Innovations in Space: Small Satellites and Membrane Spacecraft

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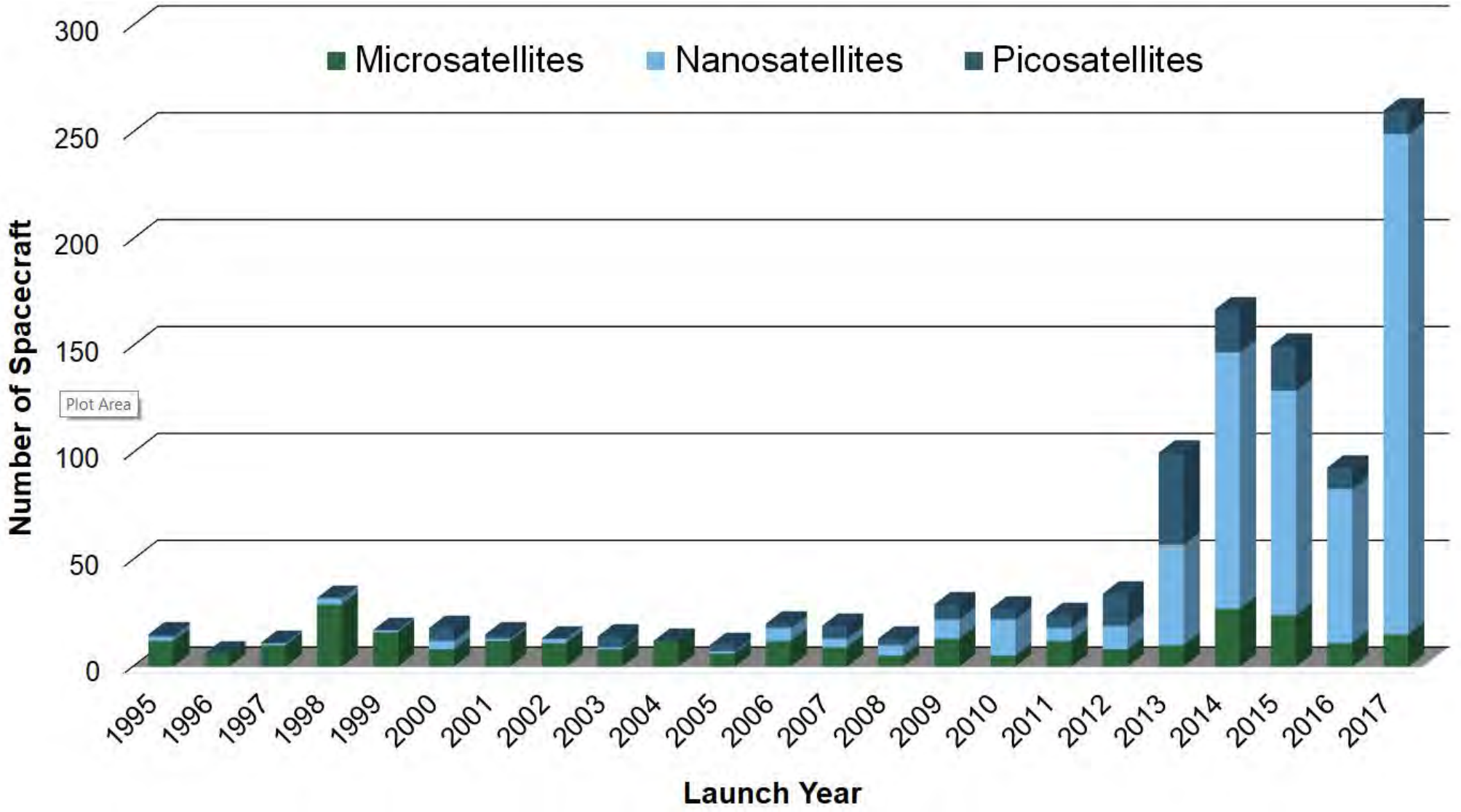
The History of Small Satellites: An Overview

