CUBESATS 101

By Bryce L. Meyer

St. Louis UNIX Users Group

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Overview

- What are Cubesats?
  - History Slide
- What are they used for?
- Cubesat Architectures and Standards
  - AIAA/IEEE standards
  - Raspberry PI, Adrino Architectures

What Are CubeSats?

- CubeSats are small spacecraft (inc. satellites) , essentially Unmanned Space Vehicles (USVs) that can be built inexpensively and launched cheaply.
  - ‘U-Class’ spacecraft: Size defined by how many U’s (like networking equipment), i.e. 1U = 10cm x 10cm x 10cm.
  - Technically ‘Nanosats’ (Nanosatellites)
  - Typically bundled with other cubesats as a secondary payload for launch.
  - Previously just for experiments, now a serious way to get equipment into space.
  - Many kinds of spacecraft:
    - Lunar and Mars Landers
    - Asteroid Probes
    - Telecom (Broadband)
    - Earth Monitoring (ex: **Planet Labs**)
    - Short Duration Missions (emergency, millitary, etc.)

- See: https://www.nasa.gov/mission_pages/cubesats/index.html

History

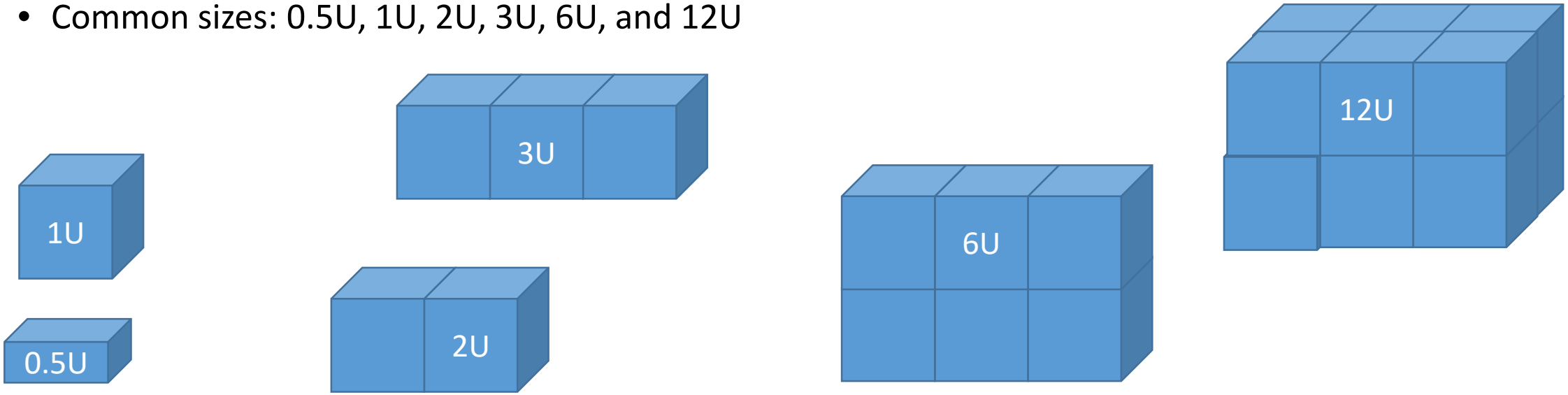
- Specification (CubeSat Design Specification) developed by Jordi Puig-Suari at CalPoly and Bob Twiggs at Standford, 1999
- Originally as a low cost way to get experiments into space, in a platform the size of Sputnik
- Initially Universities and Space Agencies
- Now Companies with many business cases and an ecosystem…

