Mitigating Interference from Mega Satellite Constellations in Optical Astronomy: Regional Case Study from Pakistan

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Overview

PART – I: Pakistan Astronomical Development Program
PART - II: Interference & Mitigation from Mega-satellite Constellations
Part – III: National Regulatory Initiatives: Status Update

PART – I: Pakistan Astronomical Development Program

Astronomical Sites & Phase-wise Development

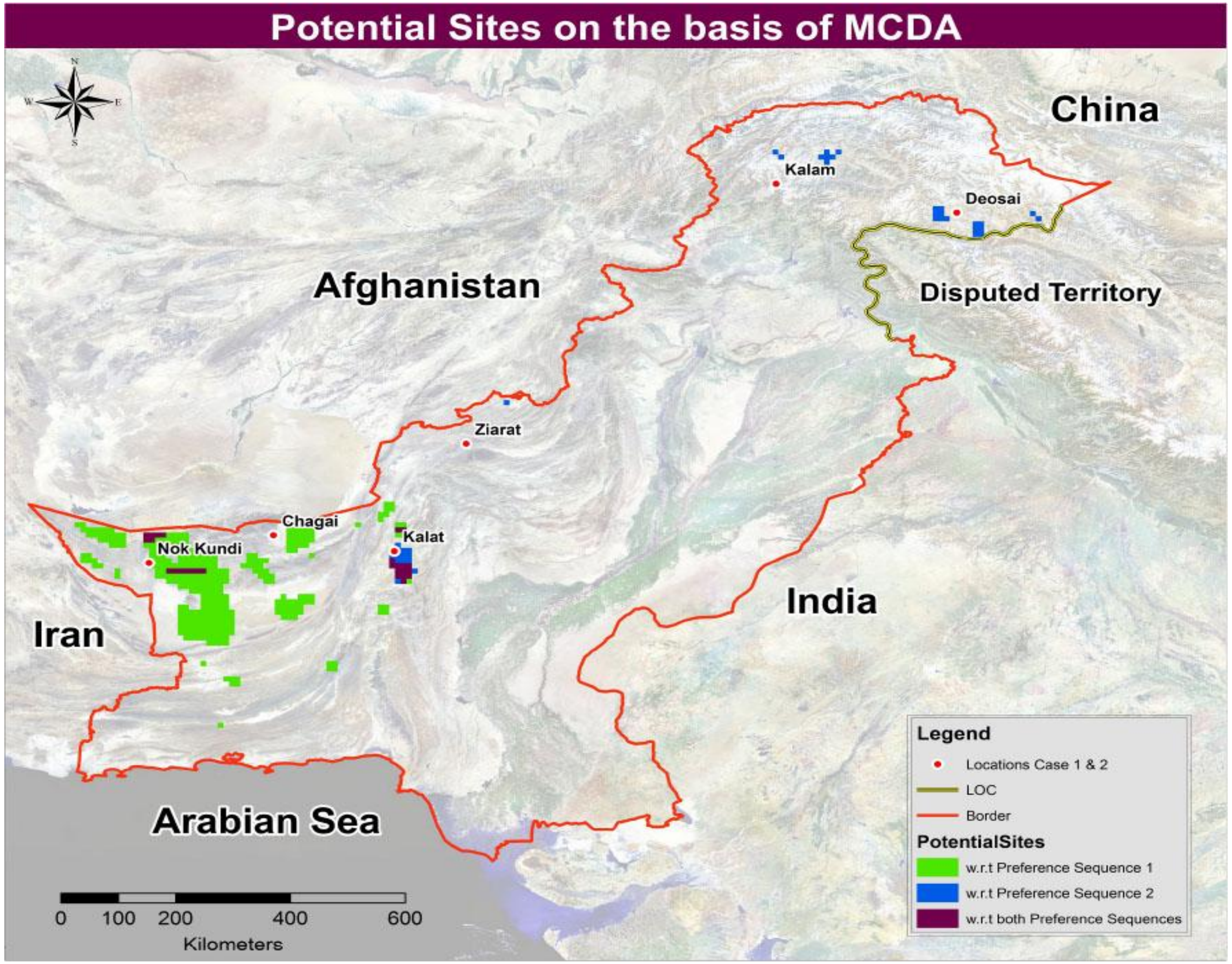
Phase 1 (2017 – 2027) – Ground-Based Optical Telescopes Network

- Observatories in Sonmiani, Balochistan (Established)
- Observatories in Deosai, Gilgit-Baltistan (In progress)

Phase 2 (2027 – 2030) – Radio Telescopes Array

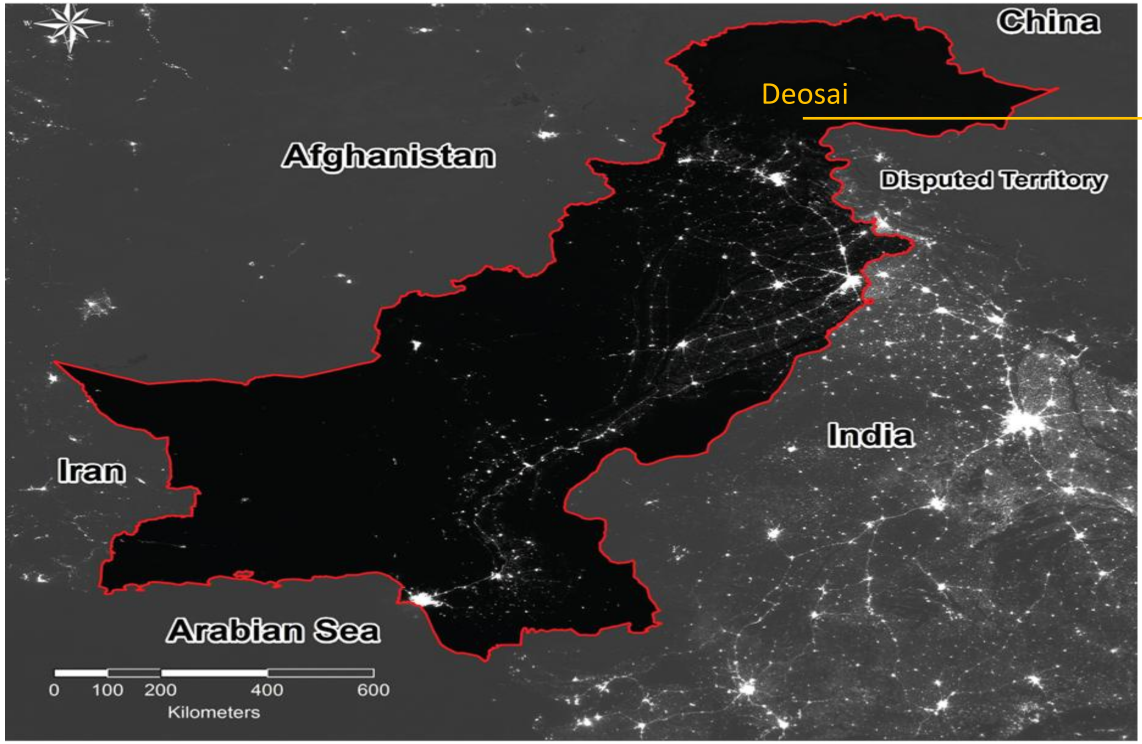
Phase 3 (2030 – 2035)– Space-based Telescopes

