

The logo is a large, light blue triangle with a white border. Inside the triangle, there is a central illustration of a three-masted sailing ship (the Europa Clipper) on the surface of Europa, with a large, glowing moon in the background. Above the ship, a satellite is shown in orbit. The text 'EUROPA CLIPPER' is written in a stylized, light blue font across the middle of the triangle. At the bottom of the triangle, the text 'JPL \* NASA \* APL' is written. Along the left and right sides of the triangle, there are names of partner institutions: 'MSU \* HIG \* ASU \* UTIG' on the left and 'SWRI \* CU-LAS' on the right.

# Europa Clipper Update to OPAG

Bob Pappalardo, Europa Clipper Project Scientist  
*Jet Propulsion Laboratory, California Institute of Technology*  
and the Europa Clipper Science Team  
February 21, 2018



# Europa Clipper Project-Level Lifecycle Schedule

## Key Project Reviews

3/23/19

FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23																																																																																					
2013			2014			2015			2016			2017			2018			2019			2020			2021			2022																																																																				
J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PRE-PHASE A									PHASE A (20 mo)			PHASE B (20 mo)			PHASE C (26 mo)			PHASE D (18 mo)			PHASE E																																																																										
NASA Reviews			▲ PCR			▲ MCR			▲ KDP-A			2/17 ▲ KDP-B			10/18 ▲ KDP-C			12/20 ▲ KDP-D			PSR 1/22			5/22 ▲ KDP-E																																																																							
Project Reviews			▲ PCR			▲ MCR						1/17 ▲ SRR/MDR			8/18 ▼ Project PDR			11/19 ▼ Project CDR			▲ SIR 10/20			ORR 3/22			MRR 4/22																																																																				
<u>06 Spacecraft</u>						L3 FS Req (Baseline) ◆			L3 FS Req (BL Rev C) ◇			FS PDR 10/17 ▼			PDR 11/17			FS CDR 11/19 ▼			CDR 12/19			▲ I&T Readiness Review			★ Launch 6/22																																																																				

- Propulsion Subsystem PDR 6/27-29/17 (GSFC)
- Propulsion Module PDR 7/24-27/17 (APL)
- Flight System PDR 10/17-20/17 (JPL)
- Europa-UVS PDR 11/16-17/17 (SWRI)
- PIMS PDR 12/6-7/17 (APL)
- EIS PDR 1/9-11/18 (APL)
- Solar Array Requirements Review 1/22/17 (JPL)
- Power PDR 1/23-24/18 (JPL)
- SUDA PDR 1/30-31/18 (CU)
- Guidance, Navigation & Control PDR 2/7-9/18 (JPL)
- Mechanical PDR 2/20-22/18 (JPL)
- Thermal PDR 2/27-28/18 (JPL)
- Radio Frequency Module / Telecom PDR 3/14-15/18 (APL)

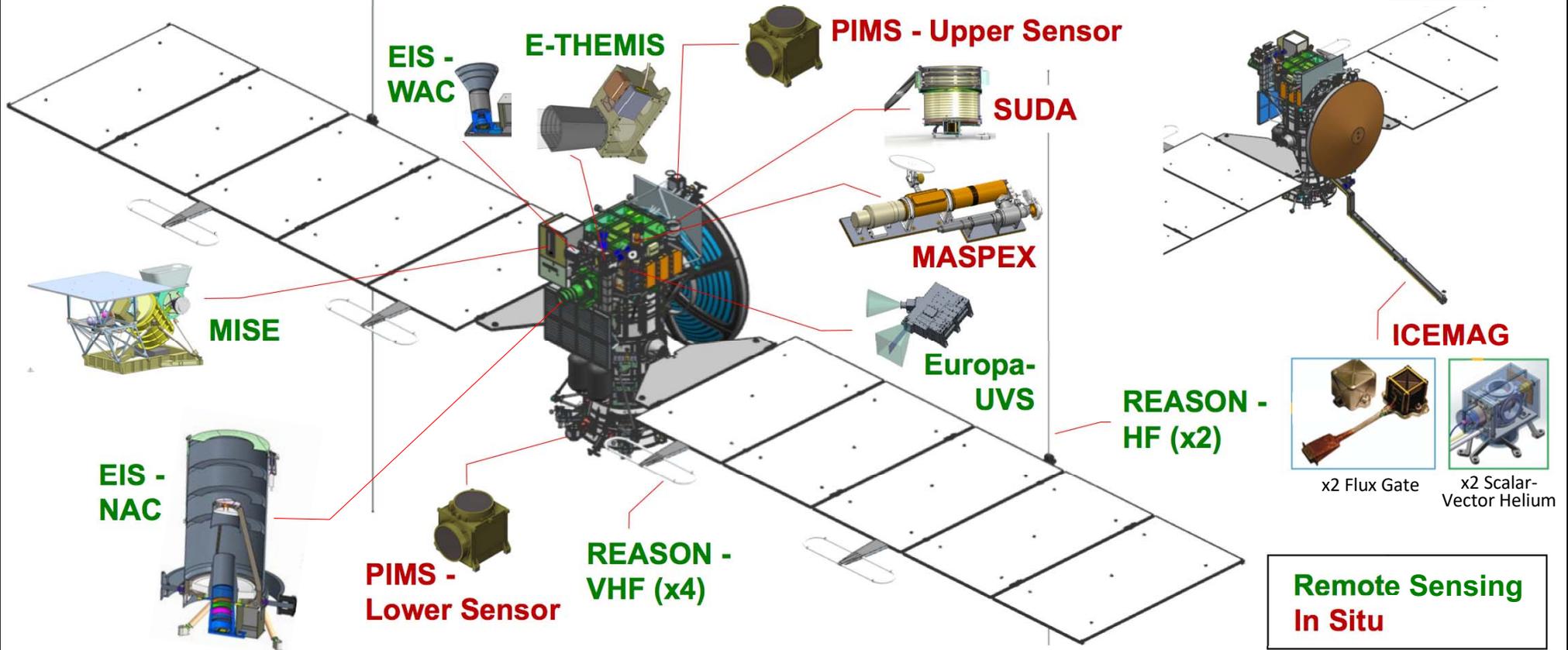
We are here



- REASON PDR 3/26-27/18 (JPL)
- Magnetometer Boom PDR 4/9-10/18 (JPL)
- ICEMAG PDR 4/11-12/18 (JPL)
- Radiation Monitor System PDR 4/17/18 (APL)
- E-THEMIS PDR 4/19-20/18 (ASU)
- MISE PDR 4/24-25/18 (JPL)
- Avionics PDR 5/7-10/18 (JPL)
- MASPEX PDR 5/15-16/18 (SWRI)
- Fault Management PDR 5/21-22/18 (JPL)
- Mission System PDR 6/19-21/18 (JPL)
- Propulsion Subsystem CDR 6/26-28/18 (GSFC)
- Solar Array PDR 7/10-11/18 (Airbus)
- Project PDR 8/20-24/18 (JPL)



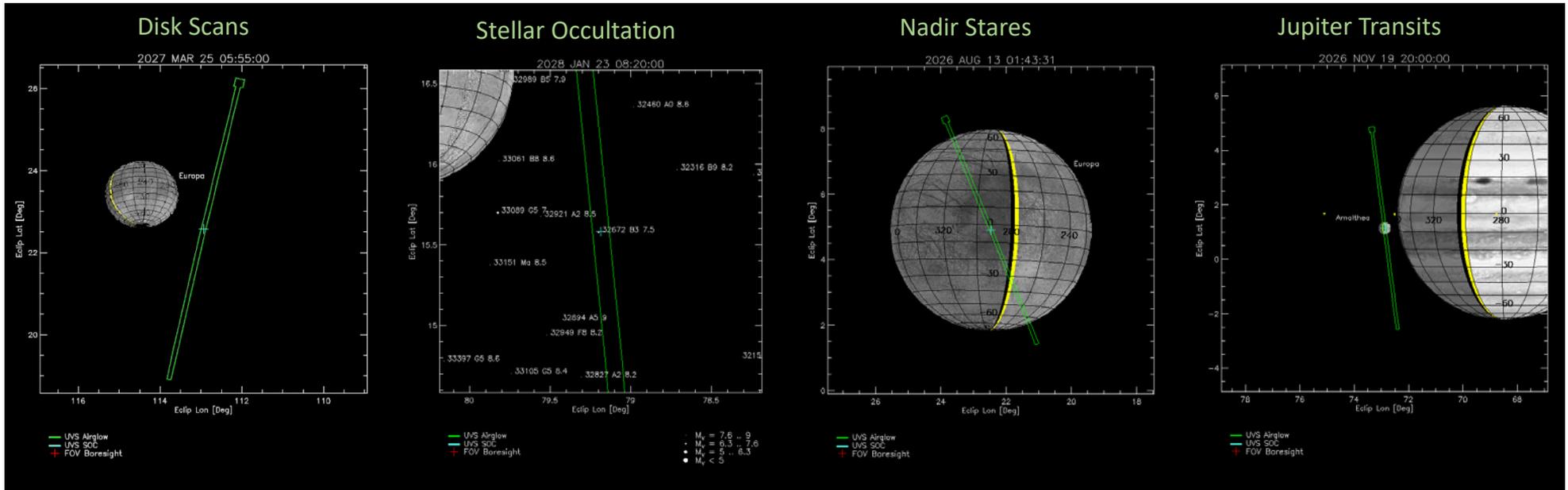
# Europa Clipper Science Instruments



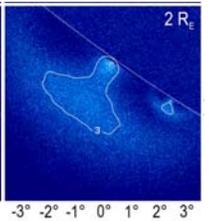


# Europa Ultraviolet Spectrograph (Europa-UVS)

PI: Kurt Retherford (SWRI, San Antonio)



