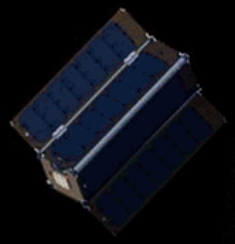
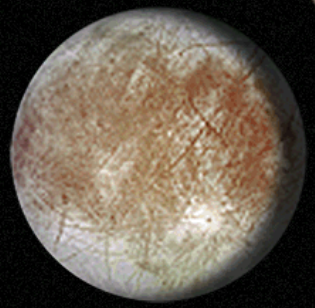
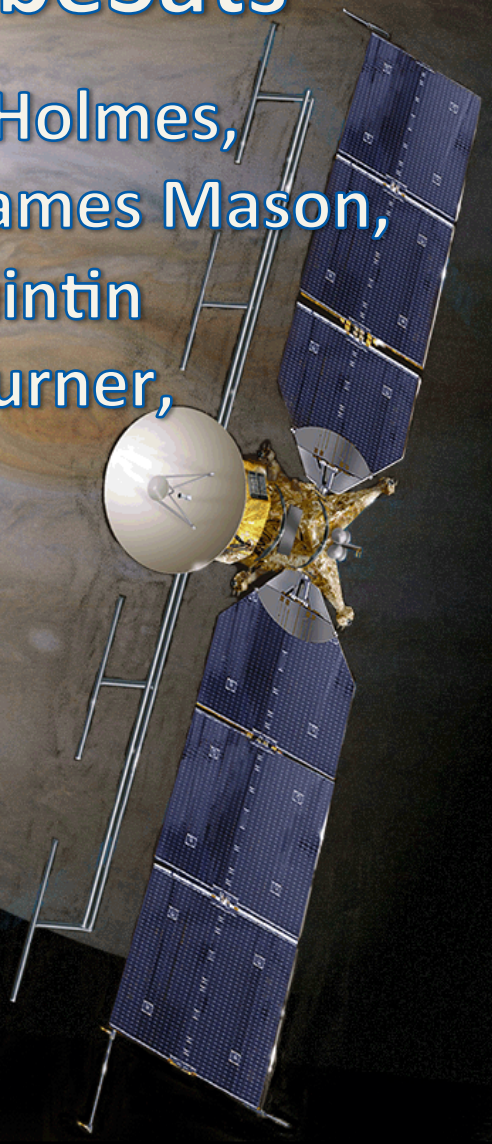
# Enhanced electromagnetic sounding of Europa's ocean using CubeSats



Frank Crary, Justin Holmes, David Malaspina, James Mason, Drake Ranquist, Quintin Schiller, Andrew Sturner, and Rick Kohnert





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University of Colorado **Boulder**

# Overview

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- Science goals: Understanding Europa's ocean
  - Europa and its ocean
  - Magnetic induction sounding
  - Limits to induction sounding, ways to overcome these limits
  - Role of a CubeSat
- CubeSAt for ice Layer Thickness (CSALT) concept
  - CubeSats and the Europa Clipper mission
  - C-SALT concept and mission profile
  - Payload
  - Radiation and planetary protection
  - CubeSats and Flagship missions
  - Requirements for the carrier spacecraft

