Time-Series Measurements for Earth System Science

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Abstract

Earth System Science is on the verge of a major leap forward through the advent of Time Series Measurements from Space, with **multiple small spacecraft in LEO making similar measurements** at different times**, coordinated with high-revisit GEO-hosted instruments**, looking at the Earth from the same vantage point multiple times a day. The result will produce orders of magnitudes more Earth Science data than NASA's existing Earth Observing System (EOS).

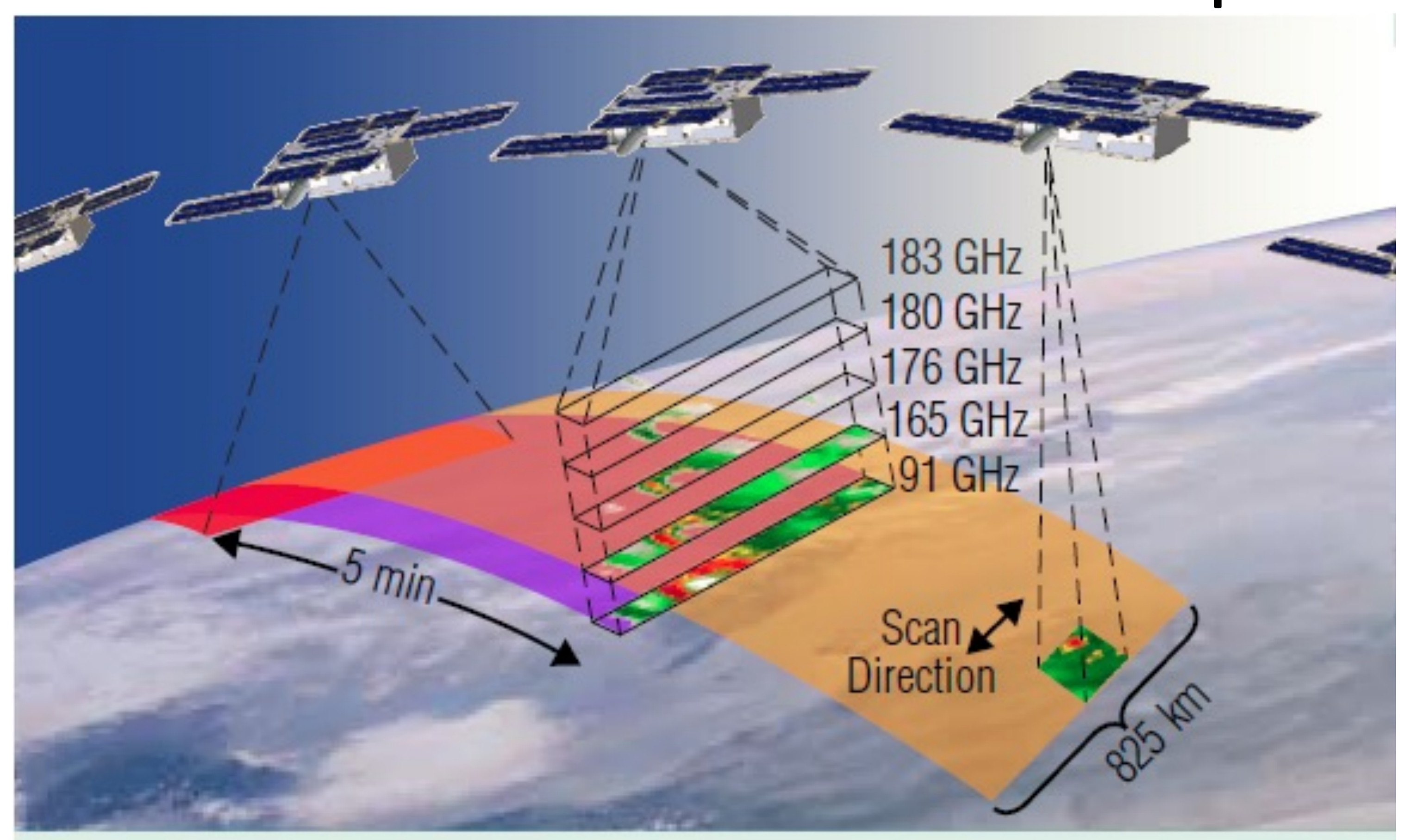
The last Earth Science and Applications Decadal Survey (DS), released in 2007, called for very few rapid revisit time-series measurements. Most new measurements in the DS reflected the heritage of the EOS system, which has two core vantage points: both sun-synchronous orbits that observe the Earth's surface at the same time of day on each orbit. In 2007 time-series measurements were seen as unaffordable, so the DS called for more frequent measurements in only a few cases: GPSRO measurements from LEO and two Geostationary systems with persistent viewing capability – GEO-CAPE and GACM. So far these recommendations have not been implemented. **Nonetheless, NASA has selected several time-series measurements through its Earth Venture program** – the recently launched CyGNSS constellation, and the TROPICS cubesat constellation; from GEO, the TEMPO and GeoCARB hosted payloads plan to observe Earth's atmosphere at intervals of minutes to hours. Commercial entities like Planet, SPIRE and GeoOptics are also starting to provide science-quality time series data.

