The Impact of Space Weather on Space Traffic Management in the NewSpace Era

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New Space Activity is dramatically changing the landscape of space

- Low Earth Orbit (LEO) is becoming much more crowded
  - *Large constellations are being deployed*
  - *Many other large constellations proposed*
  - *Greatly increased launch rates*
  - *Space tourism is on the horizon*
- Commercial activity is dominating over government programs
- There are MANY more countries launching space systems, no longer just the US and Russia, China
- Existing operators are already seeing an increase in collision alerts
- Space debris concerns interwoven with other traffic issues
- Even with responsible actors, it is a complex problem

*Some possible new constellations**

Operator	Num sats	Alt (km)	Country	Operator	Num sats	Alt (km)	Country
SpaceX 30K	30,000	320-580	US	Amazon Kuiper	3,326	590-630	US
SpaceX V-band	7,518	335-345	US	~~Yalini~~	~~135~~	~~600~~	~~Canada~~
Black Sky	60	450	US	Spire Lemur	100	650	US
Orbcomm	36	480	US	Lishui	120	700	China
Satelogic	90	490	Argentina	Iridium	66	780	US
Worldview	44	490-710	US	Theia	112	800	US
Planet Doves	150	500	US	~~Boeing~~	~~2,986~~	~~970-1030~~	~~US~~
~~Pearls~~	~~200~~	~~500~~	~~UK~~	Lucky Star	156	1000	China
Magpie	132	530	China	Telesat LEO	117	1000-1200	Canada
SpaceX Starlink	4,408	540-570	US	Hongyun	156	1070	China
Kepler	140	550	US	Hongyan	324	1100	China
EarthNow	434	550	US	*OneWeb*	*2,000*	*1200*	*UK/India*
Xingyun	80	570	China	*OneWeb*	*47,844*	*1200*	*UK/India*
Skybox	30	570	US	Viasat	300	1300	US
Hawkeye	80	570	US	Astrome Tech	200	1400	India
Swarm	450	580	US	~~LeoSat~~	~~120~~	~~1400~~	~~US~~
Fleet	100	580	Australia	Globalstar	48	1412	US

More than 100,000 satellites in the first generation

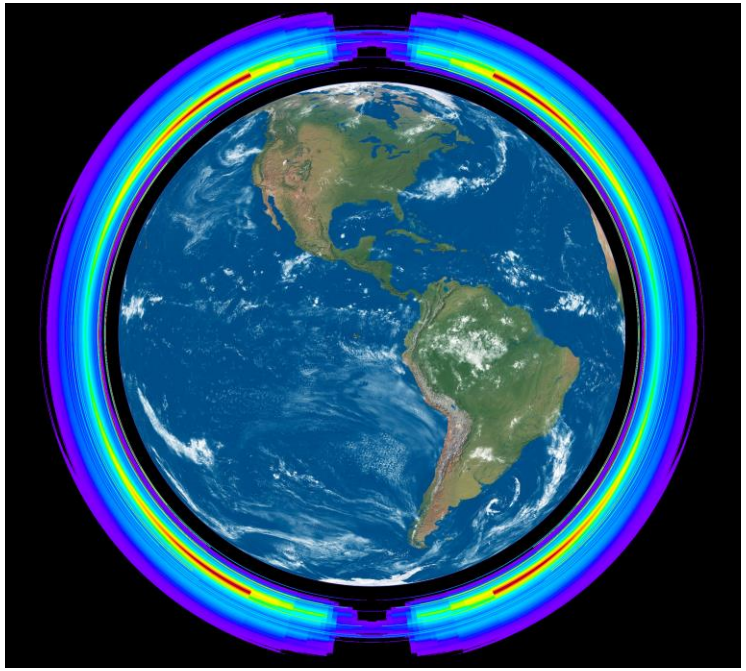
* Information from FCC filings and press releases

