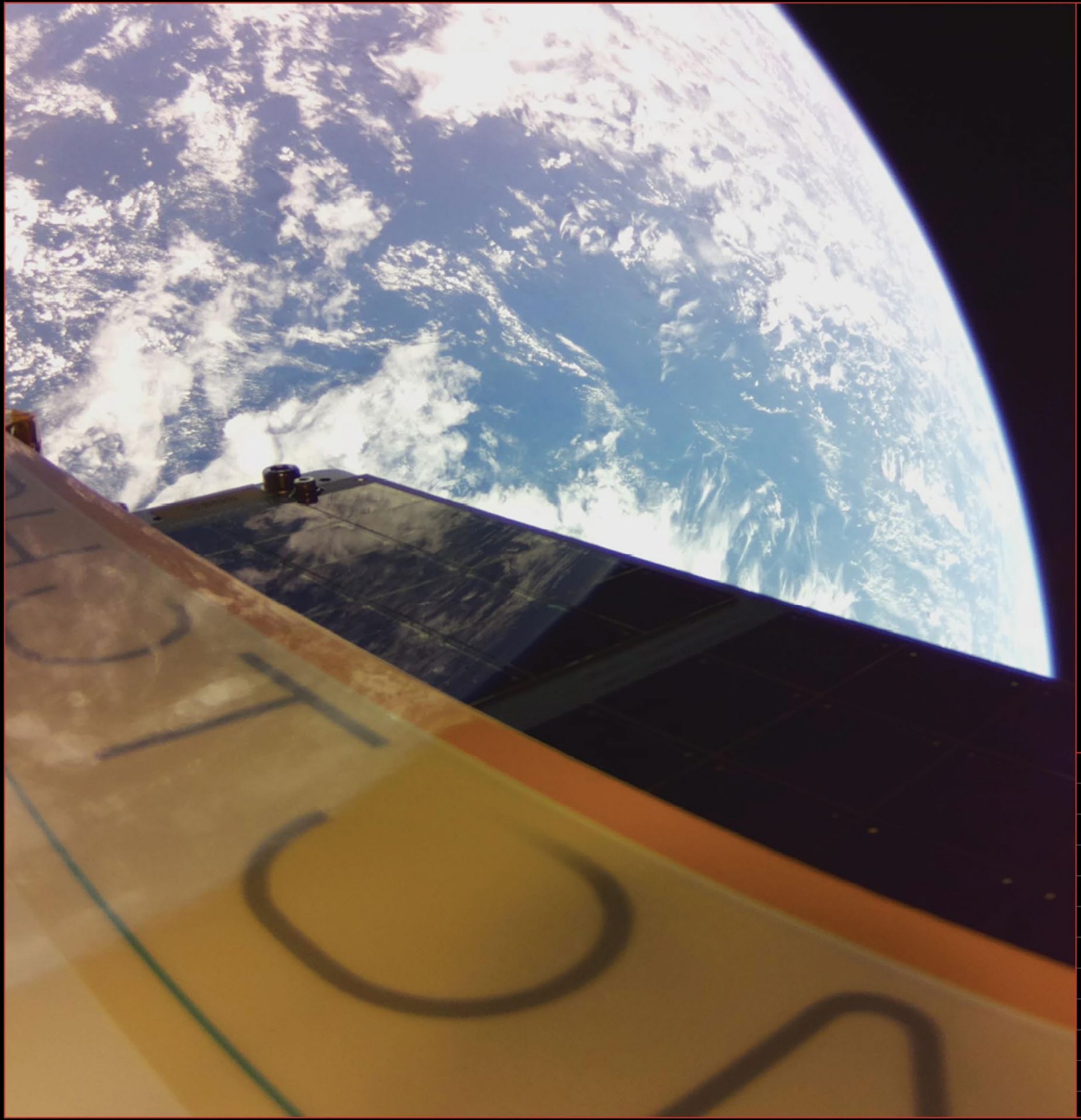


Rocket Lab USA

LEO REFUELING OF ELECTRON/PHOTON FOR HIGH-PERFORMANCE INTERPLANETARY SMALLSAT MISSIONS

Richard French (*Rocket Lab*)
Mike Loucks, John Carrico (*Space Exploration Engineering*)
Jon Goff (*Altius Space Machines*)
William Notardonato (*Eta Space*)

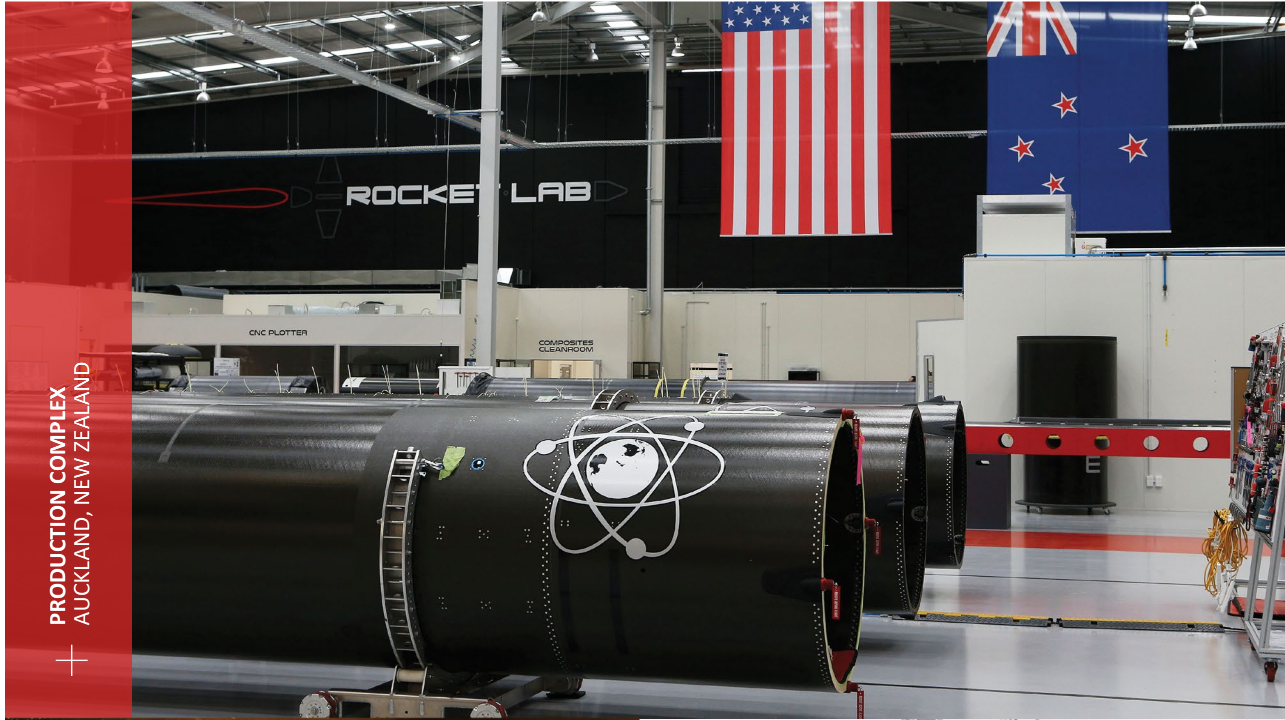
2021 INTERPLANETARY SMALL SATELLITE CONFERENCE

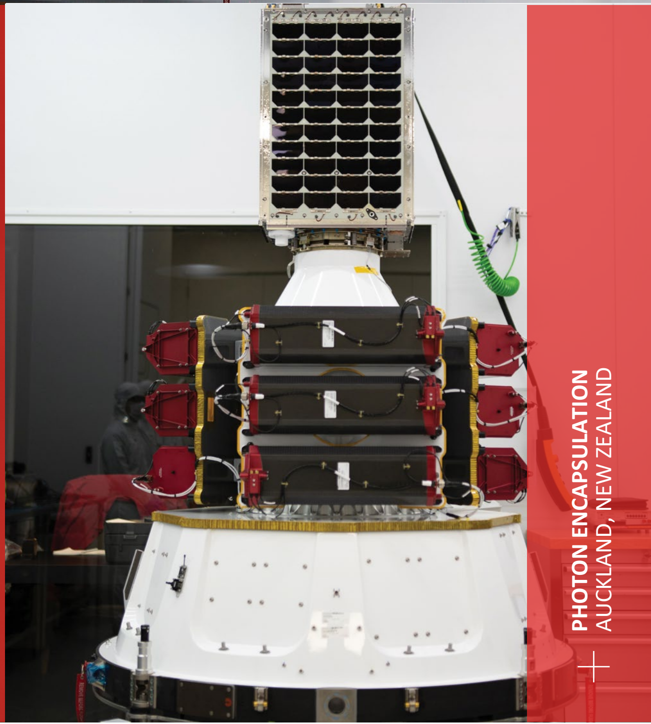
4 May 2021
rocketlabusa.com

ROCKET·LAB

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





ROCKET LAB
AT A GLANCE

A vertically integrated provider of small launch services, satellites and spacecraft components

DELIVERING END-TO-END SPACE SOLUTIONS

- **Launch:** Proven rocket delivering dedicated access to orbit for 3+ years
- **Space Systems:** Manufacturing satellites and best-in-class spacecraft components
- **Space Applications:** Uniquely positioned to leverage launch and satellite capabilities and infrastructure to build and operate our own constellations

IIN UNDER 6 YEARS

19	Launches to space
104	Satellites deployed to orbit
3	Launch pads built
2ND	Most frequently launched U.S. rocket
2	Mission control centres
7	Successful mission for USG customers
1	Strategic acquisition
2	Factories built
1	of our own satellites on orbit (+ more to come)
1	Recovered rocket
3	Interplanetary missions scheduled (Moon, Mars, Venus)
1	Awarded propellant depot mission on orbit for NASA

