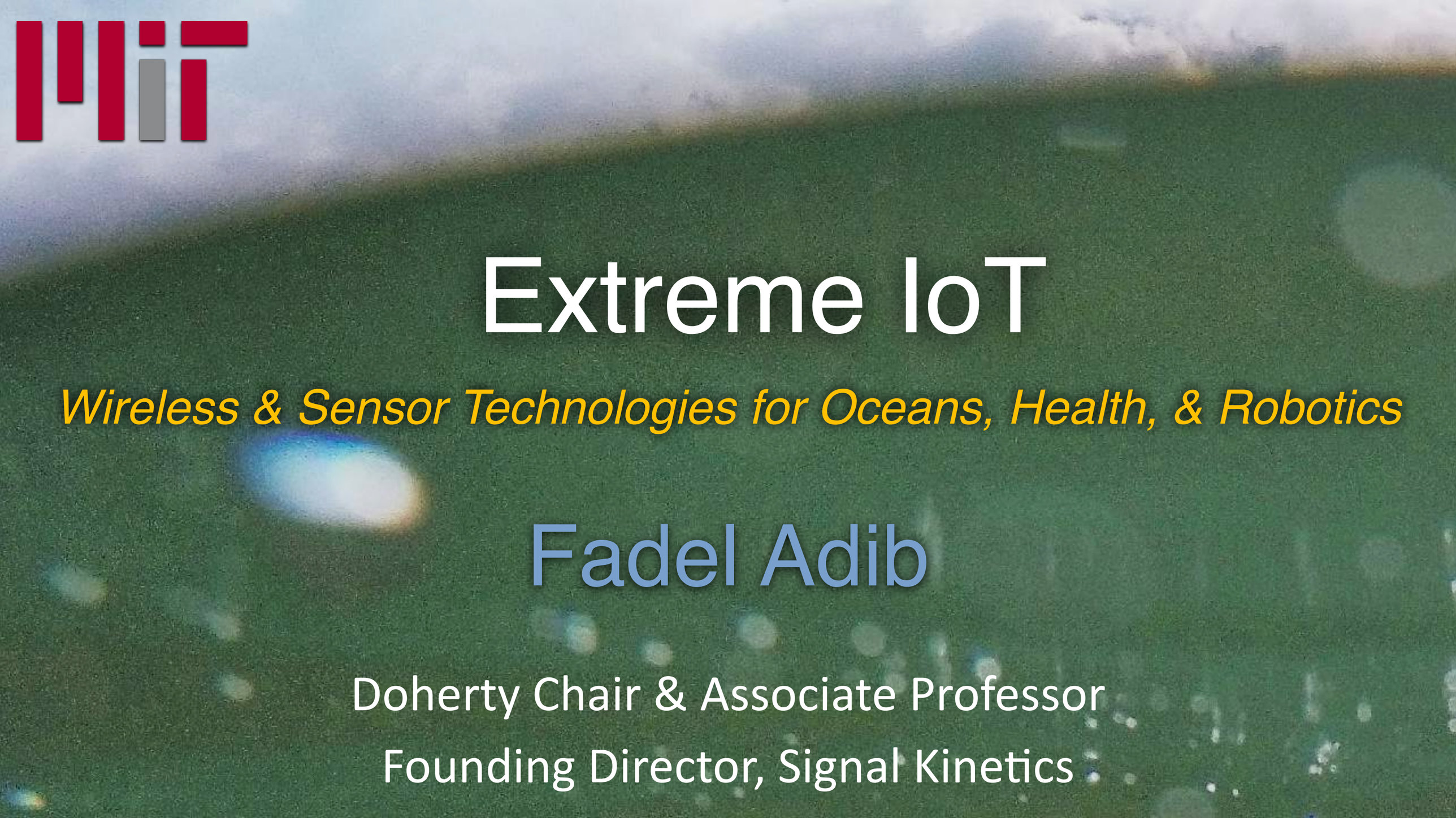


Extreme IoT

Wireless & Sensor Technologies for Oceans, Health, & Robotics

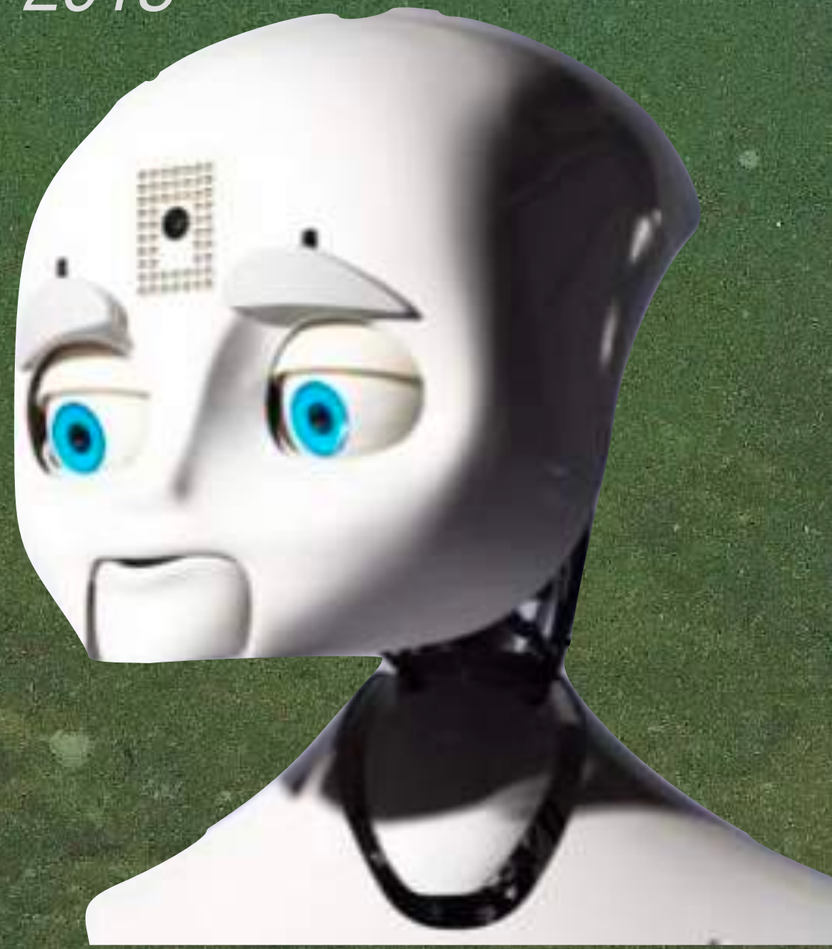
Fadel Adib

Doherty Chair & Associate Professor

Founding Director, Signal Kinetics

“More than 80% of ocean remains unobserved and unexplored.”

- NOAA, 2018

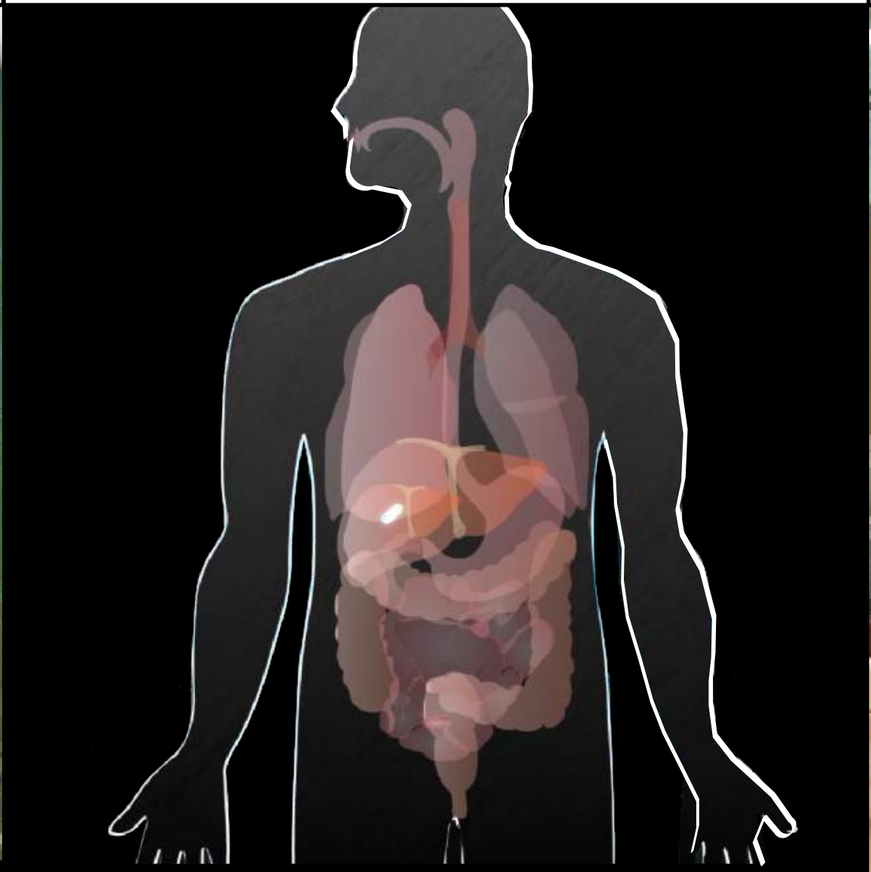


This Talk:
Extreme IoT & Sensor Technologies

Oceans

[SIGCOMM ’18a, SIGCOMM ’19, SIGCOMM’20, OCEANS’20, HotNets’20]

Human Body



[ACM SIGCOMM ’18b, MobiCom’20a, MobiCom’20b, ACM IMWUT’21]

Robotics

[ACM SIGCOMM’17, MobiCom’17, NSDI’19, NSDI ’20, IEEE ICRA’21]

Oceans

Taking the Internet of Things Underwater

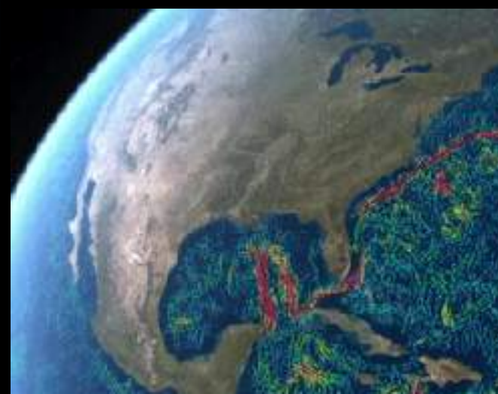
"More than 80% of ocean remains unobserved and unexplored."

- NOAA, 2018

Less than 1 in a million of IoT is underwater, even though oceans cover more than 70% of the planet

Aquaculture is the "fastest growing food sector"

- UN Food & Ag org, 2010



Problem: Battery life of underwater sensors is extremely limited

Low-power underwater transmitters consume 10s-100s of Watts and cannot be recharged easily

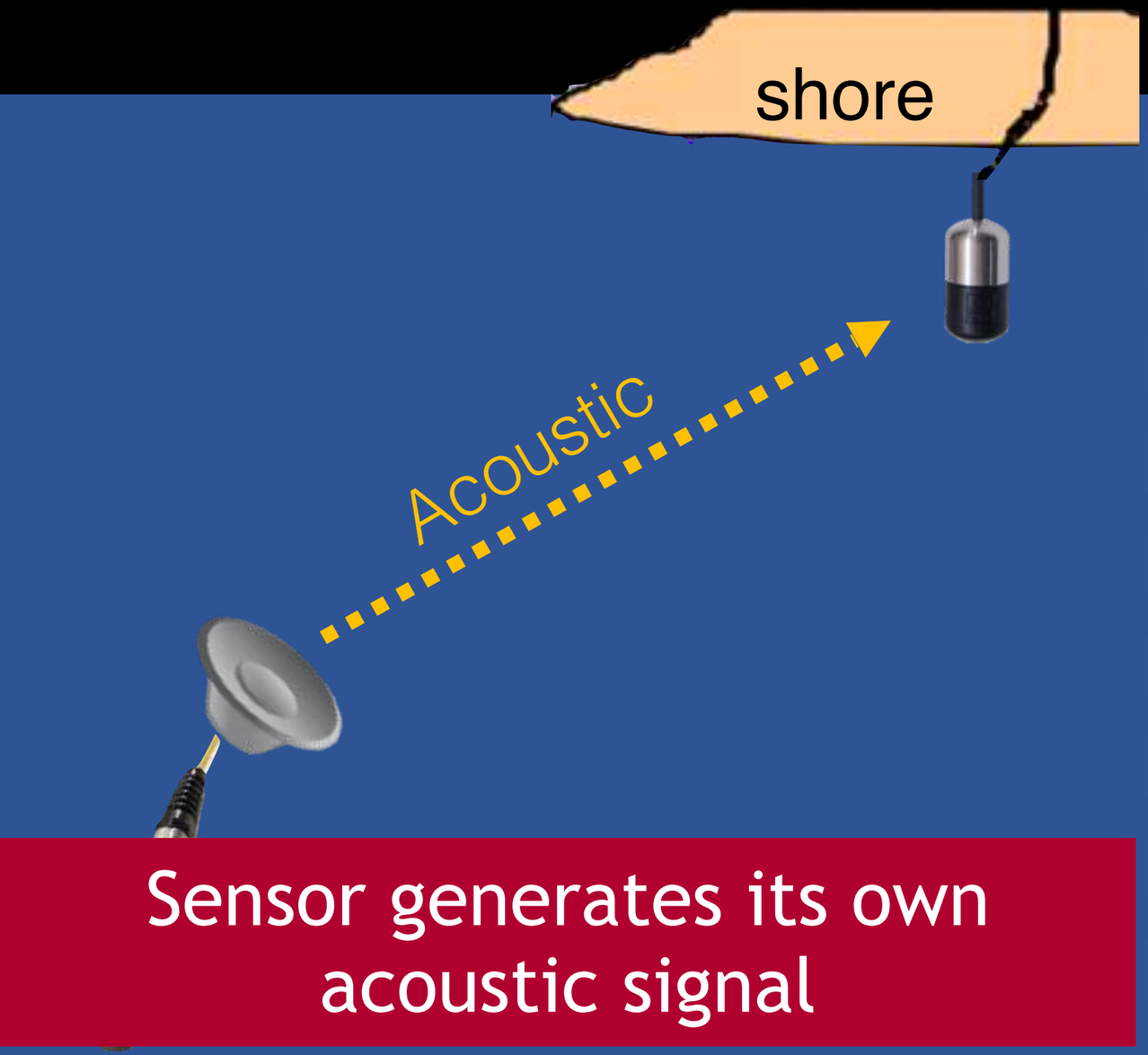
Most state-of-the-art sensors for tracking marine animals only last for few hours or days

[Animal Biotelemetry'15, Scientific Reports'17]

