Space Debris Characterization Through the Slovak Debris Light Curve Catalogue

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Outline

- 1. Introduction, motivation
- 2. Data acquisition, AGO70
- 3. Light curve construction
- 4. Pre-processing, processing and post-processing
- 5. Results
- 6. Conclusions and next work


Introduction and motivation

Motivation for space debris research

- **Light curve**
  - consecutive photometric measurements
  - except other effects, contains information about the rotational state of the object

- **Applications:**

  - Attitude determination – rotation axis determination (*Williams, 1979, Blacketer, 2019*), ADR applications (*Liou et al., 2010, Wang et al., 2018*), method cross-calibration (SLR, radar) (*Zhao et al., 2019, Kanzler et al., 2015*)

  - Attitude monitoring – fragmentation events prediction/ anomaly behavior analysis (*Slatton and McKissock, 2017*), ADR applications

  - Object characterization, identification - shape determination (*Fan and Früh, 2019*), color photometry (*Zigo et al., 2019*), albedo/size estimation (Africano et al., 2005), surface roughness (phase function, H-G parameter estimation) (Waszczak et al., 2015)


Data acquisition and processing

AGO70 telescope

- Main objective:

Perform tracking to space debris in order to support European space debris cataloguing, physical characteristics of debris

- Former ***ESA PECS HAMROptSen*** dedicated to the main objective, cooperation CU (SK, prime) + AIUB (CH)
- Currently ***ESA PECS ImpEuroLEOTrack***, cooperation CU (SK, prime) + AIUB (CH) + IWF (AUT)
- Activities cover all aspects – low-level control, planning/scheduling S/W improvement, observation planning, data acquisition, data processing, image processing SW improvement, tracklet building, object identification, orbit improvement, cataloguing, data format conversion, etc.

Telescope design	Newton
Mount	Equatorial (Open fork)
Camera	CCD
Dimension	1024 x 1024
Primary mirror diameter [m]	0.7
Focal length [mm]; focal ratio	2962.0; f/4.2
FOV [arc-min]	28.5 x 28.5
iFOV [arc-sec/pix]	1.67

Table – AGO70 telescope configuration.

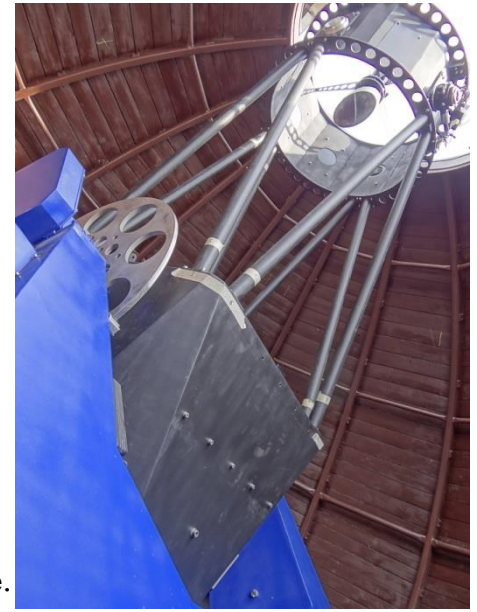


Figure – AGO 70cm telescope.

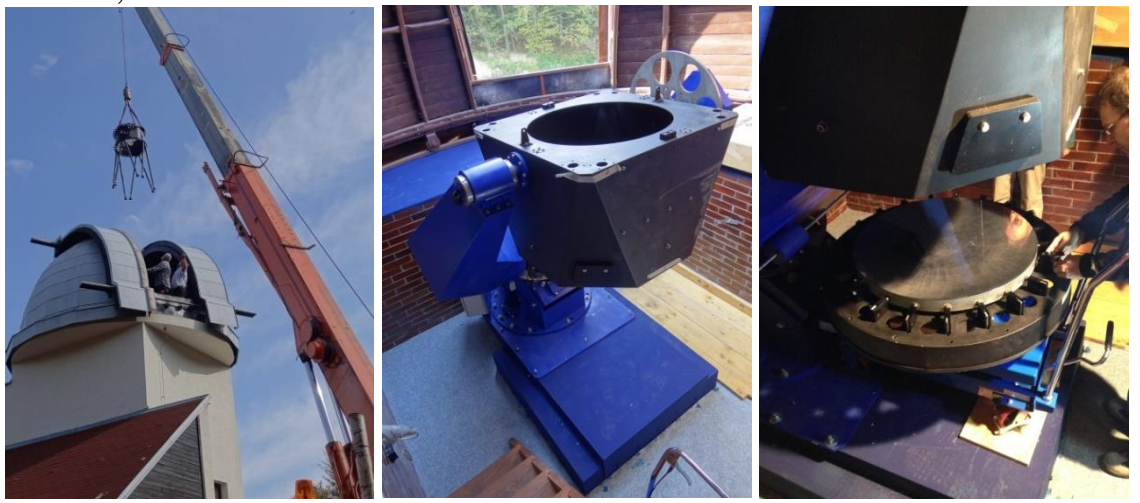


Figure – AGO 70cm telescope installation (left), mount (middle) and 70 cm primary mirror (right).

