Disruptive Technologies

(and their impact on Future Planetary Exploration)

Tony Freeman, JPL

April 2018

Jet Propulsion Laboratory, California Institute of Technology

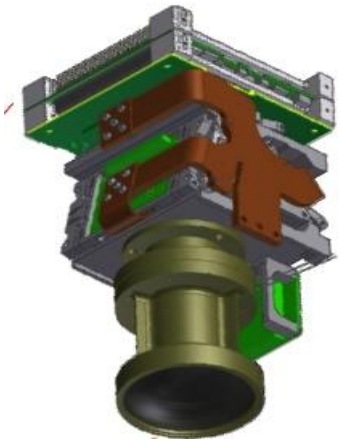
Planetary Exploration 2061, Lausanne, Switzerland (2018)

Cubesats were ‘toys’ 18 years ago…

www.youtube.com/watch?v=c0BpjPUT5FE

Science Instrument Examples (1U = 1 liter)

HARP Imaging Polarimeter(3U)

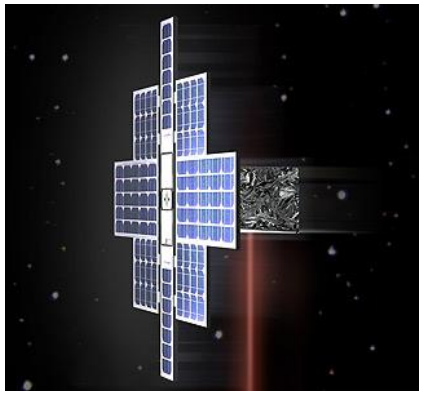


UMBC/SDL (2017)

RainCube radar (6U)

JPL (2017)

Lunar Flashlight (6U)
NIR laser



MSFC/JPL (2017)

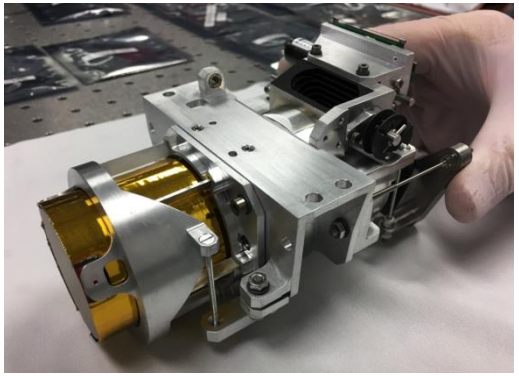
Mass Spectrometer (3U)

JPL (TBD)

LunarIceCube (6U)
IR spectrometer

GSFC (2018)

VSWIR-Dyson (2U)
spectrometer

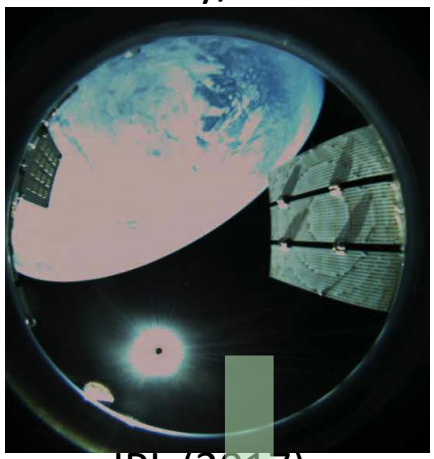


JPL (TBD)

Telecom

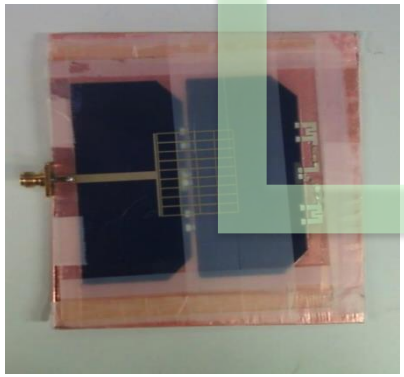
RF

ISARA
Reflectarray/Solar Array



JPL (2017)

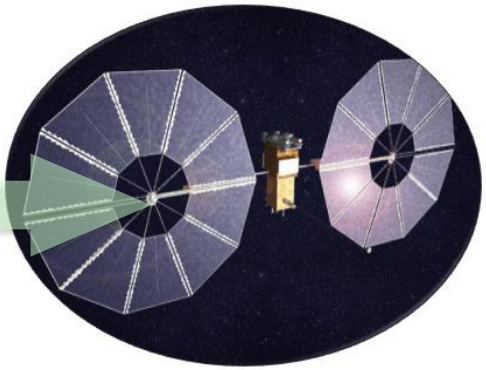
Optically Transparent/
RF Reflective Coatings



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

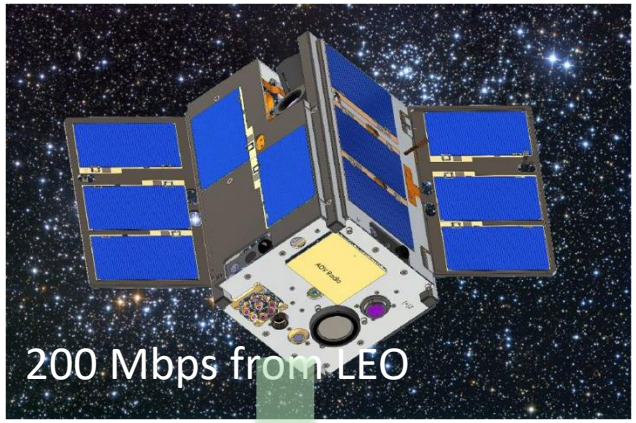
Dual-use Solar arrays



(TBD)

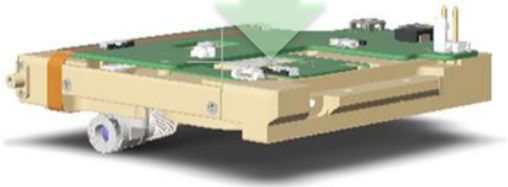
Optical

Cubesat Optical Comm Demo



Aerospace (2016/7)

Bridgesat Optical Comm Terminal



Bridgesat (TBD)

