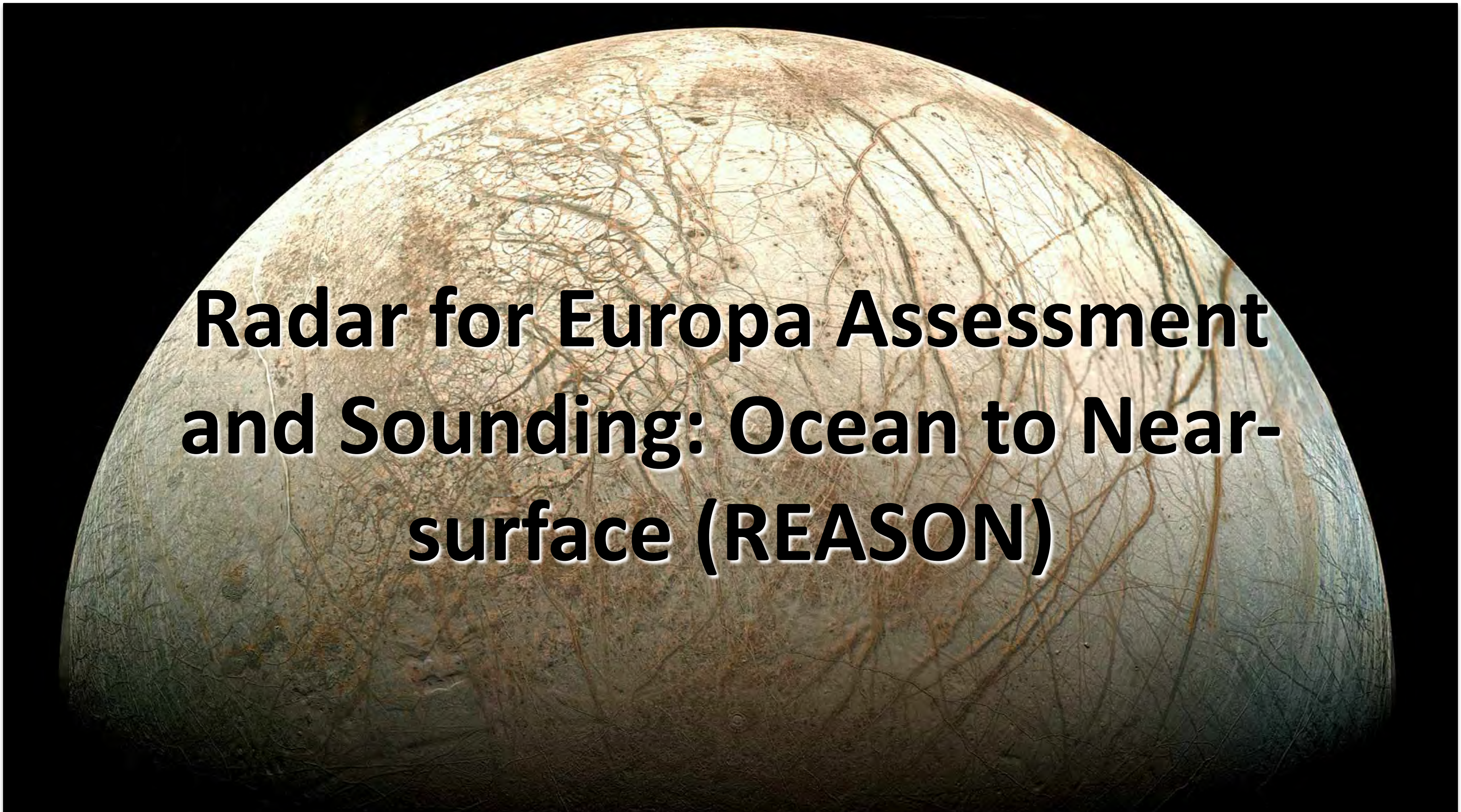


Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON)

UTIG

JPL

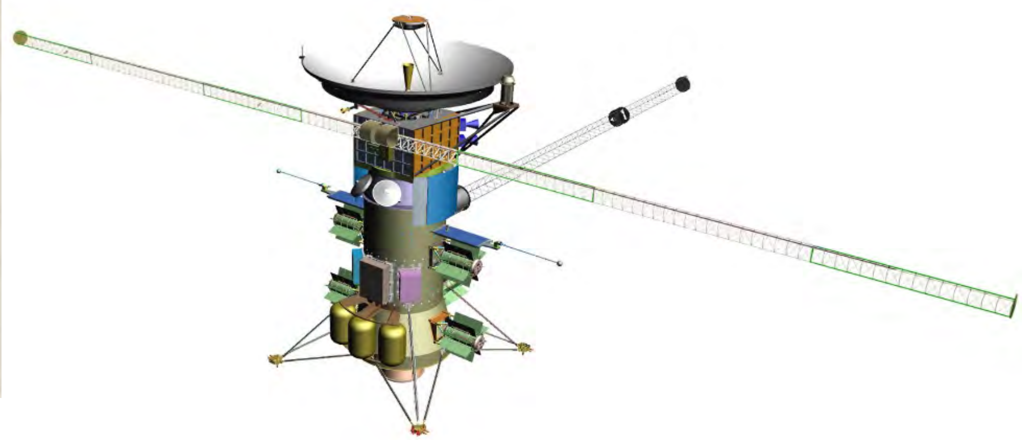
APL
Johns Hopkins
Applied Physics Laboratory

The University of Iowa

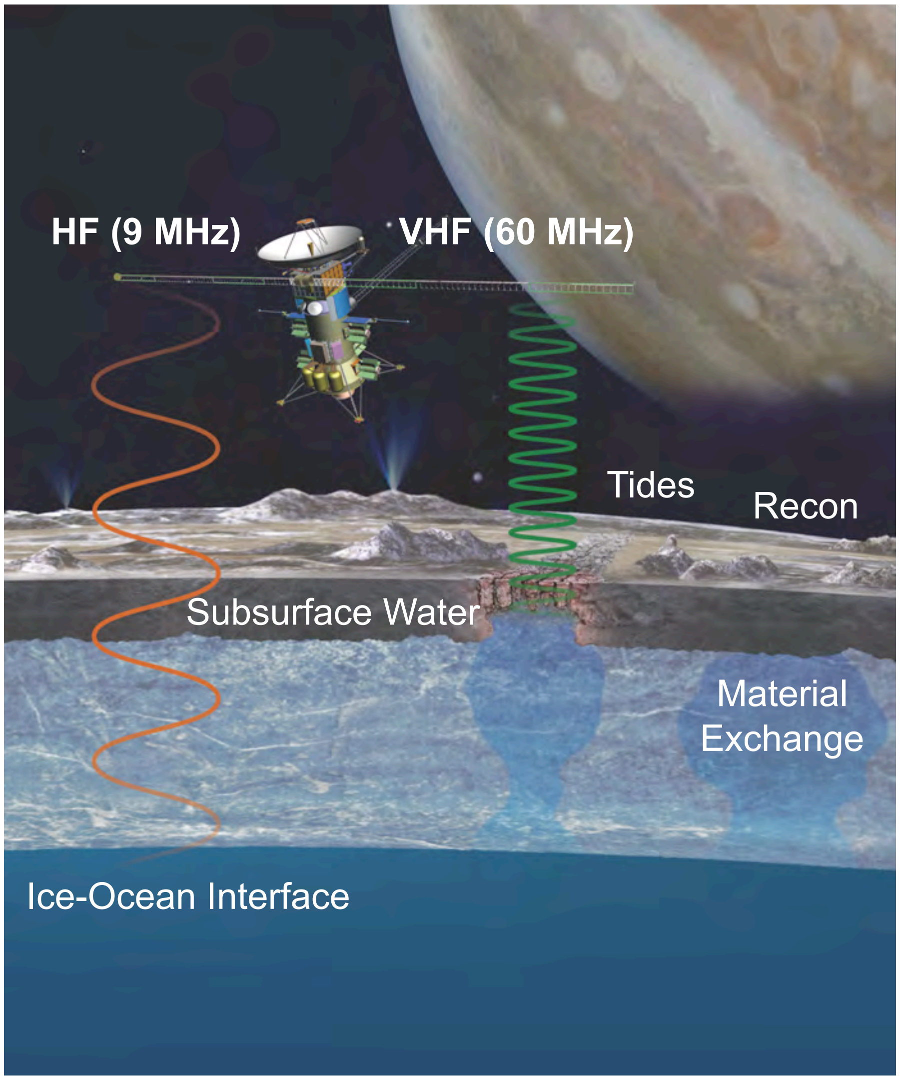
Instrument Characteristics

- **Dual Frequency Radar**
- VHF band with a center frequency of 60 MHz and a selectable in-ice vertical resolution of 15 m for shallow sounding to 4.5 km or 150 m for sub-Jovian ocean searching beyond 4.5 km
  - VHF band provides nadir altimetry profiles
  - VHF band has two separate cross-track channels for clutter discrimination
- HF band with a center frequency of 9 MHz and an in-ice vertical resolution of 150 m for anti-Jovian ocean searching to 30 km

Electronics Mass	17.5 kg
Antenna Mass	14.7 kg
Total Mass	32.2 kg
Operating Power	55 W
Antenna Length	16 m
Data Rate	5 – 80 Mbps
Data Volume per Flyby	24 Gbits



REASON Measurements

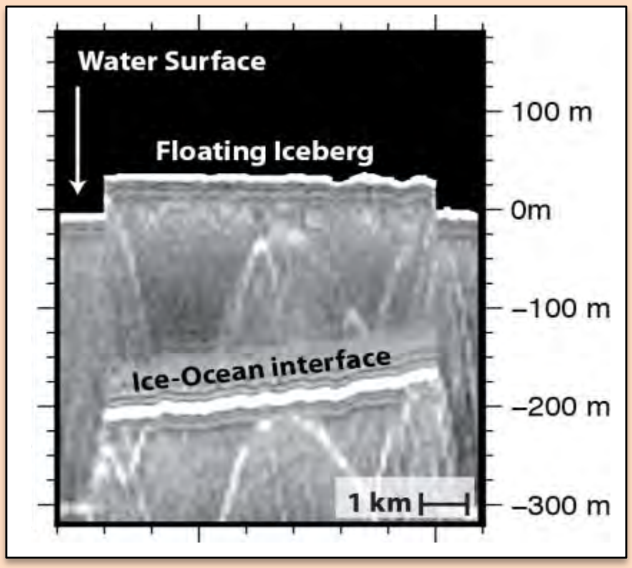


Four Key Measurements

- ***Sounding*** (shallow and deep) to probe the ice shell
- ***Altimetry*** to determine surface elevations
- ***Reflectometry*** to study surface roughness and permittivity (composition and roughness)
- ***Plasma and Particles*** to detect any active plumes by characterizing the ionosphere

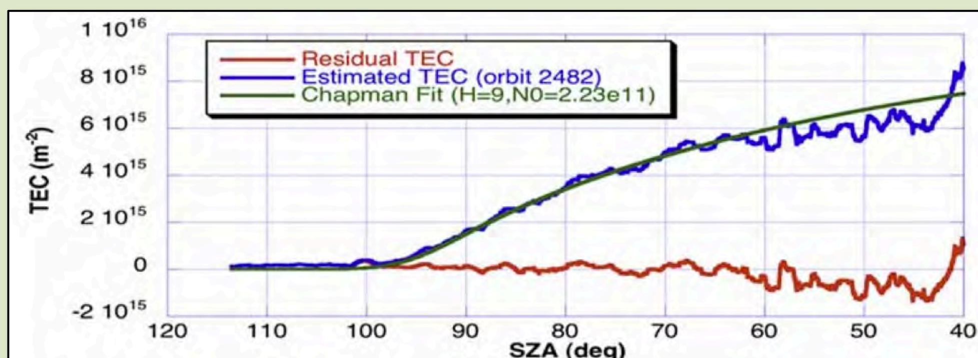
REASON Measurements

Sounding & Altimetry for subsurface structure and surface elevation. The surface and ice-ocean interface of Iceberg B15, Antarctica, appear as sharp reflectors.

