6.1820/MAS.453: Mobile and Sensor Computing
aka IoT Systems

https://6mobile.github.io/

Lecture 12: Agriculture IoT

Some slides adapted from Deepak Vasisht (UIUC) and Saad Afzal (MIT)

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Announcements

1- Project Proposals due today

2- Lab 4 due next week, April 8

3- PSet 2 due April 10

What are we learning today?

Agriculture IoT

- Aerial-based Connectivity (Loon, Aquila)
- Challenges in Agriculture IoT:
    - Internet Connectivity
    - Limited Sensor Placement
    - Power Availability

- How can you use wireless signals for produce monitoring and fruit sensing?

Aerial-based Connectivity for Remote Areas

Google X's Project Loon

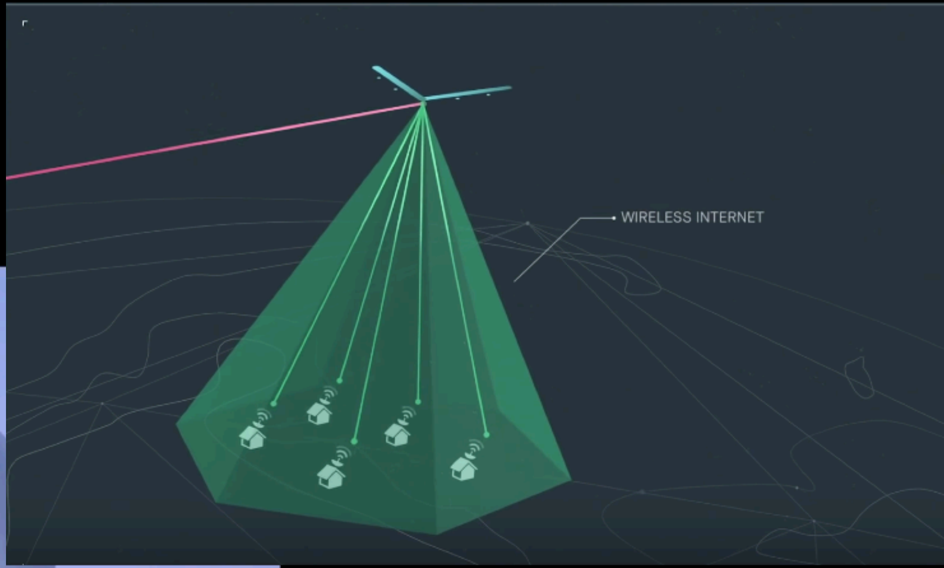
Facebook's Project Aquila

Others including Microsoft, Boeing, etc.

<u>Goal:</u> Bringing Connectivity to the Remote and Disconnected Areas of the Planet

Goal: Bringing Connectivity to the Remote and Disconnected Areas of the Planet

- Bring connectivity to rural areas



- Disaster Relief

Aquila was discontinued in 2018; Loon was discontinued in 2021

Challenges

- Power: Constrained
  - Need to last for a long time

→ Solar Energy

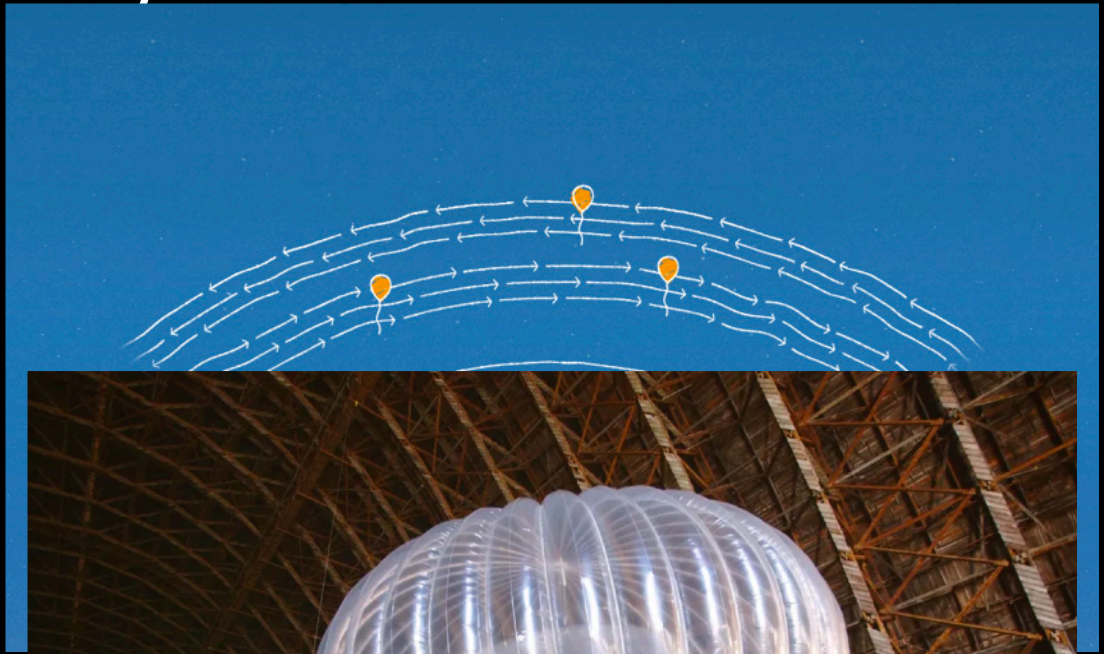
- Control: Flight paths
  - Minimal power consumption
- Communications: Long-range links
- Data Rates

Challenges

- **Power:** Constrained → Solar Energy
  - Need to last for a long time
- **Control:** Flight paths →
  - Stratosphere
  - Drone paths
  - Minimal power consumption
- **Communications:** Long-range links → Low Frequencies
- **Data Rates** →
  - 10s MHz bandwidth
  - Millimeter waves

Common Opportunities: Atmospheric Conditions and Predictability

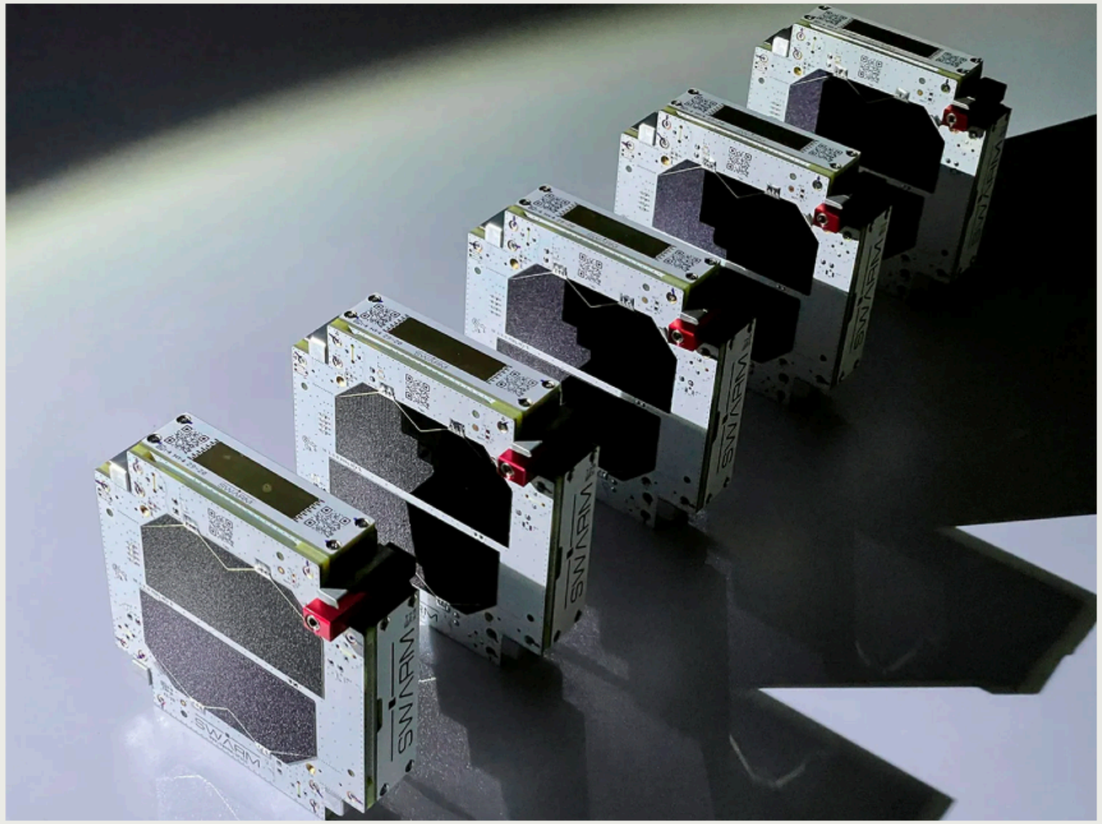
- Leverage Stratosphere in Loon/Aquila
  - No “problematic” weather conditions (rain, winds, etc.)
  - Different stratospheric layers have different predictable currents
  - How do you move vertically?



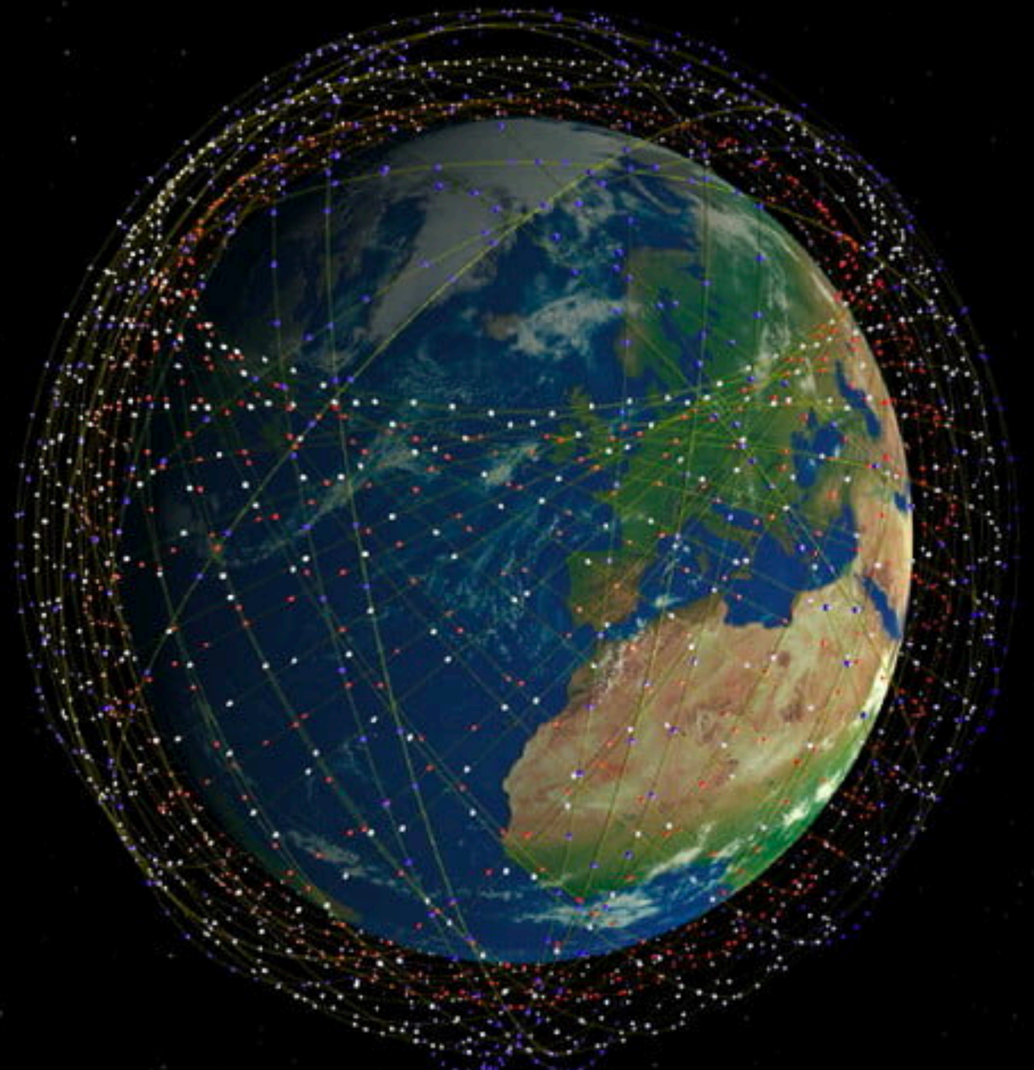
SpaceX's Starlink

Swarm Takes LoRa Sky-High › The satellite company has adapted the popular IoT technology for use in its constellation

BY MICHAEL KOZIOL | 23 MAR 2021 | 4 MIN READ



Each of Swarm's satellites is the size of a sandwich, but still has everything it needs to relay low-power signals from remote IoT networks to another point on the planet. PHOTO: SWARM



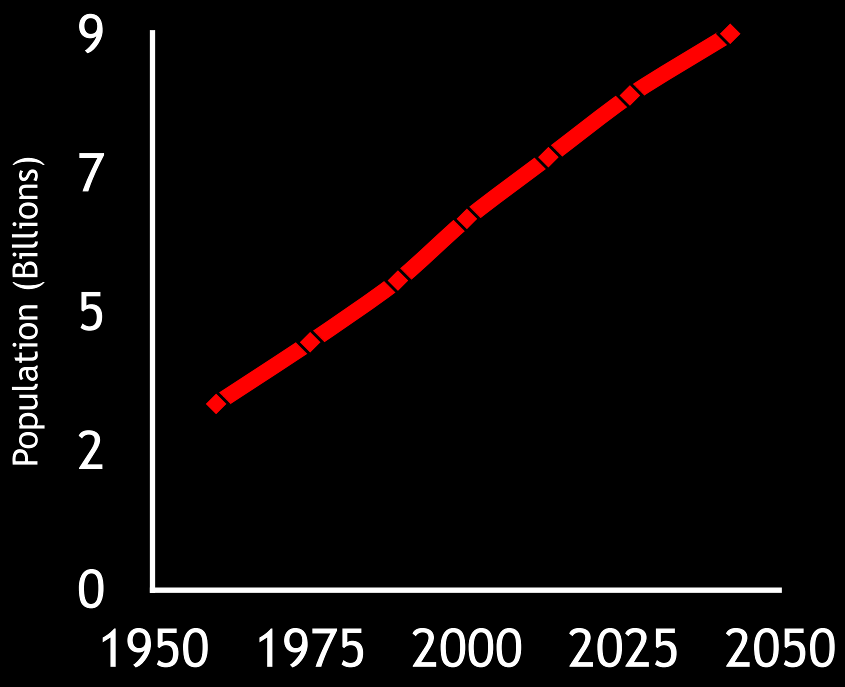
Satellite connectivity already exists (Iridium). Why/how are these constellations better/different ?

FarmBeats: An IoT System for Data-Driven Agriculture

NSDI 2017

Why Agriculture?

Agricultural output needs to double by 2050 to meet the demands
– United Nations[1]



[1]: United Nations Second Committee (Economic & Financial),

Why Agriculture?

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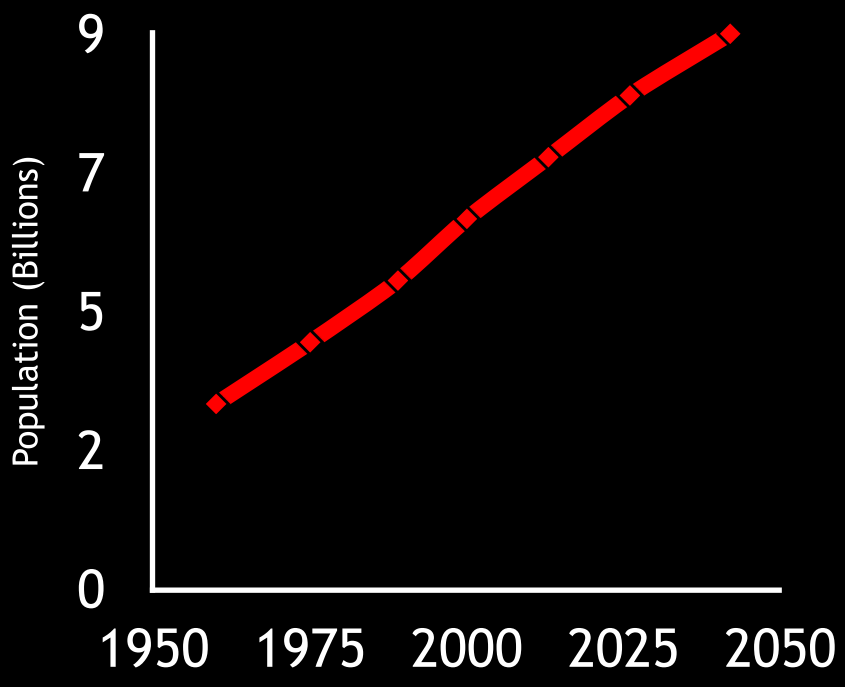

But…

- Water levels are receding
- Arable land is shrinking
- Environment is being degraded

[1]: United Nations Second Committee (Economic & Financial),

Why Agriculture?

