AN ADVANCED TOOL TO DETERMINE THE APPARENT ROTATION PERIOD OF A SPACE OBJECT FROM A FUSION OF MEASUREMENTS

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Context and scope

EU SST R&D project for the fusion of SST data in the new European services for space surveillance.

<u>Main scope</u>: characterization of the roto-translational state of a space object from the fusion of ground-based sensors measurements.

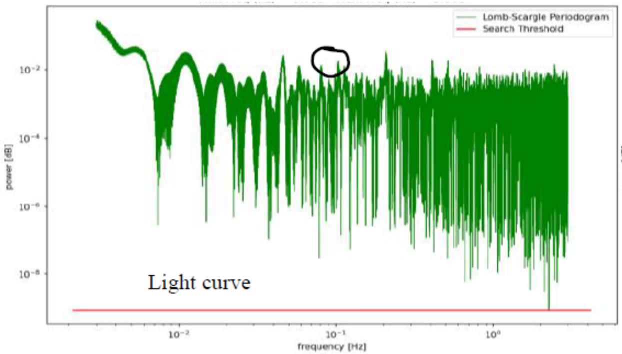
<u>Three milestones</u>:

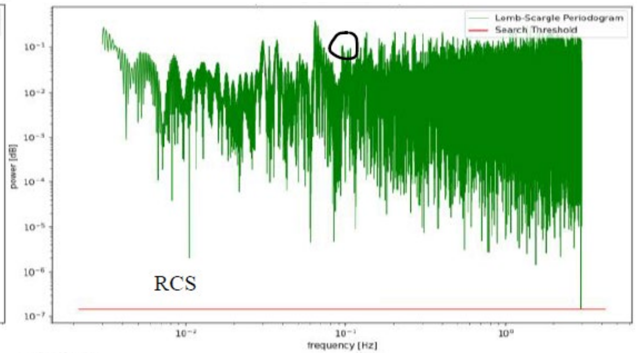
- Implementation of a **simulator** for attitude/shape related measurements (classic and laser light curves, RCS and laser ranging).
- Implementation of an **estimator** of the roto-translational state of an object.

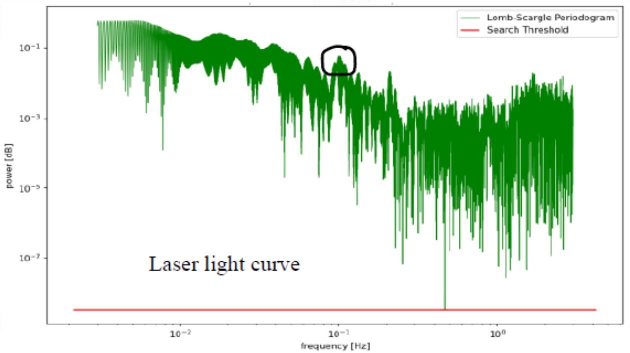
  => **Synodic rotation period estimation with data fusion.**
- Validation with simulated and real measurements => **observations campaign**

Estimation Algorithm

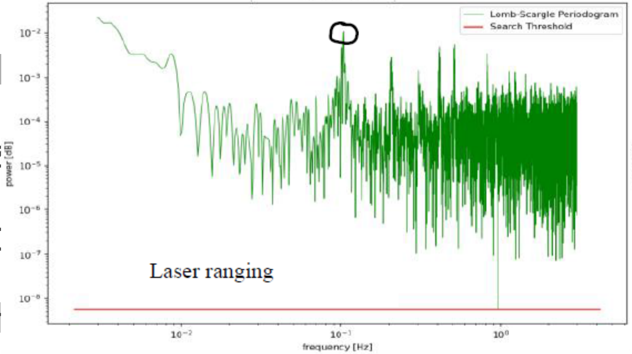
Determining candidates - Lomb-Scargle Periodogram (1/2)

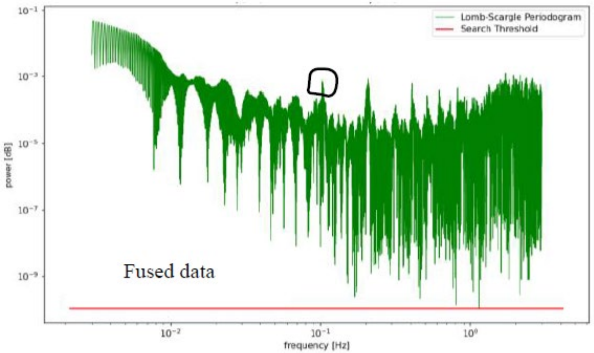






- Data Fusion ... t of input data, this al...
  - Emphasiz... s harmonics.
  - Weaken c...
  - Reduce th...