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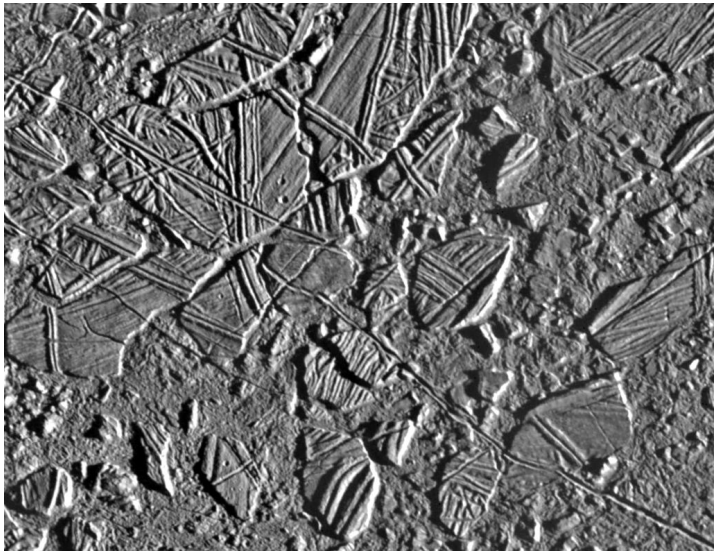
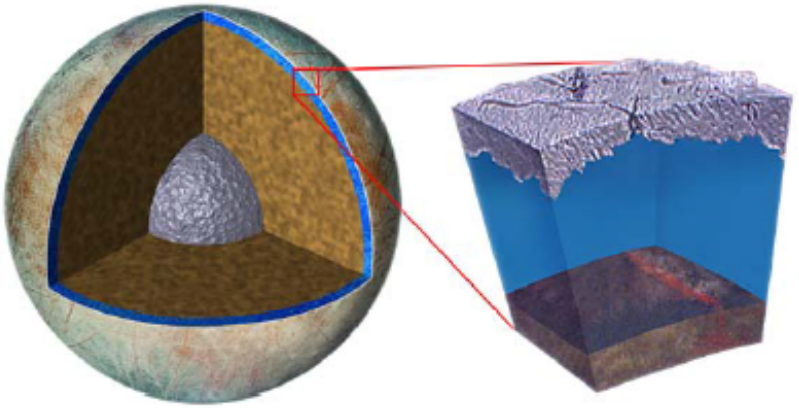
# Europa's ocean

- Europa, one of Jupiter's Galilean moons, has a liquid ocean inside an icy surface
- Evidence includes surface geology, gravity field and magnetic sounding
  - Magnetic sounding considered the best proof although indirect
- Ice shell thickness is 0-200 km
- Ocean thickness is 200-0 km
- Studying this ocean is the main goal of NASA's *Europa Clipper* flagship mission
  - Launch planned for 2022



Galileo image of Conamara Chaos, Europa



# Magnetic induction sounding

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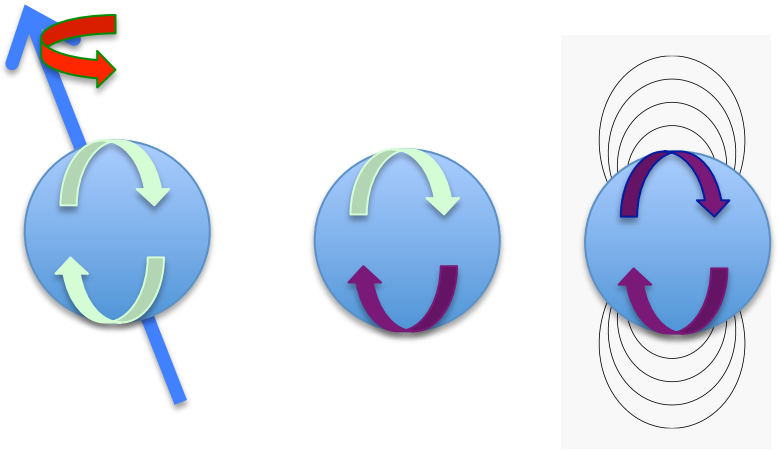
- Jupiter's magnetic field is tilted The background field at Europa rotates with a 11.1 hour period
- This produces an induced electric field which drives electric currents in the ocean



- These electric currents generate an ***induced magnetic field*** which spacecraft can observe during a flyby
- The *Galileo* magnetometer observed this induced field
  - The large uncertainty (>15%) limited the result to a detection
  - It could not a determination of ocean properties
- Measurements at 1% or lower uncertainty can reveal the ocean's **depth, thickness and conductivity (salinity.)**

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# Ocean induction versus plasma interaction

