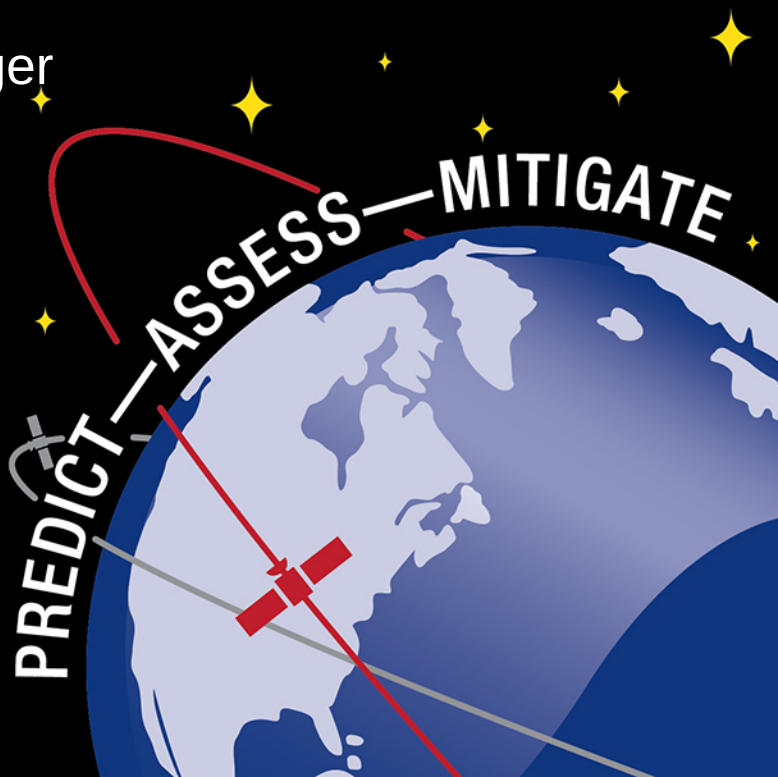
National Aeronautics and Space Administration

NASA Conjunction Assessment Risk Analysis (CARA)

