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SCIENCE, TECHNOLOGY AND KNOWLEDGE
FOR CANADA'S DEFENCE AND SECURITY

SCIENCE, TECHNOLOGIE ET SAVOIR
POUR LA DÉFENSE ET LA SÉCURITÉ DU CANADA



Canada Space Debris Measurements *Status Update*

Inter-Agency Debris Working Group
IADC 2023 (WG1 - Measurements)
May 2023

VIQAR ABBASI
Canadian Space Agency (CSA)

LAUCHIE SCOTT
Defence R&D Canada (DRDC)



Canadian Space
Agency

Agence spatiale
canadienne

Canada

(Some of) Canada's space fleet



RADARSAT Constellation

RADARSAT-2



NEOSat



On-orbit
SSA sensors

SAPPHIRE



CASSIOPE



SCISAT



New launches all commercial or academia;
No new de-orbits or mission failures;

CRAMS Overview

... for operators, by operators

Objective

Immediately following a conjunction data message notification, deliver necessary analysis to mission team to make decision on collision avoidance maneuver

Architecture

- Automation engine around Matlab & STK
- User-friendly Excel and Text files delivered via email
- Configurable for additional missions with no overhead
- Hot backup servers to ensure system up-time

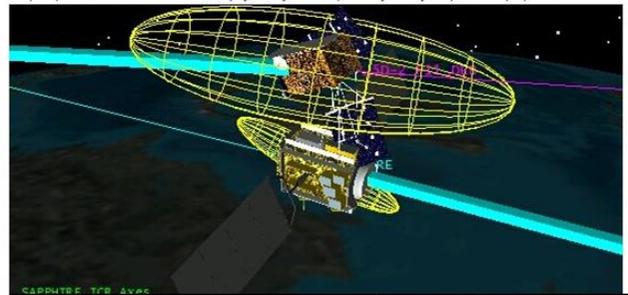
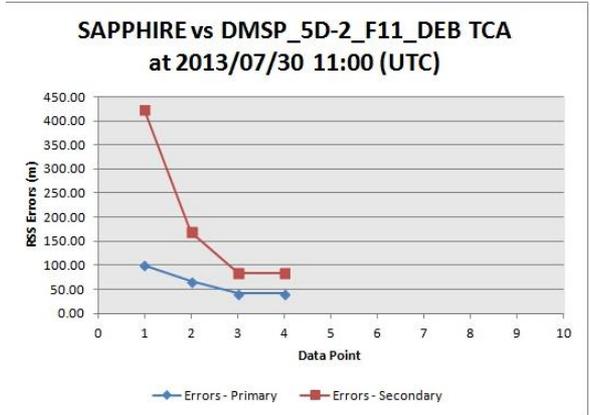
CRAMS 3.5
 Latest Datapoint (UTC) 2013-07-29 23:18:27
 TCA (UTC): 2013-07-30 11:00:00
 Run at: 2013-12-03 15:54:46
 Days to TCA 0.49 Hours to TCA 11.69

Configurable Parameters			Thresholds of Concern:	
Error scaling:	1	1	1	1
RSS Errors limit:	1700			Probability of Collision: 1.00E-04
			Depth of Intrusion:	

Date UTC	Ref #	Data Type	Miss distance (m)				Probability of Collision	Depth of Intrusion	Approach Angle (deg)	RSS Errors (m)		CRAMS Recommendation
			Radial	In-track	Cross-track	Overall				Primary	Secondary	
2013-07-27 18:08:38	1	CSM	95.2	0.1	24	98	1.17E-04	0.44	162.58	100.94	423.19	Action Required (PoC>1e-006, Miss<200m, Good data)
2013-07-28 19:51:07	2	CSM	60.5	-4.7	23.4	65	2.19E-04	0.46	162.58	66.74	169.83	Action Required (PoC>1e-006, Miss<200m, Good data)
2013-07-29 19:11:46	3	CSM	44.8	0.9	3.2	44	4.52E-04	0.36	162.58	41.81	84.57	Action Required (PoC>1e-006, Miss<200m, Good data)
2013-07-29 23:18:27	4	CSM	44.8	0.3	3.1	44	4.81E-04	0.36	162.58	41.81	84.57	Action Required (PoC>1e-006, Miss<200m, Good data)
	5											
	6											
	7											
	8											
	9											

NO WARRANTIES: The enclosed information is provided "as is" and with no warranty, either express or implied, as to the condition or suitability of the information, nor its fitness for a particular purpose

Objects	Name	SSC #	Type	Country	Launch
	SAPPHIRE	39088	PAYLOAD	CA	2013-02-25
	DMSP_5D-2_F11_DEB	28317	DEBRIS	US	1991-11-28
TCA	2013/07/30 11:00				



Over 100 missions now supported

RCM Conjunction Assessment Challenges

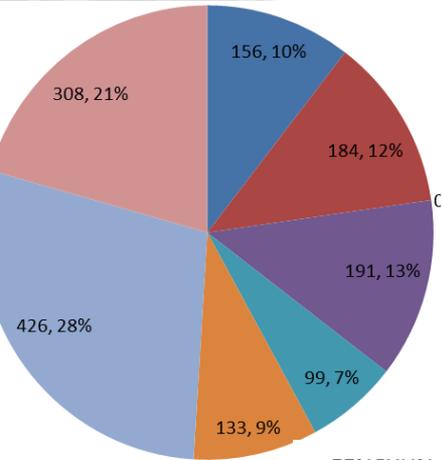
Difficulties keeping track of maneuvering RCM in SP catalog

- Differences between SP and Ephemeris-based CDMs
- Unrealistic covariance (set to default), impacting Pc
- Maneuvering increasing as we exit solar minimum, exacerbating the issue
- Increasing CDMs against operational satellites, needing a coordinated response
- CRAMS now uploads RCM ephemeris 3x daily to increase Eph-based screening

