Jet Propulsion Laboratory
California Institute of Technology

EUROPA CLIPPER

Mission Update to the Space Studies Board

June 6, 2023

Robert Pappalardo, Project Scientist

Jordan Evans, Project Manager

Jet Propulsion Laboratory, California Institute of Technology

Exploring Europa's Habitability: Ingredients for Life

Water:

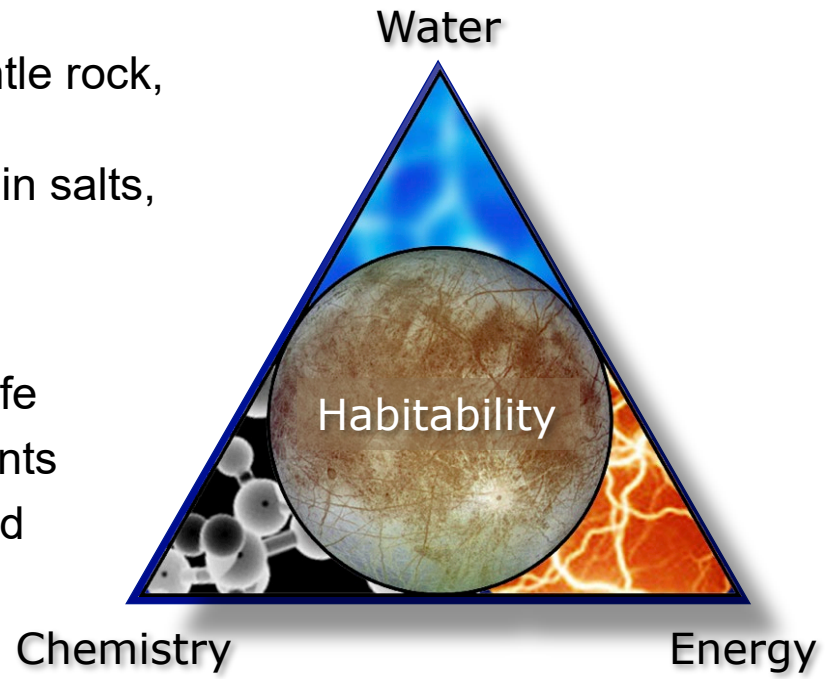
- Probable saltwater ocean, implied by surface geology and magnetic field
- Possible lakes within the ice shell, produced by local melting

Chemistry:

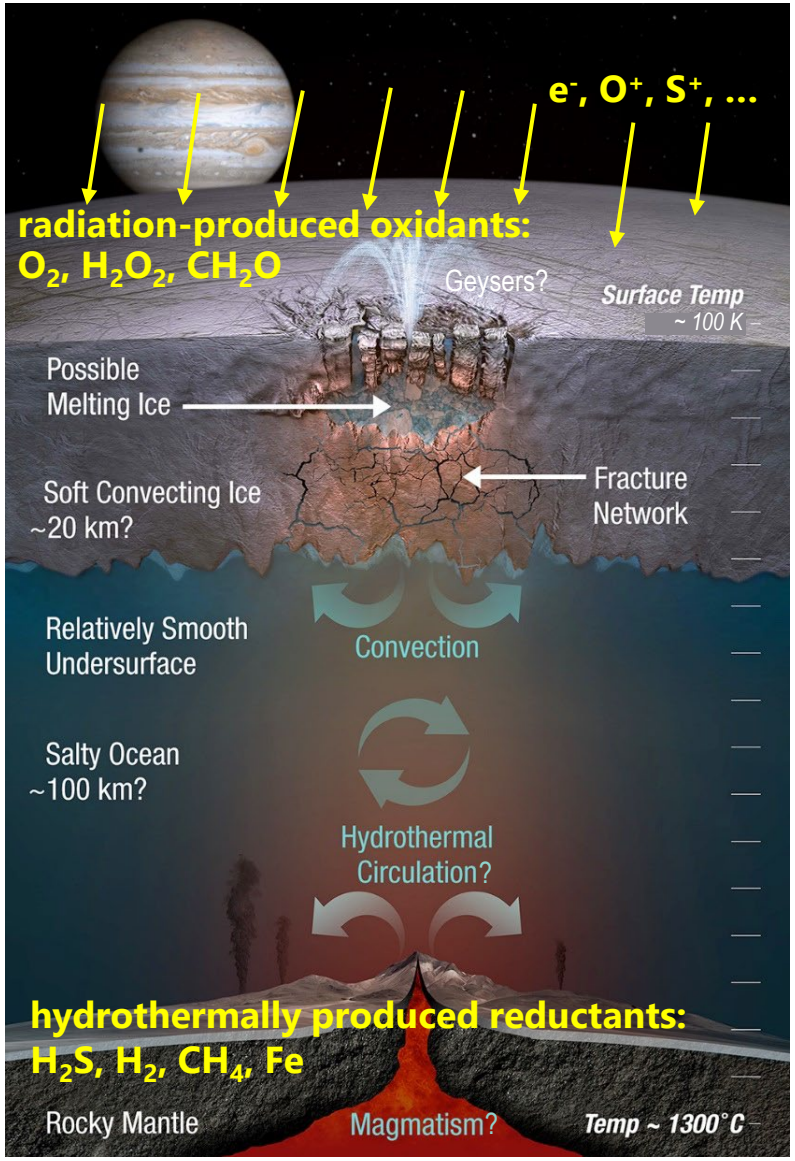
- Ocean in direct contact with mantle rock, promoting chemical leaching
- Dark red surface materials contain salts, probably from the ocean

Energy:

- Chemical energy might sustain life
- Surface irradiation creates oxidants
- Mantle rock-water reactions could create reductants (hydrothermal or serpentinization)



The Europa Clipper Mission will test key habitability hypotheses

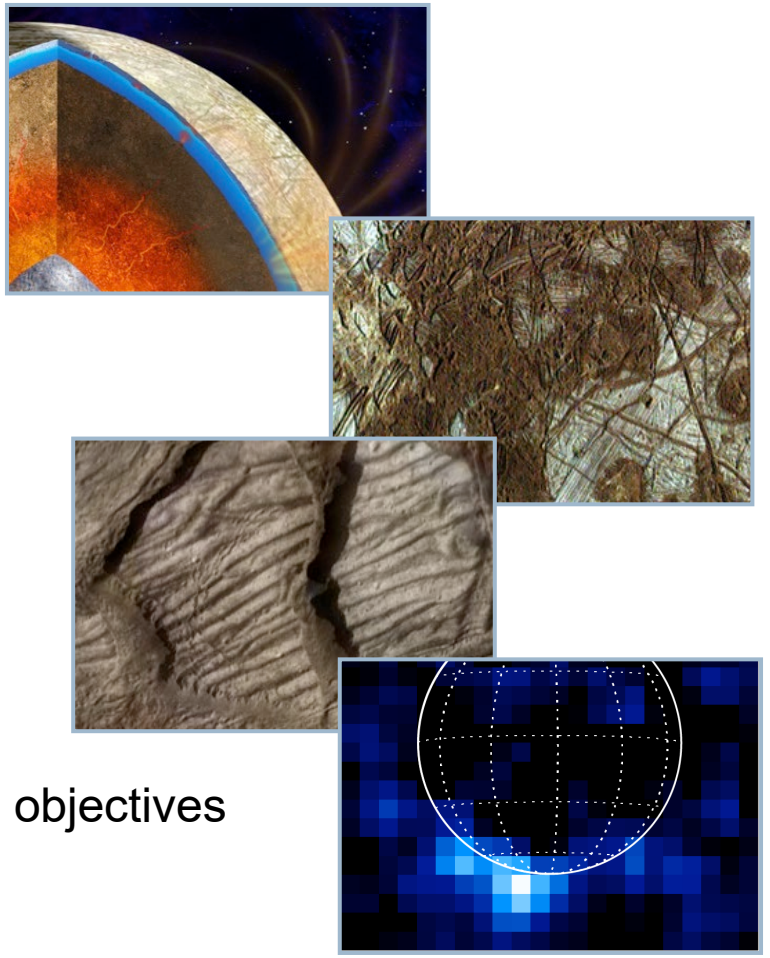


Europa Clipper Science Goal and Objectives

- *Science Goal:* **Explore Europa to investigate its habitability**

- *Science Objectives:*

  - **Ice Shell & Ocean:** Characterize the ice shell and any subsurface water, including their heterogeneity, ocean properties, and the nature of surface-ice-ocean exchange
  - **Composition:** Understand the habitability of Europa's ocean through composition and chemistry
  - **Geology:** Understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities

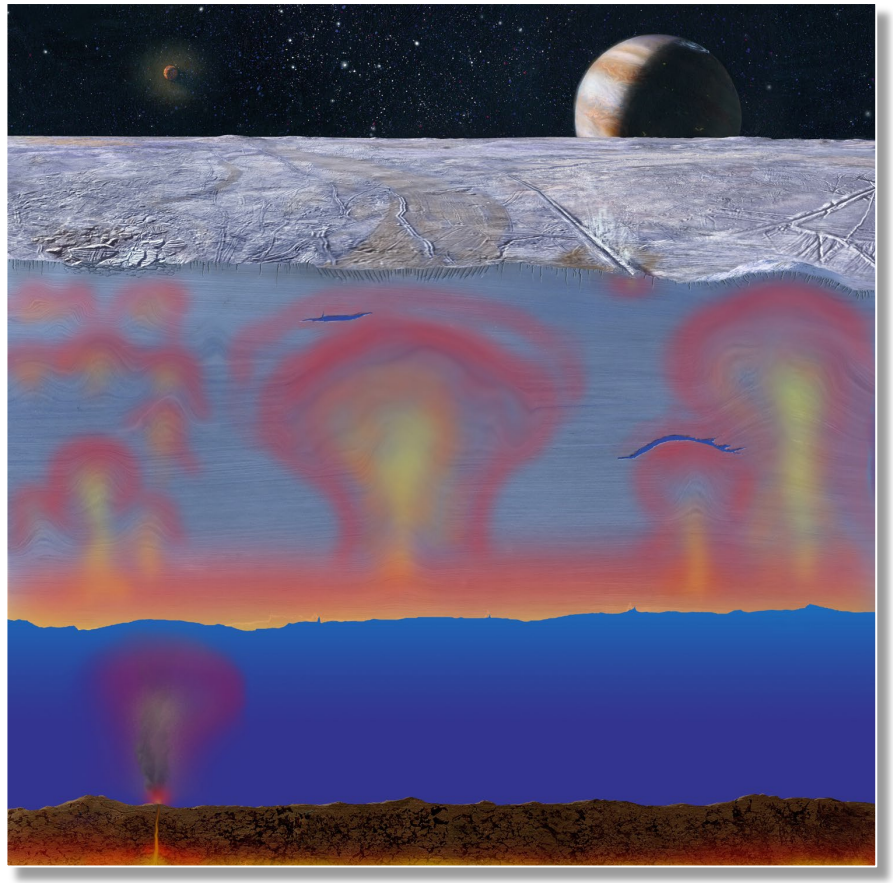


Note: **Recent Activity** cross-cuts through all three principal science objectives

Europa Clipper Science (1/3): Interior (Ice Shell & Ocean)

- ***Interior Objective:***
  Characterize the ice shell and any subsurface water, including their heterogeneity, ocean properties, and the nature of surface-ice-ocean exchange

- ***Interior Themes:***
  - **Deep Subsurface Exchange:** Deep vertical distribution of subsurface water, ice shell structure, and surface–ice–ocean exchange processes.
  - **Shallow Subsurface Structure:** Shallow vertical distribution of subsurface water, ice shell structure, and surface–ice exchange processes.
  - **Ice Shell Properties:** Thickness and thermophysical properties of the ice shell.
  - **Ocean Properties:** Existence, thickness, salinity, and composition of the ocean.
  - **Surface Thermal Anomaly Search:** Thermal signatures of current or recent geological activity.
    (Theme shared with geology objective.)



