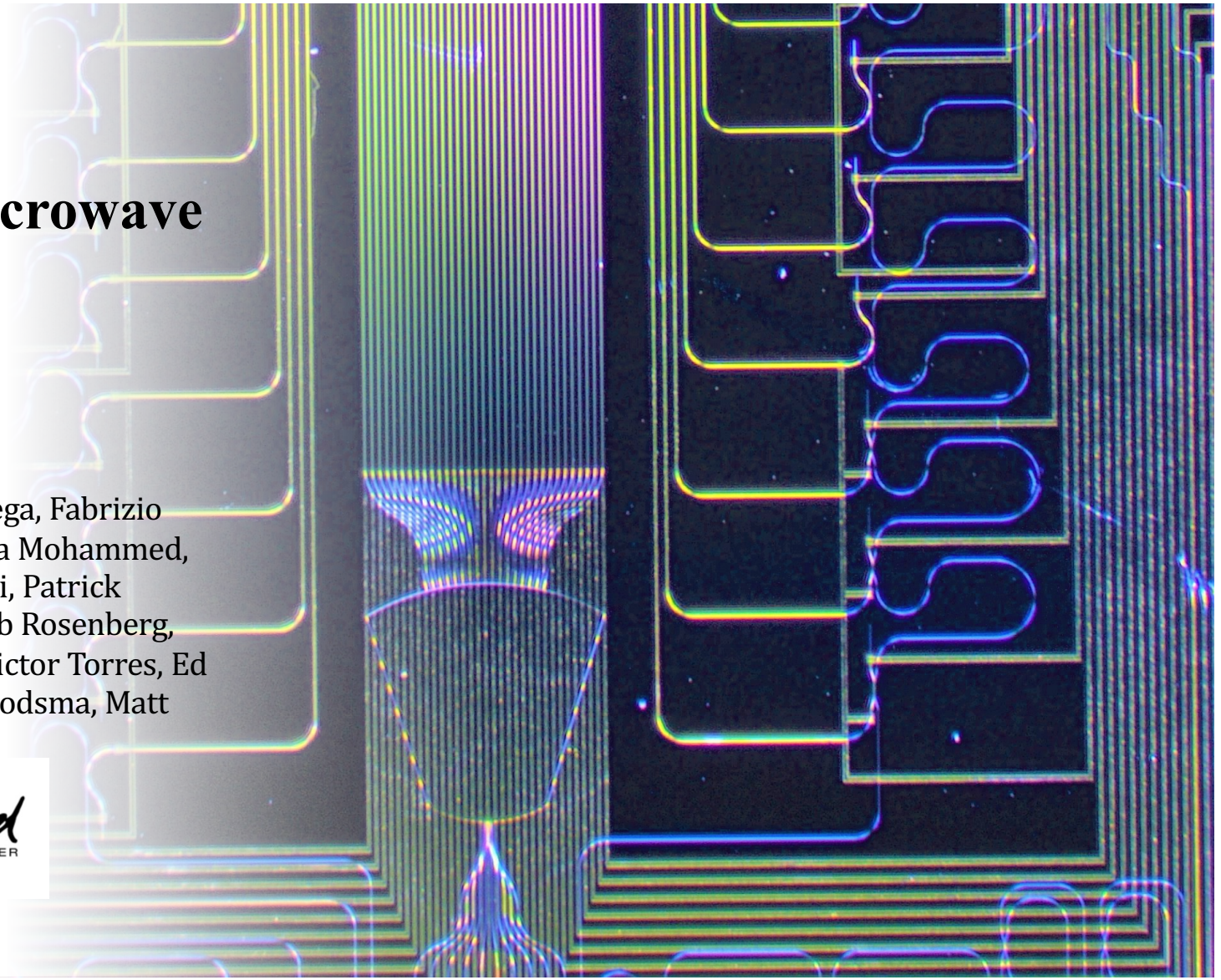
Advancements in Hyperspectral Microwave Sounding at NASA GSFC



Antonia Gambacorta, Manuel Vega, Fabrizio Gambini, Mark Stephen, Priscilla Mohammed, Alex Kotsakis, Narges Shahroudi, Patrick Stegmann, Stephen Nicholls, Bob Rosenberg, John Blaisdell, Roger Banting, Victor Torres, Ed Leong, Jared Lucey, Rachael Kroodsma, Matt Fritts and Jeff Piepmeier

NASA Goddard SPACE FLIGHT CENTER

Acknowledgements

- NASA 2021: "*Photonic Integrated Circuits (PICs) in Space: The Hyperspectral Microwave Photonic Instrument (HyMPI)*"
- https://esto.nasa.gov/project-selections-for-iip-21/#Gambacorta

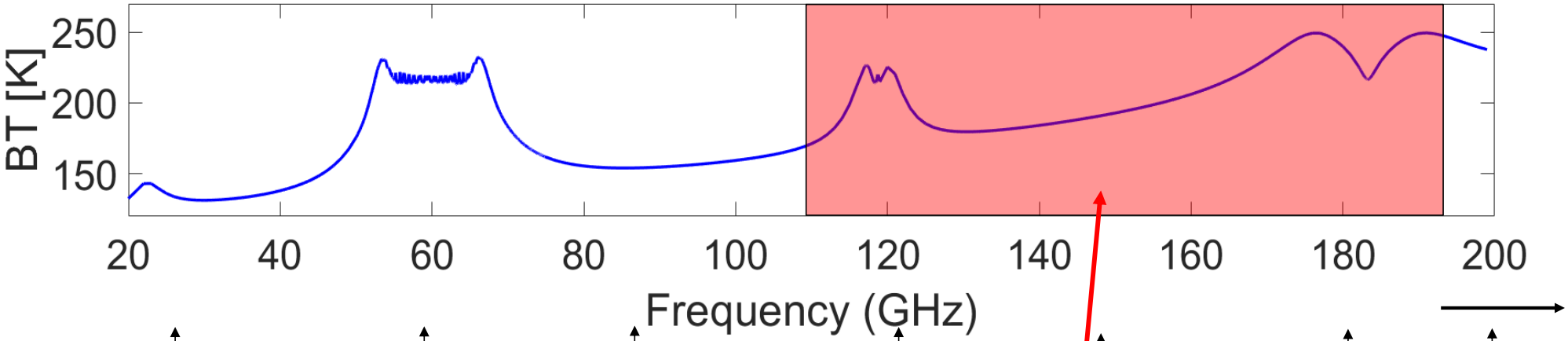
- NASA 2021*: "Hyperspectral Capability for the Conical Scanning Millimeter-wave Imaging Radiometer (CoSMIR): Enhancing Capability for Future PBL Suborbital Campaigns and Enabling PBL Science from Space*
- https://esto.nasa.gov/project-selections-for-dsi-21/#Kroodsma

- NOAA 2022: *"Developing the NOAA Next Generation Hyperspectral Microwave Sensor (HyMS): Instrument Concept and Demonstration of Benefits for the NOAA Mission"*
- https://www.nesdis.noaa.gov/news/noaa-awards-joint-venture-program-broad-agency-announcements

- NASA & NOAA 2024: *The Westcoast & Heartland Hyperspectral Microwave Sensor Intensive Experiment (WH²yMSIE) https://earth.gsfc.nasa.gov/climate/campaigns/WHyMSIE*

- **NASA 2024: "*The Advanced Ultra-High Resolution Optical and RAdiofrequency (AURORA) Pathfinder*"** -

Enabling Improved Science through Hyperspectral Microwave Measurements



Total Precipitable Water
Total Cloud Liquid Water
Light Precipitation
Surface Temperature
Surface Emissivity
Surface Wind Vector
Sea Ice Concentration
Snow Depth
Snow Water Equivalent
Bare Surface Soil Moisture