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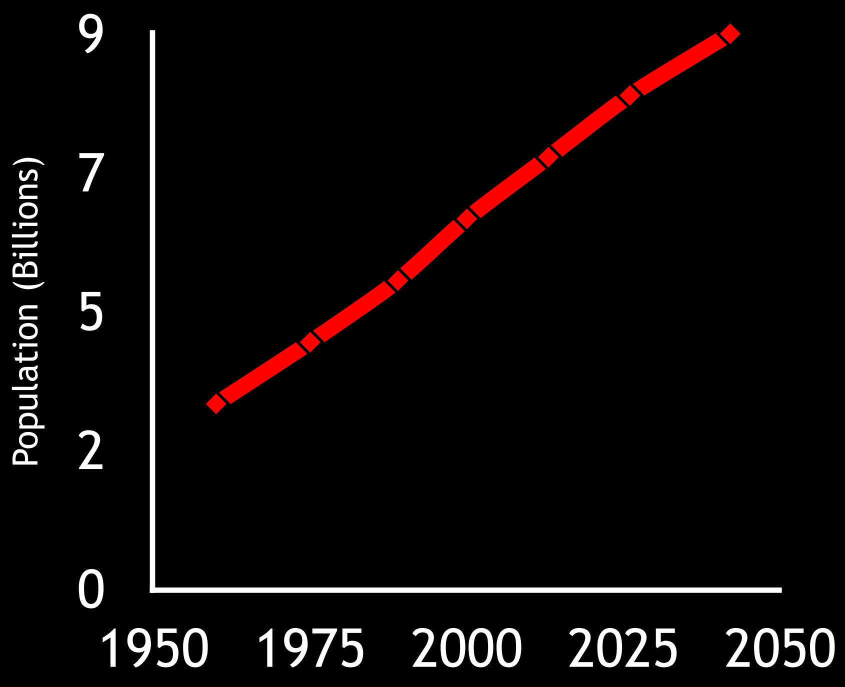
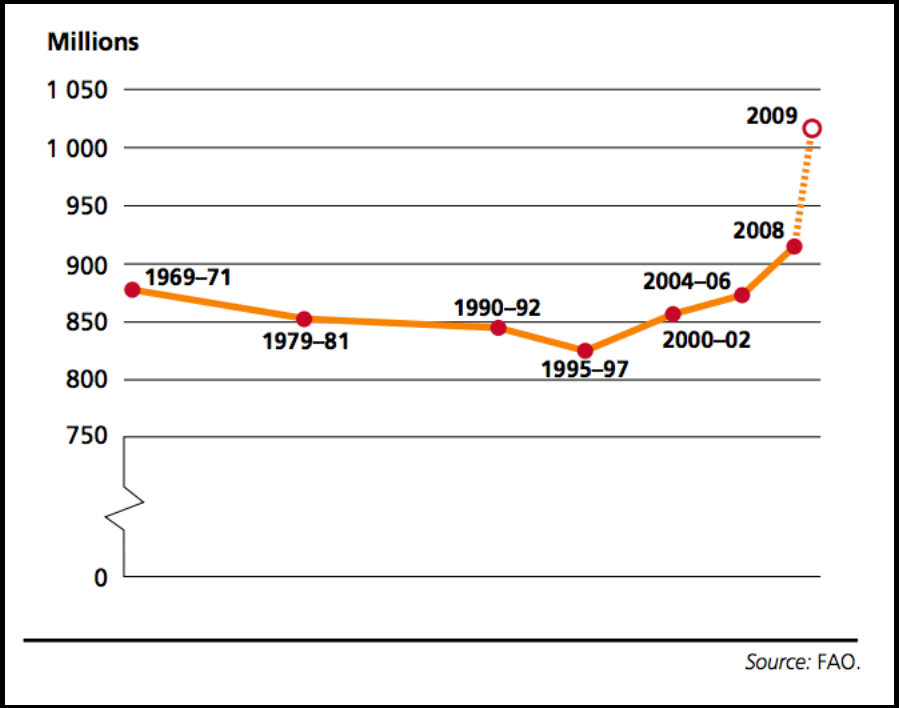
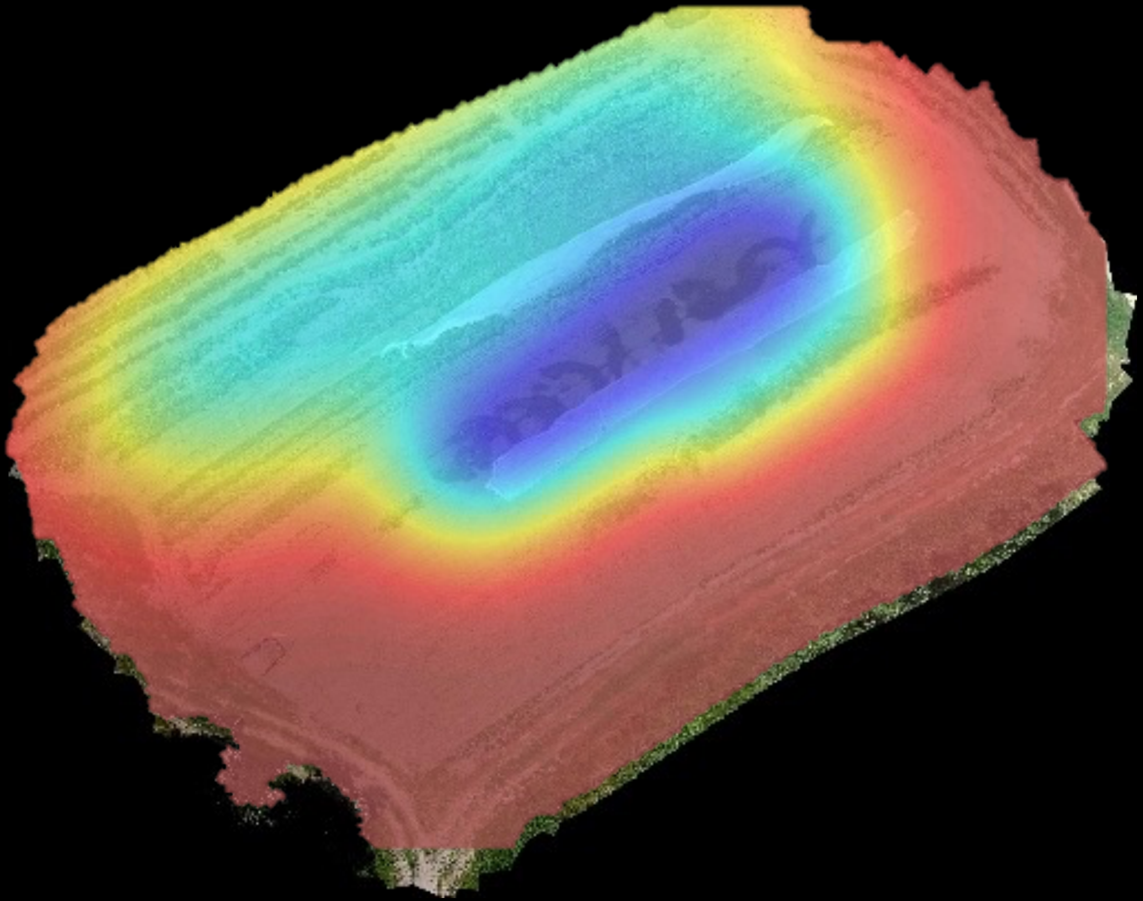
– United Nations



Number of World's Hungry People



Solution: Data-Driven Agriculture



Traditional vs Data-driven approach

Ag researchers have shown that it:

- Reduces waste
- Increases productivity
- Ensures sustainability

But…

According to USDA, high cost of manual data collection prevents farmers from using data-driven agriculture

IoT System for Agriculture

Microsoft Azure

Problems with this architecture?

Problem 1: No Internet Connectivity

- Most farms don’t have any internet coverage

- Even if connectivity exists, weather related outages can disable networks for weeks

Problem 2: No Power on the Farm

- Farms do not have direct power sources

- Solar power is highly prone to weather variability

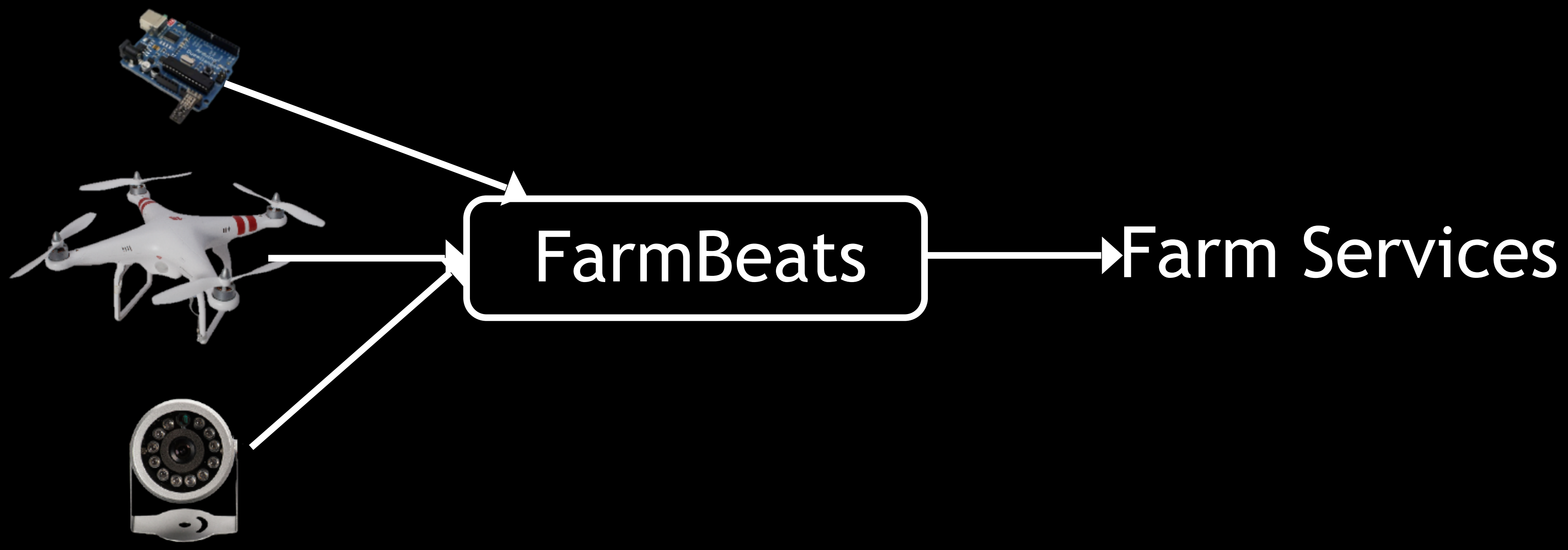
Problem 3: Limited Resources

- Need to work with sparse sensor deployments
  - Physical constraints due to farming practices
  - Too expensive to deploy and maintain

How can one design an IoT system in challenging resource-constrained environments?

Rest of this lecture

- FarmBeats: An end-to-end IoT system that enables seamless data collection for agriculture



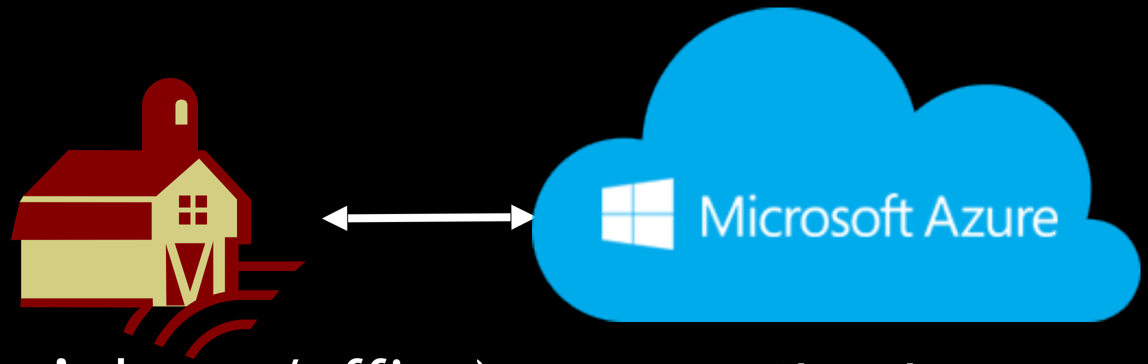
Rest of this lecture

- FarmBeats: An end-to-end IoT system that enables seamless data collection for agriculture

- Solves three key challenges:
  - Internet Connectivity
  - Power Availability
  - Limited Sensor Placement

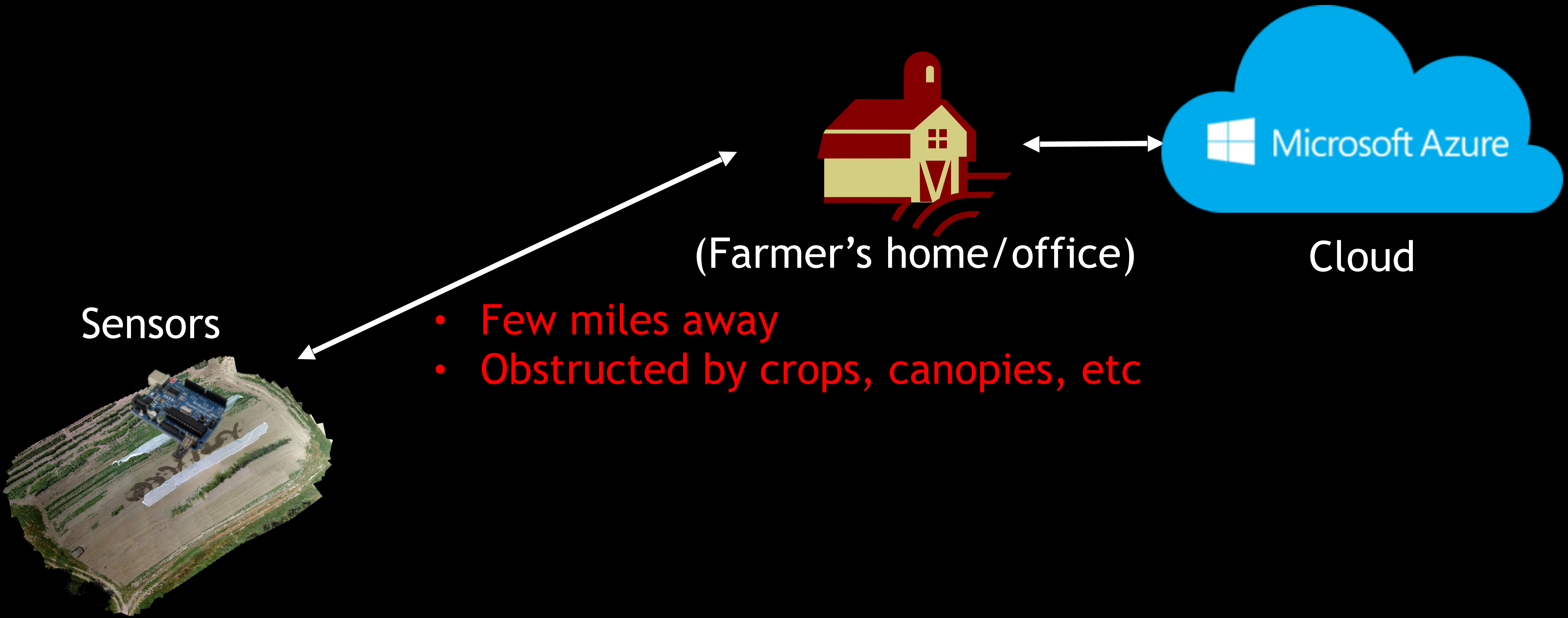
- Deployed in two farms in NY and WA for over six months

Challenge: Internet Connectivity



(Farmer’s home/office) Cloud

Challenge: Internet Connectivity

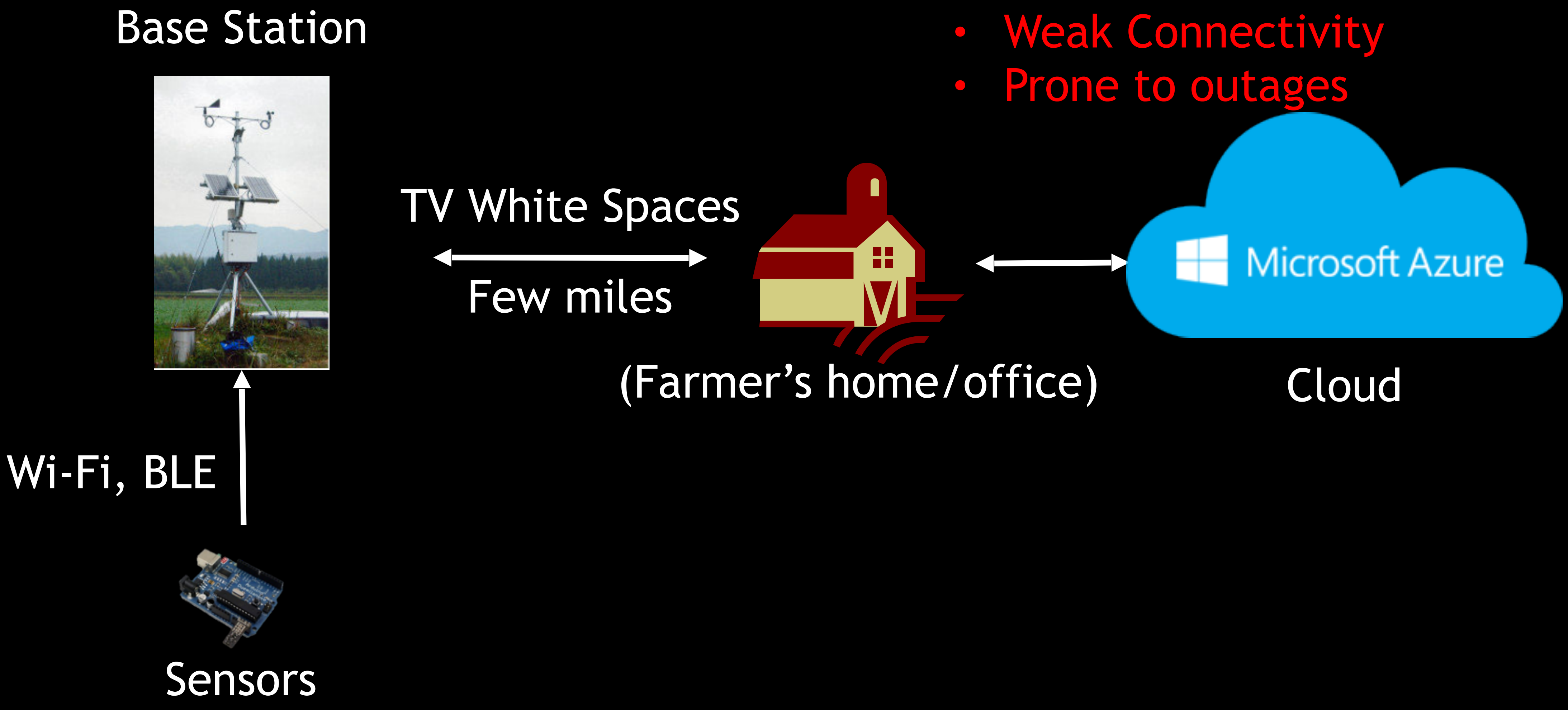


- Few miles away
- Obstructed by crops, canopies, etc

Approach: Use TV White Spaces

- Can provide long-range connectivity (10 miles)
- Can travel through crops and canopies, because of low frequencies
- Large chunks are available in rural areas=> can support large bandwidth