VERTICALLY INTEGRATED SPACE COMPANY

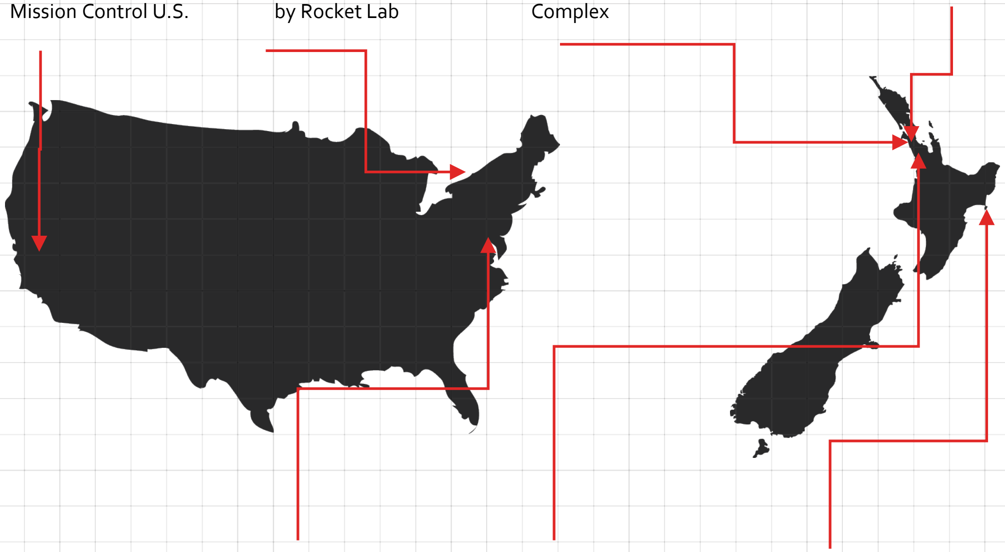
FROM RAW MATERIAL TO ORBIT

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

MEET ELECTRON

SIGNIFICANT TECHNOLOGY MOATS

104

Satellites deployed to orbit to date

1ST

Carbon composite orbital launch vehicle in the world

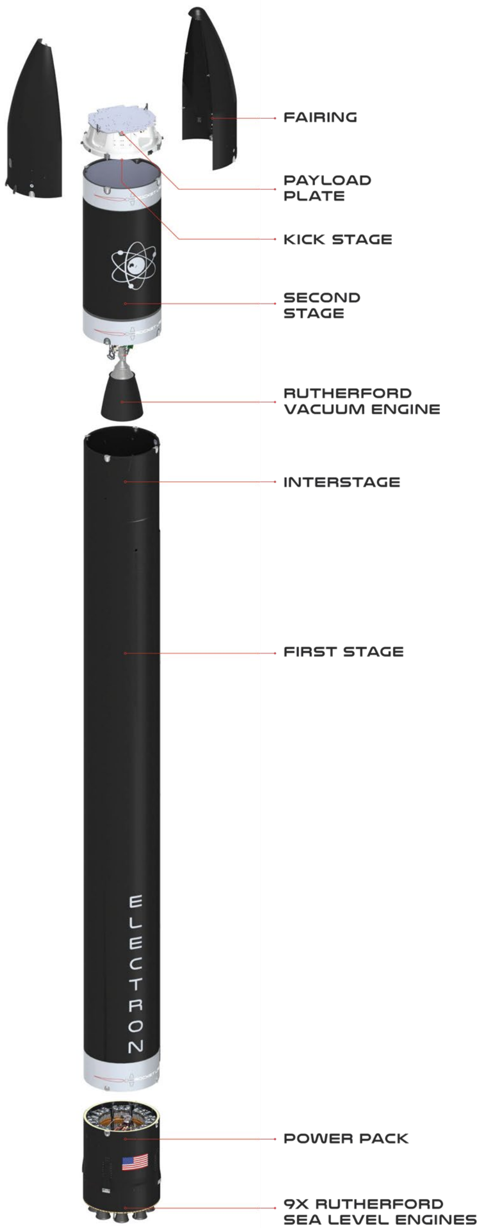
132

Launch opportunities every year across 3 launch pads

190

3D printed engines delivered to space

- Powered by the world's first 3D printed and electric-pump-fed rocket engine technology, backed by a growing IP portfolio and patent filings
- Unique Kick Stage standard with every launch to provide industry-leading precision and flexibility
- Designed for manufacturability and reliability
- Tailored for satellites up to 300 kg (660 pounds) payload class



NEXT STEP: NEUTRON

NEW ROCKET DEVELOPMENT
8-TON TO LEO PAYLOAD CAPACITY

1,500KG
Payload capacity to Venus

4.5 M
Fairing diameter

40 M
In length

REUSABLE
First stage

LAUNCHING
From Virginia, USA

DEDICATED SMALL LAUNCH IS CRITICAL

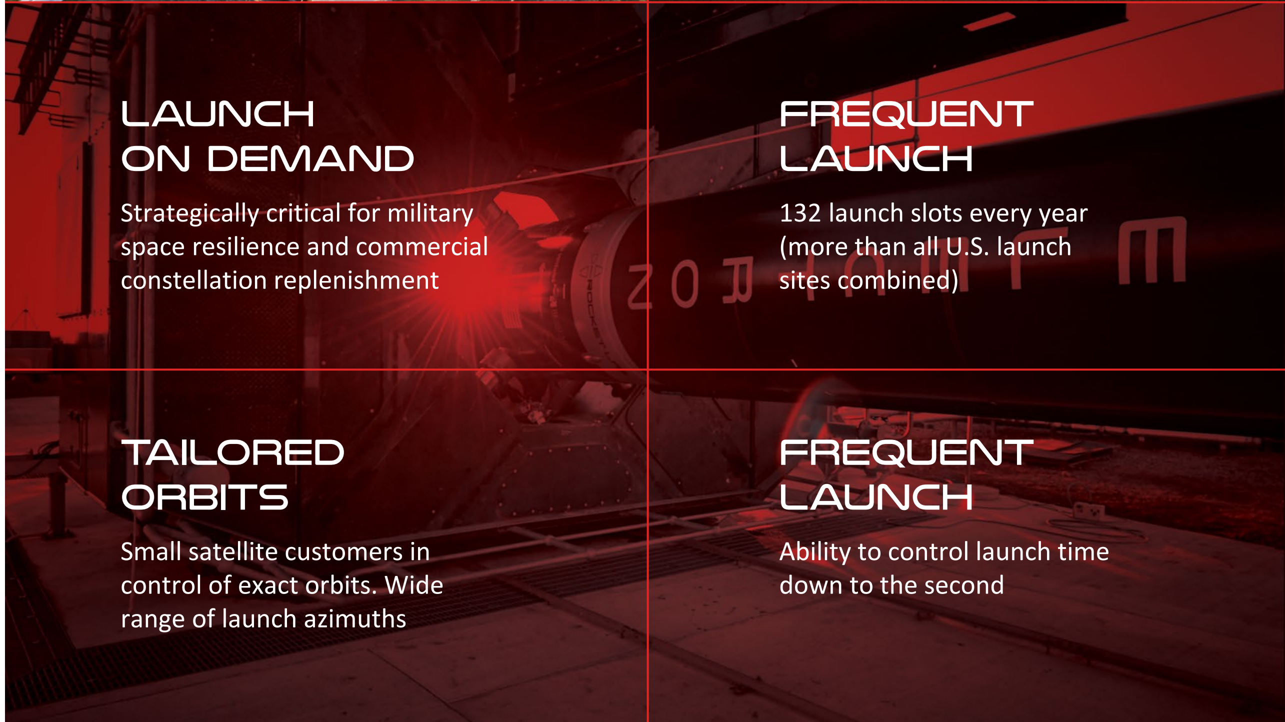
NOT ALL SPACE ACCESS IS THE SAME

Rocket Lab delivers the first dedicated ride to orbit for small satellites, providing customers control over launch schedule and enabling tailored orbits that cannot be matched by large rocket rideshare

Small satellites face costly delays when flying rideshare on large rockets due to low launch frequency

More than 50% of small satellites launched in the past 5 years were delayed from 4 months to 2 years

Large rockets do not provide adequate control for many small satellite orbital destinations



LAUNCH ON DEMAND

Strategically critical for military space resilience and commercial constellation replenishment

FREQUENT LAUNCH

132 launch slots every year (more than all U.S. launch sites combined)

TAILORED ORBITS

Small satellite customers in control of exact orbits. Wide range of launch azimuths