Aliasing problem

- Aliasing problem appears once the sampling frequency close to the signal frequency
- Source of the problem similar to Nyquist criterium, more discussed in *Binz et al. (2014)* and *Šilha et al. (2018)*
- Solution: Data acquisition with two different samplings (exposure time, readout)

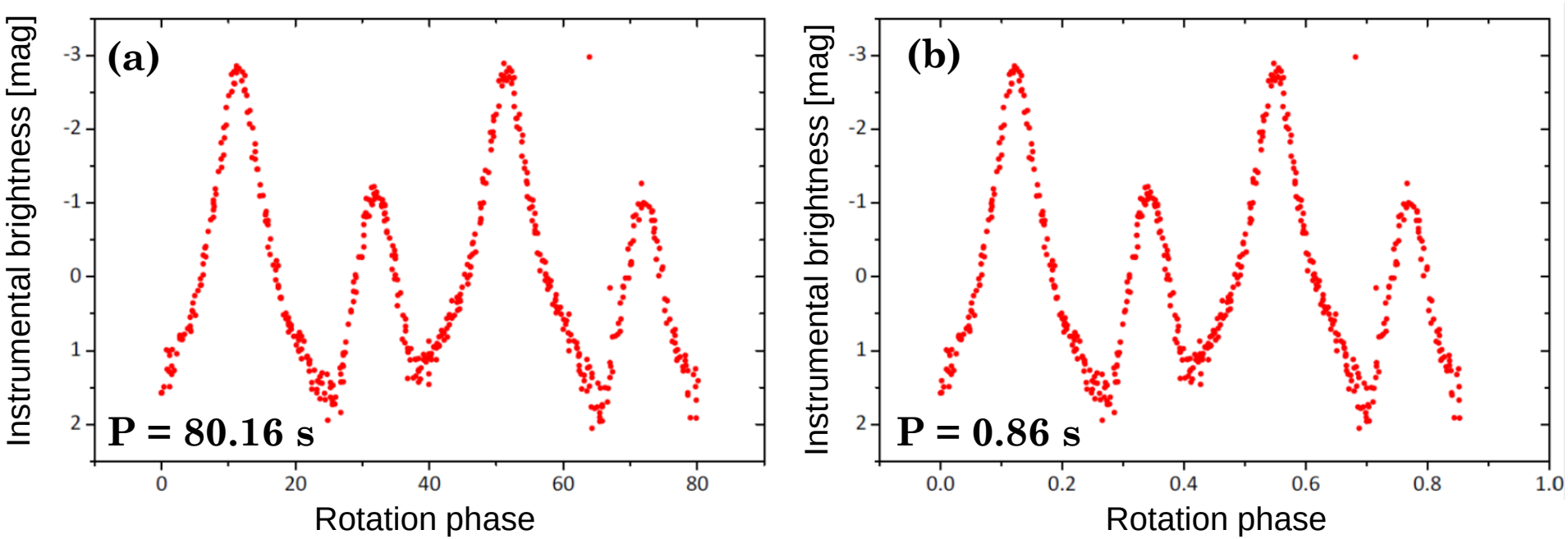


Fig. – Two identical phase diagrams constructed from the same light curve assuming two different values for the apparent rotation period, 80.16 s (a) and 0.86 s (b). Strong effect of aliasing is present in the data set. Source: *M. Hamara (2017)*

