National Aeronautics and Space Administration

NASA Conjunction Assessment Risk Analysis (CARA): CARA Process Overview, Large Constellations and Light Pollution

NASA, NSF and DOE Astronomy and Astrophysics Advisory Committee

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NASA **Conjunction Assessment Risk Analysis**

AGENDA

- CARA Overview
- Large Constellations
  - Statistics
  - Operational CONOPS
  - Ongoing coordination plans
- Light Pollution Brightness Metric
  - CARA analysis and tool
- Summary

Satellite Collision Avoidance Operations at NASA

- Human Space Flight (HSF) CA performed by Flight Operations Directorate (FOD) at JSC
  - ISS/visiting vehicles (VV), commercial crew and exploration missions
  - Support includes risk assessment and execution of collision avoidance maneuvers if required

- The NASA Conjunction Assessment Risk Analysis (CARA) program is responsible for risk assessment and mitigation support for ~100 non-human spaceflight (HSF) spacecraft
  - Started in 2005 at GSFC based on HSF process
  - Agency-central service for CA and international partnerships (i.e., JAXA, CNES)
  - Work very closely with the DoD Space Force

- CA at other central bodies (Moon, Mars, etc.) supported by the MADCAP (Multi-mission Automated Deep space Conjunction Assessment Process) program at JPL
  - Cis-lunar, Planetary and beyond

National Aeronautics and Space Administration

CARA Overview

PREDICT—ASSESS—MITIGATE

NASA **Conjunction Assessment Risk Analysis**

www.nasa.gov

CARA Program

- **CARA reduces operational risk by protecting existing and future NASA missions from threat of on-orbit collisions for both spacecraft safety and space environment protection.**

- **CARA is a complex operational undertaking involving:**
  - Mathematically sophisticated algorithms to generate decisional metrics
  - Process and procedures that involve multiple interfaces and data exchanges including with the DoD
  - Multiple decision points requiring human-handling/intervention

- CARA currently provides support to **~100 NASA missions at various stages of mission development and operations, guided by the NASA Procedural Requirements (NPR) 8079.1**:
  - Pre-mission-implementation phase support and analysis via Orbital Collision Avoidance Plan (OCAP)
  - Pre-launch support via Conjunction Assessment Operations Interface Agreement Plan (CAOIA)
  - On-Orbit real-time support for collision avoidance and event risk analysis

NASA CARA has a commitment to our customer base to take prudent measures, at reasonable cost, to improve safety of flight, without placing an undue burden on space mission execution.

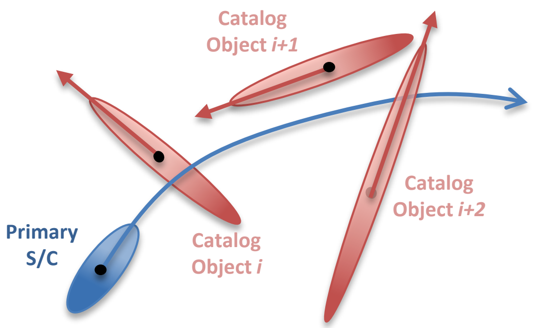
NPR 8079.1: NASA Spacecraft Conjunction Analysis and Collision Avoidance for Space Environment Protection

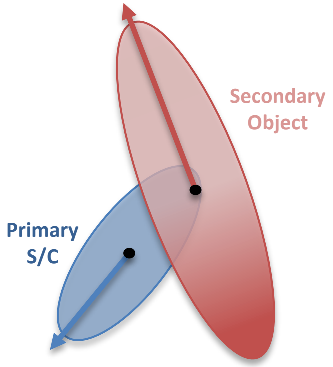
CARA Team Composition

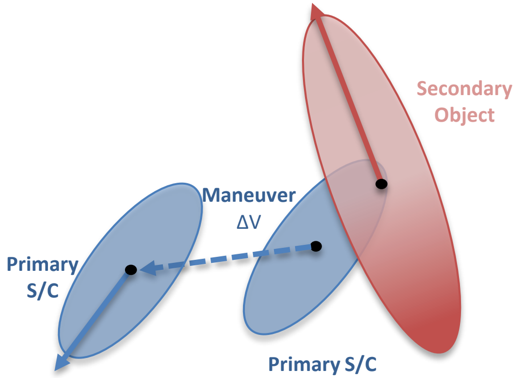
- The CARA team is comprised of 5 groups that work together to make an informed recommendation for CA support:
  - **CARA Orbital Safety Analysts** (COSAs or OSAs)
    - Perform screenings of NASA missions against the Space Catalog, create scripts to process tracking data in support of analysis, and perform orbit data actionability assessments.
  - **Operations Team**
    - Engage with missions to provide CARA support pre- and post-launch (on orbit)
  - **Analysis Team**
    - Performs technical research and algorithm development for operations support, performs on-orbit CA operations event analysis, and identifies and analyzes areas for novel implementation.
  - **Software & Ground Systems and System Administration**
    - Designs CARA Operational System Architecture, performs software development of operations tools, and perform the Ground Systems' troubleshooting and maintenance.
  - **Management**
    - Leads and manages the CARA task.

CA process: Intricate and intensive, given that each spacecraft and conjunction event is unique.

Satellite Conjunction Assessment: NASA Process Details







Conjunction Assessment (CA) is the process of identifying close approaches between two orbiting objects; sometimes called **conjunction screening**.

The **18th Space Defense Squadron (18 SDS)** at Vandenberg Space Force Base (VSFB) maintains the high accuracy catalog of space objects. Orbital Safety Analysts (OSAs) at VSFB screen protected assets against the catalog, perform tasking requests, and generate close approach data.

CA Risk Analysis (CARA) is the process of assessing collision risk and assisting satellites in planning maneuvers to mitigate that risk, if warranted.