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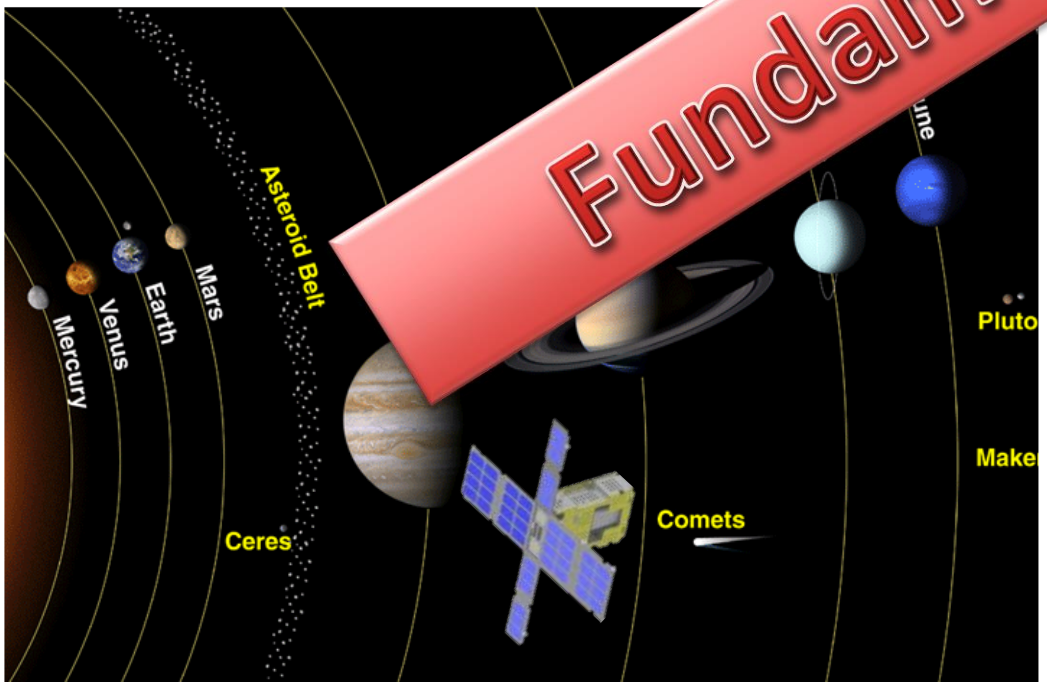
Power Systems

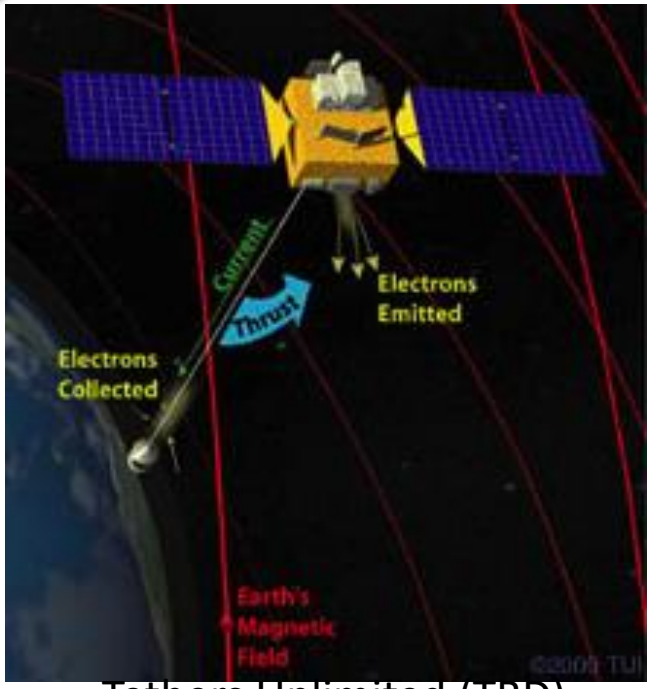
- Solar Array Plateau ~ 45% efficiency?
- Batteries that work over wide temperature ranges?
- Electromagnetic tethers – great if there's a ma
- Progress in nuclear dependent on NASA/ , Compact RTGs?

Fundamental

Solar power distance limit?