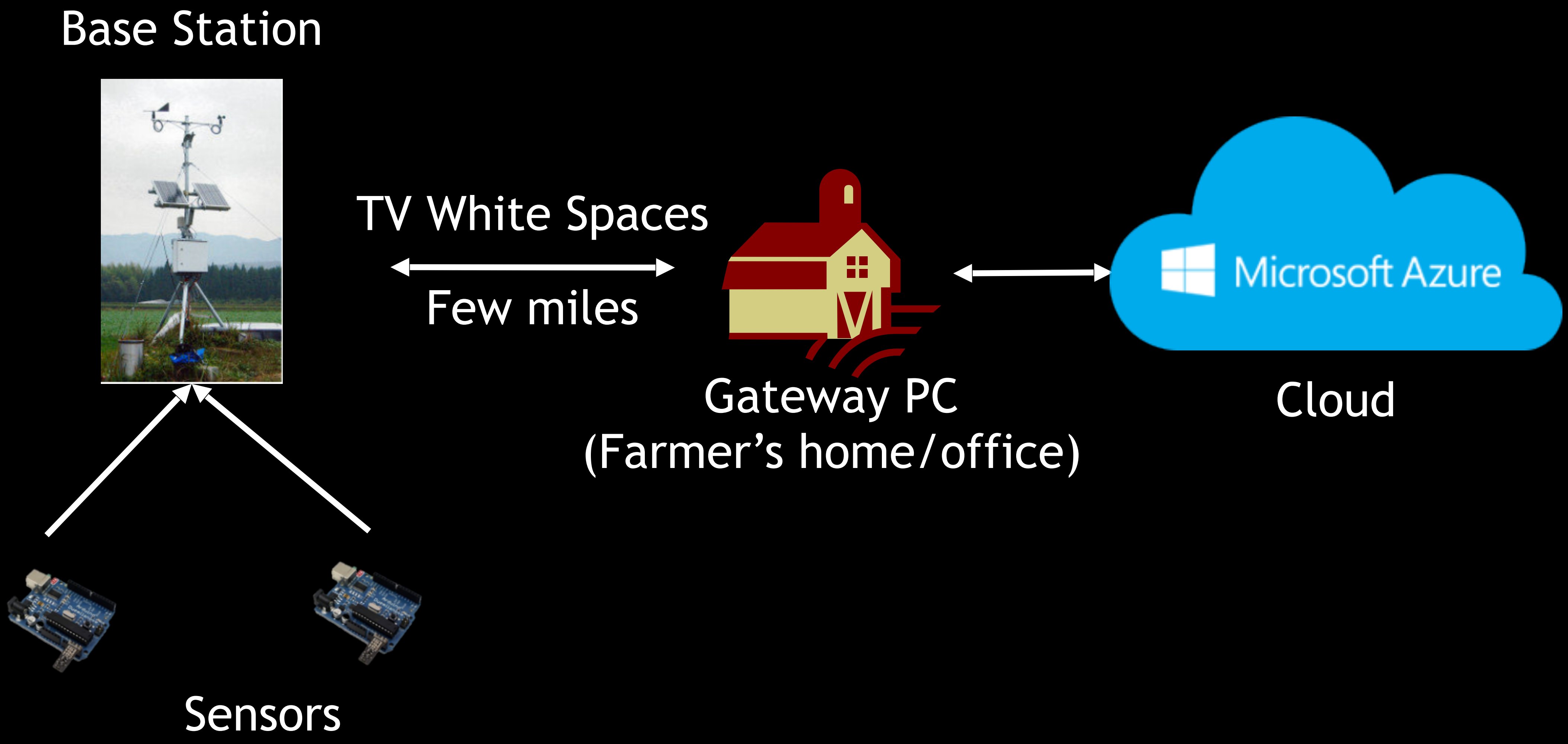
Idea: Use TV White Spaces



Approach: Compute Locally and Send Summaries

- PC on the farm delivers time-sensitive services locally
- Combines all the sensor data into summaries
- 2-3 orders of magnitude smaller than raw data
- Cloud delivers long-term analytics and cross-farm analytics

FarmBeats Design



In this lecture

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- Deployed in two farms in NY and WA for over six months

Challenge: Limited Resources

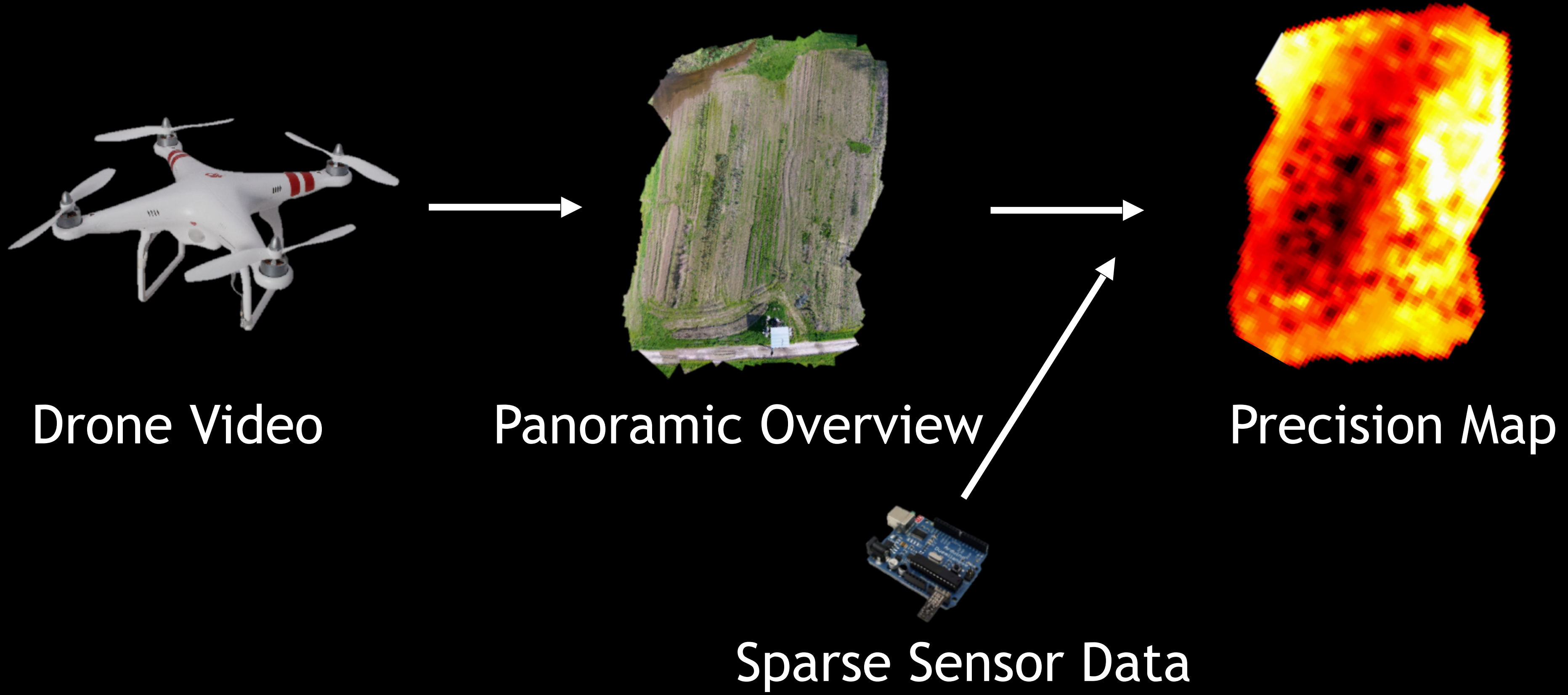
- Need to work with sparse sensor deployments
  - Physical constraints due to farming practices
  - Too expensive to deploy and maintain
- How do we get coverage with a sparse sensor deployment?

Approach: Use Drones to Enhance Spatial Coverage

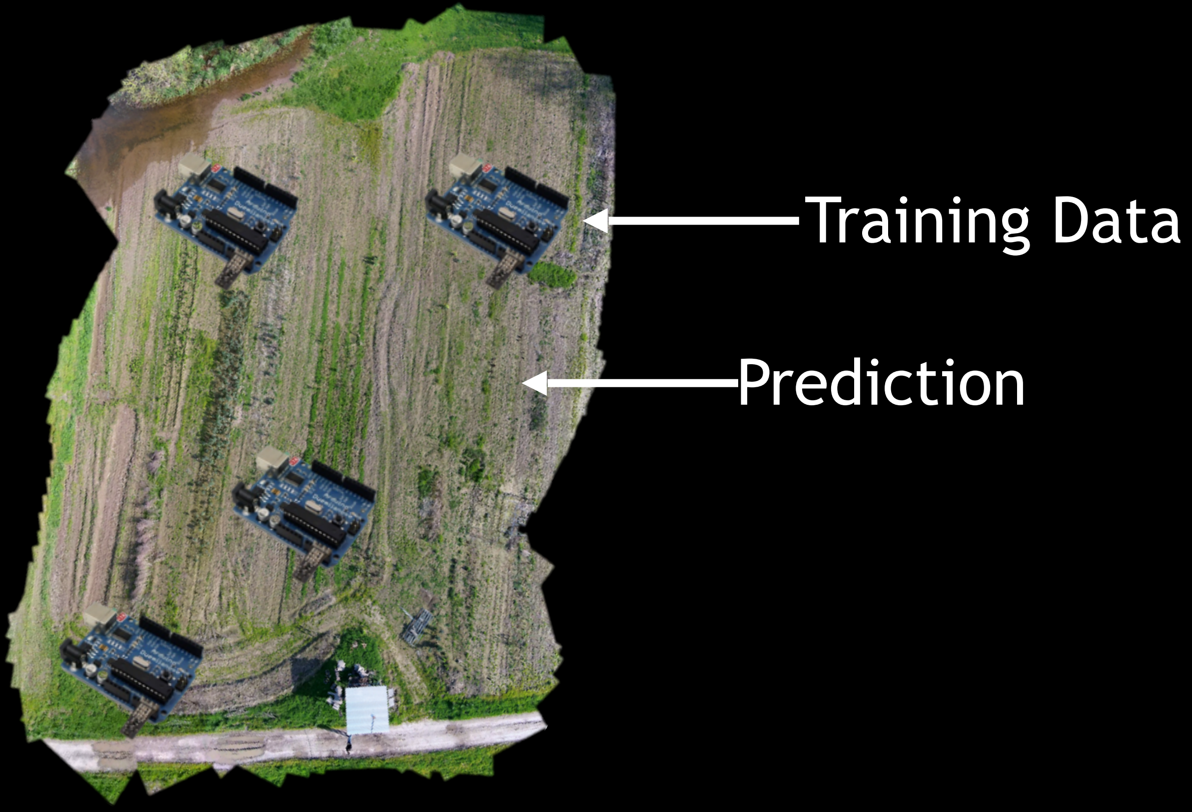
- Drones are cheap and automatic
- Can cover large areas quickly
- Can collect visual data

Combine visual data from the drones with the sensor data from the farm

Idea: Use Drones to Enhance Spatial Coverage



Formulate as a Learning Problem



Panoramic Overview

Model Insights

- **Spatial Smoothness:** Areas close to each other have similar sensor values

- **Visual Smoothness:** Areas that look similar have similar sensor values values

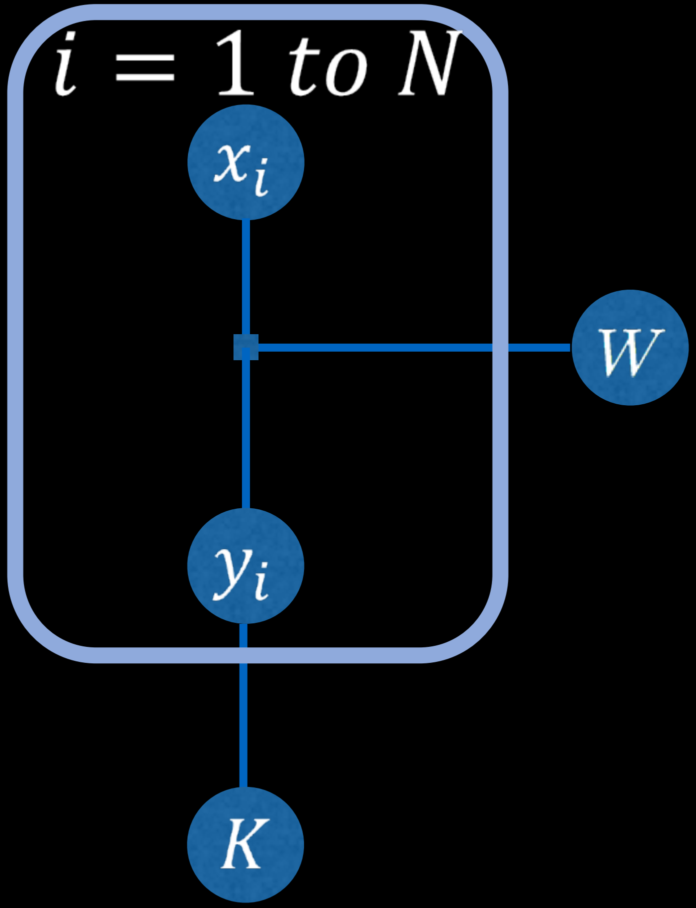
Model: Gaussian Processes

Features (visual)

Kernel (Model visual similarity)

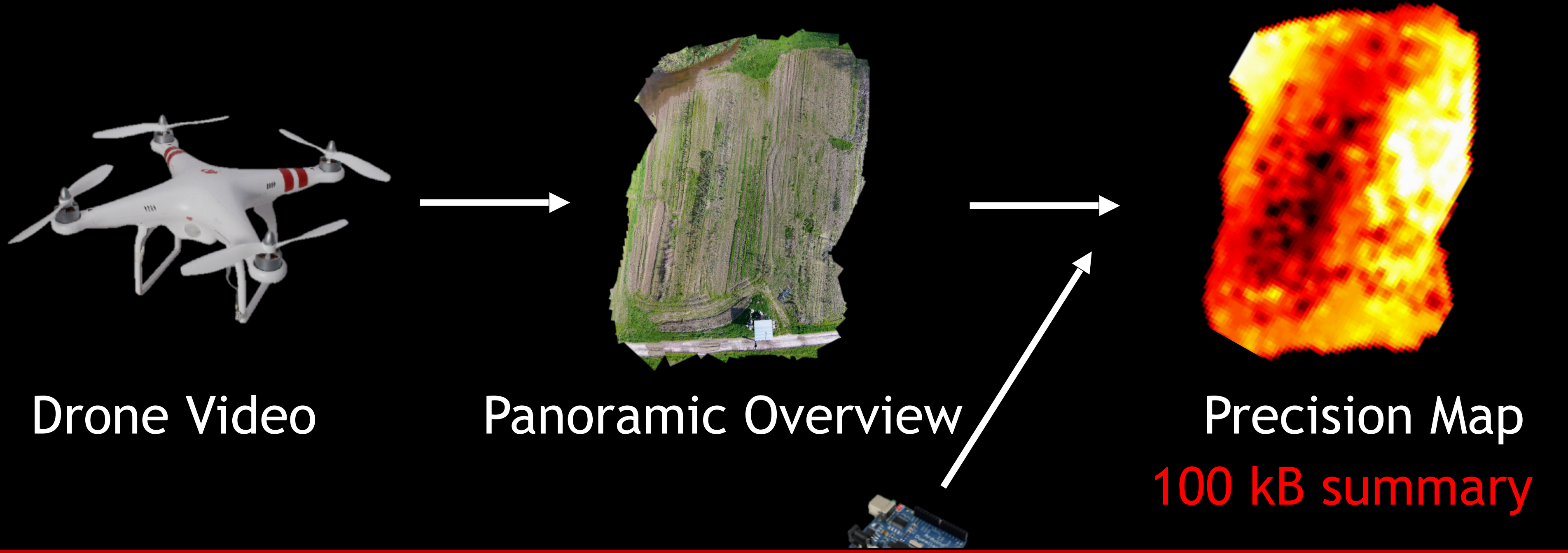
Output (say, moisture)

Spatial Smoothness



- **Training Phase:** Learn K and W
- **Test Phase:** Generate outputs for unknown areas

Using Sparse Sensor Data



FarmBeats can use drones to expand the sparse sensor data and create summaries for the farm

In this talk

- FarmBeats: An end-to-end IoT system that enables seamless data collection for agriculture

- Solves three key challenges:
  ✓Internet Connectivity
  ✓Limited Sensor Placement
  - Power Availability

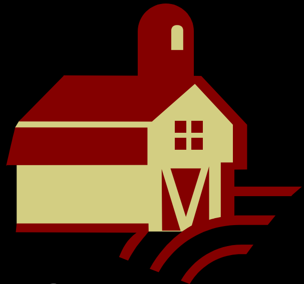
- Deployed in two farms in NY and WA for over six months

Challenge: Power Availability is Variable

Farm

Battery dies due to cloudy/rainy/snowy weather

TV White Spaces



Gateway
(Farmer's home/office)

Cloud

Challenge: Power Availability is Variable

- Solar powered battery saw up to 30% downtime in cloudy months

- Miss important data like flood monitoring

How do we deal with weather-based power variability?

