A presentation to Ground Systems Architecture Workshop

Looking Beyond the Horizon

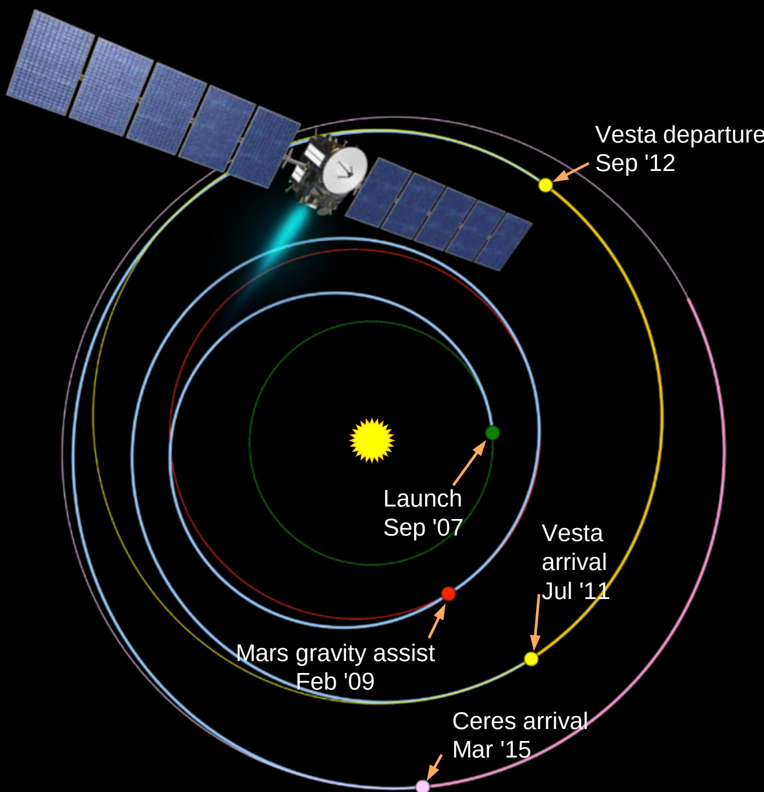
Jet Propulsion Laboratory
California Institute of Technology

Larry James, Deputy Director

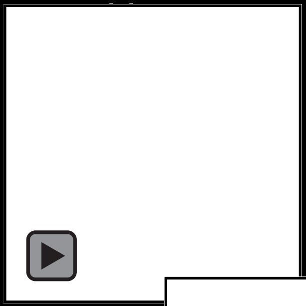
March 13, 2017

A Culture of Innovation since 1936

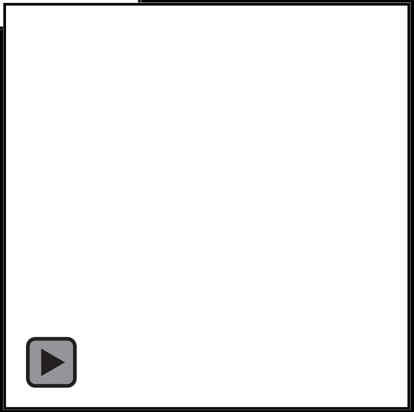
Dawn



Vesta departure
Sep '12
Launch
Sep '07
Vesta
arrival
Jul '11
Mars gravity assist
Feb '09
Ceres arrival
Mar '15