Technology that Enables Underwater Backscatter (Batteryless) Networking

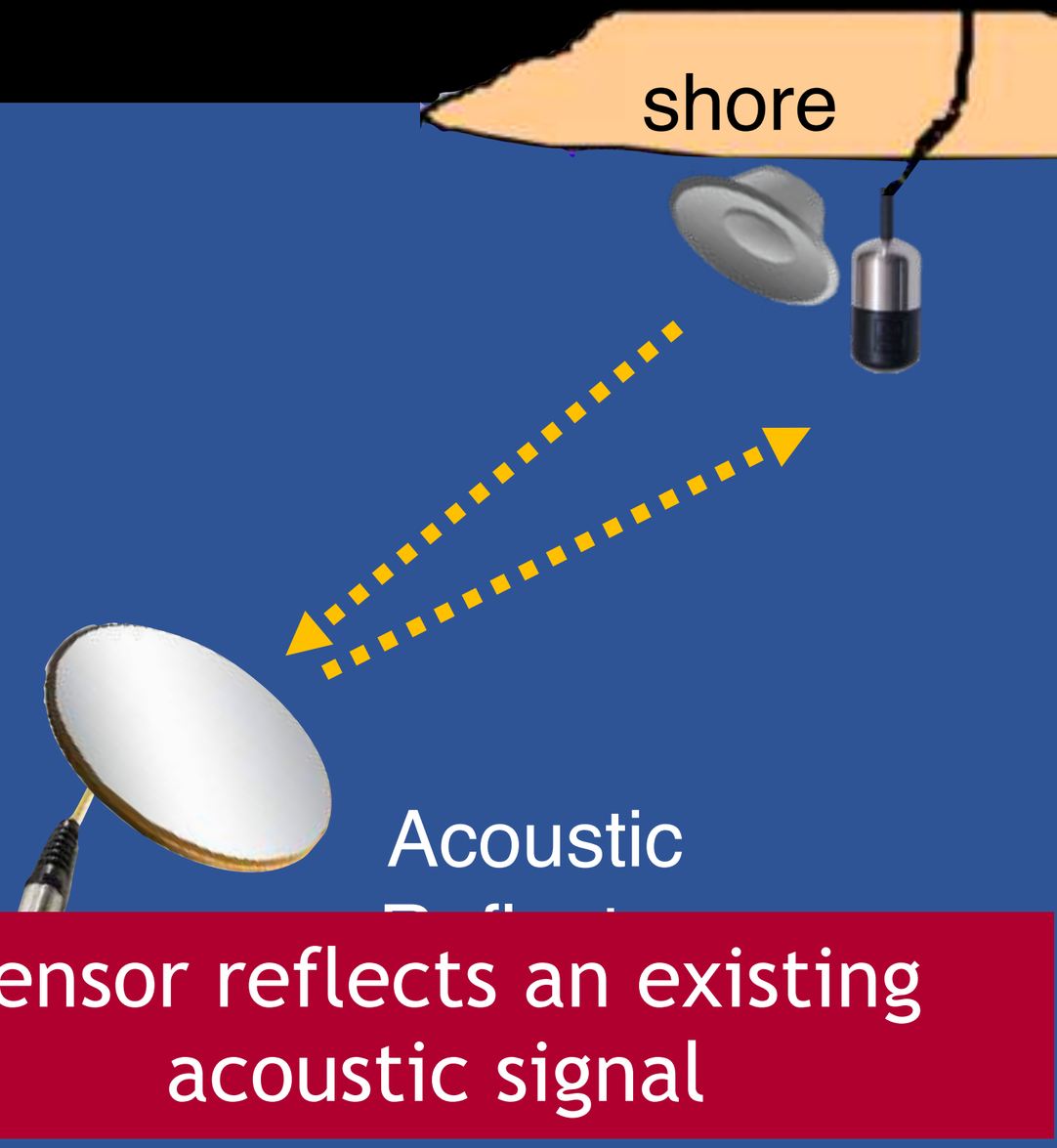
Published in: ACM SIGCOMM'19, ACM SIGCOMM'20, MTS/IEEE OCEANS'20, ACM HotNets'20

Traditional Approach



Sensor generates its own acoustic signal

Our Technology

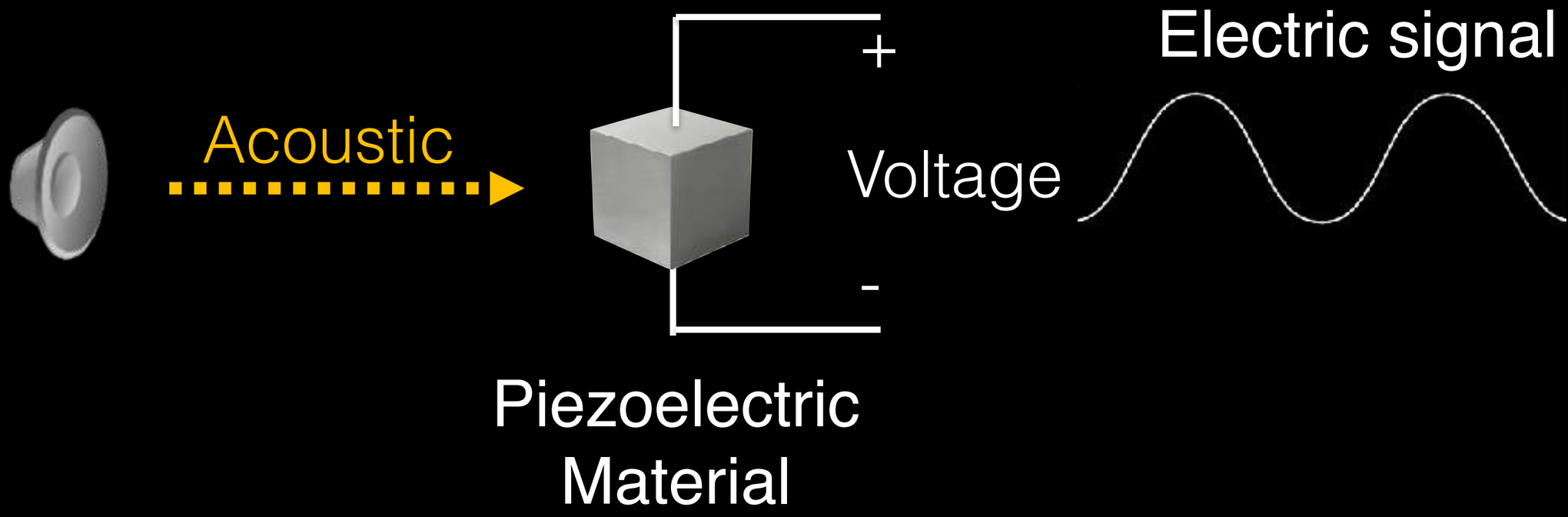


Sensor reflects an existing acoustic signal

How can we control the reflections of acoustic signals?

Key Idea: Use piezoelectricity to design programmable acoustic reflectors

Piezoelectric materials transform mechanical to electrical energy



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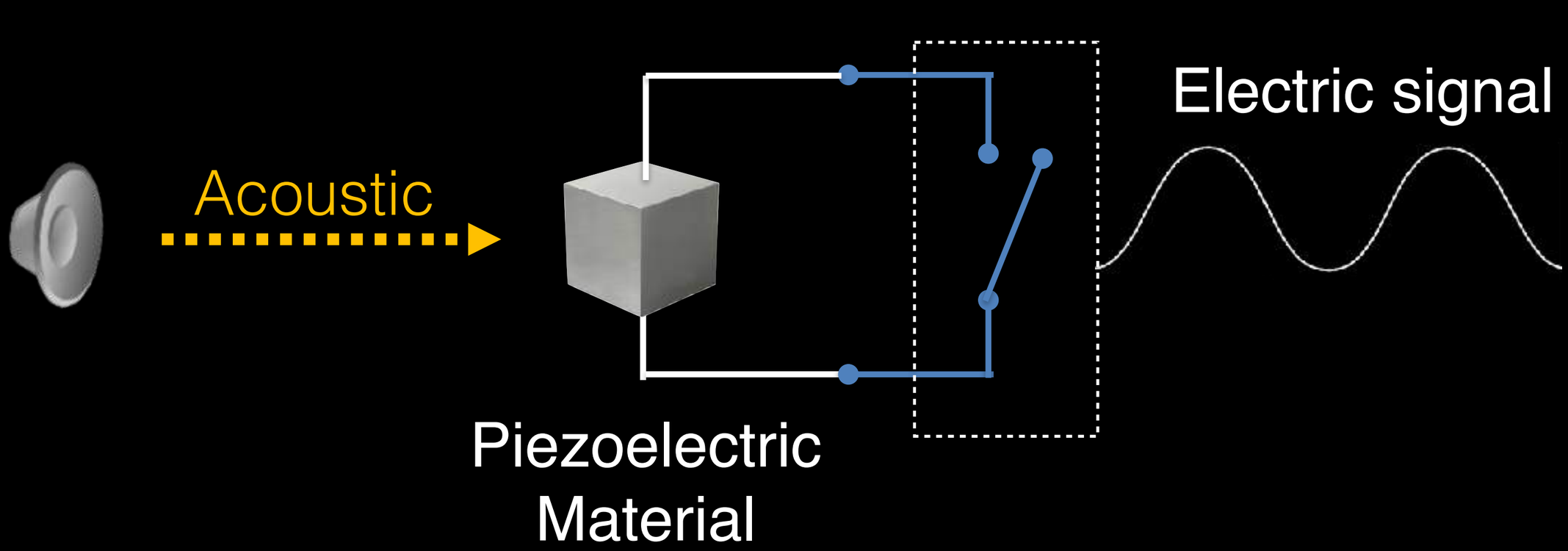

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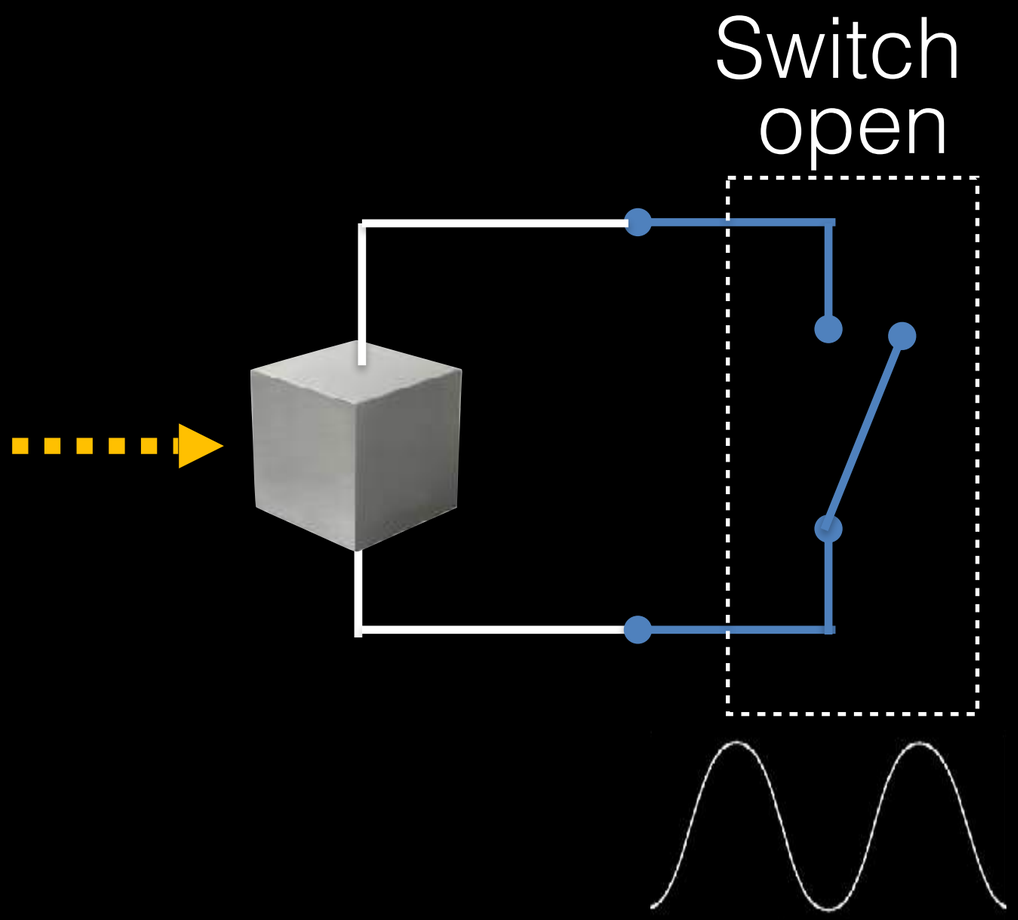
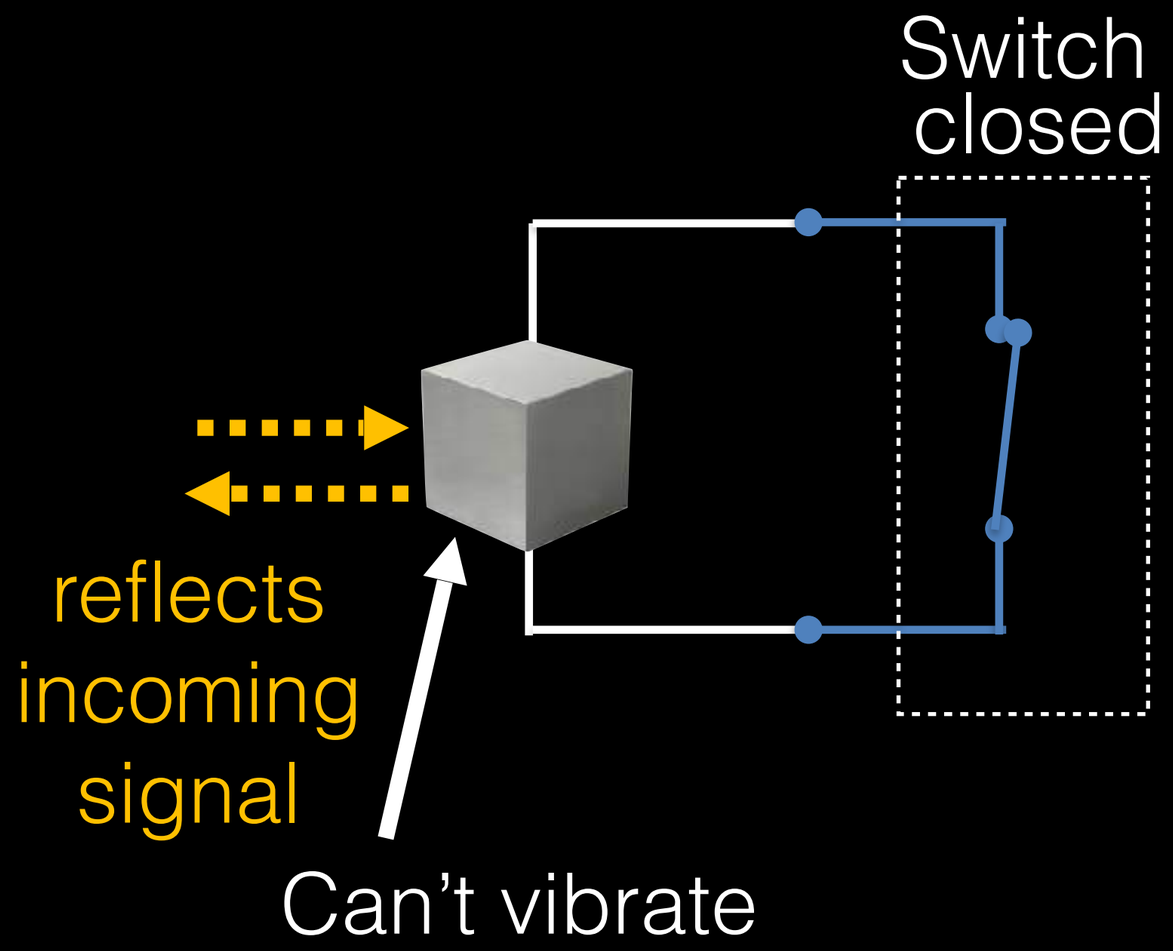
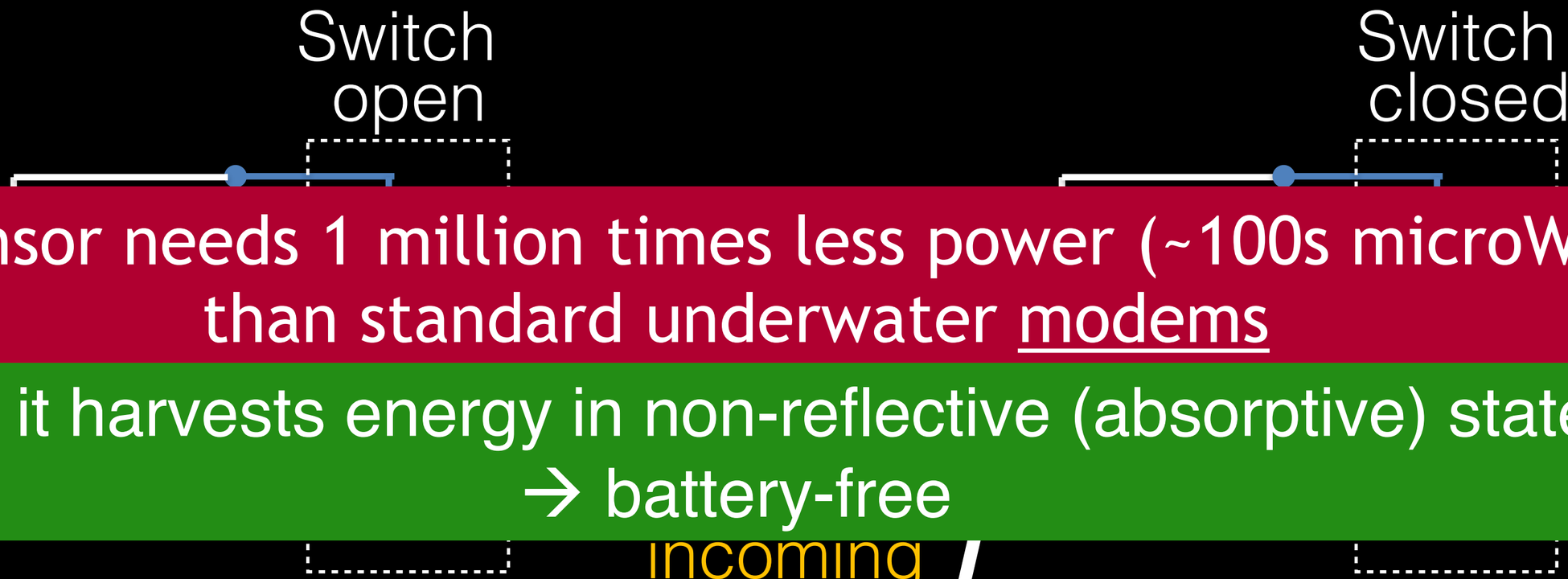


