Photonic Integrated Circuits (PICs) in Space: The Hyperspectral Microwave Photonic Instrument (HyMPI)

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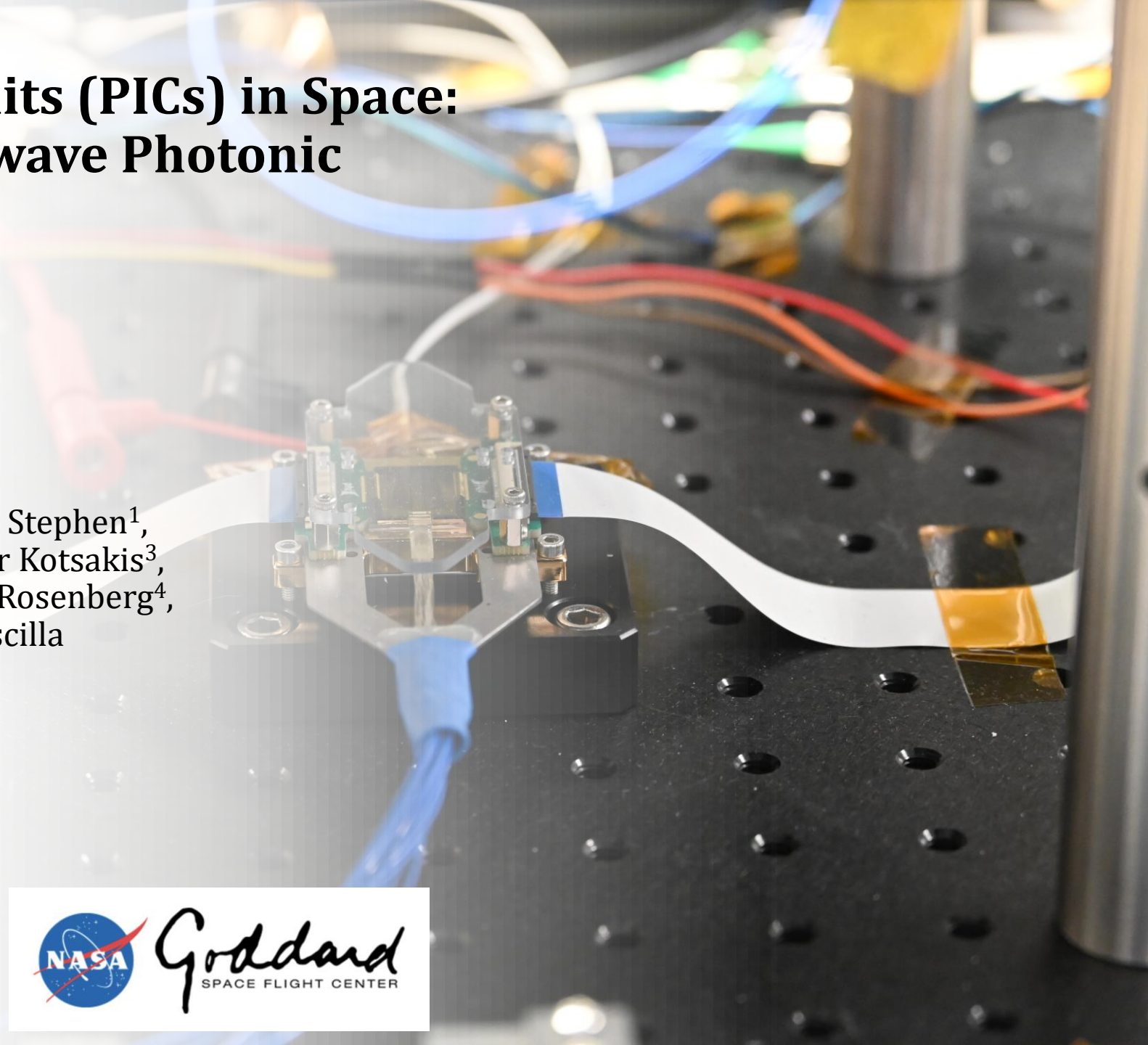
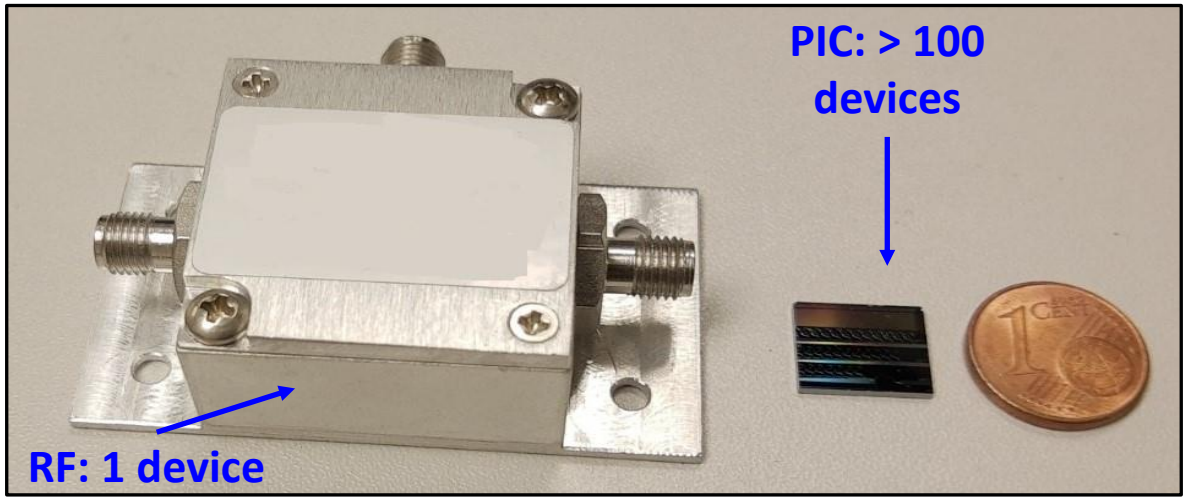