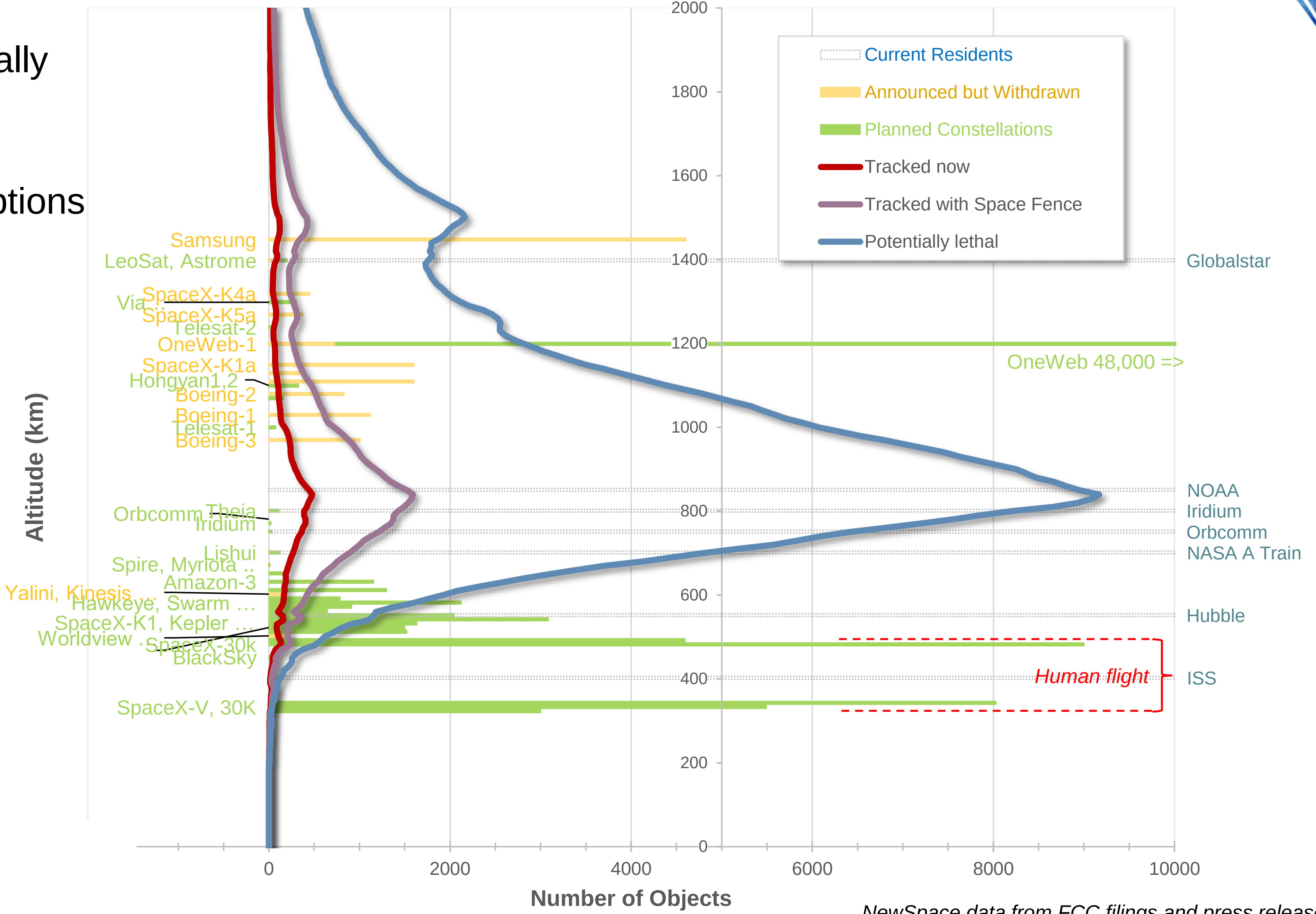
New Space Activity is dramatically changing the landscape of space

Space is BIG, but maybe not big enough

- The new systems can dramatically change the traffic patterns for existing operators
- Most operations rely on assumptions about density of spacecraft and debris that are changing

