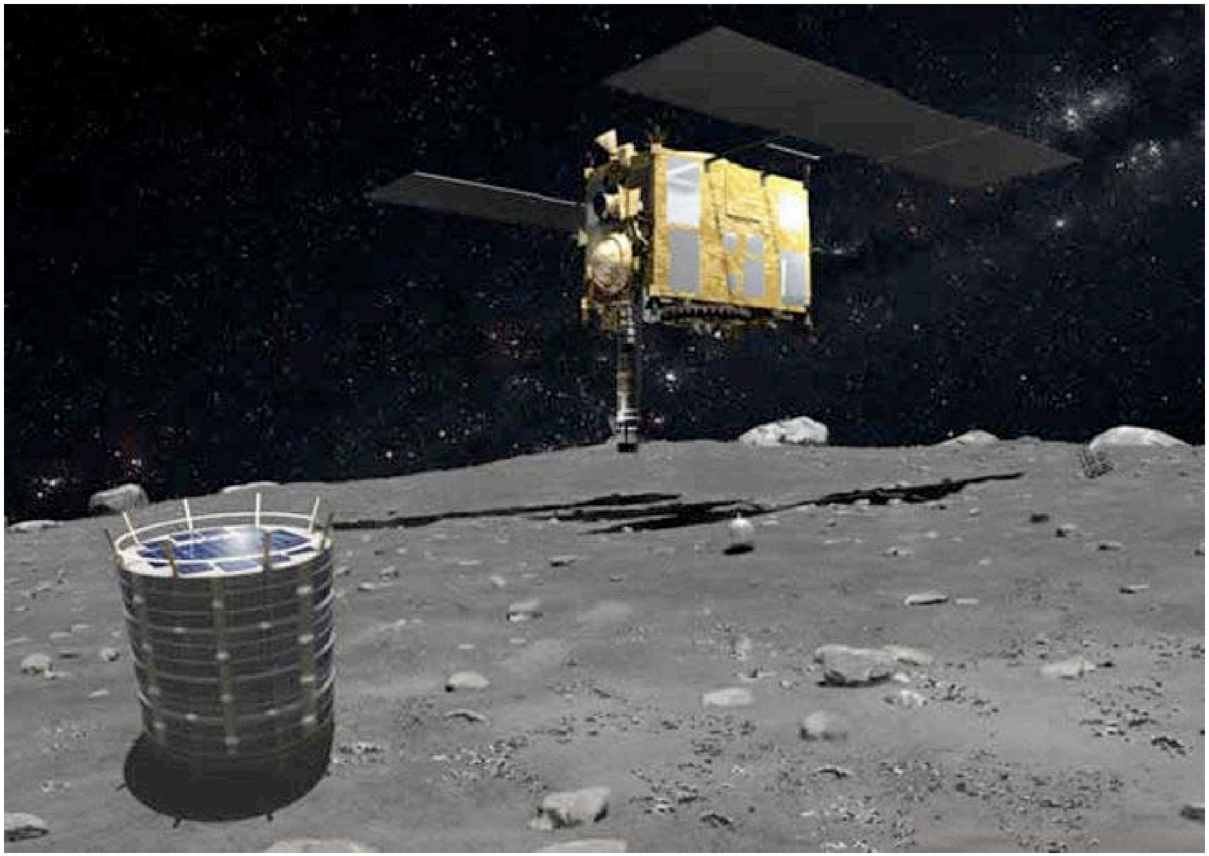
Applications of NanoSats at Small Body Objects



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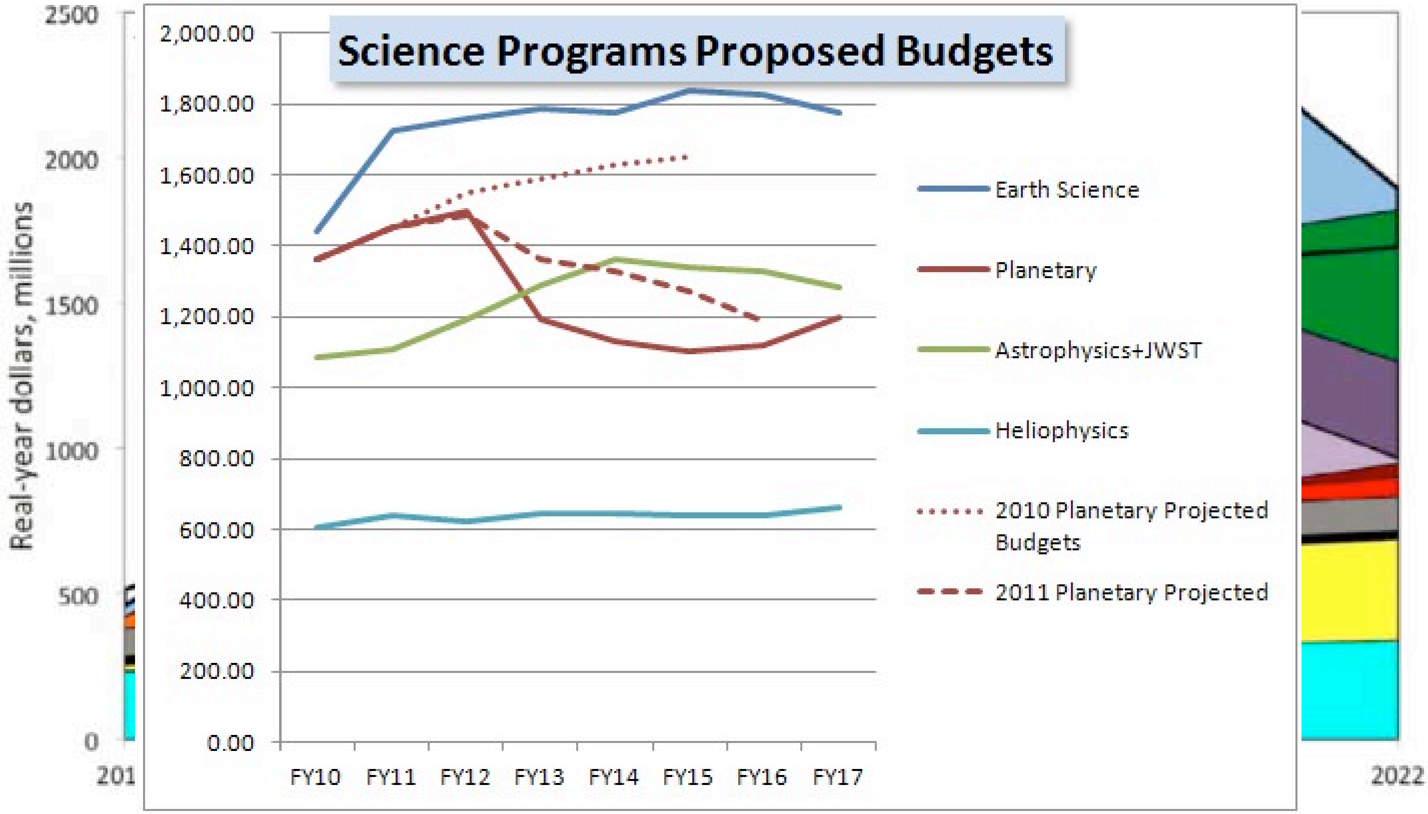
4/18/2012

