National Aeronautics and Space Administration

2019
Interplanetary Small Satellite Conference

beyond LEO

Conference Program

Small satellite developments in:

Science Goals and Instrumentation
Interplanetary Missions, Systems, and Architectures
Challenges of Small Satellites for Interplanetary Applications
Proposed Spacecraft Subsystems and Technologies
Management, Systems Engineering, Policy and Cost

Hosted by:

California Polytechnic
State University
(CalPoly)
San Luis Obispo, CA
April 29-30, 2019

www.intersmallsatconference.org

Monday, April 29, 2019

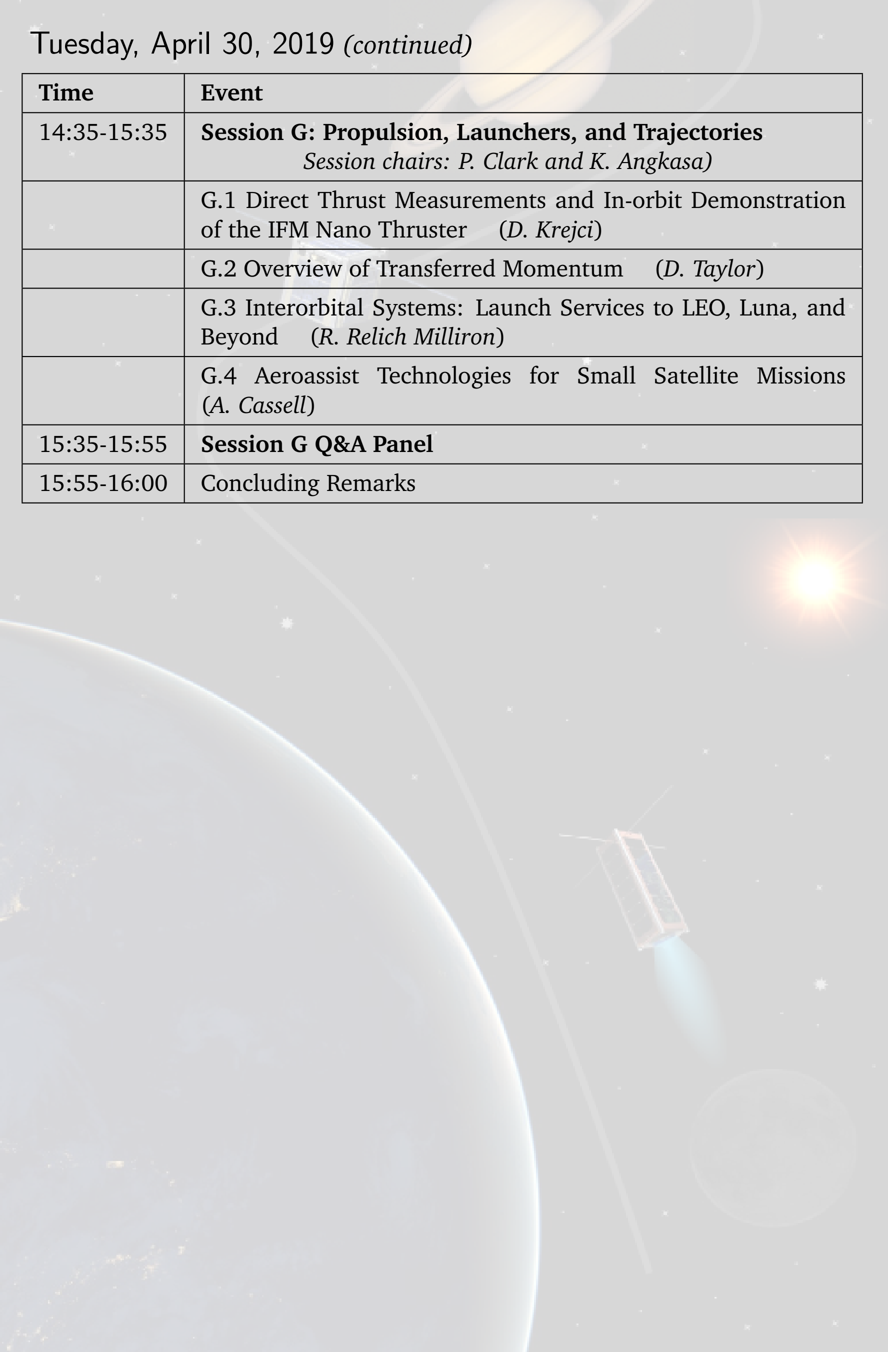
Time	**Event**
8:00-9:00	Registration & Breakfast
9:00-10:00	**Keynote Speaker: Christopher E. Baker,** **NASA Headquarters**
10:00-10:15	Coffee Break
10:15-11:30	**Session A: EM-1 Missions** *Session chairs: A. Babuscia and M. Saing*
	A.1 Update for the Lunar Ice Cube Mission (*P. Clark*)
	A.2 BioSentinel – Spacecraft and BioSensor Flight Unit Development (*R. Hanel*)
	A.3 Lunar Flashlight Mission Update (*A. Marinan*)
	A.4 Near Earth Asteroid Scout Mission Update (*A. Marinan*)
	A.5 The Lunar Polar Hydrogen Mapper Mission: Low-Altitude Planetary Neutron Spectroscopy (*C. Hardgrove*)
11:30-12:00	**Session A Q&A Panel**
12:00-13:00	Lunch
13:00-14:15	**Session B: Autonomy and Tethers Concepts** *Session chairs: A. Marinan and Cassandra Kraver*
	B.1 Autonomous Small Robot Swarms for Mars Mining Base Construction and Operation (*J. Thangavelautham*)
	B.2 Inflatable CubeSat-Sized Mars Sailplane for Science Reconnaissance (*A. Chandra*)
	B.3 Towards End to End Automated Design of Spacecraft Swarms for Small-Body Reconnaissance (*R. Teja Nallapu*)
	B.4 Automated Design and Control of Robot Swarms for Exploration of Extreme Environments on the Moon and Mars (*H. Kalita*)
	B.5 Use of Actuated Tethers for End to End Assembly, Servicing and Decommissioning of Interplanetary Spacecraft (*G. Bravo*)
14:15-14:40	**Session B Q&A Panel**
14:40-15:00	Coffee Break

Monday, April 29, 2019 *(continued)*

Time	Event
15:00-16:15	**Session C: Instrumentation and Innovative Concepts** *Session chairs: K. Angkasa and Cassandra Kraver*
	C.1 Recovering Time and State for Small Satellites in Deep Space (*A. Dahir*)
	C.2 R2D2 (*R. De Rosee*)
	C.3 Advancing Microspine Gripper Behavior Modeling and Performance Analysis for Applications on Distributed Climbing Microbots (*S. Morad*)
	C.4 Low SWaP Radiation Sensor Development and Characterization at JPL (*W. Kim*)
	C.5 Work Themes Relevant to Interplanetary Nano-satellite Technology at the NASA Ames Research Center: Exo-Brakes, Radios, Power Sources, Incremental Mission Development (*M. Murbach*)
16:15-16:45	**Session C Q&A Panel**
16:45-17:00	Coffee Break
17:00-18:15	**Session D: Special Session on Evolving Science/Engineering Partnership to Enable Interplanetary Missions** *Session chairs: P. Clark and B. Malphrus*
	D.1 Evolving the Science/Engineering Partnership to Enable Lunar Surface Payloads (*P. Clark*)
	D.2 CubeSat Deployment System Concept for Interplanetary Missions (*D. Pignatelli*)
	D.3 Adaptive Deployable Entry & Placement Technology for Interplanetary Small Satellite Missions (*A. Cassell*)
	D.4 CubeSat based Micro-Rovers and Micro-Landers (*R. Moses*)
	D.5 LUNET Platform concept: bootstrapping lunar mission services (*L. Mullin*)
18:15-18:40	**Session D Q&A Panel**
18:40-20:00	Dinner and Social

Tuesday, April 30, 2019

Time	**Event**
8:00-9:00	Registration & Breakfast
9:00-10:00	**Keynote Speaker: Anthony Colaprete,** **NASA Ames Research Center**
10:00-10:15	Coffee Break
10:15-11:45	**Session E: Mission Concepts** *Session chairs: A. Marinan and J. Thangavelautham*
	E.1 Mars Areostationary Trace Gas Localizer (*N. Patel*)
	E.2 A small spacecraft to explore the Sun's control of Jupiter's magnetosphere (*F. Crary*)
	E.3 The Coming Era of Scientific Deep Space Smallsat And CubeSat Exploration (*S. Matousek*)
	E.4 Towards Development and Testing of an Engineering Model for an Asteroid Hopping Robot (*G. Wilburn*)
	E.5 On-Orbit Centrifuge Laboratories for Simulating Low-Gravity Surface Environments (*S. Schwartz*)
	E.6 Scalable Mother-Daughter Architectures for Asteroid Belt Exploration (*L. Dean Vance*)
11:45-12:15	**Session E Q&A Panel**
12:15-13:15	Lunch
13:15-14:00	**Session F: Telecommunication** *Session chairs: A. Babuscia and B. Malphrus*
	F.1 Iris at Mars: First Use of Iris Deep Space Transponder to Support MarCO Relay Mission (*S. Holmes*)
	F.2 Iris Deep Space Transponder Testing at Space Dynamics Laboratory, Jet Propulsion Laboratory, and DSN Test Facility (DTF)-21 (*T. Chambers*)
	F.3 Implementation of Modular Electro-Mechanical Model to Detect Antenna Deployment (*A. Srivastava*)
14:00-14:20	**Session F Q&A Panel**
14:20-14:35	Coffee Break



Tuesday, April 30, 2019 *(continued)*

Time	Event
14:35-15:35	**Session G: Propulsion, Launchers, and Trajectories** *Session chairs: P. Clark and K. Angkasa)*
	G.1 Direct Thrust Measurements and In-orbit Demonstration of the IFM Nano Thruster (*D. Krejci*)
	G.2 Overview of Transferred Momentum (*D. Taylor*)
	G.3 Interorbital Systems: Launch Services to LEO, Luna, and Beyond (*R. Relich Milliron*)
	G.4 Aeroassist Technologies for Small Satellite Missions (*A. Cassell*)
15:35-15:55	**Session G Q&A Panel**
15:55-16:00	Concluding Remarks

Contents

1. Welcome

Welcome to the eighth Interplanetary Small Satellite Conference, which will address the technical challenges, opportunities, and practicalities of space exploration with small satellites.

This conference is organized by an evolving group of students, alumni, and staff from Caltech, JPL, and NASA's Small Spacecraft Systems Virtual Institute and its roots trace back to the iCubeSat 2012 conference. The scope of the conference is slightly broader and includes interplanetary small satellite missions that do not fit into the CubeSat standard. We believe that with this shift we will be able to incorporate an important segment of the community as well as encourage the "outside the box" thinking that will be critical to future interplanetary small satellite missions.

Thank you for joining us in San Luis Obispo.

—*The Organizing Committee*

2. Contacts and Hours

The registration desk will be open from 8:00 am on April 29 and from 8:00 am to 3:00 pm on April 30. Please don't hesitate to contact the organizing committee at info@intersmallsatconference.org at any time during the conference.

3. Organizing Committee

Alessandra Babuscia received her B.S. and M.S degrees from the Politecnico di Milano, Milan, Italy, in 2005 and 2007, respectively, and her Ph.D. degree from the Massachusetts Institute of Technology (MIT), Cambridge, in 2012. She is currently a Telecommunication Engineer at NASA JPL (337G). She has developed communication systems for different university missions (CASTOR, ExoplanetSat, TerSat, REXIS, TALARIS). She has been with the Communication Architecture Research Group, NASA Jet Propulsion Laboratory, Pasadena, CA. Her current research interests include communication architecture design, statistical risk estimation, multidisciplinary design optimization, and mission scheduling and planning. She was a member of the organizing committee for iCubeSat 2012 (MIT, Cambridge), and she is a session chair at the IEEE Aerospace Conference.

Carlyn Lee is a software engineer for the Telecommunication Architecture Group at NASA Jet Propulsion Laboratory. She is involved in link budget analysis tools development and optimization for space communication and navigation. Her research interests include communication systems, networking architecture, and high-performance computations.

Julianna Fishman is the founder of Technology Horse LLC, a program and project management services company. Ms. Fishman facilitates activities of the Technology Integration Agent, a process utilized by several multidisciplinary NASA programs to define mission, program, and project priorities; support requirements analysis; and perform technology assessments. From 1994 to the present, she has provided program and project formulation and implementation support to several NASA programs at both NASA Headquarters and Ames Research Center to include: Space Biology, Gravitational Biology and Ecology, Fundamental Space Biology, Biomolecular Physics and Chemistry, Astrobionics Technology Group, Dust Management Project, Small Spacecraft Technology Program, Small Spacecraft Systems Virtual Institute, and the Office of the Center Chief Technologist. In her capacities, Ms. Fishman makes contributions in the areas of program and project document content development; focus group, workshop, and review planning; and development of presentations, white papers, and communications material. She holds a Bachelor of Science degree in biology and a Master's in Business Administration from Norwich University in Northfield, Vermont.

Kristina Hogstrom received her B.S. in Mechanical Engineering with a minor in Astronomy from Boston University in 2011 and her M.S. and Ph.D. in Space Engineering from Caltech in 2012 and 2017 respectively. At Caltech, she was a NASA Space Technology Research Fellow and a Keck Institute for Space Studies Fellow. Her doctoral research focused on the behavior of deployable modules for robotically assembled space structures, such as large space-based optical reflectors. She is now a systems engineer at JPL in the mission formulation section and has an active role on Team X, a concurrent engineering team that rapidly explores, designs, and evaluates mission concepts in the early stages of development.

Chi-Wung Lau is a member of the Signal Processing Research group at Jet Propulsion Laboratories. He has been working at JPL for 15 years and has been involved with such projects as Galileo, Deep Impact, MER, Phoenix and MSL. Research areas of interest are 34 meter array tracking quantum communications, and link analysis. He received bachelor's from U.C. Berkeley in 1996 and master's from the University of Southern California in 2001.

Pamela Clark of the Advanced Instrument Concepts and Science Applications Group in the Instrument Division, at Jet Propulsion Laboratory, California Institute of Technology, is Technical Advisor of the JPL Cubesat Development Lab. She is also Science PI of the NASA EM1 Lunar IceCube Mission, as well as Convener and Program Chair for the Annual LunarCubes Workshops, and an adjunct research professor at Catholic University of America. She holds a PhD in Geochemical Remote Sensing from University of Maryland. Her interests include extending the cubesat paradigm to deep space technology demonstrations and science requirements driven cubesat missions, developing compact science instruments, evolving a low-cost development model for deep space missions, and using the cubesat paradigm to set up distributed networks for studying whole system dynamics. She is the author of several books, including Remote Sensing Tools for Exploration, Constant-Scale Natural Boundary Mapping to Reveal Global and Cosmic Processes, and Dynamic Planet: Mercury in the Context of its Environment.

Annie Marinan earned her Bachelor's degree from the University of Michigan in Aerospace Engineering in 2011 and her Master's and PhD in Aerospace Engineering (Space Systems) from the Massachusetts Institute of Technology (MIT) in 2013 and 2016, respectively. Her graduate research focused on use of CubeSats for atmospheric sounding and as technology demonstration platforms. She is currently working as a systems engineer at NASA's Jet Propulsion Laboratory (JPL) in the Project Systems Engineering and Formulation Section. She leads Team Xc, a concurrent engineering team that focuses on design and feasibility assessments for small spacecraft missions.

