Millimeter- and Submillimeter-Wave Remote Sensing Using Small Satellites

NASA Goddard Space Flight Center

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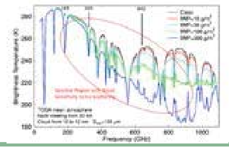
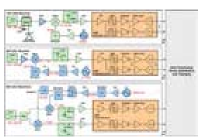
Outline



Motivation and science drive

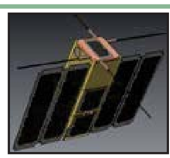
GSFC mm- and sub-mm-wave instruments

Instrument study



Candidate instrument architecture

Small rocket technology (SMART)

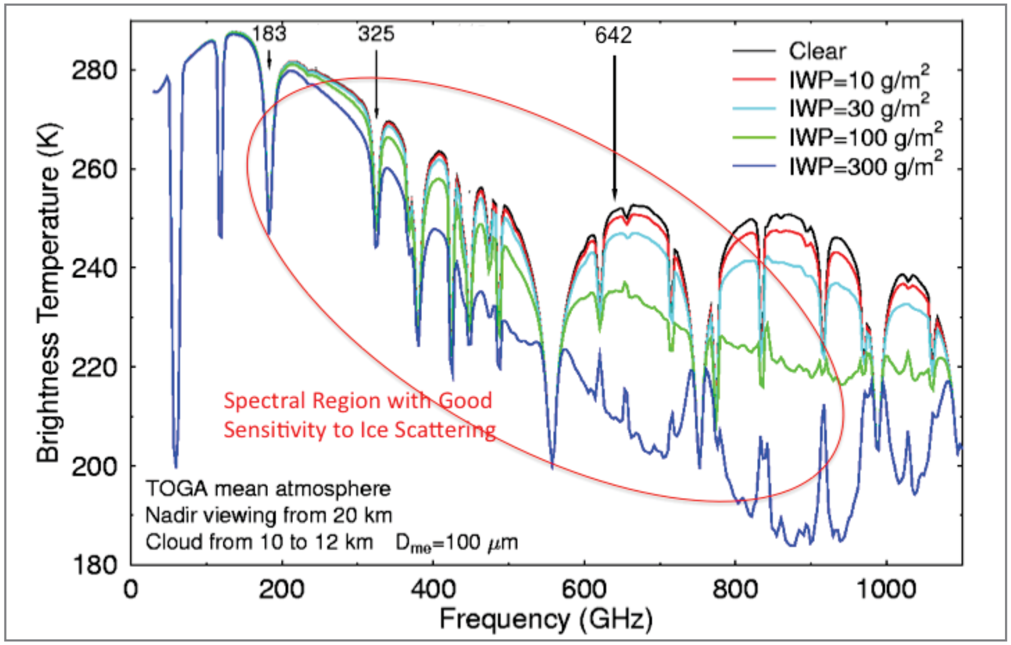


IceCube

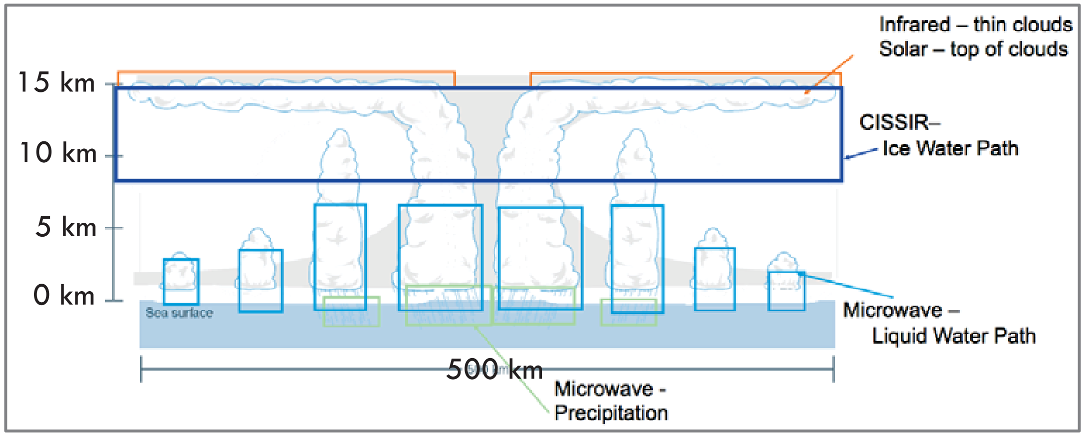
Conclusion

Motivation and science drive

- Cloud ice properties are fundamental controlling variables of atmospheric radiation and precipitation
- Large discrepancies in Ice Water Path (IWP) exist in Global Circulation Models
- Limited availability of data and poor assumptions about the cloud micro- and macro-physical properties of clouds are principle contributors to the discrepancy
- No ice cloud measurements currently exist for the intermediate altitudes
- mm- and submm-wave radiometry offers great potential to fill the measurement gap in the middle and upper troposphere



The spectral region with good sensitivity to ice cloud scattering (courtesy of Frank Evans).

