Scientific Insights into the Atlas Dark Sky Reserve

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Outline:

Part I: Atlas Dark Sky Reserve Project

1. **Survey and ALAN Measurements** in the preselected reserve area

2. **Modeling Light Pollution at Oukaimeden Observatory**
    - **Artificial Component**: Impact of nearby cities and lighting infrastructures
    - **Natural Component**: Contribution of celestial sources using the GAMBONS model

3. **Conclusion**: Key findings

Part II: Pollution from Satellite Constellations

1. **Oukaimeden Observatory: A Key Player in Satellite Observations**

2. **Observation Facilities & Tracking Tools** for monitoring satellites

3. **Data Processing & Impact Analysis** on astronomical observations

4. **Conclusion**: Challenges and mitigation strategies

The Atlas Dark Sky Reserve

The Atlas Dark Sky Reserve project is a unique project in the region. It consists in creating an international dark sky reserve covering a large territory including the Toubkal National Park.

The first zone of
ADSR PROJECT

Marrakech
2
Tahannaout
1
Asni
3
Ait Lqaq
5
Oukaimeden Observatory
Imlil
Google Earth
Image Landsat / Copernicus
40 km

Pictures from a survey in Asni village June 2021

Survey conducted at Oukaimeden

Geographic parameters for Oukaimeden region

Region	H_{Lamp}	$H_{Obstacle}$	$d_{Obstacle}$	F
Oukaimeden	10m	12m	10m	0.5

Lighting parameters for Oukaimeden region

Region	HPS	LED	MH	ULOR
Oukaimeden	95%	5%	0	1%
Ait Lqaq	100%	0%	0	1%
Asni	70%	30%	0%	5%
Imlil	5%	95%	0%	5%
Tahanaout	40%	50%	10%	1%

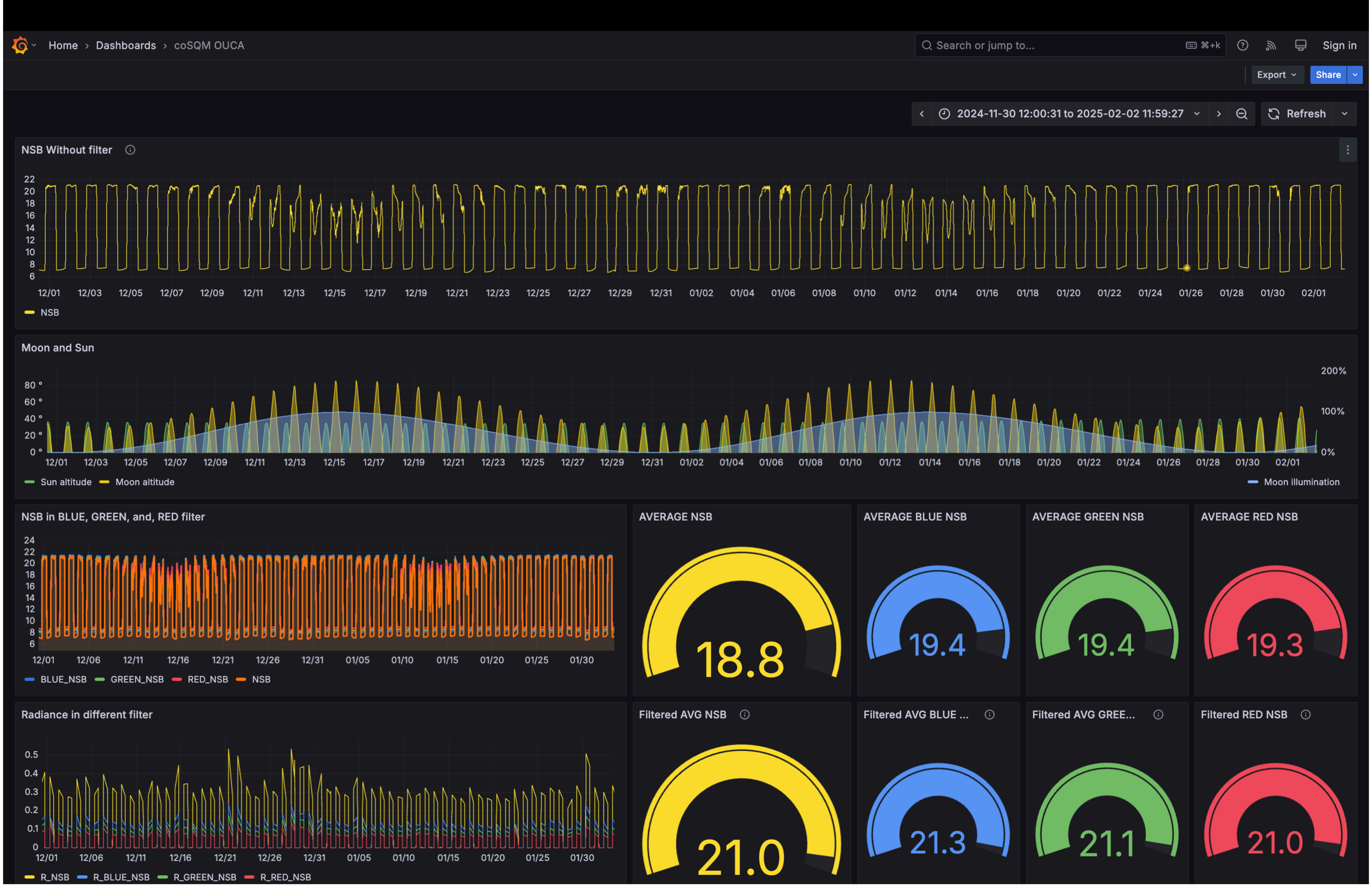
NSB measurements at the Oukaimeden Observatory

To measure the zenith night sky brightness (ZNSB), we have used the multispectral Color Sky Quality Meter.

Version 2 (CoSQM) photometer.It is composed of a filter wheel with 4 different spectral transmittances in the visible range (clear, red, blue, green) that is standing on a step motor in front of a Unihedron Sky Quality Meter (SQM).The instrument operated remotely via the SSH protocol and the data can be accessed via an integrated web server.

Utilizing CoSQM for ZNSB Measurements at Oukaimeden Observatory

- **SQM-LE Model of CoSQM:** Ensures compatibility with global SQM data.
- **High Sensitivity & Resolution:** Measures night sky brightness with good accuracy.
- **MPSAS Scale:**
  - Inverted logarithmic scale representing brightness per solid angle.
  - Higher values indicate darker skies and lower light pollution.
- **Observation Period:**
  - Data collected at Oukaimeden Observatory from 2022 to now.
- **Figure Below:** Displays Zenith Night Sky Brightness (ZNSB) variations over about one year (20024).

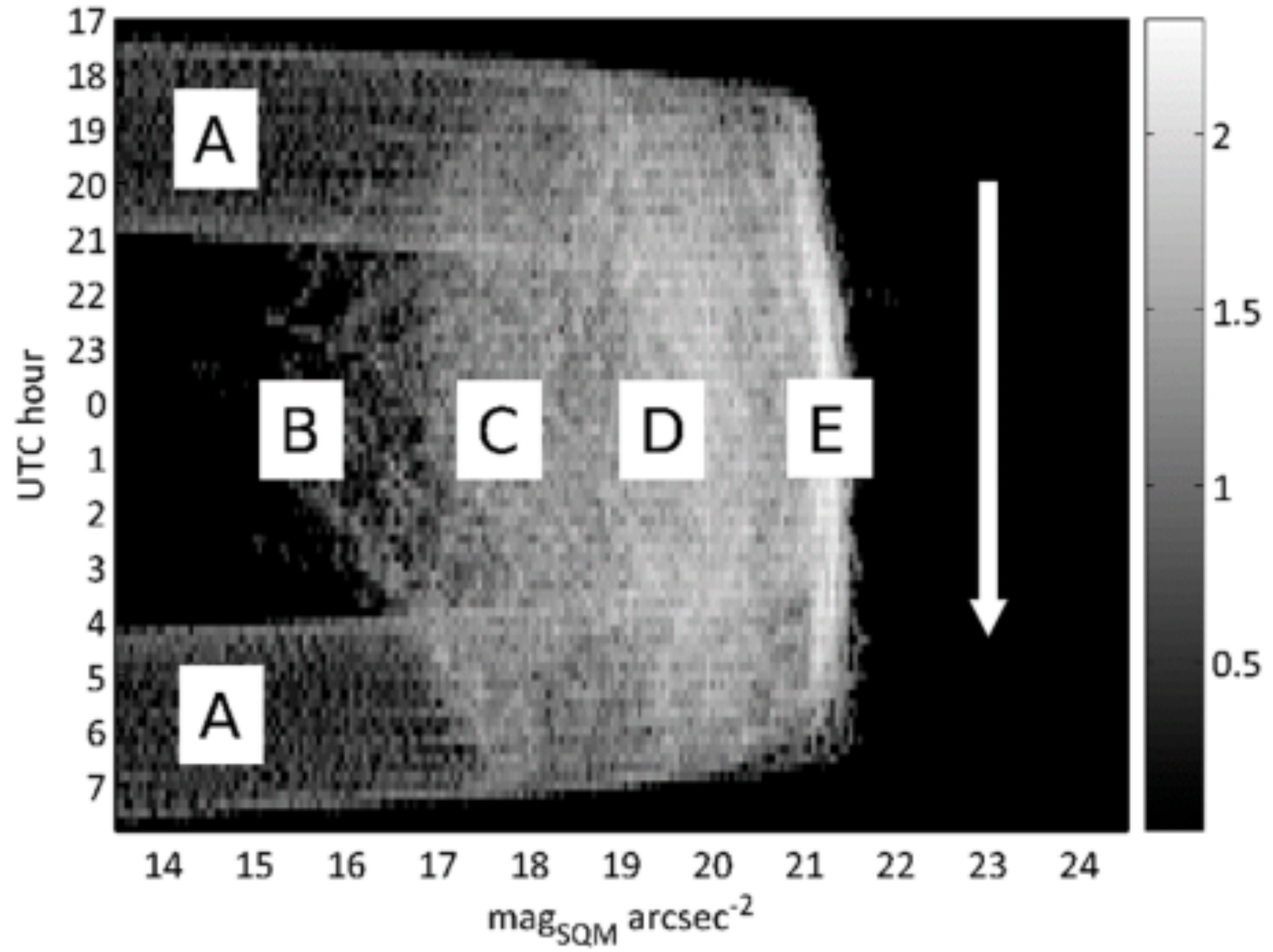

Home › Dashboards › coSQM OUCA
Search or jump to...
Sign in
Export
Share
2024-11-30 12:00:31 to 2025-02-02 11:59:27
Refresh
NSB Without filter
NSB
Moon and Sun
Sun altitude
Moon altitude
Moon illumination
NSB in BLUE, GREEN, and, RED filter
BLUE_NSB
GREEN_NSB
RED_NSB
NSB
AVERAGE NSB
18.8
AVERAGE BLUE NSB
19.4
AVERAGE GREEN NSB
19.4
AVERAGE RED NSB
19.3
Radiance in different filter
R_NSB
R_BLUE_NSB
R_GREEN_NSB
R_RED_NSB
Filtered AVG NSB
21.0
Filtered AVG BLUE ...
21.3
Filtered AVG GREE...
21.1
Filtered RED NSB
21.0