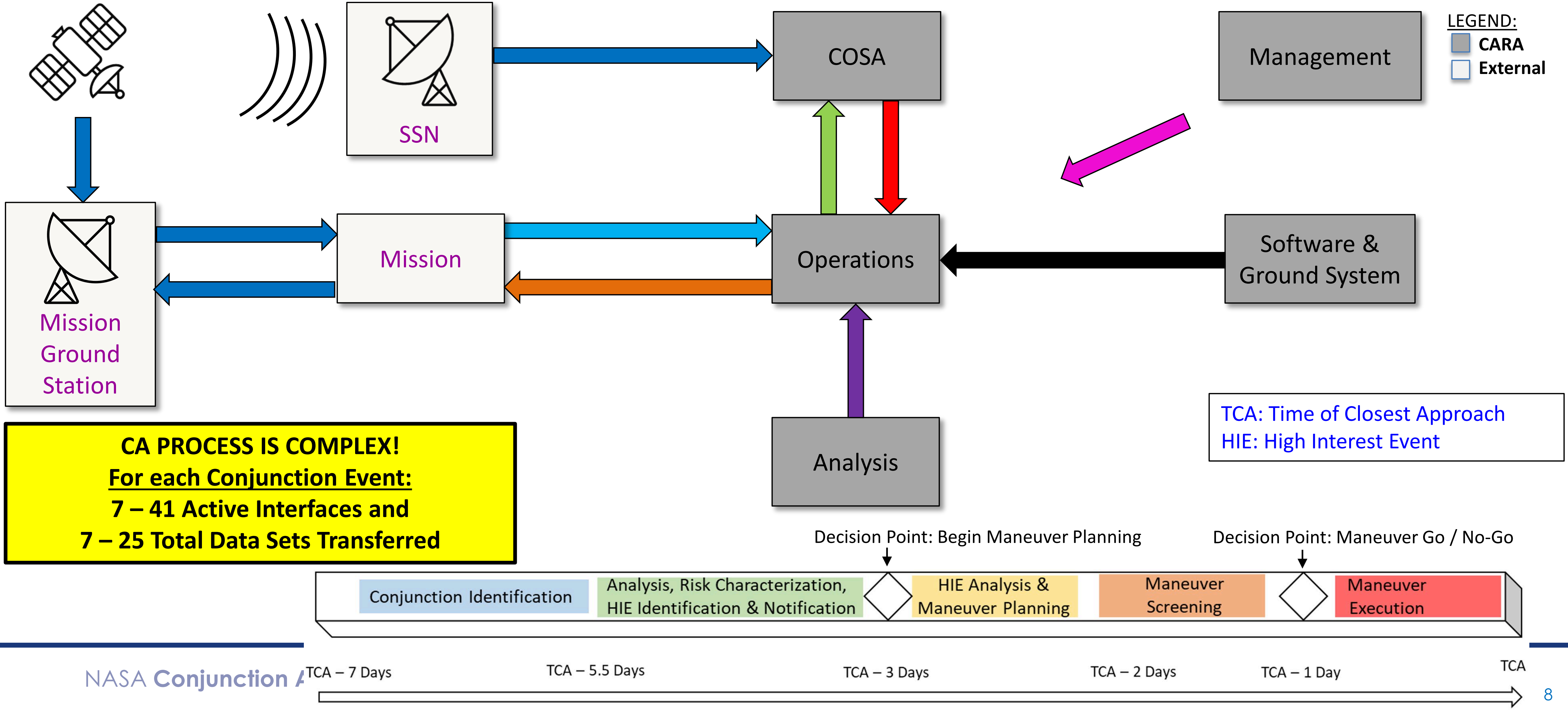
The NASA **CARA** program performs risk assessment for all NASA operational non-HSF satellites, and some partner missions.

JSC **Flight Operations Directorate (FOD)** performs risk assessment for all NASA Human Spaceflight (HSF) program assets and is the O/O for maneuver decisions and execution.

Collision Avoidance is the process of executing mitigative action, typically in the form of an orbital maneuver, to reduce collision risk.

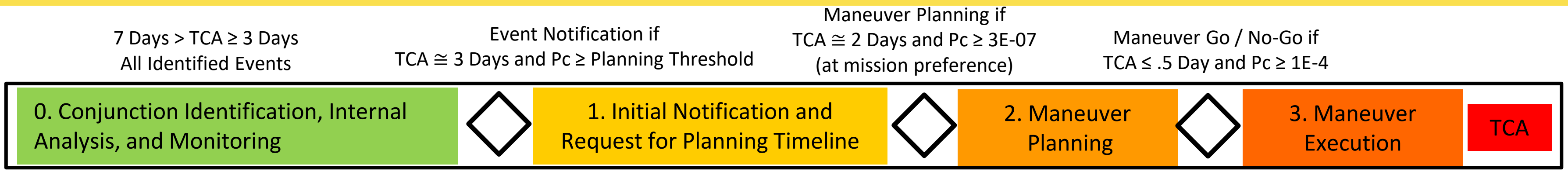
Each satellite **Owner/Operator (O/O)** – mission management, flight dynamics, and flight operations – is responsible for making maneuver decisions and executing the maneuvers.

CARA Real Time Process (3x a Day, TCA-7days)

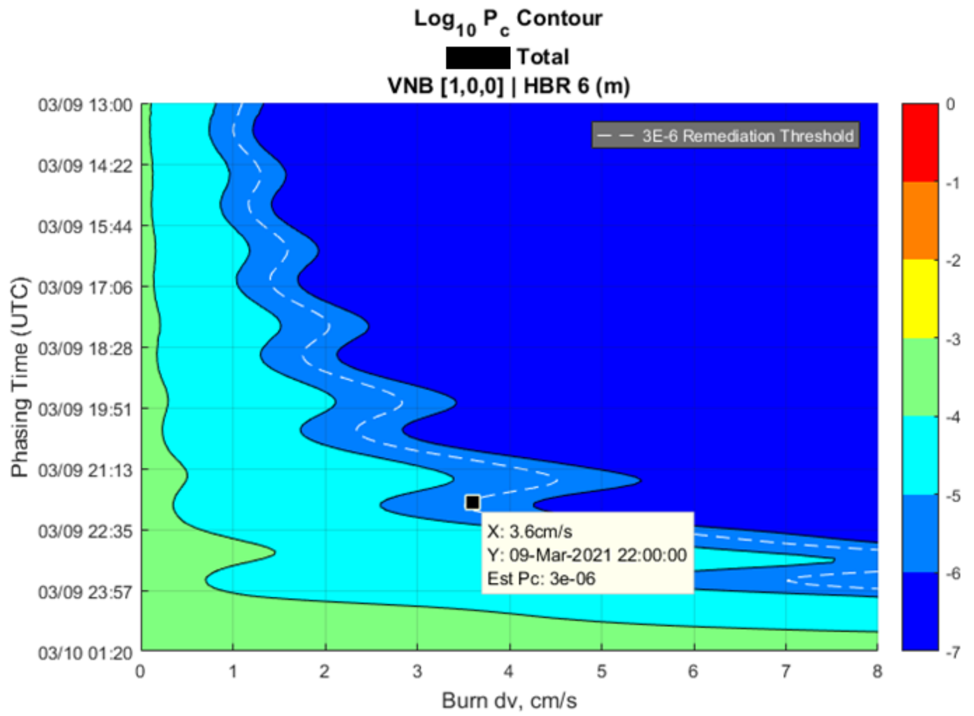


CA PROCESS IS COMPLEX!
For each Conjunction Event:
7 – 41 Active Interfaces and
7 – 25 Total Data Sets Transferred

Maneuver Planning



- Maneuver planning is an iterative process
- Cycle: Maneuver Trade Space → Generate burn ephems → Maneuver screening → Results analysis
  - Multiple cycles can be required to decide on a final maneuver
- Requires iteration between CARA and mission
  - Mission input used to generate CARA maneuver planning products
  - Mission and spacecraft considerations and/or limitations factor into CARA recommendations
  - With experience and refinements, iterative process can be reduced and/or eliminated in most cases



CARA Automated Summary Report

Aqua (27424) [HBR = 20m]

[Mission-Defined Threshold: (Pc >= 1.0e-05) or (miss <= 0.07km)]

A. High Risk Conjunction Events [Collision Probability >= 4.4e-4]

Days to TCA	TCA (GMT)	Secondary Object	Primary Ephem Source	Secondary Ephem Source	Screening Epoch (GMT)	Miss [m]	R [m]	I [m]	C [m]	Tracked Since Previous OCM?	Pc	Above Mission Threshold?
3.1	28 Mar 2019 23:34:46 Details	NOAA 16 DEB (41533)	ASW	ASW	25 Mar 2019 21:14:09	663.8	-40.2	-119.3	-651.8	N	1.20e-3 (1:830)	YES
3.1	28 Mar 2019 23:34:46 Details	NOAA 16 DEB (41533)	O/O	ASW	25 Mar 2019 21:14:09	690.1	-25.8	-126.6	-677.9	N	1.53e-3 (1:654)	YES

