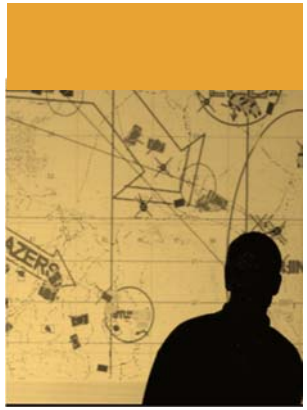
SRI International



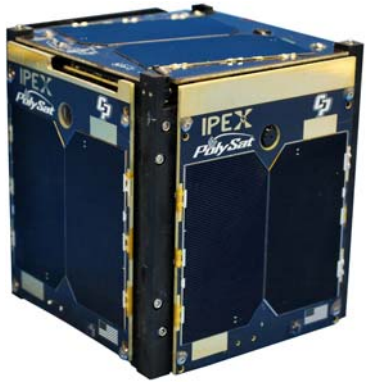
# CubeSat Radios: From kilobits to Megabits

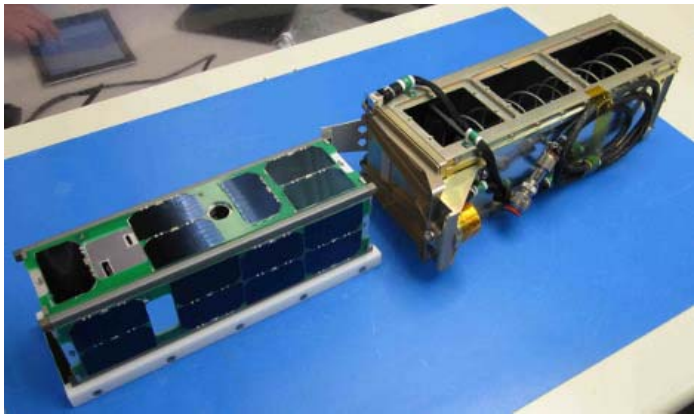
Bryan Klofas
SRI International
bryan.klofas@sri.com

Ground System Architectures Workshop
Los Angeles, California
26 Feb 2014

# CubeSat Background

- CubeSat project started in 2000 as an international educational experiment
- Mechanical standard only: 10 x 10 x 10cm, up to 1.33kg is 1U
- Deployers typically hold 3U



- GeneSat (NASA Ames) was the first Government CubeSat in 2006
- NRO Colony program accelerated the building of Government CubeSats
- CubeSats launched to date:
  - 95 University CubeSats (NSF)
  - 11 Commercial CubeSats
  - 47 US Government (NASA and DOD)

# CubeSat Launches (1 of 3)

| Name | Vehicle | Date | # CubeSats | Total U |
|---|---|---|---|---|
| NLS-1 | Rockot | 06/30/2003 | 6 | 8 |
| SSETI Express | Kosmos-3M | 10/27/2005 | 3 | 3 |
| M-V-8 | M-V-8 | 02/22/2006 | 1 | 2 |
| Minotaur-1 | Minotaur 1 | 12/11/2006 | 1 | 3 |
| Dnepr 2 | Dnepr | 04/17/2007 | 7 | 9 |
| NLS-4 | PSLV-C9 | 04/28/2008 | 5 | 9 |
| Minotaur-1 | Minotaur 1 | 05/19/2009 | 4 | 6 |
| ISILaunch-01 | PSLV-C14 | 09/23/2009 | 4 | 4 |
| H-IIA F17 | H-IIA | 05/20/2010 | 3 | 3 |
| NLS-6 | PSLV-C15 | 07/12/2010 | 2 | 2 |

# CubeSat Launches (2 of 3)

| Name | Vehicle | Date | # CubeSats | Total U |
|---|---|---|---|---|
| STP-S26 | Minotaur 4 | 10/19/2010 | 3 | 9 |
| Falcon 9-002 | Falcon 9 | 12/08/2010 | 8 | 18 |
| PSLV-C18 | PSLV-C18 | 10/12/2011 | 1 | 3 |
| ELaNa-3/NPP | Delta 2 | 10/28/2011 | 5 | 9 |
| Vega VV01 | Vega | 02/13/2012 | 7 | 7 |
| ELaNa-6/NROL-36 | Atlas 5 | 09/13/2012 | 11 | 24 |
| ISS | HTV-3/ISS | 10/04/2012 | 5 | 6 |
| PSLV-C20 | PSLV-C20 | 02/25/2013 | 2 | 4 |
| ISILaunch-02 | Soyuz | 04/19/2013 | 5 | 7 |
| Antares Demo | Antares | 04/21/2013 | 4 | 6 |