Visualizing ZNSB Distribution with Densitograms

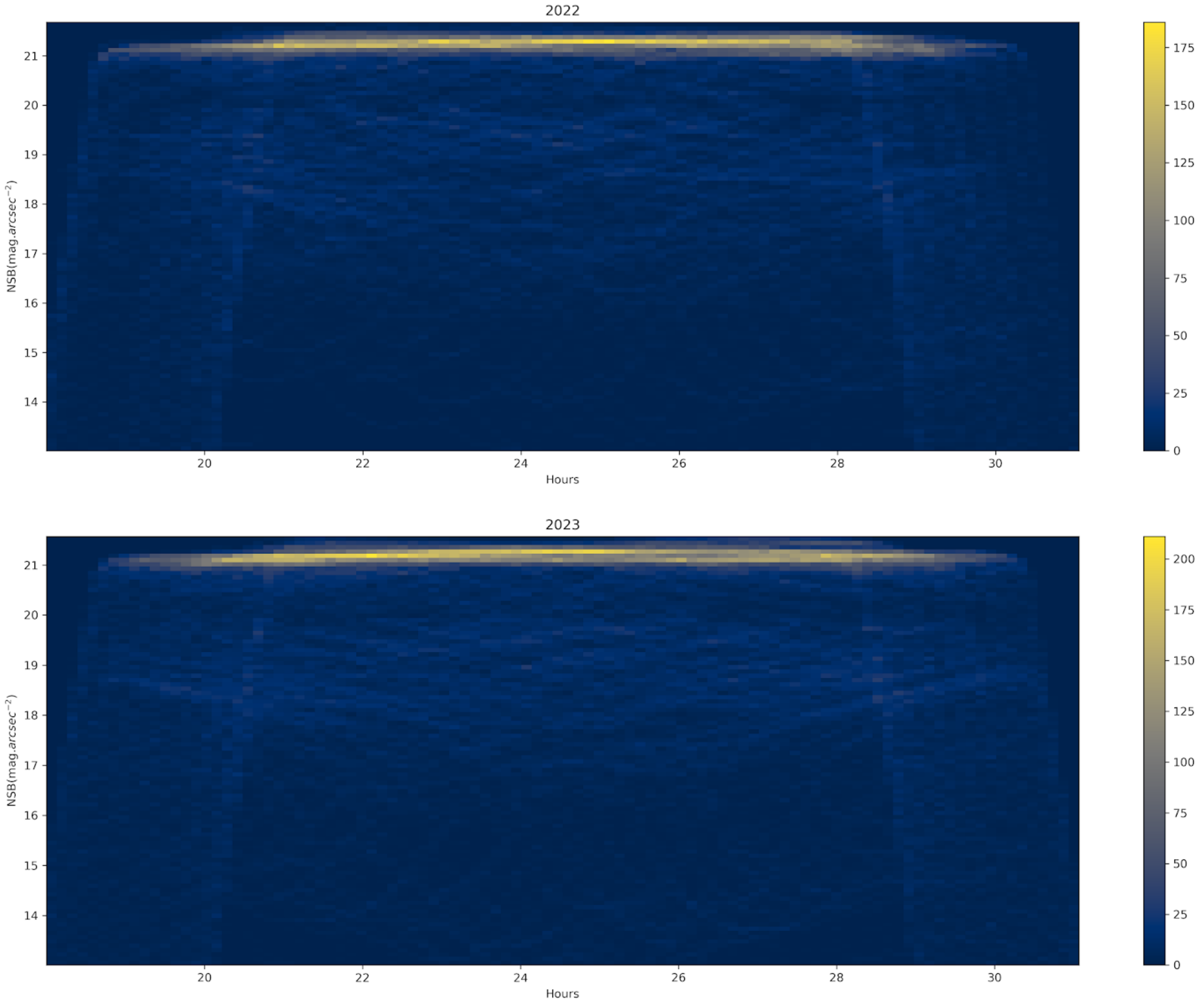
For the aims of monitoring the ZNSB, they are several graphic representations can be instrumental to obtain some insights into the NSB distribution, One particularly useful one is the densitogram (or 'jellyfish diagram', according to Posch et al.) . In this matricial representation showed in figure below, the horizontal axis corresponds to the time of the day (with, e.g., 10-min bin resolution), and the vertical one to the NSB measured in the magnitudes per square arcsecond scale (with, e.g., 0.05 mag/arcsec2 resolution bins). The value of each pixel is the number of measurements recorded along the year within each time-magnitude bin.

- The different features visible in the densitogram like :

- A : twilight periods
- B : moon within the field of view
- C : scattered moonlight,
- D : cloud reflections
- E : atmospheric scattering artificial light in clear and moonless periods.



Densitogram of Oukaimeden observatory



Modeling Light Pollution at Oukaimeden Observatory

- **Monitoring the main sources of light pollution** affecting the observatory requires evaluating **both artificial and natural light pollution**.
- **Artificial light pollution** is assessed using the **ILLUMINA Model**, which simulates human-induced sky radiance.
- **Natural light pollution** is analyzed using the **Gambon Model**, which accounts for atmospheric and celestial contributions.

Numerical simulation of ANSB using ILLUMINA model

- **ILLUMINA Model:** Advanced numerical model for simulating human-induced sky radiance.
- **Scattering Consideration:** Accounts for both first and second-order scattering, including direct emission and ground reflection.
- **Light Source Representation:**
  - Cities and towns modeled as multiple circular areas.
  - Each area characterized by homogeneous spectral properties, light output distribution, lamp height, and obstacle dimensions.
- **Geographical & Atmospheric Factors:**
  - Integrates elevation and ground reflectivity using a digital elevation model and satellite spectral albedo data.
  - Uses multiple parameters to define atmospheric conditions.
- **Simulation Output:**
  - Designed to model light scattered back to a spectrometer.
  - Provides spectral radiance output in ($W.nm^{-1}.sr^{-1}$).
  - Focuses exclusively on artificial light contributions to night-sky glow.

ILLUMINA Model Schematic

Illustration of the computational model used by ILLUMINA to determine the flux received in each direction.

- **Key Elements:**
  - **S** – Light source
  - **O** – Observer’s location
  - **n** – Any 3D cell along the observer's line of sight
- **Scattering Paths:**
  - $\mathbf{I_1}$ – First-order scattering path
  - $\mathbf{I_2}$ – Second-order scattering path
  - $\mathbf{Ir_1}$ – Reflection combined with first-order scattering
  - $\mathbf{Ir_2}$ – Reflection combined with second-order scattering
- **Reflection Considerations:**
  - **r** – Ground reflection
  - **MRR** – Maximum radius considered for reflection