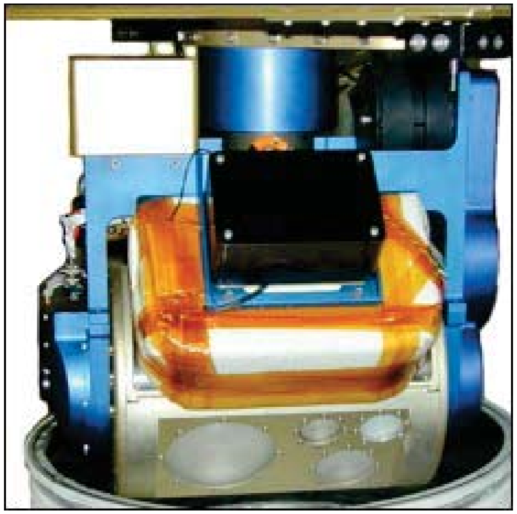


GSFC mm- and sub-mm-wave instruments

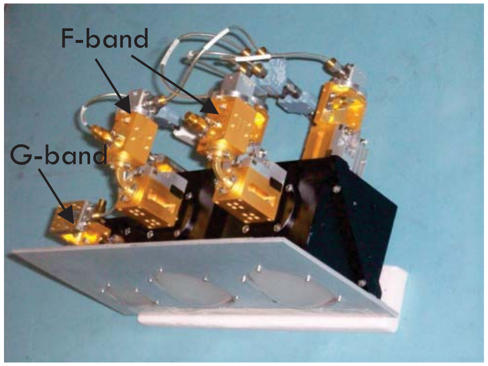
- CoSMIR: Conical scanning mm-wave imaging radiometer
  - Azimuth over Elevation dual axes gimbals for cross-track and concial scanning
  - 6 receivers, 9 channels at 50.3, 52.6, 89 (H&V), 165.5 (H&V), 183.3±1, 183.3±3, ±7
  - FOV: 4° beam width
  - Scan head: cylinder with 21.5 cm diameter and 28 cm length
- CoSSIR: Compact scanning sub-mm-wave imaging radiometer
  - 6 receivers, 12 channels at 183.3±1 ±3 ±7, 325±1.5 ±3.5 ±9.5, 448±1.4 ±3 ±7.2, 642 (H&V), 874
- HyMAS: Hyperspectral Microwave Atmospheric Sounder
  - Hyperspectral with 52 channels (in partnership with MIT-LL)
  - 6 receivers at 172-183 GHz (H&V),

  2x108-119 (H&V)
- GMI: GPM Microwave Imager
  - Receiver Components:
    - Noise sources X-band—Ka-band
    - Mixers up to G-band

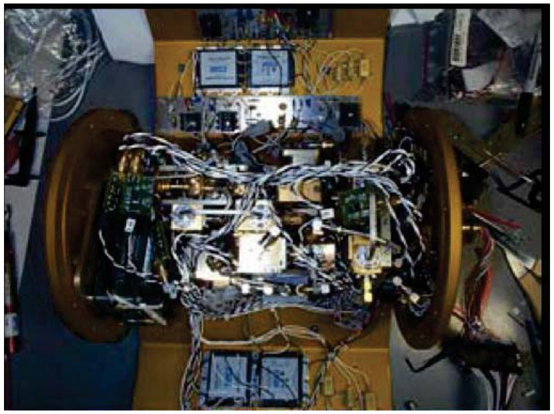
CoSMIR



HyMAS Receivers



CoSSIR interior



System Study

- A small, compact sub-mm instrument has many opportunities in future NASA, NOAA and international missions
- GSFC developed design and analysis tools to evaluate size, weight, and power (SWaP) of sub-mm-wave instruments
  - Cross-track vs. Conical scan
  - Spatial resolution, aperture size, and spatial resolution
  - Receiver selection and number of channels
- Scientifically-valuable sub-mm-instrument configuration fit within 30–50 kg mass, suitable for Earth-venture class opportunities

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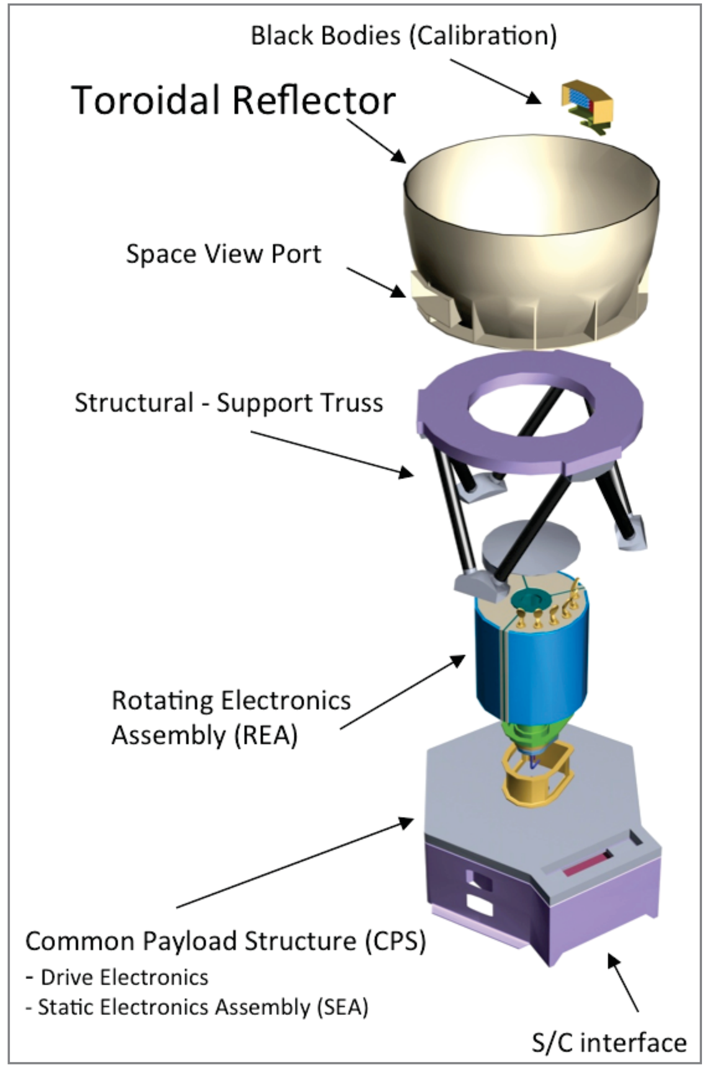
Conical Scan Instrument concept



