IceCube: Spaceflight Validation of an 874-GHz Submillimeter Wave Radiometer for 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, Greenbelt, Maryland

Earth Science Technology Forum Leesburg, VA October 28, 2014

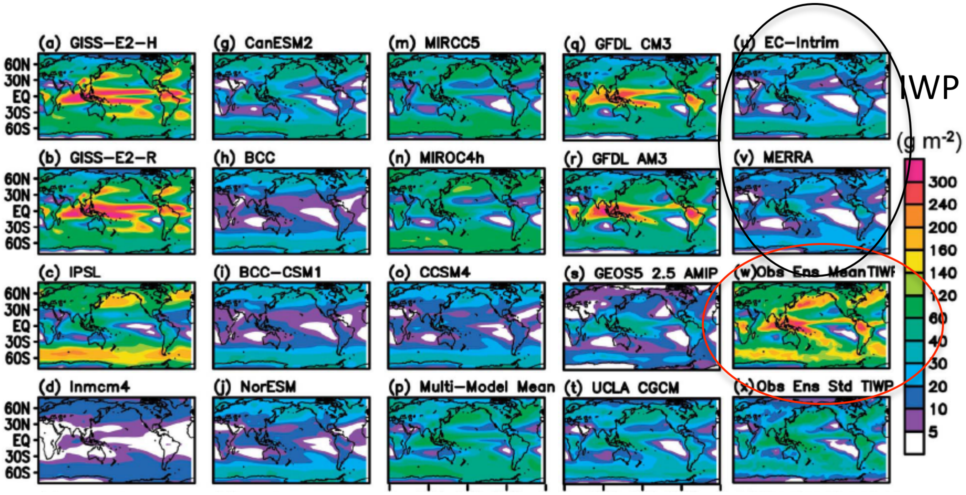
Outline

- Importance of ice clouds in Earth climate and weather systems
- Limitations and gaps of current remote sensing from space
- IceCube to enable future global cloud ice measurements at submm-wave
- IceCube project development and challenges

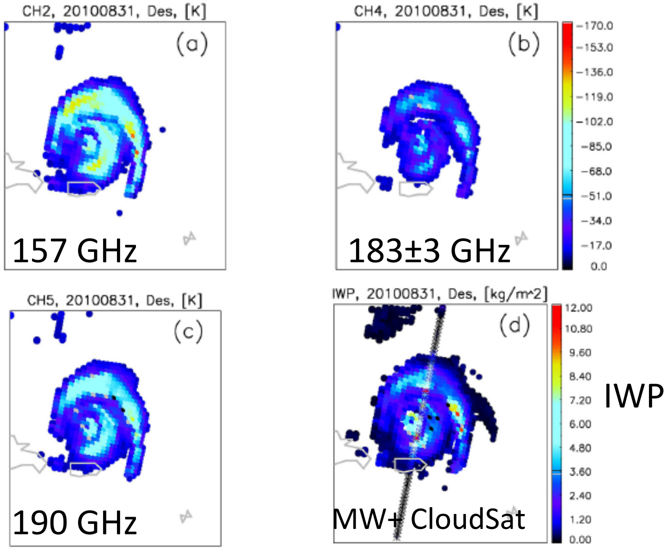
Importance of Ice Clouds and Their Processes

- Climate models
  - Cloud as the leading uncertain factor in predicting climate change on this water planet.
  - Too many degrees of freedom
  - Tunable parameters: cloud cover, water content, microphysics
  - Differences by 2x - 10x

- Cloud-precipitation processes
  - Interactions with dynamics
  - Water vapor
  - Microphysics
  - Vertical development
  - Lifecycle and distribution

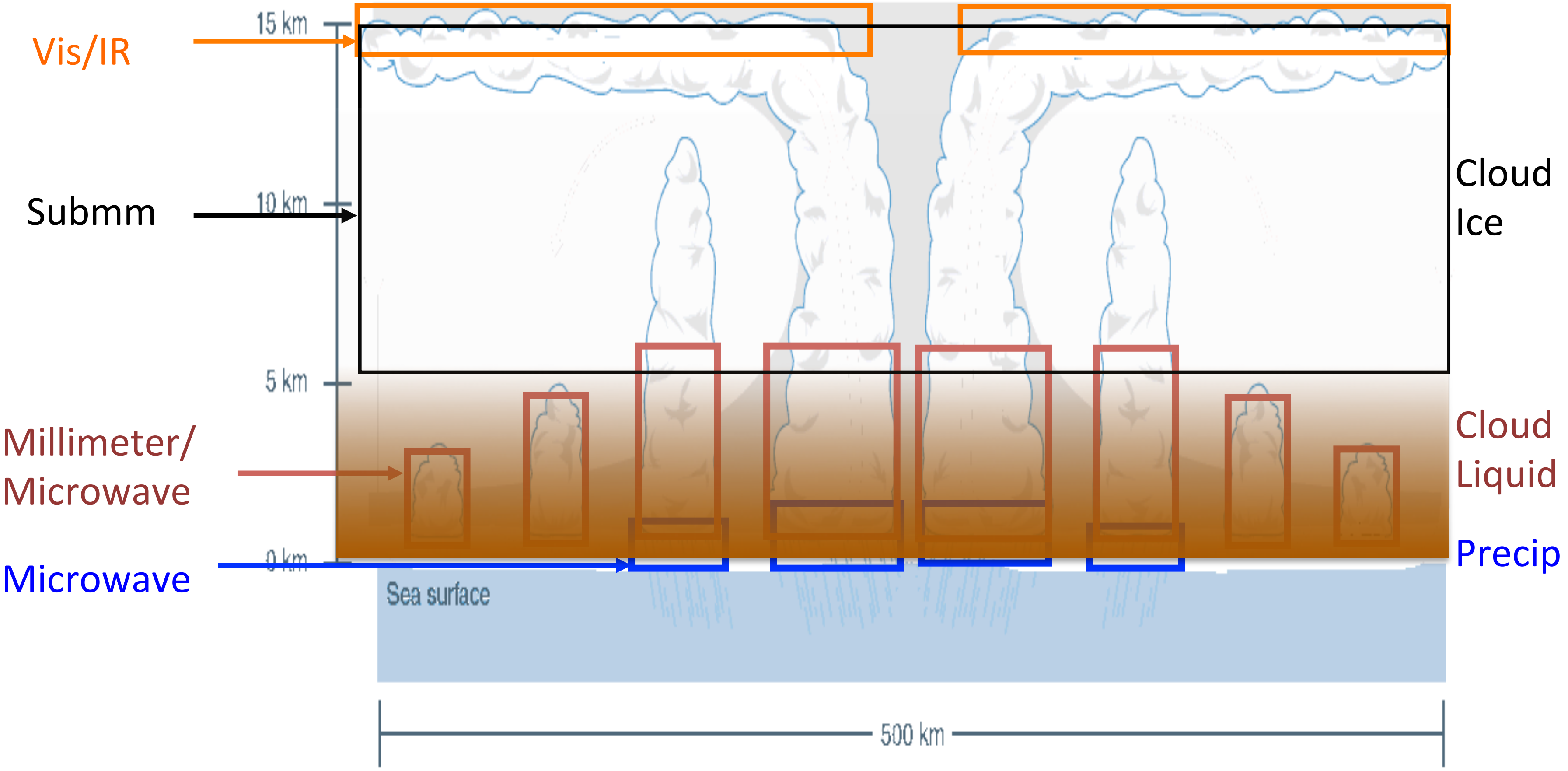


Li et al., (JGR, 2012)



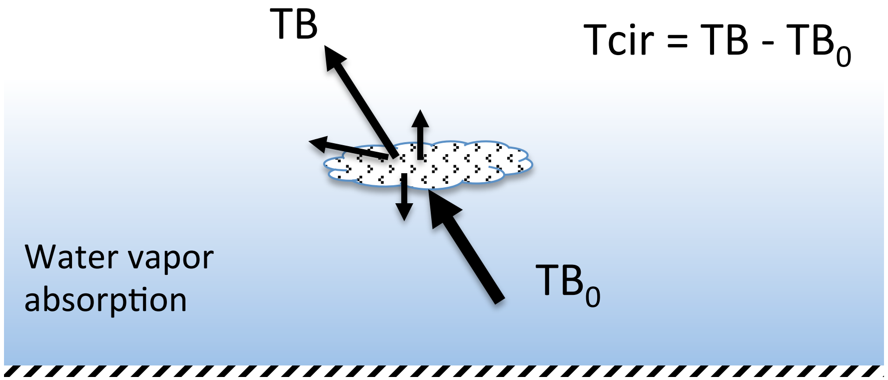
Gong and Wu (2014)