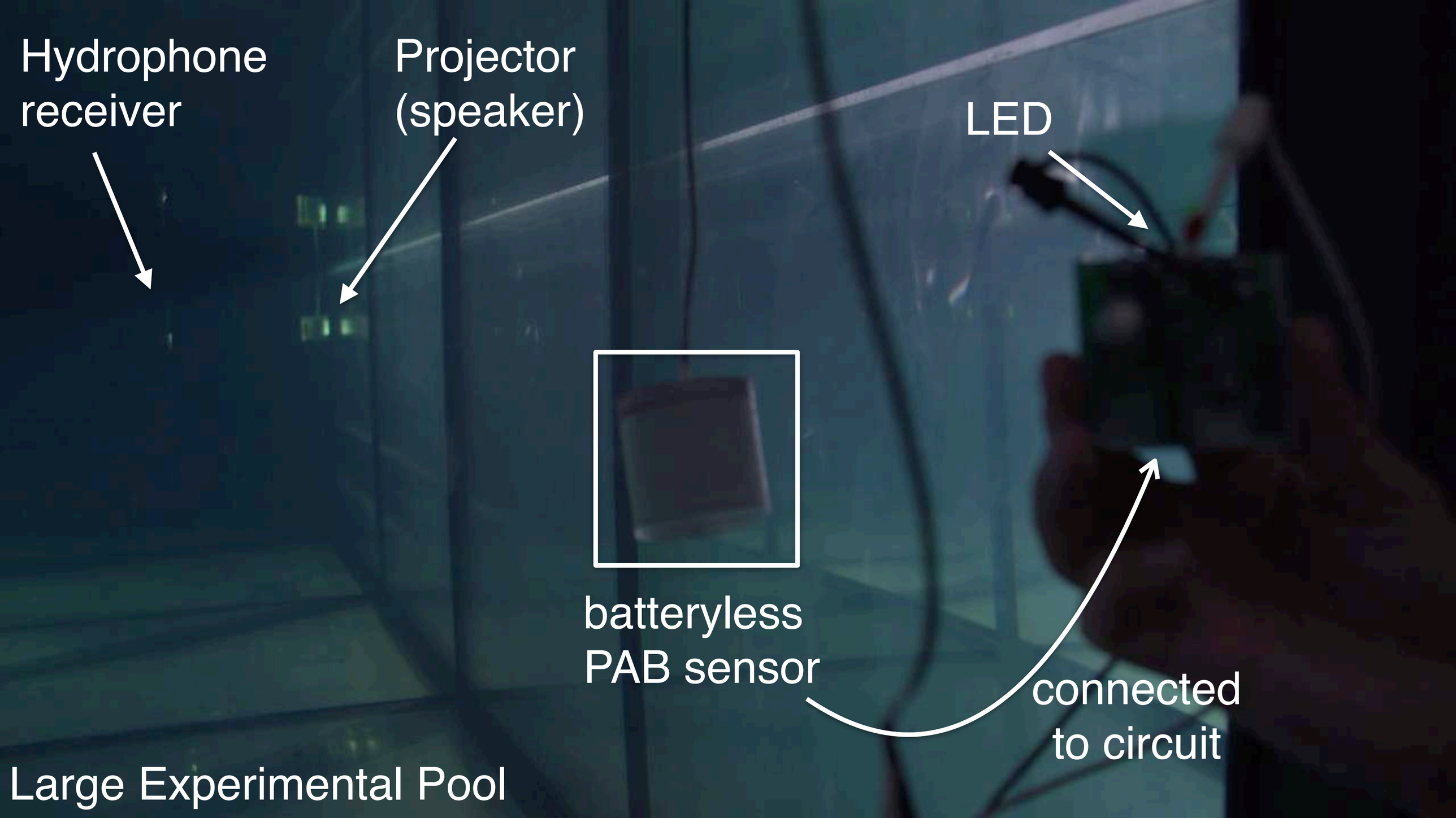


Piezo-Acoustic Backscatter

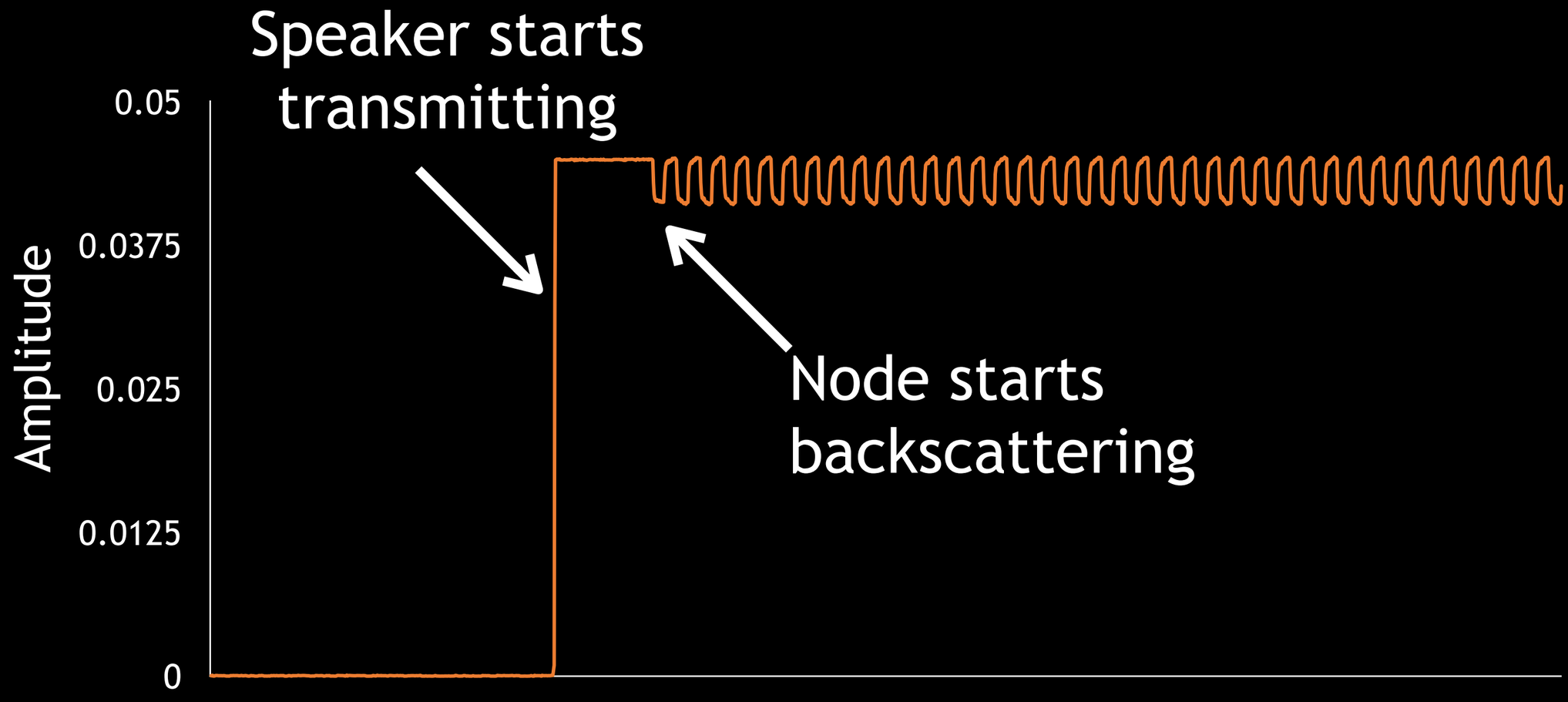


Our sensor needs 1 million times less power (~100s microWatt) than standard underwater modems

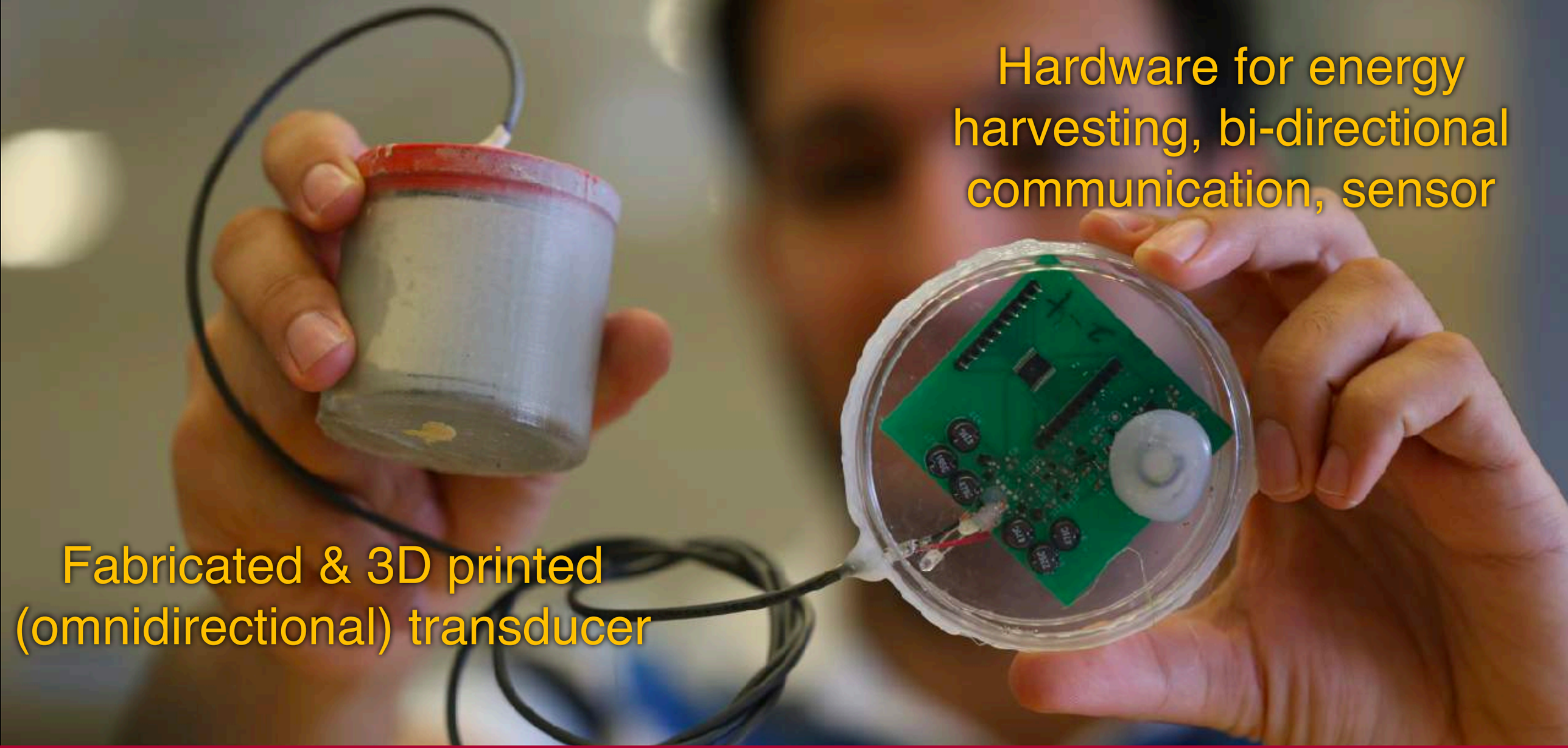
And it harvests energy in non-reflective (absorptive) state
→ battery-free


Hydrophone
receiver
Projector
(speaker)
LED
batteryless
PAB sensor
connected
to circuit
Large Experimental Pool

Measuring the Backscatter Signal (by Hydrophone)



Algorithms and techniques to scale to many nodes and deal with other reflections in the environment