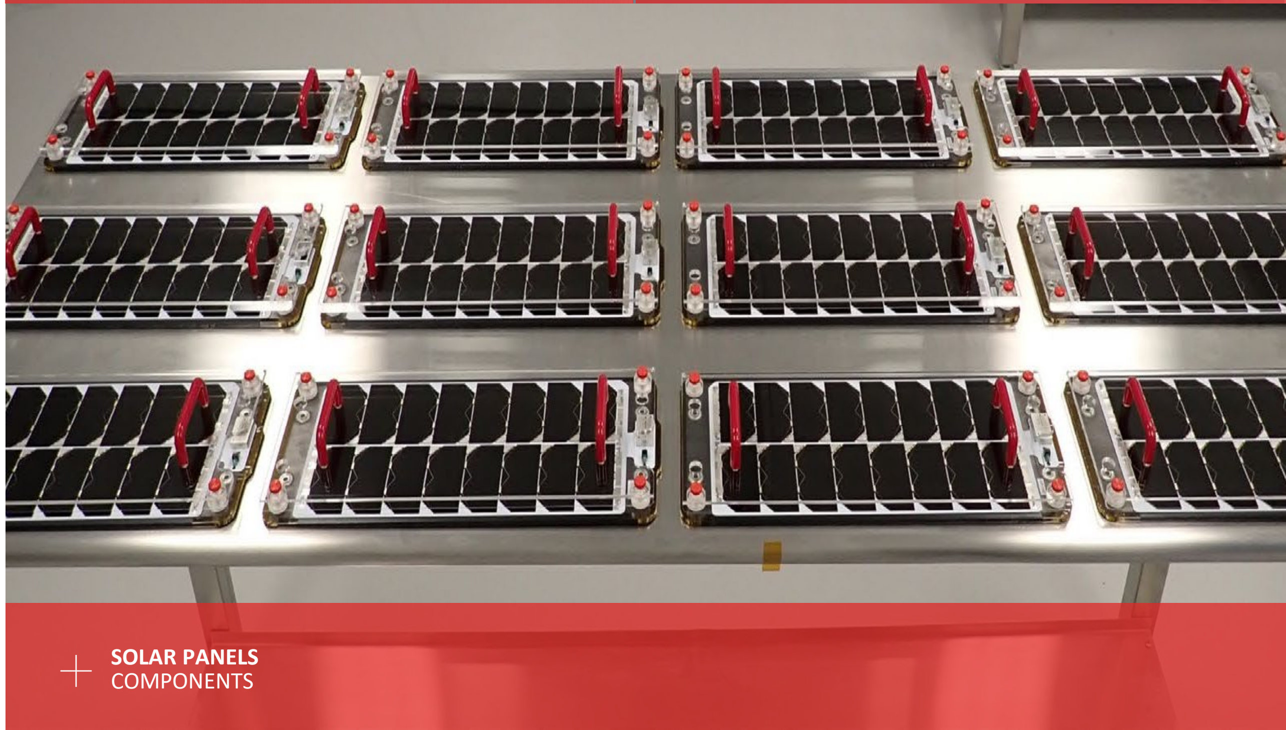
FREQUENT LAUNCH

Ability to control launch time down to the second

SPACECRAFT COMPONENTS

SPACECRAFT COMPONENTS BUSINESS SUPPORTS THE ECOSYSTEM AND IS FILLING KEY GAPS IN THE US SUPPLY CHAIN

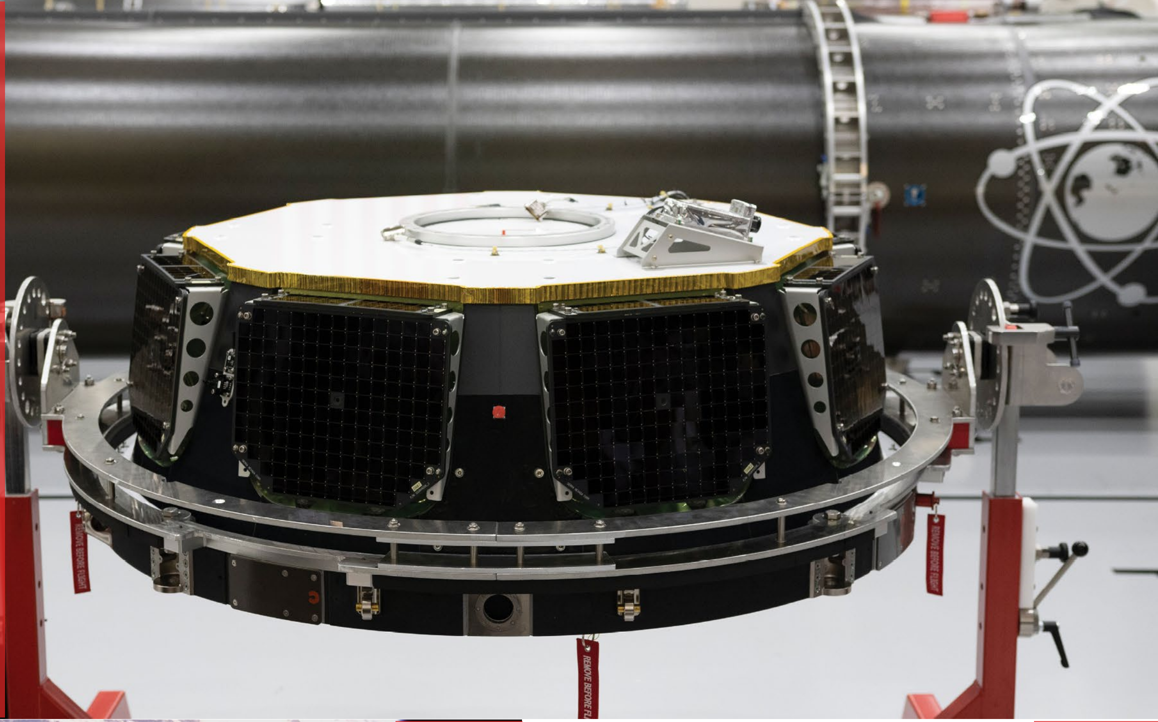
- Flight and payload computers
- Radios with coherent transponders
- Reaction Wheels (Sinclair Interplanetary by RL)
- Star Trackers (Sinclair Interplanetary by RL)
- In-space propulsion
- Reaction control systems
- Torque rods and controllers
- Batteries
- Solar panels
- Power management systems



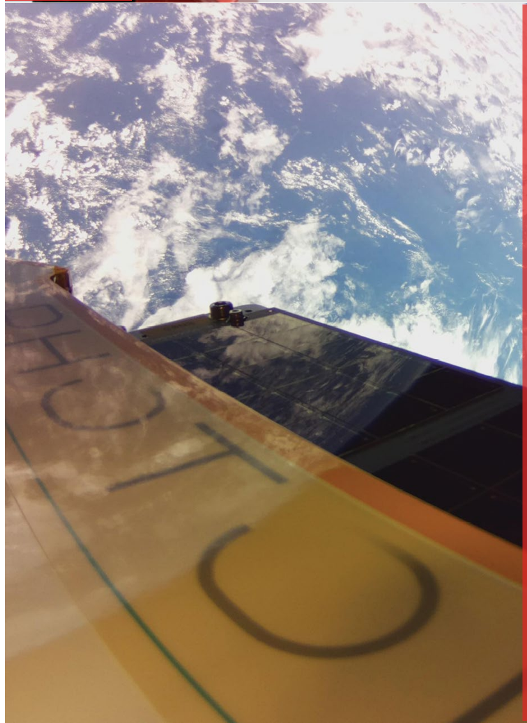
PHOTON

PHOTON ENABLES FULL USE OF THE ELECTRON FAIRING FOR PAYLOAD (SENSORS, TRANSPONDERS, ETC.)

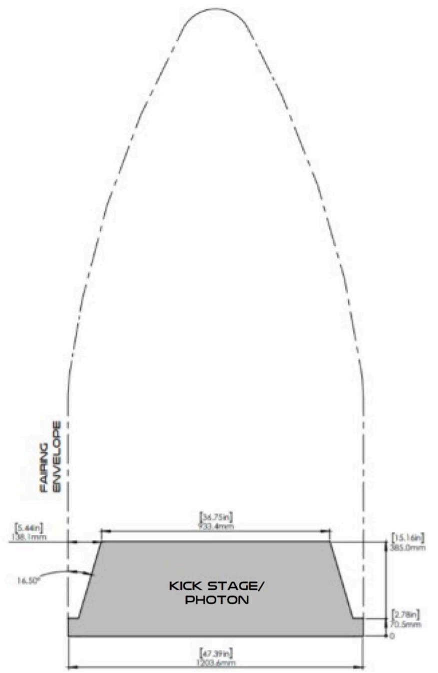
- Launch + satellite + ground + mission operations as a bundled service
- Photon eliminates the parasitic mass of deployed spacecraft and duplicative subsystems by operating as Electron's Kick Stage and as the spacecraft bus, and allowing full use of the fairing by instruments
- Can fly on Electron, Neutron, or as a payload on other LVs (primary or secondary)
- 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 PATHFINDER 1
AUGUST 2020



PHOTON FIRST LIGHT MISSION
AUGUST 2020



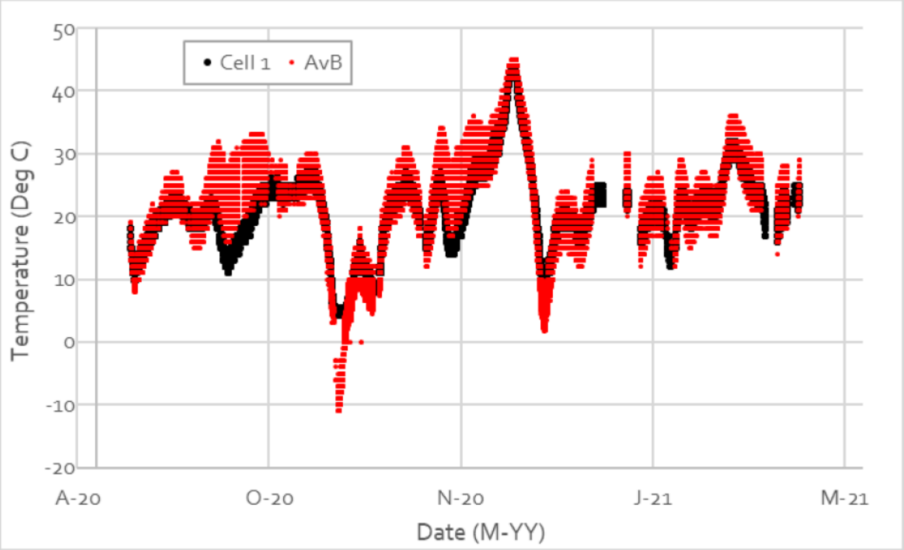
PHOTON POSITION
ELECTRON FAIRING

PHOTON
'FIRST LIGHT'

FIRST LIGHT MISSION DEMONSTRATED THE VALUE OF INTEGRATED LAUNCH + SATELLITE SOLUTIONS

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

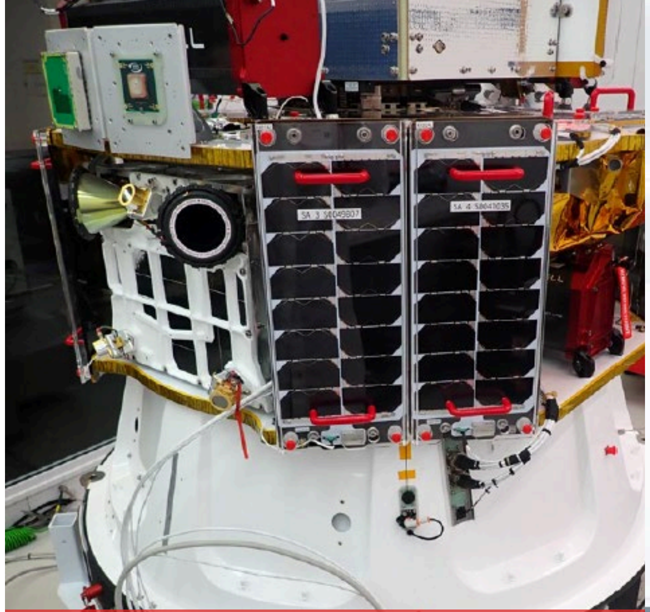


PHOTON 'PATHSTONE'

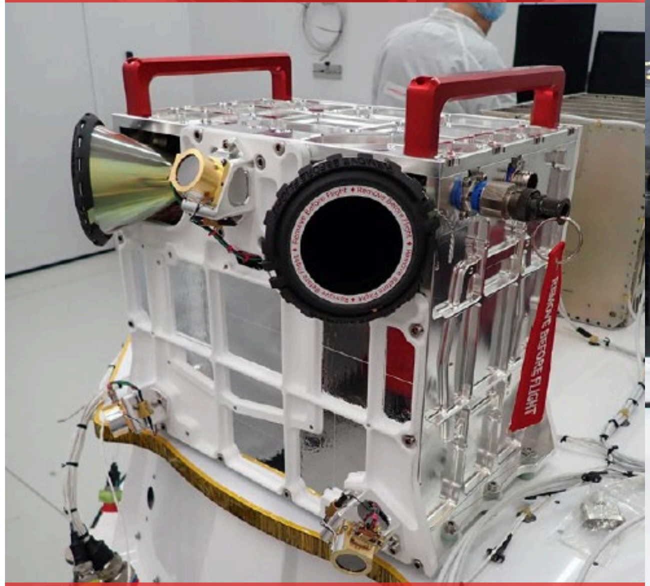
PATHSTONE MISSION IS DE-RISKING ROCKET LAB'S DEEP SPACE MISSION APPROACH FOR THE NASA CAPSTONE LUNAR MISSION

Launched in March 2021 on Flight 19, deployed BlackSky Global'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.)