Estimation Algorithm

Determining candidates - Lomb-Scargle Periodogram (2/2)

Limitations

- Precision of candidate frequencies (peaks) is related to the sampling frequency and noise of the input data.

  => **Optimization of candidates required**

- The periodogram does not allow to differentiate the real rotation frequency of the object from its harmonics or other spurious frequencies.

  => **Comparison of candidates required**

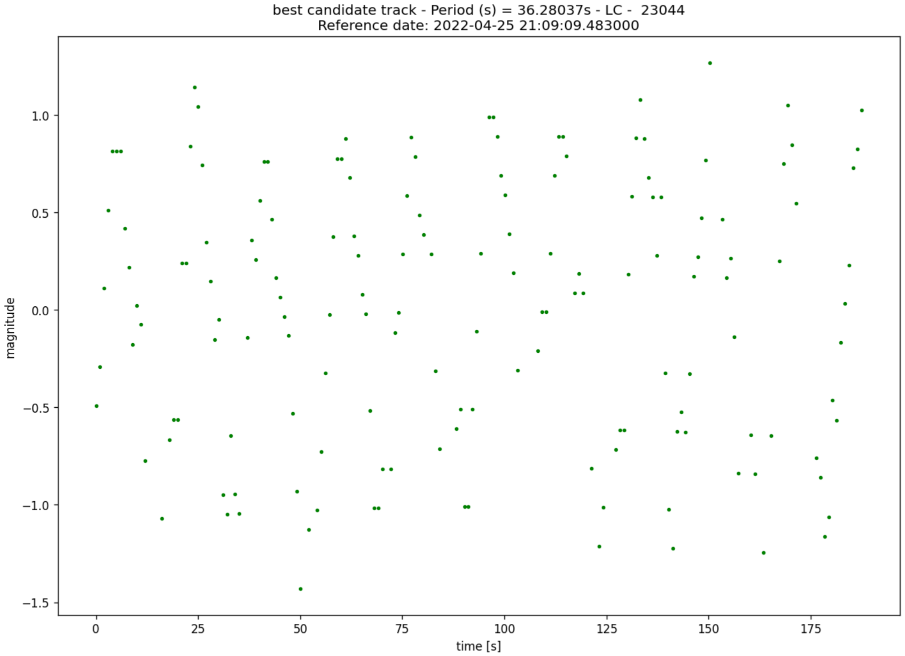
- Peaks can also be found even for a non-rotating object.

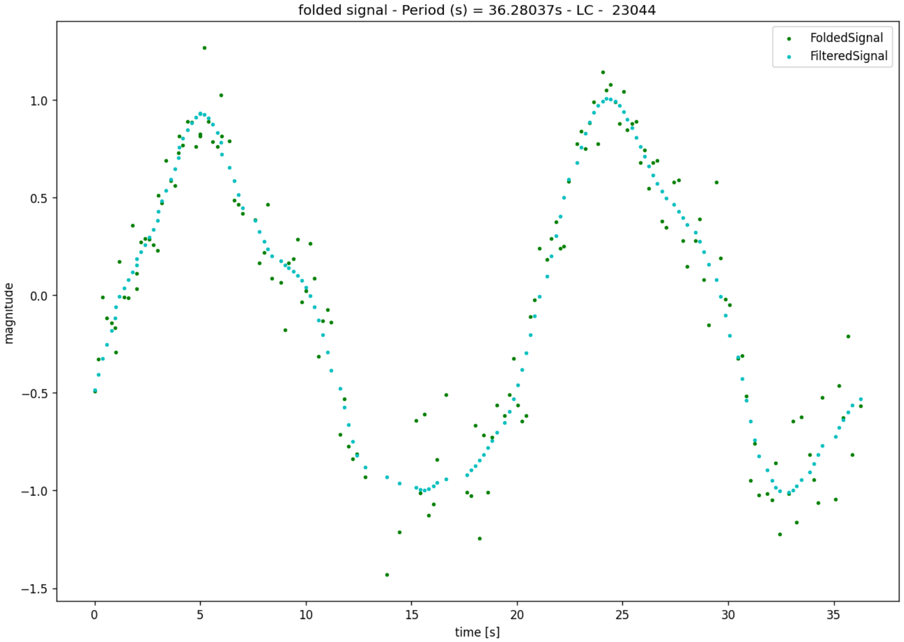
  => **A way to determine whether the object is rotating or not is required**

Estimation Algorithm

Optimizing candidates - Iterative Epoch folding (1/2)

Candidate frequency is automatically optimized using an iterative epoch folding.