- Europa-UVS has identified 464 opportunities for occultation observations of 106 UV-bright stars, with 198 scheduled, in the latest trajectory
- Europa-UVS EM electronics boards have been fabricated and are proceeding through board level testing

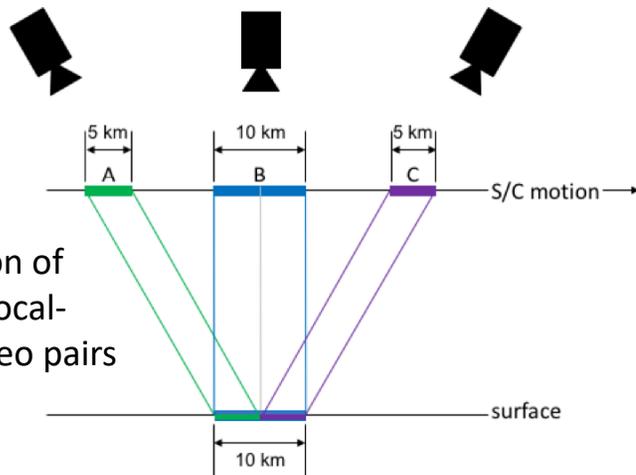
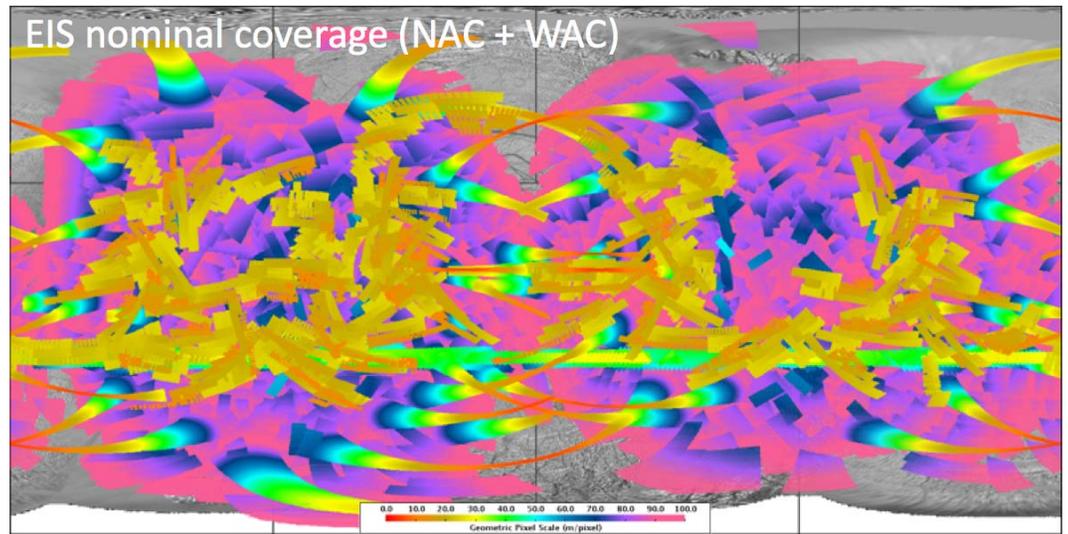




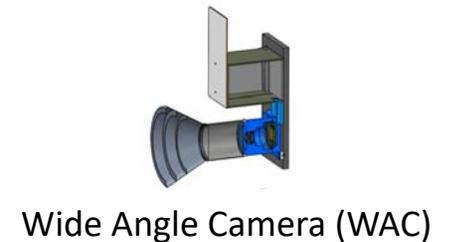
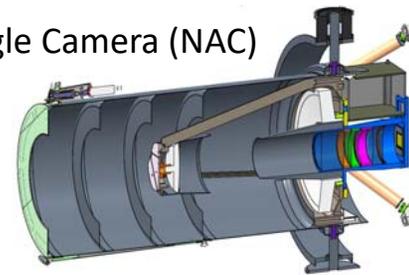
# Europa Imaging System (EIS)

PI: Elizabeth Turtle (JHU/APL)

- Demonstrated a preliminary design and operations plan that meets all science requirements
- EIS-NAC gimbal enables near-global coverage (100 m/pixel) and local-scale imaging (1 m/pixel) with stereo topography



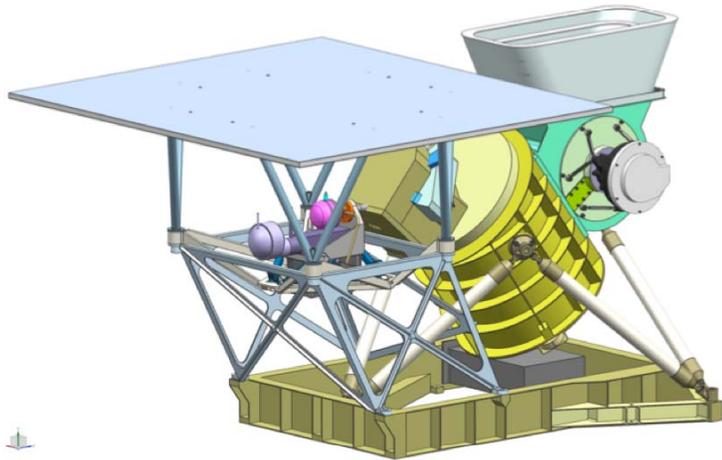
Narrow Angle Camera (NAC)





# Mapping Imaging Spectrometer for Europa (MISE)

PI: Diana Blaney (JPL/Caltech)



Prototype Cooler 1



Focal Plane Memory Card Prototype

- The instrument changed from an Offner to a Dyson design, improving S/N and reducing energy needs (single cryo-cooler)

- MISE cryo-cooler completed radiation testing

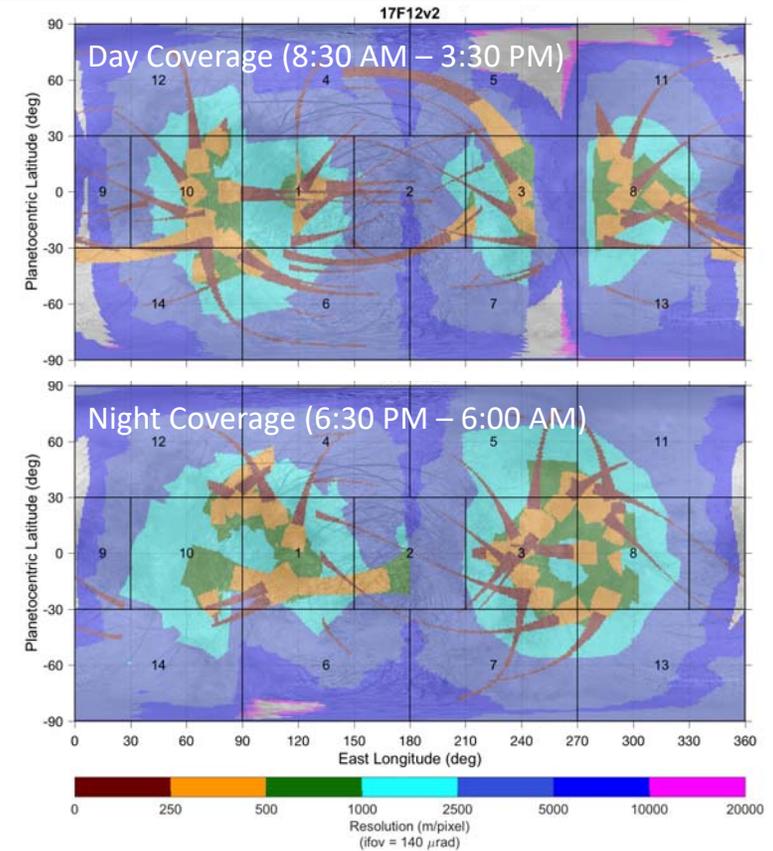
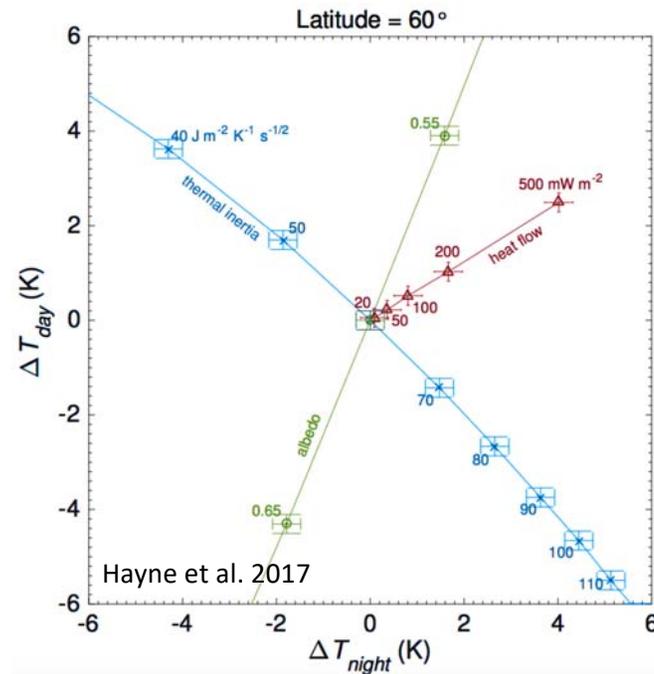
- MISE Data Processing Prototype boards fabricated and are being tested



