

The Hyperspectral Microwave Photonic Instrument (HyMPI): Technology Developments for Improved Planetary Boundary Layer Sounding

Victor Torres^{1,2}, Fabrizio Gambini^{1,2,3}, David Robles¹, Edward Leong¹, Priscilla Mohammed^{1,4}, Michael Coon¹, Jeffrey Piepmeier¹, Mark Stephen¹, Antonia Gambacorta¹, Gary Carter²

¹NASA Goddard Space Flight Center, ²Univ. of Maryland Baltimore County, ³CRESST II, ⁴Morgan State Univ.



Internal Research and Development (IRAD)



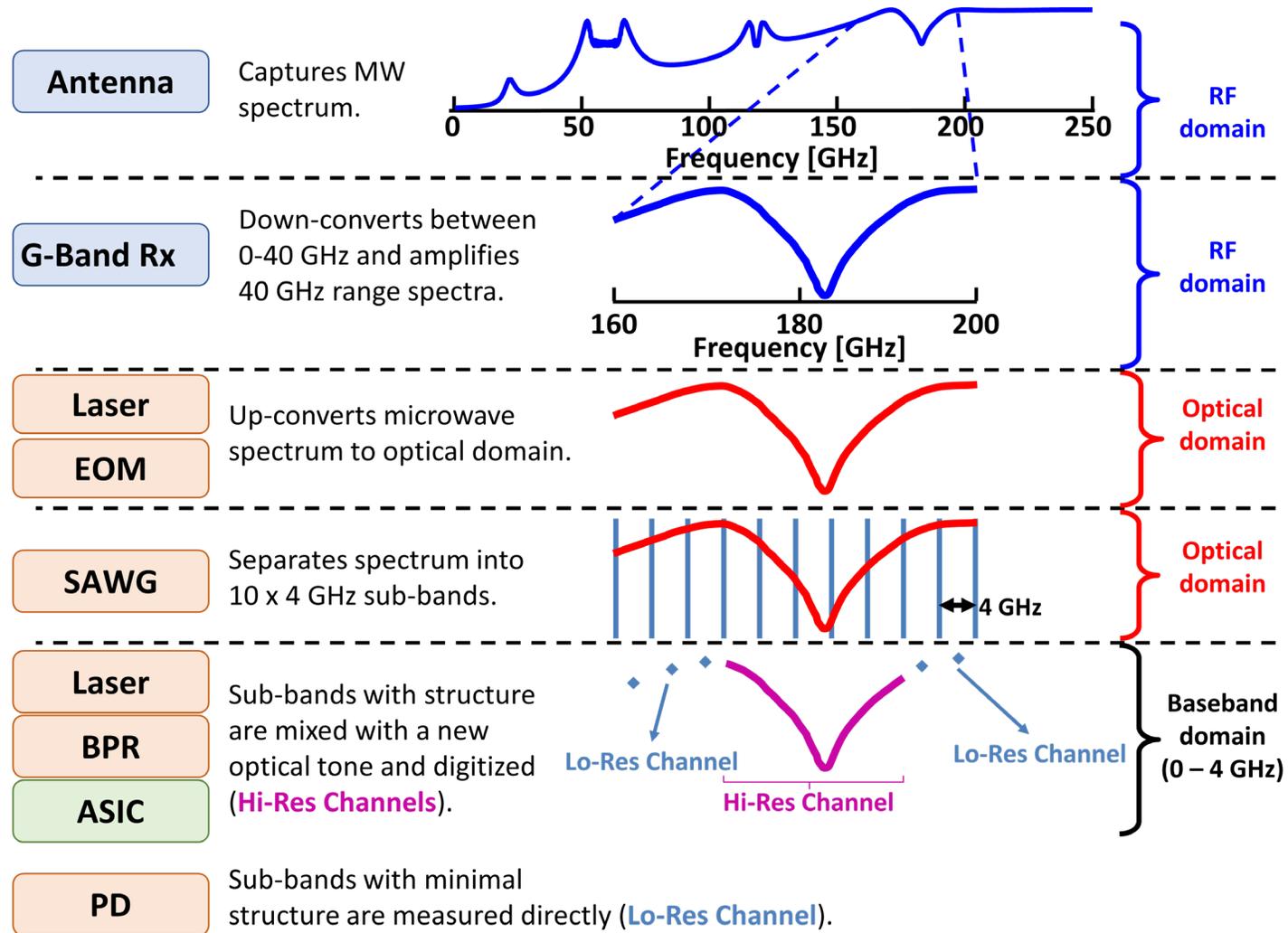
Motivation

This work presents an overview of the Hyperspectral Microwave Photonic Instrument (HyMPI) which aims at developing the very first hyperspectral microwave sensor to augment thermodynamic sounding capability from space, with a focus on the Earth's Planetary Boundary Layer.

Overview

- The instrument is based on photonic integrated circuits (PIC) – minimize size, weight and power consumption and cost (SWaP-C)
- HyMPI is a modular design, with simultaneous 40 GHz coverage
- It can be applied to multiple parts of the spectrum to obtain full coverage of the MW thermal domain
- PICs + ASICs = “PICASIC”: full, contiguous, hyperspectral resolution (thousands of channels) ultra-wideband coverage