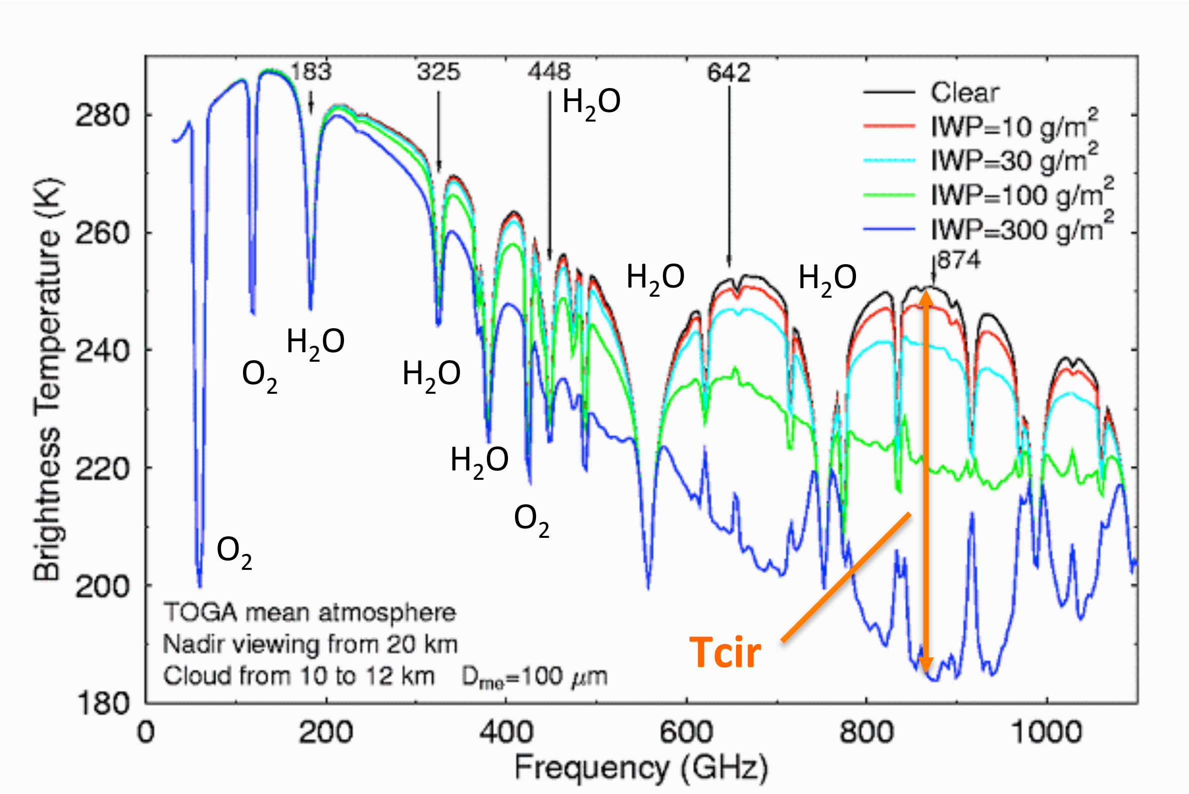
Submillimeter-Wave Radiometry for Cloud Ice Remote Sensing in the Upper Troposphere



Ice Cloud Scattering at Submm-Wave

- Higher sensitivity to cloud scattering at submm-wave
- Cloud-induce radiance, Tcir, proportional to cloud ice water path (CIWP)
- Cloud microphysical properties (i.e., particle size) from different frequencies
- Simultaneous retrievals with T, H_2O



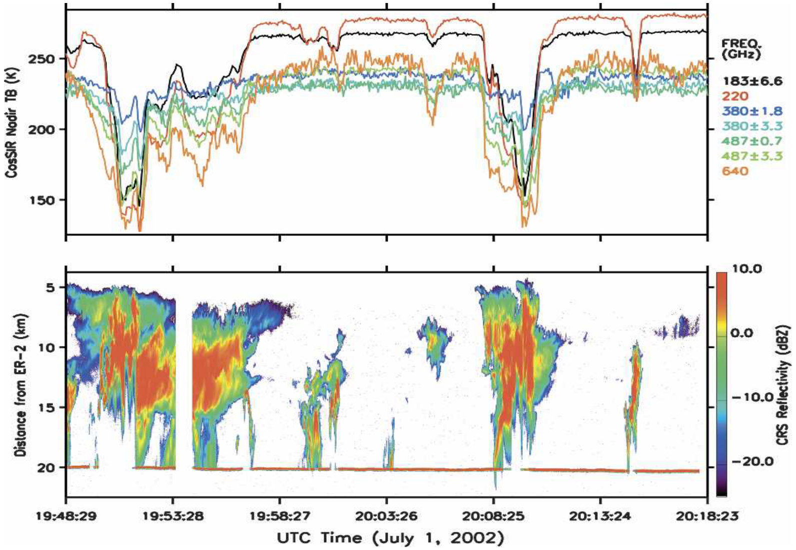


NASA/GSFC Airborne Sensor:

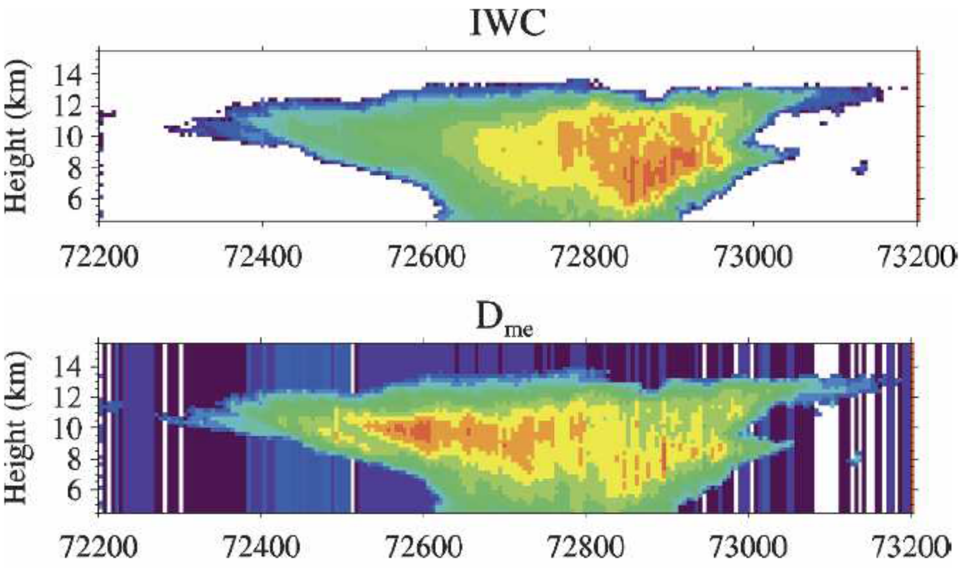
Compact Scanning Submillimeter-wave Imaging Radiometer (CoSSIR)

Evans et al. (2005)

Chn #	Freq. (GHz)	Offset (GHz)	BW(GHz)	Tsys (K)	NEDT (K)
1	183.3	1	0.5	2500	0.55
2	183.3	3	1.0	1390	0.23
3	183.3	6.6	1.5	1050	0.15
4	220	2.5	2.5	1760	0.16
5	380.2	0.8	0.7	3460	0.63
6	380.2	1.8	1.0	8440	1.23
7	380.2	3.3	1.7	4820	0.55
8	380.2	6.2	3.6	6670	0.52
9	487.25	0.8	0.35	4650	1.17
10	487.25	1.2	1.2	3890	0.85
11	487.25	3.3	2.9	4600	0.40
12	640	2.5	3.0	16000	1.33