Light curve construction

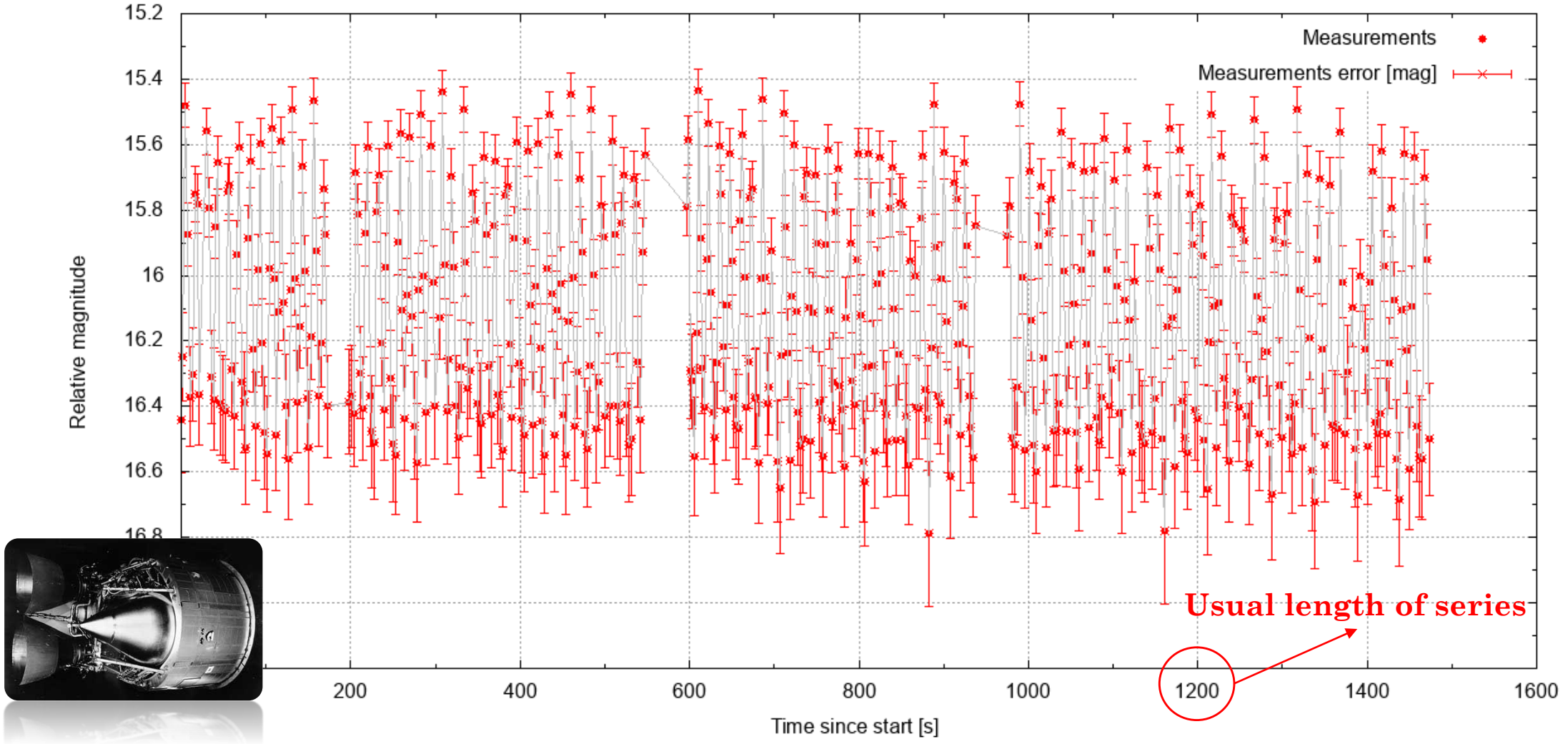


Fig. – Photometric measurements acquired by AGO 70cm telescope during night 20181016 (up) and the constructed light curve (middle) and its phase diagram (down) for the object Titan 3C Transtage R/B (74039C). Source: *Silha et al. (2019)*

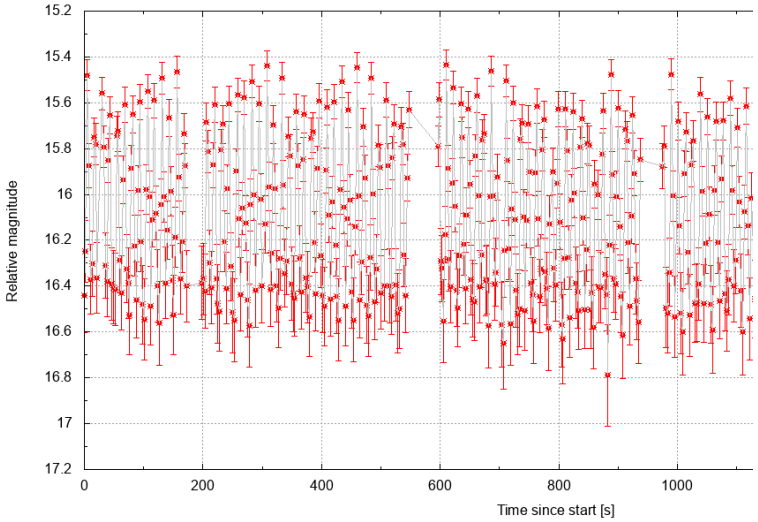
Data processing

- Search for the apparent period and phase diagram construction
  - Apparent rotation period:
    - Initial apparent rotation period – FFT and Lomb-Scargle method (*Scargle, 1982*)
    - Final apparent rotation period, phase diagram – Phase Dispersion Minimization (PDM) *(Stellingwerf, 1978)*
  - Catalogue of light curves and phase diagram (rotational curve) (period, amplitude, shape)

- Uncertainty analysis
  - Amplitude from data (measured)
  - Amplitude, period and phase error calculation (*Montgomery and Odonoghue, 1999*)

$$\sigma(A) = \sqrt{\frac{2}{N}}\sigma(m), \qquad \sigma(\Phi) = \sqrt{\frac{2}{N}}\frac{\sigma(m)}{a}, \qquad \sigma(T) = \sqrt{\frac{6}{N}}\frac{1}{\pi N \Delta t}\frac{\sigma(m)}{a}T^2$$