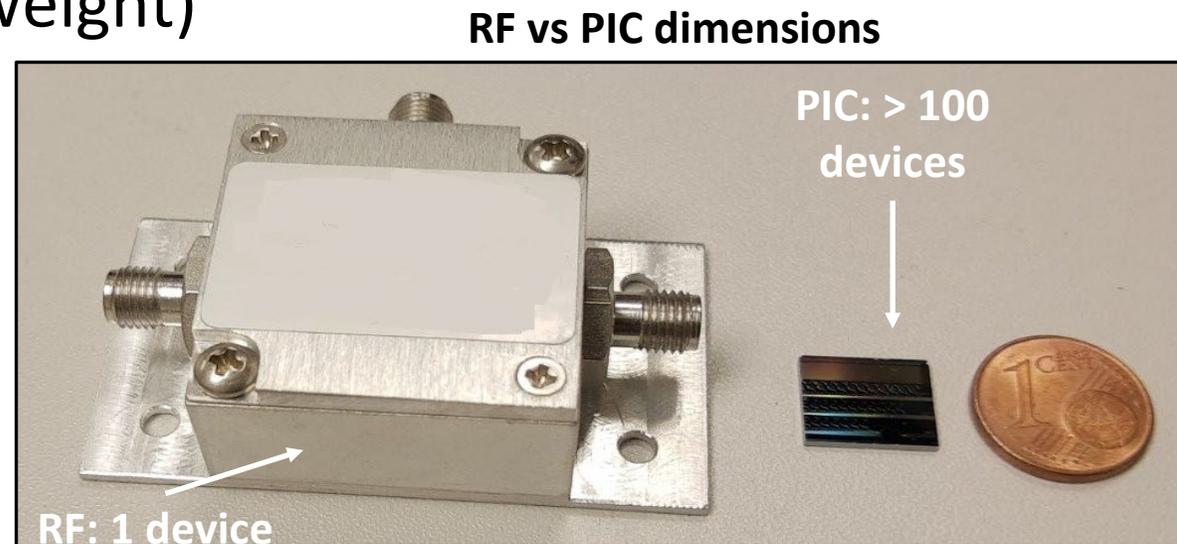
System concept



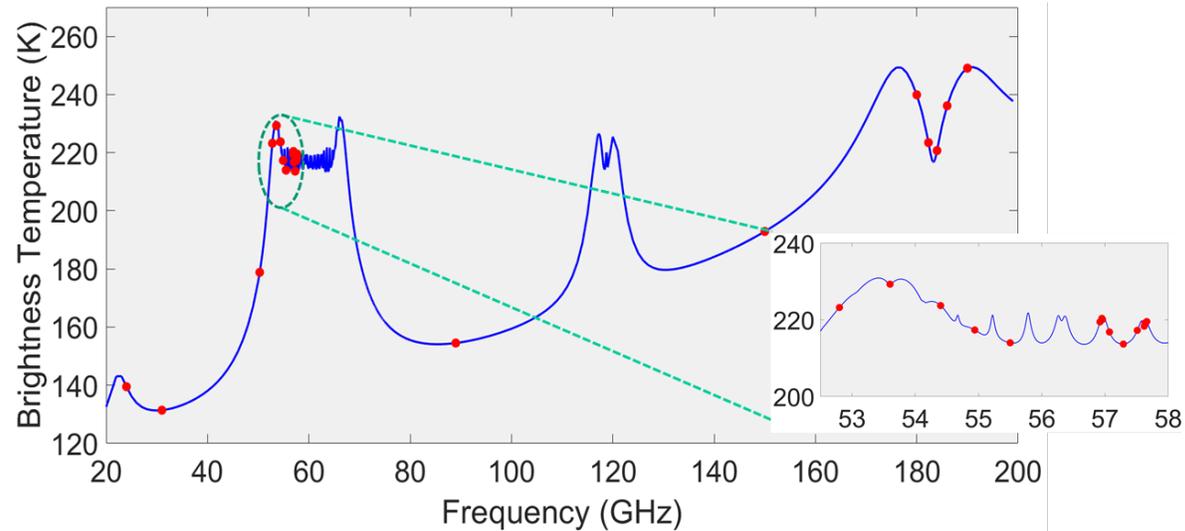
Rx: receiver - EOM: electro-optical modulator - SAWG: serial arrayed waveguide grating - BPR: balanced photoreceiver - ASIC: application specific integrated circuit - PD: photodiode

Integrated Photonics

- Integrated photonics: emerging branch of photonics in which waveguides and devices are fabricated as an integrated structure onto the surface of a flat substrate
 - The carrier of the signals are photons (not electrons)
- Properties of photonic integrated circuits (PIC):
 - Ultra compact devices (low size/weight)
 - Low power consumption
 - Process ultra-high bandwidth
 - Tunable channels
 - Reduced cost with integration
 - CMOS compatible