Density of objects in LEO





NewSpace data from FCC filings and press releases

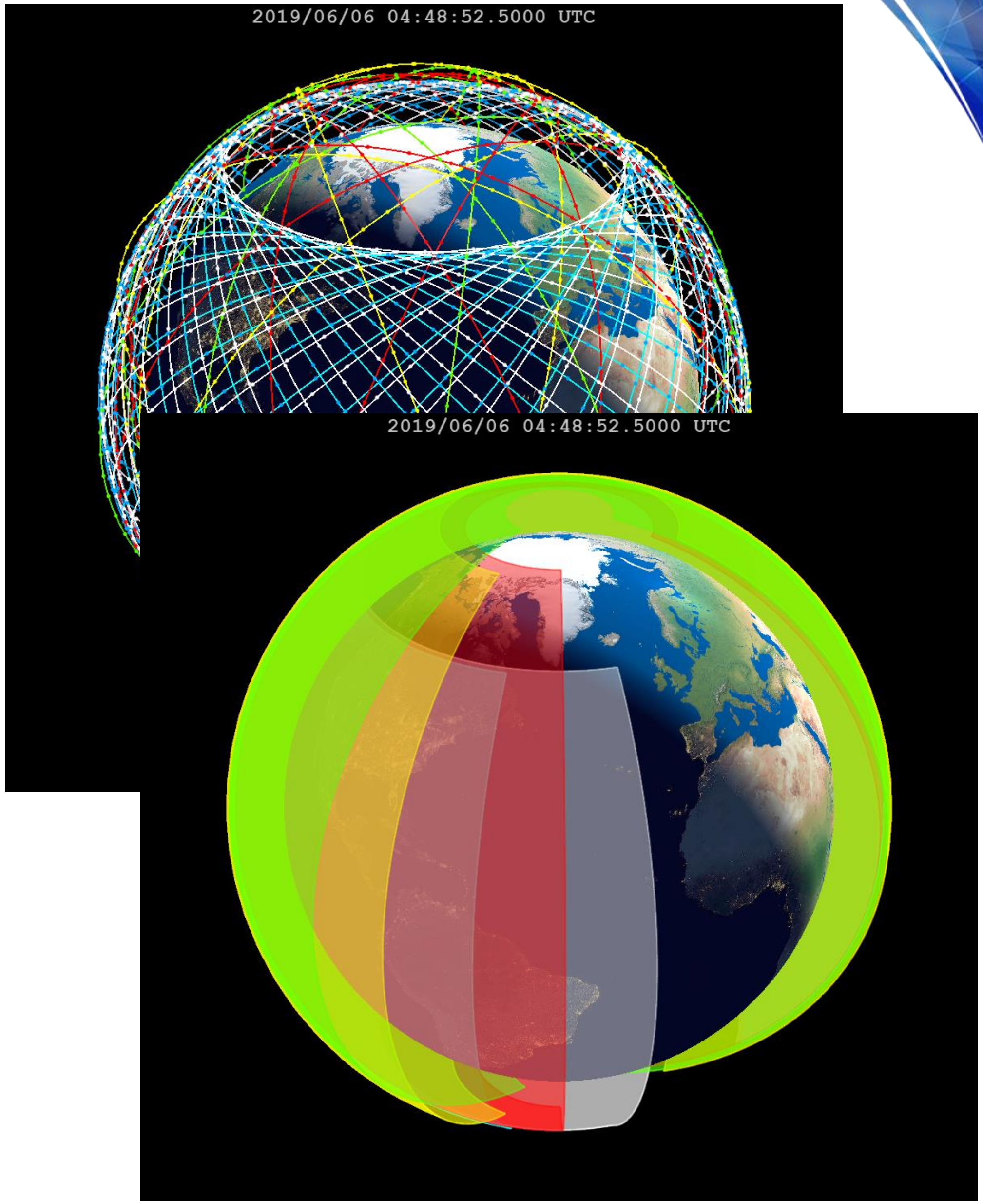
Large constellations have special new challenges

- SpaceX Starlink, OneWeb, Amazon Kuiper, and other large LEO constellations (LLCs) or proliferated LEOs (pLEO) present special challenges for neighbors

- The large number of satellites form a “shell” where a neighbor might repeatedly encounter many members of the constellation

- Large constellations can
  - *lead to **frequent** COLA warnings – thousands per day*
  - *have <u>self</u>-conjunctions in the tens of thousands per day*

- Most LLC operators plan for electric (ion) thrusters and autonomous COLA and stationkeeping
  - *The vehicles frequently adjust their orbits without human intervention*
  - *This completely invalidates the assumptions in traditional COLA since we cannot predict the position days in advance*



