SPACEX

JUNE 2026

STARLINK SPACE SAFETY AND STARGAZE

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OVERVIEW

STARLINK INTRODUCTION

- Starlink in 2026
- Starlink Collision Avoidance in 2026
- 2026 Shell Lowering Operation

SPACE SAFETY HAZARDS

- Launch COLA Gap
- Operators Maneuvering Without Sharing Ephemeris
- Poor Ephemeris Prediction Accuracy
- Space Weather Volatility

STARGAZE

- System Performance
- Case Studies

SPACE SAFETY PLATFORM

- Access to Stargaze Data
- Prediction Accuracy Analysis
- Conjunction Assessment Tools

CONCLUSION







STARLINK INTRODUCTION

STARLINK IN 2026

Starlink Constellation

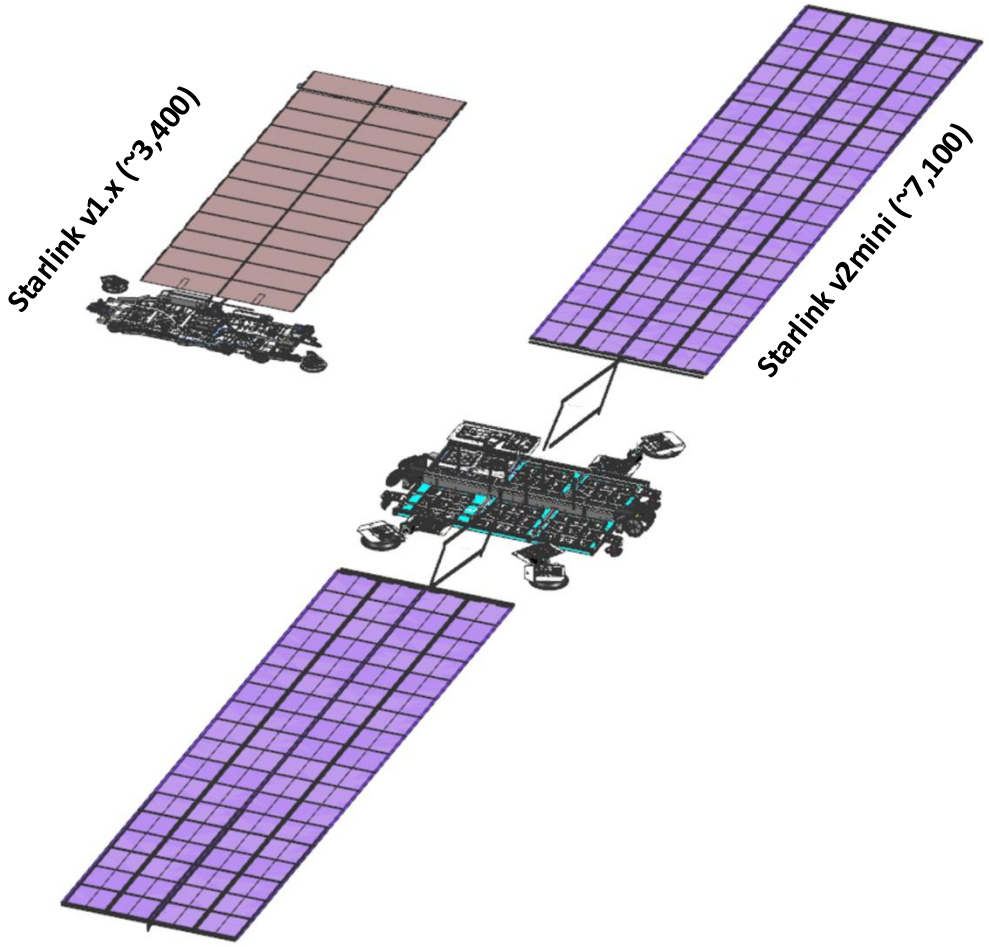
- >10 million customers
- ~12,100 Starlink satellites launched since 2019
- ~10,500 satellites in orbit as of June 2026
- ~1,600 satellites have already been deorbited
  - Starlink holds an extremely high standard for satellite health, proactively deorbiting satellites that approach end-of-life or suffer hardware failures
  - Thousands more will be deorbited in the coming future as more v1 satellites approach the end of their design life

Starlink Satellites

- ~3,400 v1 satellites
- ~7,100 v2 satellites

Design for Demise and Targeted Re-entry

- Starlink satellites are designed to demise on re-entry.
- Starlink attempts to re-enter satellites over non-populated areas to further reduce risk.



STARLINK COLLISION AVOIDANCE IN 2026

High-Level Starlink COLA Metrics

- >30,000,000 Stargaze observations processed daily
- >50,000,000 CDMs generated daily
- >150,000 daily conjunctions involving Starlink
  - Vast majority are completely benign
- >90% of the constellation actively in contact at any time

Typical Collision Avoidance Thresholds

- 12-hour COLA maneuver horizon
- 3e-7 Pc maneuver threshold
- 100m R x 1,500m T x 1,500m N physical keep-out
  - Even more conservative for select objects
- 5e-8 Pc threshold to reduce cross-sectional area

COLA Actions

- >1,000 daily automated COLA maneuvers
- >2,000 daily automated actions to reduce cross-sectional area

Failed Burn Triage

- ~99.995% Burn Success Rate
- Delta-V based burn aborts to deliver 100% of intended thrust
- Zero-tolerance for burn failures, automatically pause to troubleshoot
- Automatic fallback to high-reliability tank venting upon lit burn failure
- Test burns performed out-of-plane, where Pass/Fail is inconsequential to collision avoidance geometry
- Automated differential drag to steer away from conjunctions

Interactions with Other Satellite Operators

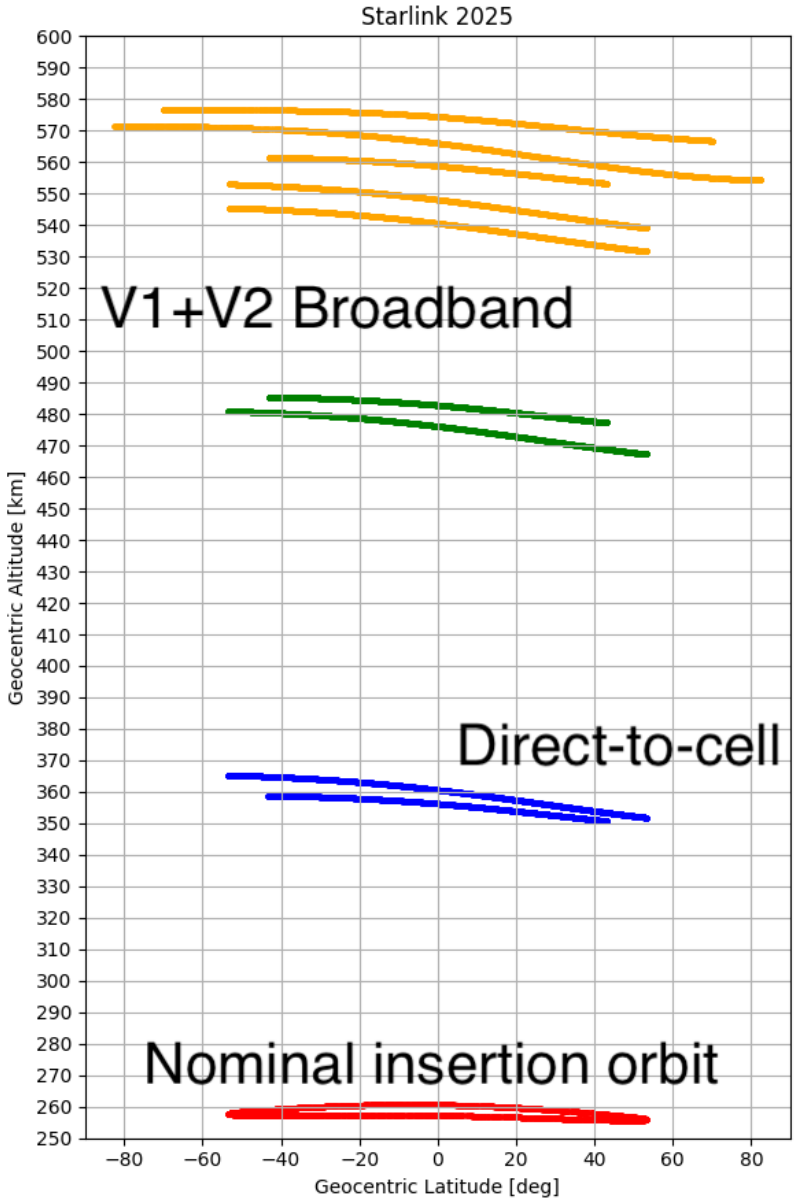
- Starlink typically defaults to taking maneuver responsibility
- “Time-domain maneuver responsibility” sharing enables:
  - Other operator can take COLA actions on long time horizons
  - Starlink takes maneuver responsibility closer to TCA (<12 hours)

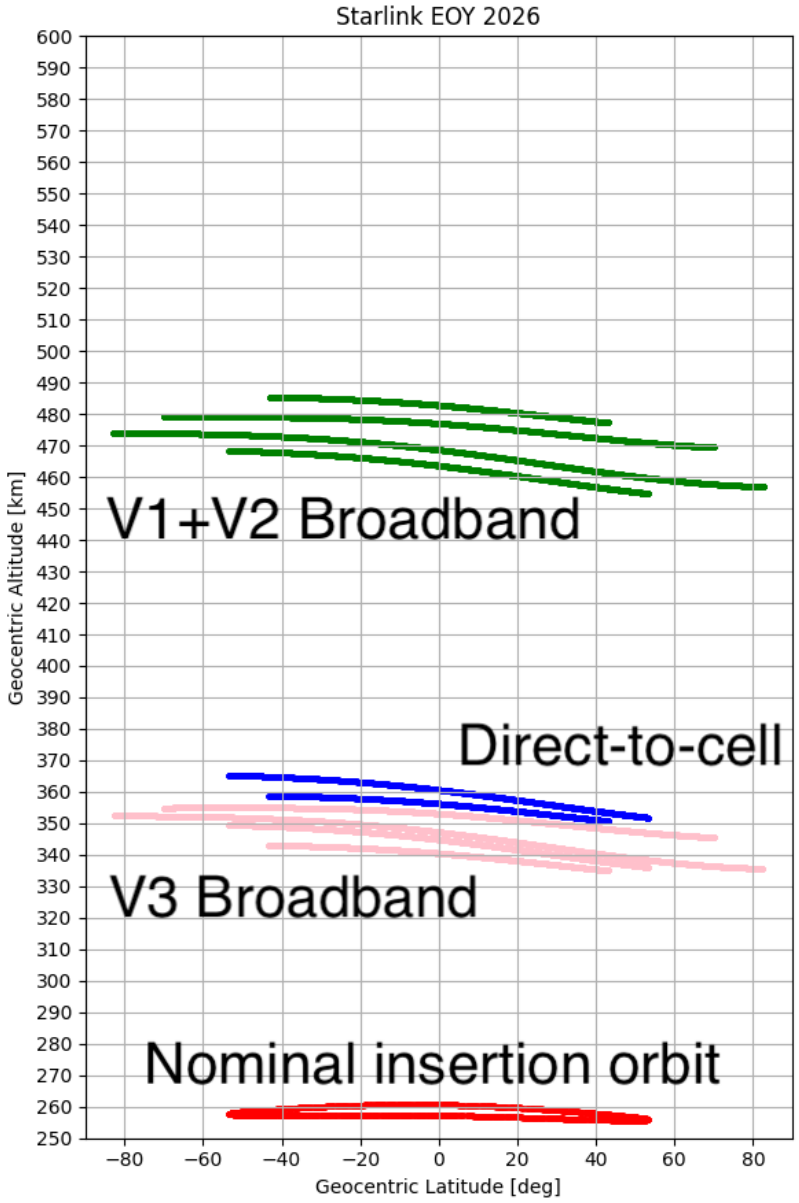
Retroactive Conjunction Data Auditing

- Automated detection of any conjunctions that were not fully mitigated
- Rapid identification of abnormal behavior, alerts operators for review
- Continuous monitoring of ephemeris quality, both mean state and covariance realism