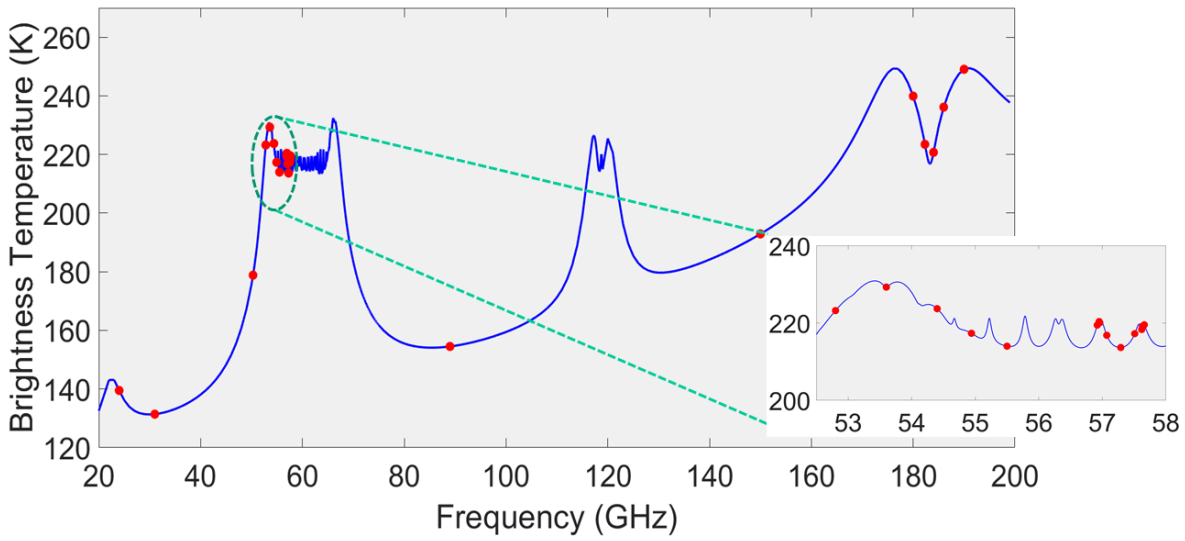
Integrated Photonics

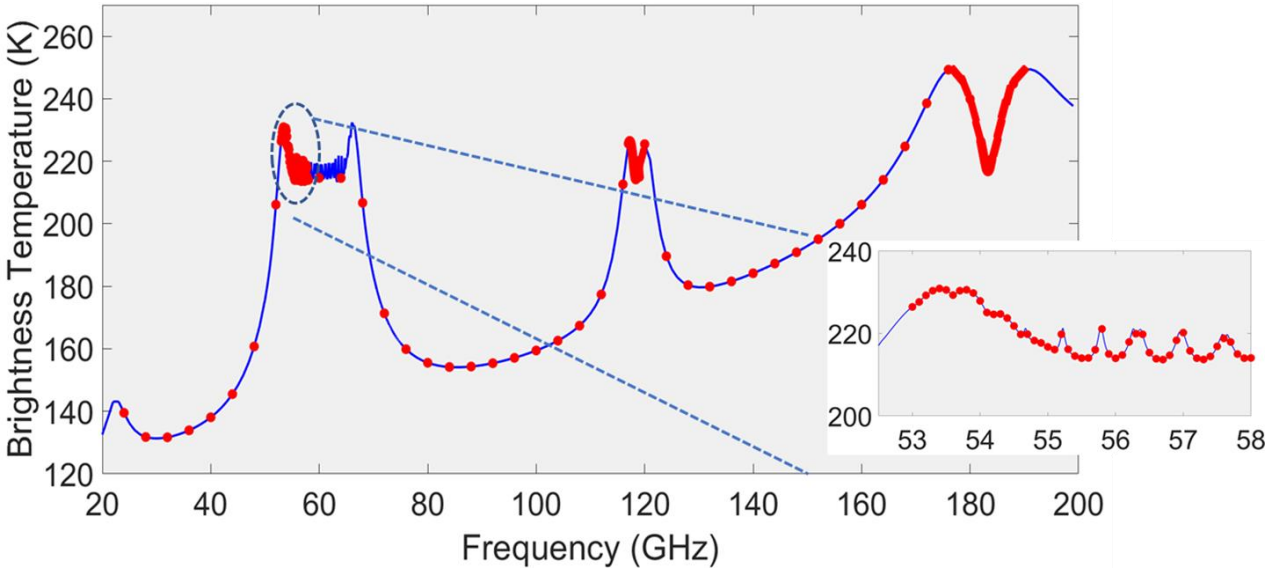
- **Integrated photonics:** emerging branch of photonics in which multiple devices are fabricated as an integrated structure onto the surface of a flat substrate

- **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 Enabled Hyperspectral MW Technology