PHOTON
F19, MARCH 2021



PATHSTONE
F19, MARCH 2021

INTERPLANETARY MISSIONS

MISSIONS AWARDED AND SPACECRAFT DEVELOPED

FIRST TO THE MOON

MOON

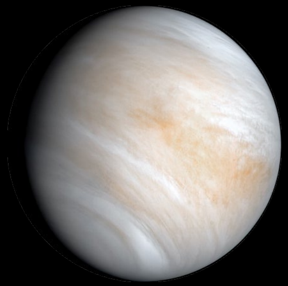
Awarded NASA
CAPSTONE mission
to the moon

Launching 2021

As a precursor for Gateway, a Moon-orbiting outpost that is part of NASA's Artemis program, CAPSTONE will help reduce risk for future spacecraft

DISRUPTING THE MARKET

VENUS



Rocket Lab's Private mission to Venus to search for life

Launching 2023

Rocket Lab will provide both the rocket and spacecraft - international research team will provide the probe and science instrument

DISPLACING LEGACY SPACE

MARS

Mission
to Mars

Launching 2024

The mission will see Photon deliver a science payload to Mars to study the planet's plasma environment

NASA CAPSTONE

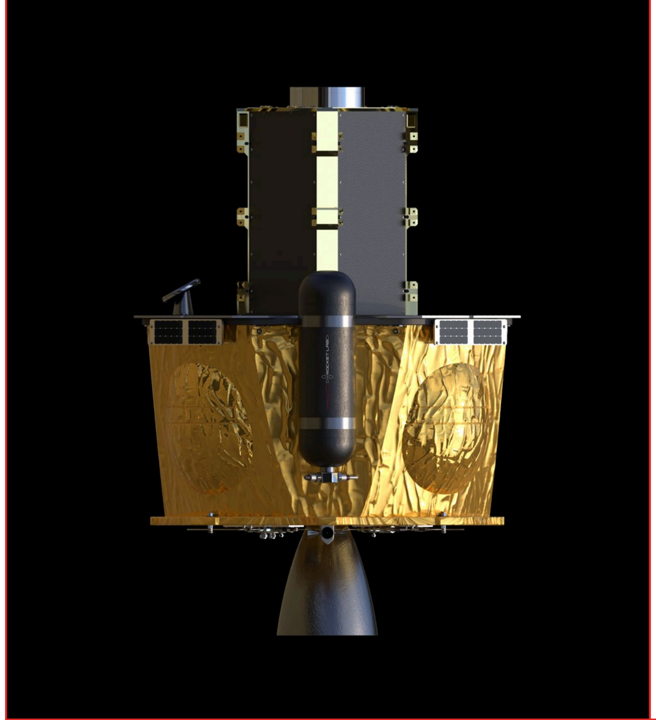
NASA CAPSTONE WILL DEMONSTRATE A FLEXIBLE APPROACH TO TARGETING ESCAPE TRAJECTORIES FOR SMALL SPACECRAFT USING A DEDICATED SMALL LAUNCH VEHICLE

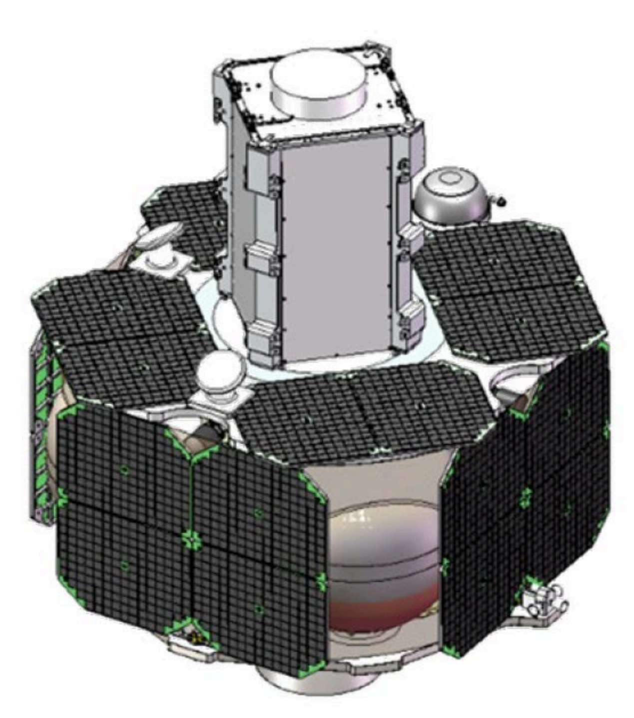
Launching the first mission of the Artemis program on a lunar trajectory in 2021

+ 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





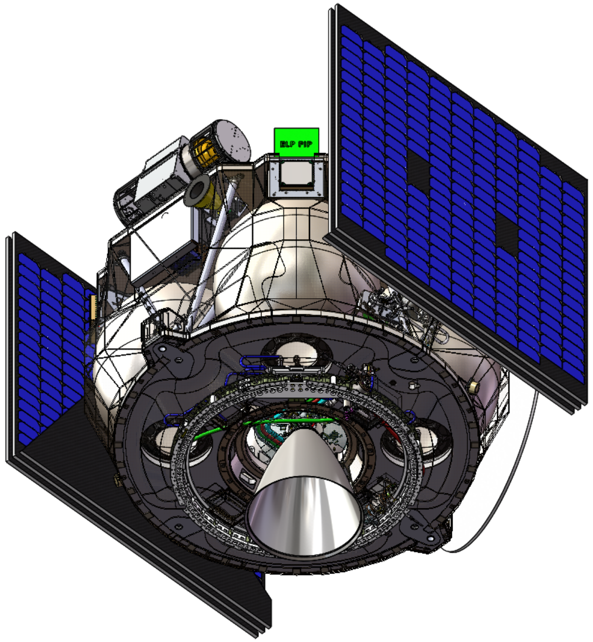
Photon Lunar stage

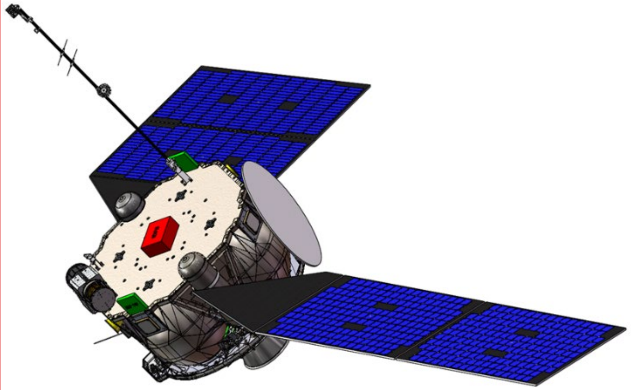
NASA ESCAPADE

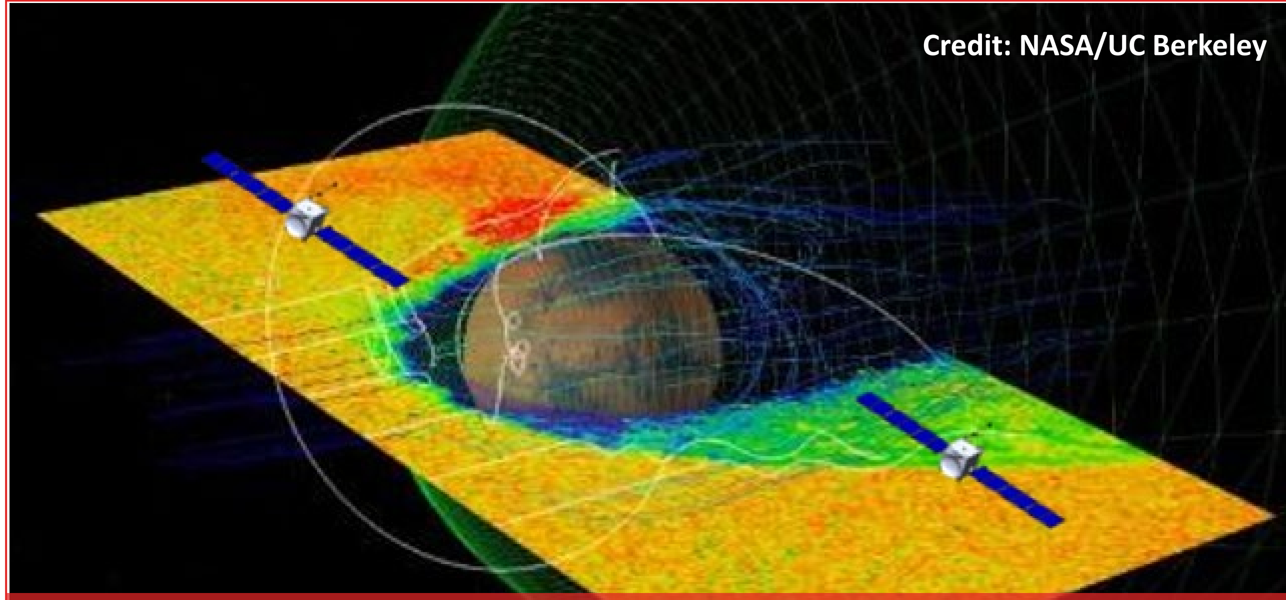
NASA ESCAPADE IS DEMONSTRATING PHOTON VERSATILITY TO LAUNCH ON OTHER LAUNCH VEHICLES, AND DEMONSTRATING AN AFFORDABLE TAILORED CLASS D IMPLEMENTATION

Launching as a rideshare mission for the NASA Science Mission Directorate's SIMPLEx program in partnership with UC Berkeley

- Selected by UC Berkeley to provide the spacecraft buses for the 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