2026 SHELL LOWERING OPERATION

- Starlink is currently lowering satellites in the > 500km altitude ranges to the 450km to 490km range.
- >80% reduction in ballistic decay time in solar minimum, from 4+ years to 10 months
- Lower shells will be denser but have a smaller altitude footprint
- Starlink plans to launch future vehicles in the 330km to 360km altitude range
- Starlink encourages other operators to analyze the background object density when choosing altitudes for satellite operations, including insertion orbits





SPACE SAFETY HAZARDS

LAUNCH COLA GAP

- Launch COLA screenings typically only cover L+3 hours, but satellite catalogging can take **days**
  - During this time, newly launched satellites may be effectively invisible to on-orbit satellites
- Objects in LEO are not uniform – constellation shell altitudes can have ~50x higher sat density vs. background
  - A 1-meter diameter payload can experience collision risk as high as 5e-5/object/day if inserted directly into a constellation shell

Scenario 1: 1 payload, 520km (sparse) insertion altitude

- (1e-6 / payload / day)** × (1 payload) × (2 days to catalog) = **2e-6** total risk
- Equivalent to ~7 COLA maneuvers*

×50

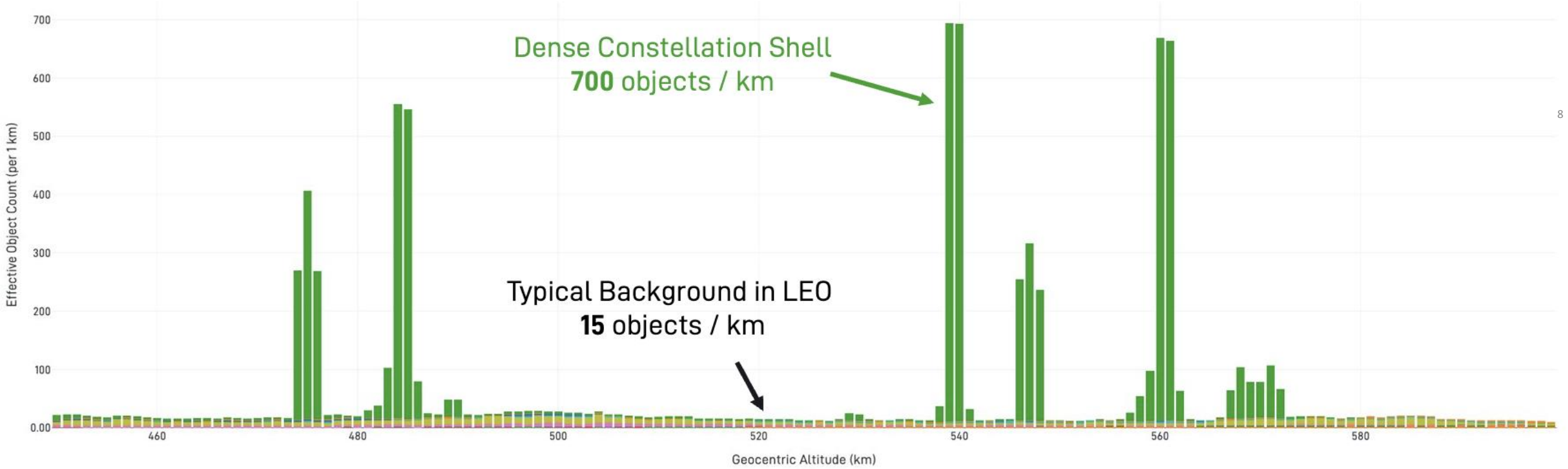
Scenario 2: 1 payload, 560km (dense) insertion altitude

- (5e-5 / payload / day) × (1 payload) × (2 days to catalog) = **1e-4** total risk
- Equivalent to ~333 COLA maneuvers*

×100

Scenario 3: 30 payload rideshare mission, 560km (dense) insertion altitude

- (5e-5 / payload / day) × (30 payloads) × (7 days to catalog)*** = **1e-2** total risk
- Equivalent to ~35,000 COLA maneuvers*



LAUNCH COLA GAP MITIGATIONS

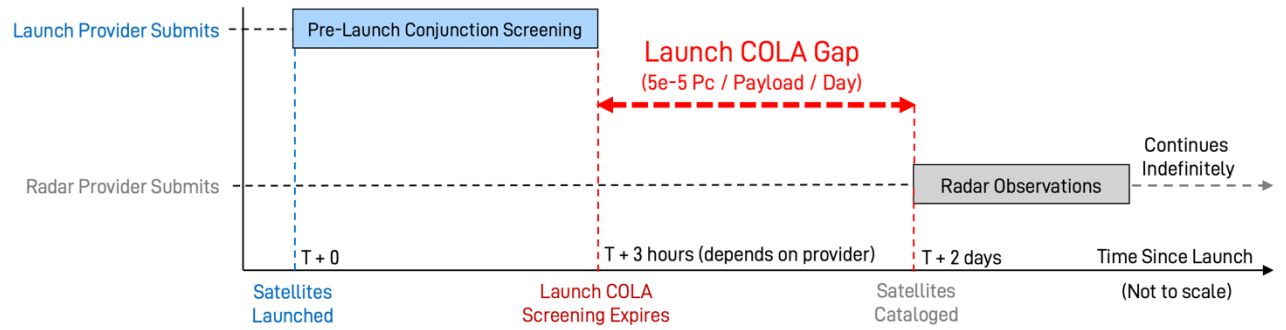
Mitigation 1: Avoid launching into high-density altitudes

- Launch into an adjacent non-overlapping altitude
- Orbit transfer to the desired operational altitude
- Starlink uses this strategy:
  - Insert below 300km, orbit transfer to higher operational altitudes

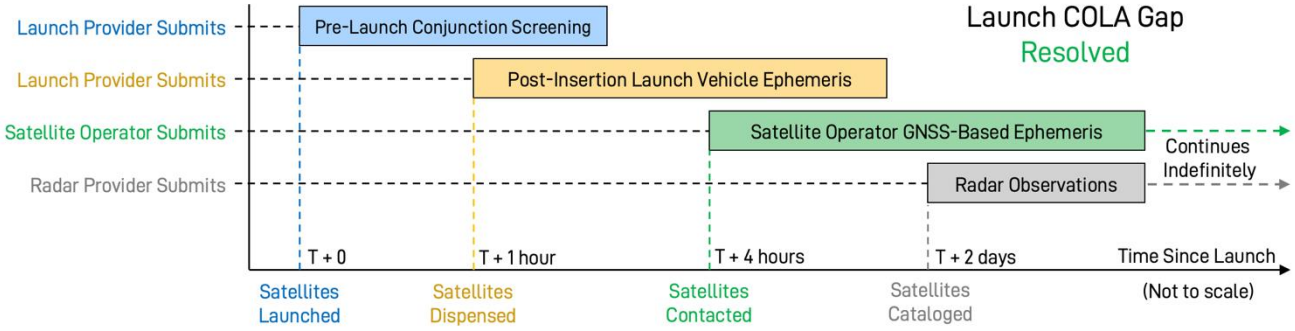
Mitigation 2: Immediately start publishing ephemeris post-insertion

- If launching into a high-density shell cannot be avoided – risk can be mitigated by publishing ephemeris immediately after insertion
  - Step 1: The **launch provider** can publish GNSS-derived propagated ephemeris immediately after insertion / payload dispense
  - Step 2: The **satellite operator** publishes ephemeris directly after contacting their satellite

Before Mitigations:



After Mitigations:



OPERATORS MANEUVERING WITHOUT SHARING EPHEMERIS

3rd party observations (radar, optical) cannot anticipate satellite maneuvers

- Ballistic predictions become invalid following a maneuver; can take radar >1 day to reconverge

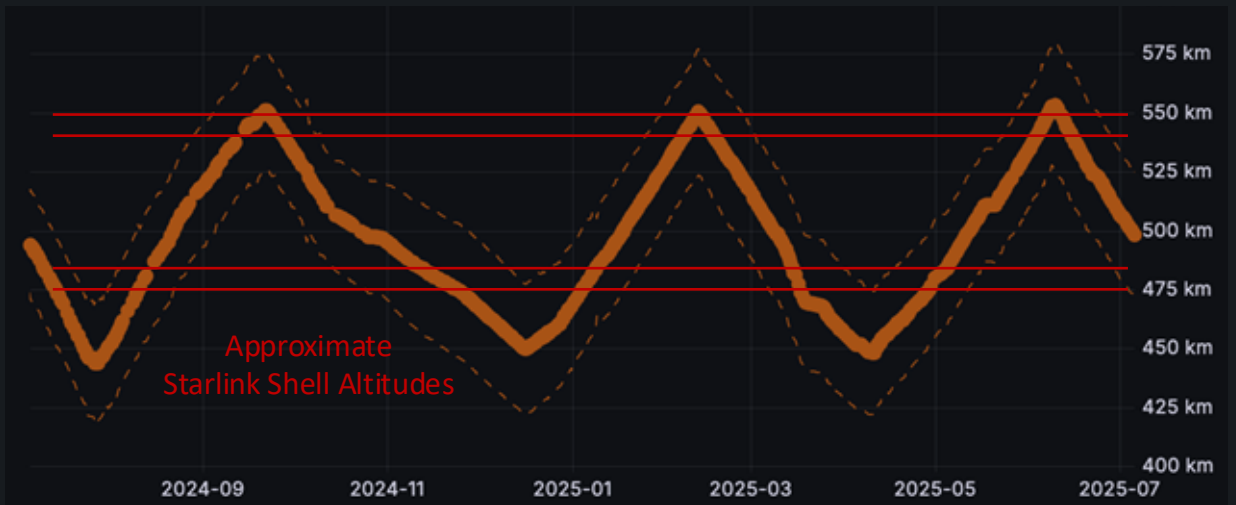
Operators of maneuverable satellites must broadcast their maneuver plans

