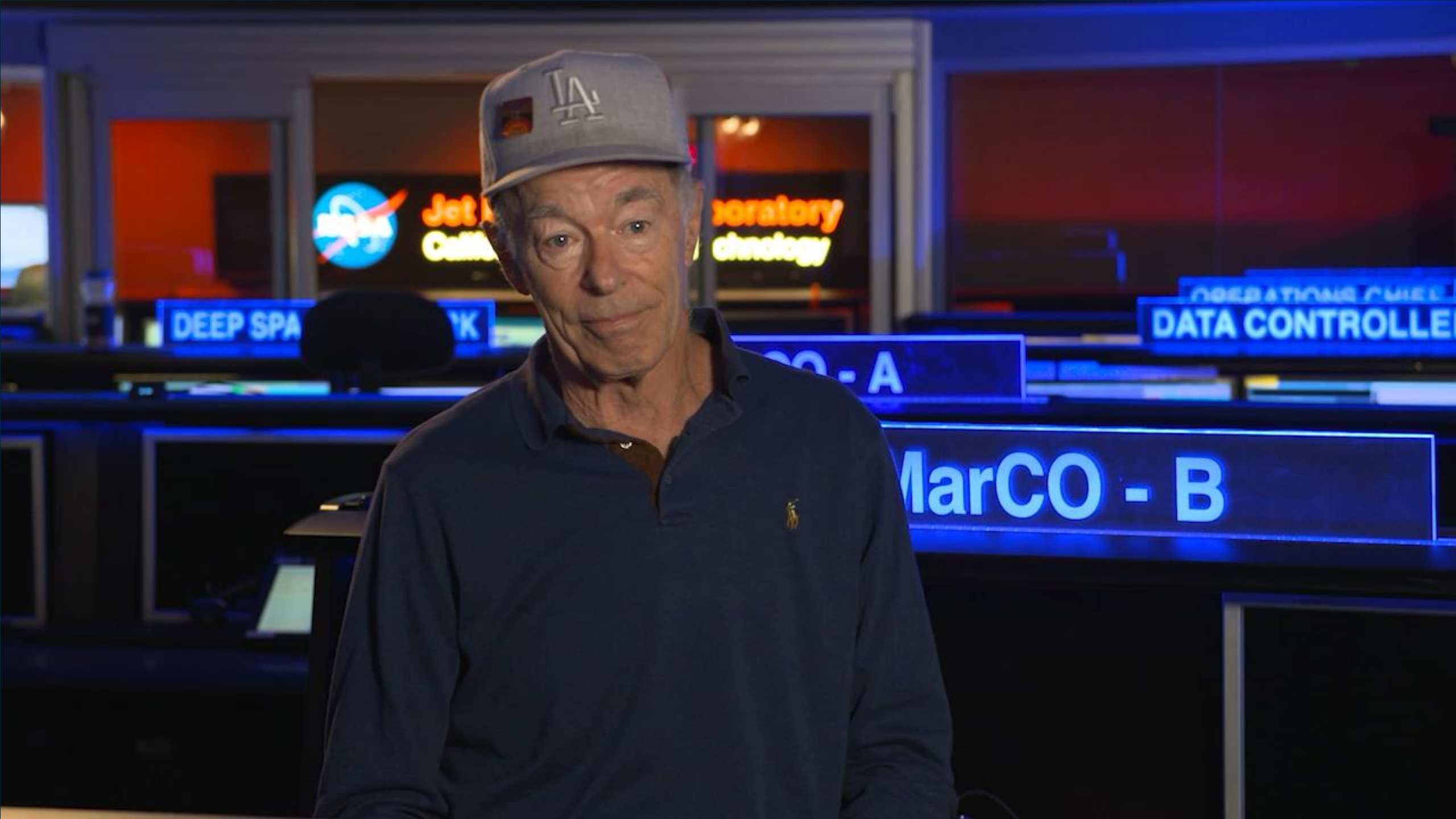
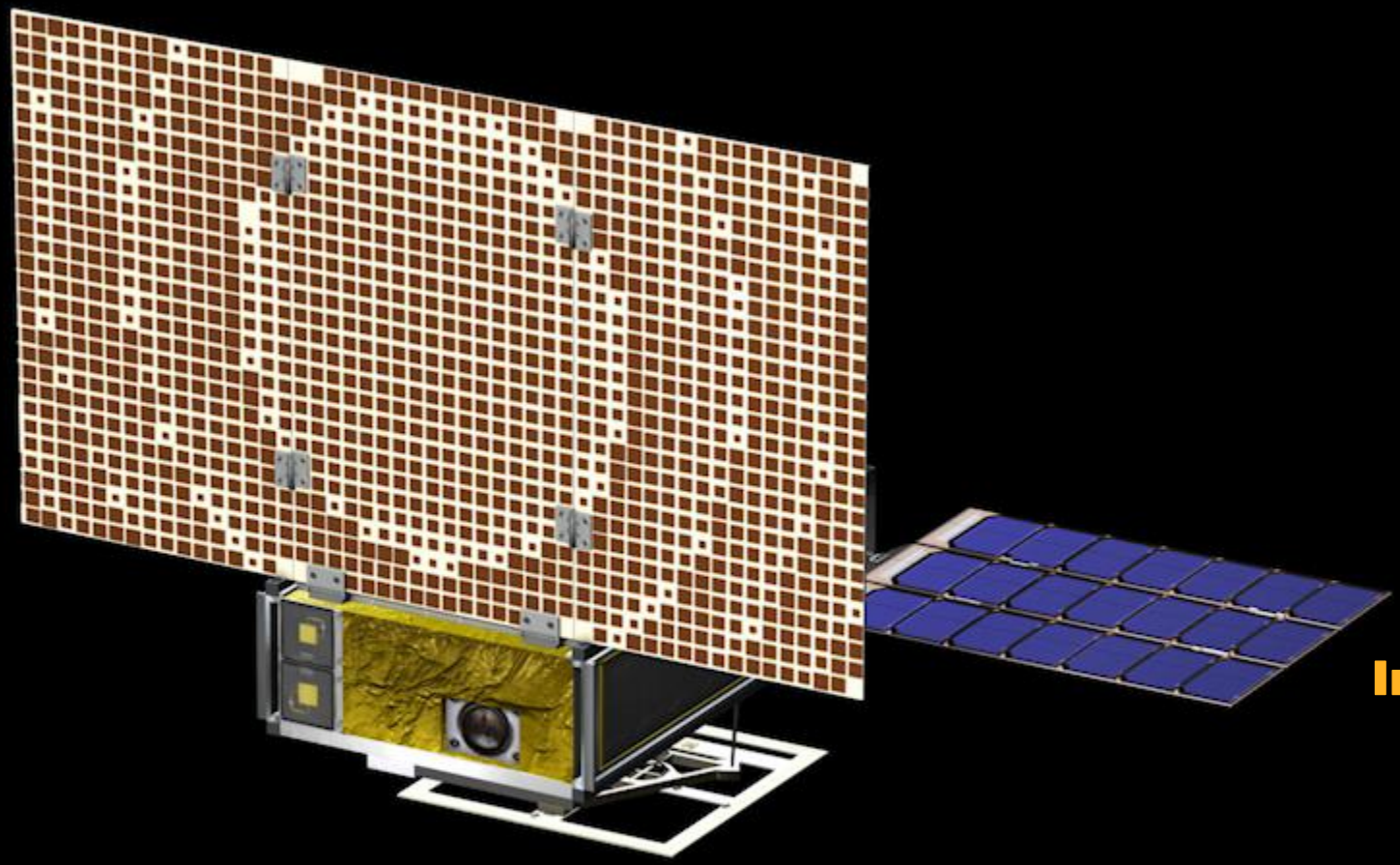
MarCO: Mars Cube One

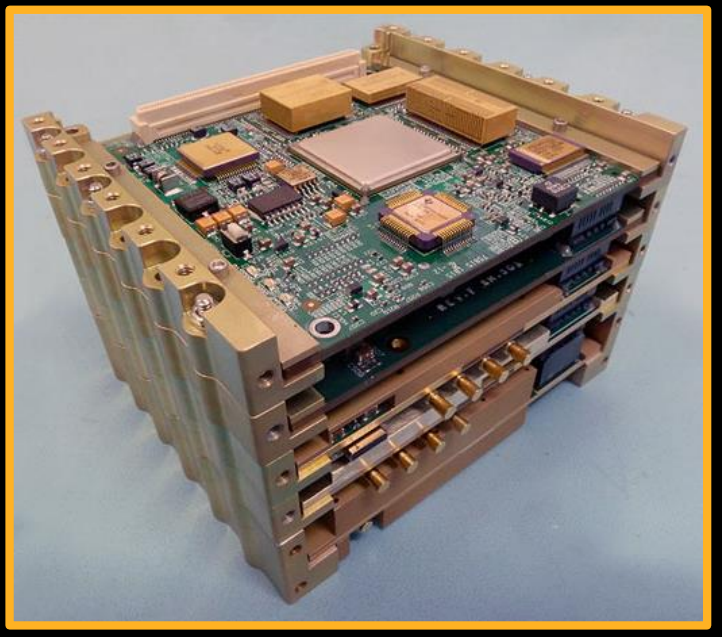
Dr. Andrew Klesh
Jet Propulsion Laboratory, California Institute of Technology

Jet Propulsion Laboratory
California Institute of Technology


DEEP SPA
DATA CONTROLLE
MarCO - B


MARCO





Iris Deep Space Transponder

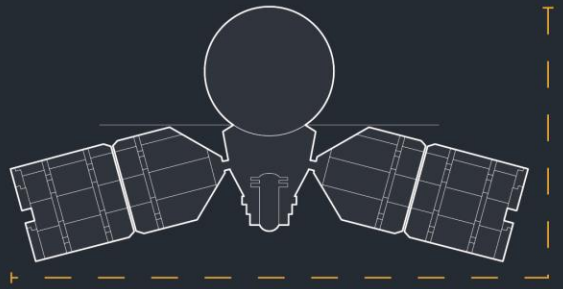
MarCO Demonstrated Miniaturized Technology Enabling Small Spacecraft Exploration

How MarCO Sizes Up

Commercial Jet

100 ft x 100 ft (60, 000 lbs)

Mars Reconnaissance Orbiter



45 ft x 21 ft (4,810 lbs)