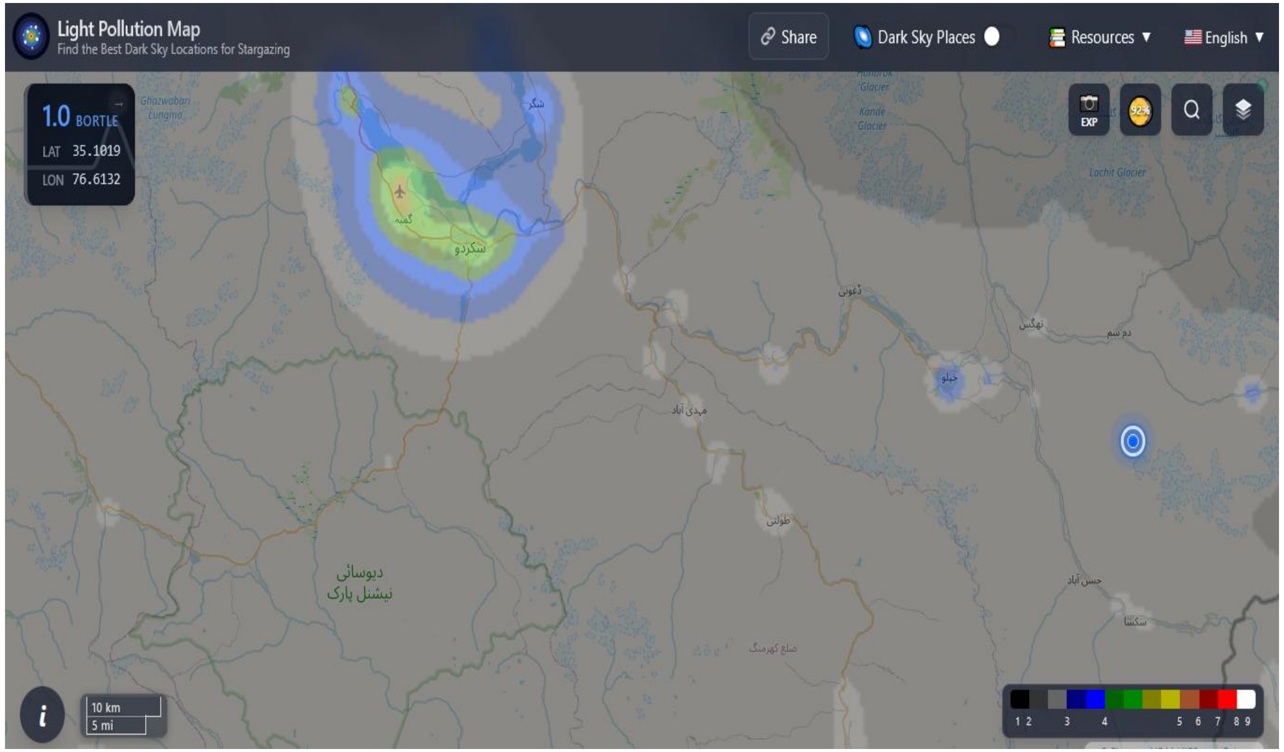
Evaluation Criteria	Preference Sequence 1	Preference Sequence 2	PriorityOrder
Criteria 1	Photometric Night Fraction	Altitude	1
Criteria 2	Night-Sky Brightness	Photometric Night Fraction	2
Criteria 3	Sky Transparency	Night-Sky Brightness	3
Criteria 4	Altitude	Sky Transparency	4
Criteria 5	Seismic Vulnerability	Seismic Vulnerability	5
Criteria 6	Accessibility	Accessibility	6
Criteria 7	Wind Speed	Wind Speed	7
Criteria 8	Terrain Slope	Terrain Slope	8
Criteria 9	Landuse/Land Cover	Landuse/Land Cover	9



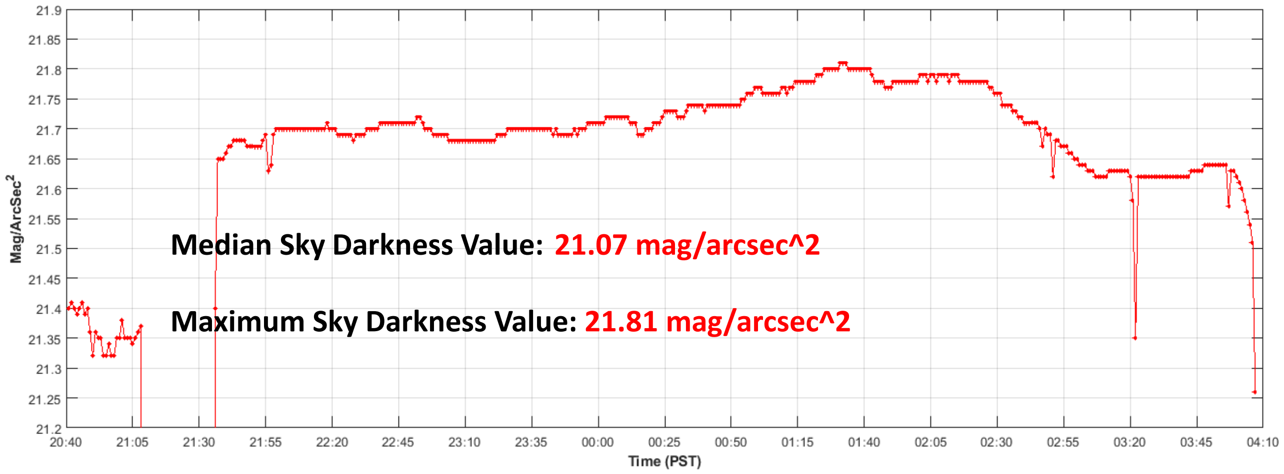
Fig/Table: Daniyal and Syed Jamil Hassan Kazmi 2019 *Res. Astron. Astrophys.* **19** 129