Vert. Temperature

Surf. Emissivity Precipitation

Vert. T

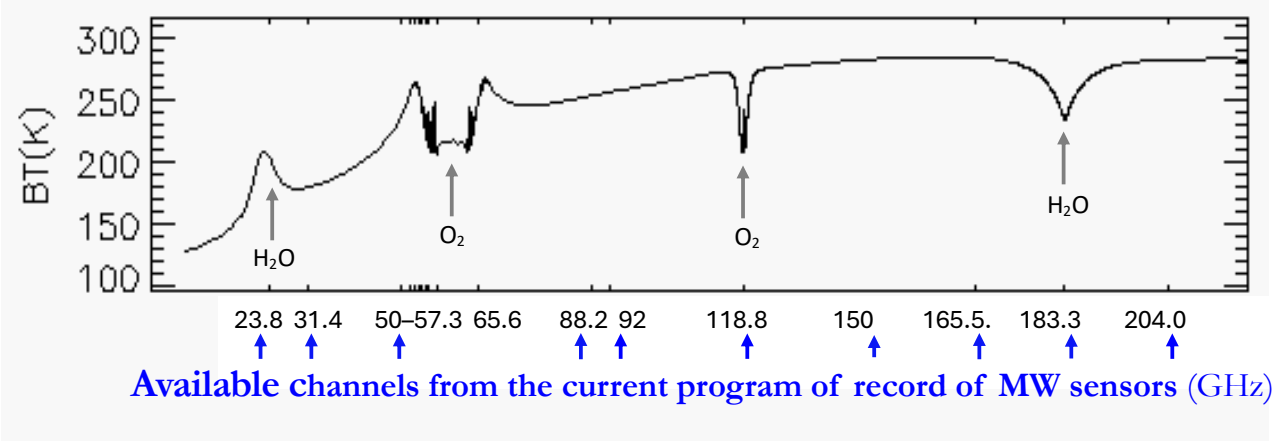
Surf. Emissivity PBL T/q structure

Vert. Water Vapor

Ice Clouds

Advanced Ultra-High Resolution Optical Radiofrequency (AURORA) Pathfinder

Photonic Integrated Circuits:
Extending the MW Program of Record into the Hyperspectral Era



MSU
4 chns
1978

AMSU A/B & MHS
20 chns
1998

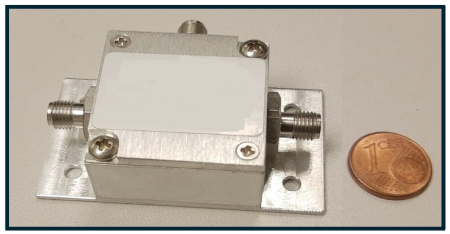
ATMS
22 chns
2011

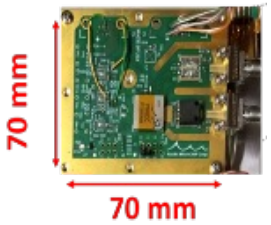
TROPICS
12 chns
2021

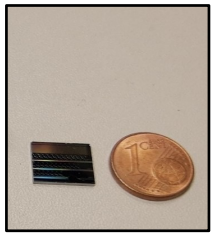
CoSMIR-H
~6000 chns
2024

AURORA Pathfinder
xx,000 chns
~2030s

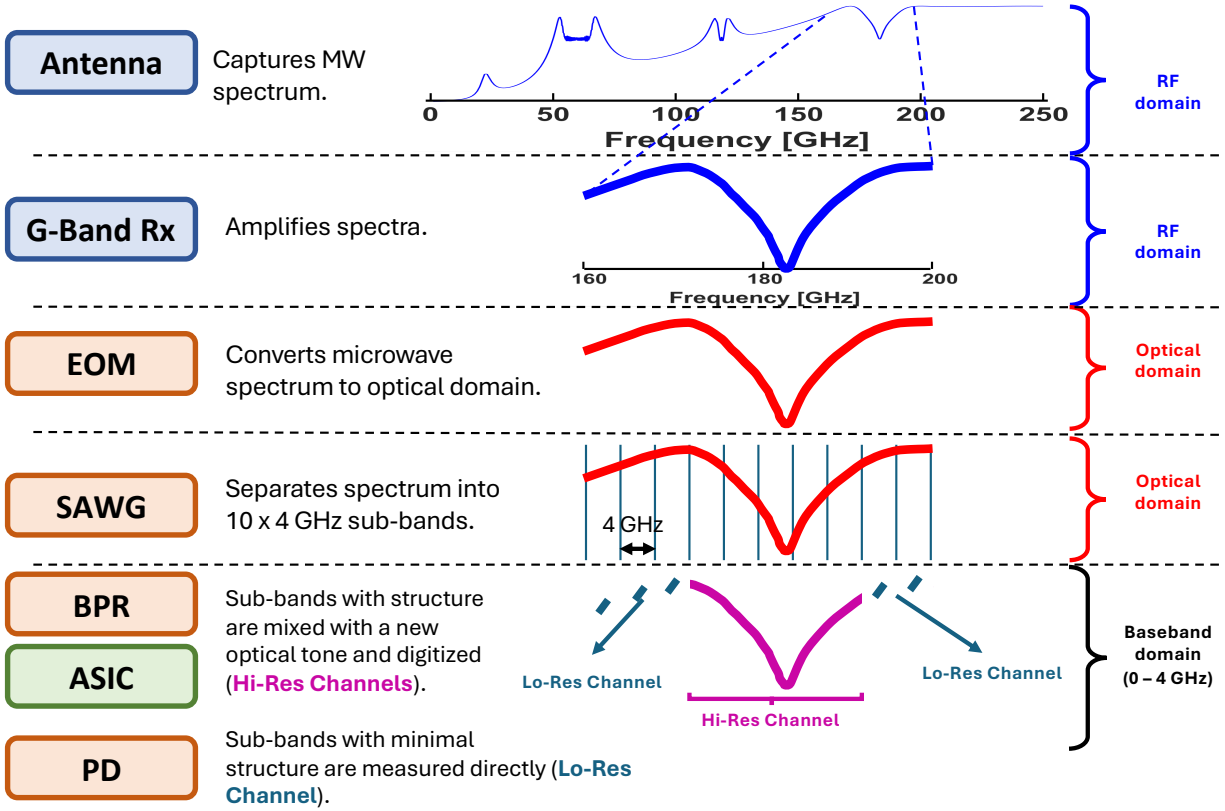
RF Splitter







Hyperspectral Microwave Photonic Instrument (HyMPI)

