MOMENTUS

IN-SPACE TRANSPORTATION

SOLVING *THE LAST-MILE* PROBLEM IN SPACE

JOEL C. SERCEL, PHD
CHIEF TECHNOLOGY OFFICER

PRESENTED AT THE
FISO TELECON
12 DECEMBER 2018

MOMENTUS TEAM

LEV KHASIS, PHD in aerospace
Chairman & Founder
Former Senior VP of Walmart

TO BE ANNOUNCED
Chief Engineer

PHILIP MAINWARING
Head of Propulsion

YUQI WANG
Aerospace Engineer
Former Space-X engineer

CHRISTIAN SALLABERGER, PHD
Board Member
Chairman of International Space University

CHARLIE FENG
Aerospace Engineer

ALIKI LOPER-LEDDY
Project Manager

JOEL SERCEL, PHD
Chief Technology Officer
Former Principle Engineer at JPL

NEGAR FEHER
VP of Products and BD
Former Head of BD in SS/L

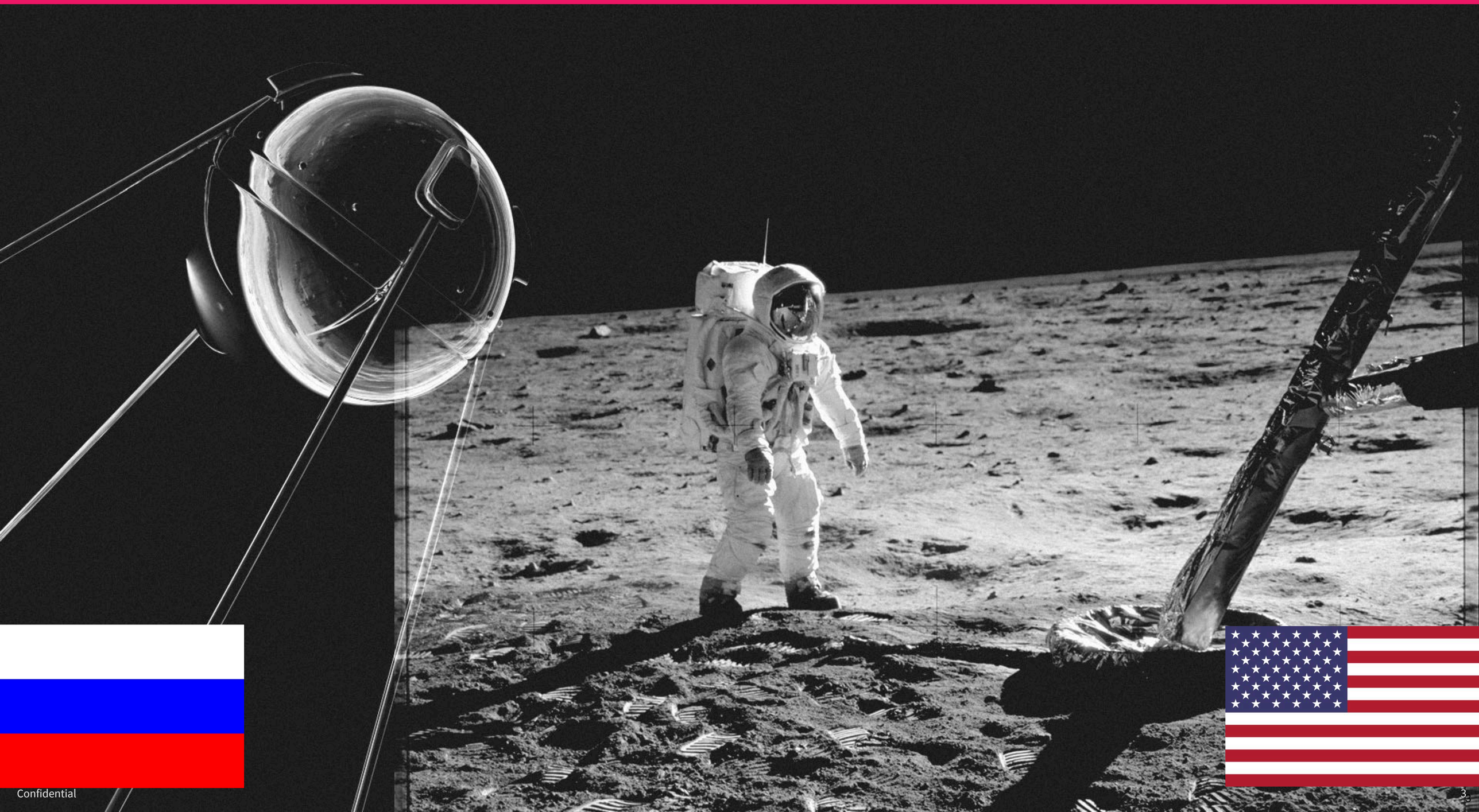
MARK CRAWFORD
Aerospace Engineer
M.S. UCLA, B.S. Math/Physics UCSB

MIKE MICCI, PHD
Advisor
Professor in PenState,
Inventor of MET

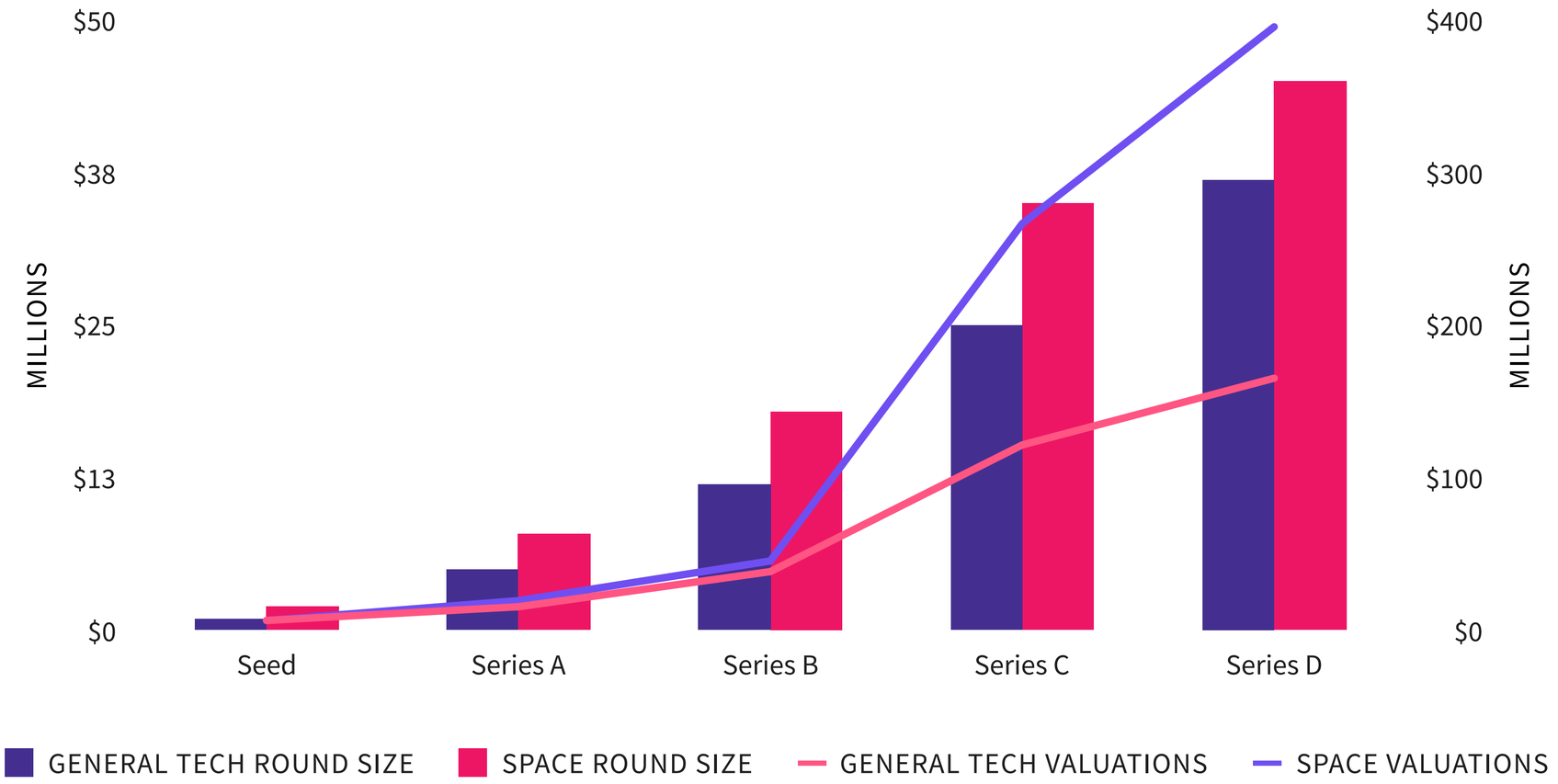
AARON MITCHELL,
SPACE SYSTEMS ENGINEER
Former JPL

MATT PARMAN
Aerospace Engineer

MIKHAIL KOKORICH
President & Founder
Founded two billion dollars companies
Created 3 space companies, launched 10 satellites

