

Methodology - orbital debris density feed

This document describes the catalog, propagator, error bars, and refresh cadence that produce the numbers at `ephem-api.YOUR-SUBDOMAIN.workers.dev/shell/density/{alt}`.

§1 Source catalog

The nightly propagation reads the CelesTrak active catalog (GROUP=active&FORMAT=tle). At the time of writing this covers approximately 10,000 objects: the union of every active-payload, rocket-body, and tracked-debris object in the public NORAD catalog for which USSF/USSPACECOM publishes an unclassified two-line element set.

Excluded: classified objects, objects with epoch older than seven days at pull time, and objects flagged as decayed. Objects propagated to altitudes below 200 km or above 2,000 km are dropped from the shell binning.

§2 Propagator

SGP4 as implemented in `satellite.js` version 5.x. SGP4 is the standard general-perturbations model for LEO propagation against two-line element sets; it is the same model USSPACECOM publishes TLEs against. We do not re-fit orbits or use a different force model - the point is that any competent analyst can reproduce our numbers from the same public catalog with the same open-source library.

Propagation epoch is the moment the nightly cron fires (03:17 UTC). Every object is propagated exactly once per run. State vectors are converted to geodetic coordinates (WGS-84) via `eciToGeodetic` in `satellite.js`.

§3 Binning

Each propagated object is assigned to one shell of 10 km radial thickness. Within the shell, latitude and longitude are binned to $5^\circ \times 10^\circ$ cells. Density is objects per km^3 within the cell, using the spherical shell volume element:

$$V(\text{cell}) = r^2 * dr * dlat * dlon * \cos(\text{lat_centre})$$
 with $r = 6371 + \text{altitude_km}$, $dr = 10 \text{ km}$, $dlat = 5 \text{ deg}$, $dlon = 10 \text{ deg}$.

§4 Refresh cadence and stability

The propagator runs at 03:17 UTC – 1 hour every day. Density envelopes are published to Cloudflare KV under `shell:{alt}` and served with a 24-hour cache TTL. A diff envelope (added / removed / shell-crossed objects vs. the previous run) is published to `shell:diff:latest`.

If the CelesTrak fetch fails on a given night, no new numbers are published - the previous night's envelope continues to serve. This is deliberate: stale-known-good beats fresh-but-partial for a feed enterprise customers make decisions from.

§5 Error bars

SGP4 accuracy against a same-day TLE is typically -1 km along-track for LEO; error grows roughly linearly with time from epoch, on the order of 1 km/day for a stable object. Because the propagator uses fresh TLEs (max age at pull ~ 24 hours), the radial error is essentially always within the 10 km shell width used for binning.

The dominant uncertainty is catalog completeness, not propagation error. Small debris (<10 cm) is under-catalogued and Ephem inherits that gap. Enterprise tier can extend the feed with a licensed model overlay (ESA MASTER, NASA ORDEM).

§6 Diff semantics

The nightly diff reports added (ids present tonight but not last night), removed (ids present last night but not tonight), and shell-crossed (objects whose shell membership changed by ≥ 1 bin - roadmap, not yet emitted).

§7 Reproducibility

Anyone can reproduce a given night's numbers from three inputs: the CelesTrak active catalog snapshot at `fetch_at`, `satellite.js` at the pinned version, and the binning parameters above. Reference reproducer at `apps/api/src/shell/propagator.ts` in the Ephem repository.

§8 Signature

Ephem Ltd. publishes and stands behind these numbers. Questions from academic or regulatory reviewers to naraxcel.studio@gmail.com; response within one business week.