B. Monitor Conjunction Events [1e-7 <= Collision Probability < 4.4e-4]

Days to TCA	TCA (GMT)	Secondary Object	Primary Ephem Source	Secondary Ephem Source	Screening Epoch (GMT)	Miss [m]	R [m]	I [m]	C [m]	Tracked Since Previous OCM?	Pc	Above Mission Threshold?
5.0	30 Mar 2019 22:49:53 Details	UNKNOWN (82379)	ASW	ASW	25 Mar 2019 15:02:31	29677	-109.9	22843	18944	N/A	No OCM	---
5.0	30 Mar 2019 22:49:52 Details	UNKNOWN (82379)	O/O	ASW	25 Mar 2019 15:02:31	16469	-75.0	12676	10515	N	3.45e-5 (1:29K)	YES

C. Low Risk Conjunction Events [Collision Probability < 1e-7]

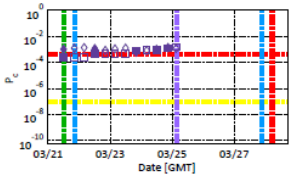
Days to TCA	TCA (GMT)	Secondary Object	Primary Ephem Source	Secondary Ephem Source	Screening Epoch (GMT)	Miss [m]	R [m]	I [m]	C [m]	Tracked Since Previous OCM?	Pc	Above Mission Threshold?
1.6	27 Mar 2019 12:38:17	UNKNOWN (80269)	ASW	ASW	25 Mar 2019 21:14:09	9563	143.4	-9239	2464	Y	0.00e00	---
1.6	27 Mar 2019 12:38:17	UNKNOWN (80269)	O/O	ASW	25 Mar 2019 21:14:09	9606	151.8	-9280	2473	Y	0.00e00	---
3.3	29 Mar 2019 04:27:47	IRIDIUM 33 DEB (35742)	ASW	ASW	25 Mar 2019 21:14:09	1514	181.5	1493	-171.7	Y	0.00e00	---
3.3	29 Mar 2019 04:27:47	IRIDIUM 33 DEB (35742)	O/O	ASW	25 Mar 2019 21:14:09	1288	198.3	1264	-146.8	Y	0.00e00	---
3.3	29 Mar 2019 06:06:47	IRIDIUM 33 DEB (35742)	ASW	ASW	25 Mar 2019 21:14:09	4241	-413.1	4196	-458.9	Y	0.00e00	---
3.3	29 Mar 2019 06:06:47	IRIDIUM 33 DEB (35742)	O/O	ASW	25 Mar 2019 21:14:09	3998	-396.0	3955	-432.3	Y	0.00e00	---
5.0	30 Mar 2019 21:51:20	COSMOS 192 (03047)	ASW	ASW	25 Mar 2019 21:14:09	11097	-661.4	9783	-5195	N/A	No OCM	---
5.0	30 Mar 2019 21:51:20	COSMOS 192 (03047)	O/O	ASW	25 Mar 2019 21:14:09	10623	-650.0	9365	-4971	N/A	No OCM	---
5.1	31 Mar 2019 01:14:04	CZ-4 DEB (20907)	ASW	ASW	25 Mar 2019 21:14:09	26077	-346.8	19488	17324	N/A	No OCM	---
5.1	31 Mar 2019 01:14:04	CZ-4 DEB (20907)	O/O	ASW	25 Mar 2019 21:14:09	25662	-341.1	19178	17047	N/A	No OCM	---
5.2	31 Mar 2019 02:52:59	CZ-4 DEB (20907)	ASW	ASW	25 Mar 2019 21:14:09	8198	-350.4	6123	5440	Y	0.00e00	---
5.2	31 Mar 2019 02:52:59	CZ-4 DEB (20907)	O/O	ASW	25 Mar 2019 21:14:09	7772	-345.9	5803	5158	Y	0.00e00	---

ESC CA Summary Report (25 Mar 2019 22:09 GMT) -- 25 Mar to 1 Apr

Conjunction Event Details - Aqua (27424) vs. NOAA 16 DEB (41533)

Days to TCA	TCA (GMT)	Secondary Object	Primary Ephem Source	Secondary Ephem Source	Screening Epoch (GMT)	Miss [m]	R [m]	I [m]	C [m]	Tracked Since Previous OCM?	Pc	Above Mission Threshold?
3.1	28 Mar 2019 23:34:46 Back	NOAA 16 DEB (41533)	ASW	ASW	25 Mar 2019 21:14:09	663.8	-40.2	-119.3	-651.8	N	1.20e-3 (1:830)	YES
3.1	28 Mar 2019 23:34:46 Back	NOAA 16 DEB (41533)	O/O	ASW	25 Mar 2019 21:14:09	690.1	-25.8	-126.6	-677.9	N	1.53e-3 (1:654)	YES

Pc History



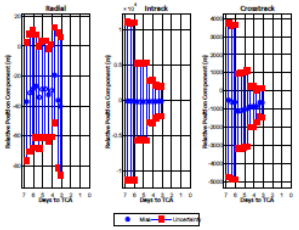
Event Flags	
Arc Cut For Primary Maneuver	N
Arc Includes Primary Maneuver	N
Repeating Conjunction	N
High Drag Secondary	N
Large RCS Secondary	N
Increased Tasking Requested	N
Increased Tasking Received	N
Pc Increased By > 2 Orders Of Magnitude	N

Secondary Object OD Information			
Avg. Tracks / Day	0.9	Single Station Tracking	Y
Fit Span	~15 days		
Time Since Last Observation	< 24 hrs	Norm. Fit Metric	2.26
Total Propagation Time	~3 days		

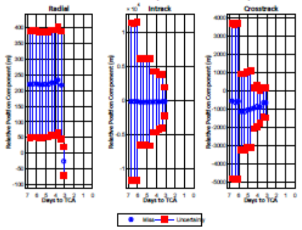
Maneuver Epoch	Magnitude [m/s]	Duration [s]	Type
2019-03-22 14:53 Z	1.206700	560	INC 64 (POSTPONED)
2019-03-28 15:55 Z	1.217800	560	INC 65

Most Recent O/O Ephemeris File	MEME_27424_aqua_0850000_SPEC_Aqua_2019085_NOBURN_S00_unclassified.txt
Ephemeris File End	2019-04-02 00:00:00
Most Recent O/O Covariance File	MEME_27424_aqua_0850000_SPEC_Aqua_2019085_NOBURN_S00_unclassified.txt

ASW Miss Component History



OO Miss Component History



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CARA Interfaces

CARA

Technical Interfaces

CNES
- Collaborate with CAESAR team and shares CA tool (JAC)

Space Weather
- Collaborate with APL, GSFC CMCC, LANL, NOAA, NRL

DoT

FAA
- Review launch license applications
- Review proposed regulations

FCC
- Review launch license applications
- Review proposed regulations

DoC
- Collaborate on STC framework

NASA

NASA HQ
- SMD: CAPO, Funding, STM
- STMD: Research and Tech Demo
- OSTP: Collison Avoidance with Space Debris
- OCE: Requirements, Technical Authority
- OSMA: documentation
- OIIR: Policy & best practices; Int. Engagement
- EPP: SSA and protection operations

NASA JSC
- TOPO/FIDO: Performs CA risk analysis for ISS and visiting vehicles and commercial crew; Collaborates on analysis, lessons learned & s/w
- MOD: SME for HSF SSA
- ODPO: Provides Debris Models

NASA JPL
- Performs Lunar & planetary CA screenings

DoD

USSPACECOM
- Provides direction for DoD space operations
- Supports NASA in SSA Data Sharing
- Collaborates with NASA on technical issues