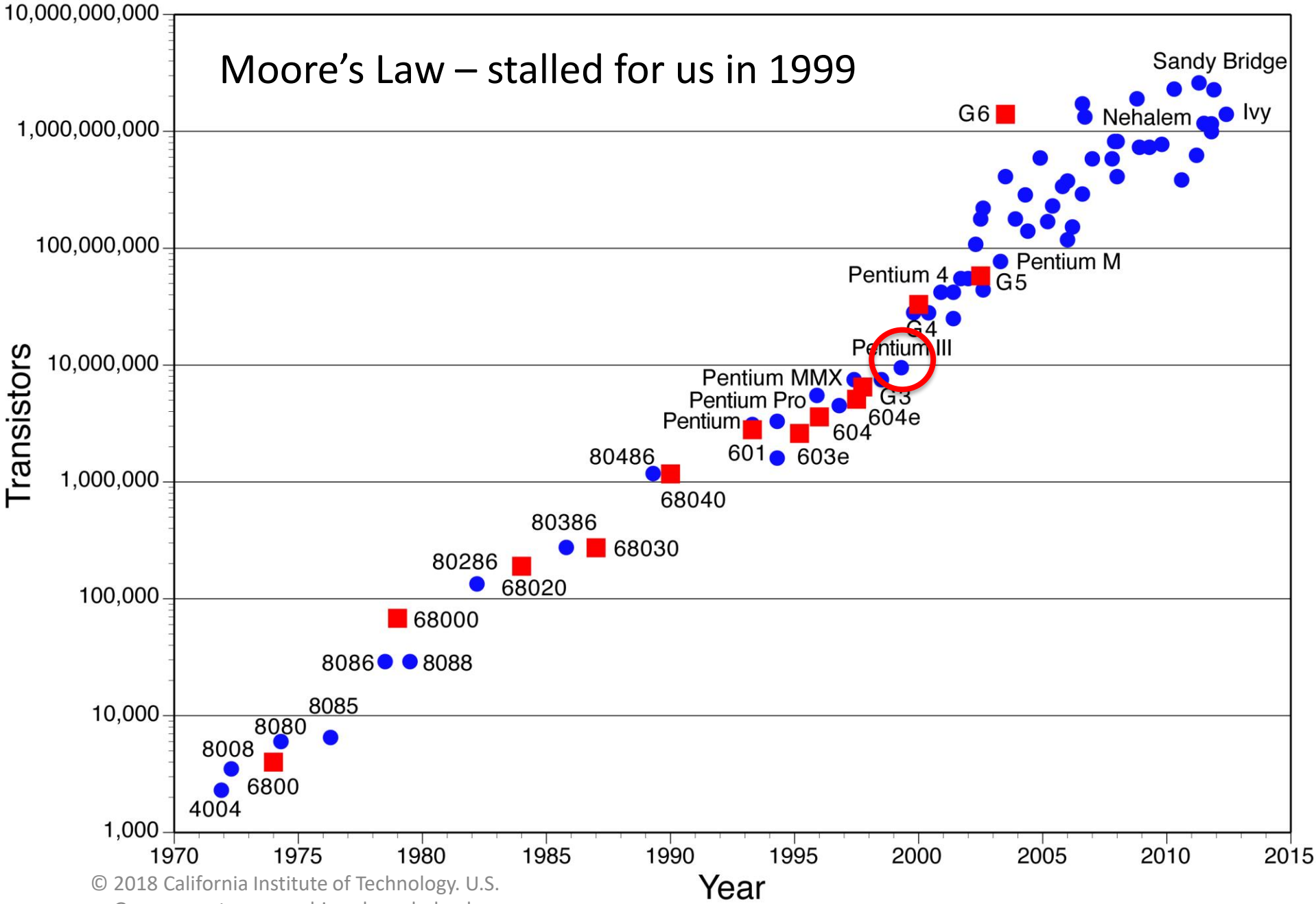


Electromagnetic Tethers



Tethers Unlimited (TBD)

Spacecraft S/W Functions



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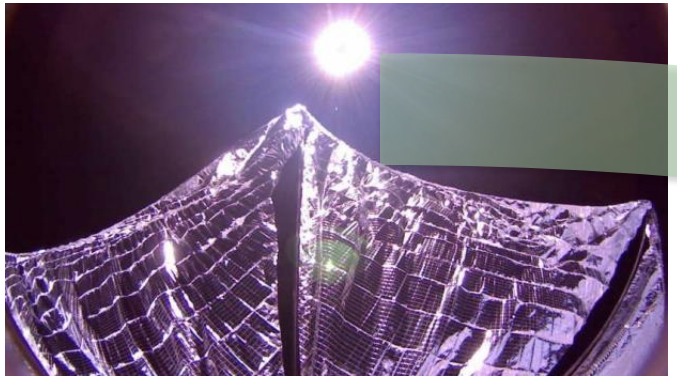
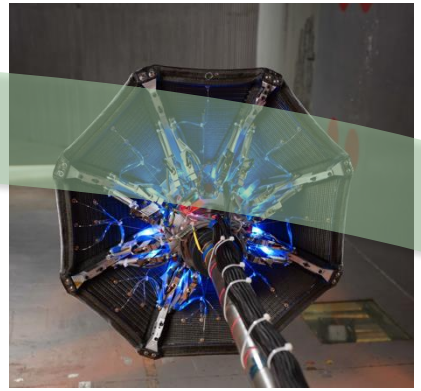
Propulsion

Solar Sail (first design in 1976)



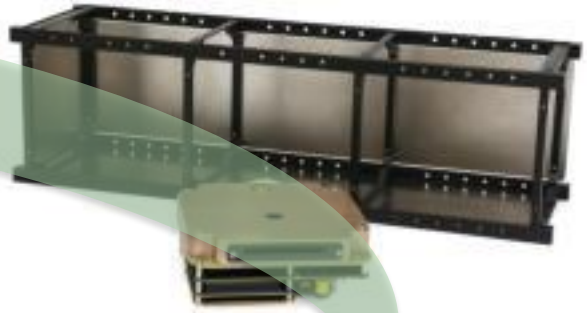
Planetary Society (2015)

Deployable Aeroshell



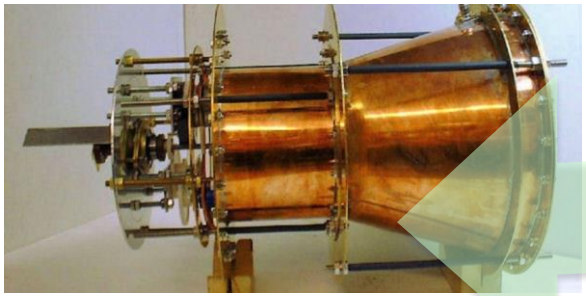
NASA Ames (2017)

MicroSpray
Electric propulsion



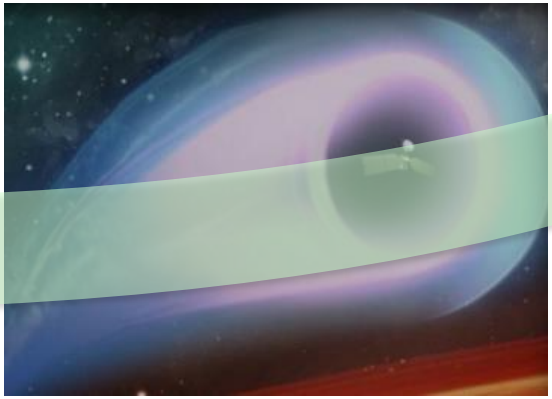
Busek (2019)

NASA EM Drive



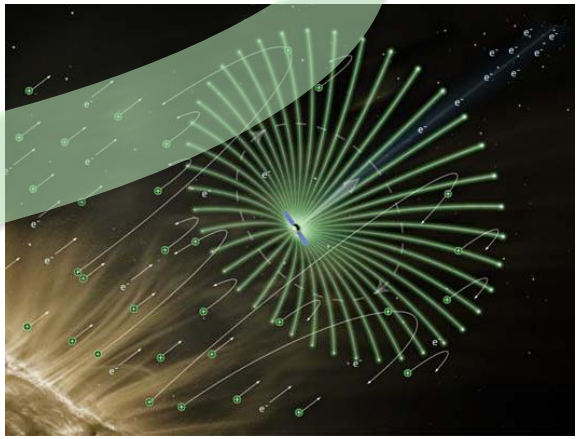
NASA JSC (???)