# Europa Thermal Imaging System (E-THEMIS)

PI: Phil Christensen (SESE, Arizona State Univ.)

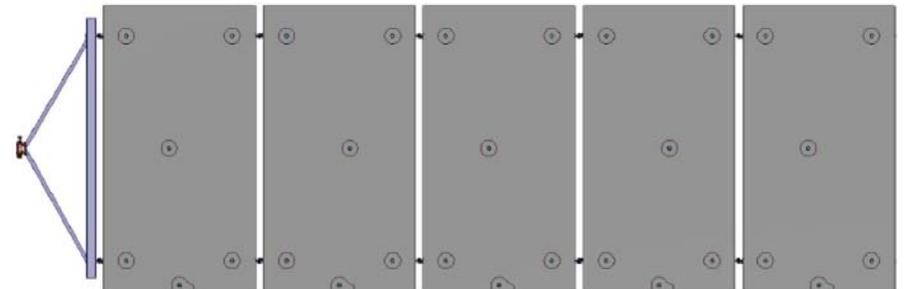
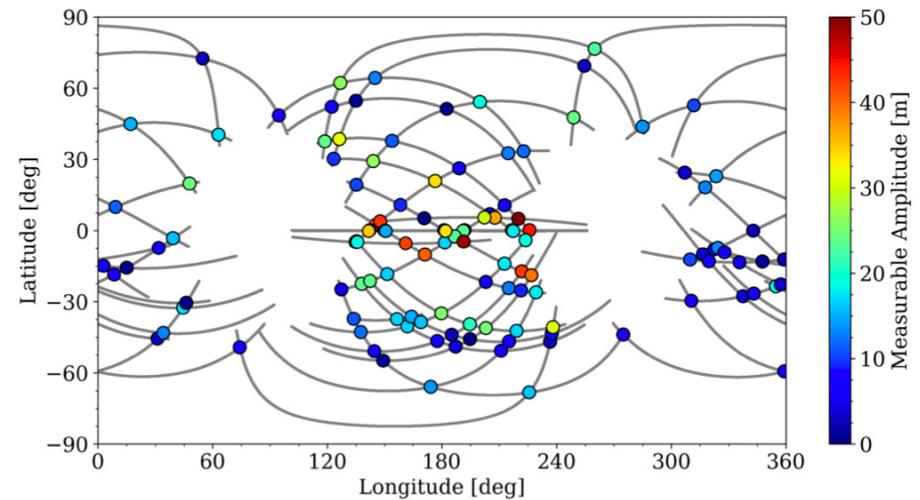
- E-THEMIS microbolometer array successfully passed radiation testing
- Refining methodology using overlapping day-night observations to quickly identify endogenic hot spots with small (0–4 K) deviations from Standard Model prediction, distinguished from thermal inertia or albedo effects





# Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON) PI: Don Blankenship (Univ. Texas Institute for Geophysics)

- Performed numerical simulations to assess the potential for estimating  $h_2$  using altimetric measurements with a combination of radar altimetry and stereo imaging data (Steinbrügge et al., EPSL, 2018)
  - Love number  $h_2$  accuracy sufficient to unambiguously confirm (or reject) global ocean hypothesis
  - Love number  $k_2$  accuracy sufficient to constrain Europa's ice shell thickness to  $\pm 15$  km
- Ensuring appropriate requirements for solar array, given the intimate association of the REASON VHF antennas which are mounted on the array (being built by Airbus)

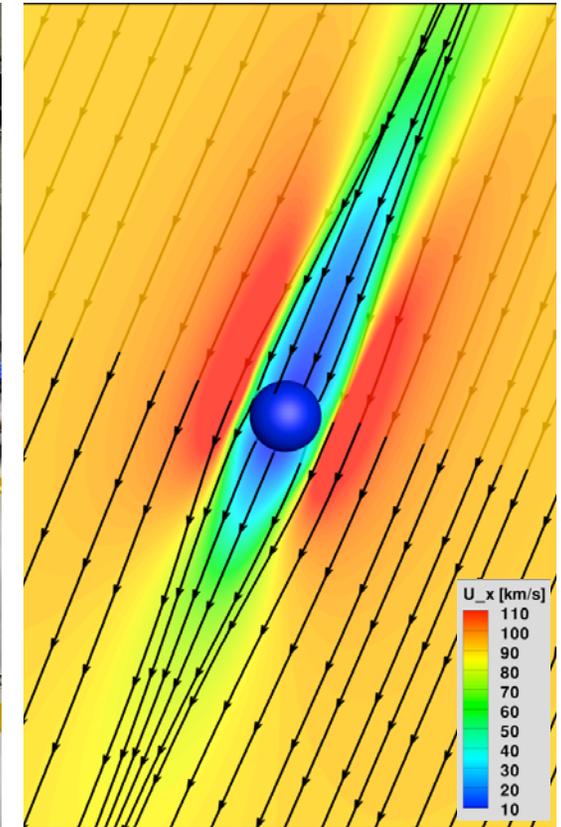
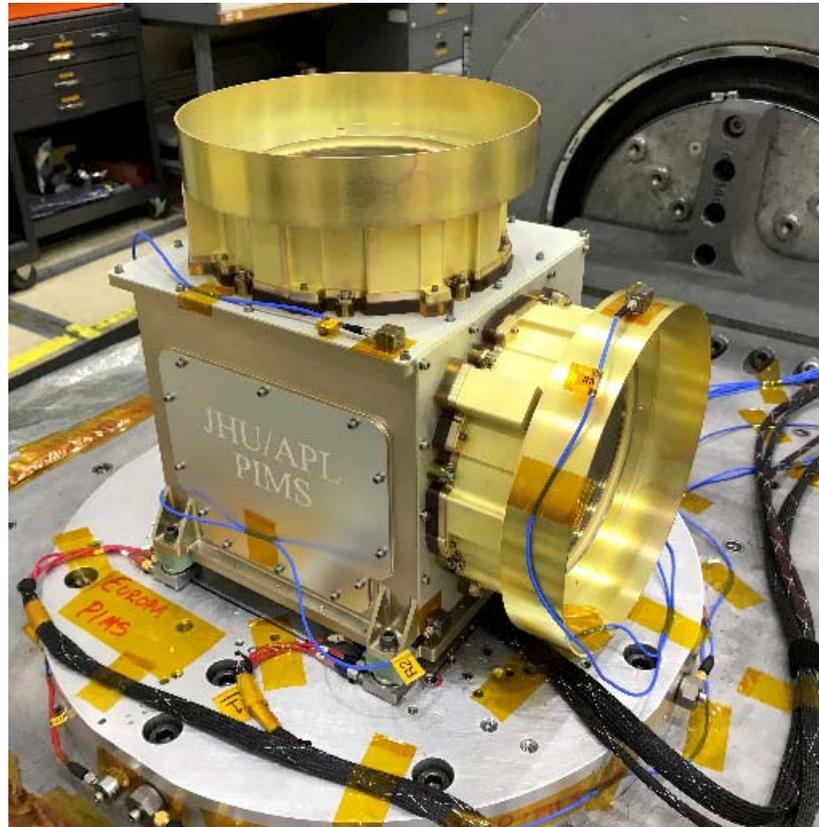