Innovations in three key areas have allowed the Earth System Science community to consider rapid-revisit time-series measurements, long thought unaffordable, as now being within reach. **Miniaturization of instrument**s **and spacecraft**, the **opening up of hosted payload slots** on GEO Comsats, and **the reduced cost of access to space** have all changed the arithmetic of such constellations.

Many dynamic phenomena in Earth System Science would greatly benefit from much more frequent coverage, enabled by time series measurements. Examples include ozone in the lower atmosphere, aerosols, gravity measurements, surface deformation, 3-D Winds, sea surface height for storm surges, tracking major storms over land and ocean, greenhouse gas fluxes, evapotranspiration, surface reflectance in the VNIR for precision agriculture. All of these are currently sampled infrequently relative to the timescales of their variability.

What role should the traditional developer of science-grade Earth-observing instruments play, in this new era? As NewSpace companies establish Earth-observing constellations in LEO, there is **a natural role in architecting new systems, developing prototype instruments**, ensuring that the resulting data is calibrated, and populating the data pipeline with proven algorithms that retrieve reliable Earth System Science data records. **Time-series observations from GEO** will still likely require high-end, science-grade instruments, but such instruments **can be used to calibrate the measurements made by LEO constellations** when they fly underneath the GEO satellite's Field of View. Finally, data streams from existing EOS satellites, and new Earth Venture time-series measurements, are ripe targets for pilot projects partnered with commercial entities to apply data science to Earth Observation data.

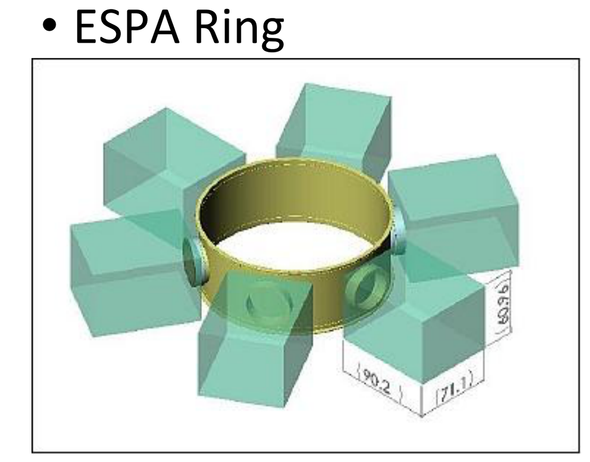
TEMPEST LEO Cubesat Constellation Concept



5 identical 6U CubeSats, each with an identical 5-channel radiometer, flying 5 minutes apart