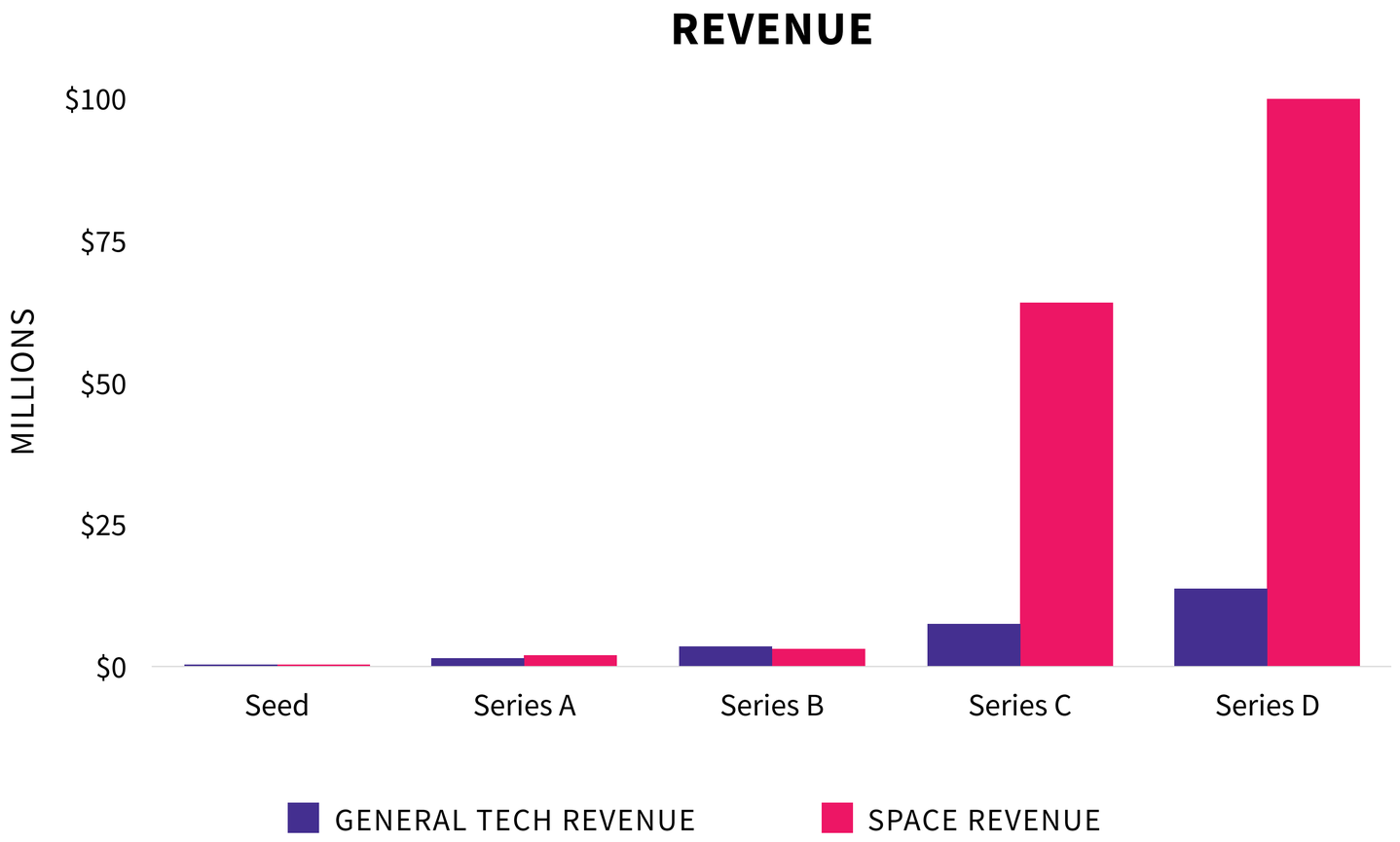


INVESTING IN SPACE VS. GENERAL TECHNOLOGY



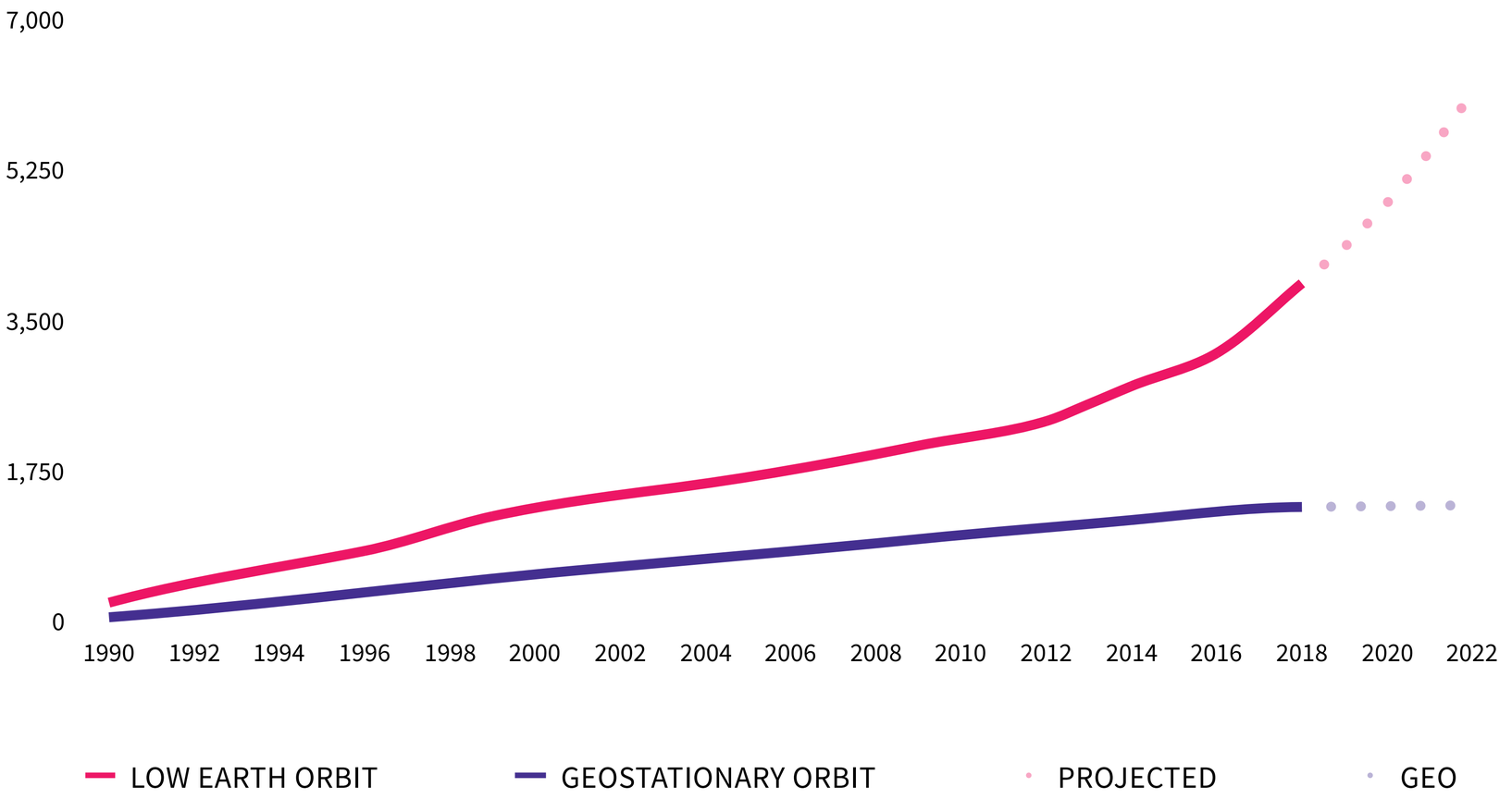
SOURCE: SPACE ANGELS

INVESTING IN SPACE VS. GENERAL TECHNOLOGY



SOURCE: SPACE ANGELS

CUMULATIVE SATELLITES LAUNCHED BY ORBIT



SOURCE: SPACE ANGELS

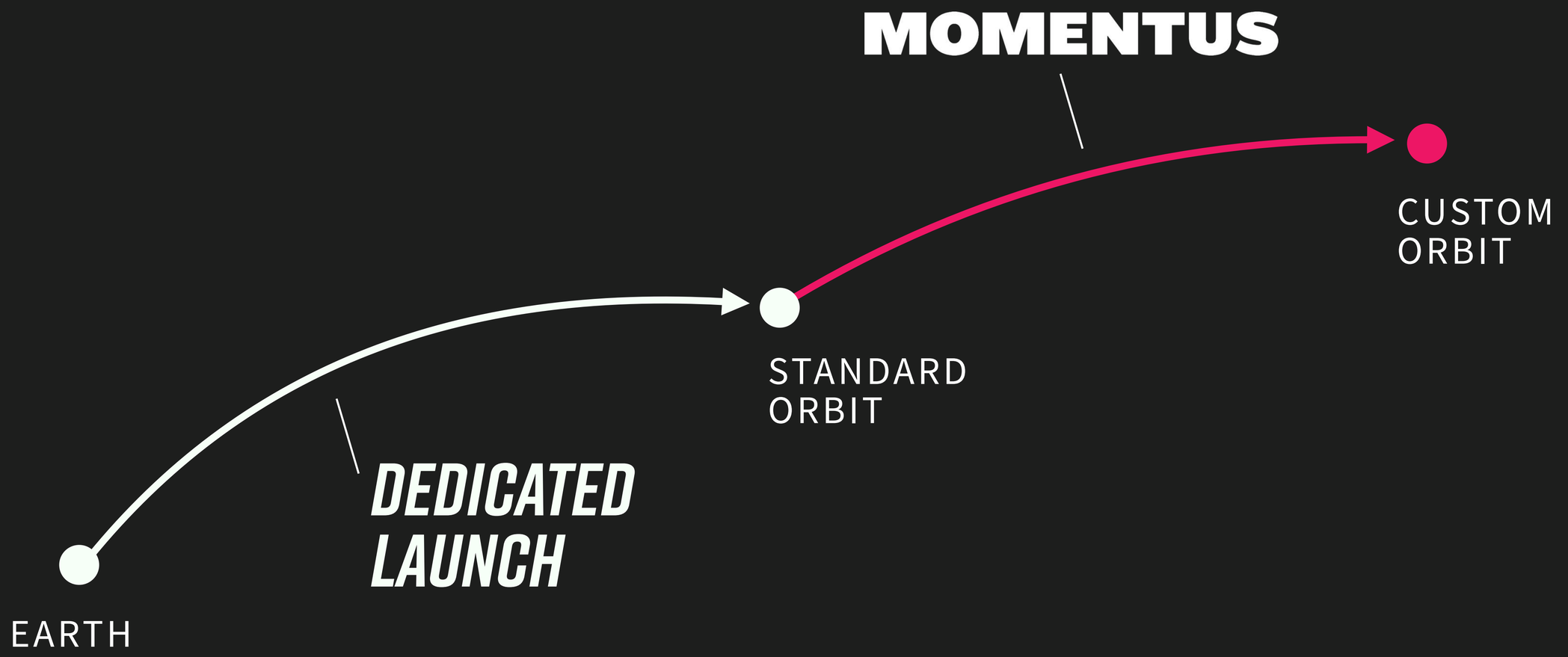
DESTINATION

ORIGIN


DESTINATION
DIRECT FLIGHT
ORIGIN


STANDARD
ORBIT
DEDICATED
LAUNCH
EARTH

CUSTOM
ORBIT


MOMENTUS
CUSTOM
ORBIT
STANDARD
ORBIT
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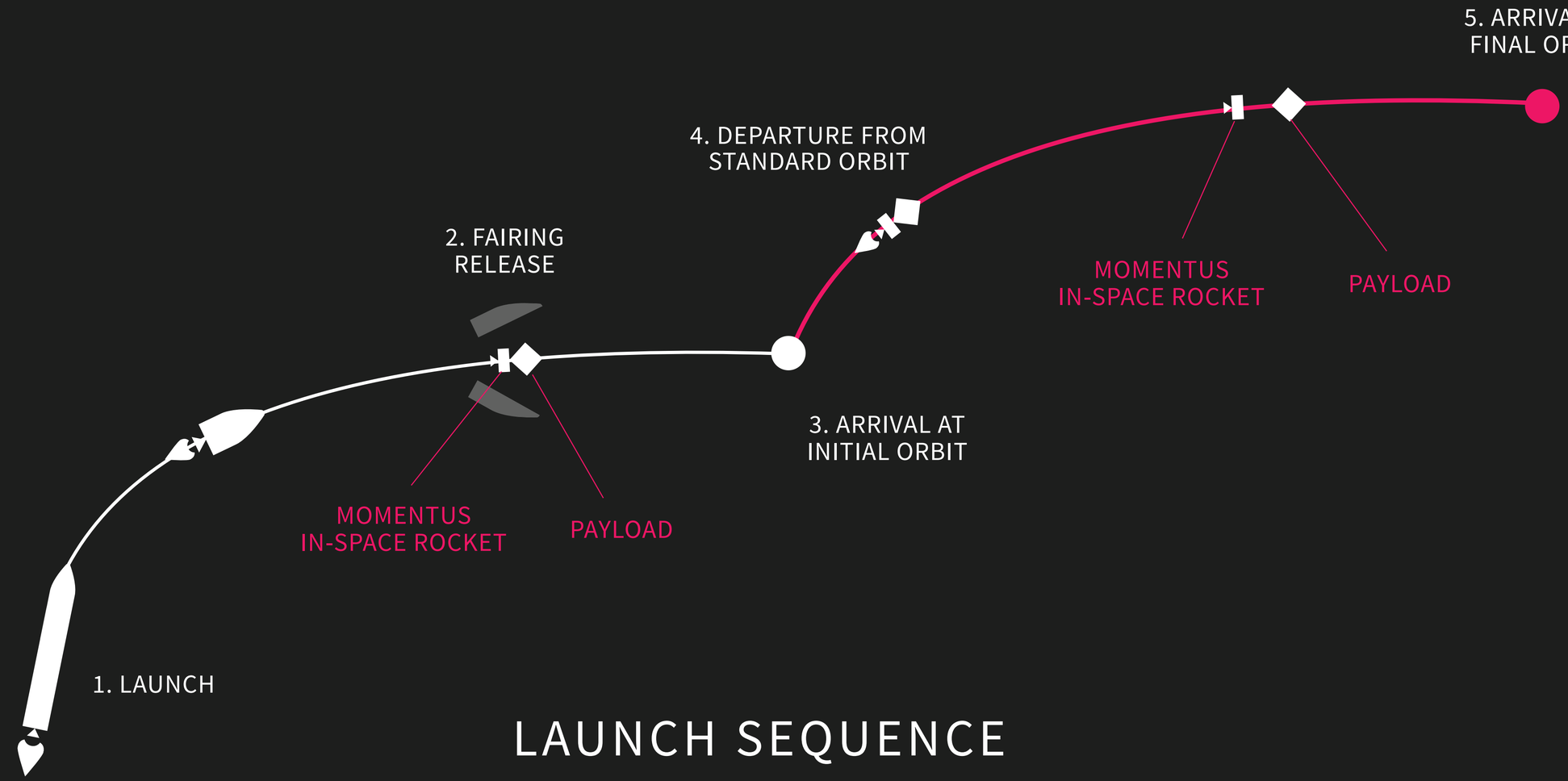
LAUNCH
EARTH