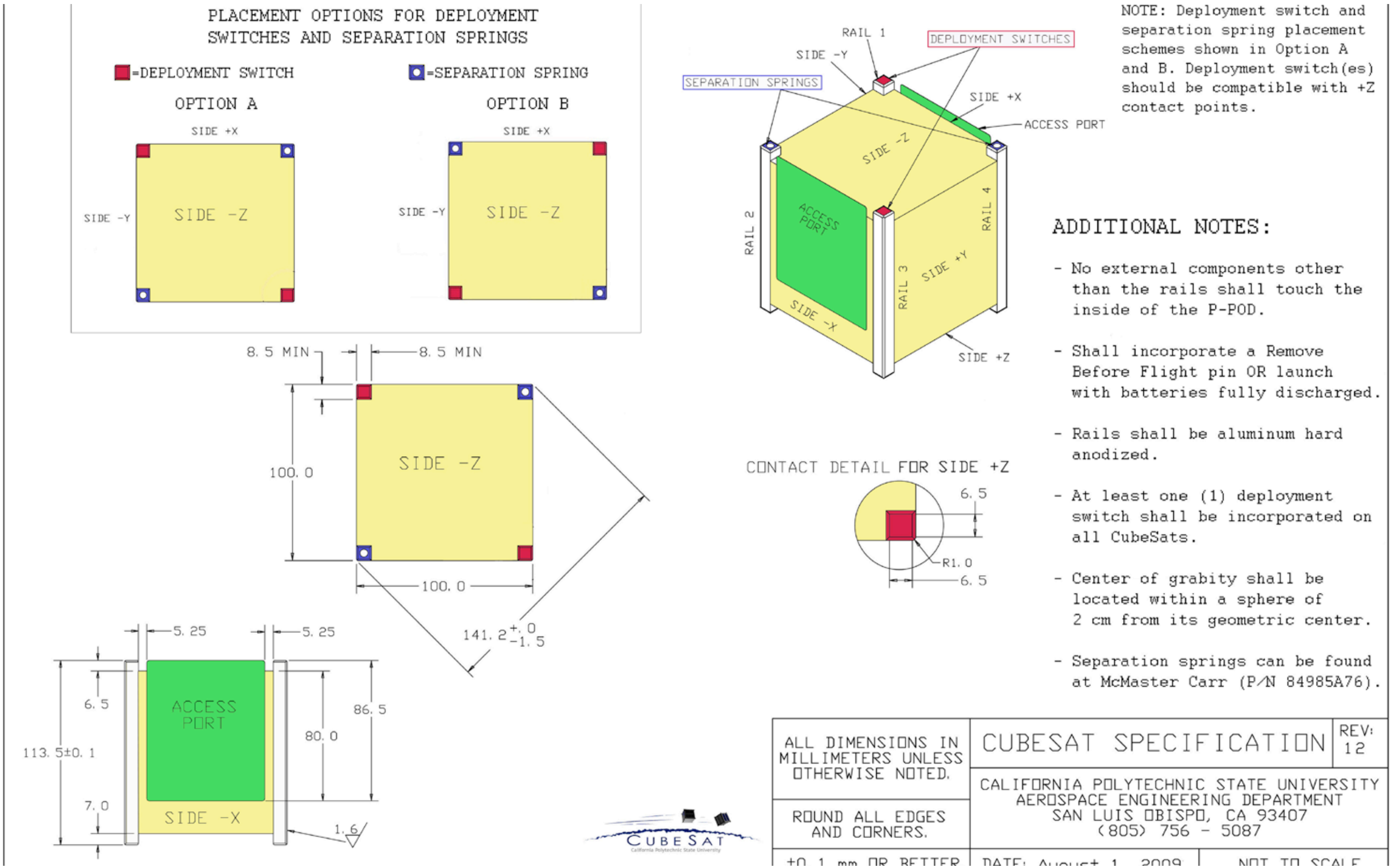
Currently Flying Overhead…

- MSL - $2.5 Billion
- Cassini - $3.27 Billion (with some contributions)
- Dawn - $446 Million

+ more than 25 other missions JPL is involved in (Voyager is still performing science!)



