Photometric program on the 70-centimeter telescope at AGO Modra

Bezovec 2020

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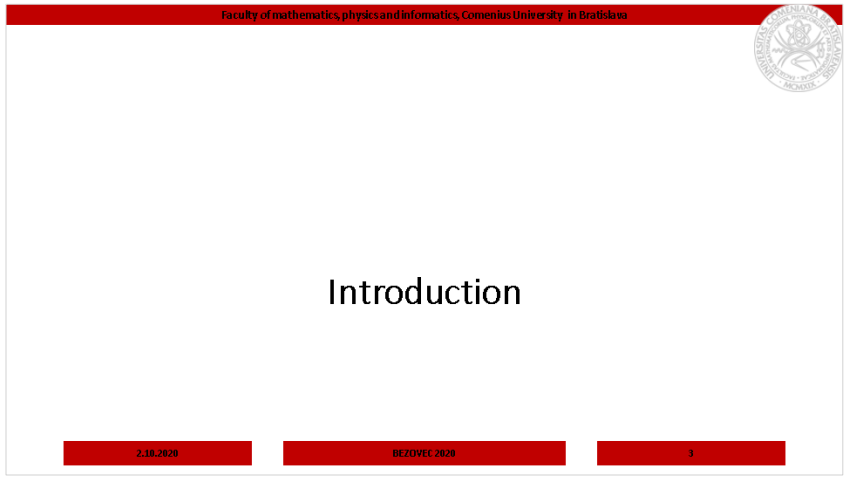
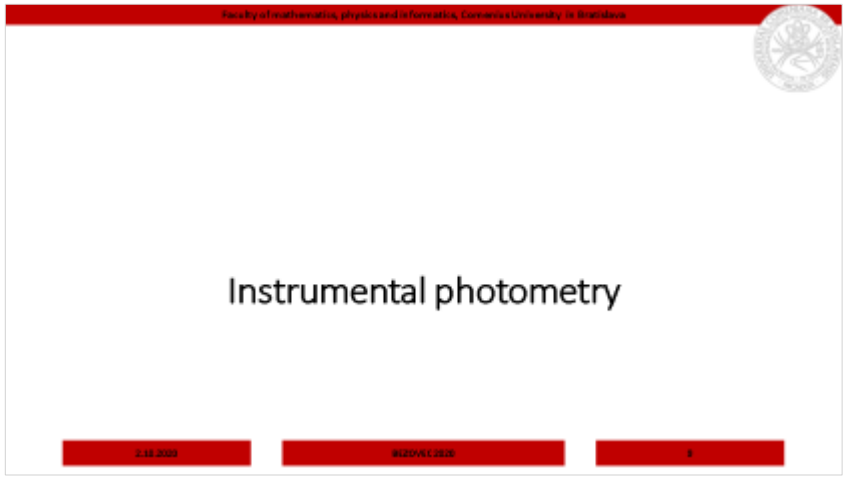
Content

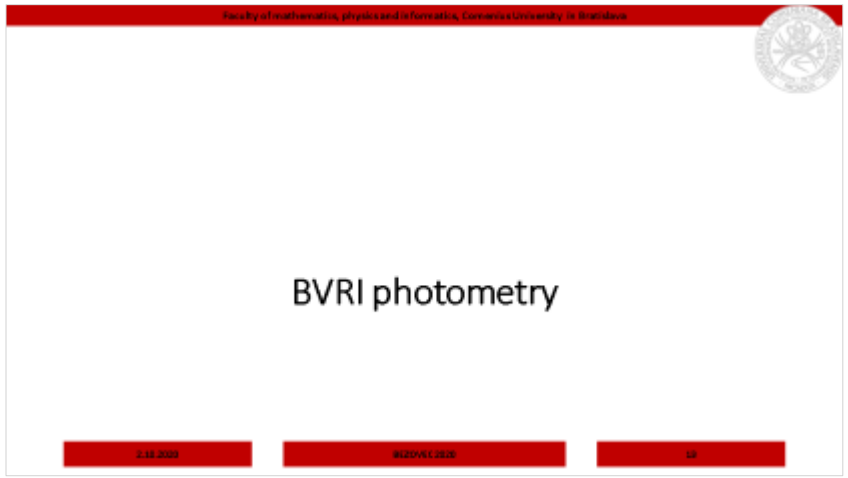
1. Introduction



2. Instrumental photometry



3. BVRI photometry



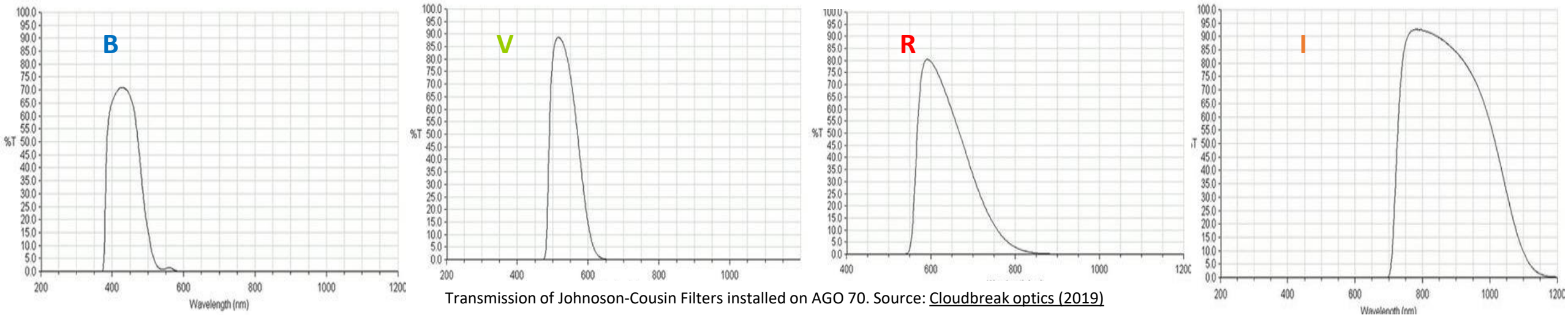
4. Development

Introduction

AGO 70

- Newtonian telescope
  - fork equatorial mount
  - 0.7m parabolic mirror - focal length – 2.9m
  - main specialization – observations of space debris objects
  - CCD FLI Proline PL1001 Grade 1, 1024 x 1024 pixels
  - iFOV = 1.67”x1.67” and FOV = 28.5’x28.5’
- Johnson – Cousin’s filters BVRI
  - B (435.3nm), V (547.7nm), R (634.9nm), I (879.7nm) (aip (2018))

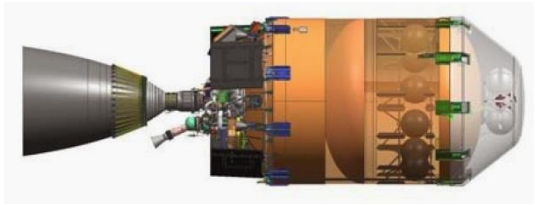
Credit: Stanislav Griguš



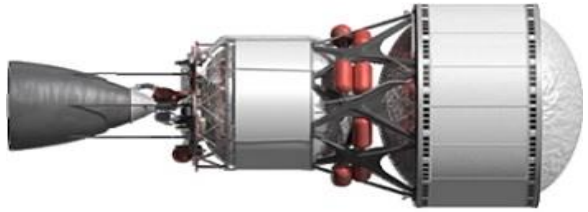
Transmission of Johnoson-Cousin Filters installed on AGO 70. Source: Cloudbreak optics (2019)

Objects of interest

- all non-functional, human-made objects, including fragments and elements thereof, in Earth orbit or re-entering into Earth's atmosphere (ESA definition)



