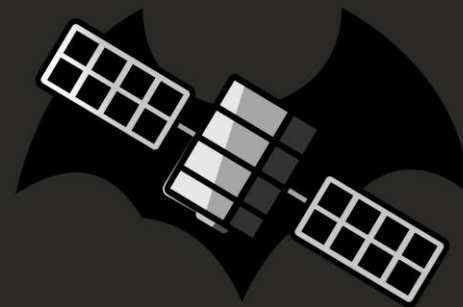


DARKNIGHT: OHV TOOL FOR PREDICTING SATELLITE VISUAL BRIGHTNESS

BAYREM ZITOUNI, MARTA POWIERZA, CATERINA PILOTTO

CLEAN SPACE DAYS 2026 | DQS SESSION | 01.07.2026



DarKnight

AGENDA



1. Introduction
2. Theoretical Background
3. Numerical Model
4. Verification & Validation
5. Conclusions

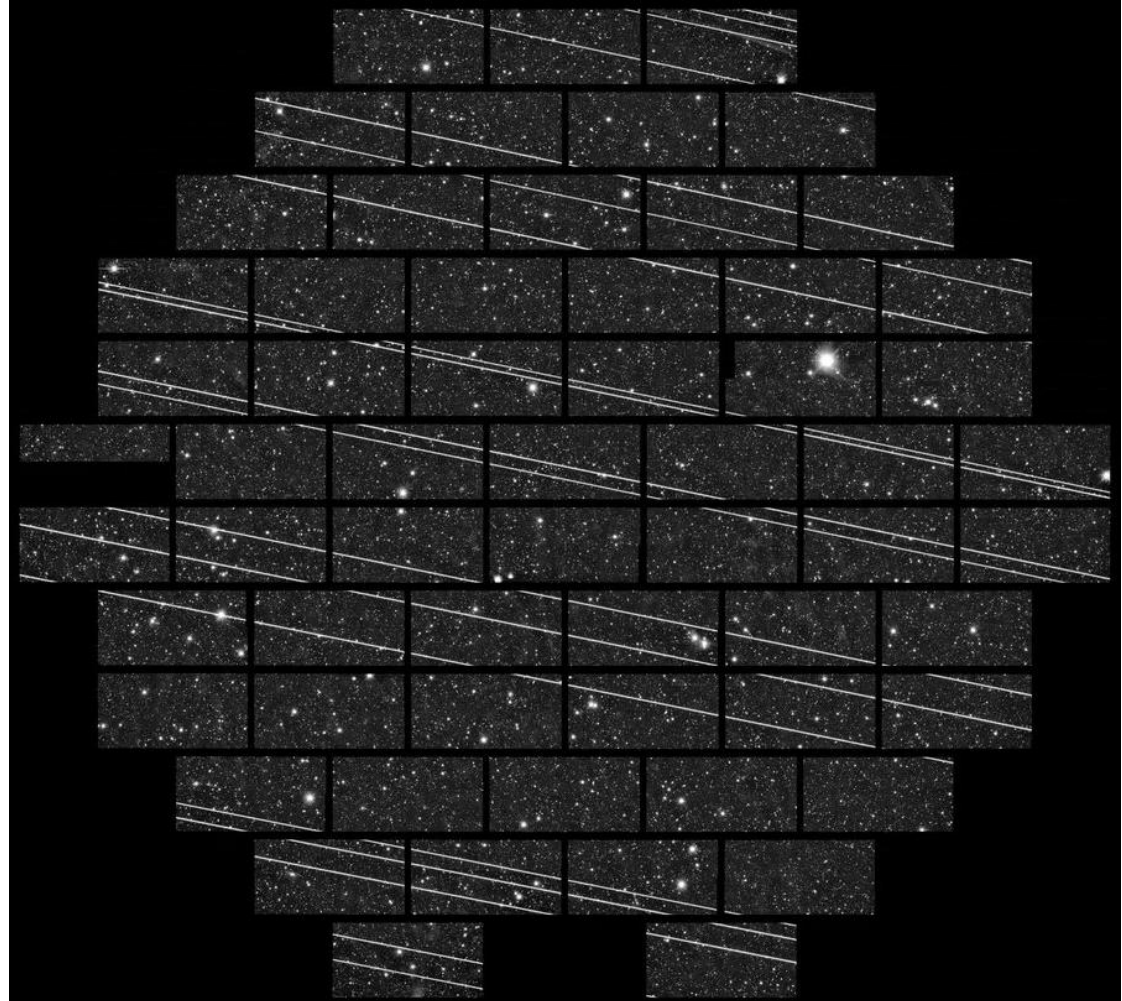


01

INTRODUCTION

MOTIVATION

- Satellite constellations in LEO
- Streaks, bright spots in telescope images, general increase in signal-to-noise ratio (Walker et al., 2020)
- ESA Space Debris Mitigation Requirements
- Section 5.6: „Dark and quiet skies“:
 - Visual brightness
 - Radio interference
- DRAMA 4.1 Brightness assessment



