National Aeronautics and Space Administration
Goddard Space Flight Center

IceCube: CubeSat 883-GHz Radiometry for Future Cloud Ice Remote Sensing

D. L. Wu, J. Esper, N. Ehsan, T. E. Johnson, W. R. Mast, J. R. Piepmeier and P. E. Racette

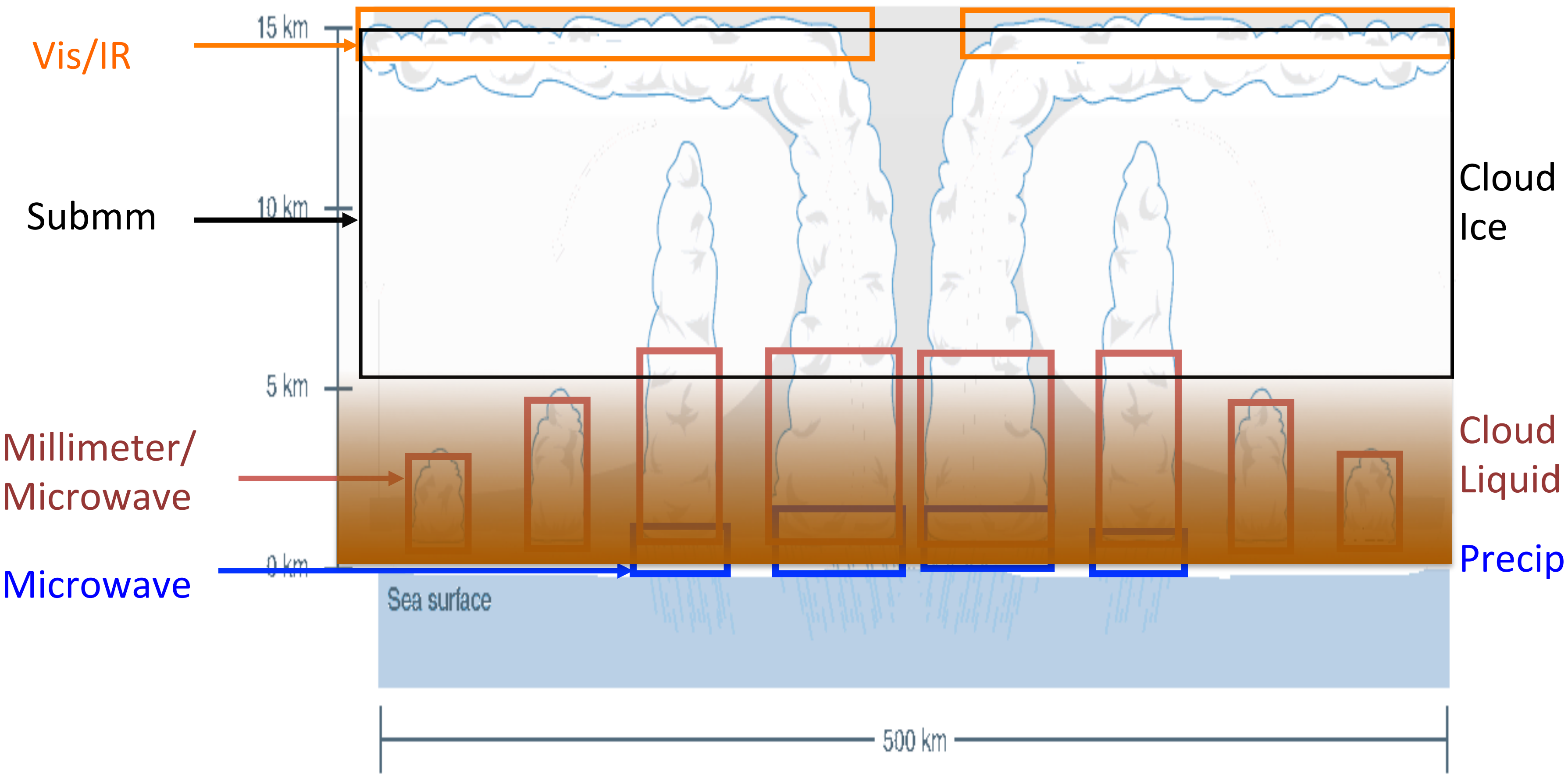
NASA Goddard Space Flight Center

Acknowledgements:
This research is sponsored by the NASA ESTO and SMD/ATIP Programs

SmallSat 2015 Logan, Utah August 8, 2015

Why Submillimeter-Wave Radiometry?
- Critical Gap in Cloud Ice Measurements –

No ice cloud measurements currently exist for the intermediate altitudes



Vis/IR

Submm

Millimeter/
Microwave

Microwave

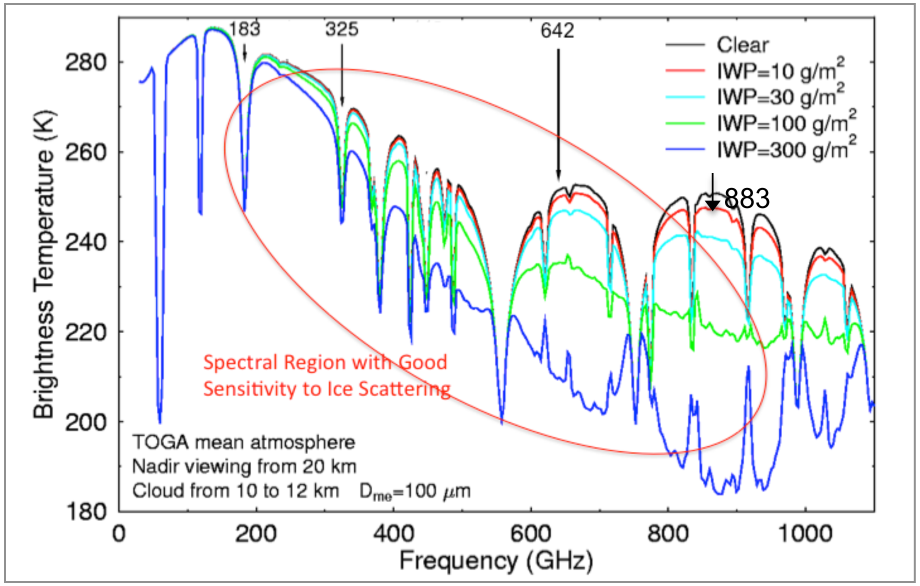
Cloud
Ice

Cloud
Liquid

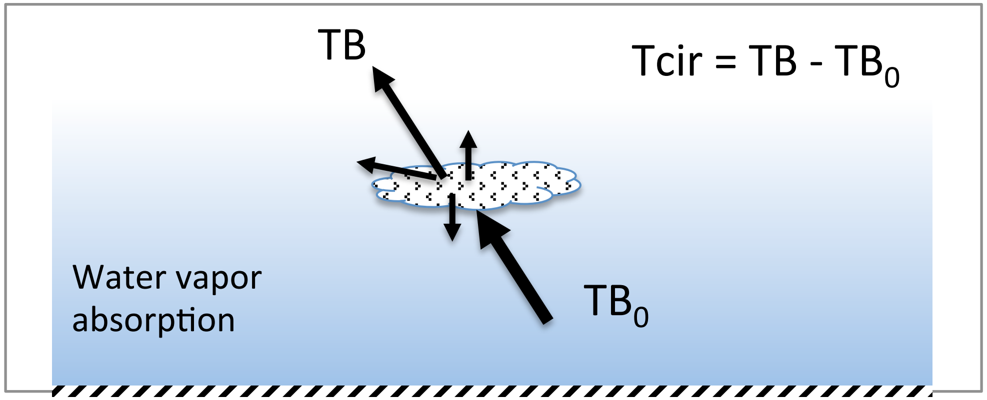
Precip

Science Motivation

- Cloud ice properties are fundamental controlling variables of radiative transfer 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).