Upper stage Falcon 9



Upper stage Delta

Upper stages Breeze-m

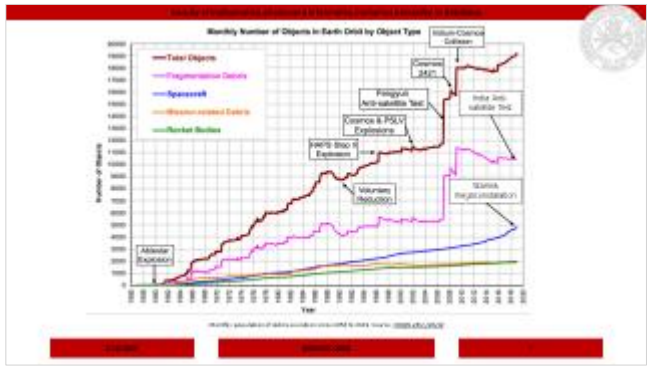
Molniya sattelite

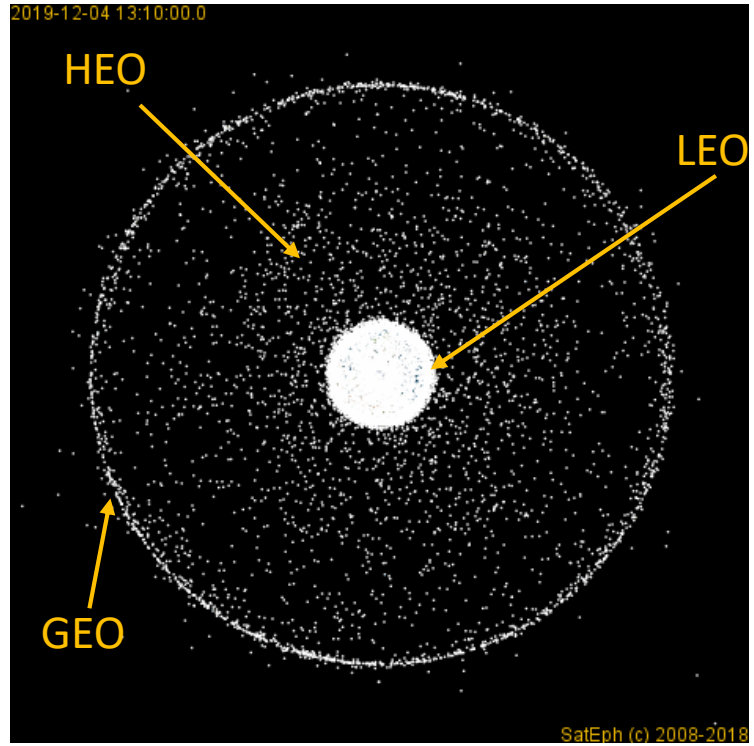
Astra sattelites

Al_2O_3

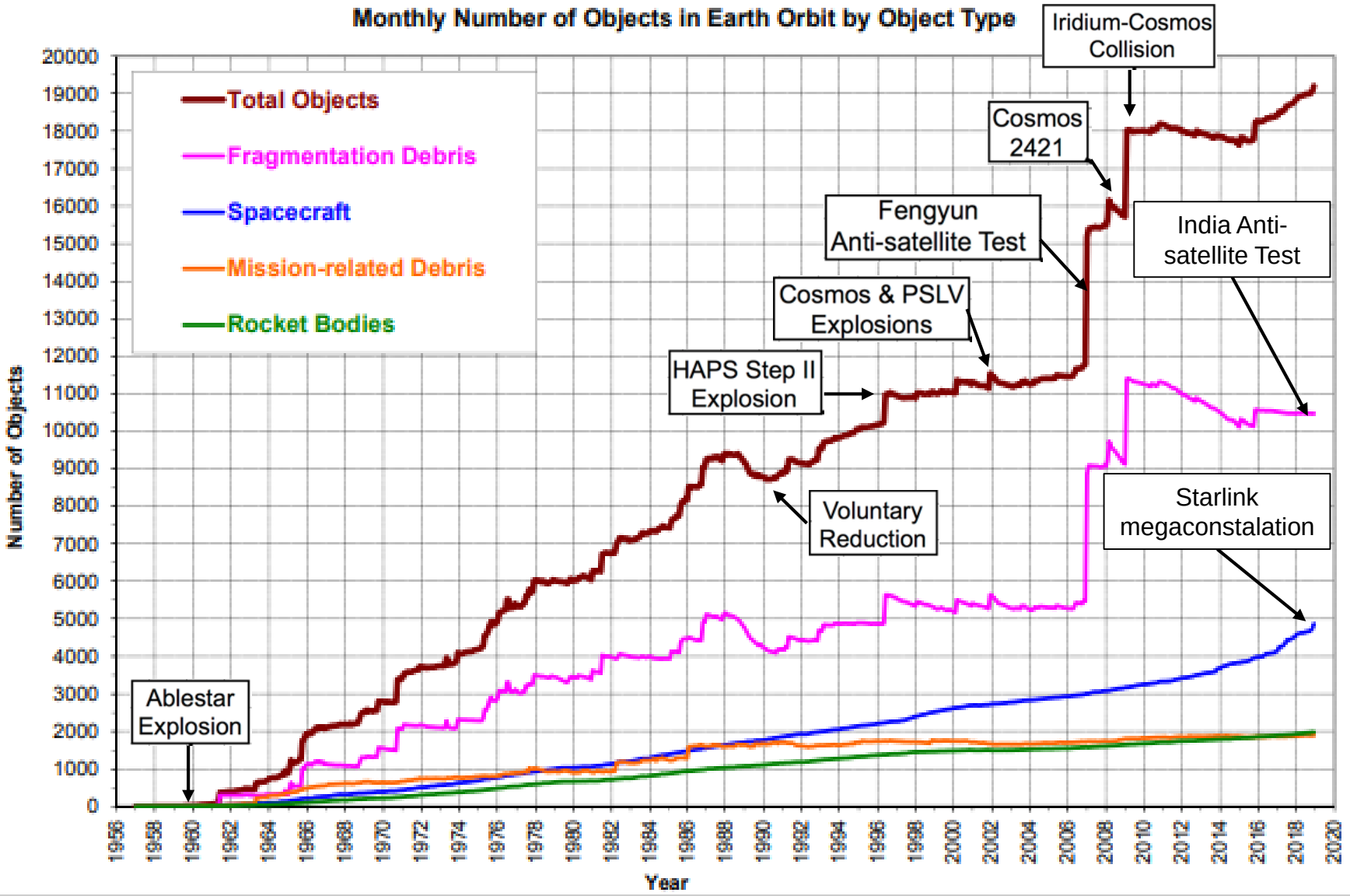
Motivation of space debris research

- Increasing population of fragments on all orbits (LEO, HEO, GEO)
- Planning active debris removal missions
- Safety of new released missions
- Early warning systems for existing satellites
- Object's identification and characterization
- Looking up for its ancestry





Actual motion of 18399 space debris objects on orbits. Source: SatEph



Monthly population of debris evolution since 1956 to 2019. Source: *ODQN 23i1 (2019)*

AGO 70

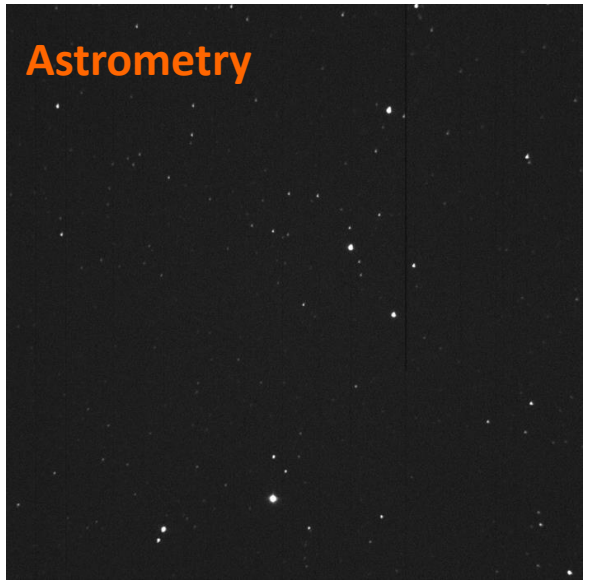
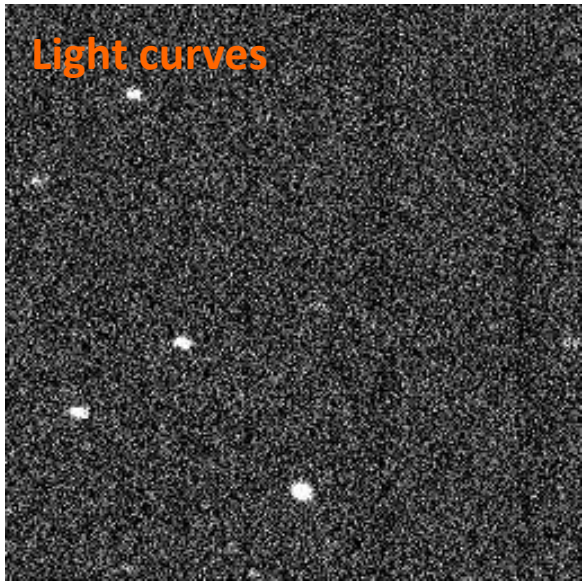


Figure – Images acquired by AGO 70cm telescope. Astrometric observations of satellite IRNSS-1A (13034A). Other four GEO satellites crossing the FOV. Used exposure time of 0.2 s.