Costs ~$100. Consumes 100 of micro-Watts, i.e., 1 million times less power than state-of-the-art low-power underwater modems

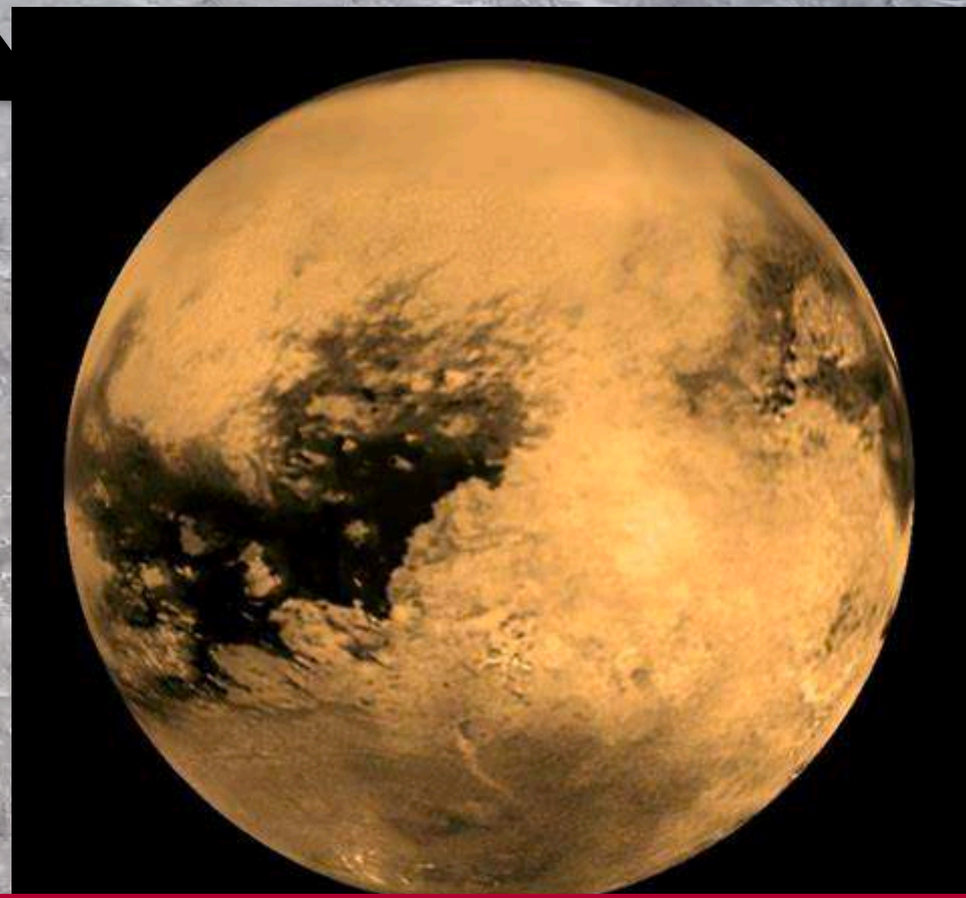
Experimental Evaluation in River (with snow & rain)

- 500+ experimental trials at different ranges, throughputs, and number of nodes

- Throughput: 20kbps
- Range: 62m
- Concurrent nodes: 10
  - *before spatial reuse*
- Localization accuracy: centimeter-scale

PAB with temp & pressure sensor

Saturn's moon Titan



Technology highlighted as an *ocean-shot* for this decade (2021-2030) by the US National Academies Committee on Ocean Sciences

Code+Schematics+Tutorials:
https://github.com/saadafzal24/Underwater-Backscatter

Opportunities & Open Problems

(1) IoT → Data → Climate modeling

Apps: Weather prediction, flooding/disaster, climate modeling, coral reefs

(2) Underwater drone localization & navigation

Apps: Mapping, mining, multi-modal navigation, awareness, defense

(3) Architectural developments

Apps: Networking, simulations, range, energy, materials

Sensors to monitor climate change (temp, animals, reefs)

Batteryless underwater GPS

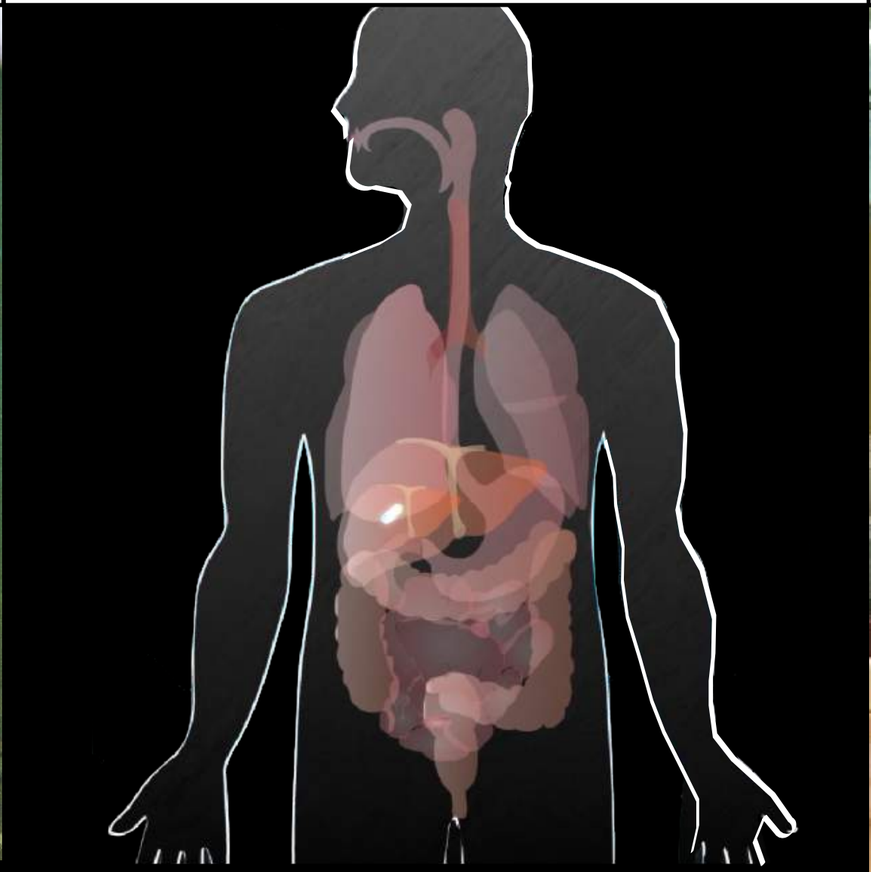
Smart Oceans 2020

1,056 registered & 400+ Institutions

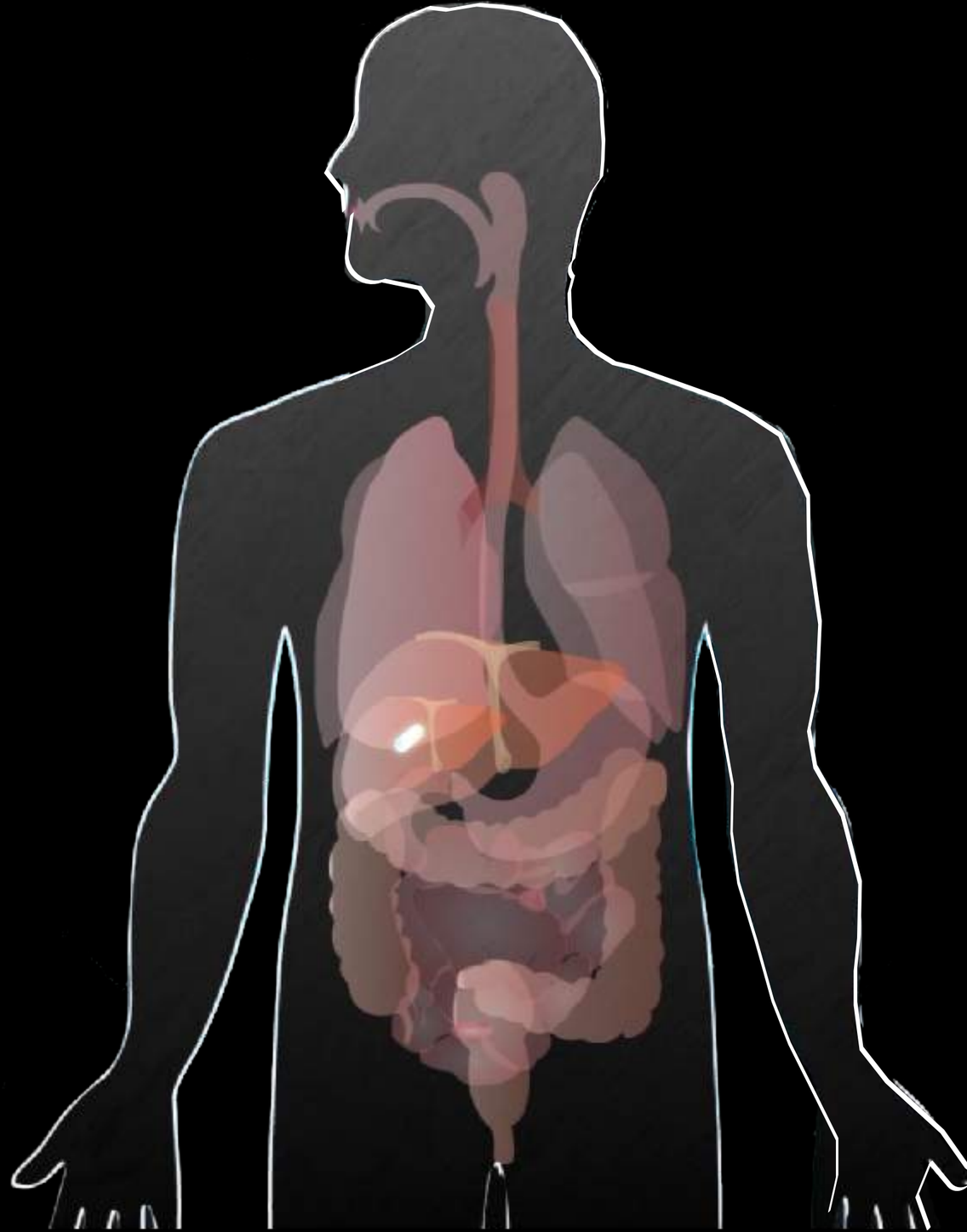
$80M+ for industry-academic collab.
LOI due May 5, 2021

Oceans

This Talk:
Extreme IoT & Sensor Technologies

Oceans	Human Body	Robotics
		
[SIGCOMM ’18a, SIGCOMM ’19, SIGCOMM’20, OCEANS’20, HotNets’20]	[ACM SIGCOMM ’18b, MobiCom’20a, MobiCom’20b, ACM IMWUT’21]	[ACM SIGCOMM’17, MobiCom ’17, NSDI’19, NSDI ’20, IEEE ICRA’21]

Human Body



Man receives under-skin chip implant live at mobile show

REUTERS

BARCELONA (Reuters) - A man volunteered t
stage at a trade fair in Barcelona on Monday, and another man who had already undergone