Data post-processing



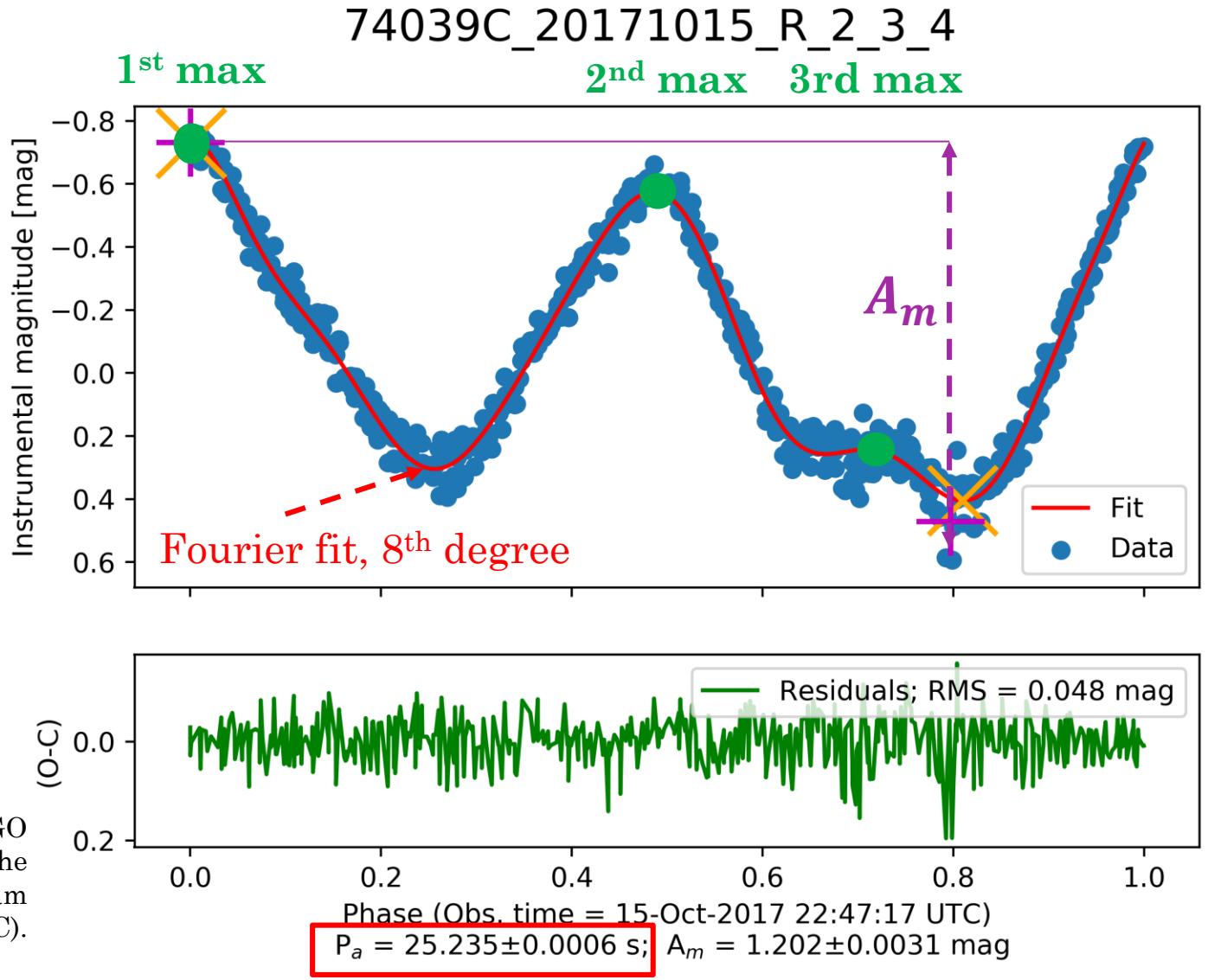


Fig. – Photometric measurements acquired by AGO 70cm telescope during night 20181016 (up) and the constructed light curve (middle) and its phase diagram (right) for the object Titan 3C Transtage R/B (74039C). Source: *Silha et al. (2019)* [5]

FMPI's space debris light curve catalogue (SDLCD)

J. Šilha, M. Zigo, T. Hrobár, Slovak Space Debris Light Curve Database and its Applications,
GNOSIS Precision SSA Workshop, Via ZOOM, 9th of July, 2020

Results

- Data acquired between 2017-05-09 and 2019-03-31, 285 light curves acquired for 226 individual objects

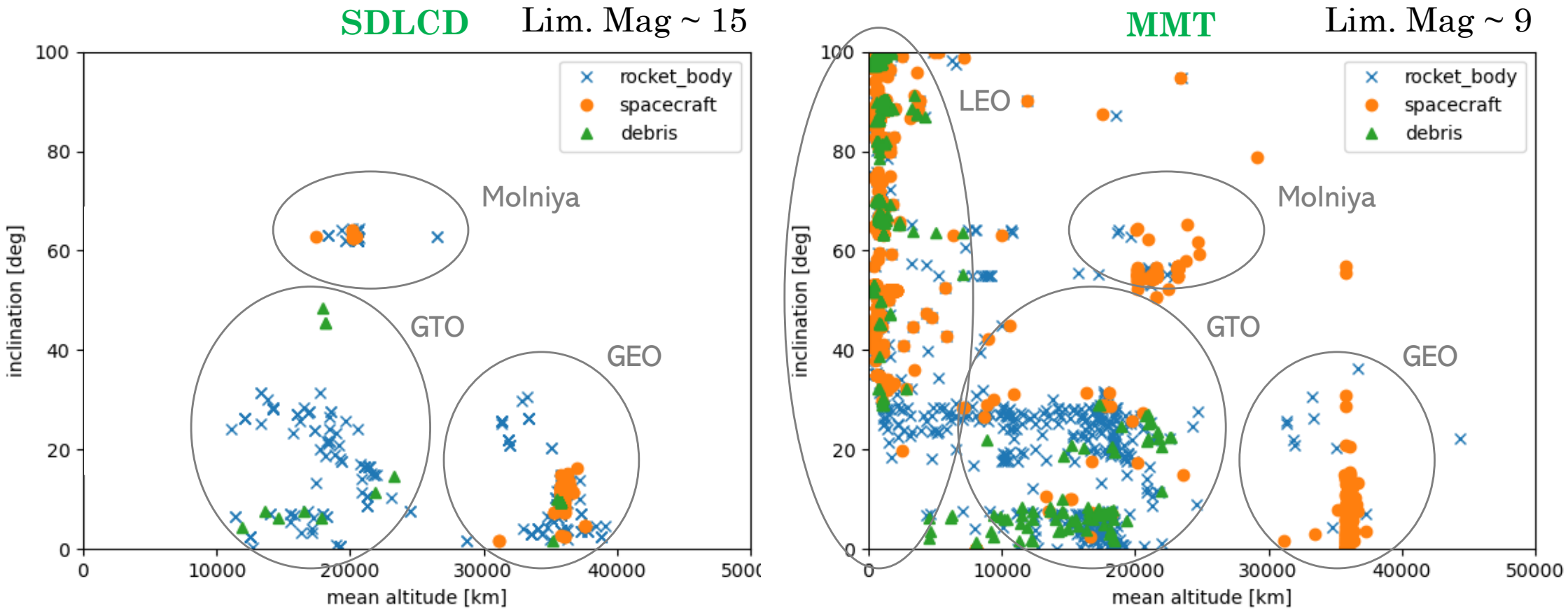


Fig. - Objects observed for photometry by AGO70 system (Silha et al., 2020) (left) and by MMT (Karpov et al., 2016) (right) according to their orbital properties, mean altitude vs orbital inclination.