MagnetoShell



NASA/MSNW (???)

eSail demo



Aaalto U. Finland (2017)

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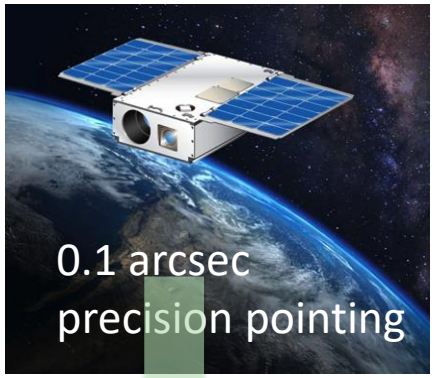
Attitude Determination and Control

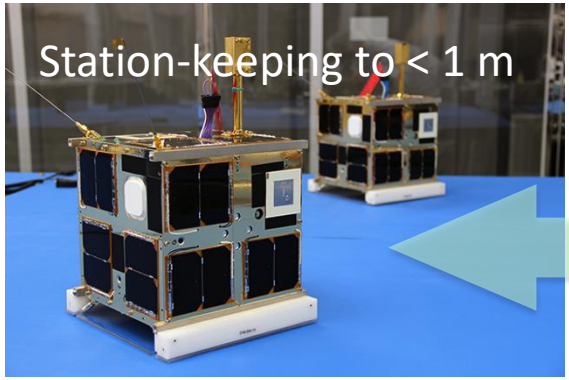
- Fraction of an arcsec pointing
- Navigation using Pulsars
- Precision Formation Flying

Asteria
Exoplanet Hunter



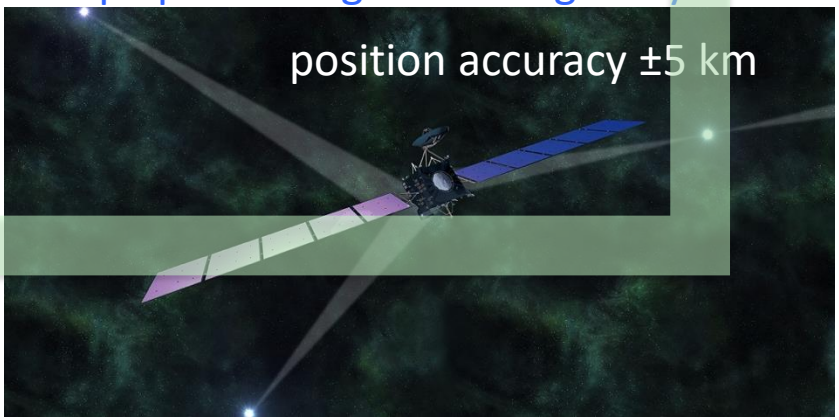
JPL/MIT (2017)

CanX-4 and -5
Precision Formation Flying



UTIAS SFL (2014)

XPNav-1
Deep Space navigation using X-ray Pulsars



China (2016)

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Cubesat Assembly
(in less than one workday)

Video clip courtesy Tyvak Corporation

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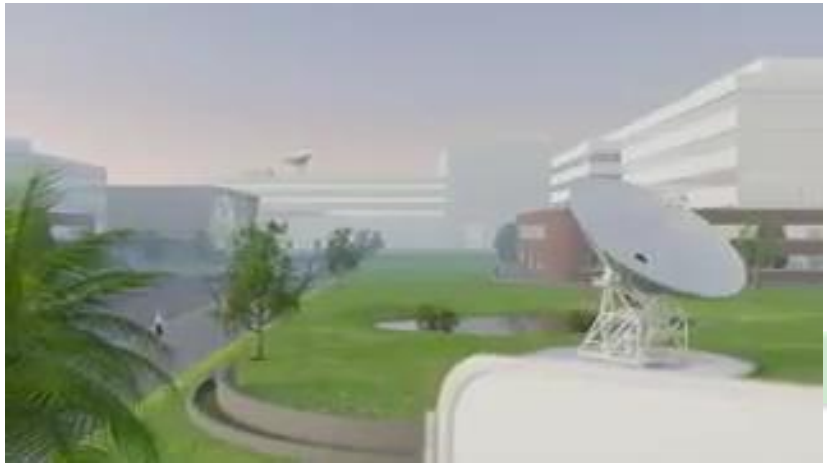
Advanced Manufacturing

- 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)

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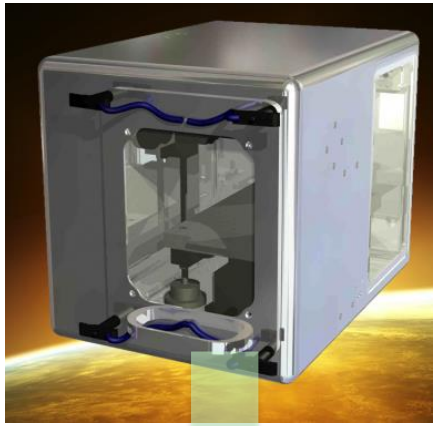
Additive Manufacturing