# CubeSat Launches (3 of 3)

| Name | Vehicle | Date | # CubeSats | Total U |
|---|---|---|---|---|
| Long March 2D | Long March 2D | 04/26/2013 | 3 | 6 |
| Vega VV02 | Vega | 05/07/2013 | 1 | 1 |
| ISS | HTV-4/ISS | 10/19/2013 | 4 | 6 |
| ELaNa-4/ORS-3 | Minotaur 1 | 10/20/2013 | 28 | 48 |
| ISILaunch-03 | Dnepr | 10/21/2013 | 18 | 33 |
| ELaNa-2/NROL-39 | Atlas 5 | 12/05/2013 | 12 | 24 |
| | | Totals: | 153 | 260 |

# Future CubeSat Launches

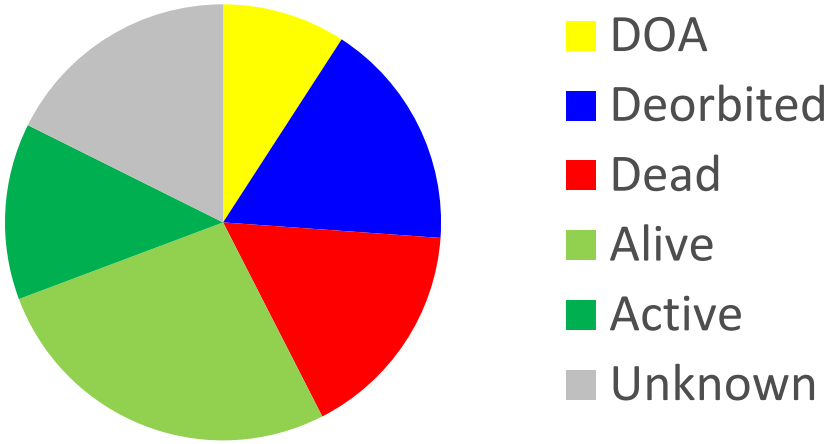
| Name | Vehicle | Date | # CubeSats | Total U |
|---|---|---|---|---|
| Orb-1/ISS | Antares/ISS | Feb 2014 | 33 | 96 |
| ISILaunch | Soyuz | Feb 2014 | 1 | 3 |
| ELaNa-5/CRS-3 | Falcon 9 | Mar 2014 | 5 | 12 |
| ELaNa-7/ORS-4 | Super Strypi | Fall 2014 | | 24 |
| ELaNa-10/SMAP | Delta II | Nov 2014 | 3 | 9 |
| GRACE/NROL-55 | Atlas 5 | Dec 2014 | | 24 |
| ULTRASat/AFSPC-5 | Atlas 5 | Feb 2015 | | 18 |
| STP-2 | Falcon 9 Heavy | Fall 2015 | | 27 |
| | | Totals: | 42+ | 213 |

# Summary of CubeSats 2003 to 2014

- 153 CubeSats Launched (not including latest Orb-1/ISS)

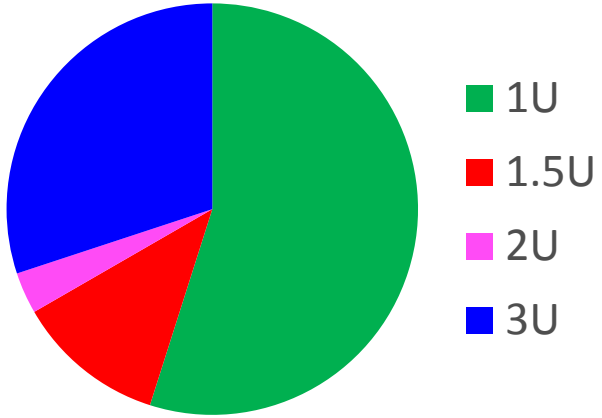
- Launch Failures:
  - Dnepr-1 launch (14)
  - Falcon-1 (2)
  - ELaNa-1/Taurus XL (3)

- Status of CubeSats as of Feb 2014:
  - DOA: 14
  - Deorbited: 26
  - Dead: 25
  - Alive: 41
  - Active: 20
  - Unknown: 27 (just launched)

