Use of a Night-Tracking during Daytime

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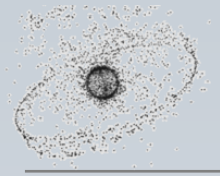
ILRS Technical Workshop
21-25 October 2019
Suttgart, Germany

AIUB



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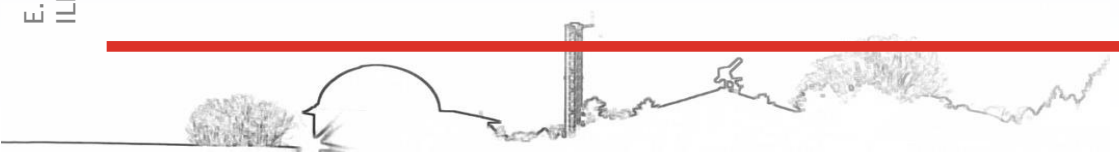
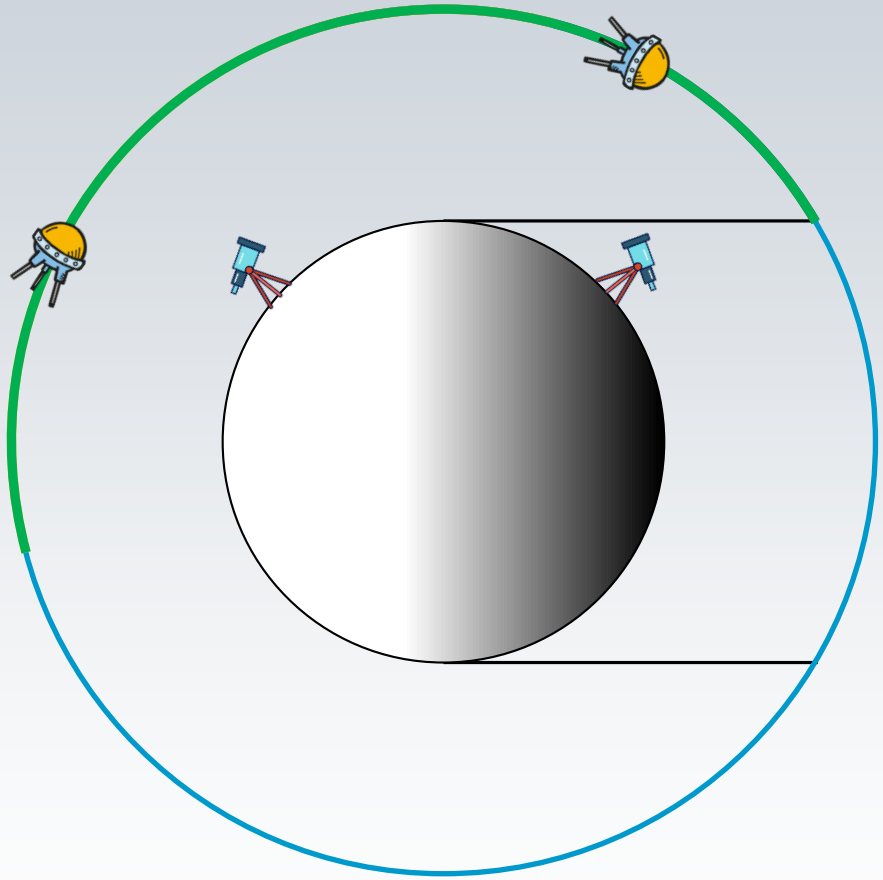


1st Motivation: Orbit Determination

Space Debris Tracking Case:

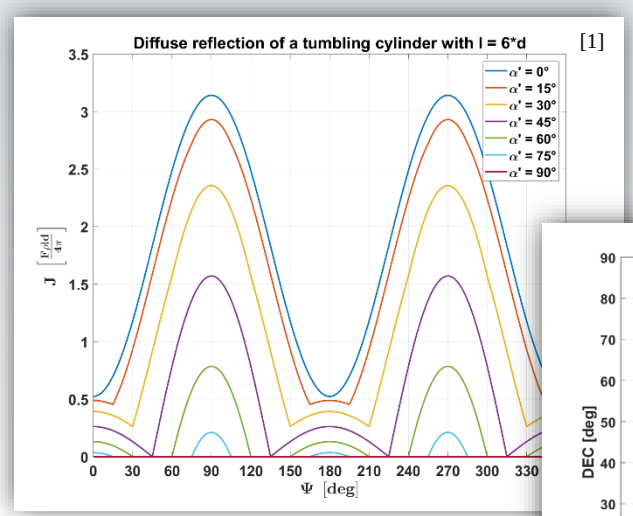
- 1 Single observatory
  - Only SLR
  - Only Optical
  - Both (even better)
- Usual case:
  - Observer in Earth shadow
  - Illuminated target
  - Observable Portion of Orbit
- Daytime observation
  - Observer and target in Sunlight
  - Observable Portion of Orbit
- Extended observation scenario (both night- and daytime)
  - Increased observable portion of orbit!!!
    ⇨ Increase of orbit determination accuracy!!!



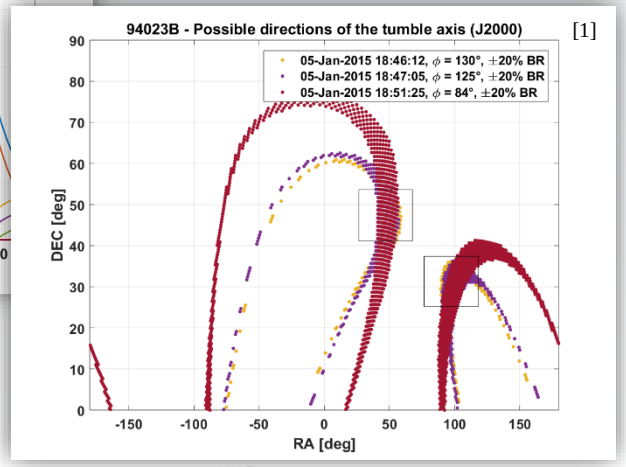
2nd Motivation: Attitude Determination

Space Debris Attitude determination from light curves:

- Object Spin: stable into the inertial system
- Light curve features depend on illumination condition (α')
- Successful attitude determination
  - Enough observation geometry variation
  - Short time difference between observation series (for MEO and GEO, ok! And for LEO?)