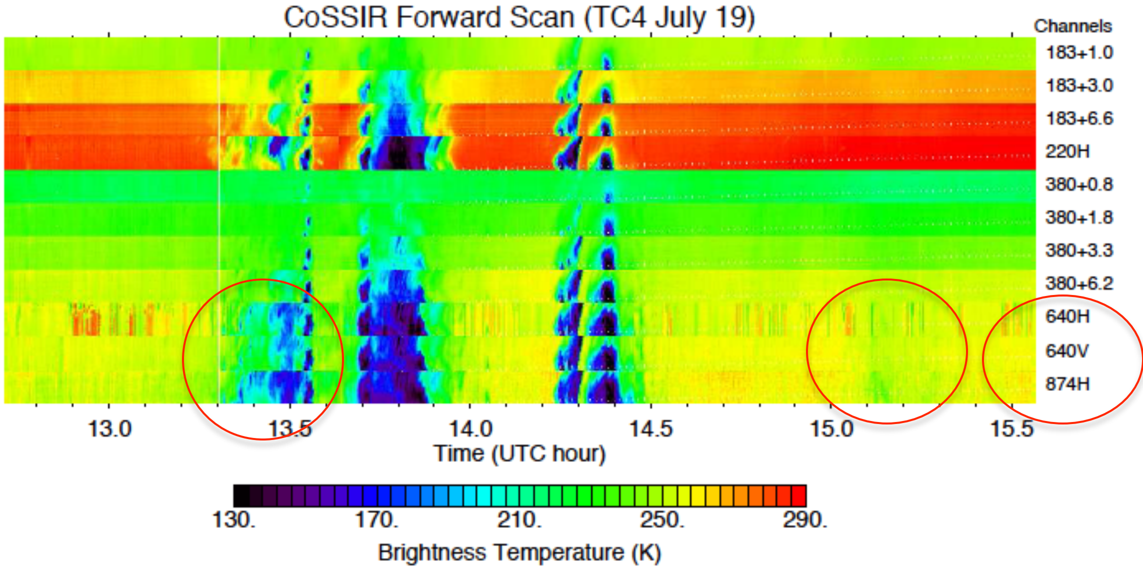
- CRYSTAL-FACE campaign near Florida in July 2002
- Co-flight of CoSSIR and 94-GHz Cloud Radar System (CRS)
- Simultaneous retrievals of ice water path (IWP) and particle size (D_{me}) from CoSSIR
- Simultaneous retrievals of ice water content (IWC) and D_{me} from CoSSIR and CRS

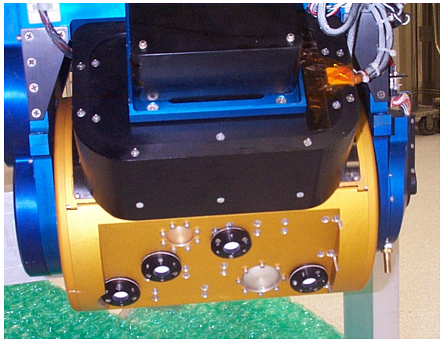


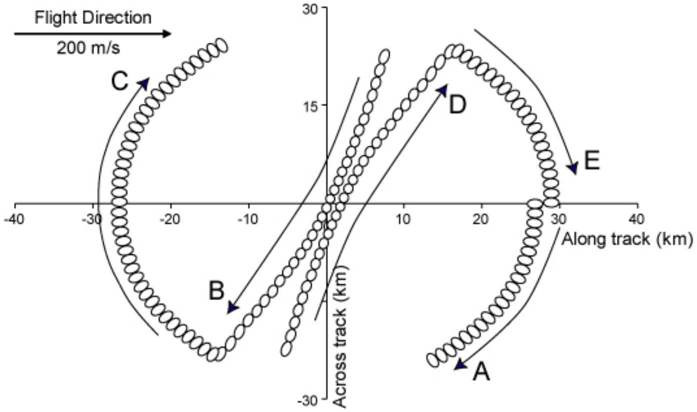
CoSSIR in Tropical Composition, Cloud and Climate Coupling (TC4)

Evans et al. (2012)

- Flights on ER-2 near Costa Rica in Aug 2007
- First time to fly 874-GHz cloud radiometer (11 channels)
- Tsys=~5000 K , BW=5 GHz, NEdT=0.84 K, H-Pol
- WB-57 and DC-8 underflights of ER-2 (CoSSIR) to study cirrus anvils
- Dual-axes gimbals for programmable scan patterns.







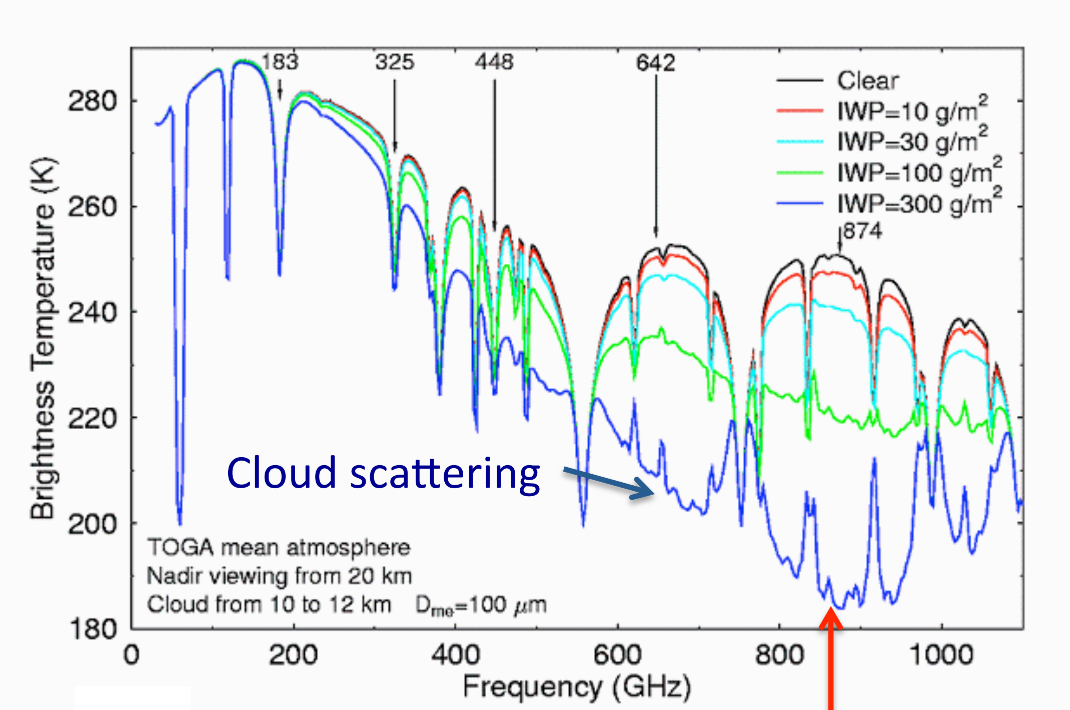
IceCube Objectives

Climate Research Needs

- Accurate cloud ice measurements.
- Cost-effective, sensitive instruments for diurnal and global coverage.
- Mature technology

IceCube Objectives

- Raise overall TRL (5->7) of 874-GHz receiver technology
- Reduce instrument cost and risk by developing path-to-space for COTS submm-wave receiver systems
- Enable remote sensing of global cloud ice with advanced technologies and techniques



Cloud scattering

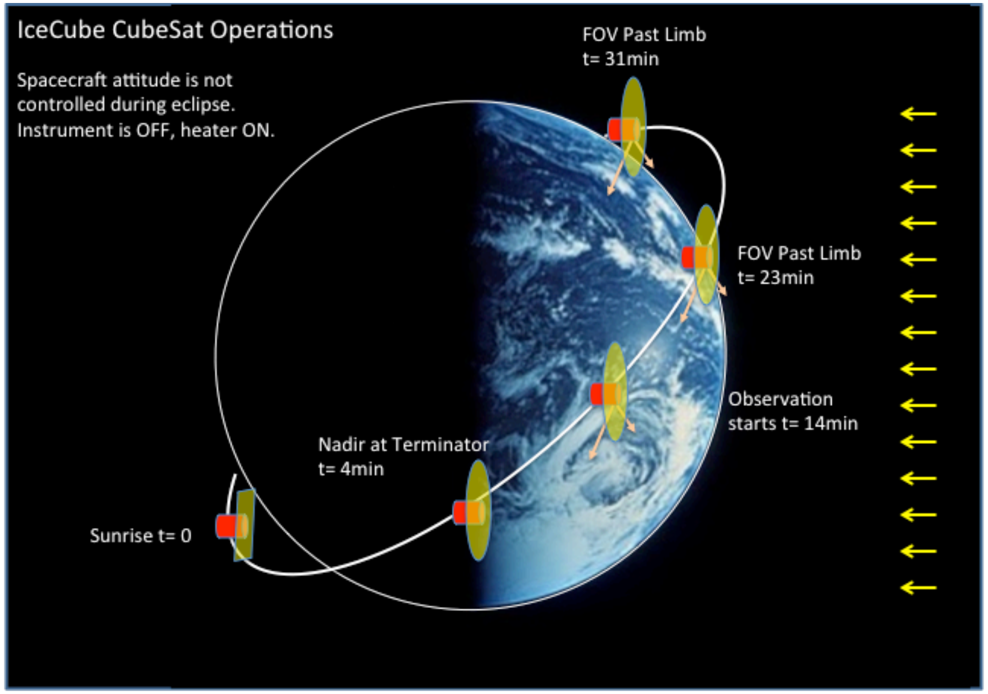
Pros

- Good sensitivity to small cloud ice
- Compact and mature receiver technology
- Day-night measurements

