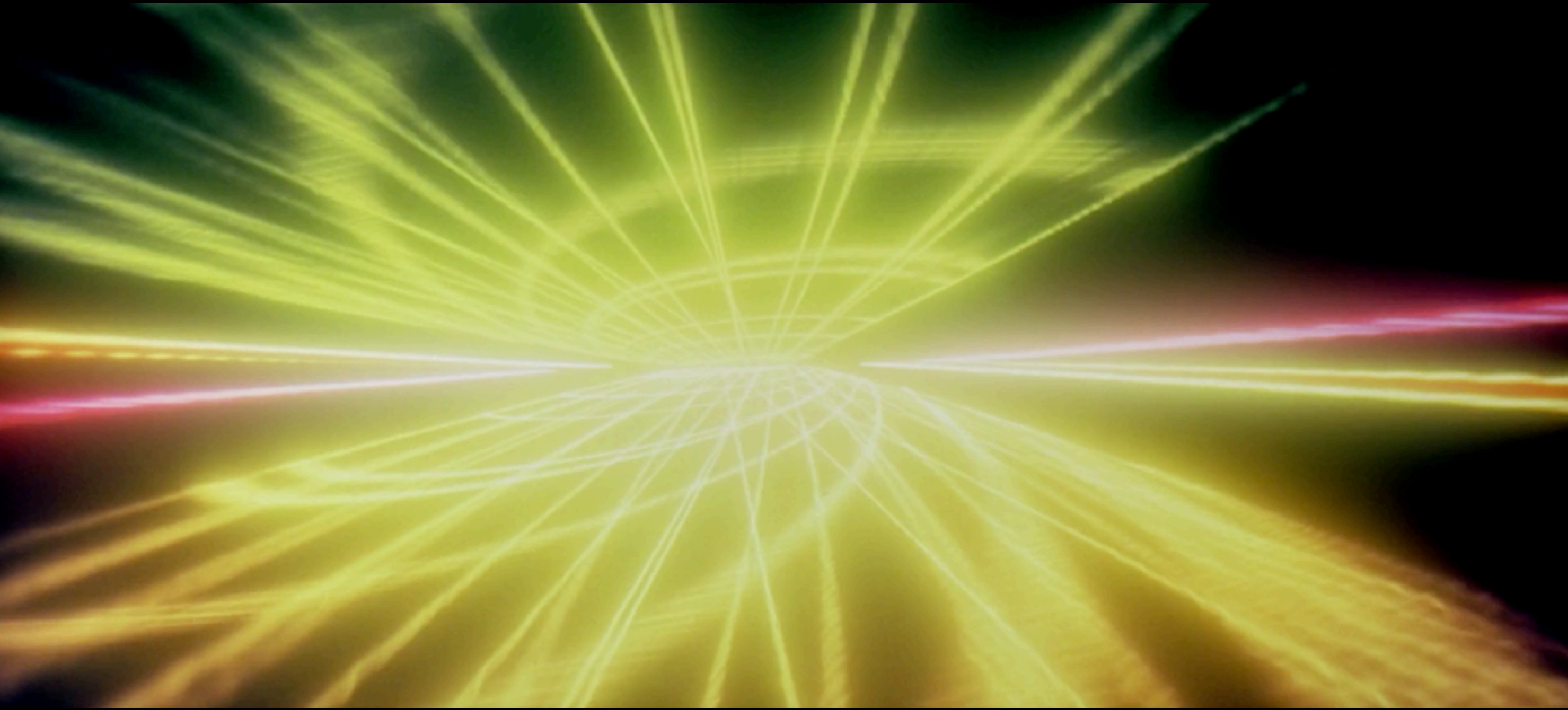
Trends in Computing



THE EDGE

What is Edge Computing?

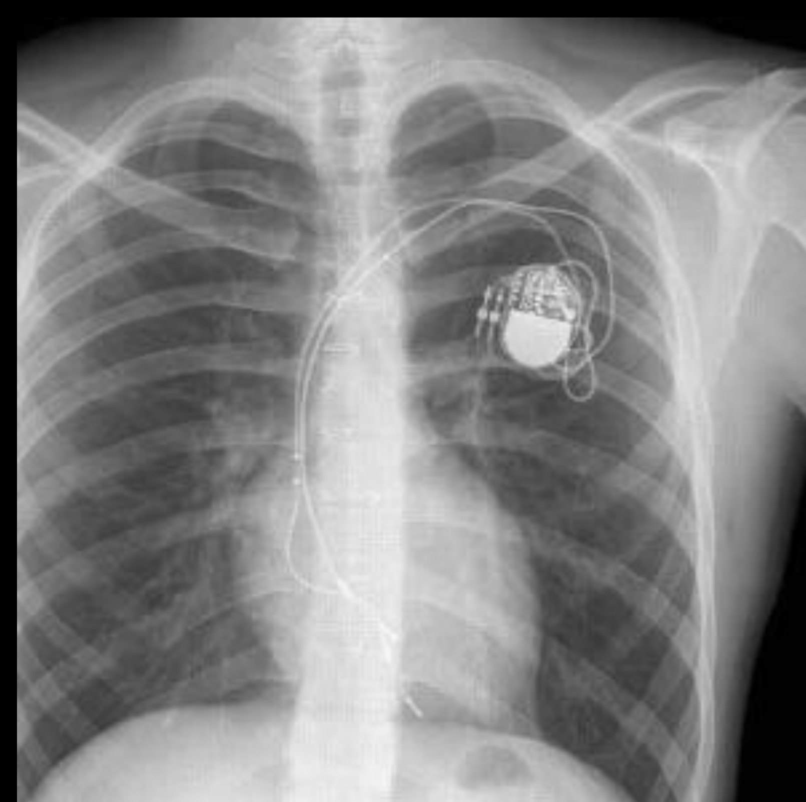
Broadly: Placing computation and data storage closer to where they are needed

- E.g. content delivery networks (CDNs)

Here: Colocating computing resources with sensors

Remote sensor network

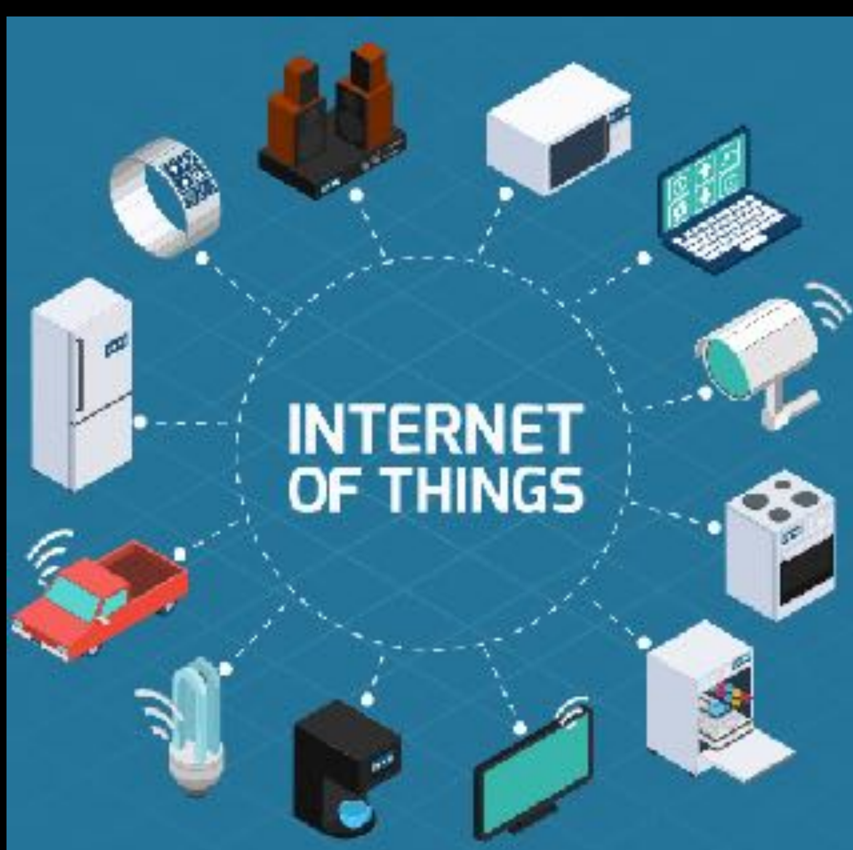
Implanted health devices

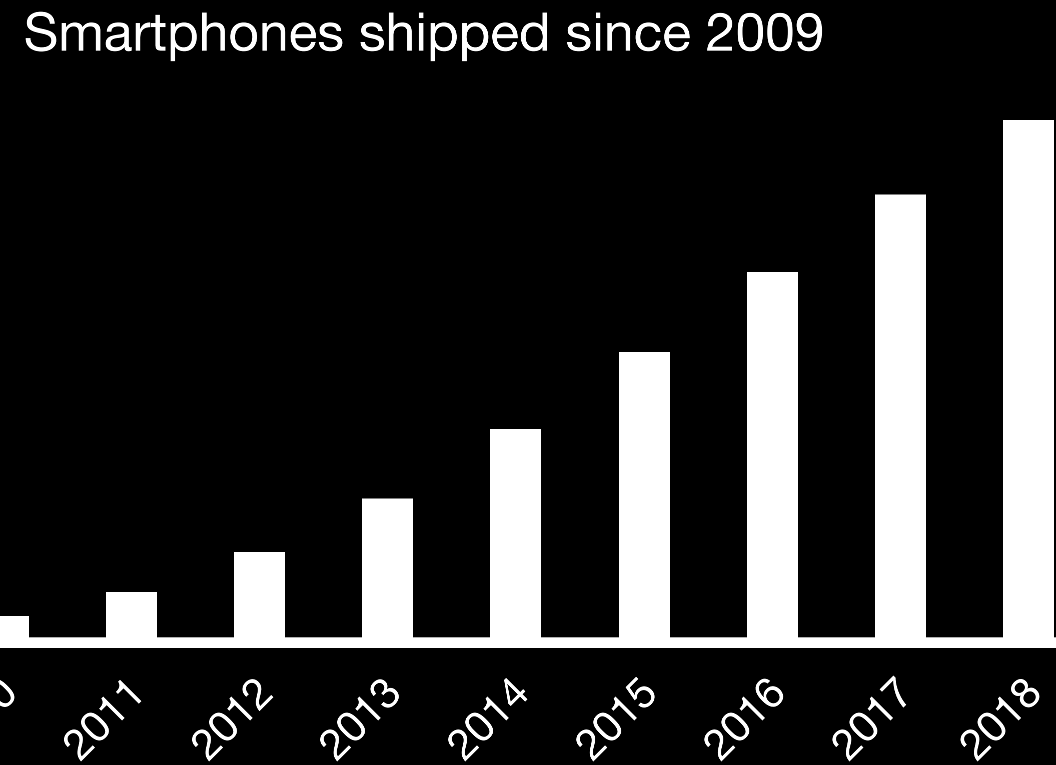


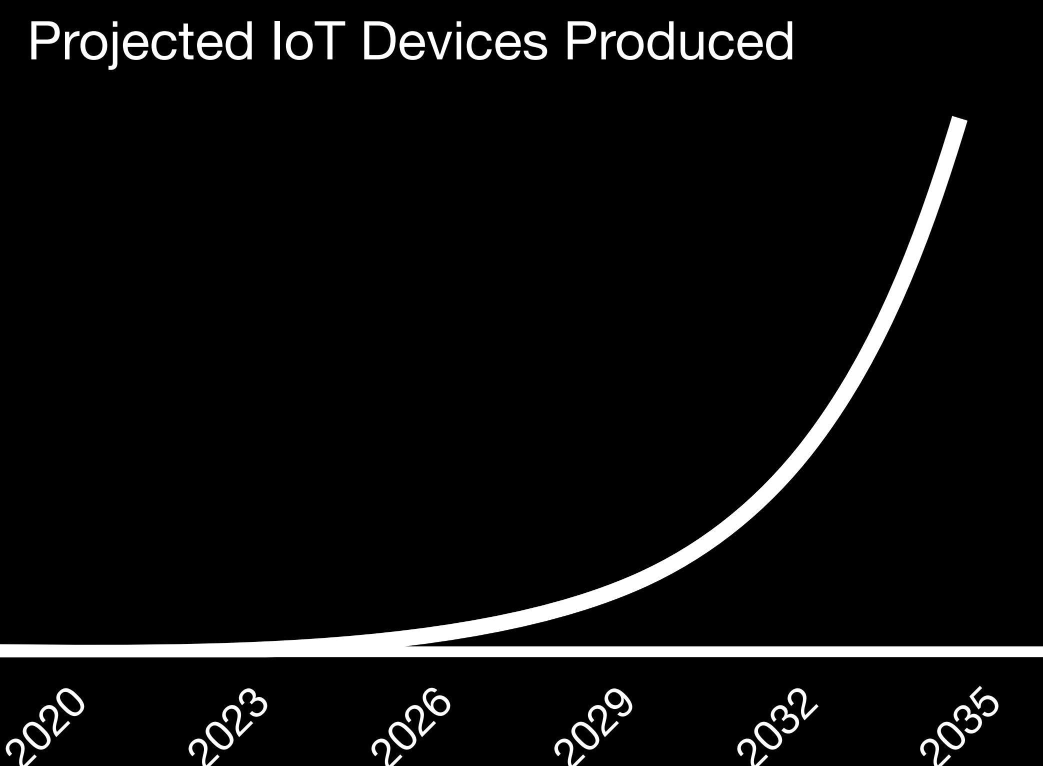
Space systems

Proliferation of Edge Devices

Smartphones







Challenges of a Proliferated Edge

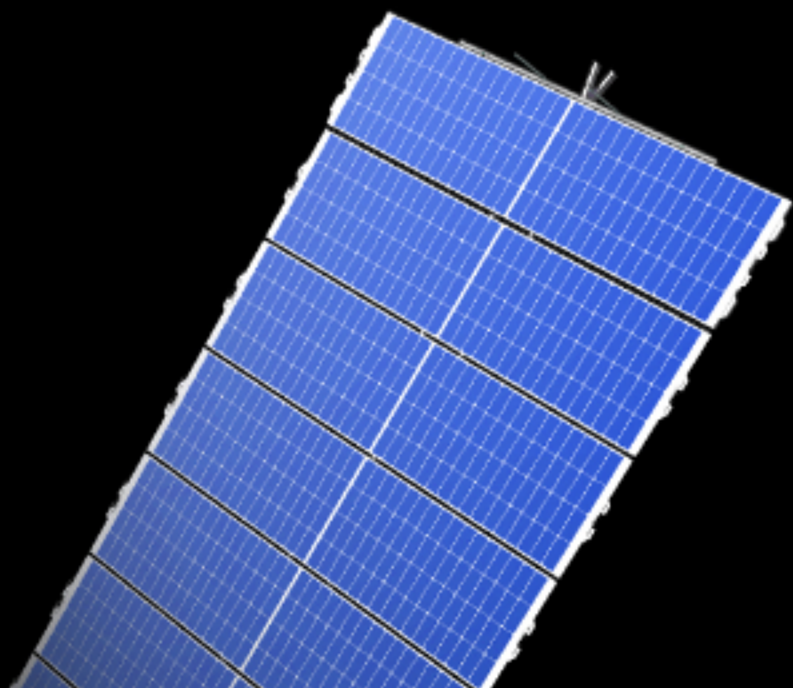
Communication and Utility
- High data volumes result in communication bottlenecks
- High energy cost

Maintainability, Sustainability
- It is infeasible to maintain trillions of edge devices
- What happens when the battery wears out?

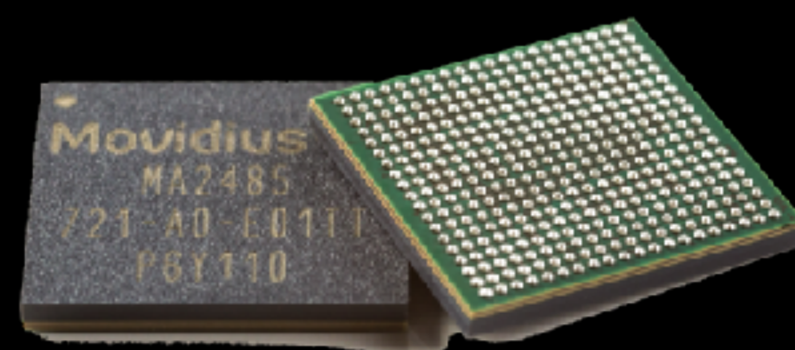
Security and Privacy
- Centralized data processing is vulnerable to attacks

Addressing Edge Challenges

Energy Harvesting and Storage



Energy-Efficient Edge Computing



Software, Runtime Techniques

```
configure mode2
task sense() {
  d = read_sensor()
  nexttask proc}
```

```
preburst burst=mode3
          exec=mode1
task proc() {
  if(motion_chk(d))
    nexttask radio_tx
  else
    nexttask sense}
```

```
burst mode3
task radio_tx() {
  radio_tx("alert!")
  nexttask sense}
```

Orbital Edge Computing

Brad Denby, bdenby@cmu.edu
Prof Brandon Lucia
Carnegie Mellon University

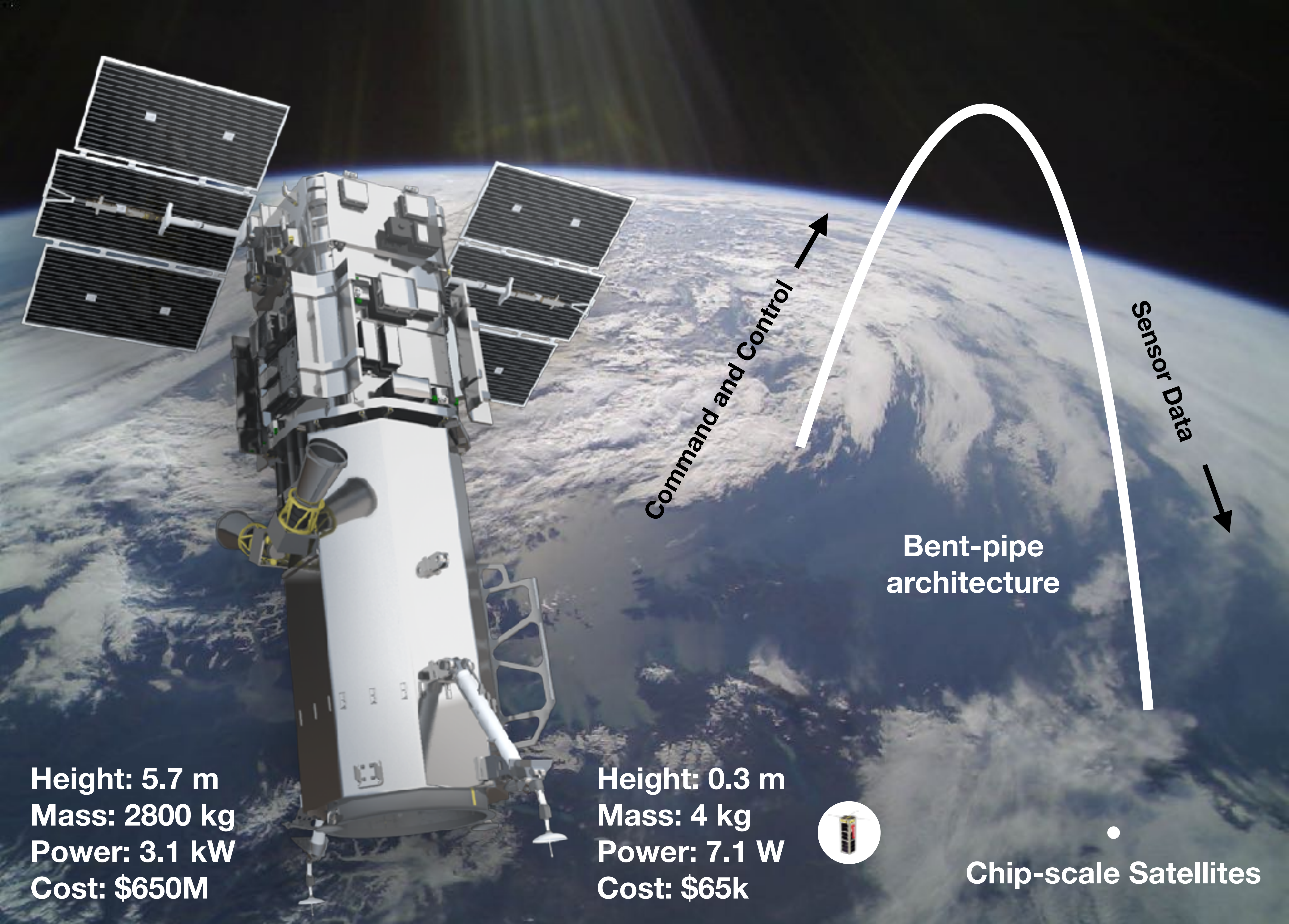
Overview

Background: Proliferating space systems

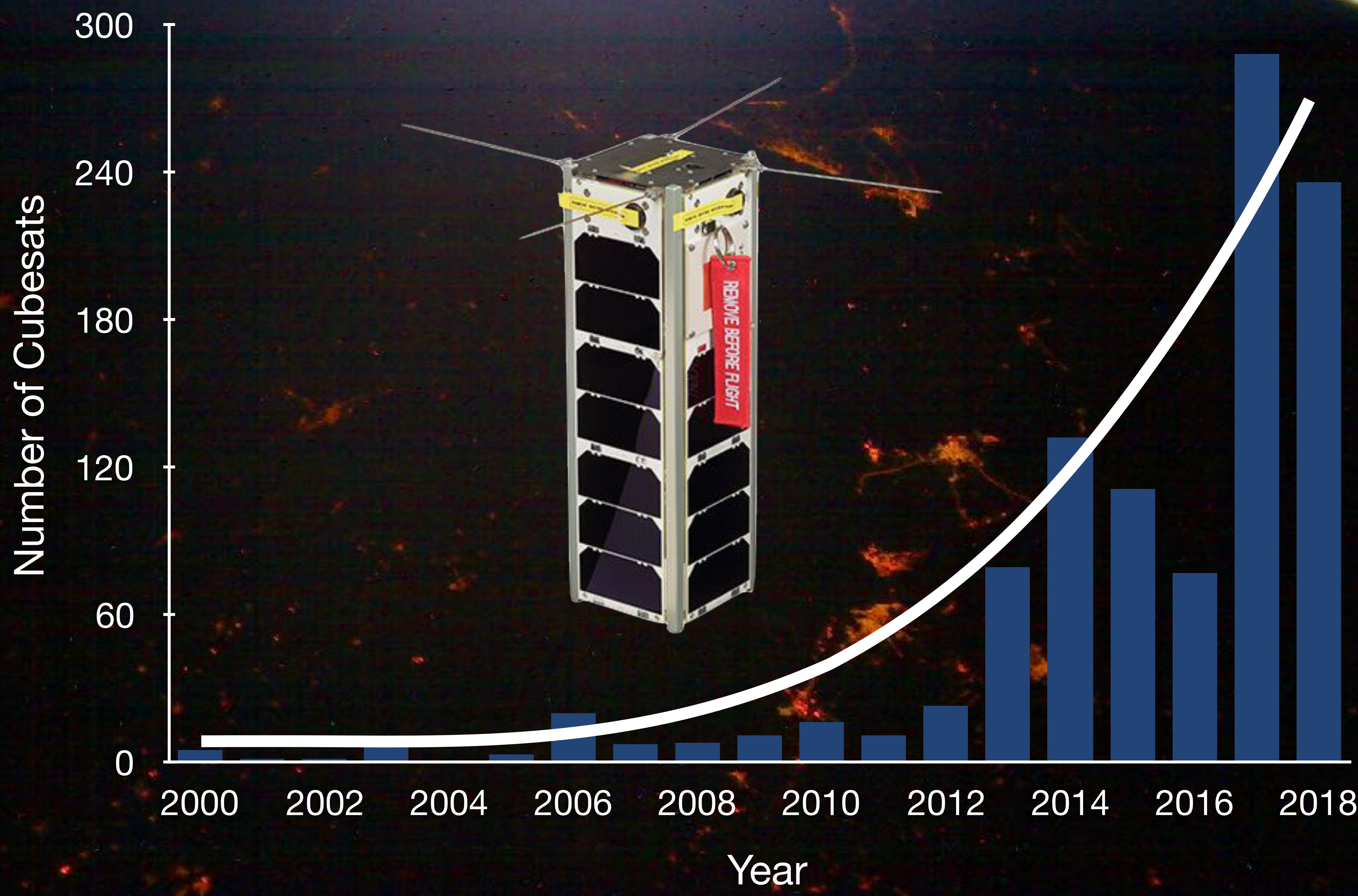
Motivation: Nanosatellite constraints

Orbital edge computing

Evaluating constellation configurations


Command and Control
Sensor Data
Bent-pipe architecture
Height: 5.7 m
Mass: 2800 kg
Power: 3.1 kW
Cost: $650M
Height: 0.3 m
Mass: 4 kg
Power: 7.1 W
Cost: $65k
Chip-scale Satellites

Cubesats Launched by Year



Data: CubeSat Database (Swartwout), Nanosats.eu

Overview

Background: Emerging satellite systems

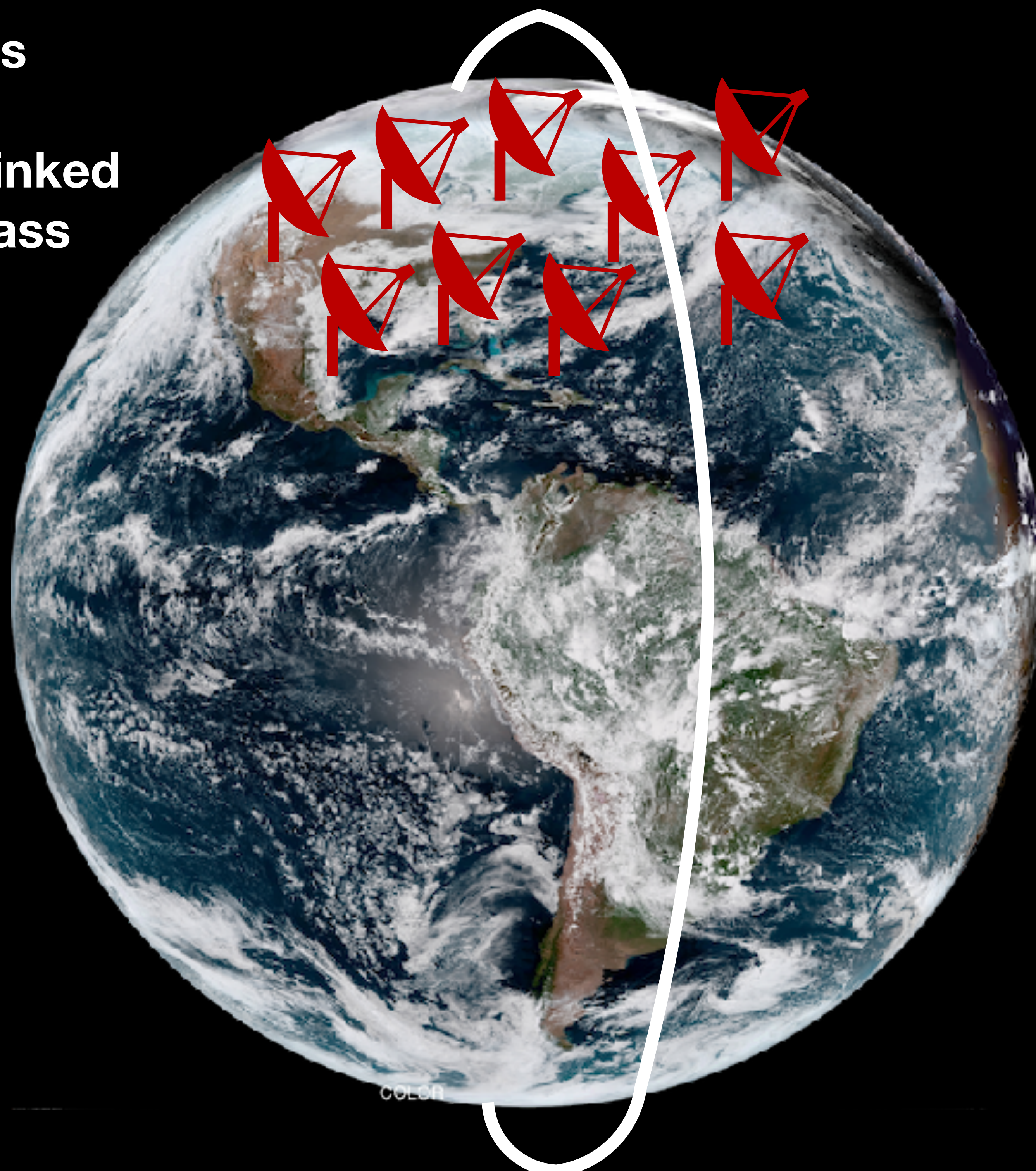
Motivation: Nanosatellite constraints

Orbital edge computing

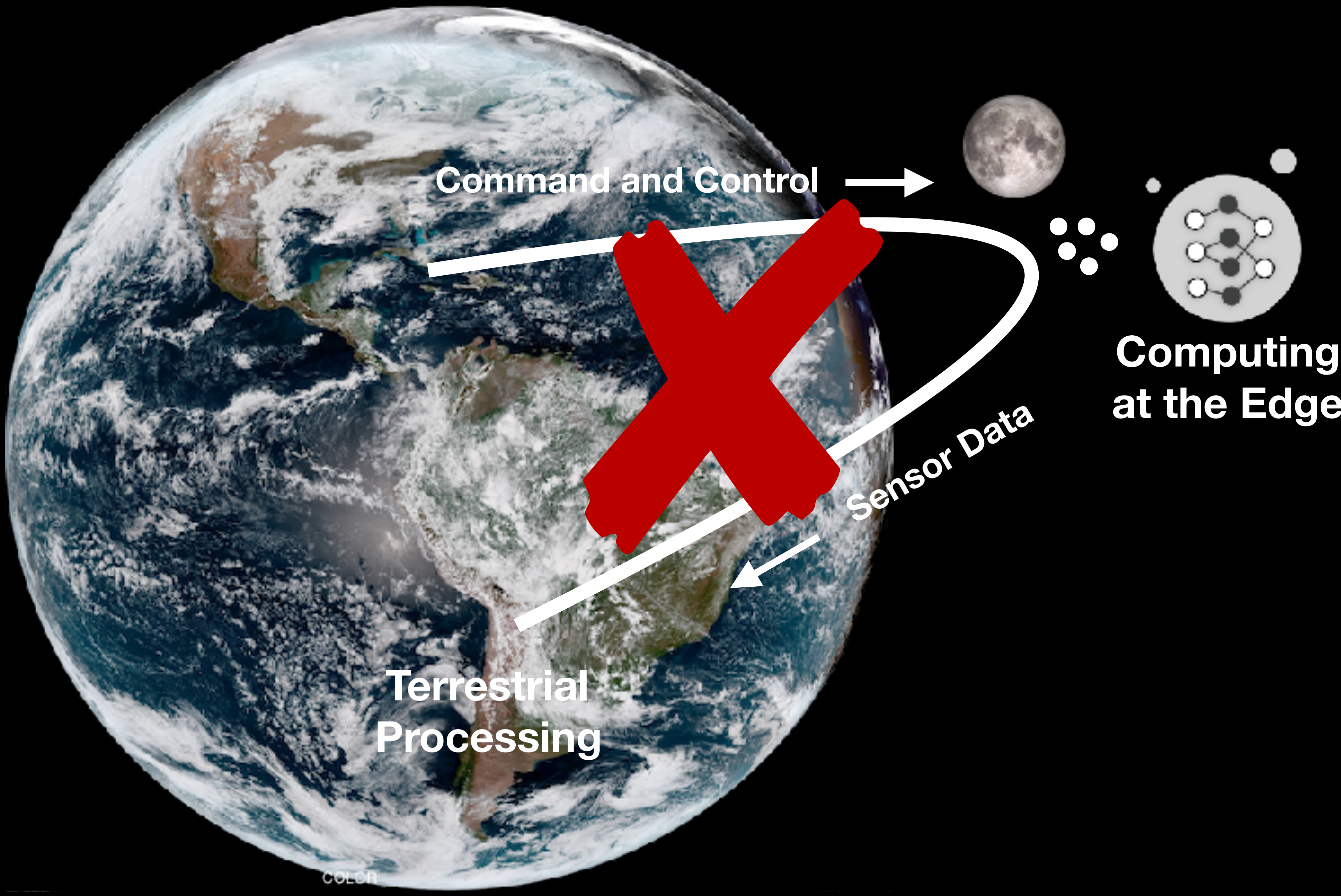
Evaluating constellation configurations

Downlinking Data Does Not Scale

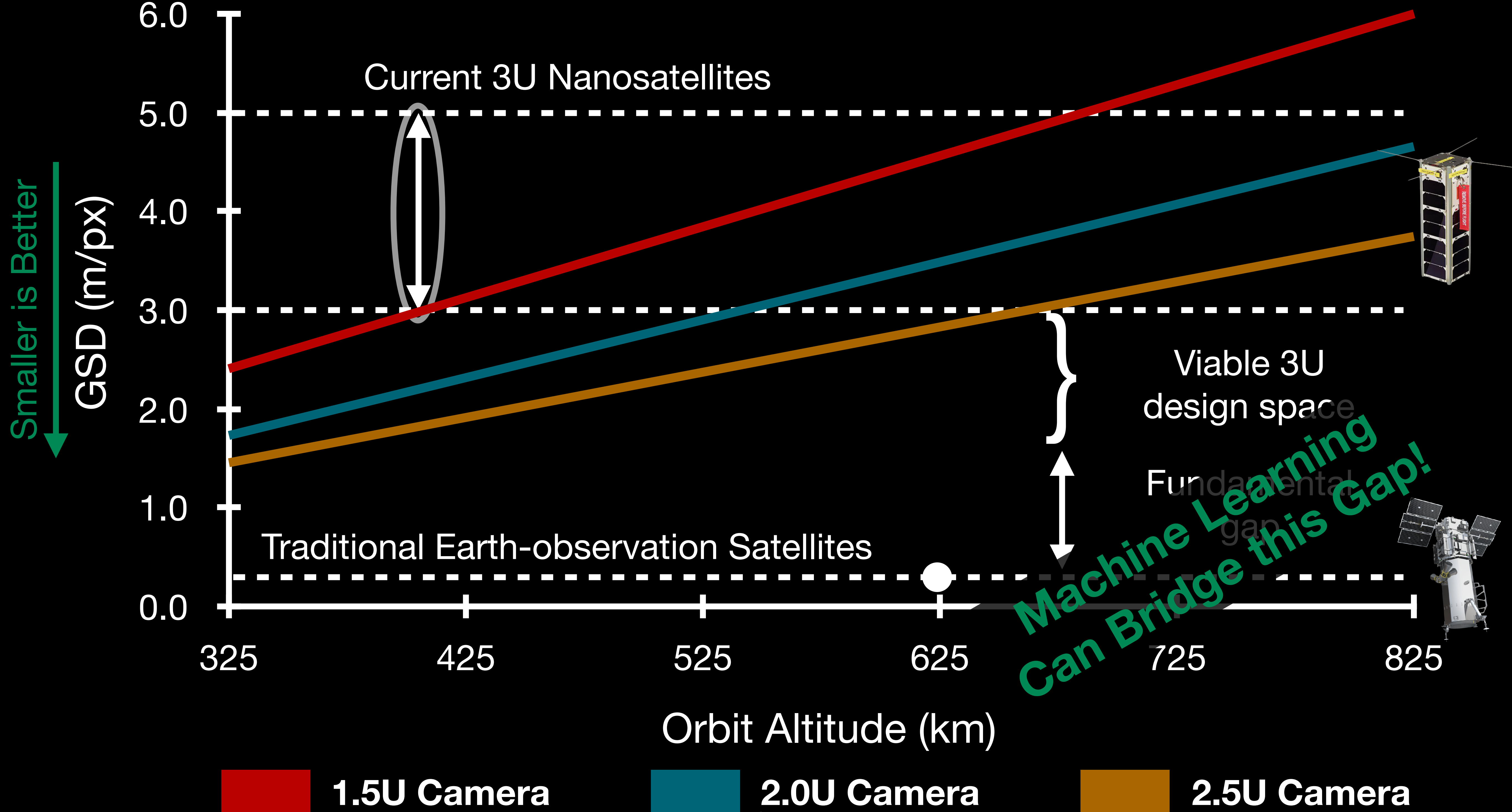
Downlink: 200 Mbps
Duration: <10 min.
Up to 15 GB downlinked per nanosatellite pass



Downlinking Data Does Not Scale

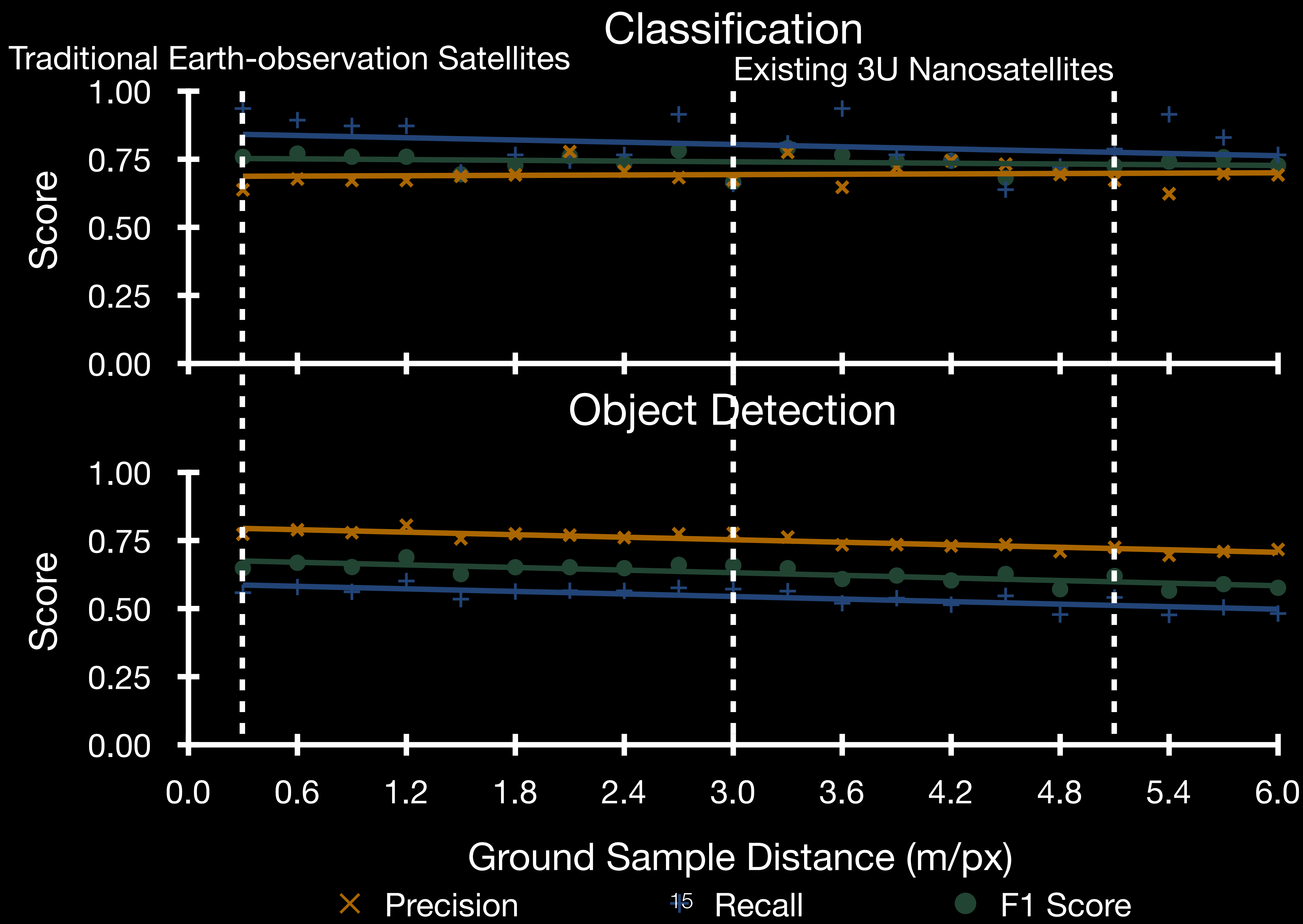


Designing for Maximum Data Quality

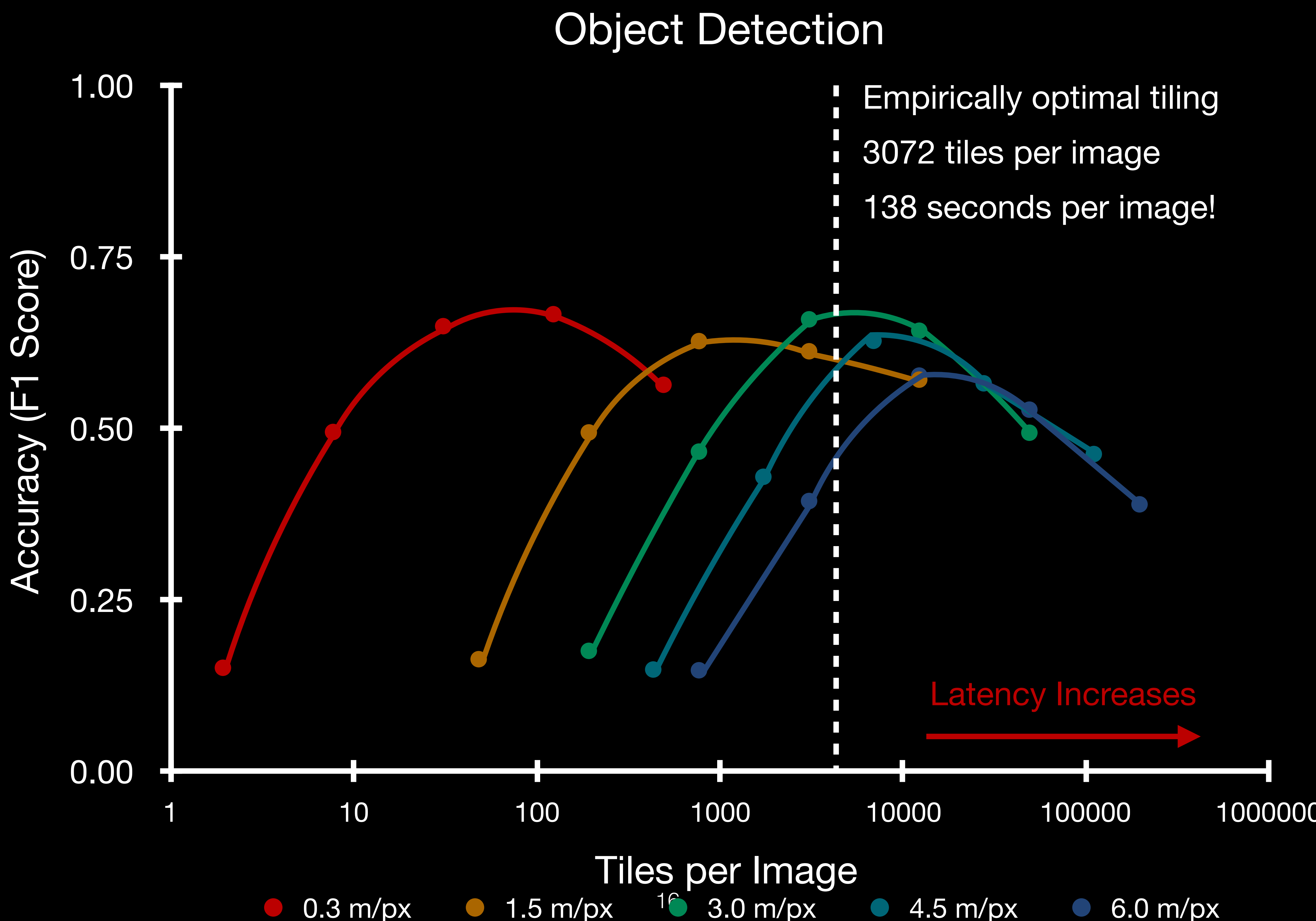



No features
Building present

ML Tolerates Low Data Quality



Tile Size Determines Accuracy, Latency



Overview

Background: Emerging satellite systems

Motivation: Nanosatellite constraints

Orbital edge computing

Evaluating constellation configurations

Orbital Edge Computing

Existing Systems

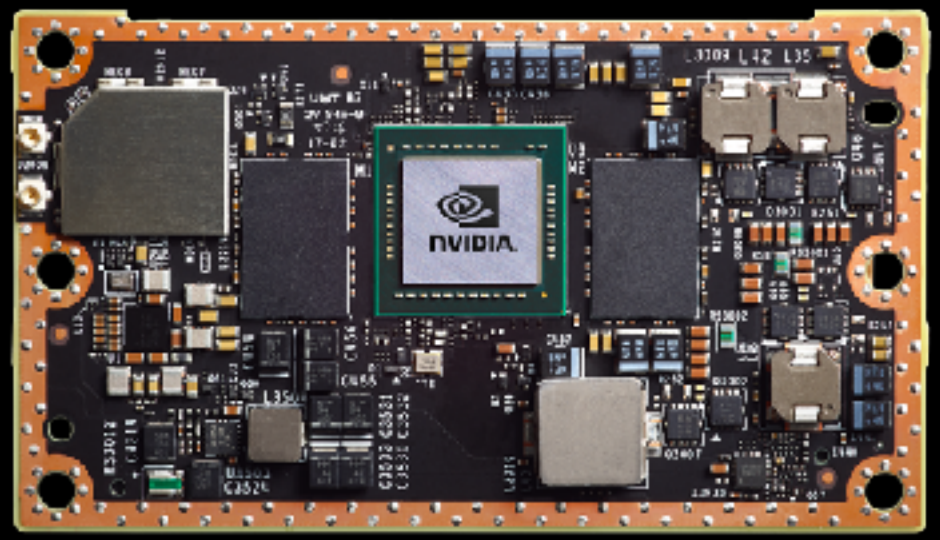
Communication

Guidance, Navigation, & Control

Sensors

Edge Computing in Space

Jetson TX2 Compute Module



Capacitor-based energy storage

Evaluating Orbital Edge Computing

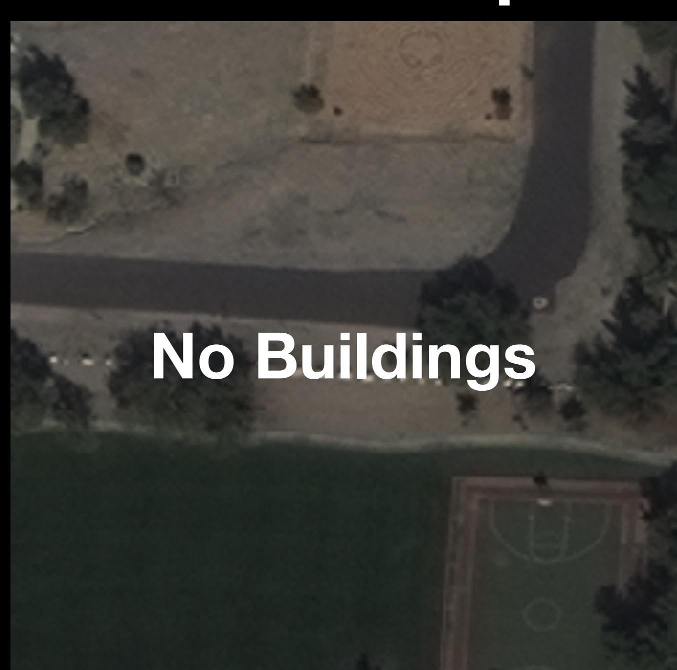
Tiled Ground Track Frames

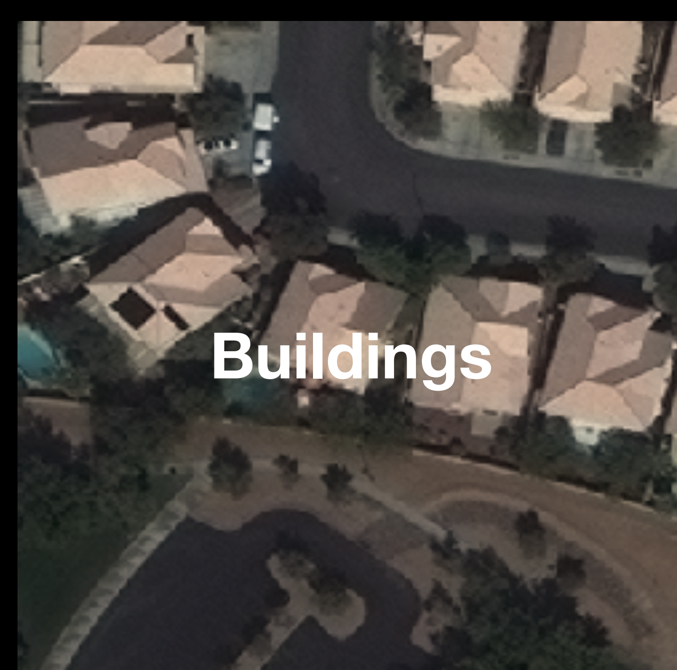
Resized Input

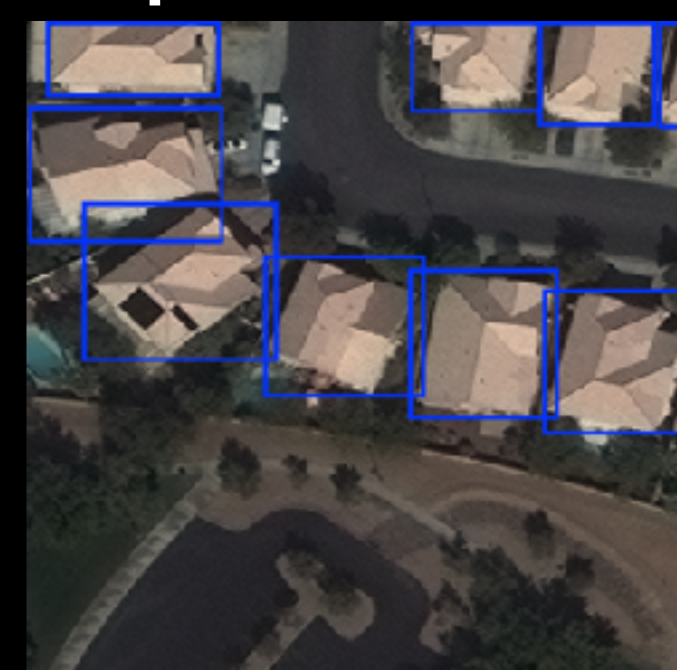
Onboard Inference

Image Classification
Average Power: 8.81W
Time per Tile: 0.0105s

Object Detection
Average Power: 11.3W
Time per Tile: 0.0449s



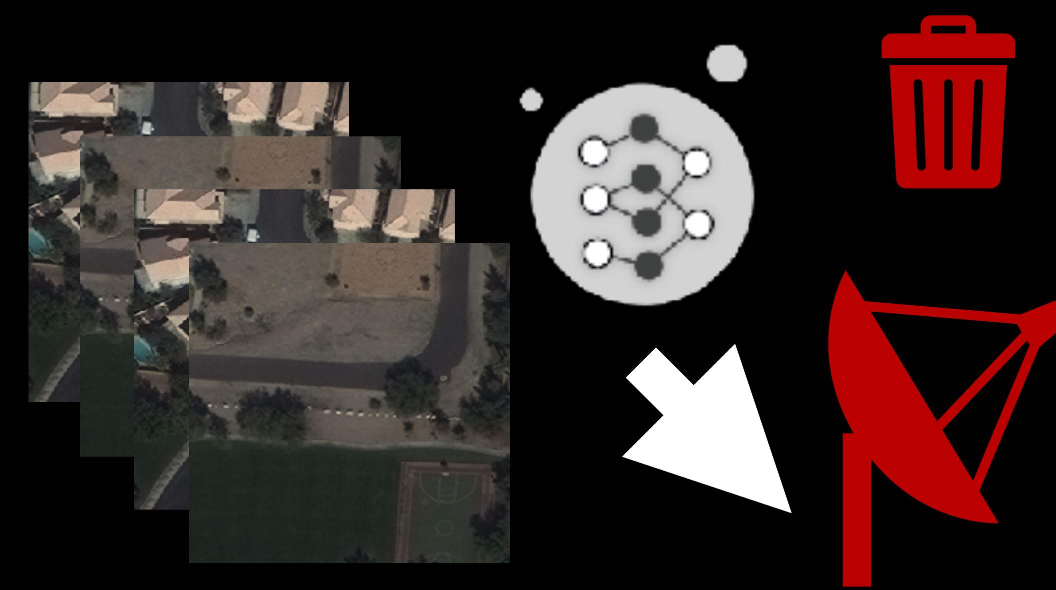




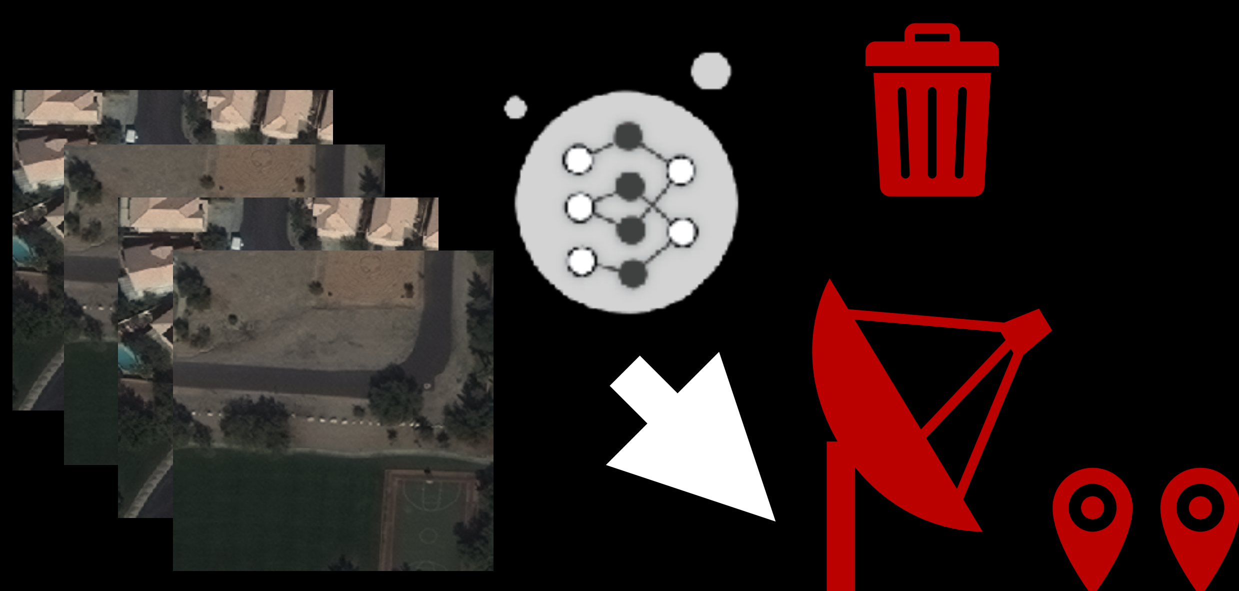
Intelligent Early Discard

Downlink All Data

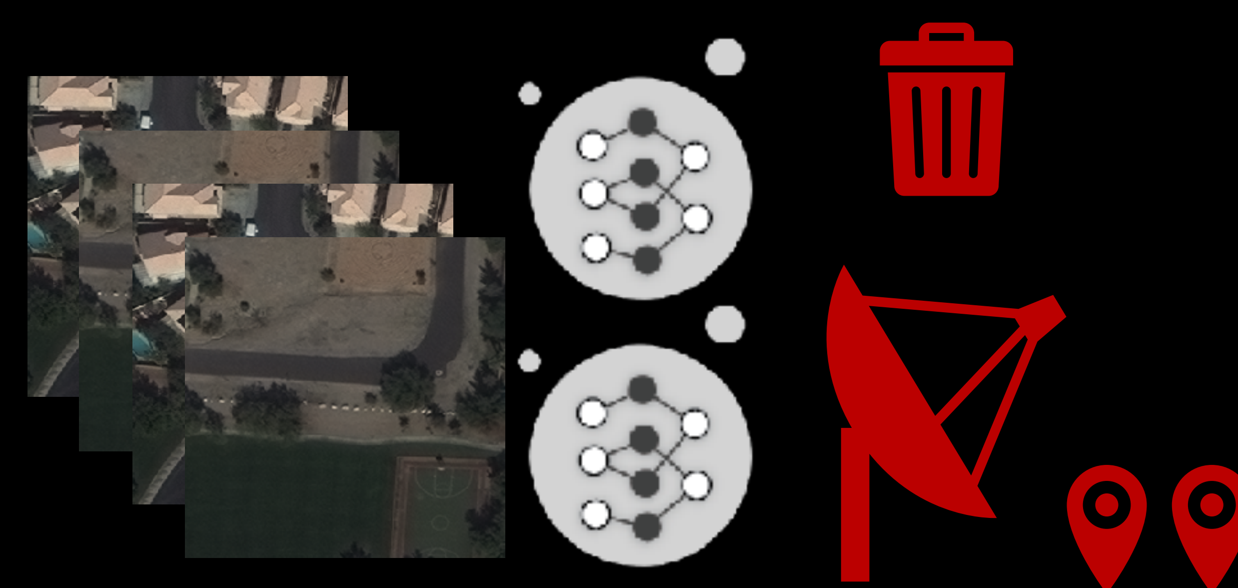
Classify and TX



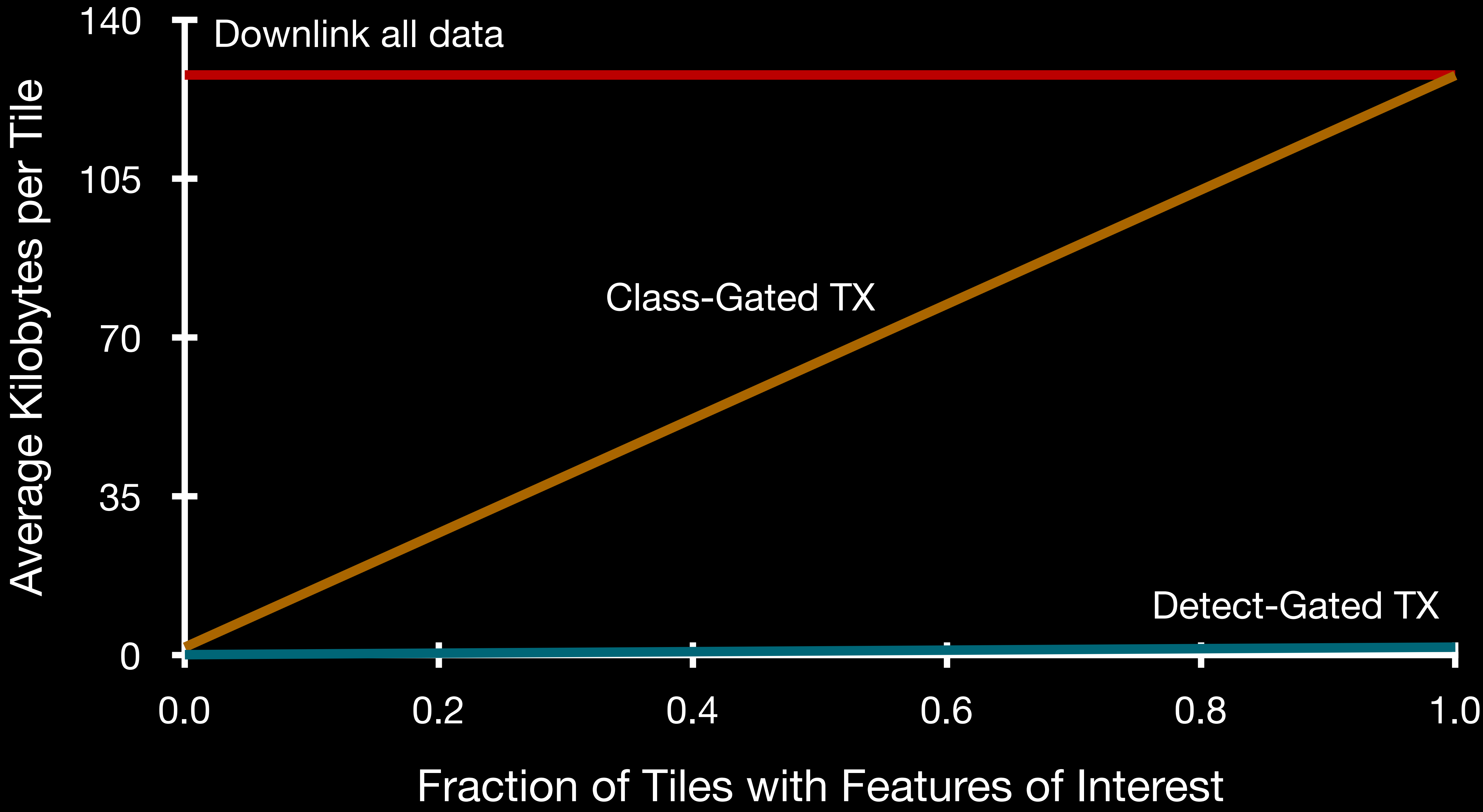
Detect and TX



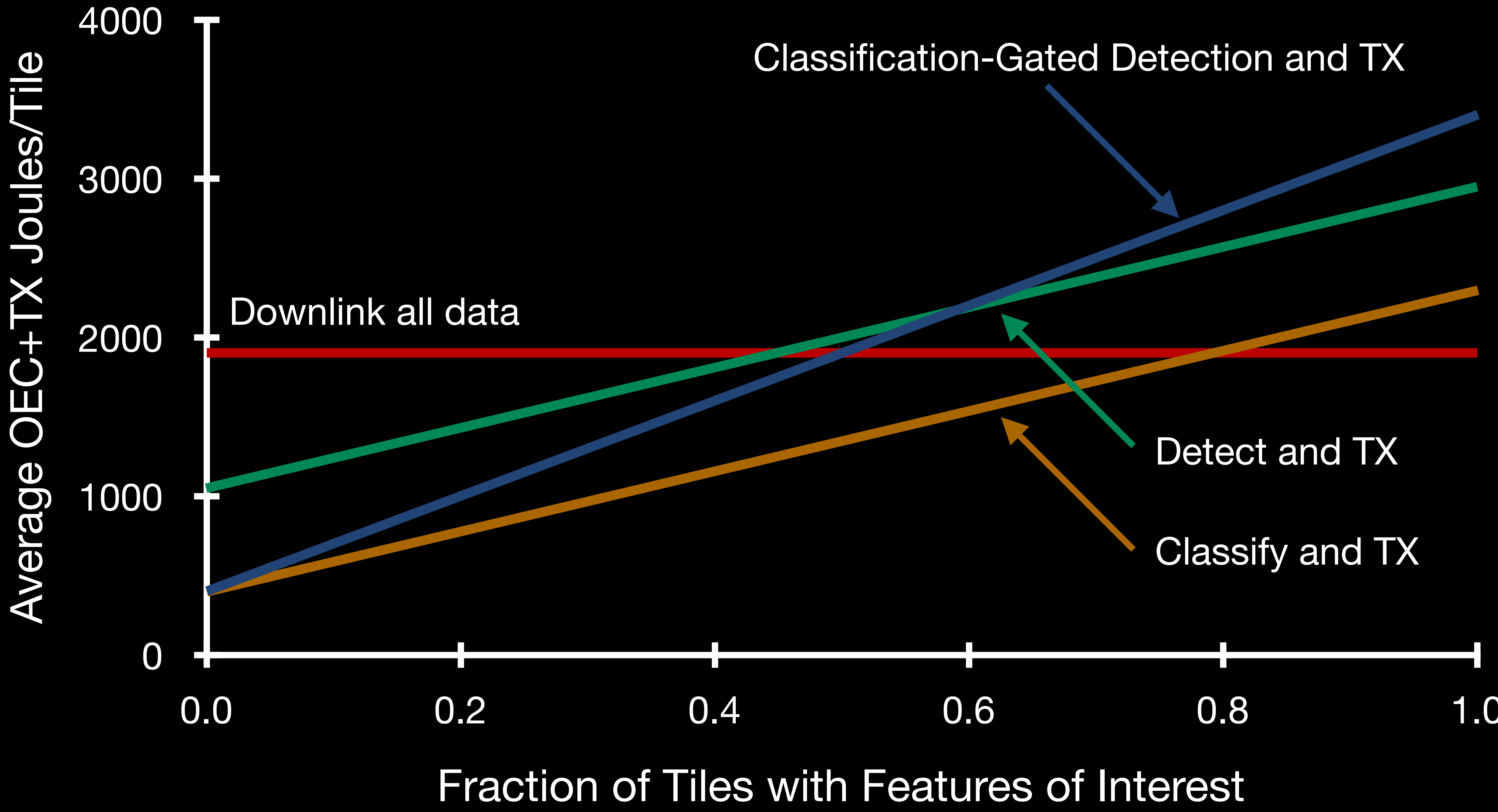
Class-Gated Detect and TX



Early Discard and Data Volume



Early Discard and Energy Efficiency



Avoiding Redundant Data

Well-defined orbit trajectories allow precise tuning of sample rates to avoid redundant data

Example:
400km orbit
4K camera
1.7s/frame

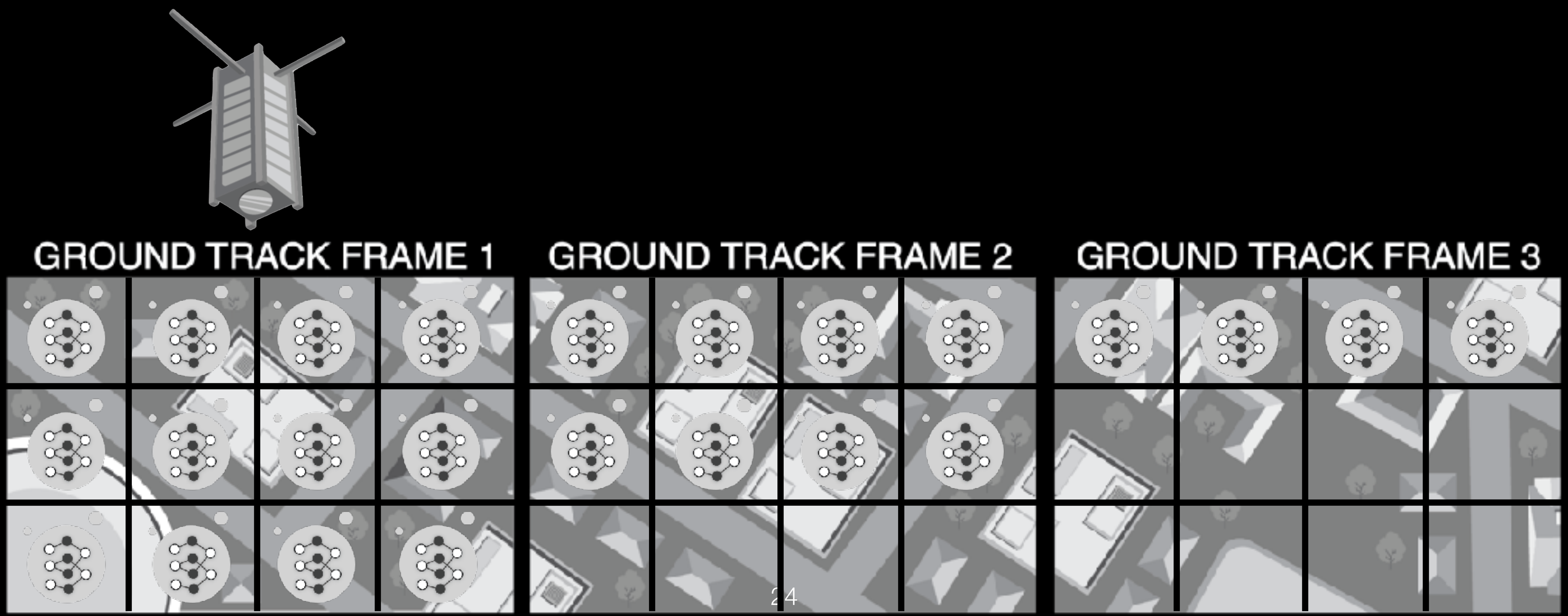
Processing Deadline

1.70 s **1.70 s**

Ground Track Frame 1 | Ground Track Frame 2 | Ground Track Frame 3 | Ground Track Frame 4

Leveraging Large Device Counts

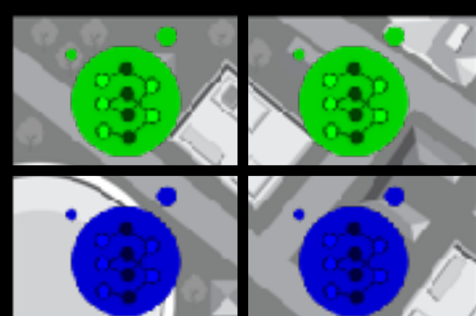
Computational Nanosatellite Pipeline: a convoy of nanosatellites in the same orbit with data processing statically distributed among devices



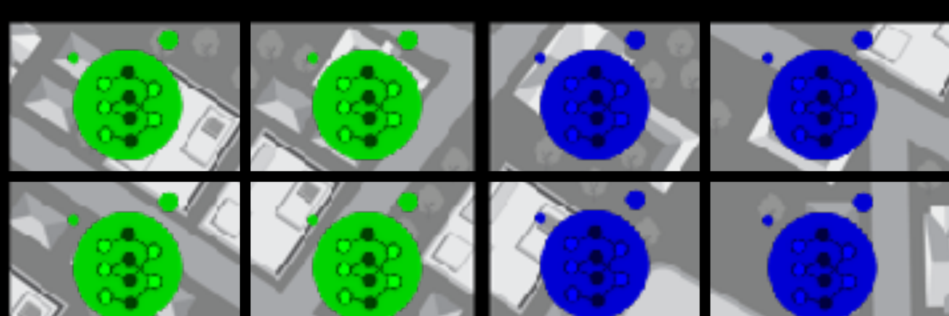
CNP Configurations

Processing Distribution

Tile-parallel



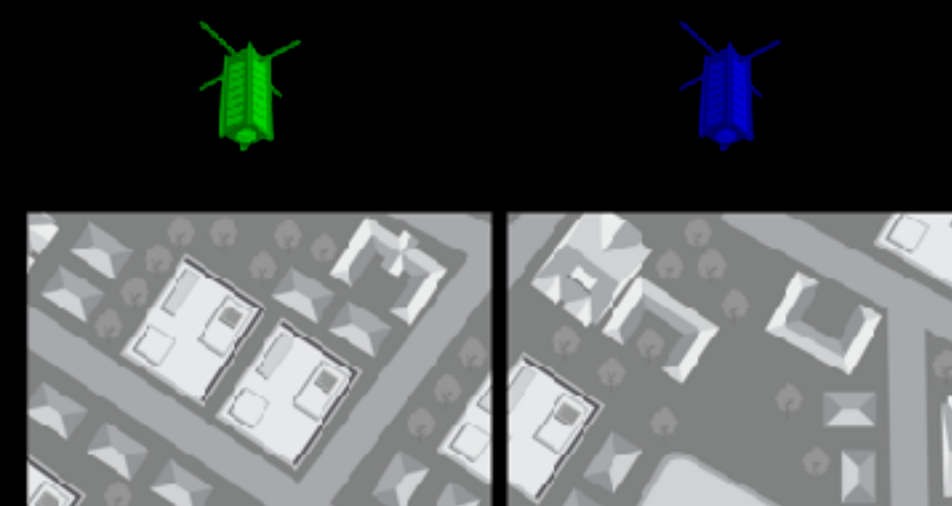
Frame-parallel



Data Distribution

Close-spaced

Frame-spaced



Overview

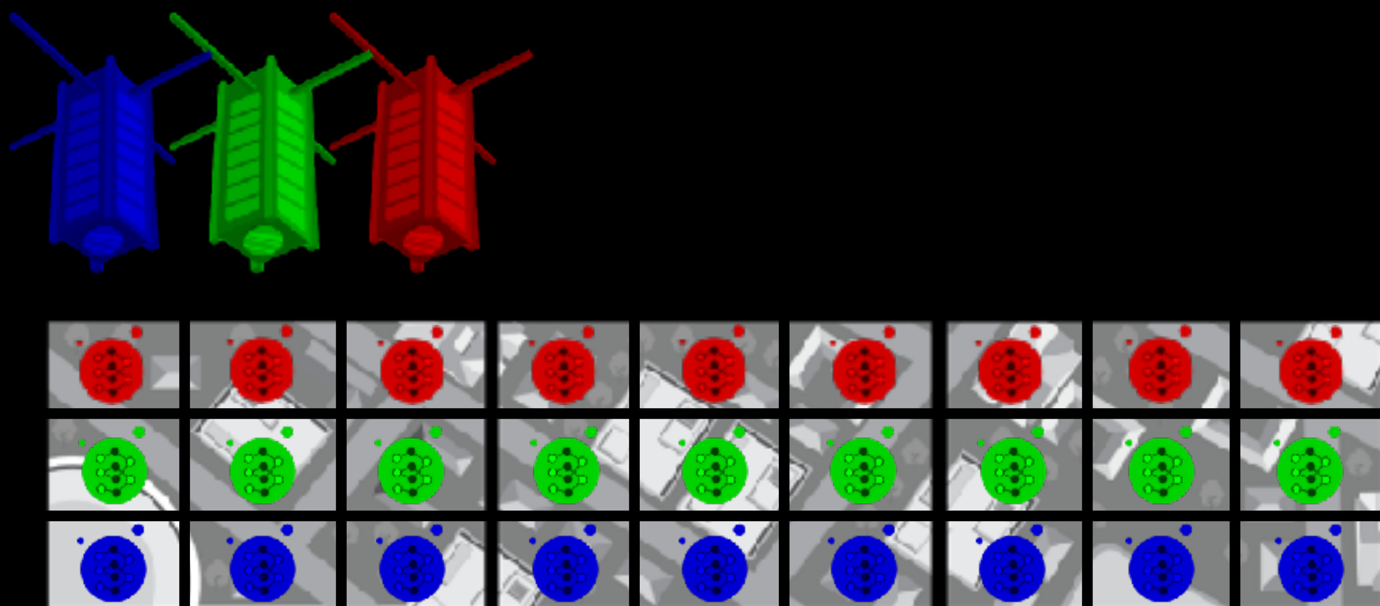
Background: Emerging satellite systems

Motivation: Nanosatellite constraints

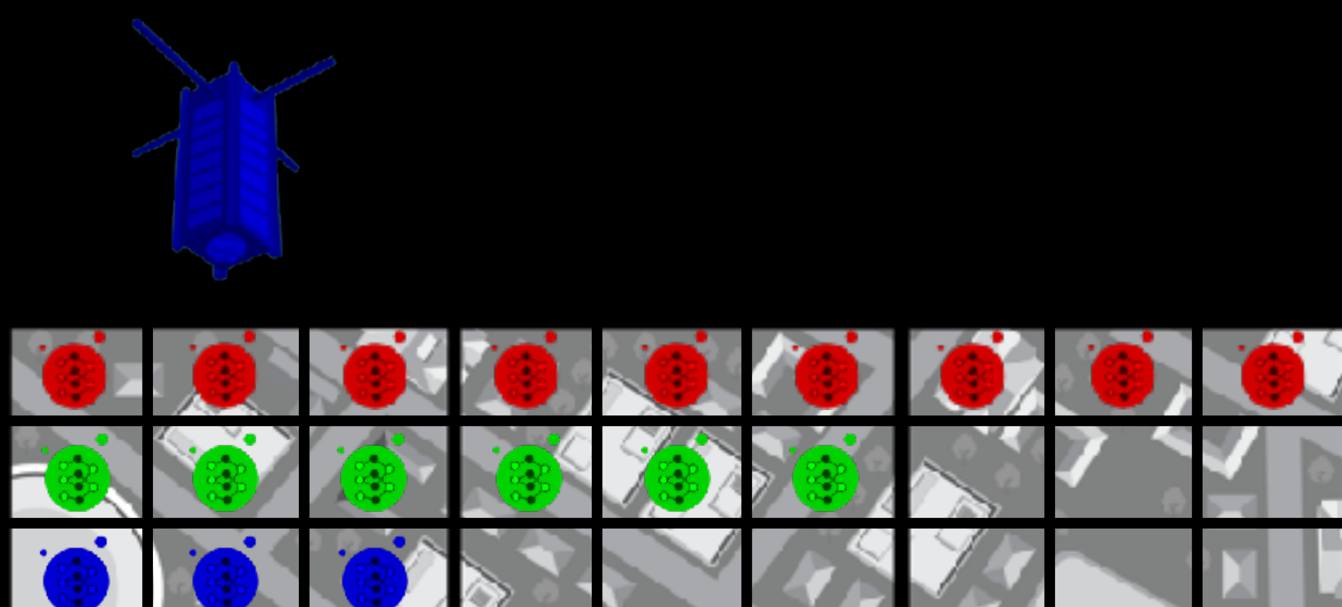
Orbital edge computing

Evaluating constellation configurations

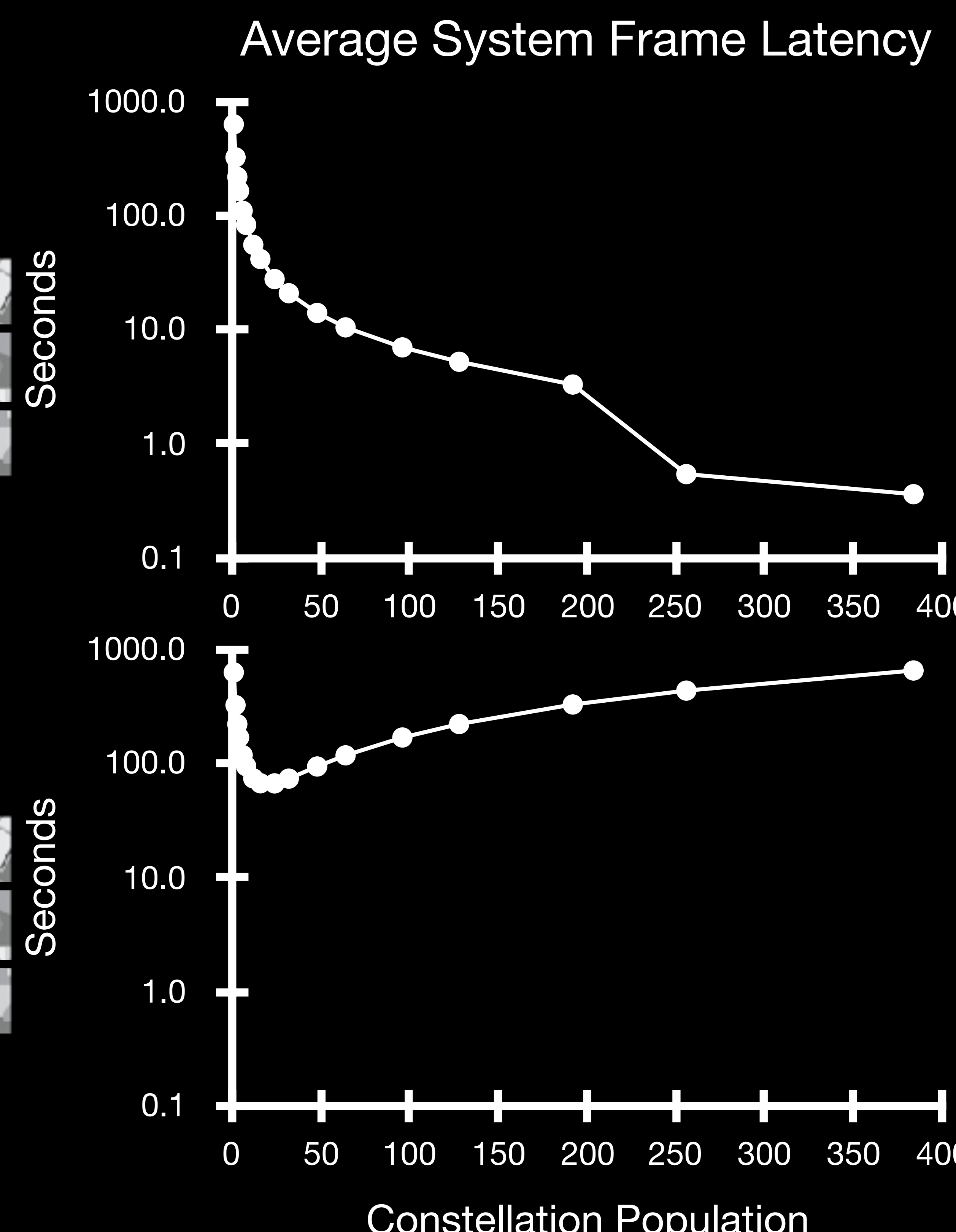
Tile-parallel: Close- vs Frame-spaced



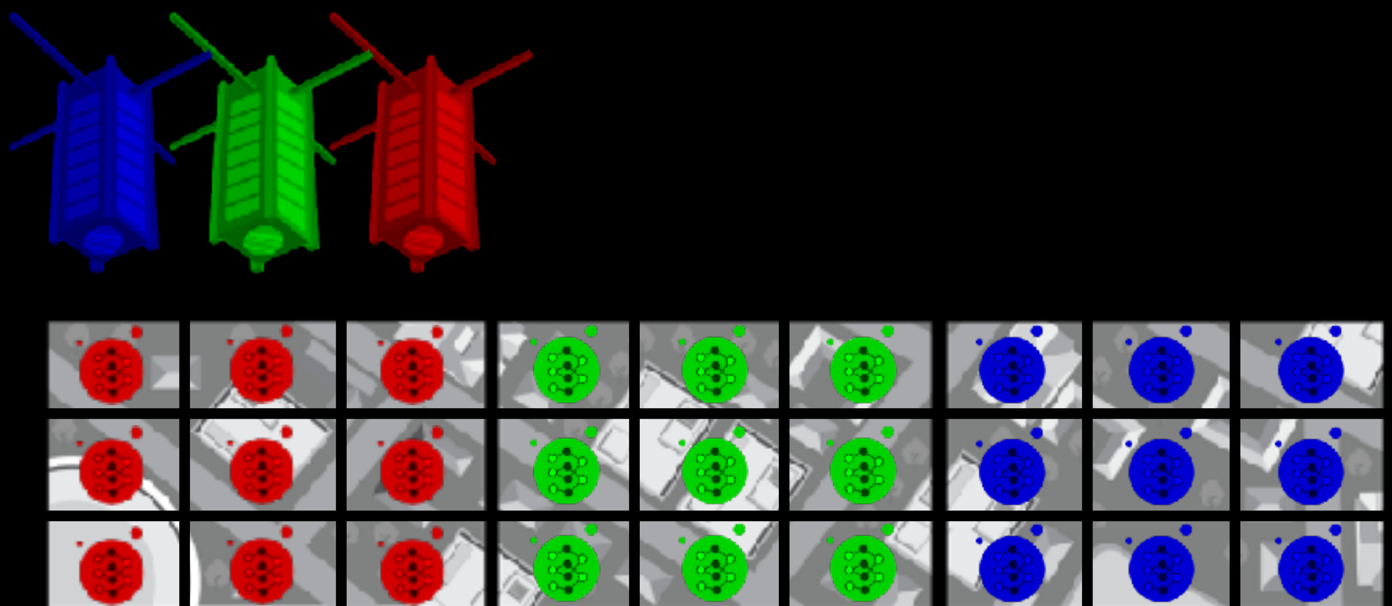