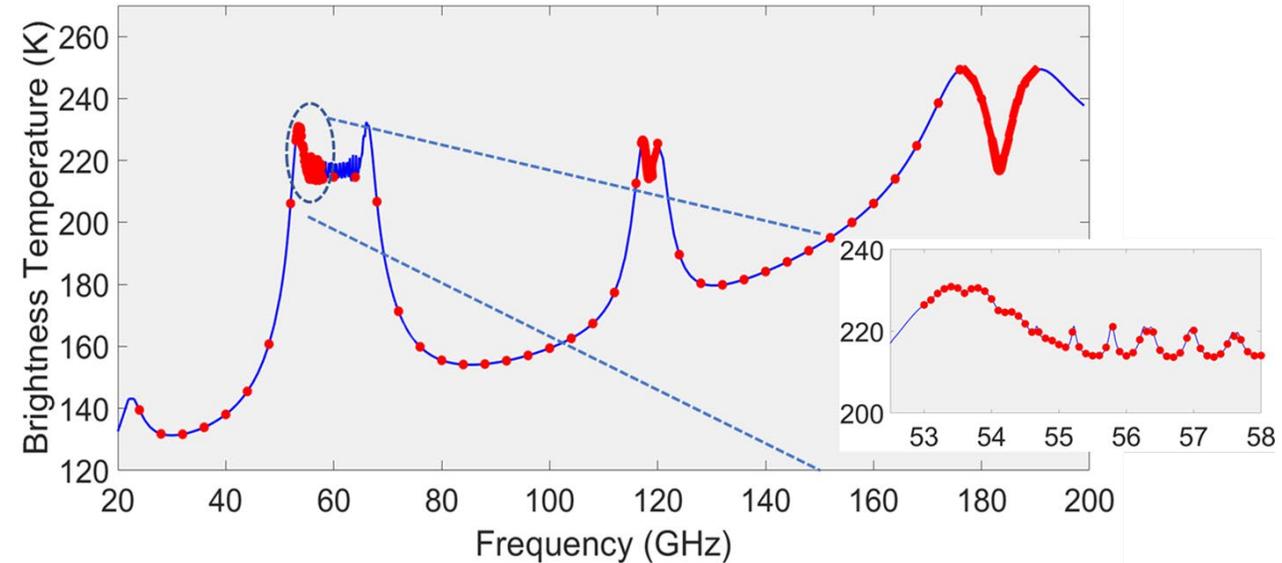


Integrated Photonics and Remote Sensing



ATMS:

- ~20 sparse channels (not contiguous spectrum)
- Missing critical information
- High footprint and power consumption

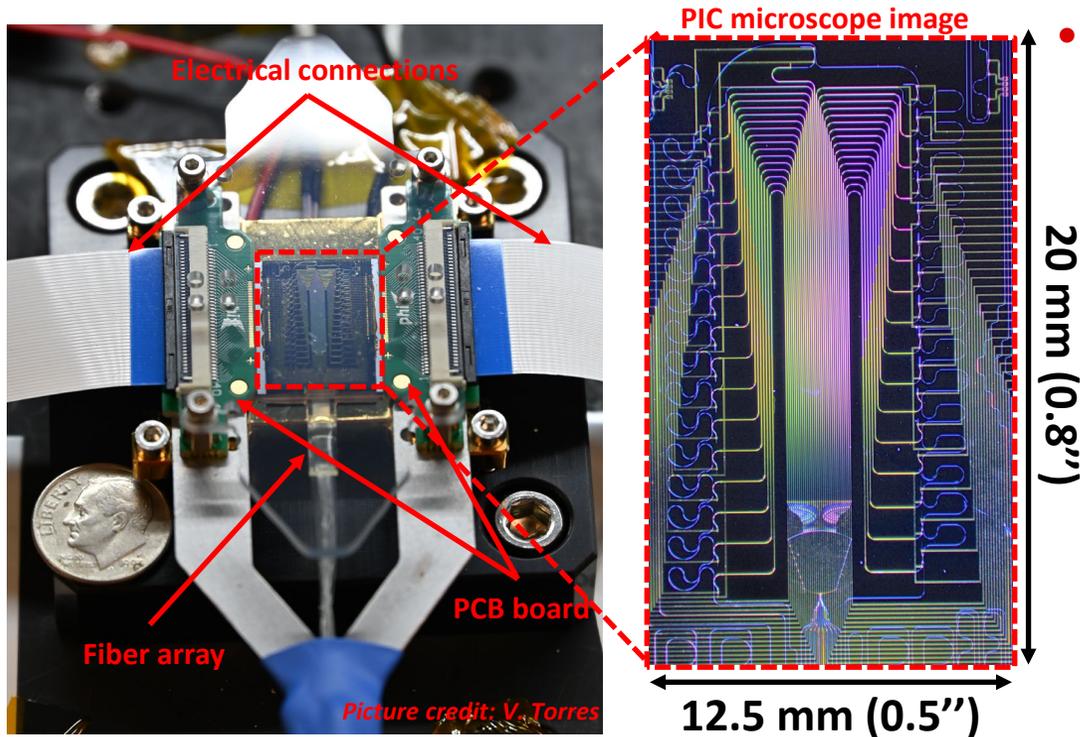


PIC enabled hyperspectral MW technology:

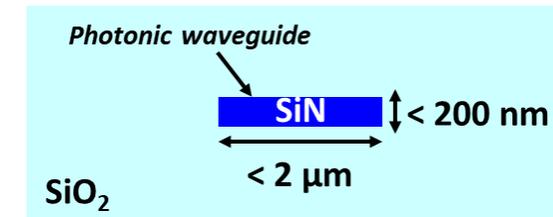
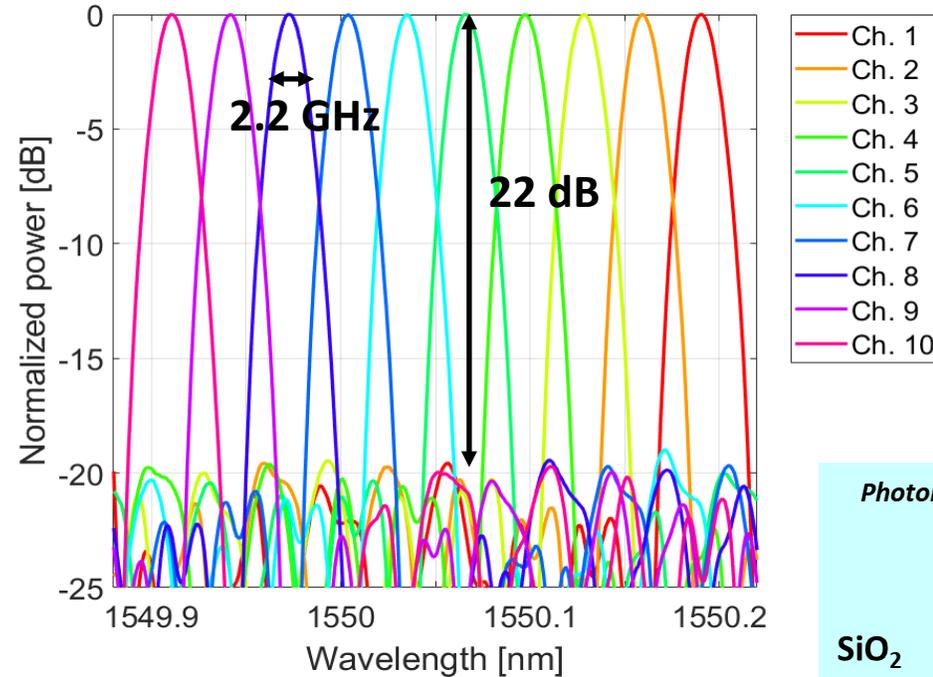
- Contiguous spectrum coverage
- Hyperspectral resolution: 10 MHz (or lower) with support of Application Specific Integrated Circuits (ASIC)
- Cubesat volume

Photonic integrated channelizer

