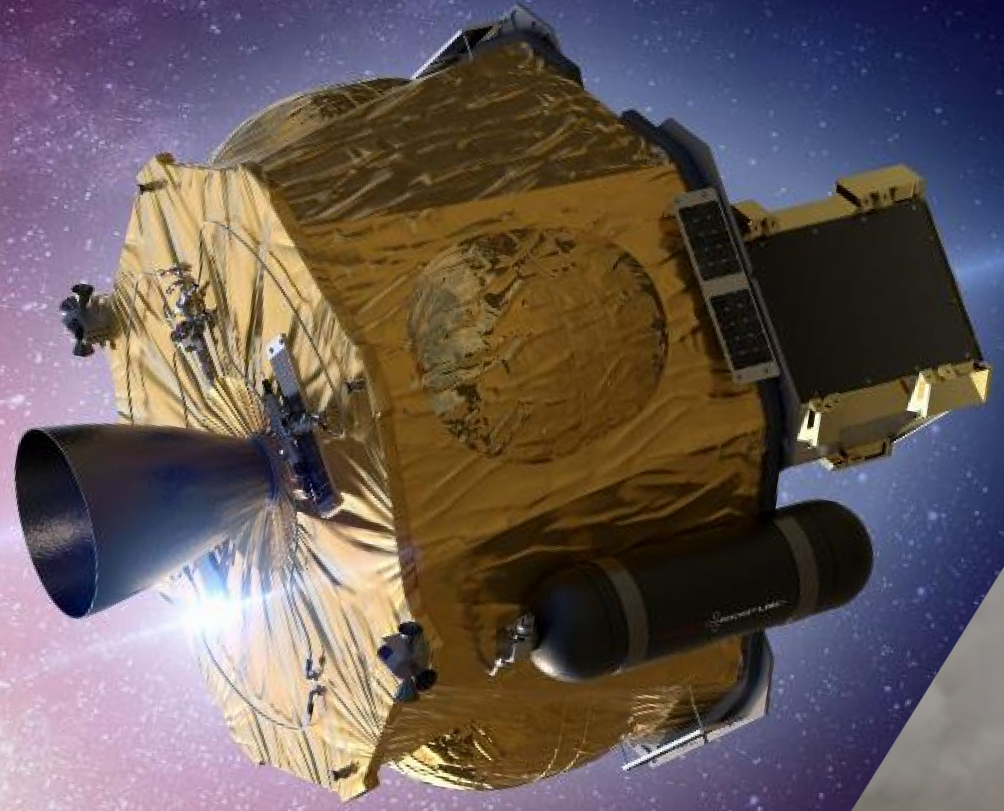
ROCKET LAB

PHOTON-ENABLED PLANETARY SMALL SPACECRAFT MISSIONS FOR DECADAL SCIENCE



Decadal Survey on Planetary Science and Astrobiology: Panel on Giant Planet Systems

March 26, 2021

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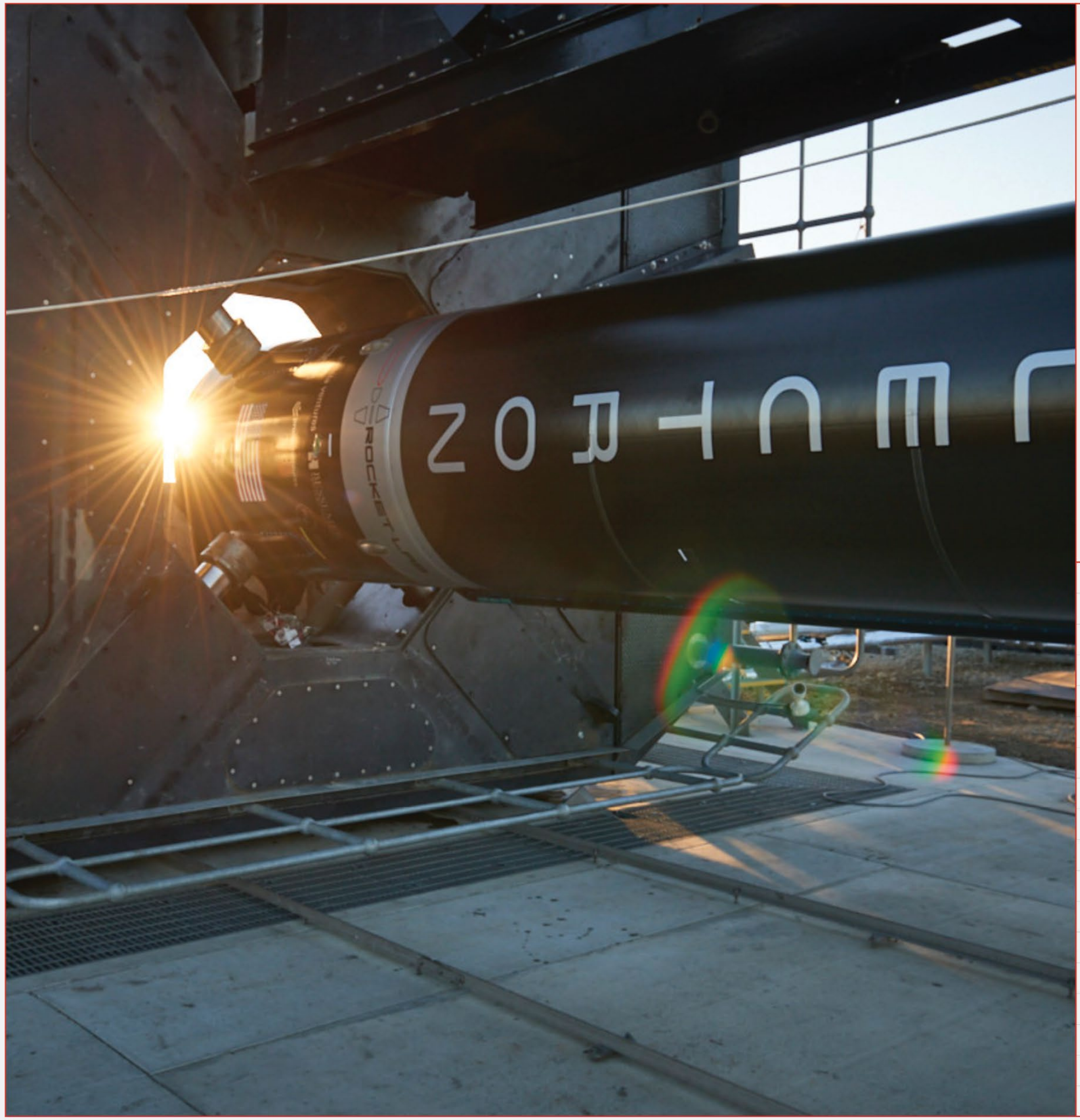
RICHARD FRENCH

Director – Business Development and Strategy, Space Systems Division

- 10+ years at NASA JPL with flight project experience (CEV, MSL, SMAP)
- 2+ years as Staff Technologist at NASA HQ leading development of STMD Tipping Point, ACO, STRI
- Led development of the Techstars Starburst Space Accelerator program & managed technology partnerships with industry in the JPL Office of Space Technology
- Rocket Lab since 2019

OVERVIEW

1. Rocket Lab Overview
2. Summary and Updated Results: *Photon-enabled Planetary Small Spacecraft Missions For Decadal Science White Paper*
3. Observations and Recommendations for the Planetary Decadal Survey
4. Questions/Discussion



SECTION

01

ROCKET LAB OVERVIEW

GLOBAL LEADER IN LAUNCH & SPACE SYSTEMS

- Founded in 2006 by Peter Beck
- US company, >$300M raised, SPAC announced, valued at over $4B
- 19 launches, 104 satellites to orbit with Electron, first NASA Cat 1 certified small launch vehicle
- Neutron medium lift launch vehicle announced
- HQ in Long Beach, CA, global infrastructure, 2 launch sites, 3 pads
- Space Systems Division providing end-to-end missions with the Photon small satellite and supplying small spacecraft components
- Acquisition of Sinclair Interplanetary in April 2020
- 1st Photon launched in August 2020, 2nd Photon in March 2021
- Implementing NASA CAPSTONE (lunar), LOXSAT 1 (LEO tech demo), and ESCAPADE (Mars) missions
- Performing MethaneSAT operations for EDF and MBIE/NZSA
- Privately-funded Venus 2023 probe mission in development

VERTICALLY INTEGRATED SPACE COMPANY

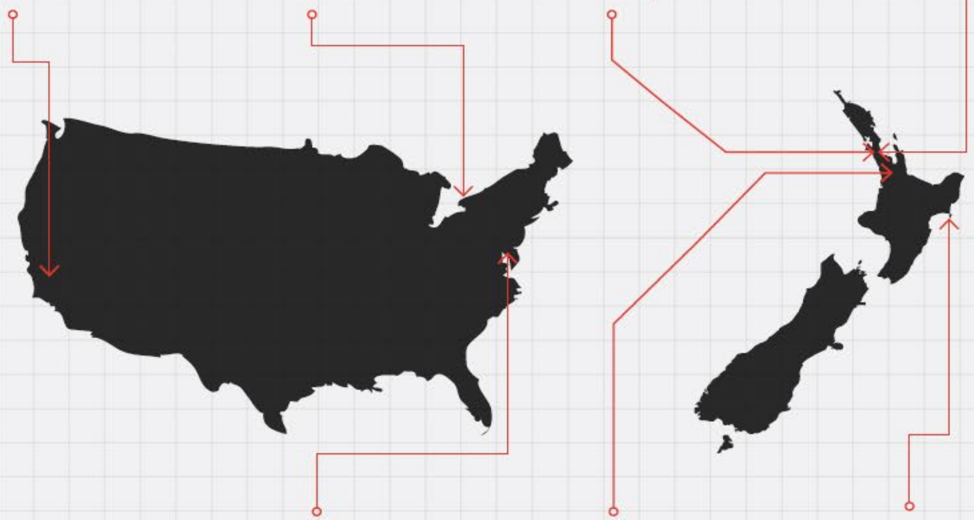
FROM RAW MATERIAL TO ORBIT

1 Rocket Lab HQ
Space Systems
Mission Control U.S.

2 Sinclair
Interplanetary
by Rocket Lab

5 Auckland
Production
Complex

6 Mission Control
New Zealand

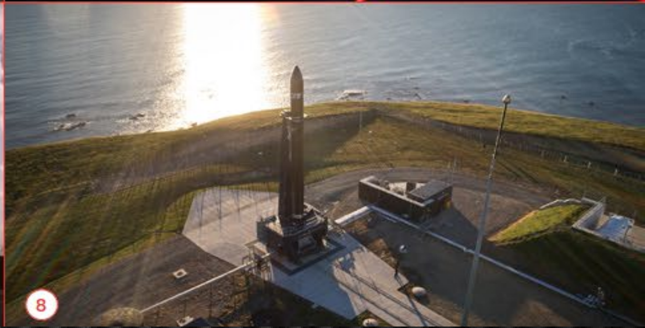


3 Global Tracking
Systems

4 Launch
Complex 2

7 Propulsion Test
Complex

8 Launch
Complex 1



ELECTRON

OVERALL

LENGTH
18M

DIAMETER (MAX)
1.2M

STAGES
2 + KICK STAGE

VEHICLE MASS (LIFTOFF)
13,000KG

MATERIAL/STRUCTURE
CARBON FIBER COMPOSITE/MONOCOQUE

PROPELLANT
LOX/KEROSENE

PAYLOAD

NOMINAL PAYLOAD
200KG / 440LBM TO 500KM SSO

PAYLOAD DIAMETER
1.08M

PAYLOAD HEIGHT
1.91M

FAIRING SEP SYSTEM
PNEUMATIC UNLOCKING, SPRINGS

STAGE 2

PROPULSION
1X RUTHERFORD VACUUM ENGINE

THRUST
5800 LBF VACUUM

ISP
343 SEC

INTERSTAGE

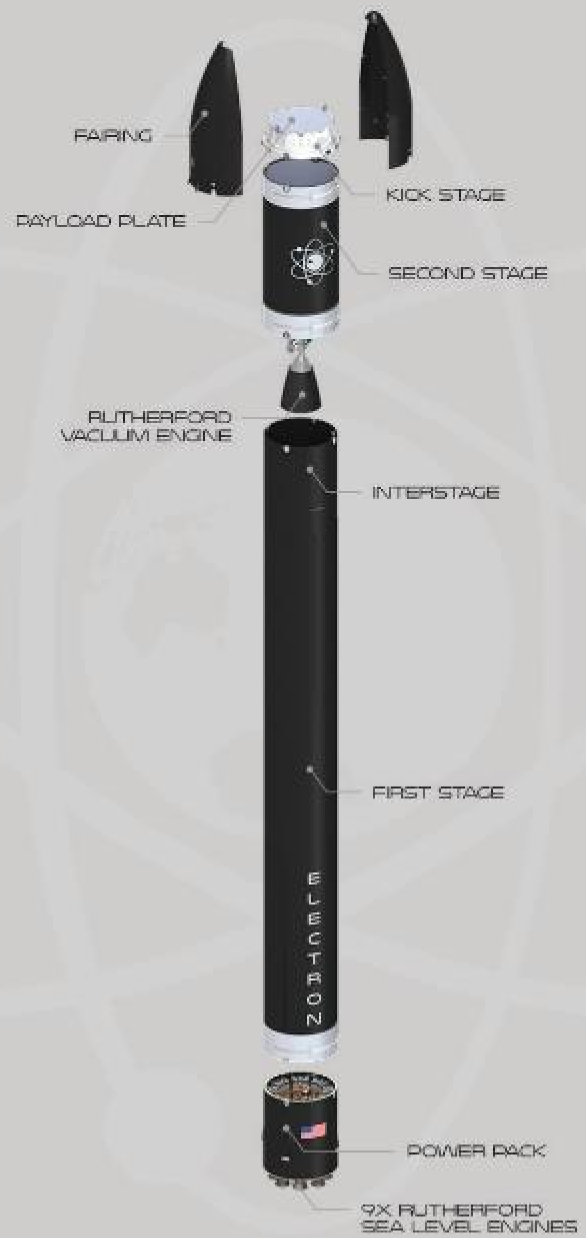
SEPARATION SYSTEM
PNEUMATIC PUSHER

STAGE 1

PROPULSION
9X RUTHERFORD SEA LEVEL ENGINES

THRUST
5600 LBF SEA LEVEL (PER ENGINE)