What is a CubeSat?

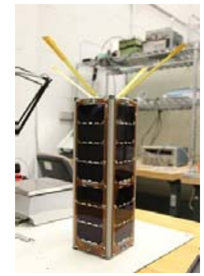


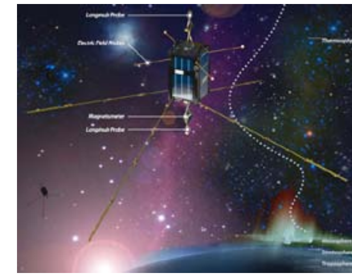
What is a CubeSat?

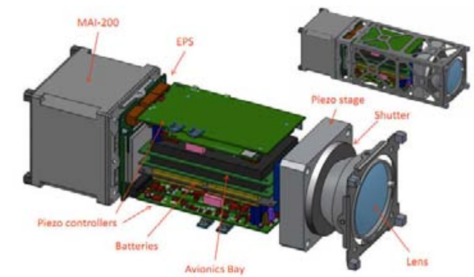
- A CubeSat is an accepted standard to enable low-cost access at the price of higher risk – but not to the primary **(encapsulation of risk)**
- **A CubeSat is a flexible platform** without defined “innards”
- **A CubeSat is an instrument** – with a few spacecraft parts tacked on.

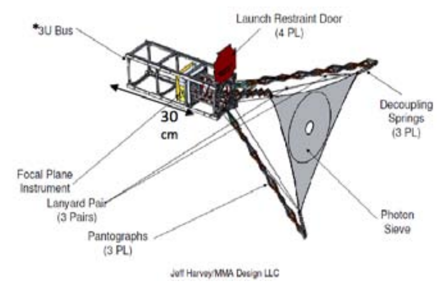
CubeSats – Example Missions

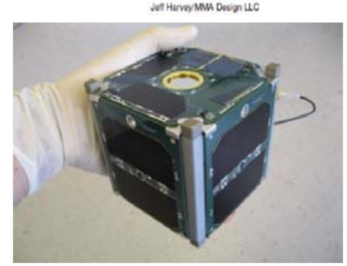
- Space Weather Science (NSF missions)
- Biological Science (NASA ARC missions)
- Astrophysics (Moorehead States's CXBN)
- Planetary Science (MIT's ExoplanetSat)
- Technology Demonstrations
  - Propulsion / Attitude (Nanosail-D)
  - Imagers (FalconSat-7)
  - Solar Arrays (NPS-SCAT)
  - FPGAs (M-Cubed/COVE)
  - Fractionated Space (DARPA F6)
  - Plug-n-Play architectures (AFRL)