- **The 1960's: Boom and Bust**
  - *Small satellite launch rates rose rapidly in early 1960's as the Space Age unfolded*
  - *Small satellite launch rates decrease in latter half of decade as launch vehicle throw weight capability increased and satellites got bigger (on average).*
- **The 1970's and 1980's: Gloom and Doom**
  - *Most satellite activity was in larger, >1000-kg spacecraft*
  - *Small satellite launch rates average ~5 per year in the West*
  - *Soviets create little LEO constellations for military communications (~20 sats per year)*
- **The 1990's: Technology development enables smaller, more capable spacecraft and new mission options**
  - *Micro/nanoelectronics, MEMS, Triple-junction solar cells and Li-ion batteries*
  - *GPS and the internet*
- **The 2000's: CubeSats provide improved access to space**
  - *Launch for a 1U CubeSat (10 x 10 x 10-cm) ranges from $40k to $110k*
  - *Russian, Indian, and Japanese launch options now exist.*
- **The 2010's: CubeSat launch rates expand rapidly**
  - *Commercial companies launch tens to hundreds of CubeSats*
  - *More nanosatellites are now being launched than microsatellites.*

Small Satellite Launch Rates Since 1995



Small satellite launch rates are now dominated by CubeSats. A launch failure in 2015 depressed launch rates in 2015 and 2016.

The Real Revolution

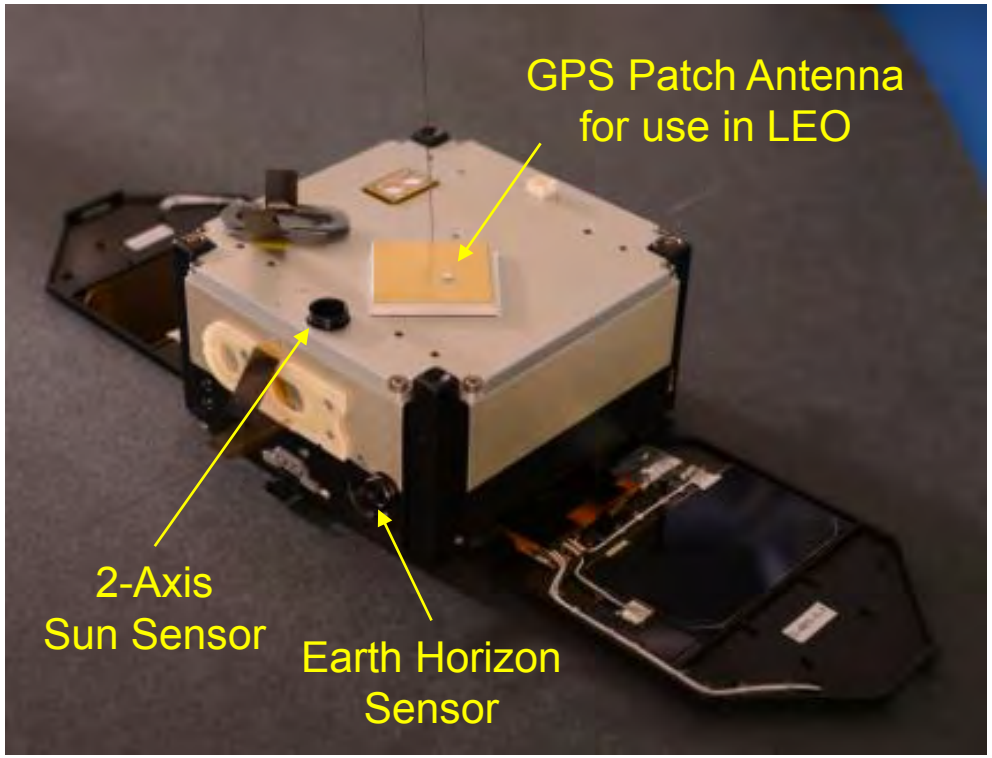
- **Traditional "large" spacecraft took 5 to 10 years to build**
  - *Technology freeze dates could be 7 years before launch*
  - *The flight computer could be two generations out-of-date at launch time*
  - *Significant amounts of ground testing, plus simulations, required to achieve high reliability*

- **CubeSats can be designed, built, tested, and flown within 1 year**
  - *Get real flight data within a year to improve device design*
  - *The evolutionary cycle for space hardware, that can fit on a CubeSat, has been reduced by a factor of roughly 7.*
  - *Get two or three successive flight validations before committing to a new technology;* ***"Fly as you Fly"***
  - *Take advantage of the latest commercially-available technologies*

The "Fly as You Fly" approach leverages the low cost and frequent flight opportunities (~10 per year) for CubeSat technology demonstrations.