ISP
311 SEC



SMALL LAUNCH IS SOLVED

A ROCKET EVERY WEEK

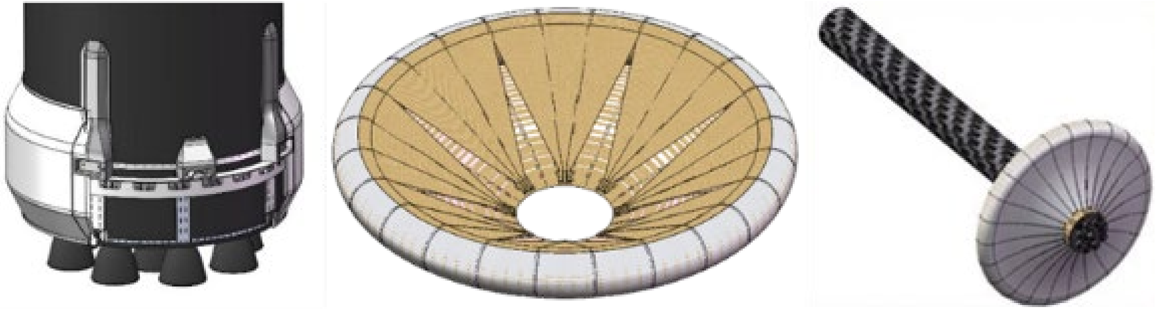
STAGE 1 RECOVERY PROGRAM

Stage 1 Recovery Goal

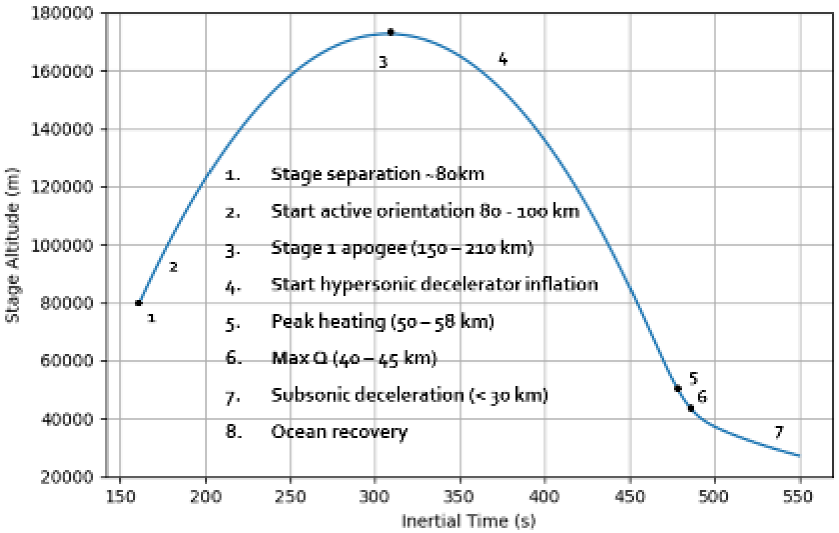
Reuse the high value engines, motor controllers, and batteries to improve production throughput

Stage 1 Recovery System

- Reaction control system (RCS) to re-orient the vehicle (exoatmospheric)
- Inflatable hypersonic decelerator to reduce entry heating
- Low supersonic drogue
- Subsonic main parachute



Inflatable decelerator a. stowed; b. & c. deployed



Recovery Sequence

Successful recovery of 1st Stage on 'Return to Sender'

NEXT STEP:
NEUTRON

NEW ROCKET
DEVELOPMENT
8-TON PAYLOAD
CAPACITY

1,500 KG
PAYLOAD CAPACITY
TO VENUS

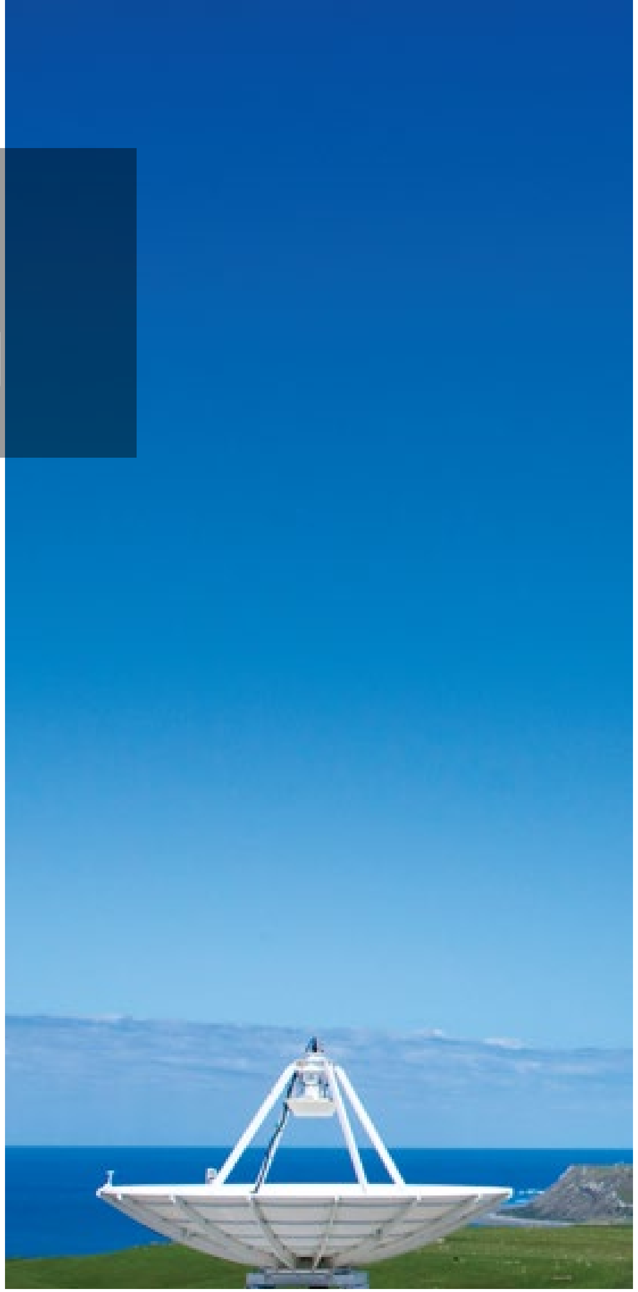
4.5 M
FAIRING DIAMETER

40 M
IN LENGTH

REUSABLE
FIRST STAGE

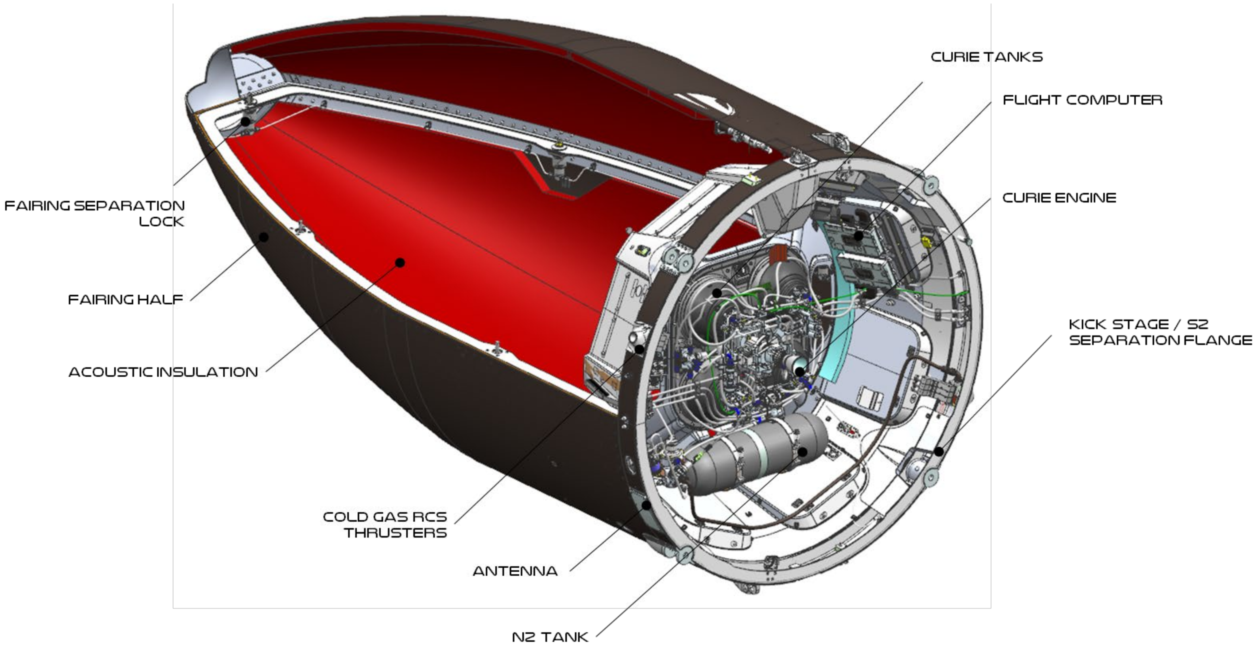
LAUNCHING
FROM VIRGINIA, USA

THE COMPLETE MISSION SOLUTION



KICK STAGE

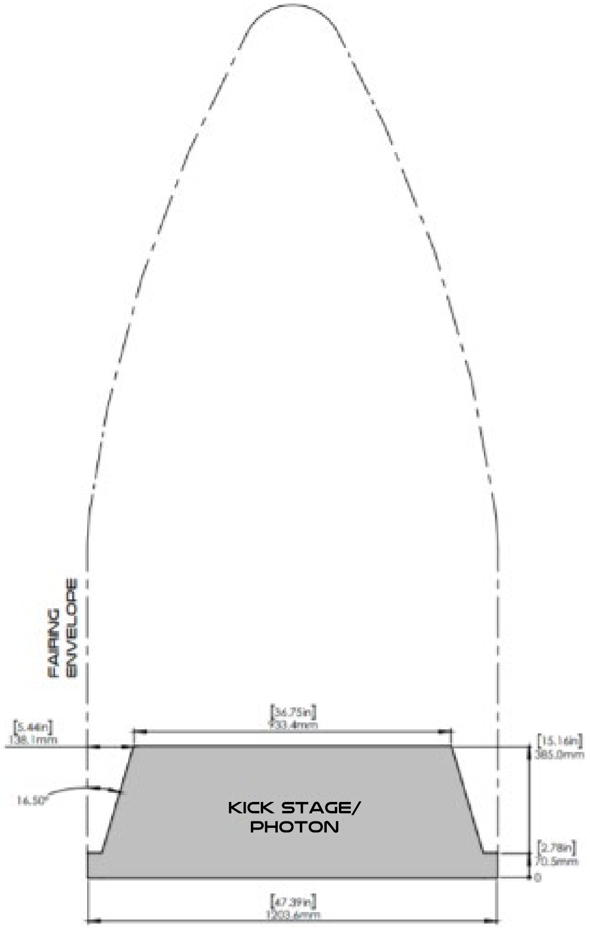
- First successful launch in January 2018, has now deployed 104 satellites to orbit across 19 launches
- Circularizes the orbit after launch, meets precise orbital insertion requirements with velocity targeting algorithm (1-2 m/sec typical performance)
    - Curie bi-propellant, pressure-fed propulsion system
    - Capable of multiple engine restarts
    - Deorbit burn for disposal, if necessary
    - Cold gas (N2) reaction control system (RCS) for precision pointing
- GNC, avionics, power, and communications subsystems that control Electron for launch phase, including flight computer, GPS receiver, IMU, S-band communications subsystem, etc.



