Study Team

Science Definition Team
- Greeley, Co-Chair (ASU)
- Pappalardo, Co-Chair (JPL)
- Bills (GSFC)
- Blankenship (Texas)
- Khurana (UCLA)
- McCord (SSI/BFC)
- Moore (UCLA)
- Paranicas (APL)
- Prockter, JSO Co-Chair (APL)
- Sogin (WHOI)

Engineering-Technical Team
- Clark
- Abelson
- Jorgenson
- Kahn
- Kirby (APL)
- Lock
- Man
- Rasmussen

Overview of Science Process

- Review current status of knowledge and consider highest-priority outstanding questions
- Work closely with engineering-technical team
- Define for Europa (update and refine previous work)
  - Goal ⇒ Objectives ⇒ Investigations (prioritized) ⇒ Measurements (prioritized)
- Trace from NRC/NASA science objectives
- Identify instruments ("straw person" payload) to enable the measurements
- Evaluate possible "platforms" (flyby, lander, orbiter) to make measurements and determine science value
- Derive baseline and performance floor scenarios
- Determine prioritized "descopes"
- Interface with JSO SDT

Science Background

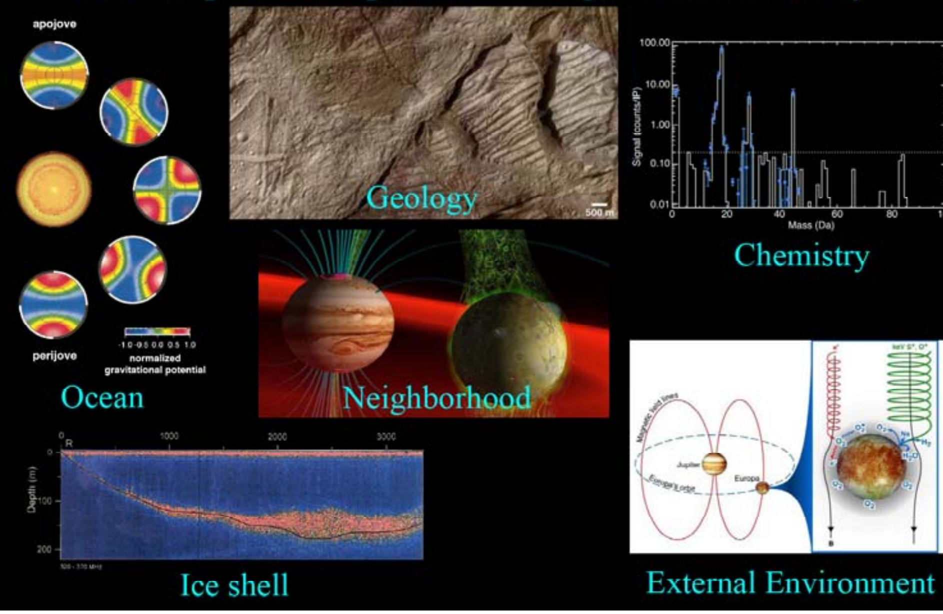
- Brief science reviews
  - led to identification of key outstanding science issues to be addressed by next mission to Europa
  - Astrobiology — Chris Chyba, Kevin Hand, Mitch Sogin
  - Geophysics/interior — Bruce Bills
  - Geology — Louise Prockter
  - Surface composition — Tom McCord
  - Magnetometry — Krishan Khurana
  - Particles — Chris Paranicas
- Goal, Objectives, Investigations, Measurements then flowed from the key science issues

Invited Presentations

- Interleaved with the science discussions, SDT received presentations on relevant engineering, technical, and sciences issues
  - "Auxiliary" payloads (landers, sub-satellites, impactor)
  - Power-source options
  - Radiation mitigation
  - Planetary protection
  - Rad-hard memory
  - Instrument concepts (laser altimetry, thermal mapper, UV, INMS, radar topomapper, radar spectrometry)

Europa Science Objectives

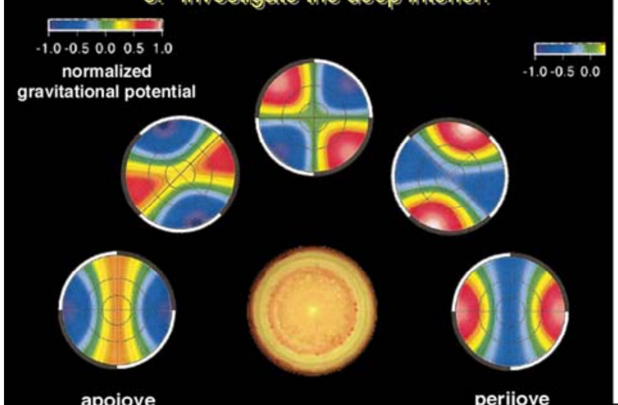
Goal: Explore Europa and investigate its habitability.

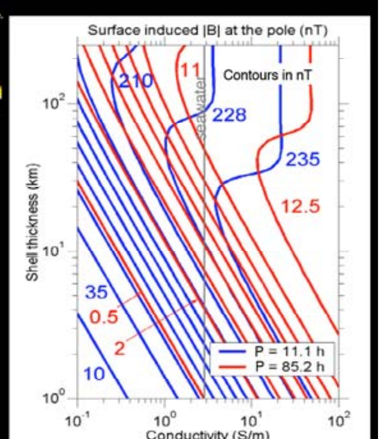


Europa's Ocean

A. Characterize the ocean and deep interior.

1. Determine the amplitude and phase of the gravitational tides.
2. Determine the induction response from the ocean over multiple frequencies.
3. Characterize surface motion over the tidal cycle.
4. Determine the dynamical rotation state.
5. Investigate the deep interior.

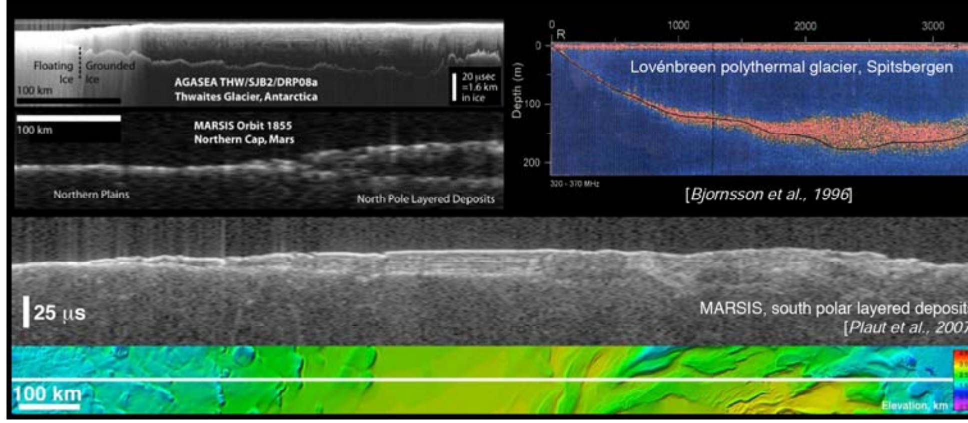




Europa's Ice Shell

B. Characterize the ice shell and any subsurface water, and the nature of surface-ice-ocean exchange.

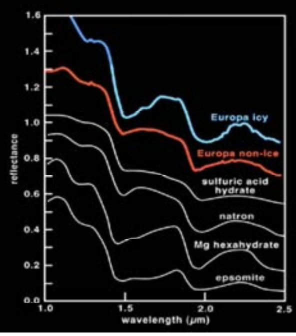
1. Characterize the distribution of any shallow subsurface water.
2. Search for an ice-ocean interface.
3. Correlate surface features and subsurface structure to investigate processes governing communication among the surface, ice shell, and ocean.

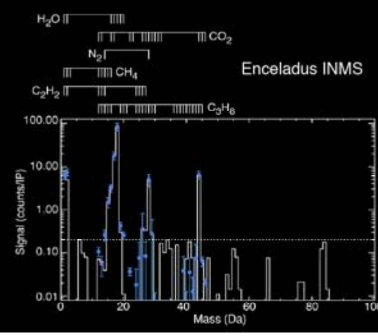


Europa's Chemistry

C. Determine global surface compositions and chemistry, especially as related to habitability.

1. Characterize surface organic and inorganic chemistry, including abundances and distributions of materials, with emphasis on indicators of habitability.
2. Relate compositions to geological processes, especially communication with the interior.
3. Determine the effects of radiation on surface materials, including albedo, sputtering, and redox chemistry.
4. Characterize the nature of exogenic materials.





Europa's Geology

D. Understand the formation of surface features, including sites of recent or current activity, and identify and characterize candidate sites for future *in situ* exploration.