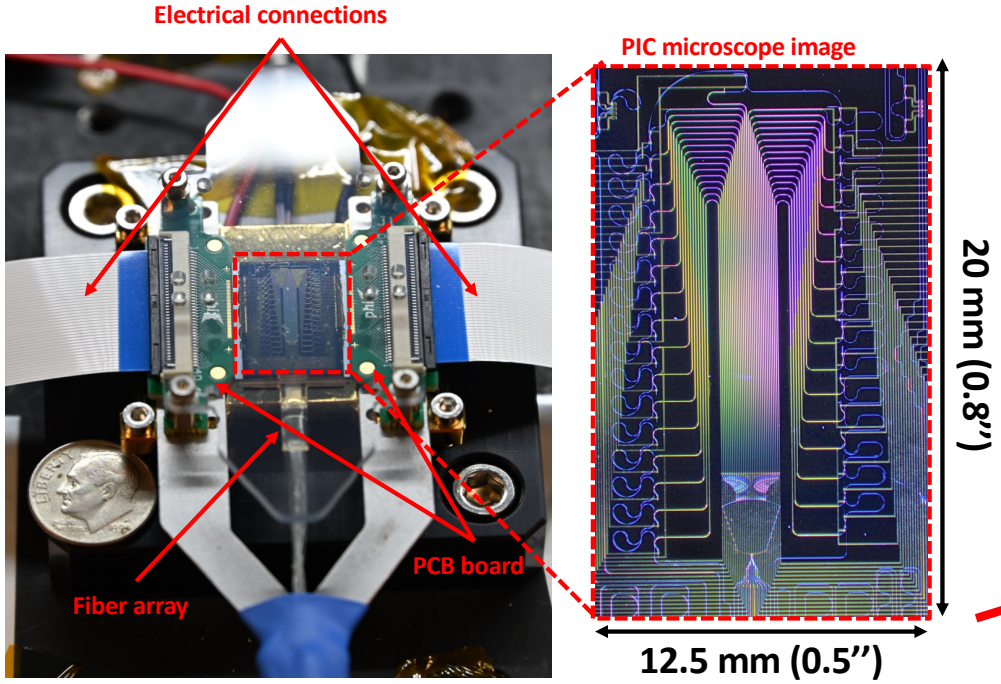


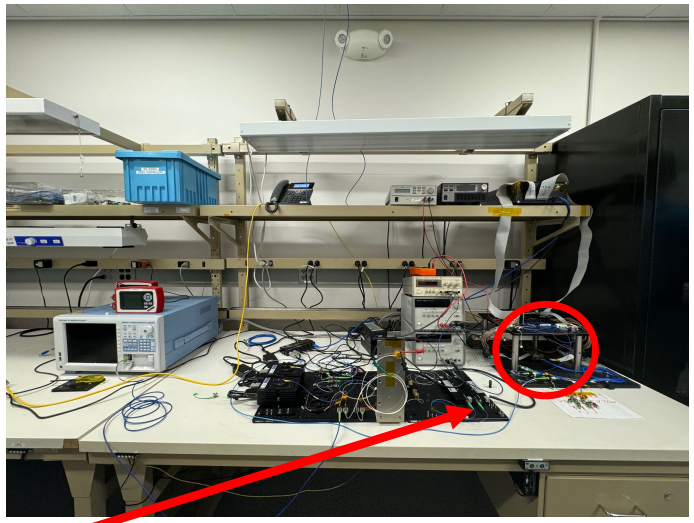
- HyMPI covers is a modular design, with simultaneous 40 GHz coverage
- Can be applied to multiple parts of the spectrum to obtain full coverage of the MW thermal domain
- Paired with ASICs - "PICASIC" – it enables full, contiguous, hyperspectral resolution coverage: **a sounder + imager in one instrument**

Gambini et al., 2024, https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=10380670

Gambacorta et al., 2022; https://ieeexplore.ieee.org/document/9883151/citations?tabFilter=papers#citations

Serial Arrayed Waveguide Grating - SAWG





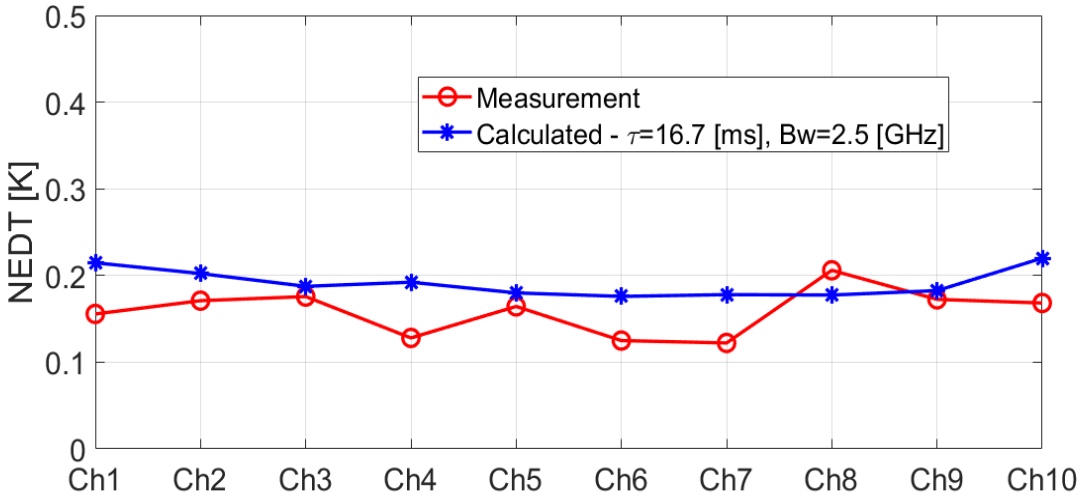
NASA GSFC, Bldg.33 Room F321

US Patent 11852864
Title: "Serial Arrayed Waveguide Grating"

Gambini et al., 2024, https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=10380670, doi: 10.1109/JLT.2024.3349932

Results from the Hyperspectral Microwave Photonic Instrument (HyMPI) Project

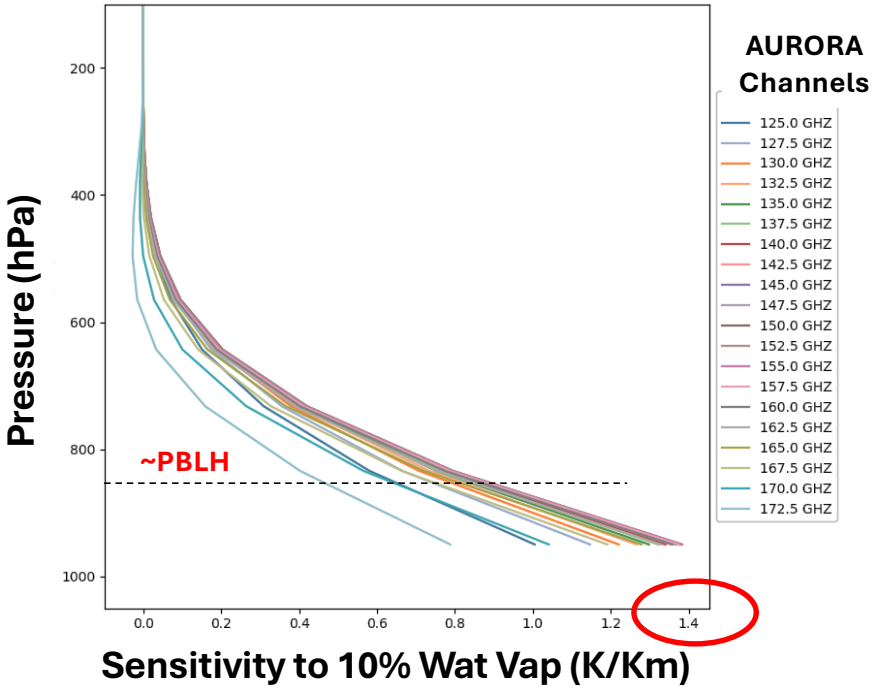
(https://esto.nasa.gov/project-selections-for-iip-21/#Gambacorta)

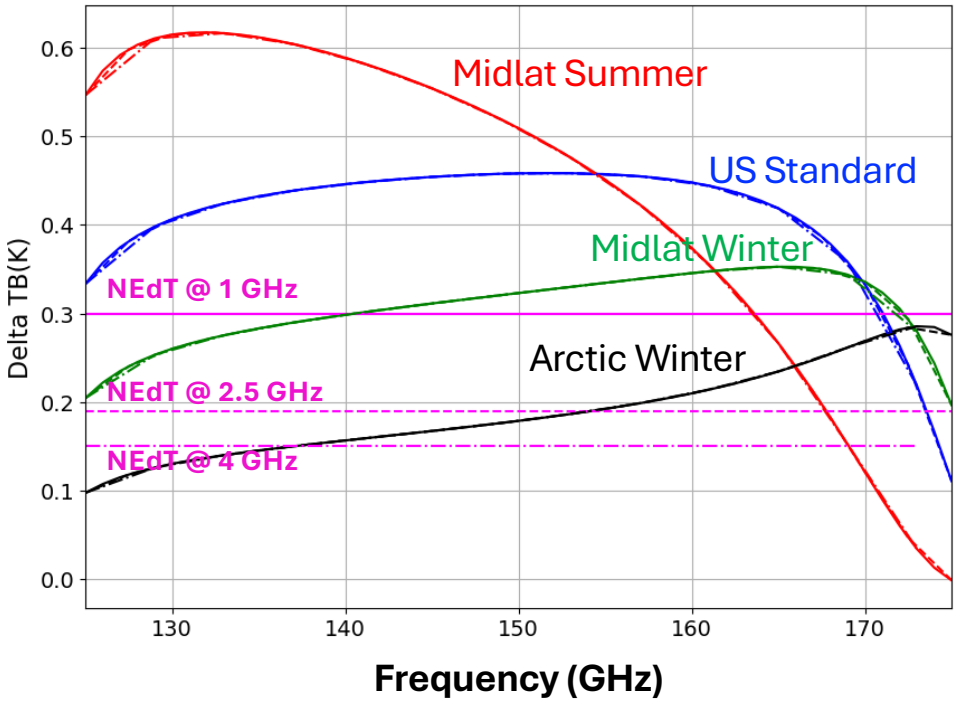


Channel separation: **4 GHz**
Channel bandwidth: **2.5 GHz**
Integration Time: **16.7 ms**