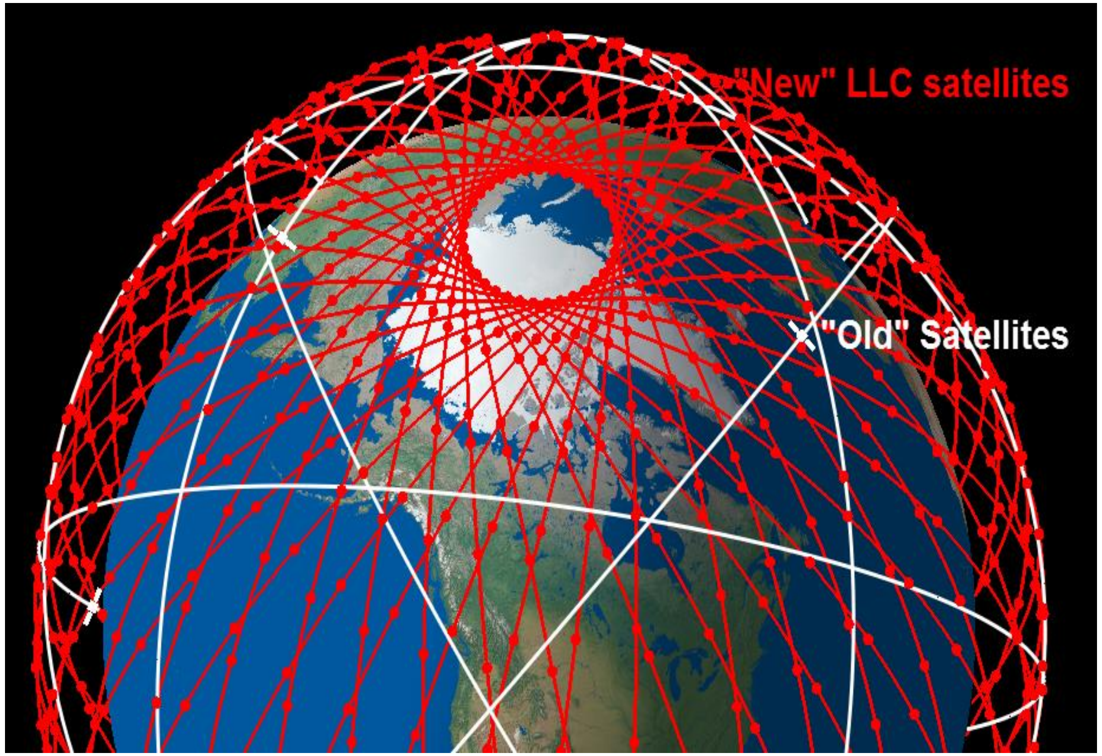
Do we make special rules for large constellations?

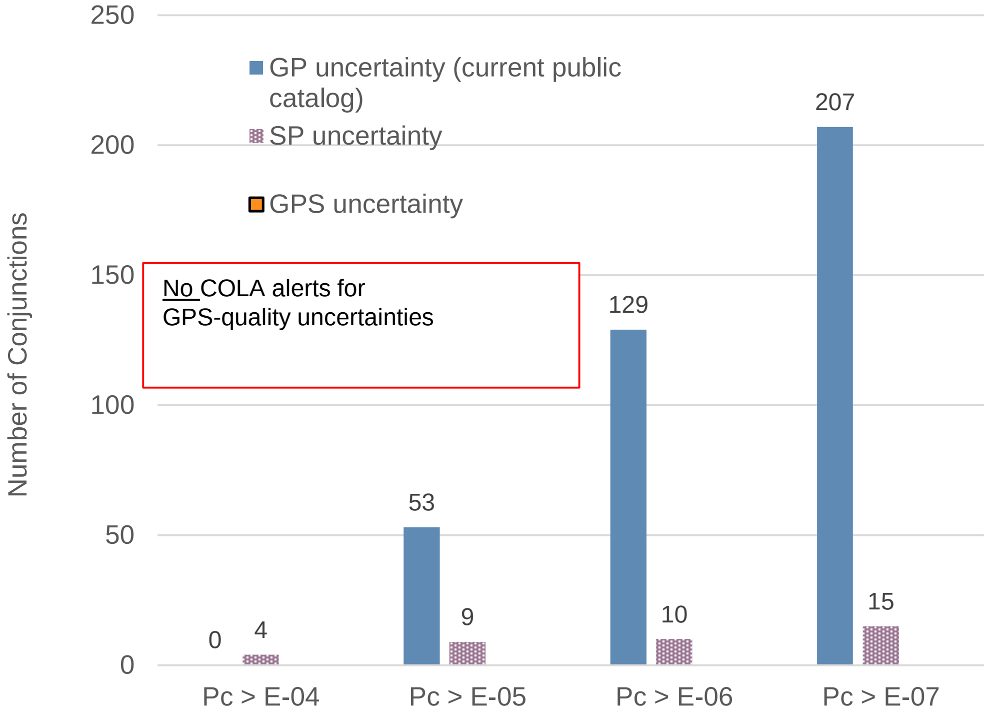
Number of problem conjunctions depends on data quality