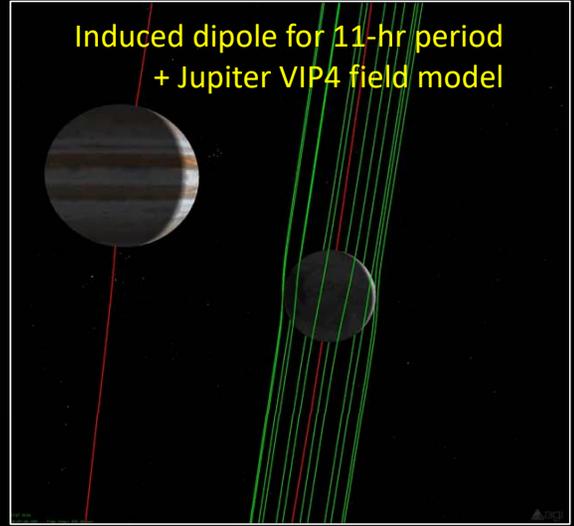
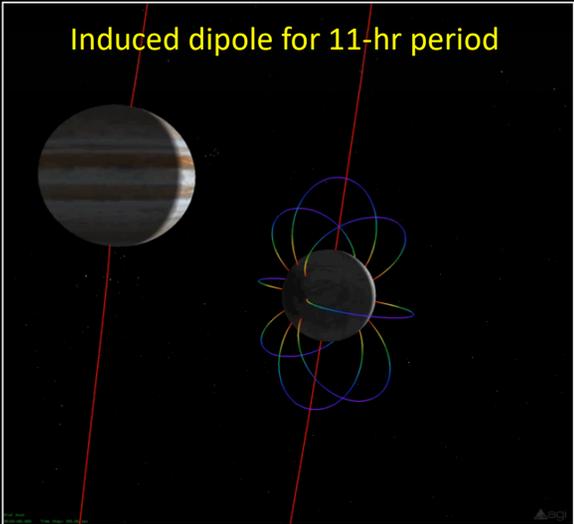
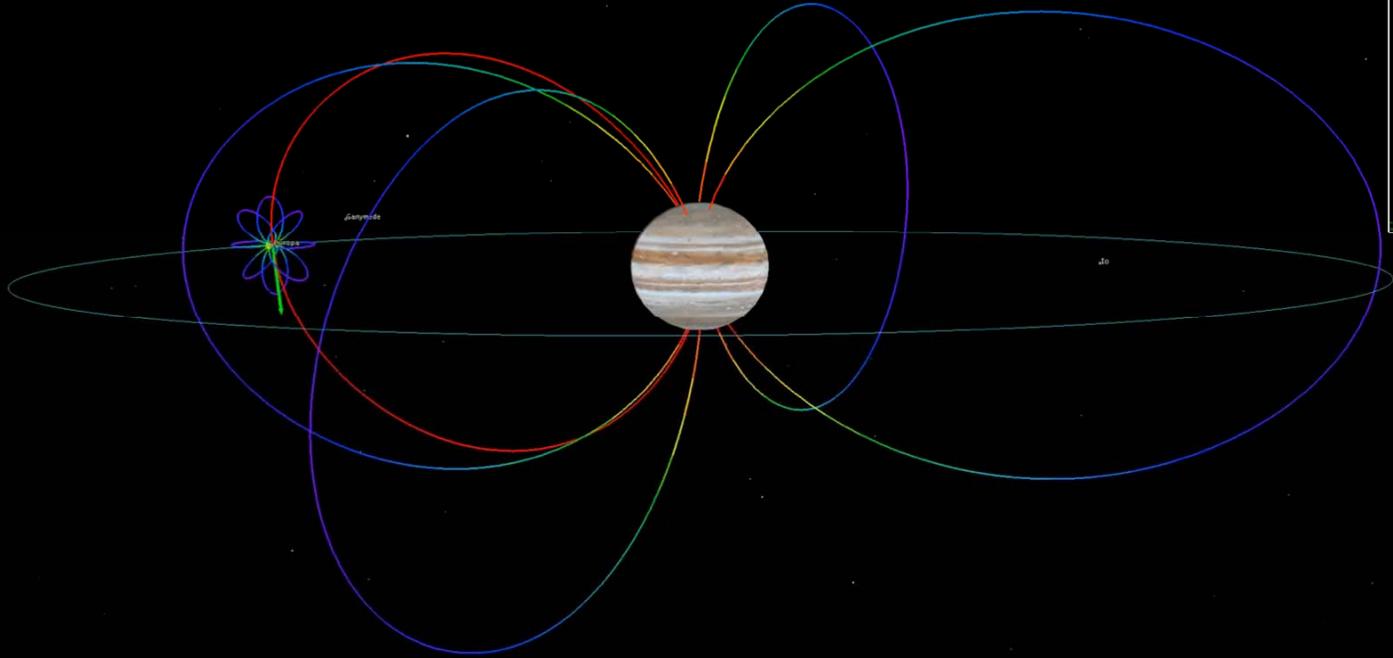
# Plasma Instrument for Magnetic Sounding (PIMS)

PI: Joe Westlake (JHU/APL)

- PIMS prototype instrument has been fabricated, assembled, and successfully completed testing (vibration, ion/electron beam, etc.)
- Progressing to Engineering Model
- Developed a multi-fluid full 3-D magnetohydrodynamic interaction model, to derive moon-plasma interaction magnetic field from simulated Europa Clipper trajectory through the model



# Simulation of Europa's Dipole Field Induced at 11-hr Synodic Period



June 1– 3, 2017;  $\Delta t = 5$  min

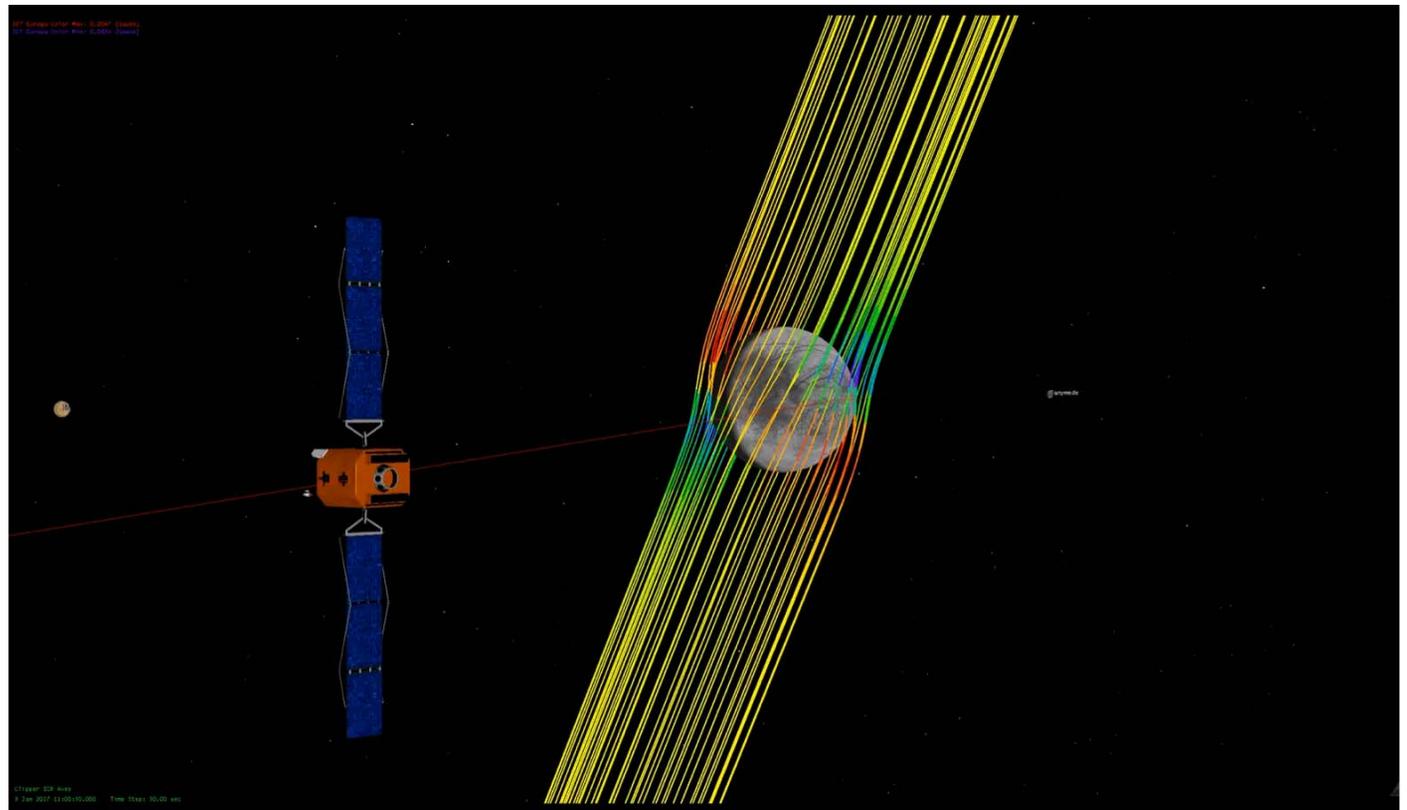
Simulations by Corey Cochrane



# Interior Characterization of Europa using Magnetometry (ICEMAG)

PI: Carol Raymond (JPL/Caltech)

