Panel on SPACOMM 2015
Monday, April 20, 2015

Topic: Small Satellite Missions: Capabilities and Challenges in Space Communications

Panelists:

Timothy Pham, Jet Propulsion Laboratory, USA

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Moderator:

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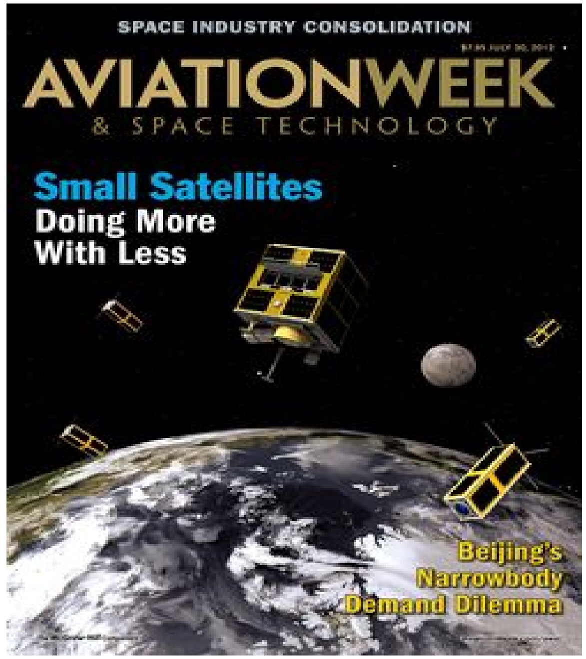
Small satellites are growing… in popularity and utility



- **That's the message from a new study looking into trends and projections for the nano/microsatellite or the so called U Class satellite market.**

- **The new assessment comes from SpaceWorks of Atlanta, Georgia and the study projects that more than 400 nano/micro satellites will need launches annually in the year 2020 and beyond.**

- **SpaceWorks is currently tracking 650 future (2014 – 2016) U Class satellites with masses between 1 kilogram and 50 kilograms in various stages of planning or development.**

CHALLENGES AND OPPORTUNITIES WITH SMALL SATELLITES

NEXCOMM/SPACOMM 2015, 20 APRIL 2015, BARCELONA

José Santiago Pérez Cano
Consultant
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www.euroconsult-ec.com

Sources

This presentation is based on proprietary information deriving from Euroconsult

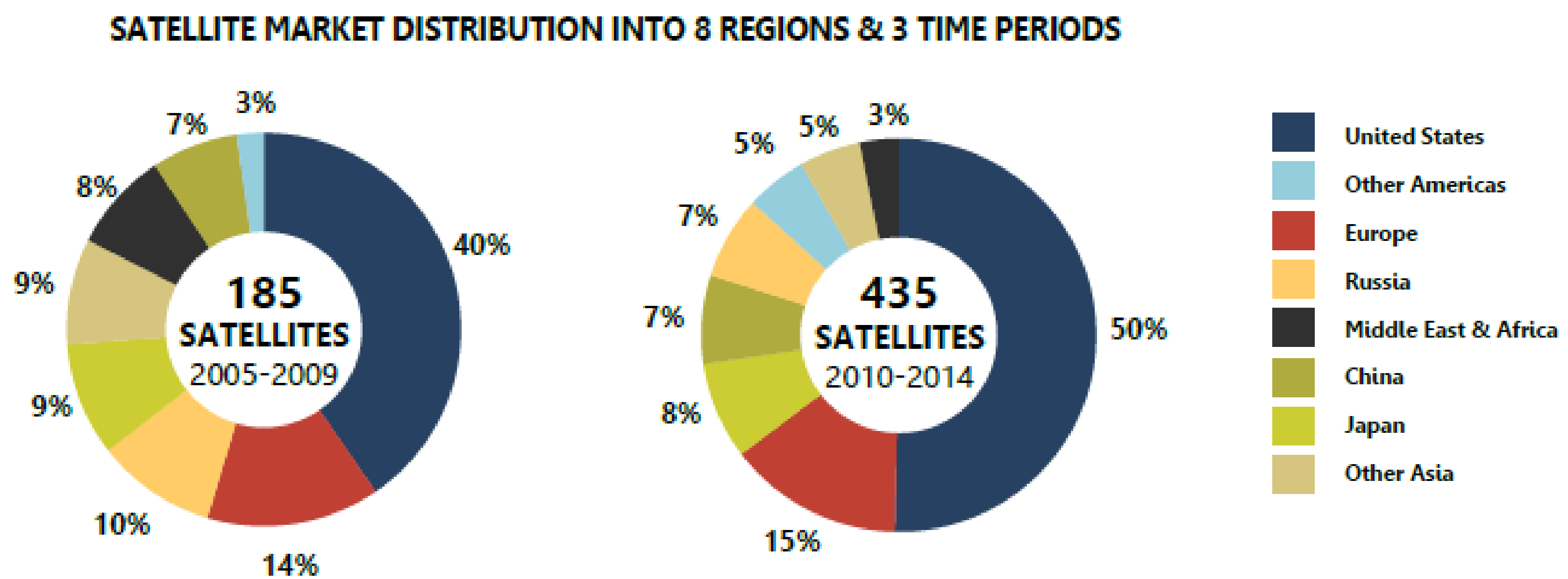
> internal research elements

> SmallSat research report

OUTLINE

> **New Space and Small Satellites, the perfect story**
> **What is New Space?**
> **Are Small Satellites a real business?**
> **10 years of Small Satellites**
> **What is next?**
> **Technological challenges in Small Satellites**

New Space and small satellites, the perfect story



In the next 5 years Europe will increase its share up to ~26% and USA will be slightly lower (43%)

