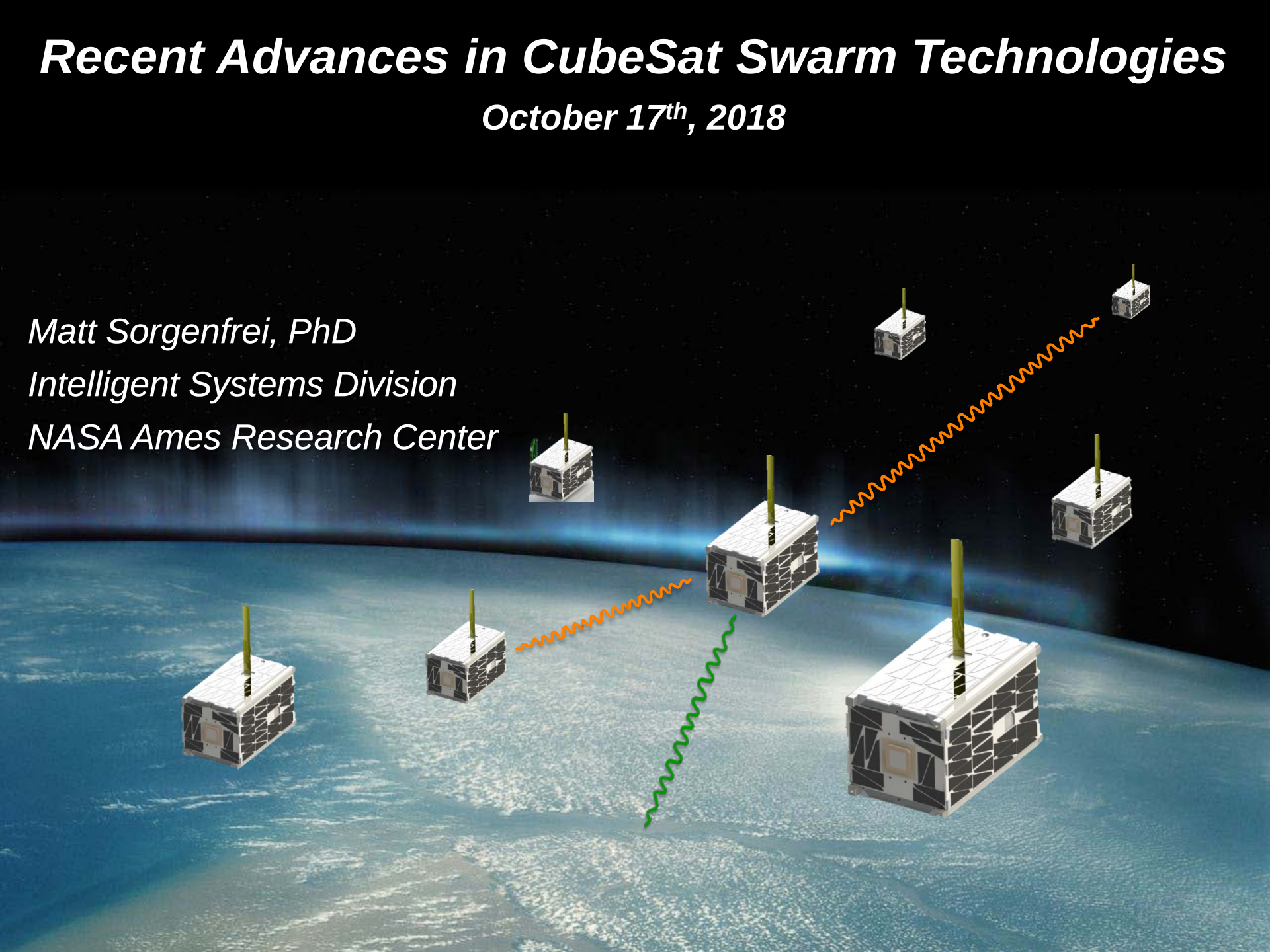
Recent Advances in CubeSat Swarm Technologies