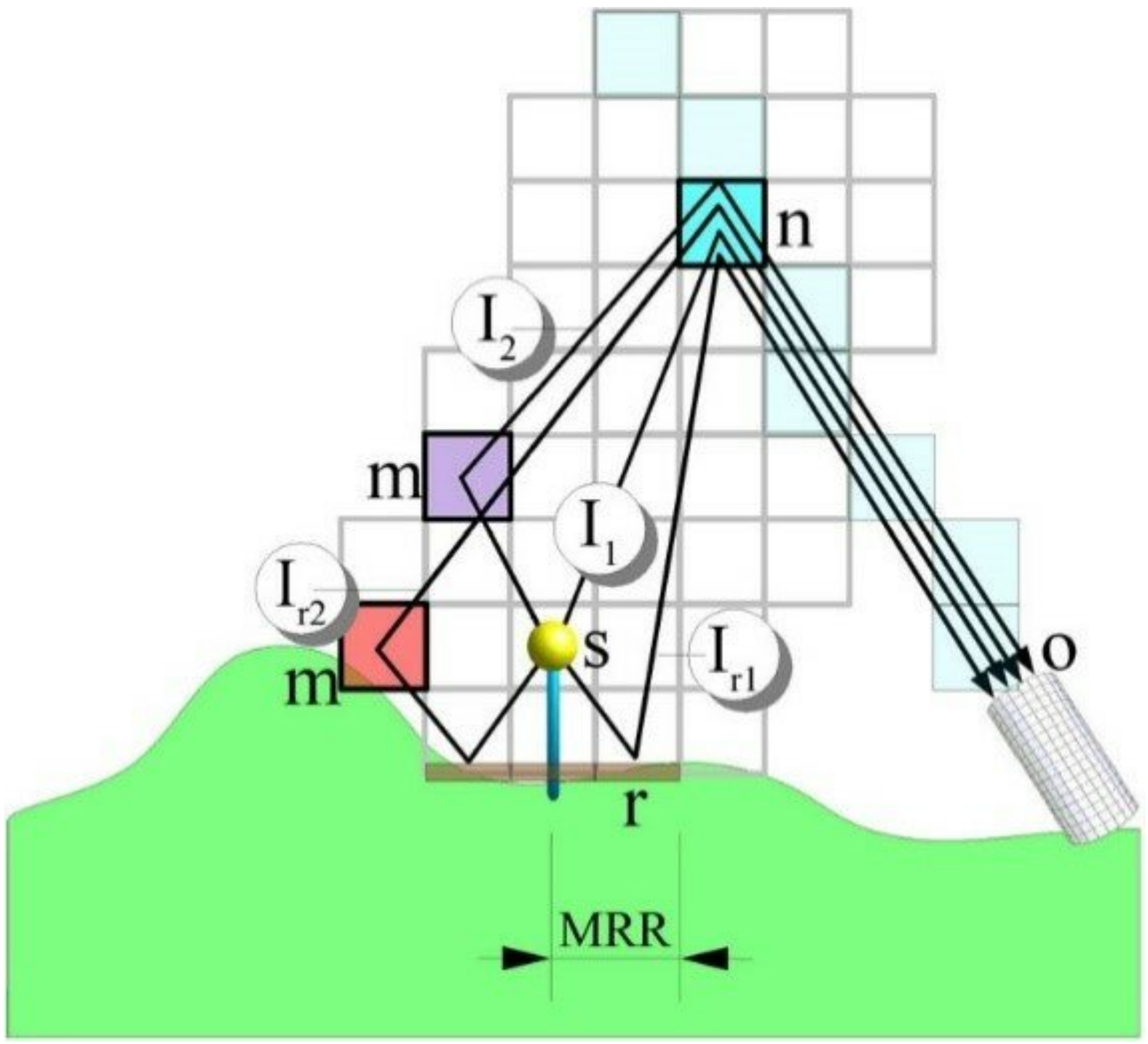


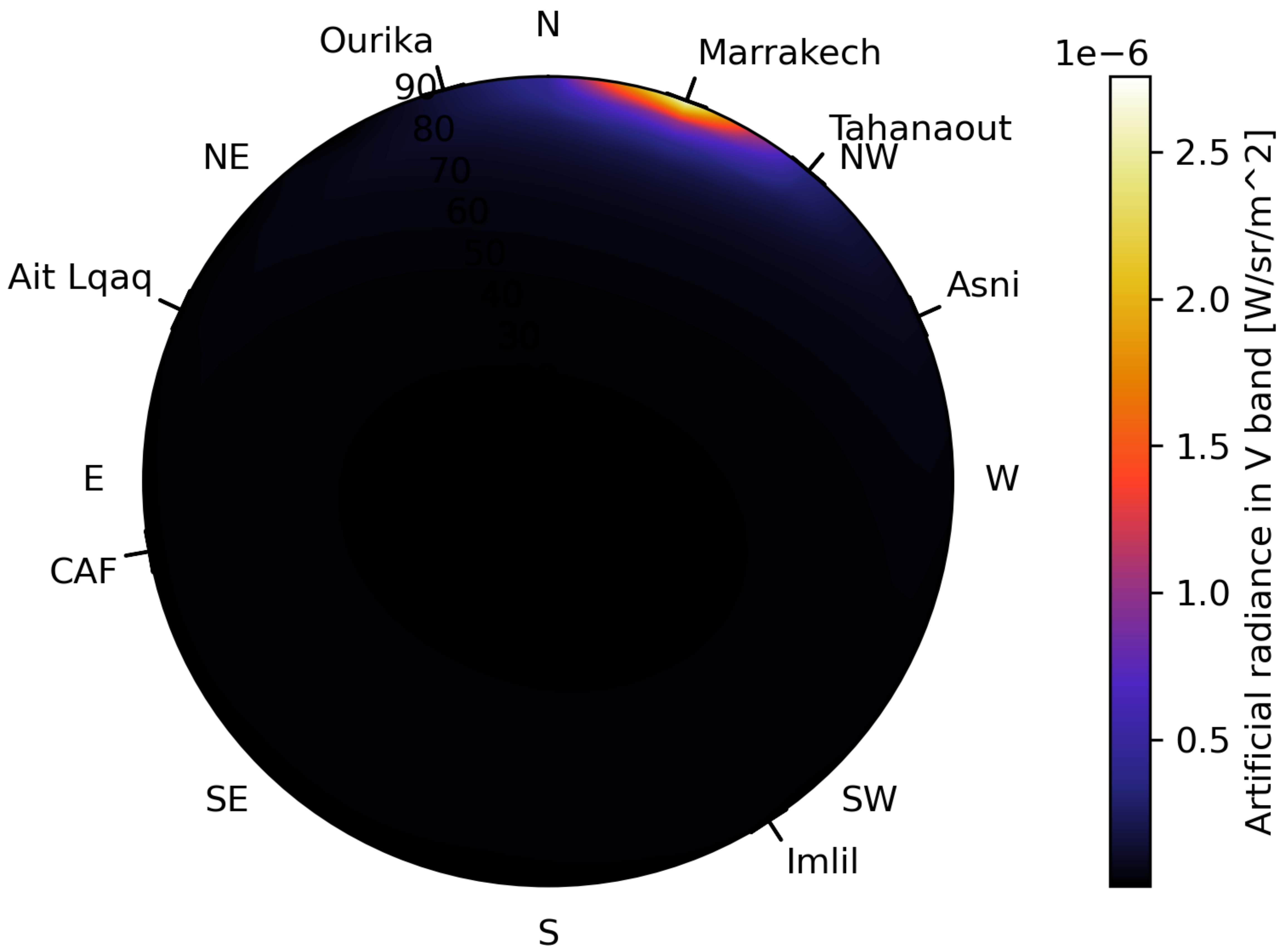
Image source: Aubé et al. (2005).

Results from Illumina model

- The figure illustrates the artificial component of the zenithal radiance in the **V-band** at Oukaimeden Observatory.

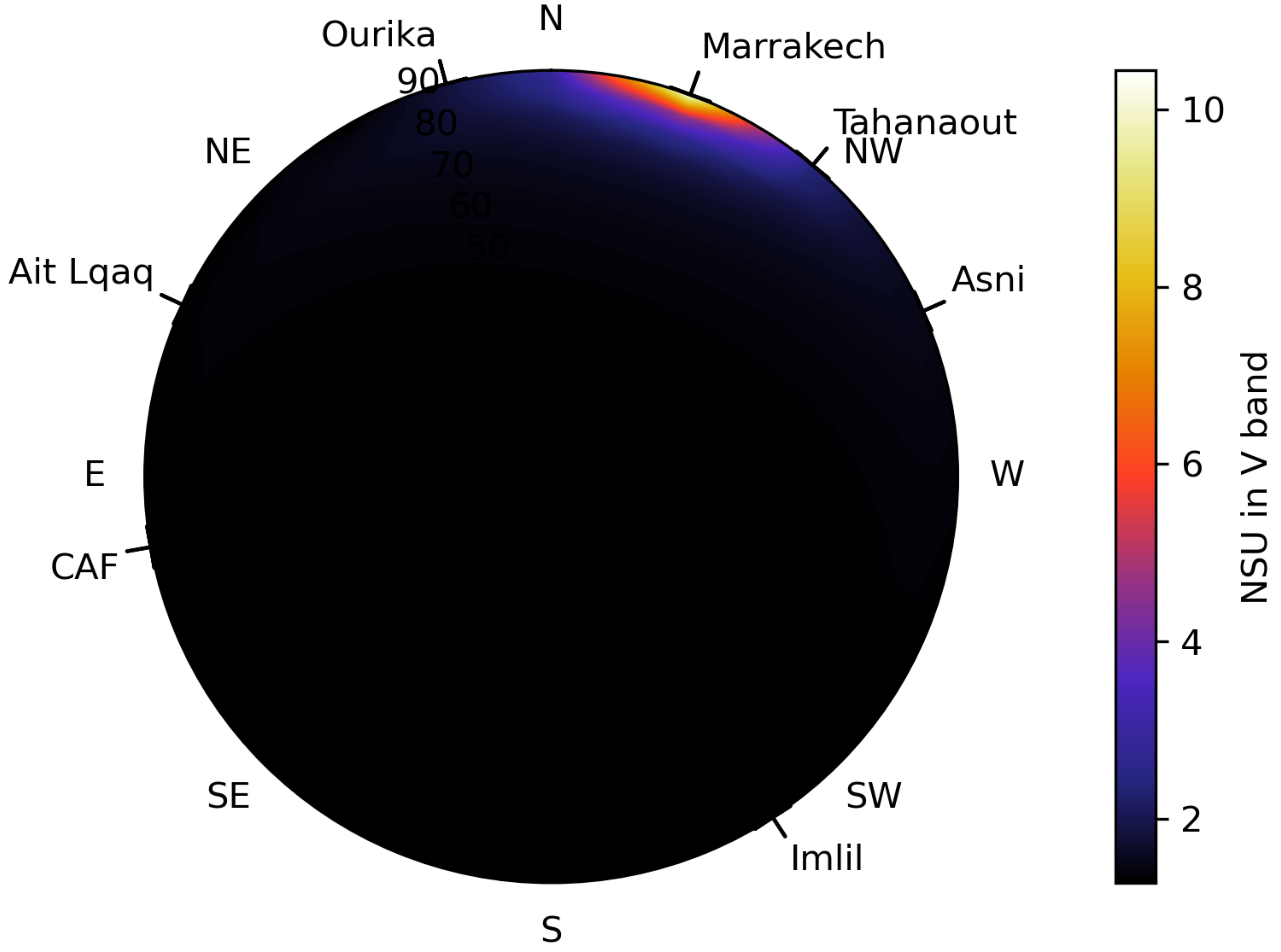
- As expected, the most impacted lines of sight are directed towards **Marrakesh city**.

- The effect is particularly pronounced at **low elevation angles**, especially up to **20°**.