- Post-maneuver trajectories should be screened + published to others, **before** departing on them

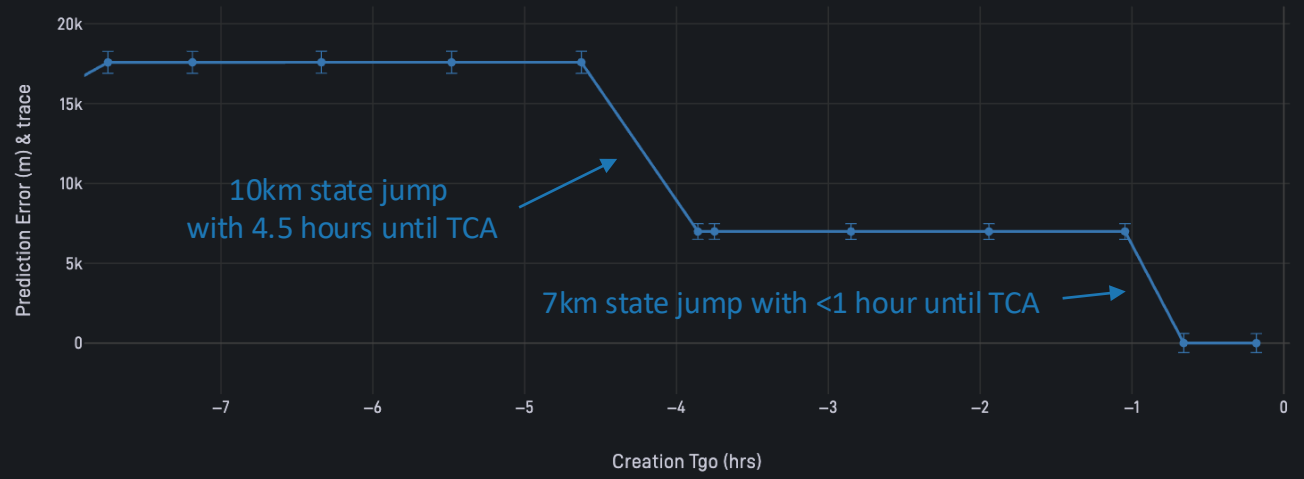
Data sharing is crucial for safe spaceflight

- Bidirectional sharing is necessary to enable validation of results by both parties
- Operators that do not share ephemeris are considerably harder to avoid (ie: Russia, China)

Example of a satellite that is propulsively transferring through LEO back and forth, performing frequent maneuvers without sharing ephemeris. Behaviors like this can pose a disproportionate collision risk in LEO.



Example of ballistic-propagation shifts leading to TCA for a frequently maneuvering object that doesn't share ephemeris. Legacy conjunction screening is ineffective for mitigating risk against an object with such large and frequent state shifts.



POOR EPHEMERIS PREDICTION ACCURACY

- Even when operators can share ephemeris – accuracy is a challenge
  - Innacurate ephemeris can be more hazardous than no ephemeris at all
- Common failure modes:
  - State-estimation errors
  - Burn failures
- Mitigations for prediction errors:
  - Real-time monitoring on high prediction error
  - Upon burn failure, pause burn execution to troubleshoot





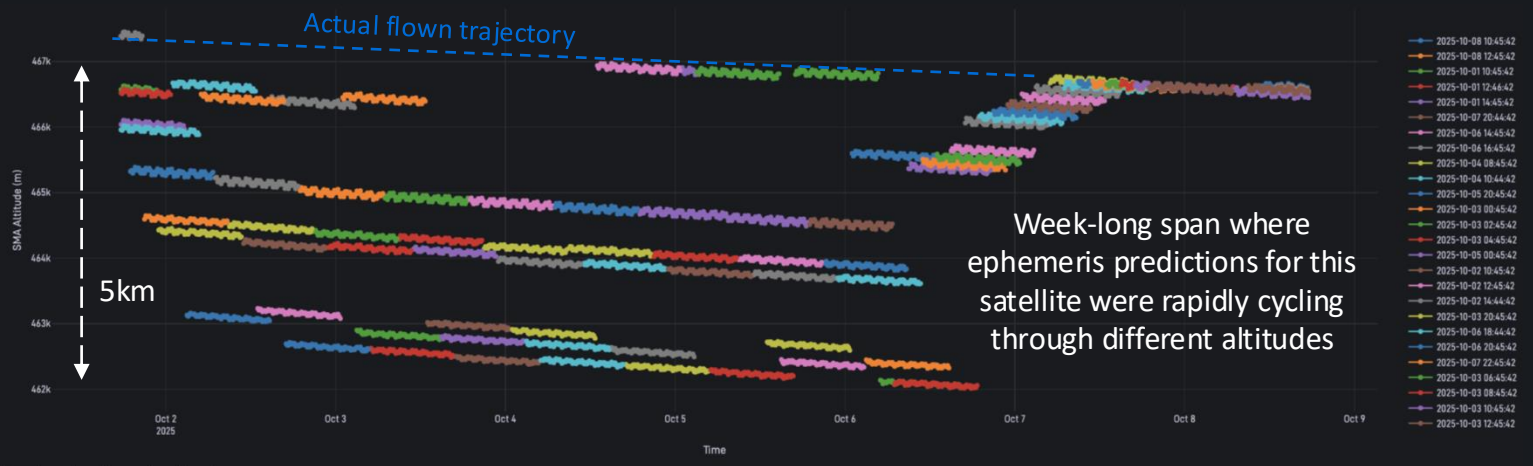
Operator Ephemeris Mean SMA Altitude



Secondary Consistency



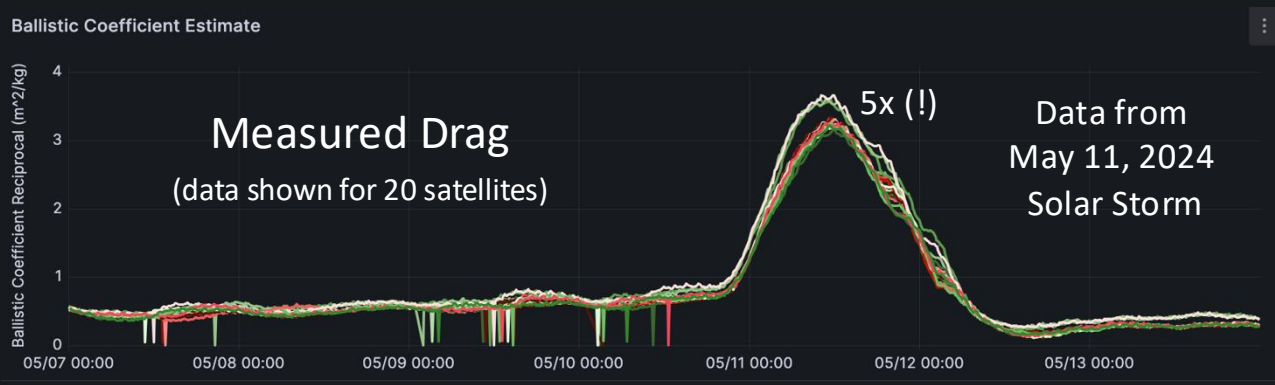
The figures shown overlay "Altitude vs. Time" of many consecutive operator ephemeris predictions for individual 3rd party satellites encountered by Starlink in LEO. Overlapping lines imply consistency across consecutive predictions. Non-overlapping lines suggest that a subsequent prediction differs meaningfully from the prior prediction.

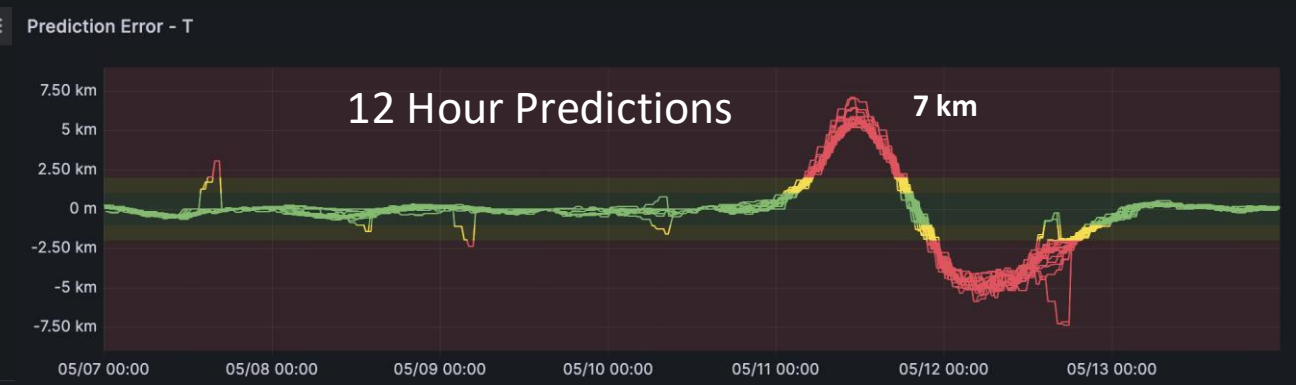


SPACE WEATHER VOLATILITY

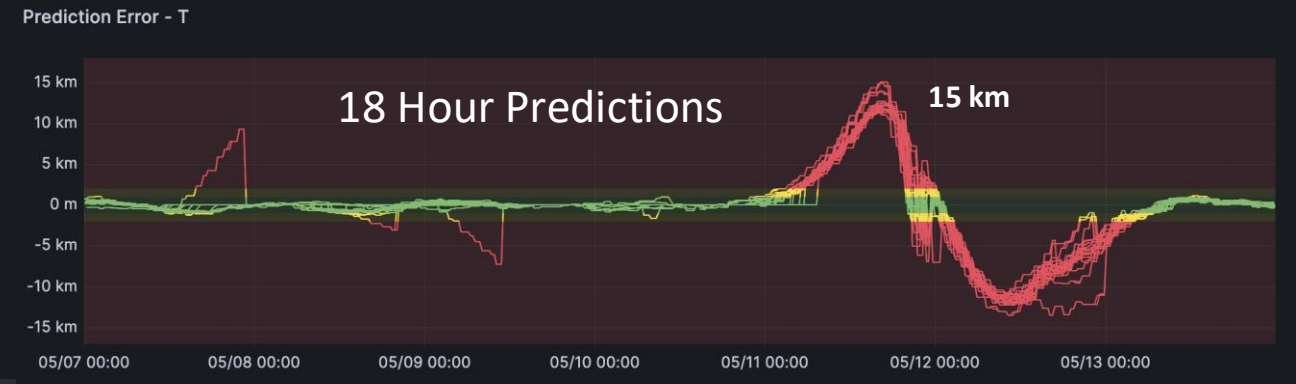
Volatile space weather can cause sudden trajectory deviations, making satellites harder to avoid

