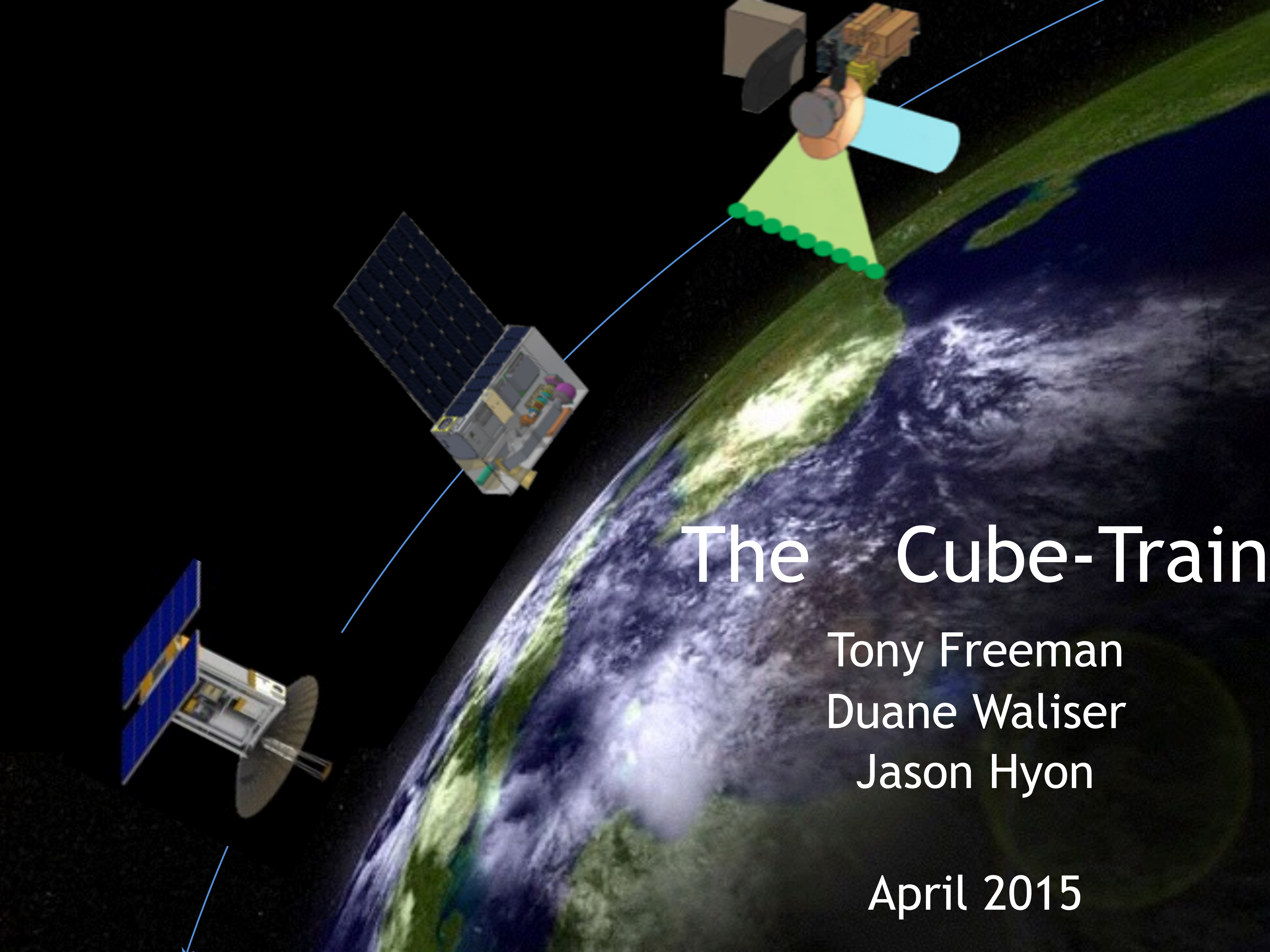


The Cube-Train

Tony Freeman
Duane Waliser
Jason Hyon

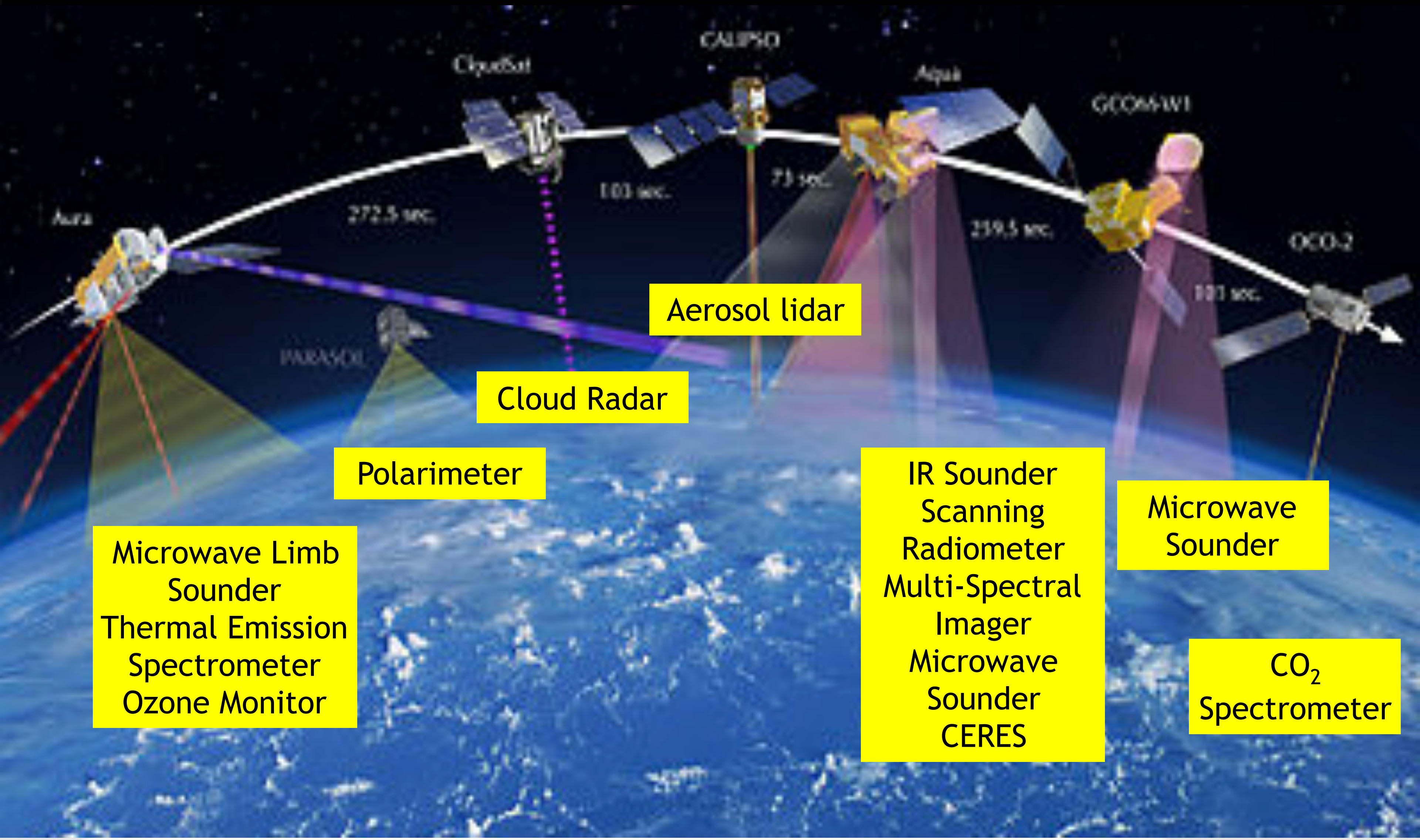
April 2015

Cube-Train

Value Proposition

- The A-Train constellation of missions managed by NASA’s Earth Science Division has for many years been a workhorse of NASA’s Earth Observing system
- Two flagship Observatories – Aura and Aqua - have been supplemented by a small armada of Earth-observing spacecraft, including Cloudsat, OCO-2, Calipso, PARASOL and GCOM-W1
- Each mission in the A-Train set out to achieve it’s own science measurement objectives, but Earth scientists have recognized the emergent properties of such a powerful, synergistic observing system, in which a multitude of instruments observe the same geographic location within seconds/minutes of each other
- The Cube-Train concept seeks to emulate this synergy at a significantly lower cost.

The A-Train


Aura
CloudSat
CALIPSO
Aqua
PARASOL
OCO-2
Aerosol lidar
Cloud Radar
Polarimeter
Microwave Limb Sounder
Thermal Emission Spectrometer
Ozone Monitor
IR Sounder
Scanning Radiometer
Multi-Spectral Imager
Microwave Sounder
CERES
Microwave Sounder
CO_2 Spectrometer