Kris Angkasa holds a B.S. in Computer Science from the California Polytechnic University Pomona and M.S. in Electrical Engineering from the University of Southern California. She is a senior engineer at the Jet Propulsion Laboratory, focusing her work in the Deep Space Network (DSN) and space communications systems. Her recent work at JPL includes the design, implementation, and integration & test of the DSN Block V Receiver, Proximity-1 Electra Radio, Small Deep Space Transponder (SDST), Universal Space Transponder (UST), and Iris Deep Space Transponder, built for the flagship missions such as, Juno, Mars Exploration Rover (MER), Mars Science Laboratory (MSL) Rover, Mars Reconnaissance Orbiter (MRO), MaVEN, and Mars 2020 Rover, as well as, the smaller missions such as, MarCO, GRACE Follow-On, and the EM-1 CubeSat missions. At Hughes Space and Communications (now Boeing), she served as the payload communications systems lead for the commercial Ka-band satellite used for DirectTV®. Currently at JPL, she is a systems engineer for the Mars 2020 Rover mission and telecom lead for the Lunar IceCube mission, slated for the EM-1 launch.

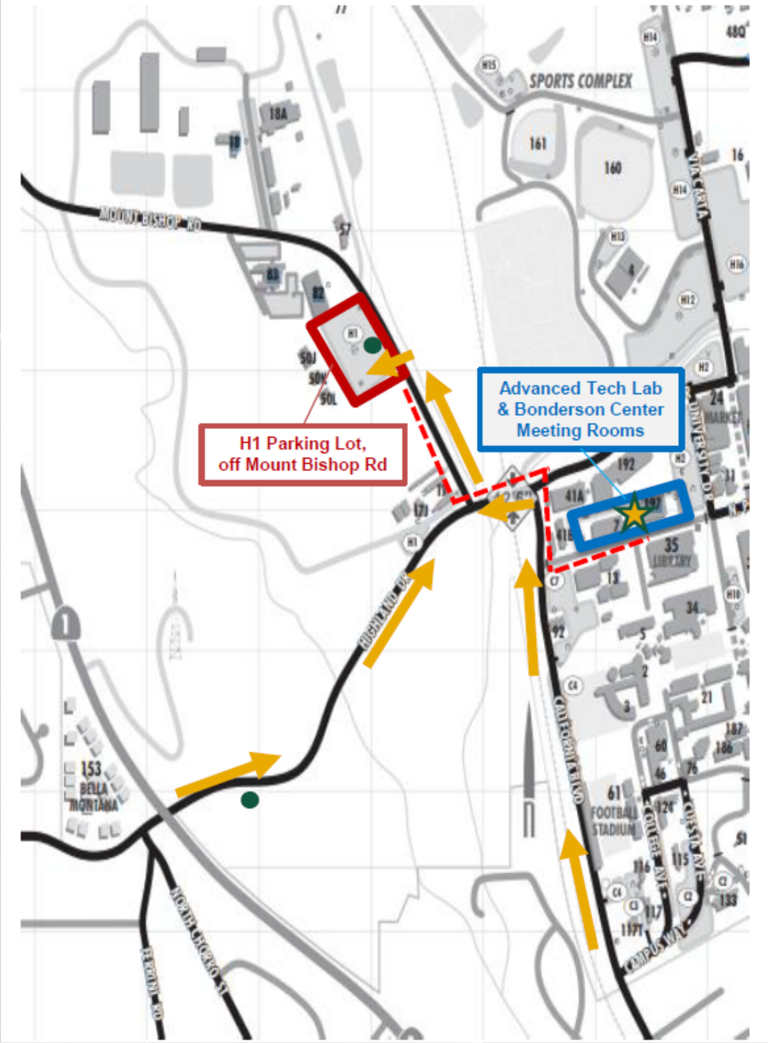
Marc Sanchez Net is a telecommunications engineer in the Communication Architectures and Research Section at JPL. His research interests include delay tolerant networking and its impact on distributed applications such as computational task sharing, spacecraft constellation management, as well as design of space communication systems in challenged environments such as the surface of the Moon. Marc received his PhD in 2017 from MIT, and also holds degrees in both telecommunications engineering and industrial engineering from Universitat Politecnica de Catalunya, Barcelona.

Ryan Nugent is currently a Co-Principal Investigator of the CubeSat Program at Cal Poly in San Luis Obispo, CA. Ryan has spent 12 years with the program, starting as an undergraduate student and continuing as a graduate student in Aerospace Engineering. Ryan took a staff position at Cal Poly in 2011. He has lead development efforts for Cal Poly dispenser designs, developing the processes required to support NASA, The U.S. Department of Defense, European Space Agency, and Commercial Organizations in certifying CubeSats and CubeSat dispensers for domestic and international launches. Overall, Ryan has supported 23 orbital launches in the U.S. and internationally involving over 155 satellites, including the MarCO CubeSats. Ryan is currently managing the CubeSat Program at Cal Poly, which manages the CubeSat Standard and is currently working on additional launch campaigns and supporting the development of 5 different satellite projects at Cal Poly.

Michael Saing is a Systems Engineer in the Project Systems Engineering and Formulation Section at the Jet Propulsion Laboratory (JPL). He develops system model, analysis, and architecture as well as a subject matter expert in space mission cost estimating and analysis. He is also one of the subsystem's engineer chair for JPL's Foundry elite concurrent engineering design team for TeamX, TeamXc, and A-Team. Michael is also tasked by NASA Headquarters particularly focusing on data collection and analysis for small satellites/cubesats and space remote sensing instruments. He graduated with an Aerospace Engineering degree (B.S.) from CSU Long Beach. While working towards completing his academics, he volunteered and worked with a group of mentor engineers and students to gain knowledge and experience in design, build, and launch reusable launch vehicles (RLV) and nanosatellite launch vehicles (NLV) for customers such as DoD and NASA. After graduation, he started his early career work at the NASA Ames Research Center in Mountain View, CA prior to joining JPL. His interests are in the areas of astrophysics and planetary science, remote sensing instruments, and satellite constellation and swarms.

4. Location, Venue, and Parking

The conference will take place at the California Polytechnic State University, located in San Luis Obispo, CA 93407, in the Advanced Tech Lab (Bldg 7) and Bonderson Center Meeting Rooms (Bldg 197), highlighted in blue in the diagram below. ISSC 2019 Event Parking is located in the H-1 Parking Lot, highlighted in red below. Parking instructions are on page 13.



H1 Parking Lot, off Mount Bishop Rd

Advanced Tech Lab & Bonderson Center Meeting Rooms

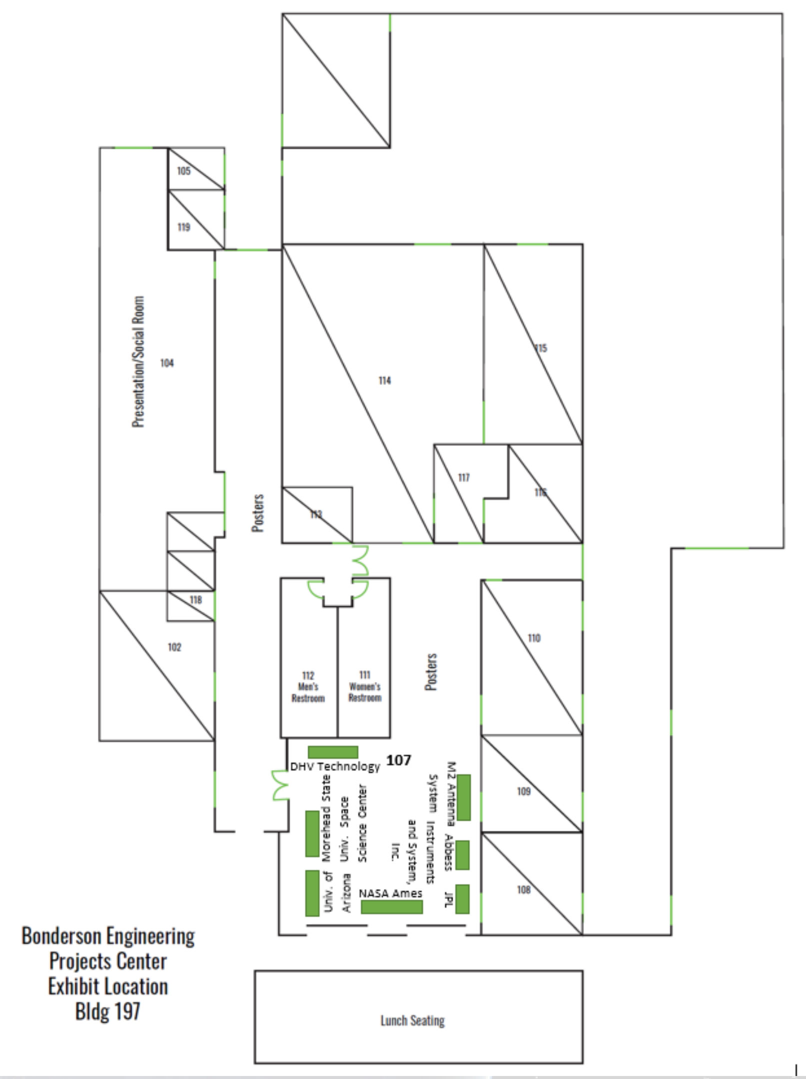
→	**Driving Directions to H-1 Parking Lot using either California Blvd or Highland Dr**
▭	**ISSC 2019 Parking**: H-1 Parking Lot.
- - - -	**Walking Directions** from H-1 Parking Lot
★	**ISSC 2019– Adv Tech Lab (Bldg 7)**
	Parking Permits required Mon-Fri from 7am-10pm.

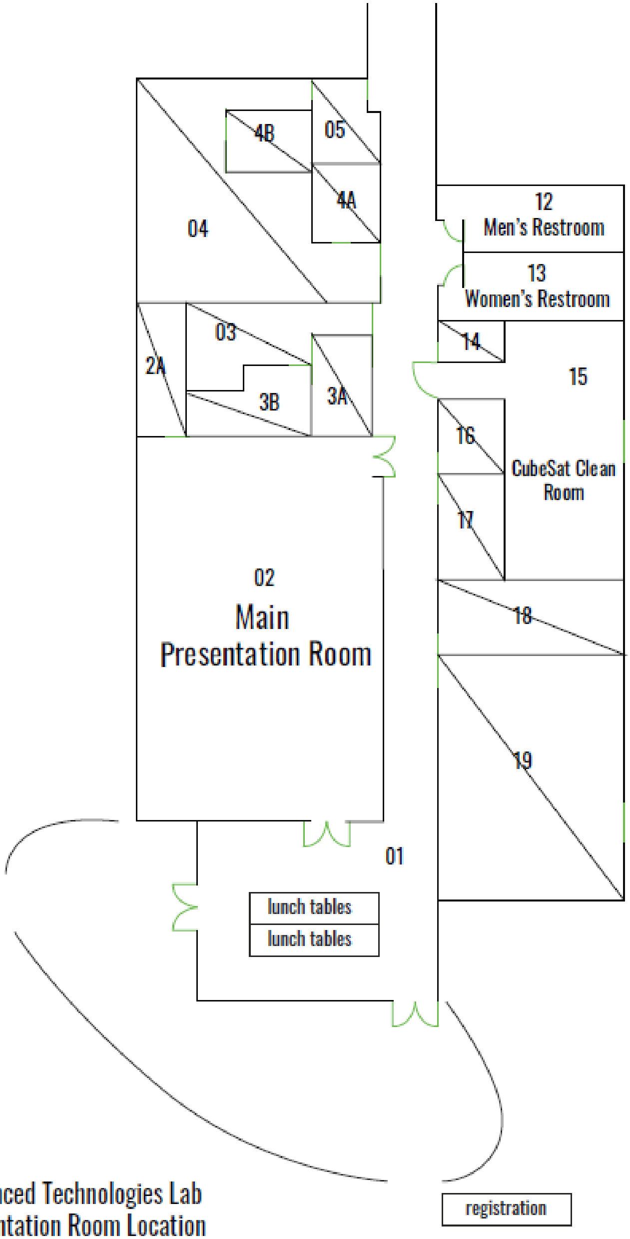
PARKING INSTRUCTIONS:

- ISSC 2019 event parking in the **H-1 Parking Lot**.
- Please print an event parking permit before you arrive on campus. Simply follow these instructions:
  - Go online to: calpoly.pmreserve.com
  - **Venue: Cal Poly Campus**
  - **Event: 4/29 Interplanetary Small Satellite Conference 2019**
  - **Access Code: ISSC19**
- Parking permits can also be purchased on campus at any available pay station●.
- A valid parking permit is required for all vehicles parking on campus Monday-Friday.
- Parking on campus is extremely limited and is not guaranteed. **We recommend carpooling, using a ride service such as Uber or inquiring at your hotel to find out if a shuttle service is offered.**

5. Exhibitors and Lunch Area Map

A rough diagram of the exhibitor area is shown below, and a map of the Lunch & Social dinner location is shown on page 16. We hope you enjoy interacting with our great sponsors and exhibitors this year!





Advanced Technologies Lab
Presentation Room Location
Bldg 7

Advanced Technologies Lab
Presentation Room Location
Bldg 7

Dinner and Social Location
Bldg 5 room 105

Bonderson Engineering Projects Center
Exhibit Location
Bldg 197

6. WiFi Access

For wireless Internet access, connect to the "CalPolyGuest" network. You will have to register to use the network; for more information see https://servicedesk.calpoly.edu/guestwifi

7. Keynote Speaker Biographies

Christopher E. Baker (*NASA Headquarters*)

Christopher Baker currently serves as the program executive for NASA's Space Technology Mission Directorate Small Spacecraft Technology program, which seeks to enable new mission architectures through the use of small spacecraft, expand the reach of small spacecraft to new destinations, and augment future missions with supporting small spacecraft. Baker also serves as the program executive for NASA's Flight Opportunities program that strategically invests in the growth of the U.S. commercial spaceflight industry by providing flight opportunities to test space exploration and utilization technologies on commercially available suborbital flight platforms. Baker previously held various positions in atmospheric and suborbital flight testing at the Armstrong Flight Research Center, and managed an agency wide early stage research and development program from NASA Headquarters. Baker is a graduate of the Worcester Polytechnic Institute where he received a Bachelor of Science in Aerospace Engineering and a Master of Science in Mechanical Engineering.

Anthony Colaprete (*NASA Ames Research Center*)

Anthony Colaprete is a planetary scientist at NASA Ames Research Center, where he currently leads the Flight Instrument Group that is charged with developing a range of flight instruments for various platforms. Dr. Colaprete also conducts basic research on planetary atmospheres and lunar volatiles. Dr. Colaprete began working on flight instrumentation while an undergraduate at the University of Colorado, where he developed spectrometers and imaging systems for the Space Shuttle Program, sounding rocket and small satellite missions. Dr. Colaprete's particular work during this time included scientific direction for the space shuttle payloads Escape, Escape II, and Distributed Automation Technology Advancement-Colorado Hitchhiker and Student Experiment of Solar Radiation (DATA-CHASER); the High Altitude Ozone Measuring & Educational Rocket (HOMER) sounding rocket payload, and scientific direction for payloads for the Citizen Explorer and 3-Corner Sat small satellite missions. After receiving his PhD in Atmospheric, Planetary and Astrophysical Science from the University of Colorado, Dr. Colaprete was hired by NASA Ames to work as a postdoctoral researcher with the NASA Ames Mars General Circulation Modeling group.

Dr. Colaprete has led or participated in several flight projects. He has served as the principal investigator and payload manager for the Lunar Crater Observation and Sensing Satellite (LCROSS) mission, and the principal investigator and instrument manager for the Lunar Atmosphere and Dust Environment Explorer (LADEE) Ultraviolet- Visible Spectrometer (UVS) instrument. In 2017 Dr. Colaprete lead a Planetary Science Deep Space SmallSat Studies (PSDS3) mission concept study for a small satellite mission named Aeolus, a mission to directly measure the winds of Mars. Currently Dr. Colaprete is the principal investigator for the Near Infrared Volatile Spectrometer Subsystem (NIRVSS) instrument, one of thirteen recently selected NASA Provided Lunar Payload (NPLP) instruments for flight on commercial lunar landers. Dr. Colaprete is also a co-investigator on the LunaH-Map Exploration Mission-1 (EM-1) CubeSat mission and the Mastcam-Z Mars 2020 instrument.