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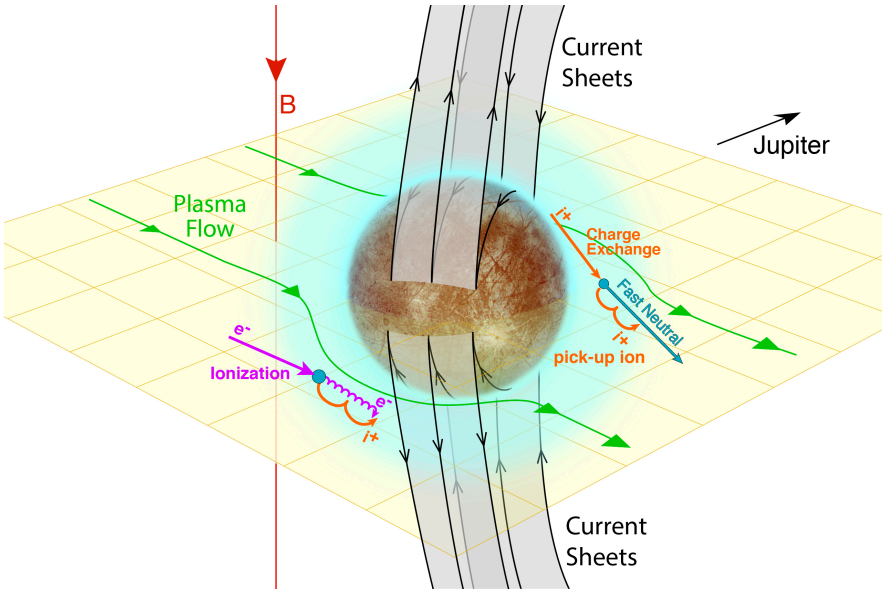
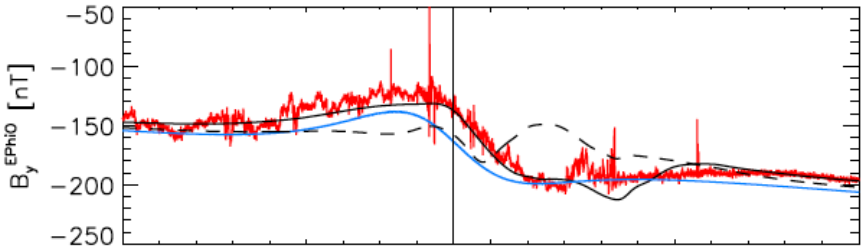
- Additional magnetic field perturbations from the interaction between Jupiter's magnetosphere and Europa's ionosphere
- Interaction introduces 10—100% systematic errors in induced field determination
- 1% accuracy needed to measure properties of the ocean (thickness, depth and salinity)




Galileo E4 measure and model of plasma interaction [Schilling et al. 2008]

# Removing the plasma interaction signature

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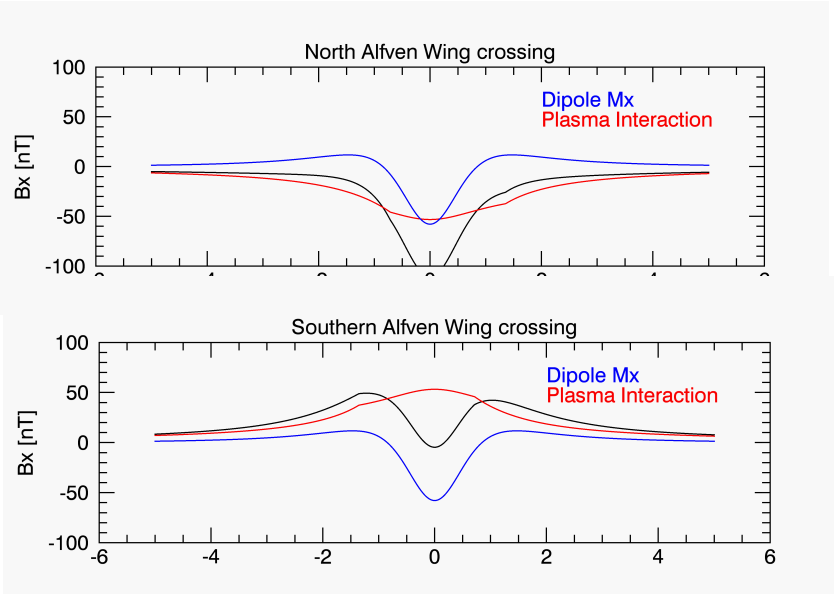
- Measure plasma interaction
  - Constrain theoretical models
  - Subtract model field from data
  - Very difficult at 1% level
  - *Europa Clipper* payload includes limited plasma instruments
- Use multiple encounters with different geometries
  - Systematic errors from plasma interaction cancel out
  - Requires multiple encounters at each phase of Jupiter's rotation
  - Plasma conditions are time variable: Requires multiple encounters at each phase and geometry to average out variability
  - Perhaps a dozen encounters per phase, more than *Clipper* has
- Use a sub-spacecraft (CubeSat)
  - Measure field along two different trajectories at the same time

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# CubeSats and *Europa Clipper*

