Small is Beautiful

Technology trends in the small satellite industry and their implications for Planetary Science missions

Tony Freeman, JPL

Feb 2017

Jet Propulsion Laboratory, California Institute of Technology

PSD Vision 2050 Workshop, Washington, DC 2017

PSD Vision 2050 Workshop, Washington, DC 2017

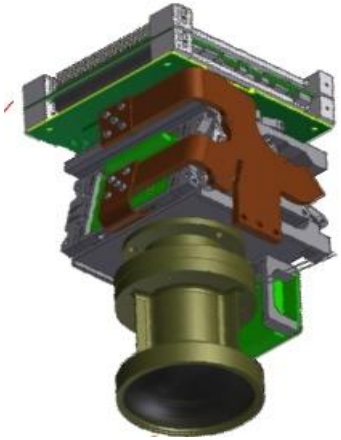
SMALL IS BEAUTIFUL

Cubesats were ‘toys’ 18 years ago…

Small is Beautiful

Science Instrument Examples (1U = 1 liter)

HARP Imaging Polarimeter(3U)

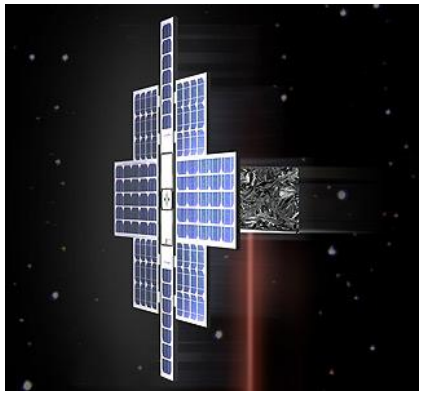


UMBC/SDL (2017)

RainCube radar (6U)

JPL (2017)

Lunar Flashlight (6U)
NIR laser



MSFC/JPL (2017)

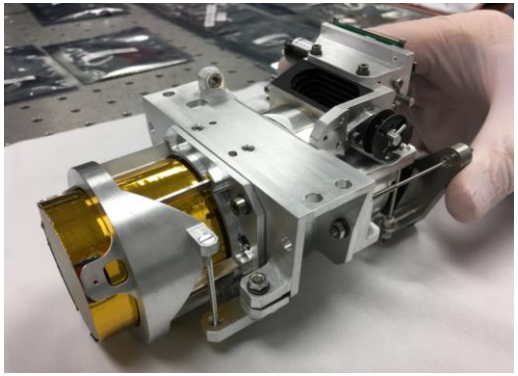
Mass Spectrometer (3U)

JPL (TBD)

LunarIceCube (6U)
IR spectrometer

GSFC (2018)

VSWIR-Dyson (2U)
spectrometer



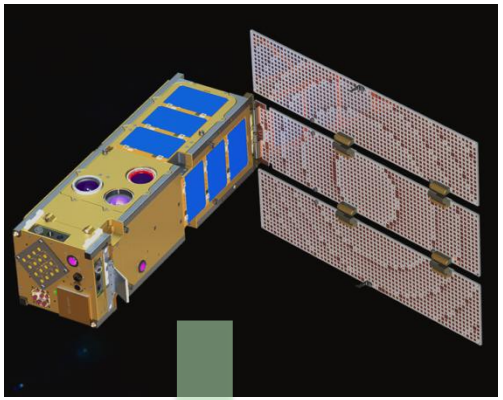
JPL (TBD)

Small is Beautiful

Telecom

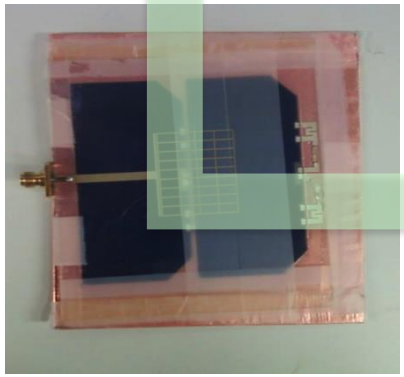
RF

ISARA
Reflectarray/Solar Array



JPL (2017)

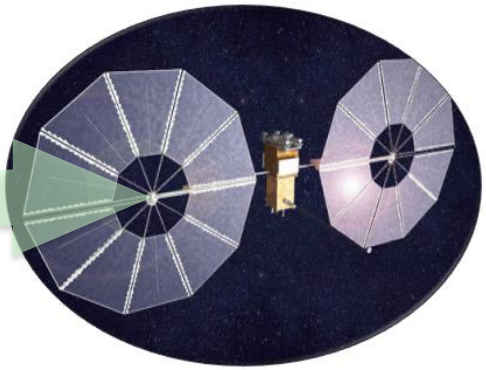
Optically Transparent/
RF Reflective Coatings



Utah State (TBD)

- RF Reflectarrays can scale to larger antennas
- Active and passive Optical Comm
- Optically transparent/RF reflective coatings printed on large solar arrays on deep space missions