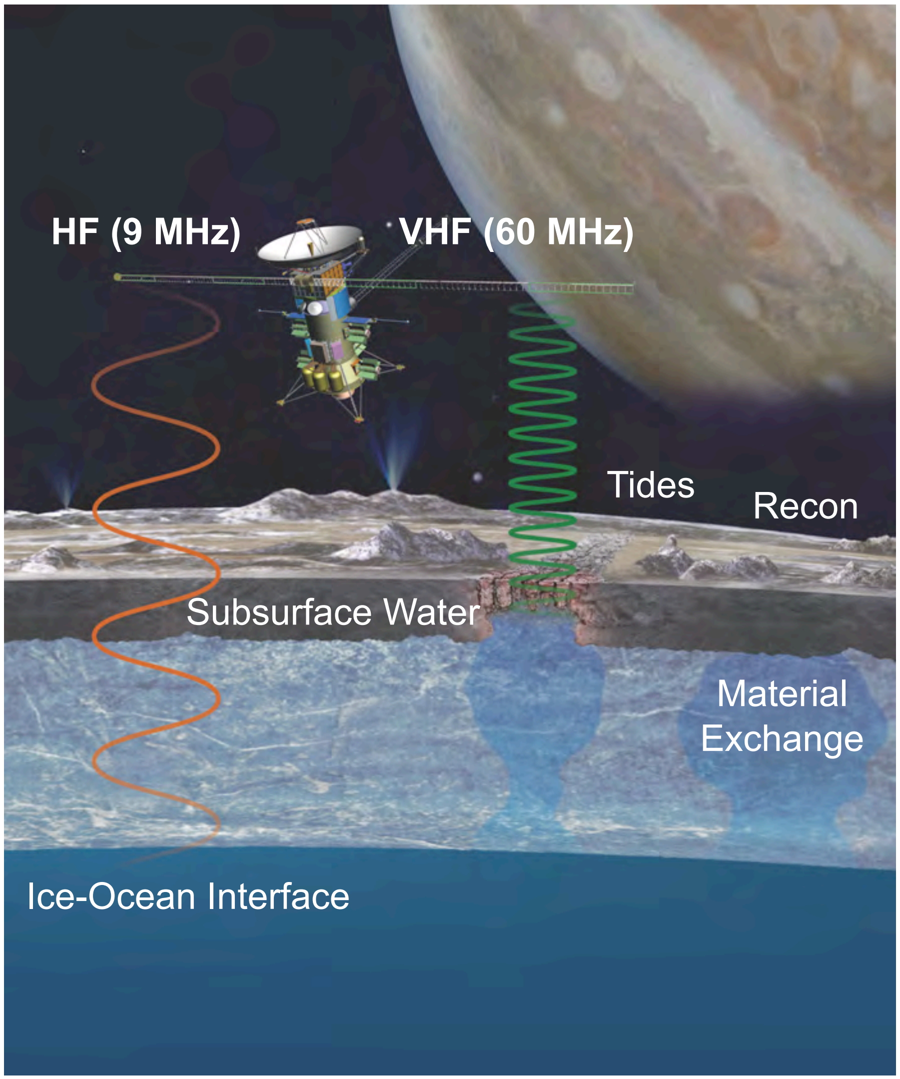


Reflectometry for near-surface roughness, porosity, and composition. Snow, firn, clean ice, dirty ice, and brine are distinguished by permittivity variations over McMurdo Ice Shelf, Antarctica.

Plasma/Particles to identify active plumes. Total electron content of Mars' ionosphere derived from MARSIS.



REASON Investigations

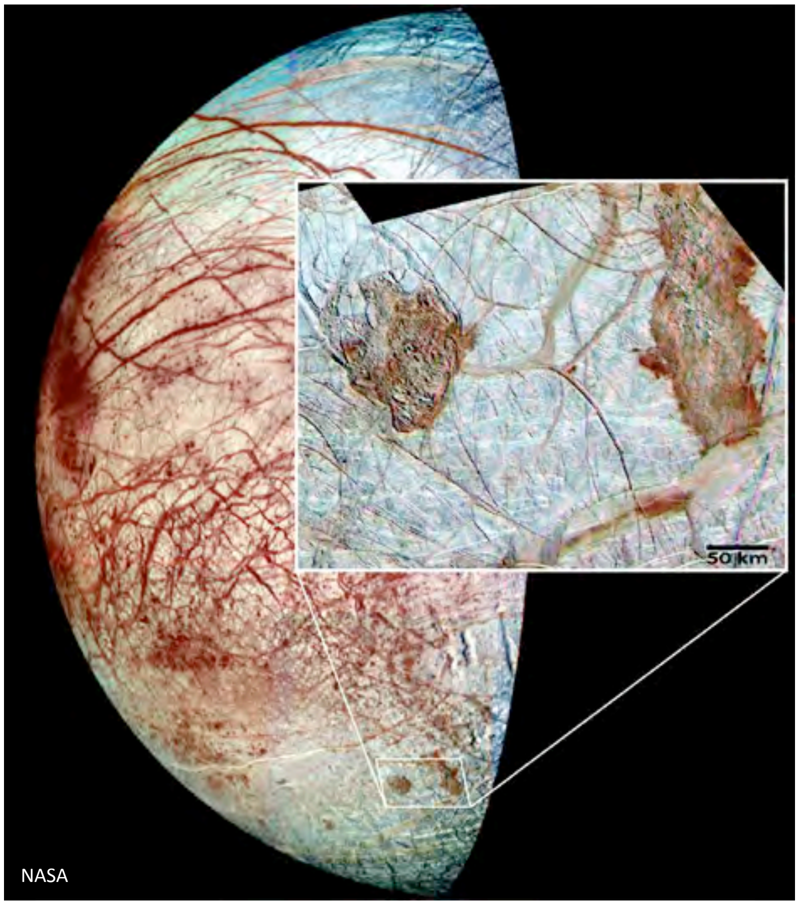


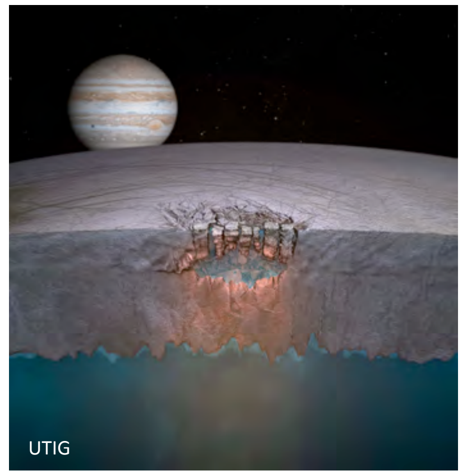
Science and Reconnaissance

1. Characterize the distribution of any shallow subsurface water
2. Search for an ice-ocean interface and characterize the ice shell's global structure
3. Investigate the processes governing material exchange among the ocean, ice shell, surface, and atmosphere
4. Constrain the amplitude and phase of gravitational tides
5. Characterize scientifically compelling sites, and hazards, for a potential future landed mission

Investigation Overview

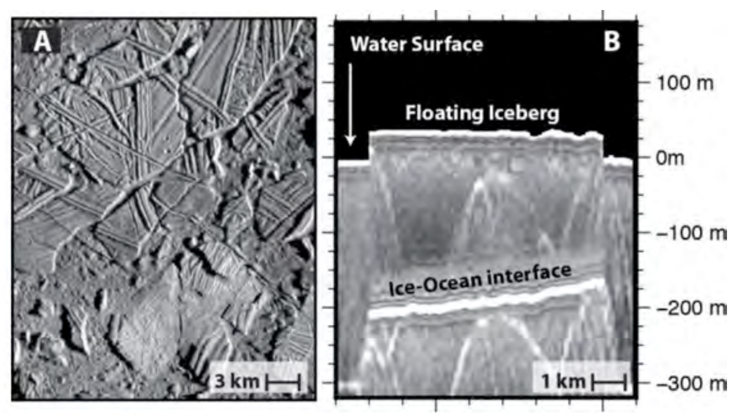
1. Characterize the distribution of any shallow subsurface water





Search for perched water bodies in the ice shell (*Sounding*)

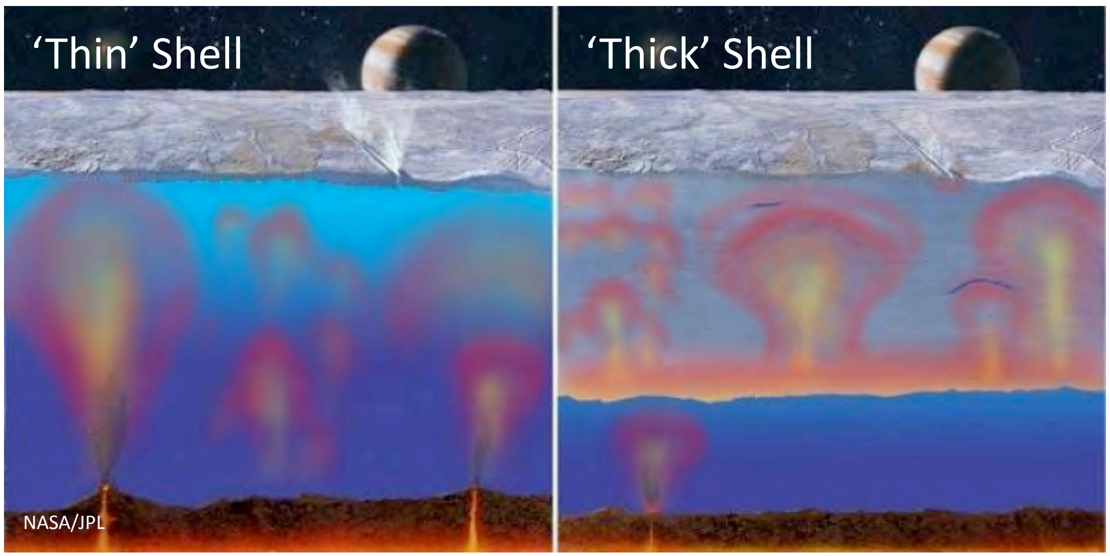
Search for any near-surface brines (*Reflectometry*)



Test for flotation of iceberg-like blocks (*Altimetry*)

