CubeSats and Mission Success: 2017 Update

(with a closer look at the effect of process management on outcome)

Michael Swartwout
Parks College of Engineering, Aviation & Technology
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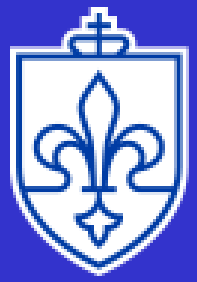
2017 Electronics Technology Workshop
NASA Goddard Space Flight Center
27 June 2017



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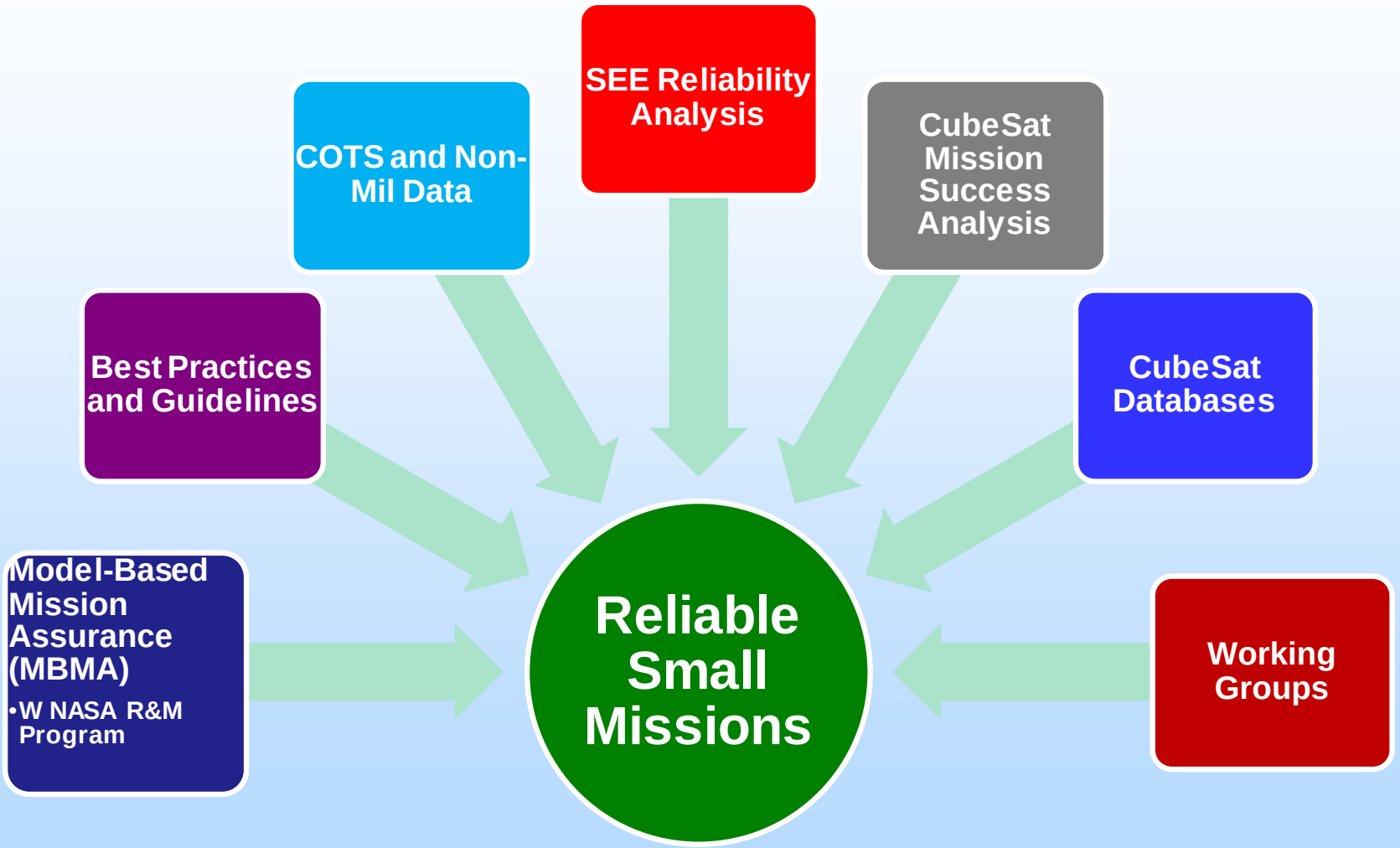
NEPP - Small Mission Efforts



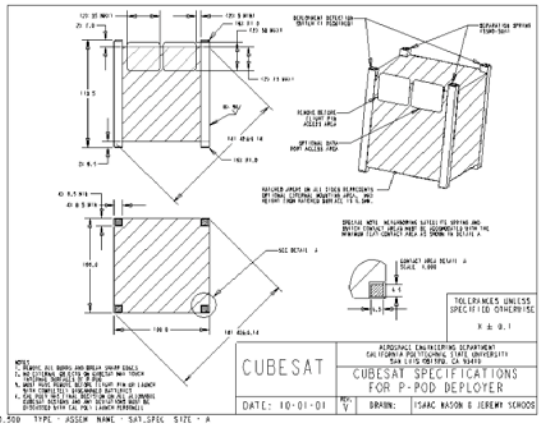
Motivation and Objectives

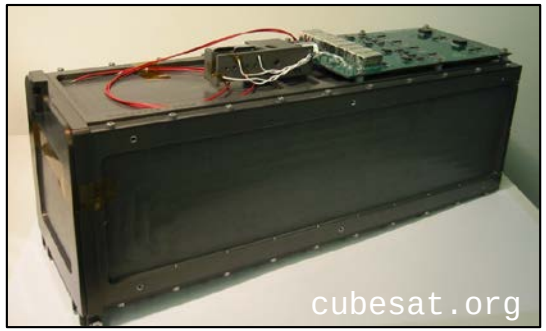
- CubeSats: Toys, tools, or debris cloud?
- CubeSats Bring Opportunities
  - Missions: Single-instrument science, **commercial constellations**
  - Schedule: Concept-to-operations in under 24 months
  - Modularity: Form-factor forcing standardized parts
- CubeSats Bring Risks
  - Actual Capabilities: Reports are confusing, conflated, and/or apocryphal
  - Cost-to-performance: Is it good? [What is good?!?!]
  - Go Fever: should we view CubeSats as a magic solution to all our space problems?
- Our Plan (sponsored by NEPP)
  - Collect data on missions, teams, performance
  - Analyze/sort
  - Identify strengths, weakness and opportunities

The Next 25 Minutes

- Define terms
  - CubeSat
  - Types of CubeSat Developers
- 2017 Update
  - Raw numbers
  - What's new: India!
  - What's new: Constellations!
  - What's not new: Failure rates!
- Mission success in CubeSats: Parts vs Process?
  - Census trends (and caveat about forecasting)
  - Helpful (?) categorizing of programs
  - Working hypotheses on mission success

[Do I Still Need to Define a CubeSat?]