$Tcir = TB - TB_0$

Measurement and Mission Overviews

883-GHz measurement requirements:

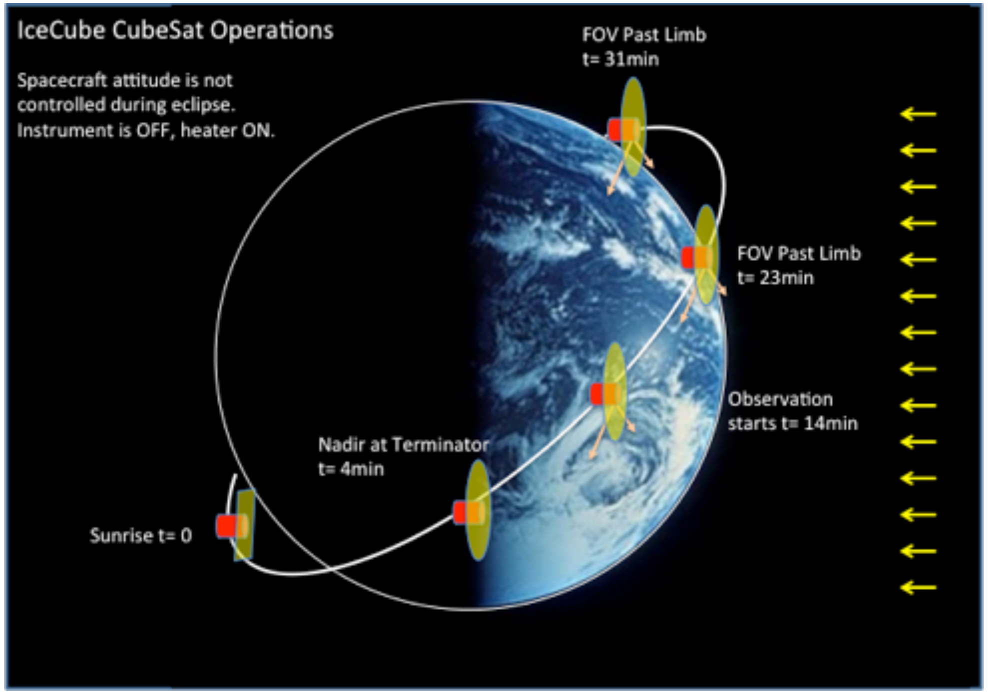
- Accuracy < 2 K
- Precision (NEdT) < 0.25 K
- Spatial resolution < 15 km

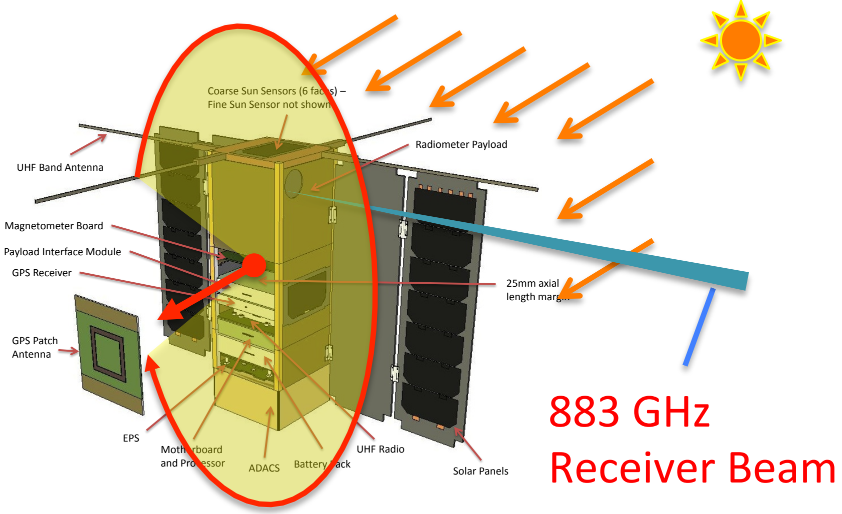
Mission requirements:

- In-flight operation 28 days
- Periodical views of Earth (science) and space (calibration) within an orbit
- Science data 30+% (8+h /day)
- Pointing knowledge < 25 km

Validation plan:

- Lab measurement and verification
- Modeled vs observed clear-sky radiances for accuracy verification
- Space-view radiances for precision





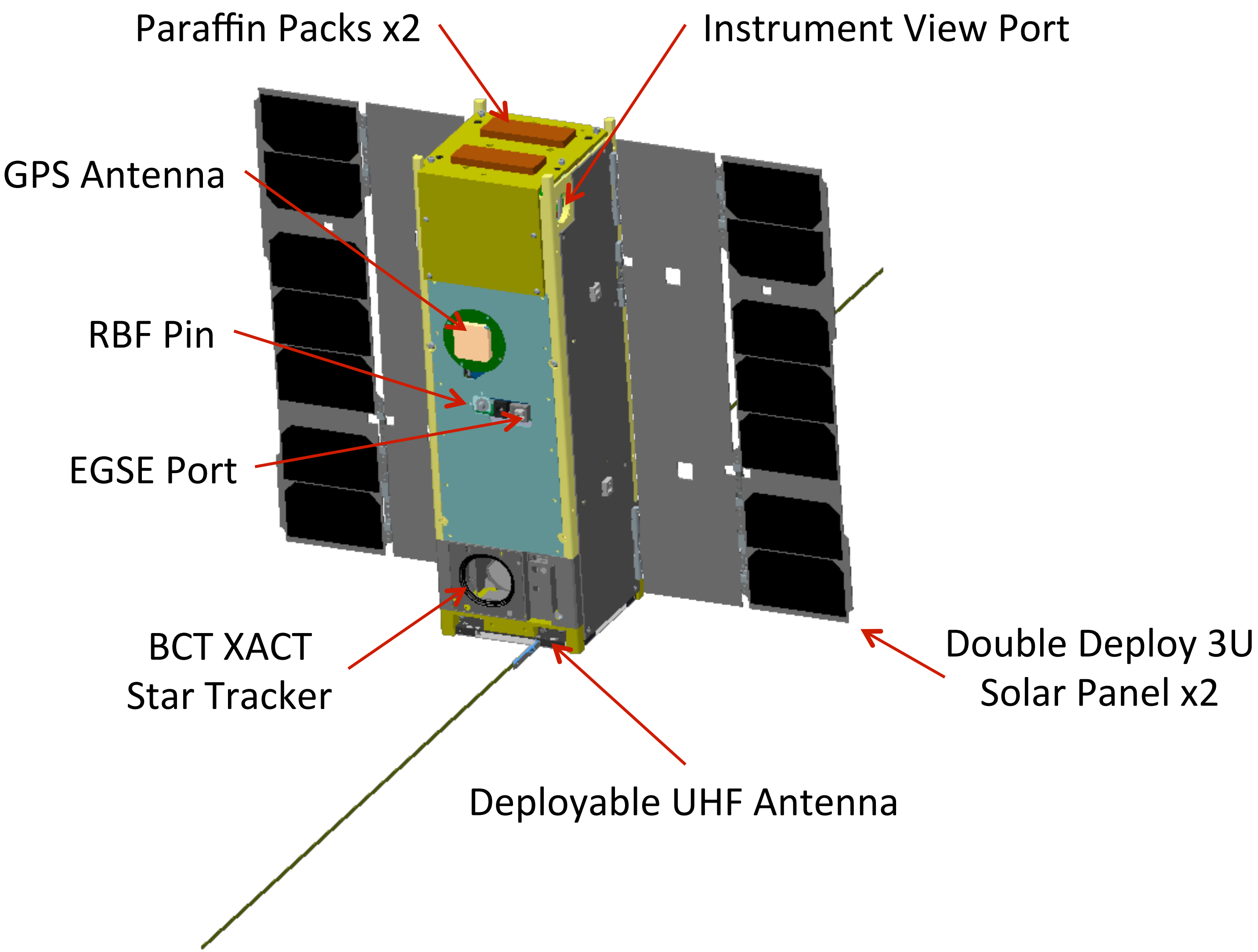
IceCube Objectives

- Enable remote sensing of global cloud ice from space with submm-wave technology
- Raise overall TRL (5->7) of 883-GHz receiver technology with spaceflight demonstration on 3U CubeSat