USSF Del 2
- Performs CA screenings for other entities
- Provides manpower, s/w, and h/w to perform the CA mission
- Collaborates with NASA on technical issues

NRO
- Performs CA for IC
- Shares Tactics, Techniques, and Procedures with NASA

CSpOC
- CFSCC's Command & Control Ops Center
- Adjudicates EMI reporting

NSDC
- CFSCC's Space Defense Ops Center
- Leverages interagency and IC partners to protect & defend space assets
- Manages Space Vault

AFRL
- Collaborates on Space Weather issues
- Conducts Orbital Debris research

NRL
- Collaborates on Space Weather issues

Commercial O/Os
- Interface for real-time close approach mitigation
- Sharing Best Practices for CA

National Aeronautics and Space Administration

Large Constellations CONOPS

NASA Conjunction Assessment Risk Analysis

www.nasa.gov

Operational Challenges with Large Constellations

Large effort to coordinate with numerous large constellation operators and secondary O/Os in general

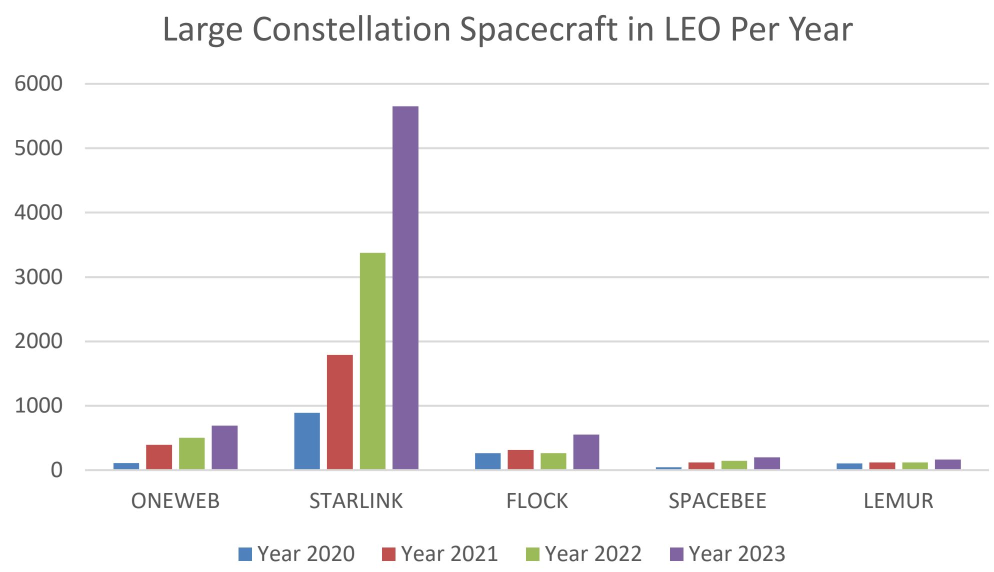
Each O/O has their **own CONOPS** and have various levels of CA CONOPS sophistication (i.e., **autonomous on-board maneuvers**)

O/O ephemeris quality evaluation is important in order to determine the **efficacy** of the O/O solution for **decision-making**

Need to continue **nominal operations** while **incorporating new large constellation** and other **secondary payload evaluation and work**

On-Orbit Constellations

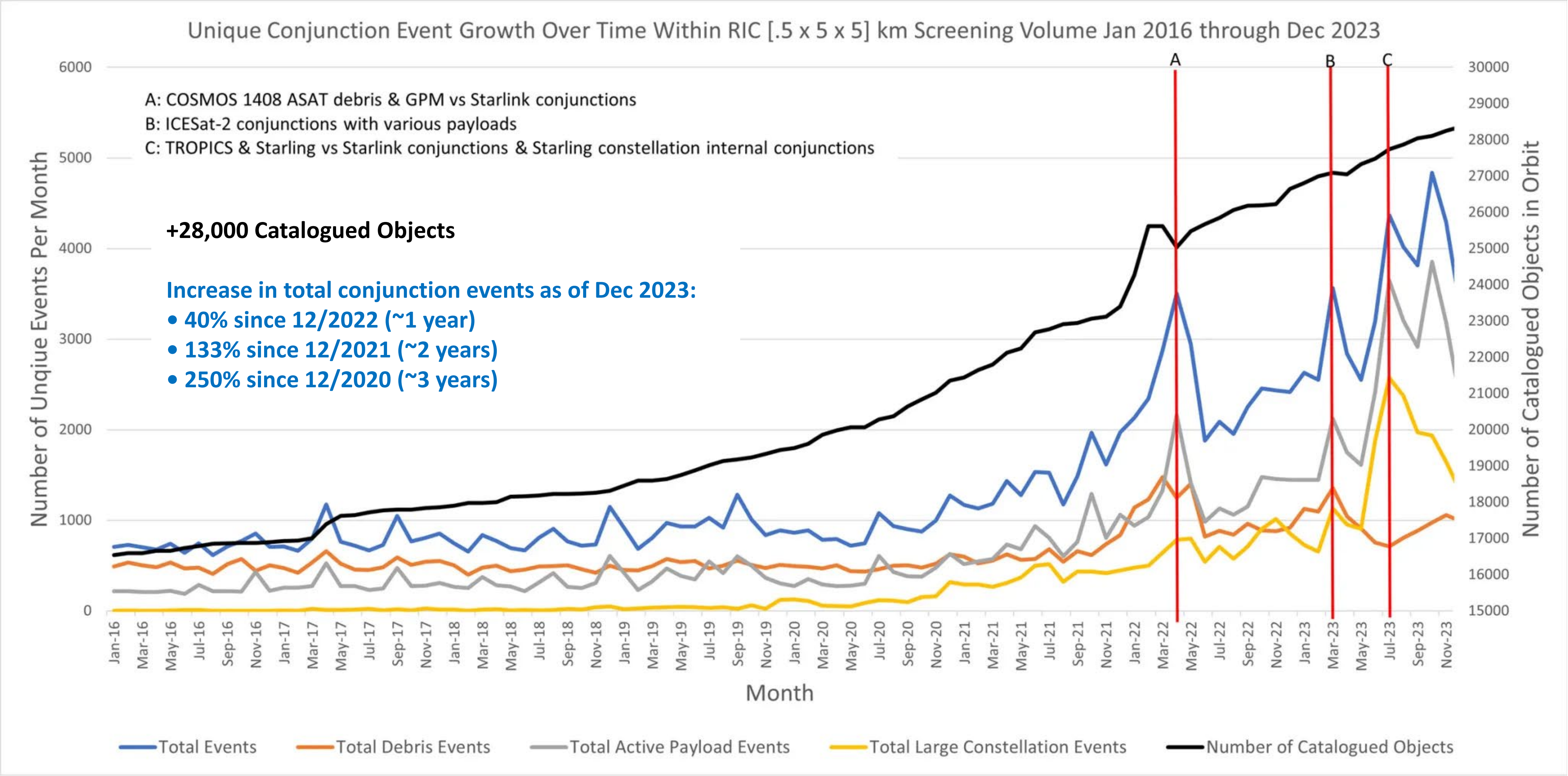
Constellation	Spacecraft Count	Altitude (km)	Maneuverability
Starlink (SpaceX)	5650	340-550	Maneuverable (Electric Hal Effect Thruster)
OneWeb	629	~1200	Maneuverable (Electric Hal Effect Thruster)
Flock (Planet Labs)	554	400-540	Differential Drag (Attitude) FEEP
SpaceBee (Swarm Technologies)	201	389-587	Non-Maneuverable
Lemur/Minas (Spire)	114	380-640	Non-Maneuverable