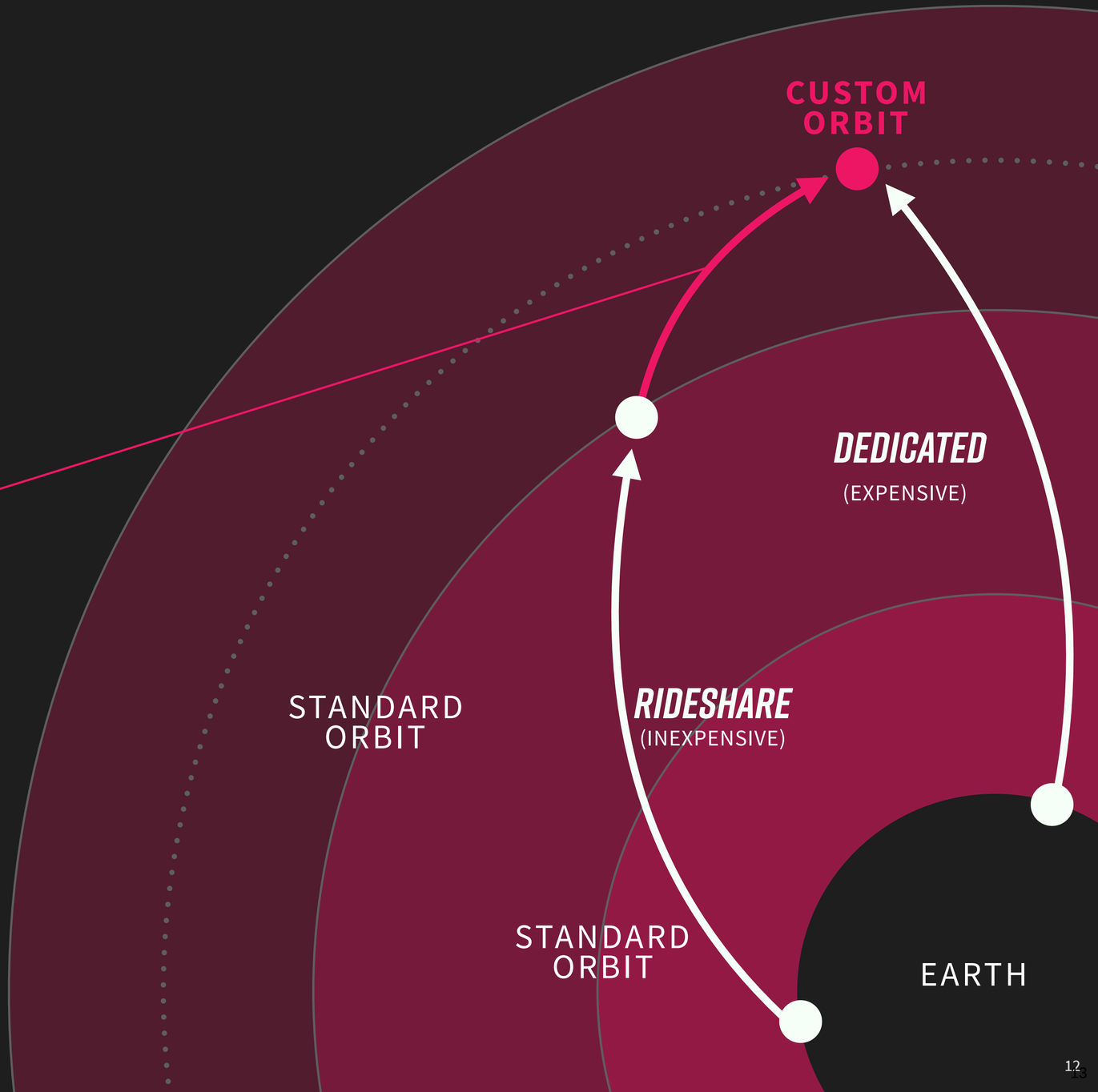
IN-SPACE CONNECTING FLIGHTS



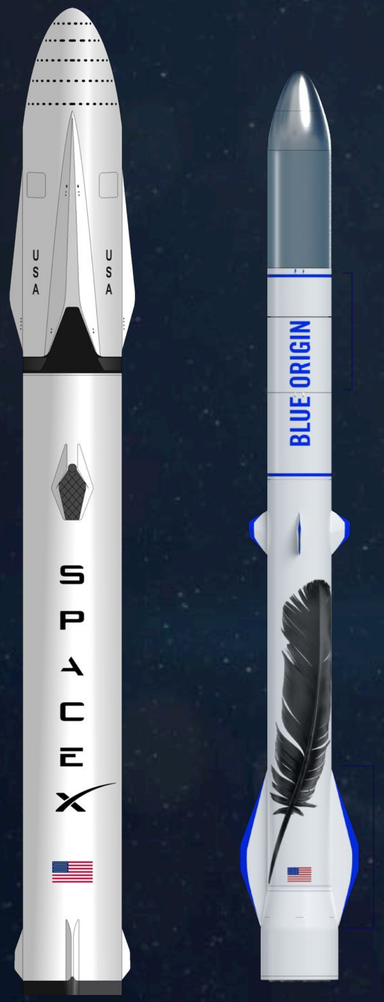
LAUNCH SEQUENCE

THE SOLUTION

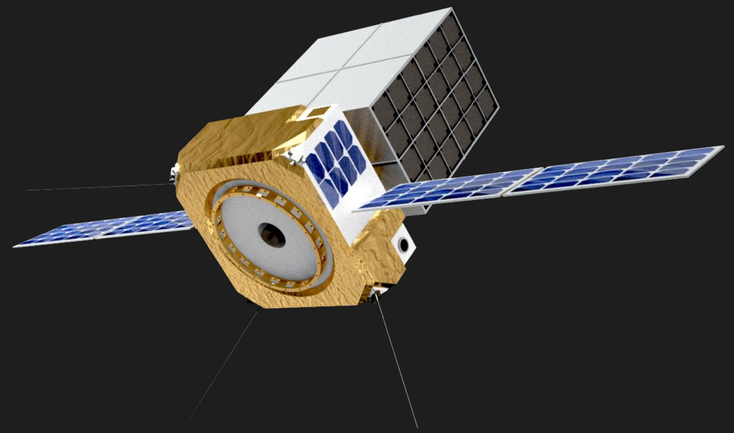
MOMENTUS



PERFECT COMPLEMENTARY SERVICES

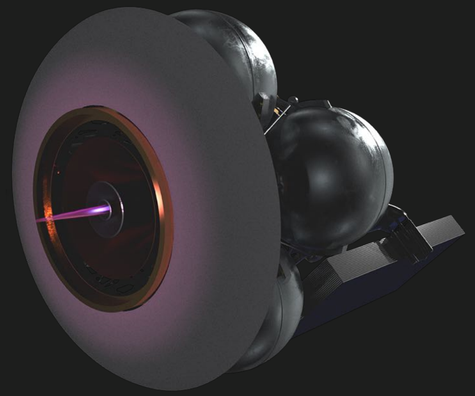


SERVICES



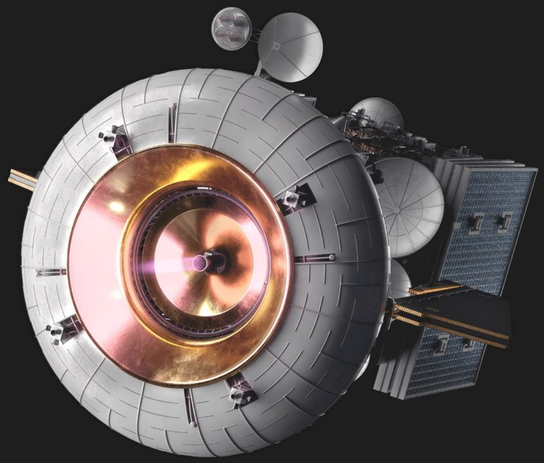
VIGORIDE

2020



ARDORIDE

2021



FERVORIDE

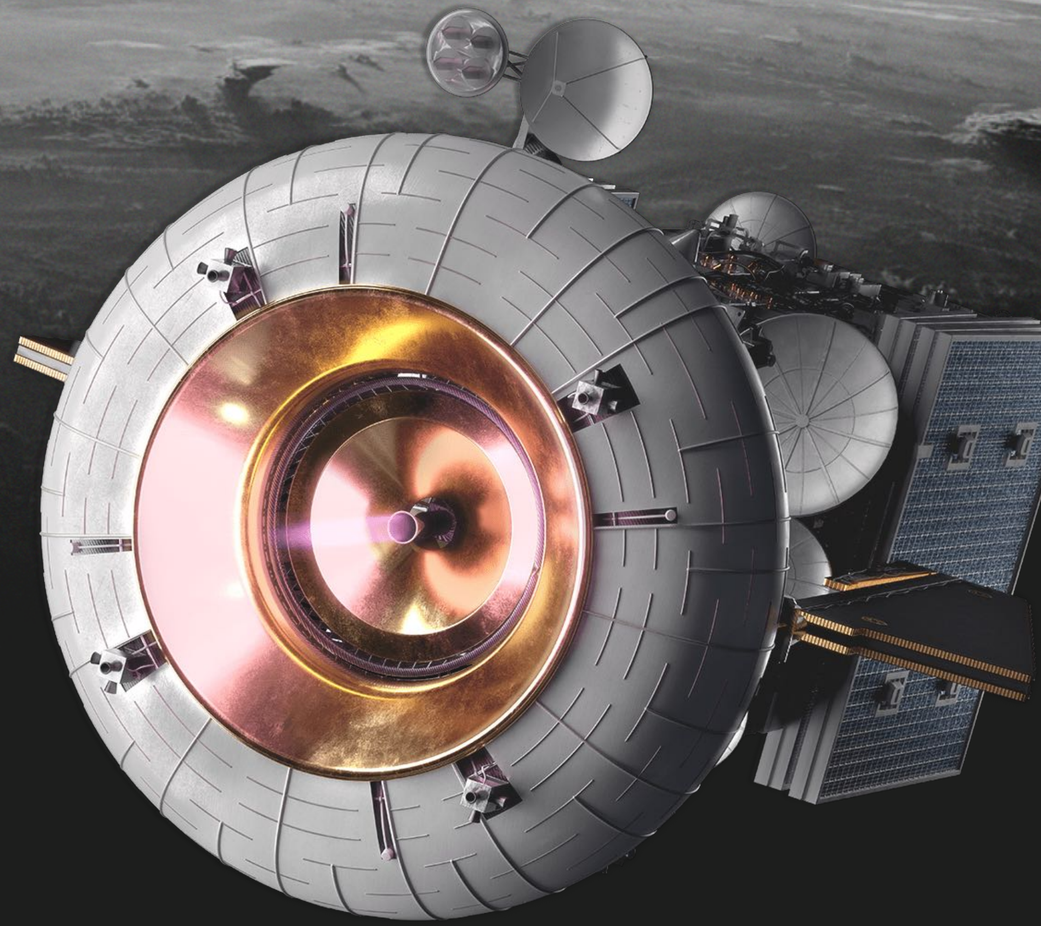
2022

0-300KG → **500-1,000**KG → **5,000-10,000**KG

MOMENTUS

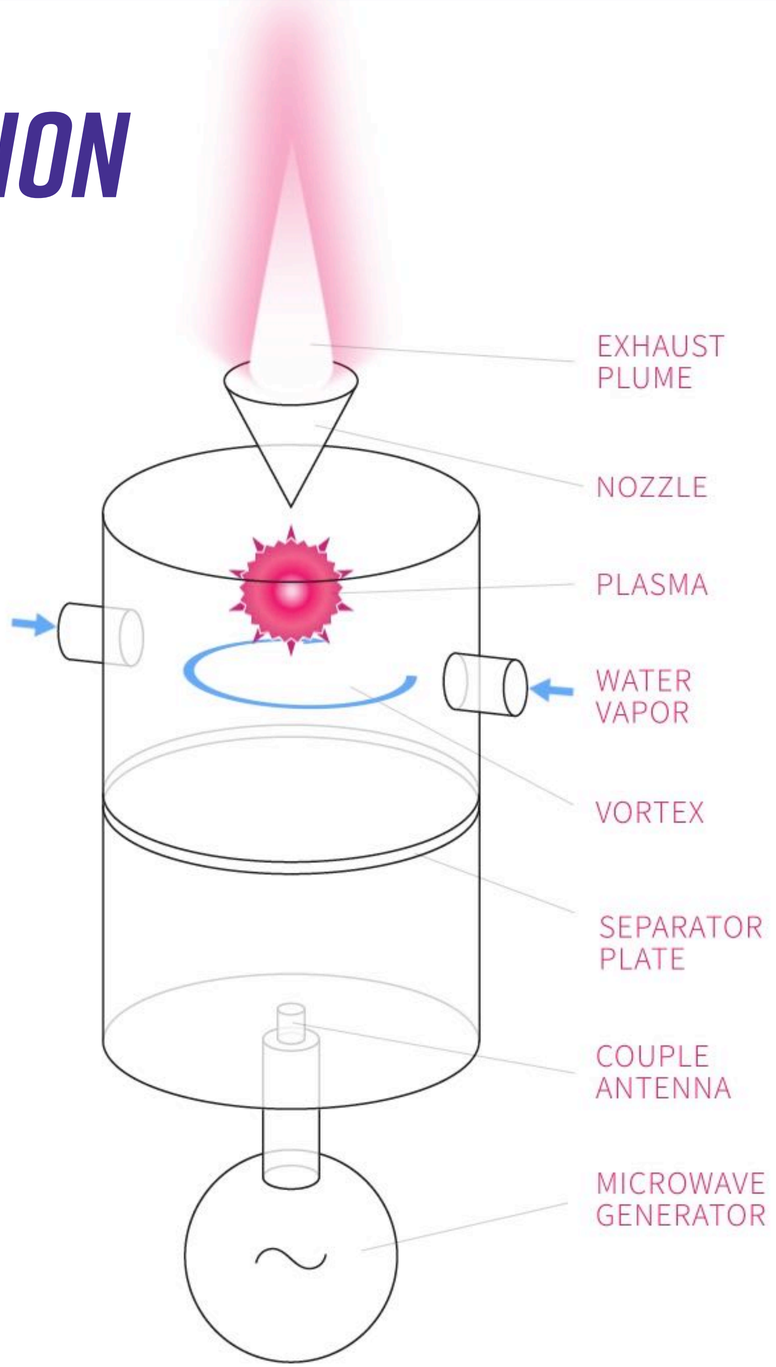
MISSION

To provide the most effective and affordable in-space transportation services supplied by resources available in deep space.



WATER PLASMA PROPULSION

- More efficient—3-4 times more than chemical rockets.
- More affordable—using water as a propellant radically reduces cost.
- Faster—3-4 times faster than ion.
- Safer—water less volatile than other propellants.

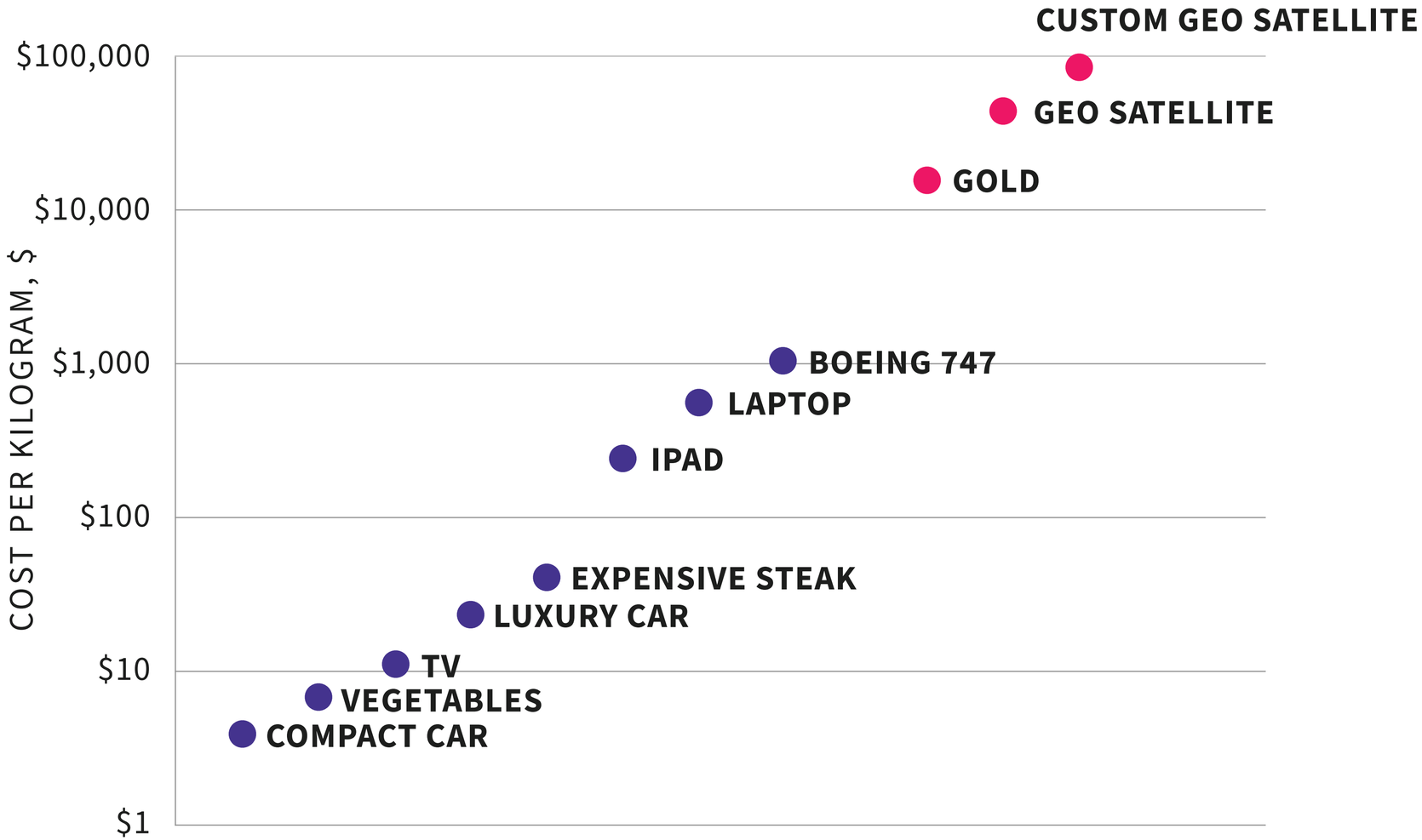


UNTIL NOW

SATELLITES

HAVE BEEN

WORTH THEIR WEIGHT IN GOLD



HOW DID THIS HAPPEN?

