CubeSat Mission Assurance Trends

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SAINT LOUIS UNIVERSITY
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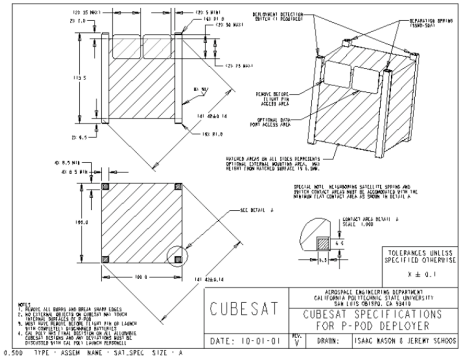
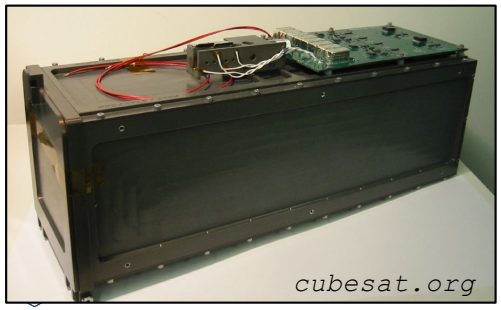
PARKS COLLEGE OF ENGINEERING,
AVIATION AND TECHNOLOGY

Outline

- Census Update
- A Mature Industry? [Maybe not yet]
  - Issue #1: Orbital Clutter (and constellations)
  - Issue #2: Developers and Mission Success
  - Issue #3: Constraint-based design
- Things to worry about
  - Getting data
  - The regulators throw up their hands … and write new regulations

