



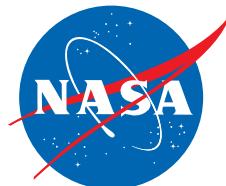
2013 IAA Planetary Defense Conference

# Trajectory and Mission Design for the Origins Spectral Interpretation Resource Identification Security Regolith Explorer (OSIRIS-REx) Asteroid Sample Return Mission

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April 16<sup>th</sup>, 2013



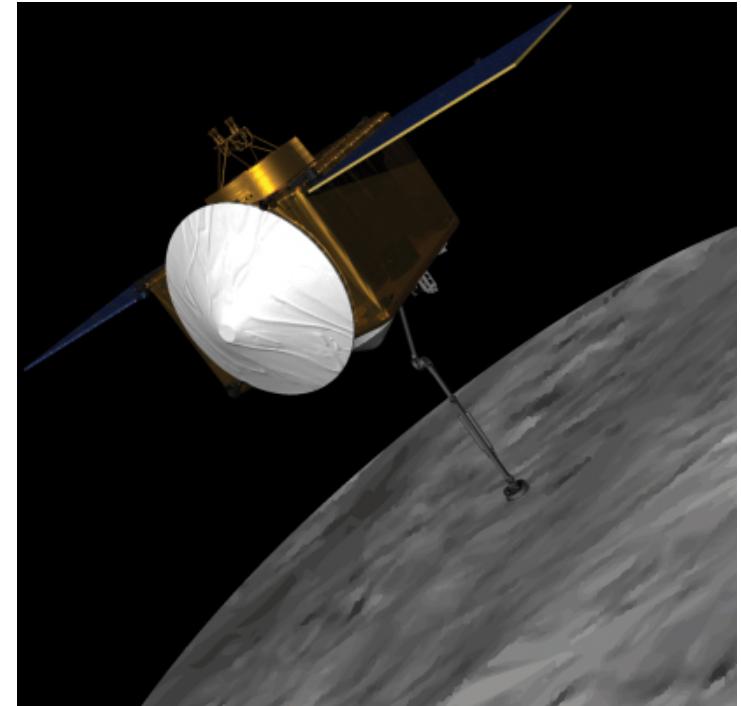
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# OSIRIS-REx Mission Overview

- Origins Spectral Interpretation Resource Identification Security Regolith Explorer (OSIRIS-REx) is the third mission selected as part of NASA's New Frontiers Program.
- Launch in September of 2016, encountering near-Earth asteroid (NEA) 101955 (1999 RQ<sub>36</sub>) in October of 2018.
- Study 1999 RQ<sub>36</sub> for up to 505 days, globally mapping the surface from a distance of 5 km to a distance of 0.5 km.
- Obtain at least 60 g of pristine regolith and a surface material sample.
- Return the Stardust-heritage Sample Return Capsule (SRC) to Earth in September of 2023.
- Deliver samples to the NASA Johnson Space Center (JSC) curation facility for world-wide distribution.



Credit: NASA/GSFC/UA

# Destination: 1999 RQ<sub>36</sub>

- 101955 (1999 RQ<sub>36</sub>) is one of 1391 currently known Potentially Hazardous Asteroids (PHAs).
- One of the most hazardous of the PHAs based on its probability of future Earth collision and impact energy of approximately 2700 MT.
- A member of the rare B-type subgroup of the carbonaceous C-type asteroids
- Its relatively low-inclination, Earth-like orbit makes it accessible to spacecraft missions.
- One of the best characterized NEAs due to the significant number of optical and radar observations collected since discovery in 1999
- Approximate diameter of 550 m.
- Retrograde rotation (obliquity of  $174^\circ \pm 10^\circ$ ) with a period of 4.2978 hours; no non-principal axis rotation detected thus far.
- Low, nominal, and high estimates for its gravitational parameter are  $2.93 \times 10^{-9}$ ,  $4.16 \times 10^{-9}$ , and  $6.6249 \times 10^{-9} \text{ km}^3/\text{s}^2$ , respectively (from radar-derived shape models and constraints on bulk density).



Simulated image of 1999 RQ<sub>36</sub> - topography overlaid on radar imagery.  
Credit: NASA/GSFC/UA

Orbital Element	Value
Semi-major axis, $a$ (AU)	1.12600
Eccentricity, $e$	0.20373
Inclination, $i$	6.03491°
Longitude of Ascending Node, $\Omega$	2.04227°
Argument of Perihelion, $\omega$	66.2686°
Mean Anomaly at Epoch, $M$	72.8280°



# Mission Timeline





# Outbound Cruise Trajectory Optimization

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- The primary and backup launch windows are defined by computing the optimal (minimum post-launch  $\Delta v$ ) outbound trajectory sequence for each day of the launch windows.
- The total post-launch  $\Delta v$  is the sum of the magnitudes of the DSM1, DSM2, AAM1, AAM2, and AAM3 maneuvers.
- The optimization is performed by holding  $C_3$  constant and varying the following parameters on each launch day:
  - The DLA and RLA.
  - The times, orientations, and magnitudes of DSM1, DSM2, and the orientations and magnitudes of AAM1, AAM2, and AAM3.
  - The time, orientation, and altitude of the EGA.
- For the backup launch window cases there is only one DSM (DSM1) and  $C_3$  is also varied.