- Twiggs (Stanford) and Puig-Suari (Cal Poly) defined a standard for carrying 10 cm, 1 kg cubes into space
- Enabling/Driving Technology: P-POD
  - Key feature: launch container
  - Volume, not mass, is the driver (!?!?)
- Milestones
  - **1999** Concept definition, flight validation
  - **2003** First flight with CubeSat specification
  - **2010** 70th flight
  - **2012** 100th flight; NASA selects 33 CubeSats to fly (backlog of 59)
  - **2013** 28 CubeSats on the same launch
  - **2014** ISS ejects 52 CubeSats over the year
  - **2015** 400th flight
  - **2017** 600th flight (101 on same launch)

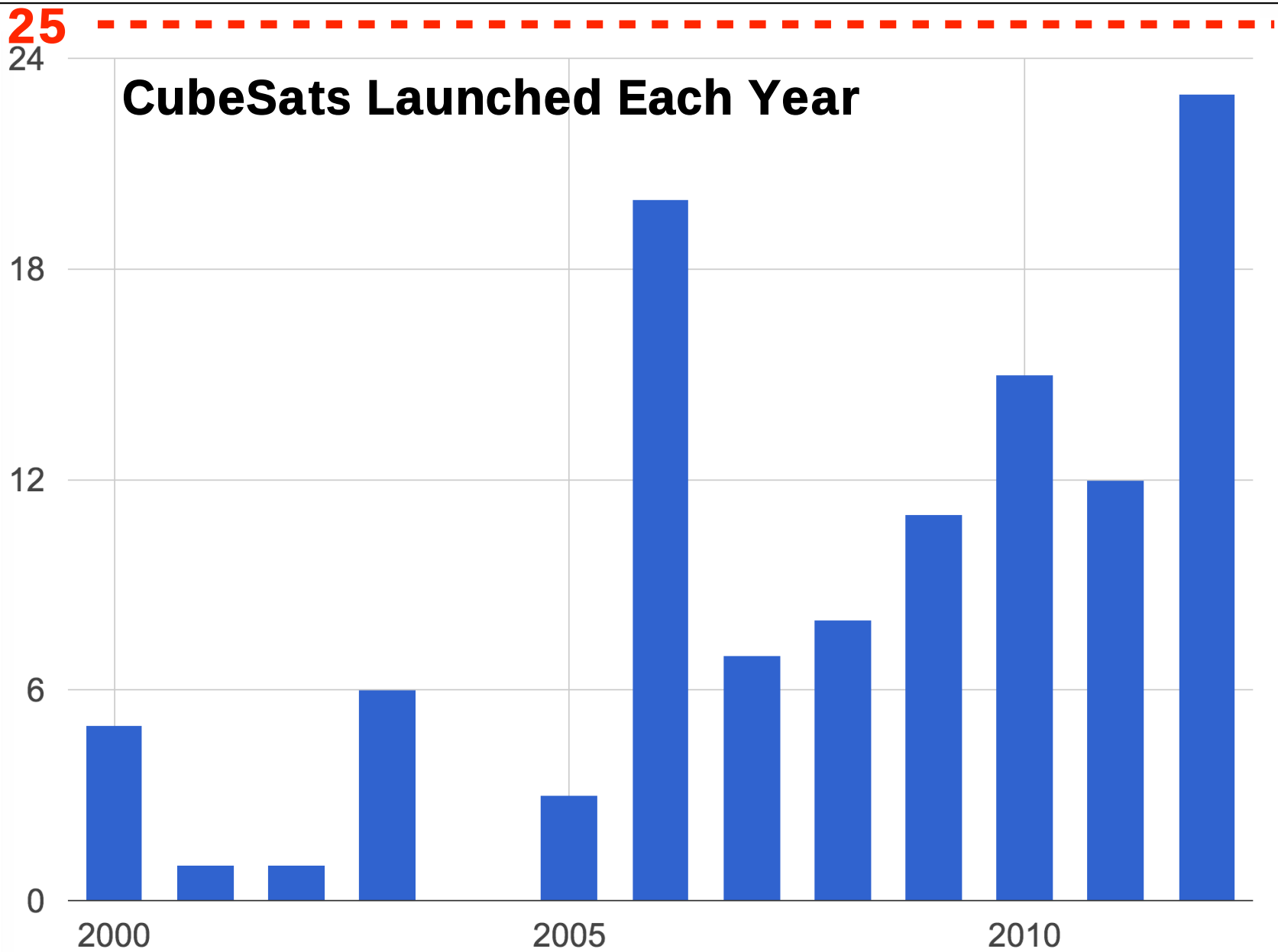
How to Create These Lovely Plots

- Scour databases, ask lots of questions
  - Public: Gunter's Space Page (international launch log)
  - Public: Jonathan's Space Report (orbital elements)
  - Public: DK3WN Satblog (university/amateur operations)
  - Public: Union of Concerned Scientists (operational status)
  - Public: Program websites, conference presentations
  - Private: Personal communications
- Compile information into a central database
  - "Census" data, plus our own internal assessments
  - Web-accessible/searchable/plotable
- Try not to pull your hair out when several dozen CubeSats deploy in the span of 3 days
- All plots (and more): https://sites.google.com/a/slu.edu/swartwout/home/cubesat-database/etw2017