[1]



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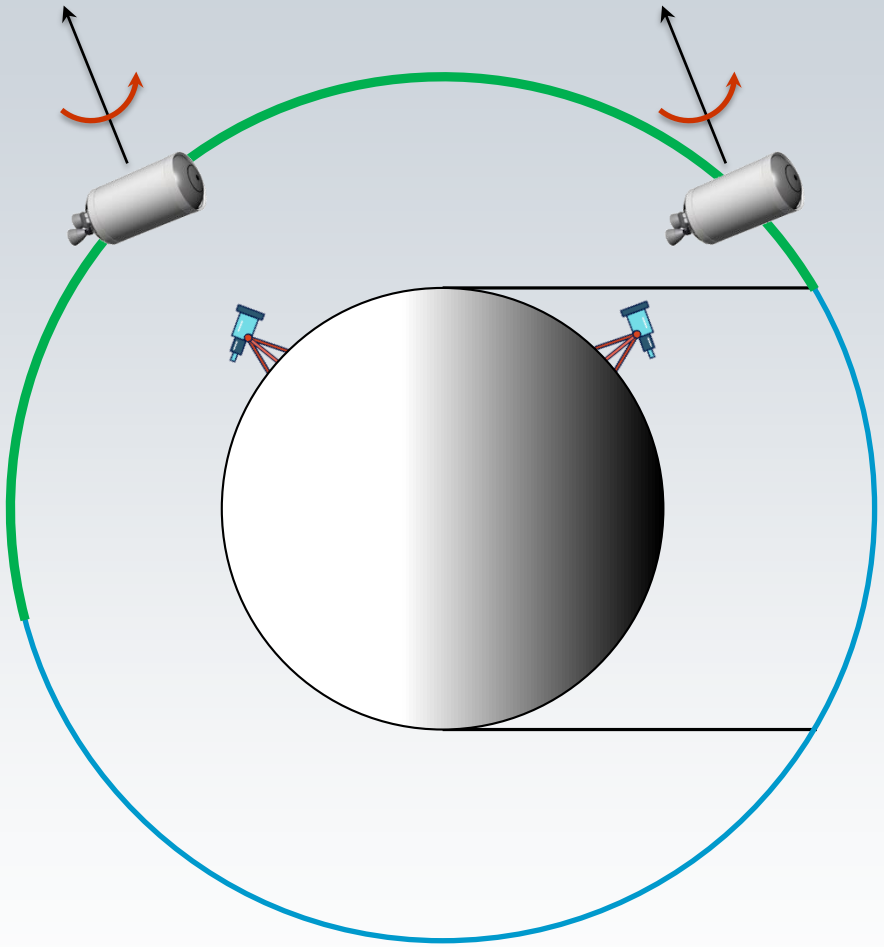


[1] Köller P., Attitude Determination of cylindrical Rocket Bodies from Optical Light Curves. Astronomical Institute University of Bern, University of Bern, 5 May 2016, Bern, Switzerland.

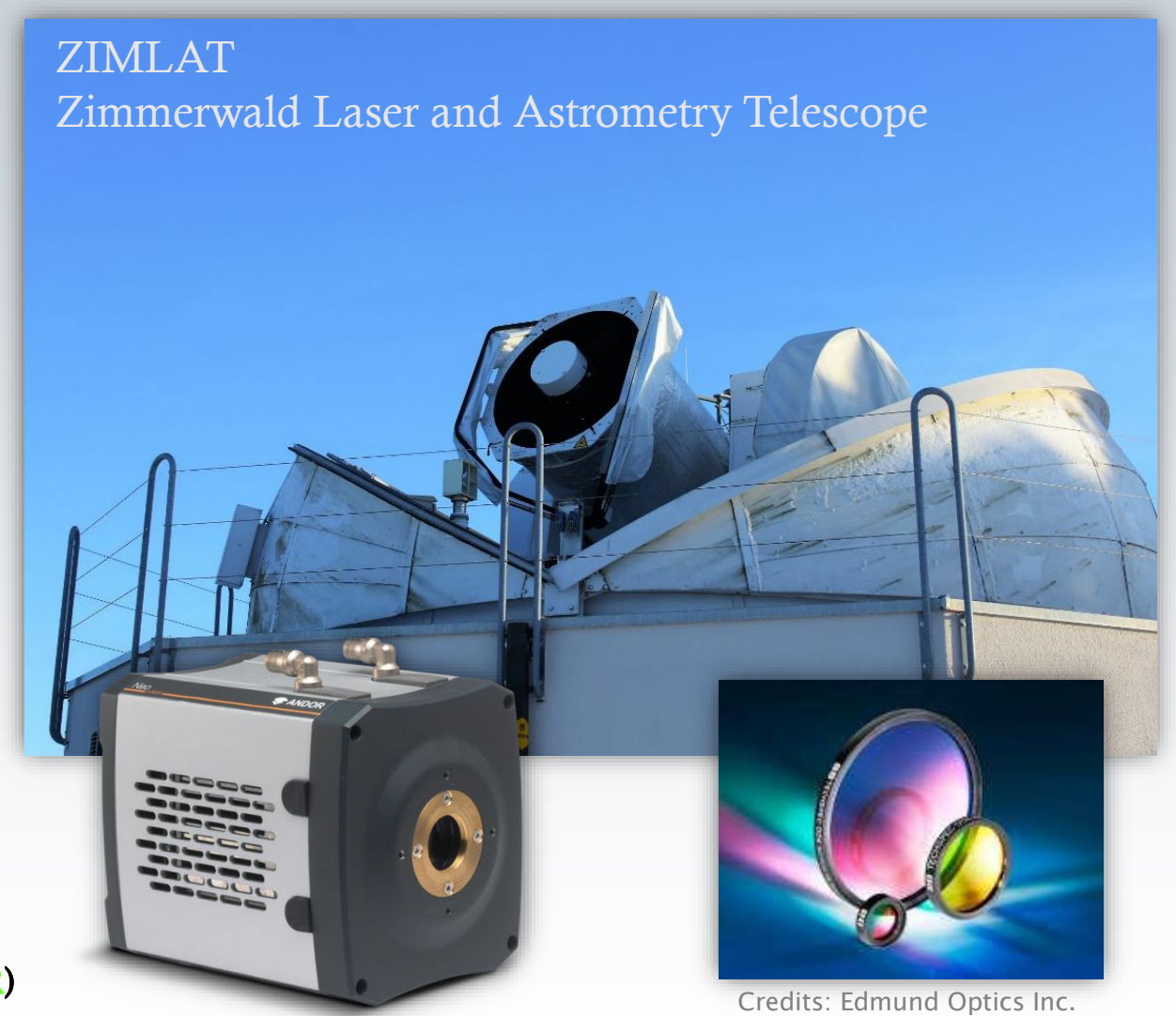
What do we use…

Tracking Camera Hardware

- **Telescope: ZIMLAT**
  - 1-m Aperture Ritchey-Crétien
  - Coudé focus for Laser
  - Nasmyth Focus for tracking and CCD cameras (available focal lengths: 1.2m, 2x4m, 8m)

- **Camera: Neo 5.5 sCMOS**
  - 1 e- read noise
  - TE cooling to -40° C
  - 5.5 megapixel sensor, 6.5 µm pixels
  - 22 mm diagonal field of view
  - Rolling and Global Shutter
  - Rapid frame rates
    - 30 fps over extended kinetic series
    - Burst to memory at 100 fps full frame

- **Filters**
  - 532nm, 25mm Dia., OD 6 Blocking Notch Filter (SLR)
  - 500nm, 25mm Dia., OD 4 Longpass Filter (Sky)