- The core of HyMPI is an ultra-compact, narrow-bandwidth, and high-density photonic integrated channelizer (Serial Arrayed Waveguide Grating - SAWG) with 10 output ports



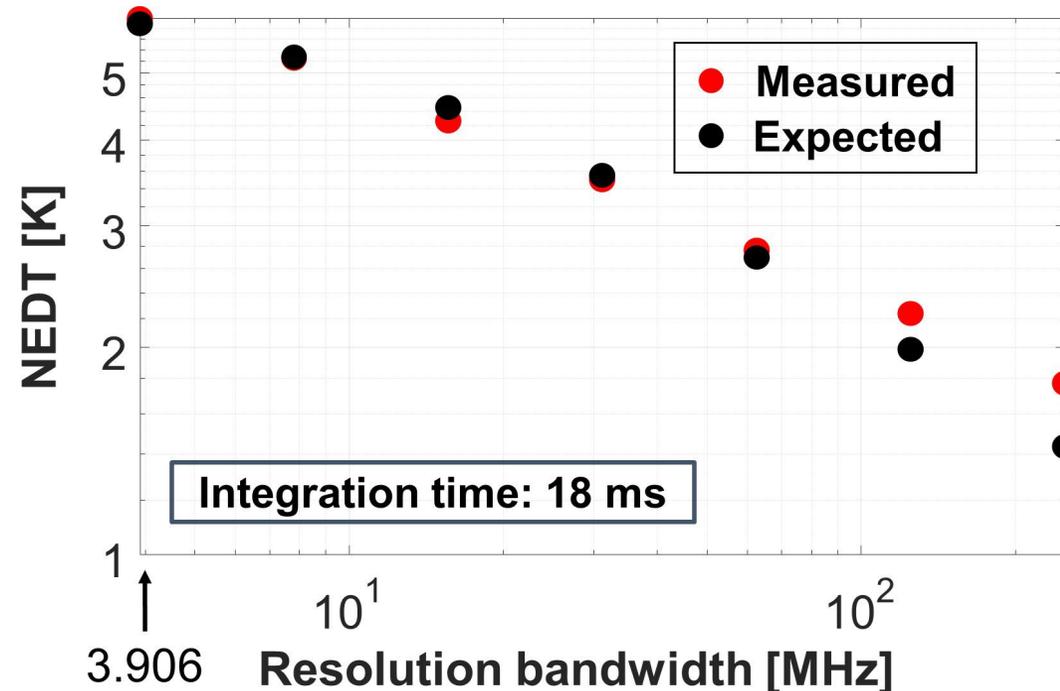
- The SAWG divides the upconverted microwave spectrum (in the optical domain) in 10 narrowband outputs