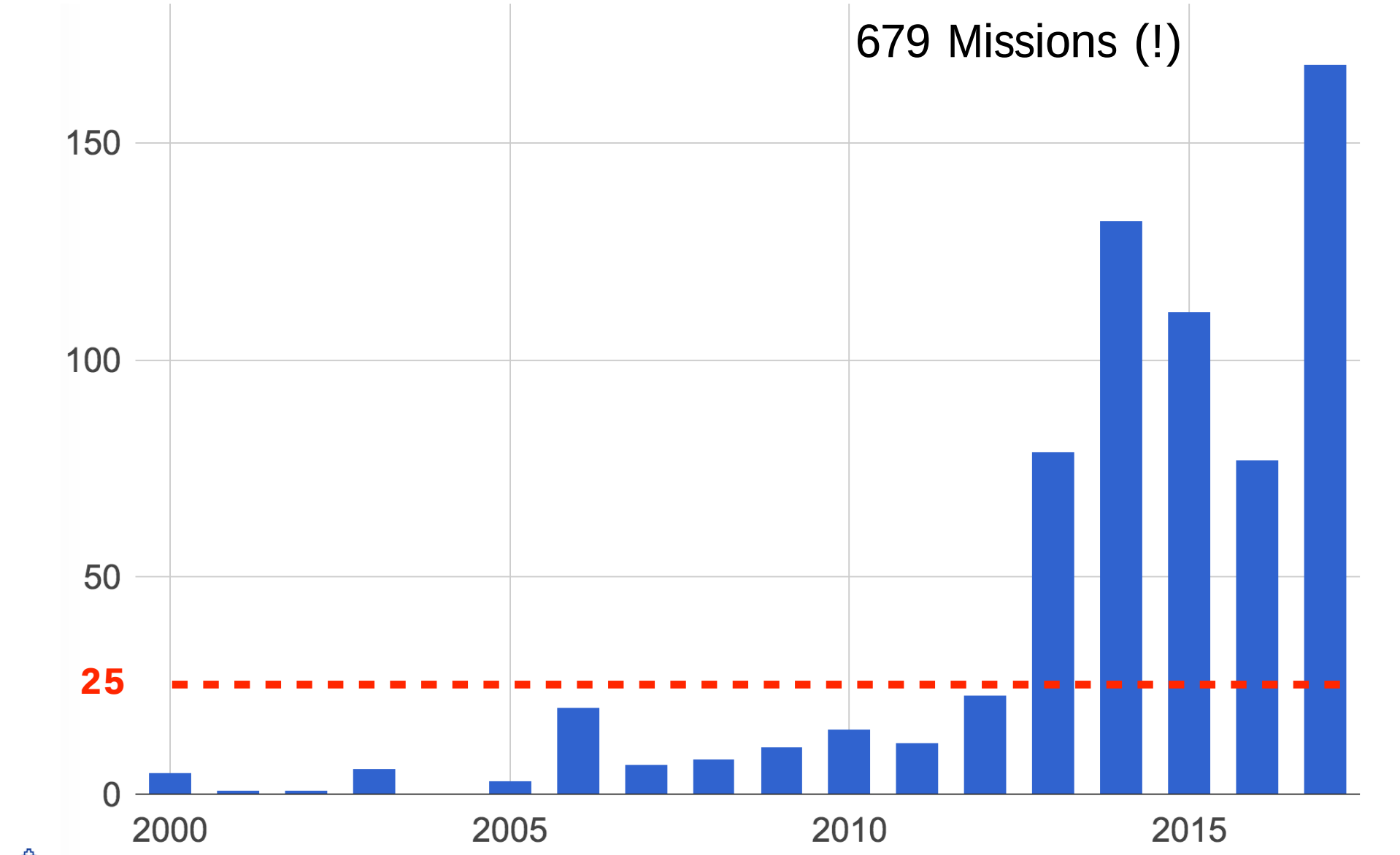
In Our Database

- Data quality: **Complete**, **partial**, **incomplete**
- Census Data
  - Identifiers (**NORAD, COSPAR, Mission Name**)
  - Basic parameters (**Mass, size**)
  - Launch and orbit (**Launch site, launch date, orbit elements, launch vehicle**, **ejector**, **decay date**)
  - Organization (**Prime contractor, user/sponsor**)
  - Mission (**Description**)
  - **Key instruments/components**
- Mission assessments
  - **Category/type of mission, developer**
  - **Mission and functional status**
  - **Operational milestones**
- Not collected (yet?)
  - Cost