Emerging Inexpensive Launch Alternatives for Cubesats/Smallsats

- ESPA Ring

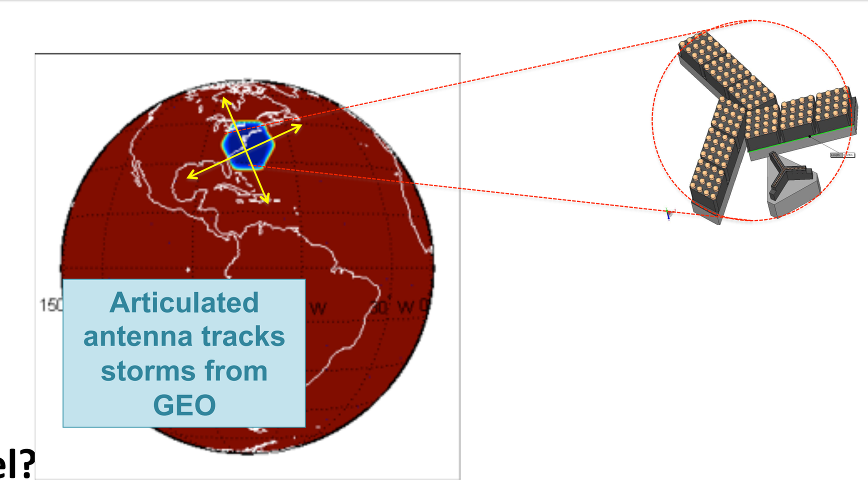


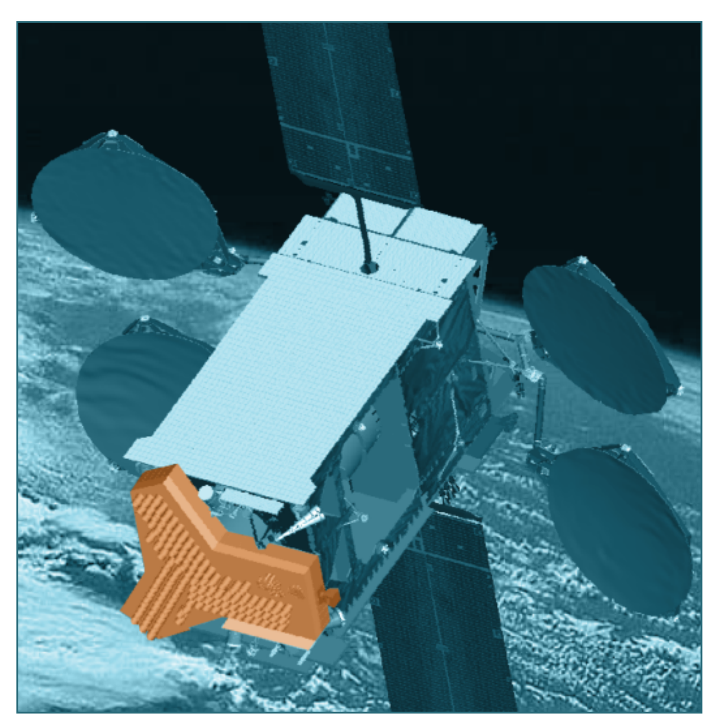
- Rocketlabs Electron

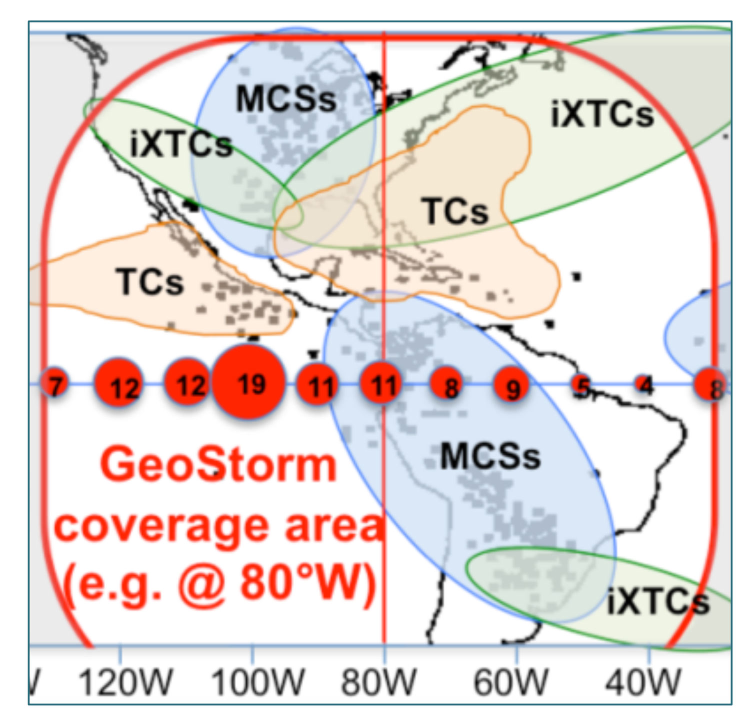
- Virgin Rocket

GEOStorm Concept