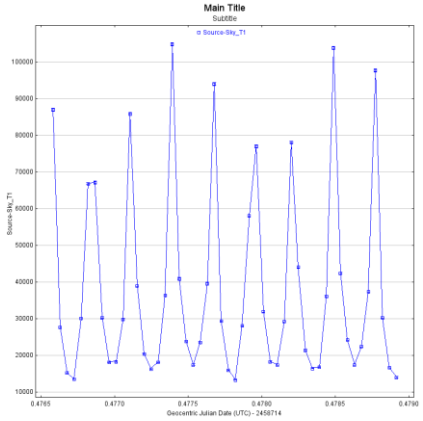


Figure – Object Falcon 9 (19009C) acquired by the AGO 70cm telescope (left) and its constructed light curve from AIJ(right).

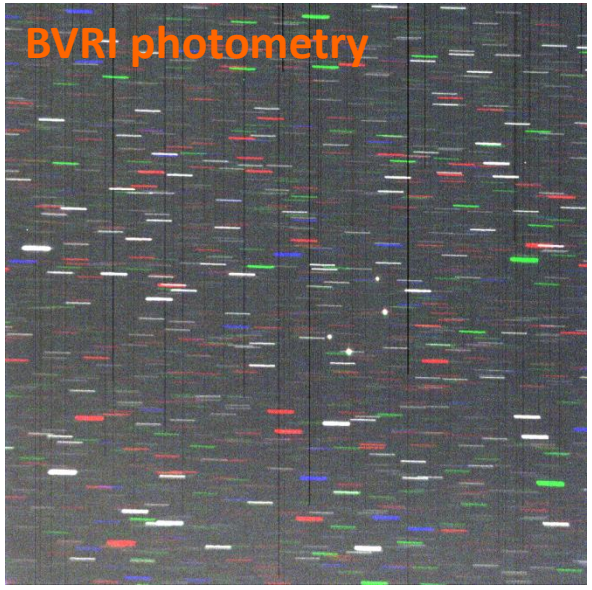


Figure – RVI images acquired by AGO 70cm telescope. Color photometry observations of ASTRA Cluster. Used exposure time of 5.0 s.

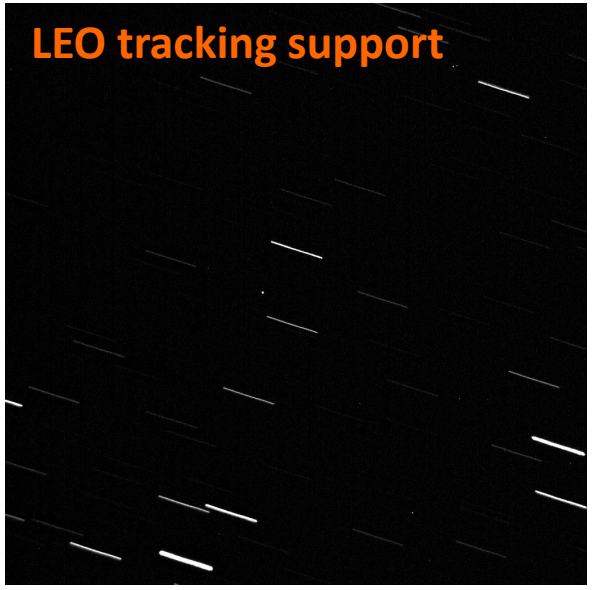
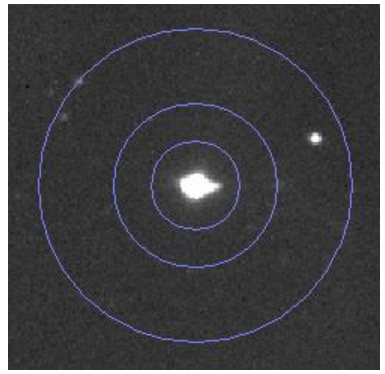


Figure – SL-12 R/B(2) (02037D) observed by AGO 70cm. Compilation of 9 frames, exp = 0.1s, filter I.