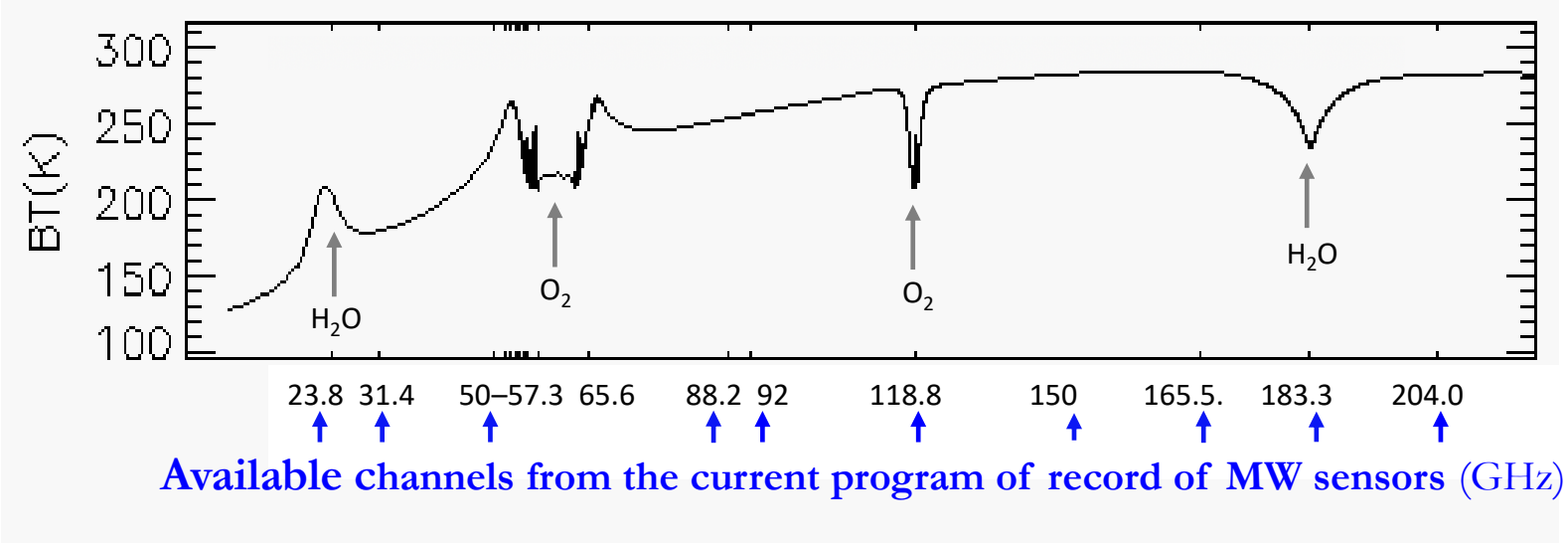
ATMS

- ~20 sparse channels (not contiguous spectrum)
- Missing critical information
- High footprint and power consumption
- 75.4 kg, 10, 200 in3, 93 W

HyMPI

- Contiguous spectrum coverage
- Hyperspectral resolution: 10 MHz (or lower!) with support of Application Specific Integrated Circuits
- Cubesat (27U: 54 kg, 2,700 in3)

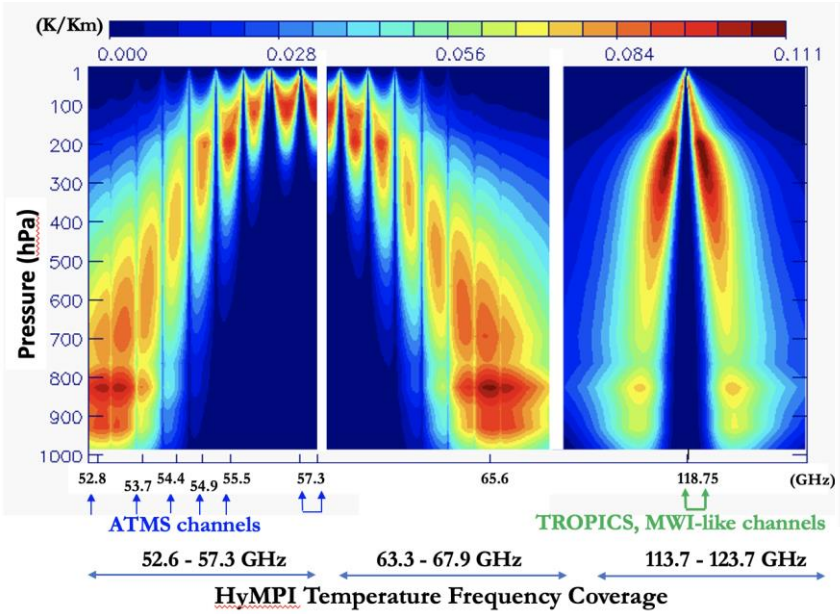
Hyperspectral Microwave Measurements of the Earth's surface and atmospheric radiation



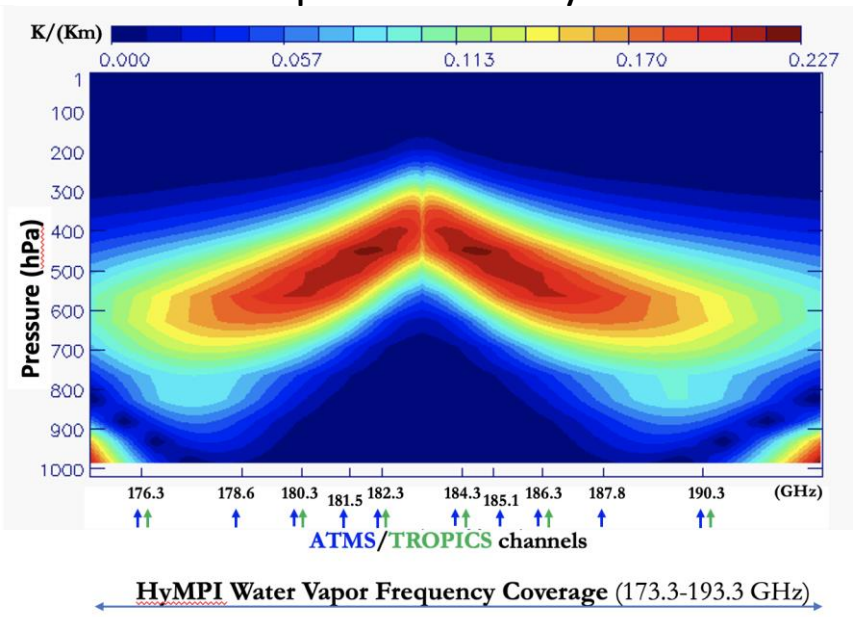
Sounder	MSU	AMSU A/B & MHS	ATMS	CoSMIR-H	HyMPI
# of Chans	4	20	22	1200	*xx,000*
Launch	1978	1998	2011	2024	~2030s