Results from Illumina model

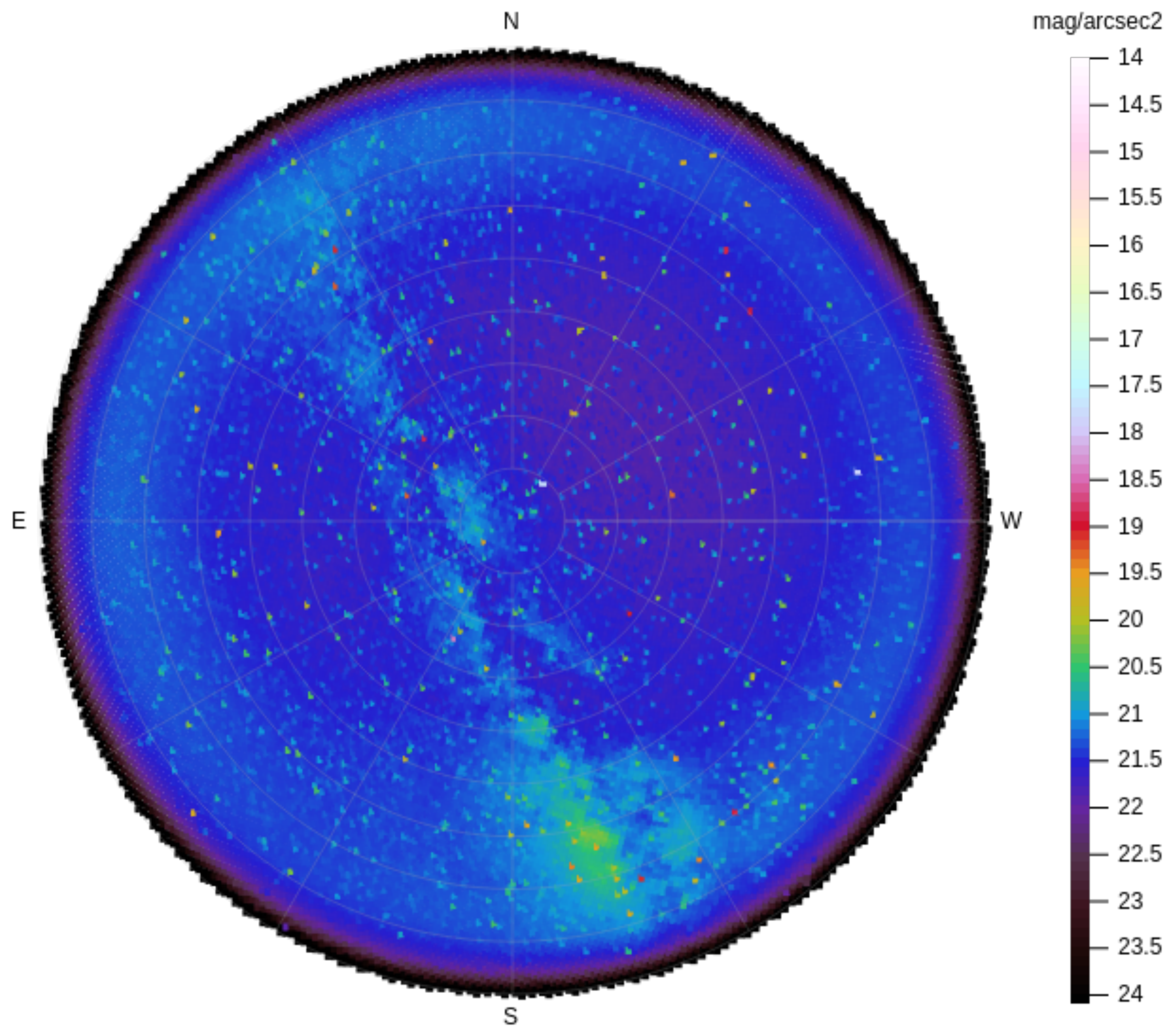
- This figure presents the **simulated night sky brightness** in **Natural Sky Units (NSU)**.
- The **NSU scale** is used to provide an intuitive and clear interpretation of how much **brighter or darker** the night sky is compared to its **natural state**.
- Different **NSU thresholds** are defined based on environmental conditions:
  - **Pristine areas** (e.g., national parks): **1–2 NSU**
  - **Rural areas**: **2–5 NSU**
  - **Suburban areas**: **5–10 NSU**
  - **Urban areas**: **10–20 NSU**
- The **Oukaimeden area** falls within the **pristine category**.



Introduction to the GAMBONS Model: Estimating Natural Night Sky Brightness

GAMBONS (GAia Map of the Brightness Of the Natural Sky) is a model designed to estimate the natural night sky brightness during cloudless and moonless nights. It is based on extra-atmospheric star radiance data derived from the Gaia catalogue, providing a detailed representation of the sky's intrinsic brightness in the absence of artificial light.

Contribution of Natural Brightness (Moonlight, Galaxies, etc.) at Oukaimeden Observatory Using the GAMBONS Model



This figure illustrates that natural light, including moonlight and celestial objects such as galaxies, is the sole source of brightness at the Oukaimeden Observatory. This is a positive outcome that should be maintained. To preserve these conditions, it is crucial to manage and control artificial light pollution around the observatory in the future.

Natural Light Pollution at Oukaimeden Observatory: Insights from the GAMBONS Model

The GAMBON model provides the natural component of light pollution, and in our study, the results indicate that the sources of pollution are primarily from galaxy and Moon. This is a positive outcome for the Oukaimeden Observatory, as it aligns with our objectives for the ADSM project.

Using the GAMBON model, we obtained a magnitude of night sky brightness (NSB) of **21 mag/arcsec^2**, which matches the values typically measured with an **CoSQM**.

The preliminary conclusion is that the Oukaimeden Observatory's sky qualifies as a Class 1 dark site, making it an excellent location for astronomical observations.

Conclusion: Part I

Source/Model	Radiance (W/m^2/str)
Artificial Light (Illumina)	5,33085 e -14
Natural Light (Gambons)	3,750 e -7

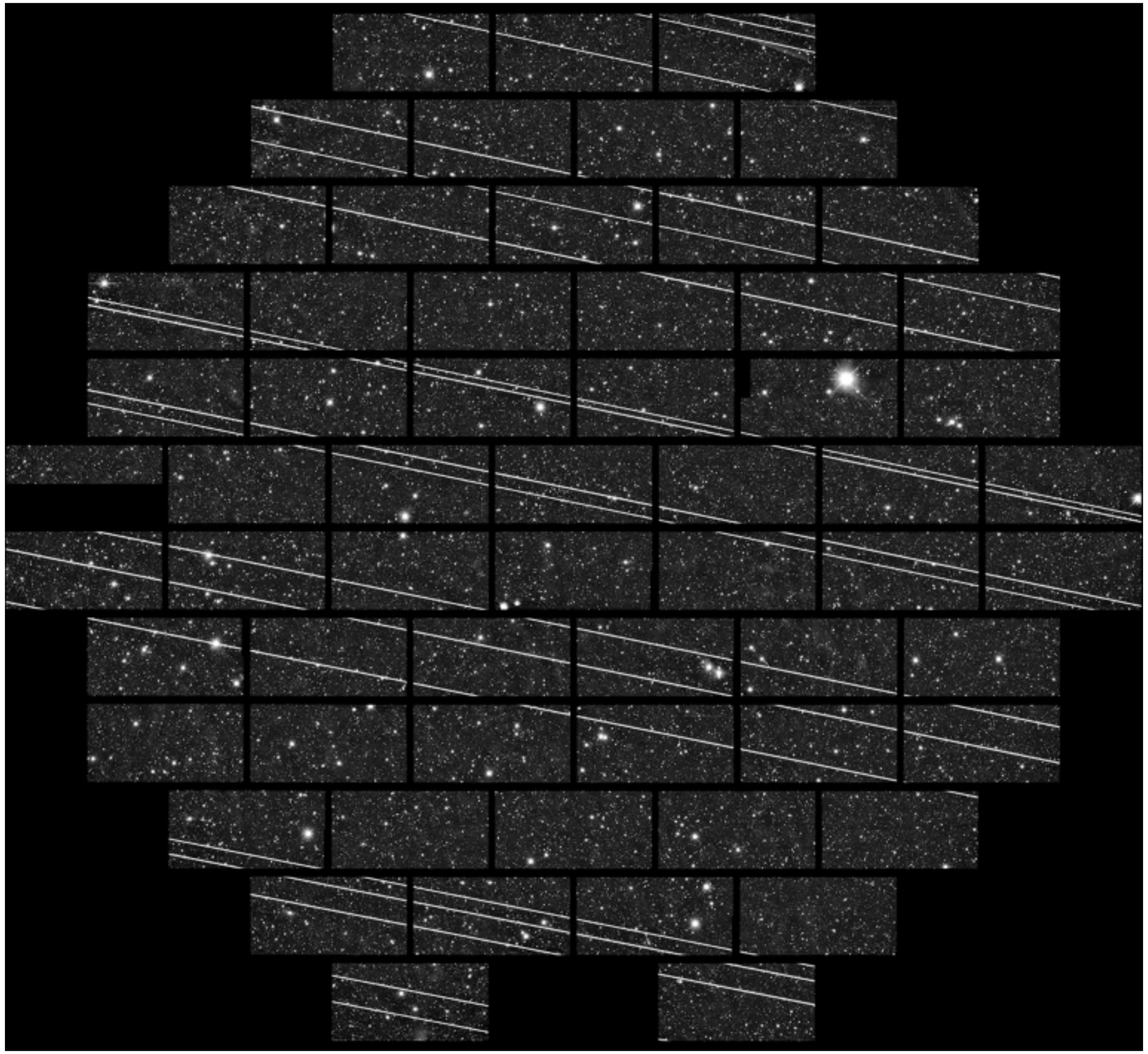
As highlighted in the previous slides, the results from both models confirm that the contribution of artificial light is minimal, while the natural light component predominates. This is a positive outcome for the observatory and supports the objectives of the ADS Reserve project.

