ICEE Team Welcome Briefing

Europa Clipper Pre-Project Team

October 23, 2013

Agenda

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Welcome

Curt Niebur

Discipline Scientist

Instrument Concepts for Europa Exploration

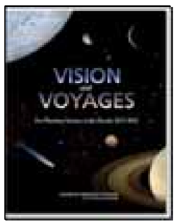
Europa Clipper Project Overview

Barry Goldstein

Pre-Project Manager

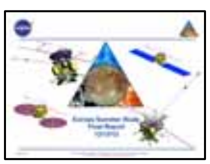
Path To Europa Clipper

- 2007 - 2011 : <u>Jupiter Europa Orbiter</u> (JEO) study team worked Pre-Phase A activities for highest rated outer planets science mission identified in previous decadal survey
  - → Together with European Jupiter Ganymede Obiter mission, responsive to all science objectives

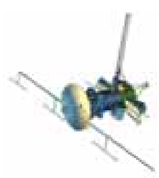


- March 2011 : Decadal Survey for 2013 – 2022 released
  - → Rated JEO science on par with Mars Sample Return, however Aerospace independent cost estimate (CATE) was an unaffordable at $4.7B
- Spring 2011 : NASA asked JPL and APL (our JEO partner) to study options for lower cost/science options, ~$1.5B - $2.0B (FY'15 excluding LV)

- November 2011 : Study report reviewed by NASA panel for reduced science orbiter and multiple flyby mission (Clipper)
  - → Clipper cost estimate $1.9B, **<u>confirmed by Aerospace CATE</u>**
- March 2012 : Study report reviewed by NASA panel for lander option
  - → Cost estimate prohibitive ~$2.8B, and high risk of landing without sufficient reconnaissance



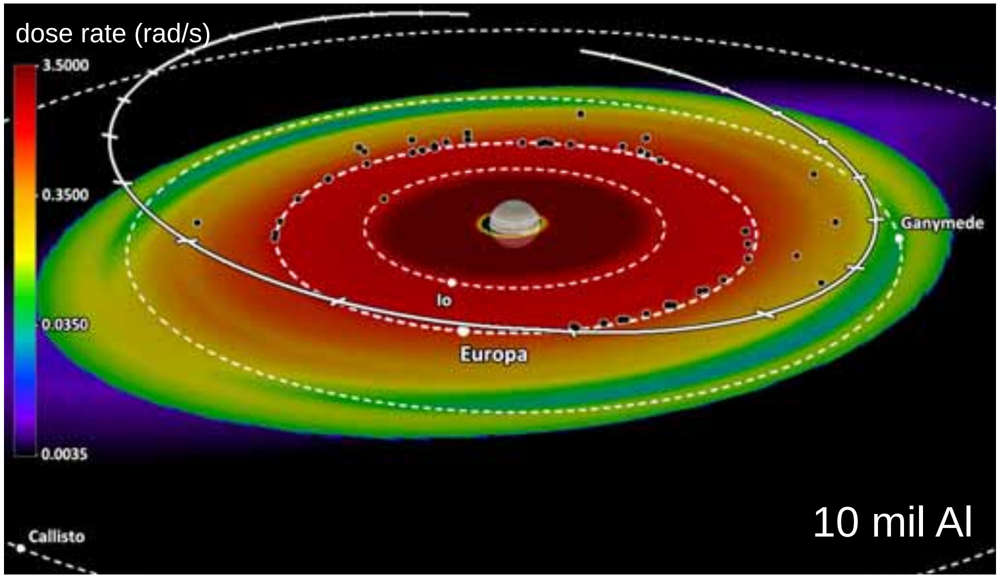
- December 2012 : Enhanced Europa Clipper proposed which include reconnaissance payload
  - → Cost estimate increased to $2.1B, and addresses biggest lander risk in hopes of a future opportunity

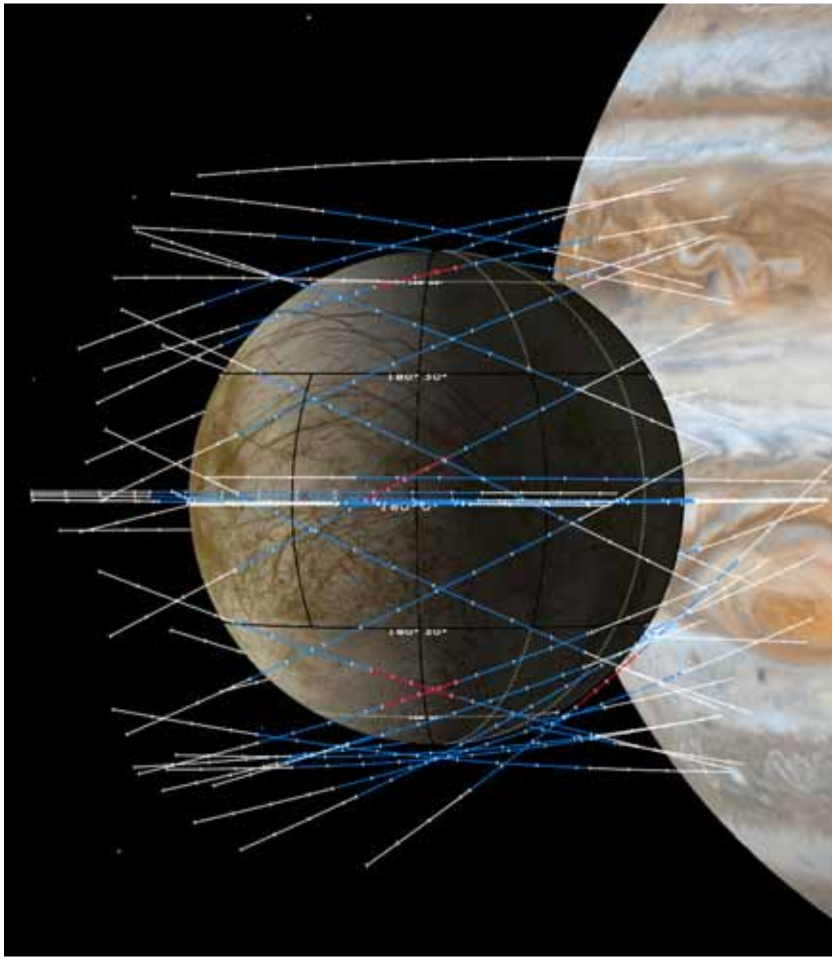


- March 2013 : NASA formally selects Clipper as down selected possible future flagship to Europa

Enabling Affordable Europa Clipper
Innovative Mission Concept

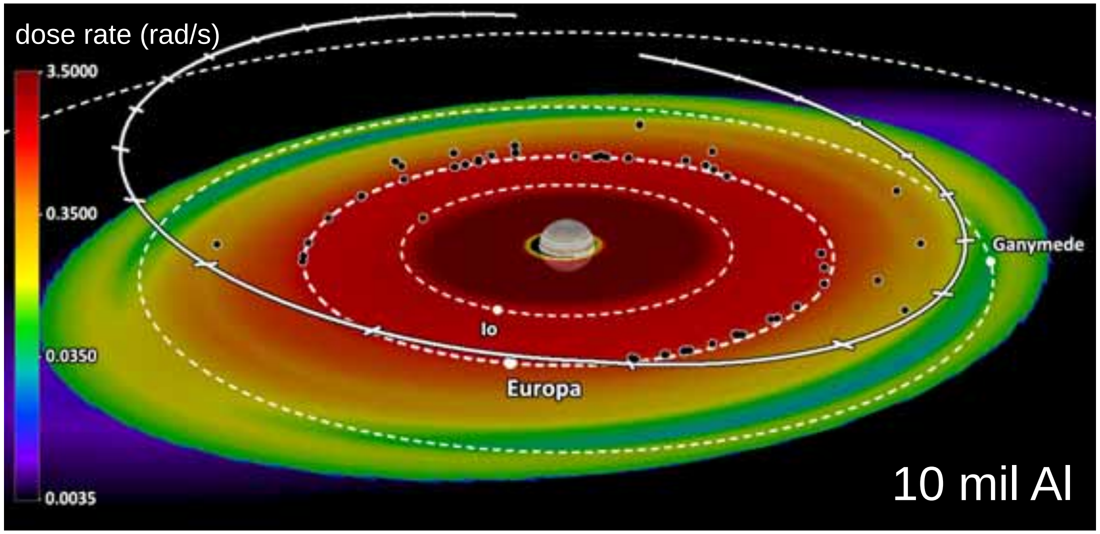
- Utilize Galilean moons as orbital perturbation sources to enable global access to Europa under varying lighting conditions
- 45 low altitude flybys of Europa from Jupiter orbit over 3.5 years
- Minimizes time in high radiation environment, with Jovian orbit inclined to the radiation toroid

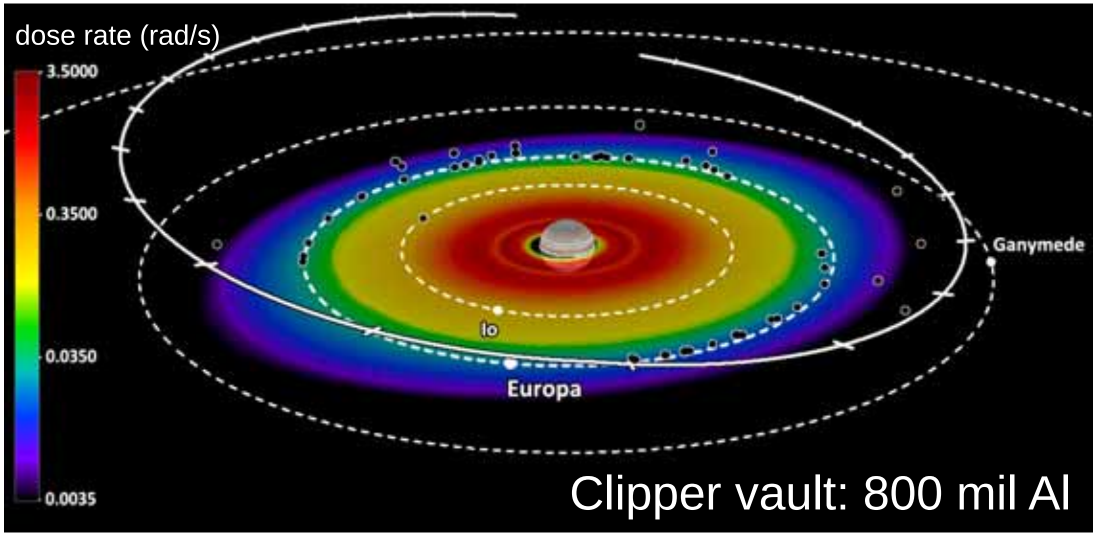




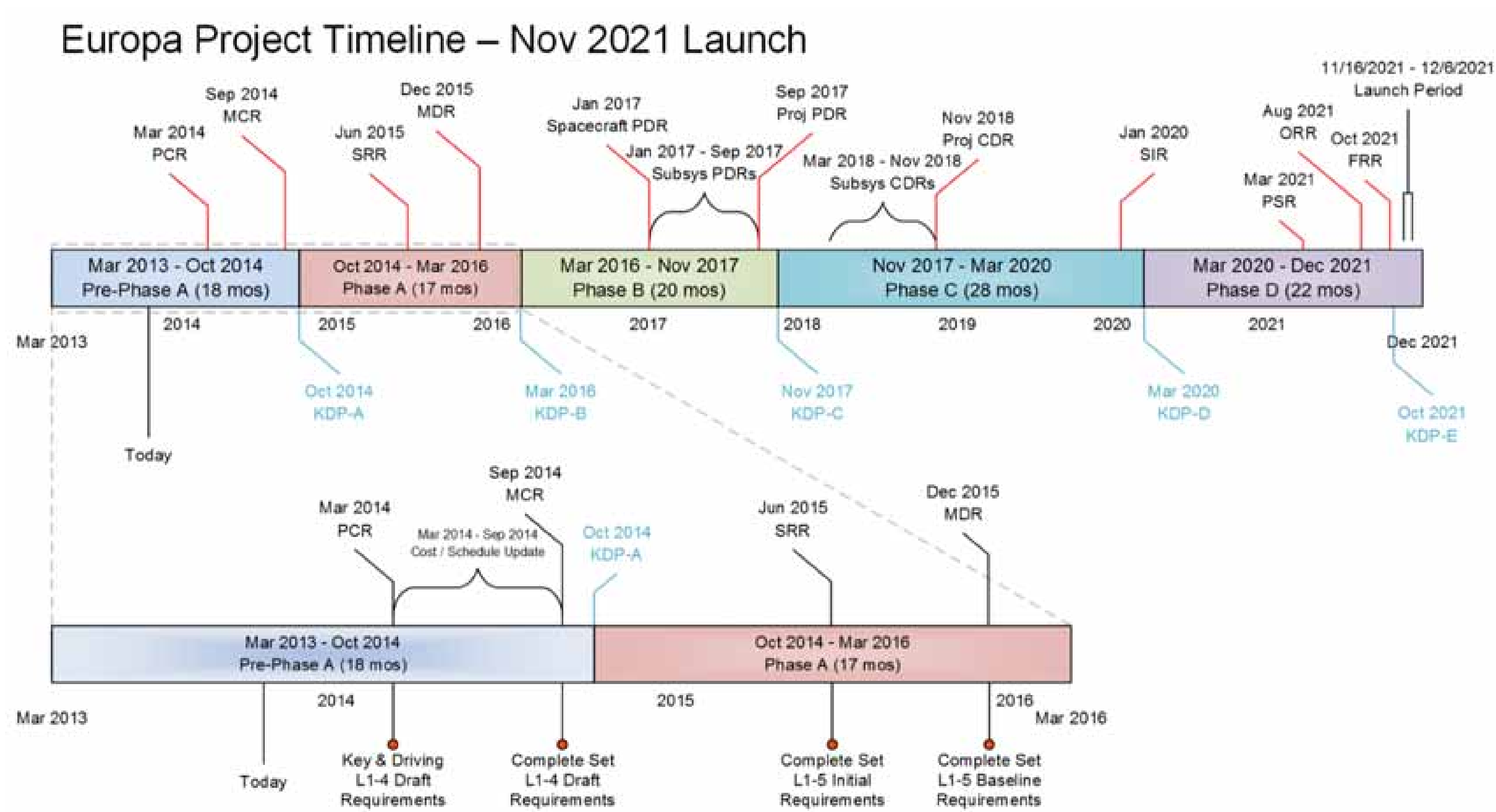
Enabling Affordable Europa Clipper
Electronics Shielding

- Mass saved from propellant (formerly used by JEO to enter Europa Orbit) traded for Clipper shielding, reducing total radiation dose
- JEO Mission concept required some electronics parts to be rated at 3 Mrad
- Clipper Mission Concept requires parts rated at 300 Krad
    - ➢ Both JEO and Clipper use radiation design margin (RDM) of 2





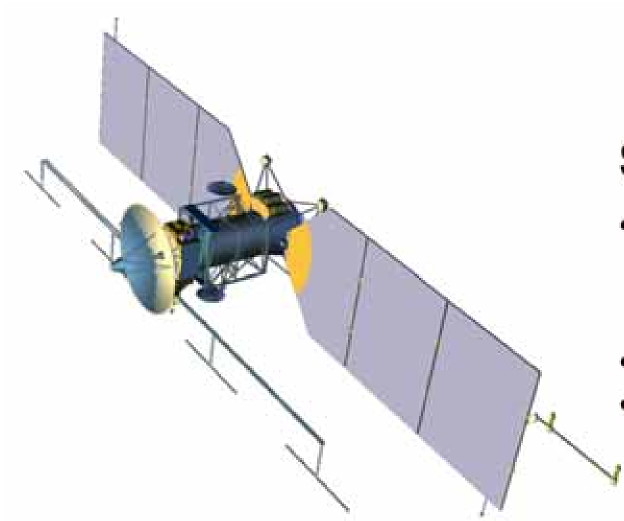
Europa Project Timeline
Present – Dec 2021



Power Source Options

MMRTG: Multi-Mission Radioisotope Thermoelectric Generator

- Demonstrated high reliability
- ^{238}Pu available to support 2021 mission is not assured
- Much higher cost than solar



Solar: Foldout Panel Solar Arrays

- Recently competed independent review, and assessment was that the technical issues to be resolved are feasible for Europa Clipper
- Highest mass, lowest cost solution
- Removes dependency on ^{238}Pu availability

ASRG: Advanced Stirling Radioisotope Generator

- Recommended by Planetary Decadal Survey
- Technical issues need resolution for compatibility with Europa Clipper
- Reliability not yet demonstrated; high per unit cost

Removed From Option Space

Potential Enhancements Provided By SLS

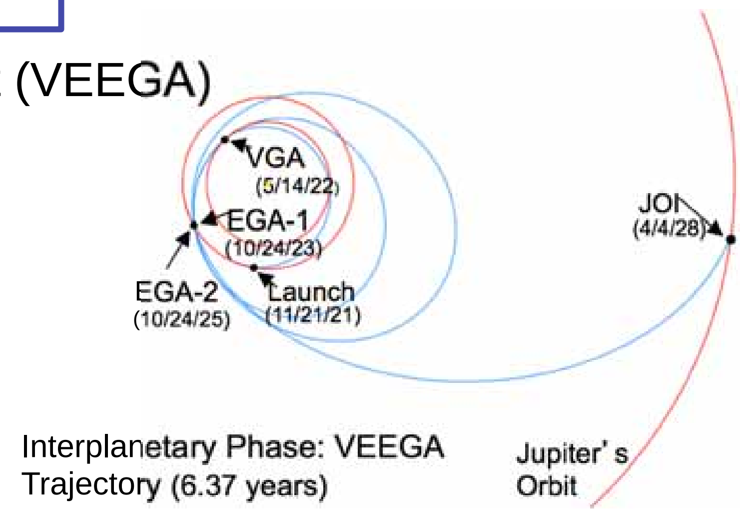
Outer Planet & Clipper Research Advantages:

- Science-driven exploration is enhanced by *'rapid'* response to discovery
- Long cruise to Jupiter make this problematic
- Direct trajectory via Block-1 SLS cuts cruise to Jupiter from 6.37 years to 1.9 to 2.7 years
- Clipper launch in June 2022 arrives in May 2024
    - Seven-month development reserve, while arriving 4 years earlier
- Enables significant mass margin
    - Valuable commodity in S/C development phase
    - Enables possible mission enhancements (e.g. – CubeSats at Jupiter)
- Annual launch opportunities
- Eliminates thermal design challenge of Venus flyby
- Eliminates significant safety precautions for Earth flybys

Launch Vehicle Trade

Atlas V-551 Current baseline

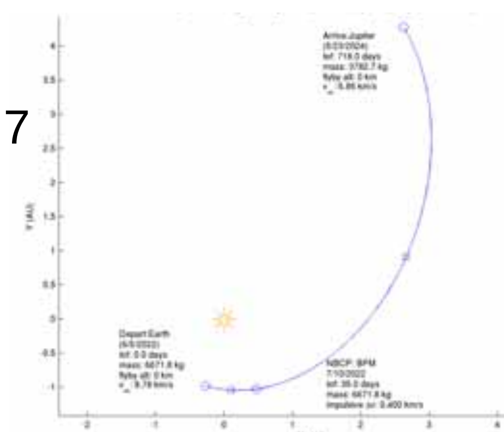
- Venus, Earth, Earth Gravity Assist (VEEGA) time of flight 6.4 years
- Estimated Cost ~$350M
- Earliest Launch : November 2021
- Earliest Arrival : April 2028



Atlas V 551

Working With MSFC On SLS Option

- Direct to Jupiter trajectory time of flight 1.9-2.7 years
- Estimated Recurring SLS Cost ~$500M
- Earliest Launch : June 2022
- Earliest Arrival : May 2024



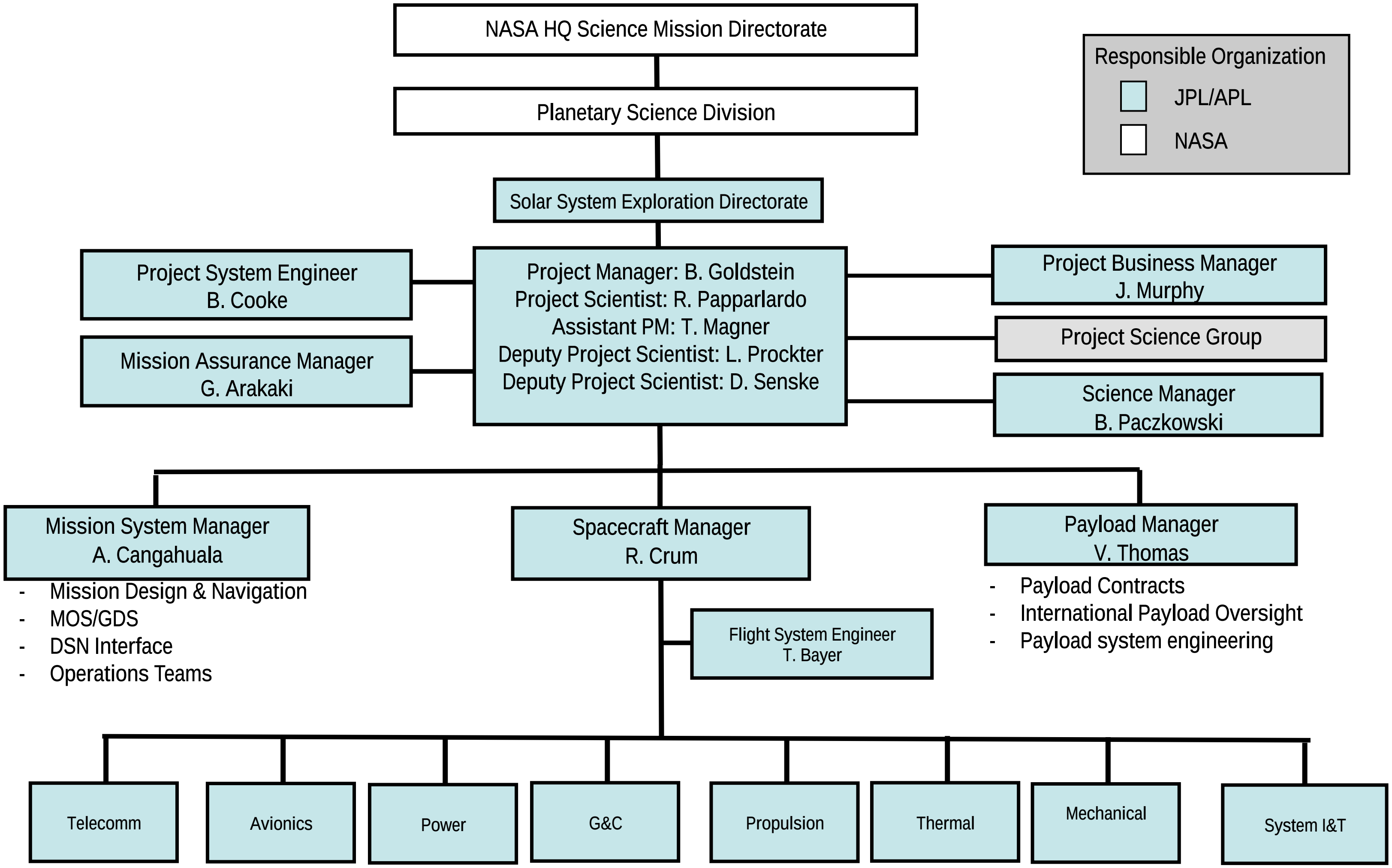
NASA SLS

On-Going and Future Work

- **Prep Work for Preliminary Mission Concept Review, 3/11/14**
  - Using model payload, iteration on mission design
    - Figures of merit → instrument performance, radiation total dose, eclipse time, etc.
  - Multiple S/C and mission trades
    - Recent stacked vs. nested prop-tank
    - Gravity Science implementation
    - Power source options
    - Launch Vehicle options
  - Mission requirements generation
    - Based on best understanding of Level 1 requirements

- **Risk Reduction Tasks**
  - Active thermal control component tests
  - Planetary Protection method
  - Electronics and materials radiation sensitivity tests
  - Thermal and Radiation testing of solar cells
  - Enhanced Li-Ion battery capacity for deep space
  - Science risk reduction tasks

Europa Clipper Pre-Project Organization Chart



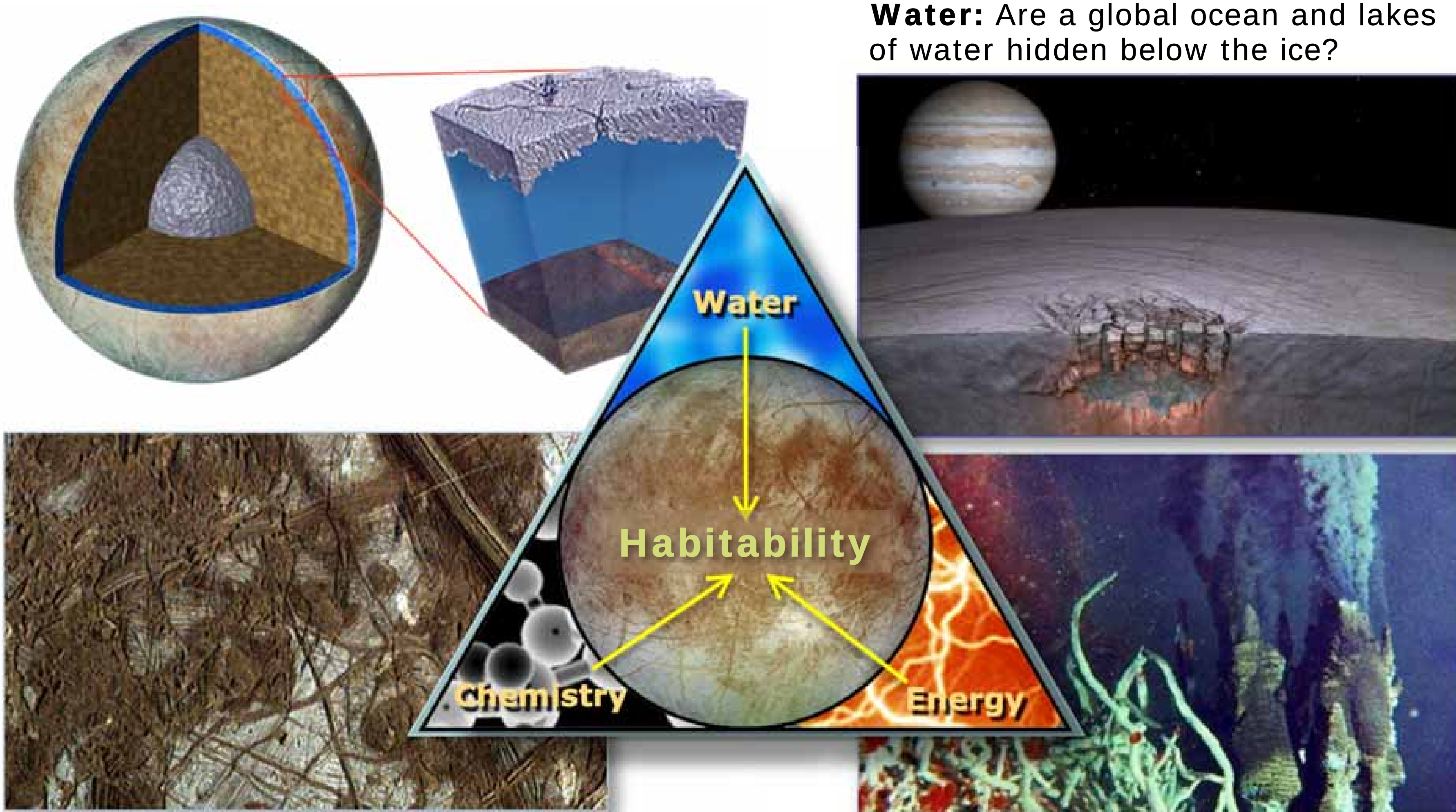
Science and Reconnaissance Overview

Robert Pappalardo

Pre-Project Scientist

Europa: Ingredients for Life?

Water: Are a global ocean and lakes of water hidden below the ice?

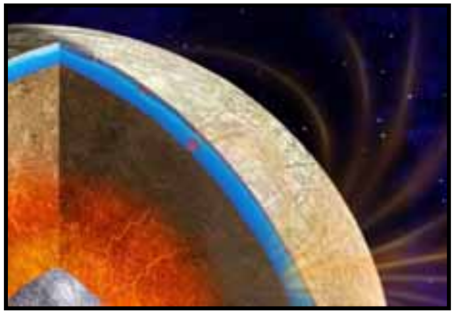


Chemistry: Do red surface deposits tell of habitability below?

Energy: Can chemical disequilibrium provide energy for life?

Europa Clipper Science

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



Science Traceability: Goal → Model Instruments

Goal
Explore Europa to investigate its habitability.

→

Objectives
Understand the habitability of Europa's ocean through composition and chemistry.

→

Investigations
Characterize the composition and chemistry of the Europa ocean as expressed on the surface and in the atmosphere.

→

Example Measurements
Measure surface Measure surface reflectance from 850 to 5000 nm with 10 nm resolution....

→

Model Instruments
ShortWave InfraRed spectrometer...

Defined by SDT

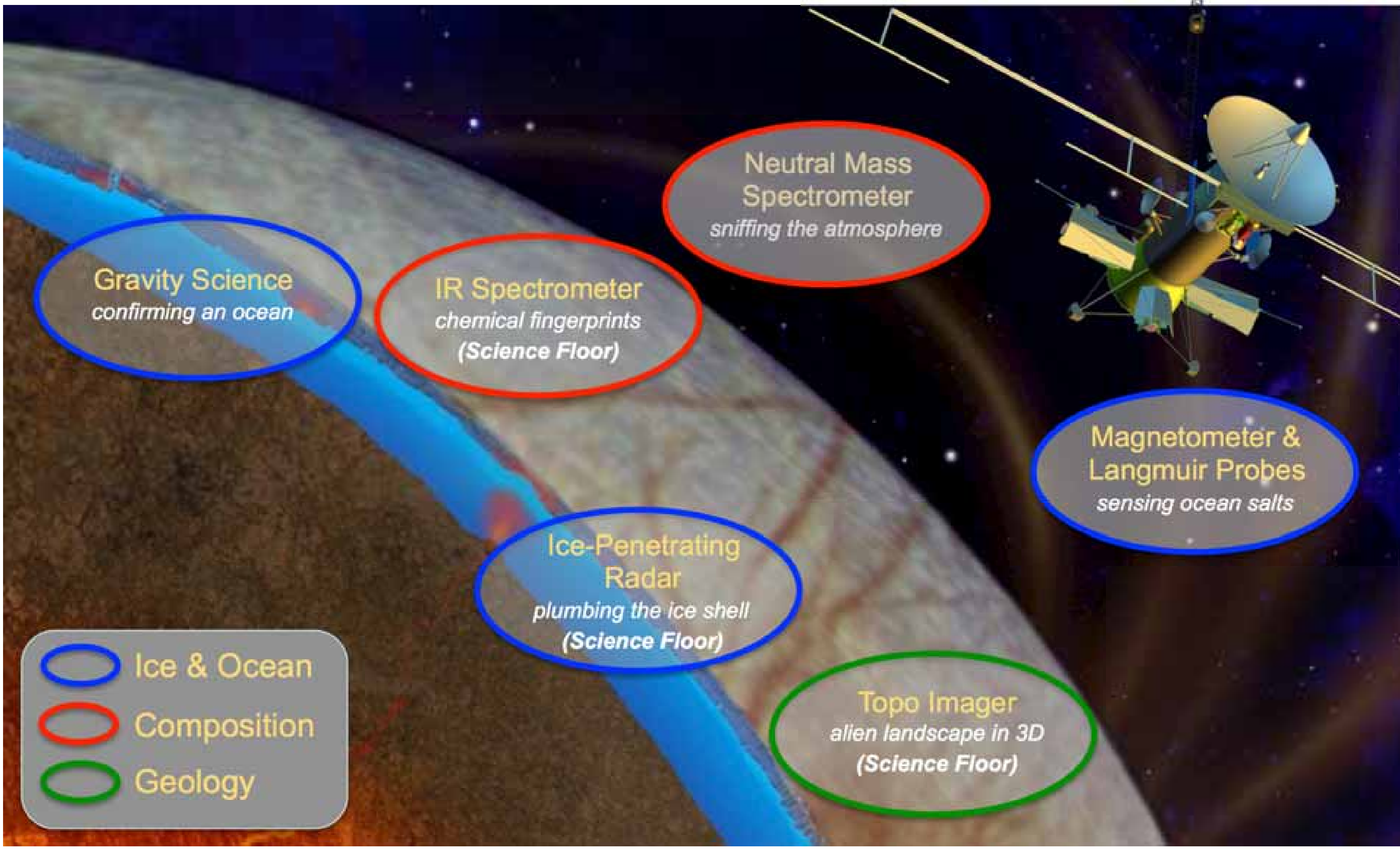
Examples presented by SDT

Science Traceability Matrix (STM)

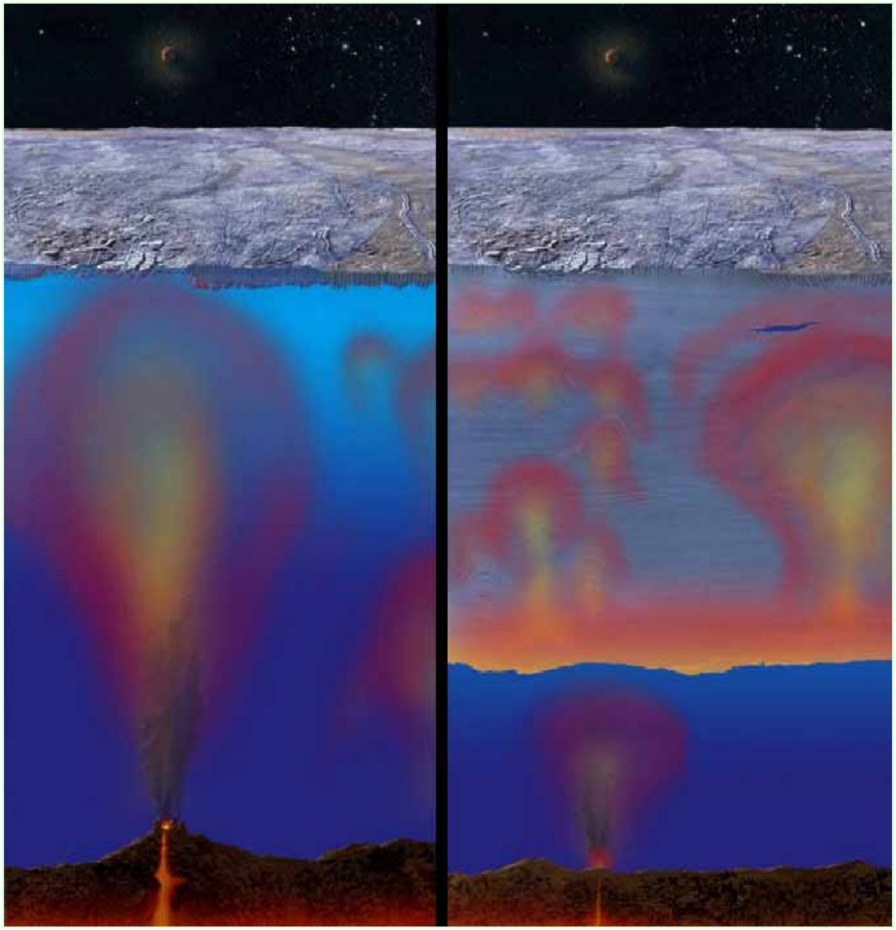
Goal		Objective	Investigation	
Explore Europa to investigate its habitability	Ice Shell and Ocean	Characterize the ice shell and any subsurface water, including their heterogeneity, ocean properties, and the nature of surface-ice-ocean exchange.	IO.1	Characterize the distribution of any shallow subsurface water and the structure of the icy shell.
			IO.2	Determine Europa's magnetic induction response to estimate ocean salinity and thickness.
			IO.3	Search for an ice-ocean interface.
			IO.4	Correlate surface features and subsurface structure to investigate processes governing material exchange among the surface, ice shell, and ocean.
			IO.5	Determine the amplitude and phase of gravitational tides.
			IO.6	Characterize regional and global heat flow variations.
	Composition	Understand the habitability of Europa's ocean through composition and chemistry.	C.1	Characterize the composition and chemistry of the Europa ocean as expressed on the surface and in the atmosphere.
			C.2	Determine the role of Jupiter's radiation environment in processing materials on Europa.
			C.3	Characterize the chemical and compositional pathways in Europa's ocean.
	Geology	Understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities.	G.1	Determine sites of most recent geological activity, and characterize localities of high science interest.
			G.2	Determine the formation and three-dimensional characteristics of magmatic, tectonic, and impact landforms.

Objectives are prioritized, and Investigations are prioritized within each Objective

Science Model Payload

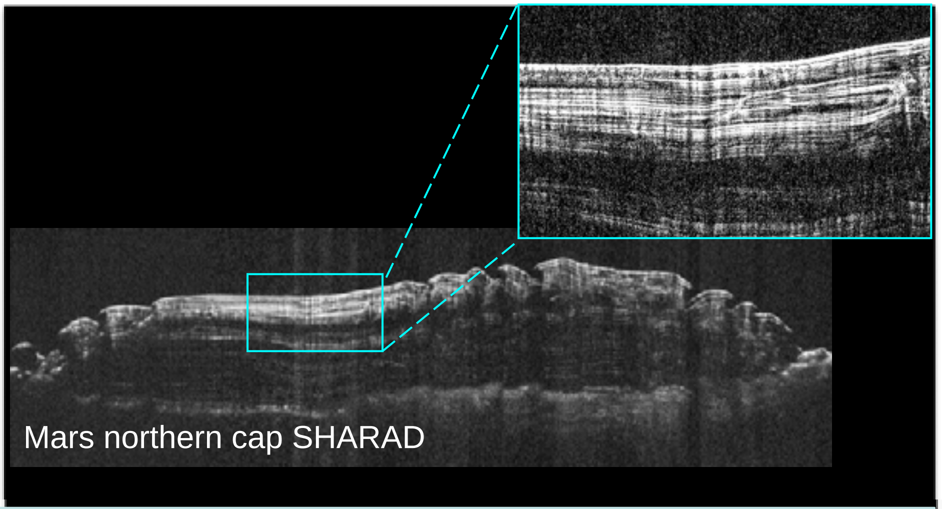


Ice Shell & Ocean • Composition • Geology



Ice shell characteristics:

- Shallow water
- Ice-ocean interface
- Material exchange
- Heat flow variations

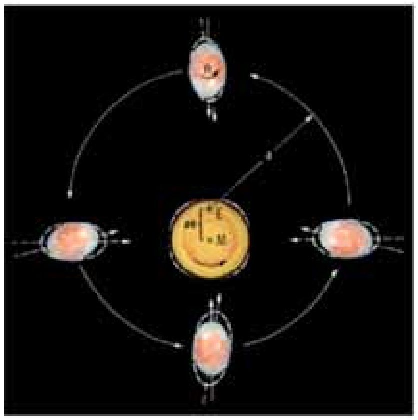


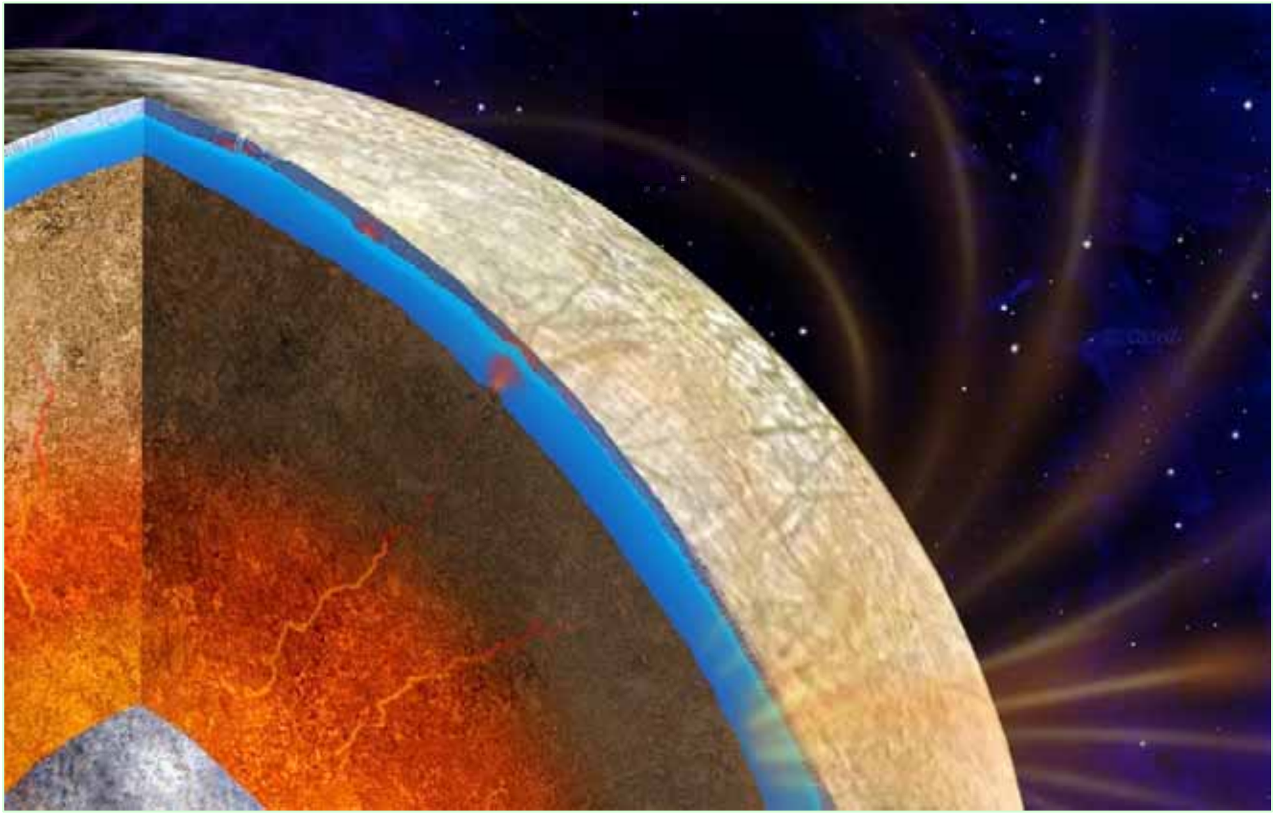
Subsurface dielectric horizons can indicate water in and beneath the icy shell

Ice Shell & **Ocean** • Composition • Geology

Ocean characteristics:

- Magnetic induction (ocean salinity & thickness)
- Gravitational tides (k_2)

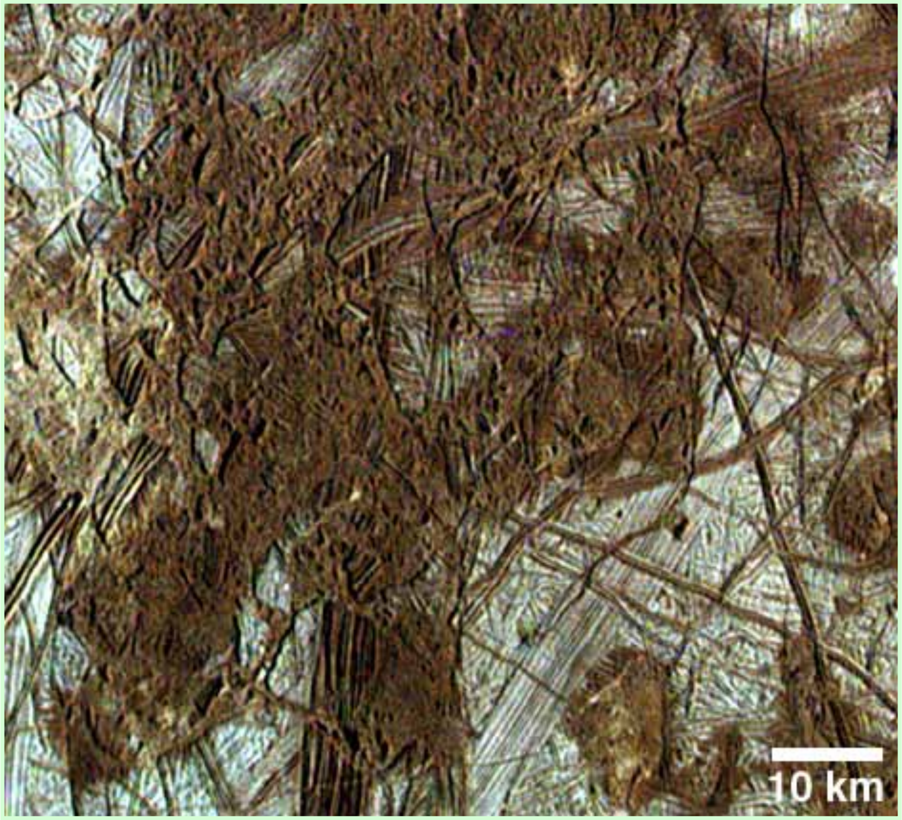




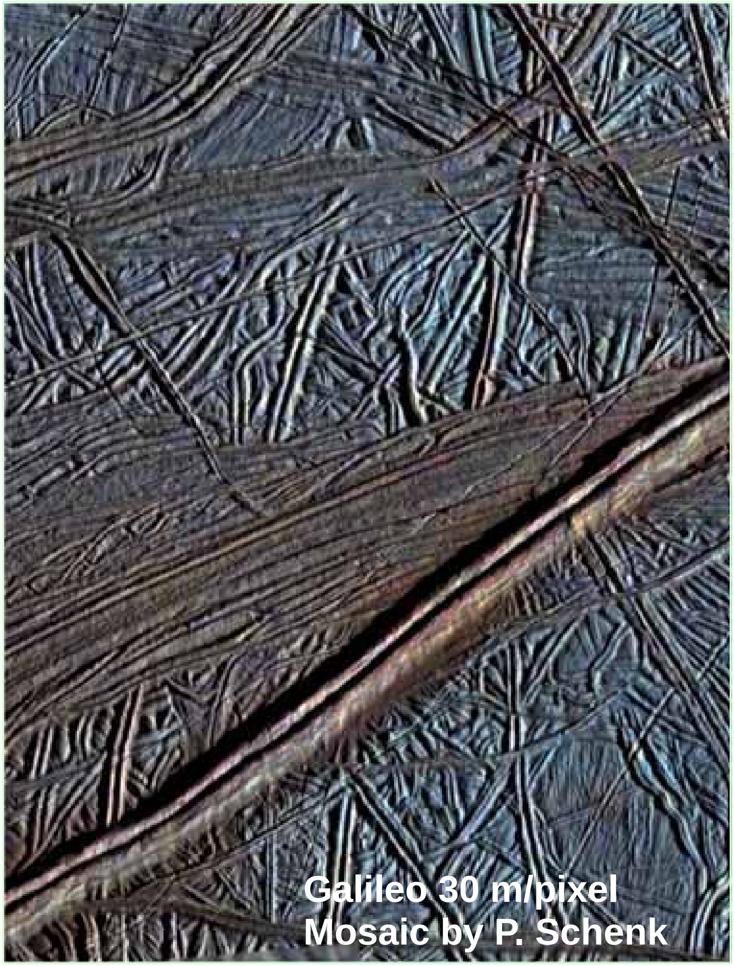
Magnetic and gravity fields can confirm and characterize the ocean