Results

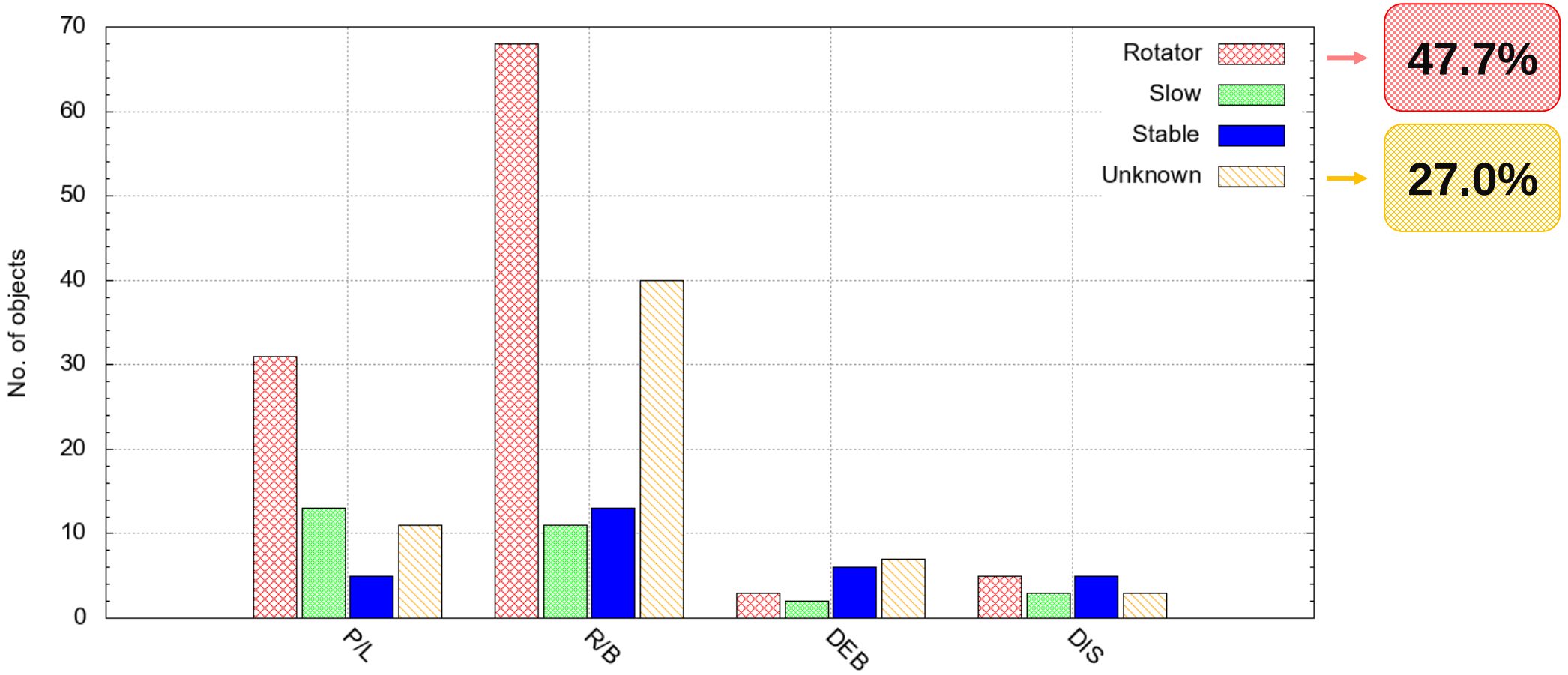


Fig. - Distribution of 226 objects observed by AGO70 system in years 2017 to 2019 according to their rotation properties and type. Plotted are rotators, slow rotators, stable objects and objects for which the light curve could not be processed. Source: *Šilha et al. (2019).*