Time-lapse image shows the passage of a Starlink satellite cluster (bright streaks) through a telescope's field of view at the Cerro Tololo Inter-American Observatory in Chile in November 2019

02

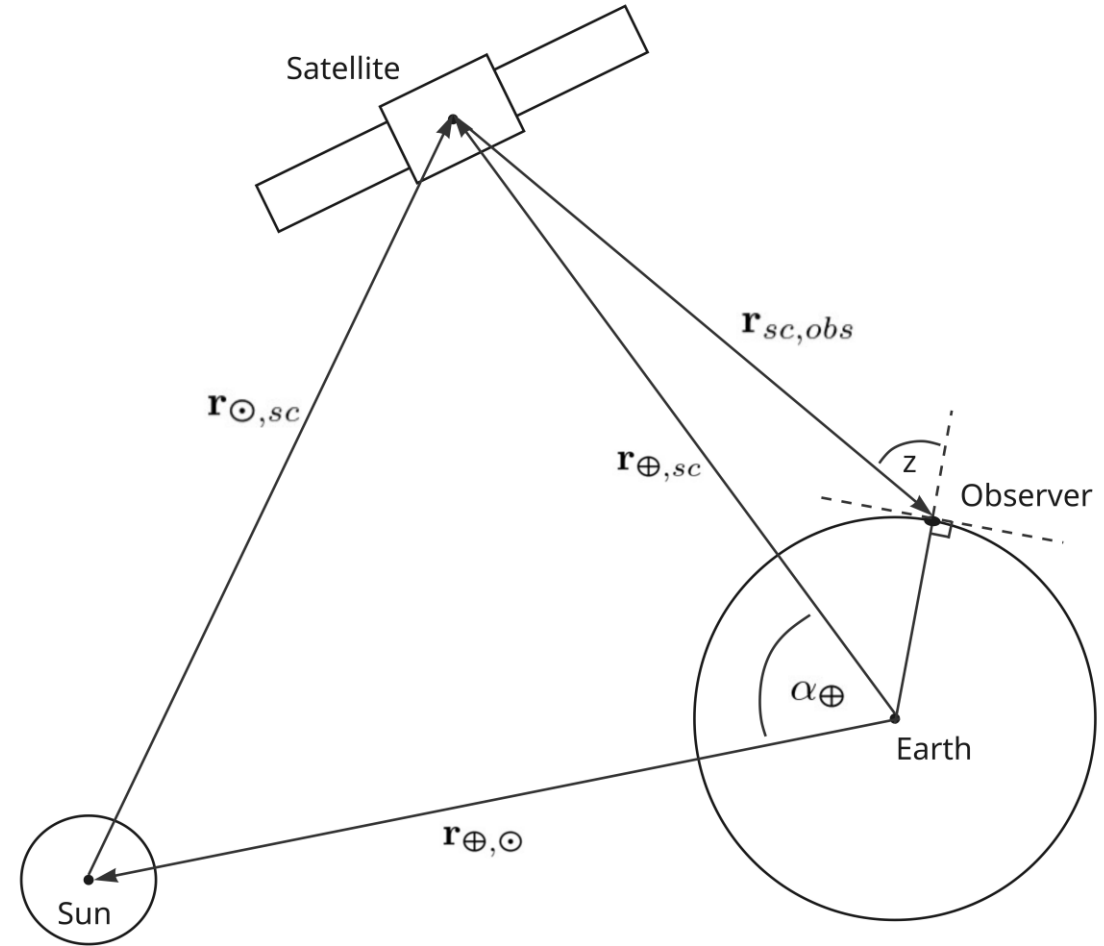
THEORETICAL BACKGROUND

VISUAL MAGNITUDE

$$m_{sc} = \underbrace{m_{\odot}}_{\text{Sun's visual magnitude}} - 2.5 \log \frac{F_{sc}}{F_{\odot}} + \underbrace{\frac{0.12}{\cos z}}_{\text{Atmospheric extinction}}$$