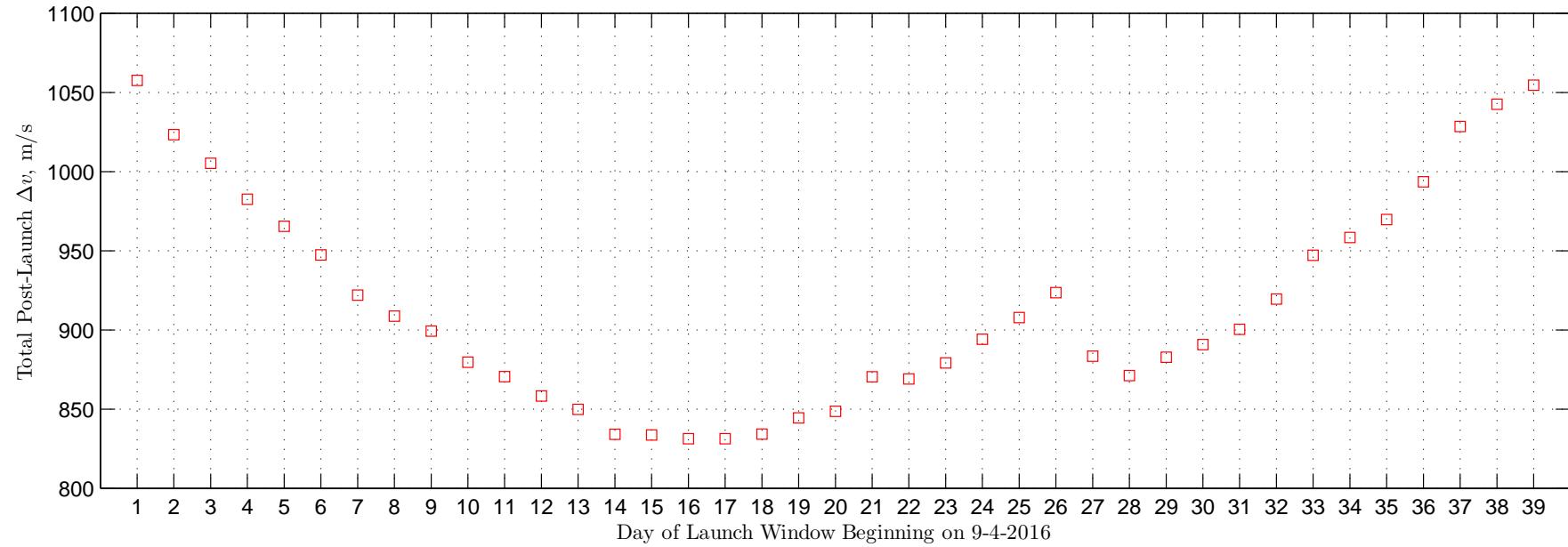
# Asteroid Arrival Sequence Overview

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- Asteroid arrival conditions are purposely standardized such the same arrival sequence will be executed regardless of which launch window and day of launch window are utilized.
  - Single set of arrival circumstances for which the spacecraft must be designed.
  - Favorable natural illumination of the asteroid from the spacecraft's point of view.
- The AAM is divided into 3 parts to create a gentle and robust approach.
  - Adequate time to optically acquire the asteroid during approach.
  - Adequate time for natural satellite survey.
  - Gracefully recover if the first AAM is not executed.
- AAM1 is performed on 2018-10-01, targeting arrival at a location 6300 km from the asteroid 14 days later on 2018-10-15; that is the same location relative to the asteroid that is targeted by DSM2.
  - Thus, if AAM1 is not executed, the spacecraft simply arrives at that same location early, on 2018-10-05.
- AAM2 is nominally performed on 2018-10-15, targeting arrival at a location 270 km from the asteroid 14 days later on 2018-10-29.
- AAM3 is nominally performed on 2018-10-29, targeting arrival at a location 19.3 km from the asteroid on 2018-11-12.



# Primary Launch Window Results

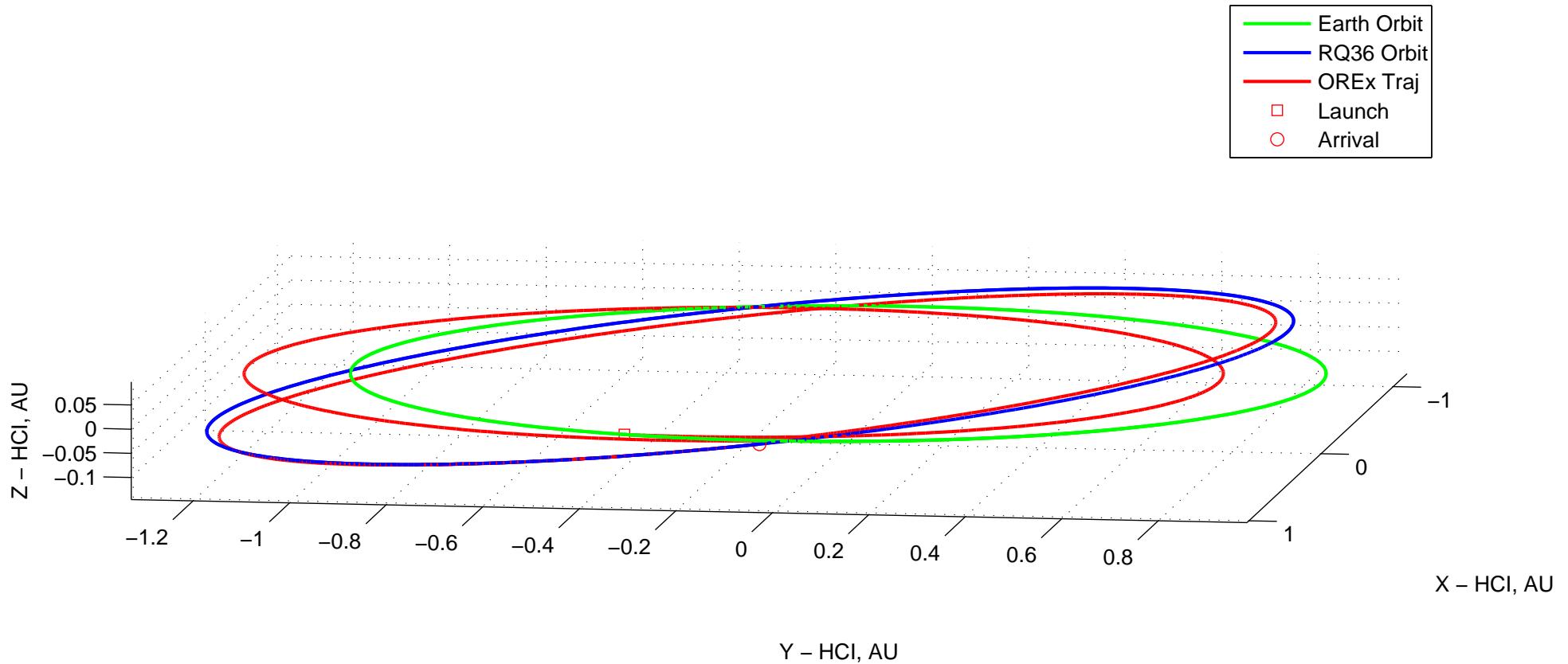


Total Post-Launch  $\Delta v$  variation throughout the primary launch window.

- The DLA is within the range of  $-9^\circ$  to  $+3^\circ$  throughout the primary launch window.
- The  $C_3$  is kept constant at  $29.3 \text{ km}^2/\text{s}^2$  throughout.
- Total post-launch  $\Delta v$  reaches a minimum of 831.3 m/s on days 16 and 17.
- The higher  $\Delta v$  at the extremes of the 39 day launch window are feasible, but the launch window could be restricted to the middle 21 days if needed to reduce  $\Delta v$  requirements.
- The discontinuity in post-launch  $\Delta v$  between days 26 and 27 is due to a relatively close lunar encounter during Earth departure.



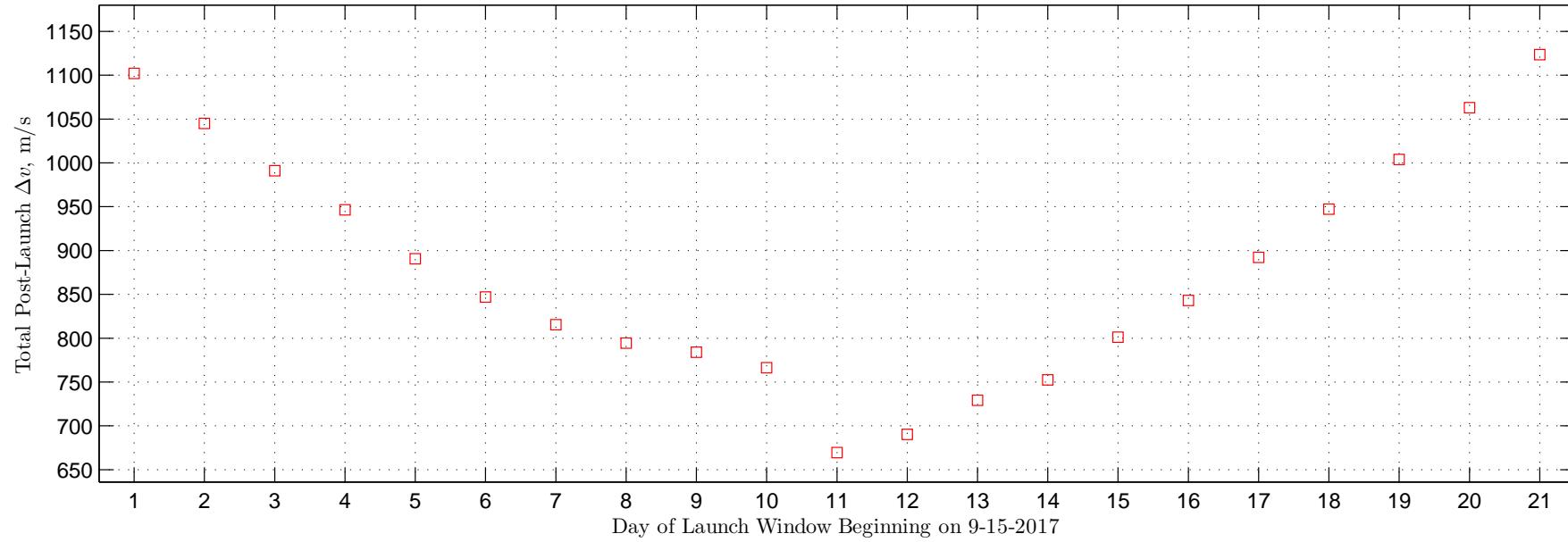
# Example Primary Launch Window Trajectory



OSIRIS-REx primary launch window outbound cruise trajectory to 1999 RQ<sub>36</sub>.