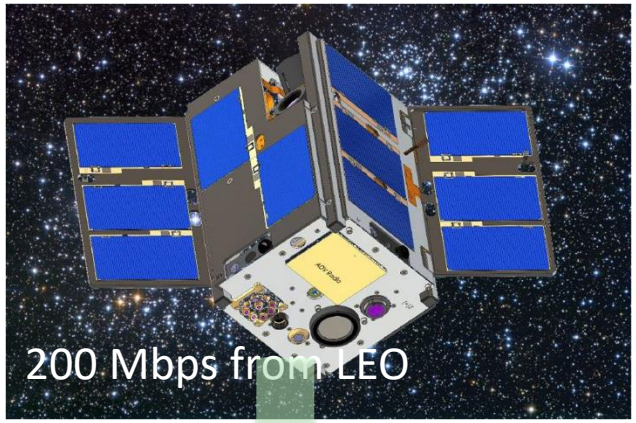
Dual-use Solar arrays



(TBD)

Optical

Cubesat Optical Comm Demo



Aerospace (2016/7)

Bridgesat Optical Comm Terminal

Bridgesat (TBD)

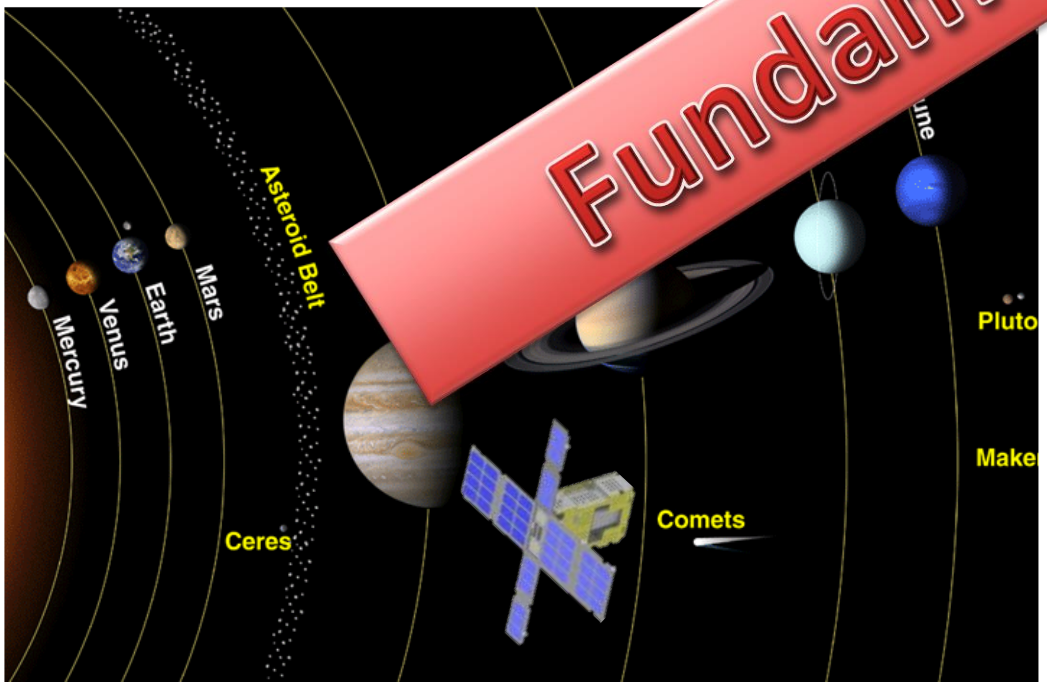
Small is Beautiful

Power Systems

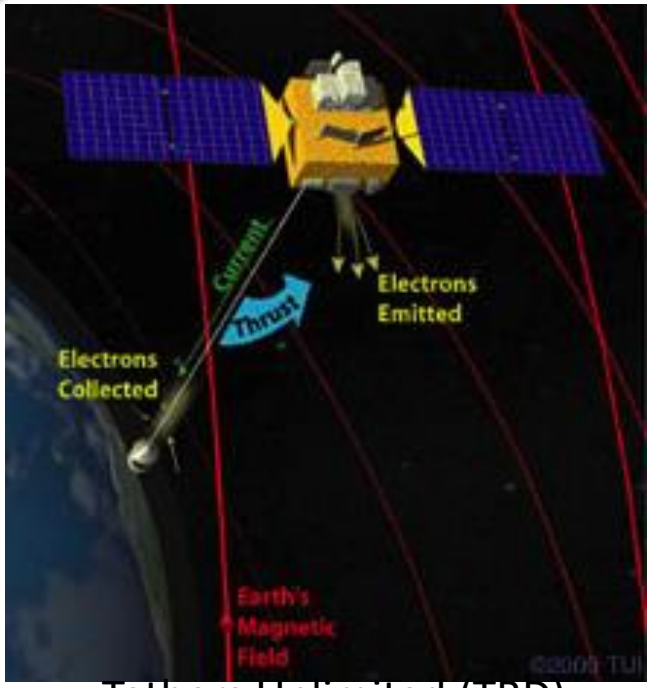
- Solar Array Plateau ~ 45% efficiency?
- Batteries that work over wide temperature ranges?
- Electromagnetic tethers – great if there's a ma
- Progress in nuclear dependent on NASA /5 , Compact RTGs?

Fundamental

Solar power distance limit?