Kick Stage circularizes the orbit to meet precise insertion requirements, capable of multiple re-starts

PHOTON

- Launch + satellite + ground + mission operations as a bundled service
- Photon eliminates the parasitic mass of deployed spacecraft and duplicative subsystems by operating as Electron's Kick Stage and as the spacecraft bus, and allowing full use of the fairing by instruments
- Can fly on Electron, Neutron, or as a secondary payload on other LVs
- Evolved from Electron's Kick Stage, building on significant flight history
  - Primary propulsion, RCS, flight computer, IMU, GPS, S-band
- Adds high power generation, high-accuracy attitude determination and control, more radiation-tolerant avionics, and high-speed downlink
- Primary propulsion capable of multiple engine restarts
  - Curie bi-propellant, pressure-fed engine; mono-propellant mode
  - Hyper Curie bi-propellant, pump-fed engine; higher Isp, thrust
- LEO, MEO, GEO, lunar, and interplanetary configurations

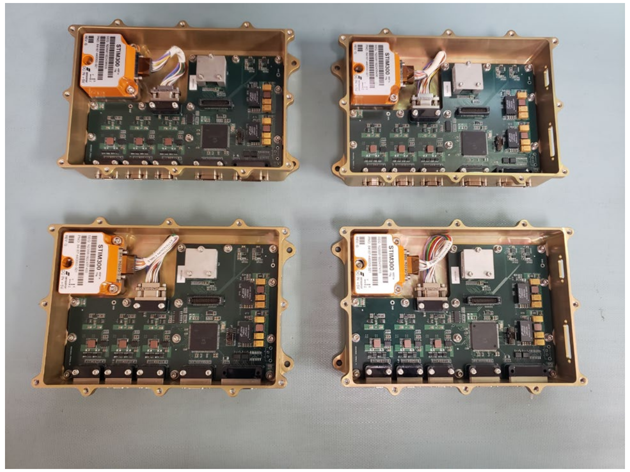


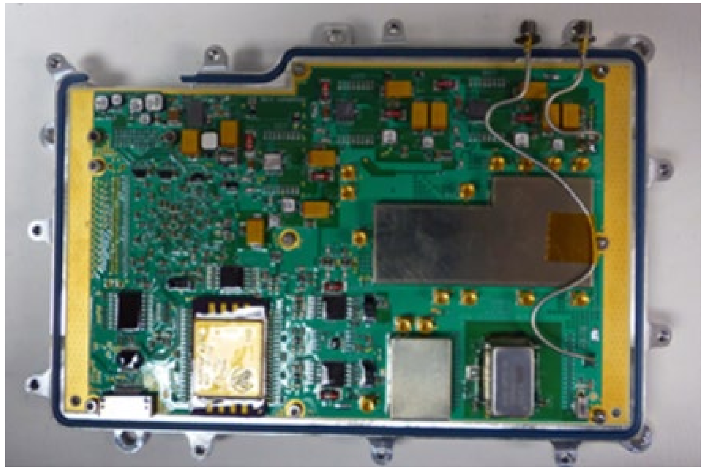
Photon enables full use of the Electron fairing for payload (sensors, transponders, etc.)

SPACECRAFT COMPONENTS

- Flight and payload computers
- Radios with coherent transponders
- Reaction Wheels (Sinclair by RL)
- Star Trackers (Sinclair by RL)
- In-space propulsion
- Reaction control systems
- Torque rods and controllers
- Batteries
- Solar panels
- Power management systems

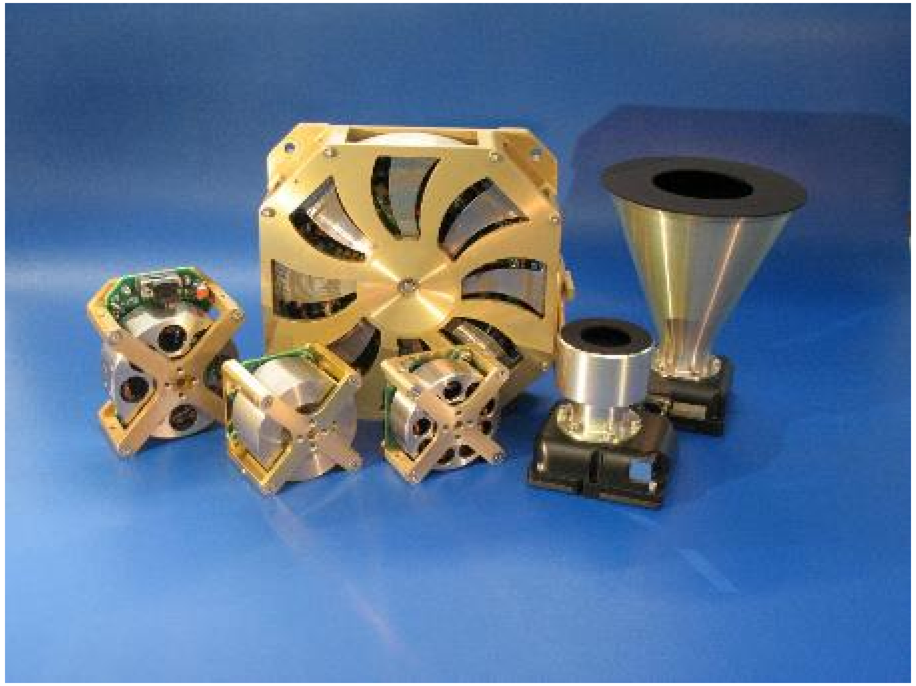
Spacecraft components and future products roadmap is well-aligned with planetary science mission requirements





SINCLAIR INTERPLANETARY BY ROCKET LAB

- Founded in 2001 by Doug Sinclair, now a Rocket Lab Tech Fellow
- Acquired by Rocket Lab in April 2020
- Industry leader for small spacecraft reaction wheel assemblies (RWA) and star trackers (ST)
- Space heritage on over 85 missions since December 2002
    - 200+ RWA units on orbit; family of wheels from 30 mNms up to 1 Nms (in production) and larger (in development)
    - 70+ ST units on orbit; high accuracy, <5 arcsec cross-boresight performance, lost in space solution
- High volume (>3,000 units/year) production capability by the end of 2021 for constellation customers



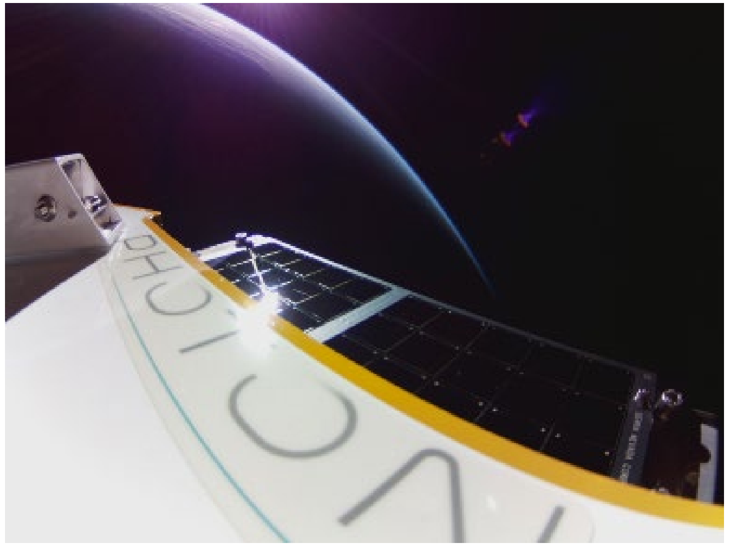
Sinclair Interplanetary by Rocket Lab's family of reaction wheel assemblies and star trackers

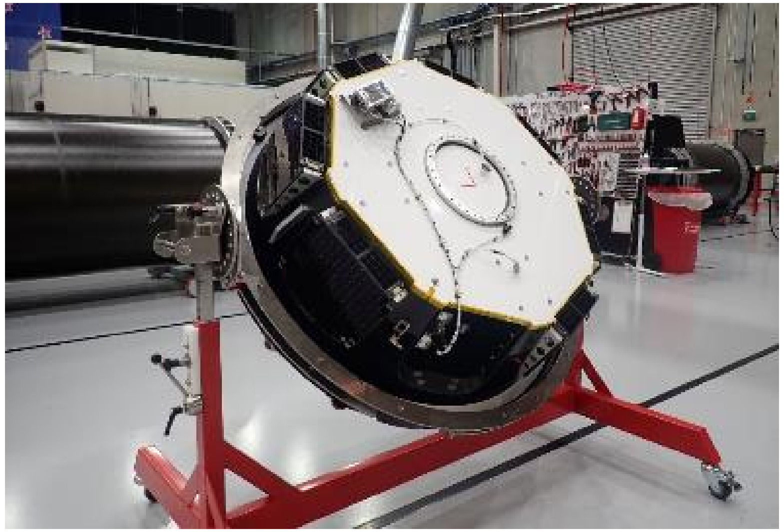
High heritage reaction wheel assemblies and star trackers help enable low cost, precision pointing for science missions

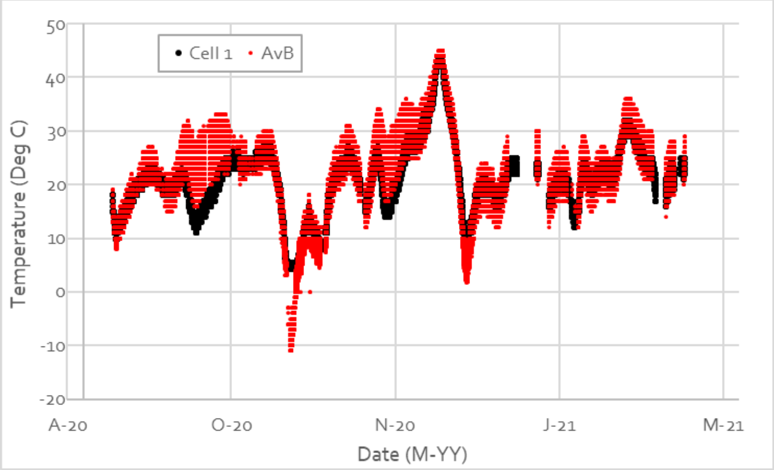
PHOTON 'FIRST LIGHT'

Launched in August 2020 on Flight 14, deployed Capella's Sequoia

- Successfully demonstrated solar arrays, power management, thermal management, and attitude control
- Now operating as an on-orbit testbed for flight and ground software validation, demonstrating lights out operations







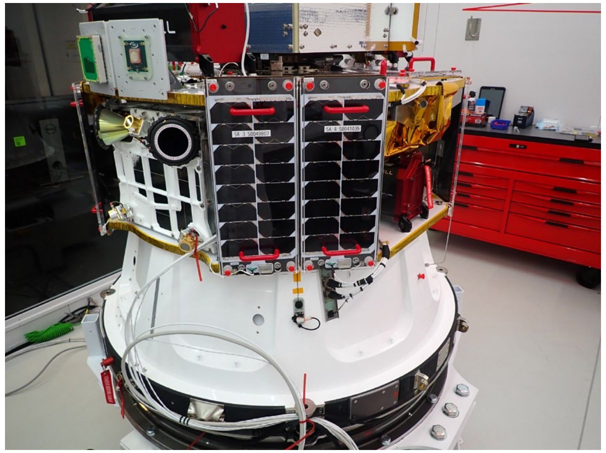
High flight rate is supporting rapid tech demo of increased Photon capabilities and increasing demonstrated lifetime

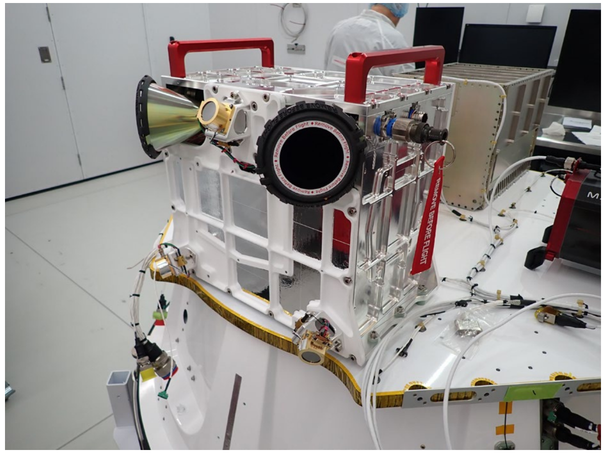
PHOTON 'PATHSTONE'

Launched in March 2021 on Flight 19, deployed BlackSky Globals's BlackSky 7

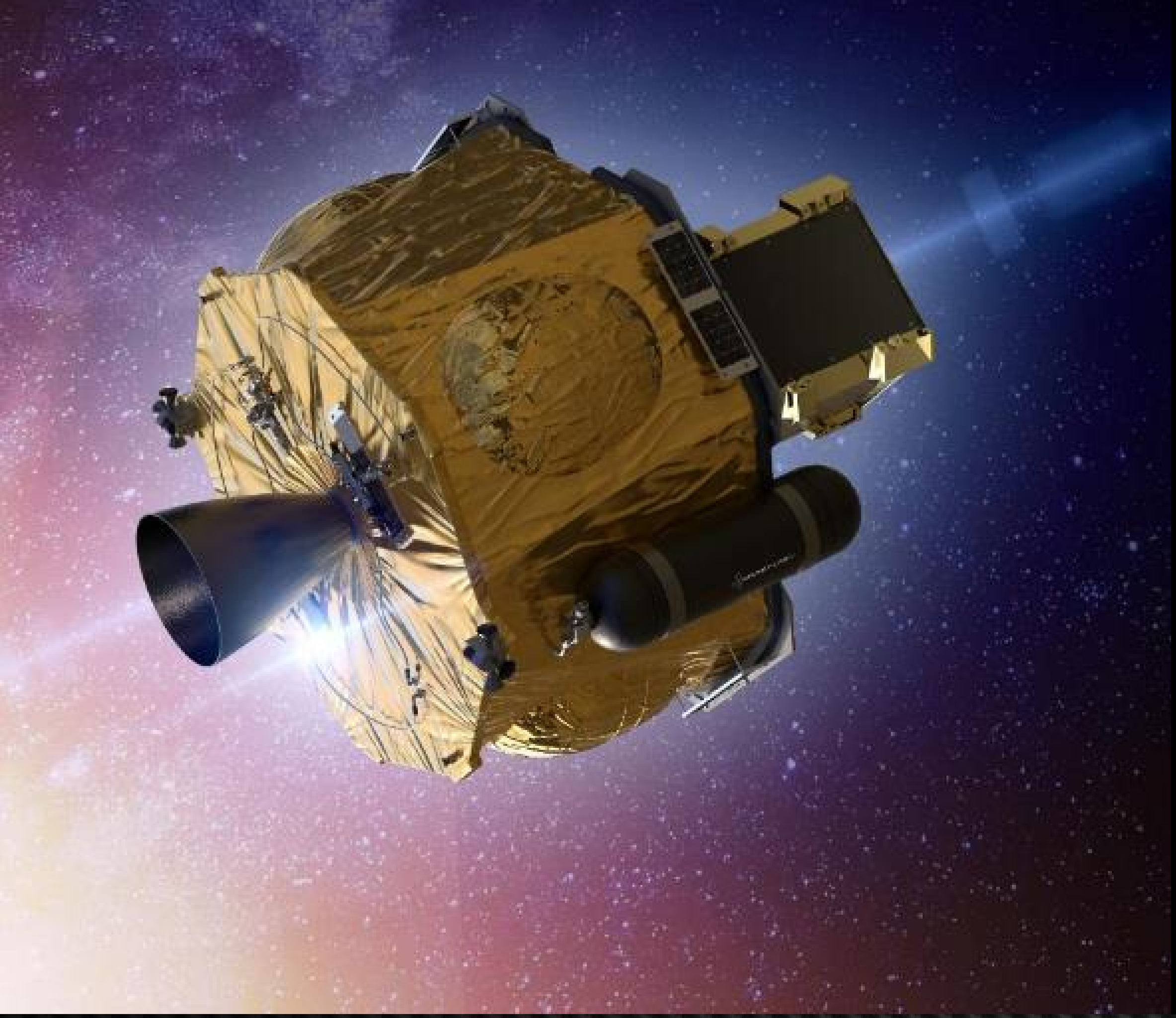
- Risk reduction mission for the NASA CAPSTONE lunar mission
- Demonstrated rapid integration of Photon core systems with existing Kick Stage production flow, required for supporting hosted payload missions and other low-cost tech demonstrations
- Demonstrating upgraded avionics, radios, CAPSTONE concept of operations (flight dynamics system, ground systems, etc.)