# Backup Launch Window Results

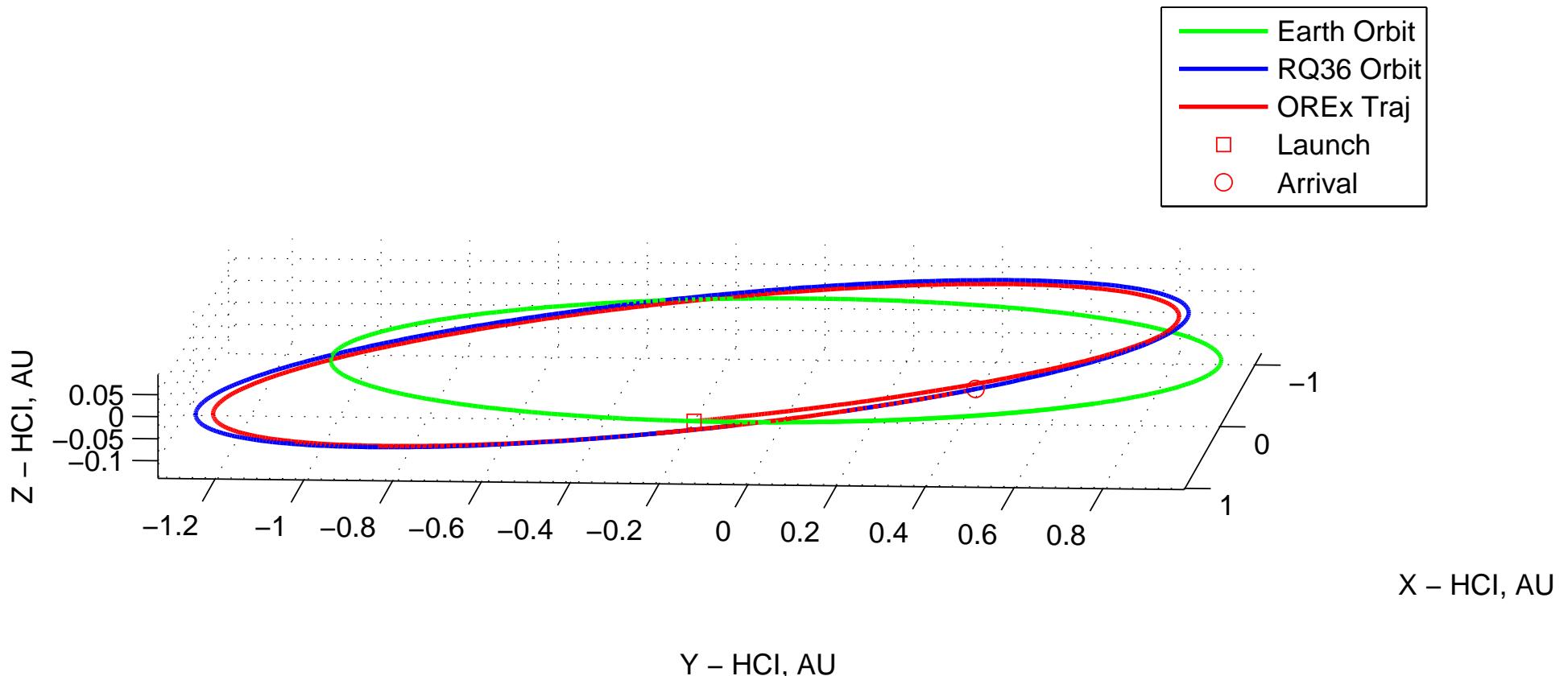


Total Post-Launch  $\Delta v$  variation throughout the backup launch window.

- The DLA is within the range of  $31^\circ$  to  $36^\circ$  throughout the backup launch window.
- The  $C_3$  is within the range of  $28.5$  to  $29.3 \text{ km}^2/\text{s}^2$  throughout.
- Total post-launch  $\Delta v$  reaches a minimum of  $669.6 \text{ m/s}$  on day 11.
- Reduced launch vehicle performance is possible (for launches from KSC) because all of the backup launch window DLA values are outside the range of  $\pm 28.5^\circ$ .
- However, the optimization strategy will maintain a constant launch vehicle payload mass of  $1955 \text{ kg}$  by adjusting  $C_3$  as needed on each day of the launch window.



# Example Backup Launch Window Trajectory



OSIRIS-REx backup launch window outbound cruise trajectory to 1999 RQ<sub>36</sub>.



# Remarks About Launch Windows

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- The highest  $\Delta v$  value in the backup launch window (1123.43 m/s) exceeds the highest  $\Delta v$  in the primary launch window (1057.57 m/s).
- From that perspective, additional  $\Delta v$  margin is available if the mission launches during the primary launch window.
- However, when considering only individual days within the launch windows, we note that the overall minimum  $\Delta v$  in the backup launch window (669.6 m/s) is actually less than the overall minimum  $\Delta v$  in the primary launch window (831.3 m/s).
- The primary launch window is nearly twice as wide as the backup launch window.
- The backup launch window reduces mission complexity by forgoing the EGA and one DSM.



# Trajectory Type Comparison

Comparison of trajectory design types for the OSIRIS-REx mission.

	Type II Lambert	Primary LW (DSMs, multi-rev, EGA)		Backup LW (DSM, multi-rev)	
		Best	Worst	Best	Worst
Earth Departure Date	09/27/2017	09/19/2016	09/04/2016	09/25/2017	10/05/2017
Earth Departure DLA	33.36°	0.11°	2.13°	33.09°	33.25°
Earth Departure $C_3$ ( $\text{km}^2/\text{s}^2$ )	29.0	29.3	29.3	29.1	29.0
Flight Time to RQ <sub>36</sub> (days)	382	784	799	413	403
NEA Arrival Date	10/14/2018	11/12/2018	11/12/2018	11/12/2018	11/12/2018
Total Post-launch $\Delta v$ to Arrive at RQ <sub>36</sub> (m/s)	874	831	1058	670	1123
Stay Time at RQ <sub>36</sub> (days)	1387	842	842	842	842
RQ <sub>36</sub> Departure Date	08/01/2022	03/03/2021	03/03/2021	03/03/2021	03/03/2021
RQ <sub>36</sub> Departure $\Delta v$ (m/s)	494	320	320	320	320
Flight Time to Earth (days)	422	935	935	935	935
Earth Arrival Date	09/27/2023	09/24/2023	09/24/2023	09/24/2023	09/24/2023
Atmospheric Entry Speed (km/s)	12.88	12.20	12.20	12.20	12.20
Total Post-launch Round-Trip $\Delta v$ (m/s)	1368	1151	1378	990	1443
Total Round-Trip Mission Duration (years)	6.00	7.01	7.05	6.00	5.97

- Late September of 2017 is an optimal time to depart Earth for asteroid rendezvous because Earth happens to be near the line of intersection between the orbit planes.
- The advanced trajectory solutions of the primary and backup launch windows trade some time at the asteroid for the benefit of reducing the mission  $\Delta v$ .
- The more advanced trajectory solutions also provide larger Earth departure and asteroid departure windows and better manage Earth return atmospheric entry speed.
- The straightforward Type II Lambert optimal total mission  $\Delta v$  is a reasonable predictor of the amount of  $\Delta v$  required by the more advanced methods.