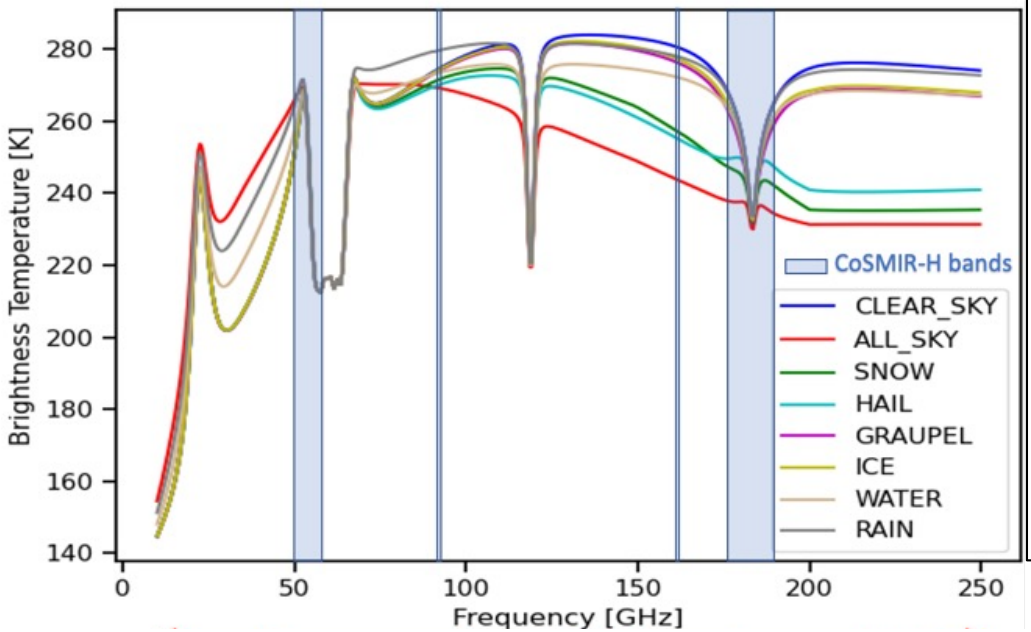
- NeDT Lab measurements are within specifications
- The Integrated Photonic module adds negligible noise to the existing front-end, enabling PBL science quality data
- Ref.: Gambini et al., DOI: 10.1109/JLT.2024.3349932; V. Torres et al., in submission, 2025.

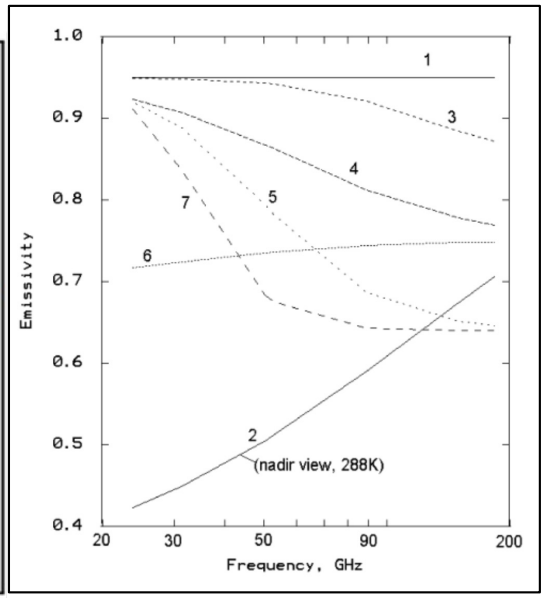
Groundbreaking PBL science requires high performing technology:
high spectral resolution, broadband coverage, **low instrument noise**.





Low instrument noise will enable measuring unexplored cloud and surface information in the MW "window" regions

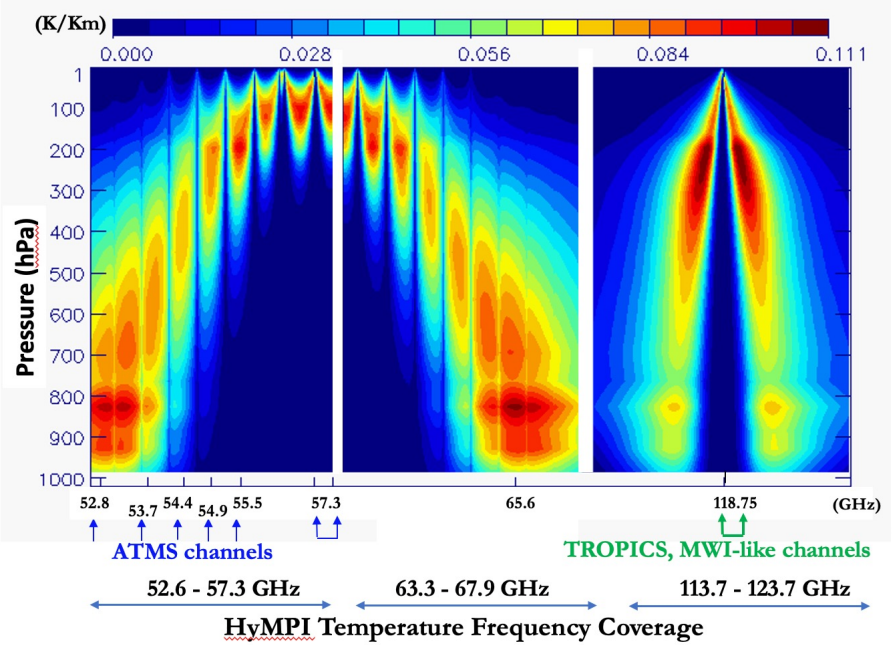




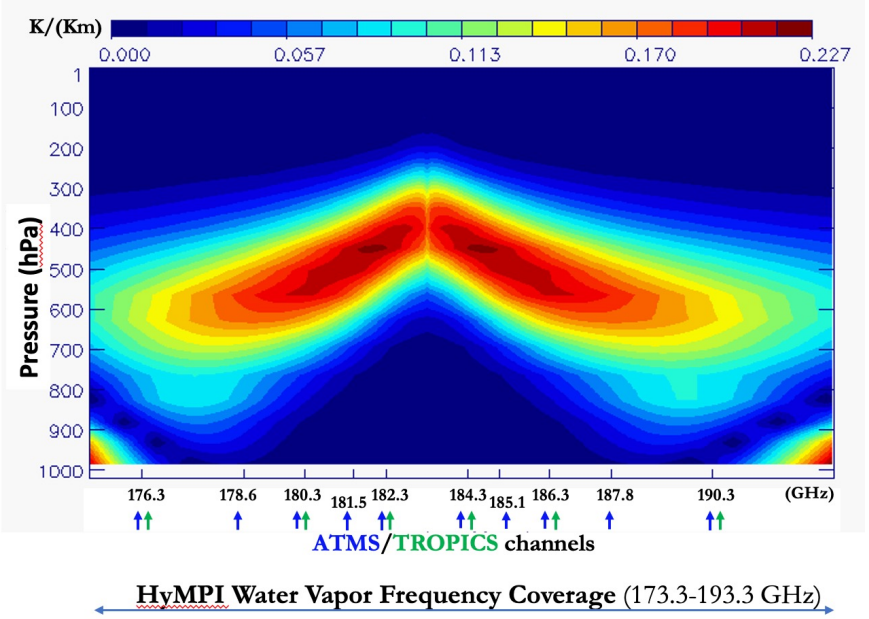
Type	Surface
0	coastline[a]
1	land
2	water[a]
3	high-emissivity sea ice
4	low-emissivity sea ice
5	snow (high-frequency scattering)
6	glacier/snow (very low frequency scattering)
7	snow (low-frequency scattering)

