the rotational velocity of the observed object. To study the recorded light curves the Fast Fourier Transform, periodogram, Welch method, Epoch folding and Lomb-Scargle periodogram methods were used. The most dominant frequency, which can be extracted from the analysis, is taken as the most probable rotation period and used for further processing.
- The third step is to test different input parameters and simulate a large number of light curves. These light curves are created with different input parameters such as surface properties, rotation axes, and orientations at the start of the pass. Only the shape of the object, the observation constellation (object, observer and sun) and rotation period, from the previous step, are known approximately.
- The last step is the calculation of the correlations between the simulated light curves and the observed light curve. The goal is to determine the most reasonable light curve out of the many simulated,

At the Technical University of Munich, several rocket upper stages as well as larger satellites such as Envisat have been observed with this method. In figure 2 the result of a pass over Munich by Envisat in November 2020 is shown. In orange the recorded light curve is illustrated and in blue the best matching simulated light curve.

The good match of the timing of the peaks indicates a well extracted rotation period and rotation axes. The magnitude of the different peaks can be found using different surface properties, rotation axes and attitudes at the beginning of the pass.

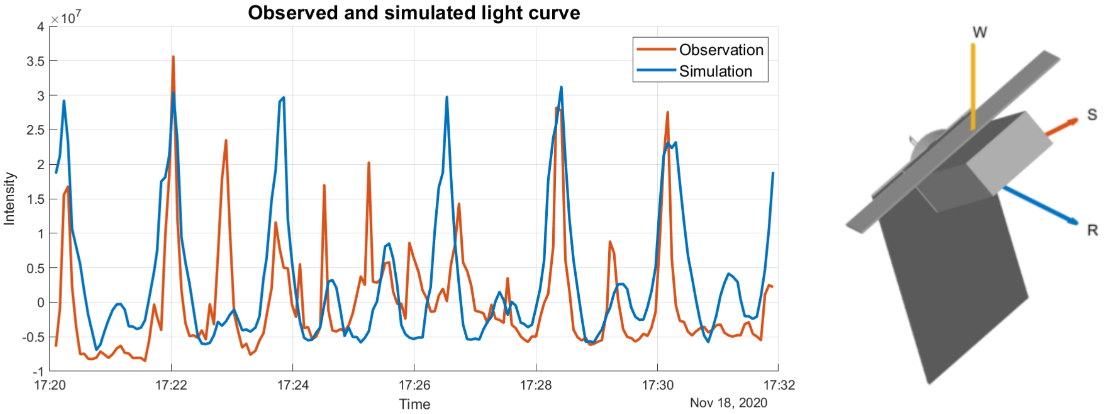

Figure 2: Observed and simulated light curve of a pass of Envisat over Munich in November 2020. Extracted was with a spectral analysis a rotation period of 113 seconds. Due to the symmetry of the shape of satellite, it could of course be a multiple of that. The figure on the right shows the starting attitude of the satellite at the beginning of the pass according to the analysis.

Problematic with this proceeding are the ambiguities

- The spectral analysis reveals several dominant rotation periods. Furthermore, rotations around different rotation axes, as well as different starting attitudes lead under certain conditions to similar light curves.
- Another problem is that very small changes in the input parameters can lead to completely different simulated light curves.

3. Null Spaces- Anlysis of the Content of Information

One approach to investigate the additional information content of light curves would be the Fisher information matrix. This is an analytical expression of the null space vectors representing the non-observable region of the rotation axes. The matrix provides information about which rotational axis is observable and which lies in the kernel of the matrix and cannot be observed.
By calculating the two null space vectors, the area can be determined that contains all axes about which rotation is not detectable with a single measurement. The aim is to determine these two vectors for a surface or object and to find out which rotations around which axes can be measured and which cannot be measured.

The area that cannot be evaluated is defined by the surface normal vector and the vector that is orthogonal to the normal and eigenvector.