Currently a complex mix of many users

- Size and standards now used for probes, landers, and long range exploration

Size Specifications

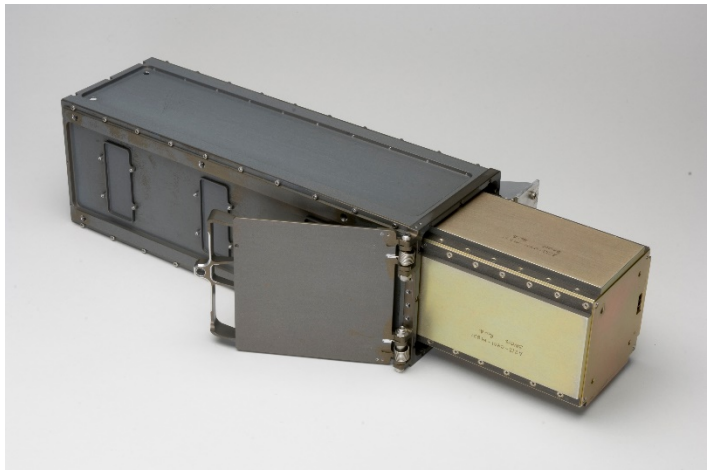
- See: http://mstl.atl.calpoly.edu/~bklofas/Presentations/DevelopersWorkshop2013/Carnahan_CubeSat_Standards_Update.pdf
- 1U
  - Volume: 10 cm x 10 cm x10 cm usable volume (10cm by 10 cm by 11.35 cm total), = 1 liter.
  - Mass: 1.33 kg per U
  - Common sizes: 0.5U, 1U, 2U, 3U, 6U, and 12U



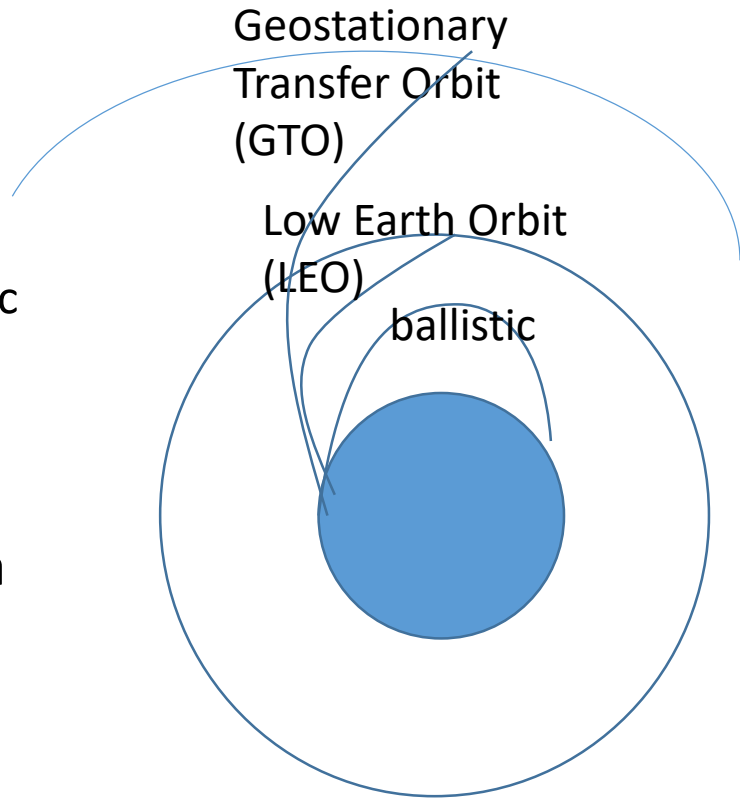
COTS Hardware

- Many companies now make parts and kits to make Cubesats
  - Kits:
    - Pumpkin Inc. http://www.cubesatkit.com/
    - IOS: http://interorbital.com/Cubesat%20Kits
    - (see also): **EEE Parts Database of CubeSat Projects and Kits – NASA**

Launching



- Can be a secondary payload or part of a primary payload
  - Launchers: Atlas, Delta, Falcon, LM, Ariane, Soyuz, PSLV, etc.
  - Made to specifically send up a few cubesats:
    - Electron, Neptune, New Armstrong/New Glenn, Virgin Galactic
    - Local: Stofiel Aersopace, etc.
  - How Much?
    - http://spaceflight.com/schedule-pricing/
    - Typically $300K to $1M for LEO, $1-3M for GTO, far less for a ballistic trajectory
    - Very soon: $50K for 1U….
- Poly-PicoSatellite Orbital Deployer (P-POD):
  - Similar to a clip in a gun, uses a spring to pop cubesats out of a launcher
- Can be shot out or pitched from the ISS too