Filling The Gap in Information Content Left by the Program of Record

Temperature Sensitivity Functions

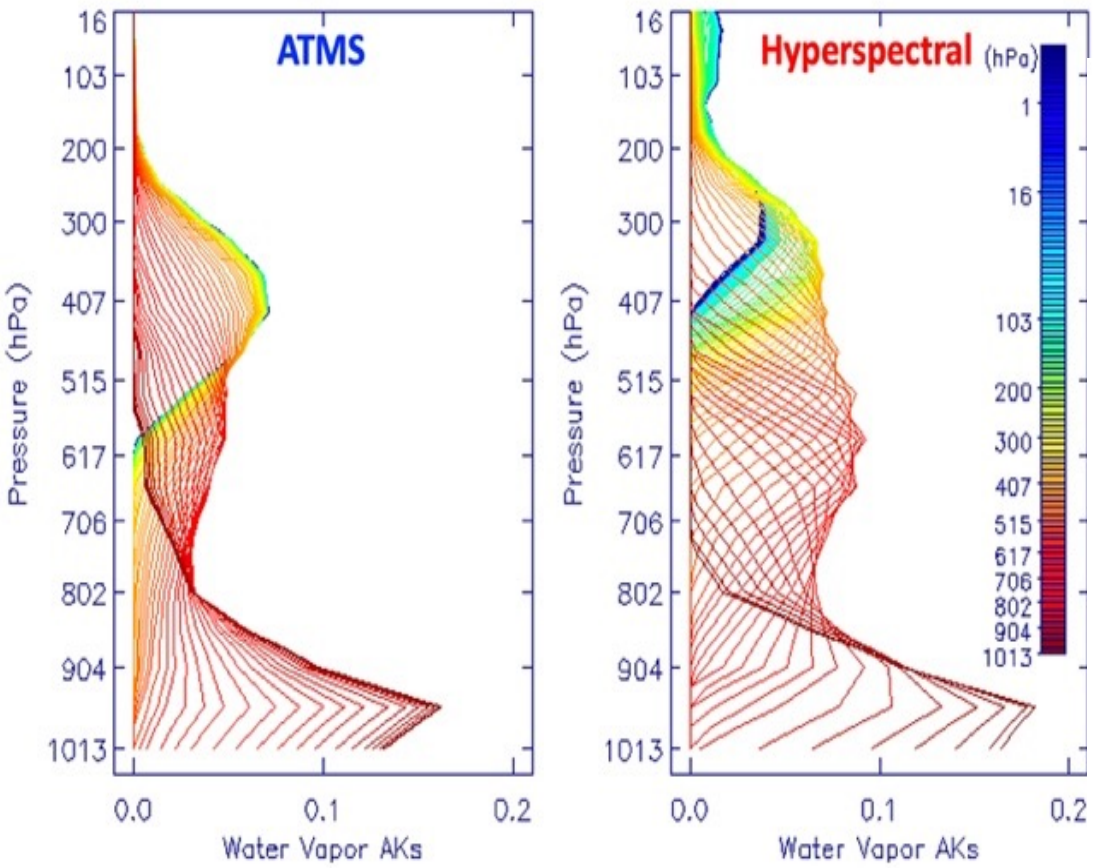


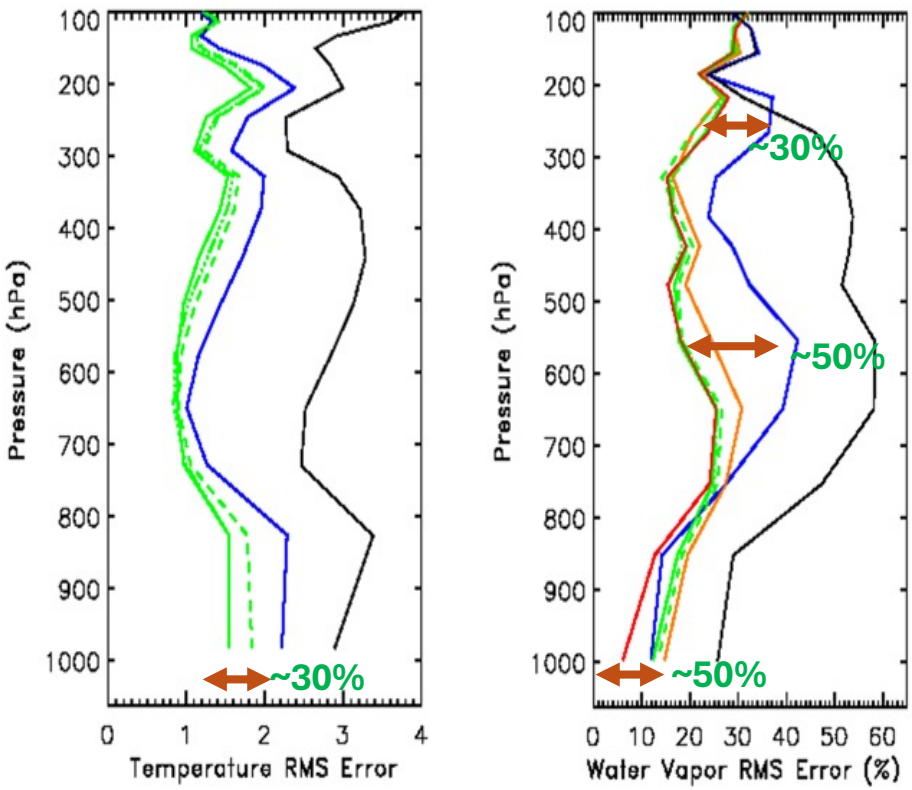
Water Vapor Sensitivity Functions



Gambacorta et al., 2023, doi: 10.1109/JSTARS.2023.3269697,
https://ieeexplore.ieee.org/abstract/document/10107761

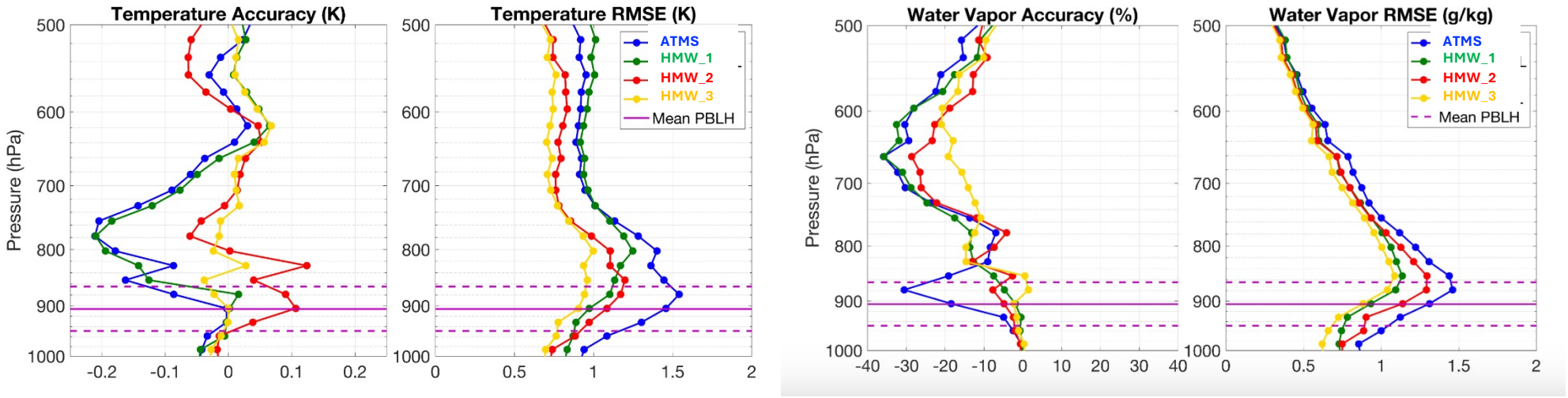
Impact on Product performance – Clear Sky





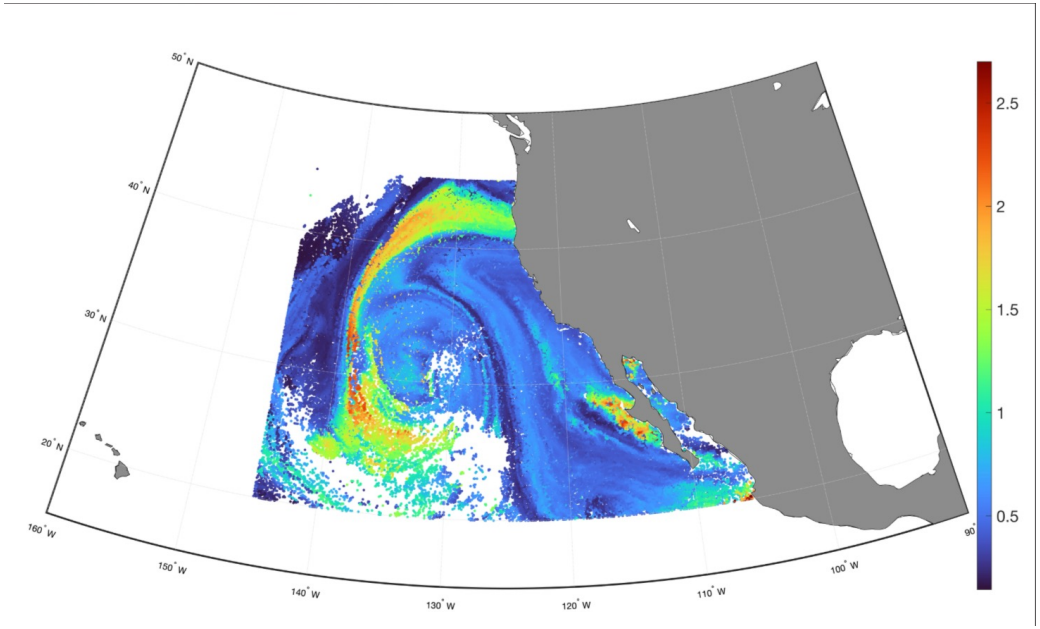
First guess; ATMS; 183 GHz band; 50 – 58 GHz band (dash); 58-63 GHz (dash-dot) 118GHz (solid); 22 surface/PBL channels