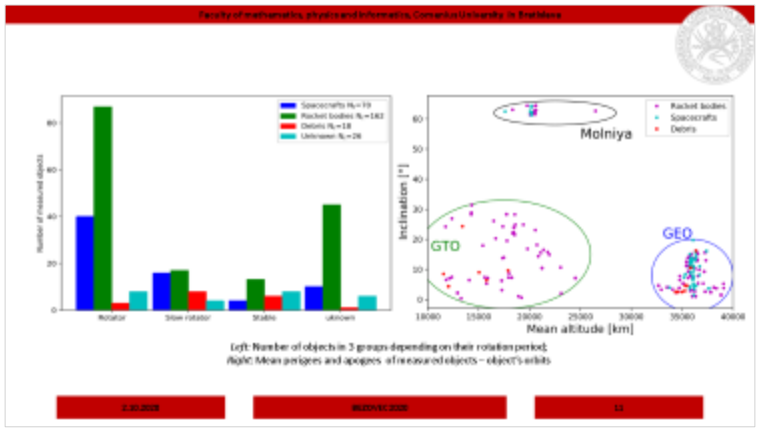
Instrumental photometry

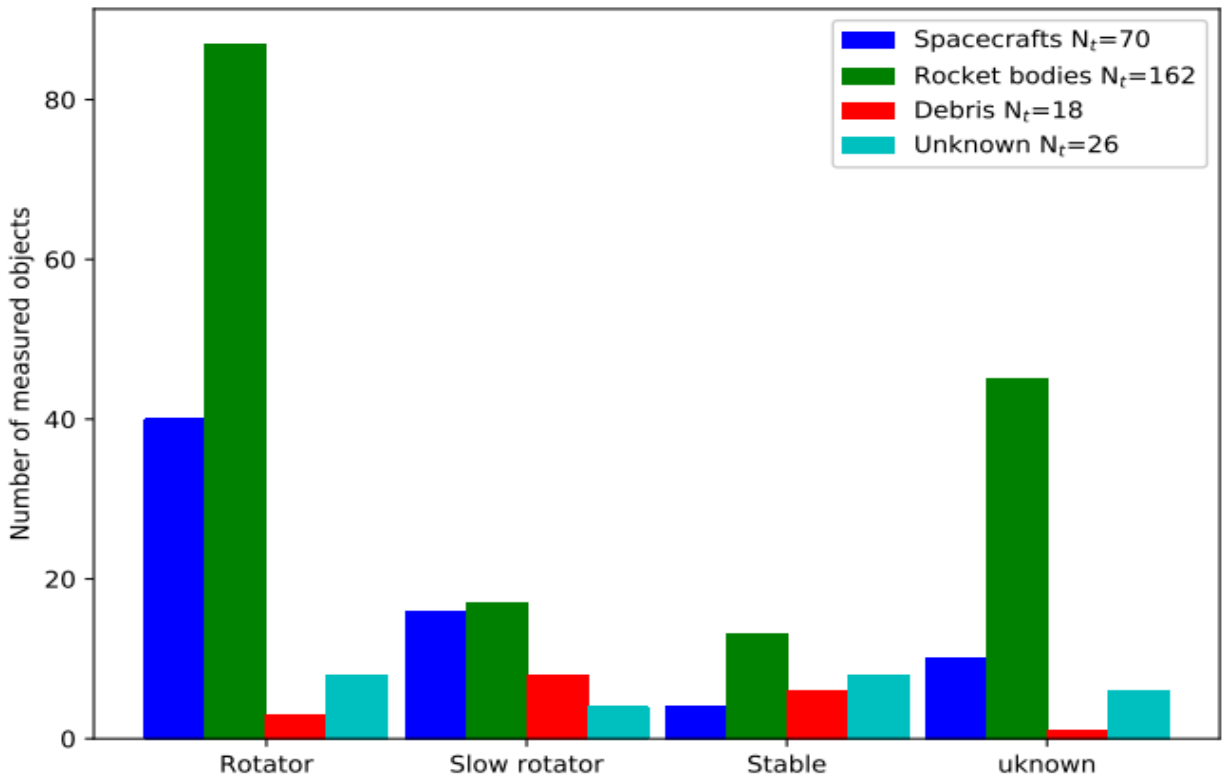
FMPI's Light Curve Catalog

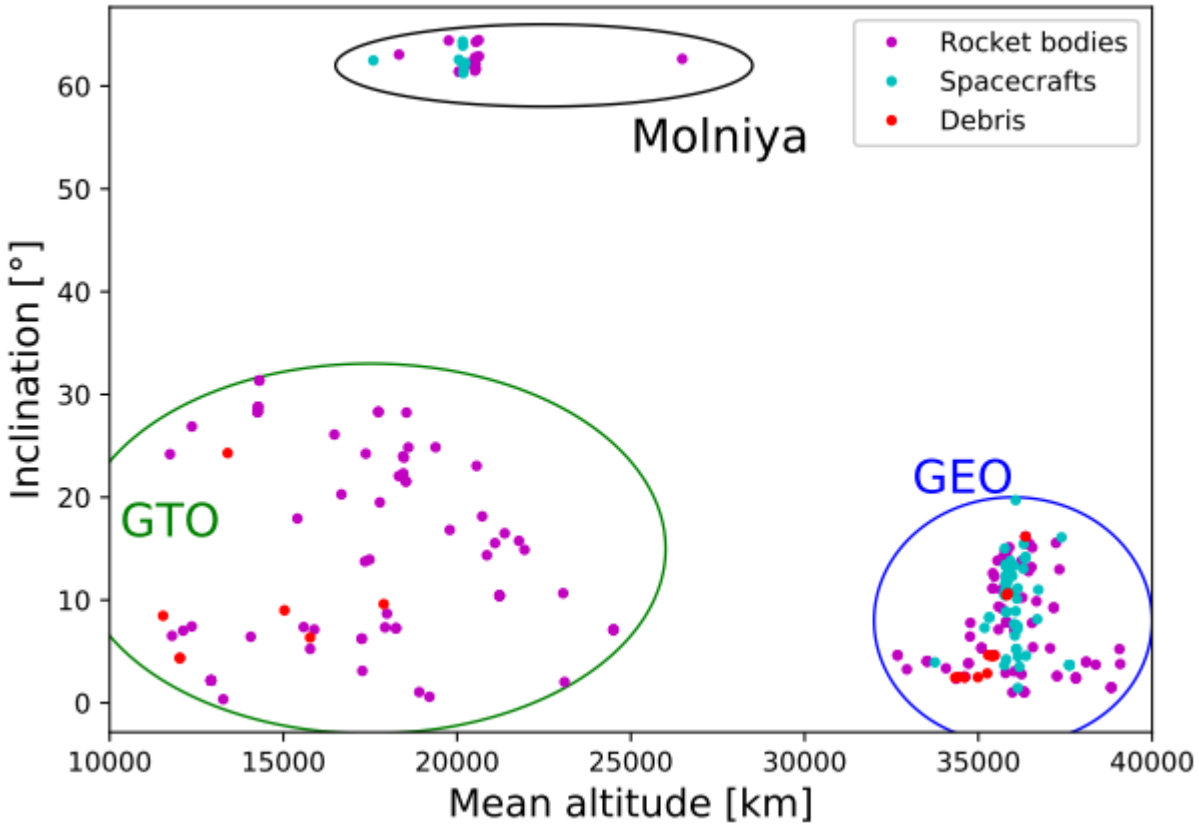
- Aperture photometry program
- Instrumental intensity– acquired using the AstroImageJ (AIJ)
- Light curves – time dependence of intensity
  - Light curve processing (Hamara dissertation thesis, (2017))
    - Apparent rotation periods – FFT and Lomb Scargle method (Feigelson and Babu, 2017)
    - Phase function – "Phase Dispersion Minimization (PDM)" (Stellingwerf ,1978)
  - Internal database of light curves and phase functions
    - 285 light curves of 226 objects up to the end of March 2019 (Šilha et al., 2020)
- Target selection
  - Any visible object – altitude > 30 deg
  - Building up the catalog for next research



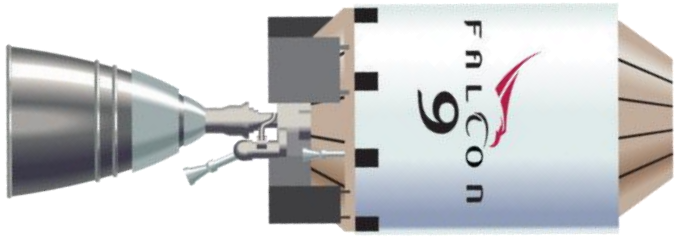
Ilustrative screenshot of AIJ aperture







Left: Number of objects in 3 groups depending on their rotation period*;*
Right: Mean perigees and apogees of measured objects – object's orbits

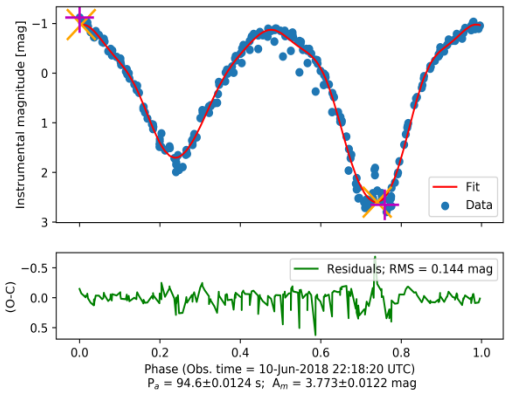


Falcon-9 stage 2. Source: VENGAGE

2017-063B

17063B	94.6	10-Jun-2018 22:18:20	Details	
17063B	94.7	11-Jun-2018 20:40:25	Details	

17063B_2_3_4_R_20180610



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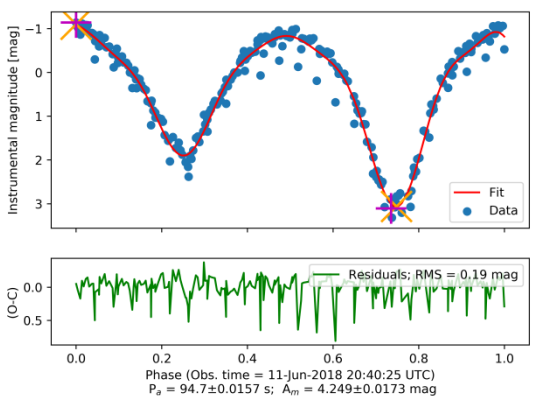
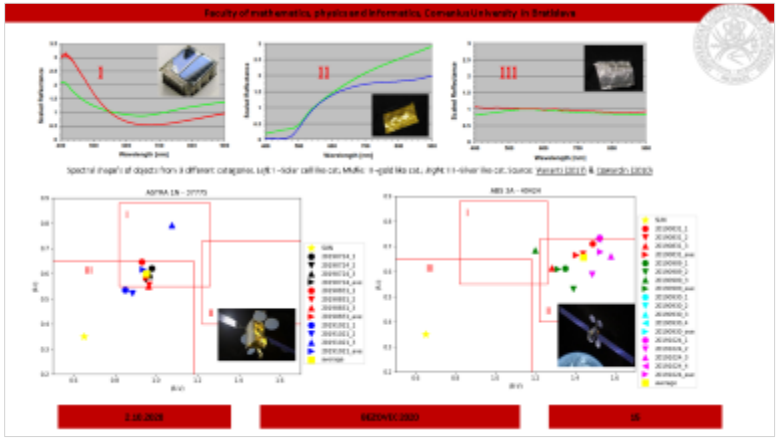