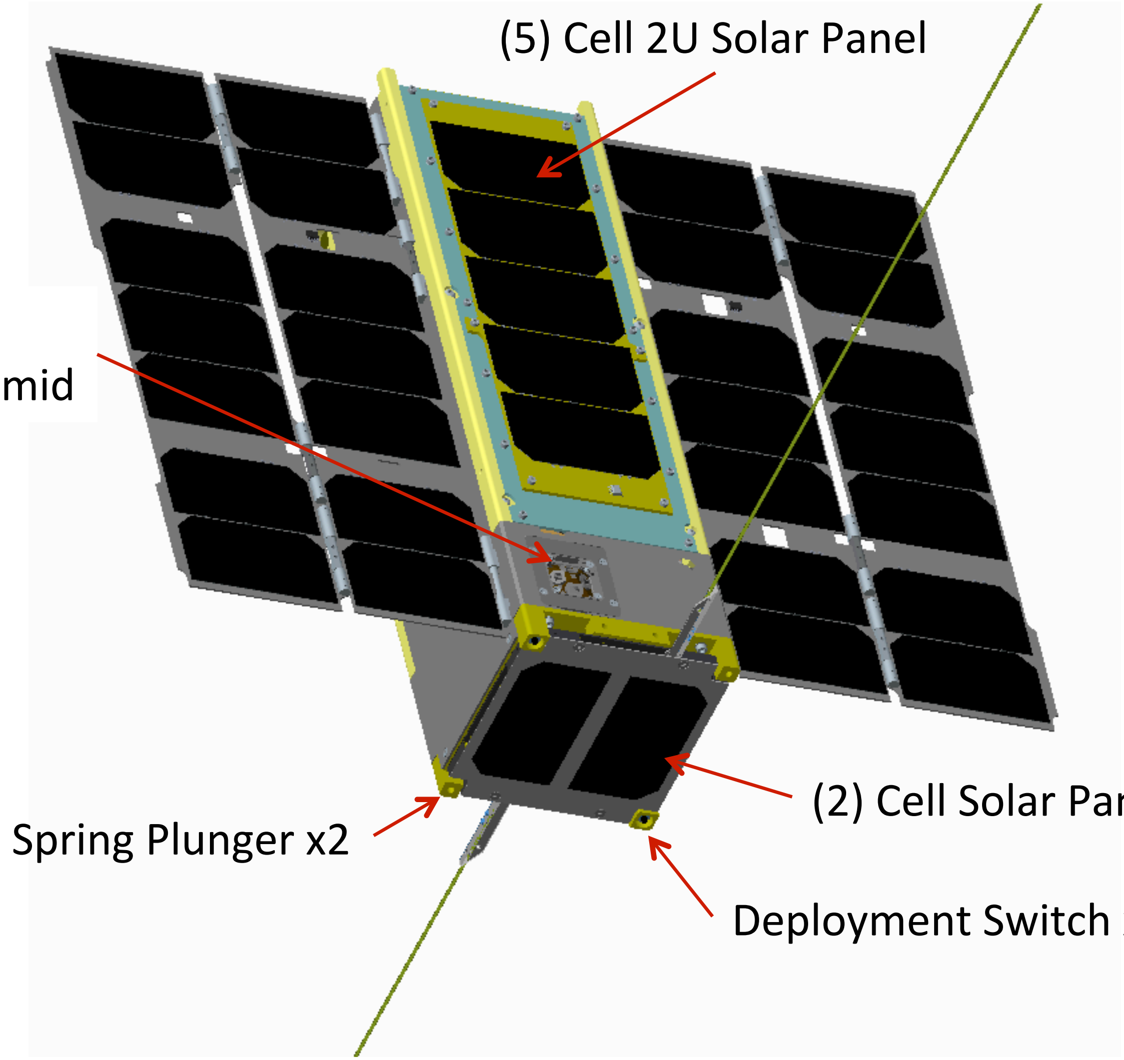
Common Goals and Benefits to NASA SMD science missions

- Miniaturize science payload for low-power and low-mass spaceborne sensors
- Reduce instrument/spacecraft cost and risk for future missions by developing efficient path-to-space with COTS receiver and CubeSat systems

External Layout - Deployed (1/2)



External Layout - Deployed (2/2)