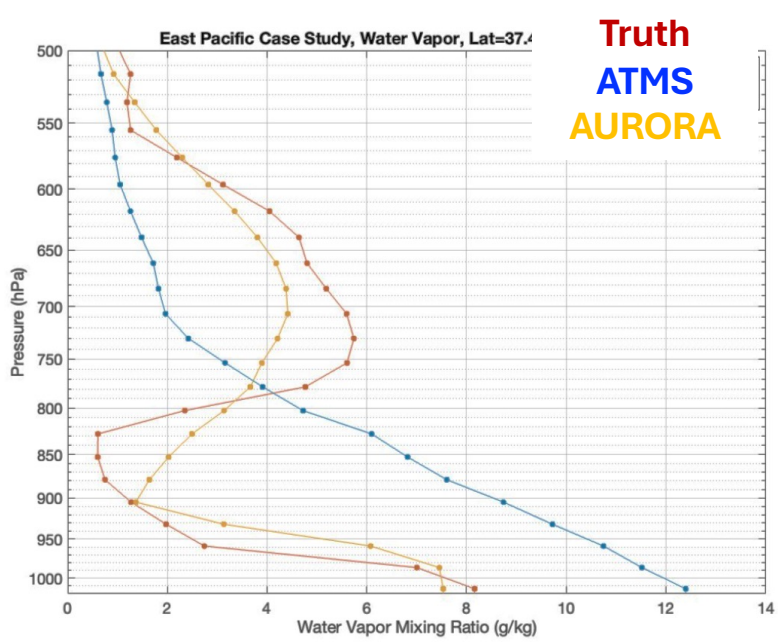
Impact on Product performance – Cloudy Case



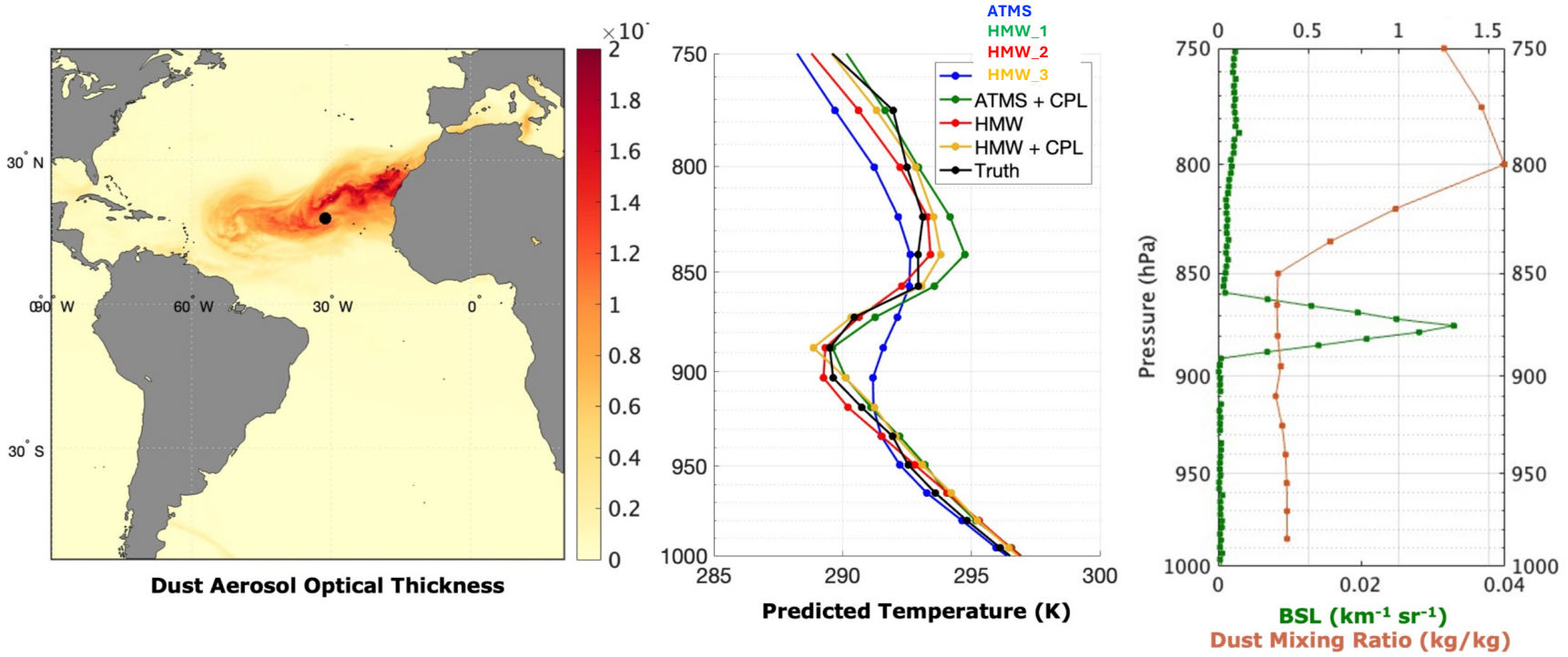
AURORA Pathfinder will enable significant improvements in temperature and water vapor performance
Under all-sky regimes

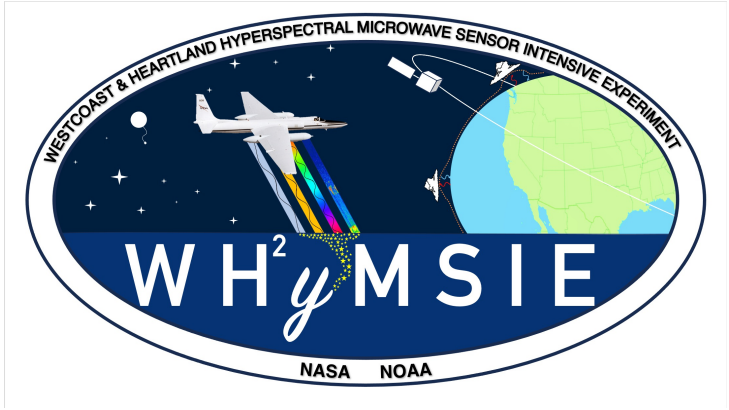
Applications: AURORA Pathfinder will enable dissecting the atmosphere under extreme weather events to protect lives, livelihoods and the economy