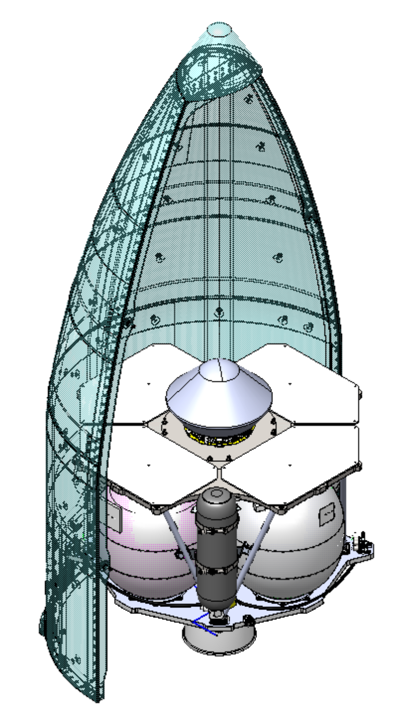
UC Berkeley ESCAPADE mission to Mars

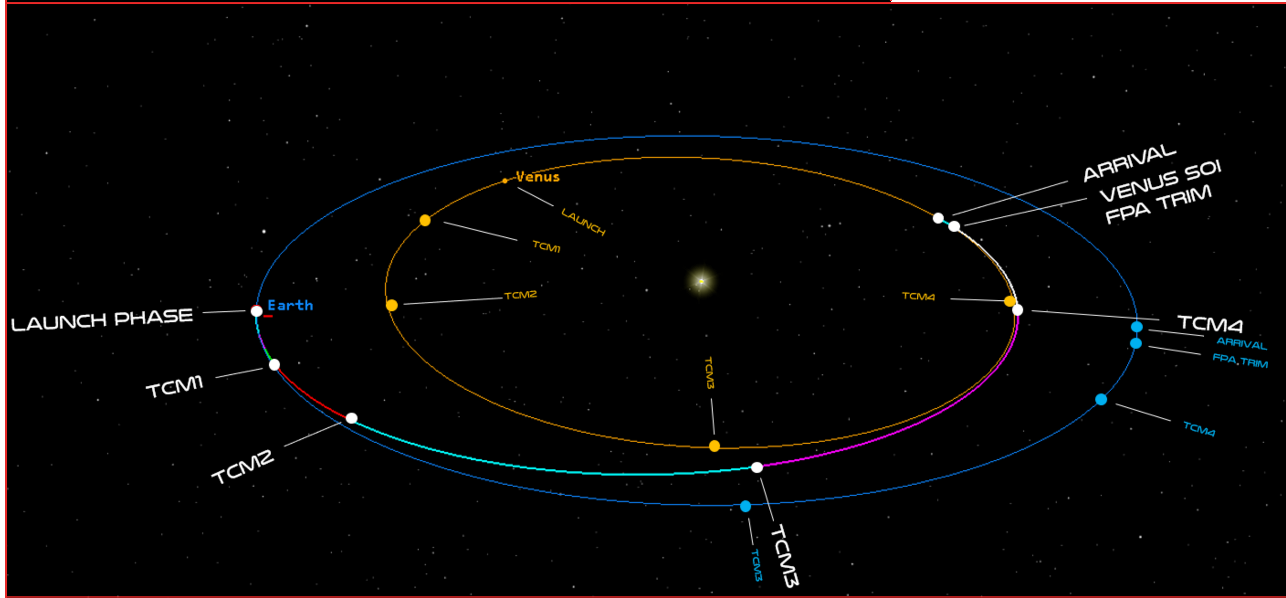
VENUS 2023

DEMONSTRATING THE VALUE OF DEDICATED LAUNCH OF SMALL SPACECRAFT FOR DECADAL-CLASS SCIENCE

Rocket lab is leading a privately funded mission to Venus in 2023 to explore habitability of the cloud layer

- Privately-funded Venus mission May 2023 launch on Electron
- Hyperbolic trajectory with high energy Photon as the cruise stage and as a communications relay
- Collaborating with leading University scientists for instrumentation and expanding partnerships with NASA





Privately-funded probe mission to Venus

LOXSAT-1

NASA STMD 2020 TIPPING POINT SOLICITED FOR PROPELLANT DEPOT TECHNOLOGY DEMONSTRATIONS

Eta Space selected under NASA STMD Tipping Point for flight tech demonstration of advanced cryogenic fluid management (CFM) technologies on Rocket Lab Electron launch vehicle and Photon small spacecraft, partnering with Altius Space Systems, Florida Tech, Sunpower (Amatek), YetiSpace, and NASA KSC, MSFC, GRC

Dedicated 9-month mission to test numerous CFM technologies in orbit

- Active and passive thermal control
- Liquid acquisition
- Pressure control
- Transfer
- Quick Disconnects
- Slosh dynamics

150 kg payload in 500 km sun-synchronous orbit launching in late 2023 on Electron integrated with Photon spacecraft

LOX chosen because it is common across all cryo-propellant combinations

LOXSAT - 1 Technology Objectives

Technology Objective	Current TRL	LOXSAT TRL	Co Investigato
Low Conductivity Supports	6	7	Eta Space
Advanced External Insulation	4	7	Eta Space
Helium Pressurization	5	7	Eta Space
Pump Mixing	5	7	MSFC
Liquid Acquisition Devices	5	7	GRC
High Capacity 90K Cryocoolers	6	7	SunPower
Cryogenic Disconnects	4	7	Altius
Tank Chill Down	4	7	Eta Space
Transfer	4	7	Eta Space
Propellant Densification	4	7	KSC
Autogenous Pressurization	4	7	MSFC

LOXSAT-2

LOXSAT-1 IS DE-RISKING THE PLAN FOR A FULL-SCALE COMMERCIAL PROPELLANT DEPOT

Eta Space is planning a full-scale commercial propellant depot to launch in 2025 focusing on LOX/RP to service near term customers and help enable small spacecraft planetary missions

20 metric tons total mass with 16 tons propellant (11.5 metric tons LOX and 4.5 metric tons RP)
- 2 meters diameter X 8.5 meters long
- 3 kW solar power

Active thermal control with zero loss storage and transfer

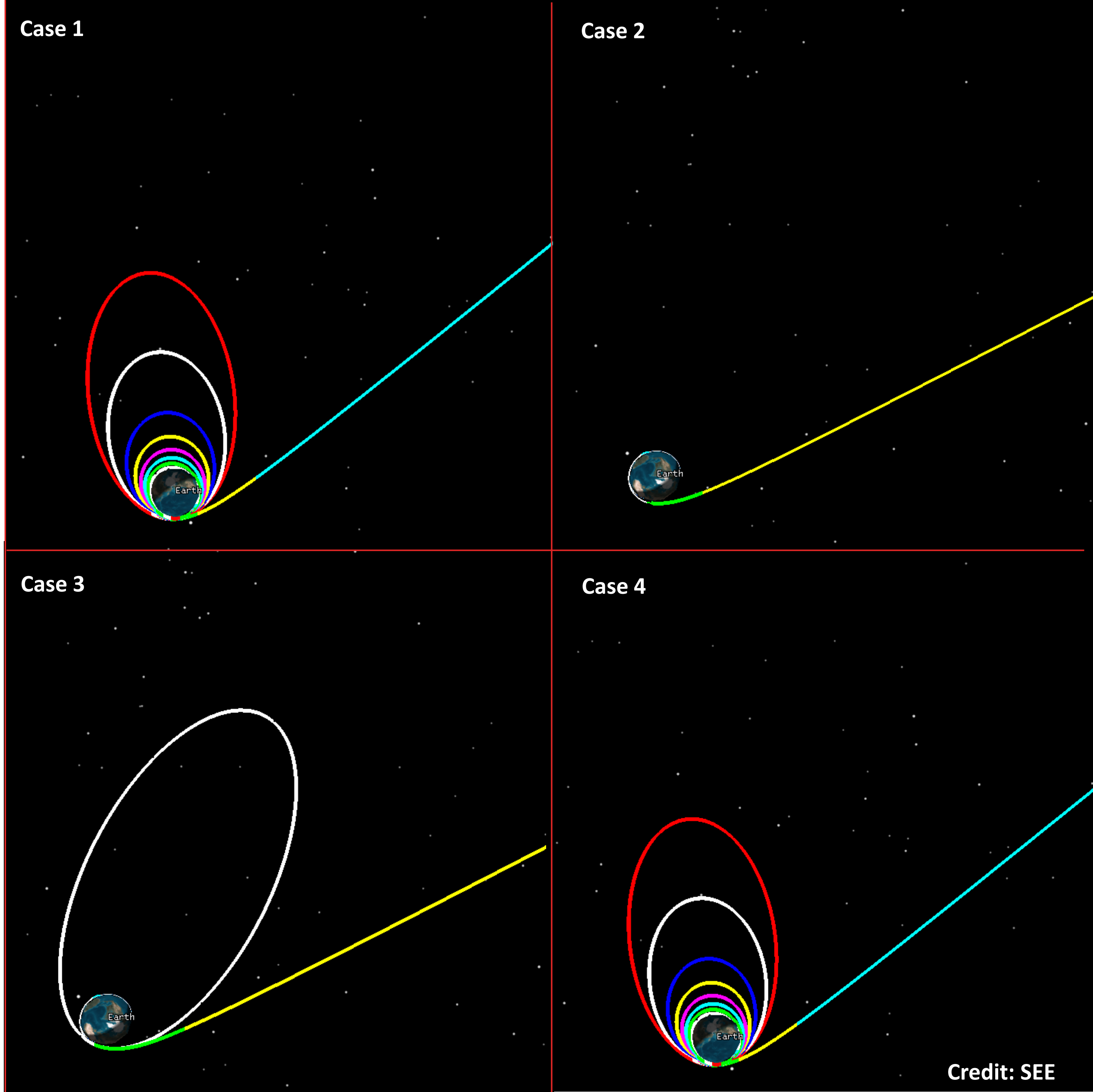
Agnostic depot with standardized interfaces
- Active systems largely on depot
- Remote manipulator for berthing to servicing umbilical