Cons

- Large attenuation from water vapor
- High power consumption

Measurement and Mission Requirements



874-GHz measurement requirements:

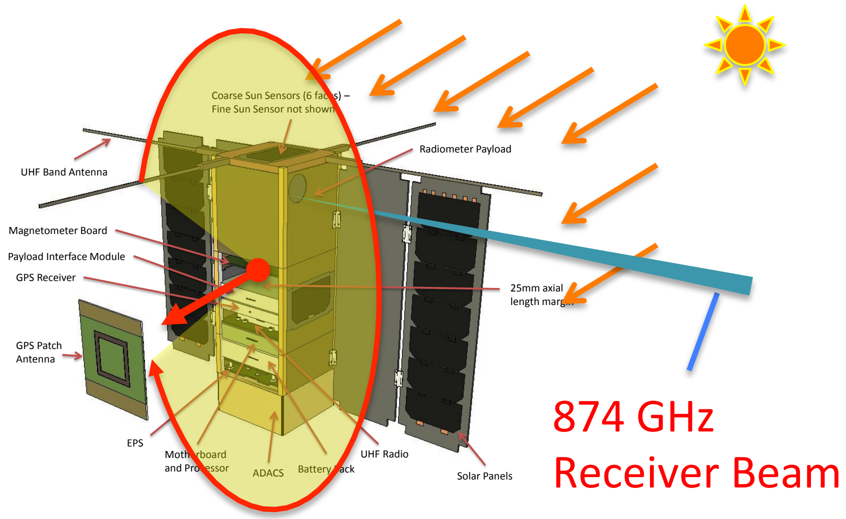
- Accuracy < 2 K
- Precision (NEdT) < 0.25 K
- Spatial resolution < 15 km

Mission requirements:

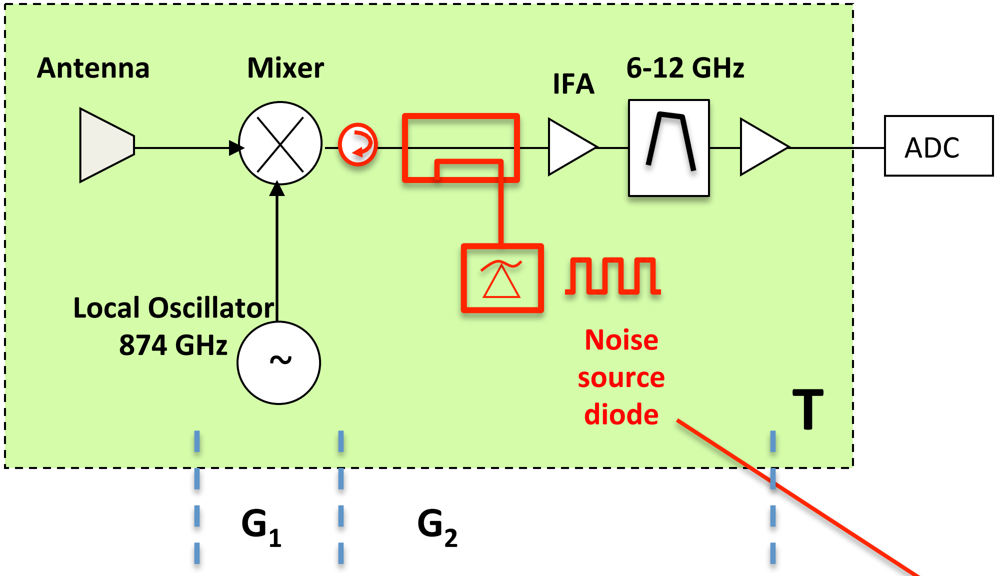
- In-flight operation 28 days
- Periodical views of Earth (science) and space (calibration) within an orbit
- Science data 30+% (8+h /day)
- Pointing knowledge < 25 km

Validation plan:

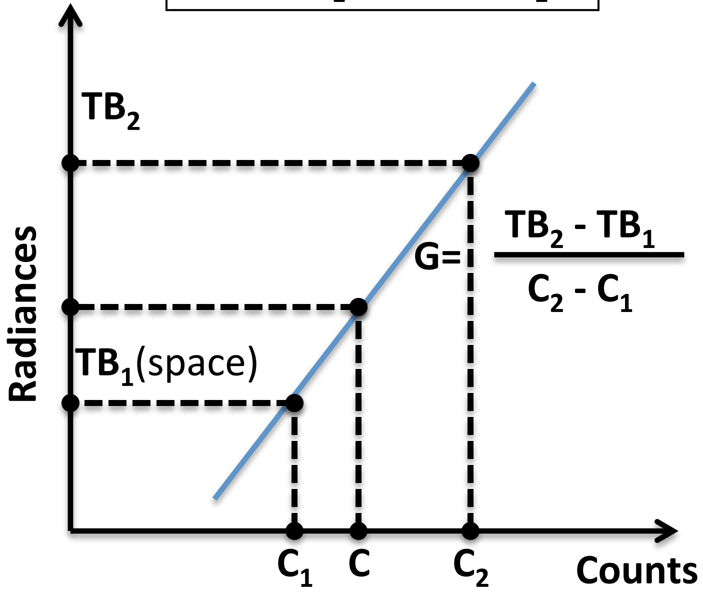
- Lab measurement and verification
- Modeled vs observed clear-sky radiances for accuracy verification
- Space-view radiances for precision



IceCube Challenge #1: 874-GHz Radiometric Calibration

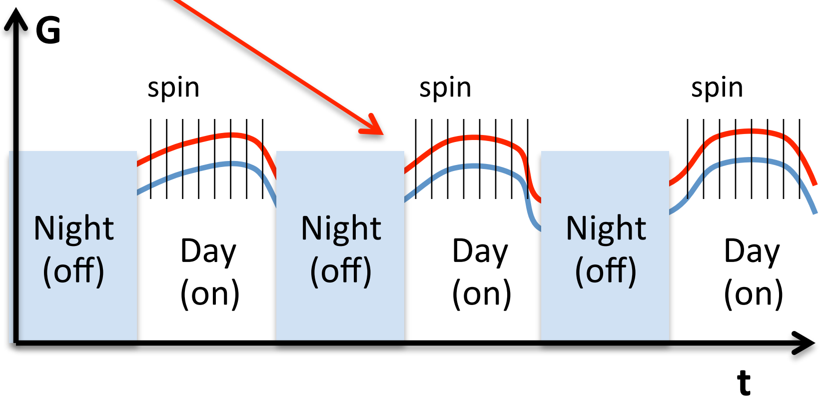


$$TB = TB_1 + G^*(C - C_1)$$



Calibration Challenges:

1. Stable C_1 from space view
   Spinning S/C (~2.25 min/rev)
2. Receiver gain variations
   $G=G_1G_2$
   G_1 $=G_1(T)$ to be measured in lab
   G_2 $=G_2(t)$ from noise diode