Pathstone mission is de-risking Rocket Lab's deep space mission approach for the NASA CAPSTONE lunar mission





PHOTON IS TAKING NASA CAPSTONE TO THE MOON



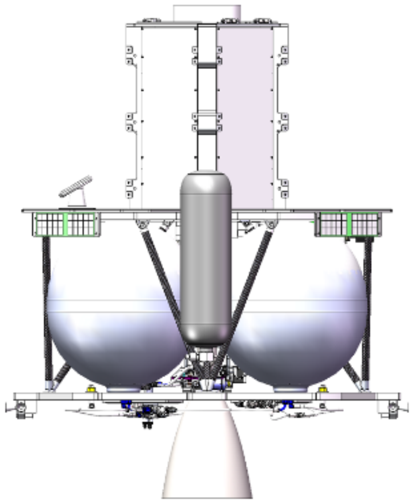
Credit: NASA/Advanced Space

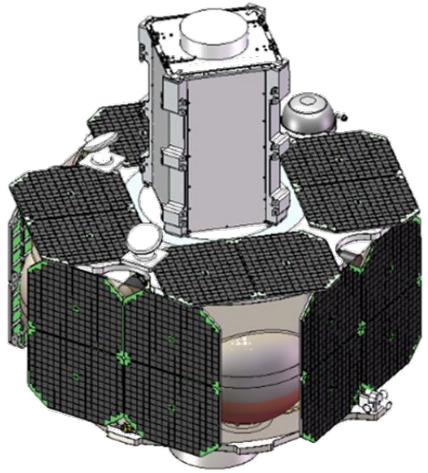
NASA CAPSTONE

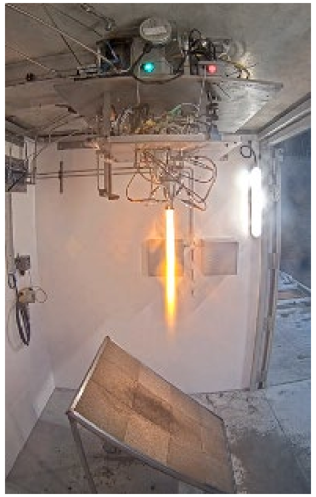
Launching the first mission of the Artemis program on a lunar trajectory in 2021

- Selected by NASA in February 2020 to deploy the CAPSTONE spacecraft, a 12U CubeSat led by Advanced Space, on a ballistic lunar trajectory; demonstrating communications and navigation technologies in Near Rectlinear Halo Orbit (NRHO)
- High energy Photon, or 'Photon Lunar' stage, with Hyper Curie engine, large propellant tanks, and precision radiometric navigation, using a phasing orbit approach to performing the translunar injection
- Passed CDR in February 2021, on track to launch within ~18 months of contract start during COVID
- Rocket Lab secondary mission will demonstrate Photon deep space operations capabilities

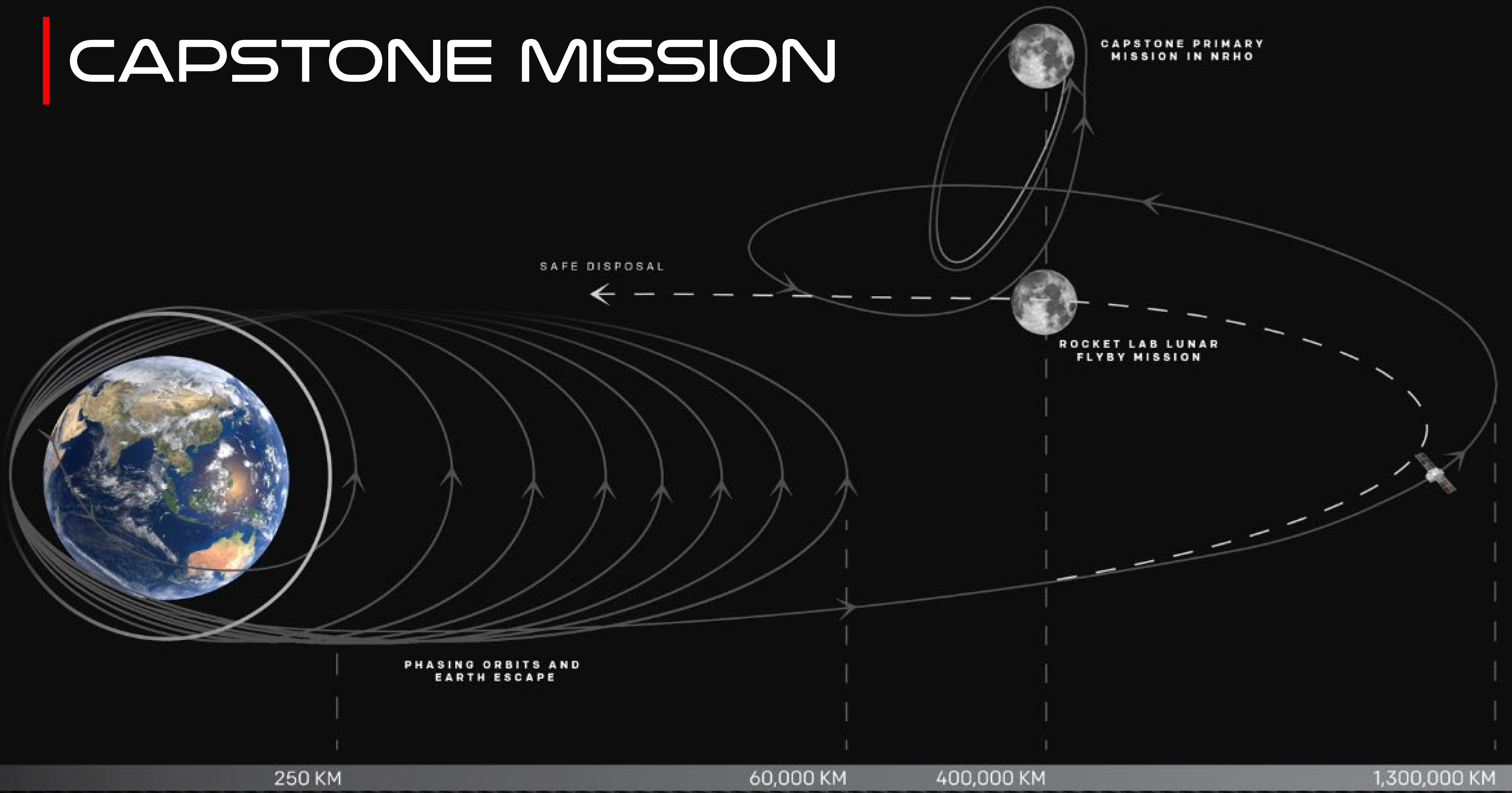
NASA CAPSTONE will demonstrate a flexible approach to targeting escape trajectories for small spacecraft using a dedicated small launch vehicle



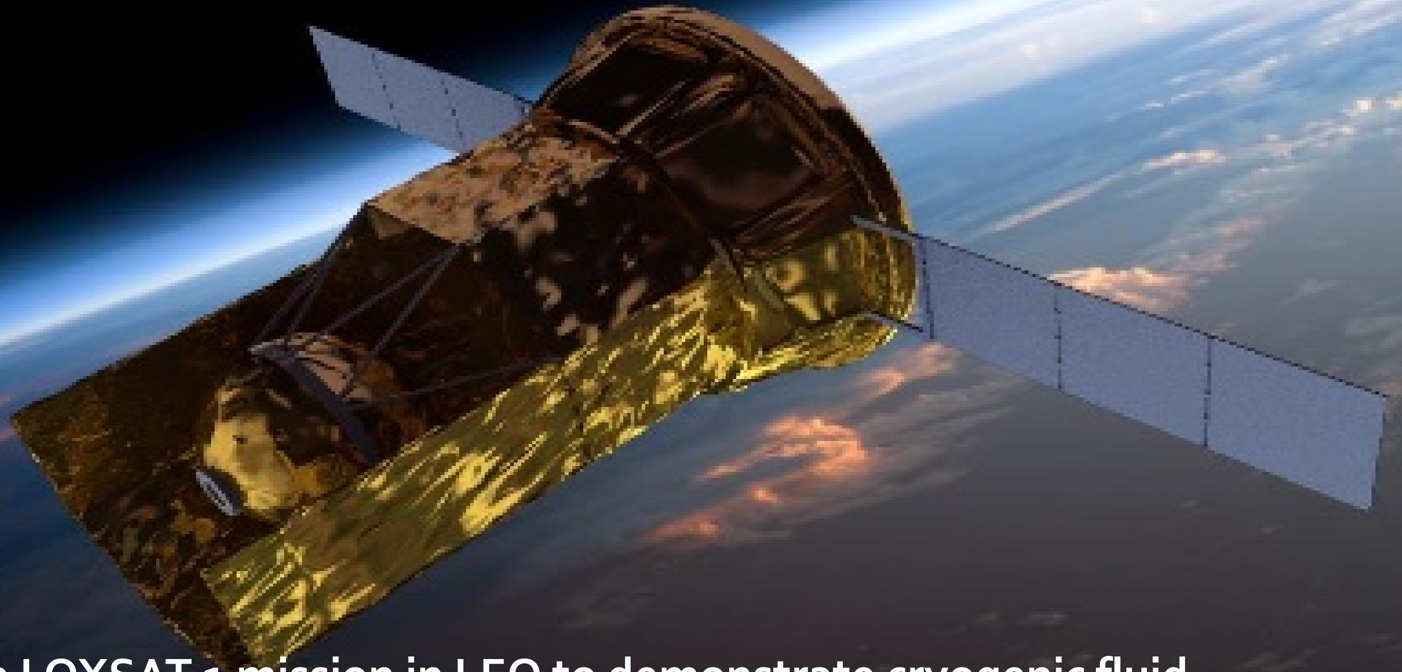




CAPSTONE MISSION



PHOTON IS DEMONSTRATING PROPELLANT DEPOT TECH FOR NASA ON LOXSAT 1



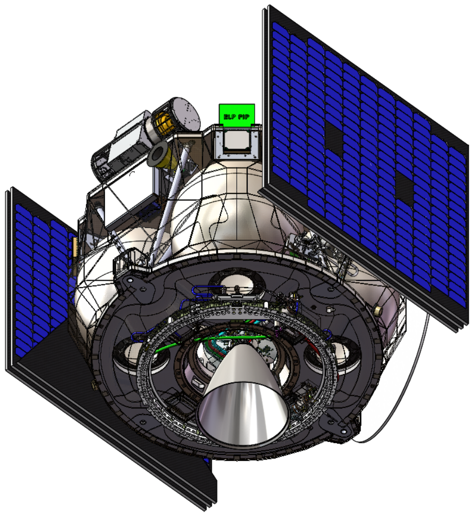
Selected by NASA for the LOXSAT 1 mission in LEO to demonstrate cryogenic fluid management technologies.

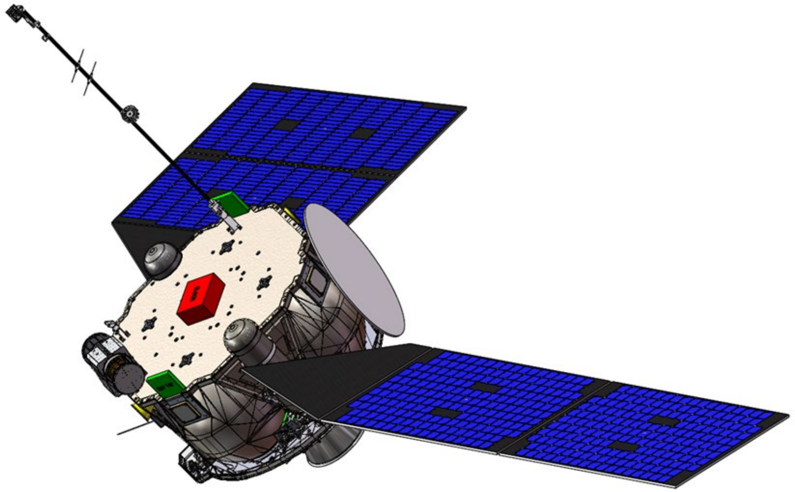
Also demonstrates the value of dedicated small launch bundled with small spacecraft for affordable end-to-end missions.

