



Extreme IoT

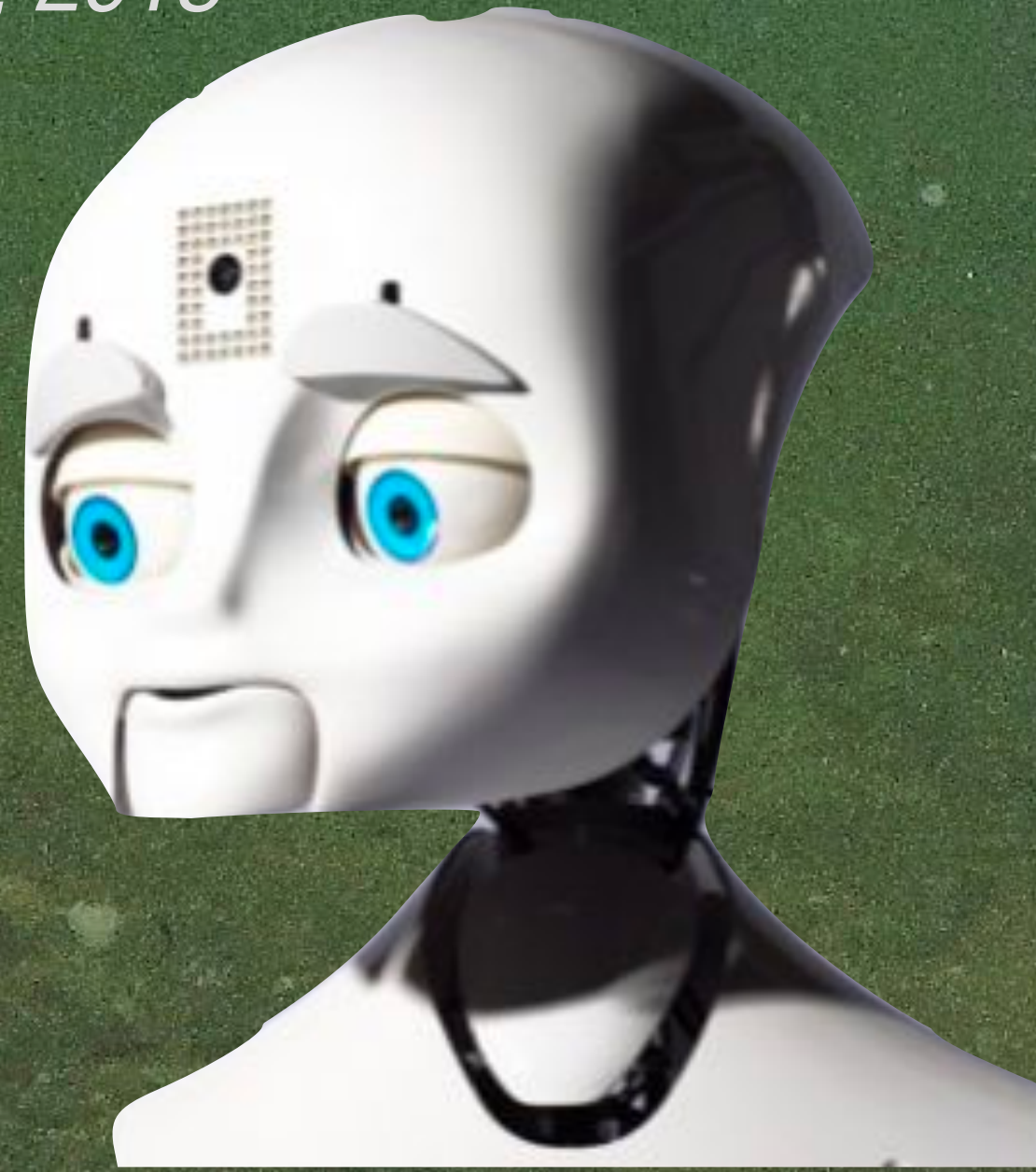
Wireless & Sensor Technologies for Oceans, Health, & Robotics

Fadel Adib

Doherty Chair & Associate Professor
Founding Director, Signal Kinetics

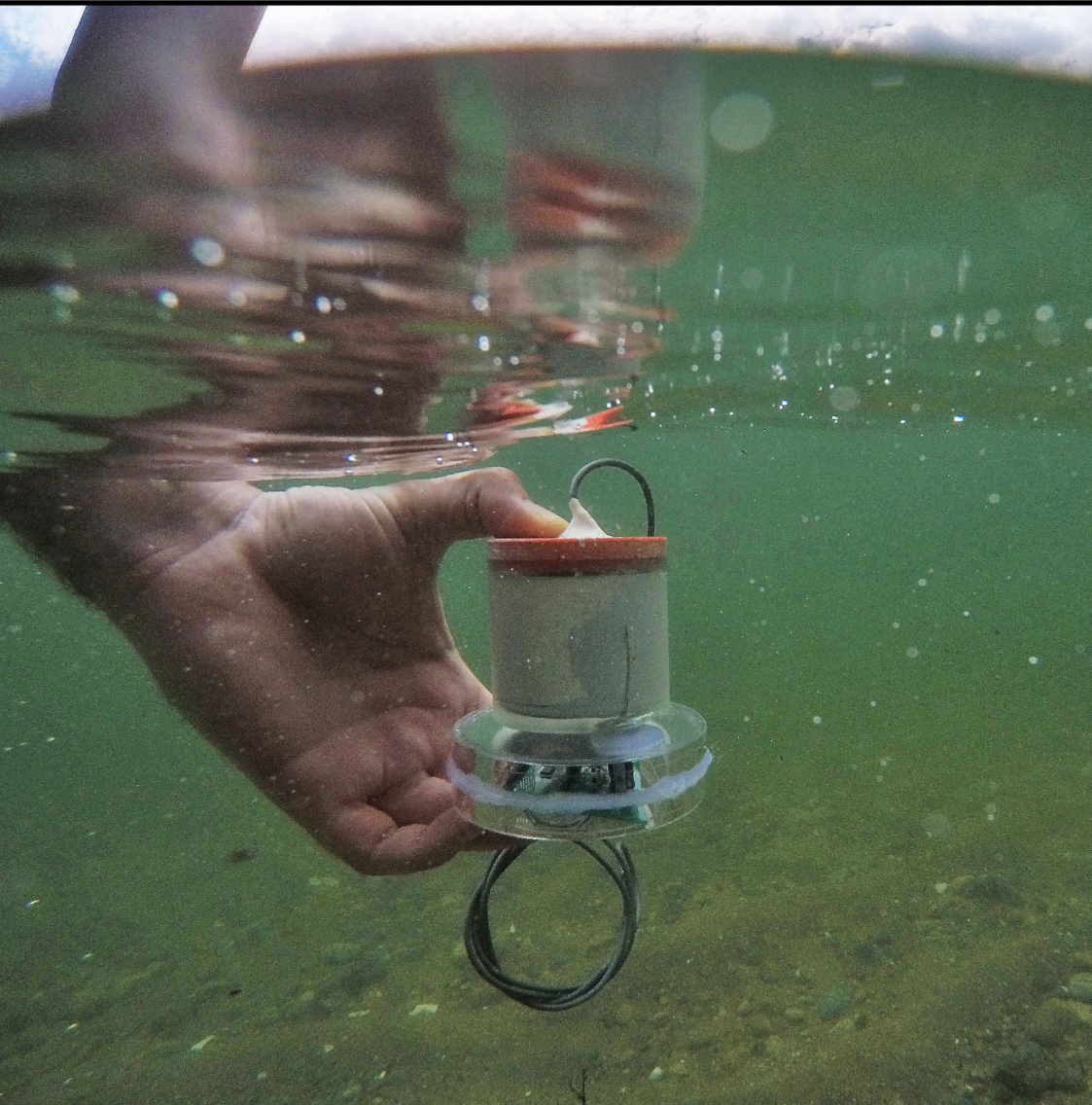
*“More than 80% of ocean remains unobserved
and unexplored.”*

- NOAA, 2018



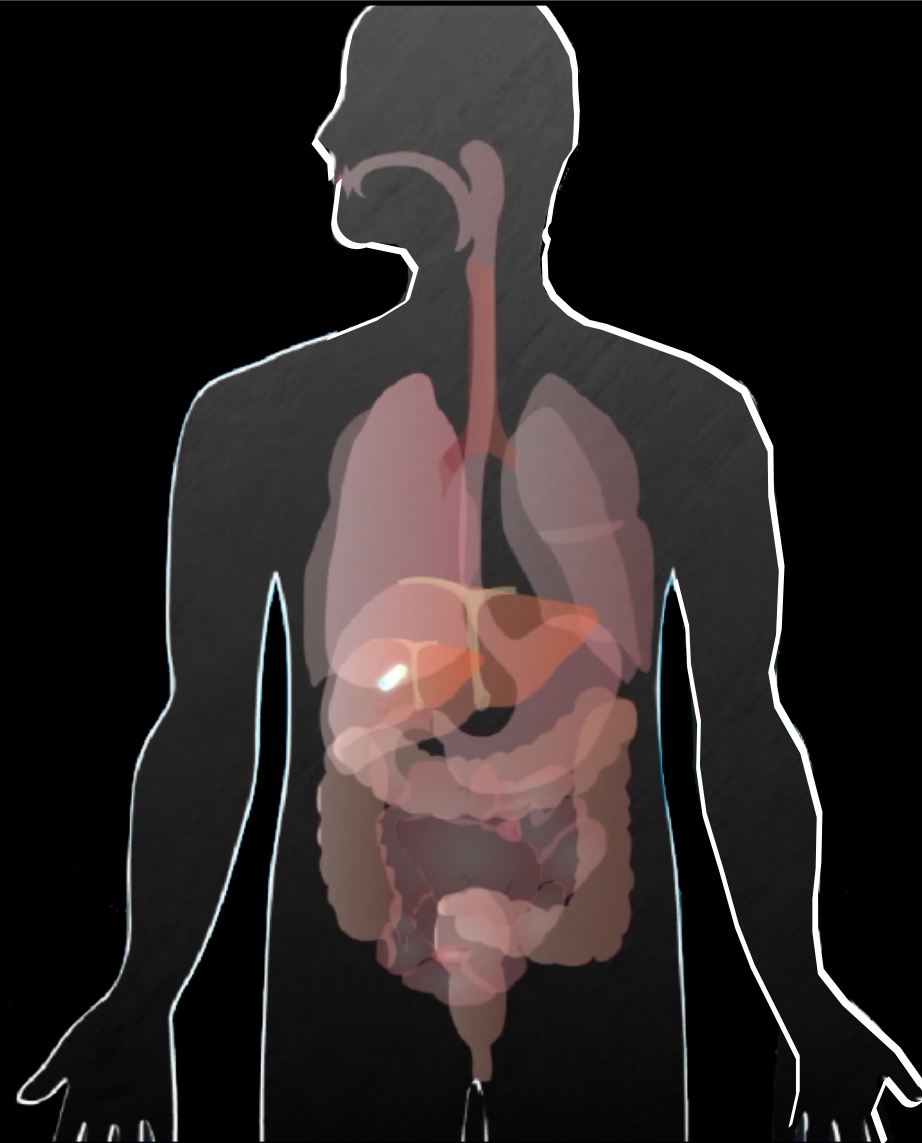
This Talk: Extreme IoT & Sensor Technologies

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]

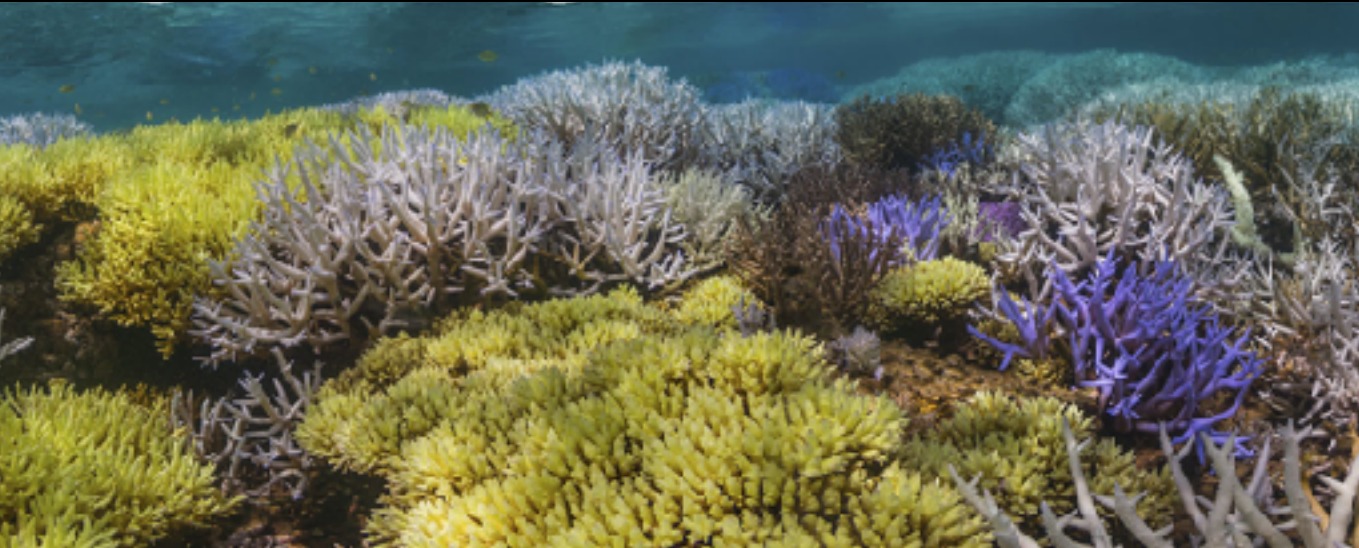


Oceans

Taking the Internet of Things Underwater

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

- NOAA, 2018

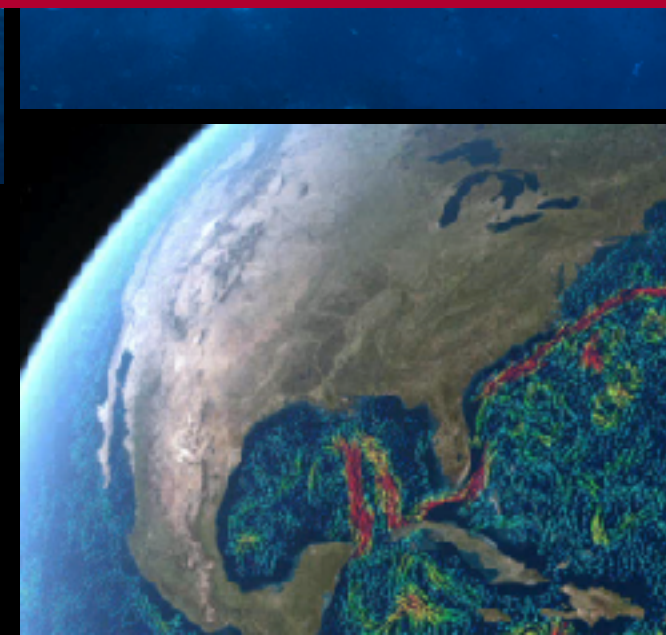


Less than 1 in a million of IoT is underwater, even though oceans cover more than 70% of the planet



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



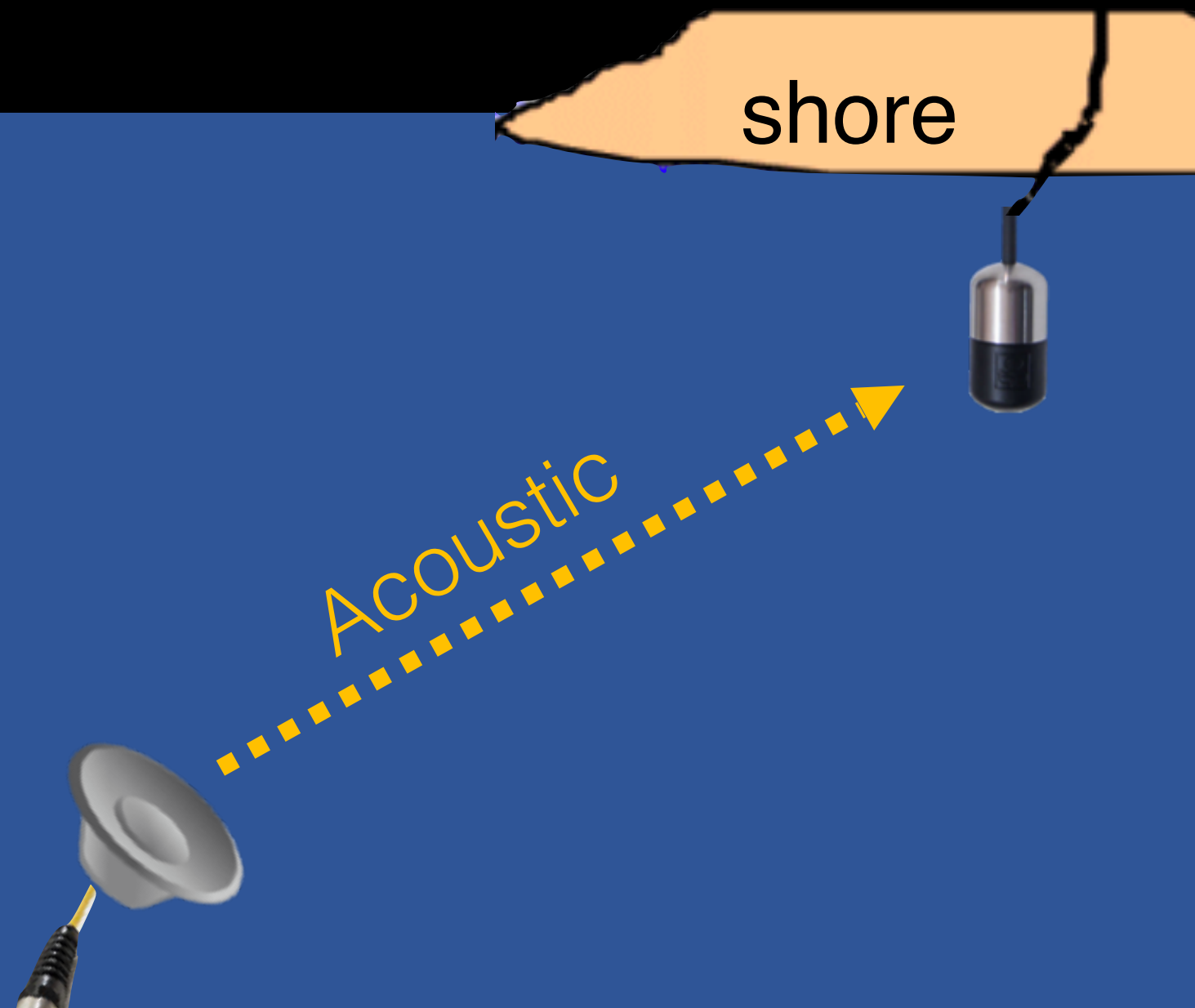
Most state-of-the-art sensors for tracking marine animals only last for few hours or days