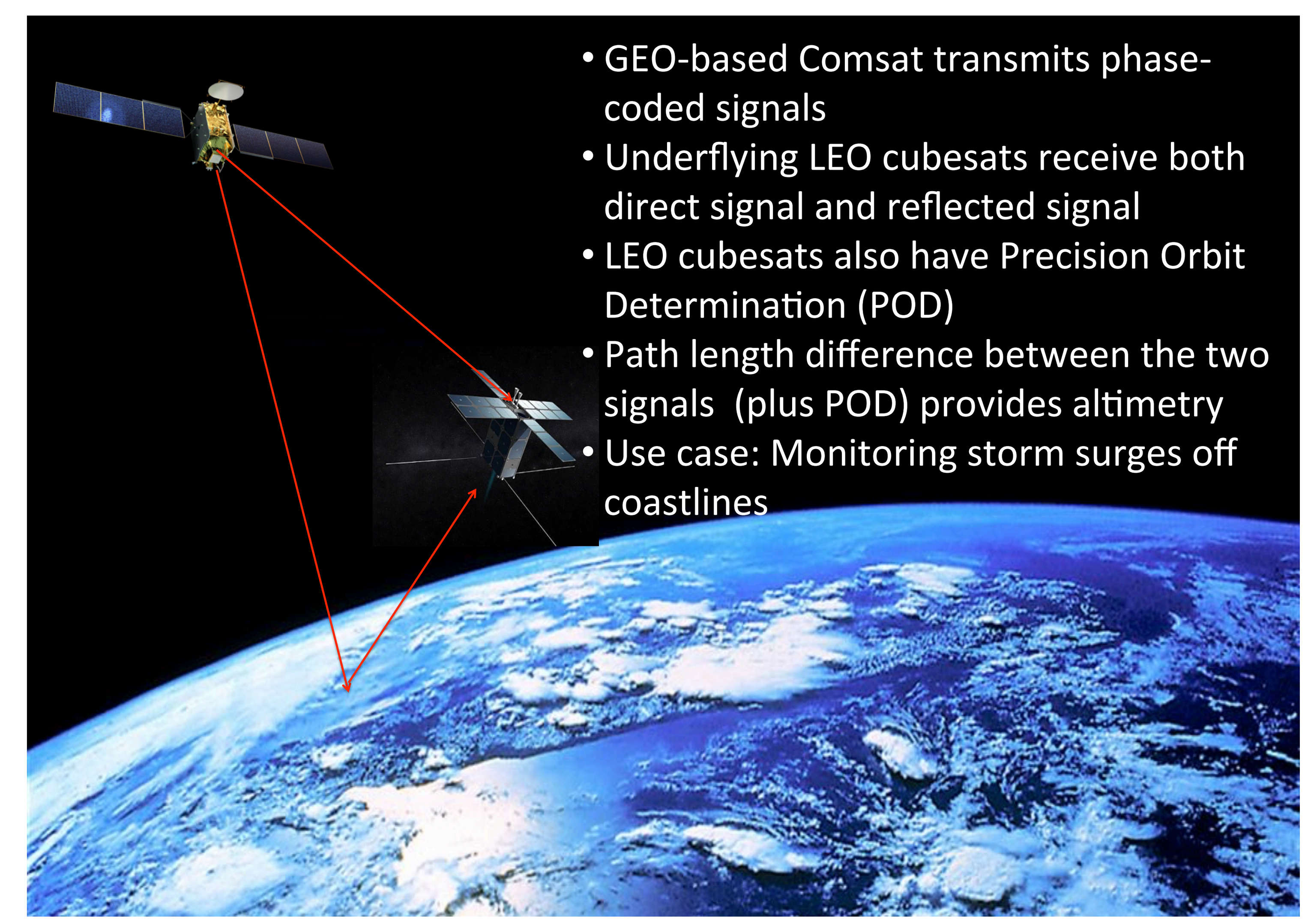
- mm-wave sounder instrument
- 118 and 183 GHz
- Measures temperature, humidity, clouds, rain, & wind
- Track storms within FOV
- Can be hosted on a GEO comsat
- Updates every 15 mins
- **Calibrate TEMPEST 183 GHz channel?**







