



Northeastern University
**Institute for Intelligent
Networked Systems**

Terahertz Integrated Sensing and Communications: **From the Near Field to Space (and the Sea)**

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Imagine your life without wireless connectivity...

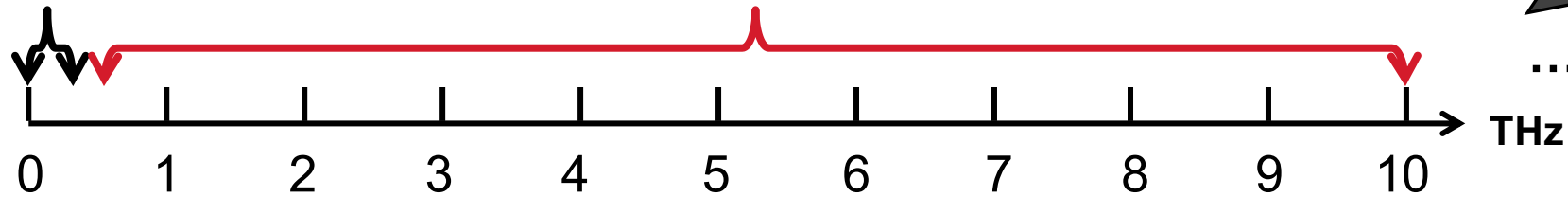
On a Quest for Spectrum

Everything: Radio, TV,
Cellular Systems, Wi-Fi, Radar,
GPS, etc.



The Terahertz Band

Optical
Wireless
Systems



Large Amount of Spectrum
[100 GHz-10 THz]
10s to 100s GHz contiguous
bandwidths

Small Wavelength
[3 mm-30 μm]
Tiny antennas, large arrays in
compact form factors

**Non-negligible
Photon Energy**
[0.41 meV up to 41 meV]
Unique electromagnetic signatures

I. F. Akyildiz, C. Han, Z. Hu, S. Nie, J. M. Jornet **“Terahertz Communications:
An Old Problem Revisited and Research Directions for the Next Decade,”**
IEEE Transactions on Communications, 2022.
2025 IEEE Communications Society Best Survey Paper Award

Takeaway: The terahertz band is the last wide-open stretch of spectrum, between radio and light.

What THz Can Do

COMMUNICATIONS



On-chip



Rack-to-rack



Fixed Wireless Access



Non-terrestrial links

SENSING



Molecular fingerprinting



Biomedical imaging



Industrial inspection



Atmospheric sounding

Takeaway: The same terahertz hardware can both carry data and sense the world around it.

Integrated Sensing and Communications

Ultrabroadband
Ultra-directional Links



Uniqueness of THz ISAC:
- Not only target detection and tracking, but also **target classification**
- All while characterizing air quality

Room occupancy: 70%
Air quality: Acceptable

Takeaway: One radio, two jobs - the signal that carries your data also senses what is around you.

Building a THz Radio: The Technology Gap

Ultra-high-speed Digital Back-ends

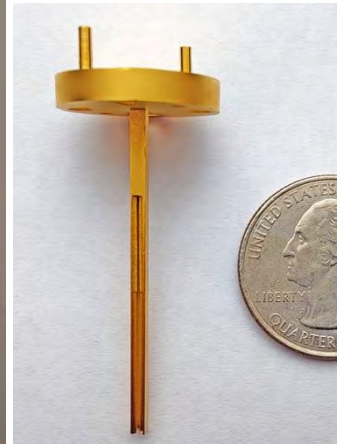
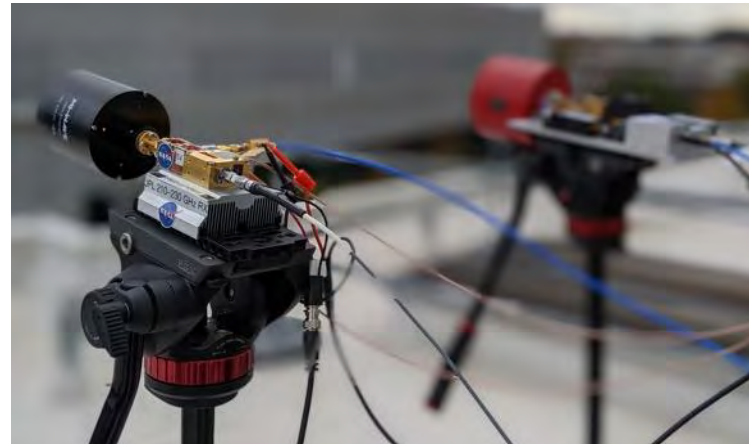
- Turns bits into samples fast enough
- Converters must sample at many GHz, with good resolution
- Often built as many channels working in parallel

Ultrabroadband Analog Front-ends

- Creates, amplifies and filters the THz carrier
- Needs multi-GHz bandwidth in one shot
- Three routes: electronics, photonics, plasmonics

Ultradirectional Antenna Systems

- Steers the beam where it is needed
- Big gain from very small antennas
- Lenses and metasurfaces extend the toolbox



Takeaway: A (sub)THz radio now matches WiFi transmit power, with far more gain and bandwidth.