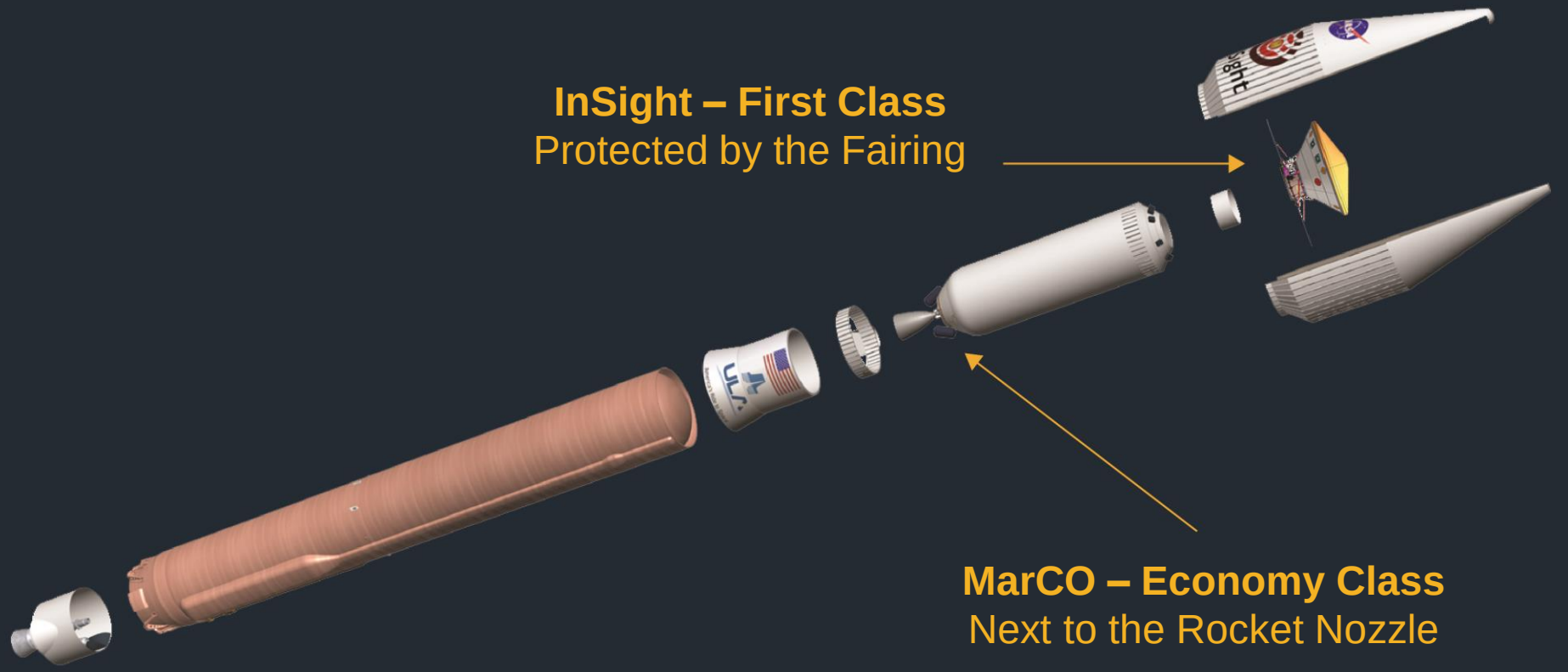
Person

14.5 in x 72 in (154 lbs)

MarCO

34 in x 22 in (30 lbs)

InSight – First Class
Protected by the Fairing



MarCO – Economy Class
Next to the Rocket Nozzle

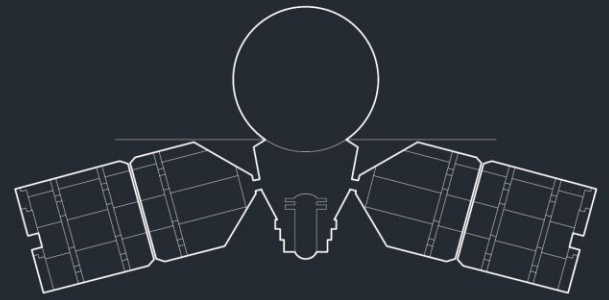
MarCO Increases the Efficiency of Launch, Enabling More Exploration

Cost & Schedule

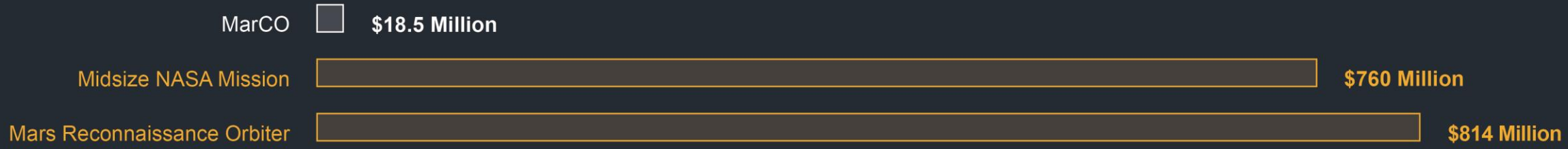
MarCO

Midsize NASA Mission

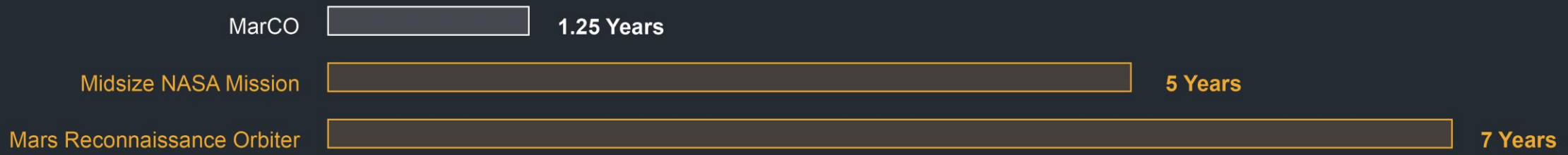
Mars Reconnaissance Orbiter

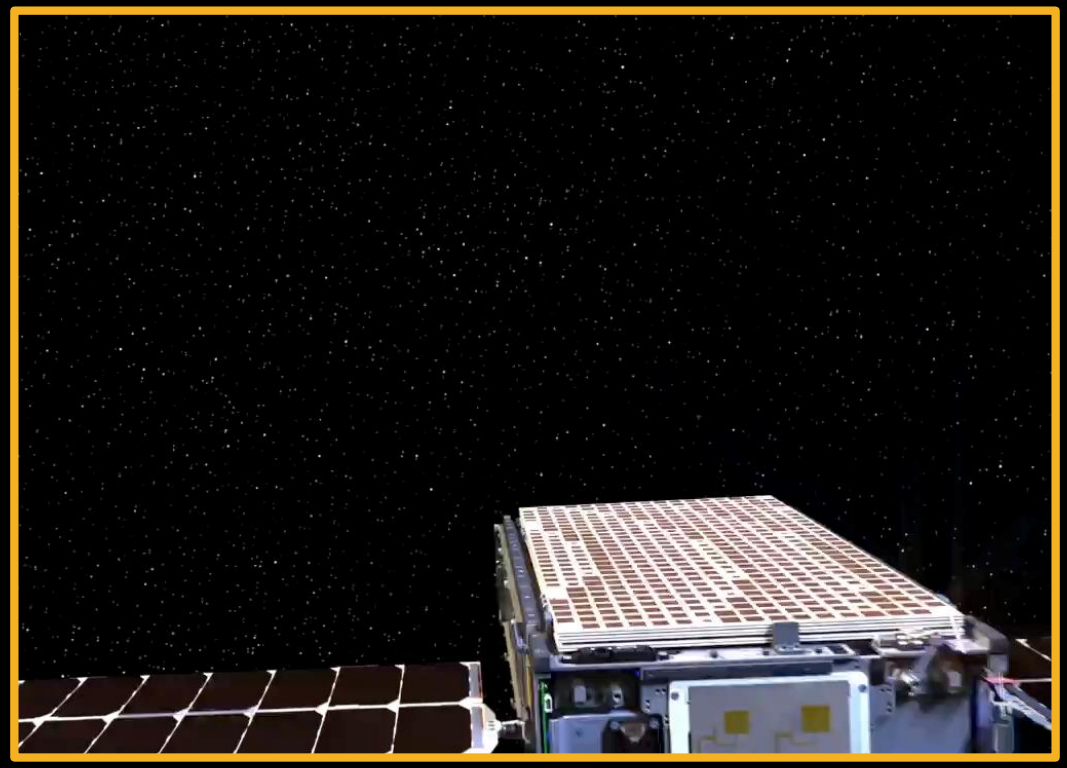


Cost



Schedule



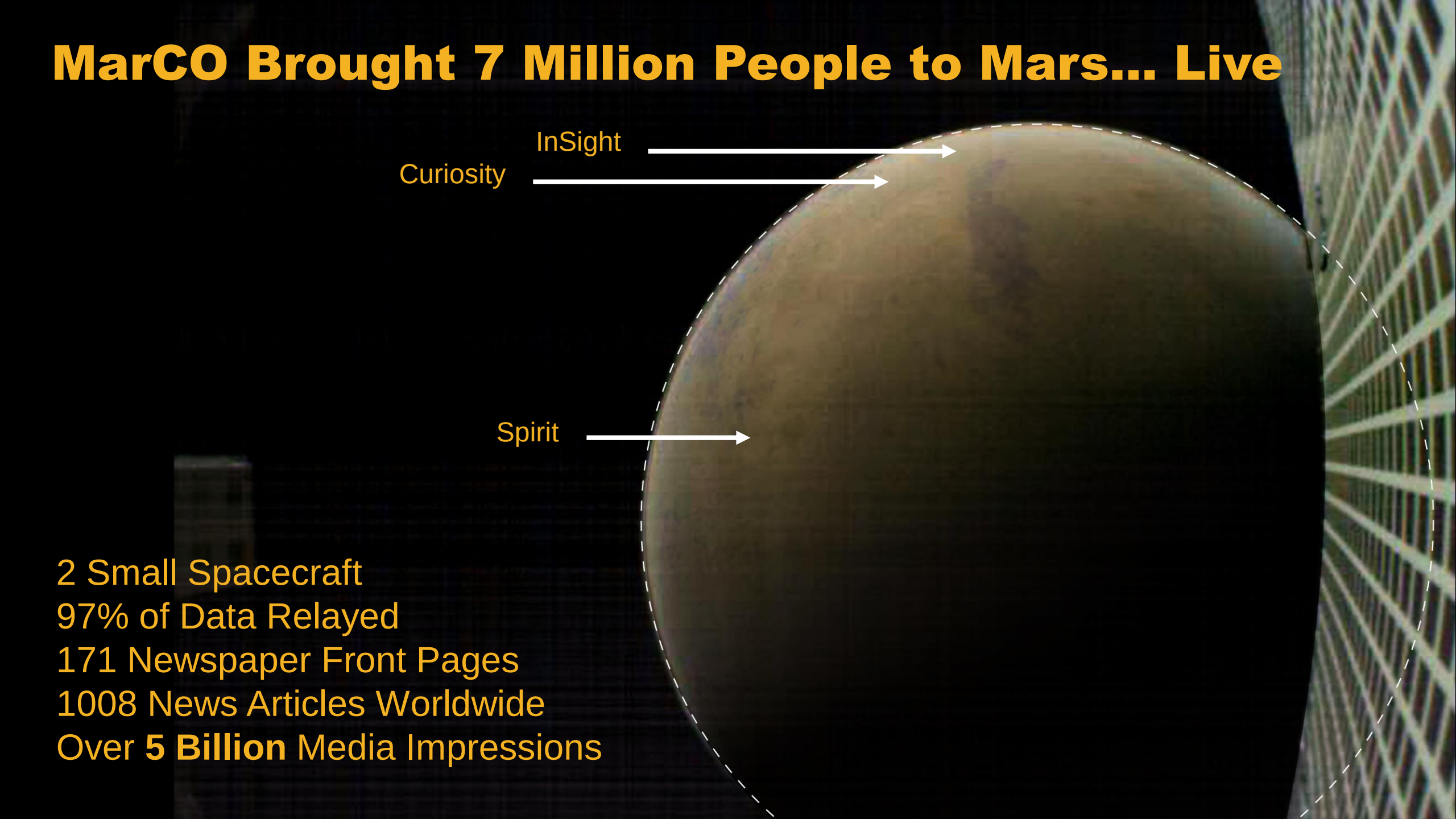


Missions to Mars

Success	22
Partial Success	2
Failure	24
Total Attempts	**48**

The only nation to complete a mission on the surface of Mars:

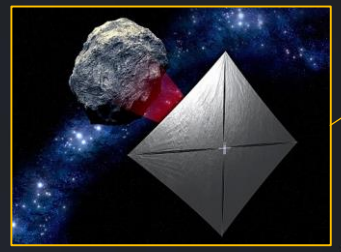
MarCO Brought 7 Million People to Mars... Live



2 Small Spacecraft
97% of Data Relayed
171 Newspaper Front Pages
1008 News Articles Worldwide
Over **5 Billion** Media Impressions

MarCO: Enabling A New Class of Explorers

Solar Sailing to a Near Earth Asteroid



NEAScout

CisLunar Explorers

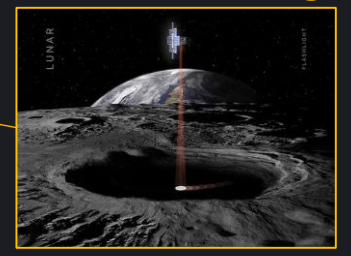
Lunar IceCube

ArgoMoon

SkyFire

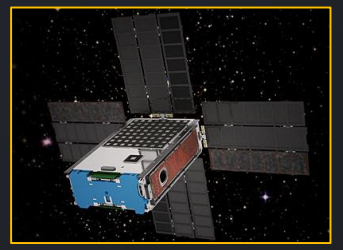
LunaH-Map

Lunar Flashlight



Illuminating Shadowed Lunar Craters with Lasers

Protecting Astronaut Health



BioSentinel

CuSP+

Earth Escape Explorer

EQUULEUS

OMOTENASHI

Team Miles

MarCO

CubeSats Have Never Before Ventured Beyond Low-Earth Orbit

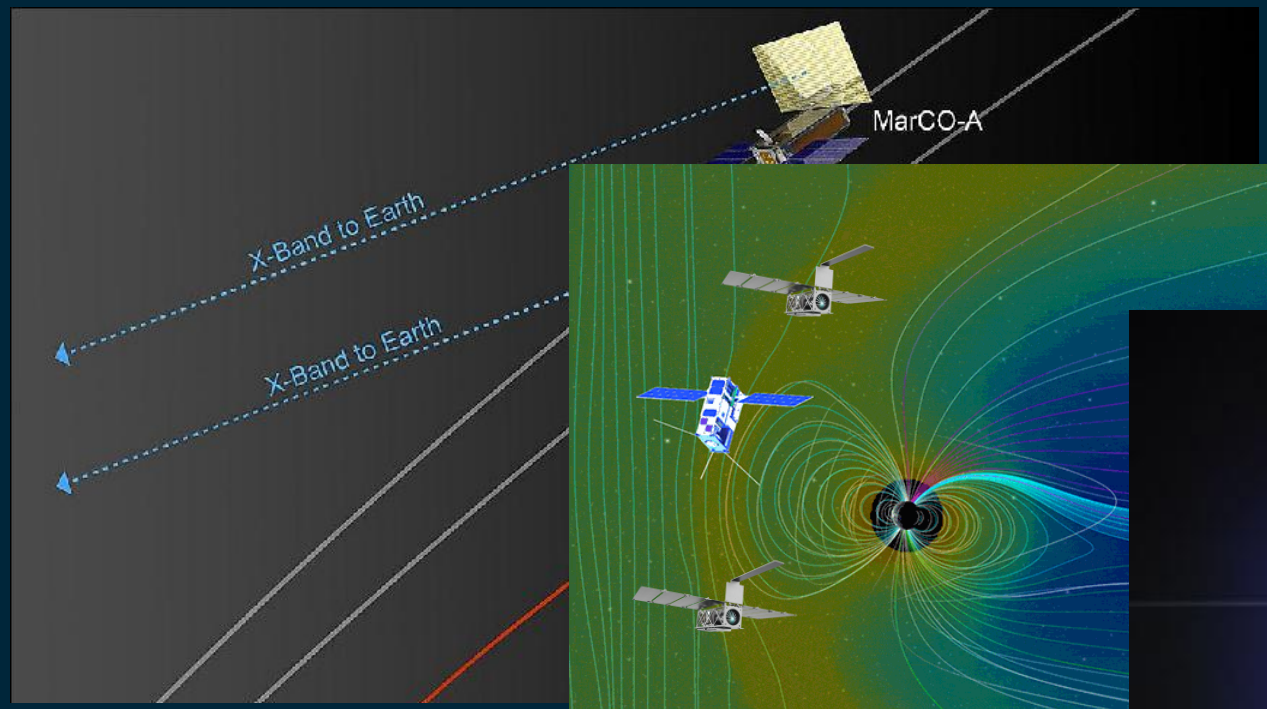
0.8 AU

1 AU