Satellite streaks appear in a photograph taken above the Pinnacles in Nambung National Park, Western Australia. Credit: Joshua Rozells

WHAT TO DO ABOUT SATELLITES HARMING ASTRONOMY

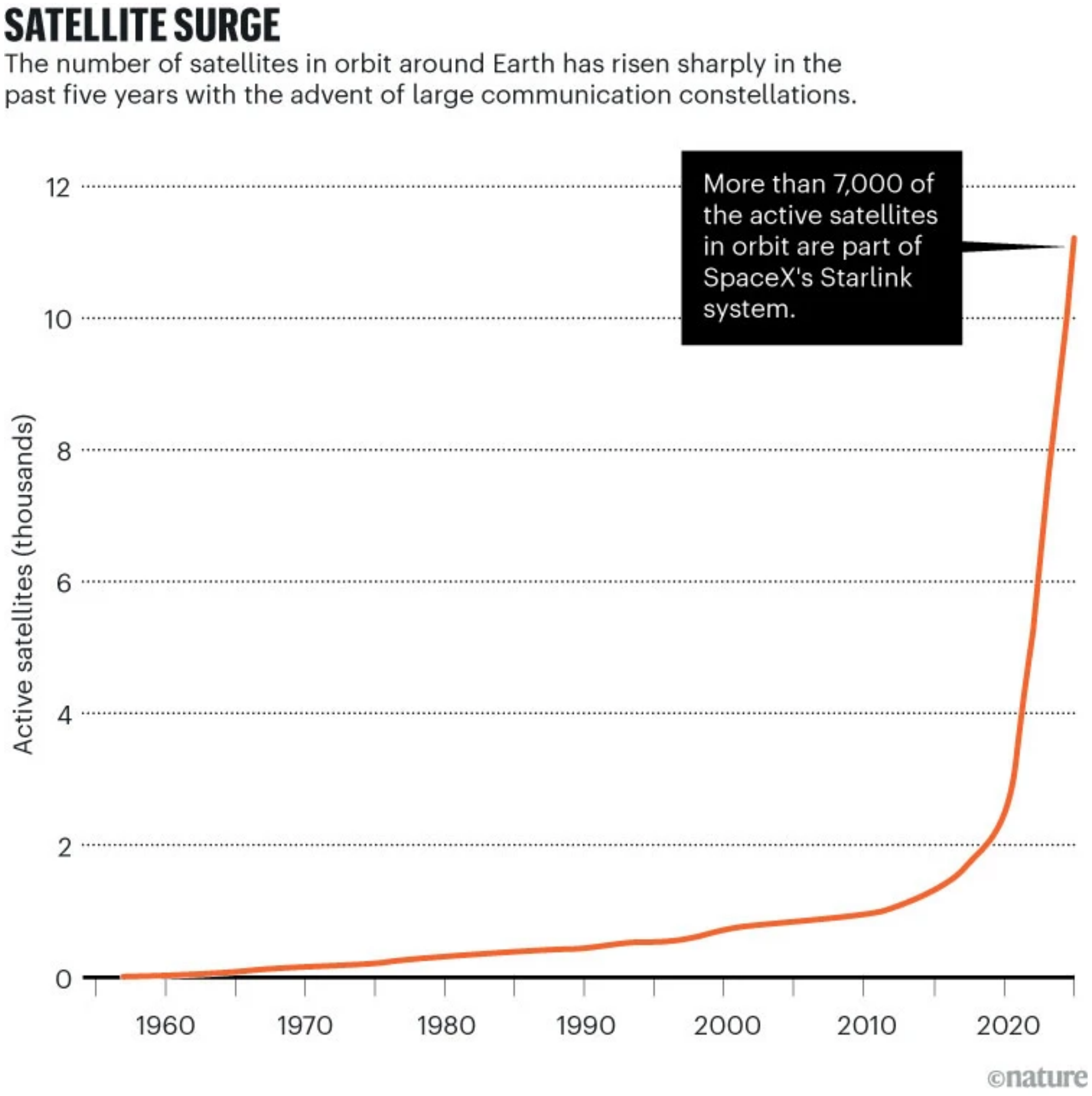
SpaceX and other companies plan to launch tens of thousands of satellites, which could mar astronomical observations and pollute the atmosphere. **By Alexandra Witze**

Nature | Vol 639 | 20 March 2025



Starlink satellites leave streaks in a 2019 image taken by a 4-metre telescope at the Cerro Tololo Inter-American Observatory in Chile.

Credit: CTIO/NOIRLab/NSF/AURA/DECam DELVE Survey



Sources: Jonathan’s Space Pages (https://go.nature.com/4IV22FD; https://go.nature.com/4225MKX)

Oukaimeden Observatory: A Key Player in Satellite Observations

As a partner of the **IAU-CPS** center, the Oukaimeden Observatory plays a crucial role in satellite observations. Equipped with a diverse array of telescopes, it provides essential observation services, conducts daily monitoring, and fosters international collaboration. Its advanced orbital data processing capabilities enhance mission planning and optimize scientific contributions.

Introduction

The rise of artificial satellites and mega-constellations poses challenges such as orbital congestion and light pollution Boley and Byers [2021], Nandakumar et al. [2023], Bassa et al. [2022].
Cadi Ayyad Observatory addresses these issues through infrastructure and multinational collaborations. Research areas include:

- Orbital parameter prediction
- Photometric studies
- AI for hazard prediction
- Impact assessment on the night sky

Observation Facilities in OUCA

- **MOSS:** 0.50 m mirror, IMX 455 CMOS, 2.1° FOV
- **OWL:** 1.75° FOV, Zerodur mirror, robotic mount, FLI-PLI16803 CCD
- **HAO:** e.g., HAO4, Takahashi FSQ 85, ZWO ASI 2600 MM Pro, 3.6° FOV
- **Spaceflux:** 40 cm Planewave, magnitude and coordinates extraction

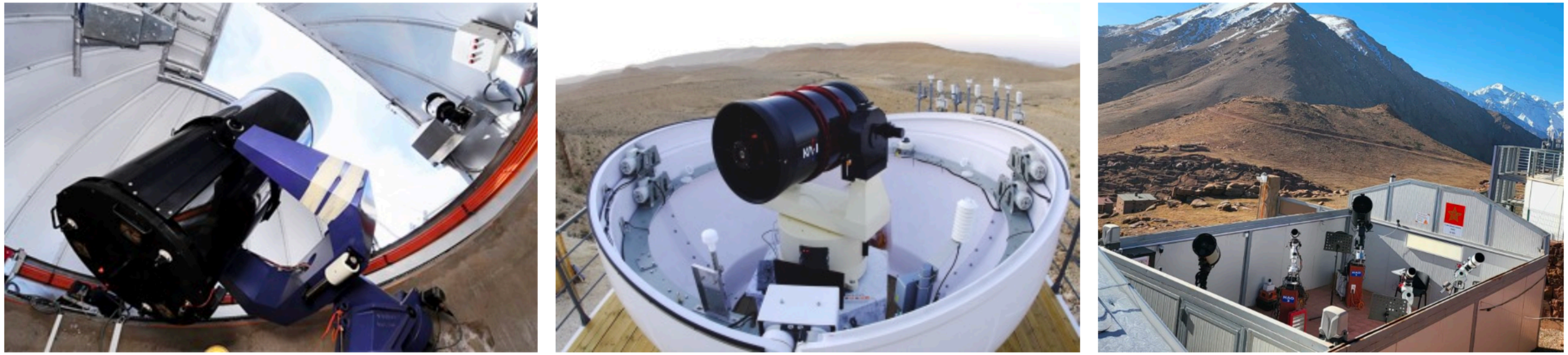


Figure: From left to right: MOSS, OWL-Net, and HAO telescopes

Observation Planning

- Website: `https://ouca.uca.ma/Satellites/`
- Target selection by magnitude: <6 for Starlink, <8 for OneWeb
- Night-beginning scheduling preferred

Figure: Observation planning interface

Example Planning Output

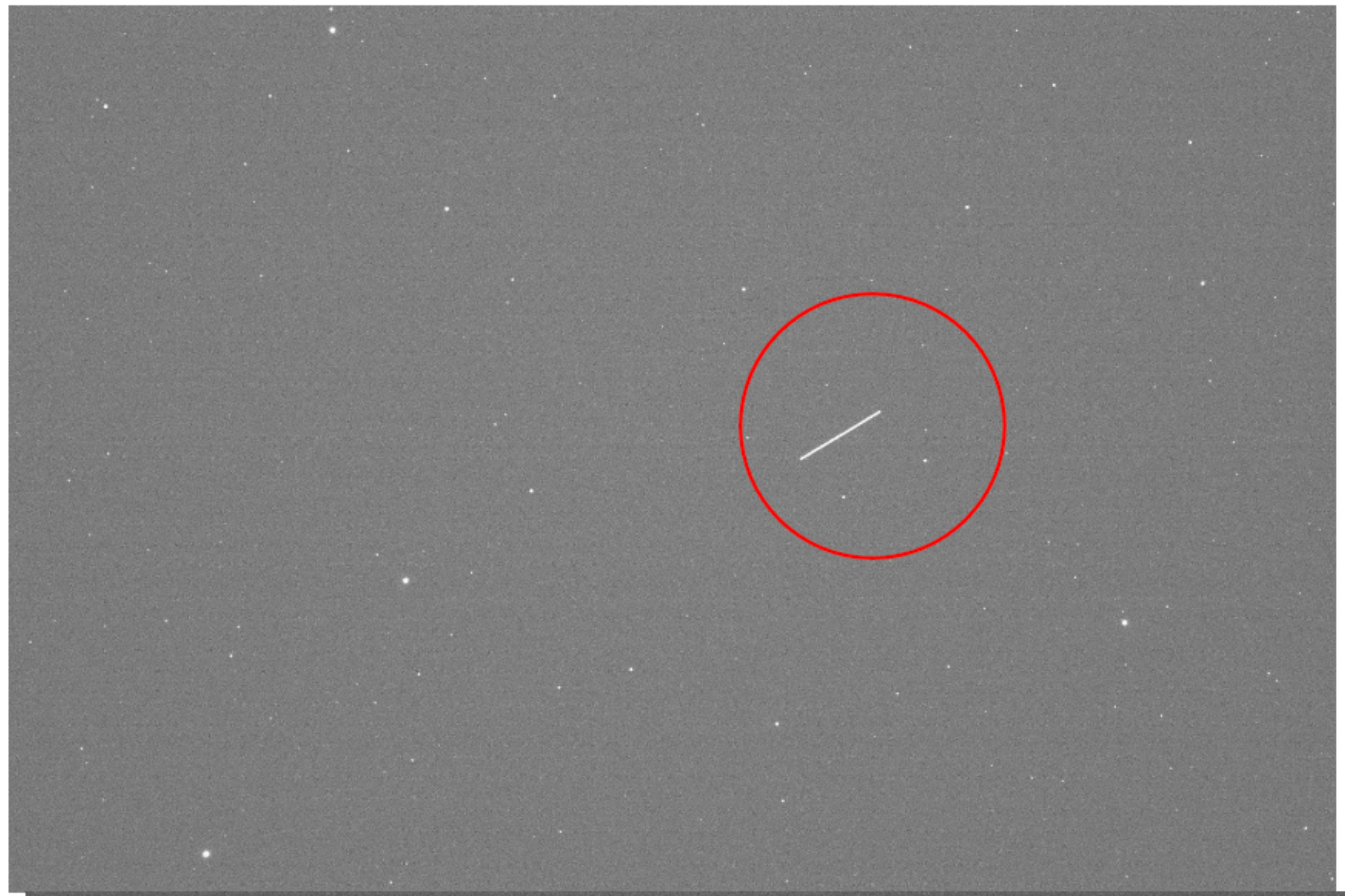
- Detailed info: name, NORAD ID, magnitude, RA/Dec, date/time
- Website provides real-time planning tables and visualization