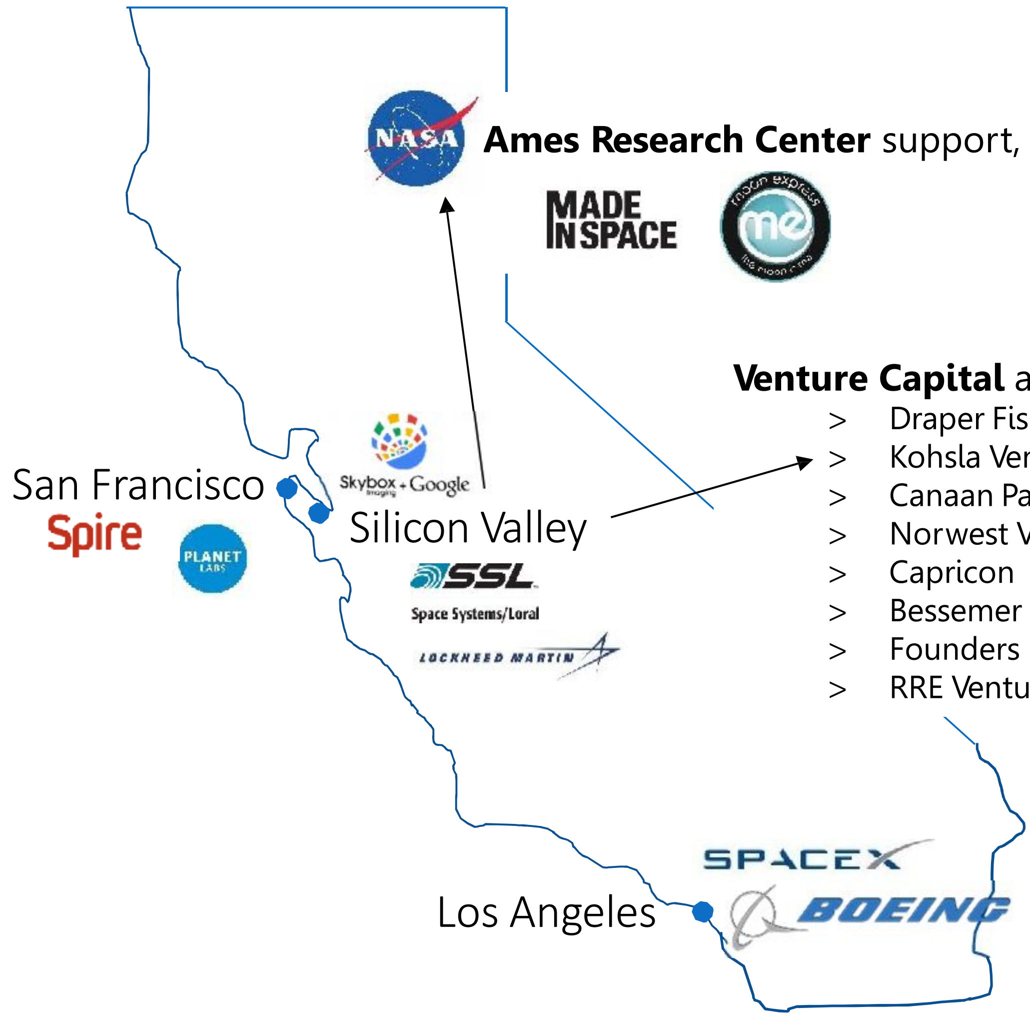
46% of those US satellites are used for commercial purposes

What is New Space?

	Creation	Emblematic Investor	Funds risen	Actions / strengths
SPACEX *Space transportation,* ***satcom constellation ?***	2002	Elon Musk	~$470 M	New actor in the space transportation Service contract with NASA Diversification of client portfolio Future smallsats manufacturing
Skybox + Google *EO*	2009	Google	~$110 M, *acquired for $500 M by Google (2014)*	SW Development for EO Two launched satellites First commercial data distribution contracts obtained before Google's arrival
EO	2010		~$65 M	Founded by former NASA employees Operartor of 100 cubesats constellation First partnership for data distribution
Antennae satcom	2012 *(spin-off from IV)*	Bill Gates	~$82 M	Reception antennae made with nano-materials. Partnership with satelite operators Prototypes phases/ Test on going phase Industrial partnership with Sharp for the industrial

What is New Space?

CALIFORNIA, THE ECOSYSTEM OF NEW SPACE FOR ESTABLISHED COMPANIES AND NEWCOMERS



Ames Research Center support, including :

Venture Capital actives in New Space :

- > Draper Fisher Jurveston
- > Kohsla Ventures
- > Canaan Partners
- > Norwest Venture
- > Capricon
- > Bessemer
- > Founders Fund
- > RRE Ventures

What is New Space?

A concept materializing in wave of investment

Private investors not yet involved in space activities commit money to develop systems/services thanks to:

- The US government leaves room to investors (i.e. stop funding new system development and instead purchase a service from a private operator) and boost the ecosystem
- Technological maturity allows to increase productivity or new uses

70s/80s

End of NASA's budget golden age, end of R&D telecom (ACTS)

Creation of private operators (e.g. PanAmSat), TDRSS commercial

90s

Private projects for telecom constellations (e.g. Ellipso), a domaine non participated by the government, ….. And so, for new private launch systems (e.g. Beal)

3 constellations funded (Iridium, Globalstar, Orbcomm); launcher projects were abandoned

2000s

Externalization to private sector, which is recognized by the government to be mature enough to fulfill their operational needs:

> 1st contract of imagery purchasing by NGA to DigitalGlobe, following a presidential directive