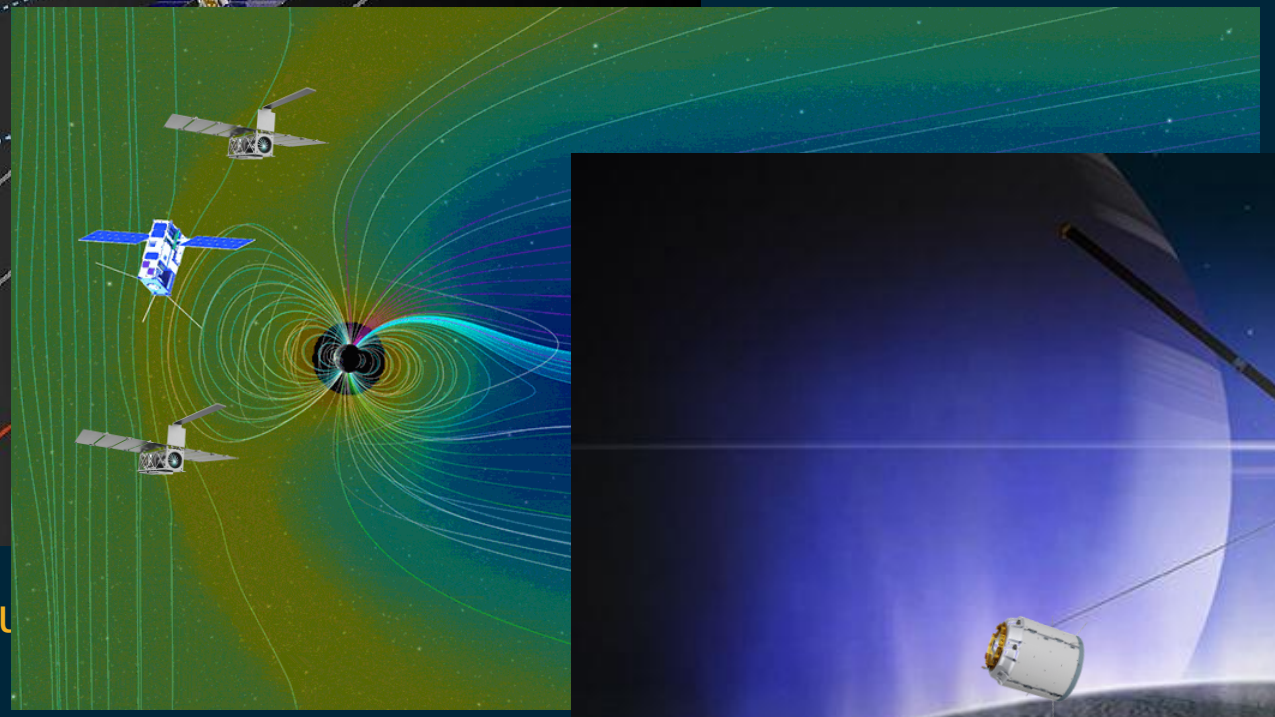
1.5 AU

>1.5 AU

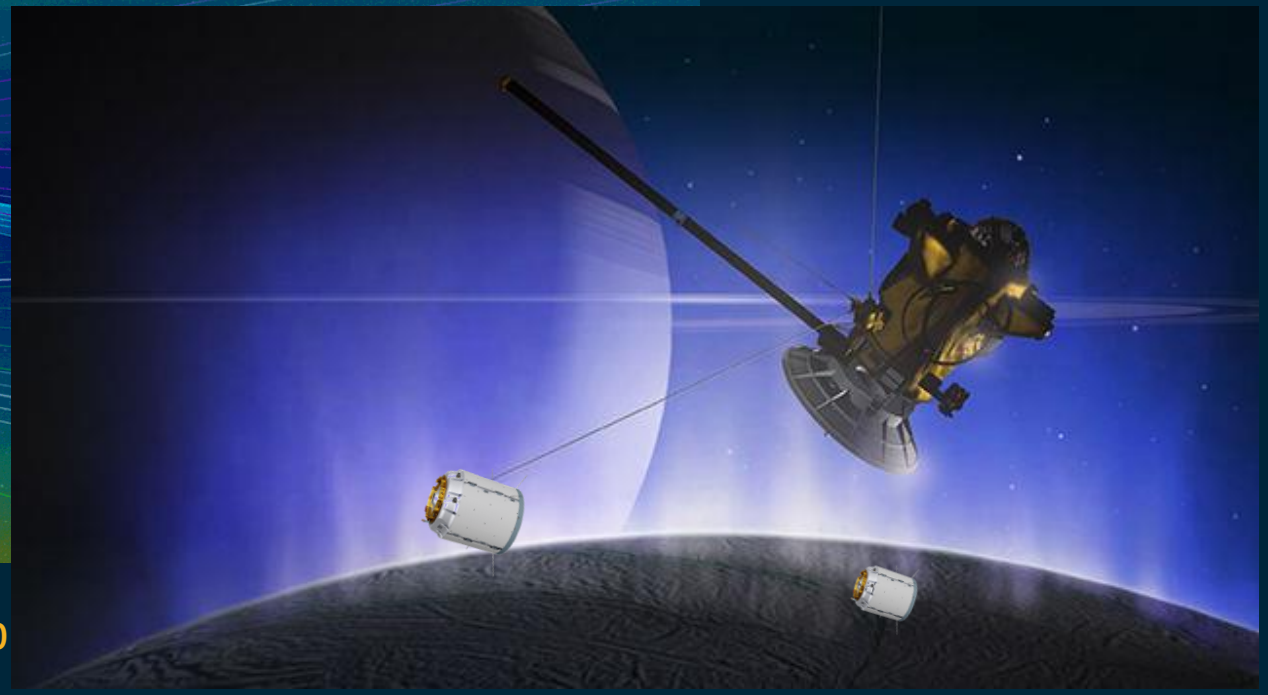
MarCO: Finding New Vantage Points



Critical Blackbox Relay Su



Low Cost Fleets Enab



Disposable Probes for Dangerous and Exciting Exploration

Dare Mighty Things

Jet Propulsion Laboratory
California Institute of Technology

Government Sponsorship Acknowledged

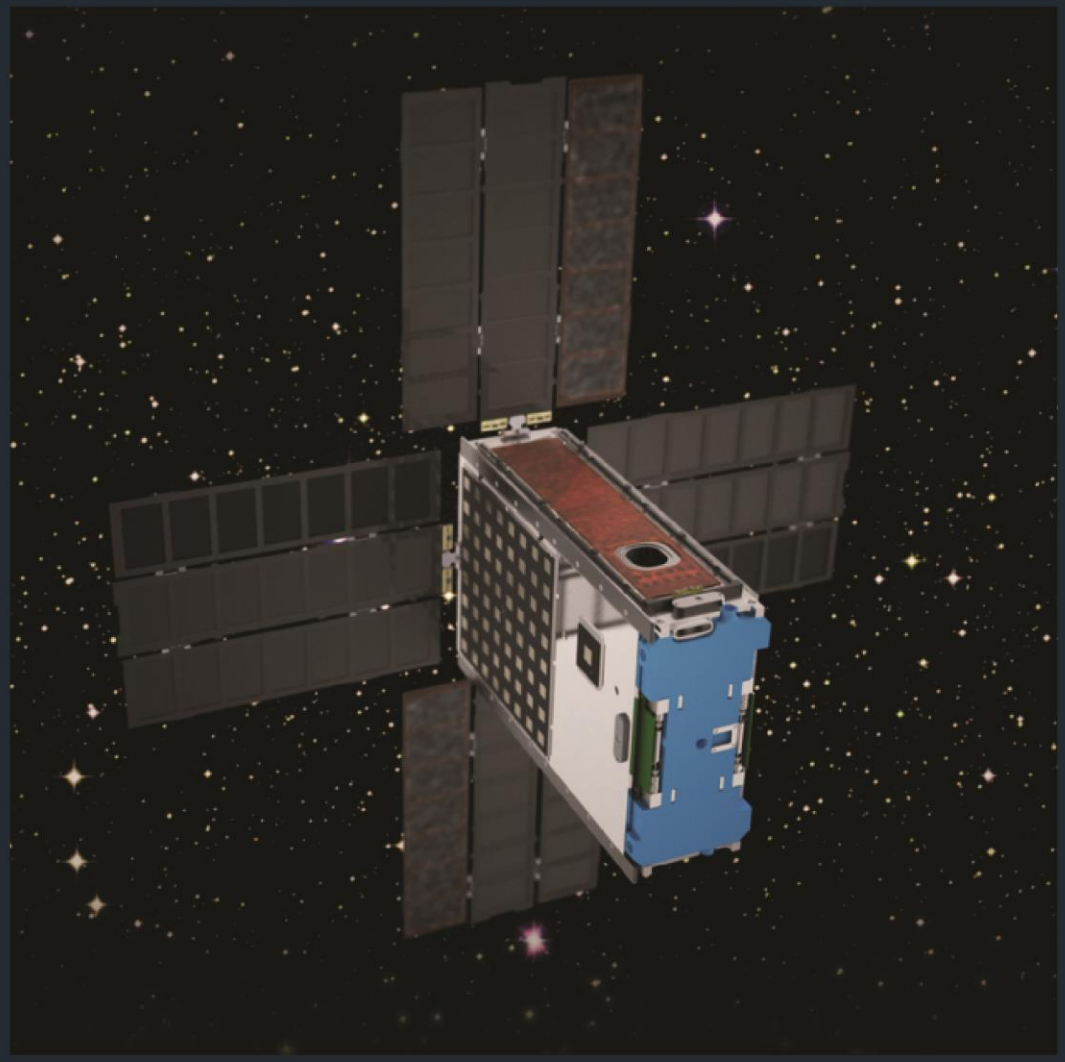
Backup

MarCO: Protecting Astronaut Health

MarCO

BioSentinel

BioSentinel



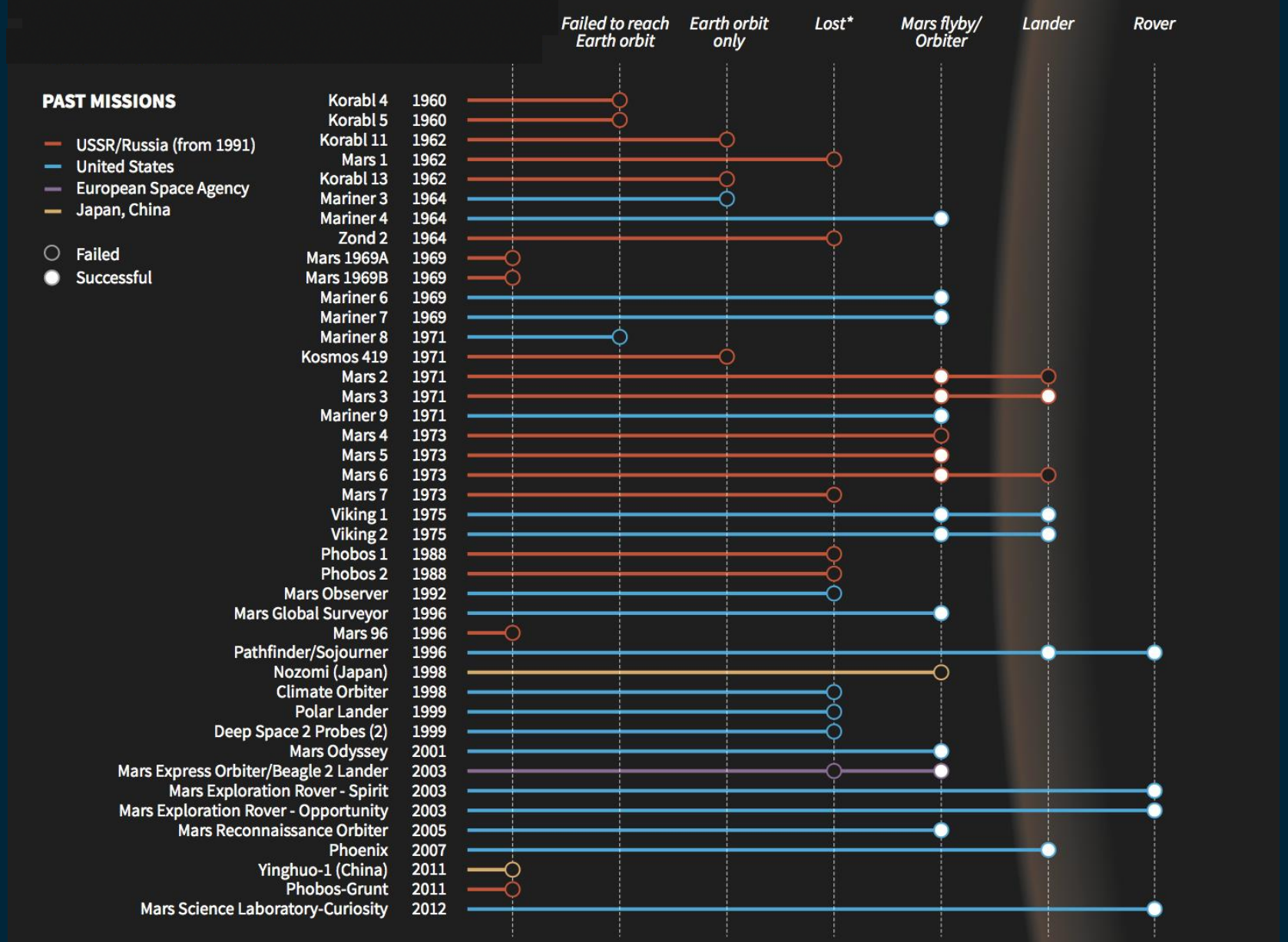
MarCO: Advancing Planetary Defense

"The idea of building SmallSats for deep space… was recently validated… when a pair of accompanying SmallSats succeeded in relaying [InSight's] radio signals back to Earth – as well as returning imagery of the Red Planet."