Europa Clipper Science (2/3): Composition

- ***Composition Objective:***
  Understand the habitability of Europa's ocean through composition and chemistry
- ***Composition Themes:***
  - **Global Compositional Surface Mapping:** Global surface composition and chemistry, including distribution and large-scale variability of materials.
  - **Landform Composition:** Surface constituents, focusing on non-water-ice and any carbon-containing compounds, on a regional and landform scale.
  - **Atmospheric Composition:** Composition and sources of non-ice volatiles, particulates, and plasma in the atmosphere, ionosphere, and possible plumes, within Europa's Hill sphere.
  - **Space Environment Composition:** Composition and sources of non-ice volatiles, particulates, and plasma in the space environment, outside of Europa's Hill sphere.
  - **Remote Plume Search and Characterization:** Remote detection and characterization of active plumes. (Theme shared with geology objective.)
  - ***In-Situ* Plume Search and Characterization:** *In-situ* detection and characterization of recent

Europa Clipper Science (3/3): Geology

- ***Geology Objective:***
  Understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities

- ***Geology Themes:***
  - **Global Surface Mapping:** Global distribution and relationships of geologic landforms.
  - **Landform Geology:** Morphology, topography, geology-composition correlations, and diversity of landforms.
  - **Local-Scale Surface Properties:** Local-scale morphological, thermophysical, and mechanical surface properties.
  - **Remote Plume Search and Characterization:** Remote detection and characterization of active plumes. (Theme shared with composition objective.)
  - **Surface Thermal Anomaly Search:** Thermal signatures of current or recent geological activity. (Theme shared with interior objective.)
  - **Surface Activity Evidence:** Surface properties and/or changes indicative of current or recent activity.

Europa Clipper Level-1 Science Requirements Are Stable

	Baseline Level-1 Science Requirements	Threshold Level-1 Science Requirements
Ice & Ocean	**I1:** Map the vertical subsurface structure in regions of potential surface-ice-ocean exchange to >3 km depth along globally distributed ground tracks achieving a total cumulative length ≥30,000 km.	**I1:** Map the vertical subsurface structure in regions of potential surface-ice-ocean exchange to ≥3 km depth along regionally distributed ground tracks achieving a total cumulative length ≥10,000 km.
	I2: Constrain our knowledge of the average thickness of the ice shell, and the average thickness and salinity of the ocean, each to ±50%.	**I2:** Confirm the presence of a subsurface ocean, and determine whether the ice shell is in a “thin” (several km) or “thick” (10s km) regime.
Composition	**C1:** Create a compositional map at ≤10 km spatial scale, covering ≥60% of the surface, sufficient to identify non-ice materials, especially organic compounds.	**C1:** Create a compositional map at ≤10 km spatial scale, covering ≥40% of the surface, sufficient to identify non-ice materials, especially organic compounds.
	C2: Characterize the composition of ≥0.3% of the surface, globally distributed at ≤300 m spatial scale, sufficient to identify non-ice materials, especially organic compounds.	**C2:** Characterize the composition of ≥0.15% of the surface, regionally distributed at ≤400 m spatial scale, sufficient to identify non-ice materials, especially organic compounds.
	C3: Characterize the composition and sources of volatiles, particulates, and plasma, sufficient to identify the signatures of non-ice materials, including organic compounds, in at least one of the above forms, in globally distributed regions of the atmosphere and local space environment.	**C3:** Characterize the composition and sources of volatiles or particulates, sufficient to detect the signatures of non-ice materials, including organic compounds, in at least one of the above forms, in distributed regions of the atmosphere and local space environment.
Geology	**G1:** Produce a controlled photomosaic map of ≥80% of the surface at ≤100-m spatial scale.	**G1:** Produce a controlled photomosaic map of ≥30% of the surface at ≤100-m spatial scale.
	G2: Characterize the surface at ≤25-m spatial scale across ≥5% of the surface with global distribution, including measurements of topography at ≤15-m vertical precision across ≥1% of Europa’s surface.	**G2:** Image the surface at ≤50-m spatial scale across ≥1.5% of the surface with regional distribution, including measurements of topography at ≤20-m vertical precision across ≥0.5% of Europa’s surface.
	G3: Characterize the surface at ~1-m spatial scale to determine surface properties, for ≥18 globally distributed sites.	N/A
Current Activity	**A1:** Search for and characterize any current activity, notably plumes or thermal anomalies, in regions that are globally distributed.	**A1:** Search for current activity, notably plumes or thermal anomalies.

Europa Clipper Investigations

MASPEX
Mass Spectrometer
PI: Jim Burch, SwRI
sniffing atmospheric composition

SUDA
Dust Analyzer
PI: Sascha Kempf: U. Colorado
detecting surface & plume composition

ECM
Magnetometer
TL: Margaret Kivelson, U. Michigan
revealing ocean properties

PIMS
Faraday Cups
PI: Adrienn Luspay-Kuti, APL
measuring plasma environment

Europa-UVS
UV Spectrograph
PI: Kurt Retherford, SwRI
seeking plume glow

EIS
Narrow-angle Camera + Wide-angle Camera
PI: Zibi Turtle, APL
mapping alien landscape

MISE
IR Spectrometer
PI: Diana Blaney, JPL
detecting chemical fingerprints

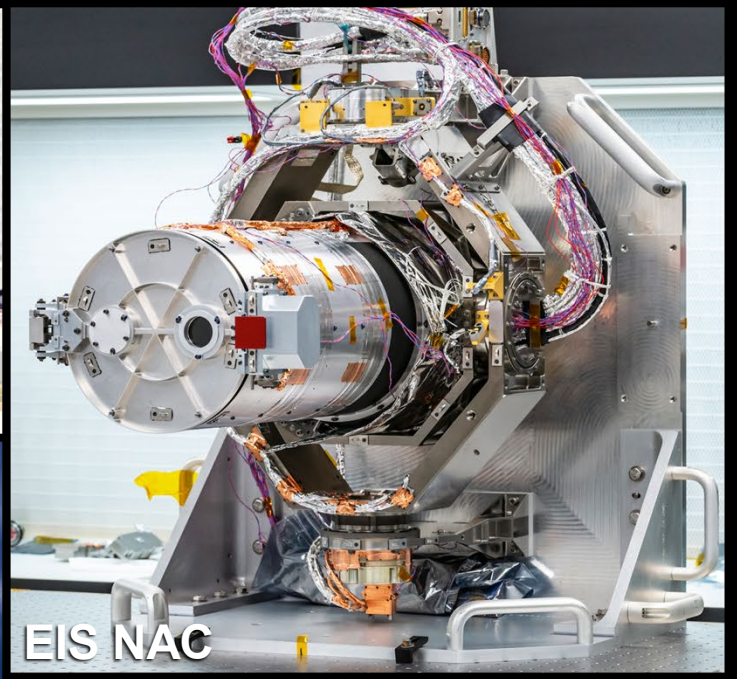
E-THEMIS
Thermal Imager
PI: Phil Christensen, ASU
searching for hot spots

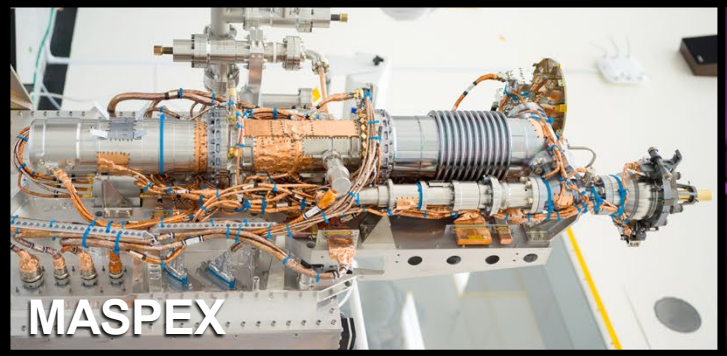
REASON
Ice-Penetrating Radar
PI: Don Blankenship, UTIG
probing the ice shell

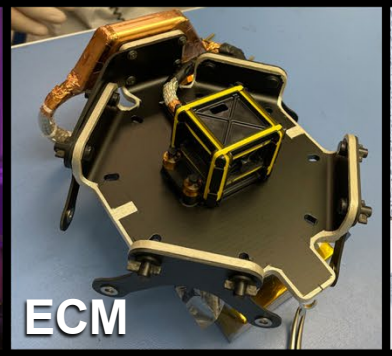
G/RS
Doppler Gravity
TL: Erwan Mazarico, GSFC
sensing interior layers

Remote Sensing In Situ

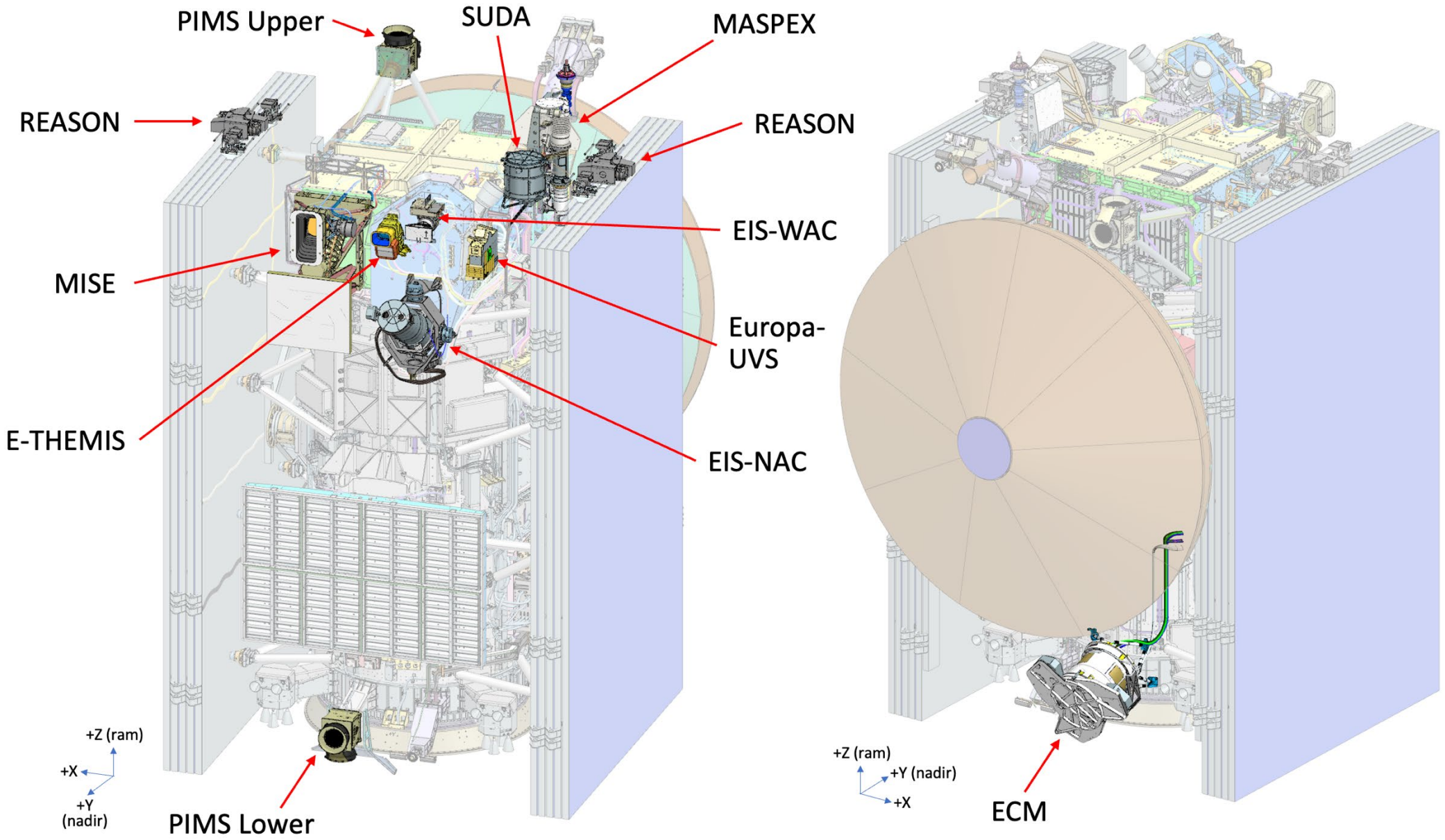
Europa Clipper Instruments Are All Delivered and Integrated!