THE TYRANNY OF SPACE TRANSPORTATION COSTS

HIGH TRANSPORTATION COSTS

INFREQUENT LAUNCHES

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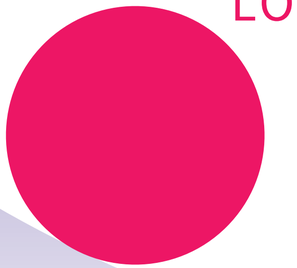
HIGHER LAUNCH COSTS

DEMAND FOR
LONGER MISSION LIFE



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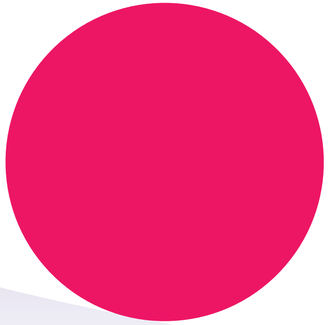
ADDITIONAL MISSION
REQUIREMENTS



HIGH TRANSPORTATION COSTS

INFREQUENT LAUNCHES

NEED FOR EXTREME RELIABILITY

HIGHER LAUNCH COSTS

DEMAND FOR
LONGER MISSION LIFE

HOW DID THIS HAPPEN?

THE TYRANNY OF SPACE TRANSPORTATION COSTS

ADDITIONAL MISSION
REQUIREMENTS

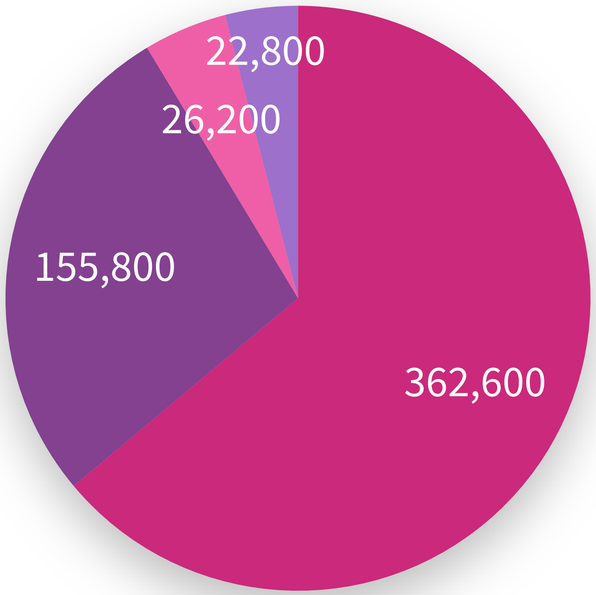
UNAFFORDABLE
SYSTEMS

BUT WHAT DRIVES LAUNCH COST?

- Energy?
- Hardware?
- Labor?

FALCON 9

TOTAL WEIGHT **567,400** KG



DRY MASS

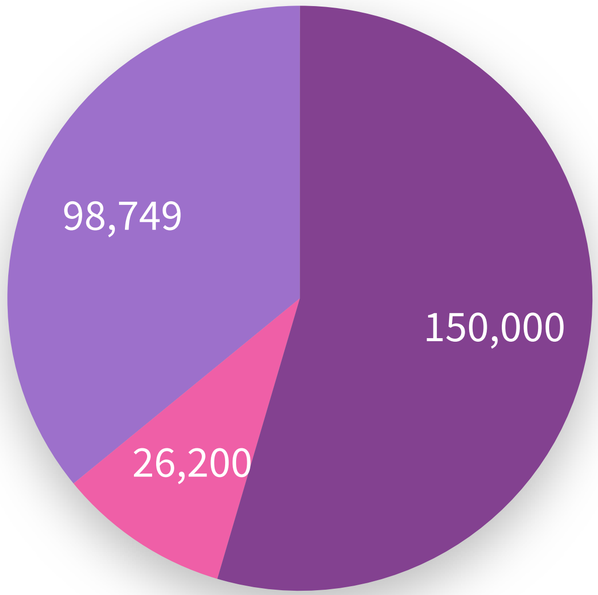
KEROSENE

LIQUID OXYGEN

PAYLOAD

BOEING 747

TOTAL WEIGHT **412,679** KG



Rocket flight can be as cheap as air travel!

BY 2028 SPACE LAUNCH COSTS WILL BE

~ **$500** /KG

BY 2050 SPACE LAUNCH COSTS WILL BE

~ **$10** /KG

WHY NOW?


WHY NOW?
AGILE METHODS PROVEN FOR AEROSPACE


WHY NOW?
THE RISE OF THE BILLIONAIRE VISIONARY

JEFF BEZOS, BLUE ORIGIN, APRIL 2017


WHY NOW?
REUSABLE SPACECRAFT PROVEN

WHY NOW?

PUBLIC-PRIVATE-PARTNERSHIP

PROVEN

WHY NOW?

WATER FROM ASTEROIDS

1999 55992

CHEAPER SPACE TRANSPORTATION

CHANGE IS HERE!

A VIRTUOUS CYCLE OF IMPROVEMENT

CHEAPER SPACE TRANSPORTATION

FREQUENT LAUNCHES

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CHEAPER SPACE TRANSPORTATION

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SHORTER MISSIONS

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INEXPENSIVE SATELLITES

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CHEAPER SPACE TRANSPORTATION

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CONSTANT UPDATE OF TECHNOLOGY

CHANGE IS HERE!

A VIRTUOUS CYCLE OF IMPROVEMENT

CHEAPER SPACE TRANSPORTATION

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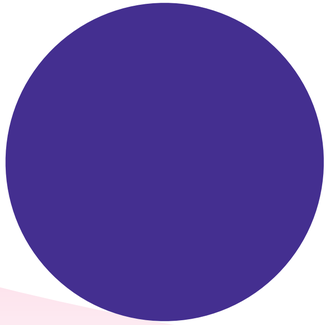
CONSTANT UPDATE OF TECHNOLOGY

ECONOMIES OF SCALE



CHANGE IS HERE!

A VIRTUOUS CYCLE OF IMPROVEMENT

CHEAPER SPACE TRANSPORTATION

FREQUENT LAUNCHES

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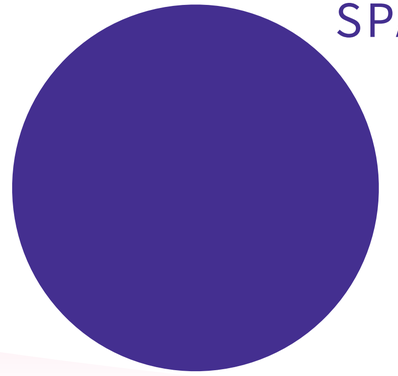
ECONOMIES OF SCALE

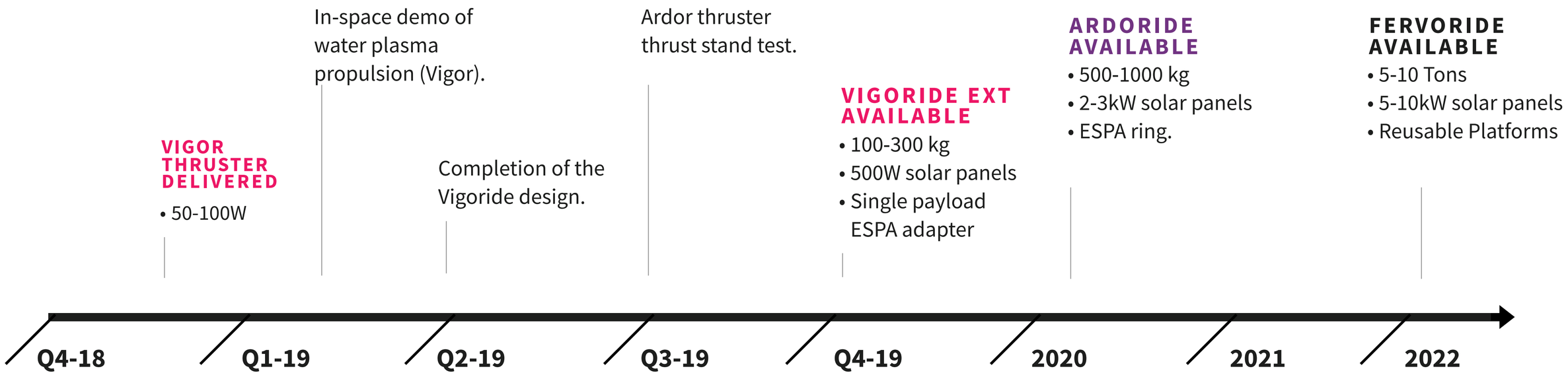
MASSIVE, AFFORDABLE SPACE INDUSTRIES



THE COMING DECADE

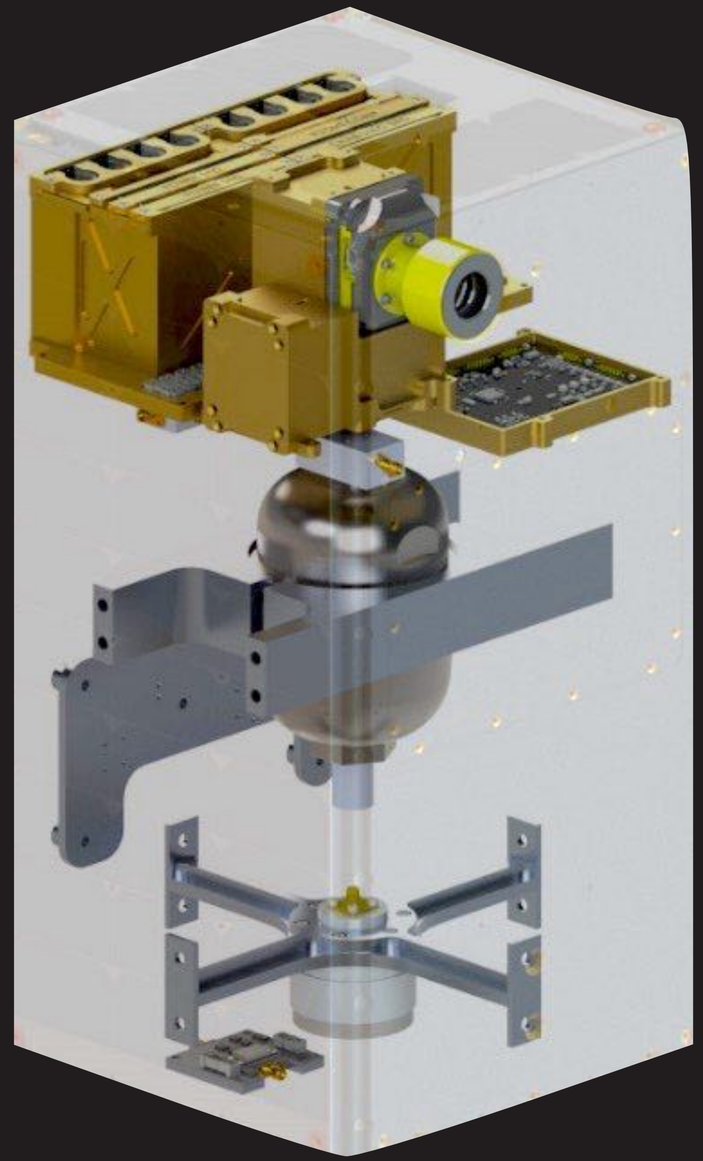
AN EXPLOSION OF NEW INDUSTRIES IN SPACE

ROADMAP


VIGOR THRUSTER DELIVERED
• 50-100W
In-space demo of water plasma propulsion (Vigor).
Completion of the Vigoride design.
Ardor thruster thrust stand test.
VIGORIDE EXT AVAILABLE
• 100-300 kg
• 500W solar panels
• Single payload ESPA adapter
ARDORIDE AVAILABLE
• 500-1000 kg
• 2-3kW solar panels
• ESPA ring.
FERVORIDE AVAILABLE
• 5-10 Tons
• 5-10kW solar panels
• Reusable Platforms
Q4-18
Q1-19
Q2-19
Q3-19
Q4-19
2020
2021
2022

MX-1 MISSION OVERVIEW

- Mission Objective: Flight Demonstration of the Momentus Designed Vigor RF Water Plasma Thruster
- Mission Success: 100 Individual Burns of 1 Minute or More
- Platform: Astro Digital Corvus-16
- Development: 4 Month Development Program
- Duration: 6 Months on Orbit
- Program Format: Mission as a Service