October 17th, 2018

Matt Sorgenfrei, PhD
Intelligent Systems Division
NASA Ames Research Center

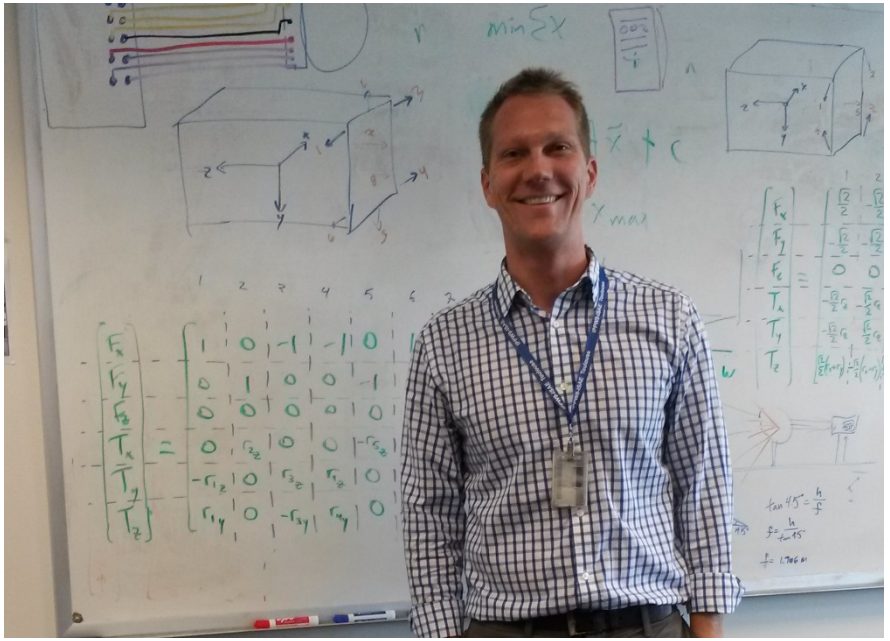


Outline

- **Introduction to NASA Ames**
- **Overview of CubeSats and Nanosatellites**
  - Past, present, and future missions and capabilities
- **The Edison Demonstration of SmallSat Networks (EDSN) Mission**

About the Speaker

- **Grew up in Palo Alto, CA**
- **Involved in FIRST Robotics in high School**
- **Bachelor's in Mechanical Engineering from Cal Poly, San Luis Obispo, Spring 2007**
- **PhD in Mechanical Engineering from UC Davis, Winter 2013**



I really have no idea what that math on the white board is all about…

A Diverse Range of Research Topics

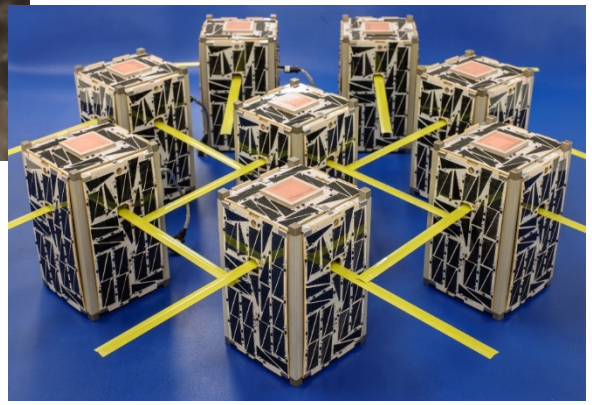
- **Aeronautics Research**
  - Fault tolerance, next generation aircraft, air traffic management
- **Thermal Protection Systems**
- **Information Systems**
  - Super computers, quantum computers
- **Robotics and Intelligent Systems**
- **Small Spacecraft**

NASA Ames Research Center, founded in 1939

How Small is Small?