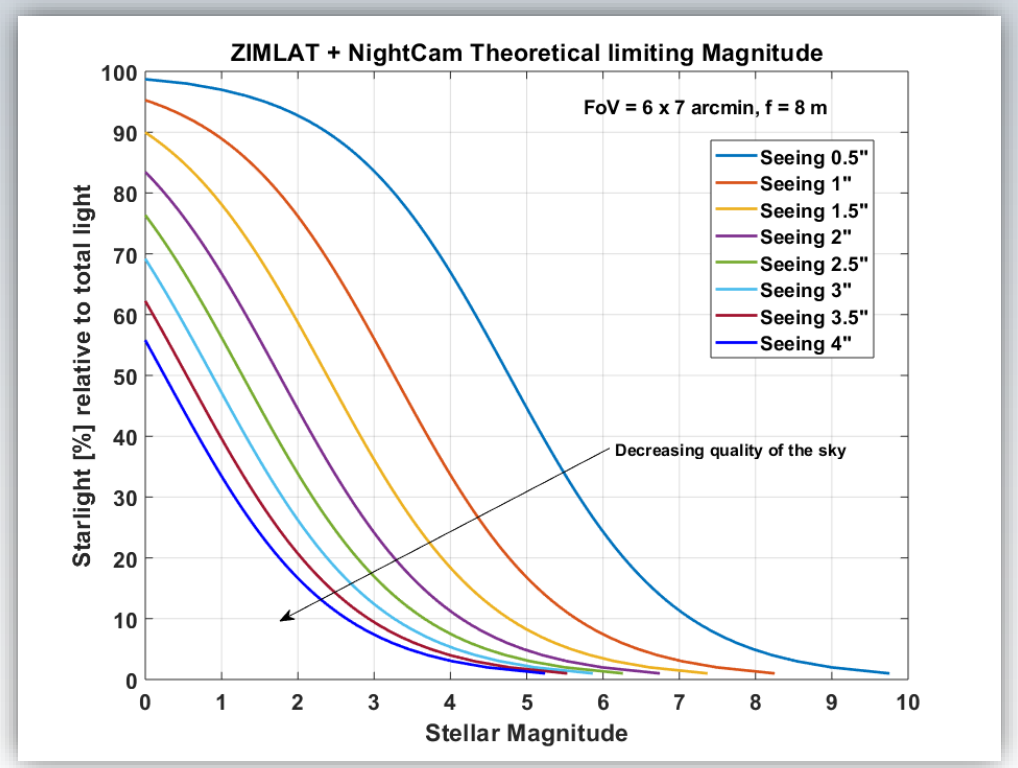
Credits: Oxford Instruments 2018

Credits: Edmund Optics Inc.

Daytime Limiting Magnitude

Factors influencing the limiting magnitude

- Sky background brightness (~3 Mag [1])
  - Distance from Sun
  - Distance from Zenith
- Astronomical Seeing
  (Zimmerwald <2 arcsec night-time)
  - Humidity
  - Extinction
  - Temperature
  - Turbulences
- Focal length = 8 m, sensor diagonal = 22 mm
  - Pixel scale = 0.17 arcsec (0.0289 arcsec²)
  - FoV = 6 x 7 arcmin
  - Affect the Signal to Noise Ratio of the observed object

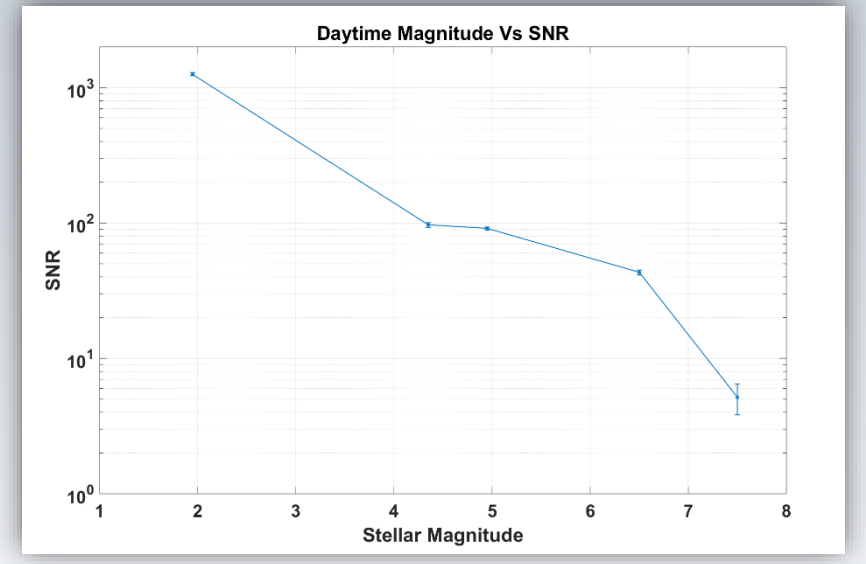


[1] Steindorfer M., Kirchner G., Koidl F., Wang P., Kucharski D.. Recent Space Debris Related Activities at the SLR Station Graz. 1st NEO and Space Debris conference, 22-24 January 2019, Darmstadt, Germany.

First Observations – Daytime Limiting Magnitude

Stars daytime observations

- Observations possible up to Magnitude 7
- Strong brightness gradient in the sky due to:
  - Distance from the Sun
  - Elevation
  - Weather conditions



First Results – Satellite Observations

Daytime satellite tracking

- Telescope: ZIMLAT
- Target: PAZ
- Altitude: 507–510 km
- Exposure time: 0.1 seconds