Composition & chemistry:

- Composition and chemistry on surface and in atmosphere
- Radiation effects
- Chemical and compositional pathways from the ocean

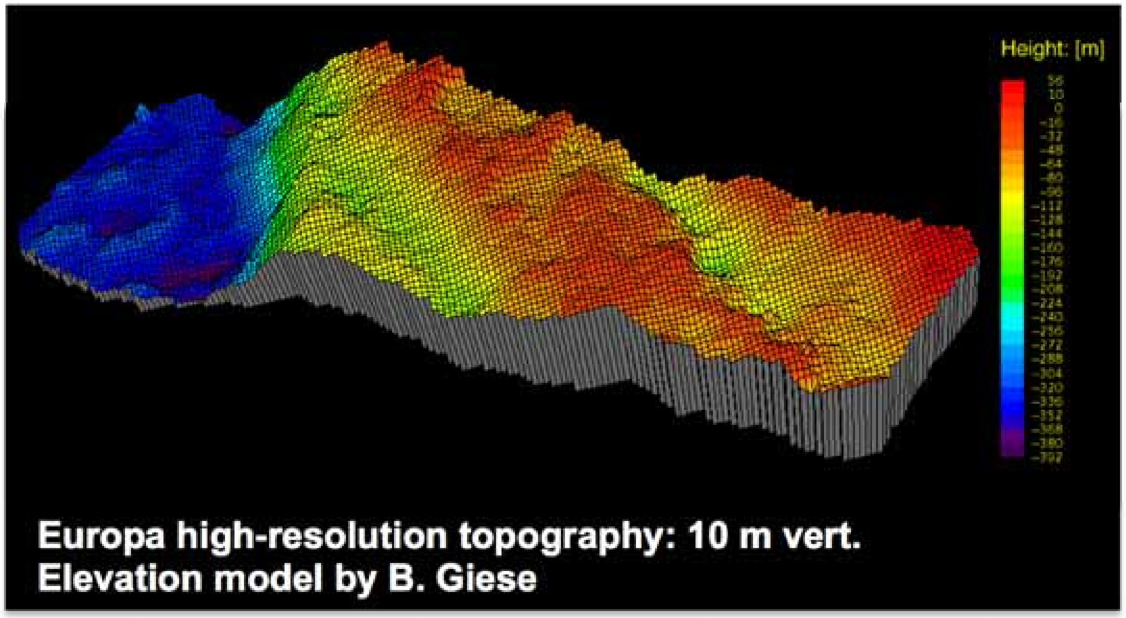


Surface reflectance and ejected surface products can indicate surface and atmospheric composition to characterize composition and chemistry



Geological activity:

- Characterize high-interest areas
- Seek signs of recent activity

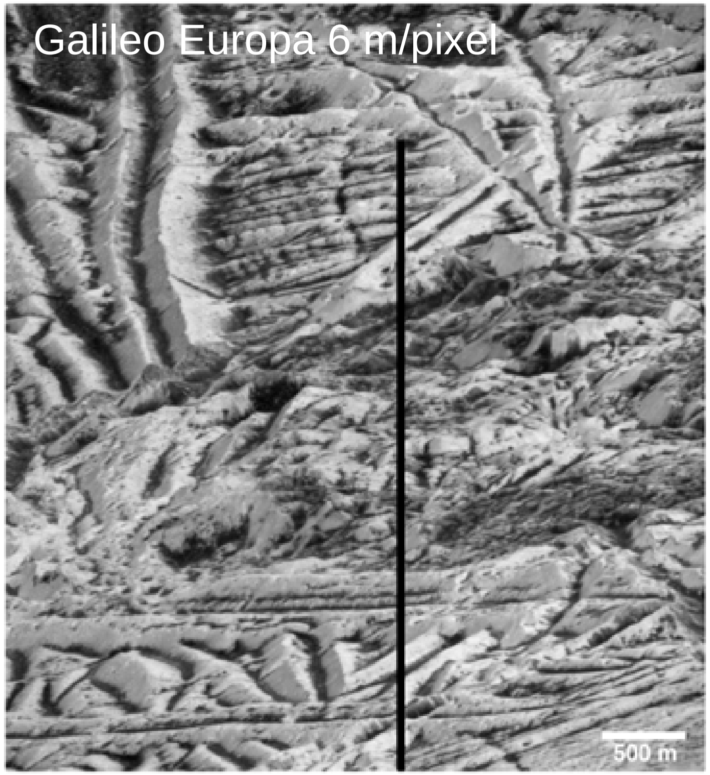


Morphology and topography can elucidate geological processes and activity

Programmatic Need for Feed-Forward Reconnaissance Data Sets

To prepare for a future lander, reconnaissance data is necessary from both science and engineering perspectives:

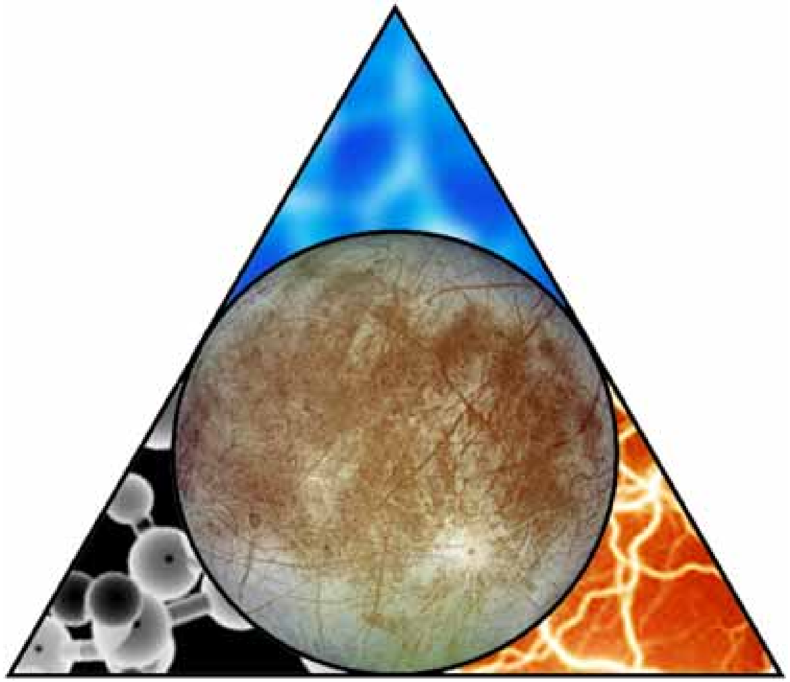
- Engineering reconnaissance for landing safety (enabled by Recon Camera and Thermal Imager)
  - Is a safe landing site (within a lander's design margins) accessible to a spacecraft?
  - Assess at least 15 sites to determine conditions and find two that are safe
- Science reconnaissance for landing site selection (enabled by science model payload)
  - Is the landing site scientifically compelling in addressing the goal of exploring Europa to investigate its habitability?



Highest Resolution Europa image currently available

Reconnaissance Traceability Matrix (RTM)

Goal		Objective	Investigation	
Characterize Safe and Scientifically Compelling Sites for a Future Lander Mission to Europa	Landing Safety	Assess the distribution of surface hazards, the load-bearing capacity of the surface, the structure of the subsurface, and the regolith thickness.	SL.1	Determine the distribution of blocks and other roughness elements within a potential landing site at scales that represent a hazard to landing.
			SL.2	Determine the distribution of slopes within a potential landing site over baselines relevant to a lander.
			SL.3	Characterize the regolith cohesiveness and slope stability within a potential landing site.
			SL.4	Determine the regolith thickness and whether subsurface layering is present within a potential landing site.
	Scientific Value	Assess the composition of surface materials, the geologic context of the surface, the potential for geologic activity, the proximity of near surface water, and the potential for active upwelling of ocean material.	SV.1	Characterize the composition and chemistry of potential landing sites with an emphasis on understanding the spatial distribution and degradation state of endogenically derived compounds.
			SV.2	Characterize the potential for recent exposure of subsurface ice or ocean material vs. degradation of the surface by weathering and erosion processes and provide geologic context for potential landing sites.
			SV.3	Characterize the potential for shallow crustal liquid water beneath or near potential landing sites.
			SV.4	Characterize anomalous temperatures (that are significantly out of equilibrium with expected nominal diurnal cycles) indicative of current or recent upwelling of ocean material at or near potential landing sites.



Project System Overview

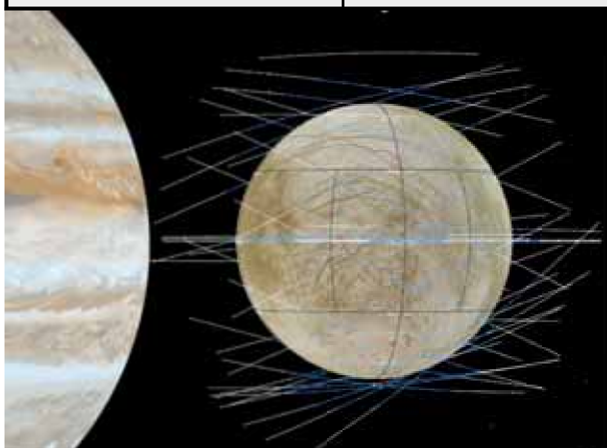
Brian Cooke, Pre-Project Project System Engineer
Todd Bayer, Pre-Project Flight System Engineer

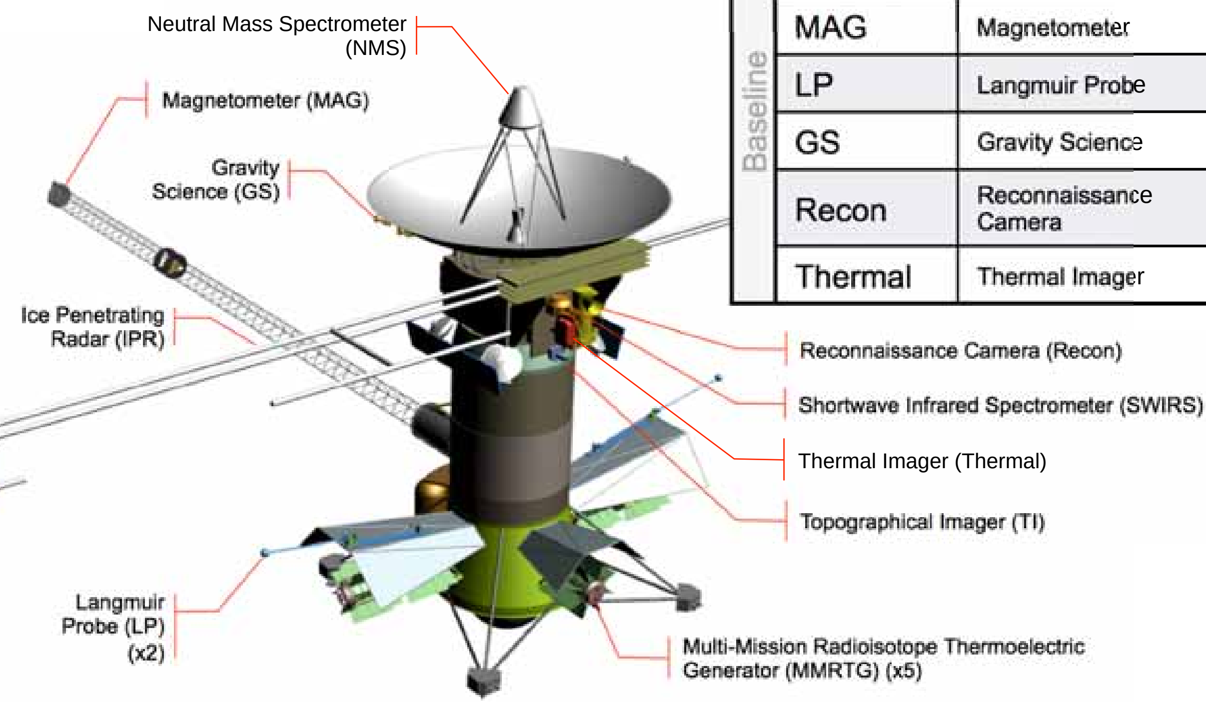
Europa Clipper Concept Overview

Oct 2013

Science	
Objective	**Description**
Ice Shell & Ocean	Characterize the ice shell, subsurface water & surface-ice-ocean interface.
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.
Recon	Characterize Safe and Scientifically Compelling Sites for a Lander Mission to Europa

Model Payload		
	Acronym	**Instrument**
Floor	IPR	Ice Penetrating Radar
Floor	SWIRS	Shortwave Infrared Spectrometer
Floor	TI	Topographical Imager
Baseline	NMS	Neutral Mass Spectrometer
Baseline	MAG	Magnetometer
Baseline	LP	Langmuir Probe
Baseline	GS	Gravity Science
Baseline	Recon	Reconnaissance Camera
Baseline	Thermal	Thermal Imager

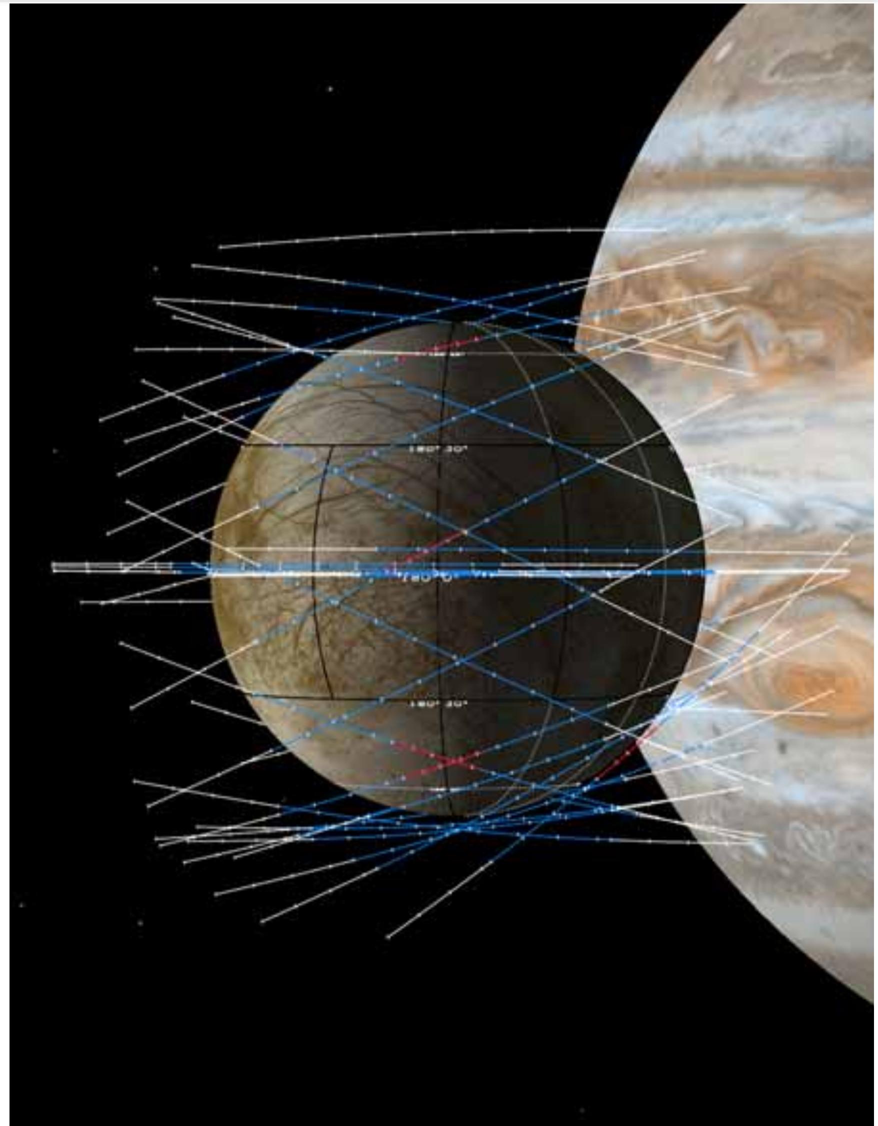




Mission Plan	
Launch	21 Nov 2021
Jupiter Arrival	4 Apr 2028
Science Tour	45 Europa Flybys
Primary Mission End	Oct 2031

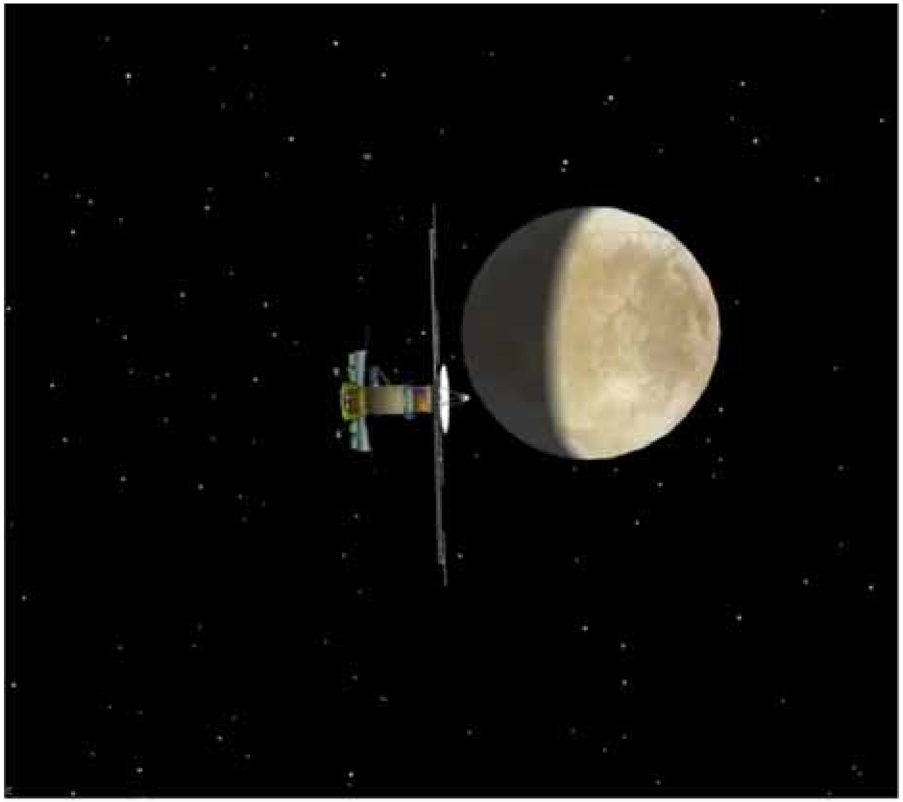
Innovative Mission Concept

- Utilize multiple Europa gravity assists to enable “global-regional coverage” of Europa while in orbit around Jupiter
- Current mission design consists of 45 low-altitude flybys of Europa from Jupiter orbit over 3.1 yr
- Minimizes time in high radiation environment (2.8 Mrad TID*)
- Simple repetitive operations
    - Nadir instrument deck
    - Repetitive operation sequence



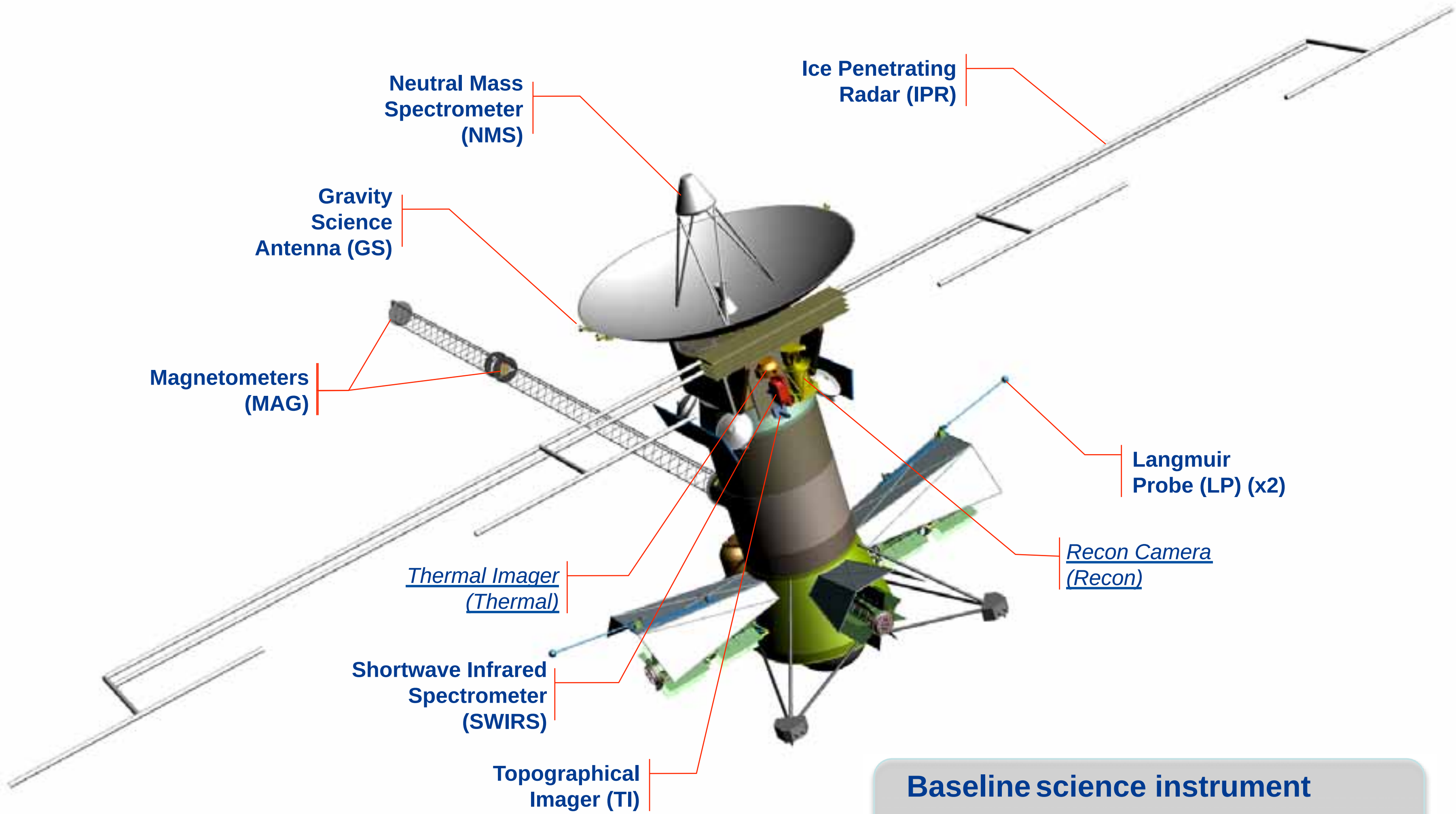
*Si behind 100 mil Al, spherical shell

Operations Concept



- Simple, repetitive Operations Concept
  – Intended to keep Operations cost down
  – Consistent with "exploration" philosophy
- Spacecraft follows same attitude profile for each flyby
  – Instrument Deck fixed nadir
  – HGA fixed in velocity (wrt Europa) direction
  – Attitude fixed below 100k km altitude
- Currently no plans to maneuver spacecraft from nadir
  – Will revisit this constraint in the future

Europa Clipper Model Payload

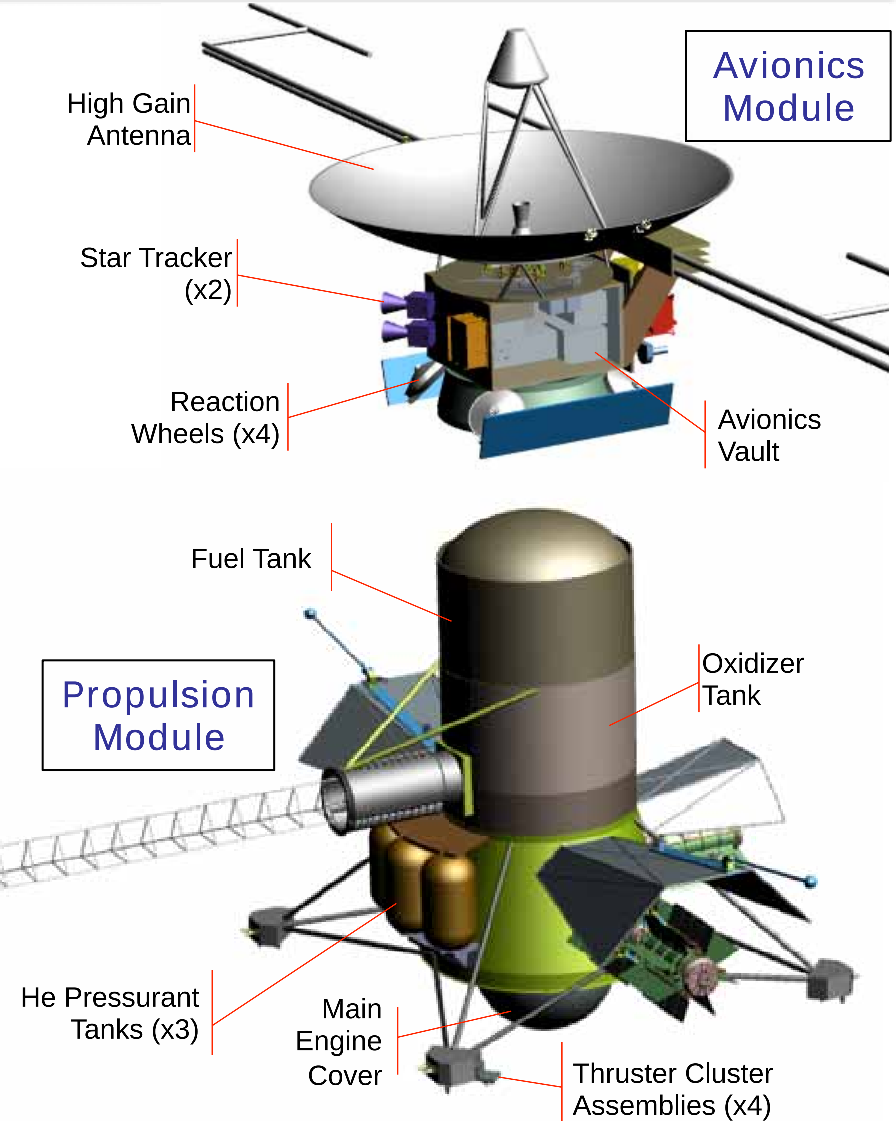


Baseline science instrument

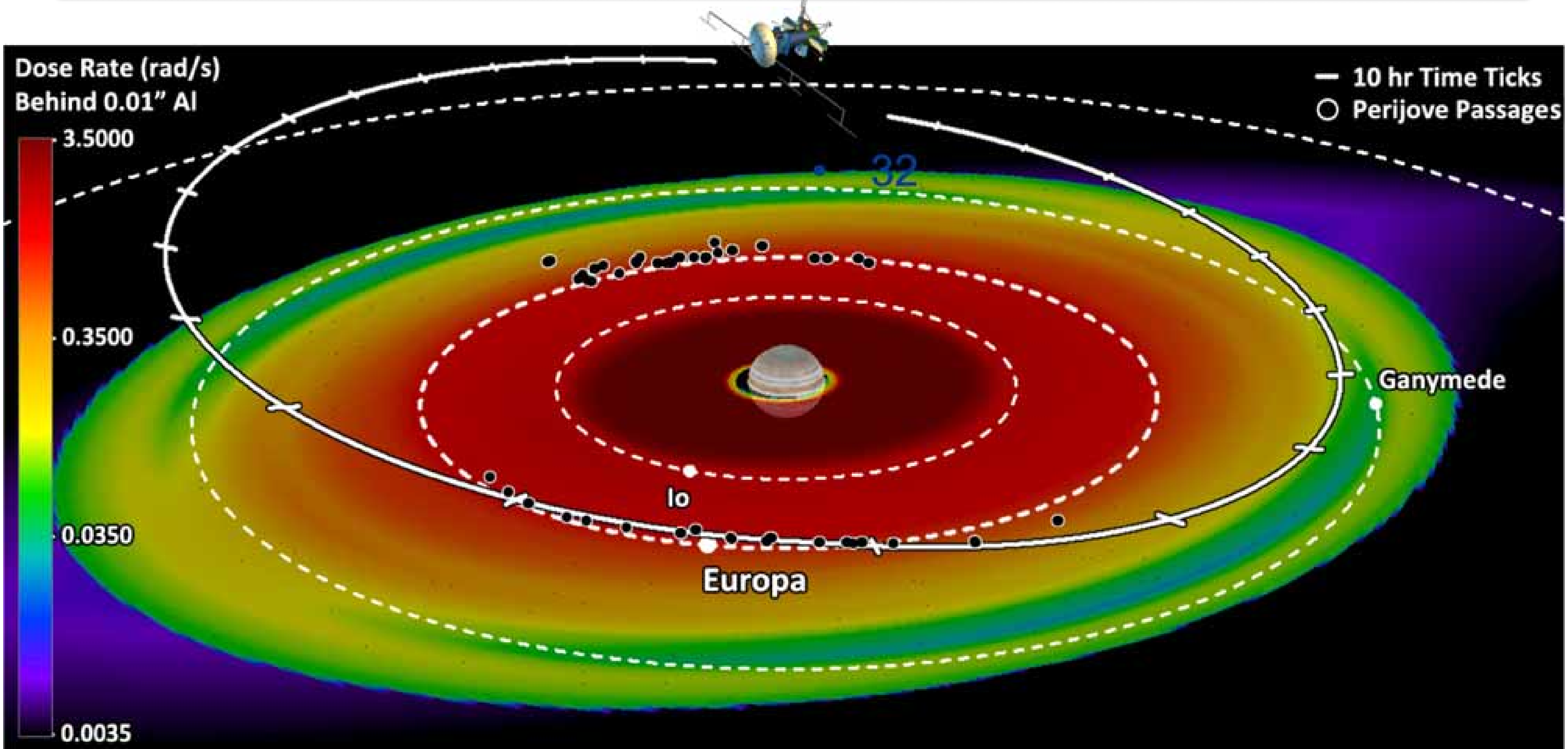
Baseline reconnaissance instrument

Modular Spacecraft Design

- Implementation flexibility
  - Parallel integration paths
  - Module level integrated testing during Phase C
  - Isolates implementation issues at the module level
- Robust schedule management
  - Decouples qualification testing until late in integration flow
- Smooth funding profile
  - Allows flexible phasing of module implementation schedules
  - This minimizes peaks in project funding profile

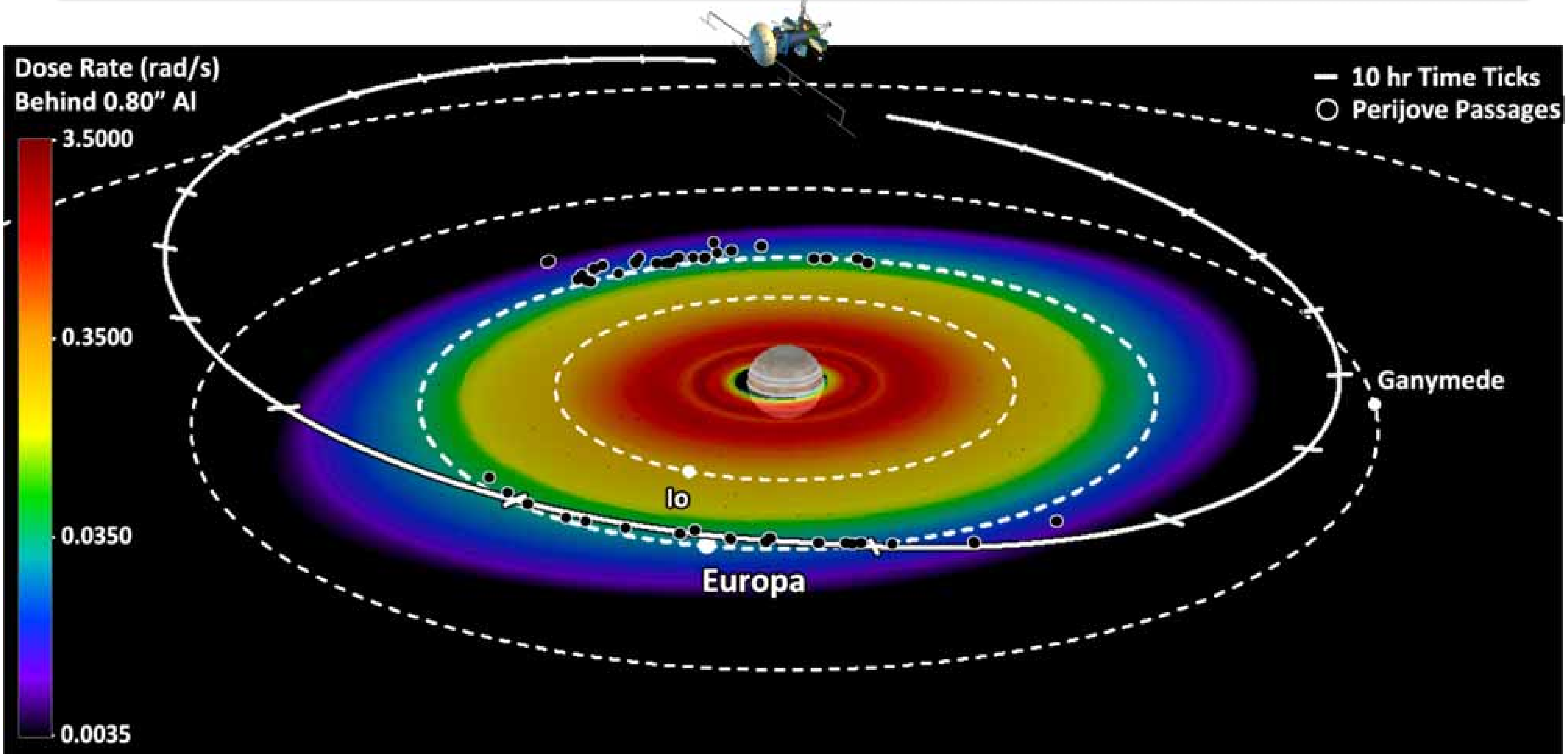


Radiation Mitigation Strategy
(Dose Rate behind 10 mils Al)



- "Toe dip" into the highest radiation zone near Europa
- Shielded vault protects the most sensitive electronics

Radiation Mitigation Strategy
(Dose Rate behind 800 mils Al)

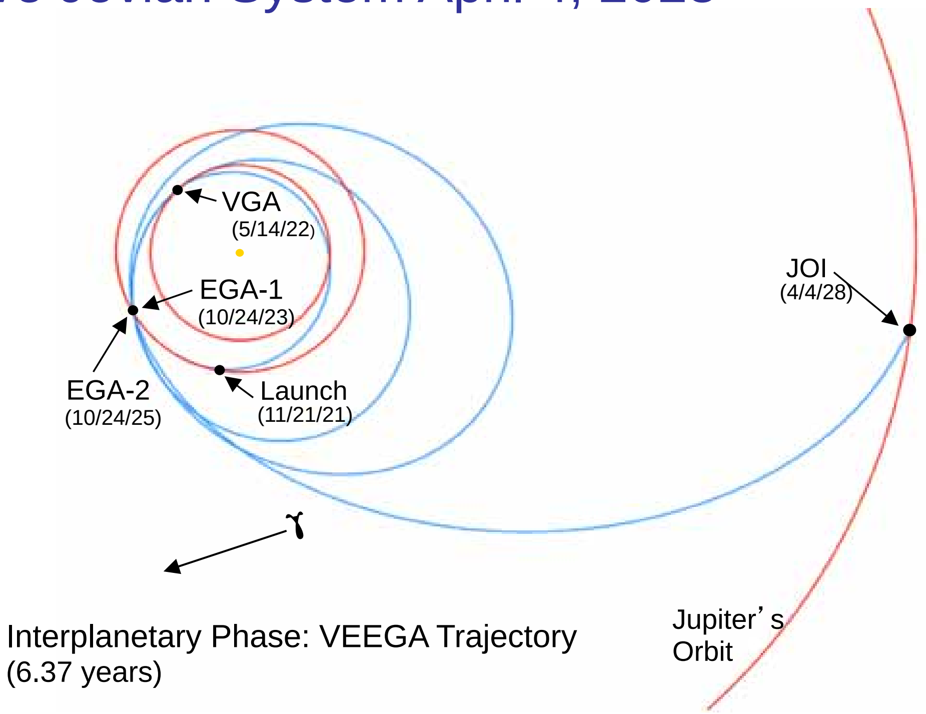


- "Toe dip" into the highest radiation zone near Europa
- Shielded vault protects the most sensitive electronics

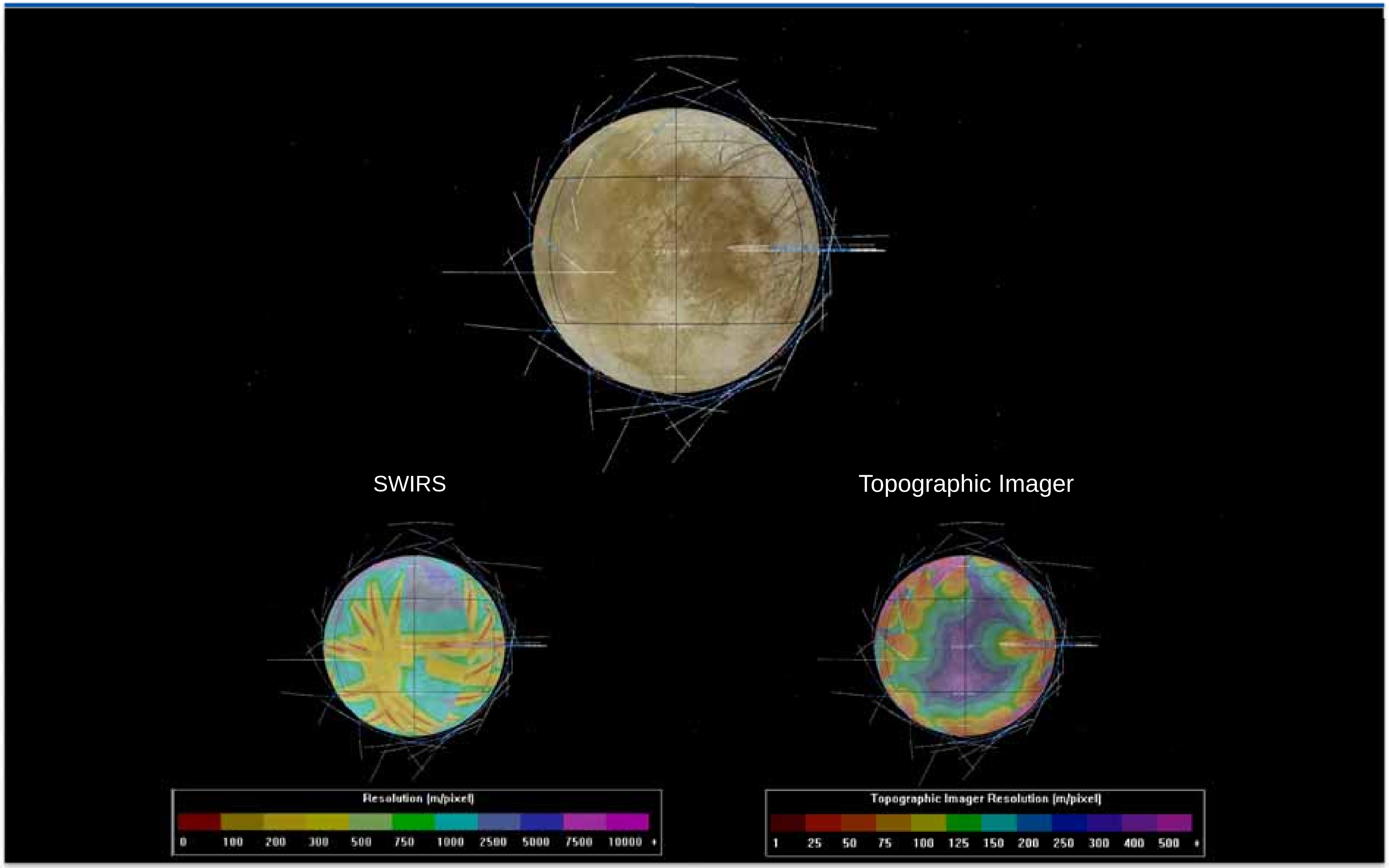
VEEGA Interplanetary Trajectory
(Atlas V 551 Baseline)

Gravity assist interplanetary trajectory with annual launch opportunities

- 21 Day launch period opens 16 Nov 2021
- Venus/Earth/Earth Gravity Assist
- Arrive Jovian System April 4, 2028



Select 13-F7 Instrument Coverage



Planetary Protection

Given Europa's potential as the Solar System's second safe harbor for life, it is vitally important that we protect it from contamination

- Unlike present day Mars, Europa may have abundant liquid water, a rich source of nutrients and energetic processes capable of fueling metabolism. This mission would seek to investigate and confirm Europa's potential habitability.
- If confirmed, Europa will posses conditions that, when found on Earth, have always resulted in the discovery of flourishing life (hydrothermal vents, Lake Vostok, etc.)
- This project accepts the scientific, legal and ethical responsibility to protect the Europan environment and the Jovian system from contamination

Planetary Protection Implications

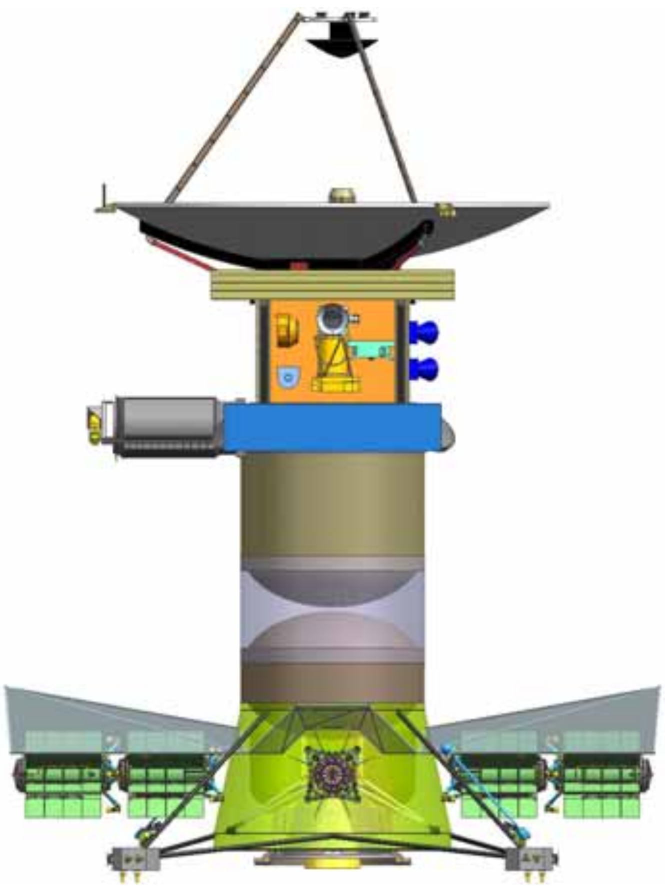
- Planetary Protection Compliance plan is an ongoing discussion within Project and with NASA HQ
- Likely strategy will be a combination of several strategies
  - Probabilistic assessment of the likelihood of contaminating Europa's ocean as a function of several factors affecting allowable launch bioburden
    - Bioburden at launch
    - Extinction during transit to Jupiter
    - Extinction in Jovian orbit
    - Probability of Europa impact
    - Extinction at Europa impact
    - Probability of transport into ocean
    - Extinction before ocean contact
    - Probability of survival in ocean
  - Board and box level sterilization using two approved processes
    - Dry Heat Microbial Reduction (>125°C for extended duration)
    - Hydrogen Peroxide Vapor Deposition
  - Instrument, assembly and system-level sterilization
    - Likely using Dry Heat Microbial Reduction

Europa Clipper
Design Assumptions

Parameter	Design Assumption
Venus flyby	Instruments shadowed by HGA (excpt NMS)
Electronics Vault for radiation shielding (TBE)	372 mil walls for 300 krad TID (RDF=2)
Field of Views Accommodation	Per Payload Resources (see detail). Nadir pointed during flybys
Data Rate – Return 64 Gbit/flyby science data	≥134 kbps average at Jupiter
Launch Vehicle Accommodation	Atlas V 551 or SLS
Design Life	13 years total: 3 Gnd, 6.5 transit, 3.5 ops
Instrument Operating Power Accommodation	132 W CBE / 199 W MEV
Instrument Mass Accommodation	88 kg CBE / 132 kg MEV
Spacecraft Pointing Stability	Nadir pointed: 25 urad/sec (SWIRS); 50 urad/sec (Recon)
Magnetometer separation from spacecraft	6 m and 10 m
Langmuir probe separation from spacecraft	1 m mast
Electronics Vault Thermal Environment	10 to 55 C
On board Data Storage per Redundant SSR	128 Gbits
Reliability	Single Fault Tolerant (w/ exceptions for instruments, tanks, etc.)