Lauri K. Newman
NASA Robotic Conjunction Assessment Manager

30 MAR 2017

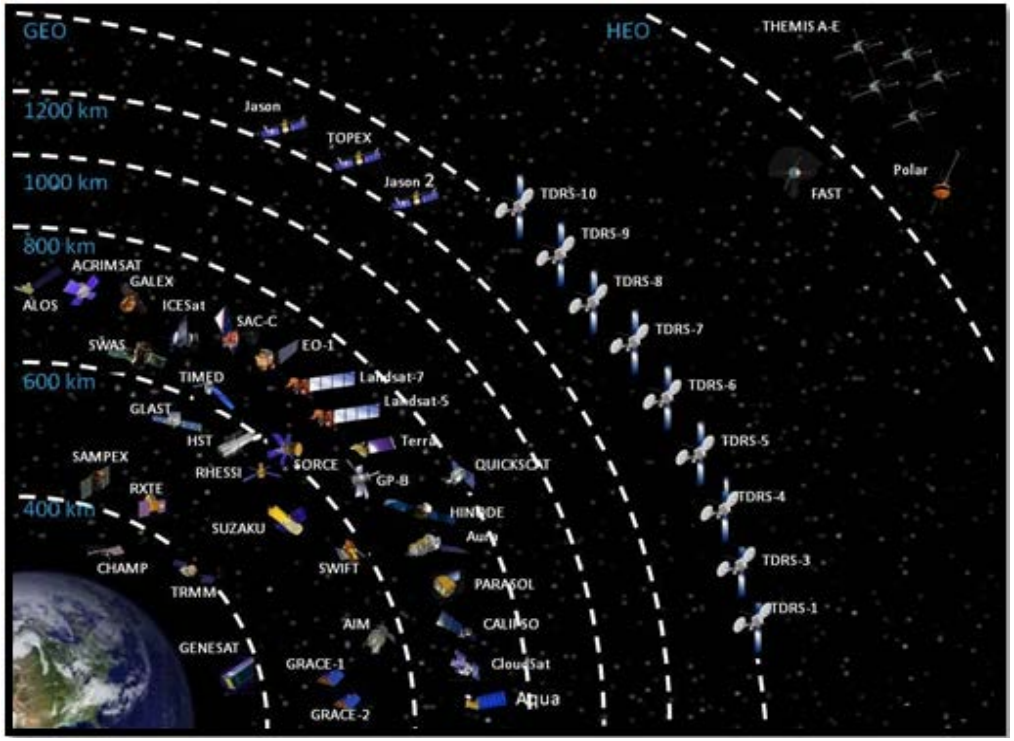


NASA ROBOTIC CARA

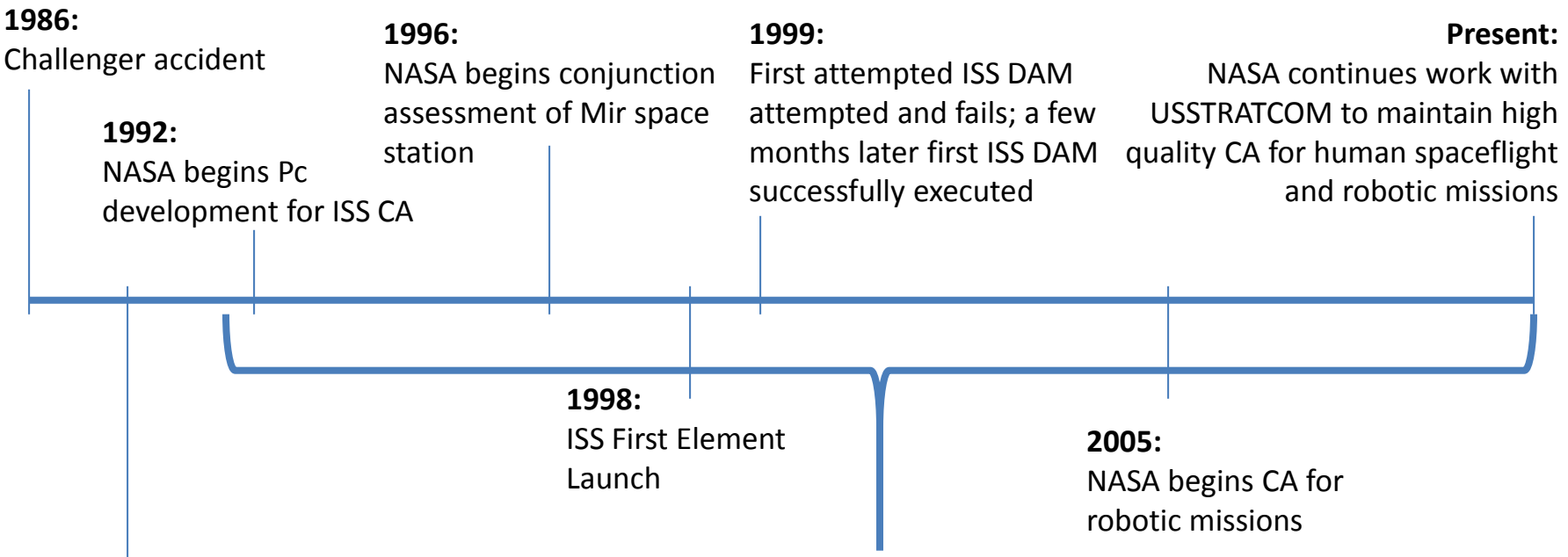
www.nasa.gov

NASA's Process: CARA

- NASA performs conjunction assessment risk analysis for safety of flight of all of its operational assets
  - Performed by CARA at NASA GSFC for robotic satellites
  - Performed by TOPO at NASA JSC for human spaceflight
- The Conjunction Assessment Risk Analysis (CARA) was stood up to offer this service to all NASA robotic satellites
  - Currently provides service to ~65 operational satellites
    - NASA unmanned assets
    - Other agency assets such as NOAA, DMSP
    - Foreign partner assets
    - Commercial assets



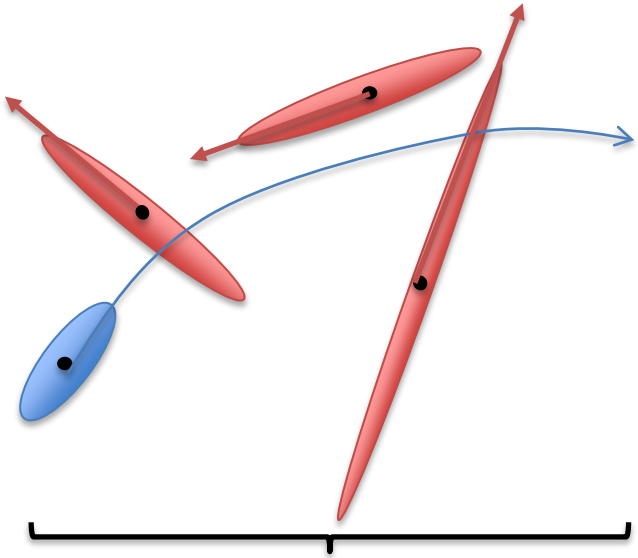
NASA Conjunction Assessment History



NASA has performed CA for 29 years. Initial USSTRATCOM capability developed with NASA.