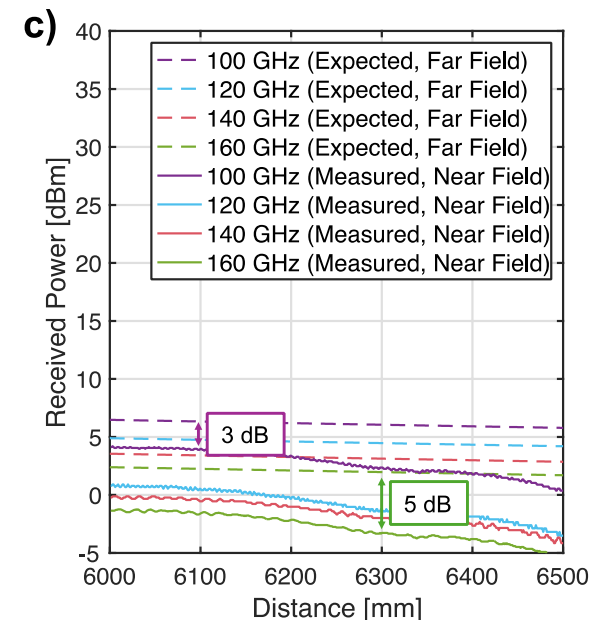
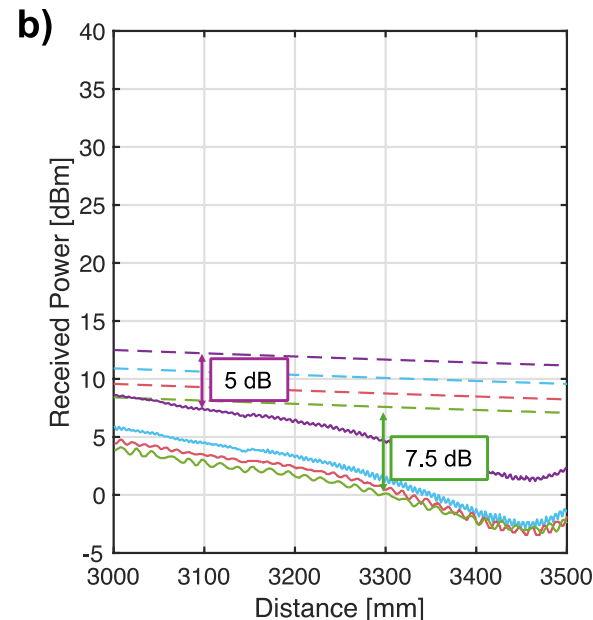
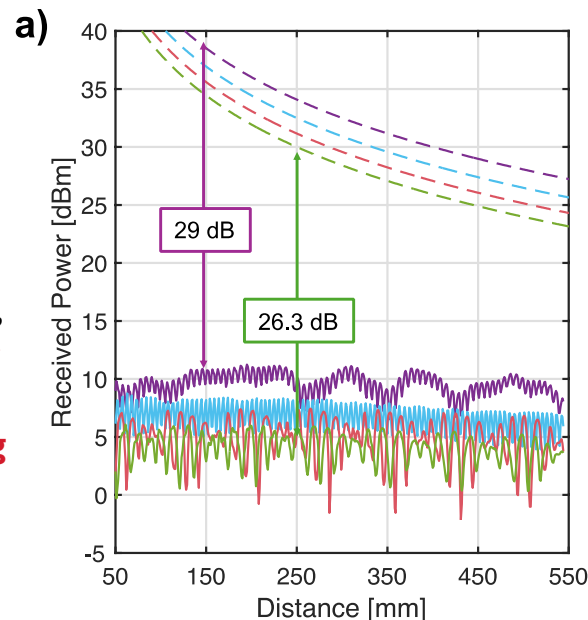
**First stop: the near field,
where the usual rules break**

Surprise: At THz, the Near Field Is Huge

- The near field reaches out to about $2D^2/\lambda$, where D is the size of the antenna
- A 10 cm array at 300 GHz: the near field reaches 20 m
- A 1 m base-station surface at 300 GHz: the near field reaches 2 km
- So most THz users will be inside the near field, not outside it

And we have
measured it...

D. Bodet, V. Petrov, S. Petrushkevich,
J. M. Jornet, “**Sub-terahertz near
field channel measurements
and analysis with beamforming
and Bessel beams,**” Scientific
Reports, Aug. 2024.

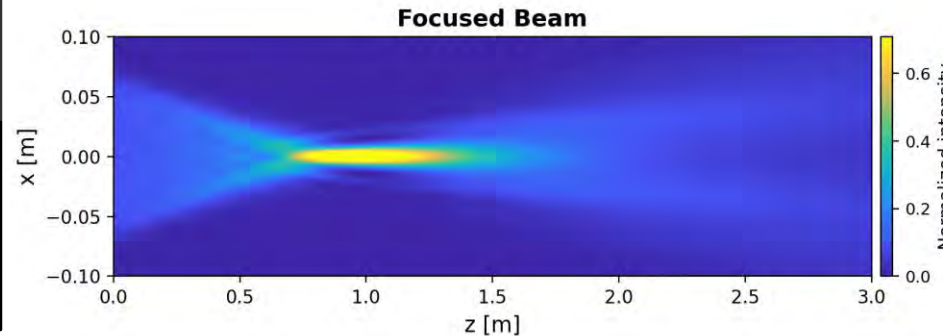


Takeaway: At THz the near field is not a lab curiosity, it is where the users are.