*Updated as of 01/09/2024

FEEP: Field Emission Electric Propulsion

Conjunction Statistics (January 2016-Dec 2023)



6 Reportable Break-up events in 2023:
Introduced between 6 – 500 debris objects per event

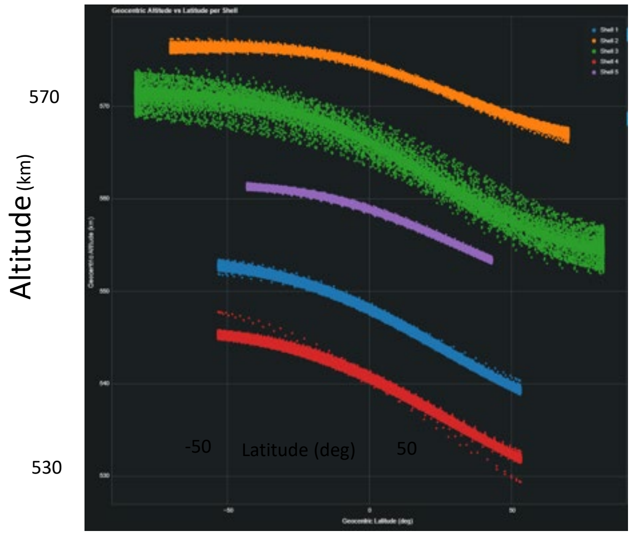
6 Break-up events in 2022:
Introduced between 6 – 500 debris objects per event

3 Break-up events in 2021:
Introduced between 12 – 1000 debris objects per event

Item of Interest: NASA-SpaceX Space Act Agreement (SAA)

- Starlink is very large constellation; ascents/ descents cross majority of NASA LEO mission orbits
- Because Starlink uses autonomous flight control, breaks usual CA paradigms
- SAA needed to codify that Starlink will take all CA mitigation actions and that NASA sats will not maneuver without 24 hours' notice
  - Only approach that allows Starlink automated CA functionality to operate properly
- NASA and SpaceX working on replacement system that will eliminate maneuver restrictions
  - Subject of STMD Starling experiment in 2024
  - Handles autonomous vs autonomous maneuver coordination situations
  - Needs to be moved to operations, hopefully by DOC

Current Starlink Population
(~4000 s/c in various shells)



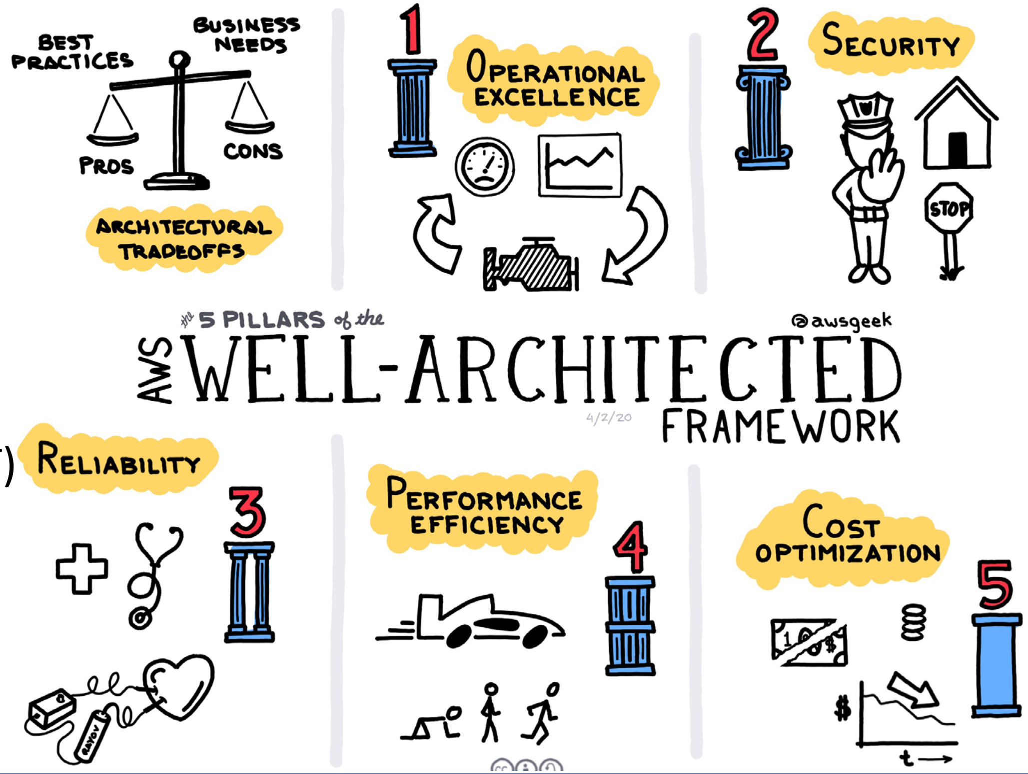
Gen 2 FCC Filing (7,500 sats approved)

Altitude	Inclination	Planes	Sats/Plane	Total Sats
535	33	28	120	3360
530	43	28	120	3360
525	53	28	120	3360
360	96.9	30	120	5280
350	38	48	110	5280
345	46	48	110	5280
340	53	48	110	5280
604	148	12	12	144
614	116.7	18	18	324

1st NASA Real-time mission operations capability on the Cloud.

CARA's Operational Cloud Computing Platform

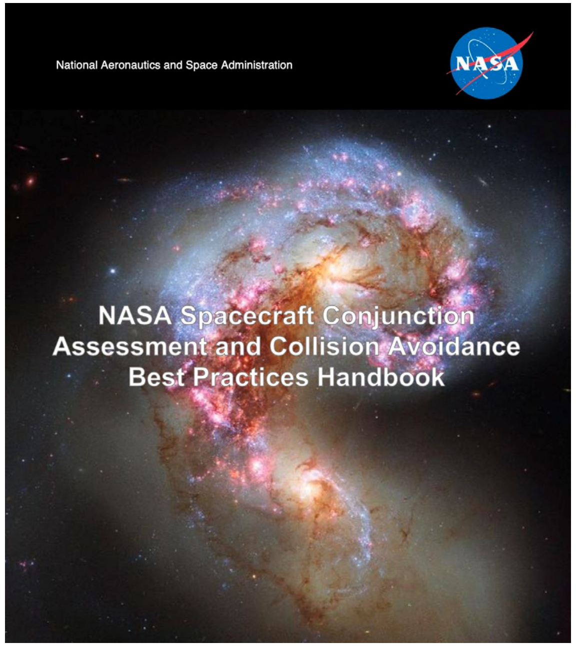
- CARA Requirements and drivers for Cloud Operations
  - Closes POA&M for backup facility requirement (geographically diverse) and allows offsite backup and accessibility
  - Eliminates routine hardware refresh costs and logistics
  - Flexible computational capacity to handle Space Fence and large constellation workload growth
- Timeline
  - CARA Software Forklift in Oct 2020 (Efficiency required S/W re-write)
  - CARA Operations failover Exercise Sep 2021
  - CARA Full-Operations Oct 2022 (Missions and DoD Interface setups)
- Lessons Learned
  - Understand Cloud Architectural Requirements (Data storage and Flow)
  - Understand Security Requirements and Permissions (MCP SLA and NIST)
  - Understand and obtain Skill-set needed (matrixed MCP SMEs)
  - Have clear goals and requirements for Cloud Operations Needs