– ESA Hera Lead Engineer


CURIOSITY ACE
OPPORTUNITY ACE
MarCO - B
MarCO - A

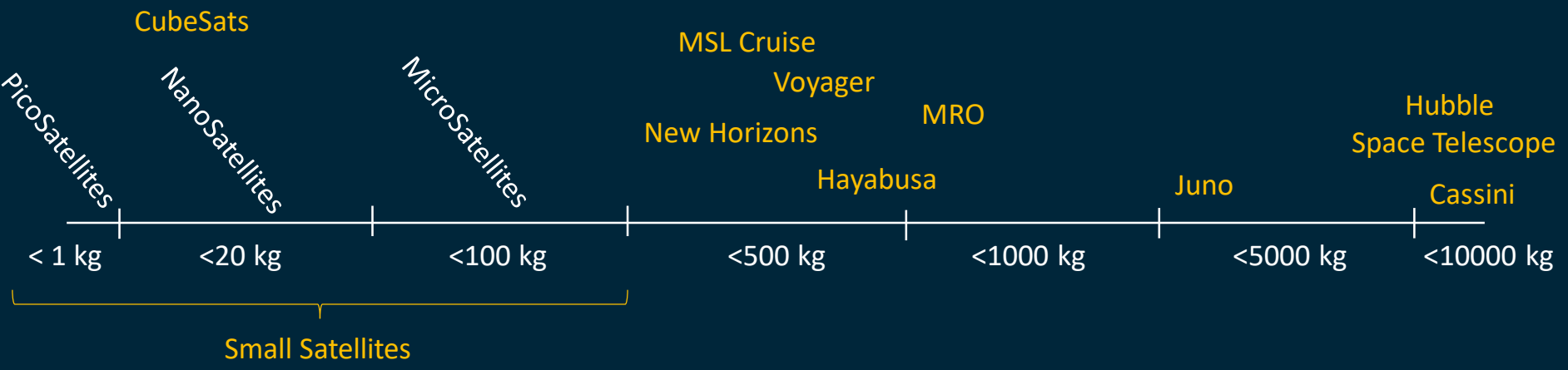
Mars missions



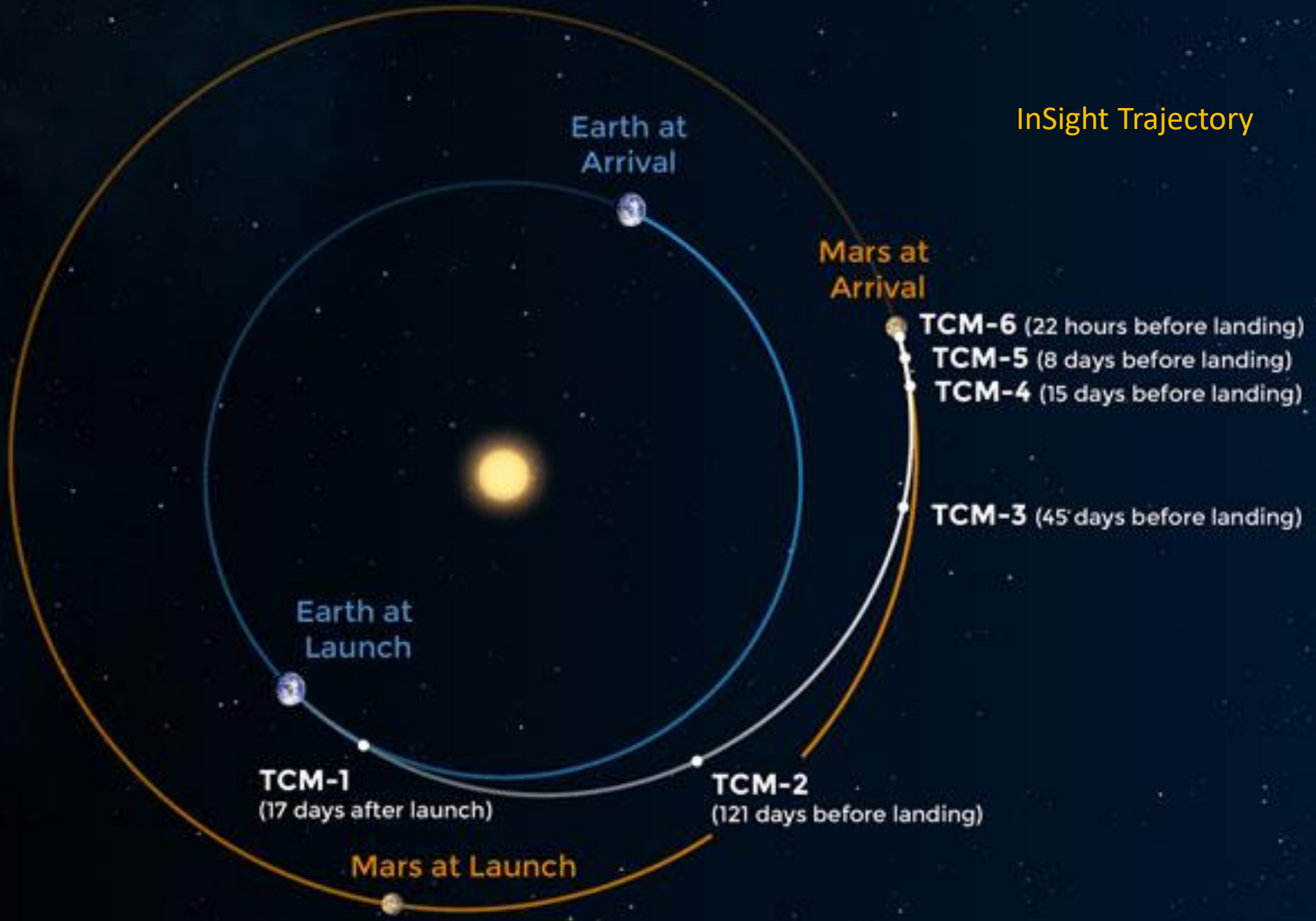
Source: NASA *En route or on arrival

C. Inton, 04/11/2013

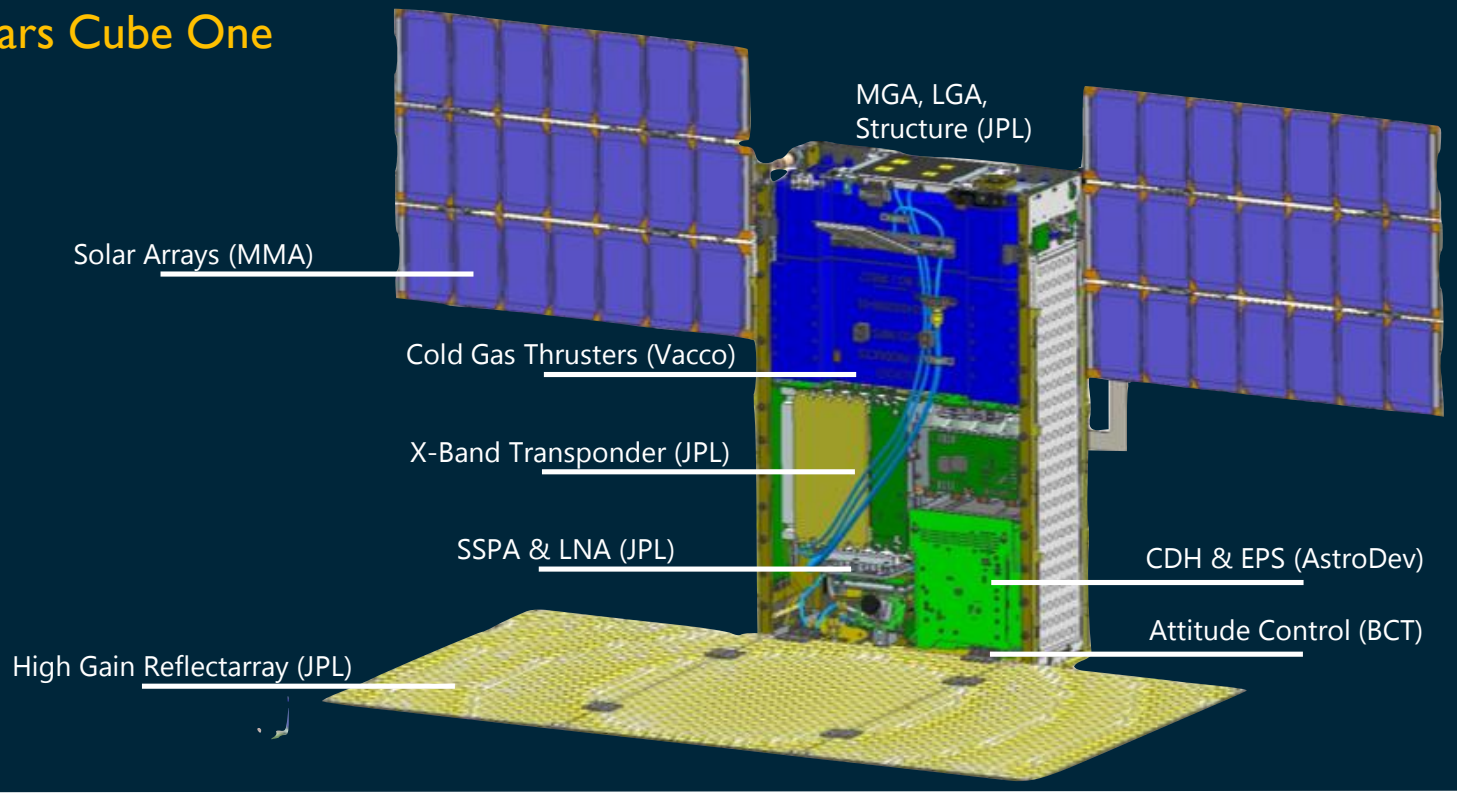
REUTERS


CubeSats
PicoSatellites
NanoSatellites
MicroSatellites
MSL Cruise
Voyager
New Horizons
MRO
Hayabusa
Juno
Hubble
Space Telescope
Cassini
< 1 kg
<20 kg
<100 kg
<500 kg
<1000 kg
<5000 kg
<10000 kg
Small Satellites