8. Conference Abstracts

K.1 Small, Rapid, Affordable and Transformative: The Continuing Evolution of Small Spacecraft from the Earth to the Moon, Mars and Beyond

Christopher Baker (*NASA Headquarters*)

Sustainable human activity in deep space requires exploration capabilities that can be fielded faster and at lower cost. Small spacecraft afford an increasingly capable platform to precede and accompany human explorers to the Moon, Mars, and other destinations to scout terrain, characterize the environment, identify risks, and prospect for resources. Small spacecraft can enable new science measurements in deep space and around planetary bodies that are not attainable using traditional approaches. Constellations of small spacecraft beyond Earth can provide multipoint measurements for heliophysics and the monitoring of space weather events to protect space assets and explorers. Distributed systems of small spacecraft can responsively provide cost effective communications, monitoring, and inspection infrastructure for exploration missions and cis-lunar commercial activity.

Small spacecraft are proving to be a disruptive innovation for exploration, discovery and space commerce. Their small size, use of commercial off-the-shelf components, and standardized format for easy safe launch as secondary payloads help keep costs and risks low. However, to enable rapid and more affordable missions to destinations beyond Earth, small spacecraft will need to push beyond their current capabilities. The recent success of MarCO A & B at Mars represents the start and not the end of this journey.

How do we enable these new missions without sacrificing the agility and innovation that has fueled the proliferation of small spacecraft for terrestrially focused applications? How do we create the regular access to destinations beyond Earth that allows for the greater risk tolerance and the opportunity to iterate through failures currently afforded to CubeSat missions in low-Earth orbit? How do we best embrace industry standardization and off the shelf electronics to create truly affordable missions? And how do we use public-private partnerships and adapt the capabilities developed for commercial applications around Earth to challenging interplanetary environments? These are questions that we must pose to ourselves and answer if we hope to achieve the promise of small spacecraft to create new mission capacities and to recreate existing capabilities for the Moon, Mars, and beyond at a fraction of the cost.

K.2 Planetary Science with Small Satellites: Opportunities and Challenges

Anthony Colaprete
(*NASA Ames Research Center*)

Small satellites aren't anything particularly new. Earth orbiting small satellites go back 30 years or more. What is new is the proliferation and access to small satellite technologies and flight opportunities. This has been in large part due to the advent of the "CubeSat" model, initially a means to develop students' engineering skills, but that has since evolved into an industry and accepted spacecraft platform within government space agencies. Until very recently these smallsats were limited to Earth orbiting missions, but with the successful flight of the MarCO spacecraft and the upcoming launch of Exploration Mission-1 (EM-1) CubeSats, the Moon, Mars and beyond are now within reach. While all this is good news, we still have a ways to go before smallsats become true planetary science tools. One could argue that Deep Space 2 (DS2) was the first planetary smallsat. Launched in 1999 and having a mass of 2.3 kg (each probe) DS2 hoped to demonstrate that "real" science could be done with a small (and less expensive) package. The DS2 failure shelved the idea of smallsats (even chilling some to "Class D" planetary missions in general) for nearly two decades. NASA has slowly come back around to smallsats for planetary missions, going so far as to support a range of mission studies (the Planetary Science Deep Space SmallSat Studies [PSDS3] program) and to create a new program (Small Innovative Missions for Planetary Exploration [SIMPLEx]) to develop such missions for opportunistic flights. The success of the MarCO mission was hugely important in maintaining (and building) this forward momentum. However, we still have yet to demonstrate "real" science from a planetary smallsat and there are some fundamental disconnects between expectation and reality.

This talk will discuss some of the opportunities and challenges that reside with planetary smallsats, focusing on two examples: LunaH-Map, the first SIMPLEx CubeSat; and Aeolus, a Mars PSDS3 smallsat concept.

A.1 Update for the Lunar Ice Cube Mission

Pamela Clark
(*Jet Propulsion Laboratory, California Institute of Technology*),
Ben Malphrus (*Morehead State University*),
Cliff Brambora and David Folta (*NASA Goddard Space Flight Center*),
Michael Tsay (*Busek*), and Matthew Grubb (*NASA/IVV*)

Lunar Ice Cube, to be launched in 2020, is a deep space cubesat mission with the goals of demon-strating 1) a cubesat-scale instrument capable of addressing NASA HEOMD Strategic Knowledge Gaps related to lunar volatile distribution (abundance, location, and transportation physics of water ice), and 2) cubesat propulsion, via the Busek BIT 3 RF Ion engine.

Payload: The payload consists of one instrument: BIRCHES [1], Broadband IR Compact High-resolution Ex-ploration Spectrometer. The versatile instrument, being developed by NASA GSFC, is designed to provide the basis for amplifying our understanding of the forms and sources of lunar volatiles in spectral, temporal, spatial, and geological context as function of time of day and latitude. BIRCHES is a compact version (1.6 U, 3 kg, 10-20 W) of OVIRS on OSIRIS-REx, a point spectrometer with a cryocooled HgCdTe focal plane array for broadband (1 to 4 micron) measurements. The instrument will achieve sufficient SNR (>100) and spectral resolution (</= 10 nm @ 3 microns) through the use of a Linear Variable Filter to characterize and distinguish spectral features associated with water. An adjustable field stop allows as to change the footprint dimensions by an order of magnitude, to adjust for variations in altitude and/or incoming signal. The compact and efficient AIM microcryocooler/IRIS controller is designed to maintain the detector temperature below 115K. In order to maintain the cold temperature ($<$220 K) of the optical system (all aluminum construction to minimize varying temperature induced distortion), a special radia-tor is dedicated to optics alone.

Mission Design: Science data-taking with the BIRCHES payload will occur primarily during the science orbit (100 km × 5000 km, equatorial periapsis, nearly polar), highly elliptical, with a repeating coverage pattern that pro-vides overlapping coverage at different lunations. Science orbit data-taking will last approximately 6 months, 6 lunar cycles, allowing for sufficient collection of systematic measurements as a function of time of day to allow deri-vation of volatile cycle models.

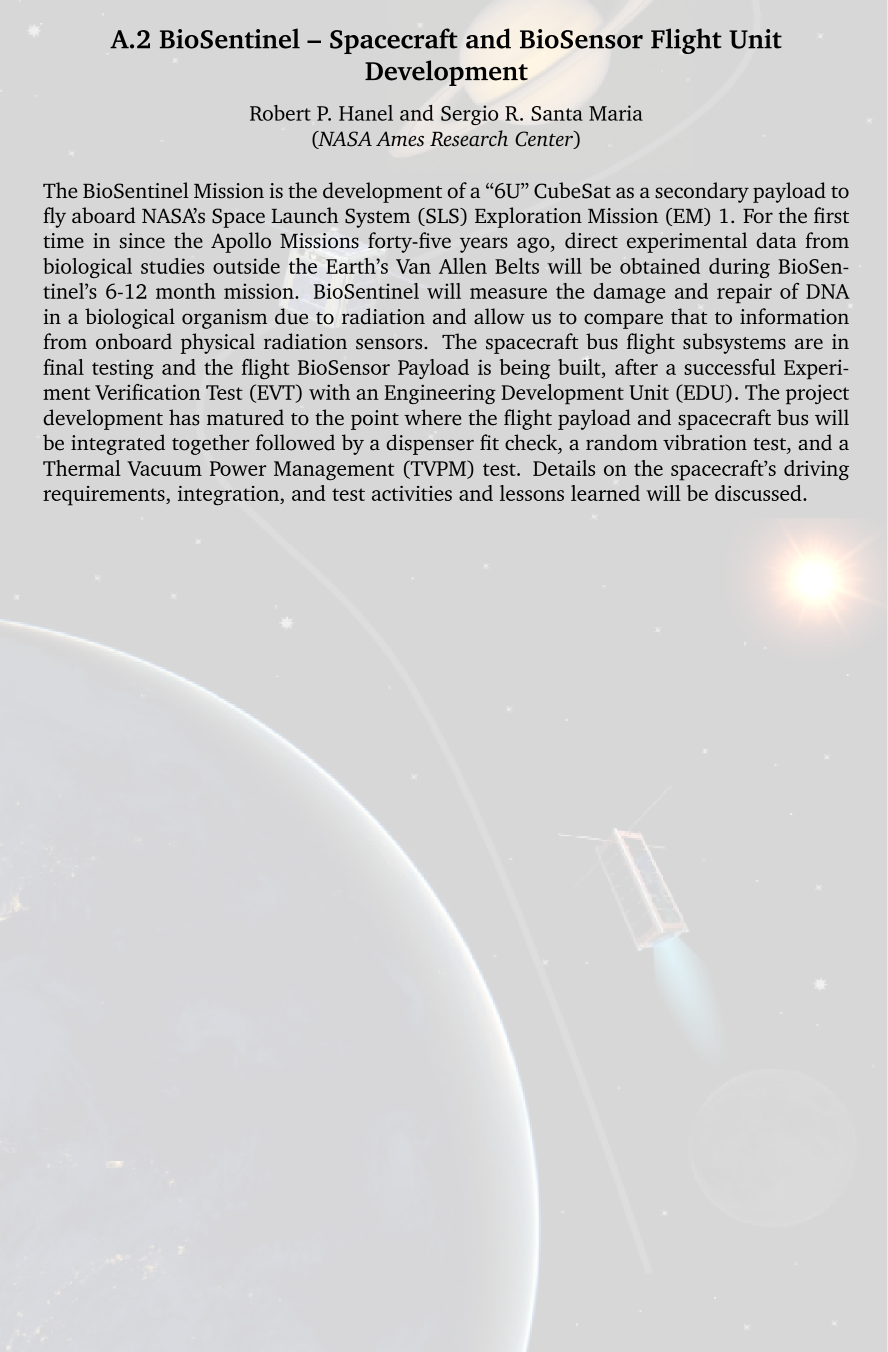
Development Status: All subsystems except the payload will have been delivered by late March. BIRCHES will complete operational environmental testing by the end of April, to be delivered in early May. Spacecraft inte-gration will occur throughout April, May, and June, with final operational environmental testing to be completed in mid-July.

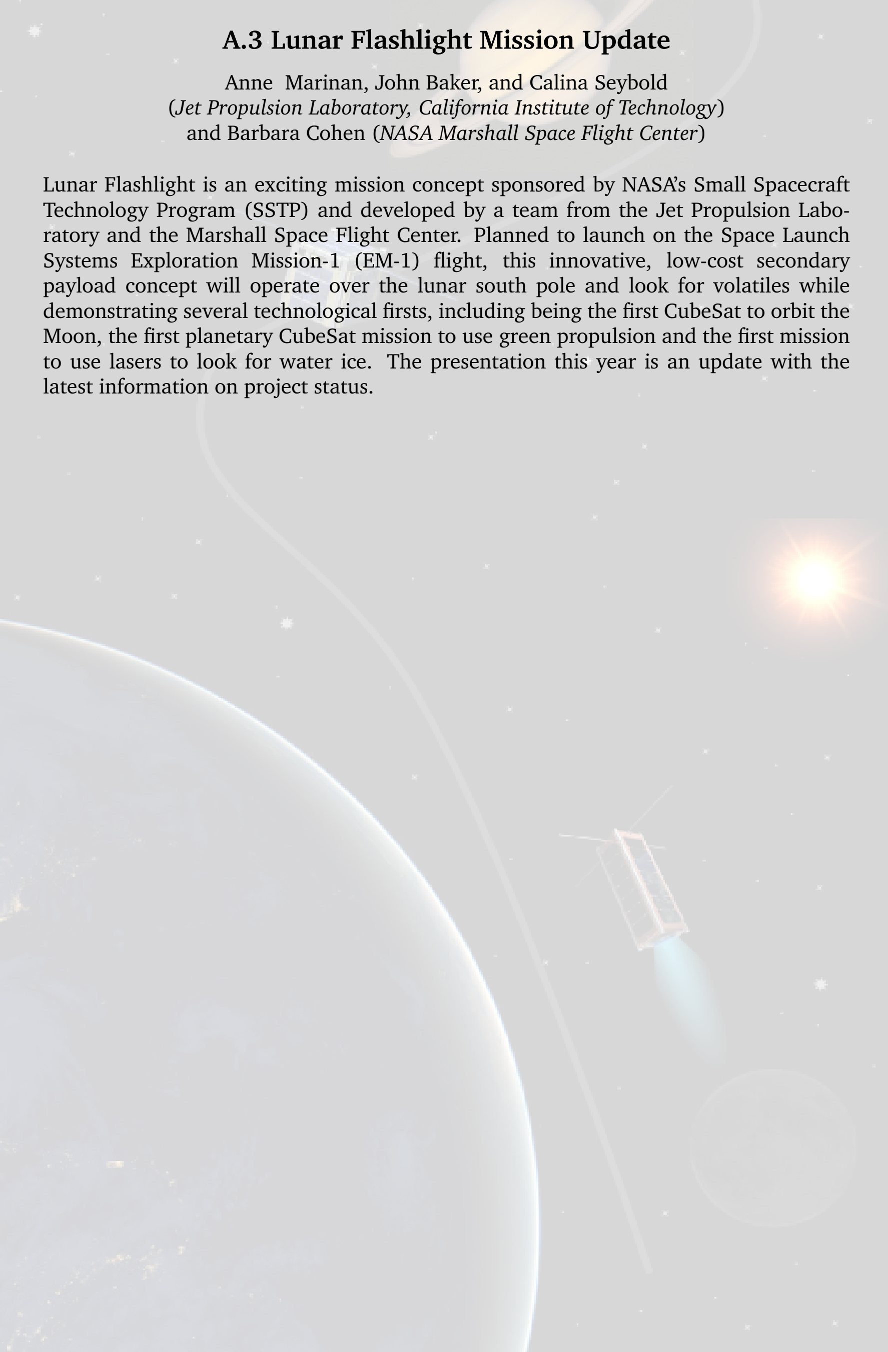
References: [1] Clark P.E. et al. (2017) SPIE Proceedings 9978, 99780C, doi:10.1117/12.2238332.

A.2 BioSentinel – Spacecraft and BioSensor Flight Unit Development

Robert P. Hanel and Sergio R. Santa Maria
(*NASA Ames Research Center*)

The BioSentinel Mission is the development of a "6U" CubeSat as a secondary payload to fly aboard NASA's Space Launch System (SLS) Exploration Mission (EM) 1. For the first time in since the Apollo Missions forty-five years ago, direct experimental data from biological studies outside the Earth's Van Allen Belts will be obtained during BioSentinel's 6-12 month mission. BioSentinel will measure the damage and repair of DNA in a biological organism due to radiation and allow us to compare that to information from onboard physical radiation sensors. The spacecraft bus flight subsystems are in final testing and the flight BioSensor Payload is being built, after a successful Experiment Verification Test (EVT) with an Engineering Development Unit (EDU). The project development has matured to the point where the flight payload and spacecraft bus will be integrated together followed by a dispenser fit check, a random vibration test, and a Thermal Vacuum Power Management (TVPM) test. Details on the spacecraft's driving requirements, integration, and test activities and lessons learned will be discussed.





A.3 Lunar Flashlight Mission Update

Anne Marinan, John Baker, and Calina Seybold
(*Jet Propulsion Laboratory, California Institute of Technology*)
and Barbara Cohen (*NASA Marshall Space Flight Center*)

Lunar Flashlight is an exciting mission concept sponsored by NASA's Small Spacecraft Technology Program (SSTP) and developed by a team from the Jet Propulsion Laboratory and the Marshall Space Flight Center. Planned to launch on the Space Launch Systems Exploration Mission-1 (EM-1) flight, this innovative, low-cost secondary payload concept will operate over the lunar south pole and look for volatiles while demonstrating several technological firsts, including being the first CubeSat to orbit the Moon, the first planetary CubeSat mission to use green propulsion and the first mission to use lasers to look for water ice. The presentation this year is an update with the latest information on project status.