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- No current plans for CubeSats on *Europa Clipper*
  - In other words, this is a hypothetical exercise
- In July, 2014, JPL solicited proposals for "stud[ies] to address a mission concept for a small CubeSat spacecraft up to 3U in size that would be carried aboard the potential Europa Clipper spacecraft, released in the Jovian system and would make measurements of Europa."
- Assumes Clipper would keep batteries charged until deployment and relay communications with an omni-directional antenna
- CubeSat should be 3U volume, <4.5 kg and stand-alone operations except for communications
- 10 proposals, including CSALT, were selected for nine-month, $25,000 studies

# CubeSAt for ice Layer Thichness (CSALT)

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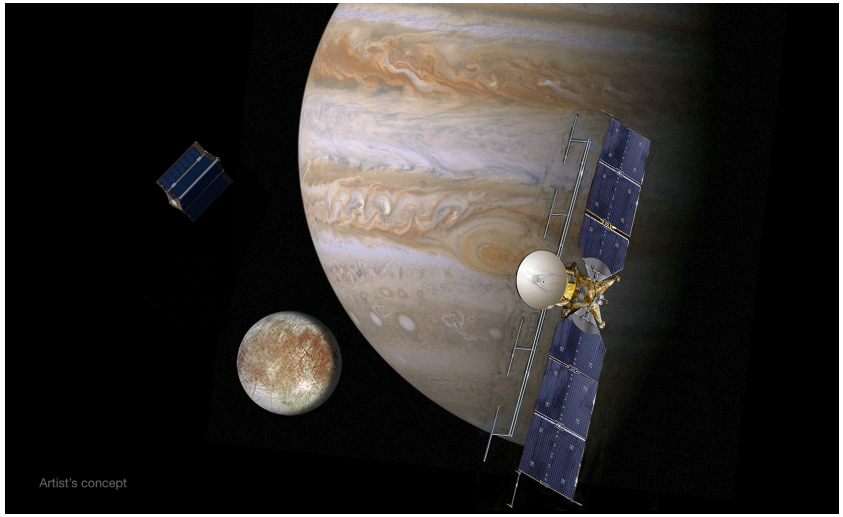


- Three 1U or Two 1.5U CubeSats
- Deploy 2 ¾ days prior to Europa encounter and drift
- Encounter Europa along a trajectory parallel to *Clipper* but separated by 1200 km
- Track spacecraft (ranging only)
- Measure magnetic fields during encounter (±1 hour, <10 $R_E$)
- Measure CubeSat orientation during encounter
  - No attitude control, only attitude determination
- Transmit data to *Europa Clipper*
- Repeat on 3 different encounters (3, 1U C-SALTs) or 2 different encounters (2, 1.5U C-Salts)
- If each encounter is worth a dozen *Clipper*-only encounters, this is a 50—75% improvement in *Clipper*'s magnetic sounding

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# Encounter timeline

- Deploy from *Clipper* at c/a - 66 hours
  - Relative velocity 5 ± 0.4 m/s
  - 1200±100 km separation at closest approach
- Drift from c/a - 66 to - 3 hours
  - Magnetometer off
  - Radio and star tracker at 40% duty cycle
  - Estimated temperature -10$^{o}$ C
- Warm up from c/a -3 hours to -1 hour
  - All systems on with 100% duty cycle, radio transmit at 0.5 W
  - Warm to stable, operating temperature of +35$^{o}$ C
- Science phase, c/a ±1 hour (within 10 $R_E$ of Europa)
  - When range increases to 3750 km (c/a +45 min) radio to 2 W
  - Temperature increases to less than +45$^{o}$ C
- Extended mission
  - 2 W telecom link to good to 7500 km (+2.2 hours)
  - Continue taking data until battery power runs out

# CSALT Payload

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| | Mass [g] | Power [W] Drift/Sci1/Sci2 | | | Based on |
|---|---|---|---|---|---|
| Magnetometer | 295 | 0 | 0.45 | 0.45 | LASP in development* |
| Star Tracker | 300 | 0.375 | 0.75 | 0.75 | Blue Canyon NanoStarTracker |
| Radio | 150 | 0.35 | 0.7 | 2.2 | AstroDev Lithium 1 |
| Battery | 195 | 69.48 W-hr | | | Boston Power 5300 Li-ion |
| PP/C&DH card | 80 | 0.35 | 0.35 | 0.35 | Custom |
| Structure/Misc. | 265 | 0 | 0 | 0 | Past LASP CubeSats |
| Total | 1290 | 0.93 | 2.25 | 3.75 | |