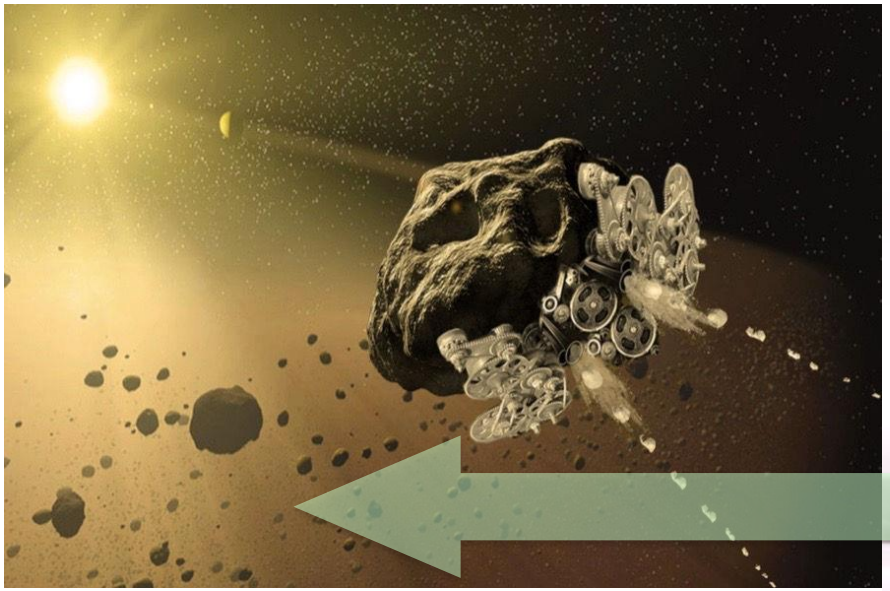
- 3-D printer as a flight payload
- Print Hardware Upgrades
- Use In situ resources
- Large-scale Structures in Space

First 3-D Printer in Space



Made In Space on ISS (2014)

Making a Spacecraft out of an Asteroid



Made In Space (TBD)

Object printed from asteroid metals

Planetary Resources (2016)

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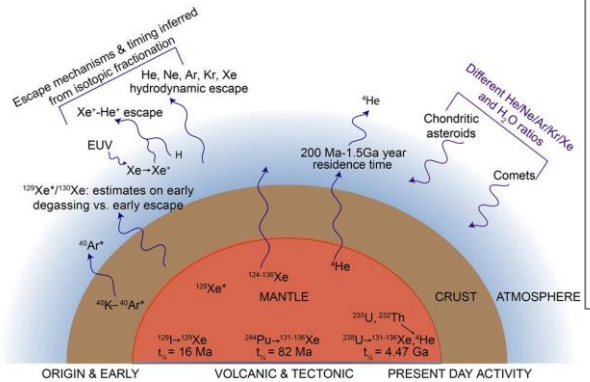
Cupid's Arrow Mission Concept

Decadal-Survey-Class Science

Address Planetary Decadal Survey Priority question 3: What governed the accretion, supply of water, chemistry, and internal differentiation of the inner planets and the evolution of their atmospheres, and what roles did bombardment by large projectiles play?'

Number 1 investigation of objective A of goal I of the VEXAG "Goals-Objectives-Investigation for Venus Exploration"

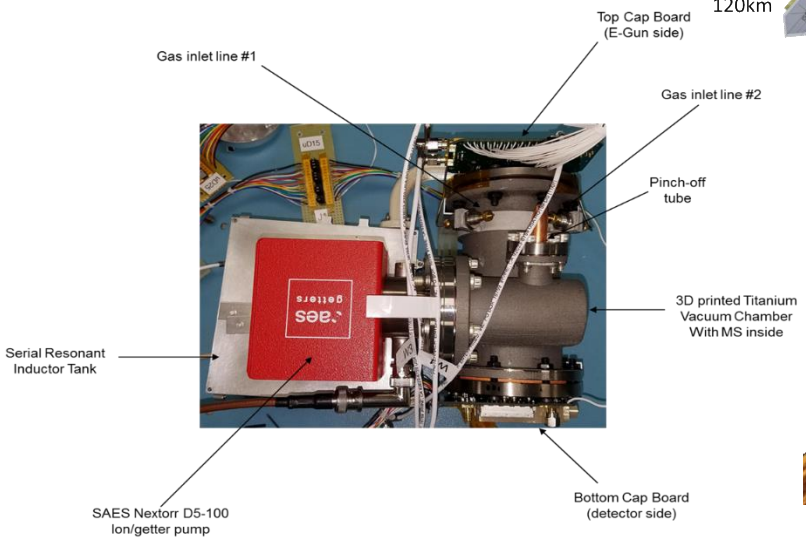
Measure the concentrations of noble gases and isotope ratios in Venus atmosphere (below the homopause @110 km).