# Conclusions

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- The OSIRIS-REx team is developing a robust set of designs that will ensure successful return of a pristine regolith sample from the potentially hazardous near-Earth asteroid 1999 RQ<sub>36</sub>.
- Advanced trajectory design techniques including multi-rev trajectories, optimized DSMs, and an Earth Gravity Assist are employed to trade time at the asteroid and mission complexity for reduced  $\Delta v$  requirements and wider, more robust launch windows.
- The Earth Gravity Assist enables launch in 2016, a full year earlier than would be possible otherwise, and provides a wide primary launch window.
- The backup launch window in 2017 provides a viable alternative if needed.
- 1999 RQ<sub>36</sub> is an exciting science target and our interactions with it will provide crucial knowledge for future missions to asteroids for robotic and human exploration, scientific understanding, and defending our planet against asteroid impacts.



# Acknowledgments

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This work is supported by the OSIRIS-REx Asteroid Sample Return Mission project, for which **Dr. Dante Lauretta** is the Principal Investigator, within NASA's New Frontiers Program. The authors are grateful for contributions to this work by the OSIRIS-REx Flight Dynamics team and other OSIRIS-REx subsystem teams. The authors are also appreciative of support and technical input from the OSIRIS-REx Science team liaisons to the Flight Dynamics team, **Dr. Steven Chesley** and **Dr. Daniel Scheeres**.



<http://osiris-rex.lpl.arizona.edu/>

# Appendices



# Overview of Mission Phases

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- Outbound Cruise
  - Earth Gravity Assist (EGA) following launch during the Primary Launch Window is bracketed by two deterministic Deep Space Maneuvers (DSMs), DSM1 and DSM2.
  - Backup Launch Window trajectories involve only one DSM (labeled DSM1, occurring between launch and asteroid arrival) and no EGA.
- Approach
  - Three deterministic Asteroid Arrival Maneuvers (AAMs): AAM1–AAM3.
  - Search vicinity of asteroid for natural satellites > 10 cm in size.
- Preliminary & Detailed Survey
  - Preliminary: Three slow ( $\sim 20$  cm/s) flybys of asteroid to within 7 km.
  - Detailed: Observations collected from specific solar phase angle stations.
  - Estimate improved values of asteroid physical characteristics that affect subsequent proximity operations (spin state, gravitational parameter, gravity field coefficients).



# Overview of Mission Phases

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- Orbital Phase
  - Spacecraft enters into gravitationally captured orbit about the asteroid.
  - Terminator plane orbits (for stability relative to solar pressure).
  - Orbit A: 2018-12-31 to 2019-01-20, nominal radius is 1.5 km (50 hour period).
  - Orbit B: 2019-01-21 to 2019-03-05, nominal radius is 1.0 km (27 hour period).
  - Candidate sampling sites are selected during orbital phase.
- Recon Phase
  - Obtain more detailed observations of candidate sampling sites.
  - Flybys reaching an approach distance of 225 m are performed in a prograde sense across sunlit side of asteroid, departing from and returning to terminator plane orbit.
- TAG Rehearsals and TAG
  - Touch And Go (TAG) rehearsals begin two weeks after final recon flyby.
  - Three TAG rehearsals are performed prior to the actual TAG.
  - During TAG the spacecraft is guided to contact the asteroid's surface with a vertical speed of 10 cm/s, regolith is ingested by the sampling mechanism, and a 0.5 m/s escape maneuver is performed to move up and away from the asteroid.
- Asteroid Departure and Earth Return
  - Nominal asteroid departure occurs on 2021-03-03 and delivers the SRC to Earth 935 days later on 2023-09-24 with an atmospheric entry speed of 12.198 km/s.



# Inbound Trajectory Overview

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- Round-trip mission duration approximately equal to one Earth/asteroid synodic period effectively decouples the outbound and inbound trajectories such that they can be optimized independently.
  - The same inbound trajectory may be flown regardless of which launch window and day within launch window are utilized for the outbound cruise.
- A continuum of asteroid departure opportunities is available:
  - 2021-03-03:  $\Delta v = 316$  m/s, 2023-09-24 Earth return, entry speed = 12.198 km/s
  - 2021-05-22:  $\Delta v = 250$  m/s, 2023-09-25 Earth return, entry speed = 12.390 km/s
  - 2021-06-28:  $\Delta v = 313$  m/s, 2023-09-27 Earth return, entry speed = 12.385 km/s
- There is a small chance of early departure from the asteroid on 2020-01-03 with departure  $\Delta v$  of 935 m/s, early Earth return on 2022-09-24, and entry speed of 12.24 km/s. Early return is only an option if a number of criteria are all met.
  - Spacecraft dry mass must not grow by more than a very small amount between now and launch.
  - Launch must occur during the middle 21 days of the 39 day primary launch window.
  - AAM1 must occur on or after 2018-10-01.
  - Science observations and sample collection must be complete within 460 days or less after AAM1.



# Earth Return Overview

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- Asteroid departure maneuver initially targets an Earth flyby at a distance of at least 10000 km.
- A series of planned “walk-in” maneuvers (total  $\Delta v$  of 4 m/s) are used to gradually lower perigee altitude, following Stardust mission heritage.
- After achieving appropriate entry trajectory, the SRC separates to continue on the entry trajectory while the OSIRIS-REx spacecraft performs a 17 m/s  $\Delta v$  to raise perigee and comply with the Planetary Protection requirement that the spacecraft reside in a solar orbit that will not approach any closer than 250 km to the Earth, Moon, or other solar system body.
- Final OSIRIS-REx spacecraft orbit has a perihelion distance of 0.5 AU, aphelion distance of 1.0 AU, and a period of 0.66 years.
- SRC entry conditions are defined by a 6503.14 km atmospheric entry interface radius, a 12.2 km/s nominal entry speed, and an inertial entry flight path angle of  $-8.2^\circ$ .
- The entry trajectory is targeted to deliver the SRC to the Utah Test and Training Range (UTTR) for retrieval after landing.