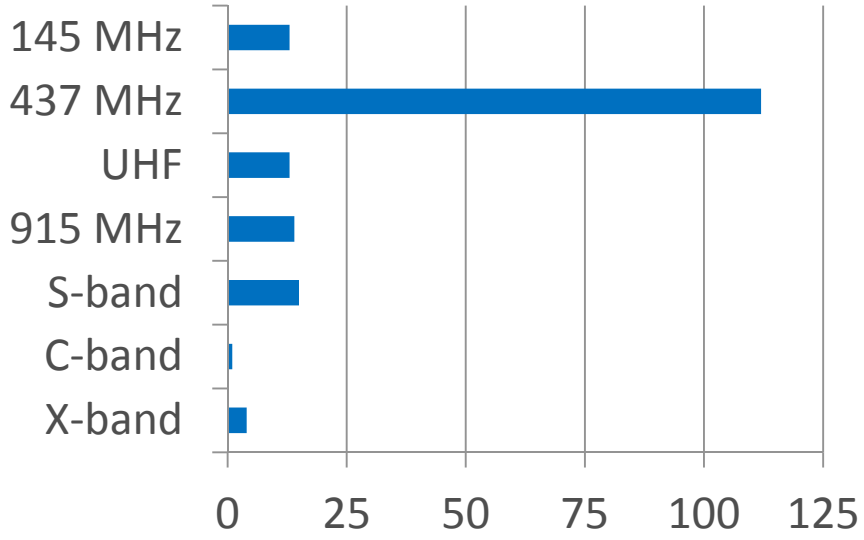


# CubeSat Details: Size and Transmitters

- Size of CubeSat (Total 153 CubeSats):
  - 1U: 84
  - 1.5U: 18
  - 2U: 5
  - 3U: 46

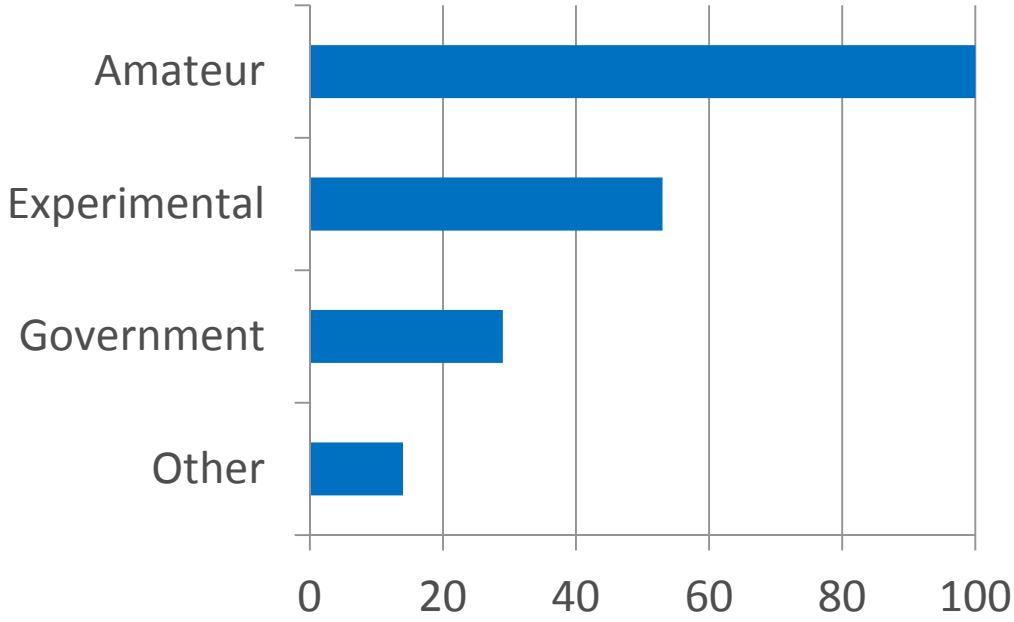



- Transmitters (Total 172 transmitters):
  - 145 MHz amateur radio: 13
  - 437 MHz amateur radio: 112
  - Other UHF spectrum: 13
  - 915 MHz experimental: 14
  - S-band: 15
  - C-band: 1
  - X-band: 4