(5) Cell 2U Solar Panel

Coarse Sun
Sensor Pyramid

(2) Cell Solar Panel

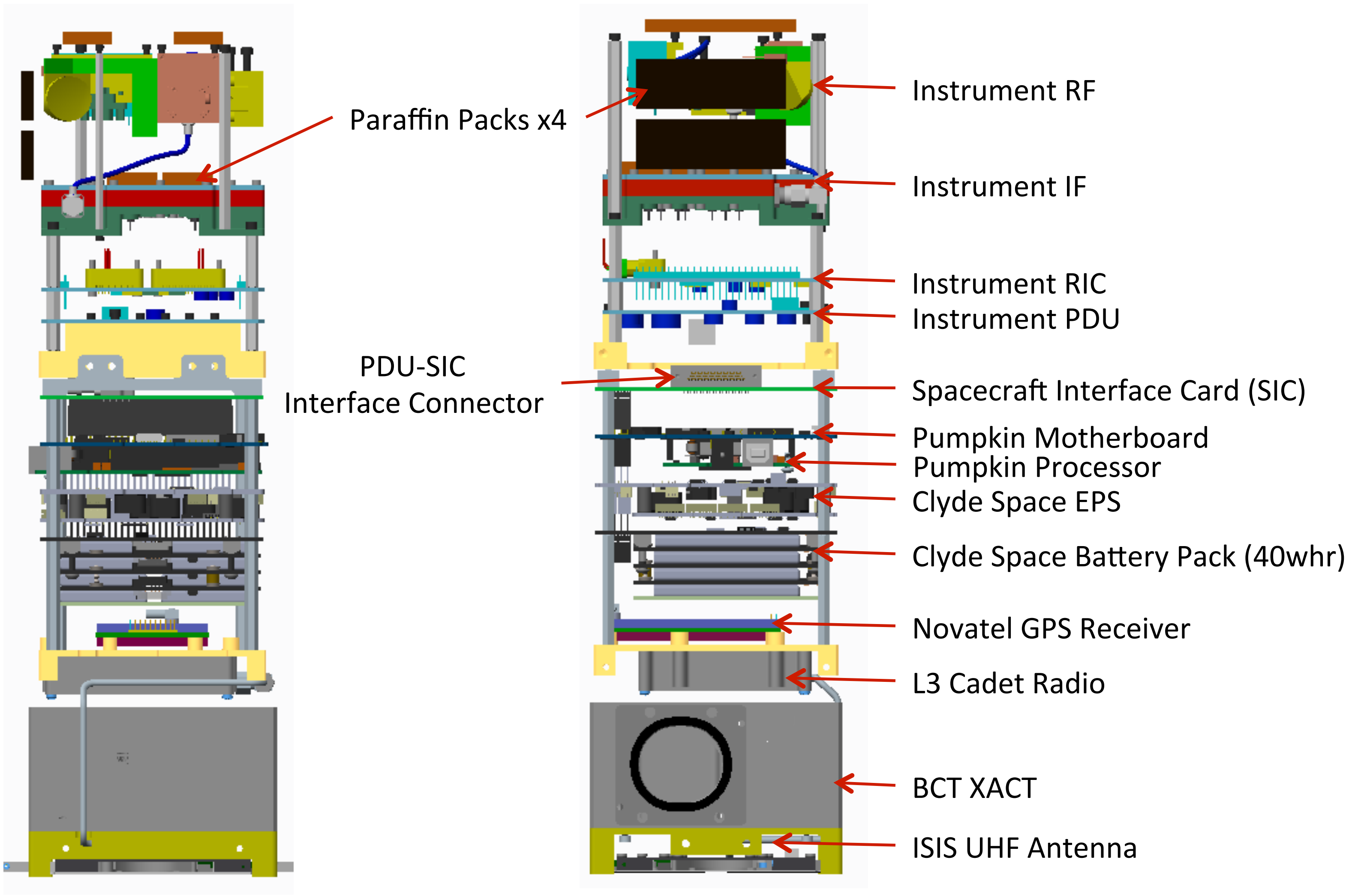
Spring Plunger x2

Deployment Switch x2

Spacecraft Subsystems – All COTS

Subsystem	Design	POC
Electrical system	Spacecraft Interface Card (SIC) PDU-SIC interface	C. Duran-Aviles
Mechanical structure	3U	J. Hudeck
GPS	Novatel GPS Receiver	T. Johnson
Navigation and Control	BCT XACT	S. Heatwole
Power system	Clyde Space EPS, Solar panels, Battery 40Whr	C. Purdy
Thermal control	Passive paraffin packs Radiating surfaces	M. Choi
Communication	L2 Cadet radio ISIS UHF Antenna,	B. Corbin
Flight software	Pumpkin Motherboard, CPU Modified DICE flight software Beacon telemetry	T. Daisey
Ground system	WFF 18m, GMSEC/DICE design	R. Stancil

Internal Layout



Paraffin Packs x4

PDU-SIC
Interface Connector

Instrument RF

Instrument IF

Instrument RIC

Instrument PDU

Spacecraft Interface Card (SIC)

Pumpkin Motherboard

Pumpkin Processor

Clyde Space EPS

Clyde Space Battery Pack (40whr)