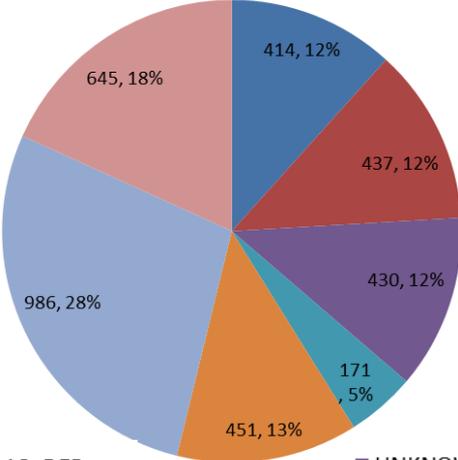
Creation Date	Ref	Data Ty	Miss distance (m)				Probability of Collisi	Depth of Intrusio	Approach Angle (de	RSS Errors (m)		CRAMS Recommendation	TCA
			Radial	In-tra	Cross-tra	Overall				Primary	Seconda		
2022-03-31 17:43:25	2	CDM	25.1	1438.1	4207.4	4446	1.33E-14	0.00	142.33	110472561.29	17562.85	No Action Required	11:09
2022-04-01 00:17:15	7	CDM	73	-222.9	-659.6	700	1.33E-14	0.00	142.33	110472561.29	12543.16	No Action Required	11:09
2022-04-02 12:26:29	12	CDM	72.6	124.2	364.1	391	1.31E-14	0.00	142.33	110472561.29	3798.57	No Action Required	11:09
2022-04-02 17:41:59	17	CDM	65.5	304.9	897.1	949	1.31E-14	0.00	142.33	110472561.29	3797.57	No Action Required	11:09
2022-04-02 23:59:58	25	CDM	121.6	493	1435.3	1522	1.31E-14	0.00	142.33	110472561.29	2804.45	No Action Required	11:09
2022-04-03 12:21:30	40	CDM	40.9	343.8	1009.3	1067	1.31E-14	0.00	142.33	110472561.29	2057.93	No Action Required	11:09
2022-04-03 16:53:33	48	CDMe	26.7	433.3	1282.4	1353	6.20E-06	0.55	142.33	635.79	1442.89	Action Required (Po	11:09
2022-04-03 17:19:41	56	CDM	43.8	271.1	802.9	848	1.31E-14	0.00	142.33	110472561.29	1665.20	No Action Required	11:09
2022-04-03 19:59:30	65	CDMe	70.5	336.5	993.9	1051	0.00E+00	1.69	142.33	635.79	395.09	No Action Required	11:09
2022-04-03 23:53:29	73	CDM	49.5	202	595.1	630	1.40E-06	0.57	142.33	291.32	1125.18	Action Required (Po	11:09
2022-04-04 00:25:03	80	CDMe	19.1	584.2	1712.6	1809	6.28E-09	0.81	142.33	635.78	1180.27	No Action Required	11:09
2022-04-04 01:49:29	91	CDMe	72.6	324.3	943	999	0.00E+00	2.20	142.33	635.79	245.85	No Action Required	11:09
2022-04-04 08:23:06	102	CDMe	74.2	323.9	938.8	995	0.00E+00	2.64	142.33	635.79	189.40	No Action Required	11:09
2022-04-04 12:01:23	110	CDM	57	40.1	118.9	137	1.26E-06	0.59	142.33	187.57	735.00	Action Required (Po	11:09

CRAMS Statistics – Evolution of LEO as seen by CSA CDMs

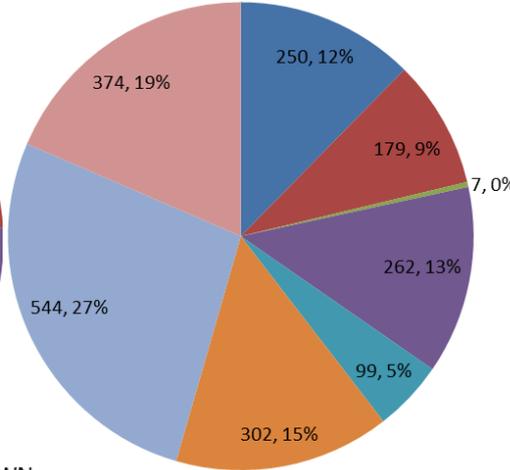
2019: 1497 events



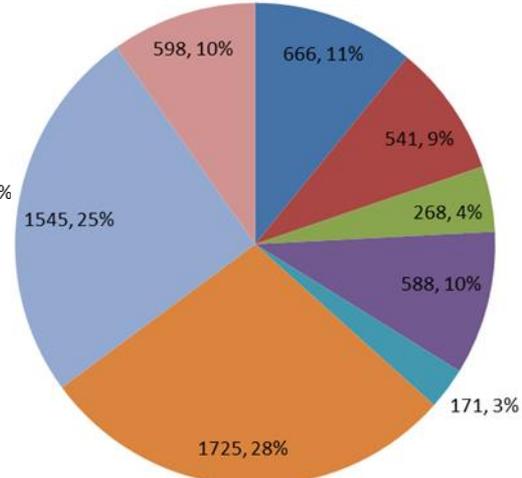
2020: 3534 events



2021: 2017 events



2022: 6102 events



FENGYUN_1C_DEB

COSMOS_2251_DEB & IRIIDIUM_33_DEB

COSMOS_1408_DEB

UNKNOWN

ROCKET BODIES

MEGA-CONSTELLATIONS

OTHER DEBRIS & COOLANT

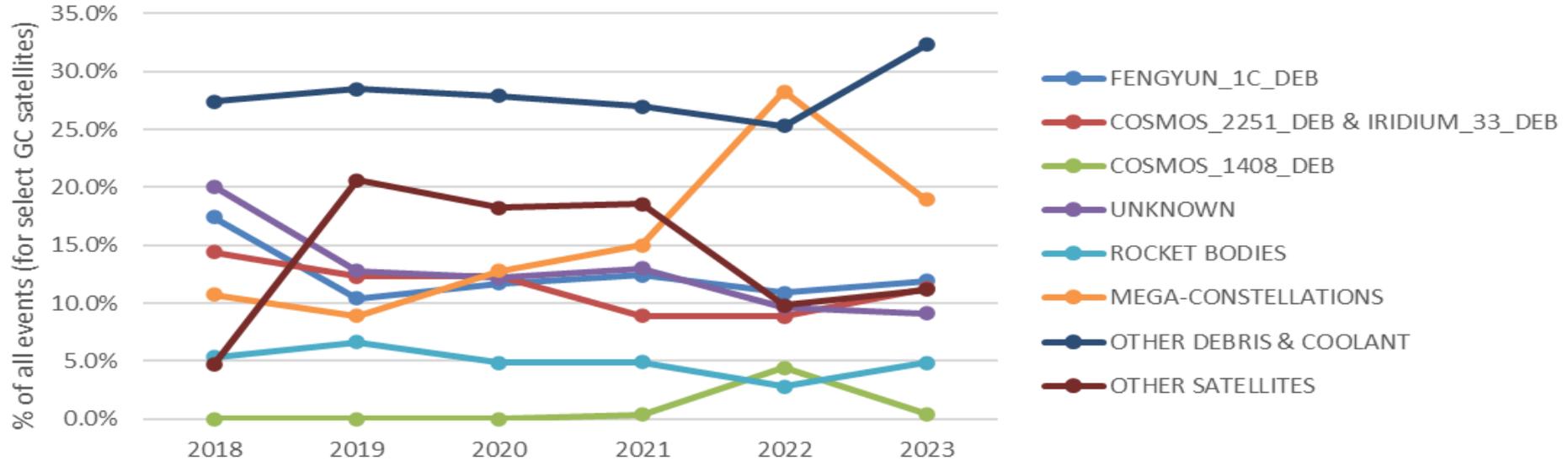
OTHER SATELLITES

Notable points:

- Rocket bodies trending down... (more payloads/launch; better return practices)
- Mega-constellations trending up... (and more complex, due to new propulsion modes – operator ephemeris and interactions becoming more important than SP catalog in more and more cases)
- UNKNOWN / analyst satellites continue to be an important contributor to conjunction events