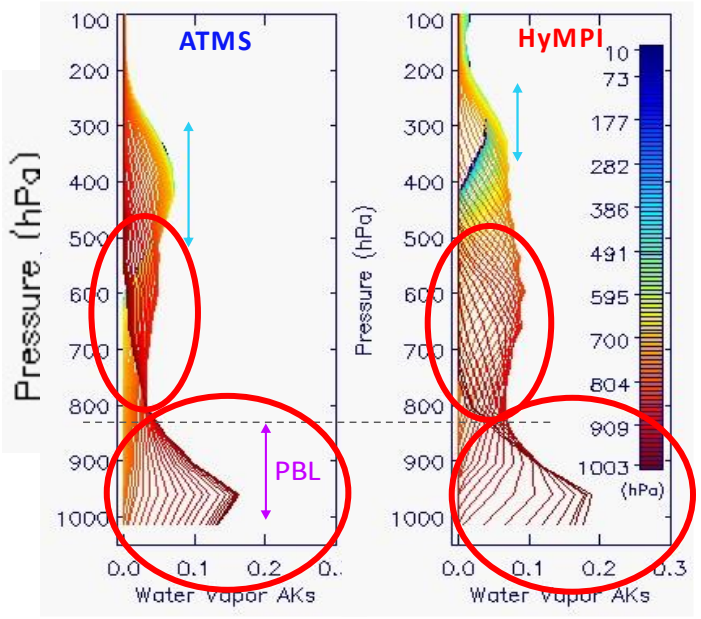
Filling the Information Gap left by the POR

Temperature Sensitivity Functions



Water Vapor Sensitivity Functions



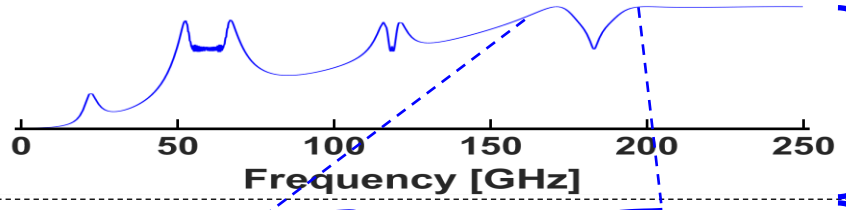


HyMPI will be configured to respond to the Science Applications and Traceability Matrix requirements outlined in the NASA Incubation PBL Study Team Report and to satisfy the broader needs of the weather and climate community.

Gambacorta et al., 2023, doi: 10.1109/JSTARS.2023.3269697

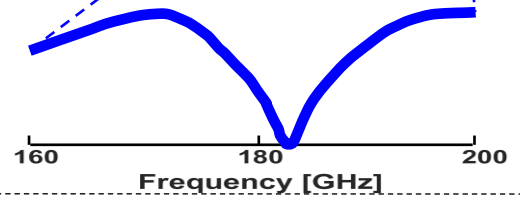
The HyMPI concept

Antenna Captures MW spectrum.



RF domain

G-Band Rx Amplifies spectra.

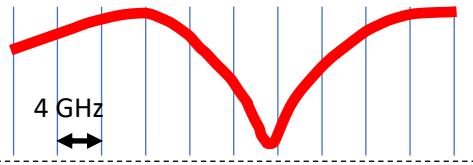


RF domain

EOM Converts microwave spectrum to optical domain.

Optical domain

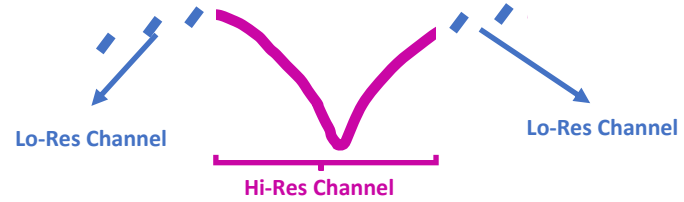
SAWG Separates spectrum into 10 x 4 GHz sub-bands.



Optical domain

BPR Sub-bands with structure are mixed with a new optical tone and digitized (Hi-Res Channels).