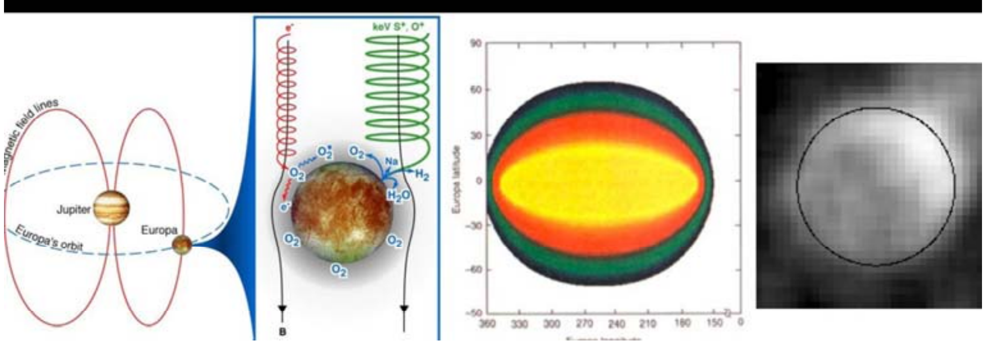
1. Characterize cryovolcanic, tectonic, and impact features.
2. Search for areas of recent or current geological activity.
3. Investigate global and local heat flow.
4. Assess relative surface ages.
5. Assess the physical properties of the regolith, and assess processes of erosion and deposition.

500 m

Europa's External Environment

E. Characterize the magnetic environment and moon-particle interactions.

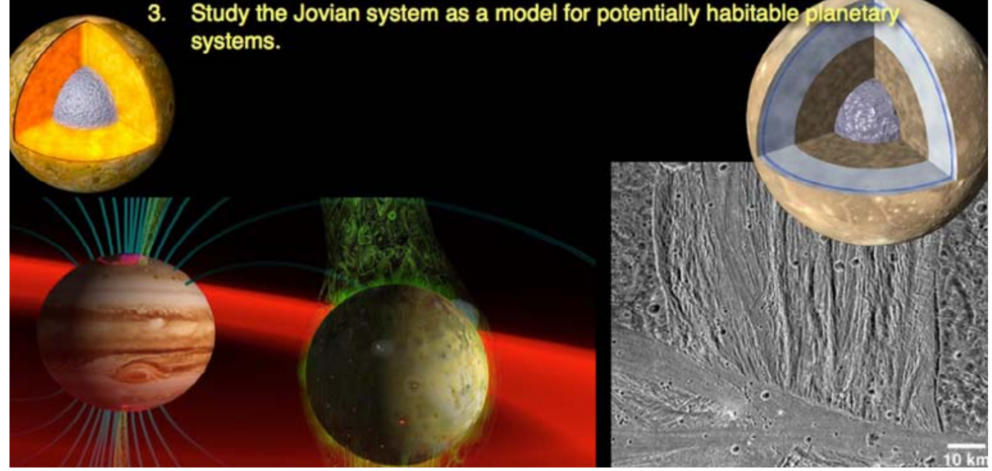
1. Characterize the magnetic environment.
2. Characterize the ionosphere and neutral atmosphere and their dynamics, with implications for surface interactions.
3. Characterize relationships between the magnetic field and plasma.
4. Characterize the global radiation environment.



Europa's Neighborhood

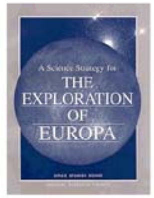
F. Determine how the components of the Jovian system operate and interact, leading to potentially habitable environments in icy moons.

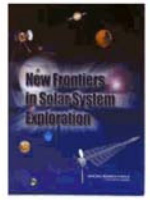
1. Determine the nature and history of the internal heat sources and interior evolution of the Galilean satellite system.
2. Investigate the geological processes and surface evolution of the Galilean satellite system.
3. Study the Jovian system as a model for potentially habitable planetary systems.



Heritage of Europa Science Objectives

- Europa Orbiter Science Definition Team (1999)
- COMPLEX, National Research Council (1999)
- NASA Campaign Science Working Group on Prebiotic Chemistry in the Solar System (1999)
- Solar System Exploration ("Decadal") Survey (2003)
- Jupiter Icy Moons Orbiter (JIMO) Science Definition Team (2004)
- Outer Planets Assessment Group (2005-2006)
- NAI Europa Focus Group (2006)
- NASA Solar System Exploration Roadmap (2006)





Traceability from NRC-NASA Reports

- NRC Decadal Survey:
  - "Scientific Goals"
- NASA Solar System Exploration Roadmap, and NASA 2007 Science Plan:
  - "Science Questions"
- Themes traced to Europa Explorer Objectives and Investigations

Solar System Exploration ("Decadal") Survey	2006 SSE Roadmap and 2007 NASA Science Plan	Theme
• Learn how the Sun's retinue of planets originated and evolved.	• How did the Sun's family of planets and minor bodies originate?	Origins
• Discover how the basic laws of physics and chemistry, acting over aeons, can lead to the diverse phenomena ovserved in complex systems, such as planets.	• How did the solar system evolve to its current diverse state?	Evolution
• Understand how physical and chemical processes determine the main characteristics of the planets, and their environments, thereby illuminating the workings of the Earth.		Processes
• Determine how life developed in the solar system, where it may have existed, whether extant life forms exist beyond Earth, and in what ways life modifies planetary environments.	• What are the characteristics of the solar system that led to the origin of life?	Habitability
	• How did life begin and evolve on Earth and has it evolved elsewhere in the solar system?	Life
• Explore the terrestrial space environment to discover what potential hazards to the Earth's biosphere may exist.	• What are the hazards and resources in the solar system environment that will affect the extension of human presence in space?	Hazards & Resources

Europa Goal, Objectives, Investigations

Goal		Science Objective	Science Investigation
Explore Europa and investigate its habitability.	A. Ocean	Characterize the ocean and deep interior.	A1. Determine the amplitude and phase of the gravitational tides.
			A2. Determine the induction response from the ocean over multiple frequencies.
			A3. Characterize surface motion over the tidal cycle.
			A4. Determine the dynamical rotation state.
			A5. Investigate the deep interior.
	B. Ice	Characterize the ice shell and any subsurface water, and the nature of surface-ice-ocean exchange.	B1. Characterize the distribution of any shallow subsurface water.
			B2. Search for an ice-ocean interface.
			B3. Correlate surface features and subsurface structure to investigate processes governing communication among the surface, ice shell, and ocean.
	C. Chemistry	Determine global surface compositions and chemistry, especially as related to habitability.	C1. Characterize surface organic and inorganic chemistry, including abundances and distributions of materials, with emphasis on indicators of habitability.
			C2. Relate compositions to geological processes, especially communication with the interior.
			C3. Determine the effects of radiation on surface materials, including albedo, sputtering, and redox chemistry.
			C4. Characterize the nature of exogenic materials.
	D. Geology	Understand the formation of surface features, including sites of recent or current activity, and identify and characterize candidate sites for future *in situ* exploration.	D1. Characterize magmatic, tectonic, and impact features.
			D2. Search for areas of recent or current geological activity.
			D3. Investigate global and local heat flow.
			D4. Assess relative surface ages.
			D5. Characterize the physical properties of the regolith, and assess processes of erosion and deposition.
	E. External	Characterize the magnetic environment and moon-particle interactions.	E1. Characterize the magnetic environment.
			E2. Characterize the ionosphere and neutral atmosphere and their dynamics, with implications for surface interactions.
			E3. Characterize relationships between the magnetic field and plasma.
			E4. Characterize the global radiation environment.
	F. Neighbors	Determine how the components of the Jovian system operate and interact, leading to potentially habitable environ-ments in icy moons.	F1. Determine the nature and history of the internal heat sources and interior evolution of the Galilean satellite system.
			F2. Investigate the geological processes and surface evolution of the Galilean satellite system.
			F3. Study the Jovian system as a model for potentially habitable planetary systems.

Themes: Origins | Evolution | Processes | Habitability | Life | Hazards & Resources

Traceability Example: Themes ⇒ Instrument

Themes:

Origins | Evolution | Processes | Habitability | Life | Hazards & Resources

↓

Goal:

Explore Europa and investigate its habitability.

↓

Objective:

C Determine global surface compositions and chemistry, especially as related to habitability.

↓

Investigation:

C1. Characterize surface organic and inorganic chemistry, including abundances and distributions of materials, with emphasis on indicators of habitability.

↓

Measurement:

C1a. Globally distributed and targeted measurements of composition and structural form at the scale of geological features, based on vibrational and electronic transitions.

↓

Quantification:

C1a. Globally distributed and targeted infra-red spectroscopy at equal to or better than 6 nm spectral resolution and ~100 m/pixel scale for globally distributed mapping and 25 m/pixel for targeted features, in selectable bands through a range of at least 0.9-5 μm.

↓

Instrument:

C1a. IR imaging spectrometer.

Traceability Example: Synergistic Measurements

Objectives	⇒ Investigations	⇒ Measurements...
C Determine global surface compositions and chemistry, especially as related to habitability.	C1. Characterize surface organic and inorganic chemistry, including abundances and distributions of materials, with emphasis on indicators of habitability.	C1a. Globally distributed and targeted measurements of composition and structural form at the scale of geological features, based on vibrational and electronic transitions.
		C1b. Characterize the composition of sputtered products from energetic particle bombardment of the surface.
		C1c. Globally distributed and targeted measurements of composition at the scale of geological features, based on electronic and charge transfer processes.
	C2. Relate compositions to geological processes, especially communication with the interior.	C2a. Targeted surface reflectance measurements of composition and structural form at the scale of geological features, based on vibrational and electronic transitions.
		C2b. Near-global identification and local characterization of physical and dielectric subsurface horizons.
		C2c. Targeted measurements of composition at the scale of geological features, based on electronic and charge transfer processes.
		C2d. High-resolution morphological characterization of targeted features.
		C2e. Very-high resolution imaging of targeted sites.
		C2f. Near-global topographic characterization, with detailed topographic characterization of targeted features.