- Visualization of a simulation of Europa's induced magnetic field including 11 and 85 hr periods using the VIP4 model of Jupiter's magnetic field, to help in tour evaluation
- Testing low-temperature performance of sensors and optical fiber to minimize thermal energy requirements

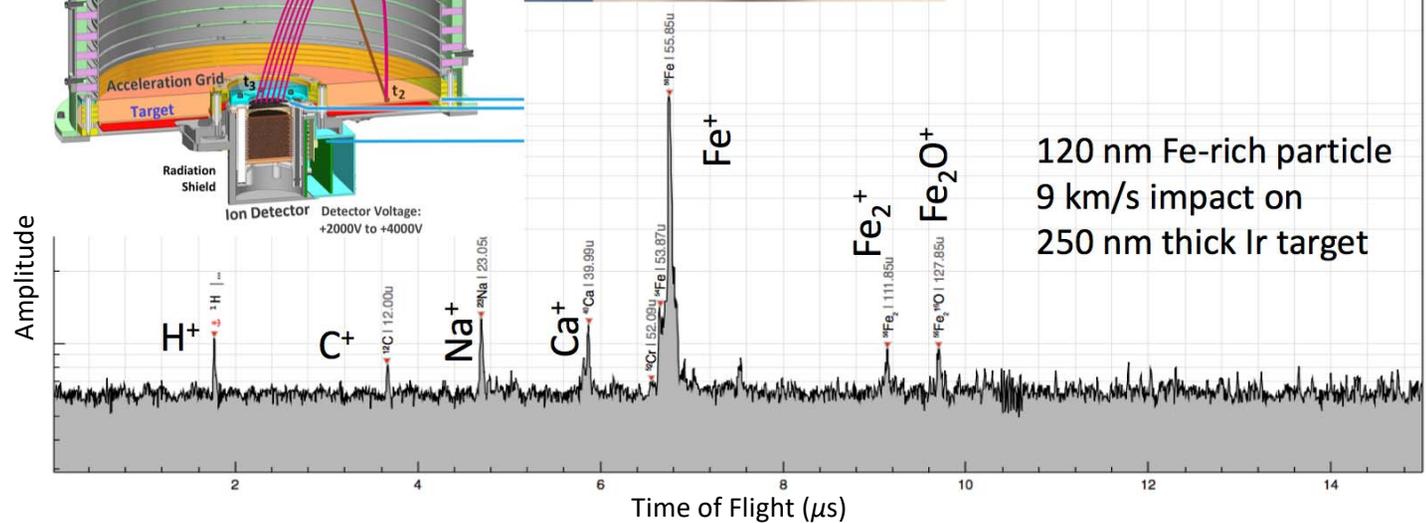
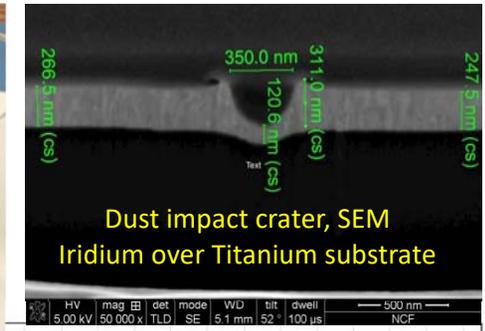
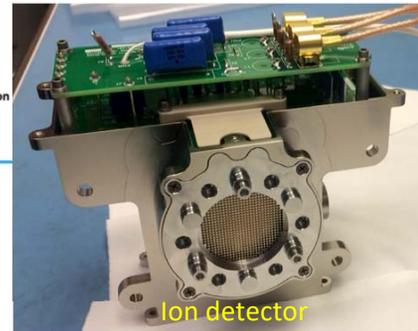
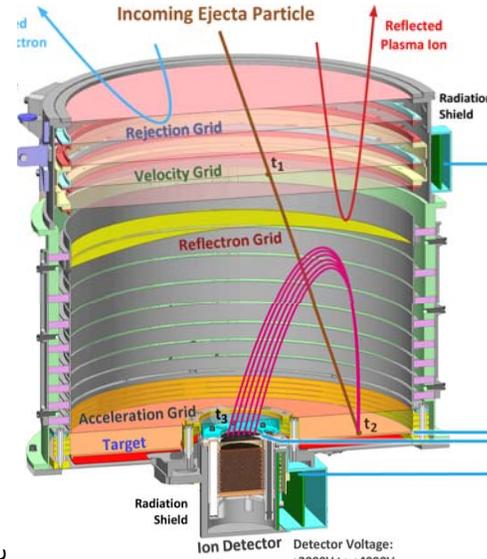




# SURface Dust Analyzer (SUDA)

PI: Sascha Kempf (LASP, Univ. Colorado)

- Ion Detector: 2 flight-like prototypes fully developed and successfully tested
  - Reached TRL 6
- Target: 4 flight-like prototypes developed and successfully tested
  - Ir-coated Ti substrate
- Successfully measured mass spectra of dust particles up to 30 km/s

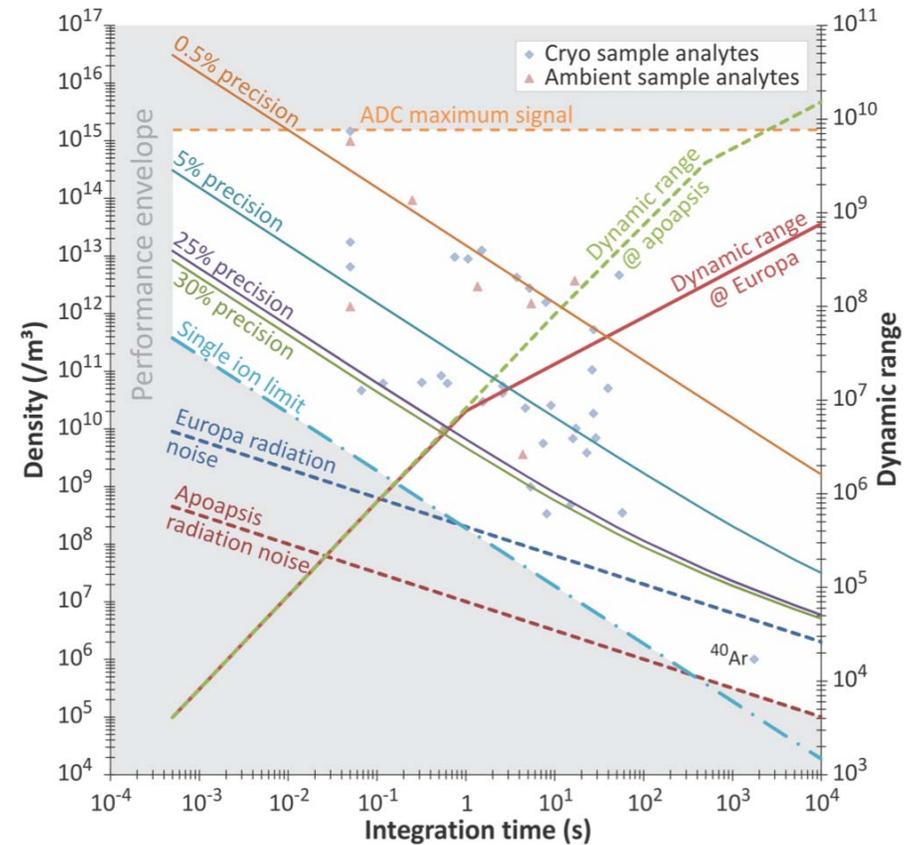
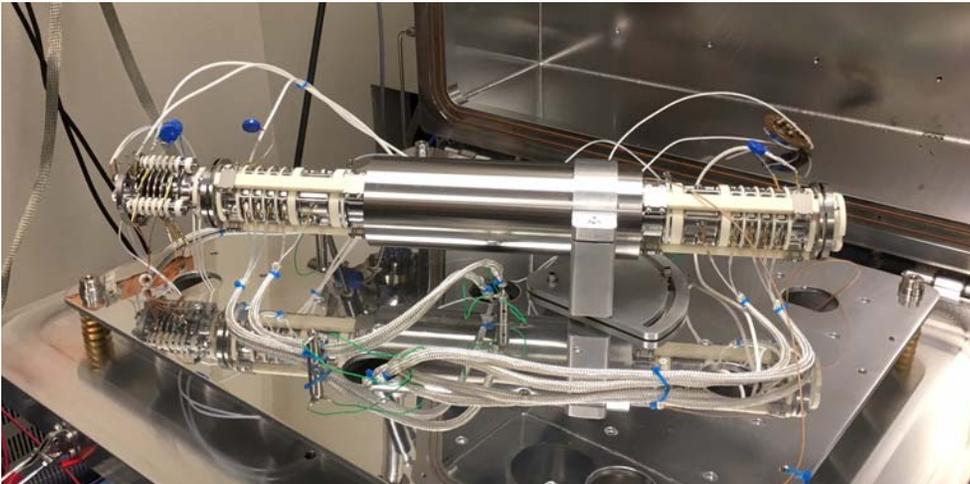