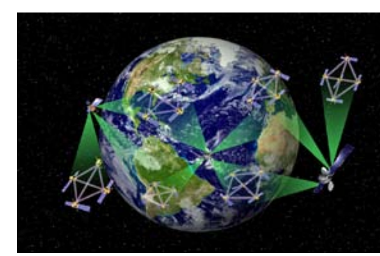




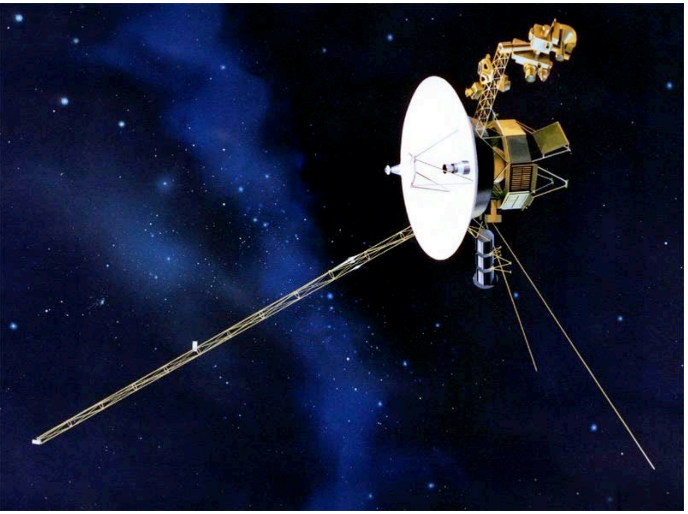


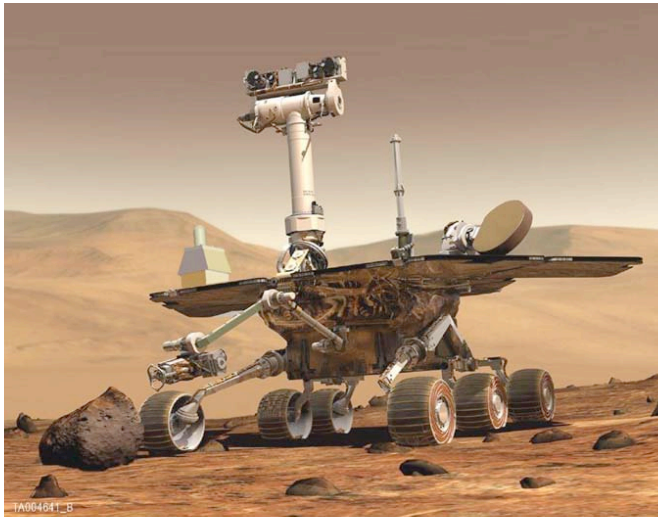




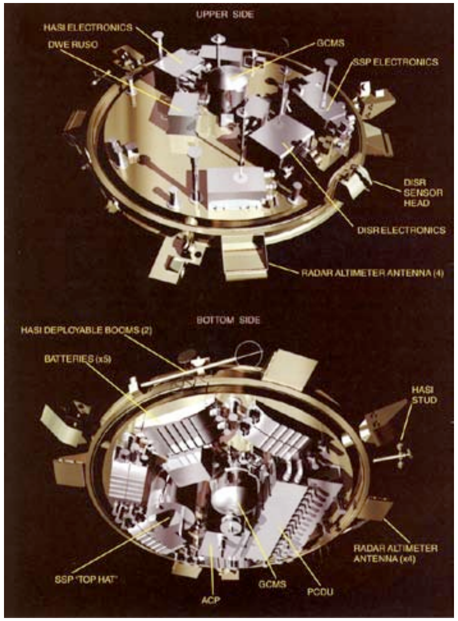


But JPL does BIG things!





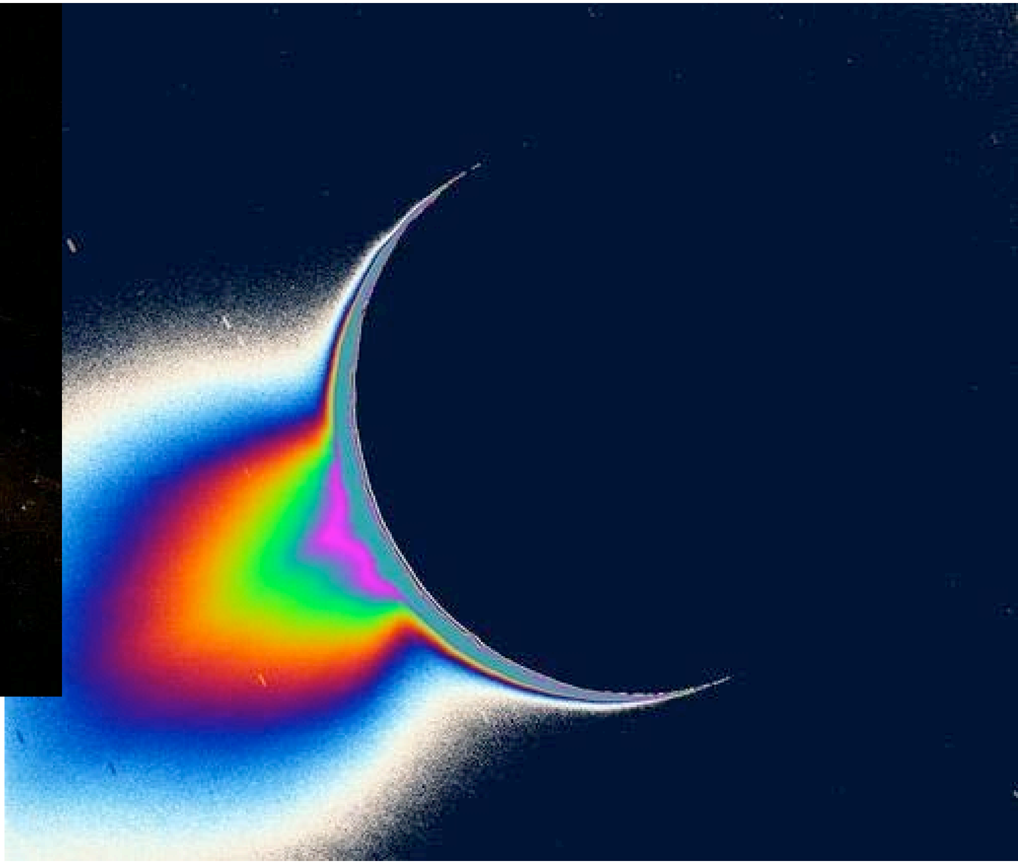
.... Except for these:

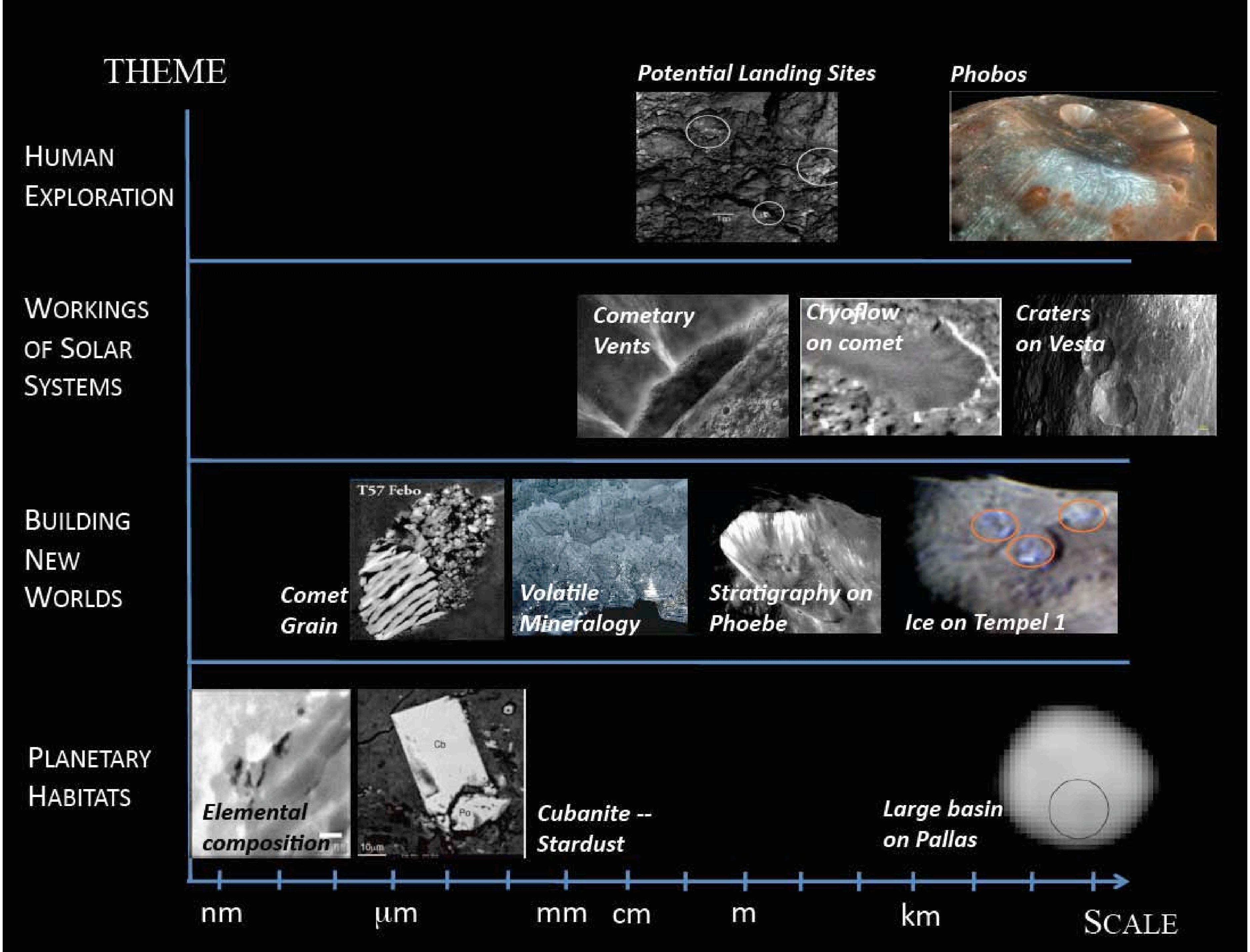


Motivation to Think Small

It’s a Scary Solar System

- NanoSatellites may be useful at other places in the solar system
- Is there compelling science enabled by this platform?




THEME
Potential Landing Sites
Phobos
Human Exploration
Workings of Solar Systems
Cometary Vents
Cryoflow on comet
Craters on Vesta
Building New Worlds
T57 Febo
Comet Grain
Volatile Mineralogy
Stratigraphy on Phoebe
Ice on Tempel 1
Planetary Habitats
Elemental composition
Cb
Po
10μm
Cubanite -- Stardust
Large basin on Pallas
nm
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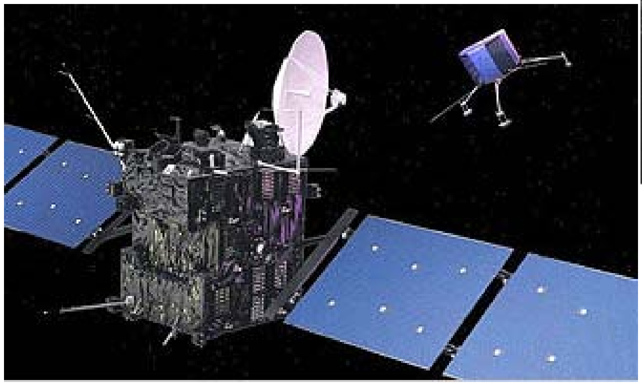
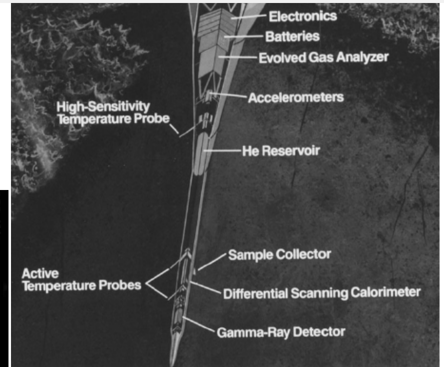
Scale

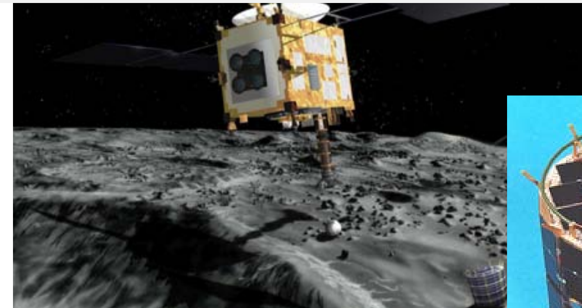
Interplanetary NanoSats



Mothership and tailored static lander (e.g., Rosetta/Philae)

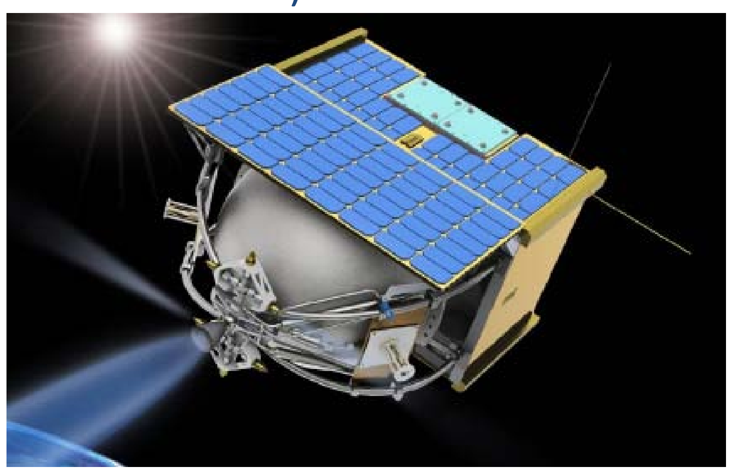


Penetrator(s) and Orbiter (e.g., CRAF)