Spinning CubeSat: In-Flight Calibration

$$TB = TB_1 + G_1(T)G_2(t)*(C - C_1)$$

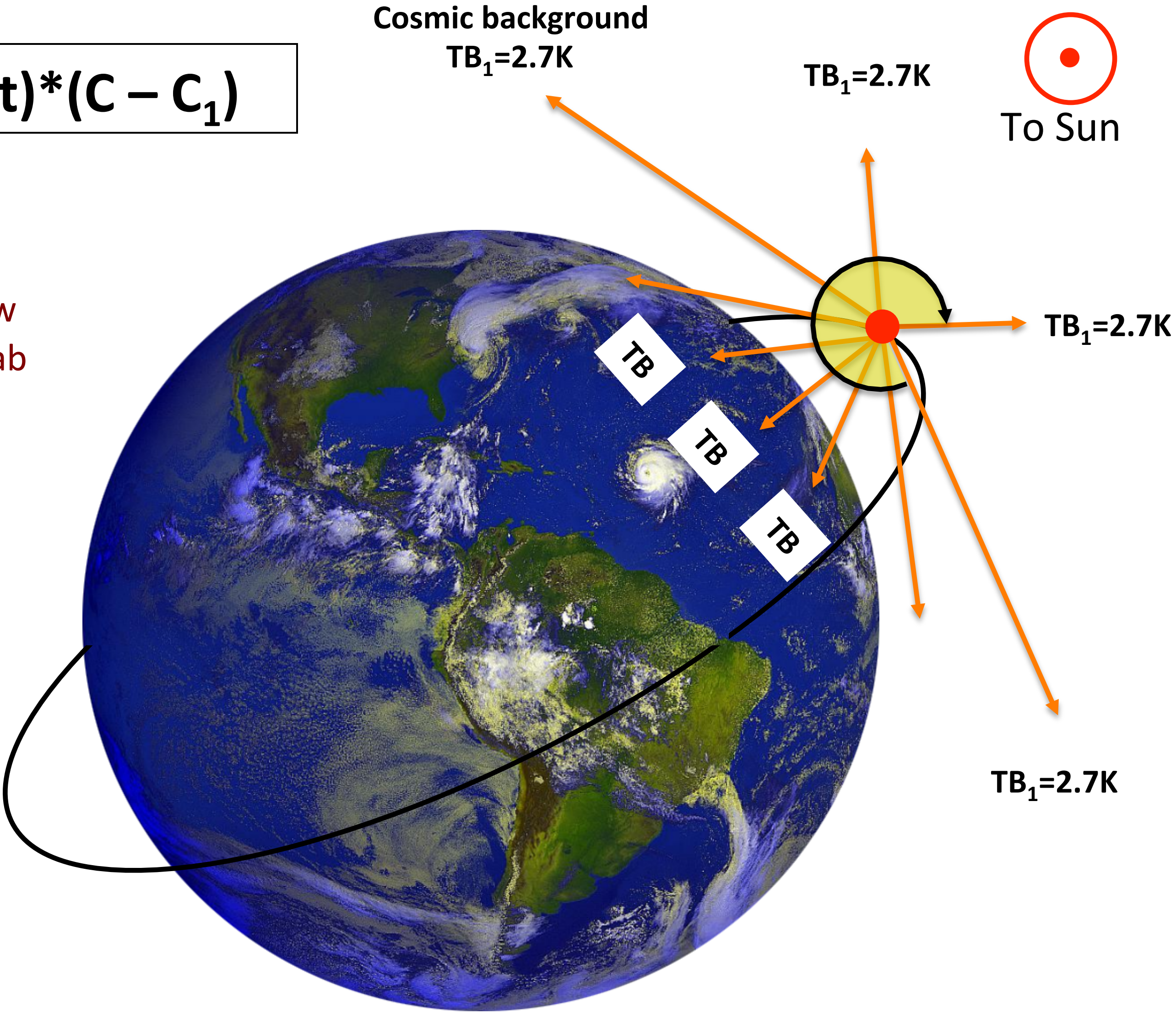
Key assumptions:

1. Linear TB-count relationship
2. C_1 constant during Earth view
3. $G_1(T)$ same as measured in lab

Note: #2 needs to be valid only within a spin cycle (2.25 minutes)

Adv. with spinning S/C:

1. Accurate gain monitoring
2. Attitude control stability
3. No moving parts needed for instrument



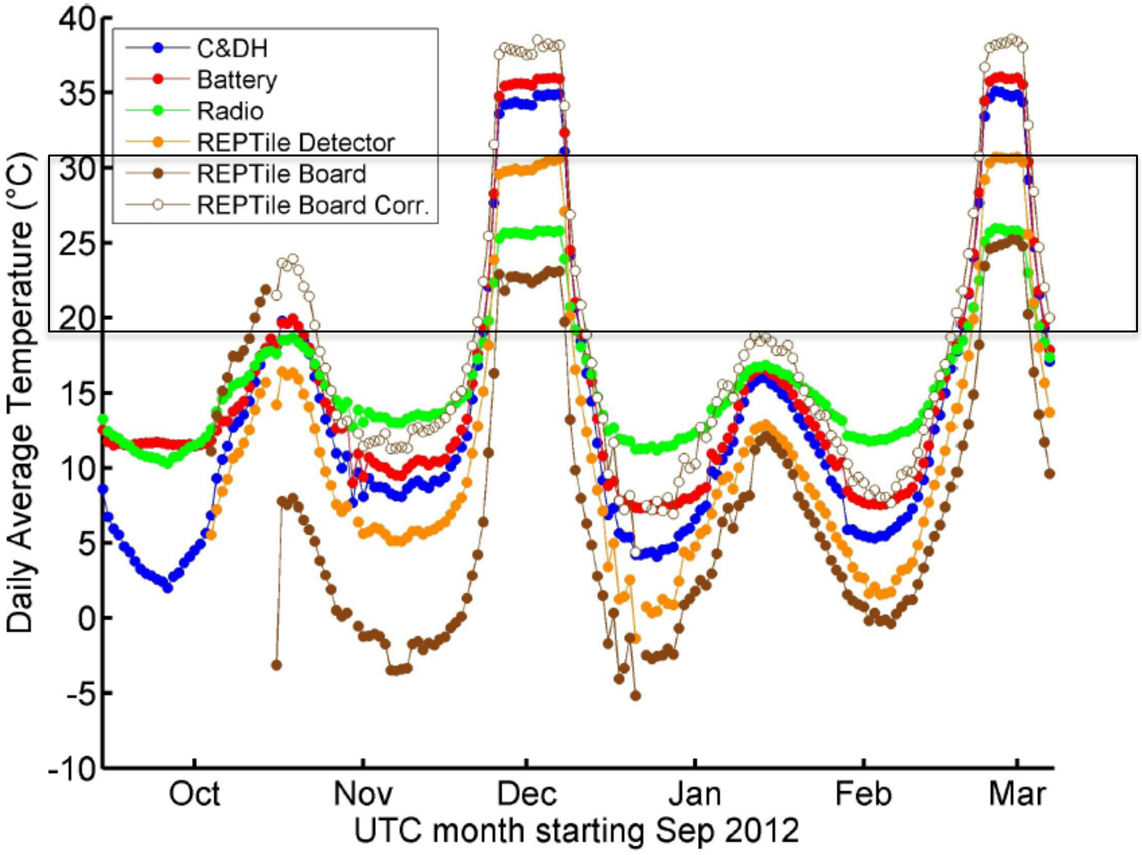
IceCube Challenge #2: Large Orbital Thermal Variations

Constraints:

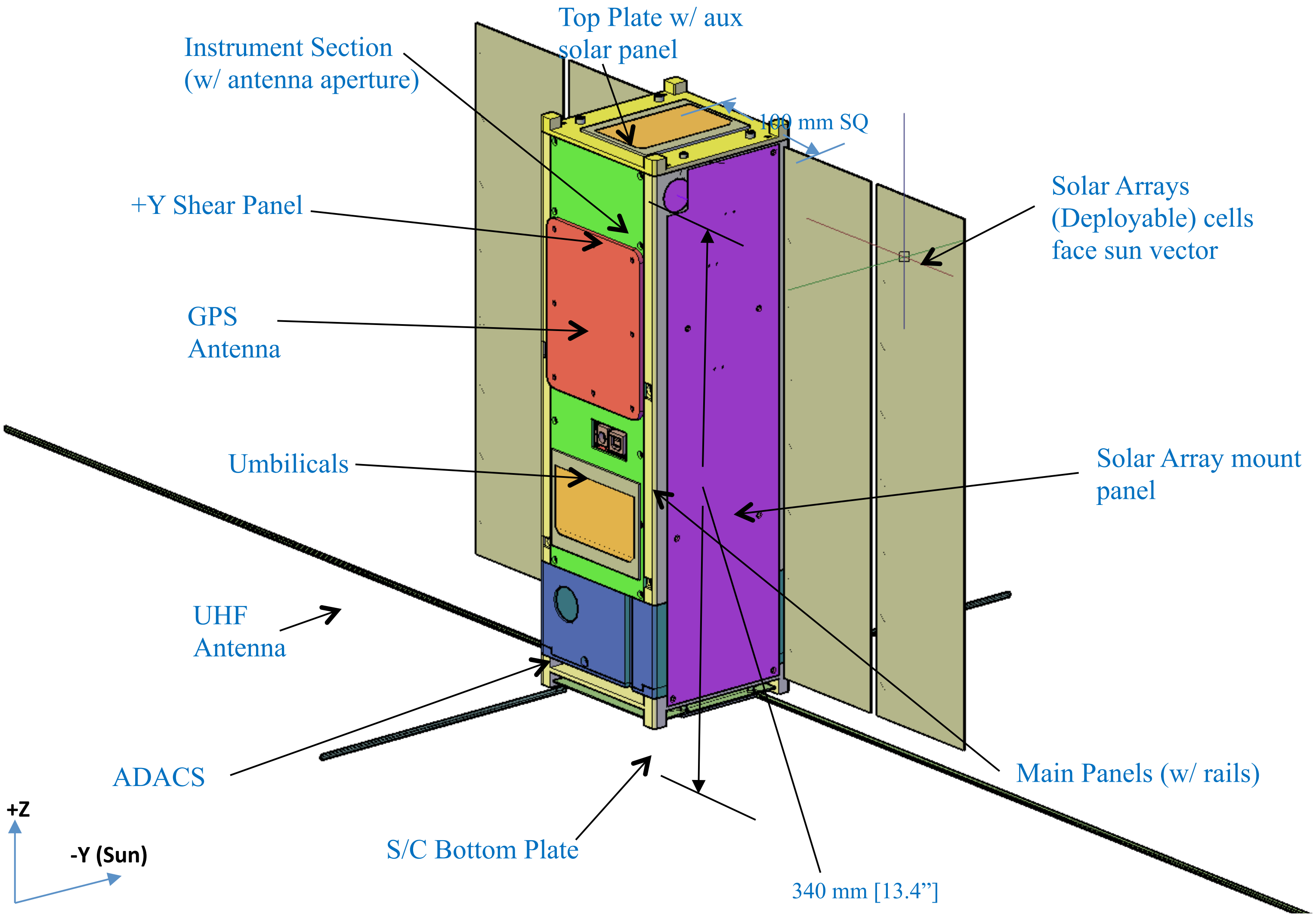
- Preferred instrument operation temperatures: 20C-30C
- Low CubeSat/instrument mass, or thermal inertia, for thermal stability
- Wide range of beta angles: -75° to 75°
- Day-on and night-off operation
- Spin around the Sun-pointing axis