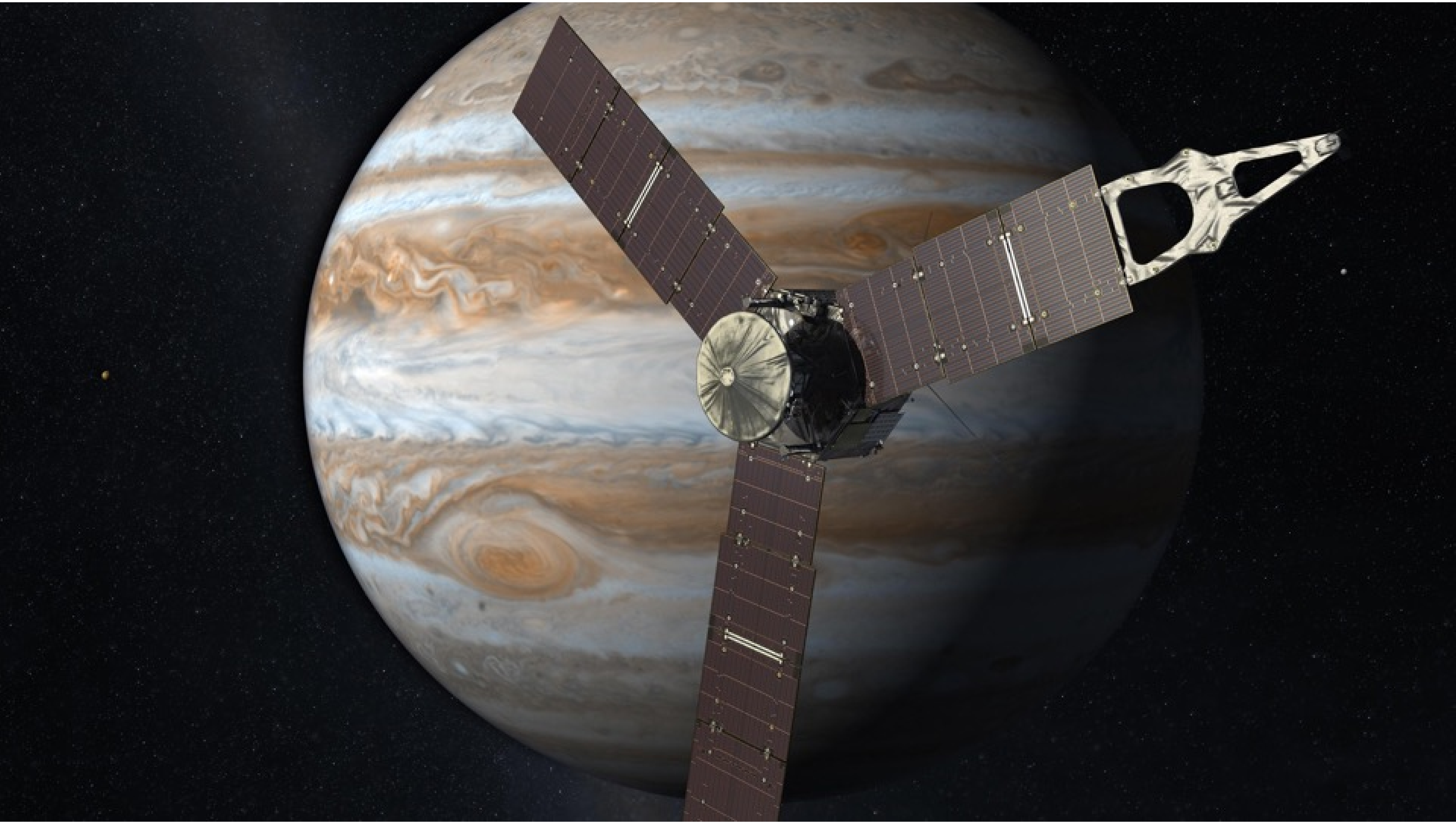


Ceres

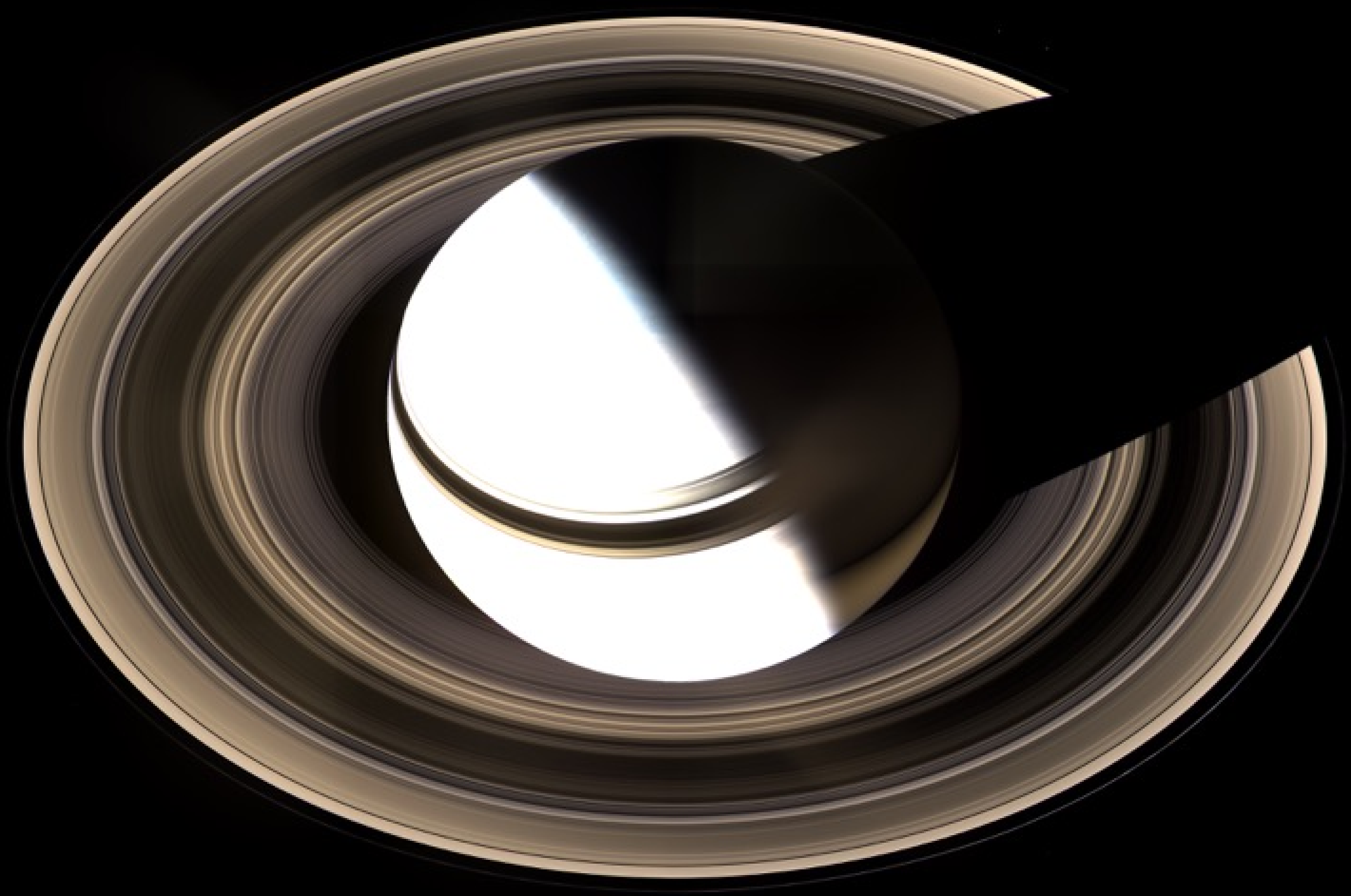


Juno

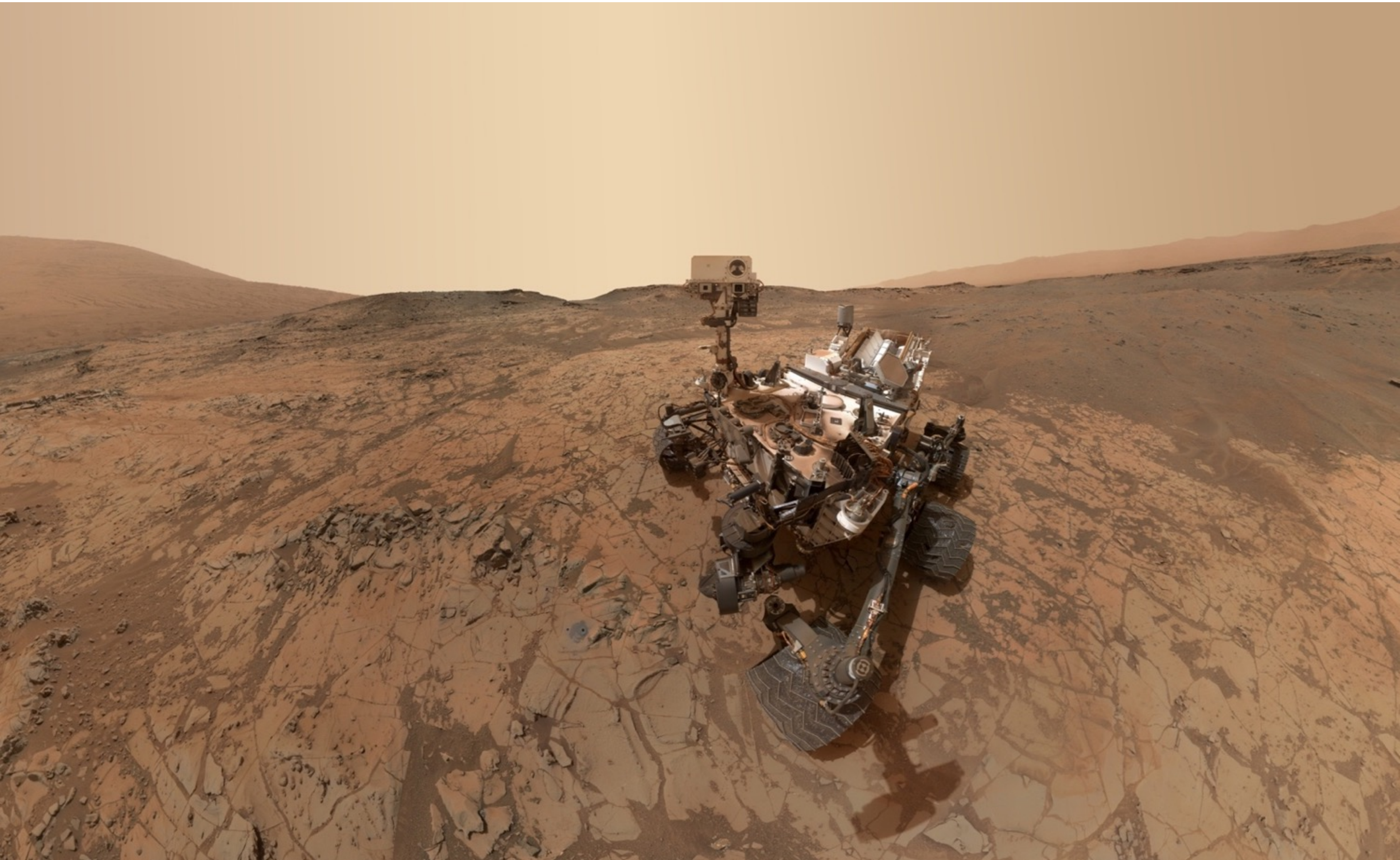
Orbit Insertion July 4, 2016



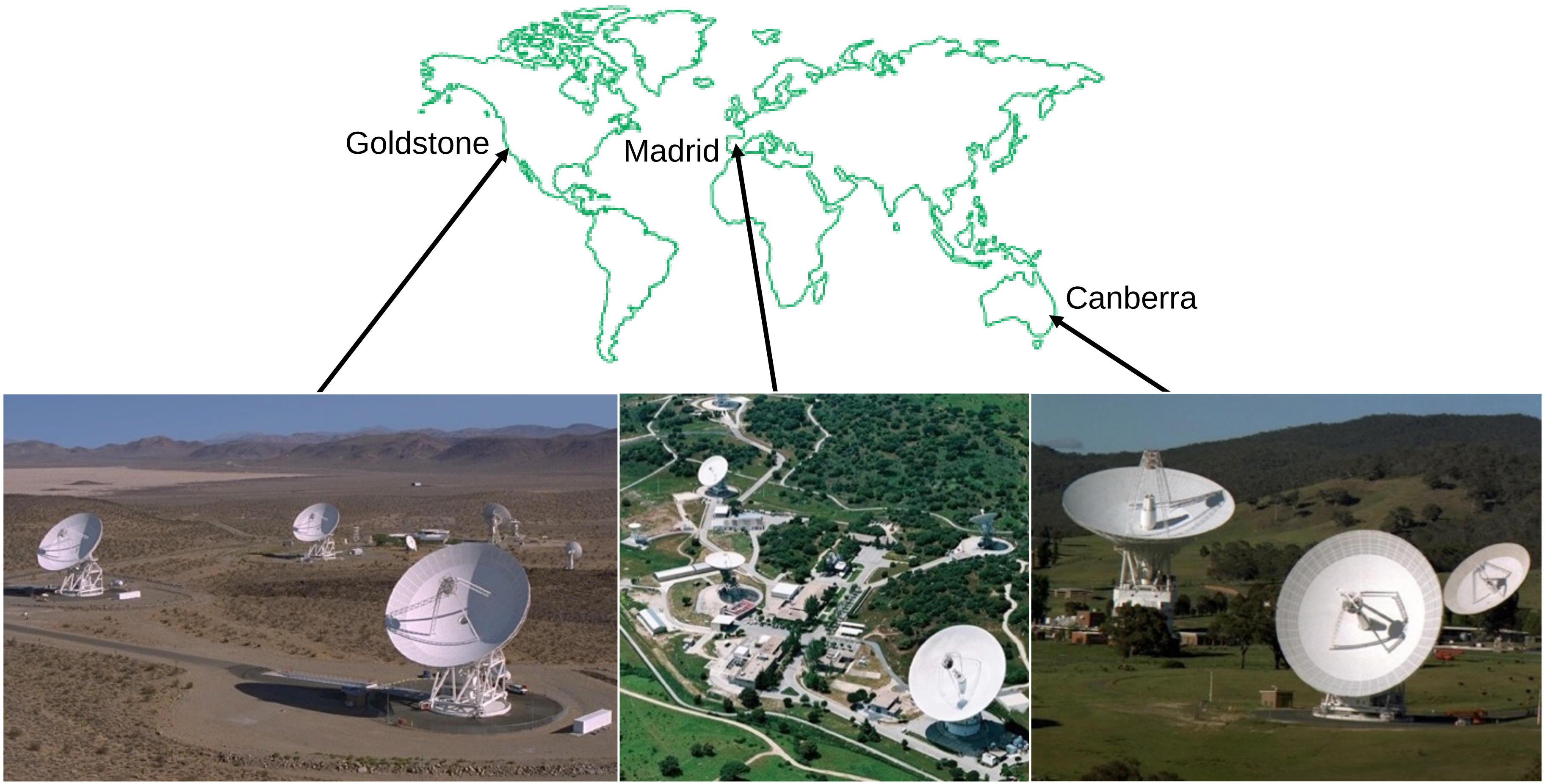
Cassini



Curiosity’s Selfie



Deep Space Network



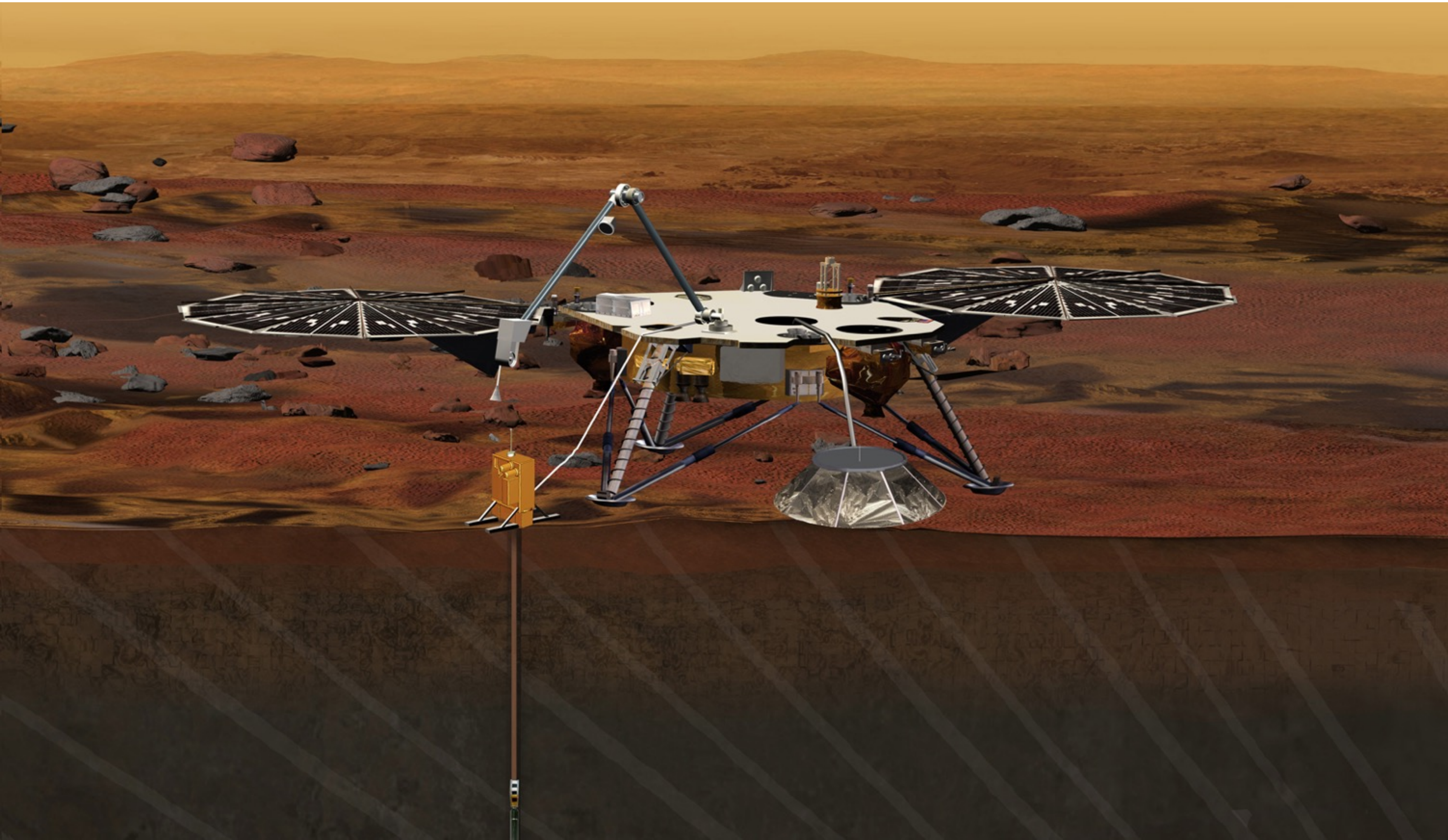
Looking Beyond the Horizon

Upcoming Missions

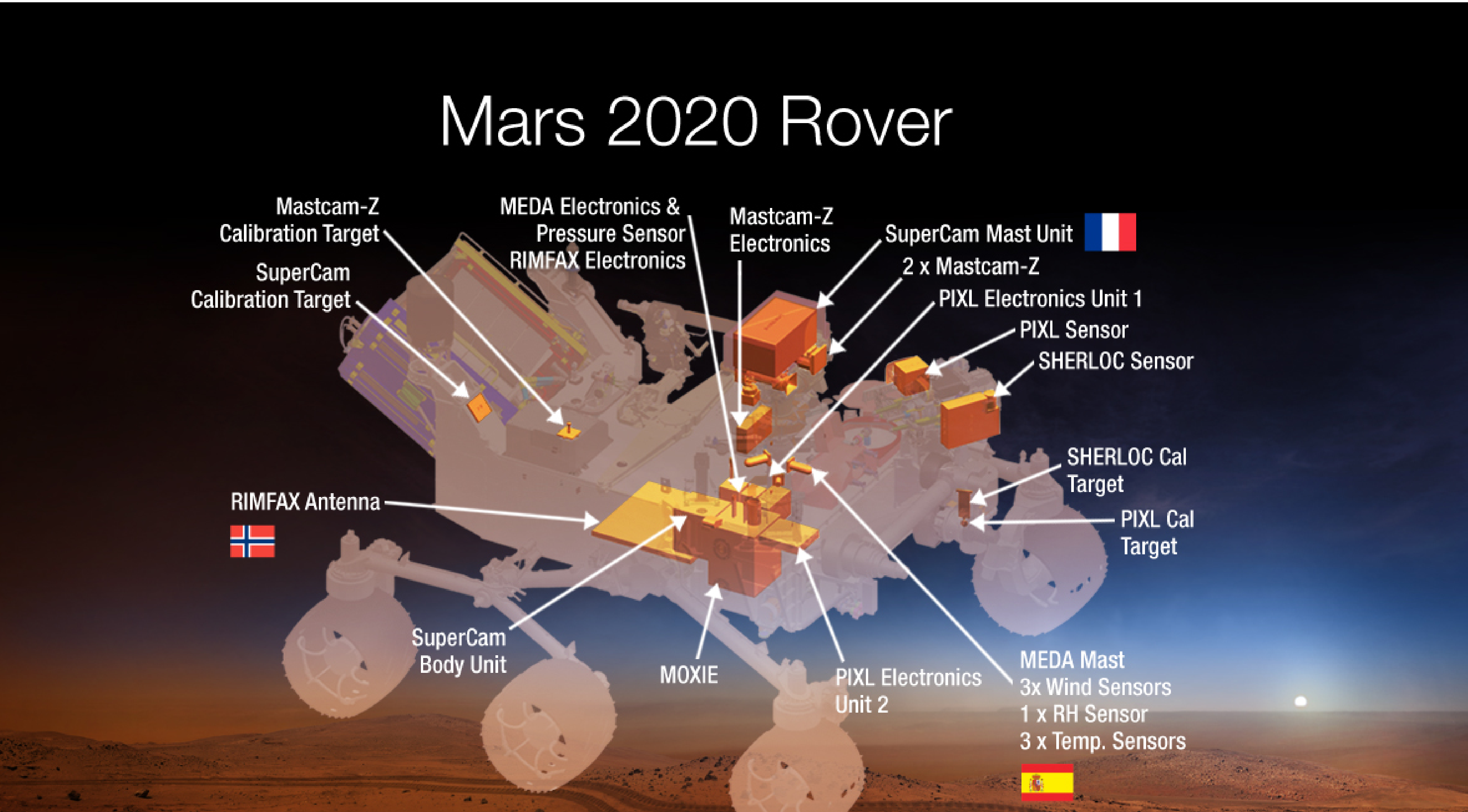
InSight

2018 Launch

Interior Exploration using Seismic Investigations, Geodesy and Heat Transport