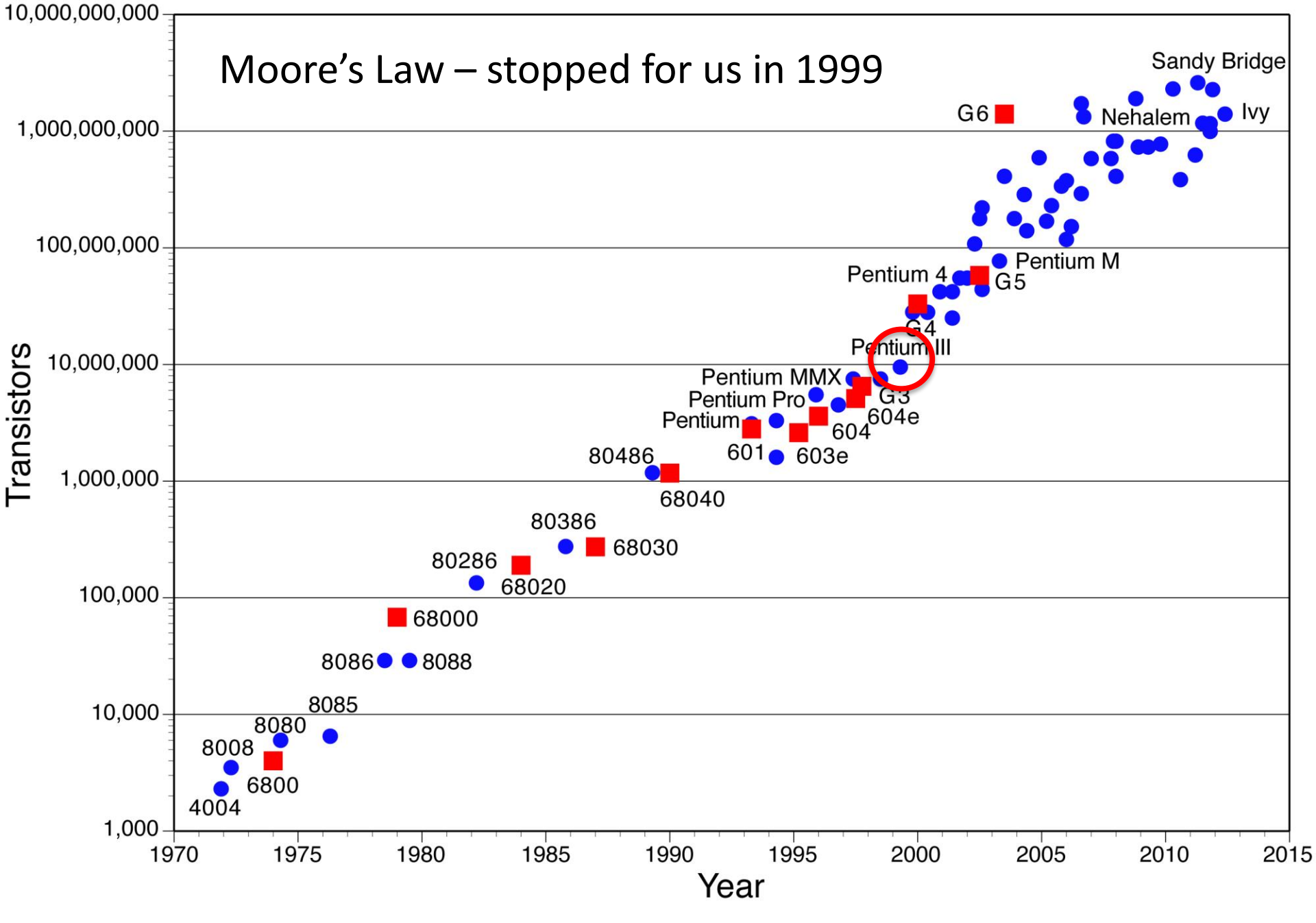


Electromagnetic Tethers



Tethers Unlimited (TBD)

Spacecraft S/W Functions



Small is Beautiful

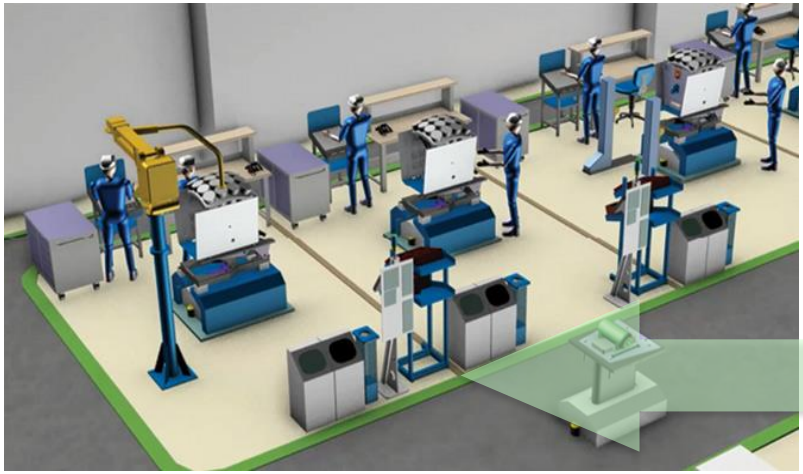
Advanced Manufacturing

- 3-D printed valves on Falcon-9
- 3-D printing of S/C components
- Multi-function Structures
- Robot-assisted Integration and Test
- S/C build cycles < 1 week

3D Printed Spacecraft

Planetary Resources (2014)

Robot-assisted assembly
[15 Smallsat S/C per week]



OneWeb (2018)