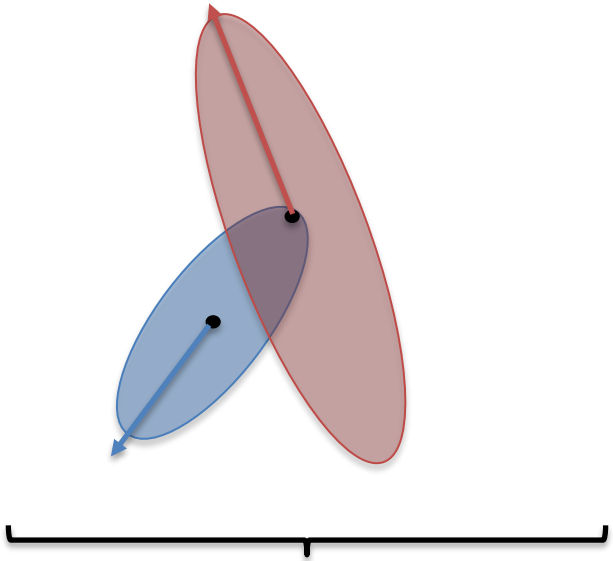
Courtesy of NASA/JSC
Ansley C. Browns

The CARA Process Helps Manage On-Orbit Collision Risk



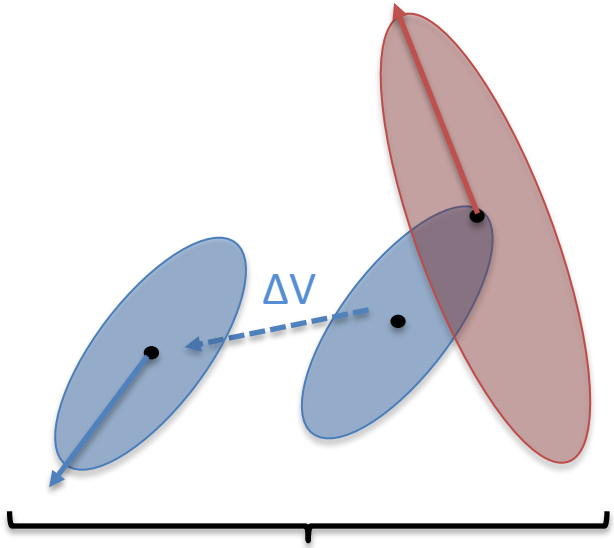
Conjunction Assessment (CA) is the process of identifying close approaches between two orbiting objects; sometimes called conjunction "screening"

The **18th Space Control Squadron** at the **Joint Space Operations Center (JSpOC)** – a USAF unit at Vandenberg AFB, maintains the high accuracy catalog of space objects, screens CARA-supported assets against the catalog, performs OD/tasking, and generates close approach data



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

The **CARA** Team at NASA-GSFC provides CARA for all NASA operational robotic satellites, as well as a service provider for some other external agency/organizations

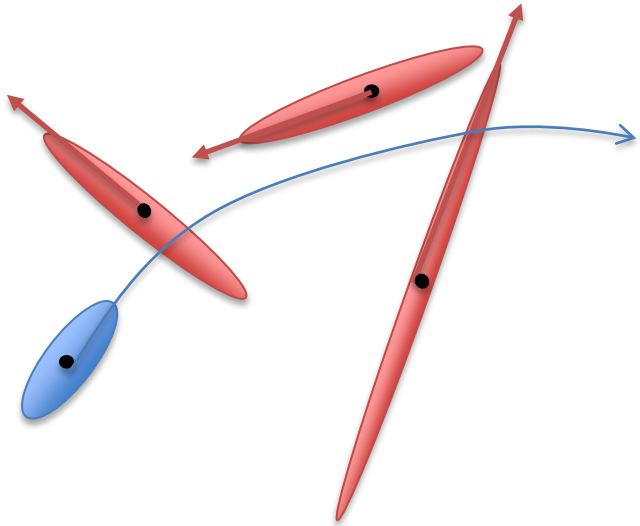


Collision Avoidance (COLA) is the process of executing mitigative action, typically in the form of an orbital maneuver, to reduce collision risk due to a conjunction