# MASS Spectrometer for Planetary Exploration (MASPEX)

PI: Hunter Waite (SWRI, San Antonio)

- MASPEX Engineering Model (EM) has been constructed, and completed vibration testing
- Ambient analytes that fall below the radiation noise line or that require integration in excess of a single flyby can be measured by cryotrapping

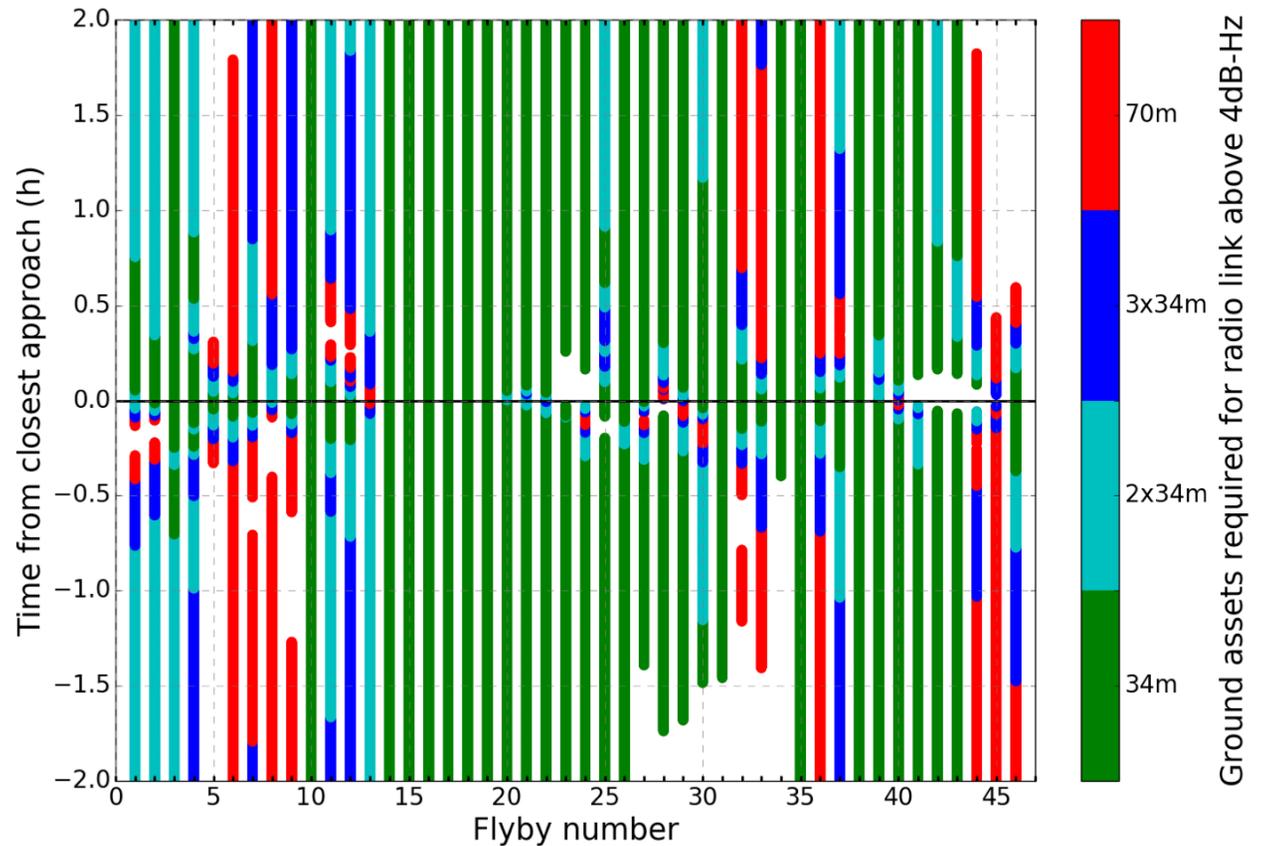
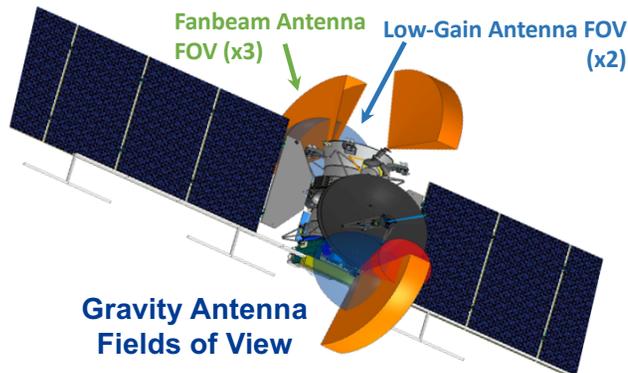




# Gravity Science

Subject Matter Expert: Jean-Luc Margot (UCLA)

- Analysis of Gravity Science capabilities (Verma and Margot, 2017)
  - Two-way Doppler data can confirm presence or absence of ocean
  - Determination of hydrostatic equilibrium is possible, pending sufficient crossover range accuracy
  - Arraying DSN stations or use of 70-m antenna can provide additional resilience on tracking requirements





# Habitability Working Group

Co-Chairs: Jonathan Lunine (Cornell) & Britney Schmidt (Georgia Tech)

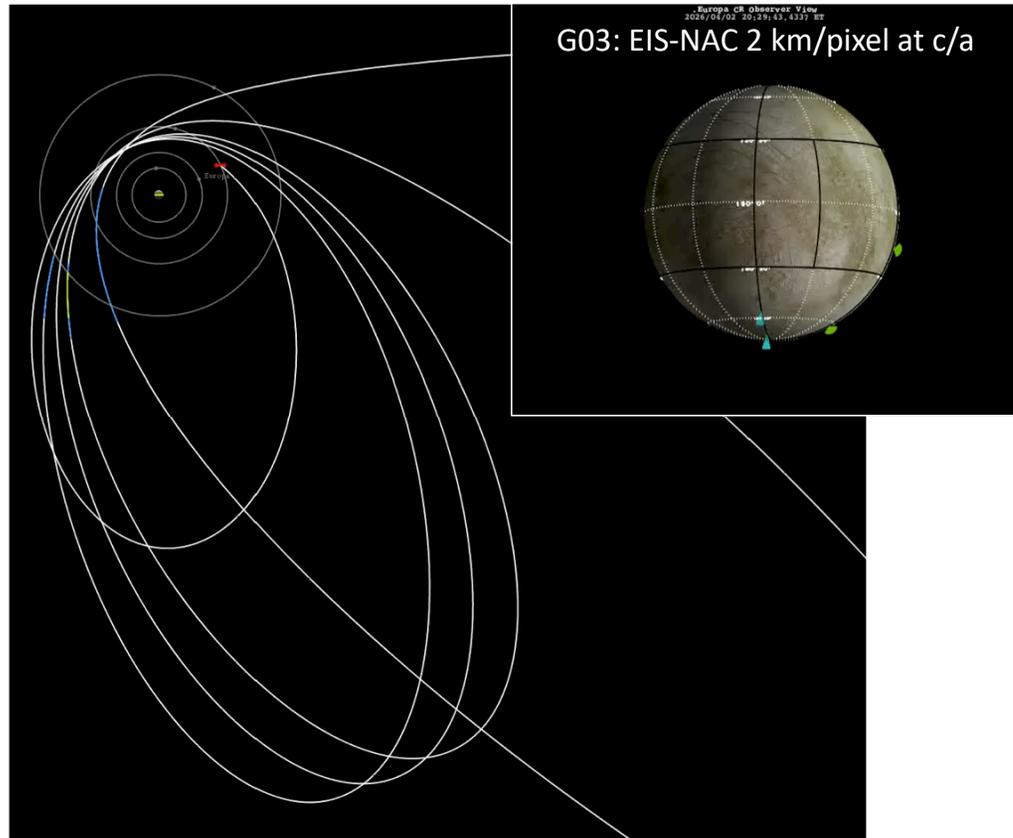
## • Identified ways that the Europa Clipper might better constrain habitability of Europa's ocean using data returned from already-planned measurements

- E-THEMIS, ICEMAG, PIMS, MISE • Temperature
- REASON • Pressure
- SUDA, MASPEX, MISE • pH
- MASPEX, SUDA, MISE • Oxidation state
- SUDA, MISE, ICEMAG, PIMS • Major ions & salinity
- E-THEMIS, MISE, MASPEX, SUDA • Physical and chemical sources of energy
- Gravity, MASPEX, SUDA, Europa-UVS, EIS, MISE • Compositional gradients (surface to ocean), mass transfer
- Concentrations of nutrients SUDA, MASPEX, MISE
- Speciation (if amino acid) MASPEX, SUDA, MISE
- Ocean vs. rock reservoirs, including salinity SUDA, MASPEX, MISE
- Composition vs. presence of organics MISE, MASPEX
- Amount of chemical disequilibrium MASPEX, SUDA, MISE
- Energy fluxes MASPEX, SUDA, E-THEMIS, Europa-UVS



