Decadal Survey for Earth Science and Applications from Space – ESAS 2017 and the Role of CubeSats in Earth Science

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Questions for Consideration

•What can CubeSats do for Earth science that is unique to the platform?

•What do you see as the hard limits – scientific, technological, or policy-related – of the usefulness of the CubeSat platform for Earth science?

•What Earth *science* (beyond technology demonstration) has already been achieved (or is currently funded) with CubeSats?

•What Earth science Decadal Survey questions could be addressed using CubeSats?

•What Earth science is enabled by CubeSats that isn't otherwise feasible with a more traditional "large" satellite (e.g., Aura), and what would such a mission architecture look like?

•What is the appetite for CubeSats in the Earth science community?

•How does the NASA Earth science division currently view the science potential of CubeSats? What investments are being made or are planned?

•How does/could the lower barrier to CubeSat participation change the way Earth science is conducted in the future?

•The NRC committee is working to define what a CubeSat is for the purposes of this report. 12U may be the imposed size limit. Is there Earth science that could be readily achieved if that size limitation were relaxed (i.e., with a smallsat(s) larger than 12U)?

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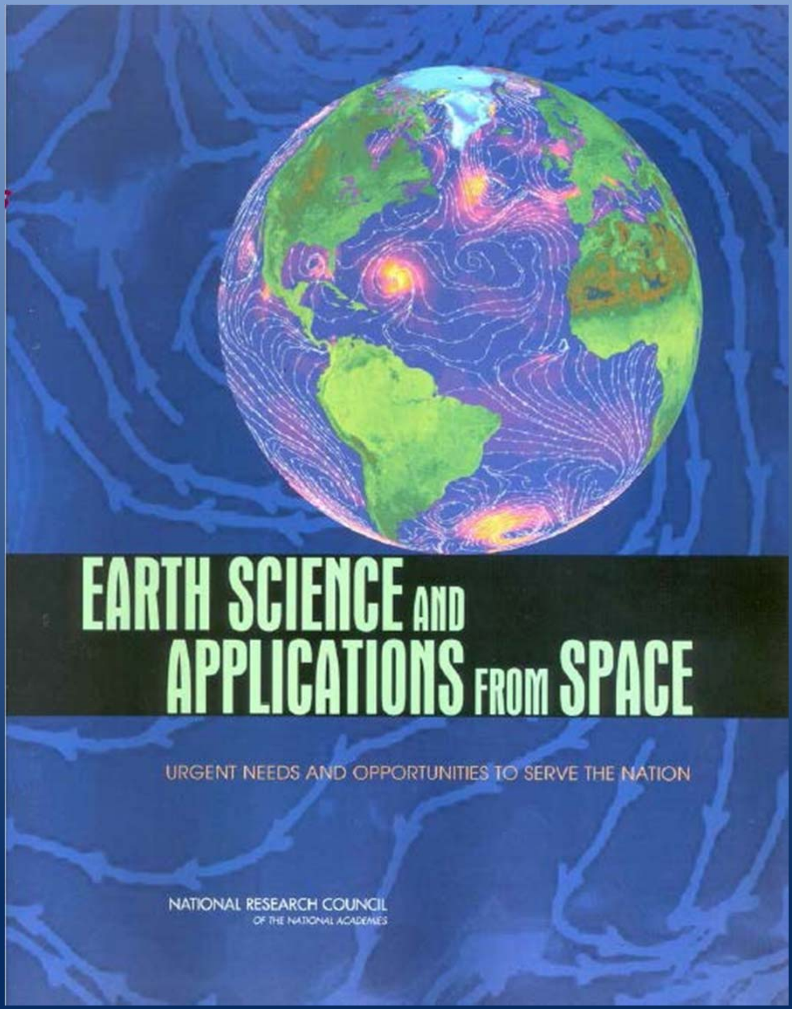
Vision of the Inaugural Decadal Survey
Advancing Earth System Science to Benefit Society

"Understanding the complex, changing planet on which we live, how it supports life, & how human activities affect its ability to do so in the future is one of the greatest intellectual challenges facing humanity. It is also one of the most important for society as it seeks to achieve prosperity & sustainability."

-- *Interim Report of the Decadal Survey, April 2005*



ESAS 2017

- Sponsors:
  - NASA-Earth Science Division;
  - NOAA-NESDIS; and
  - USGS, Climate & Land Use Change

Backdrop: In Addition to Tight Budgets…

- **NASA**: Has a backlog of missions recommended in the inaugural survey as well as increased responsibilities—without commensurate budget increases— starting after the JPSS-1 era for vertical profiles of stratospheric and upper tropospheric ozone, solar irradiance, Earth radiation budget measurements, and altimetry (beyond Jason-3).

- **NOAA**: Stabilizing the weather satellite portfolio and avoiding a potential gap between the NPP spacecraft and the first of the next-generation POES systems, JPSS-1, is a top priority. "Climate"-related instruments moving to NASA.

- **USGS**: Landsat-8 launched Feb. 2013. USGS interested in future capabilities for a sustained land-imaging imaging program. However, Landsat-9 is projected to be a near-rebuild of L-8 for launch in in 2023. (TIRS on L-8 only has 3-year design life; NASA looking at Class-D TIR free-flyer for 2019 launch, but Senate & House have rejected this option and instead ask for acceleration of launch date for L-9.)

ESAS 2017 vs. ESAS 2007

- No longer appropriate to base recommendations on an aspirational budget
- Congressionally-mandated independent Cost and Technical Evaluation (CATE) for big ticket items
- Likely that the balance across Earth System Science will be "valued" to avoid having one recommended activity grow at expense of all others
- Increased opportunities to consider "new space" ideas—new players, smaller and less costly platforms, constellations, hosted payloads
  - Challenge: developing *credible* evaluations of their potential
- Improved consideration of international partners
- Existence of high-level guidance regarding Earth observations: NASA Climate-centric Architecture; OSTP National Strategy for Civil Earth Observations (2014); 2nd National Earth Observation Assessment due 06-16

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Primary Elements of the SOT

- Assess progress in addressing the major scientific and application challenges outlined in the 2007 Earth Science Decadal Survey.

- Develop a prioritized list of top-level science and application objectives to guide space-based Earth observations over a 10-year period commencing approximately at the start of fiscal year 2018 (October 1, 2017).

- Identify gaps and opportunities in the programs of record at NASA, NOAA, and USGS in pursuit of the top-level science and application challenges—including space-based opportunities that provide both sustained and experimental observations.

- Recommend approaches to facilitate the development of a robust, resilient, and appropriately balanced U.S. program of Earth observations from space. Consider: Science priorities, implementation costs, **new technologies and platforms**, interagency partnerships, international partners, and the *in situ* and other complementary programs carried out at NSF, DoE, DoA, DoD.

New Technologies and Platforms

Will consider the agencies' ability to replicate existing technologies to improve and sustain operational delivery of public services, and also to produce consistent and reliable science and applications data products across different generations of measurement technology, as new measurement innovations are introduced.