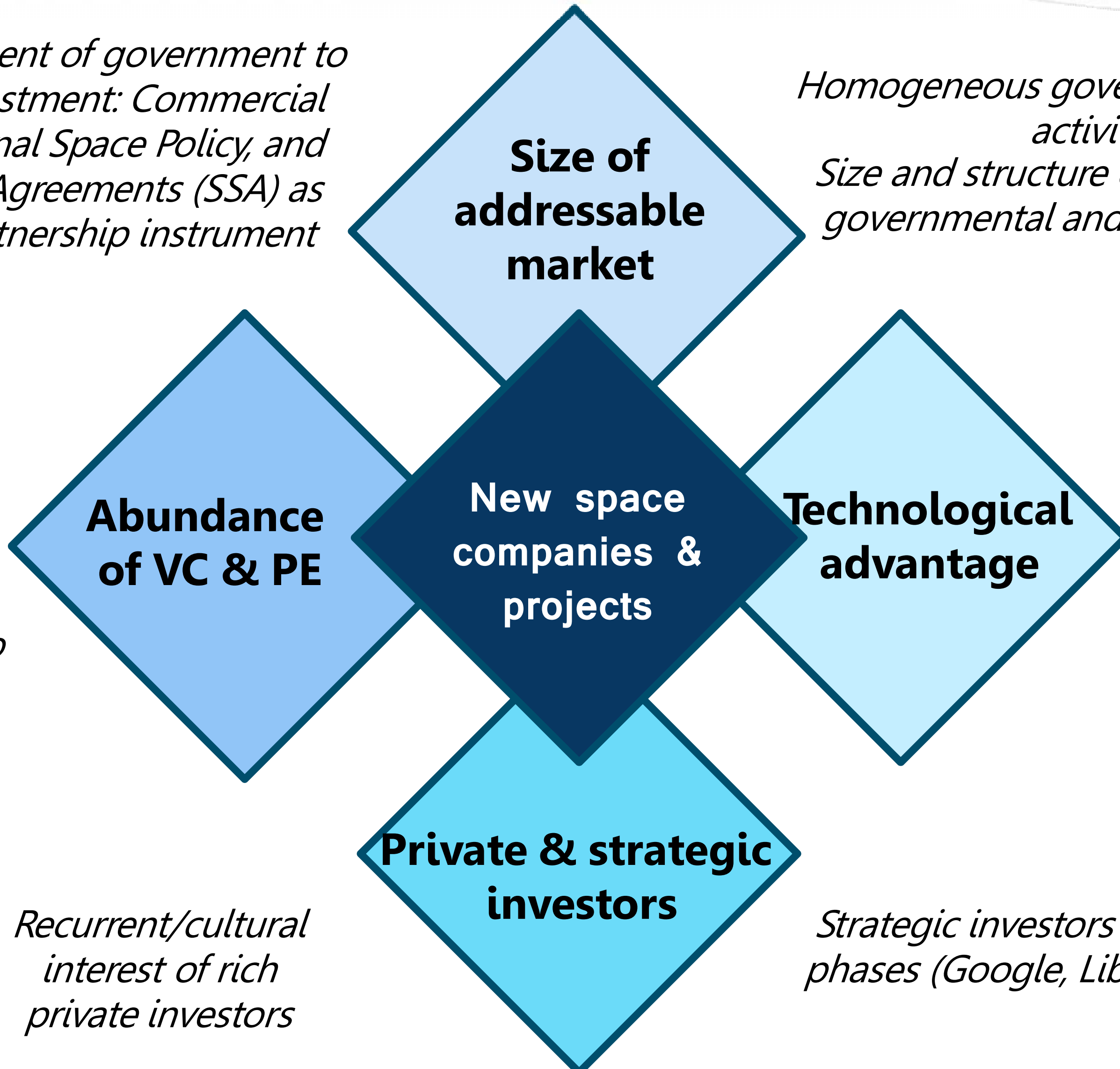
> 2 contracts NASA to SpaceX & Orbital Sciences for cargo delivery to ISS via COTS

What is New Space?

NEW SPACE'S INGREDIENTS MADE IN USA

Encouragement of government to private investment: Commercial Acts, National Space Policy, and Space Act Agreements (SSA) as NASA's partnership instrument

Homogeneous governance of space activity,
Size and structure of the national, governmental and public market



~1 billion $ risen by Silicon Valley actors (from $20M to 500M)

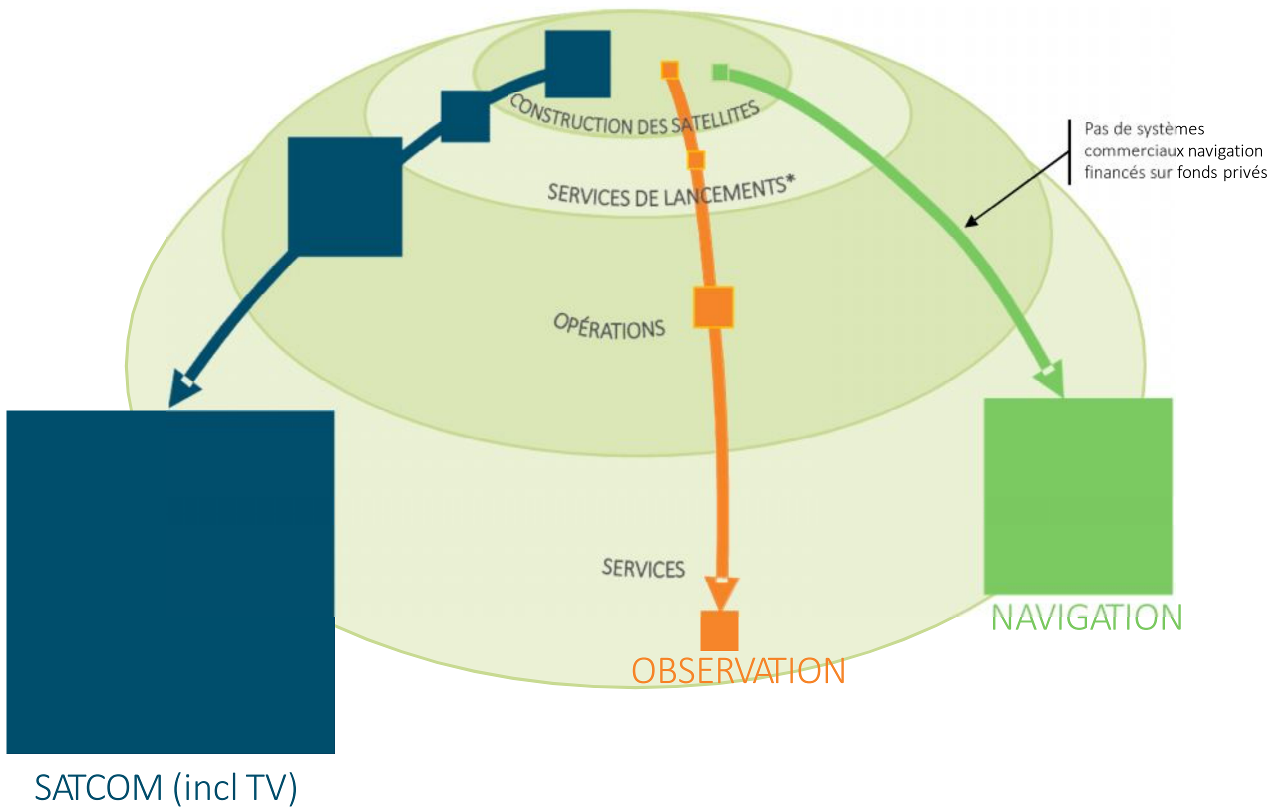
Possibility of technological and process innovation

Recurrent/cultural interest of rich private investors

Strategic investors in firsts project phases (Google, Liberty Media etc.)