⇒ Quantification	⇒ Instruments
C1a. Globally distributed and targeted infra-red spectroscopy at equal to or better than 6 nm spectral resolution and ~100 m/pixel scale for globally distributed mapping and 25 m/pixel for targeted features, in selectable bands through a range of at least	C1a. IR imaging spectrometer.
C1b. Ion mass spectrometry over a mass range of 400 Daltons (amu/charge), mass resolution of 800 to 1000, angular resolution of 15 x 15 degrees, and energy resolution of 10%.	C1b. INMS.
C1c. Globally distributed and targeted ultraviolet spectroscopy at equal to or better than 0.3 nm spectral resolution and ~100 m/pixel scale through a range of at least 0.1-0.35 μm.	C1c. UV imaging spectrometer.
C2a. Infra-red spectroscopy of targetted features at better than or equal to 6 nm spectral resolution and 25 m spatial resolution in selectable bands through a range of at least 0.9-5 μm.	C2a. IR imaging spectrometer.
C2b. Obtain global profiling of subsurface thermal, compositional, or structural horizons, with ³ 5 degree equatorial spacing, at depths of 1 to 30 km at 100 m vertical resolution, and at depths of 100 m to 3 km at 10 m vertical resolution, with targeted	C2b. Radar sounder.
C2c. Ultraviolet spectroscopy of targetted features at equal to or better than 0.3 nm spectral resolution and ~100 m/pixel scale through a range of at least 0.1-0.35 μm.	C2c. UV imaging spectrometer.
C2d. Visible stereo imaging at ~10 m/pixel over targeted sites, with 1 m vertical resolution.	C2d. Medium-angle camera (stereo).
C2e. Imaging at ~1 m/pixel over targeted sites.	C2e. Narrow-angle camera.
C2f. Near-global topography at better than or equal 100 m/pixel spatial scale and better than or equal 10 m vertical resolution and accuracy, and topographic characterization at better than 10 m/pixel scale and better than or equal 1 m vertical resolution	C2f. Wide-angle camera (stereo), medium-angle camera (stereo), and laser altimeter.

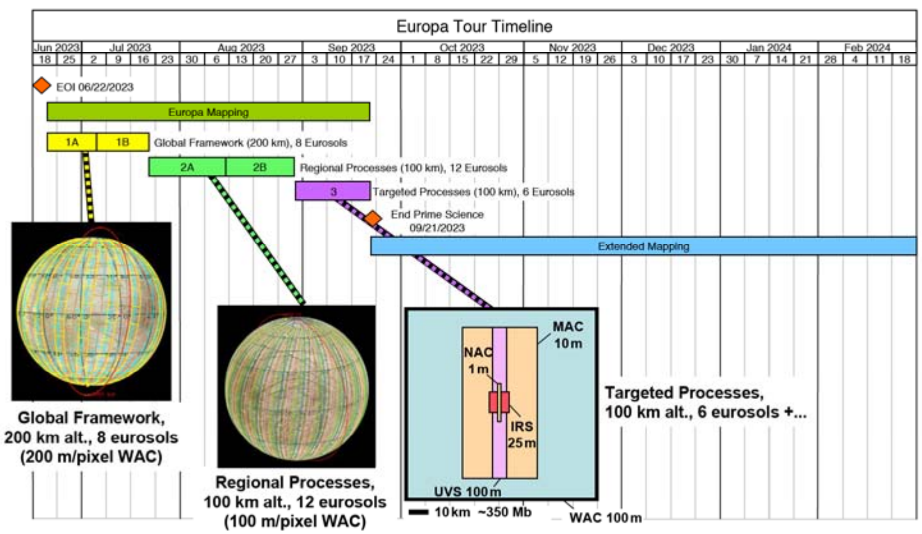
Instruments work synergistically to achieve Investigations, Objectives, and Goal.

Straw-Person Payload: Baseline

Payload Instruments	Baseline Mass (kg)	Baseline Power (W)	Data Rate (kbps)	Baseline Comment
Wide-angle Camera (WAC)	3	5	800	
Medium-Angle Camera (MAC)	10	10	6000	stereo
Narrow Angle Camera (NAC)	15	12	30000	
IR Spectrometer (IRS)	30	15	100 & 30000	
UV Spectrometer (UVS)	15	10	5 & 4000	
Laser Altimeter (LA)	15	21	12	multi-beam
Ice Penetrating Radar (IPR)	36	45	300 & 30000*	dipole & Yagi
Thermal Instrument (TI)	8	14	43	imaging
Magnetometer (MAG)	4	2	4	dual mag
Ion & Neutral Mass Spectr. (INMS)	15	28	2	
Particle & plasma instrument (PPI)	12	10	2	ion species, angular cov.
TOTALS:	163	172	~20 Gb/dy	

*IPR data are internally compressed to listed data rates.

Europa Mapping: Science Campaigns



Global Framework, 200 km alt., 8 eurosols (200 m/pixel WAC)

Regional Processes, 100 km alt., 12 eurosols (100 m/pixel WAC)

Targeted Processes, 100 km alt., 6 eurosols +...

Campaign-Based Science Value

BASELINE SCIENCE CAMPAIGNS		1 Global Framewrk 1A	1 Global Framewrk 1B	2 Regional Proc. 2A	2 Regional Proc. 2B	3. Targ. Proc.
C1a. IR imaging spectrometer.	C1a.	2	2	3	4	5
C1b. INMS.	C1b.	2	2	3	3	3
C1c. UV imaging spectrometer.	C1c.	2	3	4	4	5
C2a. IR imaging spectrometer.	C2a.	2	3	3	4	5
C2b. Radar sounder.	C2b.	3	3	4	4	5
C2c. UV imaging spectrometer.	C2c.	2	3	4	4	5
C2d. Medium-angle camera (stereo).	C2d.	2	2	3	4	5
C2e. Narrow-angle camera.	C2e.	1	2	3	3	4
C2f. Wide-angle camera (stereo), medium-angle camera (stereo), and laser altimeter.	C2f.	2	3	3	4	5
Total score (of 350):		*141*	*199*	*262*	*292*	*337*
% score:		*40%*	*57%*	*75%*	*83%*	*96%*
Eurosols into orbital mission:		*4*	*8*	*14*	*20*	*26*
Days into orbital mission:		*14*	*28*	*64*	*71*	*92*

5	Definitely addresses full science investigation.
4	May address full science investigation.
3	Definitely addresses partial science investigation.
2	May address partial investigation.
1	Touches on science investigation.
0	Does not address science investigation.

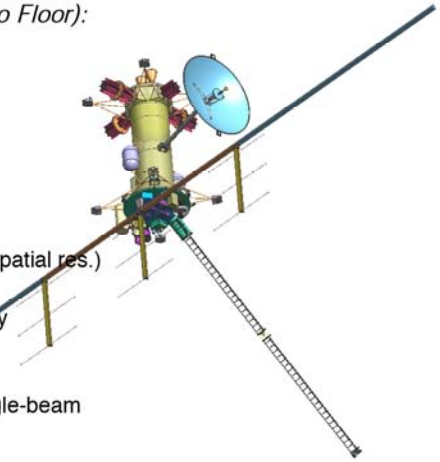
Extended Mapping phase: Yet to be considered by SDT.

Prioritized Instrument Descope List

- Notional Science-Based Instrument Descopes

  Ordered first to last (i.e., Baseline to Floor):

1. INMS scaled back by ~half
2. UV scaled back by ~half
3. Mag boom from 10 m to 5 m
4. Thermal Instrument scaled back
5. INMS removed
6. MAC stereo removed
7. Transponder drops Ka band
8. IR scaled back by 1st step (spectral & spatial res.)
9. PPI drops 1 telescope
10. PPI drops plasma sensor TOF capability
11. Magnetometers from 2 to 1
12. IR scaled back by 2nd step (λ range)
13. Laser altimeter drops from multi- to single-beam
14. Radar cuts data rate in half
15. UV removed
16. NAC removed
17. Radar loses Yagi antennas



Floor Payload: Key Science Losses

- *All highest priority science investigations addressed; however:*
  - **NAC dropped:** No meter-scale imaging for detailed surface characterization including recent activity and relative ages, and significant degradation of Jupiter system imaging.
  - **UVS dropped:** No outgassing, atmospheric emissions or structure characterization, decreased ability to characterize surface materials and history, and significant loss of Jupiter system science.
  - **INMS dropped:** No *in situ* characterization of sputtered species, including any organics.
  - **IRS degraded:** Decreased sensitivity in identification of impurities, especially organics, and poorer mapping capability.
  - **MAC stereo optics dropped:** High-resolution topographic characterization significantly degraded.
  - **Laser altimeter is single-beam:** Weaker geodetic and topographic framework.
  - **Ka-band dropped:** Poorer gravity data for high-order gravity terms.
  - **Thermal is a point sensor:** Poorer thermal sensitivity and mapping resolution.
  - **Particle and plasma instrument degraded:** Ion species unknown, and poorer angular coverage.
  - **Magnetometer is 1 sensor on short boom:** Poorer magnetometry calibration.
  - **IPR Yagi antenna dropped and data volume decreased:** Decreased ability to locate and characterize subsurface water and structure.