Investigation Overview

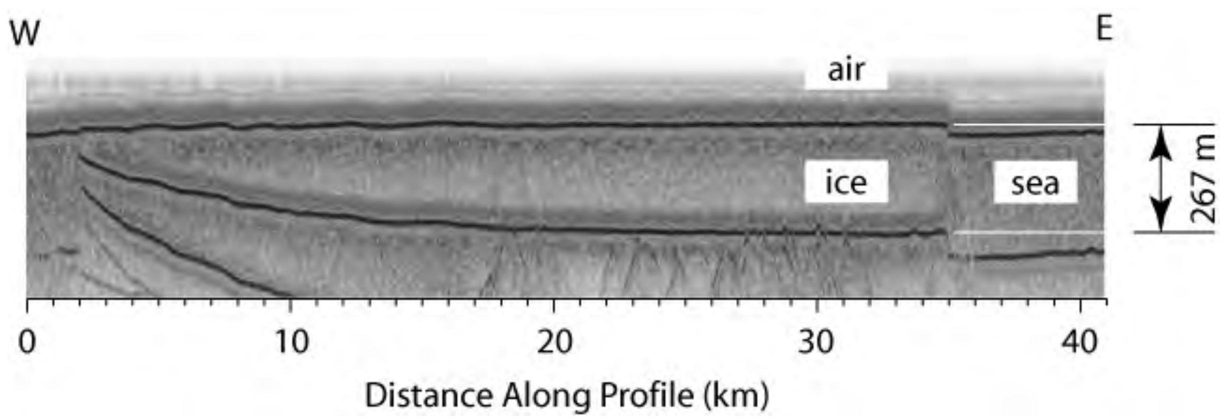
2. Search for an ice-ocean interface and characterize the ice shell's global thermophysical structure



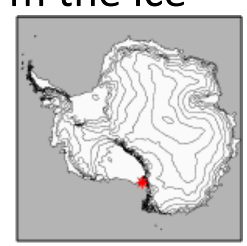
Confirm the presence of a global subsurface ocean

Solve thin versus thick ice shell debate

Determine whether the ice shell is thermally conductive or unstable to convection

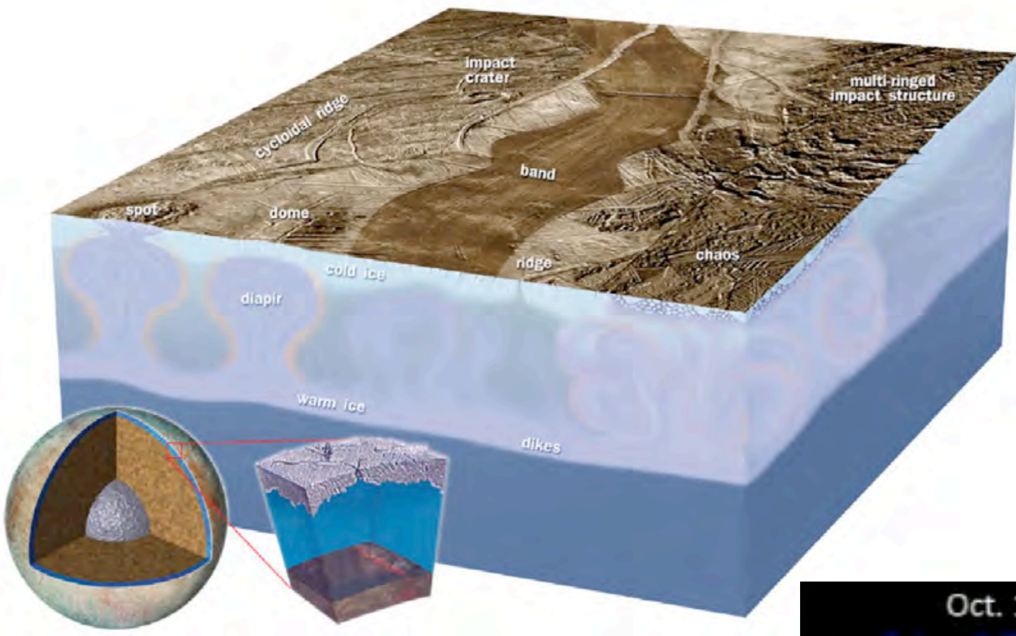


Sounding and *altimetry* will detect and confirm the ice-ocean interface



Investigation Overview

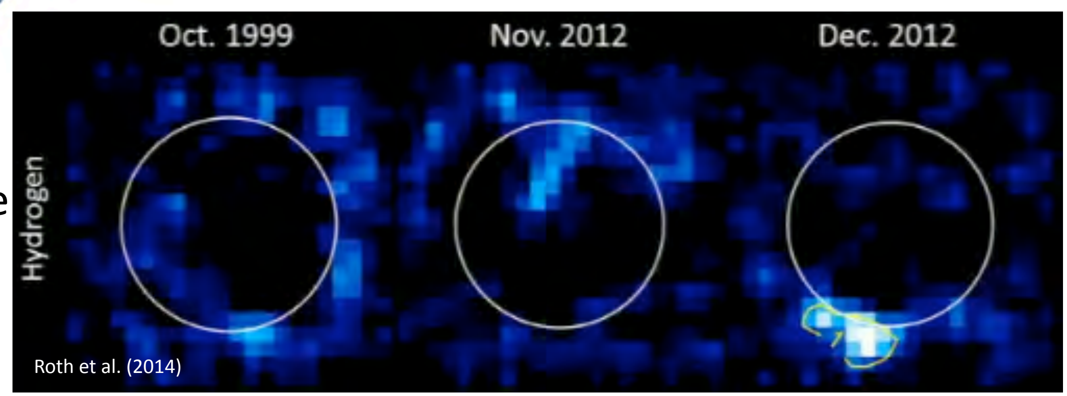
3. Investigate the processes governing material exchange among the ocean, ice shell, surface, and atmosphere



Search for water signatures, compositional and thermal variations, and buried deposits (*Sounding*, *Reflectometry*)

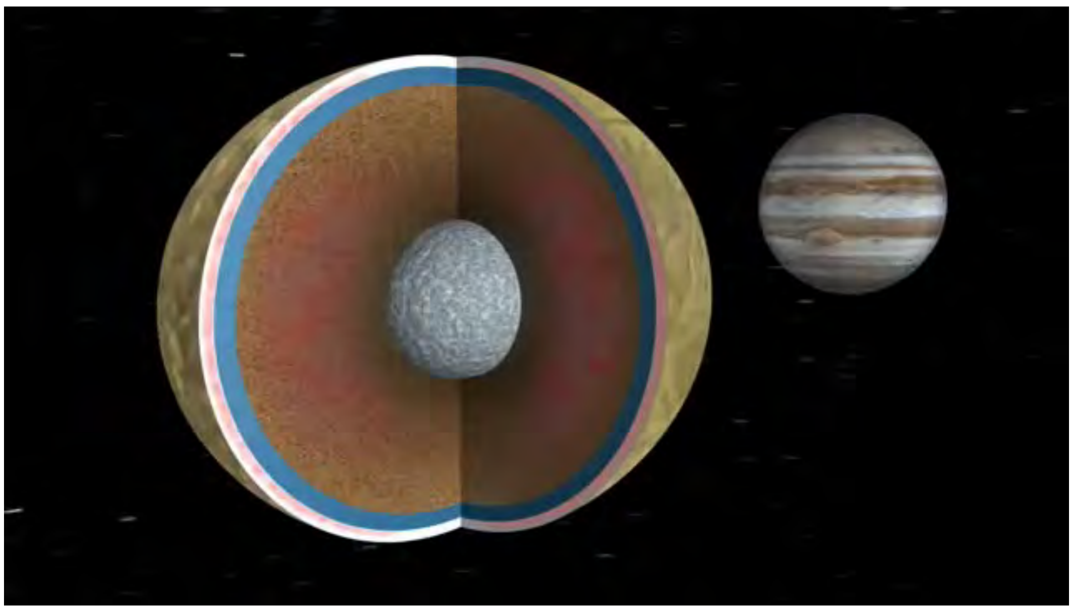
Measure surface heights for geologic context and hydraulic gradients (*Altimetry*)

Detect active plumes by measuring ionospheric anomalies and recent plume activity by detecting snow deposits (*Plasma/Particles*, *Reflectometry*)



Investigation Overview

4. Constrain the amplitude and phase of gravitational tides



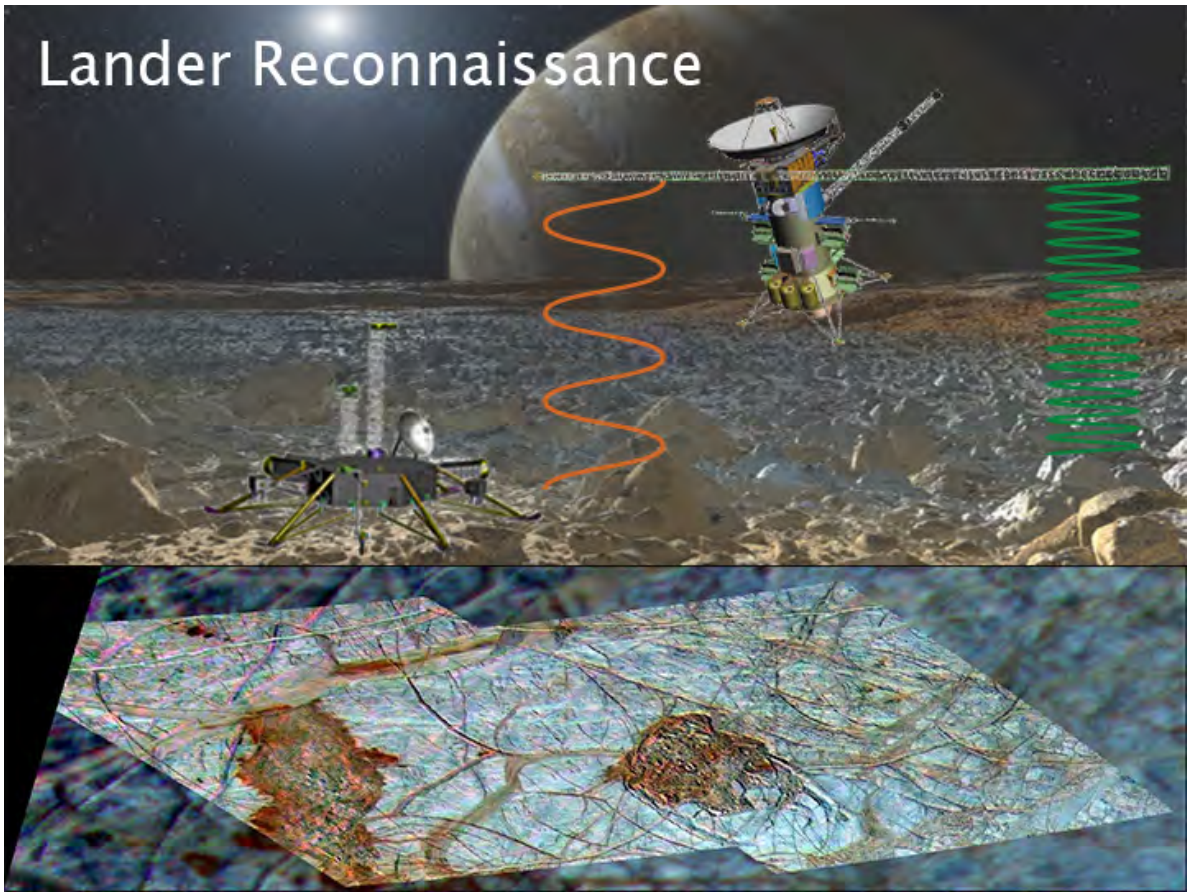
Non-circular orbit around Jupiter causes a time-varying gravitational potential

Tidal amplitude is controlled by the satellite's internal structure (30 m with an ocean, 1 m without an ocean)

Regional to global surface heights at different true anomalies will constrain Europa's tides (*Altimetry*)

Investigation Overview

5. Characterize scientifically compelling sites, and hazards, for a potential future landed mission



REASON will provide reconnaissance for a follow on
in-situ lander mission

REASON will constrain surface roughness and material properties to select sites for landing safety and scientific value (*Reflectometry, Sounding, Altimetry*)