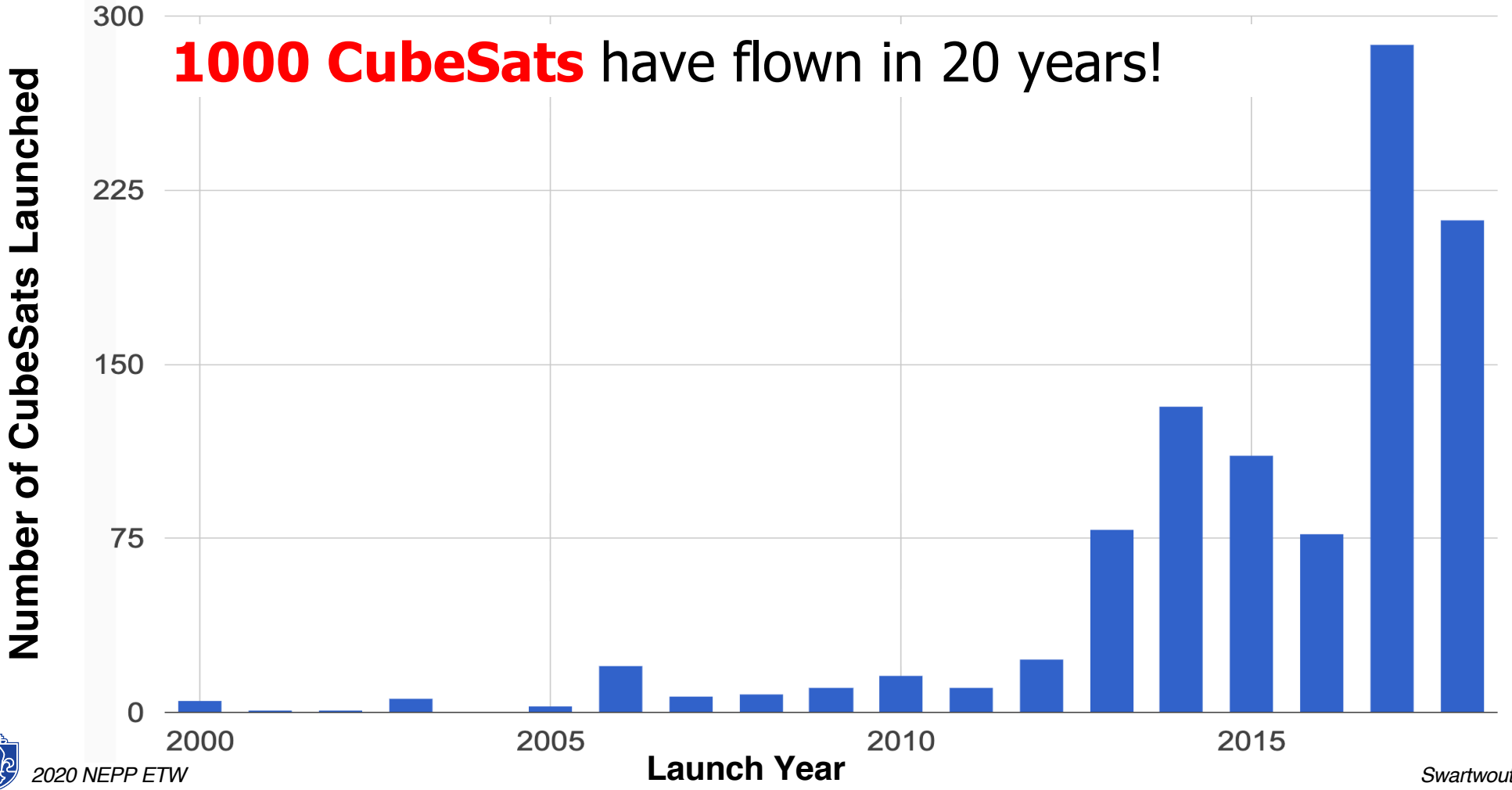
One-Chart Short Course: CubeSats





- Twiggs (Stanford) and Puig-Suari (Cal Poly) defined a standard for carrying 10 cm, 1 kg cubes into space (“1U”)
- <u>Goal: Give students easy access to spaceflight</u>
- <u>Unintended consequence: the P-POD makes launches cheap</u>
- 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)
  - **2013** 28 CubeSats on the same launch
  - **2014** ISS ejects 52 CubeSats over the course of the year
  - **2015** 400th flight
  - **2017** 600th flight, with 101 on the same launch