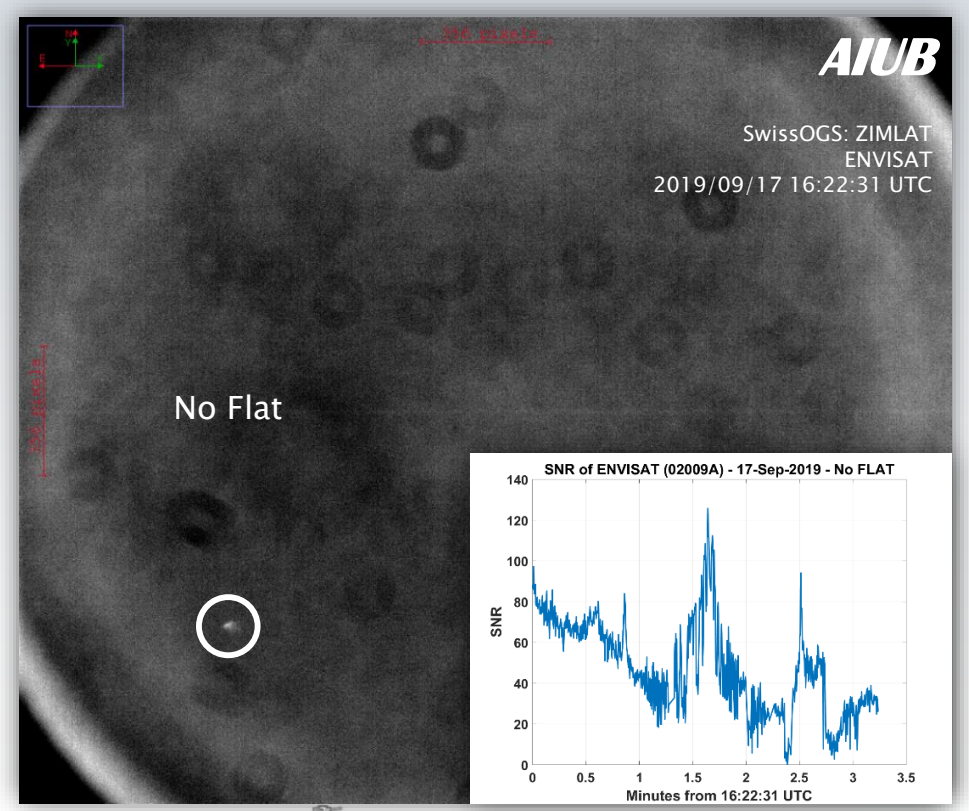
Interesting outcomes

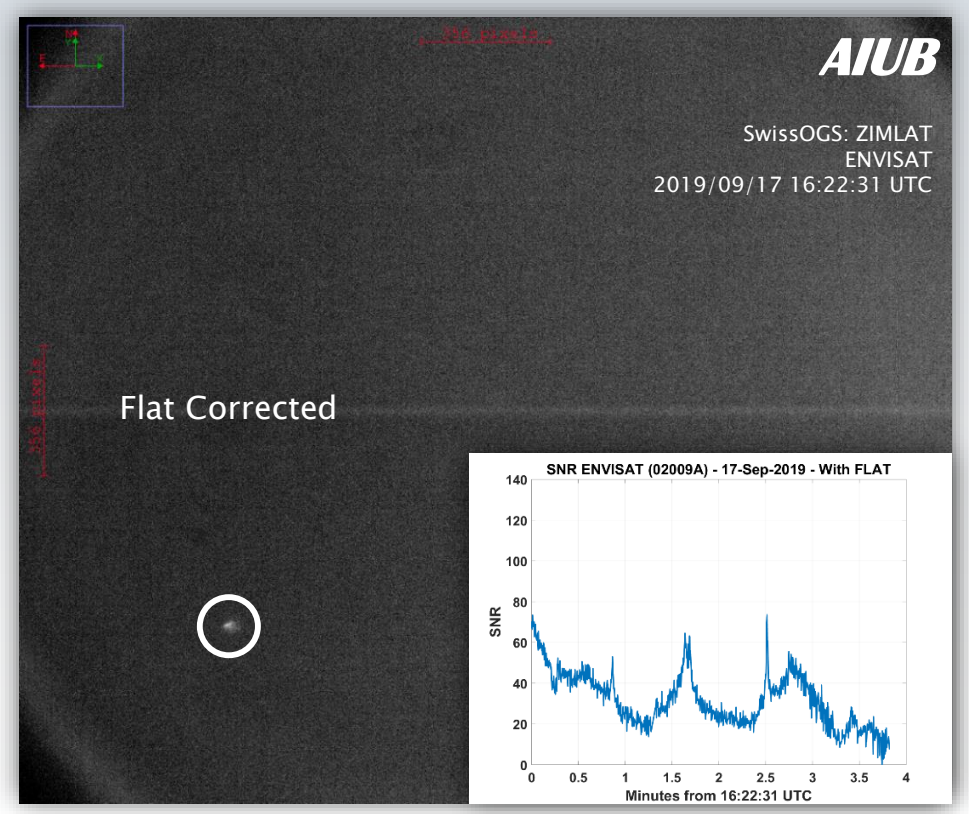
- Speckles and seeing effects on the object
- Increase of sky brightness over 1.5 minutes
- Influence of object elevation and distance from the observer

Improving Performances

Flat field Correction:

- Reduces SNR
- Reduces background noise
- Improves object detectability



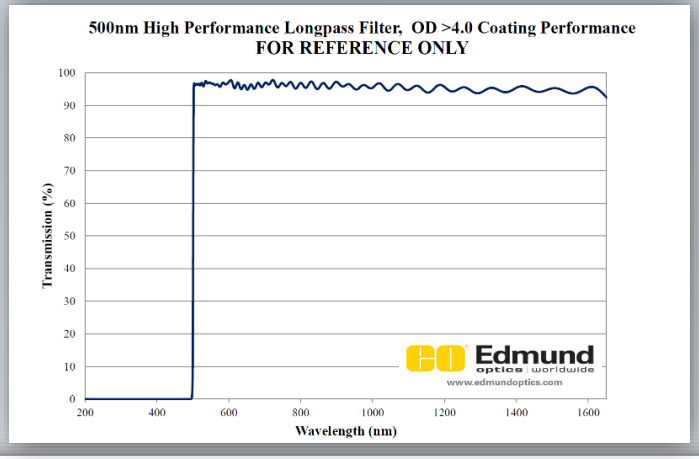


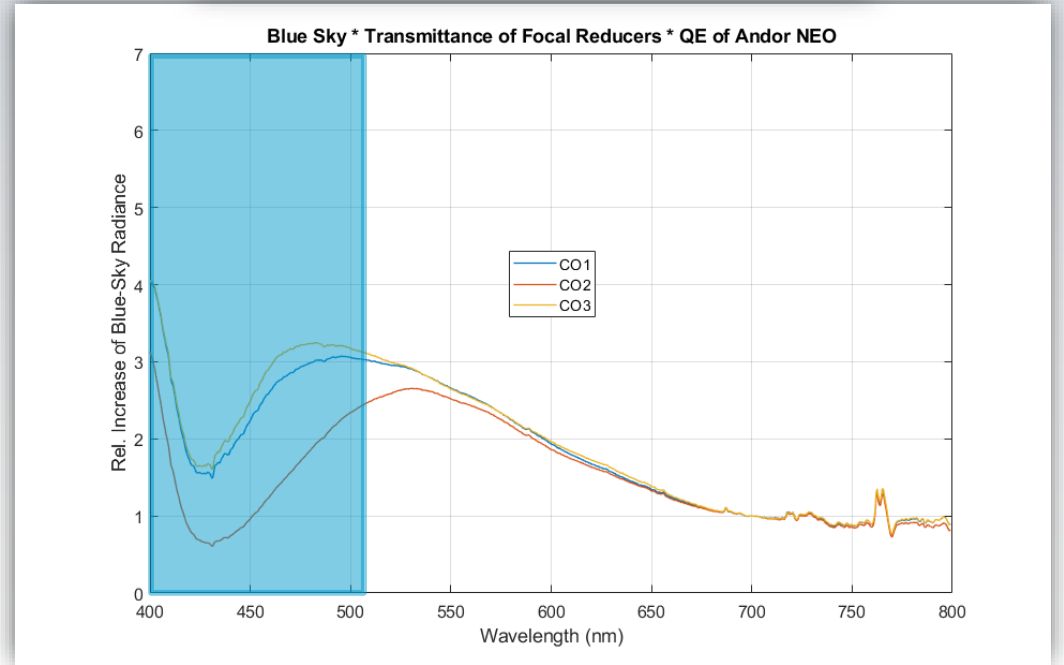
Improving Performances

Removing daytime sky contribution

- Measured the sky spectrum
- Accounting for transmittancy of focal reducers
- Accounting of Camera Quantum Efficiency
- Longpass edge filter selection (Sky Filter)

	Without Sky filter	With Sky filter
Exp time	0.05	0.05
Star Magnitude	1.95	1.95
SNR	803.05 ± 47.42	818.20 ± 19.46
Sky (ADU)	34213.16 ± 6.52	21045.41 ± 4.35





Improvement of Sky filter (500 nm)