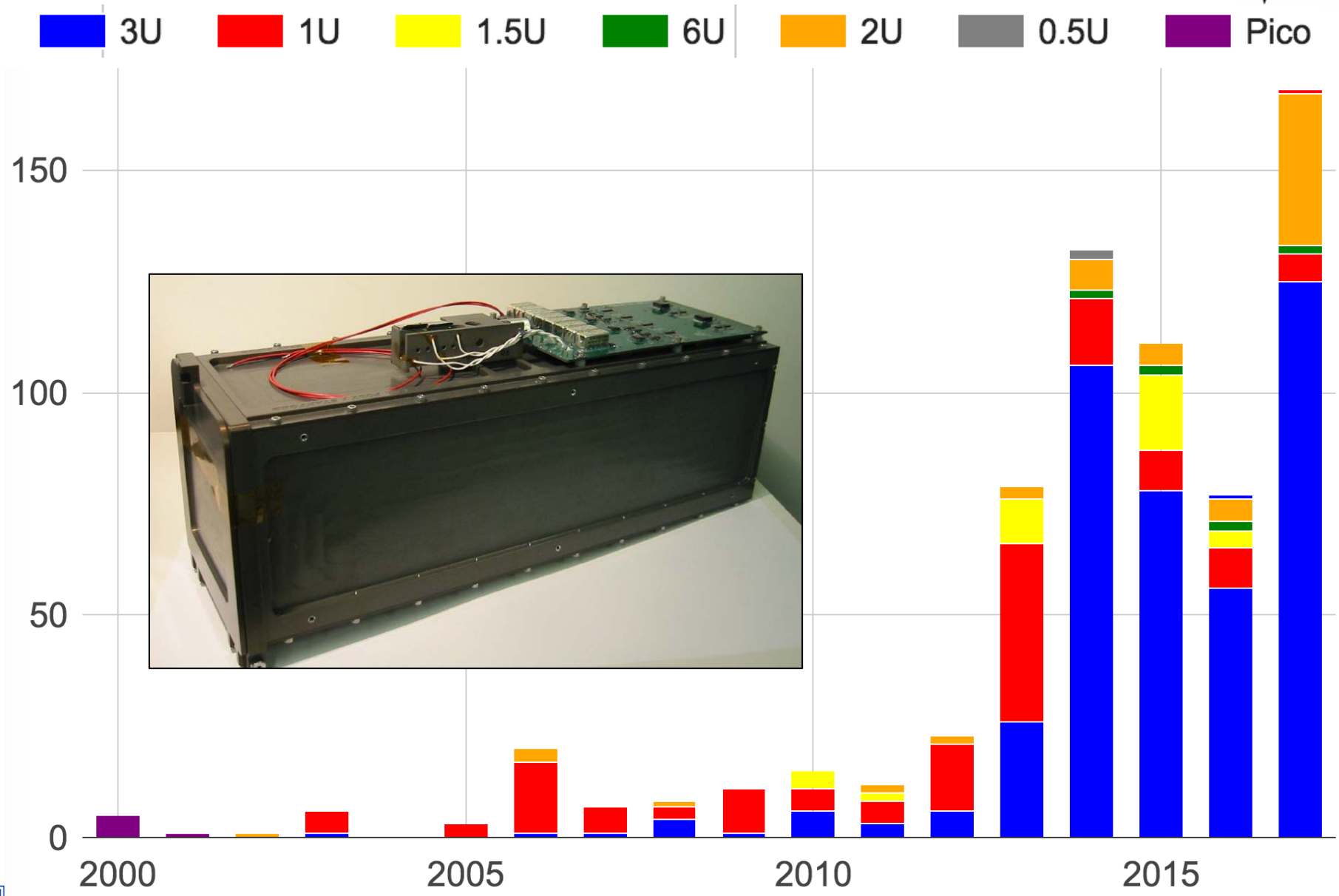
2012: I remember when …



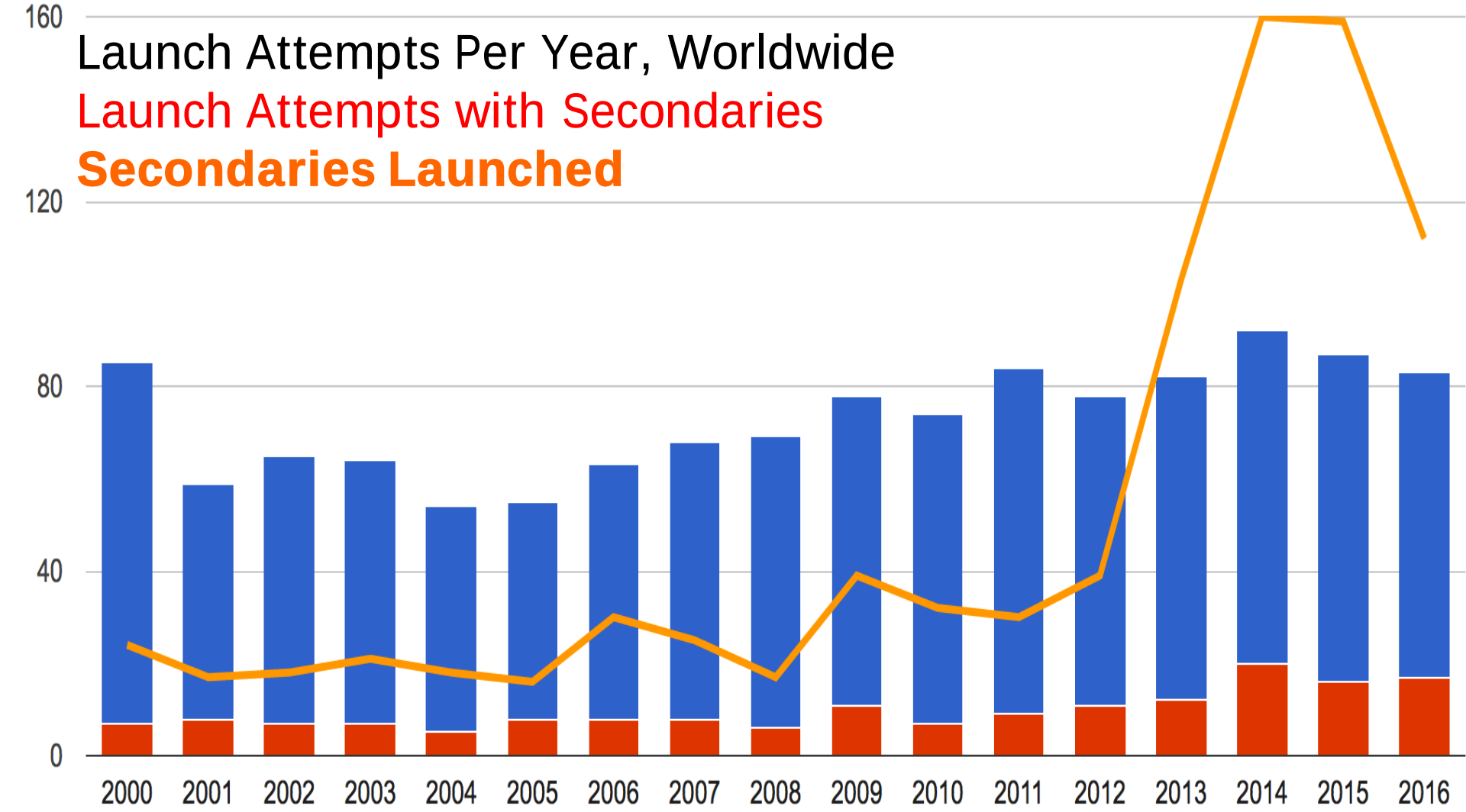
CubeSats Launched (2000-2017)



CubeSats by Form Factor

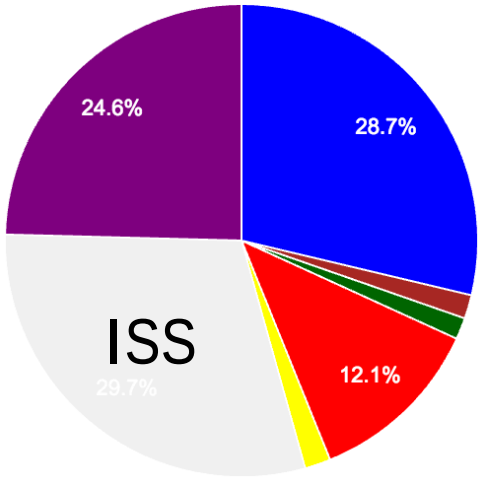


How are they reaching orbit?

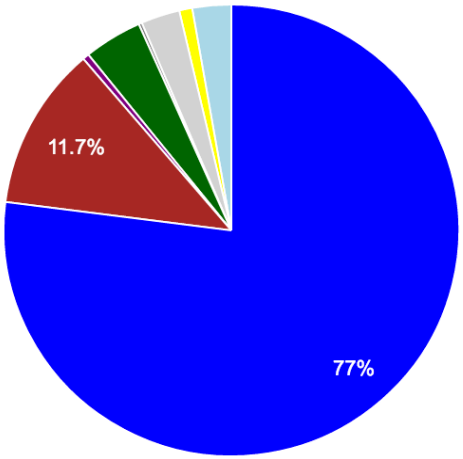


CubeSat By Nation (2000-present)

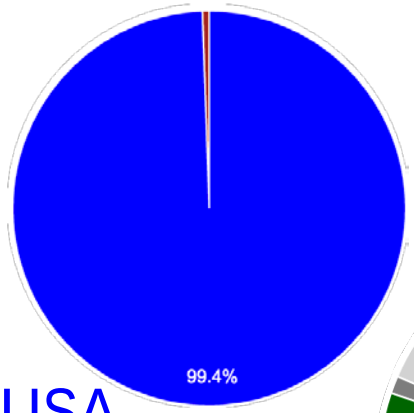
Launch Provider (679)



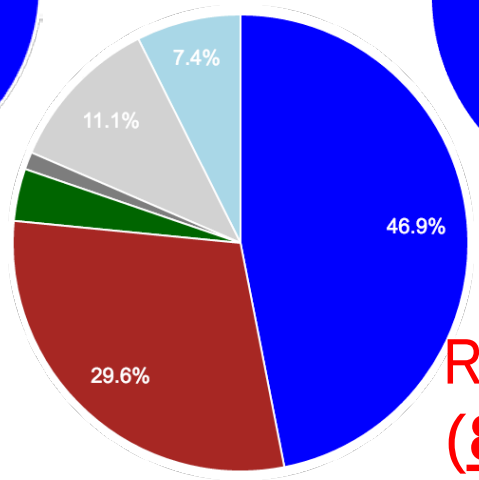
Builder (679)



CubeSats By Launch Provider

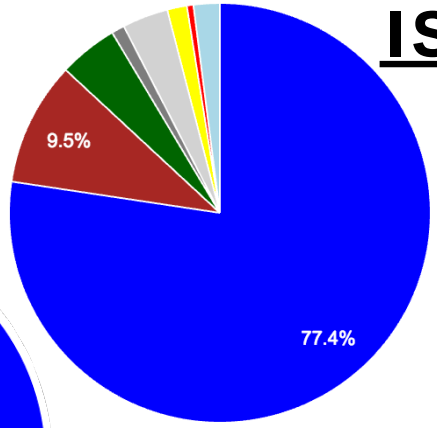


USA (195)

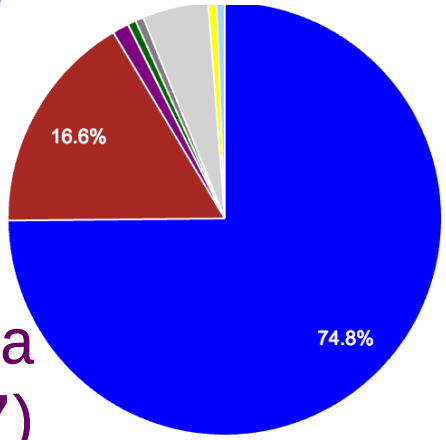


Russia (**82**)