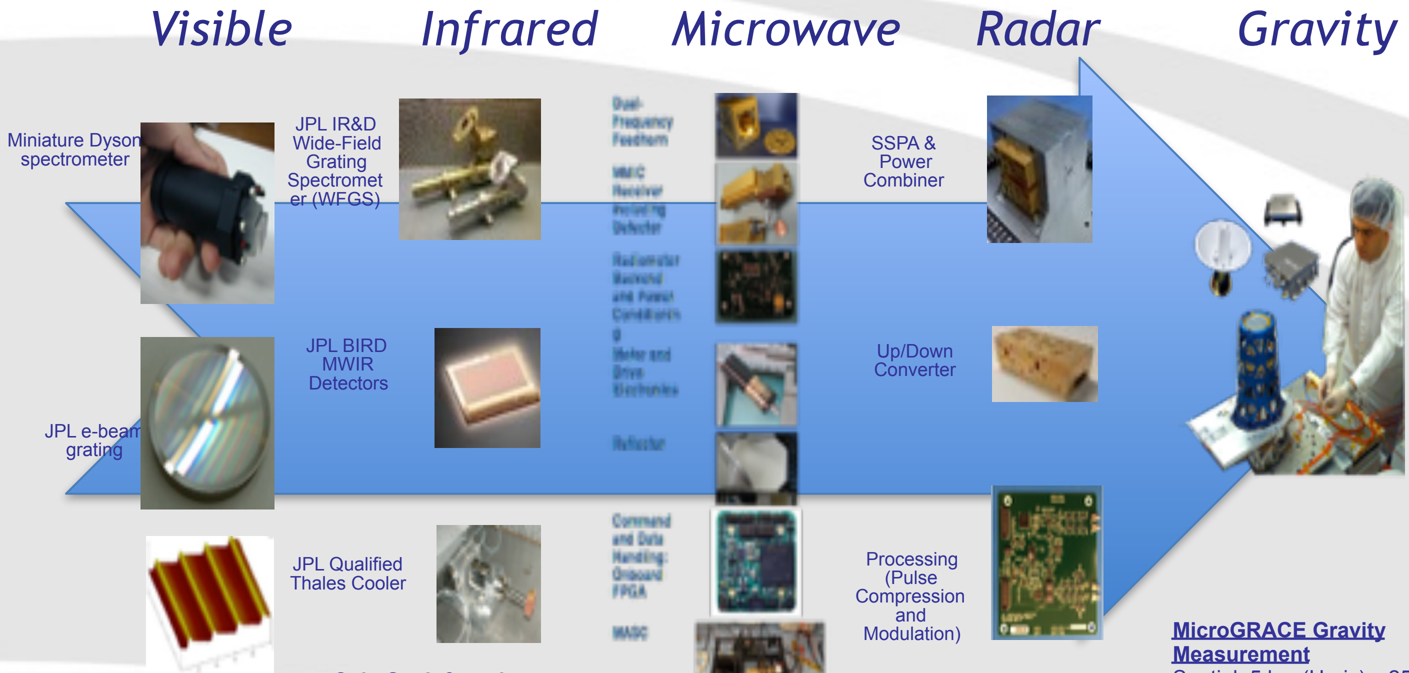
Cube-Train
dX/dt Measurements

- The local time for each A-Train measurement is roughly constant at ~1:30 pm
- Single snapshots can not capture important process information that is time-varying
- Consider a Cube-Train orbit that is near-polar and sun-synchronous
- Platform separation is small enough in time that measurements of different Climate Data Records are effectively contemporaneous
- Multiple trains separated by ~5 mins would allow measurement of local time derivatives (dX/dt) of Climate Data Records
- Alternatively a non-sun-synchronous orbit would allow characterization of diurnal variations

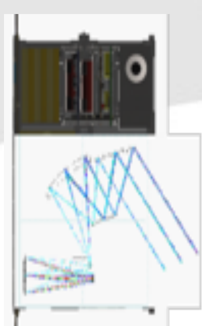
Cubesat-sized Instruments – 2012 and 2016

Technology	Selva* and Krejci, 2012	Freeman et al 2016	Justification
Atmospheric Chemistry Instruments	Problematic	Feasible	PICASSO, IR sounders
Atmos Temp and Humidity Sounders	Feasible	Feasible	
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	Problematic	Ka-Band 12U design
Imaging multi-spectral radiometers (Vis/IR)	Problematic	Feasible	AstroDigital
Imaging multi-spectral radiometers (μWave)	Problematic	Feasible	TEMPEST,
Lidars	Infeasible	Problematic	DIAL laser occultation
Lightning Imagers	Feasible	Feasible	
Magnetic Fields	Feasible	Feasible	InSPIRE
Multiple direction/polarization radiometers	Problematic	Feasible	HARP Polarimeter
Ocean color instruments	Feasible	Feasible	SeaHawk

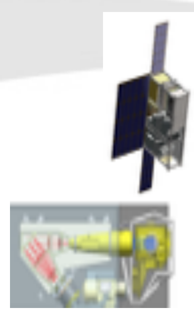
JPL's Miniaturized Weather Instruments



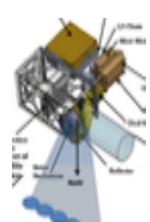
Snow and Water Imaging Spectrometer
Spatial: ±5°, 0.28 km
Spectral: 228 Bands, 350 nm – 1.65 μm
SWAP: 6U, 9 kg, 15W, 5 Mbps



CubeSat Infrared Atmospheric Sounder (CIRAS)
Spatial: ±48.3°, 13.5 km
Spectral: 1000 Channels, 4.1-5.4 μm
SWAP: 6U, 20 kg, 30 W, 1 Mbps

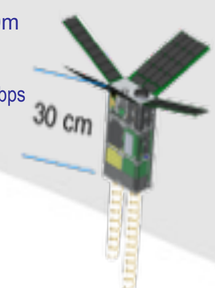


Microwave Atmospheric Sounder on CubeSat (MASC)
Spatial: ±45°, 15 km (183) – 20 km (118)
Spectral: 8 Channels: 118-183 GHz
SWAP: <0.01 m^3, 3 kg, 7 W, 10 kbps



RainCube: Precipitation Profiler
Spatial: 5 km (Horiz) x 250m (Vert)
Spectral: 35.6 GHz
SWAP: 6U, 20 kg, 30 W, <1 Mbps

MicroGRACE Gravity Measurement
Spatial: 5 km (Horiz) x 250m (Vert)
Spectral: 35.6 GHz
SWAP: 6U, 20 kg, 30 W, <1 Mbps