M. Stephen, US Patent 11852864 – Title: Serial Arrayed Waveguide Grating

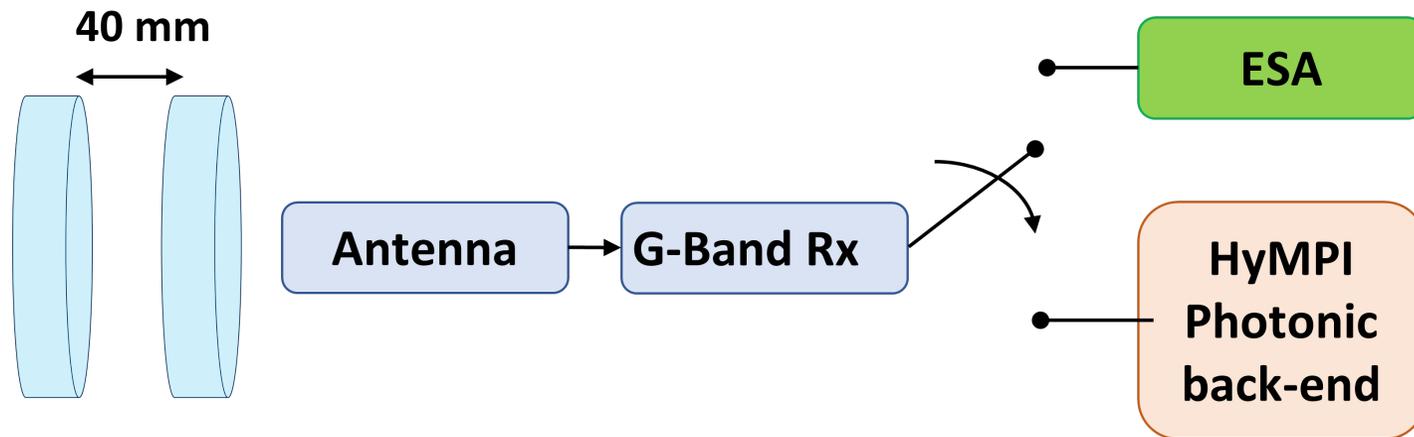
F. Gambini, et al., 2024, [doi: 10.1109/JLT.2024.3349932](https://doi.org/10.1109/JLT.2024.3349932)

Hyperspectral performance



- The Noise Equivalent Differential Temperature (NEDT) values are limited by the noise figure of the front-end
- The photonic link adds only marginal noise