An Example 0.5U CubeSat: The 10 x 10 x 5 cm AeroCube6A

AeroCube-6A



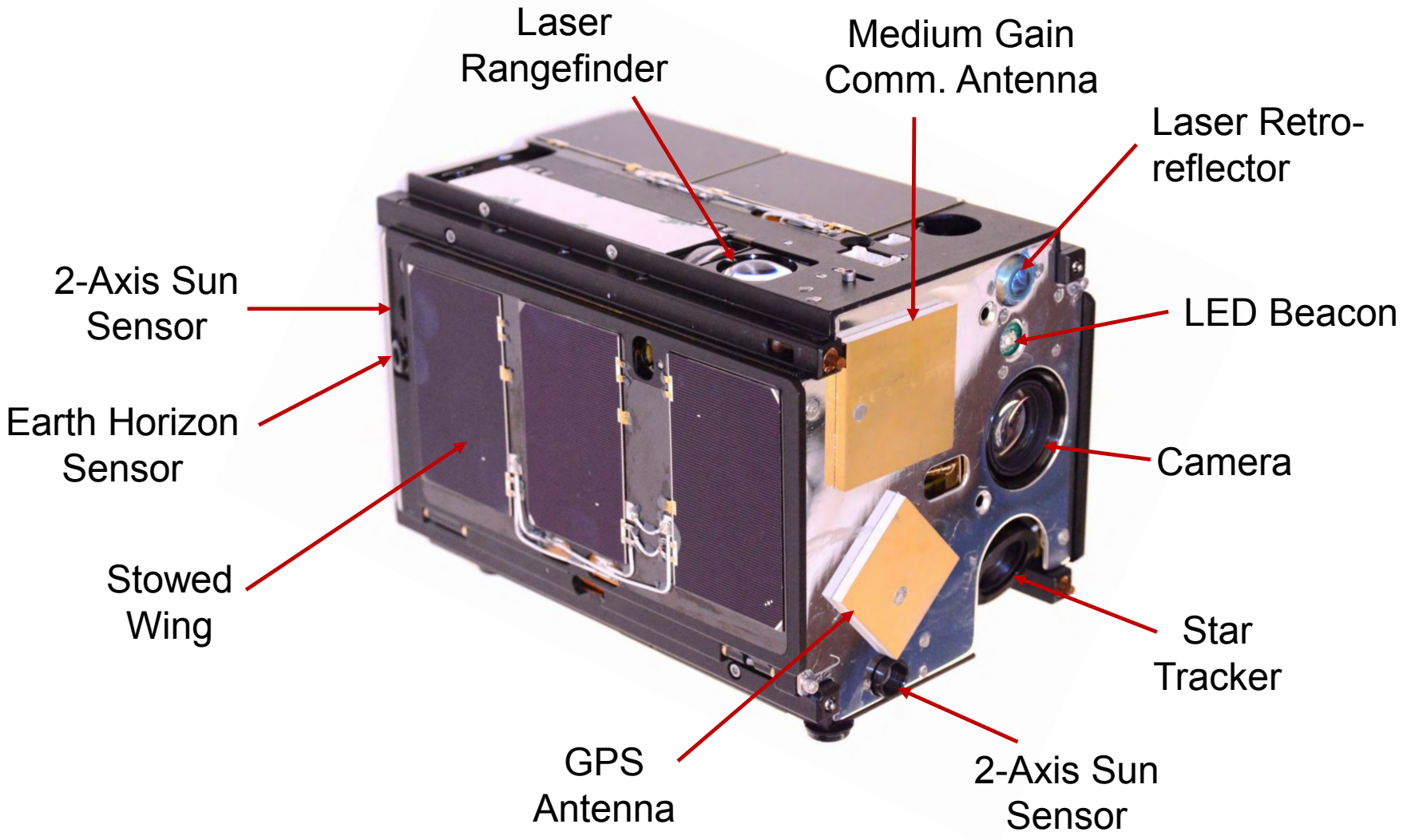
GPS/Radio/Flight Computer

The flight computer board uses commercial off-the-shelf (COTS) electronics, and contains a separate watchdog timer.

The boards on AC-6 A and B have operated successfully on orbit for 39 months and counting.

This board has flown on AC-6A, AC-6B, and AC-7A; it will also fly on AC-7B, AC-7C, and ISARA in November.