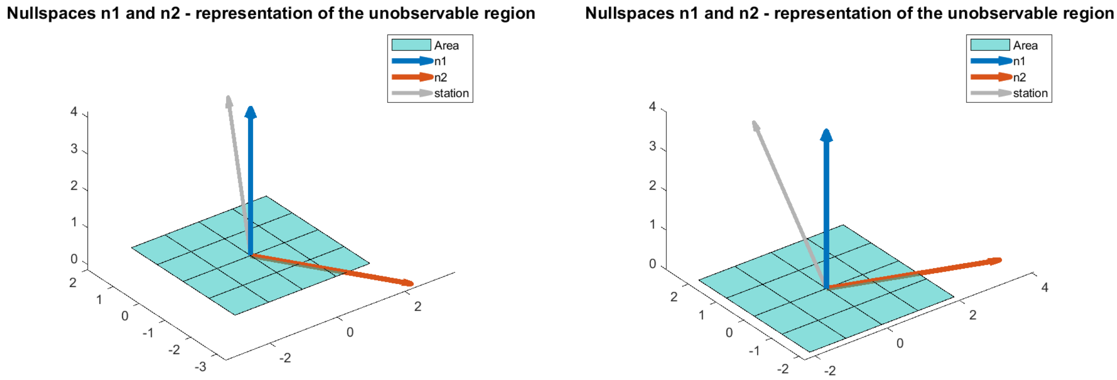

Figure 3: The left and right plot show in each case the surface normal vector n1 in dark blue and the vector orthogonal to it n2 in orange for two different stations. The vector in gray shows the direction with respect to the observer. When the orientation of the object or the position with respect to the observer is changed (flyby or additional station), the vector n2 changes and the unobservable region varies.

By a well distributed multistatic mesh of observations, as well as by the change of the observation geometry during the pass, the non-analyzable regions change, and these areas can be minimized. For a single plate, as shown in figure 2, the unobservable region can thus be reduced to only one vector, the normal vector, for an ideally distributed bistatic measurement.

4. Database

A great goal of the project is also the development of a database. In addition to the multistatic light curves, necessary data for the simulation will be stored there. This includes the brightness matrix, the CAD model, used software packages, data containing information about the sensitivity of the measurement instruments and the measurement conditions while observing, which allow a quantification of the quality of the measurements. These data are necessary to be able to combine different measurements at a later moment. Also, all additional useful data about the observed objects such as the shape of the space debris and its optical surface properties, to which category the object belongs, which orbit parameters and mass it has etc. should be stored.

5. Conclusions - Planned Research

Several analyses are planned during the project:

- An analysis of the complementarity of multistatic light curves and what additional information they contain depending on the distribution of ground stations, the shape of the space debris object and the flight altitude. For this purpose, the information content or information profit is to be quantified. Together with technical requirements, a selection of the objects to be measured can then be realized.

- Analysis of the shape of the space debris object, optical parameters and size. Only for very few objects in space these surface properties are known with sufficient accuracy. Especially the optical parameters can change during the time in space. For these reasons, the dependence of the apparent brightness on the optical parameters and the size of the surface for simple objects will be studied.
- Analysis of the sensitivity of light curves with respect to the initial attitude. By the change of the orientation of the object and by the change of the geometry sun-object-observer there are changes in the apparent brightness. The information profit by the rotation of the object is to be examined separately from that of the geometry change. Again, the information gain due to complementarity is captured and quantified.

Parallel to the theoretical investigations, measurements will also be carried out. For the acquisition of multistatic light curves, at least two stations have to observe the same space debris object simultaneously. This requires both planning of the observations and strong networking of the measurement stations. Furthermore, for multistatic measurements involving several stations, additional information besides the light curves themselves must be stored in the newly built database in order to be able to process them with each other. The observatories in Graz and Zimmerwald already confirmed their participation in the measurement campaigns carried out by the TUM in Munich and Wettzell.

If there is interest and other observatories would like to participate in the observations and provide some measurements for the database, we would be very interested in a possible collaboration.

6. References

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