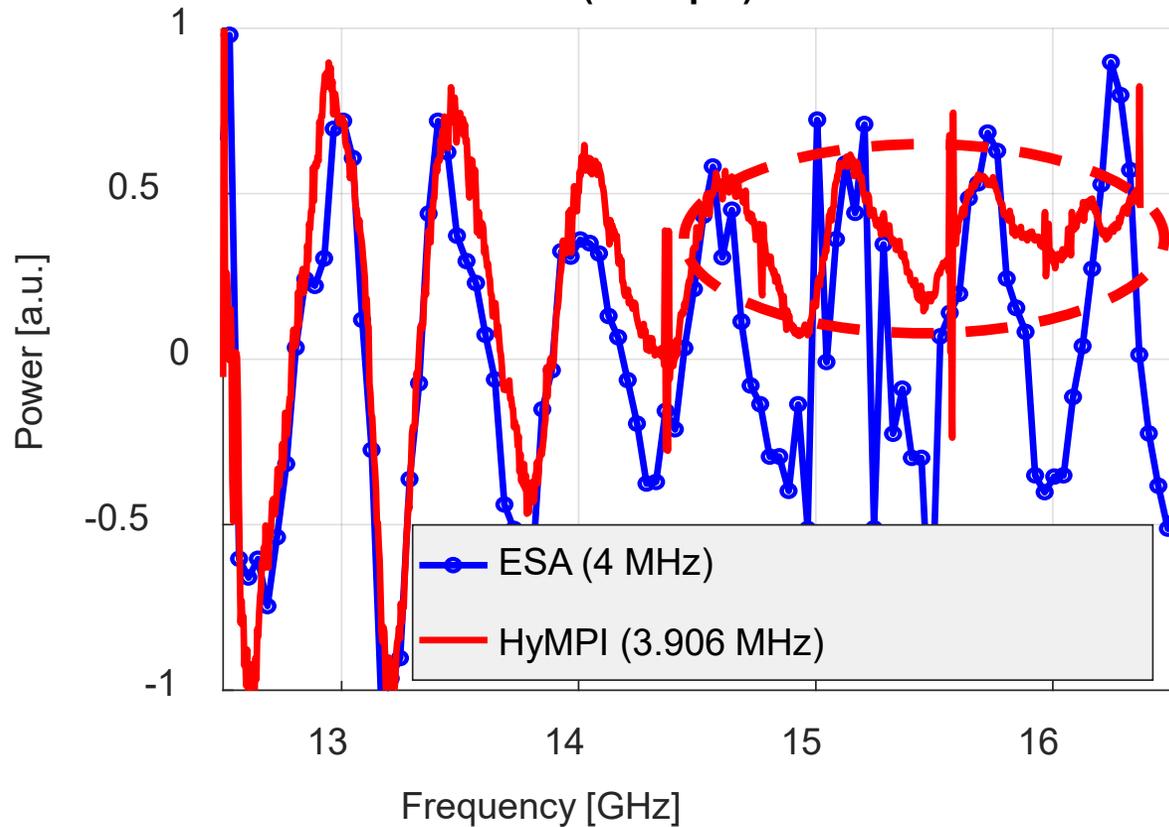
Spectrometric demonstration (Hyperspectral Resolution)



- To prove the hyperspectral performance, a MW cavity was created using two silica wafers in front of the MW antenna
- The signal at the output of the G-Band Rx was measured with a 40 GHz electrical spectrum analyzer (ESA) and with HyMPI's photonic back-end
- HyMPI can perform radiometric and spectrometric measurements of the received MW signals