MCP: Mission Control Platform (AWS Cloud provider)

Best Practices: NASA Handbook

- NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook https://nodis3.gsfc.nasa.gov/OCE_docs/OCE_51.pdf
- **Helps space system operators understand existing capabilities and processes**
  - Includes related US Space Command (USSPACECOM) and the US Space Force 18th Space Defense Squadron (SDS) best practices
- Provides technical background on NASA CA processes, including why requirements were levied and how to implement them
- **Offers best practices for use by any spacecraft** Owner/O**perator to help protect the space environment**
- Companion software repository contains many of the tools used by NASA: *https://github.com/nasa/CARA_Analysis_Tools*



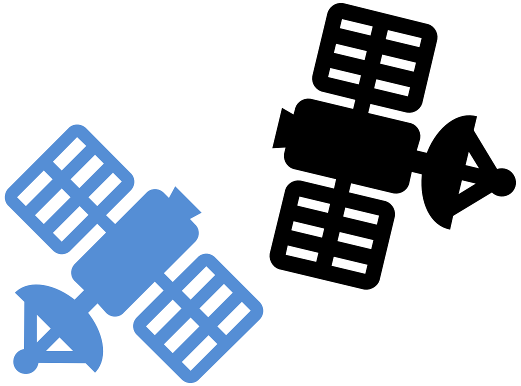
Best Practices: NASA Handbook

Content developed from a US-based inter-agency working group

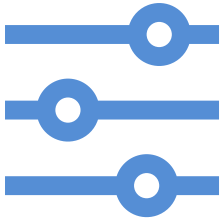
AVAILABLE HERE: https://www.nasa.gov/press-release/nasa-releases-best-practices-handbook-to-help-improve-space-safety

CARA Recommendations

Space Vehicle and Constellation Design: General Orbit Selection



On-Orbit Collision Avoidance: Safe Autonomous Maneuvering

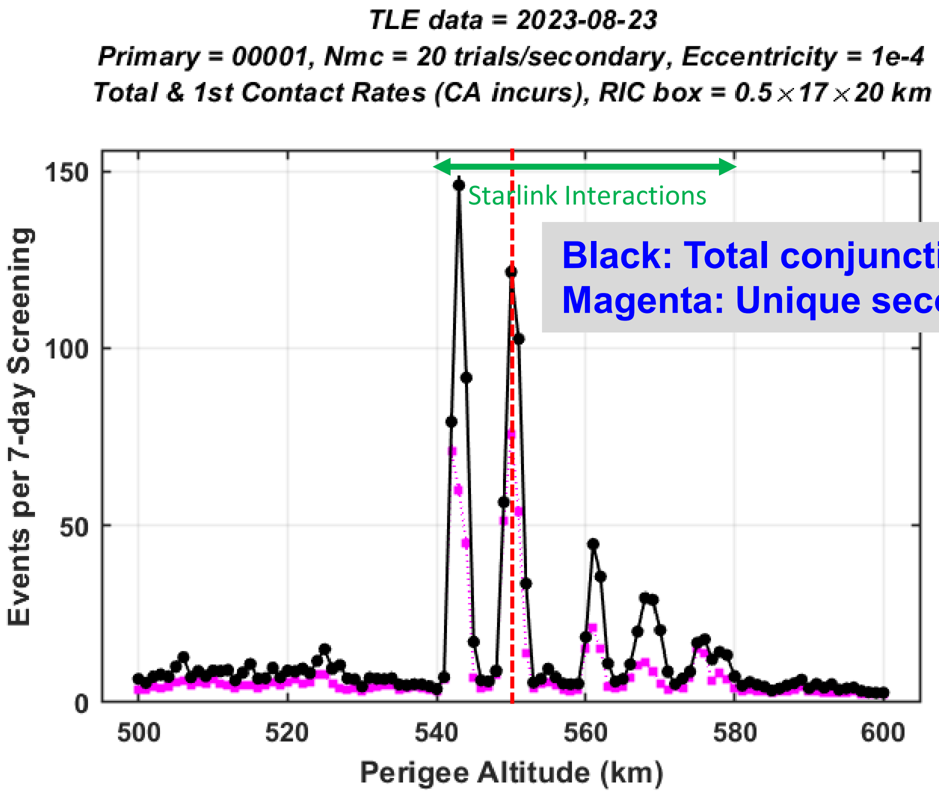


Safe Deployment Plans for Rideshare Missions

NASA CARA Activities: Work with Large Constellations as early as possible to understand their CA CONOPS. May set up Space Act Agreements with some O/Os.

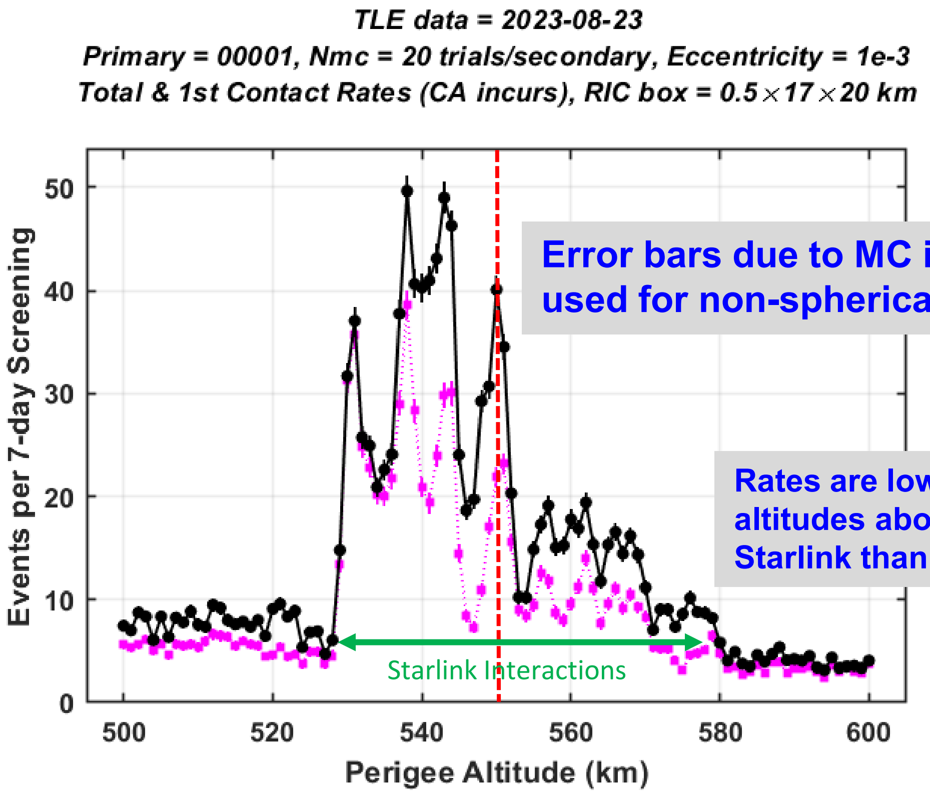
Estimated Conjunction Rate vs. Altitude

Rates with ecc. = 10^{-4}
550 km: 76 unique secondaries



Black: Total conjunctions
Magenta: Unique secondaries

Rates with ecc. = 10^{-3}
550 km: 22 unique secondaries



Error bars due to MC integration used for non-spherical SV

Rates are lower at altitudes above Starlink than below

National Aeronautics and Space Administration

Light Pollution: CARA Analysis

NASA Conjunction Assessment Risk Analysis

www.nasa.gov

Motivation

The Astronomical Community

- Constellations can interfere with ground-based astronomy
- Metrics and tools are required to quantify the effects

The NASA CARA Team

- Recommendation from the "NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook"

If the constellation, given its population, orbit, and constituent satellites, is likely to affect ground-based astronomy, reassign the satellite orbits or modify the satellite construction to eliminate this effect.