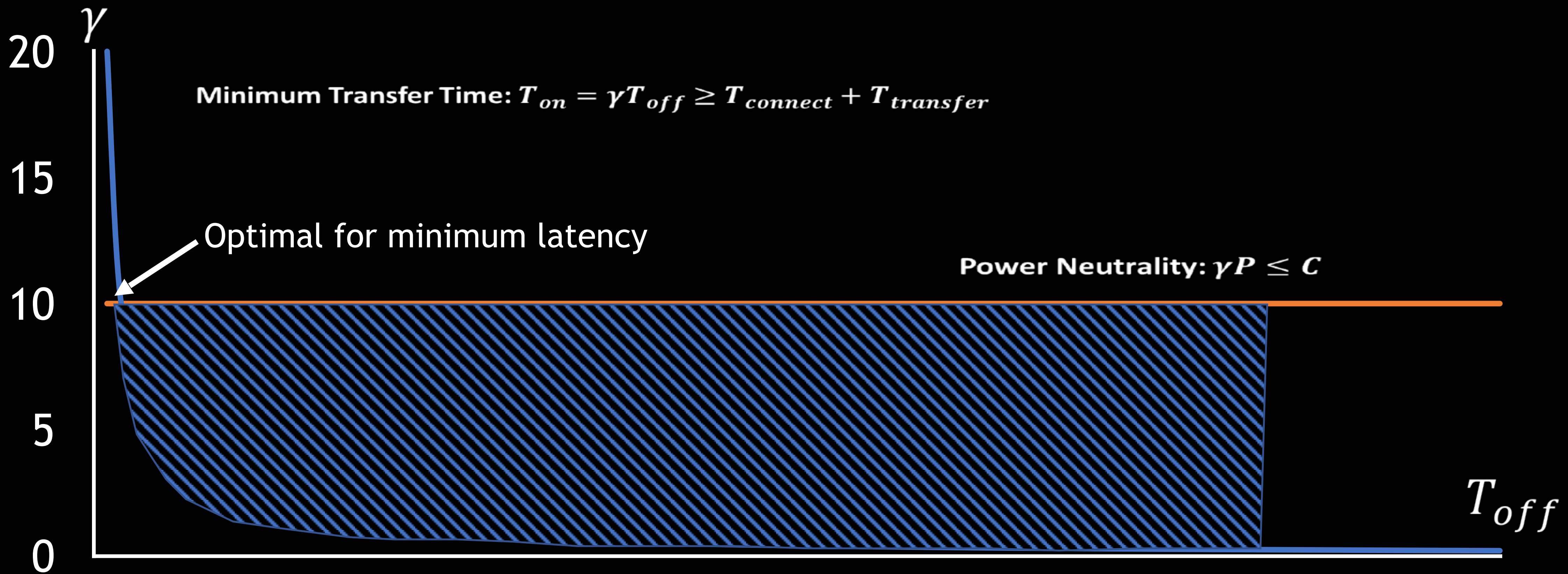
Approach: Weather is Predictable

- Use weather forecasts to predict solar energy output
- Ration the load to fit within power budget

Idea: Weather is Predictable

- γ: Duty Cycle ratio, T_{on}: On time in each cycle, T_{off}: Off time
- $\gamma = \frac{T_{on}}{T_{off}}$
- Constraints:
  - **Power Neutrality: $\boldsymbol{\gamma P \leq C}$**
  - **Minimum Transfer Time: $\boldsymbol{T_{on} \geq T_{connect} + T_{transfer}}$**

Solution: Weather is predictable



FarmBeats can use weather forecasts to duty cycle the base station, with minimum latency

In this lecture

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  - ✓Internet Connectivity
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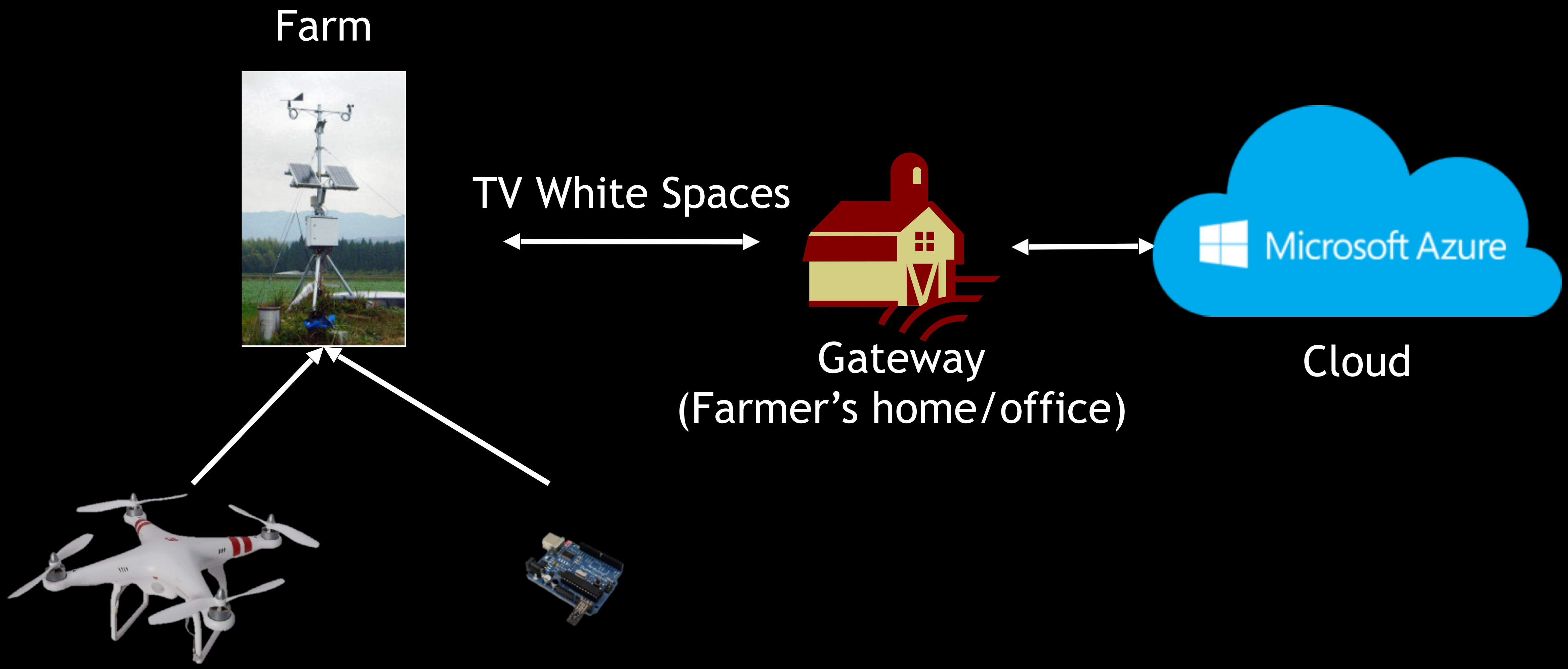
Deployment

- Six months deployment in two farms: Upstate NY (Essex), WA (Carnation)
- The farm sizes were 100 acres and 5 acres respectively
- Sensors:
  - DJI Drones
  - Particle Photons with Moisture, Temperature, pH Sensors
  - IP Cameras to capture IR imagery as well as monitoring
- Cloud Components: Azure Storage and IoT Suite

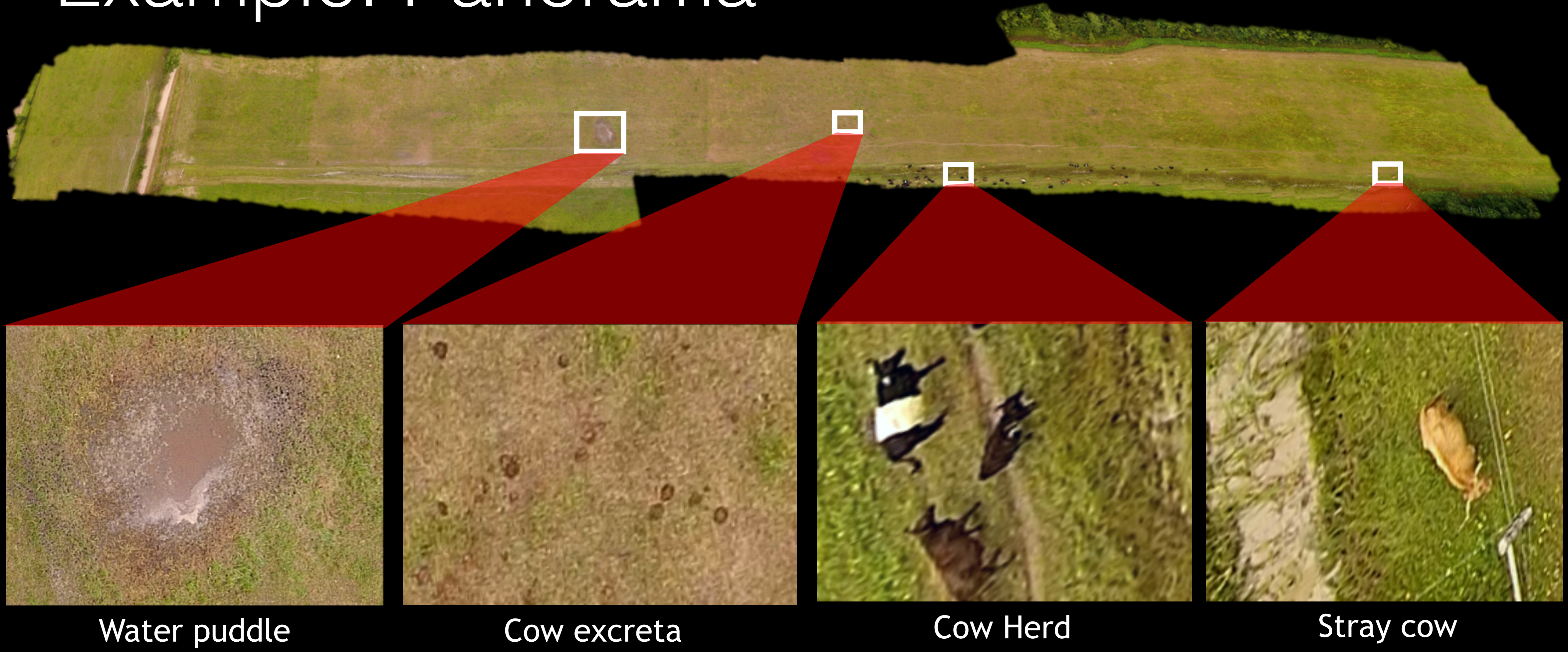
Deployment Statistics

- Used 10 sensor types, 3 camera types and 3 drone versions
- Deployed >100 sensors and ~10 cameras
- Collected >10 million sensor measurements, >0.5 million images, 100 drone surveys
- Resilient to week long outage from a thunderstorm