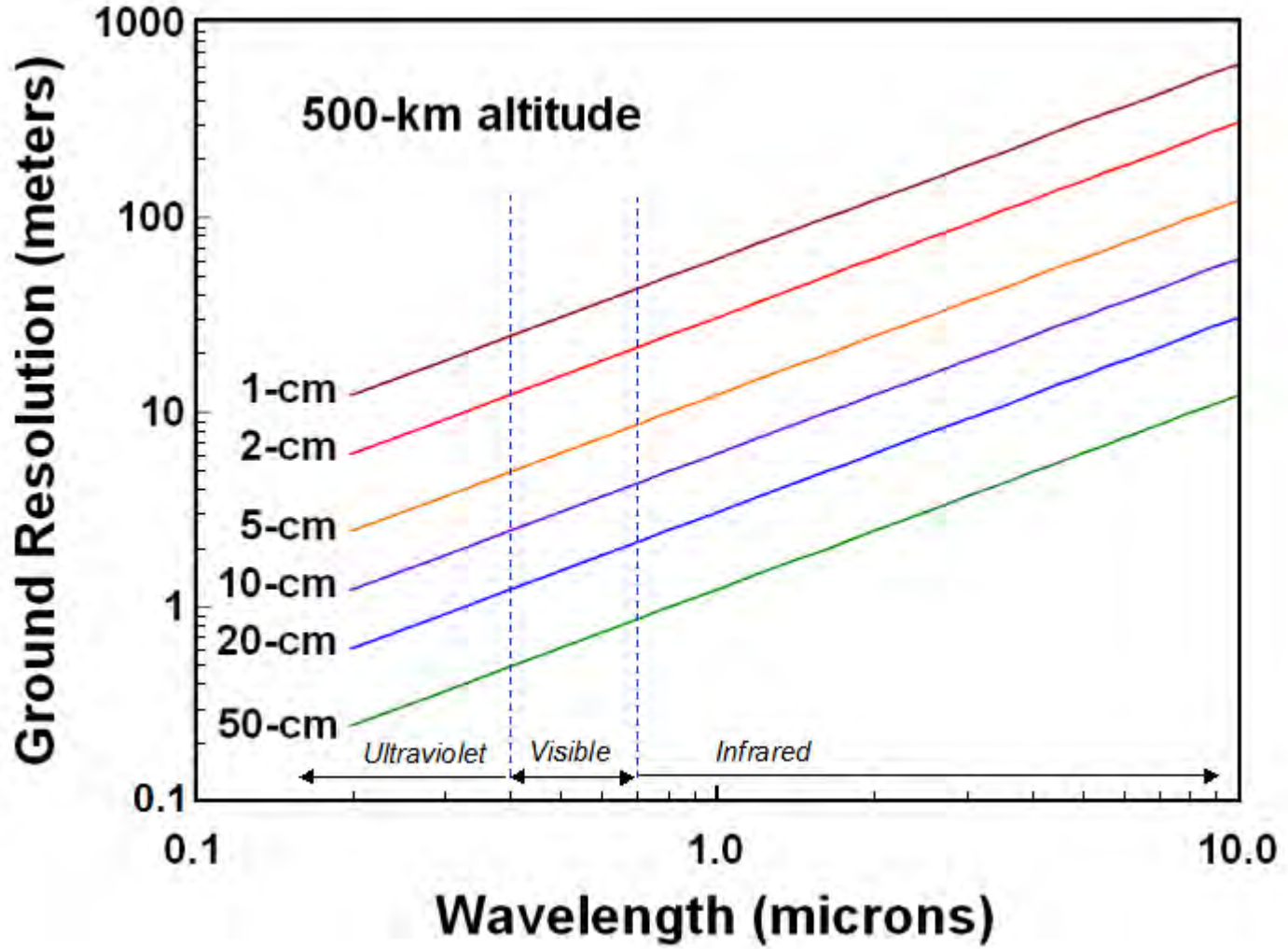
AeroCube-7A As Delivered (Stowed Wings)