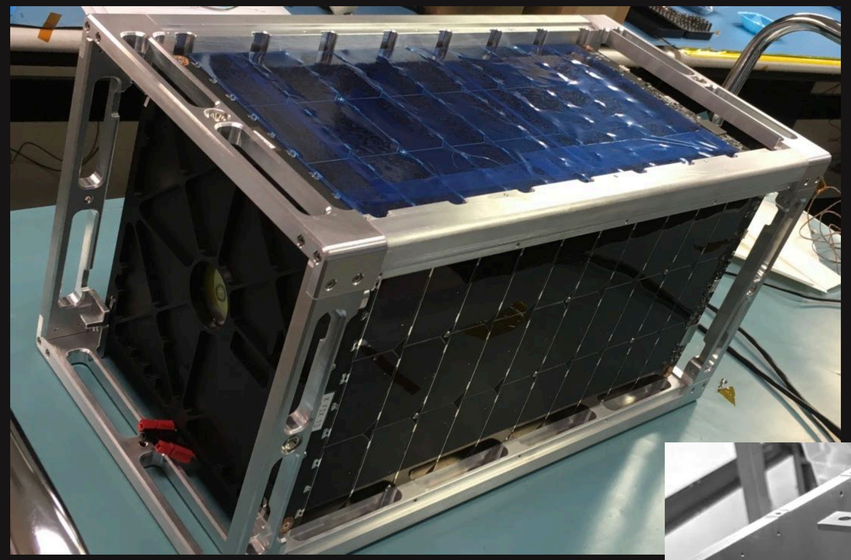


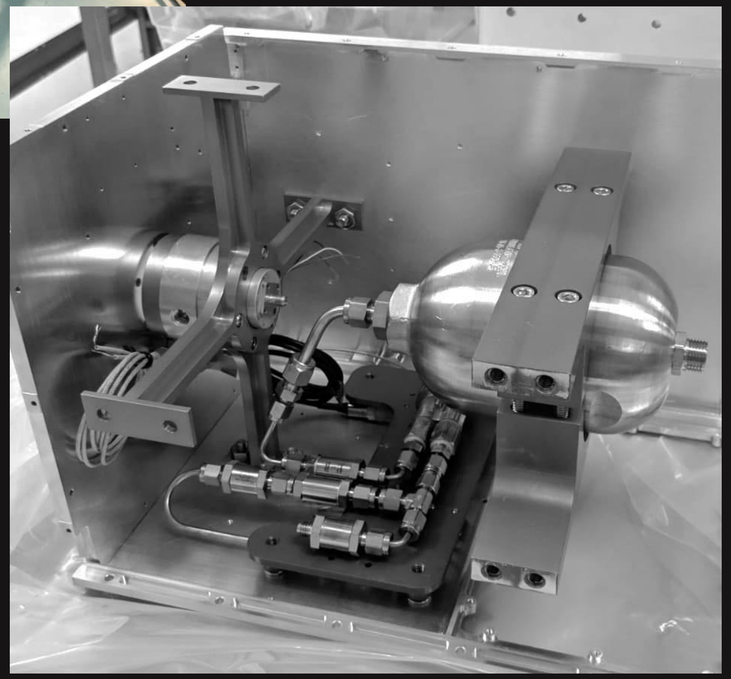
ASTRO DIGITAL

MOMENTUS

OUR FIRST MISSION

- Title: Momentus X1 (MX-1)
- In-space technology demonstration less than one year from company formation
- First flight demo of microwave electrothermal water plasma powered thrusters in space
- Launch: Q1 2019 on Soyuz



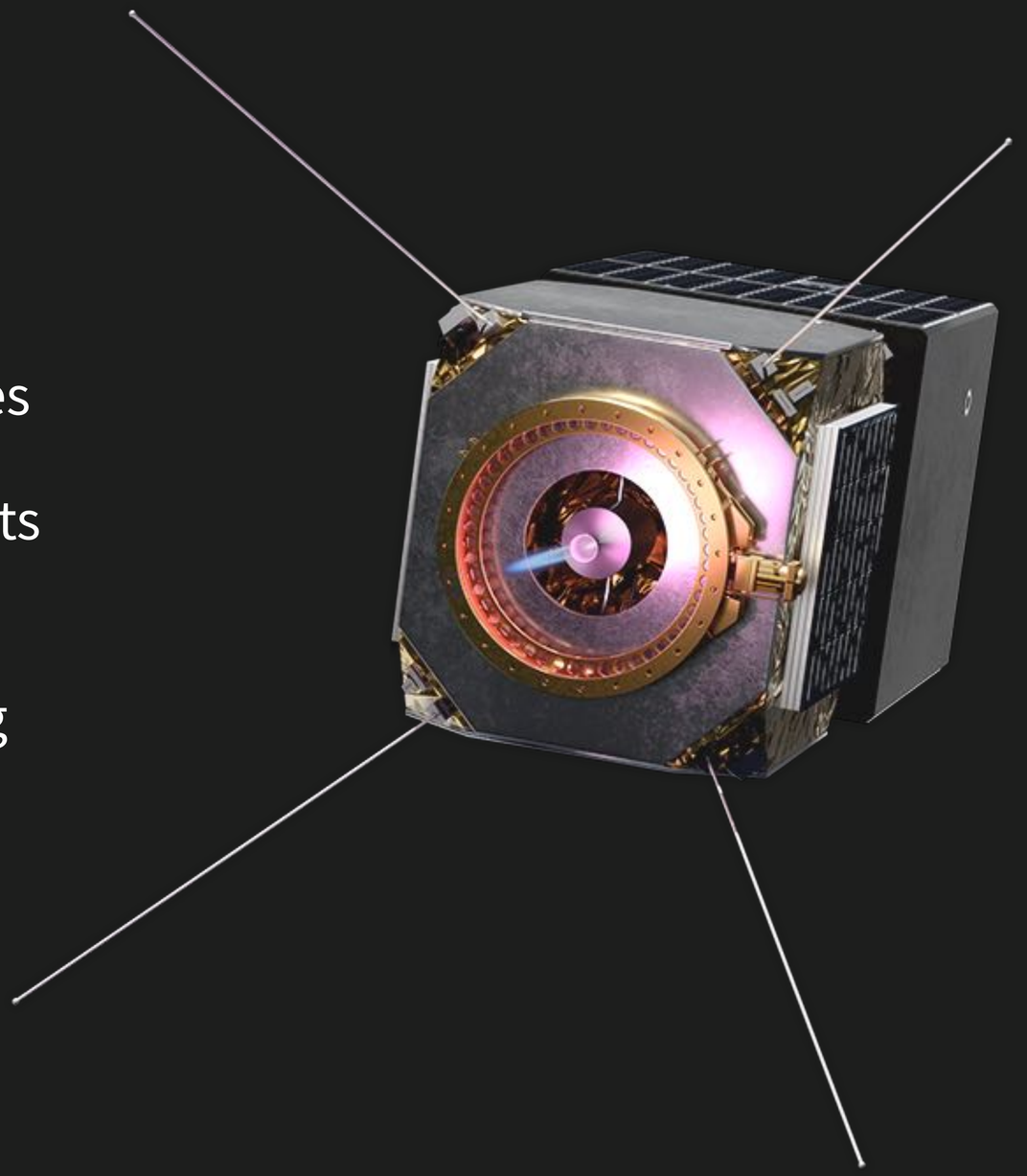


FLIGHT PROPULSION SYSTEM DELIVERED NOV 22, 2018

INTRODUCING

VIGORIDE™

- Up to 1 km/sec ΔV for spacecraft in LEO enables
- Significantly expanded mission life for CubeSats and small satellite missions
- More complex mission architectures, including orbit plane spacing for constellations
- Vastly expanded orbits and planes reachable from ISS, PSLV, and small satellite launch vehicles

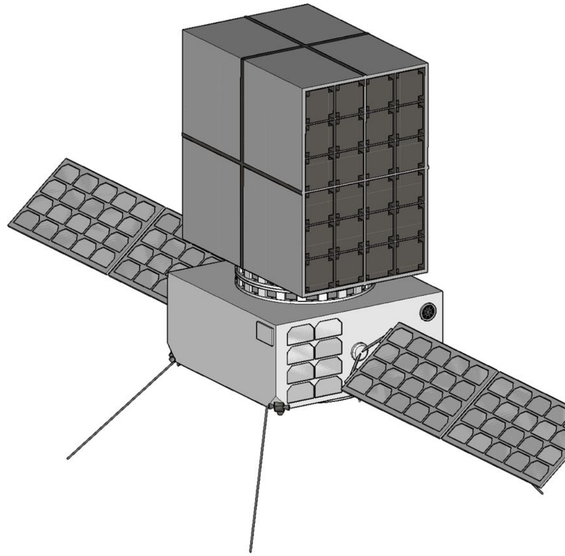


AS SAFE AS IT GETS

- Vigoride has several safety advantages which make it ideal for in-space commerical operations:
  - Propellant Toxicity: De-ionized water, completely non-toxic
  - Maximum Pressure: 1 atm baseline (alternate concepts up to 3 atm)
  - Highest Voltage: 28 V (alternate concepts at 48 V)
  - Maximum Battery Capacity: 100 Whr (Li-ion)

VIGORIDE HAS NO SIGNIFICANT HAZARDOUS MATERIAL OR COMPONENTS

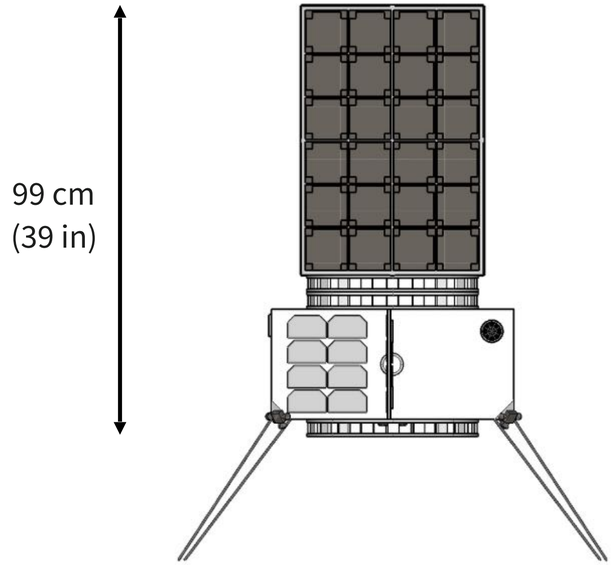
VIGORIDE SYSTEM CONCEPT

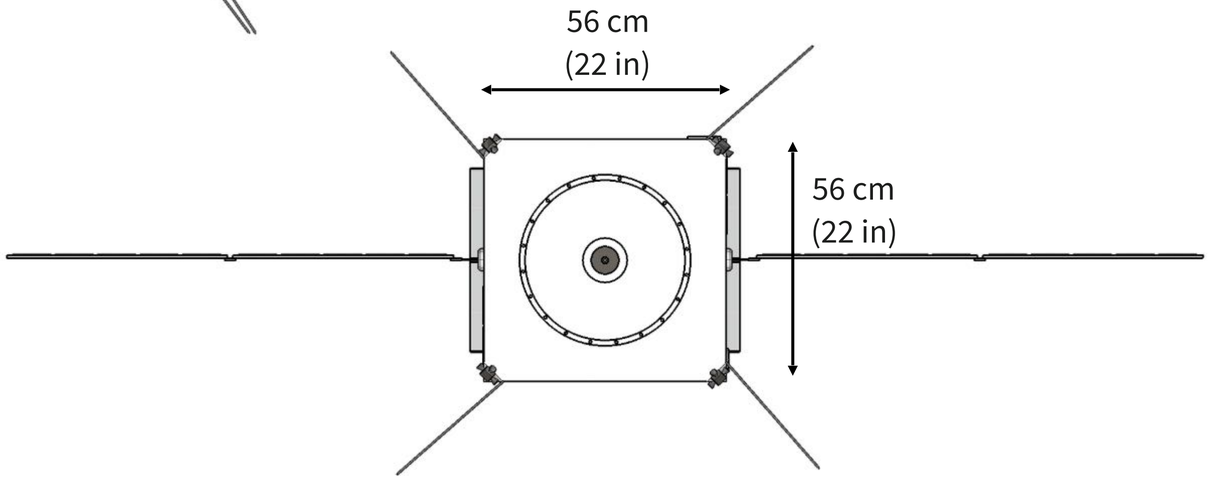


2020

0-300KG
~1 KM/SEC

$1.2 M

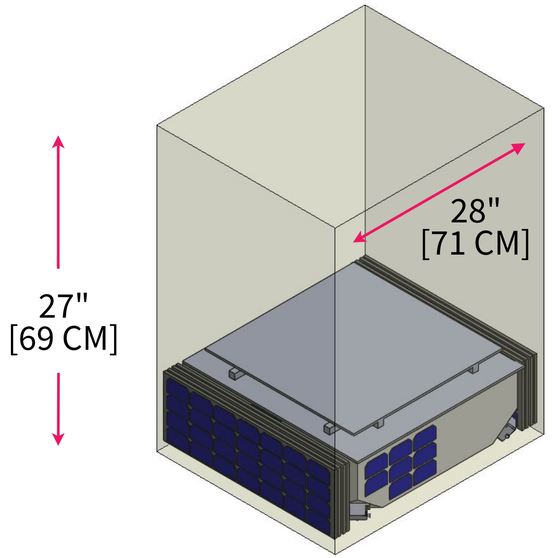




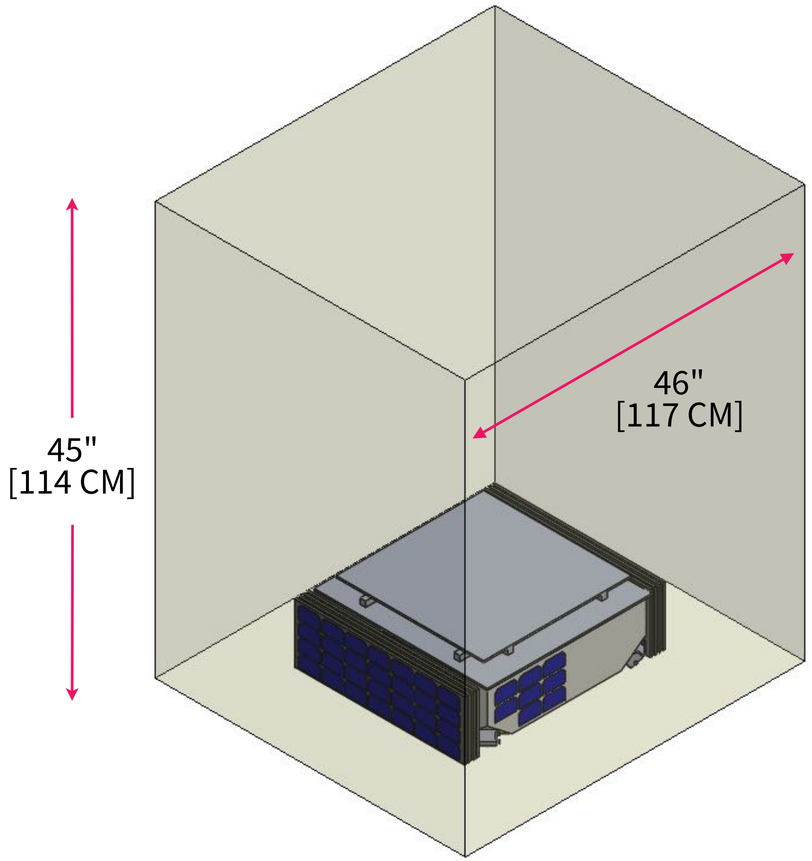
APPLICATIONS

Micro-satellites boosting
Nano-satellites clusters boosting
Platform for deorbiting services
Platform for in-orbit maintenance
Small deep space missions
In-space booster stage for small rockets