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

CARA Operational Process: Close Approach Predictions at the JSpOC

- The JSpOC maintains an accurate state for all trackable objects
  - Note that these solutions use non-cooperative tracking from the Space Surveillance Network (SSN), and do not contain maneuvers
- In support of CARA, the CARA-dedicated Orbital Safety Analysts (OSA)
  - Perform routine screenings – 3x day for LEO, 2x for GEO/HEO
    - Against JSpOC's Astrodynamics Support Workstation (ASW) solution and for some missions the O/O solution as well
  - Inspect orbit determination
  - Perform manual orbit determination, if warranted
  - Adjudicate tasking level of secondary objects; request increased tasking, if warranted
  - Generate and deliver necessary data products
- JSpOC is staffed by CARA-dedicated OSAs 20 hours/ day

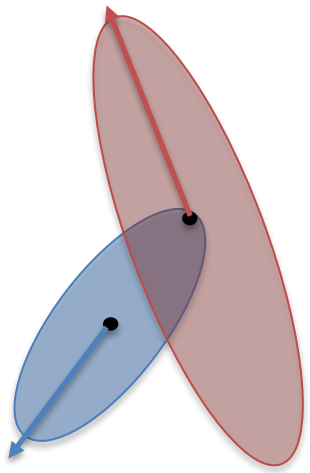


The **Screening Duration** is the "lookout" period of time for which conjunctions are identified. This is 7 days for LEO assets and 10 days for GEO/HEO assets

The **Screening Volume** is the geometric volume placed around the asset during the conjunction screening process; any objects that violate this volume trigger data products to be generated and delivered. The screening volumes are re-sized annually by CARA using a 95% capture of the relative uncertainties in each orbital regime based two-year moving window historical conjunction data

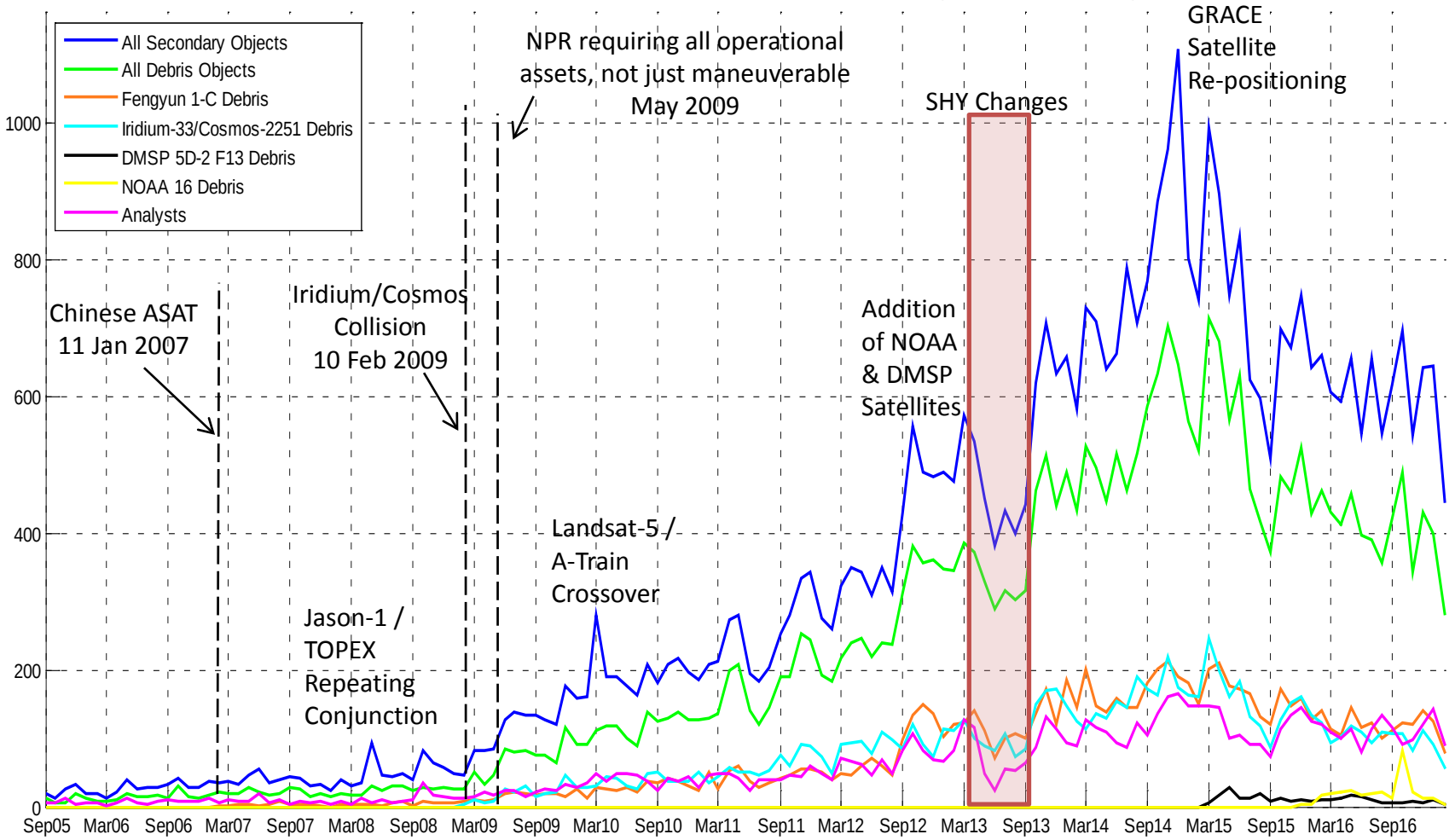
CARA Operational Process: Collision Risk Analysis at NASA-GSFC