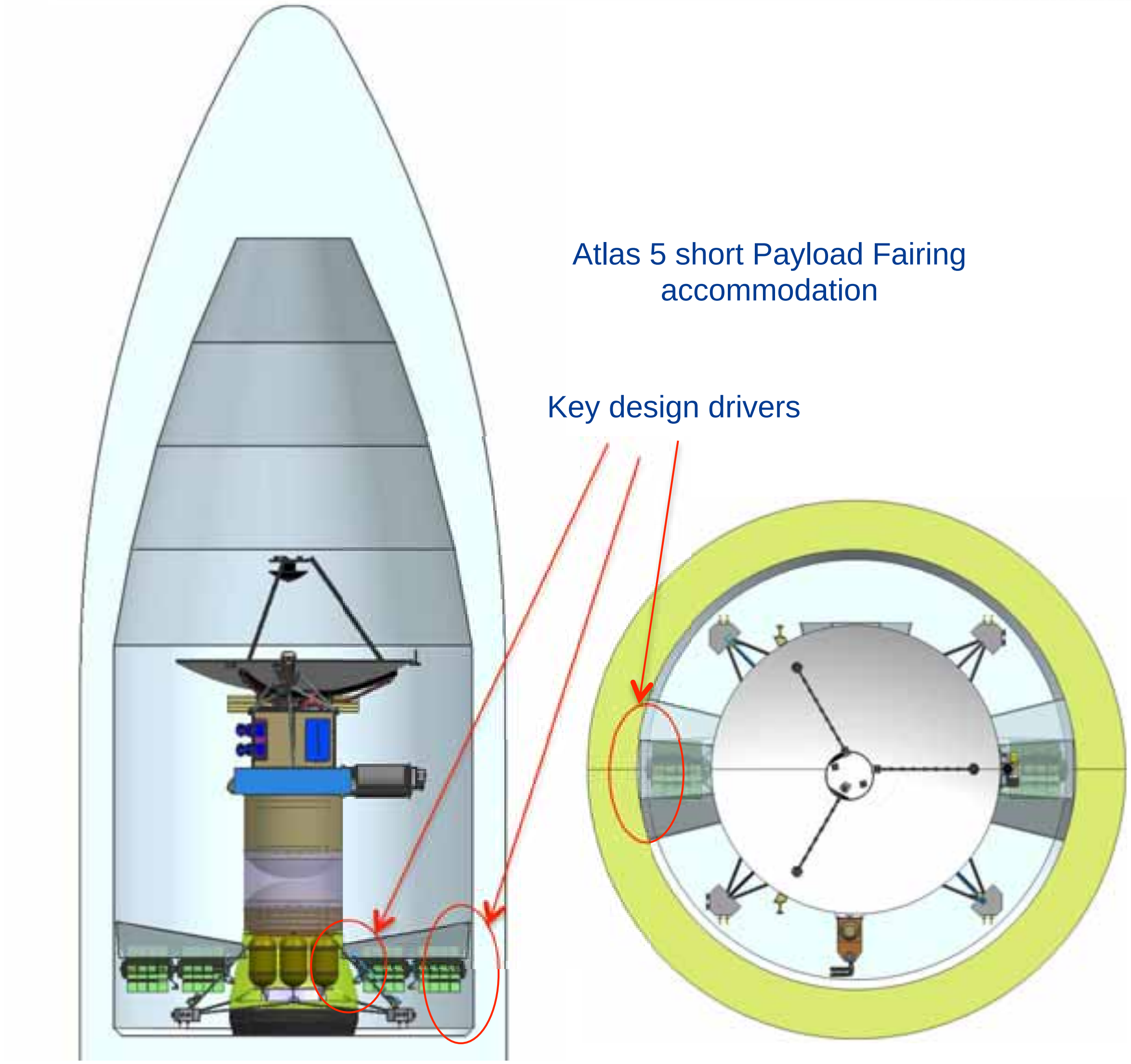
Europa Clipper
MMRTG Spacecraft Configuration

Power	•Five MMRTGs w/sunshades (404 W EOM) •40 Ah Battery for launch, JOI, flybys •Power system electronics, Power distribution
Propulsion	•Dual Mode Hydrazine propulsion subsystem •1930 kg fuel, 50 inch dia tanks •Single ~450N gimbaled main engine, 2 hr JOI •16 x 4N RCS thrusters
Avionics	•RAD750 flight computer and 128 Gb SSR
Telecom	•X-band: Receive u/l & 20W transmit d/l •Ka-band 35W: 80 kbps @ 6.4 AU max range •Science ops 8 hour on / 8 hour off •3-m HGA, MGA and LGA (2), Fanbeam GSA (1)
GN&C	• Star trackers(2), IMU(2), sun sensors(3) • 3-axis: Reaction wheels(4) for 1 mrad pointing • RCS thruster only in cruise
Thermal	•Active thermal pump loop, MLI, heaters, radiators, MMRTG heat reclaimer
Structure	•Tank-structure, sensor deck, Deployd Mag Boom •Rad vault internal 300 krad TID (RDF=2)



Mass Margin	Power Margin
45%	40%

Europa Clipper MMRTG Configuration

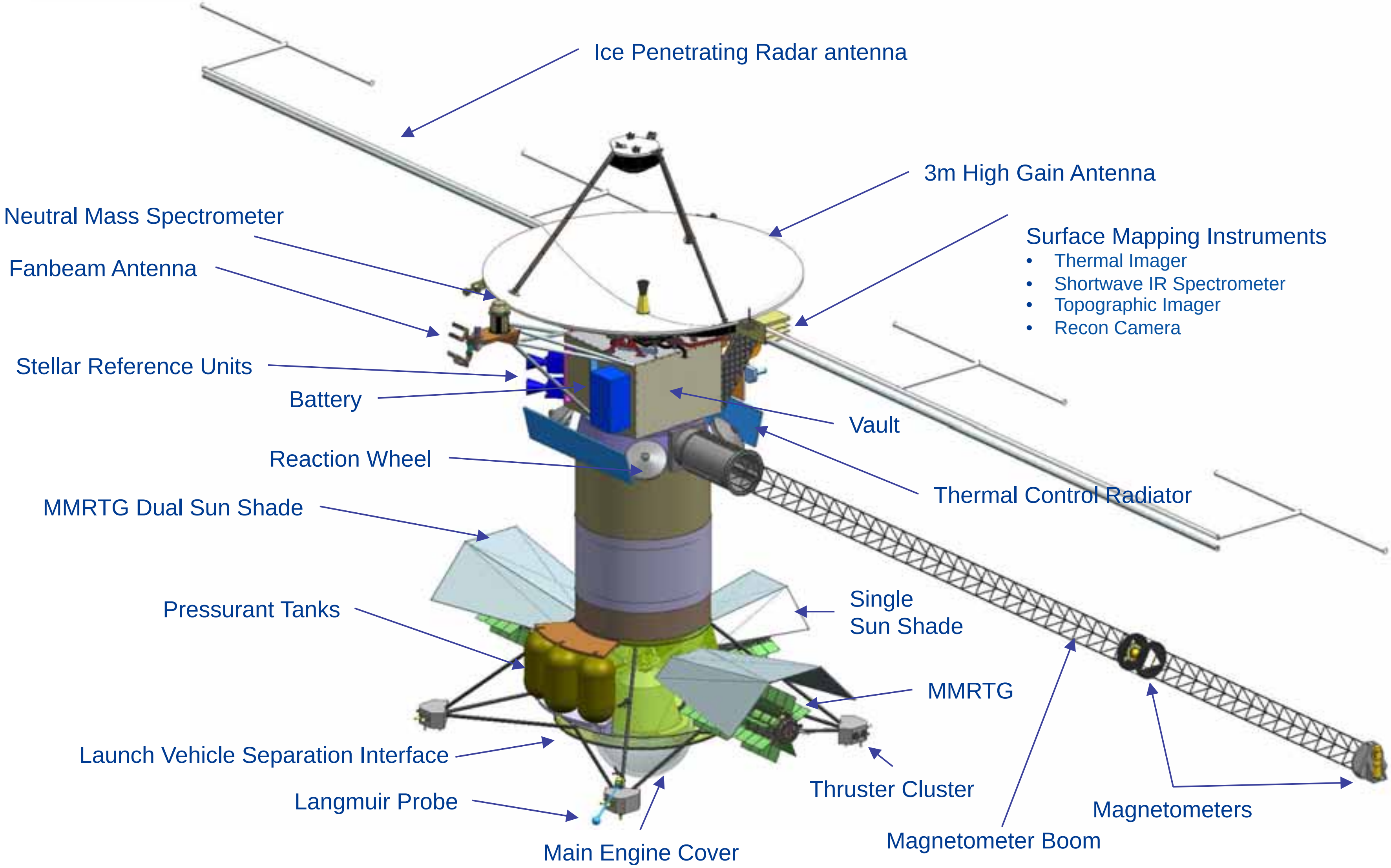


MMRTG configuration is driven by:

- 5x MMRTGs accommodation with minimum blockage of the MMRTG's radiators
- Sun shades for MMRTGs (TBC)
- MMRTG could be stacked (TBC)
- Minimizing MMRTGs thermal coupling to LVA and main engine
- LV Fairing accommodation
- S/C configuration
- Science Instruments, GSA's and GNC sensors FOV

Note. Required 3x MMRTG installation doors, plus fill & drain and enabling plugs access door

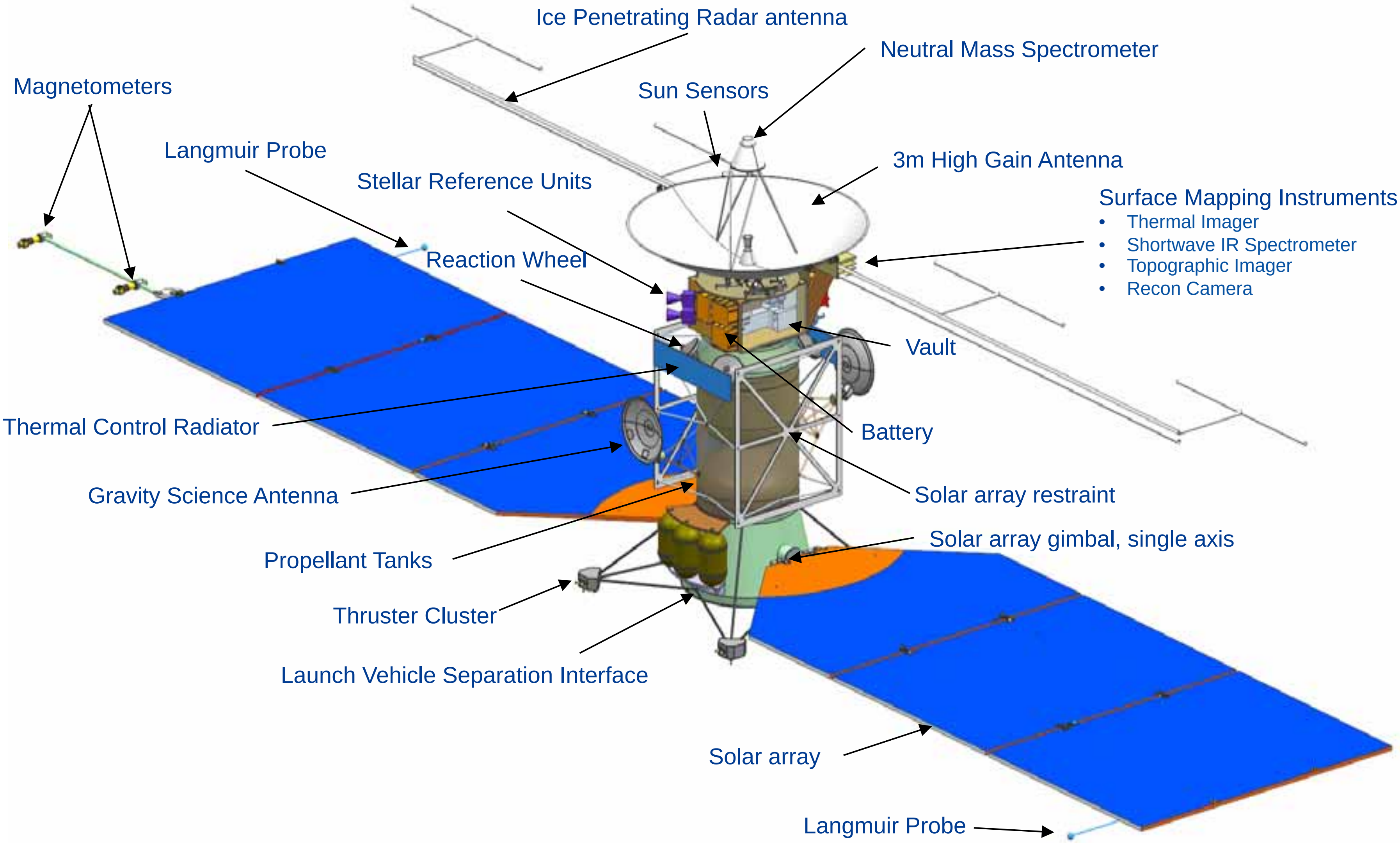
Europa Clipper MMRTG Configuration



Power Source Options

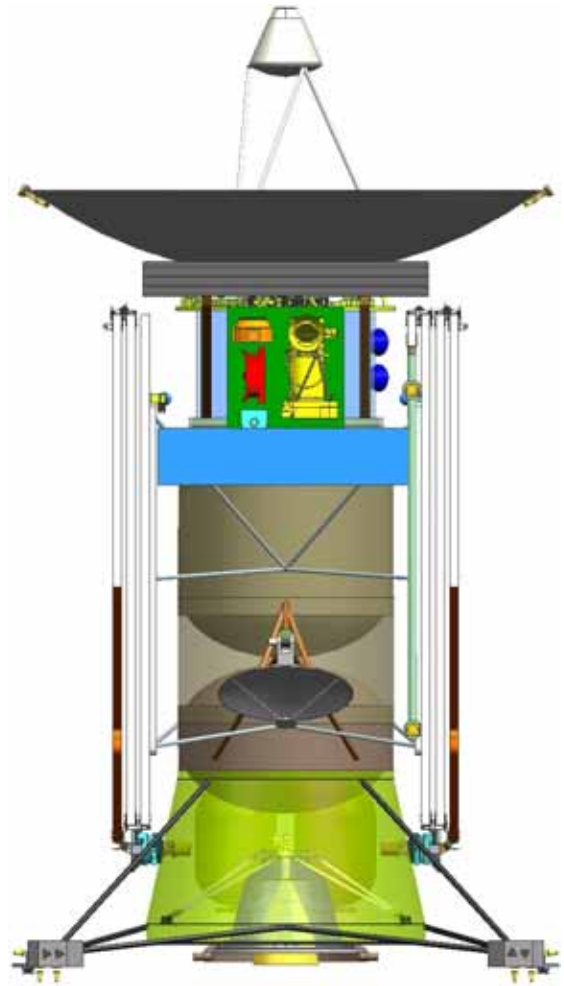
- Flight System concepts were developed for all three potential power sources in 2013: MMRTG, Solar, ASRG
- Feasibility of Solar Clipper was reviewed by an independent technical review board
  - Chaired by Chris Iannello, NASA Technical Fellow for Power
  - Board concluded:
    - Solar Clipper is feasible; no new technology required, only engineering development
    - There are risks to retire, but none which the project isn't already mitigating
    - Primary risk: cold temperature combined with radiation
- A system trade was then conducted among these three:
  - MMRTG was top choice and was selected by project
  - Solar was a close second; being kept as a backup (inactive) option
  - ASRG was eliminated
- The next few slides describe the solar concept at the conclusion of the trade (Sep 2013).

Solar Clipper Configuration
(last version, Sep 2013)



Europa Clipper
Solar Spacecraft Configuration

Power	•52 sq m active array area (520 W EOM) •160 Ah Battery for launch, eclipses JOI, flybys •Power system electronics, battery cell balancing •Power distribution
Propulsion	•Bi-Prop MMH/MON3 propulsion subsystem •1930 kg fuel, 50 inch dia tanks •Single 445N gimbaled main engine, 2 hr JOI •16 x 9N RCS thrusters
Avionics	•RAD750 flight computer and 128 Gb SSR
Telecom	•X-band: Receive u/l & 20W transmit d/l •Ka-band 35W: 80 kbps @ 6.4 AU max range •Science ops 8 hour on / 8 hour off •3-m HGA, MGA and LGA (2), 0.4m GSA (1)
GN&C	• Star trackers(2), IMU(2), sun sensors(3) • 3-axis: Reaction wheels(4) for 1 mrad pointing • RCS thruster only in cruise
Thermal	•Active thermal pump loop, MLI, heaters, radiators
Structure	•Tank as structure, sensor deck •Radiation vault: internal 150 krad TID (RDF=1)



Mass Margin	Power Margin
37%	40%

Notional Payload and Accommodation

Valerie Thomas

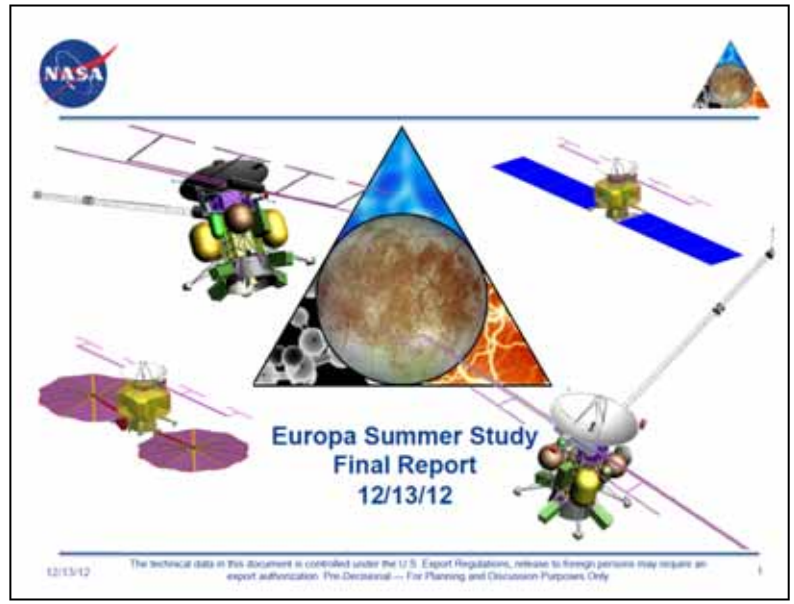
Pre-Project Payload Manager

Ken Klaasen

Payload System Engineering

Model Payload

- Europa Clipper instrument requirements and characteristics are based on a Model Payload derived from the work of a NASA-chartered Science Definition Team (SDT)
- The Model Payload consists of notional instruments that satisfy the Science and Reconnaissance Requirements and represent a high-TRL set of possible technical solutions.
- The Model Payload is employed to conduct accommodation studies in order to mature the spacecraft and mission design concepts within the project constraints



Notional Science and Reconnaissance Instrument Payload

- Seven science and two recon instruments
  - Five nadir pointed
    - Ice Penetrating Radar (IPR)
    - Topographical Imager (TI)
    - Short-wave IR Spectrometer (SWIRS)
    - Reconnaissance Camera (RC)
    - Thermal Imager (ThI)
  - One pointed in ram direction
    - Neutral Mass Spectrometer (NMS)
  - Two on booms
    - Magnetometer (MAG)
    - Langmuir Probe (LP)
  - Gravity Science Antenna (GSA) – trade study in process
- Blue text in following charts indicates changes since the December 2012 study report

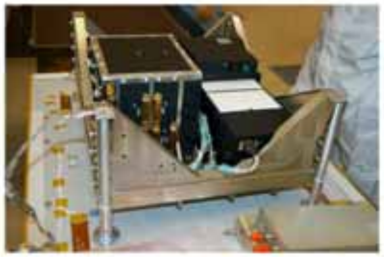
Payload to be selected by AO
Notional Payload provides guidance for Concept Design

Ice Penetrating Radar (IPR)

- **Primary Science Investigations**
  - Characterize distribution of shallow subsurface water and structure of ice shell
  - Search for an ice-ocean interface
  - Correlate surface features, subsurface structures, and geological processes
- **Measurement Requirements**
  - Shallow Mode: 10 m vertical resolution – surface to 100 m (required), 3 km depth (desired)
  - Deep Mode: 100 m vertical resolution - surface to 1 km (required), 30 km depth (desired)
  - Globally distributed intersecting and adjacent swaths, in 11 of 14 Europa "panels"
- **Supporting Requirements**
  - Nadir altimetry, 10 m vertical resolution
  - Cross-track surface topography (stereo imaging), 100 m vertical res
- **Configuration for Model Payload**
  - Dual-frequency sounder
    - 60 MHz with 10-MHz bandwidth (shallow)
    - 9 MHz with 1-MHz bandwidth (deep)
  - Deployed dipole antenna array on 15-m boom
  - Range compression, pre-summing, Doppler filtering, data averaging, resampling in IPR electronics (previously assumed performed in S/C CDH); requirements for raw data storage and transmission being developed

Similar instruments

Mars Express MARSIS



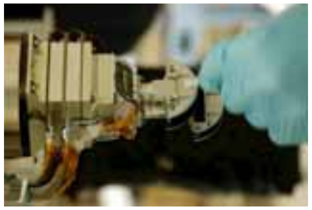
MRO SHARAD

Topographical Imager (TI)

- **Primary Science Investigations**
  - Removal of radar returns from off-nadir surface topography
  - Stereo imaging of landforms for geology
- **Measurement Requirements**
  - Spectral Range — visible
  - Spectral Bands — monochromatic
  - FOV — 58º (for stereo separation)
  - Image Width @ C/A — 100 km (matches width of radar swath)
  - Signal to Noise — ≥ 100
- **Configuration for Model Payload**
  - Pushbroom operation
  - Stereo obtained through along-track overlap with ~ 20 m vertical resolution
  - Image size — 4096x4096 pixels (was 2, 4096 line arrays)
  - Spatial Resolution — 25 m @ 100 km alt (250 µrad iFOV) (6.2 m @ 25 km alt)
  - SNR — ~100 @ 100 km alt (can increase to ~400 using TDI)
    ~27 @ 25 km alt (with TDI, can get up to ~100)
  - Exposure times — 5.5 ms for 1 pixel of smear @ 100 km alt
    1.4 ms for 1 pixel of smear @ 25 km alt
  - Radiation noise (% of pixels hit with electrons/1 cm Ta detector shielding): 0.5%

Similar instruments

MESSENGER MDIS



MRO MARCI

New Horizons Ralph/MVIC

ShortWave InfraRed Spectrometer
(SWIRS)

- **Primary Science Investigations**
  - Characterize surface composition for representative landforms
  - Characterize exogenic materials
- **Measurement Requirements**

– Spectral Range	850 nm – 5.0 μm
– Spectral Resolution	10 nm
– Spectral Channels	420
– Spatial Resolution	300 m @ 2000 km (IFOV = 150 μrad)
– Image Width	480 pixels (4.2º)
– Signal to Noise	~60 at 5 μm (1-s int), 10 at 5 μm (0.12-s int); better at shorter wavelengths

- **Configuration for Model Payload**
  - Implementation of ~4 scans for each flyby: 2 @ ≤10 km/pixel (5 min each) and ~2 @ ≤300 m/pixel (4.5 min total) (scan mirror, S/C is nadir pointing in current baseline (still investigating if S/C slewing required))
  - Single optic, single grating spectrometer & HgCdTe detector; TMC (scan mirror)
  - Passive detector and spectrometer cooling
  - Detector radiation noise: for 1-s integration, 4% pixels are hit with 9.5-cm tantalum shielding; for 0.12-s integration, 4% pixels are hit with ~3-cm Ta (calculation for worst case 0º inclination)

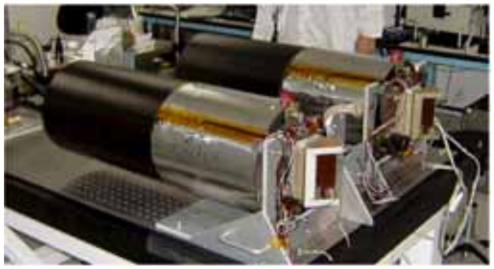
Similar instruments

Chandrayaan M^3

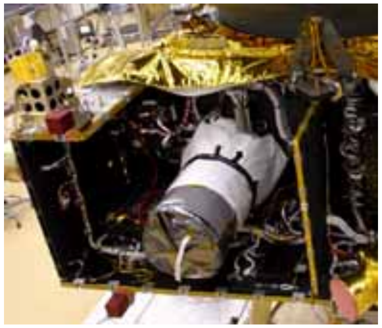
Reconnaissance Camera (RC)

- **Primary Science Investigations**
  - Potential future landing site characterization, geologic history, digital elevation maps, hazard assessment
- **Measurement Requirements**
  - ≤0.5 m/pixel resolution
  - 5×10 km areal coverage per site
  - Stereo
- **Configuration for Model Payload**
  - Pushbroom imager
  - 9216×128-pixel CCD array
  - IFOV = 10 μrad; cross-track FOV = 5.28º
    - 0.5 m/pixel; 4.6-km wide swath at 50-km flyby altitude
    - 111-μs integration time for 1 pixel of smear for 50-km flyby; 72 TDI lines
    - Panchromatic
  - Two-position flip mirror provides stereo views on a single pass
    - Viewing ~15º forward and aft for stereo
  - Resource/accommodation requirements
    - 13 kg (was 14), 20 W, up to 664 Mb/s (12-bit raw encoding, 3:1 compressed) for 25-km altitude flyby
    - Pointing requirements: 9 mrad control, 50 μrad/s stability, <4 μrad peak-to-peak jitter @ ≥50 Hz
    - Small radiator with view to dark space; minimize thruster contamination and MMRTG heating
    - Solar incidence angles between 20º and 80º; >45º preferred (70º ideal)
    - 1.5 Gb per stereo pair (compressed)

Similar instruments



LRO LROC

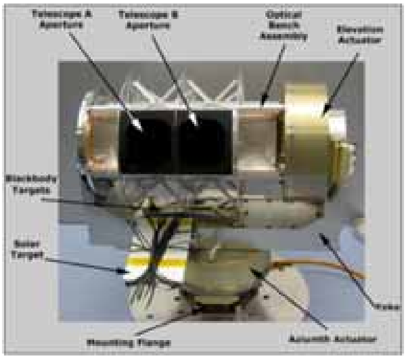


New Horizons LORRI

Thermal Imager (ThI)

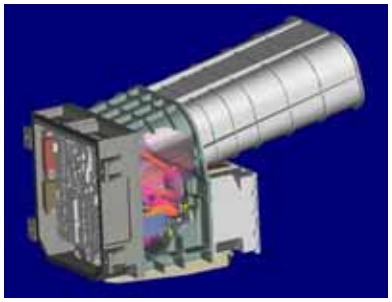
- **Primary Science Investigations**
  - Potential future landing site characterization, surface temperature, thermal inertia (rock abundance, particle cohesion), hot spot detection
- **Measurement Requirements**
  - <0.5K NEDT at 90 – 130K
  - ≤250 m/pixel resolution from 100-km range; lower resolution global/regional coverage also required
  - Include bolometric albedo measurement
  - Both day and night observations at a variety of local times are desired
- **Configuration for Model Payload**
  - Pushbroom imager
  - 40-pixel (was 21) wide thermopile array operating at room temperature
  - 2 spectral bands: 8-35 μm and 35-100 μm
  - 250-μm square pixels
  - IFOV = 2.5 mrad; cross-track FOV = 5.7º (was 3º)
    - 250 m/pixel at 100-km altitude; 10-km (was 5 km) wide swath
    - 56-ms integration time for 1 pixel of smear with 100-km flyby; meets NEDT requirement
    - Nadir viewing
  - Scan mirror to switch from nadir to space to internal blackbody target viewing
  - Resource/accommodation requirements
    - 7.2 kg, 11 W, 70 kbps at 25-km CA (was 9 kbps at 100 km) (12-bit raw encoding)
    - Relatively loose pointing requirements (10 mrad control; 0.65 mrad/s stability)
    - ~0.23 Gb (was 0.37) per flyby

Similar instruments



LRO Diviner

THEMIS



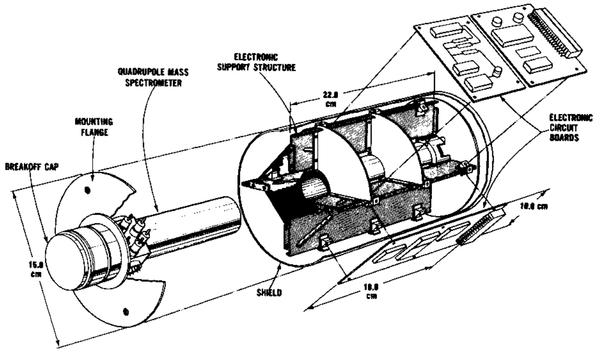
Neutral Mass Spectrometer (NMS)

- **Primary Science Investigations**
  - Elemental, isotopic and molecular composition of Europa's atmosphere and ionosphere
- **Measurement Requirements**

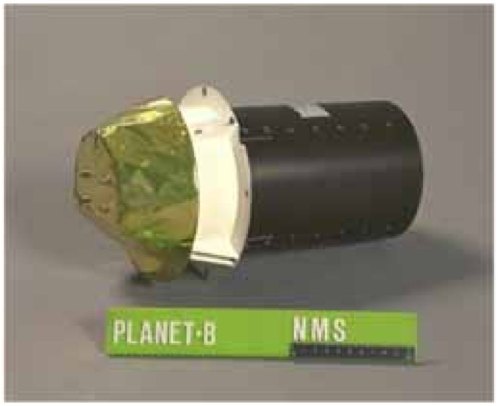
– Mass Range	1 – 150 Daltons
– Mass Resolution	200
– Sensitivity	10 particles/cm^3
– Field of View	Open source: 50 degree cone half angle;
	Closed source: ~2π sterradians

- **Configuration for Model Payload**
  - Heritage instruments need to be modified to extend the upper mass limit from 45 to 150 Da
    - Most likely requires a two-frequency RF and rod length increase in QMS with increase in mass and power of ~1 kg and 2 W
  - Secondary electron multiplier detector shielded by 0.5 cm of Ta (for addition of 0.75 kg)
  - Accommodation/ Resource requirements:
    - Ram pointed inlet and one-time opening cover on the ion-source
    - Assume the pre-amp board stays with sensor, and the rest of the electronics are accommodated in the science chassis
    - 6.8 kg (with 2 kg of shielding), 15 W, 1 Mbit per flyby

Similar instruments



Pioneer Venus Orbiter NMS

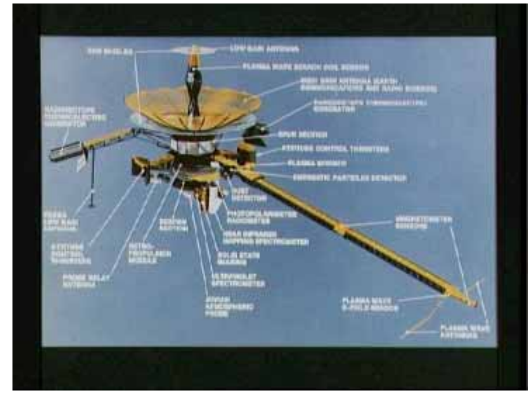


Nozomi NMS

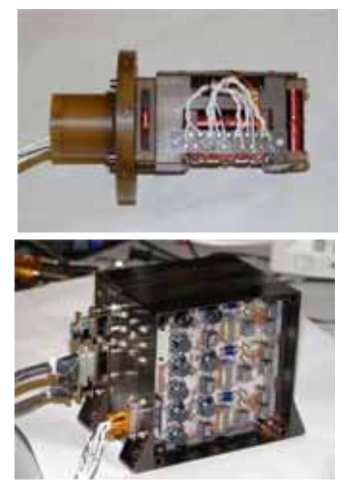
Magnetometer (MAG)

- **Primary Science Investigations**
  - Determine Europa's magnetic induction response to constrain salinity and ocean thickness
- **Measurement Requirements**
  - 3-axis magnetic field components at 8 vectors/s, sensitivity of 0.1 nT, near continuous operation
- **Configuration for Model Payload**
  - Dual 3-axis fluxgate
  - Sensitivity 0.1 nT
  - Intensity range of ±1024 nT (with goal of ±65,536 nT)
  - Maximum sampling rate of 32 Hz; sampling resolution of 0.01 nT
  - Accommodation/Resource requirements:
    - Sensors on boom 6.5 m and 10 m from S/C
    - Spacecraft cleanliness of ≤1 nT static and ≤0.25 nT variable at inboard sensor (was 0.1 nT desired, 0.5 nT required at outboard sensor)
    - Periodic S/C slow spins about two orthogonal axes for calibration
    - 1.6 kg (was 3.3 kg) (not incl. boom); 4 W; 0.1 Gb per 21-day orbit (was 1.8 Gb per 14-day orbit)

Similar instruments



Galileo MAG



MESSENGER MAG

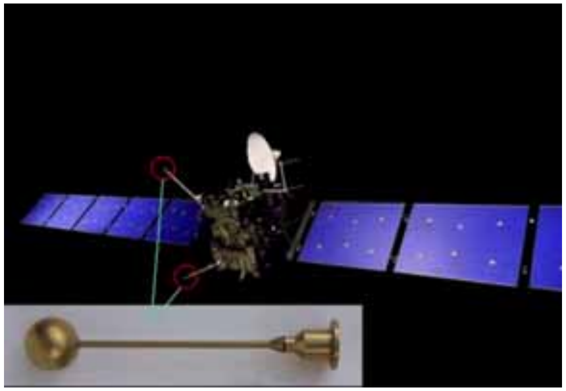
Langmuir Probes (LP)

- **Primary Science Investigations**
  - Characterize the local plasma density, temperature and flow to constrain (in conjunction with modeling) the contribution from currents not related to the surface and ocean

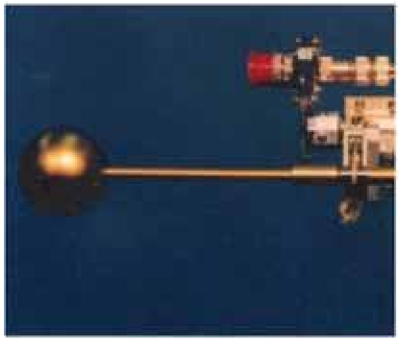
- **Measurement Requirements**
  - Local plasma density, temperature, and flow
  - Electric field vectors (near DC to 3 MHz)
  - Electron temperature
  - Ion currents
  - 4π coverage

- **Configuration for Model Payload**
  - Double 5-cm diameter spheres mounted on 1-m long booms
  - Shielded pre-amps <3 m from sensors
  - Remaining electronics in S/C vault
  - Accommodation/ Resource requirements:
    - Booms pointed >90º from each other, desire one always free of S/C wake
    - EMI/EMC cleanliness *a la* Rosetta and/or Cassini
    - 3 kg (was 4.7 kg) (incl. booms), 2.3 W, 1.2 Gb per 21-day orbit (was 0.9 Gb per 14-day orbit)

Similar instruments



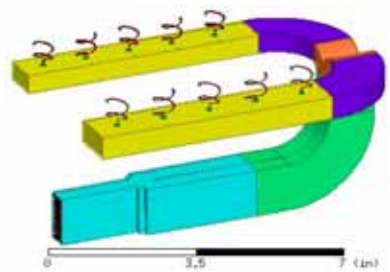
Rosetta LAP



Cassini RPWS

Gravity Science (GS)

- **Primary Science Investigations**
  - Europa's gravitational tides
- **Measurement Requirements**
  - Degree-two time-dependent gravity field, to recover k_2 amplitude at Europa's orbital frequency to ≤0.05 absolute accuracy



- **Configuration for Model Payload**
  - Baseline was two dedicated 2-axis gimbaled science antennas
  - Currently evaluating simpler methods to meet the gravity science requirement
    1. Using the existing RF fan beam antenna for gravity science (presently used for cruise phase communications)
       - Doesn't meet requirements
    2. Adding a single axis gimbal to the fan beam antenna
    3. Arraying the 34m ground stations for additional gain
    4. Adding a second fixed fan beam antennas for greater coverage during each pass
    5. Adding a two axis gimbal
  - Accommodation/ Resource requirements
    - Continuous Doppler tracking within18 Europa radii (was ±2 hours from C/A)
    - Range-rate to <0.1 mm/s at 60-s integration time
    - S/C orbit determination about Europa to accuracy of <1 m (rms) in the radial direction

Model Payload Resource Summary

Instrument	Unshielded Mass (kg)	Shielding Mass (kg)	Total CBE Mass (kg)	CBE Power (W)	Data Volume (Gb/flyby)	Comments
Ice Penetrating Radar (IPR)	28.2	5	33.2	55	23.5 (was 25.2)	Bringing down data between ± 1000 km
Topographical Imager (TI)	2.5	1.5 (was 4.5)	4 (was 7)	5.9	4.8 (was 3.1)	3:1 lossy compression; each additional 4 k x 4 k image is 0.07 Gbit compressed
ShortWave IR Spectrometer (SWIRS)	12.9 (was 12.6)	5.9 (was 9.1)	18.8 (was 20.7)	19.1	0.53 (was 1.3)	3:1 lossy compression; 2 full disk scans on approach; 2 full images during flyby
Reconnaissance Camera (RC)	11.1	2	13.1	20	up to 26.5 (was 25)	Data volume varies with flyby altitude; max for 25-km flyby
Thermal Imager (ThI)	5.9	1.3	7.2	11	0.23 (was 0.37)	Operating for ~8 hr/flyby
Neutral Mass Spectrometer (NMS)	4.8	2	6.8	15	0.001	3 Kbps rate, acquiring data between ±1000 km from surface
Magnetometer (MAG)	1.6	0	1.6	4	0.1 (was 1.8)	Operates continuously; increased sample rate E±2 hr
Langmuir Probe (LP)	2.6	0.4	3	2.3	1.2	Operates continuously
Totals:	69.6	18.1	87.7	132.3	56.9	

Key Payload Driving Requirements (1 of 2)

- Payload mass: 88 kg (was 93) (not including remote electronics chassis and shielding, MAG boom, or GSA)
- Payload operating power: 132 W (was 233) (total all instruments, not including GSA)
- Payload energy: 754 W-h (was 950) per 8-hr flyby (not including GSA)
- Payload mounting:
  - >5000 cm^2 on nadir-facing deck
    - Clear FOV of ±74°crosstrack and ±90°along track
    - Radiator views to dark space
  - 15-m wide deployable dipole antenna parallel to X axis (cross-track)
    - 4 2.5-m prongs in +Y direction (nadir)
  - 10-m long MAG boom
  - 2 1-m LP booms; at least 1 sensor clear of S/C-induced plasma wake in all directions
  - NMS 2π-sr clear FOV in +Z direction (~ram)
  - Maximize time of GSA clear view to Earth within 18 Europa radii

Key Payload Driving Requirements (2 of 2)

- Pointing
  - Track nadir throughout 25-km altitude flyby
  - Control: 7 mrad S/C, 0.5º GSA
  - Stability: 25 µrad/s (was 30)
  - Jitter @ ≥50 Hz: <4 µrad peak-to-peak
  - Relative knowledge: 150 µrad over 60s, 10 µrad over 4 s
  - Absolute knowledge: 0.7 mrad (was 0.15) body-mounted; 1.7 mrad for MAG sensors
- Data
  - Peak rate out of instrument: 25 Mbps IPR (processed) (was 130 Mbps raw); up to 1991 (raw) Mbps Recon Camera; 71 Mbps (raw) Topo Imager
  - Volume per flyby: 57 Gb (was 60)
- Remote electronics boards ≥22 (including 3 spares)
- EMI/EMC/Magnetically-clean S/C ala Cassini/Rosetta/Juno

Ice Penetrating Radar
Key Requirements & Accommodations

- Key Requirements
  - Mechanical
    - Deployment volume and orientation
      - 15-meter-wide antenna on boom
      - Co-alignment beam pattern with TI and SWIRS
    - Beam pattern shape, stability, and consistency for multiple flybys
  - Processed data rate & data volume:
    - Data rate ~ 24.5 Mb/s
    - Max volume: ~ 23.5 Gb / flyby
  - Observation tracks
    - Achieve 1600-km-long ground track below 1000 km altitude at ground speed < 6 km/s (with CA below 100 km)
    - Achieve 800-km-long ground track below 400 km altitude at ground speed < 6 km/s (with CA below 100 km) in 8 of 14 panels
      - Min. 2 tracks in each sub-Jovian panels and
      - Min. 3 tracks in each anti-Jovian panel
    - Each ground track shall intersect another ground track (across panels acceptable)

- Specific Accommodations
  - Large deployed antenna drives S/C layout implementation
    - Avoid intrusion into FOV and FOR of other instruments and sensors.
    - Antenna aligned to view in Y axis (nadir direction)
    - Minimize impact and variability of antenna beam pattern
  - Data handling
    - High-speed data interface (TBD) and/or instrument data buffering
    - Data processing/compression to accommodate current downlink budget (TBD)
  - Largest instrument power load
    - 55 Watts operational

Topographic Imager
Key Requirements & Accommodations

- Key Requirements
  - Mechanical layout
    - Nadir oriented / clear field of view (FOV) ±29°
    - Stray light keep out zone: FOV ±45°
  - Attitude stability
    - Absolute attitude knowledge: 10 mrad
    - Stability: 7 mrad/s and 250 μrad over 1 min
  - Attitude control
    - Control 100 mrad (3σ)
    - Co-alignment with:
      - SWIRS to TBD μrad
      - Thermal Imager to TBD μrad
      - Ice Penetrating Radar to TBD μrad
      - Recon to TBD μrad
  - Observations altitudes
    - Stereo imaging w/ recon at altitude <50 km
    - Stereo imaging w/ IPR at altitude <1000 km
    - Mono imaging at 4000 > altitude > 1000 km
  - Regional coverage: >25% coverage of Europa, w/stereo at altitude < 1000 km
  - Global coverage: >70% coverage of Europa
  - Solar angles:
    - Required incidence angle: 20° ≤ SIA ≤ 80°
    - Goal incidence angle: 45° ≤ SIA ≤ 70°
    - Solar phase angle: ≤ 135°

- Specific Accommodations
  - Instrument Deck
    - Stable thermo-mechanical interface to spacecraft
  - Attitude requirements enveloped by other instrument requirements
  - On-orbit calibration to Spacecraft attitude reference using stars in instrument FOV
  - Co-alignment
    - Thermo-mechanical interface stability between co-boresighted sensors
    - On-orbit co-alignment calibration to other co-boresighted optical sensors

SWIRS Measurements
Key Requirements & Accommodations

- Key Requirements
  - Mechanical layout
    - – Nadir oriented / clear field of regard:
      - 4.1º cross-track (spatial axis orientation)
      - ±45º along-track (FOR)
    - – Straylight keep-out zone goal:
      - FOV ±45º cross-track
      - FOR ±45º along-track
    - – Clear FOV for instrument radiator
  - Attitude stability
    - – Absolute attitude knowledge: 700 μrad (3σ)
    - – Stability: 25 μrad/s, 150 μrad/min (3σ)
  - Attitude control
    - – Control: 7 mrad (3σ)
    - – Co-alignment with:
      - Topographic Imager to TBD μrad
      - Recon Camera to TBD μrad
      - Thermal Imager to TBD μrad
  - Inbound and outbound observations
    - – 66,000 km to 2000 km (global / regional coverage)
    - – <2000 km (hi-res coverage)
    - – Local true solar time 9AM to 3PM

- Specific Accommodations
  - Instrument Deck
    - – Stable thermo-mechanical interface to spacecraft
    - – SWIRS 80K detector and 130K optics co-located with relatively warm TI, RC, and Th-I
  - Large field of regard
    - – Desired along-track straylight keep-out zone not currently satisfied (25º achieved vs. 45º desired) in current configuration layout
  - Spacecraft attitude knowledge and control
    - – Most stringent payload requirements for attitude knowledge and control
    - – Stringent attitude stability requirement
  - Placement on instrument deck to minimize radiator views of spacecraft (and solar array)
  - On-orbit calibration to spacecraft attitude reference using stars in SWIRS FOV
  - Co-alignment
    - – Thermo-mechanical interface stability between co-boresight sensors
    - – On-orbit co-alignment calibration

Recon Imager Measurements
Key Requirements & Accommodations

- Key Requirements
  - Mechanical layout
    - Nadir oriented / clear field of regard:
      - FOV ±2.6º cross-track, FOV ±0.0003º along-track
      - FOR ±15º along-track
    - Straylight keep-out zone:
      - FOV ±45º cross-track, FOR ±45º along-track
  - Attitude stability
    - Absolute attitude knowledge: 900 μrad (3σ)
    - Stability: 10 μrad over 4 seconds
    - Jitter: <4 μrad peak-to-peak @ ≥50 Hz
  - Attitude control: 9 mrad (3σ)
    - Co-alignment with:
      - Topographic Camera to TBD μrad
      - SWIRS to TBD μrad
      - Thermal Imager to TBD μrad
  - Observations at altitudes <50 km
  - Solar incidence angles (SIA) :
    - Required: 20º ≤ SIA ≤ 80º
    - Goal: 45º ≤ SIA ≤ 70º
  - Raw data rate & raw data volume:
    - Data rate: up to ~1.9 Gb/s
    - Max volume: ~26.5 Gb/flyby

- Specific Accommodations
  - Instrument deck
    - Stable thermo-mechanical interface to spacecraft
    - Relatively large optical system at minimum temperature of 0ºC located on thermally isolated optical bench
  - On-orbit calibration to Spacecraft attitude reference using stars in instrument FOV
  - Spacecraft dynamics
    - Most stringent payload requirements for attitude jitter
  - Co-alignment
    - Thermo-mechanical interface stability between co-boresight sensors
    - On-orbit co-alignment calibration
  - Data handling
    - High speed data interface (TBD) and/or instrument data buffering
    - Data compression to accommodate current downlink budget (TBD)
  - Energy: 170 W-hr/flyby
    - Largest payload energy consumer on per flyby basis (excluding gravity science)

Thermal Imager Measurements

Key Requirements & Accommodations

- Key Requirements
  - Mechanical layout
    - Nadir oriented / clear field of regard:
      - ±2.85° cross-track , ±0.07° along-track
    - Straylight keep-out zone:
      - FOV ±45°
  - Attitude stability
    - Absolute knowledge: 2.5 mrad (3σ)
  - Attitude control
    - Control: 10 mrad (3σ)
    - Stability: 0.65 mrad/s
    - Co-Alignment with:
      - Recon Camera to TBD μrad
      - SWIRS to TBD μrad
      - Ice Penetrating Radar
  - Observations
    - All altitudes <60,000 km
  - Solar angles (local time):
    - 10AM to 3PM for observing coincident with Recon Camera at altitudes <50 km
    - Pre-dawn (3AM to 6AM) of recon site with altitudes <6000 km

- Specific Accommodations
  - Instrument Deck
    - Stable thermo-mechanical interface to spacecraft
  - Attitude requirements enveloped by other instrument requirements
  - On-orbit calibration to spacecraft attitude reference using stars in instrument FOV
  - Co-alignment
    - Thermo-mechanical interface stability between co-boresight sensors
    - On orbit co-alignment calibration

NMS Measurements
Key Requirements & Accommodations

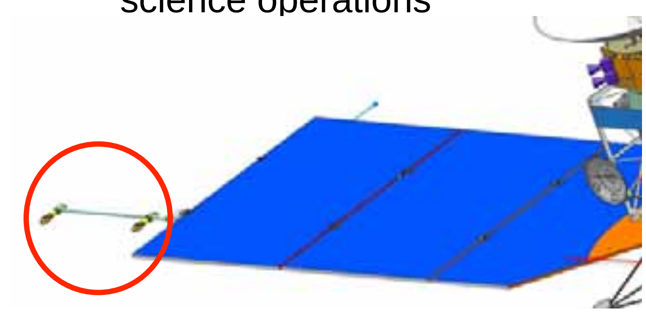
- Key Requirements
  - Mechanical layout
    - RAM-oriented during measurements w/ nearly unobstructed field of view
    - Goal of no spacecraft obscuration in the 2π sr (hemisphere) above aperture plane
  - Velocity: <7 km/s
  - Flyby altitudes: <200 km
    - Goal of altitude at CA of 25 km

- Specific Accommodations
  - Mounting on the communications high-gain antenna (view of +Z hemisphere)
    - Layout avoids obscuration
      - Competes with telecom LGA and MGA for clear FOV
    - Risk that instrument mass increase may drive structural design of HGA or force relocation
  - NMS mounted with conical FOV centered about the +Z axis
    - Z axis oriented RAM ±24° below 200 km
  - Max local velocities : <4.7 km sec
  - Un-shaded from solar illumination during Venus flyby