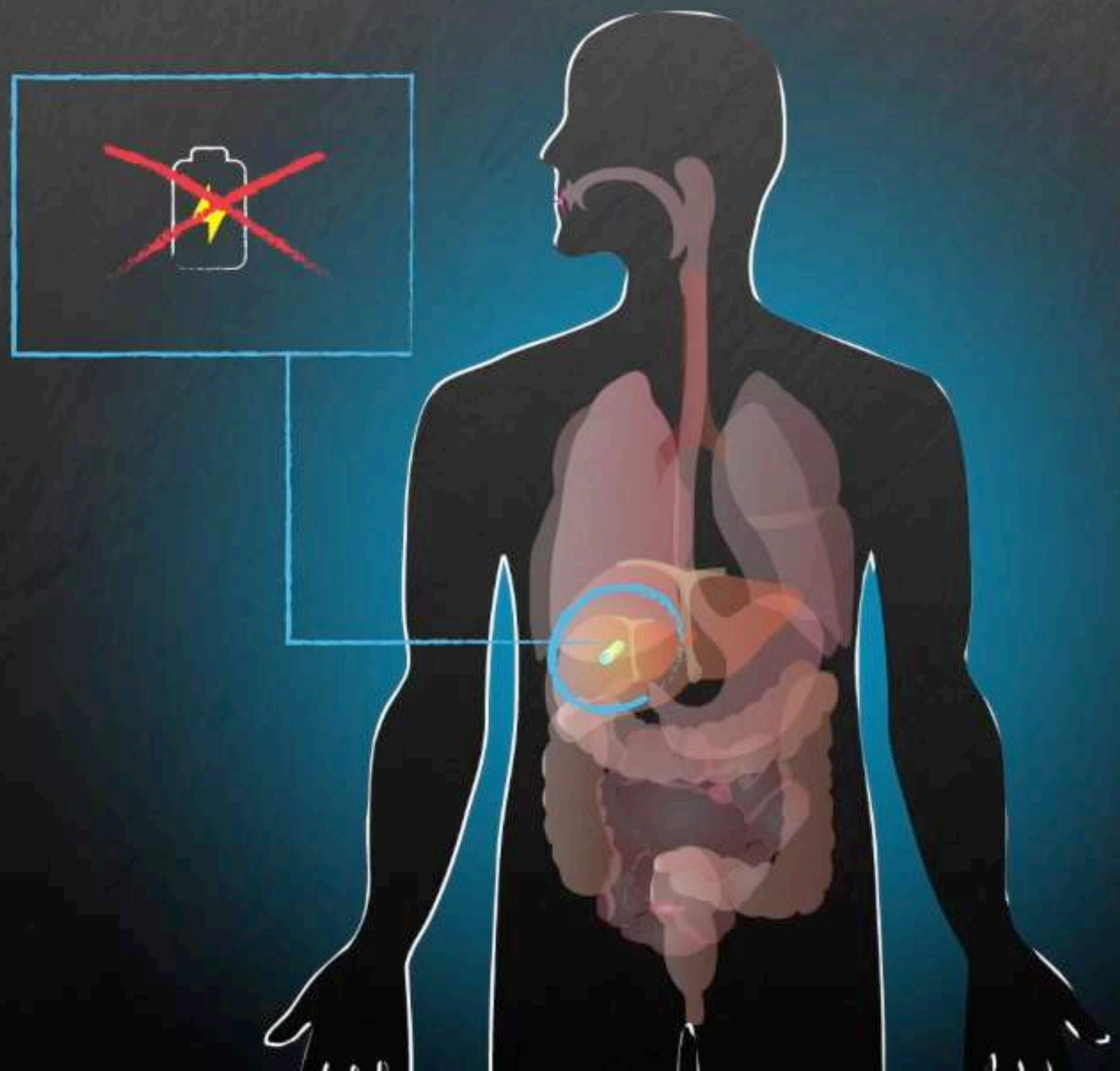
POPULAR SCIENCE

TECHNOLOGY

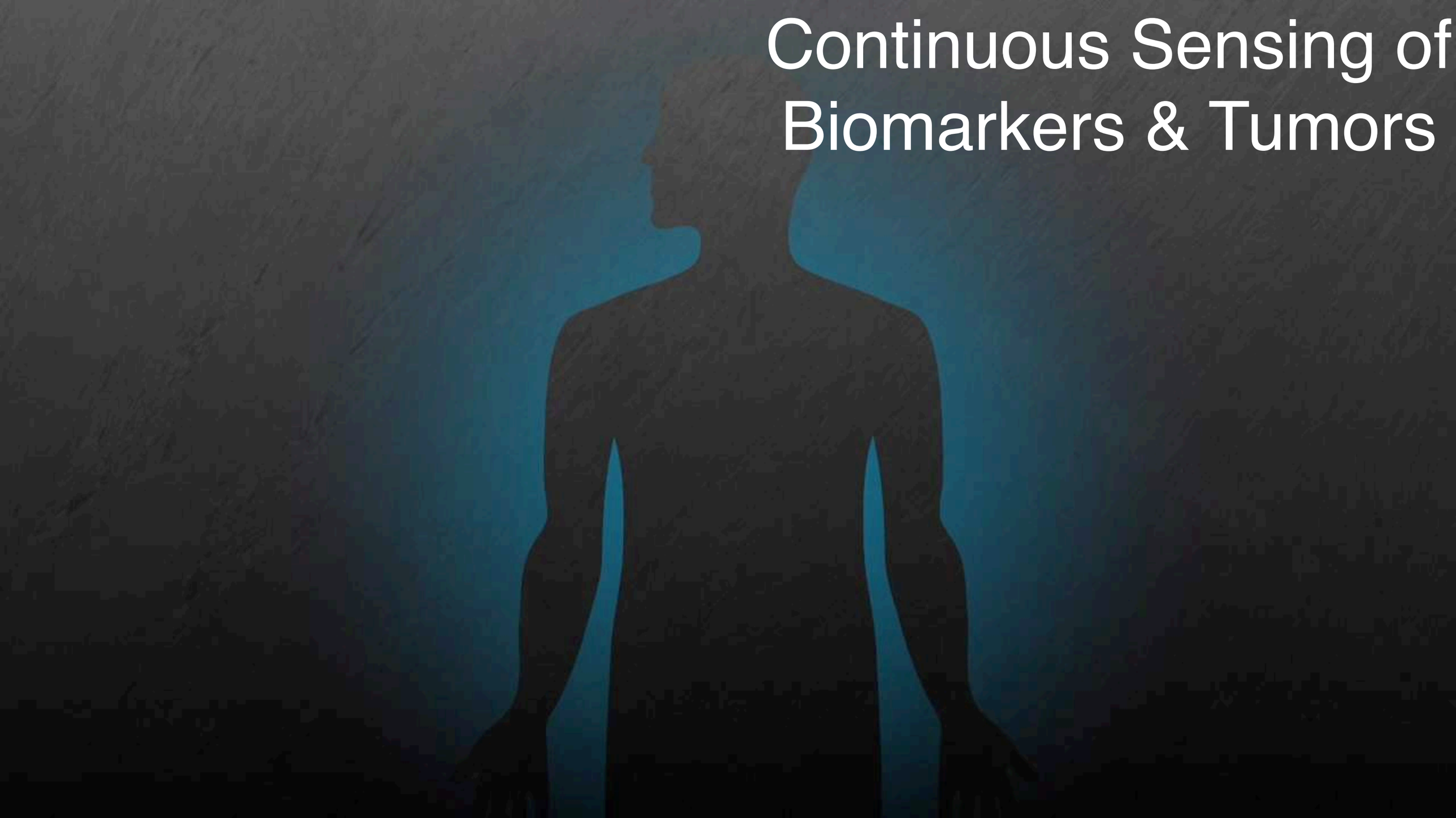
Why Did I Implant A Chip In My Hand?

My so-called cyborg life

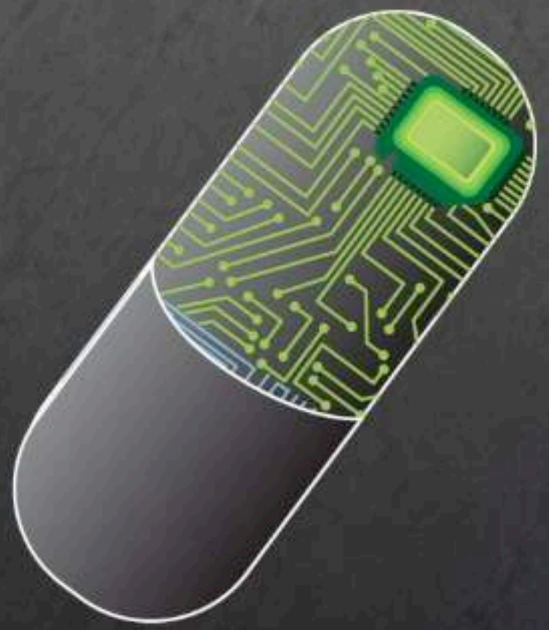
My implant is both less scary and less useful than you might think.



Wirelessly Power
& Communicate


Continuous Sensing of
Biomarkers & Tumors

Ultra Long-Lasting Drug Delivery



Technologies that can remotely power up & communicate with deep-tissue, batteryless, intelligent micro-implants

[ACM SIGCOMM’18, ACM MobiCom’20]

Key Challenge:

Wireless signals die exponentially in the human body

Key Challenge:

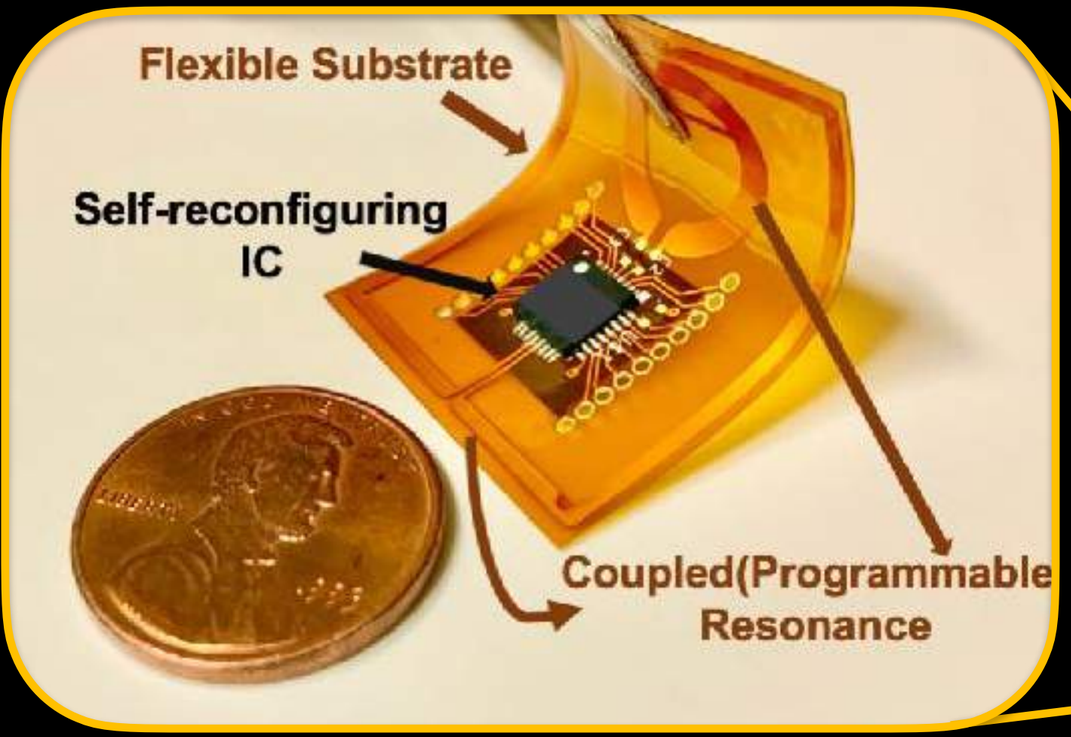
Wireless signals die exponentially in the human body

Signals decay more than 1000x faster inside the body than in air

Cannot power up batteryless sensor in deep tissues

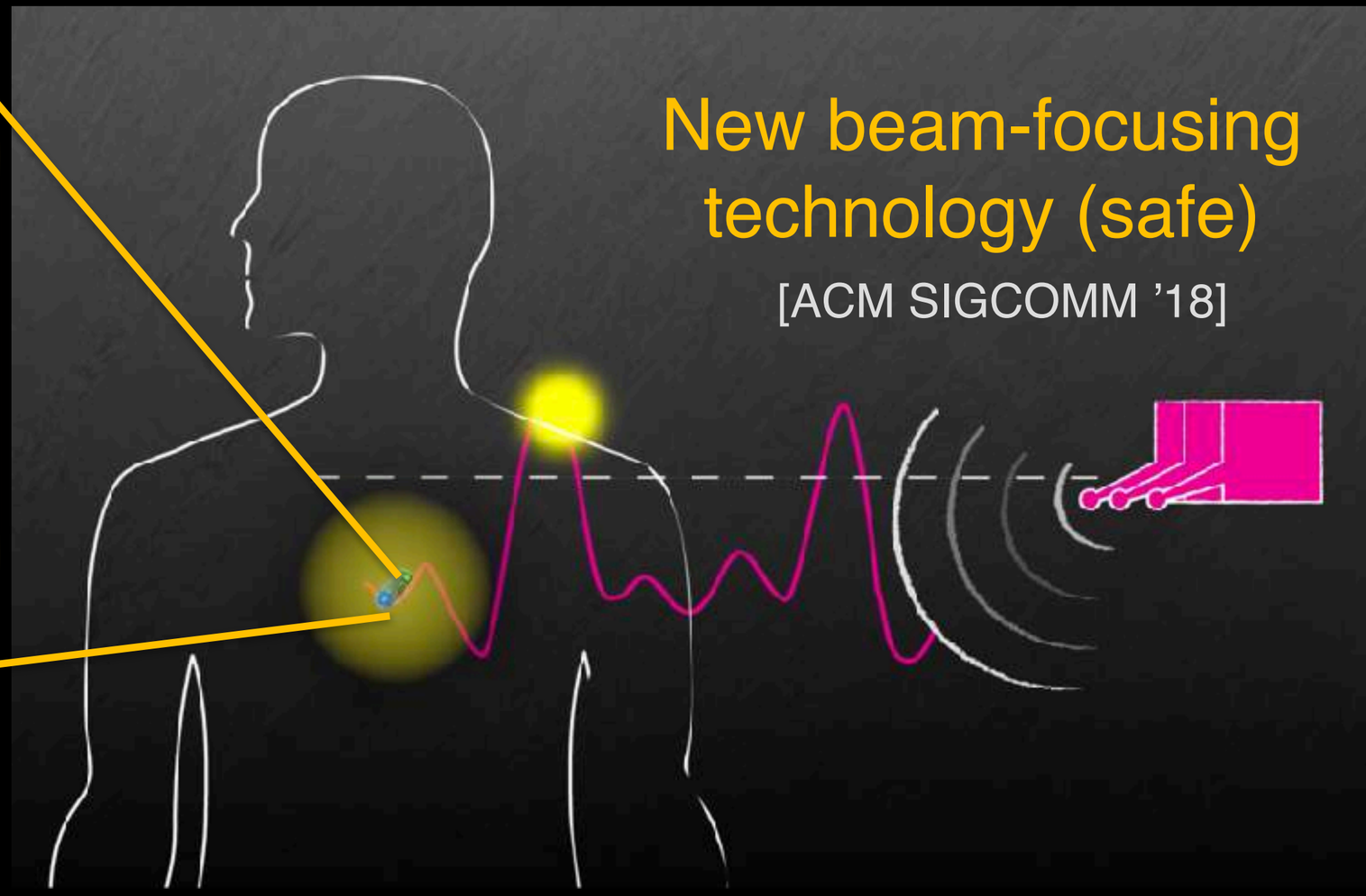
How can we power and communicate with sensors in deep tissues despite tissue attenuation & complexity?

How can we power and communicate with sensors in deep tissues despite tissue attenuation & complexity?



