30 Years of Atmospheric Radiometer Instruments and Technology Development

SUNY Albany

November 29, 2021

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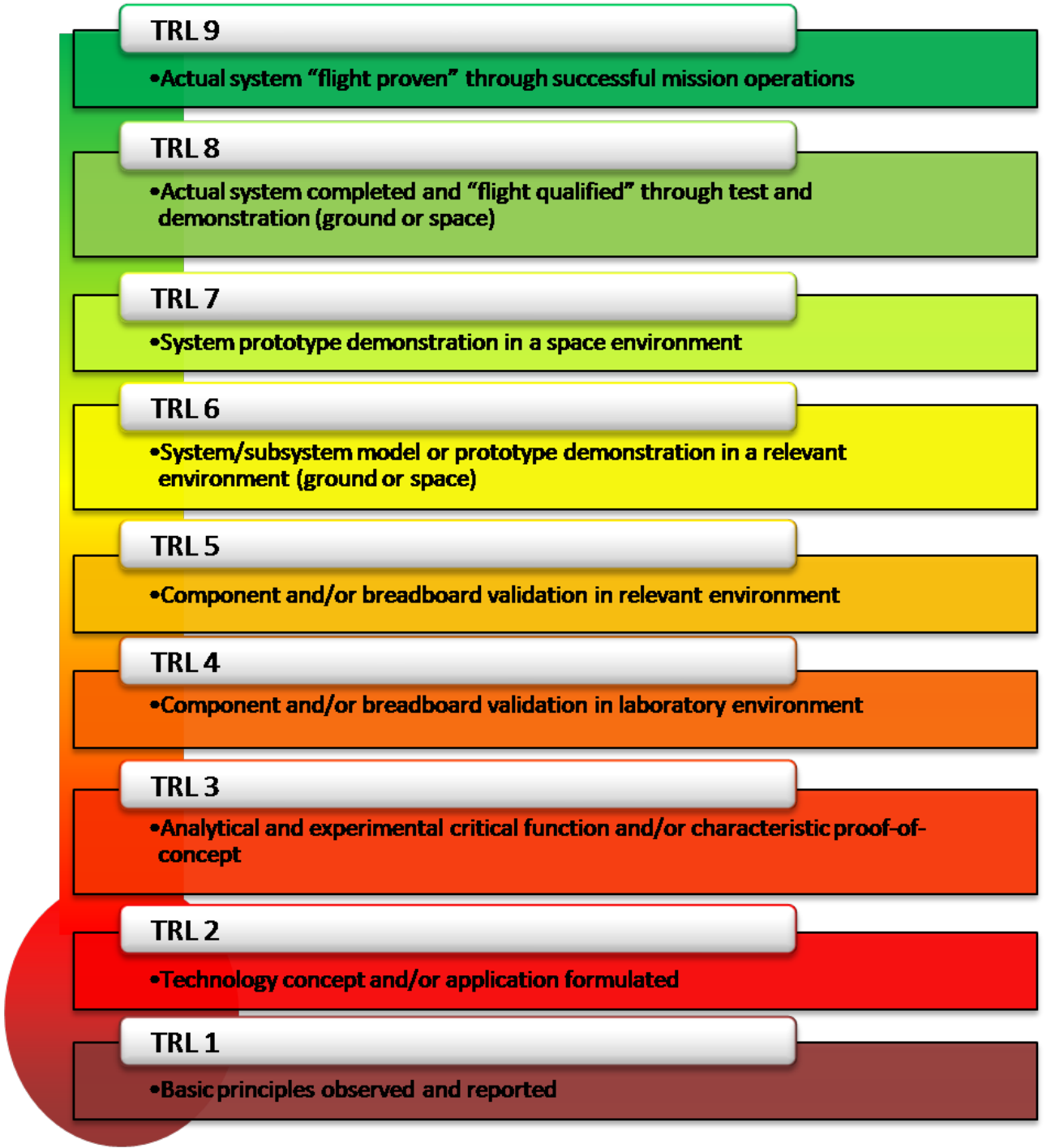
Microwave Instrument Technology Branch

NASA Goddard Space Flight Center

Outline

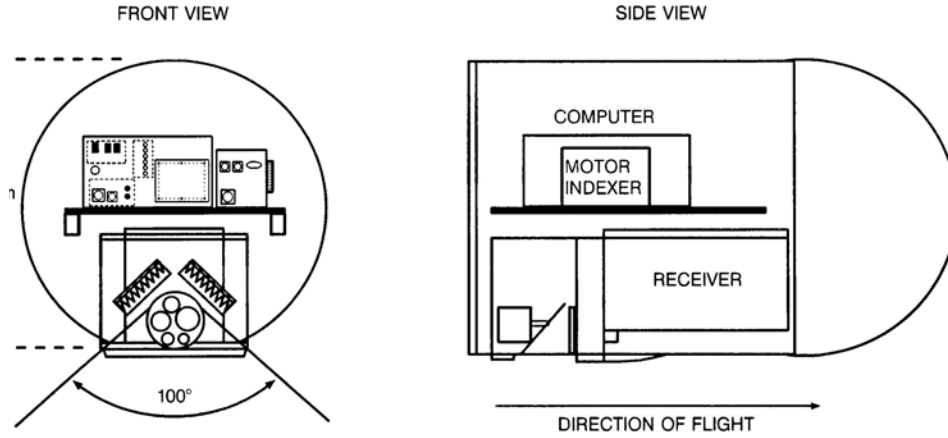
- Technology Readiness Level (TRL)
- Millimeter-wave Imaging Radiometer (MIR)
- Compact Scanning Millimeter-wave Imaging Radiometer (CoSMIR)
- Compact Scanning Submm-wave Imaging Radiometer (CoSSIR)
- IceCube – 884 GHz Ice Cloud Radiometer
- Submillimeter Enceladus Life Fundamentals Instrument (SELFI)
- Venus Wideband Submillimeter Heterodyne Spectrometer (V-WiSHeS)
- Submillimeter Solar Observation of Lunar Volitile Experiment (SSOLVE)
- Technological Thrusts

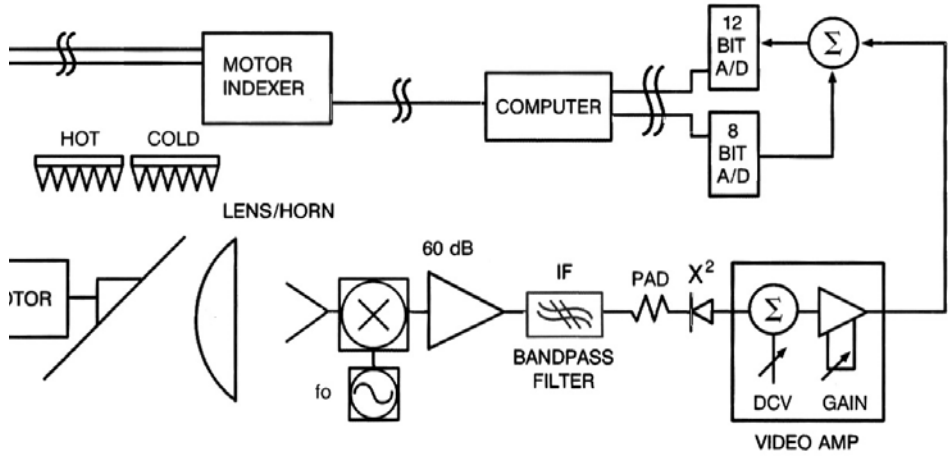
Technology Readiness Level



Millimeter-wave Imaging Radiometer (MIR)

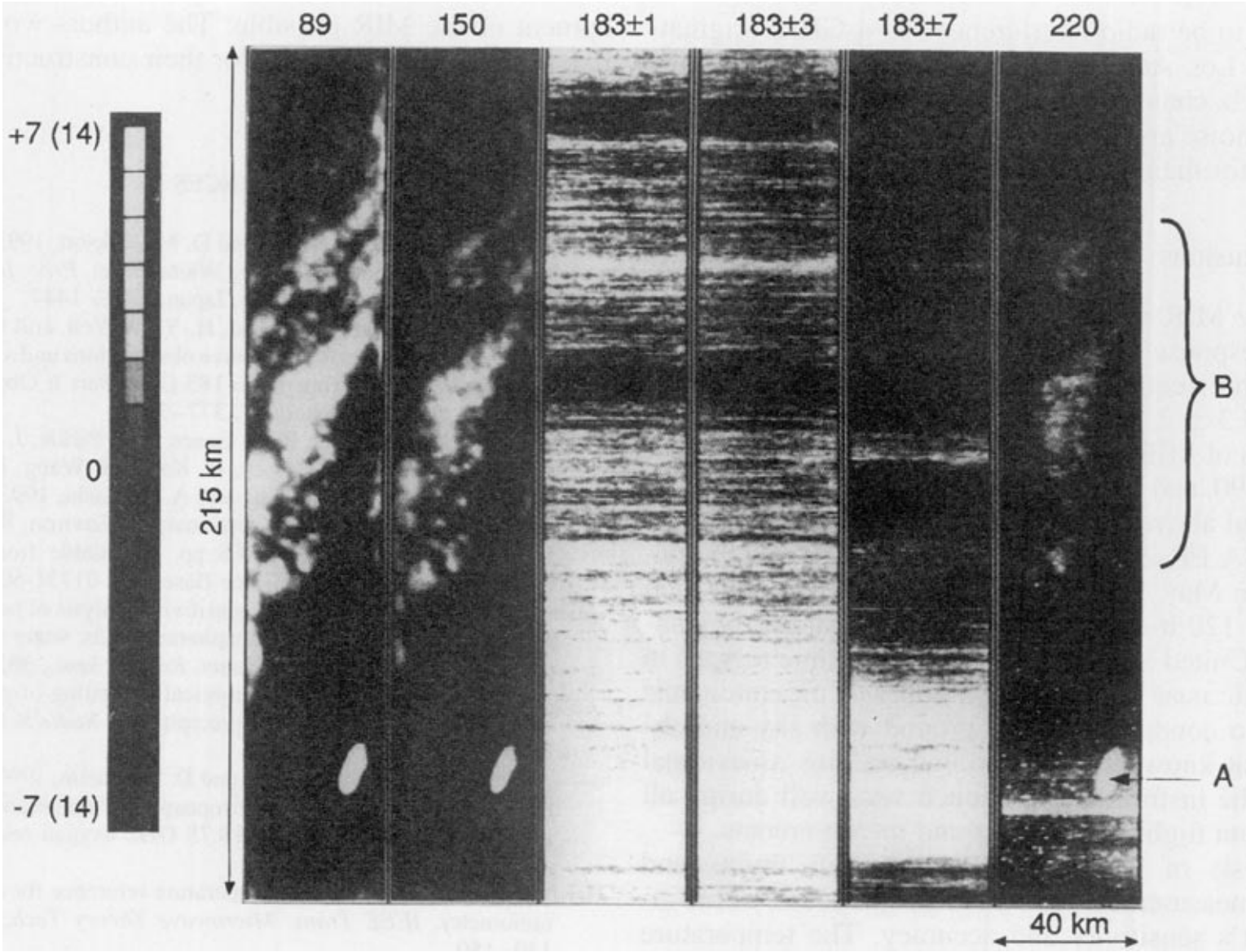
- Frequencies 89 – 340 GHz
- Maiden Flight 1992
- Sorties >150
- Flight Hours > 500
- Retired ~2005

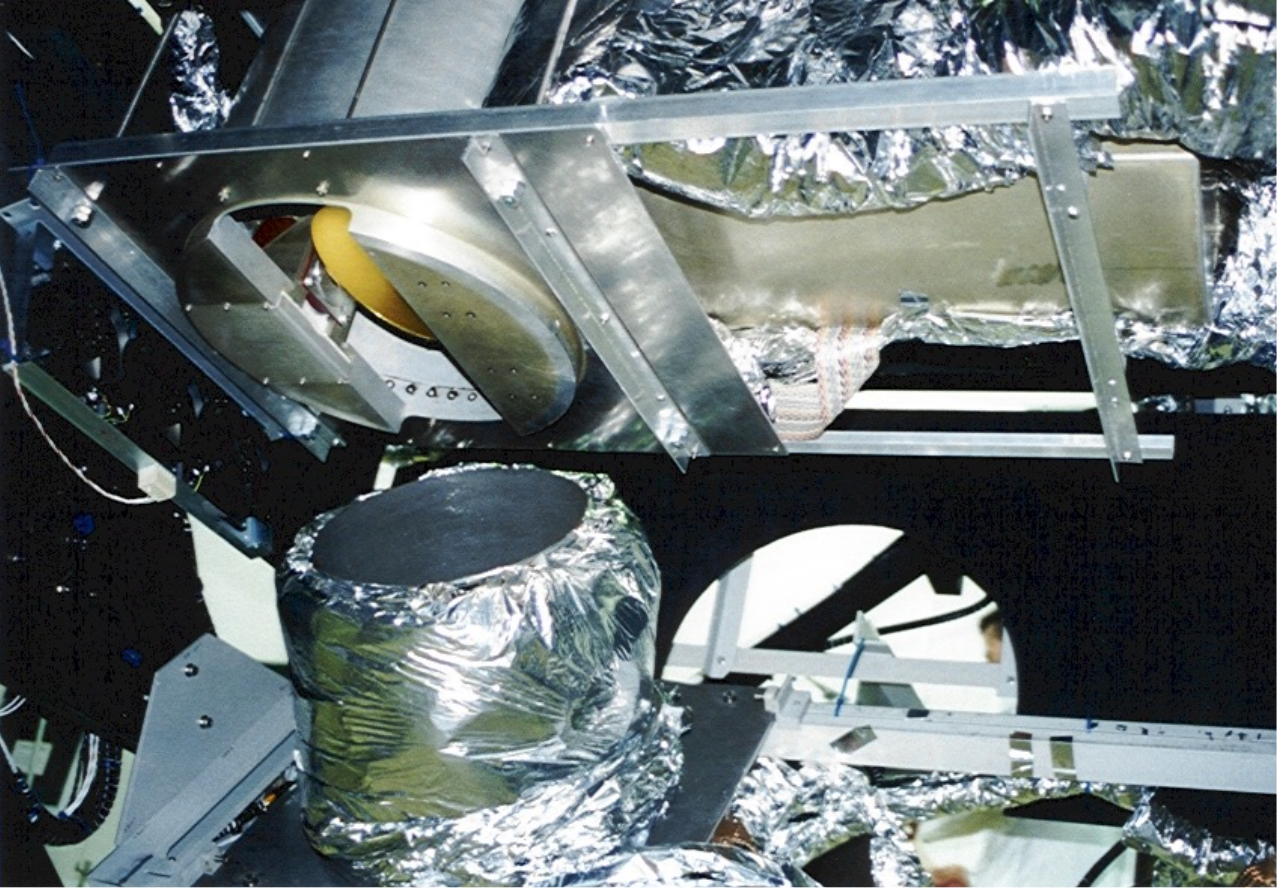




MIR Imagery

May 1992





MIR Calibration Studies

Conical Scanning Millimeter-wave Imaging Radiometer (CoSMIR)