Small rocket/spacecraft technology (SMART)

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  - Microsatellite prototype that enables focused science and technology missions with limited resources
  - Demonstration of a point design instantiation of a modular, open systems architecture micro spacecraft prototype
  - Miniaturized high-performance, power-efficient processing avionics for small expendable launch vehicles, and small orbiting spacecraft
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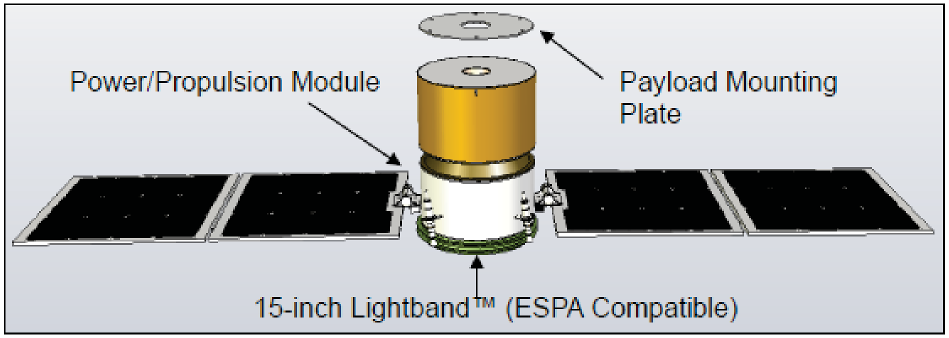
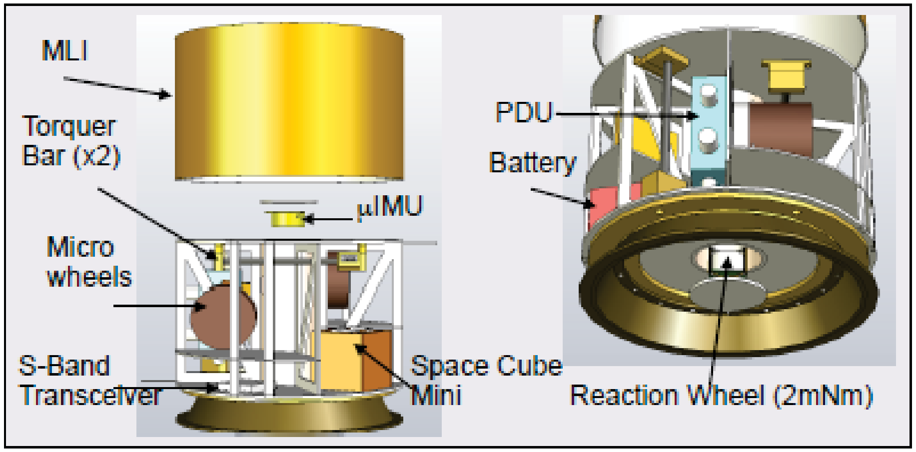
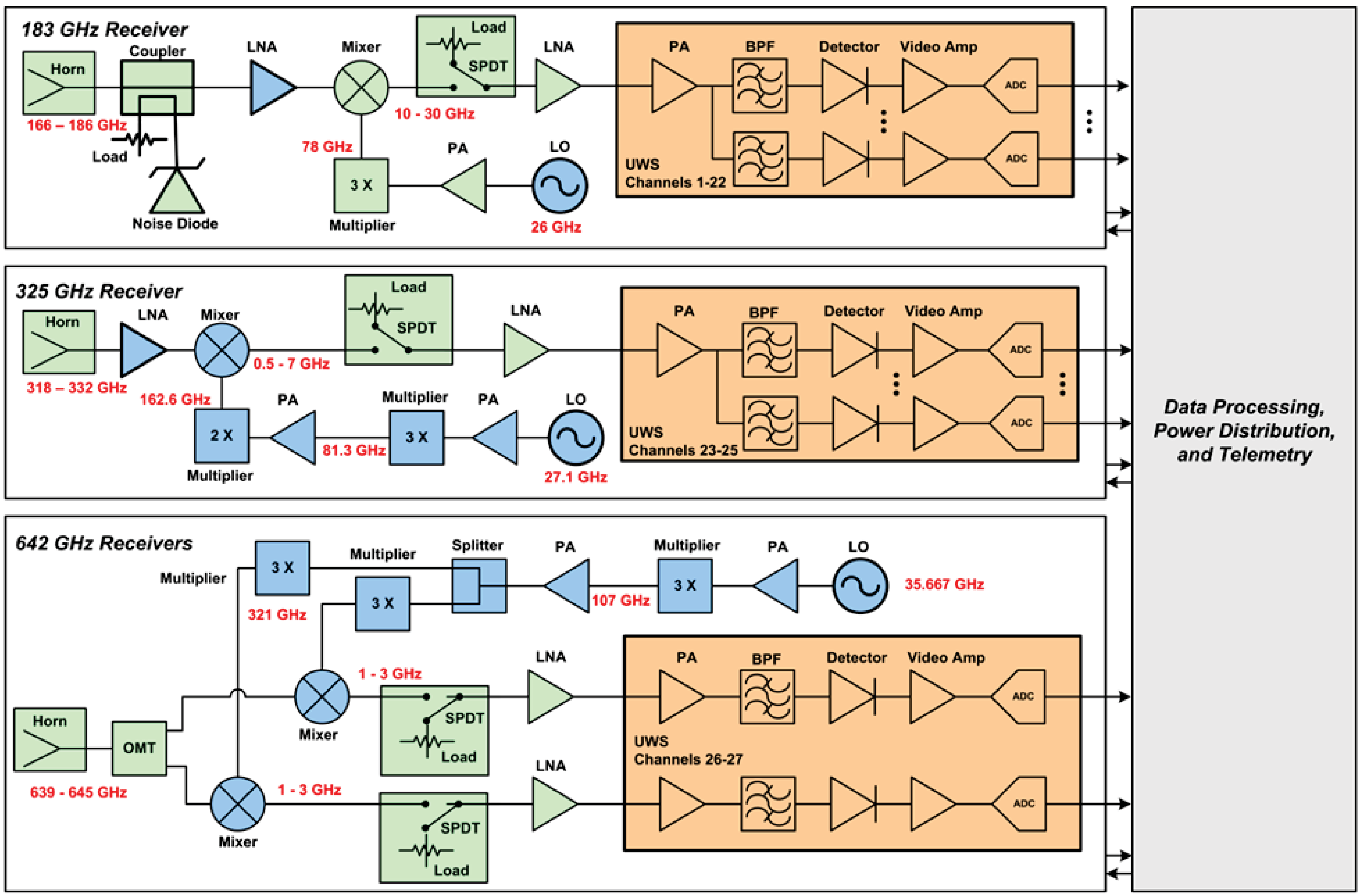
- SMART core components are mostly COTS, and replaceable
- Payload mass capability: 30–50 kg
- Payload available power: 284–314 W
- Bus dissipated power: 45–75 W

