Terahertz wireless communications: A photonics approach

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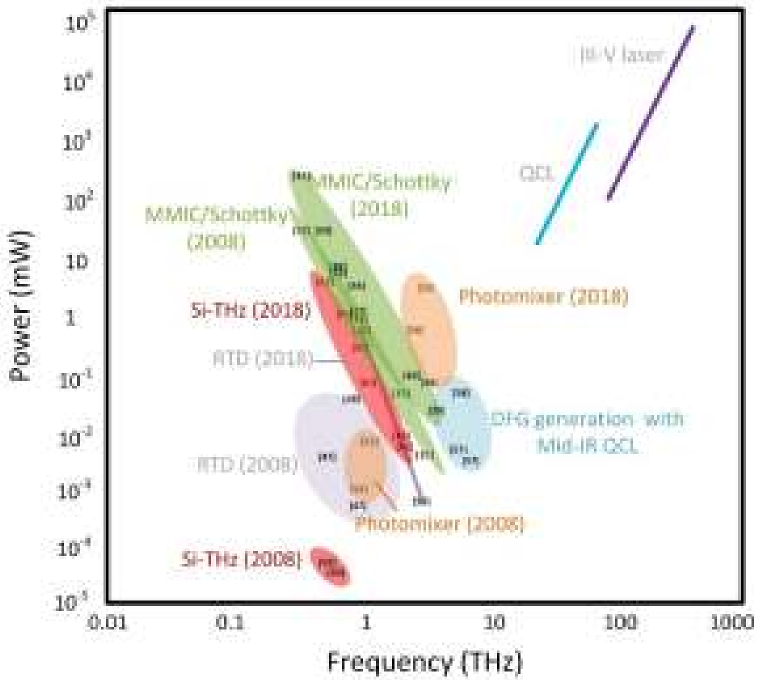
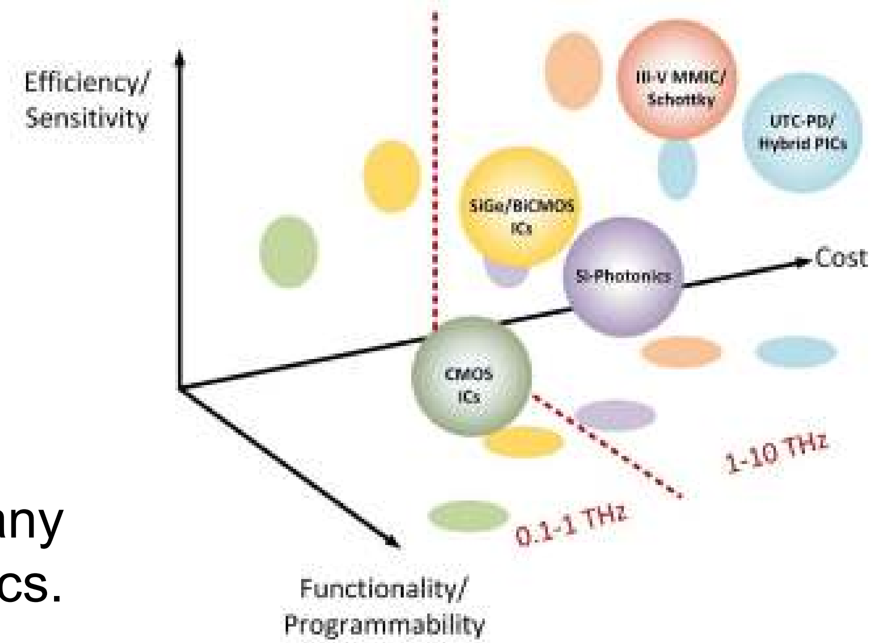
BROWN

THz systems: an ongoing merger of electronics and photonics



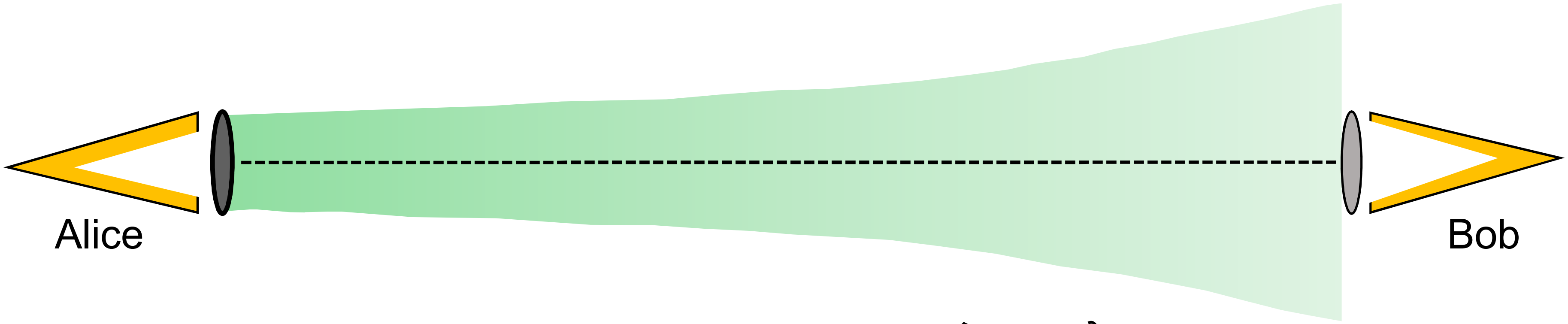
Lots of progress in recent years in some key metrics…



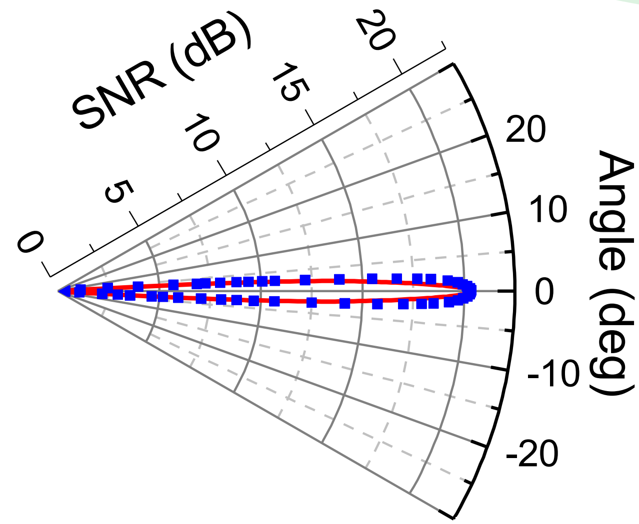
…but there are many important metrics.

K. Sengupta, T. Nagatsuma, & D. Mittleman, *Nature Electronics*, 1, 622 (2018).

THz links are highly directional



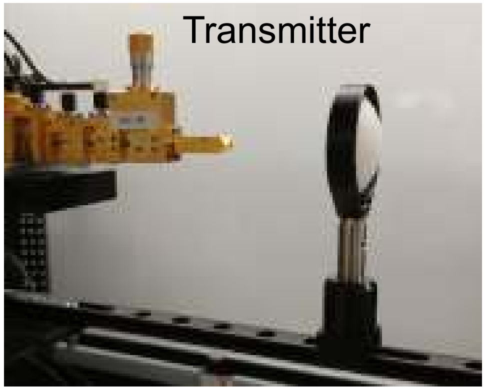
Signals which propagate as beams, not broadcasts, can often conveniently be considered in the context of optics.

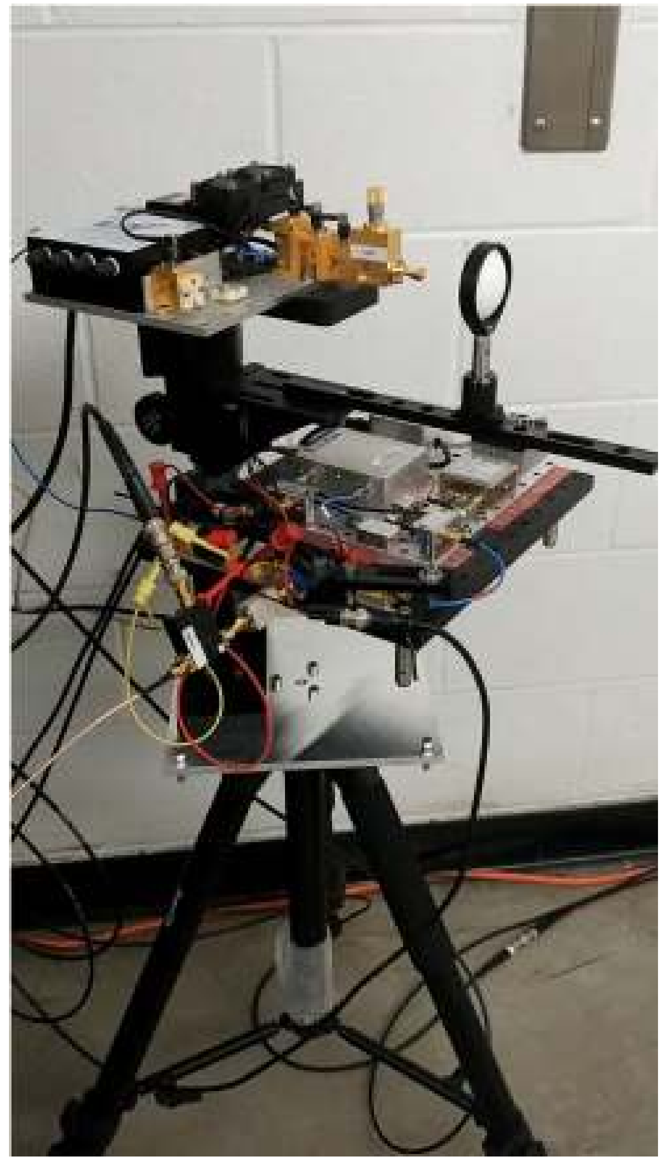


Brown University test bed:

Frequency	100 GHz	200 GHz	400 GHz
Directivity	28 dBi	34 dBi	42 dBi
Angular width	7.8º	4.0º	1.6º

THz wireless test bed at Brown University



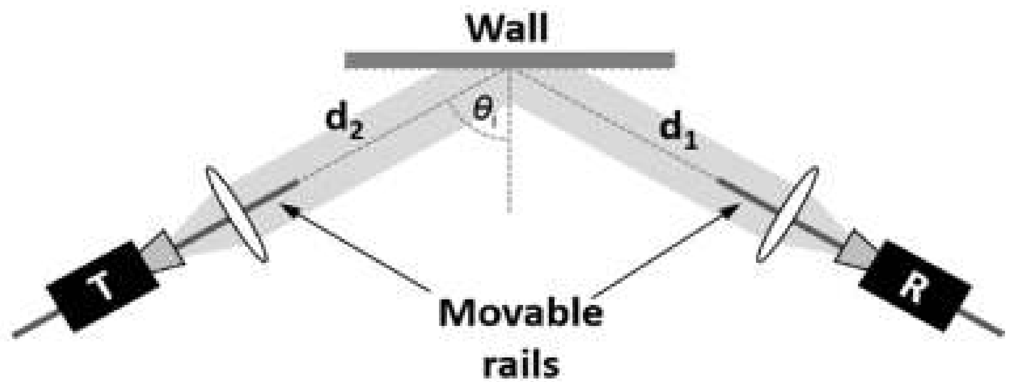


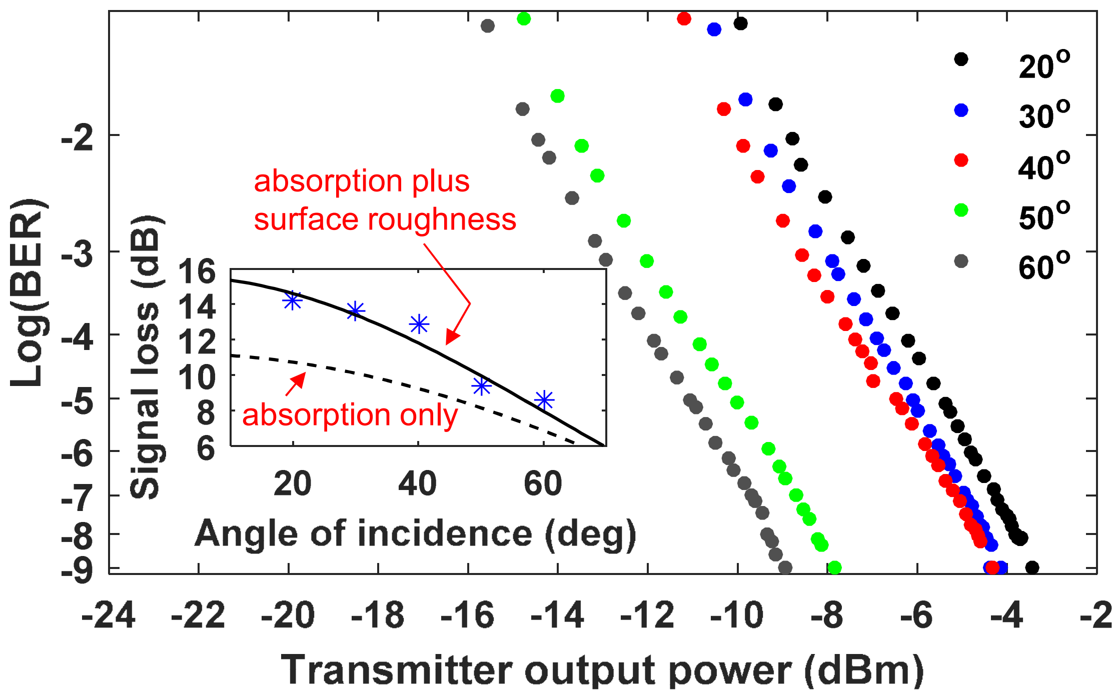
Carrier Frequency	100 GHz	200 GHz	400 GHz
IF frequency	1 GHz		
LO frequency	12.25 GHz		
PRBS	$2^7 - 1$		
Max. Tx output power	24 dBm	20 dBm	10 dBm
Tx/Rx antenna gain	21 dB	21 dB	26 dB
Tx beam directivity (angular full-width)	28 dBi (7.8°)	34 dBi (4°)	42 dBi (1.6°)
Detector responsivity	2400 V/W	6200 V/W	1700 V/W
Detector NEP	3 pW/√Hz	3 pW/√Hz	1.9 pW/√Hz
Tx/Rx polarization	vertical		

Brown University: Two-year experimental license from FCC for outdoor tests up to 400 GHz

Reflections off a wall

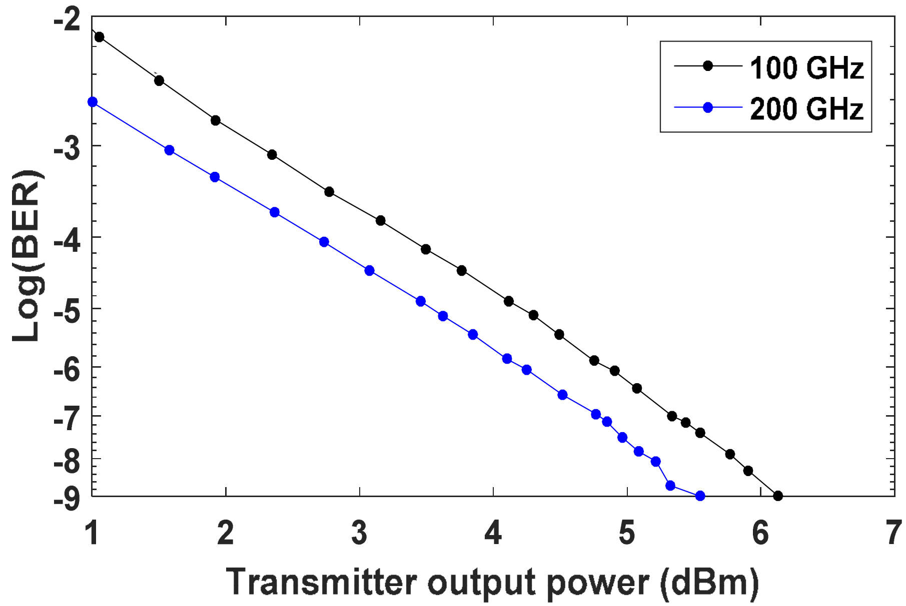
Model accounts for
- absorption
- surface roughness