Equally important are the roles of new technology and risk tolerance; identifying mission architecture options; outlining choices on the allocation of the overall budget into proportionate pools for small, medium or large missions, or continuous and research and application missions; implementing cost caps and a decision-tree process in the event of cost overruns; and maintaining a solid base for research and analysis

Suggest approaches for evaluating and integrating new capabilities from non traditional suppliers of Earth observations;

Context for "New Space" Options in the 2017-2027 Decadal Survey for Earth Science and Applications from Space

- Highly constrained agency budgets for the foreseeable future
  - NASA's Earth Science budget under particular scrutiny, but to date has stayed roughly level
  - NOAA has limited budget flexibility; budgets driven by requirements for JPSS and need to avoid a gap in the polar orbiters
  - Congress had asked for Landsat-9 options at significantly reduced cost, but has since backed off; plans for L-9 are to be a L-8 clone at similar cost

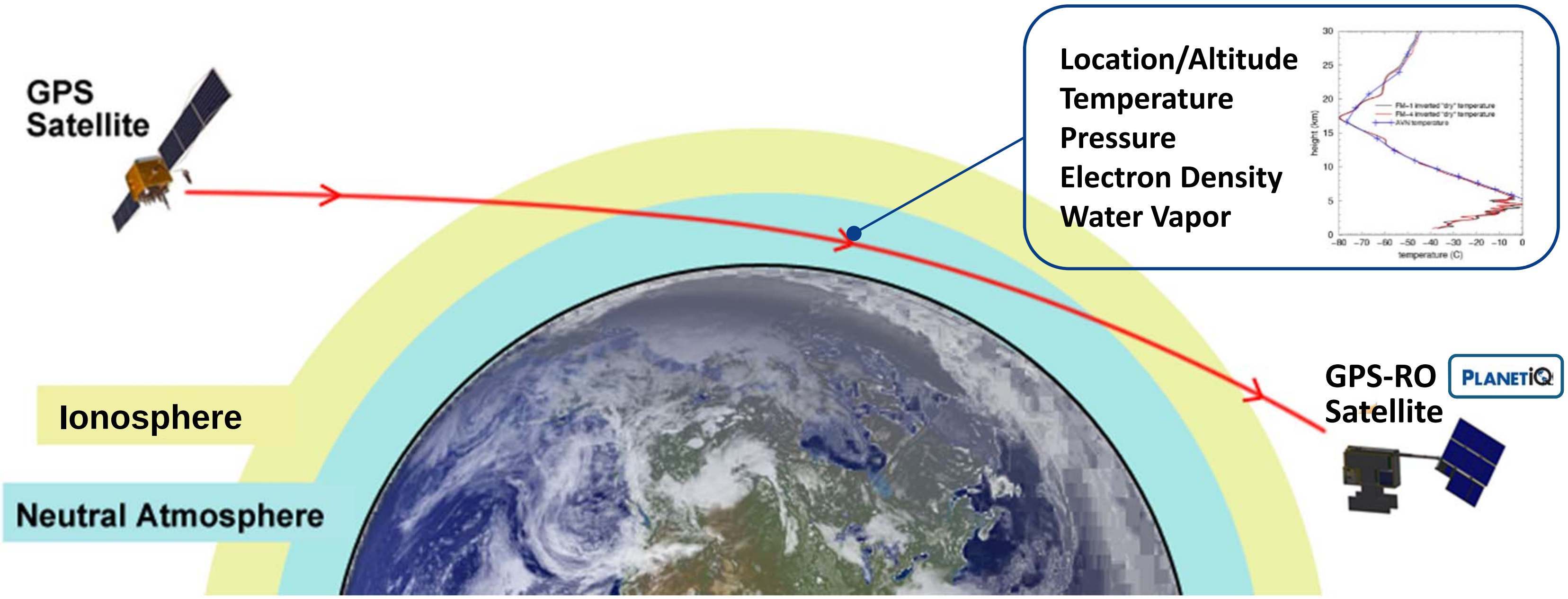
- Backlog of missions for NASA from the inaugural survey and those executed are costing 2x or more than forecast by the survey

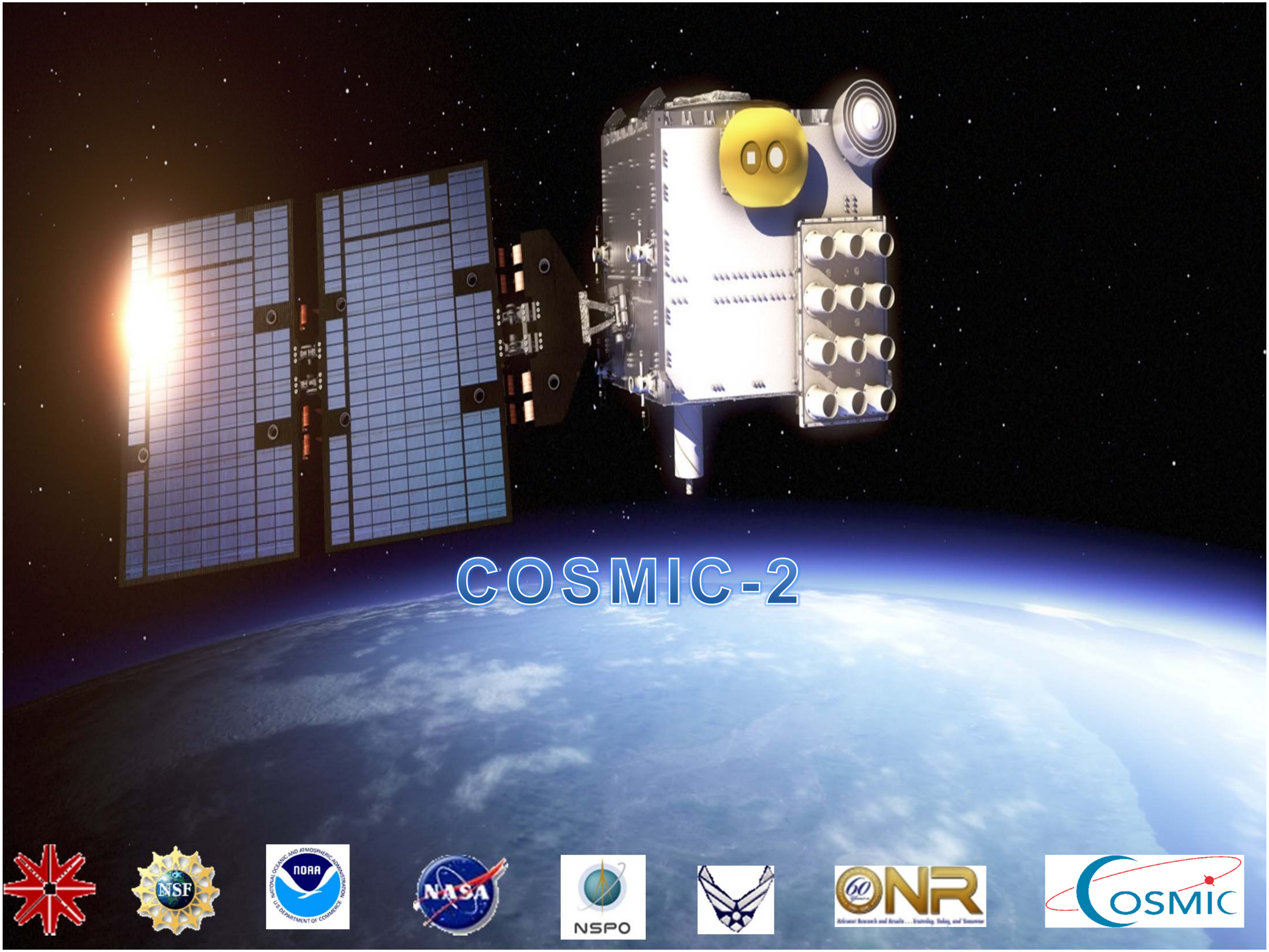
- NASA has increased responsibility, but not commensurate budget increases, for "continuity" missions formerly assigned to NOAA: total solar irradiance, ocean surface topography, ozone profile, and Earth radiation budget

"New Space" ideas—new players, smaller and less costly platforms (including CubeSats), constellations, and hosted payloads—as well as small PI-led programs (e.g., NASA's Venture-class) and additional use of the ISS platform hold promise to accomplish "more for less."