Simplified illustration of SMART





Candidate instrument architecture (SCAMPER)

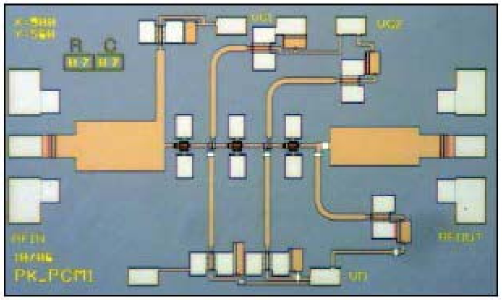


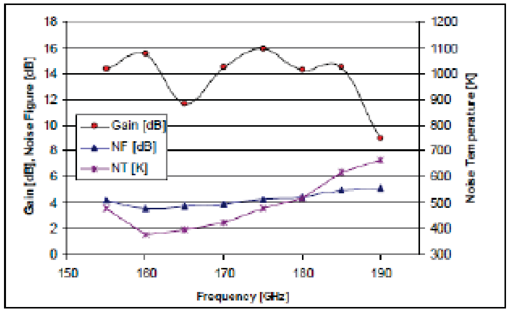
SCAMPER performance parameters

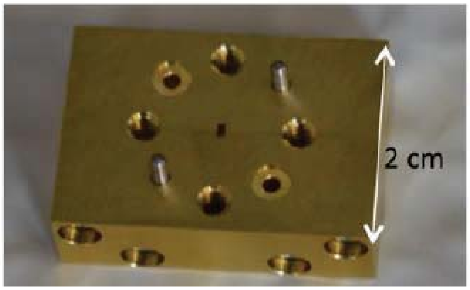
Center frequency & polarization	183 GHz V-pol	325 GHz V-Pol	642 GHz H-Pol	642 GHz V-Pol
RF pass-band [GHz]	166-186	318-332	639-645	639-645
IF pass-band [GHz]	10-30	0.5-7	1-3	1-3
Number of channels	22	3	1	1
Polarization	Vertical	Vertical	Horizontal	Vertical
Noise temperature [K]	1060 (SSB)	1540 (DSB)	4120 (DSB)	4120 (DSB)
NETD [K] @ τ_{int} = 7 ms	0.64 (650 MHz BW)	0.49 (2 GHz BW)	1.18 (2 GHz BW)	1.18 (2 GHz BW)

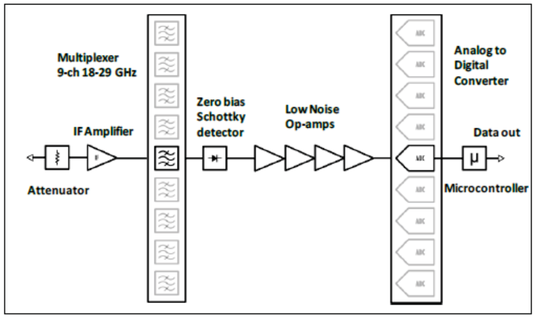
New instrument technologies

- LNAs at 183 GHz and 325 GHz
  - Advantages
    - Improved noise temperature
    - Reduced power (mixer with higher conversion loss)
    - Single side-band detection (hyperspectral receivers)
  - Available technologies
    - 35 nm InP technology NGAS/JPL [Kangaslati *et al.*, *2008*] and BAE
    - SiGe technology Georgia Tech [Coen *et al.*]
    - Teledyne HBT InP
- Coupled noise source at 183 GHz
  - 9 dB ENR @ 200 GHz noise source developed at GSFC
  - Improving receiver calibration
  - Eliminates requiring view of clear sky
- Ultra Wide Band Spectrometer (UWS) developed by MIT-LL
  - 52-channel, 100 cm^3 UWS developed for HyMAS (ESTO/ACT project)