CRAMS Statistics – Evolution of LEO as seen by CSA CDMs

Secondary Object Breakdown over last five years

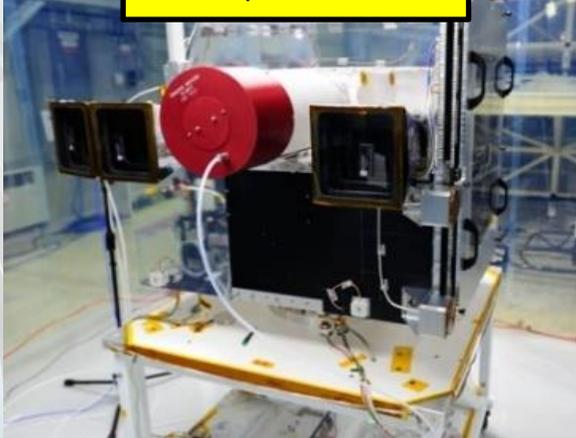


Notable points:

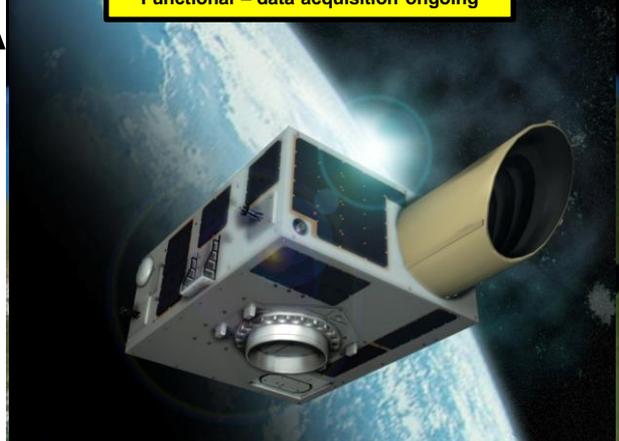
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Canadian SSA Tracking Systems – Sensor Status

Operational
Data provided to SSN



SSA R&D
Functional – data acquisition ongoing



SSA R&D



New mount / telescope /
camera updates in progress

• Sapphire (DND)

- Owner: Dept of National Defence
- Mission: operational space surveillance
- Bus: Surrey SSTL 150
- Payload: 15cm V-band anastigmat
- Sensitivity: Mv 16
- Tracking Accuracy: < 3 arcseconds
- Orbit: 785 km dawn-dusk
- Tasking: 22 Wing North Bay/ CanSpOC
- Operator: MDA (Richmond, BC)

■ NEOSSat (DND/CSA)

- Owner: Canadian DND / CSA
- Mission: SSA R&D, Asteroid, comet & exoplanet astronomy
- Bus: MOST bus lineage
- Payload: 15cm V-band Maksutov
- Sensitivity: Mv 16
- Tracking Accuracy: 2.4 arcseconds
- Orbit: 785 km dawn-dusk
- Tasking: DRDC Ottawa, CSA Observers
- Operator: CSA, St Hubert, QC

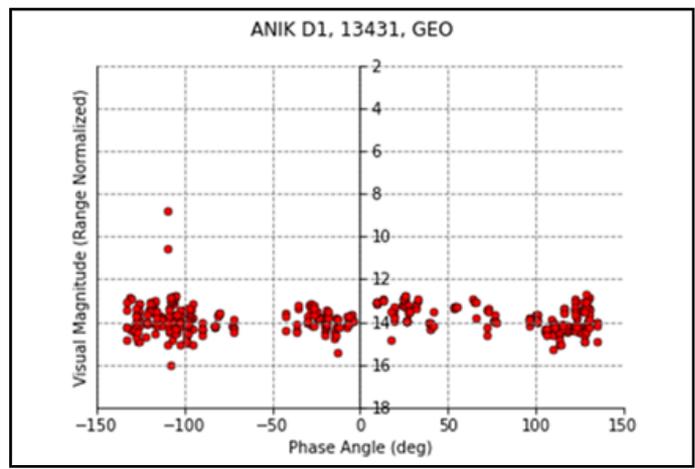
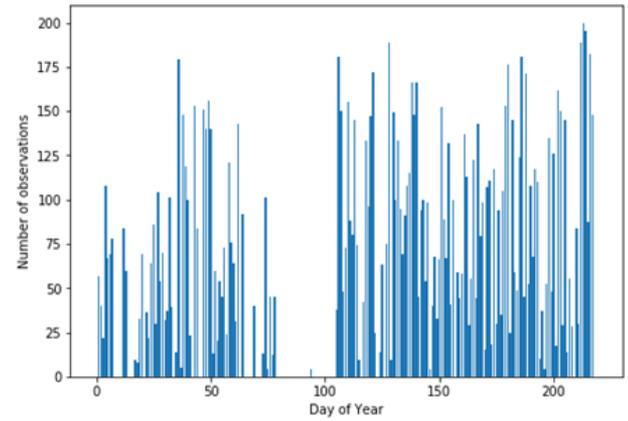
■ Ground-Based Optical Space Surveillance Observatory (SSO) (1 of 3 shown)

- Owner: Defence R&D Canada Ottawa
- Mission: Space Surveillance, SSA R&D
- Located: Suffield, AB, Ottawa, ON, Valcartier, QC
- Instrument: 35cm V-band, EMCCD/Conventional CCD
- Sensitivity: Mv 16
- Tracking Accuracy: 1.5 arcseconds

Canada recent measurement activities

- Canadian Satellite Tasking List (CSTL)
 - Since 2021, Canada maintains daily NEOSat measurements on Canadian Space objects
 - Persistent record of Canadian space object status and characteristics (astrometry and photometry)
 - Includes active and inactive Canadian objects
 - Some Canadian LEO objects now being detected and characterized
 - Data now being used to set expectations for future Canadian SSA data needs

Canadian Satellite Tasking List (CSTL) NEOSat observations by day of Year [2022]