Are Small Satellites a real business?

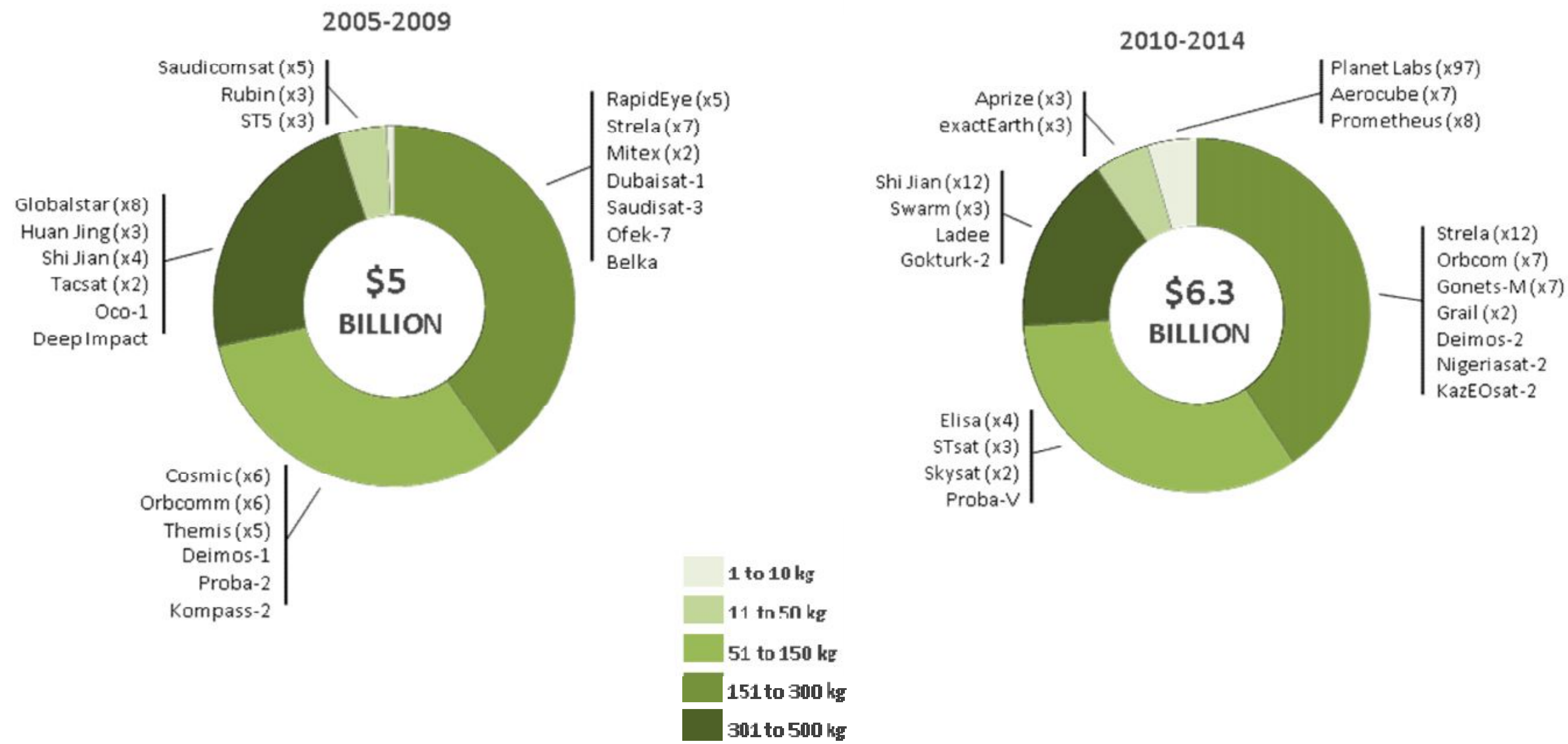
VALUE CHAIN IN SATELLITES WITH COMMERCIAL FINAL UTILIZATION (2013)



*Market value in 2013 billion € at launch

Are small satellites a real business?

PAST DECADE OF THE SMALLSAT MARKET IN TWO LAUNCH PERIODS



Are Small Satellites a real business?

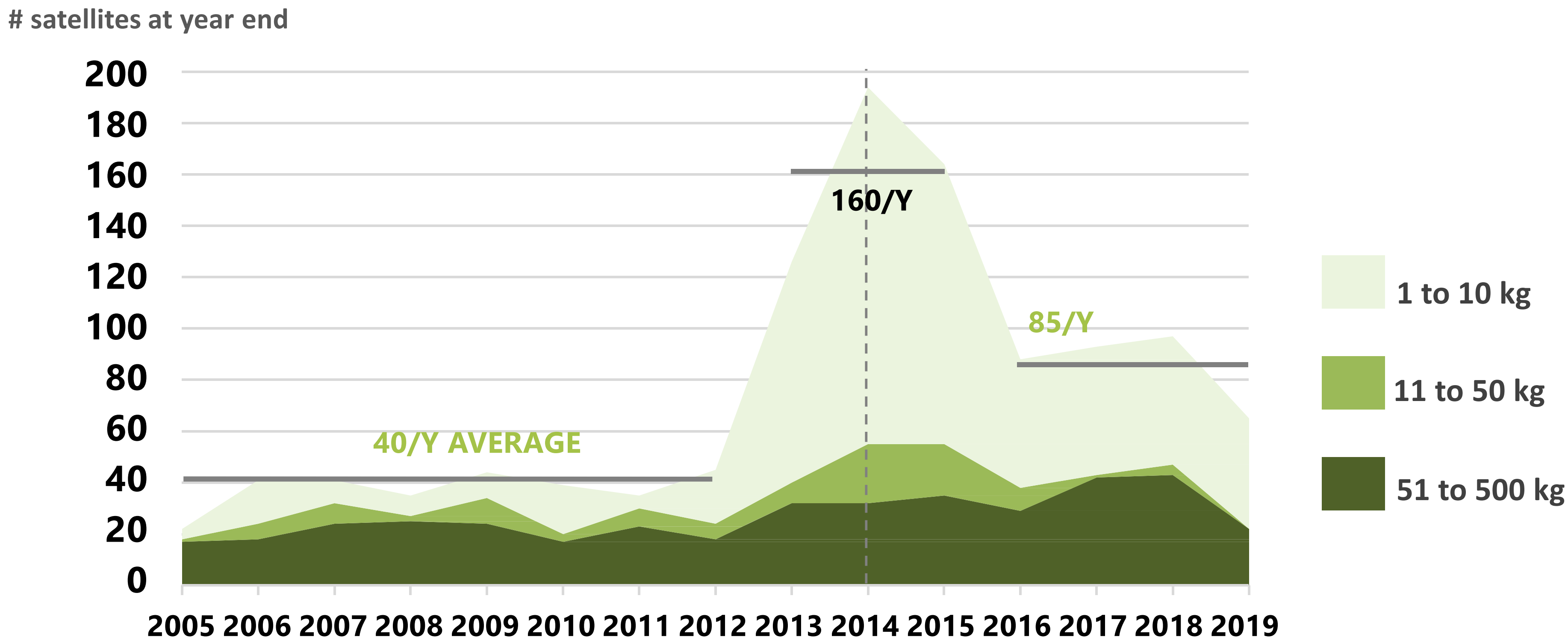
AND… WHAT IS NEXT?