ASIC



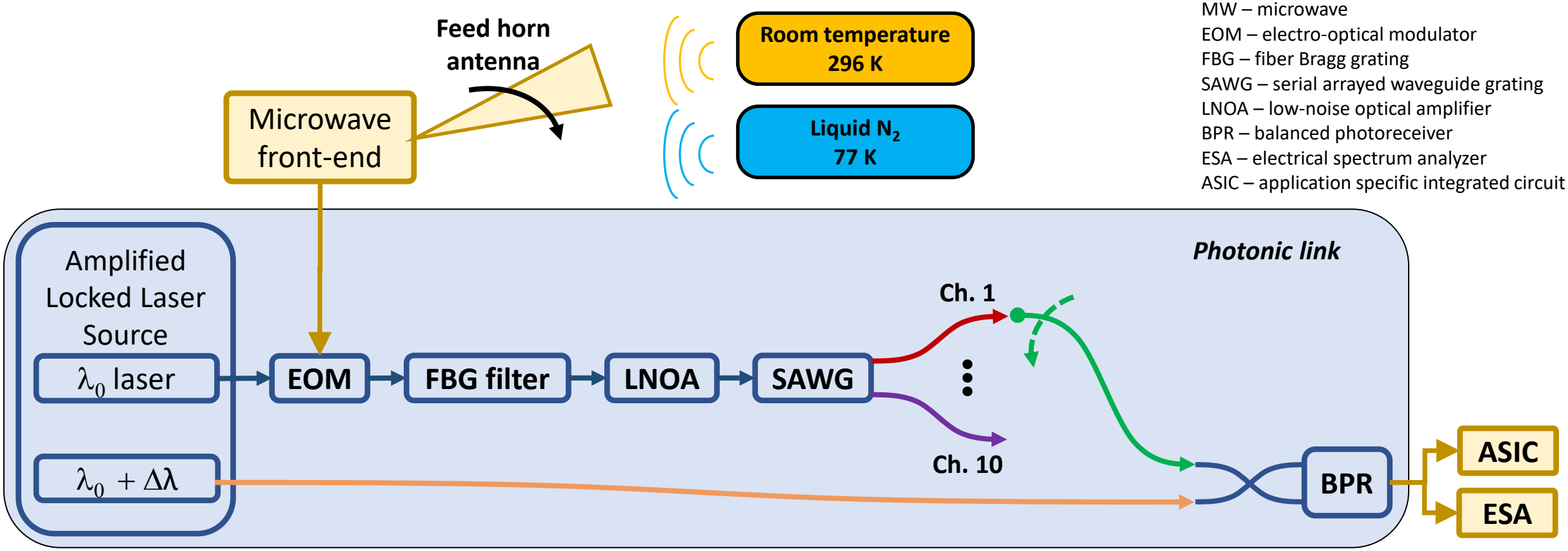
PD Sub-bands with minimal structure are measured directly (Lo-Res Channel).

Baseband domain (0 – 4 GHz)

- **HyMPI is based on PICs developed in different platforms (III-V, silicon nitride, …)**
- **HyMPI enables a modular approach**
  - **The single HyMPI system focuses on 40 GHz portion of the MW spectrum**
  - **The PICs allows to use the parallel systems to cover 250 GHz MW spectrum**
- **HyMPI's goal:**
  - **Provide broadband spectral coverage.**
  - **Hyperspectral (thousands of channels, up to 500 kHz resolution) instrument.**
  - **Limited SWaP-C for PBL sensing**

Gambini et al., 2021, doi: 10.1364/HISE.2021.HF4E.5; Turner et al., 2020, doi:10.23919/MWP48676.2020.9314456; Gambacorta et al., 2023, doi: 10.1109/JSTARS.2023.3269697