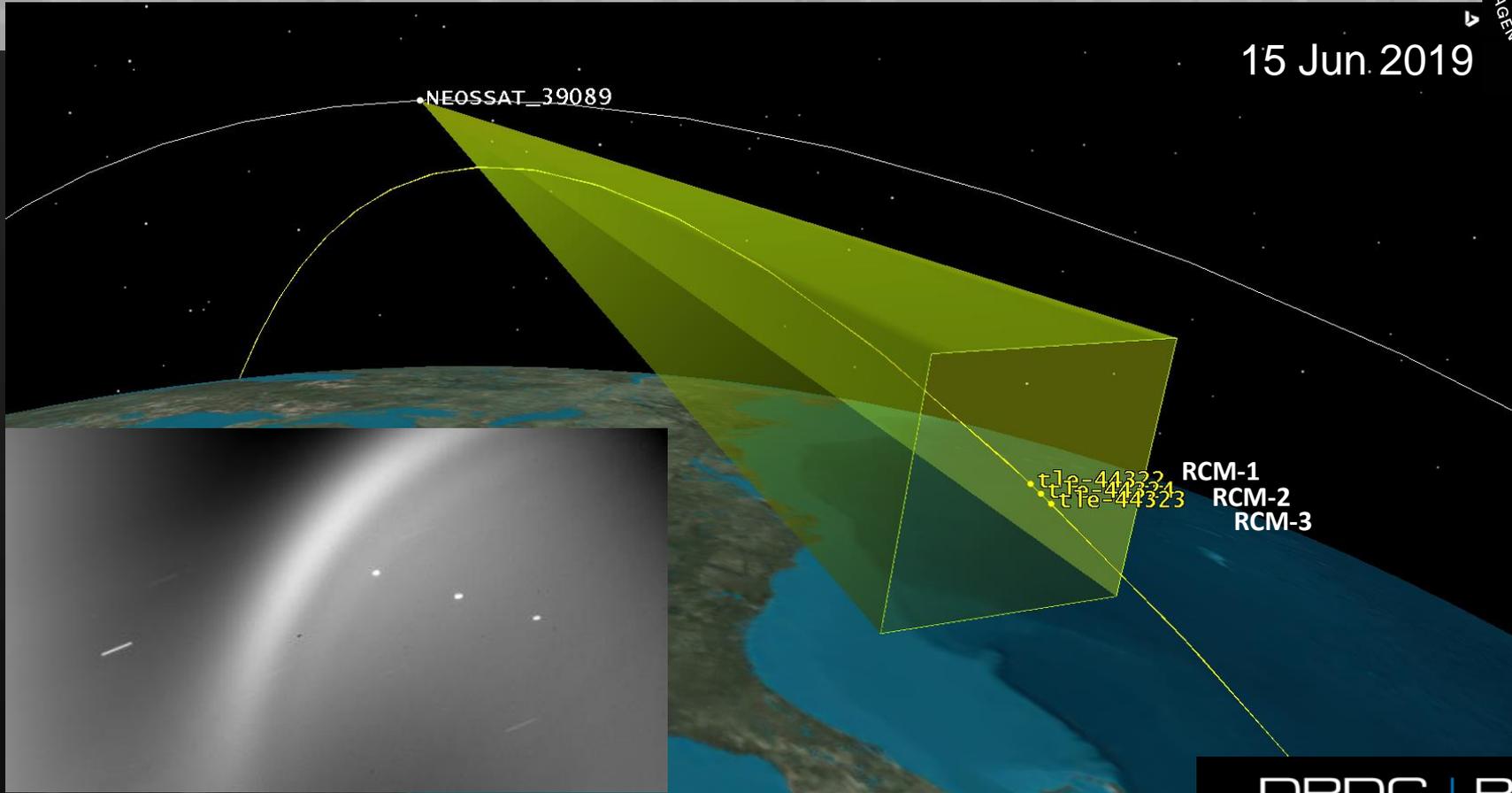
Example light curve of an inactive Canadian satellite (Anik D1)

Object Name	Object SSN	Status	# Of Successful Observations	Mean Time Between Tracks (Days)
ANIK A1	6278	Defunct	84	9.3
ANIK A2	6437	Defunct	126	7.1
ANIK A3	7790	Defunct	156	5.9
CTS	8585	Defunct	174	5.1
ANIK B1	11153	Defunct	235	3.5
ANIK D1	13431	Defunct	583	1.7
ANIK C3	13652	Defunct	587	1.7
ANIK E2	21222	Defunct	428	2.4
ANIK E1	21726	Defunct	483	2.1
ANIK F1R	28868	Active	767	1.3
ANIK F1	26624	Active	429	2.4
ANIK F2	28378	Active	406	2.5
ANIK F3	31102	Active	524	2.0
ANIK G1	39127	Active	838	1.2
TELSTAR 18V	43611	Active	825	1.2
CIEL-2	33453	Active	579	1.7
NIMIQ-1	25740	Active	673	1.5
NIMIQ-4	33373	Active	550	1.9
NIMIQ-5	35873	Active	454	2.2
NIMIQ-6	38342	Active	420	2.4
TELSTAR 11N	34111	Active	495	2.1
TELSTAR 12V	41036	Active	666	1.5
TELSTAR 14R	37602	Active	437	2.4
TELSTAR 19V	43562	Active	468	2.3
Total Obs - 2022			11,387	Mean revisit time: 2.8 Days

NEOSSat imaging RCM satellites post-launch



15 Jun. 2019

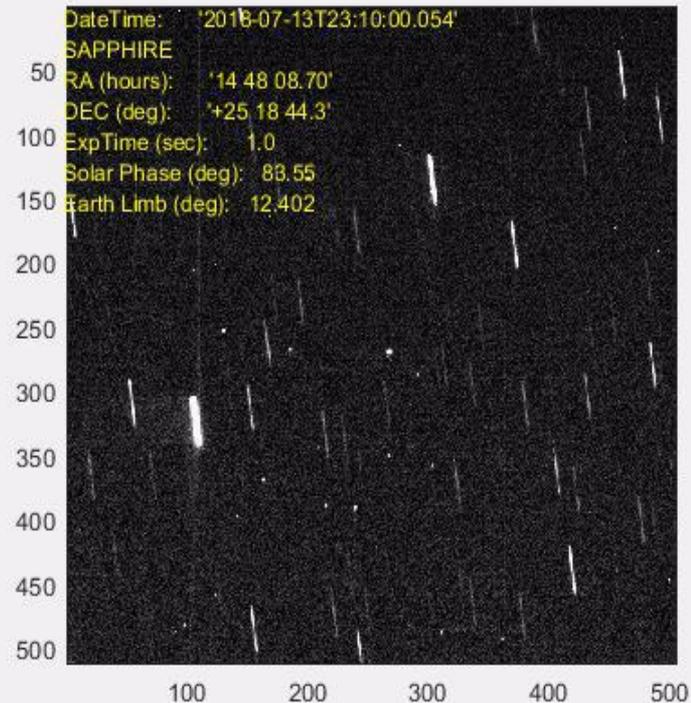
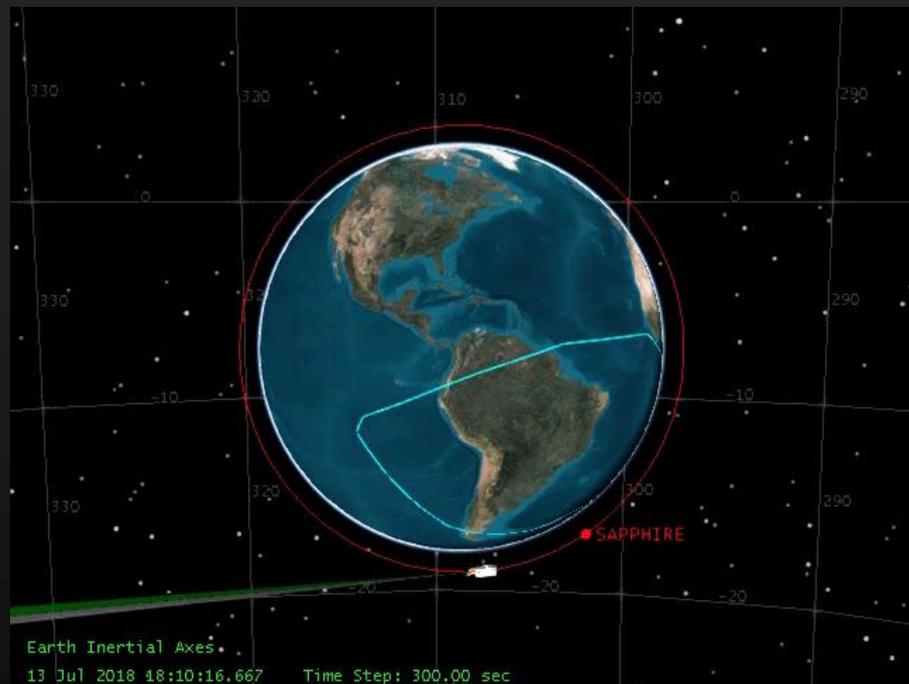