Credit: Eta Space

DESIGN CASES

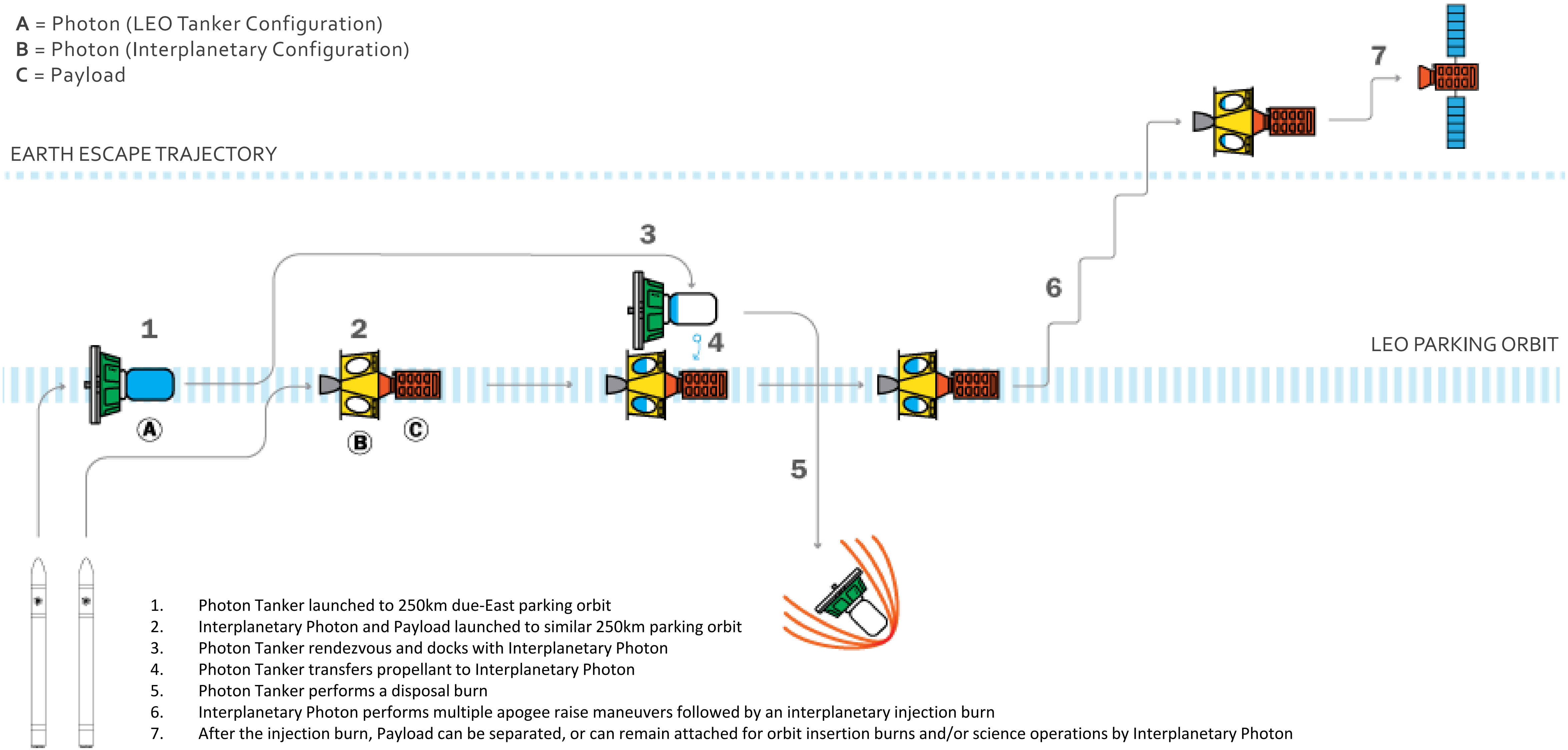
PRELIMINARY CASES BASED ON ELECTRON, HIGH ENERGY PHOTON, AND LOXSAT-2 CHARACTERISTICS

- Case 1: Launch of a pair of High Energy Photons on 2 Electrons
  - Similar to Case 4; after fueling operations, Photon performs a series of orbit raising burns and phasing orbits to escape
- Case 2: Electron Stage 2 re-fueling with typical High Energy Photon
  - Stage 2 re-fueled up to single remaining battery capacity; cases below 10 km^2/sec^2 require less propellant, cases above are at capacity
  - Stage 2 performs a direct escape burn and, for trajectories above 10 km^2/sec^2, High Energy Photon burns to target C3
- Case 3: Electron Stage 2 re-fueling with High Energy Photon re-fueling (2X typical High Energy Photon tank volume)
  - Stage 2 re-fueled up to single remaining battery capacity, all cases are at capacity
  - Stage 2 raises into a highly elliptical (~1.2 day period) orbit with High Energy Photon performing the escape burn
- Case 4: Typical Electron and High Energy Photon (reference case)
  - Similar to Case 1, after launch into LEO, Photon performs a series of orbit raising burns and phasing orbits to escape



DUAL PHOTON LAUNCH

A = Photon (LEO Tanker Configuration)
B = Photon (Interplanetary Configuration)
C = Payload

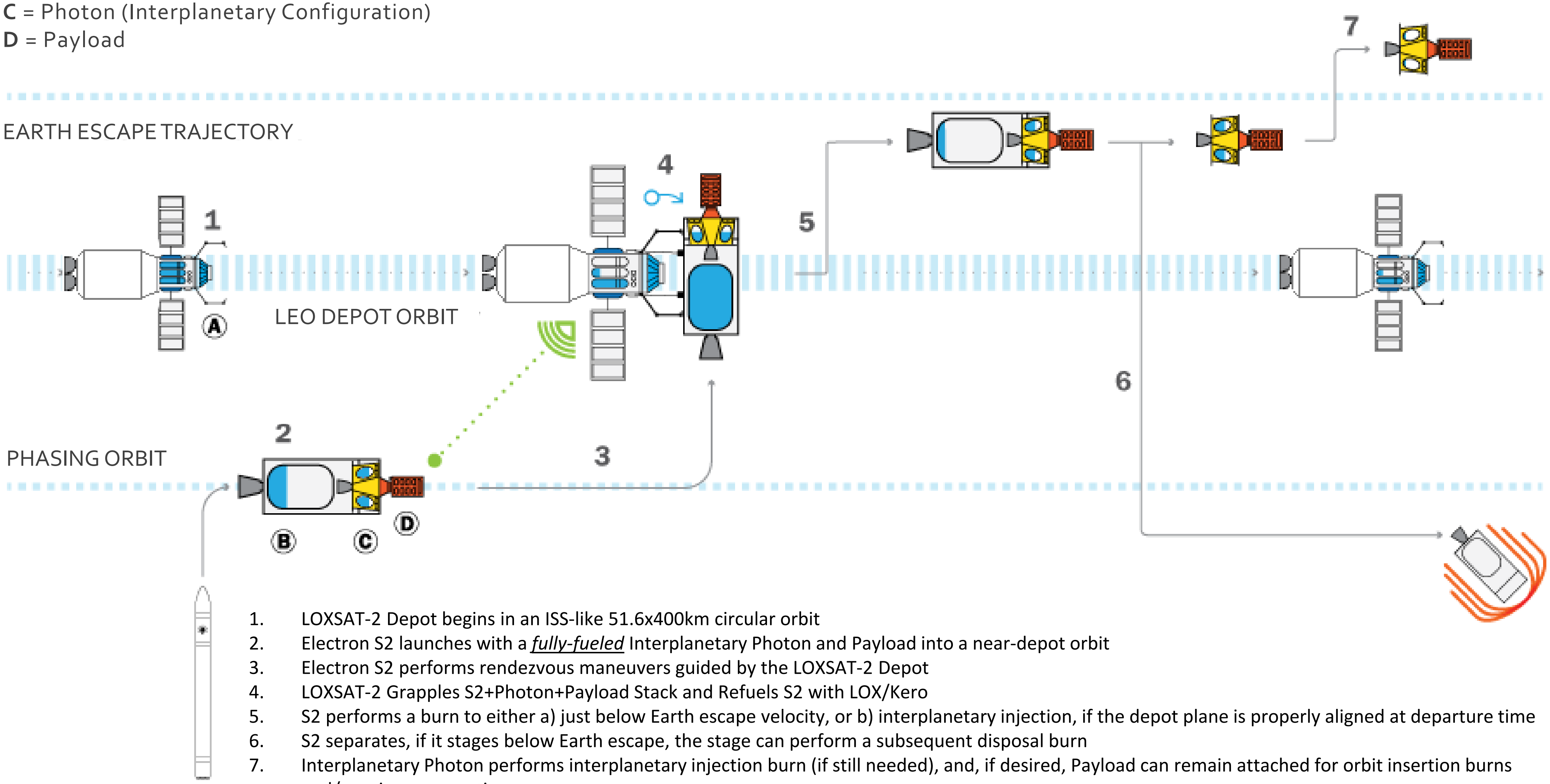


1. Photon Tanker launched to 250km due-East parking orbit
2. Interplanetary Photon and Payload launched to similar 250km parking orbit
3. Photon Tanker rendezvous and docks with Interplanetary Photon
4. Photon Tanker transfers propellant to Interplanetary Photon
5. Photon Tanker performs a disposal burn
6. Interplanetary Photon performs multiple apogee raise maneuvers followed by an interplanetary injection burn
7. After the injection burn, Payload can be separated, or can remain attached for orbit insertion burns and/or science operations by Interplanetary Photon

Credit: Altius Space Machines

STAGE 2 RE-FUELING

A = LOXSAT-2 – LEO Fuel Depot
B = Electron (Second Stage)
C = Photon (Interplanetary Configuration)
D = Payload