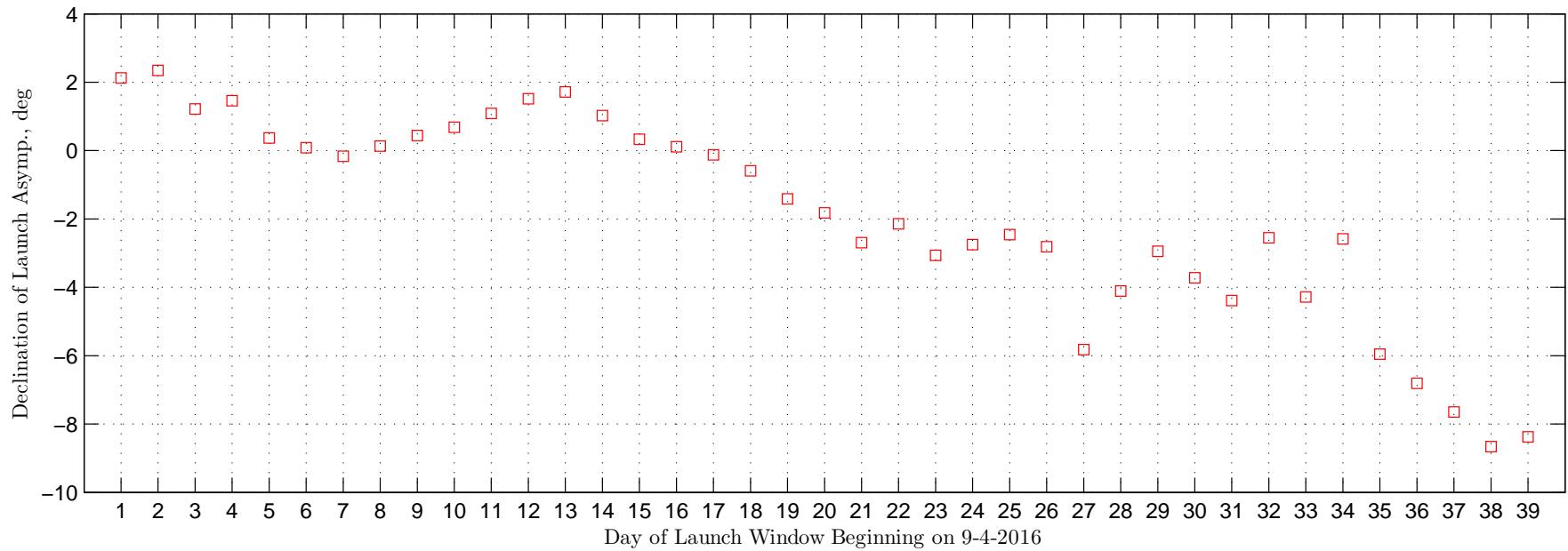
# Example Mission $\Delta v$ Budget

- This example assumes launch on the most demanding day of the primary launch window.

Maneuver/Event	Pre-Event Mass (kg)	Main $\Delta v$ (m/s)	Monoprop Mass (kg)	Pulse Mode $\Delta v$ (m/s)	Pulse Prop Mass (kg)	Post-Event Mass (kg)
Post Launch - Initial Acquisition	1955.0	0.0	0.0	1.0	1.4	1953.6
Post Launch TCMs	1953.6	52.0	44.4			1909.3
DSM1	1909.3	472.6	359.9			1549.3
Outbound Cruise ACS Desat	1549.3				4.0	1545.3
DSM2	1545.3	49.0	33.1			1512.2
AAM1	1512.2	375.8	231.5			1280.7
AAM2	1280.7	150.9	82.6			1198.1
AAM3	1198.1	4.7	2.5			1195.6
Preliminary Survey	1195.6			1.3	1.1	1194.5
Detailed Survey	1194.5			1.3	1.0	1193.5
Orbit Operations	1193.5			0.1	0.1	1193.4
Surface Reconnaissance	1193.4			1.0	0.8	1192.6
Sampling Rehearsals	1192.6			1.6	1.3	1191.2
Sampling Operations	1191.2			1.2	1.0	1190.3
$\Delta v$ to Repeat Rehearsals and Sampling Twice	1190.3			5.6	4.6	1185.7
10 Orbit Departures and Recaptures	1185.7			10.0	8.2	1177.5
Proximity Operations ACS Desat	1177.5				4.2	1173.3
1999 RQ <sub>36</sub> Departure & Earth Targeting	1173.3	320.1	154.8			1018.5
Inbound Cruise TCMs	1018.5	10.0	5.2			1013.3
Earth Return Cruise ACS Desat	1013.3				4.6	1008.7
Deflection from Earth (after sep of 50 kg SRC)	958.7	17.5	7.4			951.4
Unallocated $\Delta v$ Margin	951.4	73.0	30.2	22.0	13.9	907.2
Final Totals	891.9	1525.6	951.6	45.0	46.2	



# Primary Launch Window DLA



DLA variation throughout the primary launch window.