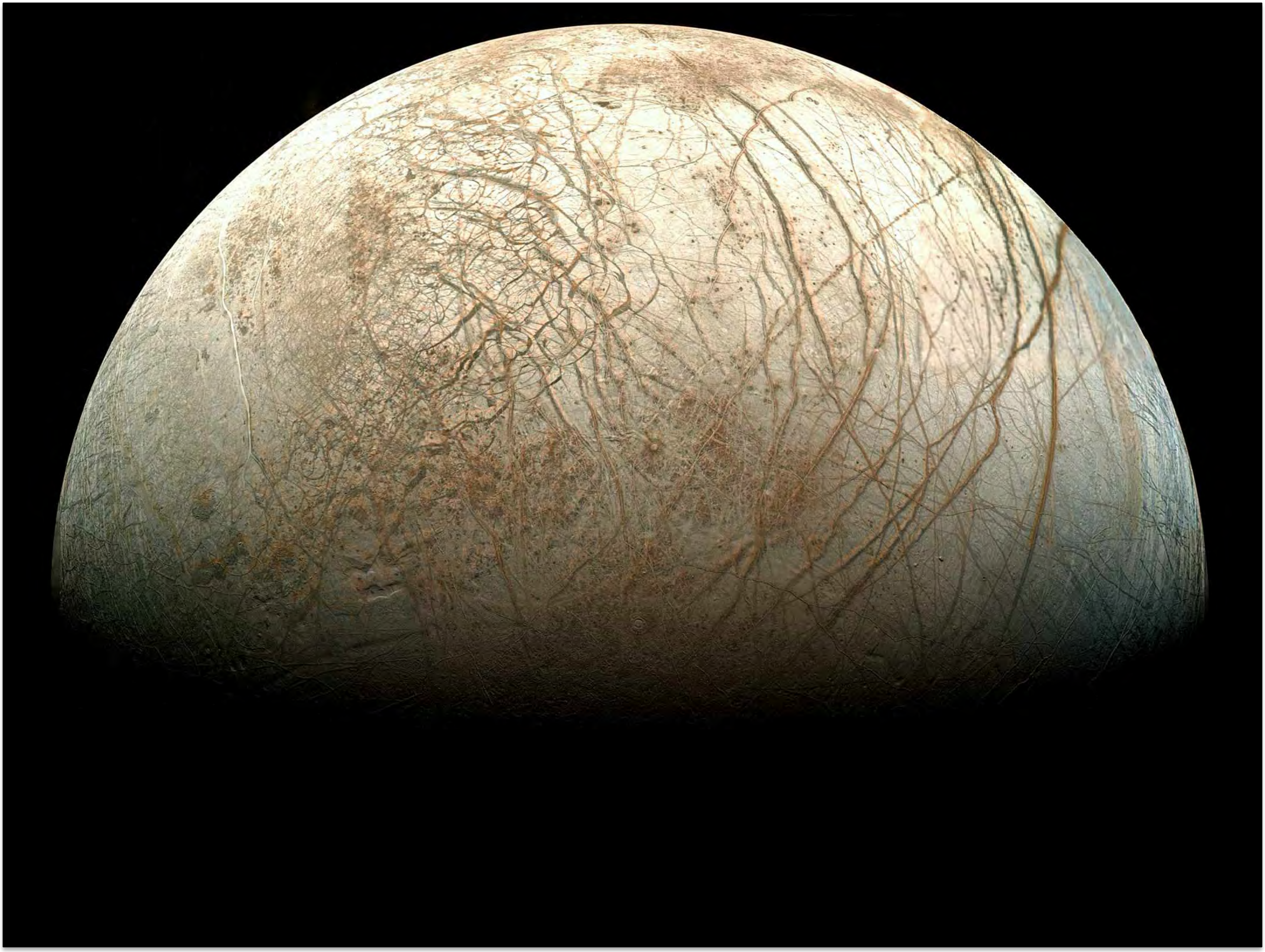
Science Team Members

- Science Team pairs senior scientists with early career scientists to ensure mission continuity

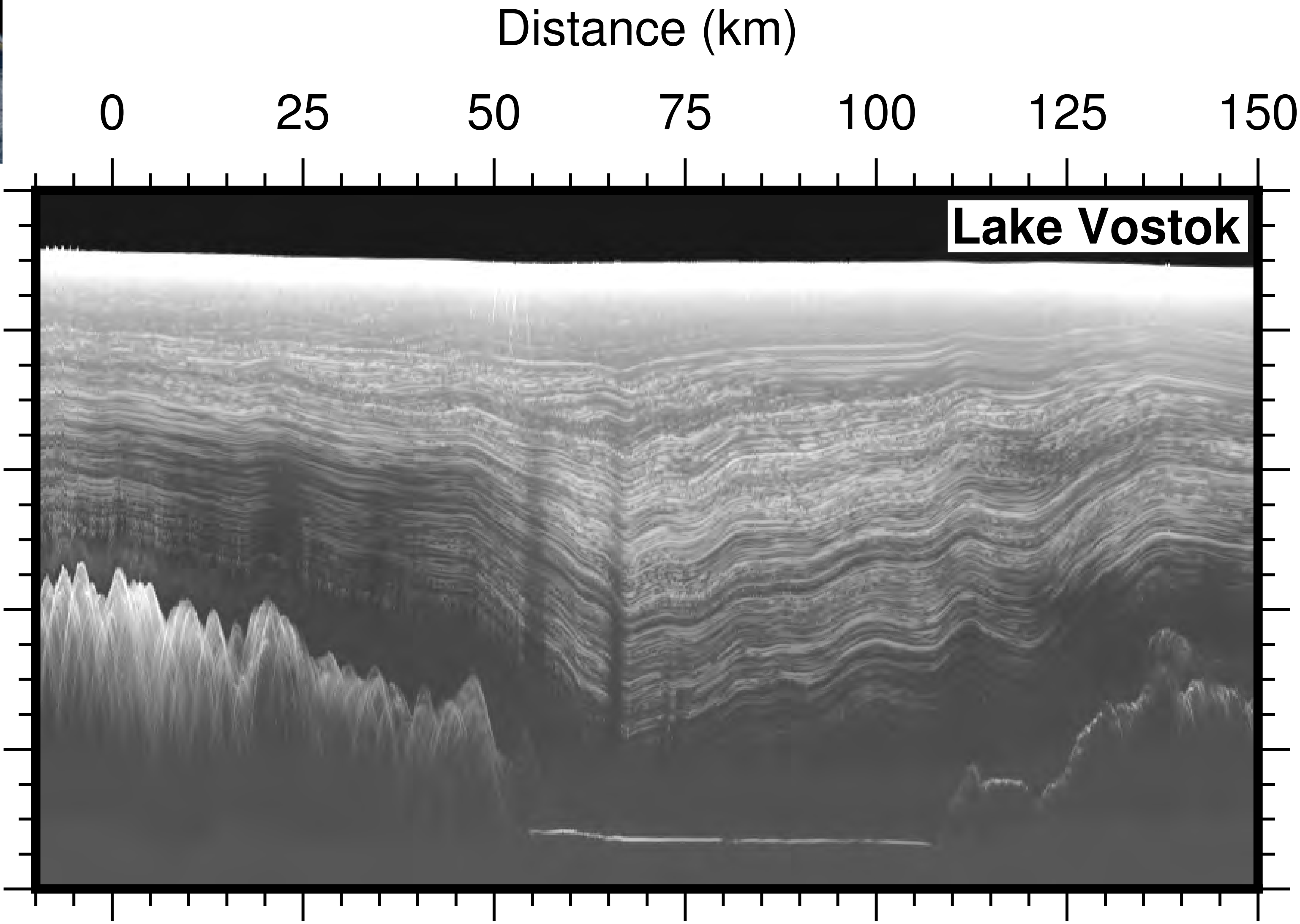
Senior	Early Career
Don Blankenship (UTIG)	Alina Moussessian (JPL)
Jeff Plaut (JPL)	Wes Patterson (APL)
Bill McKinnon (Wash U.)	Britney Schmidt (GT)
Bruce Campbell (SI)	Lynn Carter (GSFC)
Mikhail Zolotov (ASU)	Krista Soderlund (UTIG)
Bill Kurth (UI)	Carol Paty (GT)
Charles Elachi (JPL)	Cyril Grima (UTIG)
Francis Nimmo (UCSC)	Amy Barr Mlinar (PSI)
Jeff Moore (ARC)	Duncan Young (UTIG)
Yonggyu Gim (JPL)	Dustin Schroeder (JPL)

International

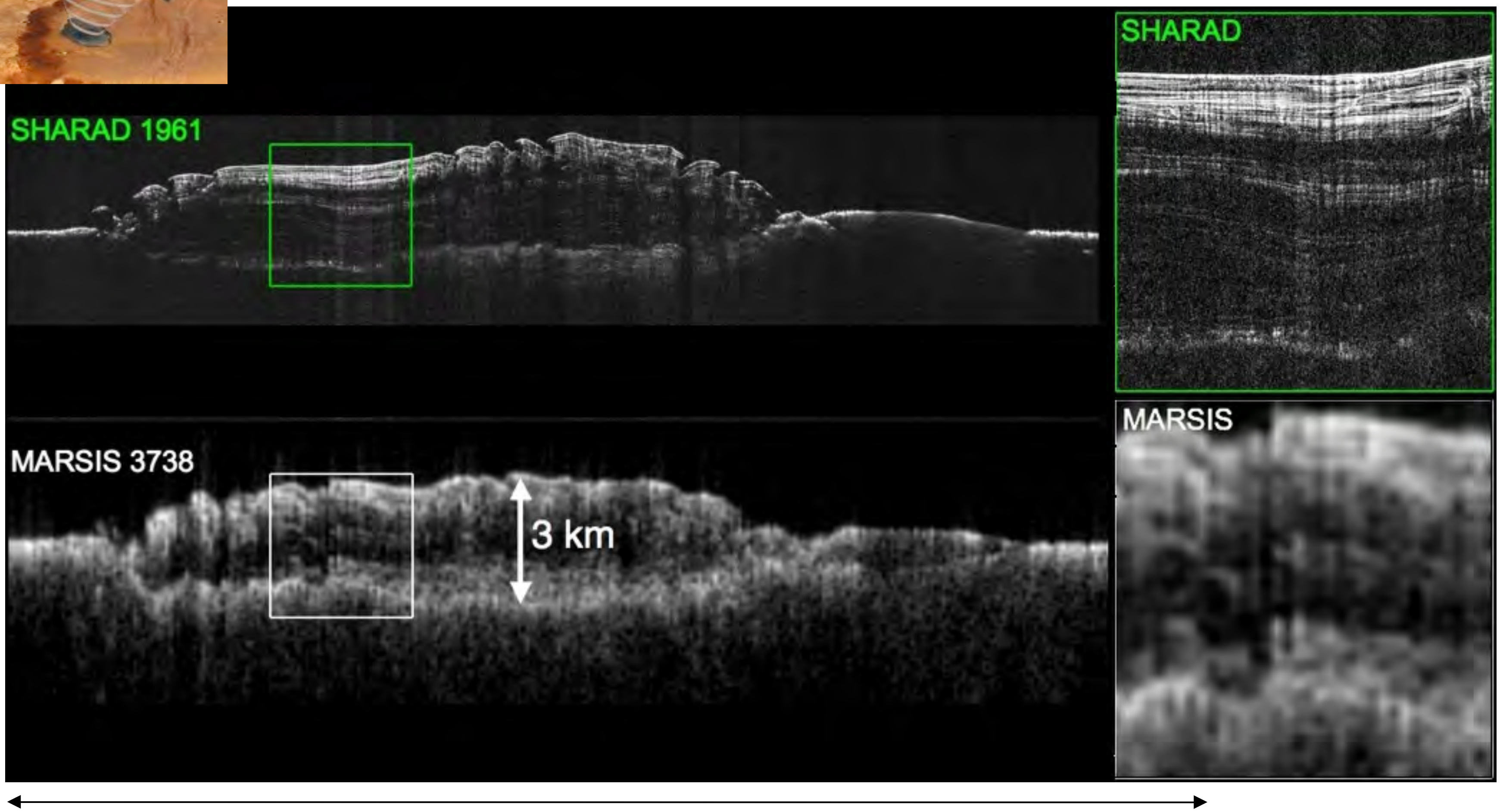
Wlodek Kofman (IPAG, France)	Alain Herique (IPAG, France)
Lorenzo Bruzzone (U. Trento, Italy)	Marco Mastrogiuseppe (U. Rome, Italy)
Dirk Plettemeier (U. Dresden, Germany)	Hauke Hussmann (DLR, Germany)