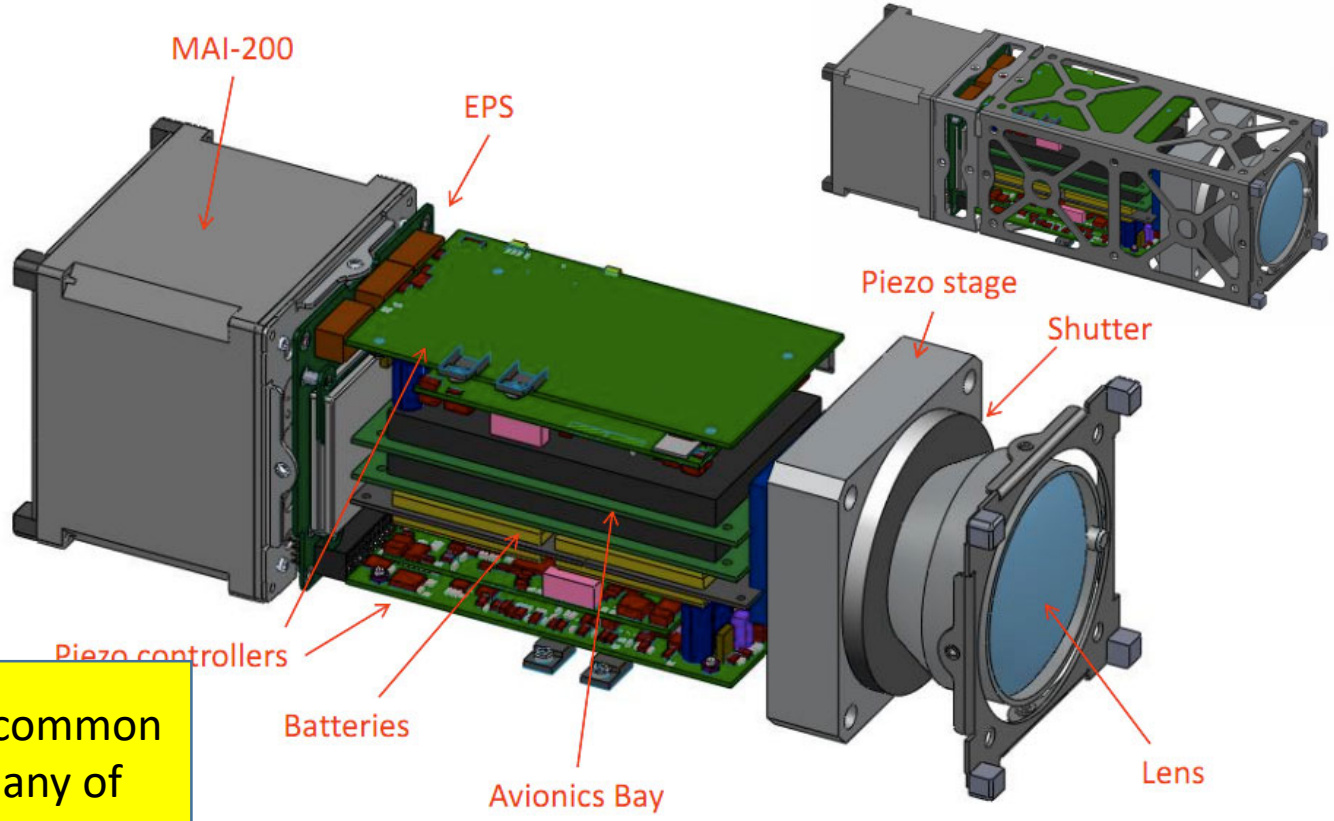
Physical Considerations

- Remember, this is going into SPACE!
  - Vibration and Acceleration Stresses
    - Heavy vibration and >3g accelerations
  - Electromagnetic
    - Ballistic/LEO = inside Van Allen radiation belts so lower radiation than GTO or further
  - Temperature
    - -120 C (-184 F) to +120 C (+248 F) at LEO
  - Vacuum
    - If it is pressurized at 16 psi (1 atm) it will need to be beefed up

Design Elements

- Structure
- Propulsion
- Attitude Control
- Power
- Environment Control
- Sensors
- WAN+LAN
- Processors and Controllers
- Mission Equipment
  - Can be Telecom….
- Redundancy

Linux common in many of these!