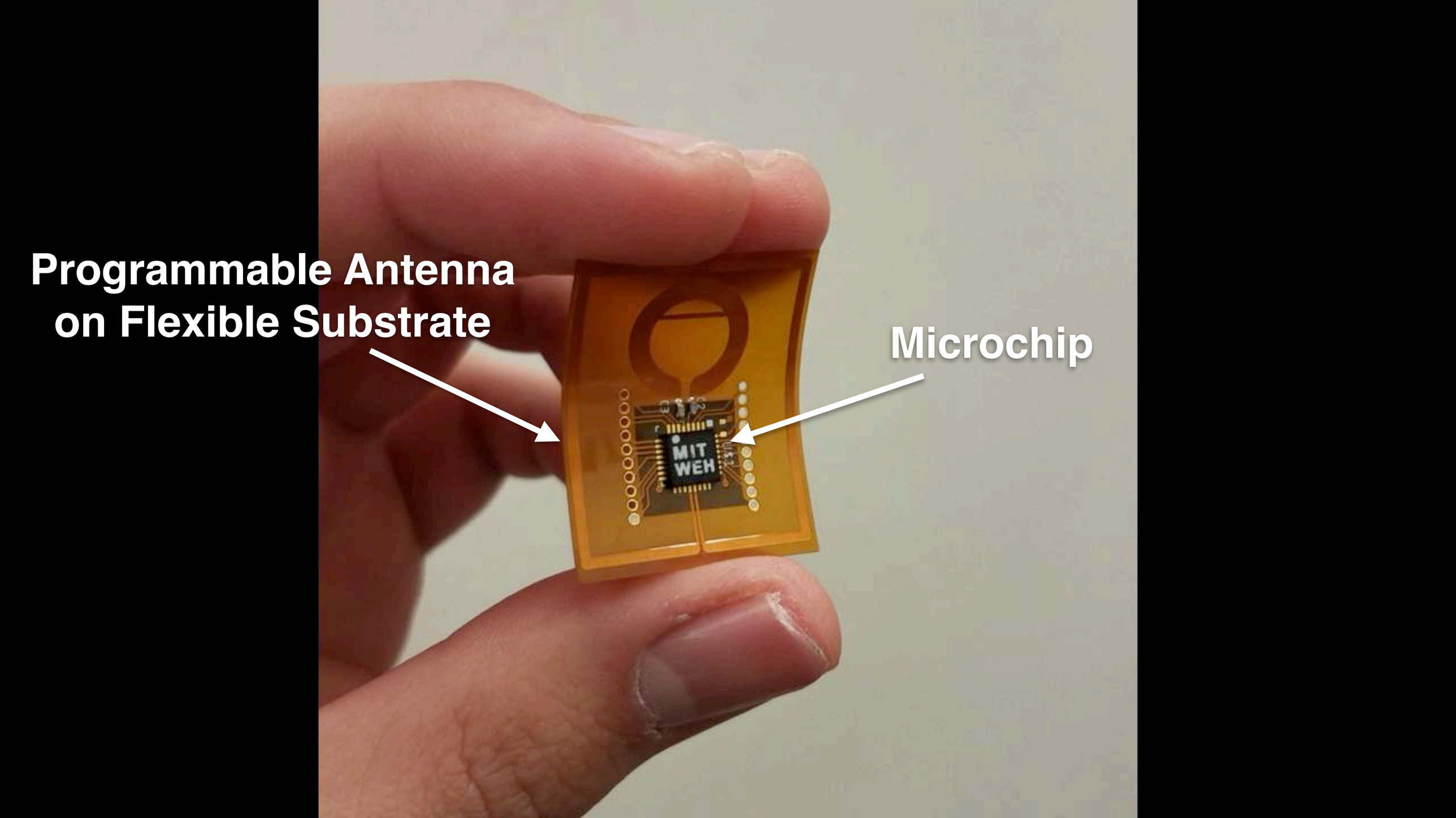
Self-reconfiguring micro-implant

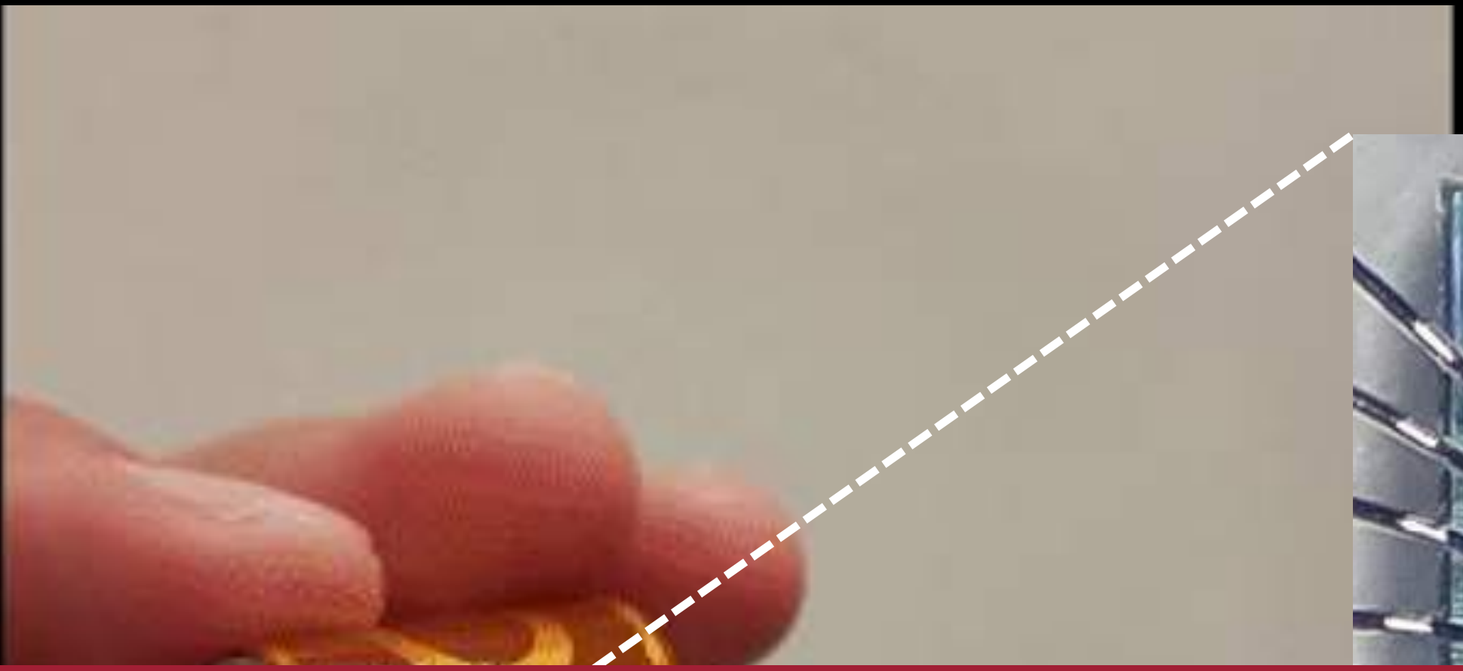
[ACM MobiCom ’20]



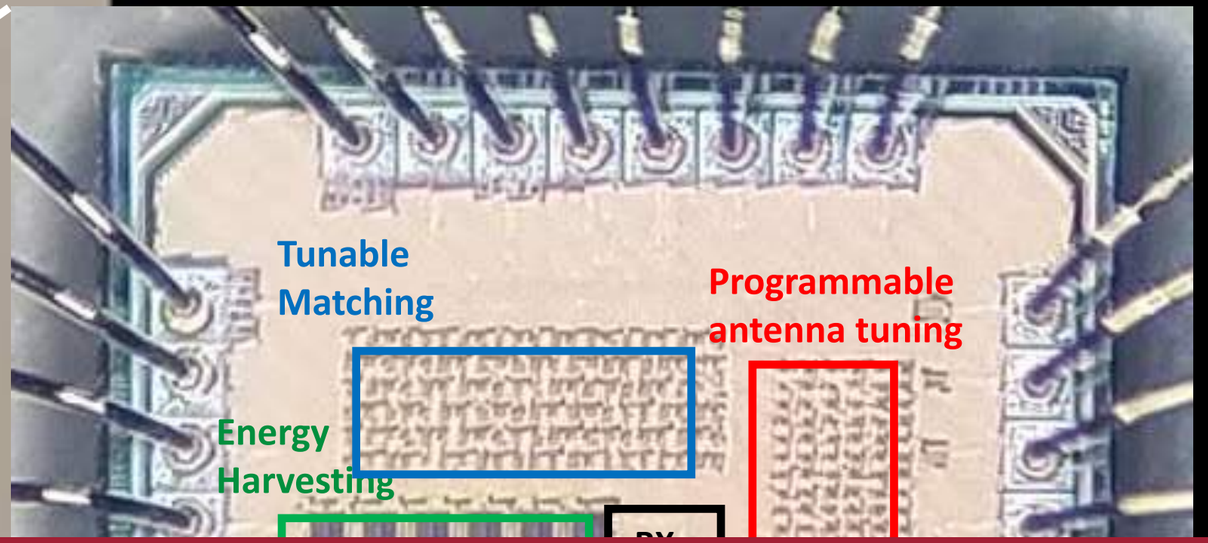
New beam-focusing technology (safe)

[ACM SIGCOMM ’18]

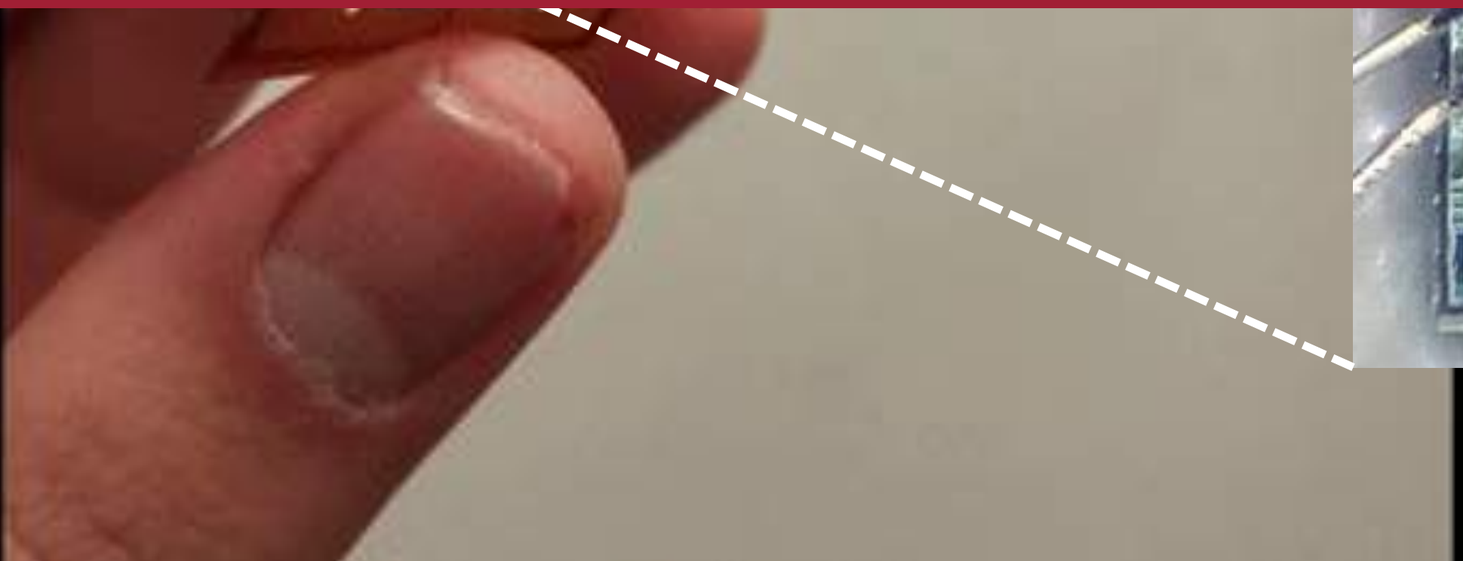

Programmable Antenna
on Flexible Substrate
Microchip
MIT
WEH

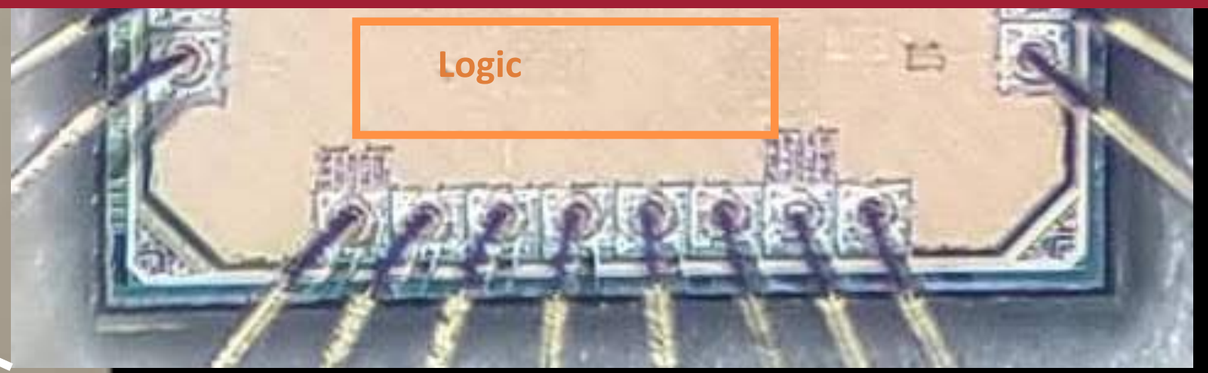


Magnified Die Micrograph



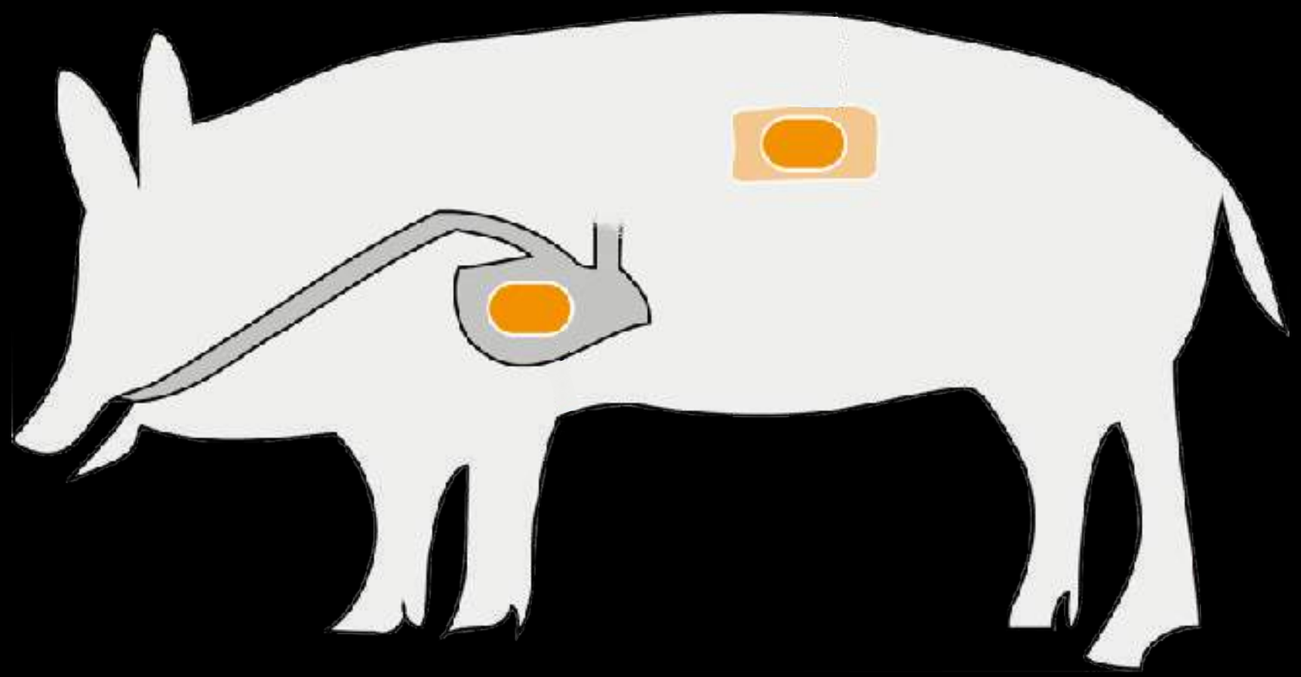
Micro-implant is wireless, batteryless, and intelligent:
consumes 350 nanoWatts, throughput of 6Mbps, & adapts to surrounding tissues