FarmBeats: Usage

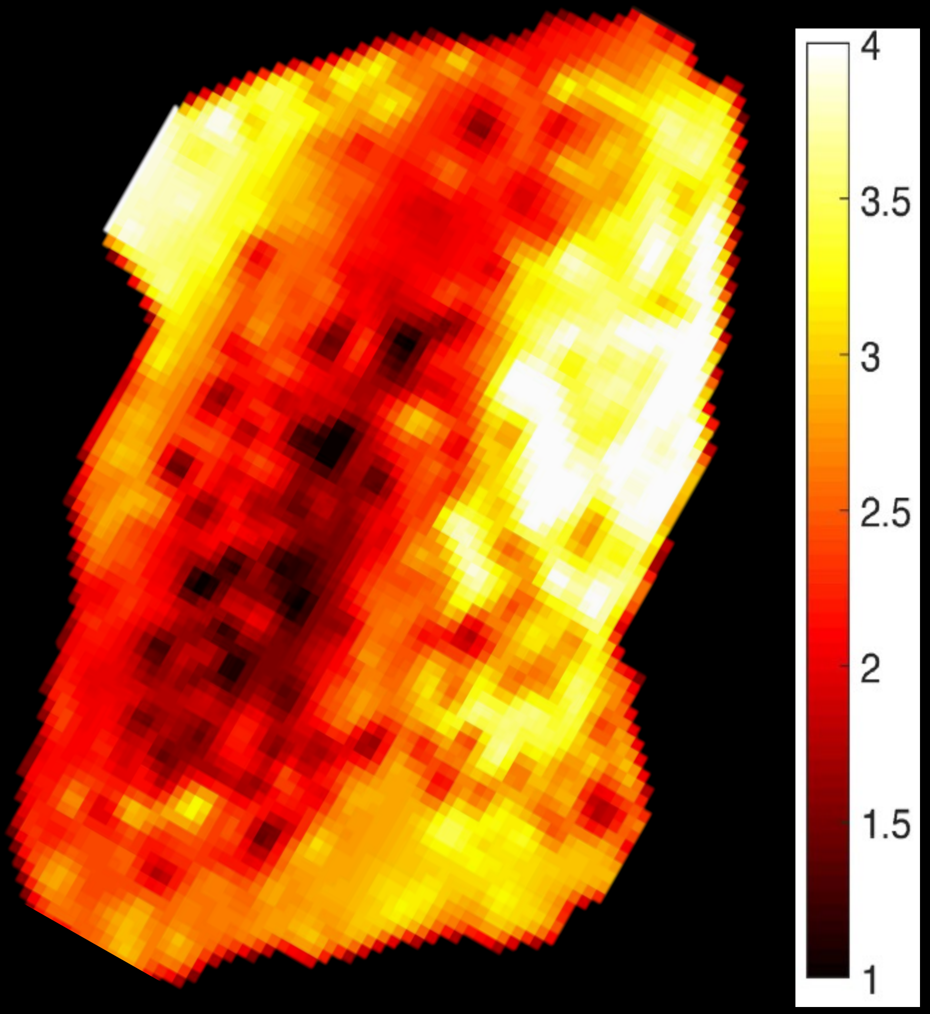


Example: Panorama

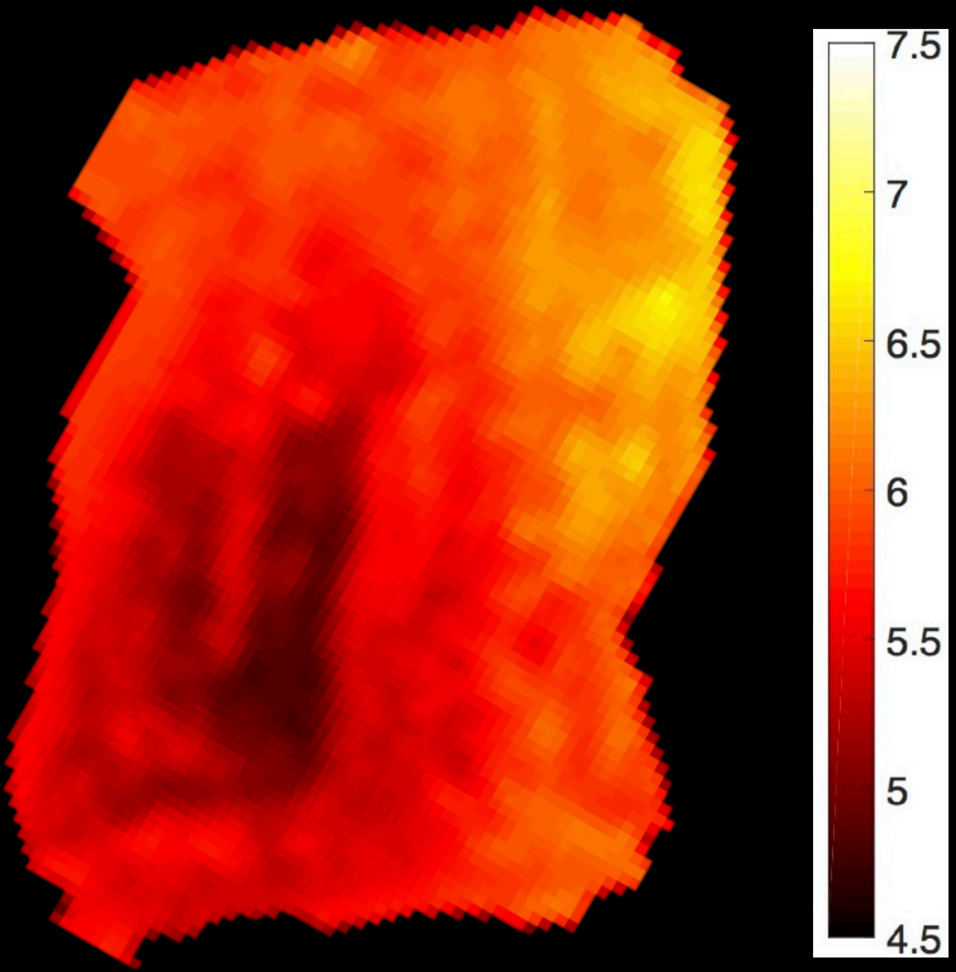


Precision Map: Panorama Generation

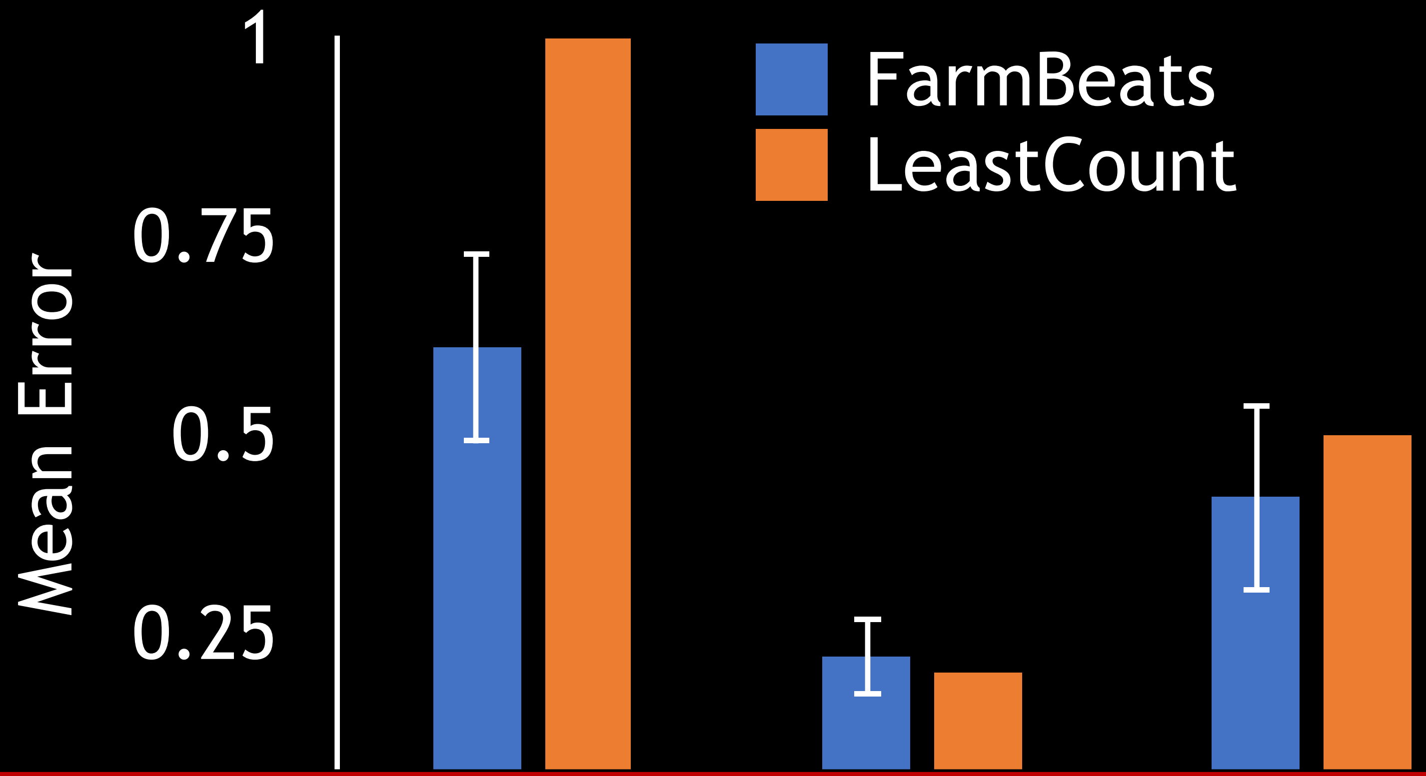
Precision Map : Moisture



Precision Map : pH

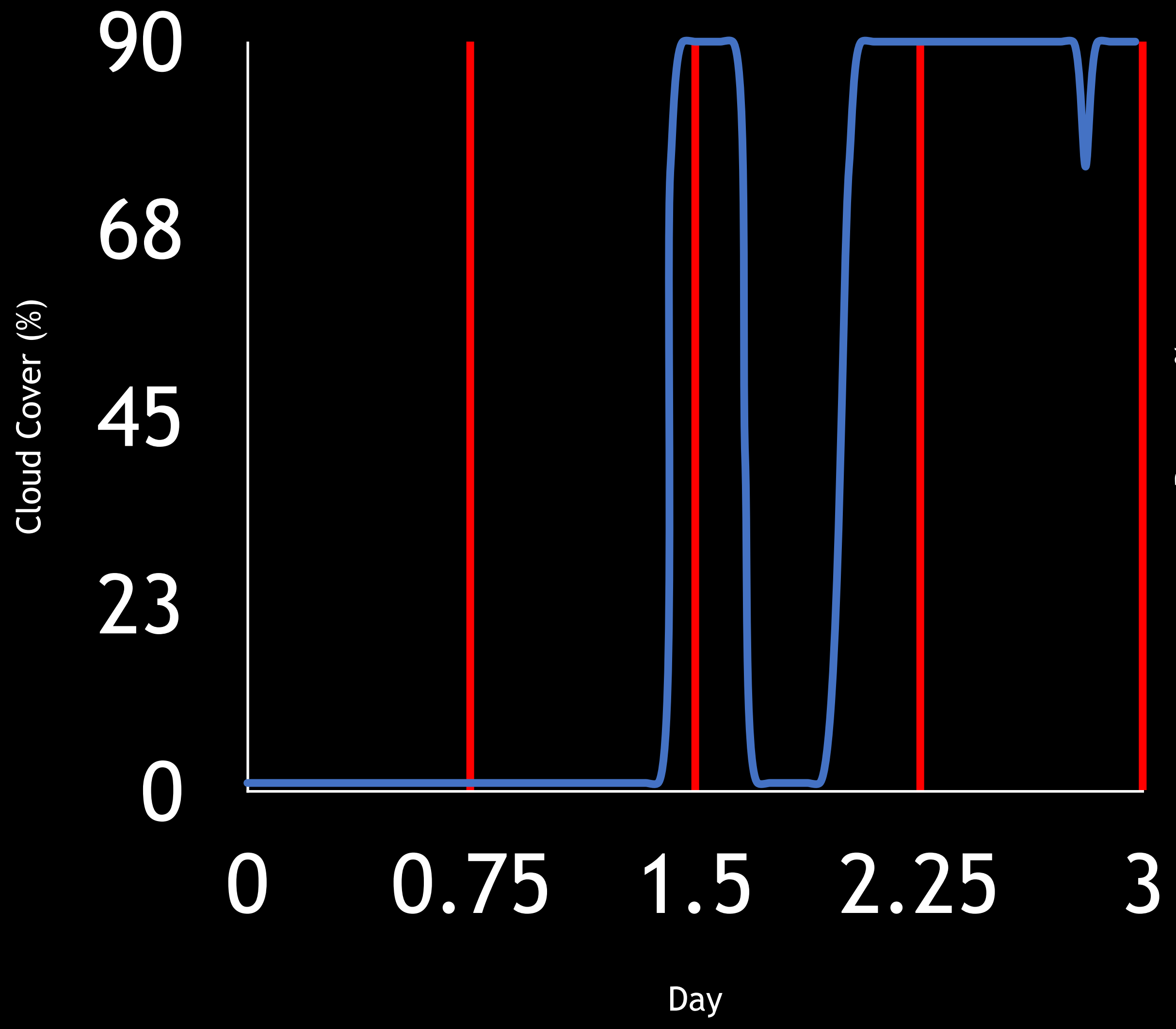


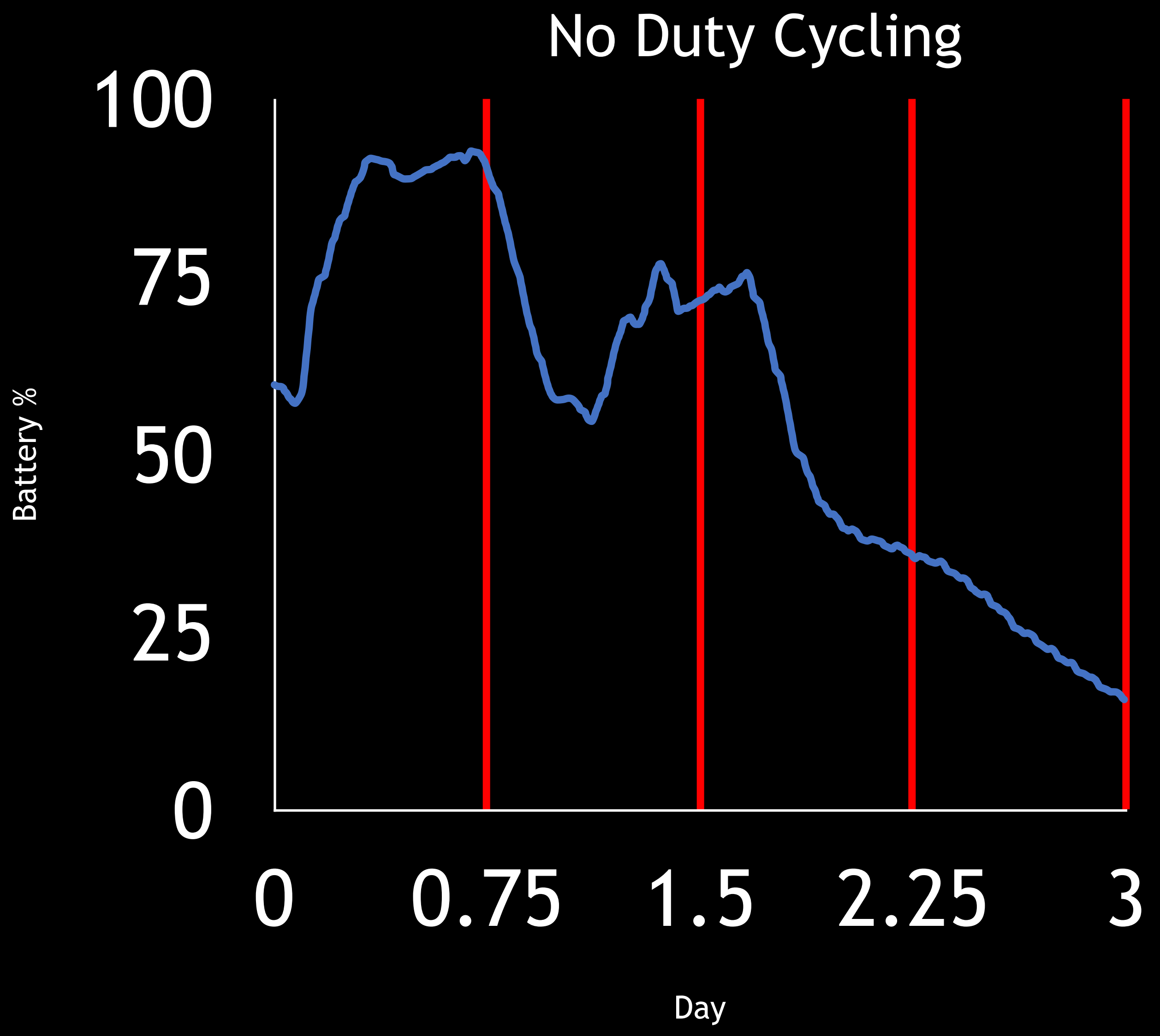
Precision Map: Accuracy



FarmBeats can accurately expand coverage by orders of magnitude using a sparse sensor deployment

Weather-Aware Duty Cycling





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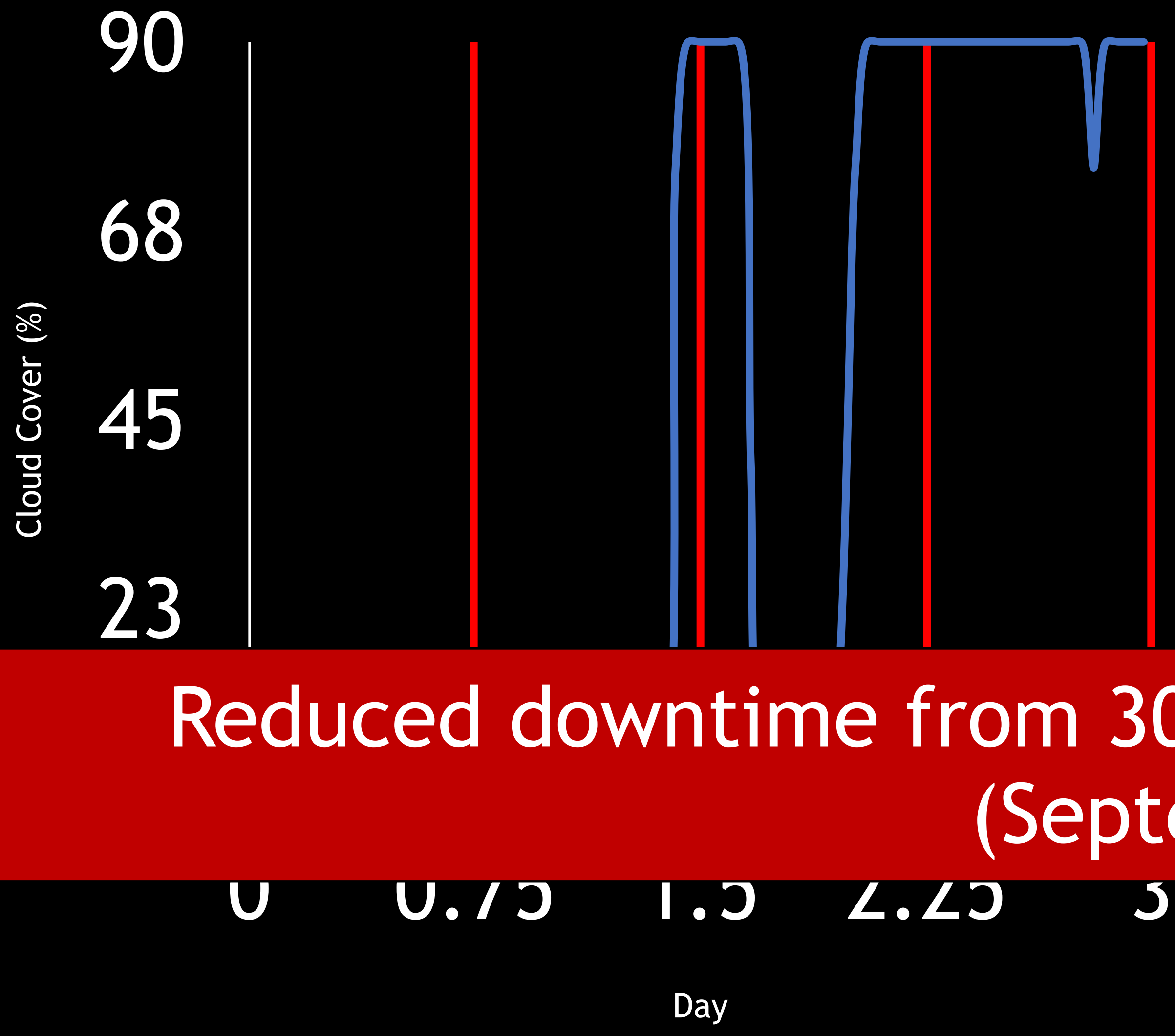
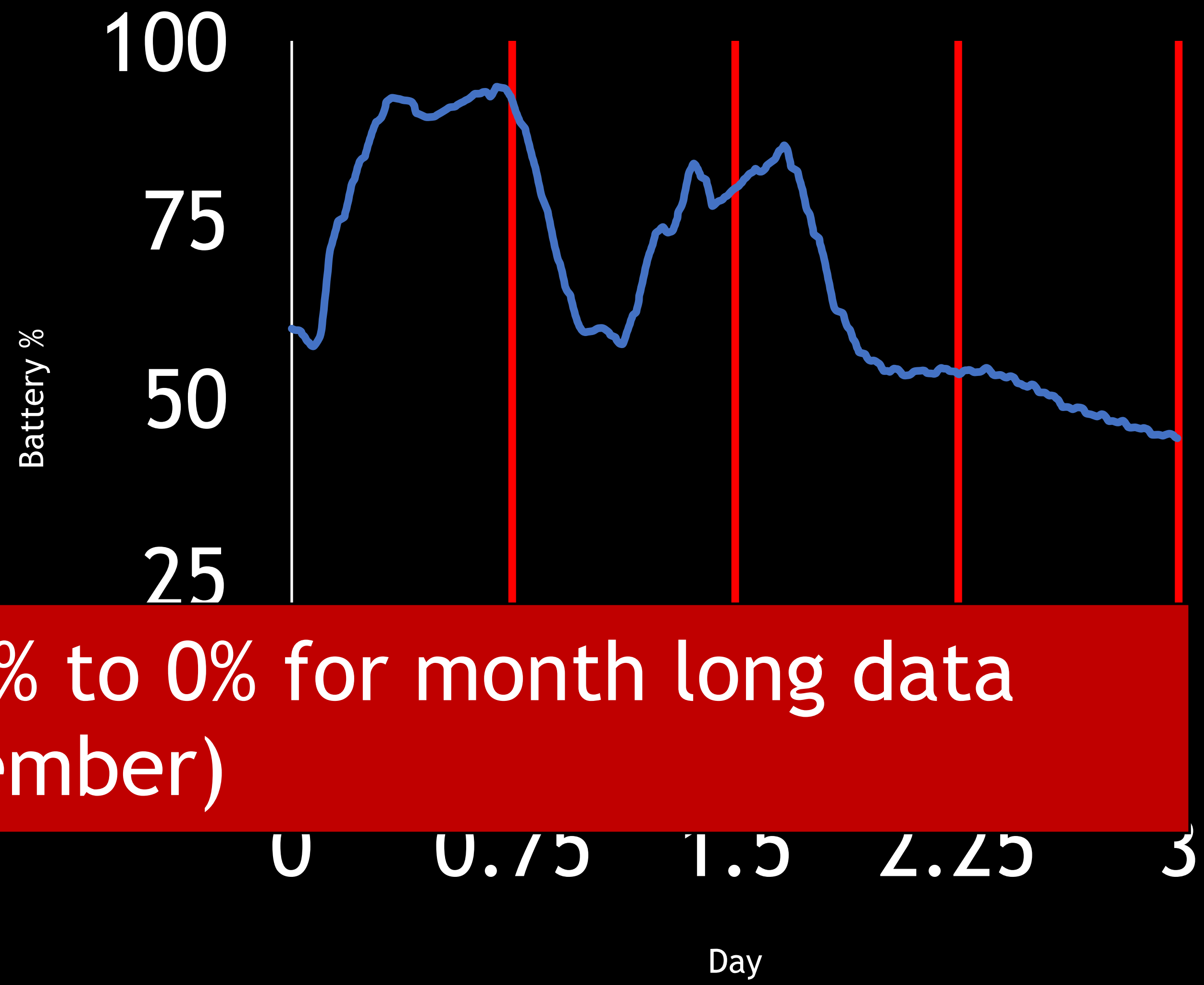


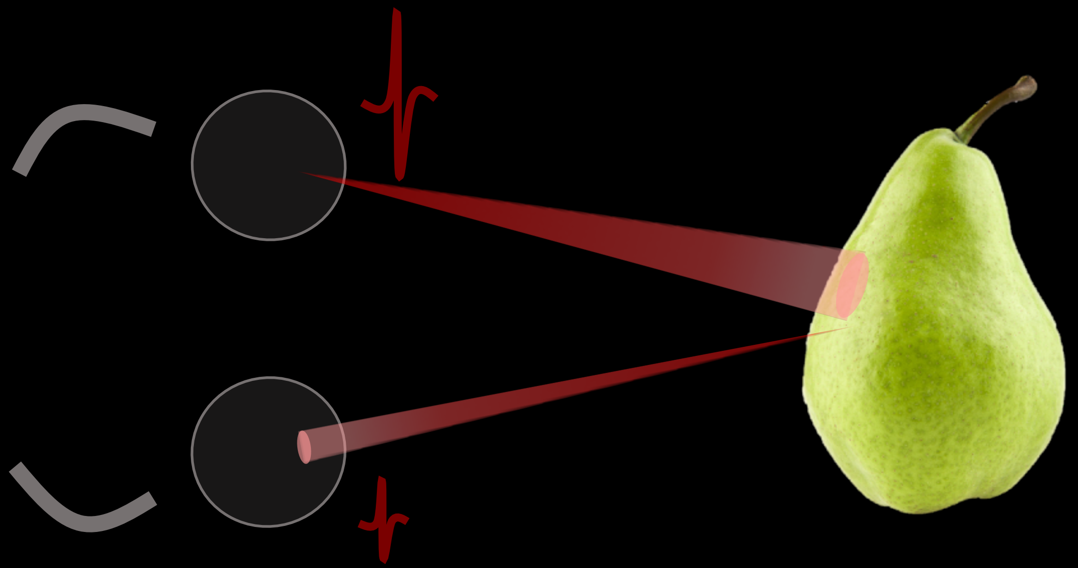


Reduced downtime from 30% to 0% for month long data (September)

Summary

- Aerial-based Connectivity (Loon, Aquila) & Agriculture IoT
- Challenges: Power, Control, Communication Range, Bandwidth, Weather
- Opportunities: Duty cycling, sparse sampling, weather prediction, thermodynamics, learning and sensor fusion, Drones
- Farmbeats: End-to-end IoT system for Farming

AgriTera: Accurate Non-Invasive Fruit Ripeness Sensing via Sub-Terahertz Wireless Signals



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Atsutse Kludze, Subhajit Karmakar,

Ranveer Chandra, Yasaman Ghasempour

Microsoft

PRINCETON UNIVERSITY

acm sigmobile

Can we detect the ripeness of fruit beneath its peel non-invasively?