Colorado Student Space Weather Experiment (CSSWE)

[Gerhardt et al., 2013]

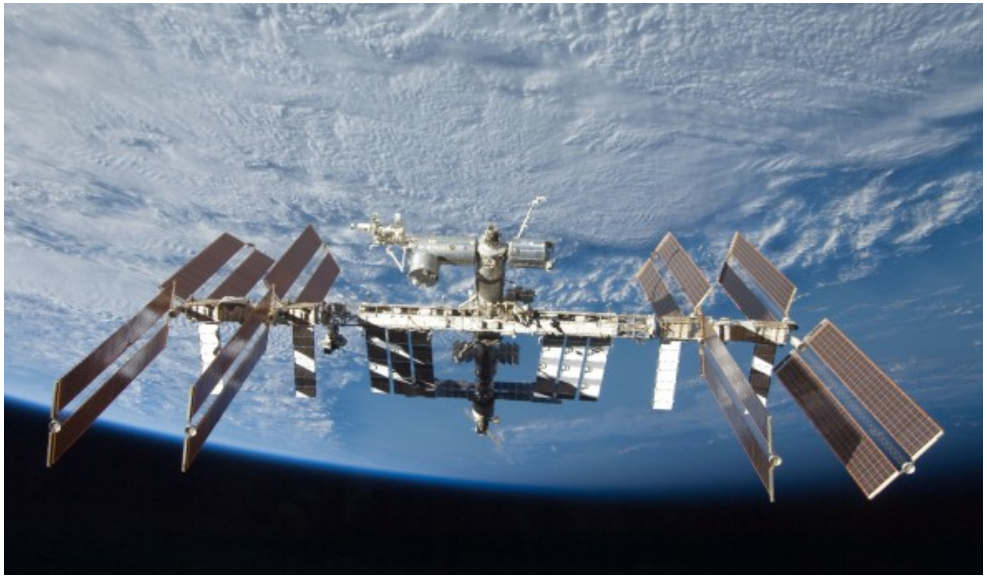


IceCube Flight Configuration



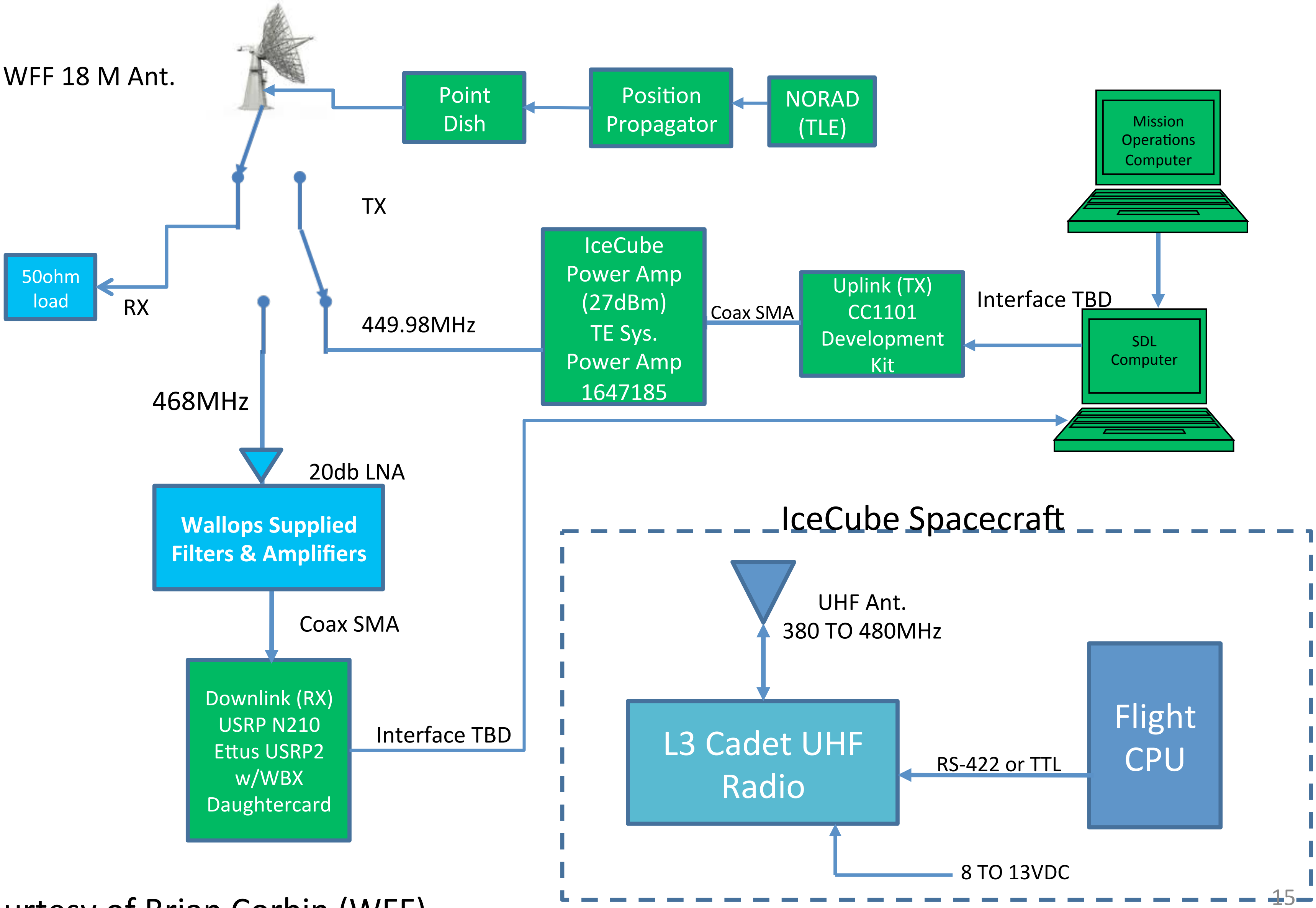
Courtesy of John Hudeck

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
  - Small-Sat Orbital Deployer (J-SSOD) from ISS/JEM
  - NASA NEXT

IceCube Communication System at NASA/GSFC Wallops Flight Facility (WFF)



WFF 18 M Ant.