Example case

- 1225 “New” satellites are distributed in 35 planes in circular orbits at 1000 km, 98 deg inclination.
- “Old” six-satellite constellation operates in nearly circular orbit at the same altitude and 63 deg inclination

- For GP-quality uncertainty and 10e-7 Pc threshold, these systems see > 200 conjunctions in 30 days
- For GPS-quality uncertainty, there were no flagged conjunctions, even for a 10e-4 Pc threshold.



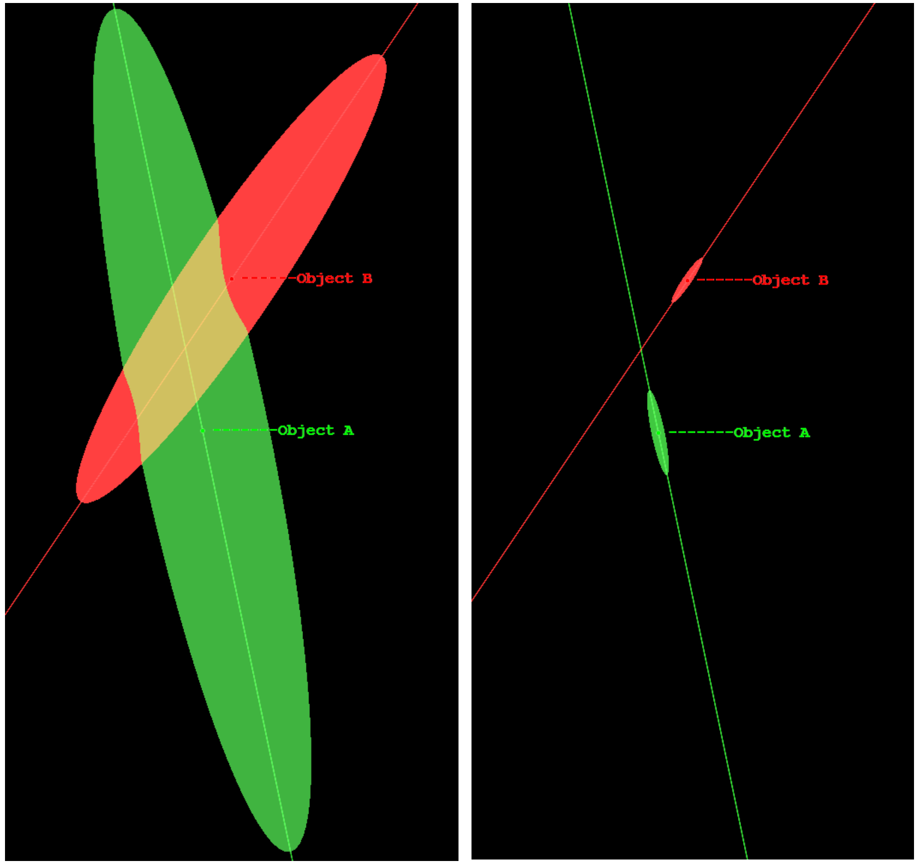


Collision Avoidance (COLA) Maneuvers

Typical historical rhythm for a worrisome conjunction

- Conjunction is noticed by Space Force 5-7 days in advance (longer notice has too-low probability due to too-large errors)
- Affected operators are notified, additional tracking of objects and better data is sought
- If conjunction remains a high enough probability a few days in advance, an avoidance maneuver might be planned
- If the conjunction is still a problem the day before, operator may choose to maneuver or ride through
- The Pc drops with distance. Distance = velocity x time, so earlier maneuvers need smaller delta velocities
- COLA maneuvers are often combined with maneuvers for other reasons