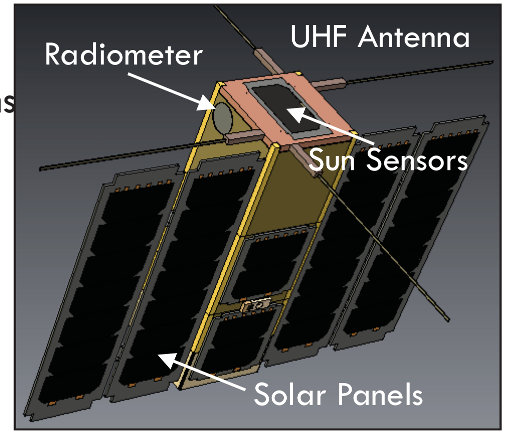


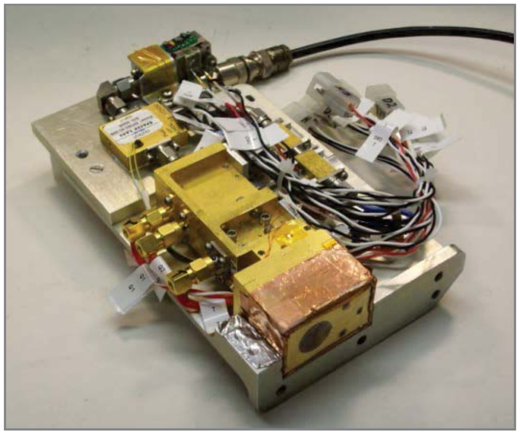


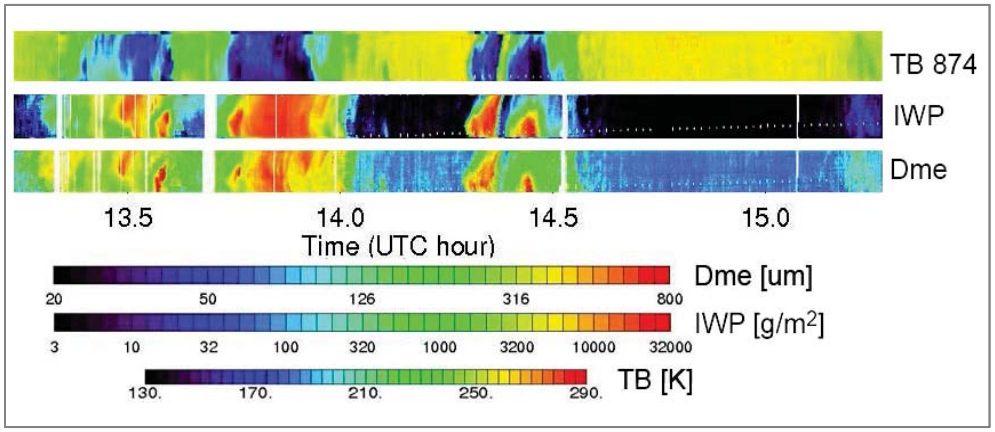


IceCube: 874 GHz radiometer on a CubeSat

- Objective
  - Develop and validate a flight-qualified 874 GHz receiver for future use in ice cloud radiometer missions
- Operation Concept
  - Orbit: LEO @ 350 km
  - Duration: 28 days
  - 15 orbits per day (31 mins pointed at Earth, 9 mins view of clear sky)
- Technologies
  - Sub-mm-wave 874 GHz receiver
    - 2^{nd} Harmonic mixer
    - Frequency doubler & triplers
    - V-band multiplied LO with power modulation
    - IF with noise injection
- Receiver performance
  - Noise temperature < 6000 K
  - NEDT < 0.1 K for 1 s integration time
  - 2 K calibration error