Non-Diverging Beams for the Near Field

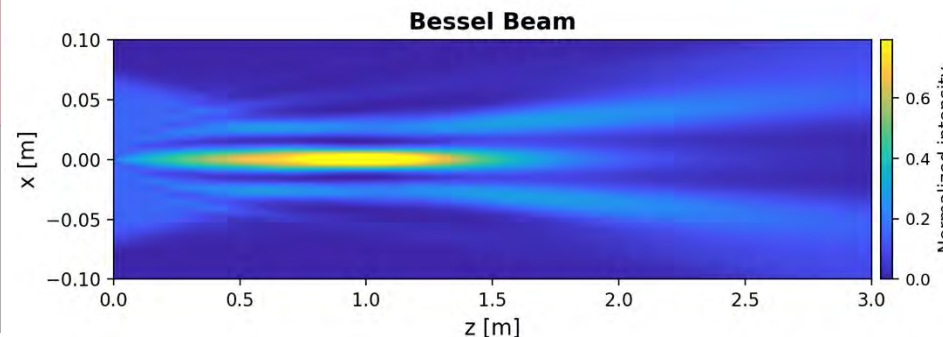
Beamfocusing

- Focus on a point
- Requires perfect channel state information



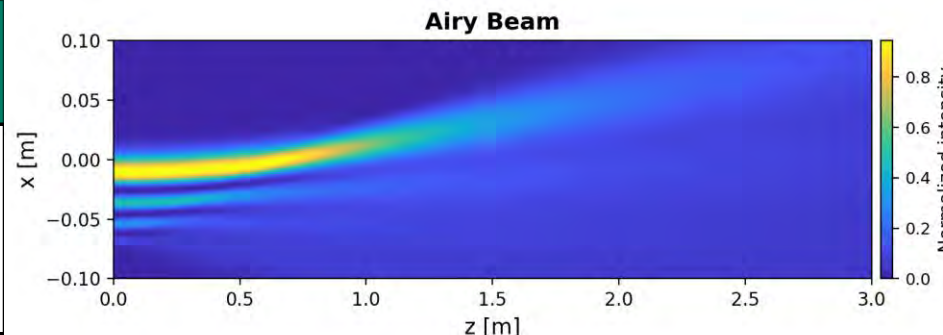
Bessel Beams

- Focus along a line
Friendlier to mobile systems

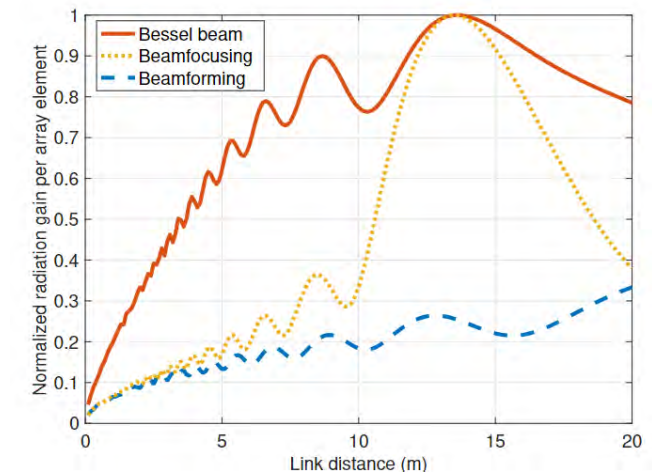


Airy Beams

- Focus along a bending line
Friendlier to mobile systems



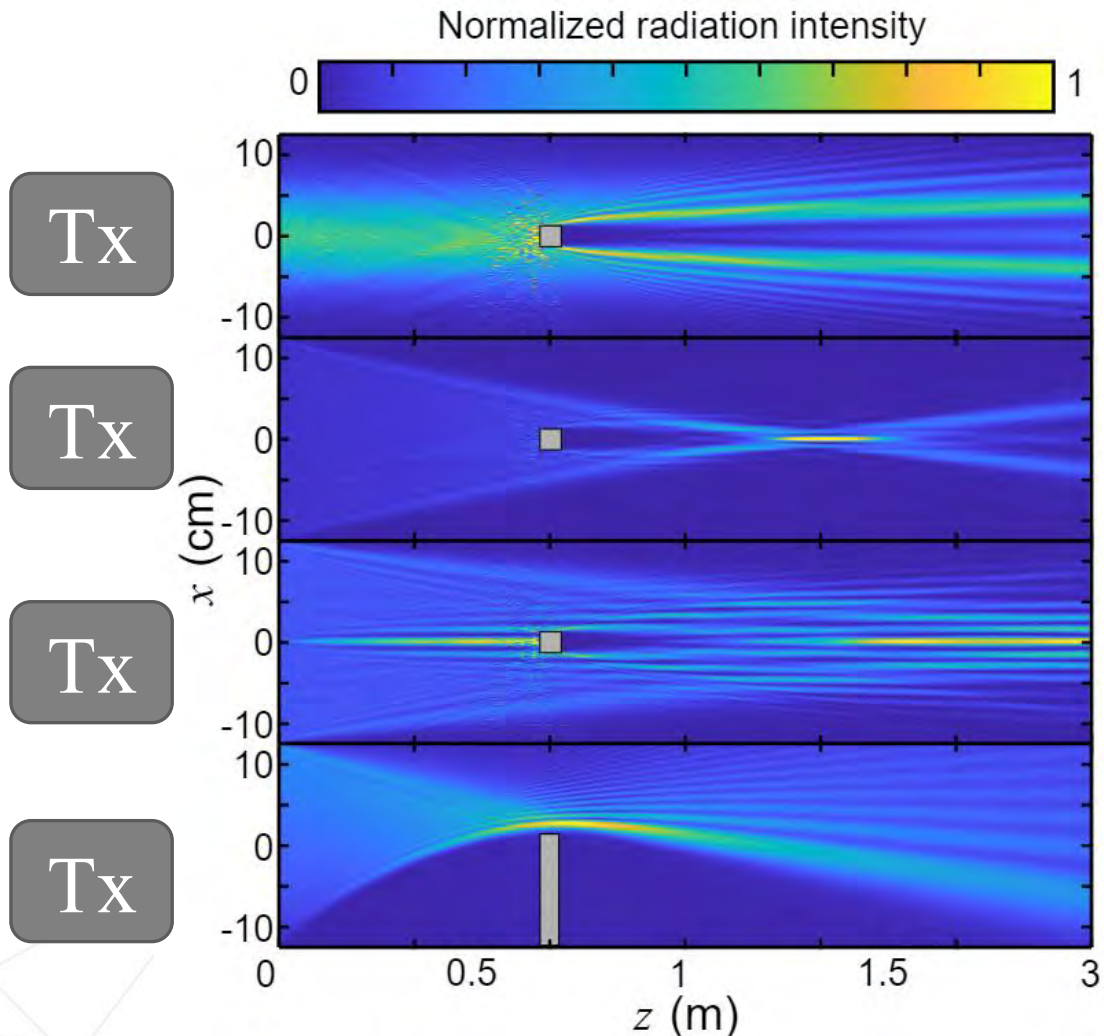
In the near field a beam does not have to spread out— so the usual path-loss rules no longer apply



A. Singh, V. Petrov, H. Guerboukha, I. V. A. K. Reddy, E. Knightly, D. Mittleman and J. M. Jornet. **"Wavefront Engineering to Realize Efficient Terahertz Band Communications in 6G and Beyond,"** IEEE Wireless Communications Magazine, 2023.

Takeaway: By shaping the wavefront, we can make a beam that focuses, bends, or heals itself.

Bonus: Blockage Mitigation



Beamforming

Beamfocusing

Bessel beams

[NEW] THz Bessel
[!] Reconstructs after an obstacle

Airy beams

[NEW] THz Airy
[!] Avoids the obstacle

Takeaway: Smart beam shapes can go around or rebuild themselves after an obstacle.

Not Just Theory: Measured in Our Lab

- Ordinary (Gaussian) beams break down when something blocks them
- Bessel beams heal themselves and keep the link alive
- Shown experimentally at THz frequencies, not only in simulation