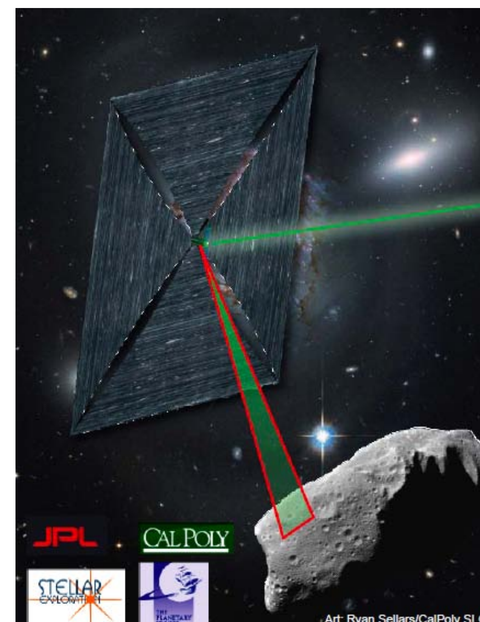


Mothership and tailored hopper (e.g., Hayabusa/Minerva)

Mothership and multiple Cubesats (e.g., Planetary Hitchhiker)

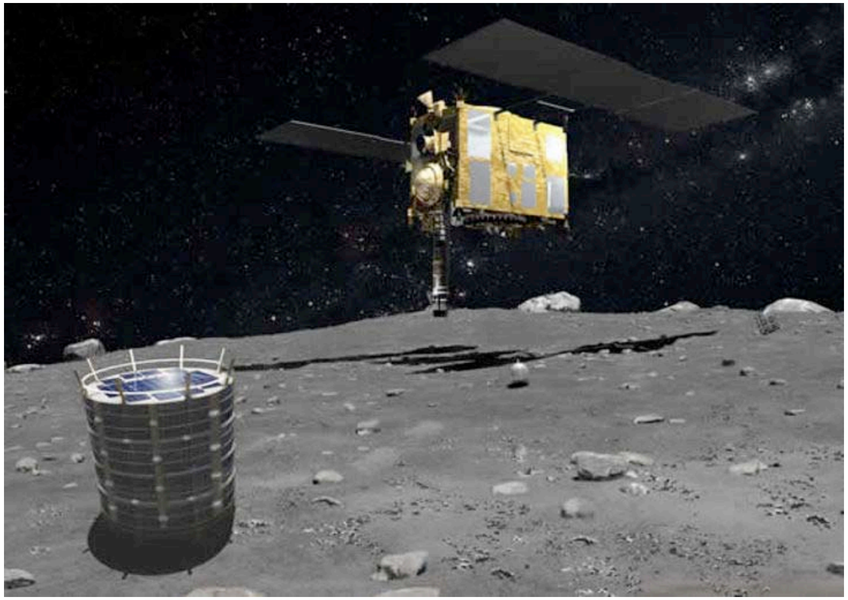


Single Cubesats (e.g., NIAC)



NanoSats and Planetary Exploration

- **Motivation**
  - 2013 Planetary Science Decadal Survey shows high-interest in small-body objects: both close proximity and in situ observations
  - The next 5-10 years may provide several mission opportunities
  - Several nano-spacecraft (Minerva and Muses-CN) have been designed for small-body exploration
  - The CubeSat community has experience with nano-spacecraft – Can we leverage this to explore small-bodies (or the solar system) in a whole new way?



Key Science Drivers for Small, Flexible Spacecrafts

- Capture the diversity of small bodies
  - Regionally (e.g., satellite systems)
  - Globally
- Need for diversified and coordinated exploration
- Characterize surface properties at all scales
  - Heterogeneity (physical and chemical)
  - Exploration of outstanding, discrete features vs. global context
- Characterize z-dimension
  - Local environment (dust, exosphere, radiations)
  - Subsurface (gravity structure, water)
- Visit high-risk/high-science return areas

Diversified and Coordinated Exploration

- Systematic, self-consistent approach for chemistry measurements
  - Elemental composition (e.g., neutron detection), isotopic ratios (e.g., mass spectrometry)
  - Correlation between remote observations, theory, and reality
- Changing the way geophysics is done from space
  - Local or regional gravity/magnetic field characterization
  - Assess risk by using expendable assets, e.g., dust dynamics, electrostatic charging, etc.

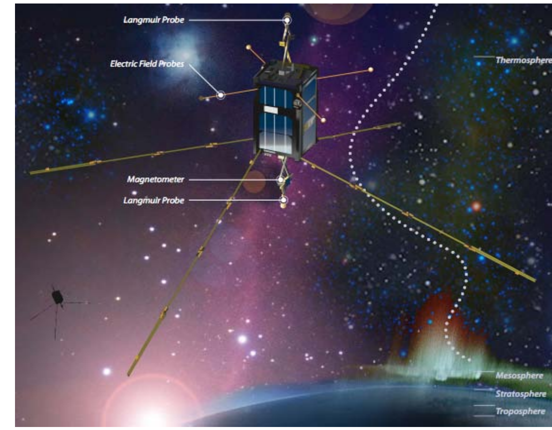
Interplanetary NanoSat Definitions

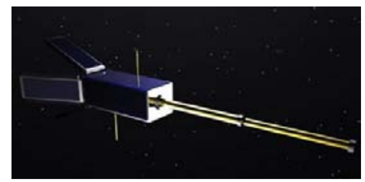
- On the order of 10 kg and 6U in volume
- Propulsion
  - Primary Propulsion (Direct from LEO) – See Rob Staehle's NIAC research
  - Secondary "Propulsion" (Launched from Mothership)
- Communications
  - Direct-to-Earth
  - Relay through Mothership
- Power
  - Solar Power (Inner Solar System)
  - Primary Batteries