A.4 Near Earth Asteroid Scout Mission Update

Anne Marinan, Julie Castillo-Rogez, and Calina Seybold
(*Jet Propulsion Laboratory, California Institute of Technology*),
Joseph Matus, Les Johnson, and Tiffany Lockett
(*NASA Marshall Space Flight Center*)

NASA is developing solar sail propulsion for the Near Earth Asteroid (NEA) Scout, a smallsat-enabled reconnaissance mission of a near-earth asteroid. The NEA Scout mission will use the solar sail as its primary propulsion to allow it to survey and image the NEA for possible future human exploration. NEA Scout will launch on the first mission of the Space Launch System (SLS). After its first encounter with the moon, NEA Scout will deploy the 86-square-meter sail and enter the sail characterization phase. A mechanical Active Mass Translation system, combined with reaction wheels and a cold gas Reaction Control System, will be used for sail momentum management. The spacecraft will perform a series of lunar flybys to achieve optimum departure trajectory before beginning its two year-long cruise. About one month before the asteroid flyby, NEA Scout will start its approach phase using radio tracking and optical navigation. The solar sail will provide NEA Scout continuous low thrust to enable a slow flyby (<20 m/s) of the target asteroid under lighting conditions favorable to geological imaging. Once complete, NASA will have demonstrated the capability to fly low-cost, high delta-V CubeSats to perform interplanetary missions. The presentation this year is an update with the latest information on project status.

A.5 The Lunar Polar Hydrogen Mapper Mission: Low-Altitude Planetary Neutron Spectroscopy

Craig Hardgrove (*Arizona State University*),
Richard Starr, Alessandra Babuscia, Igor Lazbin, Bob Roebuck, Joe DuBois, Nathaniel Struebel, Anthony Colaprete, Darrell Drake, Erik Johnson, James Christian, Lena Heffern, Anthony Genova, David Dunham, Derek Nelson, Bobby Williams, James Bell, Patrick Hailey, and Tyler O'Brien

The Lunar Polar Hydrogen Mapper mission (LunaH-Map) is a 6U CubeSat selected for flight under NASA's Small, Innovative Missions for Planetary Exploration (SIMPLEx) program. The LunaH-Map spacecraft is extremely compact, measuring approximately 30 cm tall by 20 cm long by 10 cm wide and is equipped with a low thrust ion propulsion system, gimbaled solar arrays, three reaction wheels, star tracker, radio, command and data handling system, power control system, and a compact neutron spectrometer array. The neutron spectrometer array, called the Miniature Neutron Spectrometer (Mini-NS), is comprised of two identical detector systems (each $100cm^2$ in area). Each detector consists of a two by two array of CLYC ($Cs_2LiYCl_6 : Ce$) scintillators, for a total of eight detector elements; CLYC is an elpasolite scintillator sensitive to both neutrons and gamma rays with the characteristic pulse shape of the ^6Li neutron capture reaction used to distinguish neutrons from gamma-rays. Each Mini-NS detector element is a 4.0 × 6.3 × 2 cm CLYC scintillator. A photomultiplier tube (PMT) is mounted to each crystal, with each CLYC scintillator and PMT pair comprising one of the eight detector modules. A thin Gd sheet is used to absorb thermal neutrons and covers the nadir, sides, and a portion of the back of the instrument, which provides sensitivity to only neutron energies greater than $\sim 0.4eV$. The Mini-NS uses a thin gadolinium shield to absorb thermal neutrons ($< \sim 0.4eV$), making the instrument primarily sensitive to epithermal lunar neutron albedo which is most sensitive to the hydrogen content of the lunar regolith.

The Mini-NS will acquire background measurements shortly after the LunaH-Map spacecraft deploys from the NASA Space Launch System. After initial contact and maneuvering the spacecraft to perform a lunar flyby targeting L2, LunaHMap will eventually be captured by the Moon within two months of deployment. Upon lunar capture the spacecraft will spiral down to an elliptical low-altitude science orbit with perilune at the lunar south pole where the Mini-NS will measure the lunar epithermal neutron count rate over the Moon's South Pole. During this low-altitude mapping phase, the Mini-NS will measure epithermal neutron counts about the perilune of each orbit enabling mapping of H enrichments within regions of permanent shadow (i.e. craters where water-ice is stable) at spatial scales $<$15 km^2.

B.1 Autonomous Small Robot Swarms for Mars Mining Base Construction and Operation

Jekan Thangavelautham, Aman Chandra, and Erik Jensen
(*University of Arizona - SpaceTREx*)

Beyond space exploration, the next critical step towards living and working in space requires developing a space economy. One important challenge with this space-economy is ensuring the low-cost transport of raw materials from one gravity-well to another. The escape delta-v of 11.2 km/s from Earth makes this proposition very expensive. Transporting materials from the Moon takes 2.4 km/s and from Mars 5.0 km/s. Based on these factors, the Moon and Mars can become colonies to export material into this space economy. One critical question is what are the resources required to sustain a space economy?

Water has been identified as a critical resource both to sustain human-life but also for use in propulsion, attitude-control, power, thermal storage and radiation protection systems. Water may be obtained off-world through In-Situ Resource Utilization (ISRU) in the course of human or robotic space exploration.

Based upon these important findings, we developed an energy model to determine the feasibility of developing a mining base on Mars that mines and exports water (transports water on a Mars escape trajectory). Mars was selected as water has been found trapped in the regolith in the form hydrates throughout the surface at an average of 5% by mass with bigger deposits in Northern and Southern Polar Ice Caps. Our designs for a mining base utilize renewable energy sources namely photovoltaics and solar-thermal concentrators to provide power to construct the base, keep it operational and export the water using a mass driver (electrodynamic railgun). Using the energy model developed, we determined that the base requires 2.6×10^6 MJoules of energy per sol to export 100 tons of water into Mars escape velocity. 97.8% of the energy obtained from renewable power sources is to power the mass-driver. Only 0.54% of the energy was required to excavate, process and collect water. If the base was occupied by 100 human workers, 1.66% of the energy would be needed for sustaining life-support, food productions and healthy-living.

Our studies found the key to keeping the mining base efficient is to make it robotic. Teams of robots (consisting of 100 infrastructure robots with a mass of 100 kg each) would be used to construct the entire base and fully operate the base. This would decrease energy needs by 3-folds. Furthermore, the base can be built 3-times faster using robotics and 3D printing. This shows that automation and robotics is the key to making such a base technologically feasible.

B.2 Inflatable CubeSat-Sized Mars Sailplane for Science Reconnaissance

Aman Chandra, Andrew Okonya, and Jekan Thangavelautham
(*University of Arizona - SpaceTREx*),
Adrien Bouskela and Sergey Shkarayev (*University of Arizona - Micro Air Vehicle Laboratory*), and
Alexandre Kling (*NASA Ames Research Center*)

Exploration of planets such as Mars have been achieved using orbiters, landers and rovers. State of the art cameras on orbiters such as the Mars Reconnaissance Orbiter (MRO) have provided unprecedented high-resolution global images of the surface. Landers and rovers such as the Mars Science Laboratory carry state-of-the-art science laboratories to analyze and perform experiments in small localized areas. A critical gap exists in exploring, taking images and providing services in local regions hundreds of kilometers in length. A credible solution is to launch one or more sailplanes to fly in the Martian atmosphere. The proposed sailplanes are secondary payloads packaged into a 12U CubeSat with a mass of 24 kg and can occupy some of the 190 kg of ballast of an MSL-class vehicle. The CubeSat is deployed during Entry, Descent and Landing (EDL) of the main vehicle and deploys inflatable-wings to glide through the atmosphere.

Sailplanes utilize thermals and natural convection to soar in the atmosphere. The potential is there to achieve perpetual flight as demonstrated by sailplanes on Earth. Sailplanes offer some distinct advantages over other exploration vehicles. Sailplanes are maneuverable and can provide reconnaissance images of a target area of interest from multiple viewpoints, multiple altitudes and achieve higher pixel-scale resolution than orbital assets. The sailplane can access rugged and extreme regions such as the Valles Marineris, steep crate walls and the Martian highlands that are inaccessible for the foreseeable future due to current limitations with EDL technology. Apart from carrying science cameras, that proposed framework will allow for custom 1U payloads. This could include thermal imagers and spectrometers to look for sources of methane found in the Mars atmosphere. In this work we perform initial feasibility studies to determine the configuration of a Mars inflatable sailplane that exploit dynamic soaring to remain in the Martian atmosphere for extended durations.

We further analyze the potential technologies to deploy the wing including conventional inflatables with hardened membrane, use of composite inflatables and finally quick-setting foam. In addition, we analyze potential options for communication. Finally, our work will analyze the implications of this technology for exploring other planetary bodies with atmospheres including Venus and Titan.

B.3 Towards End to End Automated Design of Spacecraft Swarms for Small-Body Reconnaissance

Ravi Teja Nallapu and Jekan Thangavelautha
(*University of Arizona - SpaceTREx*)

Understanding the physics of small bodies such as asteroids, comets, and planetary moons will help us understand the formation of the solar system, and also provide us with resources for a future space economy. Due to these reasons, missions to small bodies are actively being pursued. However, the surfaces of small bodies contain unpredictable and interesting features such as craters, dust, and granular matter, which need to be observed carefully before a lander mission is even considered. This presents the need for a surveillance spacecraft to observe the surface of small bodies where these features exist. However, there are more than 2-million small-bodies in the solar system and sending a large dedicated spacecraft to each body is intractable. A better solution is needed

While traditionally, the small-body exploration has been performed by a large monolithic spacecraft, a group of small, low-cost spacecraft can enhance the observational value of the mission and reduce cost. The challenges experienced for large spacecraft include getting into orbit around a small-body and making the right maneuvers to perform reconnaissance. In contrast, it should be noted an individual small spacecraft is quite limited by propulsion, attitude-control, communications and mission life, however a large number working cooperatively can make up for individual limitations.

In this work we propose the development of Integrated Design Engineering Automation of Swarms (IDEAS) software. IDEAS is a machine-learning based end to end automated design and control tool for conceptual design of spacecraft swarms. Using IDEAS we have been developing swarms of small-spacecraft to tackle some of the challenges of planetary mission design.

In particular we have found that swarms of flyby spacecraft maybe configured to optimize area-coverage mapping of a small-body. It may even be possible to obtain nearly 100% area coverage of small-body under desired lighting conditions. Furthermore, we have extended that approach to perform co-orbit missions to small moons in planetary systems. In this work we also look at how swarms of spacecraft can cooperatively observer localized events of interest and maximize viewing time during a flyby. Through this swarms approach we the power of dynamically reconfiguring swarms to maximize science return.

B.4 Automated Design and Control of Robot Swarms for Exploration of Extreme Environments on the Moon and Mars

Himangshu Kalita and Jekan Thangavelautham
(*University of Arizona - SpaceTREx*)

The next frontier in solar system exploration will be missions targeting extreme and rugged environments such as caves, canyons, cliffs and crater rims of the Moon, Mars and icy moons. These environments are time capsules into early-formation of the solar system and will provide vital clues of how our early solar system gave way to the current planets and moons. These sites will also provide vital clues to the past and present habitability of these environments. Current landers and rovers are unable to access these areas of high interest due to limitations in precision landing techniques, need for large and sophisticated science instruments and a mission assurance and operations culture where risks are minimized at all costs. Our past work has shown the advantages of using multiple spherical hopping robots called SphereX for exploring these extreme environments. Our previous work was based on performing exploration with a human-designed baseline design of a SphereX robot. The design of SphereX is a complex task that involves a large number of design variables and multiple engineering disciplines.

In this work we propose to use Automated Multidisciplinary Design and Control Optimization (AMDCO) techniques to find near optimal design solutions in terms of mass, volume and power for SphereX for different mission scenarios. The implementation of AMDCO for SphereX design is a complex process because of complexity of modeling and implementation, discontinuities in the design space, and wide range of time scales and exploration objectives. Moreover, the design of SphereX will depend on target environment (e.g. Moon, Mars), coordination complexity with increased number of robots, expected distance of exploration and expected mission length. We address these issues by using machine learning in the form of Evolutionary Algorithms to search through the design space and find pareto optimal solutions for a given mission task. Using this design process it is possible to find creative solution not thought of the by the experimenter.

Our earlier efforts applied to excavation robots found controllers that were human-competitive or better. The modeled disciplines are propulsion and attitude control for mobility through ballistic hopping, power consumption, energy storage, and communication. Multiple SphereX will enter a lava tube through collapsed ceiling entrance and perform coordinated exploration to rapidly form 3D maps of the environment using state-of-the-art SLAM techniques. Using this technology it is now possible to perform end to end automated preliminary design of planetary robots for surface exploration.

B.5 Use of Actuated Tethers for End to End Assembly, Servicing and Decommissioning of Interplanetary Spacecraft

Guillermo Bravo and Jekan Thangavelautham
(*University of Arizona - SpaceTREx*)

There is growing demand for satellite swarms and constellations for global positioning, remote sensing and relay communication in higher LEO orbits. This will result in many obsolete, damaged and abandoned satellites that will remain on-orbit beyond 25 years. These abandoned satellites and space debris maybe economically valuable orbital real-estate and resources that can be re-used, repaired or upgraded for future use. There is also a growing number of interplanetary missions that could benefit from on-orbit assembly, fueling and epairs/upgrades. Current methods for on-orbit capture, servicing and repair require a large service satellite as demonstrated using the DARPA Orbital Express Missions. However, by accessing abandoned satellites and space debris, there is an inherent heightened risk of damage to a servicing spacecraft. Sending multiple small-robots with each robot specialized in a specific task is a credible alternative, as the system is simple and cost- effective and where loss of one or more robots does not end the mission.

In this work, we outline an end to end multirobot system to capture damaged and abandoned space-craft for salvaging, repair and for deorbiting. In addition we look at assembly of interplanetary spacecraft modules on-orbit. We analyze the feasibility of sending multiple, decentralized robots connected by actuated tethers that can work cooperatively to per-form capture of the target satellite as a first step, followed by crawling onto damage satellites to perform detailed mapping. After obtaining a detailed map of the satellite, the robots will proceed to either repair and replace or dismantle components for salvage operations or begin assembly of a satellite using standard components. Finally, for decomissioning, remaining components will be packaged with a de-orbit device for accelerated de-orbit.

C.1 Recovering Time and State for Small Satellites in Deep Space

Andrew Dahir and Scott Palo (*University of Colorado Boulder*),
and Daniel Kubitschek (*LASP University of Colorado Boulder*)

While launch opportunities for small satellites grow with every passing year, considerations for the needs of these satellites fall short. For small satellites on the EM-1 launch, they will be released with no knowledge of their time, position or velocity (state) and must be able to communicate back with Earth. The ability to autonomously recover time and state is imperative for satellites to be able to communicate with Earth. Autonomous navigation in the satellite world is at best, a semi-autonomous solution. All systems currently require an outside presence or prior state to get a navigation. As the small satellite revolution brings about numerous more spacecraft, the need for truly autonomous navigation becomes a greater necessity for deep space travel as communication resources become limited. When spacecraft are in deep space, communication times between a satellite and the Earth can be prohibitive and ride-sharing opportunities as well as on-board faults can leave the spacecraft without time information. The proposed approach uses optical observations of available planets and corresponding celestial satellites (for interplanetary operations) to initially recover the approximate time and state. These observations are then followed by precise, filter-based determination of time, position and velocity from the chosen optical beacons available in interplanetary spaceflight.

The innovation of this approach is to use the periodicity of celestial bodies and artificial satellites to initially determine time. This capability is analogous to that of advanced star trackers that can initialize themselves by identifying any star field in the celestial sphere. Being able to quickly and autonomously recover time and position from an environment with no Earth contact will advance mission safety and automation from current methods which require an Earth contact. The impact of this concept crosses both human (full loss of communication scenario) and robotic (autonomous recovery from onboard fault) exploration applications, where some form of spacecraft-to-ground communication is required to establish approximates for time and position. In both cases, the current state-of-the-art navigation systems require some knowledge of time and some approximate position to initialize the estimation process before the mission objectives can be obtained. This presentation will examine the best-known solution for time in different scenarios related to the future of small satellite missions. While the solution is applicable to a wide range of missions, small satellites used for solar system exploration will be the focus.