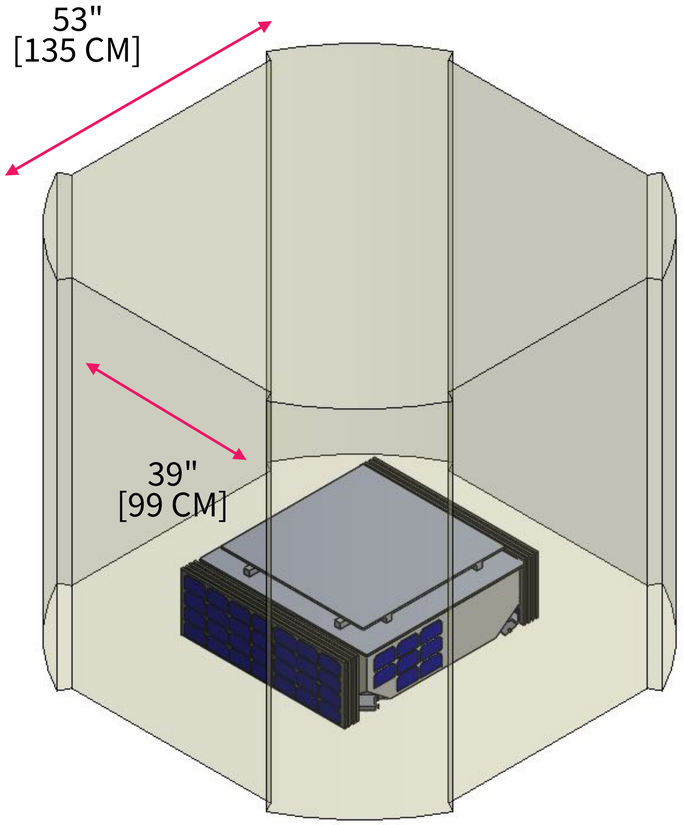
PAYLOAD VOLUME ENVELOPE



ESPA VOLUME ENVELOPE



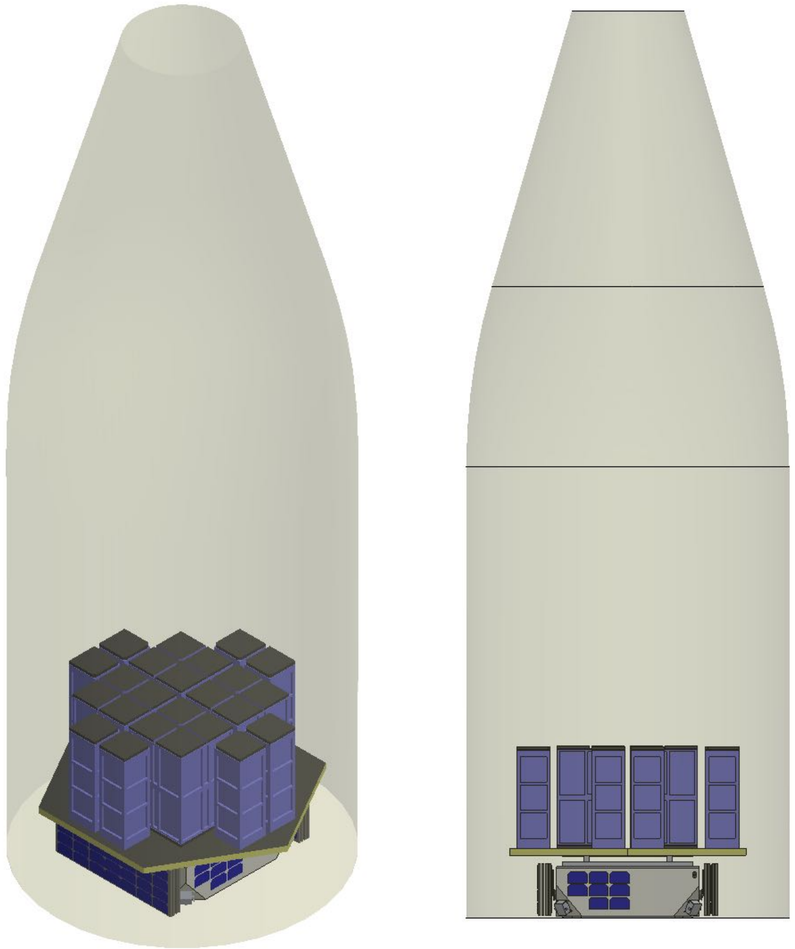
ESPA GRANDE VOLUME ENVELOPE



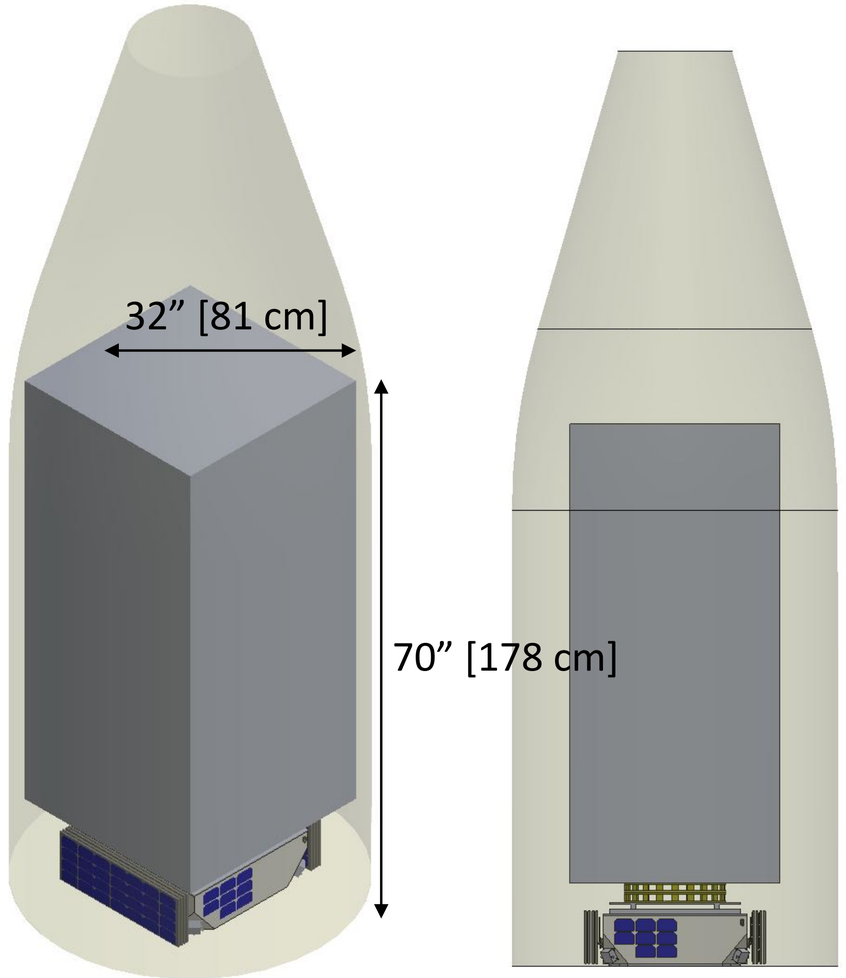
BISHOP AIRLOCK VOLUME ENVELOPE

VIGORIDE COMPATIBLE WITH ALL STANDARD SMALLSAT PAYLOAD ADAPTER INTERFACES (ESPA, BISHOP, PSLV, ELECTRON, ETC)

VIGORIDE IN LAUNCHER ONE FAIRING WITH 24X 3U CUBESATS



VIGORIDE IN LAUNCHER ONE FAIRING WITH MAXIMUM PAYLOAD VOLUME

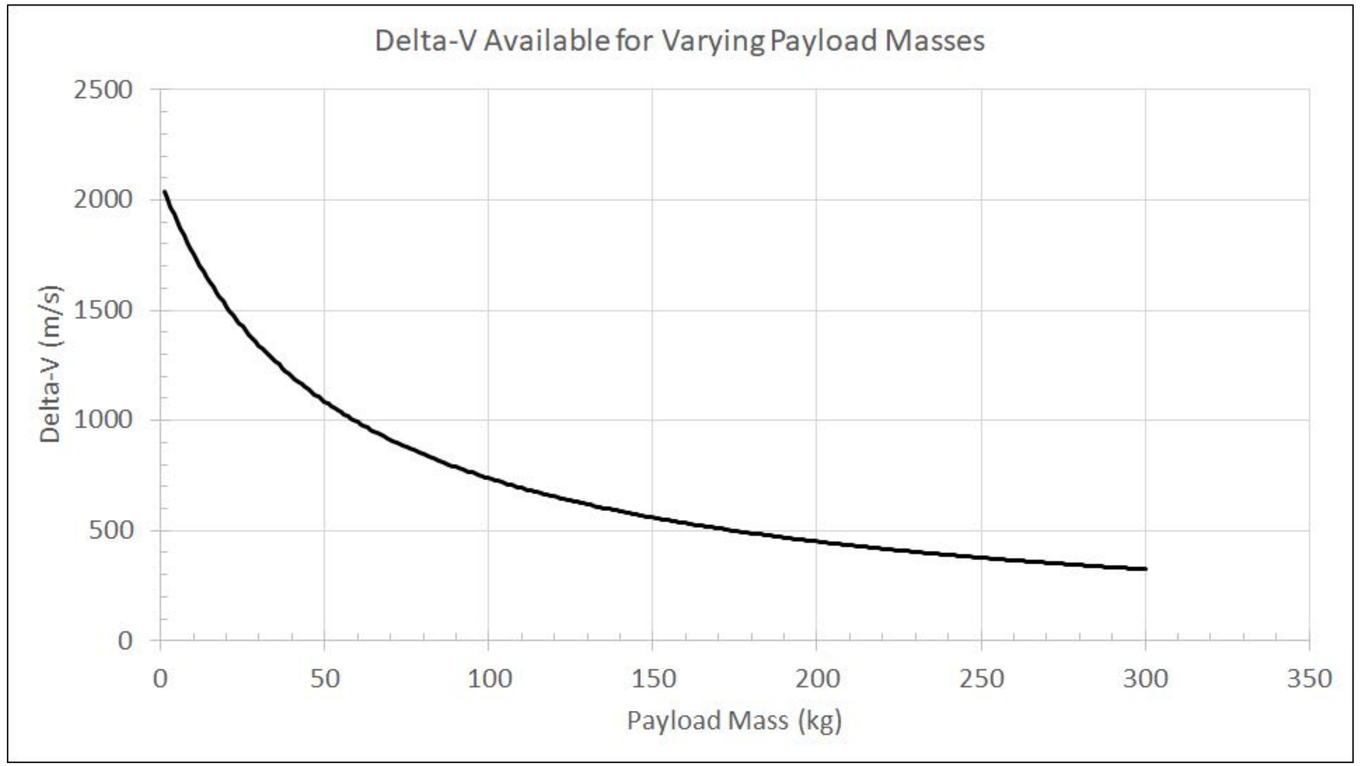


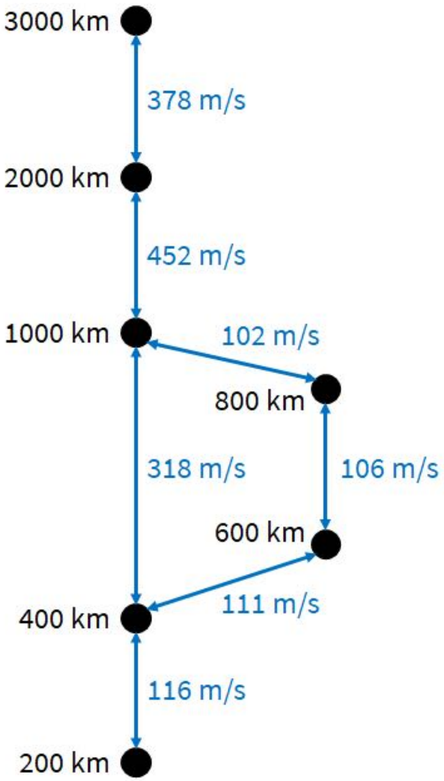
VIGORIDE MISSION PARAMETERS

PARAMETER	VALUE
IN-SPACE DRY MASS	35 KG
MAXIMUM WET MASS WITH PAYLOAD	315 KG
TOTAL IMPULSE CAPABILITY	100,000 N-S
ΔV CAPABILITY FOR 100 KG PAYLOAD	689 M/S
ΔV CAPABILITY FOR 250 KG PAYLOAD	343 M/S
PAYLOAD PERFORMANCE FROM ISS (400 KM) TO 1000 KM	142 KG, 62 DAYS

