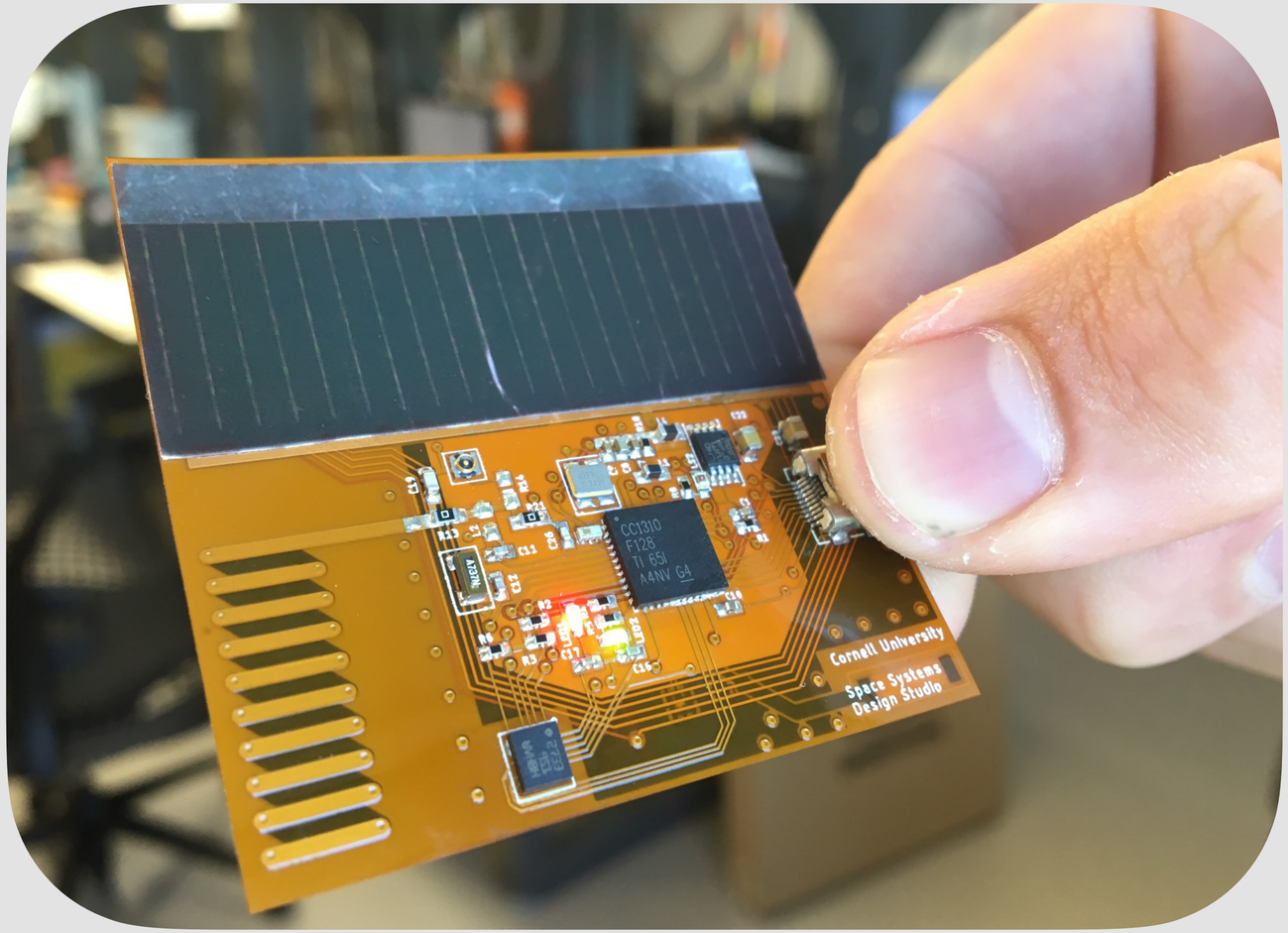
History, State of the Art, and Future of Gram-Scale Spacecraft

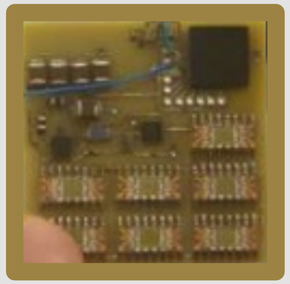


V. Hunter Adams

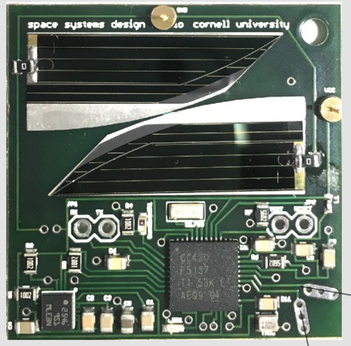
September 29, 2018

Bremen, Germany

1. (Very) brief history of the hardware
2. Description of the state of the art
3. Short-term mission and technology possibilities
4. Intermediate-term mission and technology possibilities
5. Long-term speculation



International Space Station Demo



KickSat 2

Alpha

2010

2016

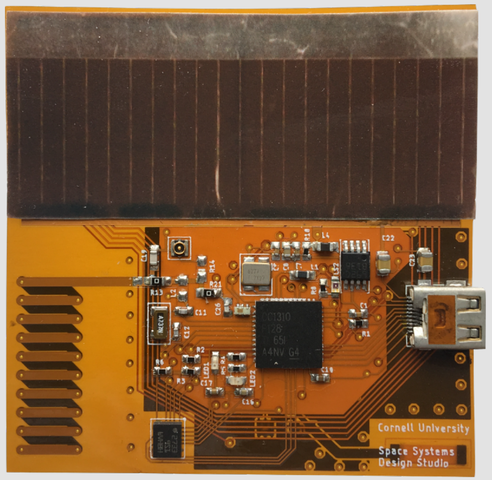
2013

2018

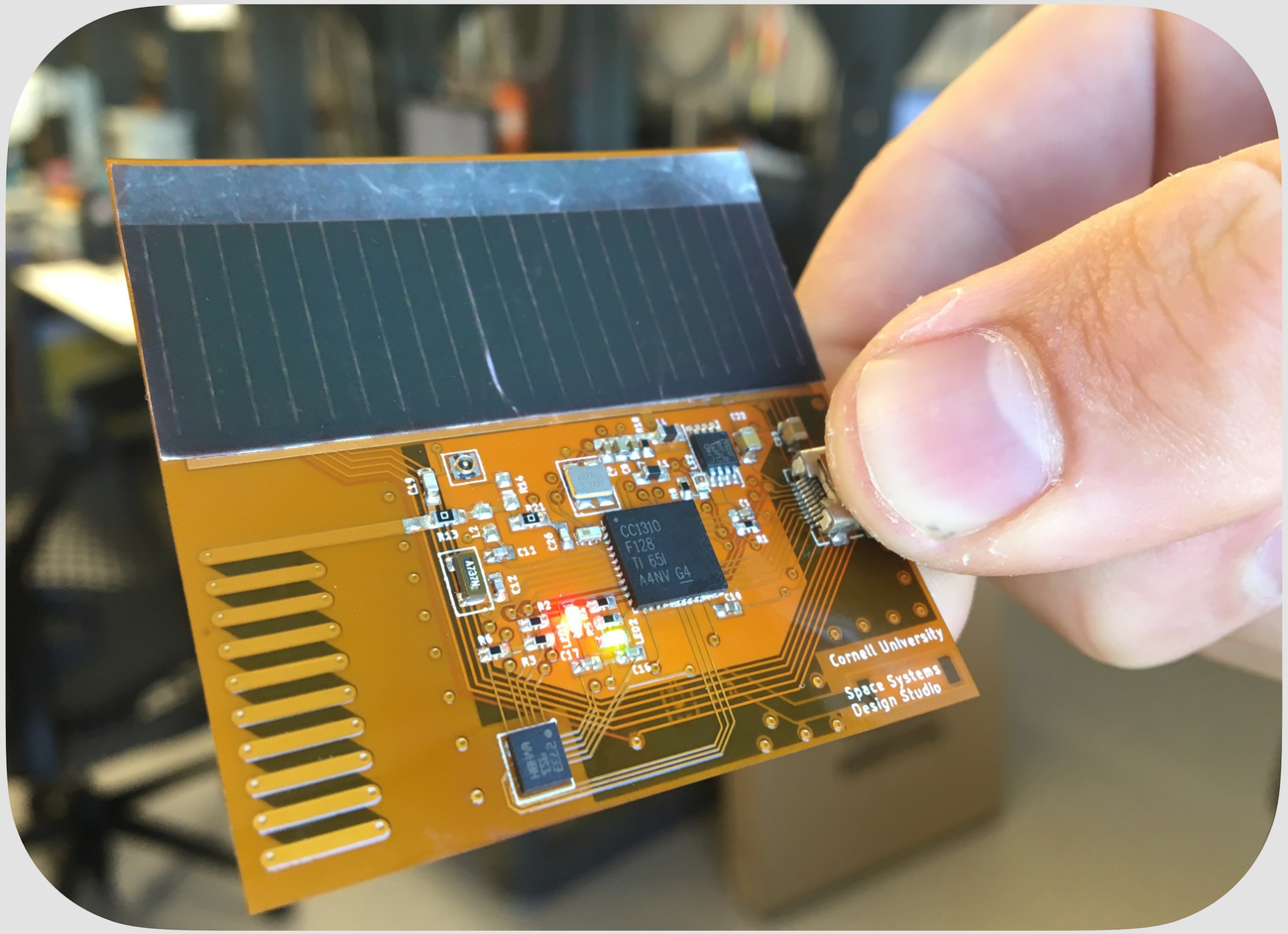
KickSat 1,2

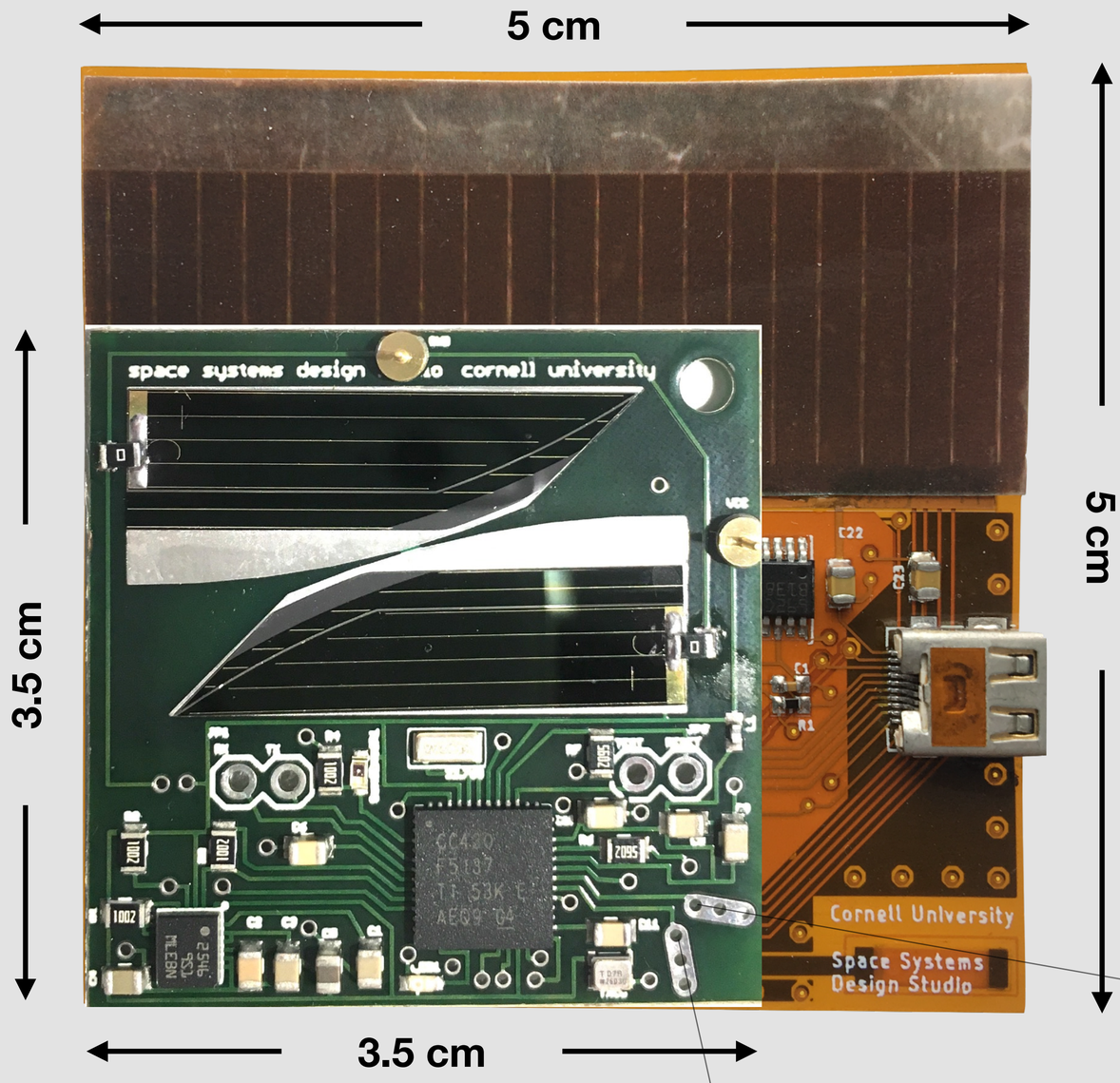
Venta 1

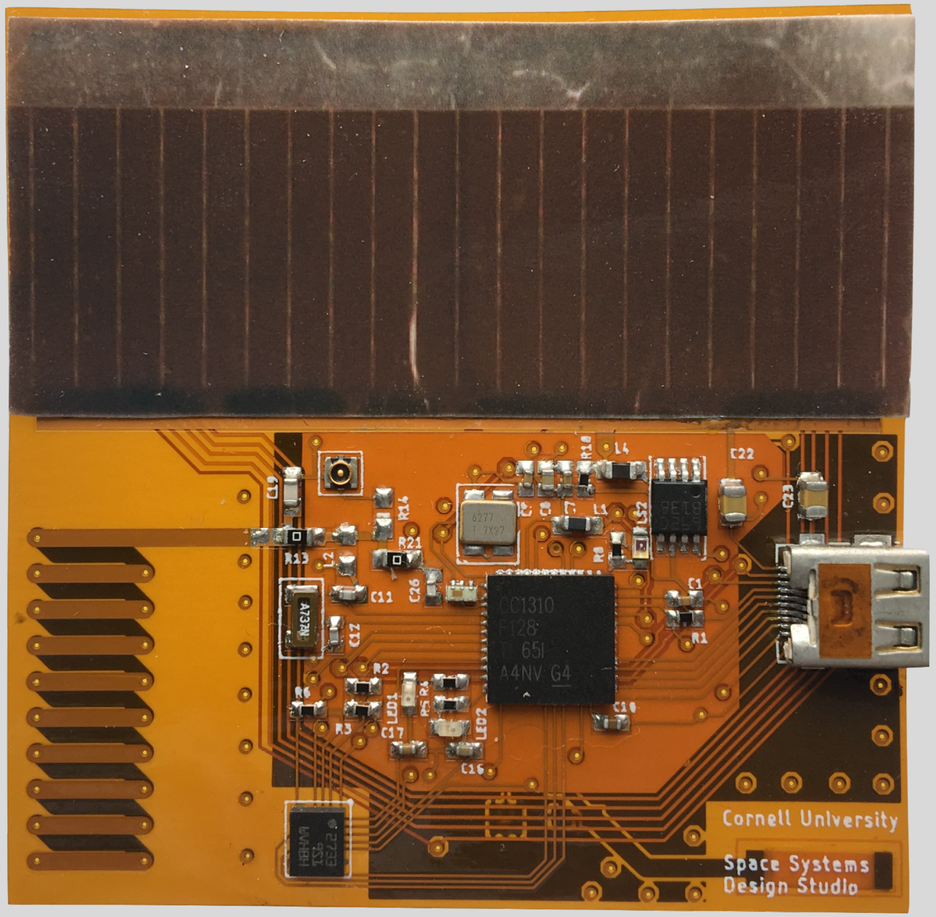
Proposals out

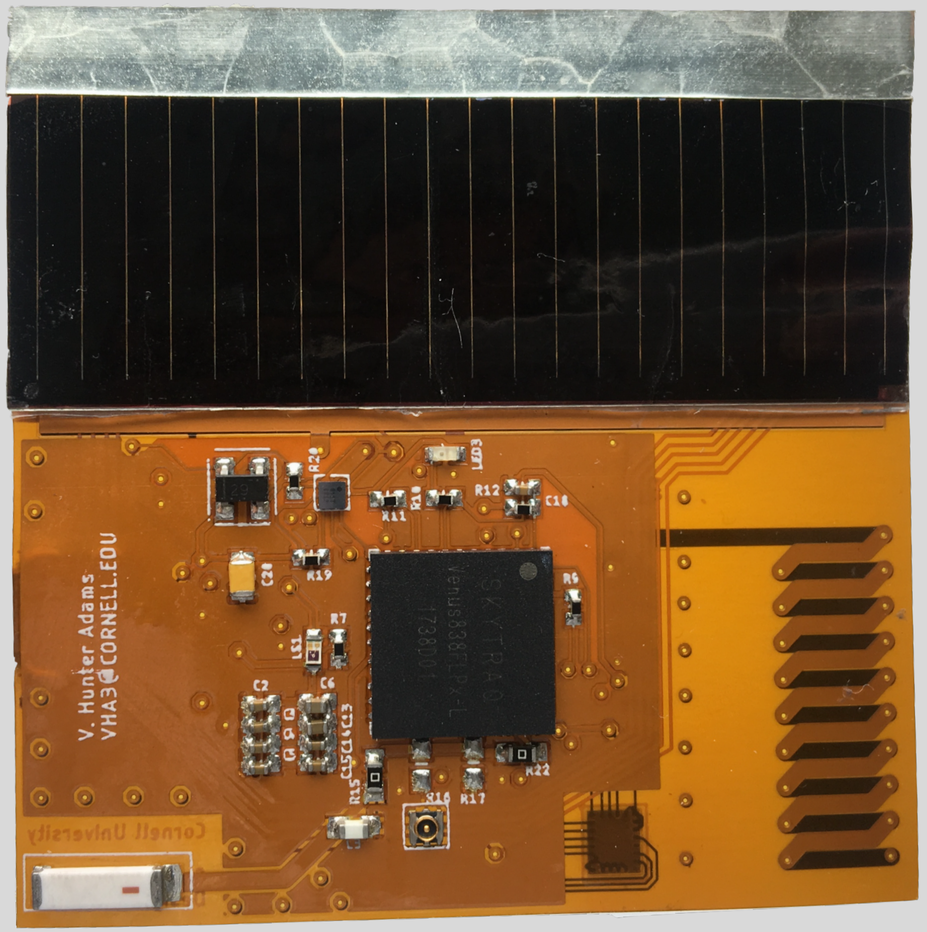


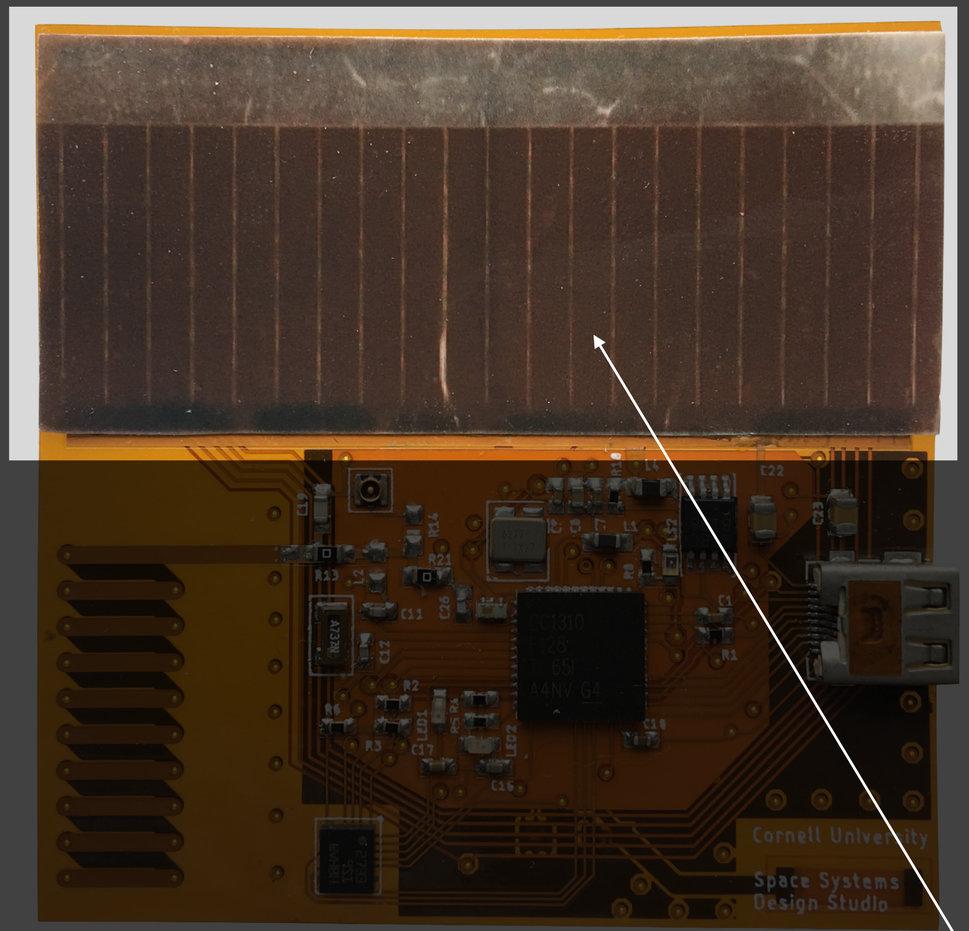
Monarch

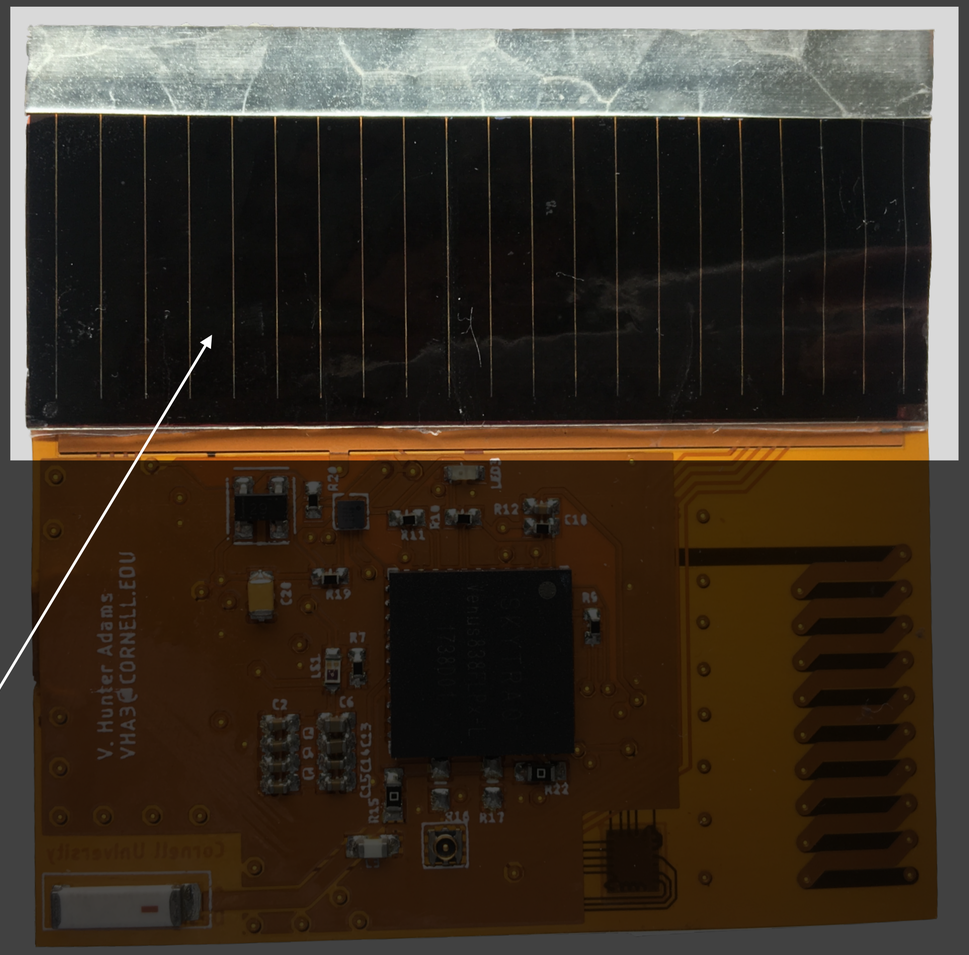

CC1310
F128
TI 65i
A4NV G4
Cornell University
Space Systems
Design Studio


5 cm
3.5 cm
5 cm
3.5 cm
space systems design
cornell university
Cornell University
Space Systems
Design Studio

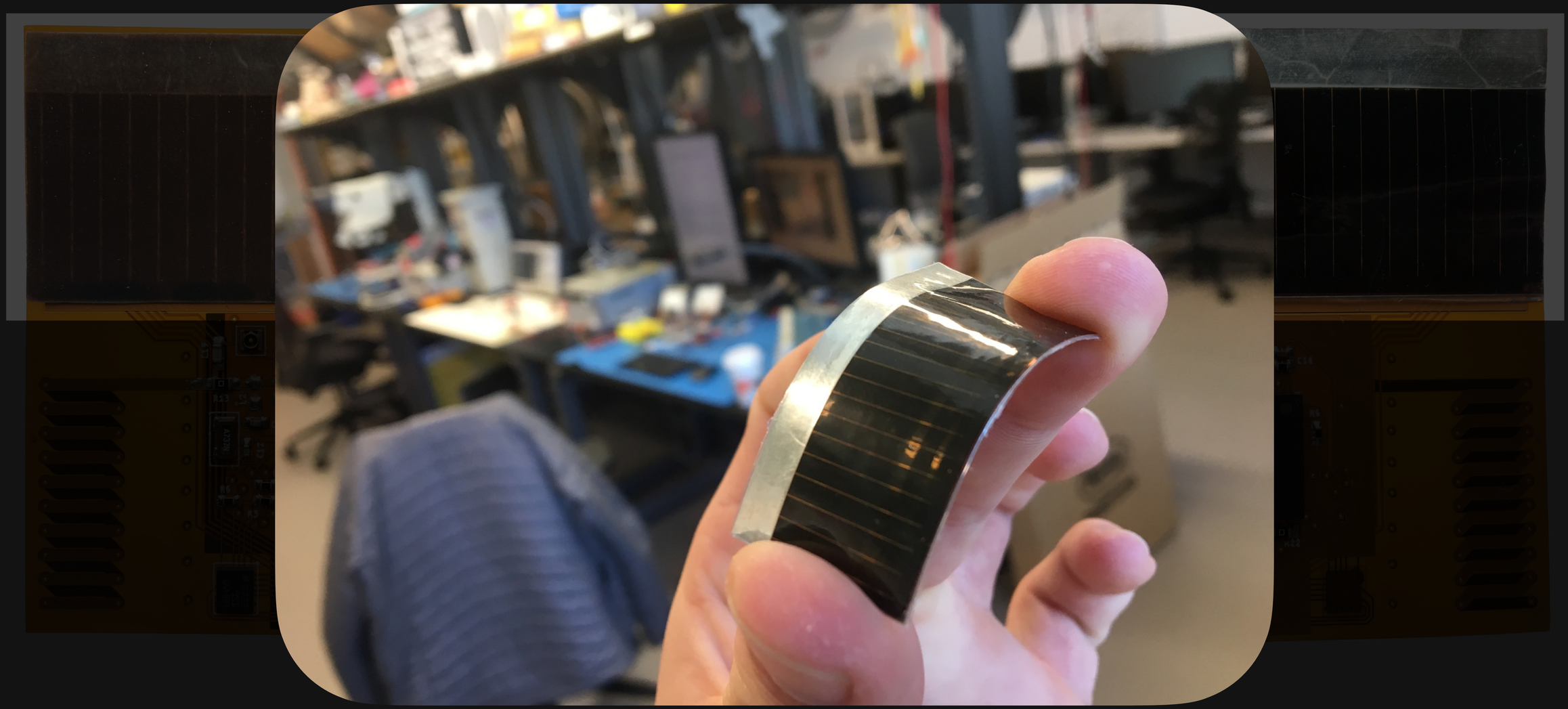

CC1310
F128
A4NV G4
Cornell University
Space Systems
Design Studio


V. Hunter Adams
VHA3@CORNELL.EDU
Cornell University

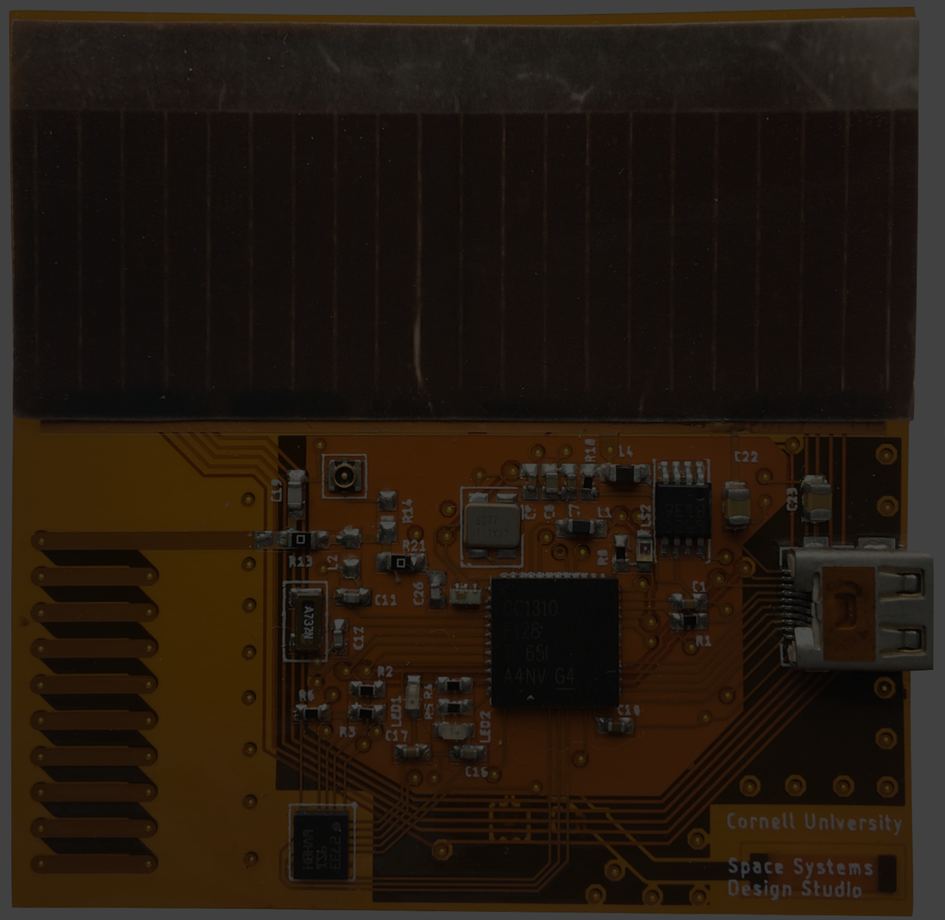




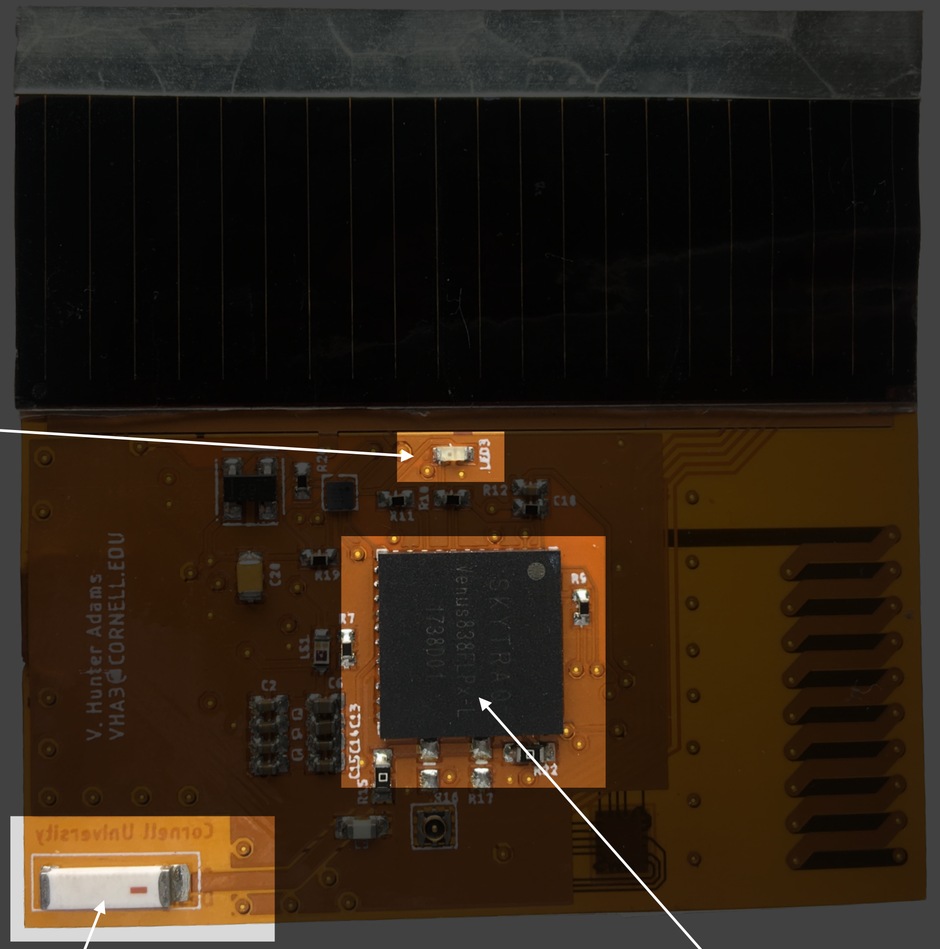
Alta Devices solar cells - 300 mW each



0.1 grams, and flexible

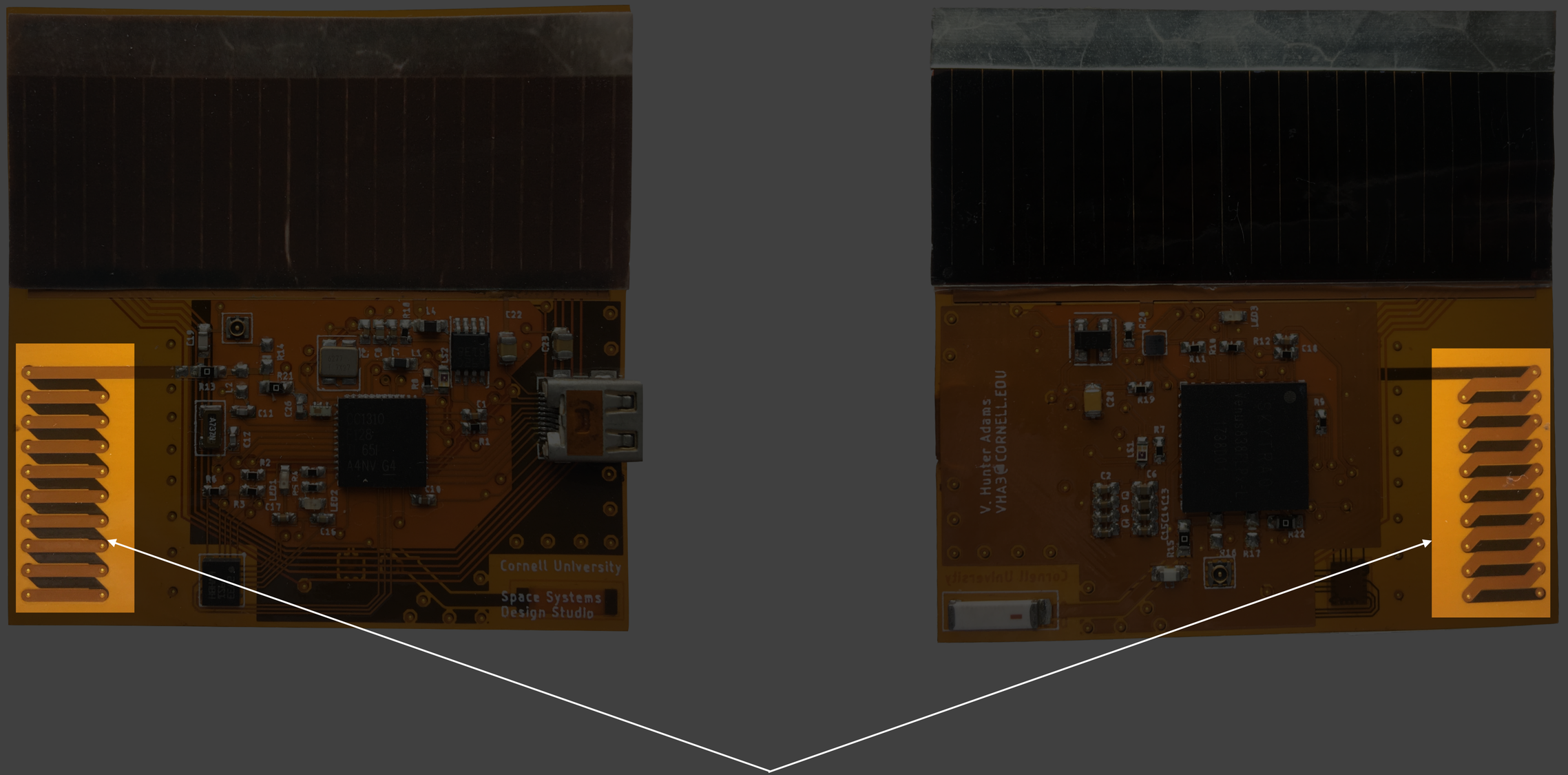


GPS fix indicator

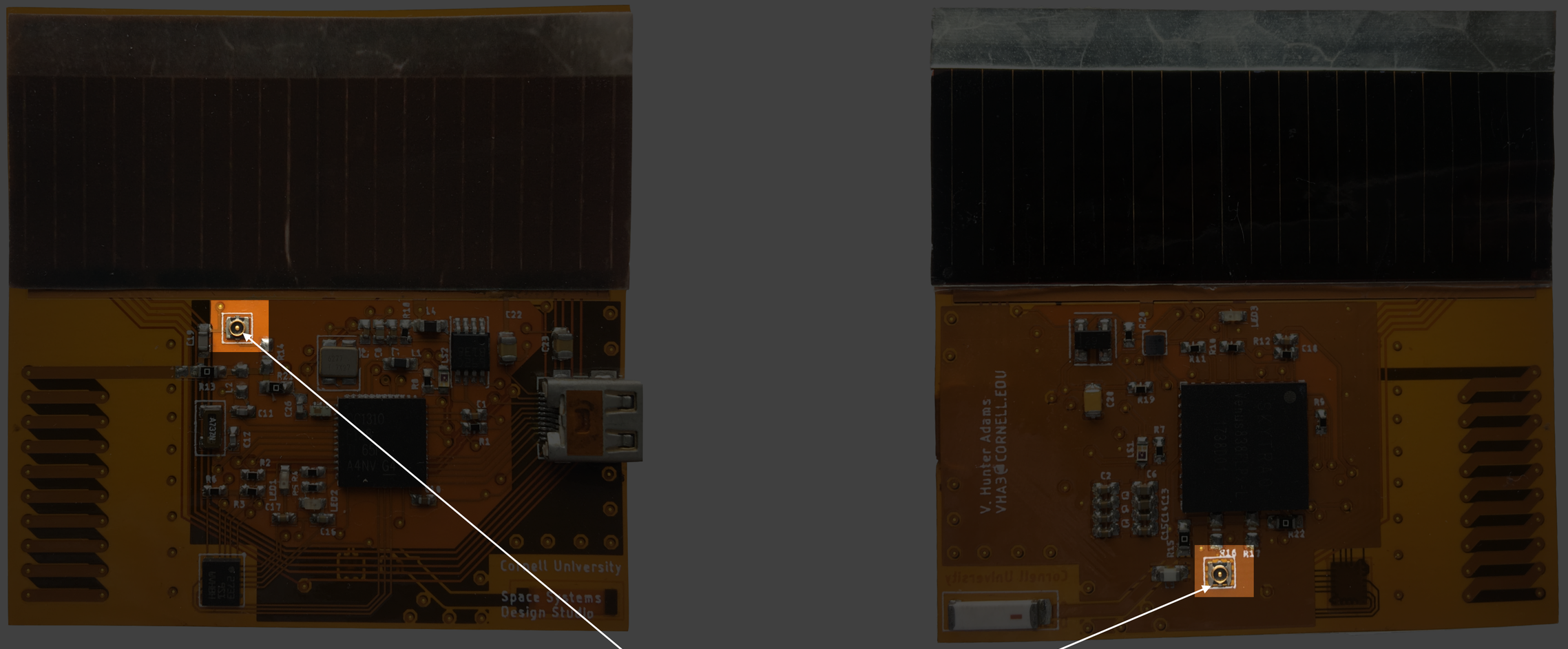


GPS antenna

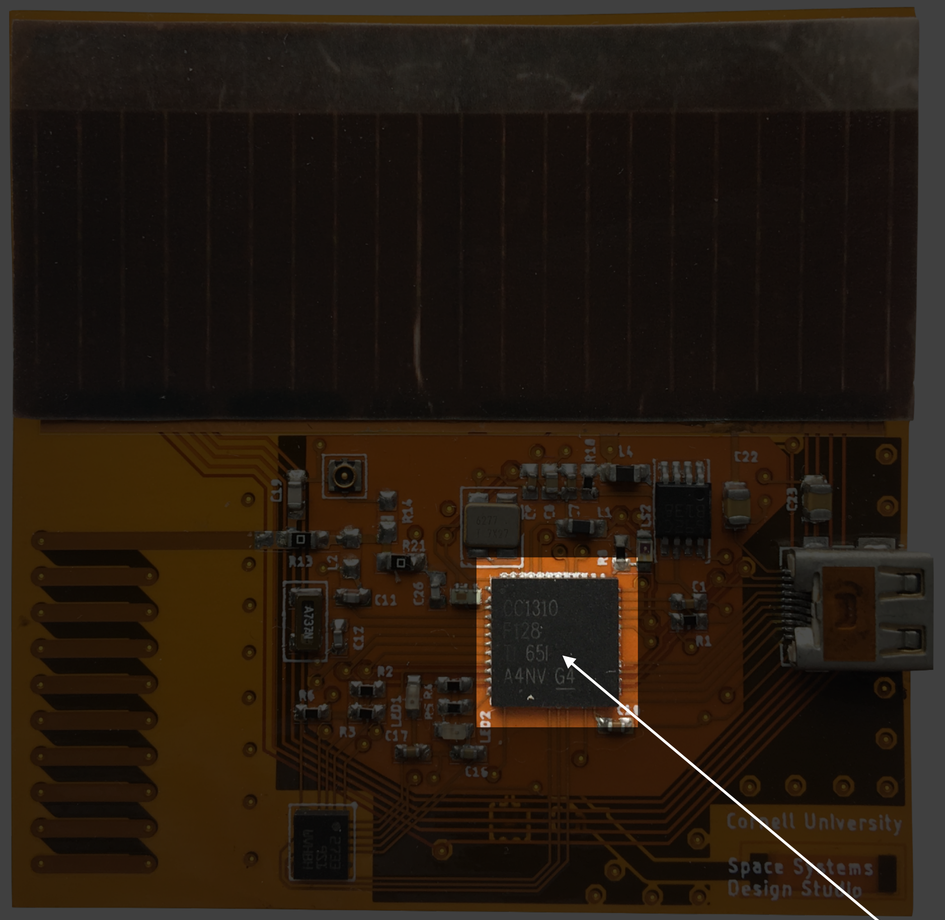
GPS module

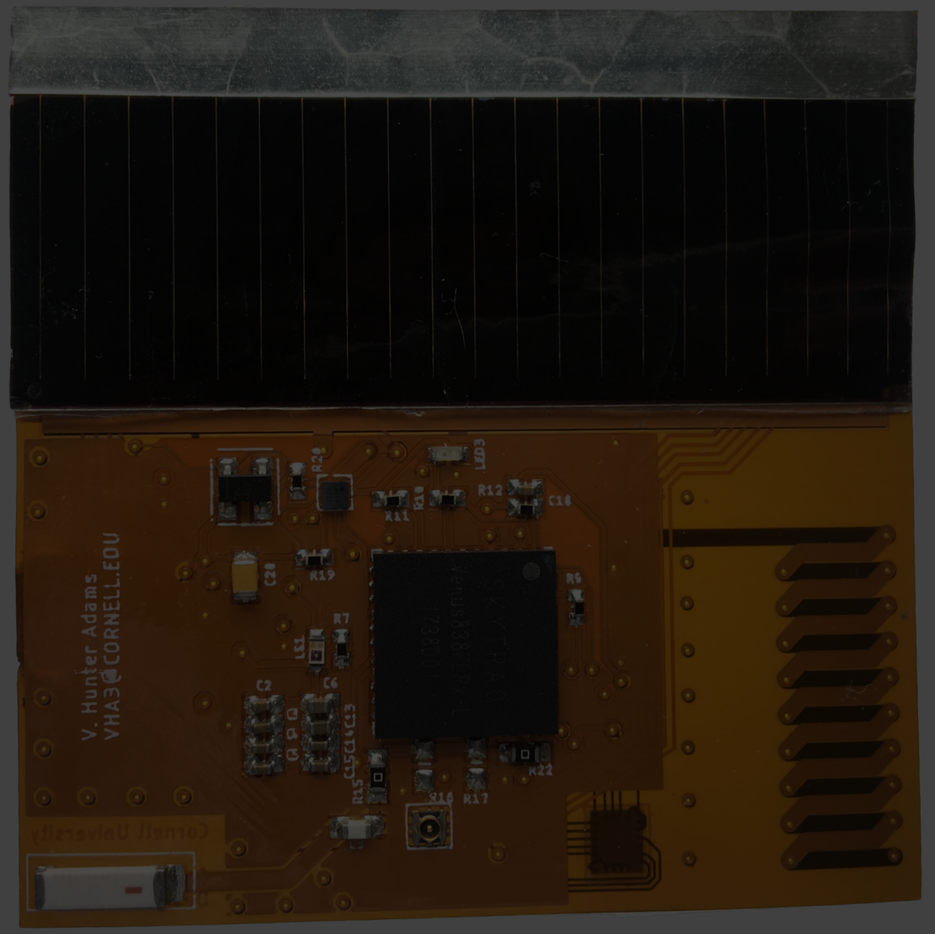


embedded PCB antenna

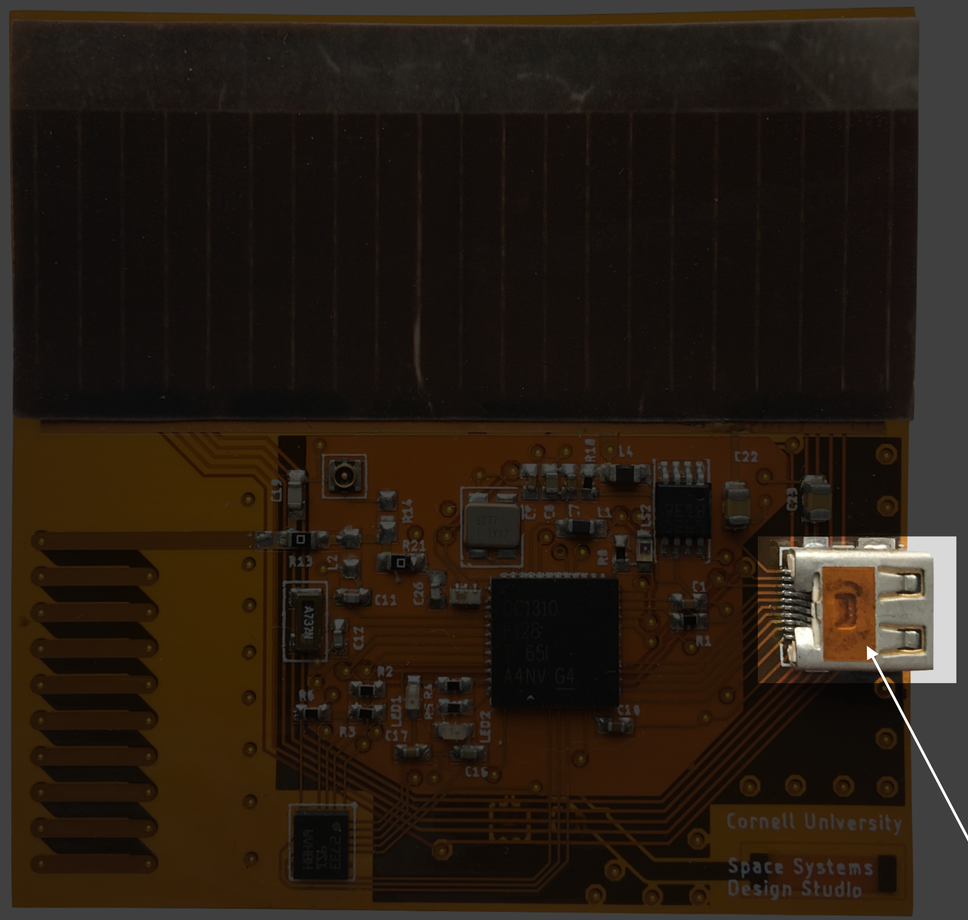


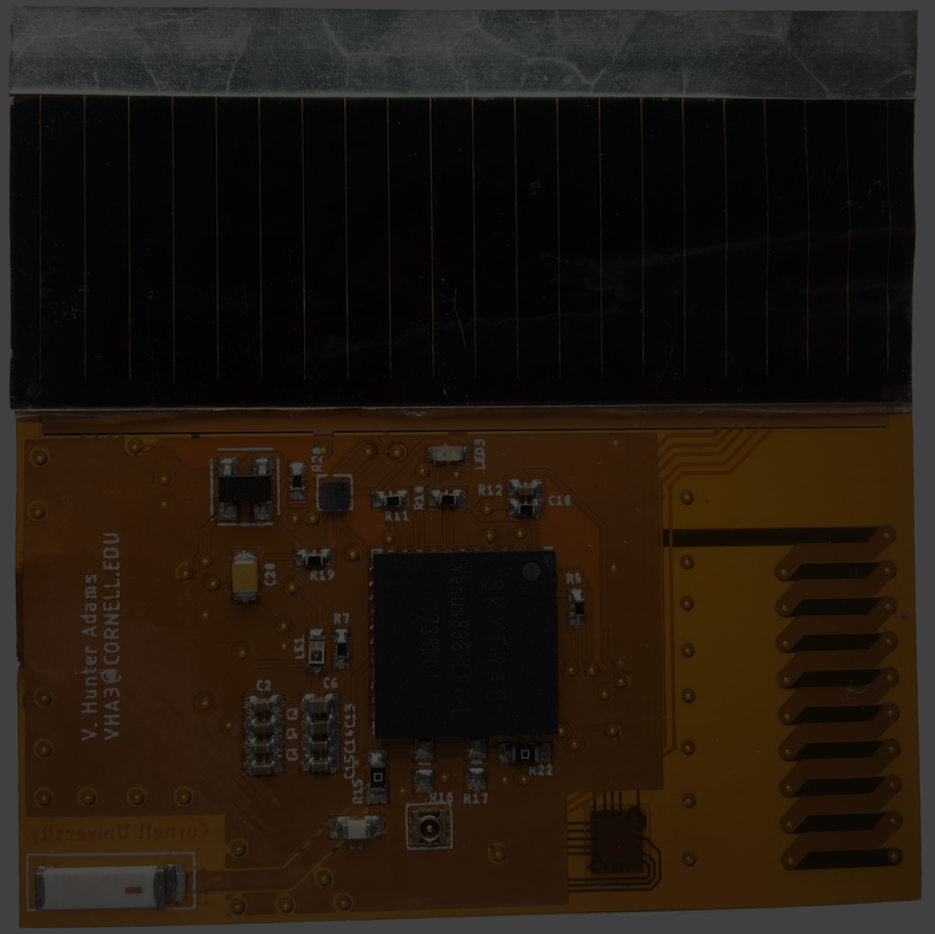
coaxial interfaces to antennas



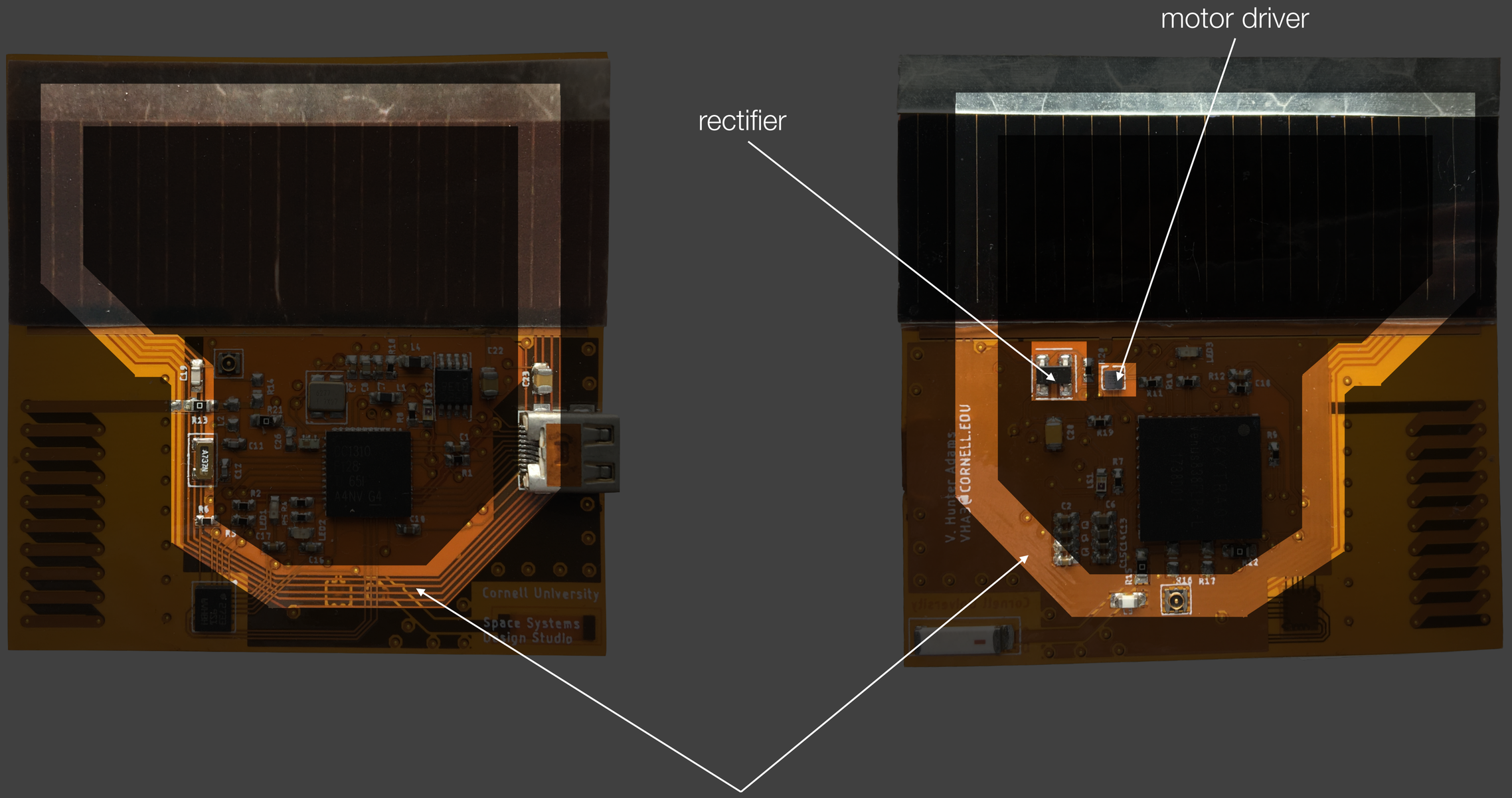


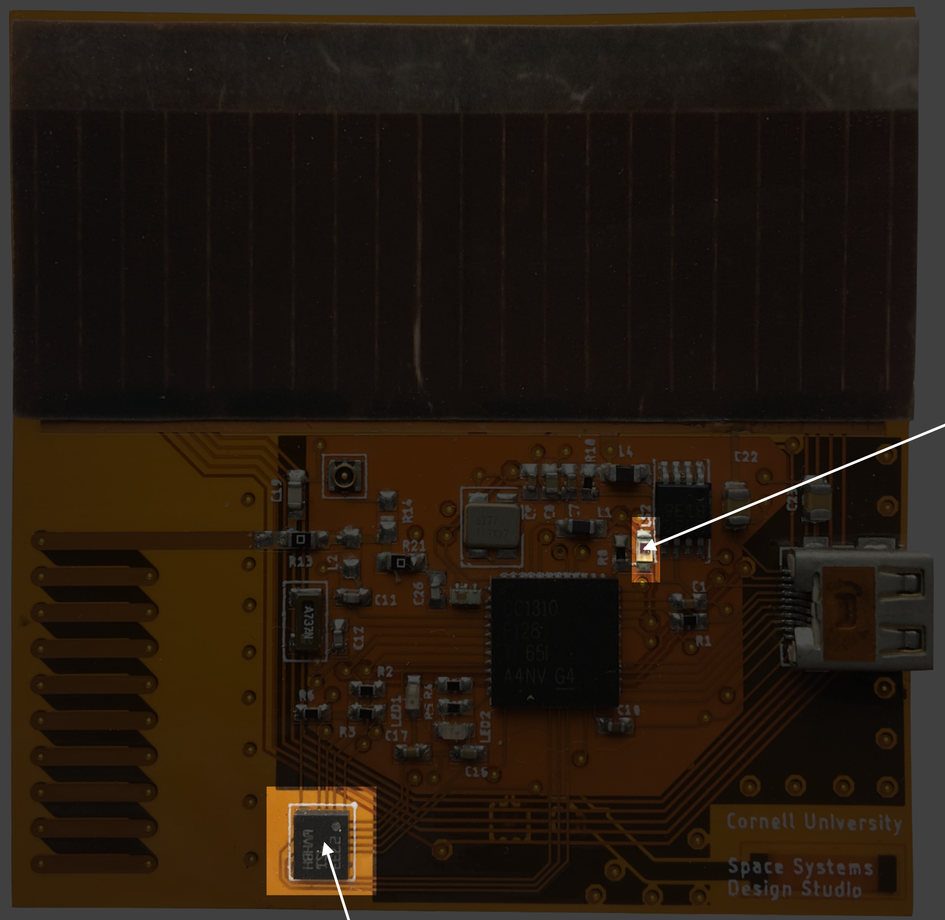
ARM processor and radio, running real-time operating system



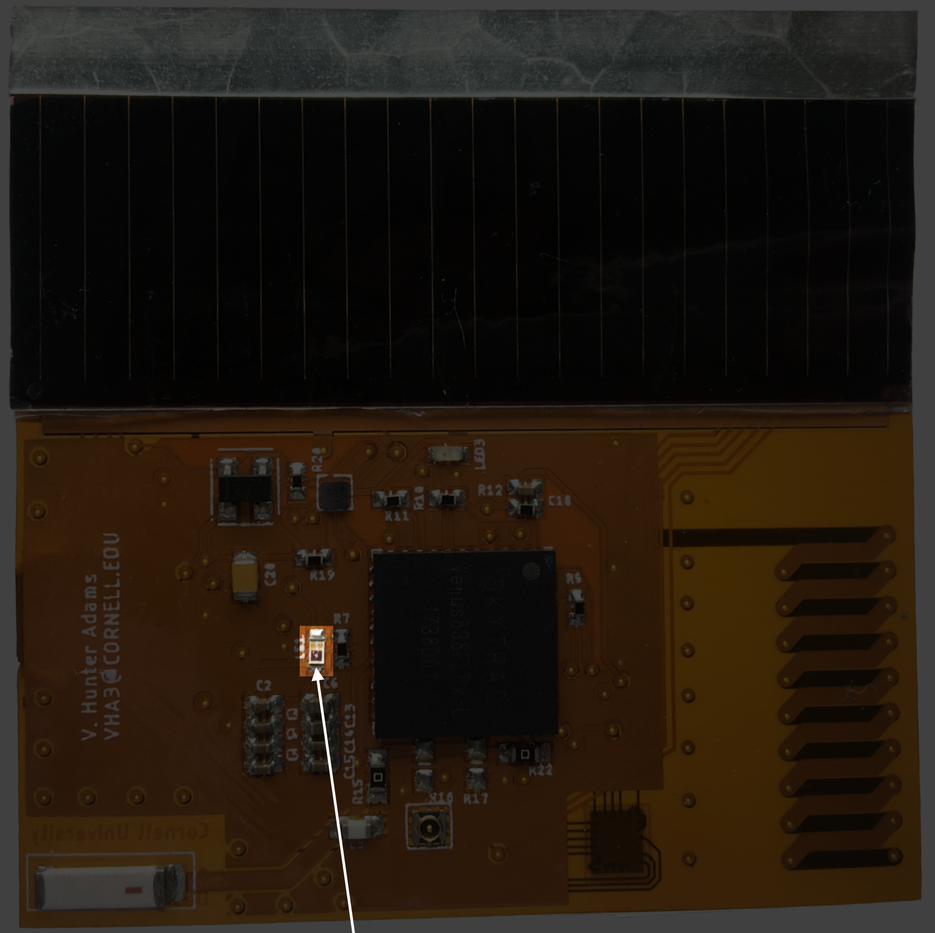


JTAG interface through HDMI port


motor driver
rectifier
torque/inductive powering coils
Cornell University
Space Systems
Design Studio
V. Hunter Adams
VHA3@CORNELL.EDU

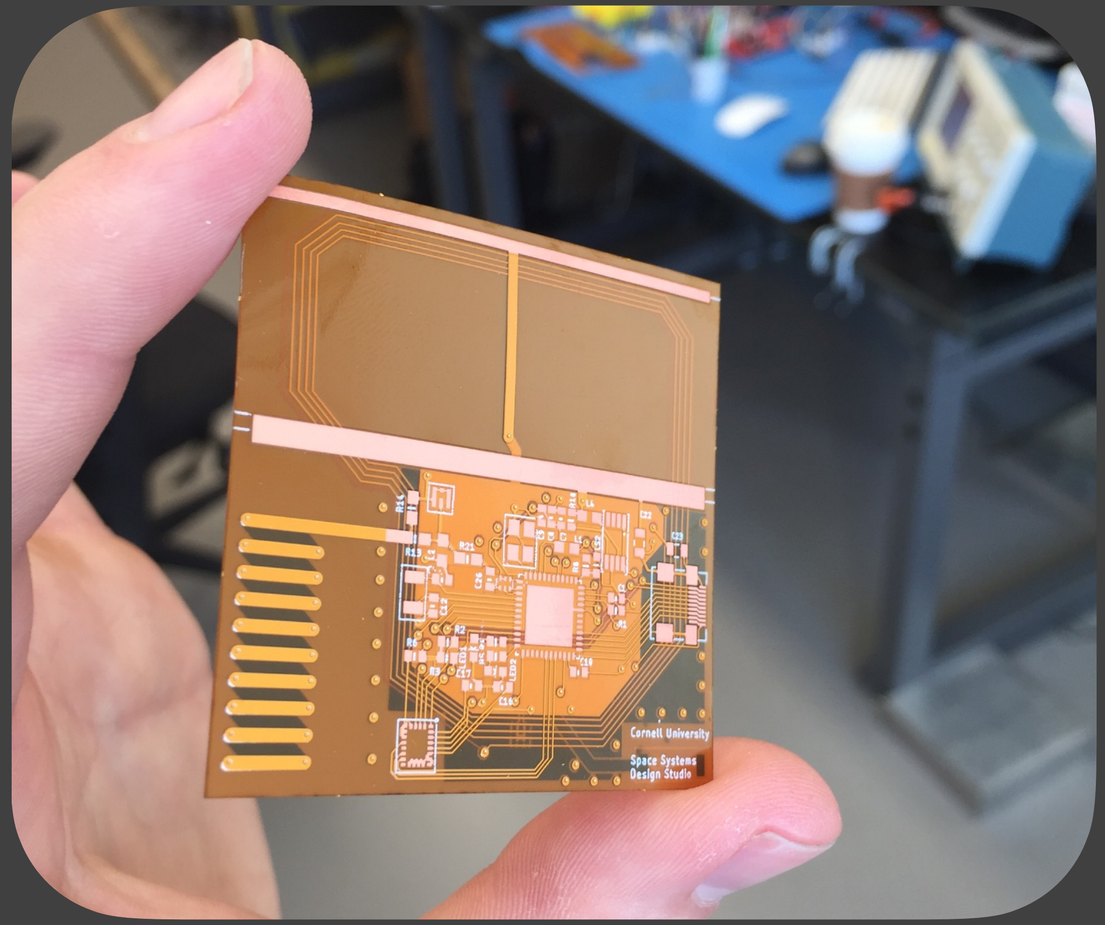


ambient light sensor

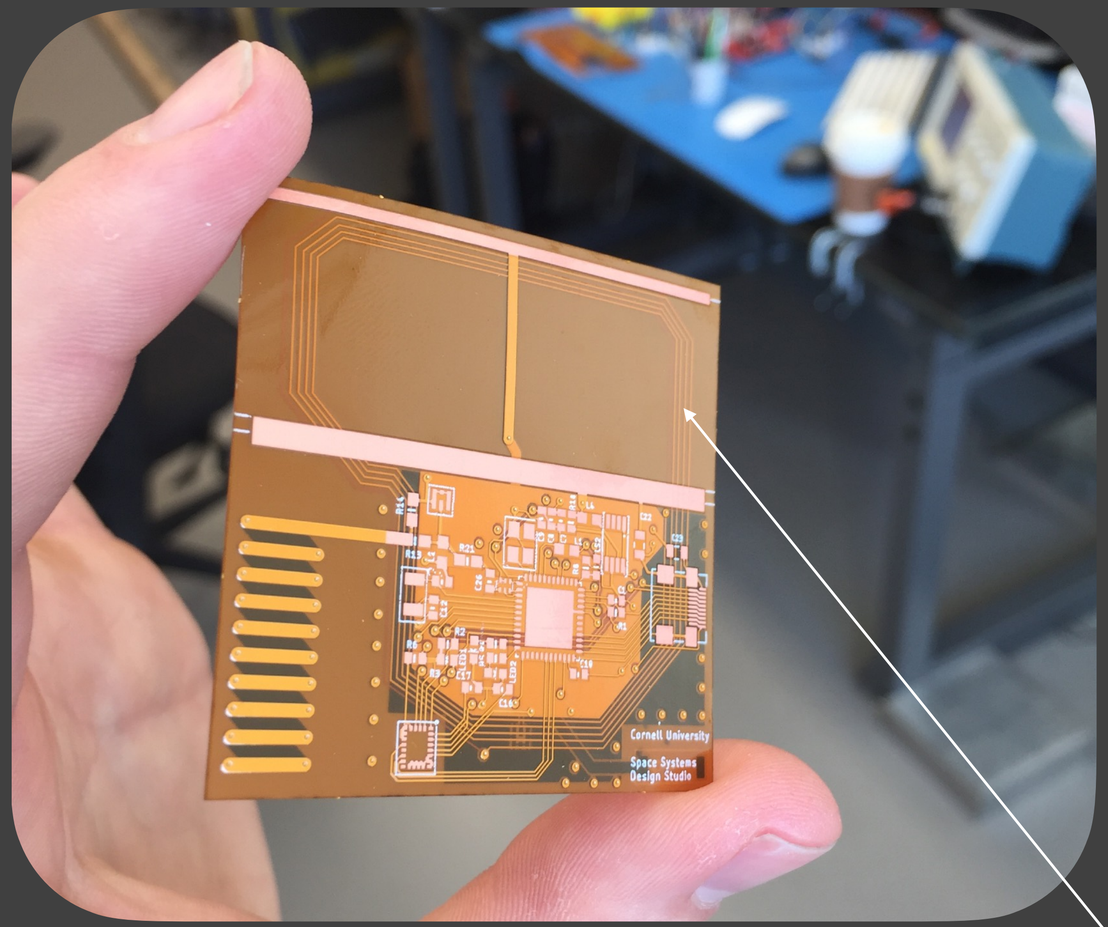


accelerometer, magnetometer, gyroscope, and thermometer

ambient light sensor



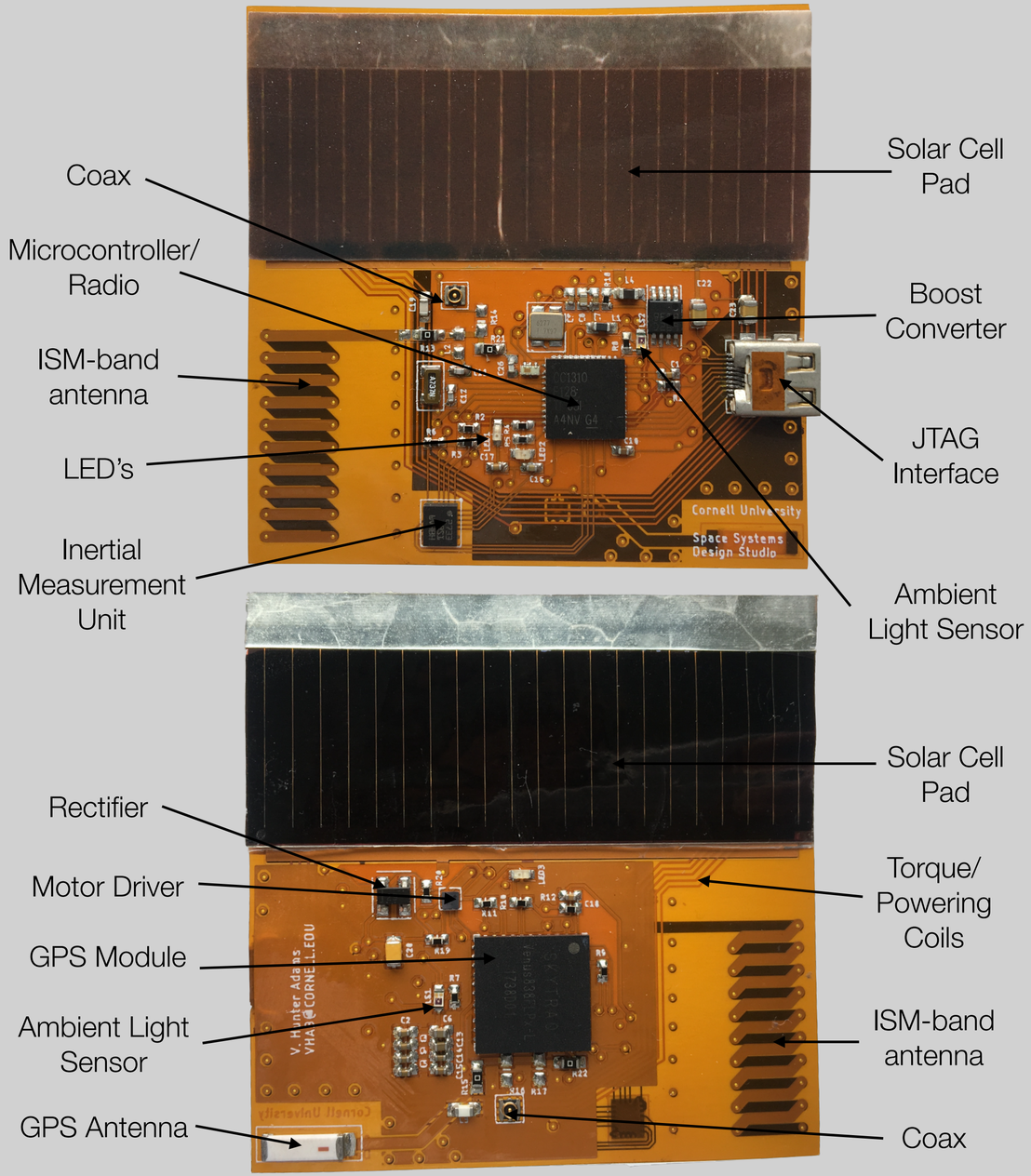
lightweight, flexible Kapton substrate

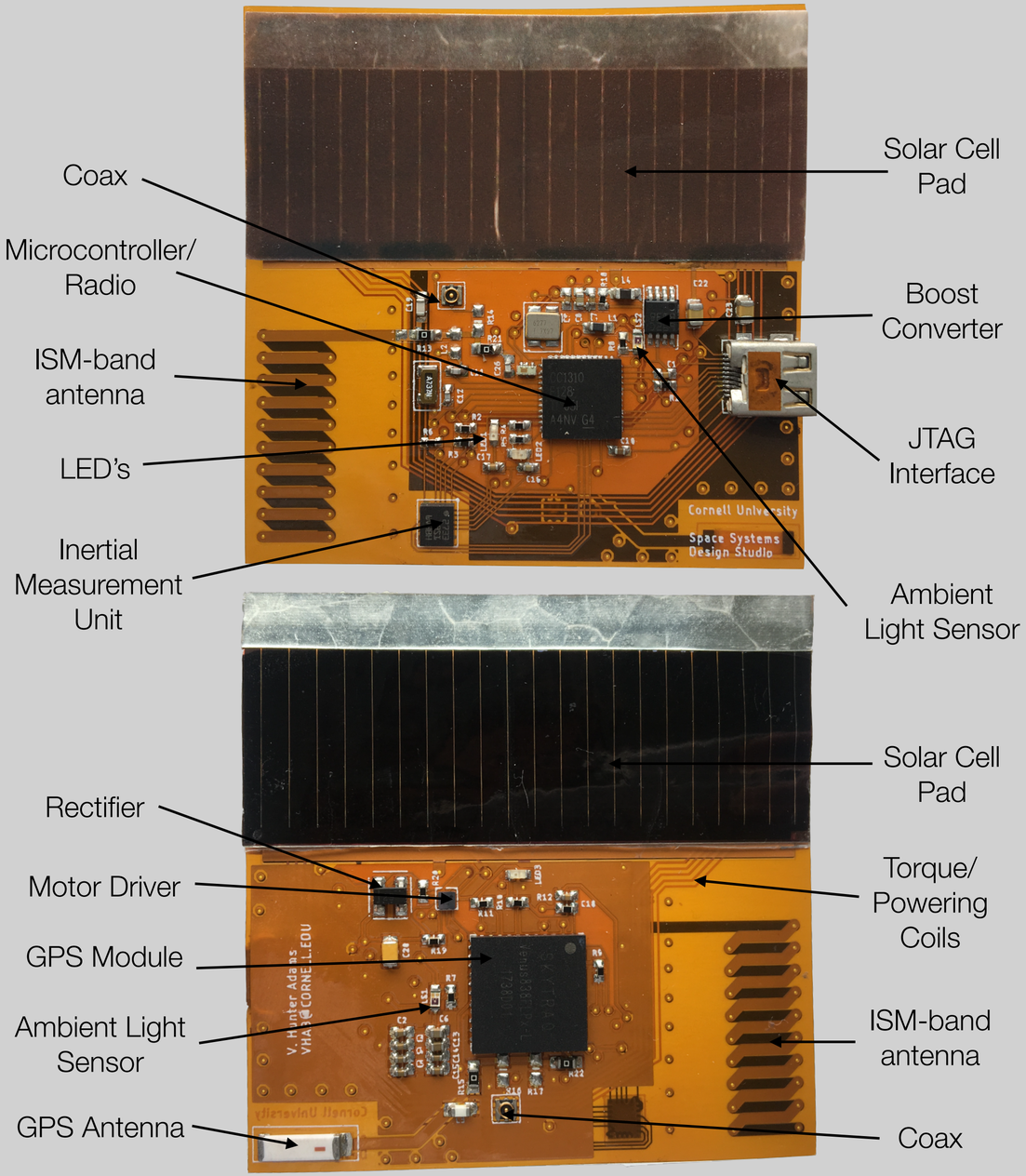


better view of torque/inductive powering coils

Hardware:

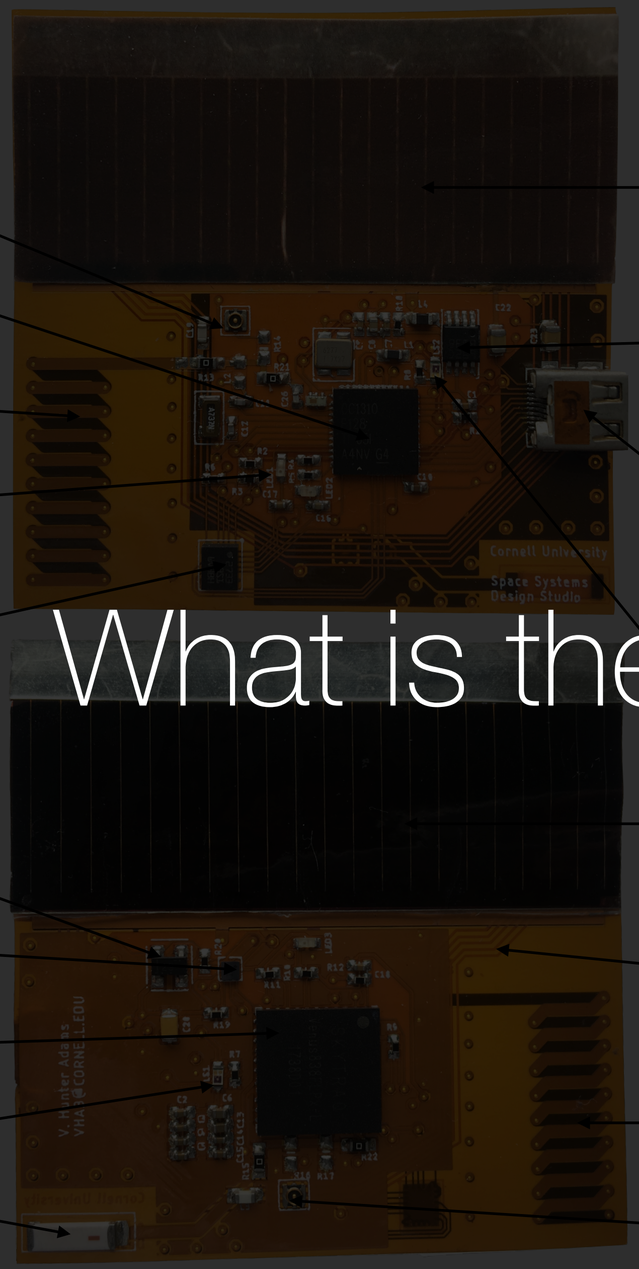
- two Alta-devices solar cells (300 mW each)
- CC1310 ARM processor running RTOS
- 25 mW radio chip
- accelerometer, magnetometer, and gyroscope
- embedded ISM-band antenna (915 MHz)
- GPS
- onboard GPS chip antenna
- JTAG interface via HDMI micro
- two ambient light sensors
- embedded torque coils for attitude manipulation
- motor driver for torque coil control
- embedded inductive powering coils
- LED's for user feedback





Capabilities:

- chip-to-chip communication from up to 1 km line of sight
- chip-to-receiver communication from >1000 km
- GPS acquisition in 30 seconds
- powering by sun and/or inductive coils
- communication among hundreds of chips on a single ISM-band frequency
- can be made to be waterproof
- extremely shock-proof (27,000 g's)
- can generate their own magnetic field
- stable flight in 0 g's
- flexible (to an extent)
- capable of accommodating any sensor that meets size and power requirements
- operating temperatures from -40 to +85 C



What is the point of all this effort?

All Capabilities:

- chip-to-chip communication from up to 1 km line of sight
- chip-to-receiver communication from up to 1000 km
- GPS acquisition in 30 seconds
- powering by sun and/or inductive coils
- communication among hundreds of chips on a single ISM-band frequency
- can be made to be waterproof
- extremely shock-proof (27,000 g's)
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Reasons to build femtosatellites:

1.
2.
3.

Reasons to build femtosatellites:

1. They can be manufactured cheaply and in bulk.
2.
3.

Reasons to build femtosatellites:

1. They can be manufactured cheaply and in bulk.
2. They can be launched and deployed in bulk.
3.

Reasons to build femtosatellites:

1. They can be manufactured cheaply and in bulk.
2. They can be launched and deployed in bulk.
3. Their size affects their orbital perturbations and impact mechanics.

Reasons to build femtosatellites:

1. They can be manufactured cheaply and in bulk.
2. They can be launched and deployed in bulk.
3. Their size affects their orbital perturbations and impact mechanics.

Femtosatellites are *not* small versions of large spacecraft. They have a different set of use cases.

Duration of the presentation:

1. Short-term mission possibilities
2. Intermediate-term mission possibilities
3. Long-term speculation


Ground Stations,
Aggregating Data
Sensor/Radio-Equipped
Monarch Node

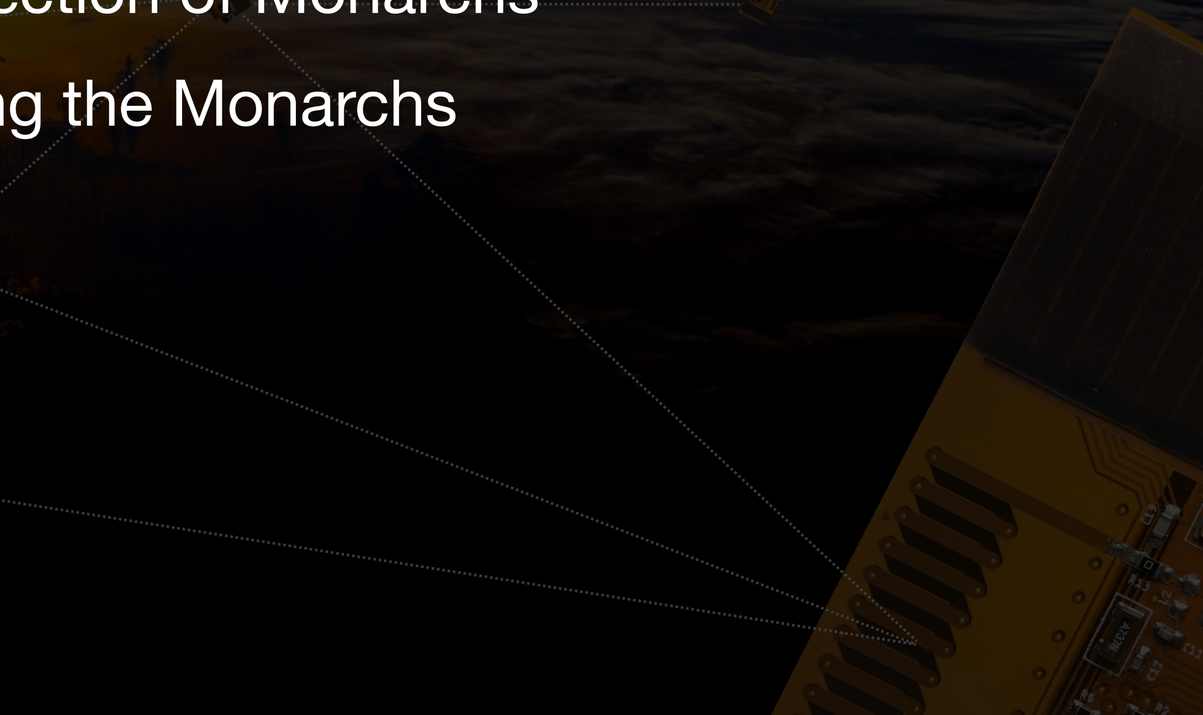

Ground
Stations, Aggregating
Data and Distributing
Swarm Commands
Sensor/Radio-Equipped
Monarch Node

Ground Stations, Aggregating Data and Distributing Swarm Commands

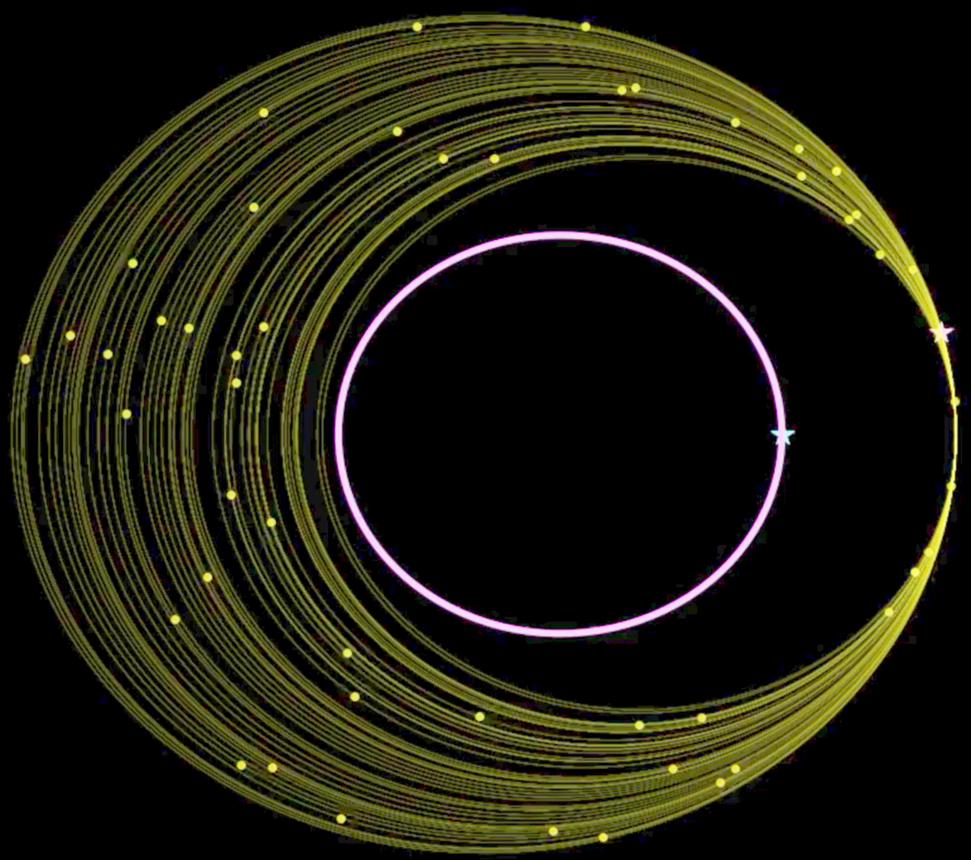
Technical requirements:

1. Routing policy over the collection of Monarchs
2. Information exchange among the Monarchs

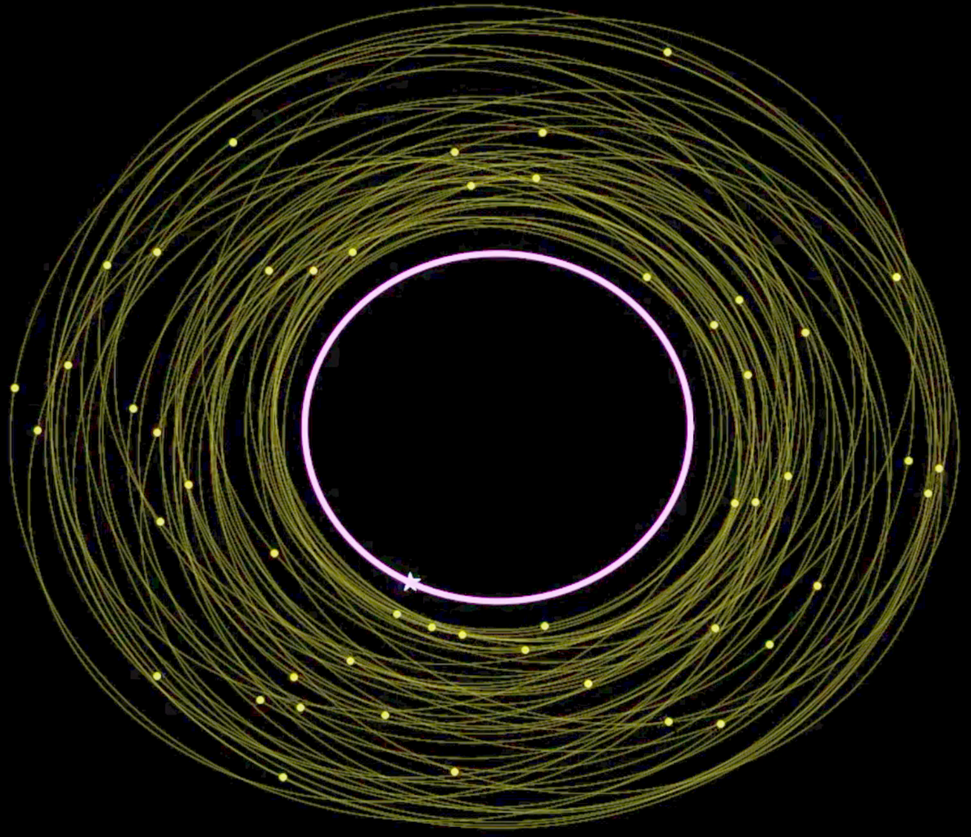
Sensor/Radio-Equipped Monarch Node



Simulation of proposed routing policy

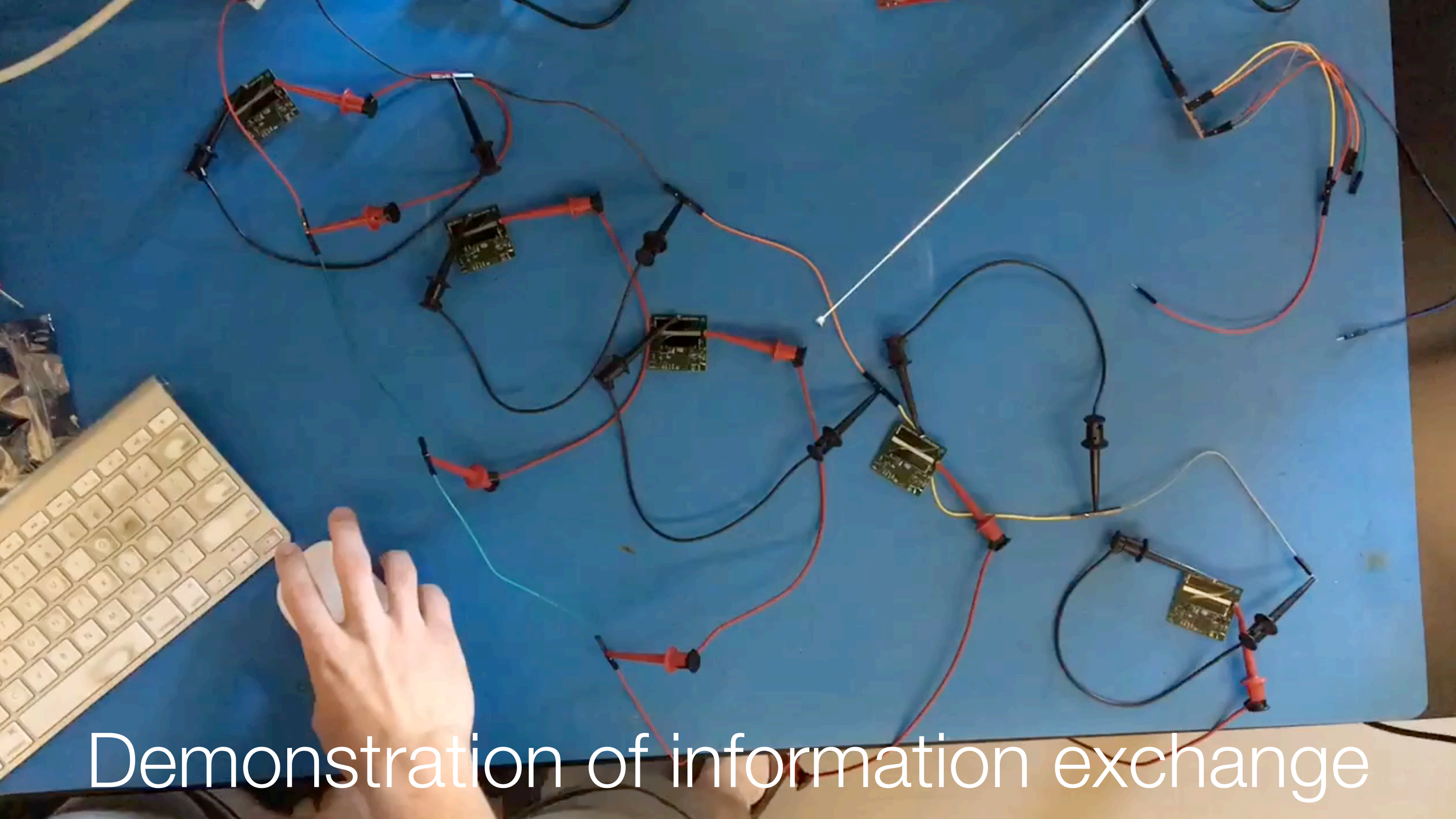


routing over nested swarm



routing over stochastic swarm

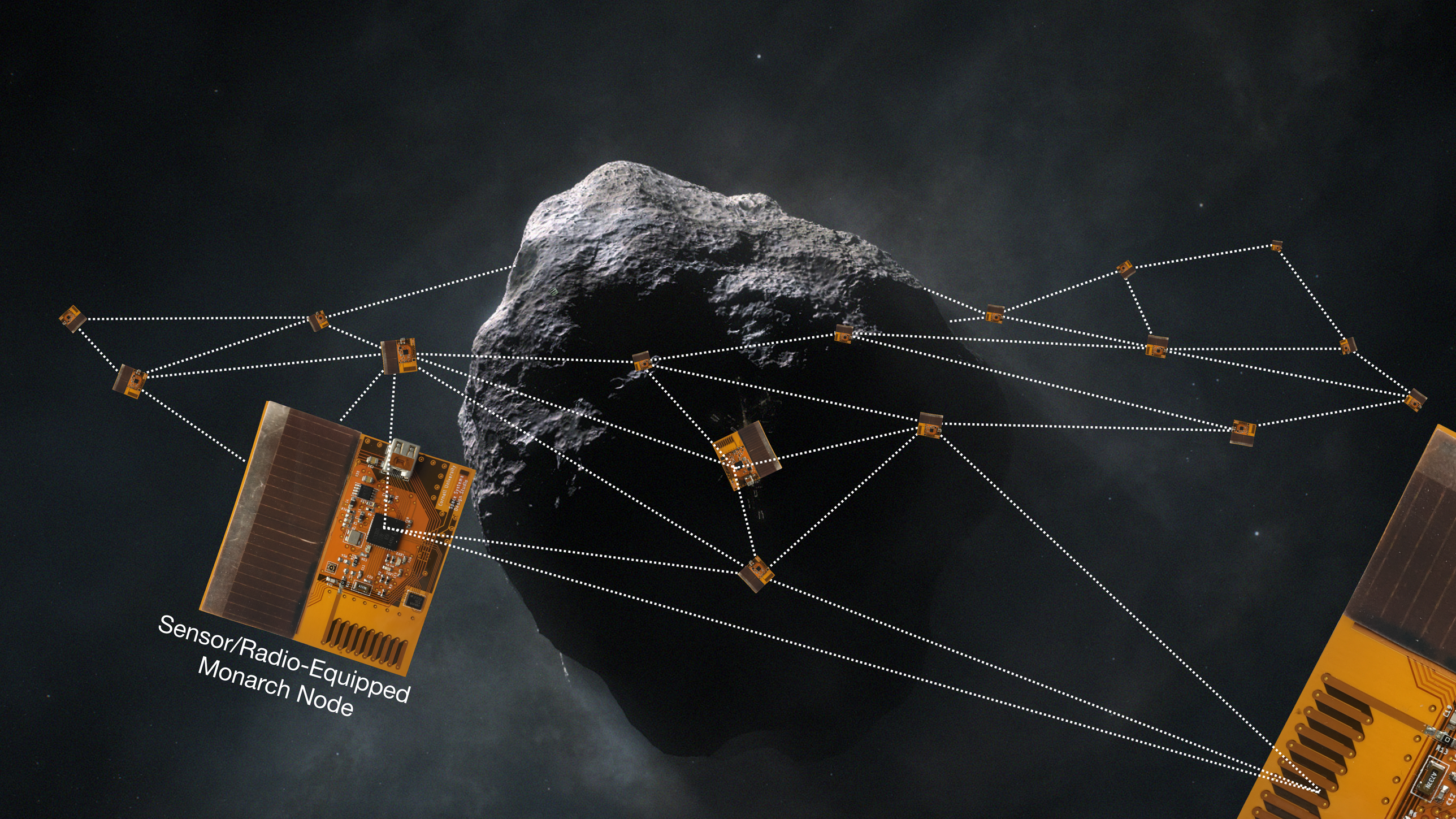
Adams, Van H., and Mason A. Peck. "A Probabilistic Network Formulation for Satellite Swarm Communications." *2018 AIAA Information Systems-AIAA Infotech@ Aerospace*. 2018. 1802.

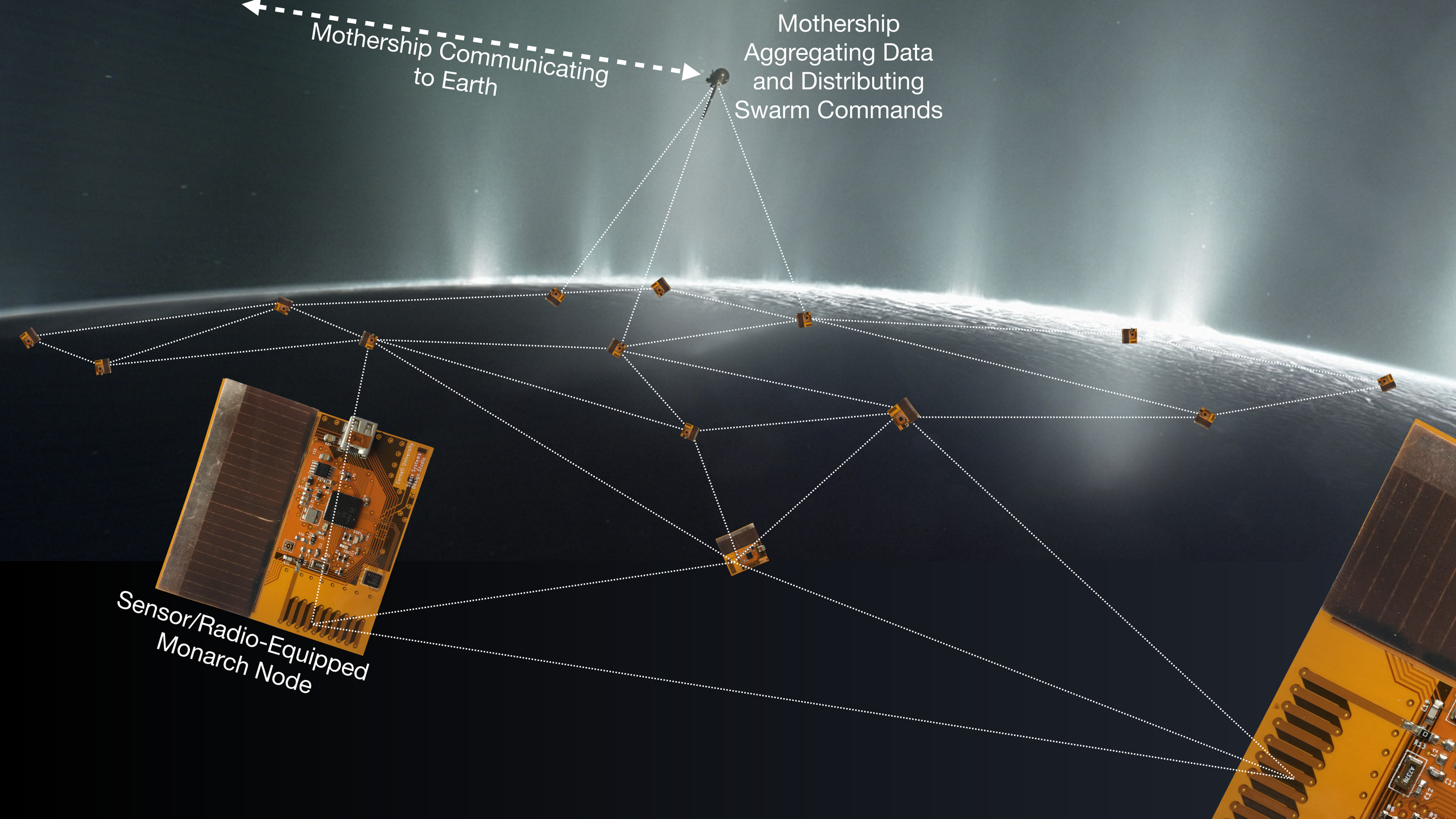


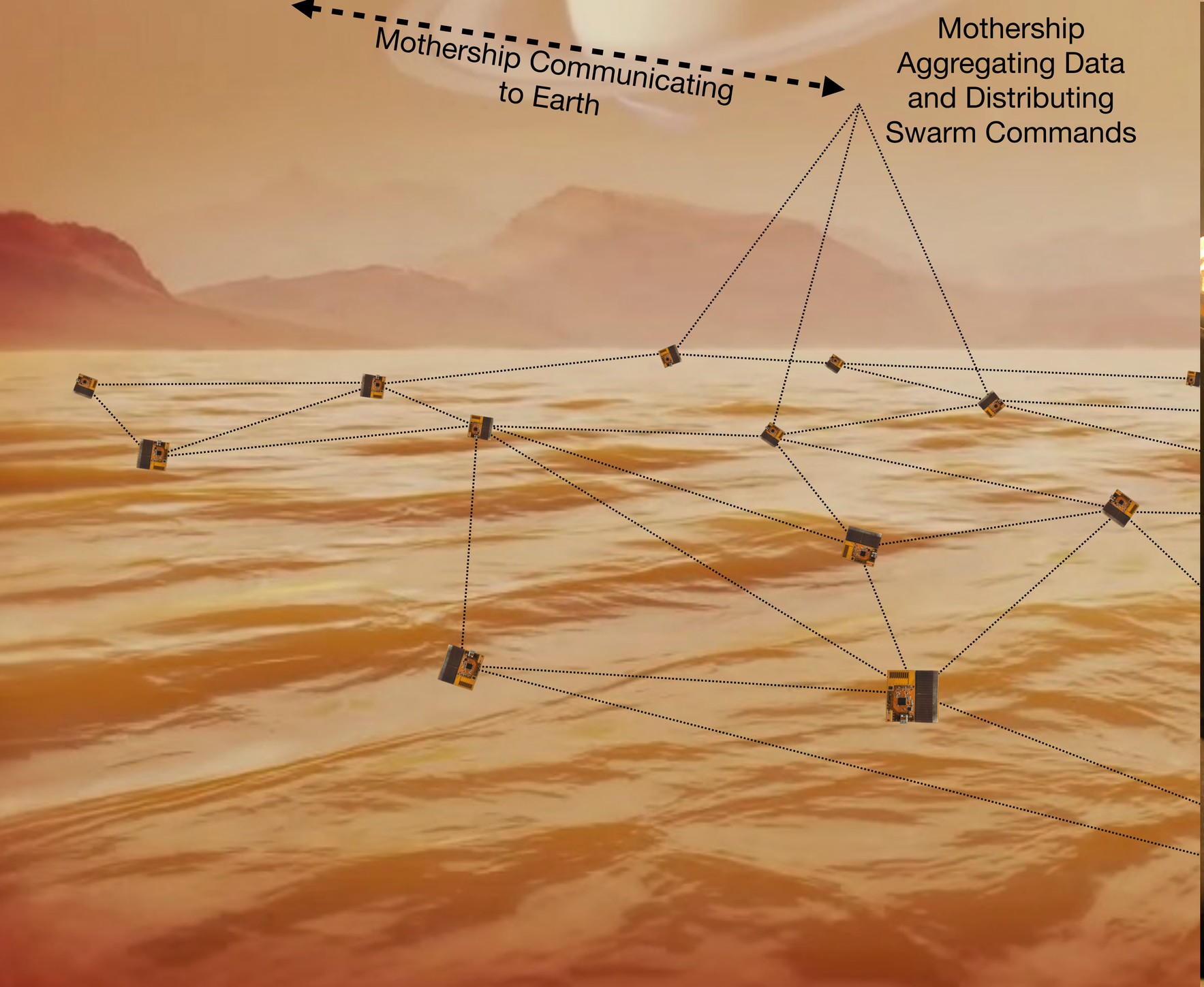
Demonstration of information exchange

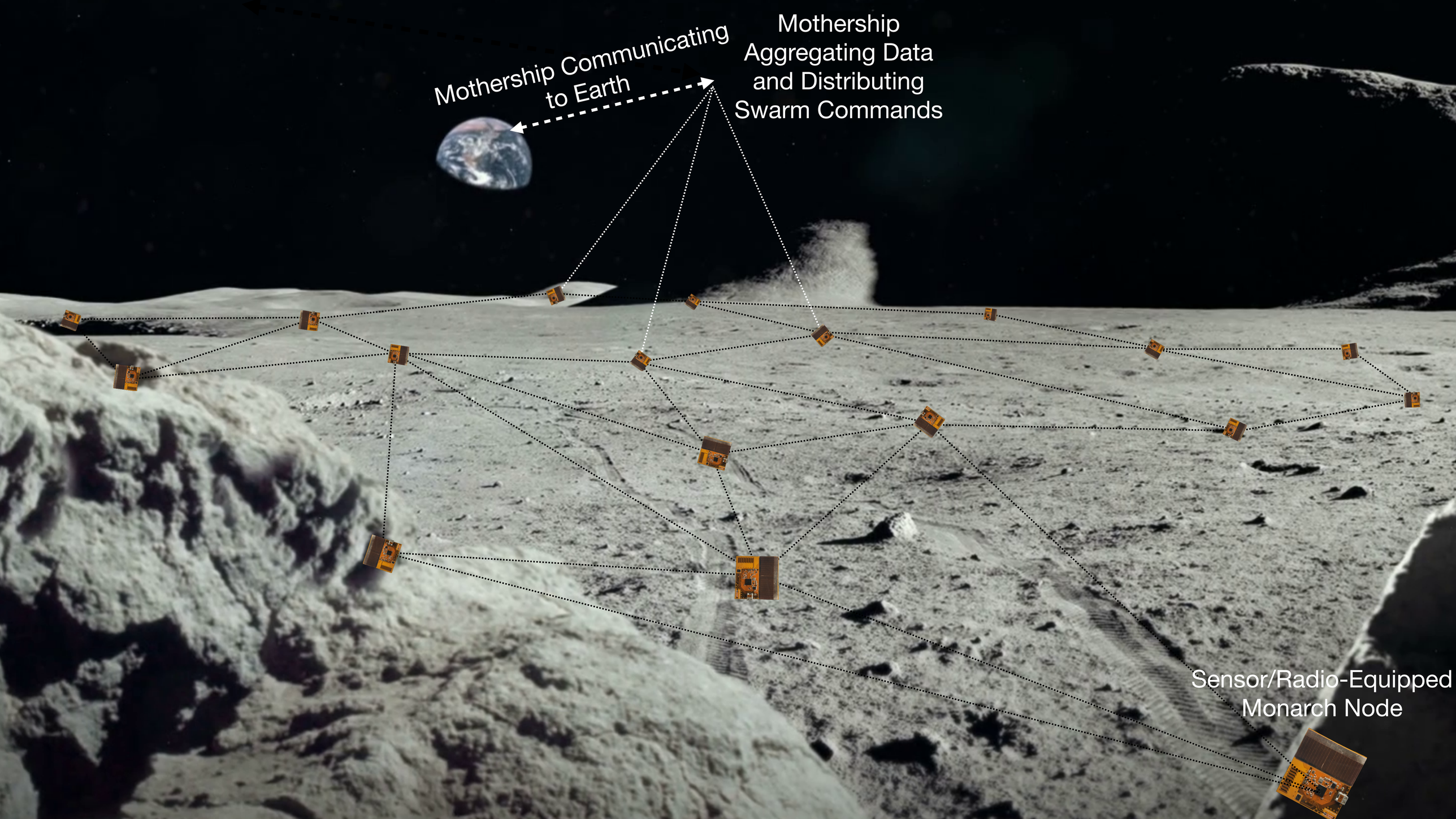

Ground
Stations, Aggregating
Data and Distributing
Swarm Commands
Sensor/Radio-Equipped
Monarch Node


Sensor/Radio-Equipped
Monarch Node


Sensor/Radio-Equipped
Monarch Node


Mothership Communicating to Earth
Mothership Aggregating Data and Distributing Swarm Commands
Sensor/Radio-Equipped Monarch Node

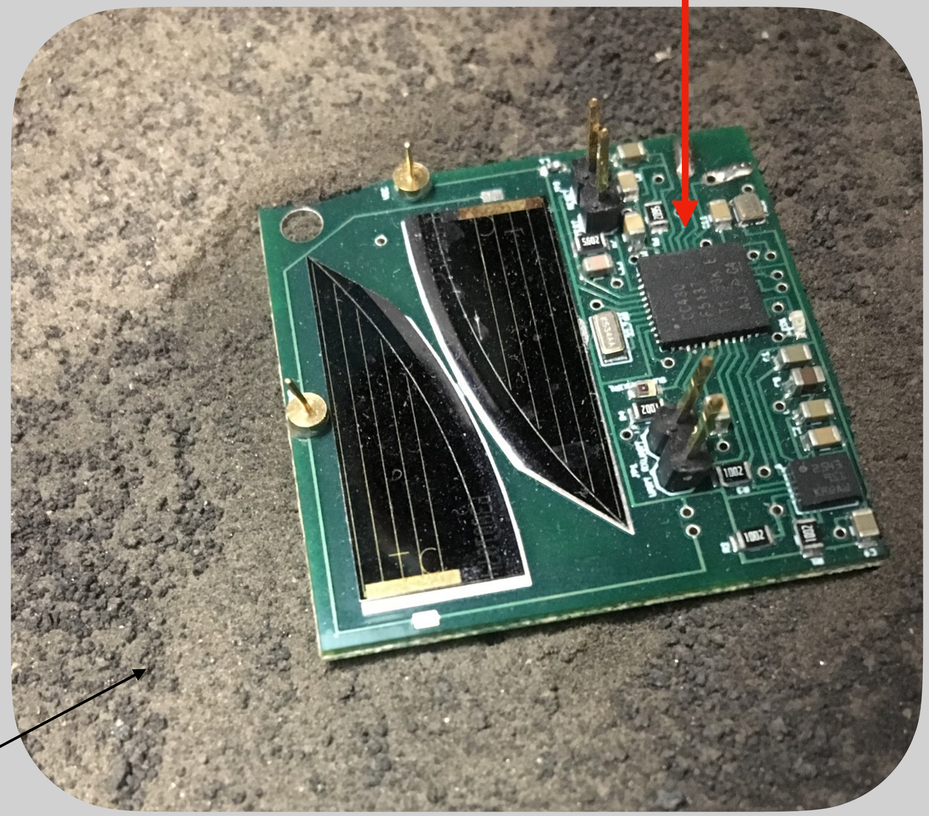

Mothership Communicating to Earth
Mothership Aggregating Data and Distributing Swarm Commands


Mothership Communicating to Earth
Mothership Aggregating Data and Distributing Swarm Commands
Sensor/Radio-Equipped Monarch Node

Would the spacecraft survive impact?

Lunar Impact Survivability Testing

5000 - 27,000 g's normal
to the board surface

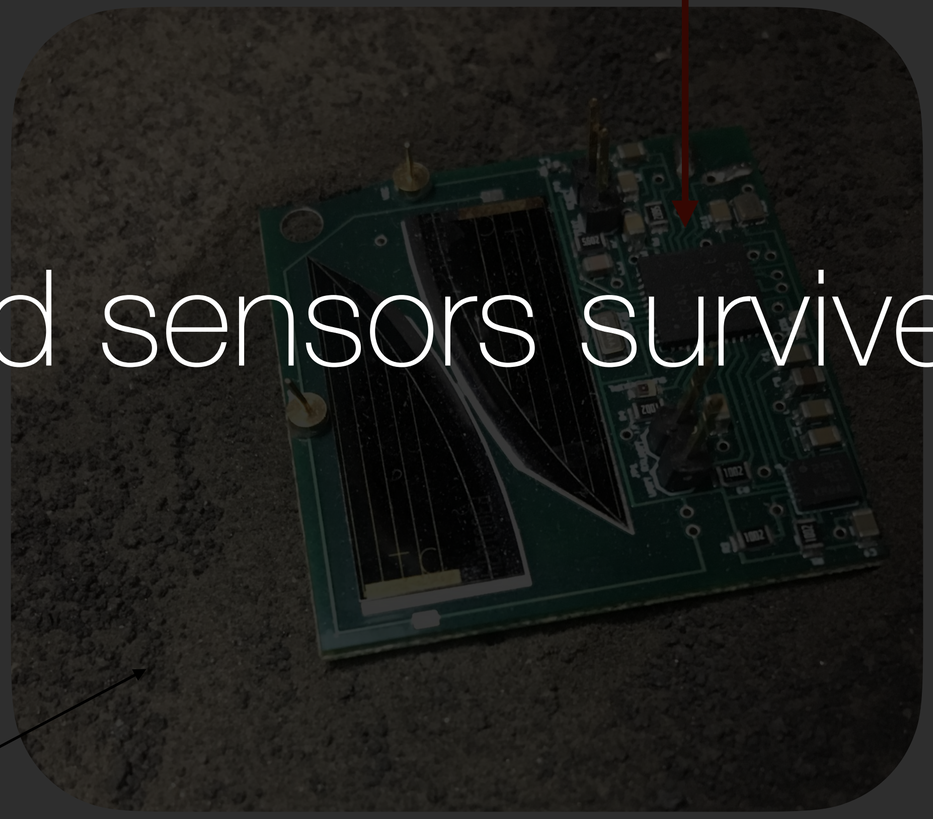


lunar regolith simulant

New Ascent

Lunar Impact Survivability Testing

5000 - 27,000 g's normal
to the board surface

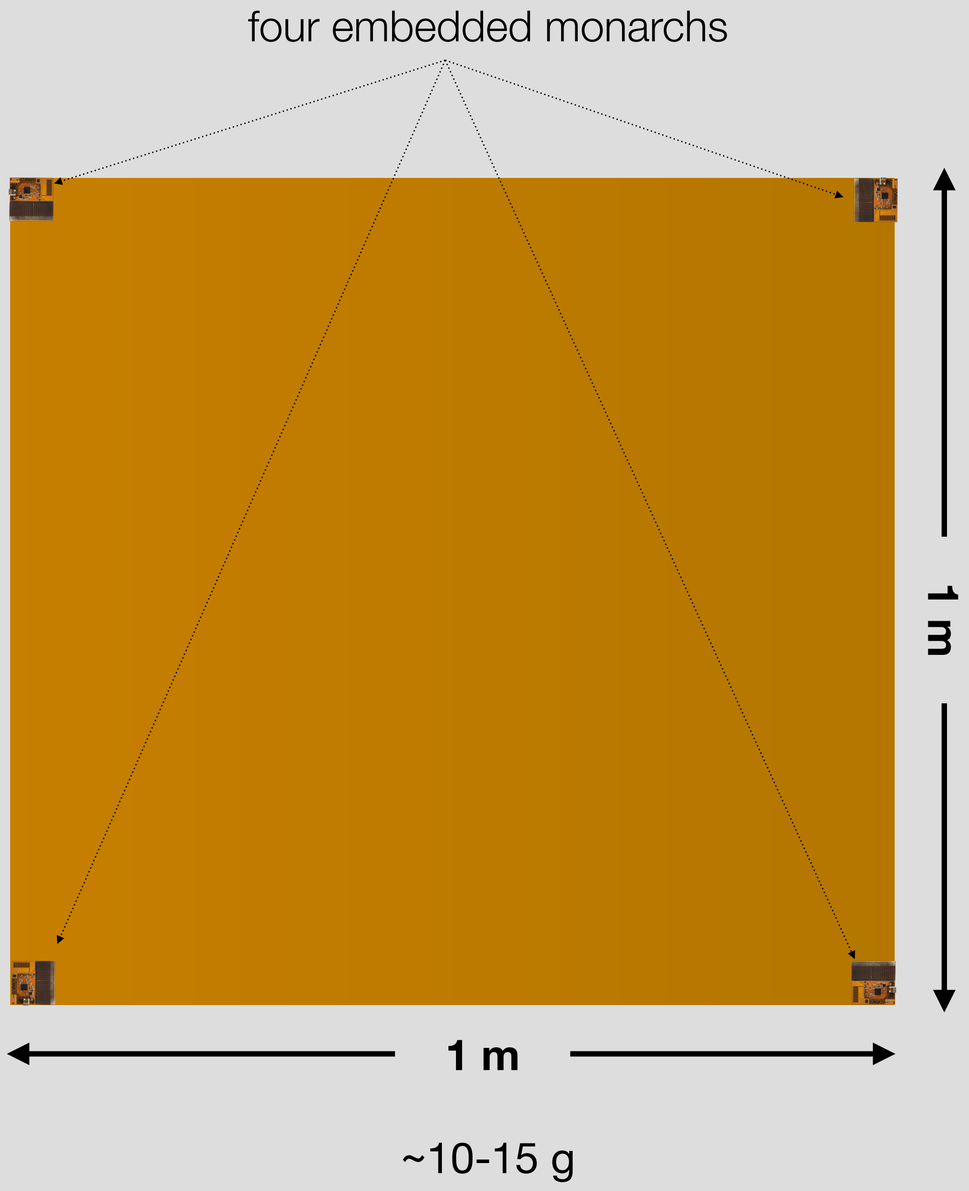


All boards and sensors survived unscathed.

lunar regolith simulant

New Ascent

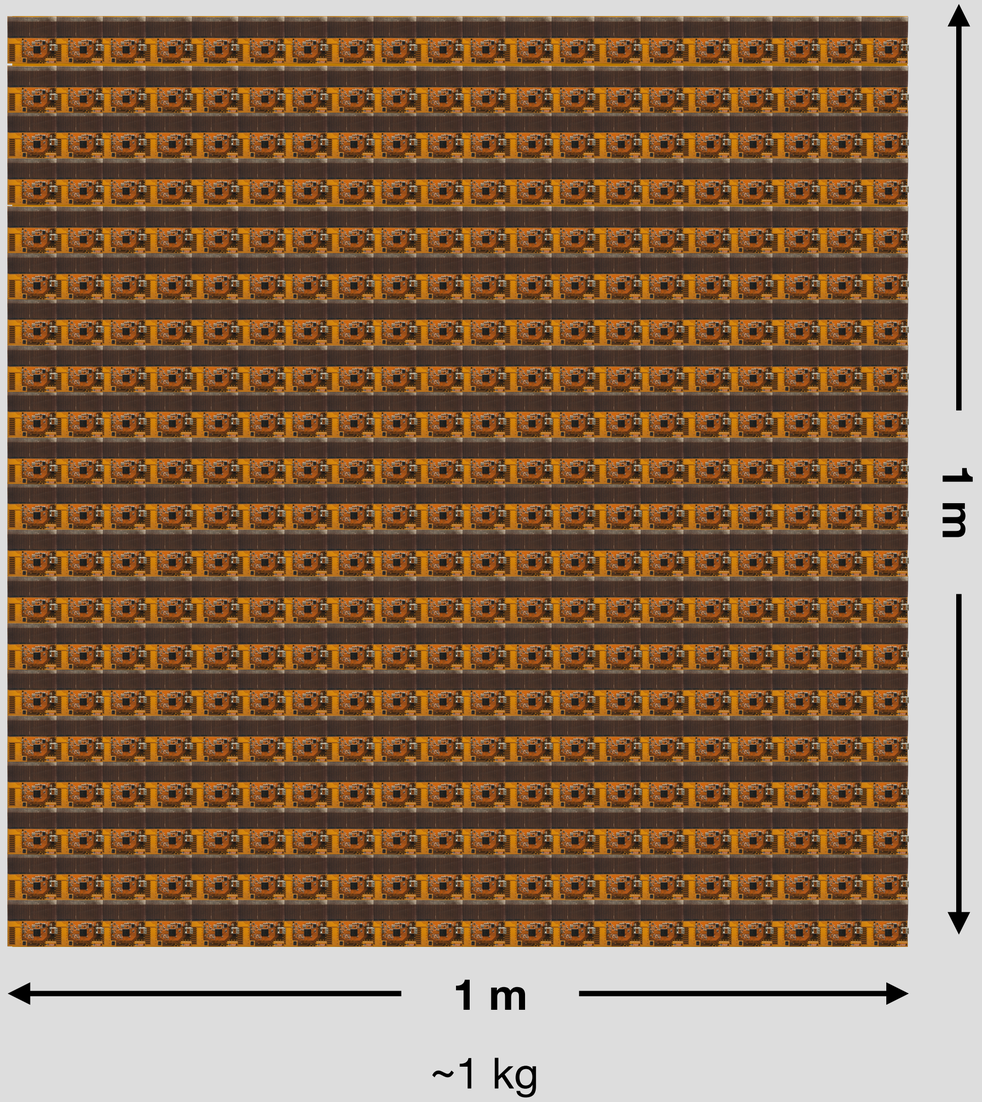
Rather than attach a sail to a spacecraft, we can create a sail that is a spacecraft.



~10-15 g

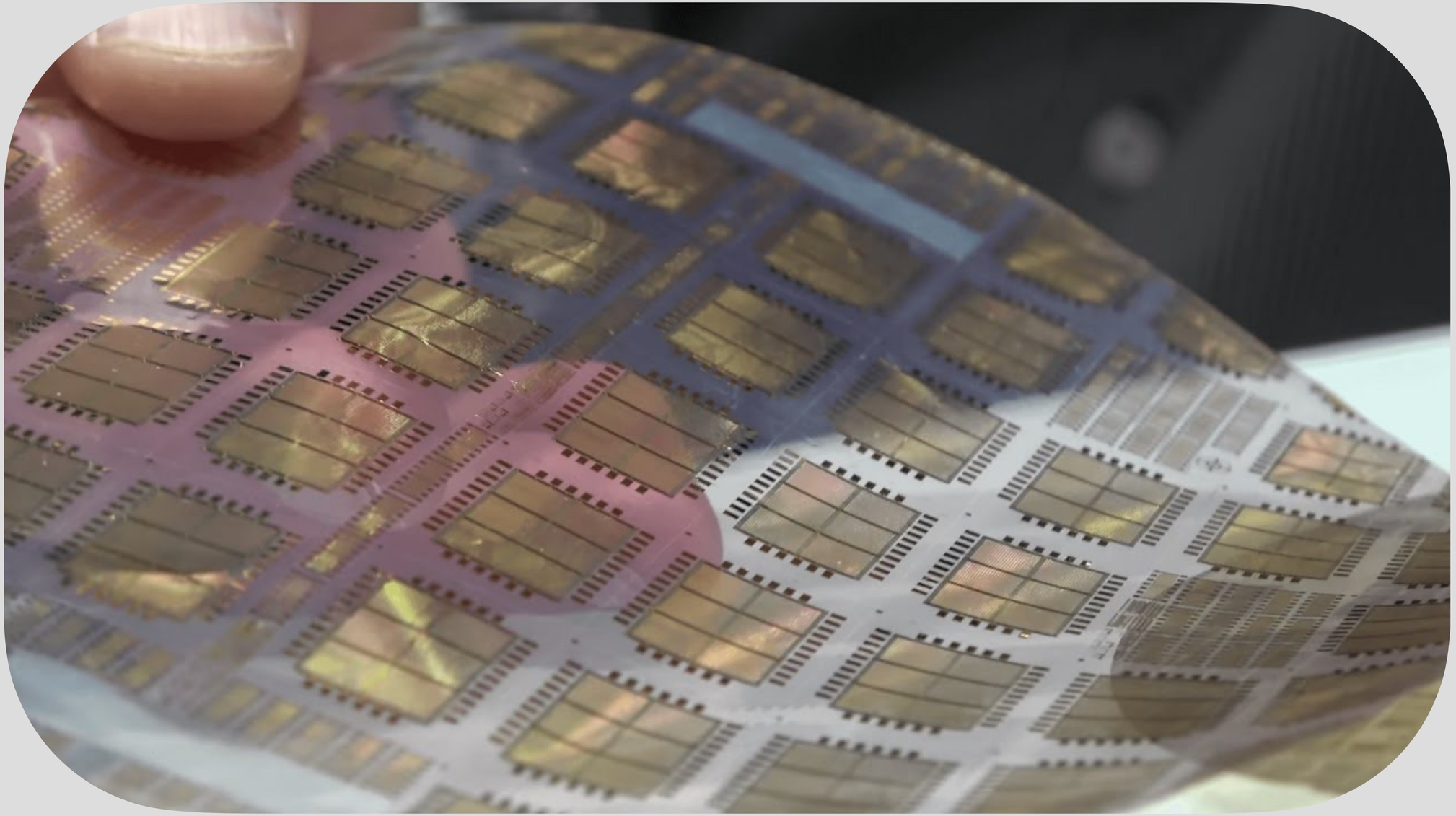
Or a sail that is composed of 400 spacecraft, with 400 sensor suites.

400 embedded monarchs

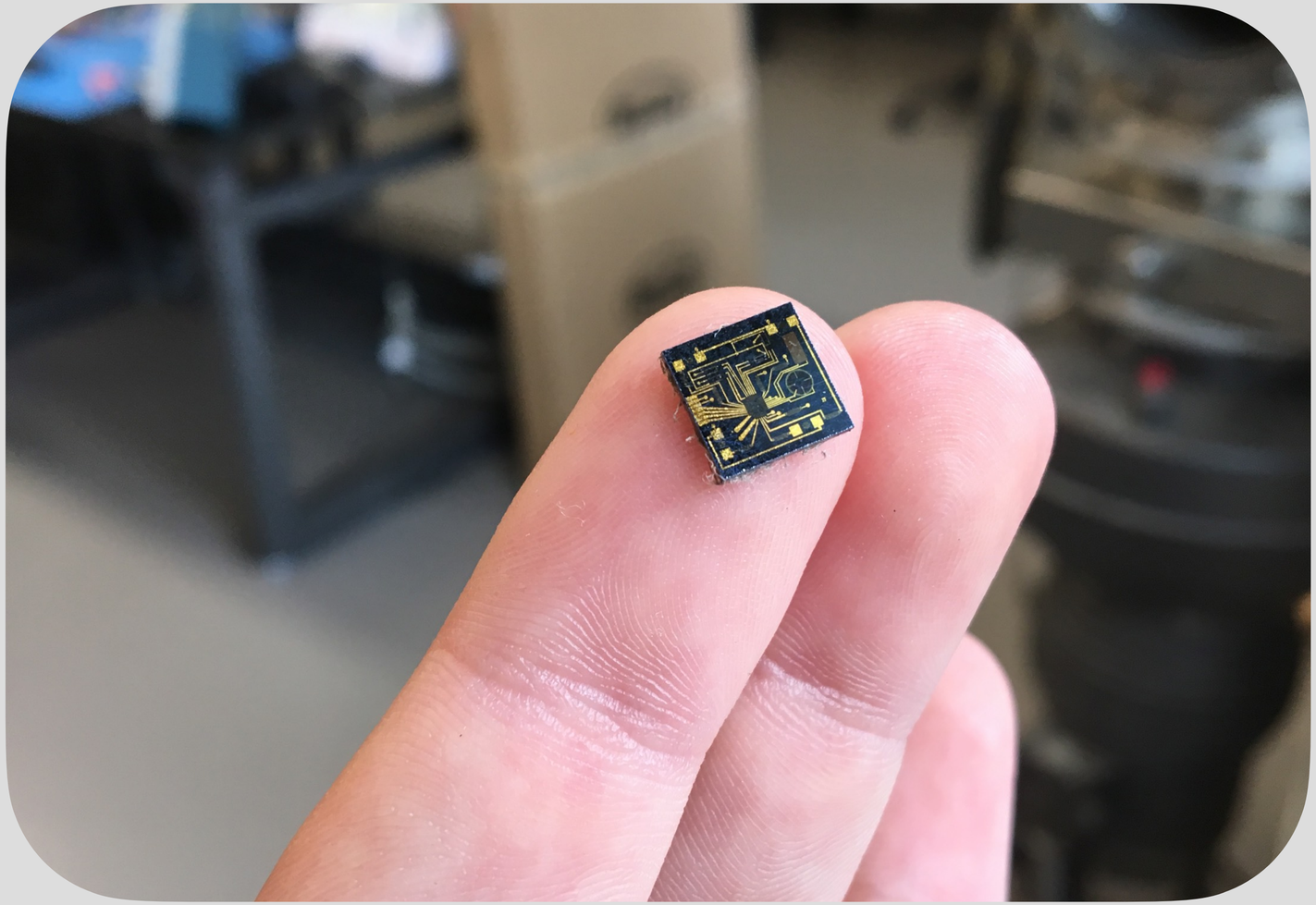


~1 kg

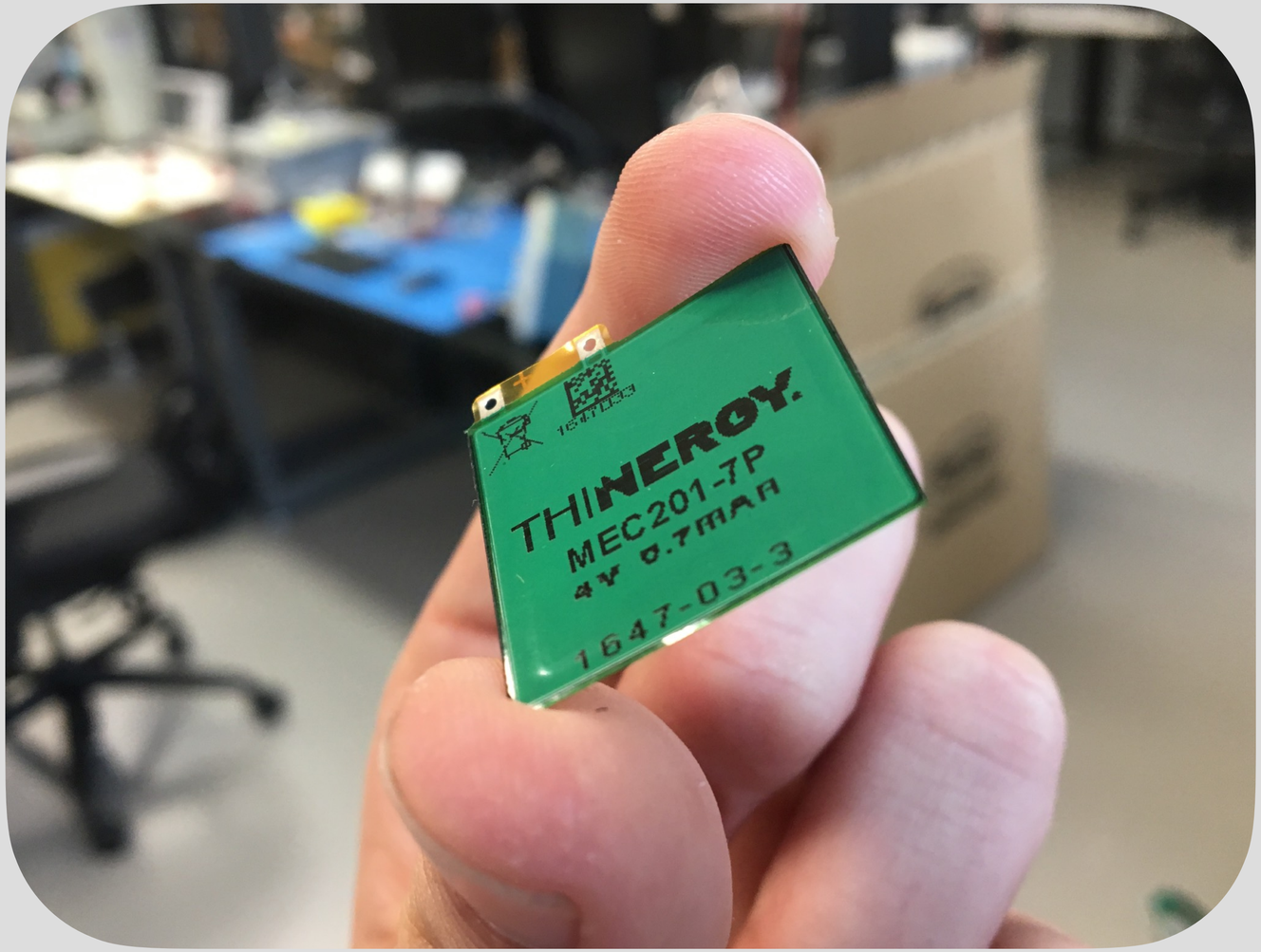
Long-term speculation . . .



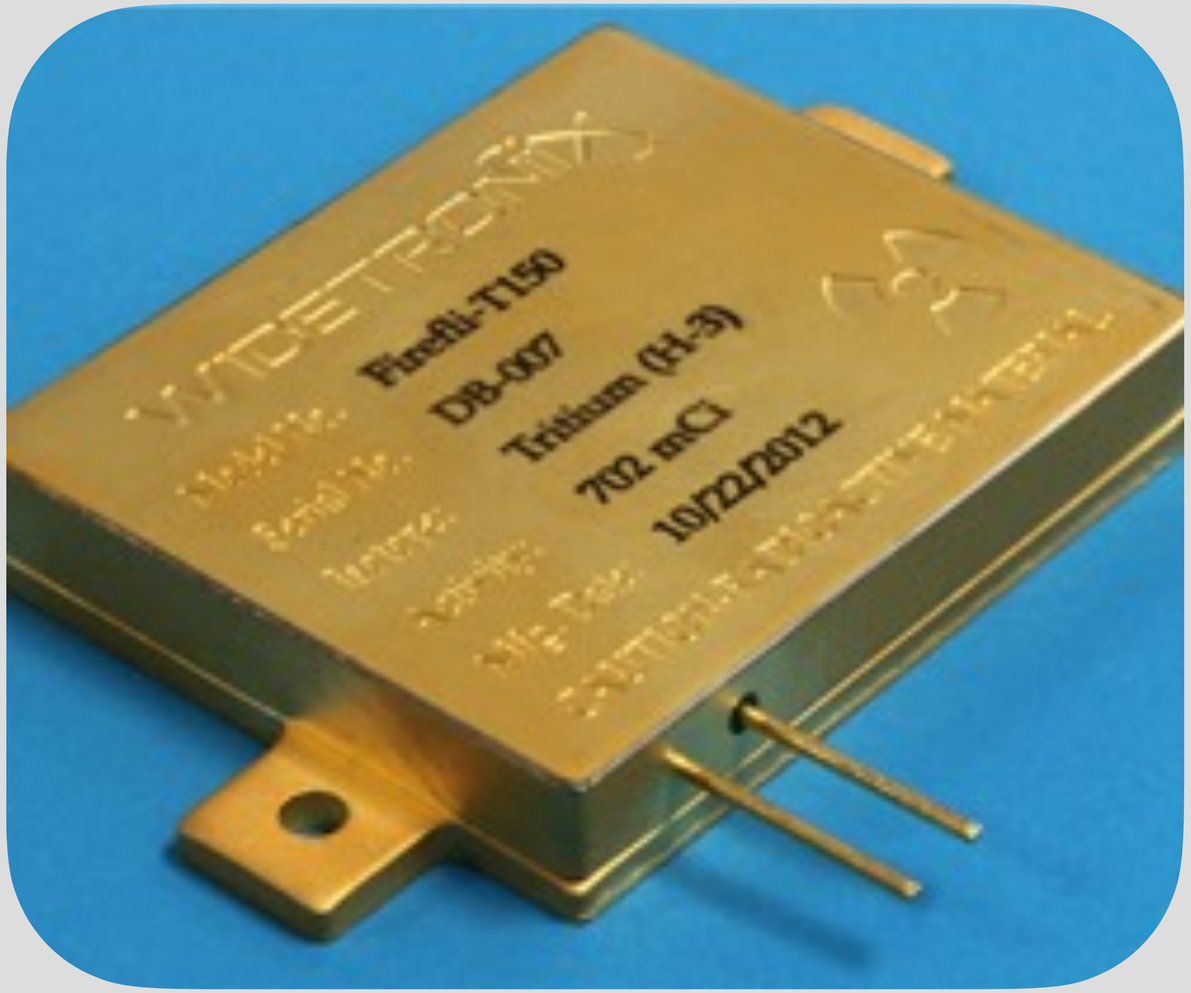
PragmatIC thin-film ARM processors



Starchip mockup

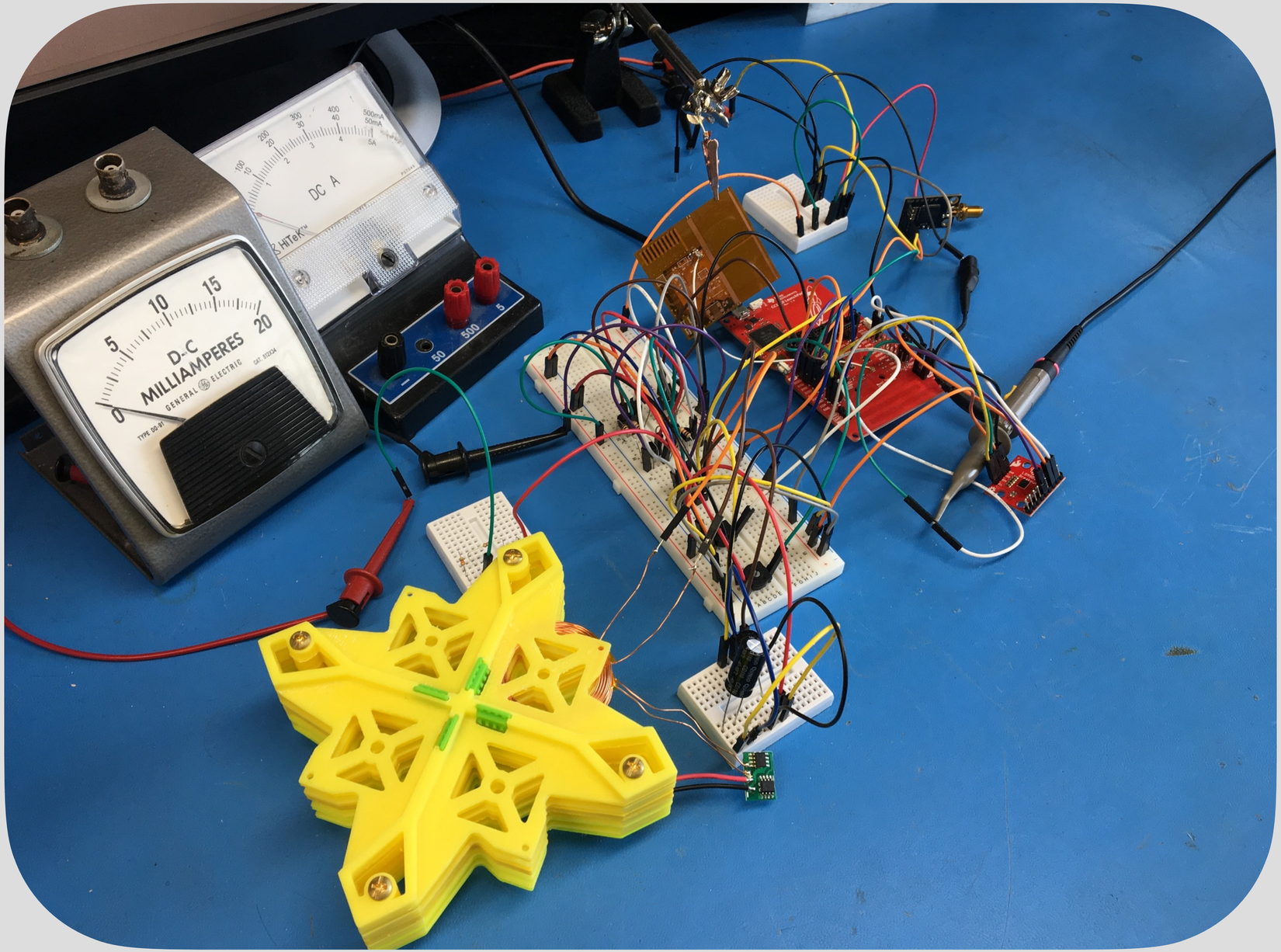


Thinergy solid-state battery



Widetronix beta voltaic nuclear battery

Emergent pattern in a murmuration of starlings



My lab bench