ISS (202)



India (**167**)

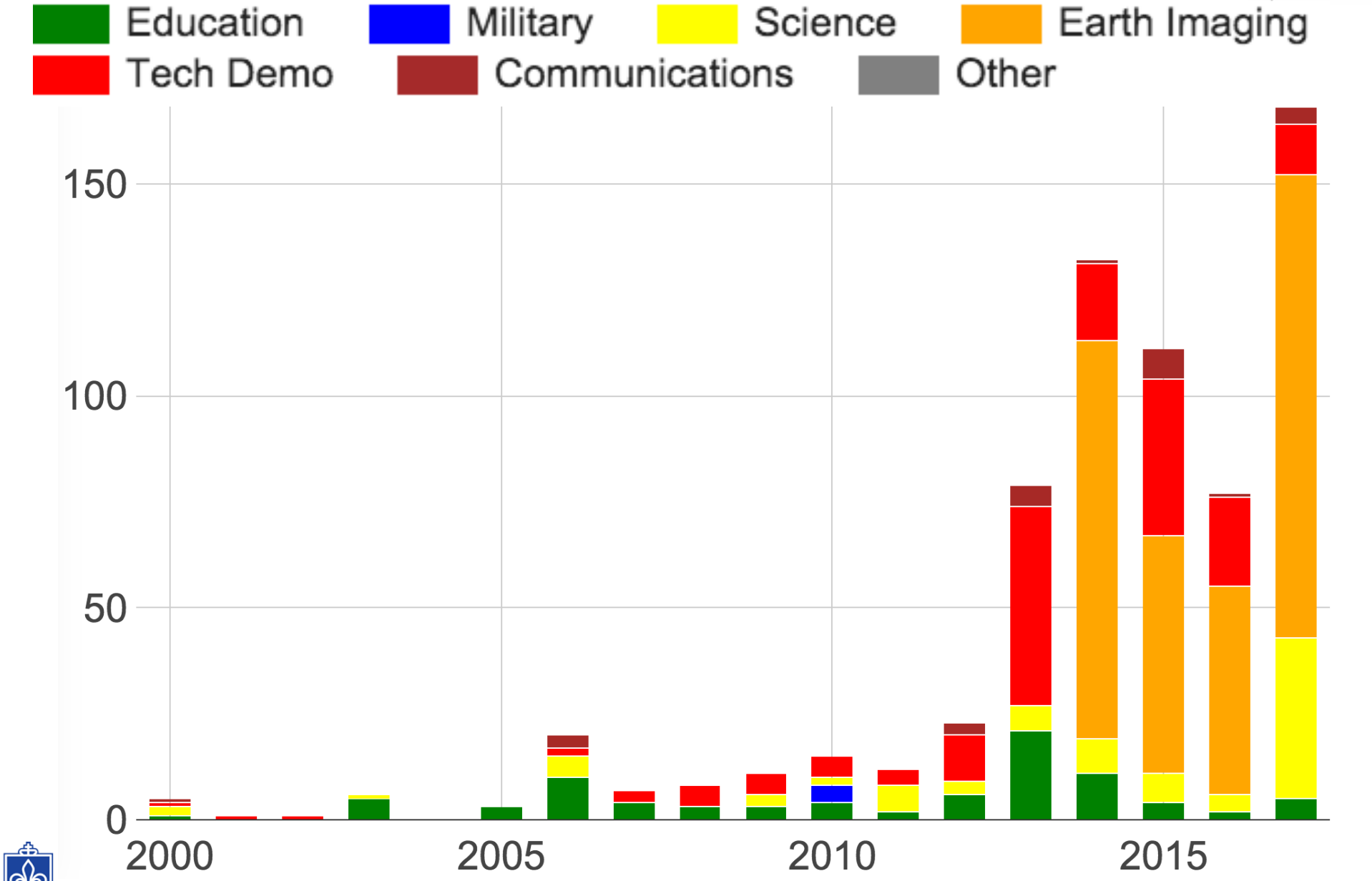


Not shown:
Europe (11)
Japan (10)
China (12)

What's New? International Changes

- Dnepr is grounded (Russia-Ukraine)
  - 66 CubeSat launches 2006-2014
  - No CubeSat launches since 2014
  - No launches at all since 2015
- India is happy to pick up the slack
  - June 2016: 20 Spacecraft (16 CubeSats)
  - Feb 2017: 104 Spacecraft (101 CubeSats)
  - June 2017: 31 Spacecraft (26 CubeSats)
- NanoRacks is close behind (~50/year via the ISS)

CubeSat by Mission Type



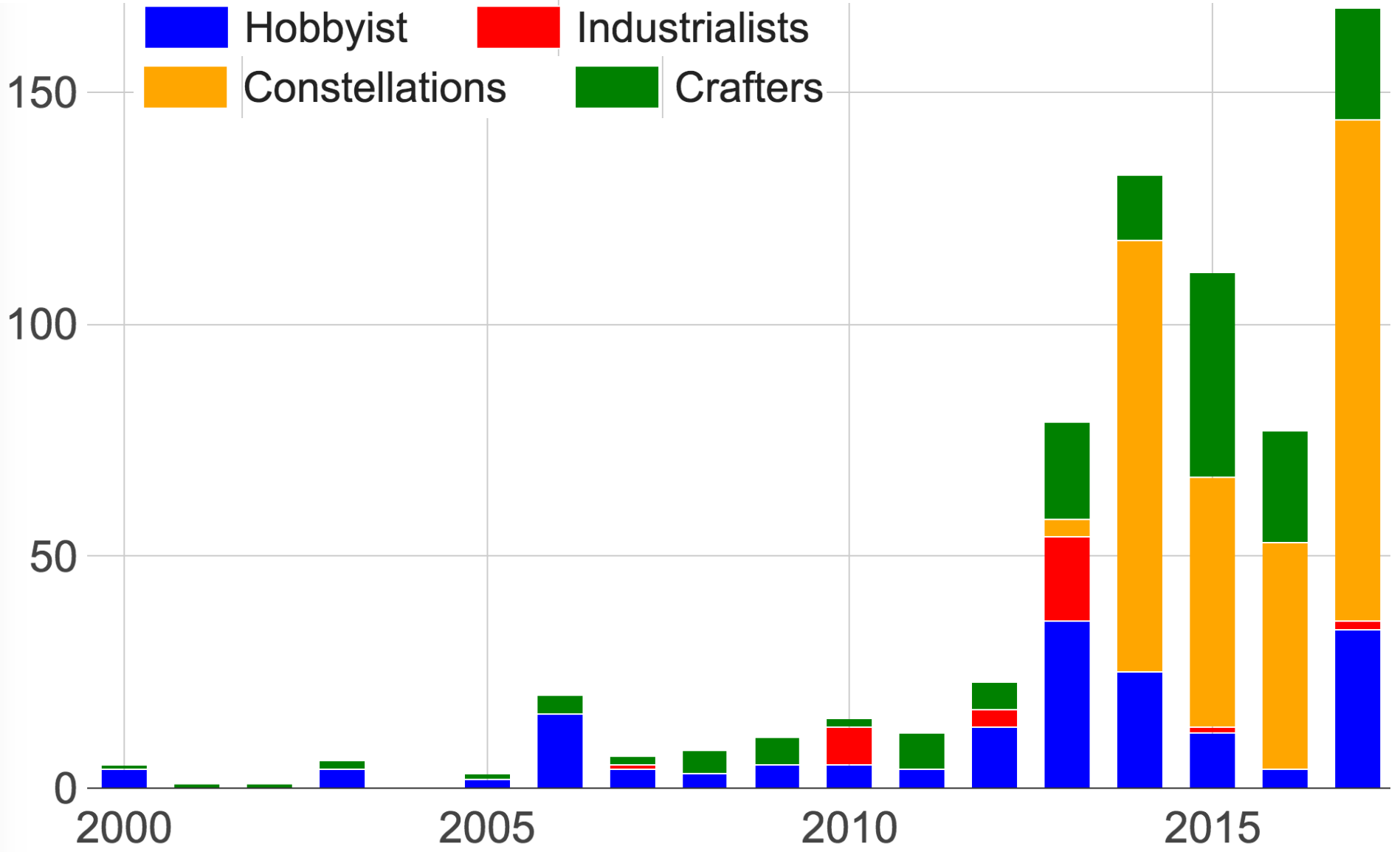
Why Fly CubeSats?