GPS Radio Occultation: How It Works

- Precise, cost-effective technique for measuring the Earth's atmosphere from space
- Highest-impact satellite data for weather forecasting and climate monitoring
- Data similar to weather balloon, but on a global scale
- Innovative ability to leverage existing investments in GPS technology




COSMIC-2
NSF
NOAA
NASA
NSPO
ONR
COSMIC

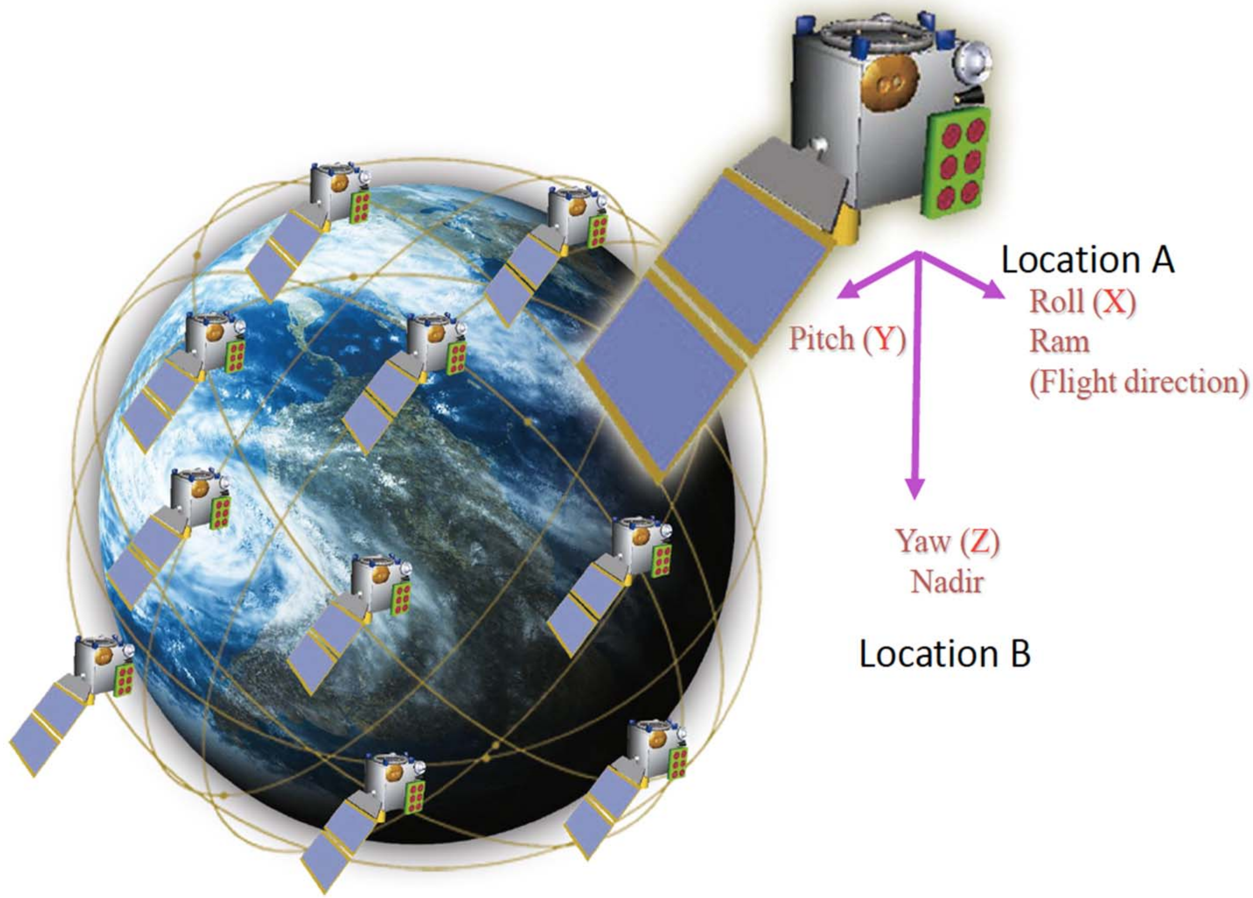
COSMIC

The mission of the COSMIC Program is to develop innovative observational techniques that use signals from Global Navigation Satellite Systems (GNSS), and to support the application of these techniques in research and operations for the broader Earth Science community.

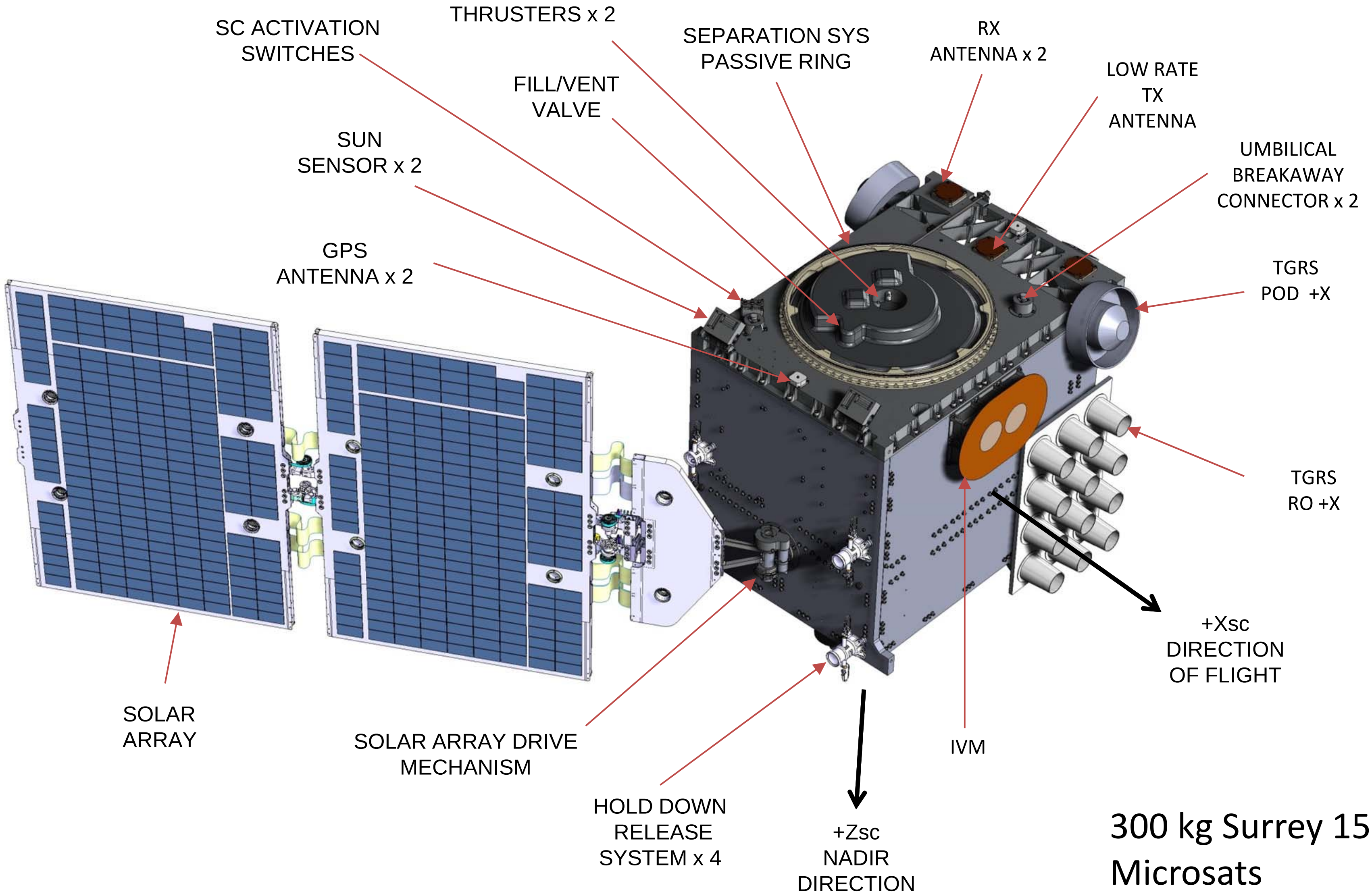
A major step toward the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) project took place in April 1995 when a prototype instrument designed by JPL went into orbit aboard the MicroLab-1 satellite on a mission conceptualized and planned by UCAR's GPS/MET team. The GPS/MET prototype obtained over 100,000 atmospheric soundings, fulfilling its role as a proof-of-concept experiment.