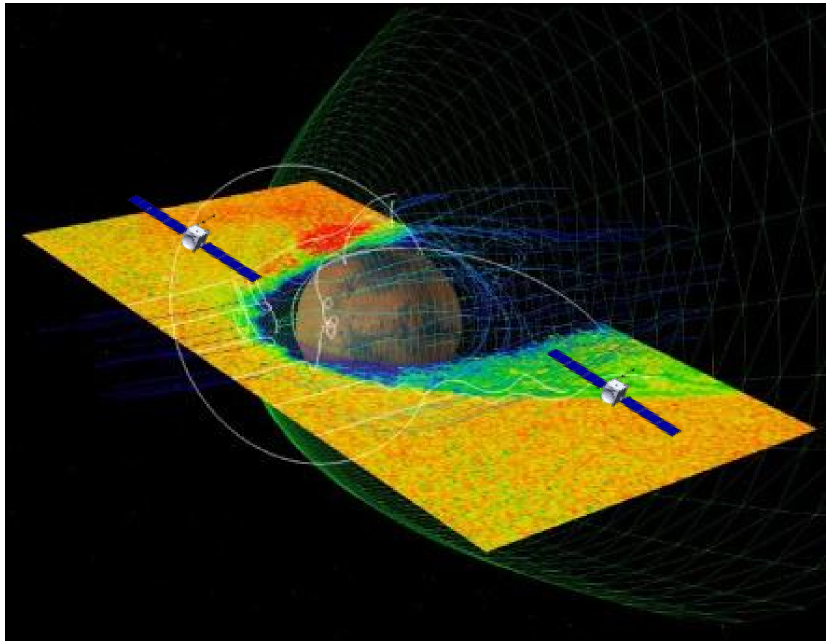
Credit: Eta Space

ESCAPADE

- Selected by UC Berkeley to provide the spacecraft buses for NASA Escape and Plasma Acceleration and Dynamics Explorers (ESCAPADE) mission
- Two spacecraft in Mars orbit to understand the structure, composition, variability, and dynamics of Mars' unique hybrid magnetosphere
- PDR in June 2021, KDP-C/confirmation in July 2021, launching as a rideshare on another launch vehicle in 2024 (TBC)







Credit: NASA/UC Berkeley/R. Lillis

ESCAPADE is maturing Photon's magnetic cleanliness, demonstrating versatility to launch on other launch vehicles, and demonstrating an affordable tailored Class D implementation

VENUS, MEET PHOTON

2023

PHOTON | ROCKET LAB

VENUS 2023

Privately-funded Venus mission

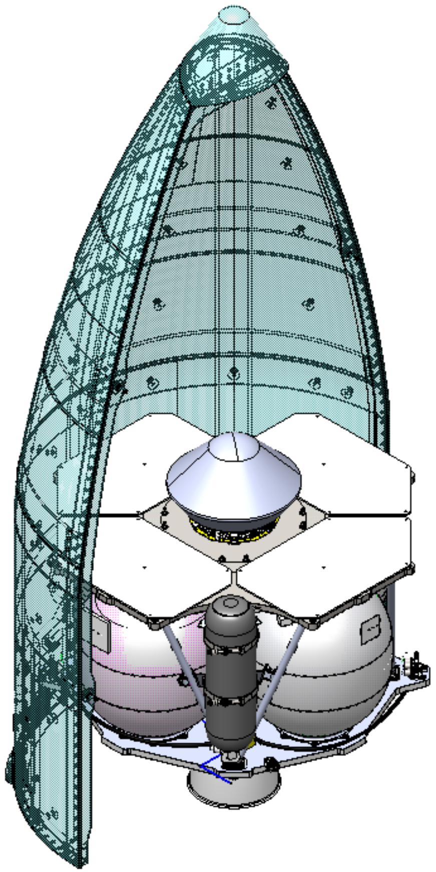
- May 2023 launch on Electron
- Hyperbolic trajectory with high energy Photon as the cruise stage and as a communications relay
- Oct 2023 probe release and entry

Probe entry mission

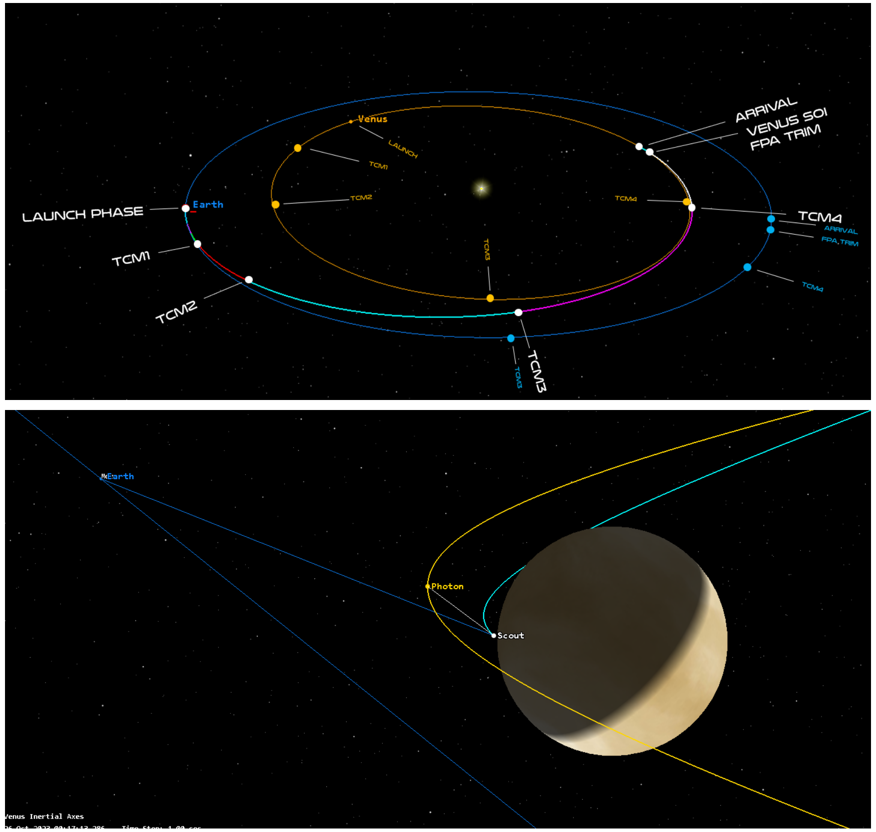
- ~15-20 kg probe
- ~270 sec in the cloud layer

Science mission to explore cloud habitability

Collaborating with leading scientists to determine best use of the payload capacity and build partnerships



Photon Venus Probe
Preliminary Configuration



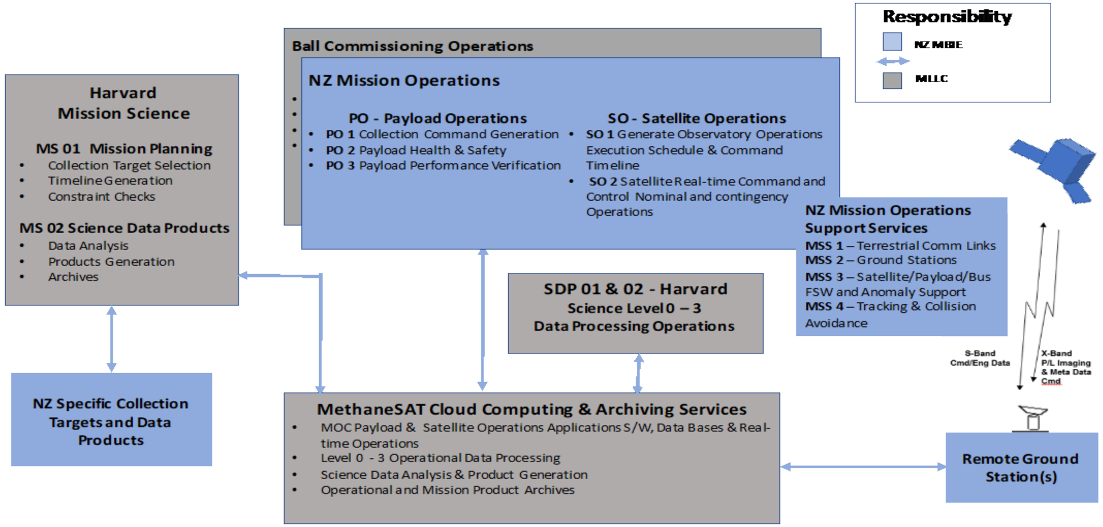
Preliminary Mission
Concept Design

MISSION CONTROL CENTERS IN LONG BEACH AND AUCKLAND

METHANESAT

- MethaneSAT, funded by the Environmental Defense Fund
- Spacecraft bus by BCT, instrument by Ball
- Science and target planning at Harvard
- Mission operations by Rocket Lab, funded by New Zealand Space Agency
  - Payload operations (excluding science data processing and target selection)
  - Satellite (observatory) operations management
  - Tracking and collision avoidance services, orbit determination and flight dynamics, and ground station operations management
- Expanding Rocket Lab’s end-to-end mission operations capabilities
  - Responsive planning and tasking based on weather, coverage, changes in anthropogenic methane emission, and other external data sources
  - Automated collection planning and optimization
  - Cloud-based mission operations control, allowing operations from anywhere on the globe
  - Automated low-thrust maneuver planning and deconfliction with collection planning

Credit: Ball/BCT/MLLC



MethaneSAT enabling lights out operations for high data volume, low latency science missions

Rocket Lab MethaneSAT Operations with University Host and Science Operations Centers

SECTION

02

PHOTON-ENABLED PLANETARY DECADAL SCIENCE

WHITE PAPER SUMMARY

High Energy Photon

- Hyper Curie Engine, high propellant mass fraction, deep space navigation capabilities

Dedicated Launch on Electron with Phasing Orbits

- C3 curve, post-departure delta-V

Secondary GTO Launch

- C3 curve, post-departure delta-V

Representative Mission Concepts with Science Objectives

- Cislunar
- Small Bodies
- Mars
- Venus
- Outer Planets

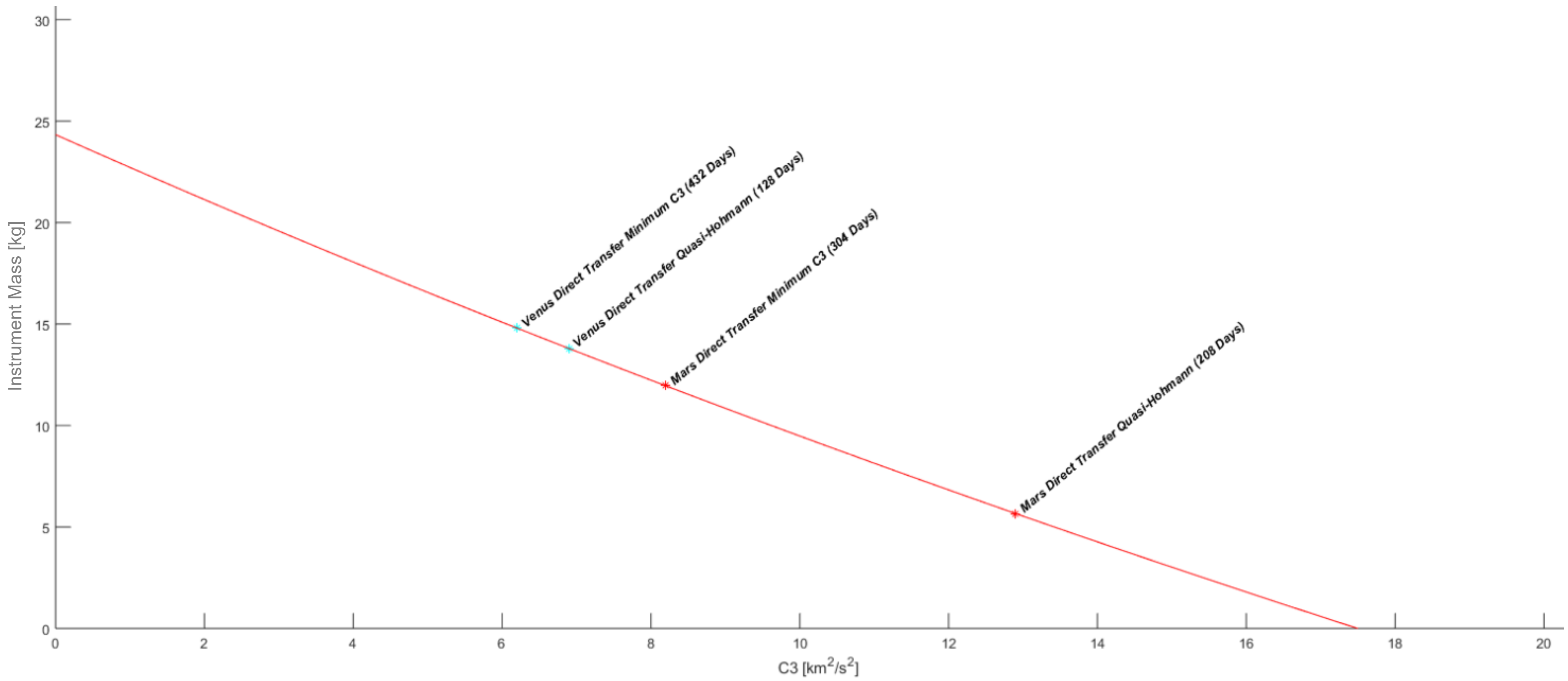
REPRESENTATIVE MISSIONS

Target	Type	Science Objective
Cislunar	Orbital	• Magnetic anomalies • Measure global distribution of ice and volatiles over extended durations • Timely missions perform studies of volatiles before the anticipated wave of human exploration alters the environment • Communications and navigation infrastructure
Cislunar	Lander	• Rocket exhaust plume interactions • Deploy a lunar seismic network • In-situ measurements of craters to support solar system chronology • Perform measurements of lunar swirls at the lunar surface • Visit unique locations like the Aristarchus plateau that may not be prioritized
Small Bodies	Flyby or Orbital	• Small body interior science for planetesimal formation • Provide a larger sampling of small bodies to better resolve the diversity of body shapes correlated to surface properties • Main Belt objects to further study origin, volatiles, and solar system evolution and advance planetary defense • Near-earth objects (NEOs) to further study origin, volatiles, and solar system evolution and advance planetary defense • Isotopic ratios to establish correlations with physical or orbital properties of comets • Small body plasma measurements • Apophis April 2029 encounter to measure the alteration in rotation state, potential internal structural alterations induced by tidal forces • Responsive mission to fly by an interstellar or Oort cloud object
Mars	Flyby or Orbital	• Characterize ionosphere, plasma, and magnetic structure • Continue studies of igneous rock geology • Improve geodesy • Determine trace gas flux and variation