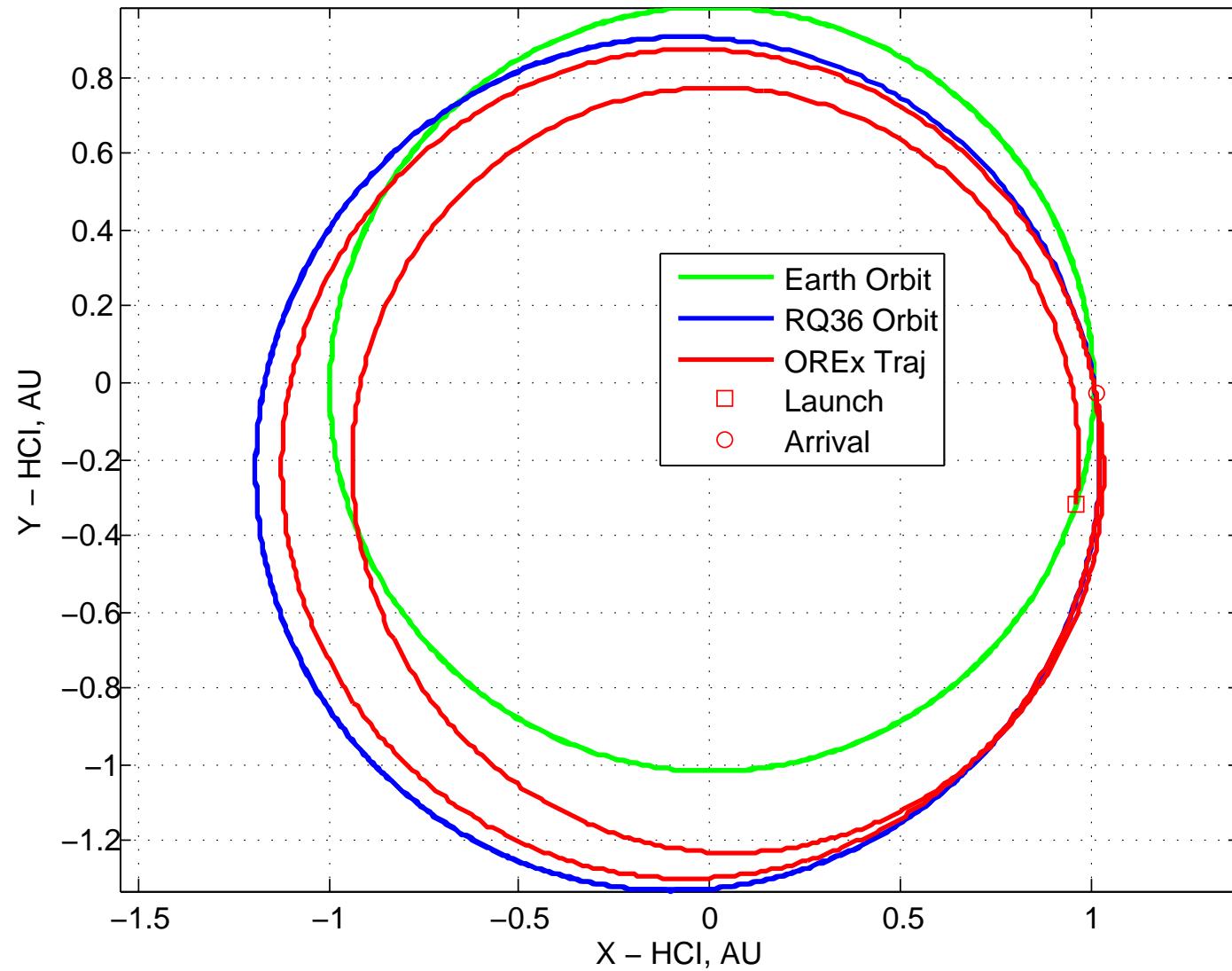


# Primary Launch Window Details

Day	Date	$C_3$ ( $\text{km}^2/\text{s}^2$ )	DLA	RLA	DSM1 (m/s)	DSM2 (m/s)	AAM1 (m/s)	AAM2 (m/s)	AAM3 (m/s)	Total $\Delta v$ (m/s)
1	9-4-2016	29.3	2.13°	173.31°	530.03	7.05	365.80	149.94	4.77	1057.57
2	9-5-2016	29.3	2.34°	174.28°	505.47	1.09	363.19	148.84	4.77	1023.37
3	9-6-2016	29.3	1.22°	174.74°	488.91	0.89	362.17	148.55	4.71	1005.24
4	9-7-2016	29.3	1.46°	175.78°	465.46	0.30	363.19	148.84	4.77	982.56
5	9-8-2016	29.3	0.37°	176.16°	448.16	1.32	362.98	148.30	4.71	965.48
6	9-9-2016	29.3	0.09°	176.93°	425.33	1.86	365.75	149.68	4.77	947.39
7	9-10-2016	29.3	-0.16°	177.66°	406.52	0.93	366.13	143.66	4.71	921.96
8	9-11-2016	29.3	0.13°	178.69°	385.97	13.31	358.00	146.61	4.77	908.65
9	9-12-2016	29.3	0.44°	179.73°	370.80	28.23	351.35	144.15	4.71	899.24
10	9-13-2016	29.3	0.69°	180.76°	356.38	25.04	350.49	142.93	4.71	879.55
11	9-14-2016	29.3	1.09°	181.83°	337.51	30.93	353.39	144.01	4.71	870.55
12	9-15-2016	29.3	1.52°	183.07°	331.28	17.00	359.62	145.62	4.71	858.23
13	9-16-2016	29.3	1.72°	184.04°	315.52	24.17	359.90	145.50	4.71	849.80
14	9-17-2016	29.3	1.02°	184.62°	297.06	26.98	359.90	145.50	4.71	834.16
15	9-18-2016	29.3	0.33°	185.21°	280.05	27.94	372.02	148.97	4.71	833.69
16	9-19-2016	29.3	0.11°	186.03°	265.07	30.84	379.31	151.37	4.71	831.30
17	9-20-2016	29.3	-0.12°	186.82°	248.63	32.13	390.75	155.06	4.71	831.30
18	9-21-2016	29.3	-0.59°	187.48°	231.35	38.89	400.64	158.59	4.71	834.18
19	9-22-2016	29.3	-1.41°	187.82°	201.43	36.83	432.48	169.02	4.71	844.49
20	9-23-2016	29.3	-1.82°	188.48°	184.43	48.45	438.99	172.07	4.71	848.64
21	9-24-2016	29.3	-2.69°	188.83°	156.13	50.55	474.64	184.34	4.71	870.38
22	9-25-2016	29.3	-2.14°	189.96°	141.92	55.97	479.49	186.98	4.71	869.06
23	9-26-2016	29.3	-3.07°	190.39°	118.14	59.25	501.52	195.52	4.71	879.14
24	9-27-2016	29.3	-2.75°	191.25°	93.83	68.76	523.07	203.75	4.71	894.13
25	9-28-2016	29.3	-2.46°	192.12°	64.93	71.33	552.13	214.68	4.71	907.79
26	9-29-2016	29.3	-2.81°	192.71°	36.32	78.40	578.98	225.12	4.71	923.54
27	9-30-2016	29.3	-5.82°	192.16°	184.44	19.35	486.67	188.19	4.78	883.43
28	10-1-2016	29.3	-4.11°	193.11°	232.00	34.49	431.40	168.62	4.71	871.22
29	10-2-2016	29.3	-2.94°	194.92°	263.39	44.92	408.56	161.11	4.71	882.70
30	10-3-2016	29.3	-3.72°	195.64°	264.57	53.69	406.64	161.16	4.71	890.77
31	10-4-2016	29.3	-4.39°	196.31°	291.09	46.75	399.41	158.37	4.71	900.34
32	10-5-2016	29.3	-2.55°	198.04°	319.11	47.10	392.45	156.07	4.71	919.44
33	10-6-2016	29.3	-4.28°	198.16°	321.45	53.17	407.12	160.65	4.71	947.11
34	10-7-2016	29.3	-2.58°	199.93°	369.32	50.39	381.33	152.63	4.71	958.37
35	10-8-2016	29.3	-5.95°	199.46°	379.43	52.71	380.39	152.43	4.71	969.66
36	10-9-2016	29.3	-6.81°	200.11°	413.02	56.78	369.60	149.38	4.71	993.50
37	10-10-2016	29.3	-7.65°	200.77°	443.61	73.92	359.41	146.79	4.71	1028.44
38	10-11-2016	29.3	-8.66°	201.16°	433.26	55.99	392.48	156.03	4.71	1042.48
39	10-12-2016	29.3	-8.38°	202.17°	474.65	49.84	374.49	150.90	4.71	1054.60



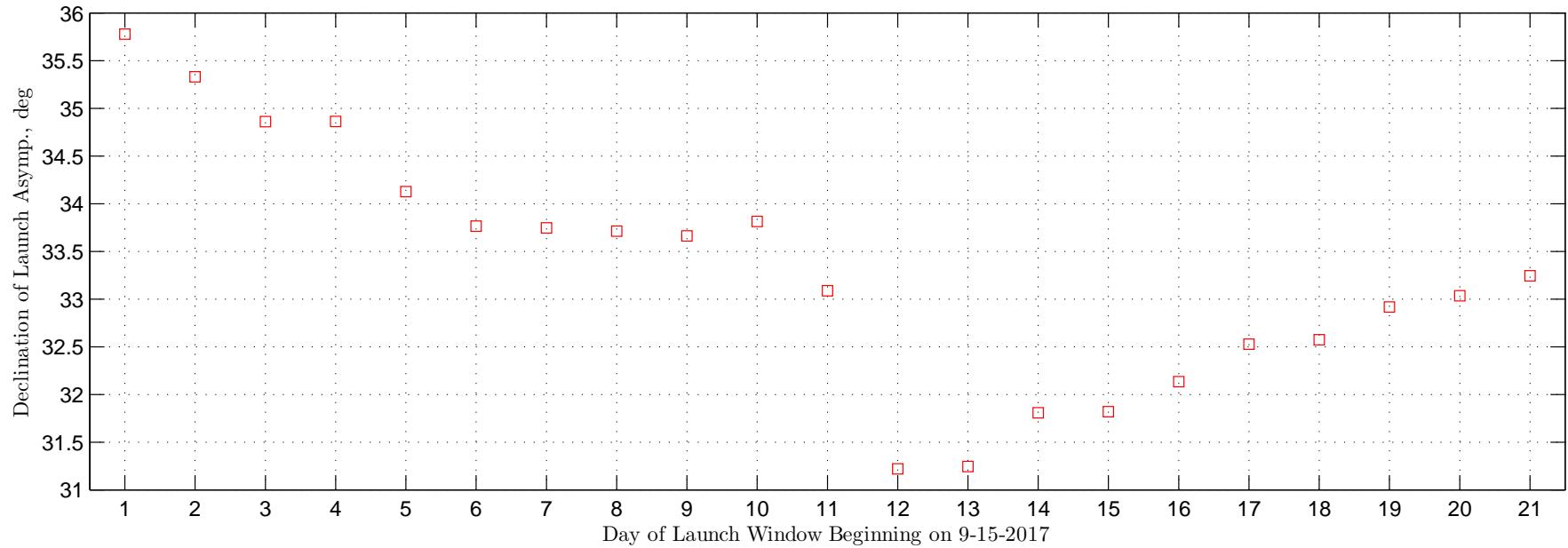
# Example Primary Launch Window Trajectory



OSIRIS-REx primary launch window outbound cruise trajectory to 1999 RQ<sub>36</sub>, ecliptic plane projection.