The next development of GPS/MET began on 4 December 1997 when UCAR signed a planning contract with Taiwan's National SPace Organization (NSPO) to explore meteorological applications of GPS satellites.

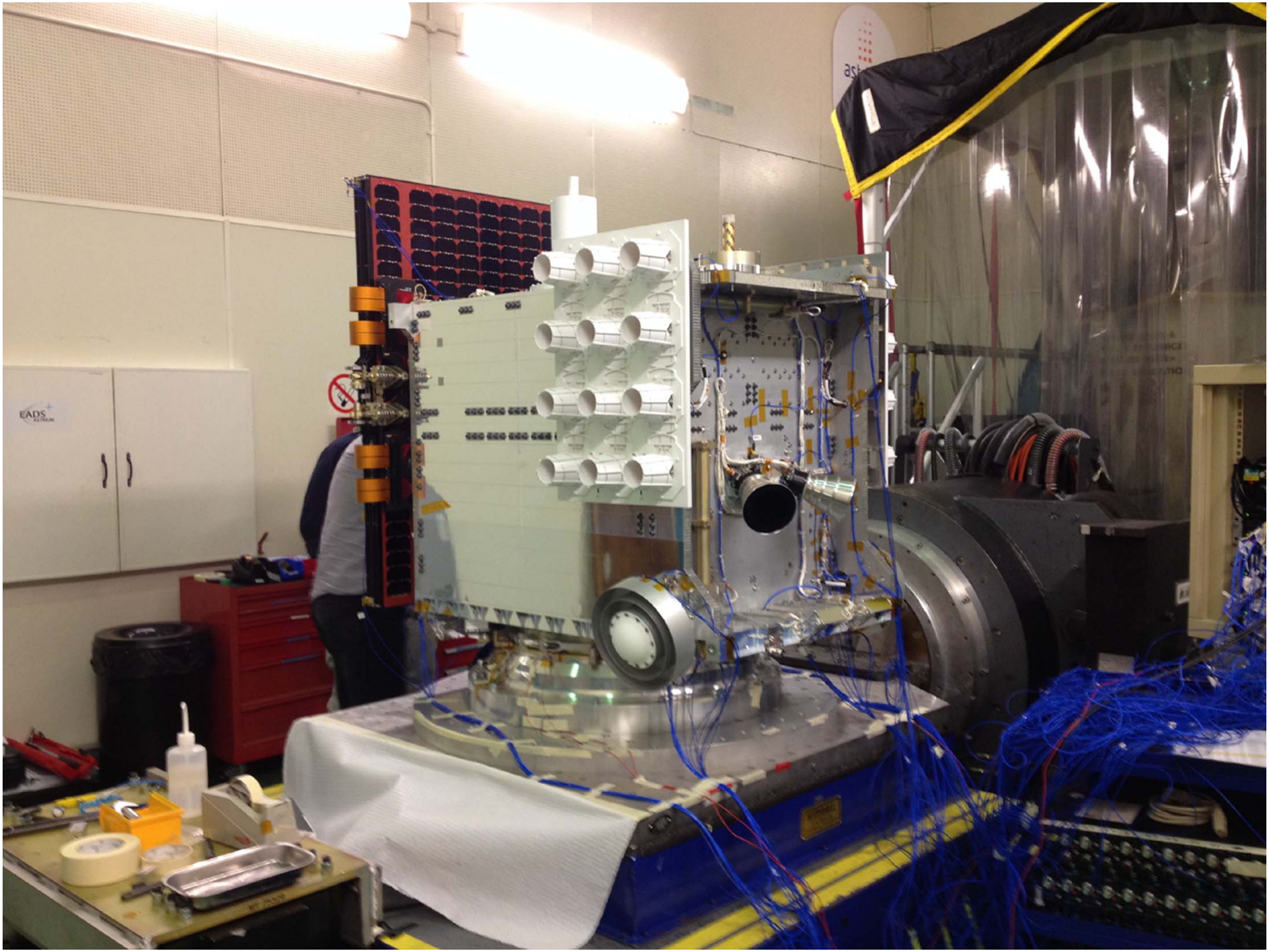
COSMIC Constellation



C-2 Spacecraft Final Design



300 kg Surrey 150 Microsats


EADS

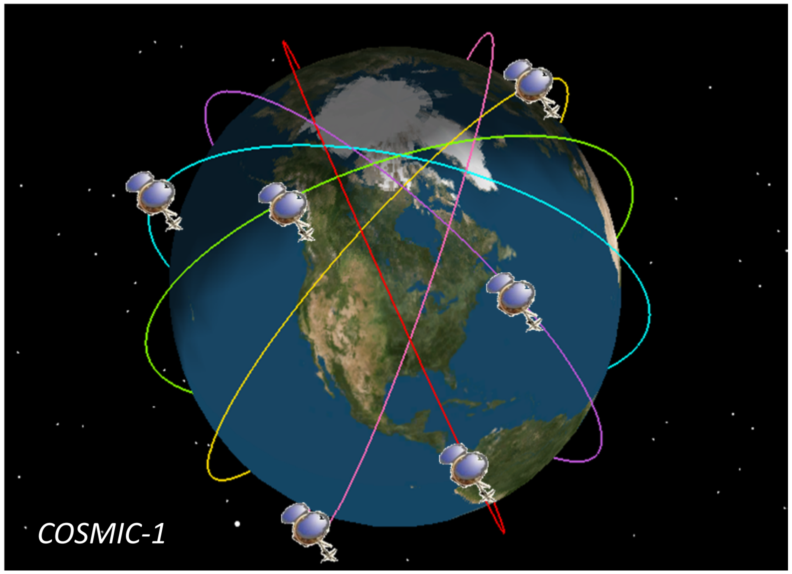
COSMIC

Since its launch in 2006, COSMIC data include electron counts in the ionosphere and atmospheric soundings of temperature, moisture, and pressure in the troposphere and stratosphere. The latter are gleaned through the radio occultation (RO) technique, whereby GPS signals are intercepted and analyzed for effects induced by the atmosphere along their paths.

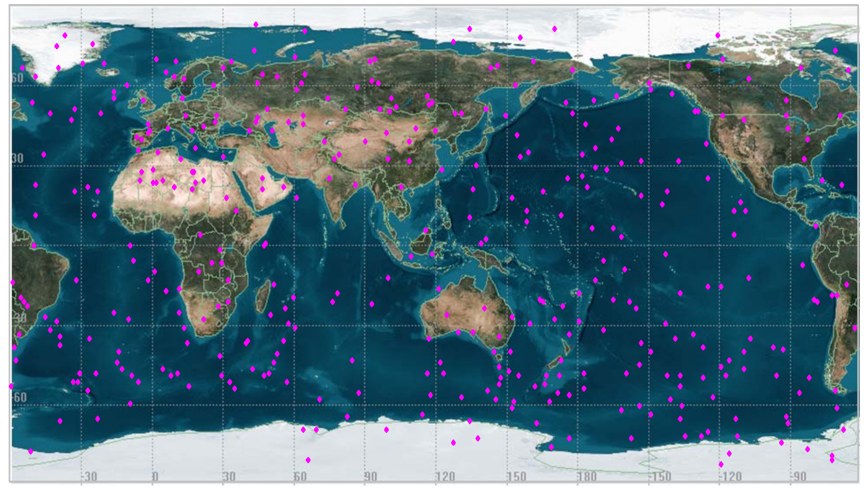
Currently, some 90% of COSMIC soundings are available within three hours of collection. These soundings are directly improving global analyses of the atmosphere, especially above the oceans, polar regions, and other hard-to-sample areas, providing a three-dimensional picture of the diurnal cycle in all types of weather.