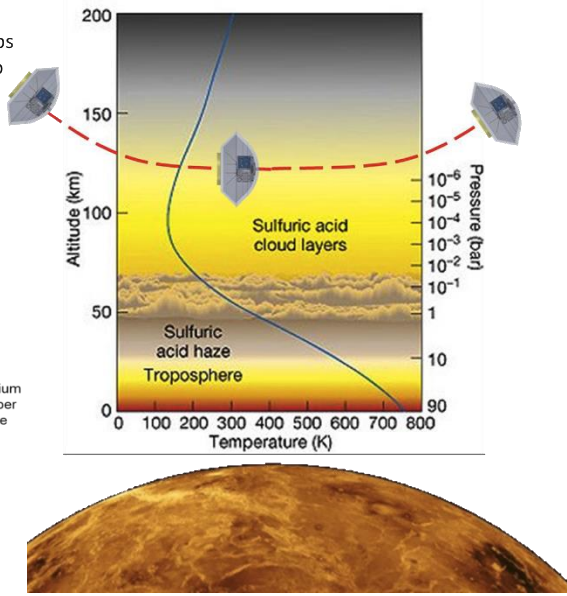
Instrument

JPL Mini-QITMS to analyze 4 samples/pass

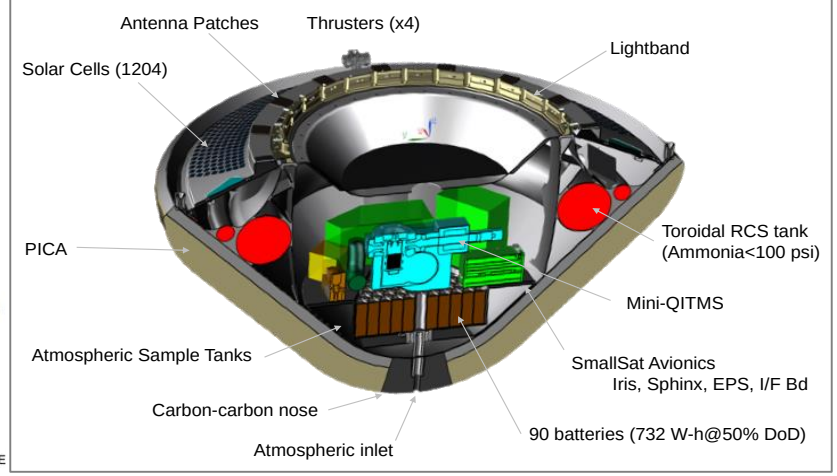
Sample chamber and electronics below



Ops Concept



Vehicle Concept

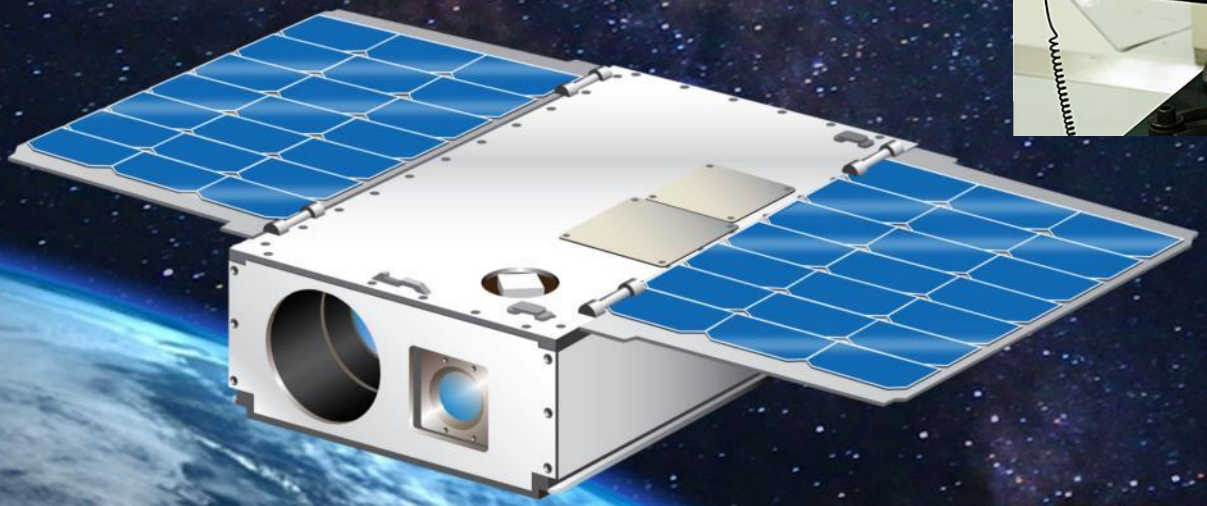


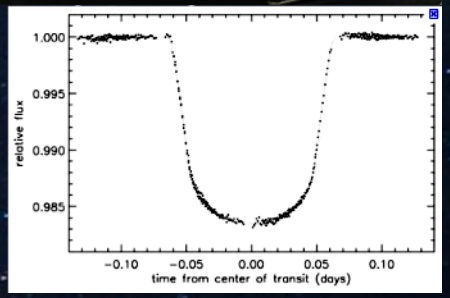
Study Team:

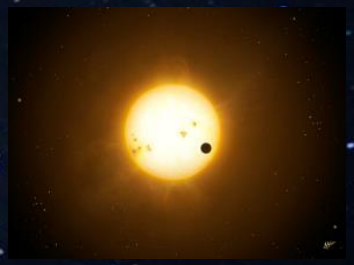
Christophe Sotin (PI)
John Baker (JPL)
Tony Freeman (JPL)
Glenn Lightsey (GATech)
Terry Stevenson(GATech)
Murray Darrach (JPL)
Bernard Marty (CRPG, FR)

ASTERIA: Arcsecond Space Telescope Enabling Research in Astrophysics

- PI: Sara Seager, MIT
- Single star at-a-time planetary transits
- 0.1 arcsec precision pointing
- Launched in 2017







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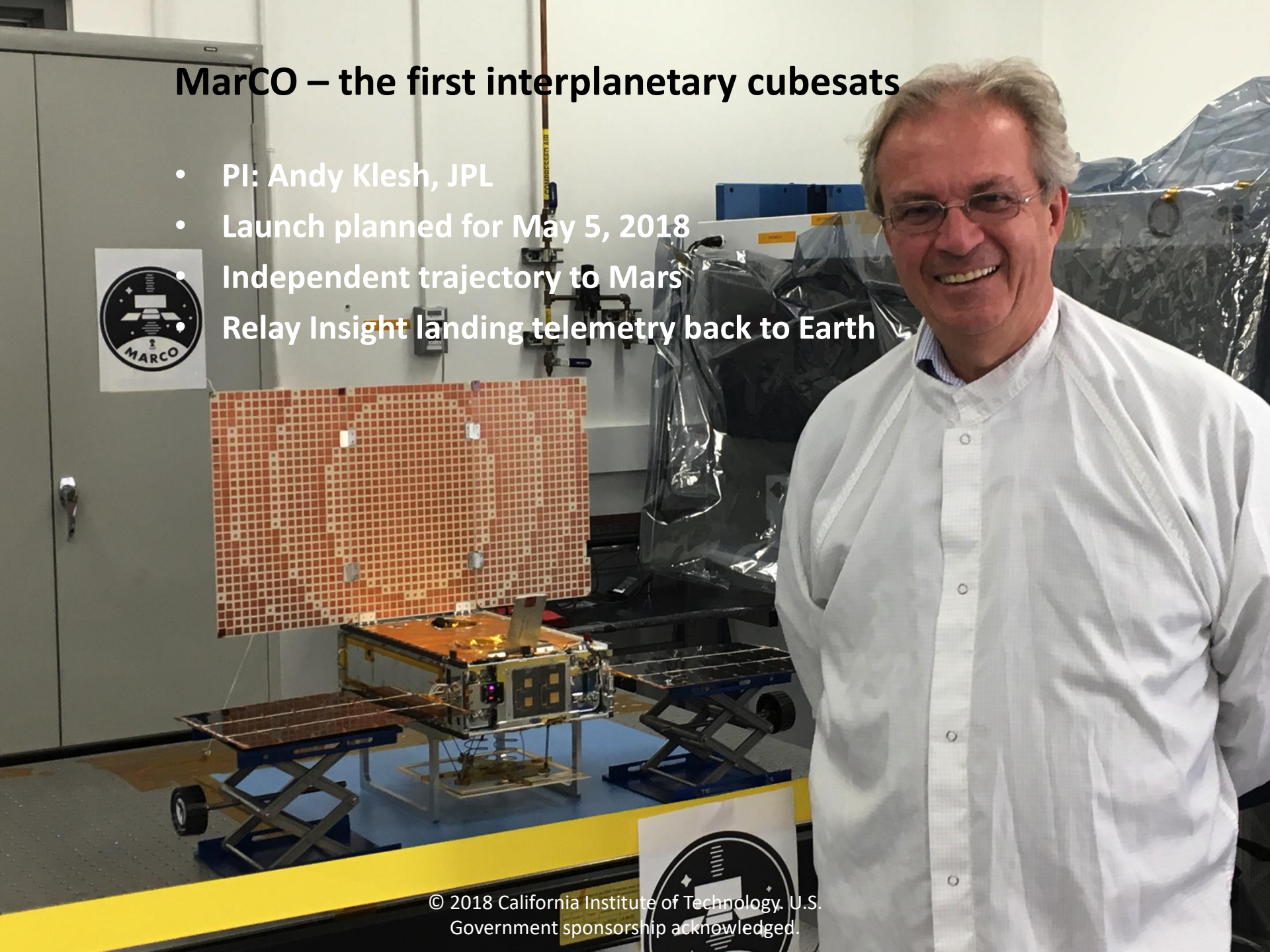
MarCO – the first interplanetary cubesats