Mission Options Science Evaluation

	A. Ocean	B. Ice	C. Chemistry	D. Geology	E. External Environment
Europa Explorer	5	5	5	5	5
Europa Explorer + Simple Lander	6	6	6	6	5
Europa Multiple Fly-bys	2	2	2	3	3
Capable Lander (No Orbiter)	3	2	4	2	1

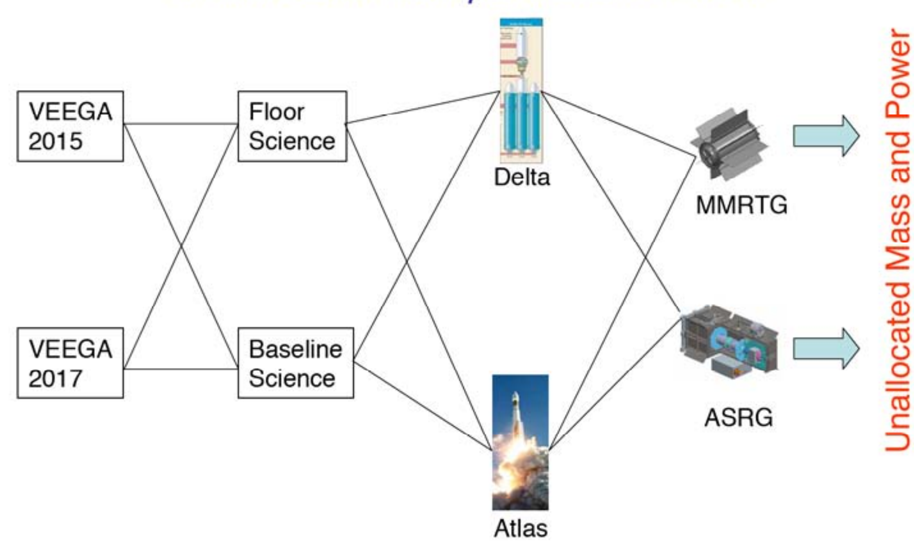
6	Exceeds science objectives.
5	Fully addresses all science objectives.
4	Addresses most science objectives.
3	Addresses some science objectives.
2	May address partial science objectives.
1	Touches on science objectives.
0	Does not address science objectives.

Notes:
- Multiple fly-bys means a dedicated Europa fly-by mission.
- Capable Lander is stand-alone (no orbiter), modeled after the Europa Astrobiology Lander.
- Orbiter + lander or Flyby + lander implies a simple lander (i.e. "seismoball" lander or penetrometer, carrying a seismometer, imager, composition experiment).

- Europa Explorer fully addresses all science objectives.
- A Europa Explorer with lander would exceed them, but at increased risk and cost.
- Both Europa Multiple Flyby mission and a capable Europa Lander alone fail to provide the minimum science.

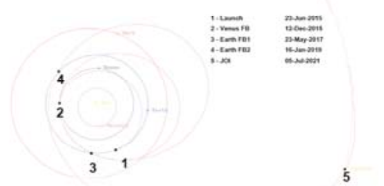
Top Level Implementation Trade Space

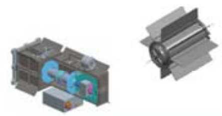
Architecture: Europa orbital mission

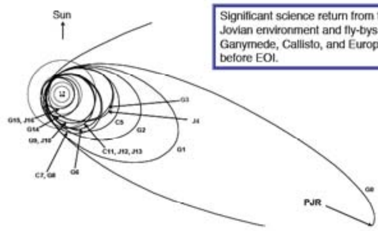


Europa Explorer Mission Concept

- Launch vehicle: Delta IV-H
- Trajectory: VEEGA
- Power supply: ASRG or MMRTG **(still tbd)**
- Mission Timeline:
  - Launch: ~6/2015
  - Jupiter arrival: ~7/2021
  - Galilean satellite tour science: ~1.5-2.5 yr
    - Tour data volume returned:~0.5 - 1 Tbit
  - Europa prime mapping: 26 eurosols
    - Additional data volume returned: ~>2 Tbits
  - Spacecraft operates until loss of control - final disposition: Europa surface Impact
    - Additional data volume returned: ~24 Gbits/eurosol
- Instruments: 11
- Mass and power margins: 54%
- Unallocated mass: 200-400 kg





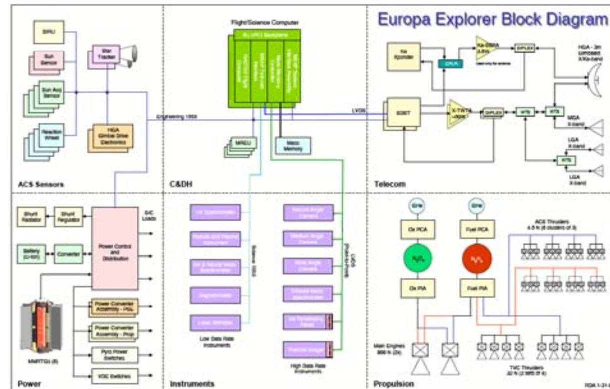


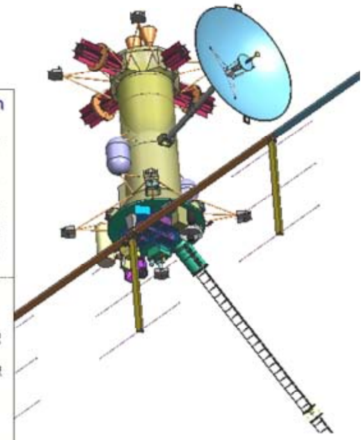
Significant science return from the Jovian environment and fly-bys of Ganymede, Callisto, and Europa before EOI.

Representative Tour Trajectory

Baseline On-orbit Configuration

- Mission Delta V: 2608 m/s
- Launch Mass: 7225 kg
- Radiation Environment at End of Mission: 2.3 Mrad



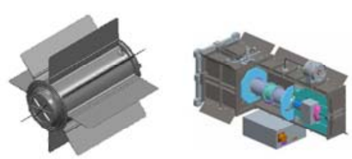


Configuration does not show required Venus thermal shade

Radioisotope Power Options

- Two options considered are:
  - MMRTG as developed for Mars Science Laboratory
  - ASRG currently under development
- ARTG considered higher risk for 2015 or 2017 launches
- MMRTG
  - Passive, graceful degradation
  - Use waste heat to heat propulsion subsystem (~300 W) as was done on cassini
- ASRG
  - Active system, less graceful degradation requires flying redundant Generator (JPL SE analysis)
  - Investigating options to use waste heat for heating propulsion system
  - Science implications evaluated by SDT- not enough detail for conclusive evaluation

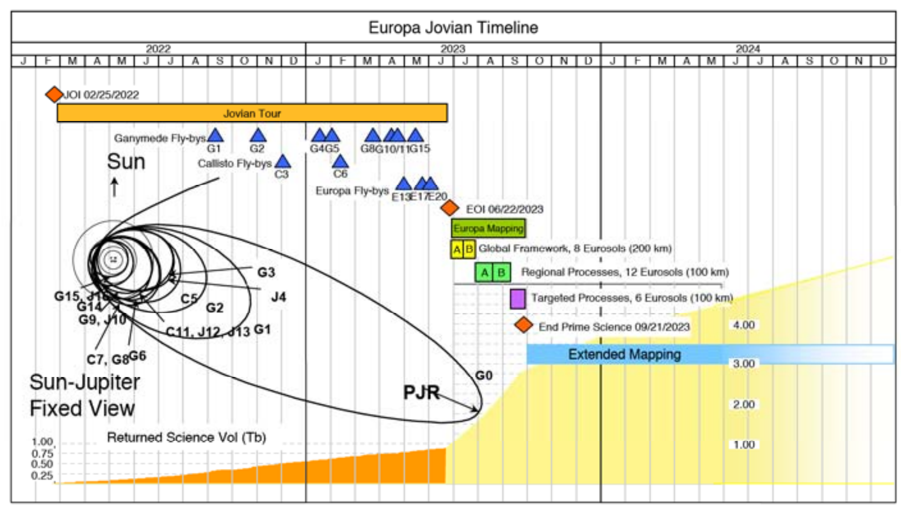
Trade still open



RPS	Pwr (W)	Mass (kg)	Spec. Pwr (W/kg)	Conv Effic.
MMRTG	125	44	2.9	6.3%
ASRG	143	21.5	7.0	28%

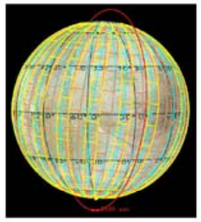
Note: Power and specific power levels are estimated at Beginning of Mission (BOM)