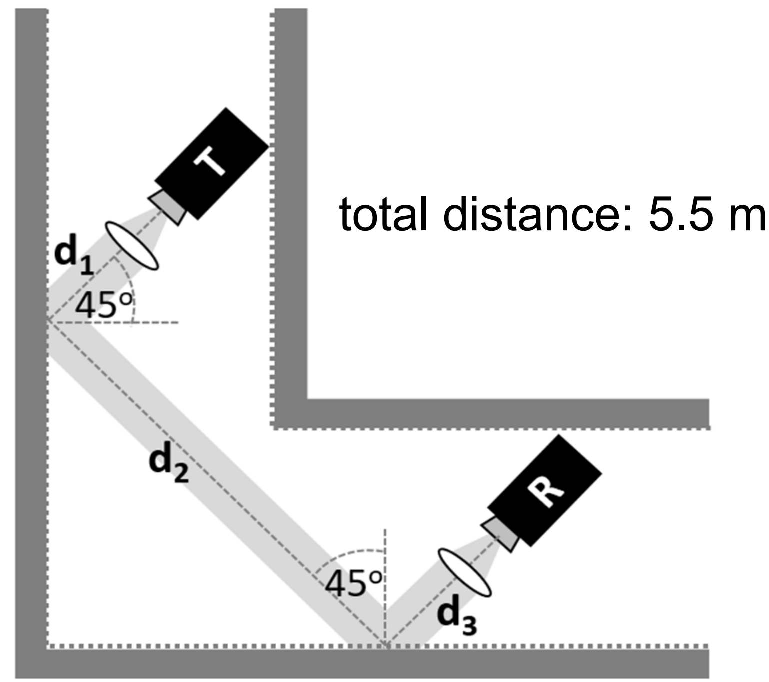




J. Ma, et al., *APL Photonics*, **3**, 051601 (2018)

Non-line-of-sight links

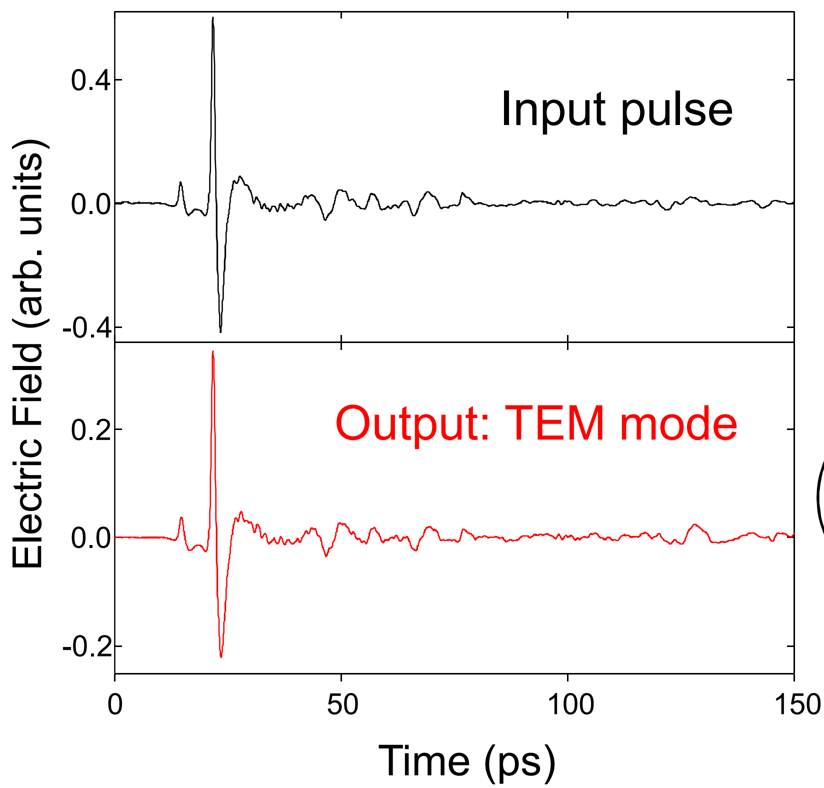


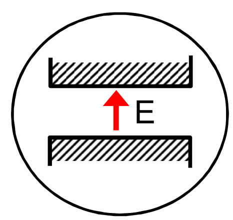


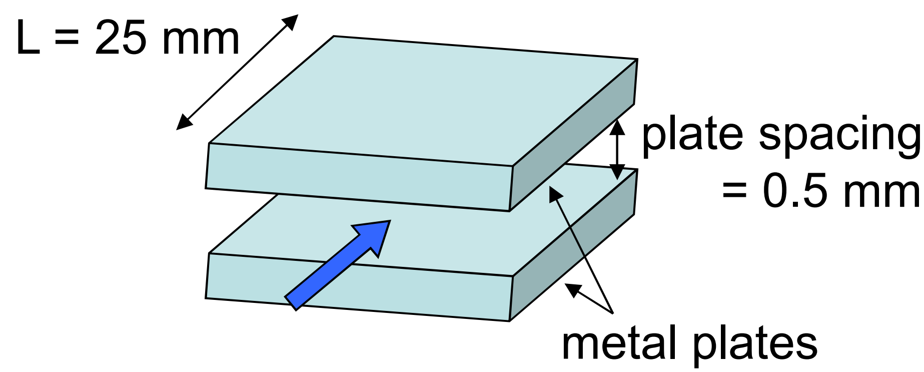
Specular non-line-of-sight links are surprisingly robust in indoor environments.

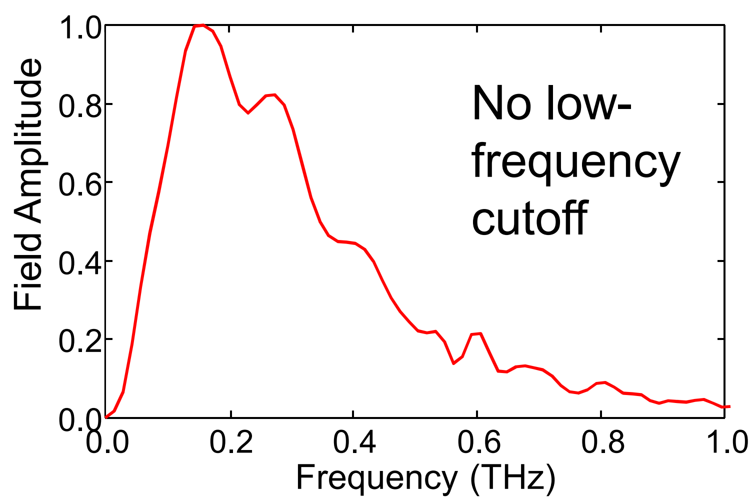
J. Ma, et al., *APL Photonics*, **3**, 051601 (2018)