Name	NORAD	i-Mag	Dist(km)	Mag	Phase	RA	Dec	Time	Latitude
STARLINK-1007	44713	5.0	603.9	3.9/1.1	85.3	16h 44m 19.99s	'+46deg 51' 06.3"	2023/09/25 18:50:43	63.5299
STARLINK-1008	44714	5.0	1511.0	6.1/3.5	80.7	13h 25m 14.19s	'+36deg 56' 45.4"	2023/09/25 19:57:35	15.0009
STARLINK-1008	44714	5.0	1466.7	6.0/3.4	79.7	13h 14m 05.19s	'+43deg 00' 10.5"	2023/09/25 19:57:59	15.8892
STARLINK-1008	44714	5.0	1439.7	5.9/3.2	78.7	12h 58m 52.82s	'+49deg 11' 15.5"	2023/09/25 19:58:23	16.4572
STARLINK-1008	44714	5.0	1430.8	5.8/3.2	77.6	12h 37m 50.26s	'+55deg 16' 16.8"	2023/09/25 19:58:46	16.6513
STARLINK-1008	44714	5.0	1440.4	5.8/3.3	76.6	12h 08m 19.95s	'+60deg 56' 46.0"	2023/09/25 19:59:10	16.4521
STARLINK-1008	44714	5.0	1468.2	5.9/3.4	75.6	11h 26m 56.99s	'+65deg 48' 57.8"	2023/09/25 19:59:34	15.8805
STARLINK-1009	44715	5.0	1509.8	6.2/3.5	85.2	13h 53m 31.68s	'+17deg 46' 56.8"	2023/09/25 19:40:01	15.0015
STARLINK-1009	44715	5.0	1354.0	5.8/3.0	83.4	13h 46m 04.29s	'+28deg 41' 40.9"	2023/09/25 19:40:44	18.3408
STARLINK-1009	44715	5.0	1251.5	5.6/2.6	81.5	13h 31m 36.57s	'+41deg 33' 15.6"	2023/09/25 19:41:28	20.9383
STARLINK-1009	44715	5.0	1216.1	5.4/2.5	79.6	13h 02m 35.66s	'+55deg 23' 03.1"	2023/09/25 19:42:11	21.9366
STARLINK-1009	44715	5.0	1253.6	5.5/2.6	77.8	11h 58m 13.65s	'+67deg 56' 15.4"	2023/09/25 19:42:55	20.905
STARLINK-1009	44715	5.0	1357.8	5.6/3.0	75.9	09h 35m 08.62s	'+75deg 11' 21.6"	2023/09/25 19:43:38	18.2955

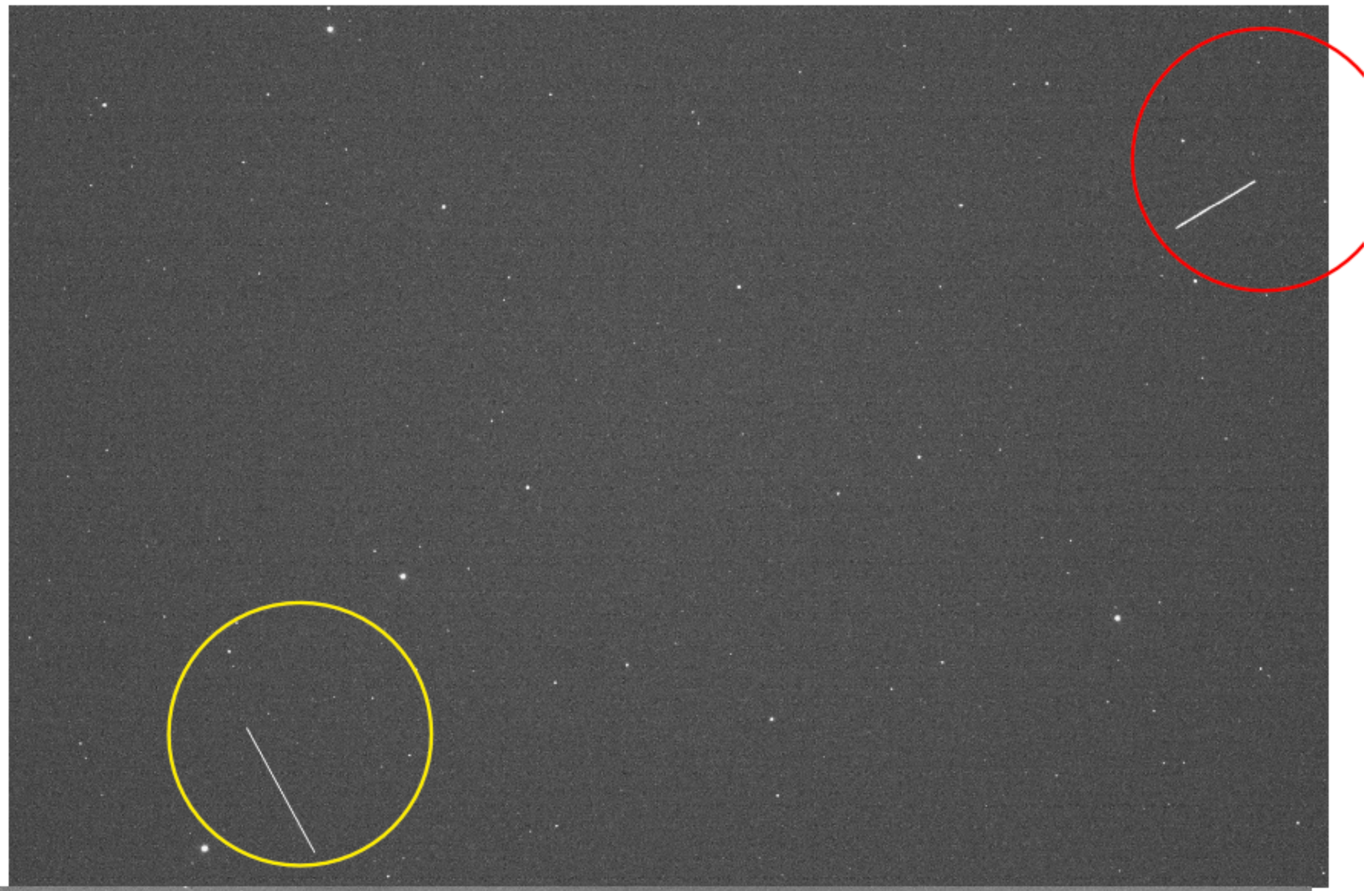
Table: Example of a planning result from the observatory website `https://ouca.uca.ma/Satellites/`. The result contains several pieces of information, including predicted magnitude, distance, phase, coordinates in the geocentric reference, and transit time.