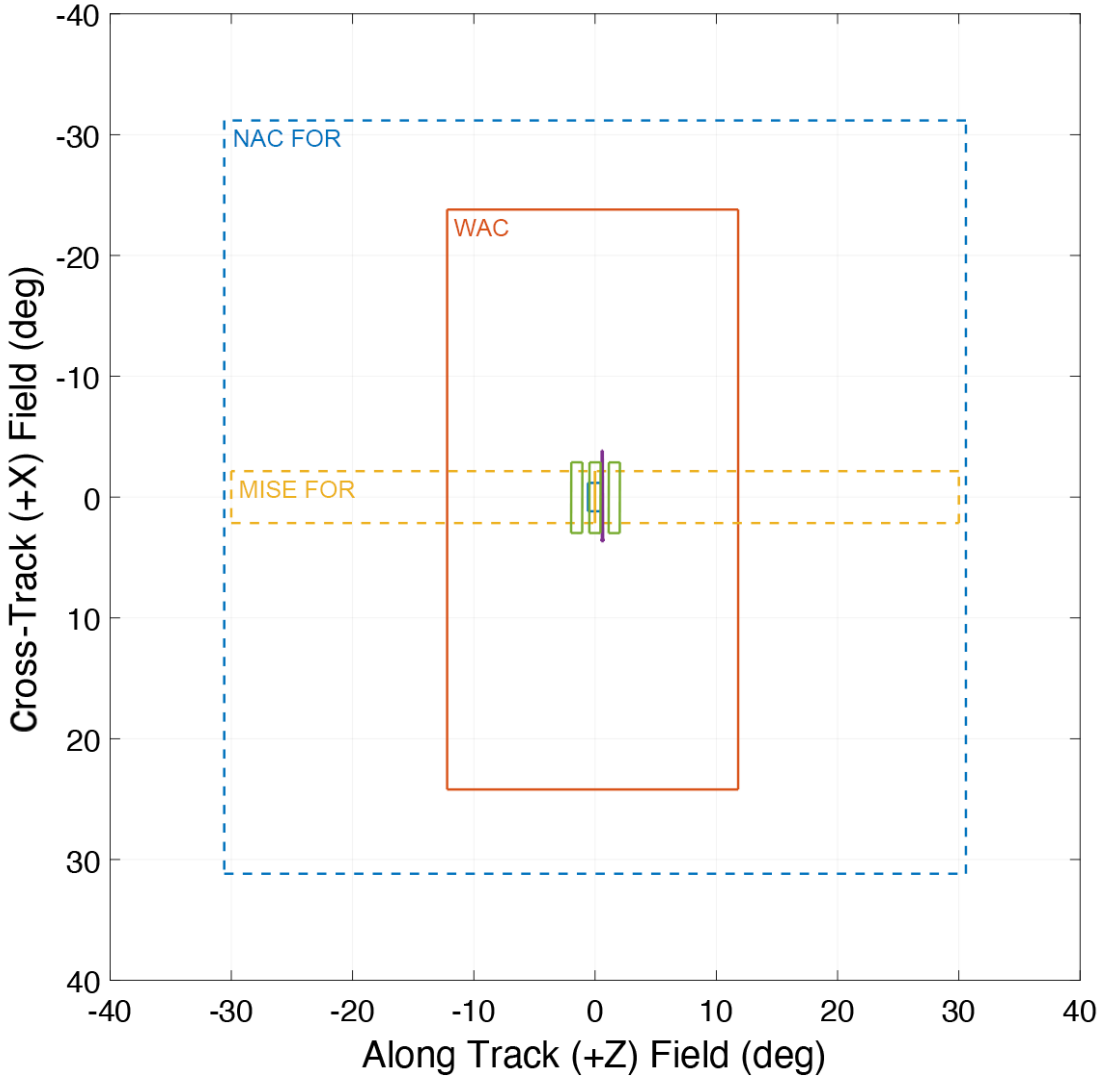


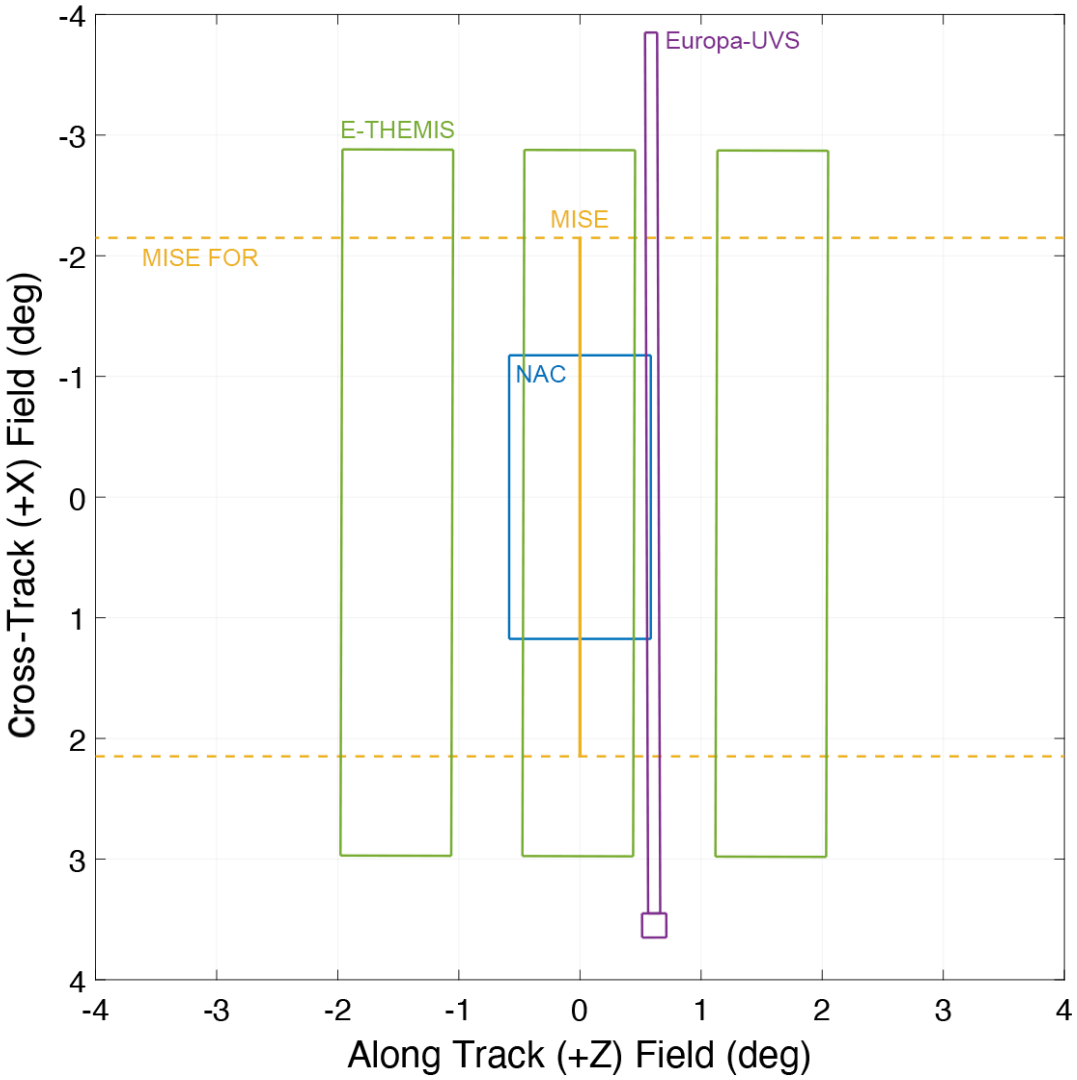


Europa Clipper Flight System: Instrument Accommodation

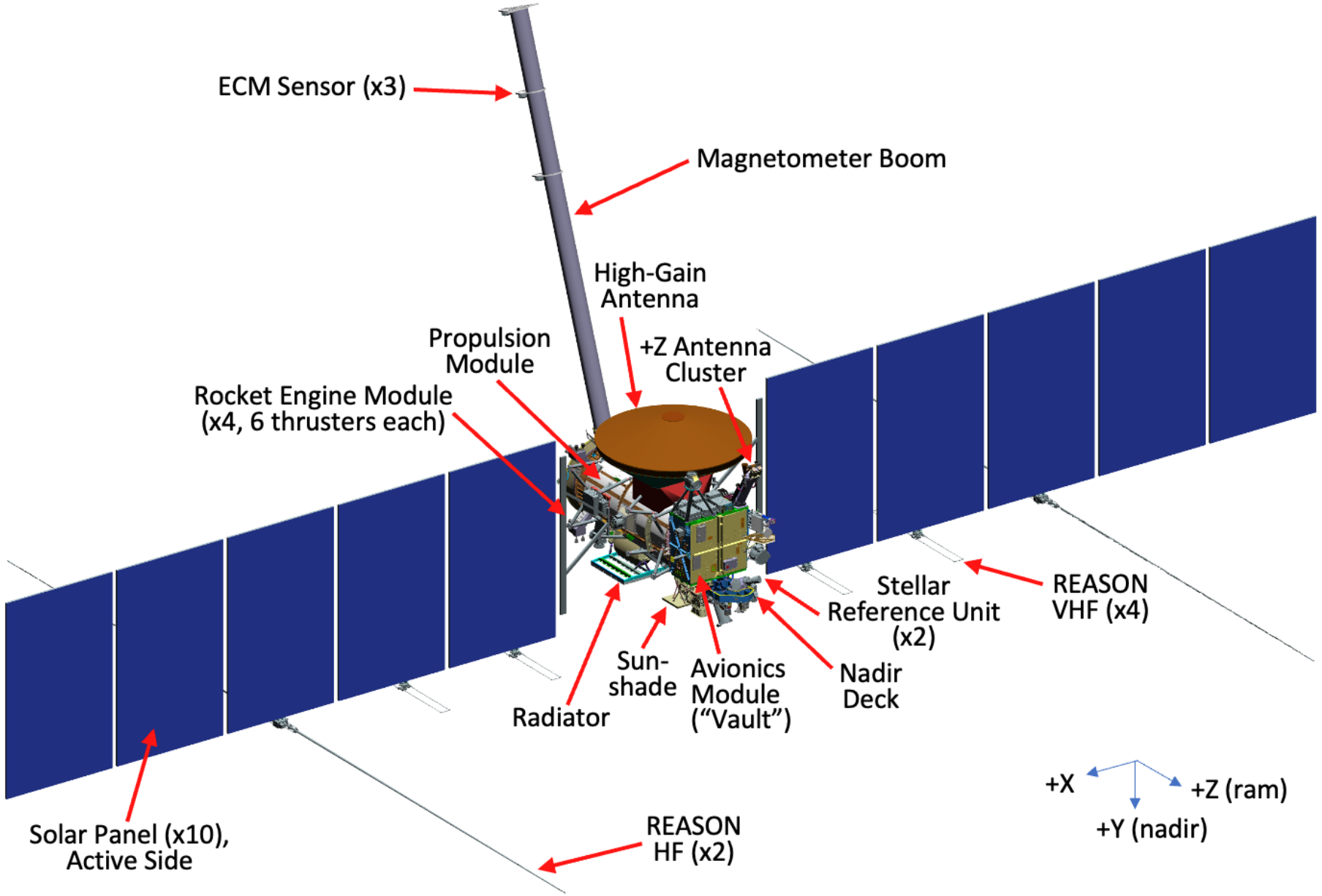


Optical Remote Sensing Fields of View

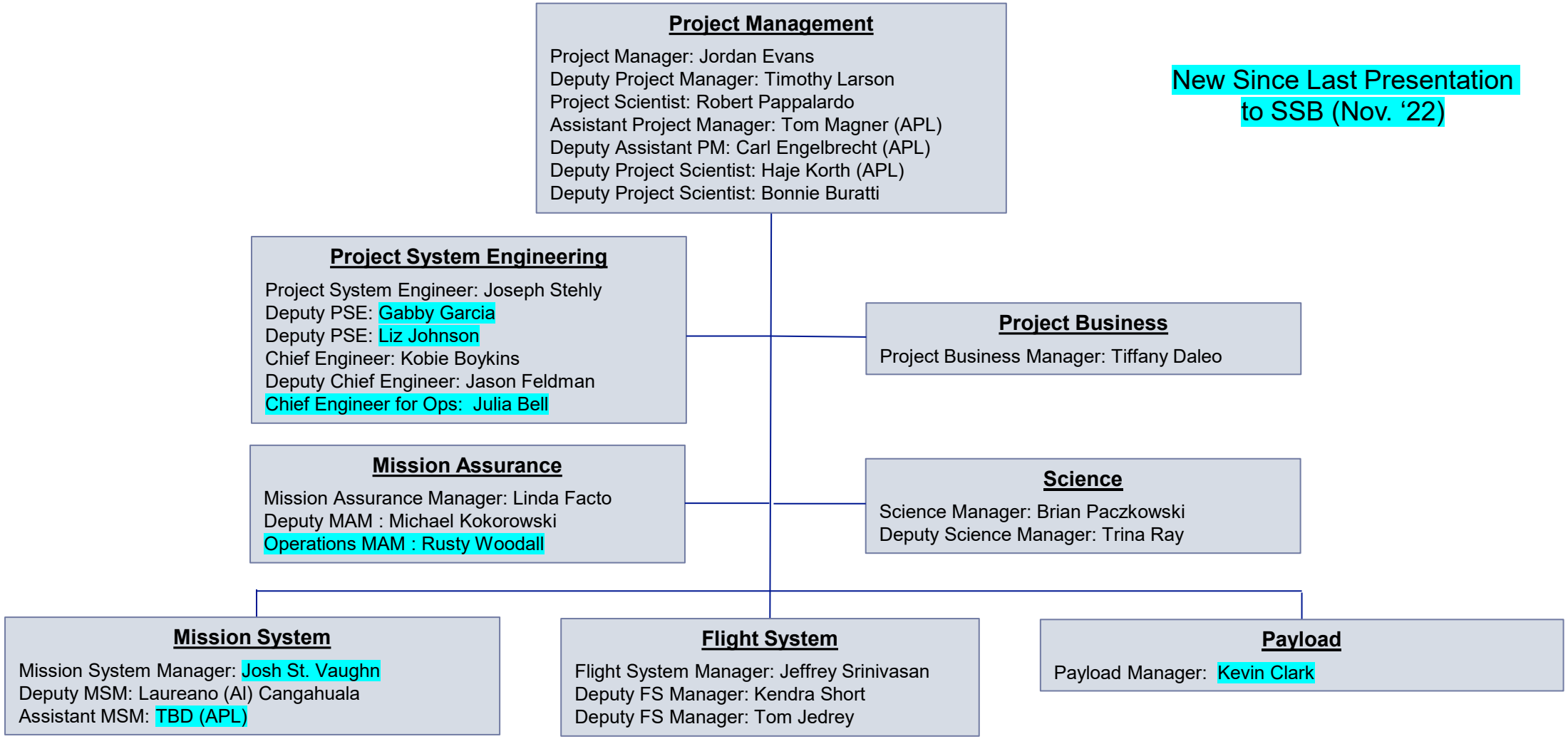




Europa Clipper Flight System



Project Organization



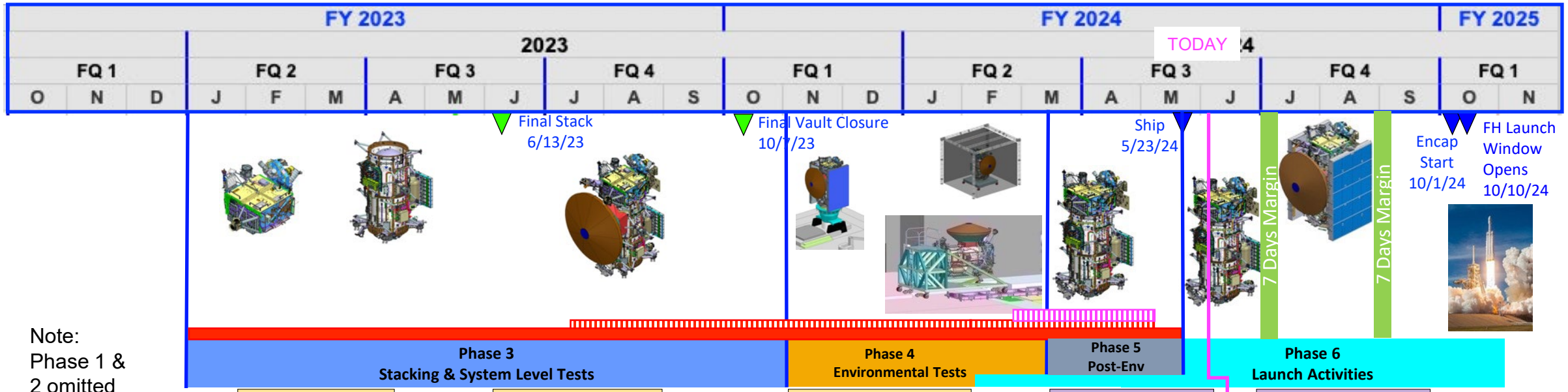
Project Status (1/2)

- Assembly, Test, and Launch Operations (ATLO) has completed all planned activities at JPL and the Europa Clipper Spacecraft is now in the Payload Hazardous Spacecraft Facility at Kennedy Space Center
  - All testing planned for completion at JPL (pre-ship) have been successfully completed!
  - The environmental test campaign was very successful, beginning with Dynamics (✓ Random Vibration, ✓Acoustic, and ✓ Clampband Separation) and finishing with ✓ EMI/EMC and ✓ System Thermal Vacuum Testing
  - The spacecraft, instruments, and flight software are very mature
    - End-to-End scenario testing of launch through Europa flybys has been successfully performed multiple times in both nominal and off-nominal (induced fault) conditions
- Of the small handful of technical issues that remain and are being worked to ensure readiness for launch, the most challenging is associated with Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs)
  - A non-NASA customer performed tests that show these transistors can, under certain conditions, fail to meet specifications at radiation levels much lower than they were designed and qualified to tolerate
  - This issue is being worked to better characterize the transistor behavior and whether it may affect the functionality of the circuits on Europa Clipper
  - The Project has time to continue this work as the spacecraft proceeds toward our October launch period

Project Status (2/2)

- Beyond ATLO and the closeout of technical issues, the Project focus remains on Ops Readiness and the Launch-to-Mars (LTM) “first 4 months”
  - The Mission System team has been augmented to ensure all products are in place in time for launch
  - The team held its second Operations Readiness Test (ORT) in early May and received very high marks from outside observers, Mission Assurance, our Chief Engineer for Ops, and our interfaces at KSC