REPRESENTATIVE MISSIONS

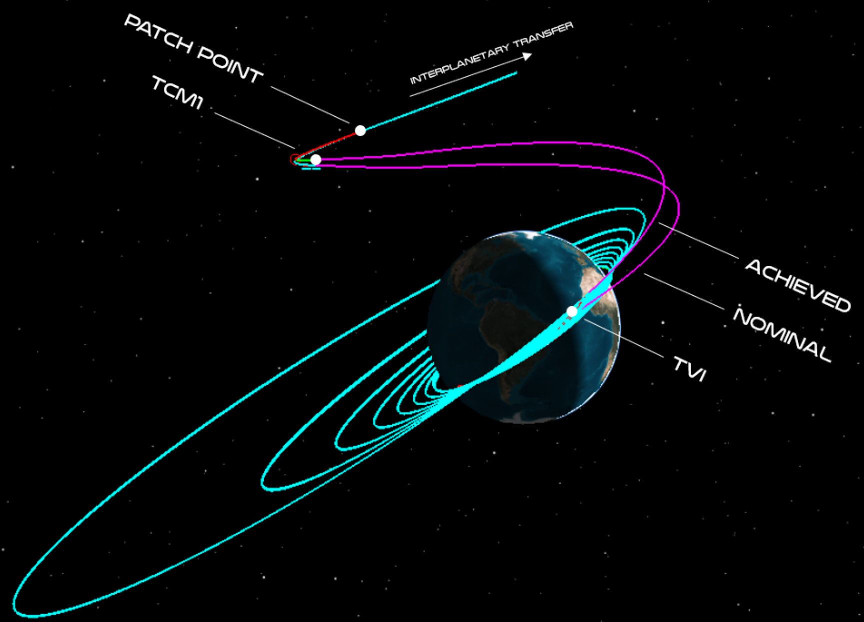
Target	Type	Science Objective
Mars, cont'd	Flyby or Orbital	• Probe the stratigraphy of the upper 10-m subsurface in the mid-latitude ice regions • Global atmospheric observation including winds • Short, long, and climatological scale atmospheric time series • Focused Phobos and Deimos investigations • Lower orbital altitudes with aerobraking or increased payload with aerocapture • Replacing telecommunications infrastructure • Technology demonstrations of distributed computing or autonomy
Venus	Flyby or Orbital, including small probe	• Remote sensing instruments to increase (spatial and temporal) monitoring of the upper atmosphere, e.g., airglow, energy and momentum transfer, solar wind interaction, and atmospheric water and other gas loss • Map volcanic activity and surface water transport • Orbital seismology or geodesy • Climatological time series • Radio science constellations • Long-Lived In-Situ Solar System Explorer (LLISSE)-based seismic stations • Rock types of the Venus tesserae • Mineralogy instruments using direct crystallographic techniques • Skimmer missions or deployment of aerobots for in-situ measurements of isotopic ratios • Habitability of the cloud layer • Lower orbital altitudes with aerobraking or increased payload with aerocapture • Telecommunications infrastructure
Outer Planets	Flyby	• Visiting Kuiper Belt Object planets • Remote sensing of outer planet satellites to study exogenous processes affecting icy satellite surfaces • Low-cost flyby mission to Calisto

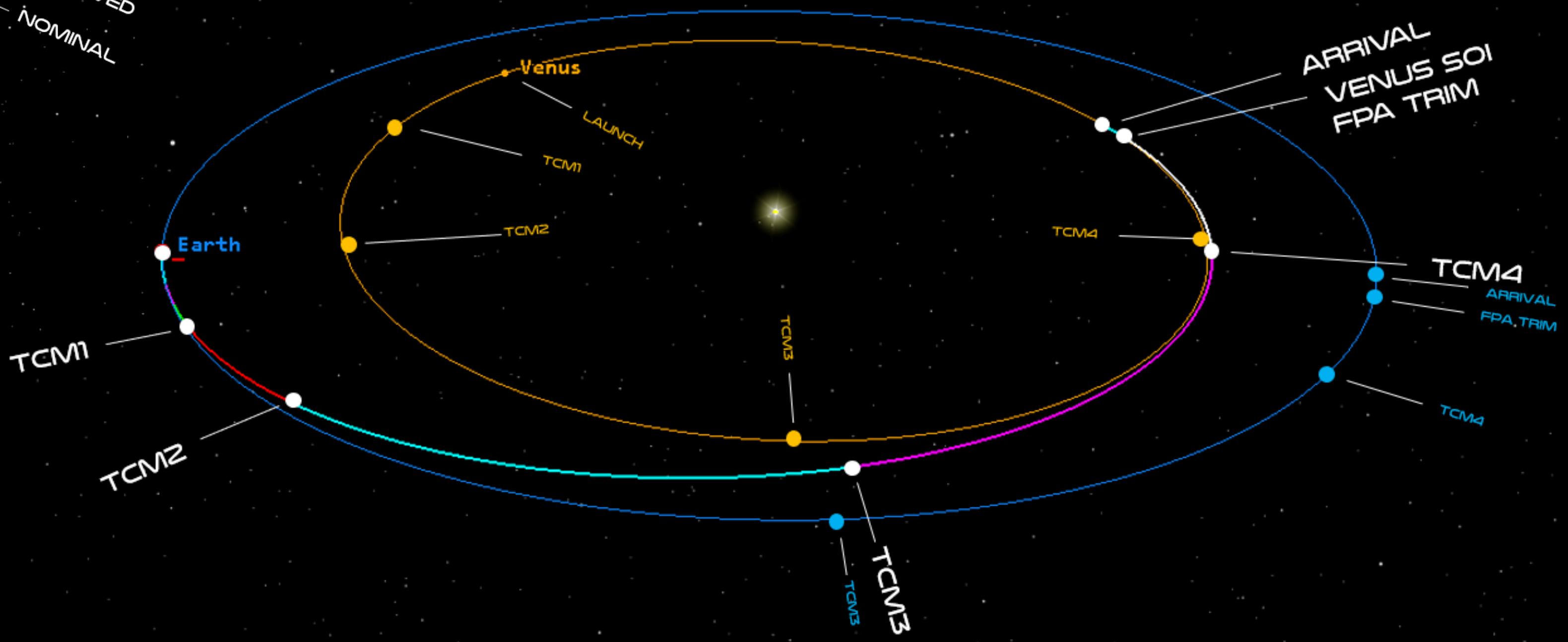
ELECTRON/HE PHOTON C3 V. INSTRUMENT



High energy Photon and Electron can delivery usable instrument masses for planetary science missions with focused investigations