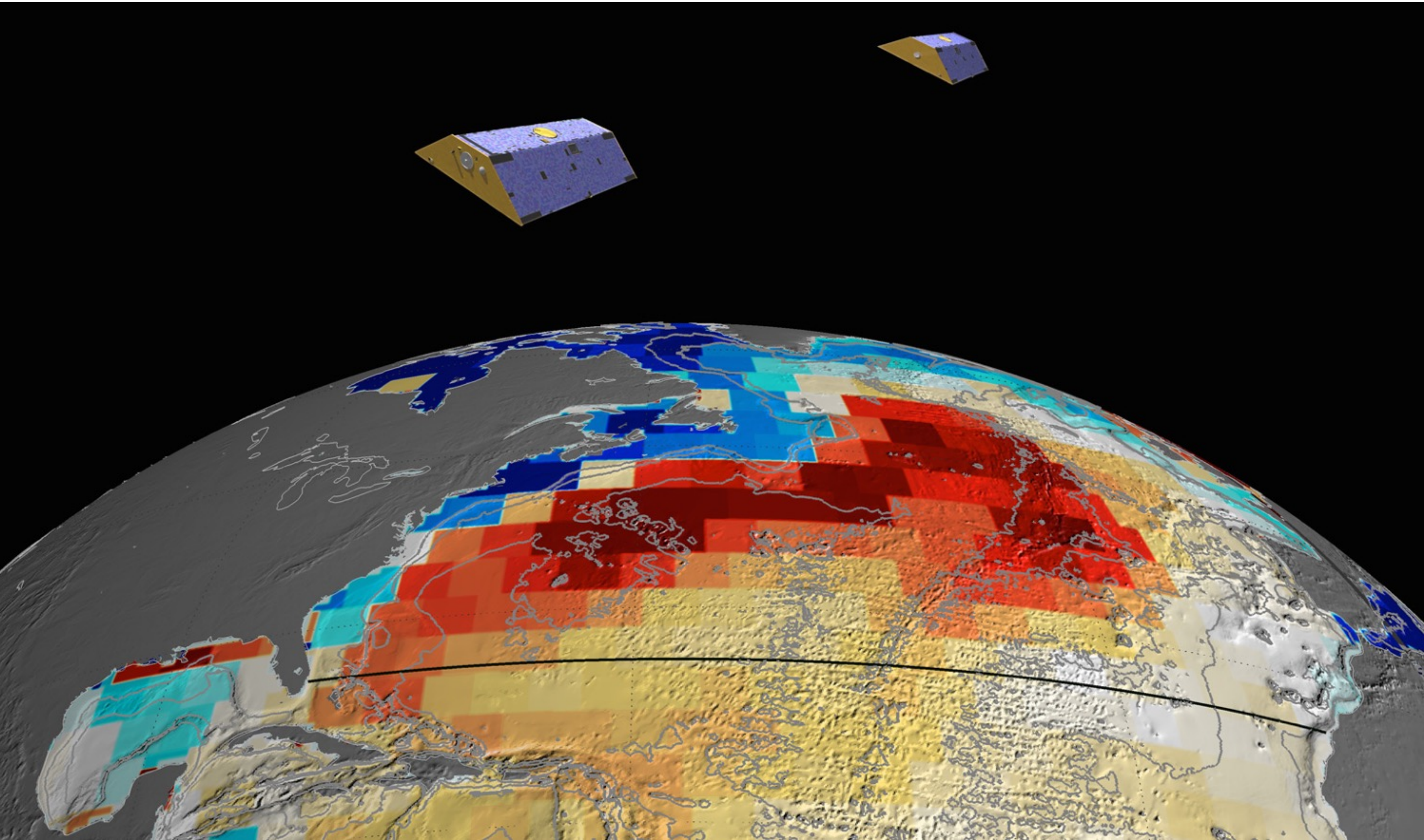
Mars 2020 Payload



Grace Follow-On

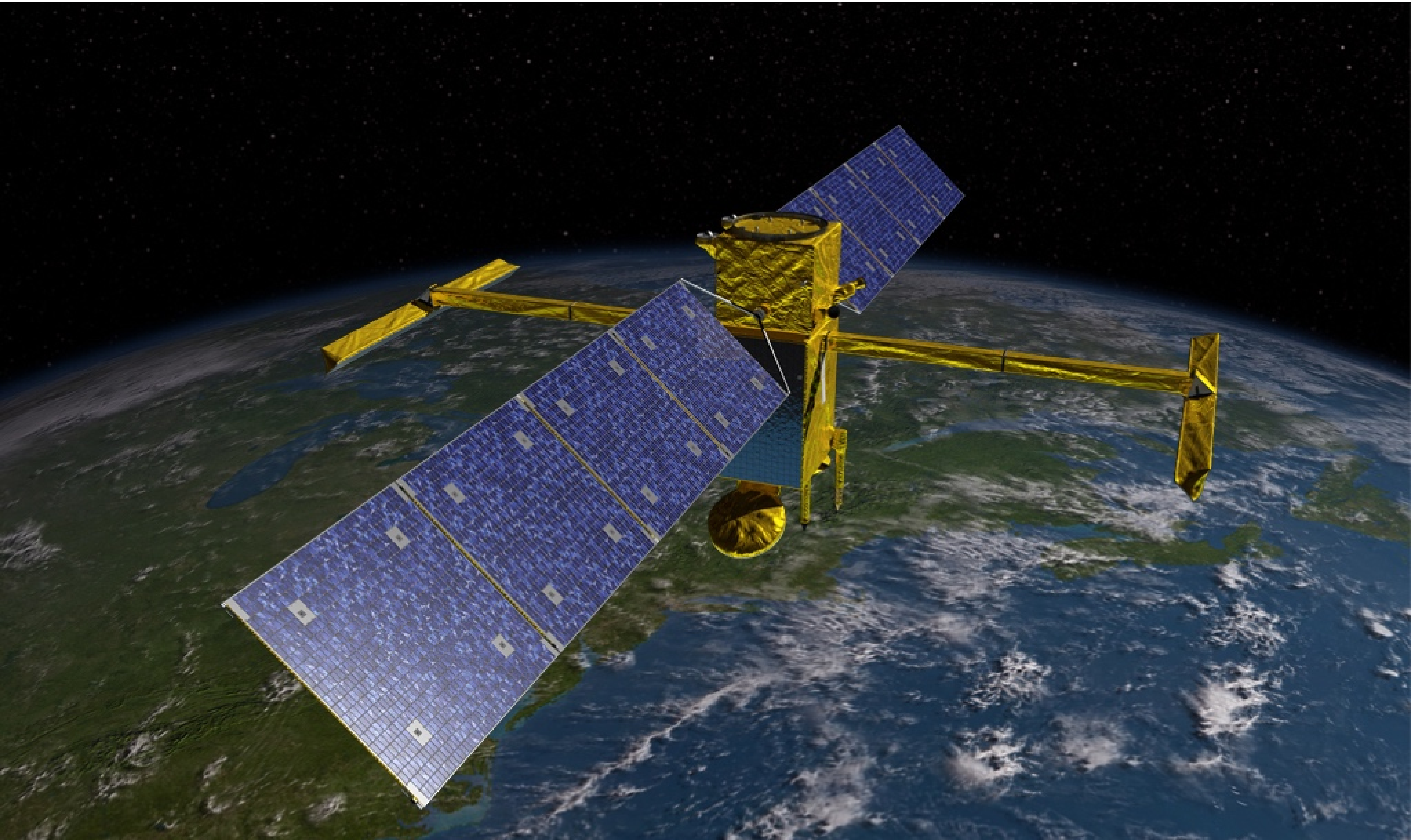
Launch: Early 2018

Demonstrating Advanced Measurement Techniques



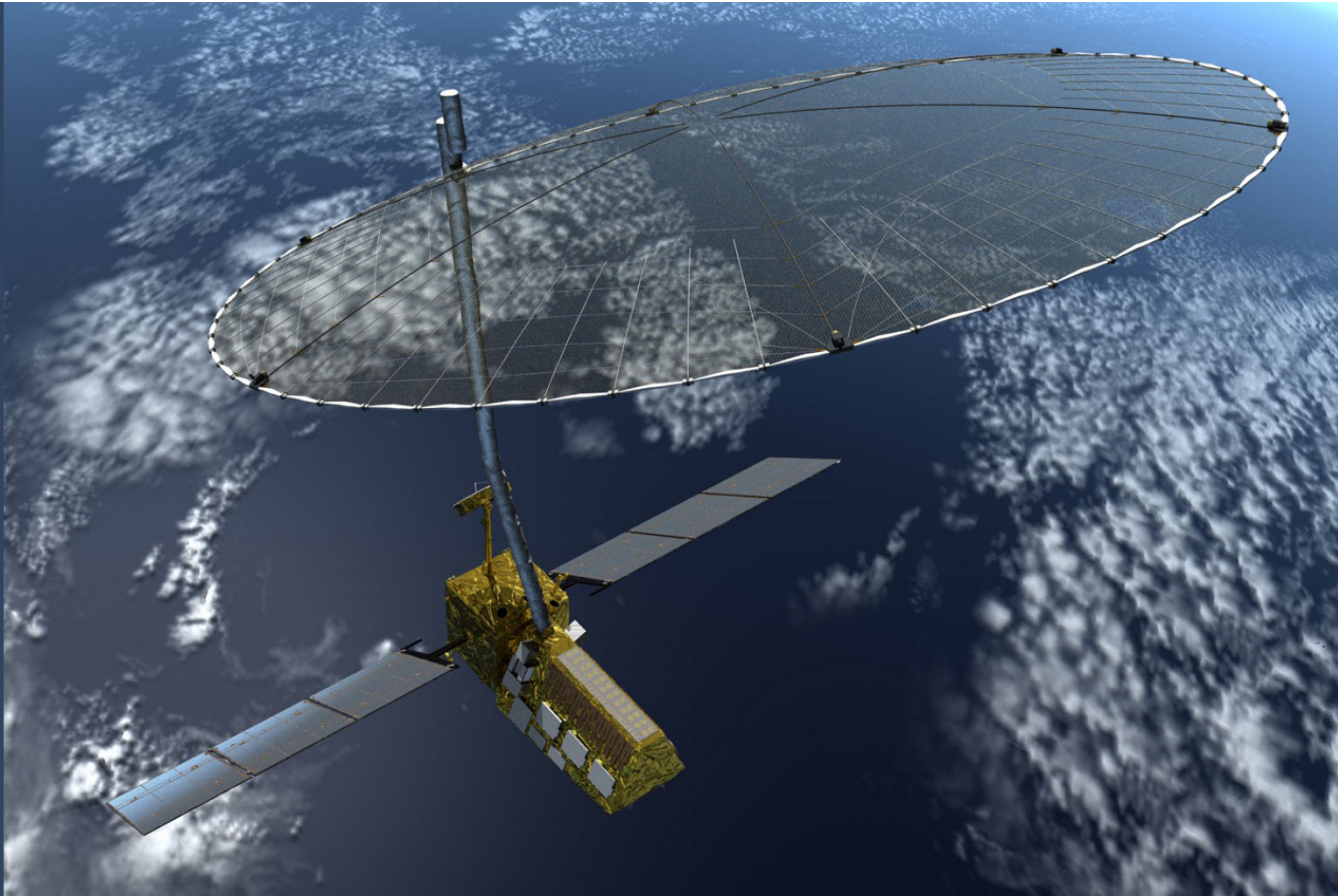
Surface Water Ocean Topography

2020 Launch



NASA-ISRO Synthetic Aperture Radar

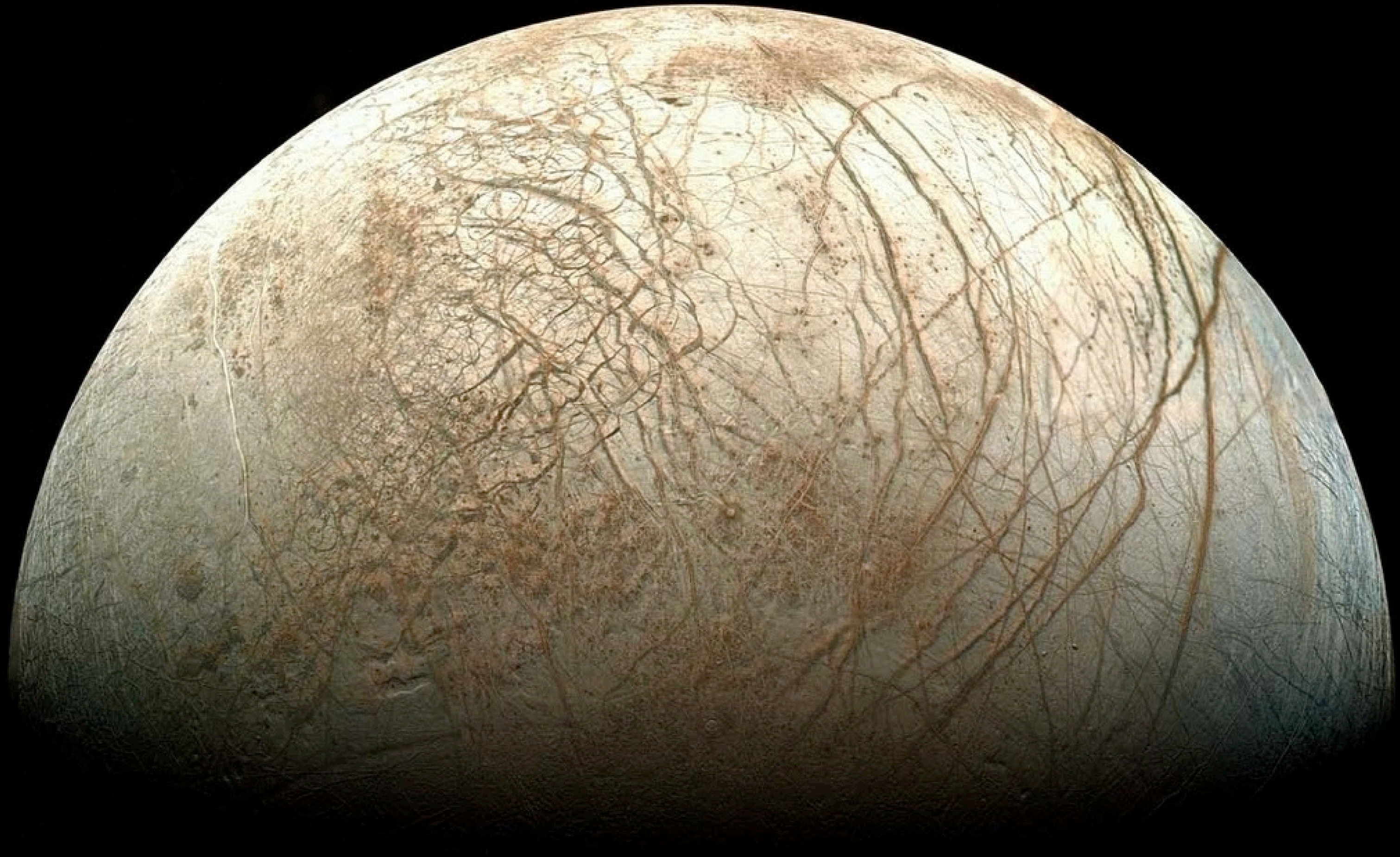
2020 Launch



Psyche: Journey to a Metal World

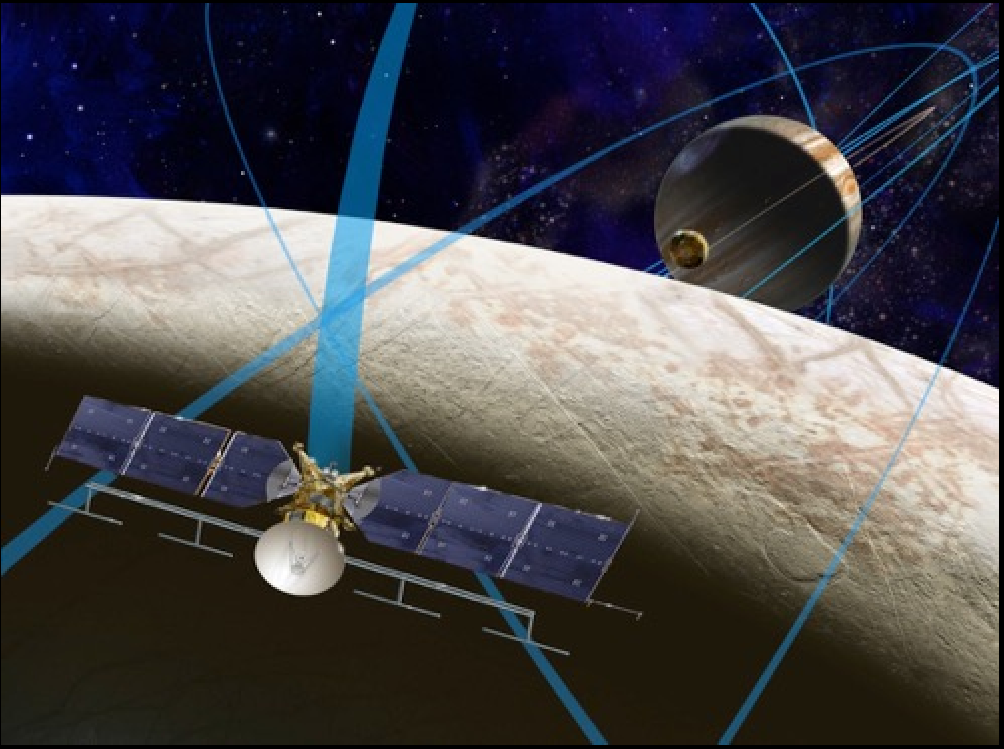
2023 Launch

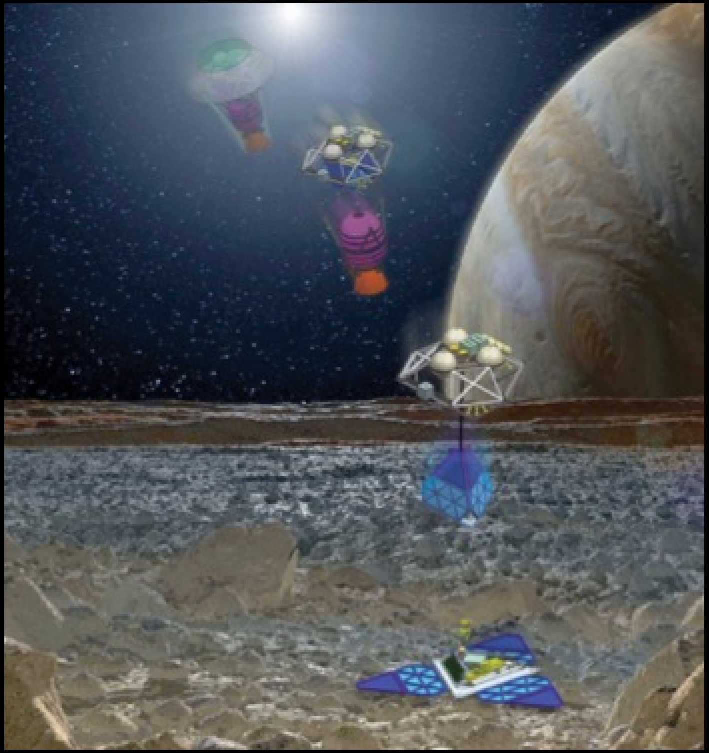