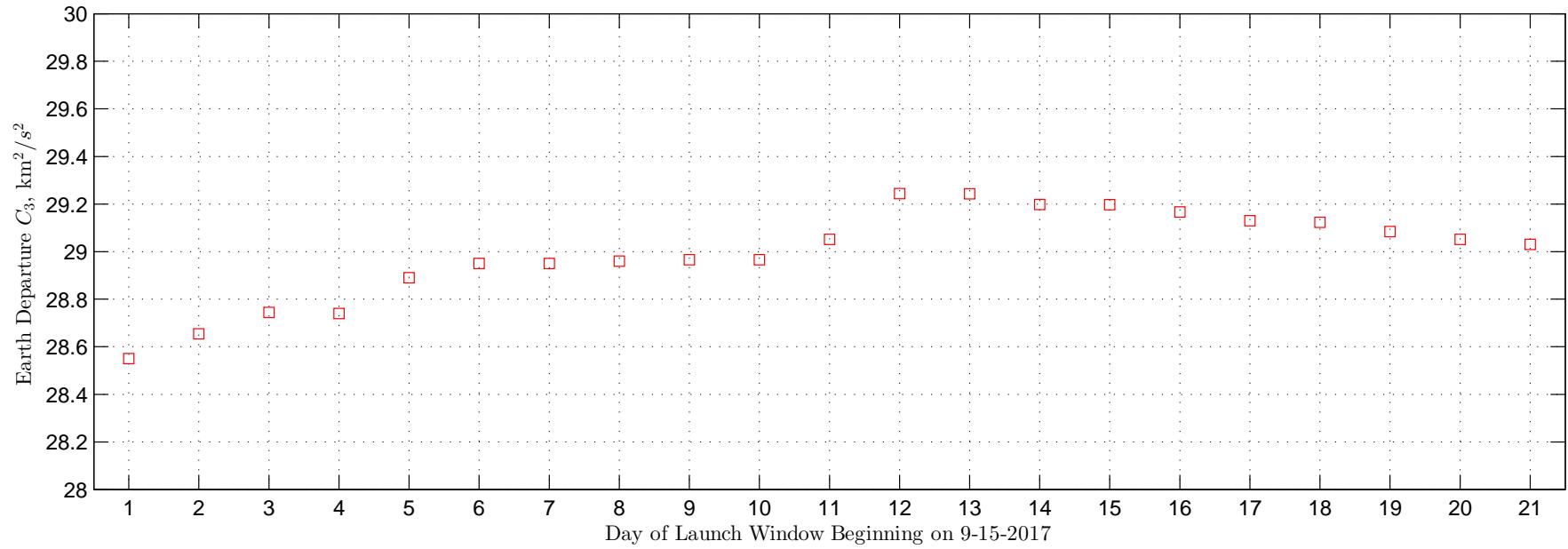
# Backup Launch Window DLA



DLA variation throughout the backup launch window.



# Backup Launch Window $C_3$



$C_3$  variation throughout the backup launch window.