NEOSSAT_39089 ICR Axes
15 Jun 2019 11:37:10.000 Time Step: 10.00 sec

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Shared orbit monitoring



Proximity Operations

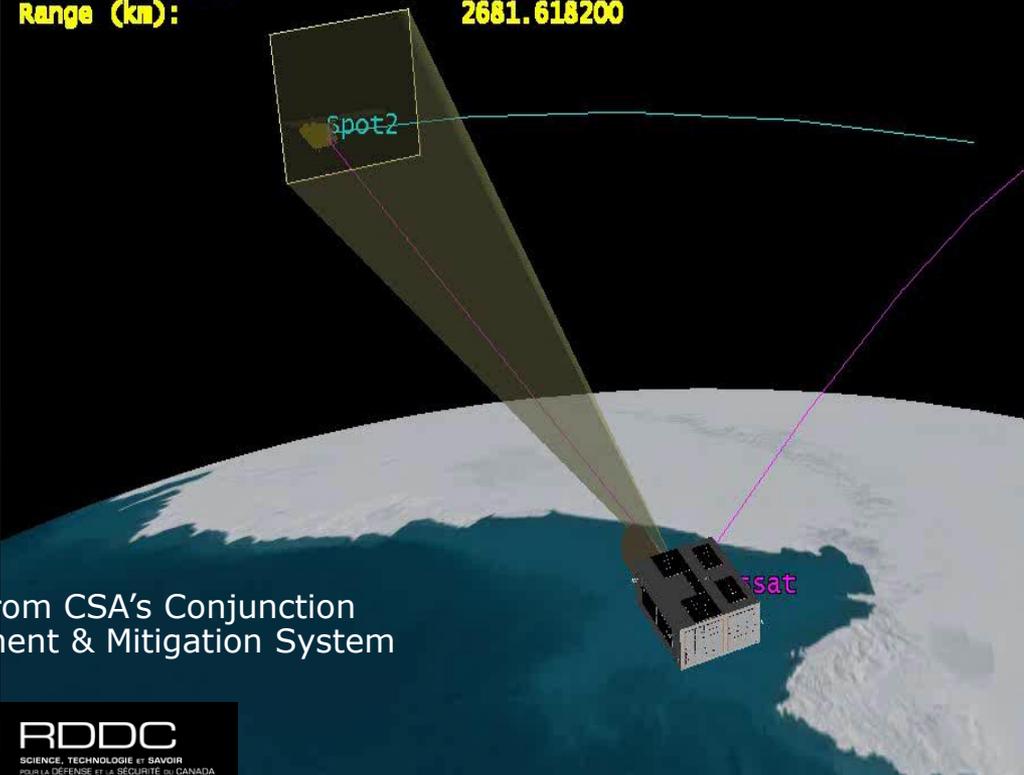
12 Jun 2018:
NEOSSat and Sapphire have minimum separation



NEOSSat observations of conjuncting objects

- Spot2 – miss distance 2.2 km

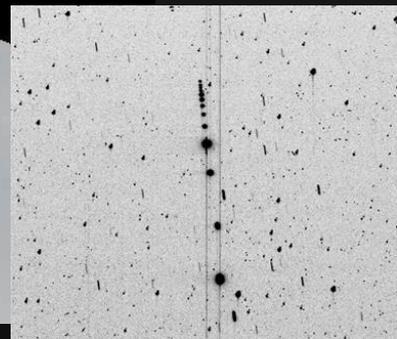
NeosSat-To-Spot2 AER
Time (UTCG): 16 Jul 2018 06:21:01.000
Azimuth (deg): 313.658
Elevation (deg): -10.937
Range (km): 2681.618200



DateTime: '2018-07-16T06:20:40.142'
SPOT-2
RA (hours): '23 45 27.10'
DEC (deg): '-12 21 19.8'
ExpTime (sec): 1.0
Solar Phase (deg): 58.54
Earth Limb (deg): 15.549



Predictions from CSA's Conjunction Risk Assessment & Mitigation System (CRAMS)

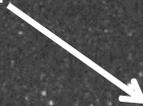


NEOSSat observations of conjuncting objects

- 20m miss

Unclassified
NEOSSat SCI Imagery
2 Feb 2023
debris object conjunction

Debris approach

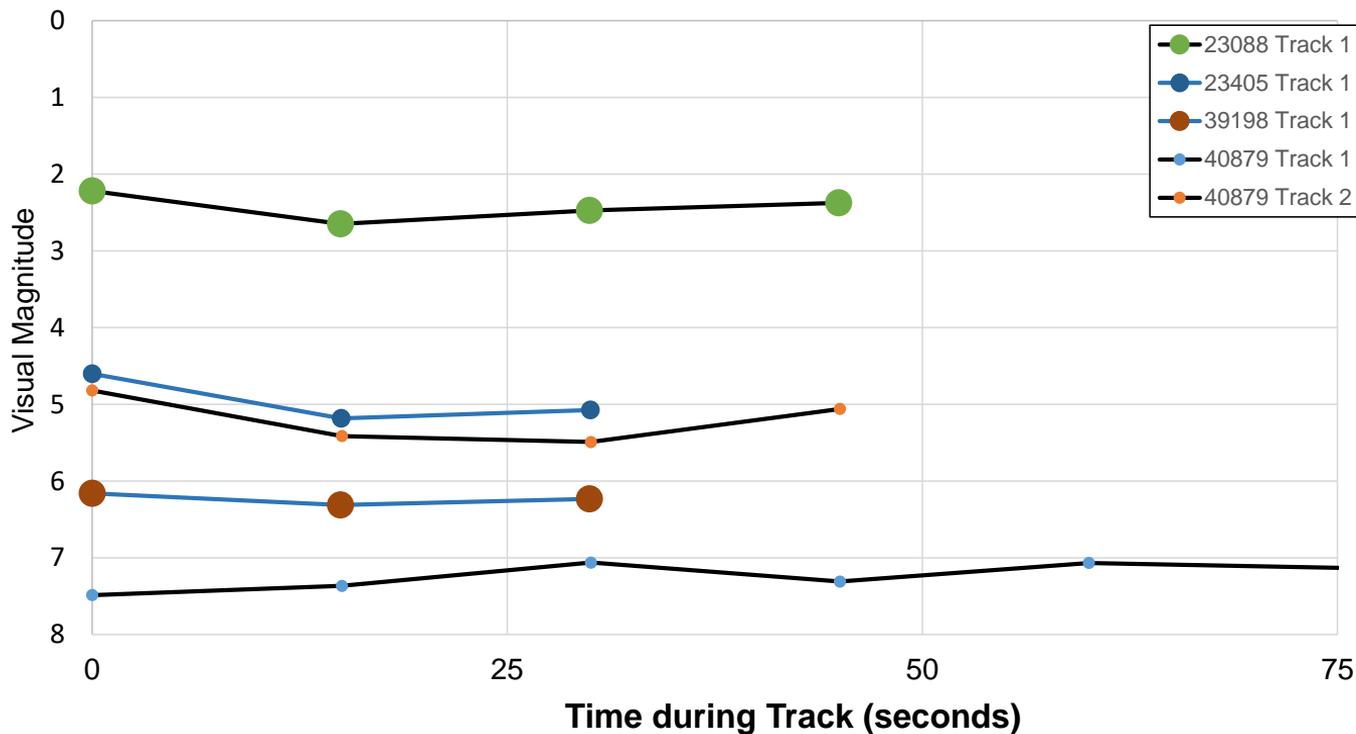


Predictions from CSA's Conjunction
Risk Assessment & Mitigation System
(CRAMS)