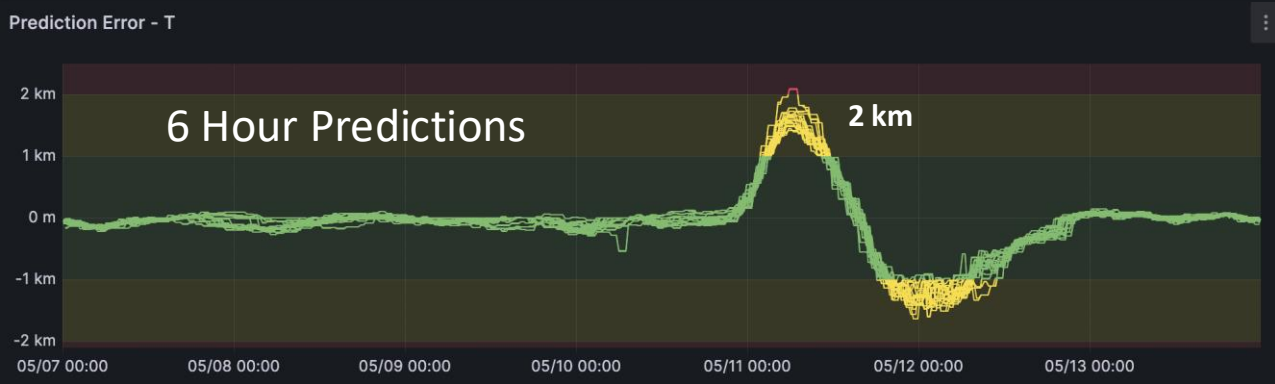
- Reliable collision avoidance in these conditions requires frequent ephemeris sharing – even if not performing maneuvers