Size:
10 x 10 x 15 cm

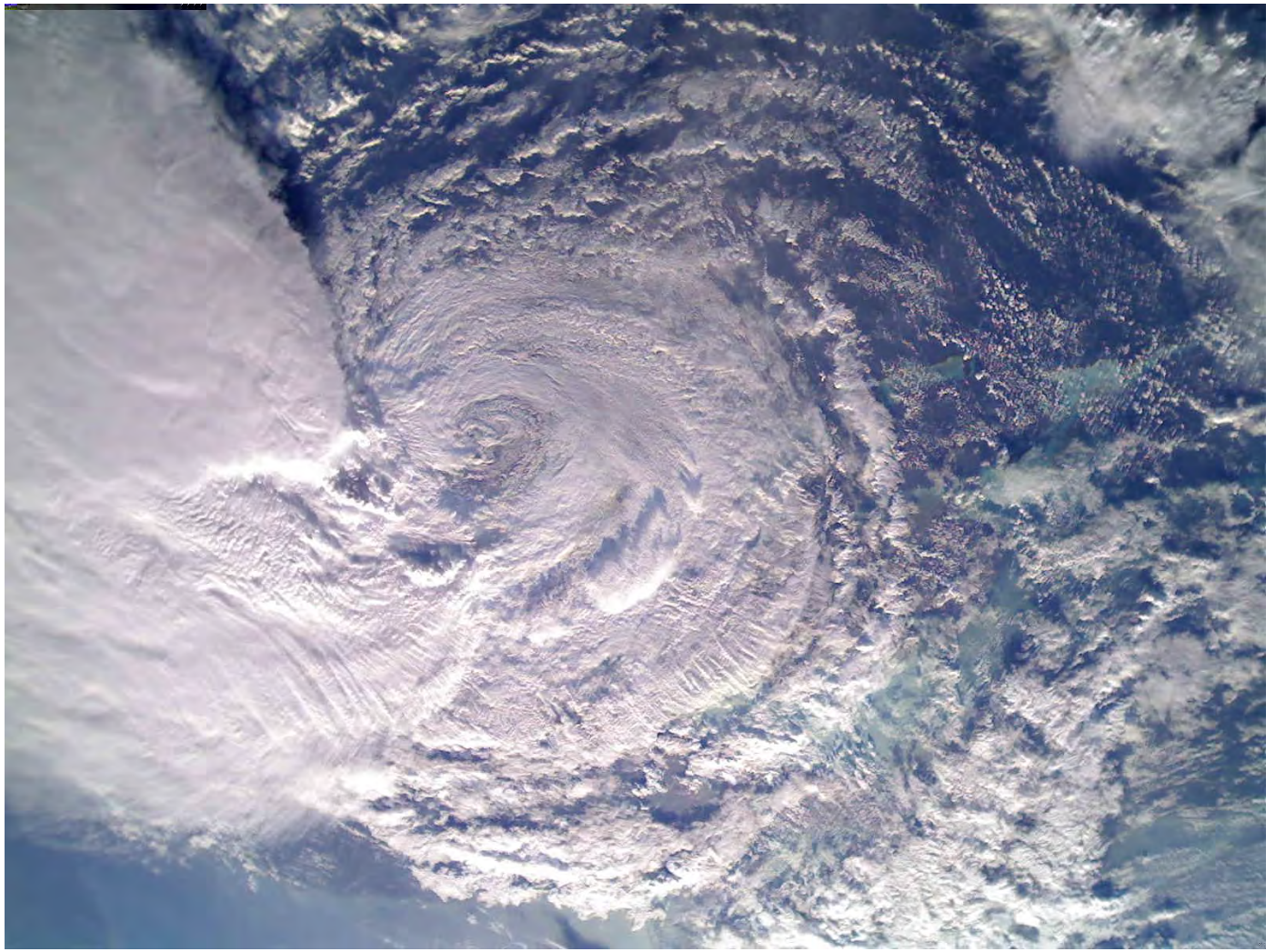
AC-7B&C will also have an additional steam propulsion module. Proximity operations will use variable drag and warm gas propulsion for maneuvering. The AeroCube-7 series has laser downlinks.

Theoretical Ground Resolution



A 10-cm aperture in a 1U, 2U, or 3U CubeSat can provide 5-meter ground resolution at 500-km altitude.
A 20-cm aperture in a 6U CubeSat could provide 2.5-meter ground resolution at this altitude.

Hurricane Sandy from Medium Field-of-View Camera



An example 100-meter resolution imagery obtained using a small camera on AeroCube-4.