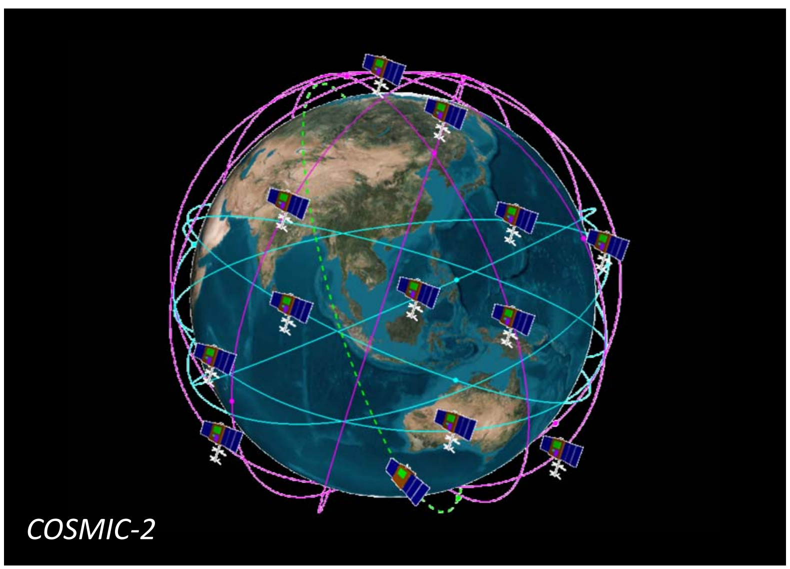
A COSMIC follow-on mission, COSMIC-2, is being planned and will place an operational system of 12 satellites into orbit: the first six in early 2016 and the remainder in early 2018.

COSMIC-1 and COSMIC-2

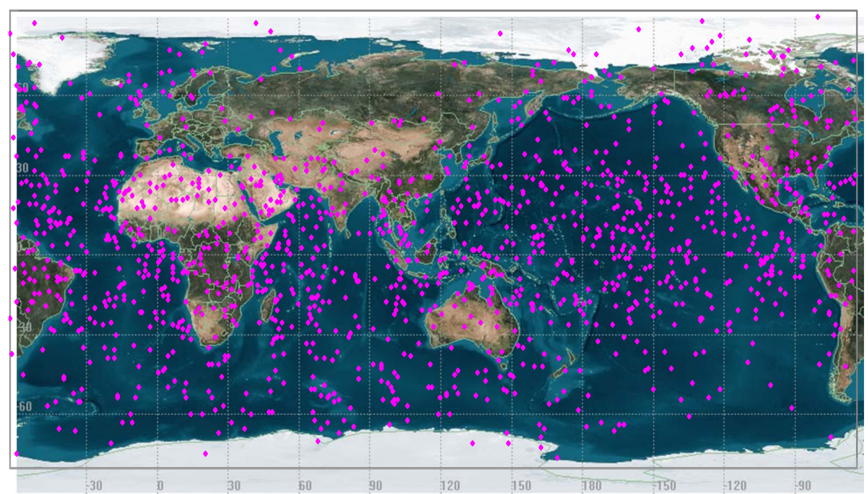


COSMIC-1 Occultations – 3 Hrs Coverage





COSMIC-2 Occultations – 3 Hrs Coverage

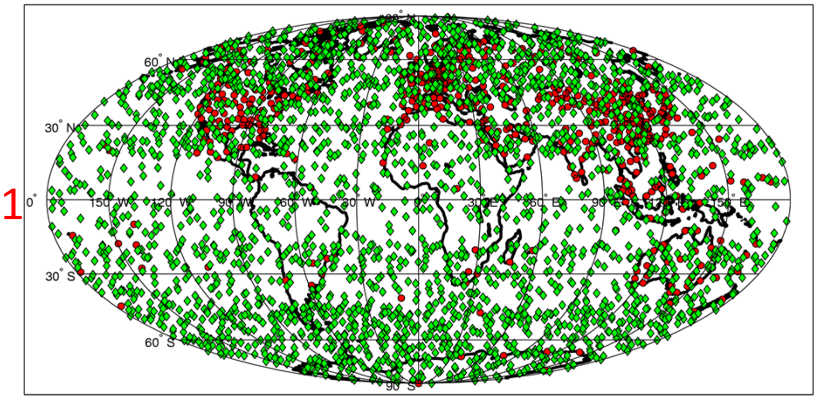


COSMIC-2 Mission

- Improved TriG receiver and better antenna will improve data quality
- 5X number of soundings---10,000/day
- Greater impact on weather forecasts
- Improve hurricane forecasts by 25-50%
- Significant improvement in space weather observing and prediction
- Mitigate potential gap in U.S. polar orbiting satellites