AN INCREASE OF ~17% IS EXPECTED IN THE PERIOD 2015-2019

7.4 BILLION EXPECTED

YES WE CAN!

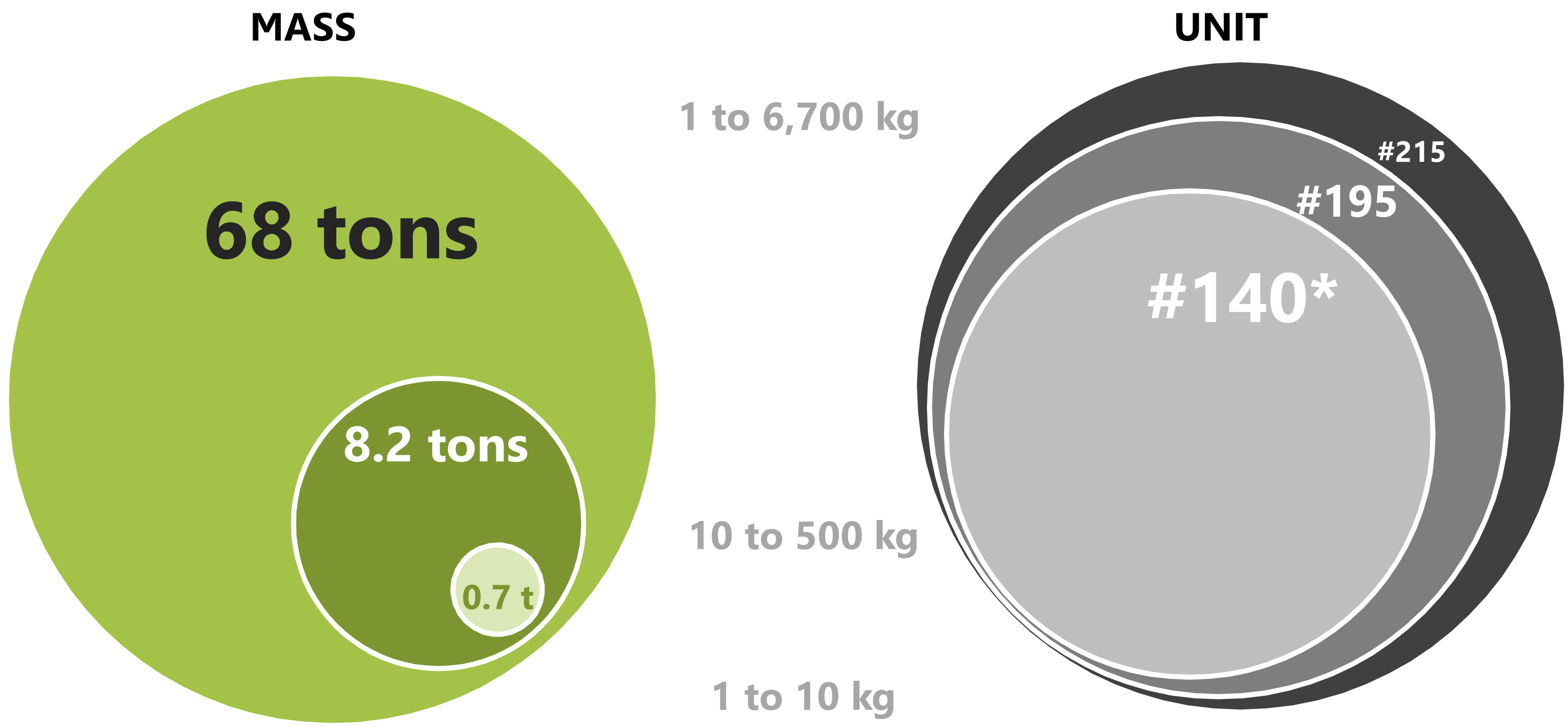
10 years of Small Satellites



32 % FROM NANO SATELLITES COMES FROM UNIVERSITIES /ACADEMIC WORLD (2005-2019)

LET'S ANALYZE 2014…

ALL SATELLITE MARKETS IN LOW EARTH ORBIT (LEO) IN 2014



* Including 93 cubesats for Planet Labs

What is next?

MEGA CONSTELLATIONS?

- There is a flurry of US commercial projects in the comsat, EOsat and metsat domains. Many believe that all are not fundable and that many changes are possible at different stages of the projets
  - No-go or merger possible at paper concept, qualif satellites, 1rst batch launch, 1G replenishment
- Constellations projects are mainly in competition for the same market (permanent metric imagery, met data with GSP-RO, AIS, IoT, M2M), however, with vastly different architectures and capex volumes
- Most of them have not yet selected a satellite manufacturer: except Skysat (SSL/MDA)
- Constellations are deployed in batches

Smallsat constellations projects	EO and meteo missions	Telecom missions	Other missions
Cubesat/nanosat **(< 20 kg launch mass)**	• Planet Lab • Perseus • Spire	• Outernet	• QB50 • ESDN • S-Net
Microsat/minisat **(< 500 kg)**	• Skysat • BlackSky • OmniEarth • PlanetIQ • AxelGlobe	• OneWeb • SpaceX / Google • LeoSat • *+ 6 other ITU filings (see next page)*	• cygnss

What is next?