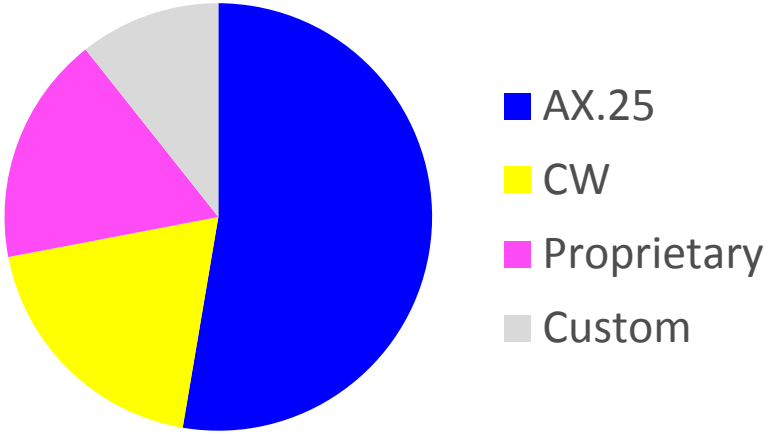
# CubeSat Details: Satellite Service Used

- Satellite Service (Total 196 transmitters):
  - Amateur: 100
  - Experimental: 53
  - Government: 29
  - Other:
    - Earth exploration: 2
    - Meteorological: 2
    - Space research: 4
    - Unlicensed/unknown: 6

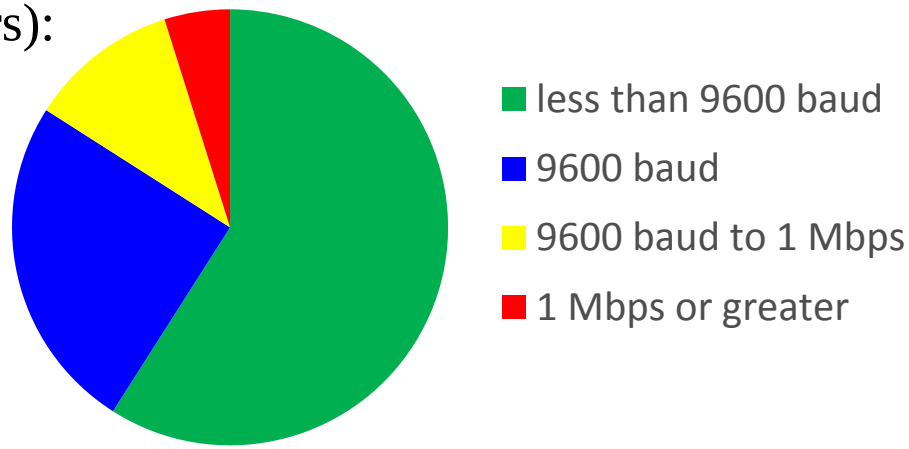


# CubeSat Details: Protocols and Data Rates

- Protocols (Total 150 transmitters):
  - AX.25: 79
  - CW: 29
  - Proprietary: 26
  - Custom: 16 (CCSDS, Mobitex, DVB-S2, etc)

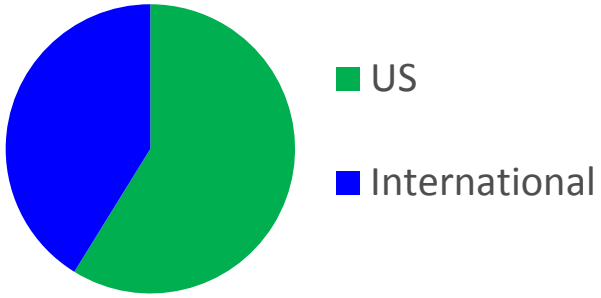



- Max data rates (Total 144 transmitters):
  - < 9600 baud or CW: 85
  - 9600 baud: 36
  - 9600 baud to < 1 Mbps: 16
  - 1 Mbps or greater: 7
    - Hayato, DICE, CINEMA, Dove+



# CubeSat Details: Countries

- Countries (Total 27 countries, 153 CubeSats):
  - USA: 90
  - Japan: 11
  - Germany: 9
  - Denmark: 4
  - Netherlands: 3
  - South Korea: 3
  - Spain: 3
  - Argentina: 2
  - Canada: 2
  - Ecuador: 2
  - England: 2
  - India: 2
  - Italy: 2
  - Norway: 2
  - Switzerland: 2
  - Turkey: 2
  - Vietnam: 2
  - Colombia: 1
  - Estonia: 1
  - France: 1
  - Hungary: 1
  - Pakistan: 1
  - Peru: 1
  - Poland: 1
  - Romania: 1
  - Singapore: 1
  - South Africa: 1



# Satellite and Ground Segment Classes

- Mission funding determines communications system
  - No funding for ground segment infrastructure
  - Very little thought given to the next mission, except using the same hardware
- In most cases, there is little funding for the ground segment
  - The satellite is more interesting
- Two classes of communications systems
  - Basic or low-speed
  - Advanced