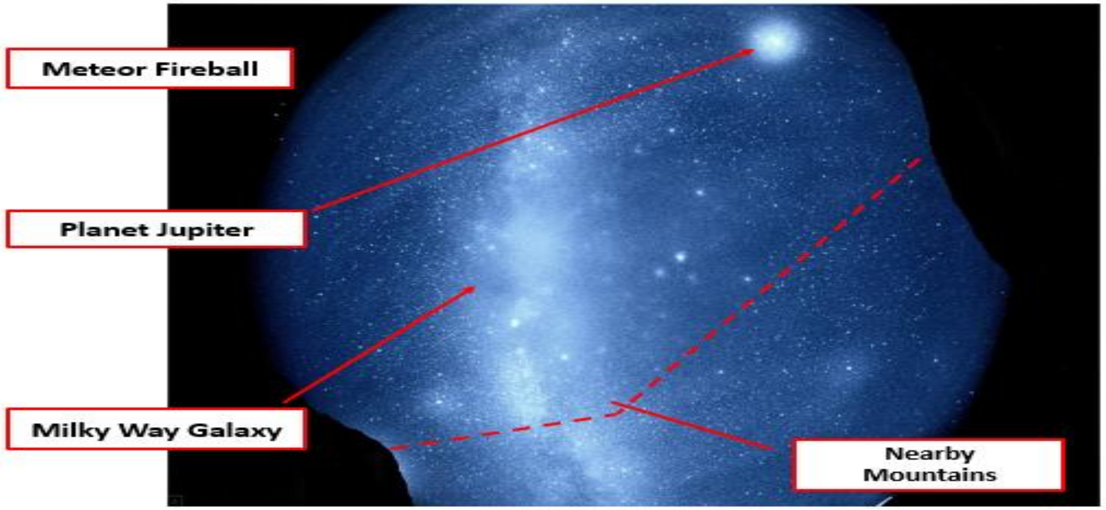
Dark Skies Pakistan - Deosai Plains





Night Sky Brightness – VIIRS Mean of Jan, Feb & March Monthly Composites

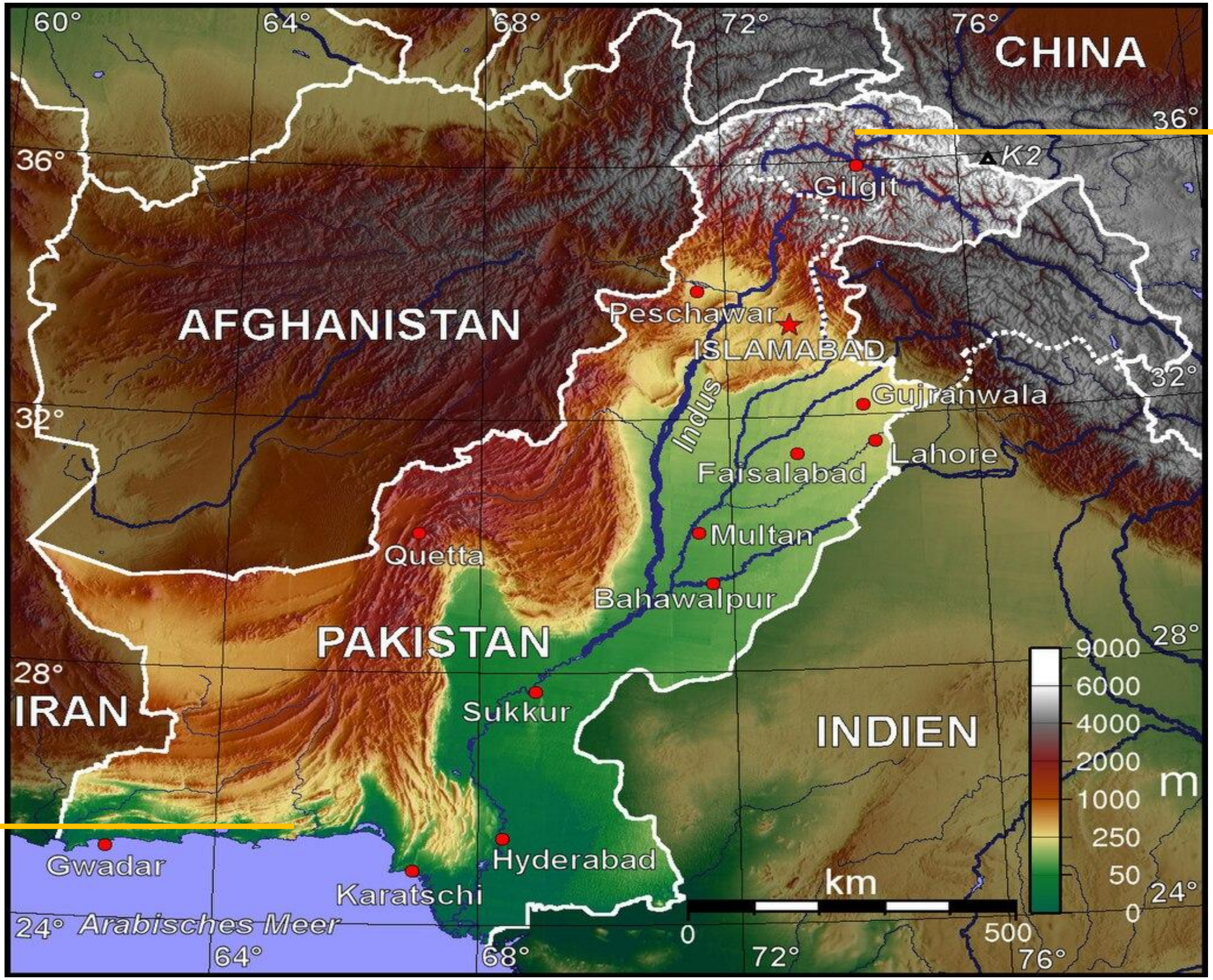




Optical Observatories Network

In Development

Sonmiani Site (S2)



Existing Facility

Deosai Site (S1)

In development

Objectives

I. Asteroid Detection
II. All Sky Survey
III. Deep-Sky Imaging (Galaxies, Nebulae, Star Clusters)
IV. Space Debris Tracking <10cm
V. Supernova & Transient Object Monitoring

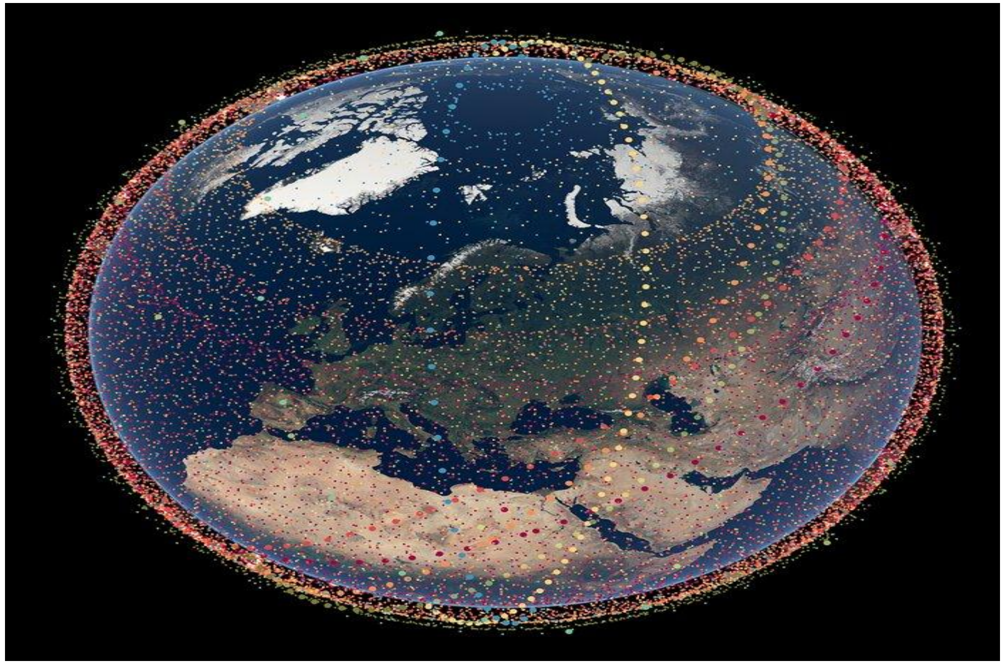
PART – II: Mega-Constellations Interference