3-D Printed Rocket Engine

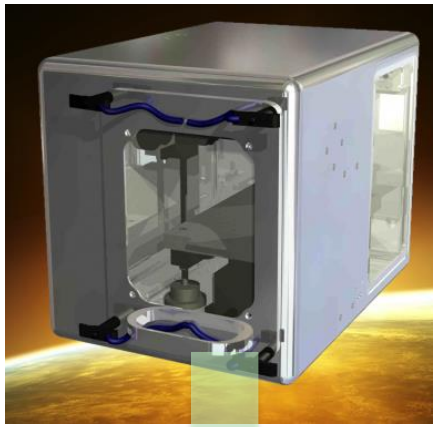
Space-X (2014)

Small is Beautiful

Additive Manufacturing

- 3-D printer as a flight payload
- Print Hardware Upgrades
- Use In situ resources
- Large-scale Structures in Space

First 3-D Printer in Space

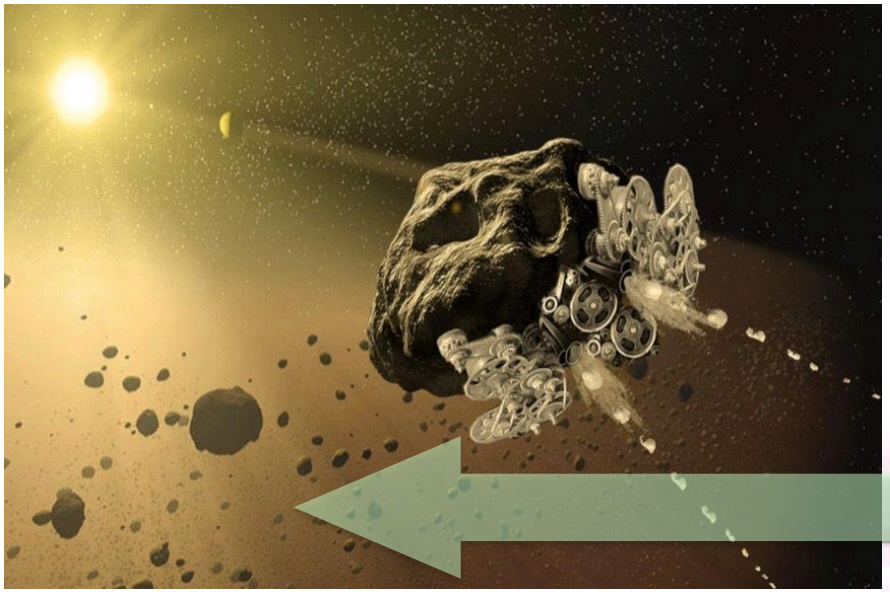


Made In Space on ISS (2014)

Object printed from asteroid metals

Planetary Resources (2016)

Making a Spacecraft out of an Asteroid

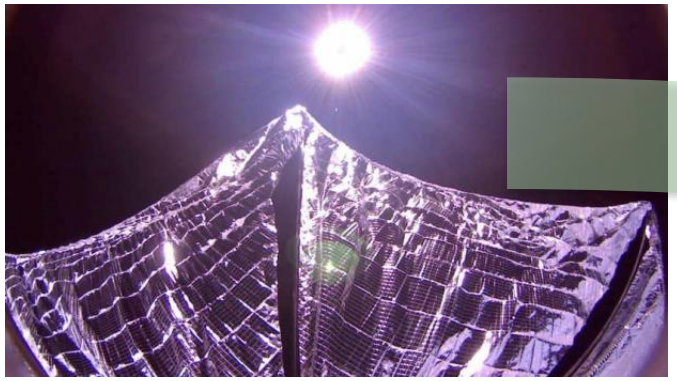


Made In Space (TBD)

Small is Beautiful

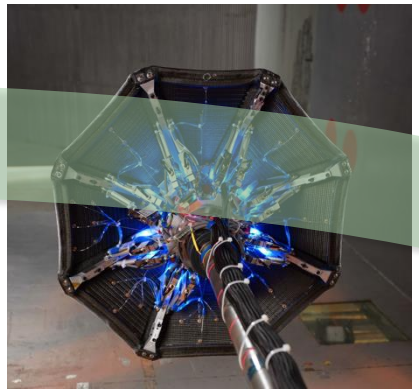
Propulsion

Solar Sail (first design in 1976)



Planetary Society (2015)

Deployable Aeroshell

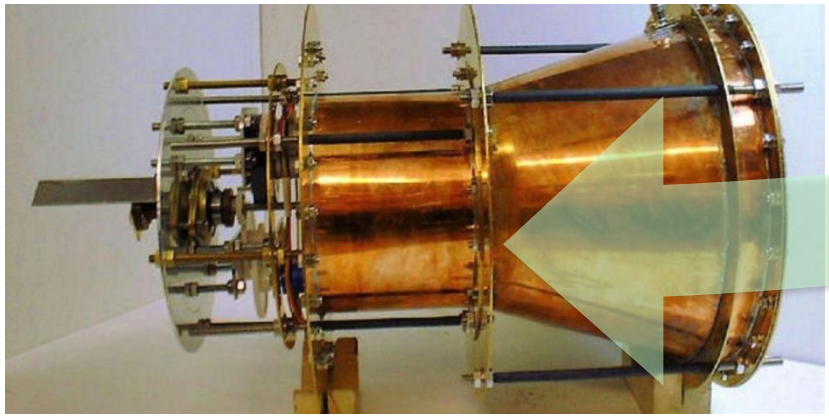


NASA Ames (2017)