- CARA is responsible for assessing, communicating, and assisting with mitigation of on-orbit collision risk
- As data is received, the CARA system automatically processes that data, and generates & delivers
  - **CARA Summary Reports** to O/O
  - **Work List** sent to CARA OSAs
- CARA team performs routine risk analysis
  - Pc; Pc sensitivity
  - Conjunction Geometry
  - OD Evaluation / Solution Consistency
  - Space Weather Sensitivity
  - Maneuver planning & evaluation
- For high-risk conjunctions, CARA builds and delivers a **High Interest Event (HIE) briefing** with detailed analyses, and planning & decision information

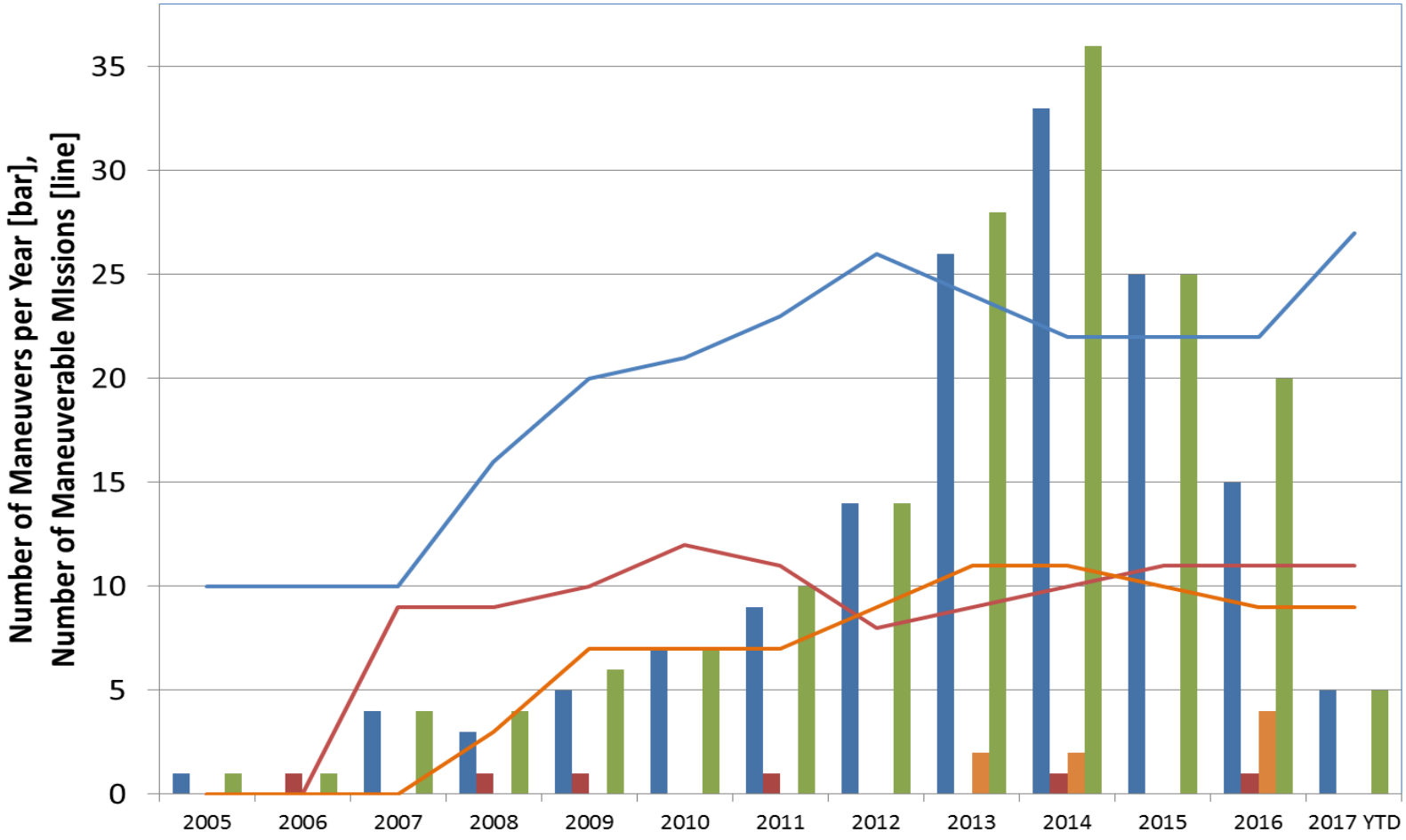


The **Collision Probability (Pc)** is the probability that, given the uncertainty in the two objects' positions as described by their covariance matrix, that the actual miss distance is less than the hard-body region

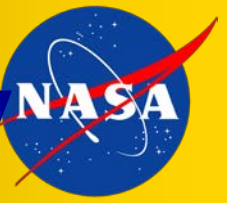
Mission Context: Number of Conjunctions in LEO



Collision Avoidance Maneuvers History



CARA Summary Report: Event Summary



GCOM-W1 (38337) [HBR = 20m]

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?
4.2	8 Nov 2015 04:45:41	TITAN 3C TRANSTAGE DEB (01722)	ASW	ASW	3 Nov 2015 19:45:32	783.0	22.8	334.1	708.4	Y	4.90e-4 (1:2K)	---
4.2	8 Nov 2015 04:45:41	TITAN 3C TRANSTAGE DEB (01722)	O/O + ASW cov.	ASW	3 Nov 2015 19:38:46	91.0	17.7	37.6	81.1	Y	2.03e-2 (1:49)	---

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?