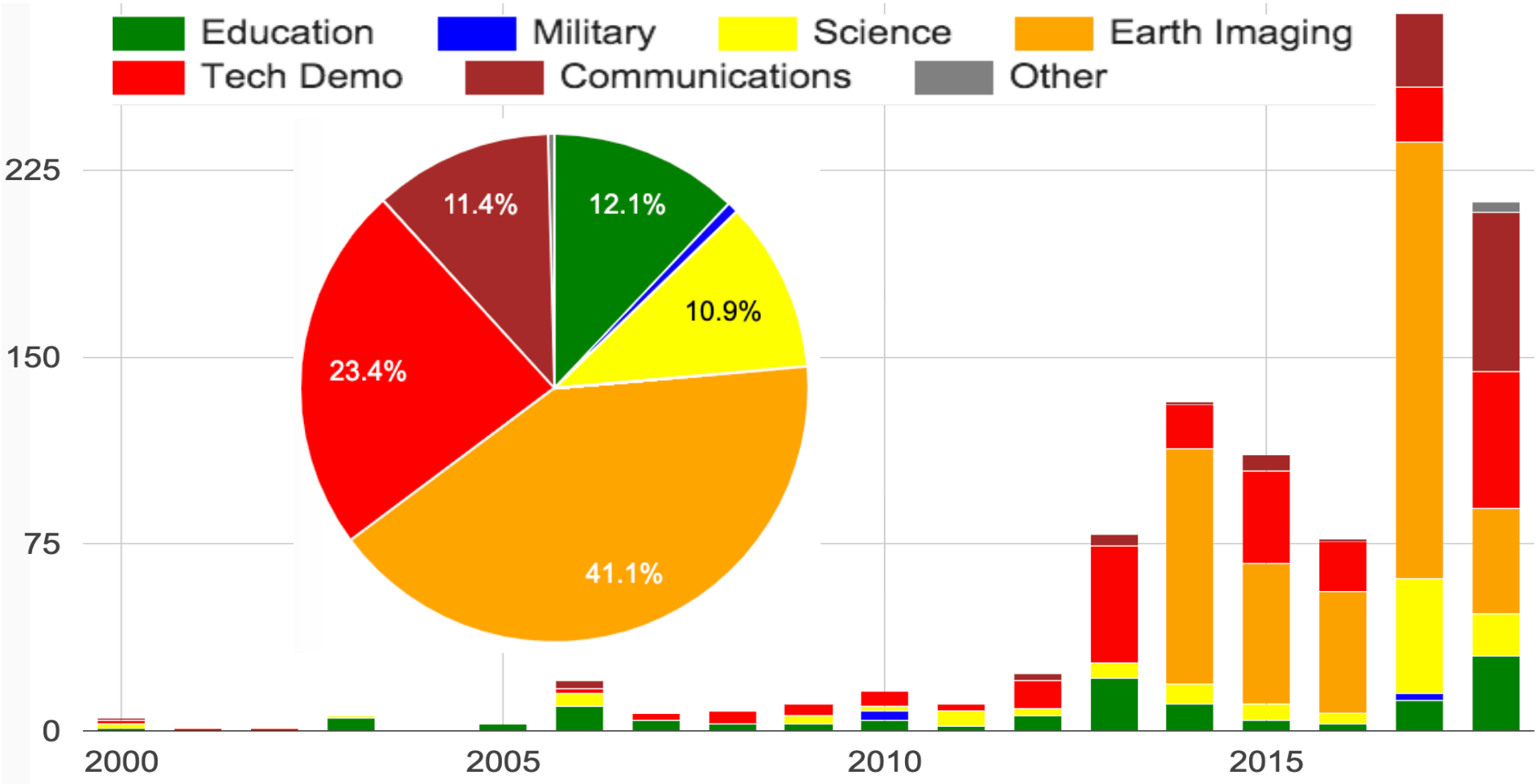
20 Years (!?!?) of CubeSats



“I’ll Take Potpourri for $400, Alex”

- My definition of CubeSat:
  Anything that fits in a “standard” container
- Secret Sauce of CubeSats
  - Cheap launch
  - Willingness to aggressively trade scope to meet [fixed] schedule and cost
- Biggest Threats to CubeSats
  - **Not** trading scope against [fixed] schedule and cost
  - 1000 CubeSats is too big a number to ignore
  - … and maybe some parts. (*Maybe*.)