All mission cases assume de-orbiting to 200 km periapsis

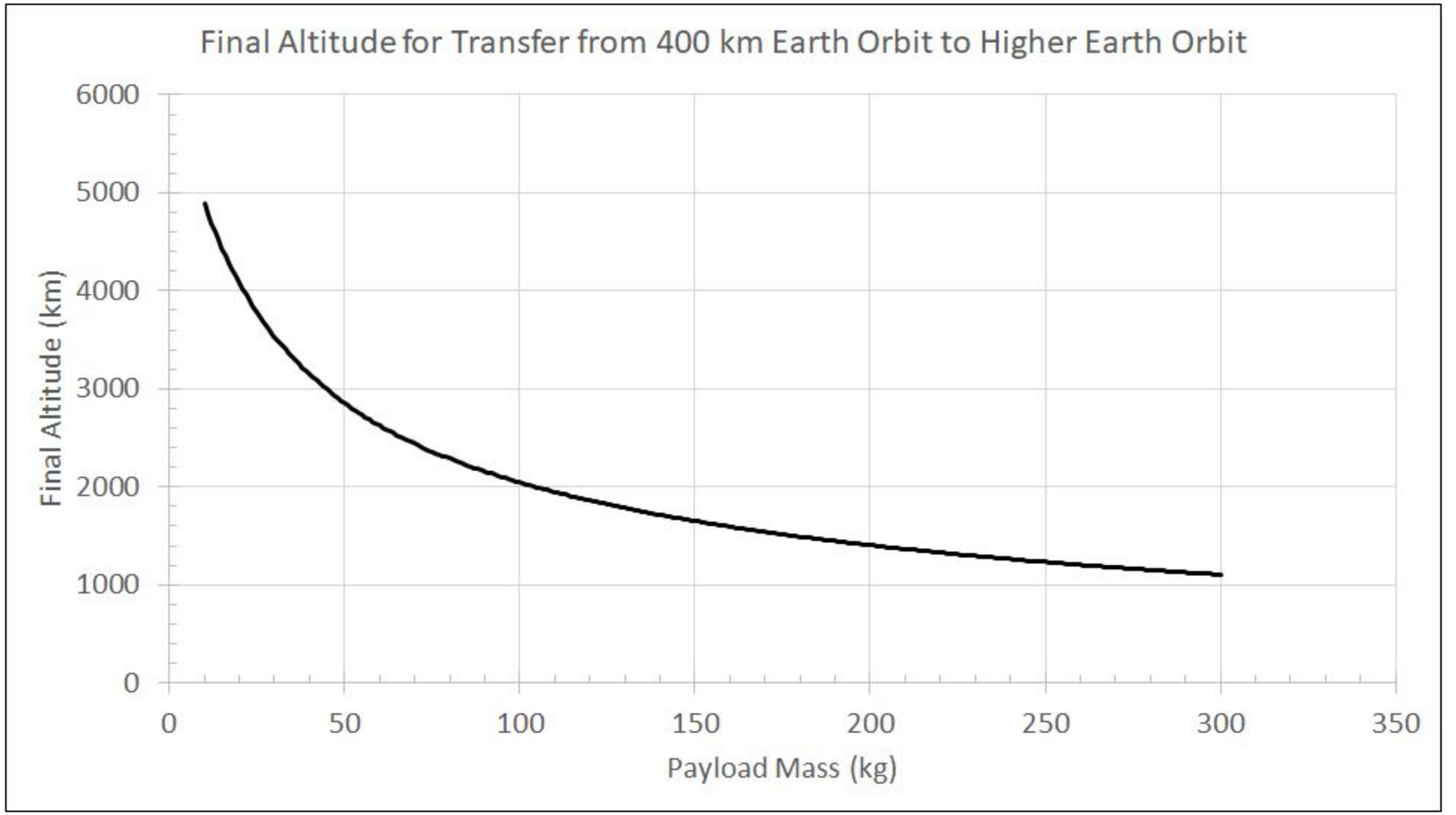
VIGORIDE ΔV PERFORMANCE





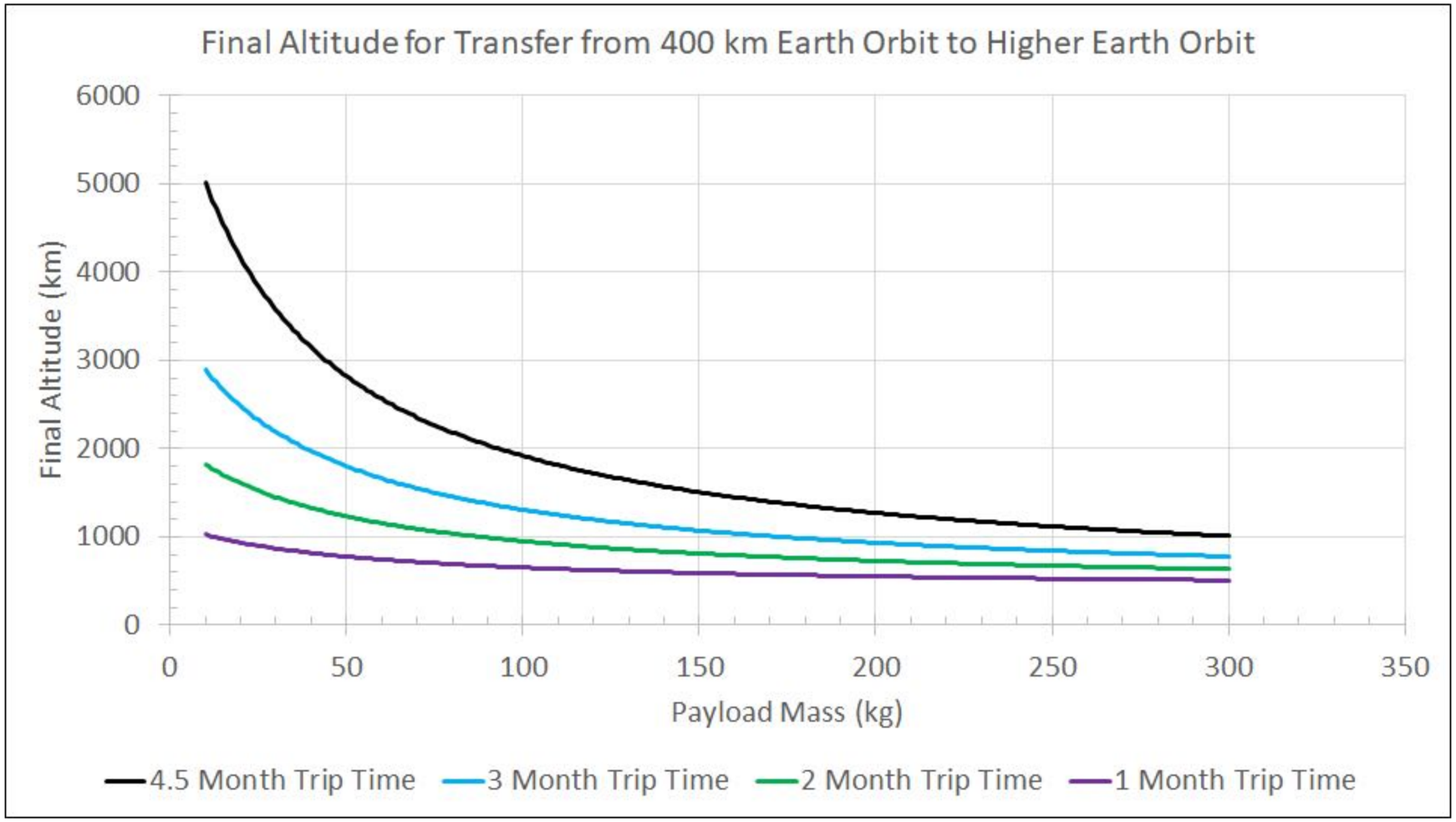
VIGORIDE CAN PROVIDE 1 KM/S FOR 50 KG PAYLOADS OR 500 M/S FOR 150 KG PAYLOADS

VIGORIDE ALTITUDE PERFORMANCE



HIGH LEO AND MEO ACCESS FOR A WIDE VARIETY OF PAYLOADS

VIGORIDE TRIP TIME PERFORMANCE



IF LESS ΔV IS NEEDED, TRIP TIME CAN BE REDUCED

VIGORIDE **EXTENDED** *IN LAUNCHER ONE FAIRING WITH 24X 3U CUBESATS*

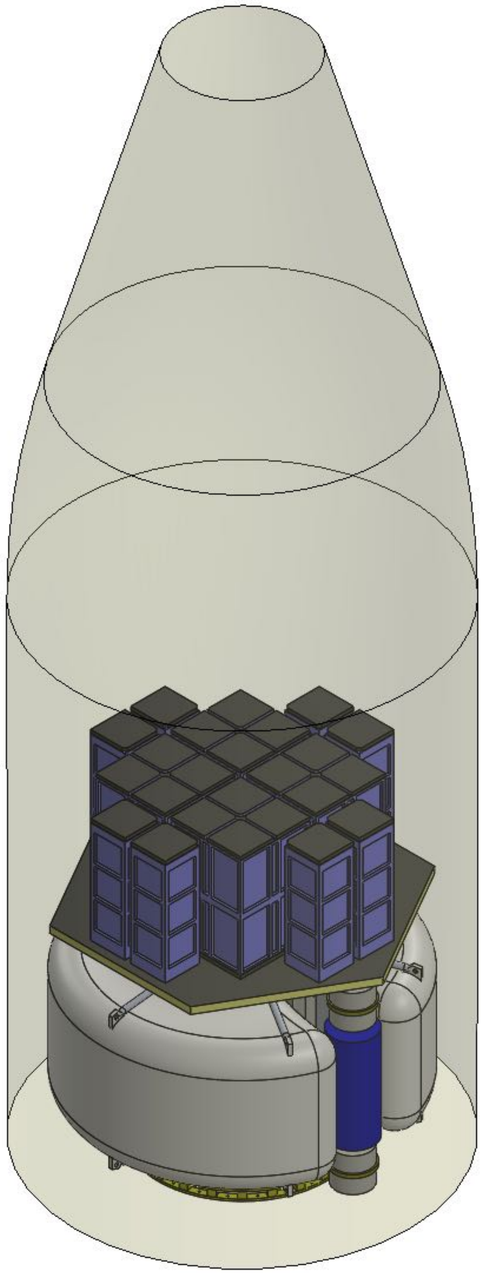
2021

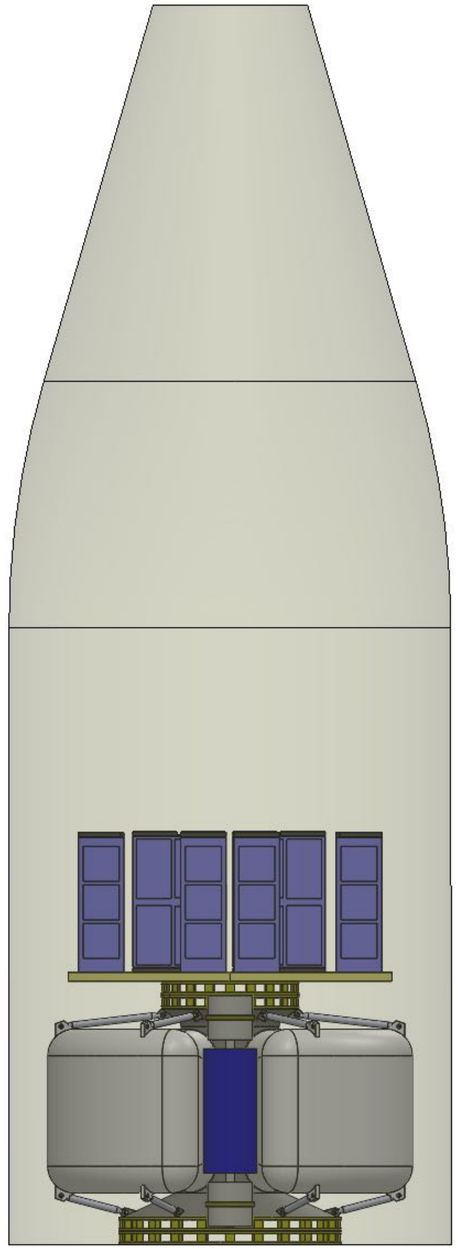
0-300 KG
>5 KM/SEC

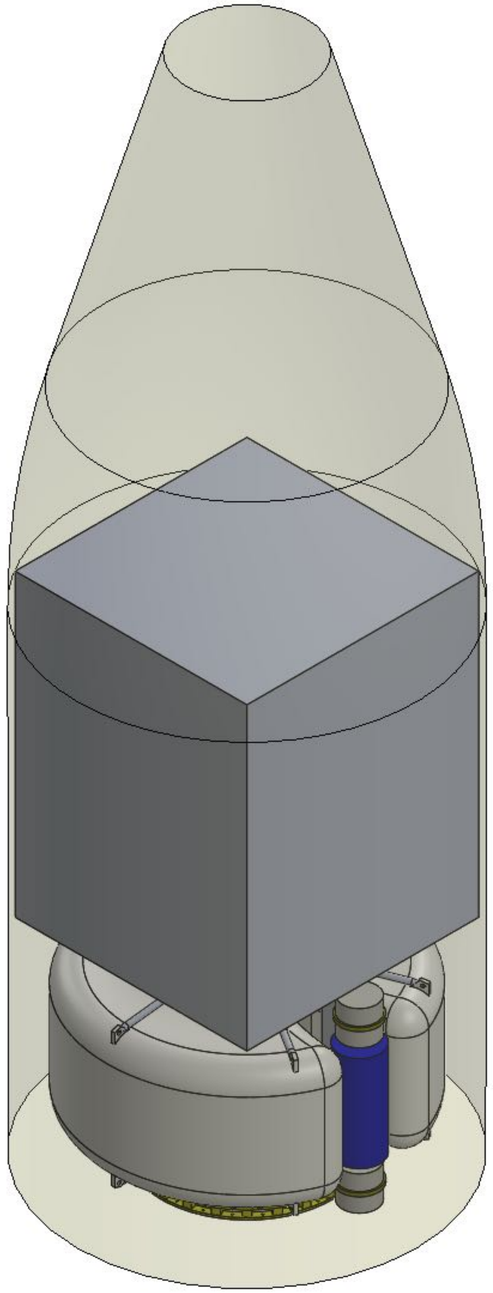
$3.5 M

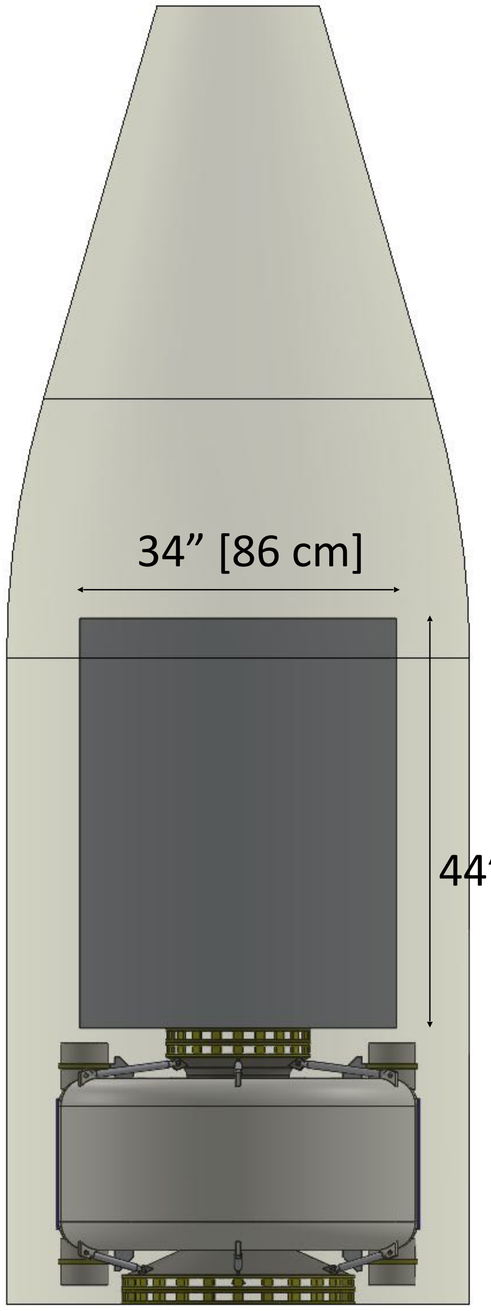
APPLICATIONS

Mini-satellites boosting
Small GEO satellite boosting
Microsatellites clusters boosting
Platform for in-orbit servicing
Deep space missions
(asteroids, lunar, Mars)
Small rocket in-space booster