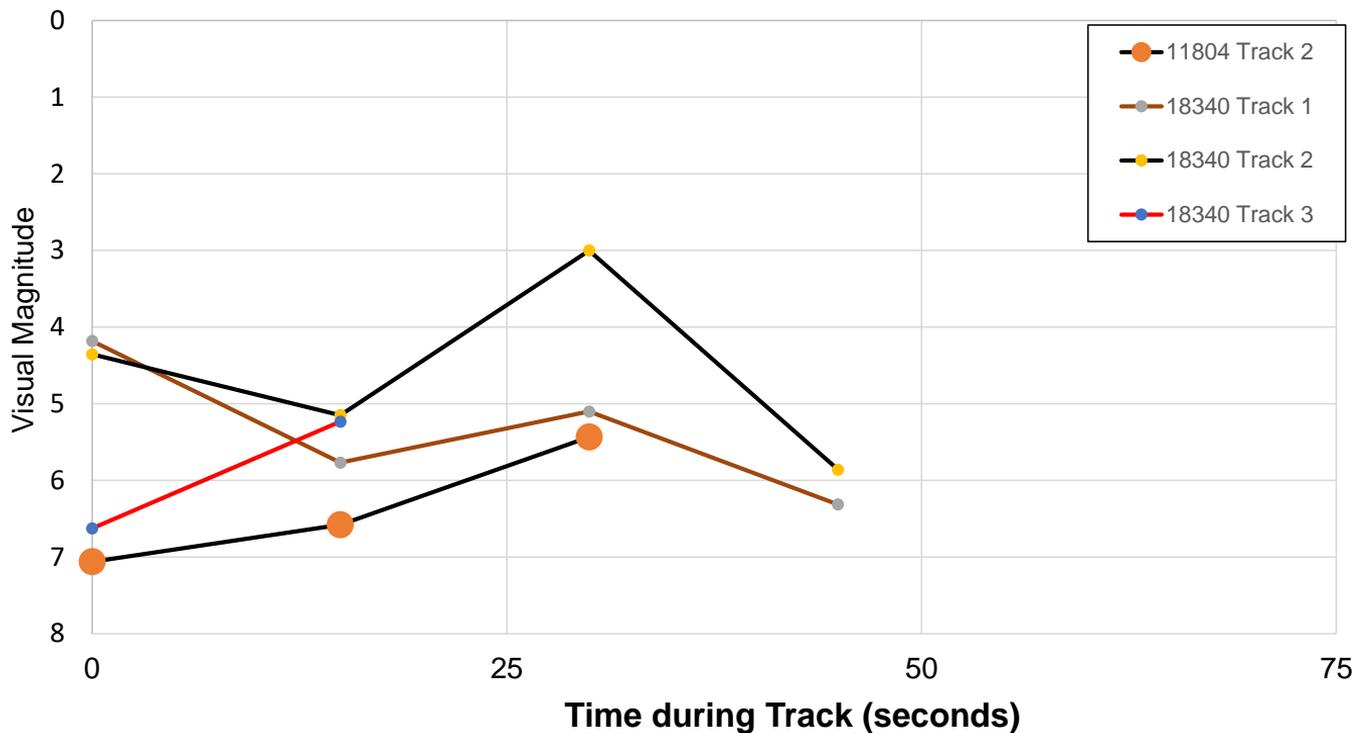
LEO Upper Stages (AI 38.2 Campaign)

NEOSSat Observations [IADC AI 38.2 R/B Campaign]
Possible Slow Rotators by Track Duration
Magnitude range normalized to 1000 km



LEO Upper Stages (AI 38.2 Campaign)

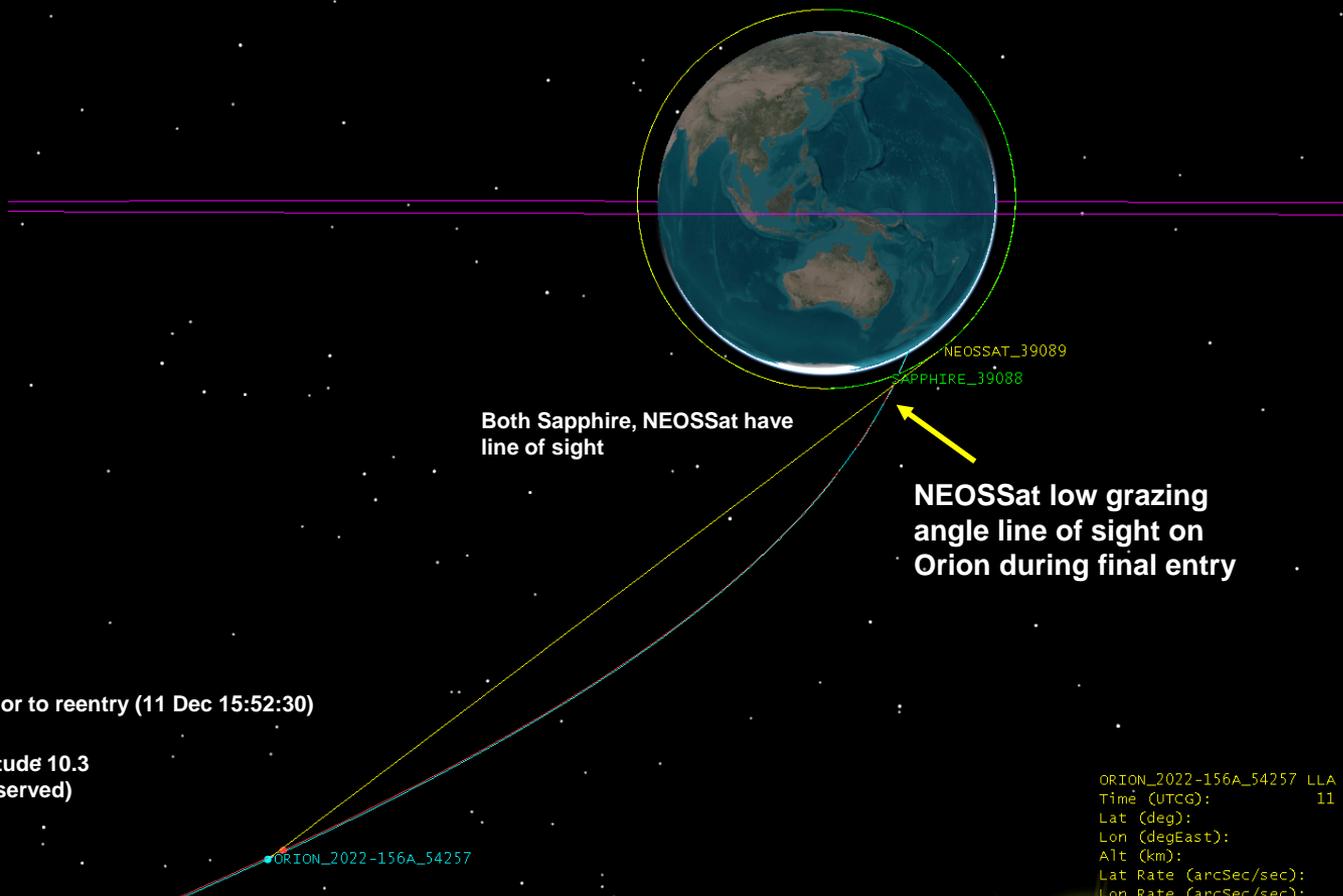
NEOSSat Observations [IADC AI 38.2 R/B Campaign]
Possible Fast Rotators by Track Duration
Magnitude range normalized to 1000 km