	OneWeb (L5)	No name	LeoSat	Steam 1&2	Comstellat ion	MCSat	CANPOL -2	3ECOM -1	ASK-1
Partners	Qualcomm, Virgin Galactic, Honeywell	SpaceX, Google, Fidelity	TAS			Thales			
System	648 sats 200 kg 1,200 km	4,025 sats 300-400 kg 1,100 km	80 then 120-140 sats 1,800 km	4,257 sats in 43 planes	794 sats 12 planes	800 to 4,000 sats	72 sats 8 planes	264 sats 12 planes	10 sats

- At least 9 projects to provide communications anywhere on Earth with smallsat constellations have been filed at the ITU
- One project more visible than the others because it is supported by one GAFA company (Google). The GAFA companies study all comm infrastructure solutions to expand the reach for their services
- The two most advanced projects are OneWeb and LeoSat: both are backed by entrepreneurs that are not new to space technology (O3b and Kymeta)
- A new paradygm for the satellite suppliers which may become risk partners in the projects and also satellite operators (make/buy decision of operation service)

Technological challenges

SATELLITE

PAYLOAD

PLATFORM

STRUCTURE & MECHANISMS
- Satellite platform standardizations
- Development of MEMS
- New structure materials

THERMAL
- Miniaturization of active thermal control system

OBDH
- High performance FPGAs
- Wireless bus
- High capacity SRAM memories

AOCS
- Miniaturization AOCS actuators
- Integration of attitude control system

PROPULSION
- Electrical propulsion
- Miniaturization of liquid & solid
- propulsion systems

COMMUNICATIONS
- High gain deployable antennae
- Software Defined Radio
- Optical communications

POWER
- 4junction solar cells
- Flat lithium ion polymer batteries

Technological challenges

LAUNCHERS

HEAVY LIFT

MEDIUM LIFT

- *ADAPTERS (ESPA for ATLAS 5, DELTA4 & FALCON 9)*
- *SPACE TUGS*
- *ISS (NASA'S NLAS, 12 QUADPACK…)*

DEDICATED LAUNCHERS

- *AIR LAUNCHED (Launcher One, SOAR…)*
- *SMALL LAUNCHER (Rocket Lab's Electron,Firefly Alpha …)*
- *ADAPTERS (i.e. for multiple nanosats)*
- *DIRECT LAUNCH (one smallsat)*

THANKS FOR YOUR ATTENTION

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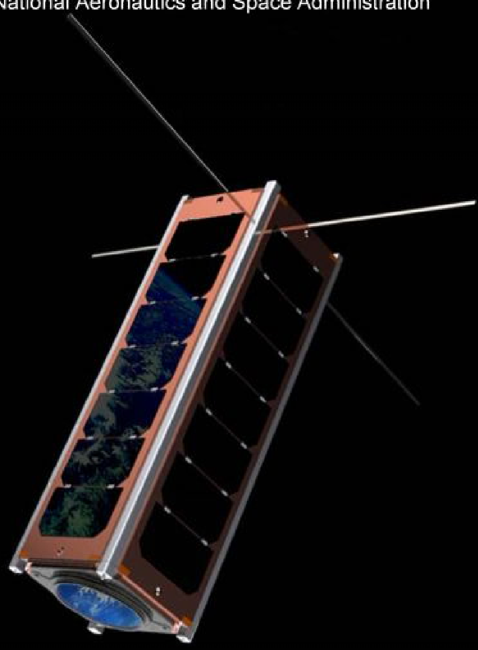
National Aeronautics and Space Administration

FASTSat-HSV



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The FASTSAT-HSV Spacecraft

Requirements and Design

- 12-month LEO mission
- Class D ESPA class spacecraft
- 6 instrument capacity
- NanoSat (CubeSat) Payload Deployer (P-POD)
- Spacecraft mass: ~150 kg
- Size 24" x 28" x 38" (ESPA)
- Payload mass: 21 kg
- Payload power: 30 W average
- S-Band downlink 1 Mbps
- S-Band uplink 50 Kbps
- Stabilization: single axis (magnetic torque rods)
- Pointing accuracy: 20°/3-axis; 10°/single axis
- Pointing knowledge: 0.1°

Dynetics *The Power of Solutions* VCSI

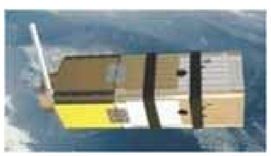
FASTSAT was designed, developed, integrated, tested and certified for flight in 15 months using an innovative business model, tailored processes, co-located and experienced team.

FASTSAT-HSV01

Six Instruments on One Platform

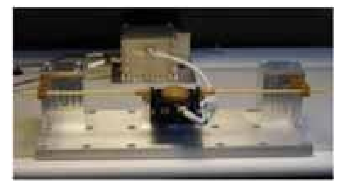
NASA and USNA Miniature Imager for Neutral Ionospheric Atoms and Magnetospheric Electrons (MINI-ME)
- Improve space weather forecasting for operational use

AFRL Light Detection System (LDS)
- Evaluate atmospheric propagating characteristics on coherent light generated from known ground stations



NASA + ARMY SMDC + AFRL + VCSI Nano Sail Demonstration (NSD)
- Demonstrate deployment of a compact 10-m^2 solar sail ejected as a CubeSat