Starlink Gen 2 Constellation

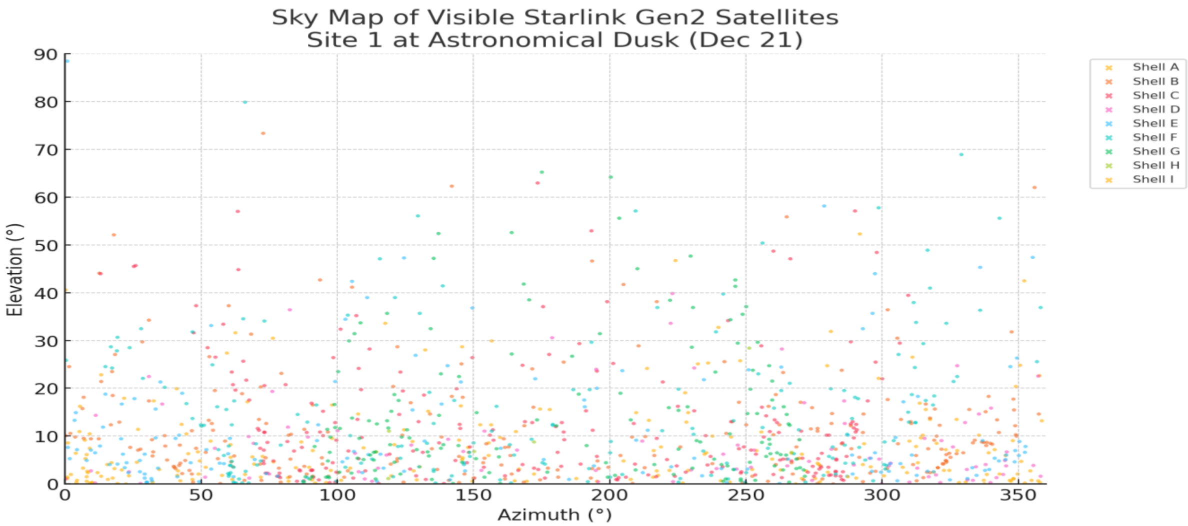
Starlink Gen1 = ~4408 satellites
Starlink Gen2 = 29,988

Layer	Altitude (km)	Inclination (°)	Orbital Planes	Satellites per Plane	Total Satellites
A	340	53	48	110	5,280
B	345	46	48	110	5,280
C	350	38	48	110	5,280
D	360	96.9	30	120	3,600
E	525	53	28	120	3,360
F	530	43	28	120	3,360
G	535	33	28	120	3,360
H	604	148	12	12	144
I	614	115.7	18	18	324
				Total	**29,988**

Table: Starlink Gen2 Constellation Properties Proposing 29,988 Satellites in Total with 19,440 in VLEO <450 km (layers A–D) and 10,548 in the Traditional LEO Range >450 km (layers E–I; W. Wiltshire 2021)



Credit: ESO Starlink Gen 2 constellation Visualization



Observational Analysis

Simulated Parameters

a. 15x 150mm Aperture
b. Focal length: 210mm±3mm;
c. FOV: 10° x 10°;
d. Spectral line: 650nm, with chromatic aberration corrected at 550-800nm;
e. Focal Ratio: about f/1.4;
f. Limiting Mag: 11 mag
g. Image Scale: ~8.83 arcsec per pixel