NEOSSat Measurements from Lunar distances to Earth (11 Dec 2022)



Unclassified
NEOSSat SCI imager
11 Dec 2022 15:52:30
Target: #54257
Last detection range: 31,574 km



Both Sapphire, NEOSSat have line of sight

NEOSSat low grazing angle line of sight on Orion during final entry

Last full NEOSSat track of Orion prior to reentry (11 Dec 15:52:30)

Artemis1/Orion detected at Magnitude 10.3
Headcount 1 (no other objects observed)

ORION_2022-156A_54257 LLA
Time (UTCG): 11
Lat (deg):
Lon (degEast):
Alt (km):
Lat Rate (arcSec/sec):
Lon Rate (arcSec/sec):
Alt Rate (km/sec):

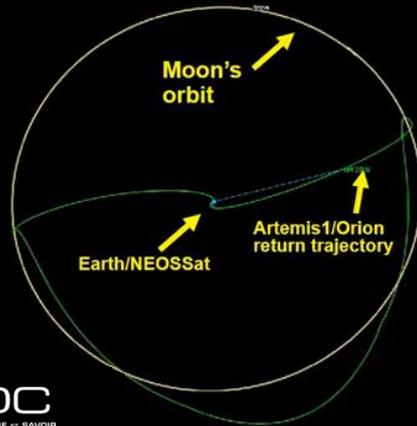
Earth Inertial Axes
11 Dec 2022 15:52:30.000 Time Step: 5.00 sec



Date: 2022-12-10T05:25:20.128
Object: Artemis-1/Orion
Visual Magnitude: 12.0
Range: 252111 km



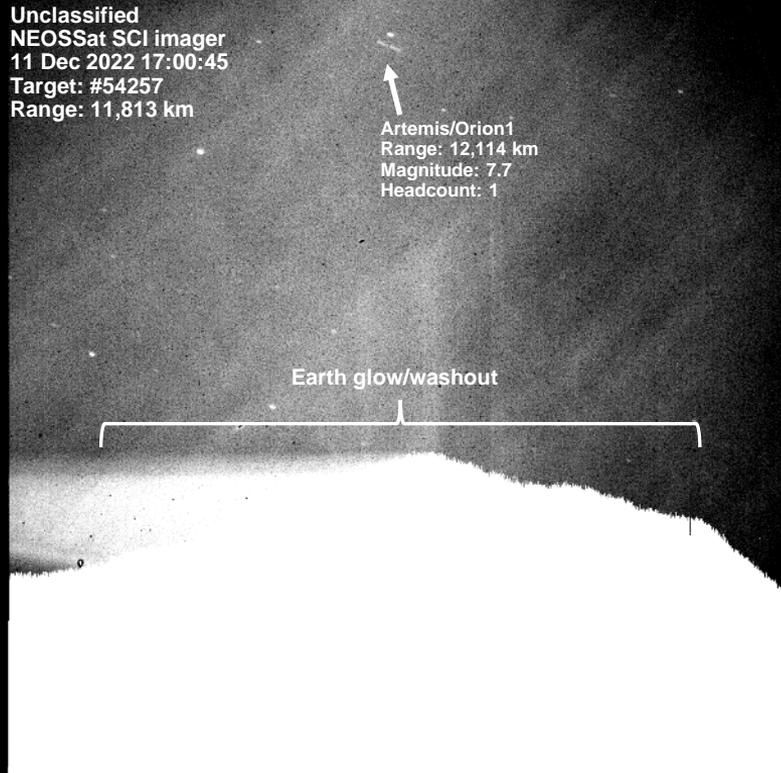
← ORION





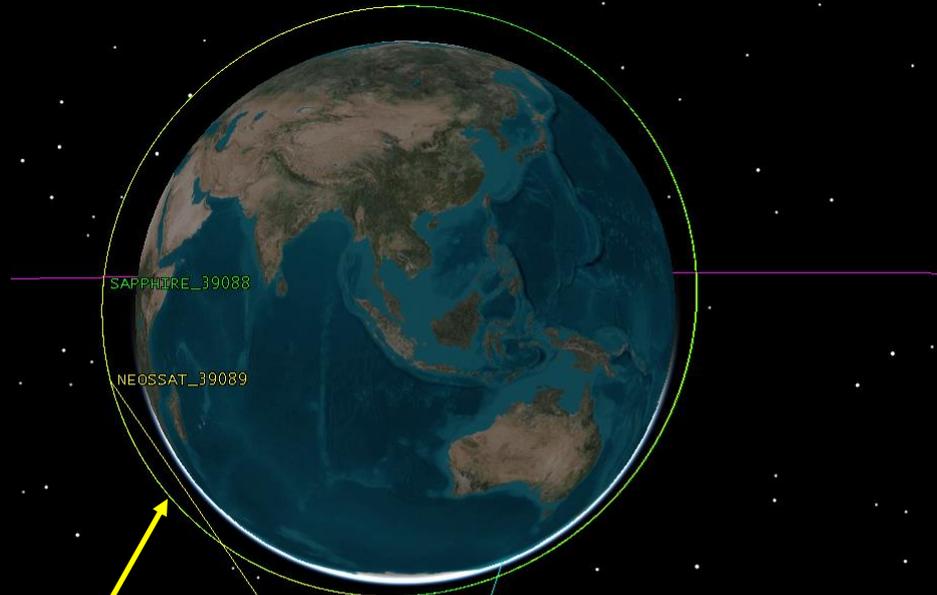
NEOSSat image of Artemis-1/Orion near its final entry

Unclassified
 NEOSSat SCI imager
 11 Dec 2022 17:00:45
 Target: #54257
 Range: 11,813 km



Artemis/Orion1
 Range: 12,114 km
 Magnitude: 7.7
 Headcount: 1

Earth glow/washout



NEOSSat low grazing angle line of sight on Orion during final entry

NEOSSat "set a trap" to wait for Orion to pass through its field of view and image acquired using time-tagged commands. This enabled NEOSSat guider to function while snapping a single frame