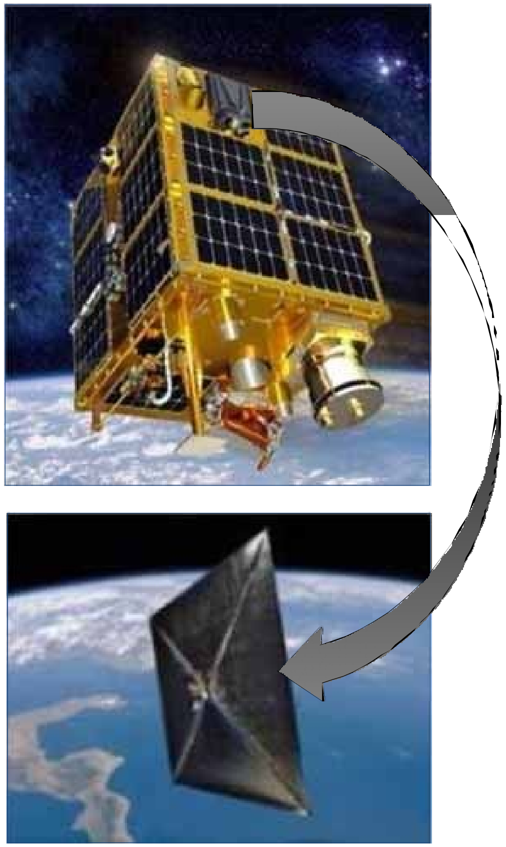
NASA and USNA Thermospheric Temperature Imager (TTI)
- Increase accuracy of orbital predictions for low-Earth orbiting assets



NASA & USNA Plasma Impedance Spectrum Analyzer (PISA)
- Permit better predictive models of space weather effects on communications and GPS signals

AFRL + NASA + AF Miniature Star Tracker (MST)
- Demonstrate small and low-power star tracker

FASTSAT Mission *By The Numbers*



- Spacecraft Status (as of July 25, 2012)
  - Launch Nov 19 at 7:25 PM CST
  - 613 days mission elapsed time
    - 9050 orbits at ~650 km
  - Spacecraft subsystem hardware checkout accomplished by day 7
  - COMM, ADCS, C&DH, Power and attitude control modes functional
- Spacecraft Operations
  - Command & telemetry nominal for all NEN ground stations
  - Down linked 223-M packets for over 17 GB
  - Uplinked 450,000+ commands
  - 9 spacecraft software updates, 5 instrument software updates
- Payload Operations
  - Payload hardware checkout completed on mission day 10
  - Ejected NSD CubeSat day 59, deployed Sail on day 62. The **first ESPA and NASA mini satellite spacecraft to eject a CubeSat**
  - All six SERB experiment operations successfully implemented within first 5 months of launch. The **first STP mission with SIX SERB payloads on a single spacecraft.**
  - Ongoing operations continue for MINI-ME, PISA, TTI, MST, and LDS
    - Over 8.4 GB of data downlinked

FASTSAT-HSV01 has completed > 20 months of flight operations, doubling pre-mission requirements and further demonstrating capabilities of an affordable ESPA class mini satellite S&T mission.

Small Satellite Missions: Capabilities and Challenges in Space Communications

Tim Pham

Jet Propulsion Laboratory

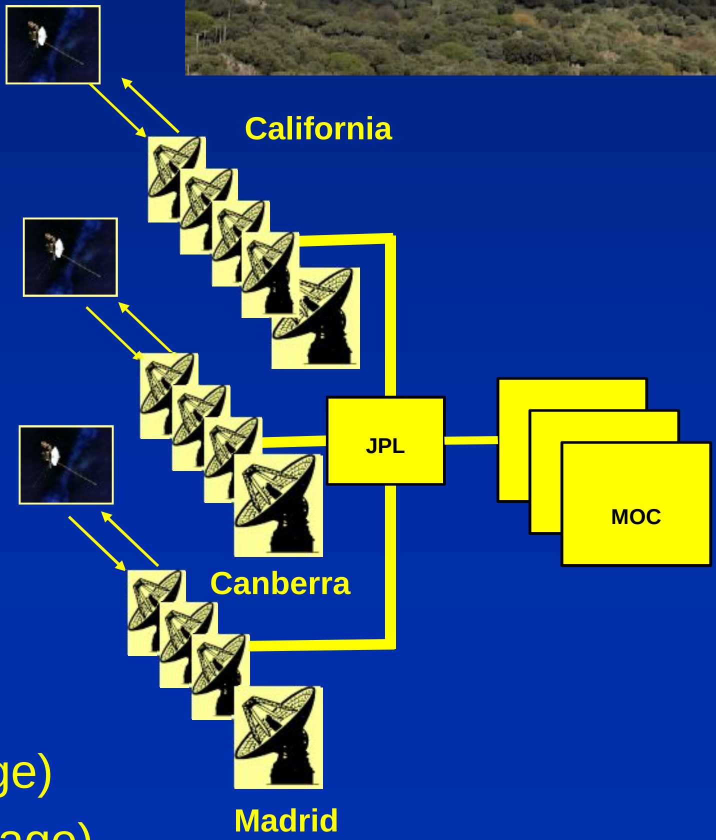
California Institute of Technology

Outline

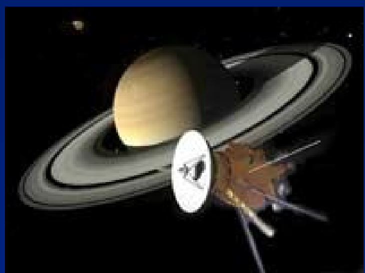
- Focus of discussion
- Deep space communications with the DSN
- NASA cubesat initiatives
- Opportunities and challenges
- One possible mitigation

Focus of Discussion

- Focus on scientific small satellites within NASA
  - Impact in deep space communications services provided by the NASA Deep Space Network
- DSN overview
  - Global coverage at 3 sites – California, Canberra and Madrid
  - Collection of a 70m and 3-4 34m antennas at each site
  - Support missions from HEO to edge of solar system
  - High performance optimal to deep space communications
    - Compared to typical 10m university/commercial tracking station
      - Low noise (~4x – 5x advantage)
      - High gain (~10x – 50x advantage)



Sample of Current Deep Space Missions

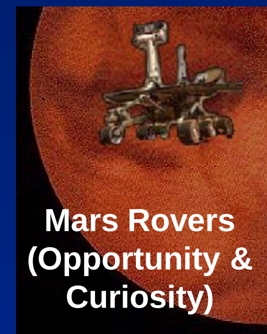


Cassini: Saturn

SIRTF: Astronomy

STEREO:Sun

Mars Odyssey



Mars Rovers (Opportunity & Curiosity)