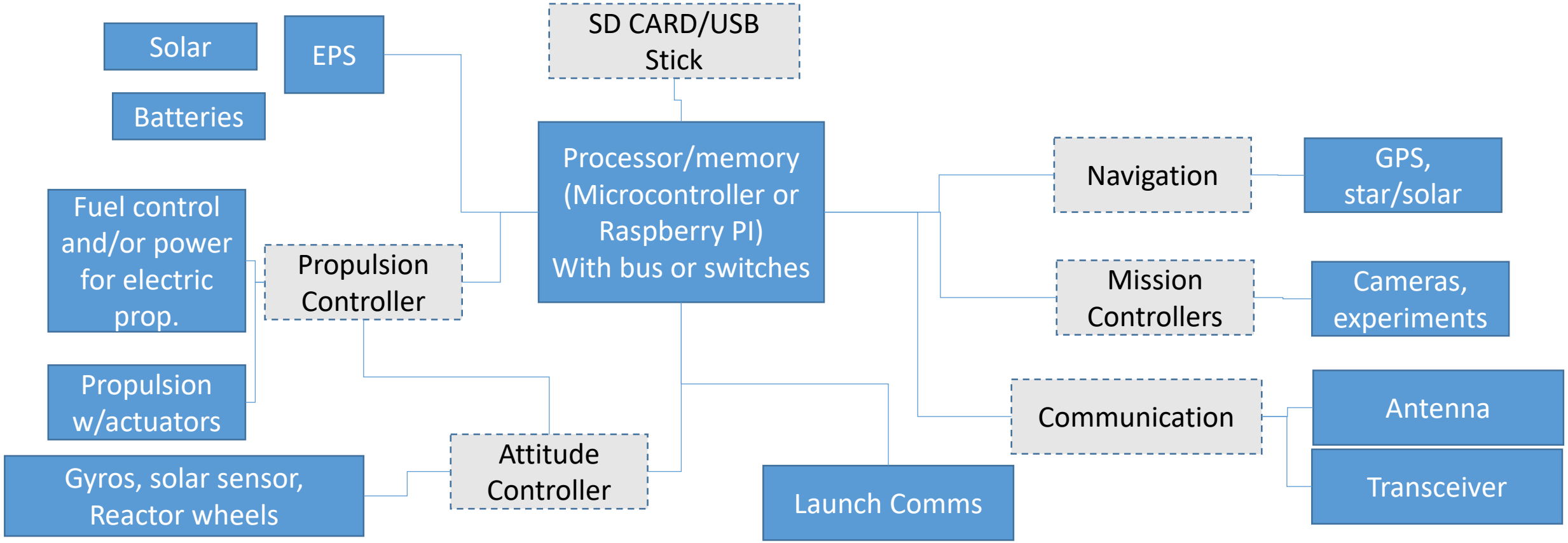
https://www.nasa.gov/topics/universe/features/cubesatstudents.html

https://www.raspberrypi.org/blog/compute module-cubesats/

http://www.cubesatkit.com/content/datasheet.html

System Architecture

- Many components are required to make a cubesat work
- COTS is key, so most things use USB standards, PC Cards, SD RAM, etc.
- here is a notional 'network' view:



Structure

- The ‘box’ is the skeleton on the cubesat
- Rails for launch
- Runs for wires and access