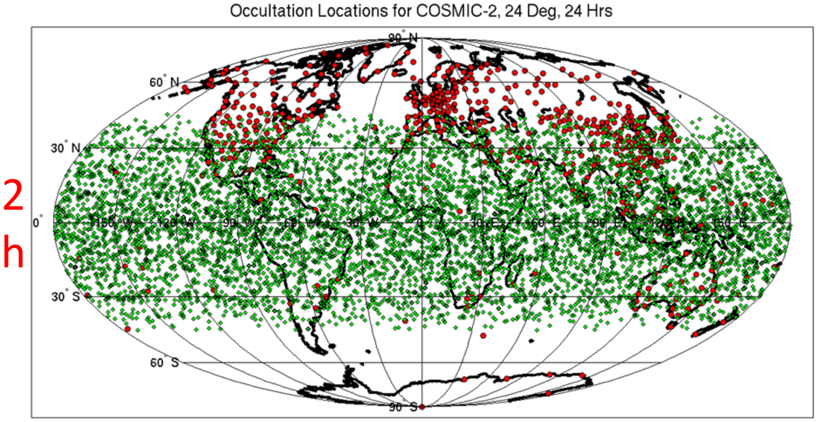
COSMIC-1

Occultation Locations for COSMIC, 6 S/C, 6 Planes, 24 Hrs



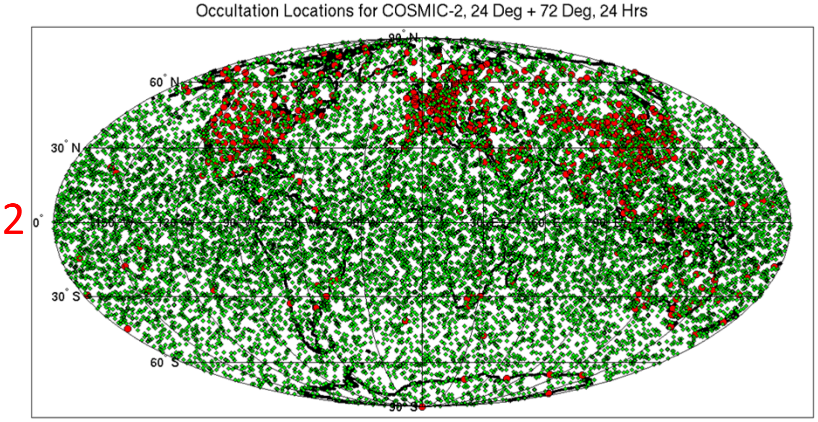
COSMIC-2
1st Launch
2016

Occultation Locations for COSMIC-2, 24 Deg, 24 Hrs



COSMIC-2
With 2nd
launch
2019

Occultation Locations for COSMIC-2, 24 Deg + 72 Deg, 24 Hrs

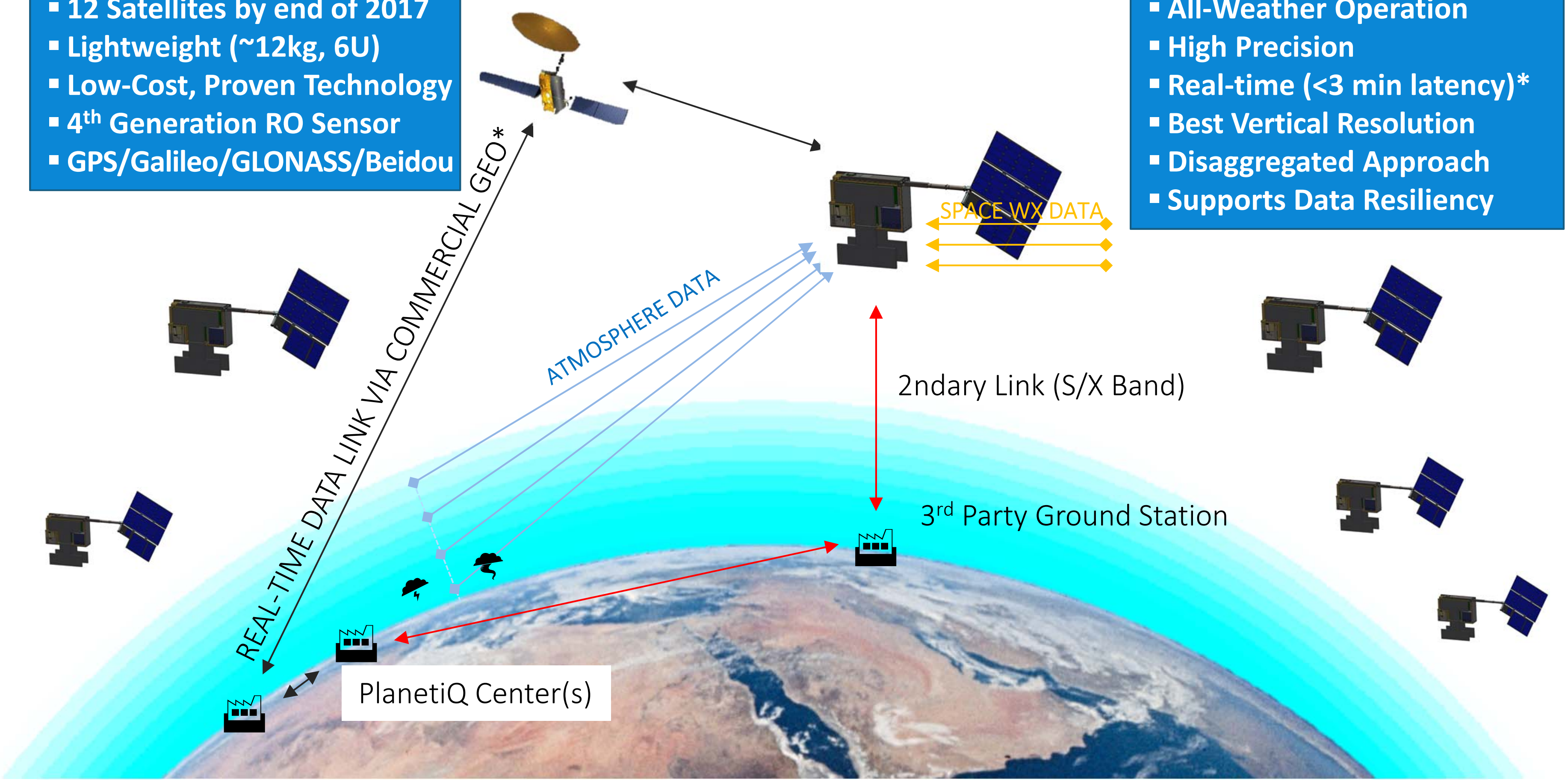


PlanetiQ Constellation

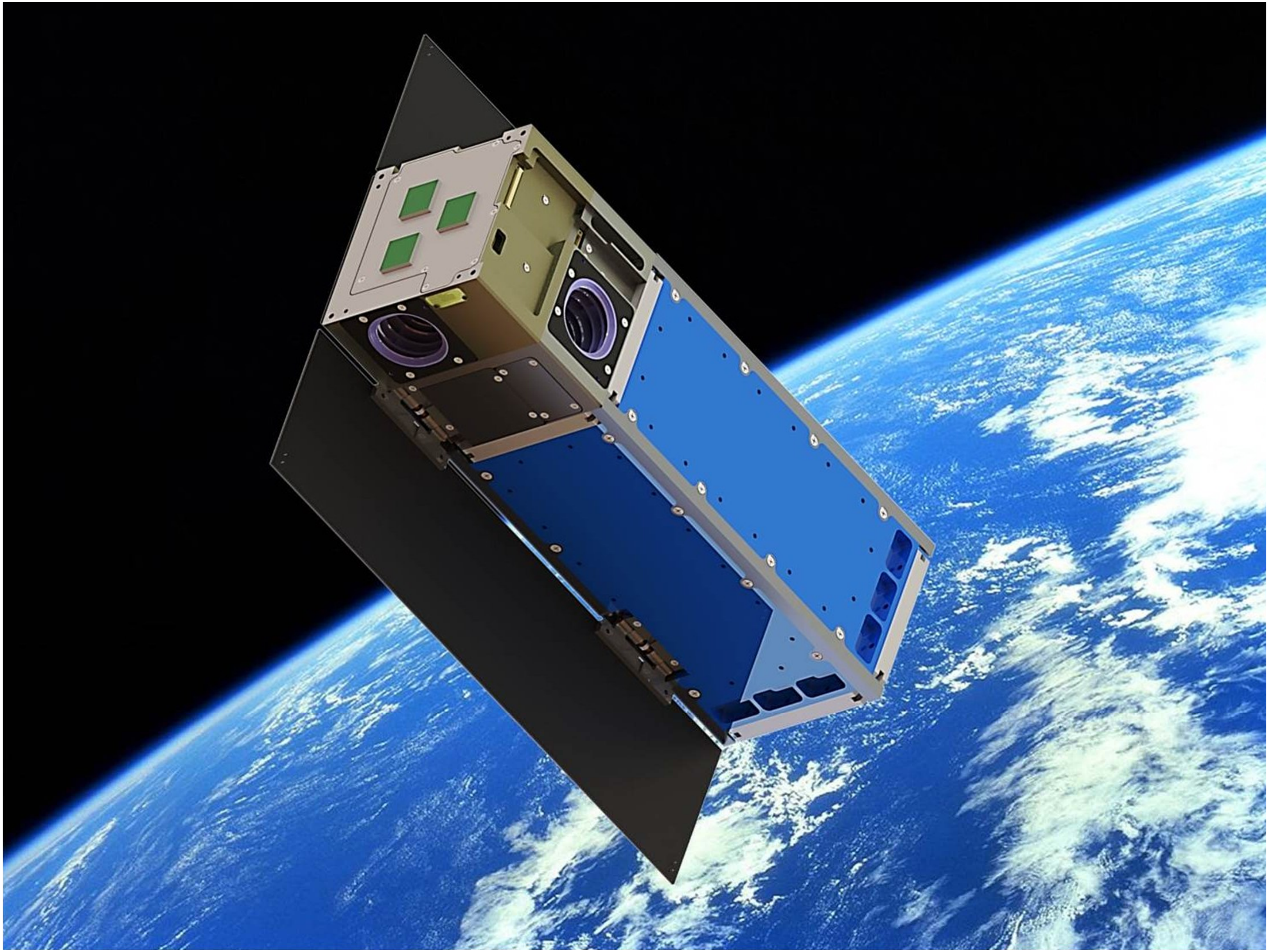
Constellation of 12-18 GPS Radio Occultation Satellites Will Collect 30,000-50,000 Occultations/Day for Weather, Climate & Space Weather