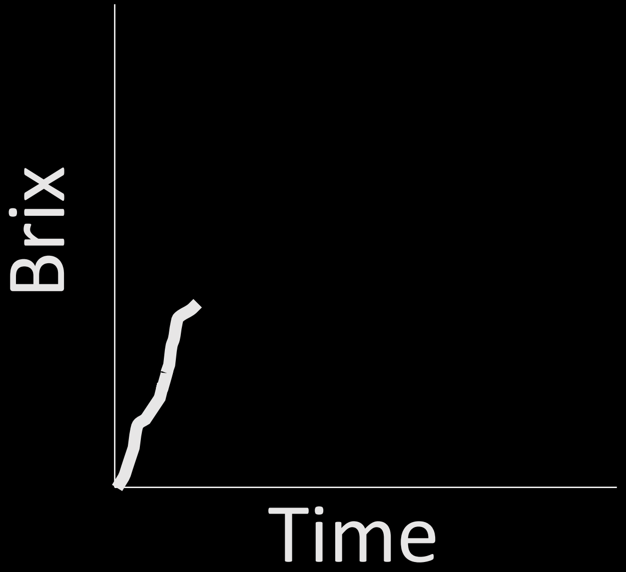
Is it ripe?

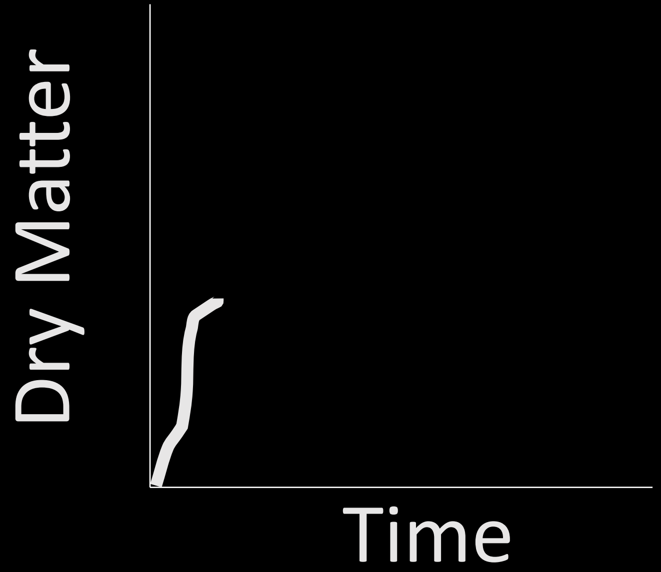
Does it feel firm?

Has it rotten?

Nearly *50%* of the fruits and vegetables produced worldwide are wasted each year

Quantifying fruit ripeness

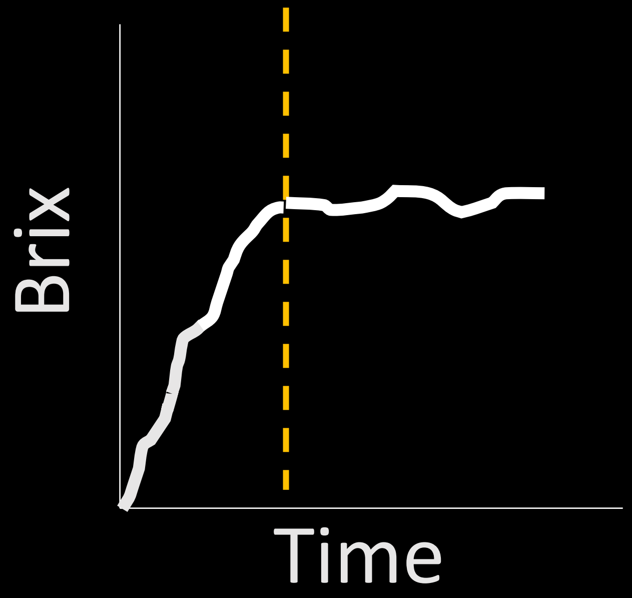




Starch

Unripe

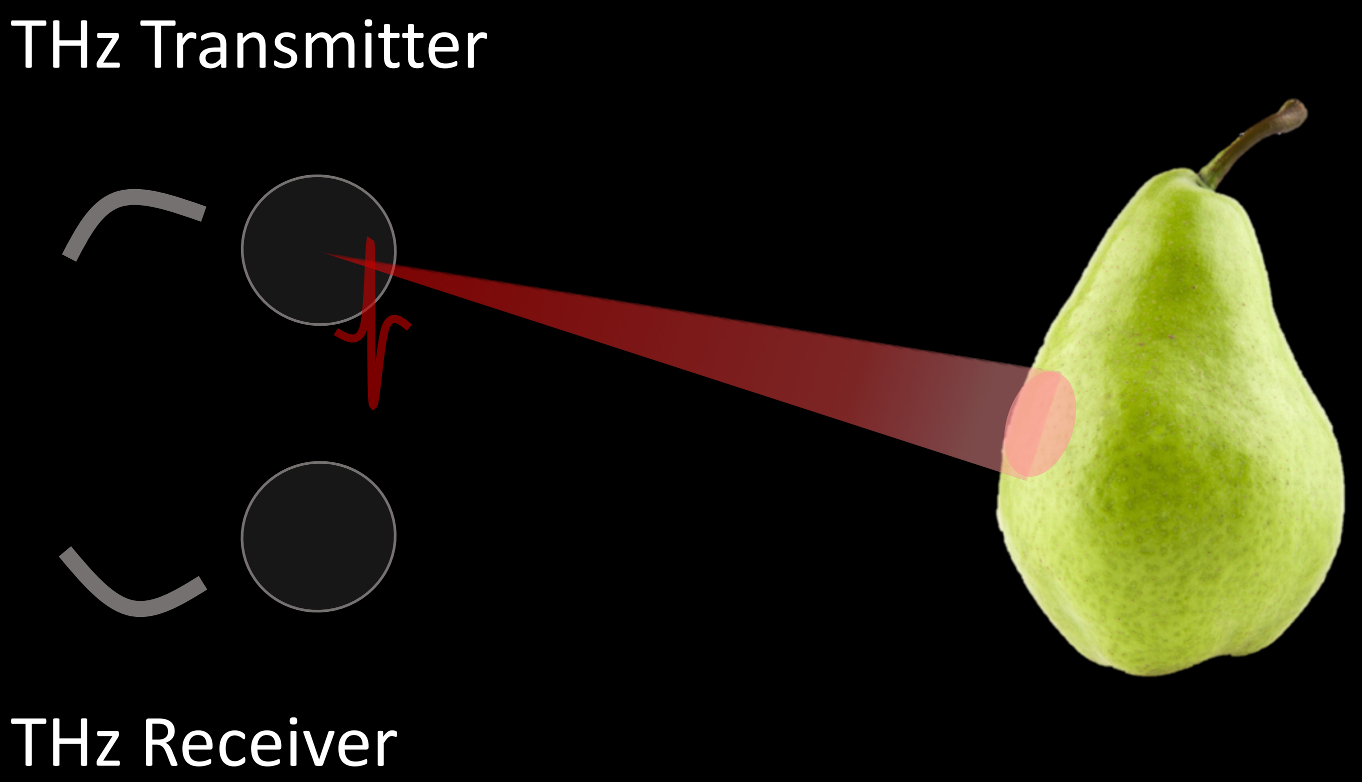
Quantifying fruit ripeness



Ripe

How can we measure Brix and Dry-Matter
non-invasively and without contact?

Approach : Exploit the sub-THz band to determine Ripeness Metrics



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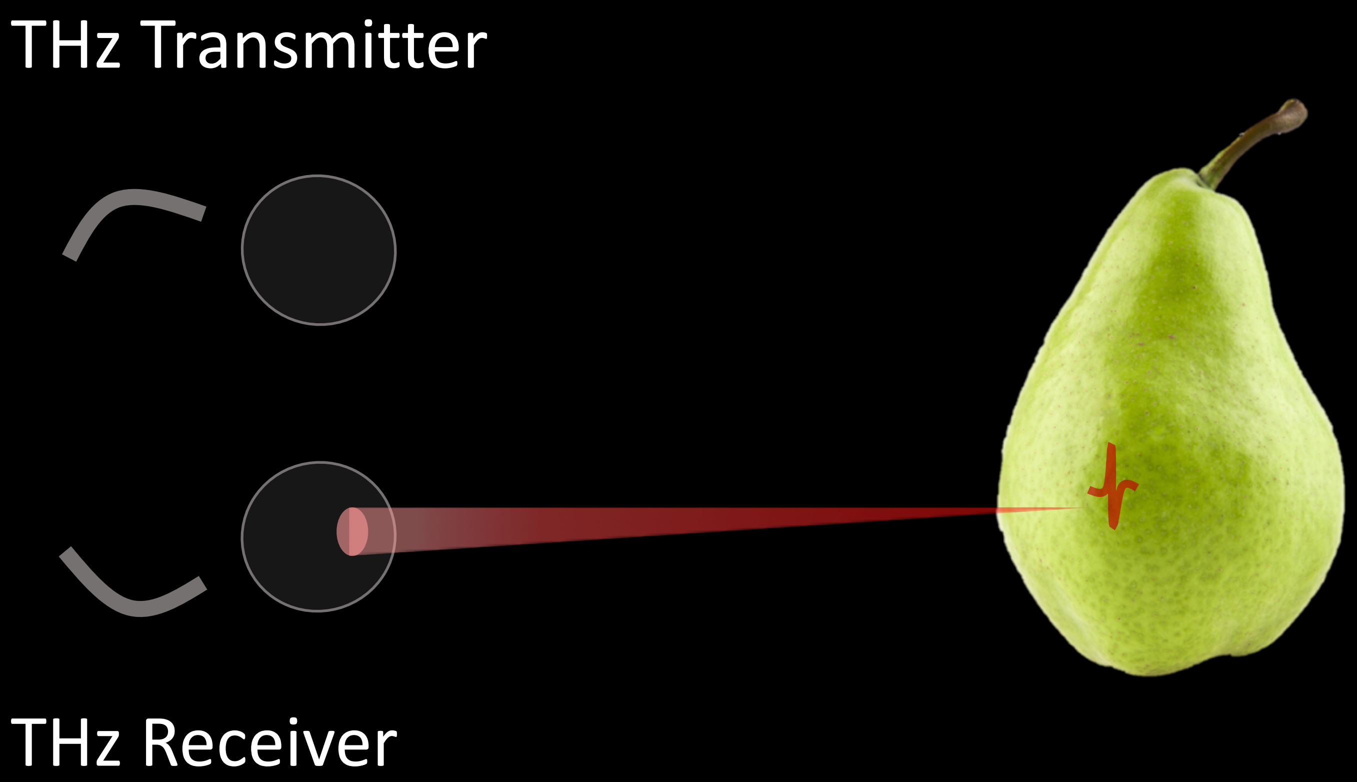

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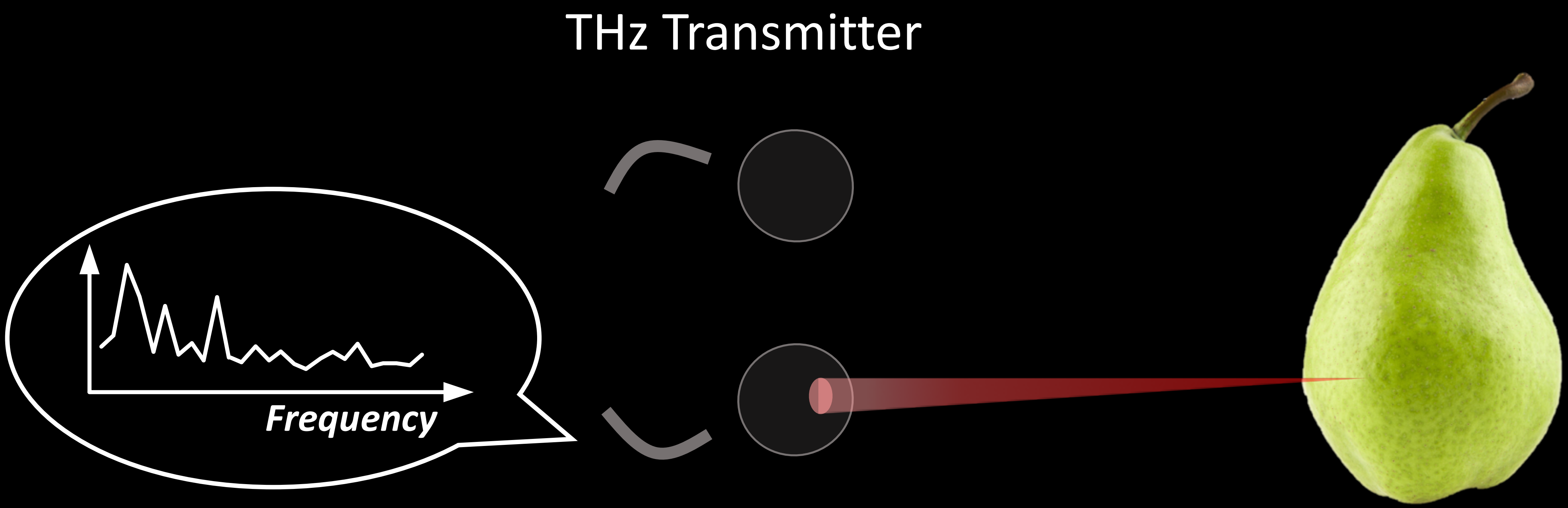
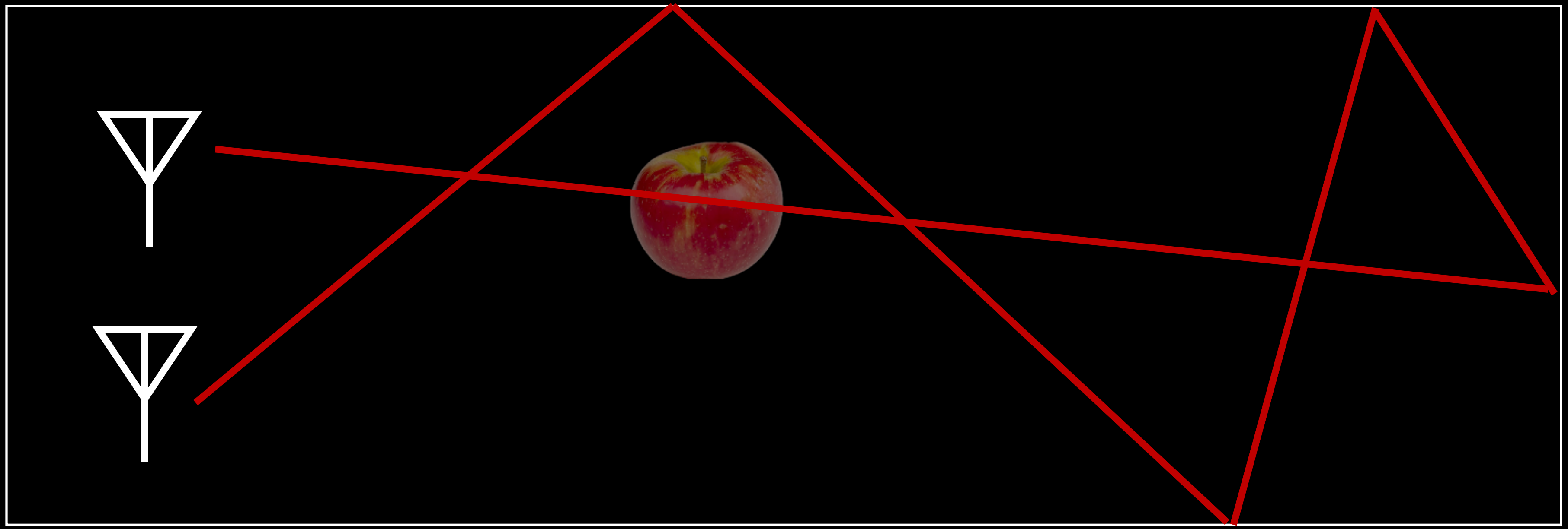
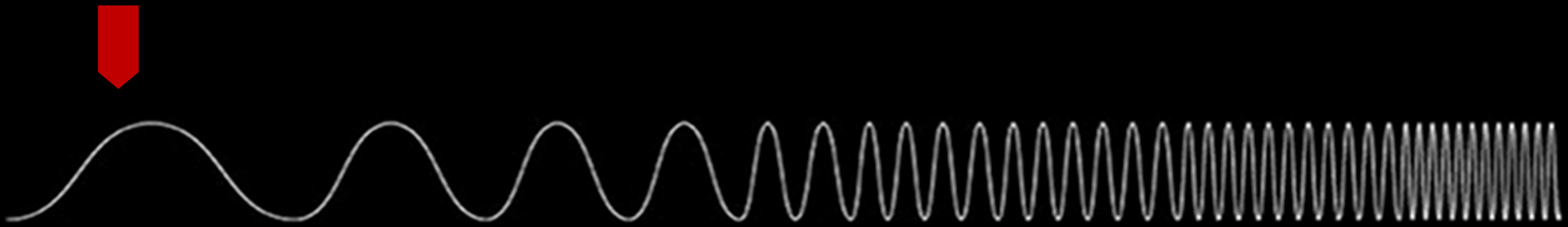


Changes in refractive-index leave a footprint in the sub-THz band

Why Sub-THz bands?