4.6	8 Nov 2015 15:04:53	UNKNOWN (87798)	ASW	ASW	3 Nov 2015 19:46:16	9503	-7.4	1224	9424	N	6.38e-7 (1:2M)	---
4.6	8 Nov 2015 15:04:53	UNKNOWN (87798)	O/O + ASW cov.	ASW	3 Nov 2015 19:38:48	9265	18.0	1194	9188	Y	6.39e-7 (1:2M)	---

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?
4.5	8 Nov 2015 13:25:58	UNKNOWN (87798)	ASW	ASW	3 Nov 2015 19:46:16	14857	111.2	1933	14730	N	0.00e00	---
4.5	8 Nov 2015 13:25:58	UNKNOWN (87798)	O/O + ASW cov.	ASW	3 Nov 2015 19:38:48	14622	136.4	1906	14497	Y	0.00e00	---
4.9	8 Nov 2015 21:40:36	UNKNOWN (87798)	ASW	ASW	3 Nov 2015 19:46:18	12239	34.9	-1516	-12144	N	2.91e-8 (1:34M)	---

Grouped by Risk using Pc thresholds

Ordered within group by Days to TCA

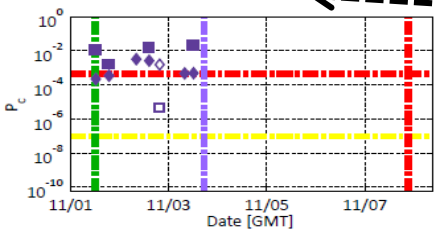
CARA Summary Report: Event Details

Conjunction Event Details - GCOM-W1 (38337) vs. TITAN 3C TRANSTAGE DEB (1722)

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?
4.2	8 Nov 2015 04:45:41 Back	TITAN 3C TRANSTAGE DEB (01722)	ASW	ASW	3 Nov 2015 19:45:32	783.0	22.8	334.1	708.4	Y	4.90e-4 (1:2K)	---
4.2	8 Nov 2015 04:45:41 Back	TITAN 3C TRANSTAGE DEB (01722)	O/O + ASW cov.	ASW	3 Nov 2015 19:38:46	91.0	17.7	37.6	81.1	Y	2.03e-2 (1:49)	---

1.

Pc History



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

2.

Secondary Object OD Information			
Avg. Tracks / Day	4.1	Single Station Tracking	N
Fit Span	~10 days		
Time Since Last Observation	< 24 hrs	Norm. Fit Metric	1.03
Total Propagation Time	~4 days		

3.