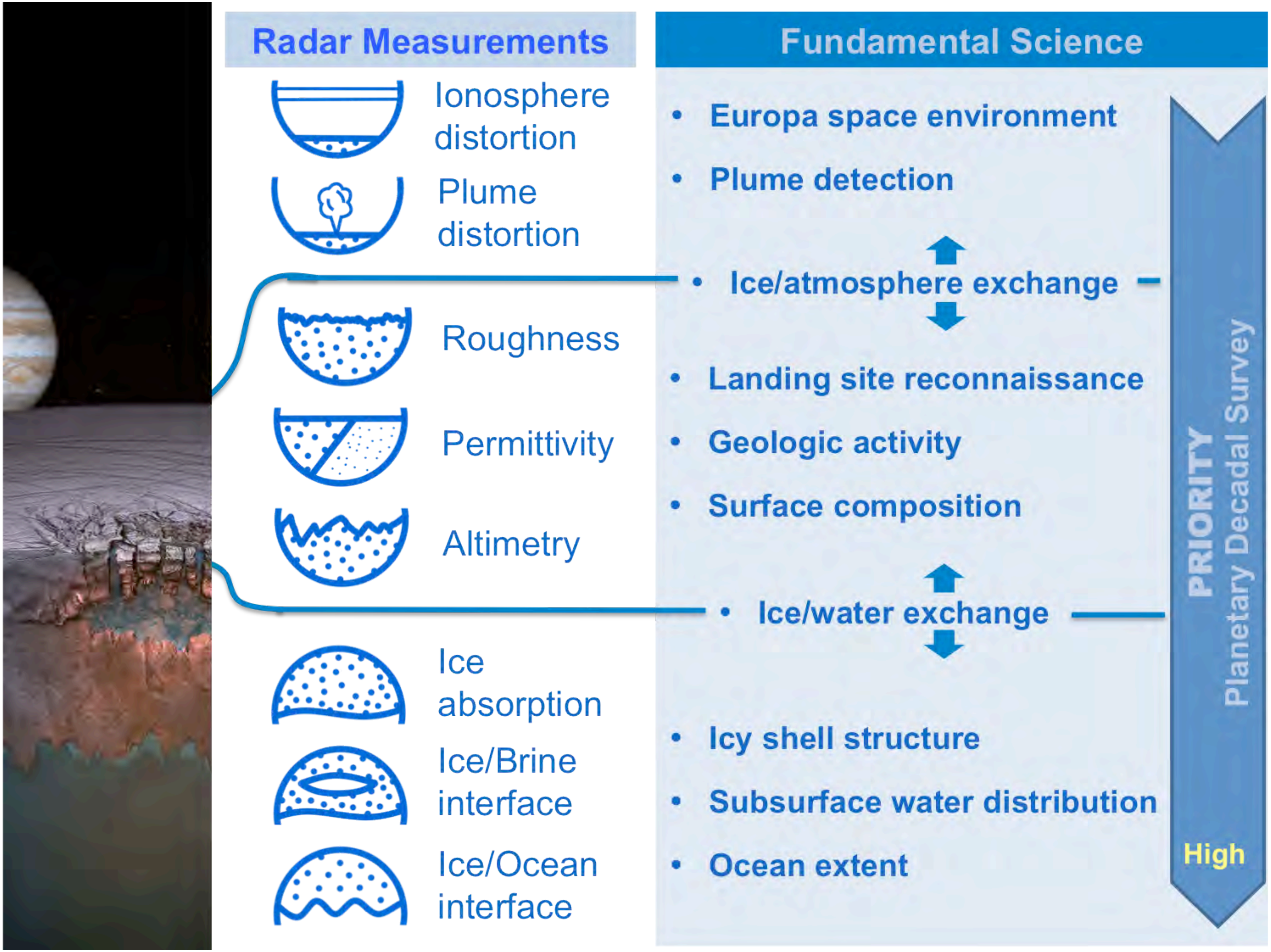
Ice-Penetrating Radar



Ice-Penetrating Radar

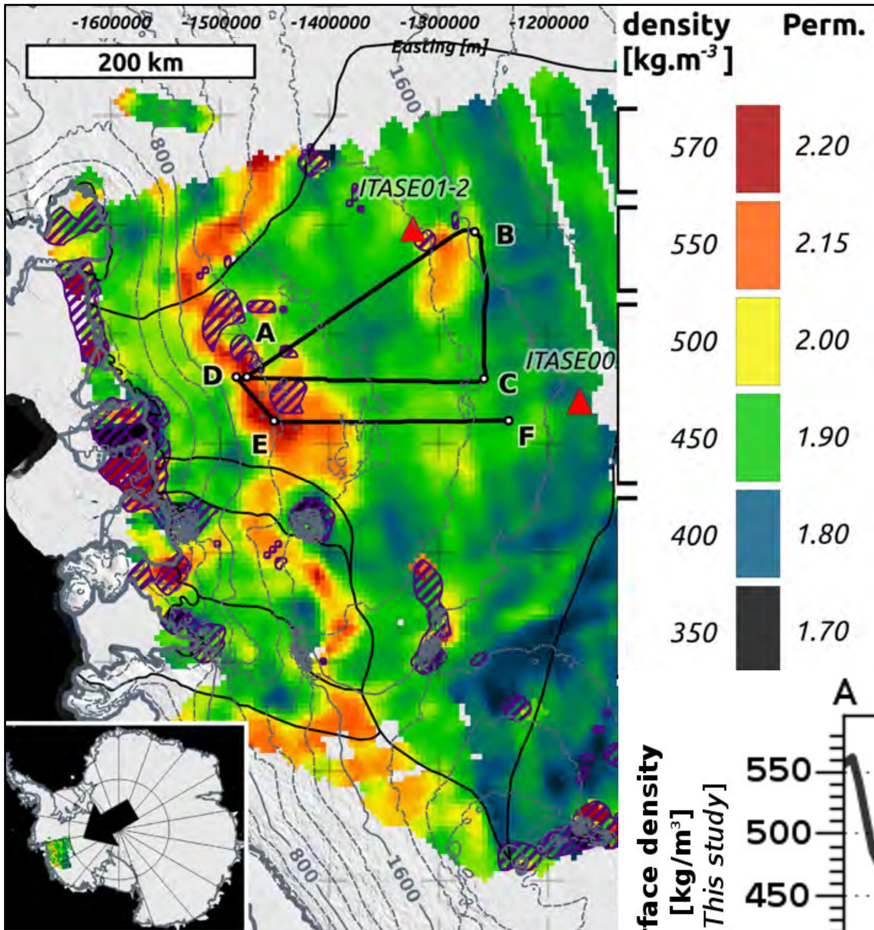


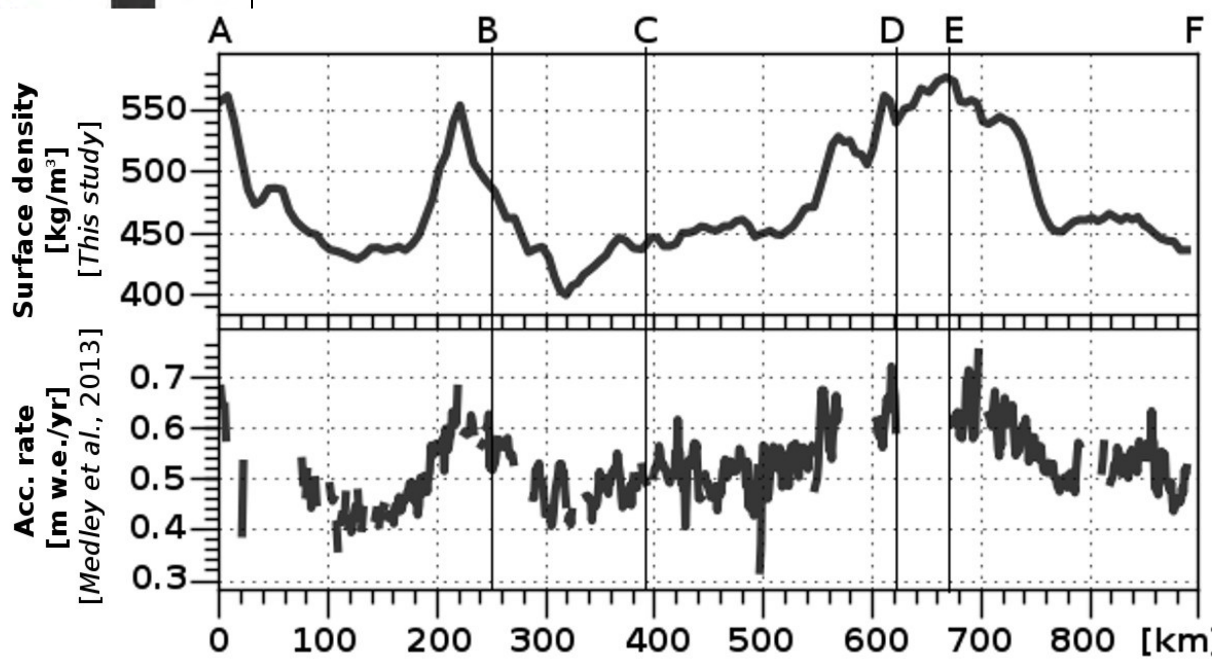
A. Safaeinili pers. comm


Radar Measurements
Ionosphere distortion
Plume distortion
Roughness
Permittivity
Altimetry
Ice absorption
Ice/Brine interface
Ice/Ocean interface
Fundamental Science
• Europa space environment
• Plume detection
• Ice/atmosphere exchange
• Landing site reconnaissance
• Geologic activity
• Surface composition
• Ice/water exchange
• Icy shell structure
• Subsurface water distribution
• Ocean extent
PRIORITY
Planetary Decadal Survey
High

Reflectometry

- Technique developed for Europa science and reconnaissance
- Firn densities imply snow accumulation rates on Earth and recent plume activity on Europa