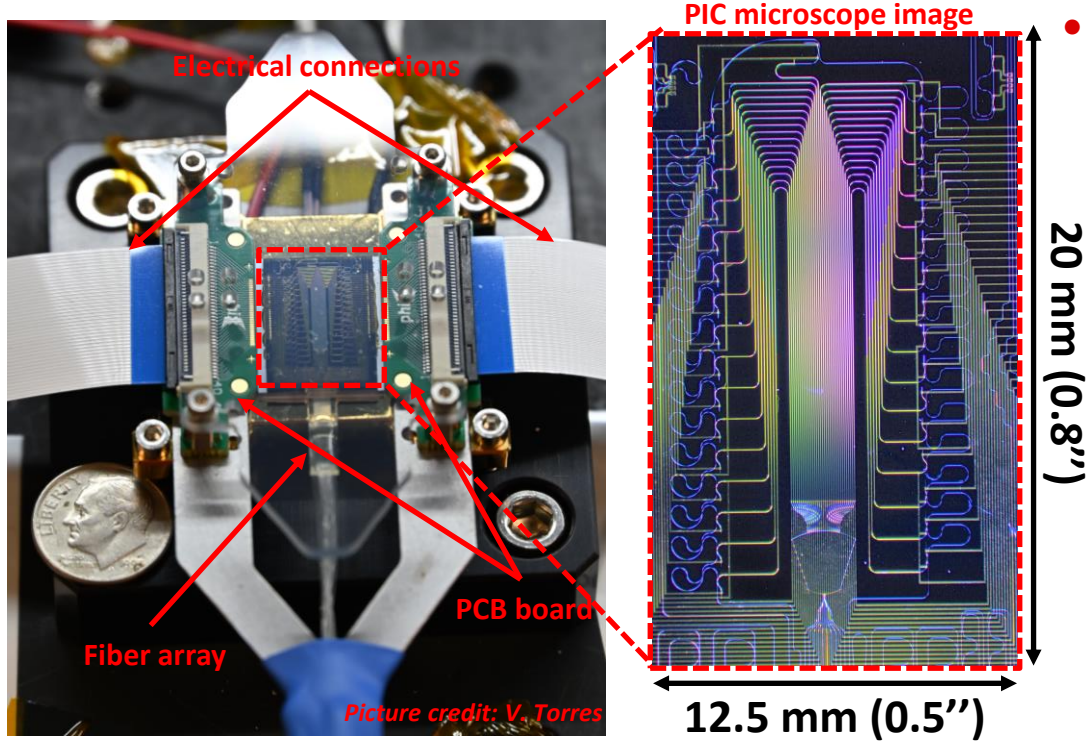
HyMPI System Testing



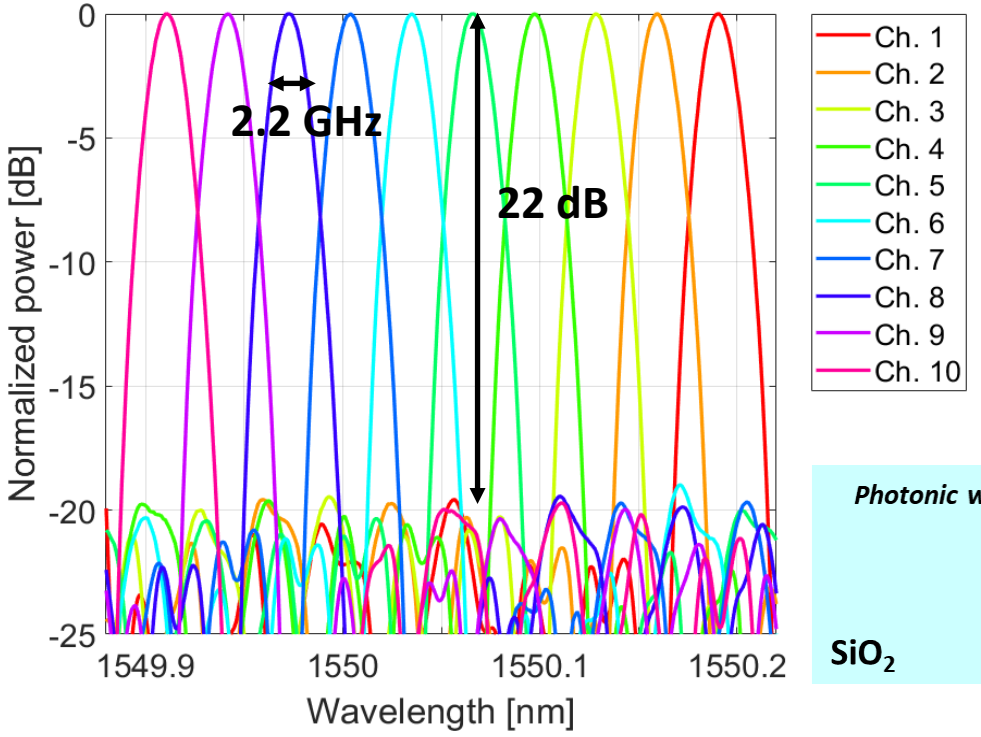
- The MTLS is not delivered yet. We are using two locked lasers for the up- and down-conversion
- EDFA is used to compensate SAWG optical loss
  - The loss will be strongly mitigated in the next SAWG design