- 12 Satellites by end of 2017
- Lightweight (~12kg, 6U)
- Low-Cost, Proven Technology
- 4th Generation RO Sensor
- GPS/Galileo/GLONASS/Beidou

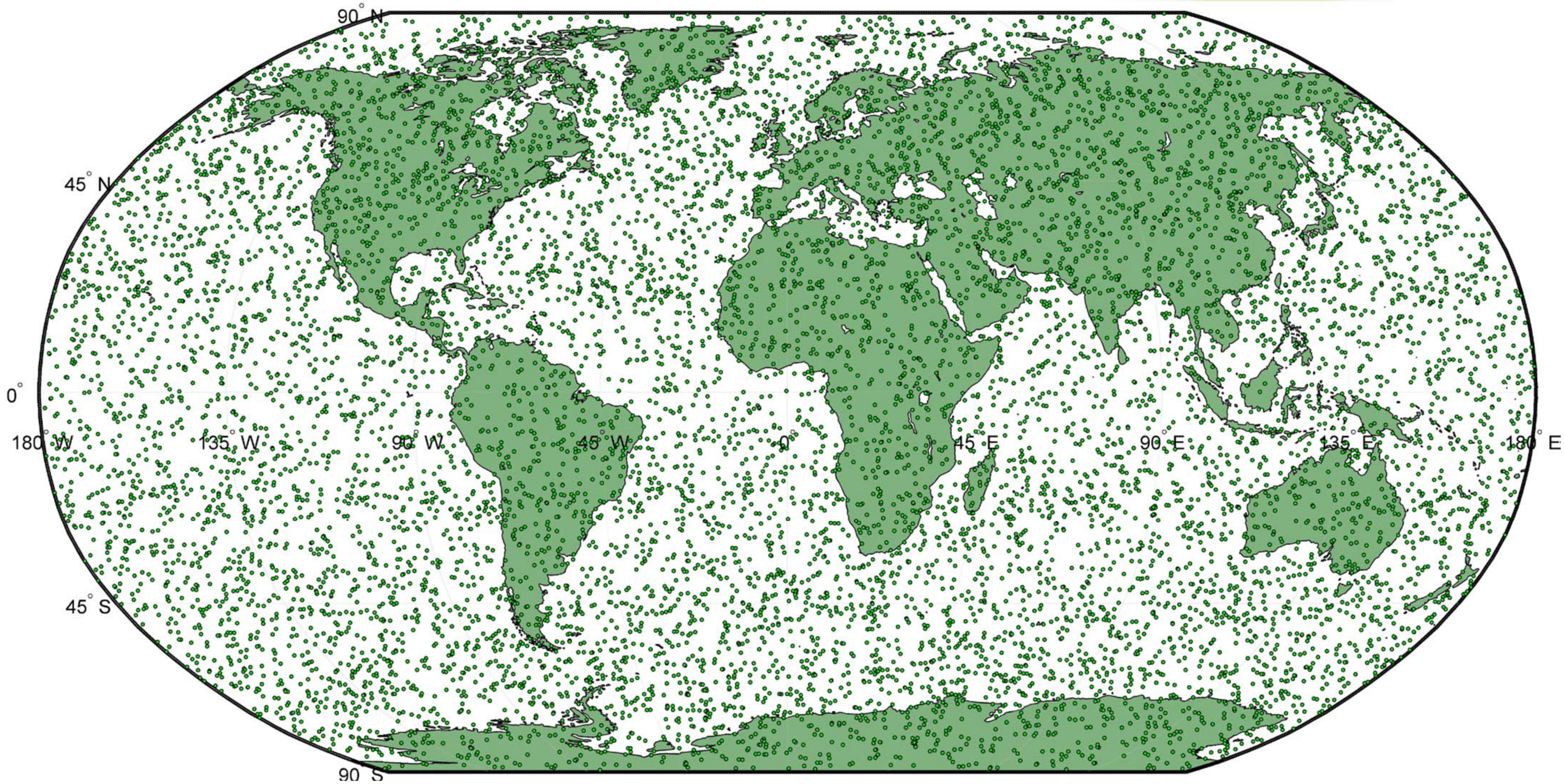
- All-Weather Operation
- High Precision
- Real-time (<3 min latency)*
- Best Vertical Resolution
- Disaggregated Approach
- Supports Data Resiliency



*Real-time data link available starting with satellites 7-12



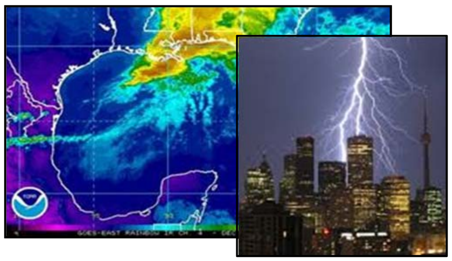
Dense Global Coverage



~34,000 soundings/day = Over 8 million observations/day of temperature, pressure, water vapor and electron density

Data Products & Applications

Weather



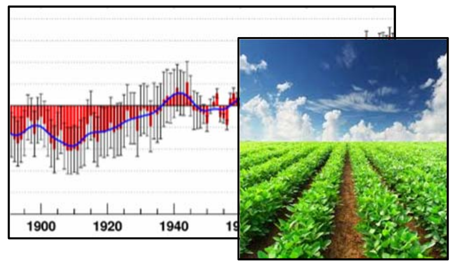
Global Atmospheric Profiles of:

- Refractivity
- Temperature
- Pressure
- Water Vapor

Greatly Improve Forecast Accuracy & Lead Time

Data Calibrates Other Atmospheric Sensors

Climate



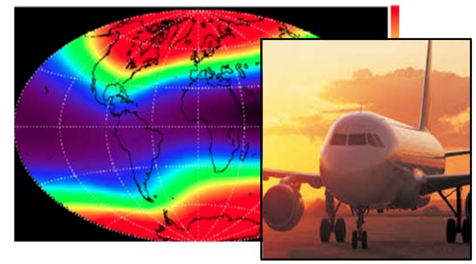
Global Atmospheric Profiles of:

- Refractivity
- Temperature
- Pressure
- Water Vapor

Most Accurate Measure of Temperature

Detect Climate Change and Improve Climate Models

Space Weather



Global Ionospheric & In-situ Measurements of:

- Total Electron Content
- Electron Density Profile
- Scintillations
- Local Charged Particles

Near Real-Time Delivery for Nowcasting & Warnings

Protect Vital Communication Systems & Power Grids

PlanetiQ Foundation: Free Data for Research

Archived data available at <u>no cost</u> to research and education users

<u>Over 8 million daily observations</u> around the world will:

- Establish long-term climate record based on most accurate measure of temperature, etc.
- Enhance climate monitoring, climate change detection, and evaluation and improvement of climate models
- Encourage research to improve the impact of GPS-RO data on weather forecasting and space weather prediction
- Empower faculty and students with high-quality data and support research on additional uses for the data

Benefits to PlanetiQ LLC include:

- Goodwill in the science and research community
- Drive demand and increase user acquaintance with GPS-RO data
- Accelerates innovation in sensor design

CESAS Fall 2014 Meeting:

Session on the Potential Role of Small Satellites, CubeSats, Constellations, and Hosted Payloads in Designing the Future Earth Observing System Architecture

10:45	Discussion with Bryant Cramer, former Associate Director of the USGS and former NASA ESD Deputy Director
11:30	Discussion with Walter Scott, Digital Globe and Committee (via WebEx)
12:15	*Working Lunch – discussion continues*
01:15	Earth Science with Hosted Payloads and Small Sat Constellations Lars Dyrud, Draper Lab
02:00	Discussion with Bill Swartz, PI RAVAN, Johns Hopkins Applied Physics Laboratory
02:45	*Break*
03:00	Perspectives on SmallSats and CubeSats Tom Sparn and Peter Pilewskie, Univ of Colorado & Laboratory for Atmospheric & Space Physics (LASP)
04:00	Discussion with John Scherrer, Project Manager for CYGNSS, Southwest Research Institute
04:45	Roundtable Discussions: Committee and Guests