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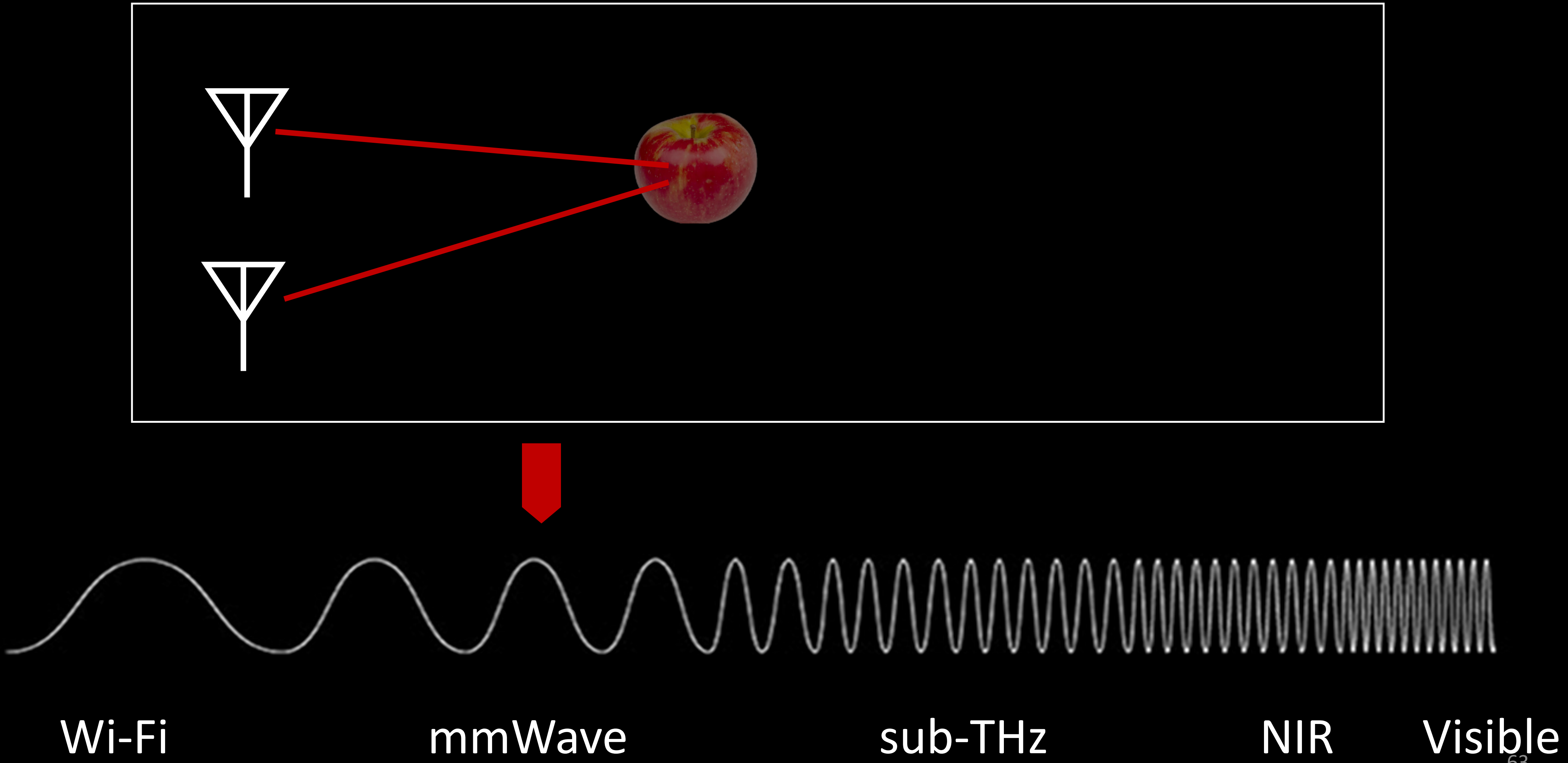

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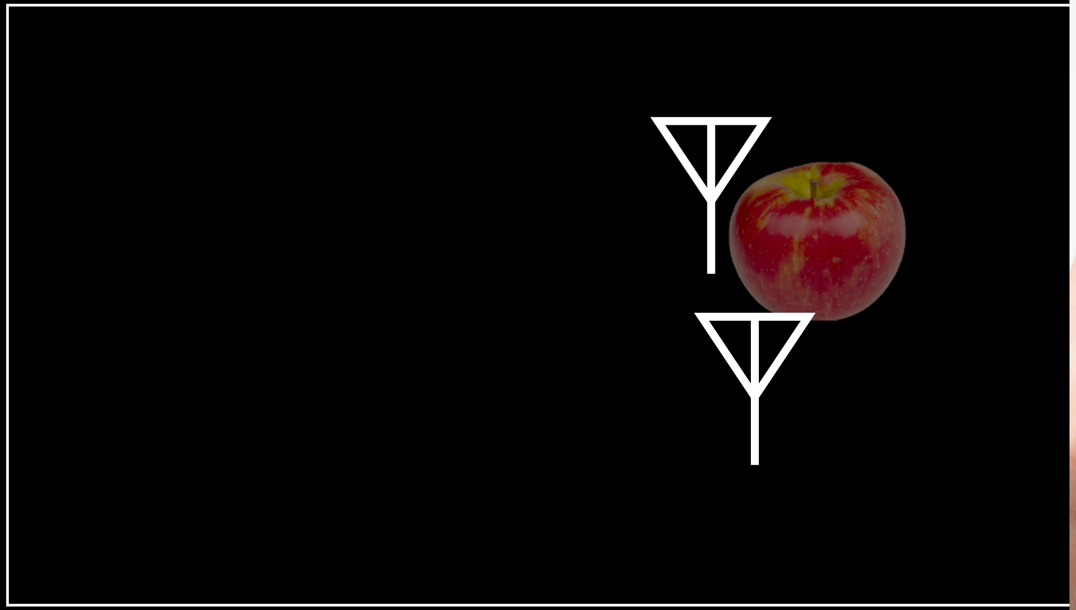

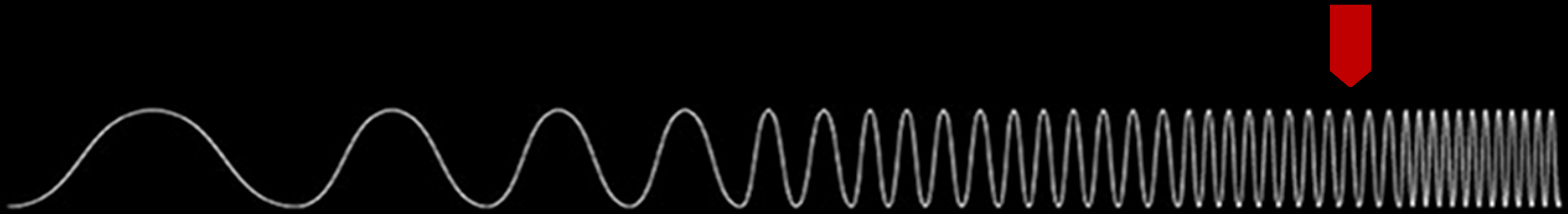

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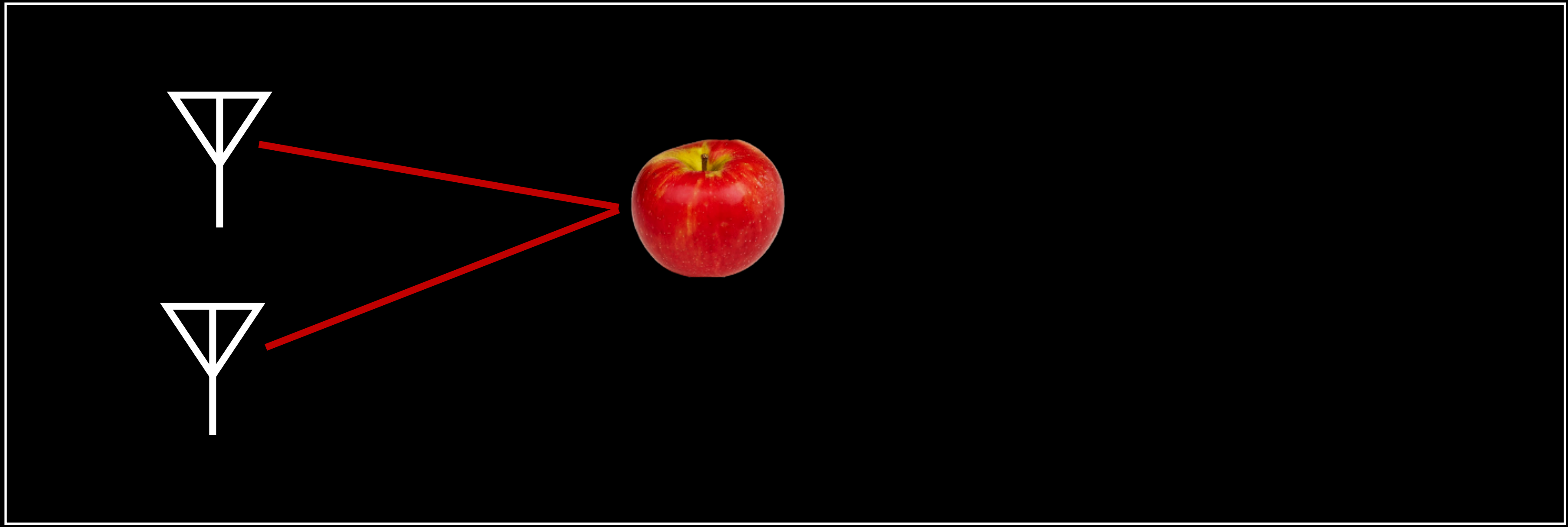
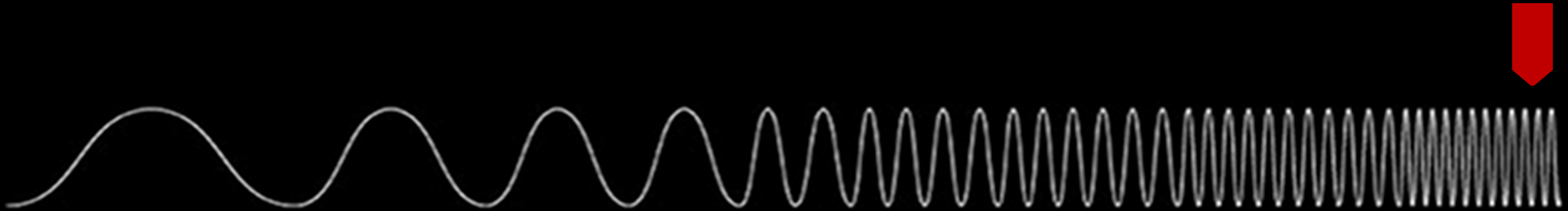
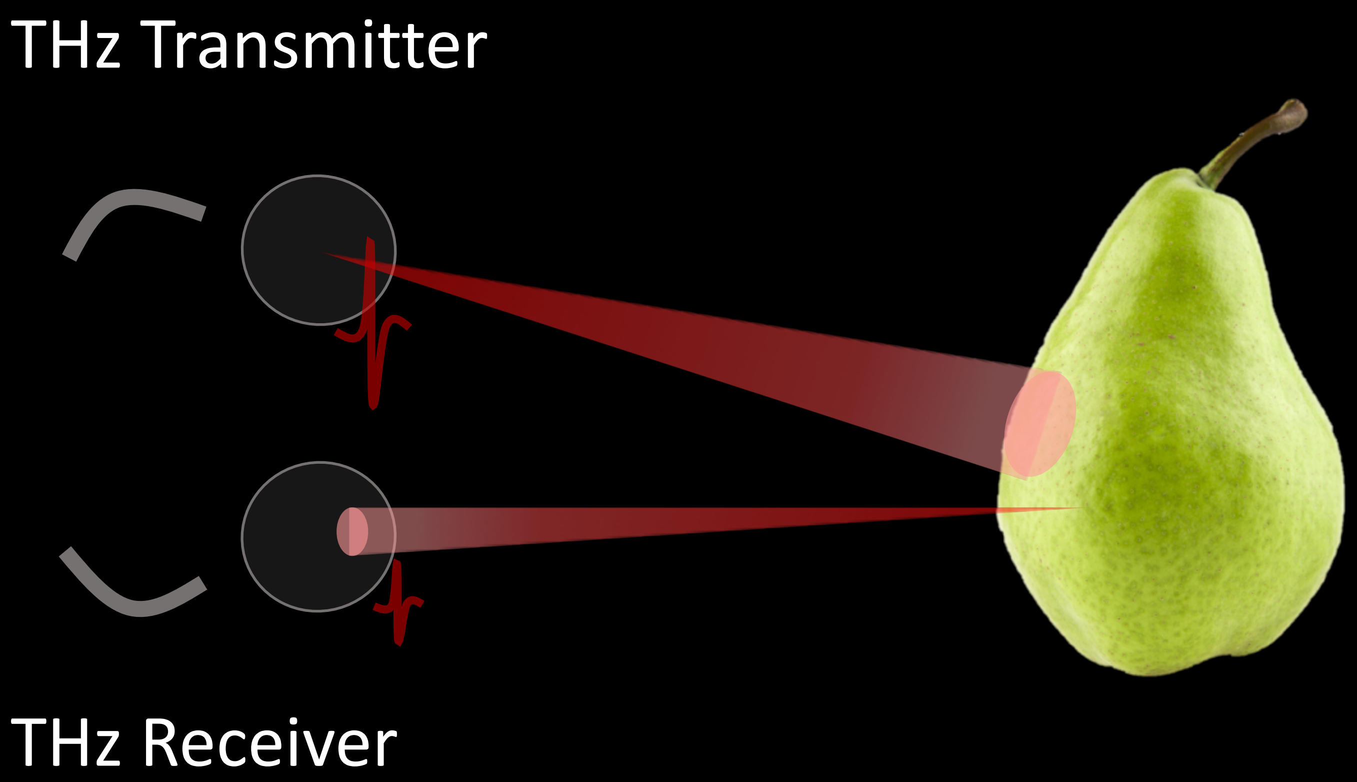




AgriTera

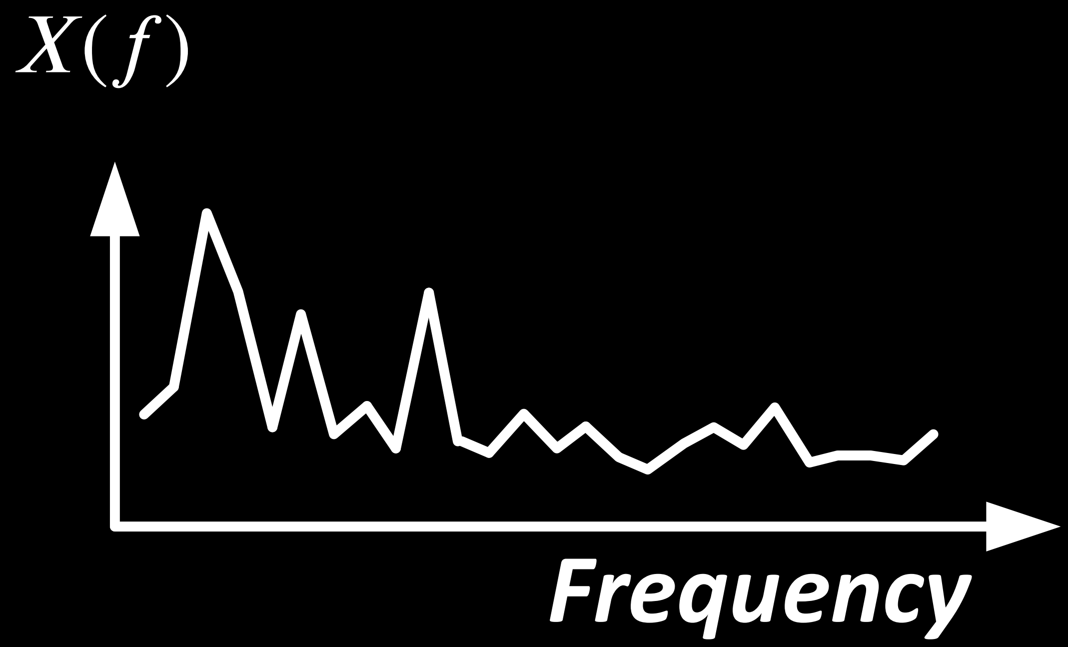
- Estimates fruit ripeness metrics such as Brix and Dry-Matter without contact
- Works accurately with different types of fruits with different structures, surface properties, peel thickness and pulp types.
- Implemented and evaluated in practical environments with an average NRMSE error of 0.55%

Key Idea : Exploit the sub-THz band to determine Ripeness Metrics



How can we map sub-THz spectra to Brix and Dry-Matter?