Europa: Gem of the Jupiter System



Europa Clipper & Lander

2022 & 2024 Launches





Looking Beyond the Horizon

Next Gen Ground System

Why change?

Today:

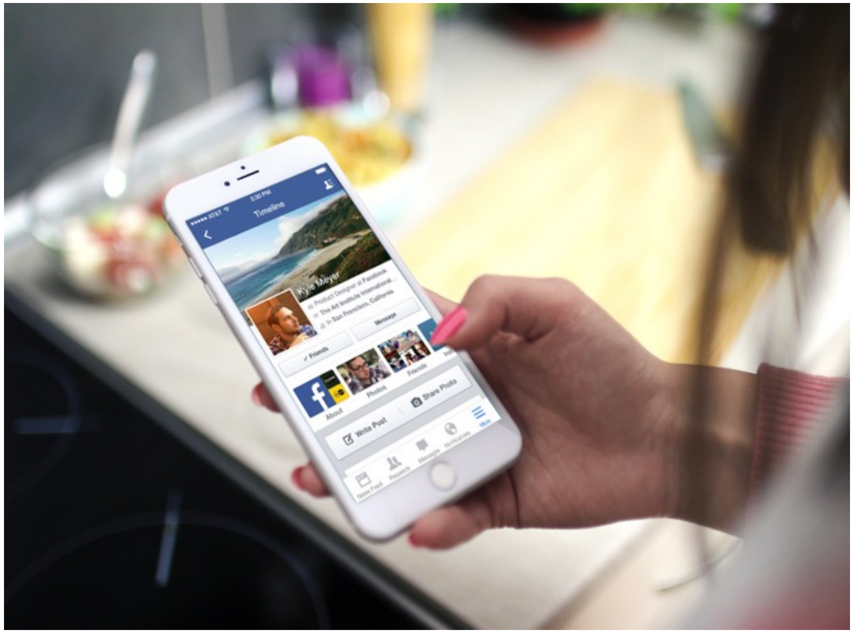
Processes from 1960's

- Hierarchical teams operating in silos

Tools from early 2000's

- Voice nets and screenshots
- Web based tools and (recently) cloud data

Meanwhile:



Apple, Facebook, Google, Twitter have changed how we interact with data

A Space-Ground Integrated Model

- Smarter more capable spacecraft in conjunction with exponentially more powerful ground control systems demand an integrated systems approach to spacecraft command, control and operations

    - Future spacecraft will be more autonomous, capable of learning, thinking for themselves, processing data on board and reacting
    - Future ground systems will also have AI, machine/deep learning, virtual reality capabilities

- Must take advantage of these paradigm shifts to leverage the capabilities of both