Metal parallel-plate waveguides: a platform for terahertz devices



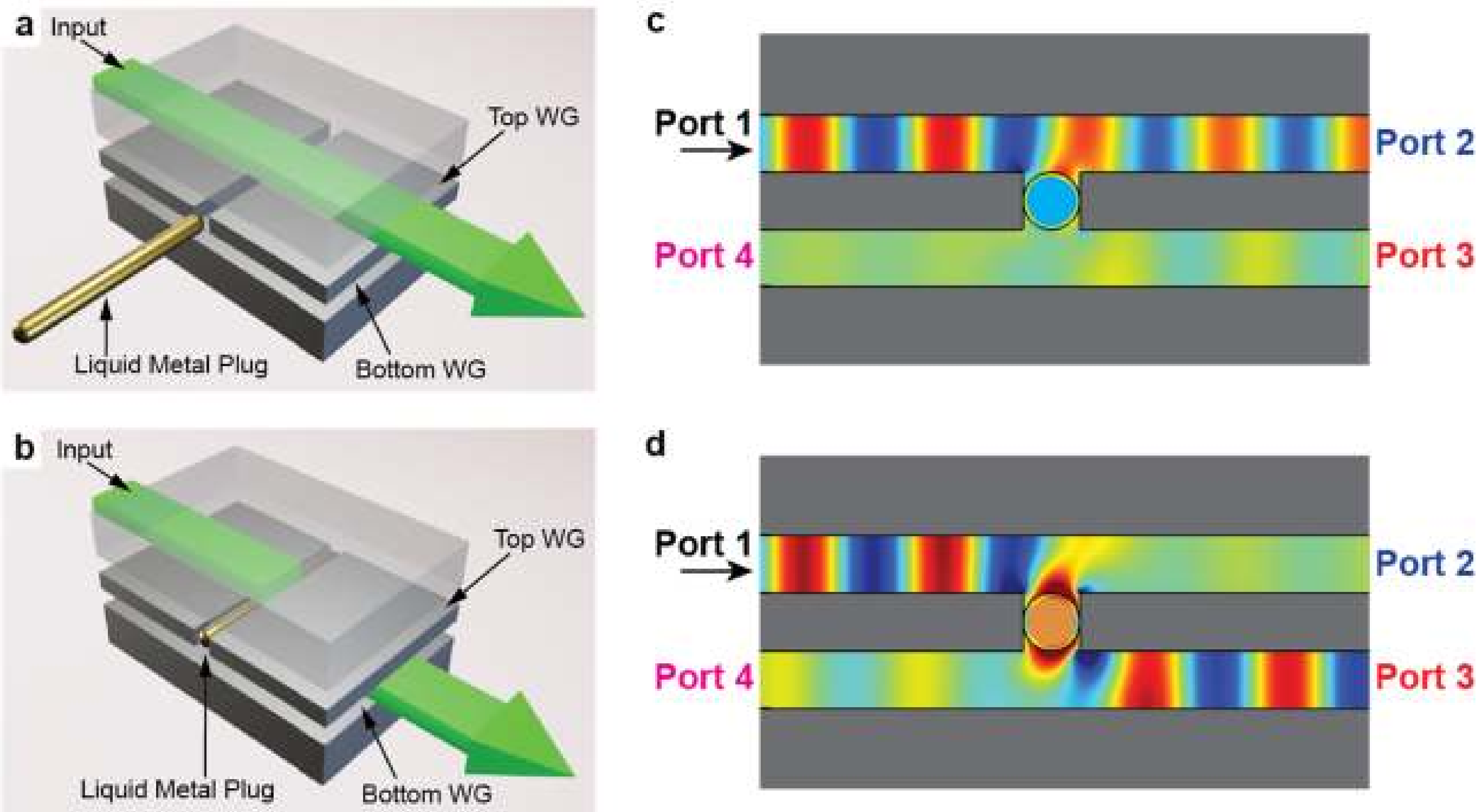






R. Mendis and D. Mittleman,
Opt. Express, **17**, 14839 (2009).

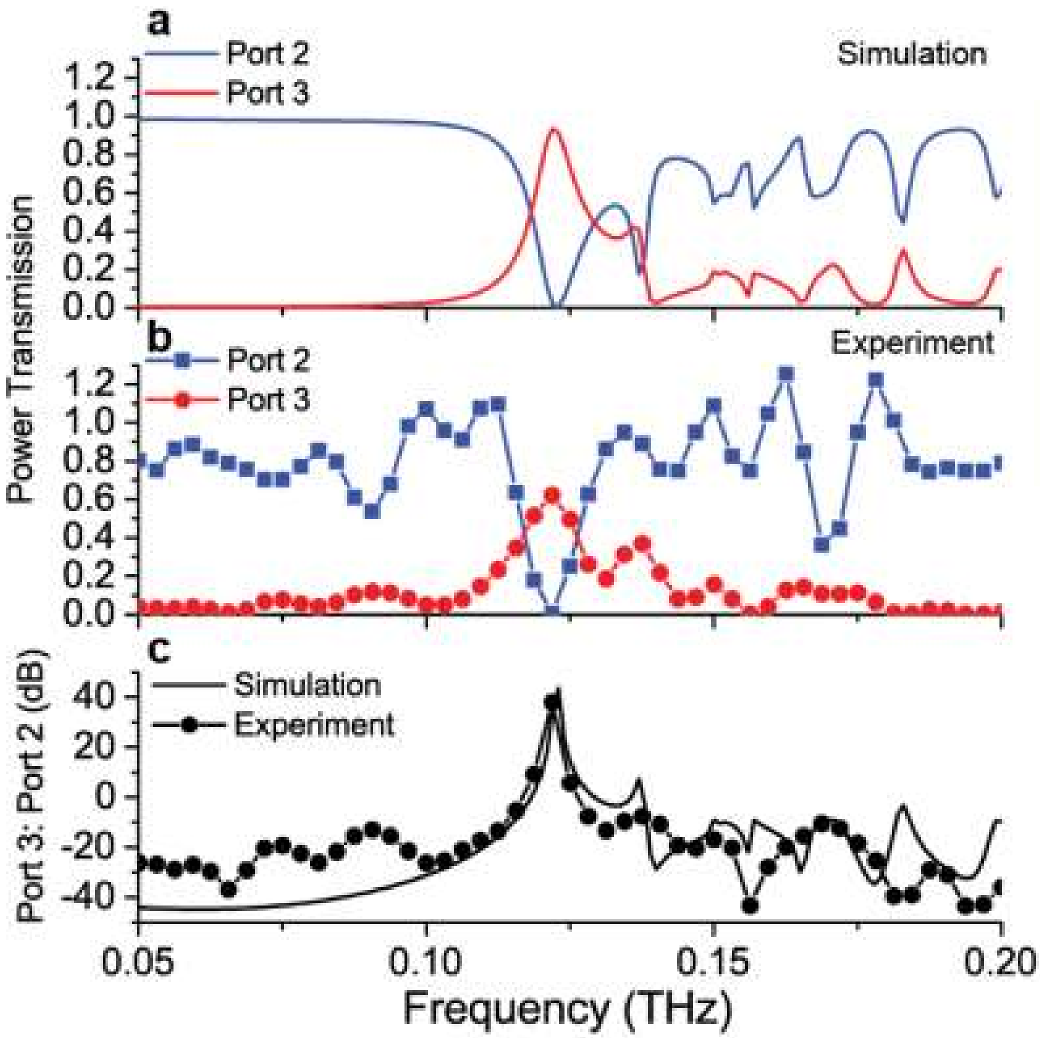
Coupling two waveguides together

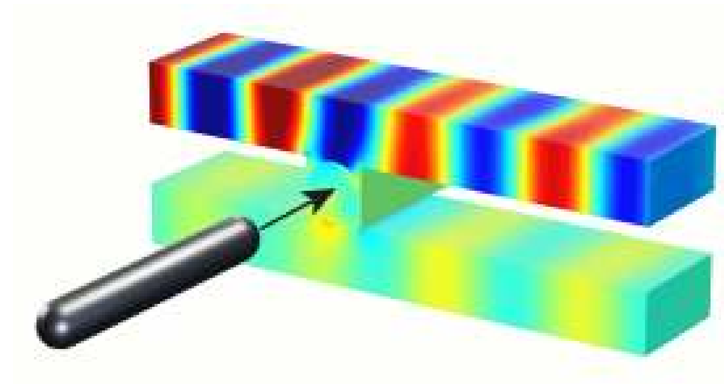


Key component: electrically actuated liquid metal plug

Collaboration with: M. D. Dickey, North Carolina State University

Electrically actuated filter at 120 GHz





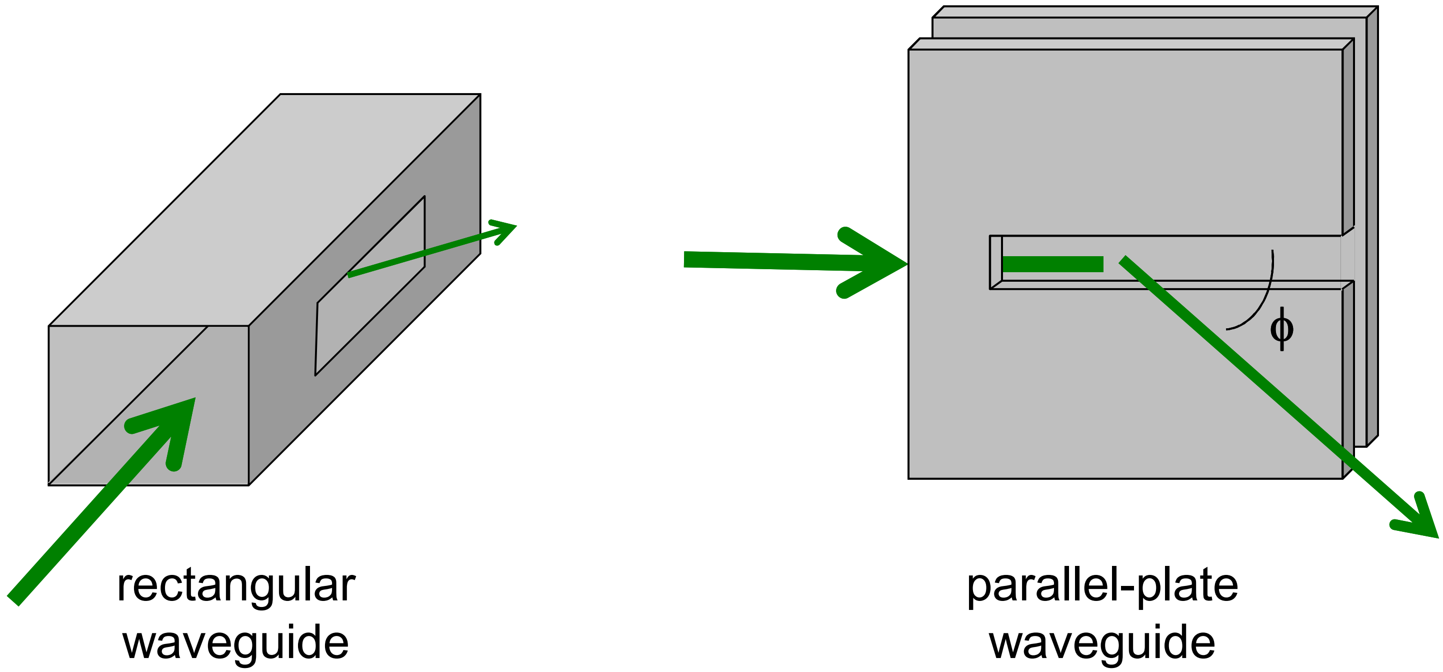
Resonant coupling between two adjacent waveguides.

Frequency determined by geometry of coupling region – a classic problem in optics!

K. Reichel, et al. *Nature Commun.* **9**, 4202 (2018)

Leaky wave devices: a candidate for multiplexing

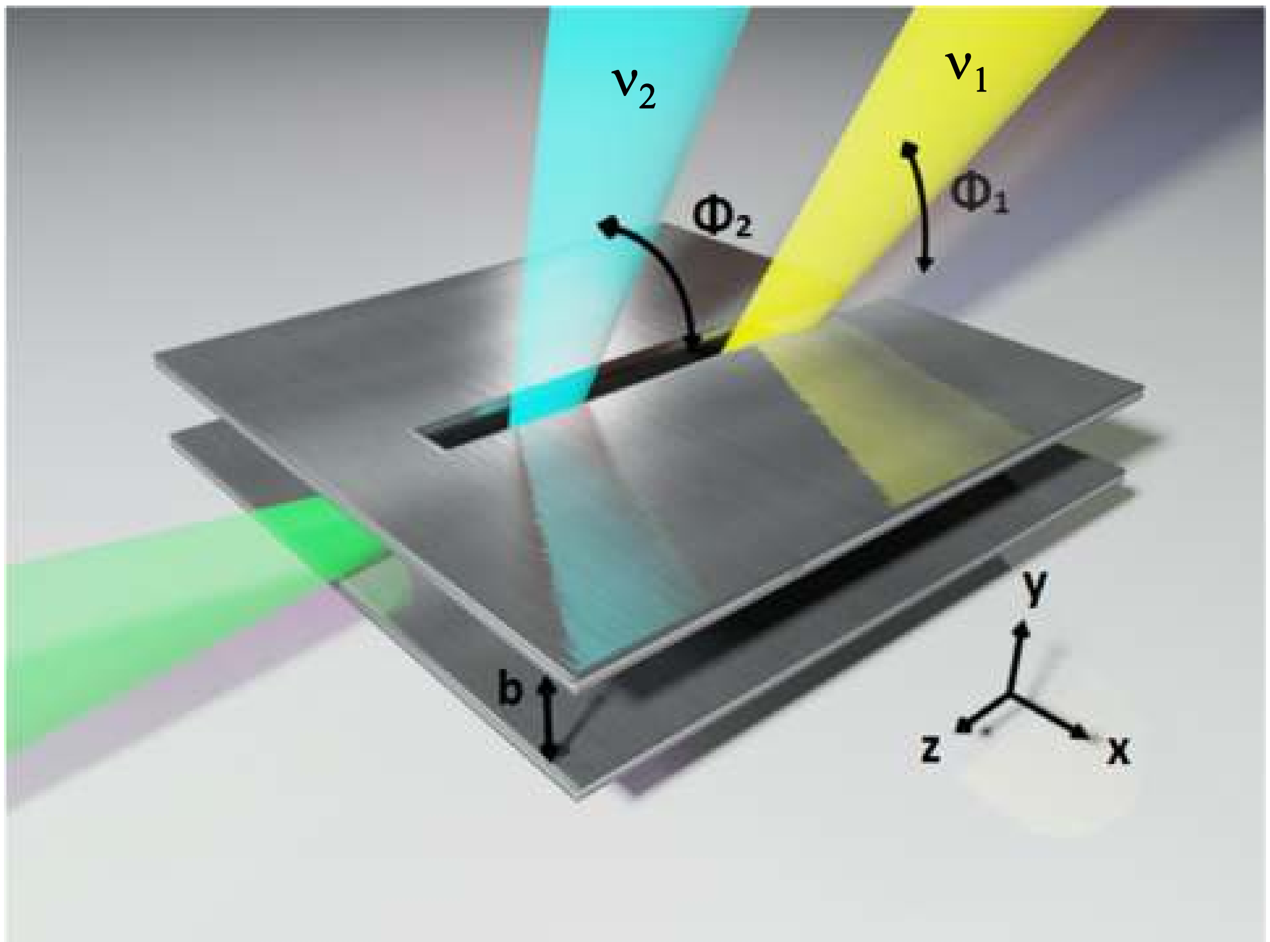
A guided wave device with an opening so that some energy can "leak" out…