Curiosity Rover: $2.5B

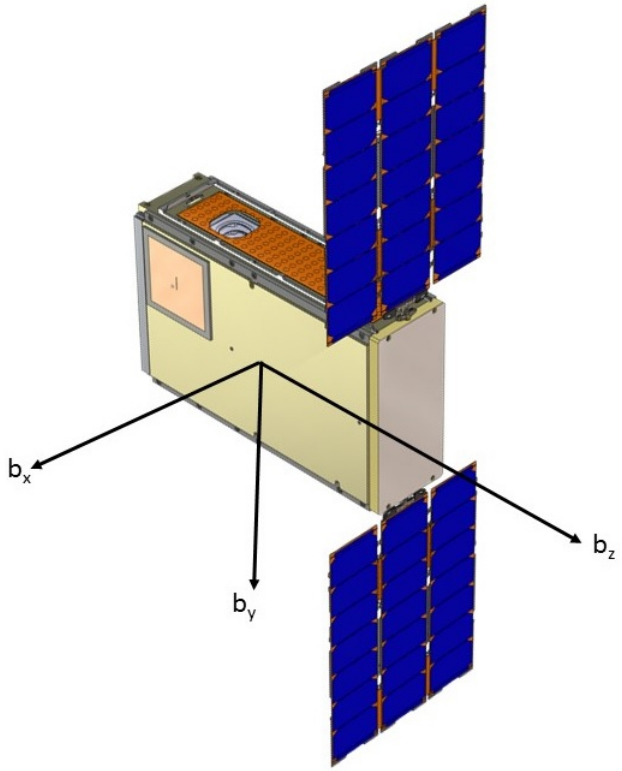
LADEE Spacecraft: $250M



EDSN Swarm: < $25M

A Brief Aside: The Attitude Determination and Control System (ADCS)

- The ADCS is responsible for determining how the spacecraft is oriented and changing that orientation as necessary
  - The spacecraft equivalent of cruise control in a typical car
- In space, we determine our orientation by looking for the sun, looking for specific stars, or measuring our spin rate
- Orientation is changed using spinning wheels, thrusters, or magnetic actuators



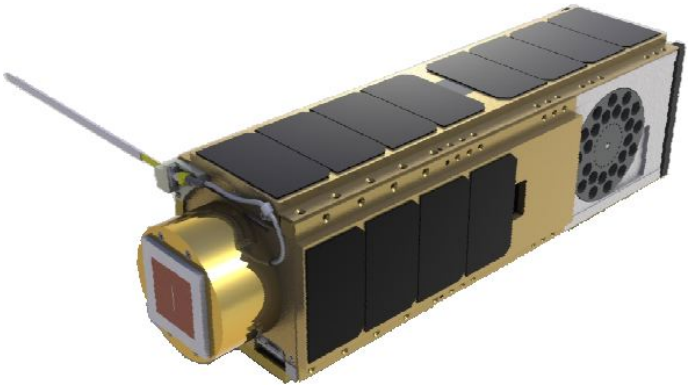
The BioSentinel Spacecraft, scheduled to launch in 2017

CubeSat (Nanosatellite) Development at NASA Ames

CubeSats at NASA Ames

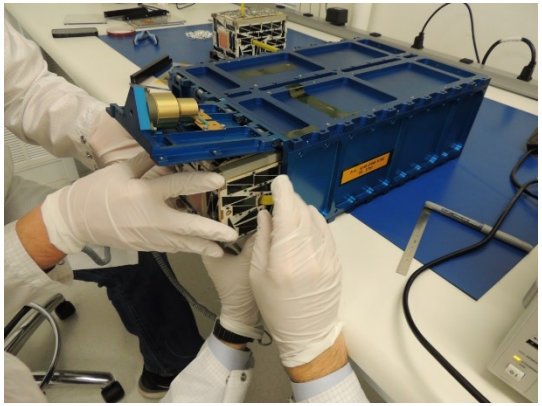
- **Single cube is 10cm x 10cm x 10cm and denoted as 1U (CubeSat standard)**
  - Natural discretization and modularity
- **Typical spacecraft range from 1U - 3U in size**
- **Volume/mass restrictions make many traditional spacecraft design approaches untenable**
- **NASA Ames has produced many scientific CubeSats**
  - GeneSat-1, PharmaSat, NanoSail-D, O/OREOS
  - Studied topics related to fundamental biology