MicroSpray
Electric propulsion

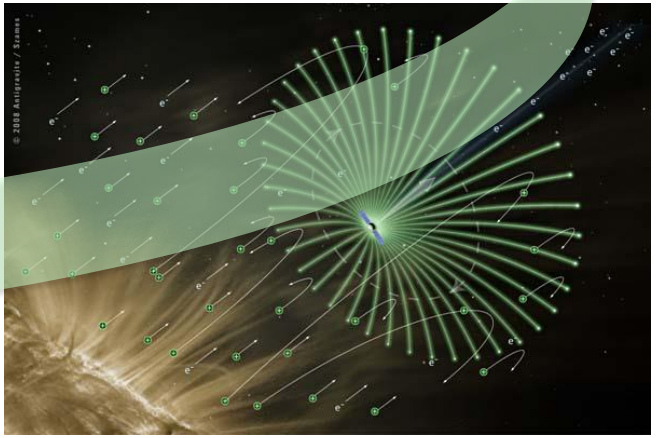
Busek (2019)

NASA EM Drive



NASA JSC (???)

eSail demo



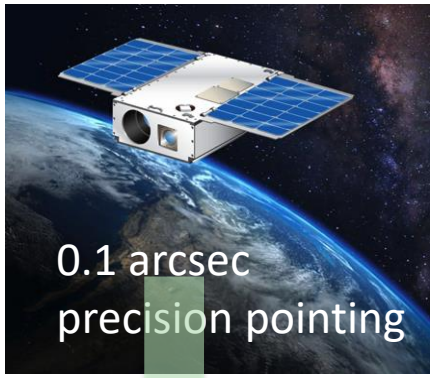
Aaalto U. Finland (2017)

Small is Beautiful

Attitude Determination and Control

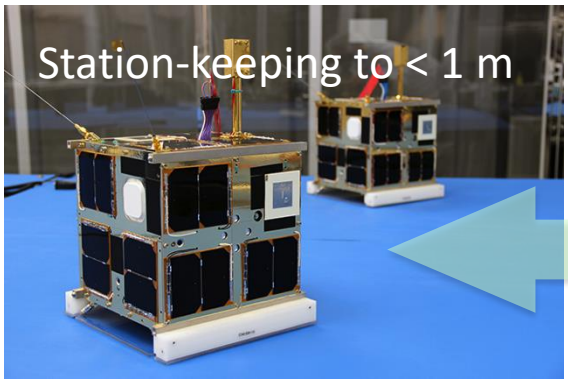
- Fraction of an arcsec pointing
- Navigation using Pulsars
- Precision Formation Flying

Asteria
Exoplanet Hunter



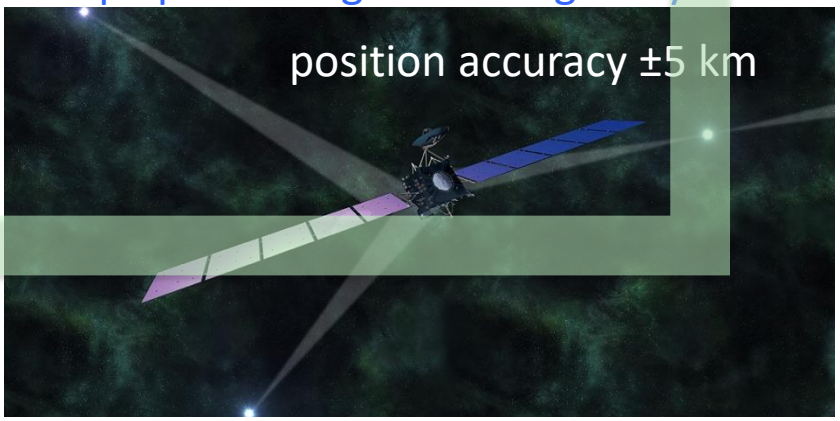
JPL/MIT (2018)

CanX-4 and -5
Precision Formation Flying



UTIAS SFL (2014)

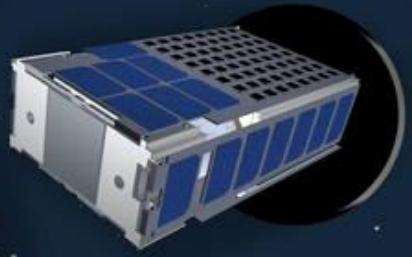
XPNav-1
Deep Space navigation using X-ray Pulsars



China (2016)

EXPLORATION MISSION-1:
LAUNCHING
SCIENCE & TECHNOLOGY
SECONDARY PAYLOADS

13
CUBESAT EXPLORERS
GOING TO DEEP SPACE WHERE FEW CUBESATS HAVE EVER GONE BEFORE.



ORION STAGE ADAPTER
SUPPORTS BOTH PRIMARY MISSION AND SECONDARY PAYLOADS

1

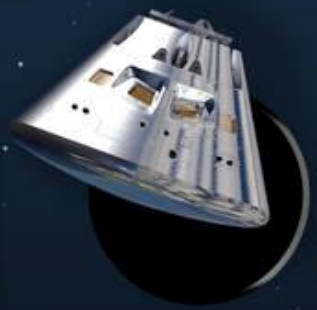
PRIMARY MISSION
TESTING SLS AND ORION

SPACE LAUNCH SYSTEM (SLS)
LIFTS MORE THAN ANY EXISTING LAUNCH VEHICLE

2

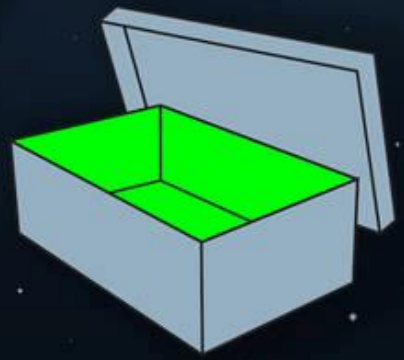
SECONDARY PAYLOADS
THE RING THAT WILL CONNECT THE ORION SPACECRAFT TO NASA'S SLS ALSO HAS ROOM FOR 13 HITCHHIKER PAYLOADS