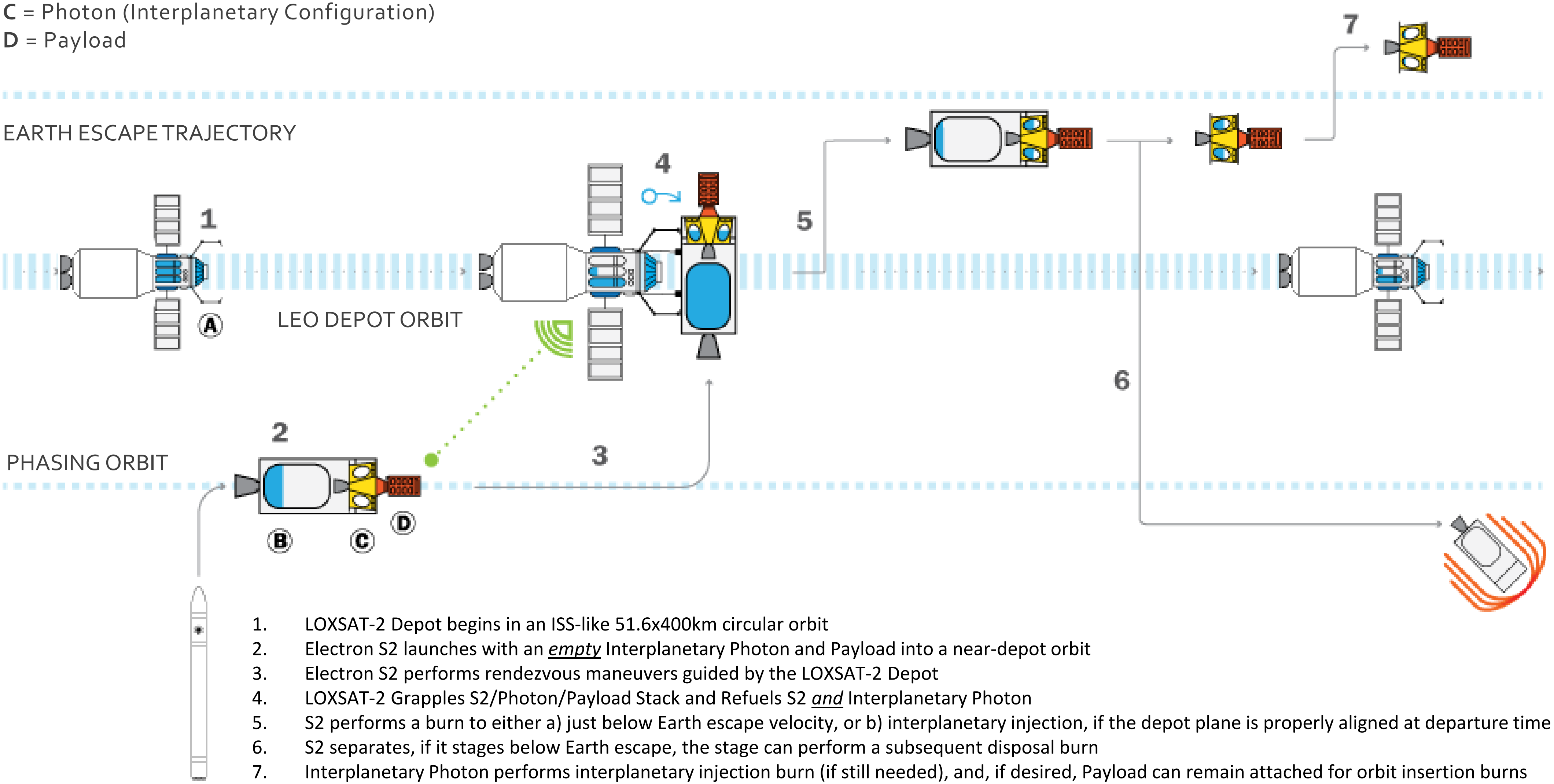


1. LOXSAT-2 Depot begins in an ISS-like 51.6x400km circular orbit
2. Electron S2 launches with a ***fully-fueled*** Interplanetary Photon and Payload into a near-depot orbit
3. Electron S2 performs rendezvous maneuvers guided by the LOXSAT-2 Depot
4. LOXSAT-2 Grapples S2+Photon+Payload Stack and Refuels S2 with LOX/Kero
5. S2 performs a burn to either a) just below Earth escape velocity, or b) interplanetary injection, if the depot plane is properly aligned at departure time
6. S2 separates, if it stages below Earth escape, the stage can perform a subsequent disposal burn
7. Interplanetary Photon performs interplanetary injection burn (if still needed), and, if desired, Payload can remain attached for orbit insertion burns and/or science operations

Credit: Altius Space Machines

STAGE 2 + PHOTON RE-FUELING

A = LOXSAT-2 – LEO Fuel Depot
B = Electron (Second Stage)
C = Photon (Interplanetary Configuration)
D = Payload

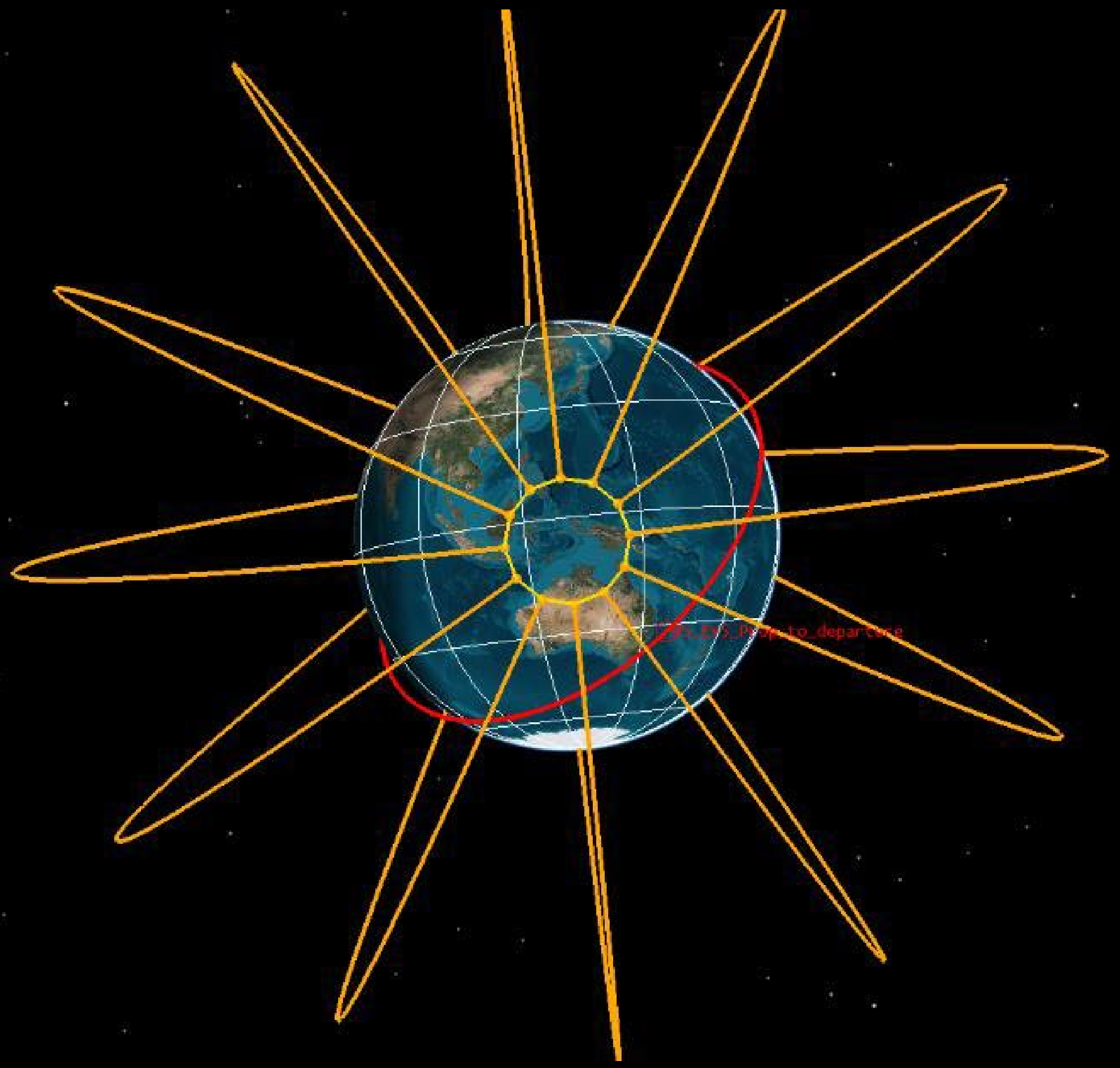


1. LOXSAT-2 Depot begins in an ISS-like 51.6x400km circular orbit
2. Electron S2 launches with an *empty* Interplanetary Photon and Payload into a near-depot orbit
3. Electron S2 performs rendezvous maneuvers guided by the LOXSAT-2 Depot
4. LOXSAT-2 Grapples S2/Photon/Payload Stack and Refuels S2 *and* Interplanetary Photon
5. S2 performs a burn to either a) just below Earth escape velocity, or b) interplanetary injection, if the depot plane is properly aligned at departure time
6. S2 separates, if it stages below Earth escape, the stage can perform a subsequent disposal burn
7. Interplanetary Photon performs interplanetary injection burn (if still needed), and, if desired, Payload can remain attached for orbit insertion burns and/or science operations

Credit: Altius Space Machines

3-BURN DEPARTURE METHODOLOGY OVERVIEW

- For Photon-to-Photon refueling missions, the two Photons can be launched into a plane *precisely-aligned* for a specific interplanetary mission's desired departure asymptote
- For depot-refueling missions, *<u>the plane of the depot is already fixed</u>*, and the odds of it being optimally-aligned for a traditional single-burn departure during any specific interplanetary departure window are not very good
    - This is not an issue for missions to GEO or Cislunar space, as the depot will line up with optimal single-burn departures for those destinations frequently (daily/weekly)
- To solve this problem of depot departures for interplanetary missions, a 3-burn departure method was devised
    - Loucks et al "RAAN-Agnostic 3-Burn Departure Methodology for Deep Space Missions from LEO Depots" 2018 AAS/AIAA Astrodynamics Specialist Conference, Snowbird, UT. AAS 18-447.
    - Goff et al "Using LEO Depots to Enable Dedicated Interplanetary Smallsat Missions" Future In-Space Operations (FISO) Working Group Telecon Presentation 28 Nov 2018.