LEO-GEO Altimeter Constellation Concept

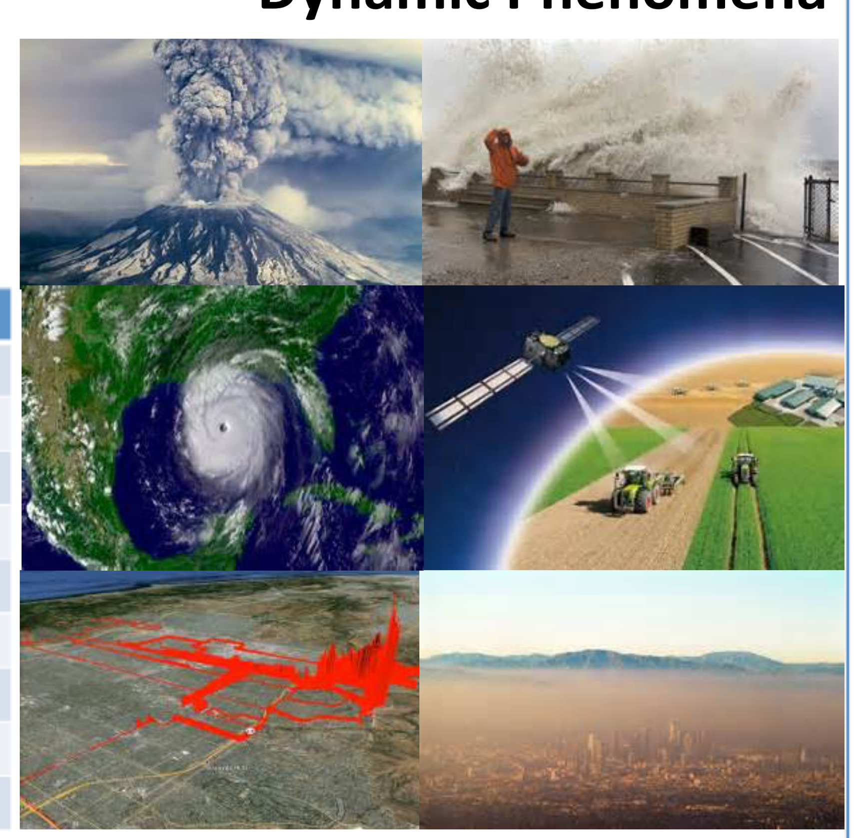


Science Drivers

Dynamic Phenomena

Examples of Dynamic Phenomena in Earth System Science and Revisit times needed to fully characterize their behavior

Phenomenon	Revisit time
Soil Moisture	2-3 days
Surface Deformation	Daily
Tropospheric Ozone	Hourly
Storm Surges	15 minutes
Aerosols	Daily
Tracking Major Storms	15 minutes
Precision Agriculture	Daily
Evapotranspiration	Daily
Greenhouse Gas Fluxes	Hourly