Rosetta: Comet

Voyager: Interstellar

Chandra: Astronomy

Mars Express

Mars Reconnaissance Orbiter

JUNO: Jupiter

Dawn: Asteroids

New Horizons: Pluto

Kepler: Exoplanets

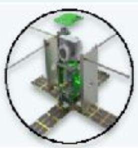
MESSENGER: Mercury

NASA Initiatives with Small Satellites

- Potentially doing science with less cost & support to Science Technology Engineering Technology (STEM) education
- CubeSat Launch Initiative (https://www.nasa.gov/directorates/heo/home/CubeSats_initiative.html)
  - 39 cubesat launched on Education Launch of Nanosatellite missions (ELANA I-VI, X) since 2011
  - 9 or more cubesats scheduled on upcoming ELANA missions (VII, IX, XI – XIII)

NASA Initiatives with Small Satellites

- Three small satellite payloads recently selected for Exploration Mission 1 (EM-1), 2018 launch, circumlunar trajectory

Payload *NASA Centers*	**Strategic Knowledge Gaps Addressed**	**Mission Concept**
BioSentinel *ARC*/JSC 	**Human health/performance in high-radiation space environments** • Fundamental effects on biological systems of ionizing radiation in space environments	Study radiation-induced DNA damage of live organisms in cis-lunar space; correlate with measurements on ISS and Earth
Lunar Flashlight *JPL*/MSFC/MHS 	**Lunar resource potential** • Quantity and distribution of water and other volatiles in lunar cold traps	Locate ice deposits in the Moon's permanently shadowed craters
Near Earth Asteroid (NEA) Scout *MSFC*/JPL 	**NEA Characterization** • NEA size, rotation state (rate/pole position) **How to work on and interact with NEA surface** • NEA surface mechanical properties	Slow flyby/rendezvous and characterize one NEA in a way that is relevant to human exploration

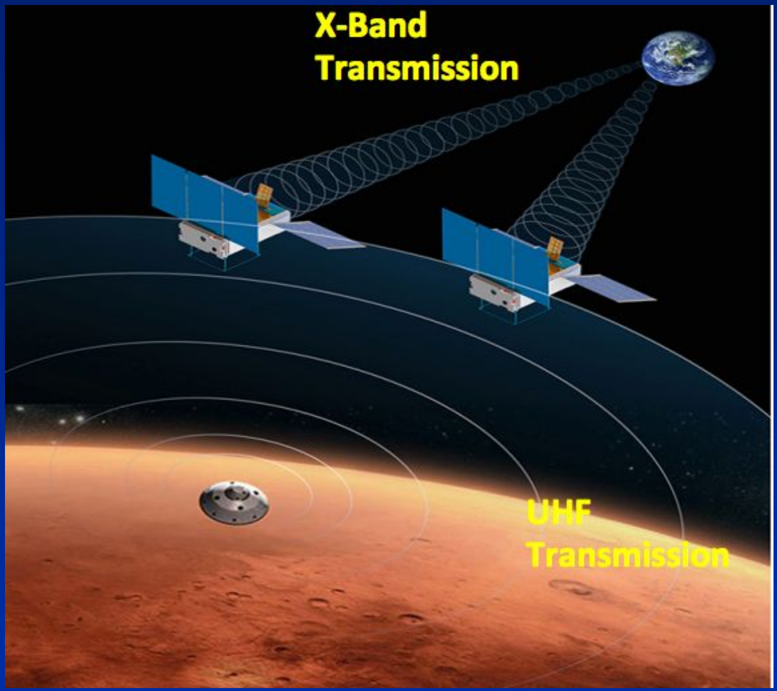
Reference: B. Cohen et al., Lunar Flashlight: Mapping Lunar Surface Volatiles Using a Cubesat, http://www.lpi.usra.edu/meetings/leag2014/presentations/cohen.pdf

JPL Cubesats Program
in Partnership with Universities

- Under NASA Cubesat Launch Initiative
  - M-Cubed/COVE 2 – Michigan Multipurpose Minisatellite/Cubesat Onboard processing Validation Experiment (launch: Dec. 2013)
  - IPEX – Intelligent Payload Experiment (launch: Dec. 2013)
  - GRIFEX – Geostationary coastal and air pollution events Readout integrated circuit In-Flight Performance Experiment (launch: Jan. 2015)
  - RACE – Radiometer Atmospheric Cubesat Experiment (launch: Oct. 2014)
  - LMRST – Low Mass Radio Science Transponder (launch: NET Aug. 2015)
  - ISARA – Integrated Solar Array and Reflectorarray Antenna (launch:TBD)
  - NSPIRE – Interplanetary Nanospacecraft Pathfinder in Relevant Environment (launch: TBD)
  - CHIRP – Cubesat VHF transmitter to study Ionospheric dispersion of Radio Pulses (launch: TBD)

Reference: http://www.jpl.nasa.gov/cubesat/

First Planetary Cubesat Mission
Mars Cube One (MarCO)



- Relaying data from Mars Insight Mission (2016) during Entry, Descent, Landing
- Two 6U cubesats, demonstrate communications/relay and navigation at planetary scale

Reference: https://marscubesatworkshop.jpl.nasa.gov/static/files/presentation/Asmar-Matousek/07-MarsCubeWorkshop-MarCO-update.pdf

Benefits and Challenges

- Benefits
  - High G/T performance of DSN antennas highly beneficial to small satellites operation
    - Enable higher data return at further distance
- Challenges
  - Schedule availability
    - Current heavy DSN schedule loading, with <10% open time
    - Support to smallsats fit within current open time? Or great impact to non-smallsat missions? Priority in time allocation?

Increase DSN Utilization with MSPA

- Multiple spacecraft per antenna (MSPA) operation increases DSN utilization
  - Simultaneous tracking of multiple spacecraft within antenna beam
  - One antenna, multiple receivers
  - DSN currently supports 2 spacecraft per antenna
    - incremental extensible to 4-MSPA and beyond in future
- More utilization efficiency can be gained with Opportunistic MSPA (http://ipnpr.jpl.nasa.gov/progress_report/42-200/200B.pdf)
  - Opportunistically capture smallsat signals as they appear in the beam when antenna tracks another spacecraft
  - Recorded data sent to smallsat users for telemetry extraction
  - Alternatively, telemetry extraction done by DSN with off-line processing
    - Tradeoff between development effort vs. WAN bandwidth demand
- Constraint
  - Spacecraft co-location within antenna beamwidth
    - X-band Footprint: 40km at GEO; 400km at Moon; 1500 km at L1/L2