CubeSats for Earth Science

To date, mostly for technology demonstration; e.g., ROSES 2012 selections:

- The Microwave Radiometer Technology Acceleration (MiRaTA) CubeSat:
  William Blackwell, MIT Lincoln Laboratory

- Advancing Climate Observation: Radiometer Assessment Using Vertically Aligned Nanotubes (RAVAN)
  Lars Dyrud, Johns Hopkins Applied Physics Laboratory

- A Cubesat Flight Demonstration of a Photon Counting Infrared Detector (LMPC CubeSat)
  Renny Fields, The Aerospace Corporation

- HyperAngular Rainbow Polarimeter HARP-CubeSat
  J. Vanderlei Martins, University of Maryland, Baltimore County

NASA's Earth Science Technology Office (ESTO) CubeSat Projects/Status

Project Title	PI Organization	Tech Category	Project Status
A Cubesat Flight Demonstration of a Photon Counting Infrared Detector (LMPC CubeSat)	The Aerospace Corporation	Flight Validation	Active
COVE: CubeSat On-board Processing Validation Experiment	JPL	Platforms	Project Complete FY12
SRI CubeSat Imaging Radar for Earth Science (SRI-CIRES)	SRI International	Sensors	Active
The Microwave Radiometer Technology Acceleration (MiRaTA) Cubesat	MIT Space Systems Laboratory	Flight Validation	Active
HyperAngular Rainbow Polarimeter HARP-CubeSat	Univ. of Maryland Baltimore County/JCET	Flight Validation	Active
Ka Band Highly Constrained Deployable Antenna for RaInCube	University of California Los Angeles	Sensors	Active
IPEX: Intelligent Payload Flight Experiment	JPL	Platforms	Project Complete FY15
COVE-2: CubeSat On-board Processing Validation Experiment 2	JPL	Platforms	Project Complete FY15
Advancing Climate Observation: Radiometer Assessment using Vertically Aligned Nanotubes (RAVAN)	JHU-Applied Physics Lab	Flight Validation	Active
GRIFEX: GEO-CAPE Read Out Integrated Circuit (ROIC) In-Flight Performance Experiment	JPL	Platforms	Active
Modular Dual-band Ku/Ka Antenna Tile with Digital Calibration (K-Tile)	JPL	Sensors	Active
On-Board Processing to Optimize the MSPI Imaging System for ACE	JPL	Information Systems	Project Complete FY12
IceCube: Spaceflight Validation of an 874-GHz Submillimeter Wave Radiometer for Ice Cloud Remote Sensing	GSFC	Flight Validation	Active

Quad charts for missions above are available at: http://www.estotechnology.us/techportfolio; search in "ESTO Projects" with keyword "cubesats"

CubeSats for Earth Science - continued

GRIFEX Technology Validation CubeSat Launched with SMAP

The GEO-CAPE Readout Integrated Circuit Experiment (GRIFEX) CubeSat was launched from Vandenberg AFB as an auxiliary payload to the Soil Moisture Active Passive (SMAP) mission.

GRIFEX is a 3-unit (3U, 10x10x30cm) CubeSat intended to verify the spaceborne performance of a state-of-the-art readout integrated circuit (ROIC) / Focal Plane Array (FPA) with in-pixel digitization and an unprecedented frame rate of 16 kHz for imaging interferometry instruments and missions. The technology specifically targets the requirements of the GEOstationary Coastal and Air Pollution Events (GEO-CAPE) mission concept.

CubeSat Applications for Earth Science

Weather:

- GPS-RO receivers (e.g., commercial company SPIRE and PlanetIQ-12 sat constellation planned for deployment in 2017)

- A NOAA-funded Lincoln Lab built 12U CubeSat to carry a miniaturized microwave sounder similar to the temperature- and humidity-sensing instruments flying on current polar orbiters. Planned to become part of the operational weather service in 2019 as part of the JPSS program, but funding issues may delay

- MIT Lincoln Labs: MicroMAS—3U CubeSat integrating a microwave radiometer payload with a three-axis stabilized CubeSat bus. The payload is a multispectral passive microwave radiometer that collects observations in the 118 GHz range, complementing existing on-orbit radiometer capability delivered by larger systems that operate in other spectral bands. "MicroMAS will provide unprecedented observations of the dynamics of hurricane and other large storm systems with significantly improved revisit times and comparable resolution to large polar-orbiting satellites."

Imaging:

- Hyperspectral Demos:
    - ESA is developing "a new hyperspectral camera compact enough to fly on CubeSat-sized missions"…"It won't replace [full-size instruments], possessing lower spectral resolution and signal-to-noise ratio, but it could do some useful complementary work as a low-cost instrument of opportunity, added to standard satellite payloads or flown on its own aboard CubeSats."

CubeSats for Earth Science--continued

Imagery:

- •Planet Labs' Flocks of Doves

- •As potential augmentations of existing land imagers; e.g.,:

  Jeffery J. Puschell; Eric Stanton,

  "CubeSat modules for multispectral environmental imaging from polar orbit"

  "approach for addressing potential gaps in continuity of critical weather and other Earth observations begun by SeaWiFS, MODIS and MISR with single band CubeSat imagers that could be used in combination either onboard a single host satellite or in a constellation of small satellites to provide stable, high SNR multispectral measurements.

  These wide field of view, high SNR imagers are enabled by large format (~4000 element long) ultraviolet-near infrared focal plane assemblies and achromatic wide field of view telescopes."

What can CubeSats do for Earth science that is unique to the platform?

Encourage constellation approaches and temporal coverage

Technology demonstration

Hold promise for reducing cost of operational monitoring

Lower cost can enable launch on demand if a ride is available

What do you see as the hard limits – scientific, technological, or policy-related – of the usefulness of the CubeSat platform for your field?

The obvious are power, weight, volume , hence:

Limitations to large apertures and high-resolution applications

Preference for passive vs power-intensive active

Challenges then to InSar, Lidar/laser

Propulsion/station keeping ability

What Earth *science* (beyond technology demonstration) has already been achieved (or is currently funded)?

For the most part limited to GPS-RO receivers

How does/could the lower barrier to CubeSat participation change the way Earth science is conducted in the future?

Platforms of opportunity for greater student engagement and innovation

Broadens the envelope of risk tolerance

The NRC committee is working to define what a CubeSat is for the purposes of this report. 12U may be the imposed size limit. Is there Earth science that could be readily achieved if that size limitation were relaxed (i.e., with a smallsat(s) larger than 12U)?

Definitional

What Earth science Decadal Survey questions could be addressed using CubeSats?

Premature

Potential to augment existing capabilities and/or lower the cost of providing particular measurements, e.g., a CERES-like measurement and or perhaps it could be used for TSIS as well

Can systematic biases can be controlled so the root N approach to achieving high accuracy works?

What Earth science is enabled by CubeSats that isn't otherwise feasible with a more traditional “large” satellite (e.g., Aura), and what would such a mission architecture look like?

Climate/continuous/long-term monitoring

Comes back to the value of a constellation of sensors of the kind that can be accommodated on the very small CubeSat platform vs. a more traditional large satellite.

Temporal coverage advantages of CubeSats in LEO, but are the trades against resolution tolerable? Perhaps the value of CubeSats for Earth science may be to augment traditional large satellites.

Maybe more of a hybrid approach, Mother Goose (active) and Cubesat Goslings (passive)

What is the appetite for CubeSats in the Earth science community?

Runs the gamut from excitement/panacea, cautious optimism, to skepticism

ESAS 2017 to:

Recommend approaches to facilitate the development of a robust, resilient, and balanced U.S. program of Earth observations from space.