Magnetic Field Measurements
Key Requirements & Accommodations

- Key Requirements
  - Magnetic cleanliness (at inboard sensor)
    - Static Field: ≤1.0 nT
    - Variable Field: ≤0.25 nT
  - Continuous operation to permit separating Jupiter rotational period and Europa orbital period
    - High-rate data sampling within 18 Europa radii
  - Attitude knowledge (reconstructed) to 0.1 degree achieved with combination of factors:
    - Sensor stability on boom <0.75º (3σ)
    - NOTE: *MAG boom absolute pointing knowledge accuracy to 0.1° within 2 Europa radii is achieved with a knowledge accuracy of <1.0° and the use of regular inflight MAG calibration rolls*

- Specific Accommodations
  - Magnetic cleanliness program
    - Electrical design & components
      - Magnetic compensation
      - Harness wiring and routing
    - Materials selection
  - Deployable boom
    - Influences S/C mass and layout
  - Solar configuration
    - SA wiring and harnessing
    - SA maintains fixed position during science operations

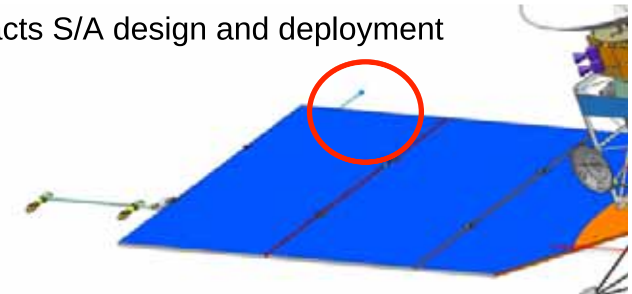


  - Calibration maneuver by spacecraft
    - Two orthogonal axis rotations of vehicle

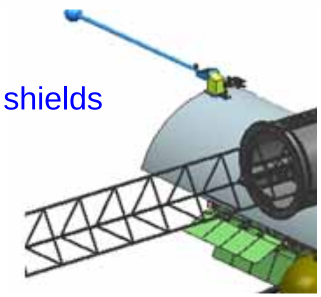
Langmuir Probe Measurements
Key Requirements & Accommodations

- Key Requirements
  - Sampling during flybys
    - CA altitudes <100 km
    - Local time daylight sampling
      - 6AM to 12PM and/or 12PM to 6PM
  - Mechanical
    - FOV 4π sr from combined pair
    - Deployed such that at least one of the paired sensors is clear of Spacecraft wake (with 15^{o} margin)
    - Booms deployed to provide $>90^{o}$ angular separation from each other
  - EMI/EMC
    - Plasma measurements sensitive to surface charging and differential charging

- Specific Accommodations
  - Spacecraft provides deployment mechanism and actuation
  - Solar array accommodation
    - One on each SA
    - Impacts S/A design and deployment



  - MMRTG Accommodation
    - On MMRTG thermal shields



  - Spacecraft bonding and surface charge control program
    - Solar array surface coating - reduces efficiency
    - Harness shielding, surface grounding and bonding

Gravity Science Measurements

Key Requirements & Accommodations

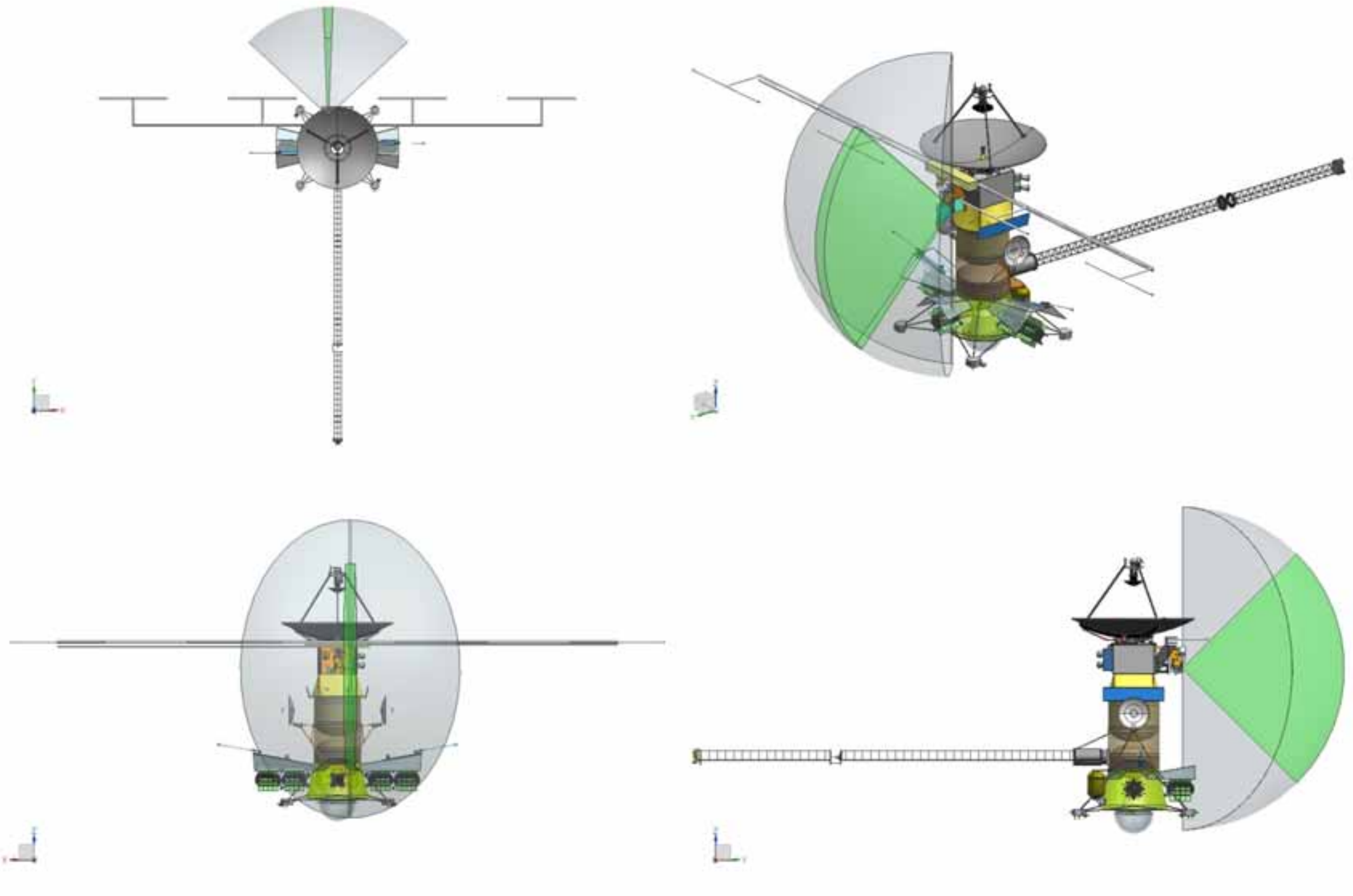
- Key Requirements
  - Continuous Doppler tracking within 18 Europa radii
    - NOTE: SC attitude constrained by nadir viewing payloads and RAM orientation during flybys
    - X-up / X-down baseline
  - Trajectory
    - Low altitude passes
      - <100 km
    - Measurement opportunities will avoid solar conjunction
    - Measurements required:
      - Various options being considered

- Specific Accommodations
  - A medium gain, x-band fan beam antenna configuration is under evaluation
  - Dedicated gravity science flybys may be considered if conceptual design doesn't close

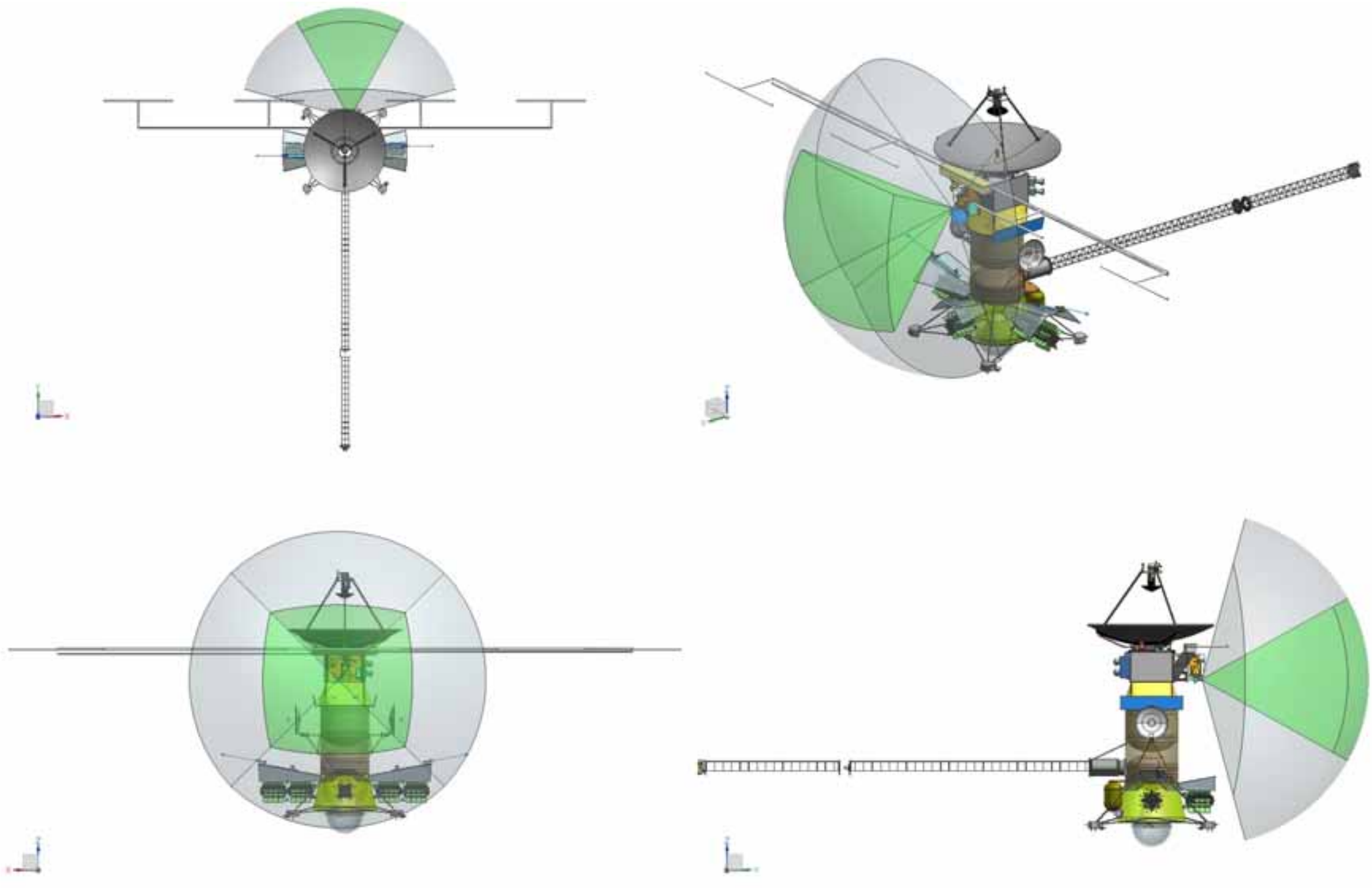
Fields of View Accommodation

Instrument	Cross-Track					Along-Track				
	FOV	FOR	Design Buffer	Target Keep-Out	Currently Achieved	FOV	FOR	Design Buffer	Target Keep-Out	Currently Achieved
	(º)	(º)	(º)	(º)	(º)	(º)	(º)	(º)	(º)	(º)
SWIRS	4.2 (±2.1)	N/A	±45	±47	±59.5	0.001	±45	±25 ±45 goal	±70 ±90 goal	±70
TI	58 (±29)	N/A	±25 ±45 goal	±54 ±74 goal	±59.5	58 (±29)	N/A	±45	±74	±75
Recon	5.3 (±2.7)	N/A	±45	±47.5	±59.5	0.004	±15	±45	±60	±60
Th-I	5.7 (±2.9)	N/A	±45	±47.9	±59.5	0.14	N/A	±45	±45	+50 -70
NMS	±90	N/A	N/A	2π sr	2π sr	±90	N/A	N/A	2π sr	2π sr
IPR	12	Beam Pattern Analysis Acceptable				22	Beam Pattern Analysis Acceptable			

SWIRS FOR and Straylight Buffer

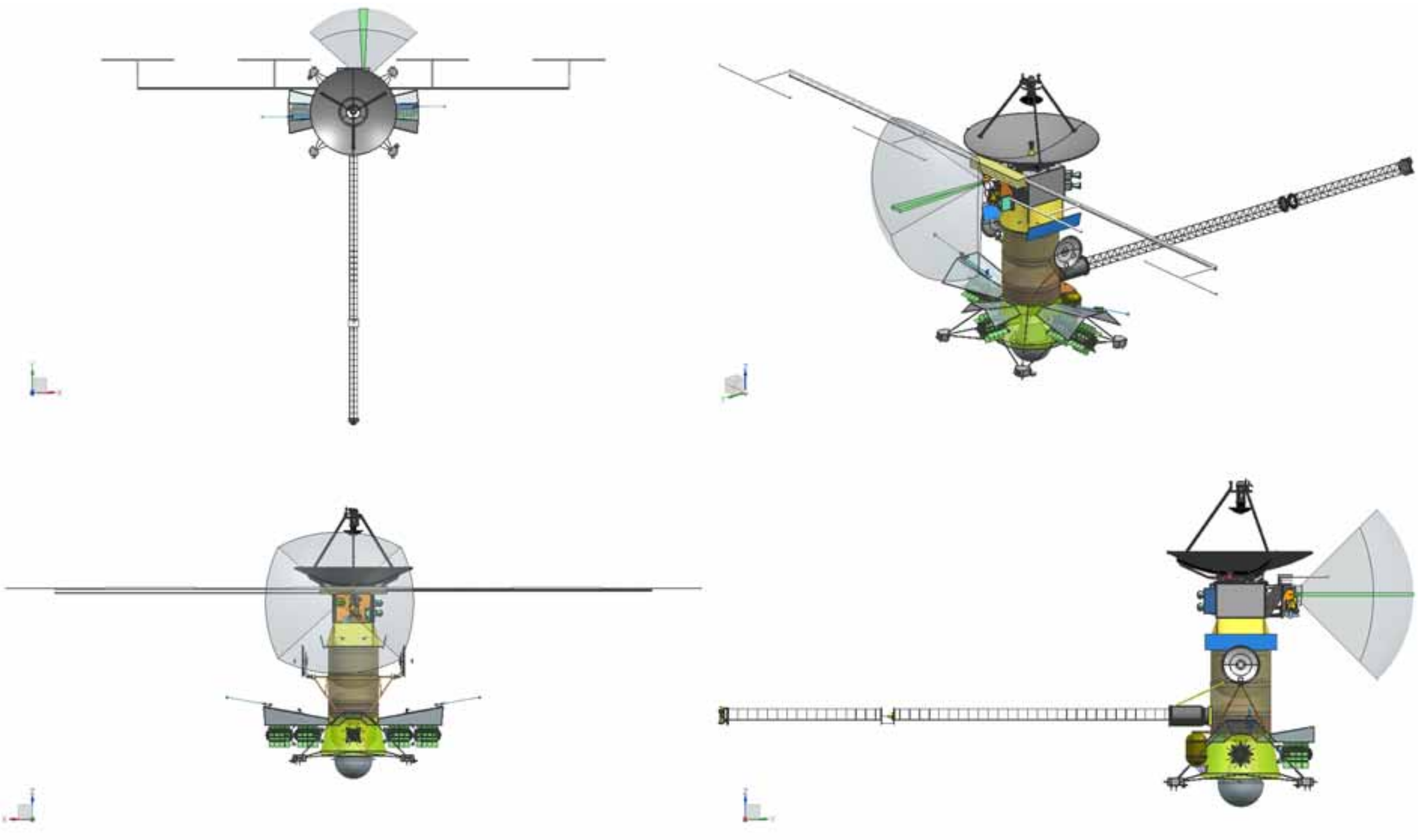


Topo Imager FOV and Straylight Buffer



Recon Imager FOR and Straylight Buffer

Thermal Imager FOV and Straylight Buffer



Data Assumptions

Instrument	Baseline Required			Science Data Interface
	Max Raw Data rate	Uncompressed Data Volume per flyby	Assume Storage Required Volume per flyby	
Recon camera	1991 Mb/s	79.5 Gb	26.5 Gb	**Instrument Specific** or Any Standard Interface
Ice Penetrating Radar	25.2 Mb/s*	24.2 Gb	24.2 Gb	Standard High Speed I/F
Topographical Imager	71 Mb/s	14.5 Gb	4.8 Gb	Standard High Speed I/F
Shortwave Infrared Spectrometer	2.4 Mb/s	1.6 Gb	0.53 Gb	Standard High Speed I/F
Thermal Imager	70 kb/s	0.03 Gb	0.23 Gb	Any Standard Interface
Magnetometer	4 kb/s	0.1 Gb	1.8 Gb	Any Standard Interface
Neutral Mass Spectrometer	3 kb/s	0.003 Gb	0.001 Gb	Any Standard Interface
Engineering Telemetry	2.3 kb/s	0.14 Gb	0.93 Gb	Any Standard Interface
Langmuir Probe	2 kb/s	3.6 Gb	1.2 Gb	Any Standard Interface
Total		~ 124 Gb	~ 60 Gb	

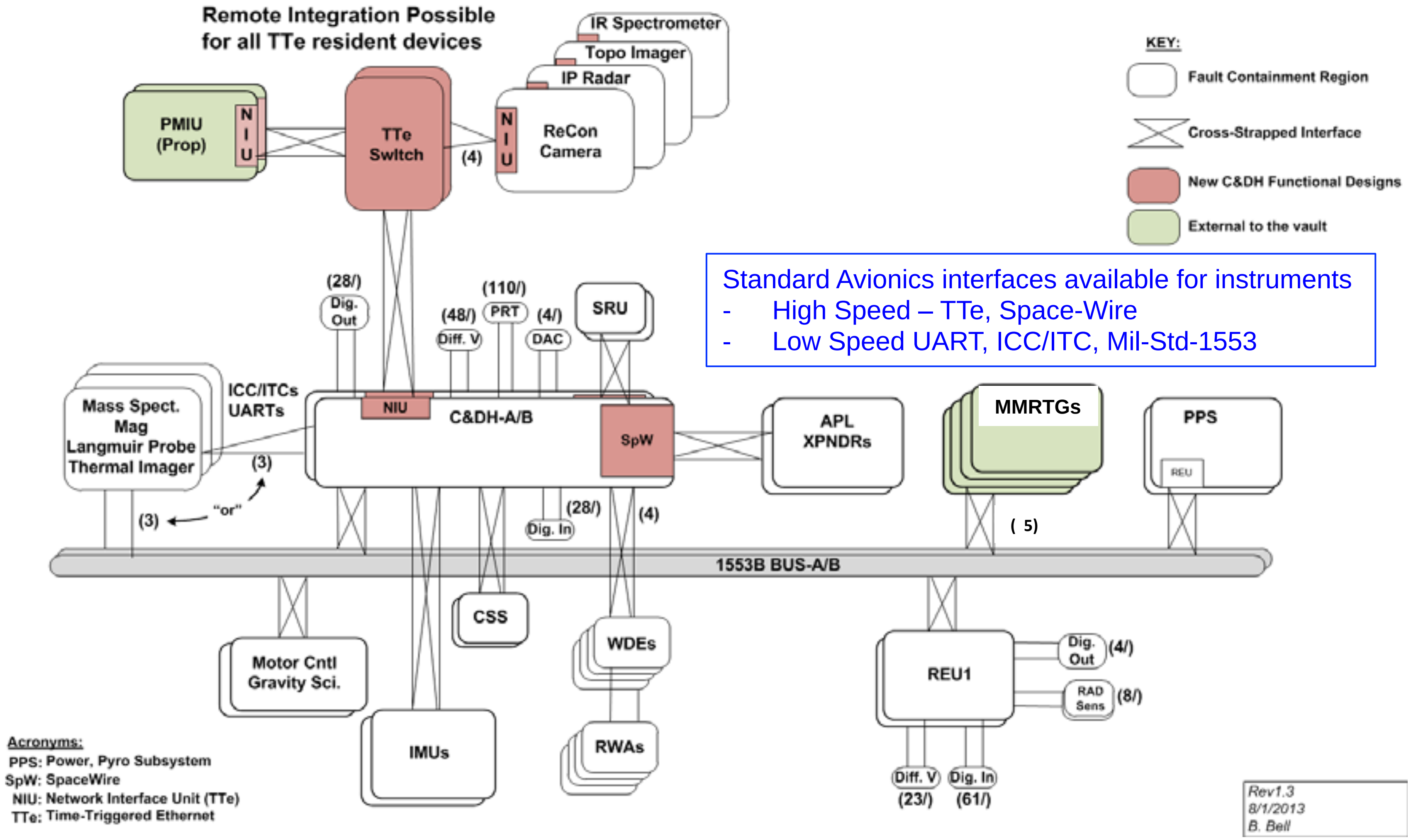
*processed; raw data requirements being developed

- Recon Camera will require either:
  1. Instrument buffering in order to reduce instantaneous data rate to be compatible with a Standard Avionics Interface

     --- or ---
  2. Avionics will require a instrument unique interface for Recon Camera

CDH Architecture & Implementation

- Europa C&DH Context Diagram



Standard Avionics interfaces available for instruments
- High Speed – TTe, Space-Wire
- Low Speed UART, ICC/ITC, Mil-Std-1553

Candidate Interfaces

- Instruments are free to propose against the following 5 interface types:
  - Time Triggered Ethernet (TTe) <1 Gb/s
  - ICC/ITC <8 Mb/s
  - UART <2 Mb/s
  - Mil-STD-1553B <1 Mb/s
  - SpaceWire <400 Mb/s

- High Level Guideline: Instruments can propose to be hosted on an interface that operates over a range that meets or exceeds the throughput requirements for that instrument
  - Only one interface per instrument will be supported for science, command and telemetry

Notional Optical Payload Thermal Parameters

(Does not include 125 C Planetary Protection Soak)

	Thermal					Comments	
	Power (On)	Power (Standby)	Survival	Operational Temp Limits	Non-operational Temp Limits	Heritage	Comments
Instruments							
SWIRS						Chandrayaan MMM	One-time-deployed or reclosable cover for contamination,initial release controlled by SC
SWIRS Optics (< 130°K)				-160 C to -143 C	-170 C to 60 C		
SWIRS Detector (< 80°K)	5.57	3.75	3.00	-213 C to -193 C	-213 C to 60 C		
SWIRS local electronics				-30 C to +60 C	-40 C to +70 C		
TI						Mess MDIS	One-time-deployed or reclosable cover for contamination,initial release controlled by SC
Topographical Optics/stucture				0 C to 30 C	-40 to 60		
Topo Detector WAC CMOS	2.10	1.20	1.20	-110 C to -80C	-140 C to 60 C		
Topo local electronics				-30 C to +60 C	-40 C to +70 C		
IPR						MRO MARSIS	
Antenna House Structure				TBD	TBD		Does the IPR need a pre-deploy heater?
IPR Antenna(4 element)							
IPR HCIPE Transmitter Elx	20.00	3.00	3.00	-30 C to +60 C	-40 C to +70 C		Located at base of antenna
IPR Sensor	5.00	2.00	2.00	TBD	TBD		
Reconnaissance Camera (RC)						LORRI, LROC	One-time-deployed or reclosable cover for contamination,initial release controlled by SC
RC Detector				-110 C to -80C	-140 C to 60 C		
RC optics/telescope	13.00	10.00	4.00	0 to 40C	-20 to 50C		
RC local electronics				-30 C to +60 C	-40 C to +70 C		
Thermal Imager						MRO MCS; LRO Diviner;	Rotating baffle mirror mechanism (controlled by instrument)
Telescope				-20 Cto +40 C	-20 Cto +40 C		
Detector electronics	7.00	3.00	3.00				
Calibration system				0 C to +50C			Controlled by internal instrument heaters

Open Studies/Analysis

- Verification that the 13F7 trajectory meets science and reconnaissance requirements
- Analysis of whether the S/C needs to provide a slow scanning mode on approach and departure to support SWIRS, Topo Imager, and Thermal Imager observing
- SWIRS design optimization considering recon site observation requirements
- Recon Camera, Topo Imager, and IPR data I/F rate and storage volume
- Instrument versus S/C-provided data compression/editing
- Instrument radiator FOV and cover deployment provisions
- MAG pointing reconstruction knowledge implementation
- Shared shielded science chassis vs. separate shielded electronics for each instrument
- Instrument operational and survival temperature limits
- Instrument inflight calibration requirements
- Gravity Science Trade

Mission Assurance Considerations

Genji Arakaki

Pre-Project Mission Assurance Manager

Agenda

- General Mission Assurance Requirements
- Mission Assurance Documentation
- Driving Environmental Requirements
- Preferred Parts List (as opposed to Approved Parts List)
- Risk reduction tasks and other information

General Mission Assurance Requirements

- Level 1, Class A Mission
  - Full Mission Assurance process, minimal tailoring
    - Discussions with instrument providers for special cases
  - Reliability Requirements
    - Worst Case Analysis (WCA), including radiation effects
    - Single Event Effects Analyses (SEEA)
  - Parts Requirements
    - Level 1 (Class "S") parts
  - Environmental Requirements (See following pages)

Driving Environmental Requirements

- Europa Clipper Mission Presents a Unique (and Driving) Set of Environmental Requirements
  - Radiation
    - Project Policy requires a Radiation Design Margin (RDM) of 2
    - GIRE-2 radiation model predicts a 2.84 MRad Ionizing Dose behind 0.100 inch of Aluminum (Spherical Shell)
    - Single Event Effects (SEE) shall be analyzed
  - Radiation approach
    - Approach for flight systems has majority of electronics in a “Vault”
      - Modeling indicates vault walls will be ~0.37” thick aluminum
      - Goal is to get the radiation dose in the vault down to 150 Krad
    - Instrument electronics envisioned to be accommodated in vault, with detector/ proximity electronics in separate shielded enclosures external to vault
  - Document development schedule
    - Preliminary Environmental Description Document (available Dec. 2013)
    - Preliminary Environmental Requirements Document (with test levels, available Mar. 2014

Other Driving Environmental Requirements

- Radiation effects and challenges on sensors
  - Parametric degradation due to Displacement Damage dose
    - Example degradation issue: Hot pixels/Dark signal non-uniformity in focal plane arrays
  - Transient noise due to penetrating electrons and protons
    - Likely to be a key driver for instrument design strategies related to shielding, sensor operation, data processing, and flight software
- External Charging Environment (Plasma)
  - Surface potentials can lead to differential charging that can cause surface arcs and distort plasma measurements
- Internal ElectroStatic Discharge (IESD)
  - IESD is of particular concern as it can cause electrostatic discharge internal to the spacecraft shielding and Faraday cage protection systems.
  - See NASA Guideline 4002A for mitigations

Other Driving Environmental Requirements (con't)

- Thermal environment
  - Solar input at 0.65 AU (Venus gravity assist)
  - Eclipse at Jupiter (up to 4.5 hours)
- Launch dynamics (Atlas V, SLS)
  - Acoustics
  - Random vibration
- EMI/EMC
  - Radar source
  - Magnetic cleanliness

Preferred Parts List

- A Preferred Parts List (PPL) will be developed for the Europa project
  - Will consist of electronic parts which have been verified to survive TID of 300 Krad (with RDM of 2)
    - May also include specific electronic parts that survive to 100 Krad with known or tested characterization to 300 KRad
  - Not an Approved Parts List
    - Will still require parts review for reliability and radiation – will contain criteria for design limits as appropriate
    - Intended as a recommended list for design guidance designs
  - Parts Program Requirements development schedule
    - Initial draft available: Feb. 2014
    - Final release available: Mar. 2014

MA Risk Reduction Tasks

- Several Risk Reduction Tasks may be of Interest
  – Field Programmable Gate Array (FPGA) radiation effects
  – Volatile (SDRAM) memory radiation effects
  – Non-Volatile (Flash) memory radiation effects
- ASIC vs. FPGA guidelines will be developed
  – High TID response due to latest foundry processes potentially enables either option
  – Document development schedule
    - Initial draft available: Feb. 2014
    - Final release available: Mar. 2014

13F7-A21 Trajectory Overview

Brent Buffington, Ralph Roncoli
Mission Design and Navigation

Mission Design Goals

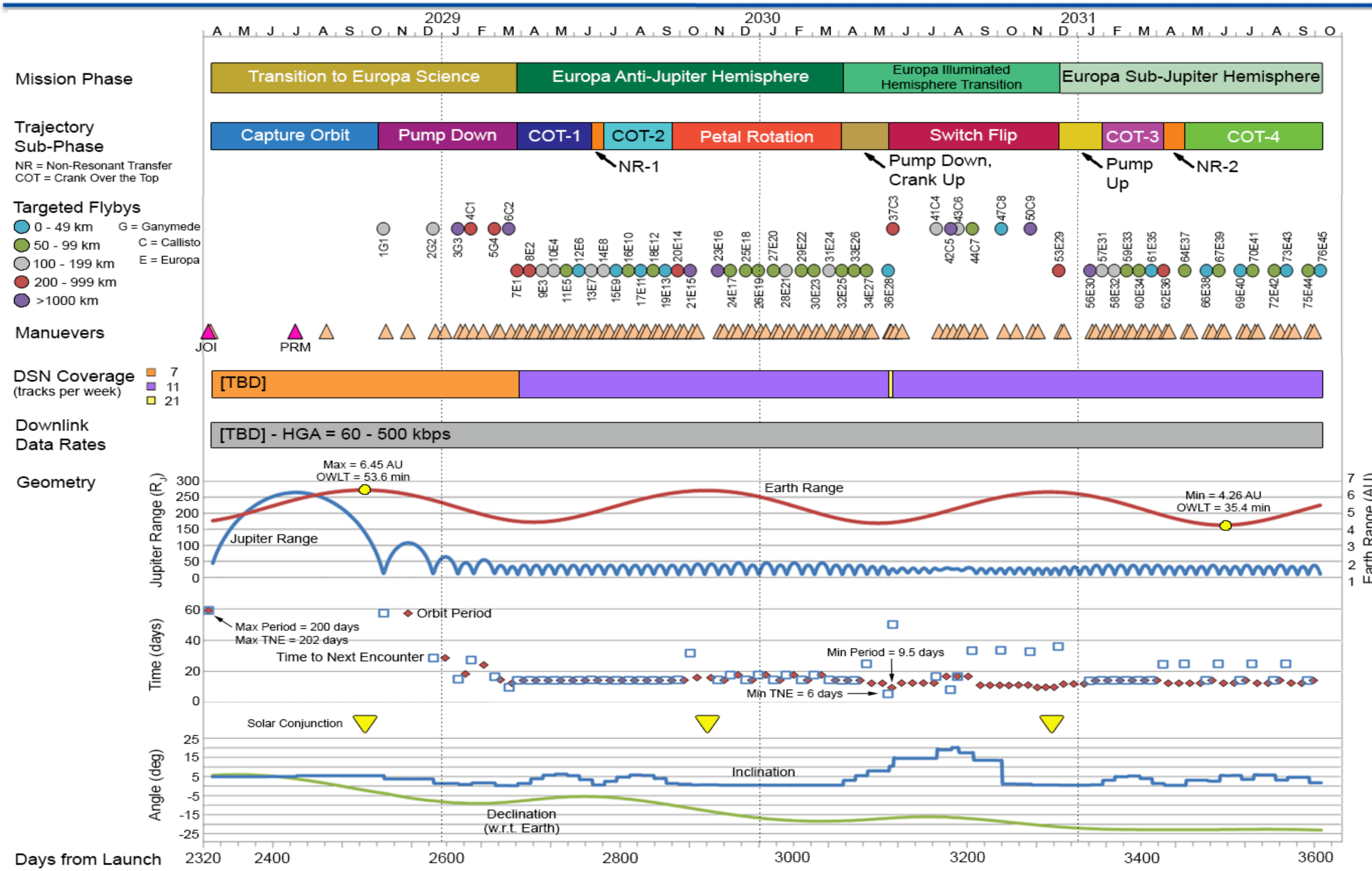
- Maximize science return
- Minimize:
  - ΔV
  - Total ionized dose (TID)
  - Time-of-flight
- Adhere to ground system and spacecraft operational constraints
  - Navigational feasibility
  - Solar conjunctions
  - Time between key events
  - Data downlink margins

13F7-A21 Summary

- Tour duration: 3.5 years
- Number of targeted flybys:
  - Europa: 45
  - Ganymede: 5
  - Callisto: 9
- Time between flybys:
  - Max: 50 days
  - Mean: 5.5 days
  - Min: 18.3 days
- ΔV:
  - JOI: 837 m/s
  - PRM: 121 m/s
  - Tour: 370 m/s [Deterministic: 150 m/s, Statistical (99%): 220 m/s]
- Maximum Inclination: 20.1º (Jupiter mean equator)
- Max eclipse duration: 4.5 hours
- Total Ionized Dose (TID): 2.82 Mrad*

*GIRE2, Si behind 100 mil Al, spherical shell

13F7-A21 Tour Timeline

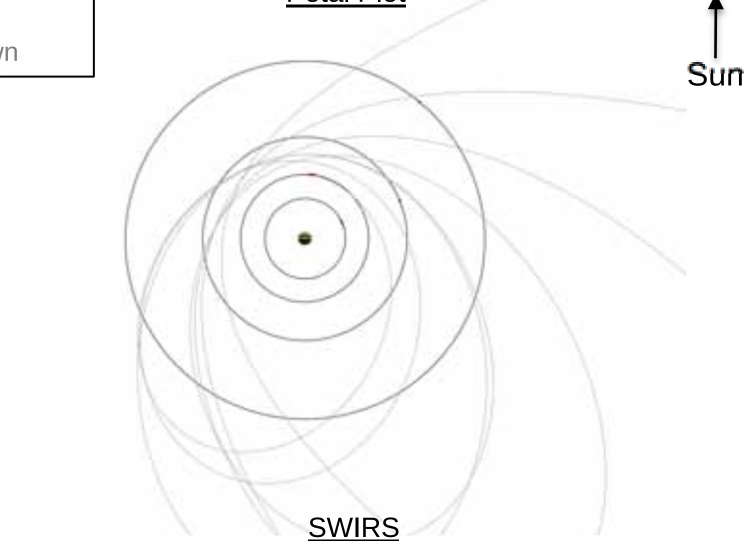


Select Instrument Coverage Build-Up

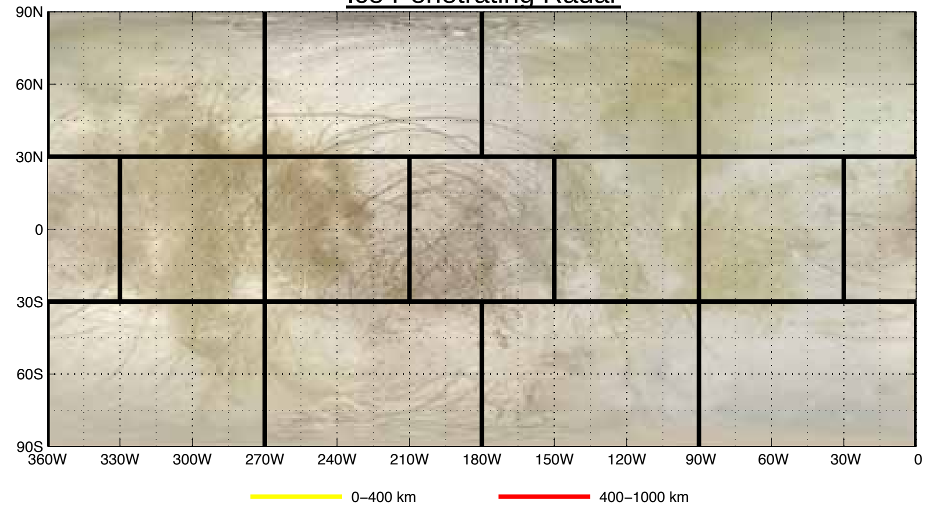
Pump Down

Key:
- Pump Down

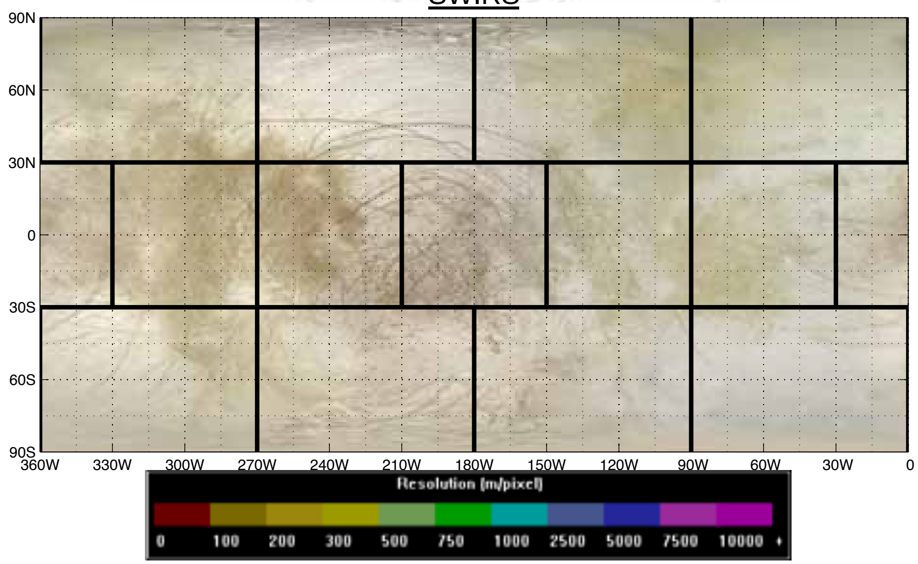
Petal Plot



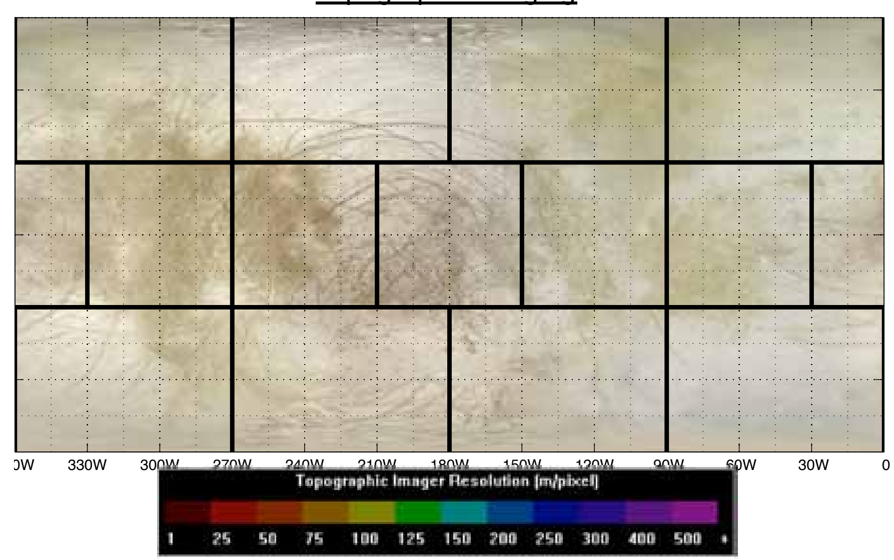
Ice Penetrating Radar



SWIRS



Topographic Imaging

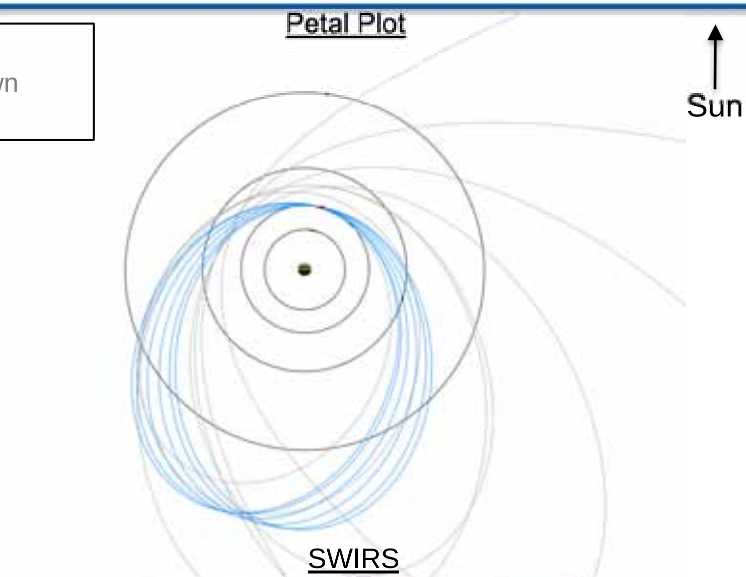


Select Instrument Coverage Build-Up

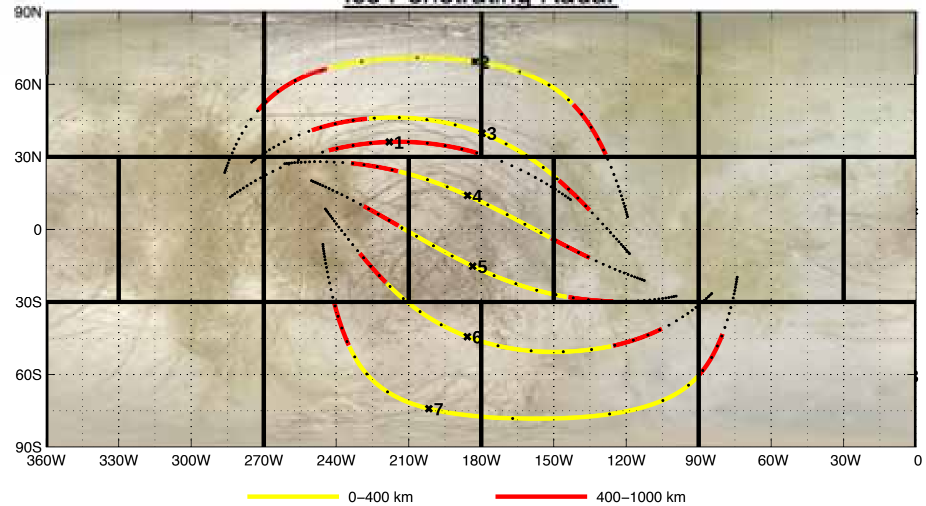
COT-1

Key:
- Pump Down
- COT-1

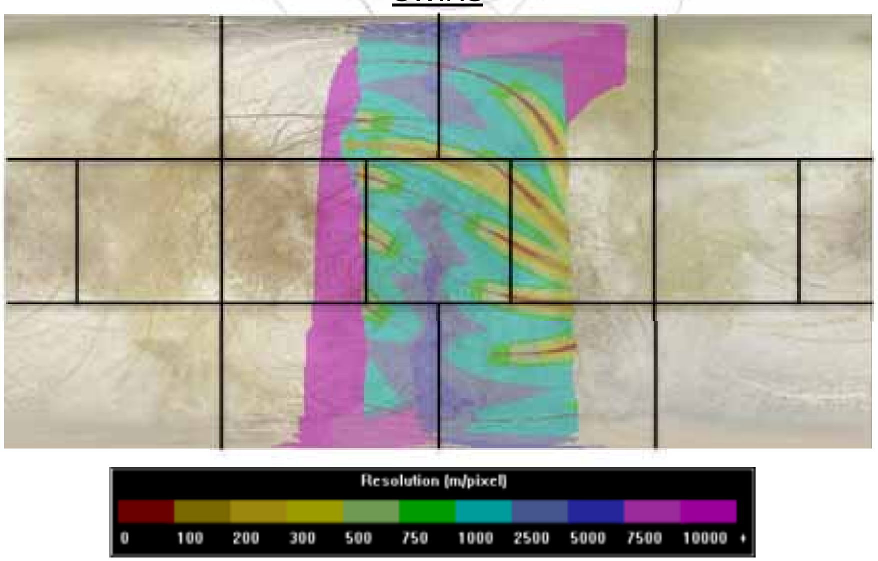
Petal Plot



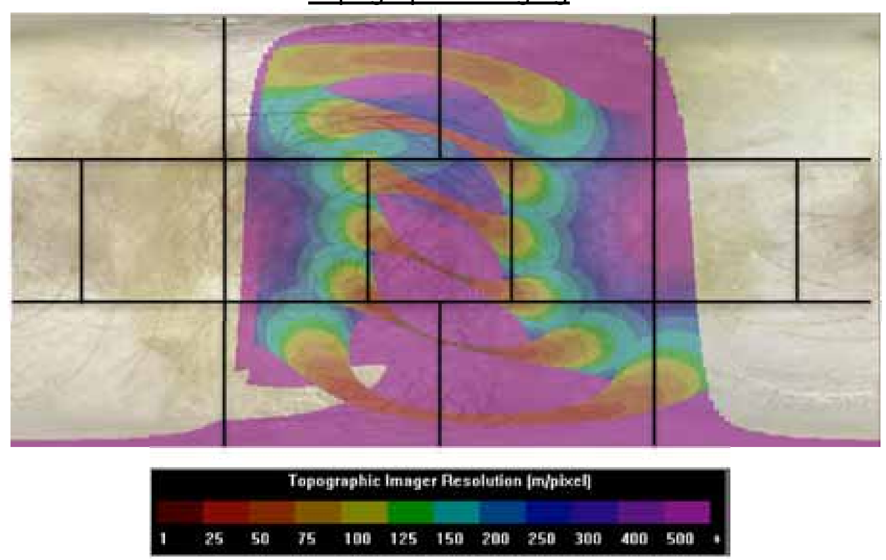
Ice Penetrating Radar



SWIRS



Topographic Imaging

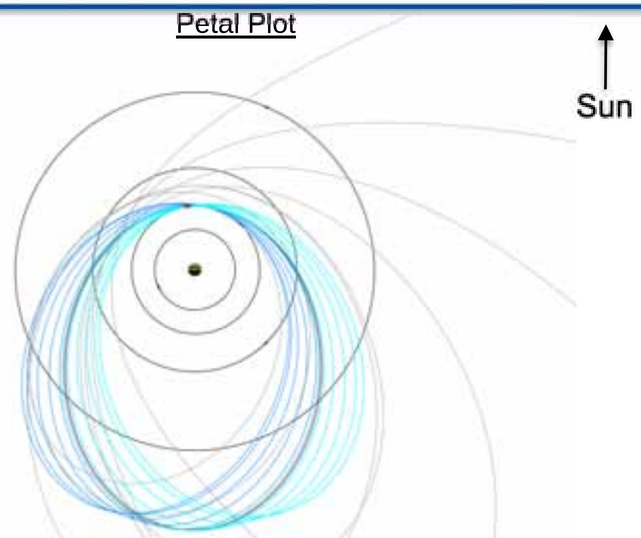


Select Instrument Coverage Build-Up

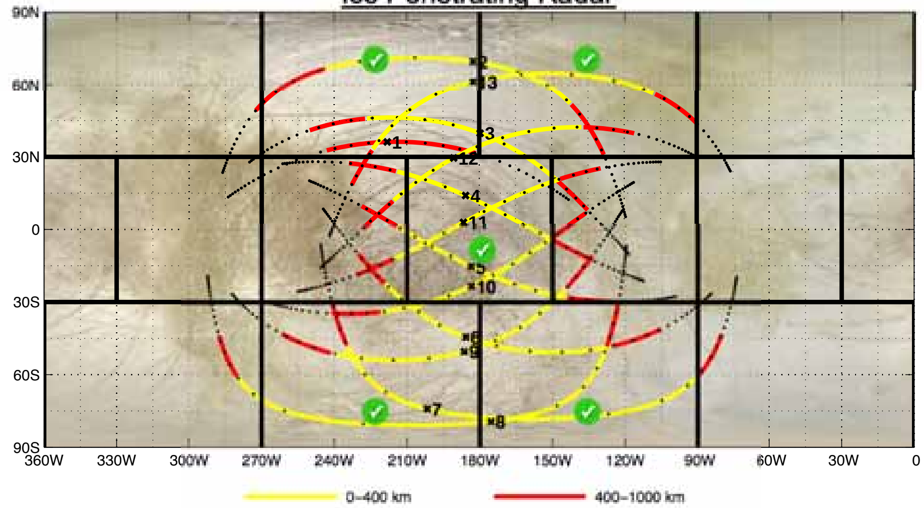
COT-2

Key:
- Pump Down
- COT-1
- Non-Res
- COT-2

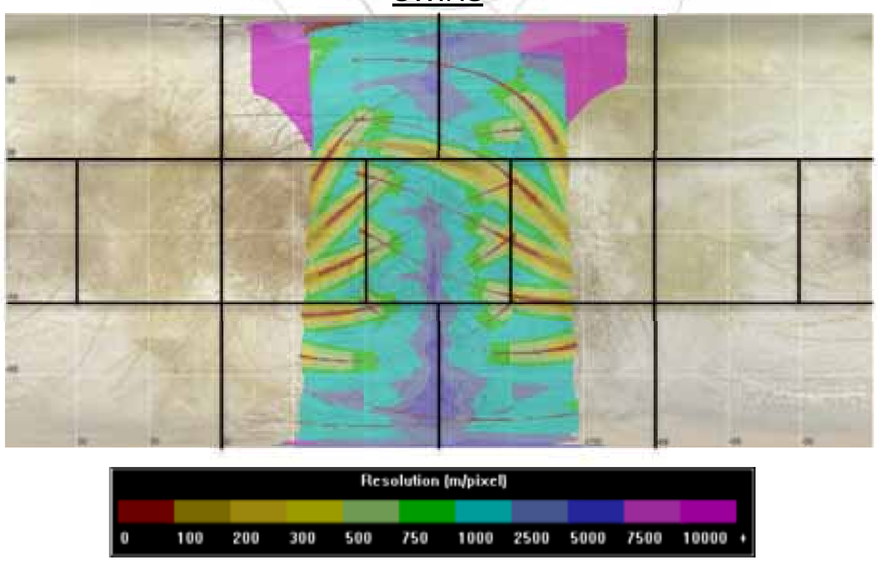
Petal Plot



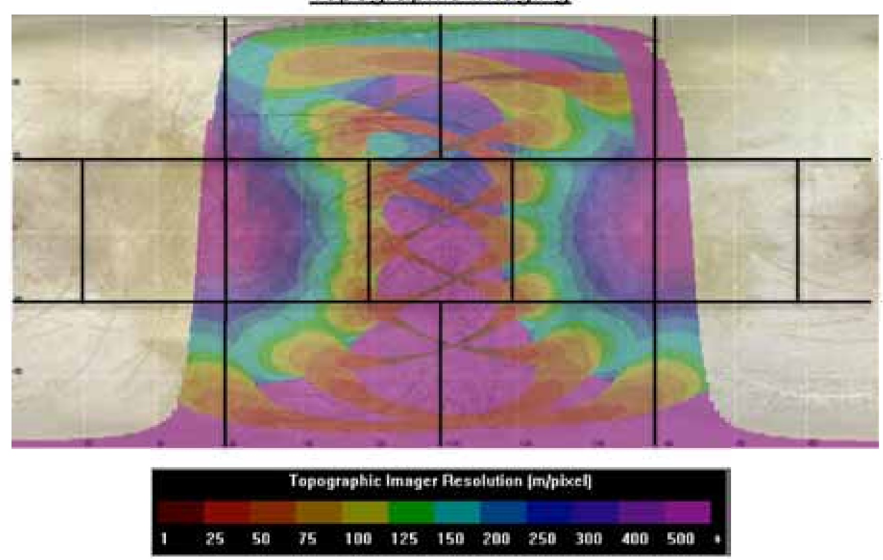
Ice Penetrating Radar



SWIRS



Topographic Imaging

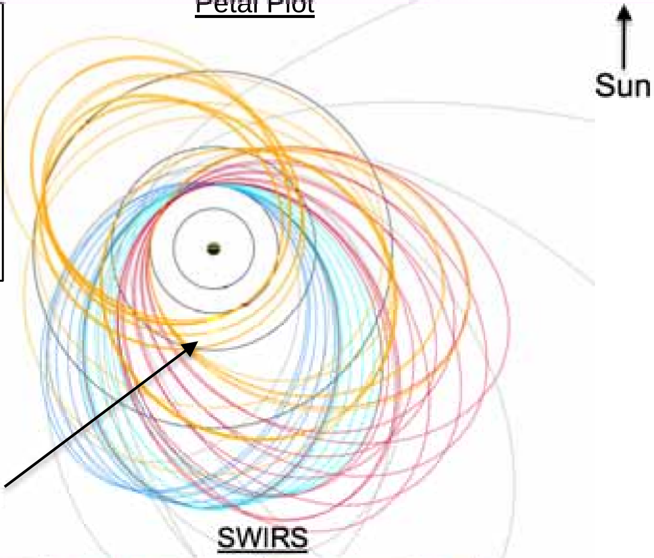


Select Instrument Coverage Build-Up

Petal Rot., Change Illuminated Hem.