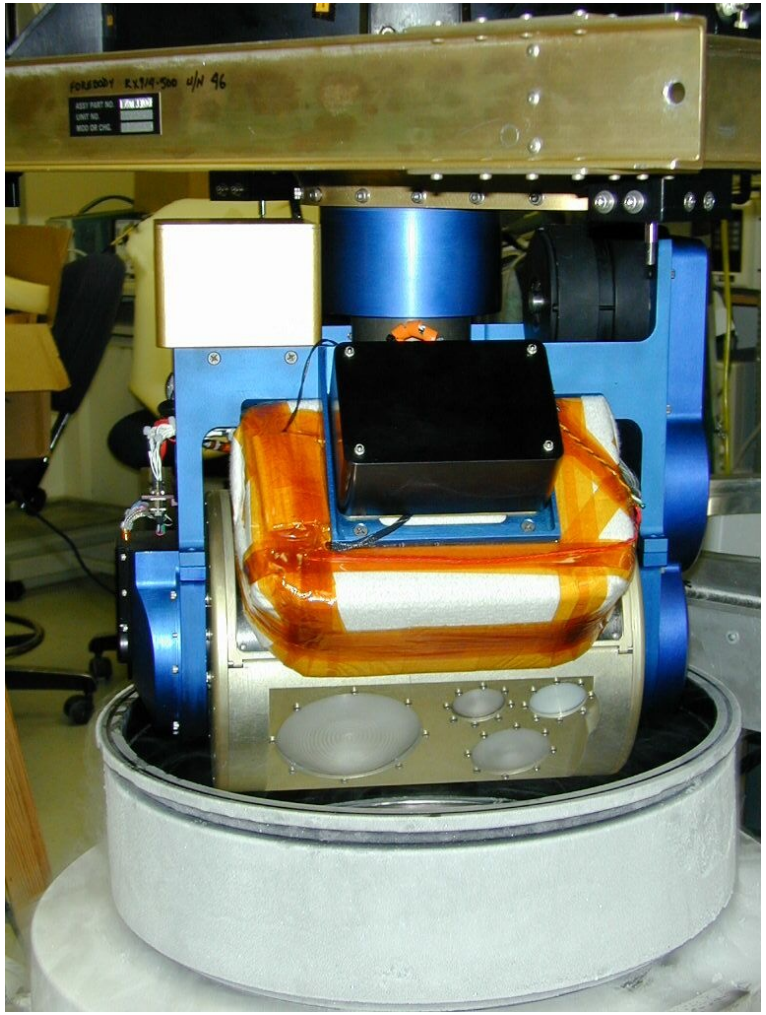
Co-Sponsored by the DoD and NASA for the DMSP SSMIS cal/val program.

Designed to fly on ER-2 high altitude (~20km) aircraft.

Dual-axis gimbals provide fore and aft conical scan, two cross-track scans, and two calibrations every 10 seconds.

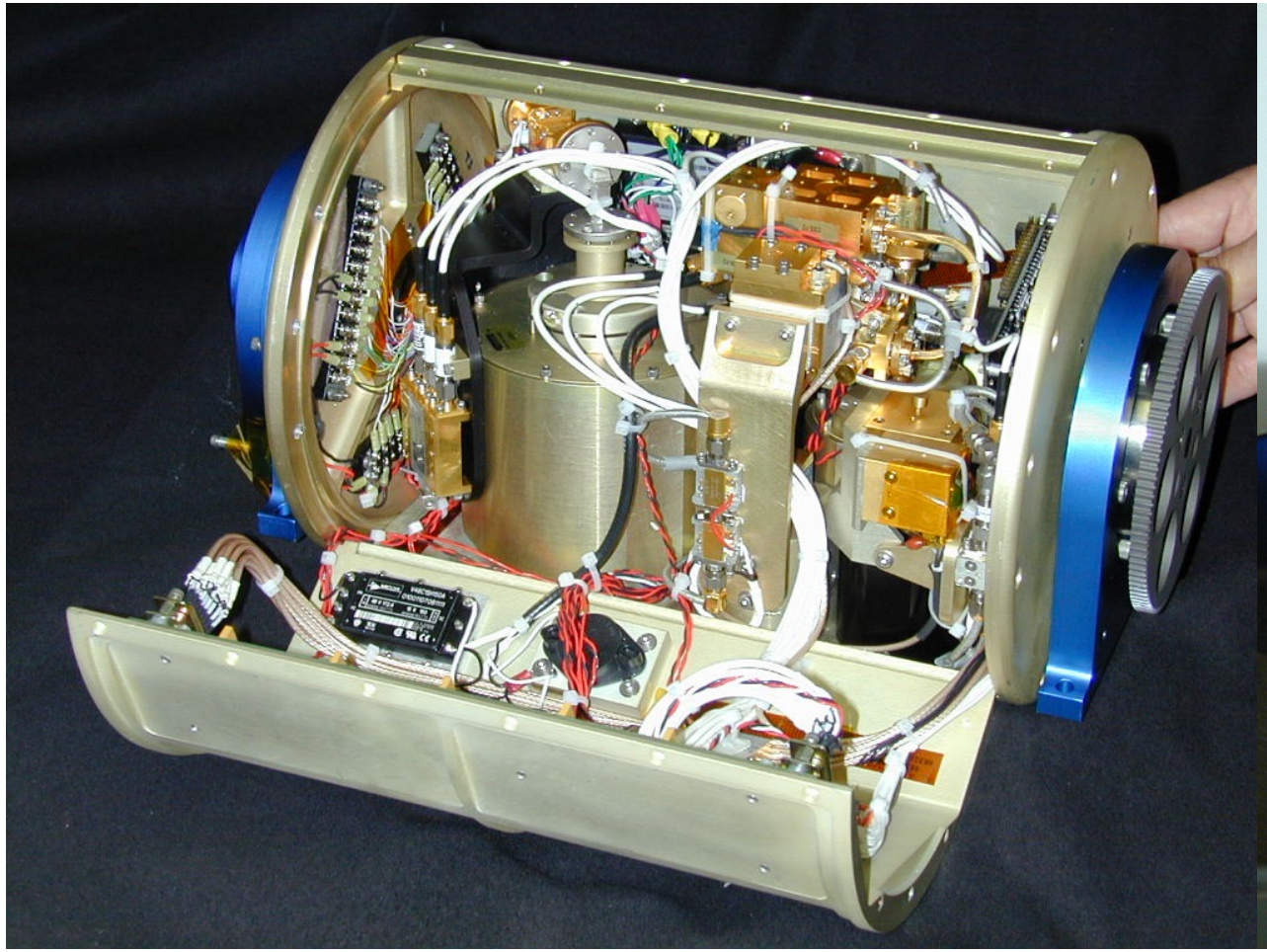
Calibration is achieved by periodic looks (~5s) at hot (330 K) and cold (~250K) close-coupled blackbody references.

First flight: March 2001

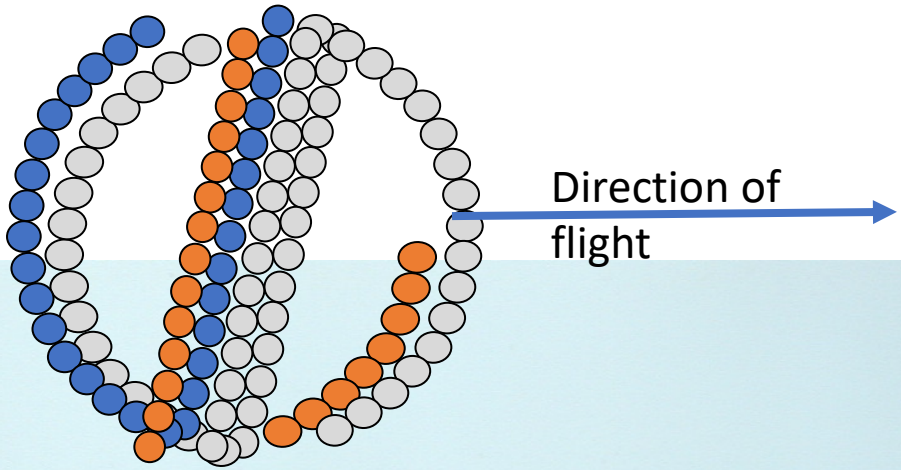


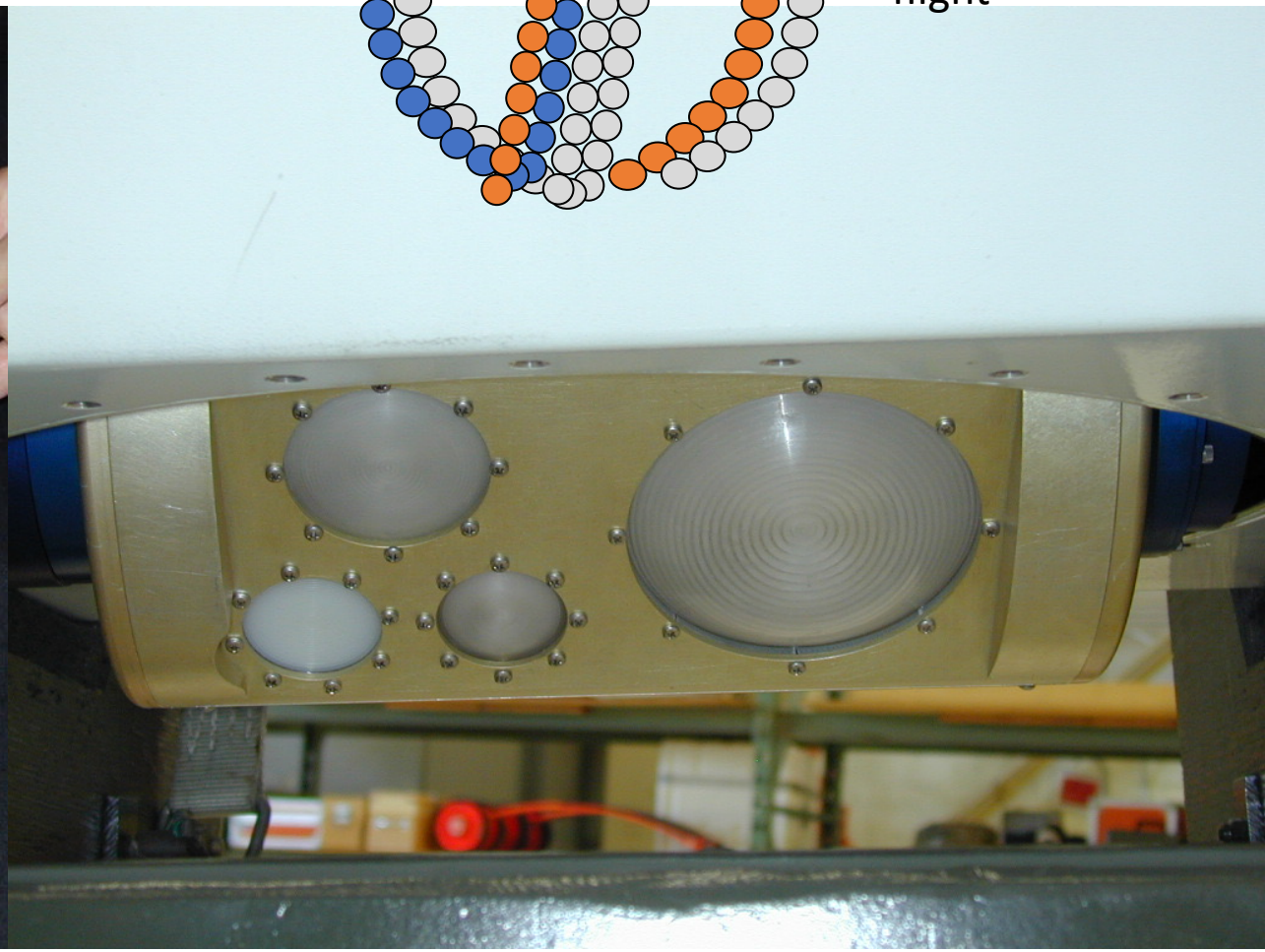
Center Frequency (GHz)	Bandwidth (MHz)	Noise Figure (dB)	NEΔT for τ = 100 ms (K)	Beamwidth (degrees)	Polarization
50.3	400	4.8	0.13	< 5	Horizontal
52.8	400	4.8	0.13	< 5	Horizontal
53.596	400	4.8	0.13	< 5	Horizontal
91.655	1500	6.5	0.10	4	Dual-linear
150.0	1500	7.5	0.13	4	Horizontal
183.3±1	500	8.7	0.30	4	Horizontal
183.3±3	1000	8.7	0.21	4	Horizontal
183.3±6.6	1500	8.7	0.17	4	Horizontal