Results

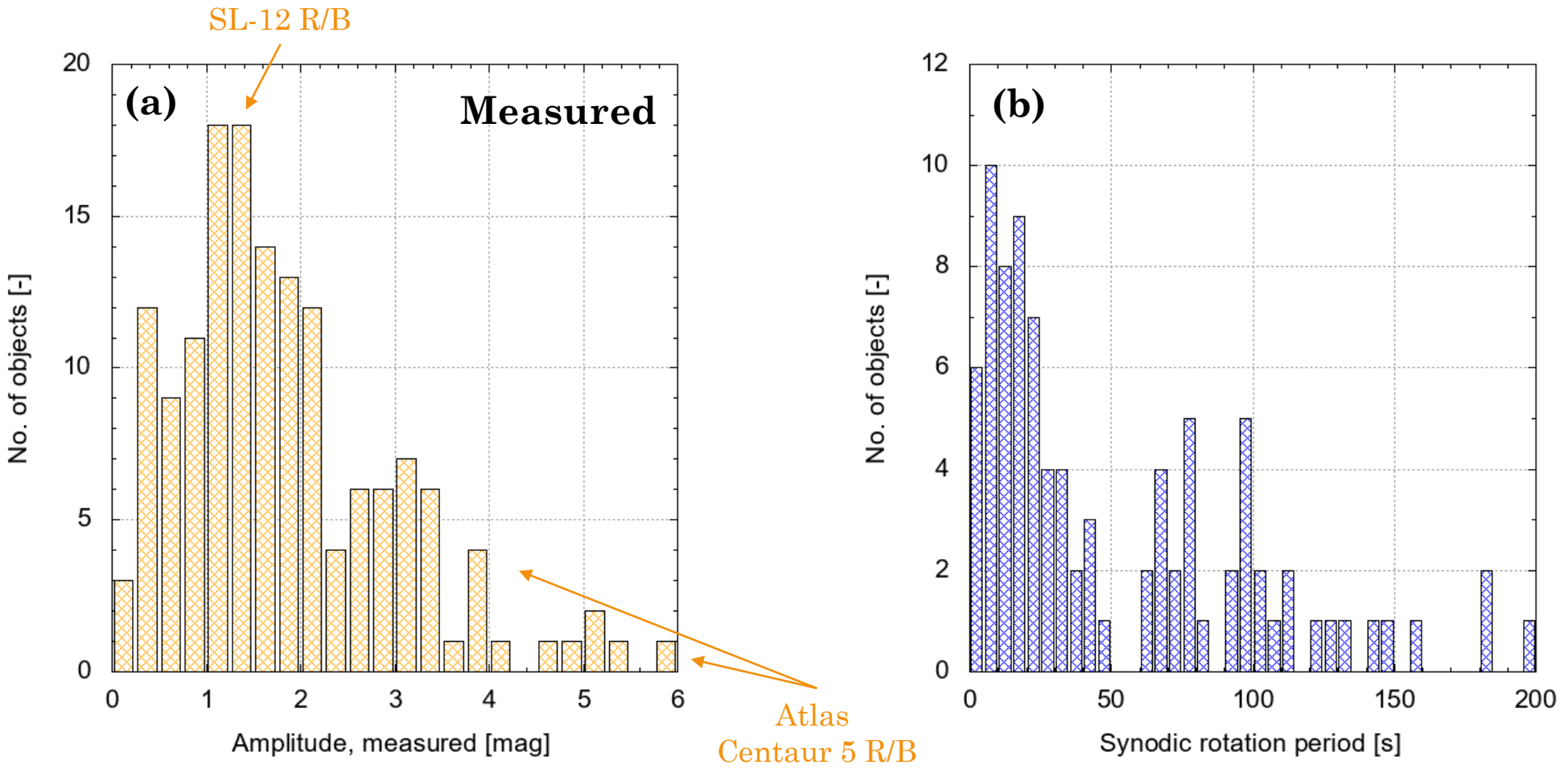


Fig. - Distribution of measured amplitudes Am (a) obtained from 153 phase diagrams/light curves and distribution of obtained synodic rotation periods for 107 objects (b) acquired by AGO70 system in years 2017 to 2019. Used bin width is 0.25 mag and 5 s, respectively. Source: *Šilha et al. (2019)*.

Results

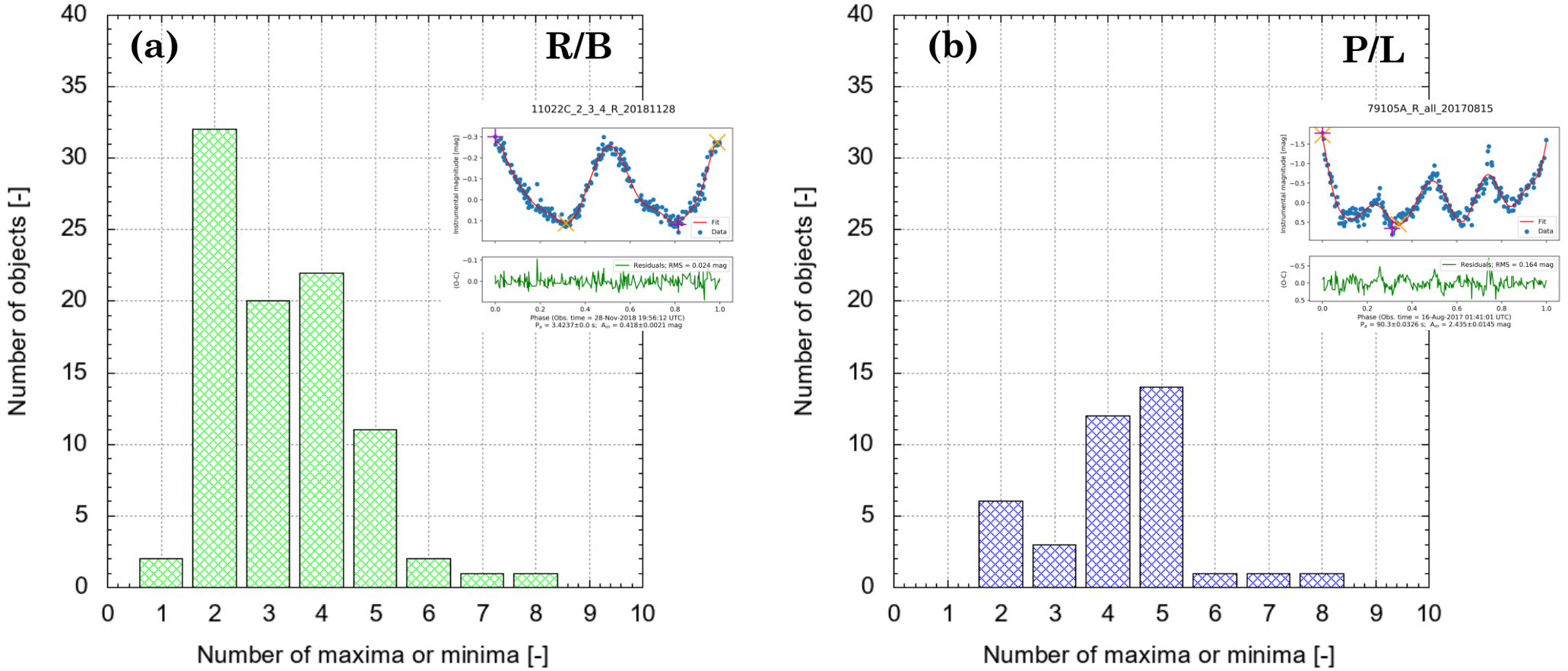


Fig. – Number of maxima or minima in given phase diagram for 153 phase diagrams/light curves. Distinguished are upper stages (R/B) (a) and payloads (P/L) observed by AGO70 system in years 2017 to 2019. Source: *Šilha et al. (2019)*.