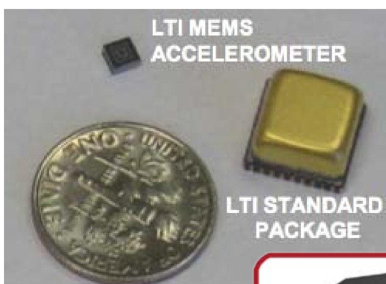
CubeSat Instruments/Sensors

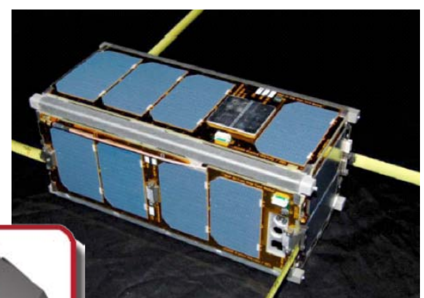
Instrument Examples

- Imagers (Vis, IR, Hyperspectral)
- Spectrometers
- Bolometers
- Field/particle sensors
- Radio science
- Magnetometers









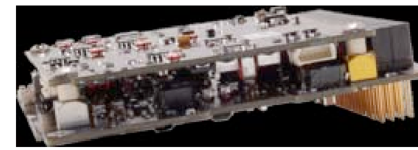
Navigation Sensor Examples

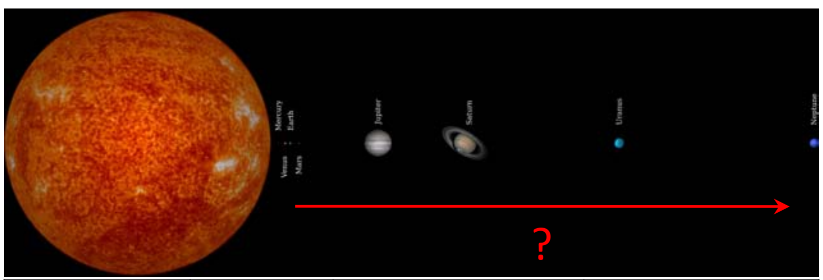
- Star trackers
- Sun sensors
- Horizon sensors
- MEMS gyros and accelerometers (<1 ug)
- X-band transponders

Some instruments/sensors can be dual-purposed!

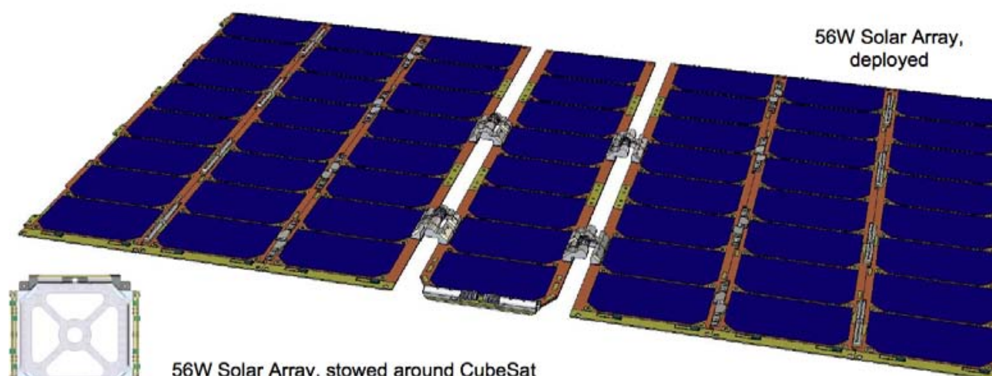
CubeSat Capabilities – Power

- Deployable solar arrays pushing the power envelope
  - Current COTS-available maximum is 56 Watts instantaneous
  - Up to 80-Watt deployable arrays on the horizon
  - Solar array drive systems
- COTS Power Systems
  - 30 Watt nominal power regulation, up to 70 Watts instantaneous
  - Battery packs with up to 33 W-hr have been flown in LEO
- What about power beyond Earth/Lunar orbits?





	Distance (AU)	Solar Power Reduction Factor	80-Watt Earth Array Power at Target (W)
Mars	1.52	2	34.63
Ceres	2.77	8	10.43
Jupiter	5.2	27	2.96
Saturn	9.5	90	0.89
Uranus	19.6	384	0.21
Neptune	30	900	0.09



CubeSat Capabilities Demonstrated

- Structures: 1U, 3U structures available (6U this year)
- Communications: Flexible radios in multiple bands (VHF, UHF, S-Band)
- C&DH: Multiple levels of complexity and radiation-hardening
- Power: Deployable Panels (and other pieces)
- Propulsion: Cold-Gas and EP on the market, sail decelerator demonstrated – further developments upcoming through Edison
- Payloads: 2U and larger payloads available on 3U systems

- **CubeSats are ready to go interplanetary – but what will we do?**

Applications of NanoSats at Small Body Objects

- Workshop in January held at JPL on the use of NanoSpacecraft at Small-Body Objects