CoSMIR Scanhead and Scan Profile



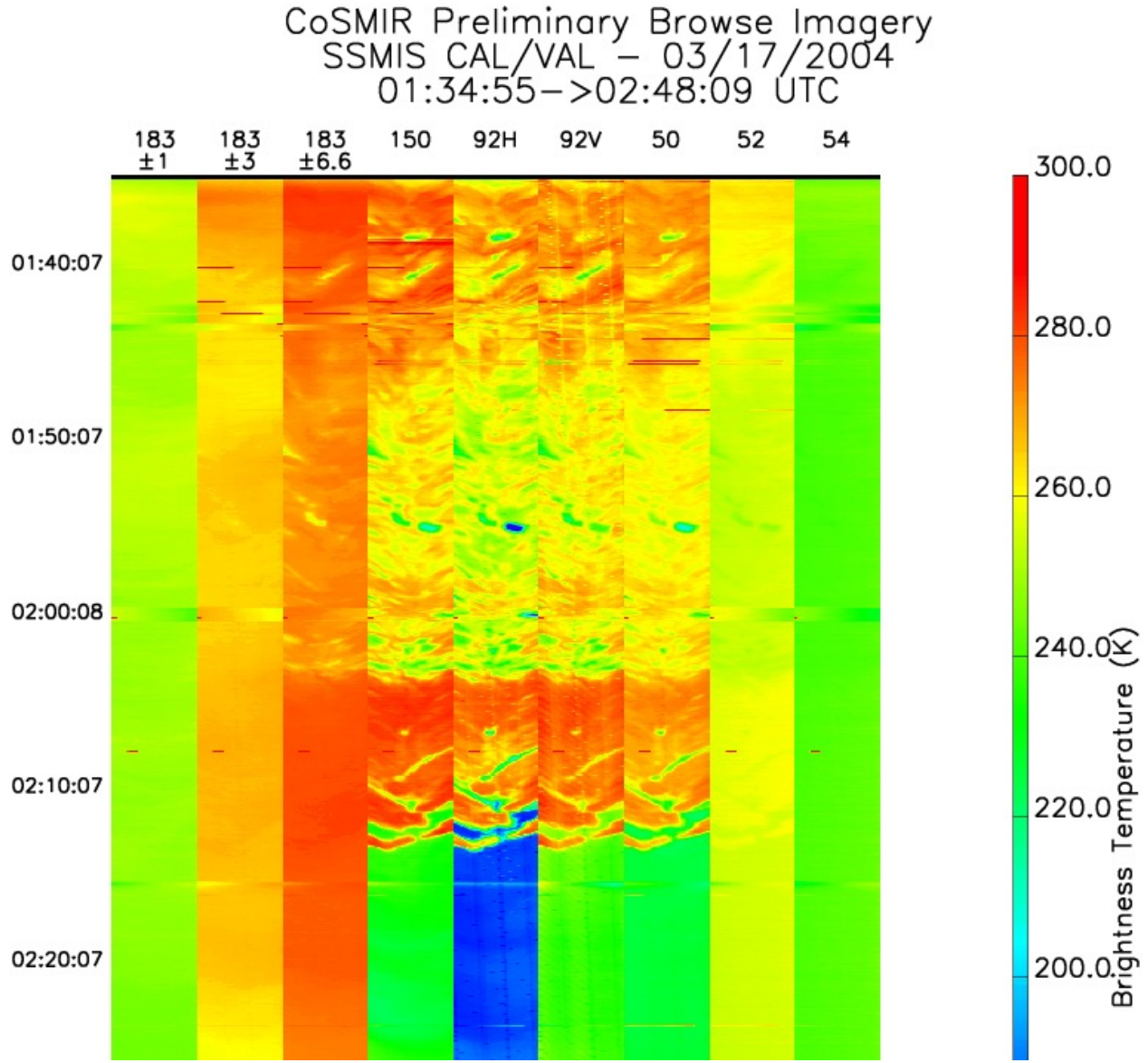
Conical/Cross-track Scan Profile





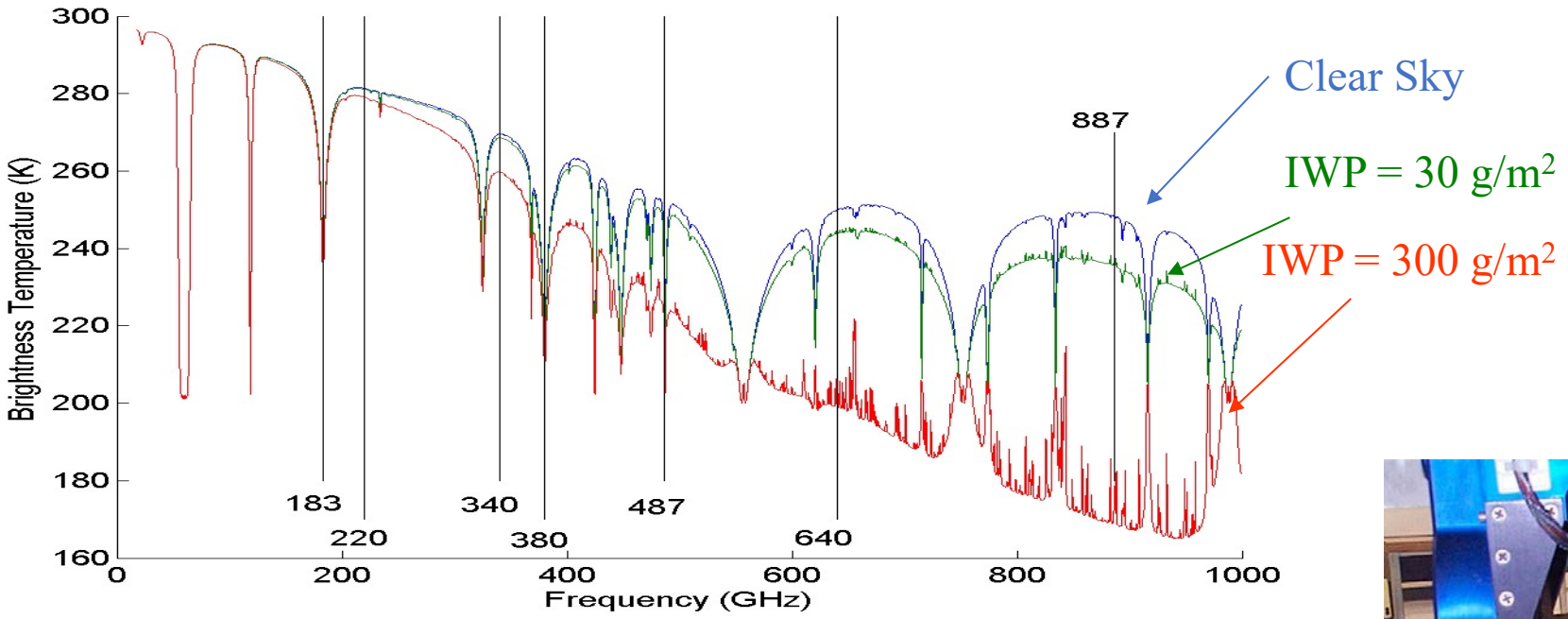
CoSMIR Data

- An example of CoSMIR 9-channel brightness temperature images over San Francisco Bay area. Data are not geolocated. Some stripes in the images are times when the aircraft making turns.



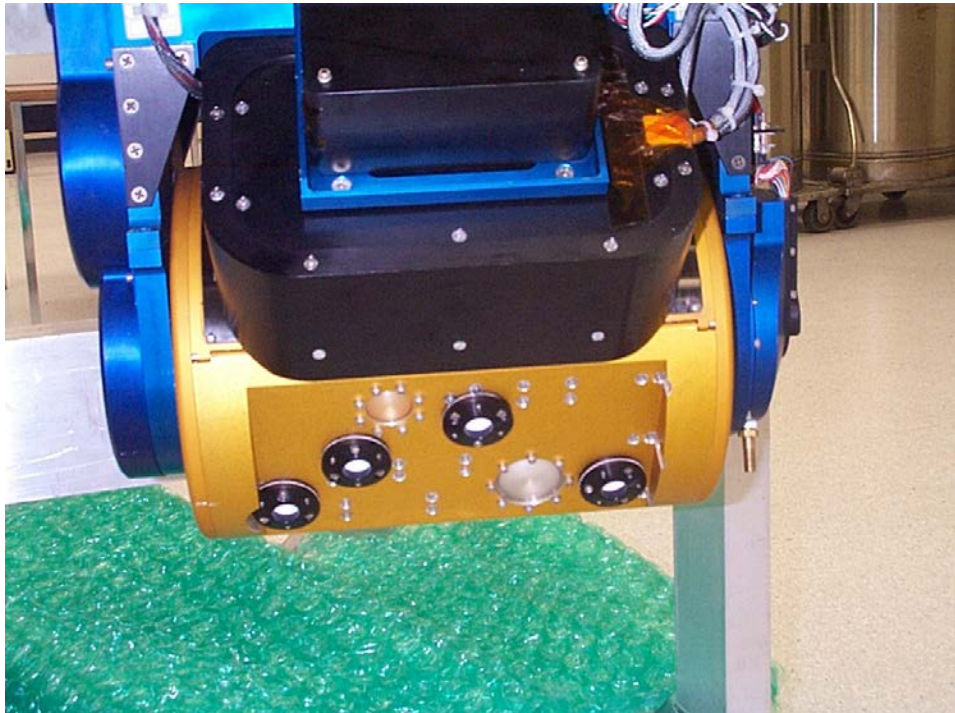
CoSSIR's 15 Channels Response to Cirrus

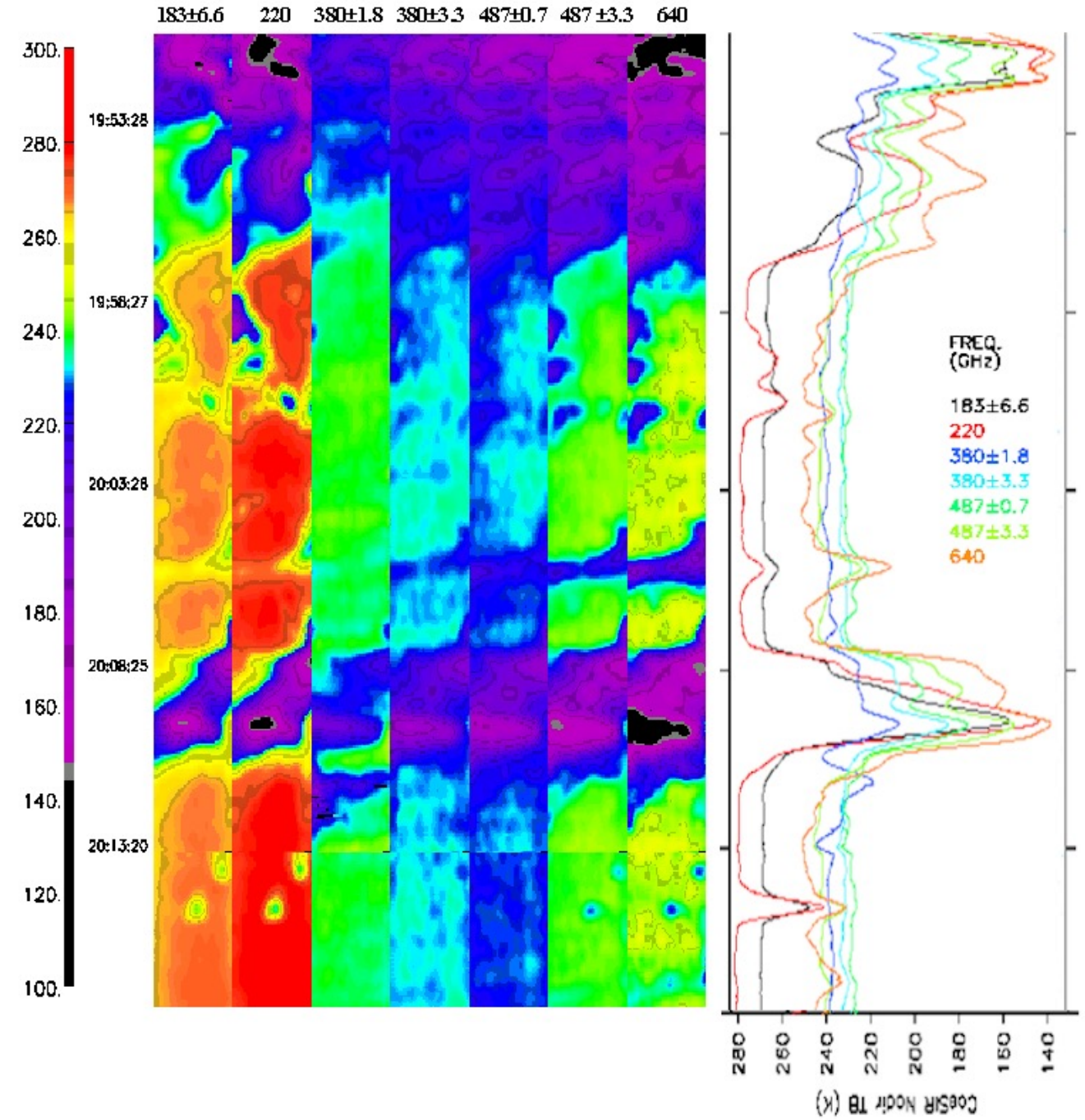
Response of Upwelling Radiation to the Presence of Cirrus Clouds



Frequency (GHz)	Channels (GHz)	Polarization
183	±1, ±3, ±6.6	H
220	±3	H
380	±0.8 ,±1.8,±3.3, ±6.2	H
487	±0.7, ±1.2, ±3.3	V & H
640	±4	H
874	±6	H

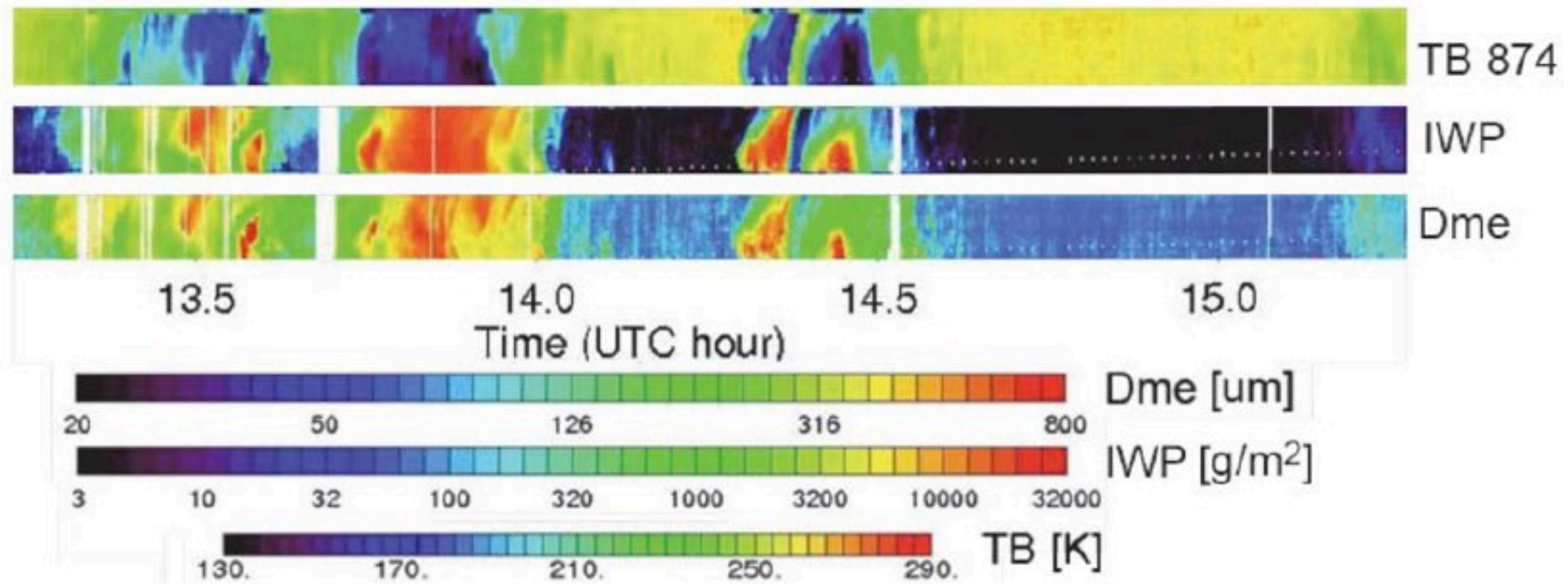
CoSSIR Scanhead





CoSSIR Airborne Data

CoSSIR's 874 GHz Brightness Temps & Retrieved Ice Cloud Parameters



National Aeronautics and Space Administration

Goddard Space Flight Center

IceCube: CubeSat Demonstration of Commercial 883-GHz Cloud Radiometer

Dong Wu, Tom Johnson, Negar Ehsan, Jaime Esper, Brian Abresch, Jeff Piepmeier, Paul Racette, and the IceCube Team