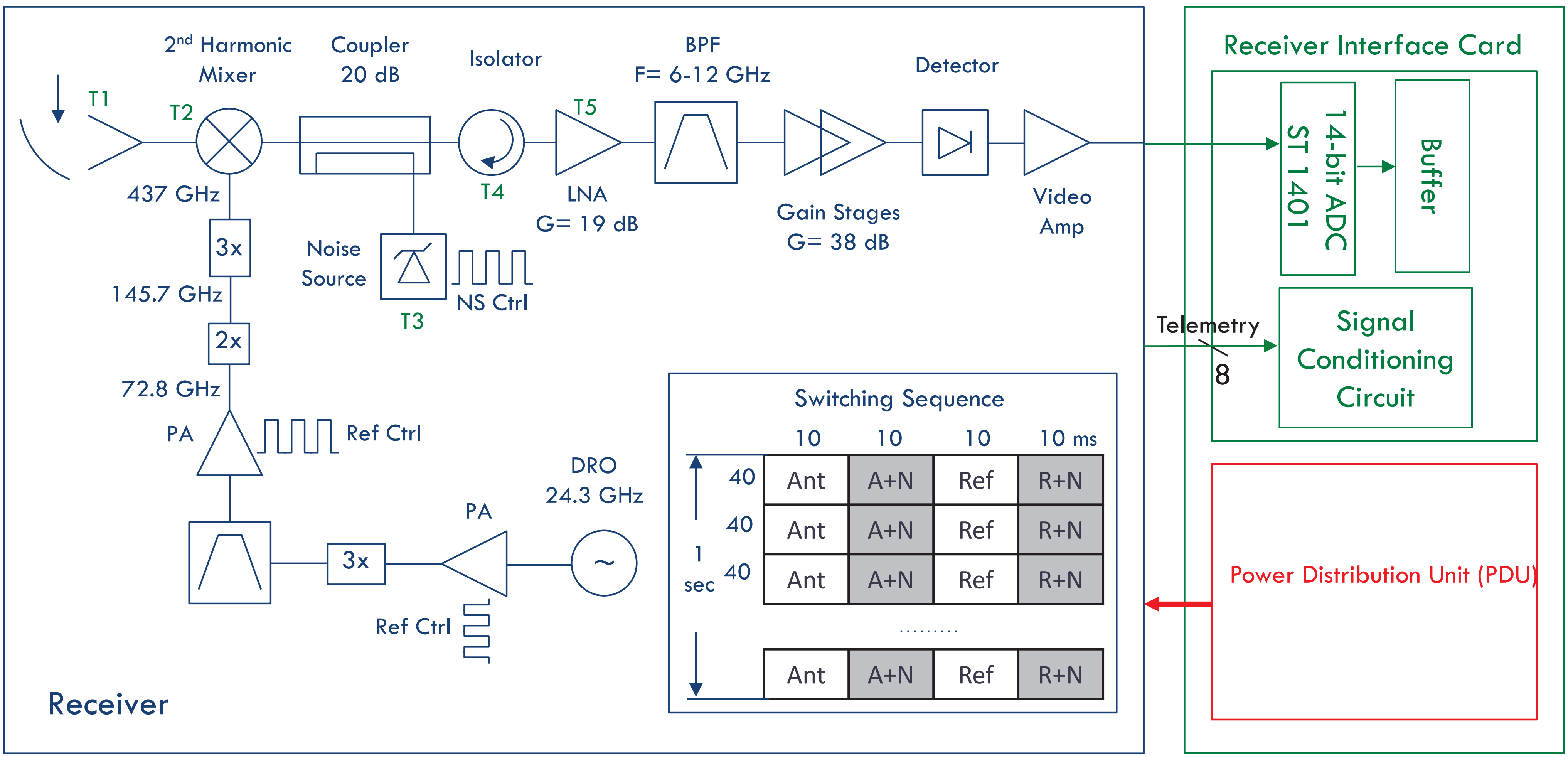






(a) Conceptual drawing of IceCube (radiometer at top). (b) The 874 GHz CoSSIR. (c) First ever 874 GHz cloud measurements acquired by CoSSIR in 2008. CoSSIR measurements of ice clouds were used to successfully demonstrate retrieval of ice water path (IWP) and ice particle median mass-weighted ice particle size (D_{me}).

IceCube: receiver



Conclusion

- Distributed satellite systems are required to retrieve IWP with 25 % accuracy, to enable improved ice cloud modeling
  - Highly sensitive
  - Cost effective
  - Compact mm- and sub-mm-wave instrument with multiple channels

		SCAMPER	SSMIS	MHS	GMI
Science capabilities	Cloud ice	Yes	Yes	Yes	Yes
	Ice particle size	Yes	Limited	Limited	Limited
	Ice particle shape	Yes	No	No	Limited
Instrument properties	Frequencies [GHz]	183, 325, 642, 874	19, 22, 37, 91, 50-63,183	89,157, 183, 190	10 18, 23, 36, 89, 165, 183
	IF channels	28	24	5	13
	Dual-pol [GHz]	642	19, 37, 91	None	10.7, 18.7, 36.5, 89,165.5
	RF cal [GHz]	183	None	None	10.7, 18.7, 23.8, 36.5

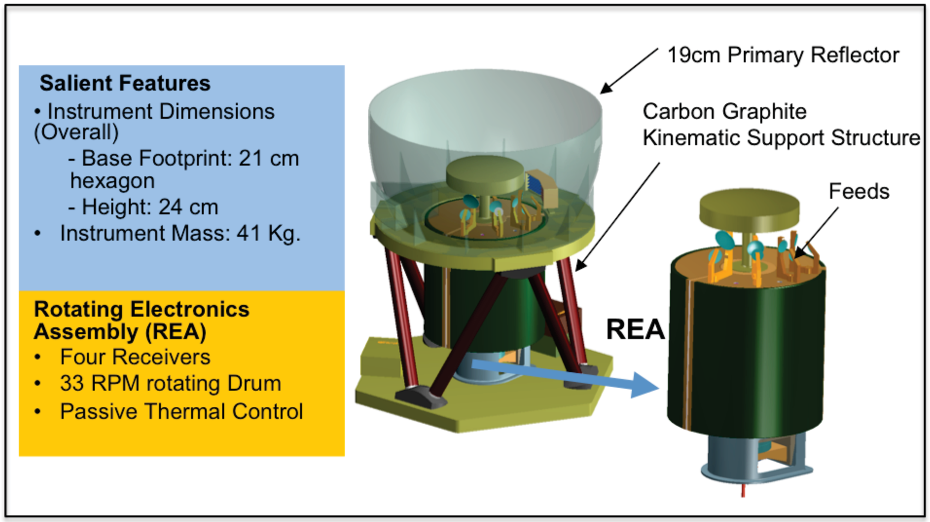
Questions?

Backup: system study

- Distributed satellites
  - Observations of ice clouds requires frequently updated measurements by a distributed satellite system, due to a strong diurnal variation
- Conically scanning/ Cross track
  - Polarization preservation
- Radiometric stability
  - Antenna is not exposed to open air
- mm- and sub-mm-wave receivers

  housed in the compact scan head
- Mass budget
  - 41 kg
- Power budget:?