- PI: Andy Klesh, JPL
- Launch planned for May 5, 2018
- Independent trajectory to Mars
- Relay Insight landing telemetry back to Earth



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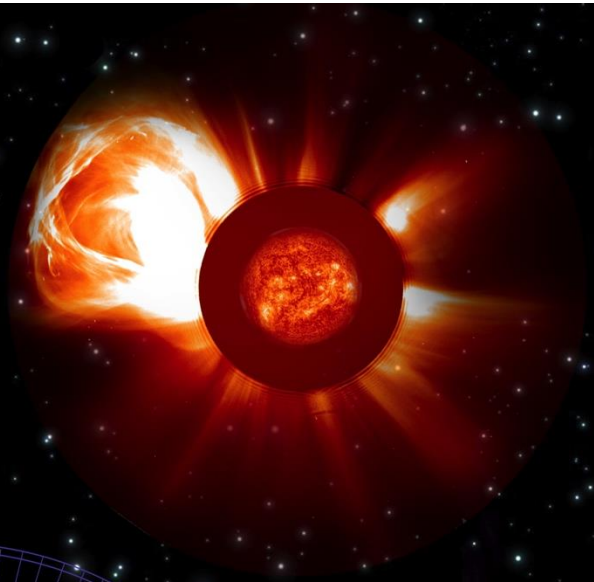
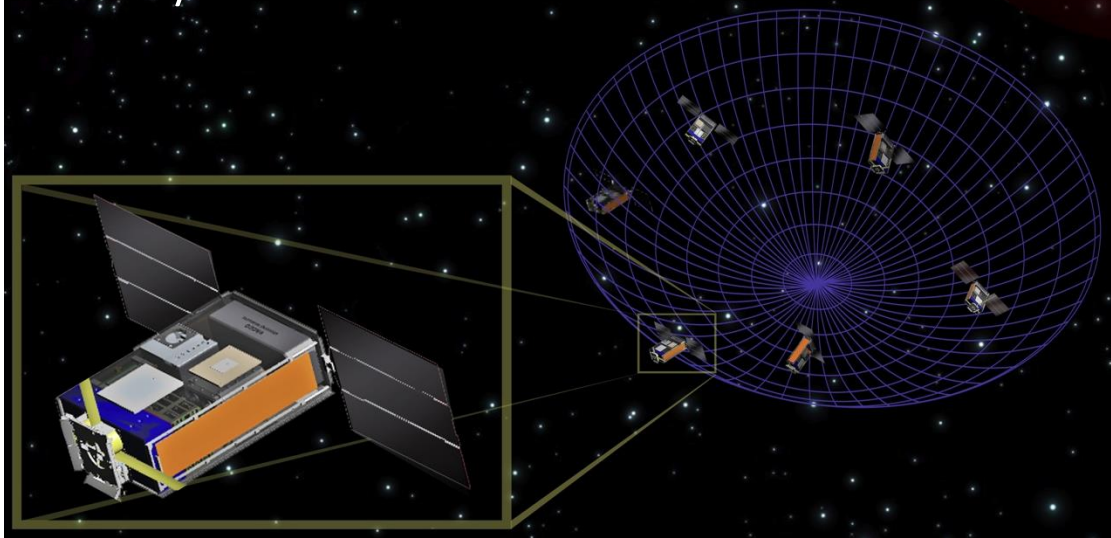
Sun Radio Imaging Space Experiment
- first science swarm to form an RF Interferometer?

SMEX Heliophysics Step II selection - Mission Concept

- PI: Justin Kasper, U of MI
- PS: Joe Lazio (9X)
- Use radio emission to track CME particle acceleration and transport
- 6 spacecraft synthetic aperture
- D33 payload (GPS + HF rcvr)
- SDL S/C and I&T