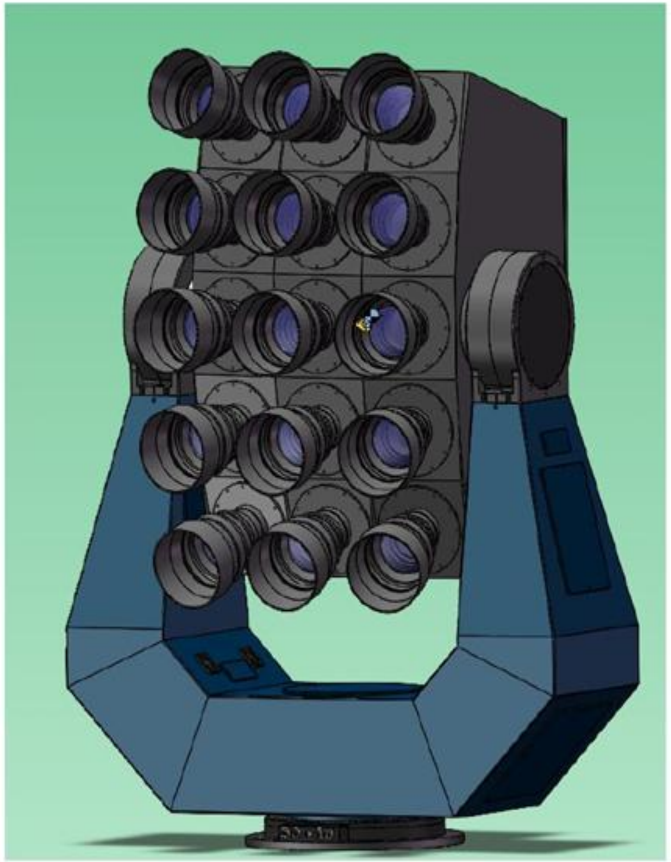


Fig: 15x array Telescope

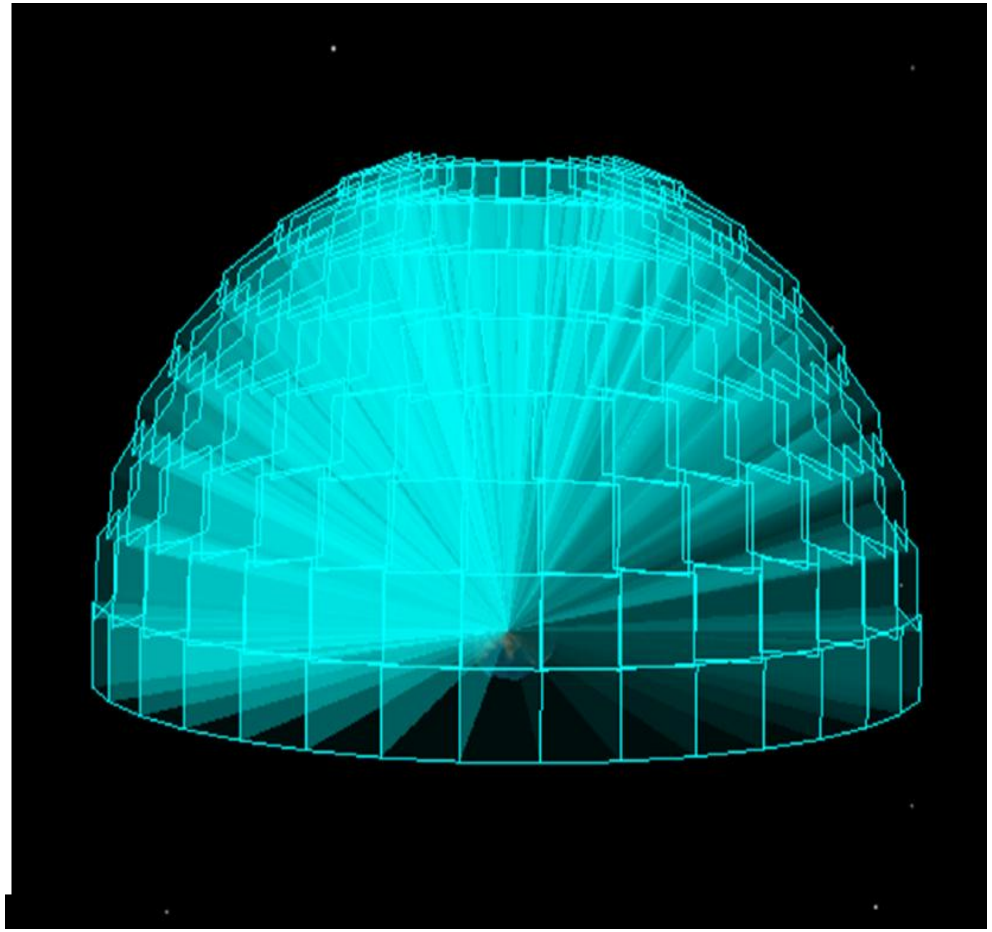
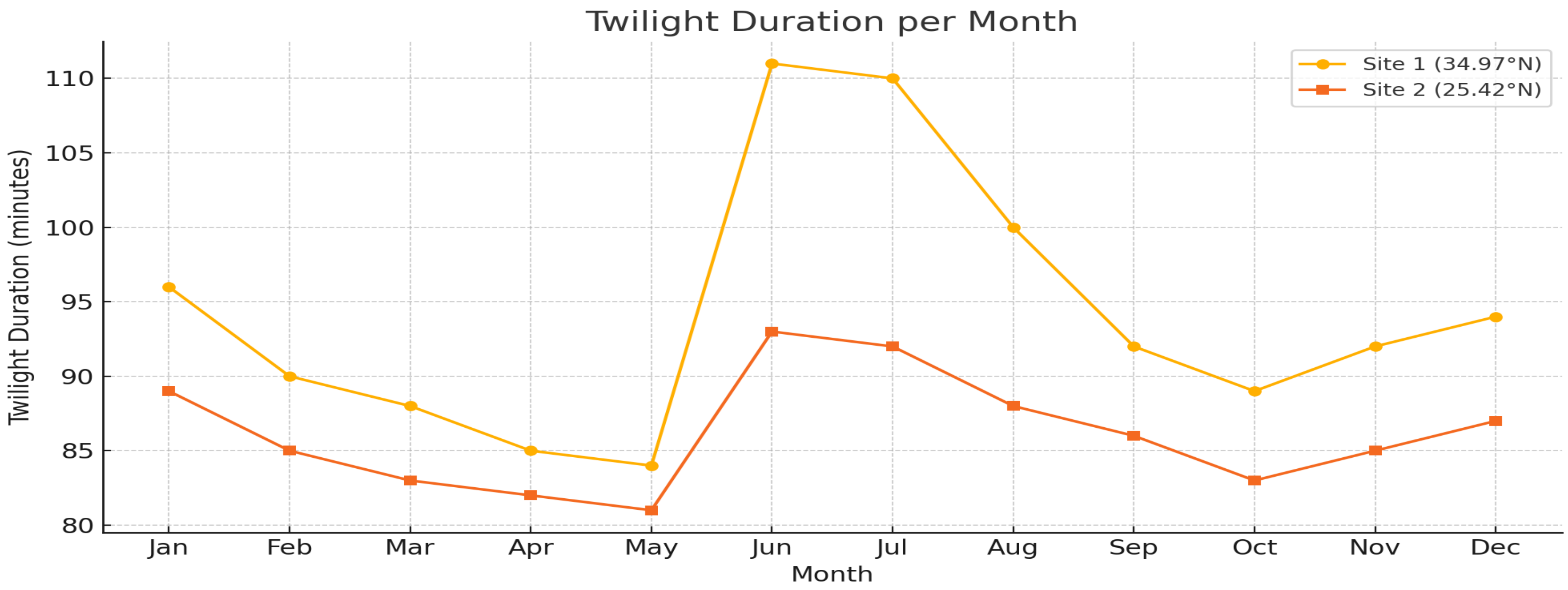