[Animal Biotelemetry'15, Scientific Reports'17]

Technology that Enables Underwater Backscatter (**Batteryless**) Networking

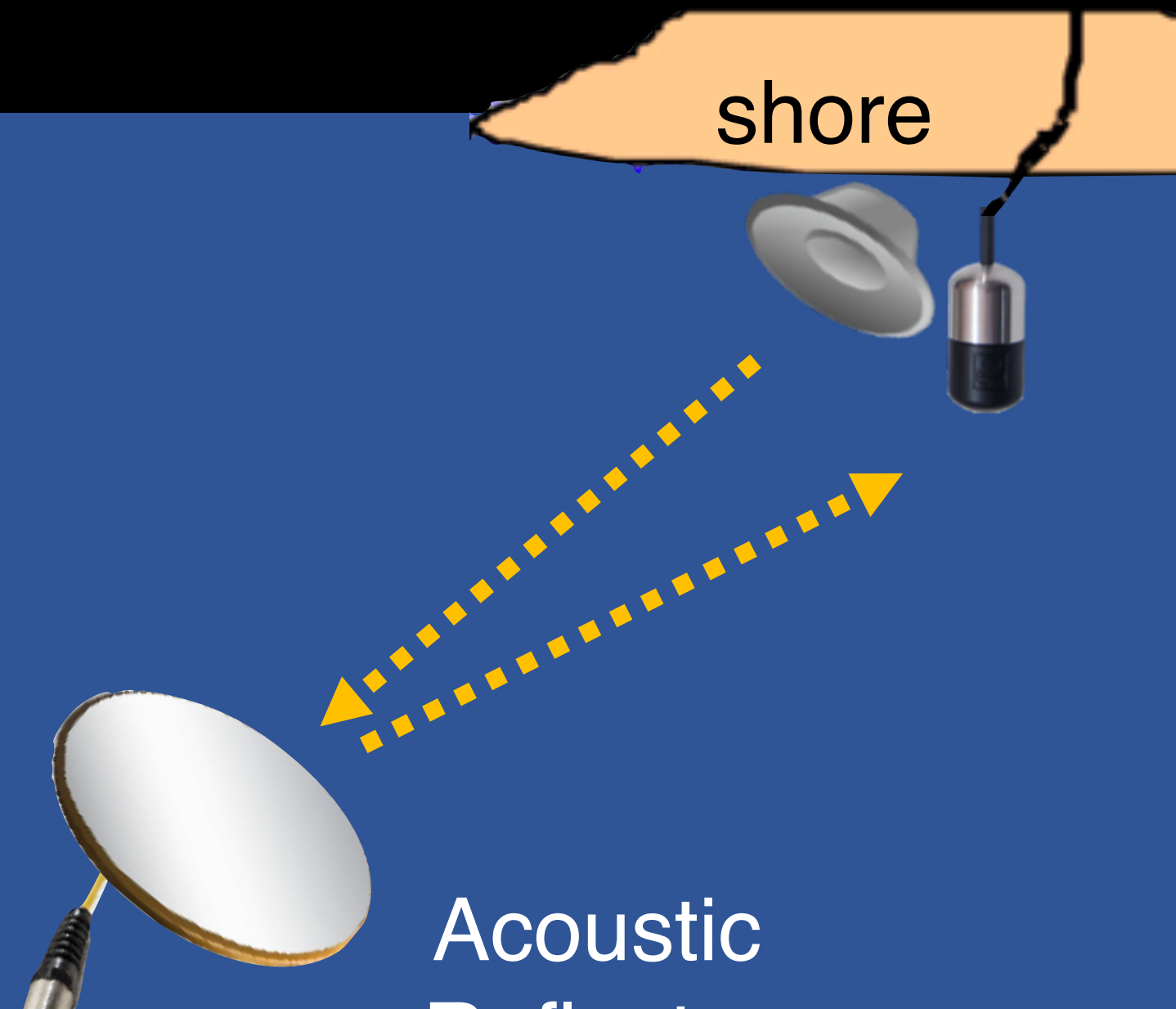
*Published in: ACM SIGCOMM'19, ACM SIGCOMM'20,
MTS/IEEE OCEANS'20, ACM HotNets'20*

Traditional Approach



Sensor generates its own
acoustic signal

Our Technology

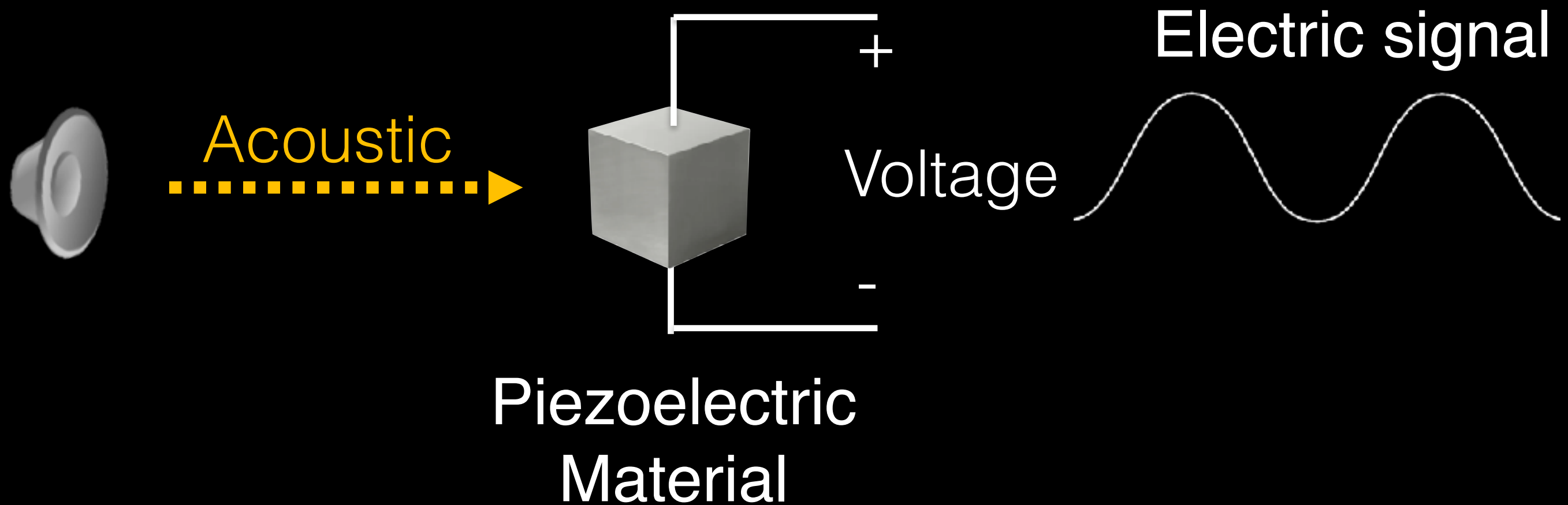


Sensor reflects an existing
acoustic signal

How can we control the reflections of
acoustic signals?

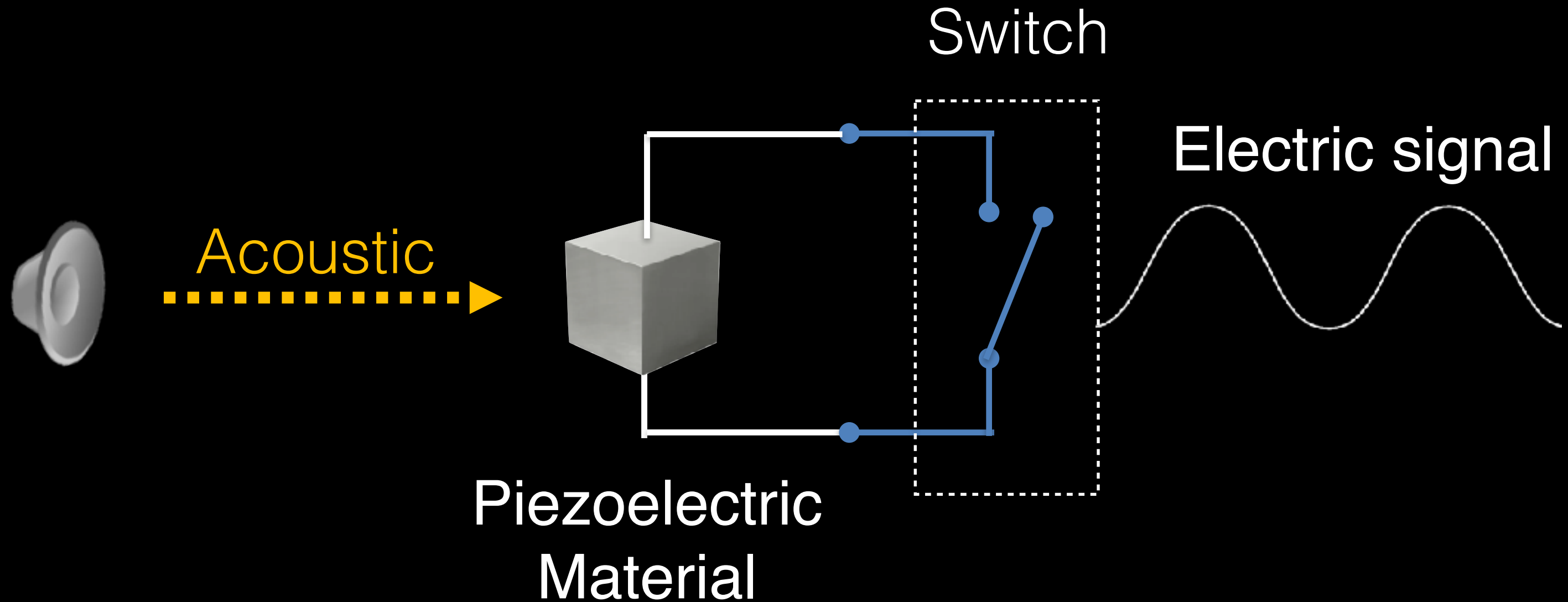
Key Idea: Use piezoelectricity to design programmable acoustic reflectors

Piezoelectric materials transform mechanical to electrical energy



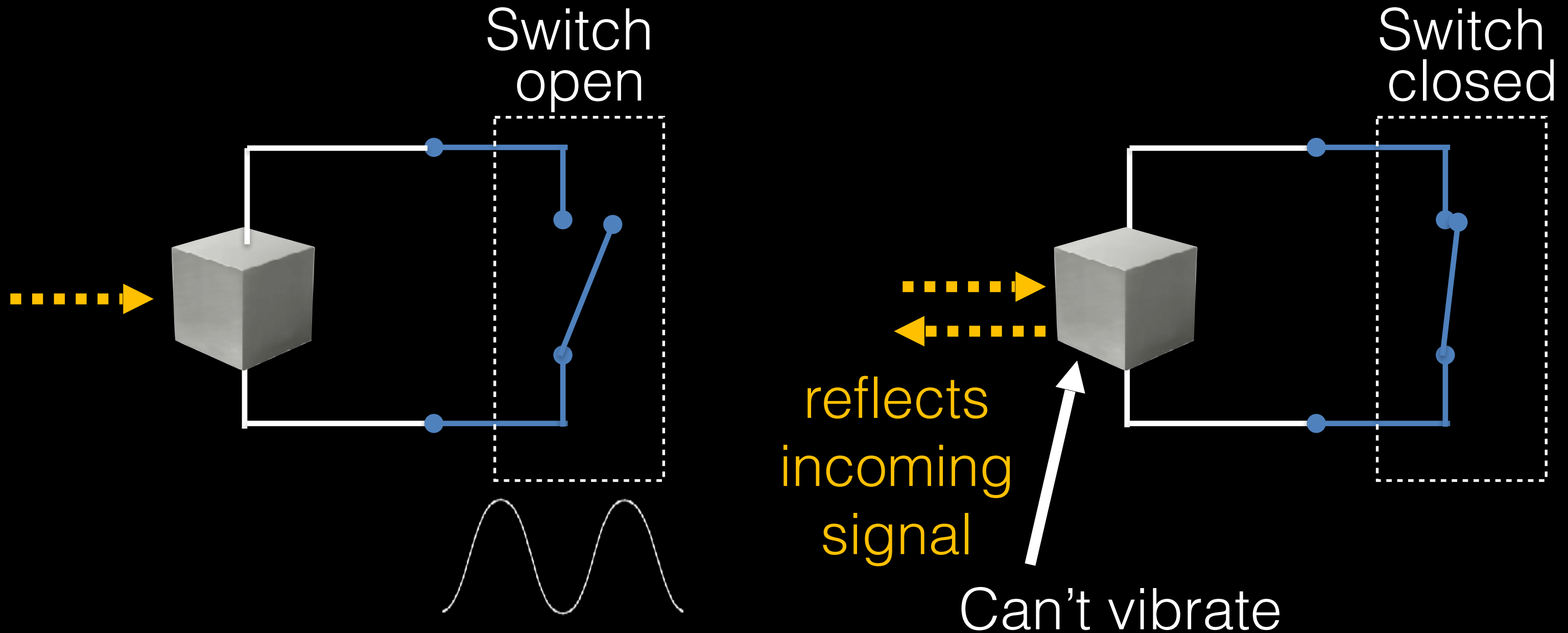
Key Idea: Use piezoelectricity to design programmable acoustic reflectors