- Operators say **timely and high-quality conjunction predictions** (probability) are of primary importance
  - *Poor quality data may be un-actionable*
  - *Large constellation owners may be overwhelmed with false alarms using current practices*



Non-Cooperative Tracking Network uncertainty
(Shown at Time of Closest Approach)

GPS Transponder uncertainty
(Shown at Time of Closest Approach)

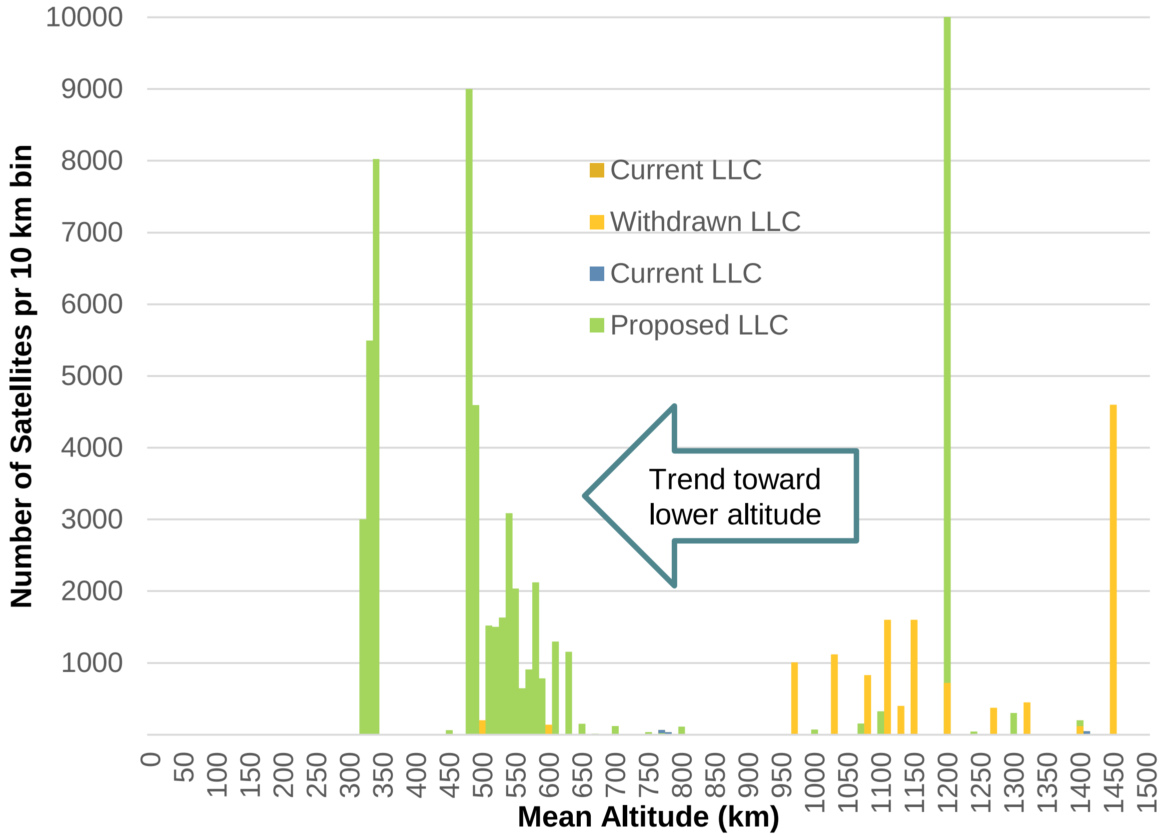
Atmospheric Density Models will DIRECTLY impact Orbit Prediction

- All orbit models have terms for estimating drag forces
  - *Dependent on spacecraft cross-sectional area, attitude, drag coefficient*
  - *Highly dependent on atmospheric density*

- The lower the mean altitude of an orbit, the greater the impact of drag – greater uncertainty

- Uncertainty in atmospheric density contributes directly to orbit position and velocity uncertainty – drives along-track error covariance