⇨ +1.88% SNR

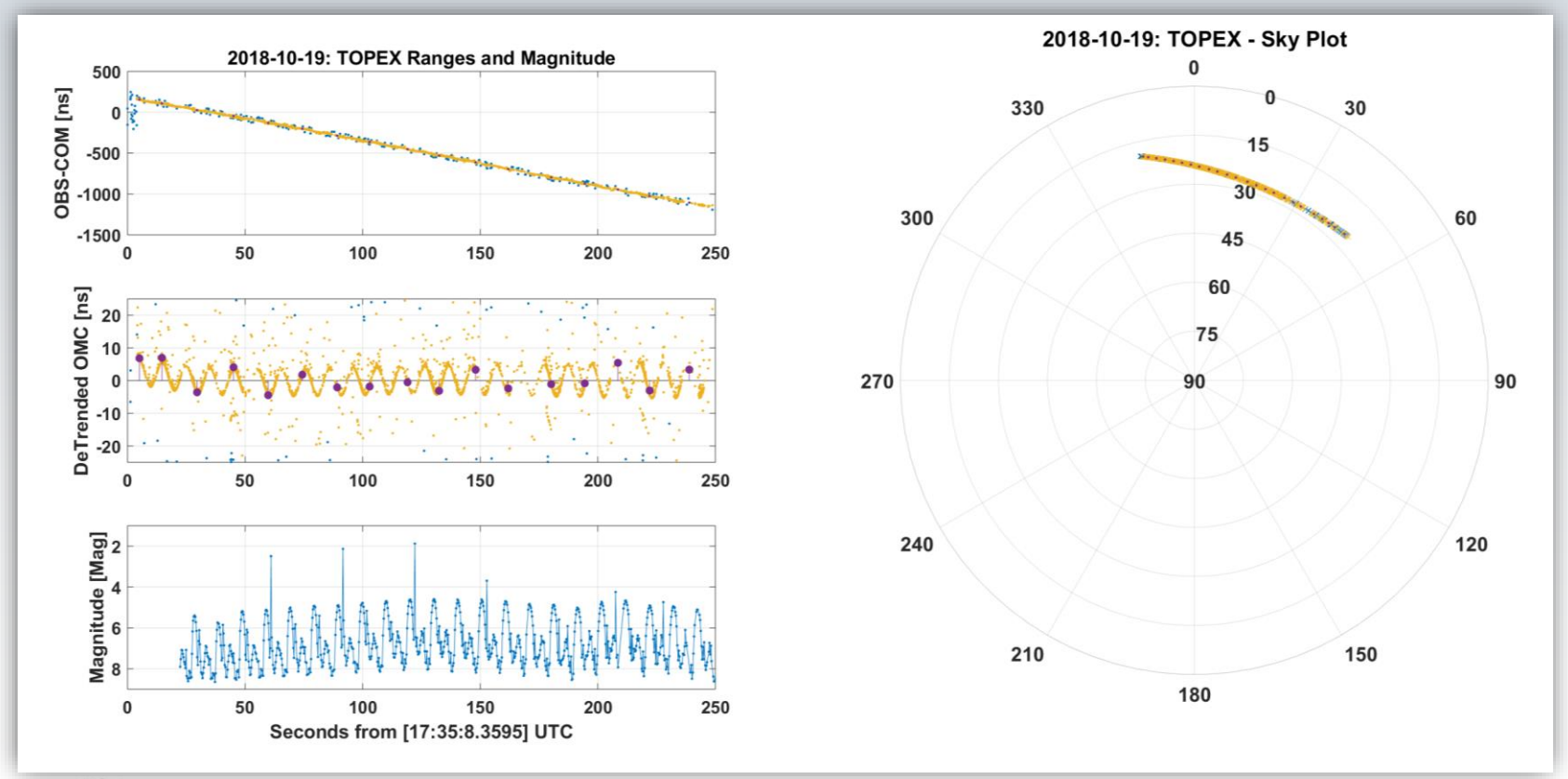
⇨ −38.5% of Sky background (same exp. Time)

⇨ ~ Sky background value (96.57%), +60% Exp. time

Tracking Camera Output Data

Night-Tracking Camera output:

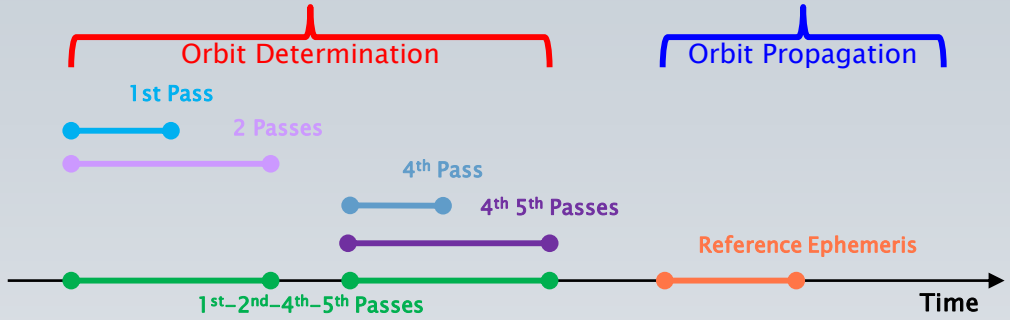
- Orbit determination
  - Angular direction of telescope pointing (encoders)
  - Laser Ranges
- Attitude Determination
  - Light curve
  - «Laser light curve»