NPOESS Gap Filler CubeSats

JPSS

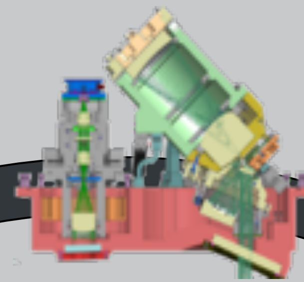
VIIRS

CrIS

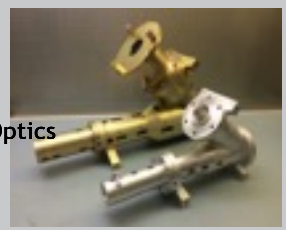
ATMS

JPL Technologies

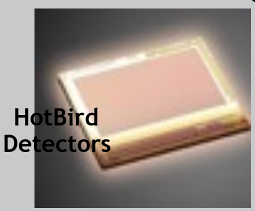
PRISM



WF Optics



HotBird Detectors

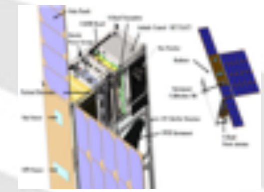


Microwave

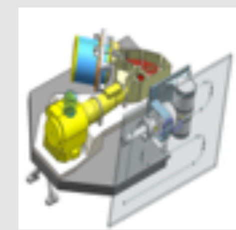
Radar

JPSS Gap Filler

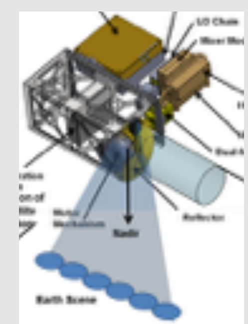
CWIS Cubesat VSWIR



MIRIS Cubesat Infrared

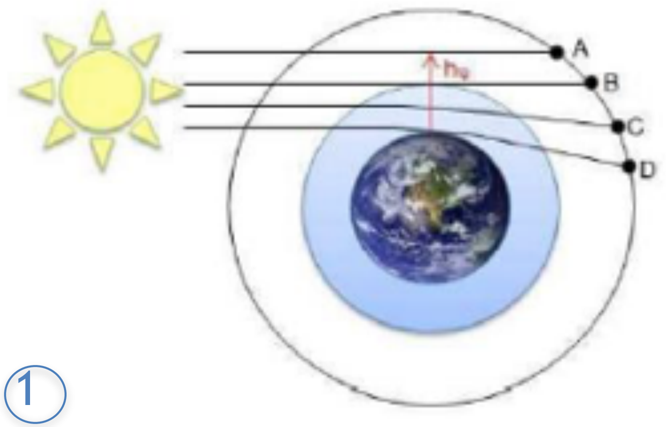


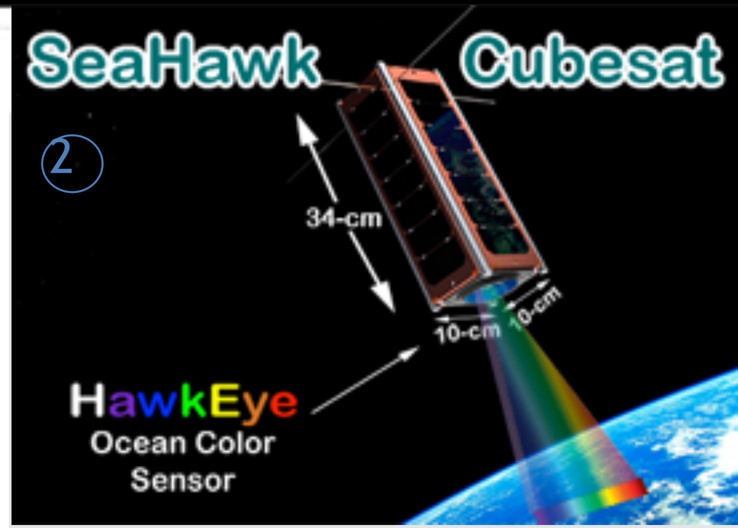
Cubesat MW Sounder



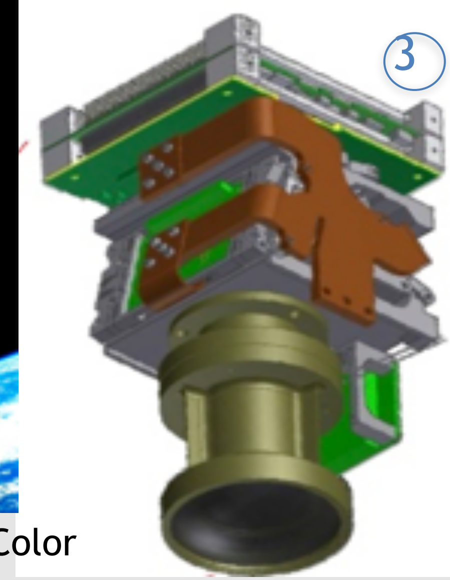
New Cubesat Instruments

PICASSO - Stratospheric Ozone via Solar Occultation



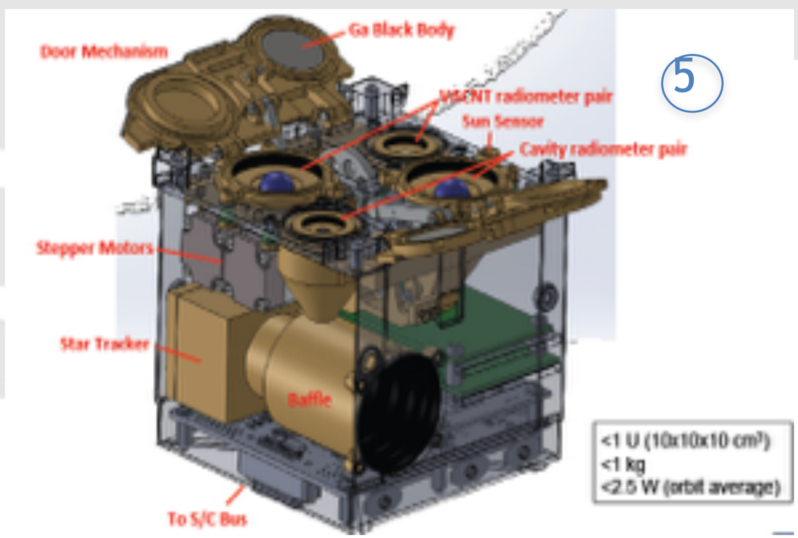


SeaHawk Multi-Spectral Imager for Ocean Color

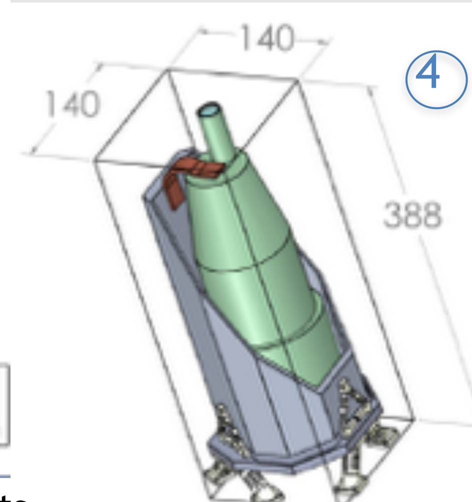


HARP – Imaging Polarimete

1. Mero, B., et al, 'PICASSO - A State of the Art Cubesat', Smallsat Conference, Logan Utah (2015)
2. Clark,C., 'SeaHawk: A Nanosatellite Mission for Sustained Ocean Observation', ClydeSpace (2015)
3. Vanderlei Martins, J., et al, 'HARP CubeSat – An innovative Hyperangular Imaging Polarimeter for Earth Science Applications', Smallsat Conference, Logan Utah (2014)
4. Lampen, S., et al, 'IR Sounder Smallsat for polar orbit weather measurements', Smallsat Conference, Logan Utah (2015)
5. Swartz, W. H., et al, 'RAVAN – Meeting Earth science objectives with less', NRC Committee on Earth Science and Applications from Space ((2014)