- Many operators are proposing using more satellites in lower mean altitudes
  - *Shorter lifetime is insurance for failures*
  - *Need for better predictions is growing*

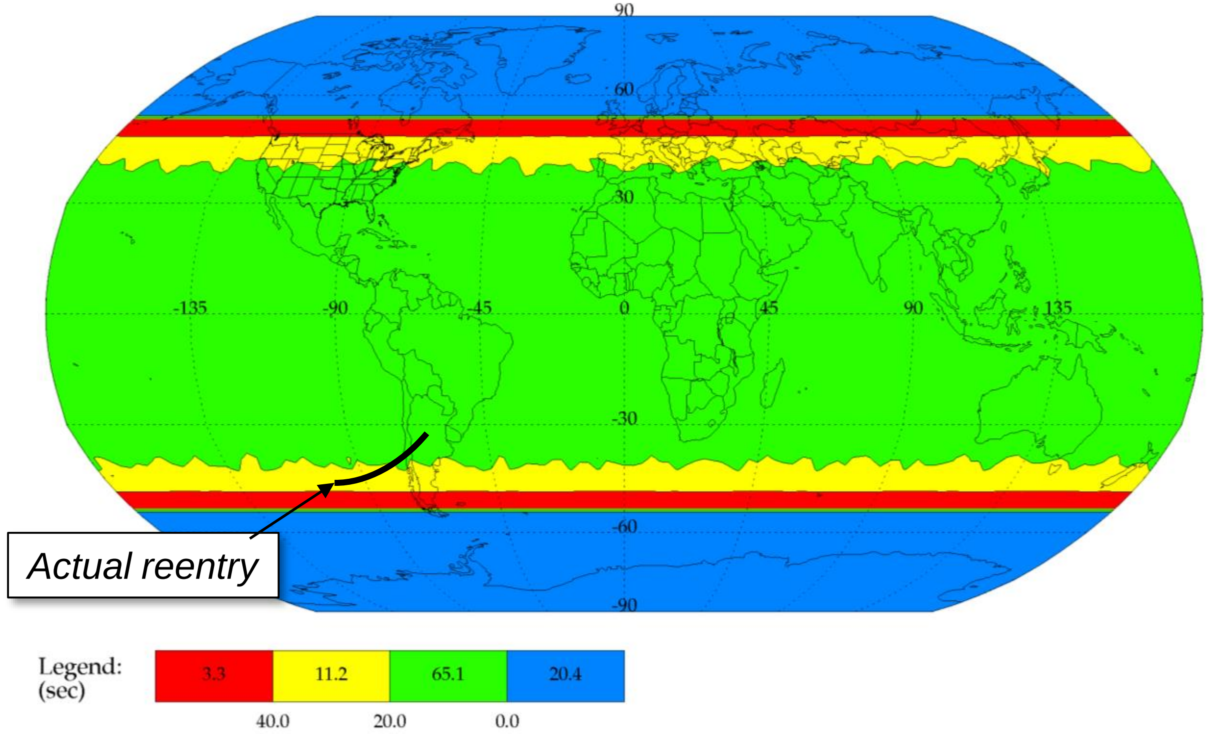


What Goes Up Must Come Down

The issues with reentry

- New Space Operators are planning to launch tens of thousands of spacecraft in each generation (5-7 years)
- The majority are planning uncontrolled, “random” reentries instead of controlled reentries targeted to a low population area (e.g. South Pacific “graveyard”)
- Reentry location prediction with current models has a 20% error in time-to-go:
  - *~2 month error a year in advance*
  - *~1 week error a month in advance*
  - *~1 day error a week in advance*
  - *3 orbits a day in advance – anywhere around the planet*
  - *1 min error can equate to hundreds of miles downrange*
- Uncertainty in reentry prediction exposes larger population to calculated risk.
- Current guidelines for reentry casualty risk must be < 1/10,0000. ➔ multiplied by thousands of reentries