InSight Trajectory



MarCO: Mars Cube One

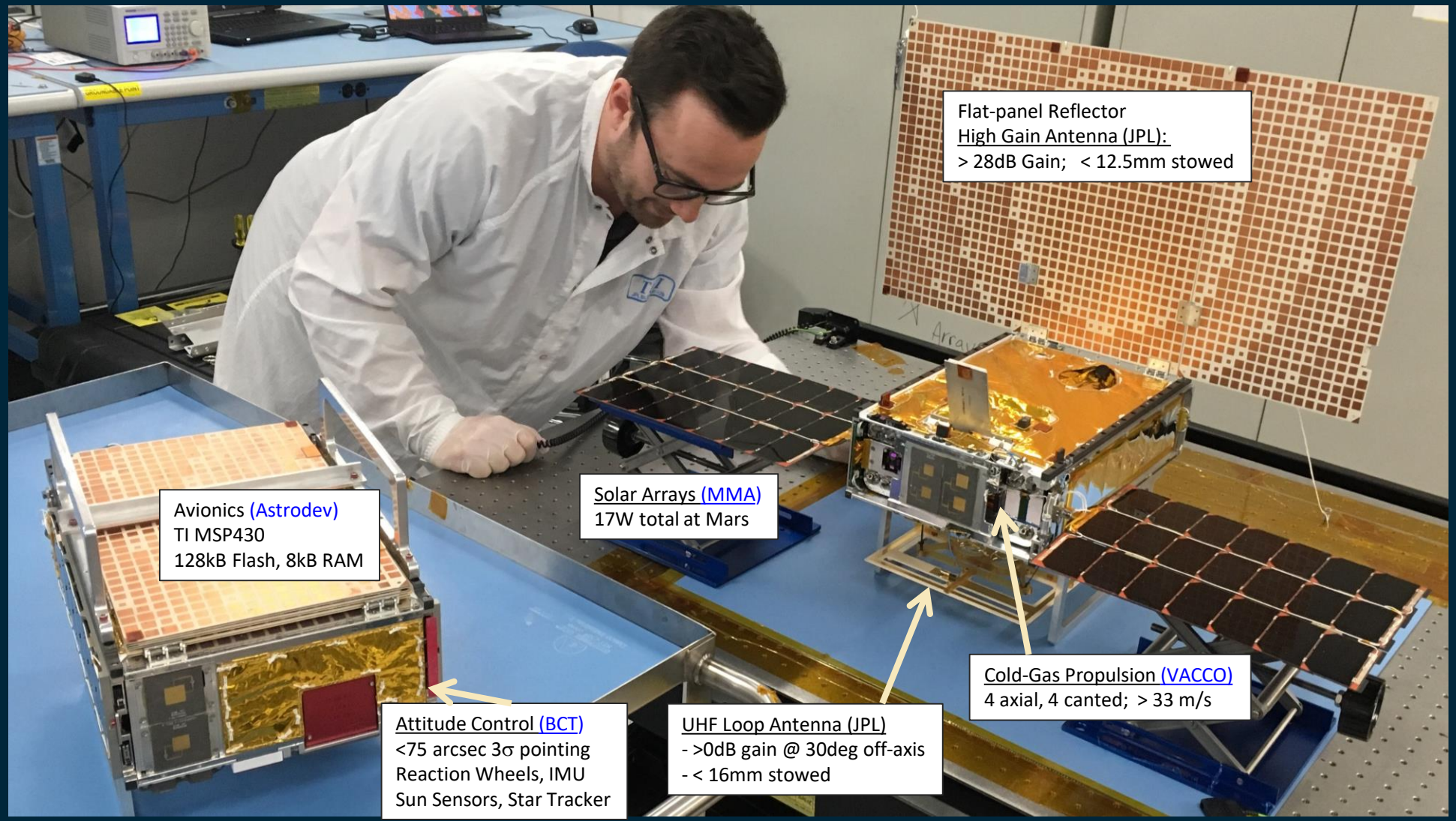


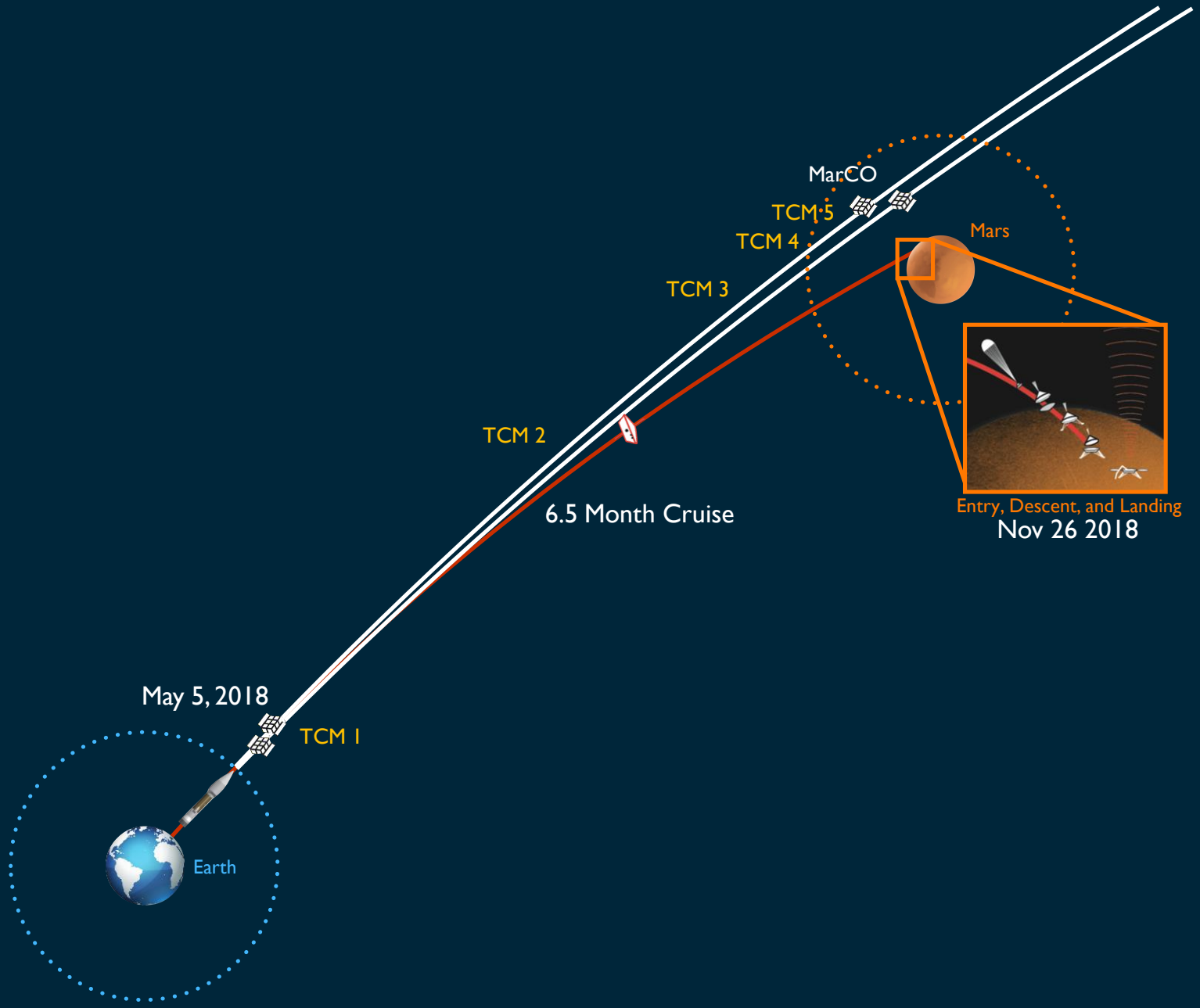
MarCO Overview:
Volume: 2 x 6U (12x24x36cm)
Mass: 14.0 kg
Power Generation:
Earth: 35 W / Mars: 17W
Data Rates: 62-8,000 bps
Delta-V: >40 m/s

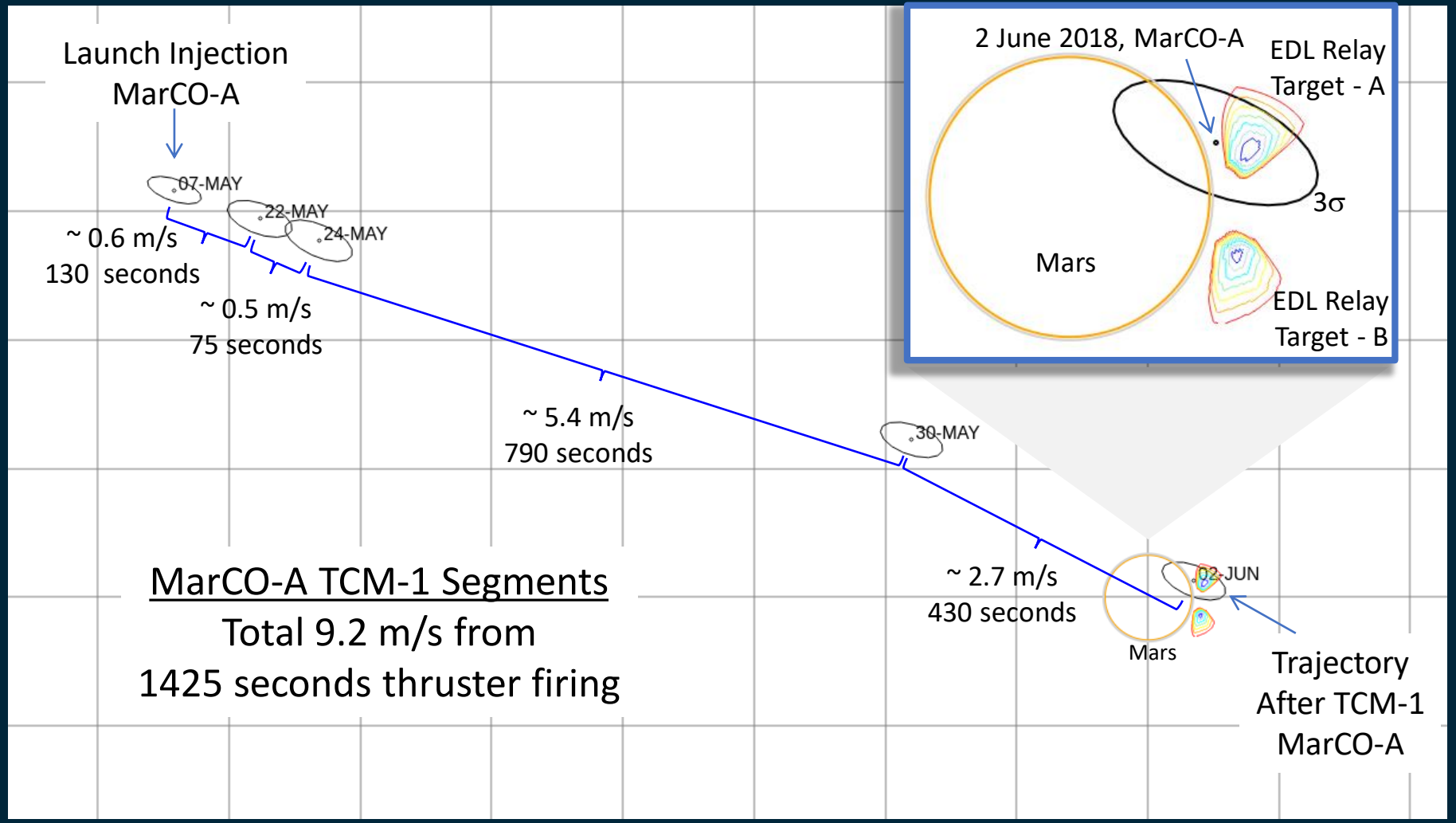
Software:
FSW: protos (JPL)
GSW: AMPCS (NASA/JPL)

I&T:
In-house S/C I&T, testing, Tyvak NLAS/Launch Integration

Operations:
Primary: DSN 34m
EDL: Madrid 70m


Flat-panel Reflector
High Gain Antenna (JPL):
> 28dB Gain; < 12.5mm stowed
Avionics (Astrodev)
TI MSP430
128kB Flash, 8kB RAM
Solar Arrays (MMA)
17W total at Mars
Attitude Control (BCT)
<75 arcsec 3σ pointing
Reaction Wheels, IMU
Sun Sensors, Star Tracker
UHF Loop Antenna (JPL)
- >0dB gain @ 30deg off-axis
- < 16mm stowed
Cold-Gas Propulsion (VACCO)
4 axial, 4 canted; > 33 m/s