Smarter Spacecraft

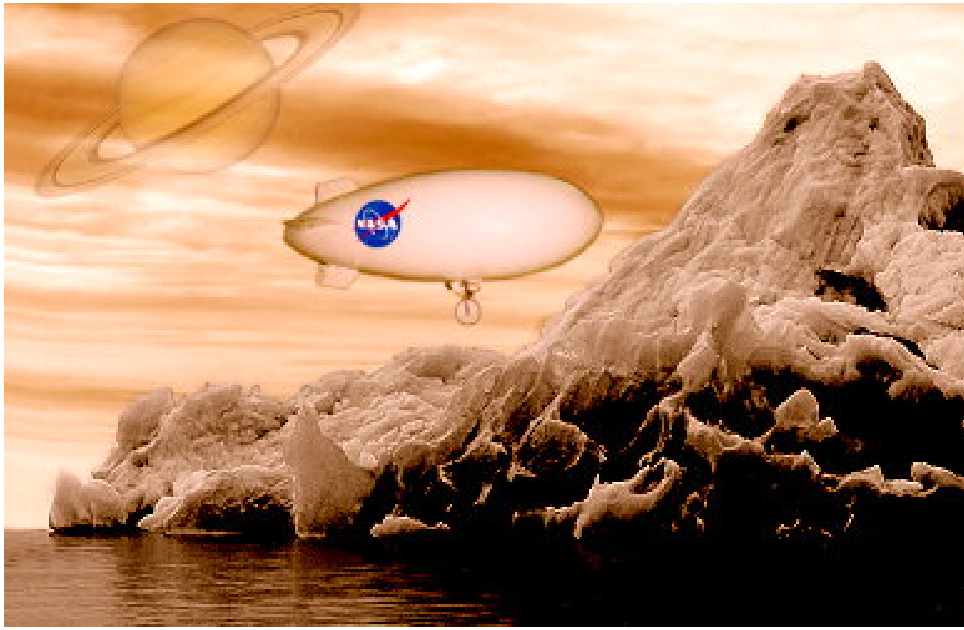
Voyager computer
- 8,000 instructions/sec and kilobytes of memory

iPhone
- 14 billion instructions/sec and gigabytes of memory

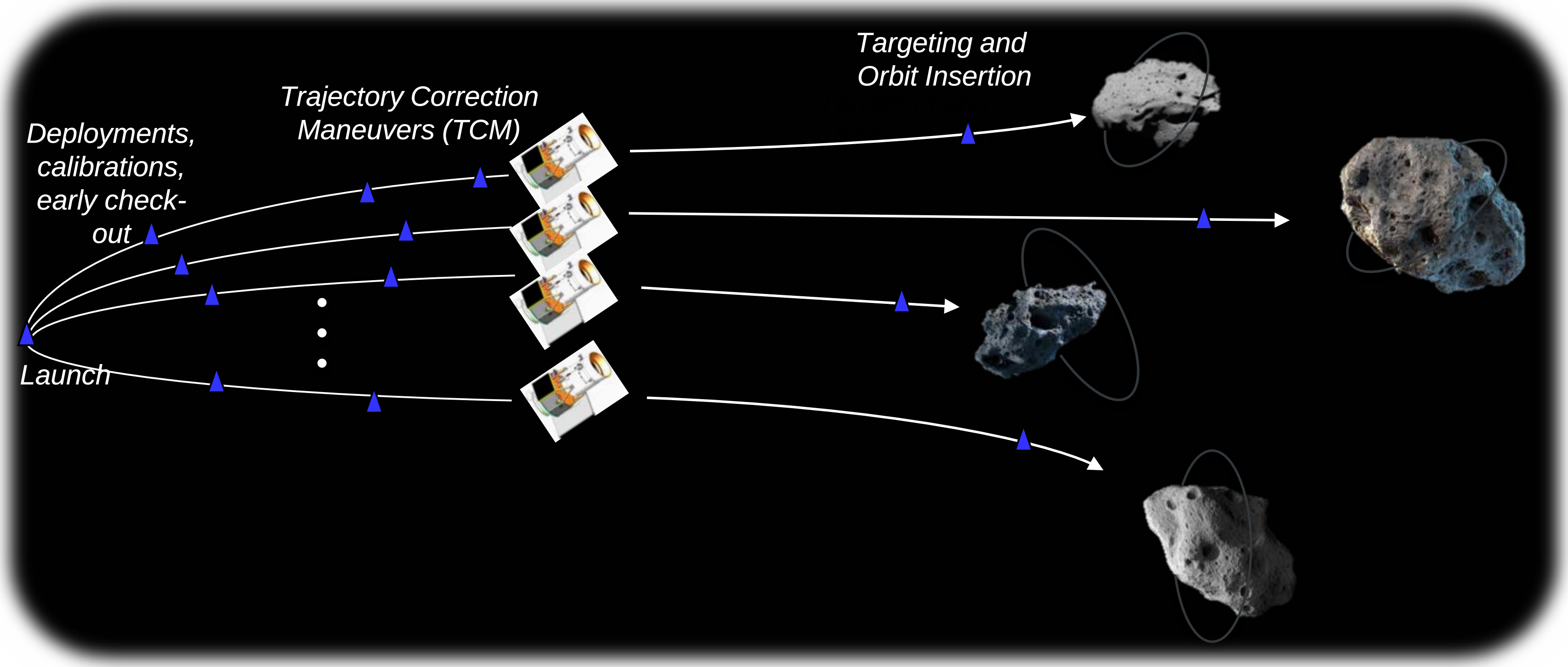
Curiosity (Mars Science Laboratory)
Processor: 200 MHz BAE RAD750
256 MB RAM
2 GB Flash
256 KB EEPROM

Future Concept: Titan Aerobot

- Penetrate the dense atmosphere
  - Search for complex organic molecules
- Dynamic environment/extreme distance
  - Autonomy for time critical exploration
- Robust operations under varying environmental and spacecraft conditions
  - Dynamically sense and react
  - Spacecraft focus on characterization of high priority targets
    - Rapidly select/characterize
    - Respond to events

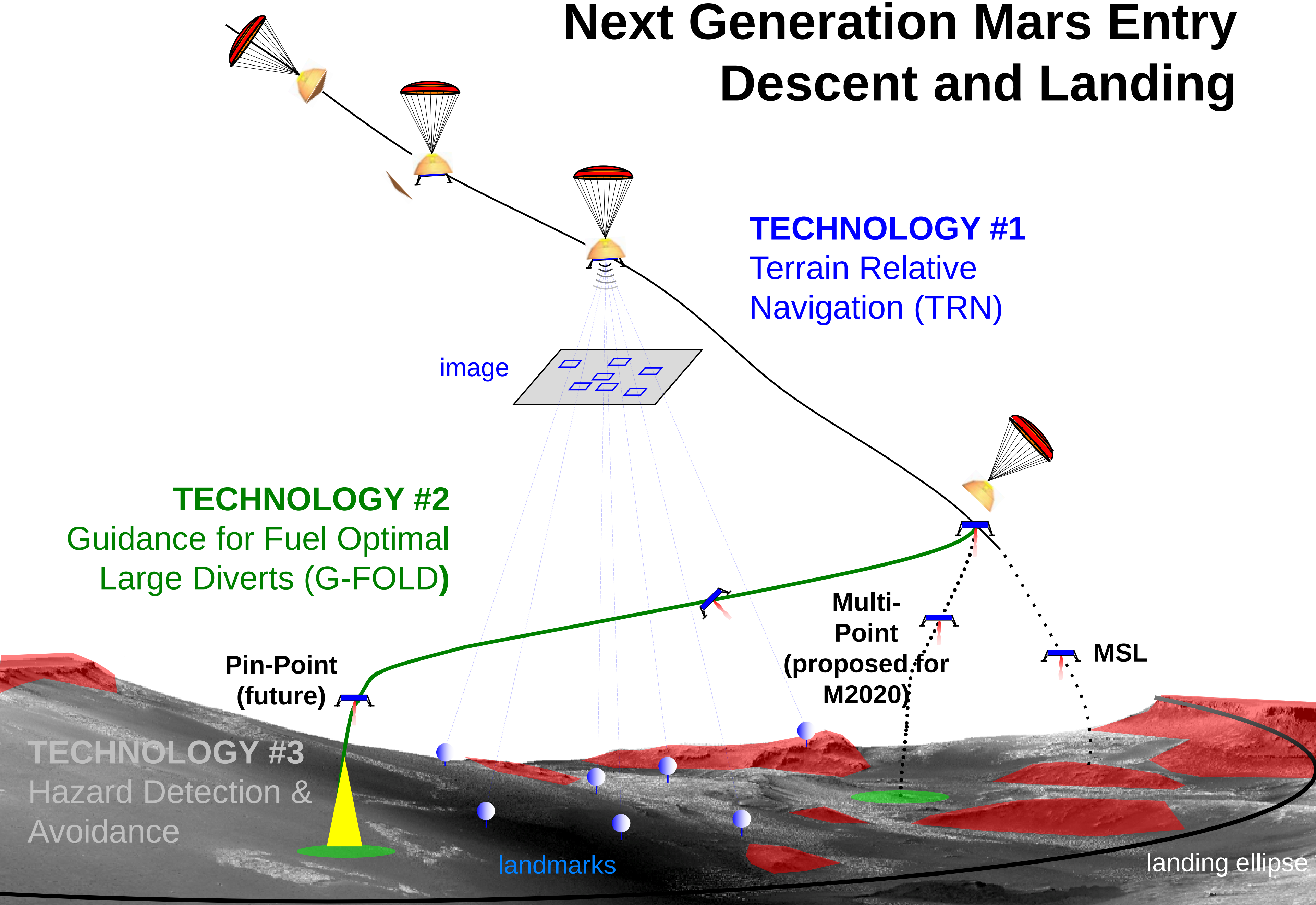


Future Concept: Small Body Fleet



Autonomously cruise and rendezvous with small bodies with little to no intervention of teams of ground operation personnel and equipment