NASA Goddard Space Flight Center

IceCube Released from ISS on May 16, 2017

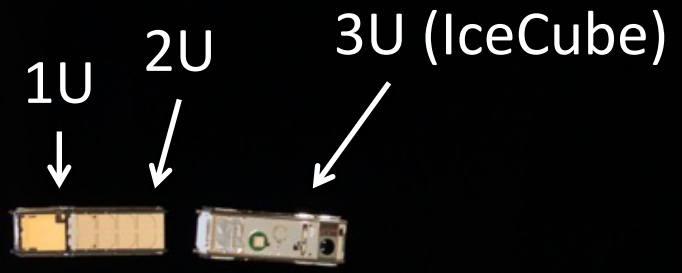
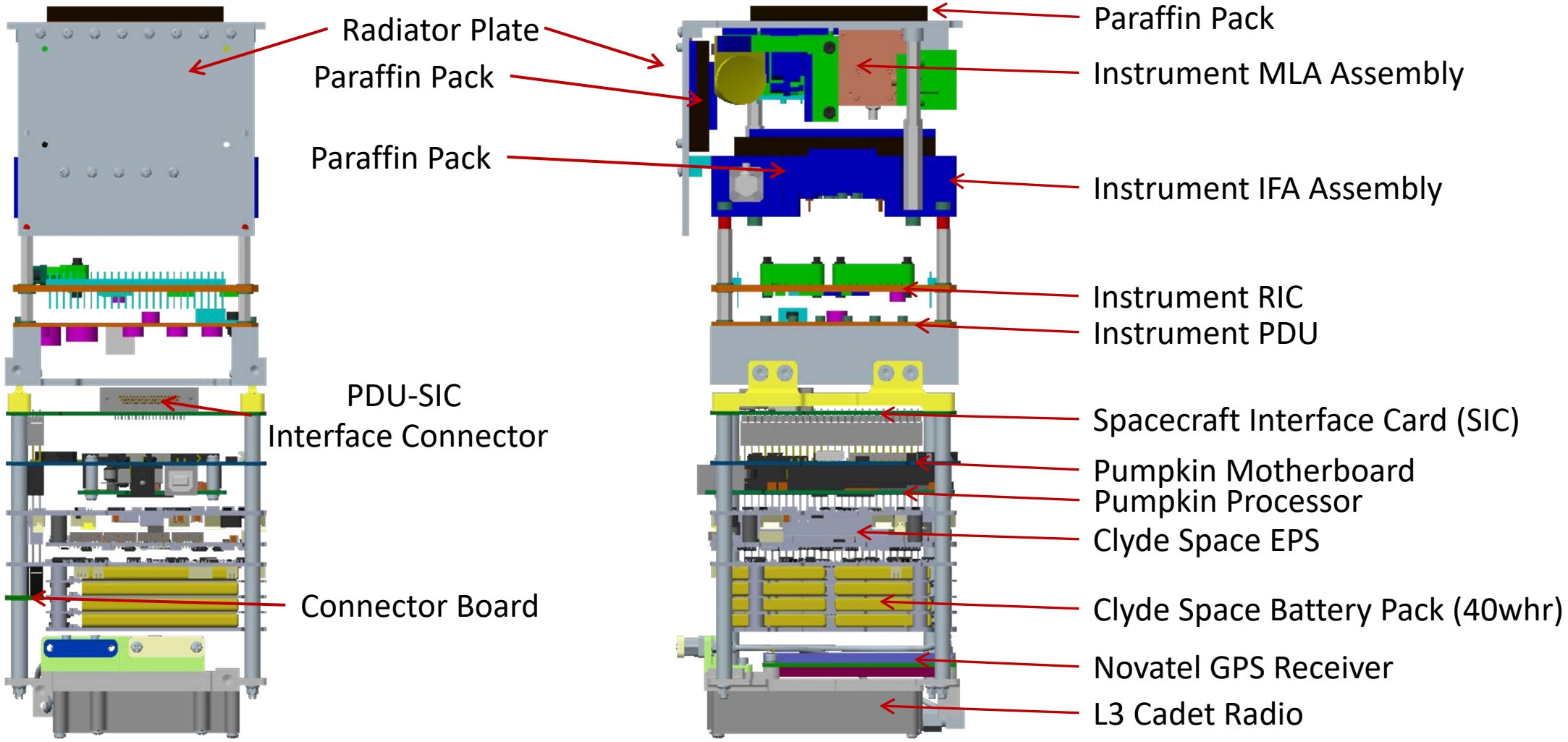


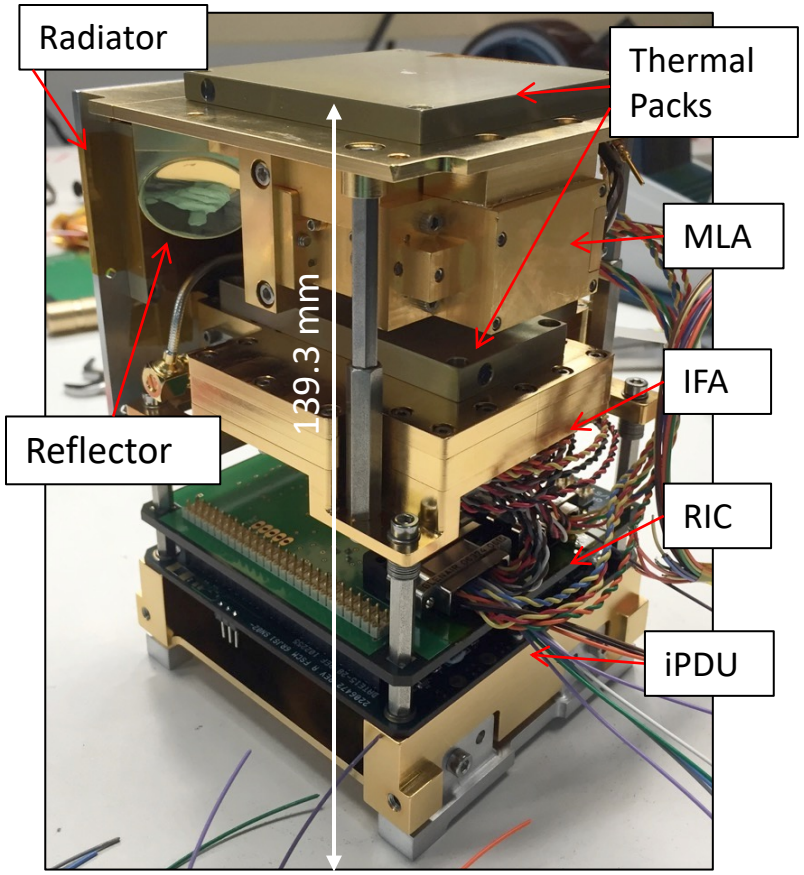
Photo Credit: ISS and NanoRacks

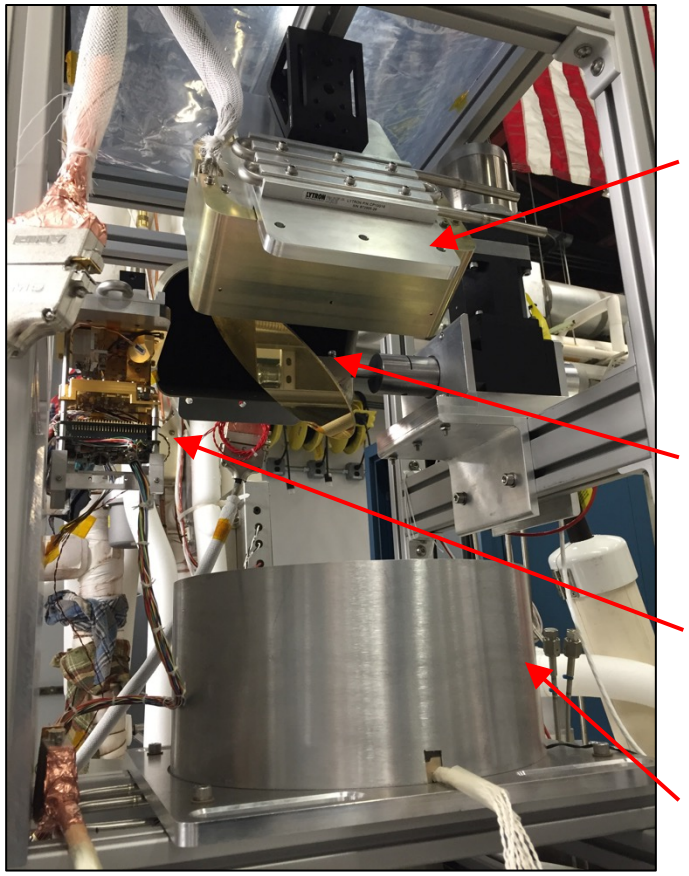
IceCube 3U Observatory



Instrument Integration & Test

Flight Model IceCube Instrument





IceCube Calibration Fixture
(57 cm x 57 cm x 91 cm)

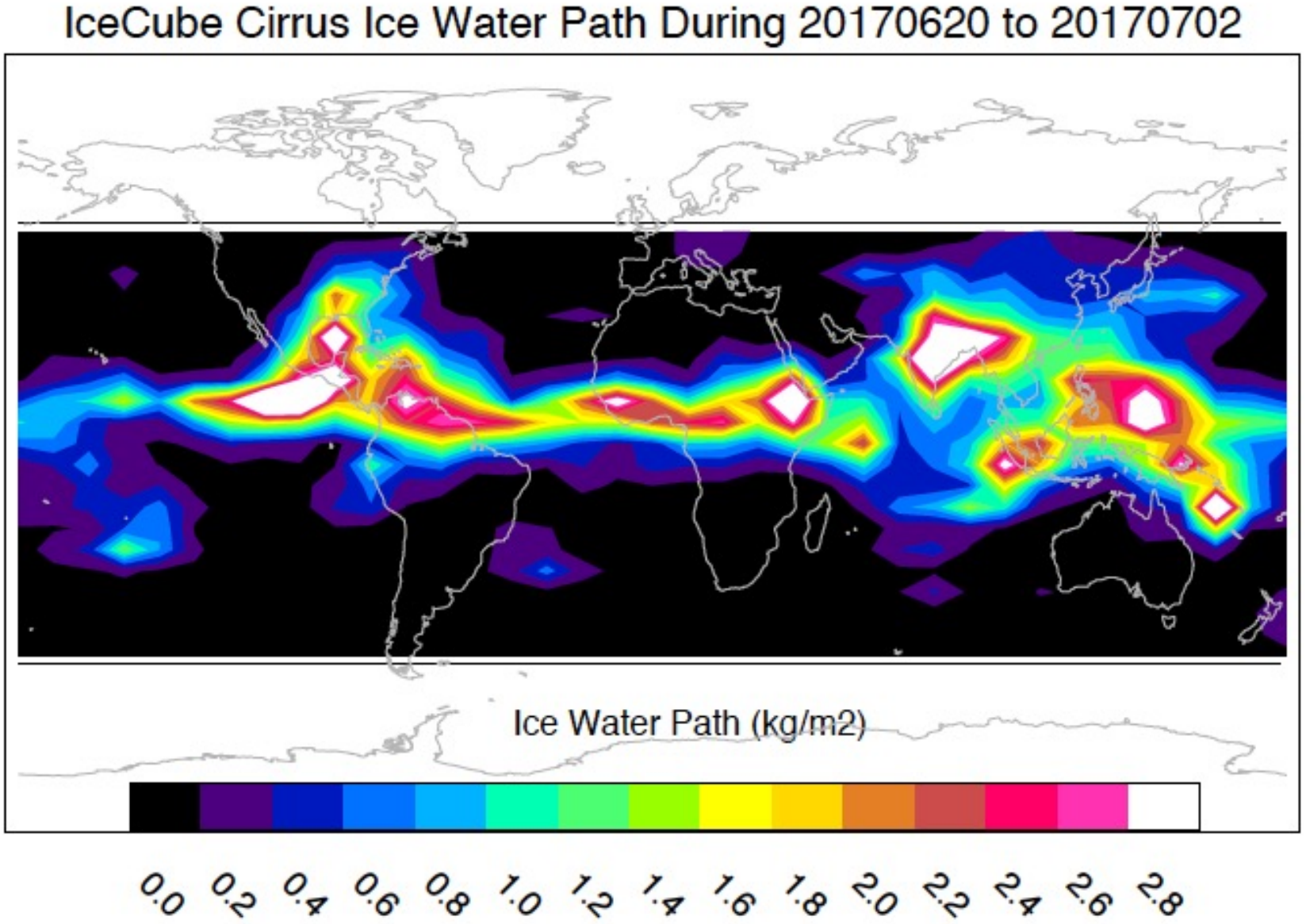
Sub-MMW blackbody cold target (100 K) & hot target (300 K) for external calibration; tolerance ± 1 K

45° offset rotating mirror to alternate observed scene/target

Instrument

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

First 883-GHz Cloud Ice Map



Picture this SELFI:

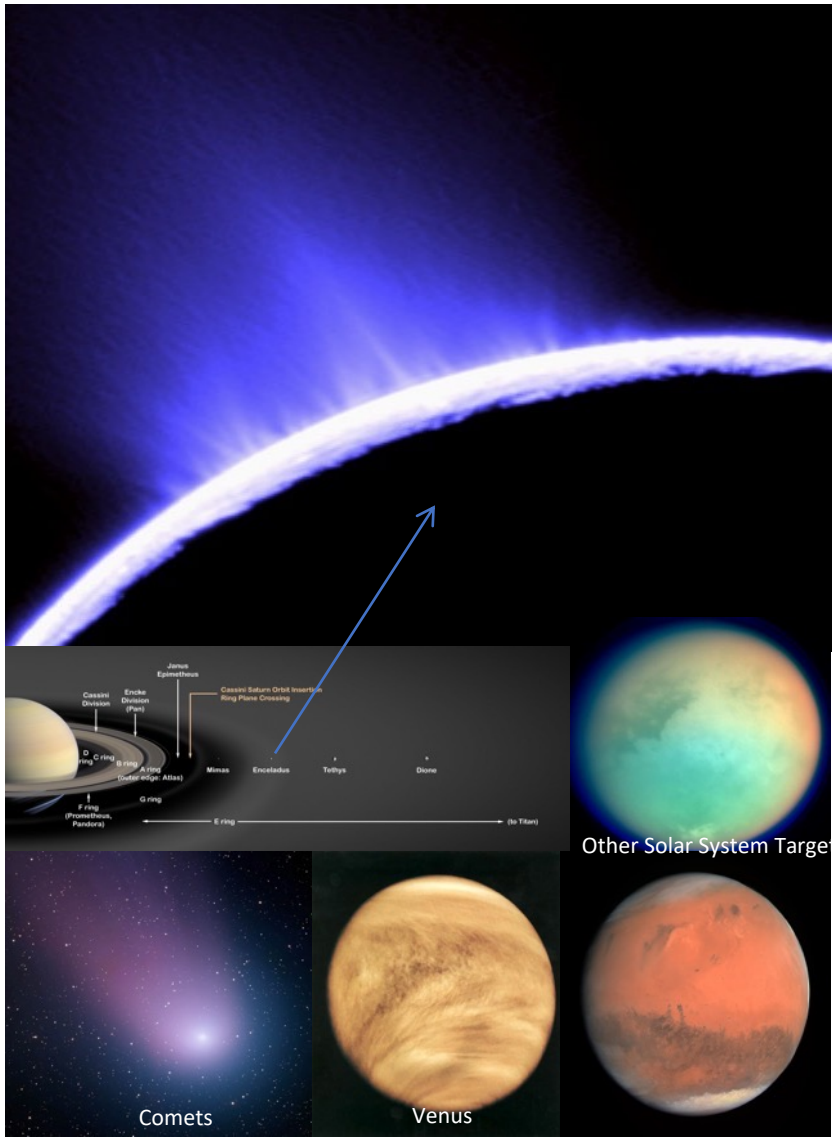
Submillimeter Enceladus Life Fundamentals Instrument

Principal Investigator

Dr. Gordon Chin

Code 693, Goddard Space Flight Center

SELFI Science Objectives



SELFI observes nearly simultaneously 14 molecular species that are important in the context of life and habitability (five of **CHNOPS** elements necessary for life) of the Enceladus' subsurface ocean.

- Assess plume spatial/temporal compositional variability;
- **H_2O**, **HDO**, and **$\partial^{18}O$**, and **$\partial^{17}O$** evidence of ocean evolution;
- **H_2O_2,** and **O_3** oxidation state of the sub surface ocean;
- **CO, NH_3, CH_3OH, HCN and HNC** are biologically relevant species;
- **SO_2** and **H_2S** links to pre-biotic molecules and volcanoes;
- **NaCl** provides salinity level of the subsurface ocean and the source of salt in the Saturn ring system.

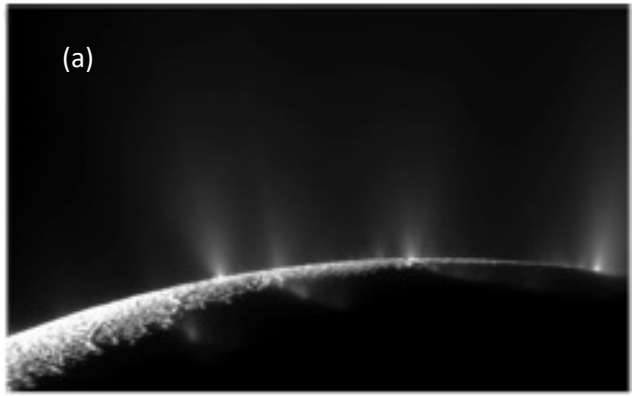
Continuum observations measure surface temperature from 30 - 250 K with 0.1 K resolution.

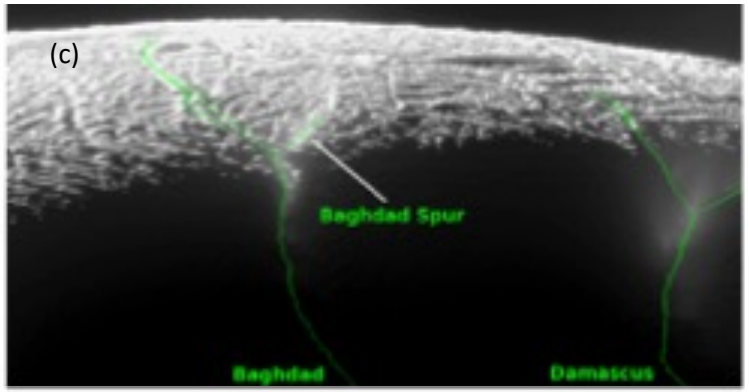
- Correlation of plume activity with surface temperature.

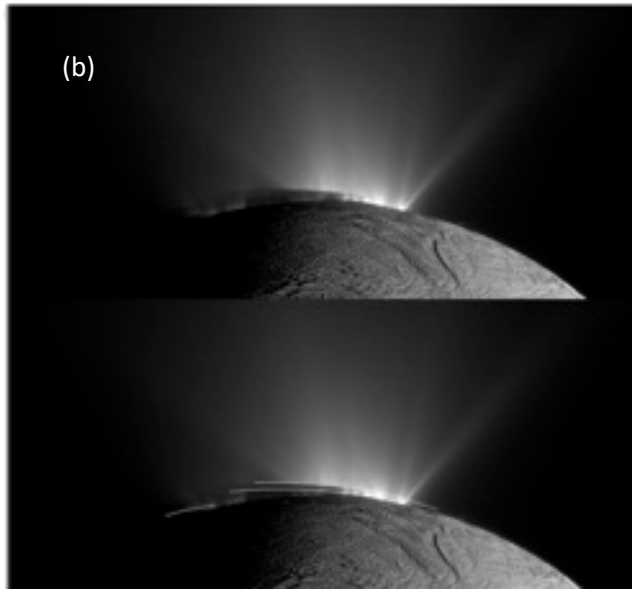
Enceladus Plume Observations

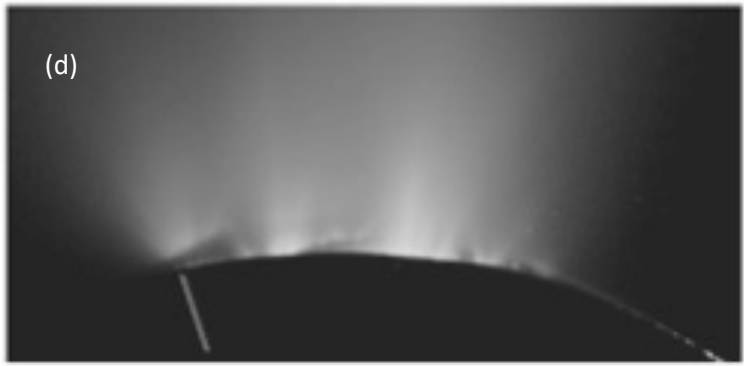
Enceladus' plumes are spatially (a) and temporally (b) variable, arising from fractures called Tiger Stripes (c), and may be curtains of eruptions whose density inhomogeniety gives an observational appearance of individual plumes (d).

From Porco, DeNino, and Nimmo Astronomical Journal 248, No. 3, 2014.



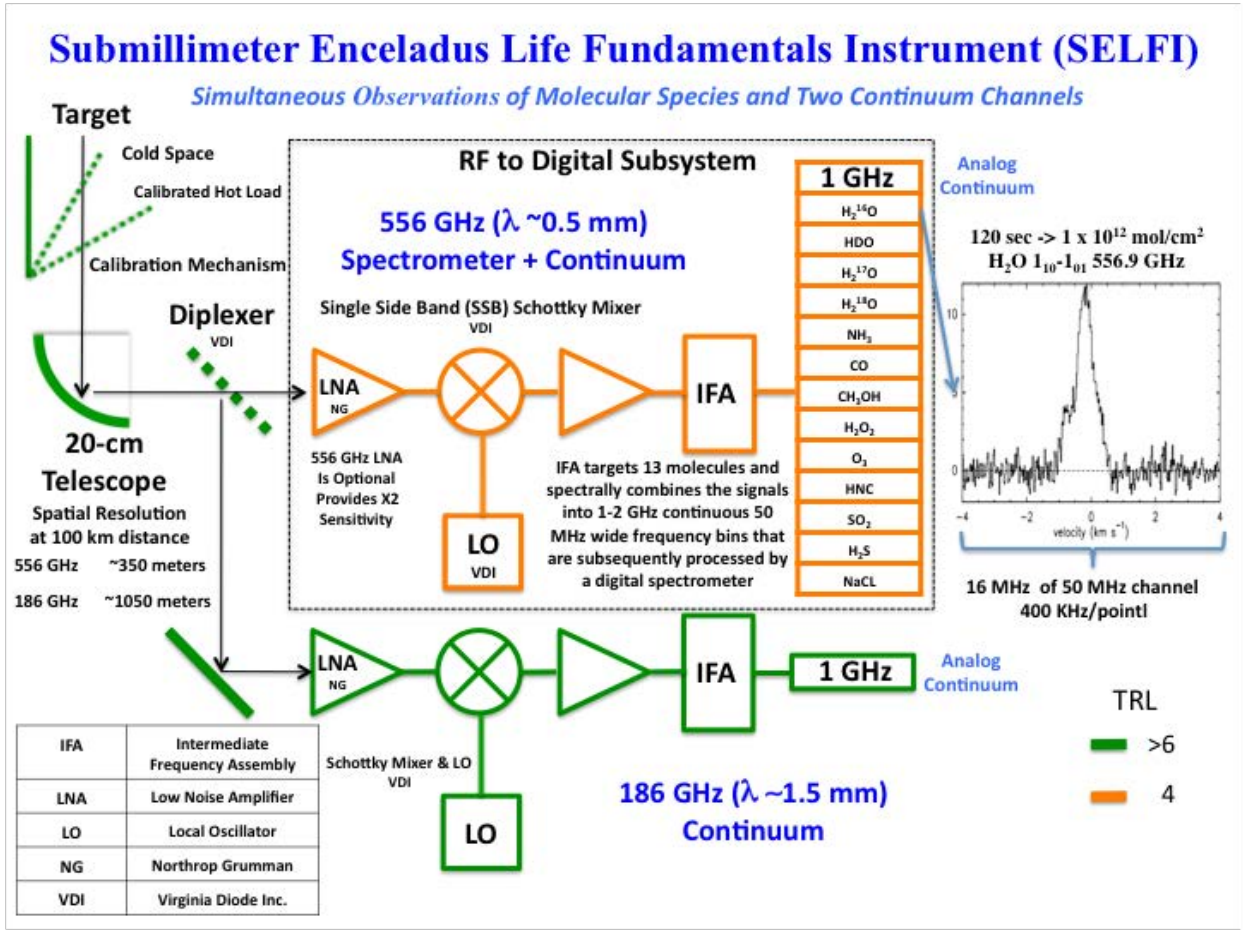






SELFI Technical Objectives

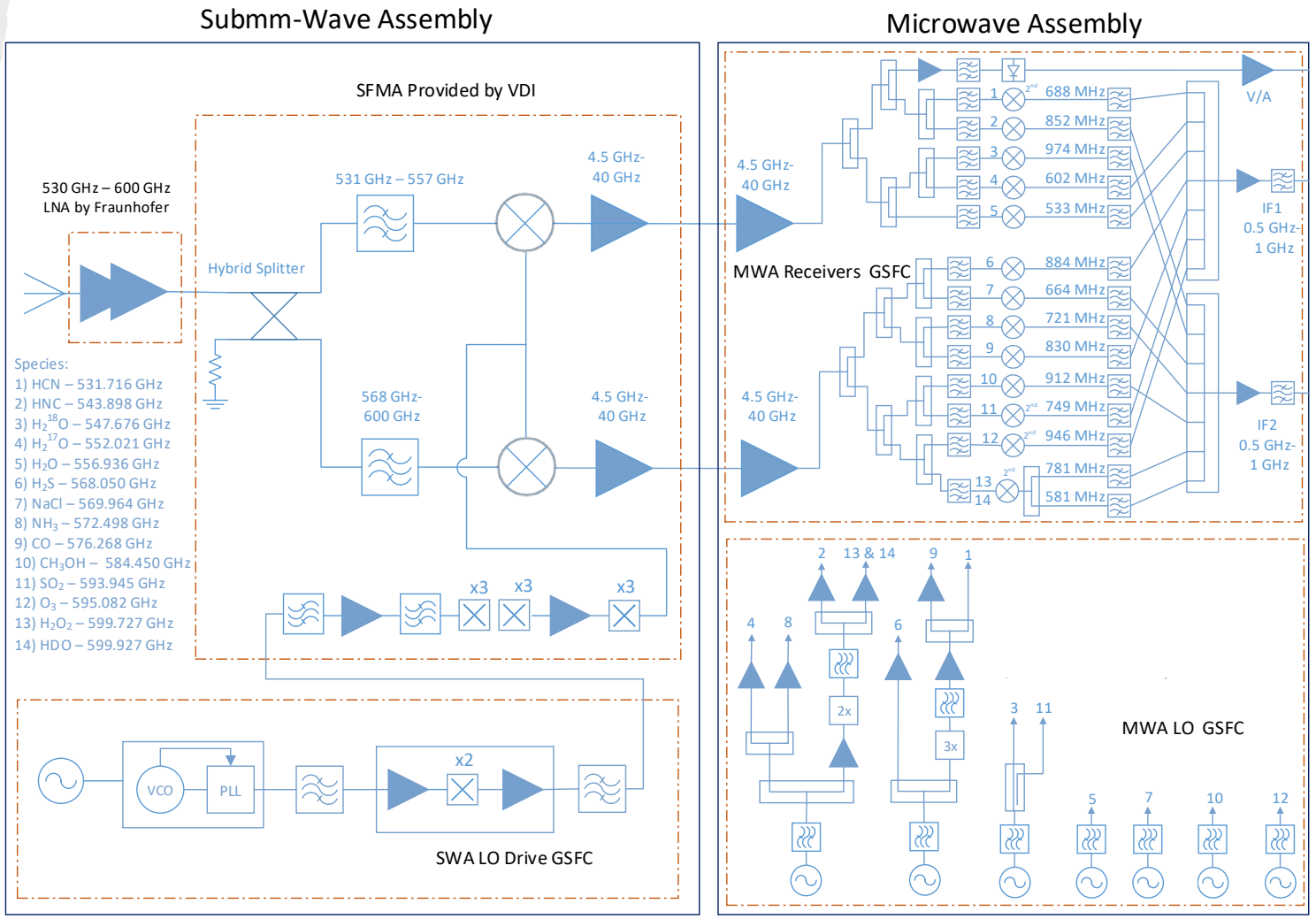
- Advance the TRL of RF Low Noise Amplifier (RF LNA)
  - Optimize Noise Figure & Gain
- Advance TRL of Mixer & LO Assembly (MLA)
  - Partnership with Virginia Diodes, Inc. via Phase 3 SBIR
- Design, build and test Microwave Assembly (MWA)
  - In-house build leveraging COTS where possible
- Design, build and test Digital Spectrometer Assembly (DSA)
- Raise TRL to 6 of SELFI RF-to-Digital Spectrometer through functional and environmental testing
  - Reduce risk of flight instrument development