An exploded view of the PharmaSat spacecraft

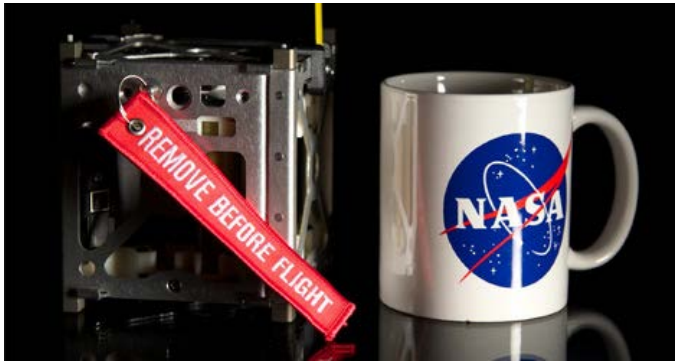


The O/OREOS spacecraft with two 1U science experiments

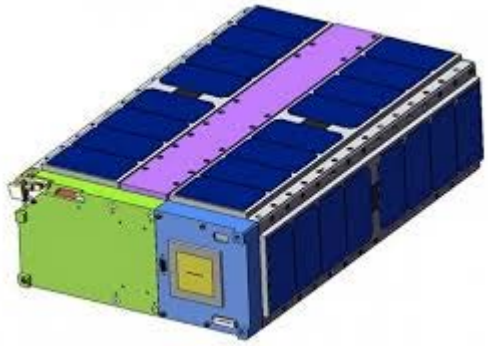
Rapid, Inexpensive Access to Space



An Increasing Range of Capabilities



The PhoneSat spacecraft makes use of a Google Nexus One phone



EcAmSat will be the first 6U spacecraft launched by NASA Ames

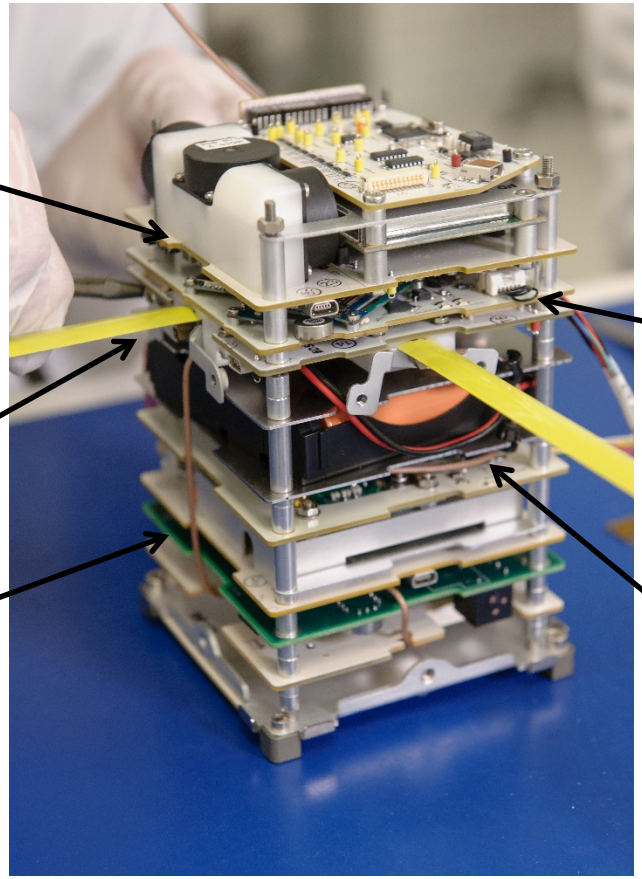
- **NASA Ames is expanding its range of CubeSat missions to include 1U, 1.5U, and 6U form factors**
- **The 1U PhoneSat series of missions leverages open source Android and Java technologies**
- **EcAmSat represents the first 6U spacecraft built by NASA Ames**
- **What could we do with multiple CubeSats?**