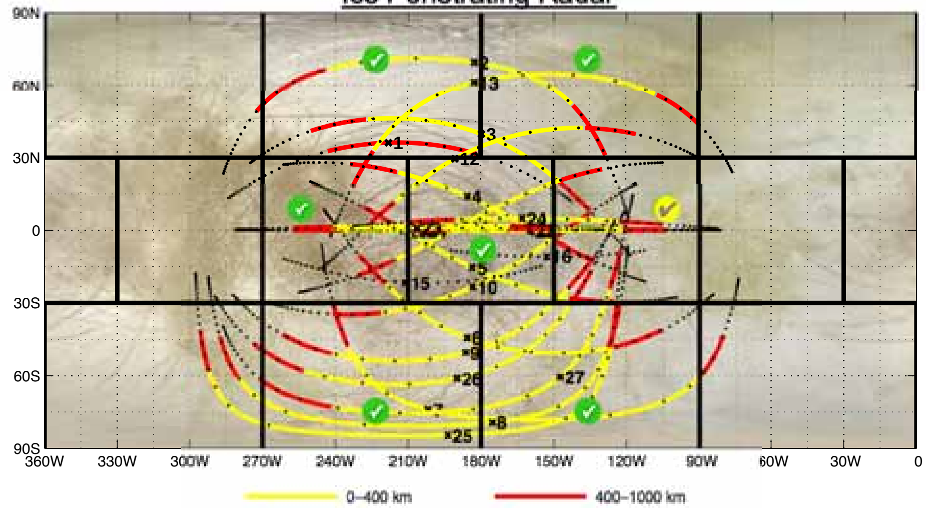
Key:
- Pump Down
- COT-1
- Non-Res
- COT-2
- Petal Rotation
- Change Illuminated Hem.

Petal Plot

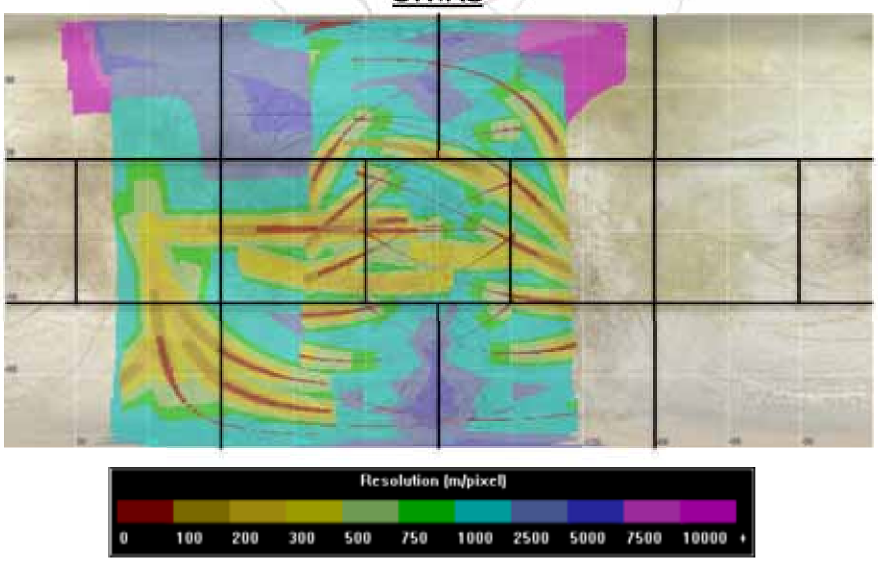


Yellow: Spacecraft in Jupiter eclipse

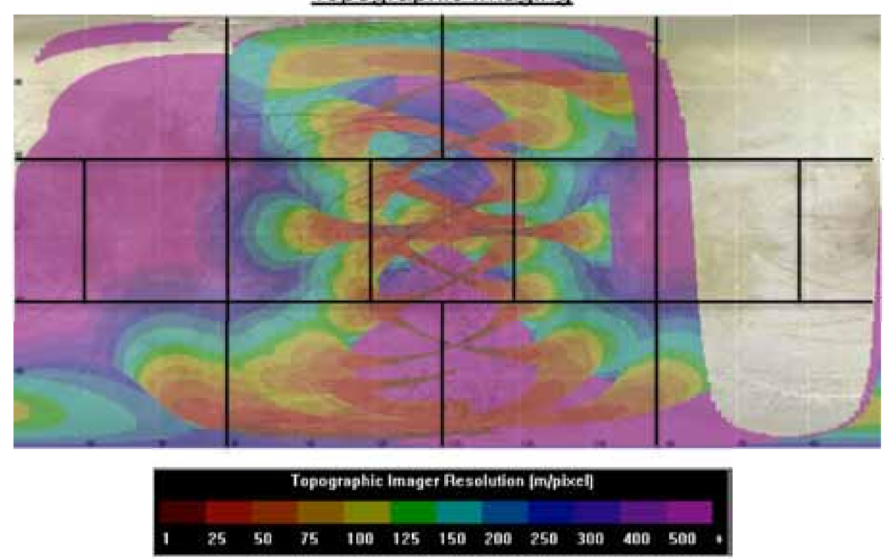
Ice Penetrating Radar



SWIRS



Topographic Imaging

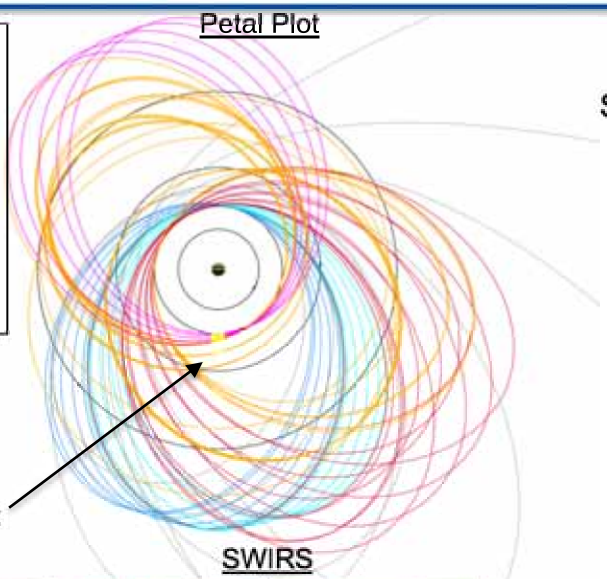


Select Instrument Coverage Build-Up

COT-3

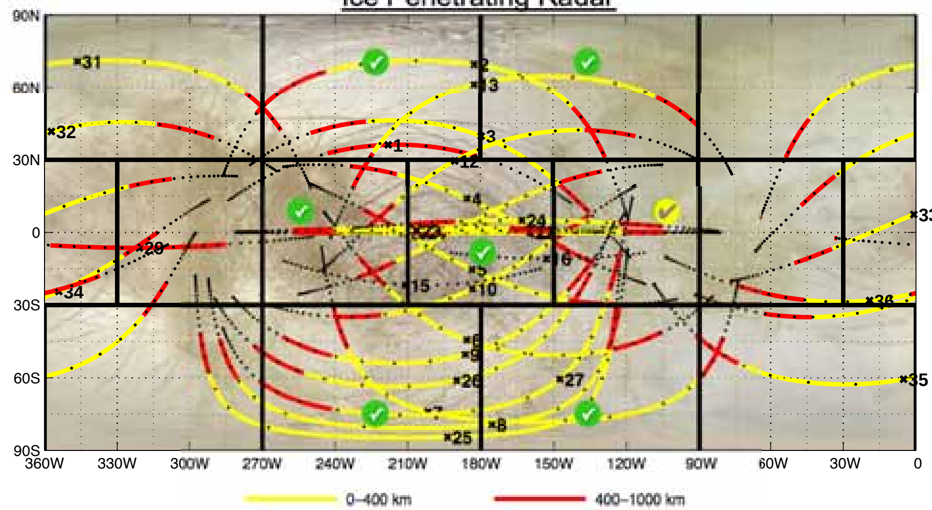
Key:
- Pump Down
- COT-1
- Non-Res
- COT-2
- Petal Rotation
- Change Illuminated Hem.
- COT-3

Petal Plot

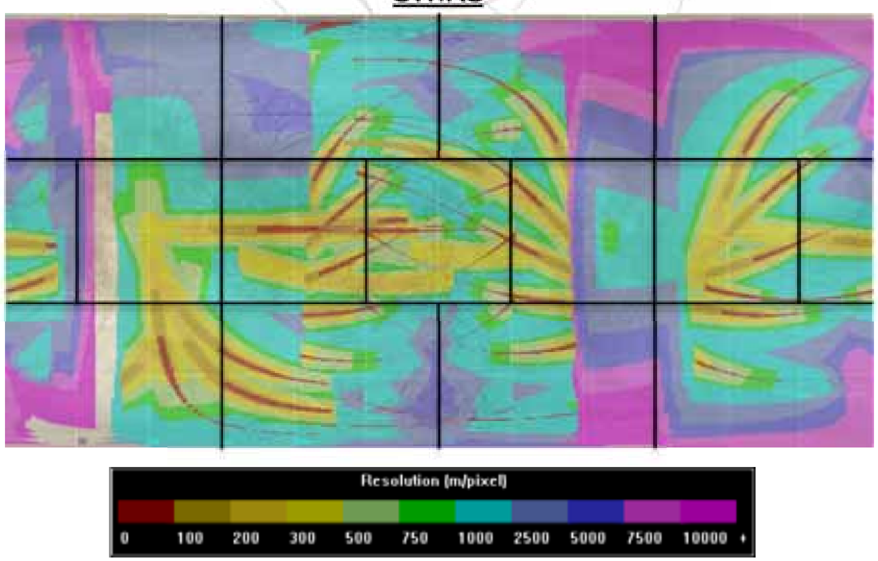


Yellow: Spacecraft in Jupiter eclipse

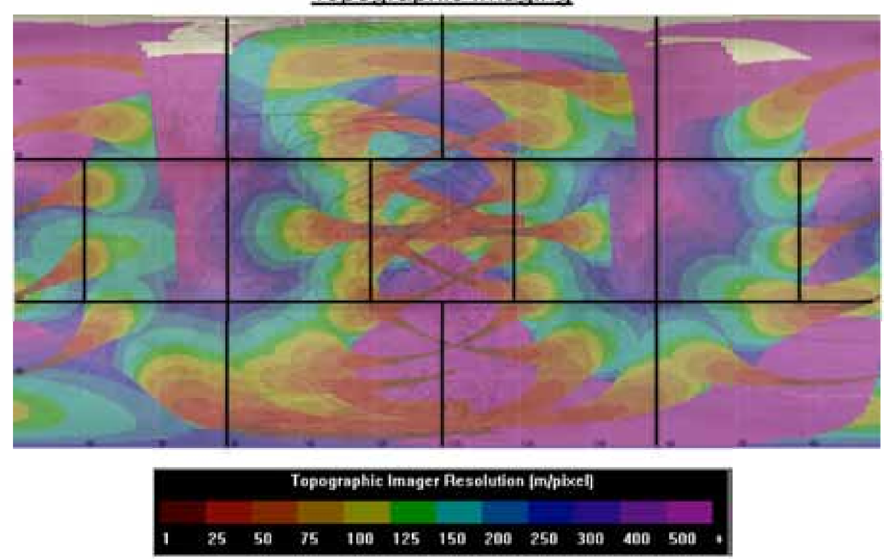
Ice Penetrating Radar



SWIRS



Topographic Imaging

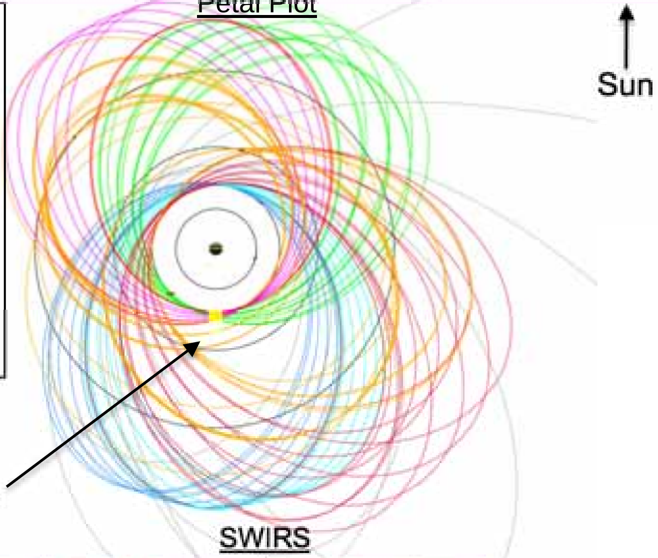


Select Instrument Coverage Build-Up

COT-4

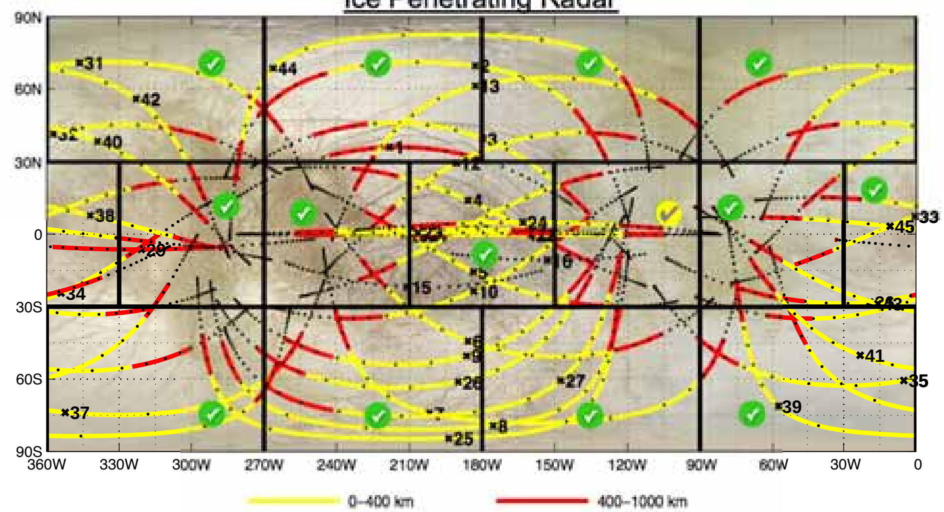
Key:
- Pump Down
- COT-1
- Non-Res
- COT-2
- Petal Rotation
- Change Illuminated Hem.
- COT-3
- Non-Res
- COT-4

Petal Plot

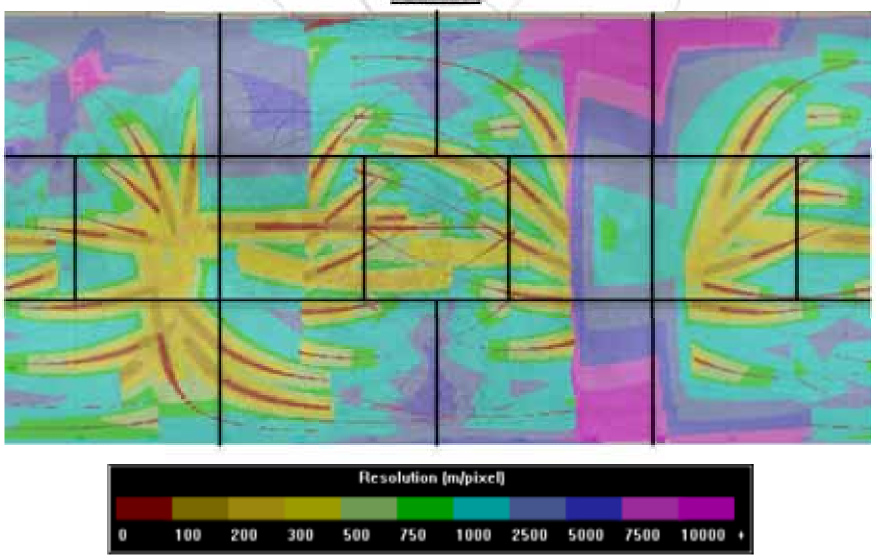


Yellow: Spacecraft in Jupiter eclipse

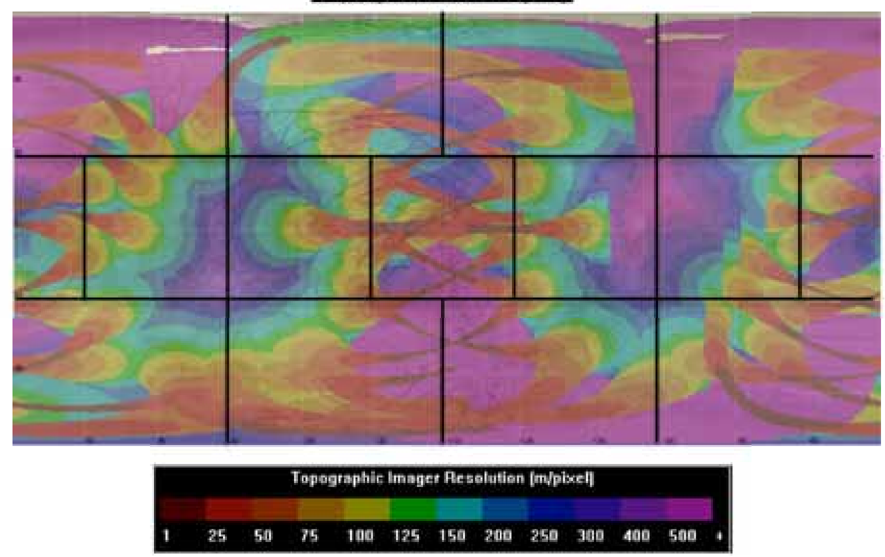
Ice Penetrating Radar



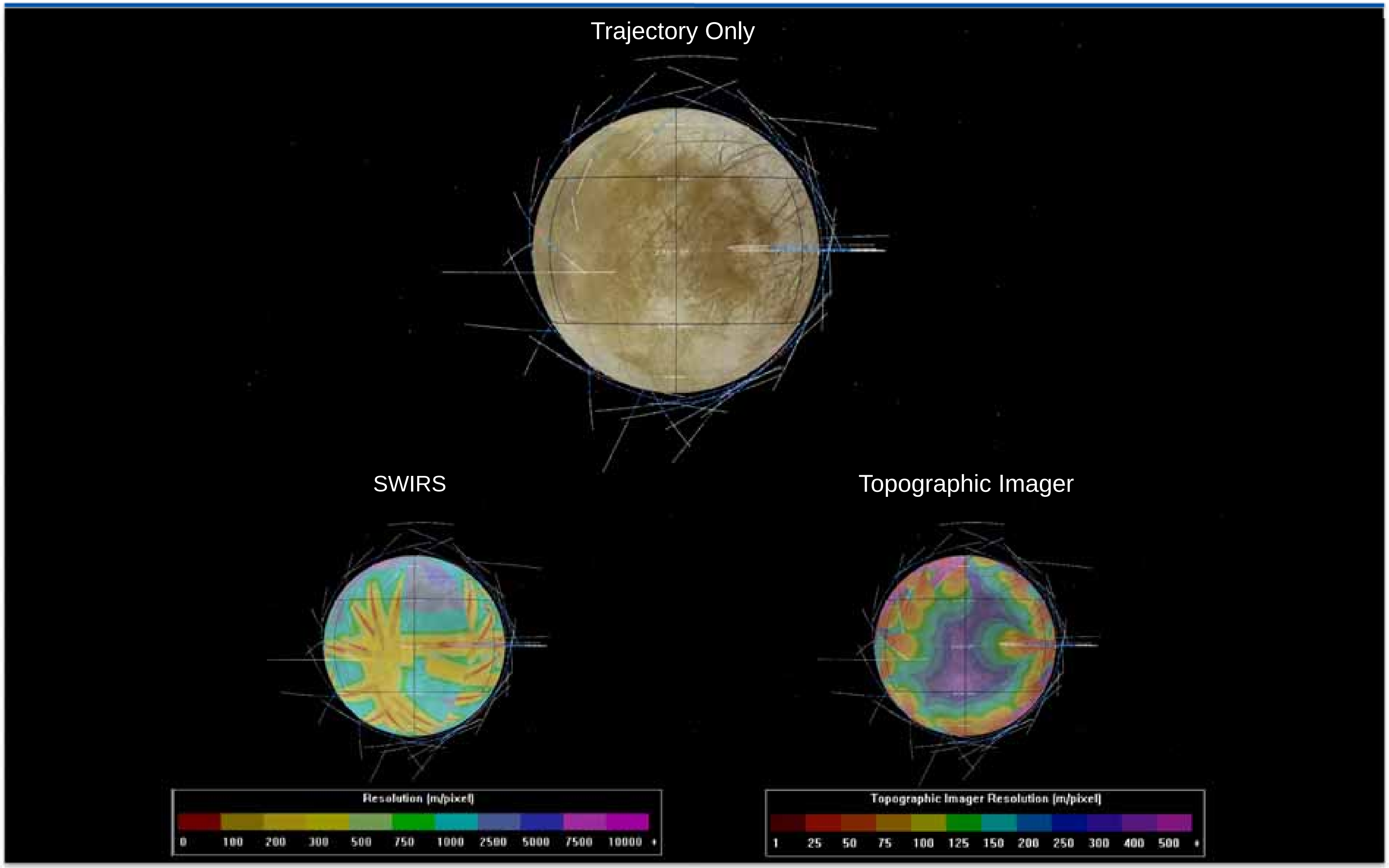
SWIRS



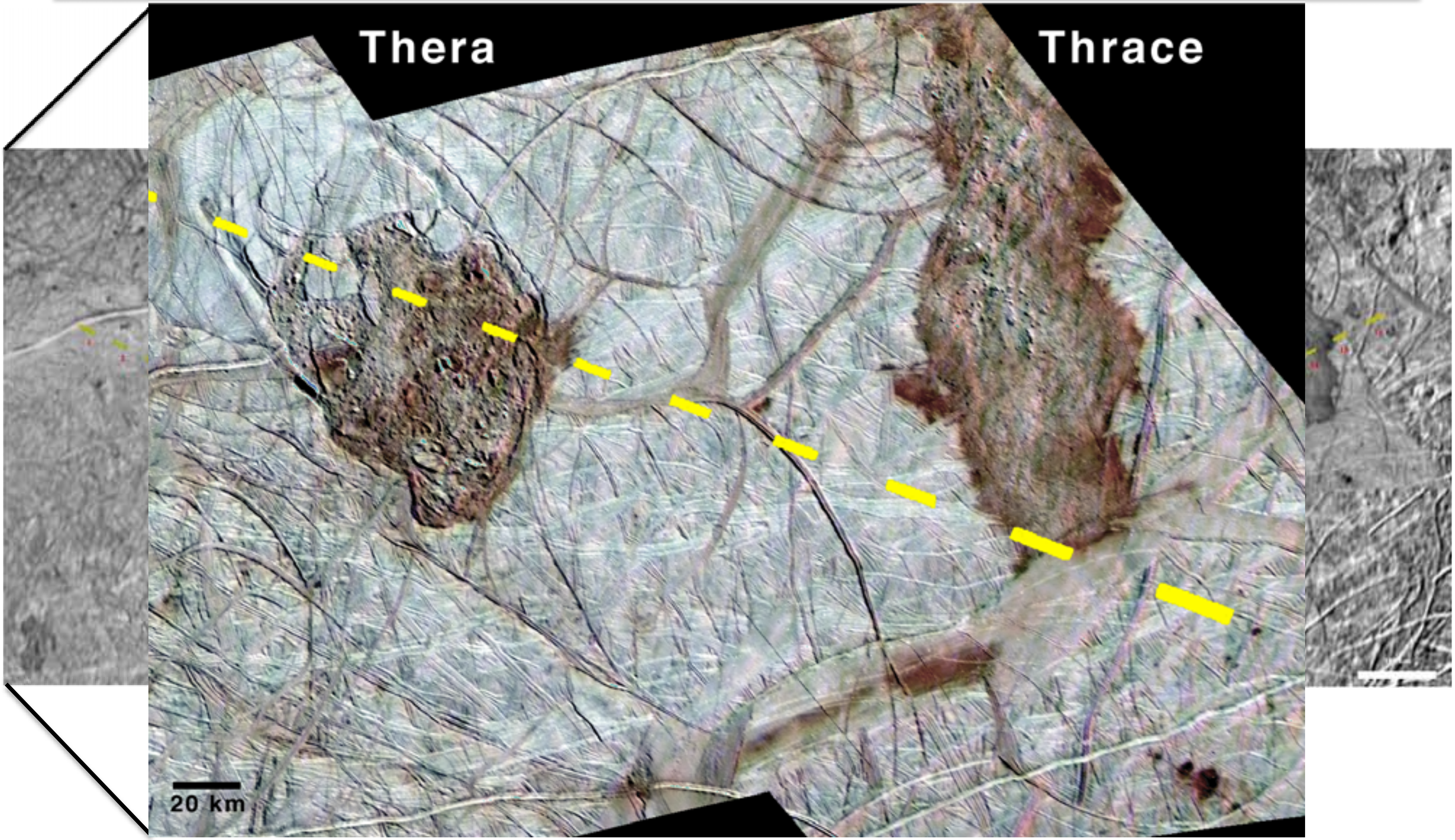
Topographic Imaging



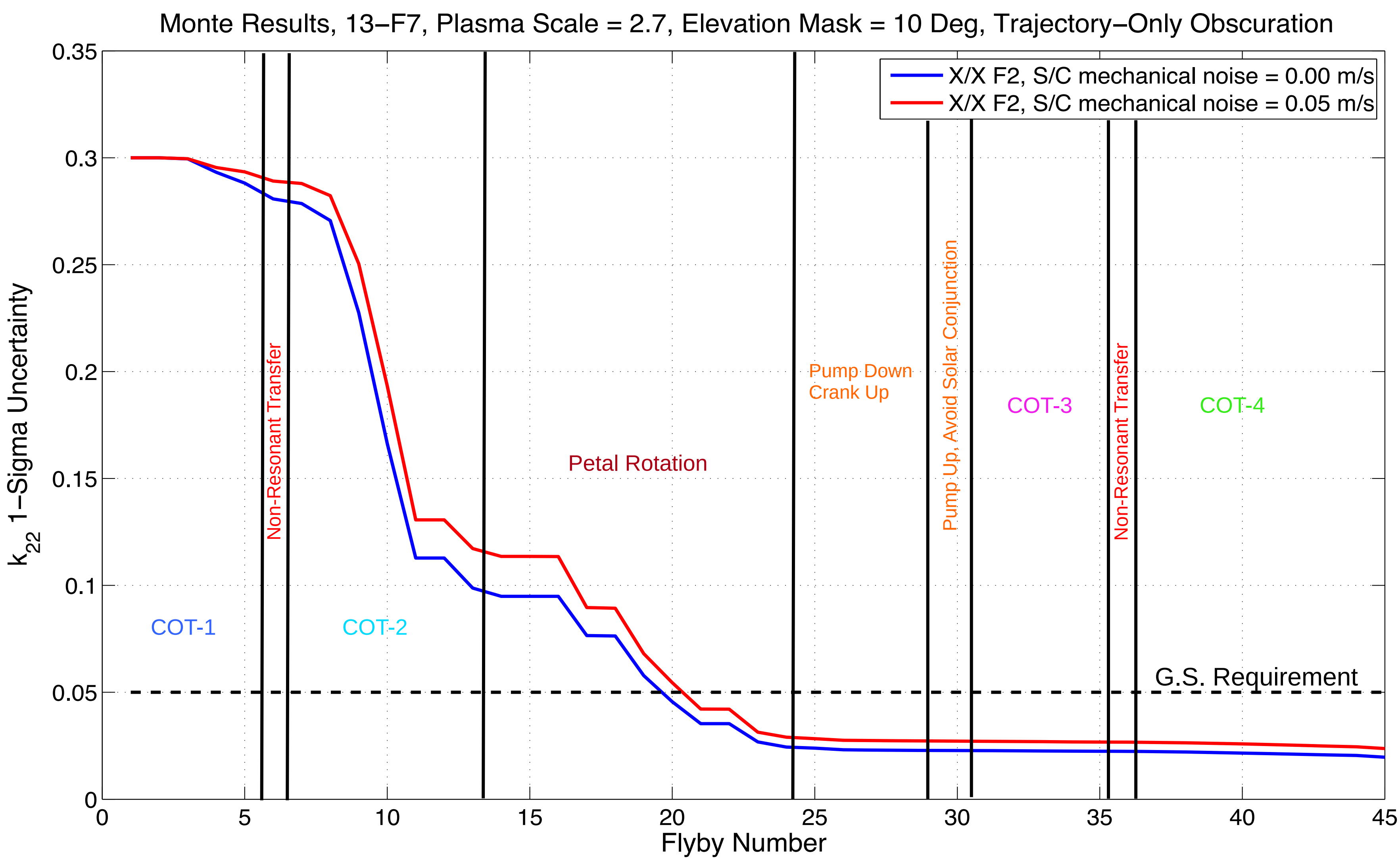
Select 13-F7 Instrument Coverage



13F7-A21 Reconnaissance

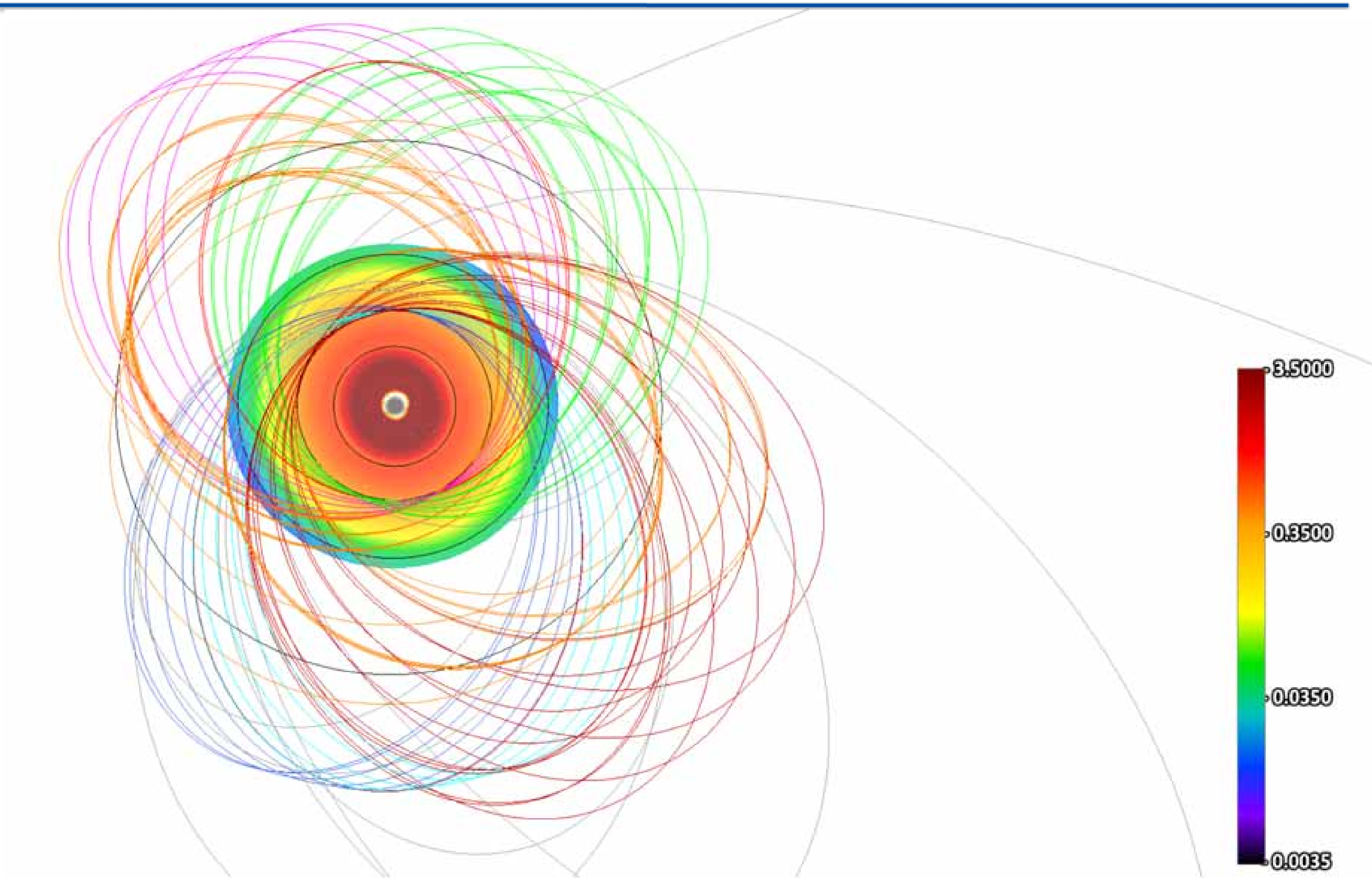


13F7-A21 Gravity Science Potential



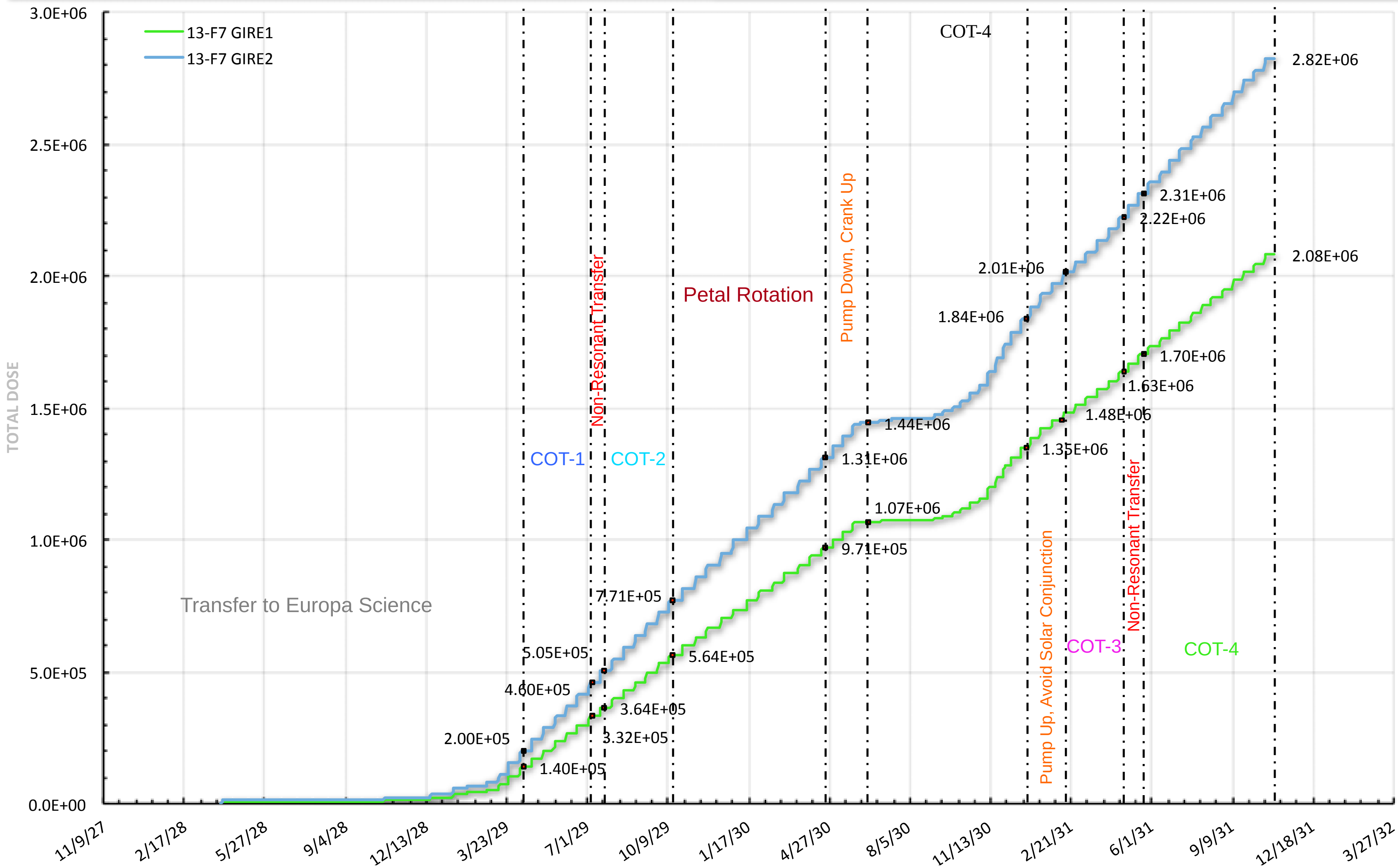
13F7-A21 Petal Plot

[GIRE2: Dose Rate Contours* (rad/s)]



13F7-A21 TID Build-Up

[Si behind 100 mil Al spherical shell]

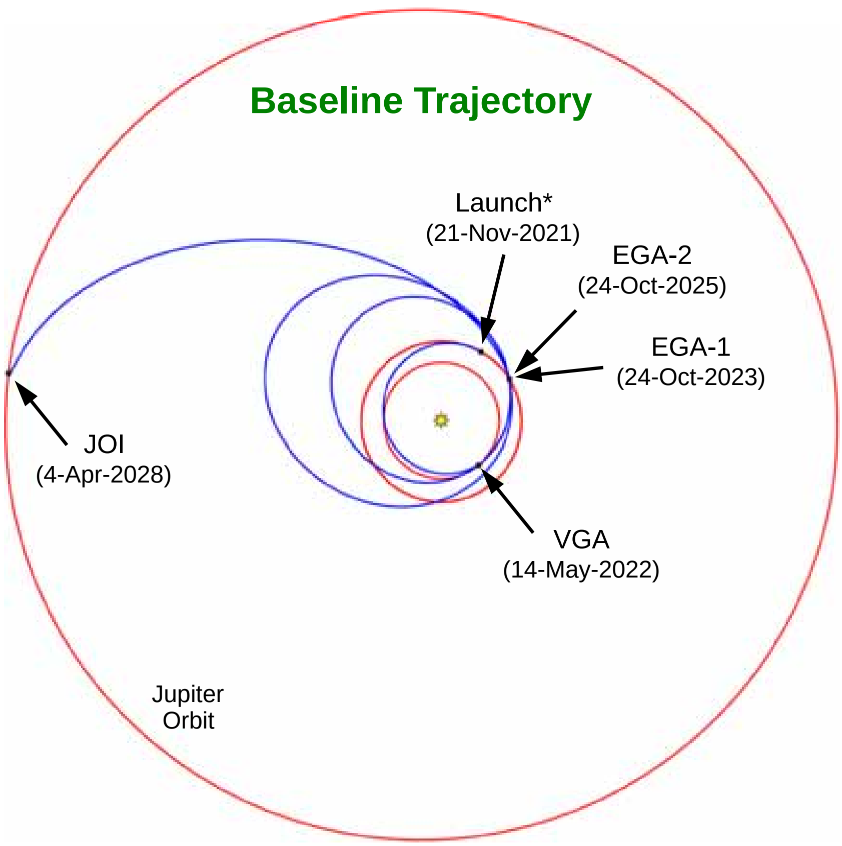


Back-up Material

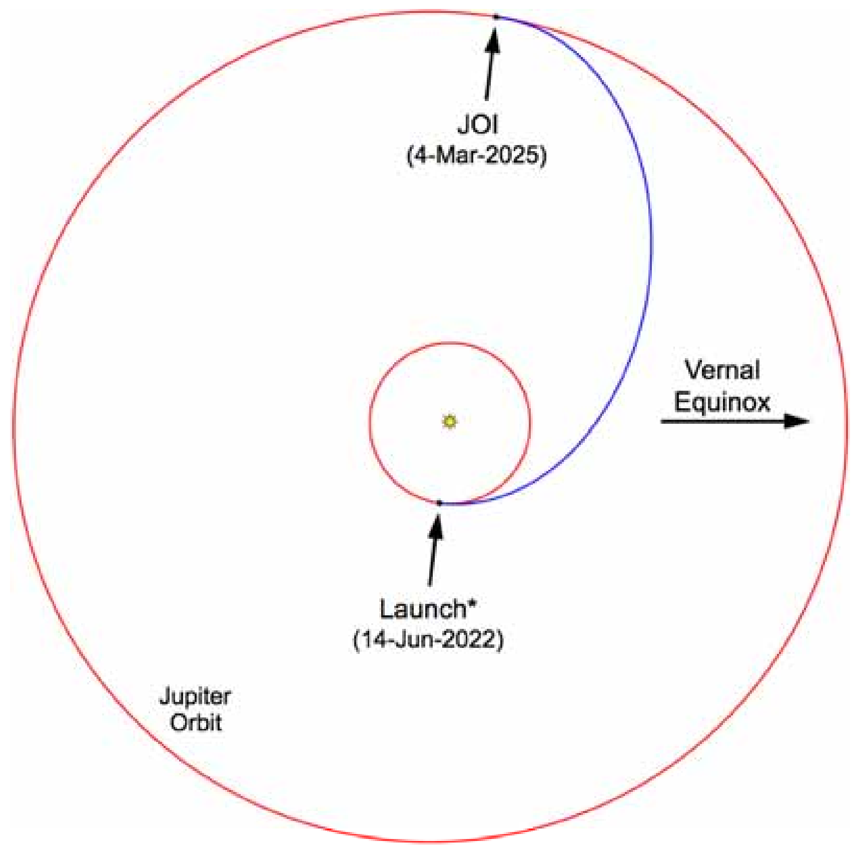
Interplanetary Trajectories

Interplanetary Trajectory Options

Atlas V 551
2021 VEEGA Trajectory
(6.37 year flight time)



SLS
2022 Direct-to-Jupiter Trajectory
(2.73† year flight time)



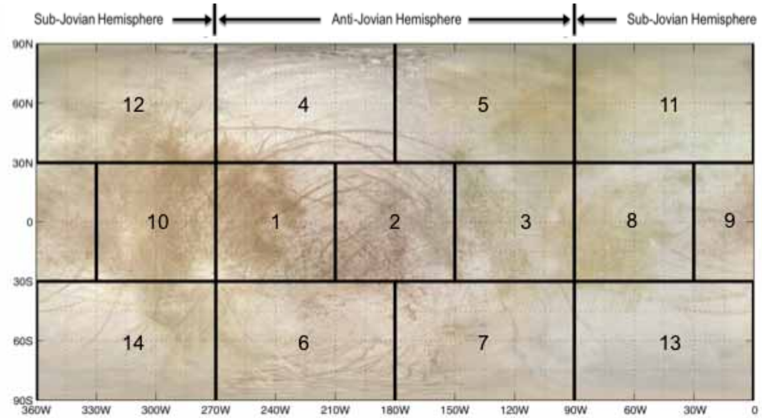
* Launch dates shown are the optimal launch dates, not the open of a launch period

†**Opportunities exist to reduce flight time down to 1.9 yrs.**

Instrument Specific Mission Design Drivers

Ice Penetrating Radar and Topographic Imager

- Solar phase 50-70º (20-80º acceptable) when alt ≤ 400 km
- Closest approach (c/a) relative velocity < 5 km/s
- c/a altitude: 25–100 km
- Coverage: Satisfy the following constraints in **11 of 14 panels**:
  - Three 800 km groundtracks in anti-Jovian panels, and two 800 km groundtrack segments in each sub-Jovian panel (altitude ≤ 400 km)
  - Each groundtrack must intersect another groundtrack (intersection may be outside the panel of interest) below 1,000 km (when altimetry mode begins)
  - Cover anti-Jupiter hemisphere first (preference)



NMS

- c/a relative velocity < 7 km/s
- c/a altitude: < 200 km (lower the better)

Mission Design Drivers [cont.]