Advance our technical capabilities, reduce technical risks and gain the knowledge necessary to build an instrument to make submm spectroscopic measurements of Enceladus plumes

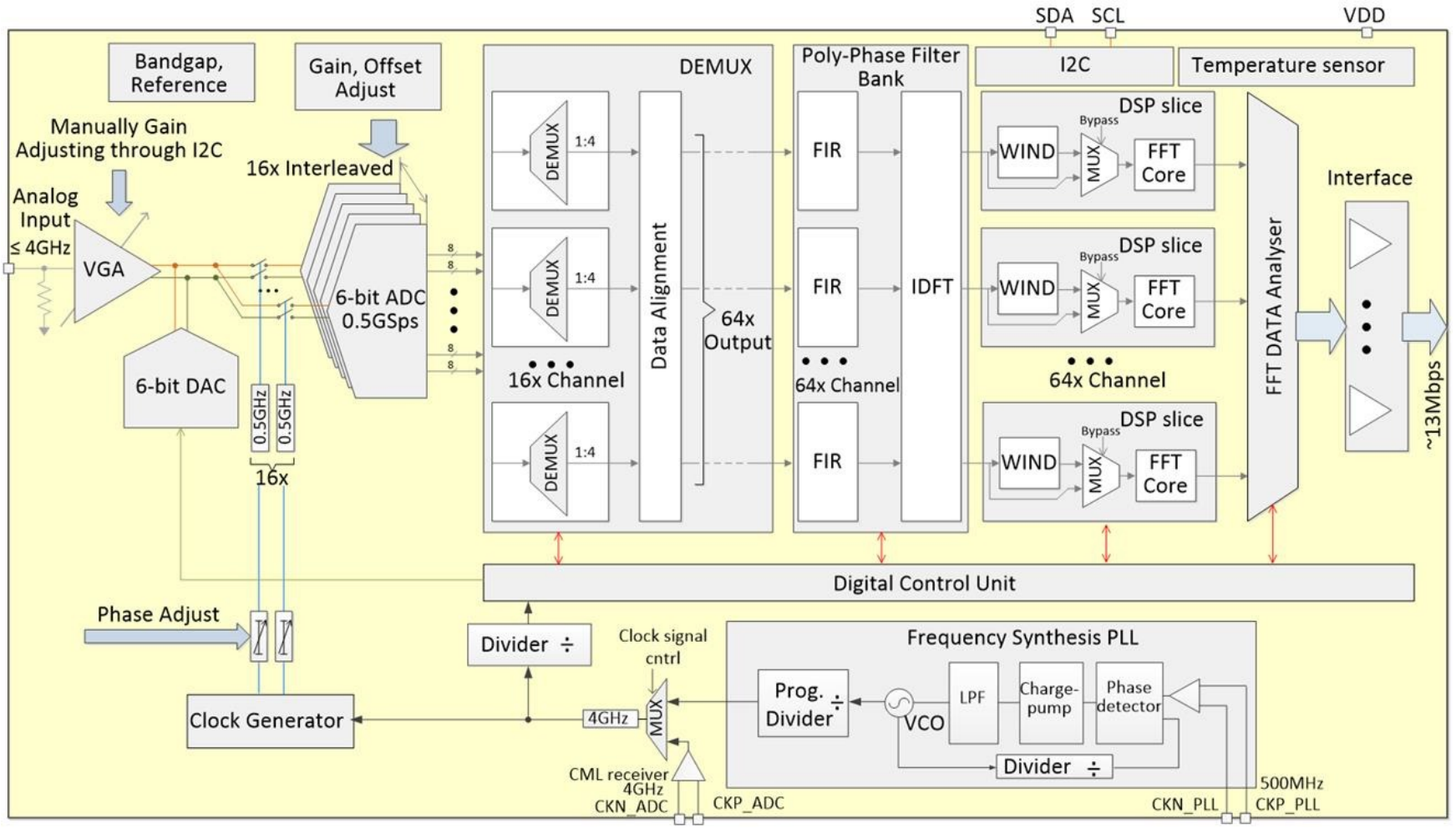
RF System Architecture

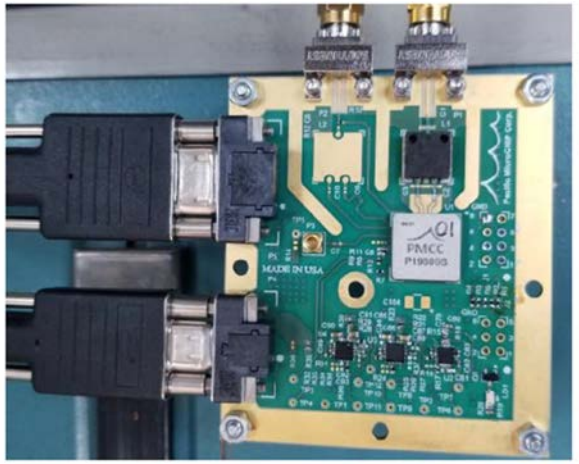
- Cascaded RF LNA has > 20 dB gain and < 12 dB NF
- Hybrid Coupler and dual-mixer downconverts upper/lower sidebands into two 35 GHz IF bands
- SWA LO Drive provides frequency switching for baseline subtraction
- Microwave Assembly downconverts 14 species into two 500 MHz bandwidths



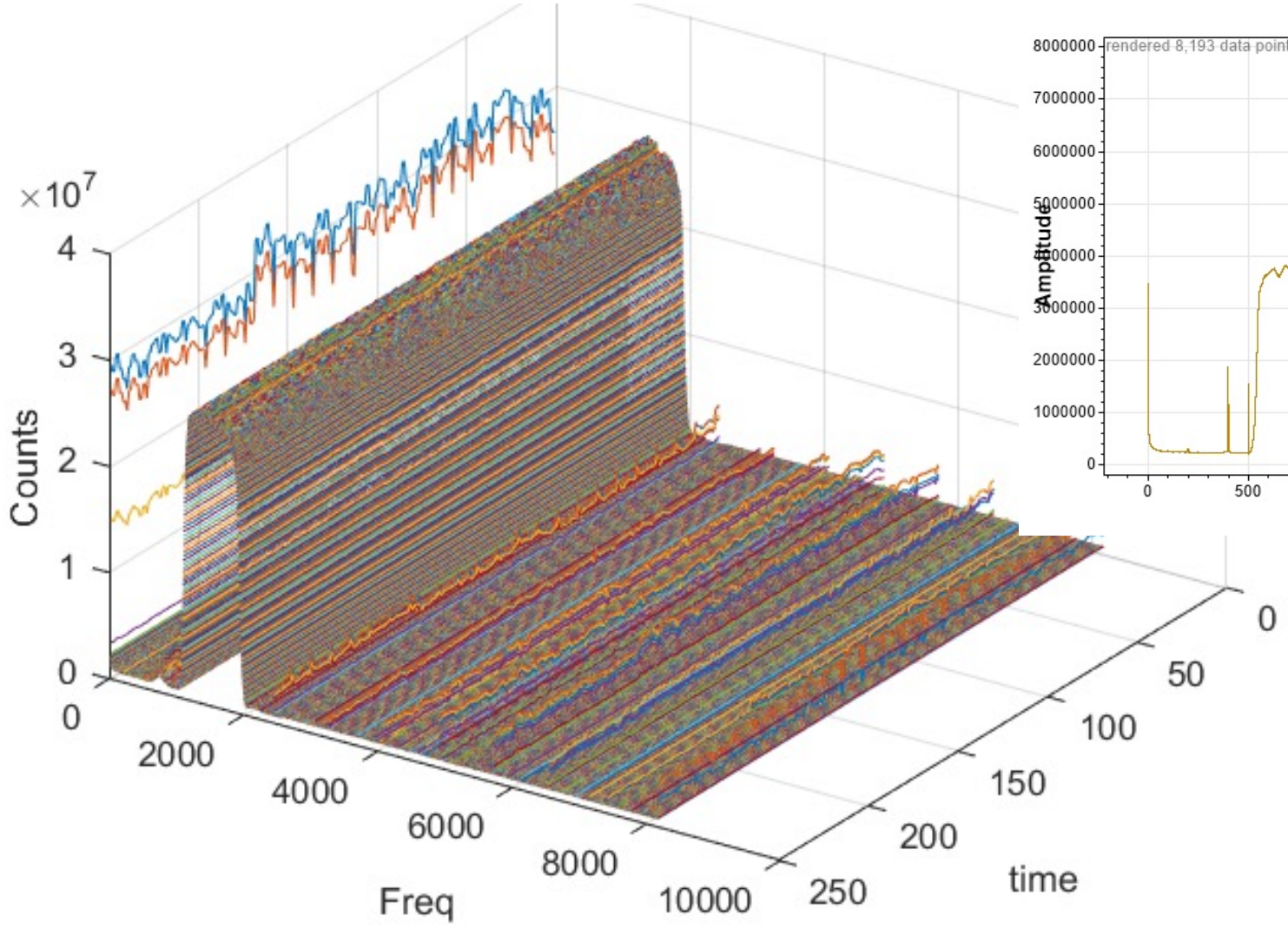
Enabling Technology: Low-Power Digital Spectrometers

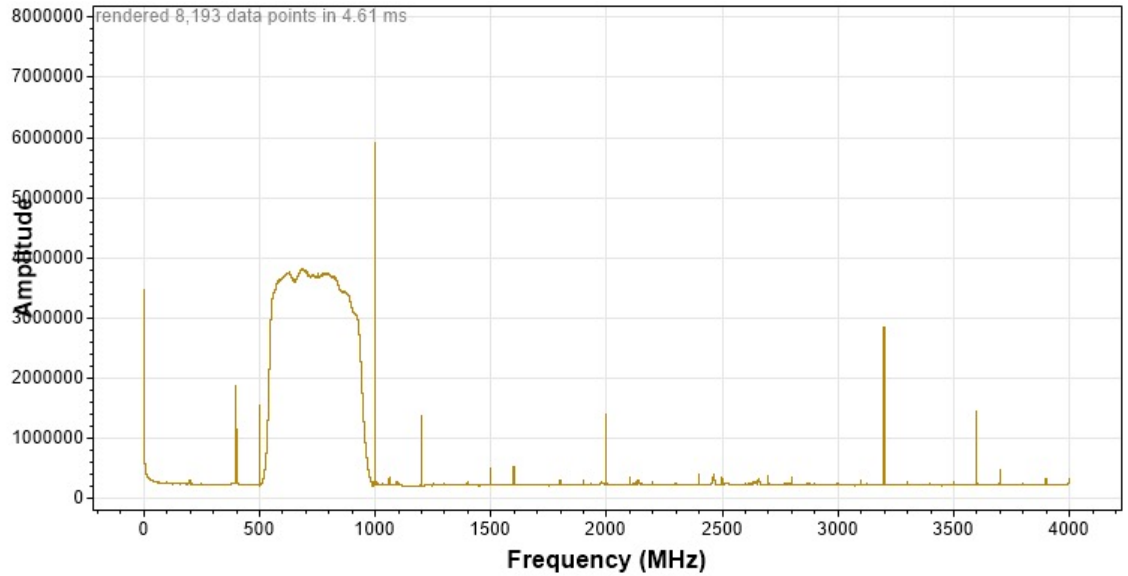
Radiation Tolerant 4GHz Bandwidth 8k Channel Spectrometer ASIC