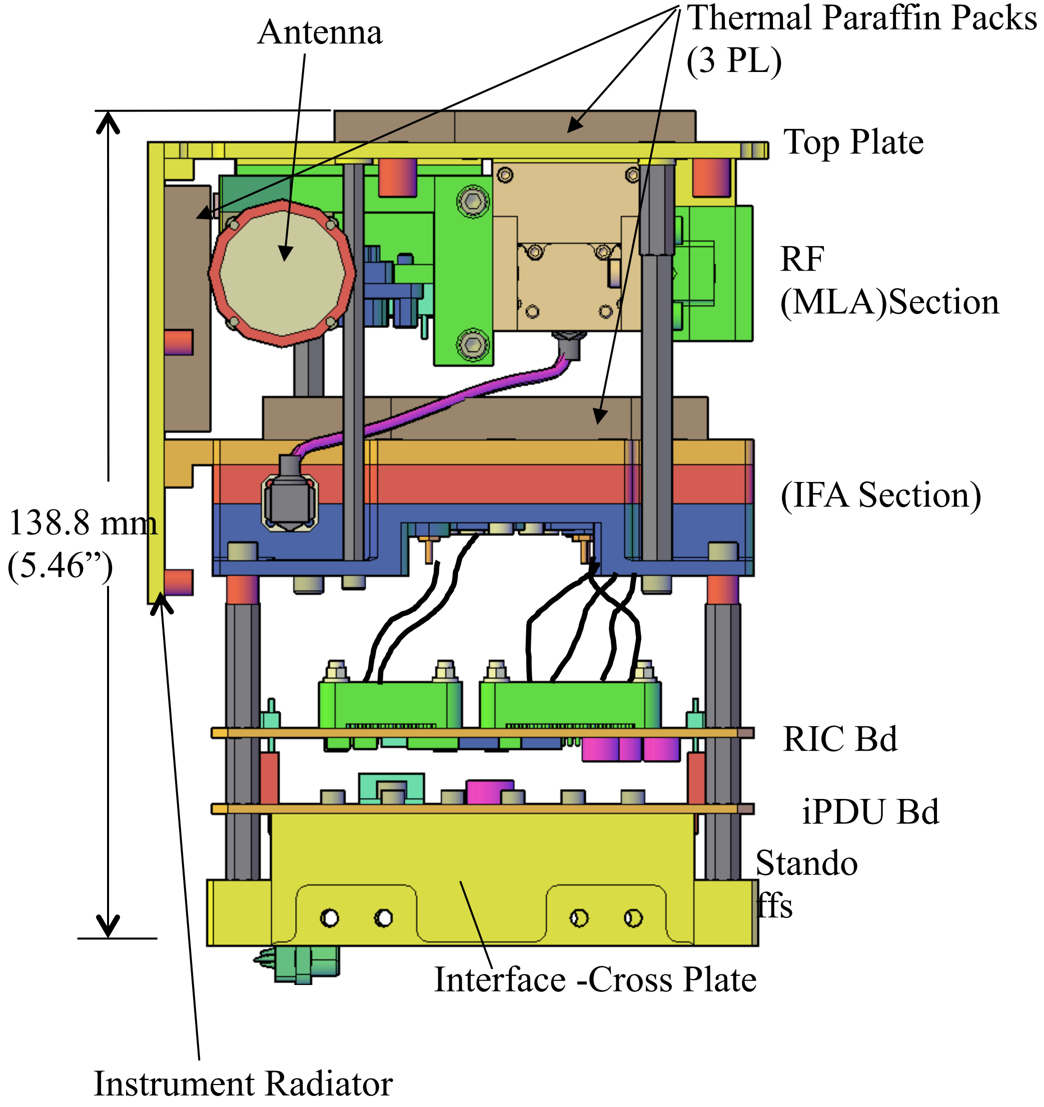
Novatel GPS Receiver

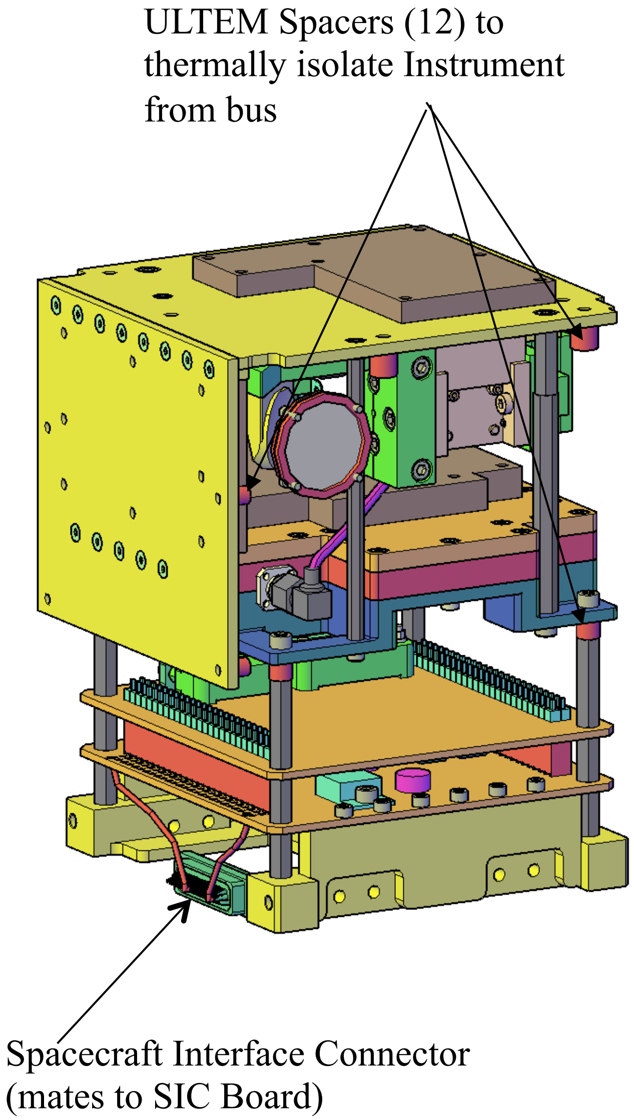
L3 Cadet Radio

BCT XACT

ISIS UHF Antenna

Instrument





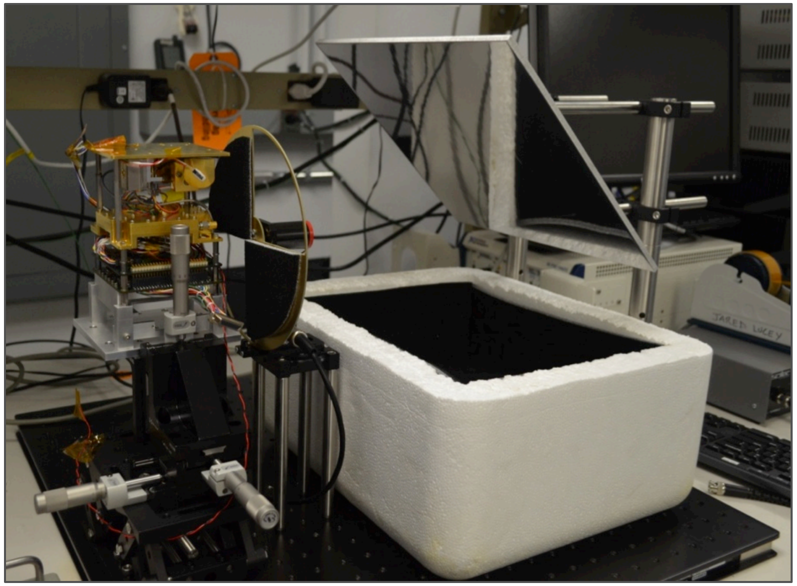
Courtesy of Mike Solly Code 562

Instrument Integration & Test

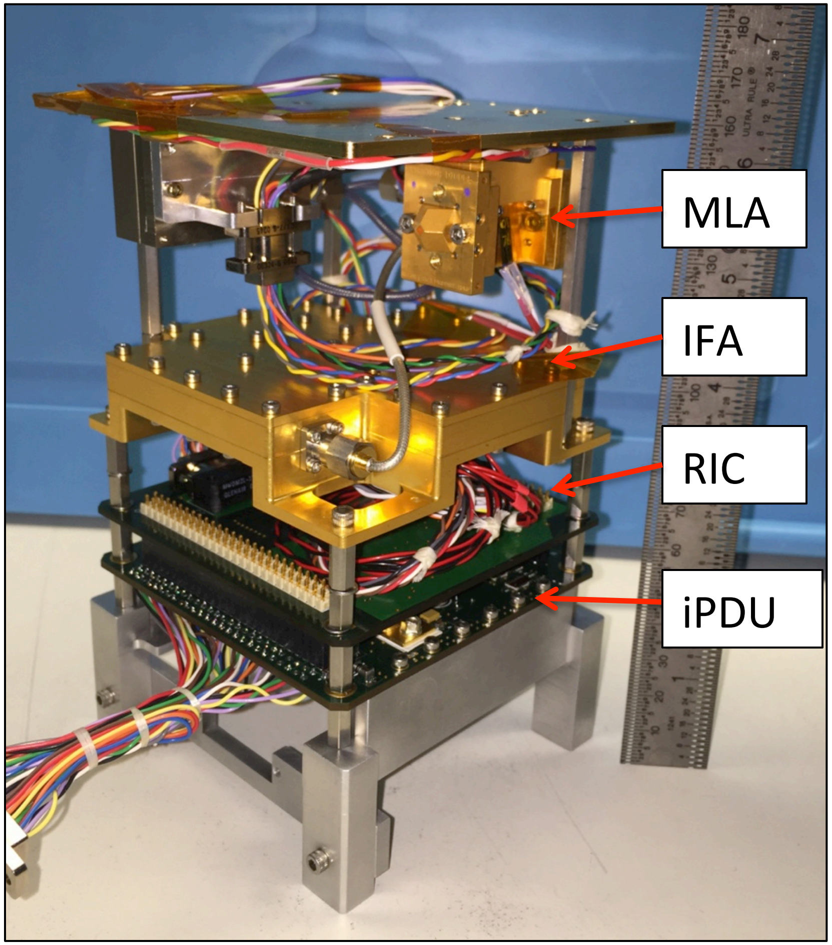
- Verification has been done via alternating between room temperature and LN_2 target

- Ambient setup includes:
    - Chopper wheel with room temperature absorber
    - 12” x 12” mirror
    - GSE spacecraft simulator
    - LN_2 absorber (Eccosorb AN 72)

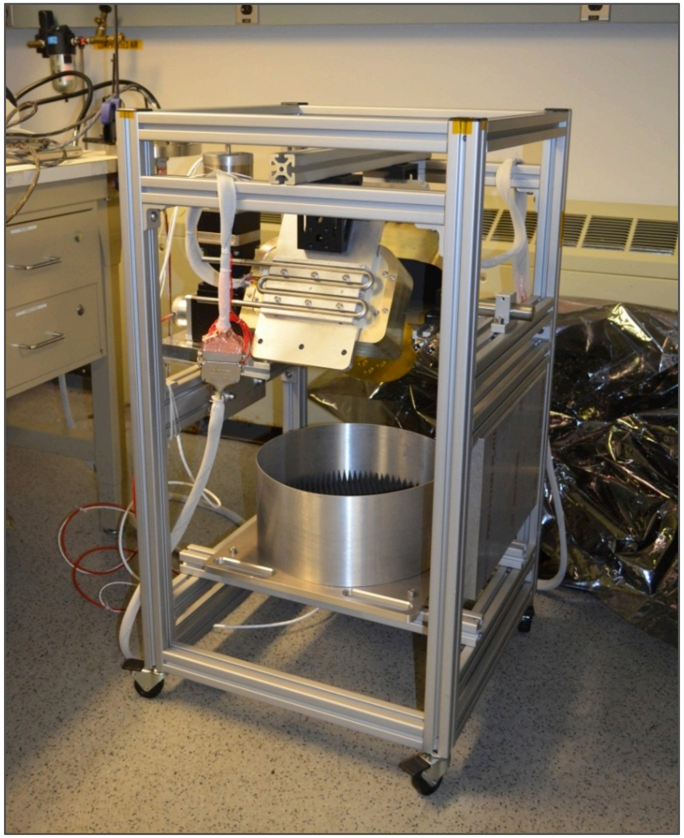
- The instrument will be tested over temperature with a Thermal Vacuum Chamber (TVAC)