Next Generation Mars Entry Descent and Landing



Data Lifecycle Model
for NASA Space Missions

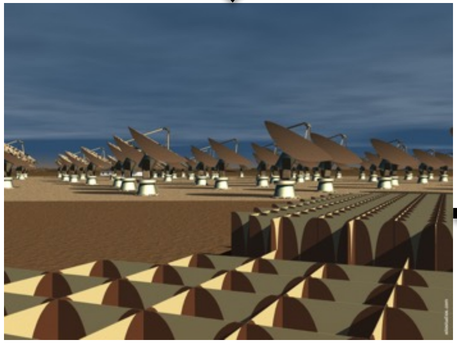
Emerging Solutions
- *Onboard Data Data Analytics*
- *Onboard Data Prioritization*
- *Flight Computing*

(1) Too much data, too fast; cannot transport data efficiently enough to store

Observational Platforms / Flight Computing

Massive Data Archives and Big Data Analytics

Emerging Solutions
- *Intelligent Ground Stations*
- *Agile MOS-GDS*



Emerging Solutions
- *Data Discovery from Archives*
- *Distributed Data Analytics*
- *Advanced Data Science Methods*
- *Scalable Computation and Storage*

(2) Data collection capacity at the instrument continually outstrips data transport (downlink) capacity

Ground-based Mission Systems

(3) Data distributed in massive archives; many different types of measurements and observations

Towards a Scalable, Automated Ground System Environment

Intelligent Ground Stations

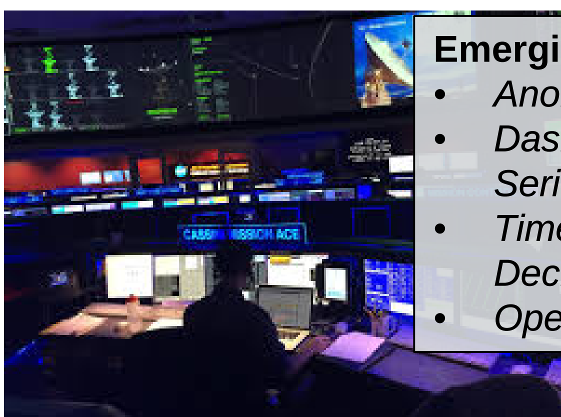
Emerging Solutions
- *Anomaly Detection*
- *Combining DSN & Mission Data*
- *Attention Focusing*
- *Controlling False Positives*

Data-Driven Discovery from Archives

Emerging Solutions
- *Automated Machine Learning - Feature Extraction*
- *Intelligent Search*
- *Learning over time*
- *Integration of disparate data*

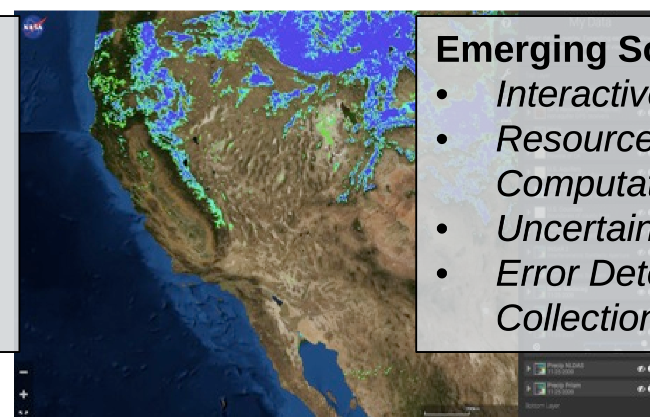
Technologies: Machine Learning, Deep Learning, Intelligent Search, Data Fusion, Interactive Visualization and Analytics

Agile MOS-GDS



Emerging Solutions
- *Anomaly Interpretation*
- *Dashboard for Time Series Data*
- *Time-Scalable Decision Support*
- *Operator Training*

Data Analytics and Decision Support



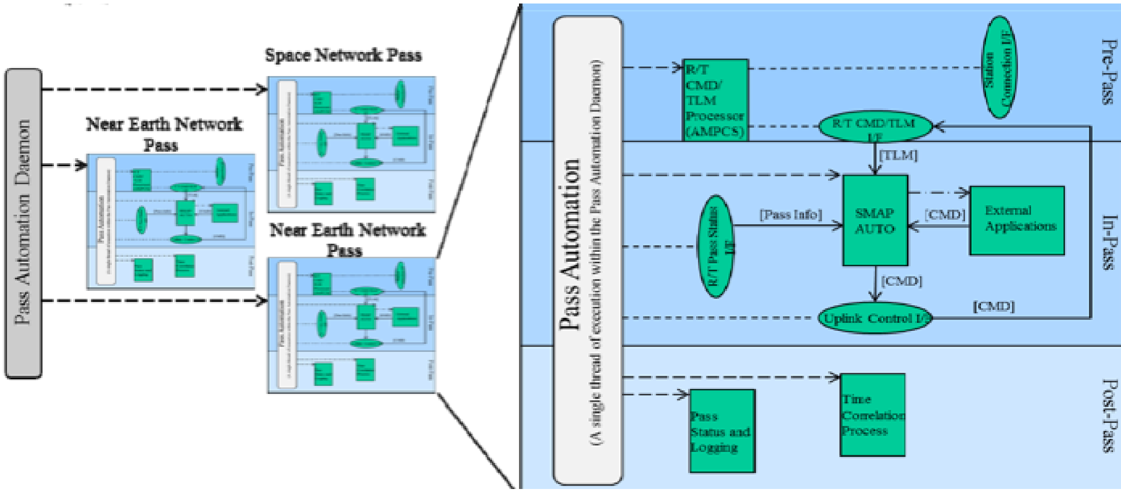
Emerging Solutions
- *Interactive Data Analytics*
- *Resource Analysis of Computational Workflows*
- *Uncertainty Quantification*
- *Error Detection in Data Collection*

SMAP Ground Automation

Pass Automation Daemon (PAD)

Description

- Automation engine
- Drives ground-based pass automation across NASA Near Earth Network (NEN)
- Integration/orchestration of project-level uplink automation, time correlation, and pass processing



Benefits

- Operational since January 2015
- Success Percentage: 99.8%
- Provides an estimated workforce savings of 3-4 FTE

Path Forward

- Missions that use NASA AMMOS for command and telemetry interface to ground stations (AMPCS) can directly inherit PAD capability
- Current missions: SMAP
- Intended missions: NISAR, SWOT

Ground Operations Tool: Machine Learning

Machine Learning/Spacecraft Telemetry Anomaly Detection

- Description
  - Aids human operators by identifying and predicting anomalies more quickly, greatly streamlining mission operations
- Benefit
  - By reducing the time required to identify and resolve the root cause of anomalies, the spacecraft will be safer and will have more time for science operations
- Path Forward
  - Developed an operational system for Curiosity mission, **MARTTE** (**M**SL **A**nomaly Detecto**R** **T**elemetry **T**ool Suit**E),** which is an anomaly detector system that shows mission operations staff a list of high-interest anomalous telemetry readings
    - Adapt across systems and missions

Deep Space Network (DSN) Scheduling

- Automated scheduling tool deployed for managing DSN communication services
  - Handles over 500 activities per week, 300 project service requirements, 38 project users
  - Manages timing communication windows, operation rules, hardware constraints, preferences, etc.
  - Provides collaborative environment enabling mission users to view, manage and negotiate schedule requests
- Enables a *request-driven* approach to scheduling (vs. past activity-driven approach)
- Reduced workforce from 12.5 to 9.5 FTEs with further reductions possible

Lead contact: Mark Johnston

What happens if we apply modern computing practices to operations?

iPhone/Android apps
• Google Maps

Intuitive GUI interfaces

Mobile Access

Instant Messaging and Chat

Instantly share telemetry analysis

Messaging replace emails and voice nets

Social Networks
• Facebook • Instagram

Flatten Hierarchy

Collaborative problem resolution

Dashboards replace voice polls

Integrated Development Environments
• Eclipse & Xcode

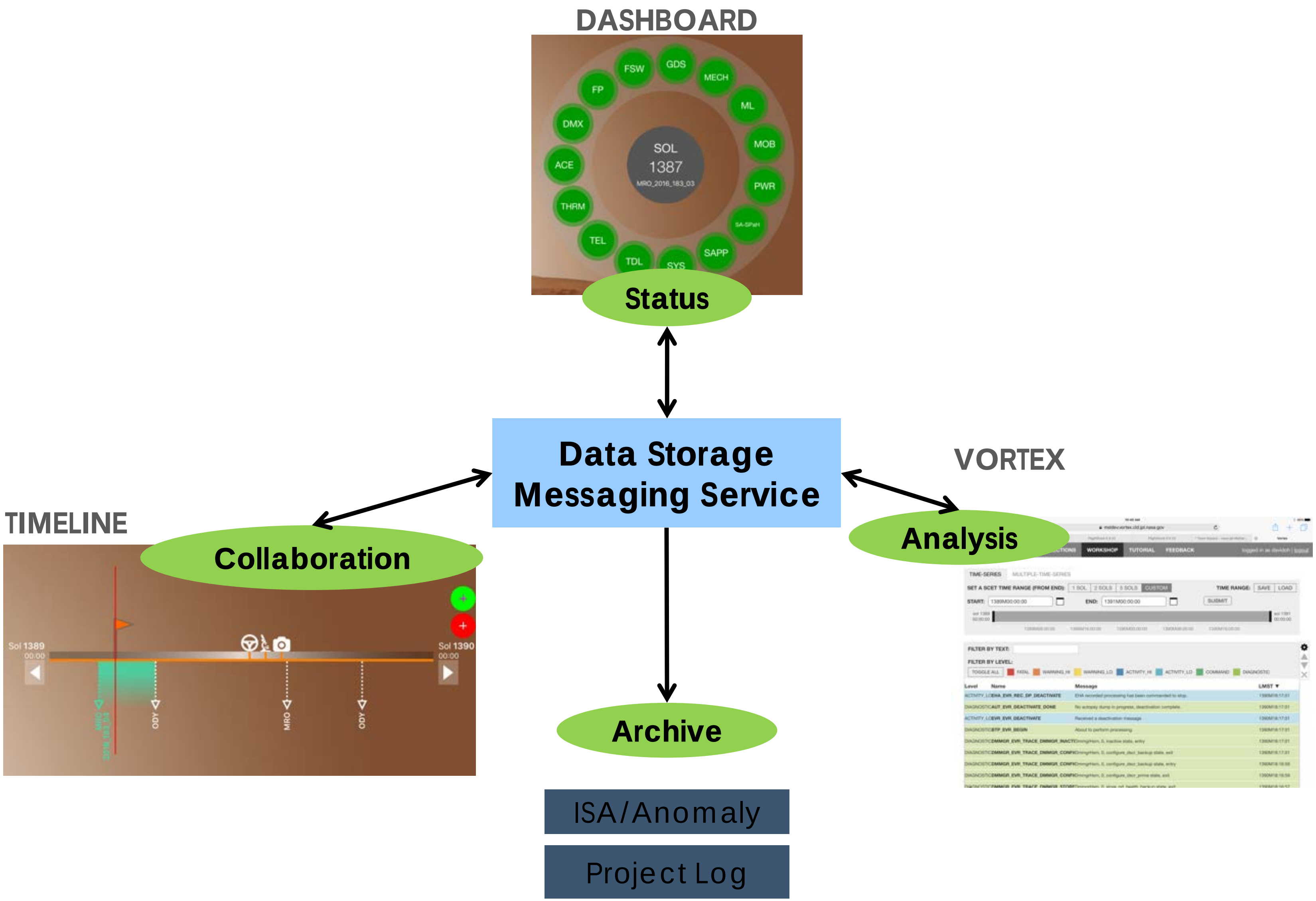
Seamless integration of tools, plans, systems