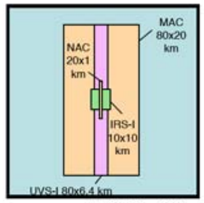
Europa Science Mission Timeline



Orbital Mission Data Acquisition Strategy

- Continuous: fields & particles, laser altimetry, low-rate UV, thermal
- 3 campaigns:
  1. **Global Framework:** 8 Eurosols (200 km orbit, to EOI+28 days)
     - A: • 1st-order gravity field and shape
       • global color map
       • IPR shallow water search
       • targets of opportunity of high interest terrain types
     - B: • global stereo map
       • IPR deep ocean search
       • targets sample high interest terrains
  2. **Regional Processes:** 12 Eurosols (100 km orbit, to E+71 days)
     - A: • regional color map
       • IPR shallow water hunt
       • targets emphasize processes
     - B: • regional stereo map
       • IPR deep ocean hunt
       • targets emphasize processes
  3. **Targeted Processes:** 6 Eurosols (100 km orbit, to E+92 days)
     - • emphasis on coordinated, process-oriented, targeted observations



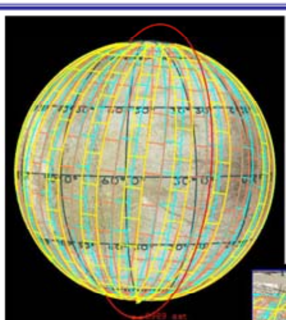


WAC 100 x 100 km

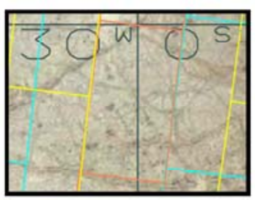
Data Collection Strategy

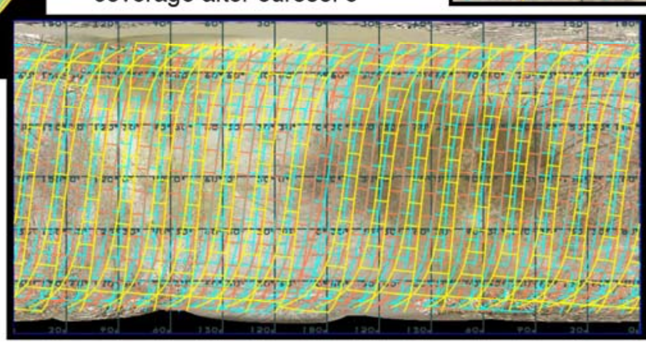
- Orbit-to-orbit operations scenario
  - Always on: Laser Altimeter, Magnetometer, Ion and Neutral Mass Spectrometer, Particle and Plasma Instrument, Thermal Imager (profile mode, 80% duty cycle)
  - 2 orbit repeating scenario (permits power and data rate equalization)
    - Even orbits emphasize remote sensing (non-IPR) data collection
      - WAC and IRS (profiling mode) operate at 40% duty cycle (80% over sunlit side)
      - Remote sensing instruments emphasize coordinated targeted observations
    - Odd orbits emphasize IPR sounding data collection
      - IPR operates at 40% orbit duty cycle (80% of sunlit side)
- Targeted data acquisition is limited by data rate
  - Significant data volumes available for targeting (~ 30%)
  - Target data volumes developed for IPR, MAC, NAC, IRS and UVS
    - IR spectrometer imaging targets defined as 400x400 pixels, 400 wavelengths
    - IPR targets defined as 30 sec data takes at 30 Mbps
    - UVS and MAC targets defined as high resolution swaths 80km long
    - NAC targets defined as 20 km long

200 km Orbit CWAC Swaths



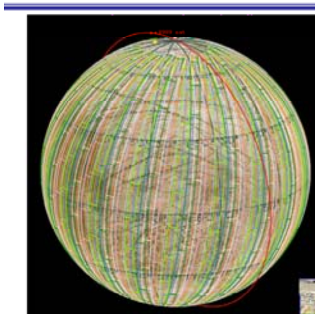
- 4 eurosol near-repeat orbit
- WAC resolution 200m/pixel
- Complete coverage (>95%) in 3 eurosols
- Nearly complete stereo coverage after eurosol 6



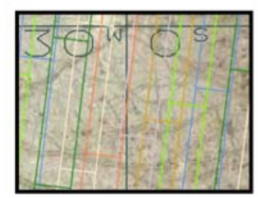


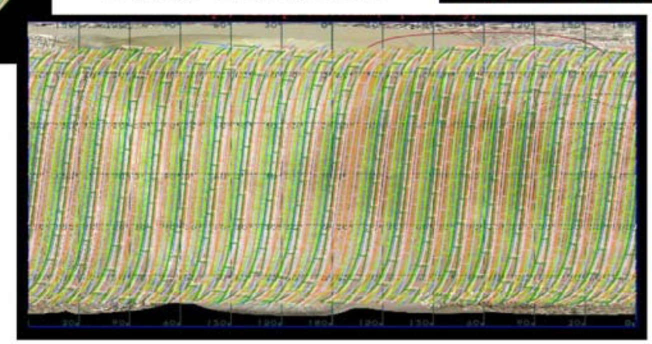
- eurosol 1
- eurosol 2
- eurosol 3

100 km Orbit CWAC Swaths



- 8 eurosol near-repeat orbit
- WAC resolution 100m/pixel
- complete coverage (>95%) in 7 eurosols
- Nearly complete stereo coverage after eurosol 12





- eurosol 1
- eurosol 2
- eurosol 3
- eurosol 4
- eurosol 5
- eurosol 6
- eurosol 7

Preliminary Coverage Summary

Campaign 1: Global Framework

Reference S/C (Baseline)	Glob data per day (Gb)	Targ data per day (Gb)	% tot vol	Avg Targ per day	Cam Tot Targ	Cam Tot Vol (Gb)
Data Volume	10.0	7.2				483
CWAC	1.1		6%			31
SMAC[1]	0.0	0.8	5%	14 T	380	17
NAC[2]	0.0	1.0	6%	14 T	373	21
IRS[3]	0.4	1.5	11%	14 T	377	60
IPR[4]	4.9	1.8	39%	3 T	70	201
TII	1.5		9%			42
UVS	0.4	1.9	13%	16 T	438	65
MBLA	1.0		6%			29
MAG2	0.3		2%			10
INMS	0.1		1%			4
PPI2	0.2		1%			5

Campaign 2: Regional Processes

Reference S/C (Baseline)	Glob data per day (Gb)	Targ data per day (Gb)	% tot vol	Avg Targ per day	Cam Tot Targ	Cam Tot Vol (Gb)
Data Volume	11.1	8.0				803
CWAC	2.9		15%			122
SMAC[1]	0.0	1.4	7%	12 T	481	58
NAC[2]	0.0	1.7	9%	12 T	483	72
IRS[3]	0.7	1.5	11%	12 T	484	91
IPR[4]	4.9	1.8	35%	2 T	84	282
TII	0.5		2%			19
UVS	0.4	1.7	11%	14 T	578	87
MBLA	1.0		5%			44
MAG2	0.3		2%			15
INMS	0.1		1%			5
PPI2	0.2		1%			7

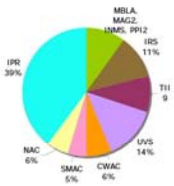
Campaign 3: Targeted Processes

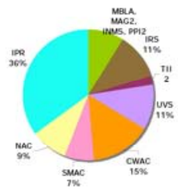
Reference S/C (Baseline)	Glob data per day (Gb)	Targ data per day (Gb)	% tot vol	Avg Targ per day	Cam Tot Targ	Cam Tot Vol (Gb)
Data Volume	3.1	20.0				486
CWAC	0.2		1%			3
SMAC[1]	0.0	1.5	6%	12 T	254	30
NAC[2]	0.0	4.5	19%	30 T	630	95
IRS[3]	0.7	1.6	10%	12 T	254	47
IPR[4]	0.0	10.8	47%	12 T	252	227
TII	0.2		1%			4
UVS	0.4	1.7	9%	14 T	298	45
MBLA	1.0		4%			22
MAG2	0.3		1%			7
INMS	0.1		1%			3
PPI2	0.2		1%			4

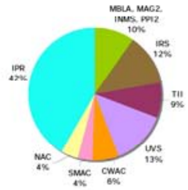
Totals

Reference S/C (Baseline)	Total Targets	% total vol	Total Vol (Gb)
Data Volume			1772
CWAC		9%	156
SMAC[1]	1115 T	6%	105
NAC[2]	1486 T	11%	188
IRS[3]	1116 T	11%	199
IPR[4]	406 T	40%	709
TII		4%	65
UVS	1313 T	11%	197
MBLA		5%	94
MAG2		2%	31
INMS		1%	12
PPI2		1%	16

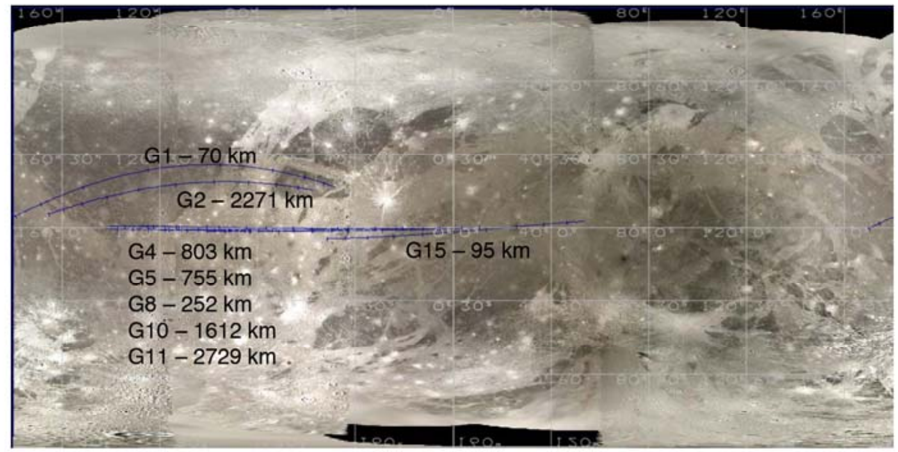
[1] SMAC targets are 1 minute duration (71 km @200 km, 78 km @100 km)
[2] NAC targets are 15 seconds duration
[3] IRS targets are each 400x400 pixels, 128 Mb
[4] IPR targets are each 30 Mb/s x 30 s, 900 Mb