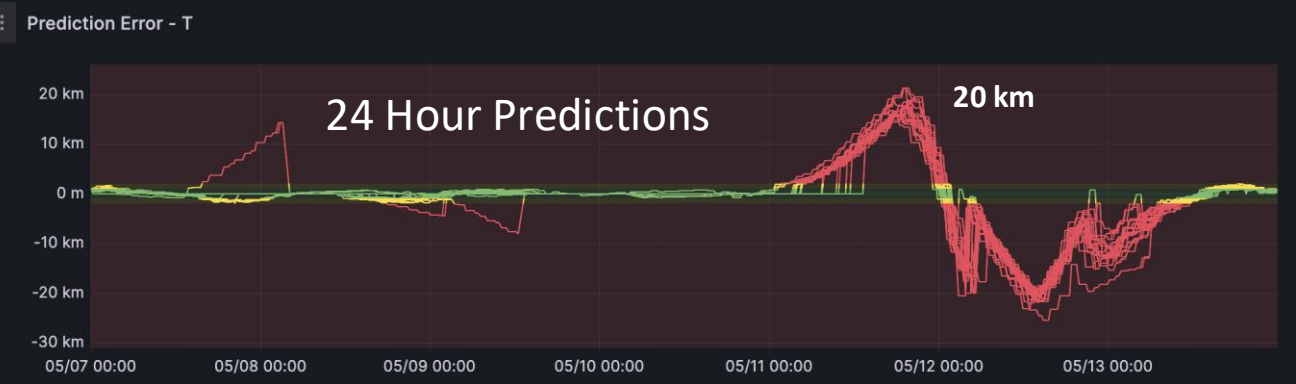




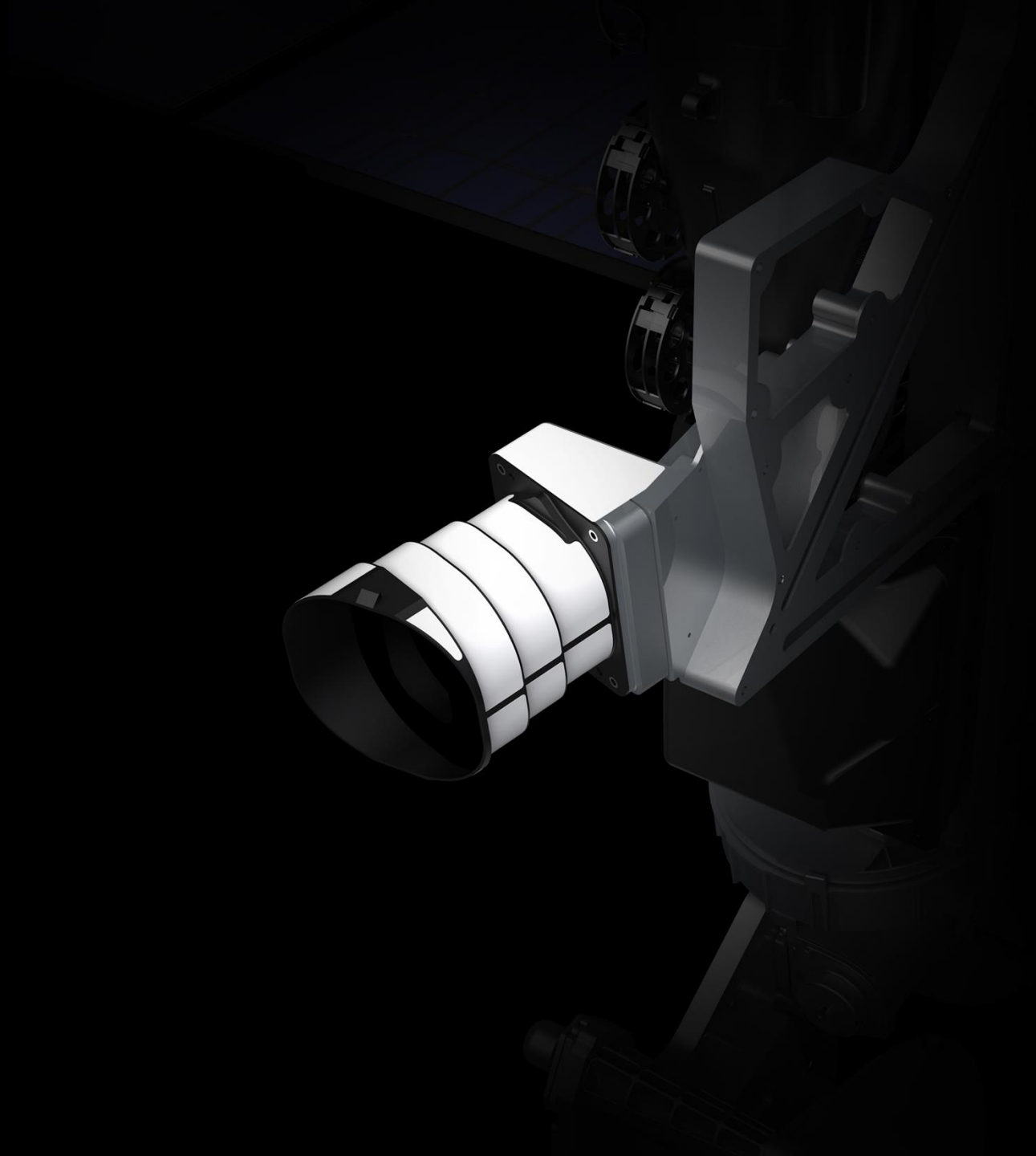








STARGAZE



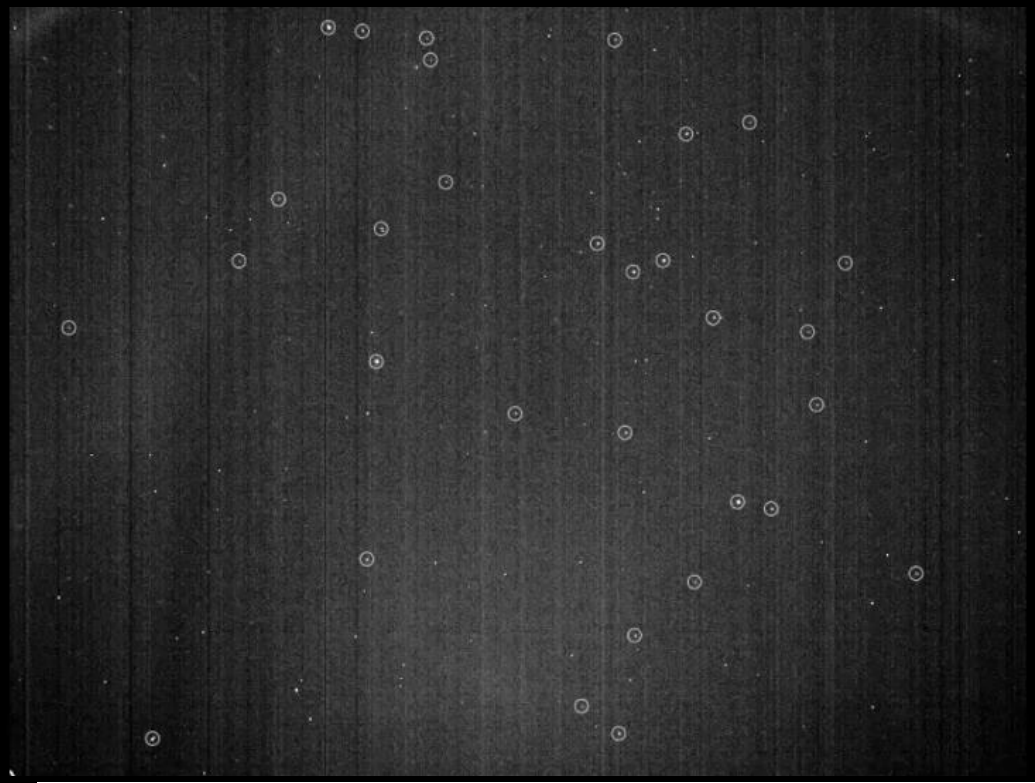
STARGAZE OVERVIEW

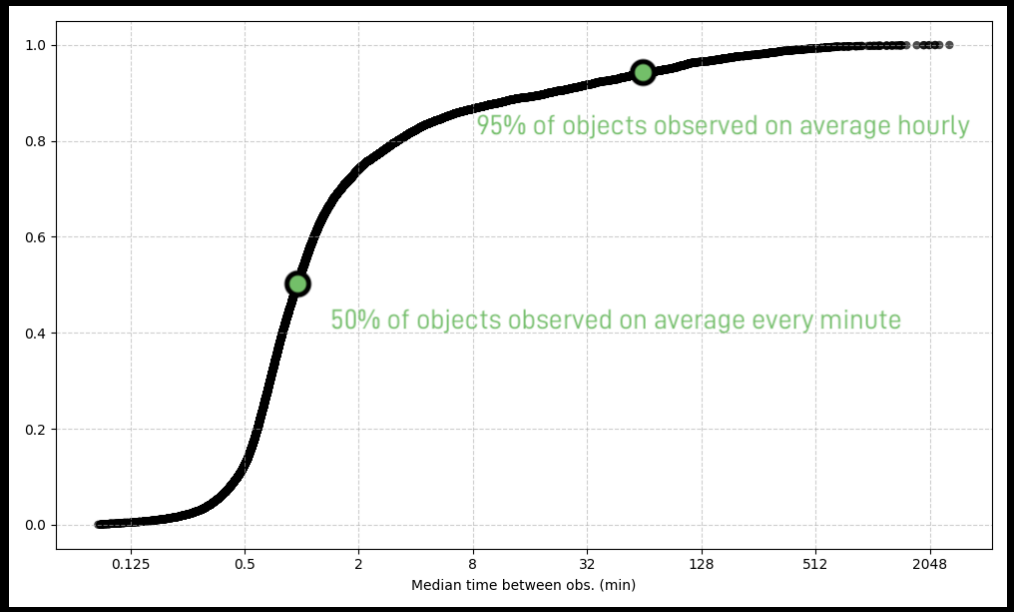
SYSTEM OVERVIEW

- > 10,000 observer satellites with >30,000 Star trackers
- Onboard object-detection and transit building
- Ground-based association, orbit determination, catalog management
- Initial orbit determination independent of NORAD catalog
- States are propagated (24-hour duration, as frequently as every 10 minutes) and uploaded to the Space Safety Platform
- Next-generation star trackers are starting to launch and will increase the sensitivity of the system

SYSTEM PERFORMANCE

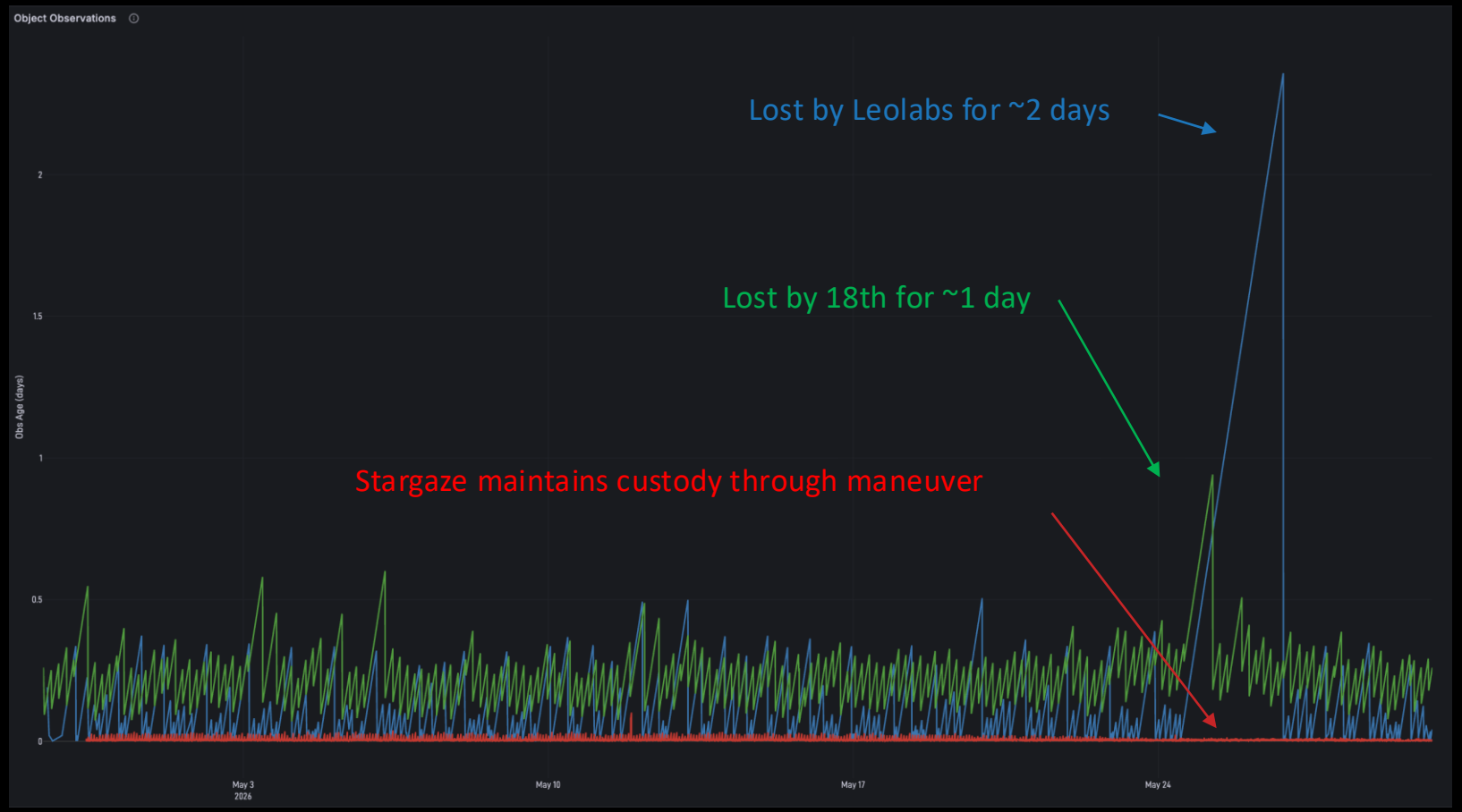
- Tracks 16,500 objects (6,700 non-Starlink), roughly 48% of the catalog
- Tracks objects down to ~1m diameter reliably
- Very high revisit rate: 15,800 objects observed > 10x/hour
- Very low latency: p99 Observation to OD update is 5 minutes





STARGAZE VS RADAR SYSTEMS

- Stargaze tracks uncooperative secondaries through maneuvers, where radar systems can lose custody for ~days
- Paired with low-latency screening, observations can generate CDMs in minutes
- Stargaze can perform initial orbit determination within hours of a launch, leading NORAD catalog by days
- Stargaze is not a standalone replacement for radar data today, but is best used to supplement its shortcomings



STARGAZE CASE STUDIES

LOW LATENCY MANEUVER DETECTION

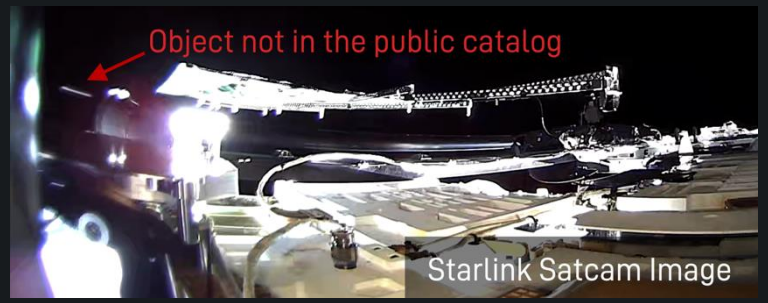
- Conjunction with a catalogued object not sharing ephemeris performed a maneuver with 10.5 hours prior to TCA
- Stargaze generated a CDM within minutes
- Radar providers did not publish a CDM with the secondary state update until between 2.5h and 1.5h prior to TCA