Object name:	FALCON 9 R/B	**Source**	LC
COSPAR:	17063B	**Period [sec]:**	94.6
Object type:	rocket body	**Period error [sec]:**	0.012393
NORAD:	42968	**Amplitude [mag]:**	3.773
Orbital period:	619.40	**Amp. error [mag]:**	0.01225
Inclination [deg]:	28.29	**Number of points:**	277
Perigee [km]:	205	**Exposure [sec]:**	1.0996
Apogee [km]:	35179	**Mean samp. [sec]:**	4.6659
Decayed:	false	**Filter:**	R

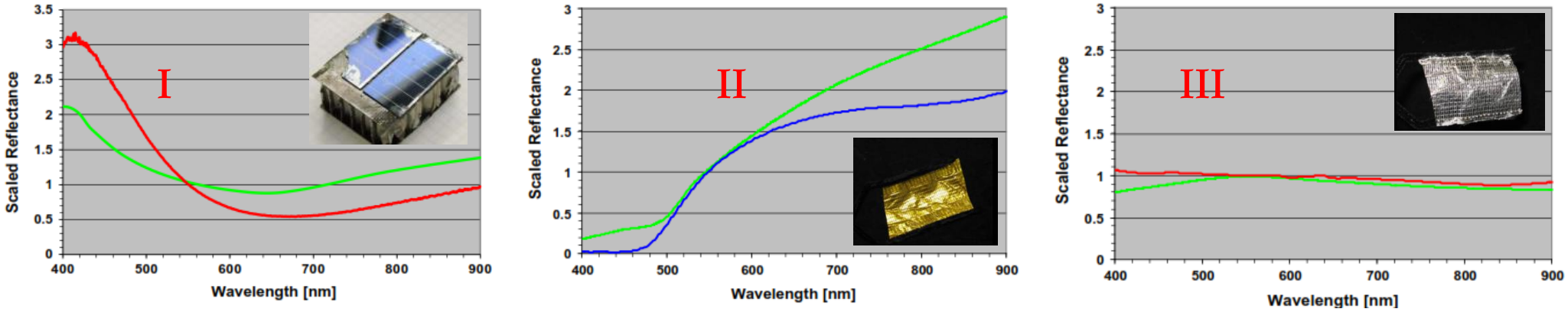
Report of Falcon's 9 rocket body from FMPI's internal catalog. Source: Screen shot of Screenshot of public catalogue (Silha et al., 2020)

BVRI photometry

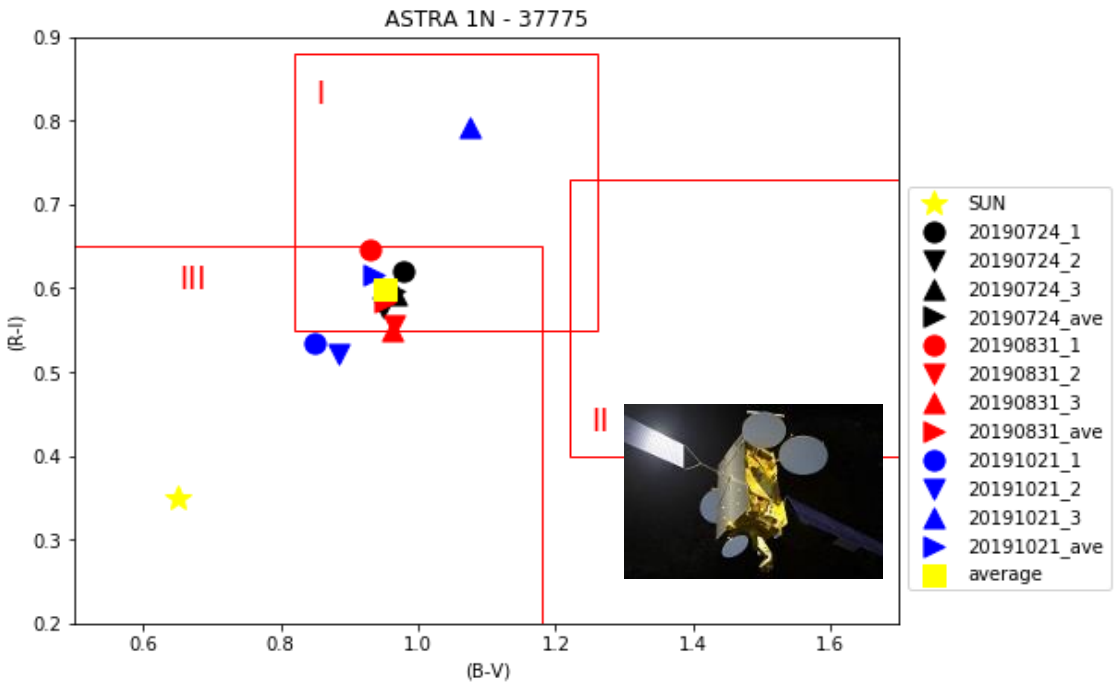
BVRI photometry

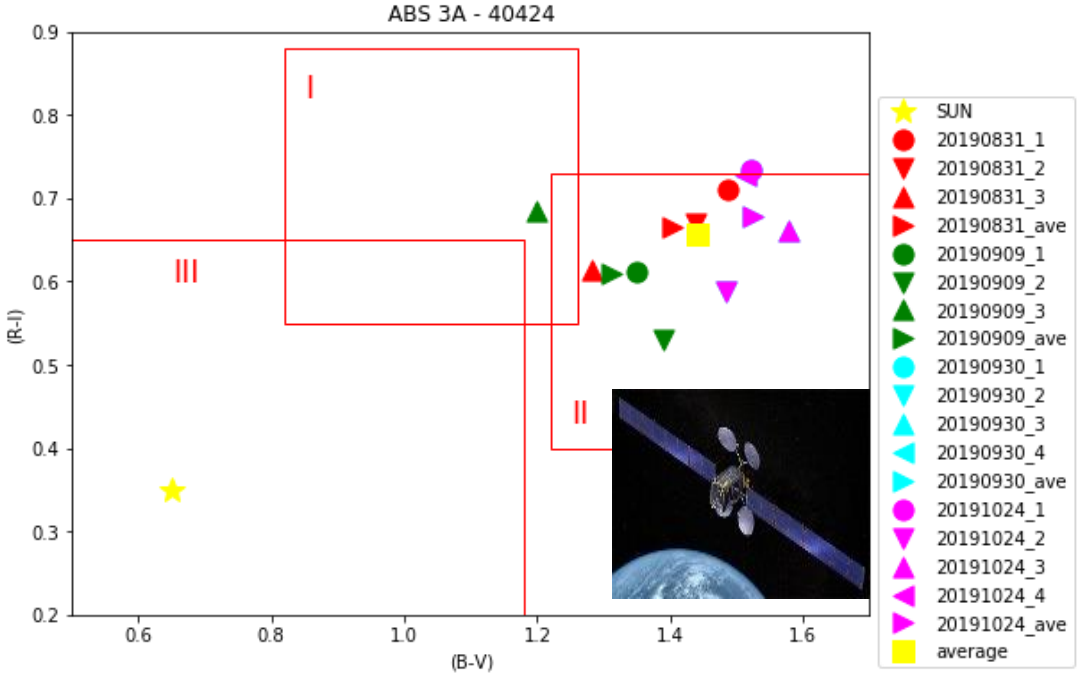


- Absolute photometry in BVRI filters
  - Instrumental intensity transformed to standard system of magnitudes
  - Transformation using standard stars
  - Requires good weather conditions and high source SNR(≈ 40)
- Color index – numerical expression of object‘s color
  - Depends on phase angle
  - Difference of brightness in two filters - B-V, V-R, R-I, V-I,
  - Detected color index depends on object’s surface properties
  - Sorting objects into 3 groups according to shape of spectra (Vananti (2017))
    - I - relatively flat with possible negative slope in blue range – solar cell similarities
    - II - monotonic increasing with concave up shape– gold similarities
    - III- monotonic increasing with concave down shape – silver similarities
  - Aging of objects and spaceweathering effects