SHOEBOX SIZE
PAYLOADS EXPAND OUR KNOWLEDGE FOR THE JOURNEY TO MARS



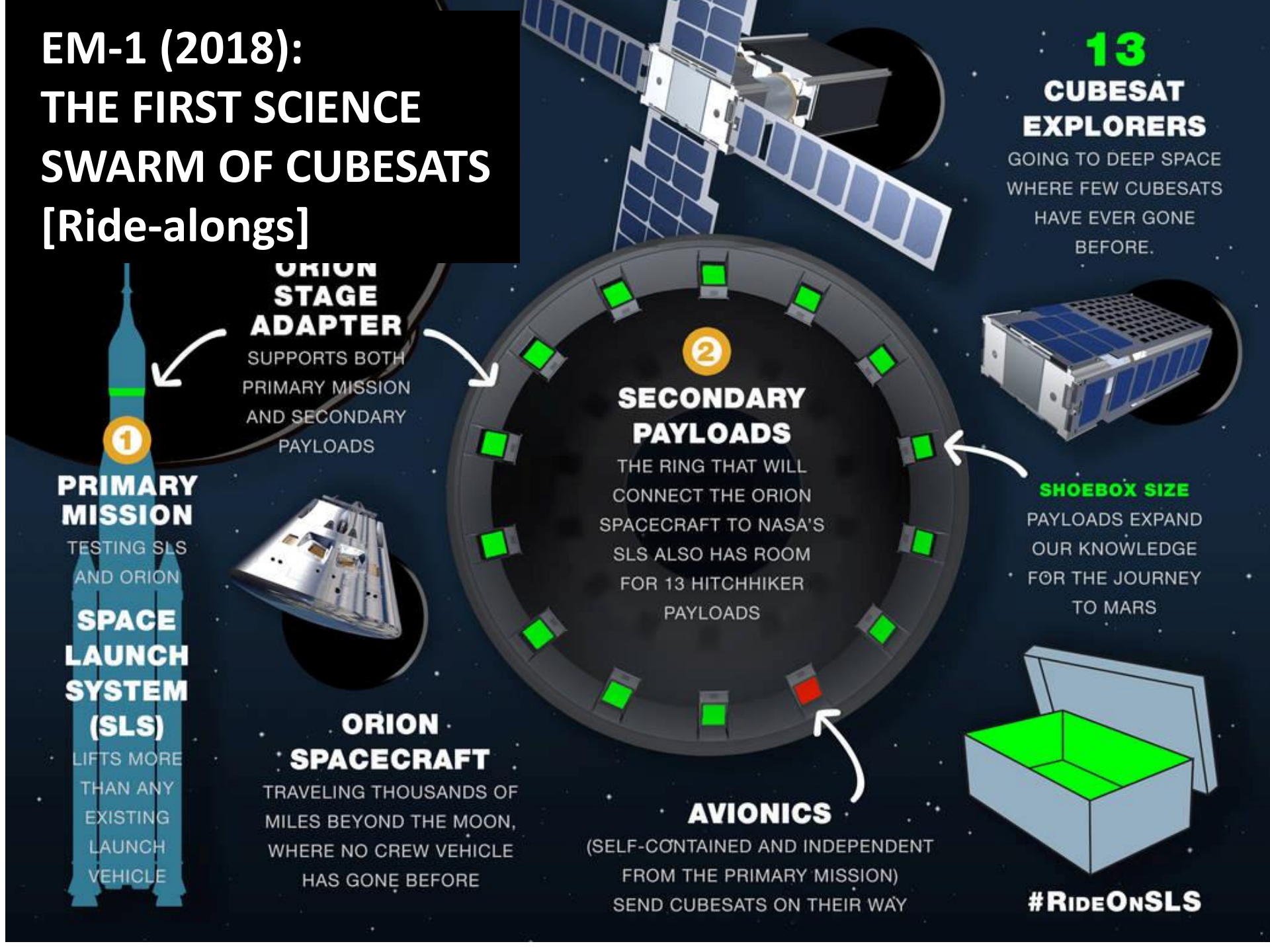
ORION SPACECRAFT
TRAVELING THOUSANDS OF MILES BEYOND THE MOON, WHERE NO CREW VEHICLE HAS GONE BEFORE

AVIONICS
(SELF-CONTAINED AND INDEPENDENT FROM THE PRIMARY MISSION) SEND CUBESATS ON THEIR WAY



#RIDEONSLS

EM-1 (2018): THE FIRST SCIENCE SWARM OF CUBESATS [Ride-alongs]