Data Processing: Filtering Algorithm

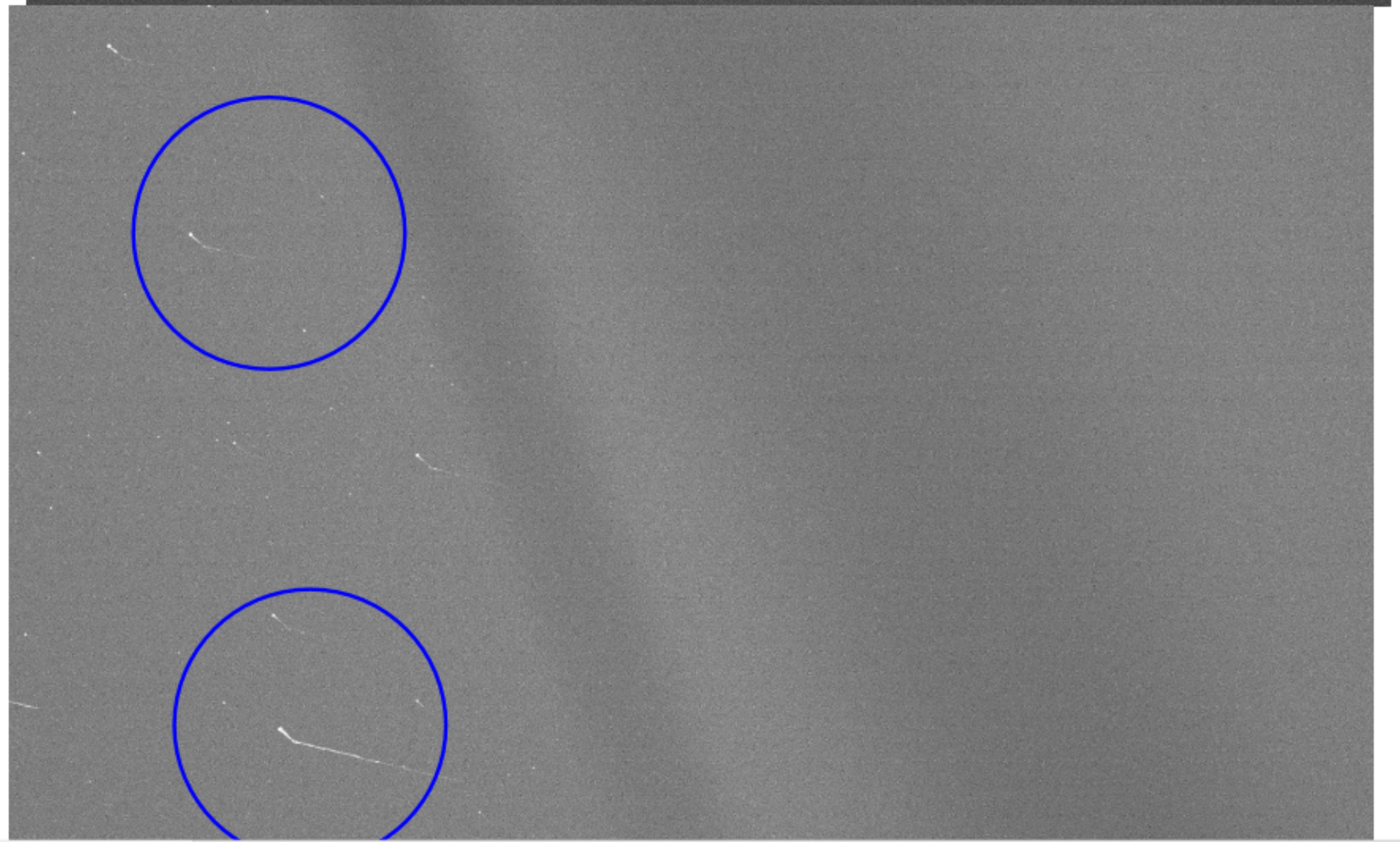
- Identify valid satellite streaks using TLE-based prediction
- Reject false positives: star trails, distorted signals



Accurately identifying the desired streak and false streak



Eliminate any distorted or incomplete streaks.



Photometry and Astrometry

Satellite magnitudes are calculated
by identifying the brightest stars and trails using PROSE Garcia et al. [2022]. The positions of the stars extracted from the image are then compared with the Gaia catalog via Twirl Garcia et al. [2022], enabling catalog data, such as magnitude and distance, to be associated with the detected stars.
The generation of the World Coordinate System (WCS) for an image is simplified using Astropy Price-Whelan et al. [2018]

- Brightest stars and streaks measured using PROSE
- Gaia catalog via Twirl for reference data
- WCS generated using Astropy

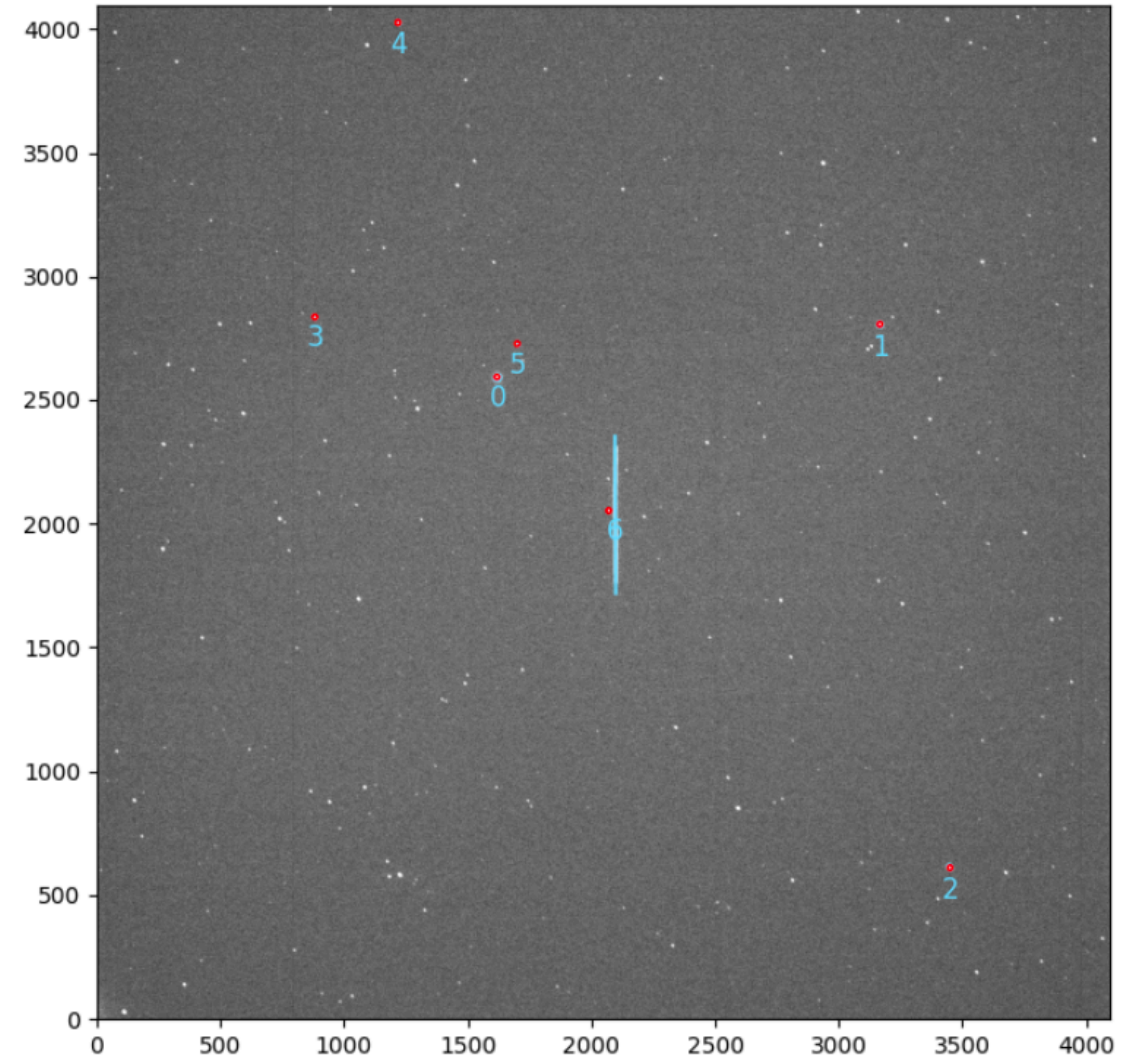


Figure: Classify the stars in the image by intensity value order and import their characteristics from the Gaia catalog after completing the plate-solving process.

Example of Photometry Results

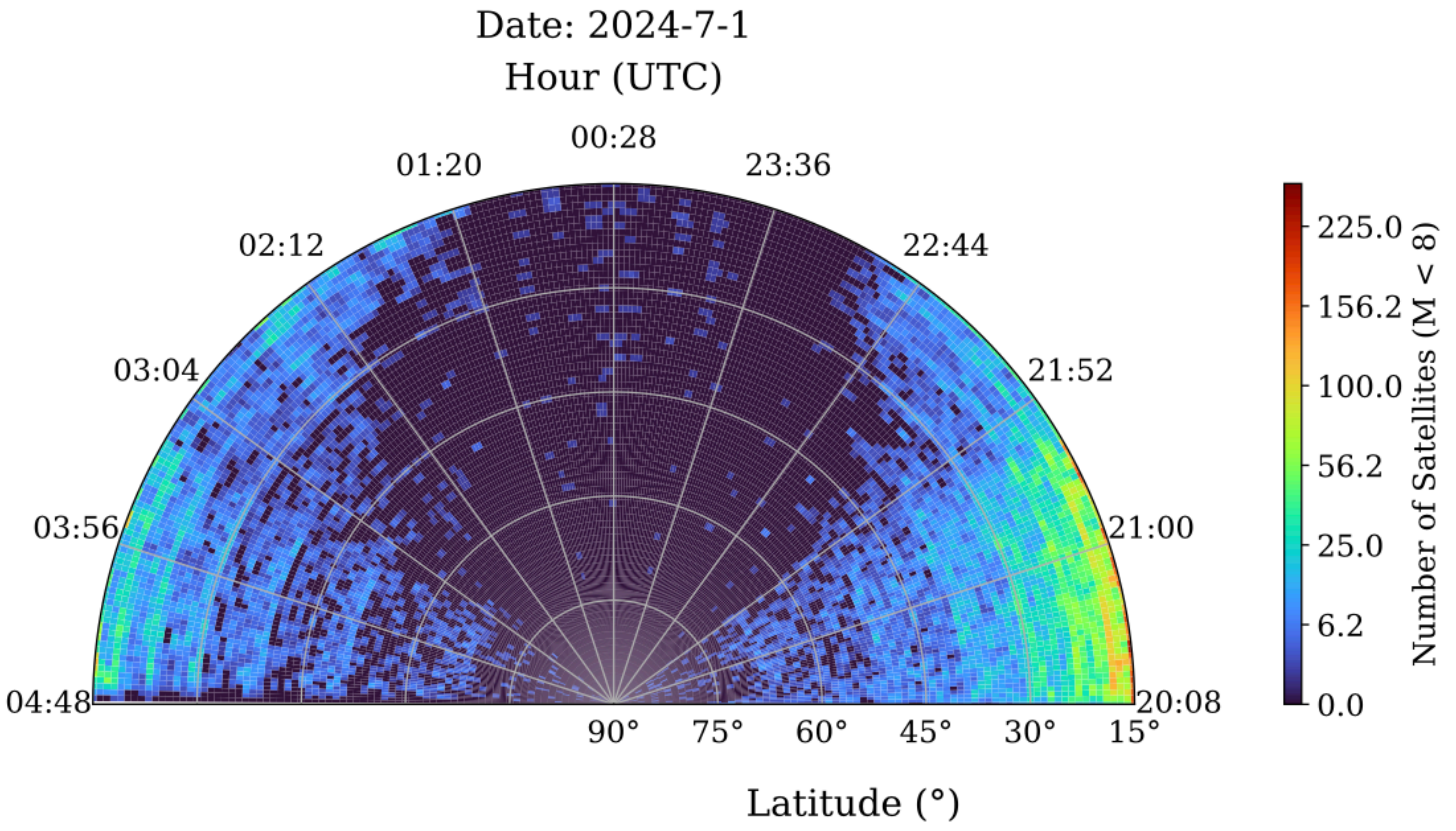
The result of the classification is reported in the table 2, including the total intensity of the streak.