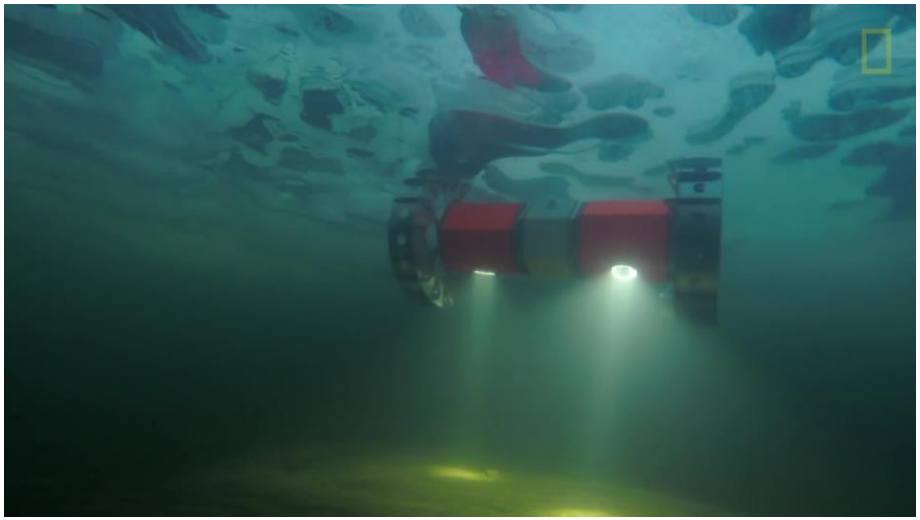


Pre-Decisional Information -- For Planning and Discussion Purposes Only

Concepts for Surface Mobility Systems

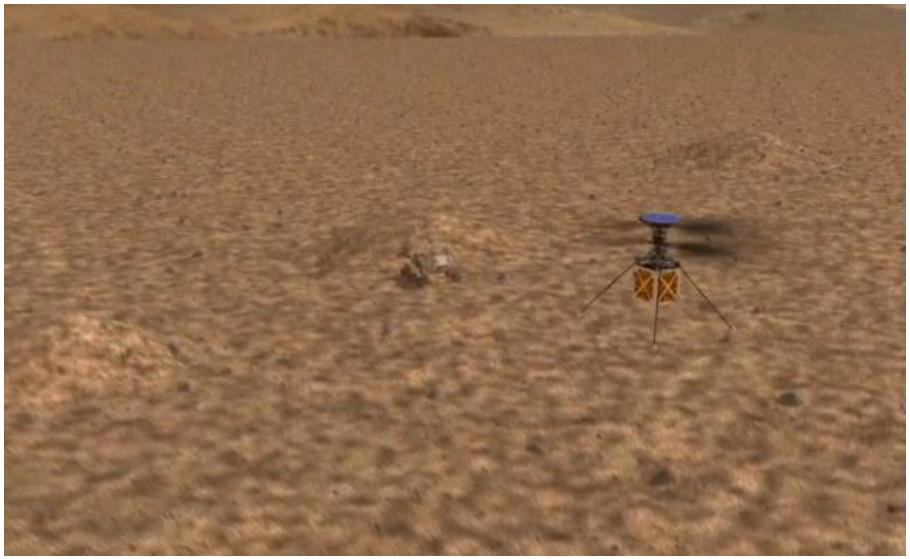
Clockwork rovers on Venus

Probing under the Ice



Puffer minibots

Helicopters on Mars



Clip + still courtesy Andrew Shapiro-Scharlotta, JPL

Gecko Grippers enable Exploration of a Lava Tube

Movie Clip courtesy Aaron Parness, JPL

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Humanoid Robots

Kirobo on ISS

“That’s one small step for me”

Bulk Metallic Glass Gears (enabling)

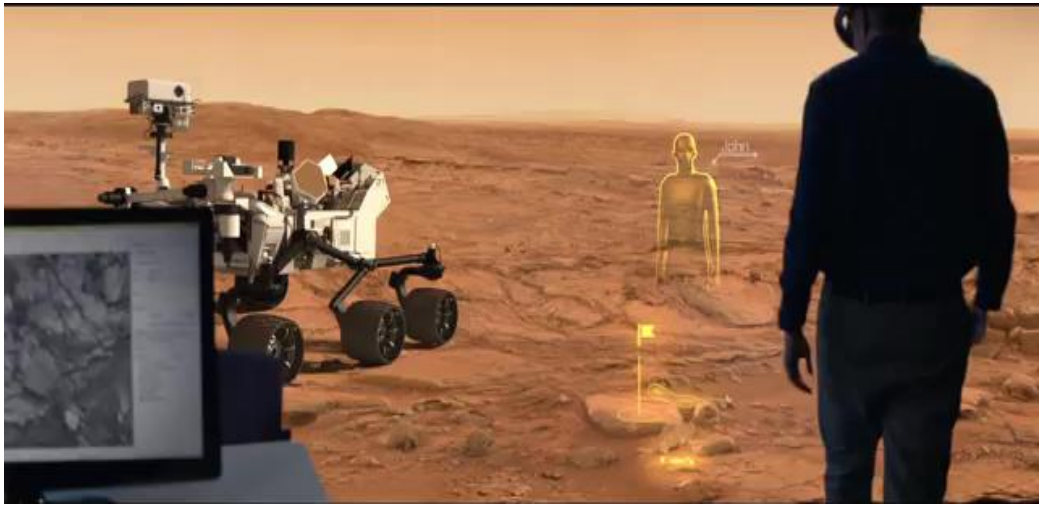
www.youtube.com/watch?v=abhawiDPXSU

Humanoid Robots

Artificial Intelligence?

Tool use - DARPA

Augmented Reality



Motion Capture

Voyager I left our solar system in 2012

Voyager I
Launched in 1977 (40 years ago!)
Current Speed 17 km/s
140 AU from the Sun

Downlink telemetry 16 bits/sec
Uplink telemetry 160 bits/sec
Onboard Computer Memory 70 kBytes

Power available 249 W
Flight Software: FORTRAN/C

What will the Voyager of 2061 be like?

voyager.jpl.nasa.gov

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FLIGHT SYSTEM UPGRADES @ 4 LY

3-D PRINTER

+

MINERAL STOCKS

=

NEW COMPONENTS

SOFTWARE

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Summary

- On Earth, some technologies – smaller instruments, AI, robotics, adv. manufacturing – are taking off exponentially
- Miniaturization of instruments in particular has seen significant progress (see talk by Sabrina Feldman, JPL)
- Advanced mobility systems will allow robot explorers to go where none have gone before!
- Smallsats allow fast-track infusion of technology for <u>all</u> future deep space missions
  - Don't have to wait 40 years like we did for solar sails
- As these exponential technologies converge and are space-adapted they will open up amazing possibilities!

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