Point Dish

Position Propagator

NORAD (TLE)

Mission Operations Computer

TX

RX

50ohm load

449.98MHz

IceCube Power Amp (27dBm) TE Sys. Power Amp 1647185

Coax SMA

Uplink (TX) CC1101 Development Kit

Interface TBD

SDL Computer

468MHz

20db LNA

Wallops Supplied Filters & Amplifiers

Coax SMA

Downlink (RX) USRP N210 Ettus USRP2 w/WBX Daughtercard

Interface TBD

IceCube Spacecraft

UHF Ant.
380 TO 480MHz

L3 Cadet UHF Radio

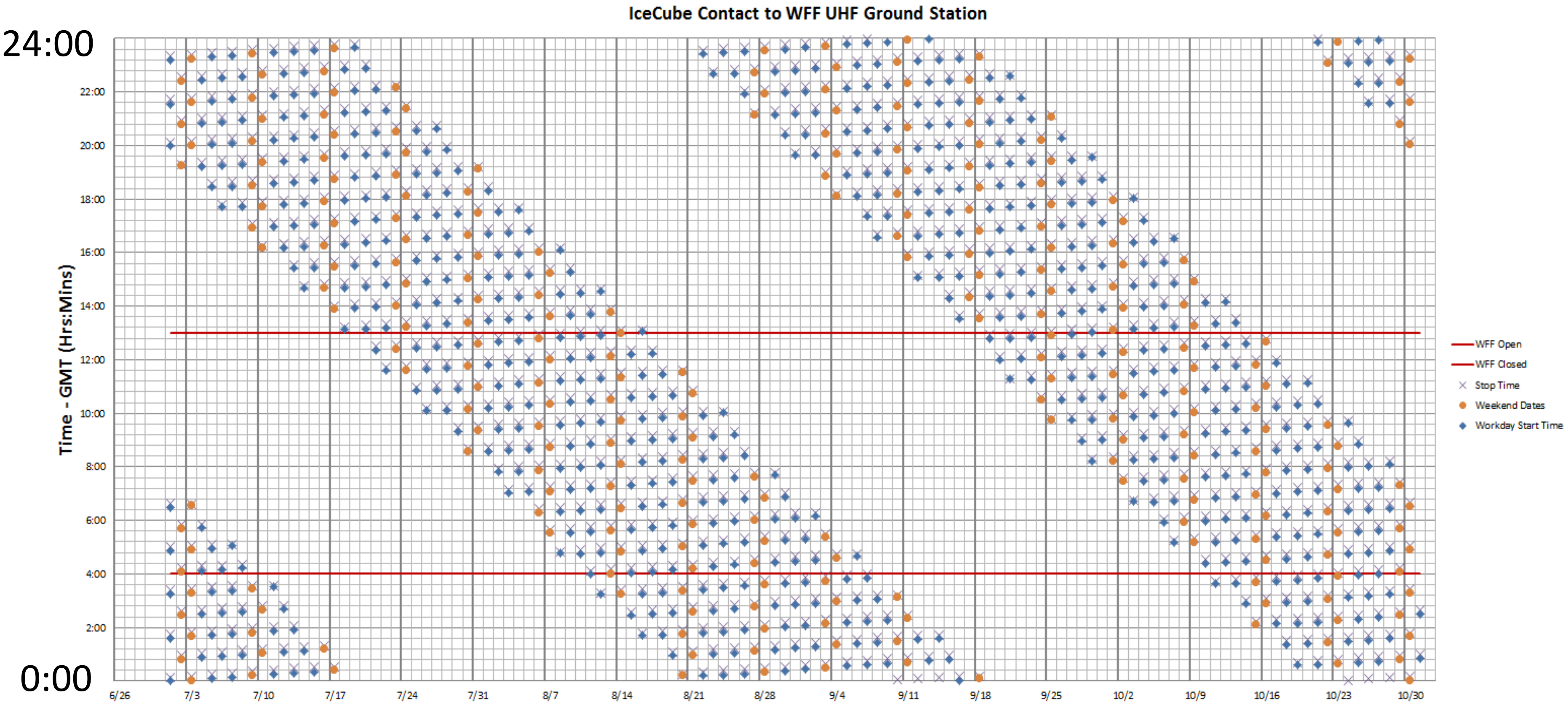
RS-422 or TTL

Flight CPU

8 TO 13VDC

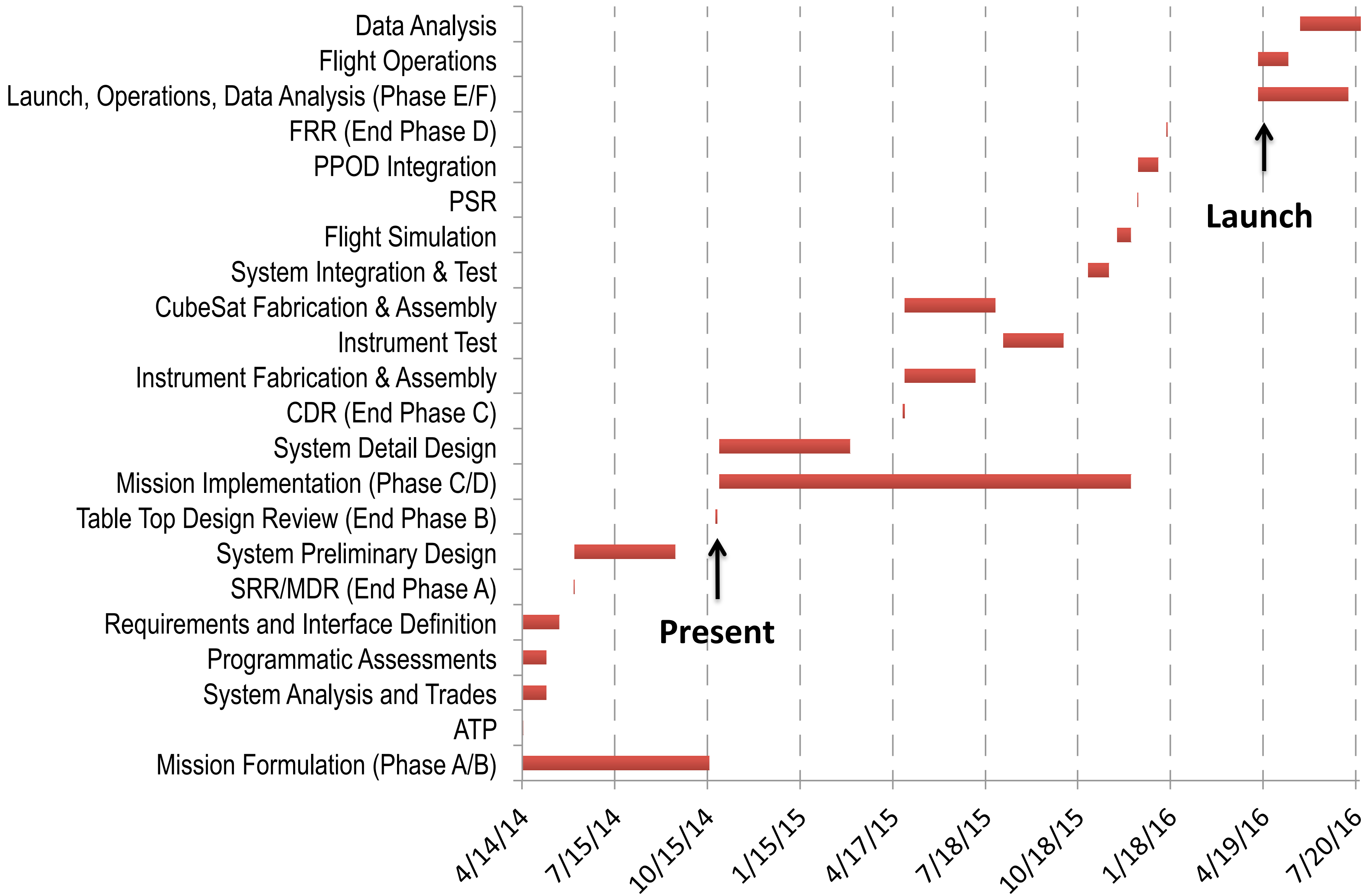
Courtesy of Brian Corbin (WFF)

WFF UHF Ground-station Contacts



6/26 MM/DD in 2016 10/30

Project Schedule



Project Challenges and Pathways

- Not traditional kind of NASA missions
  - Limited resources and tight schedule
  - Short, quick path to space for science exploration
- Risk management
  - Take risks and spread them evenly
  - Mitigate risks associated with CubeSat and instrument thermal environments

Acknowledgments

- NASA ESTO, SMD and CSLI supports
- IceCube Team

PI	Wu, Dong (GSFC)
Deputy-PI	Piepmeier, Jeffrey (GSFC)
Tech Lead	Esper, Jaime (GSFC)
Mission Sys Engr.	Mast, William (WFF)
Mgt. Support	Johnson, Tom (WFF)

Instrument (Greenbelt, MD)

Inst. Scientist	Racette, Paul
Inst. Lead	Ehsan, Negar
Antenna Engr.	Du Toit, Neils
Integration	Horgan, Kevin
IF subassembly	Lucey, Jared
Power	Pellerano, Armi
Power	Ortiz-Acosta, Melyane
Mechanical Engr.	Solly, Michael
Parts Support	Fetter, Lula (Lu)
DSP Engr.	Wong, Mark (Englin)
Inst Video Amp/RIC	Lu, Daniel
RF Engr.	Hersey, Ken