# Basic Satellite Radios

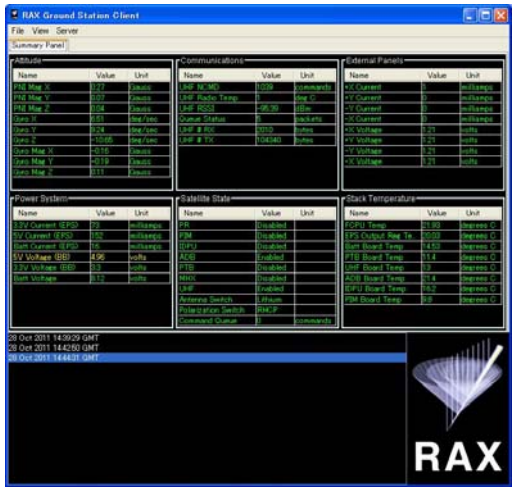
- First CubeSat radios were modified handheld amateur radios
  - Alinco DJ-C5
  - Yaesu VX-2R
- In schools with RF experience, single-chip transceivers were used
  - Designed for keyless entry systems
  - CC1000
  - RF2905
- By 2010, basic radios built for CubeSats were commercially available
  - AstroDev
  - ISIS
  - Gomspace


# Basic Ground Stations

- Typically use UHF amateur radio spectrum
  - Easy to obtain a frequency license
  - Hardware is very inexpensive
- Amateur radio transceivers and TNCs
  - Icom 910 or Yaesu TS-2000 hardware radios
- Yagi antennas
- 9600 baud or less
- AX.25 packet formatting
  - No encryption or error correction
- Total cost $10k or less

# Basic Ground Station Networks

- With very slow data rates, the only way to increase the amount of data downlinked is to use multiple ground stations
- Many teams have built software programs that interested people can install on their ground station to upload data
- If implemented well, these ad hoc networks can provide hundreds of MBytes to the PI
- These programs are usually closed-source and work with only one mission
  - University of Michigan Java decoder is open-source, and used across their three missions and CSSWE



# Advanced Satellite Radios

- As CubeSat missions get more advanced, the amount of data to downlink is increasing dramatically
- First publically-acknowledged high-speed radio was DICE, October 2011
  - L3 Cadet-U radios on 465 MHz at 2.6 Mbps
  - Wallops 18-m UHF dish for free
  - Total downloaded: 8.4 GBytes
- CHDC working group looking into this issue
- No current radios support NEN, DSN, or other existing commercial ground station networks
- Each radio at least $10k

# Advanced Ground Segments

- Except for Government CubeSats, most teams do not have the resources to build or use advanced ground stations
  - Satellite radio and ground station hardware is cost-prohibitive
  - Latest NSF teams have more resources from other university programs
- NASA Wallops trying to build a network with L3 Cadet
- University of Michigan designing a USRP network

# Advanced Ground Station Networks

- Most university teams can't even support a single advanced ground segment, and can't support a network
- For those teams that would like to rent time on a network, there are several hurdles:
  - Commercial networks (USN) are cost-prohibitive
  - No cost model to support single satellites
- No standard downlink protocols or data rates
  - The future is software-defined radios, so lack of standards is not a factor
- No established low-cost networks, so most teams create their own
  - Planet Labs (COTS DVB-S2 hardware)
  - NanoSatisfi (USRP)
- Government ground station networks do exist
  - Naval Postgraduate School and MC3 network
  - USAF
  - NASA Ames/SCU

# Future

- Hundreds more CubeSats will be launched in the next few years
- For universities and small teams, existing ground segment solutions and frequencies will dominate for the near future
- Constellations will break the small ad hoc ground segment networks
  - More dispersed ground segments must be built
  - Ground station networks must be fully automated
- Organizations are building CubeSat constellations
  - Perseus
  - Planet Labs
  - QB50
- Cost is the driving factor for all missions (except US government-funded)

# Thank You


*Headquarters: Silicon Valley*

**SRI International**
333 Ravenswood Avenue
Menlo Park, CA 94025-3493
650.859.2000

*Washington, D.C.*

**SRI International**
1100 Wilson Blvd., Suite 2800
Arlington, VA 22209-3915
703.524.2053

*Princeton, New Jersey*

**SRI International Sarnoff**
201 Washington Road
Princeton, NJ 08540
609.734.2553

*Additional U.S. and international locations*

**www.sri.com**