VIGORIDE EXTENDED IN LAUNCHER ONE FAIRING WITH NOTIONAL MAXIMUM VOLUME PAYLOAD

VIGORIDE EXTENDED MISSION PARAMETERS

PARAMETER	ESPA GRANDE	LAUNCHER ONE
IN-SPACE DRY MASS	135 KG	135 KG
MAXIMUM WET MASS WITH PAYLOAD	700 KG	500 KG
TOTAL IMPULSE CAPABILITY	$2X10^6$ N-S	$1X10^6$ N-S (TYPICAL)
PAYLOAD: LEO TO GTO	300 KG	175 KG
PAYLOAD LEO TO GEO	225 KG	125 KG
PAYLOAD LEO TO LUNAR ORBIT	150 KG	100 KG
PAYLOAD TO ESCAPE	100 KG	75 KG
MAIN THRUSTER	650 SEC ISP, 0.8 N	650 SEC ISP, 0.8 N

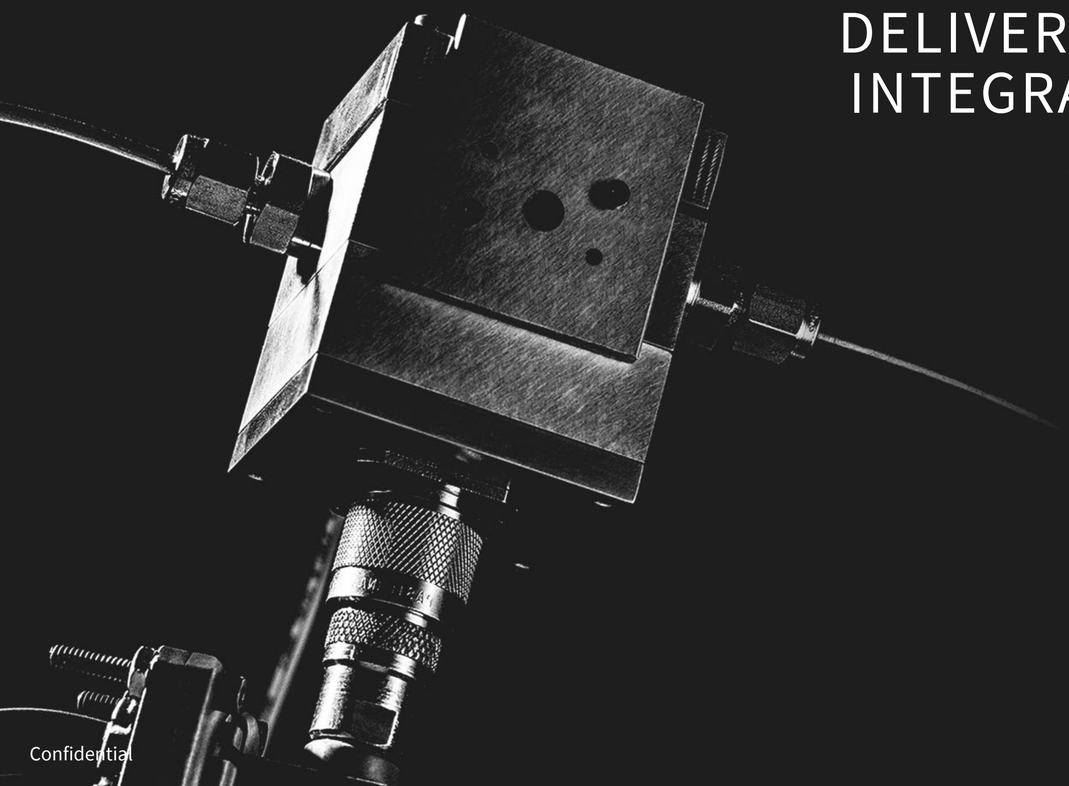
LEO departures from 200 km circular orbit

MOMENTUS IS BUILDING AND FLYING REAL HARDWARE

X1 HARDWARE DELIVERED & INTEGRATED 2018

HIGH POWER VIGORIDE EXTENDED TESTS 2019

VIGORIDE COMMERCIAL SERVICE 2020



13+ CLIENTS

$420 MILLION IN LOI'S

$1 MILLION IN REVENUE

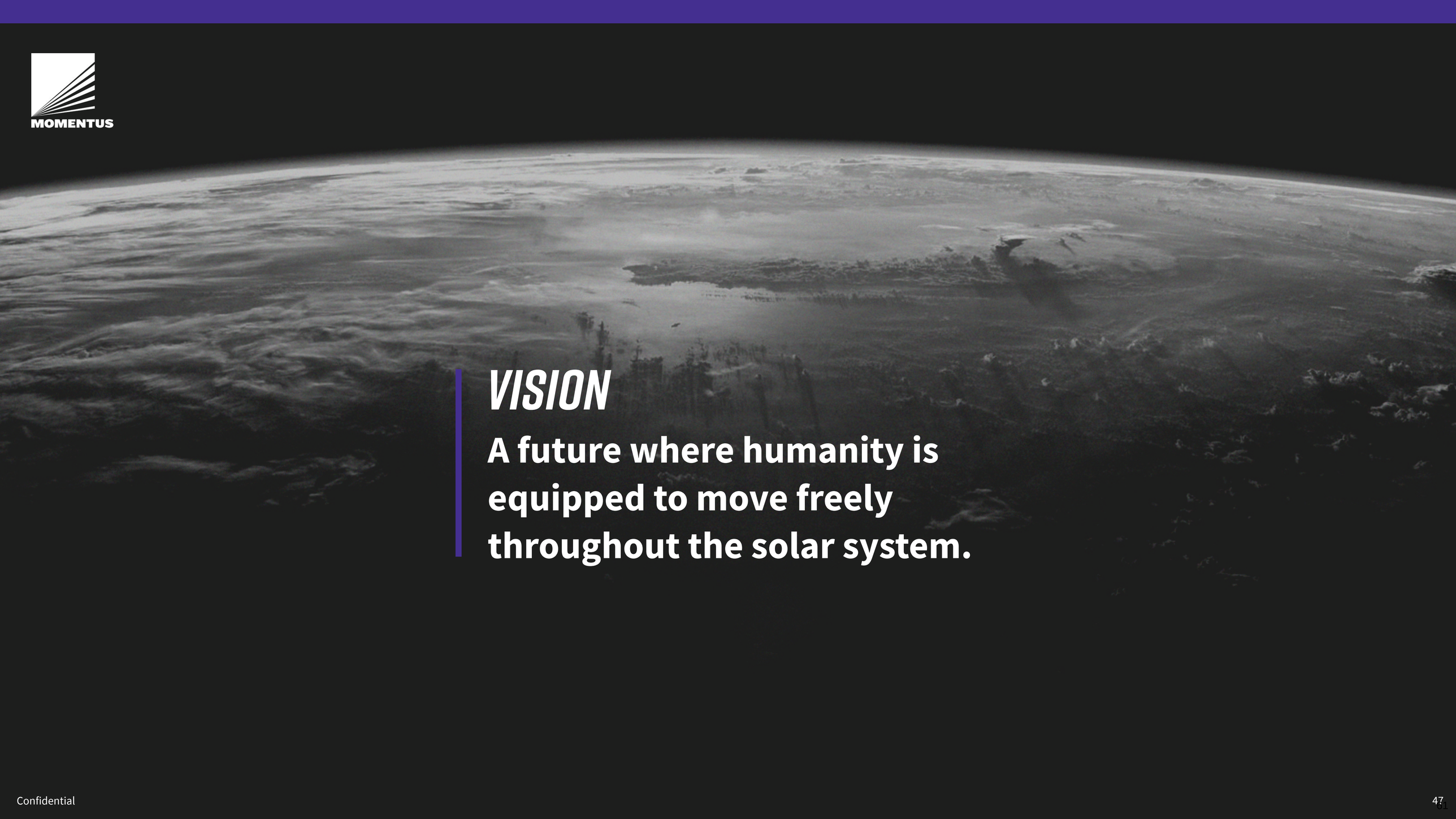
$8.3 MILLION IN SEED

NANORACKS

BLUE CANYON TECHNOLOGIES

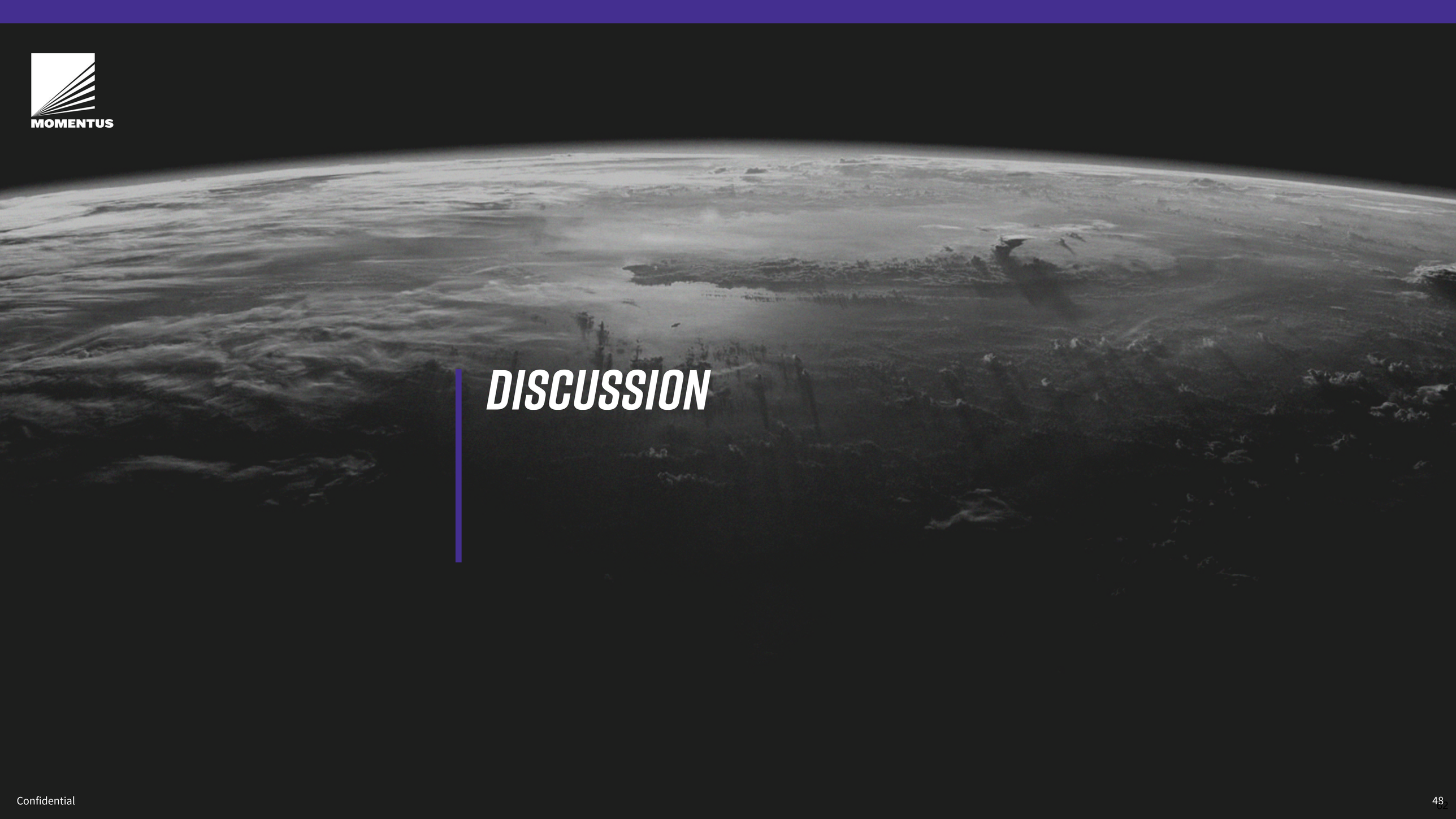
elecnor deimos

ECM LAUNCH SERVICE www.ecm-space.de



VISION

A future where humanity is equipped to move freely throughout the solar system.



DISCUSSION