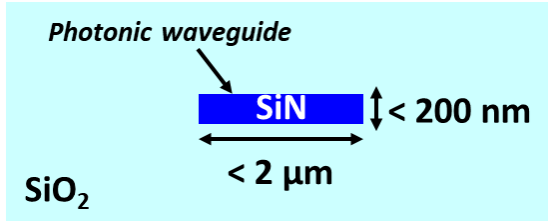
HyMPI Development Status Update

- 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**

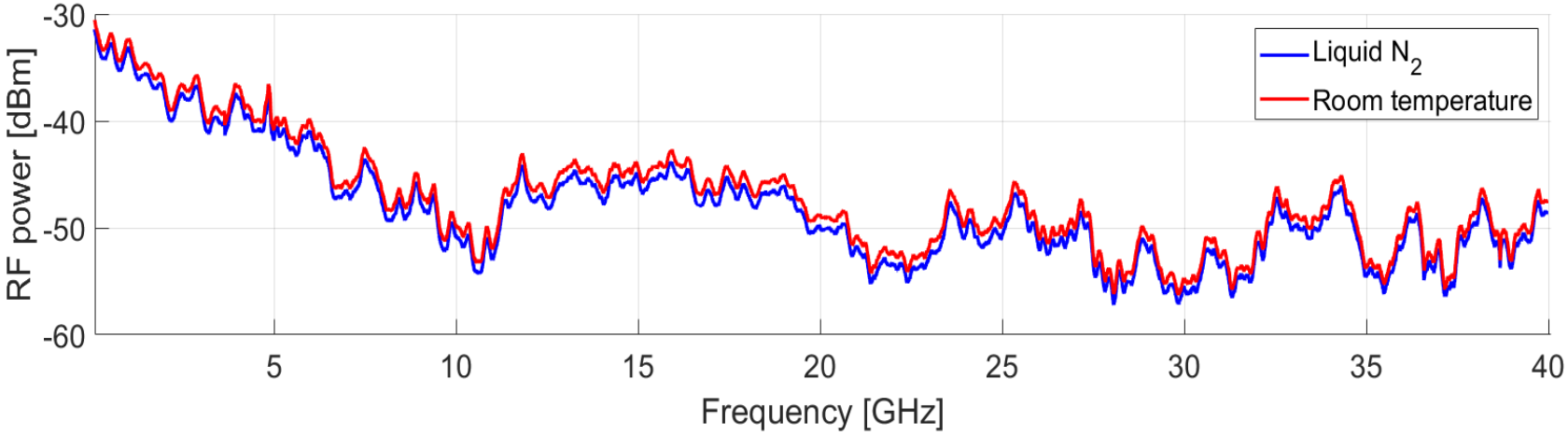


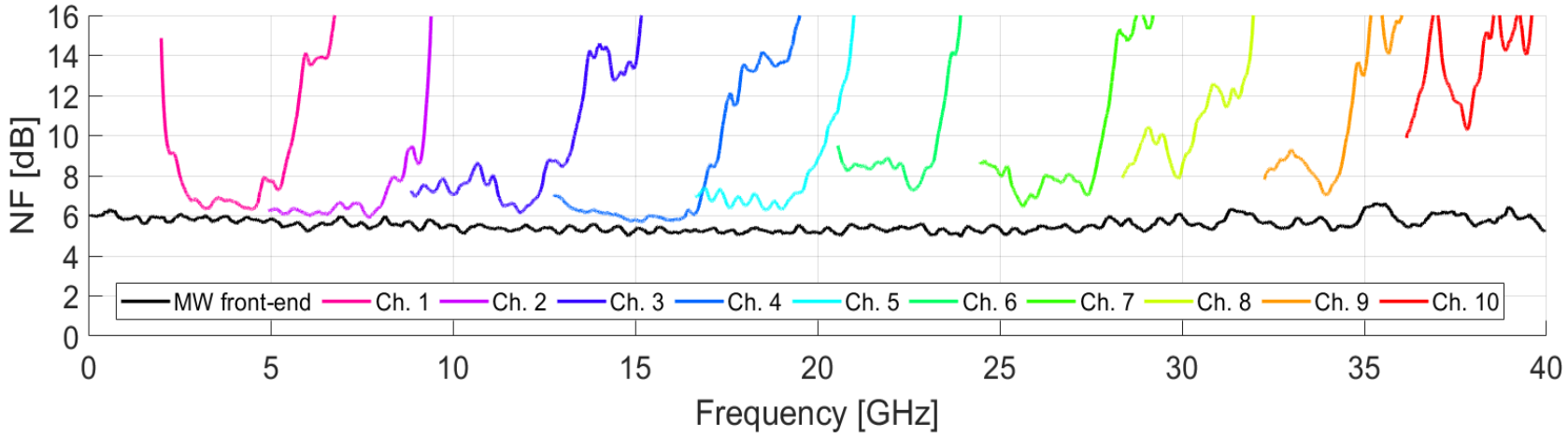


US Patent 11852864 – Title: Serial Arrayed Waveguide Grating

Gambini, et al., 2024, doi: 10.1109/JLT.2024.3349932

HyMPI System Testing

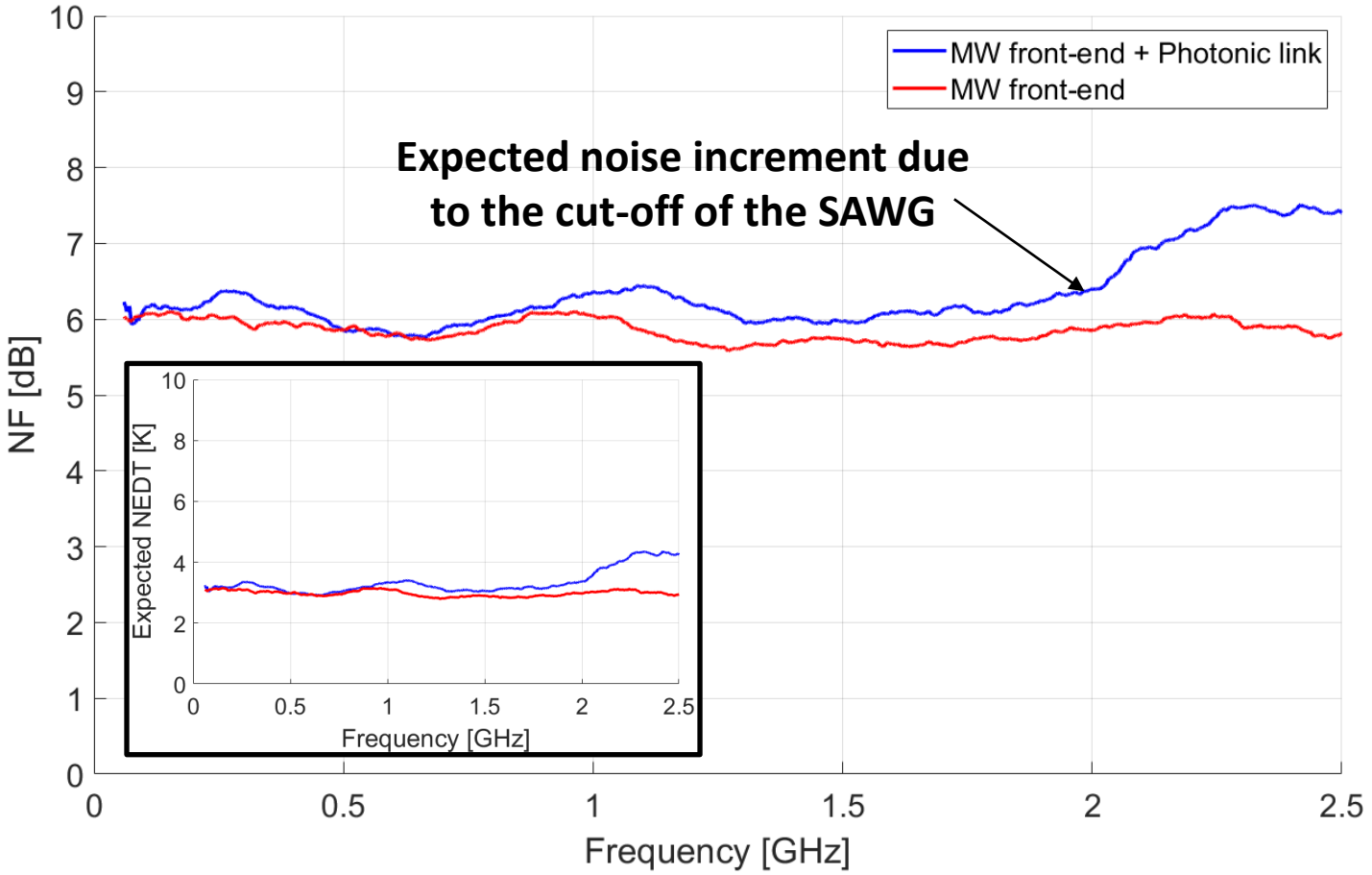




- **The power provided by the front-end is higher for lower frequency**
- **The NF of all the 10 channels has been measured**
- **The noise figure degrades for higher frequency channels due to the lower power provided by the MW front-end**