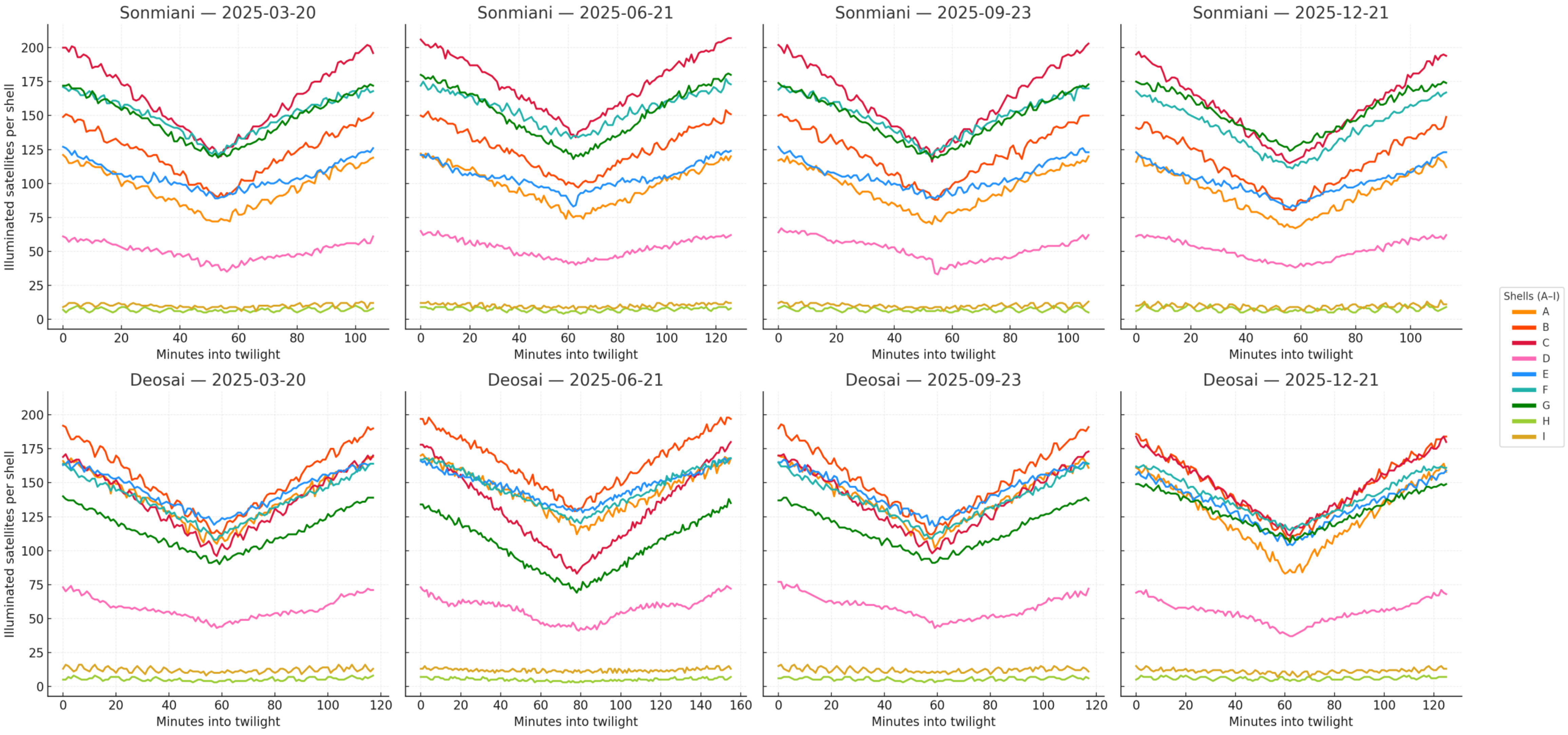
Fig: 20 to 90 Degree Elevation Sky Area Coverage

Sites - Twilight Conditions

Site	Latitude	Astronomical Twilight (sun –12° to –18°)	Longest Night (approx)	Shortest Night (approx)
Site 1 (Deosai)	34.97°N	~40–45 minutes	~14.4 h (Dec)	~9.6 h (Jun)
Site 2 (Sonmiani)	25.42°N	~25–30 minutes	~13.6 h (Dec)	~10.4 h (Jun)

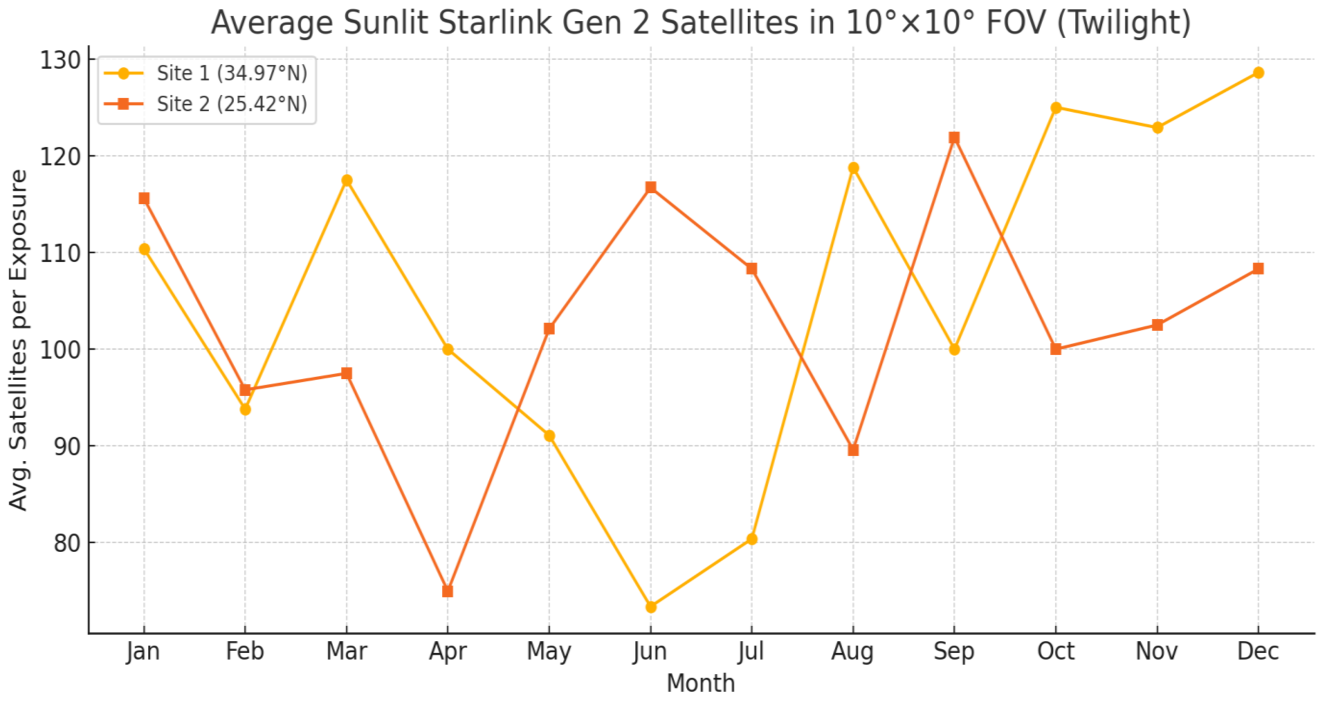


Satellites Visibility



STREAK COUNTS (PER EXPOSURE)

Shell	Altitude	Typical Heatmap Behavior
A/B/C (340–350 km)	VLEO	Appear **very bright and fast**, concentrated at **40–60° elevation**.
D (360 km, 96.9° incl)	Polar	Forms **rings around full azimuth**, visible at all az.
E/F/G (525–535 km)	Mid-inclination	Largest counts, most uniform sky coverage.
H (604 km, 148°)	High-inclination	Distinctive **north–south arcs**.
I (614 km, 115°)	Retrograde	Broad dispersal, more **eastern/western** clusters.