Not Optimally-Aligned Depot Plane

Credit: Loucks, Goff, et al.,

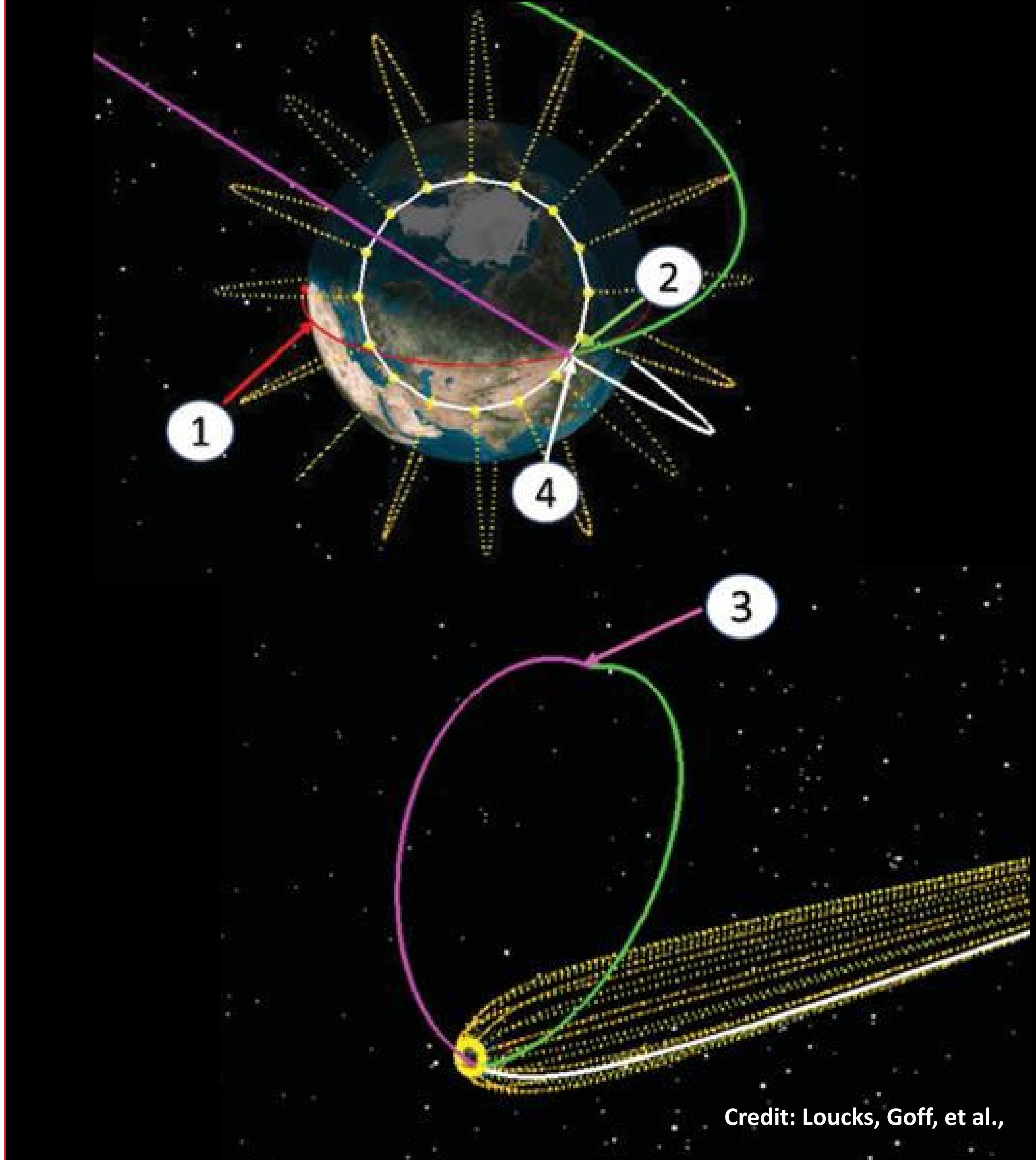
3-BURN DEPARTURE METHODOLOGY OVERVIEW

1. The S2+Photon+Payload start in the depot orbit (Red)

2. Prior to the departure window, during an orbit that crosses the locus of periapses, the spacecraft performs a burn centered on the point where it intersects the locus, entering a highly-elliptical phasing orbit (Green). The phasing orbit period is selected so that after an integer number of loops, the spacecraft returns to perigee at the departure date.

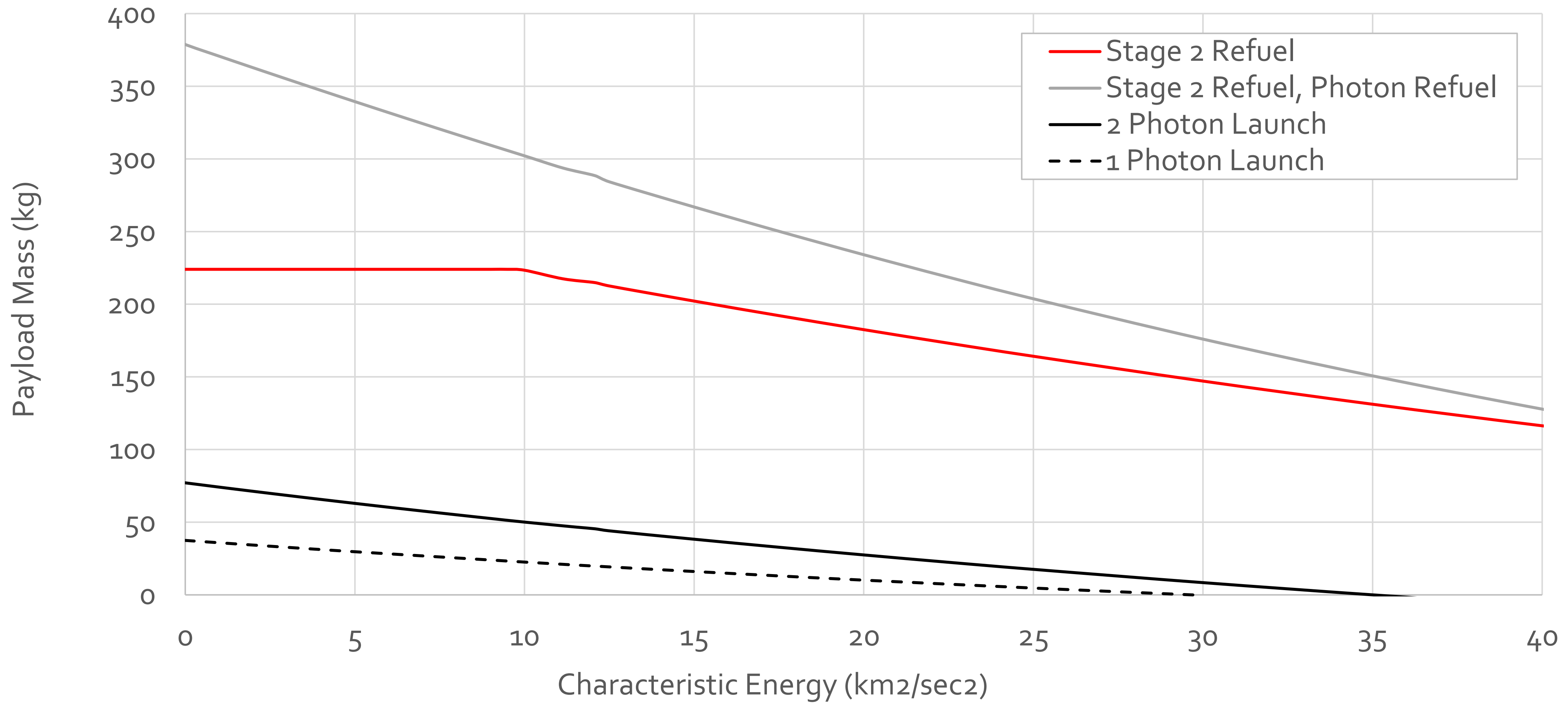
3. At apogee on the last phasing loop, the spacecraft performs a maneuver to cancel out any solar/lunar perturbations and to align its orbital trajectory (Pink) with the departure asymptote.

4. When the spacecraft returns to perigee on the last loop, it is aligned properly for its departure burn, entering the desired hyperbolic departure trajectory (White).



Credit: Loucks, Goff, et al.,

PRELIMINARY RESULTS

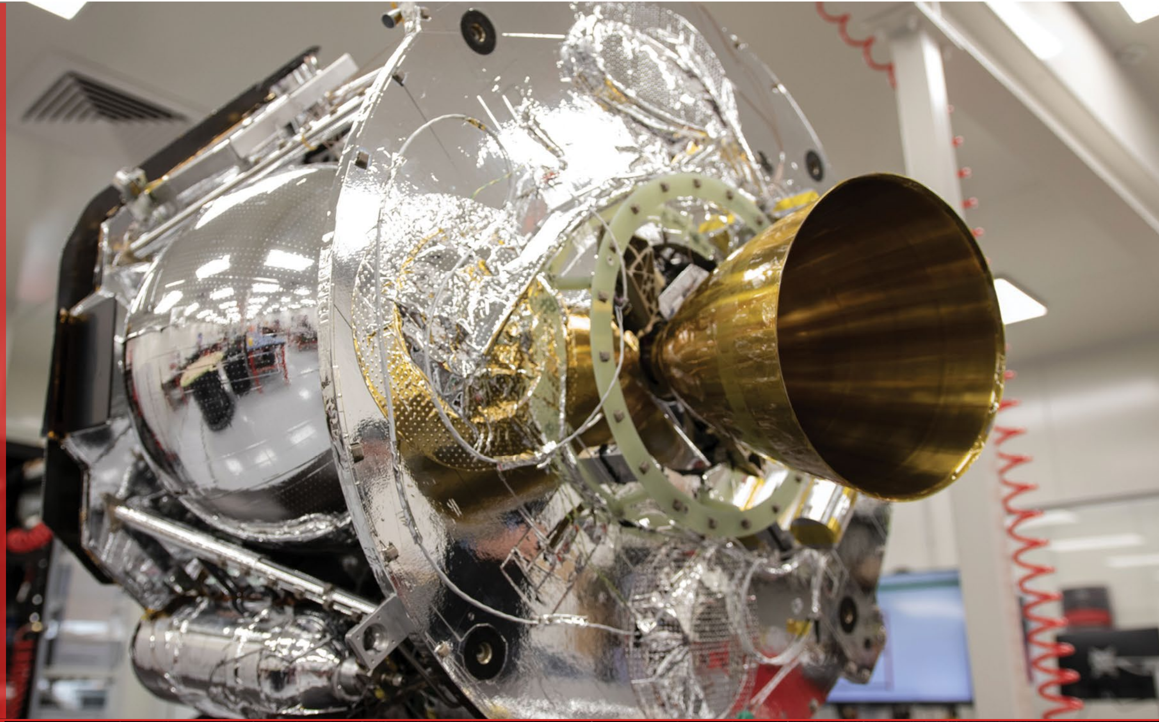


PRELIMINARY RESULTS

ON-ORBIT REFUELING FOR PLANETARY SMALL SPACECRAFT MISSIONS CAN INCREASE PAYLOAD MASS

- Photon to Photon re-fueling almost doubles payload mass for inner solar system missions to the Moon, Mars, and Venus
- Electron Stage 2 re-fueling significantly increases payload mass for planetary small spacecraft missions – performance below ~10 km^2/sec^2 set by battery capacity
- Electron Stage 2 and Photon re-fueling shows additional improvements beyond Stage 2-only re-fueling case

HIGH ENERGY PHOTON



LOXSAT-2 LOX/RP ON-ORBIT FUEL DEPOT

QUESTIONS/DISCUSSION

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