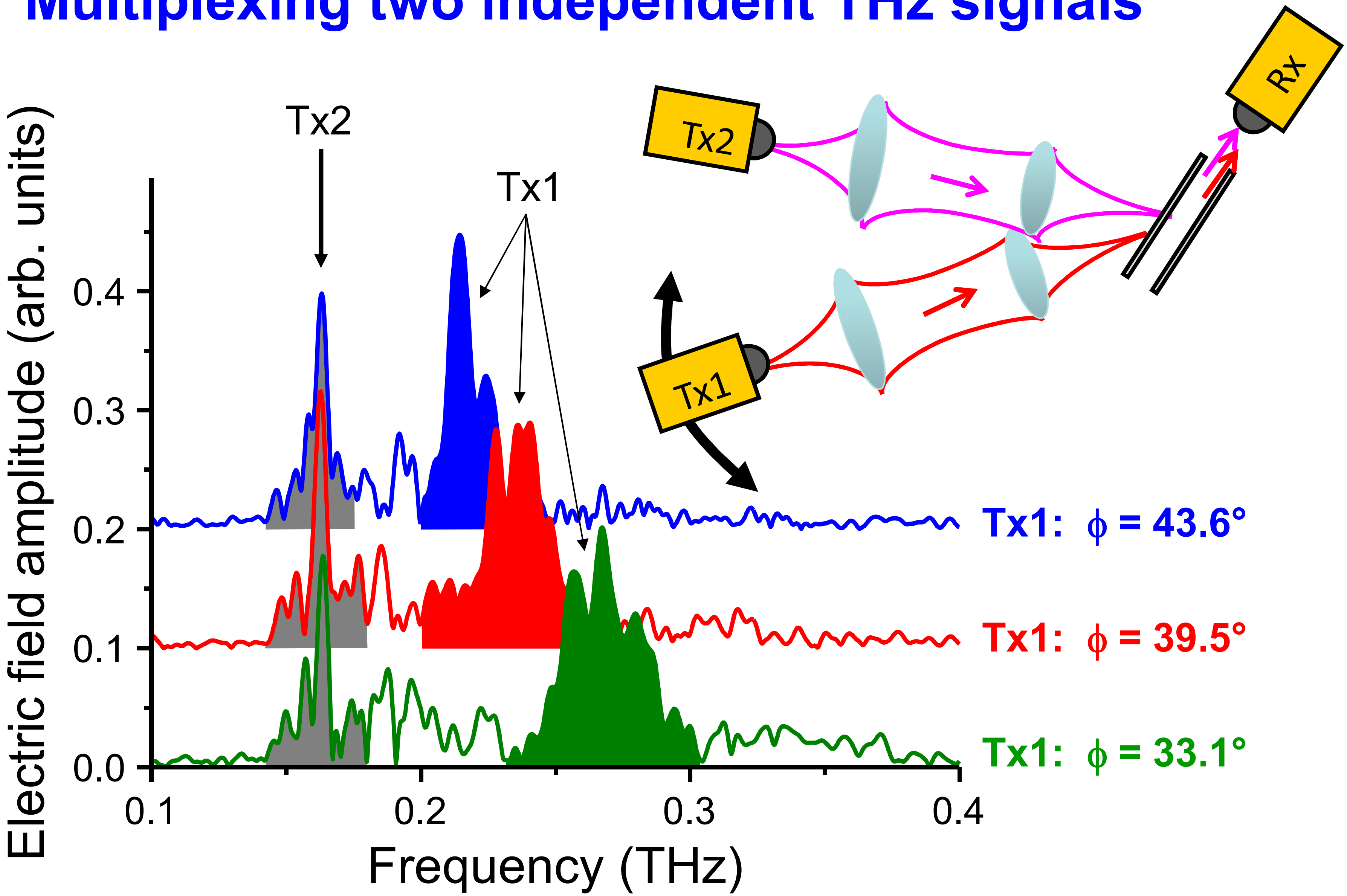
For this to work, the guided mode must be a <u>fast wave</u>, with $v_{phase} > c_0$ → TE waveguide mode

Multiplexing: the idea

Terahertz signals are highly directional. Distinct frequencies can be associated with distinct propagation directions.

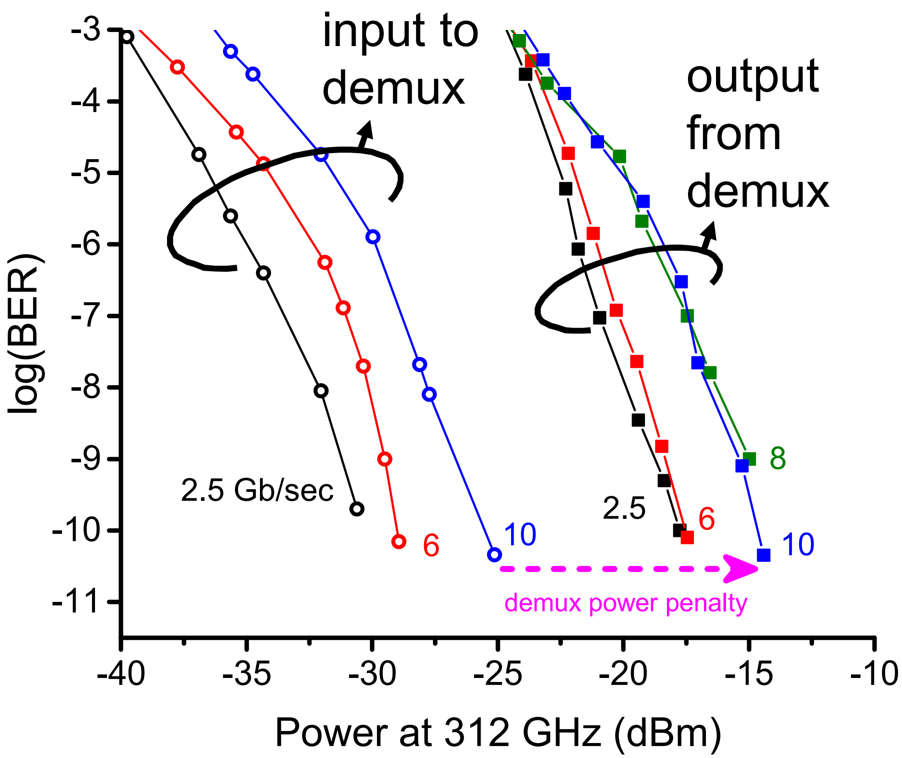


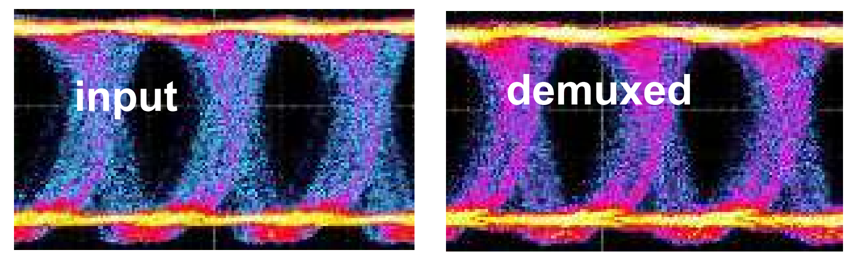
Multiplexing two independent THz signals