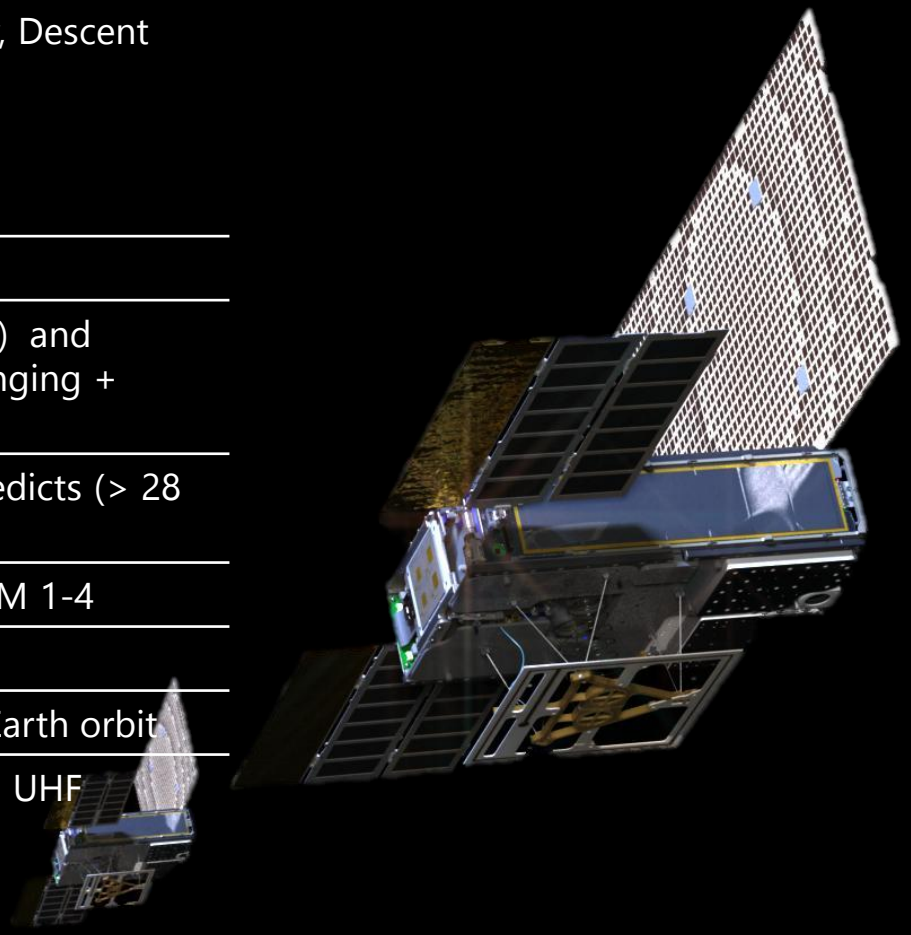

MarCO
TCM 5
TCM 4
TCM 3
TCM 2
Mars
6.5 Month Cruise
Entry, Descent, and Landing
Nov 26 2018
May 5, 2018
TCM 1
Earth

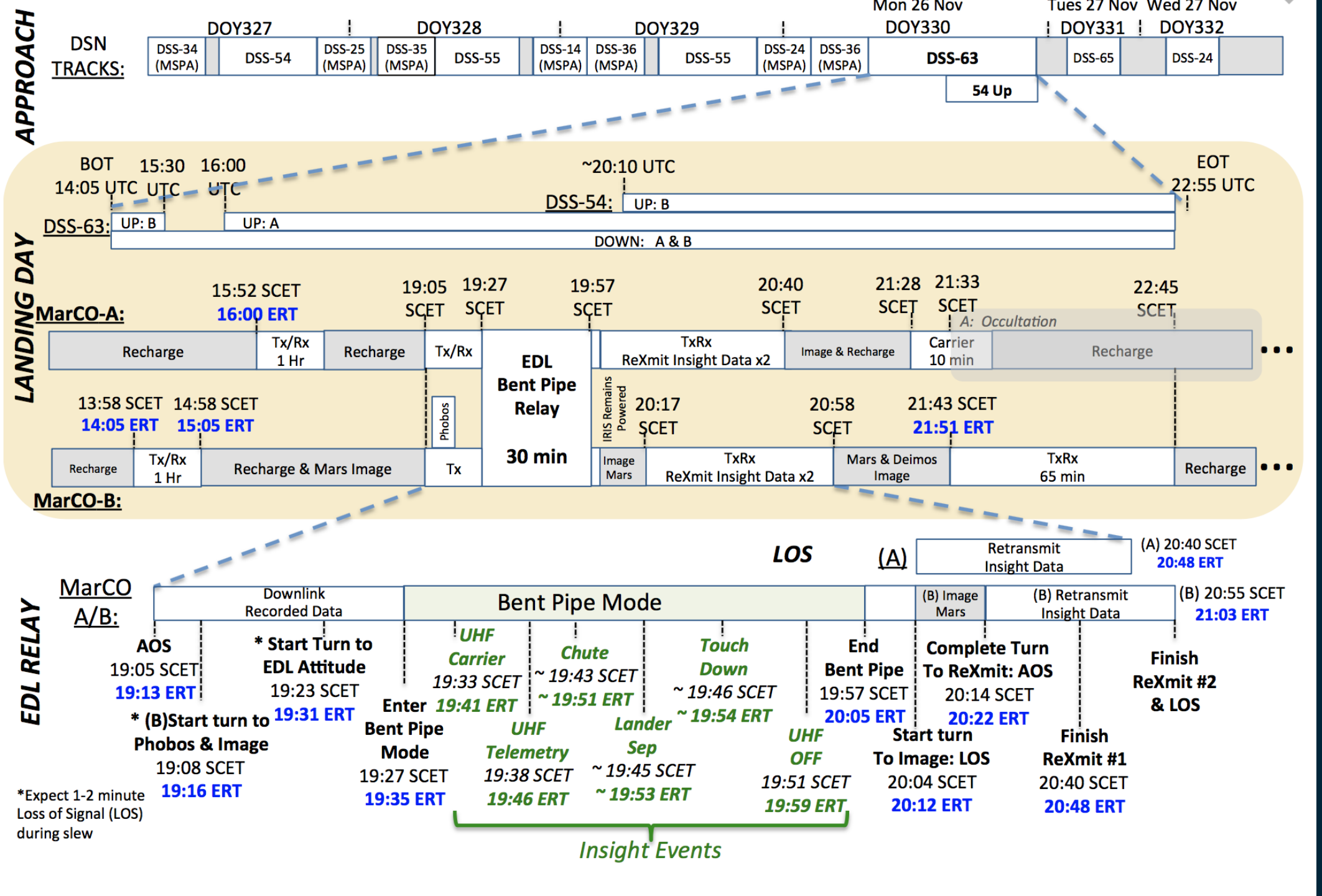

Launch Injection
MarCO-A
07-MAY
22-MAY
24-MAY
~ 0.6 m/s
130 seconds
~ 0.5 m/s
75 seconds
~ 5.4 m/s
790 seconds
30-MAY
~ 2.7 m/s
430 seconds
02-JUN
Mars
Trajectory
After TCM-1
MarCO-A
2 June 2018, MarCO-A
EDL Relay
Target - A
3σ
Mars
EDL Relay
Target - B
MarCO-A TCM-1 Segments
Total 9.2 m/s from
1425 seconds thruster firing

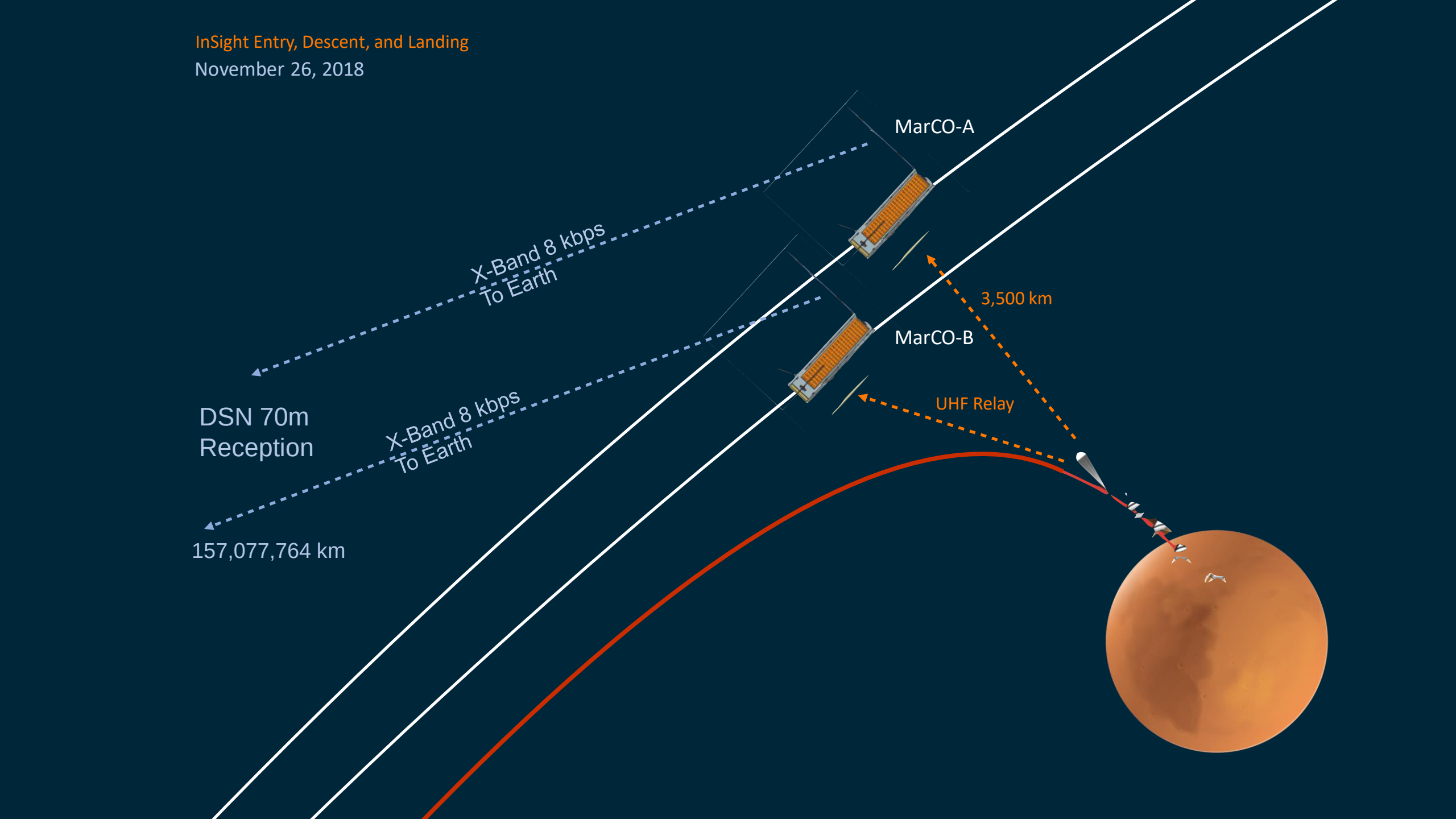
Mission Objective

- Provide an 8kbps real-time relay for InSight's Entry, Descent and Landing at Mars