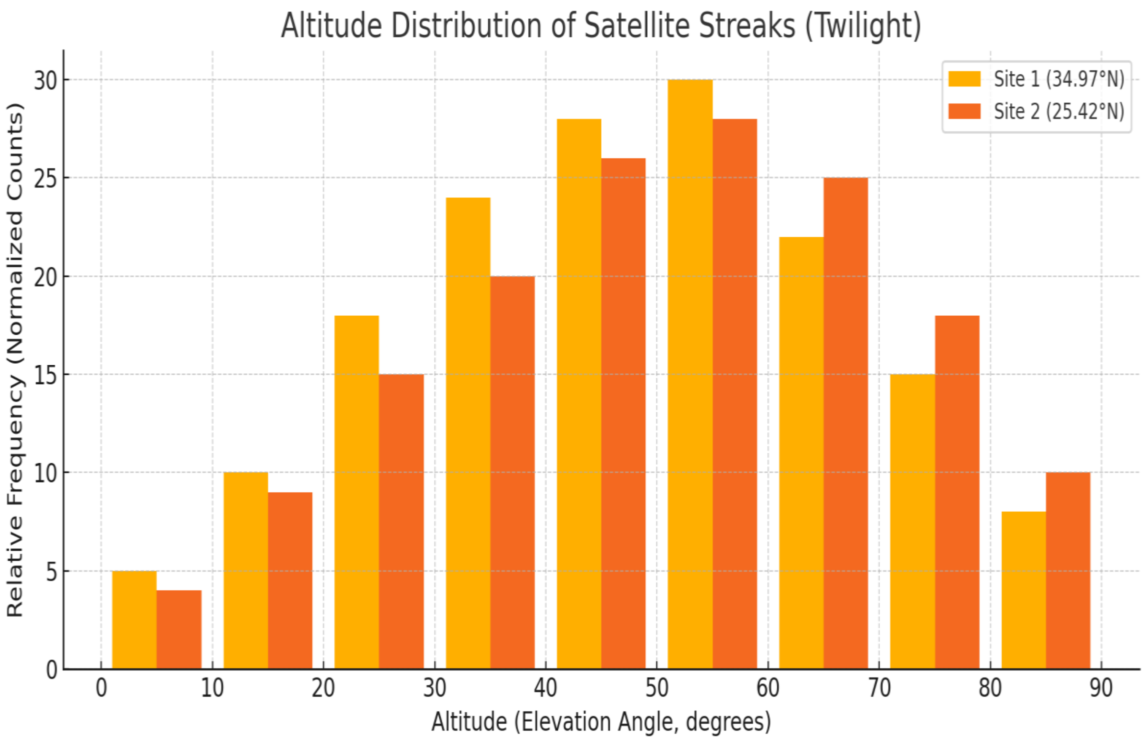


Fig: Altitude histogram shows where satellite streaks are most commonly observed

Satellite Avoidance Strategy

Night (date)	Block label (relative to local sunset)	Sun-altitude range	Risk level	Sky region to avoid	Scheduler / operator action (concrete)
All four nights (apply same rules)	Block A — Sunset → Sun −6° (Civil twilight)	0° → −6°	Very high	Azimuth: ±90° around Sun; All low-elevation pointings (elevation < 40°)	Do not perform long exposures. Use bright-star imaging, calibrations, or ≤0.1 s exposures only. For any imaging require elevation ≥40° and point well away from Sun azimuth sector.
All four nights	Block B — Sun −6° → −12° (Nautical twilight)	−6° → −12°	High	Continue avoiding ±90° Sun sector and low elevations (<35°)	Prefer exposures ≤1 s. If 1–10 s are needed restrict to elevation ≥35° and azimuth well away from Sun sector. Use short stacks and active masking.
All four nights	Block C — Sun −12° → −18° (Astronomical twilight)	−12° → −18°	Moderate	Avoid low elevations (<30°); moderate caution near antisolar direction (where high-alt sats linger)	Exposures up to ~10 s OK at elevation ≥30°. For exposures ≥30 s, split into subframes (e.g., 3×10 s) to allow streak rejection.
All four nights	Block D — Sun < −18° → first deep-night hour	Sun < −18° (first 60 min)	Lower but non-zero	Avoid very low elevations; still be cautious near horizon toward twilight direction	Long exposures allowed but use subframe stacking and aggressive streak-masking in pipeline. For sensitive programs, prefer fields >30° elevation.
All four nights	Block E — Deeper night (after ~1 hour post Sun<-18°)	Deep night	Low	Normal operations — minimal avoidance other than routine constraints	Resume standard observing programs. Keep streak-detection active; avoid low elevations if you want minimal contamination.

Findings

Twilight is the worst-case contamination window across all dates and both sites:

- Shells **A–C (VLEO)** dominate the earliest part of twilight.
- Shells **E–G (LEO mid-altitude)** remain illuminated longest.
- Polar shells **H and I** always remain lit the longest at **Deosai**.

Latitude dependence is very strong

- **Deosai (35°N)** shows **longer twilight illumination**, especially for high-inclination shells (D, H, I).
- **Sonmiani (25°N)** has shorter twilight exposure and steeper illumination decay.

Solstices behave differently

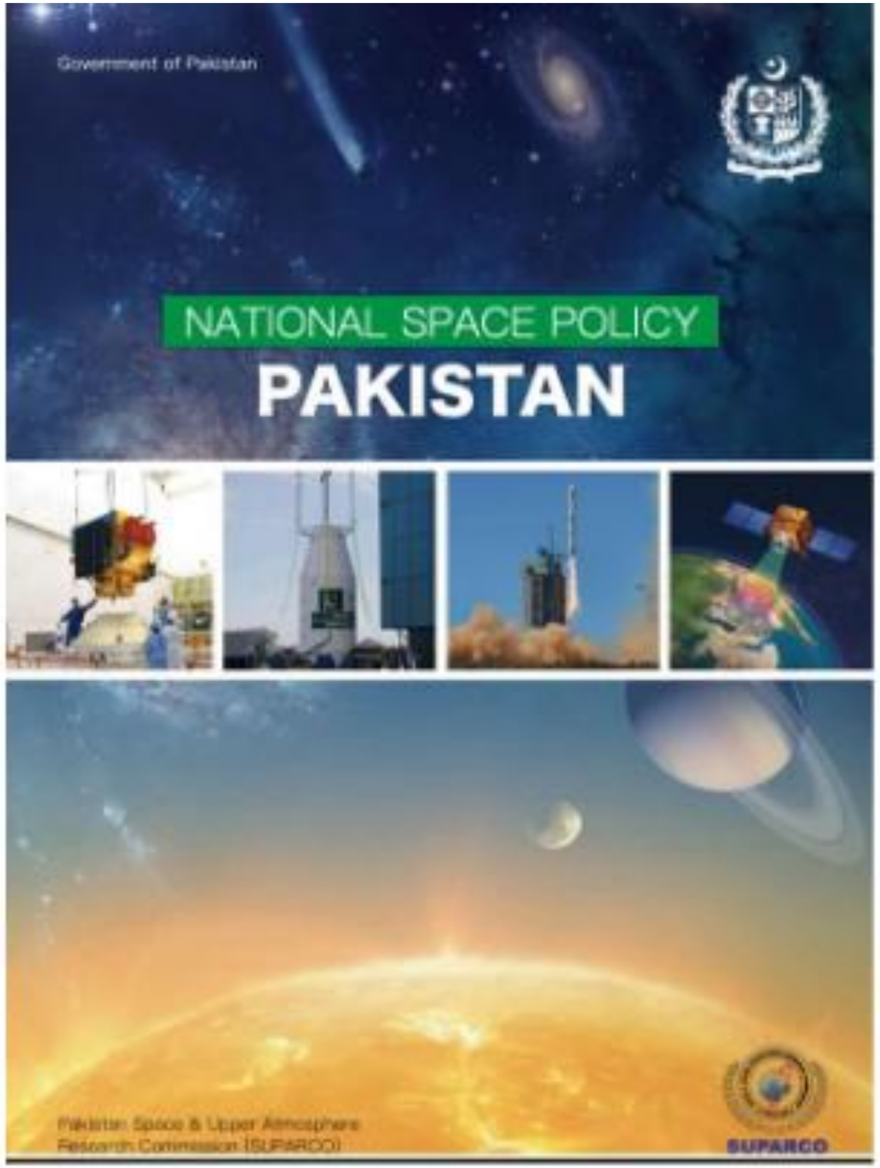
- **June Solstice** → longest illumination for all shells, especially polar shells.
- **December Solstice** → shorter twilight, fewer illuminated satellites.