VENUS PROBE 2023 MISSION DESIGN

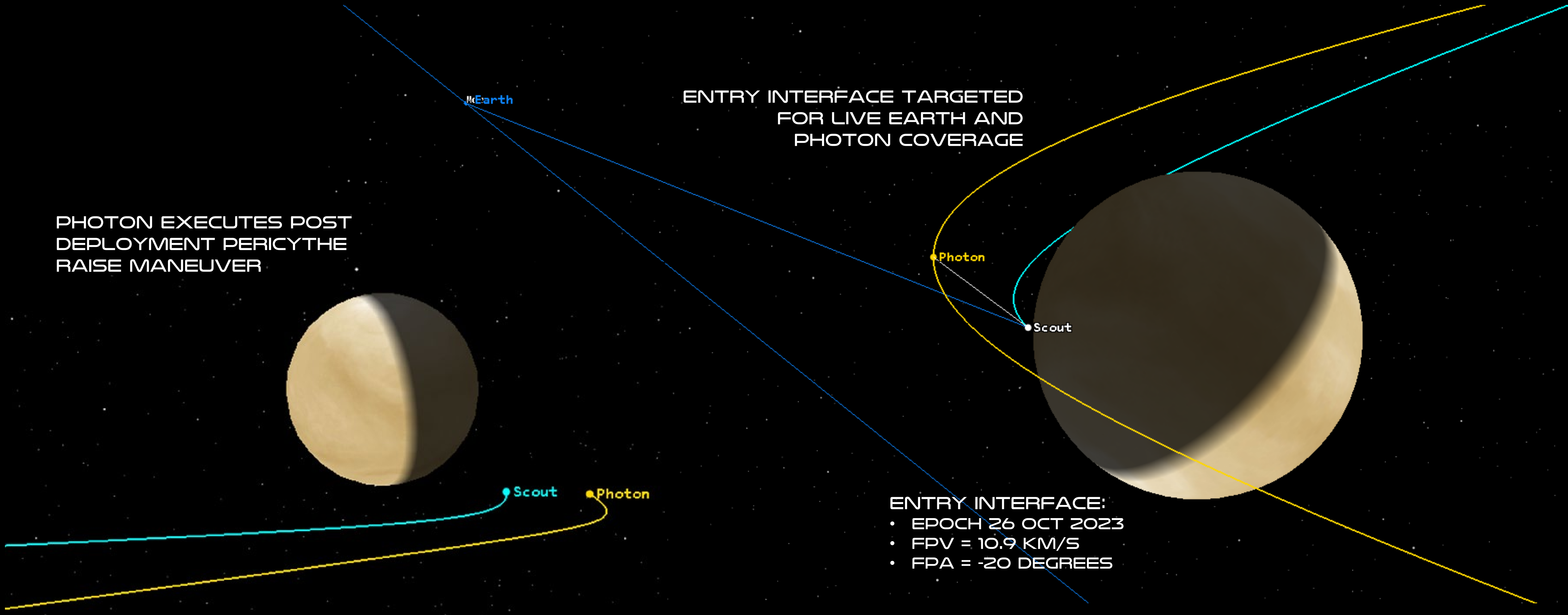




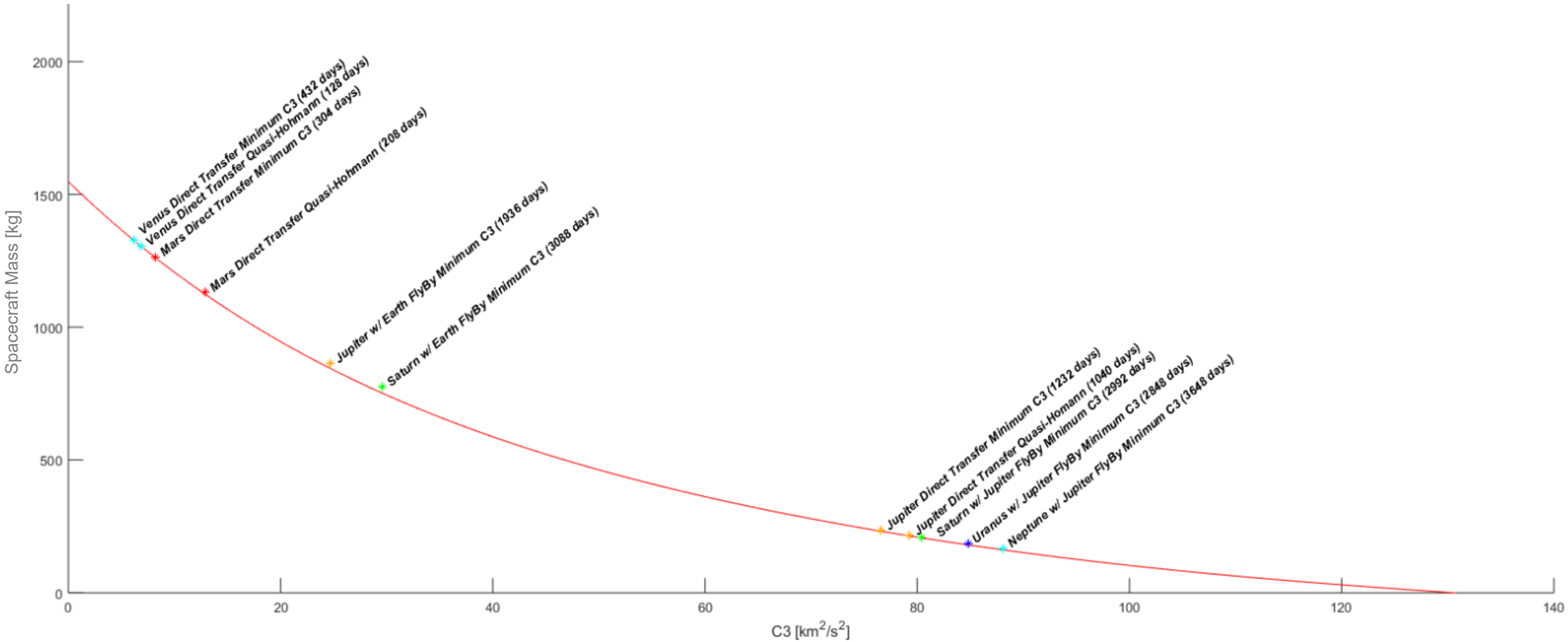
TVI TARGET

- EPOCH 24 MAY 2023
- C3 = 6.29 KM2/S2
- RA = 145.686
- DEC = 9.850

VENUS PROBE 2023 MISSION DESIGN



NEUTRON C3 VS. SPACECRAFT MASS

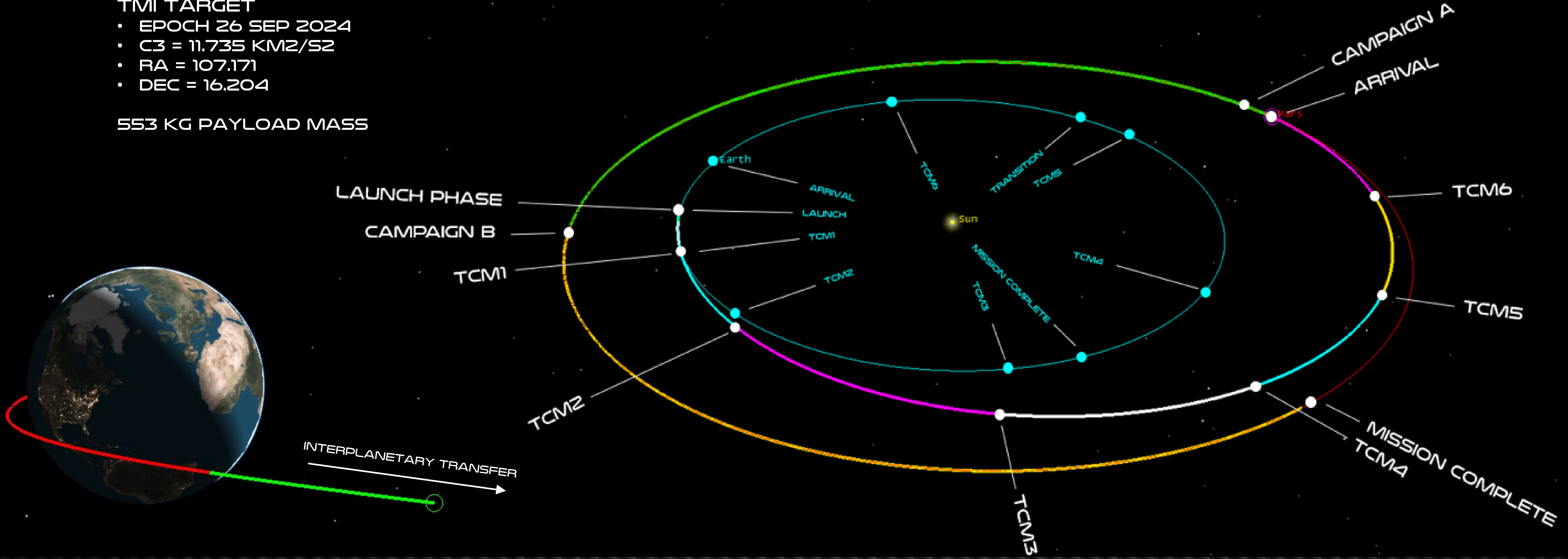


Neutron with a representative upper stage can enable medium-class missions to the inner solar systems and small-class missions to the outer solar system

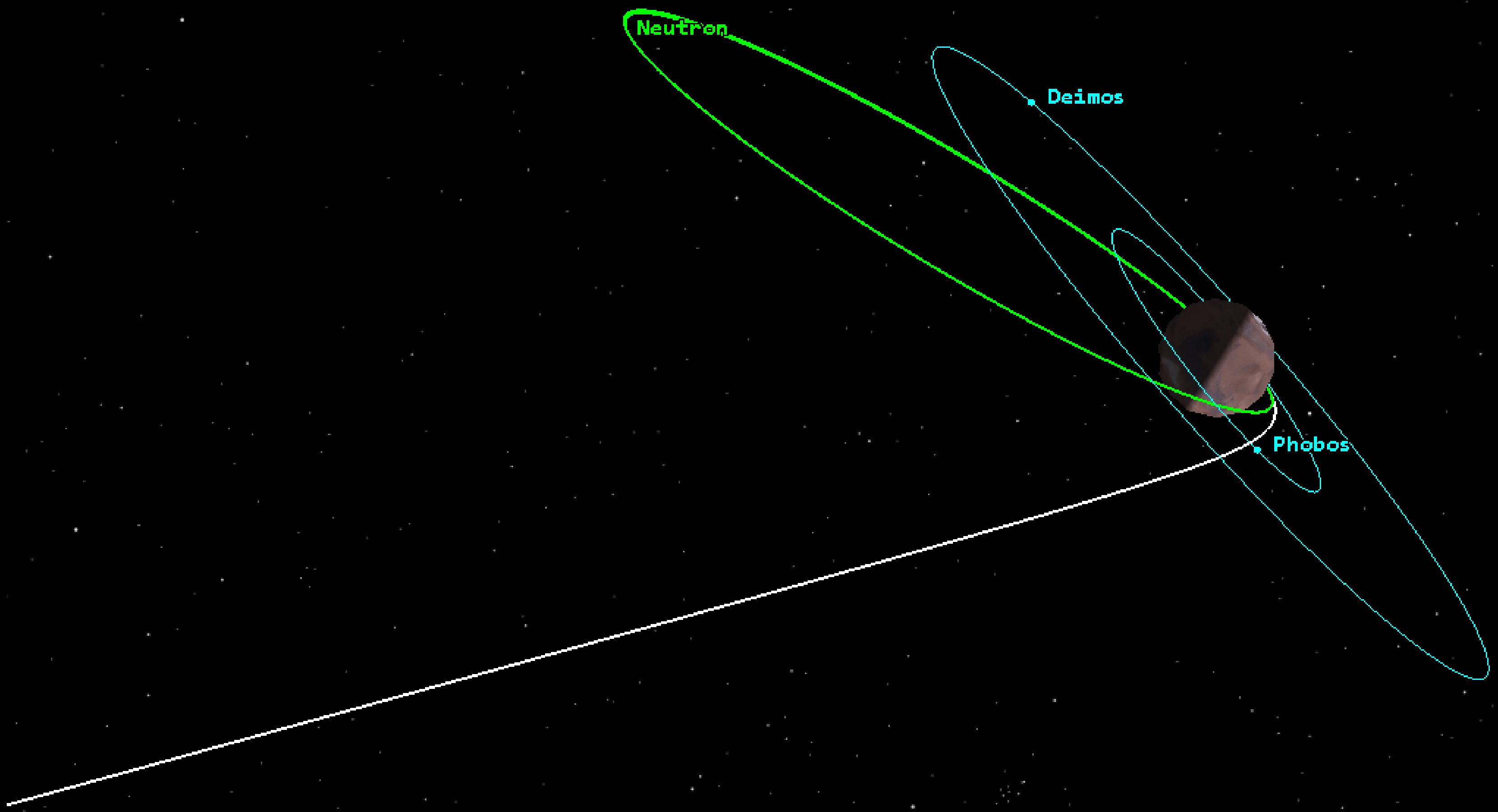
NEUTRON MARS MISSION DESIGN

TMI TARGET
- EPOCH 26 SEP 2024
- C3 = 11.735 KM2/S2
- RA = 107.171
- DEC = 16.204

553 KG PAYLOAD MASS



NEUTRON MARS MISSION DESIGN



REPRESENTATIVE NEUTRON ORBITAL KICK STAGE (BASED ON THE HYPER CURIE ENGINE) TO ACHIEVE A STABLE CAPTURE ORBIT AT C3 = -2 KM2/S2