CubeSat by Mission Type

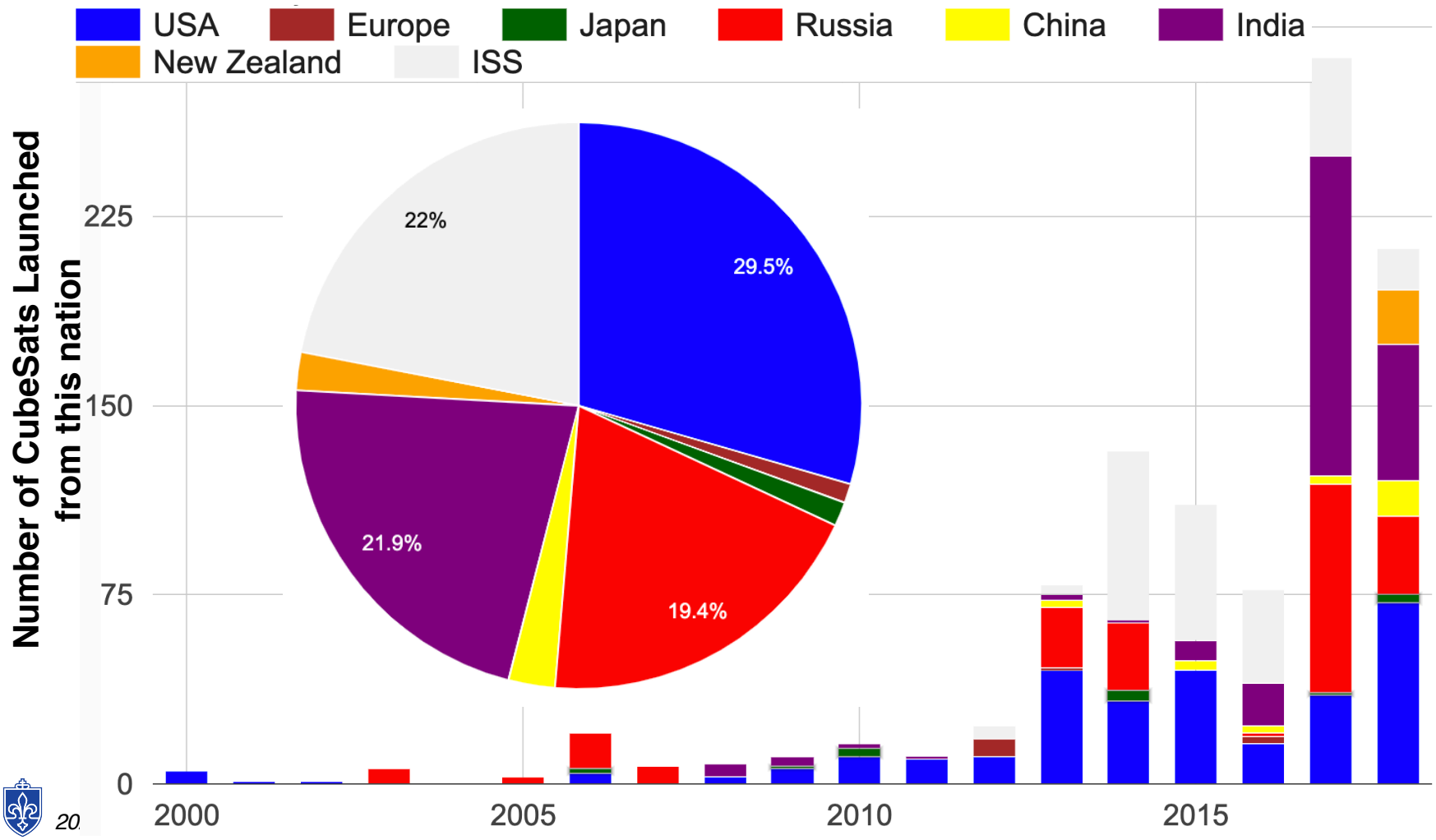


Swartwout

Why Fly CubeSats?

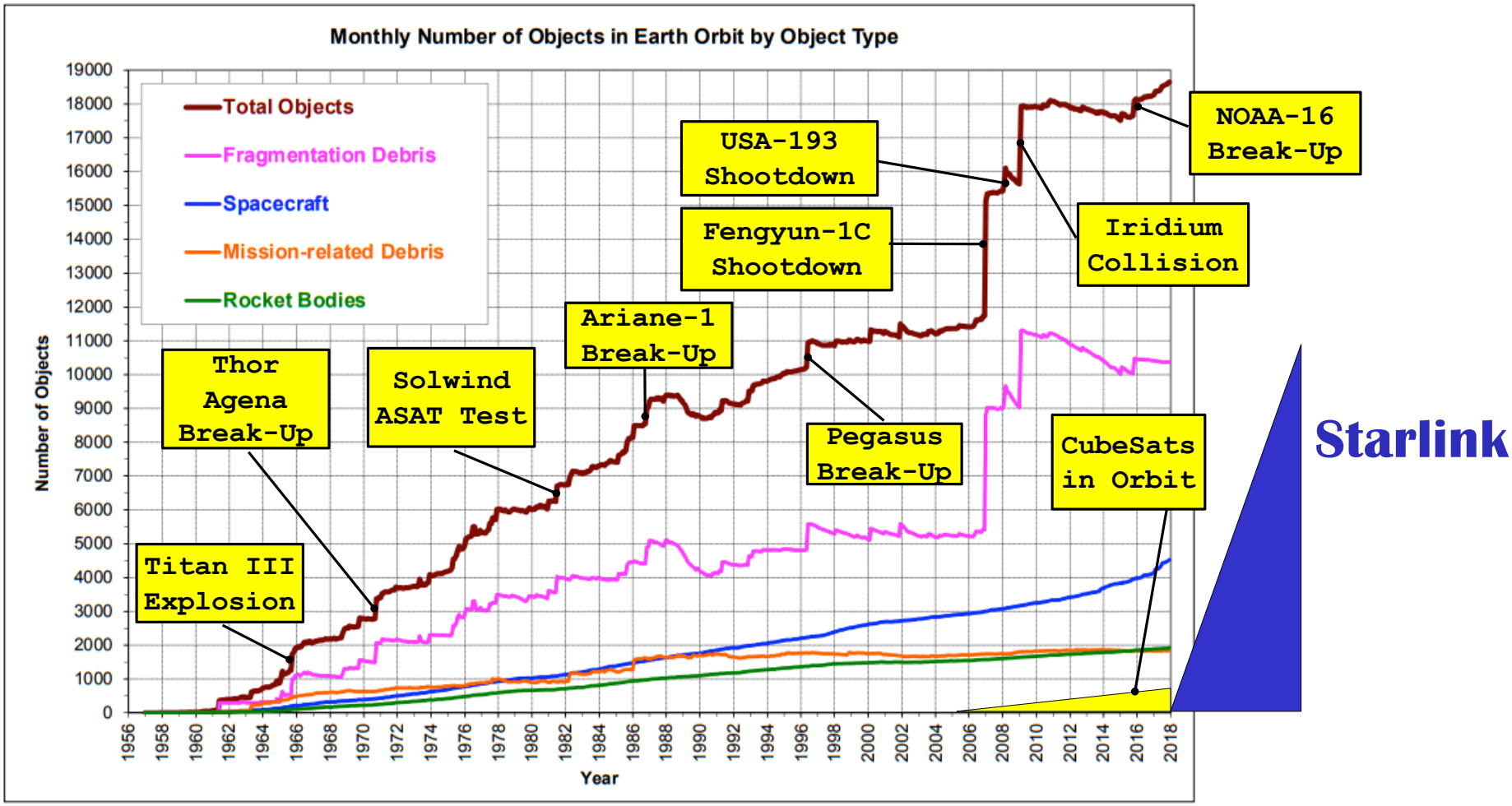
- Let's give the kids something to do
  - Nothing teaches systems engineering like … doing systems engineering
  - Let students (or new hires) burn their fingers on short, low-consequence missions
- Kick-start a space industry
- The mission fits the form factor
  - Single-instrument science
  - Flight-testing new technologies
  - Low-rate communications (but persistent!)
  - Loose constellations (shotgun-style coverage and lots of ground processing)
  - Rapid(ish) turnaround