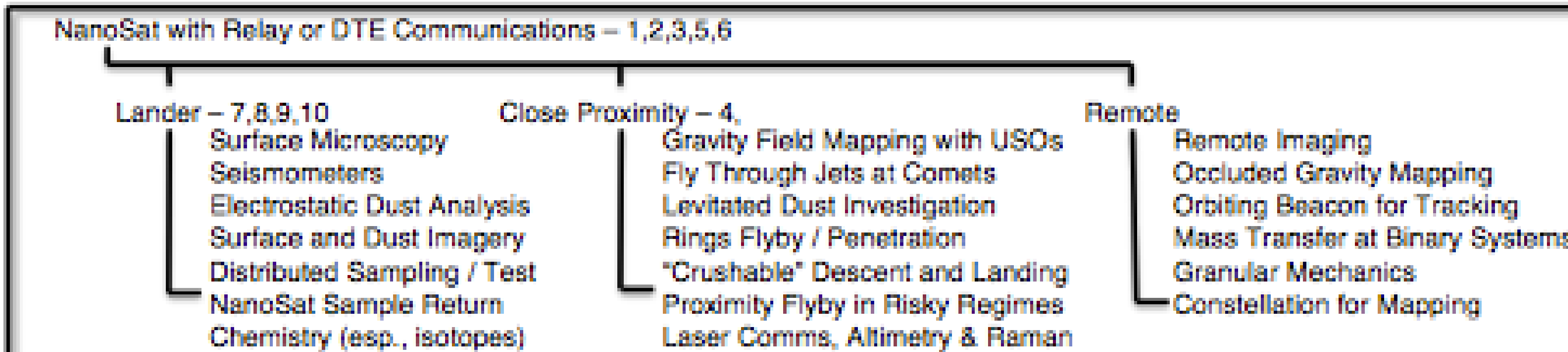


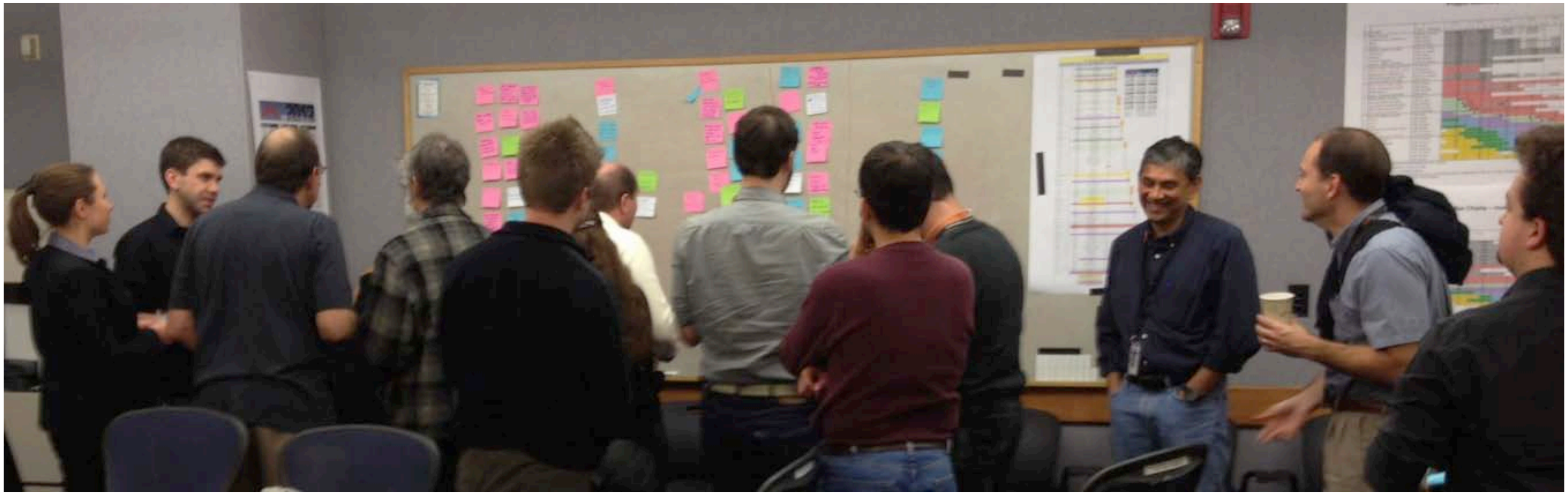
Figure 1: A small selection of science applications categorized by utility location and tied to the technology roadmap.

- U. Michigan, U. Colorado, Naval Postgraduate School, CalPoly – SLO, JPL

- A paper summary will be released at GLEX 2012
- Interest in exploring secondary support options for large missions
- Interest in using a "standard" bus with multiple deployments throughout the solar system.

Applications of NanoSats at Small Body Objects

- Identified 100 science applications enabled by NanoSats
- Developed a technology roadmap towards enabling interplanetary NanoSats
- High-TRL, miniaturized instruments are already available and cover broad range of measurements
- Technologies for the development of small mass spectrometers are in PIDDP/ASTID
- 3 kg payload can combine reconnaissance (Pancam) + geophysical (accelerometers, thermoprobe) + chemical (XRD/XRF, mass specs) observational capability



Finding the Partnership

- There is a strong desire to explore small-body objects, yet **funding is slim**.

- **CubeSats are not providing solutions to traditional planetary problems** (getting lots of data back from far away places) – big spacecraft are just better at that.

- **Partnerships between the CubeSat community and planetary scientists** may result in novel approaches to traditional missions – enabling a new type of exploration.

- **Lessons learned from CubeSats can inform appropriate decisions on risk** – sacrificial elements and cheap vehicles can still be used to perform spectacular science.

- **Co-developing platforms (scientists with engineers)** for interplanetary space is critical – better integration between heritage hardware and novel investigations.

Where will NanoSats go next?