ARRIVAL CONDITIONS

- EPOCH = 31 AUG 2025
- PERIAERION ALT = 300 KM
- APOAERION ALT = 35,000 KM
- INCLINATION = 43 DEG
- PERIOD = 94,000 S

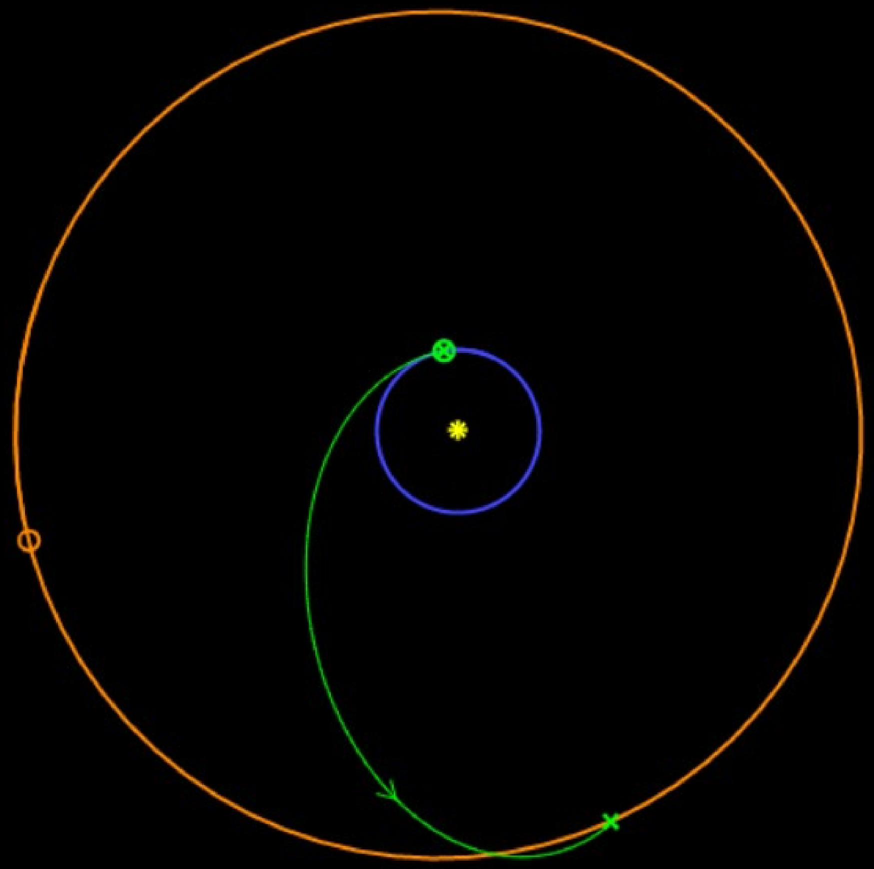
NEUTRON JUPITER DIRECT MISSION DESIGN

TJI TARGET
- EPOCH = 31 DEC 2028
- C3 = 76.6 KM2/S2

TRANSFER
- DURATION = 1232 DAYS
- DSM DV = 0 KM/S

ARRIVAL
- EPOCH = 16 MAY 2032
- RELATIVE VELOCITY = 60 KM/S

234 KG PAYLOAD MASS



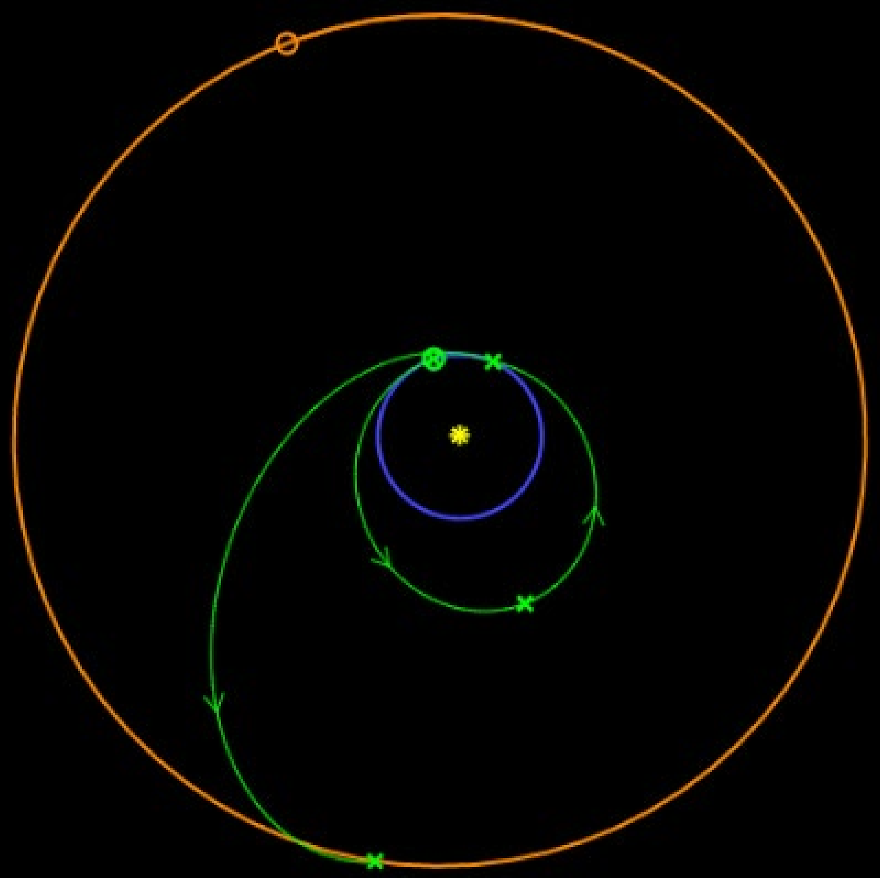
NEUTRON JUPITER W/EARTH FLYBY MISSION DESIGN

TJI TARGET
- EPOCH = 08 JAN 2026
- C3 = 24.7 KM2/S2

TRANSFER
- DURATION = 1936 DAYS
- DSM DV = 0.735 KM/S

ARRIVAL
- EPOCH = 28 APR 2031
- RELATIVE VELOCITY = 0.244 KM/S

862 KG PAYLOAD MASS



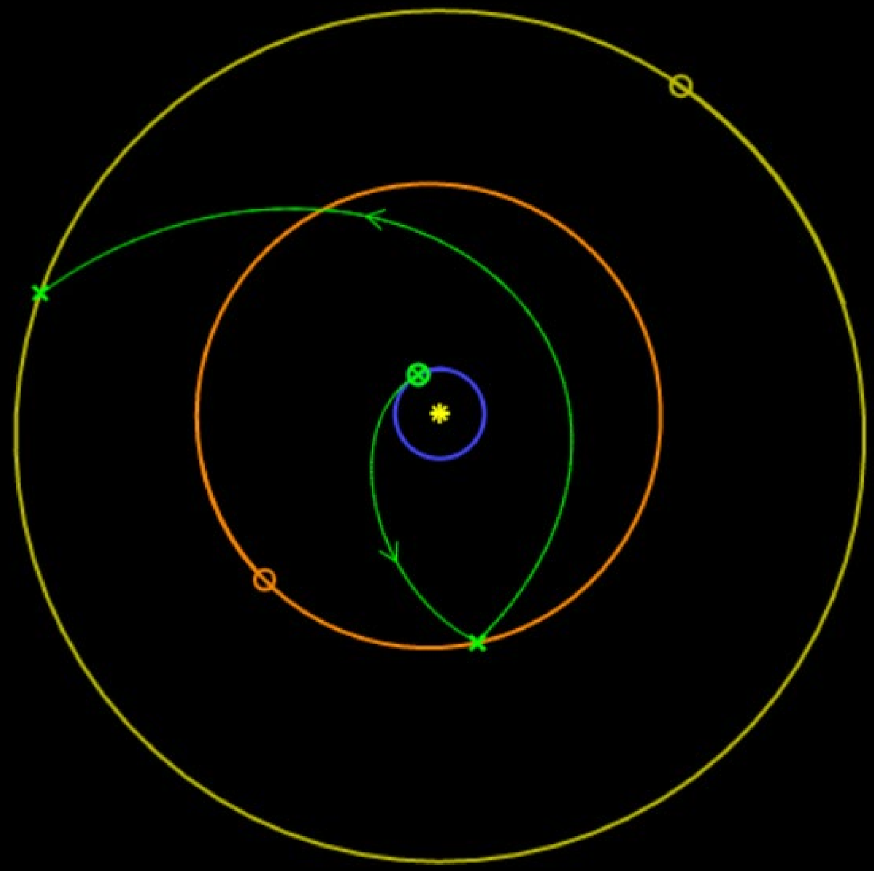
NEUTRON SATURN W/JUPITER FLYBY MISSION DESIGN

TSI TARGET
- EPOCH = 19 JAN 2030
- C3 = 80.4 KM2/S2

TRANSFER
- DURATION = 2992 DAYS
- DSM DV = 0.005 KM/S

ARRIVAL
- EPOCH = 30 MAR 2038
- RELATIVE VELOCITY = 0.385 KM/S

207 KG PAYLOAD MASS



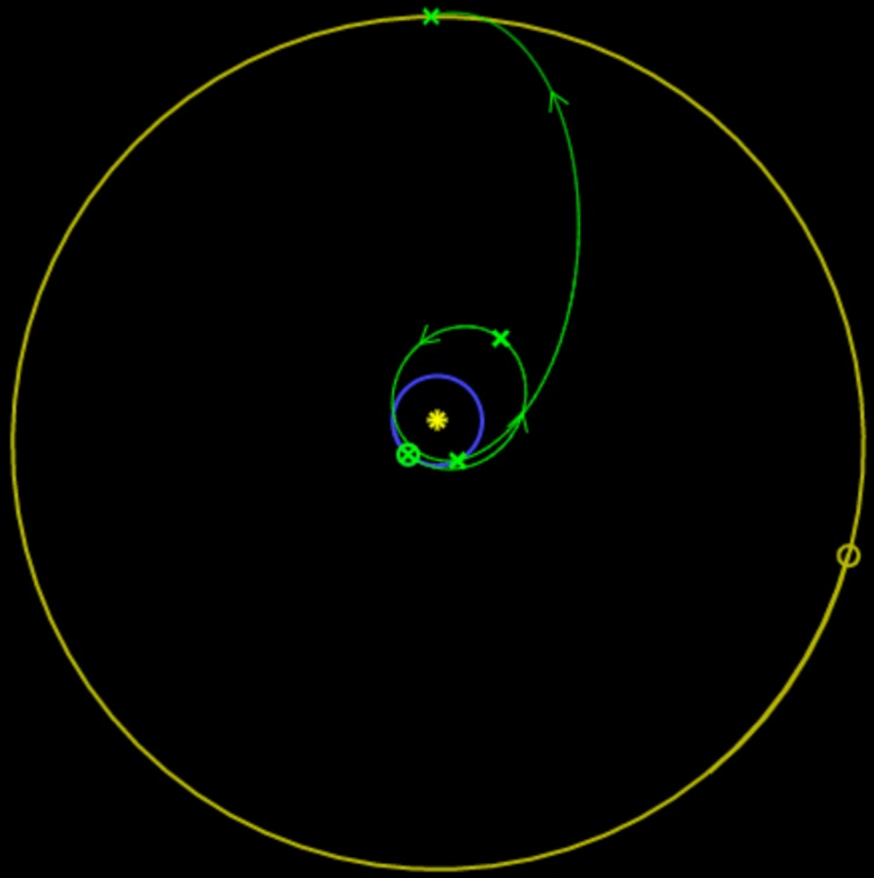
NEUTRON SATURN W/EARTH FLYBY MISSION DESIGN

TSI TARGET
- EPOCH = 10 MAY 2024
- C3 = 29.6 KM2/S2

TRANSFER
- DURATION = 3088 DAYS
- DSM DV = 1.857 KM/S

ARRIVAL
- EPOCH = 23 OCT 2032
- RELATIVE VELOCITY = 0.474 KM/S

774 KG PAYLOAD MASS



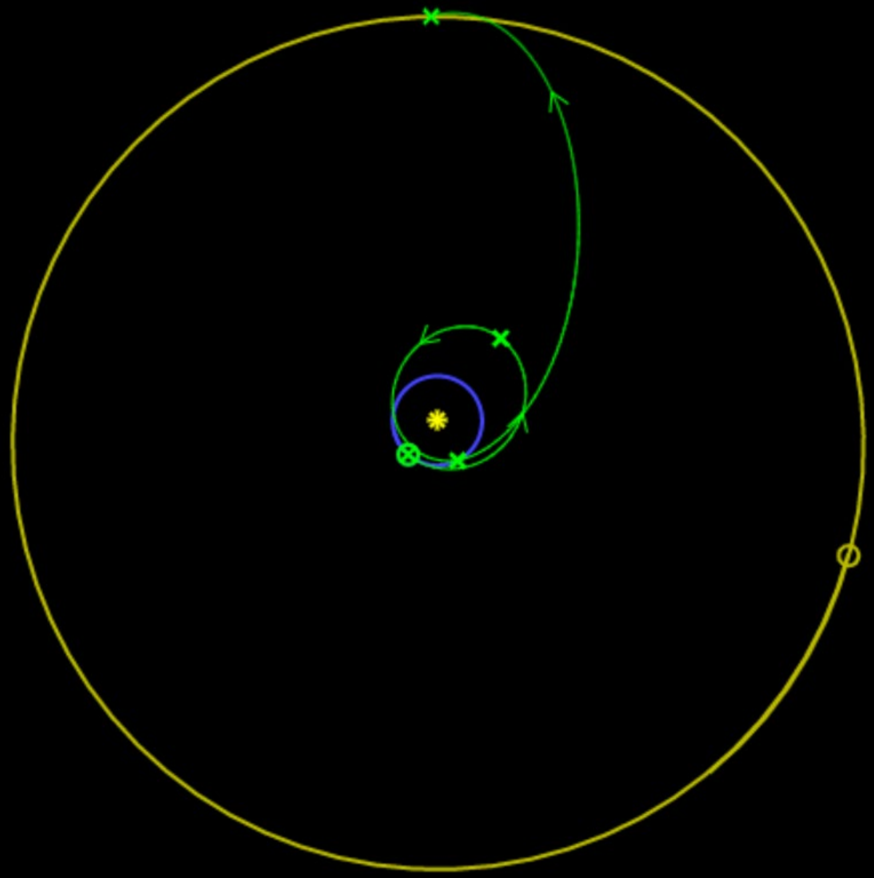
NEUTRON URANUS W/JUPITER FLYBY MISSION DESIGN

TSI TARGET
- EPOCH = 10 MAY 2024
- C3 = 29.6 KM2/S2

TRANSFER
- DURATION = 3088 DAYS
- DSM DV = 1.857 KM/S

ARRIVAL
- EPOCH = 23 OCT 2032
- RELATIVE VELOCITY = 0.474 KM/S

774 KG PAYLOAD MASS



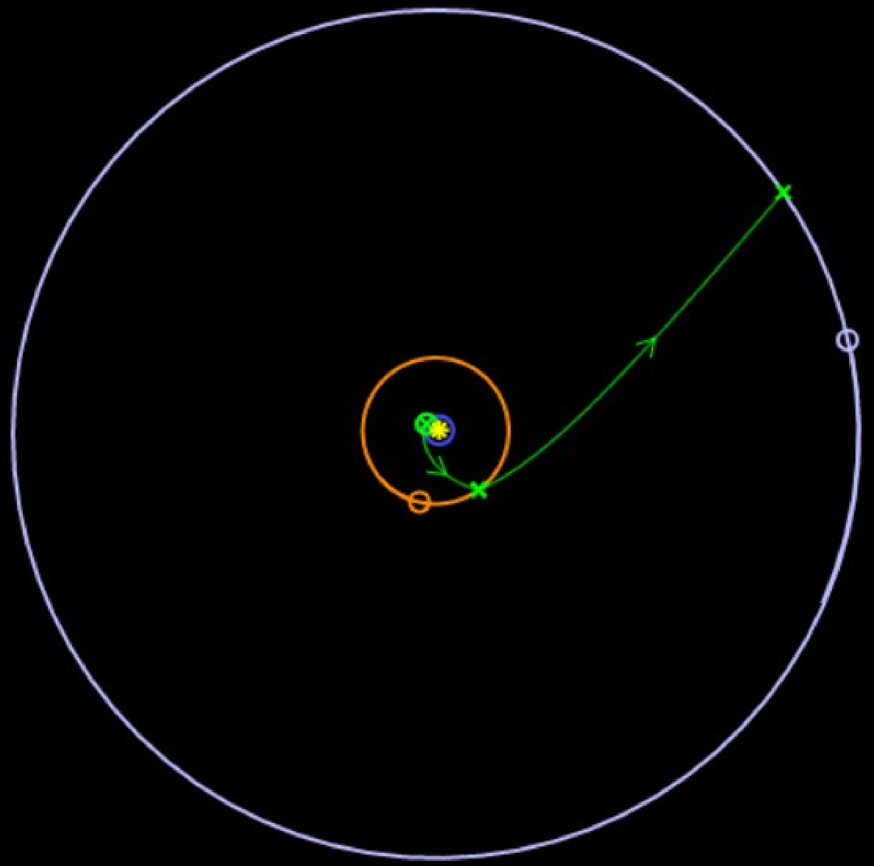
NEUTRON NEPTUNE W/JUPITER FLYBY MISSION DESIGN

TNI TARGET
- EPOCH = 23 FEB 2031
- C3 = 88.1 KM2/S2

TRANSFER
- DURATION = 3648 DAYS
- DSM DV = 0.007 KM/S

ARRIVAL
- EPOCH = 18 FEB 2041
- RELATIVE VELOCITY = 27.34 KM/S

166 KG PAYLOAD MASS



SECTION

03

OBSERVATIONS & RECOMMENDATIONS FOR THE DECADAL SURVEY

OBSERVATIONS

- Small spacecraft, like Photon, have the potential to deliver more regular Decadal-class planetary science, grow more young scientists and engineers, and allow more organizations, like innovative commercial space companies and universities, to lead focused investigations
- Small spacecraft launched on more affordable dedicated launch vehicles, like Electron and Neutron, have the potential to increase the rate of science return and enable new missions, like rapid response missions to newly discovered small bodies
- Rideshare can drive programmatic, cost, schedule, and technical risk into planetary missions
- There are few opportunities for competitive planetary science missions today, particularly for small spacecraft: SIMPLEx is the only competitive planetary science mission that innovative commercial companies can lead and the only planetary small spacecraft program at NASA
- Integrated satellite/launch solutions cannot be proposed in most NASA AOs today, including SIMPLEx, or are de-incentivized through the AO structure, limiting innovation
- A capability-driven approach with science objectives set within commercial capabilities could lower the cost of performing some measurements and help balance the mission portfolio

Small spacecraft launched on dedicated small launch vehicles have the potential to increase the rate of planetary decadal-class science return

RECOMMENDATIONS

- Provide for annual releases of SIMPLEx with a slightly higher cost cap that includes launch to help balance the Planetary science mission portfolio and increase the rate of science return
- Allow dedicated launch vehicles in SIMPLEx to level the playing field with respect to launch and ensure that the full cost and risks of the mission, including launch, are assessed at the time of selection
- Allow PI-provisioned launch services in SIMPLEx so that integrated launch+satellite solutions, like the high energy Photon and Electron, can be proposed by innovative PI's

Increasing the frequency of SIMPLEx and better empowering PIs will help balance the Planetary science portfolio

SECTION

04

QUESTIONS & DISCUSSION

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