Results

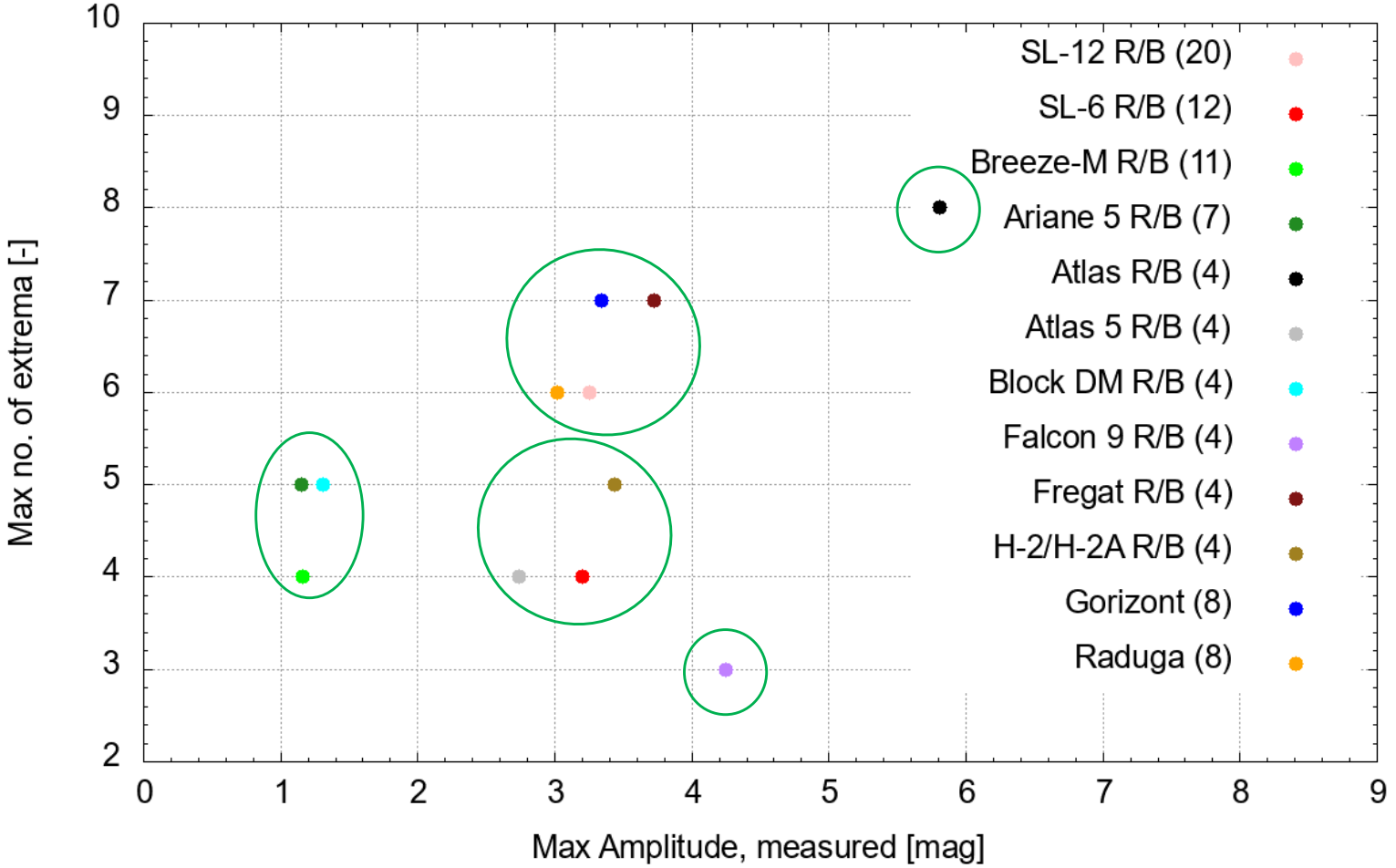
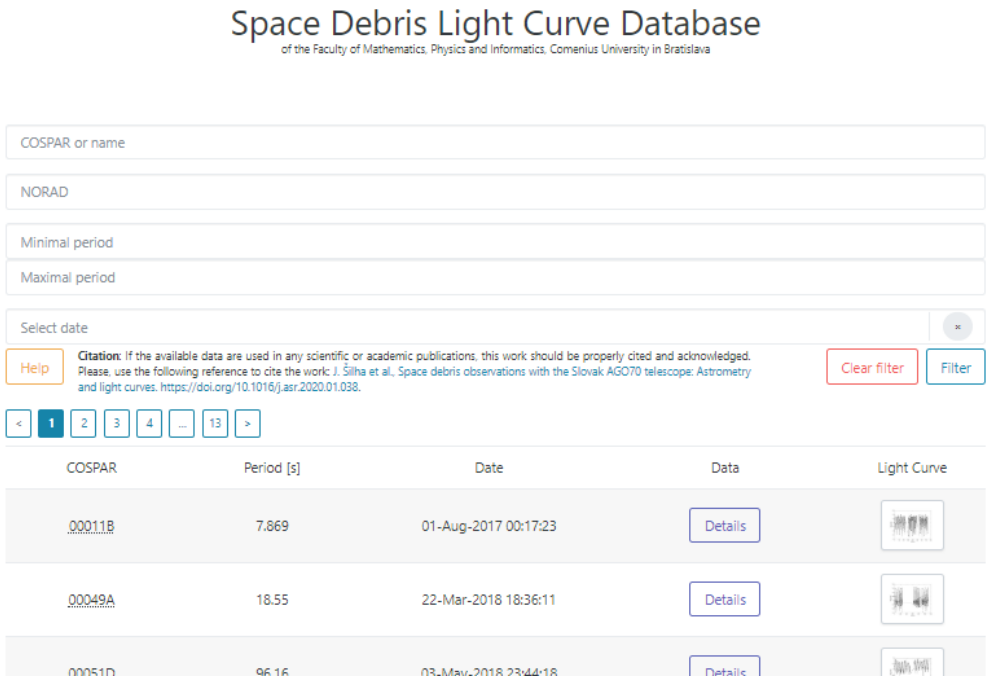