Worldwide Launches of CubeSats



Swartwout

The Debris Cloud is Already Here … Sort Of



Source: NASA Orbital Debris Quarterly (Feb 2018)

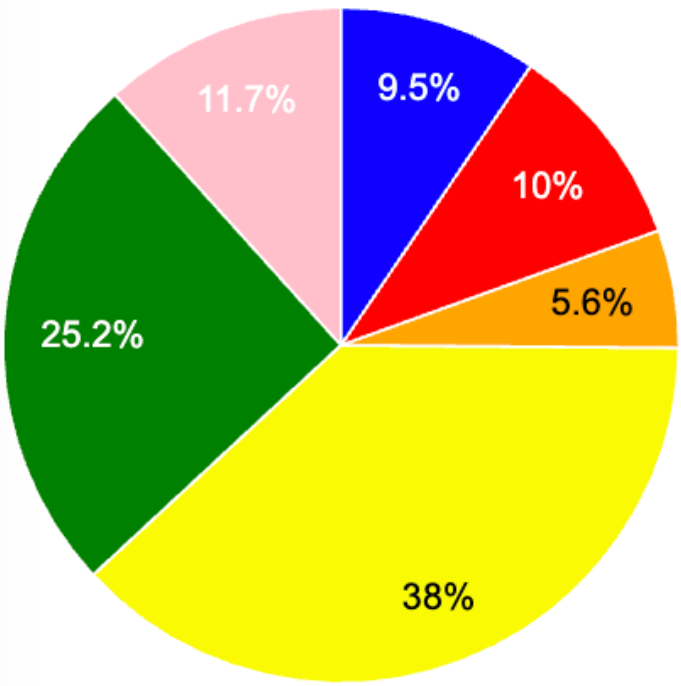
Revenge of the Regulators *(and Constellation Check-In)*

Organization	First Launch	Launched to Date	Launched in 2018	Mission
Planet	4/19/2013	375	36	Whole-Earth Imaging
Spire	11/19/2013	103	28	Meteorology, AIS
QB50	6/19/2014	36	0	Upper-atmosphere physics using global assortment of home-built spacecraft
Satellogic S.A.	5/30/2016	5	2	Earth Imaging
Sky and Space Global	6/23/2017	3	0	Narrowband Communications
Cicero	6/23/2017	7	3	Radio Occultation (atmospheric physics)
Corvus	7/14/2017	6	2	Agricultural Mapping
German Orbital Systems GmbH	11/28/2017	4	3	Communications
Swarm Technologies	1/12/2018	7	7	IoT Applications
Fleet Space	11/11/2018	4	4	IoT Applications
AIStech	12/3/2018	2	1	ADS-B constellation
Astrocast	12/3/2018	2	1	IoT Applications
Magpie	1/21/2019	2	0	Earth Imaging
	Totals	**556**	**87**	

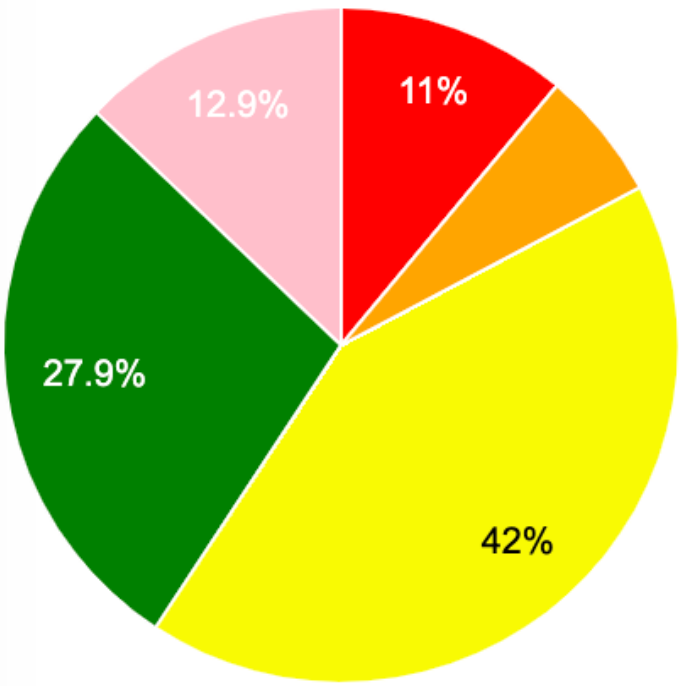
- *[Insert Dire Warning About FCC proposed rules]*
- *[Insert Dire Warning About NOAA proposed rules]*

CubeSat Mission Status, 2000-2018

All Missions
(1011)



All missions reaching orbit
(915)



Truth in Advertising

- I don't have that data … nobody does (***but hold that thought***)
- Overheard at the 2018 NASA Smallsat Reliability Technical Interchange Meeting
  - Systems engineer, mid-sized contractor:
    "More than 90% of the failures I see on the ground or in space are not parts-related"
  - Technical engineer, small component supplier:
    "I second that"
  - Systems engineer, large contractor:
    "I third that"
  - The other 30+ engineers from four NASA centers, the DoD, several contractors and a lot of suppliers:
    [general agreement and nodding of heads]

None of These Things are Quite Like the Others …

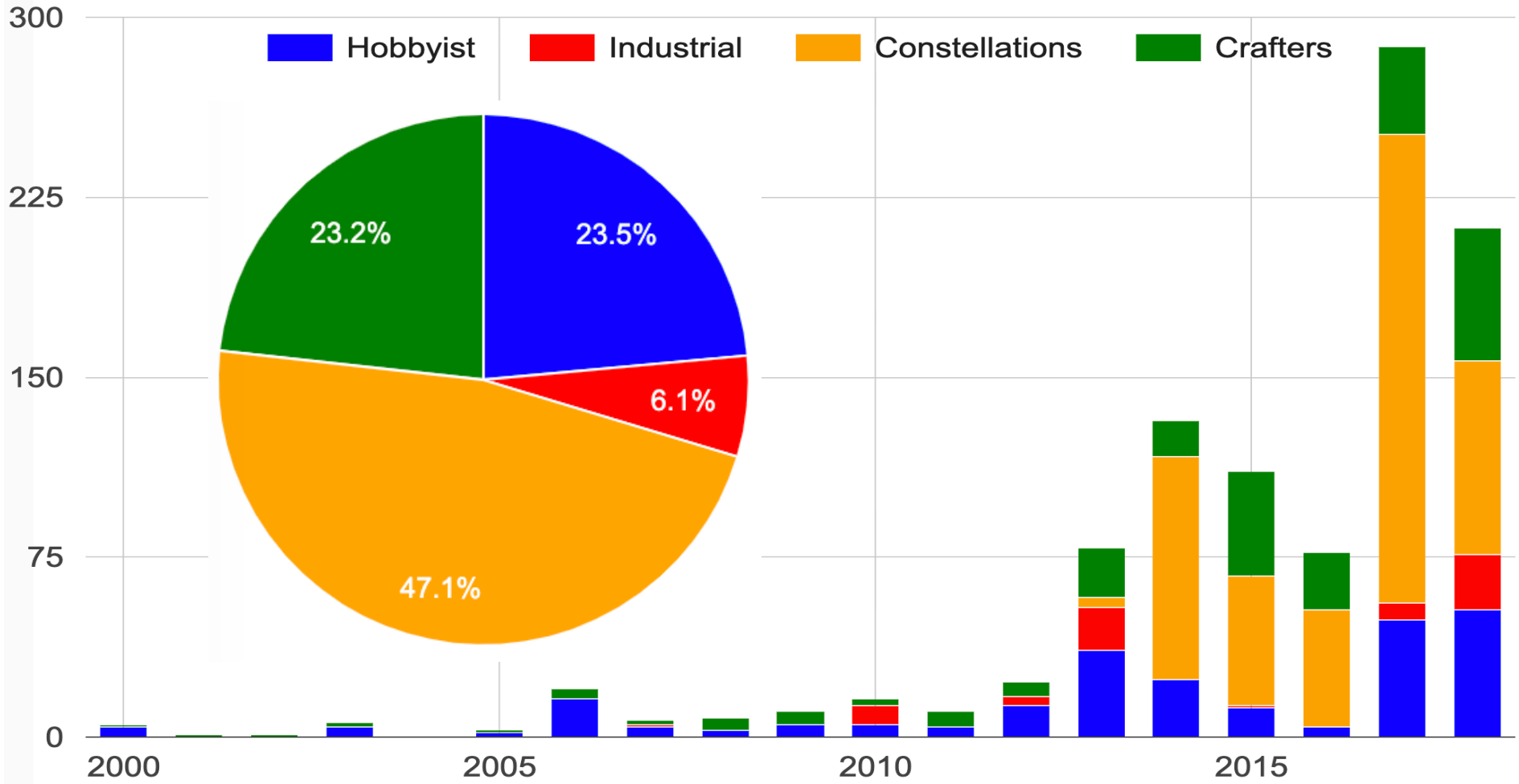
- **Hobbyist**
  - No real experience in the field
  - Building for fun & future profit
  - **Ad hoc practices**

- **Industrialist**
  - Experienced builders of big spacecraft
  - Building under gov't contract
  - **Standard space system practices, with some truncation**

- **Crafter**
  - Experienced builders of small spacecraft
  - Working under contract
  - **Streamlined practices, experientially developed**

- **(Smallsat) Constellations**
  - Providing a geographically-distributed service (imaging, comm)
  - **Mission can be met with an ad hoc (?!?) implementation of orbits**
  - Spacecraft/launch costs are effectively free (I did say "*effectively*")

CubeSat by Developer Class

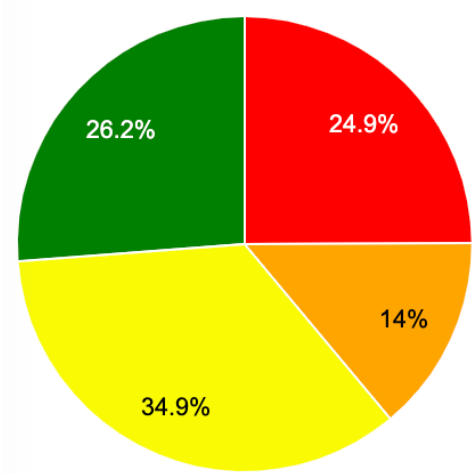


A distinction with a difference

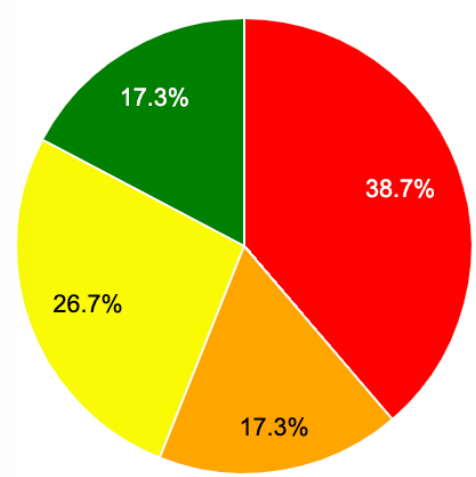
Mission status (1999-2019), omitting constellations

- DOA
- Early Loss
- Partial Mission
- Full Mission

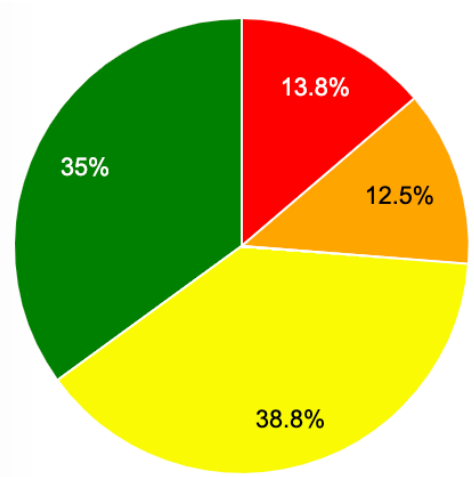
All Missions
(432 Total
39 launch failures
123 Unknown)