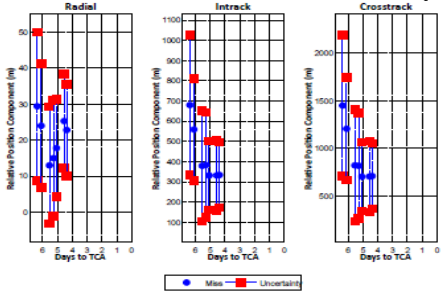
Maneuver Epoch	Magnitude [m/s]	Duration [s]	Type
2015-10-28 01:23 Z	0.098000	N/A	DMU

4.

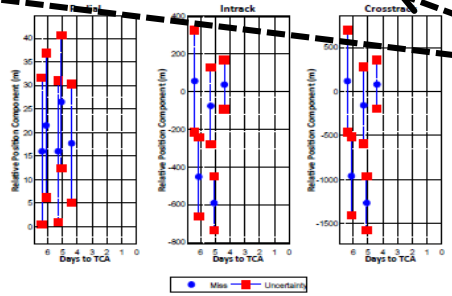
Most Recent O/O Ephemeris File	SOEMP-PRE_GCOMW1_F20151103_000000_T20151111_000000
Ephemeris File End	2015-11-11 00:00:00
Most Recent O/O Covariance File	N/A

5.

ASW Miss Component History



OO Miss Component History



6.

Summary header
- Days to TCA
- Secondary Name & ID
- Screening Epoch
- Latest Miss Distance
- Latest Pc & Risk Characterization

Pc History and Event Flags

Latest secondary object OD & tracking information
- Avg Tracks / Day
- Time Since Last Observation
- Total Propagation Time of vector
- Single Station Indicator

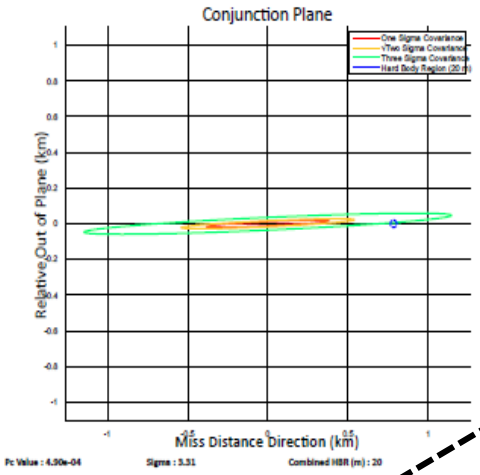
Maneuver information

Filenames of O/O Products used

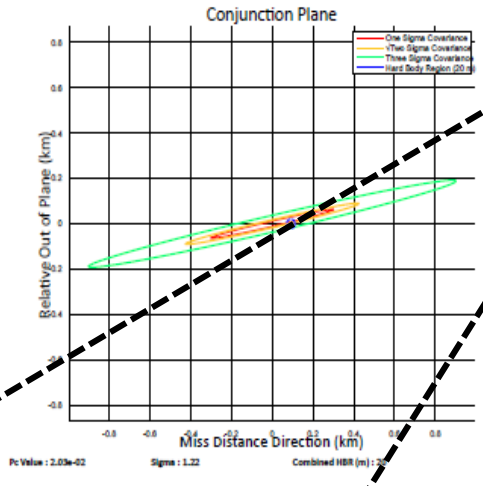
ASW and O/O Miss Component History

CARA Summary Report: Continued

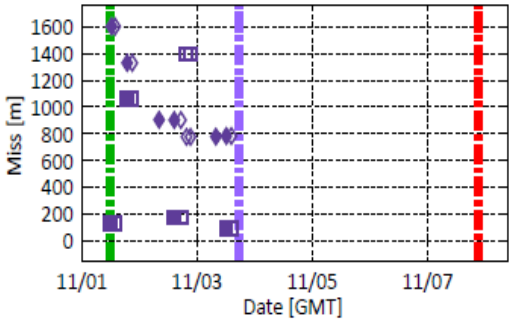
ASW Conjunction Plane



OO Conjunction Plane



Miss History



Event Geometry	ASW	O/O
F-Value (scaled/unscaled)	8.0 / 9.1	N/A
Radial Sigma [m]	12.7	12.6
Intrack Sigma [m]	161.9	130.0
Crosstrack Sigma [m]	346.4	278.3
Relative Velocity [m/s]	13592.0	13592.0
Approach Angle [deg]	129.9	129.9

1. ASW and O/O Conjunction Planes
2. Miss History
3. ASW and O/O Event Geometry

OSA Work List

- CARA system automatically generates & delivers a prioritized work list
  - CARA OSAs perform their duties in priority order
  - Ensures limited resources are used effectively – in the order of risk or potential to become high risk
  - Closed-loop process between OSAs and CARA
  - Representative format:

Grouped by Risk using Pc thresholds

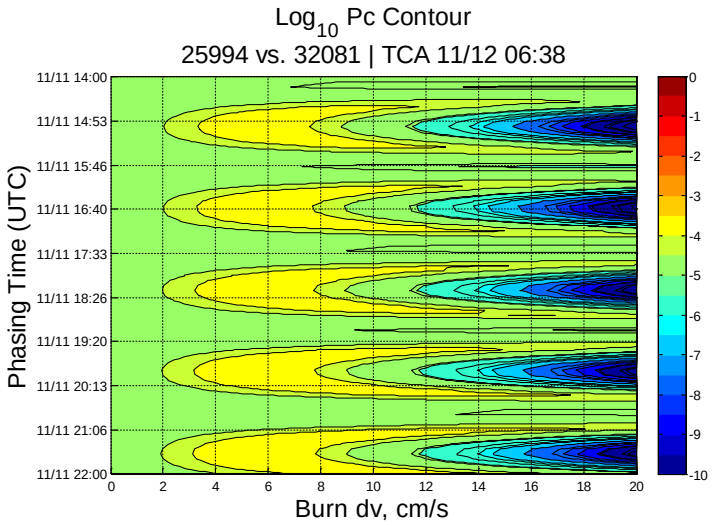
1. Aqua vs. 12345
2. Aqua vs. 23456
3. Aqua vs. 34567
4. Aqua vs. 45678
5. Aqua vs. 56789

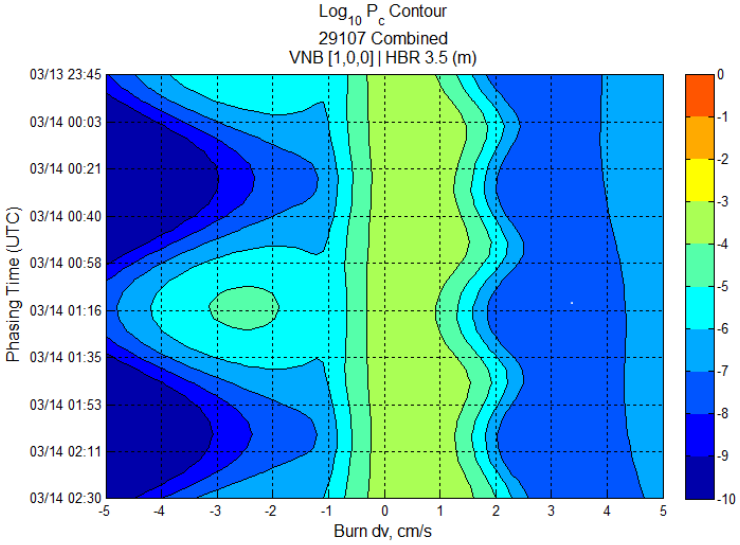
Rank-ordered within group by increasing OD quality

- Also includes list of recent (for indicating when OD should be cut) and upcoming maneuvers (satisfies NASA maneuver reporting requirement)

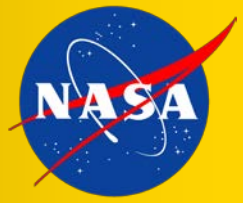
Maneuver Planning

- A trade-space contour plot shows the effect that a range of phase times and delta-v magnitudes have on miss distance
  - Single conjunction event (top)
  - Multiple events (bottom)
- Assists with initial maneuver planning
  - Save time-expensive iteration cycles for high fidelity maneuver planning





Continuous Enhancement Process



- CARA is continuously trying to enhance its service offering through analysis
- Recent Enhancements
  - Calculation of 3D Pc
  - Space weather trade space
  - Multiple event maneuver planning
  - Covariance realism and Pc uncertainty
- Current/ongoing areas of inquiry
  - Screening Volume sizing/shaping
  - S-band Fence CA impacts
  - Automated OD quality assessment, covariance quality estimates, and related sensor tasking modification recommendations
  - Pc calculations that accommodate non-Gaussian uncertainty volumes

Future Challenges

- Low / No Thrust Protected Assets
- Space Fence
  - Compensatory algorithm development
  - Advanced risk assessment methods (event aggregation)
  - Non-traditional risk mitigation techniques
  - Threshold Agency Standards
- CubeSats / SmallSats
- Mega Constellations
- Improved Atmospheric Density Modeling (and Uncertainty Quantification)
- Extremely fast non-linear orbit propagation
- Co-location & Systematic Conjunctions
- Space Traffic Management