IR Spectrometer (SWIRS)

- Local Solar Time: 9 am - 3 pm (the closer to noon the better)
- Solar phase angles < 45 degrees (preferred)
- c/a relative velocity < 6 km/s
- c/a altitude: 25–100 km
- Coverage:
  - Ability to target specific geologic features that are globally distributed (300 m/pixel, **11 of 14 panels**)
  - ≥ 70% coverage at ≤ 10 km per pixel

Other considerations:

- Total ionizing dose (TID)
- Tour time-of-flight
- Total Δv

Mission Design Drivers [cont.]

Gravity Science

- c/a altitude: ≤100 km
- Flybys distributed between near Europa's periapsis and near Europa's apoapsis and at 2 different locations; occur far from solar conjunction
- Spacecraft must not be occulted by Europa during ±2 hr around c/a

Magnetometer and Langmuir Probes

- c/a altitude: 25-100 km
- Flybys across a range orbital phases (true anomaly) and variety of Jovian System III longitudes

Reconnaissance Camera

- c/a altitude: ≤ 50 km
- 4 required, 15 sites desired (Each site: 5 x 10 km)
- Solar phase angles of 20-80º, >45º preferred, (70º ideal)

Thermal Imager

- Local solar time: 10 AM - 3 PM (and 3 AM – 6 AM for layers and hot spot investigations)
- Image same terrain as reconnaissance camera

Mission Design Assumptions

- Jupiter capture: Ganymede-assisted JOI
- ~200-day capture orbit
- Flyby altitude: Step-down approach
  – 500 km → 250 km → 100 km → 50 km → 25 km
- Keep average time-of-flight between flyby at ≥~14 days
- Two deterministic maneuvers between each flyby
  – Special cases exist (short TOF permits only one determinstic maneuver)
- Solar conjunction (assuming X-band up):
  – Prior to solar conjunction: ≥ 2 days of tracking must be obtained at SEP ≥ 10º when a maneuver is to be performed
  – No maneuver can be performed below 5º SEP (telemetry data cannot be downlinked and scheduling backup maneuver windows are troublesome)
  – After solar conjunction, maneuvers must be at least 3 days after 10º SEP to allow for 2 days of tracking plus an additional day to design the maneuver

13F7-A21 Flybys

Phase	Sub-phase	Flyby		In/ Out	Date (ET)	Altitude (km)	B-Plane Ang (deg)	V_∞ (km/s)	Inc. (deg.)	Peri (R_J)	Apo (R_J)	SEP Angle (deg)	m	n	Period (days)	Time to Next Encounter (days)	Total Time-of-Flight (months)
Jupiter Approach		Ganymede0	0G0	I	03-Apr-2028 11:58:34	500	0.1	7.97	5.4	12.96	265.1	156	N	R	200	202.2	0.0
Approach to Europa Science		Ganymede1	1G1	O	22-Oct-2028 17:14:57	100	-152.7	6.39	3.7	12.00	107.8	17	8	1	57.2	57.2	6.7
Approach to Europa Science		Ganymede2	2G2	O	18-Dec-2028 23:07:28	100	-147.9	6.44	1.3	11.09	64.4	64	5	1	28.6	28.6	8.6
Approach to Europa Science		Ganymede3	3G3	O	16-Jan-2029 13:49:12	1035.5	188	6.43	0.8	10.20	45.9	90	N	R	18.3	14.9	9.6
Approach to Europa Science		Callisto1	4C1	I	31-Jan-2029 12:29:59	911.6	156.2	5.54	1.6	12.33	55.0	105	N	R	24.1	27.3	10.1
Approach to Europa Science		Ganymede4	5G4	O	27-Feb-2029 18:42:49	523.6	163.5	5.24	0.2	11.17	37.0	133	N	R	14.6	16.5	11.0
Approach to Europa Science		Callisto2	6C2	I	16-Mar-2029 06:22:27	2635.9	178.3	4.35	0.2	9.22	33.9	150	N	R	12.4	9.7	11.6
Europa Anti-Jupiter Hemisphere Coverage	COT-1	Europa1	7E1	O	25-Mar-2029 22:26:46	752.7	-36.2	4.00	1.4	9.29	38.0	161	4	1	14.2	14.2	11.9
Europa Anti-Jupiter Hemisphere Coverage	COT-1	Europa2	8E2	O	09-Apr-2029 02:40:15	250	-71.1	3.93	3.8	9.37	37.9	176	4	1	14.2	14.2	12.4
Europa Anti-Jupiter Hemisphere Coverage	COT-1	Europa3	9E3	O	23-Apr-2029 07:42:56	100	-44.3	3.96	5.7	9.44	37.9	168	4	1	14.2	14.2	12.8
Europa Anti-Jupiter Hemisphere Coverage	COT-1	Europa4	10E4	O	07-May-2029 12:42:32	100	-15.9	3.97	6.3	9.48	37.8	152	4	1	14.2	14.2	13.3
Europa Anti-Jupiter Hemisphere Coverage	COT-1	Europa5	11E5	I	21-May-2029 17:42:13	50	14.7	3.97	5.5	9.47	37.8	137	4	1	14.2	14.2	13.8
Europa Anti-Jupiter Hemisphere Coverage	COT-1	Europa6	12E6	I	04-Jun-2029 22:42:16	25	46.7	3.96	3.3	9.40	37.9	123	4	1	14.2	14.2	14.2
Europa Anti-Jupiter Hemisphere Coverage	Non-Res (I/O)	Europa7	13E7	I	19-Jun-2029 03:44:29	100	78	3.93	0.5	9.38	38.1	109	4	1+	14.3	14.5	14.7
Europa Anti-Jupiter Hemisphere Coverage	COT-2	Europa8	14E8	O	03-Jul-2029 15:16:07	100	80.8	3.97	2.5	9.38	37.9	96	4	1	14.2	14.2	15.2
Europa Anti-Jupiter Hemisphere Coverage	COT-2	Europa9	15E9	O	17-Jul-2029 20:14:27	25	53	3.99	4.7	9.41	37.9	84	4	1	14.2	14.2	15.7
Europa Anti-Jupiter Hemisphere Coverage	COT-2	Europa10	16E10	O	01-Aug-2029 01:15:16	50	27.3	4.00	5.8	9.45	37.9	72	4	1	14.2	14.2	16.2
Europa Anti-Jupiter Hemisphere Coverage	COT-2	Europa11	17E11	I	15-Aug-2029 06:11:34	25	-2.5	4.00	5.5	9.42	37.9	60	4	1	14.2	14.2	16.6
Europa Anti-Jupiter Hemisphere Coverage	COT-2	Europa12	18E12	I	29-Aug-2029 11:07:50	50	-34.1	4.00	4.0	9.31	38.0	49	4	1	14.2	14.2	17.1
Europa Anti-Jupiter Hemisphere Coverage	COT-2	Europa13	19E13	I	12-Sep-2029 16:00:57	25	-63	3.98	1.4	9.25	38.1	38	4	1	14.2	14.2	17.6
Europa Anti-Jupiter Hemisphere Coverage	Petal Rotation	Europa14	20E14	I	26-Sep-2029 21:15:22	565.2	-88.7	3.92	0.9	9.25	38.2	26	4	1+	14.3	14.5	18.0
Europa Anti-Jupiter Hemisphere Coverage	Petal Rotation	Europa15	21E15	O	11-Oct-2029 09:12:54	1872.2	21.6	3.96	0.6	9.29	41.9	15	9	2–	16.0	31.7	18.5
Europa Anti-Jupiter Hemisphere Coverage	Petal Rotation	Europa16	23E16	I	12-Nov-2029 01:39:22	2710.3	10.7	4.08	0.4	9.16	38.3	10	4	1+	14.3	14.6	19.6
Europa Anti-Jupiter Hemisphere Coverage	Petal Rotation	Europa17	24E17	O	26-Nov-2029 14:57:34	50	-1.9	4.02	0.4	9.28	45.5	21	5	1–	17.7	17.6	20.1
Europa Anti-Jupiter Hemisphere Coverage	Petal Rotation	Europa18	25E18	I	14-Dec-2029 04:40:32	50	-0.3	4.01	0.5	9.18	38.3	35	4	1+	14.3	14.5	20.7
Europa Anti-Jupiter Hemisphere Coverage	Petal Rotation	Europa19	26E19	O	28-Dec-2029 17:39:59	81.2	0.1	4.04	0.5	9.30	45.5	47	5	1–	17.7	17.6	21.1
Europa Anti-Jupiter Hemisphere Coverage	Petal Rotation	Europa20	27E20	I	15-Jan-2030 07:07:07	50	0.5	4.04	0.5	9.19	38.3	62	4	1+	14.3	14.5	21.7
Europa Anti-Jupiter Hemisphere Coverage	Petal Rotation	Europa21	28E21	O	29-Jan-2030 20:00:01	100	0.1	4.04	0.5	9.37	45.4	75	5	1–	17.7	17.6	22.2
Europa Anti-Jupiter Hemisphere Coverage	Petal Rotation	Europa22	29E22	I	16-Feb-2030 09:40:09	50	0.2	4.04	0.5	9.27	38.2	91	4	1+	14.3	14.5	22.8
Europa Anti-Jupiter Hemisphere Coverage	Petal Rotation	Europa23	30E23	O	02-Mar-2030 22:49:08	50	-0.8	4.08	0.4	9.39	45.4	105	5	1–	17.7	17.6	23.3
Europa Anti-Jupiter Hemisphere Coverage	Petal Rotation	Europa24	31E24	I	20-Mar-2030 12:05:36	100	-4.9	4.08	0.5	9.29	38.2	122	4	1+	14.3	14.5	23.9

13F7-A21 Flybys [cont.]

	Phase	Flyby		In/ Out	Date (ET)	Altitude (km)	B-Plane Ang (deg)	V_∞ (km/s)	Inc. (deg.)	Peri (R_J)	Apo (R_J)	SEP Angle (deg)	m	n	Period (days)	Time to Next Encounter (days)	Total Time-of-Flight (months)
Change Illuminated Hemisphere	Crank Up Pump Down	Europa25	32E25	O	04-Apr-2030 01:17:21	50	84.8	4.10	3.0	9.31	38.0	137	4	1	14.2	14.2	24.4
		Europa26	33E26	O	18-Apr-2030 06:13:37	50	63.1	4.12	5.4	9.40	37.9	153	4	1	14.2	14.2	24.8
		Europa27	34E27	O	02-May-2030 11:03:14	50	74.2	4.13	7.9	9.45	33.9	168	7	2	12.4	24.9	25.3
	Switch-Flip	Europa28	36E28	O	27-May-2030 07:36:51	25	109.5	4.14	10.4	9.36	26.9	165	N	R	9.5	5.5	26.1
		Callisto3	37C3	I	01-Jun-2030 20:43:23	466.5	-138	2.84	14.5	14.77	28.7	159	3	4	12.5	50.0	26.3
		Callisto4	41C4	I	21-Jul-2030 21:11:53	100	-98.8	2.84	19.0	23.05	28.7	109	1	1	16.7	16.6	28.0
		Callisto5	42C5	I	07-Aug-2030 12:47:17	1828.2	-64.1	2.84	20.1	26.11	29.6	94	pi-trans		16.7	8.2	28.5
		Callisto6	43C6	O	15-Aug-2030 18:43:56	100	-177.6	2.81	17.4	21.84	26.5	86	1	1	16.7	16.6	28.8
		Callisto7	44C7	I	01-Sep-2030 10:18:29	50	-40.7	2.83	13.6	12.47	30.8	72	2	3	11.1	33.3	29.4
		Callisto8	47C8	I	04-Oct-2030 17:52:50	25	-106.3	2.80	1.1	11.15	27.8	45	2	3	11.0	33.5	30.5
		Callisto9	50C9	I	07-Nov-2030 06:37:49	3673.1	-4.4	2.97	0.5	9.01	29.2	18	N	R	9.7	32.7	31.6
Europa Sub-Jupiter Hemisphere Coverage	Pump Up, Avoid Sol. Conj.	Europa29	53E29	I	09-Dec-2030 22:16:02	546.7	173.6	3.99	0.4	9.18	27.9	7	10	3+	11.8	35.9	32.7
		Europa30	56E30	O	14-Jan-2031 21:03:57	1009	-8.7	4.05	0.7	9.34	32.8	36	4	1–	14.1	13.9	33.9
	COT-3	Europa31	57E31	I	28-Jan-2031 18:06:21	100	-108.7	3.99	3.1	9.36	37.8	48	4	1	14.2	14.2	34.3
		Europa32	58E32	I	11-Feb-2031 23:08:16	100	-135.8	3.97	4.9	9.42	37.9	60	4	1	14.2	14.2	34.8
		Europa33	59E33	I	26-Feb-2031 04:12:04	50	-169.8	3.95	5.3	9.46	37.9	72	4	1	14.2	14.2	35.3
		Europa34	60E34	O	12-Mar-2031 09:13:49	50	152.7	3.96	3.9	9.39	37.9	84	4	1	14.2	14.2	35.8
		Europa35	61E35	O	26-Mar-2031 14:15:56	25	118.5	3.97	1.3	9.35	37.9	97	4	1	14.2	14.2	36.2
	Non-Res (O/I)	Europa36	62E36	O	09-Apr-2031 18:29:44	303.4	151.7	3.91	0.3	9.28	37.9	111	7	2–	12.4	24.5	36.7
	COT-4	Europa37	64E37	I	04-May-2031 06:22:09	50	105.1	3.89	3.1	9.33	33.9	135	7	2	12.4	24.9	37.5
		Europa38	66E38	I	29-May-2031 03:37:23	25	187.1	3.78	2.6	9.40	34.0	161	4	1	14.2	14.2	38.4
		Europa39	67E39	I	12-Jun-2031 07:37:03	50	96.4	3.81	5.5	9.41	37.9	177	7	2	12.4	24.9	38.8
		Europa40	69E40	I	07-Jul-2031 04:32:14	25	-139.5	3.79	3.5	9.38	33.9	157	4	1	14.2	14.2	39.7
		Europa41	70E41	I	21-Jul-2031 08:16:17	50	124.8	3.80	5.9	9.41	37.9	142	7	2	12.4	24.9	40.1
		Europa42	72E42	O	15-Aug-2031 05:17:42	50	-112.9	3.80	3.1	9.38	33.9	117	4	1	14.2	14.2	41.0
		Europa43	73E43	O	29-Aug-2031 08:56:27	25	-210.5	3.76	4.6	9.35	37.9	104	7	2	12.5	24.9	41.4
		Europa44	75E44	O	23-Sep-2031 05:37:41	50	-82.1	3.74	1.7	9.34	33.8	81	4	1	14.2	14.1	42.3
		Europa45	76E45	O	07-Oct-2031 08:47:53	25	-177.6	3.68	1.5	9.28	37.9	69	7	2	12.5	NA	42.7

13F7-A21 / 11F5-A21 Comparison

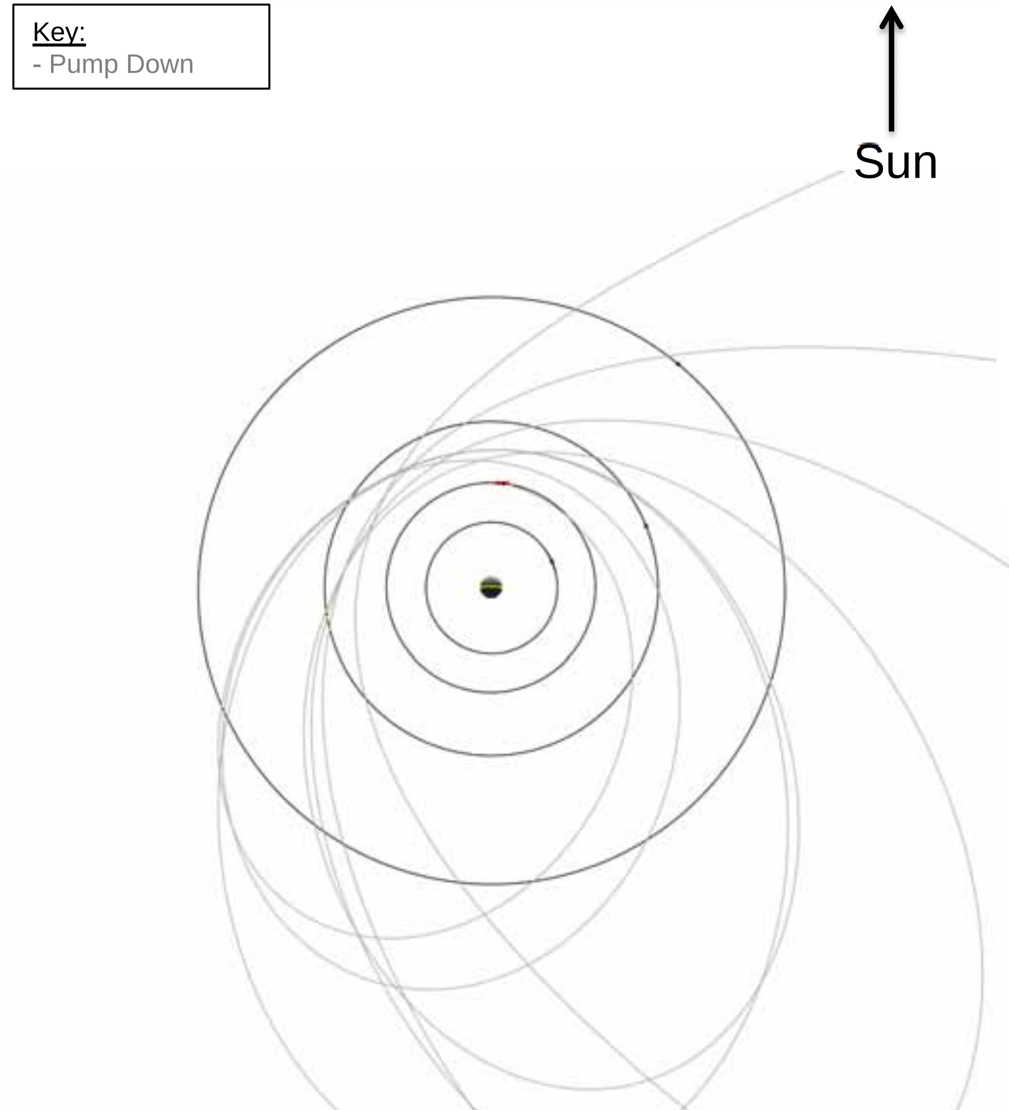
	11-F5	13F7-A21	Comments
Tour Duration	2.4 years	3.5 years	Initial conditions from Nov 2021 VEEGA trajectory
Number of Flybys: Europa Ganymede Callisto	 34 9 0	 45 5 9	
Time between Flybys: Maximum Minimum Mean	 28.7 days 3.5 days 15.5 days	 50.0 days 5.5 days 18.3 days	Maximum and mean values excluding the 200 and 50 day orbits post JOI and G1
Deterministic ΔV post-PRM	157 m/s *	147 m/s	* Value for 11-F5A tour was 143 m/s
Maximum Inclination	15º	20.1º	
Maximum Eclipse Duration	6.8 hours *	4.5 hours	* Value for 11-F5A tour was 9.6 hours
Total Ionized Dose (TID)	2.06 Mrad	2.08 Mrad	Si behind 100 mil Al, spherical shell

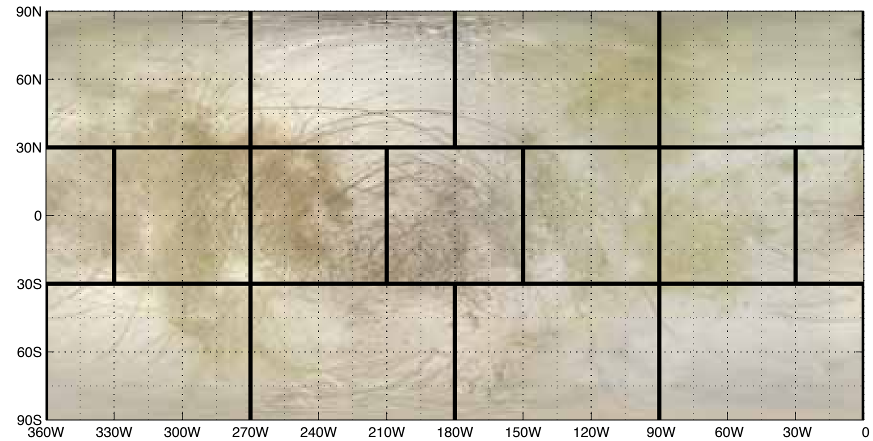
- Key Improvements
  - Significantly increases science return
  - Reduces maximum Jupiter solar eclipse durations
  - Increases data margins by increasing the average time-of-flight between Europa flybys
  - Avoids placing key events (flybys and maneuvers) during solar conjunction periods
  - More conservative flyby altitude step-down approach for Europa
    - 500 km → 250 km → 100 km → 50 km → 25 km (Ganymede and Callisto skip 250 km step)

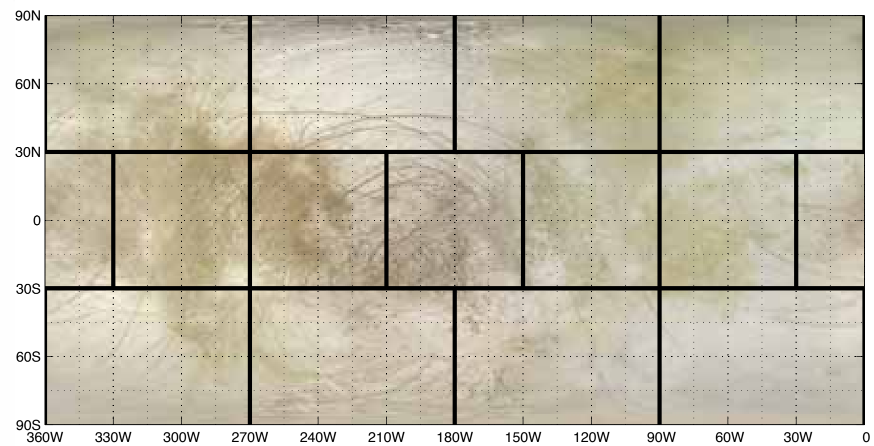
13F7-A21 Phases: Cumulative Build-Up

[Pump Down]

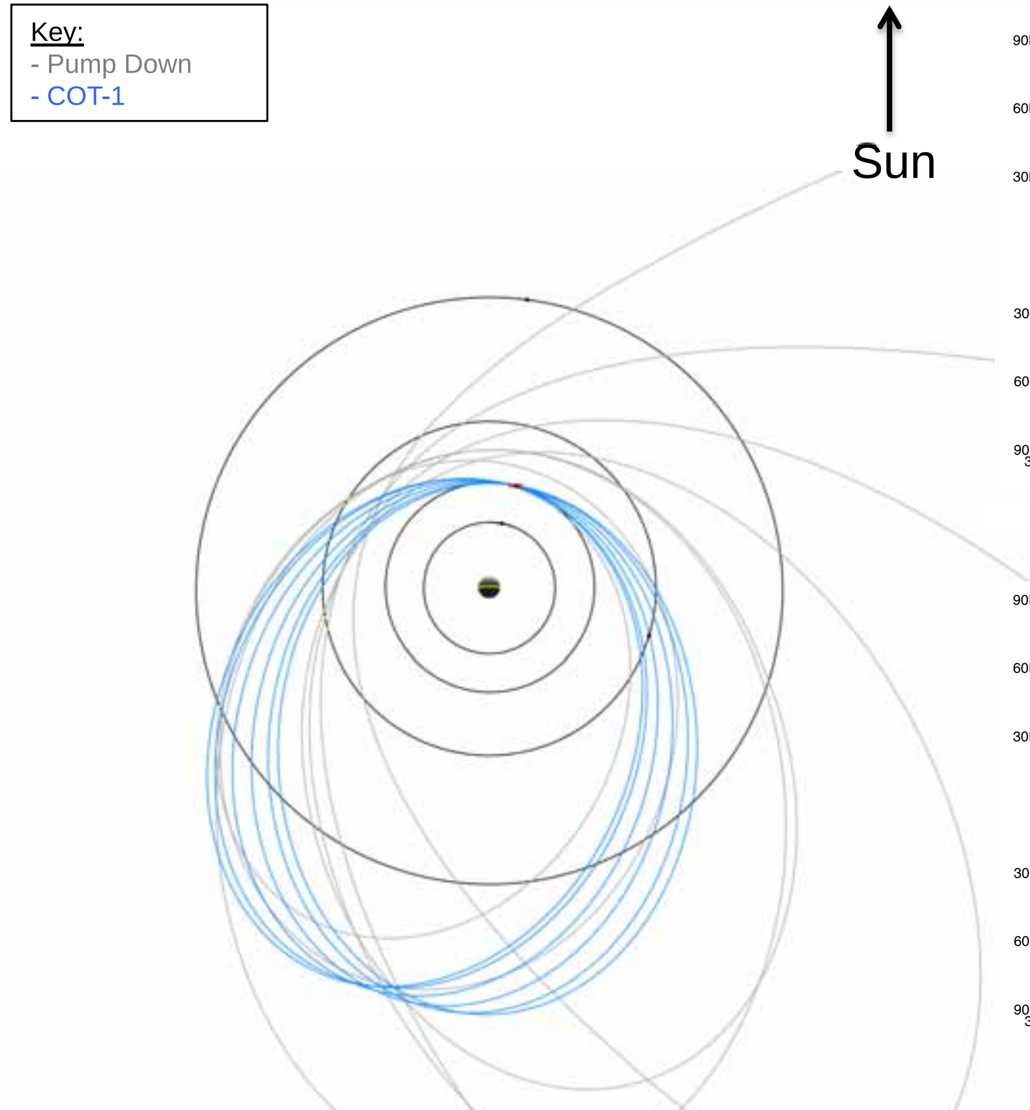
Key:
- Pump Down

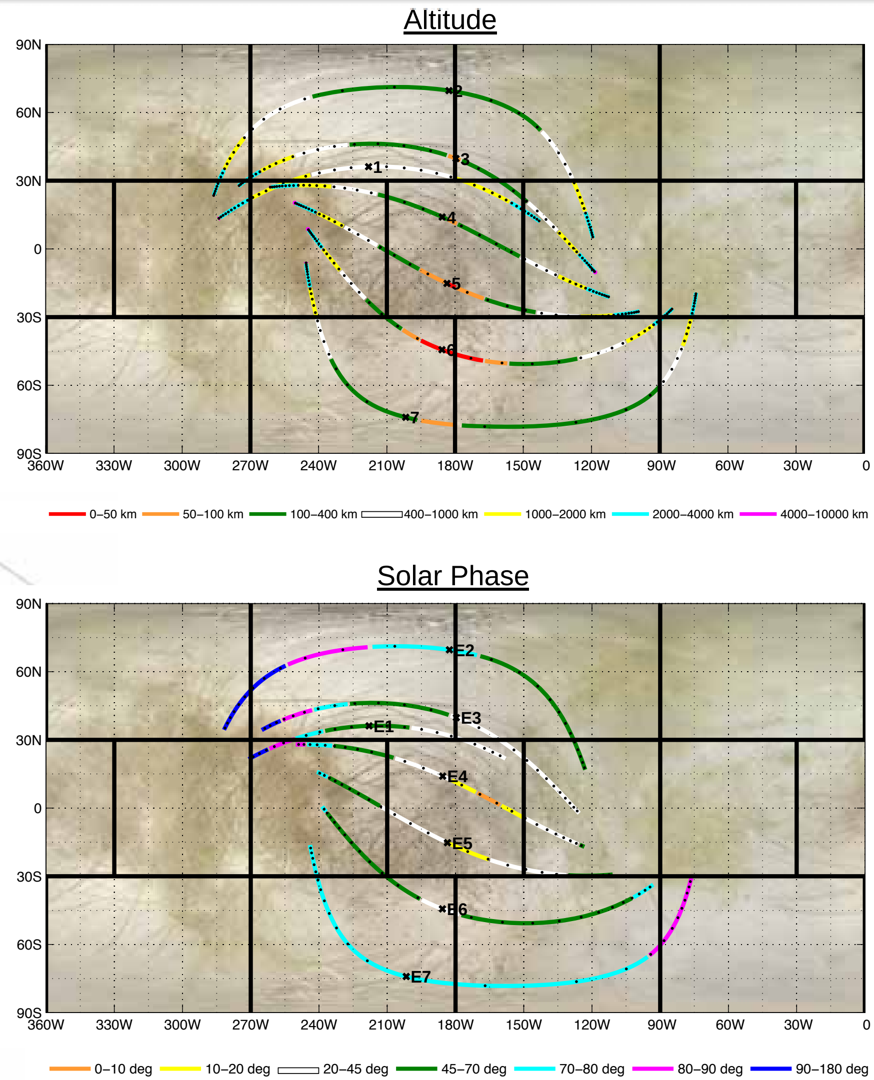






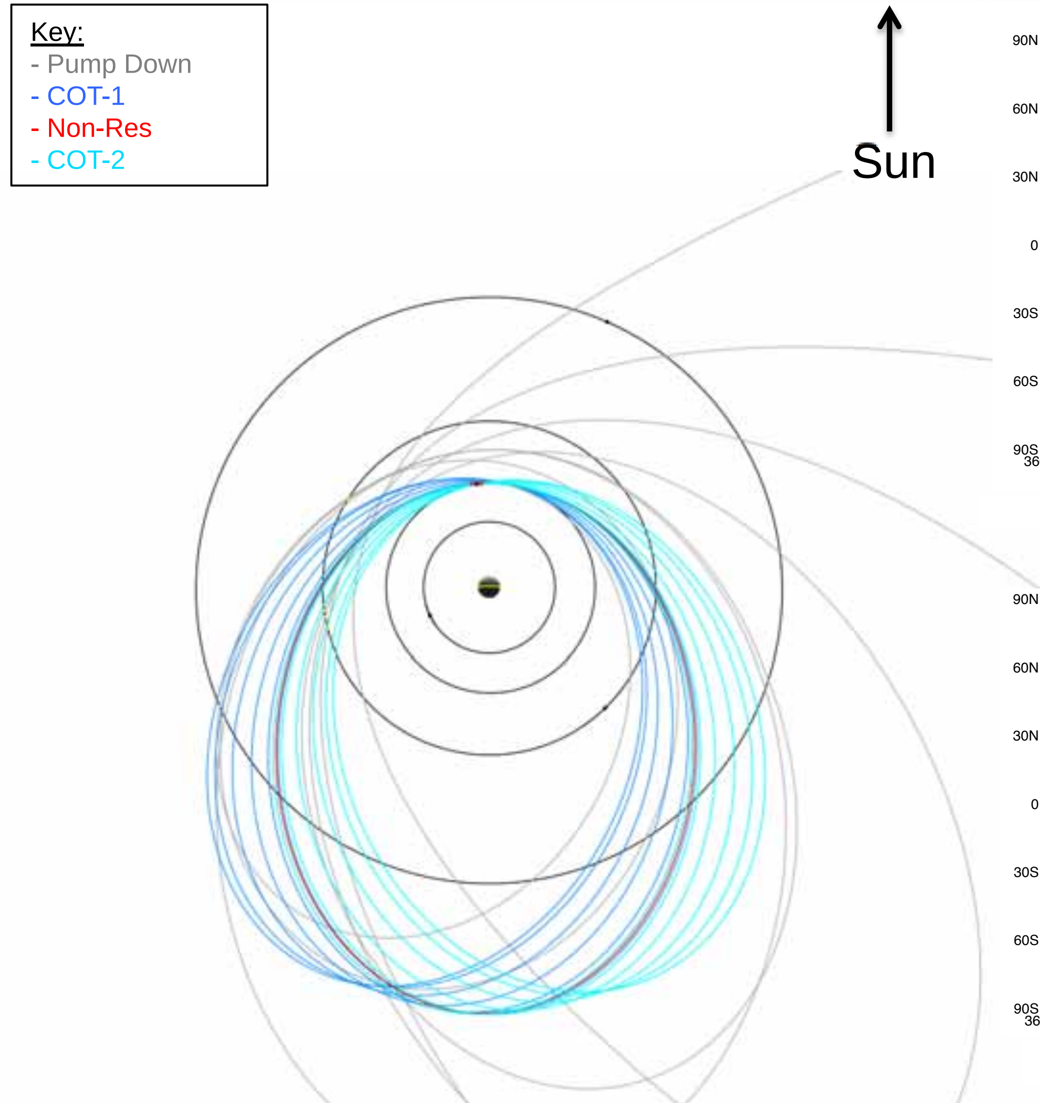
13F7-A21 Phases: Cumulative Build-Up
[COT-1]

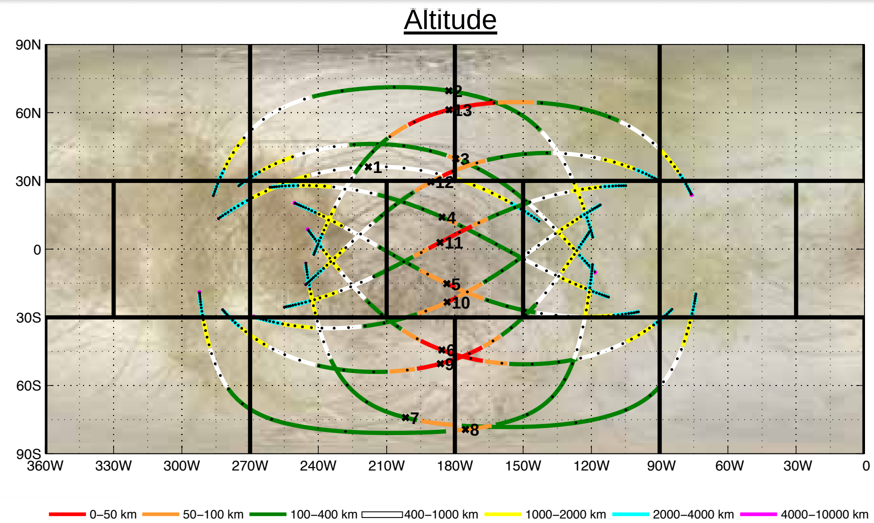


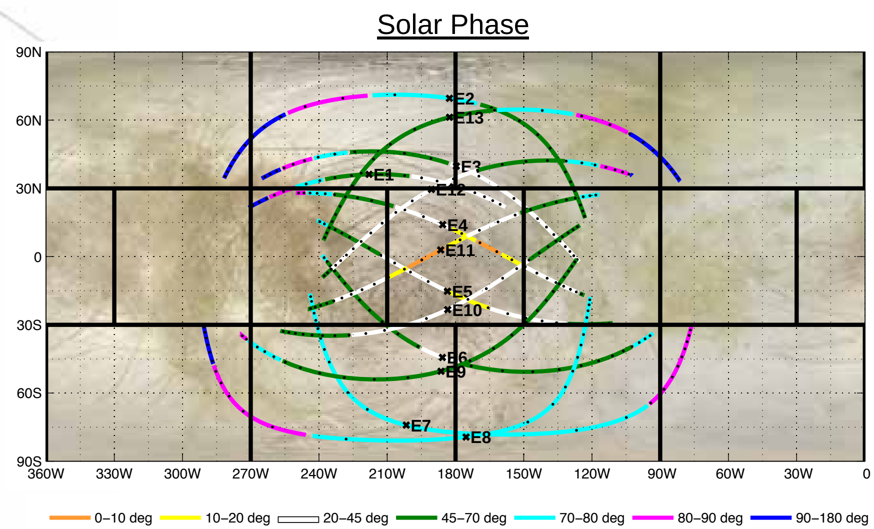


13F7-A21 Phases: Cumulative Build-Up

[COT-2]



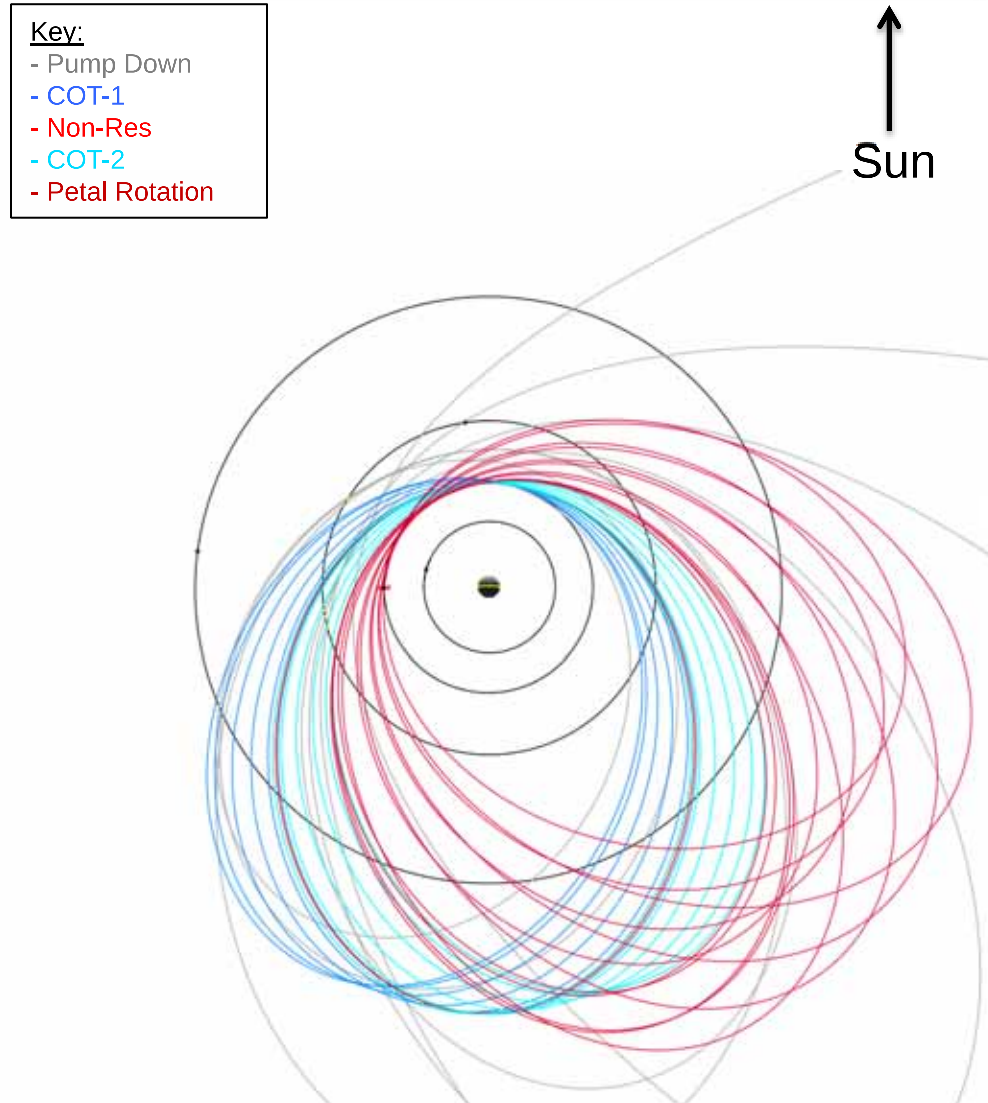


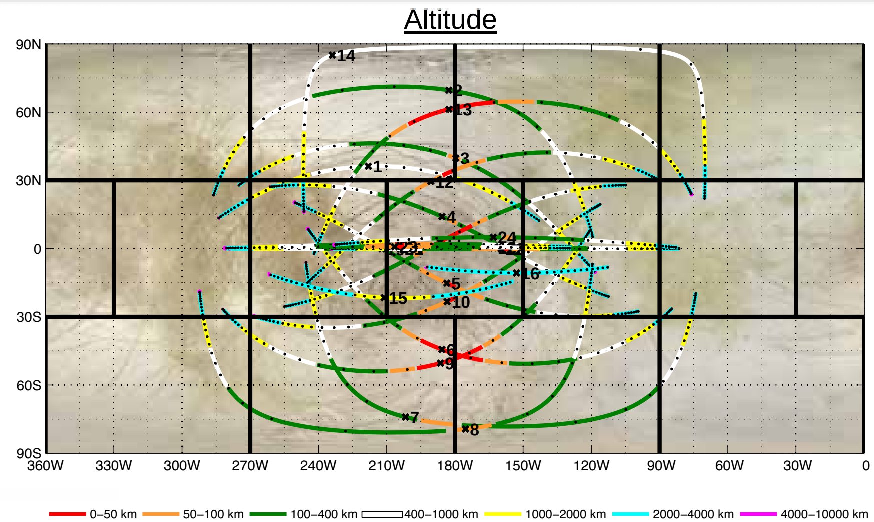


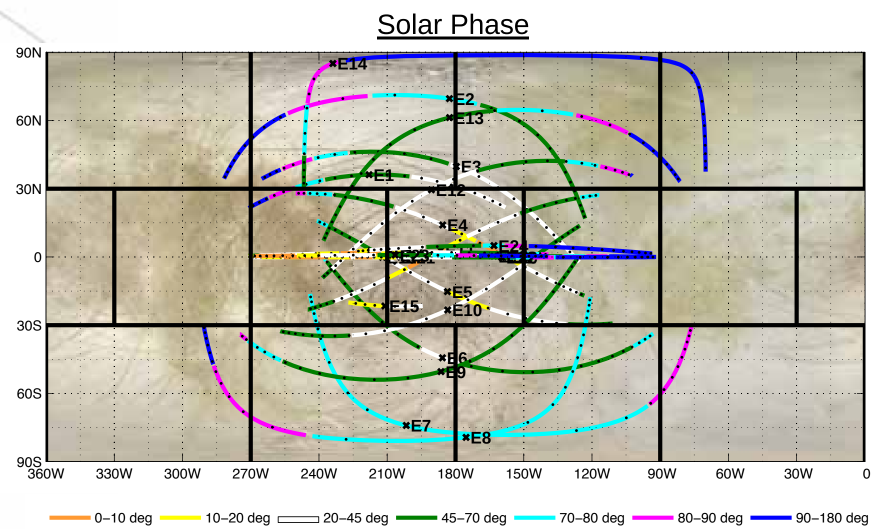
13F7-A21 Phases: Cumulative Build-Up

[Petal Rotation]