Piezoelectric materials transform mechanical to electrical energy

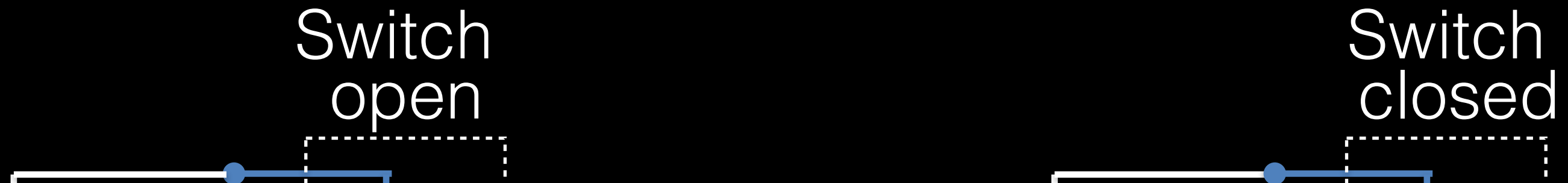


Key Idea: Use piezoelectricity to design programmable acoustic reflectors

Piezoelectric materials transform mechanical to electrical energy

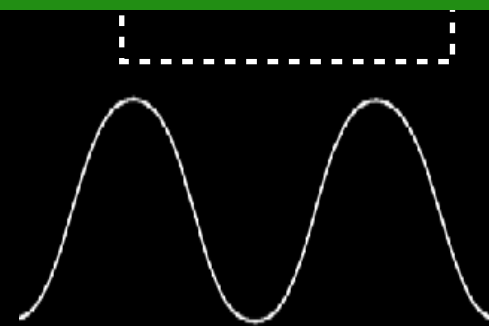


Piezo-Acoustic Backscatter



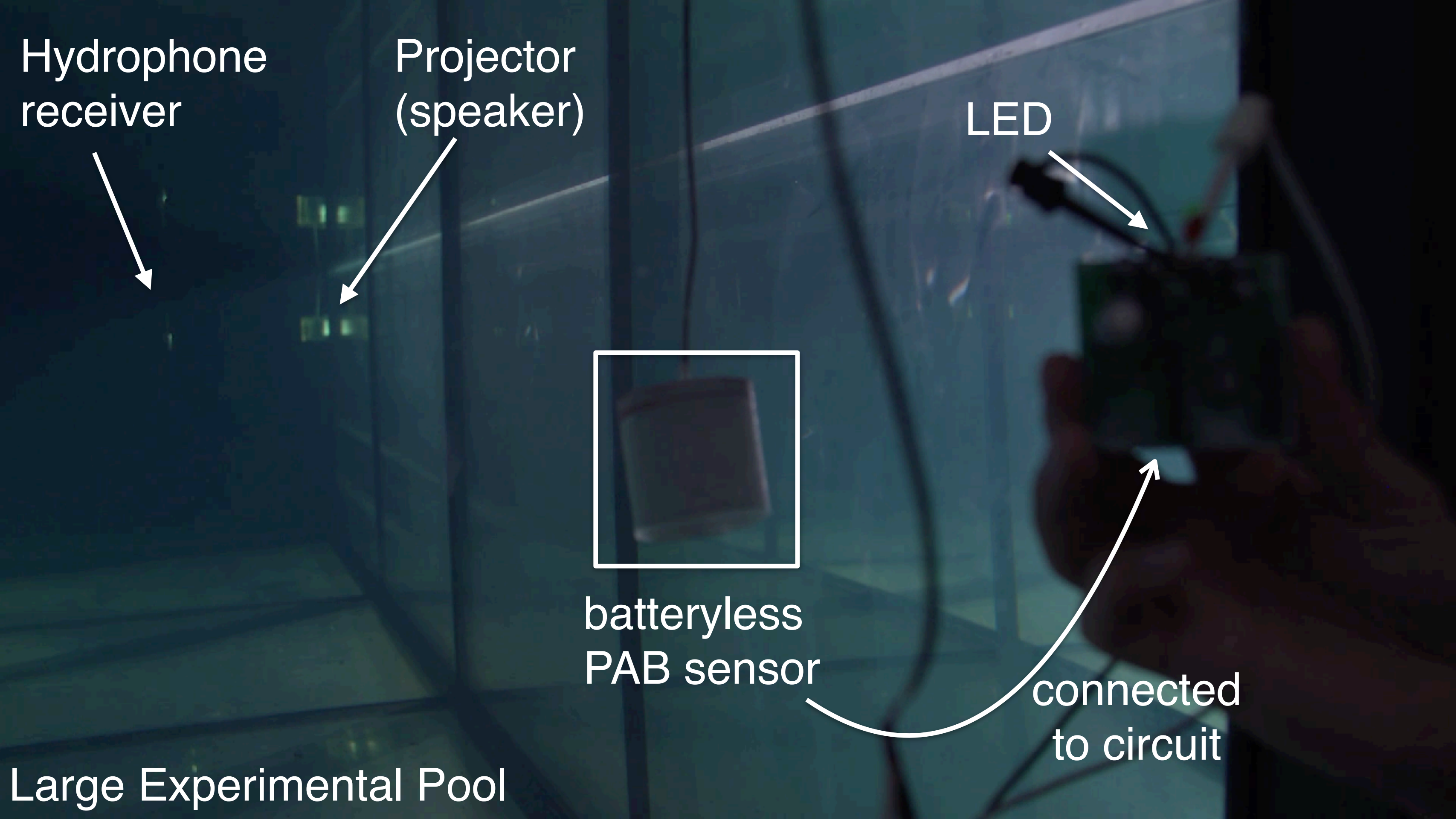
Our sensor needs 1 million times less power (~100s microWatt) than standard underwater modems

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



Incoming
signal

Can't vibrate



Hydrophone
receiver

Projector
(speaker)

LED

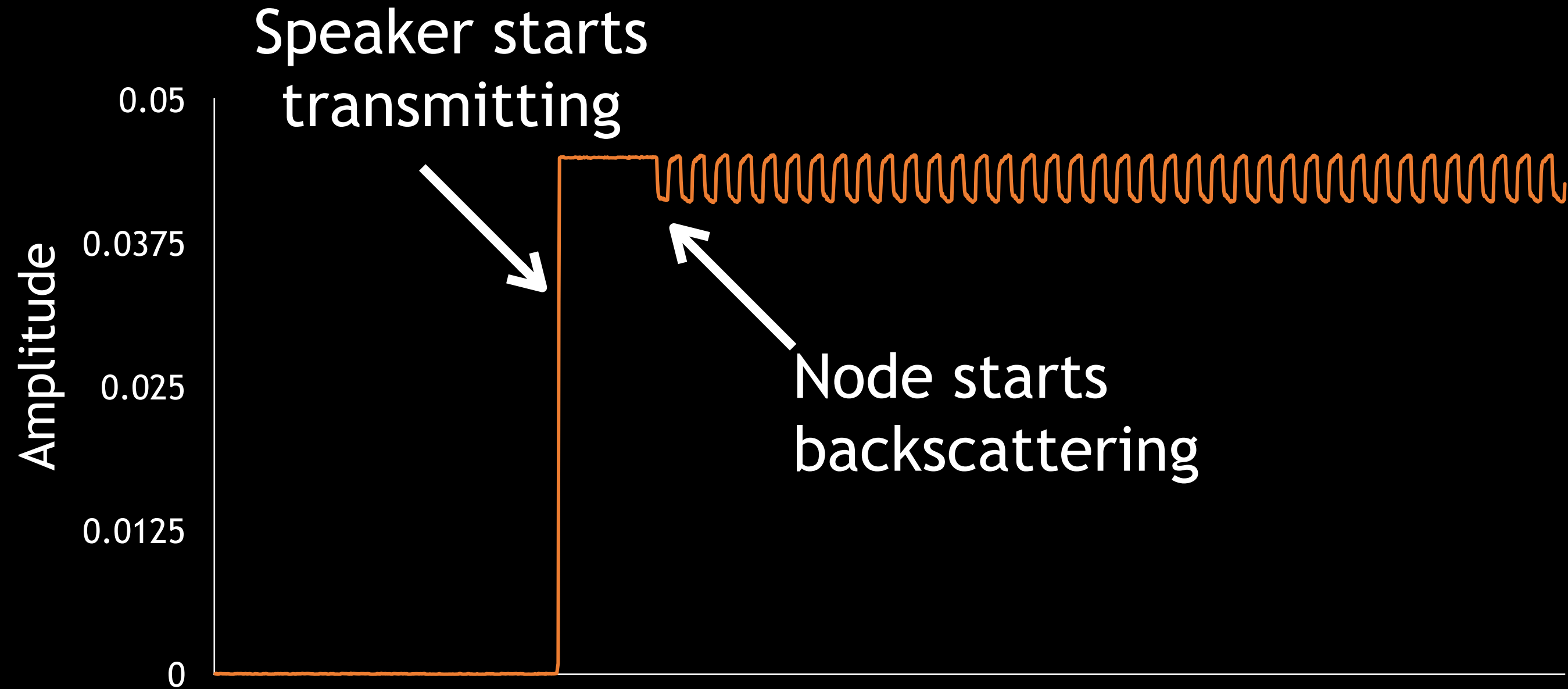


batteryless
PAB sensor

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



Hardware for energy
harvesting, bi-directional
communication, sensor

Fabricated & 3D printed
(omnidirectional) transducer

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

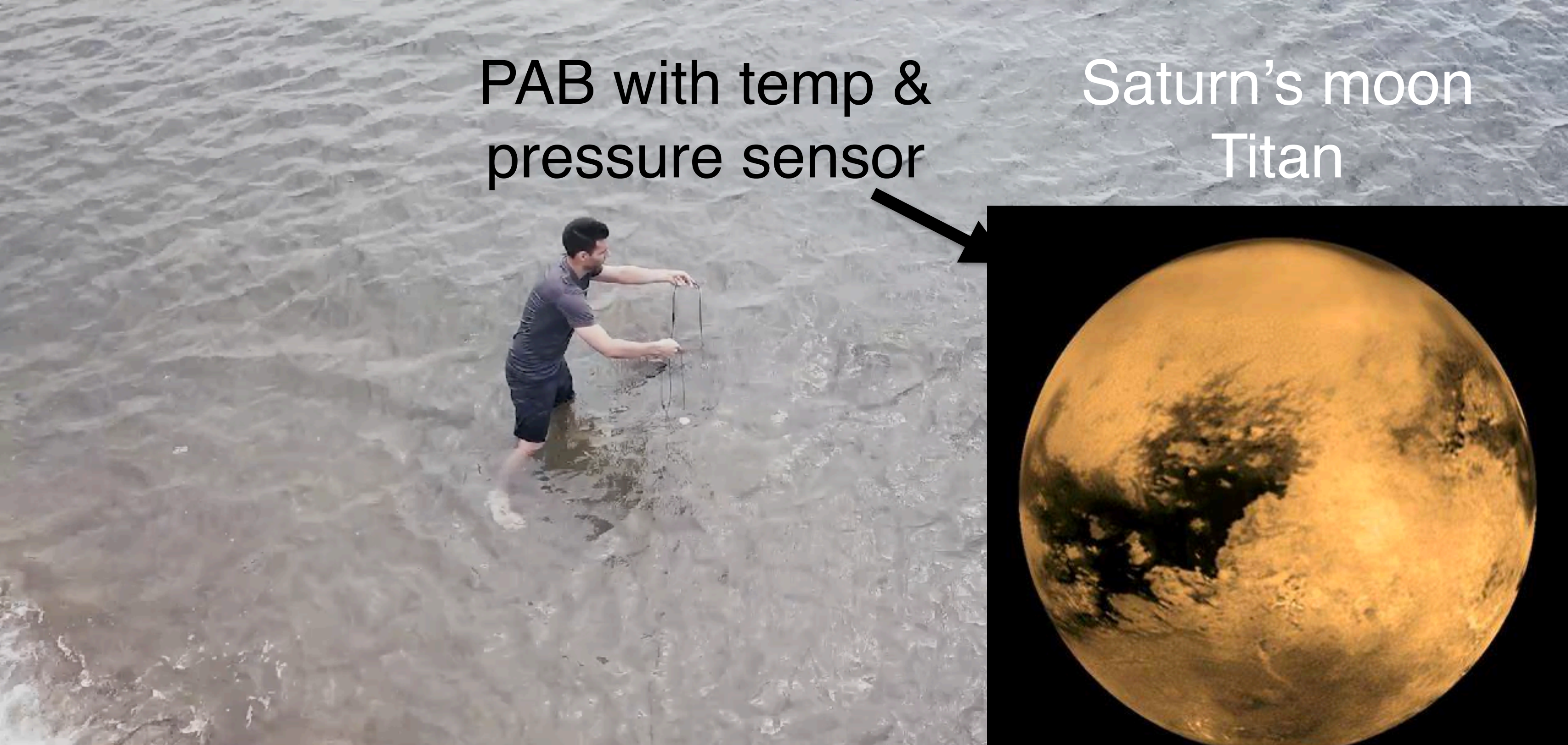
Experimental Evaluation in River (with snow & rain)

- 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

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

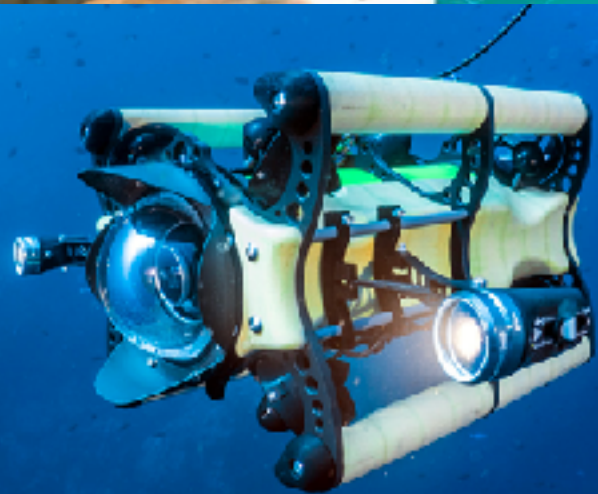
(3) Architectural developments

Apps: Networking, simulations, range, energy, materials

Code+Schematics+Tutorials:

[https://github.com/saadafzal24/
Underwater-Backscatter](https://github.com/saadafzal24/Underwater-Backscatter)

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



Batteryless underwater GPS



Smart Oceans 2020



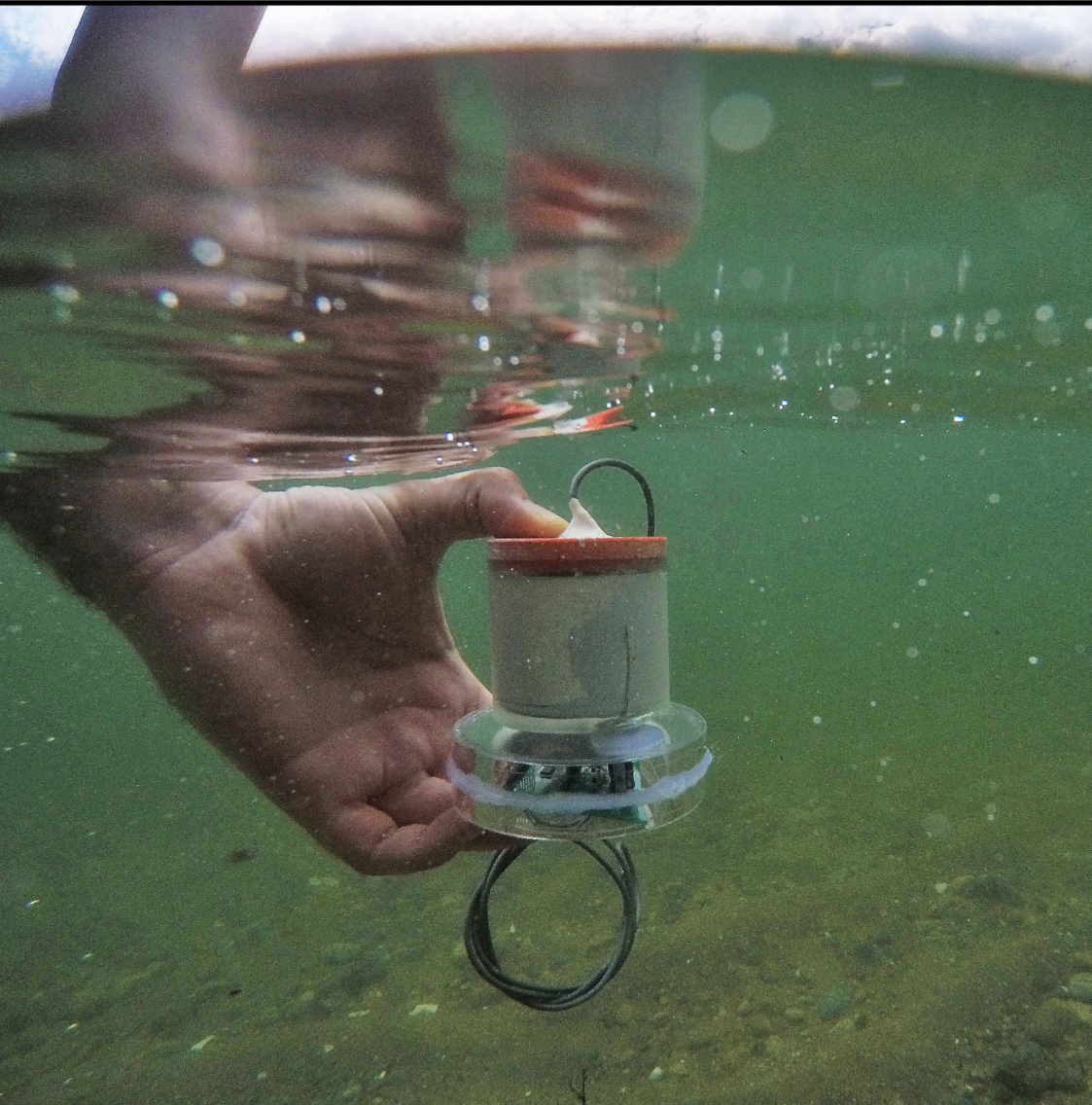
*\$80M+ for industry-academic collab.
LOI due May 5, 2021*