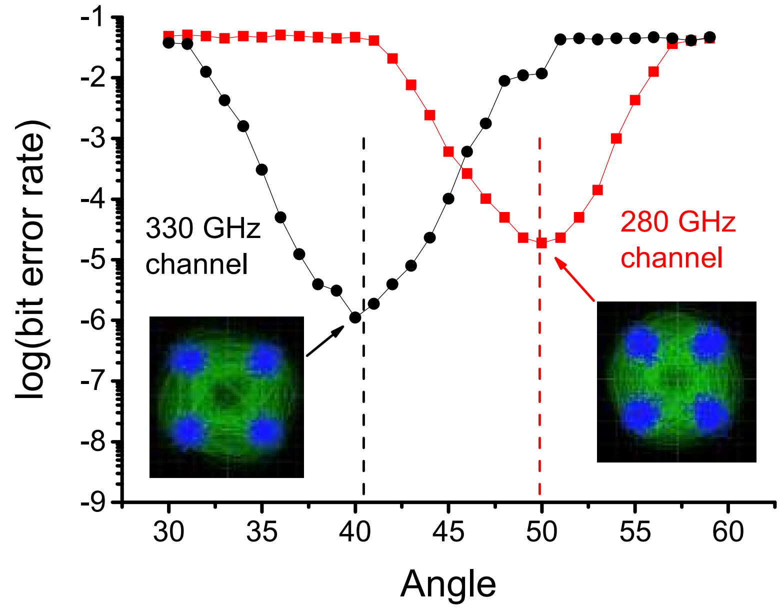
N. Karl, et al., *Nature Photonics*, **7**, 717 (2015)

Multiplexing two independent THz signals





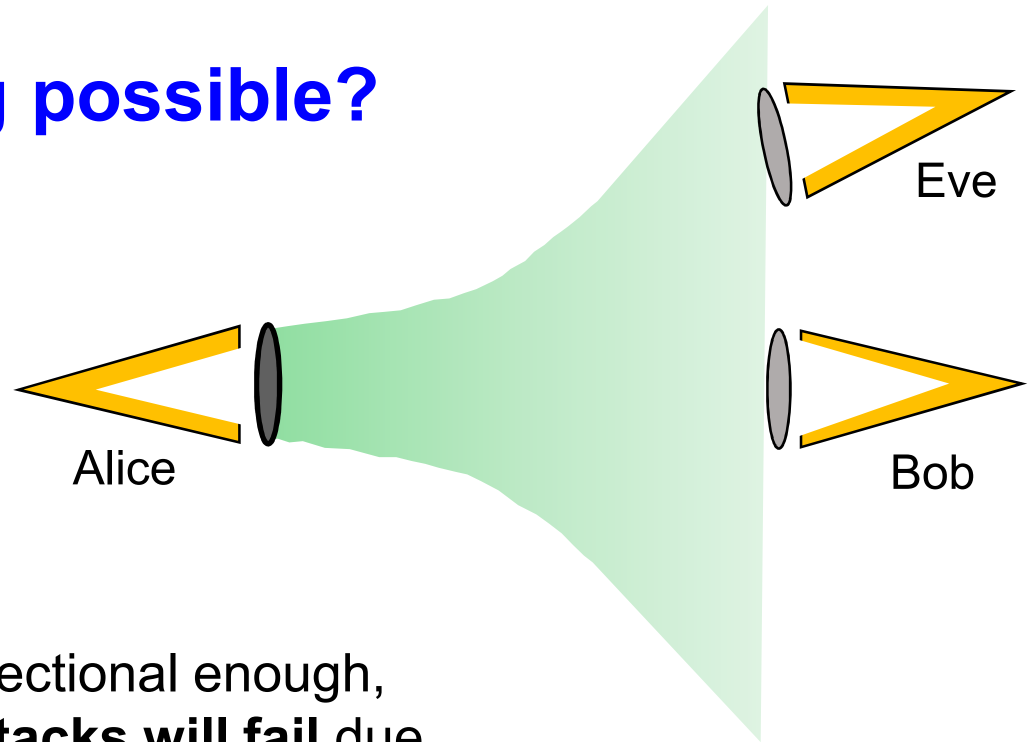
Up to 50 Gbit/sec!



J. Ma, G. Ducournau, et al., *Nature Commun.* **8**, 729 (2017).

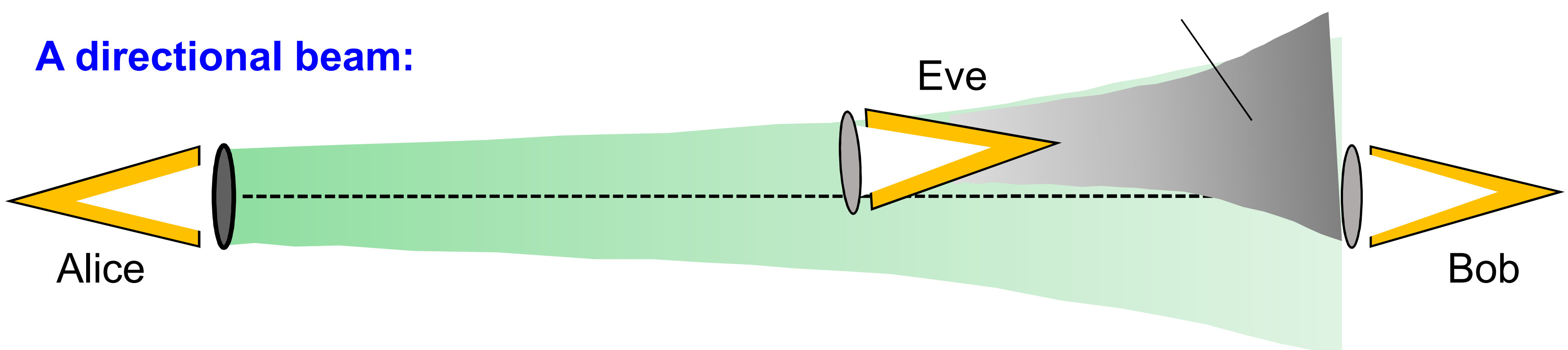
Is eavesdropping possible?

A wide-angle broadcast:

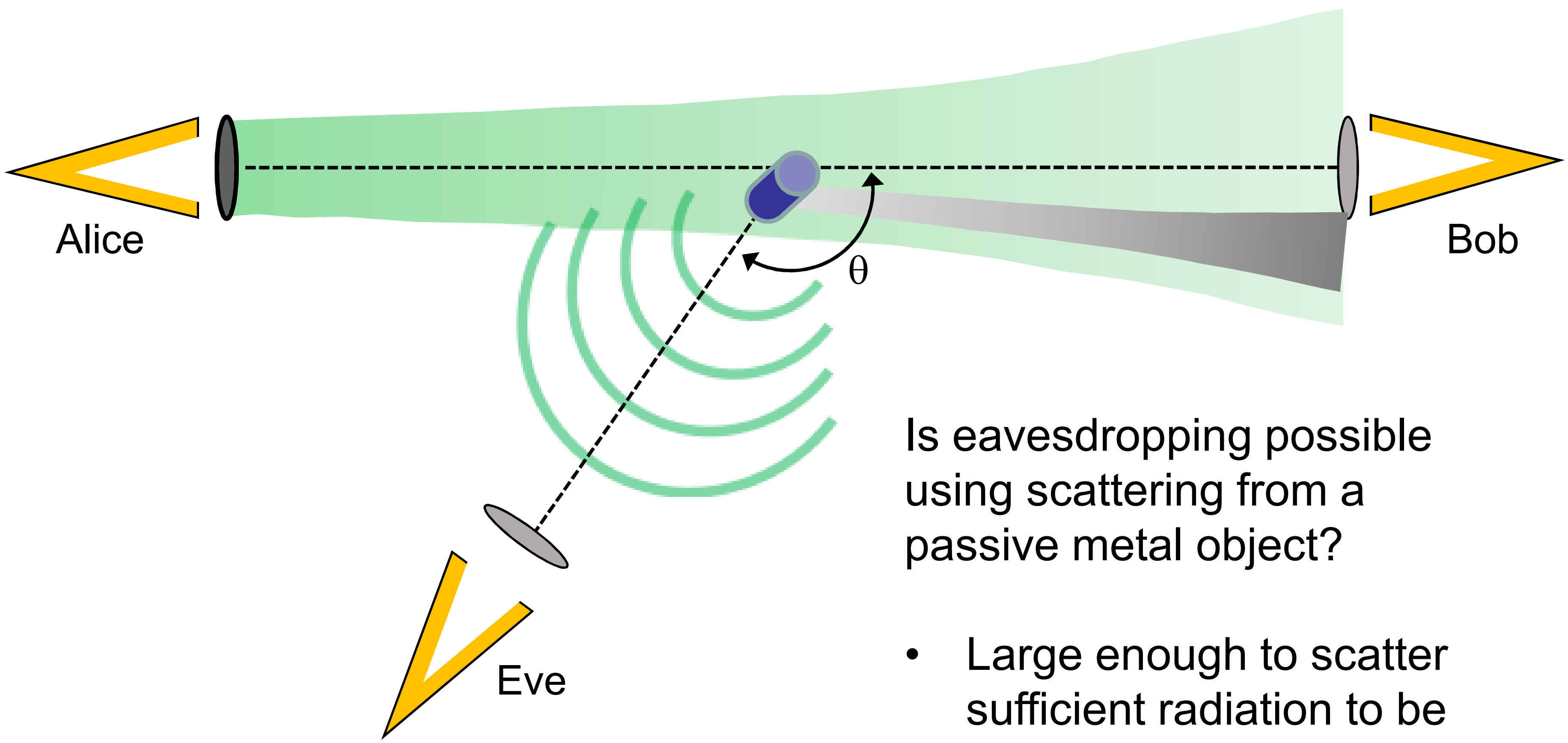


If the beam is directional enough, **conventional attacks will fail** due to blockage of the intended receiver.