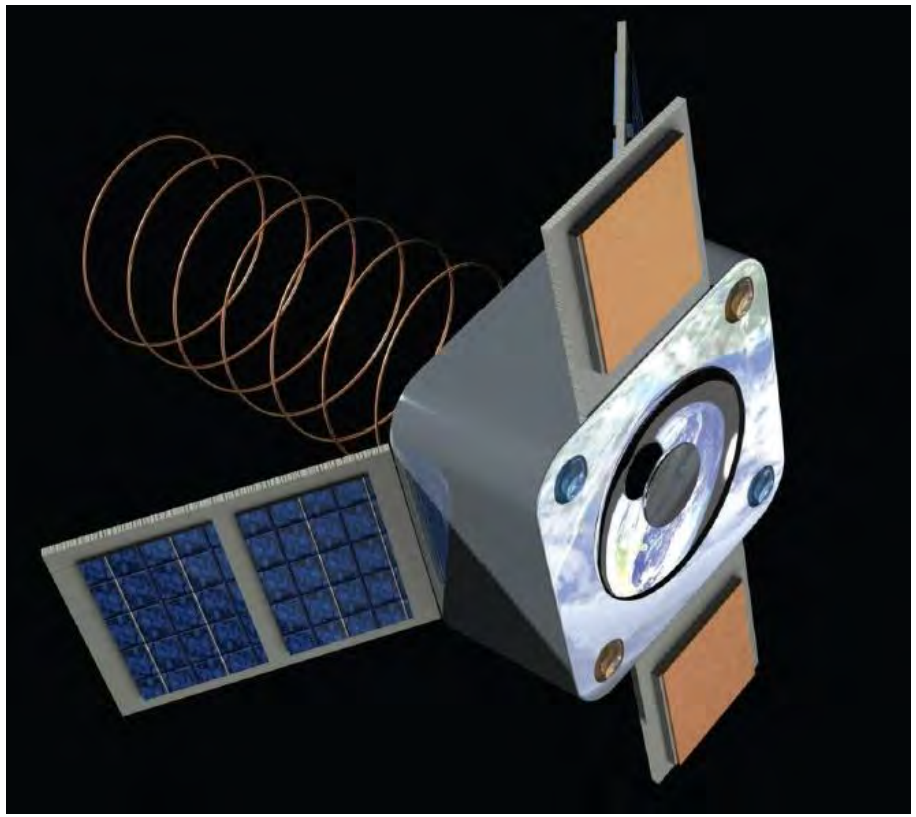
Near-Term: Highly-Capable CubeSats

Predicted in 2009:

- *Watts of orbit average power*
- *Data rates > 1 Mbps*
- *Orbit change capability*
- *Pointing to < 0.1 degrees*
- *5-meter ground resolution*

Current Reality:

- *Proliferation of 3U and 6U CubeSats*
- *100 to 260 CubeSats launched per year*
- *10 to 20 W of orbit-average power*
- *3-axis pointing to < 0.05 degrees*
- *Commercially-available 5-meter visible ground resolution (PlanetLabs)*



Limitations:

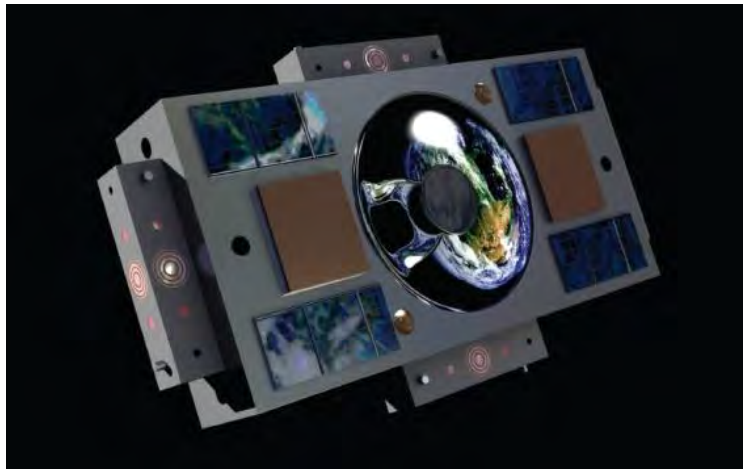
- *Pointing accuracy*
- *Data download rates*

Pointing accuracy is required for Earth imaging. Even the smallest CubeSat can acquire and store a Terabyte of information. Need downlink rates of at least 1 gigabit/s to get that information in a week, not years.