Solar flux at Earth

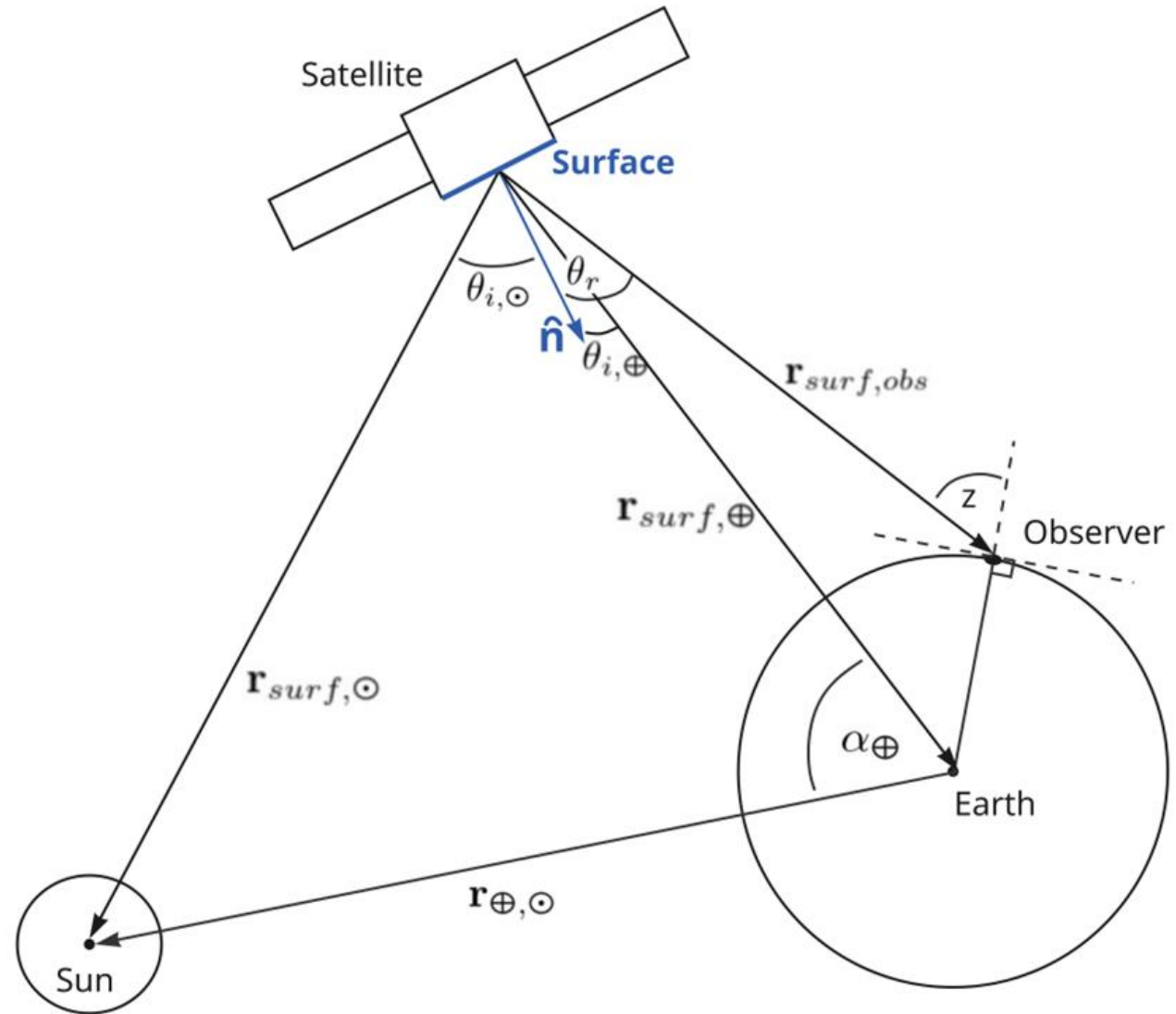
- Sunshine and Earthshine reflection component
- Bidirectional Reflectance Distribution Function (BRDF) recommended by ESA:
 - Diffuse reflection
 - Specular reflection



PER-SURFACE COMPUTATION

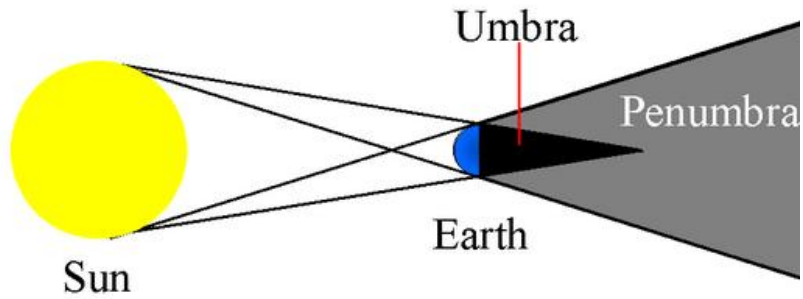
Dependent on:

- Normal vector \hat{n}
- Surface area
- Incidence angle θ_i
- Reflection angle θ_r
- Material properties: diffuse and specular reflection coefficients, shininess coefficient



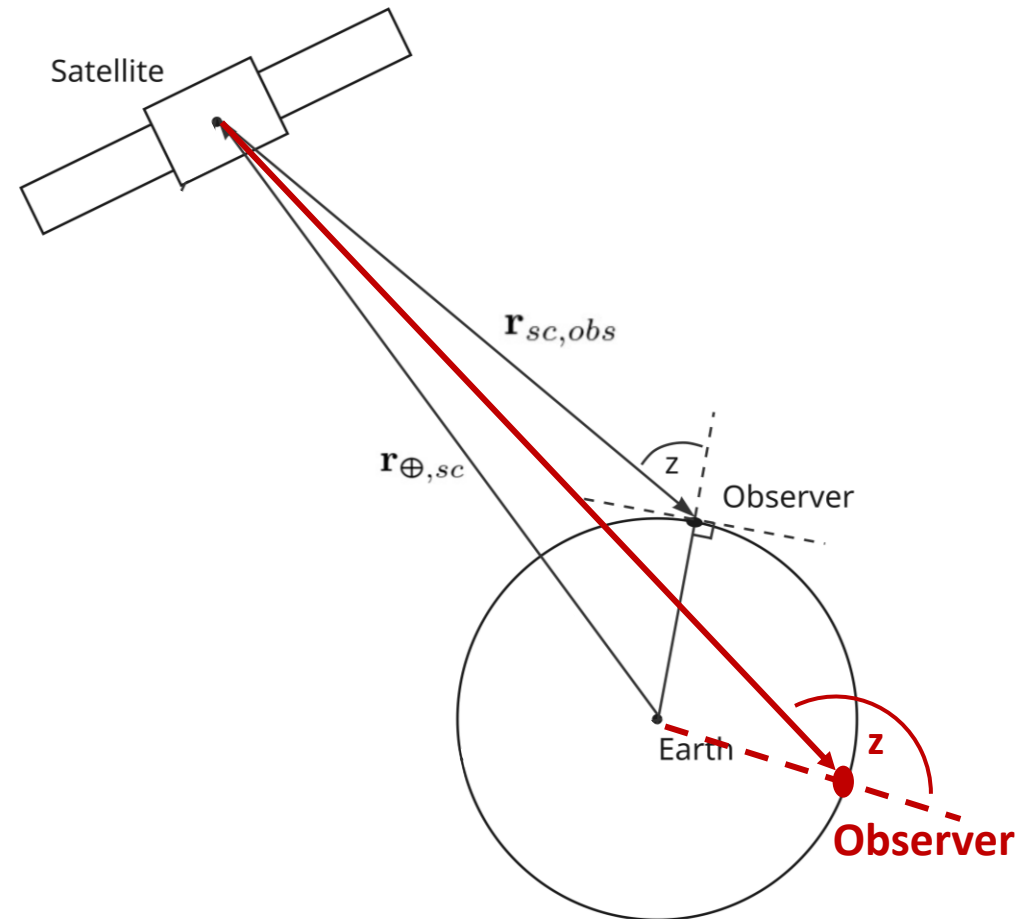
OCCULTATION AND SHADOWING

1. Illumination by the Sun



- Use of multipliers S and V :
 - Values between 0 and 1 assigned based on those conditions