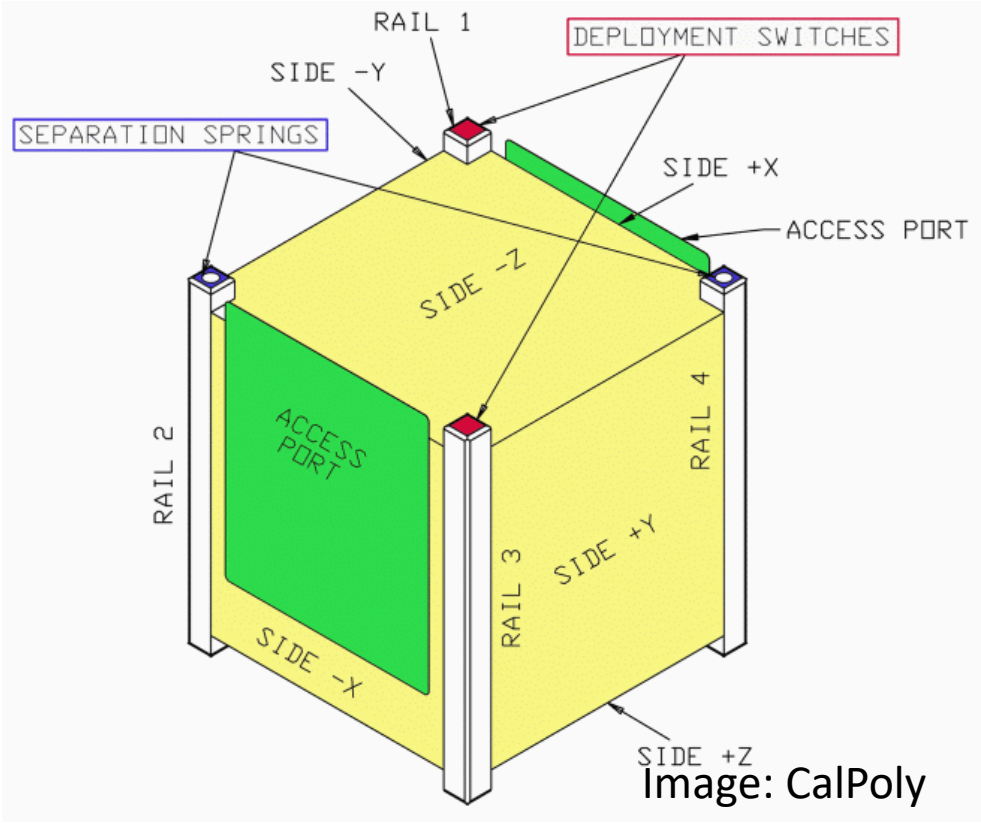
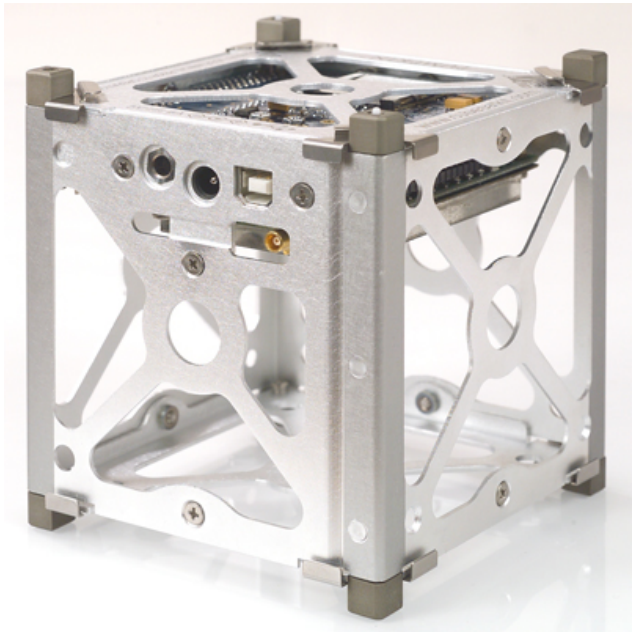