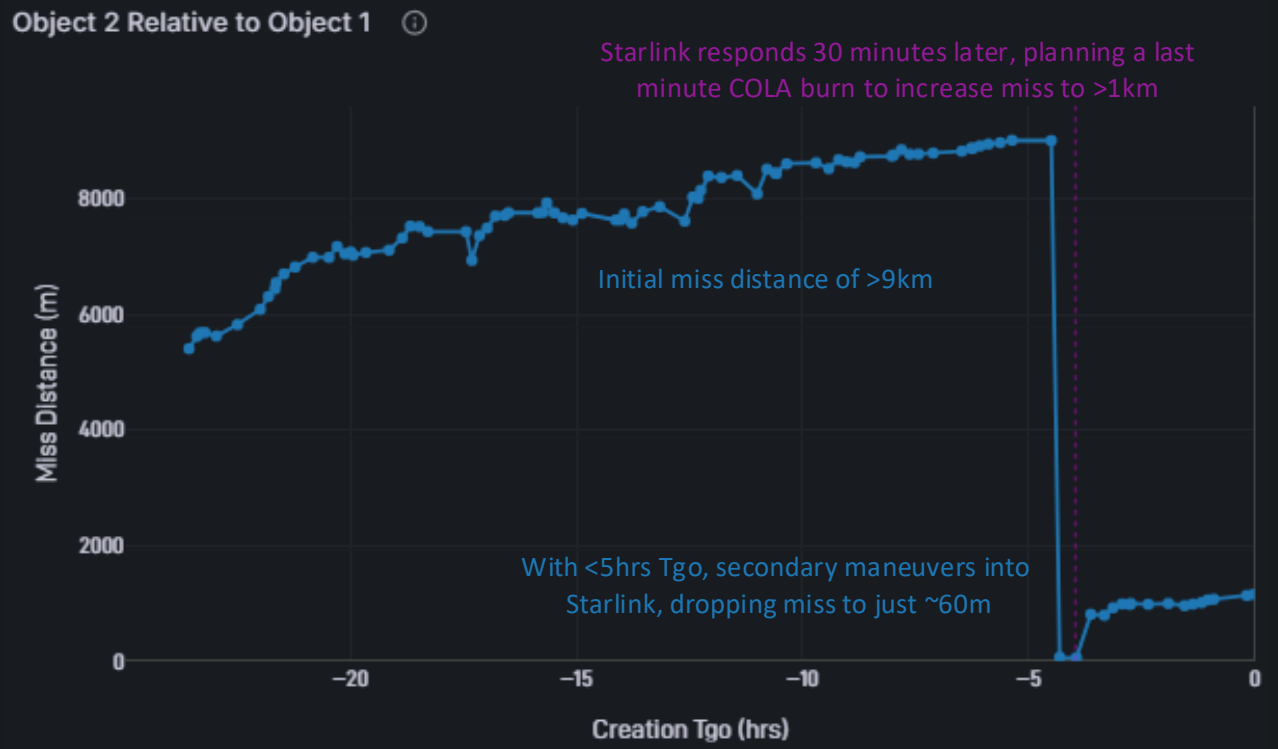


UNCATALOGUED MANEUVERING OBJECT

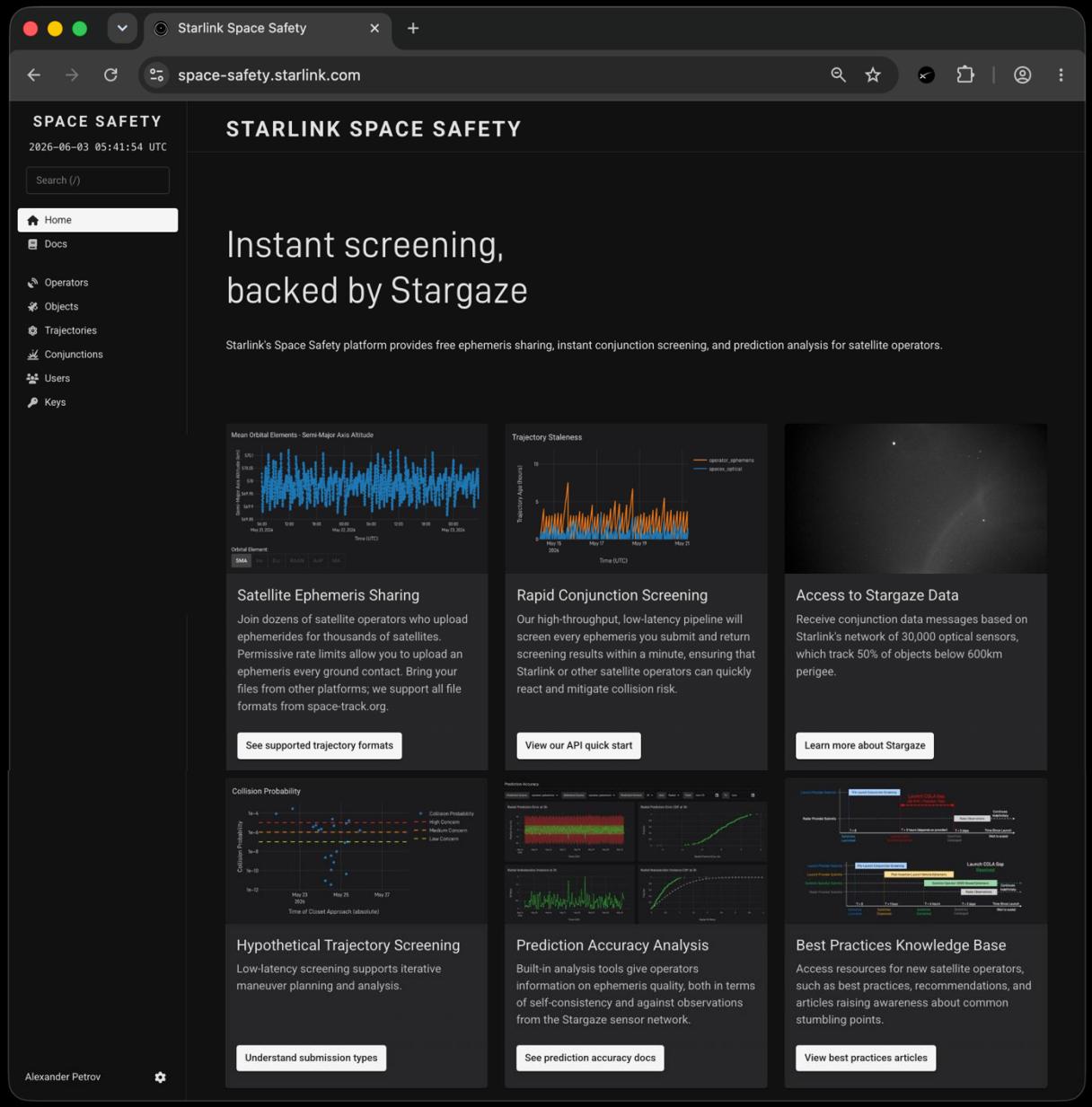
- Uncatalogued satellite maneuvered within ~4.5h of TCA, dropping miss distance from 9km to ~60m, and an estimated Pc of 7e-3
- The Starlink planned a maneuver within 30 minutes that increased miss distance to > 1km and reduced Pc to 0%

Stargaze does not replace the need for operators to share ephemerides and maneuver plans. Both events were dangerous and could have resulted in collisions.



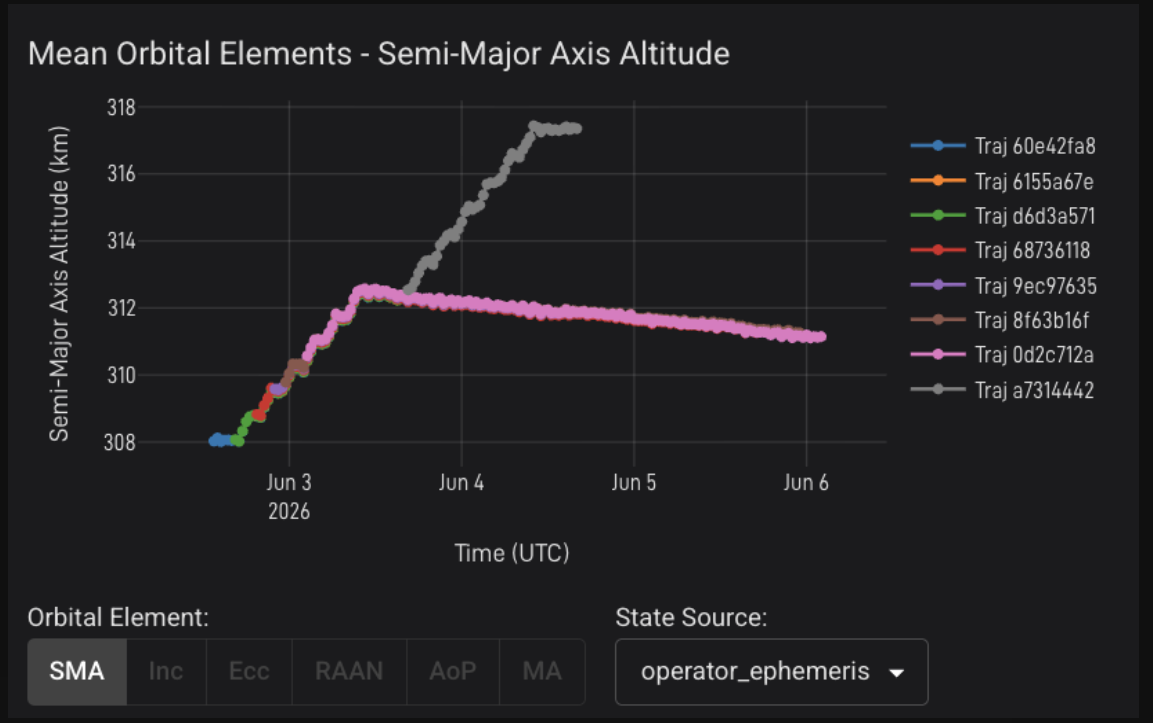


SPACE SAFETY PLATFORM



SATELLITE EPHEMERIS SHARING

- Operators publishing ephemeris receive CDMs against all other users
- System supports all file formats from space-track.org and CCSDS OEM/OCM. Upload/Download in ECI or ECEF.
- Not constrained by rate limits of other platforms—Starlink states can be updated here ~hourly. Screen your ephemerides every time your satellite makes ground contact.
- In addition to Starlink, > 30 operators have submitted 80,000 ephemerides for > 500 objects in the past week
- Platform-wide visibility for O/O ephemerides
- Platform is always free of charge



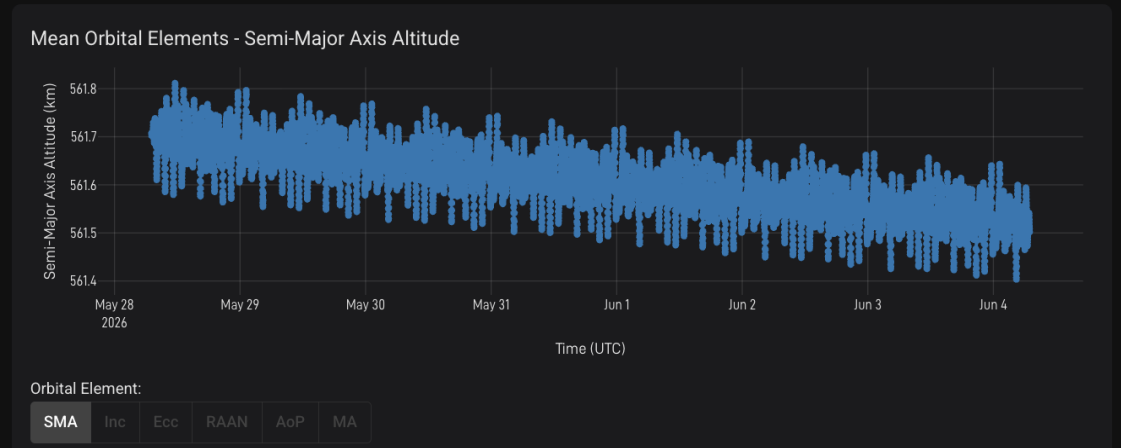
Trajectories

Trajectory 3103e78b

Download

Screened Status	Screened At (UTC)	Created At (UTC)	Uploaded At (UTC)
screened	2026-05-28 08:16:57	2026-05-28 08:15:06	2026-05-28 08:16:20

Operator	SpaceNav
Object	GNOMES-4
Object NORAD Id	58462
State Source	operator_ephemeris
Type	definitive
Start At (UTC)	2026-05-28 07:00:00
End At (UTC)	2026-06-04 07:00:00



RAPID CONJUNCTION SCREENING

- >500,000 ephemeris files screened daily
- CDMs are produced within ~1 minute of trajectory submission
- Larger 2km x 44km x 51km (half-widths) screening volume
- CDMs are grouped into conjunction events for better tracking,
  - "Active" vs "Inactive" CDMs provide positive confirmation when objects leave the screening volume