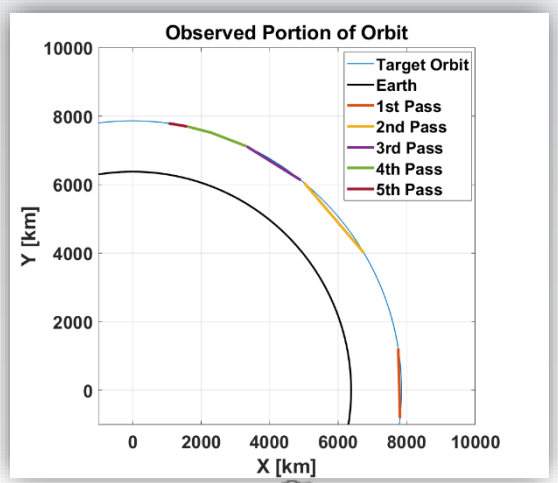


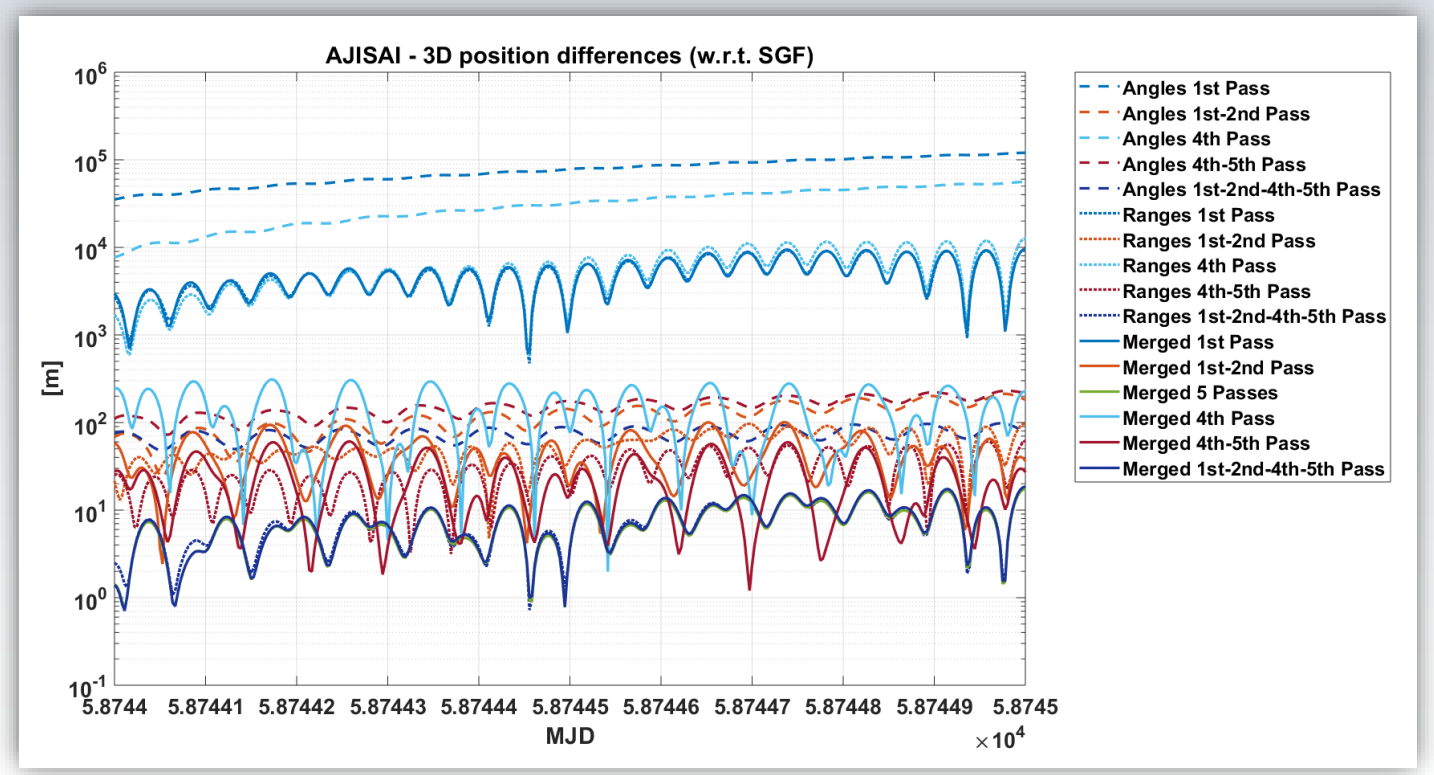
Orbit Determination Using Daytime Data

Ajisai Analysis

- Telescope: ZIMLAT
- Only Real Measurements
  - Angles from telescope encoder
  - Ranges from SLR
  - Total of 5 consecutive passes
- Date: 2019/09/17
  - 1st Pass 13:30 UTC
  - 2nd Pass 15:30 UTC
  - 3rd Pass 17:30 UTC
  - 4th Pass 19:30 UTC
  - 5th Pass 21:30 UTC







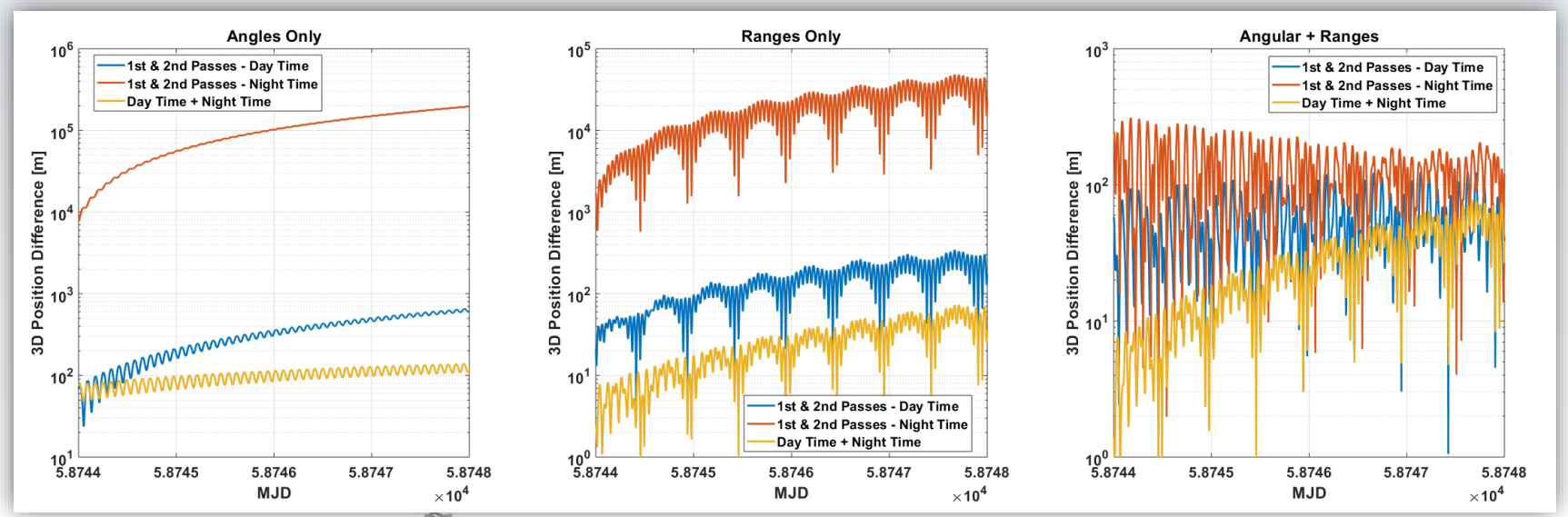
Orbit Determination Using Daytime Data

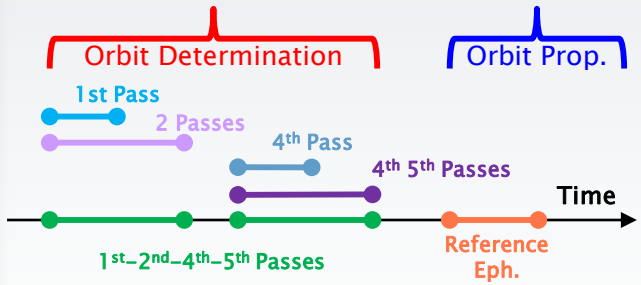
Ajisai Analysis – Playing with observables

Same observation scenario, comparison of accuracies obtainable by processing different observables

⇨ Improvement of up to 2 order of magnitude given by increased portion of observation arc

Ajisai – 3D Position Difference w.r.t. SGF [m]			
Length of Observation arc	Angles Only	Ranges Only	Merged
1 Pass Daytime	202077.98	12938.65	12755.87
2 Passes Daytime	336.38	138.58	51.43
1 Pass Nighttime	102461.79	18393.05	126.34
2 Passes Nighttime	320.28	89.87	19.47
2 Daytime + 2 Nighttime	97.97	25.51	26.82
All available (5 passes)	115.43	25.34	25.49