- The resolution of technical issues continues to consume reserves (Unallocated Future Expenditures – UFE) and the Project and has been working mitigations with the Program Office and SMD
- The next major Project milestone is our Operations Readiness Review/Mission Readiness Review (ORR/MRR), July 30th – August 2nd
  - This will be followed by the cascade of Management Council meetings associated with NASA Key Decision Point (KDP) – E, the approval to transition to Phase E (Operations)
- The entire Project team continues to make great progress and Europa Clipper remains on track for the October 2024 launch

ATLO Phases & High-Level Activities (Road Map)



Note:
Phase 1 & 2 omitted

B179 HB1
- Temp stack
- MLI patterning
- DSN Compat
- Early FP
- Temp destack
- SP3T swap
- REASON Install
- MASPEX Install
- ECE FM swap/EM
- IPA install
- IMU-B Install
- PCDA FM swap
- NAC Install E-Box
- NAC Sensor install
- Remove ECIPA
- MASPEX Sensor
- SUDA Sensor
- Re-install RF Module

B179 HB1
- Remove REU FM A
- Remove ECE EM B
- Remove REU FM B
- Remove ECE FM A
- Vault Closure
- Final Stack AM/PM
- Open Vault
- Install ECE FM A
- Install ECE FM B
- Install REU FM A
- Install REU FM B
- Install MISE E-Boxes
- Install MISE Sensor
- Early FP Tests
- HGA Install
- Sys Test 1
- FP Test 1

B179 HB1
- SADA Install
- ECM Boom install
- ECIPA re-Install
- Final Vault Closure
- Install SAMS

B144
- Acoustics
- Random Vibe
- CB Sep Tests

- Remove SAMS
- Sys Test 2
- EMI/EMC
- Magnetics
- Swap ECM w/TTM
- Install SATS

B150
- TVAC-Cruise

PHSF
- G-Neg set up
- PX Wing/REASON
- MX Wing/REASON

B179 HB1
- Remove SATS
- Remove TTM ECM
- Prop Leak Check
- Sys FP 2
- Alignments
- GNC Phasing
- ~~ECM install~~
- Sys Test 3
- HGA Uninstall
- Install FM Batt
- Pack & Ship FS

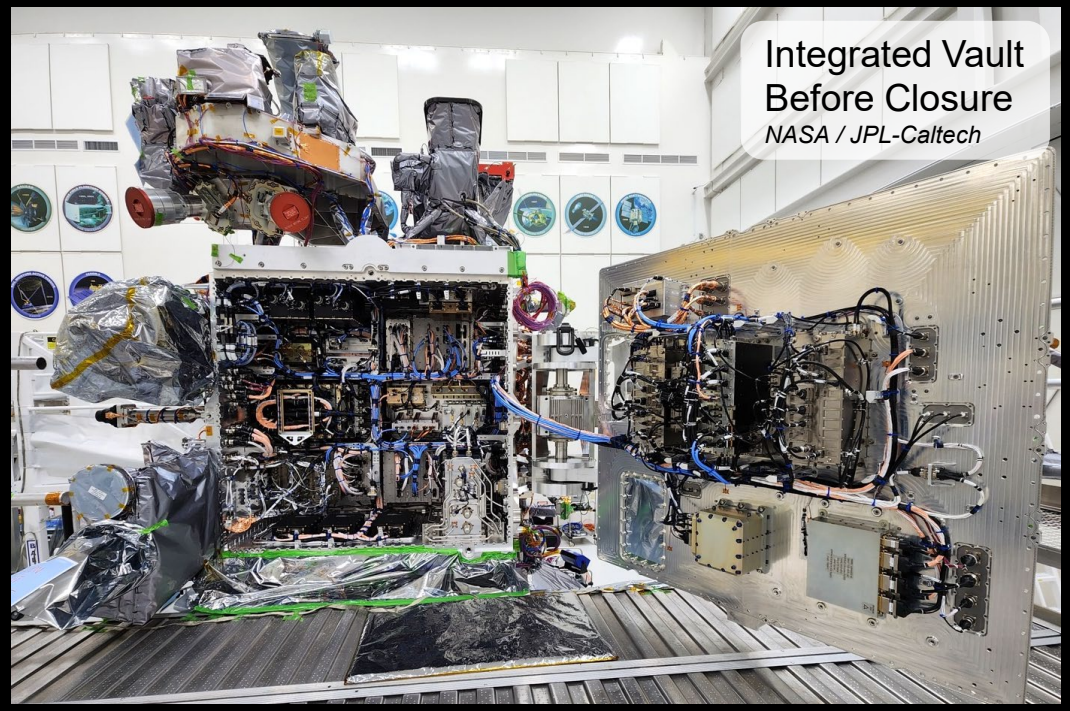
PHSF
- Unpack GSE & FS
- Install HGA
- ECM Rework/Test
- Install SA Wings
- Sys Test 4
- MIL-71 ETE Compat
- Prop Leak Test
- Final Alignments
- Propellant Loading
- RBF/IBF Closeouts
- Final Mass Prop
- Install FS onto PAF & Encapsulate

Hangar 39A/Pad 39A
- Chkout/Batt Charge
- Integrate to LV
- Chkout/Batt Charge
- Config for Launch
- Launch

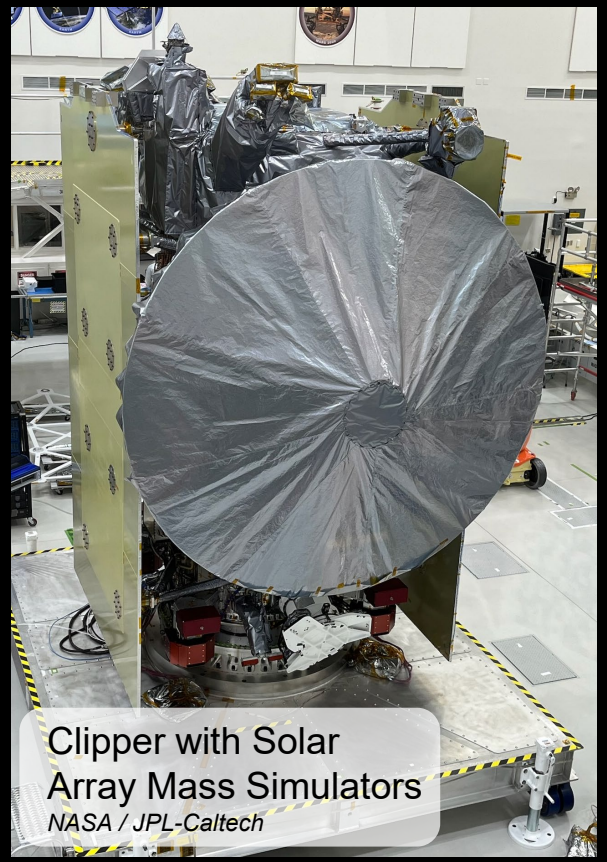
Sunday shifts
Saturday shifts
Two shift operations
Sig Accomplishments since last report