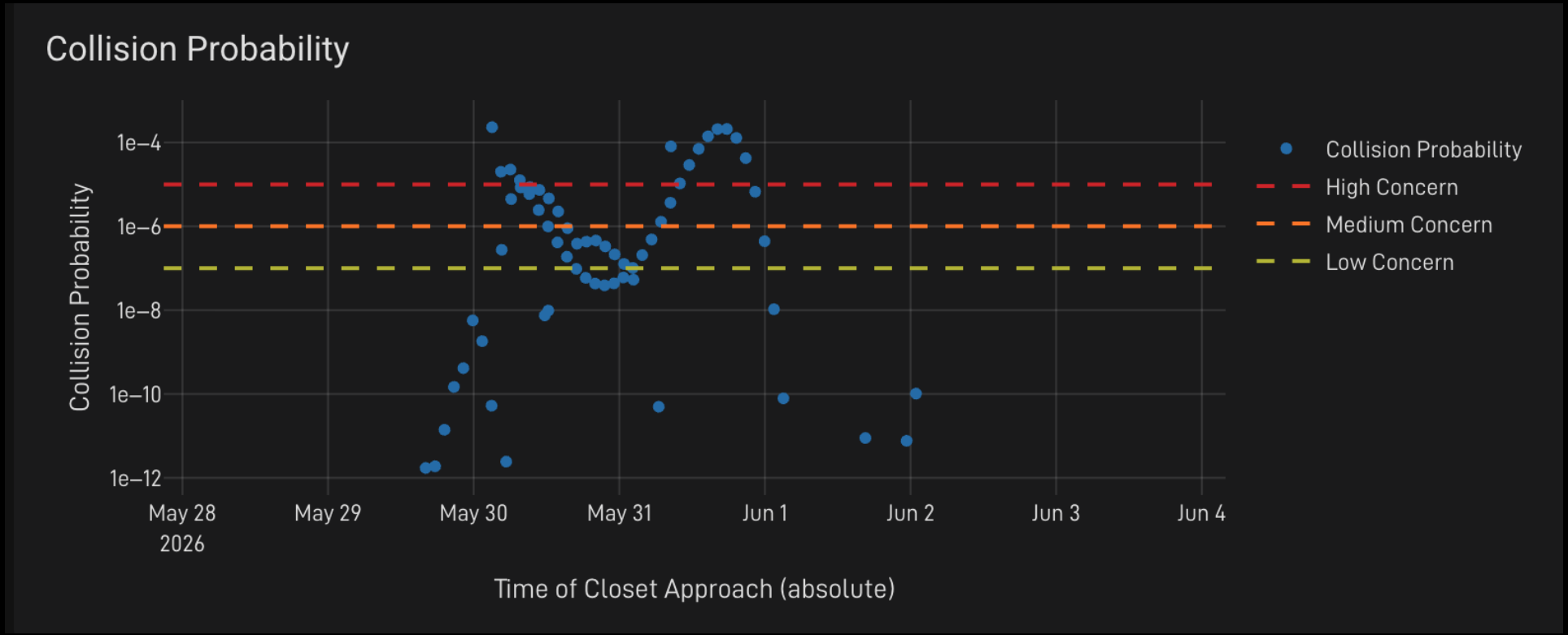
Conjunction Data Messages (CDMs)

Showing 50 of 92 CDMs

Id	Is Active	Collision Probability	TCA (UTC)	Object 1 Name	Trajectory 1 State Source	Object 2 Name	Trajectory 2 State Source	Created At (UTC)	File
e14753cb	true	0.0e+0	2026-06-03 10:55:12	VSP RF C1	spacex_optical	STARLINK-34173	operator_ephemeris	2026-06-03 05:31:20	json kvn
9a5e6913	false	0.0e+0	2026-06-03 10:55:12	VSP RF C1	spacex_optical	STARLINK-34173	operator_ephemeris	2026-06-03 05:10:28	json kvn
e3b7ac52	false	0.0e+0	2026-06-03 10:55:12	VSP RF C1	spacex_optical	STARLINK-34173	operator_ephemeris	2026-06-03 04:31:38	json kvn
e14753cb	false	0.0e+0	2026-06-03 10:55:12	VSP RF C1	spacex_optical	STARLINK-34173	operator_ephemeris	2026-06-03 04:22:45	json kvn
74bf84b8	true	3.3e-8	2026-06-03 10:55:12	VSP RF C1	operator_ephemeris	STARLINK-34173	operator_ephemeris	2026-06-03 04:22:45	json kvn
534df8b4	false	0.0e+0	2026-06-03 10:55:12	VSP RF C1	spacex_optical	STARLINK-34173	operator_ephemeris	2026-06-03 04:21:35	json kvn
6506da5b	false	0.0e+0	2026-06-03 10:55:12	VSP RF C1	spacex_optical	STARLINK-34173	operator_ephemeris	2026-06-03 03:48:01	json kvn
d061e91a	false	0.0e+0	2026-06-03 10:55:12	VSP RF C1	spacex_optical	STARLINK-34173	operator_ephemeris	2026-06-03 03:33:17	json kvn
534df8b4	false	0.0e+0	2026-06-03 10:55:12	VSP RF C1	spacex_optical	STARLINK-34173	operator_ephemeris	2026-06-03 02:48:27	json kvn
51dcbcad	false	0.0e+0	2026-06-03 10:55:12	VSP RF C1	spacex_optical	STARLINK-34173	operator_ephemeris	2026-06-03 02:44:05	json kvn
74bf84b8	false	4.3e-8	2026-06-03 10:55:12	VSP RF C1	operator_ephemeris	STARLINK-34173	operator_ephemeris	2026-06-03 02:44:05	json kvn
51dcbcad	false	0.0e+0	2026-06-03 10:55:12	VSP RF C1	spacex_optical	STARLINK-34173	operator_ephemeris	2026-06-03 02:12:58	json kvn
6fd37c28	false	0.0e+0	2026-06-03 10:55:12	VSP RF C1	spacex_optical	STARLINK-34173	operator_ephemeris	2026-06-03 01:56:20	json kvn
7998de56	false	0.0e+0	2026-06-03 10:55:12	VSP RF C1	spacex_optical	STARLINK-34173	operator_ephemeris	2026-06-03 01:11:20	json kvn
81366472	false	0.0e+0	2026-06-03 10:55:12	VSP RF C1	spacex_optical	STARLINK-34173	operator_ephemeris	2026-06-03 01:05:42	json kvn

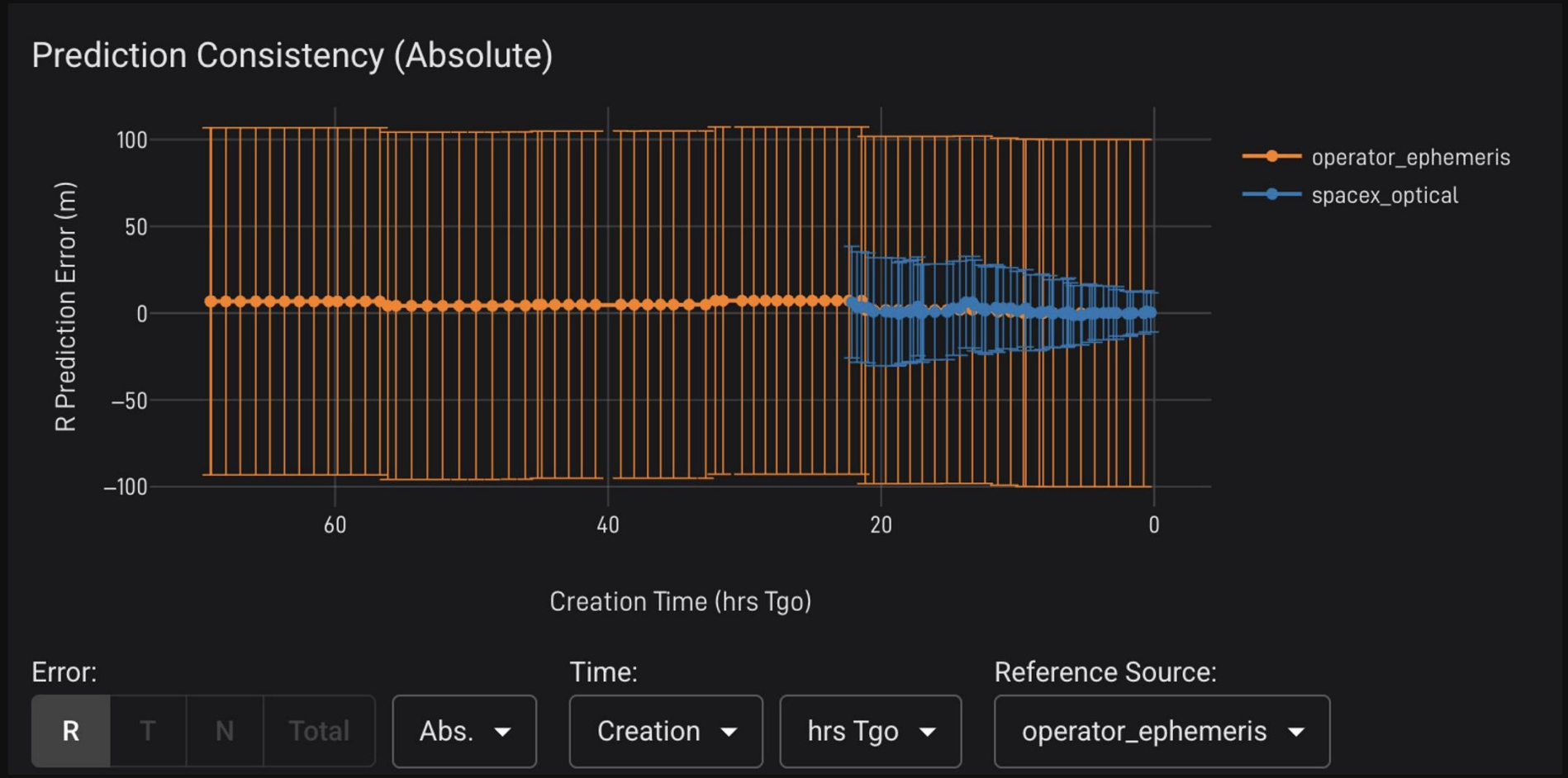
HYPOTHETICAL TRAJECTORY SCREENING

- "Hypothetical" trajectories provide a way to privately pre-screen maneuvers
  - Analagous to Space-Track's "Special" screening
- ~1 minute hypothetical trajectory screening turnaround allows rapid iterative maneuver planning
- Parallel submissions enable simultaneous evaluation of many candidate maneuvers