CubeSat, Ground System, Op (WFF, VA)

Power Systems	Purdy, Christopher
Power Systems	Corbin, Brian
Software/Avionics	Daisey, Ted
Software/Avionics	Lewis, Christopher
Mechanical/Thermal	Hudeck, John
Mechanical/Thermal	Smith, Sally
GN&C	Heatwole, Scott

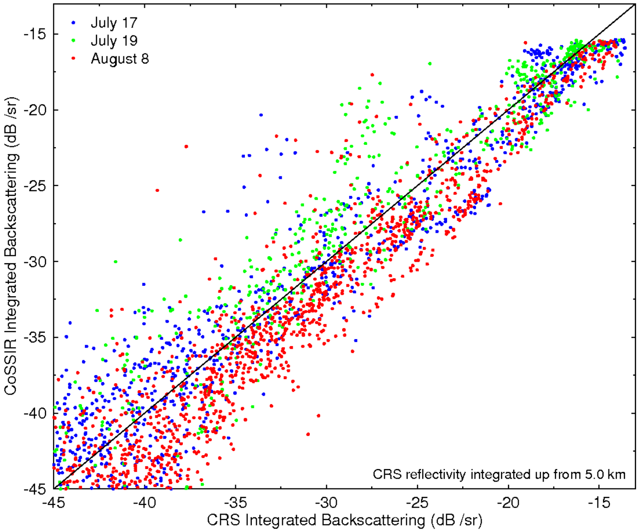
874-GHz Receiver (Virginia Diode, Inc)

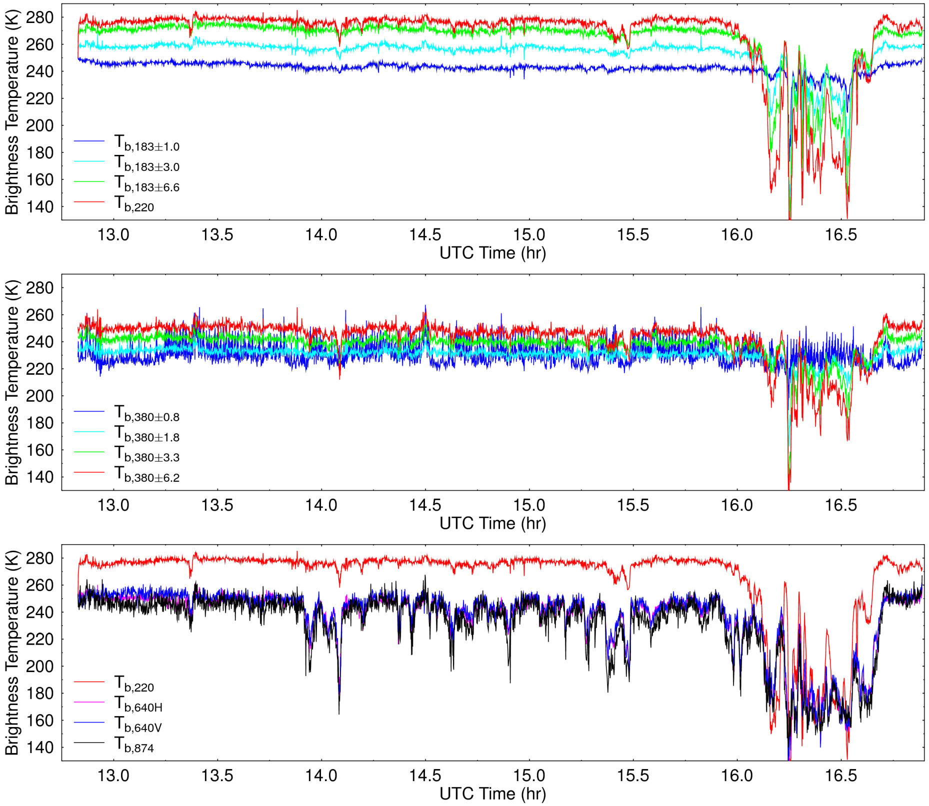
Tech POC	Hesler, Jeff
LO Drive Module Design	Bryerton, Eric
Integration and Testing	Retzloff, Steven
CAD and Mechanical	Neff, Chuck

Backup Slides

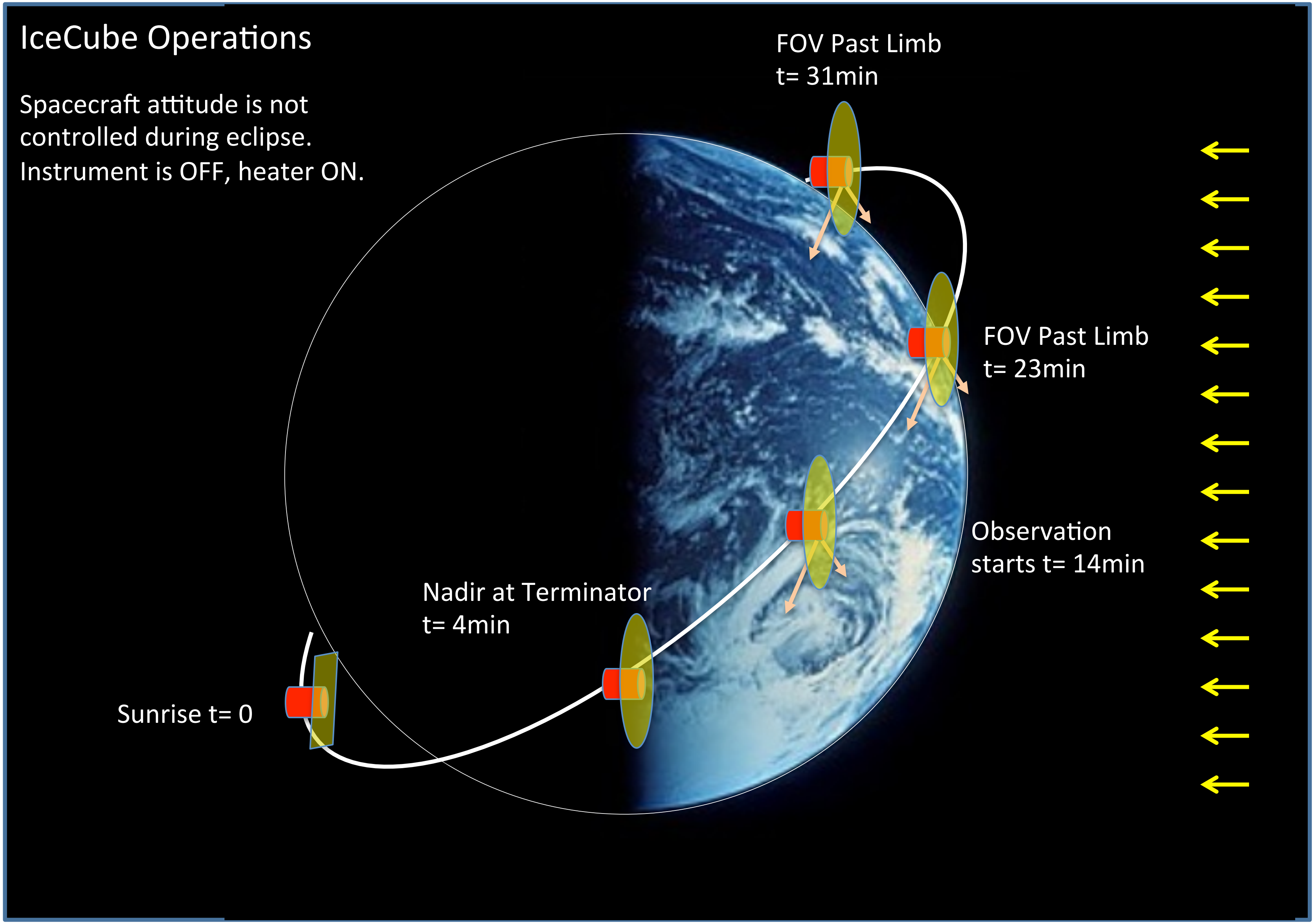
Examples CoSSIR in TC4

Evans et al. (TC4 Sci Meeting, 2008)


CoSSIR Retrieved and CRS Integrated 94 GHz Backscatter


CoSSIR Nadir T_b (July 17, 2007)

IceCube Operation



IceCube Operations

Spacecraft attitude is not controlled during eclipse. Instrument is OFF, heater ON.