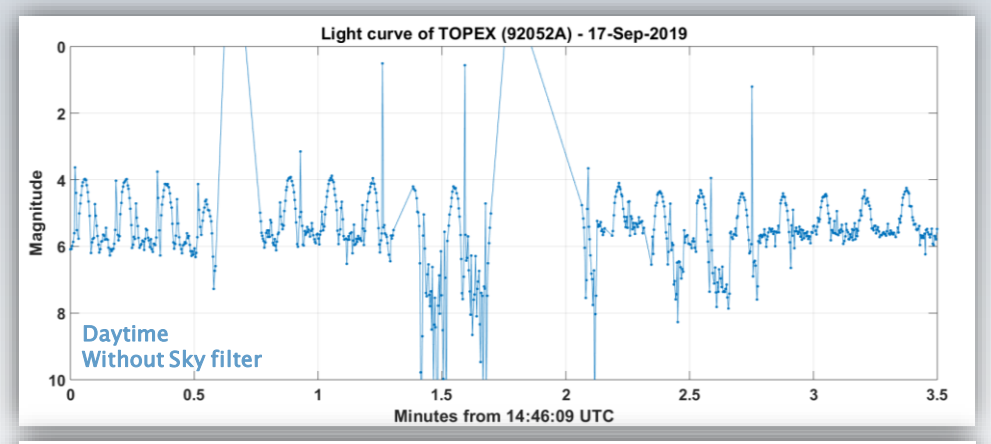


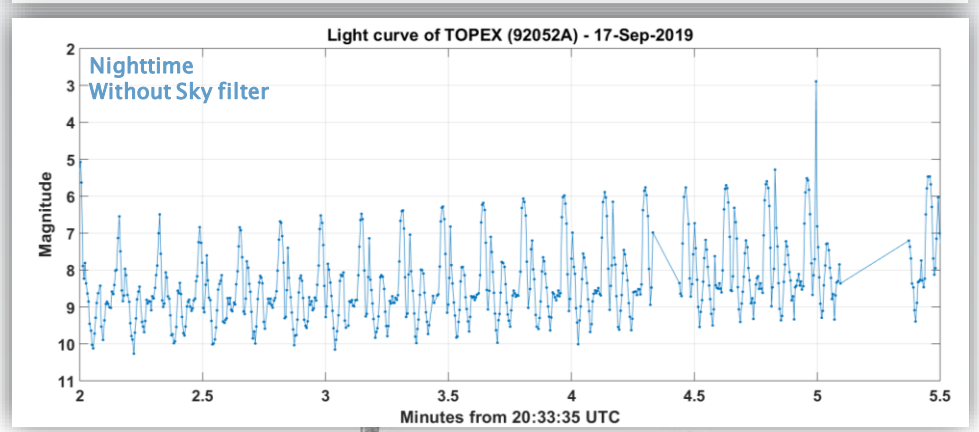


Observation for Attitude Determination

TOPEX

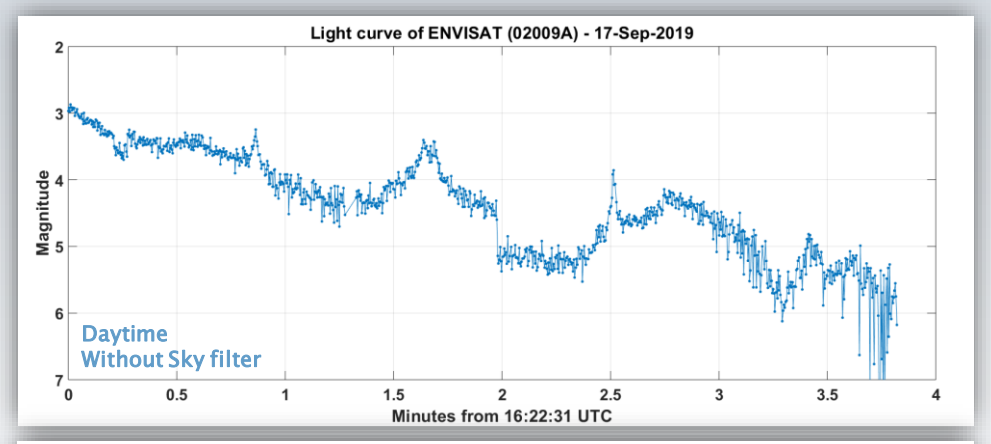
- Telescope: ZIMLAT
- Observation time:
  2019/09/17 14:46 & 16:40 & 18:30 & 20:33 UTC
- Exp. Time: 0.05 seconds & 0.1 seconds
- Without Sky filter

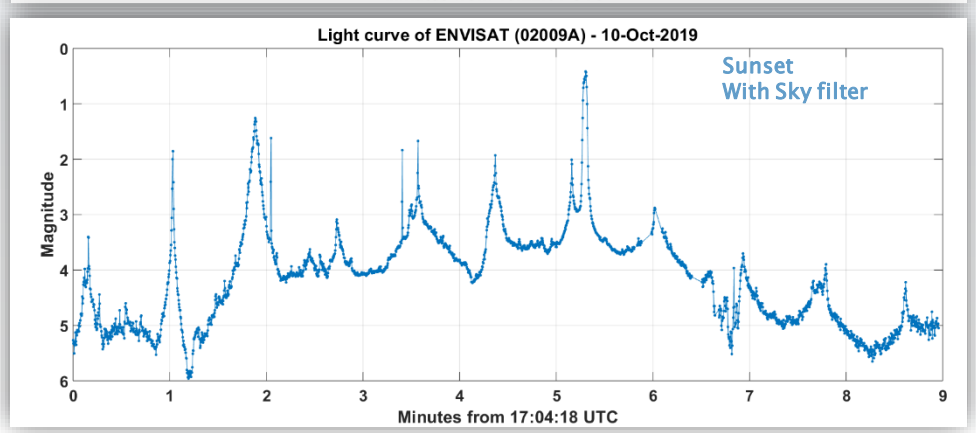




ENVISAT

- Telescope: ZIMLAT
- Observation time:
  - 2019/09/17 16:25 UTC Without Sky filter
  - 2019/10/10 17:04 UTC With Sky filter
- Exp. Time: 0.01 seconds 0.05 seconds