Predicted Reentry risk for Phobos-Grunt

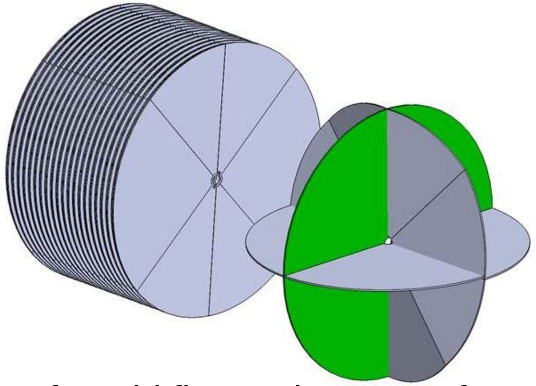


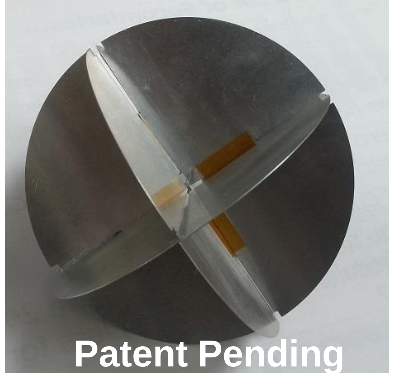
Atmosphere Models Directly Affect Reentry Risk Estimation

AeroCube 10A – Atmospheric Probes

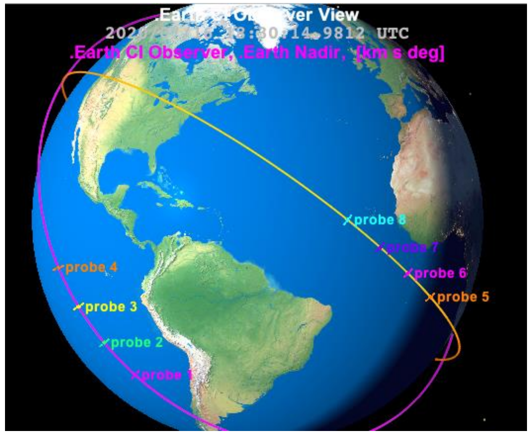
An orbital weather balloon…

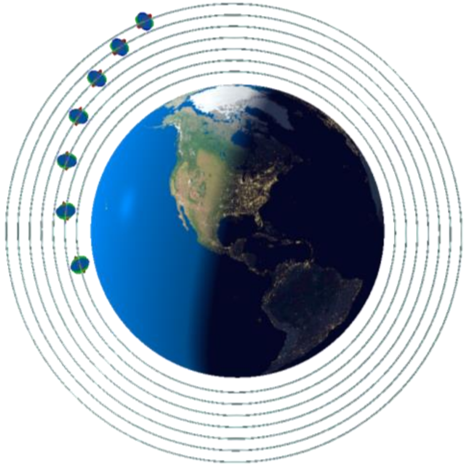
- Last year Aerospace launched an experimental 1.6 U CubeSat (AeroCube 10A) carrying 28 atmospheric retroreflector probes
  - *Low mass, a high ballistic coefficient, and constant drag profile regardless of orientation – very sensitive to density variations*
  - *Very inexpensive, highly radar reflective, trackable (S-Band)*
  - *High drag equates to relatively short lifetime (~4-5 months) – no long-term debris*
  - *3 probes released so far and tracked (~250-500 km)*
- Conceptually, series of probes could provide in-situ measurement of thermospheric density at multiple altitudes simultaneously (Next generation falling sphere experiment)
  - *Improvement on current orbit average density usage in drag models*
  - *May provide global information on thermospheric tides, gravity waves, and traveling atmospheric disturbances (TADs)*
- CubeSat-compatible form-factors (i.e., 6 or 12U) could contain hundreds of probes for regular, periodic release
- Assessment of density extraction quality underway





Left: Fold flat, spring out to form three planes in a spherical shape when released. Right: Assembled AeroCube 10 probe





Multiple orbit planes of probe group releases provides horizontal and vertical density resolution.

Summary

- New Space very large constellations are changing the space operations environment
  - *Orders of magnitude changes in most metrics*
  - *Previous operational experience and assumptions may not hold*

- The need for active space traffic management is immediate and growing

- Previous operational practices for collision avoidance will not work – need new approaches to obtaining better information, reducing orbit prediction covariances

- Improved models and real-time data for atmospheric density in low orbit are needed for space traffic management and reentry predictions

Business as usual will not work.