The Edison Demonstration of SmallSat Networks (EDSN) Mission

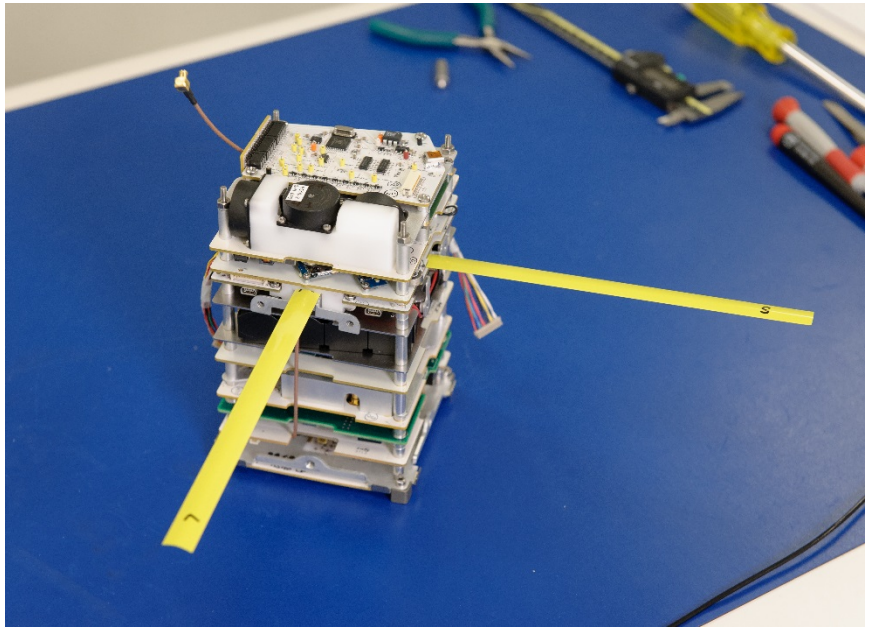
Mission Overview

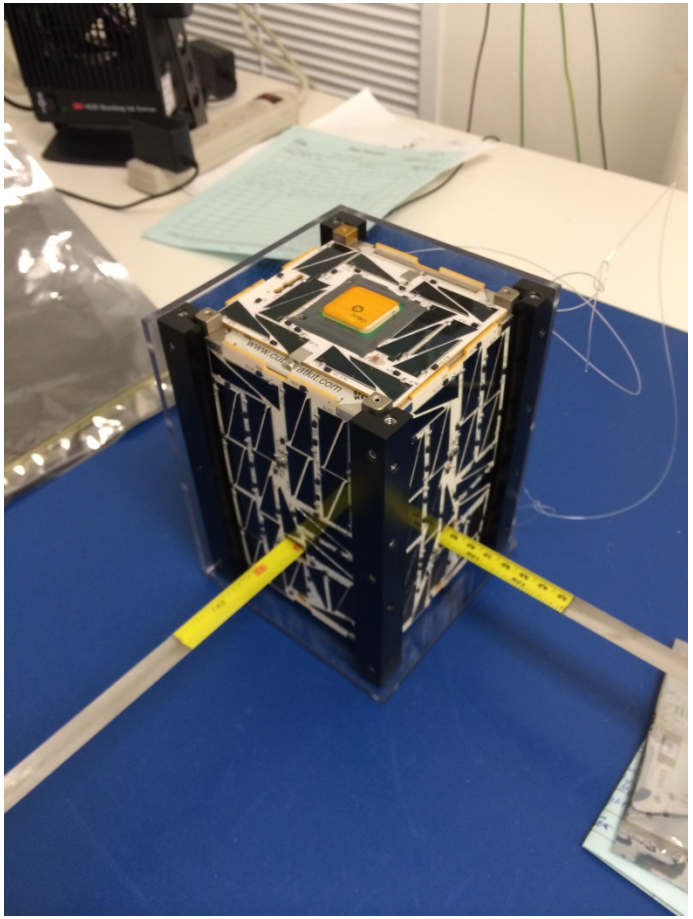
- **A swarm of eight 1.5U CubeSats deployed to low Earth orbit**
  - To be launched on a Department of Defense rocket in late 2015
- **Objective is to prove a range of concepts required for future multi-point science missions**
- **All eight spacecraft are identical**
  - Carry a radiation measurement experiment (EPISEM) provided by Montana State University, all the standard spacecraft subsystems, and **three** different radios
- **Ground Station support provided by Santa Clara University**