- Giving Youngsters Something to Do
  - Nothing teaches systems engineering like, well, doing systems engineering
  - Let students (or fresh-outs) burn their fingers on short, low-consequence missions
- The Mission Fits
  - **Single-instrument science**
  - Flight-testing new technologies
  - **Low-rate communications** (but persistent!)
  - Modest power, data and lifetime needs
  - Rapid(ish) turnaround
- High-Risk, High-Reward

None of These Things are Quite Like the Others …

- **Hobbyists**
  - No real experience in the field
  - Building for fun & future profit
  - **Ad hoc practices**
- **Industrialists**
  - Experienced builders of big spacecraft
  - Building under gov't contract
  - **Standard space system practices**, with some truncation
- **Crafters**
  - Experienced builders of small spacecraft
  - Building under contract (including services)
  - **Streamlined practices**, experientially developed
- **Constellations**
  - Dozens of vehicles in improvised constellations
  - Mission success is for aggregate system
  - Mission success depends on sustained delivery of service
  - **Proprietary practices**, which may not apply to other programs, anyway

CubeSat by Developer Class



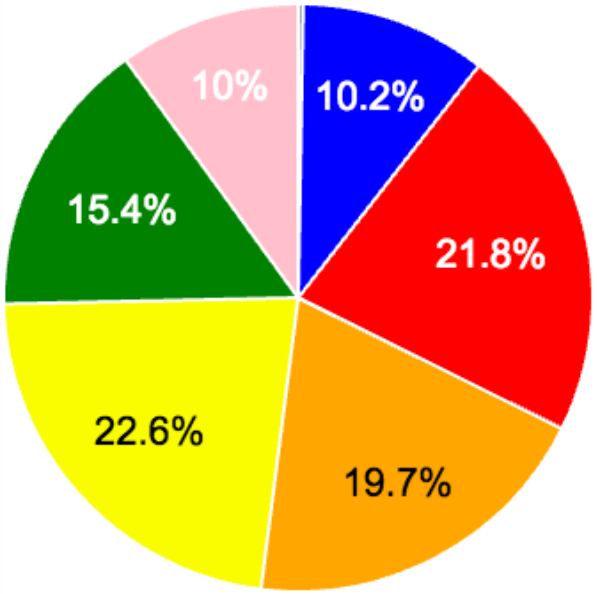
What's New? Constellations

- Planet (263): Whole-Earth imaging
- Spire (41): Meteorology, AIS
- Sky and Space Global (3): Narrowband communications
- Cicero (1): Radio signal occultation (science)

- QB50 (37): Upper-atmosphere physics (heterogeneous spacecraft)

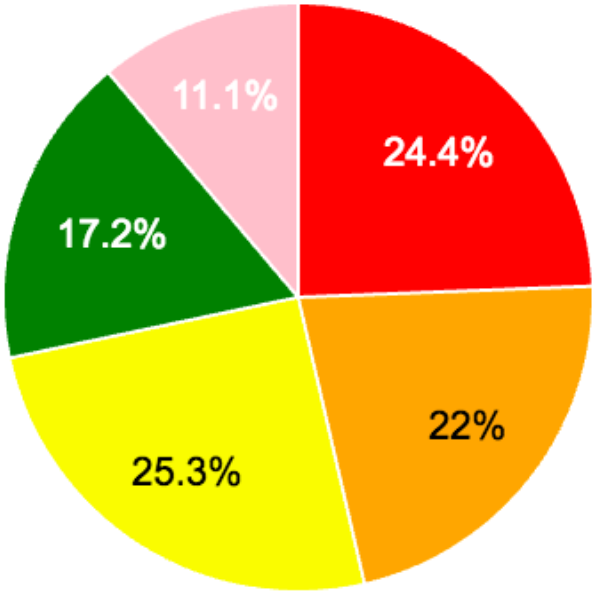
CubeSat Mission Status, 2000-2016 (No Constellations)

All Missions (371)

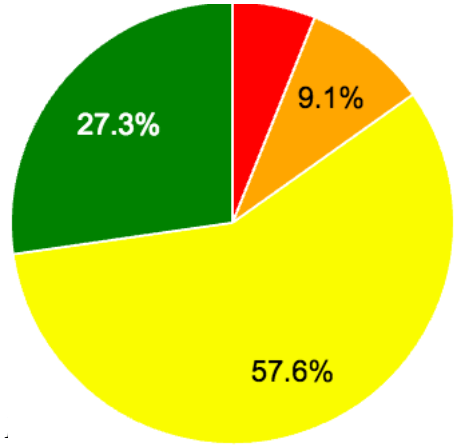


Prelaunch
Launch Fail
DOA
Early Loss
Partial Mission
Full Mission
Unknown

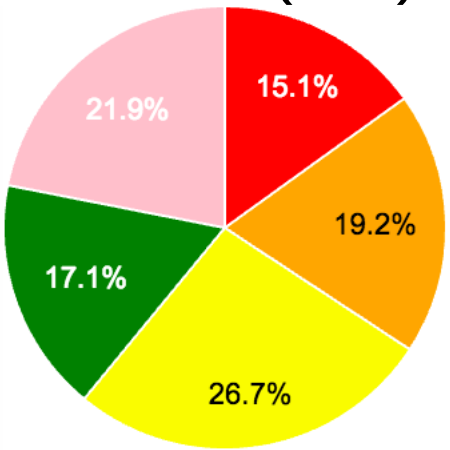
All missions reaching orbit (332)