Estimation Algorithm

Optimizing candidates - Iterative Epoch folding (2/2)

Selecting folding interval with data fusion

- Data Fusion means here selecting an interval of a single type of data within the whole dataset **maximizing the following criterion** (dimensionless):

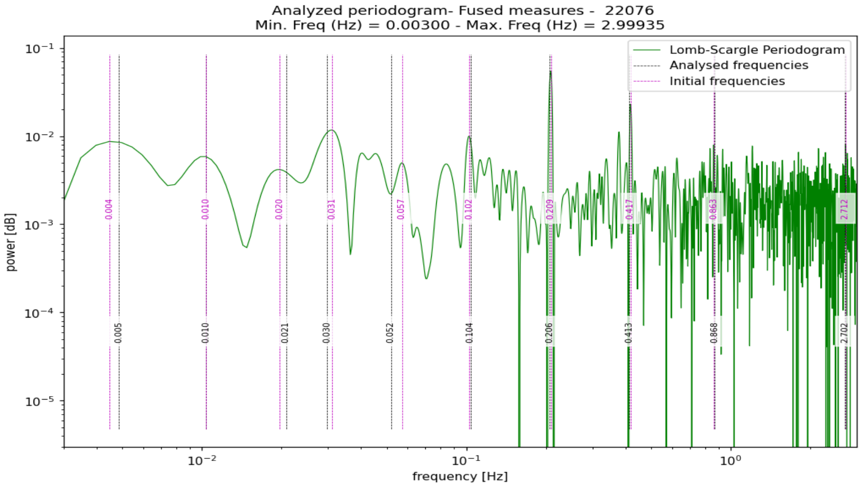
$$criterion = \frac{data\ density\ x\ data\ stdDev}{data\ noise}$$

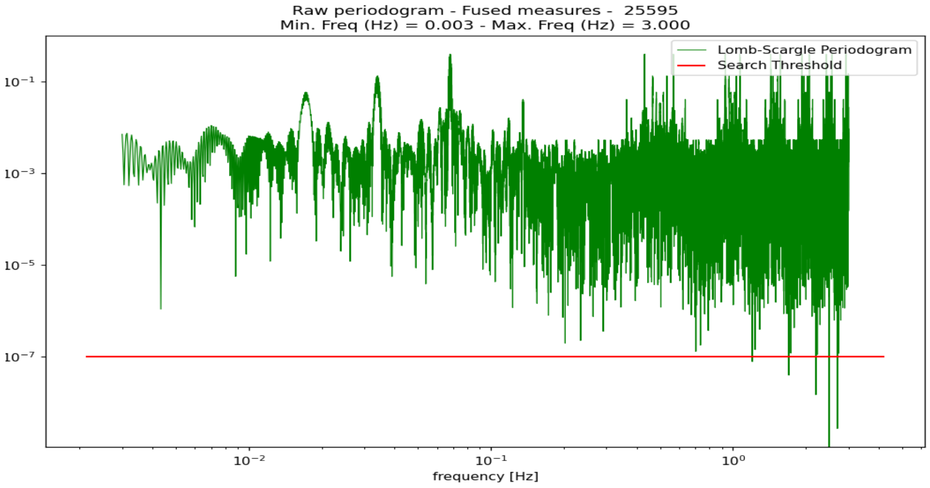
, where data noise is computed from a reference defined by a Butterworth's filter fitting.

Estimation Algorithm

Comparing optimized candidates

Problematic:



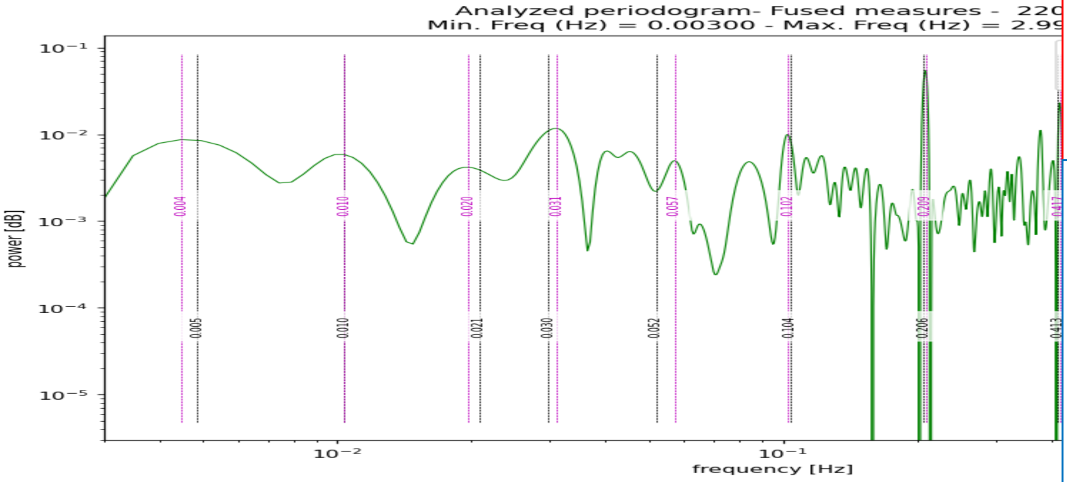


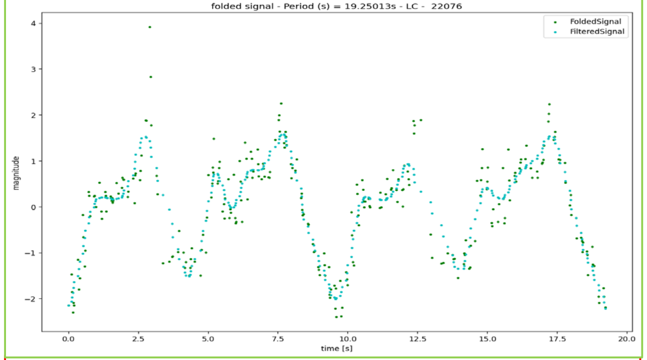
Estimation Algorithm

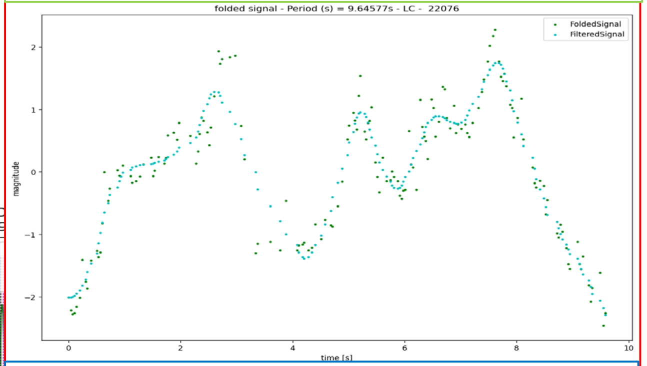
Example

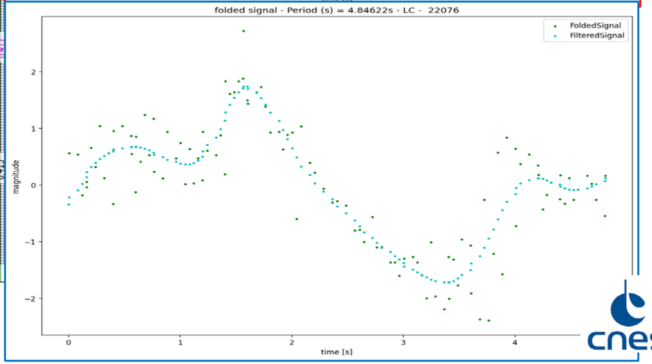
```
# Satellite name =  22076

LIST OF THE FOLDED PERIODICITIES (CLASSIFIED ACCORDING TO THE STD ERROR)
```

Period (s)	Frequency (Hz)	Folding Error (ratio)	Signal type
9.64577	0.10367	1.270	LC
19.25013	0.05195	1.310	LC
33.61389	0.02975	1.418	LC
47.98698	0.02084	1.418	LC
96.31500	0.01038	1.454	LC
4.84622	0.20635	1.750	LC
1.15170	0.86828	3.186	LC
2.41923	0.41335	3.456	LC
0.37010	2.70195	3.516	LC