2. Visibility from the observer location





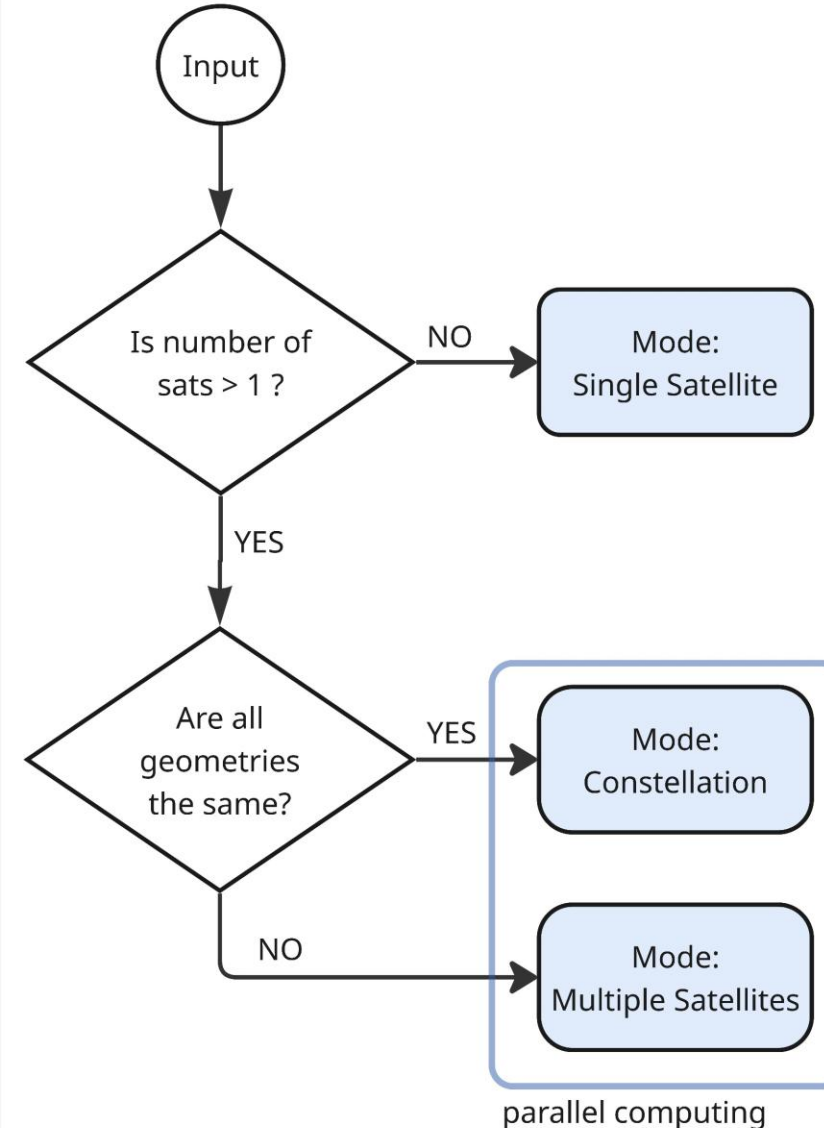
03

NUMERICAL MODEL

MODEL CAPABILITIES

MODES

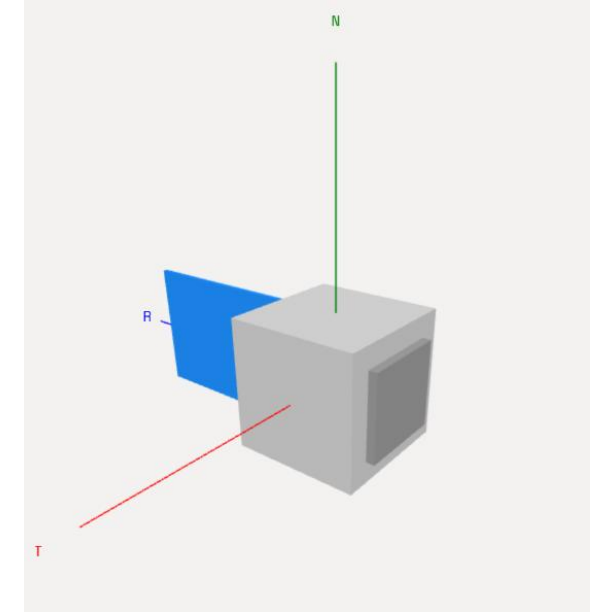
- 3 modes:
 - Single satellite
 - Constellation
 - Multiple different satellites
- Discrete model (brightness evaluated per time step)
- 3D geometry definition
 - 3 components: main body, solar array, antenna
- Editable materials database
- Default observatory locations
 - Custom inputs allowed
- Parallelised code (1 sat per CPU core)



MODEL CAPABILITIES

GEOMETRY & MATERIALS

- 3D geometry definition
 - 3 components: main body, solar array, antenna
- Main body:
 - Fixed in body frame RTN, one surface nadir-pointing (same as DRAMA)
- Solar array:
 - Can be chosen Sun-fixed, Earth-fixed, Observer-fixed, body-fixed
- Antenna:
 - Can be disabled/enabled
 - Can be chosen Sun-fixed, Earth-fixed, Observer-fixed, body-fixed
- Materials:
 - “preliminary”: default database
 - “detailed”: materials from literature



Material	Diffuse reflection [-]	Specular reflection [-]	Shininess [-]
MLI	0.03	0.0	100
Solar Array	0.01	0.0	100
Antenna	0.65	0.0	100