Long-Term: Modular Reconfigurable Spacecraft

- **Plug-and-Play modules with electronics, mating ports, and actuators**
  - *Mass-producible modules*
  - *Spacecraft can grow in time as more modules are added*
  - *Spacecraft geometry can change to adapt to new missions*
  - *Spacecraft electronics can be upgraded incrementally over time*

- **Applications**
  - *Large geosynchronous bus for "plug-and-play" payloads*
  - *Phased array that grows with time*
  - *Phased array with variable aperture*
  - *Spacecraft that physically disperse*
  - *Spacecraft that interchange components as needed*

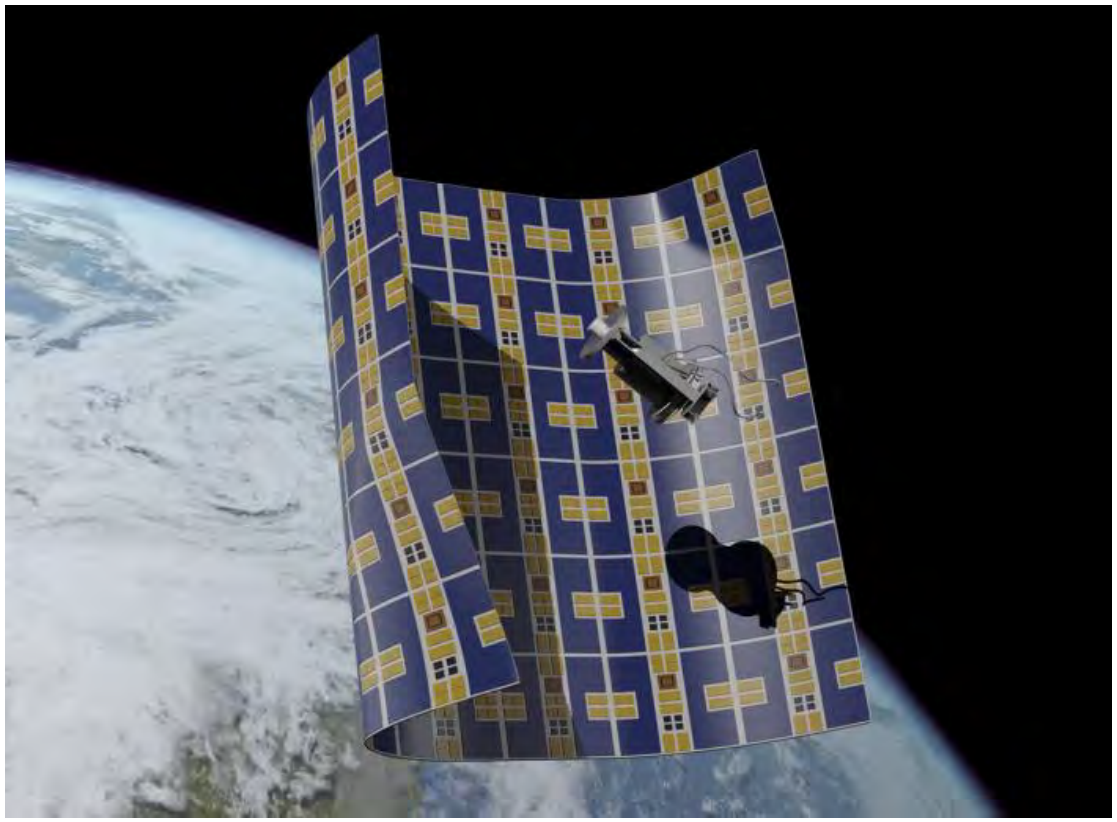


Reconfigurable spacecraft offered a new space paradigm, and still do!

Long-Term: Active Membrane Spacecraft

- Start from an initial orbit
- Move to target's orbit
  - *Major Thrusting*
- Rendezvous with target
  - *Minor thrusting*
- Wrap around target
  - *Shape change*
- Lower altitude to ~200km
  - *Major thrusting*
- Open up
  - *Shape change*
- Release target object
- Boost to higher altitude
  - *Major thrusting*
- Go after another target

Brane Craft: An Active Membrane Spacecraft



(Graphic: Joseph Hidalgo)

A Brane Craft is thinner than a human hair, yet has enough delta-V (ability to change velocity) to deorbit multiple space debris objects in different orbits. This mass-producible concept offers significantly reduced costs for deorbiting 1-kg class objects from low Earth orbit. It is funded by NASA's Innovative Advanced Concepts (NIAC) group.