Europa Clipper remains on track for our October 2024 launch

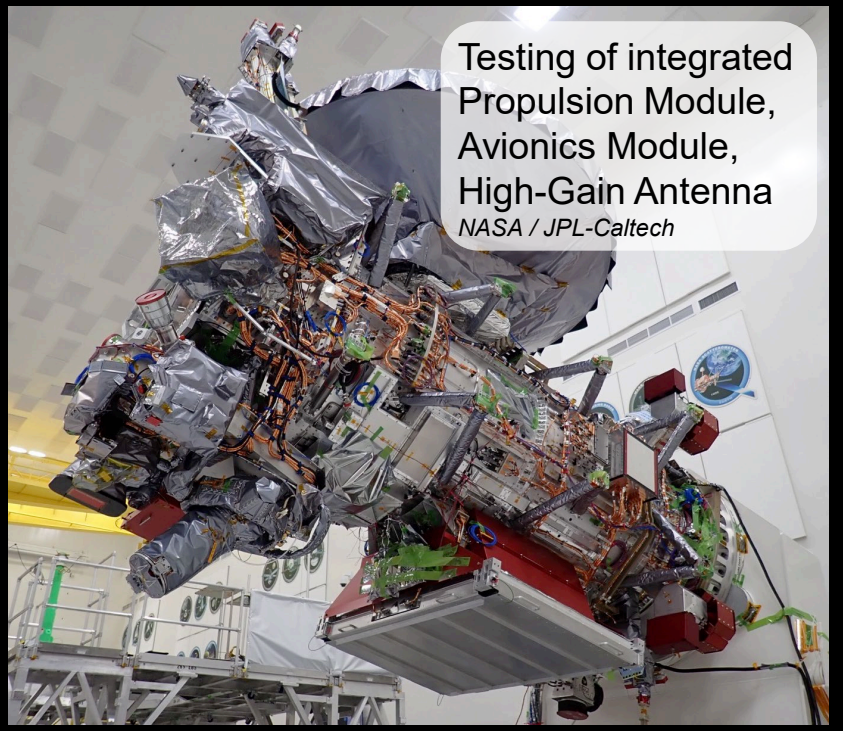
Spacecraft Integration



Integrated Vault Before Closure
NASA / JPL-Caltech



Clipper with Solar Array Mass Simulators
NASA / JPL-Caltech

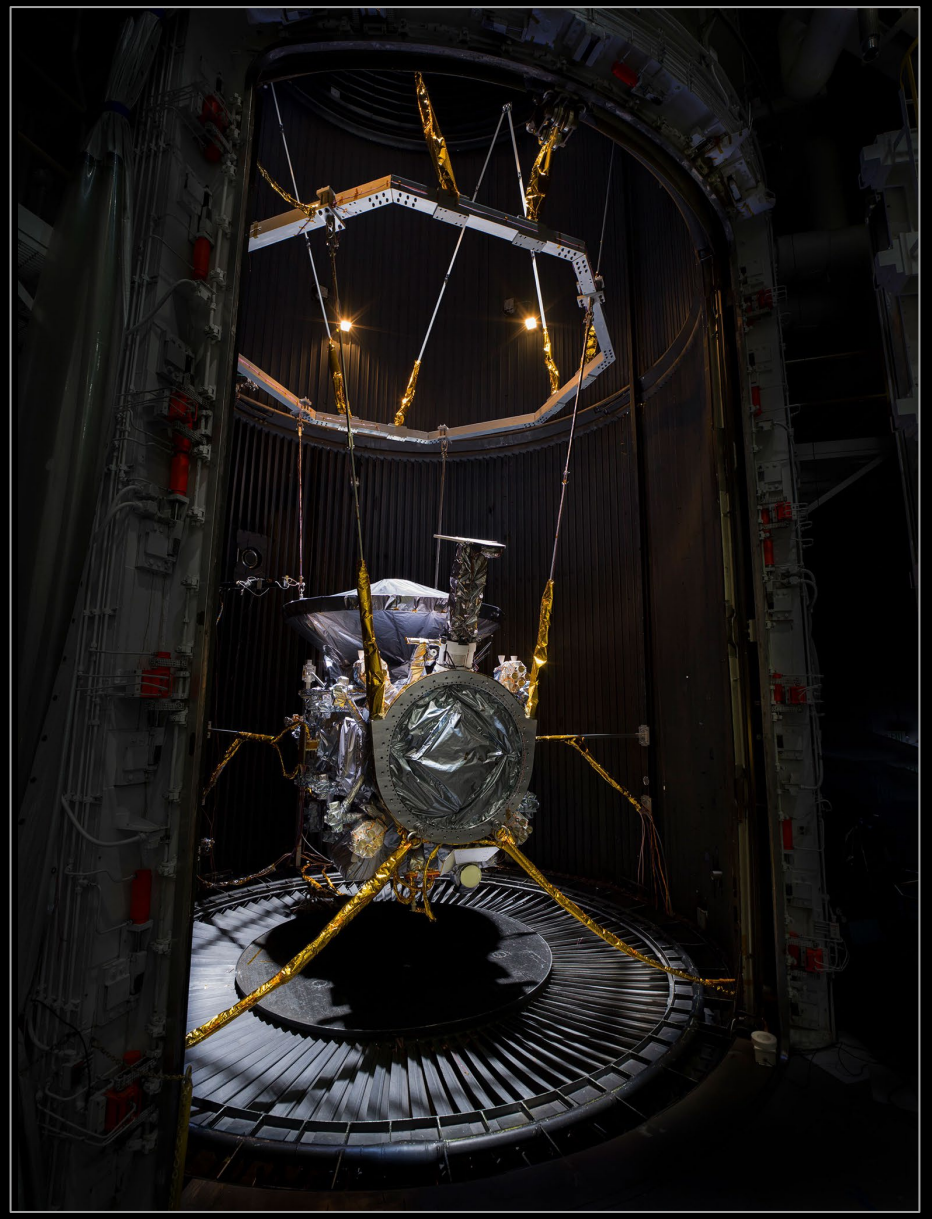


Testing of integrated Propulsion Module, Avionics Module, High-Gain Antenna
NASA / JPL-Caltech

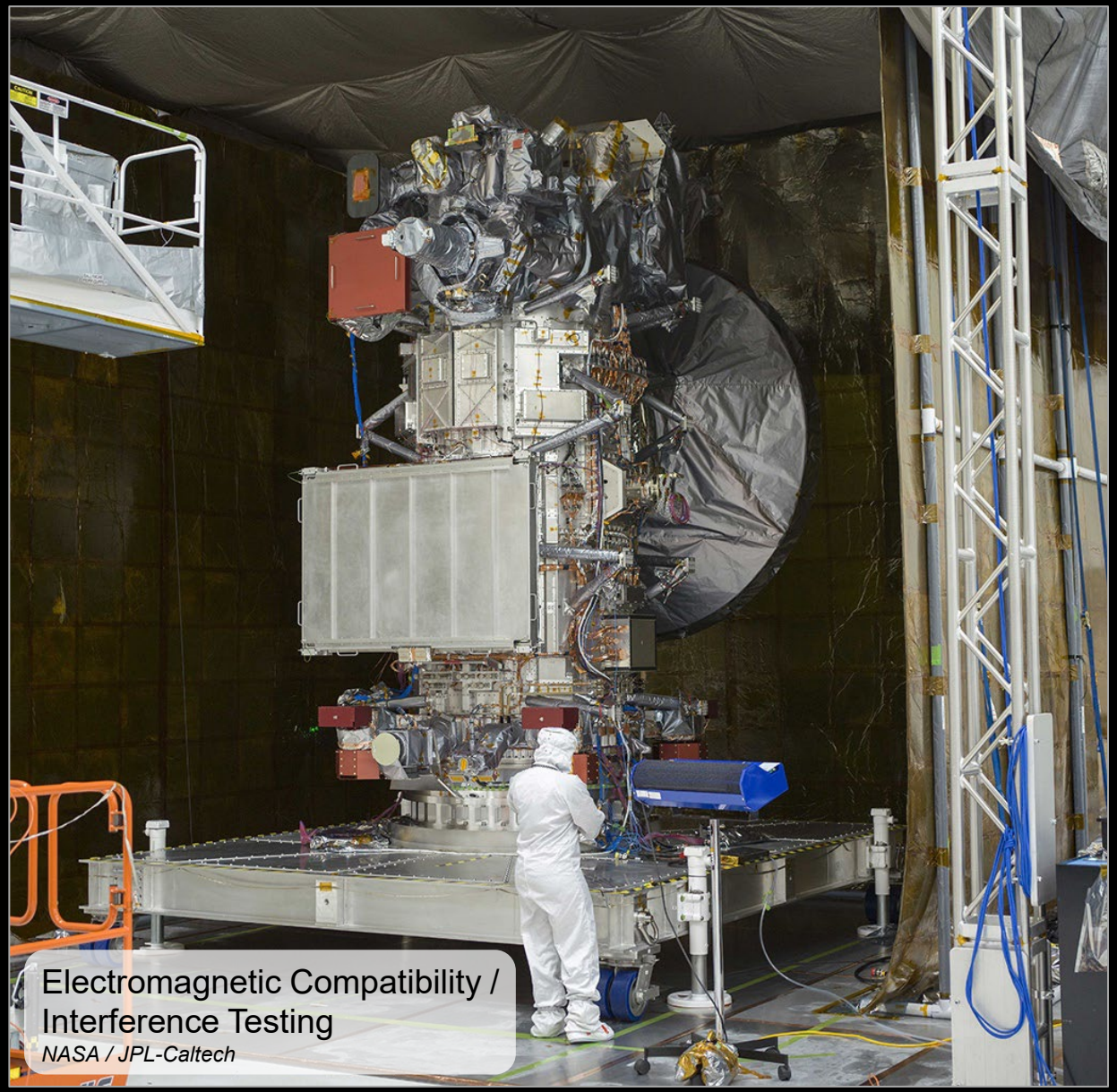
Mag Boom Deployment Test
NASA / JPL-Caltech