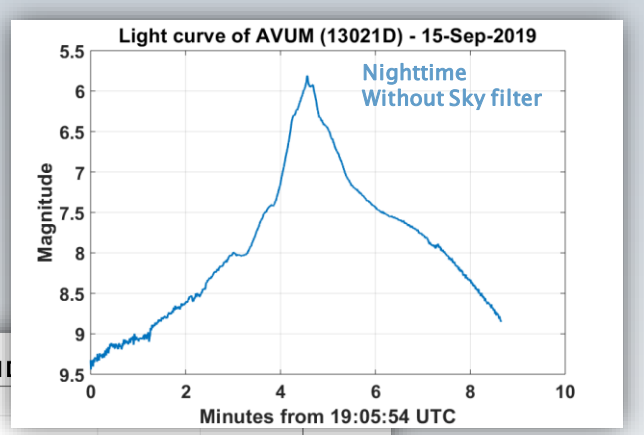


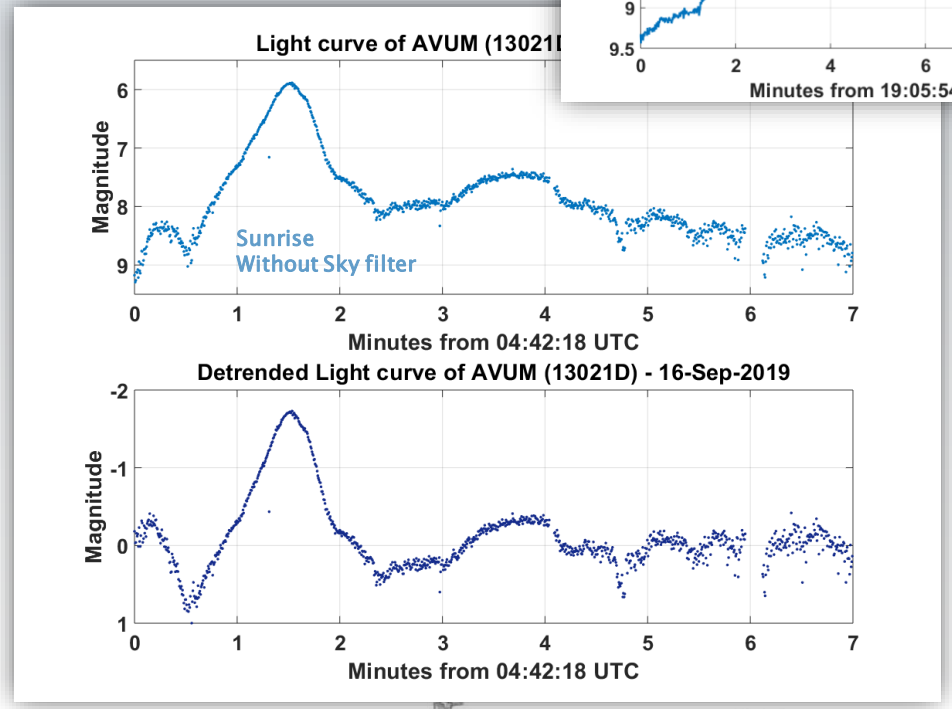


Observation for Attitude Determination

AVUM DEB (ADAPTOR)

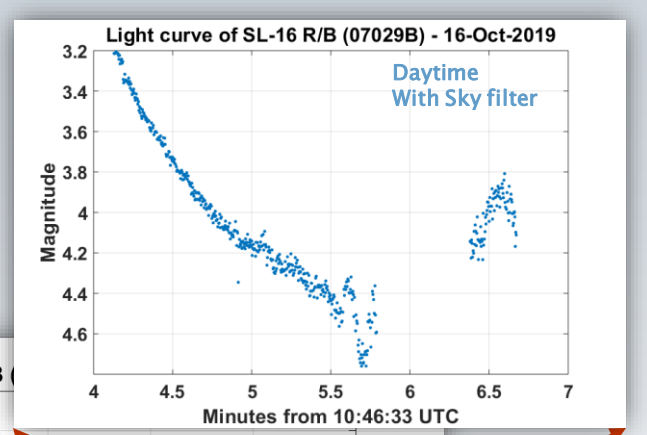
- Telescope: ZIMLAT
- Observation time:
  2019/09/15 19:10 UTC
  2019/09/16 04:45 UTC
- Exp. Time: 0.2 seconds
- Without Sky filter

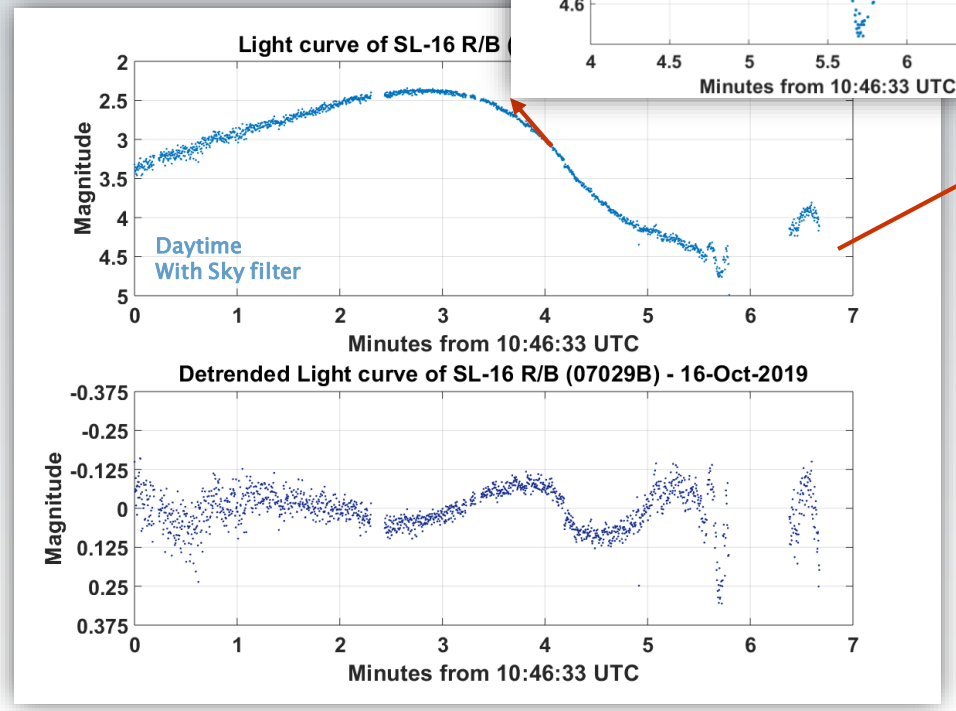




SL-16 R/B

- Telescope: ZIMLAT
- Observation time:
  2019/10/16 10:50 UTC
- Exp. Time: 0.035 seconds
- With Sky filter





Summary

- Employment of the Night-Tracking Camera for Daytime observations
- Investigation of the limits of the system
  - Observation possible up to Magnitude 7 during daytime
- Evaluation of possible system improvement
  - Sky filter
  - Flat field correction
- Acquisition and analysis of measurements for:
  - Orbit determination
    (up to 2 orders of magnitude of accuracy improvement)
  - Attitude determination
  - Active tracking
    - debris tracking
    - re-entering objects

Observed Objects during daytime		
Name	COSPAR ID	Altitude [km]
ENVISAT	02009A	800
TOPEX	92052A	1350
AJISAI	86061A	1485
AVUM DEB	13021D	664-800
SL-16 R/B	07029B	843-846
H-2A R/B	12025E	579-655
CZ-4C R/B	19066B	435-612
CZ-4B R/B	02024C	809-882
GEO-IK-2	16034A	943
HY-2A	11043A	971
HY-2B	18081A	971
CRYOSAT2	10013A	720
PAZ	18020A	507-510
TanDEM-X*	07026A	514

* Together with TerraSAR-X

Summary & Outlook

Pros & Cons

- **Advantages of daytime observations:**
  - Increase of the length of the observation arc
  - Improve the achievable orbit determination accuracy
  - Big change in the illumination conditions

- **Disadvantages of daytime observations**
  - Limit to lower and bright objects
  - Diffuse sky-light degrade the image quality highlighting dust and defect on optical path
  - Strong background brightness changes due to
    - Weather
    - Distance from the Sun
    - Elevation of the object

Next Steps

- **Automation**
  - Test Object Recognition algorithm day- and nighttime
  - Adjustment of Image contrast
  - Ephemeris Correction (from Az, El to Along-, Cross-track)
  - Object Planning

- **Real time Flat field?**
  - Could improve for object recognition
  - Improve post process analysis


Thank you for your attention