C.2 R2D2

Rodolphe De Rosee
(*NASA Ames Research Center*)

In the heart of Silicon Valley, NASA Ames Research Center has been at the forefront of nanosat development and adoption for the past 20 years. Continuing these efforts, a new program is underway that is focused on advancing smallsat technologies by on-orbit demonstration of new capabilities in sensors, subsystems and components with a rapid deployment cadence. Technologies that enable interplanetary exploration are a high priority for demonstration. The initial goal is to have at least two experiment platforms launched every year and to increase the cadence from there. We intend to bridge the TRL valley of death and make incremental progress with actual, on-orbit demonstrations. The workshop and labs developing these systems will rely on COTS technology as much as possible and have a great degree of freedom with development practices and policies. Success will be determined by the series of experiments over multiple flights, not by the performance of any one experiment. Lessons learned from the TechEdSat program will be used to incorporate student involvement to enhance the creativity and energy of the program while working alongside experienced engineers. In this presentation, we lay out the framework for this program and invite the community to participate in advancing all of our interests.

C.3 Advancing Microspine Gripper Behavior Modelling and Performance Analysis for Applications on Distributed Climbing Microbots

Steven Morad and Jekan Thangavelautham
(*University of Arizona - SpaceTREx*)

Future exploration targets will consist of extreme environments that are rugged, hard to navigate and have low gravity. They include the surface of asteroids, rugged canyons, cliffs and craters on the Moon and Mars. These targets are time-capsules that can provide insight into early geo-history, major impact events and evidence of natural weathering.

Traversing these surfaces require new kinds of gripping actuators. One promising type of actuator is the microspine gripper which was inspired by the design of gecko feet. The gripper mechanism has over the years been refined to climb onto rough surfaces including rocks and rugged walls. Radial microspine grippers have been proposed for many purposes by NASA including for low gravity mobility and asteroid operations.

Specifically, the Asteroid Redirect Mission concept consisted of a microspine gripper to carry a boulder from an asteroid to Lunar orbit. Use of microspine grippers have been proposed for several distributed tethered robot designs intended to traverse through extreme environments. In addition, the grippers have been proposed for use on distributed tethered robots to perform on-orbit servicing, space debris capture and reuse. The use of distributed tethered robots provide multiple independent points of contact with a surface and even if one robot were to loose its grip, the rest can remain secured.

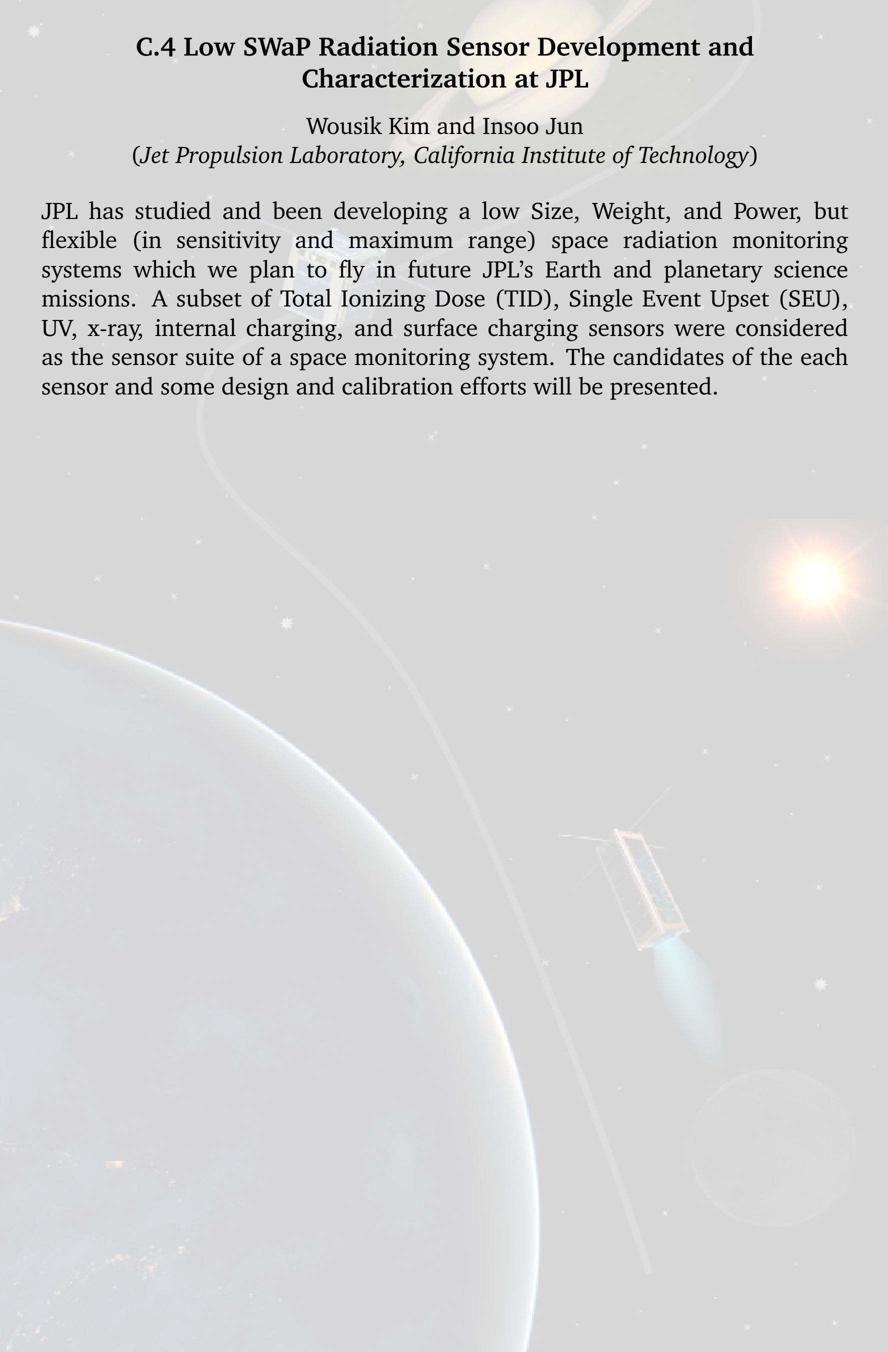
The microspine gripper consists of many small hooks that grab onto surface imperfections, also known as asperities. While the micro-scale physics of microspines are fairly well known, modeling gripping spine performance on the macro scale and in aggregate is still an active area of research. It is critical to understand and model the behavior of this kind of actuator to assist autonomous control systems in utilizing these grippers.

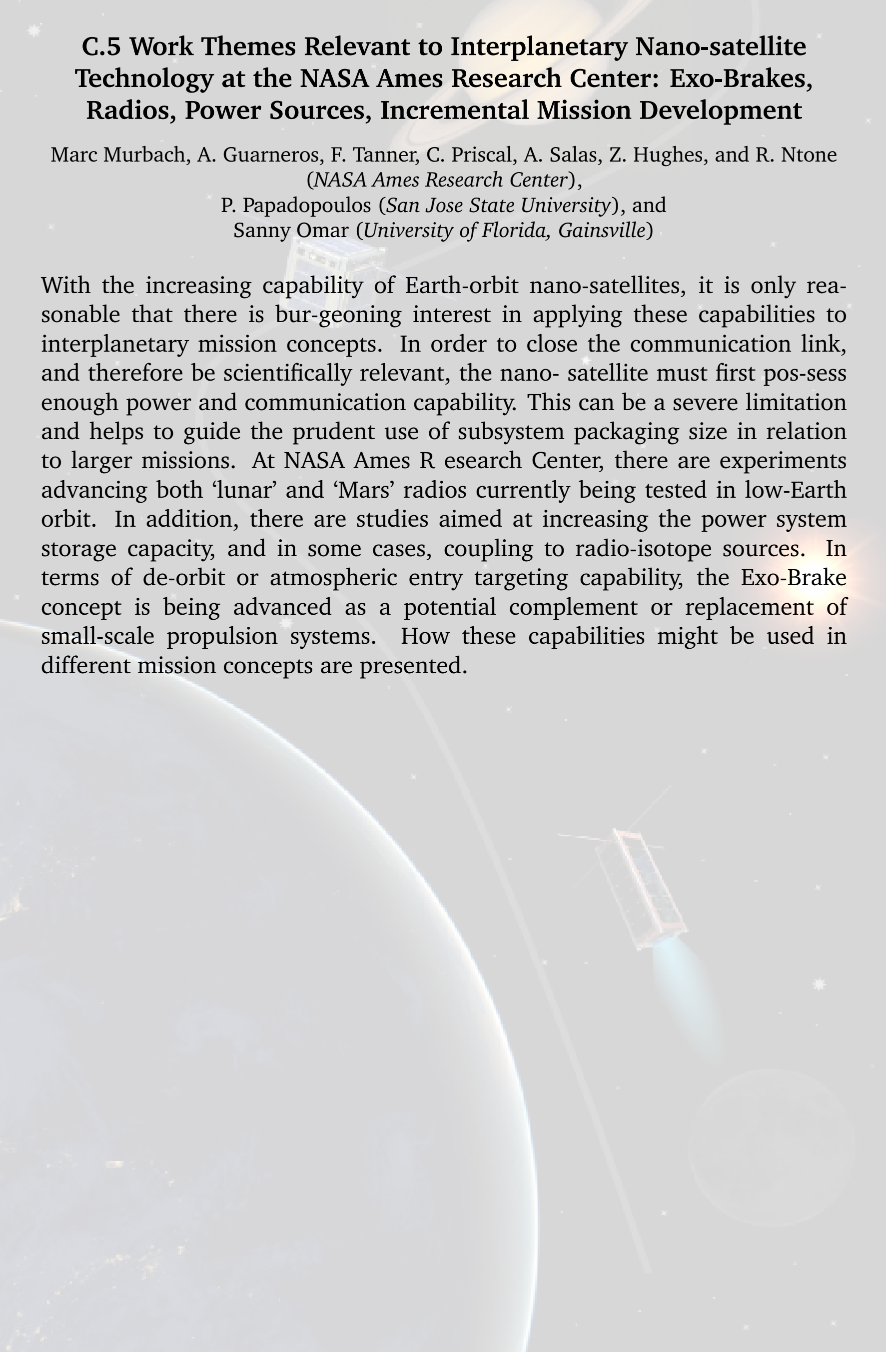
We propose the use of Bayesian networks to model uncertainties in the anchor surface and create a probabilistic model of where the radially arranged anchor spines will catch on a surface. A Bayesian network is a graphical probabilistic tool used to understand the structure of complex Bayesian processes with many random variables. This provides first- order estimates of the ”grippability” of a surface patch and can be integrated into future motion planning for evaluating or scoring potential grips. We then apply this refined ‘gripabbility’ model towards planning and navigation on rugged canyon walls, cliffs and crater rims. We identify the implication of the models on distributed robot design and identify pathways to optimize the design of climbing robots.

C.4 Low SWaP Radiation Sensor Development and Characterization at JPL

Wousik Kim and Insoo Jun
(*Jet Propulsion Laboratory, California Institute of Technology*)

JPL has studied and been developing a low Size, Weight, and Power, but flexible (in sensitivity and maximum range) space radiation monitoring systems which we plan to fly in future JPL's Earth and planetary science missions. A subset of Total Ionizing Dose (TID), Single Event Upset (SEU), UV, x-ray, internal charging, and surface charging sensors were considered as the sensor suite of a space monitoring system. The candidates of the each sensor and some design and calibration efforts will be presented.





C.5 Work Themes Relevant to Interplanetary Nano-satellite Technology at the NASA Ames Research Center: Exo-Brakes, Radios, Power Sources, Incremental Mission Development

Marc Murbach, A. Guarneros, F. Tanner, C. Priscal, A. Salas, Z. Hughes, and R. Ntone
(*NASA Ames Research Center*),
P. Papadopoulos (*San Jose State University*), and
Sanny Omar (*University of Florida, Gainsville*)

With the increasing capability of Earth-orbit nano-satellites, it is only reasonable that there is bur-geoning interest in applying these capabilities to interplanetary mission concepts. In order to close the communication link, and therefore be scientifically relevant, the nano- satellite must first pos-sess enough power and communication capability. This can be a severe limitation and helps to guide the prudent use of subsystem packaging size in relation to larger missions. At NASA Ames R esearch Center, there are experiments advancing both 'lunar' and 'Mars' radios currently being tested in low-Earth orbit. In addition, there are studies aimed at increasing the power system storage capacity, and in some cases, coupling to radio-isotope sources. In terms of de-orbit or atmospheric entry targeting capability, the Exo-Brake concept is being advanced as a potential complement or replacement of small-scale propulsion systems. How these capabilities might be used in different mission concepts are presented.

D.1 Evolving the Science/Engineering Partnership to Enable Lunar Surface Payloads

Pamela Clark, David Bugby, and Doug Hofmann
(*Jet Propulsion Laboratory, California Institute of Technology*)

Purpose: Credible opportunities for delivery of small payloads to the lunar surface via commercial landers are emerging. Characterization of the highly interactive lunar environment requires continuous operation. Due to the extreme lunar surface conditions (high radiation, 2-week <100 K night, 2-week up to 400 K day), radioisotopes have been required for either full day and night operation (Apollo Lunar Surface Experiment Package using RTGs) or day operation and night survival only (all others including Lunakhod, Yutu, proposed commercial designs using RHUs).

Background: The most challenging problem is creating low-cost, thermally isolating, generic, reconfigurable, and easy to integrate packaging for compact (cubesat-scale) packages without relatively costly radioisotopes to, at minimum, survive, and preferably operate on limited duty cycle, during lunar night. A Lunar Geophysical Network (LGN) study indicated a 400:1 thermal switching ratio is required for battery mass viability. Preliminary environmental modeling indicated that the availability of a reverse thermal switch (to maintain a thermal control box) with 1000:1 switching ratio, 10 times better than state of the art MER ratio of 100:1, would be required to allow cubesat-scale package (<20 kg, <2W during lunar night) to survive lunar night. Recently, Bugby and coworkers [1] have demonstrated the capability of a reverse thermal switch with a 2500:1 switching ratio.

Thermal Concept: Two prototypes of the crucial thermal switch components were designed, built, and tested. Their basis of operation is the mating/de-mating of parallel (near mirror finish) flat metal surfaces. The physical mechanism causing the motion is the DTE of mid-CTE, high thermal conductivity (k) metallic end-pieces compared to a low-CTE, low k two-piece metal/polymer support beam. The requirements of operation were to be fully ON above 300 K with 1335 N force and fully OFF below 260 K. Testing to raise the TRL of the switches to 6 has been completed. In addition to the thermal switches, Ball high performance MLI [2] and kevlar pulley packaging system, both of which have successfully flown in space, would provide even greater performance enhancement in thermal packaging.

Applications: Two instruments with very different requirements, including SILVIR, an imaging camera requir-ing a cryocooler and window, and a dual magnetometer (VHM and FGM) with external sensors on booms, provided the basis for requirements and thermal modeling of the generic package concept to confirm that all instrument com-ponents would remain within acceptable temperature limits. In principle, compact instruments ranging from spec-trometers to field/particle instruments could be accommodated.

D.2 CubeSat Deployment System Concept for Interplanetary Missions

Dave Pignatelli, Ryan Nugent, and Alicia Johnstone
(*Cal Poly, San Luis Obispo*)

Over the past decade, the number of CubeSat launches per year has grown significantly. As a result, CubeSat deployment systems have become refined and reliable systems for facilitating on-orbit deployment of CubeSats. For the most part, CubeSats only have to remain stowed while in space for a relatively short amount of time. However, following the success of the MarCO mission, it is clear that CubeSat payloads can be extremely valuable on interplanetary missions, to enhance or supplement a primary mission or carry out its own mission. For any mission requiring CubeSats to remain stowed for interplanetary transit times, additional CubeSat dispenser design considerations are required in order to ensure predictable and reliable deployment. In addition to the deployment requirements, a dispenser used for a deep space mission must be designed with requirements to ensure the CubeSat will survive interplanetary transit and reduce requirements of the primary payload which it will catch a ride on. Some of those considerations include: independent thermal control, provide an electrical interface between the CubeSat and an electrical source, facilitate health checks and battery charging, and communication to the ground. If these design considerations are addressed to create a standard interface between the CubeSat and primary payload, CubeSats on deep space interplanetary missions become a feasible option.