Approach: Chemometric Analysis for Extracting Ripeness Metrics



$$< X(f),\ P >$$

Frequency Subspace

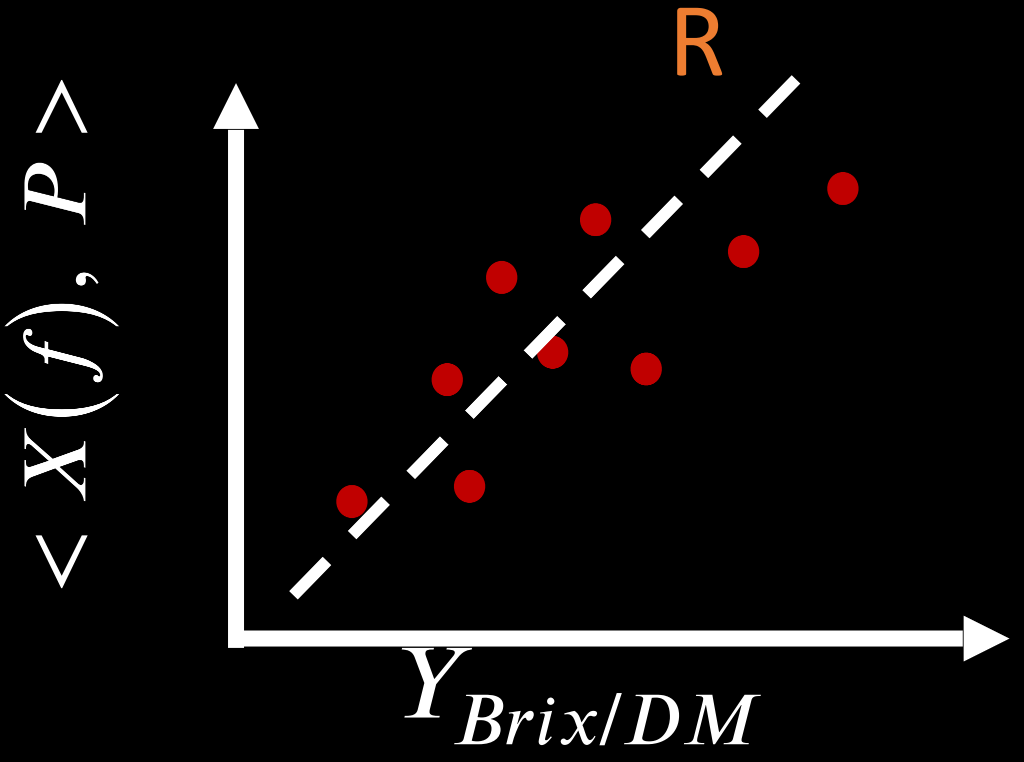
N Measurements

N Projections

Approach: Chemometric Analysis for Extracting Ripeness Metrics

$$< X(f),\ P >$$

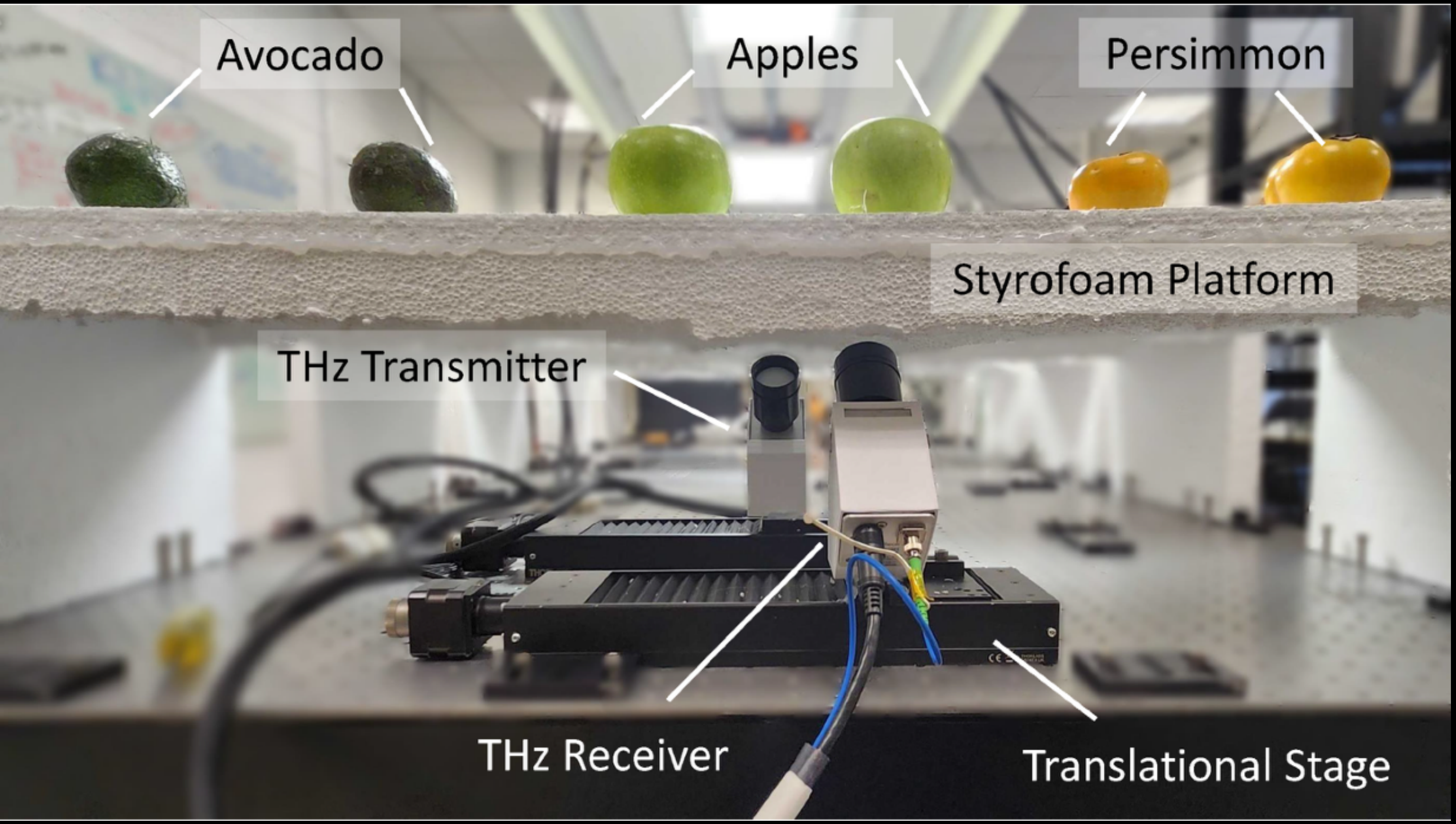
$Latent\ Space$

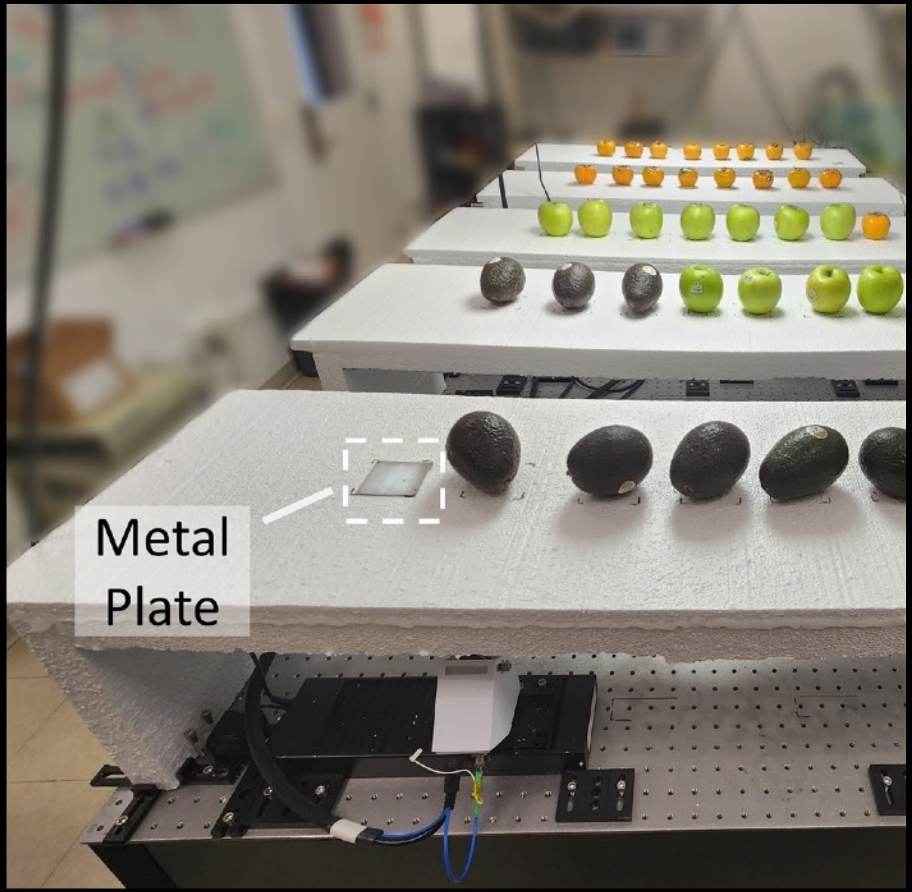


$$\beta = PR$$

$$\tilde{Y}_{Brix/DM} = \tilde{X}(f)\ \beta$$

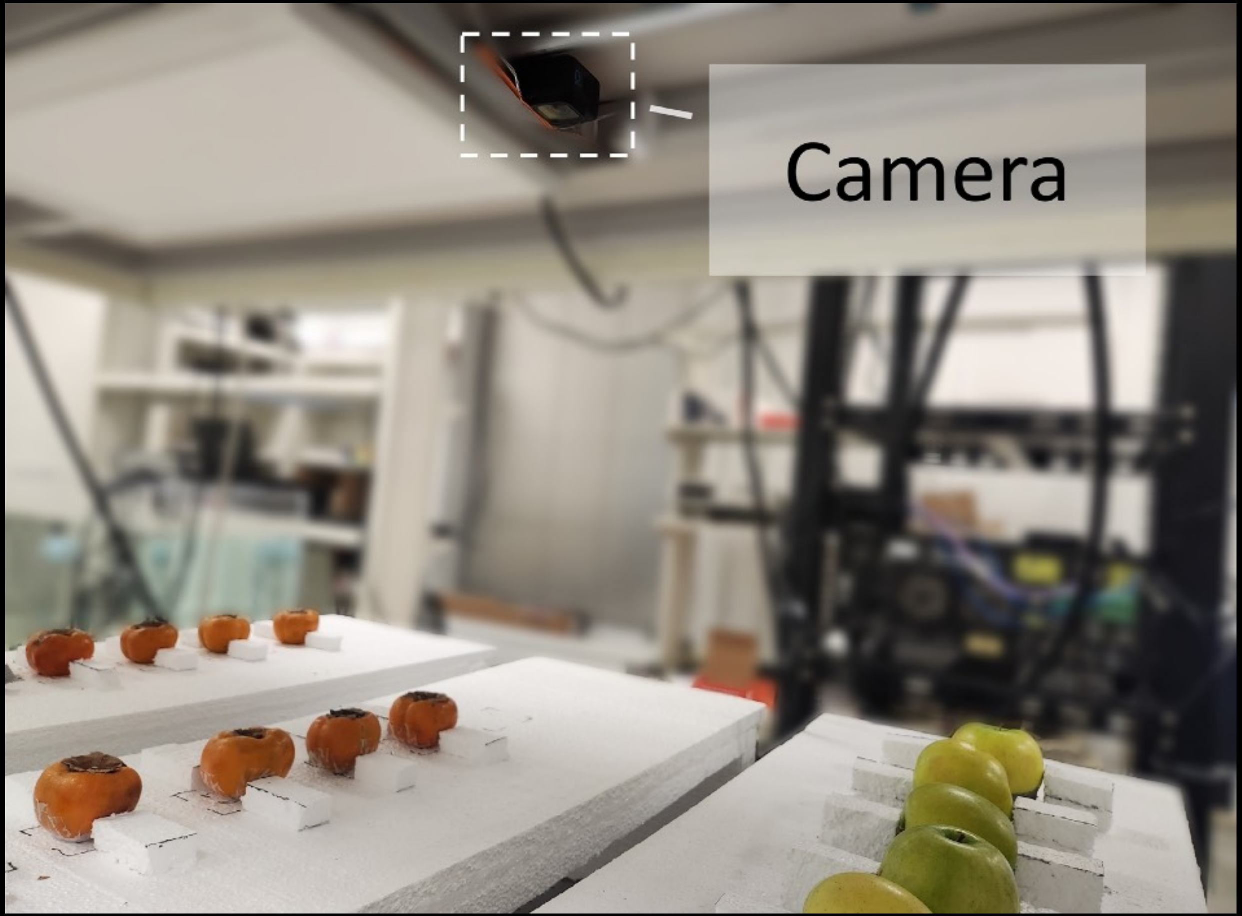
Implementation





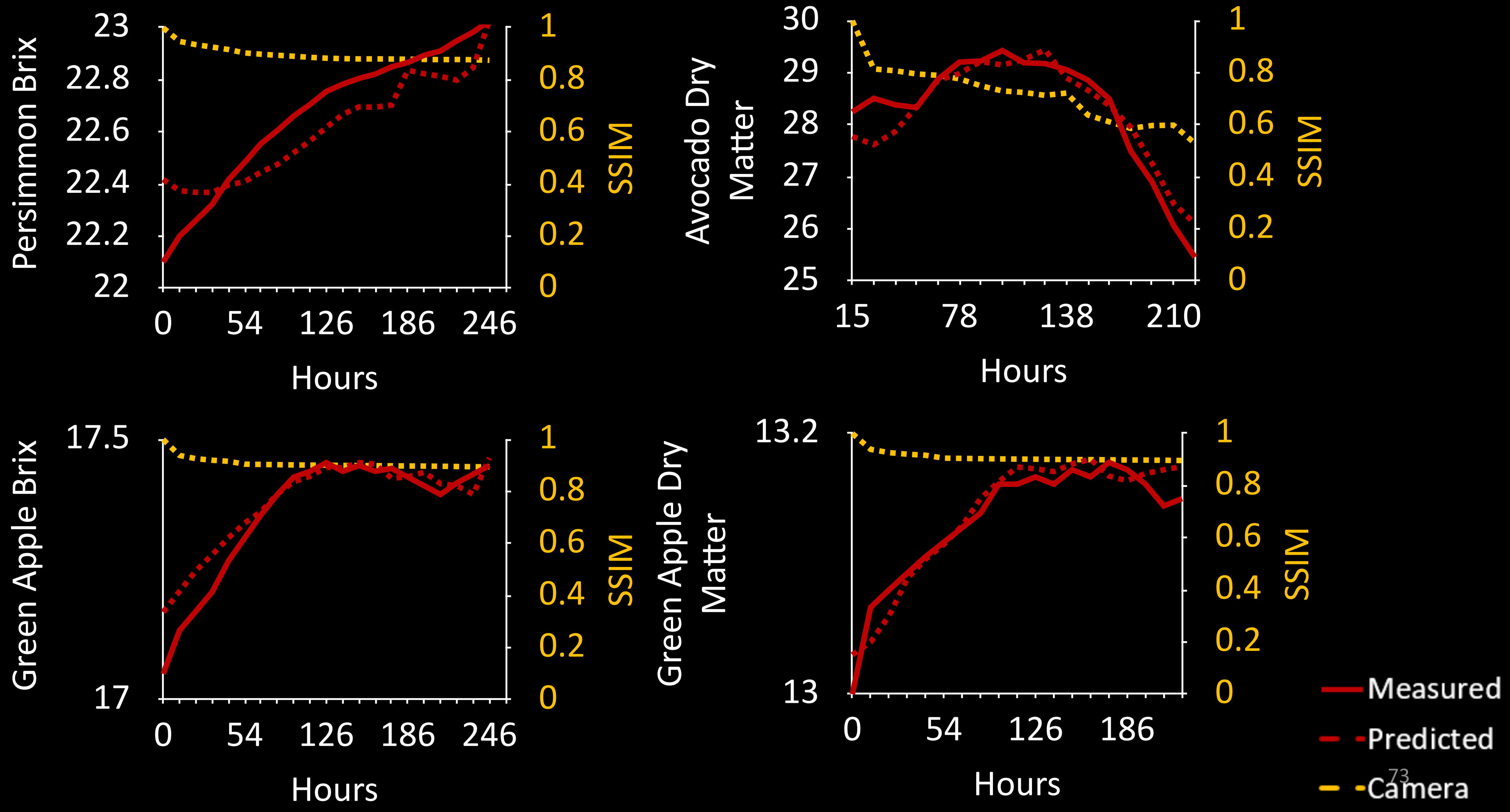
Implementation

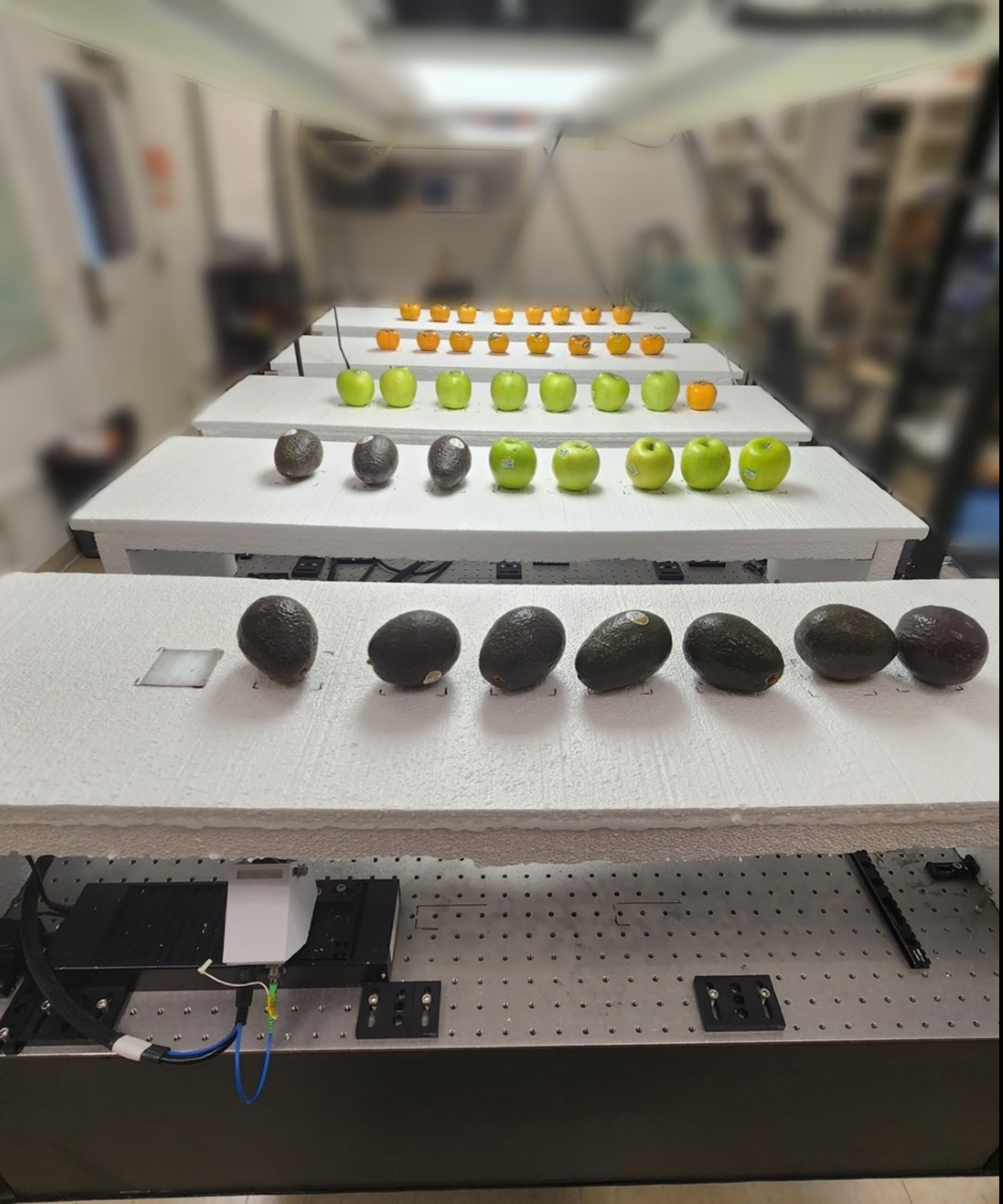
Ground Truth



Baseline

AgriTera Ripeness Prediction during Ripening Cycle





Conclusion

- Agri-Tera utilizes the sub-THz band to infer about ripeness metrics of fruits
- It can accurately determine Dry Matter/ Brix for a variety of different types of fruits
- Future work: Enabling a mobile system for fruit sensing using AgriTera

What did we cover today?

Agriculture IoT

- Aerial-based Connectivity (Loon, Aquila)
- Challenges in Agriculture IoT:
  - Internet Connectivity
  - Limited Sensor Placement
  - Power Availability

- IoT for Produce Monitoring and Fruit Sensing

TODO:

1- Project Proposals due today

2- Lab 4 due next week, April 8

3- PSet 2 due April 10