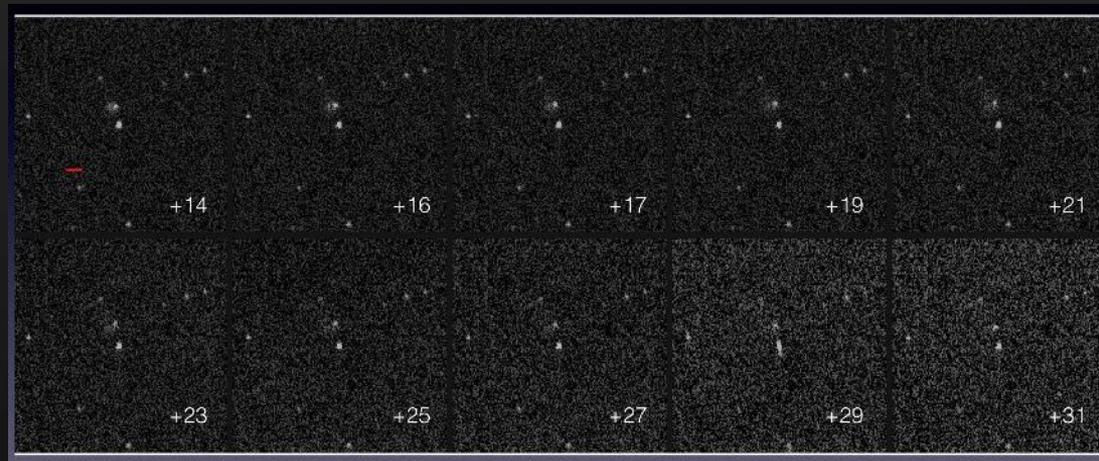
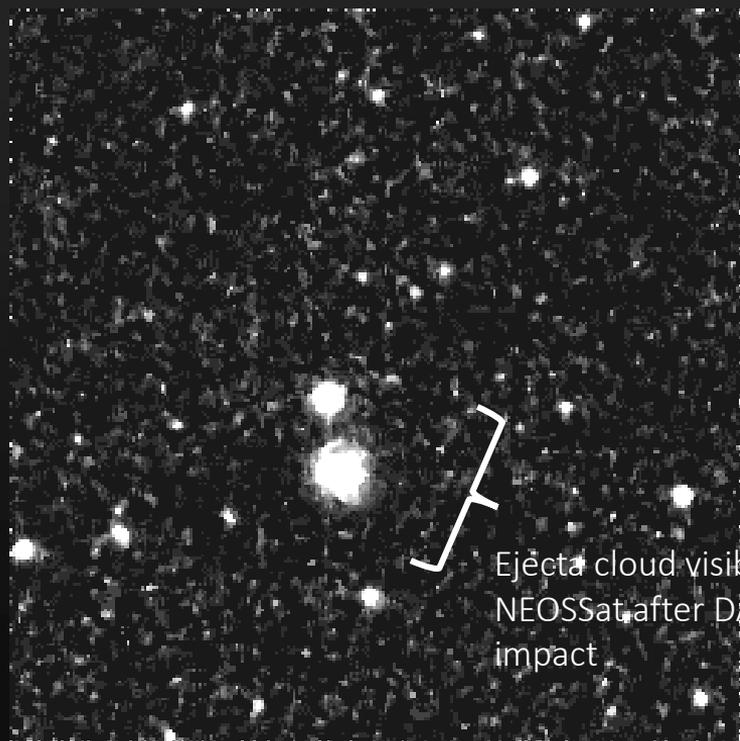
ORION_2022-156A_54257 LLA Position
 Time (UTCG): 11 Dec 2022 17:00:45.000
 Lat (deg): -81.693
 Lon (deg): 96.864
 Alt (km): 4966.132454
 Lat Rate (arcSec/sec): -98.297731
 Lon Rate (arcSec/sec): 382.277903
 Alt Rate (km/sec): -5.394560



Observing impact of NASA's DART on near-Earth asteroid Didymos



*DART - Didymos asteroid impact event by NEOSSat
2022-Sep-26 23:28, 14 minutes after impact*



*Raw images available on CSA Open Data portal and
Canadian Astronomy Data Centre (CADC)*

NEOSSat Way Forward



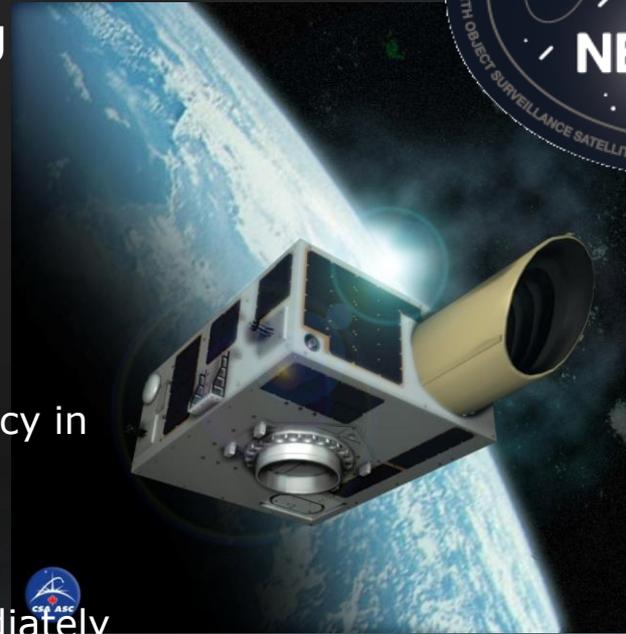
Astronomy & SSA missions ongoing

Health & Safety:

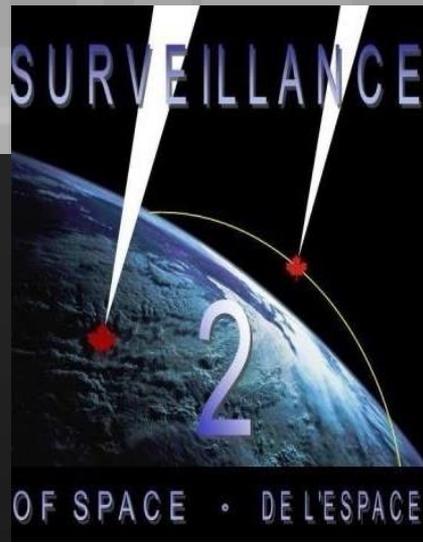
- Innovative software saved satellite after magnetometer & torque rod failures
- New GPS & desaturation techniques
- Improved resiliency for space assets
- Lost wheel redundancy but still have redundancy in TT&C, GPS, CSS, ...

Open Data:

- Astronomy images shared as open data immediately after downlink
- NEOSSat predicted & definitive ephemeris published as open data weekly, enabling LEO tracking system calibration



Upcoming SDA Measurement Initiatives



- **Surveillance of Space 2**

- **Mission:** Operational SDA mission for Canadian Armed Forces
 - Contributing sensor to US SSN / CSpO (SAPPHIRE follow-on)
- **Architecture Includes:**
 - Up to 3 ground-based optical sensors
 - Color photometry capable
 - One or more Space-based sensor(s)
 - Sensitivity limit of M_v 17.5

- **Redwing SSA mission**

- **Multi-purpose Space Surveillance Satellite (MSSSat)**
- **Mission:** SDA R&D (NEOSSat follow-on)
- **Instruments/Capabilities:**
 - Increased observation rate on LEO, Deep Space Objects
 - Resolved imaging capability on RCM
 - Proximity awareness sensor
 - Intersatellite-link tasking capability
 - High performance attitude control for LEO-tracking





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