Most CubeSat deployment systems utilize some sort of mechanical spring to provide the ejection force upon deployment. A mechanical spring stowed for an extended duration can degrade, which can produce an uncertainty in deployment velocity. This long-term storage can also affect the reliability of dispenser components, increasing the risk of deployment issues. Regarding the CubeSats themselves: CubeSats must be kept within a safe temperature range to stay healthy, and they will need to be kept fully charged to be ready to complete their mission upon deployment. Ideally, a CubeSat dispenser on an interplanetary mission would be mounted to the primary spacecraft and would appear to be simply a 'black box' that requires nothing more from the primary beyond a power source. The dispenser would then need to be mostly autonomous.

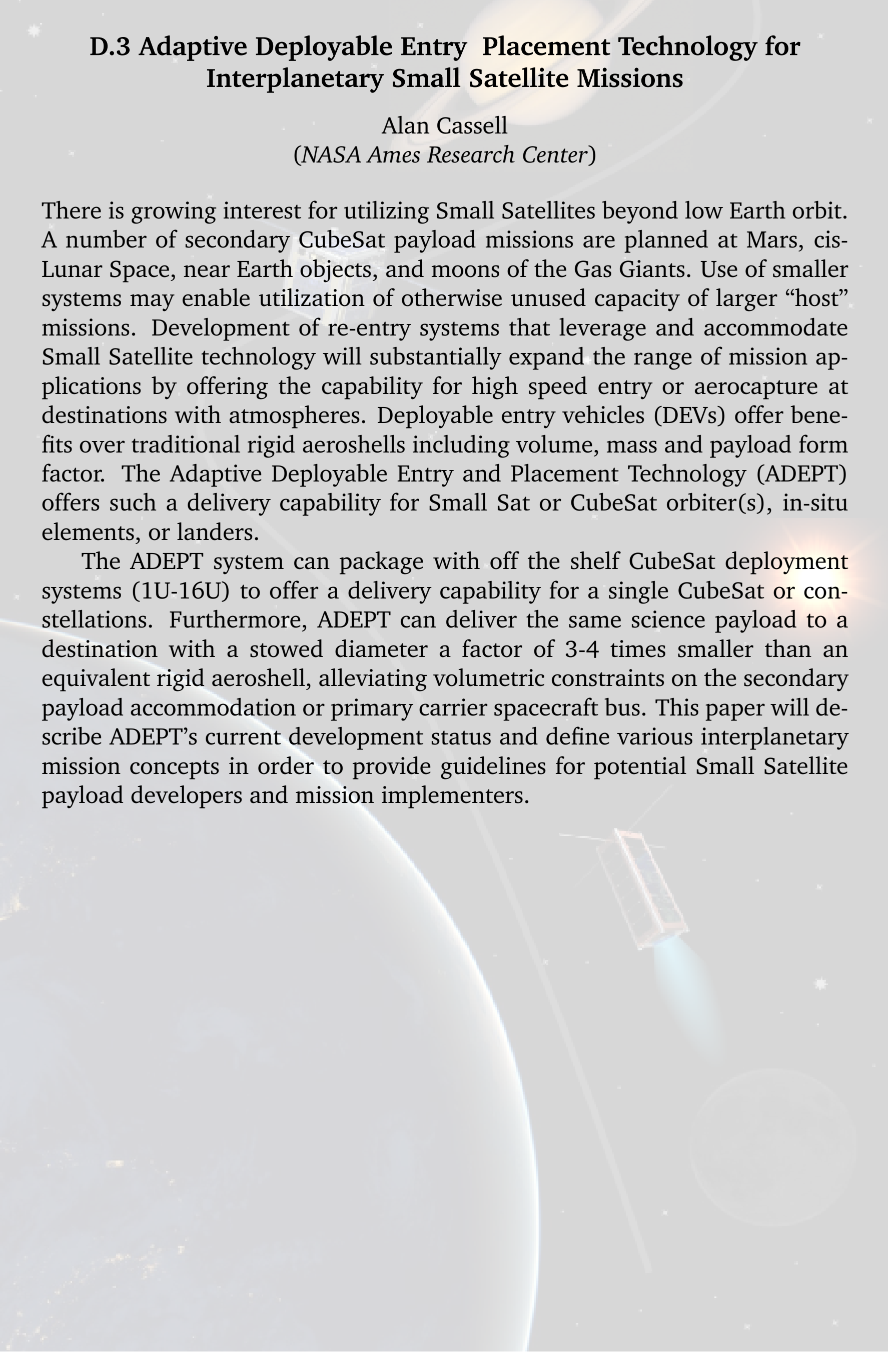
Cal Poly has developed a conceptual design and ConOps for a CubeSat dispenser that would be capable of completing a hypothetical interplanetary mission, which solves some of the concerns associated with CubeSat dispensers on deep space missions. Bringing this design to flight readiness creates significant opportunities to gain science from interplanetary missions through the use of secondary CubeSat payloads.

D.3 Adaptive Deployable Entry Placement Technology for Interplanetary Small Satellite Missions

Alan Cassell
(*NASA Ames Research Center*)

There is growing interest for utilizing Small Satellites beyond low Earth orbit. A number of secondary CubeSat payload missions are planned at Mars, cis-Lunar Space, near Earth objects, and moons of the Gas Giants. Use of smaller systems may enable utilization of otherwise unused capacity of larger “host” missions. Development of re-entry systems that leverage and accommodate Small Satellite technology will substantially expand the range of mission applications by offering the capability for high speed entry or aerocapture at destinations with atmospheres. Deployable entry vehicles (DEVs) offer benefits over traditional rigid aeroshells including volume, mass and payload form factor. The Adaptive Deployable Entry and Placement Technology (ADEPT) offers such a delivery capability for Small Sat or CubeSat orbiter(s), in-situ elements, or landers.

The ADEPT system can package with off the shelf CubeSat deployment systems (1U-16U) to offer a delivery capability for a single CubeSat or constellations. Furthermore, ADEPT can deliver the same science payload to a destination with a stowed diameter a factor of 3-4 times smaller than an equivalent rigid aeroshell, alleviating volumetric constraints on the secondary payload accommodation or primary carrier spacecraft bus. This paper will describe ADEPT’s current development status and define various interplanetary mission concepts in order to provide guidelines for potential Small Satellite payload developers and mission implementers.



D.4 CubeSat based Micro-Rovers and Micro-Landers

Rachel A. Moses, Aman Chandra, and Jekan Thangavelautham
(*University of Arizona*)

The miniaturization of electronics, sensors and actuators, and wide-availability of high-reliability COTS components has made the small satellite revolution possible. In addition, the CubeSat approach has provided standard that has enabled a commercial marketplace of modular components. Utilizing these low-cost technologies it is possible to conceive short, low-cost, high-risk, high-reward missions. To date, CubeSats have been proposed as Earth-orbiting and planetary spacecraft on flyby missions. A few have been proposed for orbital missions. The technology has the potential for further applications including as planetary rovers and landers.

Our present work focuses on CubeSat based landers and micro- rovers meant to explore extreme environments. Micro-rovers can explore and search smaller areas for traces of water and life. With a generic micro-rover design, scalable to each CubeSat size, any investor could utilize the advantages of both a low-cost CubeSat lander and a micro-rover for surface exploration. We present designs that can be packaged into CubeSat form factors making them suitable as payloads on board satellites of sizes 6U and above. The generic architecture has been developed that is scalable to structures of increasing sizes. Emphasis has been made on the reduction of mechanical complexity and ease of deployment. We present preliminary analysis of expected structural behavior in these environments. Software such as SolidWorks and ANSYS are used to perform analysis concentrated on aspects such as stability, volume efficiency, and payload mass of the micro-rover. Our analysis points towards the feasibility of such systems being deployed in large numbers on planetary surfaces while conforming to CubeSat design specifications. The results of our present work will contribute insight into the formation of a structurally dependable and scalable micro-rover and micro-lander designs.

D.5 LUNET Platform concept: bootstrapping lunar mission services

Dr Laura Mullin
(*LUNET Mission Services*)

New opportunities for lunar science and exploration are opening up. National space agencies are expanding exploration programs, while commercial lunar ride shares are soon to start operating. CubeSat applications are beginning to extend to interplanetary missions, greatly expanding the potential for lower cost missions from a wider range of participants. It has long been recognized that in situ exploration infrastructure has the potential to reduce costs further.

While aspects of communications, data handling and navigation support are already technically feasible, implementation costs have always to be justified by the expected return. The need for high upfront investment has been and continues to be a barrier to advancing infrastructure development. To address this, the LUNET platform concept proposes a bootstrapping approach. It comprises a scalable CubeSat constellation in lunar orbit that can support lunar missions with adjunct and auxiliary data services, on a primary, augmentation or contingency basis. To achieve economic feasibility, these CubeSats utilize high TRL subsystems and commercial lunar ride-share services; the platform capacity and capability can be scaled incrementally with the additional of new modules in due time.

The 1st generation core modules are 3U. Taking this as the default LUNET system module size does circumscribe the potential capabilities of the individual modules. However, system capacity can be built up using distributed space system (DSS) architectures. A modular DSS approach builds capacity by deploying numbers of identical 3U modules; a fractionated DSS approach builds capability by using variants of 3U modules that when combined provide the desired functionality. Furthermore, the LUNET platform can and will be made to be interoperable with other infrastructure systems in the lunar environment, mutually augmenting capabilities on both sides and providing each with contingency options.

LUNET Mission Services Ltd is a project vehicle established in the UK to carry out the LUNET project. This presentation will describe the concept of operations, the top-level system overview, and program status and plans.

E.1 Mars Areostationary Trace Gas Localizer

Nirmal Patel, Vishnu Saravanan, Ryan Whitney, James Apfel, James Cooney, Shawn Lu,
Taylor Morton, Sotirios Dedes, Paul Knudson, and Abhiram Krishnan
(*University of Michigan*)

Previous expeditions to Mars have successfully measured background levels and small spikes of methane, but none have been able to localize any sources or sinks. Localization of methane detections would contribute towards addressing questions about potential current Martian life and disprove any notions that previous methane observations were errors. This would help discriminate between biological and abiotic methane formation hypotheses as methane can be linked to microbial activity and geochemical/geophysical processes.

Our proposed Mars Areostationary Trace Gas Localizer (ATGL) mission aims to identify and track methane plumes over 3 Martian years, with a spacecraft cost under $300M. Located in an areostationary orbit, ATGL's ultra-high miniaturized spectrometer would be capable of capturing methane variations in a predetermined area with multiple degrees of fidelity: a coarse observation mode for large scale localization and fine observation mode for Regions of Interest (ROIs). With a nominal on-orbit mass of 300 kg, the spacecraft is a low-mass, low-cost system to answer an important question.

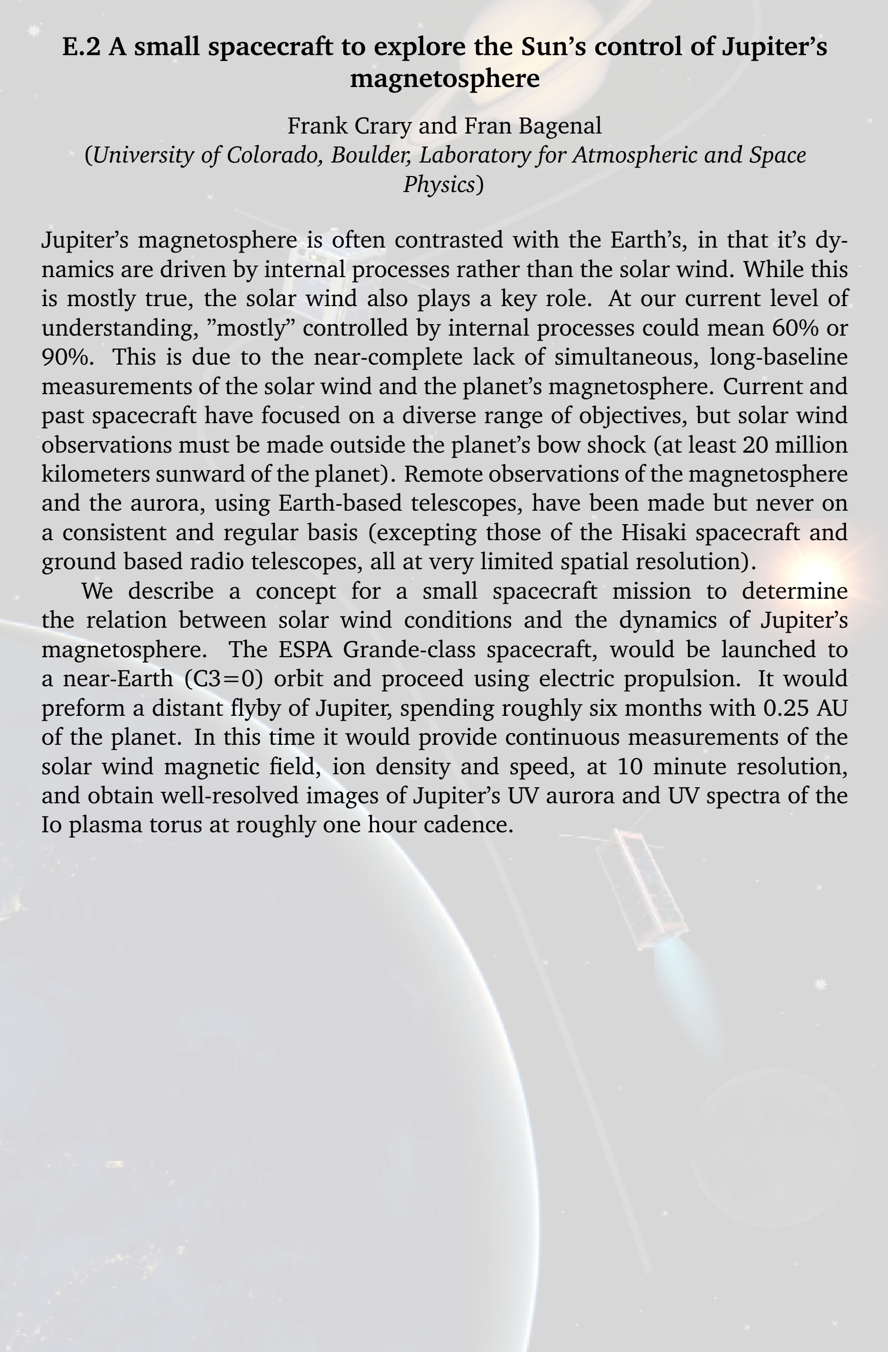
Proposed to launch on an Atlas V in 2024, ATGL could be integrated as a secondary payload on an ESPA Grande platform. This levied some difficulties with the integration of a complex system but these were addressed via extensive analysis in mechanical, power, propulsion, command and data handling, and thermal systems. For example, with AGI's Systems Tool Kit, we have designed a propulsion system using a configuration of RIT 10 EVO electric propulsion thrusters for delivering the satellite from a geostationary transfer orbit to an areostationary orbit. A spacecraft bus has been designed to fit its subsystems within its volume constraints (0.85m × 0.94m × 0.77m) while delivering enough power to the spacecraft via deployable solar panels. Further, a communications architecture using 0.78m X-Band antenna has been chosen for direct-to-Earth communication capabilities. This design has the potential to lead to small robust satellites that enable a focused, yet compelling set of science goals aligned with high-priority questions in planetary sciences.