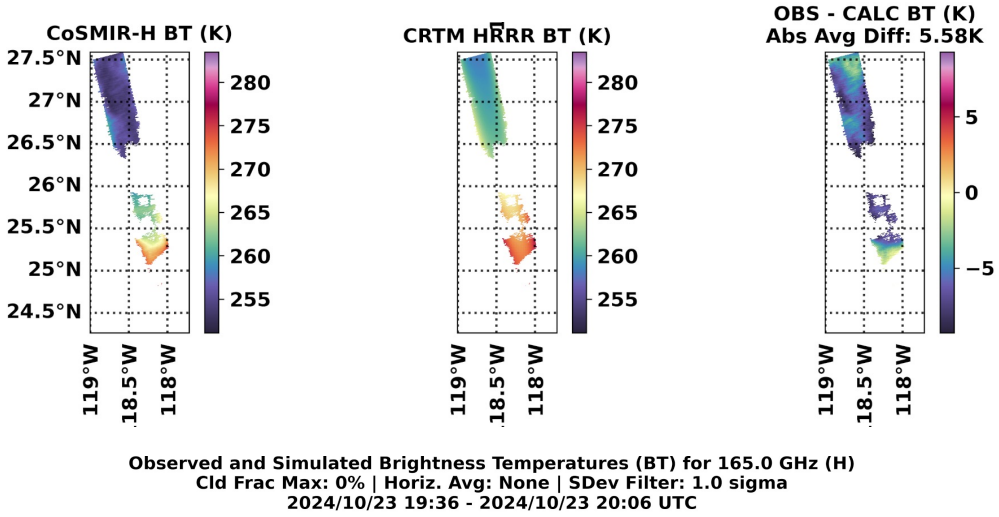




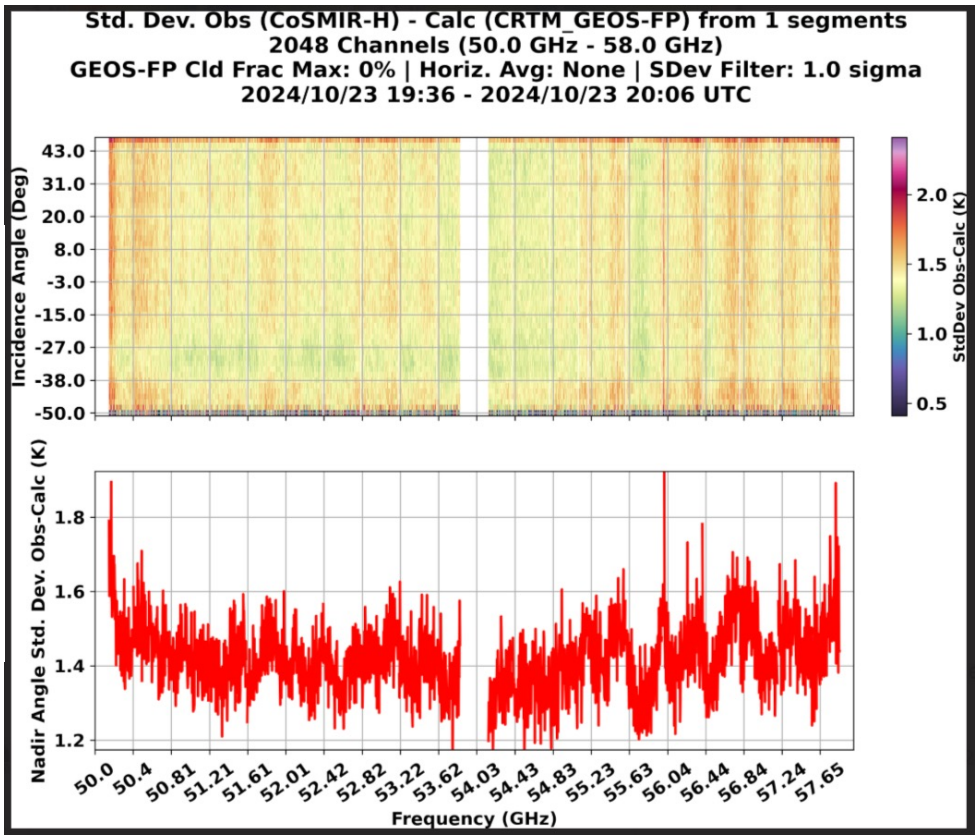
Applications: AURORA Pathfinder will enable new discoveries in atmospheric processes linking temperature, water vapor, aerosol and clouds







Observed and Simulated Brightness Temperatures (BT) for 165.0 GHz (H)
Cld Frac Max: 0% | Horiz. Avg: None | SDev Filter: 1.0 sigma
2024/10/23 19:36 - 2024/10/23 20:06 UTC



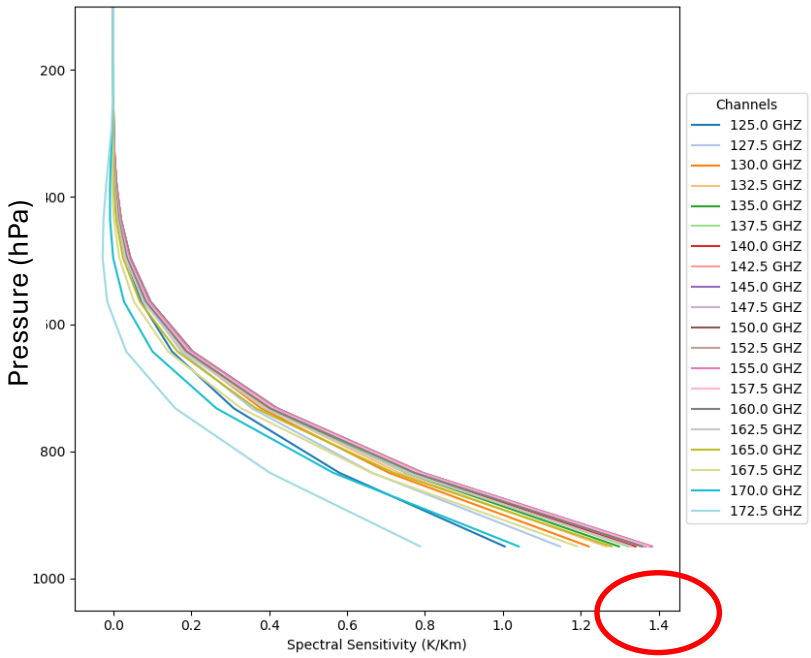
WH2yMSIE offers an opportunity to cross-compare CoSMIR-H with co-registered ATMS, AWS, AMSU