Key:
- Pump Down
- COT-1
- Non-Res
- COT-2
- Petal Rotation

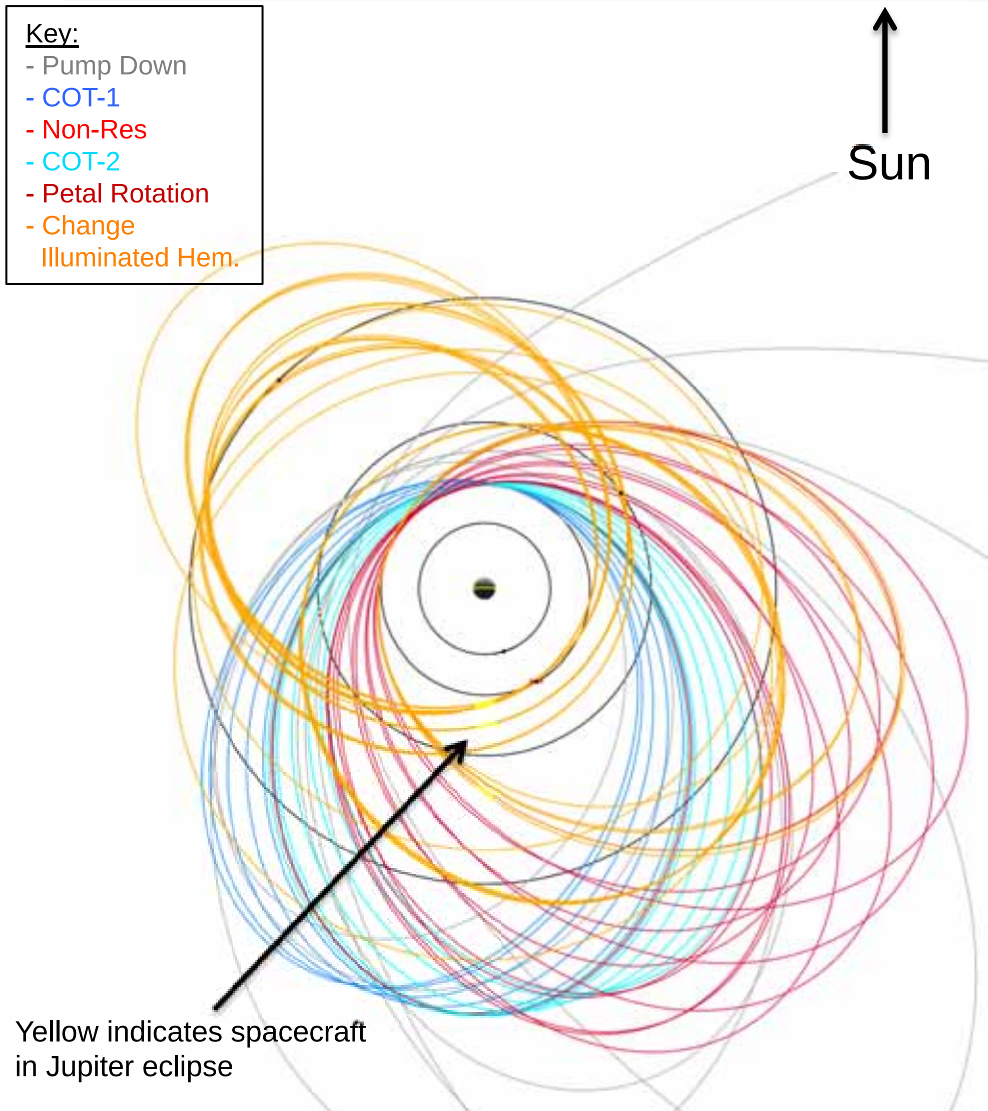


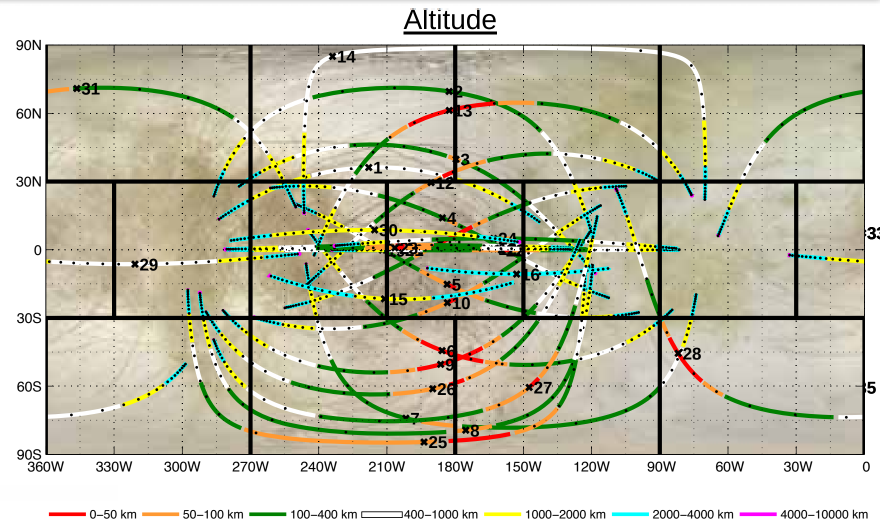


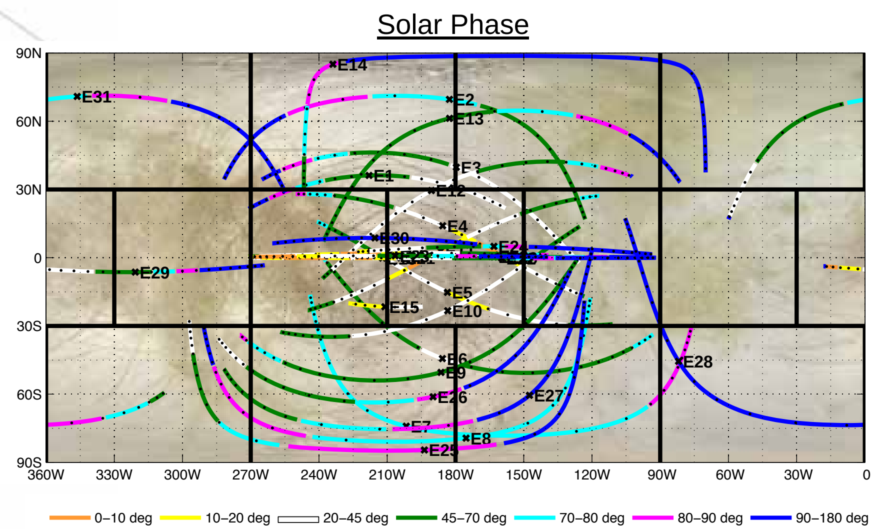


13F7-A21 Phases: Cumulative Build-Up

[Change Illuminated Europa Hemisphere]

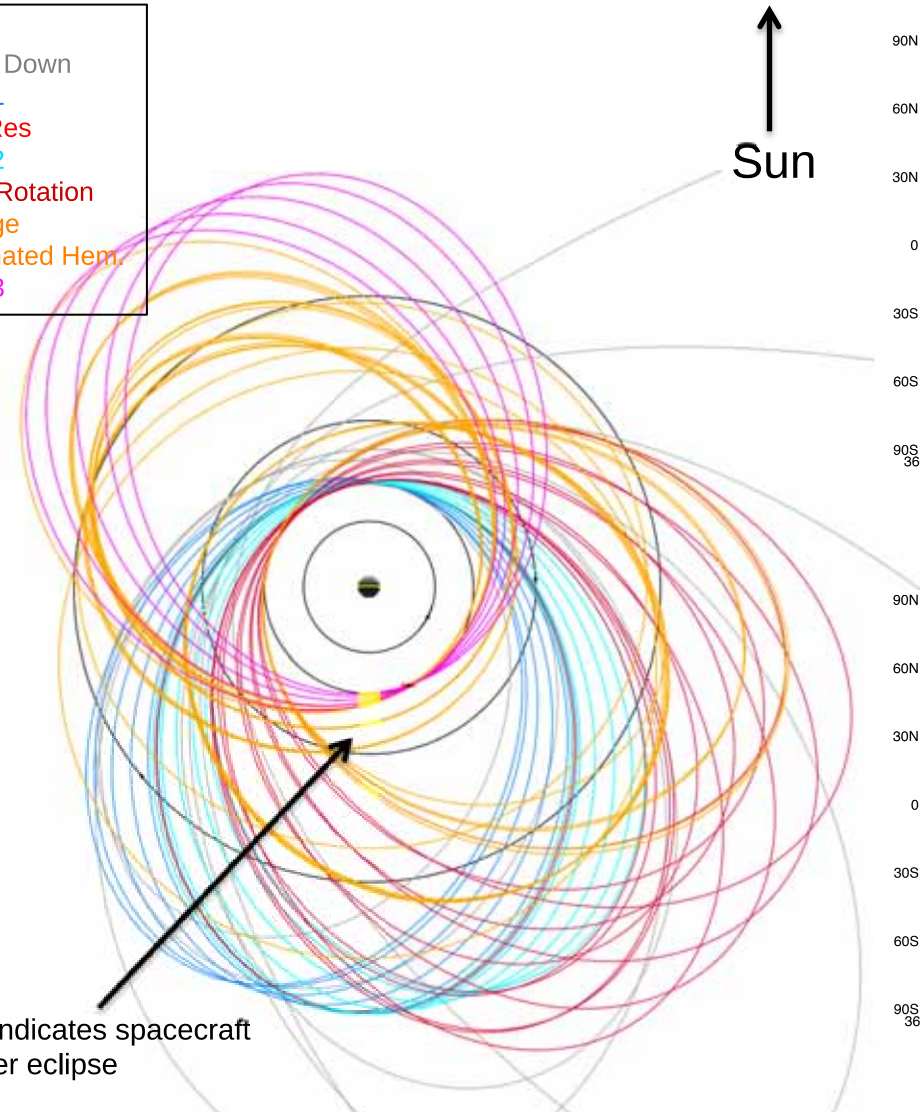


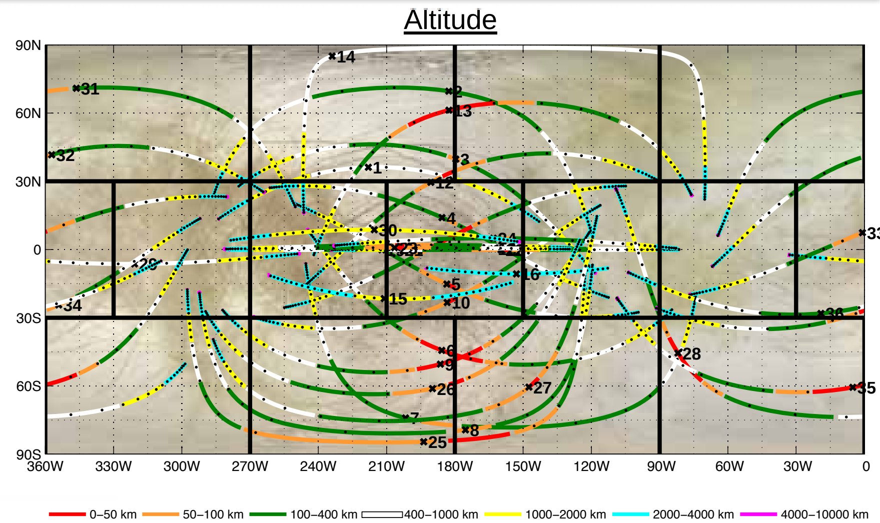


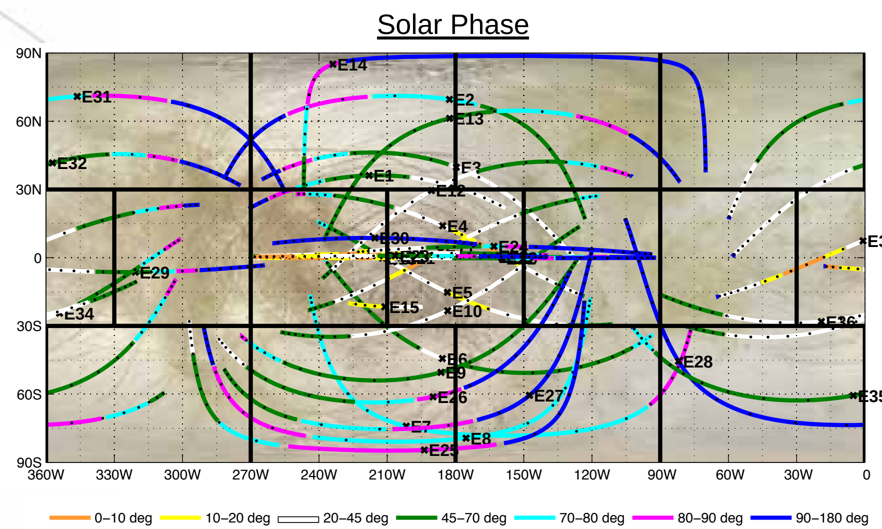


13F7-A21 Phases: Cumulative Build-Up
[COT-3]

Key:
- Pump Down
- COT-1
- Non-Res
- COT-2
- Petal Rotation
- Change Illuminated Hem.
- COT-3



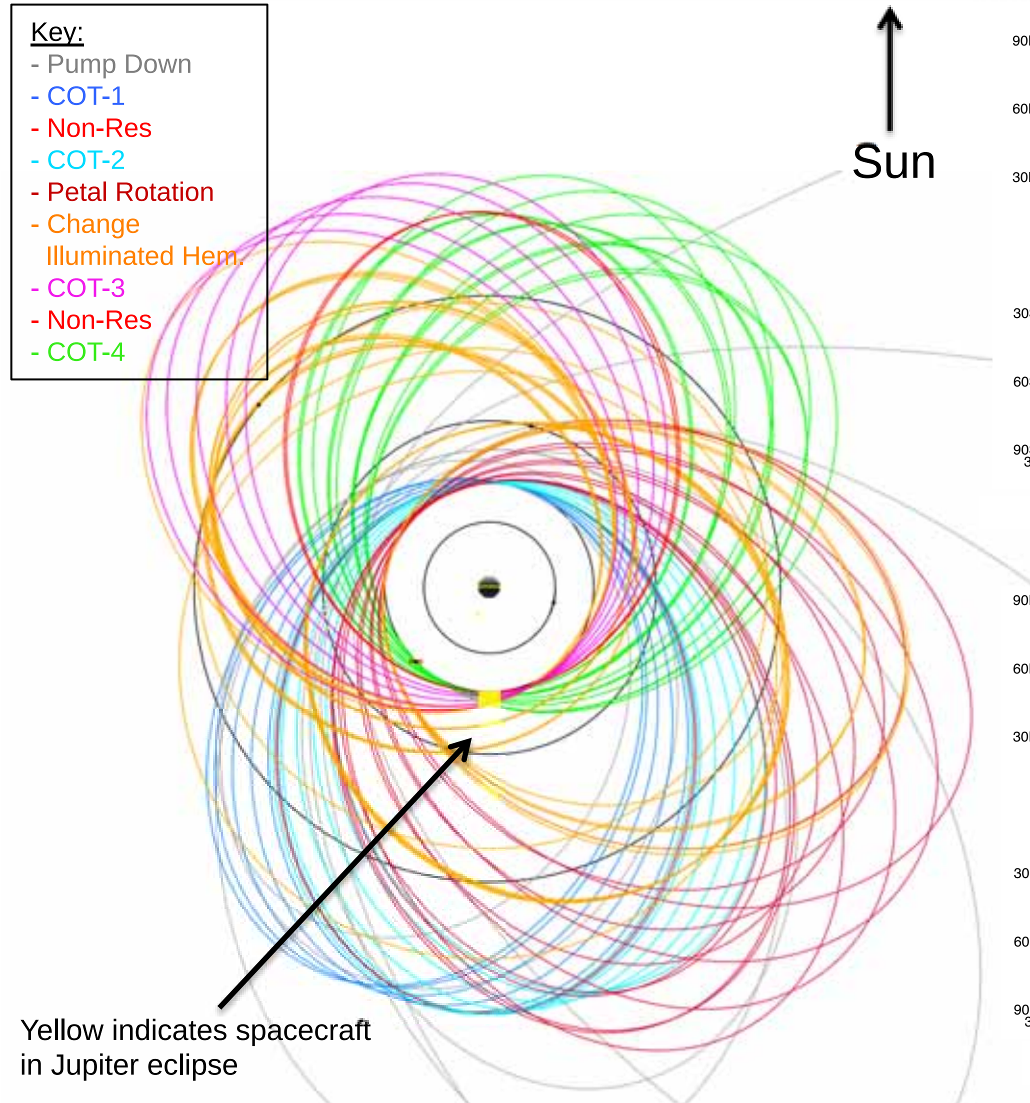




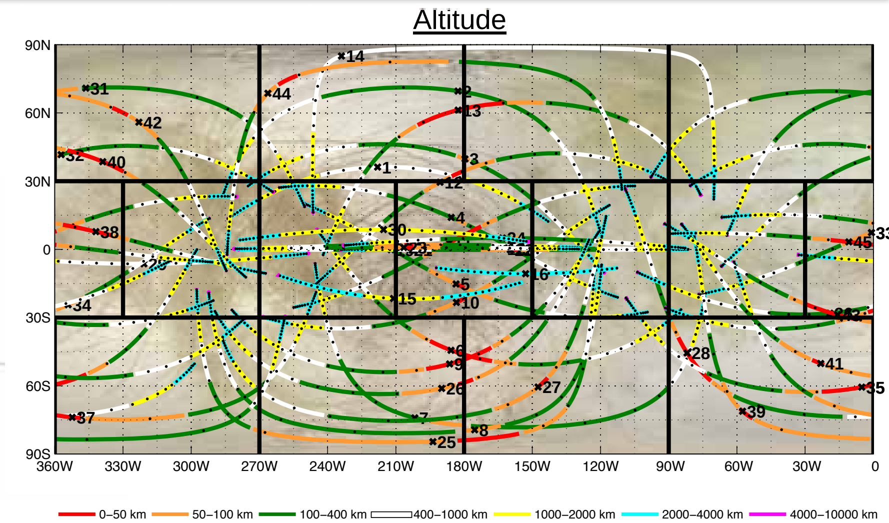
13F7-A21 Phases: Cumulative Build-Up

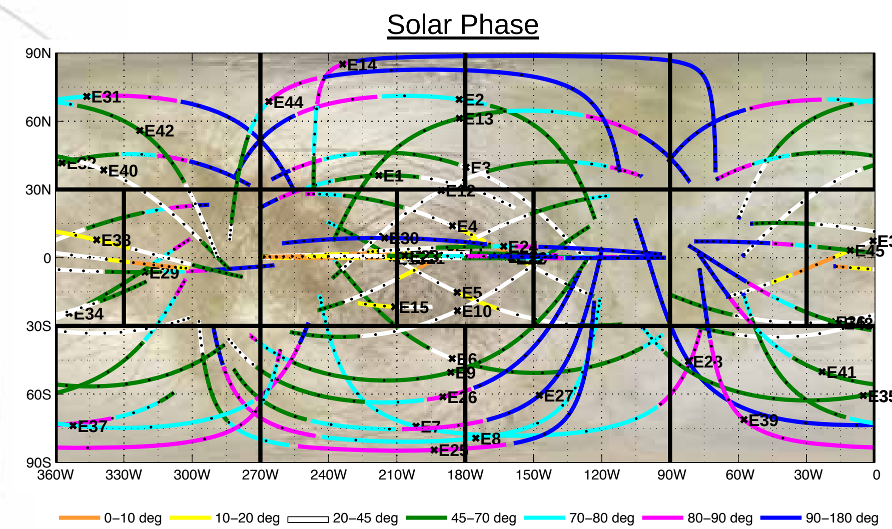
[COT-4]

Key:
- Pump Down
- COT-1
- Non-Res
- COT-2
- Petal Rotation
- Change Illuminated Hem.
- COT-3
- Non-Res
- COT-4



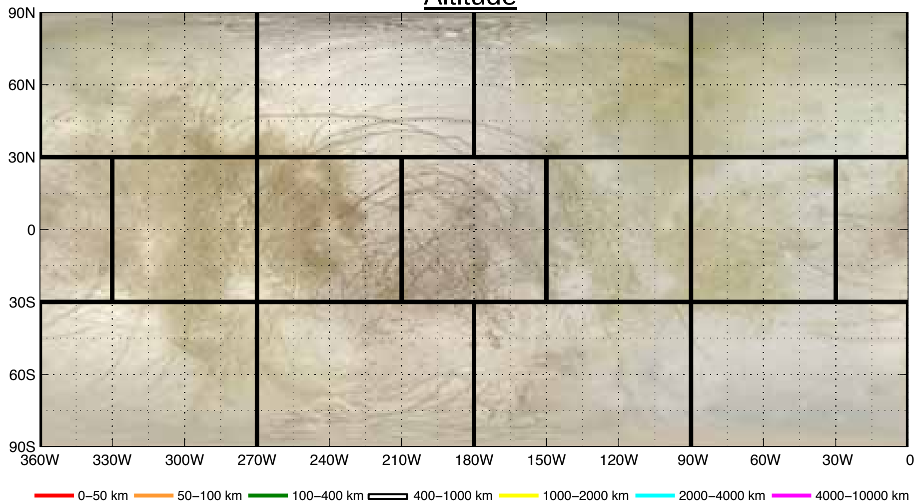
Yellow indicates spacecraft in Jupiter eclipse



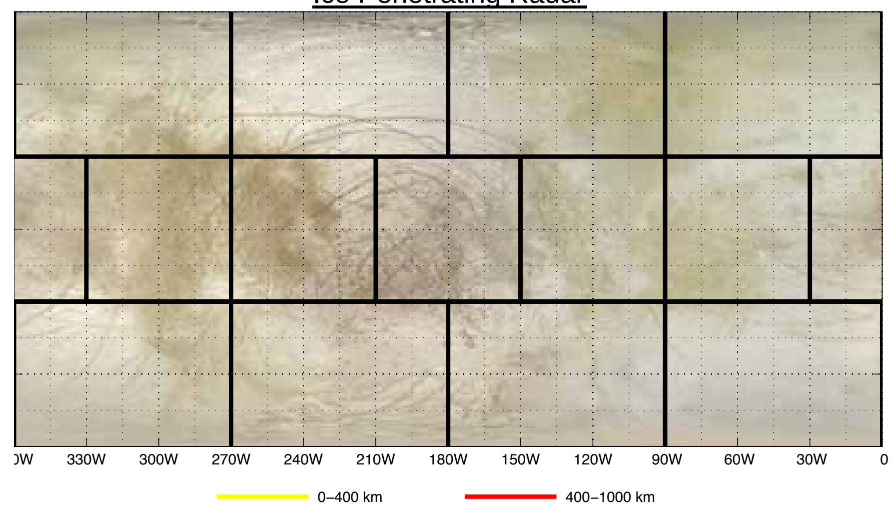


Select Instrument Coverage Build-Up

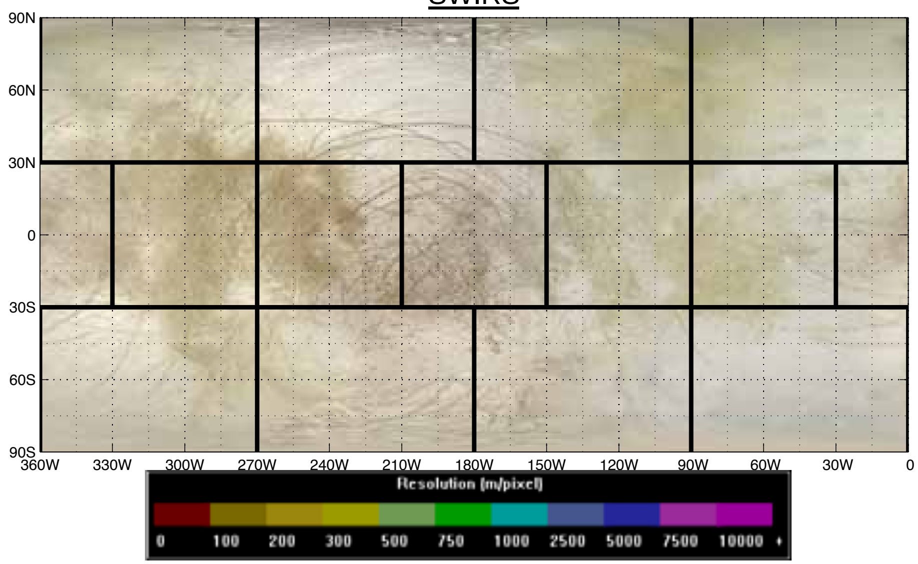
Altitude



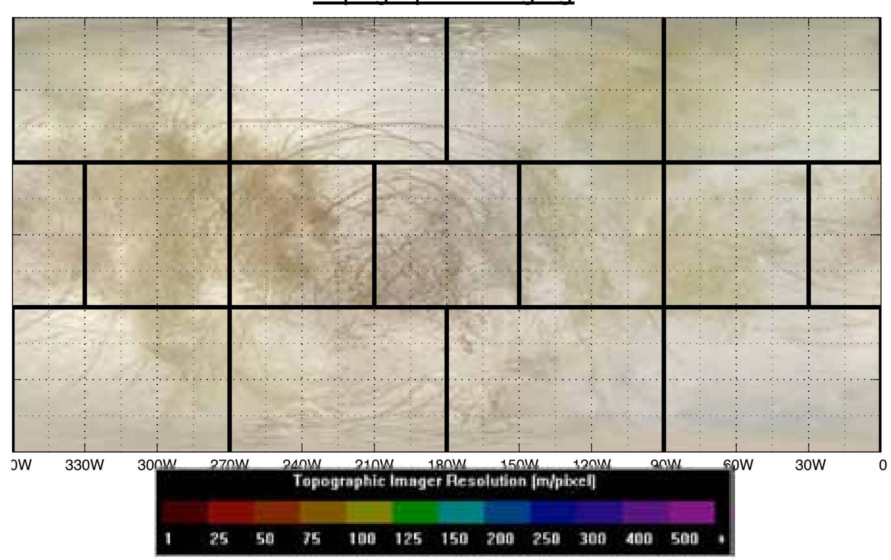
Ice Penetrating Radar



SWIRS



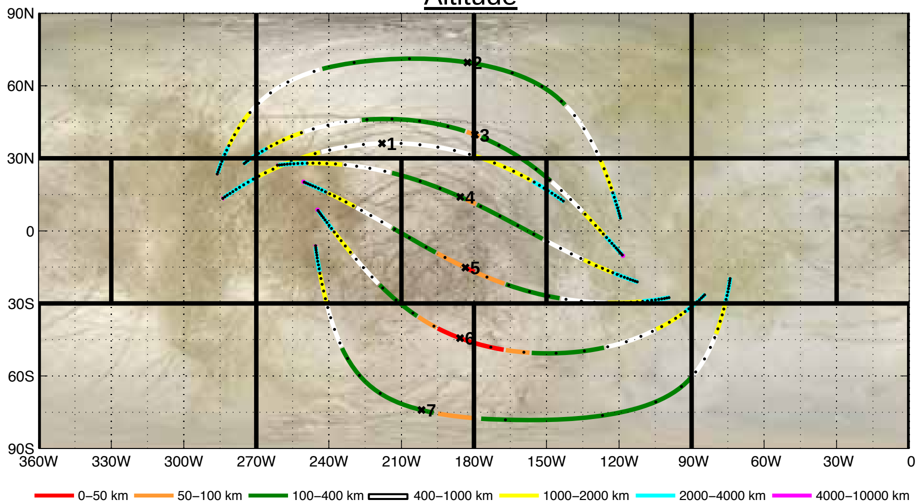
Topographic Imaging



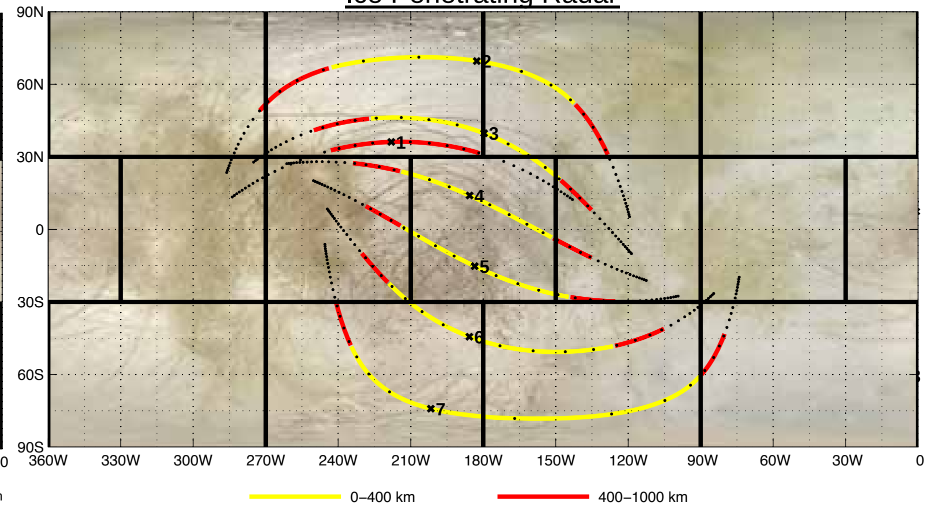
Select Instrument Coverage Build-Up

COT-1

Altitude



Ice Penetrating Radar



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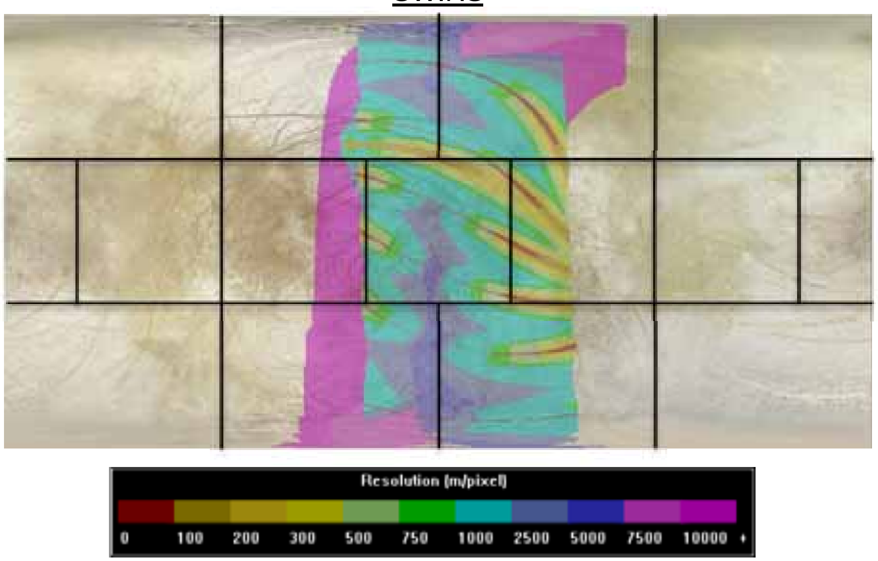
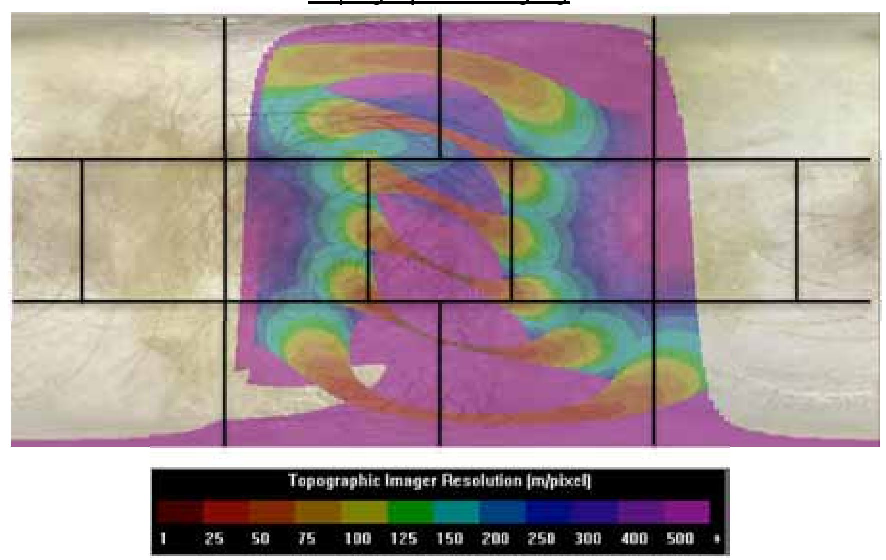


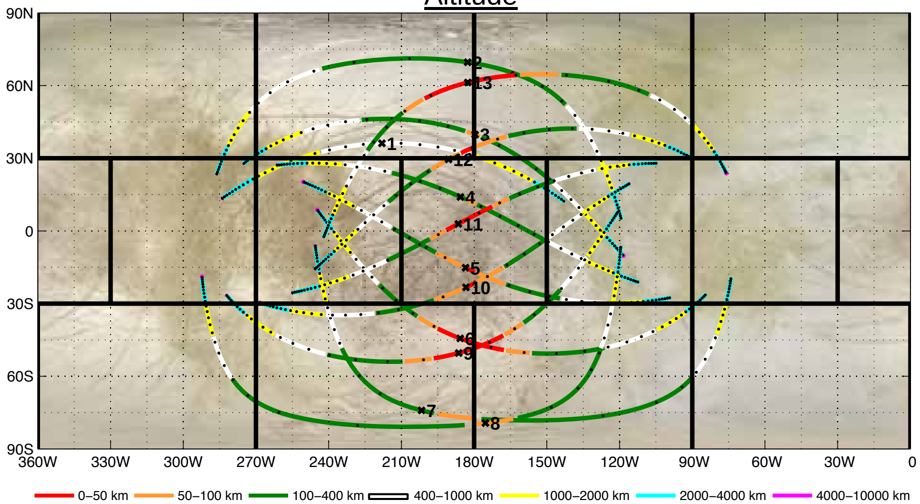
Topographic Imaging



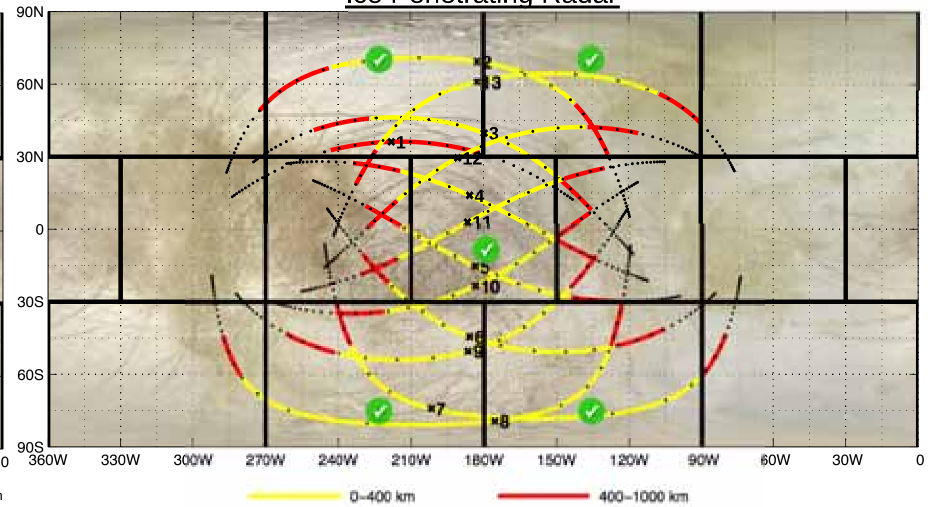
Select Instrument Coverage Build-Up

COT-2

Altitude



Ice Penetrating Radar



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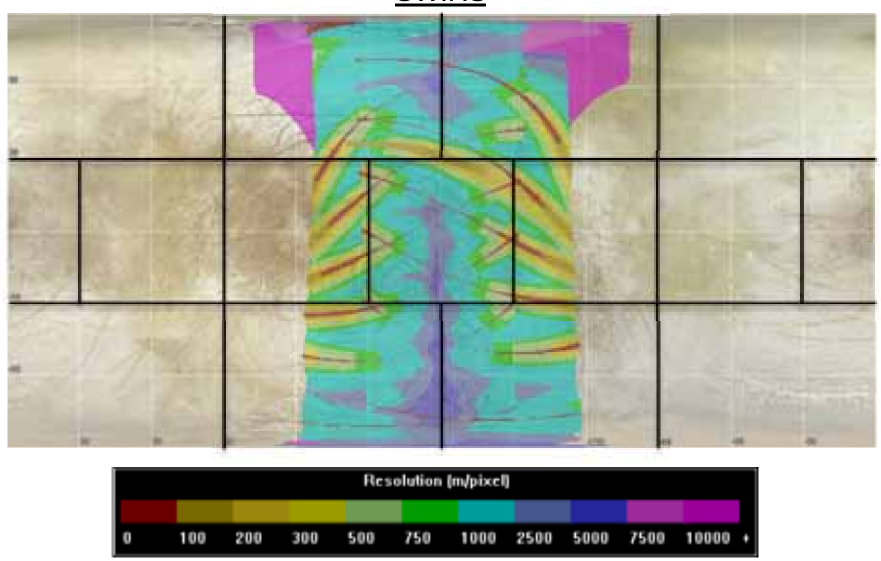
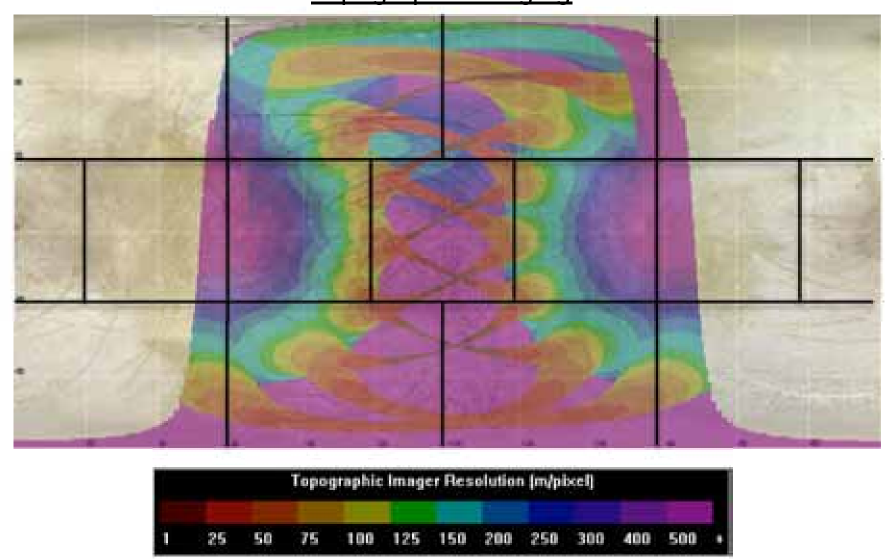


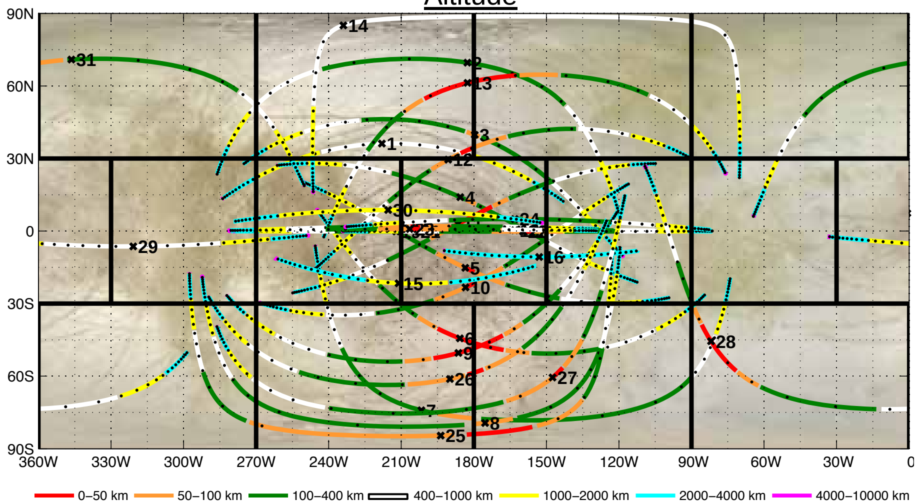
Topographic Imaging



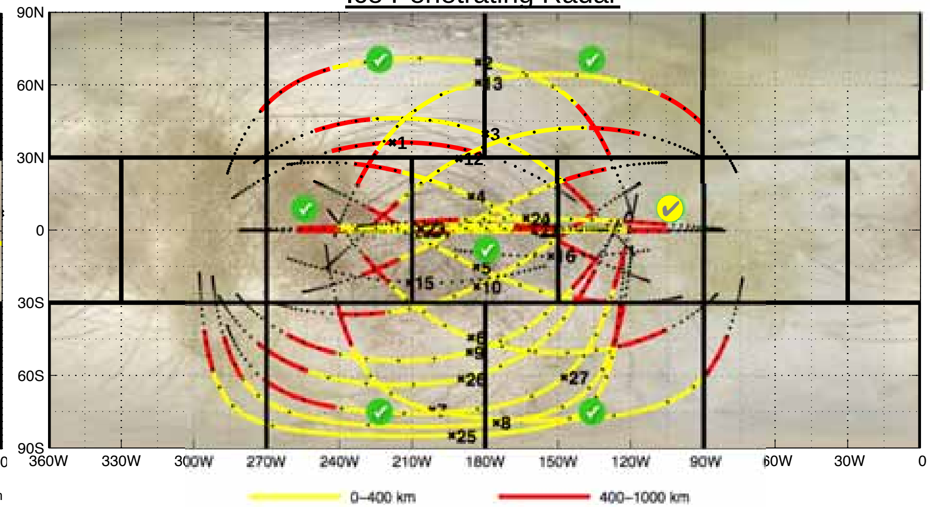
Select Instrument Coverage Build-Up

Petal Rot., Change Illuminated Hem.

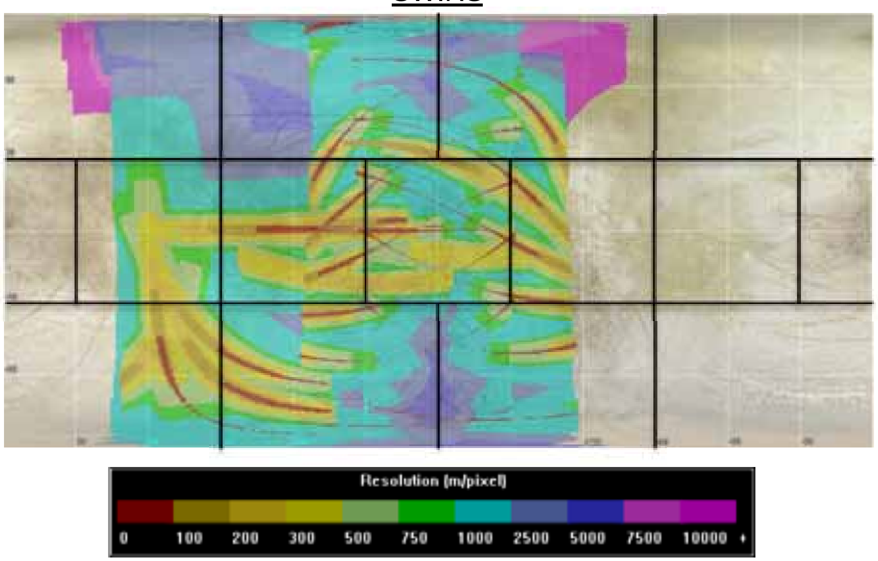
Altitude



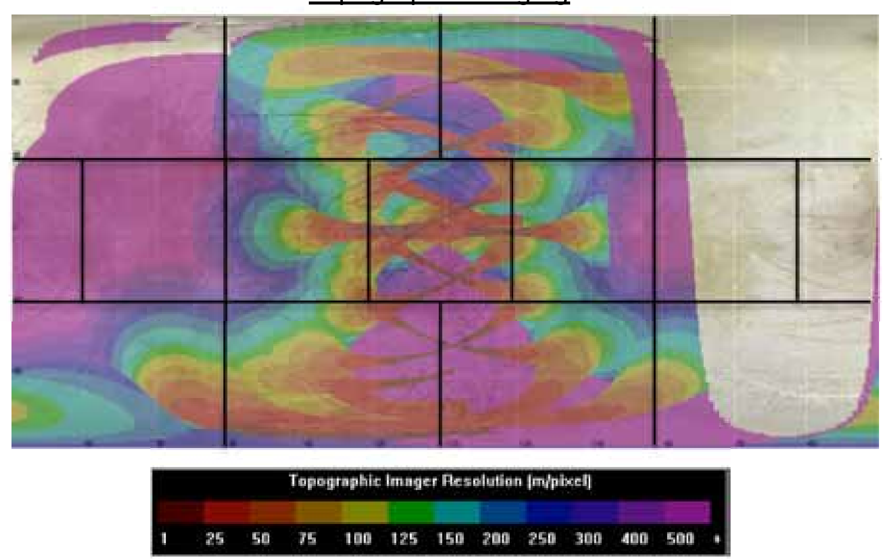
Ice Penetrating Radar



SWIRS



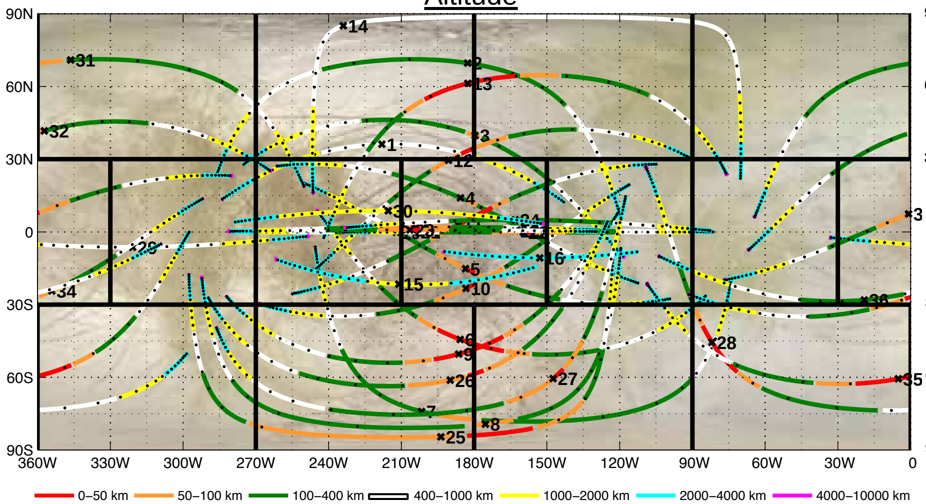
Topographic Imaging



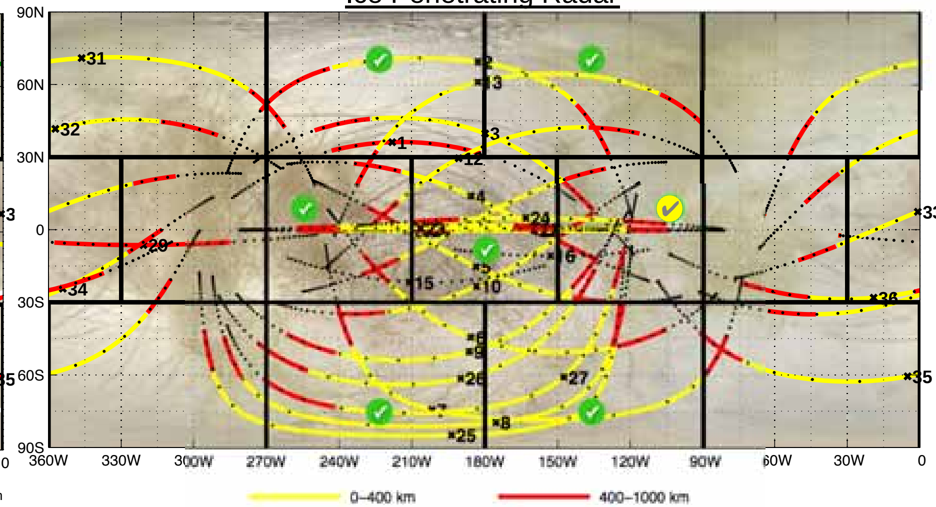
Select Instrument Coverage Build-Up

COT-3

Altitude



Ice Penetrating Radar



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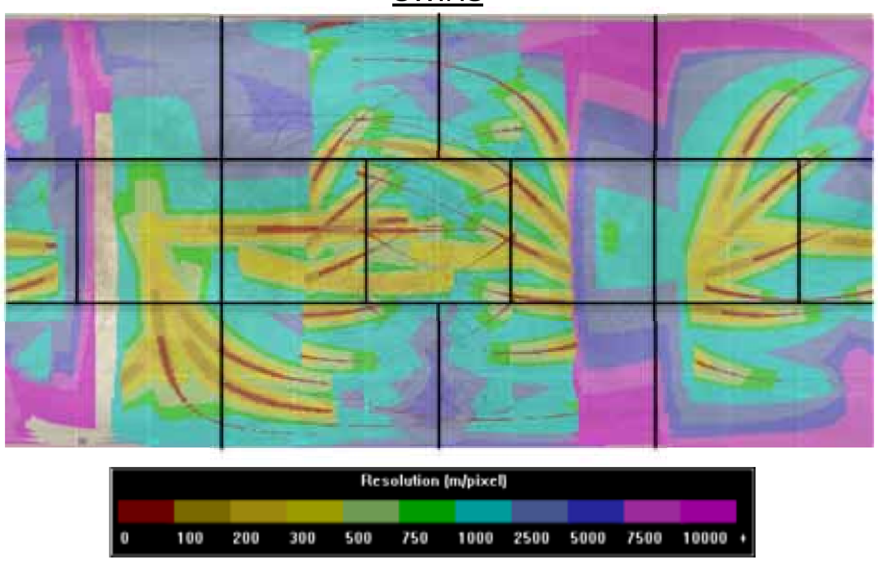
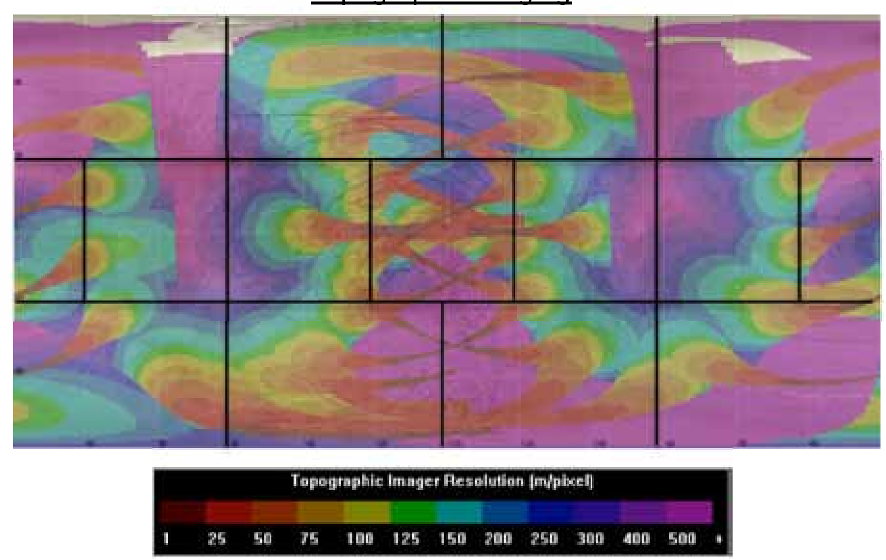