Oceans

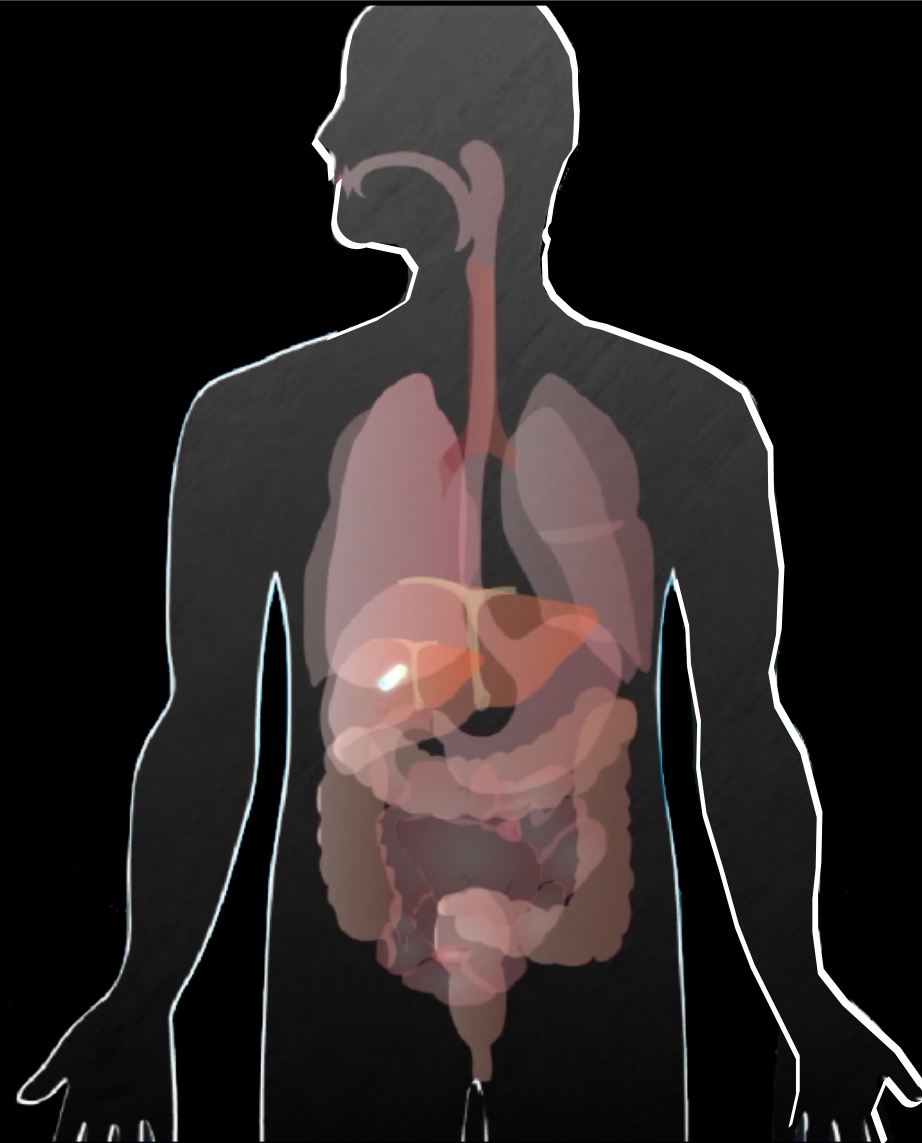
This Talk: Extreme IoT & Sensor Technologies

Oceans



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

Human Body



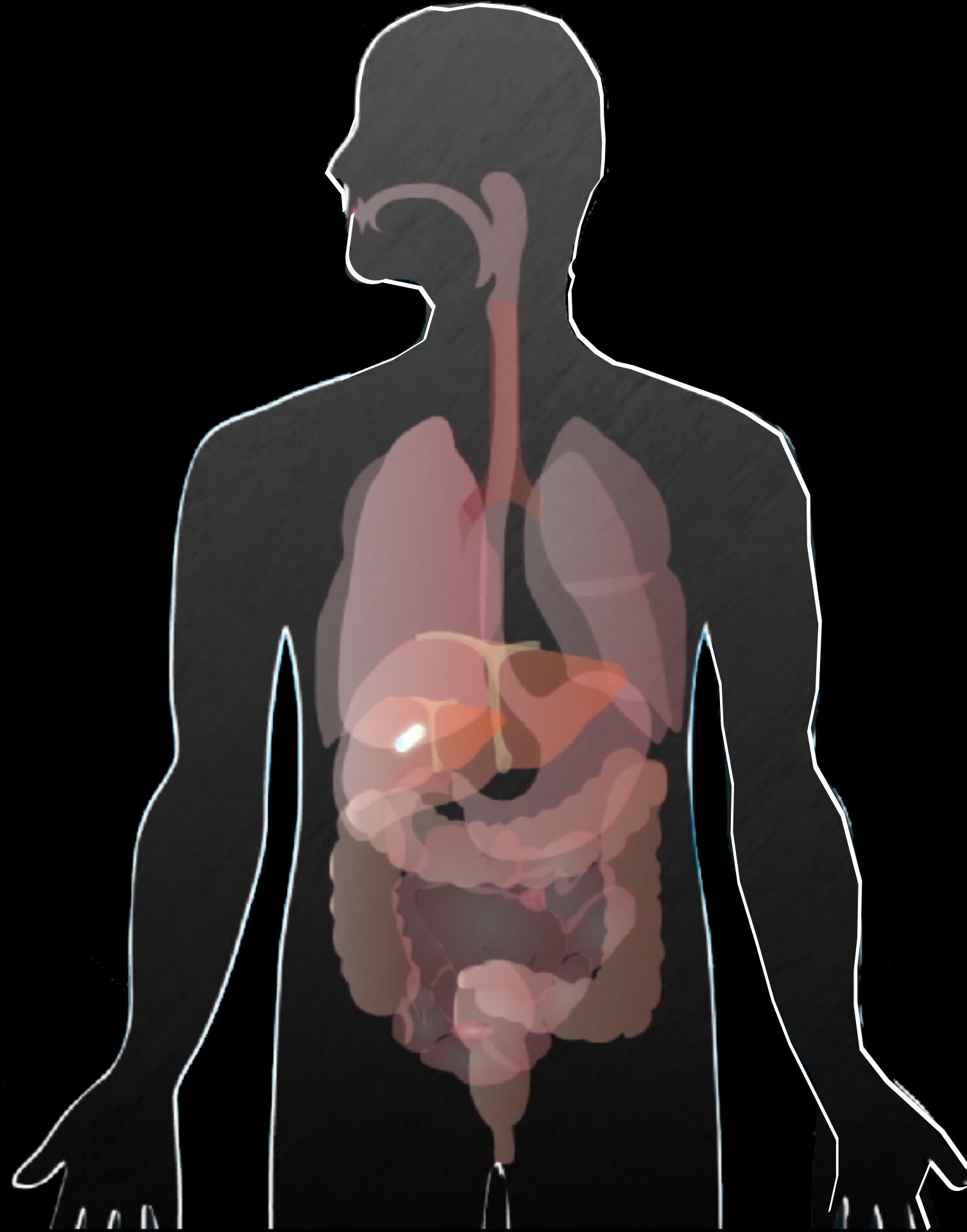
[ACM SIGCOMM '18b, MobiCom'20a,
MobiCom'20b, ACM IMWUT'21]

Robotics



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

Human Body



Man receives under-skin chip implant live at mobile show



**POPULAR
SCIENCE**

TECHNOLOGY

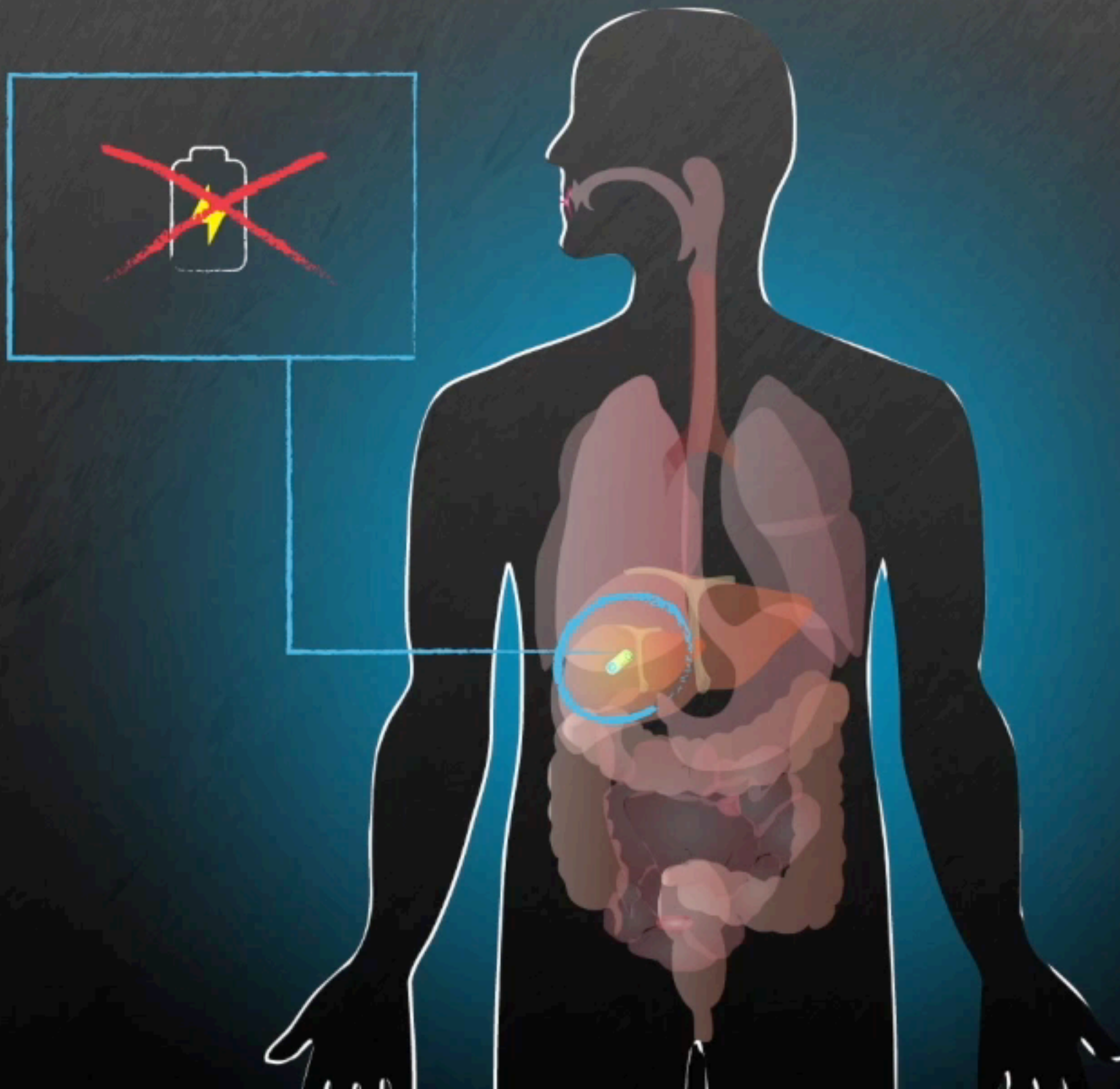
Why Did I Implant A Chip In My Hand?

My so-called cyborg life

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

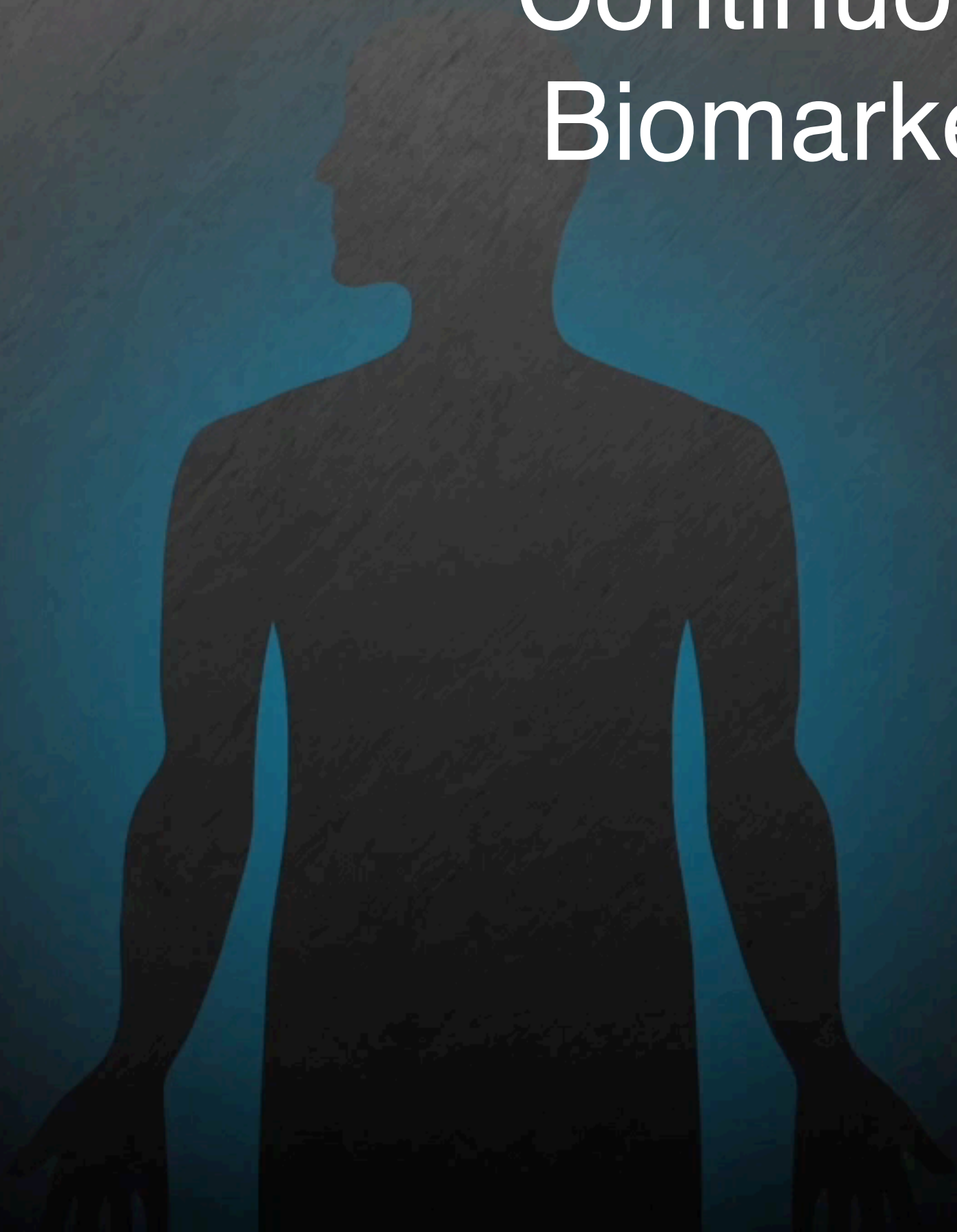
BARCELONA (Reuters) - A man volunteered to be on stage at a trade fair in Barcelona on Monday, and another man who had already undergone



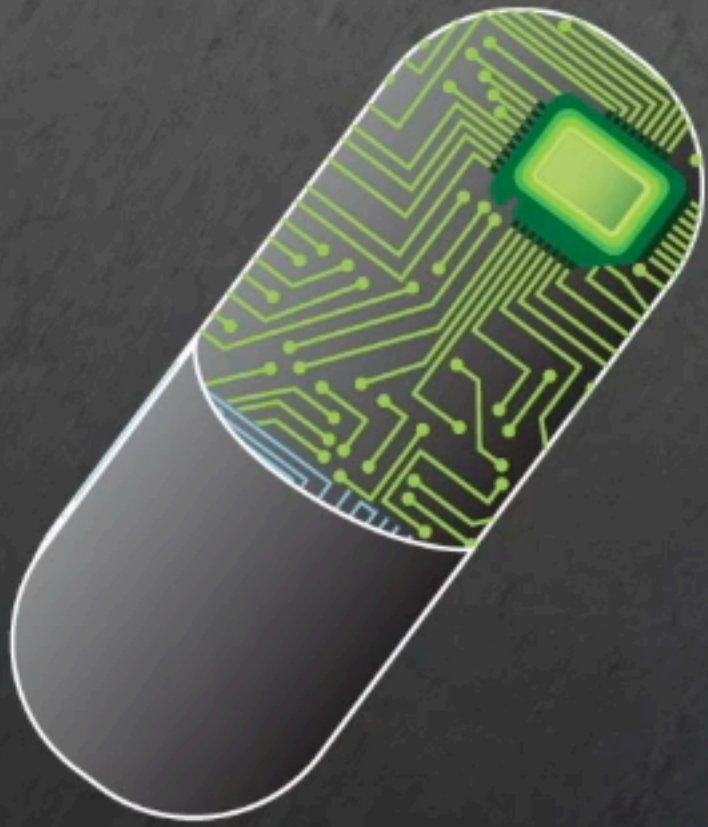


Wirelessly Power
& Communicate

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]

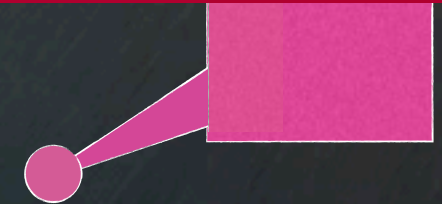
Key Challenge:

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

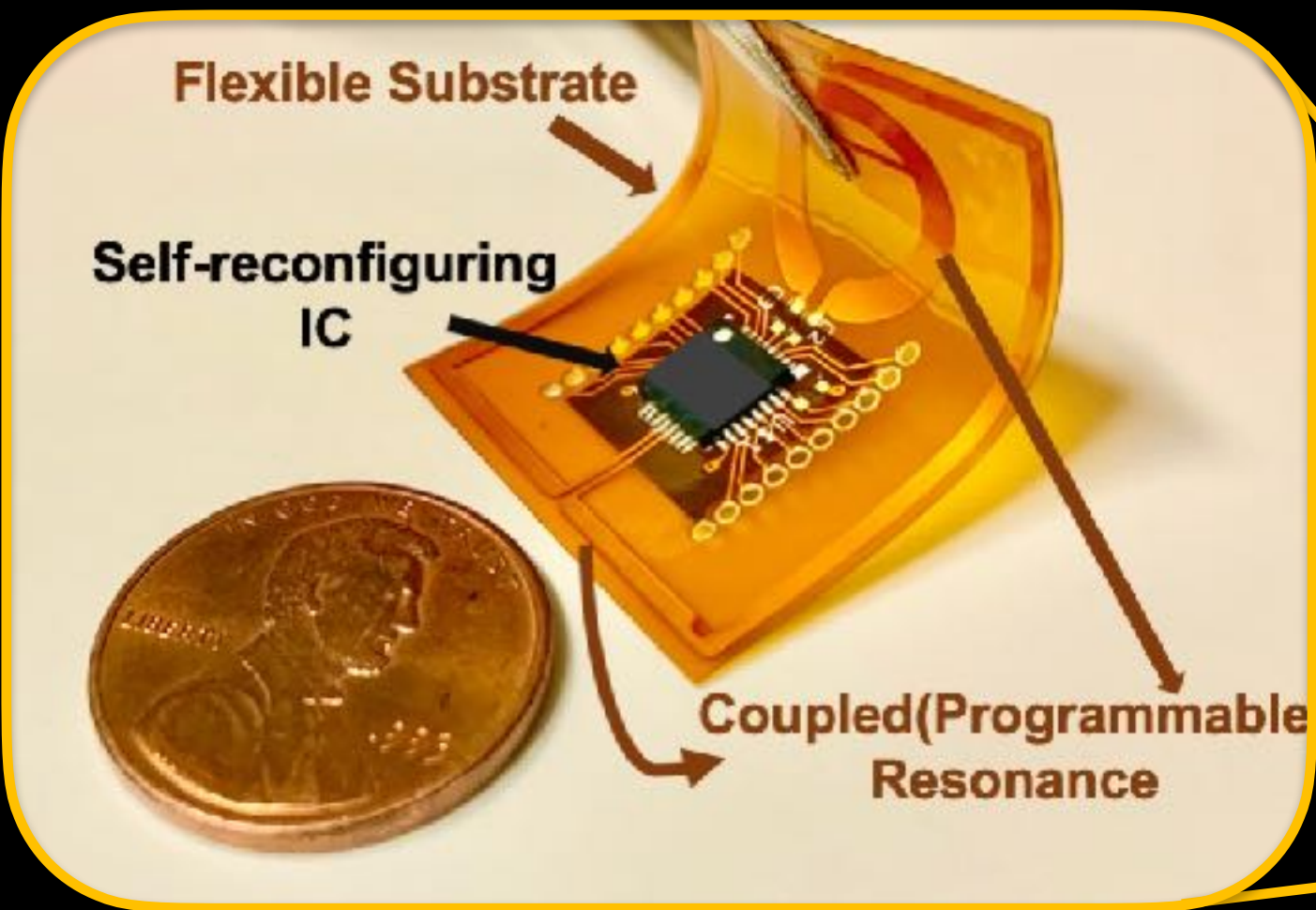


Cannot power up batteryless sensor in deep tissues



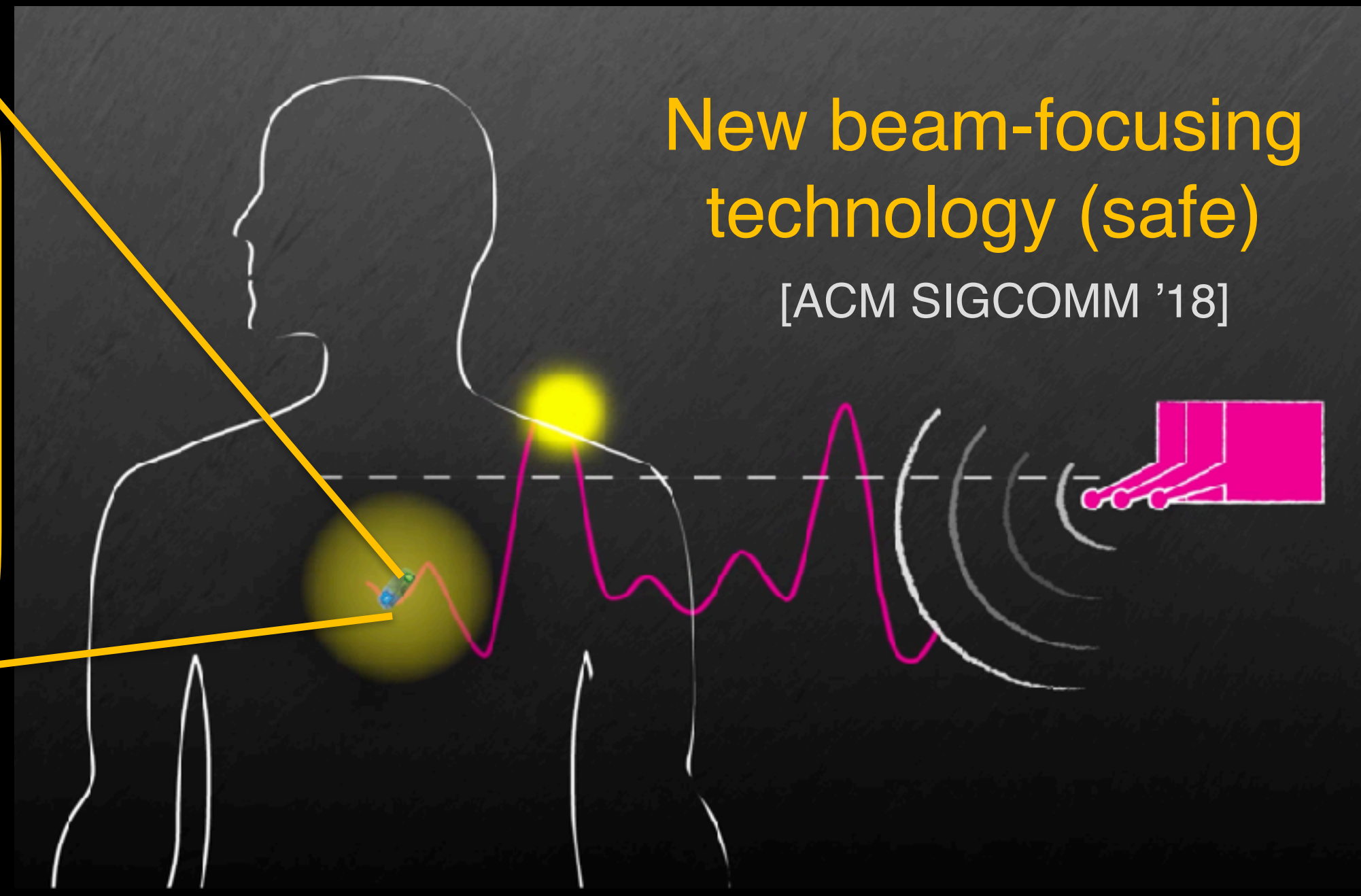
How can we power and communicate with sensors in deep tissues despite tissue attenuation & complexity?

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



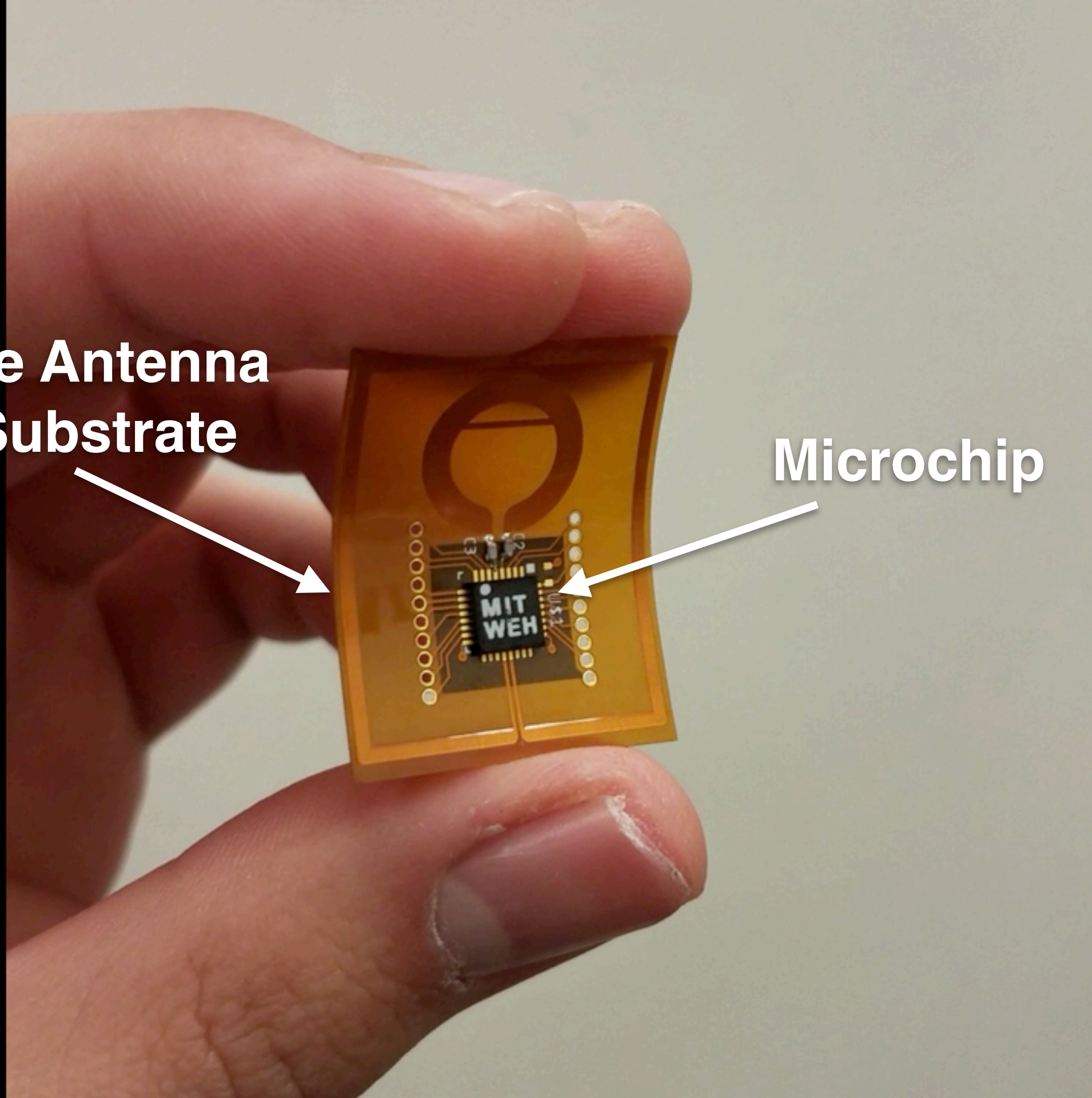
Self-reconfiguring micro-implant

[ACM MobiCom '20]