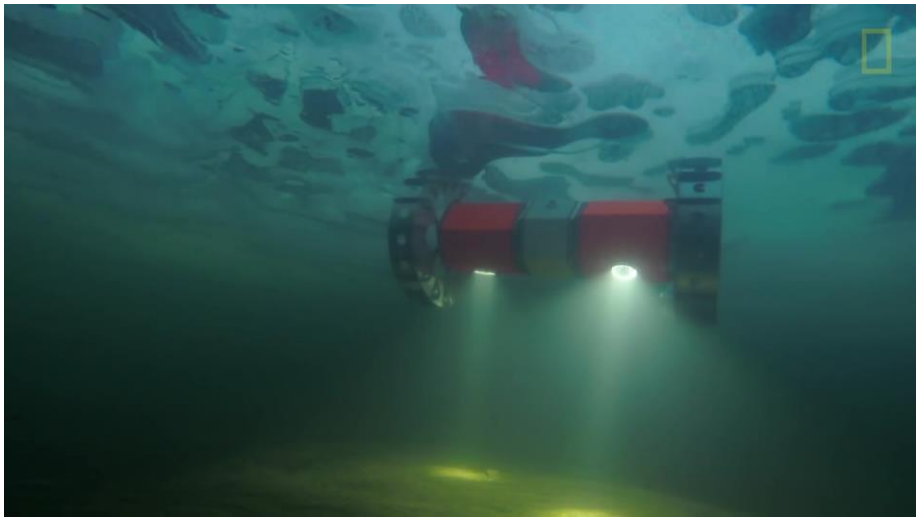


Small is Beautiful

Concepts for Surface Mobility Systems

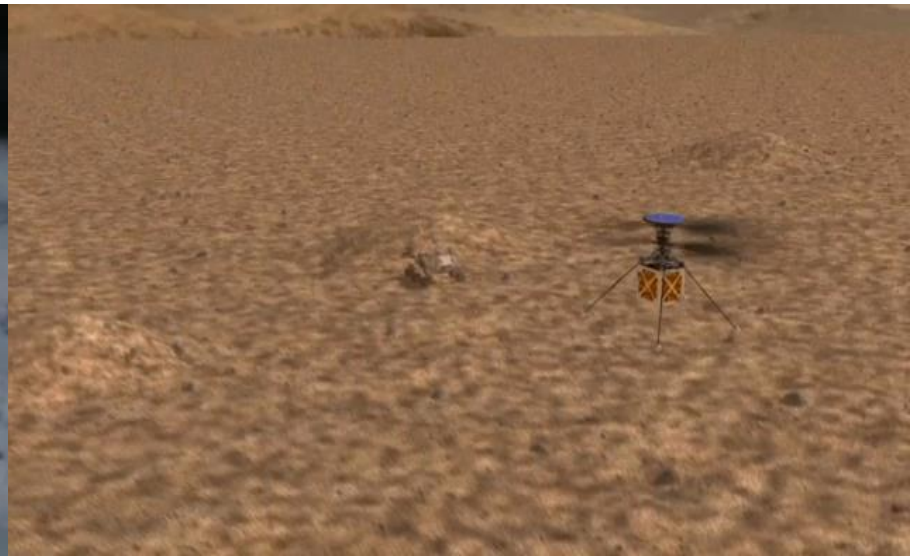
- Subsurface probes
- Drones on Titan or Mars

Under the Ice



Through the Ice

Exploring Mars



Small is Beautiful
Humanoid Robots

Kirobo on ISS

“That’s one small step for me”