Tour Example: Ganymede Flybys



Discipline and Systems Reviews

Integrated Systems Review
5/10/07
Chair: Joe Srour - Aerospace
JPL, APL, SWRI, SAIC, Aerospace

Environment Review
4/18/07 Done
Chair: Chris Paranicas - APL
JPL, GSFC, APL, UCLA, U of Kansas

Transport and Shielding Review
4/19/07 Done
Chair: Jeff Johnson - ORNL
JPL, LANL, ORNL, SAIC, Aerospace

Parts and Materials Workshops
4/26/07, Off-line
Chairs: Ron LaCoe – Aerospace; Paul Willis - JPL
JPL, AFRL, GSFC, GRC, SNL, Aerospace

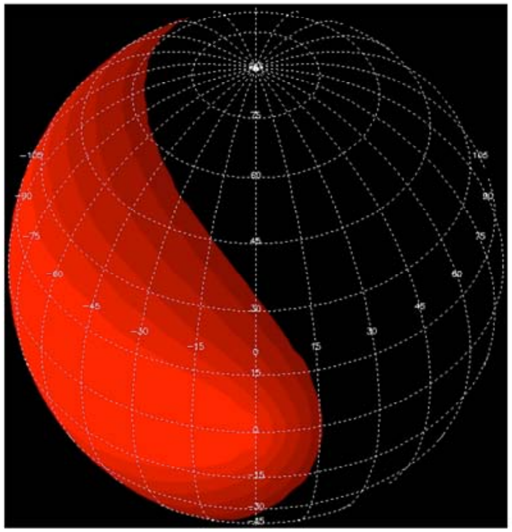
Discipline Systems Workshop
4/24/07
Chair: Richard Kingsland - ITI
JPL, APL, GSFC, ITI

Radiation Design Peer Reviews

- Peer review process in place to assess validity of radiation design approach
- Further analysis of Galileo data has allowed lowering of the expected TID radiation environment while in orbit at Europa
  - SDT members have reviewed and endorsed approach
  - Peer Review - ***"The radiation dose approach results in an estimate for TID that is reasonable and conservative."***
- Transport Analysis and Shielding design
  - Peer Review -***"… the committee feels the shielding mass estimates are conservative at this phase of the design process.", "The committee finds that the modeling assumptions and approach are appropriate for this phase of the design."***
- Systems Engineering and Operations
  - Peer Review – ***"The Europa team has done an outstanding job of dealing with the comprehensive considerations generated by the radiation environment and developing innovative operational modes to address the foreshortened lifetime of the Europa spacecraft when operating in the radiation environment."***
- Parts
  - Peer Review – ***"All classes of parts have a path toward a solution. However, there are certain classes of parts that have significant risks:"***

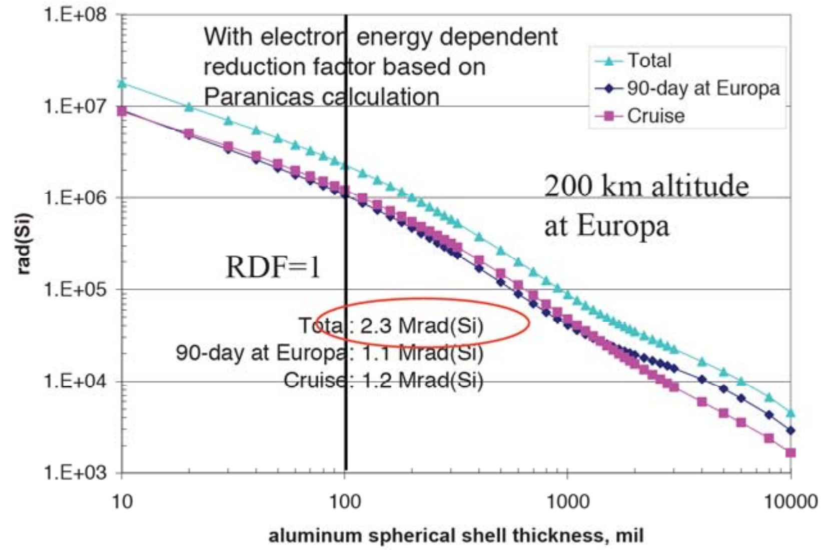
Energetic Electron Radiation at Europa

- MeV electrons trapped by Jupiter's magnetosphere enter from upstream (left), and precipitate non-uniformly into Europa's surface.
- Most will impact trailing hemisphere, leaving regions above the poles and leading hemisphere depleted of MeV electron flux.
- Contours (bright red is highest) show calculated dose into surface ice based on s/c electron measurements.



Paranicas et al., in prep.

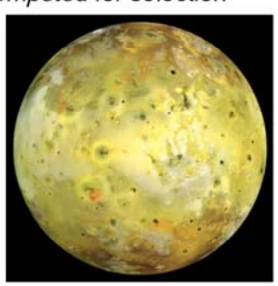
Dose-Depth: Jovian Environment



OPAG Input Invited

"Break-out" session this afternoon: All welcome!

- Goal, Objectives, Investigations, Measurements, Quantification
  - What's missing?
- "Straw-person" payload
  - Generic instruments intended, as needed to obtain primary measurements
  - SDT identified in order to determine payload/resource requirements
  - Europa SDT recommends that these would be *competed* for selection
- Descope approach
- Jupiter system science
  - There is substantial potential here!
- "Extended Mapping" strategy
- Use of "unallocated" mass
- Anything else...?



Back Up Slides

Goal and Objectives

- *Goal:* Explore Europa and investigate its habitability.
- *Level 1 Objectives:*

A. Europa's Ocean: Characterize the ocean and deep interior.
1. Determine the amplitude and phase of the gravitational tides.
2. Determine the induction response from the ocean over multiple frequencies.
3. Characterize surface motion over the tidal cycle.
4. Determine the dynamical rotation state.
5. Investigate the deep interior.

B. Europa's Ice Shell: Characterize the ice shell and any subsurface water, and the nature of surface-ice-ocean exchange.
1. Characterize the distribution of any shallow subsurface water.
2. Search for an ice-ocean interface.
3. Correlate surface features and subsurface structure to investigate processes governing communication among the surface, ice shell, and ocean.

C. Europa's Chemistry: Determine global surface compositions and chemistry, especially as related to habitability.
1. Characterize surface organic and inorganic chemistry, including abundances and distributions of materials, with emphasis on indicators of habitability.
2. Relate compositions to geological processes, especially communication with the interior.
3. Determine the effects of radiation on surface materials, including albedo, sputtering, and redox chemistry.
4. Characterize the nature of exogenic materials.

Goal and Objectives (cont.)

D. Europa's Geology: Understand the formation of surface features, including sites of recent or current activity, and identify and characterize candidate sites for future *in situ* exploration.
1. Characterize cryovolcanic, tectonic, and impact features.
2. Search for areas of recent or current geological activity.
3. Investigate global and local heat flow.
4. Assess relative surface ages.
5. Assess the physical properties of the regolith, and assess processes of erosion and deposition.

E. Europa's External Environment: Characterize the magnetic environment and moon-particle interactions.
1. Characterize the magnetic environment.
2. Characterize the ionosphere and neutral atmosphere and their dynamics, with implications for surface interactions.
3. Characterize relationships between the magnetic field and plasma.
4. Characterize the global radiation environment.

- *Level 2 Objective:*

F. Europa's Neighborhood: Determine how the components of the Jovian system operate and interact, leading to potentially habitable environments in icy moons.
1. Determine the nature and history of the internal heat sources and interior evolution of the Galilean satellite system.
2. Investigate the geological processes and surface evolution of the Galilean satellite system.
3. Study the Jovian system as a model for potentially habitable planetary systems.

Europa Science Goal and Objectives

Goal: Explore Europa and investigate its habitability.

Level 1:

A. EUROPA'S OCEAN:
Characterize the ocean and deep interior.

B. EUROPA'S ICE SHELL:
Characterize the ice shell and any subsurface water, and the nature of surface-ice-ocean exchange.

C. EUROPA'S CHEMISTRY:
Determine global surface compositions and chemistry, esp. as related to habitability.

D. EUROPA'S GEOLOGY:
Understand the formation of surface features, including sites of recent or current activity, and identify and characterize candidate sites for future *in situ* exploration.