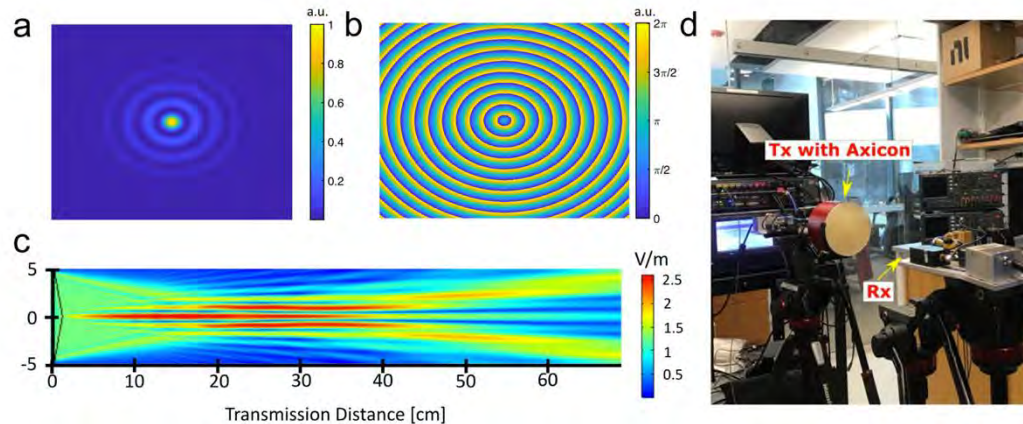
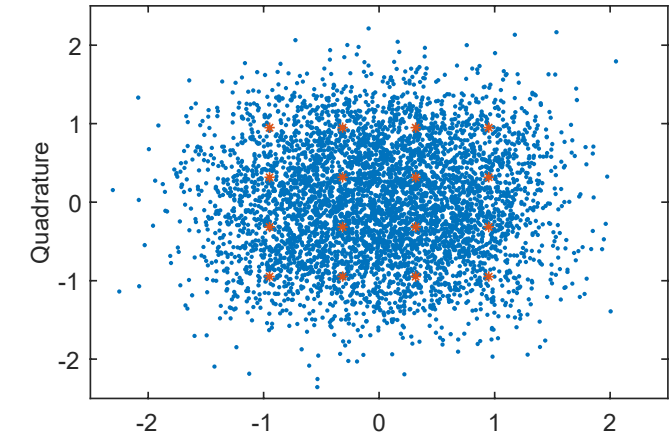
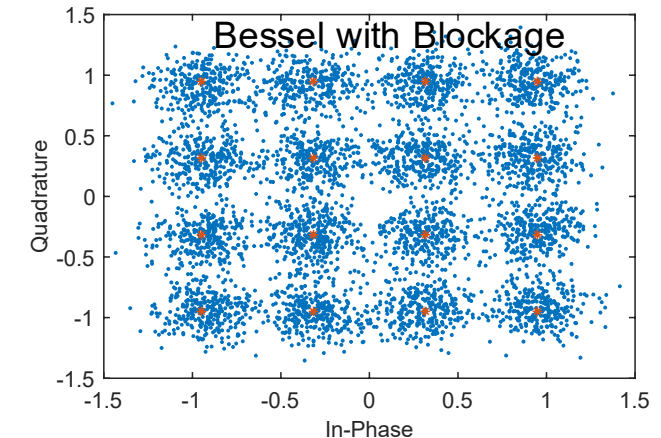


Fig. 1 Terahertz Bessel beam (BB) generation. **a** Amplitude profile of a generic BB; **b** Phase profile of the same BB shown in (a); **c** A 2D simulation (XZ-profile) of BB generated through the designed axicon; **d** terahertz testbed with an axicon mounted to the transmitter (Tx) while the receiver (Rx) is placed 40 cm away from the Tx.

Gaussian with Blockage



Bessel with Blockage



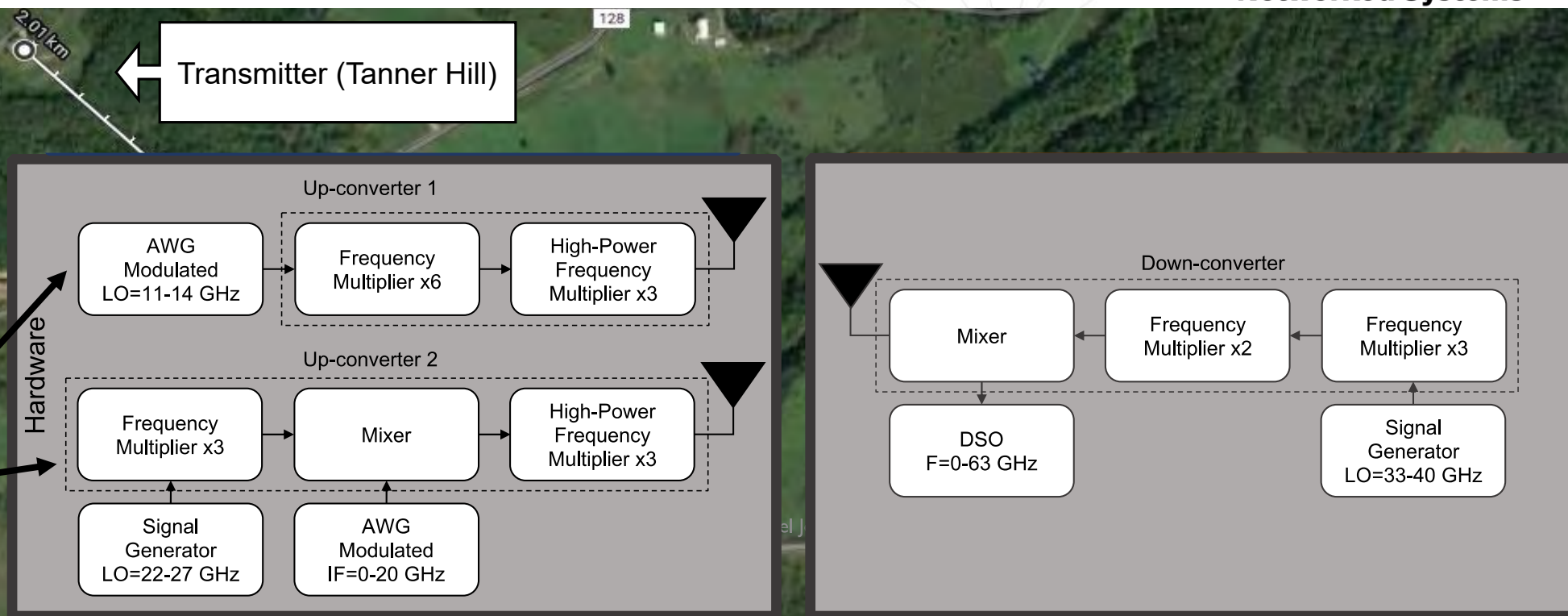
I.V.A.K. Reddy, D. Bodet, A. Singh, V. Petrov, C. Liberale, J. M. Jornet, “**Ultrabroadband Terahertz-band Communications with Self-healing Bessel Beams**,” *Communications Engineering, Nature*, 2023.

Takeaway: Self-healing beams survive blockage that would kill a conventional link.