Symmetry at Equinoxes

- Light curves for:
- **March** and **September** are nearly mirror images.
  This matches astronomical expectations.

Part II: National Regulatory Framework

National Space Policy



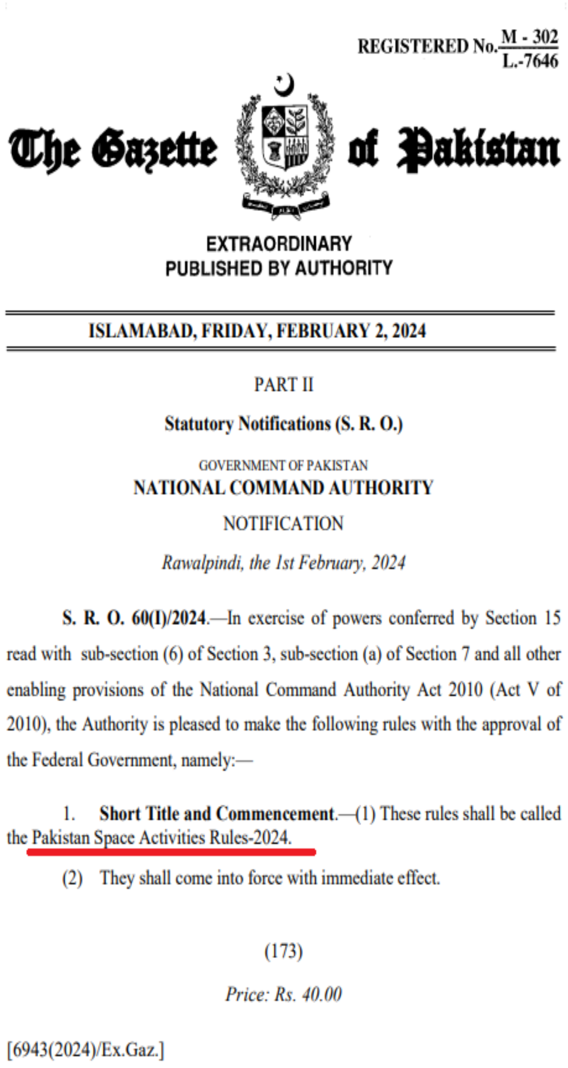
Pakistan approved its *first National Space Policy* in December 2023, establishing a unified national vision for civil, commercial, and scientific space activities.

- **Introduces a national regulatory regime** governing all Pakistani space activities in line with UN space treaties *(NSP Section 2.1–2.2)*.
- **Emphasizes safety, security & sustainability of outer space**, directly supporting efforts to protect dark and quiet skies.
- **Mandates creation of national laws & rules** for satellite licensing, registration, and oversight *(Section 4.3)*.
- **Commits to Space Traffic Management (STM)** — essential for mitigating optical interference from LEO constellations.
- **Encourages coordination with international bodies** (UNOOSA, ITU, COPUOS), creating alignment with dark-sky protection initiatives.

Message:

Pakistan's NSP establishes the **legal and policy basis** needed to integrate dark-sky preservation into national space governance.

Space Activities Rules, 2024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PART II

Statutory Notifications (S. R. O.)

GOVERNMENT OF PAKISTAN
NATIONAL COMMAND AUTHORITY

NOTIFICATION

Rawalpindi, the 1st February, 2024

S. R. O. 60(I)/2024.—In exercise of powers conferred by Section 15 read with sub-section (6) of Section 3, sub-section (a) of Section 7 and all other enabling provisions of the National Command Authority Act 2010 (Act V of 2010), the Authority is pleased to make the following rules with the approval of the Federal Government, namely:—

1. **Short Title and Commencement.**—(1) These rules shall be called the Pakistan Space Activities Rules-2024.

(2) They shall come into force with immediate effect.

(173)

Price: Rs. 40.00

[6943(2024)/Ex.Gaz.]

In 2024, Pakistan introduced the Space Activities Rules, operationalizing the policy through a dedicated authority:

- **Pakistan Space Activities Regulatory Board (PSARB)**
- **Licensing requirements for NGSO/LEO systems** (e.g., mega-constellations) allow Pakistan to introduce:
  - Orbit-use permissions
  - Operational constraints
- **Opportunity identified:** integrate *optical interference assessment* into satellite licensing criteria.
- **Lesson learned:** Emerging space nations need *regulatory readiness* early—before LEO constellations scale further.
- **Message:**
  Pakistan's evolving regulatory framework provides an opportunity to embed **dark-sky protection mechanisms** into satellite licensing and oversight.
- .

Way Forward

Strengthening National Measures for Dark & Quiet Skies

- Establish national dark-sky zones around high-value astronomical sites (Sonmiani, Deosai)
- **Integrate** Astronomical Protection Guidelines
  Incorporate **dark-sky impact assessments** in licensing reviews
- Require **TLE-sharing & pass-prediction coordination** with observatories

Develop a National "Sky Protection Roadmap"

Establish cross-agency coordination (SUPARCO, PSARB, PTA, MoST, universities) to harmonize environmental, astronomical, and regulatory oversight.

Launch a Satellite Optical Impact Registry

Require operators to provide updated albedo data, attitude behavior, and deployment timelines to PSARB for predictive modelling.

Adopt Regional Satellite Risk Mapping

Institutionalize routine TLE-based hazard mapping for all licensed operators—aligned with international guidelines.

Mandatory Mitigation Plans for NGSO Operators

Include requirements for:

- Brightness mitigation coatings
- Attitude management during twilight passes
- Pre-launch coordination with national observatories

Capacity Building for Monitoring & Enforcement

Expand national SSA infrastructure and develop compliance audit mechanisms for LEO operators.

PC: ESO