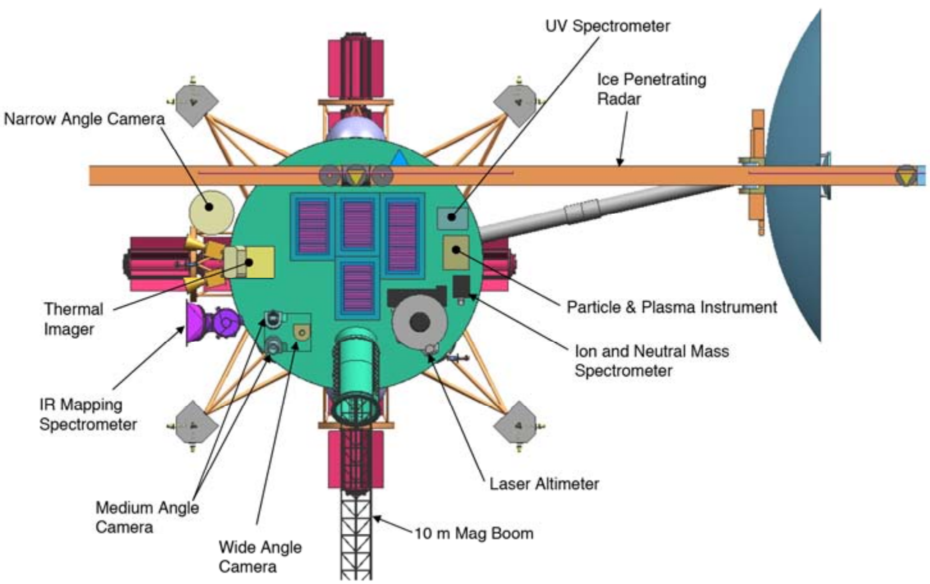
E. EUROPA'S EXTERNAL ENVIRONMENT:
Characterize the magnetic environment and moon-particle interactions.

Level 2:

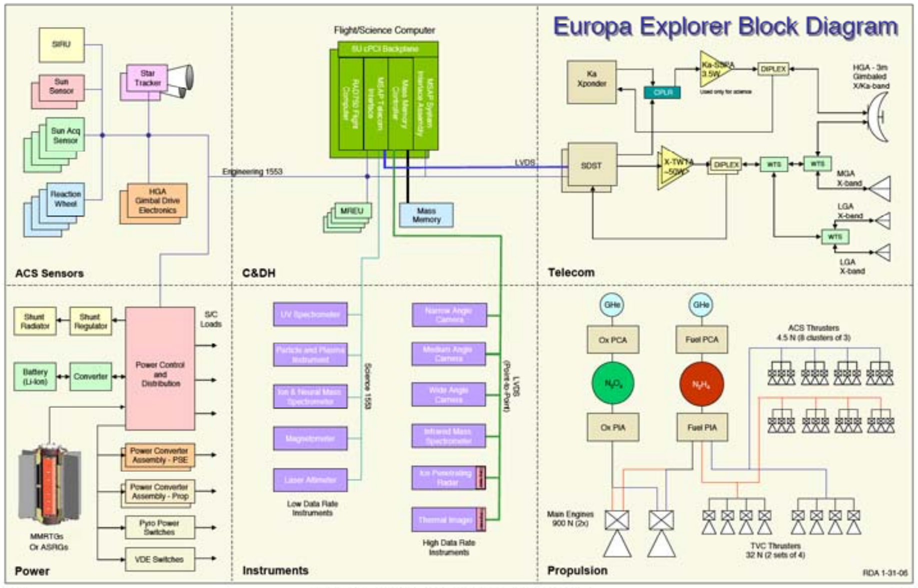
F. EUROPA'S NEIGHBORHOOD:
Determine how the components of the Jovian system operate and interact, leading to potentially habitable environments in icy moons.

- *No prioritization is intended for Level 1 Objectives.*
- *Numbered Investigations are in priority order.*
- *It might not be possible to meet all of the Investigations, but they should be addressed by priority.*

Tentative Payload Accommodation



Europa Explorer Concept Block Diagram



Mass and Power Summaries

Subsystem	Mass, kg		
	CBE	Contingency	CBE + Contingency
Payload	**163**	**30%**	**212**
Instruments	163.0	30%	211.9
Bus	**1512**	**25.0%**	**1889**
AACS	52.8	40%	73.8
CDH	27.5	37%	37.7
Power (w/o RPSs)	50.4	27%	64.0
RPS System w/ Adapters	338.0	5%	354.9
Cabling	140.4	30%	182.5
Propulsion	211.9	32%	278.9
Structures & Mechanisms	554.7	30%	721.1
Telecom	57.9	29%	74.5
Thermal	78.4	30%	101.8
Radiation Shielding	**127.2**	**30%**	**165.4**
System Margin	-	**28%**	**506.1**
Spacecraft Total Dry (e.g., Separated Dry Mass)	**1802.1**	**54%**	**2773**
Propellant	4109		4109
Spacecraft Total Wet (e.g., Separated Wet Mass)	**5911**		**6882**
LV Adapter (LV Side)	110	54%	169
Launch Mass Wet	**6021**		**7051**
Injected Mass Capability			7225
Remaining LV Capability			**174**

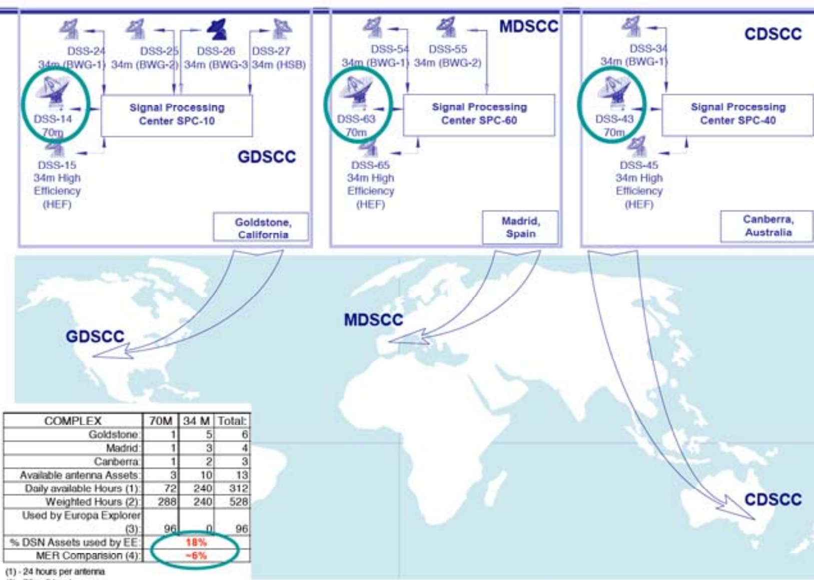
Subsystem	Power, W	
	Comm. Mode	Non-Comm. Mode
Payload	**103.0**	**91.0**
Instruments	103.0	91.0
Bus	**364.7**	**252.7**
AACS	103.0	99.0
CDH	50.7	50.7
Power	31.7	31.7
Propulsion	13.0	13.0
Structures and Mechanisms	11.0	0.0
Cabling	16.4	12.0
Telecom	120.9	28.3
Thermal	18.0	18.0
Total Power Level (CBE), W	**467.7**	**343.7**
Contingency%	**54%**	
Total Power Level w/ Contingency, W	**719**	**529**
Orbit Period, hrs	2.05	
Mode Duration per Orbit, hrs	1.29	0.76
Energy Used per Mode, W-hr	929	401
Energy Used/Orbit, W-hr	**1330**	
Average Total Power Used per Orbit, W	**649**	
Final estimate of # of MMRTGs	**6.3**	
Final integer estimate of reqd # of MMRTGs	**7**	
Total MMRTG Power Produced at EOM, W	**720**	
Excess MMRTG power available, W	**71.4**	

Europa Explorer Parameter Table

Parameter	Value	Notes
Instruments		
Number of instruments	**11**	**Does not include Ka-band uplink/downlink equipment used for gravity science that is tracked within the telecom subsystem.**
Instrument mass	**212 kg**	**Includes 163 kg (CBE) with 30% contingency. Does not include 5.2 kg (CBE) Ka-band uplink/downlink equipment tracked in telecom mass estimate, or 18 kg (CBE) for instrument shielding.**
Instrument power	**130 W**	**Average power: Includes 99W (CBE) average power use over two successive science orbits (one radar orbit and one imaging orbit) with 30% contingency. Does not include power for Ka-band uplink/downlink equipment.**
Science Accommodation		
Pointing accuracy	**5 mrads (3σ)**	**S/C body pointing control accuracy during nadir-oriented non-thrusting orbital period.**
Pointing stability	**1 mrad/s (3σ)**	**For body-fixed instruments in science orbit during non-thrusting periods.**
Minimum duration between reaction wheel orbit desaturations	**24 hours**	**Minimum duration between desaturation thruster firings.**
Data storage	**2.4 Gbits**	**Includes ~1 Gbit for science data, with balance for flight system software loads, telemetry, and margin.**
Data volume	**20 Gb/day**	**Assumes range of 5.5 AU, 3 dB link margin, multiple data rates optimized for elevation, Jupiter presence, 70 m stations receiving whenever in view and 90% weather.**
Spacecraft		
Processor speed	**132 MHz**	**Applies to flight computers.**
Available power at EOM	**720 W**	**Power output from 7 MMRTGs after 8.5 years**
Main engine thrust level	**900 N**	**Two 900-N engines included (one prime and one spare)**
Delta V capability	**2608 m/s**	**Assuming launch mass is equal to the launch vehicle capability (7225 kg).**
Radiation tolerance	**2.3 Mrad**	**Plus a Radiation Design Factor (RDF) ≥ 2.**
Heliocentric operating range	**0.66 to 5.5 AU**	**Minimum range defined by VEEGA trajectory.**