From the lab bench to the real world on Earth

2018: Multi-Gigabit, Multi-Kilometer-Long Links

What made it possible:
A record-power frequency tripler from NASA JPL
A simpler transmitter with no mixer at RF



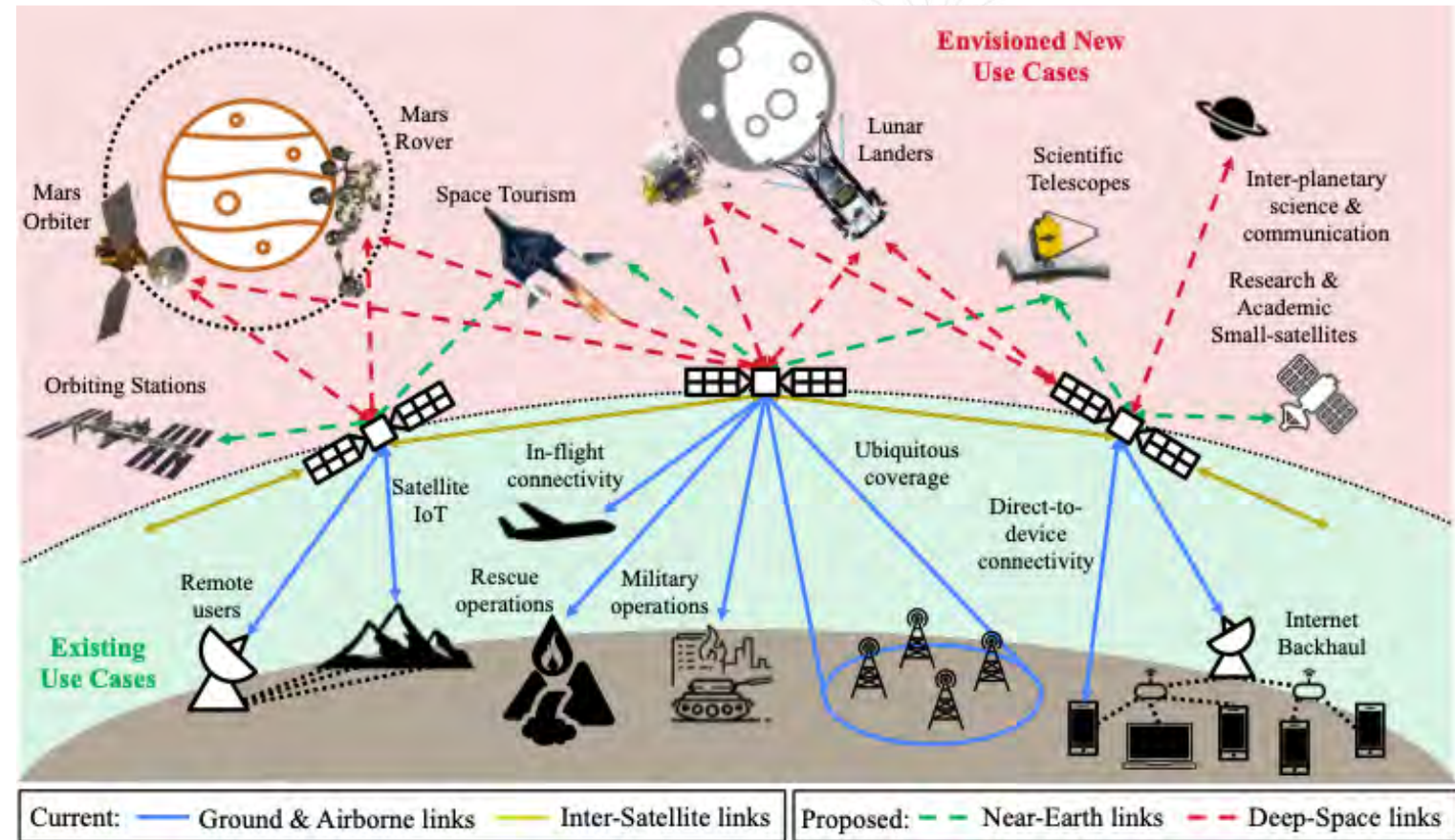
Opportunity: Bridging the Rural Digital Divide with sub-THz wireless backhuls

Receiver (Irish Hill)

Why to stop on the ground?

Today: Non-Terrestrial Networks in 6G

- Broadband connectivity where no infrastructure exists, or where it has been destroyed
- A backhaul in the sky, looking down at Earth
- An intermediate hop, looking up toward deep space



S. Aliaga, V. Petrov, M. Sanchez, and J. M. Jornet, “**Non-Terrestrial Networks (NTN) for space vehicles beyond 6G: Applications, Architecture, and Capacity Limits,**” in the **Proc. of the Asilomar Conference**, Oct. 2024.

Takeaway: Space is becoming part of the network rather than a separate system.