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

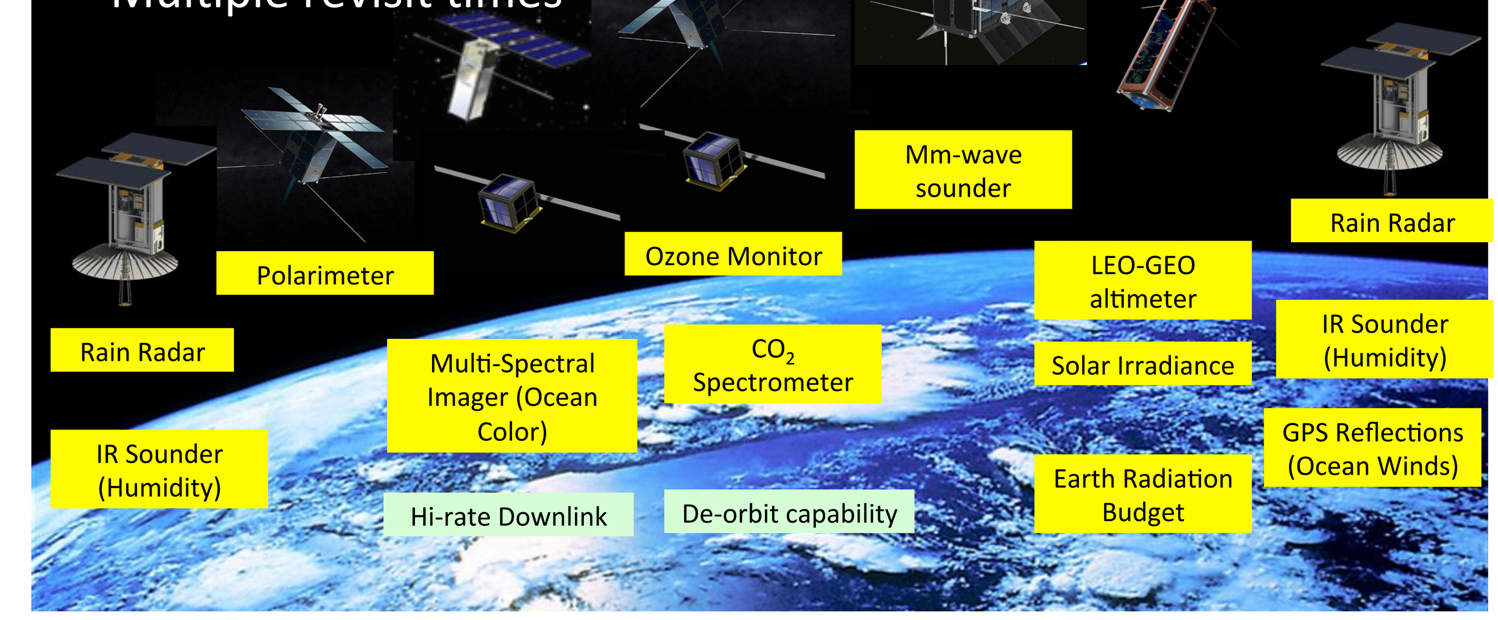
Evolution of Cubesat-sized Instruments from 2012-2017

Technology	Selva* and Krejci, 2012	Update 2017	Justification
Atmospheric Chemistry Instruments	Problematic	Feasible	PICASSO, IR sounders
Atmos Temp and Humidity Sounders	Feasible	Feasible	MicroMAS
Cloud Profile and rain radars	Infeasible	Feasible	JPL RainCube Demo
Earth Radiation Budget radiometers	Feasible	Feasible	SERB, RAVAN
Gravity Instruments	Feasible	Feasible	Need a demo mission
Hi-res Optical Imagers	Infeasible	Feasible	Planetlabs
Imaging microwave radars	Infeasible	Feasible	Ka-Band 12U design
Imaging multi-spectral radiometers (Vis/IR)	Problematic	Feasible	AstroDigital
Imaging multi-spectral radiometers (μWave)	Problematic	Feasible	TEMPEST,
Lidars	Infeasible	Feasible	DIAL laser occultation
Lightning Imagers	Feasible	Feasible	Firefly
Magnetic Fields	Feasible	Feasible	InSPIRE
Multiple direction/polarization radiometers	Problematic	Feasible	HARP Polarimeter
Ocean color instruments	Feasible	Feasible	SeaHawk
Precision orbit	Feasible	Feasible	CanX-4 and -5
Radar altimeters	Infeasible	Feasible	Bistatic LEO-GEO
Scatterometers	Infeasible	Feasible	GPS refl. (CyGNSS)

*Selva and Krejci, A survey and assessment of the capabilities of Cubesats for Earth observation, Acta Astronautica, 74, 50–68 (2012)

Cube-Train(s) Concept

- Diverse set of measurements
- Multiple revisit times



Acknowledgement

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