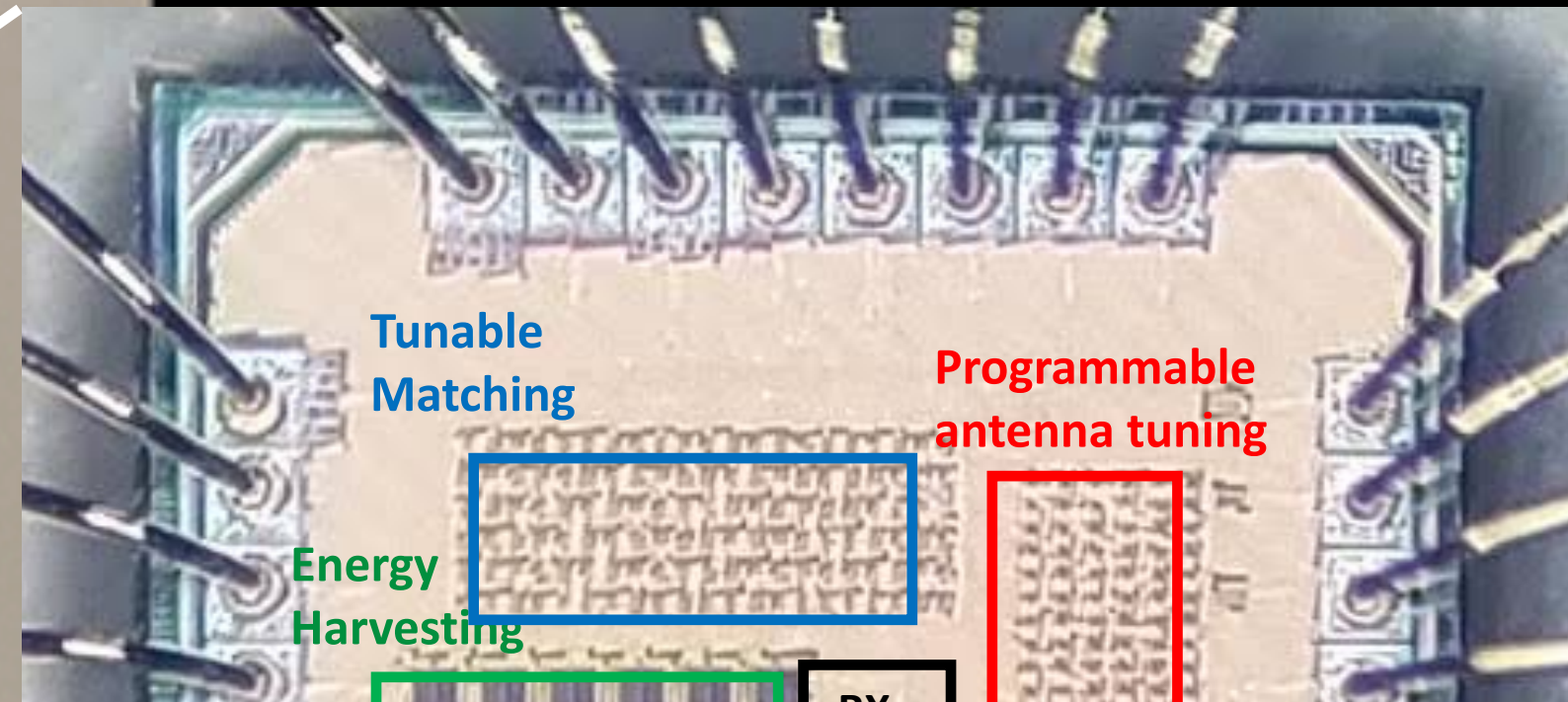


**Programmable Antenna
on Flexible Substrate**

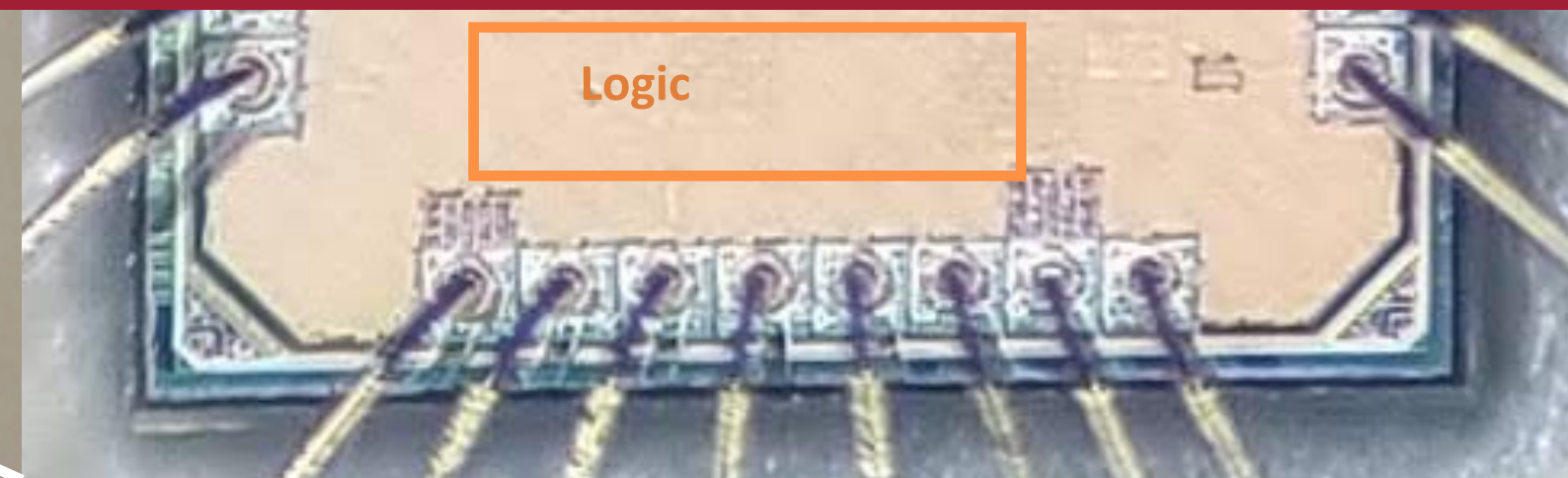
Microchip



Magnified Die Micrograph

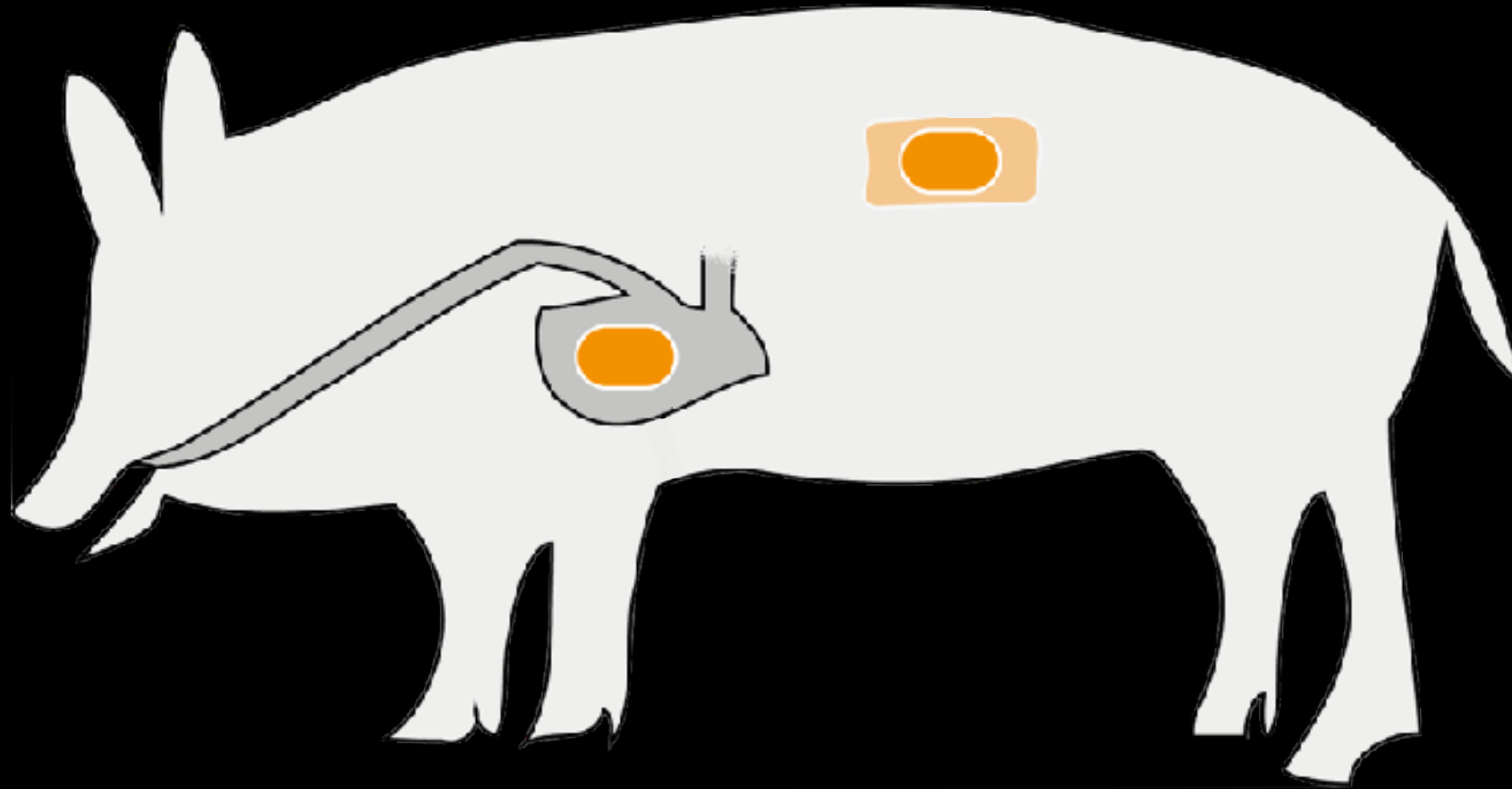


Micro-implant is wireless, batteryless, and intelligent:
consumes **350 nanoWatts**, throughput of **6Mbps**, & adapts to surrounding tissues



In-Vivo Evaluation with Living Animal

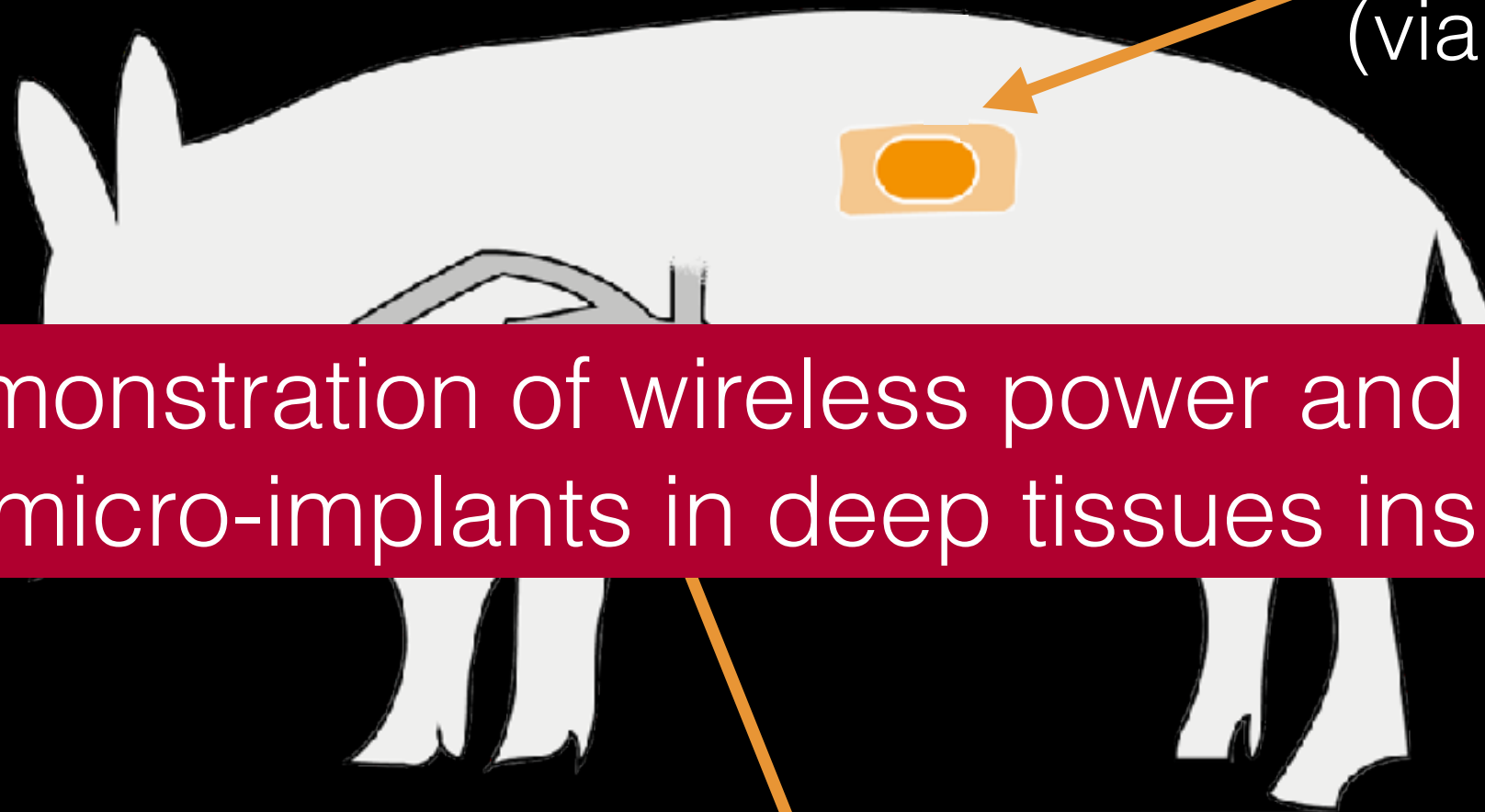
Female yorkshire pig weighing 85 kg



In-Vivo Evaluation with Living Animal

Female yorkshire pig weighing 85 kg

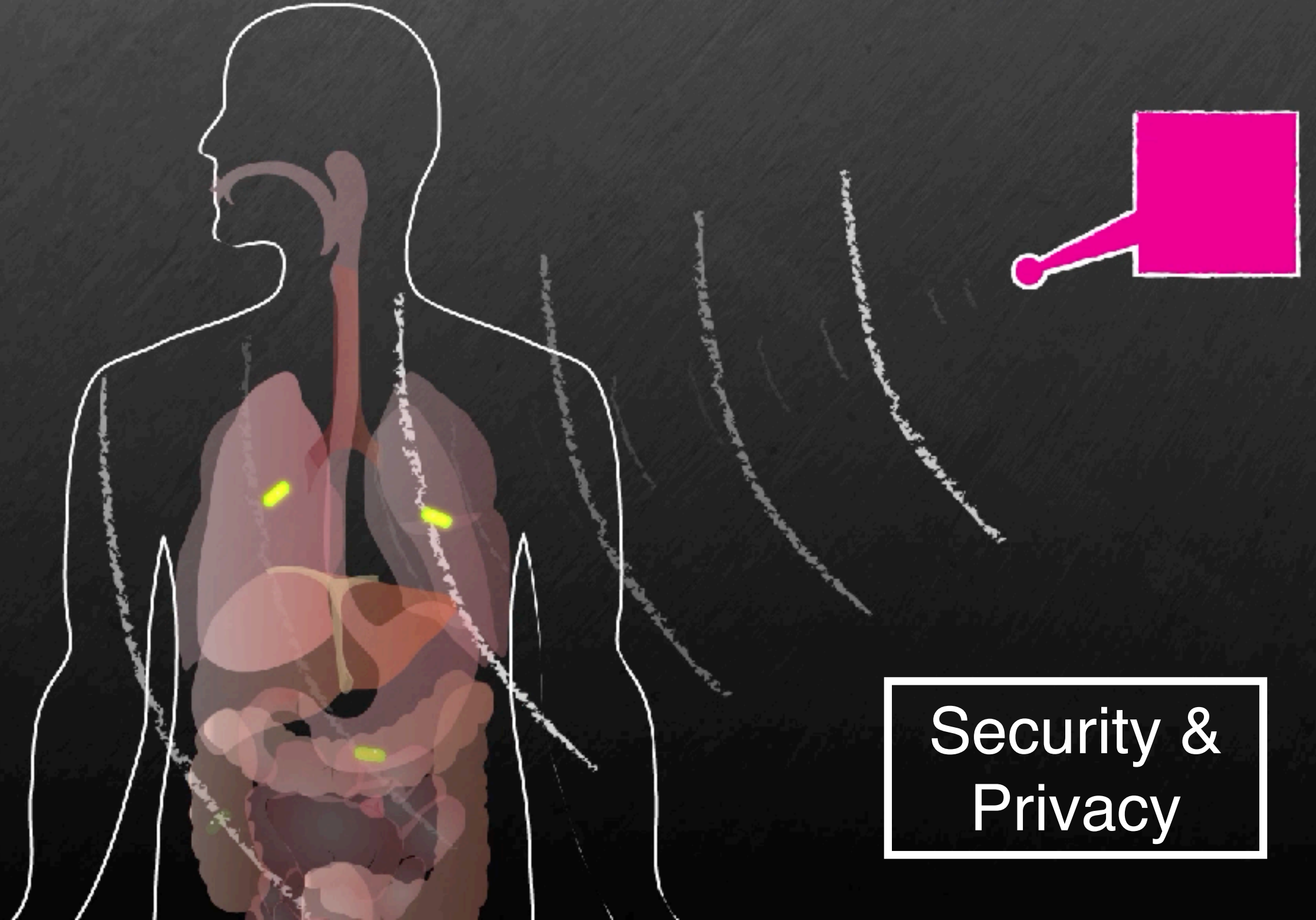
under the skin
(via than 3cm incision)



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

inside the stomach

Looking Ahead



Security &
Privacy

Contactless Breath Monitoring using Wireless Signals



Baby Monitoring

2014-03-14 21:50:30

Our technology (startup
patients with AL



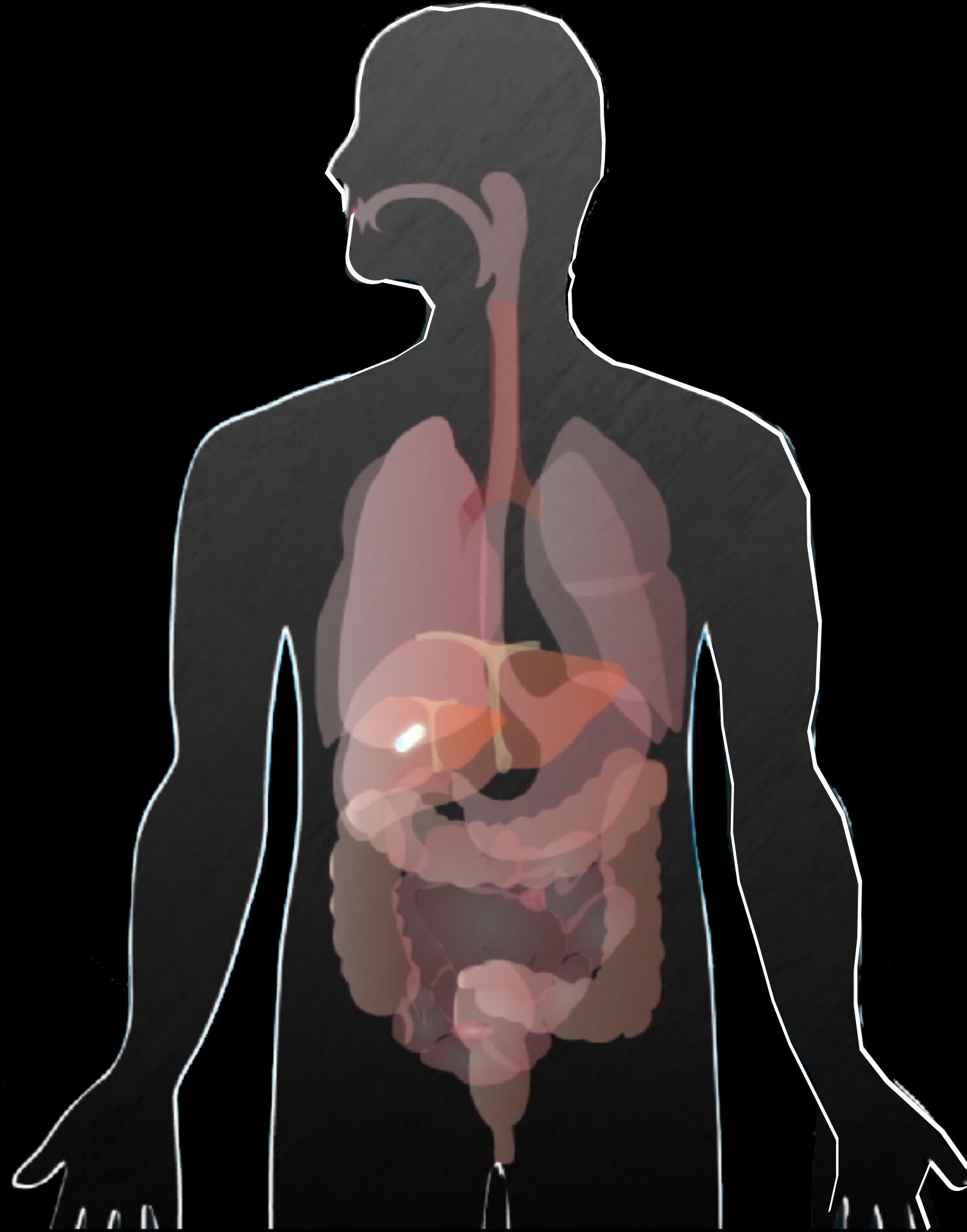
How can we capture heart recordings?



98-99% accuracy in timing
micro-cardiac events

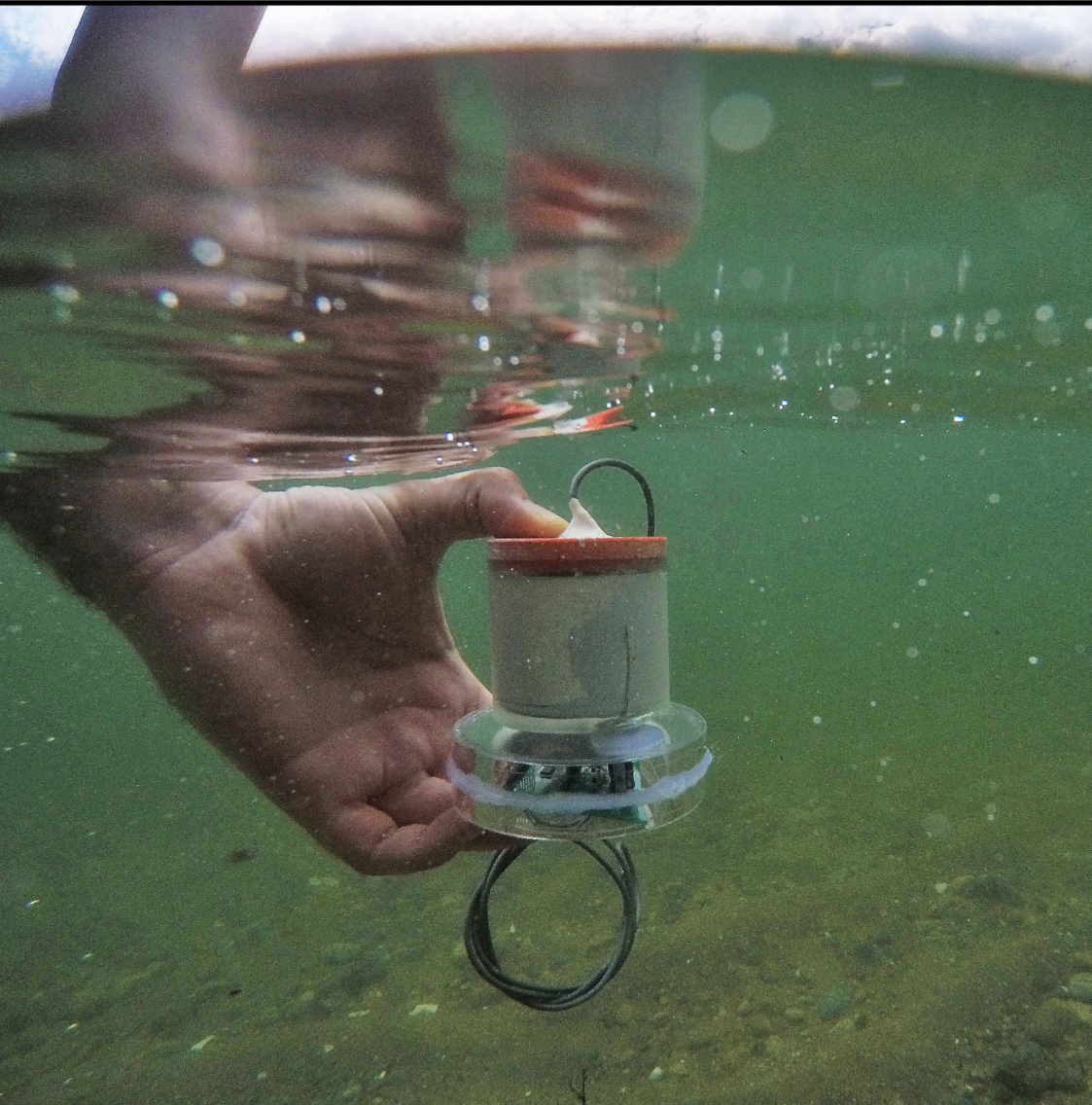
[ACM MobiCom'20]