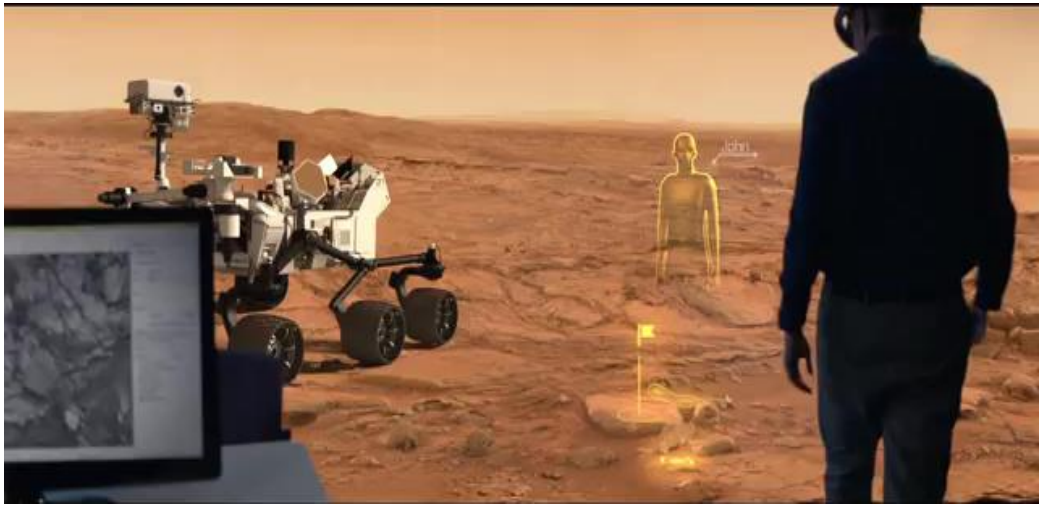
Small is Beautiful

Humanoid Robots

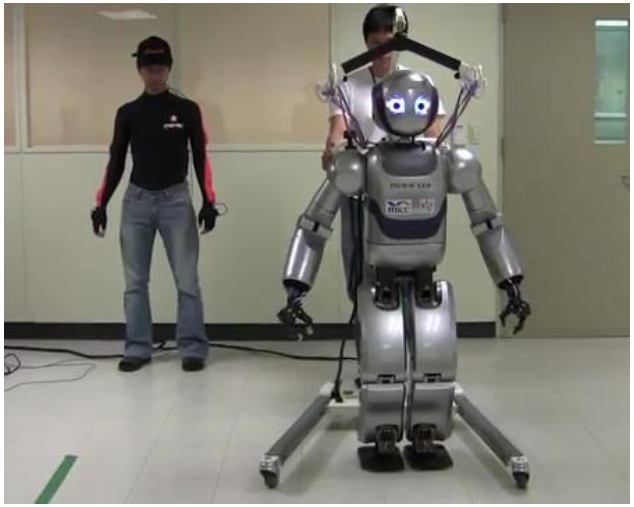
Artificial Intelligence?

Tool use - DARPA

Augmented Reality



Motion Capture

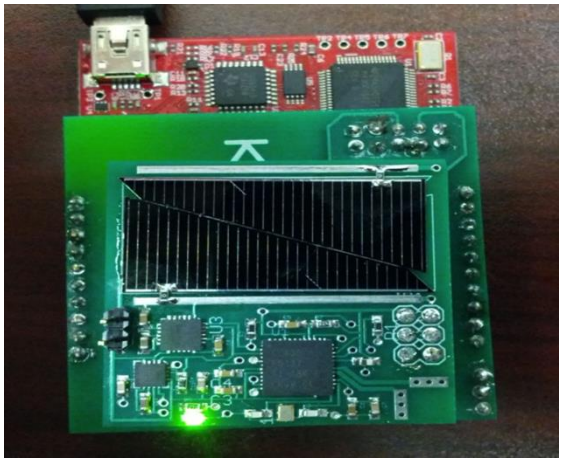


Small is Beautiful

Going Interstellar

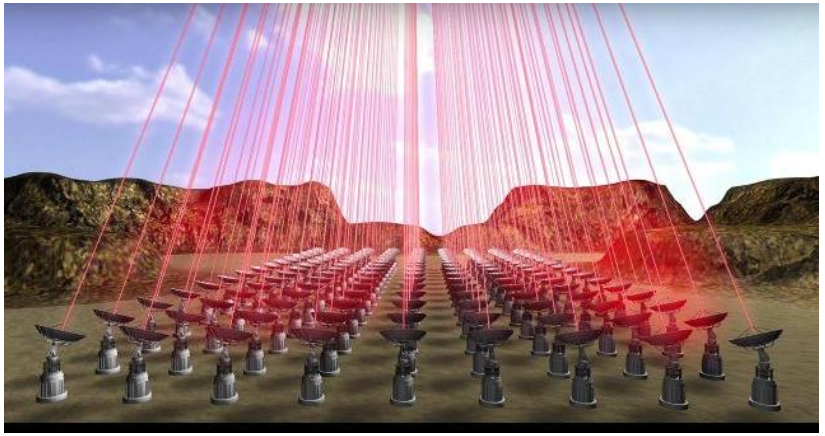
Breakthrough Starshot

Kicksat Sprite



picosat (1-2 g)

breakthroughinitiatives.org/Initiative/3



Small is Beautiful

Summary

- The building blocks are lining up for some really exciting "Discovery-class" Smallsat missions in the very near future
- Smallsats allow fast-track infusion of technology for all future deep space missions
  - Don't have to wait 40 years like we did for solar sails
- On Earth, some technologies – smaller instruments, AI, robotics, adv. manufacturing – are taking off exponentially
- When these exponential technologies converge and are space-adapted they will open up mind-blowing possibilities!
- Invite the NewSpace innovators in – give them challenges to solve

Small is Beautiful
Relevant Contributions

- Hardgrove C. Ehlmann B. L., *Achieving Visionary Planetary Science Goals with Deep Space CubeSats* [#8183]
- Wyatt E. J. Castillo-Rogez J. C. Chien S. A. Clare L. P. Fraeman A. A. et al., *Novel Planetary Science Enabled by Networked Constellations* [#8091]
- Johnson L. Krause L. H. Wiegmann B. Bilen S. Gilchrist B., *Propulsion and Power Using Electrodynamics* [#8069]
- Castillo-Rogez J. C. * Feldman S. M. Baker J. D. Vane G., *Small Instruments for Planetary Science Applications — Status and Way Forward* [#8160]
- Aslam S. A'Hearn M. F. Clark P. Daly M. Feaga L. et al., *Waypoints for Opportunistic SmallSat/CubeSat Missions to Comets and Asteroids* [#8182]
- Mardon A. A. Mardon C. A., *The Position of Artificial Intelligence in Robotic Space Missions in the Inner and Outer Solar System in 2050* [#8040]
- Mercer C. R. Landis G. A., *Interactive Science on Mars* [#8054]
- Scheidt D. H. Hibbitts C. A. Chen M. H. Paxton L. J. Bekker D. L., *On the Need for Artificial Intelligence and Advanced Test and Evaluation Methods for Space Exploration* [#8114]