# Plume Focus Group

Co-Chairs: Matt Hedman (Univ. Idaho) & Carly Howett (SWRI, Boulder)



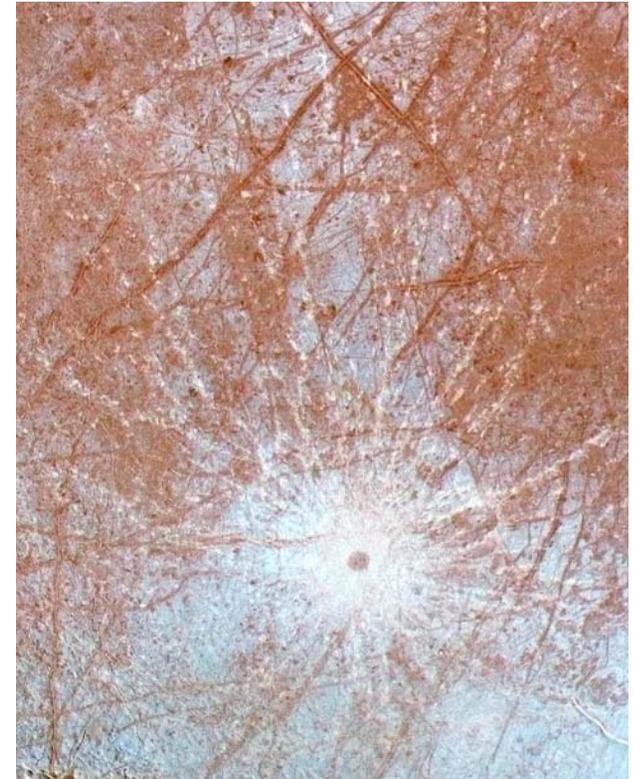
- Identified targets of opportunity to search for current activity *prior to* first Europa flyby:
  - EIS: Plume search
    - Terminator; High phase limb; Europa eclipse
  - Europa-UVS: Plume search & atm. variability
    - Europa scans; Europa transits; Stellar occultations,
  - E-THEMIS: Surface temperatures
  - EIS: Surface color changes
  - MASPEX: Europa torus
  - SUDA: Escaped grains
  - Europa-UVS: Neutral cloud & torus stare



# Composition Working Group

Co-Chairs: Murthy Gudipati (JPL/Caltech) & Jason Soderblom (MIT)

- Settled on key priorities in evaluating potential tours, including ensuring acceptable remote sensing and *in situ* observations of:
  - Landform variety
  - “Young” landforms
  - Leading & trailing hemispheres
- Key focuses have been laboratory data and Europa's radiation environment:
  - Plans to hold a community workshop to discuss the current state of laboratories and laboratory data, and what will be needed to best interpret the multi-instrument Europa Clipper data
  - The formation of the Radiation Focus Group (next slide)

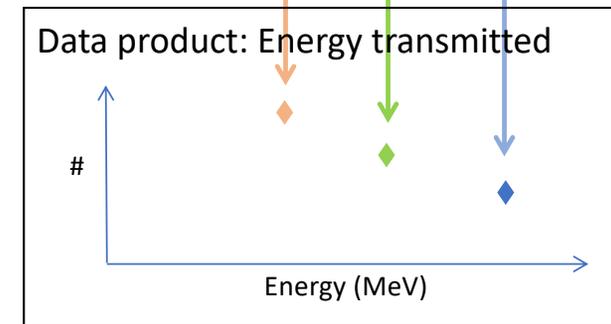
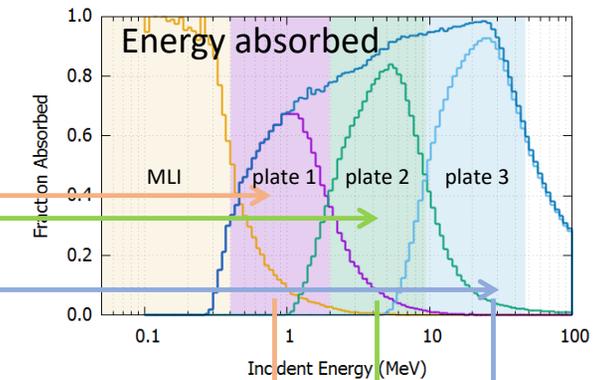
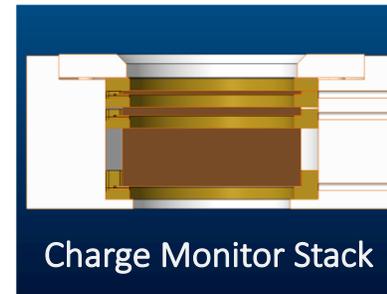




# Radiation Focus Group

Co-Chairs: Roger Clark (PSI) & Abi Rymer (JHU/APL)

- To focus on understanding both the Europa radiation environment and its effects on the surface, and to advise the Project on trades relevant to radiation science
- Briefed on status of the Radiation Monitoring System
  - Charge monitor stack: Three plates of selected thickness provide crude energy spectra
  - Dosimeters: ~8 distributed around the spacecraft, plus hosted in science instruments, each returning integrated radiation flux above an energy determined by local shielding

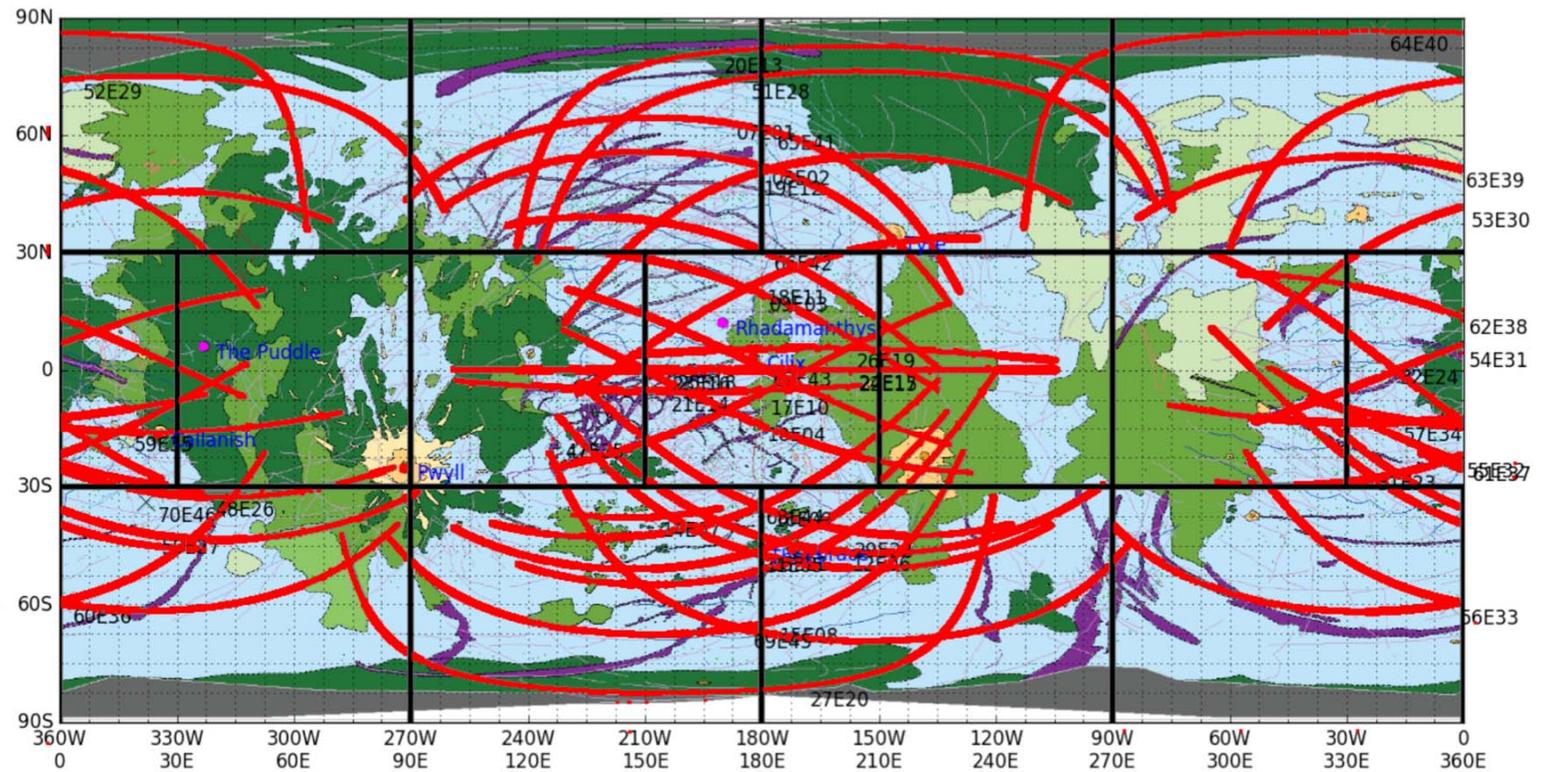




# Geology Working Group

Co-Chairs: Geoff Collins (Wheaton Coll.) & Julie Rathbun (PSI)