Human Body



This Talk: Extreme IoT & Sensor Technologies

Oceans



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

Human Body

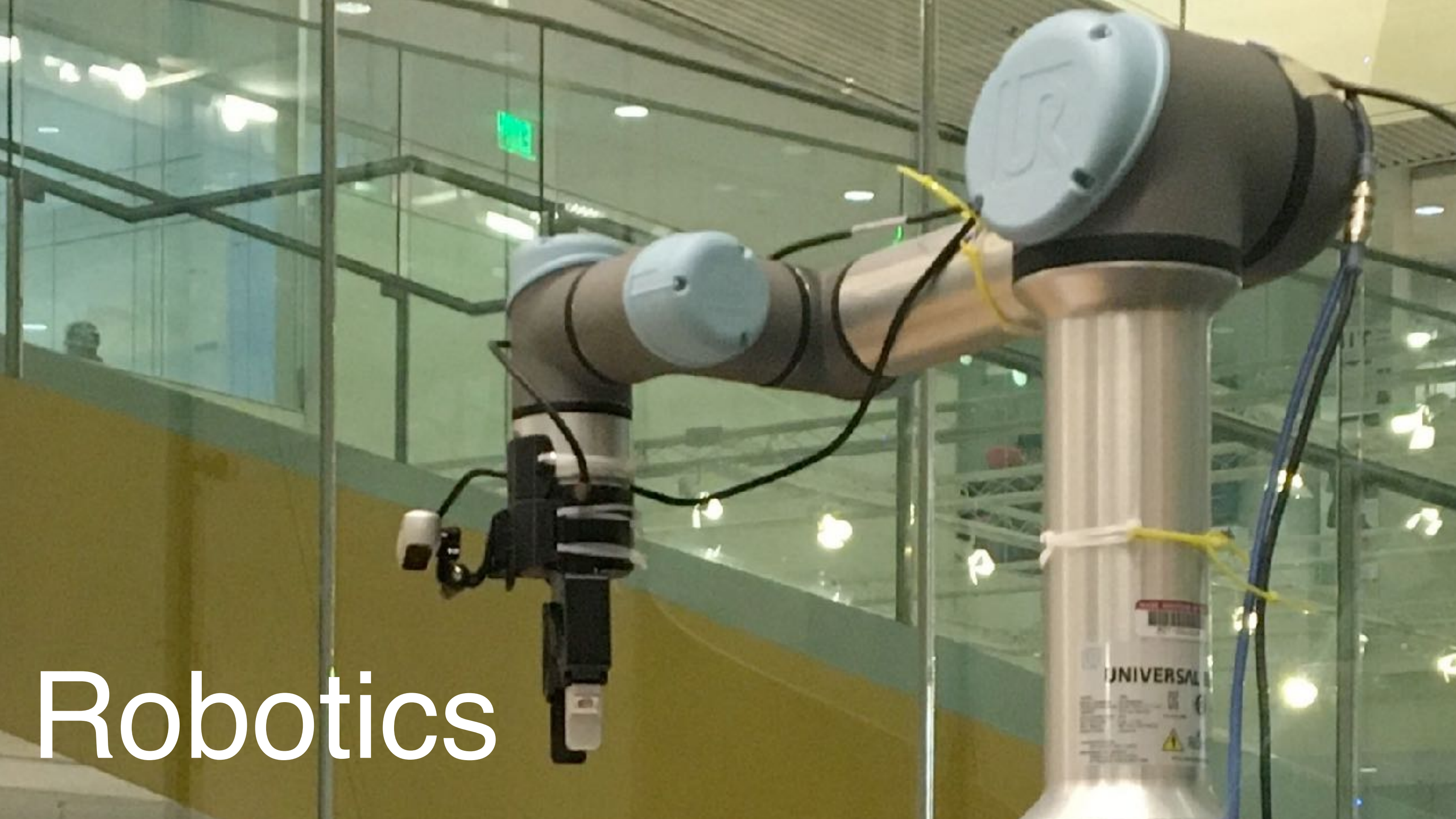


[ACM SIGCOMM '18b, MobiCom'20a,
MobiCom'20b, ACM IMWUT'21]

Robotics

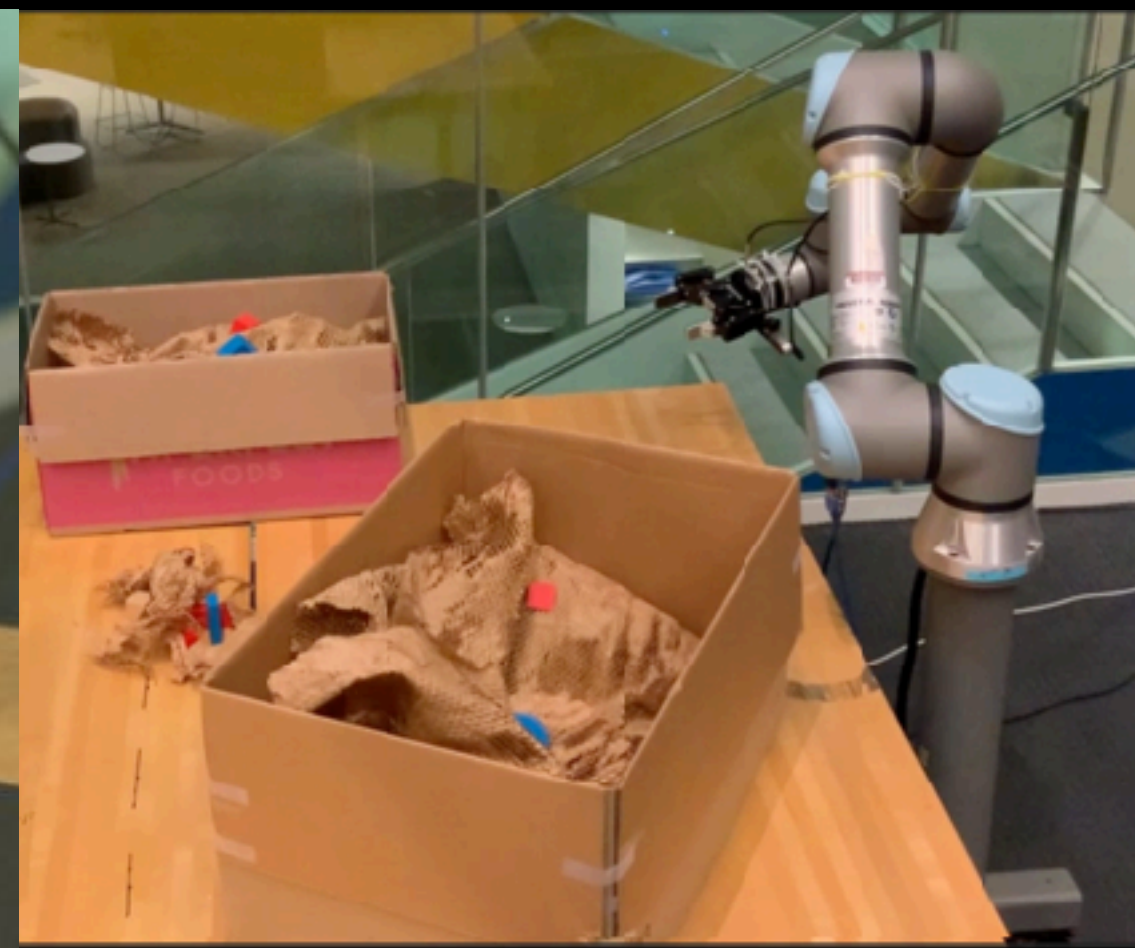


[ACM SIGCOMM'17, MobiCom'17,
NSDI'19, NSDI '20, IEEE ICRA'21]



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?*

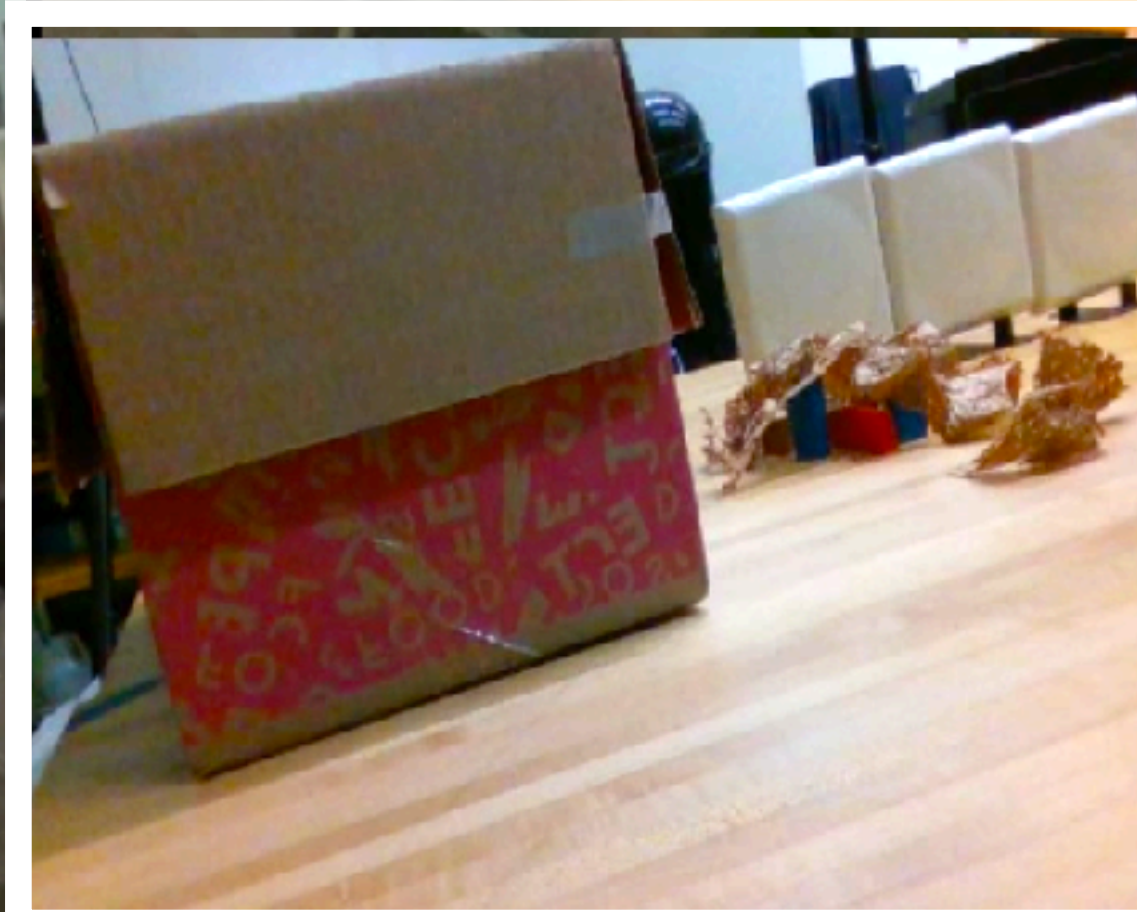
*Can it fetch items it **cannot see**?*

Augment Robots with **Wireless** Perception

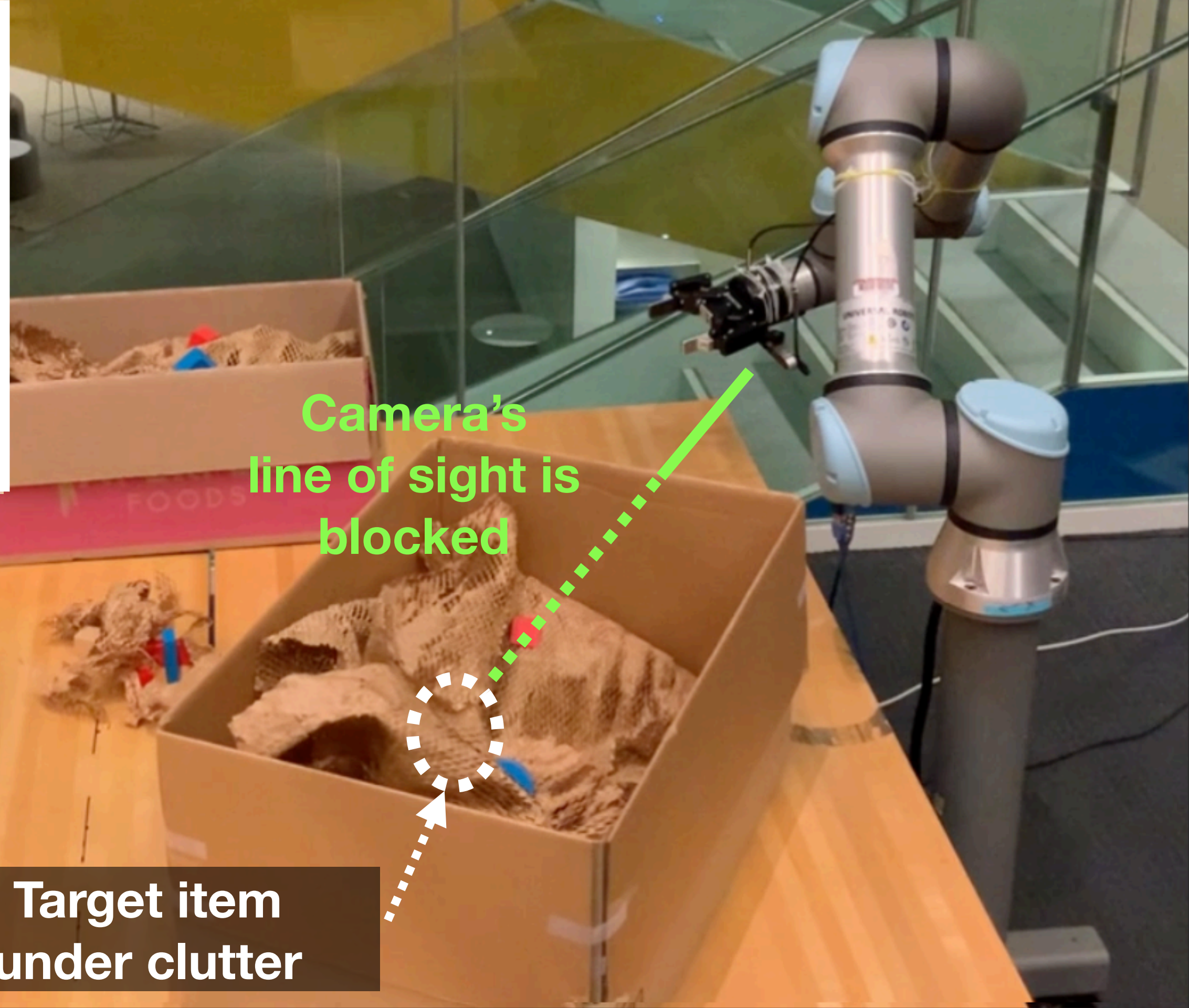
Radio Frequency (RF) signals traverse occlusions