MODEL CAPABILITIES

OBSERVATORIES

- DarKnight includes an observatory locations database: pre-defined (in the GUI) or editable (custom)

Observatory Name	Abbreviation in the GUI	Latitude [deg]	Longitude [deg]	Altitude [m]
Very Large Telescope	VLT	-24.6275	-70.4042	2636
Mauna Kea Observatory	MKO	19.8222	-155.475	4205
Observatorio del Roque de los Muchachos	ORM	28.7636	-17.8947	2396
Yunnan Astronomical Observatory	Yunnan	25.0333	102.7833	2014
Vainu Bappu Observatory	VBO			
Southern African Large Telescope	SALT			

Observer Location

Select observatory: MKO

or

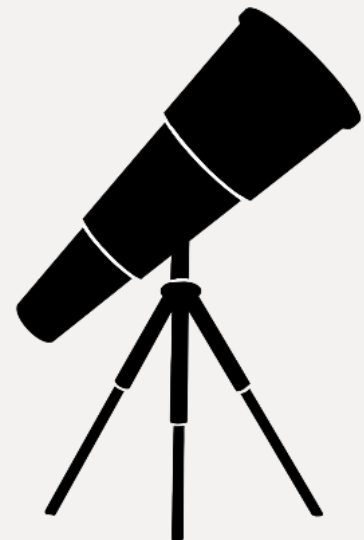
Define custom:

Latitude: 19.8222

Longitude: -155.475

Altitude: 4205

- MKO
- ORM
- SALT
- VBO
- VLT
- Yunnan



04

VERIFICATION & VALIDATION

VERIFICATION & VALIDATION STRATEGY

STRATEGY



1. Option to use Two Line Elements (TLE) to retrieve orbits of in-orbit satellites

2. Observations obtained from:
 - Paper about OneWeb brightness (Littoriano, 2021)
 - Seesaw archive
 - Satellite Constellation Observation Repository (SCORE)

3. Materials data:
 - Default MLI, solar array, antenna materials (Rodriguez et al., 2007; Littoriano, 2021) → Mode: “Preliminary analysis”
 - Specific material data obtained from the Thermal department → Mode: “Detailed analysis”

APPLICATION CASES

CASES

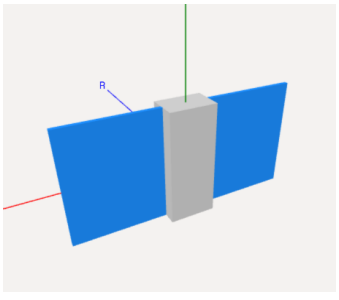
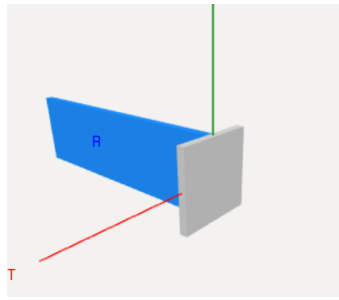
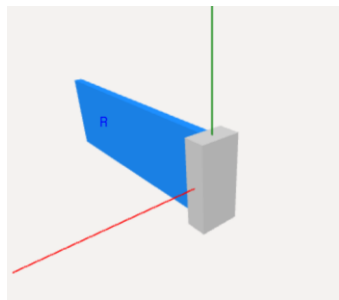
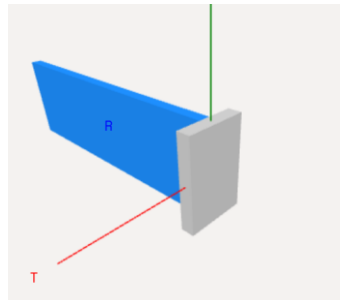
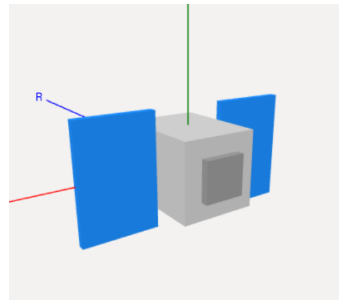
OneWeb