A directional beam:



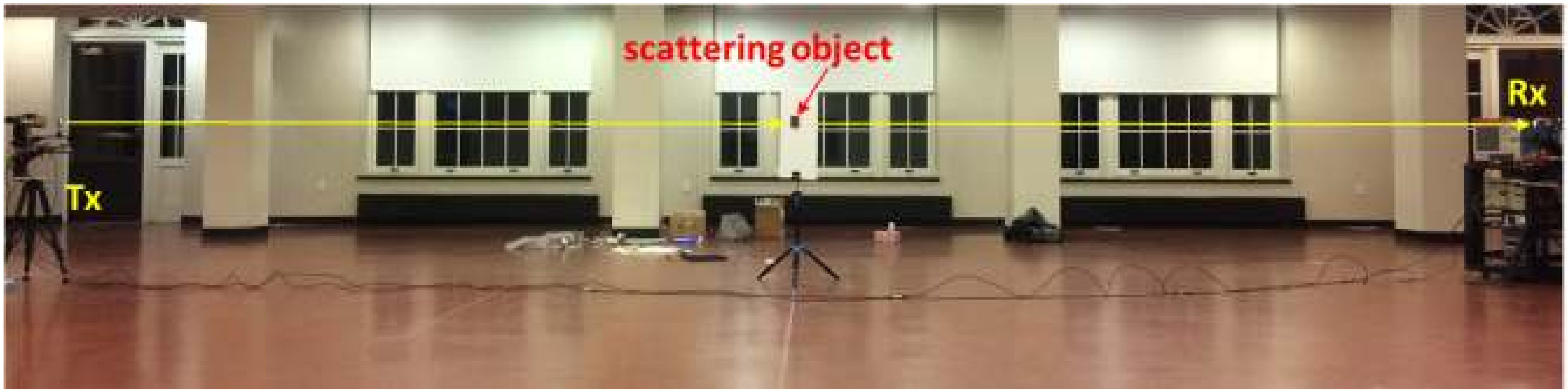
Directional THz links: eavesdropping



Is eavesdropping possible using scattering from a passive metal object?

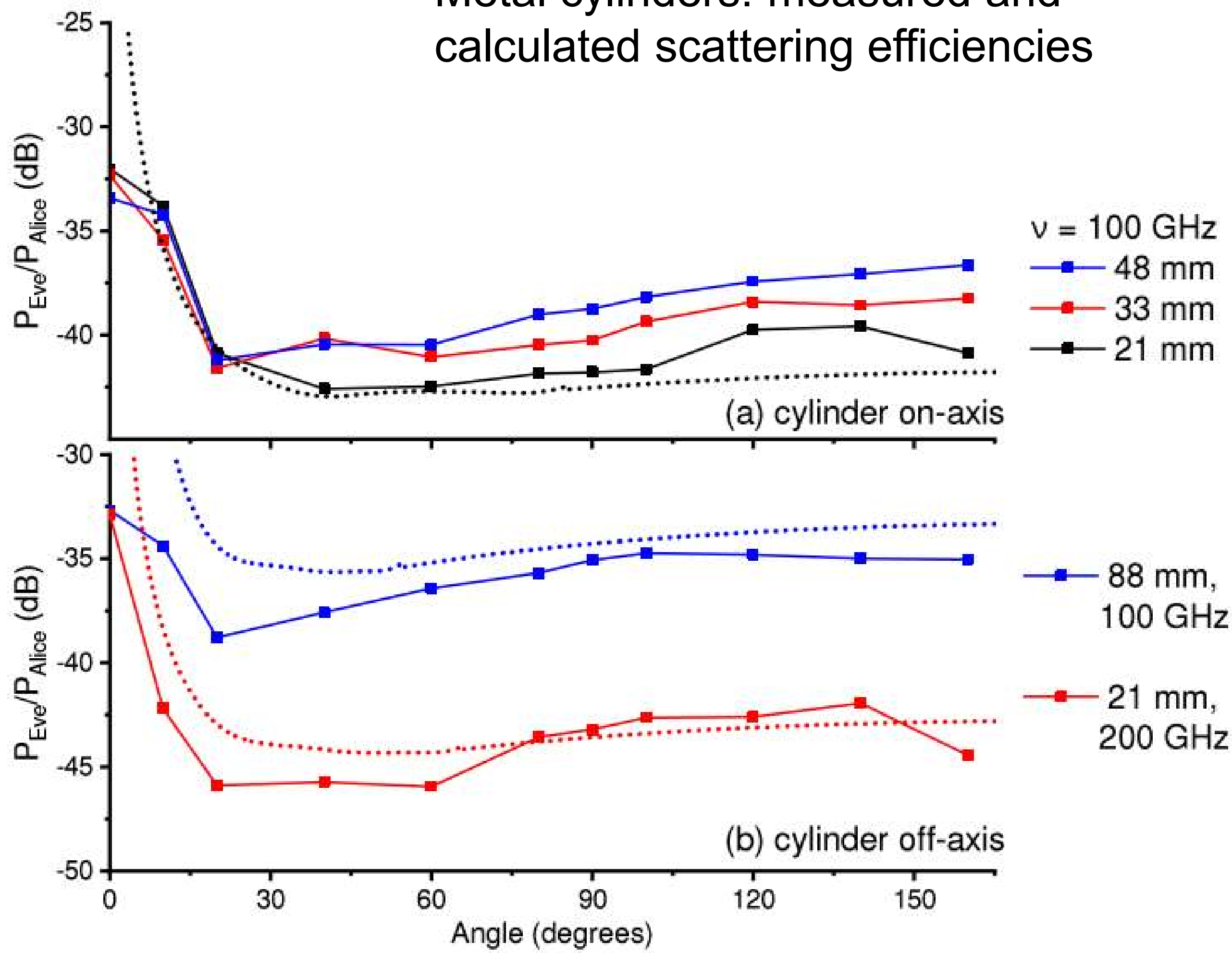
- Large enough to scatter sufficient radiation to be detected
- Small enough to avoid casting a shadow on Bob

Eavesdropping test bed



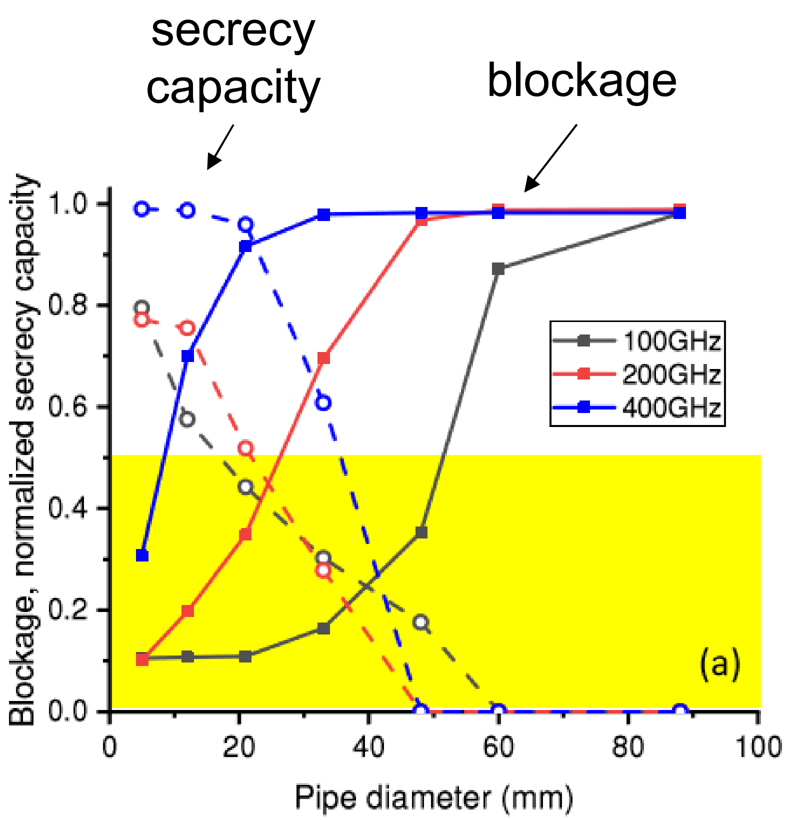
Directional THz links: measuring scattered light