Solar Arrays
Airbus, Netherlands

Thermal-Vacuum Testing in the JPL Space Simulator



Europa Clipper EMI/EMC and Magnetometer Testing

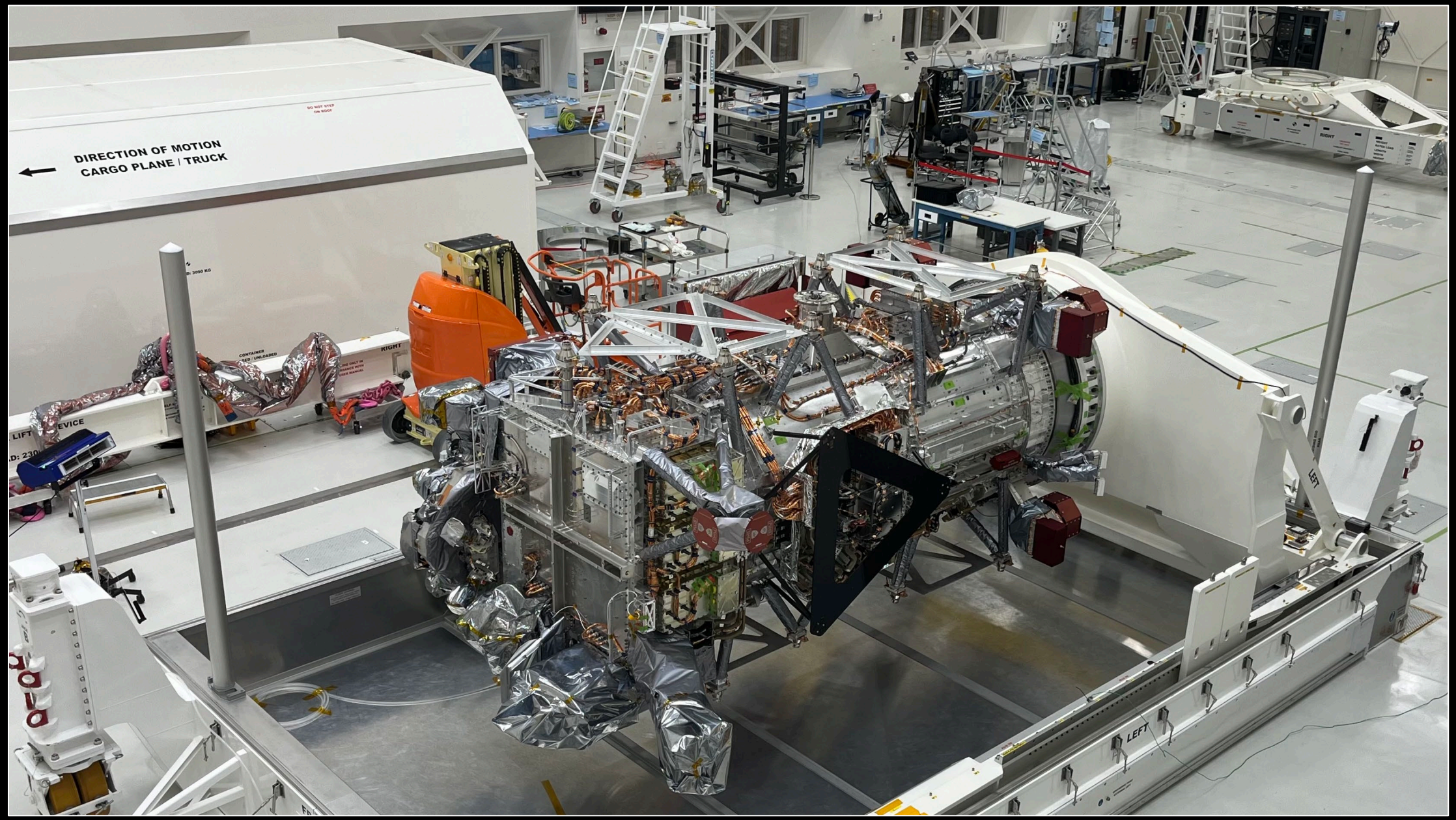


Electromagnetic Compatibility / Interference Testing
NASA / JPL-Caltech

Magnetometer Helmholtz Coil Testing
NASA / JPL-Caltech / Corey Cochrane

REASON Antennas Attached to Solar Arrays at KSC

Europa Clipper Packed for Shipment to KSC



Europa Clipper Shipped from JPL to KSC

Clipper departs JPL
NASA / JPL-Caltech / Bob Pappalardo

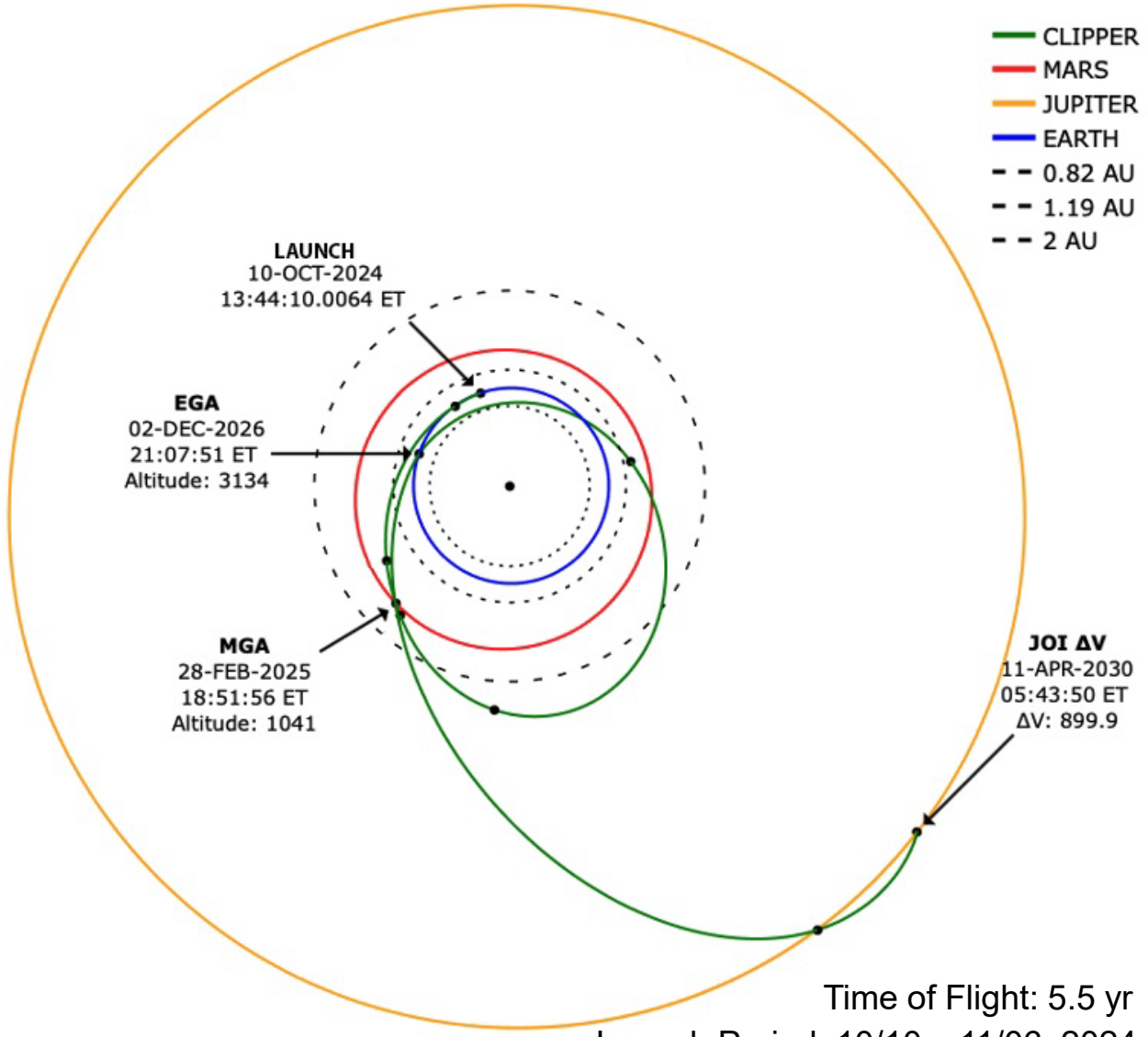
Offloading Clipper at KSC
NASA / Isaac Watson

C-17 flight to KSC
NASA / Isaac Watson

Clipper arrival at KSC Payload Servicing Facility
NASA / Isaac Watson

Interplanetary Trajectory: Mars-Earth Gravity Assist (MEGA)

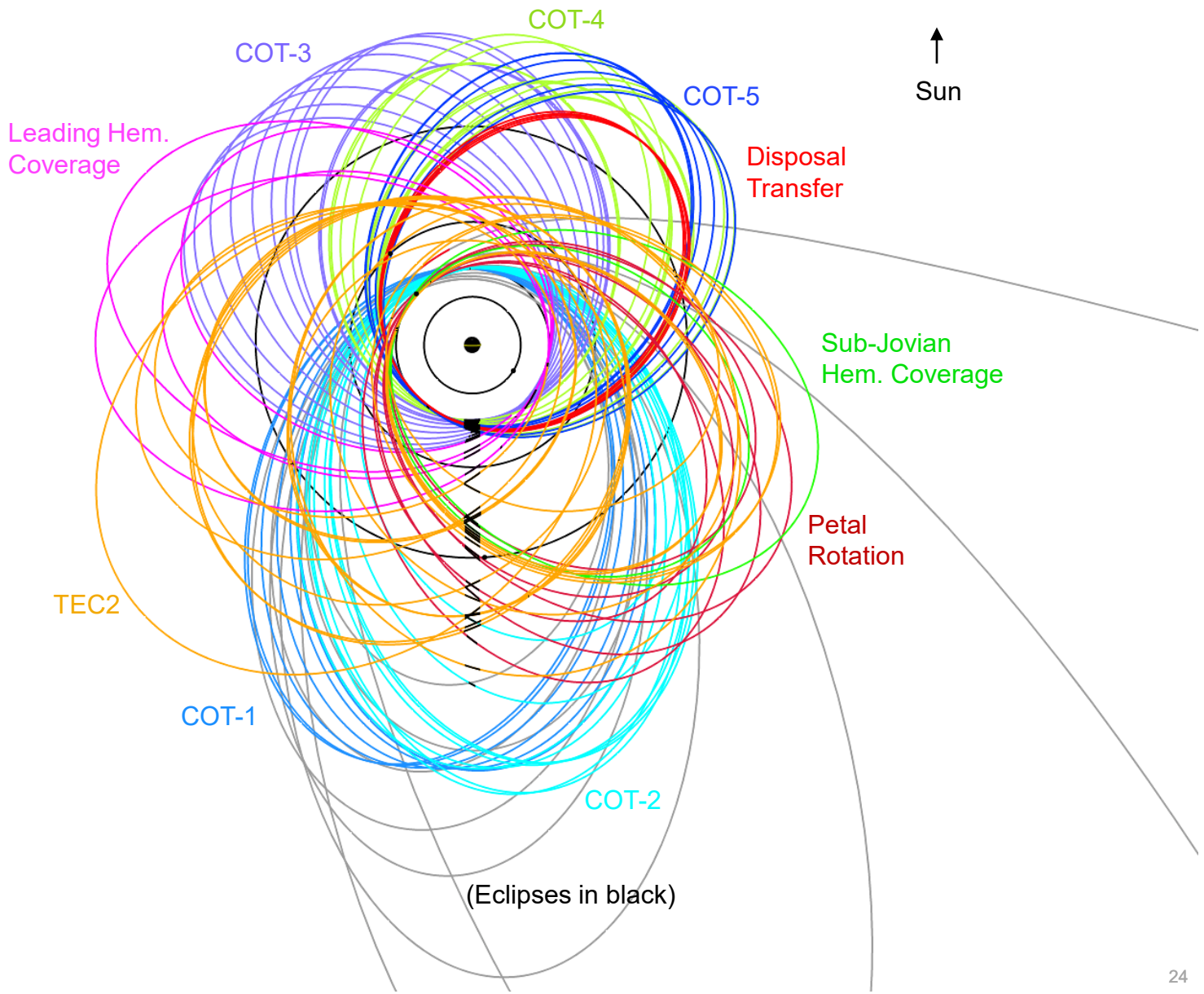
SpaceX Falcon
Heavy Launch Vehicle



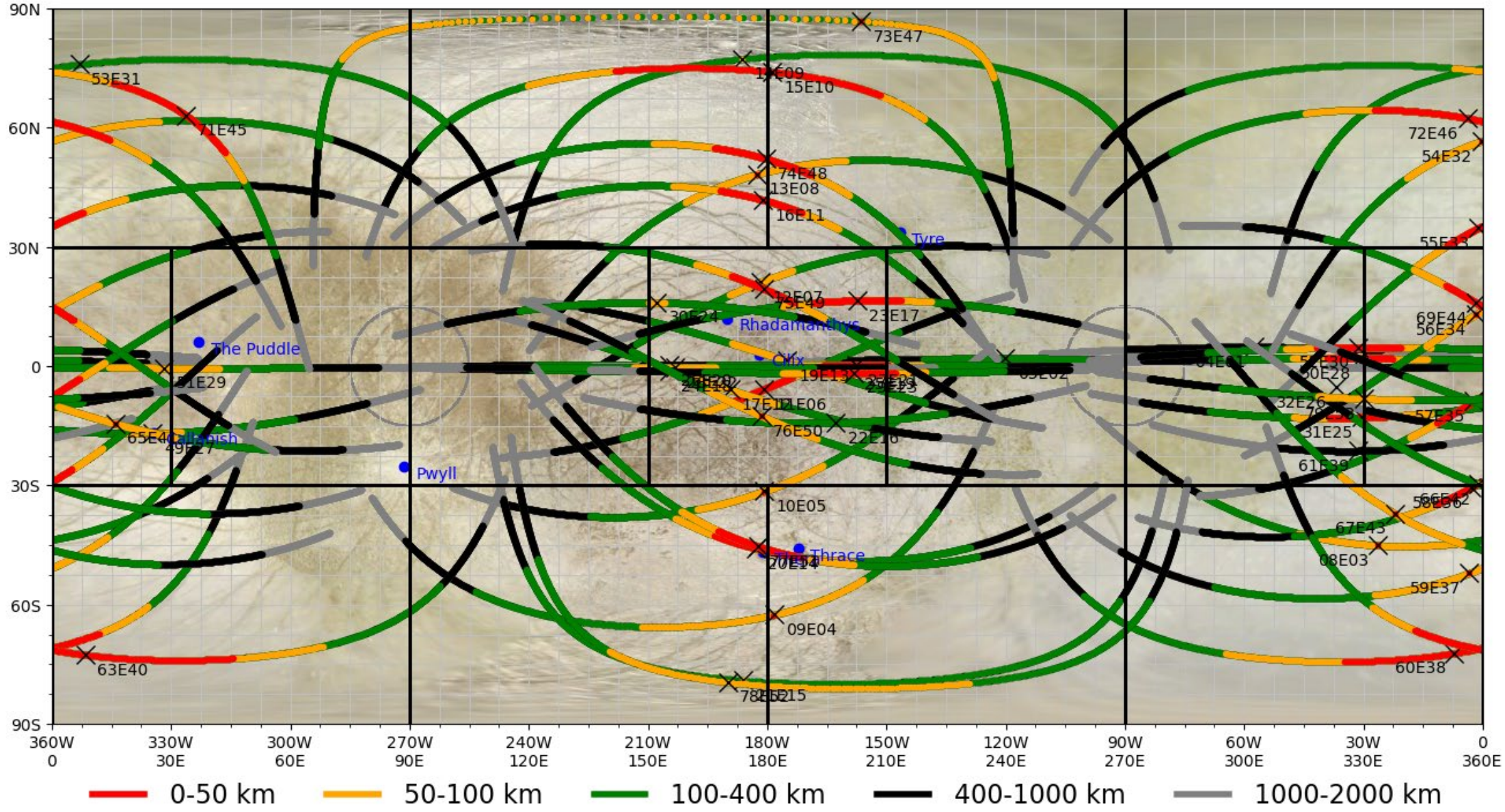
Time of Flight: 5.5 yr
Launch Period: 10/10 – 11/06, 2024