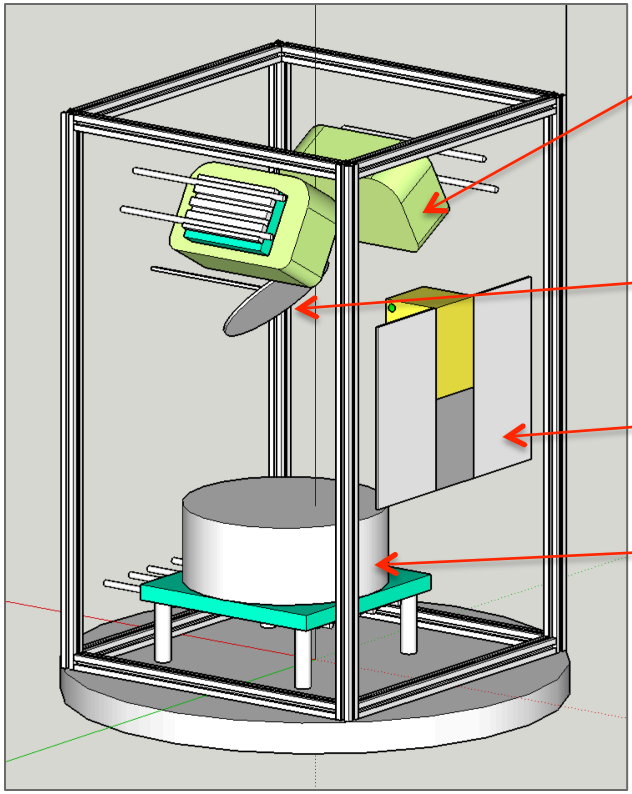
Engineering Model IceCube Instrument



Instrument TVAC



Courtesy of Kevin Horgan, 555 (inspired by MIT Lincoln Laboratory MicroMAS TVAC structure)



Sub-MMW blackbody cold target (100 K) & hot target (300 K) for external calibration; tolerance ± 1 K

45deg-offset rotating mirror to alternate observed scene/target

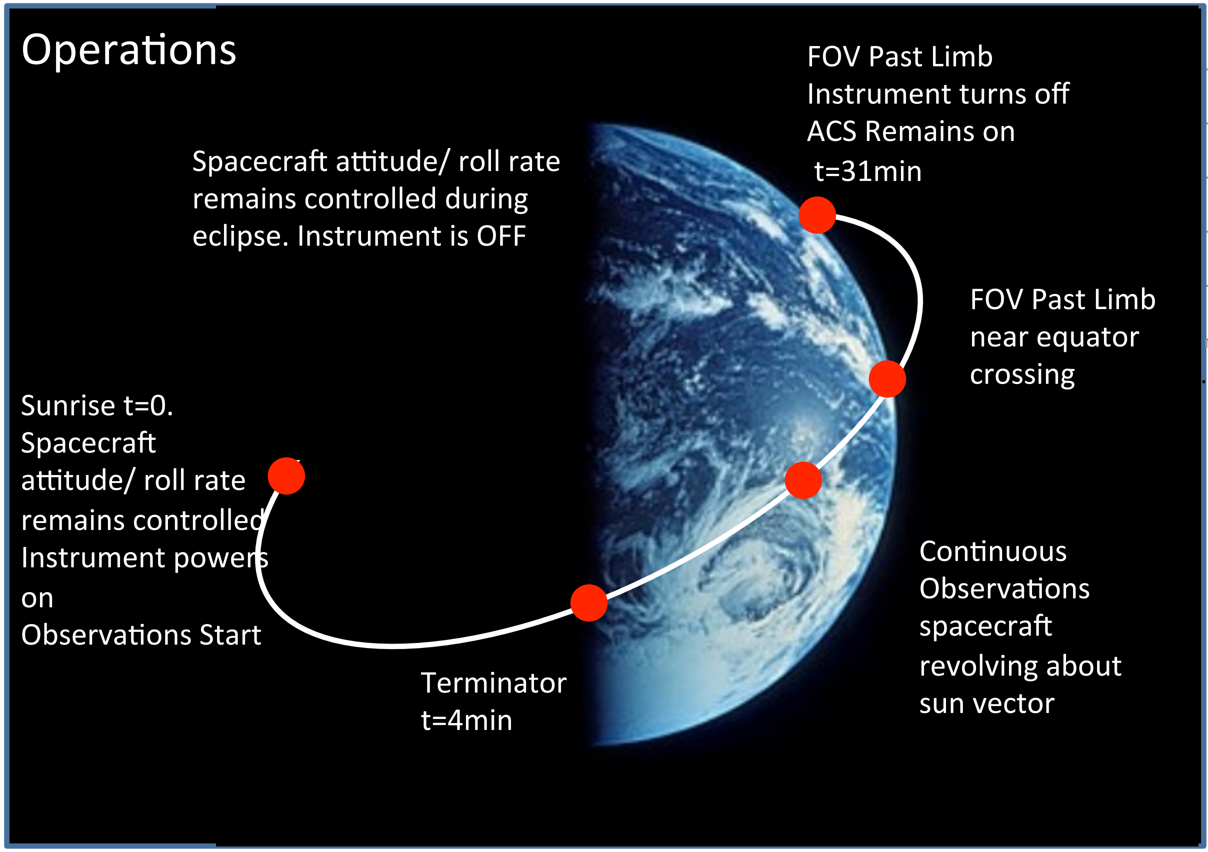
Instrument/IceCube

Sub-MMW blackbody target (variable 100-300 K); tolerance ±1 K

IceCube Calibration Fixture
(mounting hardware not shown)
(22.6” x 22.6” x 36”)

Concept of Operations

NASA CRS/COTS Orbit Baseline
Altitude = 424-422 km Period = 90.5 min Inclination = 51.65°



Operations

FOV Past Limb
Instrument turns off
ACS Remains on
t=31min

Spacecraft attitude/ roll rate remains controlled during eclipse. Instrument is OFF

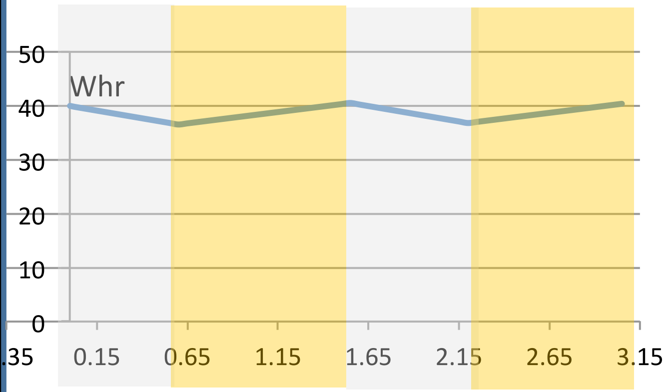
FOV Past Limb near equator crossing

Sunrise t=0.
Spacecraft attitude/ roll rate remains controlled
Instrument powers on
Observations Start