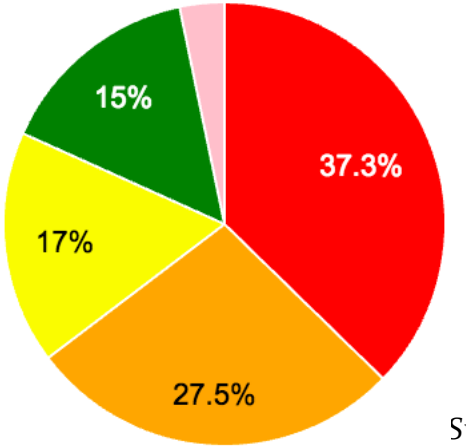
Industrialists (33)



Crafters (146)



Hobbyists (153)

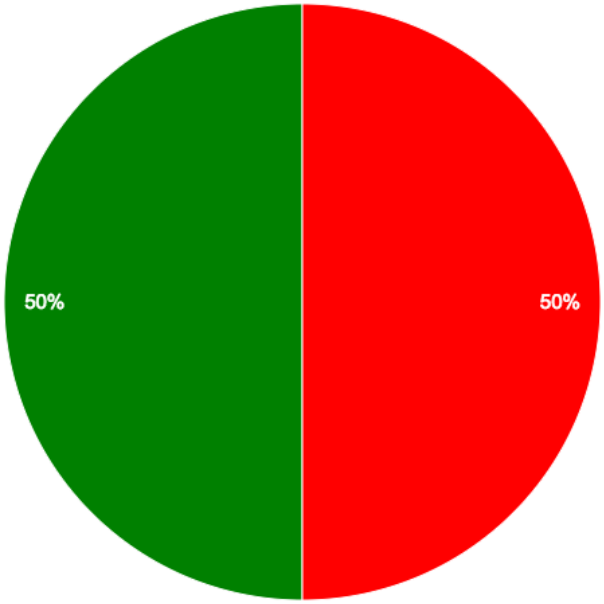


Why the discrepancy?

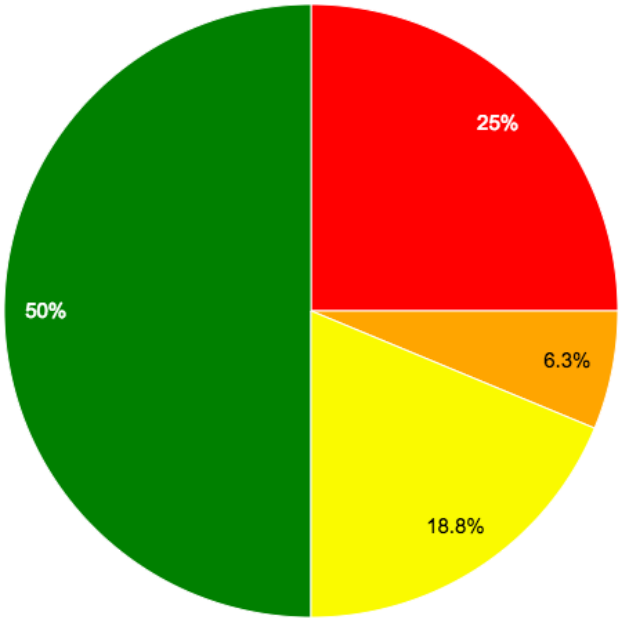
- Industrialists: You get what you pay for!
- Crafters: Failures appear to be a result of ambitious technology infusion (i.e., acceptable losses)
- Hobbyists:
  - Lack of time spent on integration & test
  - Workmanship (vs space environment)
  - The terrestrial skill sets don't always translate well into space success

2016 Rewind: Are They Getting Better? Yes.

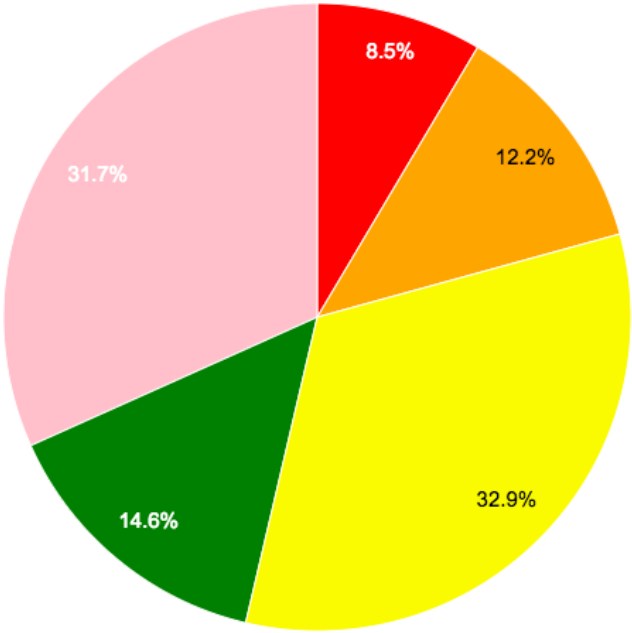
All SmallSat-Class CubeSats



2000-2005
6 missions



2005-2010
16 missions

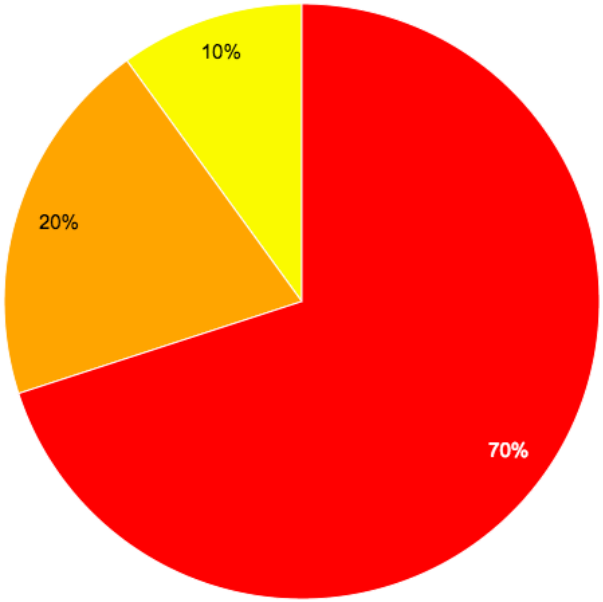


2010-2015
82 missions

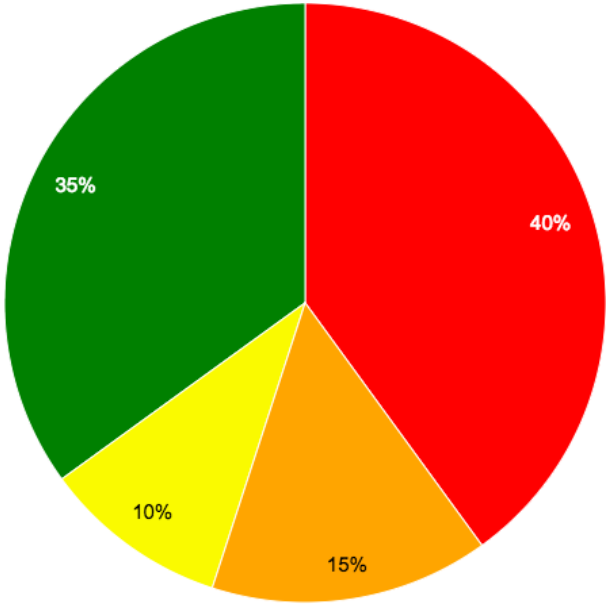
- DOA
- Early Loss
- Partial Mission
- Full Mission
- Unknown