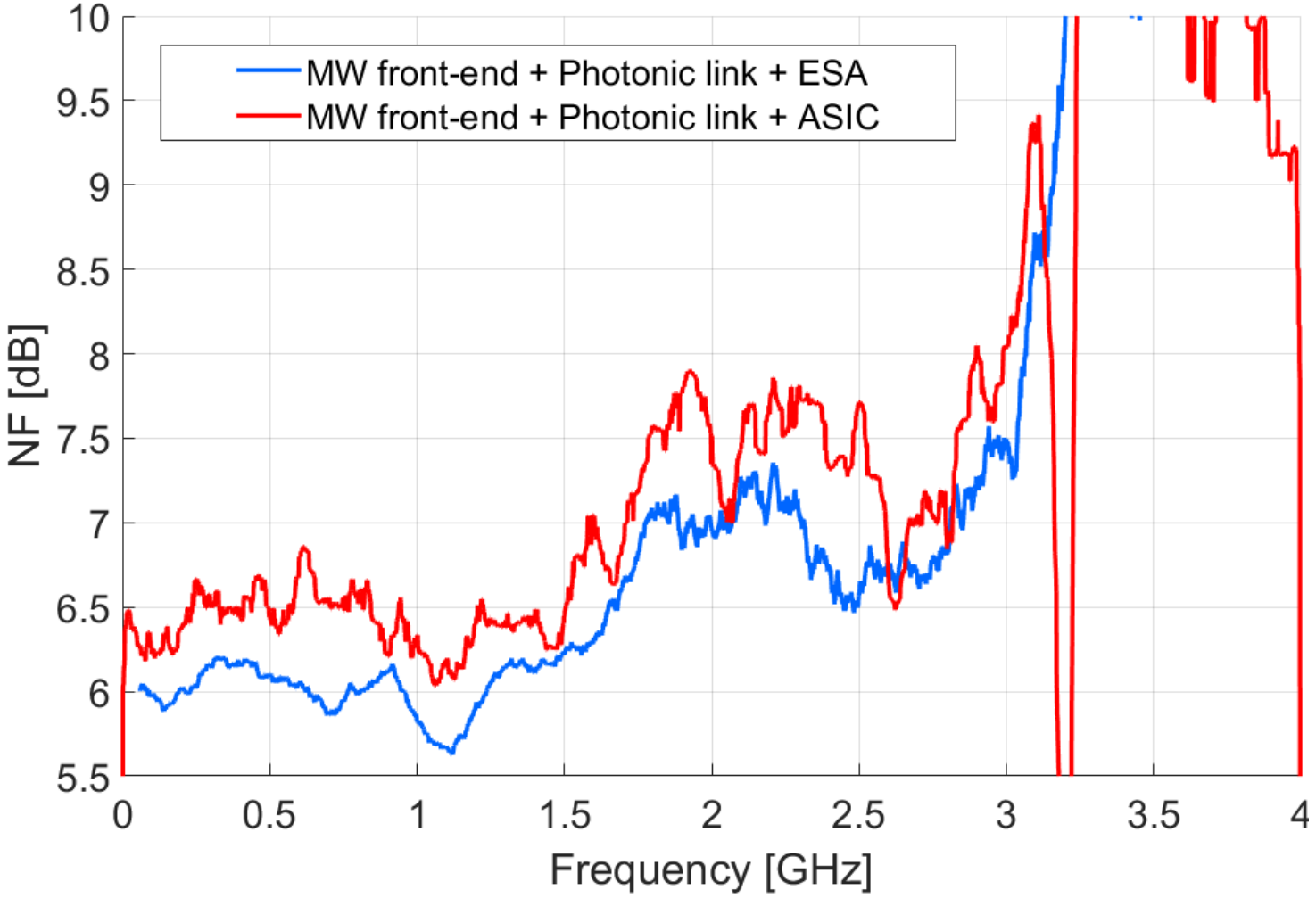
Experimental results

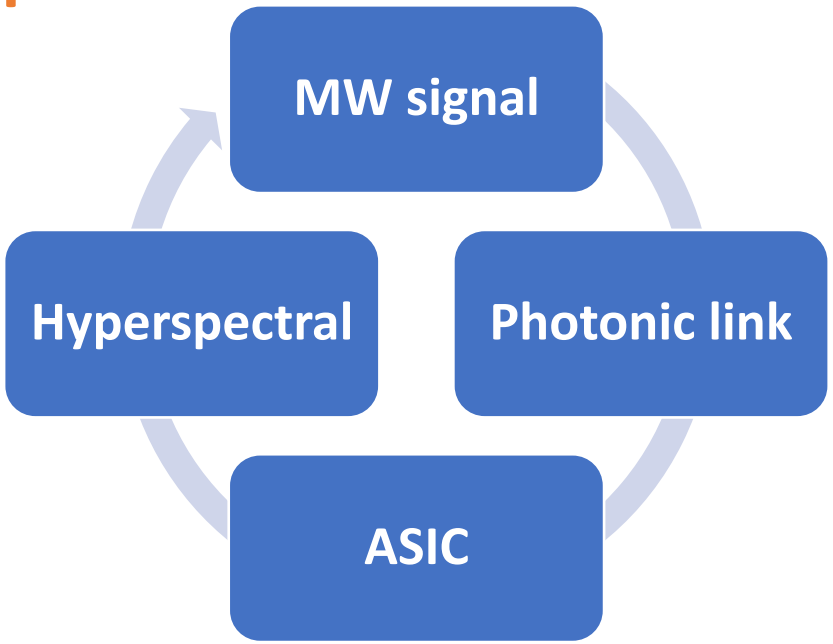
Base-band down-converted channel noise analysis:



- **The noise figure (NF) measurements and prediction of the noise equivalent differential temperature (NEDT) were performed using:**
  - **Resolution: 8 MHz**
  - **Integration time: 18 ms**
- **Measured NF and expected NEDT of the MW front end are: 6 dB and 3 K, respectively**
- **The results show that HyMPI enables <u>hyperspectral resolution sounding without a significant noise increase</u>**

TRL 4 Demonstration Accomplished





- We demonstrated in principle the photonic link can work without compromising the noise
- The ASIC is added in the system and preliminary results show a low impact on the noise

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Questions?

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Thank you!

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