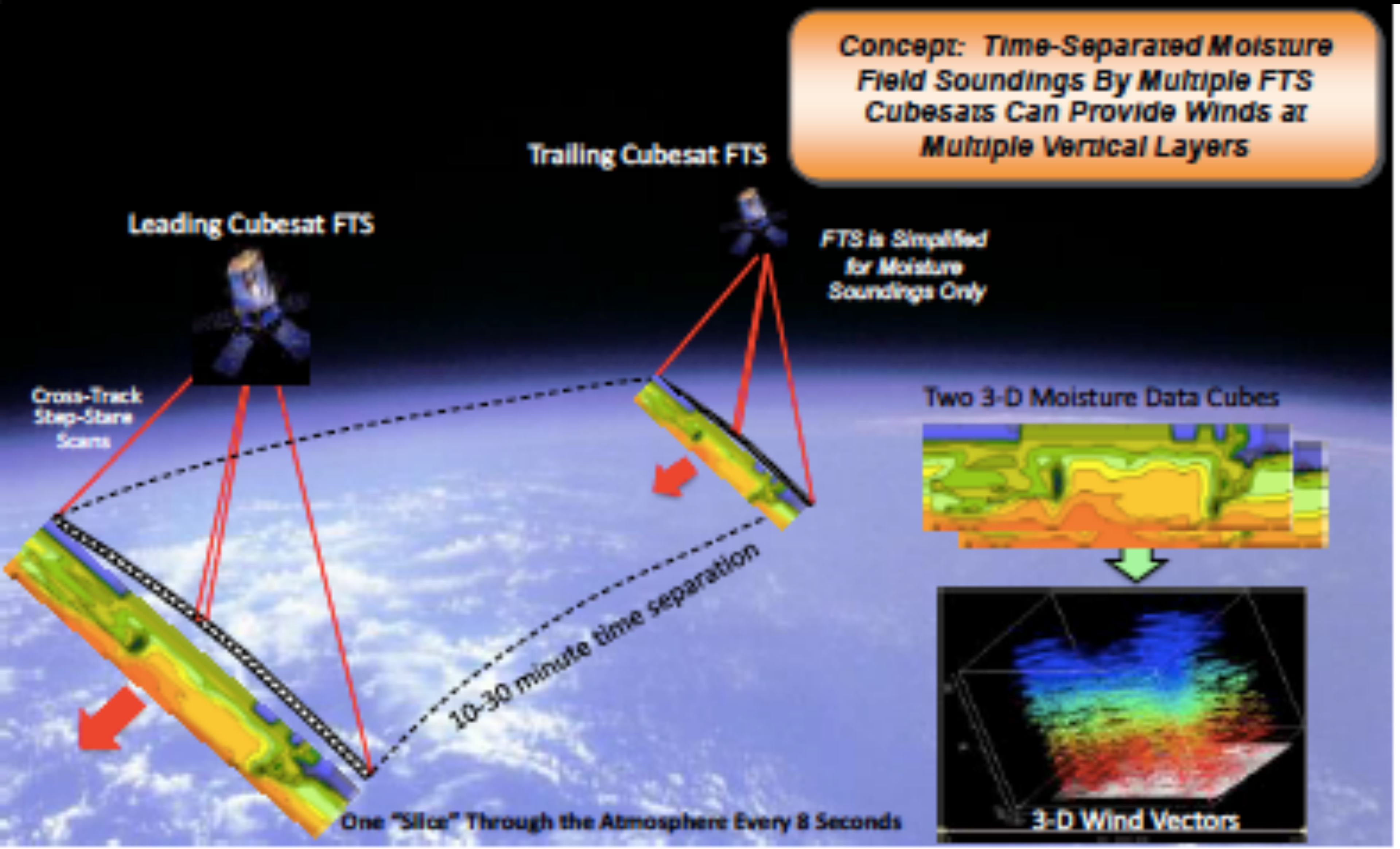


RAVAN Earth Radiation Budget measurements



IR Sounder for CO_2 and H_2O

3-D Winds Measurement Concept



Source: Glumb, R., et al, A Constellation of FTS Cubesats for Global Measurements of 3-D Winds, Smallsat Conference, Logan UtAh (2015)

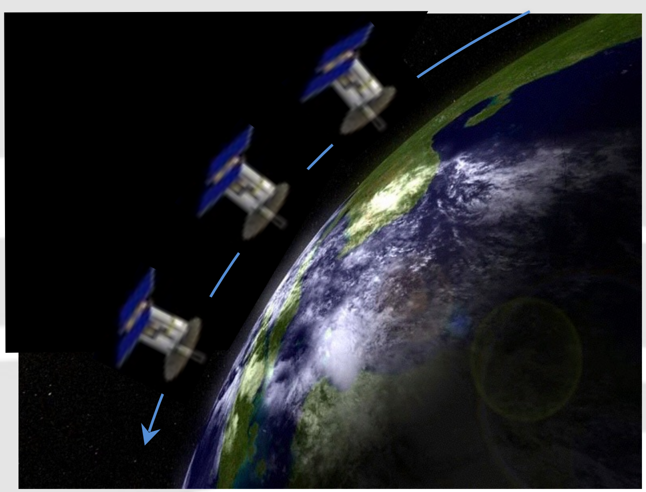
Active Microwave

RainCube

PI: Eva Peral, JPL

- Precipitation measurements from LEO from a cubesat sounding radar

RainCube matches the performance of the Global Precipitation Mission (GPM)'s Ka-band radar at a fraction of the cost, allowing many more precip radars to be flown in a constellation