Starlink V2 Mini

Starlink V1.5

Qianfan

Pelican 3001

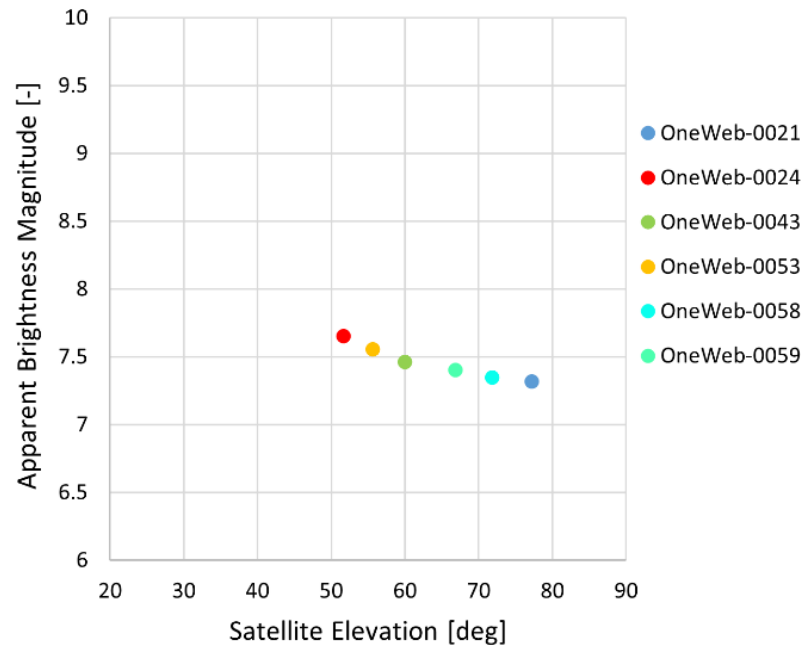


Test Case / Scenario	Observation Source	Comparison Tool
OneWeb	Littoriano, SEESAW	Littoriano model, DRAMA 4.1
Starlink V2 & V1.5	SCORE	DRAMA 4.1
Qianfan Constellation	SCORE	—
Pelican 3001	Public observations	—
Synthetic aluminium plate case	Analytical scenario	Lumos-sat