Terahertz Communications in Space

Up and Down Links

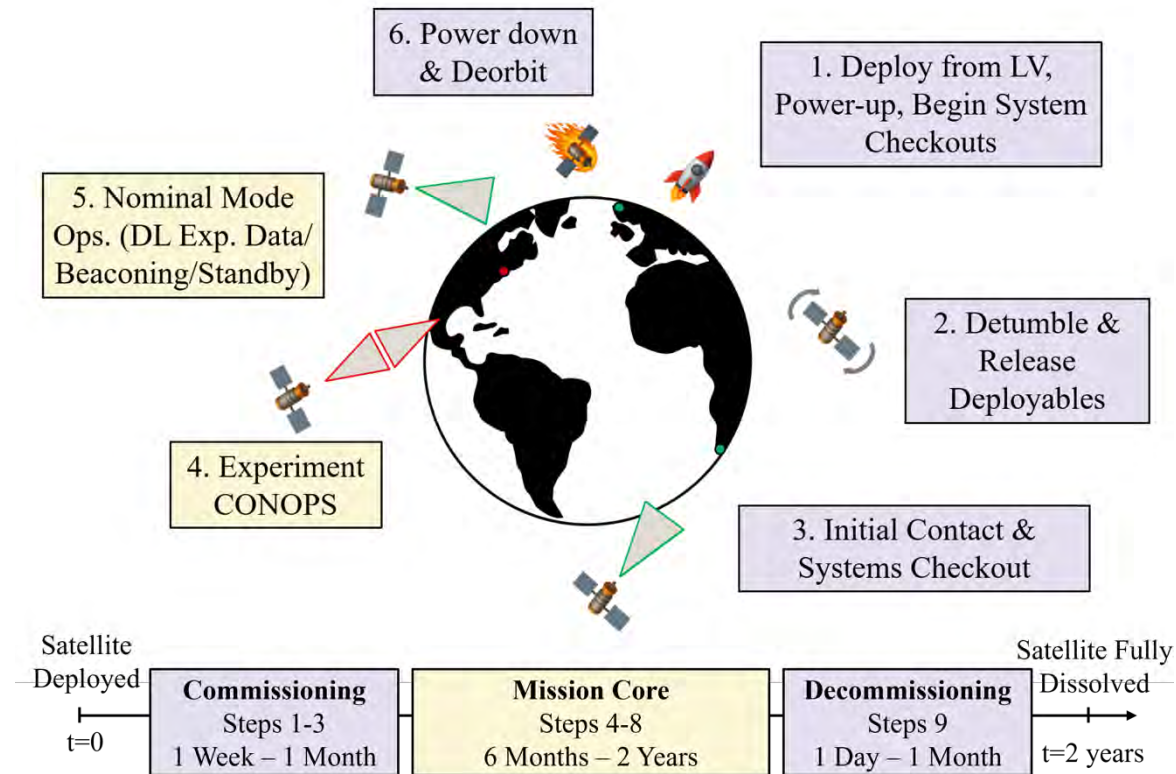
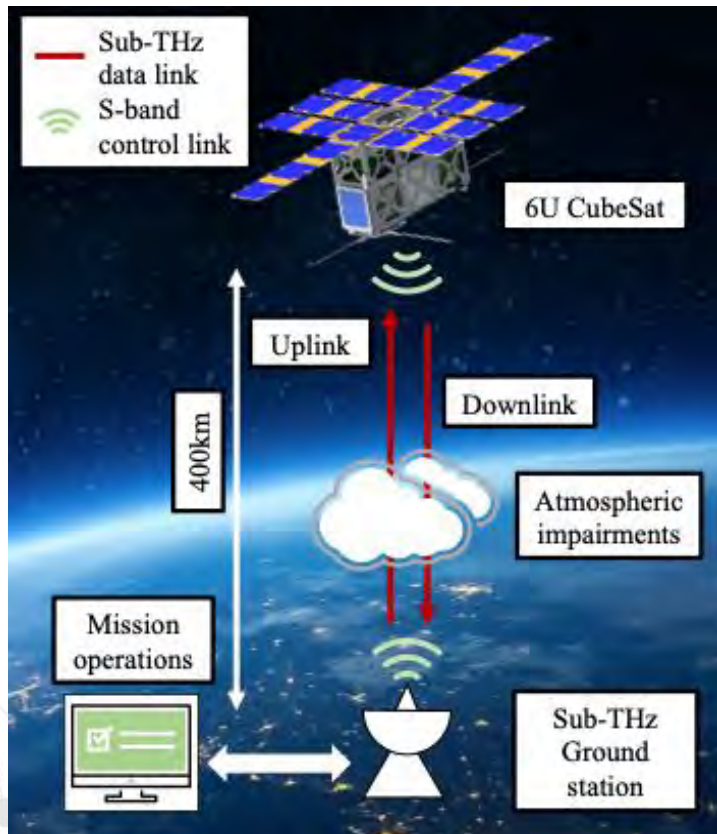
- **Goal:** fast links between the ground and space
- **Competing technology:** mmWave
- **Still far more bandwidth above 100 GHz than at Ka/Ku bands**
- **For the same antenna size, THz gain is much larger**
- **Why not lasers?** Fog, clouds, rain and turbulence
- **Takeaway:** THz sits in the sweet spot, with laser-like capacity and radio-like robustness.

Inter-Satellite Links

- **Goal:** fast links between satellites
- **Competing technology:** laser (optical) links
- **THz beams are far easier to point: degrees, not millidegrees**
- **Above the atmosphere there is no absorption, so the channel is close to ideal**
- **Space debris blocks laser links more than it blocks THz**

Demonstrating THz in Space for the First Time

- With support from NSF, AFRL and NASA, we are launching a CubeSat to test THz communications in space
- It will carry the world's first up and down links at THz frequencies (225 GHz)

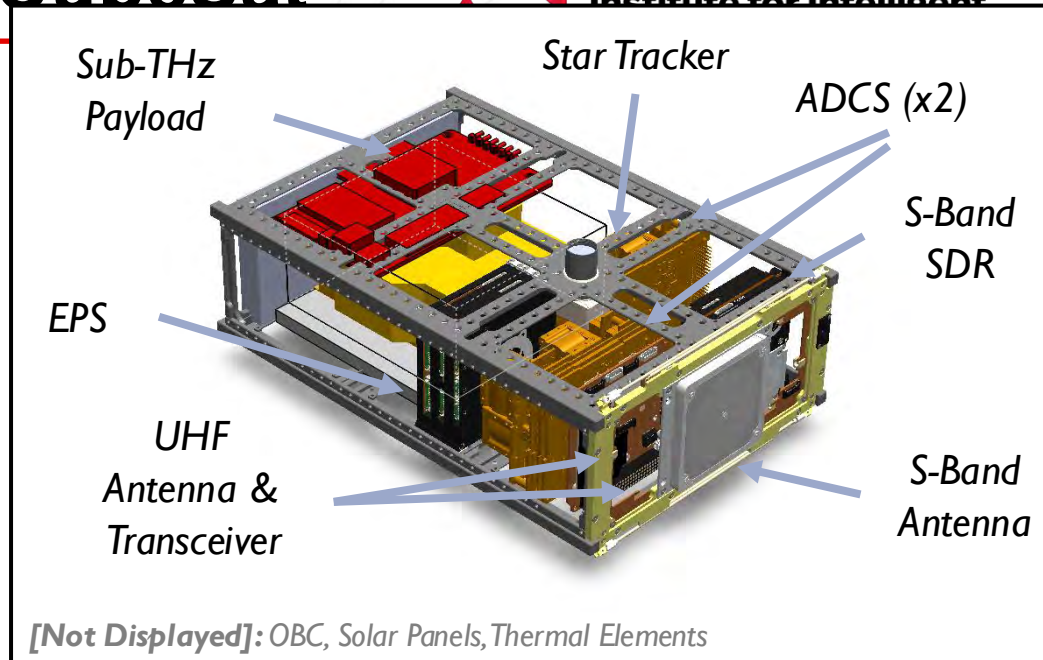


Takeaway: The first terahertz link to space is being built right here at Northeastern.