Star	**Coordinates** α, δ	**Flux**	**Magnitude**
0	**149.02, -40.82**	**894813.28**	**5.57**
1	**149.57, -40.76**	**425403.24**	**6.48**
2	**149.68, -41.35**	**205551.8**	**7.13**
3	**148.75, -40.75**	**96736.40**	**7.99**
4	**148.87, -40.43**	**96025.45**	**8.022**
5	**149.05, -40.78**	**58376.28**	**8.58**
6	**148.90, -40.85**	**54862.36**	**8.71**
Streak Magnitude		**2010547.6**	**4.70**

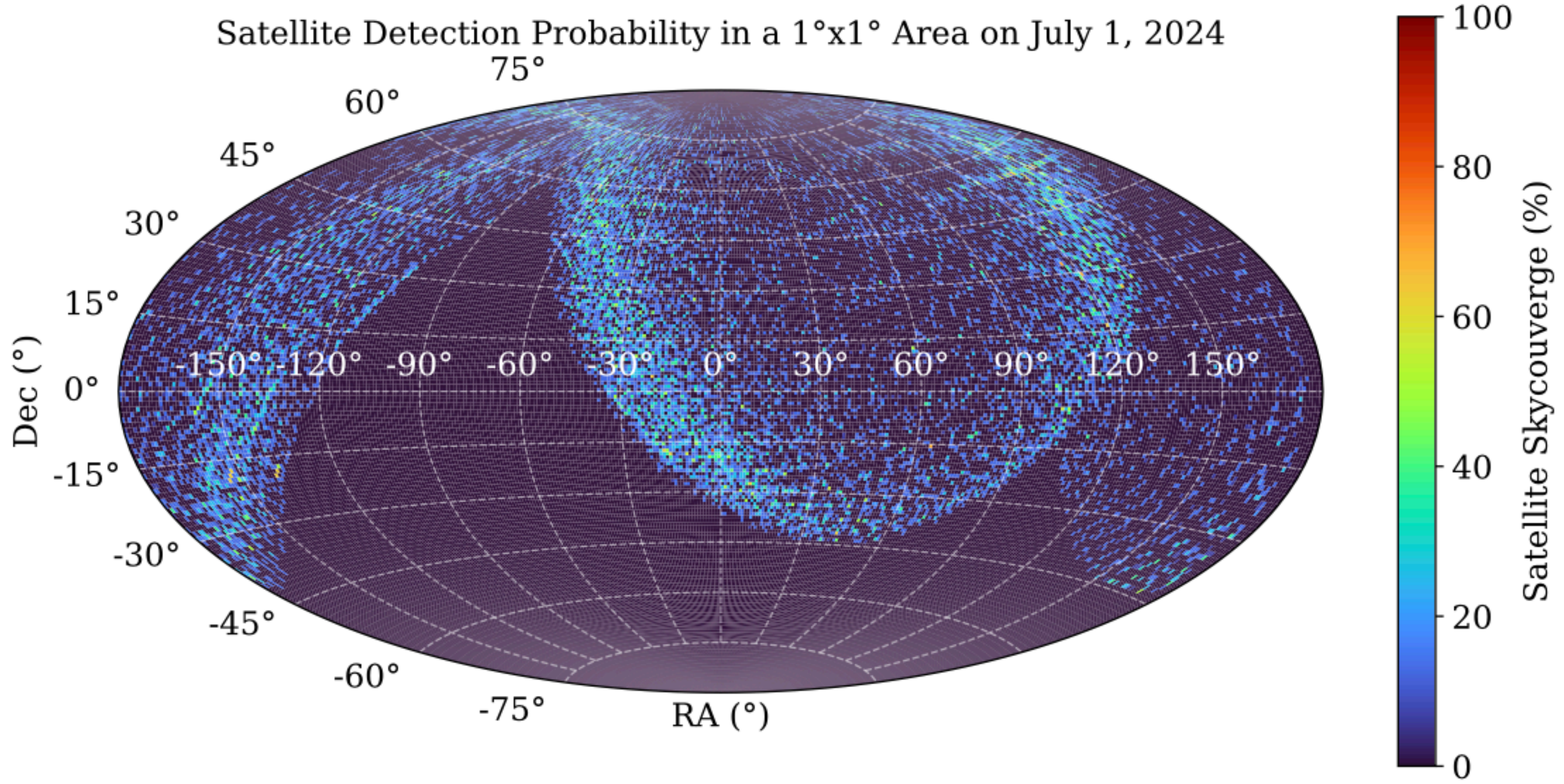
Table: The estimated magnitude of the streak is obtained by integrating the flux.

Satellite Sky Impact at OUCA

We simulated the visibility of 56,081 satellites based on their intrinsic magnitudes from Oukaimeden Observatory. Using a visual magnitude limit of 8, the simulation tracks satellite presence from sunset to sunrise. Data was sampled every 2 minutes across each degree of latitude to assess sky coverage.

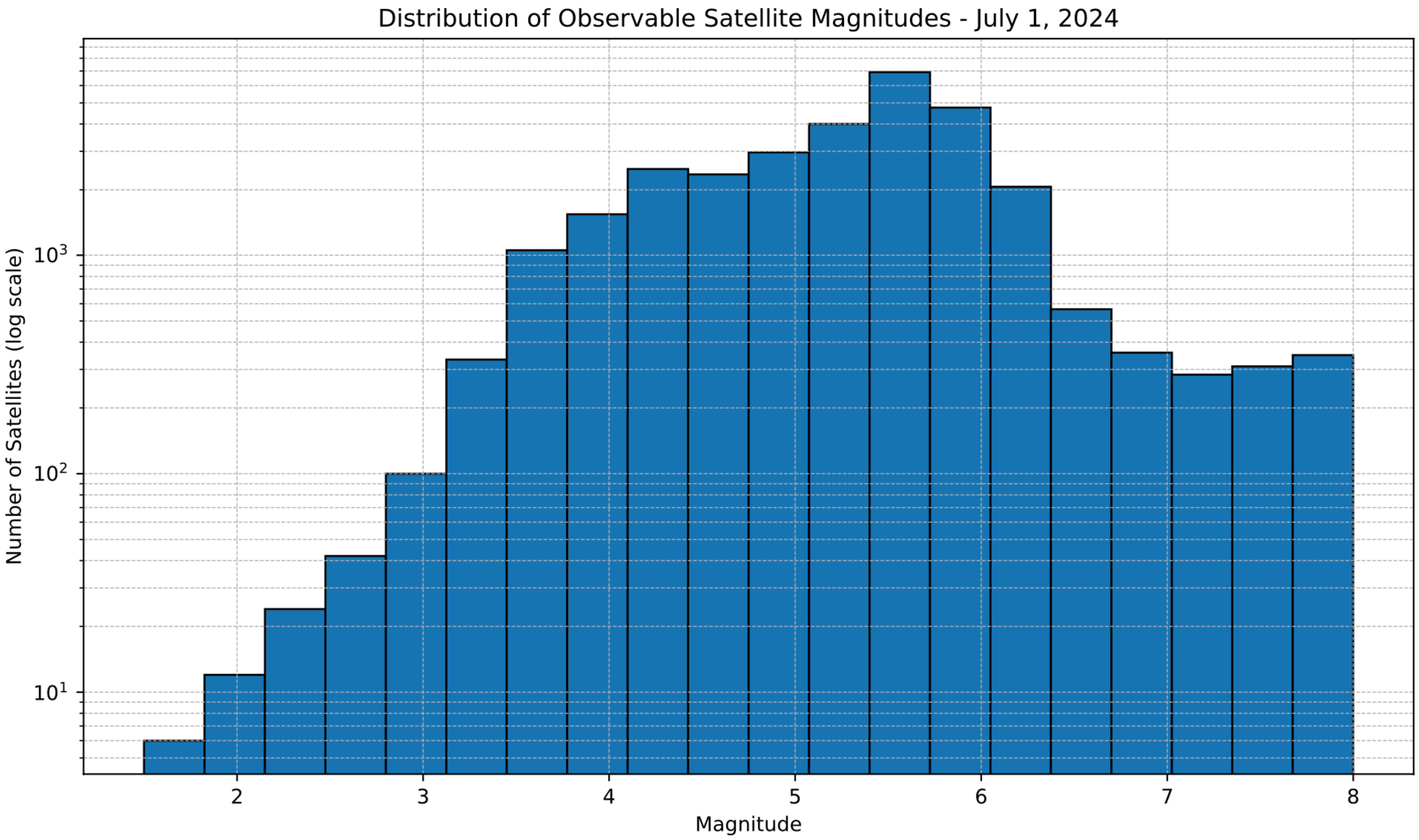


(a) Satellite observable density during the night at different latitudes



(b) Sky coverage of observable satellite

Distribution of the numbre of observable satellite by magnitude



Conclusion Part II

- OUCA has advanced satellite tracking infrastructure and analysis capabilities
- Collaboration and research expand global efforts to preserve the night sky
- Future goals: improve methods and partnerships for dark-sky protection

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THANK YOU FOR YOUR TIME AND ATTENTION