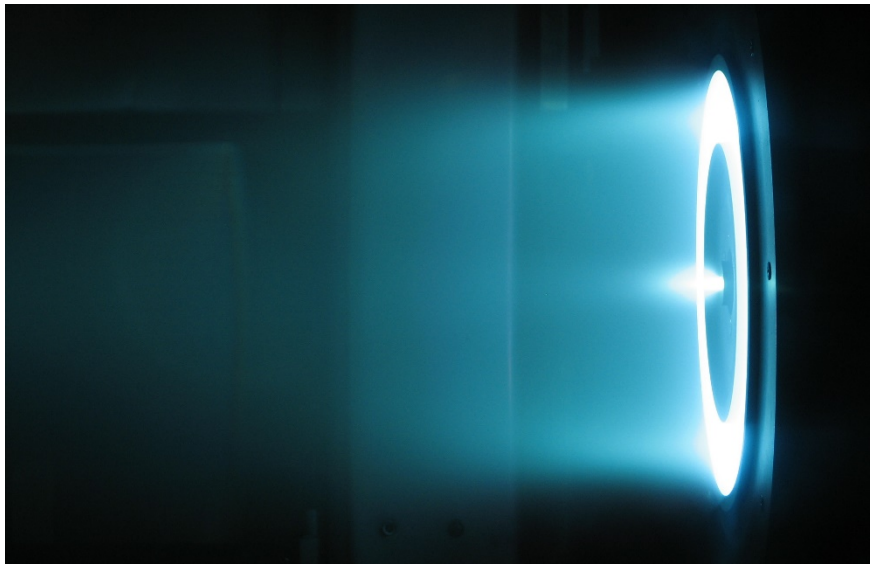
Image: CalPoly

CubeSatKit by Pumpkin, Inc.
http://www.cubesatkit.com/



Propulsion

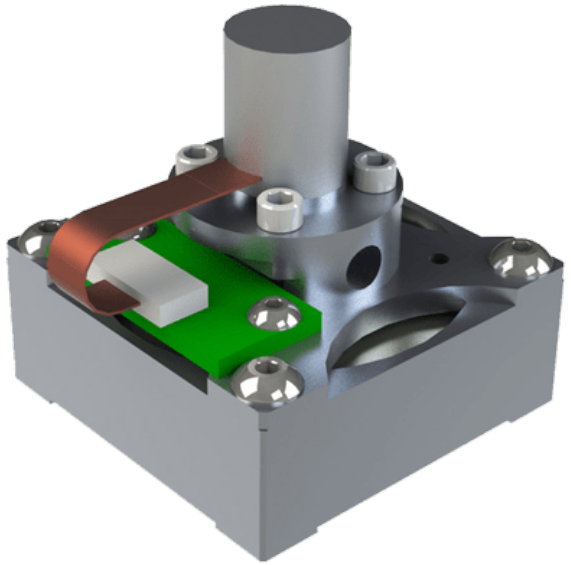
- Need propulsion to: Keep Orbit, Change Orbit, Maneuver
- Many use Chemical Propulsion due to low electrical cost
  - ex: VACCO
- Some have gone to Electric Propulsion too:
  - Ex: BUSEK Hall Effect
- Solar Sails are also in consideration



Attitude Control

- Attitude Control is what keeps a cubesat pointed in a direction
- Typically combinations of gyroscopes and reaction wheels
- VERY important for imagery collection (i.e. pointing the satellite back at the Earth, Moon, etc.)