NEDT Hyperspectral demonstration example

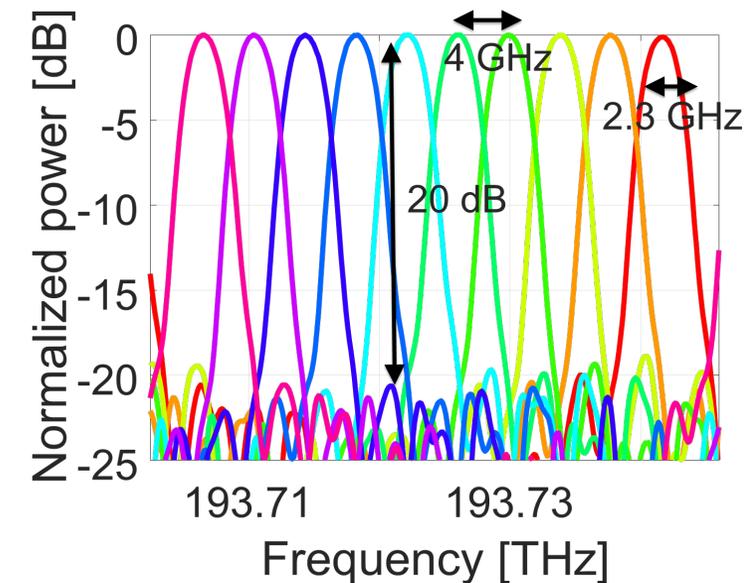
Channel 7 (example):



Attenuation due to the cut-off of the SAWG filter channel ($B_{-3\text{ dB}} = 2.3\text{ GHz}$)

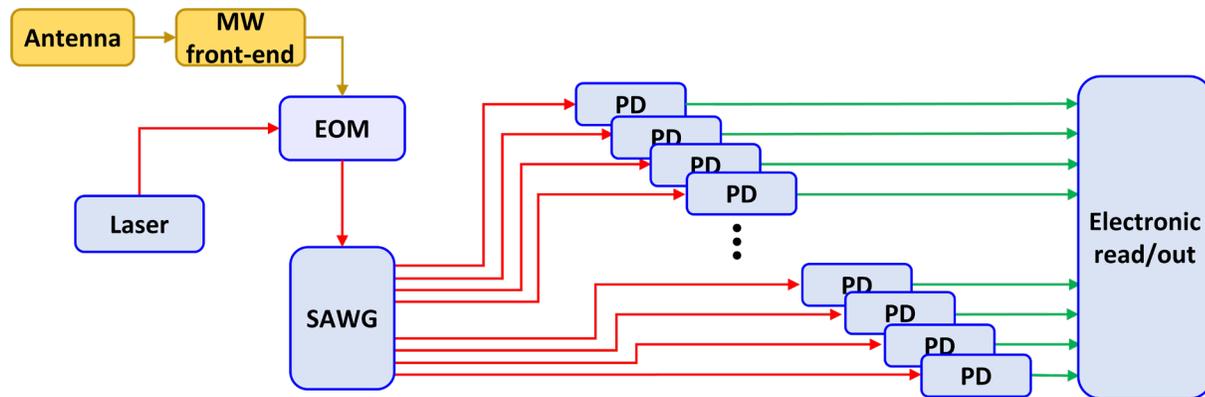
Spectrum is not calibrated (attenuation includes both SAWG and ASIC)

SAWG response:



Next Step: AURORA Pathfinder

Success of the HyMPI team at  and its photonics technology development in PICs will be transferred to AURORA



- Space-based technology demonstration of broad-spectrum and hyperspectral microwave photonics-based sounders for future NASA science missions
- Lead: NASA GSFC (PI: A. Gambacorta) in collaboration with NASA JPL

Conclusions

- HyMPI enables wide-band, hyperspectral resolution and contiguous spectral coverage without increasing the noise level significantly:
 - We demonstrated the full end-to-end system performance at hyperspectral-resolution (3.906 MHz)
 - We demonstrated that the photonic link does not increase the noise
- PICs can overcome the limitation of the current MW technology:
 - As predicted, PICs do not contribute to the noise of the system
 - They can minimize the size, weight, power consumption and costs of the instrument
- Going from 22, sparsely sampled channels on ATMS to thousands channels will enable improved retrievals of surface and atmospheric temperature and water vapor.
 - Simulated results have shown a 50% improvement in atmospheric temperature and water vapor retrievals, including in the Earth's Planetary Boundary Layer (Gambacorta et al., 2023, doi: 10.1109/JSTARS.2023.3269697)