Metal cylinders: measured and calculated scattering efficiencies

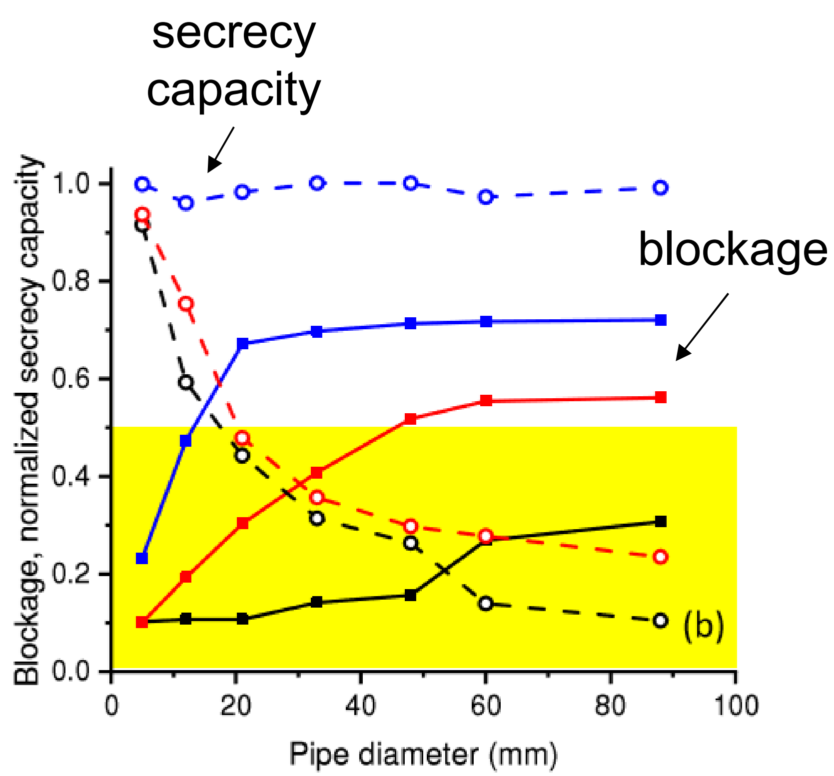


J. Ma, et al., *Nature*, **563**, 89 (2018)

Directional THz links: blockage, secrecy capacity



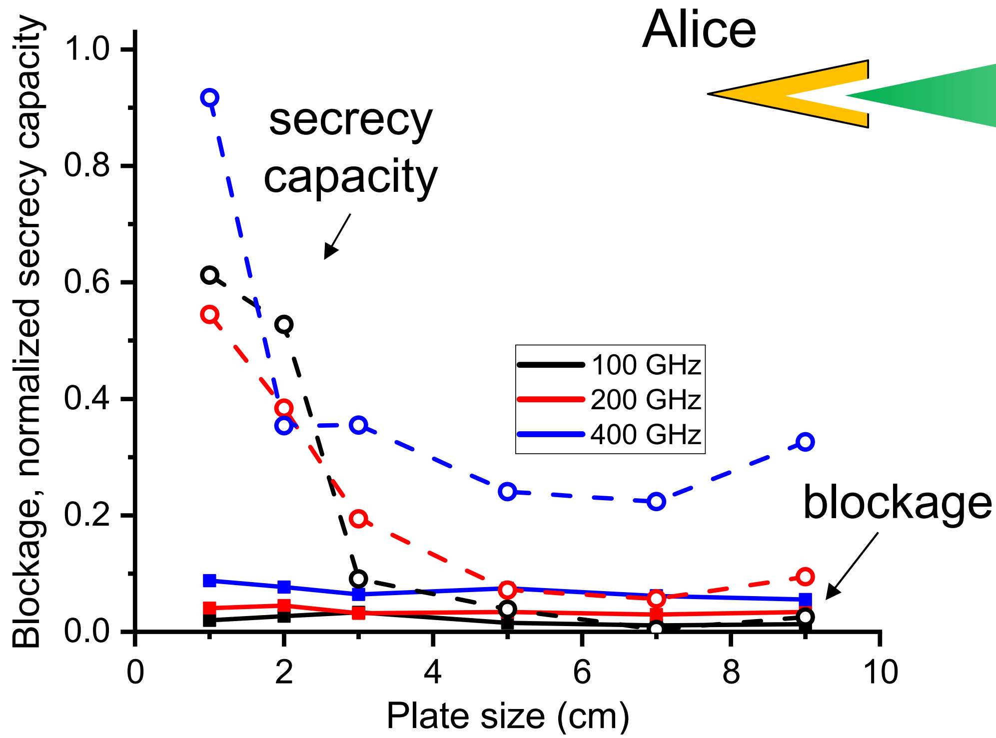
On axis

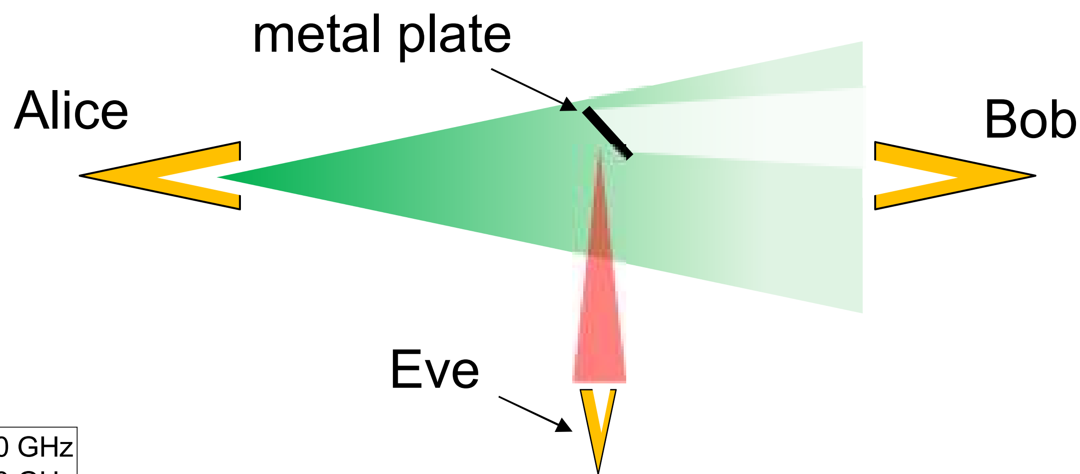


Off axis

J. Ma, et al., *Nature*, **563**, 89 (2018)

Directional THz links: blockage, secrecy capacity

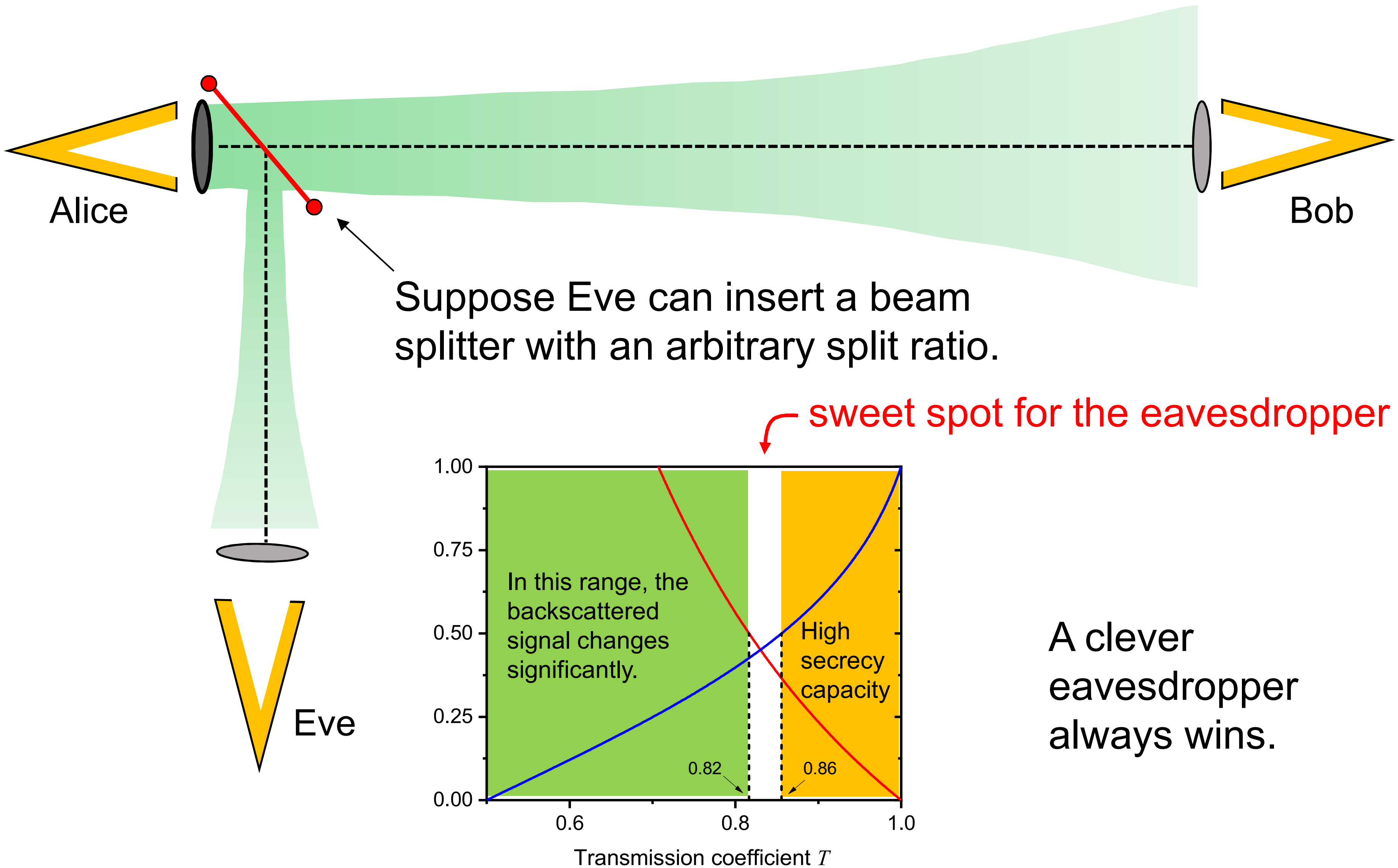




Metal plates: even more effective
(although Eve has less freedom)

J. Ma, et al., *Nature*, **563**, 89 (2018)

Eavesdropping using a tuned beam splitter



A clever eavesdropper always wins.

J. Ma, et al., *Nature*, **563**, 89 (2018)

Conclusions

- THz communications: will be inevitable
- **Many** challenges remain
- THz links: this is not merely ‘microwaves with a few extra zeros.’ Things are fundamentally different.
- Channel characteristics: there is still a lot of ‘conventional wisdom’ that needs correcting.
- Borrowing ideas from optics: very inspiring!

Funding: