CubeSats and Mission Success: 2016 Update

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2016 Electronics Technology Workshop

NASA Goddard Space Flight Center
14 June 2016

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PARKS COLLEGE OF ENGINEERING,
AVIATION AND TECHNOLOGY

Motivation and Objectives

- CubeSats: Toys, tools, or debris cloud?

- CubeSats Bring Opportunities
  - Missions: Single-instrument science, constellations
  - Schedule: Concept-to-operations in under 24 months
  - Modularity: Form-factor forcing standardized parts

- CubeSats Bring Risks
  - <u>Actual</u> 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
- Data collection: Progress to date
  - Data collected and sources
  - Known holes in the data
  - Plan for filling in the holes
- Interim Analysis
  - Census trends (and caveat about forecasting)
  - Helpful (?) categorizing of programs
  - Working hypotheses on mission success

cubesat.org

cubesat.org
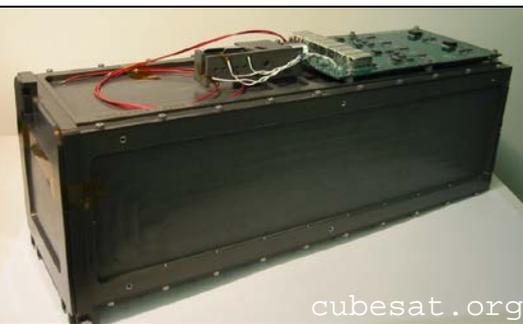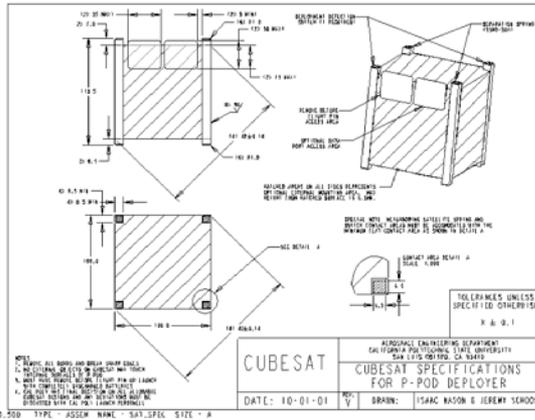
- Twiggs (Stanford) and Puig-Suari (Cal Poly) defined a standard for carrying 10 cm, 1 kg cubes into space

- *Enabling/Driving Technology: P-POD*
  - Key feature: launch container
  - Volume, not mass, is the driver (!?!?)

- Timeline
  - 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)
  - 2014 Planet Labs flies dozens
 - 2015 400th flight

Tilting at Windmills

- At CubeSat scales the primary constraint is **volume**, not mass (!)

- Micro/nano/pico mass boundaries don't fit
  - An 0.8-kg 1U ("pico" satellite) has a lot in common with a 5-kg 3U ("nano" satellite)
  - A 5-kg 3U has less in common with a 20-kg Marmon-clamped secondary

- What do I propose? Interfaces
  - CubeSat (all the variants)
  - NLAS / CSD (the 6U)
  - ESPA / ASAP
  - XPOD (Canada)

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

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

CubeSats Launched (2000-2015)

CubeSats by Form Factor

Legend: 3U, 1U, 1.5U, 6U, 2U, 0.5U, Pico
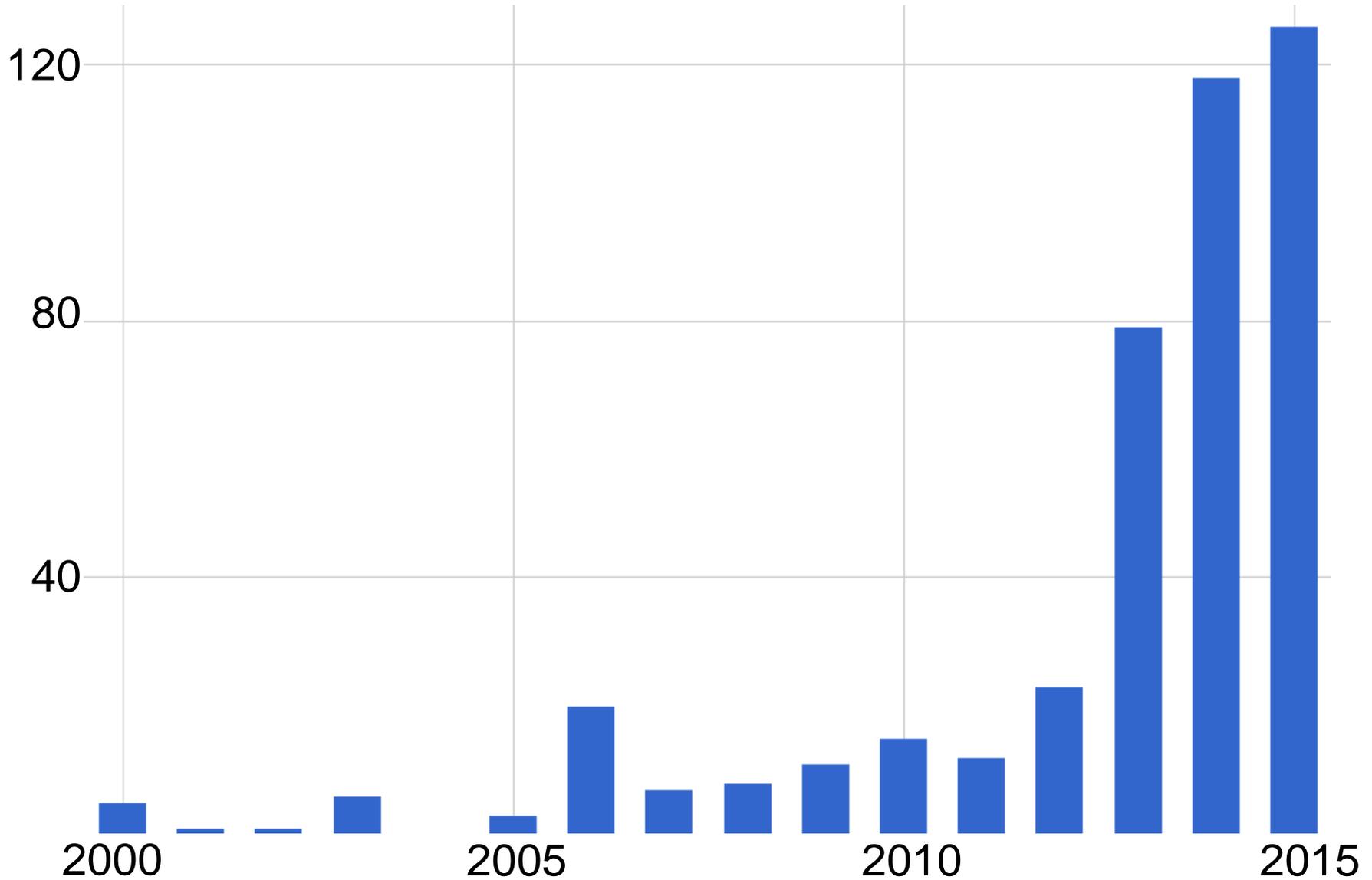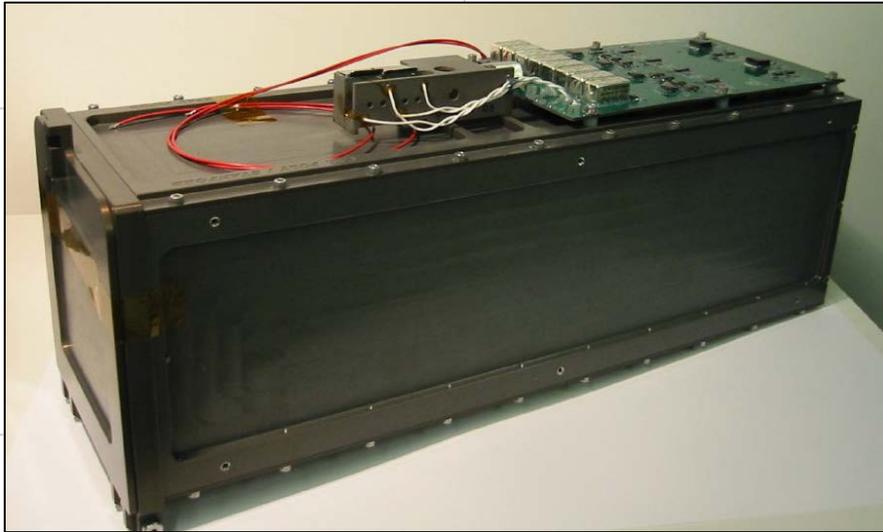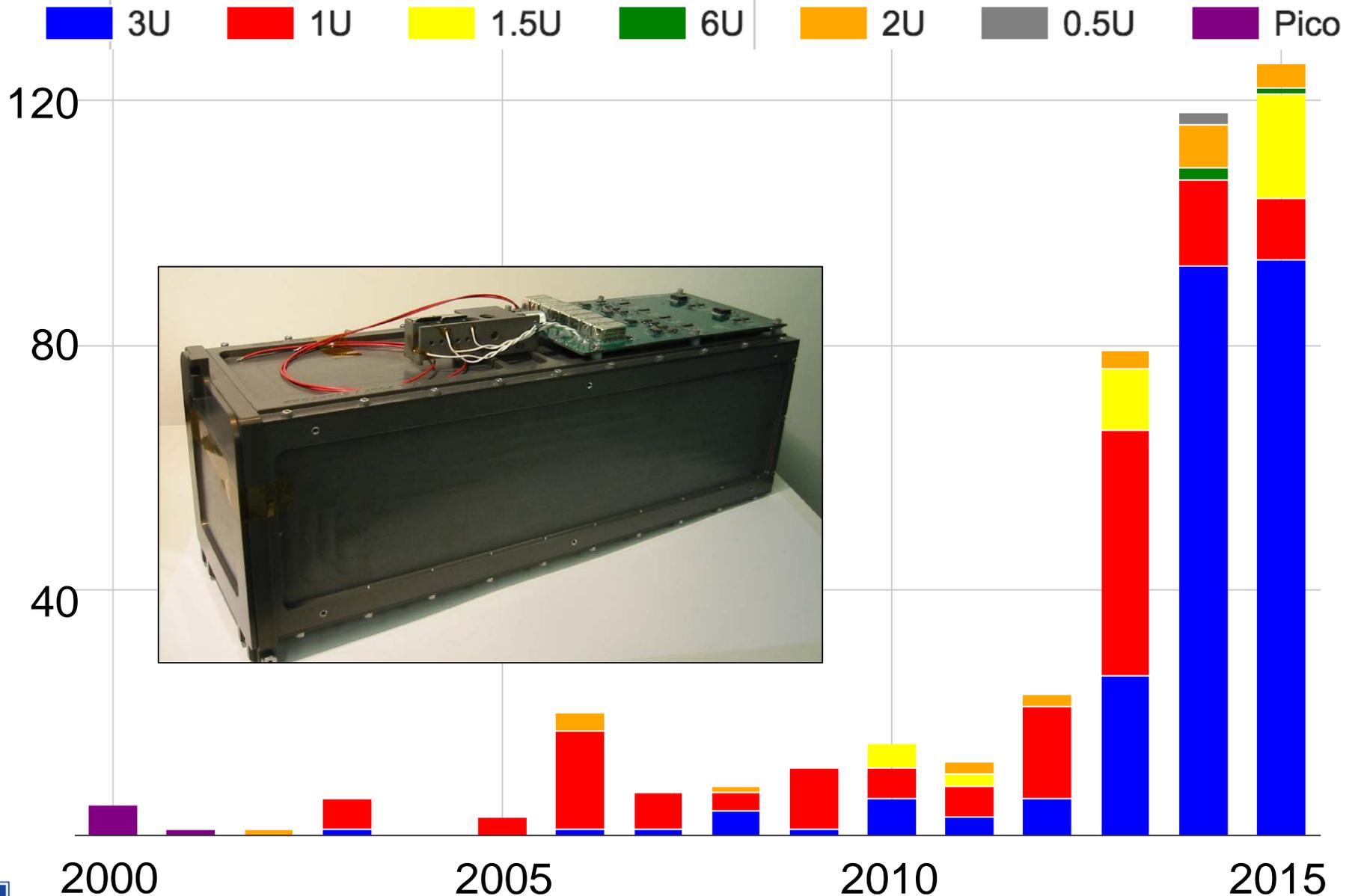
CubeSat By Nation (2000-2015)

A·S·S·R·L

Launch Provider (435)

ISS · 40.9% · 18.6%

Builder (435)

11.7% · 77%
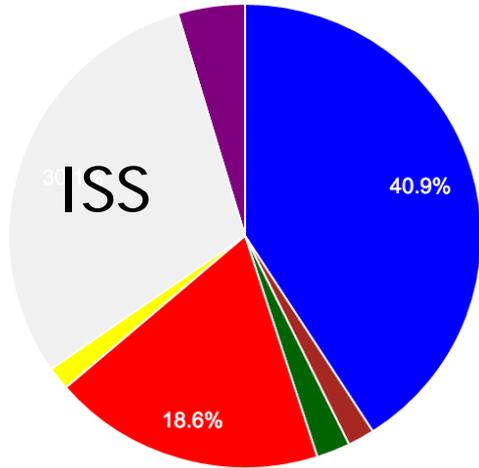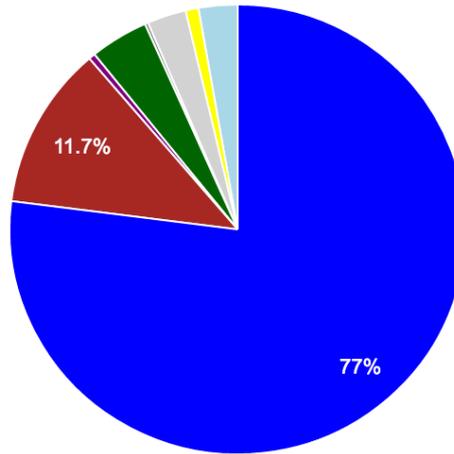
Legend:
- USA
- Europe
- India
- Japan
- Africa
- Asia
- China
- Russia
- Latin America

CubeSats By Launch Provider

USA (178)
99.4%
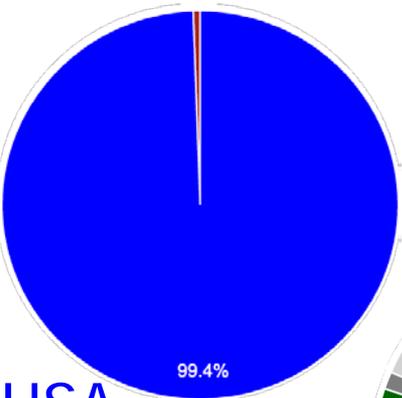
Russia (81)
46.9% · 29.6% · 11.1% · 7.4%

ISS (131)
88.5%
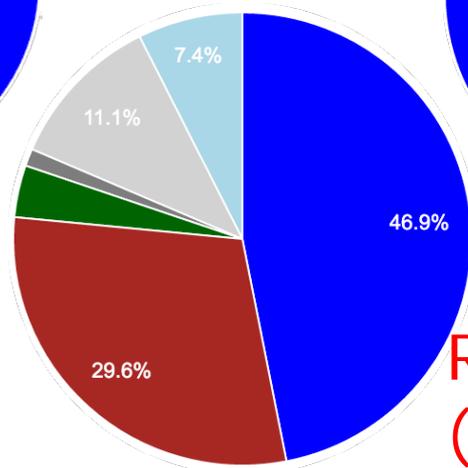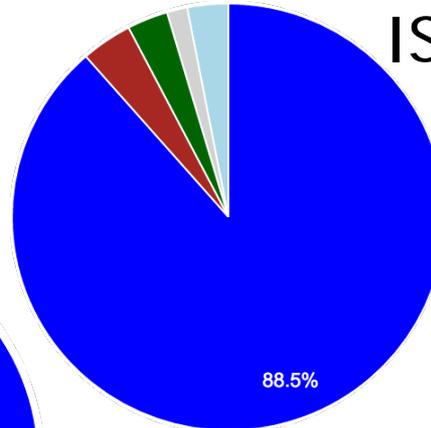
India (20)
20% · 10% · 5% · 5% · 60%
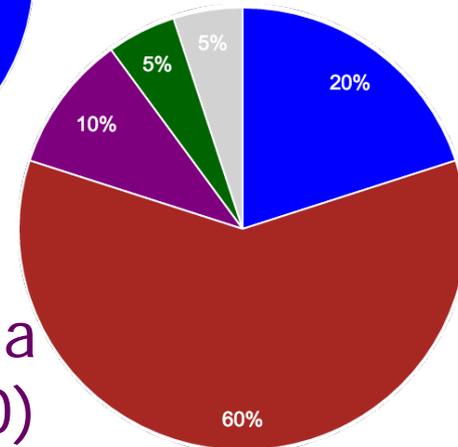
Not shown:
Europe (8)
Japan (10)
China (7)

*Swartwout*

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 <u>short</u>, low-consequence missions
- The Mission Fits
  - Single-instrument science
  - Flight-testing new technologies
  - Low-rate communications (but persistent!)
  - <u>Modest</u> power, data and lifetime needs
  - <u>Rapid</u>(ish) turnaround
- High-Risk, High-Reward

CubeSat by Mission Type

Legend: Education, Military, Science, Earth Imaging, Tech Demo, Communications, Other

2000 · 2005 · 2010 · 2015
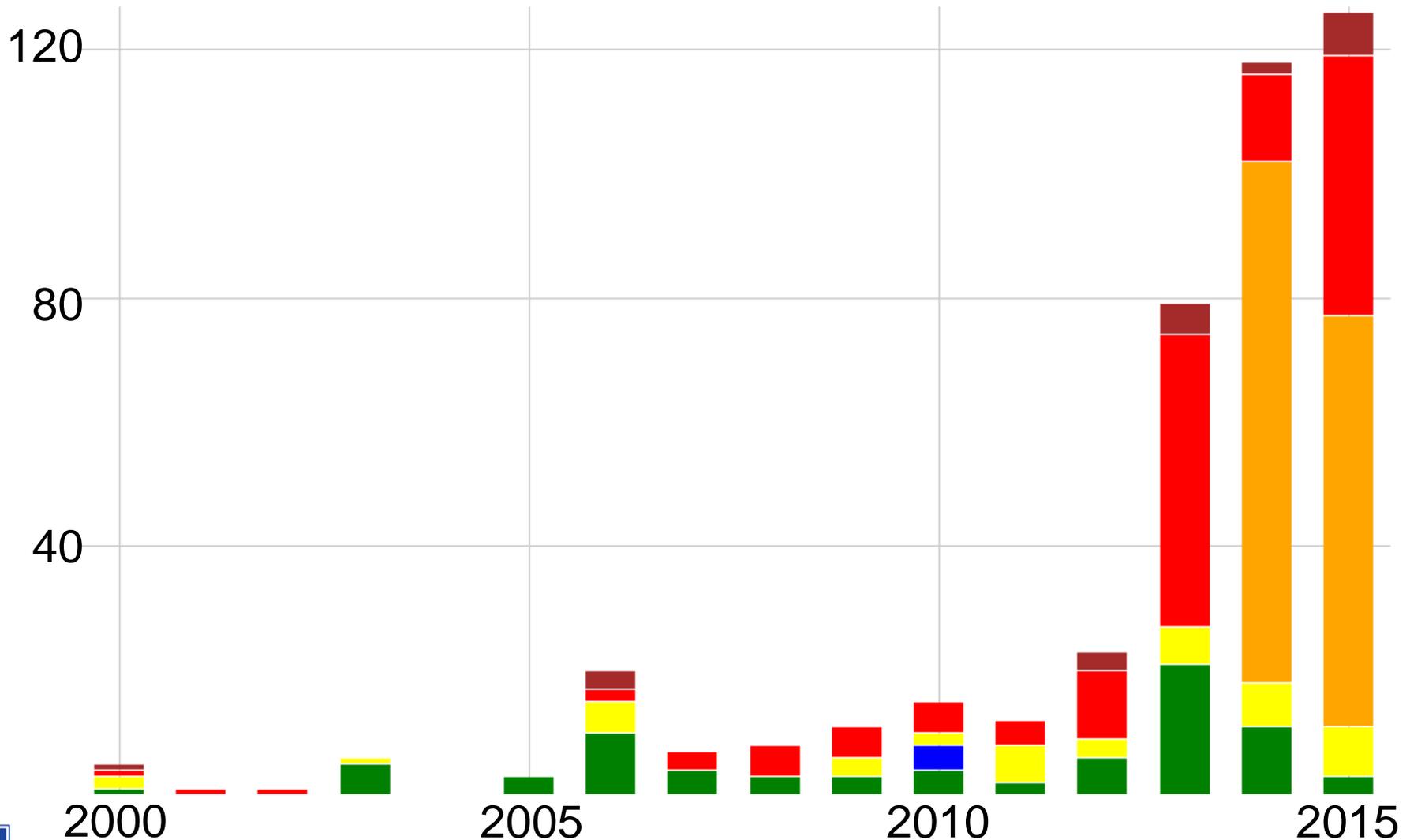
Definition: Mission Status

- Mission status increments at each milestone

- A mission that stalls at one status is given a success/failure assessment

  0 Prelaunch (*Cancelled*)

  1 Launched (*Launch failure*)

  2 Deployed (*Dead on Arrival*)

  3 Contacted (*Premature Failure*)

  4 Commissioned (*Partial Mission Success*)

  5 Primary mission complete (*Mission Success*)

CubeSat Mission Status, 2000-2015 (Except for Planet Labs)

All Missions (288)
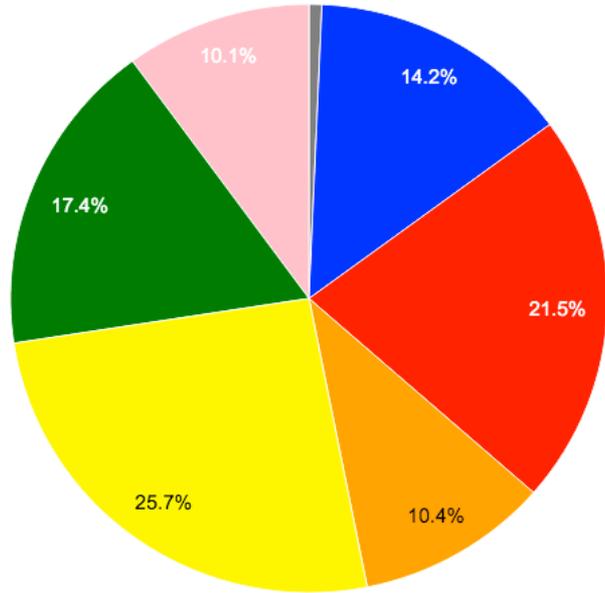
All missions reaching orbit (245)
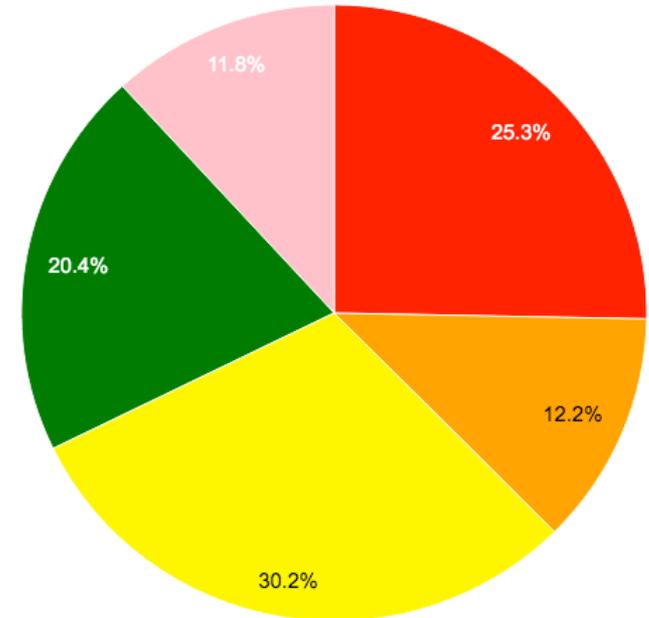
Legend:
- Prelaunch
- Launch Fail
- DOA
- Early Loss
- Partial Mission
- Full Mission
- Unknown

All Missions (288):
- Launch Fail: 14.2%
- DOA: 21.5%
- Early Loss: 10.4%
- Partial Mission: 25.7%
- Full Mission: 17.4%
- Unknown: 10.1%

All missions reaching orbit (245):
- DOA: 25.3%
- Early Loss: 12.2%
- Partial Mission: 30.2%
- Full Mission: 20.4%
- Unknown: 11.8%

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None of These Things are Quite Like the Others …

[With profound apologies for my working titles]

- Hobbyists (or Homebrew?)
  - No real experience in the field
  - Building for fun & future profit
  - Ad hoc practices
- Traditionalists (or Industrial?)
  - Experienced builders of big spacecraft
  - Building under gov't contract
  - Standard space system practices, with some truncation
- SmallSatters (or Crafters?)
  - Experienced builders of small spacecraft
  - Building under contract (including services)
  - Streamlined practices, experientially developed
- And then, there's Planet Labs (and, soon, Spire)

CubeSat by Developer Class
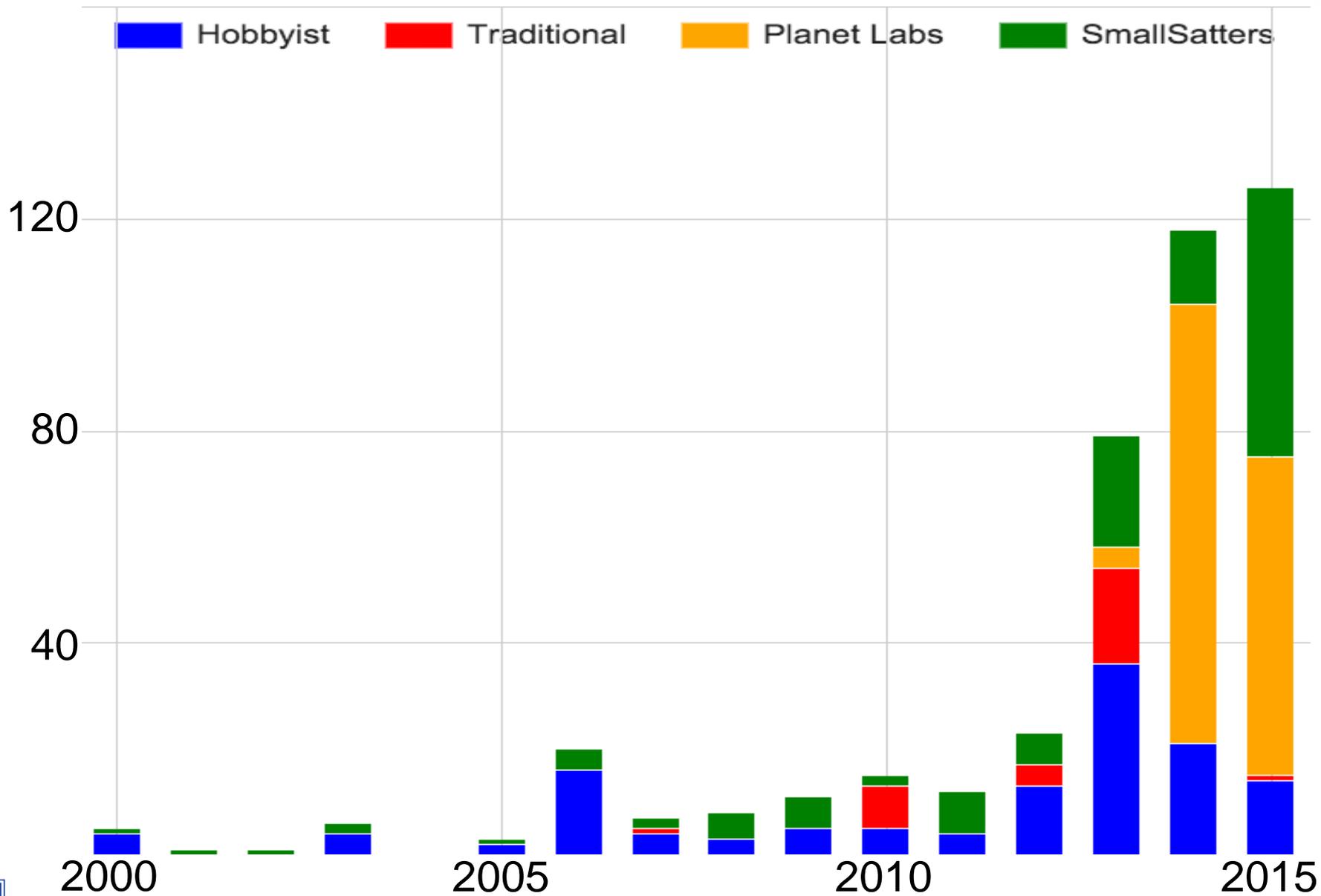
CubeSat Mission Type by Developer Class (2000-2015)

SmallSatters (125)

Legend:
- 🟢 Education
- 🔵 Military
- 🟡 Science
- 🟠 Earth Imaging
- 🔴 Tech Demo
- 🟤 Communications
- ⚪ Other

SmallSatters pie:
- 6.6% Education
- 21.2% Science
- 4.4% Earth Imaging
- 59.9% Tech Demo
- 8% Communications

Traditionalists (32)

- 12.5% Military
- 9.4% Communications
- 75% Tech Demo
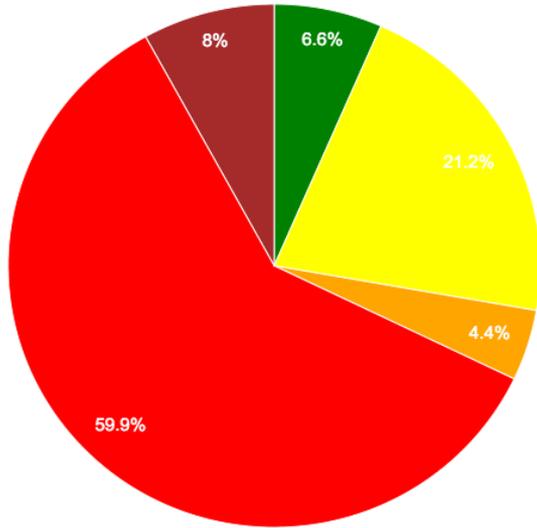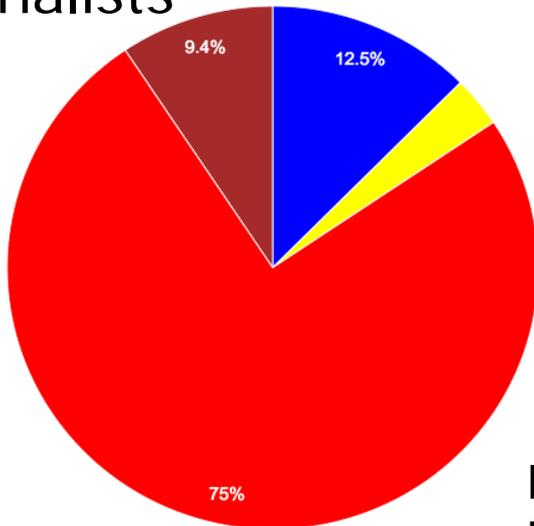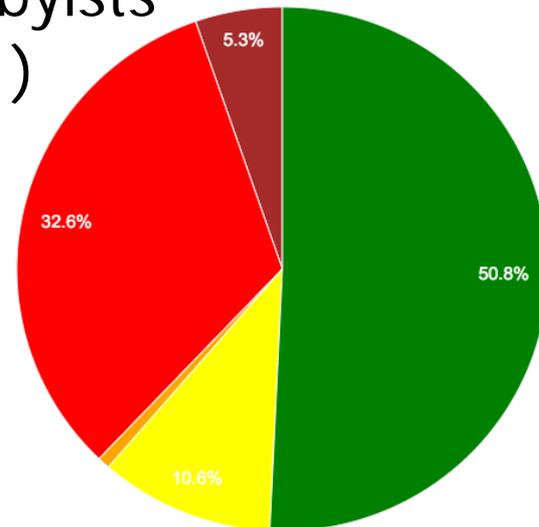
Not shown:
Planet Labs (147)

Hobbyists (131)

- 50.8% Education
- 10.6% Science
- 32.6% Tech Demo
- 5.3% Communications

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CubeSat Mission Status, 2000-2015 by Developer Class (Except for Planet Labs)
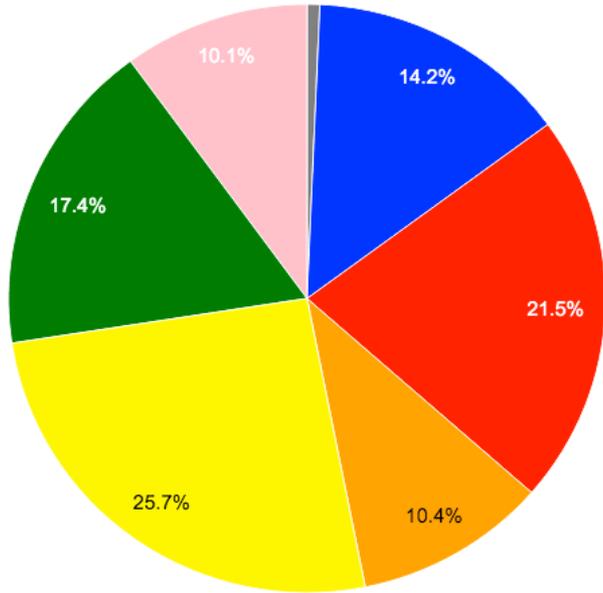
All Missions (288)

Launch Fail 14.2%
DOA 21.5%
Early Loss 10.4%
Partial Mission 25.7%
Full Mission 17.4%
Unknown 10.1%

All missions reaching orbit (248)

DOA 25.3%
Early Loss 12.2%
Partial Mission 30.2%
Full Mission 20.4%
Unknown 11.8%

Legend
- Prelaunch (grey)
- Launch Fail (blue)
- DOA (red)
- Early Loss (orange)
- Partial Mission (yellow)
- Full Mission (green)
- Unknown (pink)

Traditionalists (32)

DOA 6.3%
Early Loss 6.3%
Full Mission 28.1%
Partial Mission 59.4%

SmallSatters (104)

DOA 10.9%
Early Loss 9.9%
Partial Mission 29.7%
Full Mission 22.8%
Unknown 26.7%

Hobbyists (112)

DOA 43.8%
Early Loss 16.1%
Partial Mission 22.3%
Full Mission 16.1%

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Why the discrepancy?

- Traditionalists: You get what you pay for!

- SmallSatters: Failures appear to be a result of ambitious technology infusion (i.e., acceptable losses)

- Hobbyists: *[My reckless, semi-informed speculation]*
  - Lack of time spent on integration & test
  - Workmanship (?)
  - Uncaptured best practices?

Are We Getting Better at This?

All CubeSats (Except Planet Labs)
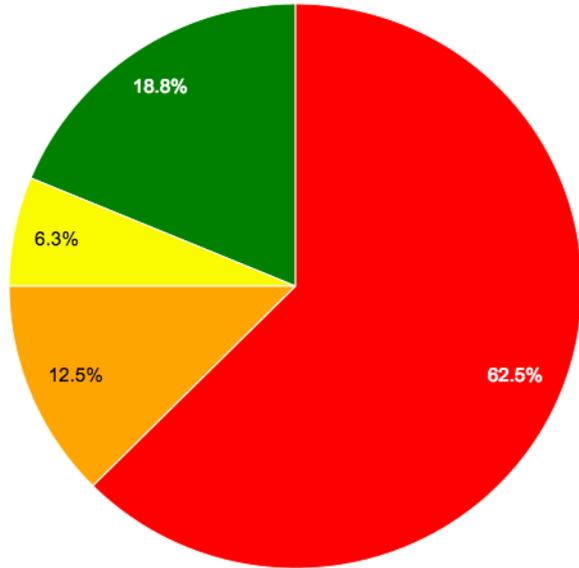
2000-2005
16 missions
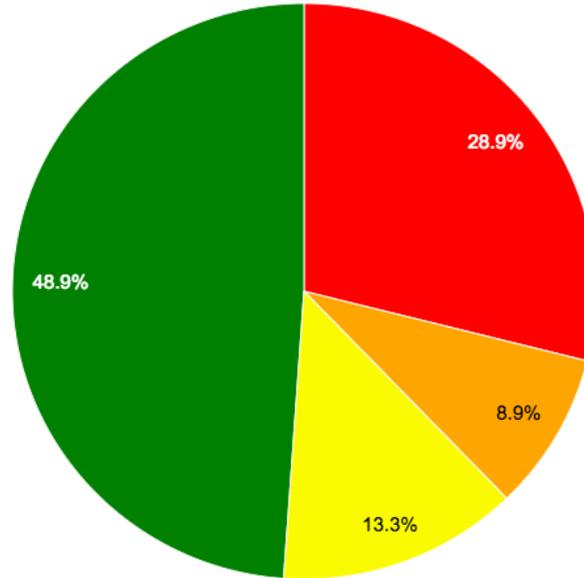
2005-2010
45 missions

2010-2015
187 missions

Legend:
- 🔴 DOA
- 🟠 Early Loss
- 🟡 Partial Mission
- 🟢 Full Mission
- 🟤 Unknown

2000-2005 pie chart: 62.5% (DOA), 12.5% (Early Loss), 6.3% (Partial Mission), 18.8% (Full Mission)

2005-2010 pie chart: 28.9% (DOA), 8.9% (Early Loss), 13.3% (Partial Mission), 48.9% (Full Mission)

2010-2015 pie chart: 22.5% (DOA), 14.4% (Early Loss), 35.3% (Partial Mission), 13.9% (Full Mission), 13.9% (Unknown)

Are They Getting Better? Yes.

All SmallSat-Class CubeSats
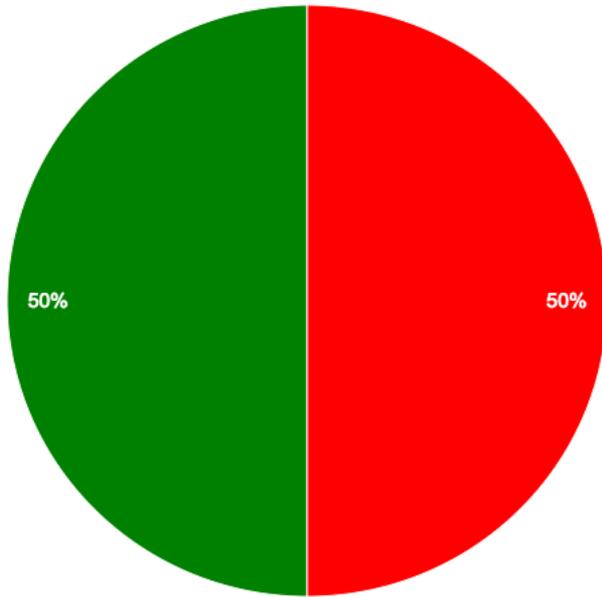
2000-2005
6 missions
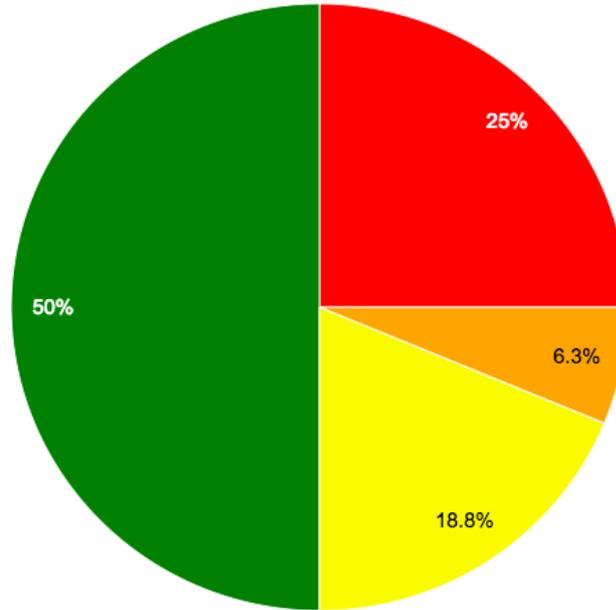
2005-2010
16 missions
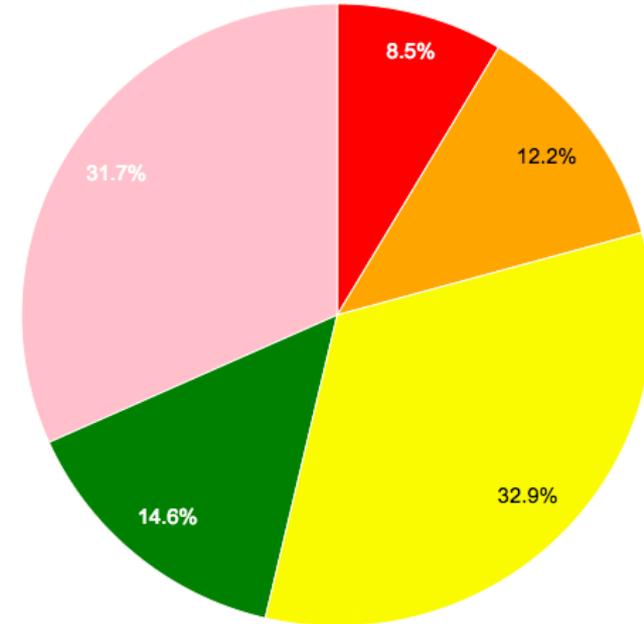
2010-2015
82 missions

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

Are **They** Getting Better? No.

All Hobbyist-Class CubeSats
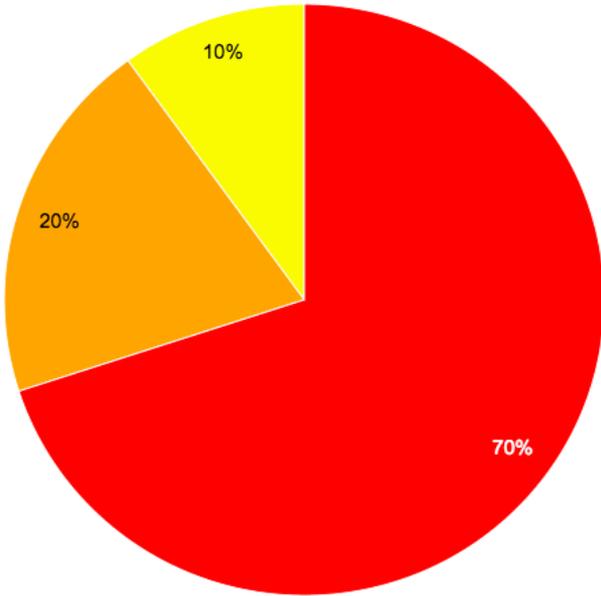
2000-2005
10 missions
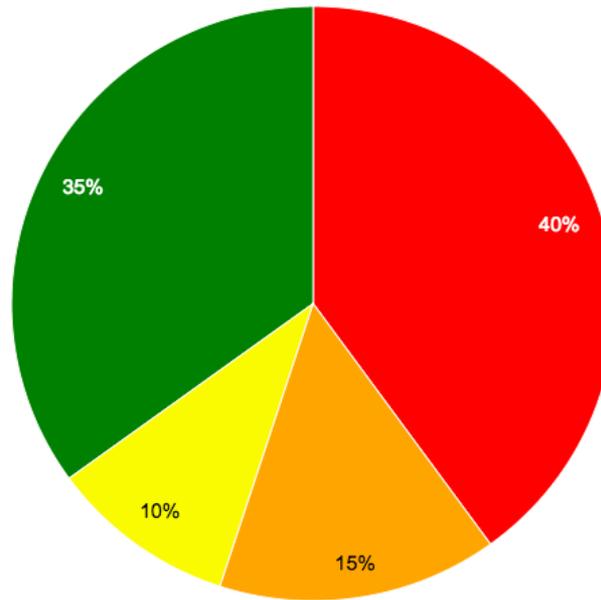
2005-2010
20 missions
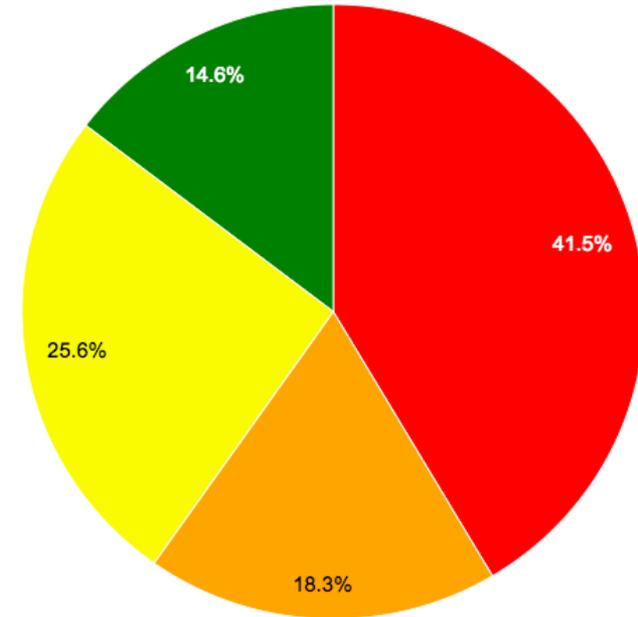
2010-2015
82 missions

- 🔴 DOA
- 🟠 Early Loss
- 🟡 Partial Mission
- 🟢 Full Mission
- 🩷 Unknown

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QA Approach: "Because I Said So!"
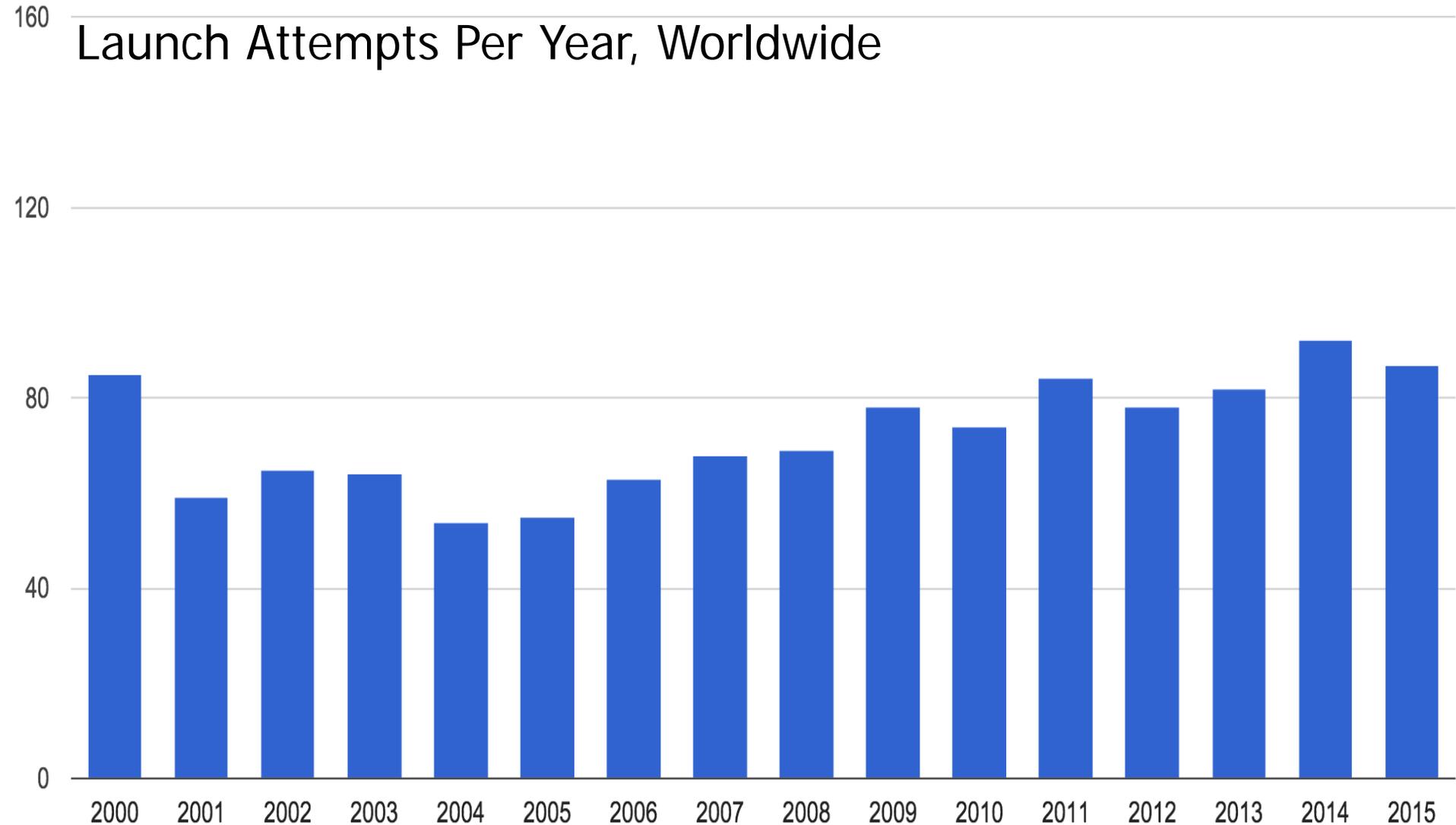
Mission Space

Development Approaches that Lead to Mission Failure

Standard CubeSat Acceptance Testing

Industry "Best Practices"

Hobbyists' Best Practices

How are they reaching orbit?

Launch Attempts Per Year, Worldwide

How are they reaching orbit?

Launch Attempts Per Year, Worldwide
Launch Attempts with Secondaries

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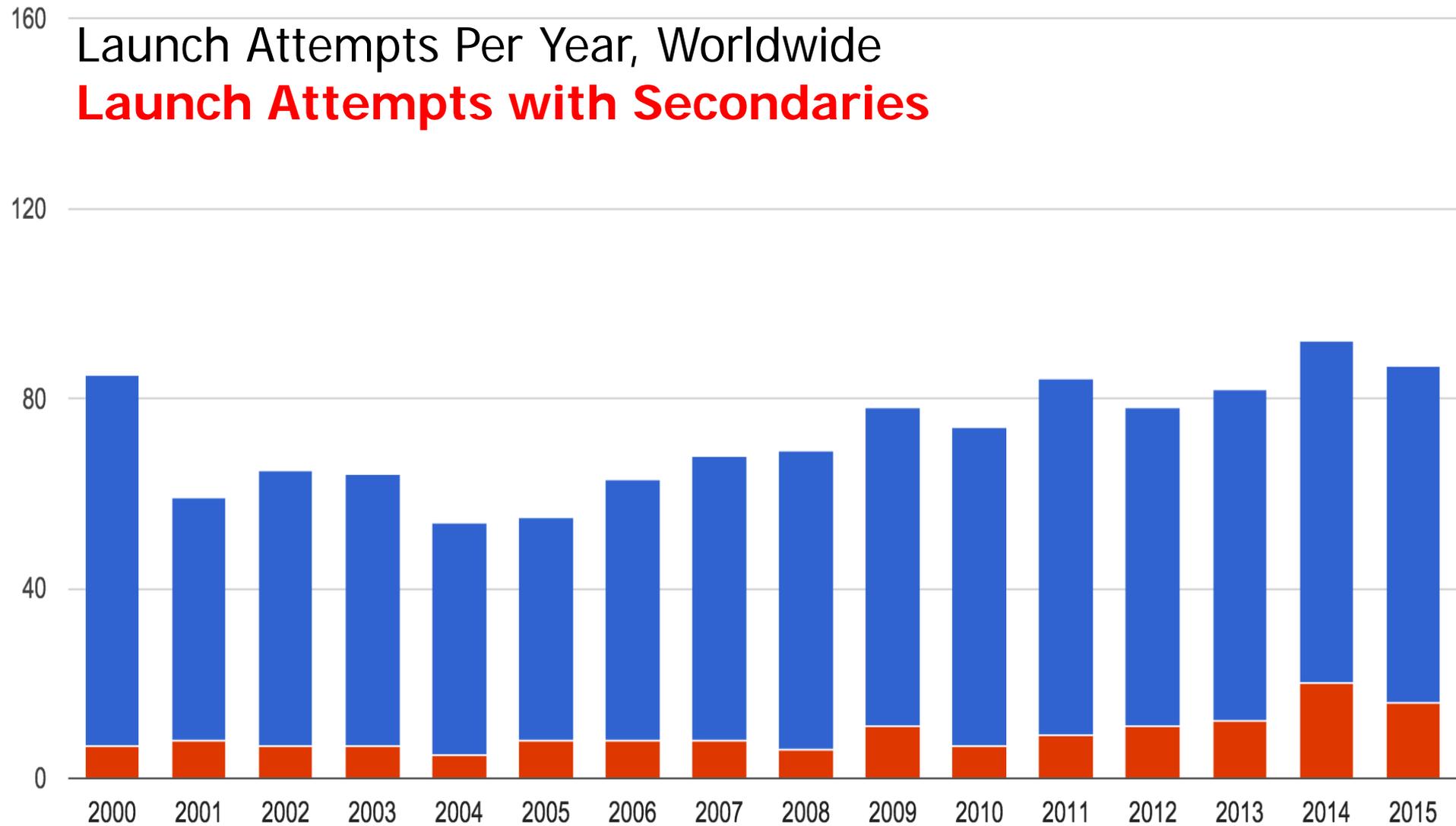
How are they reaching orbit?

Launch Attempts Per Year, Worldwide
Launch Attempts with Secondaries
Secondaries Launched
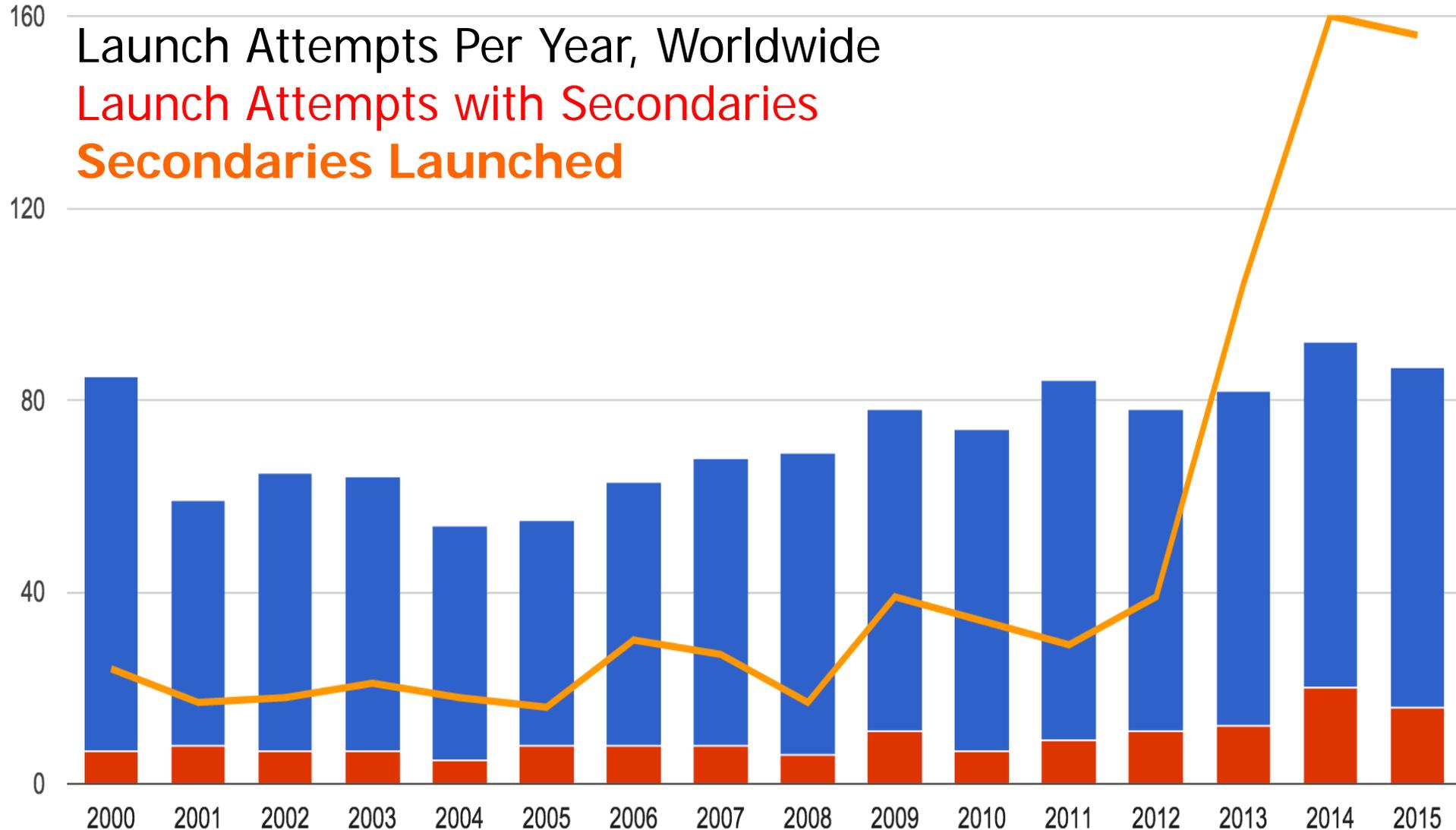
That's a Lot of Secondaries…

- … a whole lot of secondaries!
  - More secondaries than primaries in 2014-2015
  - ISS is capable of releasing 100+ per year
  - ULA, others making 24U standard for launches
  - We haven't seen the peak
- Is there a business case for a dedicated launcher?
  - Lots of CubeSats are freeloaders
  - Would you rather have control over a 24-month launch schedule, or pay (much?) less for a ride 6 months out?

The Cynical Page

- Mission success
  - As long as new programs build new CubeSats, failure rates will be high
  - Experienced programs do (much) better
  - Hobbyists (and some Smallsatters?) are missing something crucial to mission success
- The laws of physics are still against us
  - Power, communications and many instruments need aperture
  - There's a reason Boeing, Lockheed, Arianespace, Orbital, & SpaceX build bigger rockets, not smaller
- We've made a lot of work for these folks.
  When do they revolt?
  - FCC (frequency allocation)
  - NOAA (imaging)
  - JSPOC (tracking)
 - Everyone (debris management)

Update on Data Collection

- Upgraded Internal Database
  - From "Research-grade" to "Shareable"
  - Automated updates to tables, charts
  - Readily shareable via NEPP
- Data collection improvements
- Rolling out interview process

Acknowledgements

- Census Data Sources
  - 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
  - Public: Bryan Klofas (communications/operational status)
  - Private: Personal communications
- Support
  - AFOSR / UNP (original work)
  - NASA NEPP (ongoing)

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