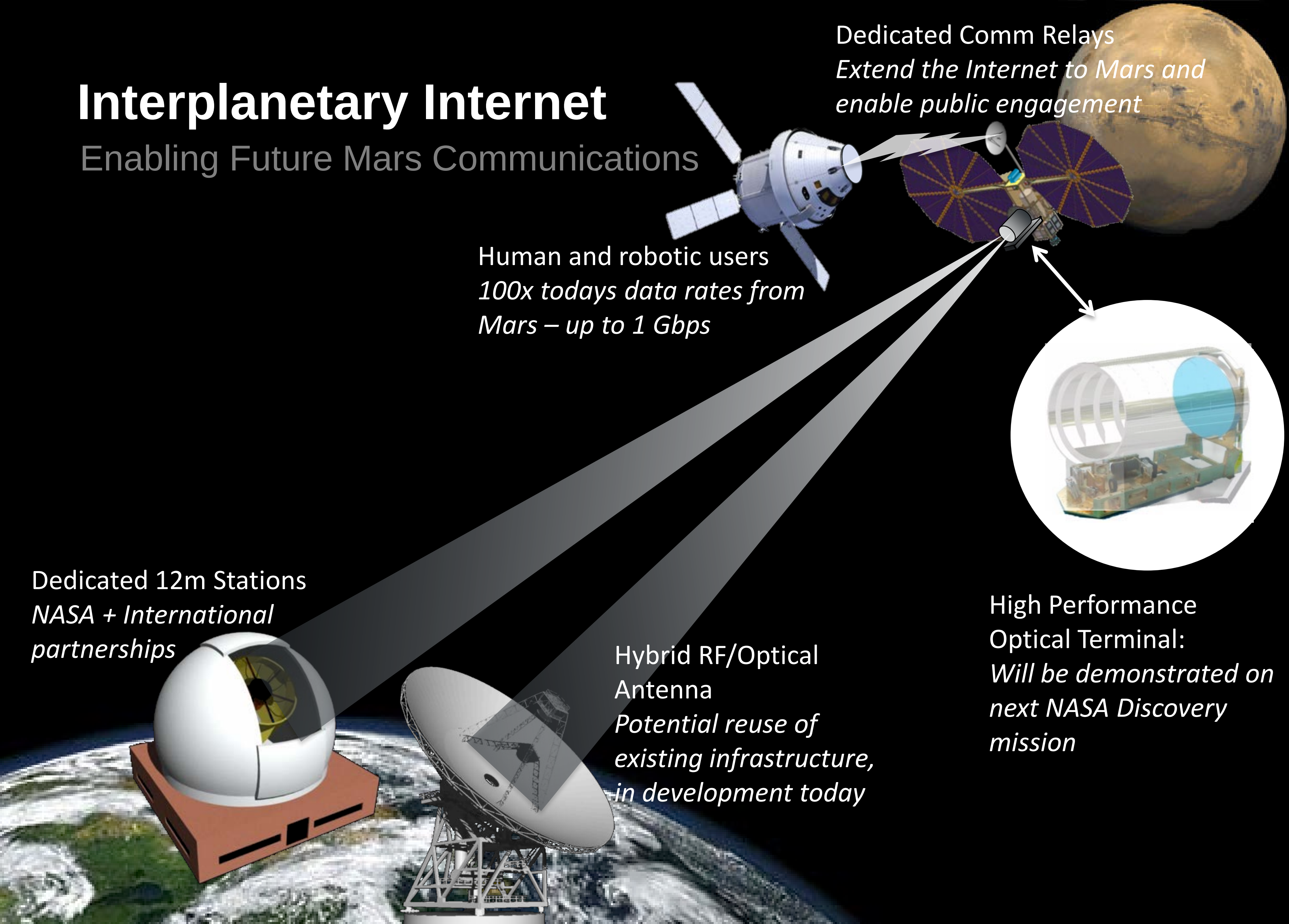
Integrated Operations Environment

Modern internet tools and methods can dramatically improve operations in mission control

JPL

Single Integrated, Collaborative Operations Environment




Interplanetary Internet
Enabling Future Mars Communications
Dedicated Comm Relays
Extend the Internet to Mars and enable public engagement
Human and robotic users
100x todays data rates from Mars – up to 1 Gbps
Dedicated 12m Stations
NASA + International partnerships
Hybrid RF/Optical Antenna
Potential reuse of existing infrastructure, in development today
High Performance Optical Terminal:
Will be demonstrated on next NASA Discovery mission

Virtual Mars

Virtual + Augmented Reality

JPLOps Lab

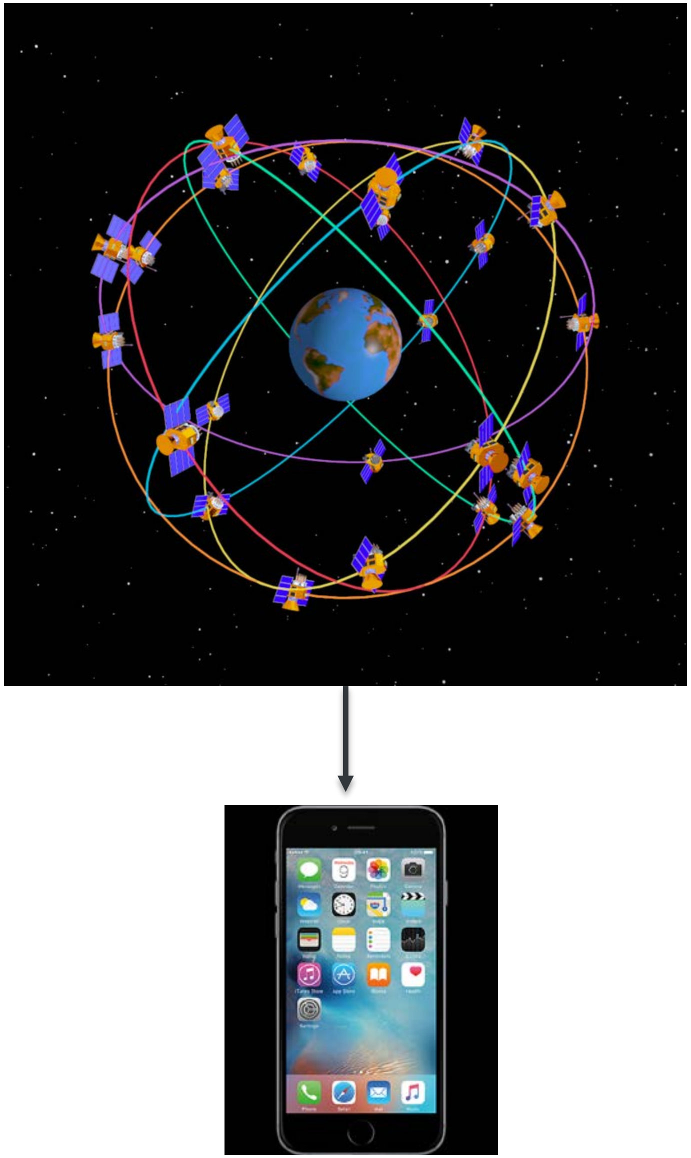
OnSight enables scientists to "work on Mars" together from their offices. Supported by the Mars 2020 and MSL missions, it is in use by a pilot group of scientists for rover operations. Press release: http://go.nasa.gov/1RAbGpU

Sidekick's goal is to augment and assist astronauts as they perform tasks onboard the ISS. Project hardware arrived on ISS in Dec 2015 and initial use is expected in early 2016. Press release: http://go.nasa.gov/1ZMRk1n

Destination: Mars will offer the public the opportunity to walk on Mars with Buzz Aldrin. This one-of-a-kind experience will debut at a top-tier museum in mid-2016.

A new Ops Lab project brings 3D spacecraft designs into the world to solve problems before they're real. Initial mission users include Europa Clipper, Mars 2020, and SWOT.

The Future Ground Control System



Changing the paradigm of operations

Dare Mighty Things