Small Satellite Mission Concept



Backup: concept study table

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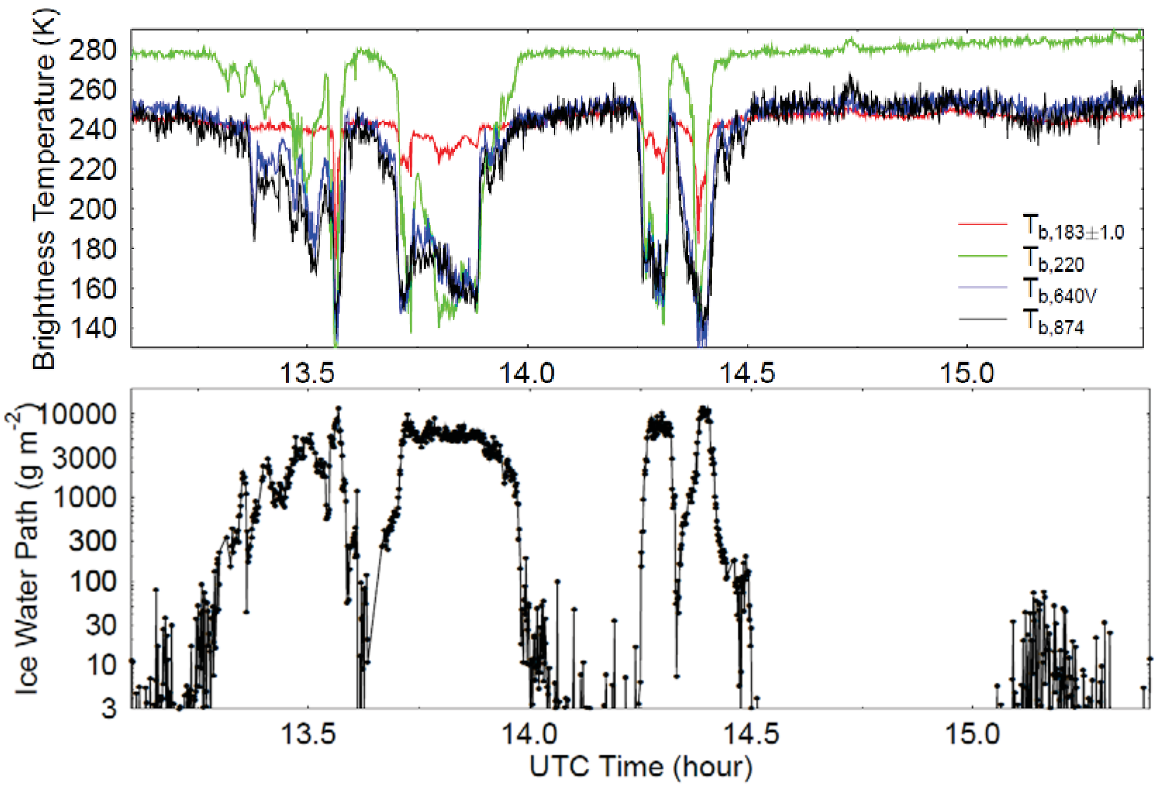
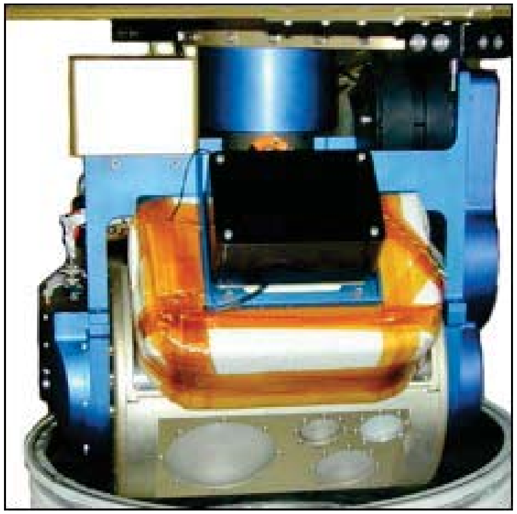


CoSSIR nadir brightness temperature and retrieved IWP [K. F. Evans *et al.*]

CoSMIR



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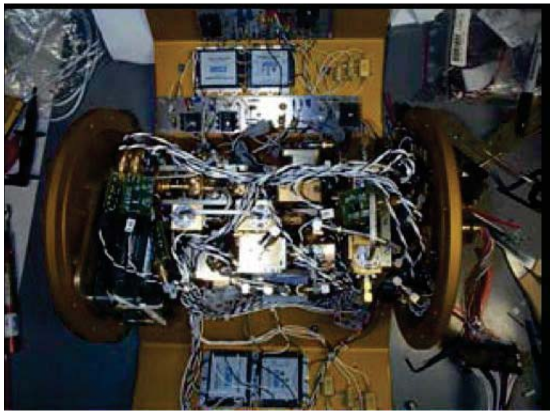

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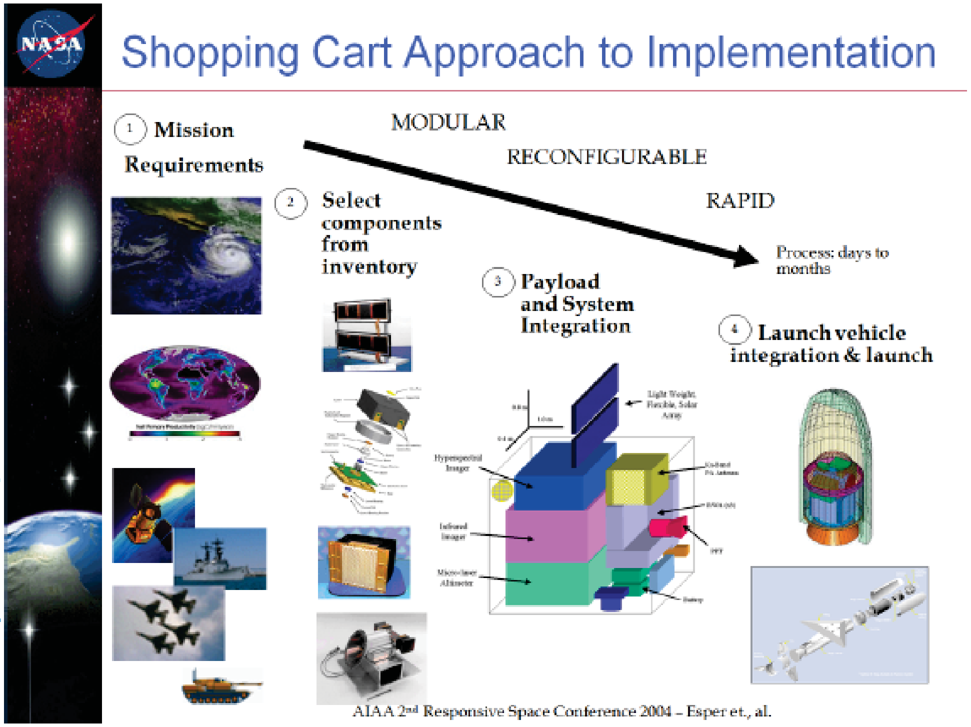