E.2 A small spacecraft to explore the Sun's control of Jupiter's magnetosphere

Frank Crary and Fran Bagenal
(*University of Colorado, Boulder, Laboratory for Atmospheric and Space Physics*)

Jupiter's magnetosphere is often contrasted with the Earth's, in that it's dynamics are driven by internal processes rather than the solar wind. While this is mostly true, the solar wind also plays a key role. At our current level of understanding, "mostly" controlled by internal processes could mean 60% or 90%. This is due to the near-complete lack of simultaneous, long-baseline measurements of the solar wind and the planet's magnetosphere. Current and past spacecraft have focused on a diverse range of objectives, but solar wind observations must be made outside the planet's bow shock (at least 20 million kilometers sunward of the planet). Remote observations of the magnetosphere and the aurora, using Earth-based telescopes, have been made but never on a consistent and regular basis (excepting those of the Hisaki spacecraft and ground based radio telescopes, all at very limited spatial resolution).

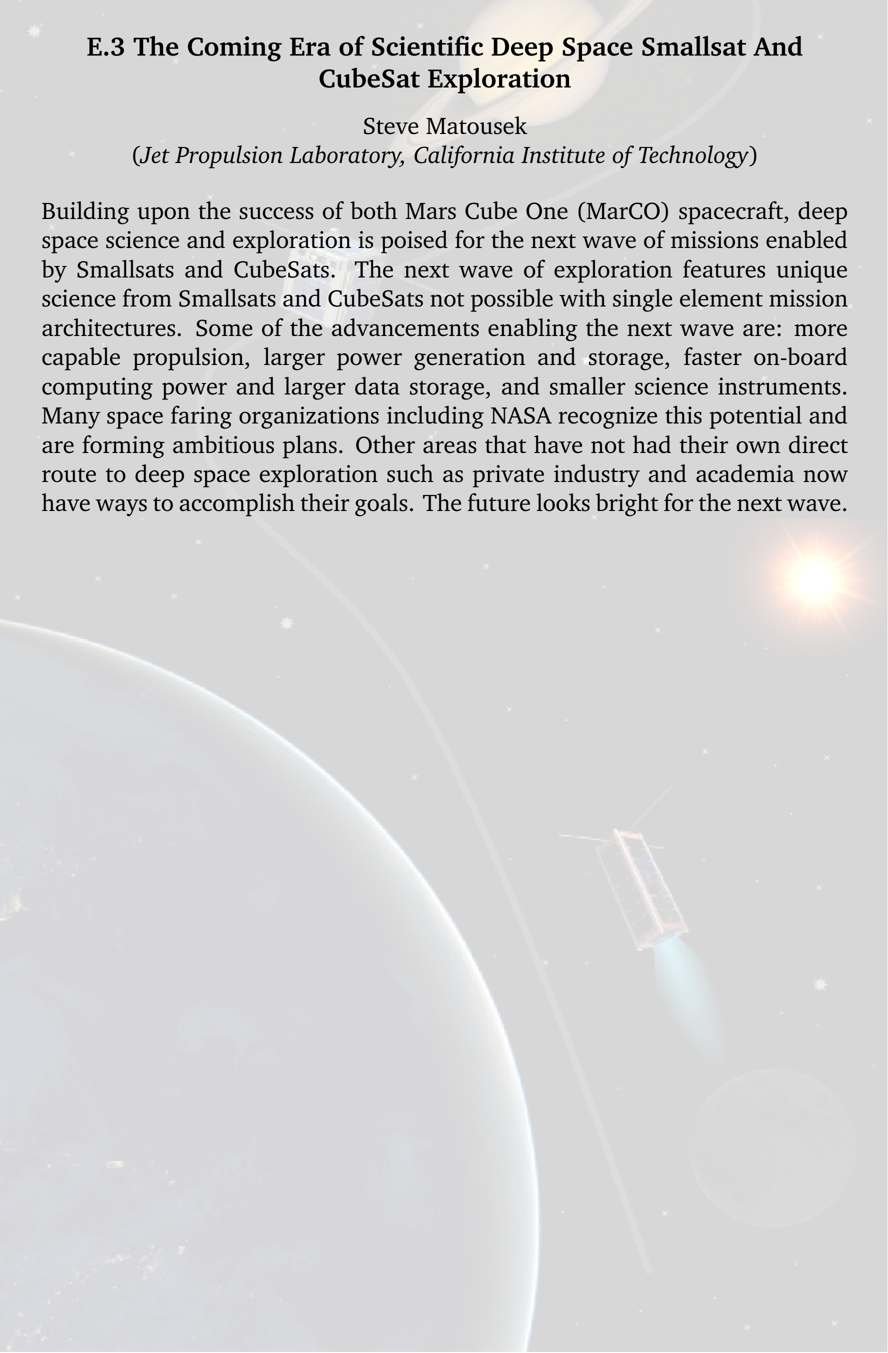
We describe a concept for a small spacecraft mission to determine the relation between solar wind conditions and the dynamics of Jupiter's magnetosphere. The ESPA Grande-class spacecraft, would be launched to a near-Earth (C3=0) orbit and proceed using electric propulsion. It would preform a distant flyby of Jupiter, spending roughly six months with 0.25 AU of the planet. In this time it would provide continuous measurements of the solar wind magnetic field, ion density and speed, at 10 minute resolution, and obtain well-resolved images of Jupiter's UV aurora and UV spectra of the Io plasma torus at roughly one hour cadence.



E.3 The Coming Era of Scientific Deep Space Smallsat And CubeSat Exploration

Steve Matousek
(*Jet Propulsion Laboratory, California Institute of Technology*)

Building upon the success of both Mars Cube One (MarCO) spacecraft, deep space science and exploration is poised for the next wave of missions enabled by Smallsats and CubeSats. The next wave of exploration features unique science from Smallsats and CubeSats not possible with single element mission architectures. Some of the advancements enabling the next wave are: more capable propulsion, larger power generation and storage, faster on-board computing power and larger data storage, and smaller science instruments. Many space faring organizations including NASA recognize this potential and are forming ambitious plans. Other areas that have not had their own direct route to deep space exploration such as private industry and academia now have ways to accomplish their goals. The future looks bright for the next wave.



E.4 Towards Development and Testing of an Engineering Model for an Asteroid Hopping Robot

Gregory Wilburn, Erik Asphaug, and Jekan Thangavelautham
(*University of Arizona - LPL and SpaceTREx*)

The science and origins of asteroids is deemed high priority in the Planetary Science Decadal Survey. Two of the main questions from the Decadal Survey pertain to what the “initial stages, conditions, and processes of solar system formation and the nature of the interstellar matter” that was present in the protoplanetary disk, as well as determining the “primordial sources for organic matter.” Major scientific goals for the study of planetesimals are to decipher geological processes in SSSBs not determinable from investigation via in situ experimentation, and to understand how planetesimals contribute to the formation of planets. Ground based observations are not sufficient to examine SSSBs, as they are only able to measure what is on the surface of the body; however, in situ analysis allows for further, close up investigation as to the surface characteristics and the inner composure of the body.

The Asteroid Mobile Imager and Geologic Observer (AMIGO) is a 1U stowed autonomous robot that can perform surface hopping on an asteroid with an inflatable structure. It contains science instruments to provide stereo context imaging, micro-imaging, seismic sensing, and electric field measurements. Multiple hopping robots are deployed as a team to eliminate single-point failure and add robustness to data collection. An on-board attitude control system consists of a MEMS thrusters-on-a-chip which contains discretized micro-nozzles that provides hopping thrust and on-board micro-reaction wheels for controlling the third axis.

For the continued development of the robot, here we present plans to design and build an engineering model of AMIGO and test critical control algorithms. Three enabling technologies for the mission will be tested. One of the primary components is the inflatable structure that enables context imaging, communication with a mother spacecraft, and solar collection. The other two components tests are for a small reaction wheel system and the MEMS thruster assembly. The inflatable, once properly deployed, is filled with helium to provide a buoyant force simulating micro-gravity conditions and the attitude control system is tested. One algorithm to be tested is organized motion planning to efficiently explore the surface of a simulated asteroid. To enable this path planning, the stereo camera must provide context imaging and the system autonomously determines a point of interest to hop to.

E.5 On-Orbit Centrifuge Laboratories for Simulating Low-Gravity Surface Environments

Stephen Schwartz, Erik Asphaug, and Jekan Thangavelautham
(*University of Arizona - LPL and SpaceTREx*)

In the next 35 years, we aspire to be on our way to sending human and robotic explorers to every corner of our solar system to perform orbital, surface and even subsurface exploration. These explorers will pave the way towards cataloging the diverse surface environments, physical processes and structure of the planets and small bodies answering fundamental questions about the origins of the solar system, conditions to sustain life and prospects for resource utilization and off-world human settlement. Achieving this major exploration milestone remains technologically daunting but not impossible.

One of the major challenges has been understanding the impact of low-gravity on planetary surface physics. This impacts surface regolith properties, including strength, angle of repose, cohesion. These factors impact the design, control and operation of landers and rovers that need to traverse this environment. On asteroids, the additional challenge is the changing local gravity vector and escape velocity. To address these challenges we have proposed the development of on-orbit centrifuge laboratories that spin producing a centripetal force and thus generate artificial gravity. Inside these laboratories, we carry materials representative of an asteroid surface such as crushed meteorites. To demonstrate this technology we have designed the AOSAT 1 mission consisting of a 3U CubeSat, the size of a loaf of bread. The CubeSat would spin at 1 RPM to simulate gravity of an asteroid up to 2 km in diameter. As a follow-up to AOSAT 1, we have proposed AOSAT+ consisting of a larger 12U CubeSat that utilizes standard TRL-9 CubeSat components and a custom designed science chamber to simulate crater formation, use of instruments, surface mobility techniques and analyze regolith properties.

Beyond, AOSAT+ we believe a series of large, permanent low-gravity centrifuge laboratories are needed to simulate the low-gravity of asteroids and other planetary bodies. Potential options include reuse of the Cygnus and Dream Chaser vehicles as on-orbit centrifuge labs. In this work, we will evaluate the initial feasibility of this approach. By letting us have persistent access to simulated versions of these off-world environments, these laboratories will allow us to forecast and avoid surprises in-situ, and to increase confidence and support for such ambitious exploration endeavors. Such laboratories are expected to be lower cost to maintain than program to these off-world targets and hence can be better sustained in changing political and financial conditions.

E.6 Scalable Mother-Daughter Architectures for Asteroid Belt Exploration

Leonard Dean Vance, Erik Asphaug, and Jekan Thangavelautham
(*University of Arizona - LPL and SpaceTREx*)

There is an estimated 2 million small-bodies in the solar system. Exploring these small-bodies will be the next frontier in solar-system exploration. Understanding the origins, the evolution and composition of these asteroids will give insight into the origins of the solar-system, origins of Earth and organic matter. However, many of the small-bodies are only tens to hundreds of meters in size and are scattered between Mars and Jupiter, near Earth and in the Kuiper Belt.

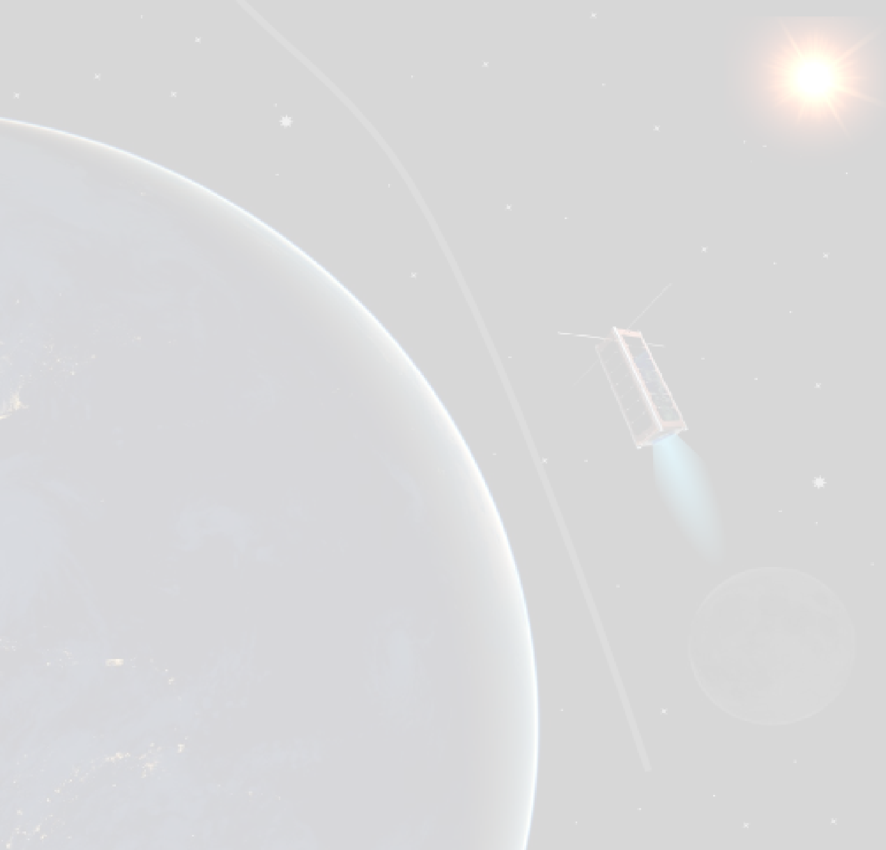
Sending a dedicated mission to each of these asteroids is not logistically feasible at this time. Instead what is required is a scalable architecture to perform asteroid tours. In this work we focus on the main asteroid belt. We examine the effectiveness of an asteroid exploration architecture comprised of multiple nanosat-sized spacecraft deployed from a single mother ship into a heliocentric orbit in the main asteroid belt where the mothership is ideally located in region of high density of asteroids. The architecture opens the possibility of scaling the size of a spacecraft towards immediate science needs on a mission. When the mothership flybys an asteroid of interest, it can choose to deploy a nanosat to get a closer look, obtain samples or perform impact studies. Basic mission requirements associated with a Mother-Daughter architecture are established utilizing a relatively large number (10-20) daughter spacecraft distributed from a mothership within the asteroid belt for the purpose of executing sample and return missions.

A number of trade analyses are performed to establish system performance to changes in initial orbit, delta-v capability and maximum small spacecraft flight time. The balance between the initial delta-v burn and asteroid velocity matching are also examined, with a goal of minimizing the amount of fuel needed in the small spacecraft. Preliminary requirements for the system are established using these results, and a conceptual design is presented for comparison to other asteroid exploration techniques. Preliminary results indicate that the presented concept of a mothership with small spacecraft is viable and should be considered as an alternative approach to first order surveying of the asteroid belt.

F.1 Iris at Mars: First Use of Iris Deep Space Transponder to Support MarCO Relay Mission

Sarah Holmes, M. Michael Kobayashi, and Mazen Shihabi
(*Jet Propulsion Laboratory, California Institute of Technology*)

In 2015, the Jet Propulsion Laboratory developed the second version of the Iris Deep-Space Transponder to be used on the Mars Cube One (MarCO) mission. Iris is a software-defined radio (SDR) which interoperates with NASA's Deep Space Network (DSN) on X-Band frequencies (7.2 GHz uplink, 8.4 GHz downlink) while in a package size designed for CubeSats. For MarCO, it successfully performed bent-pipe relay direct to Earth during entry, descent, and landing (EDL) of the InSight lander, including InSight's first image from the surface of Mars. This talk will discuss the development of Iris for the MarCO mission, including key features and requirements, as well as the testing and behavior of Iris during MarCO's cruise and on EDL day.