- Planned nadir ground tracks (red) overfly diverse landforms
- More distant remote sensing can observe other features



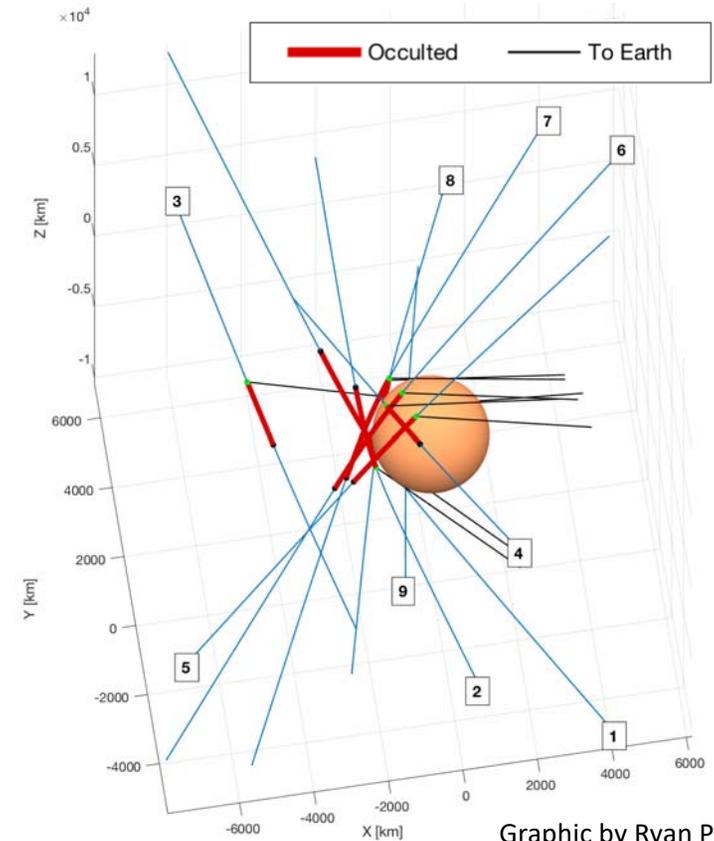
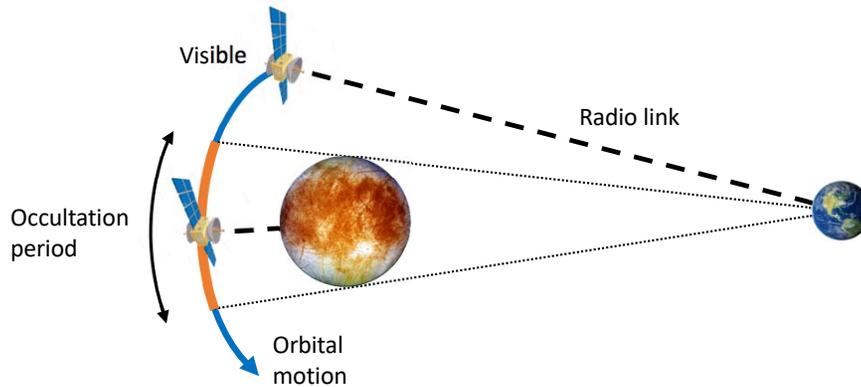
Leonard et al. (2018)



# Interior Working Group

Co-Chairs: Carol Paty (Georgia Tech) & James Roberts (JHU/APL)

- Several occultation opportunities exist for the Europa Clipper trajectory, using existing telecom system
  - LGAs & fanbeam antennas (X-band)
  - Two-way: Uplink radio signal from Earth, receive at spacecraft, and retransmit back to Earth
- Would provide vertical profiles of electron density in ionosphere, and useful for Europa position and shape
- Not yet baselined, but seems achievable and valuable



Graphic by Ryan Park



# Project Science Team Bystander Intervention Training

- Europa Clipper Project Science team (which includes Investigation Scientists) retreat featured Bystander Intervention Training by Moses Milazzo (USGS)
- “Bystander intervention is an evidence-based framework intended to reduce victims’ burden of protecting themselves from harassment and shift the burden to the community” (Milazzo et al., LPSC, 2018)
- Given extremely positive feedback, the entire Europa Clipper Science Team will be strongly encouraged to participate in future training opportunities, including at Europa PSG meetings.





## Upcoming Science Events (Programmatic)

- Mini- Project Science Group Meeting
  - March 23, The Woodlands, Texas
- Project Science Group meeting #6
  - June 11 – 15, JPL
- JUICE – Europa Clipper collaborative science workshop
  - July 22, Caltech



# JUICE – Europa Clipper Collaborative Science Discussions

Members of the JUICE and Europa Clipper science teams will discuss potential scientific synergies between the Europa Clipper and JUICE missions

- Investigations if both missions *are* in the Jupiter system at the same time:
  - Multi-point measurements of the characteristics of the Jovian magnetodisc, with each spacecraft providing far-field context for the other
- Investigations if both spacecraft *are not* in the Jupiter system at the same time:
  - Opportunities for observations that are spatially or otherwise complementary, e.g.
    - Complementary coverage in spatial, spectral, energy, and geometric domains
  - Observations providing long temporal baselines, e.g.
    - Time-variability of the Jovian magnetodisc
    - Europa's atmosphere and potential plume activity
- Combined data sets will offer a more complete view of the Europa, Ganymede and the Jupiter system, while enabling in-depth comparative studies of the ocean worlds Ganymede and Europa.





# Europa Clipper Science Team

PIs, Co-Is, Project Science (Currently 119 total)

Oleg Abramov  
Amy Barr Mlinar  
Jordana Blacksberg  
Diana Blaney  
Don Blankenship  
Scott Bolton  
Christelle Briois  
Tim Brockwell  
Shawn Brooks  
Lorenzo Bruzzone  
Bruce Campbell  
Lynn Carter  
Tony Case  
Phil Christensen  
Roger Clark  
Corey Cochrane  
Geoff Collins  
Kate Craft  
Brad Dalton  
Ingrid Daubar  
Ashley Davies  
Serina Diniega  
Charles Elachi  
Carolyn Ernst

Paul Feldman  
Leigh Fletcher  
Yonggyu Gim  
Randy Gladstone  
Thomas Greathouse  
Robert Green  
Cyril Grima  
Eberhard Gruen  
Murthy Gudipati  
Kevin Hand  
Candy Hansen  
Alex Hayes  
Paul Hayne  
Matt Hedman  
Alain Herique  
Karl Hibbitts  
Mihaly Horanyi  
Howett, Carly  
Terry Hurford  
Hauke Hussmann  
Xianzhe Jia  
Steven Joy  
Justin Kasper  
Sascha Kempf

Krishan Khurana  
Randy Kirk  
Margaret Kivelson  
Rachel Klima  
Wlodek Kofman  
Haje Korth  
William Kurth  
Yves Langevin  
Jonathan Lunine  
Marco Mastrogiuseppe  
Tom McCord  
Alfred McEwen  
Melissa McGrath  
Bill McKinnon  
Ralph McNutt  
Mike Mellon  
Jeff Moore  
Olivier Mousis  
Alina Moussessian  
Scott Murchie  
Neil Murphy  
Francis Nimmo  
Bob Pappalardo  
Chris Paranicas

Wes Patterson  
Carol Paty  
Cynthia Phillips  
Sylvain Piqueux  
Jeff Plaut  
Dirk Plettmeier  
Frank Postberg  
Louise Prockter  
Lynnae Quick  
Julie Rathbun  
Trina Ray  
Carol Raymond  
Kurt Retherford  
Christina Richey  
James Roberts  
Lorenz Roth  
Chris Russell  
Abigail Rymer  
Joachim Saur  
Juergen Schmidt  
Britney Schmidt  
Dustin Schroeder  
Frank Seelos  
Dave Senske

Mark Sephton  
Everett Shock  
James Slavin  
Todd Smith  
Jason Soderblom  
Krista Soderlund  
John Spencer  
Ralf Srama  
Andrew Steffl  
Alan Stern  
Michael Stevens  
Robert Strangeway  
Ben Teolis  
Nick Thomas  
Gabriel Tobie  
Zibi Turtle  
Steve Vance  
Hunter Waite  
Ben Weiss  
Joe Westlake  
Danielle Wyrick  
Duncan Young  
Mikhail Zolotov