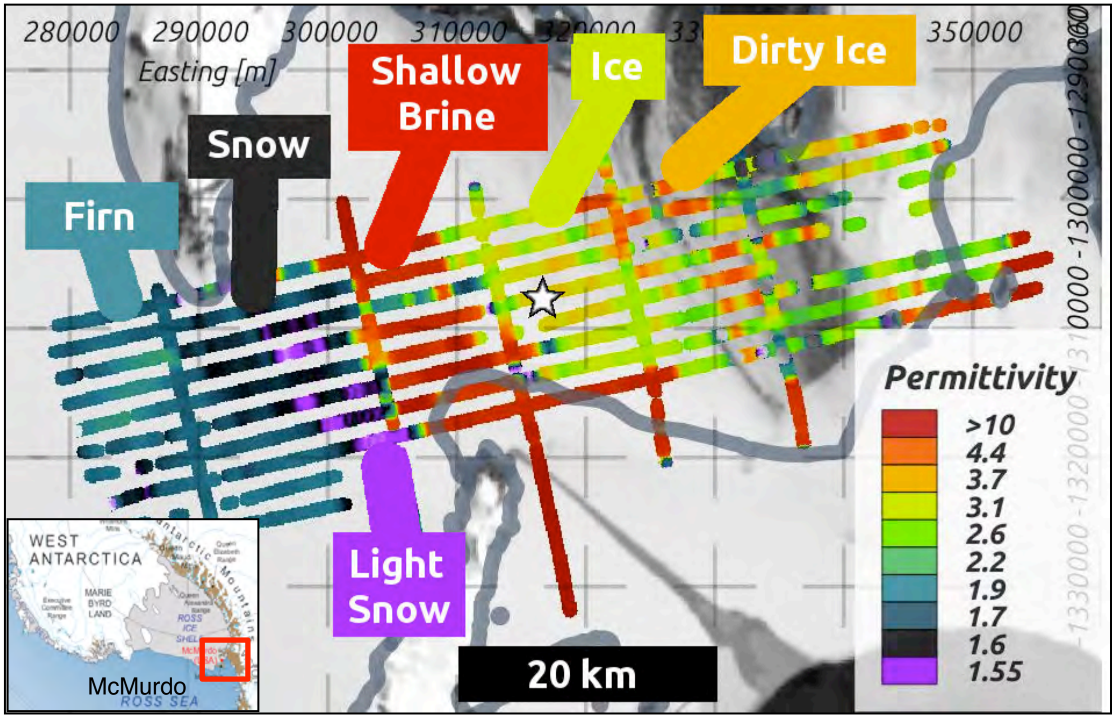




- Validation over Thwaites Glacier, Antarctica

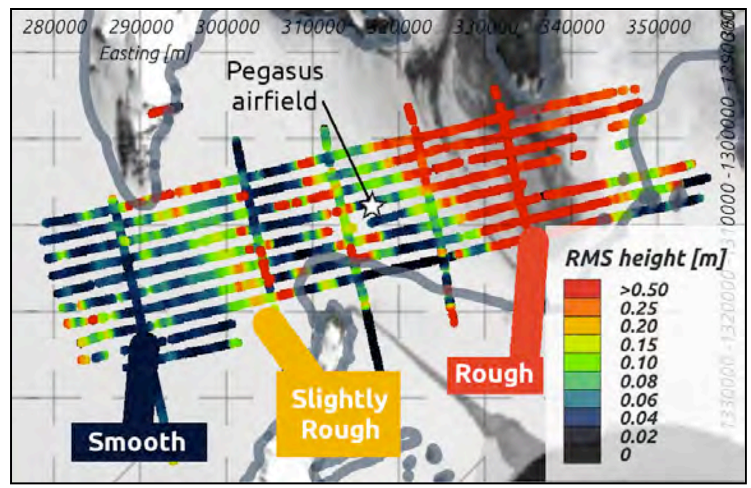
Grima et al., GRL 2014

Reflectometry



- Brine detection and impurity identification is important for potential habitability and reconnaissance

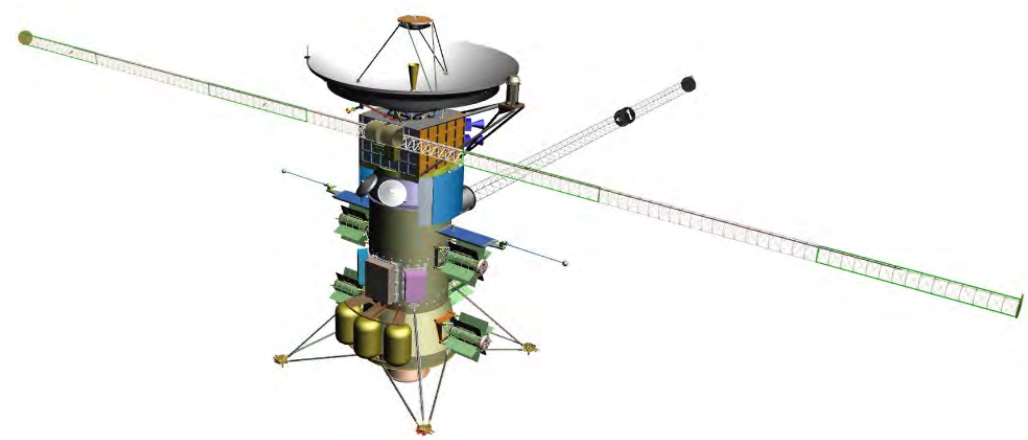
- Safe landing site reconnaissance must map surface roughness



Grima et al., in prep

Instrument Characteristics

- **Dual Frequency Radar**
- Simultaneous collection at two frequencies provides robustness to demanding conditions (e.g., surface scattering, ice properties)
  - VHF band provides performance robustness to Jovian noise
  - HF band provides performance robustness to surface roughness
- Built-in clutter discrimination capability (multi-phase)
- Meets all environmental and radiation requirements

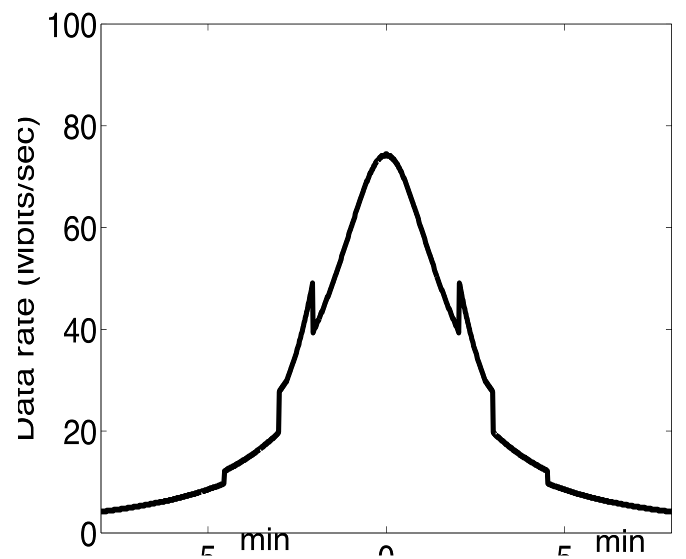


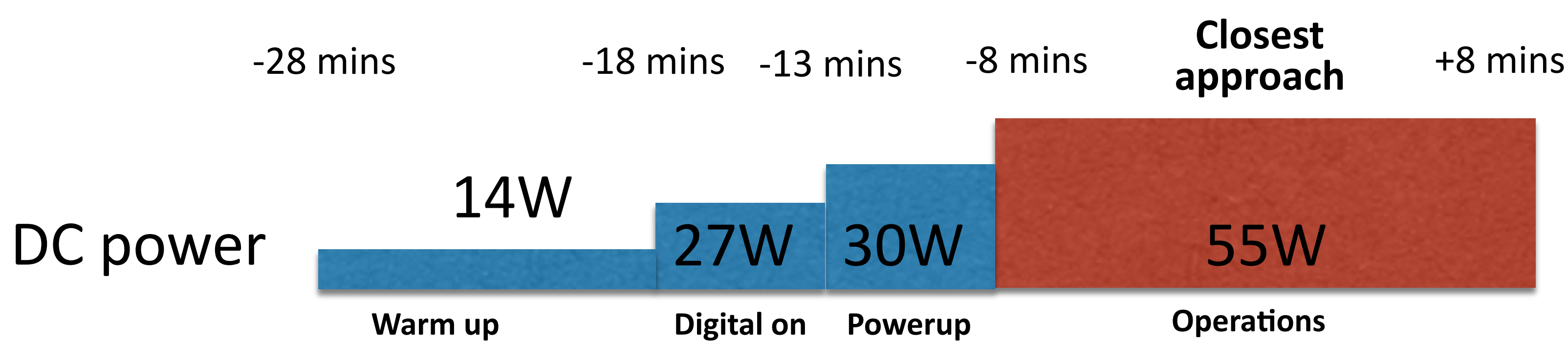
Operations

- Two encounter modes - same data rate
  - Anti-jovian shallow VHF/deep HF
  - Sub-jovian shallow VHF/deep VHF
  - \+ non transmitting 'listen' mode

shallow obs: 400 km to 10 km altitude
deep obs: <1000 km altitude
altimetry: <1000 km altitude
reflectometry: <1000 km altitude
plumes: <1000 km altitude

max data rate: 80 Mbps
data per flyby: 24 Gb





REASON Data Interdependencies

Sounding:

- Clutter characterization
  - EIS WAC/NAC image data
  - EIS WAC stereo topography
- Ice shell structure
  - E-THEMIS
  - MISE
- Ice shell thickness
  - ICEMAG
  - PIMS

Altimetry:

- Heights of surface features
  - EIS WAC/NAC stereo topography
- Surface characteristics (permittivity)
  - E-THEMIS
  - UVS
  - MISE
- Tides
  - EIS WAC/NAC
  - Gravity

REASON Data Interdependencies

Reflectometry:

- Surface characteristics
  - E-THEMIS
  - UVS
  - MISE
  - EIS WAC/NAC

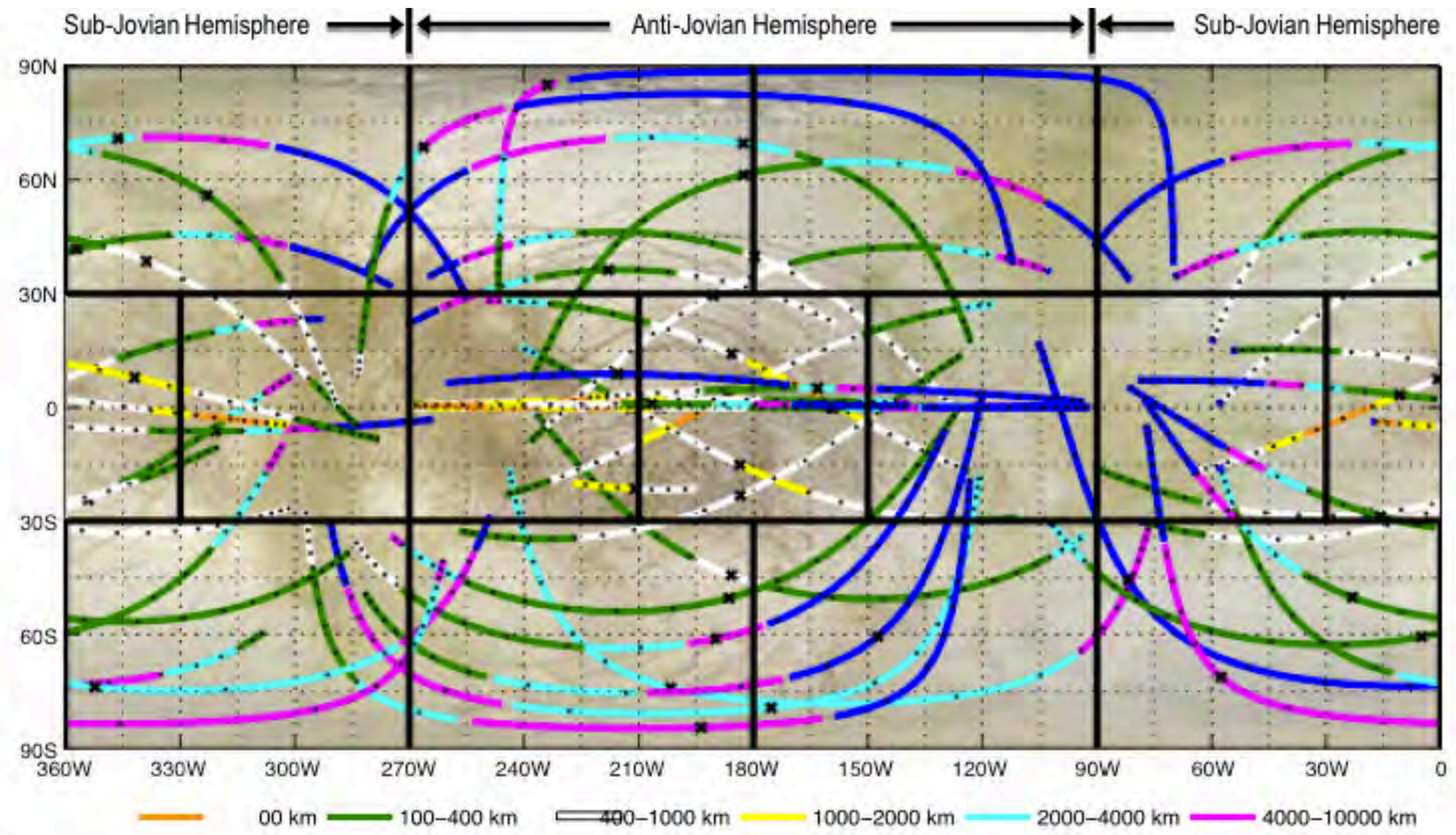
Plasma & Particles:

- Plumes
  - UVS
  - PIMS
  - SUDA

Management and Major Partners

- **University of Texas Institute for Geophysics**
  - Principal Investigator: Donald Blankenship
  - Investigation implementation, operations, and data flow management within cost and schedule
- **Jet Propulsion Laboratory**
  - Deputy Principal Investigator: Alina Moussessian
  - Associate Deputy Principal Investigator: Jeff Plaut
  - Instrument management, system engineering, hardware development, safety and mission assurance, integration and testing
- **Johns Hopkins University Applied Physics Laboratory**
  - Associate Deputy Principal Investigator: Wes Patterson
  - Science planning and communication with the Europa Project
- **University of Iowa**
  - Transmitter, antennas and associated electronics

Mission Requirements: Coverage



Mission Requirements: Coverage

- Shallow Science and Recon:
  - Globally distributed, intersecting regional profiles with >800 km groundtrack lengths
  - Three or more 800 km groundtrack segments in each anti-jovian equatorial and polar panels
  - Two 800 km groundtrack segments in each sub-jovian panel
  - **Baseline**: Above requirements satisfied in any 11 of the 14 panels with one groundtrack intersection within each panel
  - **Threshold**: Two or more 1600 km groundtrack segments in five anti-jovian panels and five 1600 km groundtrack segments on the sub-jovian hemisphere
- Deep Science:
  - Globally distributed profile segments totally >1600 km in length per intersecting groundtrack with two profiles per panel
  - **Baseline**: Above requirements satisfied in any 11 of the 14 panels with one groundtrack intersection within each panel
  - **Threshold**: Two or more 1600 km groundtrack segments in five anti-jovian panels and five 1600 km groundtrack segments on the sub-jovian hemisphere

Mission Requirements: Operations

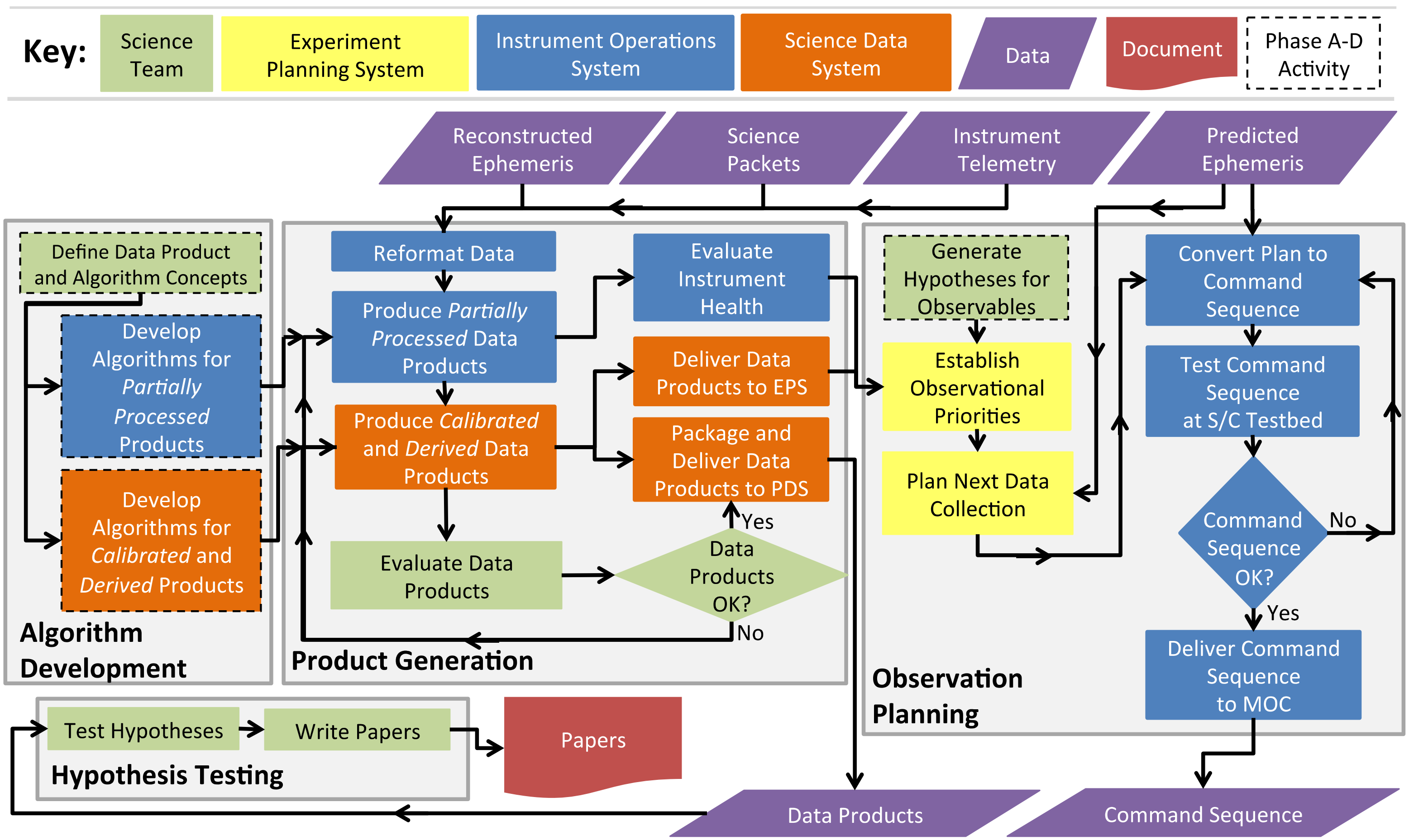
- Shallow Science and Recon:
  - Global VHF with HF anti-jovian operations at altitudes below 400 km and spacecraft velocities < 5 km/s
  - **Baseline**: Operating altitudes > 50 km
  - **Threshold**: Operating altitudes > 10 km
- Deep Science:
  - Global VHF with HF anti-jovian operations at altitudes below 1000 km and spacecraft velocities < 5 km/s
  - **Baseline**: Operating altitudes > 50 km
  - **Threshold**: Operating altitudes > 10 km

Data Plan

- APL: Experiment Planning System – Planning Data Collections [Yellow on chart]
- JPL: Instrument Operations System – Command Sequences, Instrument Health, Partial Processing [Blue on chart]
- UTIG: Science Data System – Produce and archive Calibrated and Derived Data Products [Orange on chart]
- Science Team: [Green on chart]

Data Plan

The REASON instrument Science Operations Center (iSOC) is responsible for data flow, from planning to distribution



Data Products

REASON data will be processed on the ground to produce interpretable data products

Data Product	Description	Application
Raw Digitizer traces	Reformatted downlinked data	Input for all products
Partially processed Uncompressed records	Raw data with ephemeris and instrument corrections	Input for *calibrated* products (range compressed radargrams with VHF interferometry and HF with ionospheric corrections)
Calibrated Unfocused SAR radargrams	Coherent integration for flat interface detection	Ocean search and support for shallow water/ exchange
Calibrated Focused SAR radargrams	Maximum along-track resolution through azimuth focusing	All sounding investigations
Calibrated Altimetry radargrams	Maximum independent sampling for surface statistics	Input for *derived* products
Derived Surface altimetry profiles	Ranges from radar to the surface	All altimetry investigations
Derived Reflectometry profiles	Statistical characterization of the surface properties	All reflectometry investigations
Derived Plasma and particles profiles	Total electron content between radar and surface	All plasma and particles investigations

Data Analysis

A variety of data analysis approaches will be implemented to address the science questions

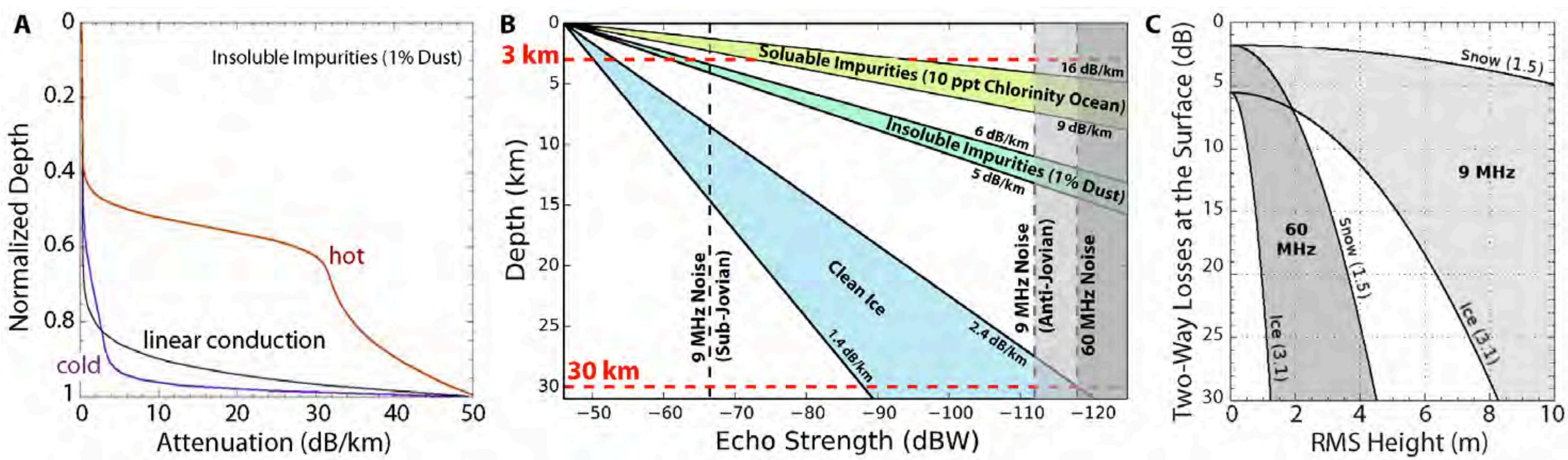
Results (Analysis Tool)	Creation from Lower Level Data	Use for Fundamental Science
Radargrams (Echo Coherence)	Coherent and incoherent sums	Enhance the detection of relatively smoothly reflecting subsurface water interfaces by the coherence of the bed echoes
Radargrams (Focused images)	SAR focusing	Morphological interpretation of SAR focused radar images for water detection, structure, and processes in the subsurface
Radargrams (Doppler delay)	Separate return by Doppler bin	Provide constraints on the material (e.g. thermal attenuation rate) and geometric (e.g. scattering function) of the deep and shallow subsurface
Radar Altimetry Profiles	Range estimate of surface return	Provide range registration for any topo-imager and ionospheric corrections. Provide surface profile context for subsurface features
Reflectometry profiles	Fit echo amplitude distributions	Provide estimate of surface roughness and dielectric properties for surface processes (e.g. brines and snow) and suitability for landing.
Frequency Dependence	Compare VHF and HF echoes	Provide constraints on material and geometric shallow subsurface properties (e.g. brines and snow)
Radar Echo Strengths	A variety of processing: (e.g. focusing, filtering)	Quantitative interpretation (e.g. hypothesis testing, modeling, formal inversion) of echo strengths for material (e.g. dielectric) and geometric (e.g. roughness) properties of the surface and subsurface.