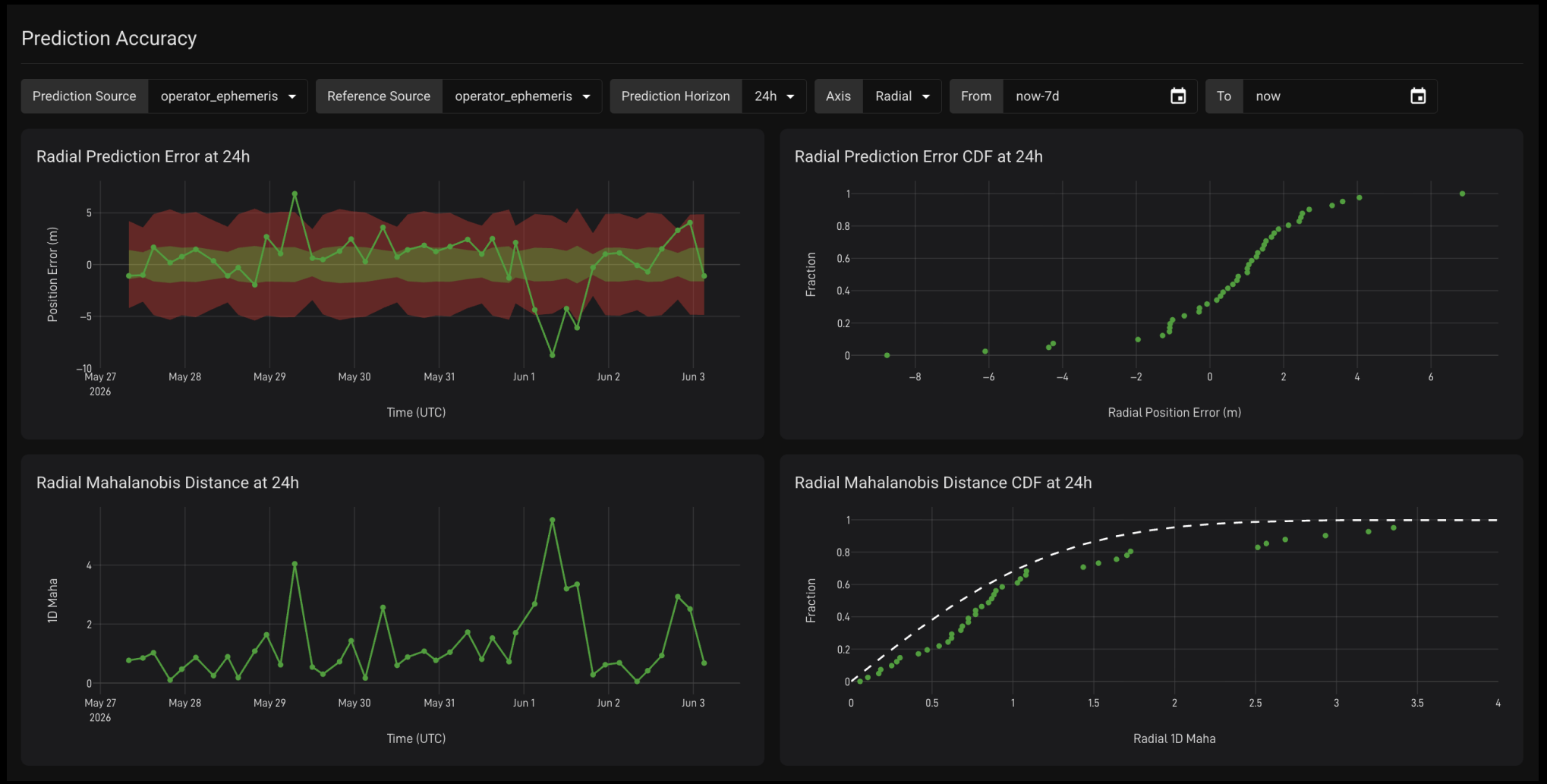
ACCESS TO STARGAZE DATA

- CDMs generated with Stargaze-based trajectories are available to participating operators who submit O/O ephemeris
- Screening will generate CDMs using both the secondary Stargaze state and secondary O/O ephemeris if available



PREDICTION ACCURACY ANALYSIS

- Measures self-consistency across consecutive submissions
- Measures cross-consistency of O/O ephemeris vs. Stargaze data if available
- Evaluates empirical error and covariance realism



KNOWLEDGE BASE

https://docs.space-safety.starlink.com/docs/category/space-safety-articles/

Growing collection of educational articles on space safety; intended to pass on best practies and common pitfalls to newer operators

Space Safety Articles › Space Safety Best Practices

Space Safety Best Practices

Satellite Design

- Equip satellites with propulsion such that they can perform collision avoidance maneuvers to minimize risk of collision with other objects
- Equip satellites with GNSS receivers so that you are capable of producing high-accuracy state estimates without relying on third-party observations of your satellite.
- Design satellites and your mission to ensure safe end-of-life disposal (see below)

Ephemeris Sharing

- Generate and publish propagated ephemeris and share it with other satellite operators,
- Publish ephemeris frequently, ideally updating them with every ground contact. In LEO, drag is the dominant external source of trajectory uncertainty, and drag fluctuations are difficult to predict.
- Publish covariance with your ephemeris to convey your degree of confidence in your predictions.
- Monitor the quality of your predictions, both in terms of absolute error and in covariance realism (using metrics such as Mahalanobis distance).

Maneuver Planning

- Incorporate upcoming maneuvers into your ephemeris exports, to inform other operators of them before they are executed.
- Continuously monitor predicted vs. executed thrust to ensure that your maneuver predictions align with actual performance.
- Do not tolerate burn failures, which make your ephemeris exports inaccurate. Do not continue to attempt burns using a faulty thruster to compound the error; pause operational burns to troubleshoot if necessary.

Coordination

- Provide accurate contact information for your organization for conjunction coordination on a public platform, such as space-track.org, this platform, or both.
- Provide accurate size and maneuverability status for objects that you own on a public platform.
- Ensure that ephemeris is available on a public platform. It should not be treated as proprietary information, it is critical for safe flight.

Launch and Early Mission

- After launch, work with the US Space Force to accelerate object cataloging, ideally by sharing ephemeris.
- Be cognizant of the Launch COLA GAP. Work with launch providers to launch into low-density altitudes, and plan to share ephemeris as soon as the satellite establishes contact.

End-of-Life Disposal

- Proactively deorbit satellites at end-of-life. Do not leave dead satellites in space.
- Proactively deorbit unhealthy satellites that risk dying on orbit.

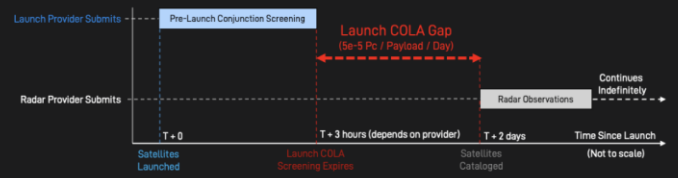
Space Safety Articles › Launch and Early Mission

Launch and Early Mission

The "Launch COLA GAP"

The "Launch Collision Avoidance (COLA) Gap" refers to the period of time after a new satellite is launched, but before it can be reliably avoided by other on-orbit satellites. This brief window can contribute a disproportionate amount of lifetime collision risk for a satellite - operators should be mindful of the hazard posed by it and the mitigations available to them.

Launch providers often perform pre-launch "Launch COLA" screenings, either themselves, or through government organizations. However, typical pre-launch COLA screenings only protect against conjunctions for a few hours after orbital insertion. Large launch vehicle orbit insertion uncertainties make it challenging to effectively screen long durations for collision risk. Even in circumstances where providers opt to perform a longer screening, challenges like "Covariance Dilution" can render them ineffective at mitigating post-launch risk.



Newly launched satellites may not able to react to conjunctions for hours or days after insertion, due to early mission activation and checkout sequences. In these circumstances, it is critical that other operators have access to high-quality ephemerides so they can perform effective collision avoidance against newly-launched objects. It can take days, or weeks for reliable radar-based predictions to become available for newly-launched payloads, especially for large rideshare missions, which can dispense dozens of payloads in one launch.

Fortunately, there are opportunities available to operators to proactively mitigate these risks, such as avoiding insertions directly into high density altitudes, as well as post-launch ephemeris sharing.

Altitude Dependence

There is a large variation of object density across different altitudes in low earth orbit (LEO). Most altitudes are comparatively sparse, averaging around ~15 objects per kilometer of altitude. In contrast, altitudes occupied by large satellite constellations can be considerably more dense, with over >1,000 satellites per kilometer of altitude. Intuitively, risk from the Launch COLA Gap scales proportional to the size and quantity of objects in the desired insertion altitudes, and inserting directly into altitudes that overlap with large constellations can face launch COLA risks that are 50x higher than a conventional insertion into a sparsely populated altitude.

Below shows the Low Earth Orbit environment as of early 2026, provided as an approximate visualization. Actual launch COLA planning should reference latest catalog information at the time of launch planning.

FUTURE WORK

Prediction Monitoring

- Multi-Object Prediction Accuracy Insights (Aggregated)
- Empirical Covariance Fitting
- Per-Object Data Source Quality Comparison

Historical Analysis

- Per-Object As-Flown "Truth" Trajectories
- Retroactive Processing of "Truth" Close Approaches

Maneuvers

- Burn Plan Submission + Stargaze Predictions Using Upcoming Maneuvers
- COLA Maneuver Suggestions

Stargaze

- Stargaze Detection of Smaller Objects
- CDMs for Uncatalogged Objects

Launch COLA

- Launch COLA Screening (T0-Selection)
- Launch-on-Launch Deconfliction

CONCLUSION

SUMMARY OF SPACE SAFETY CHALLENGES AND BEST PRACTICES

Challenges

Satellites Maneuvering without Sharing Ephemeris

- Radar predictions can only estimate ballistic trajectories
- Satellites that maneuver without publishing operator ephemeris cannot be reliably avoided by other satellites

Launch COLA Gap

- Satellites take time to be cataloged after a launch, cannot be reliably avoided by others during this time
- Launches directly into dense altitudes can contribute high risk

Prediction Quality

- Burn failures and state estimation upsets can render operator provided predictions ineffective for collision avoidance

Space Weather Volatility

- Space weather is hard to predict
- Solar storms can drastically degrade prediction accuracy for long prediction horizons

Best Practices

Publish Propagated Ephemeris for Satellites

- Generate propagations based on latest orbit state estimates, incorporate the anticipated effect of upcoming maneuvers
- Share ephemeris with other operators

Minimize Risk from Launches

- Avoid launching directly into high-density altitudes - instead, launch to an adjacent altitude and orbit transfer
- Publish ephemeris immediately after launch so that other satellites can start avoiding you as quickly as possible

Monitor Prediction Accuracy

- Propagate using real-time on-orbit drag to ensure accuracy
- Publish covariance to convey prediction confidence to others
- Frequently evaluate prediction accuracy and covariance realism, adjust if necessary

Low-Latency Data Sharing

- Publish ephemeris as frequently as possible (every contact)
- Utilize rapid screening systems to avoid unnecessary delays

Stargaze CDMs and the **Space Safety Coordination Platform** are being provided to satellite operators **free-of-charge** to assist in mitigating such hazards.

We invite all satellite operators to use the platform, start benefiting from this data, and share their own data - enabling a **safer LEO environment for all.**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