2016 Rewind: Are They Getting Better? No.

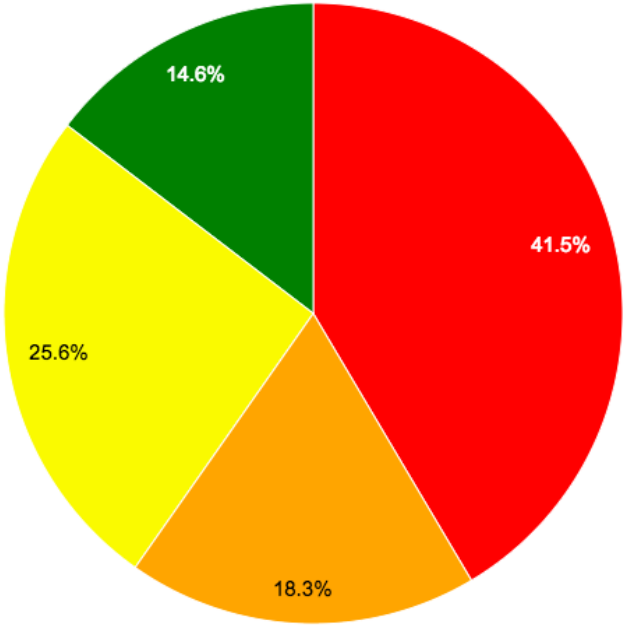
All Hobbyist-Class CubeSats



2000-2005
10 missions



2005-2010
20 missions



2010-2015
82 missions

- DOA
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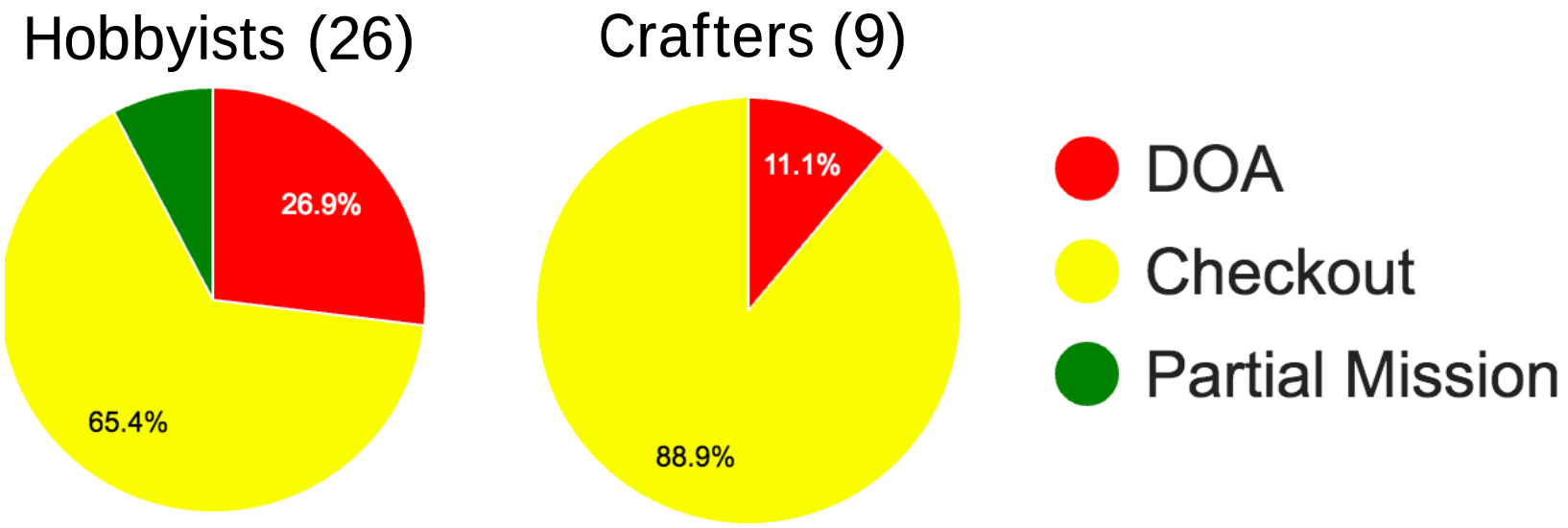
Case in Point: QB50

- QB50: Confederation of universities performing lower-thermosphere science measurements
  - Standard instruments
  - Custom-built spacecraft
  - 35 launched in 2017 (2 batches)



Parts vs. Process

- Mission success: it depends on how long you need this to work
- Success stories of Process: Crafters
  - MINXSS-1 (6 mos, deorbit)
  - STRAND-1 (4+ years)
  - RAX-2 (18 mos)
  - HRBE (3 years, decommissioned)
- Cautionary tales of Process: Hobbyists
- We can't answer the question, but there are finally enough people to ask!
  - Colorado/LASP (MINXSS-1, MINXSS-2 upcoming)
  - Constellations, constellations, constellations (if they'll talk)
  - QB50 (meet me in Logan)

The Cynical Page (2017 Edition)

- Mission success
  - If new programs keep building new CubeSats, failure rates will be high
  - Experienced programs do (much) better
  - Hobbyists (and some Crafters?) are missing something crucial to mission success
- The laws of physics are still against us
  - Power, communications and many instruments have minimum effective sizes (> 3U)
  - There's a reason why Boeing, Lockheed, Arianespace, Orbital, & SpaceX build bigger rockets, not smaller. (Ask India about the value of a "dedicated" CubeSat-class launch vehicle.)
- We've made a lot of work for the FCC, NOAA, JSPOC and debris-worriers. When do they revolt?
- Would you rather:
  Pay $2M to launch to a specific orbit in 18-24 months, or
  Pay $200k for a sun-synch-ish orbit in 6 months?

The Cynical Page: Homework Edition

Iridium	Roton
Globalstar	Athena
Teledesic	QuickReach
Odyssey	K1
Ellipso	Priboi
ICO	R2150
Astrolink	Eclipse Express
STARSYS	Conestoga 1229
LEOCOM	Eaglet
ARIES	Intrepid

Acknowledgements

- Census Data Sources
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  - Public: Jonathan's Space Report (orbital elements)
  - Public: DK3WN Satblog (university/amateur operations)
  - Public: Union of Concerned Scientists (operational status)
  - Public: Program websites, conference presentations
  - Public: Bryan Klofas (communications/operational status)
  - Private: Personal communications
- Support
  - AFOSR / UNP (original work)
  - NASA NEPP (ongoing)

CubeSats and Mission Success: 2017 Update

(with a closer look at the effect of process management on outcome)

Michael Swartwout
Parks College of Engineering, Aviation & Technology
Saint Louis University

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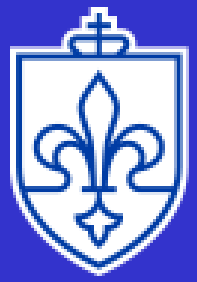

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