MAI-400 Reaction Wheel



https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140002972.pdf

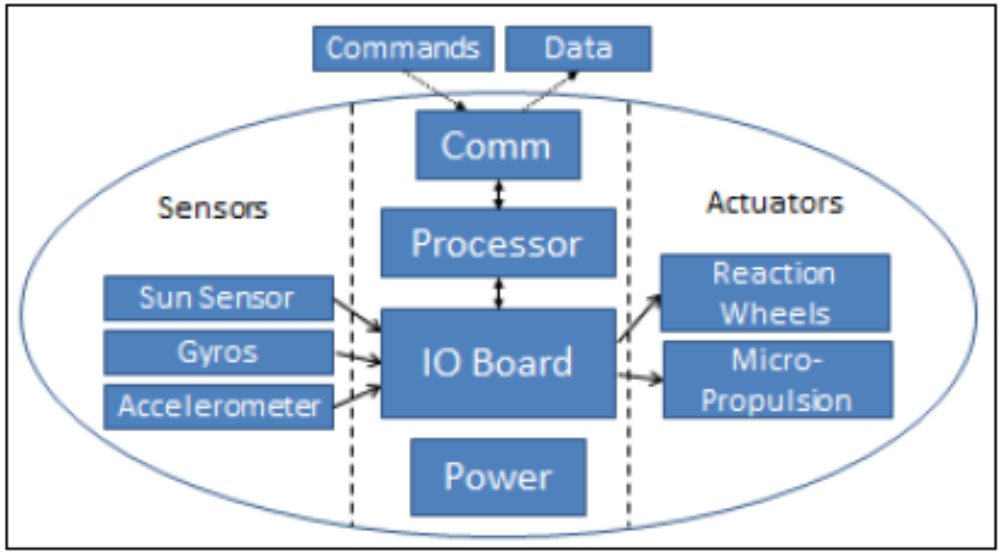


Figure 2 - System Architecture

Power

- 3.3 VDC and 5 VDC.
- Usually Batteries with or without solar cells
- For ballistic or short duration missions, batteries may be good enough.
  - Batteries however, may need to be cooled or heated….
- Solar cells are unfolded after launch
- EPS (Electrical Power System) controller and processor to make sure voltage, etc. are AOK for the rest of the cubesat.

Sensors

- LEO and Ballistic orbiting cubesats can use GPS for location
- Optical:
  - For Navigation: Stellar and Solar
  - Imagery (Earth, Astronomy)
- Electromagnetic
- Accelerormeters
- Etc. etc.
- Will need to be networked (bussed) with processors, etc.

Processors and Controllers + Actuators

- Usually a motherboard-card architecture:
  - http://www.cubesatkit.com/content/datasheet.html

Communications

- VHF, UHF, L-, S-, C- and X-band
- Usually means having a pop-out antenna of some type….
- Not just ‘calling home’. Cubesats can mesh and network together for many uses (including making ‘orbital clouds’, etc.)

Software (and Linux!)

- Cubesats run a real time (or RT like) OS, usually a flavor of Linux, or a directly compiled OS
  - Can use LINUX! (especially if they use a Raspberry PI as central processor!)
    - Also can use other distros with Real Time libraries/skins, Usually stripped of all unneeded parts
      - Ex: RTLinux
    - See also: http://mstl.atl.calpoly.edu/~bklofas/Presentations/SummerWorkshop2012/Fitzsimmons_Open_Source_Software.pdf
  - Microcontroller or processor RTOSs
    - http://www.cubesatkit.com/docs/press/20120812_Pumpkin_CSDWLU_2012-1.pdf
    - FreeRTOS, TinyOS, etc.
    - Ex: **Salvo (see also: http://www.pumpkininc.com/content/doc/manual/SalvoUserManual.pdf)**
      - **Runs on the microcode of a controller/processer, written in C**

Opportunities in data and software

- Many opportunities exist in the cubesat world including:
  - Parts and software to run on cubesats and components
  - Software to process big data from cubesats
  - Software to use information from big data from cubesats
  - Etc. etc.

Corporate Users

- In addition to universities and space agencies, companies have lofted and use cubesats.
- Planet, inc. https://www.planet.com/ uses hundreds of CubeSats for imaging
- Nanosatisfi LLC: Sells data from cubesats for a variety of uses
- Boeing
- Google, Amazon have examined them for broadband extension

https://en.wikipedia.org/wiki/List_of_CubeSats

Local Competitions/Users

- Missouri S&T Cubesat Team (M-SAT):
  - http://web.mst.edu/~mrsat/
  - (They were at ISDC 2017…
- Univ. of Illinois
  - http://cubesat.ae.illinois.edu/
- Wash U
  - https://source.wustl.edu/tag/cubesats/

CONCLUSIONS

- Anyone can make a cubesat
  - Launch may not be cheap now, but will be!
  - Lots of kits and COTS
- Cubesats have many uses
  - Anything that can be squeezed into 1U, 3U, 6U, etc.
- Cubesats can and do run LINUX and other RTOSs
  - Many open source design tools and software
- Data mining from cubesats is a big deal!
  - Anyone can get into this too!