https://earth.gsfc.nasa.gov/climate/campaigns/WHyMSIE

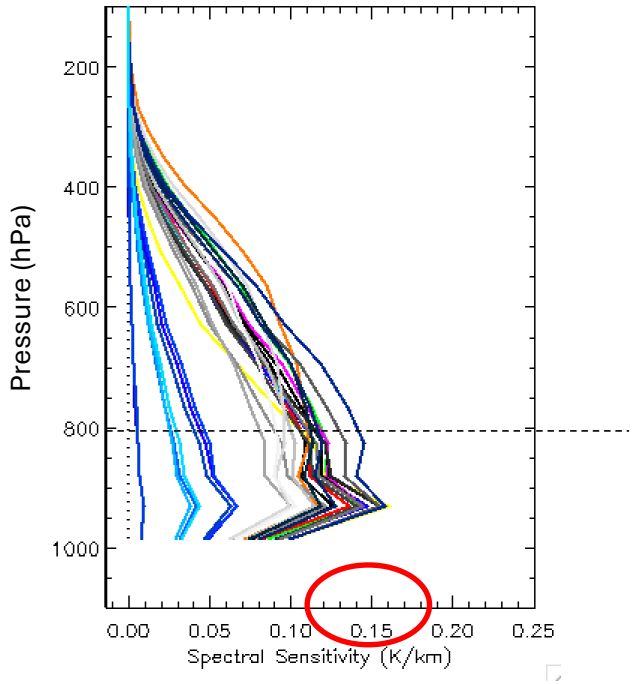
Back up slides

Harnessing New PBL Information Content In Unexplored HMW Domain

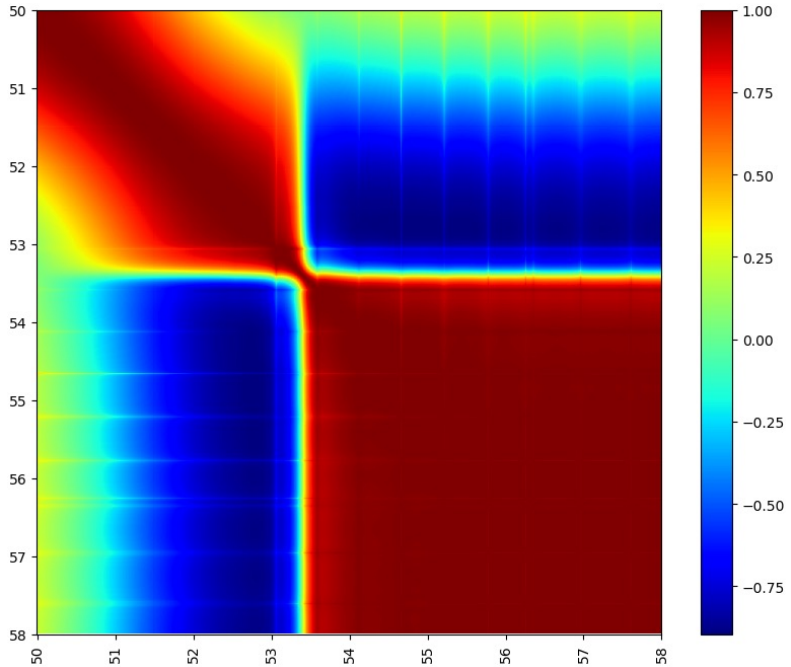
PBL Water Vapor AURORA Channels



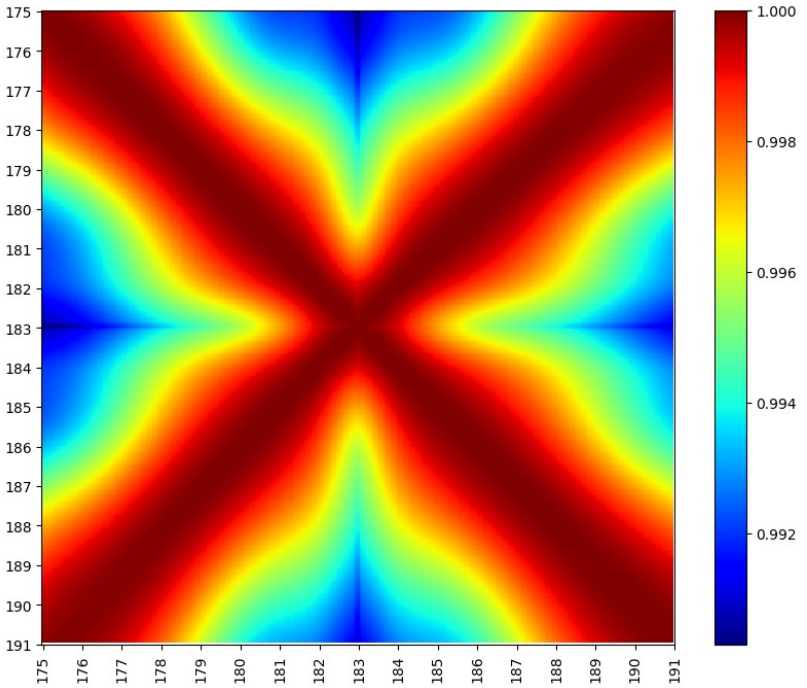
PBL Water vapor Infrared Channels (AIRS v6 & v7)



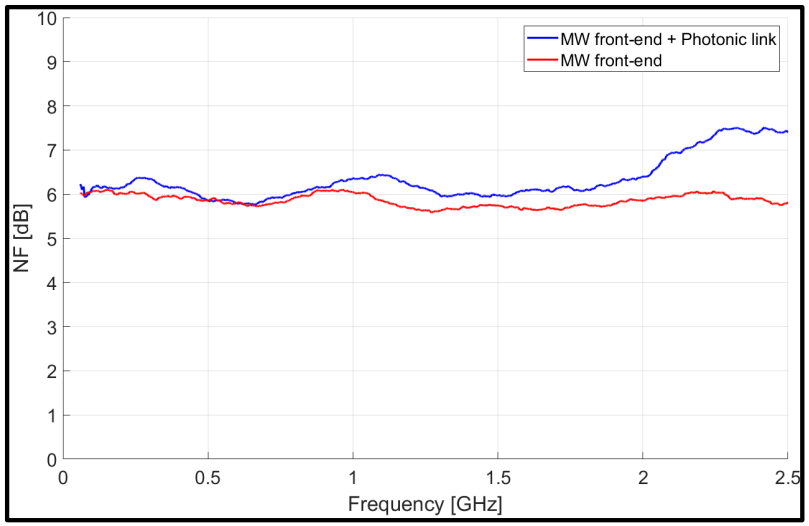
50-58 GHz band



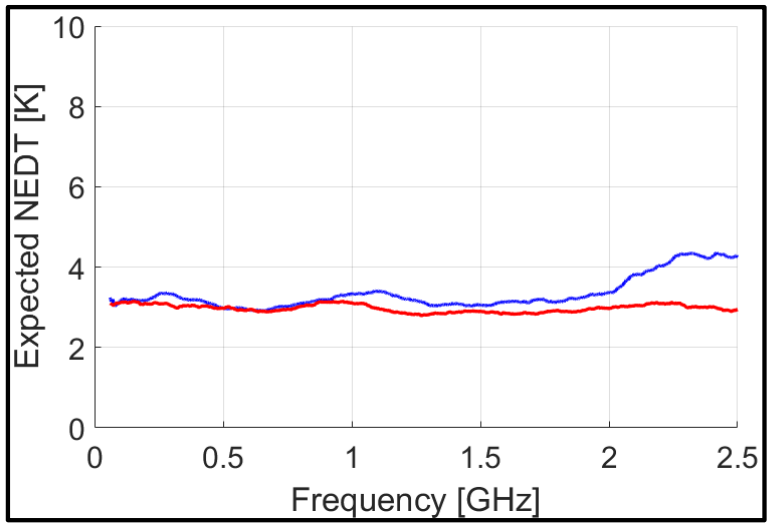
175-191 band



Instrument Noise Lab Measurements: Base-band down-converted channel noise



Measured Noise Figure (NF)



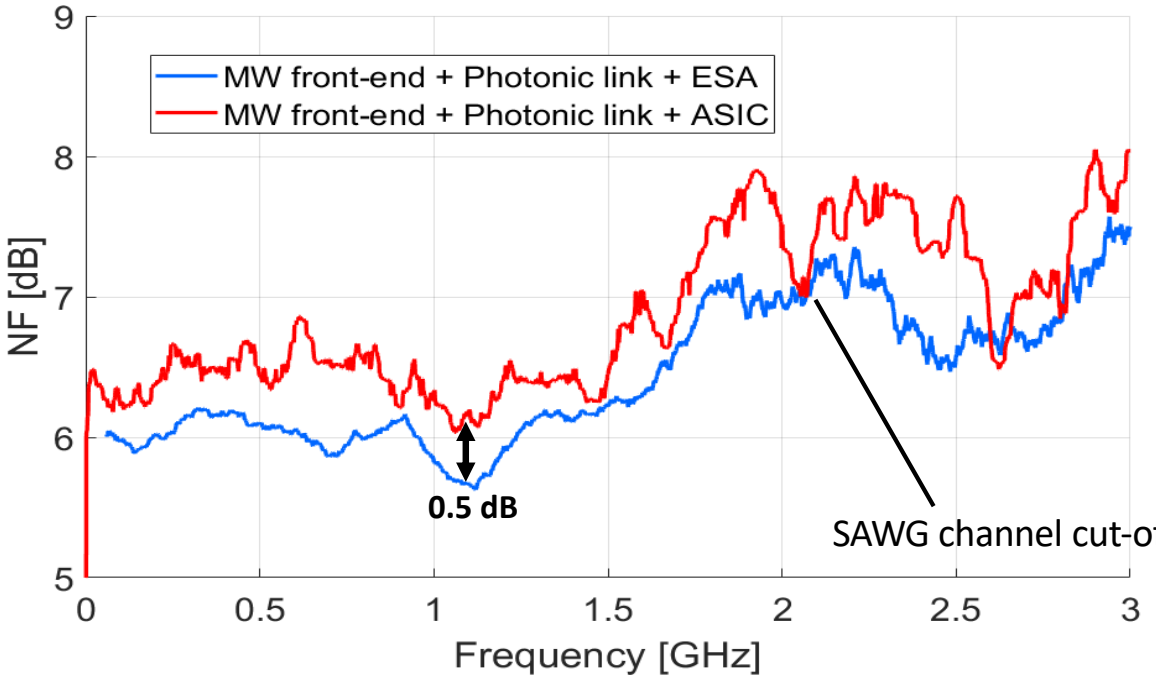
Predicted Noise Equivalent Differential Temperature (NeDT)

Spectral Resolution: **8MHz**
Integration Time: **18msec**

The Photonic link adds marginal noise to the existing front-end noise, enabling science quality data

V. Torres et al., in submission, 2025

Instrument Noise Lab Measurements:
Base-band down-converted channel noise – Full 40GHz band



Spectral Resolution: **8MHz**
Integration Time: **18msec**

The Photonic link + the ESA/ASIC add marginal noise to the existing front-end noise, enabling science quality data. Measurement has been extended across the full band.

V. Torres et al., in submission, 2025