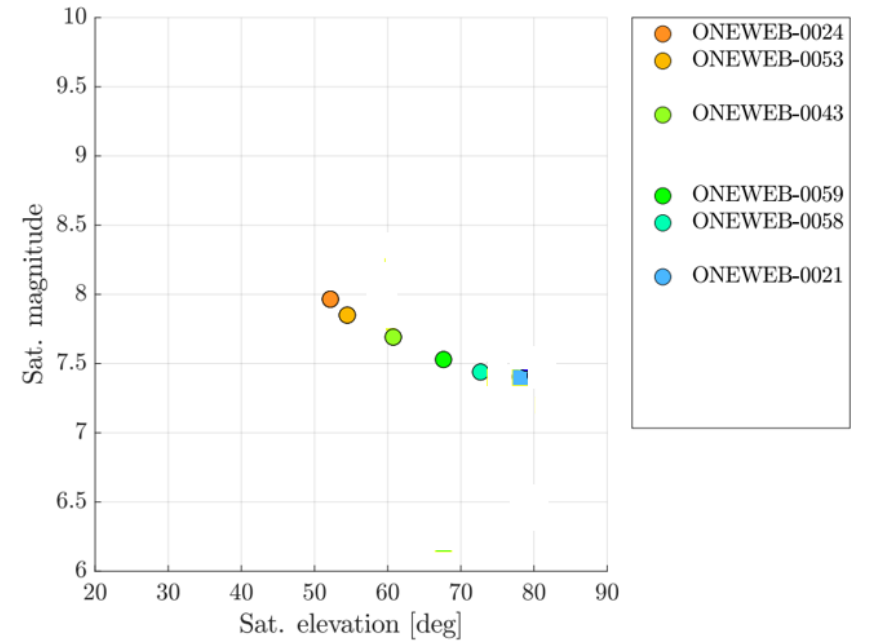
APPLICATION CASES

ONEWEB MAY 2021

DarkKnight



Littoriano

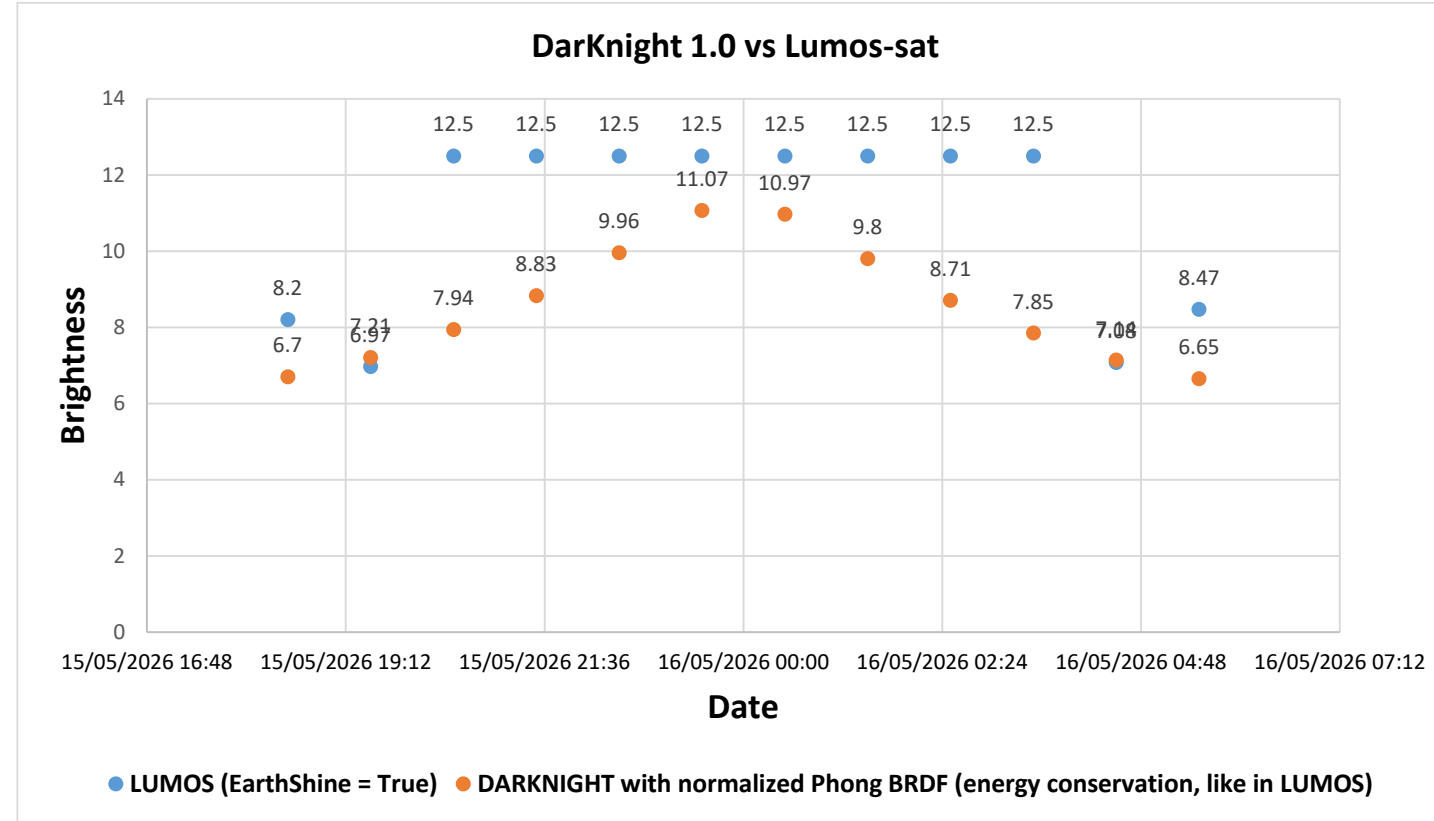


APPLICATION CASES

DARKNIGHT VS LUMOS-SAT



- BRDF Model Choice:
 - LUMOS uses ABG BRDF, empirically tuned for aluminium
 - DarKnight uses Lambert + Phong
 - These models distribute reflected energy differently across angles.
- Atmospheric Extinction:
 - DarKnight applies extinction
 - LUMOS does not
- Shadow / Penumbra Handling
 - DarKnight applies illumination multipliers
 - LUMOS does not smooth illumination in this setup





06

CONCLUSIONS

SUMMARY

Case	DarkKnight vs Observation (average in %)		Comment
	'Preliminary analysis'	'Detailed analysis'	
OneWeb	10%	7%	Verification with a different model, reliable observations
Starlink V2 Mini	13%	32%	Mitigation measures likely
Starlink V1.5	9%	23%	Mitigation measures possible
Qianfan	10%	24%	New constellation, mitigation measures likely
Pelican 3001	12%	-	Dimensions obtained using approximations

CONCLUSIONS

- Successful model implementation
- Validation with multiple real-life cases
- Validation on OH B satellites observations:
 - Collaboration with an astronomer/observatory
 - Use of internal knowledge about the structure and mission operations
- Evaluate mitigation solutions
- More detailed pointing modelling – specific deg tilt wrt. Earth or Sun vector
- Self-shadowing and self-illumination
- Automatic assessment against Space Debris Mitigation Requirements Verification standards



THANK YOU!



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