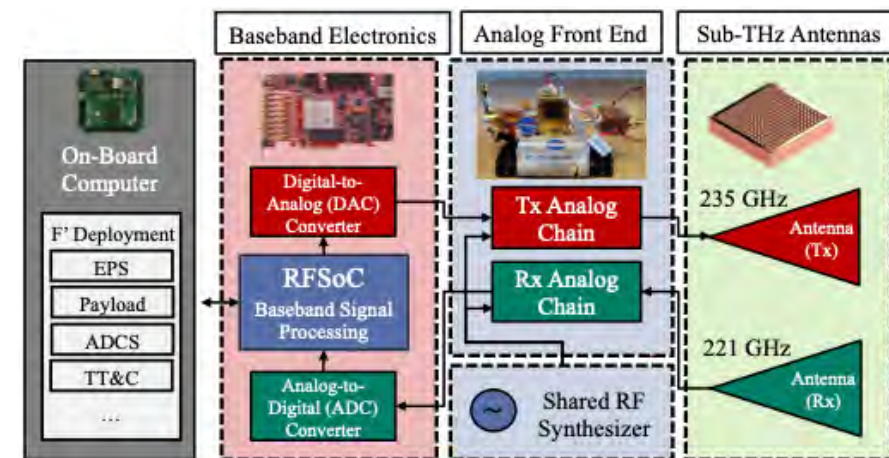
Timeline: Building and Launching the CubeSat

- **2023-2024**  **Completed**
 - Conceptual Design
 - Feasibility Analysis
- **2024-2026**  **We are here**
 - Sub-system design, implementation and verification
- **2026-2027**  **Planned stages**
 - Sub-system integration
 - Environmental testing
 - CubeSat Launch
- **2028**  **Planned stages**
 - Measure and report results

CubeSat bus



Sub-THz Payload



Takeaway: A CubeSat mission is a multi-year team effort, and students work on every stage of it.

Growing Interest for THz in Space

Federal Communications Commission

FCC 25-29

Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of	)	
	)	
Satellite Spectrum Abundance	)	SB Docket No. 25-180
	)	
Expanding Use of the 12.7-13.25 GHz Band for Mobile Broadband or Other Expanded Use	)	GN Docket No. 22-352
	)	
Shared Use of the 42-42.5 GHz Band	)	WT Docket No. 23-158
	)	
Use of Spectrum Bands Above 24 GHz For Mobile Radio Services	)	GN Docket No. 14-177
	)	

**FURTHER NOTICE OF PROPOSED RULEMAKING AND NOTICE OF PROPOSED
RULEMAKING**

Adopted: May 22, 2025

Released: May 27, 2025



SpaceX requested “W-band”
frequencies (92–114 GHz range)



**NASA JPL Deep Space Optical
Comms** team visited Northeastern
seeking collaboration to overcome
atmospheric limitations



TeraLink Technologies has *just*
demonstrated THz drone comms

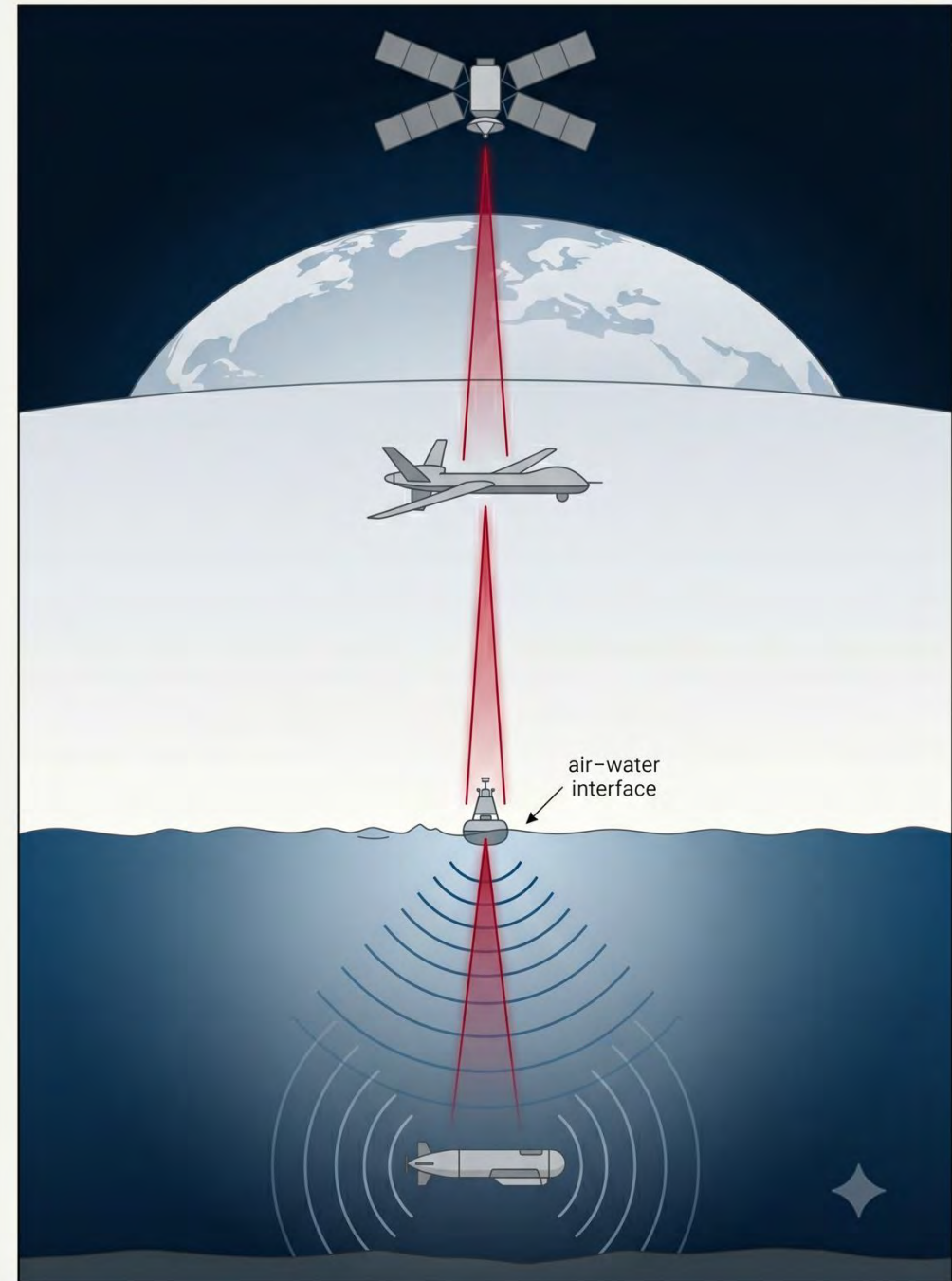


Takeaway: Industry and space agencies are moving toward THz right now, so this work is timely.

From space back down to the sea: the last unconnected frontier

From Space to the Sea

- Imagine if...the same ultrabroadband spectrum that links satellites, aircraft, and the ground could now reach beneath the ocean surface.
- The air-water interface is the last barrier. It reflects both RF and acoustic signals, isolating everything below the surface from the networks above.
- What if a single link could reach straight through it?