In-Vivo Evaluation with Living Animal

Female yorkshire pig weighing 85 kg

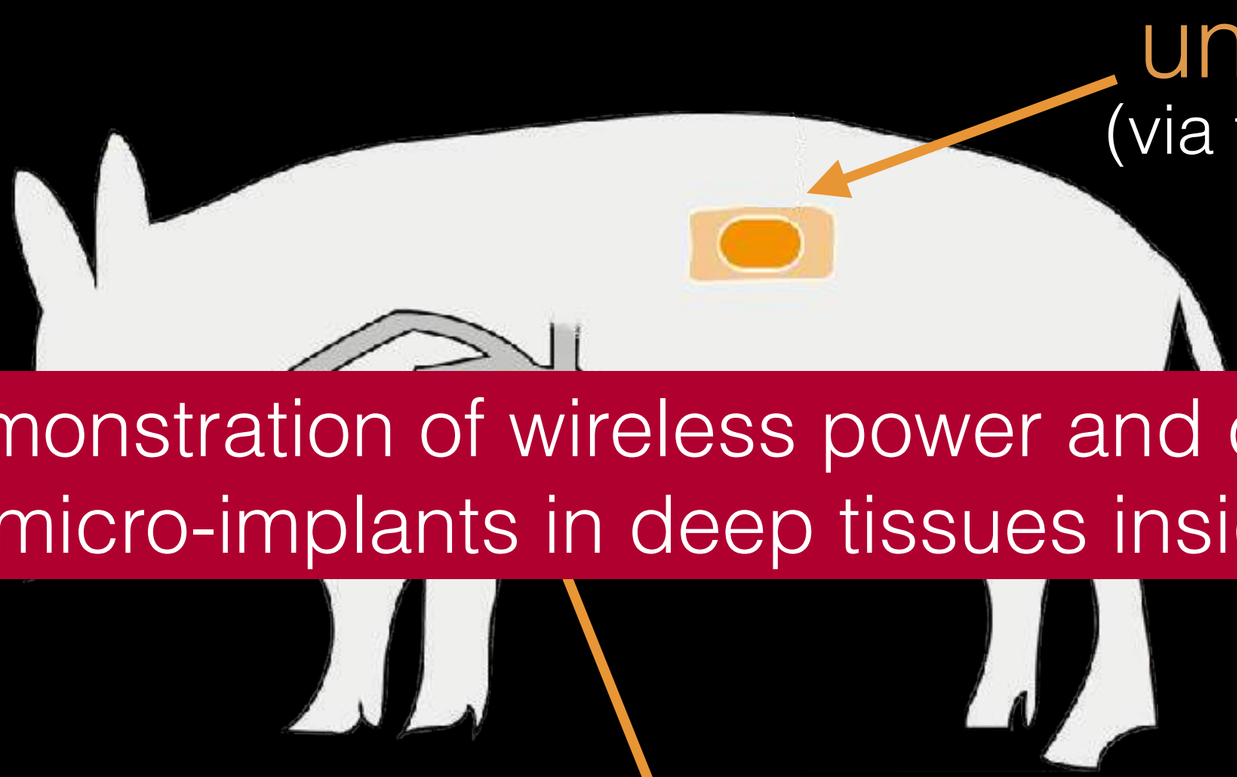


HARVARD MEDICAL SCHOOL

BWH BRIGHAM AND WOMEN'S HOSPITAL

In-Vivo Evaluation with Living Animal

Female yorkshire pig weighing 85 kg

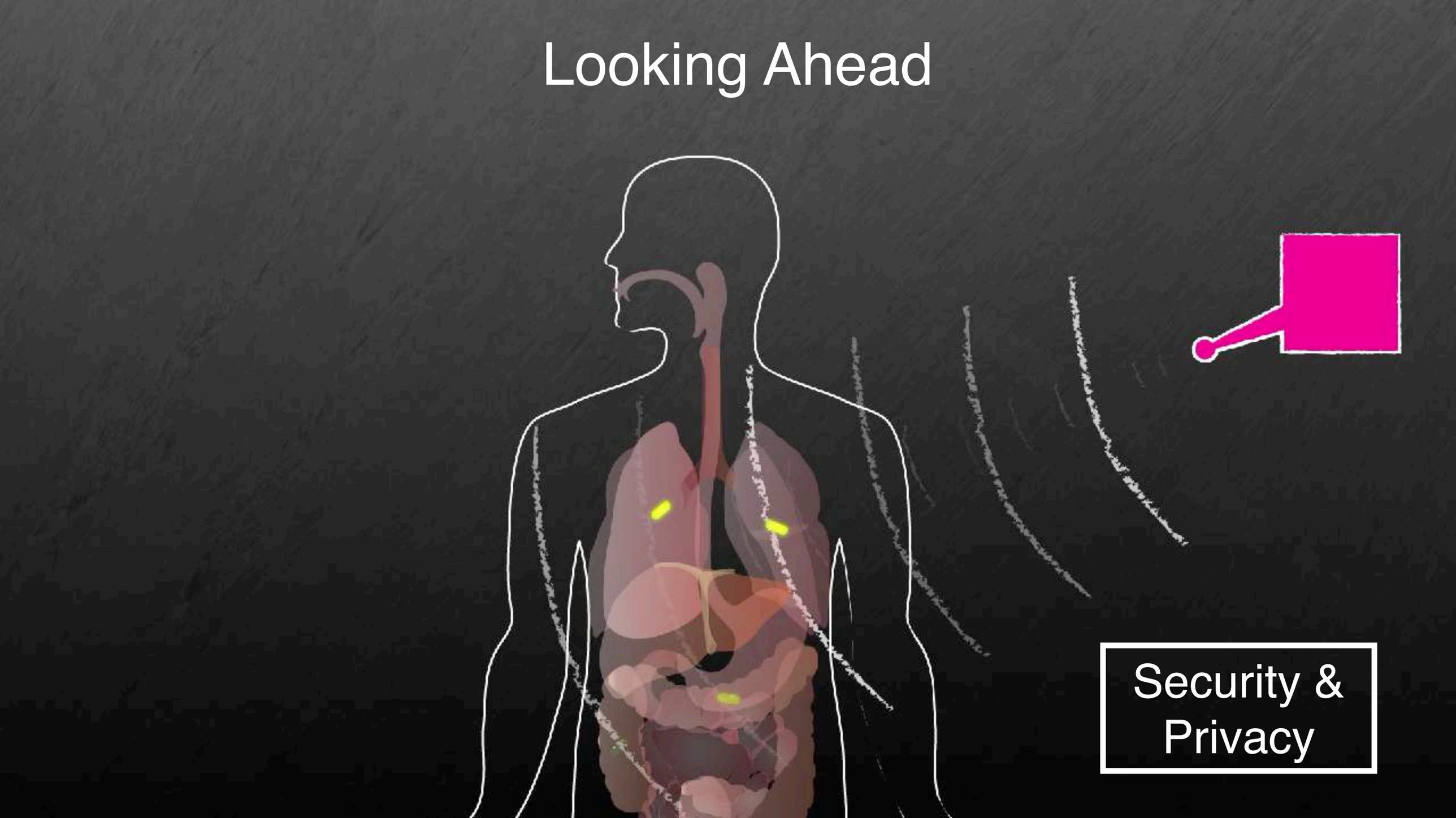


Successful demonstration of wireless power and communication with batteryless micro-implants in deep tissues inside living animals

HARVARD MEDICAL SCHOOL

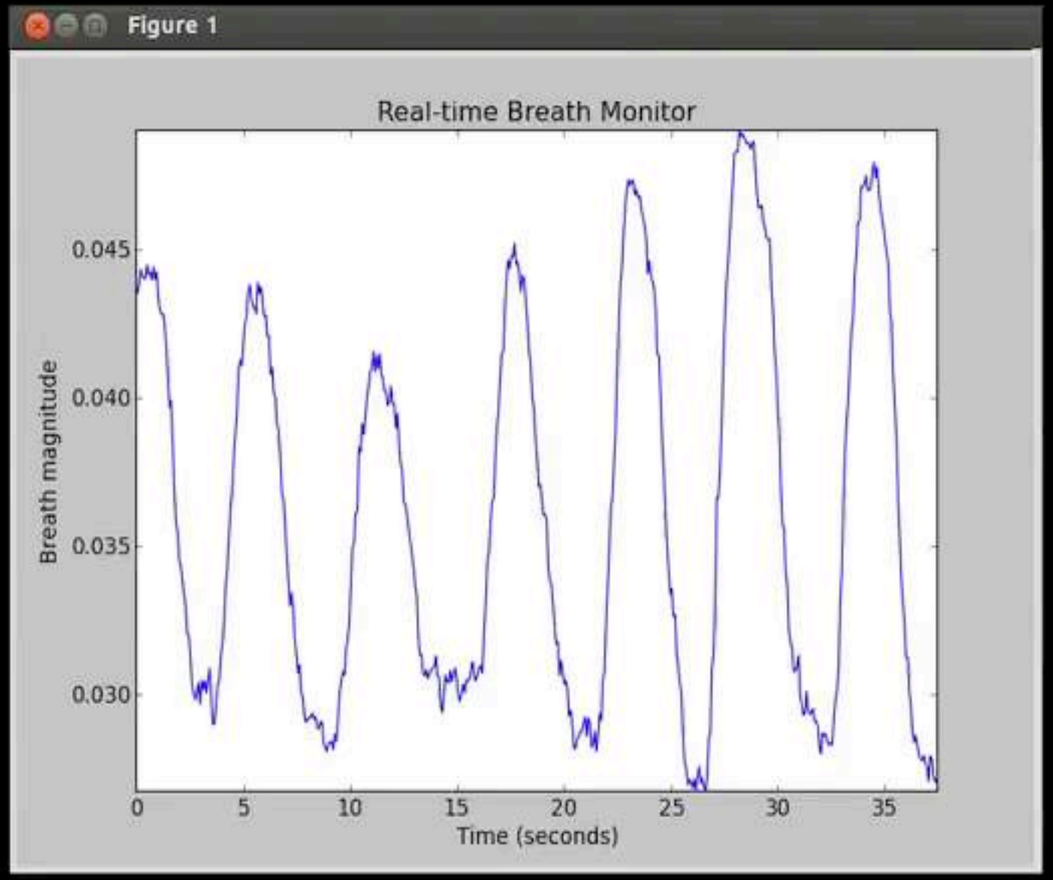
BWH BRIGHAM AND WOMEN'S HOSPITAL

Looking Ahead



Security &
Privacy

Contactless Breath Monitoring using Wireless Signals



[ACM MobiCom'14, ACM CHI'15]

Baby Monitoring

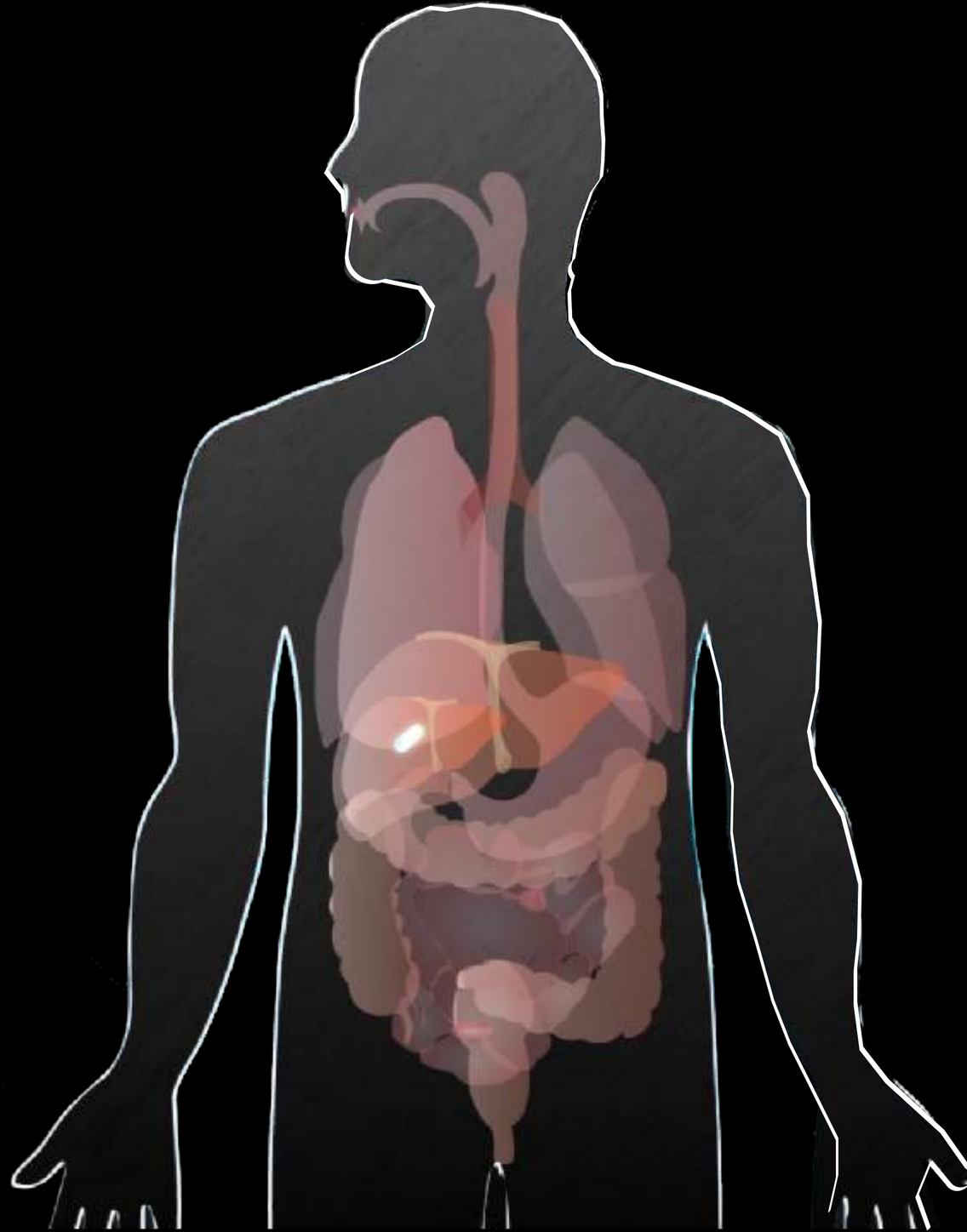
Our technology (startup
patients with Al

How can we capture heart recordings?