Spectral shape's of objects from 3 different categories. *Left:* I –Solar cell like cat; *Midlle:* II –gold like cat.; *Right:* III –Silver like cat. Source: Vananti (2017) & Cowardin (2010)



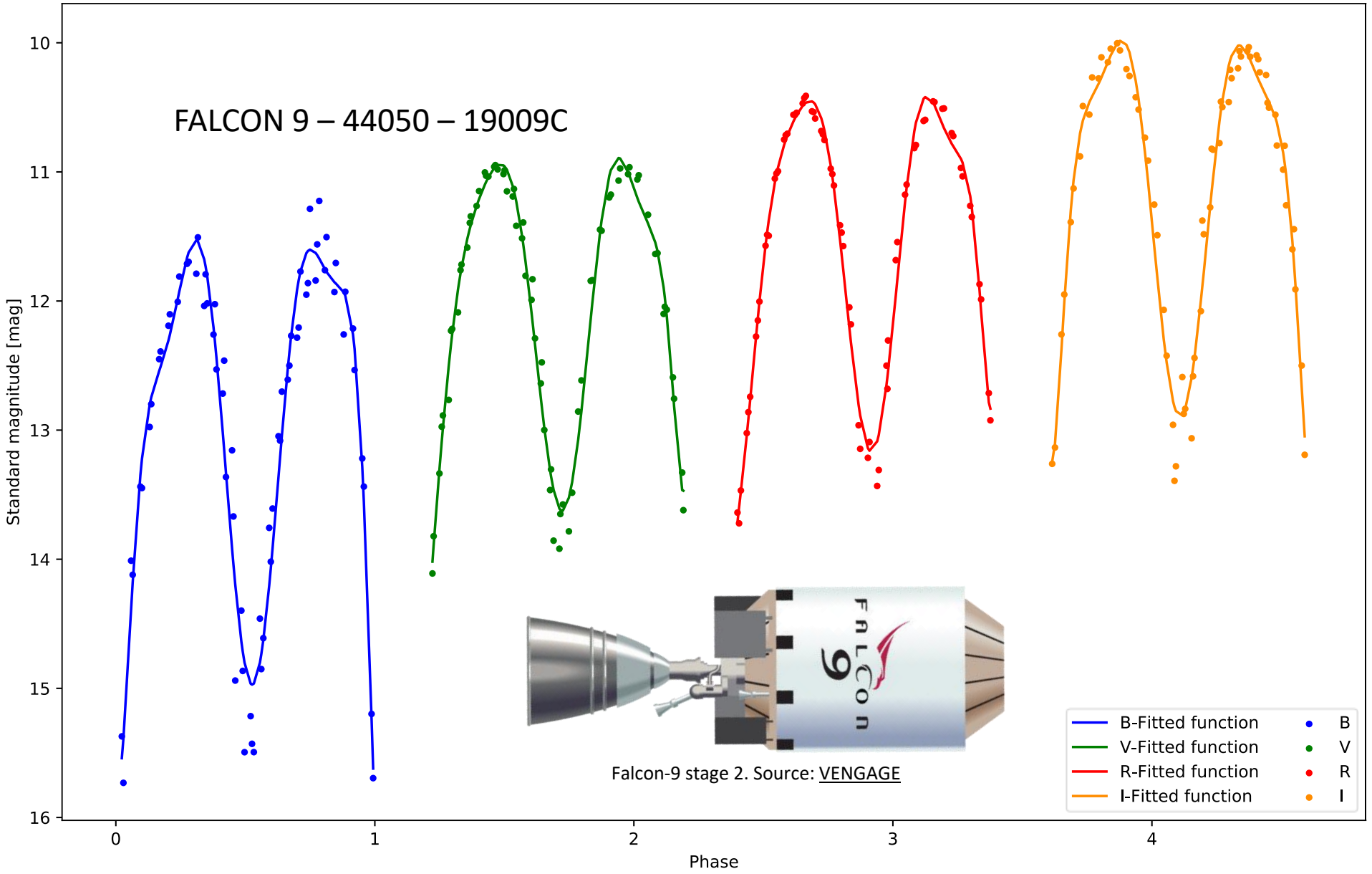


Phase dependence of the color indices

- From pre-processed data is extracted the light curves in each passband
- Phase is reconstructed using the *LCprocessing.m* (Hamara, 2017) simultaneously for each filter
- Estimated period is used for phase construction using formula $t_{phase} = \frac{t-t_0}{P} - \left[\frac{t-t_0}{P}\right]$
- The phase functions are then optimized using the Fourier series of 8th degree

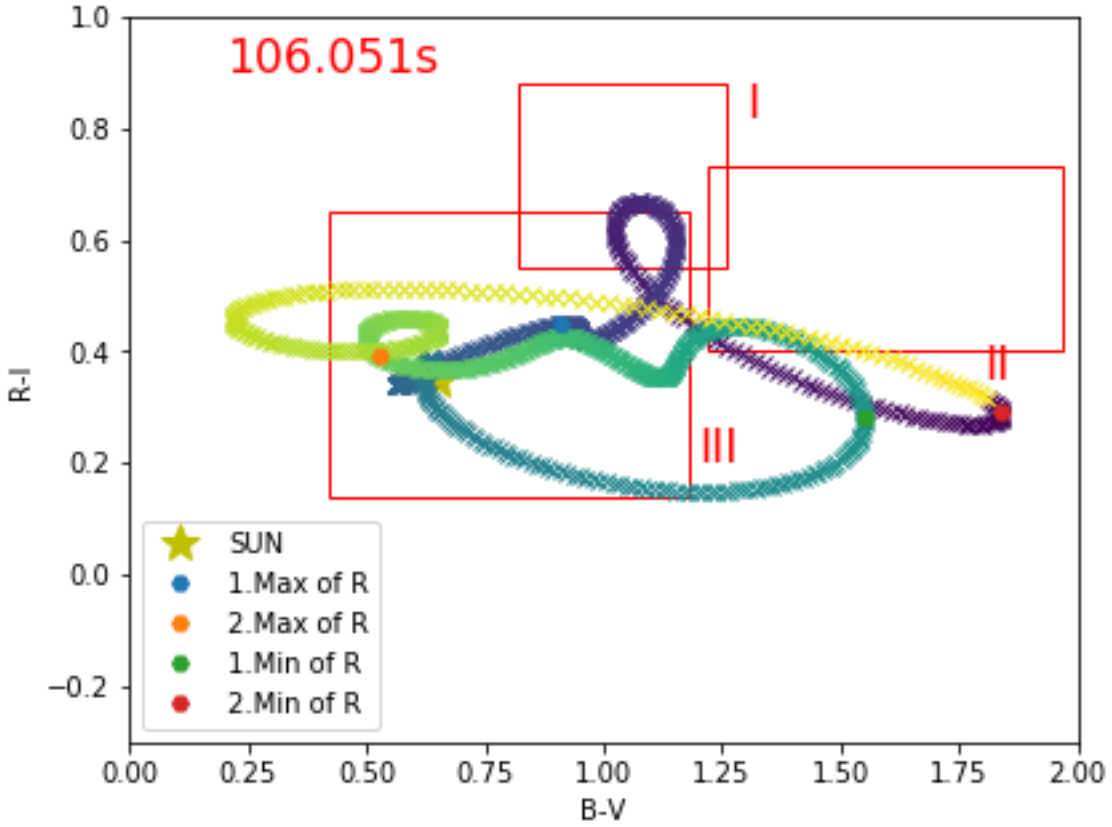
$$m = a_0 + \sum_{i=1}^{8} [a_i \cdot \cos(i \cdot t_{phase}) + b_i \cdot \sin(i \cdot t_{phase})]$$

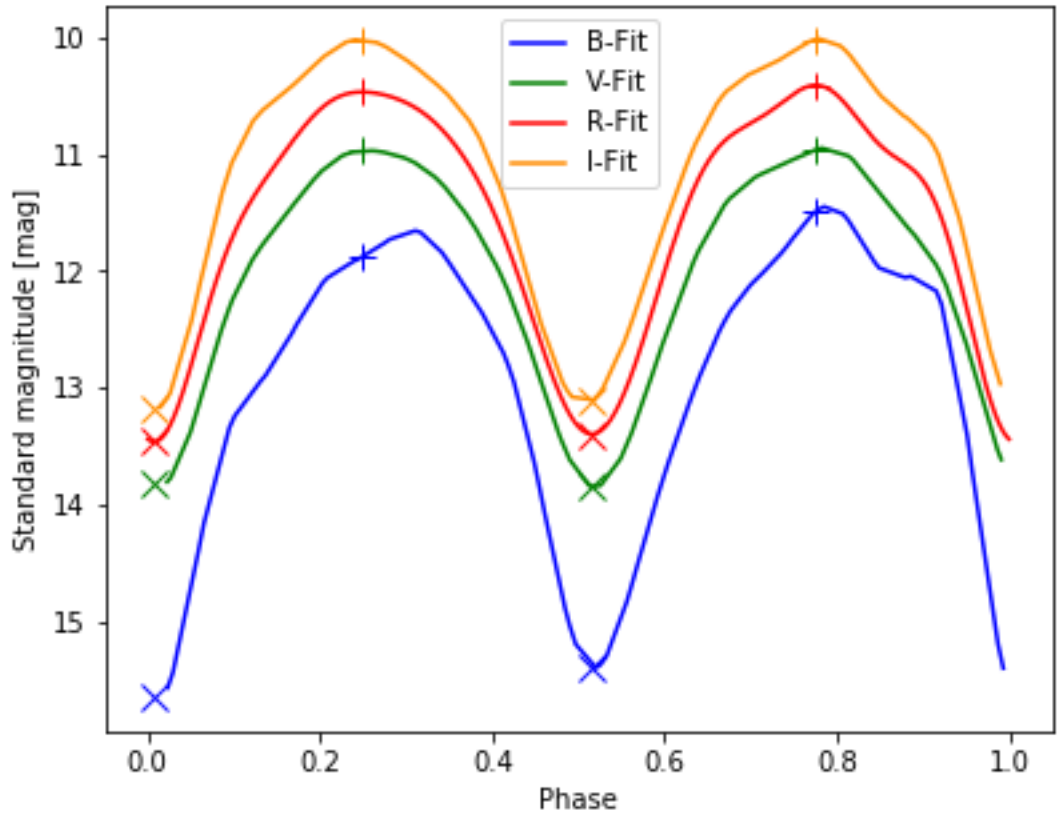
- Where a_i, b_i are free parameters, which are optimized
- Fourier fit is inspired by the dissertation thesis (Világi,2007)
- Then the phase is soften and color indices along the phase are calculated



Falcon-9 stage 2. Source: VENGAGE

BVRI diagram of the Max/Min of R filter - object 44050_5





Development

Low-Earth orbit object tracking

- New telescope control unit developed by FMFI
- Polar and declination axis are operated separately
- Maximum tracking speed for both axis is around 5400 arcsec/sec
- Sensor able to monitor all objects higher than 800km
  - Space debris (range > 800 km);
  - Near-Earth objects;
  - Close-Encounters (e.g. NEA with range < 0.1 Lunar Distance km);

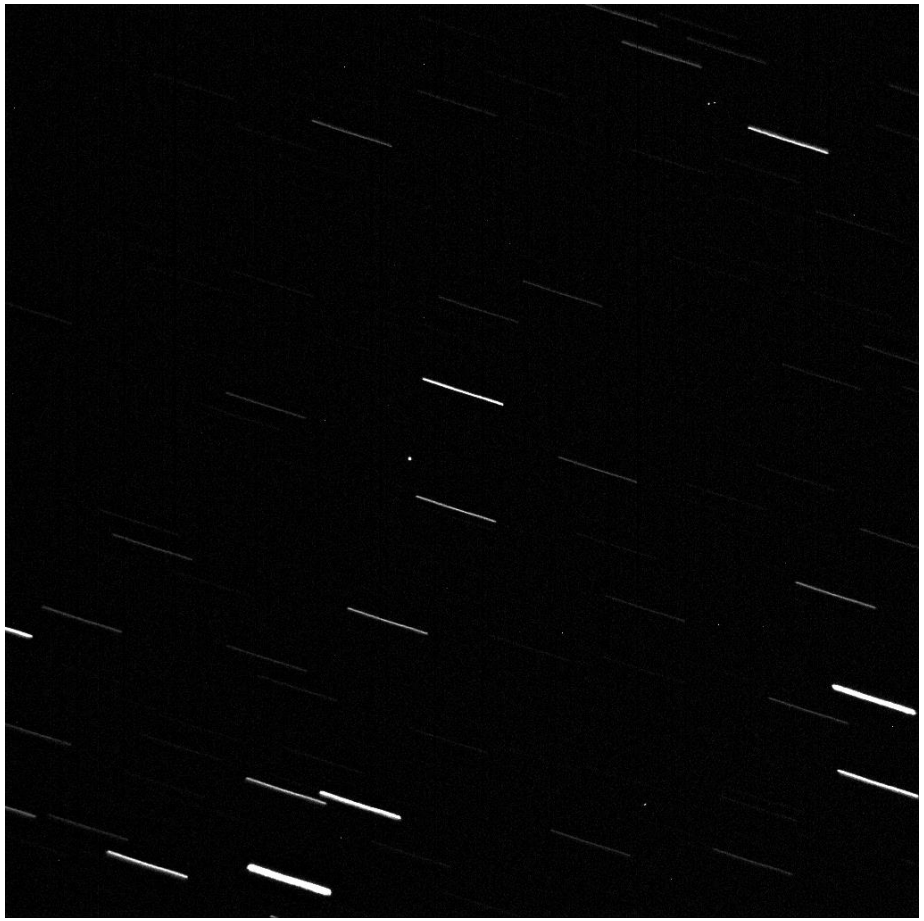
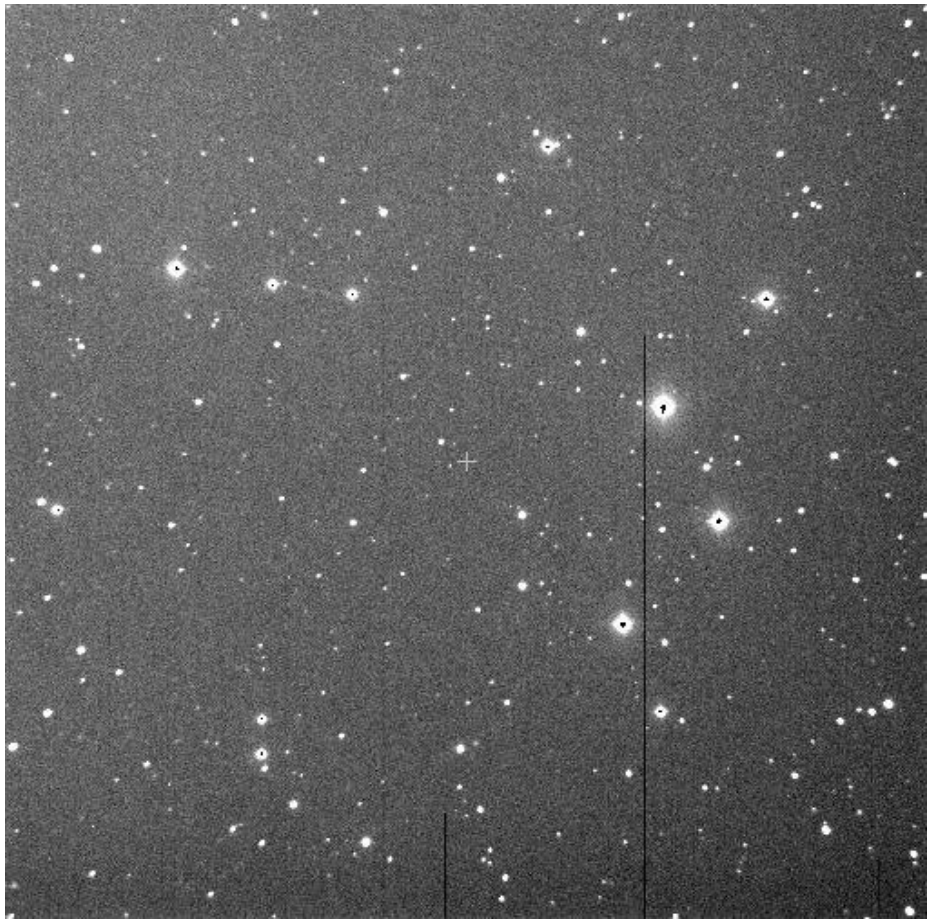
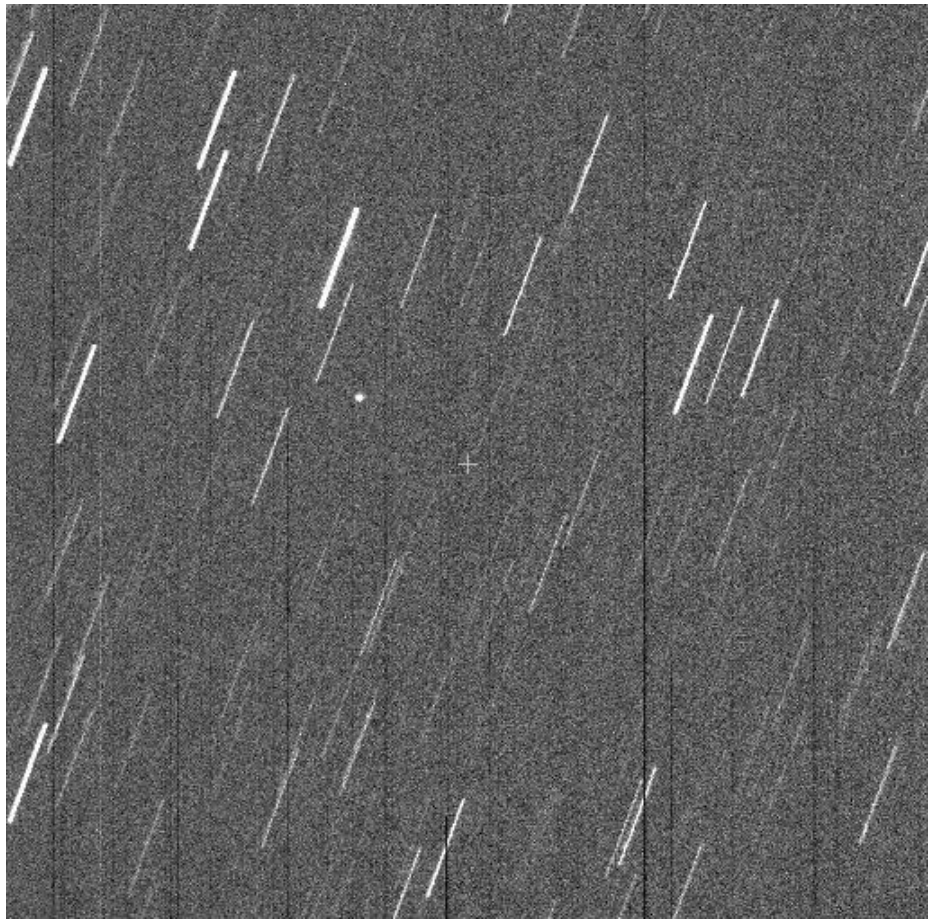


Image processing system

Sidereal tracking



Object tracking



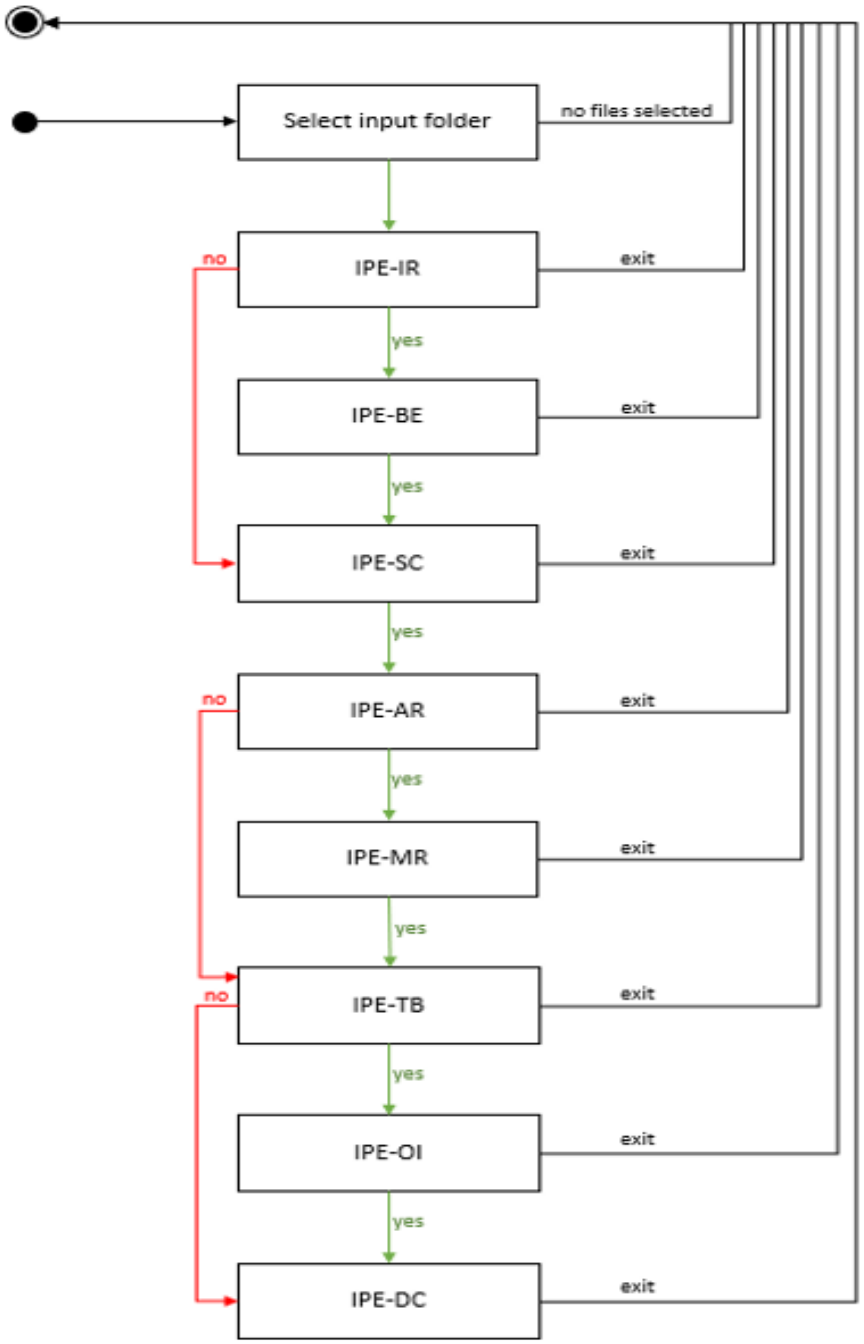


Image processing system

- Modular image processing system
- Each component can be run separately
- Motivation: fast processing of raw images to object's tracklet for TLE improvement
- IPS contains:
  - Casual image calibration
  - Background extraction
  - Search and Centroiding
  - Astrometric reduction
  - Masking
  - Tracklet building
  - Object identification
  - Data conversion

Conclusion

- We presented the current state of the 70-centimeter telescope at AGO
- Instrumental photometry – processing, light curve database
- BVRI photometry – long-term monitoring of average color index, phase dependency of the color index
- Further development of object tracking and image processing system
- An observational campaign has started for calibration and validation of the sensor

Thank you for attention !

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