Continuous Observations spacecraft revolving about sun vector

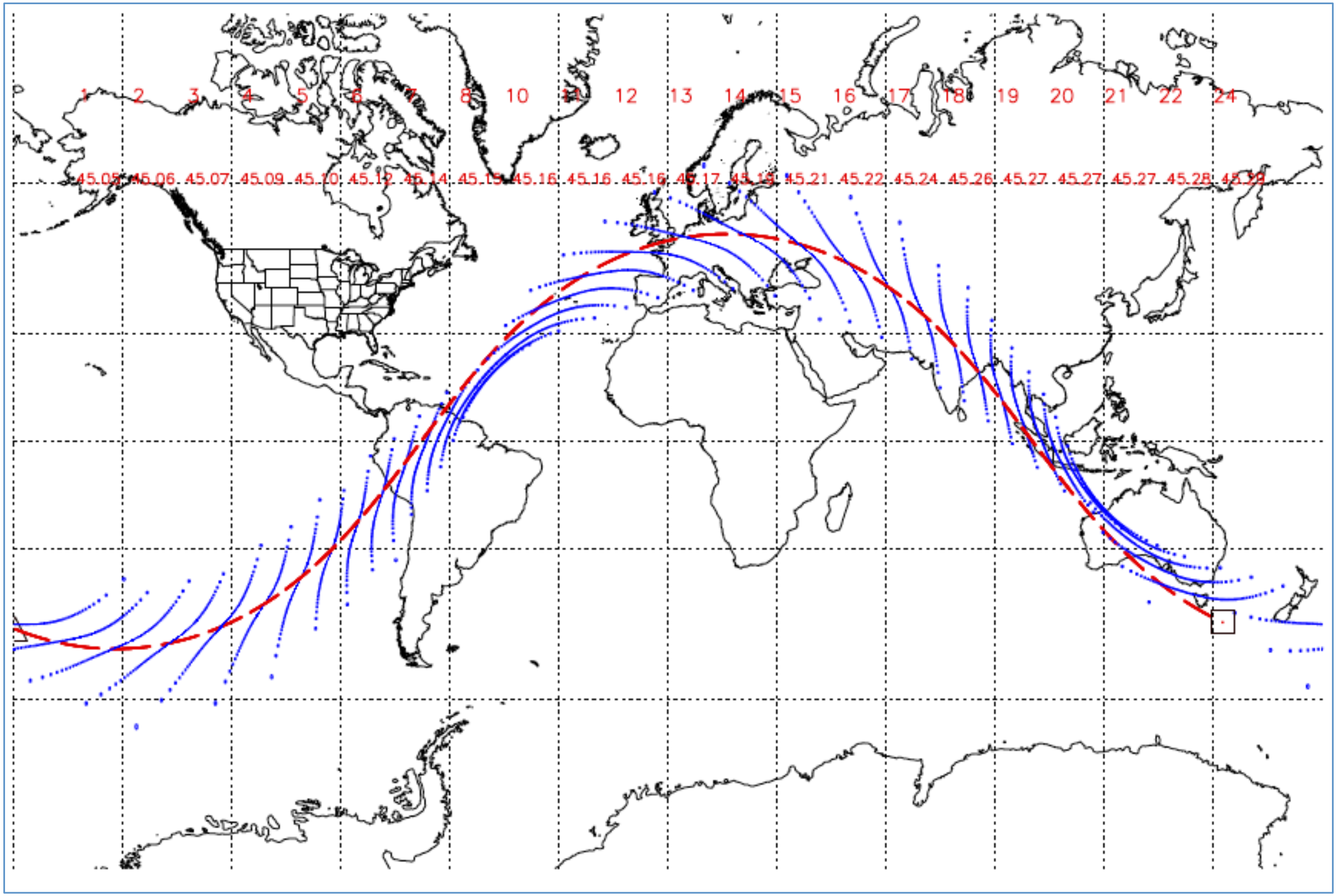
Terminator
t=4min

Science only in Sun Limit 20% DOD



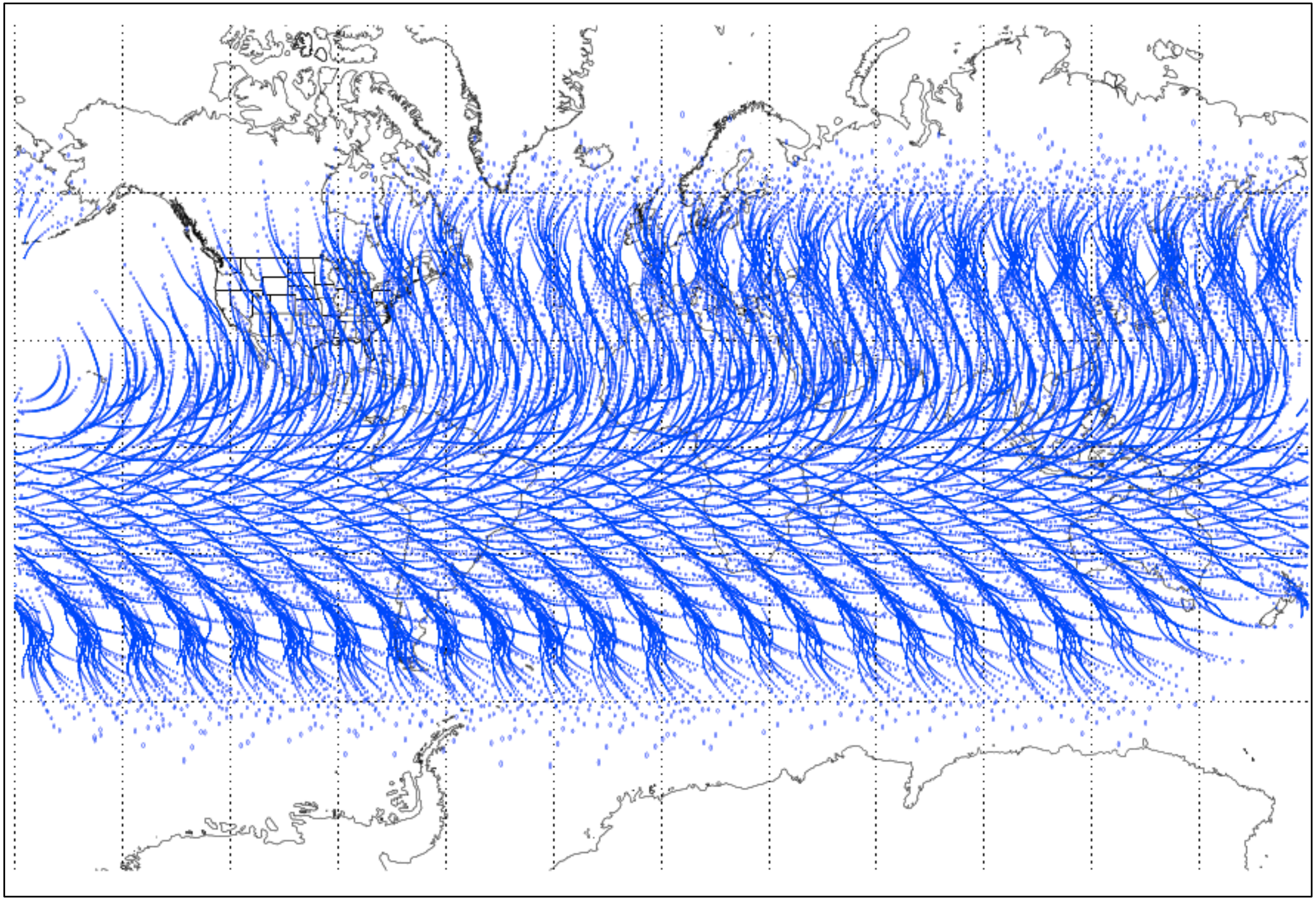
	Sun	Eclipse
	W	W
Instrument	5.4	0
GN&C/C&DH	4.145	4.145
Com	0.32	0.32
Power	0.31	0.46
EPS Losses 16%	1.628	0.788
Total out	11.803	5.713
Arrays	25	0
PDU losses 20%	-5	0
Total in	20	
Cell Temp Loss 20%	-4	
Total in	16	0