Digital Spectroscopy - Time Series Spectra

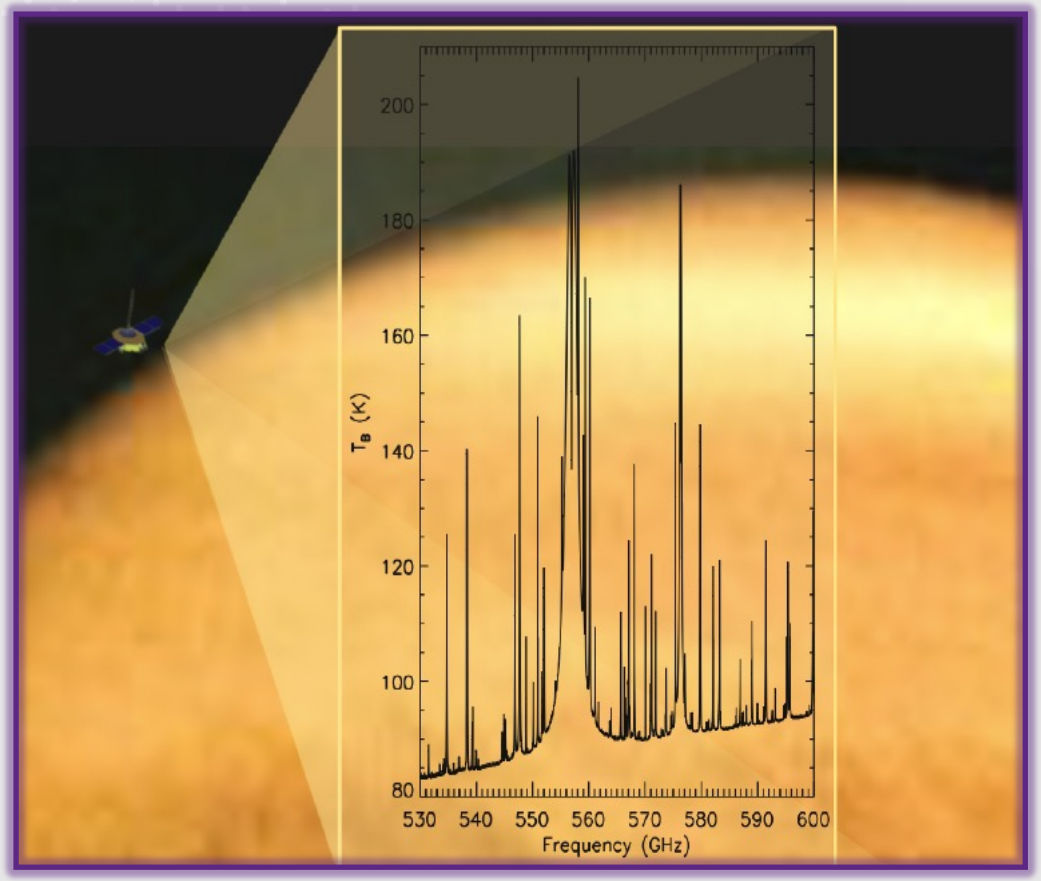




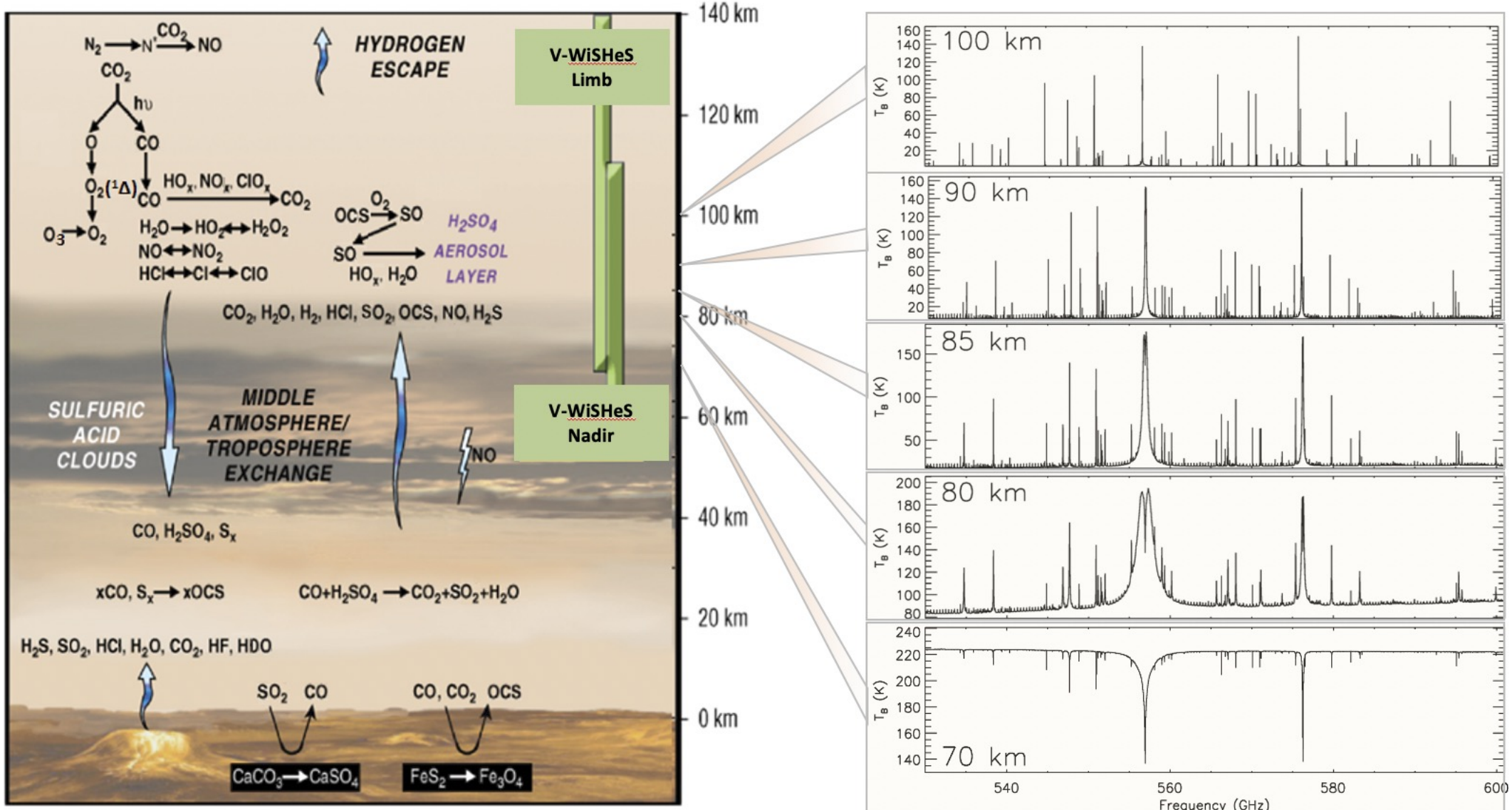
V-WiSHeS: Venus Wideband Submillimeter Heterodyne Spectrometer

PI: Carrie Anderson

NASA's Goddard Space Flight Center

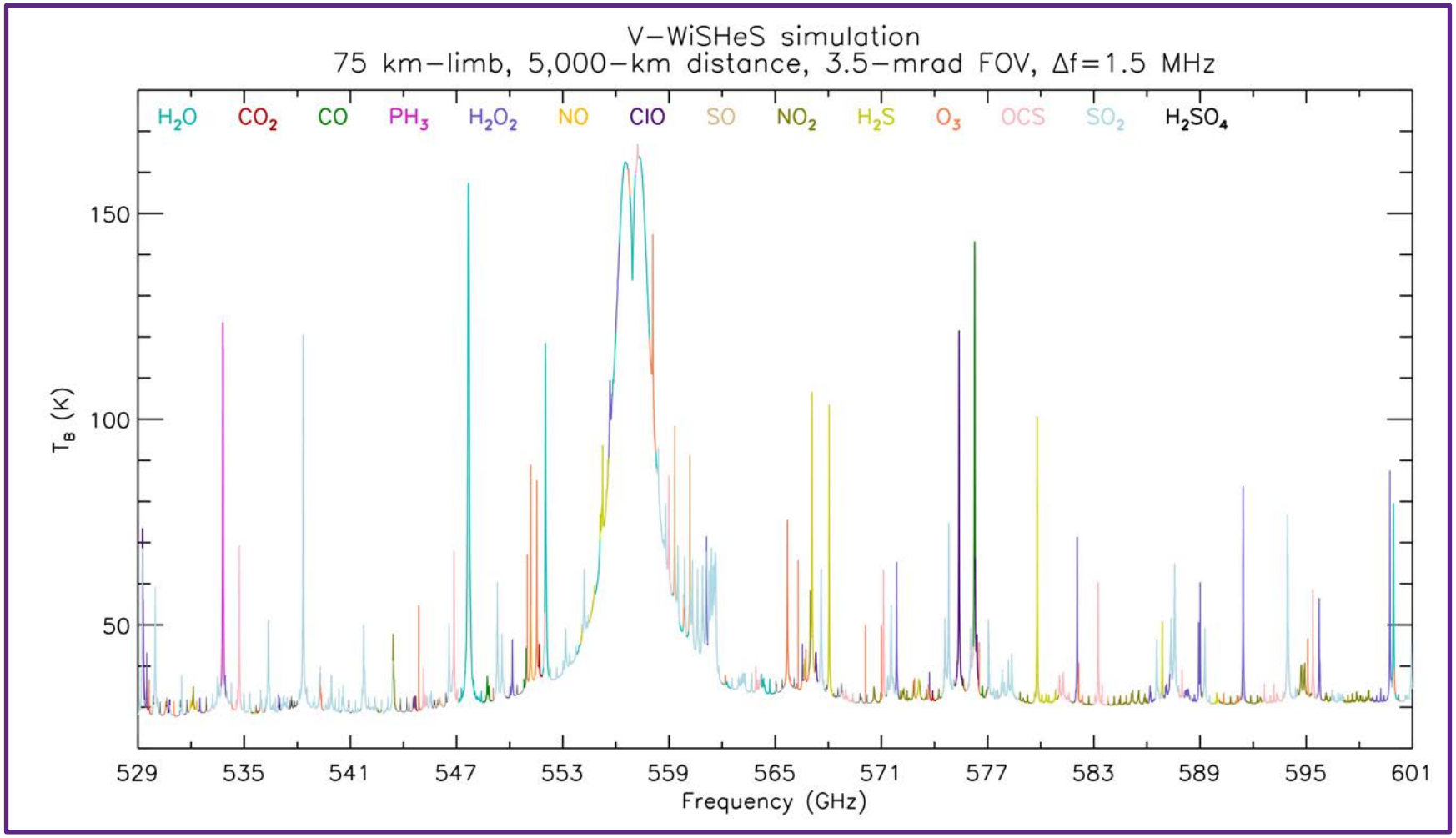


Venus Atmospheric emission at different tangent heights



Science Summary

- V-WiSHeS is optimized to measure trace gases and continuum opacities in Venus' middle atmosphere, enabling spatial and temporal profile measurements of wind, temperature, aerosol opacity, and concurrent isotopic abundances of H_2O, $H_2{}^{17}O$, $H_2{}^{18}O$, HDO, $CO^{18}O$, $CO^{17}O$, $^{13}CO^{18}O$, $^{13}CO^{17}O$, CO, ^{13}CO, $C^{18}O$, $O^{18}O$, O_3, $OO^{17}O$, $OO^{18}O$, H_2S, $H_2{}^{34}S$, $H_2{}^{33}S$, H_2SO_4, ClO, ^{37}ClO, H_2O_2, SO, SO_2,$^{34}SO_2$, OCS, $O^{13}CS$,$OC^{34}S$, $OC^{33}S$, NO, and NO_2.