F.2 Iris Deep Space Transponder Testing at Space Dynamics Laboratory, Jet Propulsion Laboratory, and DSN Test Facility (DTF)-21

Krisjani Angkasa, Alessandra Babuscia, Lauren McNally, Brandon Burgett, and James Lux
(*Jet Propulsion Laboratory, California Institute of Technology*)

Thirteen deep-space CubeSats have been selected as secondary payloads on the Space Launch System (SLS) Exploration Mission (EM)-1 launch of the Orion spacecraft. Six of these CubeSats - Lunar Polar Hydrogen Mapper (LunaH-Map), Lunar IceCube, Lunar Flashlight, CubeSat for Solar Particles (CuSP), Near-Earth Asteroid Scout (NEA Scout), and BioSentinel - have baselined the Iris deep space transponder as the main telecommunications and navigation radio for their missions. These CubeSats have unique science goals, ranging from mapping the presence of water on the moon, to exploring the effects of deep-space radiation on the biology of yeast. As such, missions have exploited the flexible architecture of the Iris radio in order to meet their specific telecom requirements (e.g. higher data rates for lunar missions versus heliocentric missions, use of turn-around ranging as opposed to the delta-differential one-way ranging (DDOR), etcetera). This paper shows the different Iris testing, conducted at the various test facilities i.e. vendor-specific testing at the Space Dynamic Laboratory (SDL), mission-specific testing at the Jet Propulsion Laboratory (JPL), and RF compatibility testing at the DSN Test Facility (DTF)-21

F.3 Implementation of Modular Electro-Mechanical Model to Detect Antenna Deployment

Archit Srivastava and Nishant Agarwal

On account of lesser availability of such detection mechanisms, the chances of complete failure of satellites increases. Employing mechanisms like these ensures fool proof transmission and reception of signals. A deployment detection mechanism using a circuit in the form of modules placed on an antenna has been analysed. The installed modules will send a signal once full deployment is observed. Simulation software such as High Frequency Structure Simulator (HFSS) a commercial finite element method solver for electromagnetic structures from ANSYS is used to simulate the deployment mechanism and get the desired results. This can be used in RVSAT-1, a 2U nanosatellite hosting a biological payload for experimentation in space. The described model can also be employed to nanosatellites designed for interplanetary missions, as the accuracy of this mechanism will help gain crucial information regarding antenna deployment, which will assure the certainty of such missions which is necessary, because of it's complexity and also it reduces the probability of failure. The mechanism described in the paper also has a significant advantage over many of the present detection models because of the accuracy of deployment detection and its simplicity relative to present different detection models. The need of a proper deployment detection system is to remove the ambiguity, within the grey period after de-tumbling and to ensure full antenna deployment before the first communication link is established. The paper emphasizes more on the model being applied for a 180-degree deployment of tape antennas being used by the Telemetry Tracking and Command (TT&C) subsystem of RVSAT-1.

G.1 Direct Thrust Measurements and In-orbit Demonstration of the IFM Nano Thruster

David Krejci, Tony Schönherre, and Alexander Reissner
(*Enpulsion*)

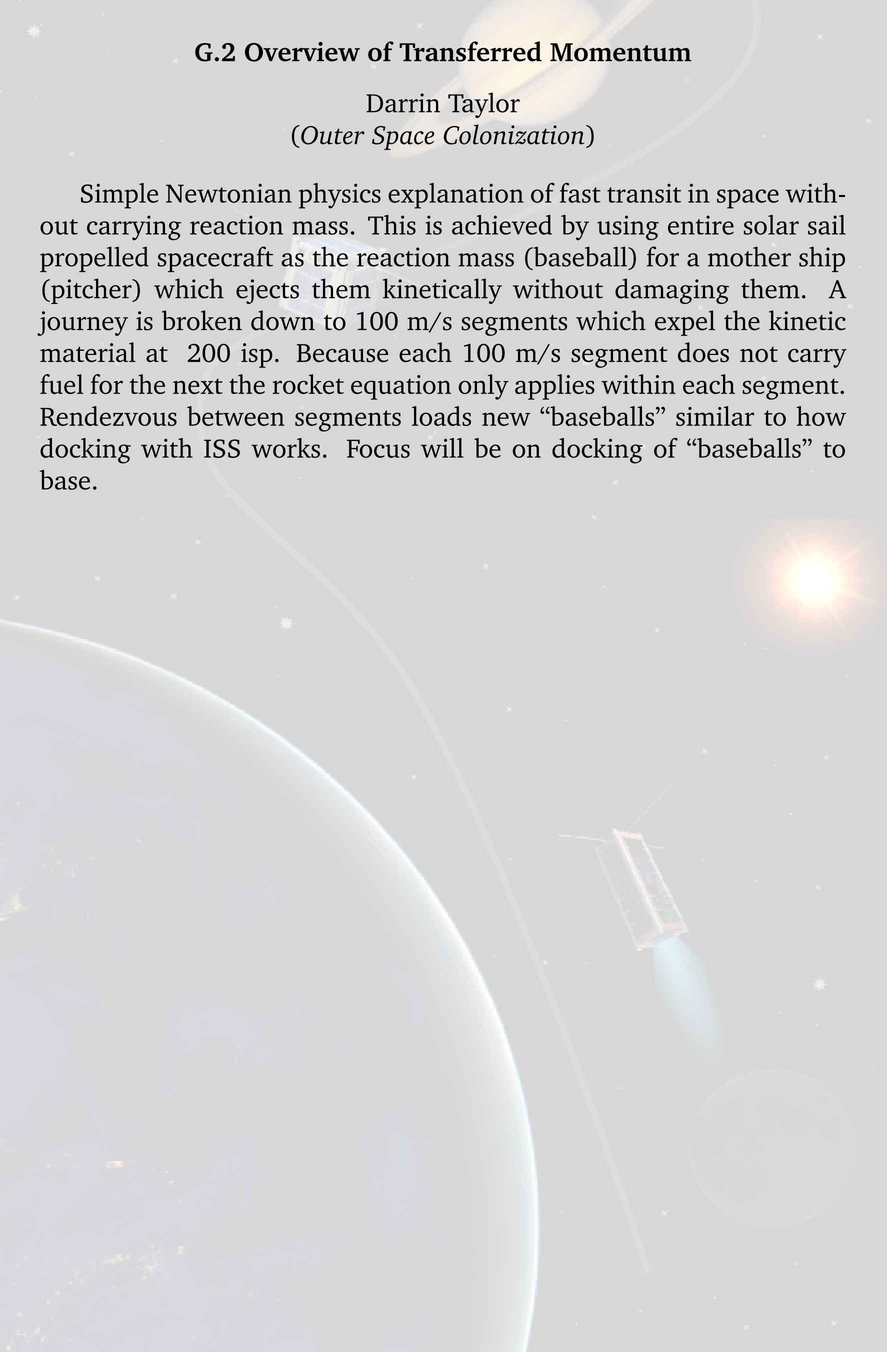
The IFM Nano Thruster is a high delta V propulsion system that demonstrated in space a Planet Dove 3U Cubesat in early 2018, and is currently in orbit on multiple customer spacecrafts providing different sets of capabilities, including orbit raising, constellation flight control, attitude control and momentum wheel dumping. The thruster is a liquid metal propulsion system in which Indium is ionized and accelerated to produce thrust using electrostatic potentials. A passively fed, porous ion emitter consisting of 28 sharp emitter tips is used as ion source to multiplex thrust. The Indium propellant is a safe and inert metal which remains in solid state during assembly, integration and launch, and is only liquified once in orbit. Using differential biasing of the emitter and extractor potentials, the IFM Nano Thruster is capable of operating over a wide range of specific impulse from 2000s to 6000s and beyond. At a total input power of 40W, including heater for propellant liquefication and neutralization to maintain spacecraft charge, the IFM Nano Thruster can provide up to 350μN.

This work presents a summary of the in-orbit commissioning phase and direct thrust measurements conducted at ESA ESTEC Space Propulsion Laboratory.

G.2 Overview of Transferred Momentum

Darrin Taylor
(*Outer Space Colonization*)

Simple Newtonian physics explanation of fast transit in space without carrying reaction mass. This is achieved by using entire solar sail propelled spacecraft as the reaction mass (baseball) for a mother ship (pitcher) which ejects them kinetically without damaging them. A journey is broken down to 100 m/s segments which expel the kinetic material at 200 isp. Because each 100 m/s segment does not carry fuel for the next the rocket equation only applies within each segment. Rendezvous between segments loads new “baseballs” similar to how docking with ISS works. Focus will be on docking of “baseballs” to base.



G.3 Interorbital Systems: Launch Services to LEO, Luna, and Beyond

Randa Relich Milliron
(*Interorbital Systems*)

The expense of buying passage for a small satellite payload is often more than a small business or an academic institution can afford, and usually more than a government or military entity would like to spend. Waiting for an opportunity to launch as a secondary payload is often a frustrating, if not endless process. Global competitions among hundreds of student satellite projects for these rare flights leave all but the one or two lucky winners without a ride to orbit. An inexpensive, dedicated launcher; an assortment of affordable small satellite kits; and low-cost, rapid-response launch services are urgently needed to create and carry small experimental, academic, government, art, and military payloads to orbit. Interorbital Systems' (IOS) NEPTUNE modular rocket series: N1; N3; N5; and N8 LUNA; and IOS' Personal Satellite Kits will fill those needs.

After a decade of RD, the NEPTUNE 1 (N1) is undergoing its final suborbital flight tests in preparation for two orbital flights as part of the DARPA Launch Challenge. The N1 is designed to launch a 20-kg small-sat payload(s) to LEO for under $1 million. Interorbital's orbital launch manifest now numbers 157 picosats. Orbital launch services are set to begin in Q1, 2020, followed by a 2021 Moon impactor mission, Lunar Bullet, with Ed Belbruno's Innovative Orbital Design.

A 2019 suborbital launch of the NEPTUNE CPM 2.0 will test IOS' guidance and control systems and provide a platform for flight-testing significant science applications and breakthrough technologies like the Wayfinder II, a 3U CubeSat and hosted–payload platform designed and integrated by Boreal Space, NASA Ames Research Park. It carries a mission called SHRINE.

SHRINE stands for the Stanford, Hakuto, Raymix, Inventor, NUS Experiment. Five separate organizations provided payloads for integration into the Wayfinder spacecraft bus. The Extreme Environments Lab at Stanford University supplied a Gallium-Nitride-based magnetic-field instrumentation payload. Japan's Team Hakuto (now iSpace), provided a robotics experiment to validate their hardware and software assembly. The National University of Singapore contributed a materials experiment to research potential changes to a graphene sample when subjected to launch loads. Space Inventor of Aalborg, Denmark supplied their SpaceLink UHF radios for which they seek TRL advancement. Finally, the popular Latin American artist Raymix contributed a musical piece for downlink from the SpaceLink radios. This launch's flight data will complement payload performance data, allowing participating teams to iterate and improve designs, and raise Technology Readiness Level (TRL) for future missions.

G.4 Aeroassist Technologies for Small Satellite Missions

Alan Cassell (*NASA Ames Research Center*) and
Alicia M. Dwyer-Cianciolo (*NASA Langley Research Center*)

Orbit insertion operations that require large ΔV maneuvers using conventional propulsive technologies are mass inefficient and challenging to package within SmallSat form factors such as the popular CubeSat. Aeroassist technologies offer an alternative approach for ΔV maneuvers and could revolutionize the use of SmallSats for exploration missions and increase the science return while reducing costs for orbital or entry missions to Mars, Venus and return to Earth. Aeroassist refers to the use of an atmosphere to accomplish a transportation system function using techniques such as aerobraking, aerocapture, aeroentry, and aerogravity assist. Aeroassist technologies are power efficient and tolerant to the radiation and thermal environment encountered in deep space, and can be integrated around or within SmallSat geometries. This presentation will discuss various Aeroassist technologies including conventional rigid aeroshells, inflatable decelerators, mechanically deployable decelerators and other drag devices and control methods that should be considered by Small Satellite mission design teams.

9. Social Program

Dinner Reception (April 29th)
Dinner is included in the cost of registration for all conference attendees at 6:40 pm on Monday, April 29th located in Bldg 5, room 105 (see page 16 for map). Meals can also be purchased for guests of attendees. All participants are encouraged to attend!

Acknowledgments

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- California Polytechnic State University for hosting this year's conference
- Small Spacecraft Systems Virtual Institute for their co-sponsorship
- Jet Propulsion Laboratory/California Institute of Technology staff for their technical and logistical support

We offer a special thanks to our speakers, exhibitors, and sponsors who make this conference a success year after year.

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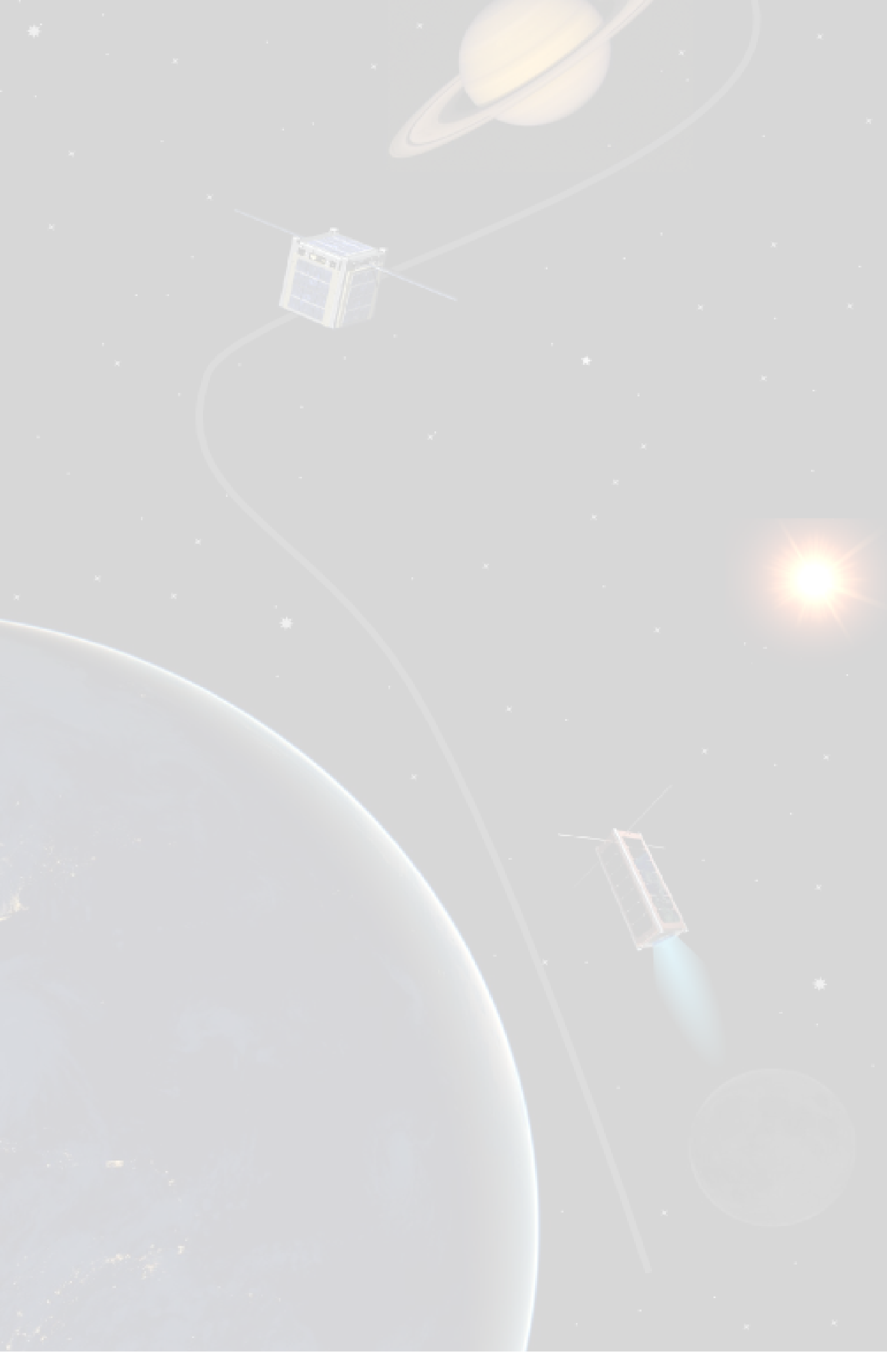

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