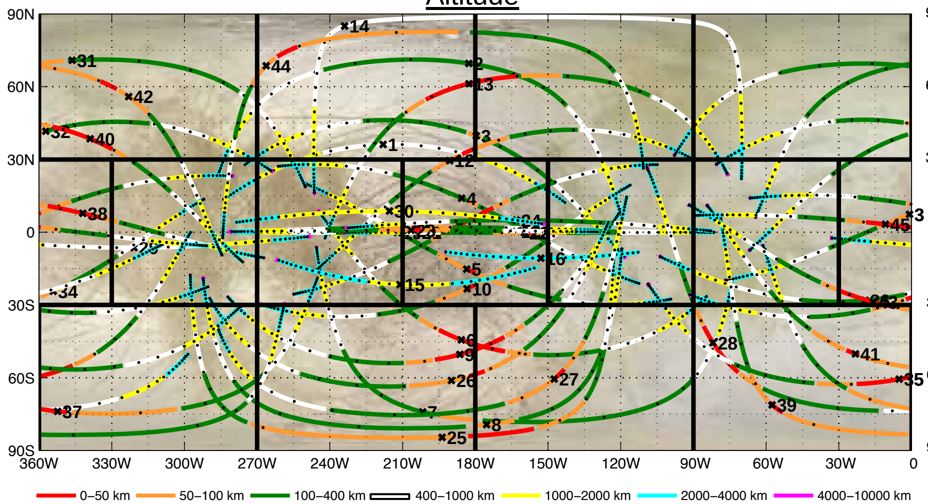
Topographic Imaging



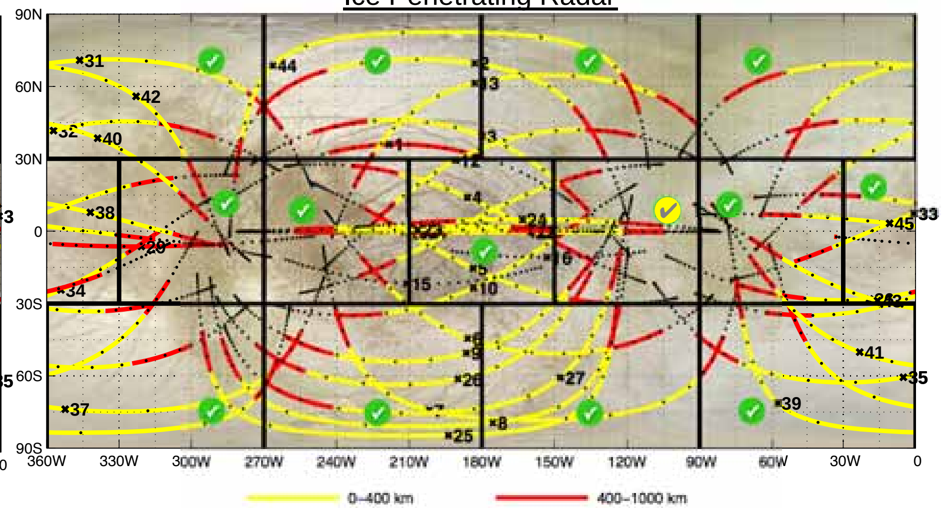
Select Instrument Coverage Build-Up

COT-4

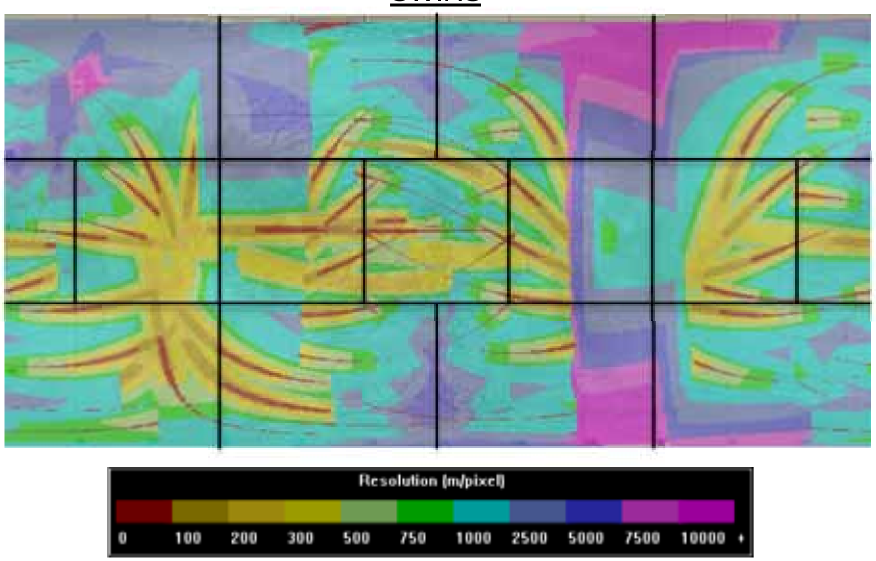
Altitude



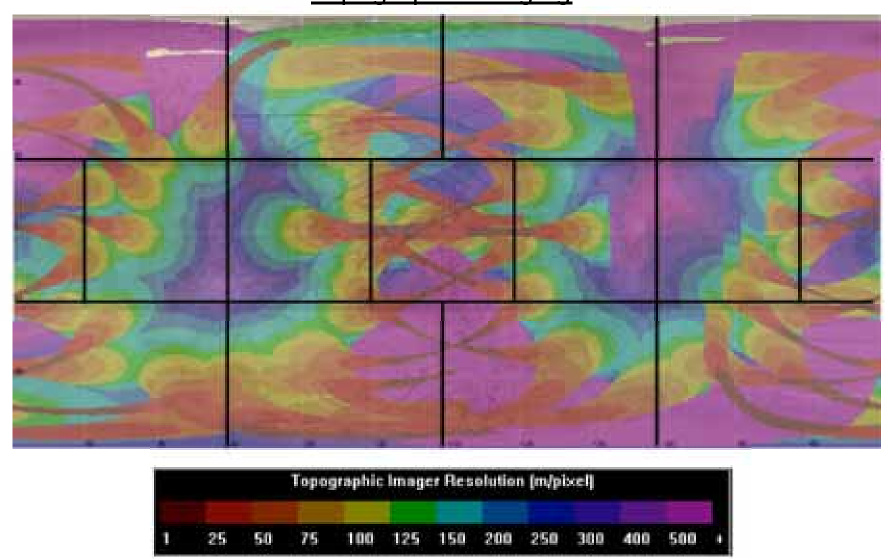
Ice Penetrating Radar



SWIRS



Topographic Imaging

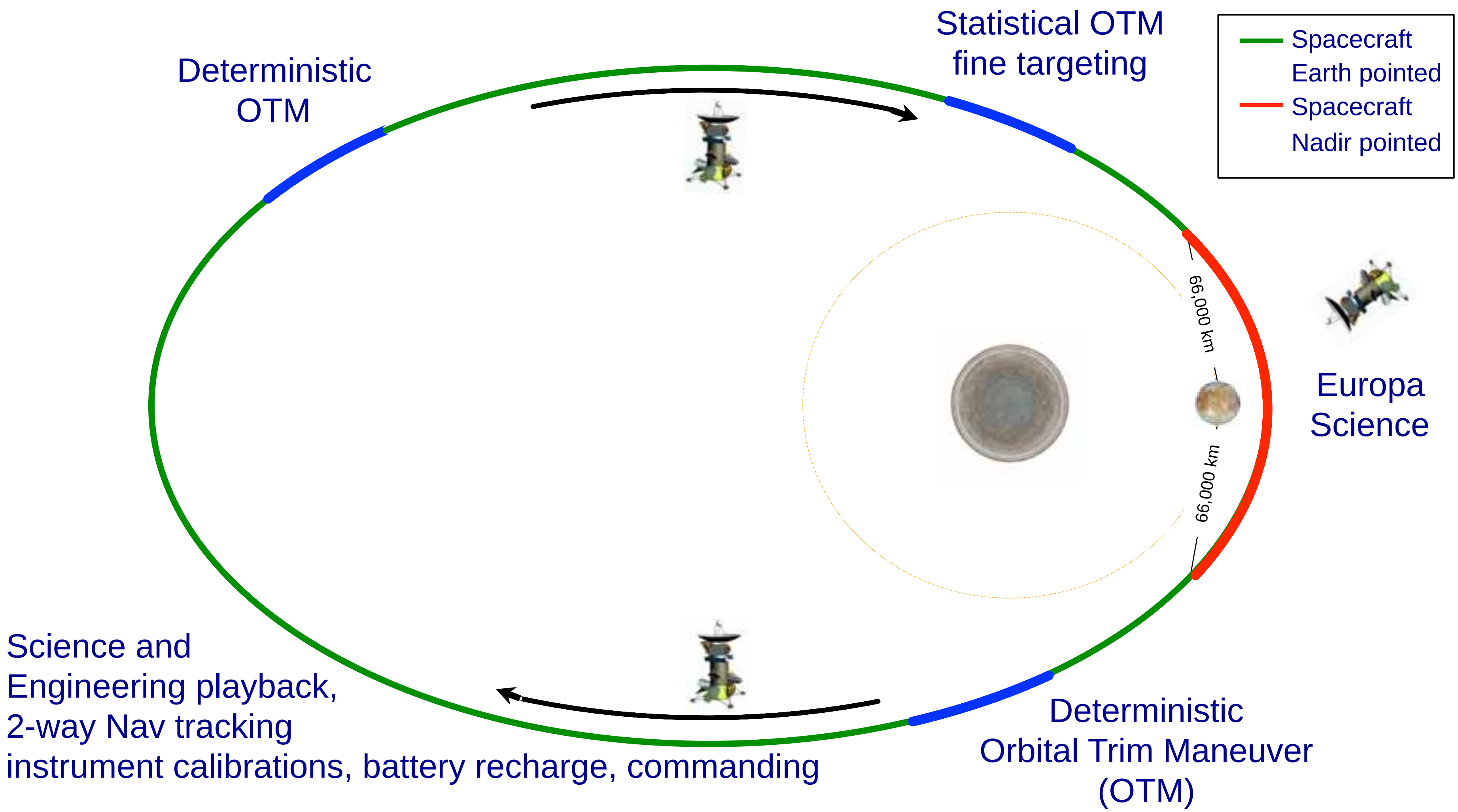


Operations Concept

Tom Magner

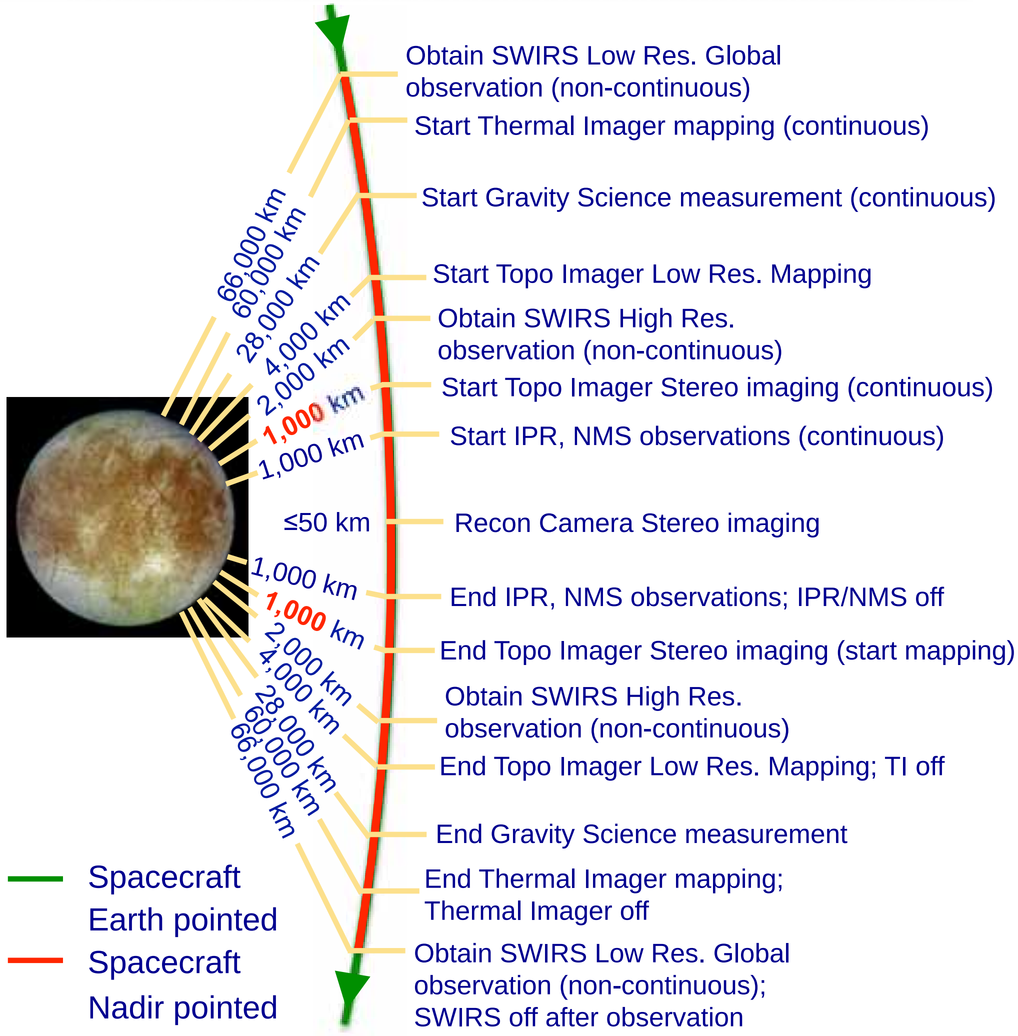
Pre-Project Assistant Manager (APL)

Typical Flyby Petal



Flyby Operations Concept for the Notional Payload

1. **Magnetometer and Langmuir Probes**
   - Continuous measurements
2. **ShortWave InfraRed Spectrometer (SWIRS)**
   - Low res. global observation below 66,000 km
   - High res. observation below 2,000 km
   - Data not acquired continuously
3. **Thermal Imager**
   - Continuous pushbroom thermal imaging below 60,000 km
4. **Gravity Science**
   - Continuous measurements below 28,000 km
5. **Topographical Imager (TI)**
   - Lower res. monoscopic imaging between 4,000 and 1,600 km
   - Pushbroom stereo imaging below 1,600 km
6. **Ice Penetrating Radar (IPR)**
   - Continuous surface observations below 1,000 km
7. **Mass Spectrometer (NMS)**
   - Continuous *In situ* observation below 1,000 km
8. **Reconnaisance Camera**
   - Stereo imaging below 50 km



Data Downlink Scenario

- Science data collection uses model instrument data for altitudes for instrument on times and allocated data volumes
- Instrument calibrations scheduled outside of DSN tracks
  - They add to the data volume, but do not interrupt the science downlinks
- Data remains on-board until transmission confirmation
- The project currently maintains a minimum of 40% data downlink margin
- Current project design can store 4 flybys of science data

Data Downlink Scenario

- DSN Schedule
  - 8 hours on/ 8 hours off
  - 20° minimum elevation
  - 34m antennas: Goldstone, Canberra, Madrid
- Ka band for science data playback
  - 20° elevation, 140 kbps at 5.5 AU
  - 35° elevation, 200 kbps at 5.5 AU
  - 45° elevation, 262 kbps at 5.5 AU
    - All scaled by 10^(2.0log10(5.5/Earth Range))
    - Earth range varies from 4.26 AU to 6.45 AU

Science and Reconnaissance Traceability Updates

Steve Vance (JPL) and Wes Patterson (APL)

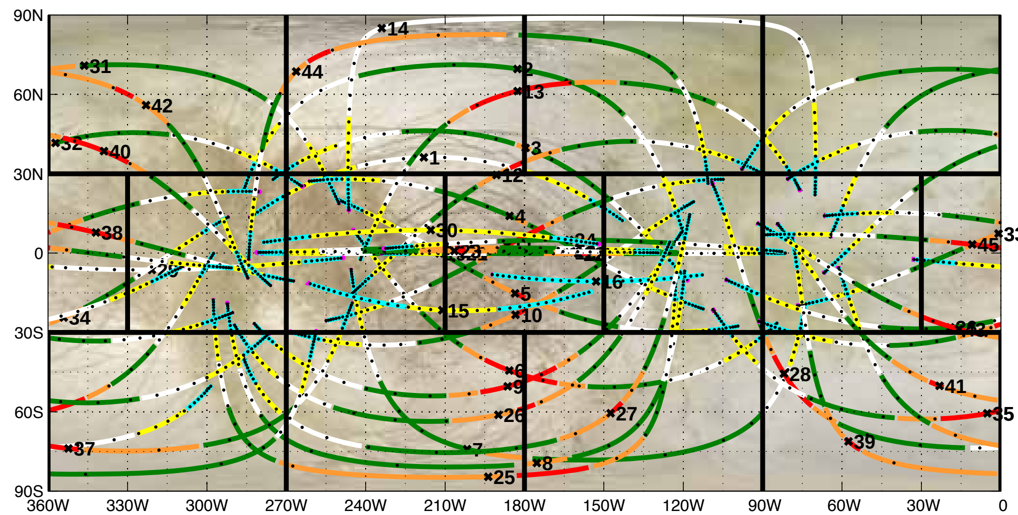
October 23, 2013

Recent Science Traceability Updates

- Since the Dec. 2012 report, details of the Science Traceability Matrix (STM) have been clarified based on comments from the Mission Design group and discussion with SDT members
  - ➢ Clarified wording and understanding
  - ➢ Vetted and quantified measurements by vetting measurement techniques
  - ➢ Clarified “required” vs. “desired” and "baseline" vs. "floor”
  - ➢ Reduced reliance on derived quantities

Science Traceability Clarifications I

- Smoothed wording of the Ice & Ocean objective
- Eliminated vestigial Ice Shell & Ocean measurement (IO.5b) to determine orbital position of Europa's center of mass rel. to Jupiter
- Measurements designated as either "required" or "desired" rather than "baseline" or "floor"
- Clarified that coverage in "any" 11 (baseline) or 8 (floor) of the 14 panels is sufficient coverage (with associated caveats)
- Measurements occurring within "± 2 hours" of c/a now expressed as ± 18 Europa radii
- Sampling a "variety" (e.g. System III longitude, true anomaly) is quantified as sampling at better than 30° and independent of each other



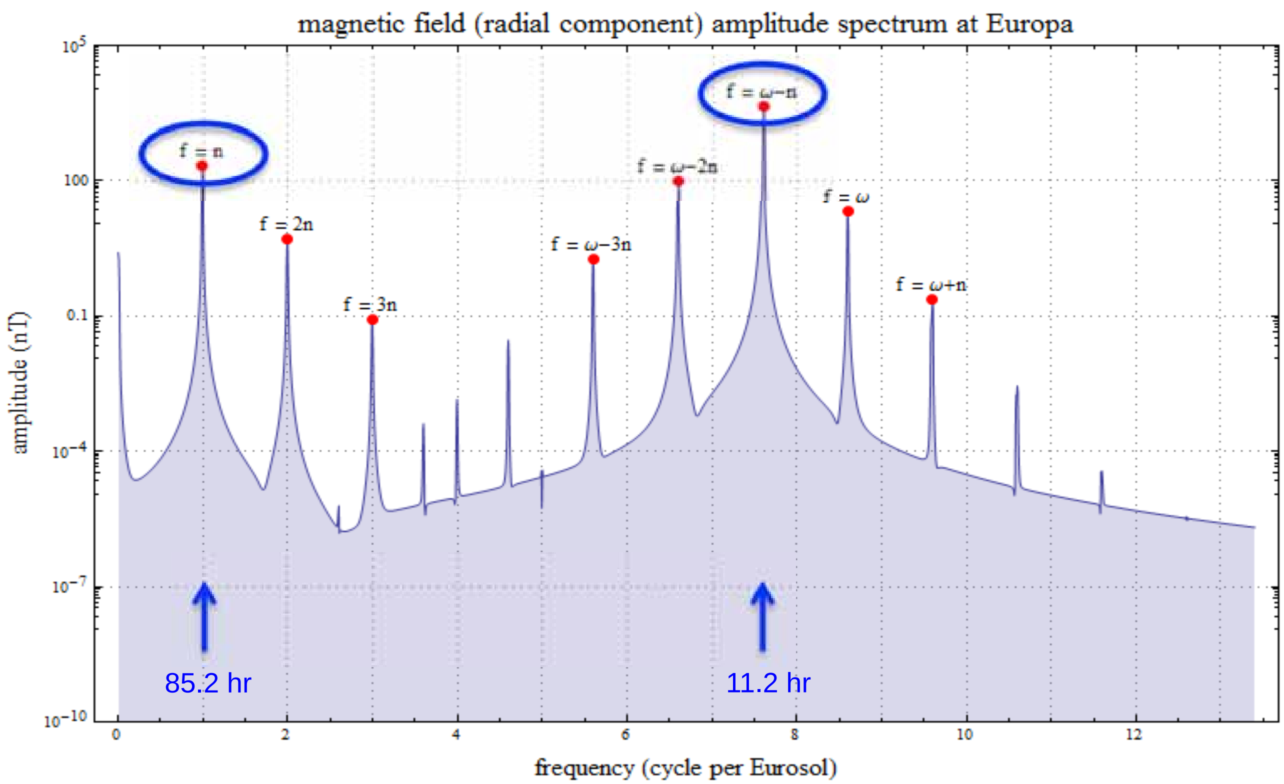
Science Traceability Clarifications II

- Clarified that subsurface horizons should be identifiable “extending 100 meters (required) to 3 km (desired) depth from the surface”
- Clarified that sounding profile width should be encompassed by topographic data
- For composition, clarified that “ability of spacecraft to smoothly scan over the surface" implies instrument articulation, while the spacecraft should be stable and quiet
- Stated the desired stereo imaging coverage as ≥25% of Europa, with sampling in any 11 (baseline) or 8 (floor) of the 14 panels
- Clarified that many of the surface reflectance and high-resolution stereo targets will be selected prior to JOI; stereo targets will lie along the ground track
- For local plasma density, clarified high rate data is assumed as 256 current measurement "sweep" per second
- For composition of ejected surface products, clarified that flyby velocity of < 7 km/s is the baseline

Magnetometry from Flybys

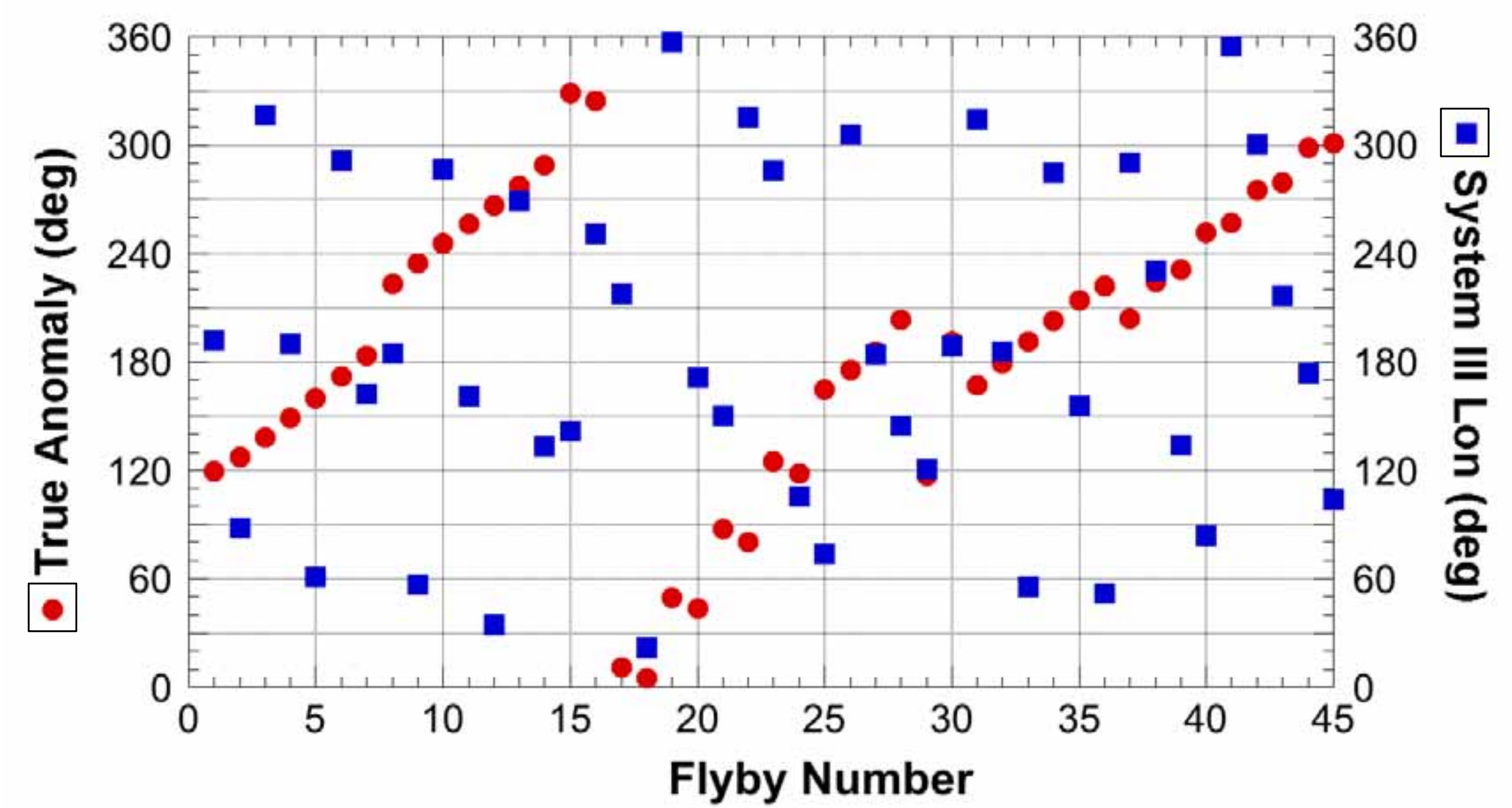
- From 45 flybys of the 13-F7 trajectory, Europa Clipper could measure induction response at the 2 periods with largest input amplitude, necessary to infer ocean salinity and thickness
  - 11.2 hr (Europa synodic period); 85.2 hr (Europa orbital period)

Europa Clipper petal plot



Gravity and Magnetometry from Flybys

- Europa Clipper flybys sample a wide range of true anomalies and Jupiter longitudes to enable gravity (k_2) and magnetic (induced field) measurements

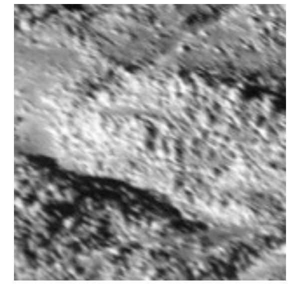


Reconnaissance for a Future Lander

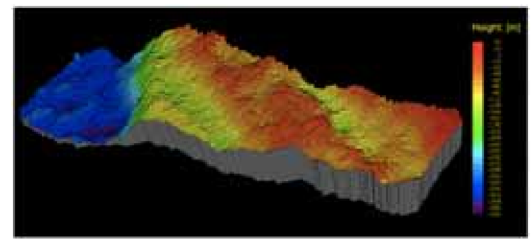
Landing Site Safety and Scientific Value

Reconnaissance Camera:

- High-res imaging for meter-scale roughness

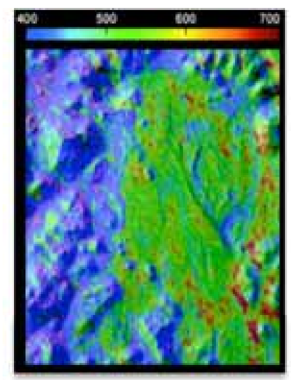


- Stereo imaging for slopes and hazards



Thermal Imager:

- Thermal inertia for block abundance



Radar Scatter:

- Surface roughness

Reconnaissance Traceability Matrix

Reconnaissance Traceability Matrix (RTM) has been scrubbed and updated as follows:

- Two investigations with identical measurements have been merged
- Measurement format has been simplified
- All reconnaissance measurements have been assigned relative priorities

Europa Reconnaissance Traceability Matrix								Priority	Areal coverage (km)		Incidence angle range (degrees)		Spatial resolution (m/pixel)		Local time of day range (hr)		Spectral characteristics	Coincident instrument
	Objective		Investigation		Measurement	Short name	Model Instrument		Baseline	Floor	Baseline	Floor	Baseline	Floor	Baseline	Floor		Baseline
SL. Characterize the Safety of Landing Sites on Europa	Assess the distribution of surface hazards, the load-bearing capacity of the surface, the structure of the subsurface, and the regolith thickness.	SL.1	Determine the distribution of blocks and other roughness elements (e.g., scarps, steps, cracks, divots, cusps, spires, etc.) within a potential landing site at scales that represent a hazard to landing.	SL.1a	Measure the occurrence and lengths of shadows cast by blocks protruding 1 m or more above the surface, and the abundance and nature of surface roughness elements at scales from >10 m to <1 m, through monochromatic imaging at a spatial resolution on the surface of <=0.5 m/pixel.	Blocks	Reconnaissance Camera (RC)	R1	5x10	2x10	45-70	20-80	0.5				Monochrome	
				SL.1b	Characterize the fractional area of block coverage and the areal distribution of roughness elements by measuring the contrast in thermal emission between at least 2 spectral channels (with less than 80% overlap) at local times of day between 10 AM and 3 PM and at a spatial resolution on the surface of <= 250 m/pixel.		Thermal Imager (ThI)	R2	5x10	2x10			<250		10-3 pm	10-3 + Additional times	2 spectral channels <80% overlap	Recon camera
		SL.2	Determine the distribution of slopes within a potential landing site over baselines relevant to a lander.	SL.2a	Measure surface slopes of up to 25° on a 3 m baseline for all azimuths by acquiring stereo paired images with a spatial resolution of <=0.75 m/pixel.	Slopes	Reconnaissance Camera (RC)	R1	5x10 (>90% cross- and down-track overlap)	2x10 (>90% cross- and down-track overlap)	20-70 (each pair); 15-30 convergence angle		<0.75				Monochrome	
				SL.2b	Characterize the statistical distribution of slopes from nadir track altimetric information having a relative height accuracy of 1 m.		Ice Penetrating Radar (IPR)	R3	SAME AS SCIENCE TRACEABILITY MATRIX*									Recon camera
		SL.3N	Characterize the regolith cohesiveness and slope stability within a potential landing site.	SL.3a	Determine the regolith-component thermal inertia of the upper decimeter-scale surface layer by measuring the contrast in thermal emission between at least 2 spectral channels (with less than 80% overlap) at	Regolith cohesion	Thermal Imager (ThI)	R3	SAME AS 1B									
				SL.3b	Identify small scale landforms associated with mass movement from monochromatic		Reconnaissance Camera (RC)	R3	SAME AS 1A									

Reconnaissance Measurement Prioritization

Reconnaissance measurements have been prioritized as to be accommodated in the operations plan or descoped if necessary

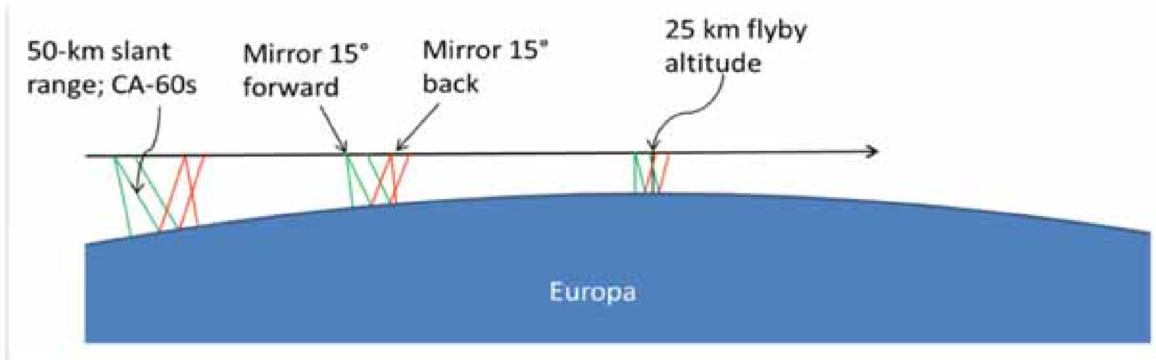
- R1: Highest priority
  - Required: Fully characterize 15 sites containing landforms of high scientific interest. Acquire for floor measurement ellipses (2 x 10 km).
  - Desired: Acquire for baseline measurement ellipses (5 x 10 km)
- R2: Medium priority
  - Required: Characterize all major landform types
  - Desired: Acquire over all candidate floor (2 x 10 km) landing ellipses
- R3: Lowest priority
  - Acquire on a best-effort basis

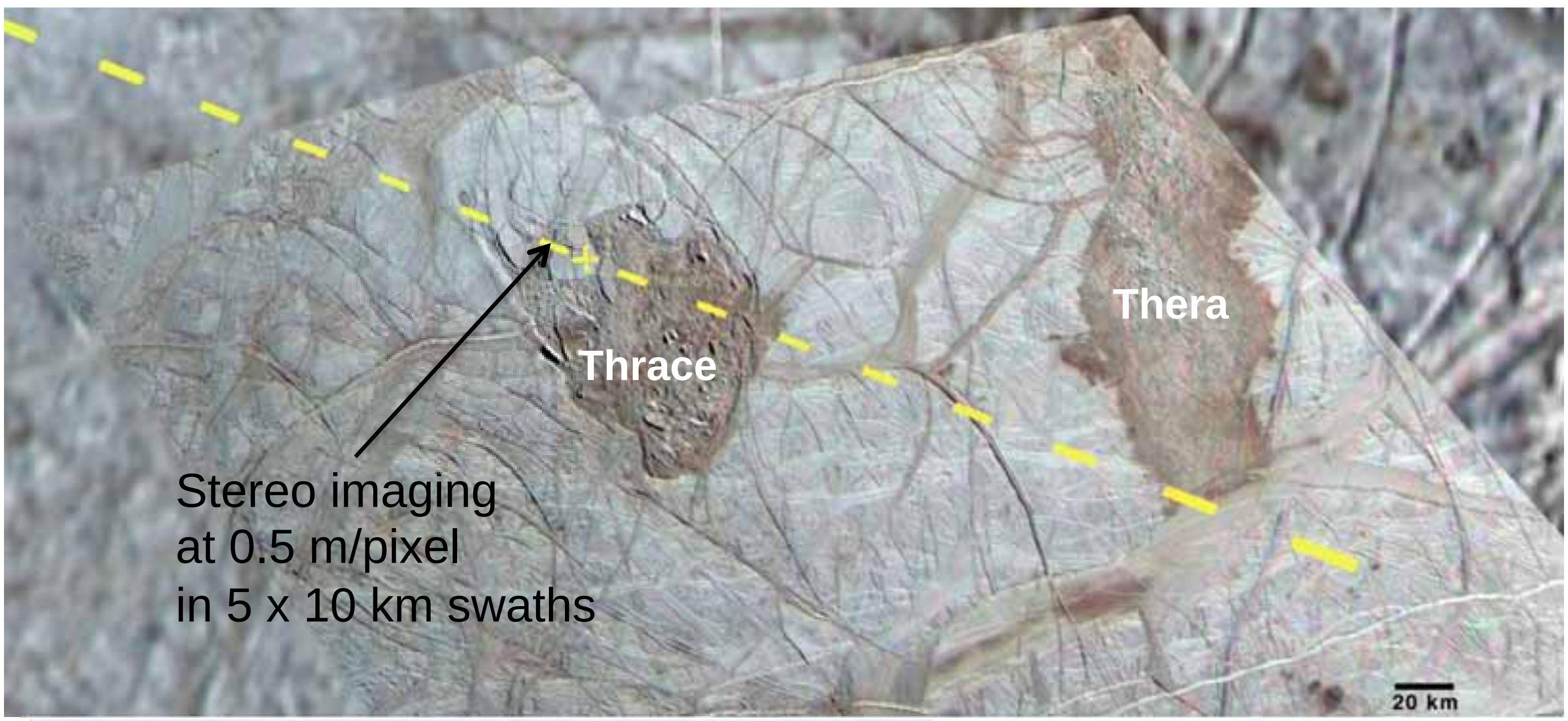
Note: Recon-compatible flybys (25 km altitude) to be chosen ahead of time, providing nadir targeting opportunities.

Reconnaissance Imaging Scenario

Example:

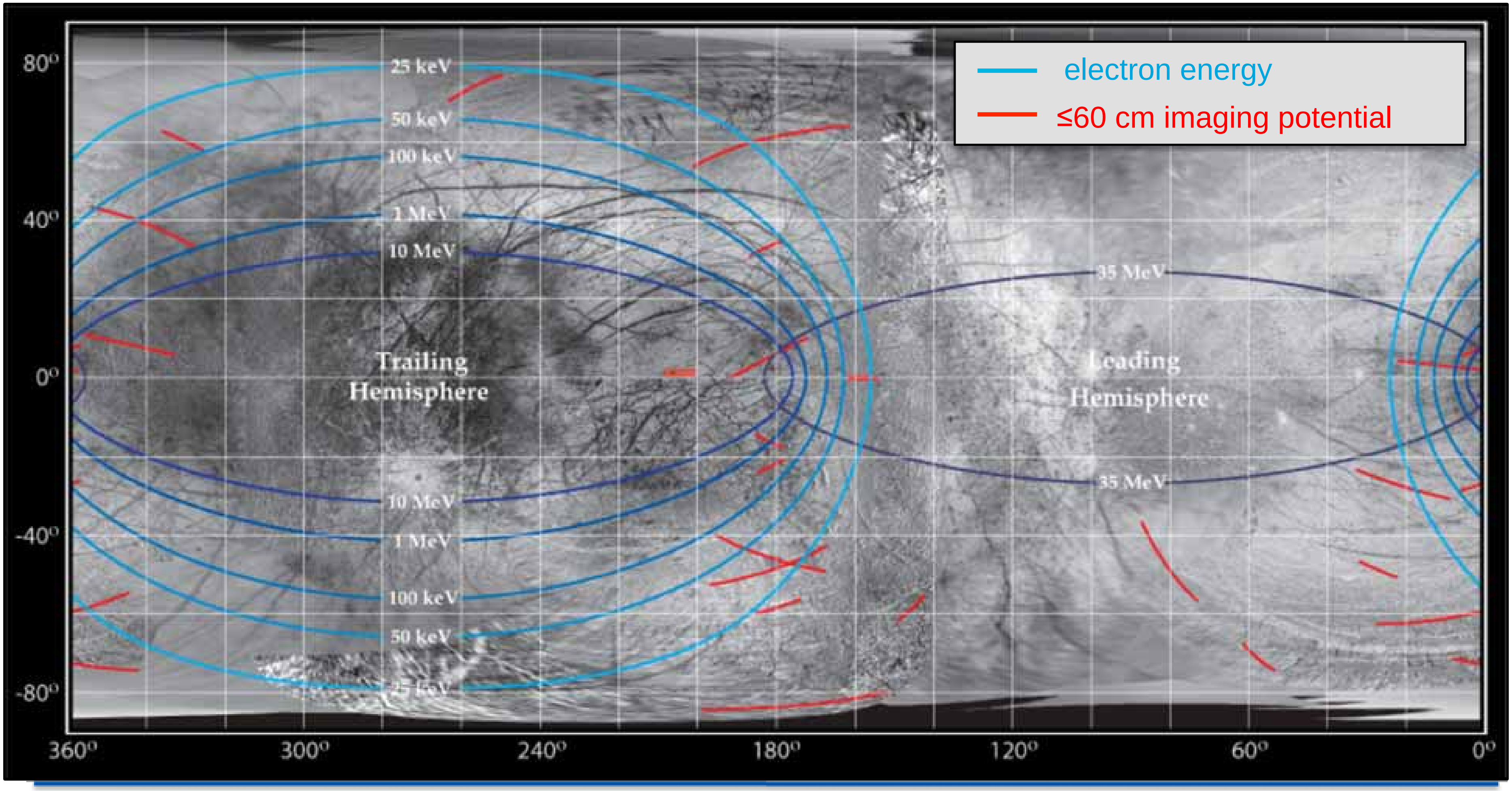
Reconnaissance Camera

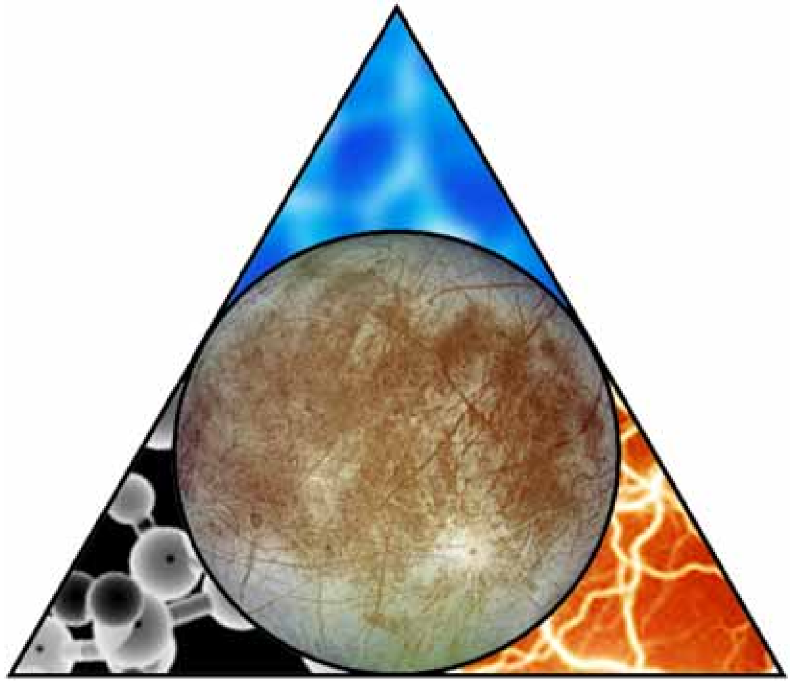




Reconnaissance Site Distribution

- Landing site reconnaissance globally, including in lower radiation regions most relevant to a future lander mission





Logistics and Closing Remarks

Valerie Thomas

Pre-Project Payload Manager

Future Interactions

- Future engagement between ICEE teams and the Europa Pre-Project Team is fully voluntary, and the following opportunities are offered:
  - Teams that have additional questions can contact the Pre-Project directly to arrange for individual follow-up phone calls
  - Europa Pre-Project team members can arrange to visit individual PI institutions. High-level topics of discussion will be documented by the Pre-Project; details will only be documented with permission or request from an individual team
  - The Europa Pre-Project Team will establish regular individual telecons with each PI, if interested. It is anticipated that these would be ½ hour once a month. Again, high level topics of discussion would be documented by the Europa Pre-Project; details will only be documented with permission or request from an individual team

Documentation

- An external website has been established to post all presentations, documents, and artifacts provided to the teams. This information will be available to all the ICEE teams, the rest of the scientific community, and the public, in order to include those potential proposers that were not selected for an ICEE award.
- Science and Reconnaissance traceability matrices have been placed under configuration control and will be available on the website, including a change log with change rationale.

Information that would be Beneficial to the Europa Pre-Project Team

- It is the intent of the Europa Pre-Project accommodation studies to develop concepts that are inclusive of innovative candidate instrument solutions.
- Payload accommodation information, issues or concerns that the ICEE teams identify will be particularly helpful in formulating the Europa Clipper mission and developing the supporting documentation, including the PIP, for the AO.
- Given the challenging radiation environment and planetary protection requirements, the Pre-Project team offers the opportunity to review and comment on ICEE team radiation test plans or planetary protection approaches. This would be of mutual benefit to ICEE proposers and the Europa Pre-Project team, given that these represent two of the most significant project risks.
- The Europa Pre-Project Team also requests permission to attend the ICEE teams' final briefings at NASA headquarters, in order to understand instrument accommodation, radiation and planetary protection related issues.

Protection of Proprietary Information

- The Europa team is hopeful that the PIs will wish to share details of their instrument concepts with us. While all information the Europa Pre-Project team presents to the ICEE teams will be made publicly available, it is clear that not all information provided or disclosed by the ICEE teams can or should be made public.

- To ensure that proprietary information and competition sensitive information such as design and performance information is protected, Non-Disclosure Agreements (NDAs) can be executed between JPL/APL and the PI institutions.
  - We kindly ask that general accommodation information not be marked as “proprietary information” or have any other restrictive markings.
    - Examples of general accommodation information are mass, power or volume data, which would allow the verification of current estimates for the Europa Clipper Model payload.
  - JPL-led teams would not need NDAs if JPL is not disclosing Caltech proprietary information to someone other than NASA
  - APL-led teams working on Europa Clipper subcontracts should be covered by the subcontracts General Provisions
  - Specific details of the NDAs can be worked individually with each additional instrument team.

Contact Information

Payload Manager: Valerie Thomas
valerie.c.thomas@jpl.nasa.gov
818-354-5429

Project Manager: Barry Goldstein
barry.g.goldstein@jpl.nasa.gov
818-354-6462

Project Scientist: Bob Pappalardo
pappalardo@jpl.nasa.gov
818-354-5837

Presentation material, documents and other information will be posted on this public website:

http://solarsystem.nasa.gov/europa/technical.cfm

Closing Remarks

The Europa Team looks forward to having a productive dialog with you on how to best explore Europa and hopes to establish arrangements with each of you for future engagement.

Q&A