→ Extend perception beyond line-of-sight

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



Camera View



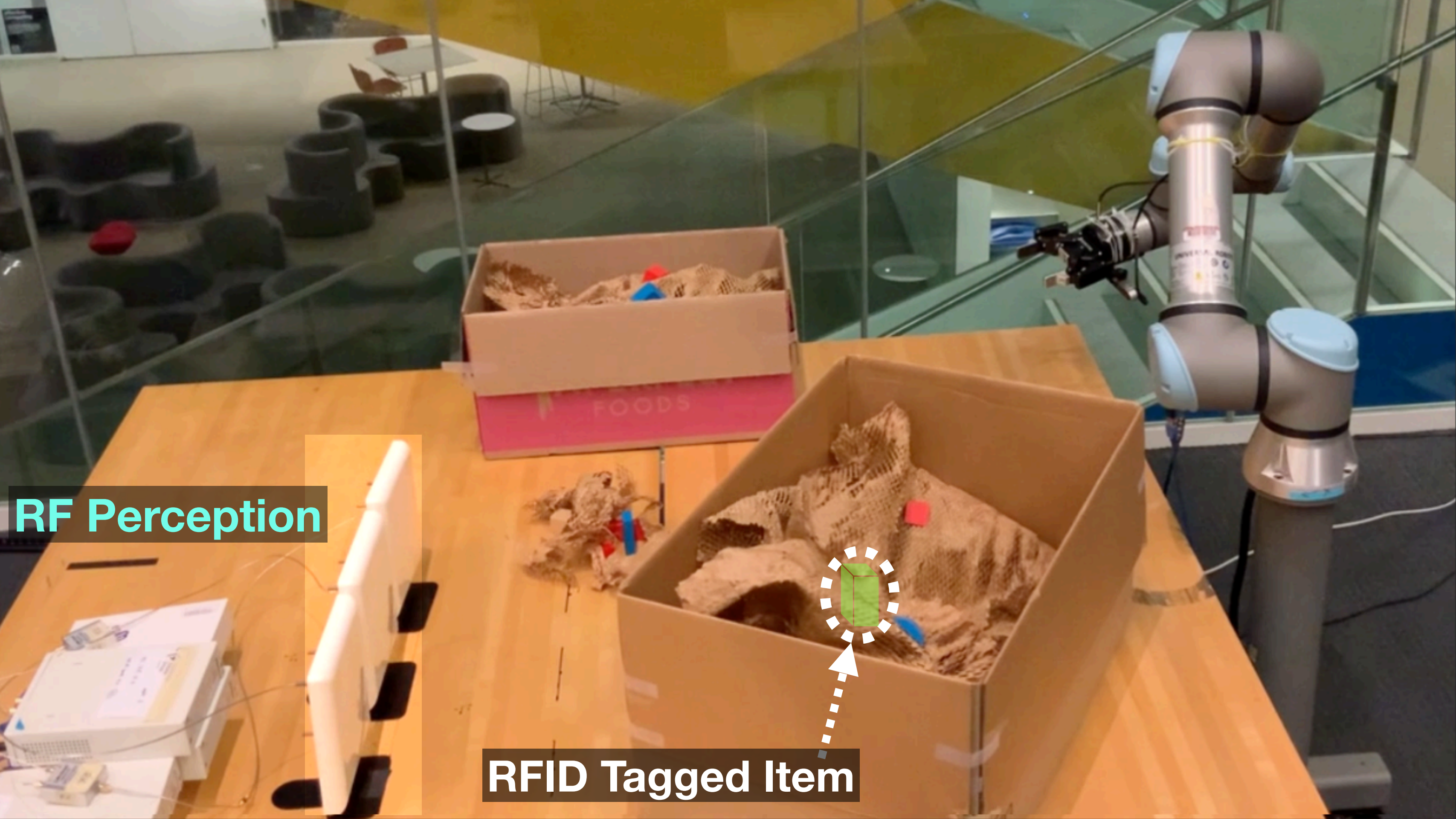
**Camera's
line of sight is
blocked**

**Target item
under clutter**



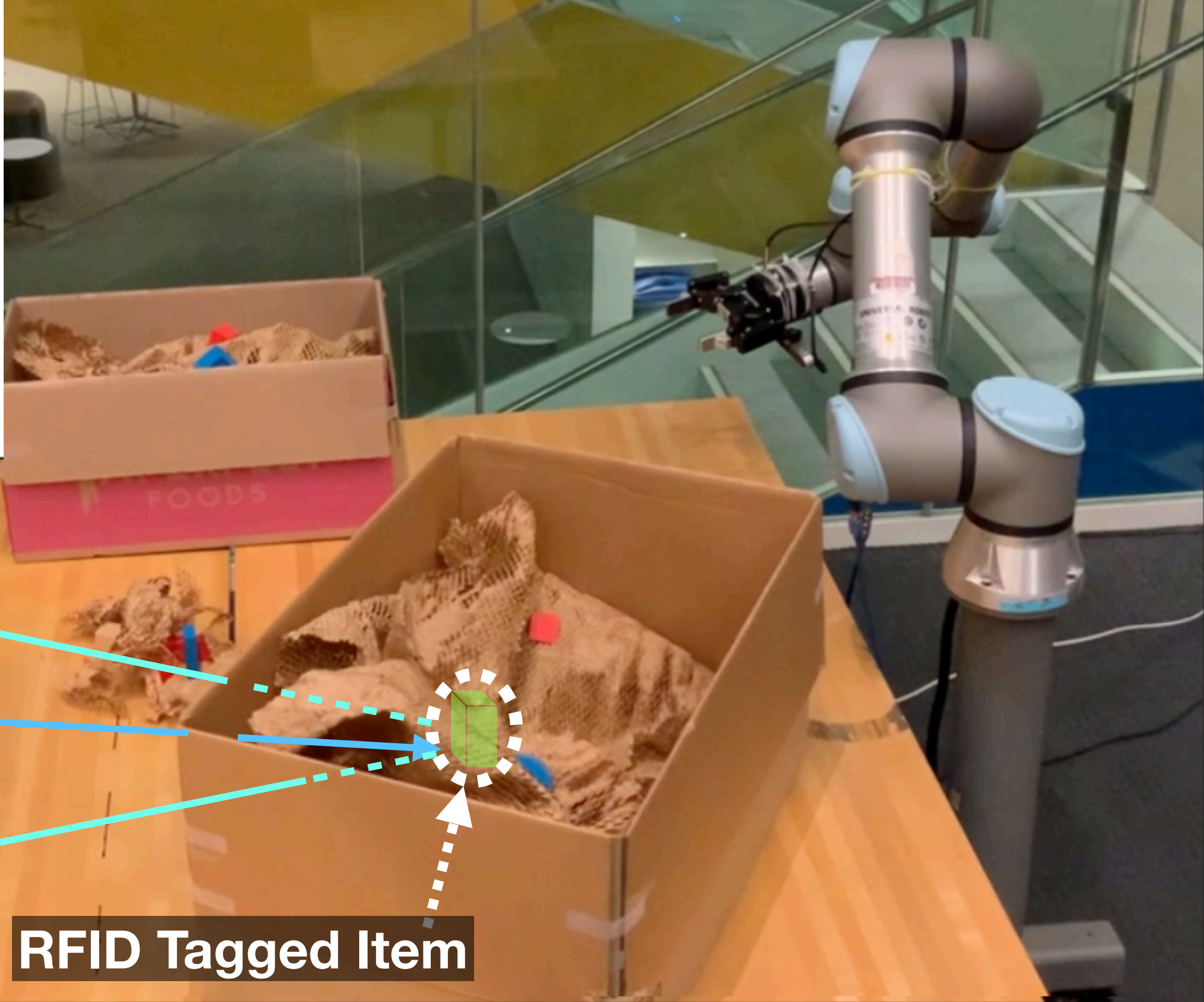
RF Perception

RFID Tagged Item

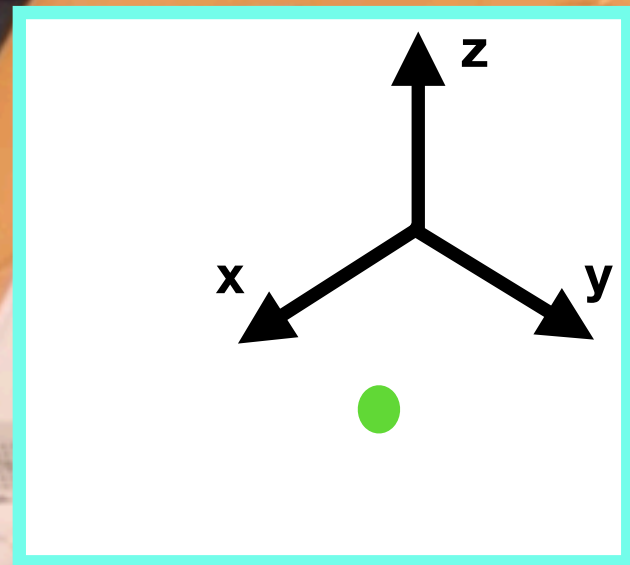




Camera View



RF Perception

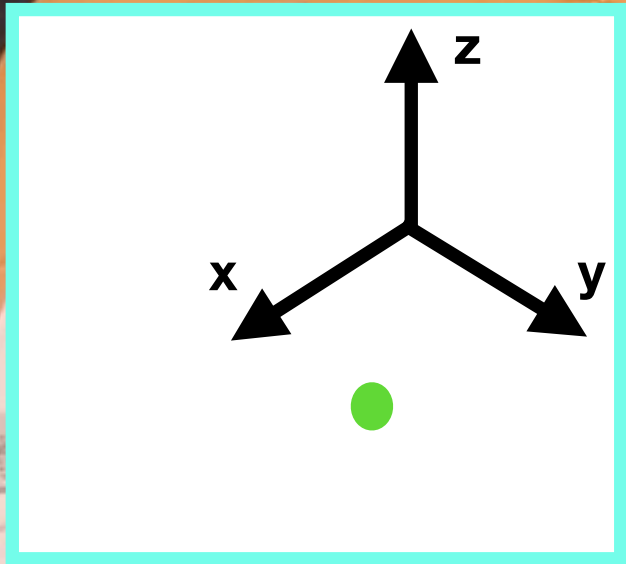


RFID Tagged Item



Camera View

RF Perception

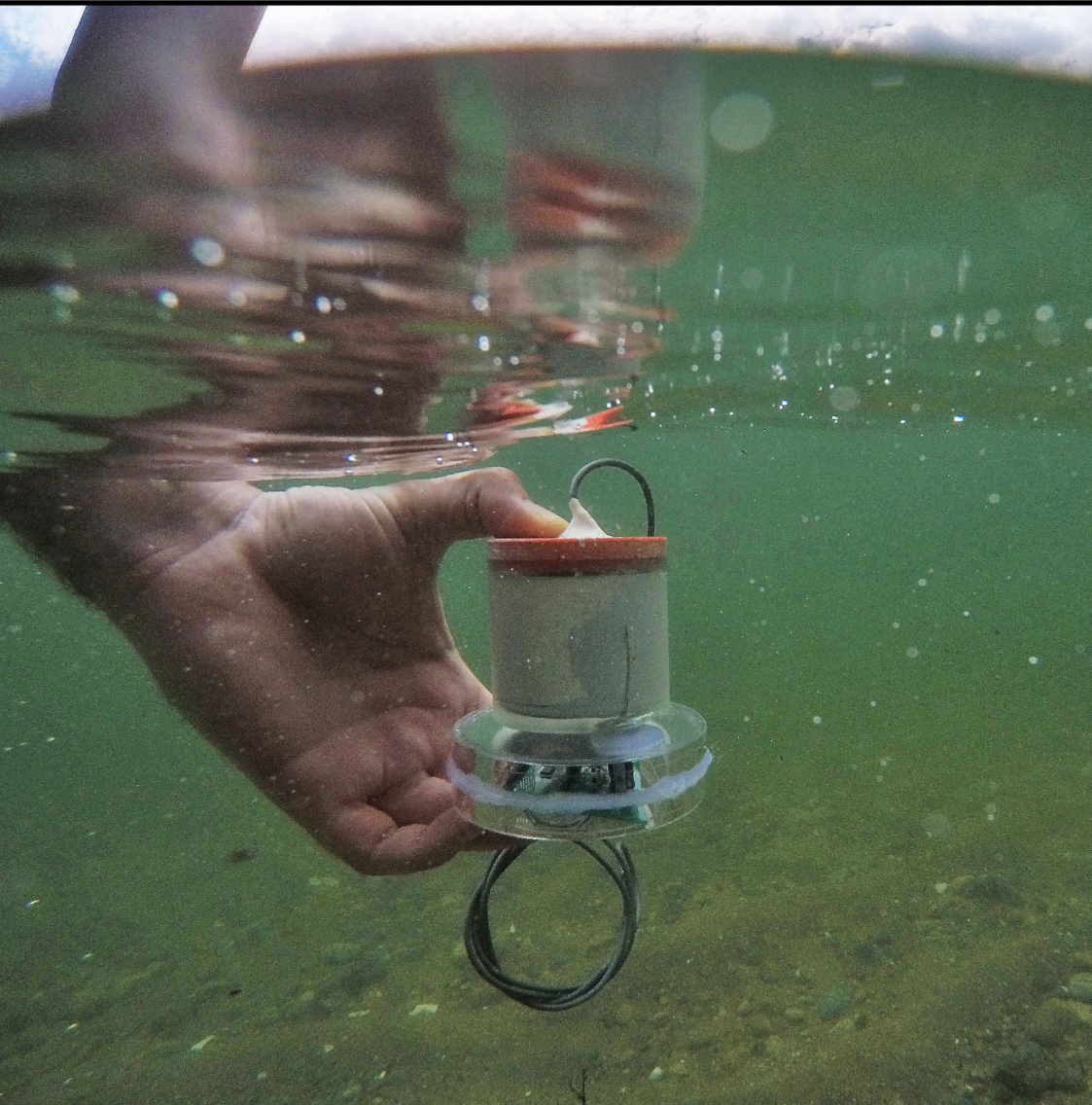


Successful grasp

Upcoming IEEE ICRA'21 paper

This Talk: Extreme IoT & Sensor Technologies

Oceans



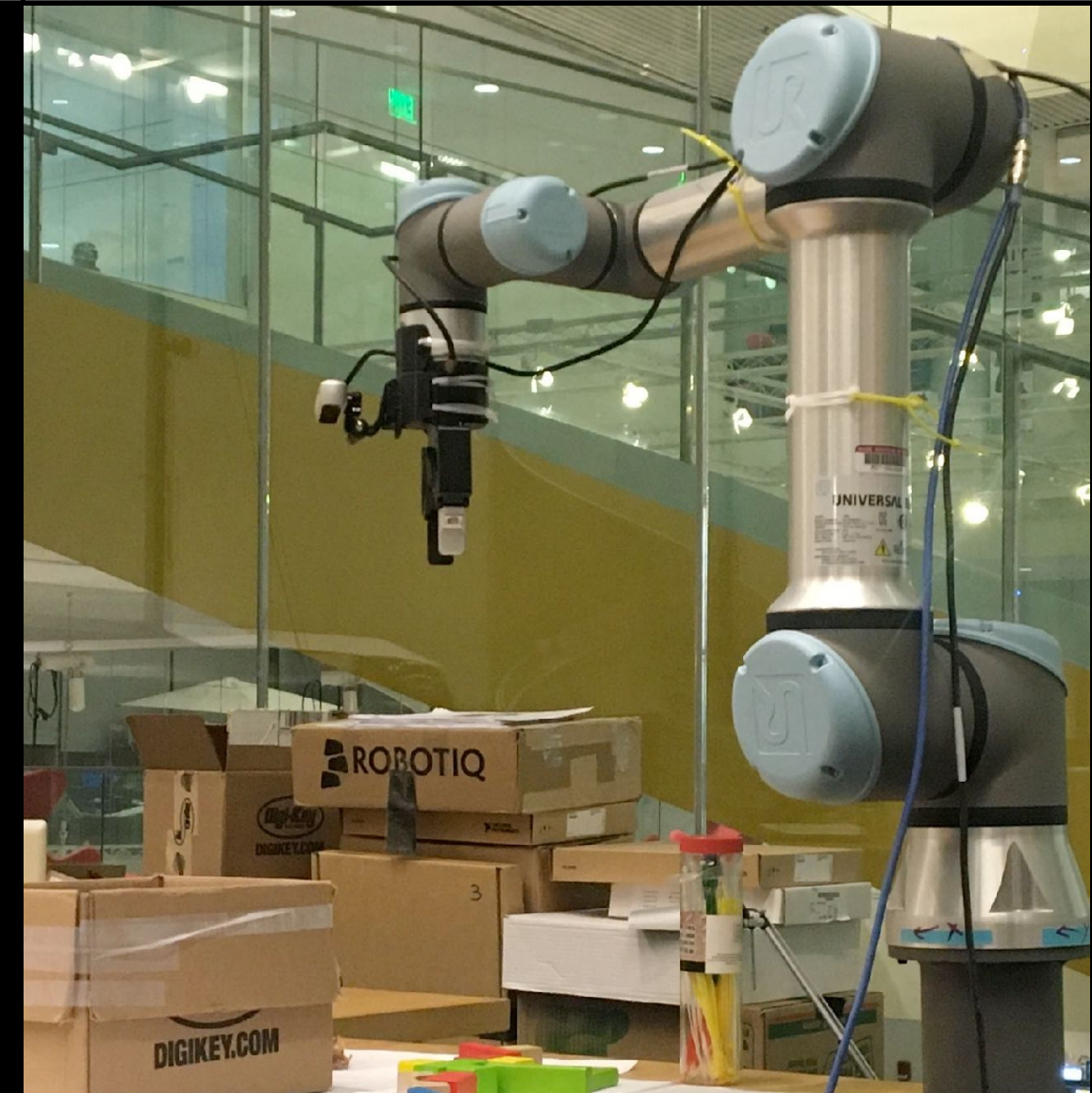
[SIGCOMM '18a, SIGCOMM '19,
SIGCOMM'20, OCEANS'20, HotNets'20]

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]



Mario Doumet



Mergen Nachin



Harris Brkic



Waleed Akbar



Andrew McCall



Muhammed Sulema S Thaniana



Joshua Craig Anderson



Unseo Ha



Osby Rodriguez



Monica Liu



Tara Boroushaki



Sayed Saad Afzal



Holly Birns



Isaac Perper



Mohamed Radwan Abdelhamid



Reza Ghaffarivardavagh

Extreme IoT & Sensor Technologies

Join Us!

Collaborations

(research, deploy, commercialize)

Openings

(grad, postdocs, staff, engineers)

Stay in Touch!



@fadeladib



@mit_sk_lab