Under the Hood



Before and After

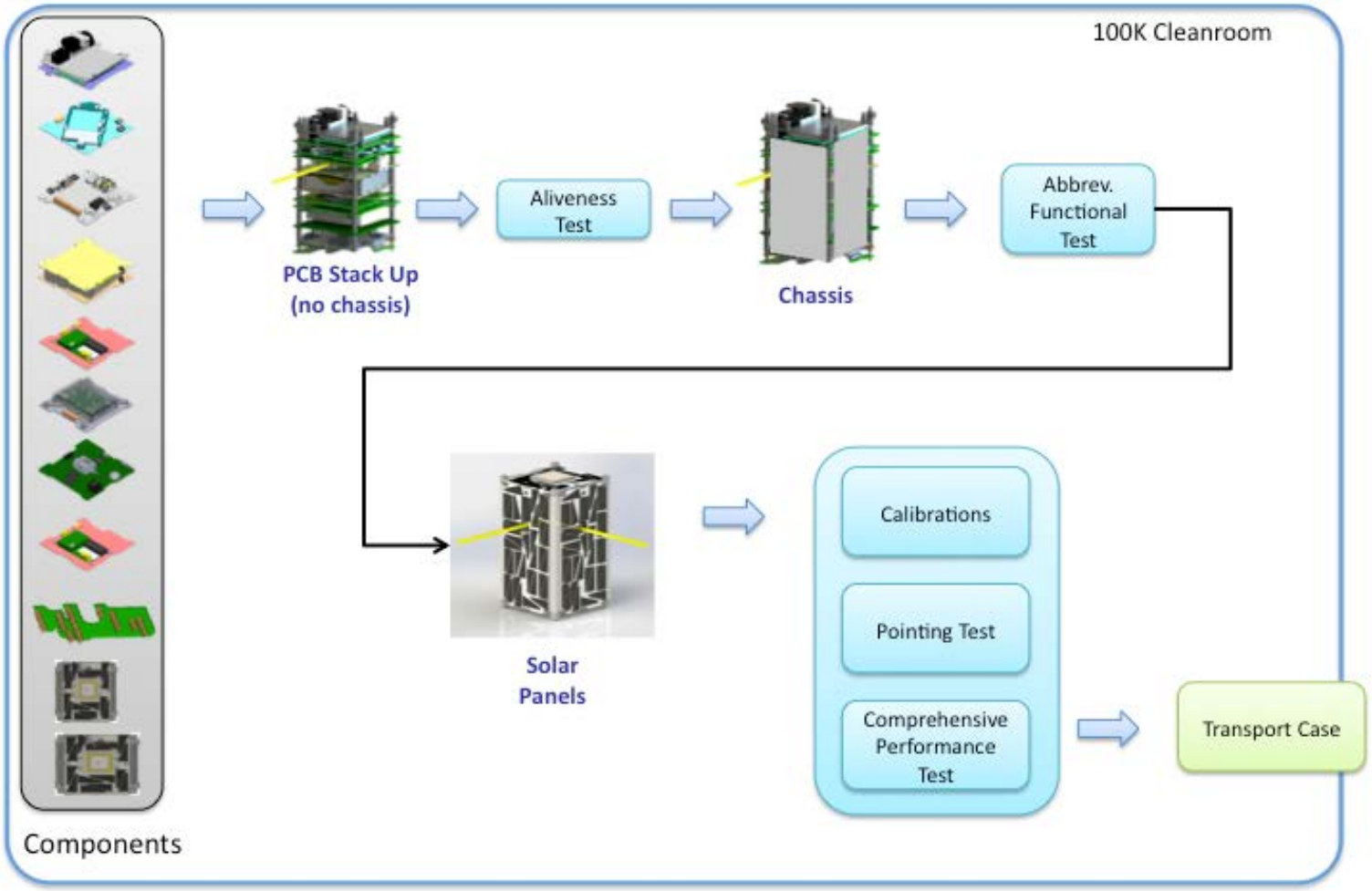




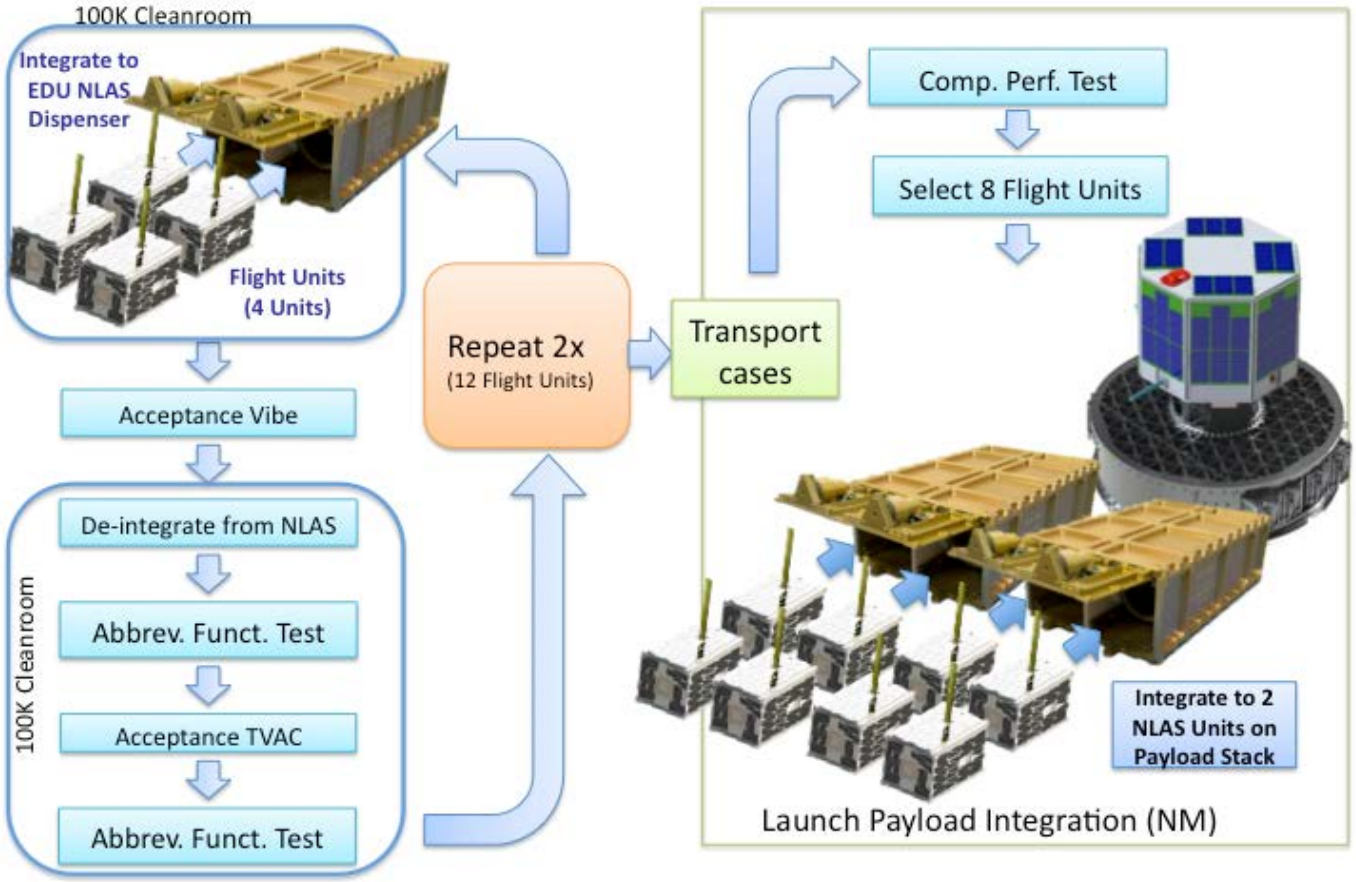
Integration and Testing Challenges

- **To guarantee a swarm of 8 flight units can be successfully delivered a total of 16 units will be built**
  - 4 Engineering Development Units (EDUs) and 12 flight units
  - Best-performing 8 will be selected from the 12 flight units
- **Every unit must be tested for basic aliveness/functionality as well as minimally acceptable performance**
  - Re-tests occurs after major testing events (thermal/vacuum, shock and vibe)