Research and Development Objectives

- Research: Develop indicators to quantify light pollution effects
  1. The brightness of individual constellation satellites, including the effects of temporal variability
  2. The statistically expected number of visible and illuminated constellation satellites above a ground-based observer
  3. The expected number that are brighter than the maximum brightness limit recommended by the astronomical community
- Development: Implement a software tool for use by the CARA team that issues recommendations with supporting analysis
  – Use global and yearly peak of light pollution indicator #3 above, which incorporates the effects of a constellation's population, orbital distribution, brightness, and variability
  – Enable evaluation for both current and proposed constellations, as well as single- and multi-shell constellations

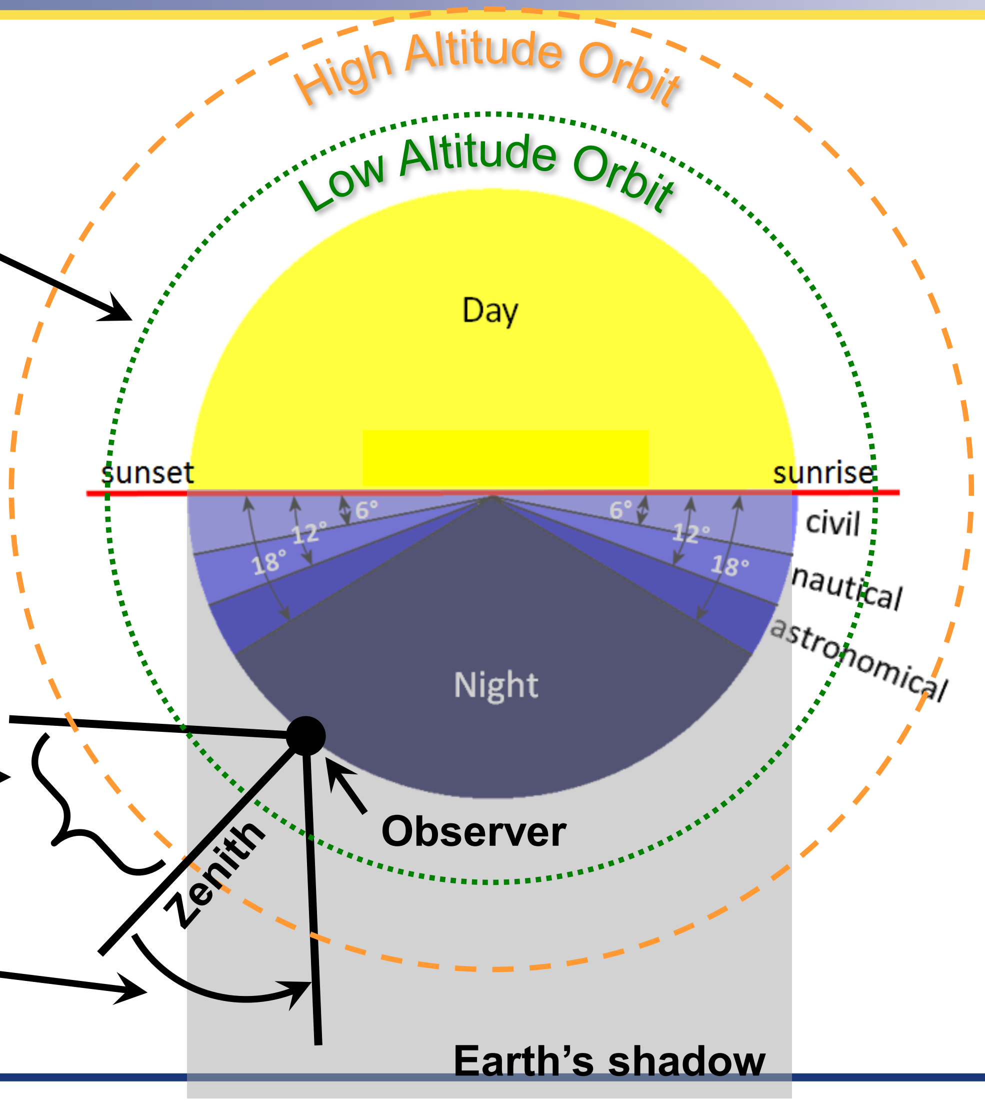
Overview of Constellation Light Pollution in the Visible and Near-Infrared Spectral Bands

- Visible/near-IR brightness is typically dominated by reflected sunlight
  - The solar depression angle (SDA) measures how far the sun is below an observer's local horizon
  - Twilight period: 0° < SDA < 18°
  - Astronomical night: SDA ≥ 18° (often the most valuable observation time)
- Goal: Mitigate global light pollution during astronomical night time
- Light pollution analysis parameters
  - Intrinsic satellite brightness/variability
  - Constellation orbital shell populations, altitudes, and inclinations
  - Observation solar depression angle
  - Observation zenith angle

Satellites in lower altitude constellations can be brighter because they are closer to ground-based observers

But satellites in higher altitude constellations can be illuminated much longer into astronomical night

Observation zenith angle

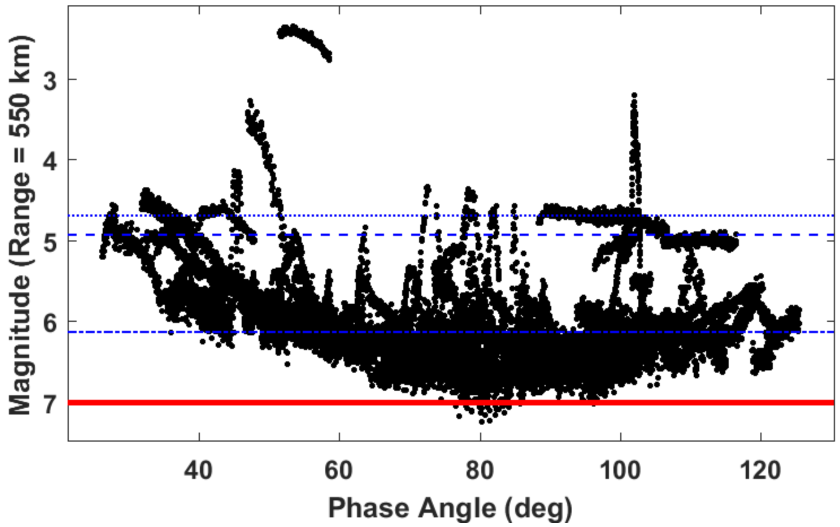


Observed Brightnesses of Constellation Satellites

- Visible band brightnesses are measured in stellar magnitudes
  - Often normalized to a range equal to the constellation's altitude, h
  - Measured magnitudes are highly variable
  - Statistical analysis shows that the M(90%) and M(50%) quantile levels often differ by 1 magnitude or more
- The maximum brightness limit recommended by the Astronomical Community, from the "*SatCon-1*" workshop[1]