Deep Space Network (DSN) Facilities (Current)

Deep Space Communications Complexes (DSCC)



COMPLEX	70M	34 M	Total:
Goldstone:	1	5	6
Madrid:	1	3	4
Canberra:	1	2	3
Available antenna Assets:	3	10	13
Daily available Hours (1):	72	240	312
Weighted Hours (2):	288	240	528
Used by Europa Explorer (3):	96	0	96
% DSN Assets used by EE:		18%	
MER Comparision (4):		~6%	

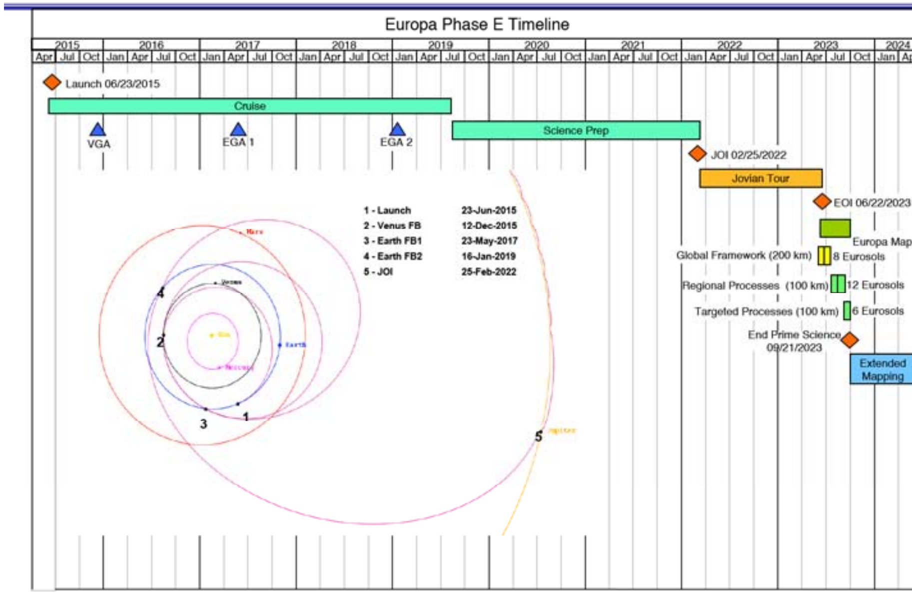
(1) - 24 hours per antenna
(2) - 70m=34mx4
(3) - Continuous 70M coverage (24 hours/day) (Weighted: 24 x 4 =96)
(4) ~ 8 hours 70M coverage per day on surface

Straw-Person Payload: Baseline and Floor

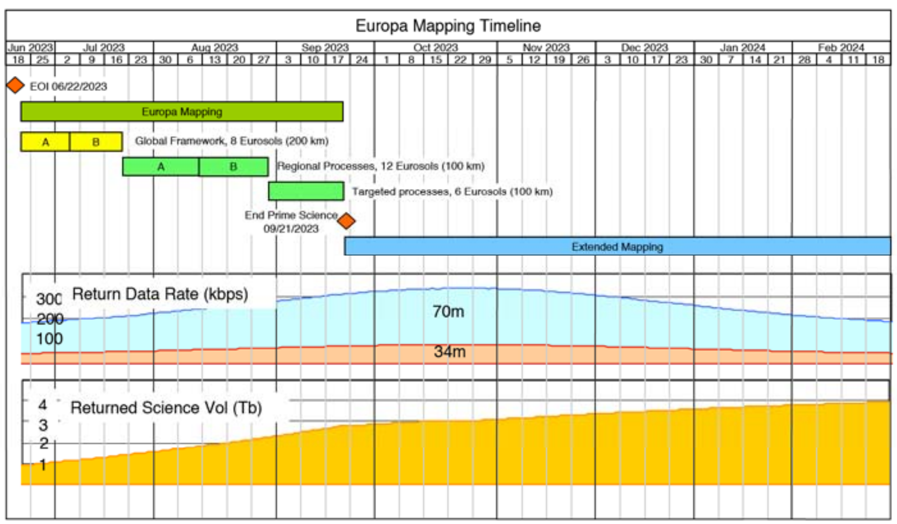
Payload Instruments	Baseline Mass (kg)	Baseline Power (W)	Data Rate (kbps)	Baseline Comment	Floor Mass (kg)	Floor Power (W)	Data Rate (kbps)	Floor Comment
Wide-angle Camera (WAC)	3	5	800		3	5	500	
Medium-Angle Camera (MAC)	10	10	6000	stereo	7	7	3000	mono
Narrow Angle Camera (NAC)	15	12	30000					
IR Spectrometer (IRS)	30	15	100 & 30000		10	9	100	less spect.& spatial res.
UV Spectrometer (UVS)	15	10	5 & 4000					
Laser Altimeter (LA)	15	21	12	multi-beam	7	15	2	single beam
Ice Penetrating Radar (IPR)	36	45	300 & 30000*	dipole & Yagi	31	45	140 & 30000*	dipole only
Thermal Instrument (TI)	8	14	43	imaging	5	5	4	point
Magnetometer (MAG)	4	2	4		2	1	3	
Ion & Neutral Mass Spec. (INMS)	15	28	2					
Particle & Plasma Instr. (PPI)	12	10	2	ion species, angular cov.	10	8	2	no ion species
TOTALS:	163	172	~20 Gb/dy		75	95	~7 Gb/dy	

*IPR data are internally compressed to listed data rates.

Europa Total Mission Timeline



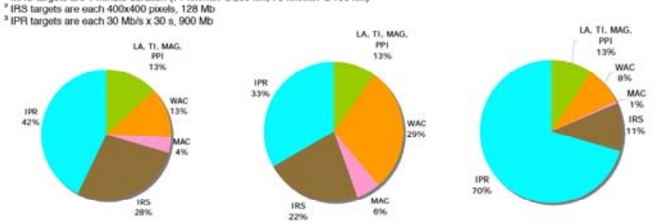
Europa Mapping Mission Timeline



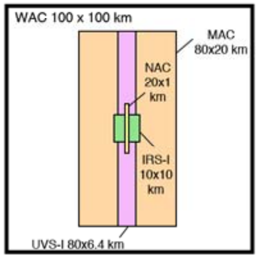
Preliminary Floor Coverage Summary

Reference S/C (Floor)	Campaign 1: Global Framework — Glob data per day (Gb)	Targ data per day (Gb)	% tot vol	Avg Targ per day	Cam Tot Targ	Cam Tot Vol (Gb)	Campaign 2: Regional Processes — Glob data per day (Gb)	Targ data per day (Gb)	% tot vol	Avg Targ per day	Cam Tot Targ	Cam Tot Vol (Gb)	Campaign 3: Targeted Processes — Glob data per day (Gb)	Targ data per day (Gb)	% tot vol	Avg Targ per day	Cam Tot Targ	Cam Tot Vol (Gb)	Total Targets	% total vol	Total Vol (Gb)
Data Volume	3.4	2.3				158	5.0	2.2				305	2.1	5.6				161			624
WAC	0.7		13%			20	2.1		29%			87	0.6		8%			13		19%	121
MAC[1]	0.0	0.2	4%	9 T	252	6	0.0	0.4	6%	7 T	294	17	0.0	0.1	1%	1 T	21	1	567 T	4%	25
IRS[2]	0.4	1.2	28%	9 T	252	44	0.7	0.9	22%	7 T	294	67	0.7	0.1	11%	1 T	21	17	567 T	21%	129
IPR[3]	1.5	0.9	43%	1 T	28	68	1.5	0.9	33%	1 T	42	102	0.0	5.4	70%	6 T	126	113	196 T	45%	284
TI	0.2		3%			5	0.2		2%			7	0.2		2%			4		3%	16
LA	0.2		3%			5	0.2		2%			7	0.2		2%			4		3%	16
PPI	0.2		3%			5	0.2		2%			7	0.2		2%			4		3%	16
MAG	0.2		4%			6	0.2		3%			9	0.2		3%			5		3%	20

[1] MAC targets are 1 minute duration (71 km/min @200 km, 78 km/min @100 km)
[2] IRS targets are each 400x400 pixels, 128 Mb
[3] IPR targets are each 30 Mb/s x 30 s, 900 Mb

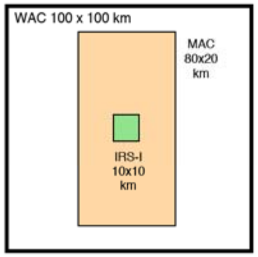


Nested Targeted Images



Baseline

Data Volume for Nested Images	
MAC	45 Mb
NAC	60 Mb
IRS-I	128 Mb
UVS-I	120 Mb
Total	353 Mb



Floor

Data Volume for Nested Images	
MAC	45 Mb
IRS-I	128 Mb
Total	173 Mb