Instrument Performance

- Sounding Requirements (Geometric):
  - Shallow Science and Recon:
    - Characterize structures between depths of 300 m to 3 km with <15 m vertical resolution (in ice)
    - Surface cross-track azimuth resolution of 3 degrees
    - Nyquist sampling of the Doppler bandwidth
  - Deep Science:
    - Search for structures between depths of 3 km to 30 km with <150 m vertical resolution (in ice)
    - Nyquist sampling of the Doppler bandwidth
- Sounding Performance (Geometric):
  - VHF:
    - Shallow sounding depths of 300 m to 4.5 km with 10 m vertical resolution (globally)
    - Surface cross-track azimuth resolution of 0.8 degrees
    - Deep sounding depths of 1-30 km at 100 m vertical resolution (sub-jovian)
    - Better than Nyquist sampling of the Doppler bandwidth
  - HF:
    - Deep sounding depths of 1-30 km with 100 m vertical resolution (anti-jovian)
    - Better than Nyquist sampling of the Doppler bandwidth

Instrument Performance

- Sounding Requirements (Radiometric):
  - Shallow Science and Recon:
    - VHF radar potential of 57 dB for an altitude of 400 km
  - Deep Science:
    - VHF or HF radar potential of 51 dB for an altitude of 400 km
- Sounding Performance (Radiometric):
  - VHF: 60 MHz radar potential of 72 dB for an altitude of 400 km (globally)
  - HF: 9 MHz radar potential of 63 dB for an altitude of 400 km (anti-jovian)



Instrument Performance

- Altimetry Requirements (Geometric):
  - VHF range resolution of 15 m
- Altimetry Performance (Geometric):
  - 60 MHz vertical resolution of <20 m (in vacuum) = <10 m (in ice)
  - Flat surface (0 m): 1 m range precision over 10 km horizontal scales
  - Nominal roughness (35 m): 1 m range precision over 100 km horizontal scales
  - Extreme roughness (75 m): 1 m range precision over 1000 km horizontal scales

Investigation	**Range Resolution**	**Horizontal Scale**	**<u>Range Precisions for RMS Heights</u>** 0 m	35 m	75 m
Gravitational Tides	15 m	10 km	1.1 m	2.2 m	4.1 m
		100 km	0.35 m	0.68 m	1.3 m
		1000 km	0.11 m	0.22 m	0.41 m

- Altimetry Requirements (Radiometric)
  - VHF radar potential of 43 dB for an altitude of 400 km
- Altimetry Performance (Radiometric)
  - 60 MHz radar potential of 72 dB for an altitude of 400 km

Instrument Performance

- Reflectometry Requirements (Geometric):
  - Statistical characterization requires ~1000 observations over 10 km length scales
  - Nyquist sampling of the Doppler bandwidth
- Reflectometry Performance (Geometric):
  - Statistical characterization requires >2000 observations over 10 km length scales
  - Better than Nyquist sampling of the Doppler bandwidth

- Reflectometry Requirements (Radiometric):
  - Radiometric stability of 1 dB to distinguish permittivity contrasts
  - VHF and HF radar potential of 35 dB for an altitude of 400 km
- Reflectometry Performance (Radiometric):
  - Radiometric stability of 1 dB to distinguish permittivity contrasts
  - 60 MHz radar potential of 72 dB for an altitude of 400 km (globally)
  - 9 MHz radar potential of 63 dB for an altitude of 400 km (anti-jovian)

Instrument Performance

- Plasma & Particles Requirements:
  - VHF and HF time resolutions better than 3 μs to measure phase dispersion
  - VHF surface ranges
  - HF surface echoes for plasma sounding
- Plasma & Particles Performance:
  - 60 MHz time resolution of 0.1 μs
  - 9 MHz time resolution of 1 μs
  - 60 MHz surface ranges
  - 9 MHz surface echoes for plasma sounding

Instrument Specs

Radar Characteristics	REASON		RIME	SHARAD	MARSIS
Electronics Mass (kg) – K	17.50		~11	11	14
Antenna Mass (kg) – K & D	14.75		from S/C	6	7
DC Power (W) – K	55		~21	25	50
Antenna Length (m) – K & D	16		16	15	40
Frequency Band – K & D	HF & VHF		HF	HF	HF
Radiated Power (W) – K	10–30		10	10	1
Pulse Length (μs)	30–100		20–100	85	250
PRF (kHz) – K	0.2–3		0.2–0.5	0.7	0.1
ADC Bits	12		8	8	8
On-Board Processing	Pre-sum		Pre-sum	Pre-sum	Doppler filter
Vertical Resolution (m) – K	15–150		50	15	150
Data Rate to S/C (Mbps) – K	5-80		0.25–2.7	0.3–20	0.02–0.08
Operational Altitude (km)	10–1000		200–1000	300	300–1000
Radar Potential (dB) HF&VHF	63 & 72		59	62	49

Instrument Specs

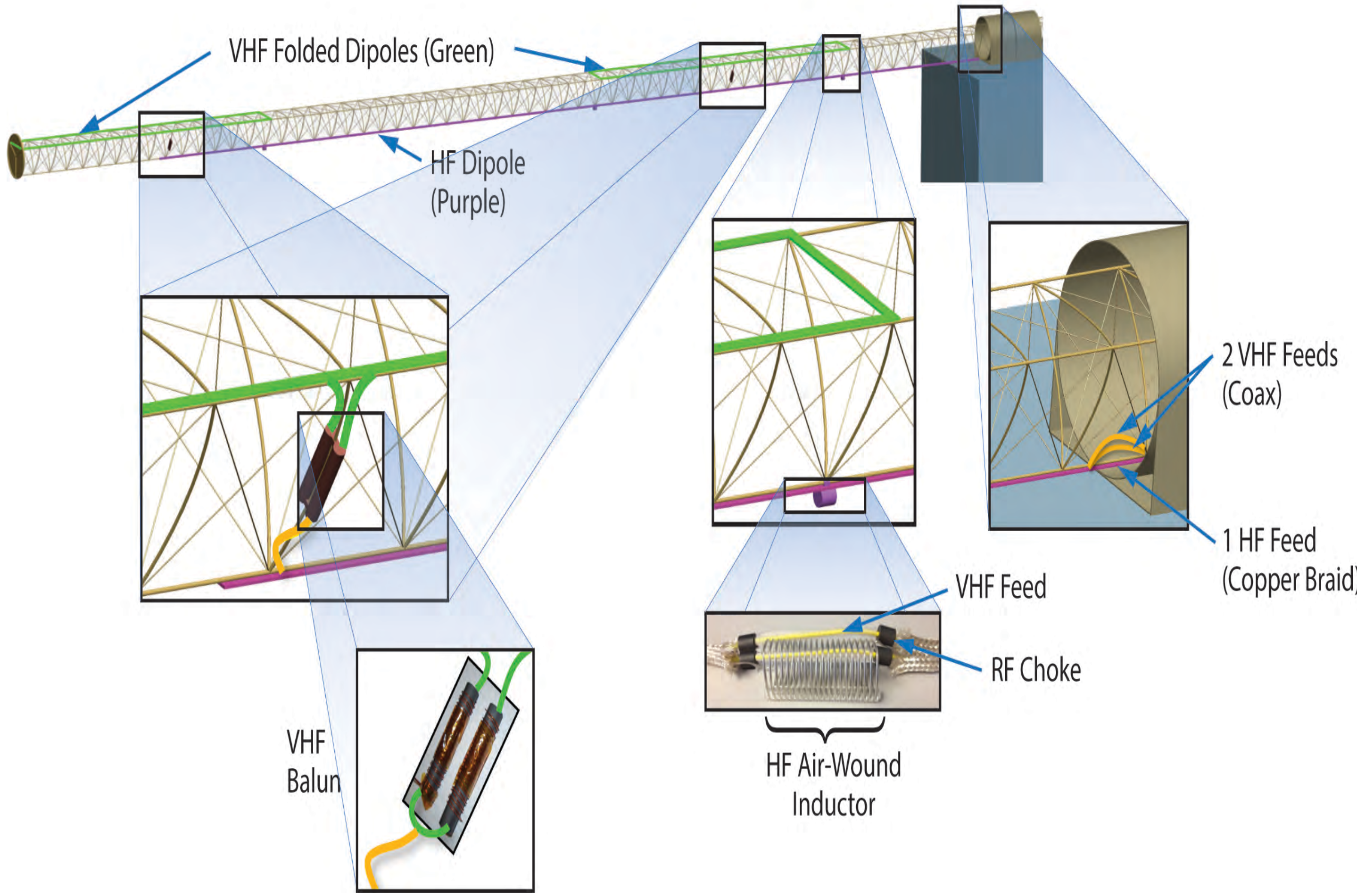
Resource	CBE	Contingency	MEV	Margin	MPV
Instrument Mass (kg)	32.25	25%	40.3	25%	50.4
Radiation Shielding Mass (kg)	0	0	0	0	0
Total Mass (kg)	32.25	25%	40.3	25%	50.4
Energy per flyby science operations (Whr)	21.75	20%	26.1	25%	32.6
Operating Power (W)	55	15%	63.3	25%	79.1
Survival Heat Power (W)	0	0	0	0	0
Compressed Data volume per flyby (Gbits)	24	30%	31.2	25%	39

Instrument Specs

Radar parameter	HF band	VHF band	Unit
Peak radiated power	10		dBW
Wavelength squared	30	14	dBm^2
Beam gain squared	2	16	dBi
Propagation loss	140		dBm^{-2}
Power at perfect reflector	-98	-100	dBW
Noise bandwidth	1.2	12	MHz
Noise temperature	400,000	10,000	K
Noise power	-112	-118	dBW
Raw radar potential	14	18	
Range-compression gain	20	30	dB
Azimuth gain	29	24	dB
Processed radar potential	63	72	dB
Required radar potential	51	57	dB
Echo Strength	-49	-46	dBW

Instrument Specs

Both VHF and HF radiating elements to operate on a single boom, reducing antenna mass.



Instrument Specs

- **Spacecraft Accommodation Highlights**
- Antenna orientation with respect to solar panels and S/C bus
  - Antenna performance impacted by conductive materials in the near-field of the antenna
  - Need antenna nadir looking with long axis perpendicular to nadir and perpendicular to direction of flight
  - Want antenna long axis to be perpendicular to solar panel long axis
  - Need to evaluate the phase stability for the interferometric channels
- Minimize electrical length from electronics in vault and antenna
- EMI/EMC
  - Low frequency radar very sensitive to noise produced by the rest of the S/C