AquaTera: Crossing the Air-Water Interface with Sub-Terahertz Radiation



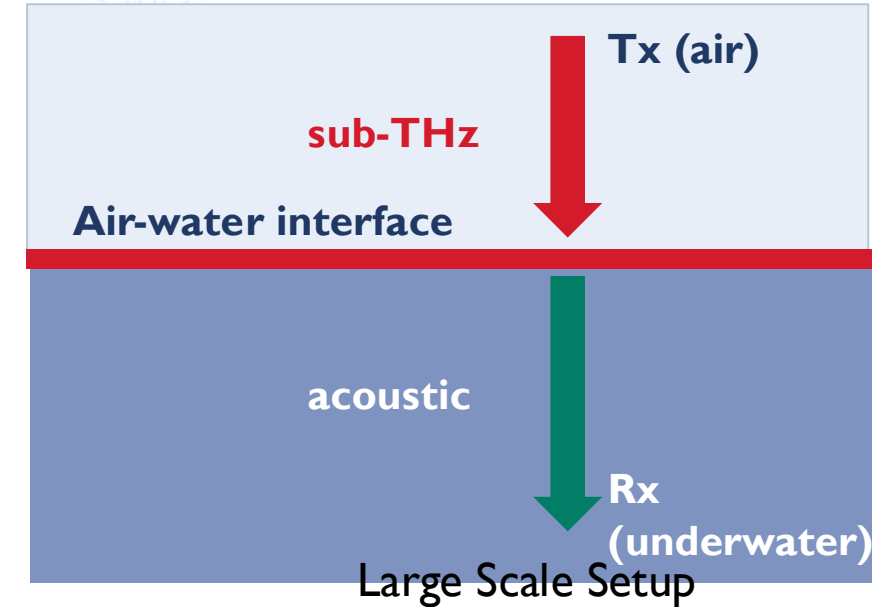
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Why it is hard to cross

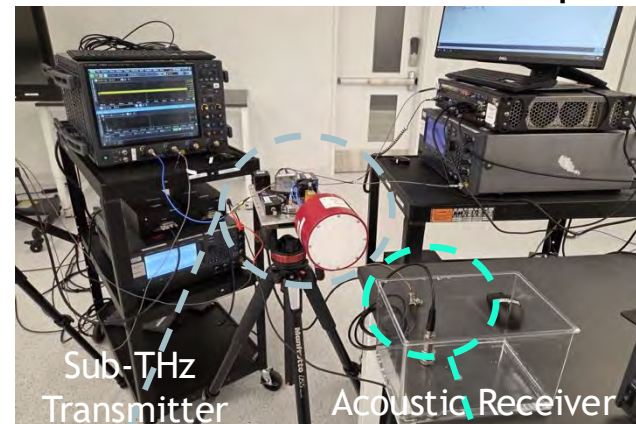
- Radio waves barely make it across the surface, and they fade fast once underwater.
- Sound bounces almost entirely off the surface, because air and water carry it so differently.

What AquaTera does

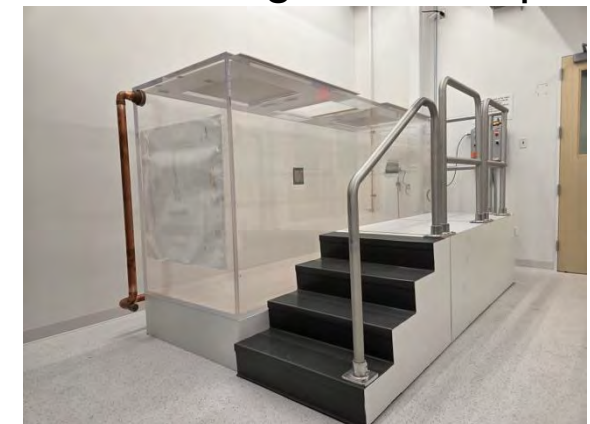
- It carries data on a sub-terahertz signal in the air, then converts it to sound at the surface.



Small Scale Setup



Large Scale Setup



A. H. Hridhon, S. Badran, J. M. Jornet, Z. Shaikhanov,
“**AquaTera: Sub-Terahertz Wireless to Enable Air-Water Communication,**” ACM HotMobile’26.

A. H. Hridhon, S. Badran, T. Soni, J. M. Jornet, Z. Shaikhanov,
“**SWAT: A Cross-Media Air-Water Communication Foundation via Sub-Terahertz Wireless to Acoustic Transduction,**” *under review, 2026.*

Takeaway: One link reaches from the air, through the surface, to a receiver underwater.

Open Research Challenges

Devices

THz radios still burn too much power and are barely reconfigurable

Channels

We need models for the near field, for rain, and for the air–water interface

Algorithms

Beam alignment under mobility, and AI-driven beam management

Sensing + comms

One waveform that is genuinely good at both jobs

Policy

Above 275 GHz there are still no satellite allocations

Takeaway: Almost every layer of the THz stack is still open, and that is the opportunity.

How Undergraduate Students Contribute



Measure

Run channel experiments in the anechoic chamber and process the data



Code

Write Python and MATLAB tools that turn raw captures into results



Build

Assemble testbed electronics, controllers and CubeSat subsystems



Model

Simulate beams, links and networks before we build them



Explain

Make the figures, posters and demos that carry the work to other people

Takeaway: You do not need a PhD to do real work here — you need curiosity and persistence.

From First-Year Student to Researcher

- Year 1, get in the door: take the intro course, visit the lab, email a professor, join as a volunteer or work-study student
- Year 1-2, learn the tools: Python, MATLAB, Git, basic signal processing; shadow a PhD student on a real setup
- Year 2-3, own a piece: a genuine subtask, such as calibrating a THz receiver or automating a measurement
- Year 3-4, contribute results: co-author a paper, present a poster at RISE, apply for a PEAK award or fellowship
- After graduation: graduate school, a national lab, or industry research and development
- Takeaway: Every researcher in this lab started by asking one question and staying with it.

Research Opportunities for Students

- Pathways in the UN Lab: volunteer, work-study, PEAK award, co-op, honors thesis, REU summer research
- Example projects: THz channel measurements; CubeSat payload testing; beam-steering software; AI for beam management; maritime link modeling
- Skills you can learn: wireless communications, AI and machine learning, embedded systems, networking, sensing, space communications
- How to start: email me with your year, the courses you have taken, and one thing you are curious about
- Contact: j.jornet@northeastern.edu | www.unlab.tech | [add lab visit / office hours link]



Thank you!