Close-spaced, tile-parallel



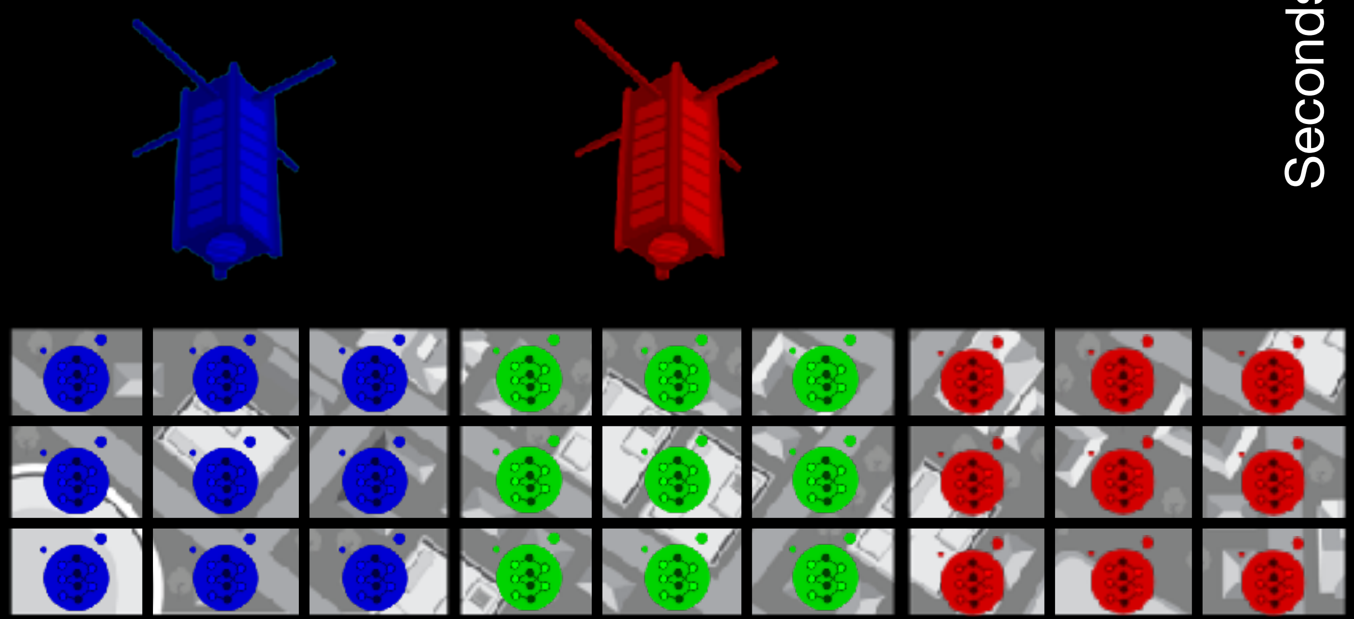
Frame-spaced, tile-parallel



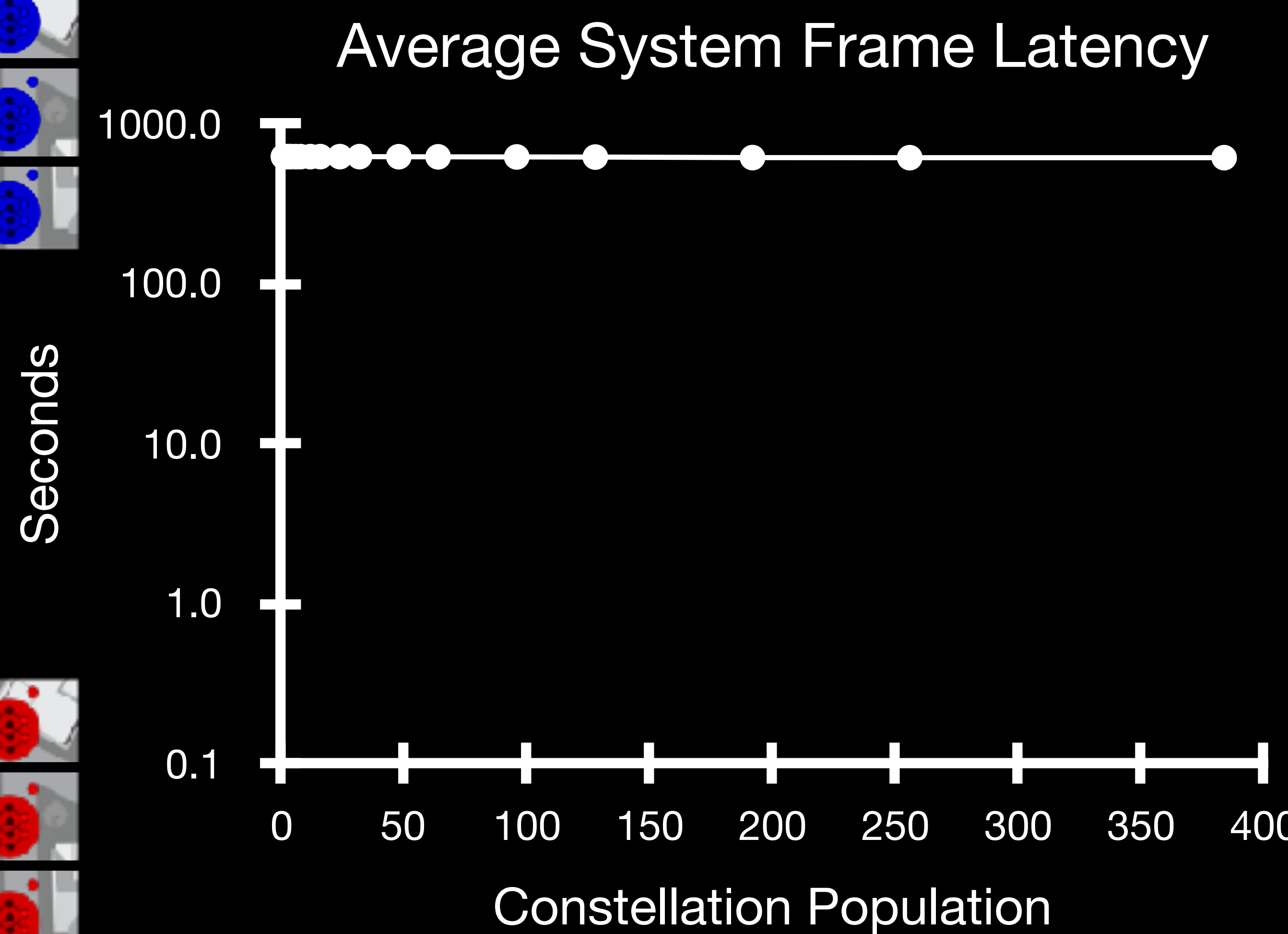
Frame Parallel Configurations



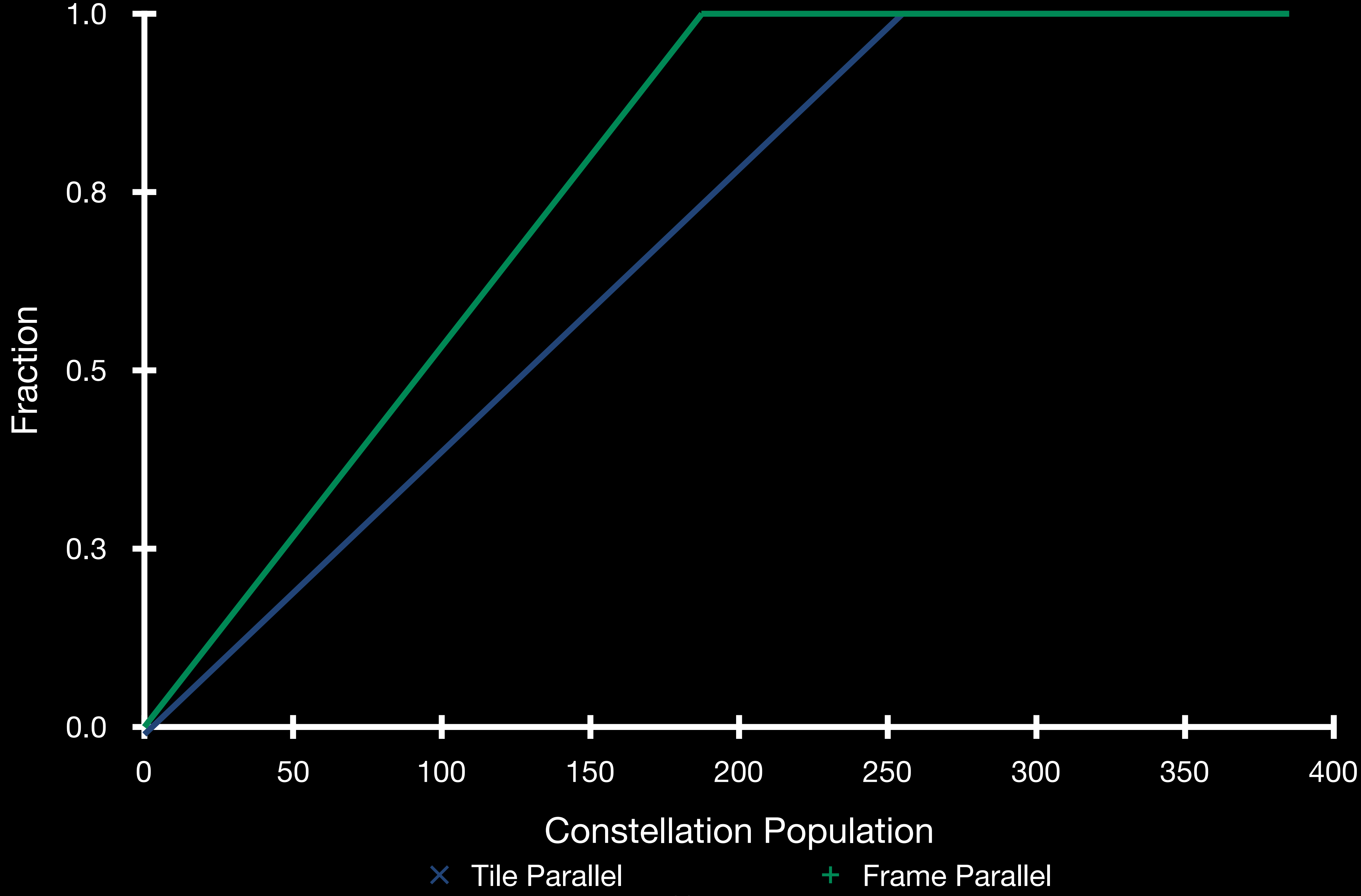
Close-spaced, frame-parallel



Frame-spaced, frame-parallel



Ground Track Coverage



Summary

Tile-parallel processing requires close-spaced configuration for low latency

Frame-parallel processing cannot provide low latency, but physical distribution has no affect

OEC gives full ground track coverage with populations matching existing constellations