Europa Clipper Trajectory (21F31_V6): Overview

Jovian Tour	21F31_V6
Launch Period Opens	**10/10/24**
Mars Gravity Assist (1041 km)	**2/28/25**
Earth Gravity Assist (3134 km)	**12/2/26**
Jupiter Orbit Insertion (JOI) Date	**4/10/30**
Interplanetary Trajectory	**MEGA**
Tour Duration (years)	**4.27**
EC1 Europa Resonance	**6:1**
Number of Flybys Europa Ganymede Callisto	 **49 of 53** **7** **9**
Number of Night Side Europa Flybys	**11**
Number of Jupiter Orbits	**79**
Time between Flybys (days) Maximum (not including capture orbit) Minimum Minimum (Europa-to-Europa)	 **64.4** **9.4** **13.8**
Deterministic Tour ΔV, post-JOI (m/s)	**214.8**
Maximum Inclination (deg.)	**7.7**
Maximum Eclipse Duration (hours)	**7.8**
Total Ionizing Dose (Mrad)	**2.97**
Disposal – Targeted Impact Body	**Ganymede**



Europa Clipper Trajectory (21F31_V6): Europa Groundtracks



Strategic Science Planning Guide (SSPG_v0) Development

SSPG Purpose and Approach

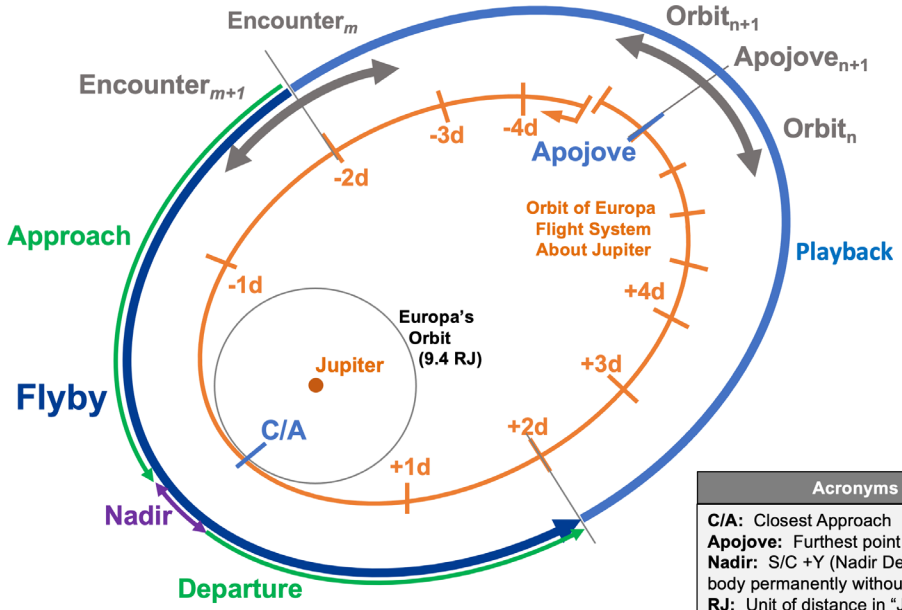
- Guides science-based resource use, as key interface between strategic and tactical operations
- Informs observation timeline development in cruise
- Investigation Teams provide initial input, then Thematic Working Groups filter through discipline-based synthesis
- Preliminary inputs occurring now, before science team is "bath-tubbed" during cruise, and revisited before JOI

Nadir Inputs

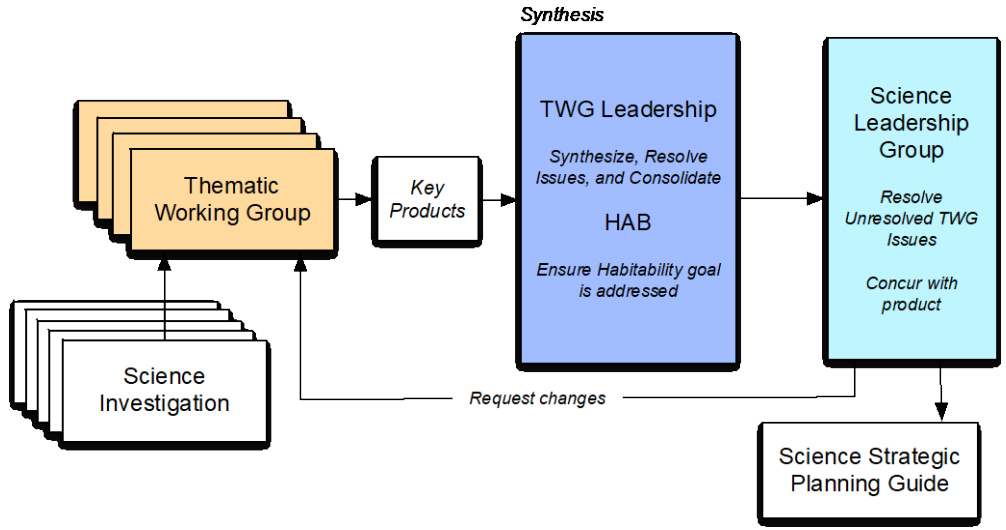
- For the period near closest approach, all instruments are taking data in simple, repeatable manner
- Timeline incompatibilities not expected, given synergistic flight system design
- Focus is on what makes each flyby geometry unique, to understand potential "sunny" and "rainy" day scenarios

Non-Nadir Inputs

- Planning for the few science observations outside the nadir-phase of the flyby, notably plume searches
- Create an ordered list of science activities, toward addressing any potential timeline incompatibilities



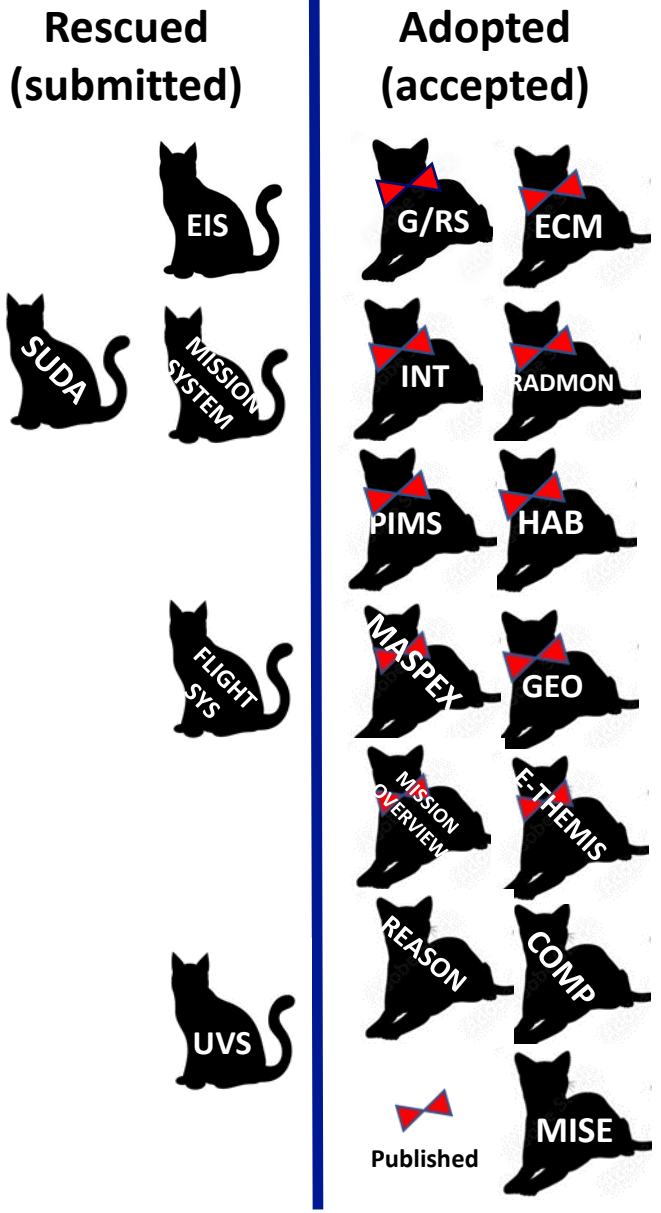
Acronyms & Definitions
C/A: Closest Approach
Apojove: Furthest point in FS orbit from Jupiter
Nadir: S/C +Y (Nadir Deck) pointed towards target body permanently without breaks
RJ: Unit of distance in "Jupiter Radii"



Space Science Reviews Europa Clipper Topical Collection

Table: *Space Science Review* papers completeness status

Instrument, Working Group, or Overview	Authors	Status
ECM (Magnetometer)	Kivelson et al.	Published
Gravity/Radio Science	Mazarico et al.	Published
PIMS (Faraday Cups)	Westlake et al.	Published
Radiation Monitors	Meitzler et al.	Published
Interior (Working Group)	Roberts et al.	Published
Habitability (Working Group)	Vance et al.	Published
Geology (Working Group)	Daubar et al.	Published
Composition (Working Group)	Becker et al.	Accepted
E-THEMIS (Thermal Imager)	Christensen et al.	Published
SUDA (Dust Analyzer)	Kempf et al.	Submitted, minor revisions
MASPEX (Mass Spectrometer)	Waite et al.	Published
MISE (IR Imaging Spectrometer)	Blaney et al.	Accepted
REASON (Ice-Penetrating Radar)	Blankenship et al.	Accepted
Mission Overview	Pappalardo et al.	Accepted
EIS (NAC and WAC cameras)	Turtle et al.	Submitted; in review
E-UVS (UV spectrograph)	Retherford et al.	Submitted; in review
Flight System	Srinivasan et al.	Submitted
Mission System	Cangahuala et al.	Submitted



Synergistic Science Opportunities with ESA's JUICE Mission

- Europa Clipper and JUICE expected to be in the Jupiter system simultaneously
- A joint JUICE-Clipper Science Steering Group has been formed to lead the identification of highest-value joint scientific opportunities
- Informal joint Clipper-JUICE workshop held during EPSC 2022 conference to discuss possible synergies
- Many interesting opportunities identified for consideration
- For example, JUICE E2 and Clipper E23 flybys are <4 hr apart, offering insights into rapid temporal phenomena

Project Science Group Meeting #13: San Juan, Puerto Rico

Nov. 6–10, 2023

- Meeting site chosen to bring Europa Clipper to our “Here To Observe” (H2O) partners in Puerto Rico

Spanish-Language Broadcast For Local Elementary Schools

- Europa Clipper Deputy PM Tim Larson and JPL STEM Education Specialist Brandon Rodriguez

Presentations by Puerto Rico Astronomy and DEIA Experts

Dr. Gerardo Morell, Puerto Rico Space Grant Director (Univ. Puerto Rico, Rio Piedras)

Dr. Abel Méndez
(Univ. Puerto Rico, Arecibo)

Planetary ReaCH: Drs. Edgard Rivera-Valentin (APL), Kennda Lynch (LPI), Alexandra Matiella Novak (APL)

Engagement with Local Astronomy Groups at El Morro

- Reading of “In Praise of Mystery” by its Spanish language translator, Roque Raquel Salas Rivera

Local TV Press Coverage with the H2O Observers

- Meteorologist, Science Reporter, and NASA Solar System Ambassador Ada Monzón interviews meeting participants

Hands-On Activities with Local Middle & High School Students

- Over 400 Puerto Rico students engaged in a single morning

NASA & Europa Clipper Career Day with UPR STEM Undergrads

- Over 50 UPR undergraduate participants

From One Ocean World to Another

In Praise of Mystery: A Poem for Europa

U.S. Poet Laureate Ada Limón

In Praise of Mystery: A Poem for Europa

Arching under the night sky inky
with black expansiveness, we point
to the planets we know, we

pin quick wishes on stars. From earth,
we read the sky as if it is an unerring book
of the universe, expert and evident.