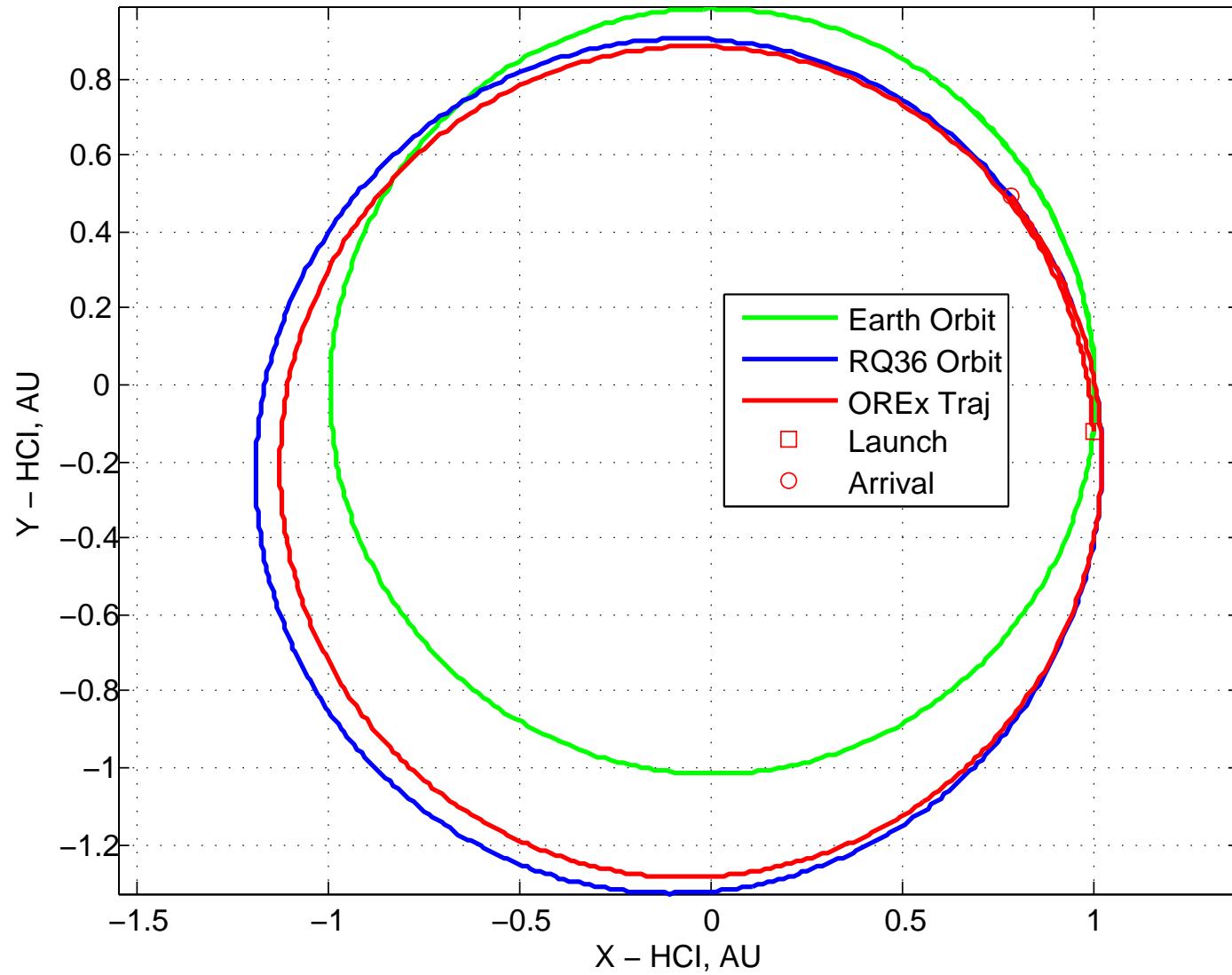


# Backup Launch Window Details

Day	Date	$C_3$ (km $^2$ /s $^2$ )	DLA	RLA	DSM1 (m/s)	AAM1 (m/s)	AAM2 (m/s)	AAM3 (m/s)	Total	$\Delta v$ (m/s)
1	9-15-2017	28.5	35.78°	185.63°	684.67	288.29	124.42	4.77	1102.15	
2	9-16-2017	28.7	35.33°	186.17°	621.44	292.94	126.03	4.70	1045.10	
3	9-17-2017	28.7	34.86°	186.76°	562.92	296.10	127.21	4.70	990.93	
4	9-18-2017	28.7	34.86°	186.80°	482.37	323.28	136.09	4.70	946.44	
5	9-19-2017	28.9	34.13°	187.53°	436.46	315.63	133.74	4.70	890.53	
6	9-20-2017	29.0	33.76°	187.90°	374.00	329.66	138.56	4.70	846.91	
7	9-21-2017	28.9	33.75°	187.92°	289.71	368.72	152.25	4.70	815.37	
8	9-22-2017	29.0	33.71°	187.97°	209.25	412.39	168.11	4.70	794.45	
9	9-23-2017	29.0	33.66°	188.03°	134.48	459.35	185.57	4.70	784.10	
10	9-24-2017	29.0	33.81°	188.88°	85.04	482.20	194.26	4.70	766.20	
11	9-25-2017	29.1	33.09°	189.26°	39.73	444.37	180.80	4.70	669.60	
12	9-26-2017	29.2	31.22°	189.28°	59.29	444.38	181.88	4.70	690.25	
13	9-27-2017	29.2	31.24°	190.27°	101.60	441.47	181.52	4.70	729.28	
14	9-28-2017	29.2	31.81°	191.56°	157.39	417.00	173.27	4.70	752.36	
15	9-29-2017	29.2	31.82°	192.49°	206.40	416.42	173.58	4.70	801.10	
16	9-30-2017	29.2	32.13°	193.58°	263.01	405.42	170.06	4.70	843.19	
17	10-1-2017	29.1	32.53°	194.70°	321.22	398.45	167.91	4.70	892.28	
18	10-2-2017	29.1	32.57°	195.63°	378.31	396.52	167.70	4.70	947.22	
19	10-3-2017	29.1	32.92°	196.70°	437.79	394.26	167.07	4.70	1003.83	
20	10-4-2017	29.1	33.03°	197.64°	495.71	394.89	167.65	4.70	1062.94	
21	10-5-2017	29.0	33.25°	198.63°	561.13	391.36	166.24	4.70	1123.43	



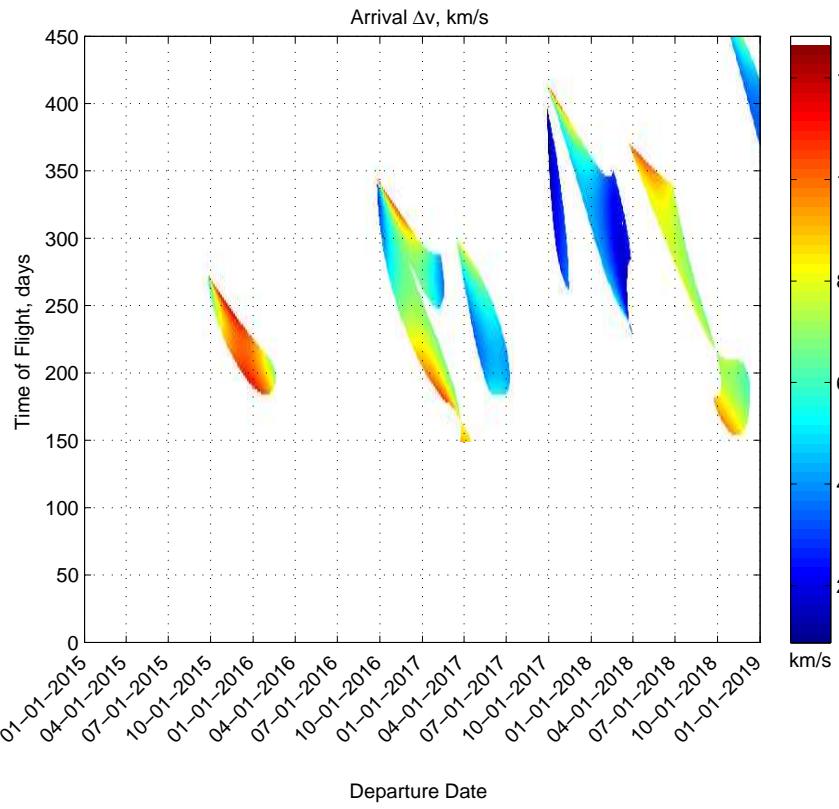
# Example Backup Launch Window Trajectory



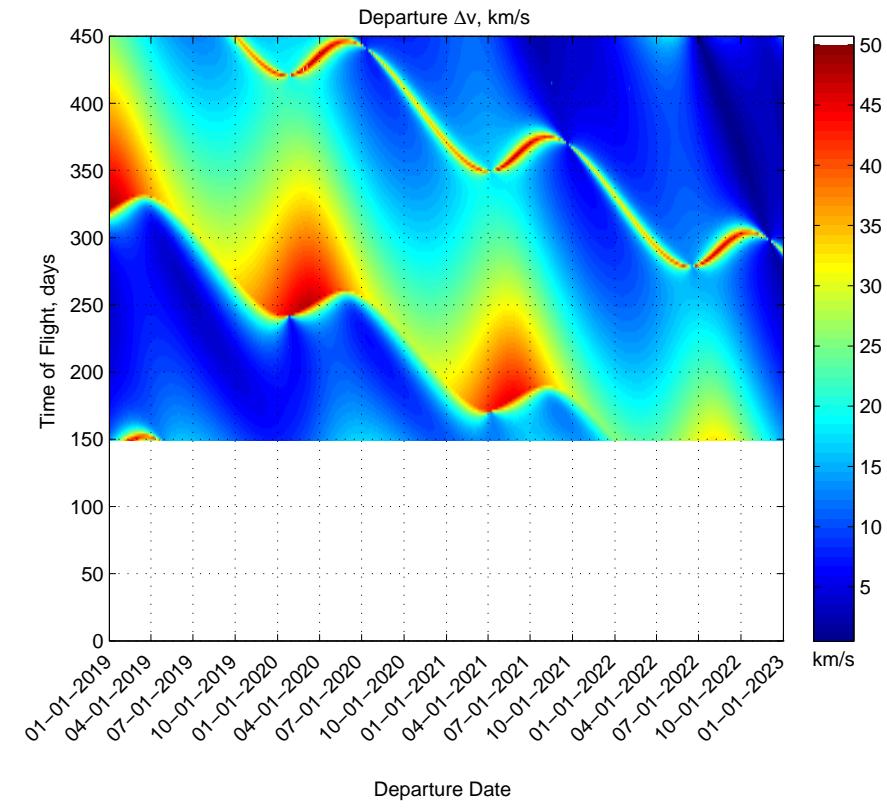
OSIRIS-REx backup launch window outbound cruise trajectory to 1999 RQ<sub>36</sub>, ecliptic plane projection.



# Preliminary Trajectory Analysis Scans



$\Delta v$  to arrive at RQ<sub>36</sub>.



$\Delta v$  to depart from RQ<sub>36</sub>.