All values without margin or contingency

Sci1 is Science phase range to *Clipper* < 3750 km, Sci 2 is range >3750 km

*TRL4, other, similar magnetometers in development (e.g. JPL helium cell)

Magnetometer assumes no boom (would require 1.5U with boom)

- Magnetically clean components exist, CubeSat-sized components exist
- Magnetic cleanliness study in progress

# Radiation at Jupiter

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- *Europa Clipper* is a high radiation mission
  - EOM total integrated dose behind 100 mils Al is 2.1 Mrad
  - Most is accumulated after beginning start of Europa phase
    - 117 krad at 1st Europa encounter, then 33 krad/enc.
- *Clipper* and CubeSat provide significant shielding
  - 1.33 kg/0.001 $m^3$ is denser than water
  - Parts at the center have 970 mils Al equiv. shielding
- CSALT spacecraft deploy before the 5th encounter
- Estimated does at 5th encounter + nominal mission
  - 7.2 krad at CubeSat center, 82 krad at Cube face
- Manageable with rad hard parts
- Will require some replacement of parts or redesign of COTS components (everything)

# Planetary Protection

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- NASA has strong planetary protection requirements
  - Avoid contamination of subsurface ocean with microbes
  - If communication between surface and subsurface possible, also avoid contamination of surface
- *Europa Clipper* will impact Jupiter at end of mission
  - Requirements based on risk of accidental Europa impact
- CSALT will impact Europa, eventually
  - Left in Europa-crossing Jovian orbit
  - No propulsive capabilities to change orbit
  - Probably time to impact is 5 years
- CSALT has no shielded vault
  - After 5 years, every part exposed to 145 krad, some to 5 Mrad
  - Will eliminate bio-burden from all but extremophile bacteria
- Greater probability of impact offset by lower bio-burden
  - Pre-launch precautions similar to *Clipper* should be adequate

# CubeSats and flagship missions

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- CSALT fits into a 1U with no margin and COTS parts
- Parts will require some modifications
  - Replacement of radiation soft with radiation hard parts
- These parts are no longer TRL9
  - What margin would be required?
  - CubeSat design principles are based on Class D missions
  - *Europa Clipper* is a Class A mission ("Failure is not an option")
- Given redesign, some parts could be optimized
  - Magnetometer designed for ±64,000 nT, CSALT requires only ±1,000 nT. Would reduce power
  - Radio has unused high rate modes and features, lacks ranging and antenna selection (done by PP/C&DH card)
  - This is getting away from the CubeSat way of doing things
- Assumption for CSALT is 3, 1U CubeSats
  - Contingency for mass/power/volume growth is to descope to 2, 1.5U Cube Sats and science two, rather than three, encounters

# Requirements on *Europa Clipper*

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- Thermal
  - Maintain CubeSats at > 0° C prior to deployment
  - Li-ion battery charging requirement
- Deployment
  - Deploy CubeSats one at a time
    - P-POD releases all its contents at once
    - Non-standard deployer with arresting mechanism?
    - Non-standard deployers, one per 1U or 1.5U?
  - Deploy at 5 ± 0.4 m/s (18 km/hr or 11 mph)
    - Higher velocity than P-POD, stiffer springs
    - Higher precision than P-POD, test/select springs
    - Achieved with of *Galileo*, *Huygens* and *Philae* probes
  - Deploy with specified direction ±4°
    - Reorient spacecraft at c/a – 66 hours

# Requirements on *Europa Clipper*

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- Telecommunications
  - Receive with omnidirectional antenna
  - Store data and retransmit to Earth
    - 1200 kbps for ~4 hours or  less than 18 Mbits per enc.
  - Transmit to CubeSat for ranging and antenna selection
- Ranging
  - ±10 km per measurement
  - Send and time return message to ±33 µs accuracy
  - Large latency allowed, must be known and constant

# Summary

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- CubeSats can contribute to the *Europa Clipper* mission
- For CSALT the value  is data along a parallel trajectory
- This sort of planetary CubeSat needs a carrier vehicle
  - Transport the CubeSat to the destination
  - Provide a communications relay
  - Provide ranging (navigation) support
- Some modifications to the deployer are necessary
- Some modifications to COTS parts are necessary
- There are inconsistencies between usual CubeSat development practices and Class A mission requirements
  - Needs to be resolved
- Planetary CubeSats are a good, viable concept

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