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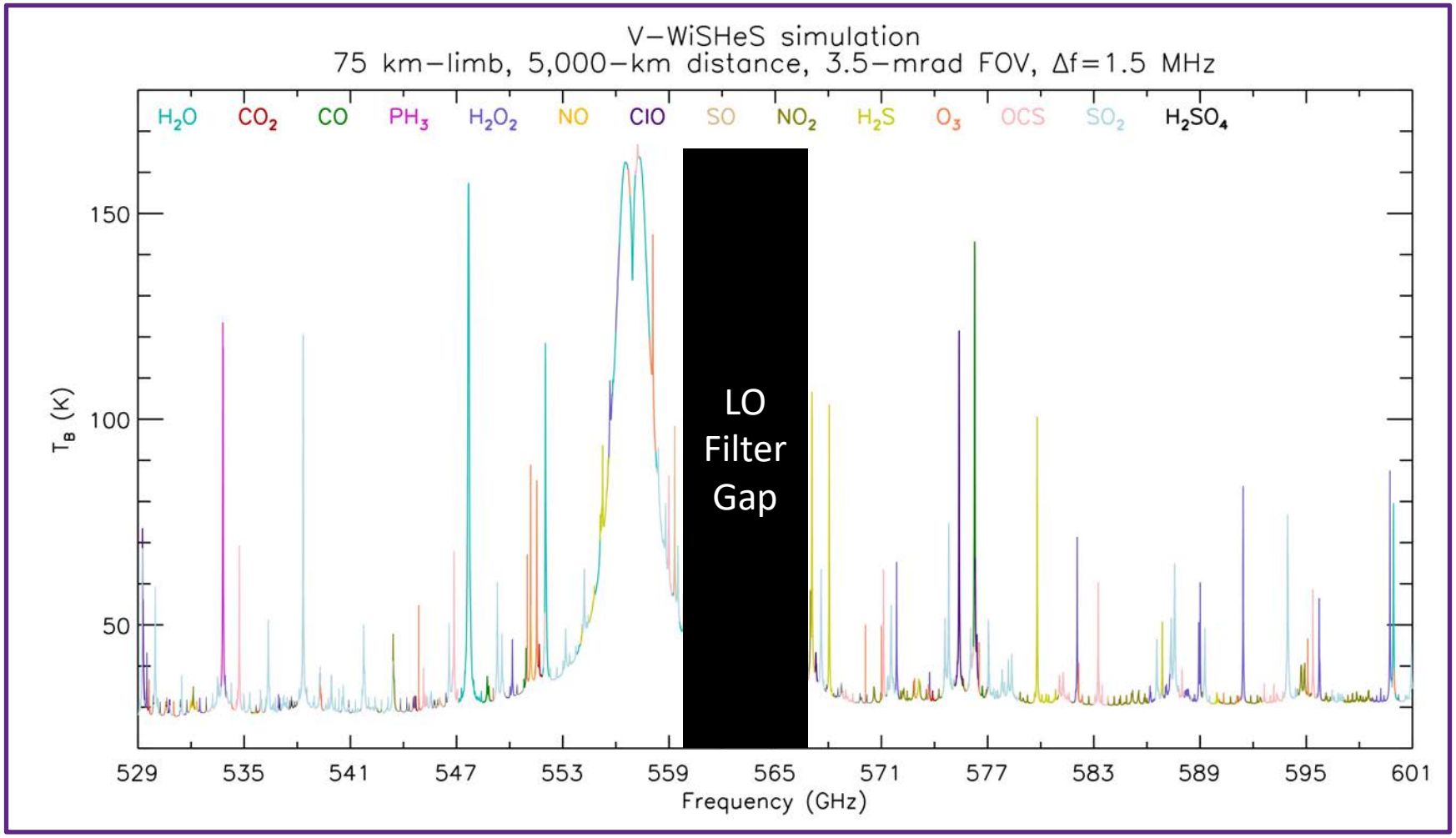
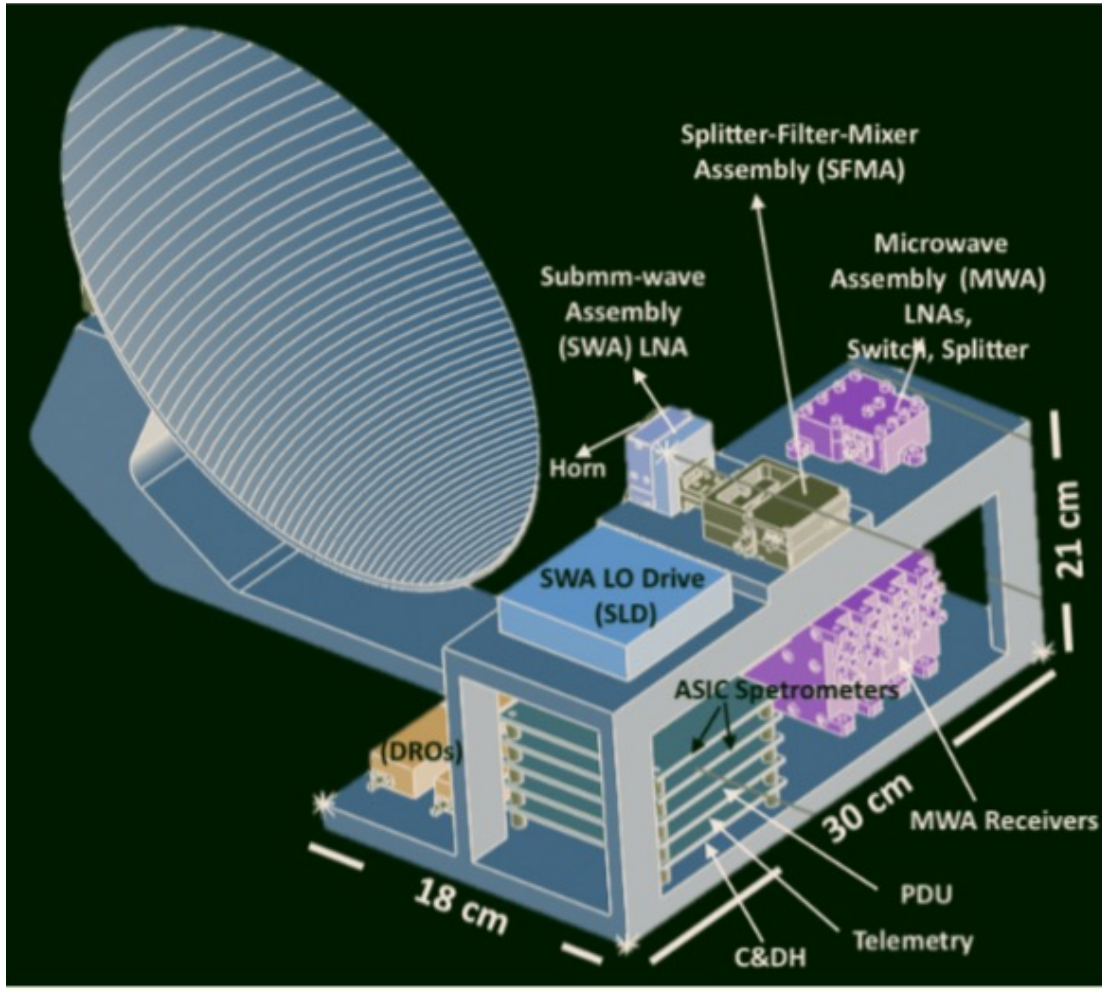
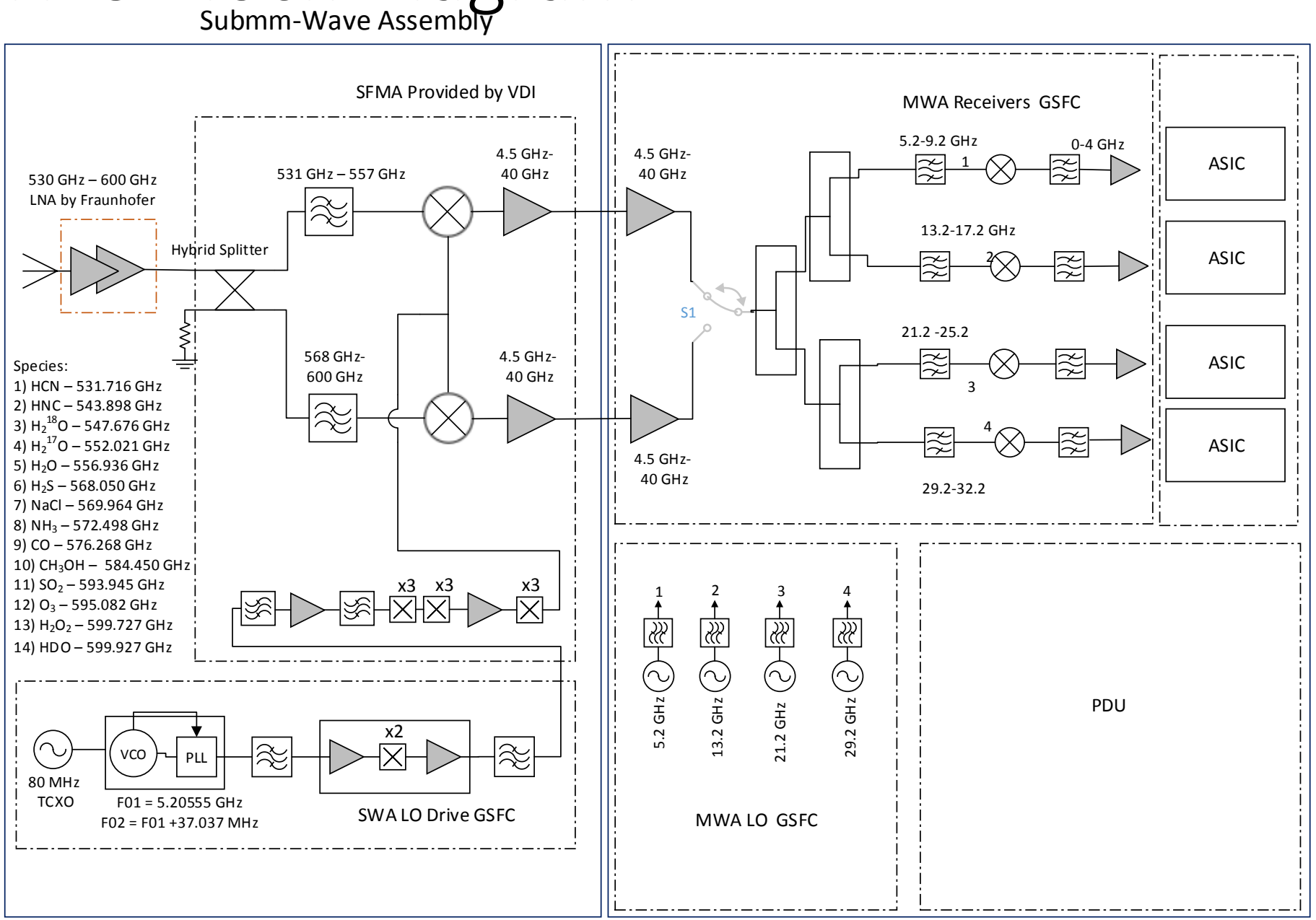


V-WISHES Architecture & Key Parameters



Total Power	25 W
Mass	12 kg
Spectral Coverage	529 – 600 GHz
Measured Bandwidth	64 GHz
Spectral Resolution	500 kHz
Digital Spectrometer	ASICs with PFB
Receiver Noise Figure	$\leq$ 12 dB
Aperture Size	21 cm
Field of View	3.5 mrad
Field of Regard	$>$ 180 degrees

V-WISHES Block Diagram

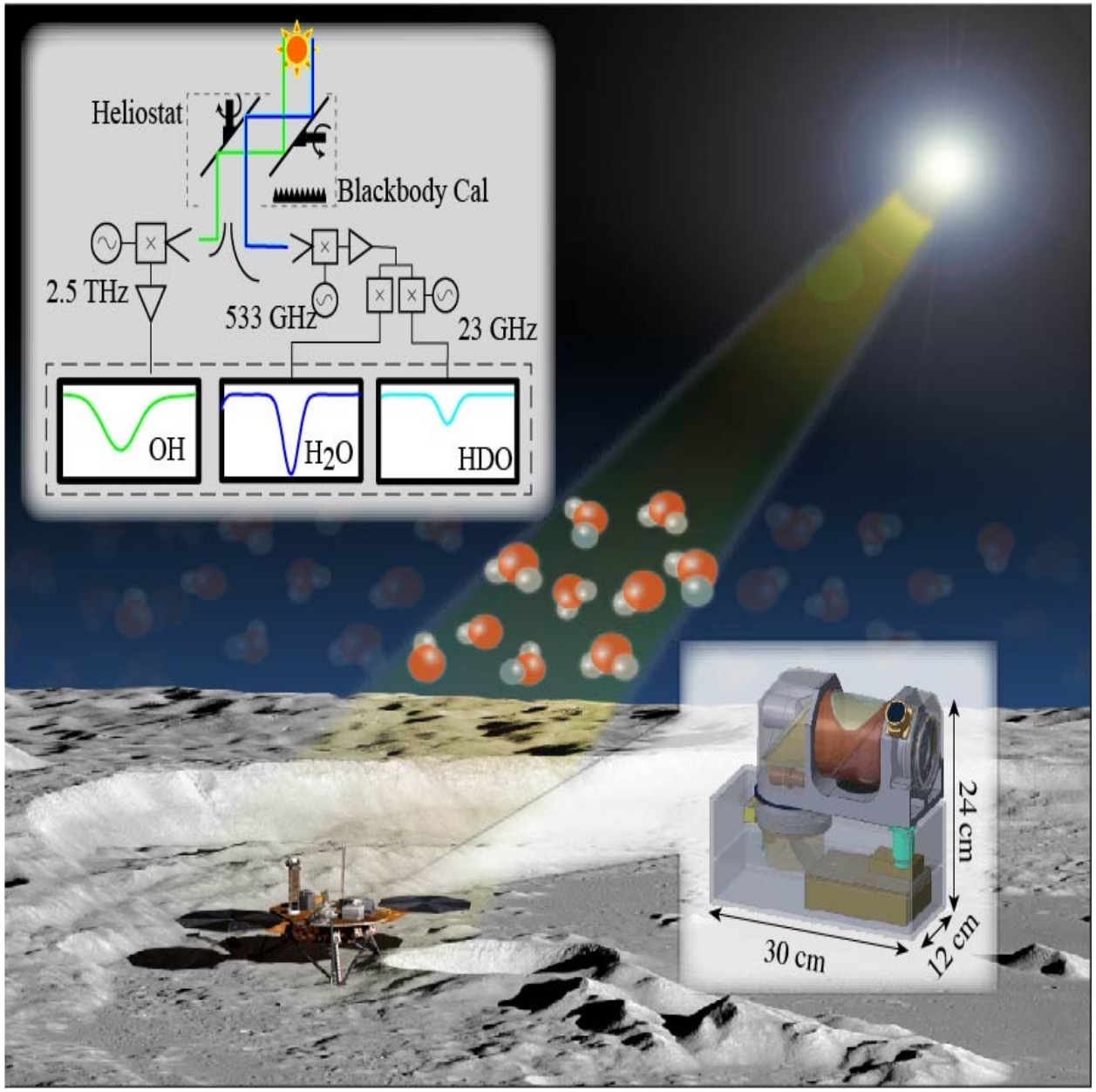


Solving the mystery of water in the Moon's exosphere.

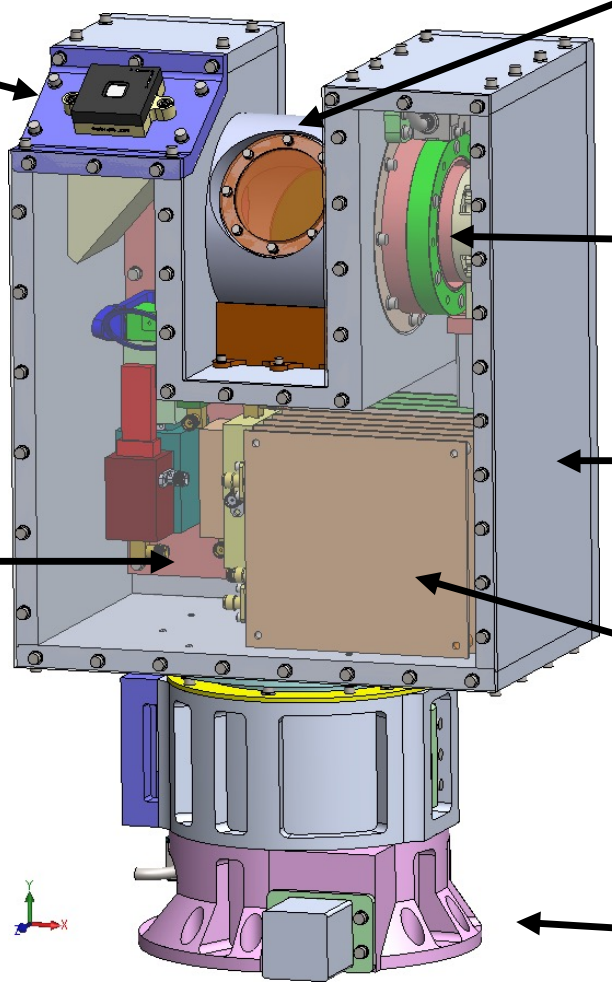
PI: Dr. Tim Livengood/University of Maryland

SSOLVE Science Measurements

- Measure spectral absorption of water species against Sun as backlight.
  - Absolute species ID
  - Additional physics from line shape, frequency
- Heliostat to track Sun, point to other targets
  - Calibrate internal water against calibration source.
  - Calibrate local water against neighboring surface.



SSOLVE Instrument Diagram



SSOLVE TRL Assessment

SSOLVE Technology Entry TRL and Exit TRL					
		Entry TRL		Exit TRL	
	Technology	TRL Description	TRL#	TRL Description	TRL#
1	550 GHz Receiver (B1-2) : extended temperature	• Laboratory measurements of comparable receiver • Operation spans 10-35°C	5	• Mixer & LO meet requirements over operational temperature range, 10 – 70 C, TRL – 5 • Thermal vacuum and vibration test	6
2	2.5 THz receiver (B3-4)	• Planar Schottky diode mixer, 1.25 THz Local Oscillator • LO multiplier chain	4	• NF and conversion loss test over 10 – 70 C – TRL5 • Thermal vacuum and vibration test	6
3	Blackbody target	• Absorbing tiles have good reflectivity from 500 GHz to over 1 THz	5	• Characterize reflectivity at SSOLVE frequencies • Used for calibrating integrated instrument	6
4	Heliostat Scan Assembly	• Design based on available spaceflight components	4	• Functional test and optics design validation • Thermal vacuum and vibration test	6
5	SSOLVE Instrument	• Laboratory testing of 2.5 THz and 550 GHz receivers	4	• Demonstration of integrated SSOLVE science measurement in relevant environment.	6

Technological Thrusts

- Antenna Technologies
  - Deployable apertures
  - Reflectarrays, active phased arrays
- Size, mass, power and cost (SWaP-C)
  - ASICs
  - Highly integrated receivers, MMICs
  - Advanced manufacturing (e.g. 3D printing, polystrata)
- Performance
  - Spectral coverage
  - Calibration
  - Smart Sensors

Thank You!