- **In addition to functional and performance tests, it is necessary to perform a mission simulation test to ensure that all mission objectives will be met**

Spacecraft Build-Up



Sample Testing Workflow

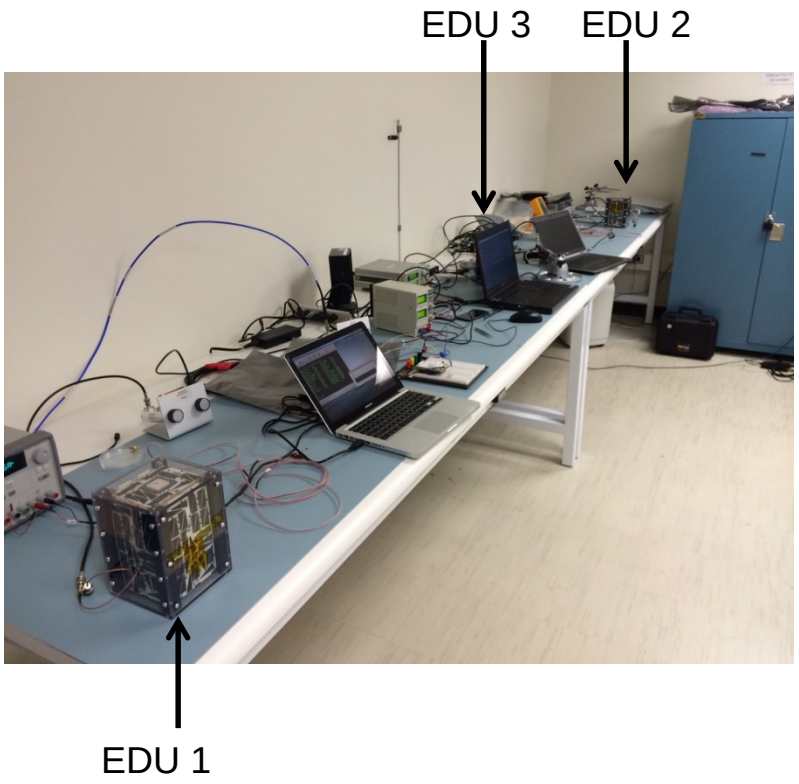


Functional and Performance Testing

At least we look good in hair nets….

- **Verify that spacecraft was built correctly and that software was loaded correctly**
- **Testable functions:**
  - Reaction wheel directions
  - Torque coil directions
  - Radio transmit/receive
  - GPS receive
  - EPISEM packet collection
  - Phone functionality
  - Sensor functionality

Mission Simulation Test



- **Verify that autonomous spacecraft operations can be carried out as expected**
- **Testable functions:**
  - Delayed start-up after tip-off from launch vehicle
  - Detumble operations
  - “Spoofed” GPS receive
  - EPISEM packet collection
  - Spacecraft Crosslink
  - Data downlink

Lessons Learned

- **CubeSats performing both science and attitude control must be very densely packed—assembly is complicated!**

- **16 spacecraft (even CubeSats) require a lot of space in which to be built**
  - One large clean room? Multiple clean rooms?

- **Produce flight software releases early and often**
  - Crucial for de-bugging software in a timely manner

Questions?

matthew.c.sorgenfrei@nasa.gov