Fig. – Measured amplitude vs number of maxima for phase diagrams/light curves acquired for upper stages. Distinguished are upper stages (R/B) observed by AGO70 system in years 2017 to 2019. Source: *Šilha et al. (2019)*.

Summary

- The whole light curve program established at FMPI – data planning, acquisition, pre-processing, processing and post-processing, cataloguing
- **Catalogue publicly available (Šilha et al., 2019)**, focus on the monitoring of the objects over time, applicability to other prograns - color photometry program, attitude determination, object characterization



Future work

- Light curve data continues to be routinely acquired by using AGO70 system
- New data to be regularly published in the public catalogue, DR1 should be in the fall 2020
- Improvement of the data fit and error prediction and extension for reduction to the standard system (Johnson-Cousins R filter)
- Full automatization of processing by using FMPI's IPS
- Extension of the analysis to LEO and highly eccentric objects
- H/W replacement, e.g. CCD → CMOS

Future work – extension to LEO/HEO

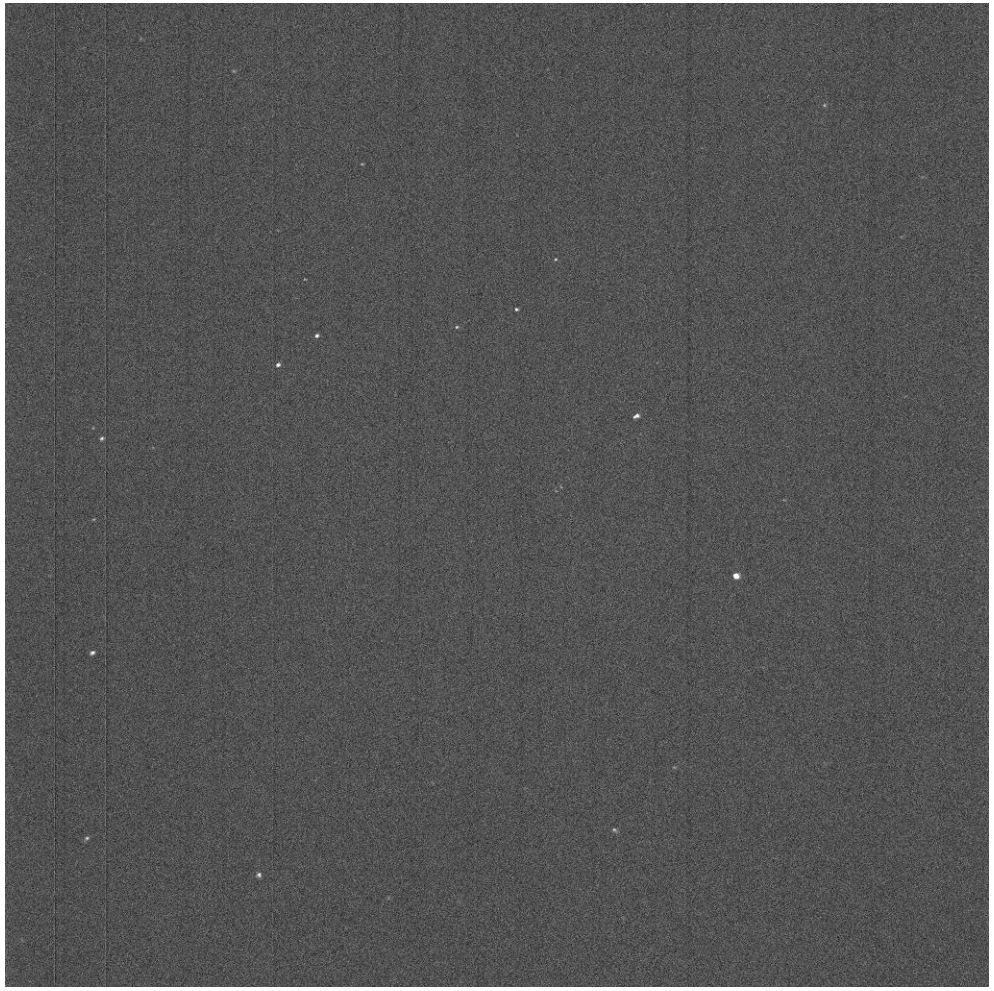


Fig. – Compilation of 105 FITS frames of Thor R/B (62060B) acquired by AGO70 during night 2020-06-26. Used R filter and exposure time of 0.1 s. Mean altitude ~ 1100 km.

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