Still, there are mysteries below our sky:
the whale song, the songbird singing
its call in the bough of a wind-shaken tree.

We are creatures of constant awe,
curious at beauty, at leaf and blossom,
at grief and pleasure, sun and shadow.

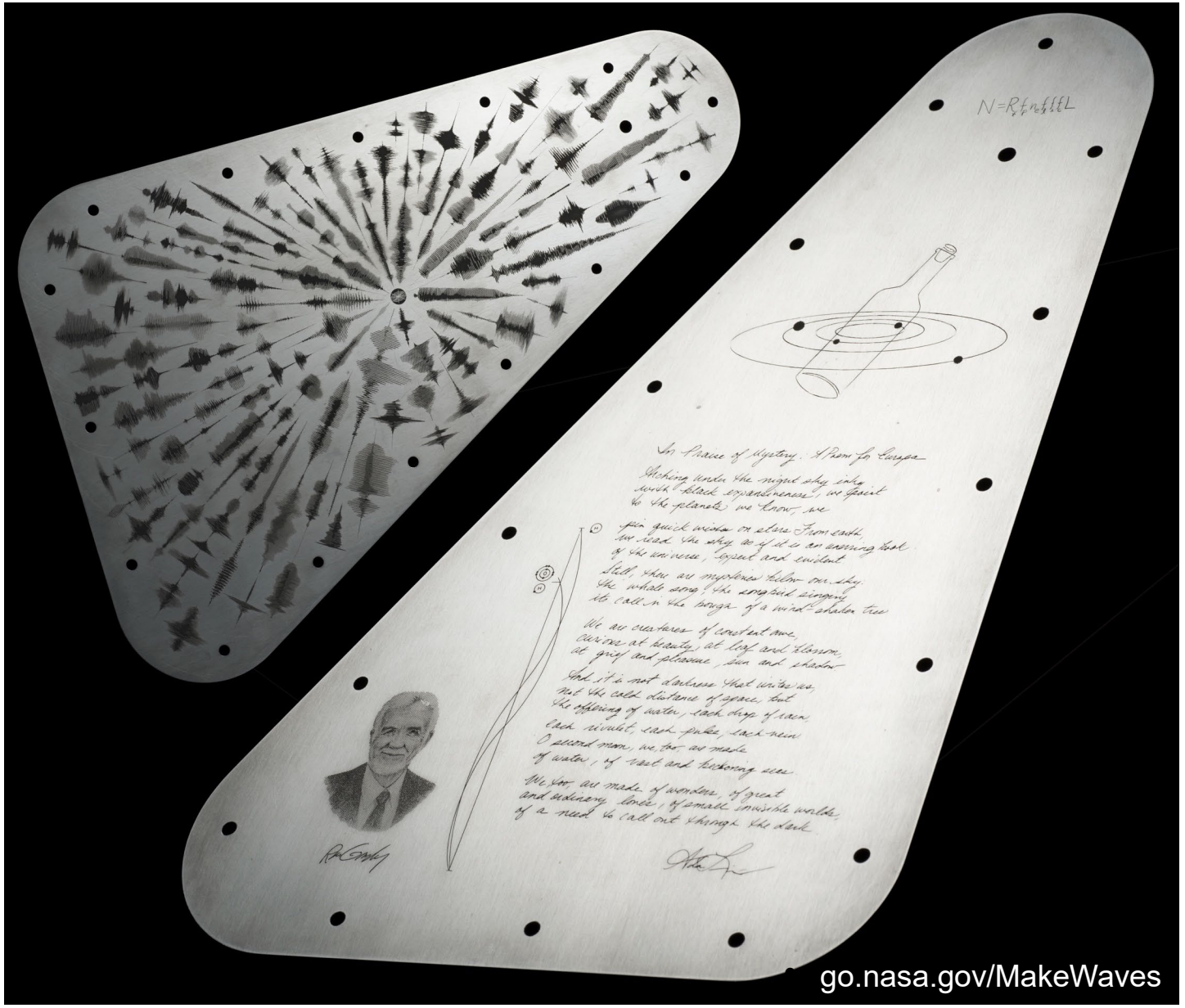
And it is not darkness that unites us,
not the cold distance of space, but
the offering of water, each drop of rain,

each rivulet, each pulse, each vein.
O second moon, we, too, are made
of water, of vast and beckoning seas.

We, too, are made of wonders, of great
and ordinary loves, of small invisible worlds,
of a need to call out through the dark.

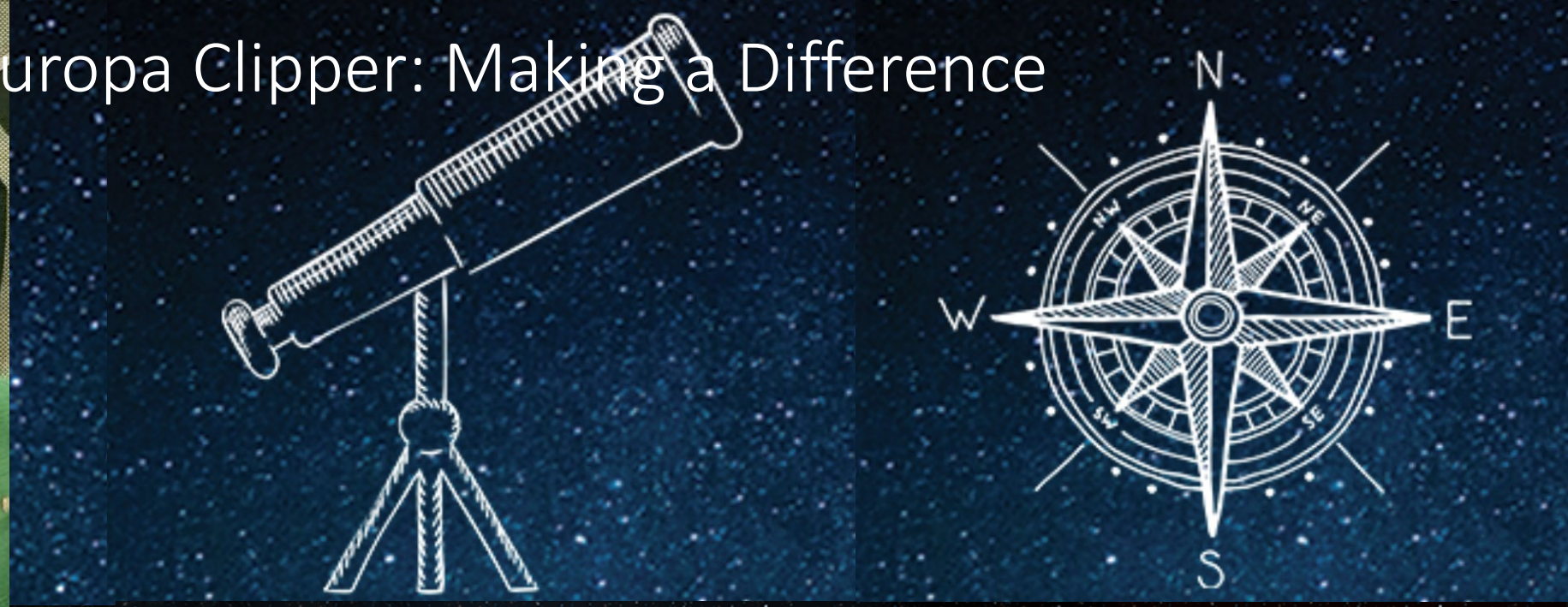
Europa Clipper Vault Plate (“Poem Plate”)

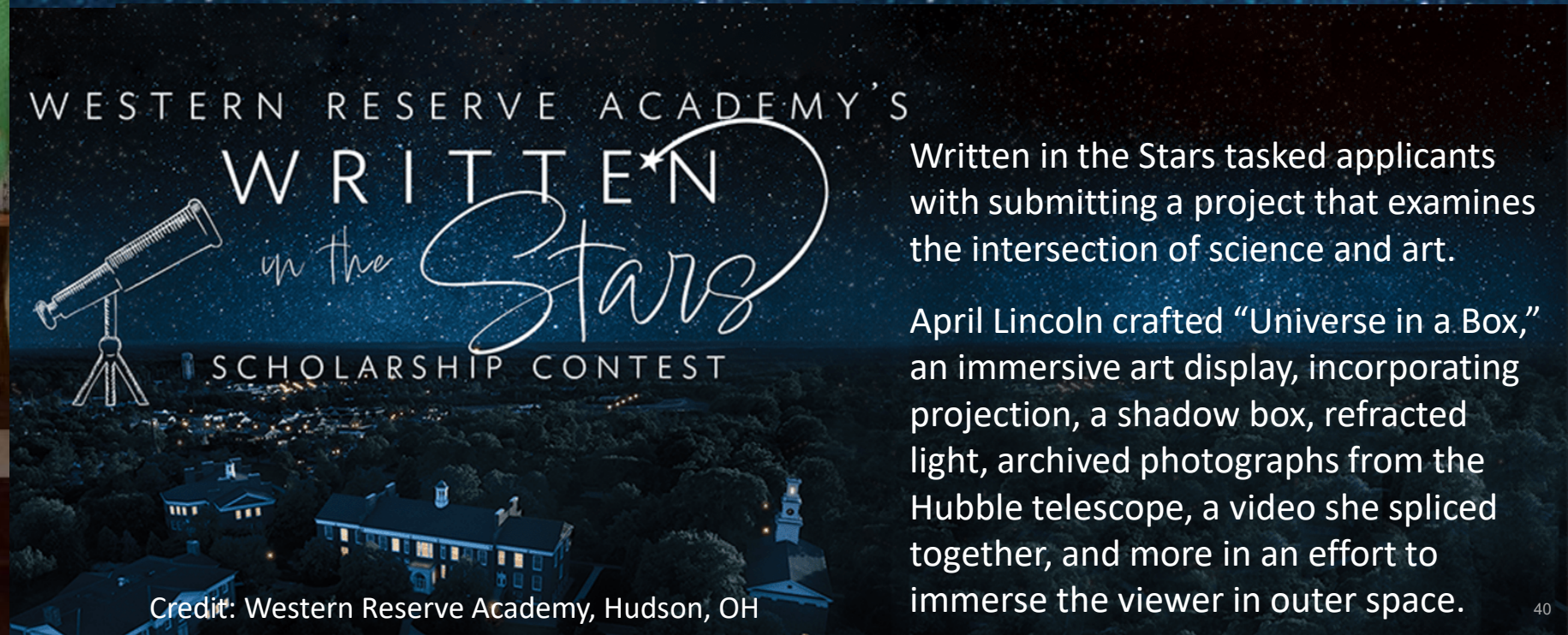
- **Outward-facing side:**
  - Spoken words for water in 103 languages from across the globe, shown as waveforms
  - Center American Sign Language representation for water
- **Inward-facing side:**
  - In Praise of Mystery: A Poem for Europa by U.S. Poet Laureate Ada Limón, in her own handwriting
  - Hand-drawn portrait of planetary scientist Ron Greeley
  - Drake Equation, in Frank Drake’s handwriting
  - OH and H radio waves (“water hole”)
- **Designs representing human connections:**
  - Between humans on Earth, between Earth and Europa, and between humankind and the cosmos, as we seek to learn about the possibilities of life beyond Earth
  - Each element derived from human voices or hand drawn



Europa Clipper Vault Plate (“Poem Plate”) Installation

Europa Clipper: Making a Difference





Credit: Western Reserve Academy, Hudson, OH

Written in the Stars tasked applicants with submitting a project that examines the intersection of science and art.

April Lincoln crafted "Universe in a Box," an immersive art display, incorporating projection, a shadow box, refracted light, archived photographs from the Hubble telescope, a video she spliced together, and more in an effort to immerse the viewer in outer space.

Jet Propulsion Laboratory
California Institute of Technology