Technology	Tech Objectives / Results
Threshold	
Miniaturized deep space radio (IRIS)	Successful uplink (62.5 – 1k) and downlink (62.5 – 16k) + ranging + Delta-DOR
Flat Panel Antenna	Measured gain matches predicts (> 28 dBi)
TCMs on a CubeSat	Completed execution of TCM 1-4
Baseline	
CubeSat in deep space	Viable operations beyond Earth orbit
Bent-Pipe Relay	Inflight demo with Stanford UHF bent-pipe + Insight EDL

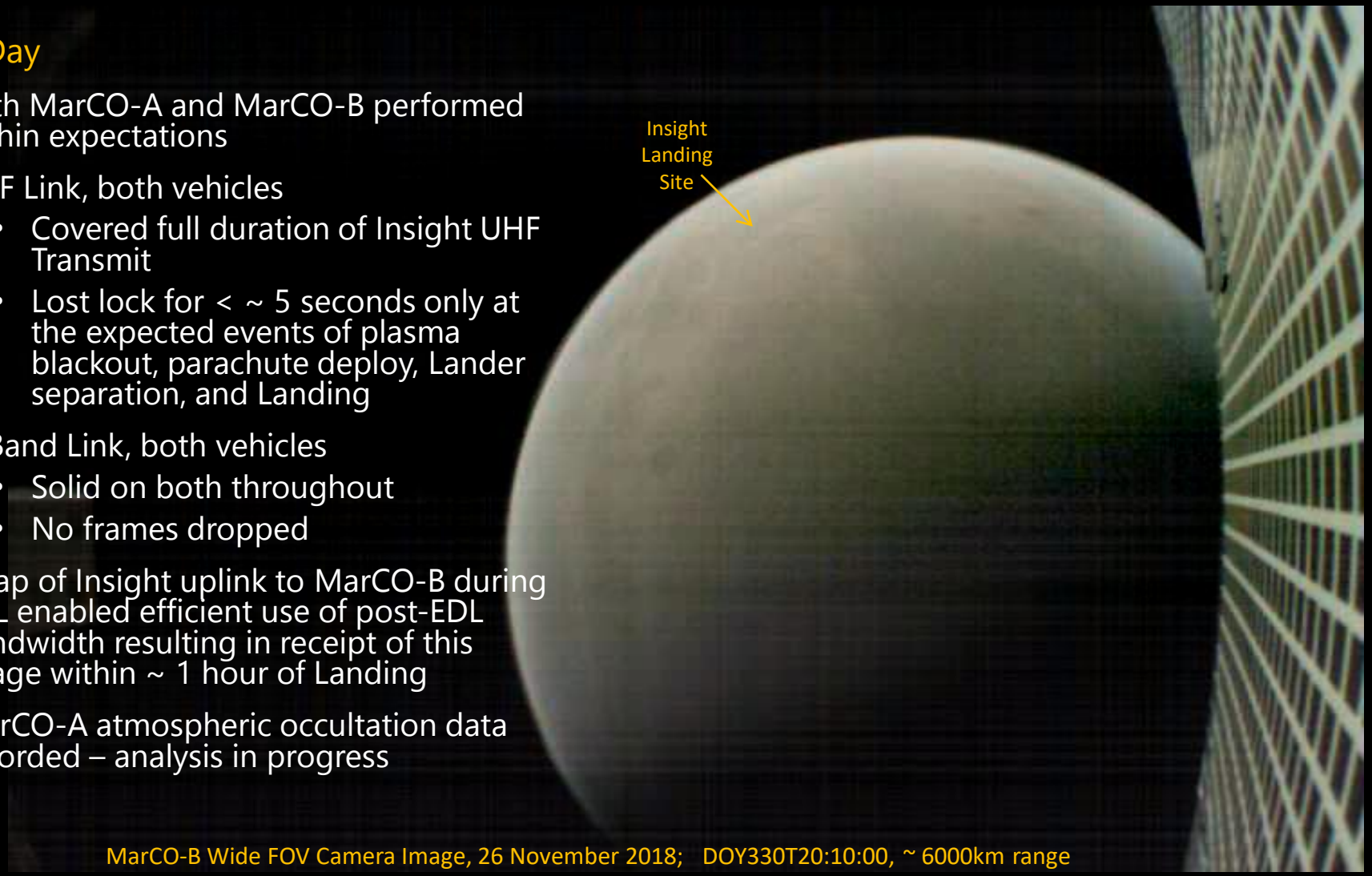



APPROACH
DSN TRACKS:
DOY327
DOY328
DOY329
Mon 26 Nov
DOY330
Tues 27 Nov
DOY331
Wed 27 Nov
DOY332
DSS-34 (MSPA)
DSS-54
DSS-25 (MSPA)
DSS-35 (MSPA)
DSS-55
DSS-14 (MSPA)
DSS-36 (MSPA)
DSS-55
DSS-24 (MSPA)
DSS-36 (MSPA)
DSS-63
54 Up
DSS-65
DSS-24
LANDING DAY
BOT 14:05 UTC
15:30 UTC
16:00 UTC
~20:10 UTC
EOT 22:55 UTC
DSS-54:
UP: B
DSS-63:
UP: B
UP: A
DOWN: A & B
MarCO-A:
15:52 SCET
16:00 ERT
19:05 SCET
19:27 SCET
19:57 SCET
20:40 SCET
21:28 SCET
21:33 SCET
22:45 SCET
A: Occultation
Recharge
Tx/Rx 1 Hr
Recharge
Tx/Rx
EDL Bent Pipe Relay
30 min
TxRx ReXmit Insight Data x2
Image & Recharge
Carrier 10 min
Recharge
13:58 SCET
14:05 ERT
14:58 SCET
15:05 ERT
Phobos
IRIS Remains Powered
20:17 SCET
20:58 SCET
21:43 SCET
21:51 ERT
Recharge
Tx/Rx 1 Hr
Recharge & Mars Image
Tx
Image Mars
TxRx ReXmit Insight Data x2
Mars & Deimos Image
TxRx 65 min
Recharge
MarCO-B:
EDL RELAY
LOS
(A)
Retransmit Insight Data
(A) 20:40 SCET
20:48 ERT
MarCO A/B:
Downlink Recorded Data
Bent Pipe Mode
(B) Image Mars
(B) Retransmit Insight Data
(B) 20:55 SCET
21:03 ERT
AOS
19:05 SCET
19:13 ERT
* Start Turn to EDL Attitude
19:23 SCET
19:31 ERT
* (B)Start turn to Phobos & Image
19:08 SCET
19:16 ERT
Enter Bent Pipe Mode
19:27 SCET
19:35 ERT
UHF Carrier
19:33 SCET
19:41 ERT
Chute
~ 19:43 SCET
~ 19:51 ERT
Touch Down
~ 19:46 SCET
~ 19:54 ERT
End Bent Pipe
19:57 SCET
20:05 ERT
Complete Turn To ReXmit: AOS
20:14 SCET
20:22 ERT
Finish ReXmit #2 & LOS
UHF Telemetry
19:38 SCET
19:46 ERT
Lander Sep
~ 19:45 SCET
~ 19:53 ERT
UHF OFF
19:51 SCET
19:59 ERT
Start turn To Image: LOS
20:04 SCET
20:12 ERT
Finish ReXmit #1
20:40 SCET
20:48 ERT
*Expect 1-2 minute Loss of Signal (LOS) during slew
Insight Events


InSight Entry, Descent, and Landing
November 26, 2018
MarCO-A
X-Band 8 kbps
To Earth
3,500 km
MarCO-B
UHF Relay
DSN 70m
Reception
X-Band 8 kbps
To Earth
157,077,764 km

EDL Day

- Both MarCO-A and MarCO-B performed within expectations
- UHF Link, both vehicles
  - Covered full duration of Insight UHF Transmit
  - Lost lock for < ~ 5 seconds only at the expected events of plasma blackout, parachute deploy, Lander separation, and Landing
- X-Band Link, both vehicles
  - Solid on both throughout
  - No frames dropped
- Swap of Insight uplink to MarCO-B during EDL enabled efficient use of post-EDL bandwidth resulting in receipt of this image within ~ 1 hour of Landing
- MarCO-A atmospheric occultation data recorded – analysis in progress



MarCO-B Wide FOV Camera Image, 26 November 2018; DOY330T20:10:00, ~ 6000km range

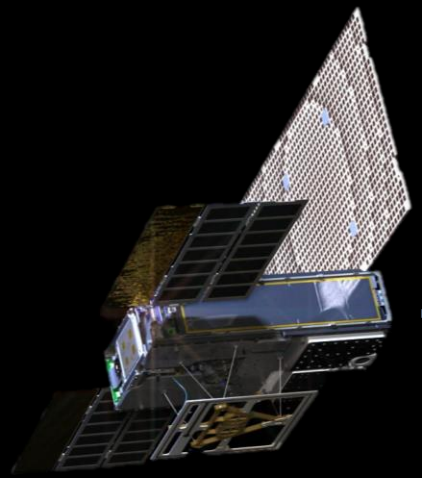
MarCO Achievements

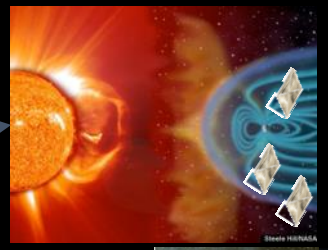
1. Demonstrated necessary technology and techniques for deep space small spacecraft

2. Provided unique vantages and support for InSight lander (MarCO returned 97% of InSight EDL data; MRO returned 76%)

3. Challenged perception of the achievable

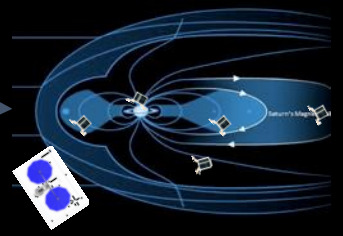
High risk addressed through isolation from primary, redundancy, and MRO backup





Low-Cost Heliophysics: Constellation of 50 standalone 10 kg spacecraft to monitor the solar wind 3D structure at Sun-Earth L1

Supplemental Science: Sacrificial probes used to scout plume passage or descend into high magnetic fields.



Enabling Novel Science: Use multiple nano s/c to allow for distributed flybys, capturing multiple vantage points simultaneously.