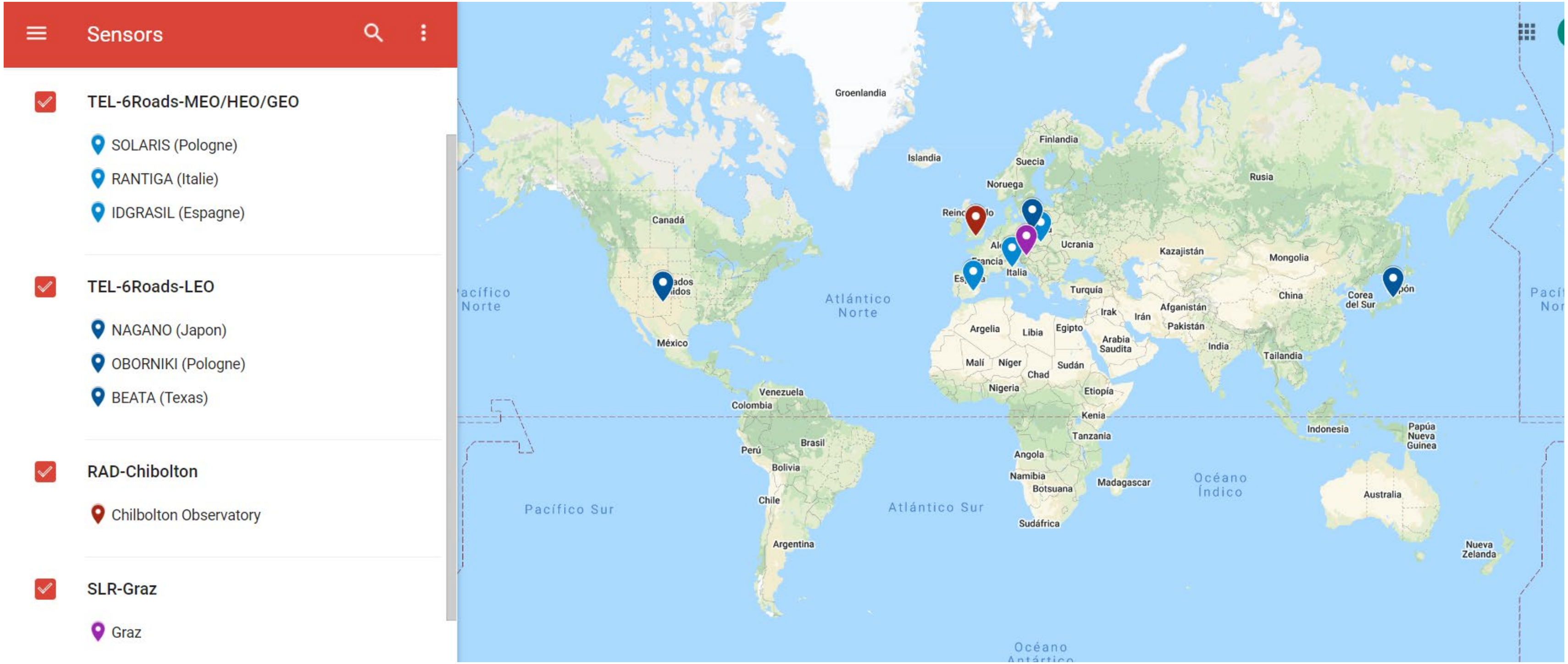






Validation: Observations Campaign

Sensors network



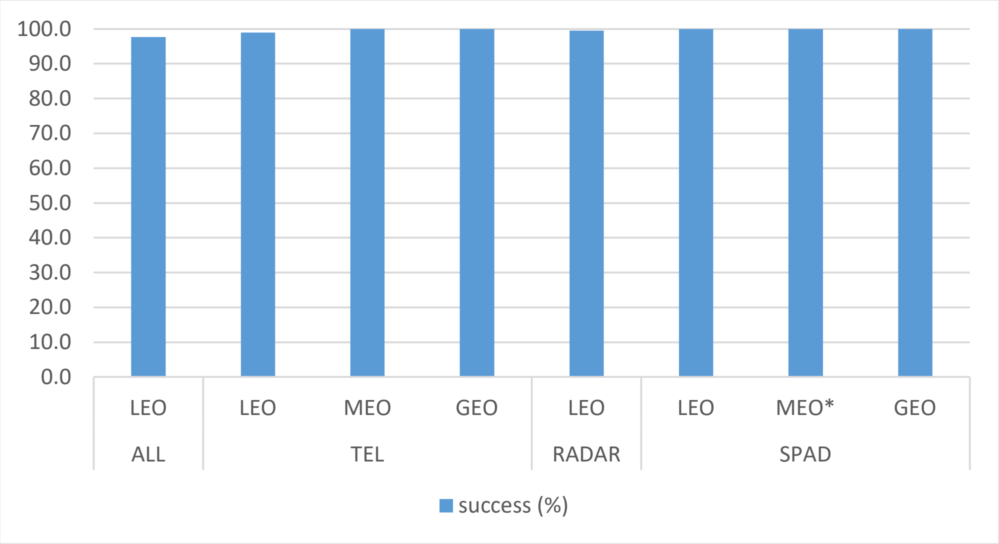
Validation: Observations Campaign

Observed objects

- **Objects selection and reference data** from 2 sources:
  - **CelesTrak SATCAT** (https://celestrak.com/pub/satcat.csv): *name*, *identifier*, *object type*, *operation status, size* and *orbit* (only large objects are retained).
  - **MMT9** (http://mmt.favor2.info/satellites/download): *rotational state* and *period* of objects in CelesTrak's and McCants' catalogues (no CIS satellites).
- **33 days of observation**.
- **57 3-axis stabilized objects observed**: 35 LEO, 10 MEO, 12 GEO.
- **22 rotating objects observed**: 6 LEO, 12 MEO, 4 GEO.
- **1324 tracks**: 677 from telescopes, 426 from radar, 31 from laser, 160 from SPAD.

Validation: Results

Determining non-rotation of 3-axis stabilized objects



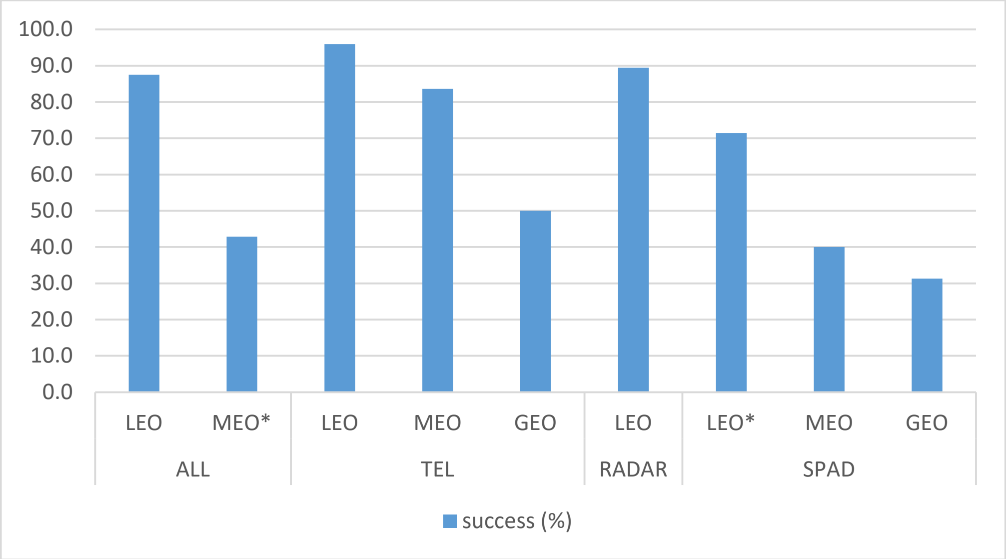
Based on daily estimations for each object

** Not confident with value because of few number of tracks used*

- **Very good results in all regimes with all types of measurements** (LC, RCS, LLC).
- **Very good results with Data Fusion in LEO**.
- No conclusions for Data Fusion in other regimes because of lack of stereoscopic observations.
- No conclusions for LR as very low number of exploitable tracks.

Validation: Results

Determining synodic period of rotating objects



Based on daily estimations for each object

** Not confident with value because of few number of tracks used*

- **Very good results in LEO with LC and RCS**.
- **Very good results with Data Fusion (LC and RCS) in LEO**. Reduced stereoscopic sample compared with TEL or RADAR only.
- **Success rate with LC, LLC or their fusion decreases with orbit altitude** => Lower luminosity variations getting closer to measurement noise.
- No conclusions for Data Fusion in other regimes because of lack of stereoscopic observations.
- No conclusions for LR as very low number of exploitable tracks.

Validation: Results

Precision of synodic rotation period determination

- Always **less than 1%** using simulated measurements of objects of different shapes, orbital regimes and inertial rotation periods.
- 0.2% using MMT9 measurements of METEOSAT 8 (MSG 1), which is spin-stabilized at 0.6 s period.

Acknowledgements

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Thank you

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