Simulated IceCube Sampling for Feb 25, 2015



(Courtesy of Y. Liu, SSAI)

Simulated Sampling for June 10-16, 2015 (Daytime-Only)



(Courtesy of Y. Liu, SSAI)

Wallops-Morehead Ground Network (NWMGN)

- Two large-aperture Earth Stations:
    - Wallops 60’ diameter UHF Radar CubeSat Ground Station
    - Morehead State University 21-Meter Ground Station
- NWMGN can provide services to a wide variety of mission customers at multiple frequency bands through all phases of a mission’s lifetime
- Cutting-Edge CubeSat communication over a government-licensed UHF frequency allocation that enables high data rates (>2.0 Mbit/Sec)

Wallops UHF CubeSat Groundstation

Data Demand Drives Cubesat Ground Network
By Frank Morring, Jr.
Source: Aviation Week & Space Technology

August 19, 2013

Credit: Morehead State University

The groundswell of cubesat projects underway at universities, government labs and private companies worldwide promises to generate more data than the ad hoc communications systems originally devised for the tiny birds can handle. But just as the former graduate students who pioneered cubesats a couple of decades ago are finding ways to advance their small-space technology as entrepreneurs, teachers and corporate engineers (see p. 37), the community is starting to grapple with the flow of data expected to be generated as short-lived cubesats give way to swarms of tiny spacecraft carrying cameras, telescopes and other high-data sensors.

When cubesats were getting started as relatively inexpensive teaching tools for engineering professors canny enough to see the lure for prospective students of hands-on experience with real spacecraft, communication with the ground was almost secondary. Typically, each student mission devised its own communications link, usually with a one-off transmitter designed to work on an amateur-radio frequency. That held the cost down at both ends, and it met the relatively simple needs of the day.

Now many see small satellites as the wave of the future for science and military applications, with cubesats at the crest. There seems to be no limit to the applications the undergraduates are dreaming up, after cutting their teeth on simple 1-U cubesats, and the ham-radio links are no longer adequate. One solution proposed at the annual small-satellite conference at Utah State University in Logan looks back to when satellites were small—the beginning of the Space Age—for the infrastructure needed to handle the growing bandwidth needs of cubesats and their slightly larger kin.

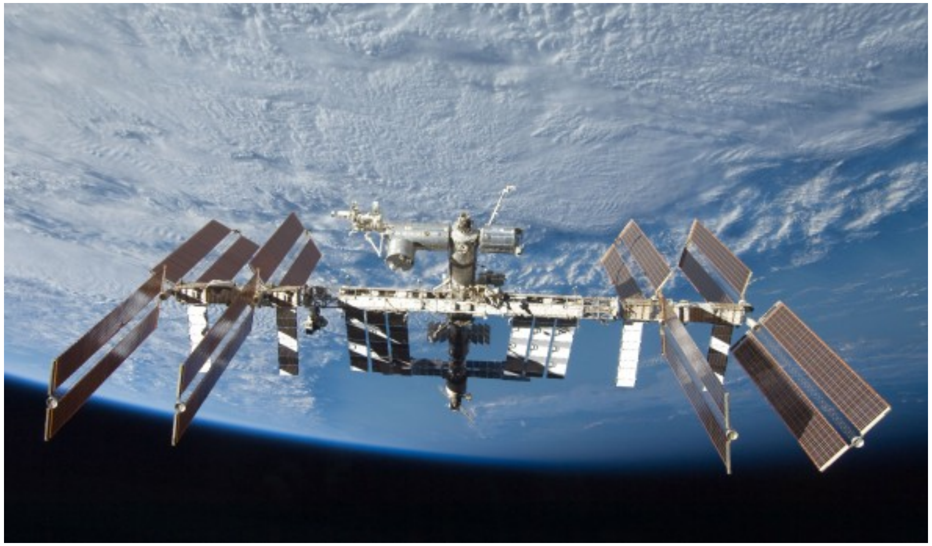
“It was built in 1960 like a battleship; in fact, I think the gears came off a battleship,” says NASA’s Scott Schaire of an 18-meter (59-ft.) tracking dish at the Wallops Flight Facility in Virginia.

Aviation Week and Space Technology Article Highlighting Wallops UHF CubeSat groundstation, August 19, 2013

Morehead State University 21 Meter antenna

Launch Opportunity and Orbit

- NASA CubeSat Launch Initiative (CSLI)
  - Coordination of upcoming launches
  - 1U, 2U, 3U, or 6U
- International Space Station (ISS)
  - Secondary cargo payload on ISS resupply missions
  - Mid 2016
  - 350-450 km, 51.6° inclination near-circular orbit
  - β angle variation: 0-75°
- 3U CubeSat Launchers
  - NanoRacks CubeSat Deployer from ISS



Conclusion

- IceCube is NASA’s Science Mission Directorate (SMD) first Earth Science related CubeSat mission
  - It will raise the technology readiness level of an 874 GHz Sub-millimeter wave radiometer
- All spacecraft components are Commercial Off The Shelf (COTS)
- Ready for launch in 2016!

Questions?

- NASA ESTO, SMD and CSLI supports
- IceCube Team

PI	Wu, Dong (GSFC, 613)
Deputy PI	Piepmeier, Jeffrey (GSFC,555)
Tech Lead	Esper, Jaime (GSFC, 592)

Instrument (GSFC)

Inst. And Sys. Lead	Ehsan, Negar (555)
Inst. Scientist	Racette, Paul (555)
Antenna	Du Toit, Neils (555)
Integration & Test	Horgan, Kevin (555)
Calibration Alg.	Hudson, Derek (555)
IF subassembly	Lucey, Jared (555)
Assembly Tech.	Macmurphy, Shawn (562)
Pathways Intern	Cooke, Caitlyn (555)
Power Lead	Hernandez, Amri (563)
Power	Ortiz-Acosta, Melyane (563)
Mechanical	Solly, Michael (562)
Parts Support	Fetter, Lula (560)
RIC Lead	Wong, Mark (564)
Video Amp/RIC	Lu, Daniel (555)
GSE Software	Topper, Alyson (561)

CubeSat, Ground System, Op (WFF, GSFC)

Mission Sys Engr.	Mast, William (WFF, 598)
Mgt. Support	Johnson, Tom (WFF, 8000)
Power Systems	Purdy, Christopher (WFF, 569)
Power Systems	Corbin, Brian (WFF, 569)
Software/Avionics	Daisey, Ted (WFF, 589)
Software/Avionics	Lewis, Christopher (WFF, 569)
Mechanical/Thermal	Hudeck, John (WFF, 548)
GN&C	Heatwole, Scott (WFF, 598)
SIC	Duran-Aviles, Carlos (GSFC, 564)
SIC	Rush, Kurt (GSFC, 564)
Thermal Analysis	Choi, Michael (GSFC, 545)

874 GHz Receiver (Virginia Diode, Inc)

Tech POC	Hesler, Jeff
LO Drive Module Design	Bryerton, Eric
Integration and Testing	Retzloff, Steven
CAD and Mechanical	Neff, Chuck