$$M = 7 + 2.5 \times \log_{10}[h/(550\ \mathrm{km})]$$

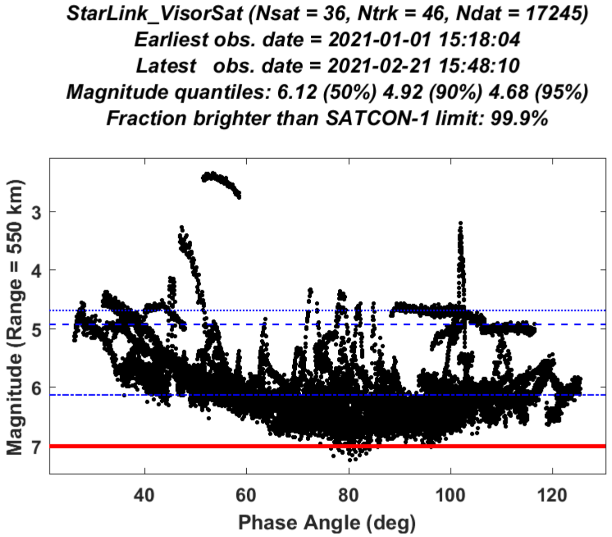
- Many constellation satellites are often observed to be brighter than this limit
  - For instance, early Starlink constellation satellites exceeded this recommended brightness limit most of the time (as shown in the plot)
- Evaluation Goal: Issue no light pollution warnings for constellations with satellites expected to be consistently less bright than the recommended *SatCon* brightness limit

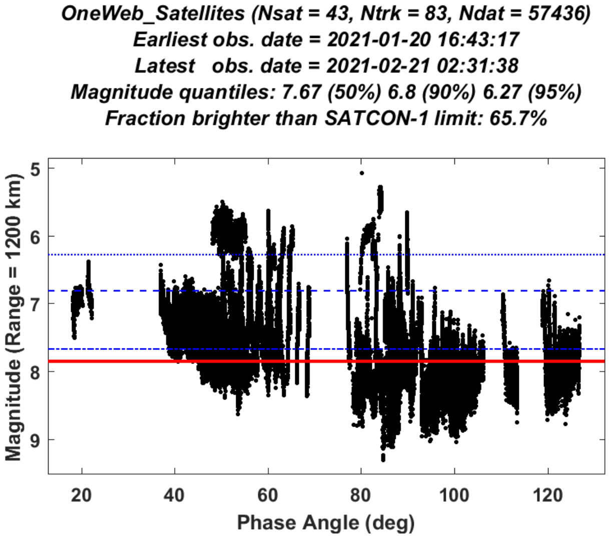


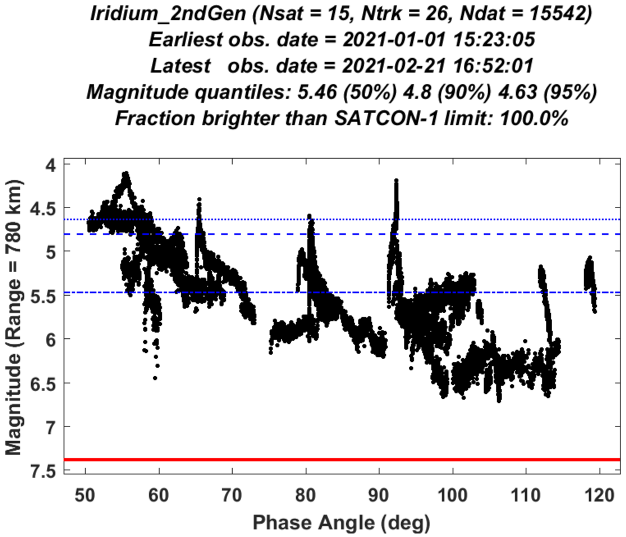
Range-normalized magnitudes for 36 Starlink satellites[2] observed during the first 50 days of 2021

[1]Walker, C., *et al.*, "Impact of Satellite Constellations on Optical Astronomy and Recommendations Toward Mitigations" *SatCon-1 Workshop*, 2020.
[2]Malama, A., "The Brightness of VisorSat-Design Starlink Satellites" 2021.

Comparing Satellite Brightnesses for Three Current Constellations







Starlink Constellation 1st Shell

99.9% of observed zenith brightnesses exceed the *SatCon* recommendation marked with red line*

OneWeb Constellation Phase 1

65.7% of observed zenith brightnesses exceed the *SatCon* recommendation marked with red line*

Iridium 2nd Generation Constellation

100% of observed zenith brightnesses exceed the *SatCon* recommendation marked with red line*

*Neglecting atmospheric extinction, and based on clear-filter photometric light-curve data measured by the MMT automated observatory: Karpov, S., *et al.*, "Photometric Calibration of a Wide-Field Sky Survey Data from Mini-MegaTORTORA," *Astronomical Notes*, 2018.

Constellation Light Pollution Color Coded Evaluation Levels

Light Pollution Evaluation Indicator: N_b = the statistically expected global and yearly maximum number of brighter-than-recommended satellites above ground-based observers during astronomical night time periods*

Light Pollution Level	Color Code	Light Pollution Indicator Range
Very High	Magenta	$N_b \geq 10$
High	Red	$1 \leq N_b < 10$
Medium	Yellow	$0.1 \leq N_b < 1$
Low	None	$N_b < 0.1$

*Hall, D., "Semi-Empirical Astronomical Light Pollution Evaluation of Satellite Constellations," Journal of the Astronautical Sciences, Jan. 2023.

Summary

- Orbit environment is rapidly growing, especially through Large constellations
- CARA is a large and complex organization supporting real-time ops
- No existing space traffic regulation means relying on technical best practices
  - CARA leading effort to socialize NASA's Best Practices CA Handbook.
  - Office of Space Commerce working Space Policy Directive-3, to oversee space traffic coordination and provide basic SSA services to commercial and civil space operations
- A lot of important factors to consider in predicting the future use of the space environment.

CREDIT: ESA (2017): 18,000 Catalogued Space Objects

ACRONYMS REFERENCE

ASAT	Anti-Satellite Test
CA	Conjunction Assessment
CAOIA	Conjunction Assessment Operations Interface Agreement
CAPO	Conjunction Assessment Program Office
CARA	Conjunction Assessment Risk Analysis
CCSDS	Consultative Committee for Space Data Systems
CIC	Commercial I Cell
COSA	CARA Orbital Safety Analysts
COSMOS	Kosmos (Russian satellites operated by the former Soviet Union and subsequently Russia)
DOC	Department of Commerce
DOD	Department of Defense
EGA	Earth Gravity Assist
ESMO	Earth Science Missions Office
FAA	Federal Aviation Authority
FCC	Federal Communications Commission
HBR	Hard Body Radius
HIE	High Interest Event
HSF	Human Space Flight
MADCAP	Multimission Automated Deepspace Conjunction Assessment Process
MRPP EMI	Mission Resilience and Protection Program Electro Magnetic Interference
MSA	Maneuver Screening Analysis
NID	NASA Interim Directive
NOAA	National Oceanic and Atmospheric Administration
NPR	NASA Procedural Requirements
NSDC	National Space Defense Center
OADR	Open Architecture Data Repository
OCAP	Orbital Collision Avoidance Plan
OD	Orbit Determination
OEM	Orbit Ephemeris Message
O/O	Owner/Operator
OSA	Orbital Safety Analysts
PC	Probability of Collision
PPBE	Planning, Programming, Budgeting, and Execution
SAA	Space Act Agreement
SAC-T	Sprint Advanced Concept Training
SC	Spacecraft
SDS	Space Defense Squadron
SMD	Science Mission Directorate
SME	Subject Matter Expert
SSA	Space Situational Awareness
SSN	Space Surveillance Network
SW	Software
TCA	Time of Closest Approach