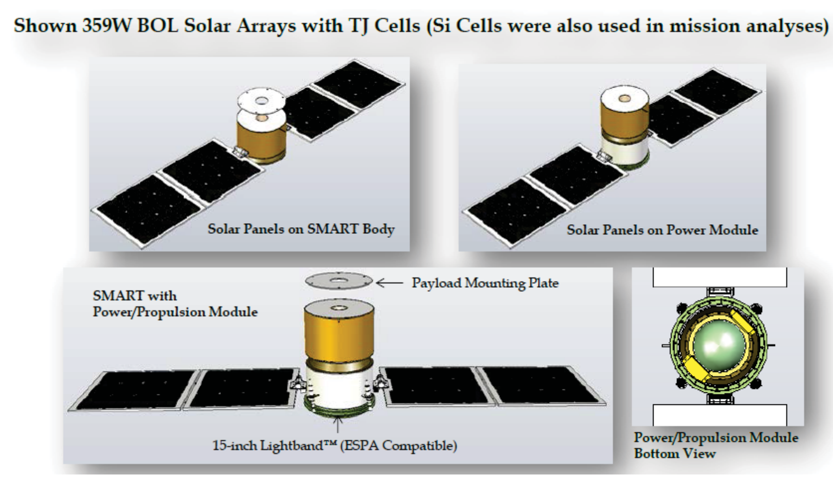

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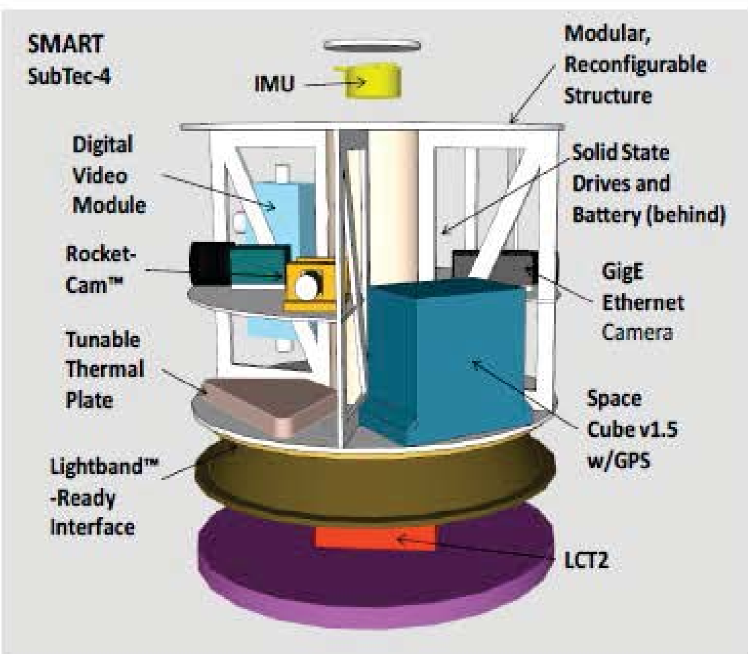
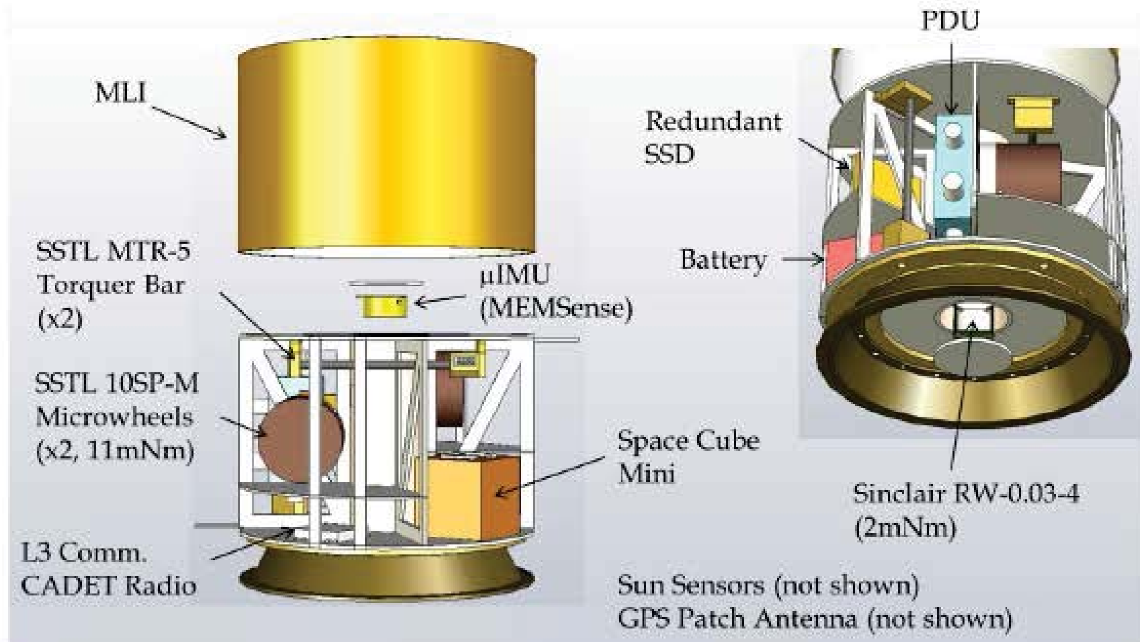
SMART Configuration



Multi-use Payload Platform



Backup: atmospheric sensing spectral regions