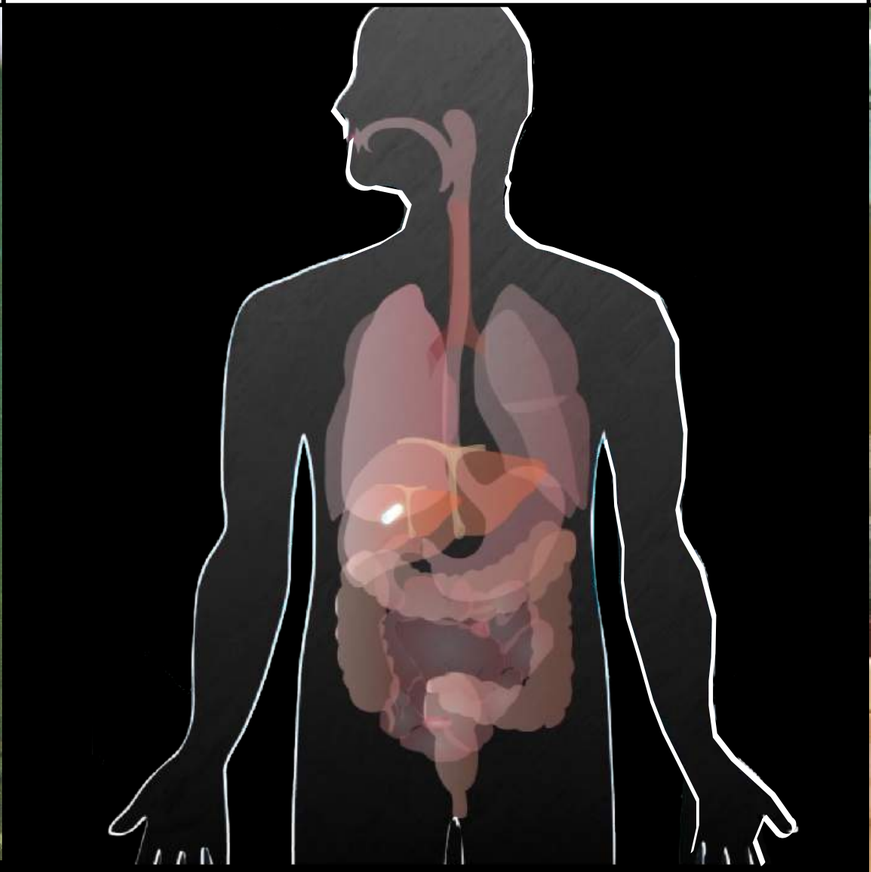
98-99% accuracy in timing micro-cardiac events

[ACM MobiCom'20]

Human Body



This Talk:
Extreme IoT & Sensor Technologies

Oceans	Human Body	Robotics
		
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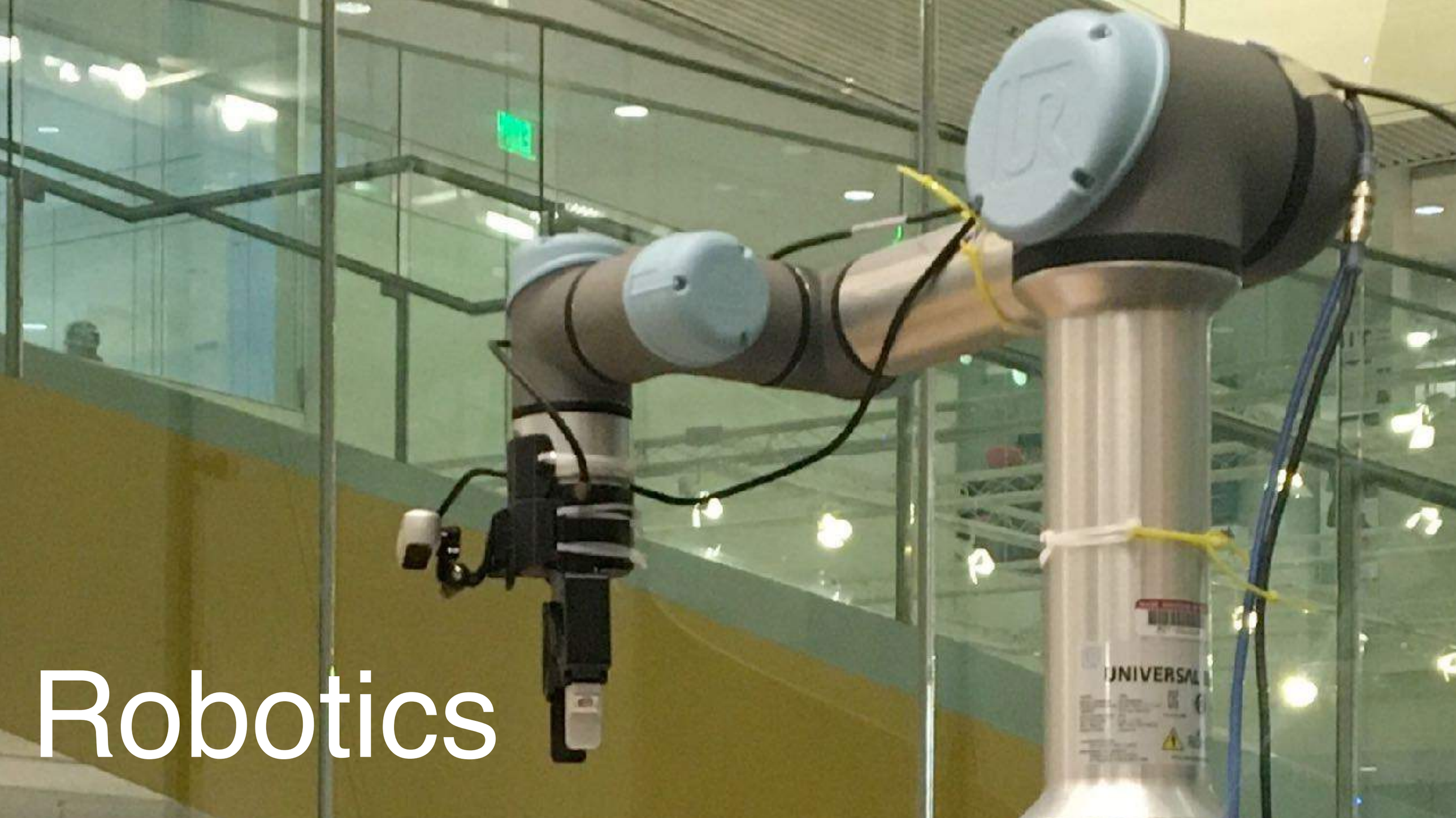


Robotics

Can we Enable Robots to Perceive Things that Are Invisible to the Human Eye?

What's inside a closed box?

Is food/medicine in a closed bottle safe?

Can it fetch items it cannot see?

Augment Robots with Wireless Perception

Radio Frequency (RF) signals traverse occlusions

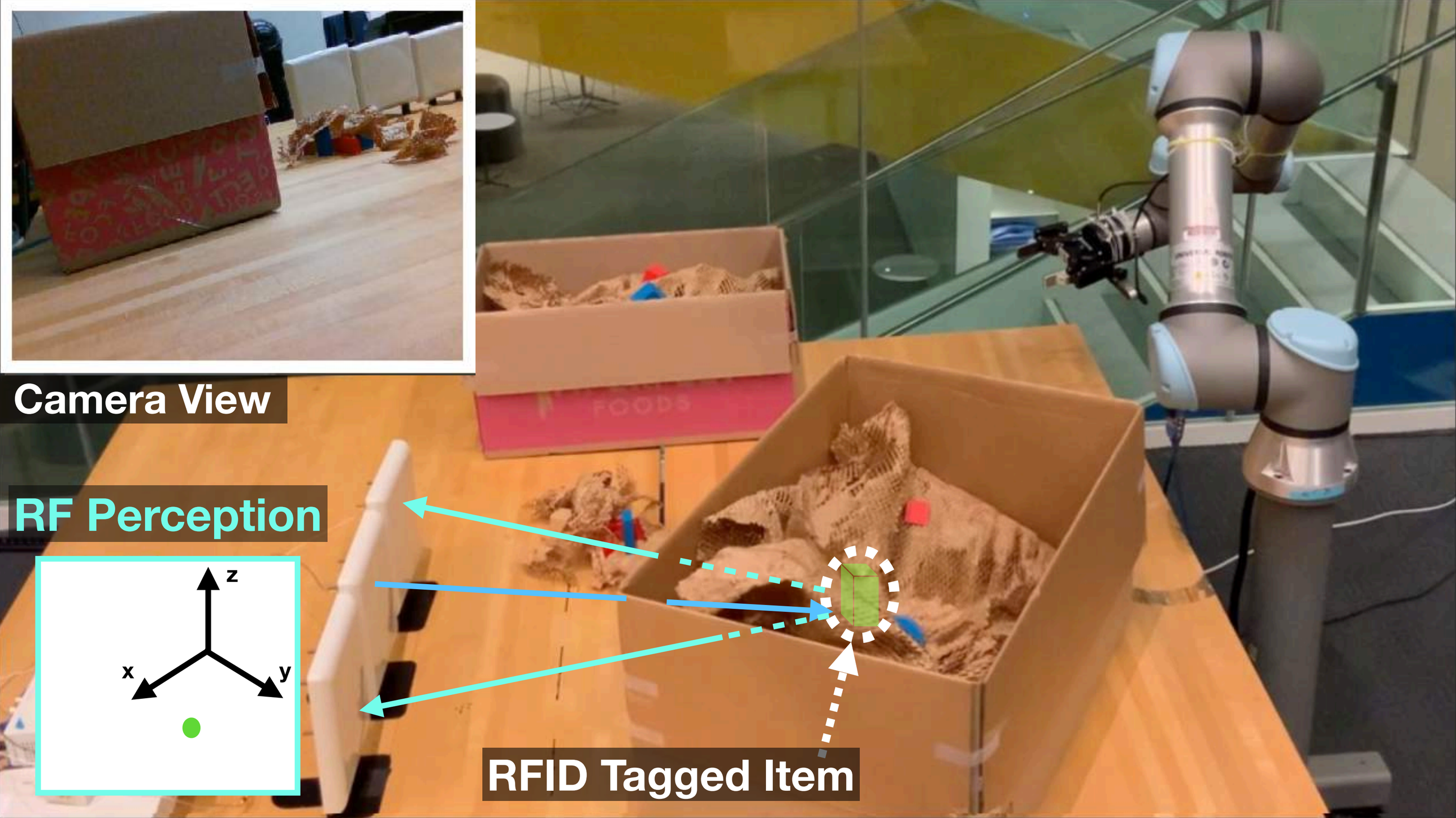
→ Extend perception beyond line-of-sight

[ACM SIGCOMM'17, ACM MobiCom '17, Usenix NSDI'19,
Usenix NSDI '20, IEEE ICRA '21]

Camera View
Camera's
line of sight is
blocked
Target item
under clutter

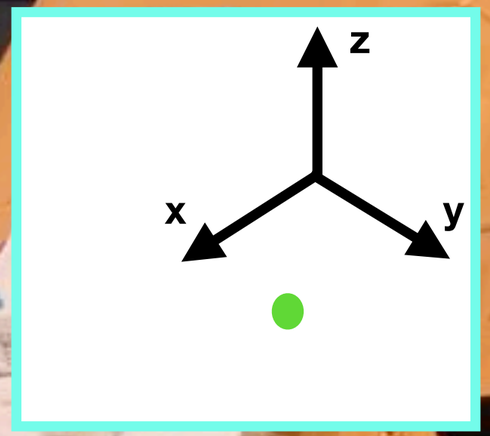
FOODS

RF Perception
RFID Tagged Item


Camera View
RF Perception
z
x
y
RFID Tagged Item

Camera View

RF Perception



Successful grasp

Upcoming IEEE ICRA'21 paper

x3

This Talk:
Extreme IoT & Sensor Technologies

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	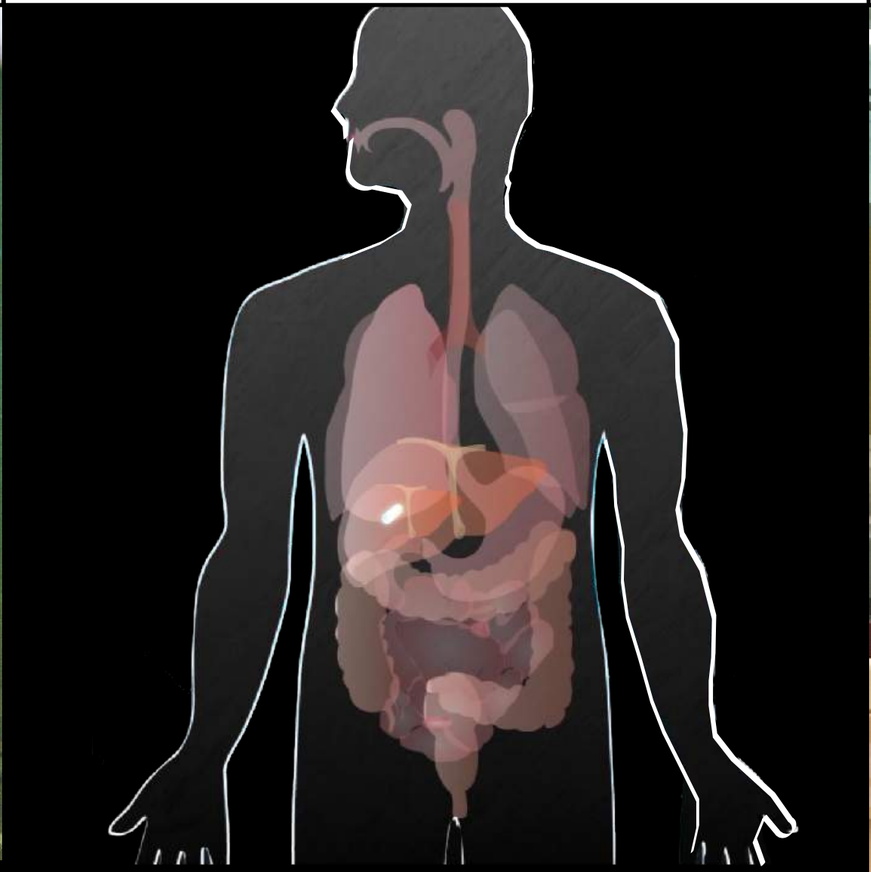	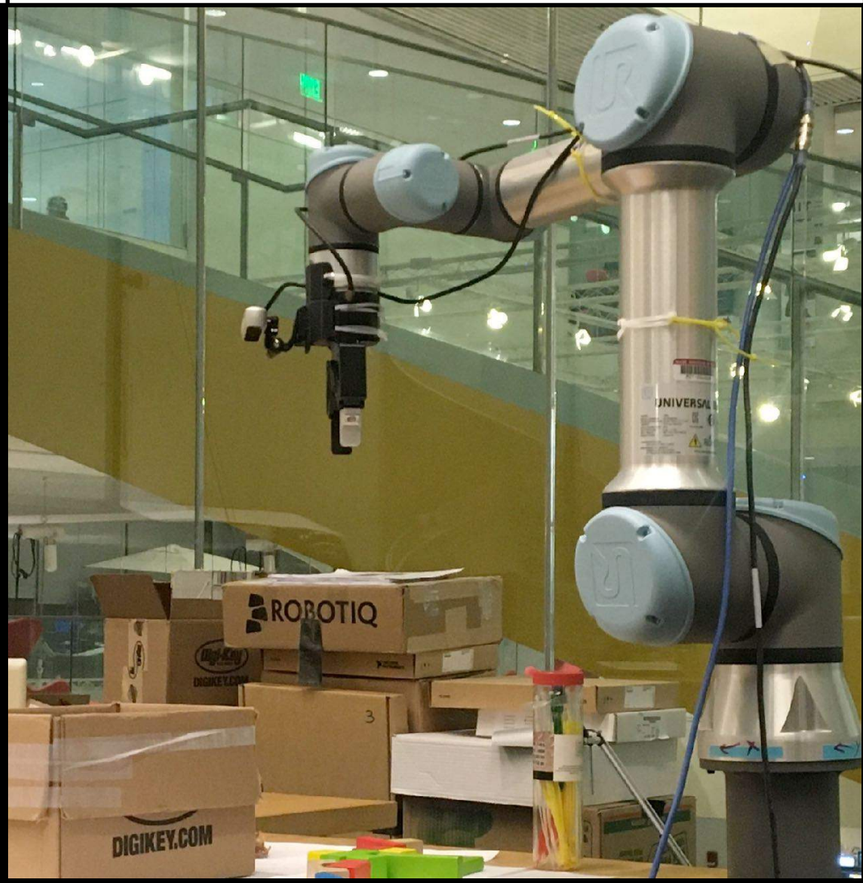
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Mergen Nachin
Haris Brkic
Waleed Akbar
Andrew McCall
Muhammed Sulema S Thaniana
Joshua Craig Anderson
Unsoo Ha
Osvy Rodriguez
Monica Liu
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Extreme IoT & Sensor Technologies

Join Us!

Collaborations

(research, deploy, commercialize)

Openings

(grad, postdocs, staff, engineers)

Stay in Touch!

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