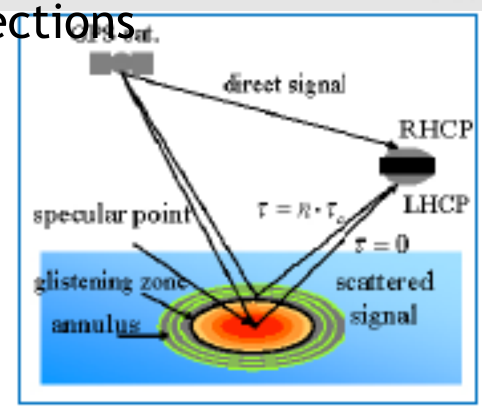
RainCube Ka-band Radar
30 centimeters (linear) 6U CubeSat
12 kg, 30 W
5 km (horiz) / 250 m (range) spatial resolution

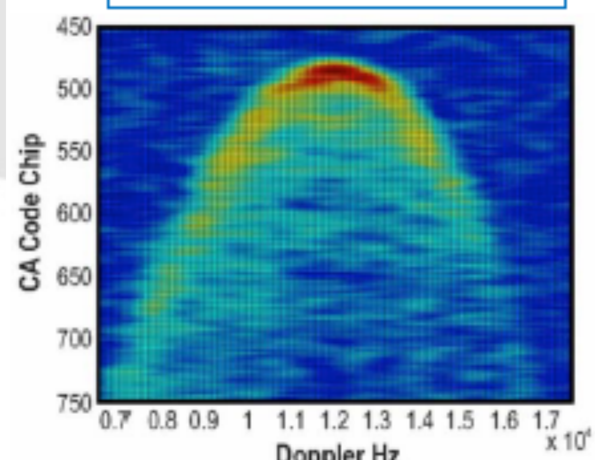
CyGNSS

PI: Chris Ruf, UMich

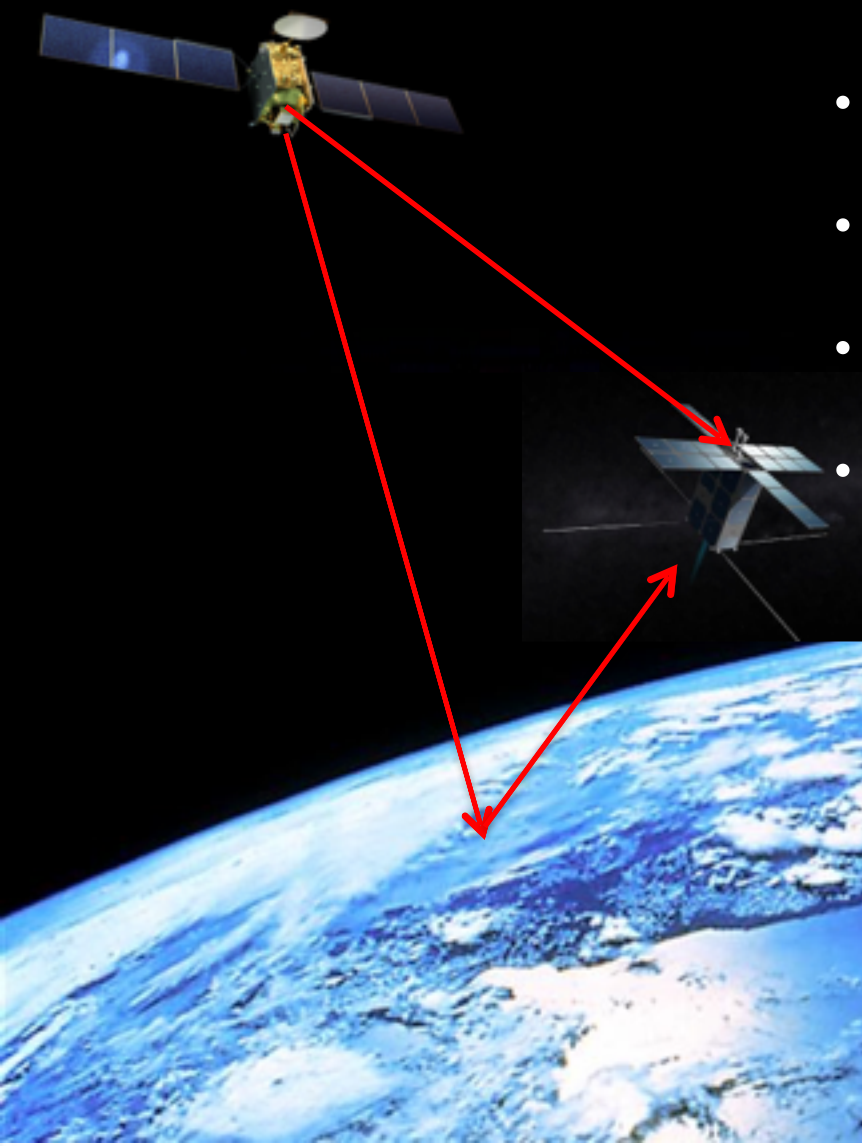
- Bistatic GPS reflections measurements of ocean surface roughness

Innovative form of scatterometer measures amplitude and Doppler from GPS reflections





LEO-GEO Altimeter Concept

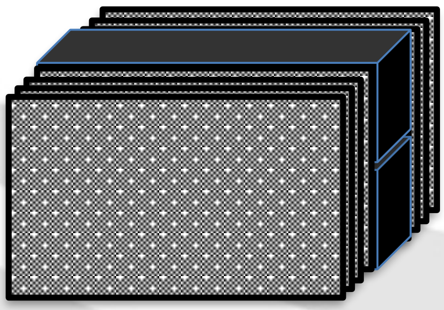


- GEO-based Comsat transmits phase-coded signals
- LEO cubesat receives both direct signal and reflected signal
- LEO cubesat also has Precision Orbit Determination (POD)
- Path length difference between the two signals (plus POD) gives altimetry
- Use case: Monitoring storm surges off coastlines

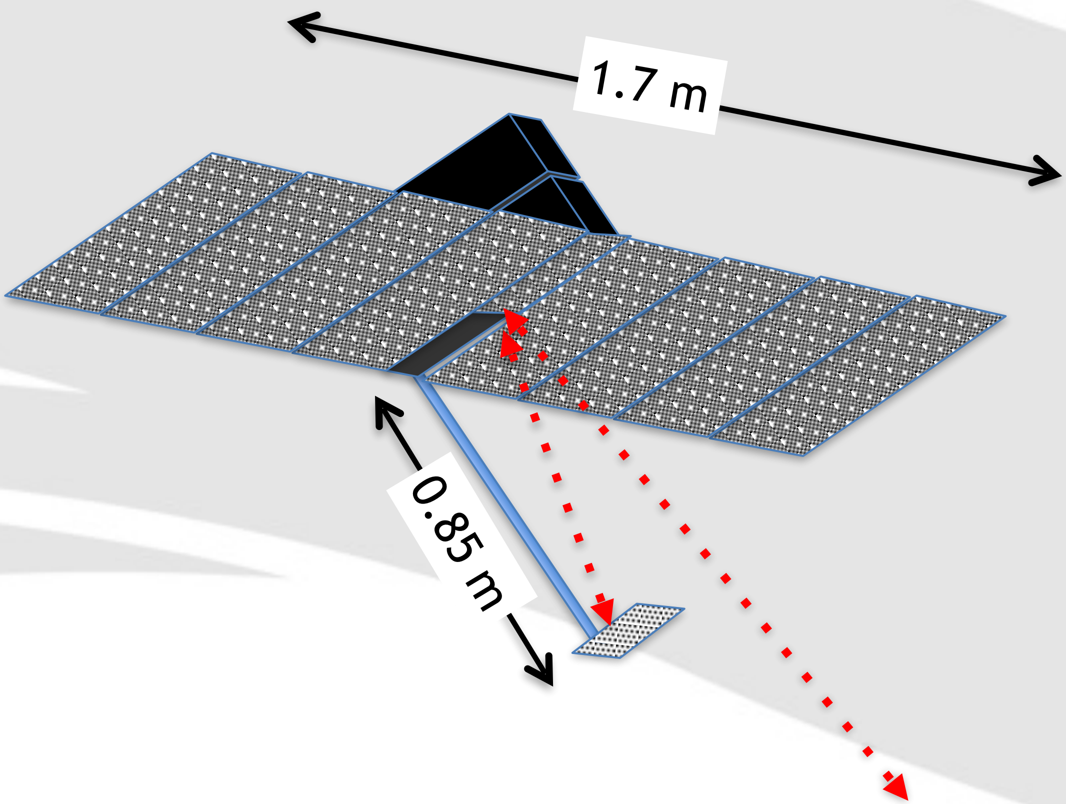
Ka-Band CubesatSAR Concept

Parameter	Value
Orbit altitude	400 km
Center frequency	35 GHz
Incidence angle	30 deg
Tx Power	120 W
DC power (burst mode)	80 W
Pulse length	50 μs
Antenna size (L X W)	1.7 X .3 m
F/D ratio	0.7
Bandwidth	30 MHz
Data rate (burst mode)	104 Mbps
On-time per orbit	3 mins
Downlink rate	40 Mbps
Noise-equivalent σ^o	-17 dB
Spatial res./ [# looks]	10 m/ [2]

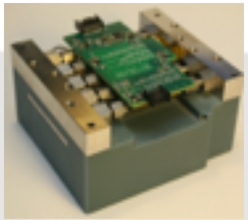
- Stowed Configuration:
  - 6U Spacecraft
  - 12U total volume



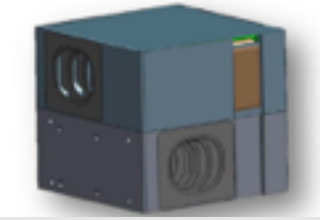
- Deployed Configuration
- Solar array + reflectarray (like ISARA)



CubesatSAR Concept



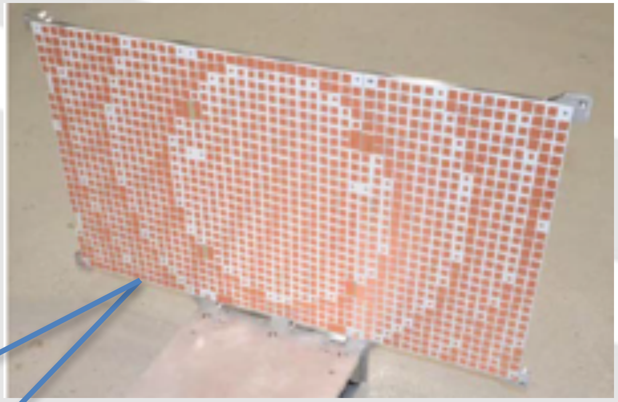
Cold-Gas ACS
(0.3 U)



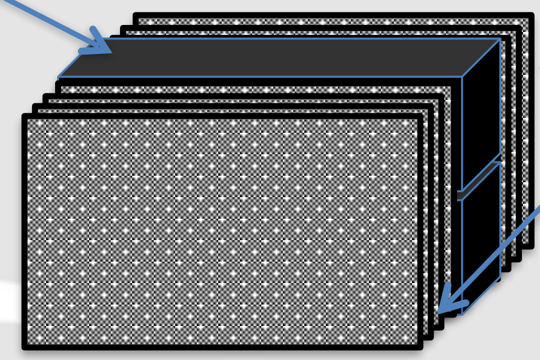
BCT **S/C avionics**
(1U)

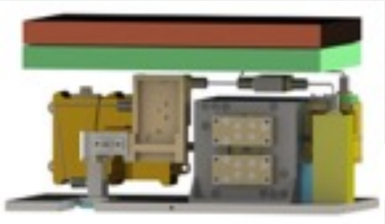
Electrical Power System +
Battery Board (0.5U)

Ka-Band patch feed



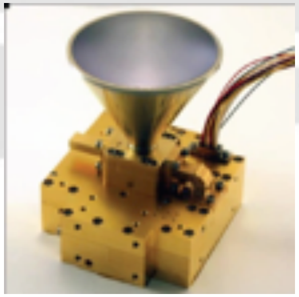
Pair of 4 Stacked and folded 30 cm x 20 cm solar array + reflectarray panels
(Mass : ~7 kg)





Radar electronics assembly
Size: 2U

Data Handling Unit
(0.2U)

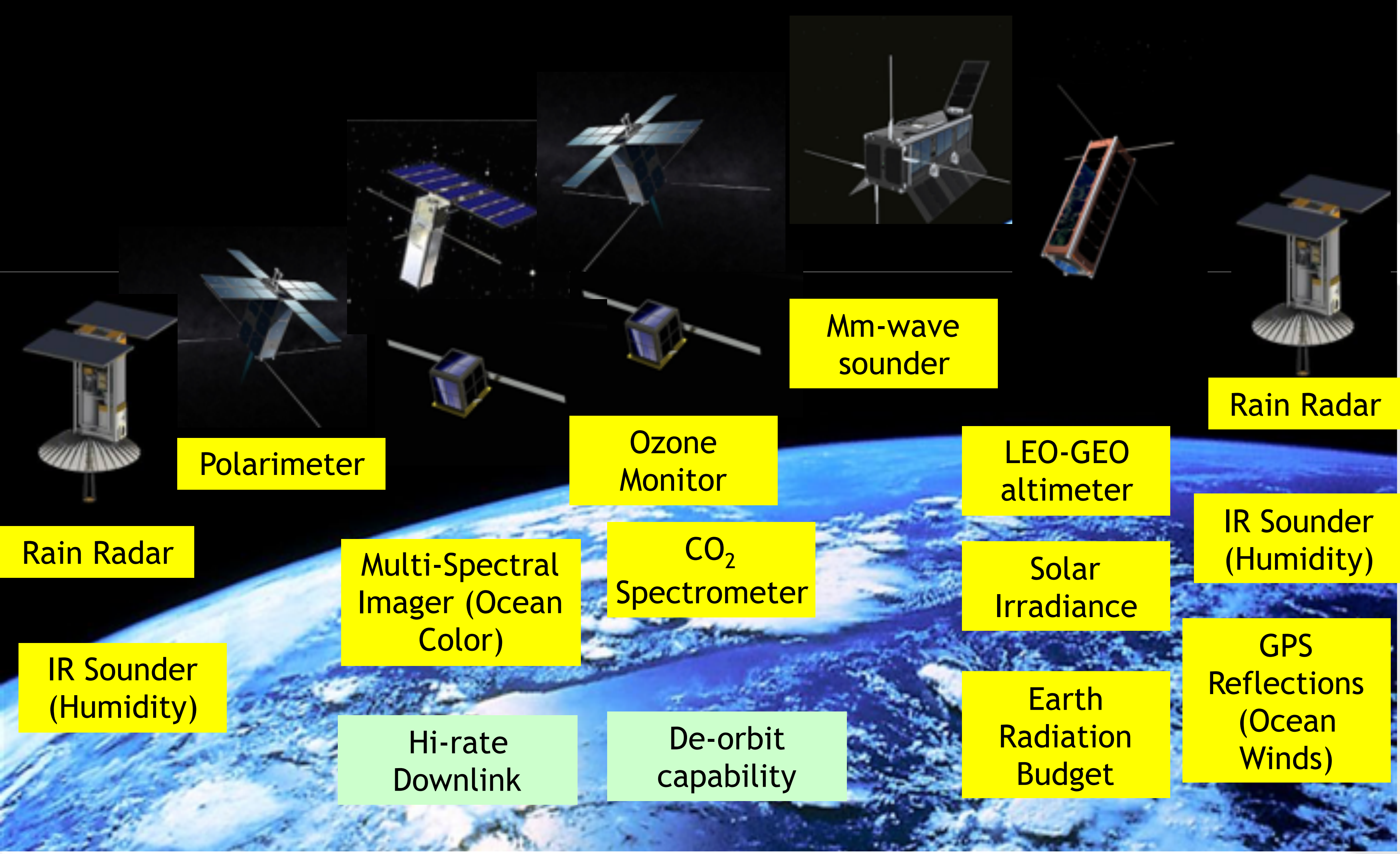


Ka-Band transmitter
Size: 1U

Ka-Band radio
Size: 0.5U

1.5 m deployable boom
(0.5U)

Single Cube-Train Concept



Cube-Train Concept
Summary

- Cube-Train offers a lower-cost way to replicate some of the successful synergies of the A-Train (but not all)
- Multiple Cube-Trains allows measurements of time-derivatives not seen with the A-Train
- Reliability of cubesats is expected to increase over time, but early mortalities could easily be replenished at low cost
- ESTO support for new, cubesat-sized instruments enable this concept
- Vision is of a multi-faceted constellation, with cubesat contributions from:

    1. NASA Centers
    2. Universities
    3. International Partners

- Cost for a single Cube-Train with ~ 15 cubesats is expected to be comparable to that of just one low- to medium-class Earth Science mission