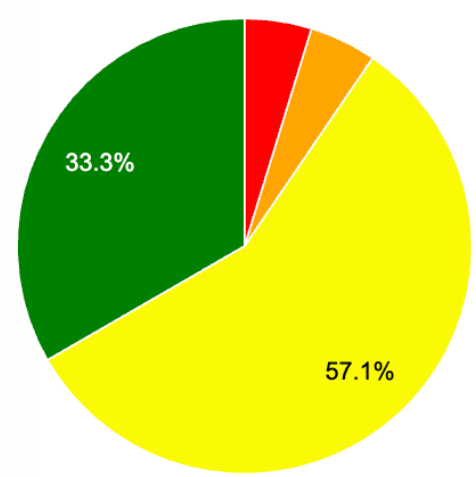
Hobbyists
(191 Total
27 launch failures
32 Unknown)



Crafters
(160 Total
12 launch failures
74 Unknown)



Industrialists
(42 Total
17 Unknown)

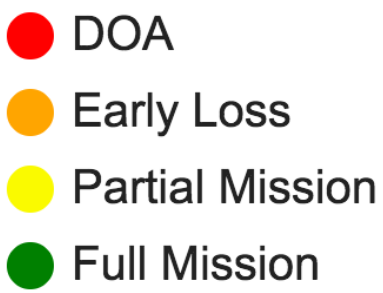


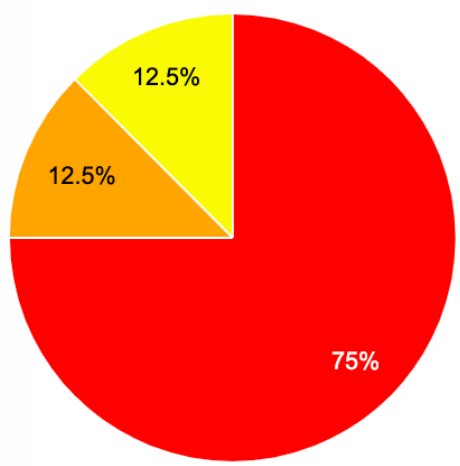
What's Going On?

- **Industrialists**: You get what you pay for!
- **Crafters**: Failures appear to be a result of ambitious technology infusion *(i.e., acceptable losses)*
- **Hobbyists**:
  - Ad hoc procedures for design, integration, test
  - Lack of time spent on integration & test
  - Workmanship (?)
  - Uncaptured best practices?
- *[Insert Discussion about Mission Assurance-based categories]*

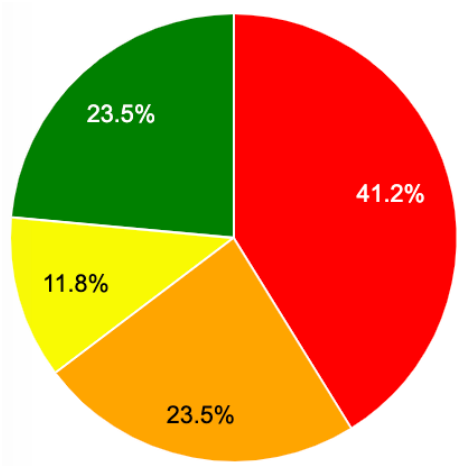
Are They Getting Better? No.

All Hobbyist-Class CubeSats

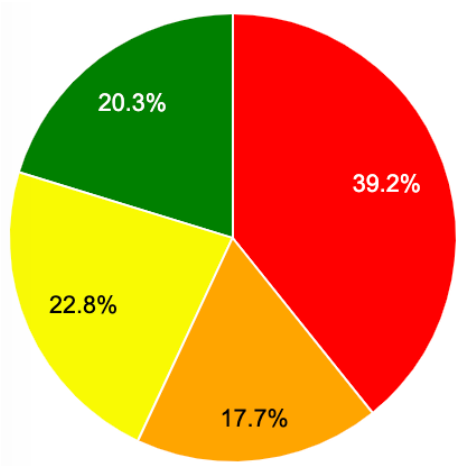




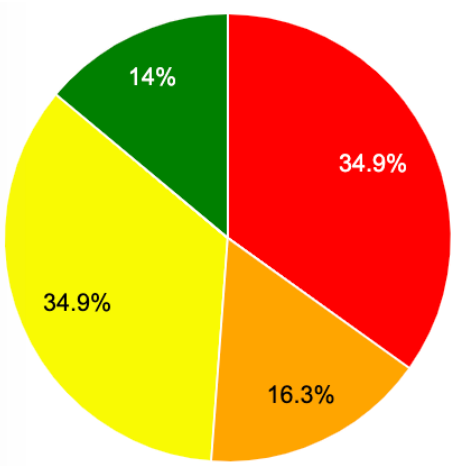
2000-2004
8 missions



2005-2009
17 missions

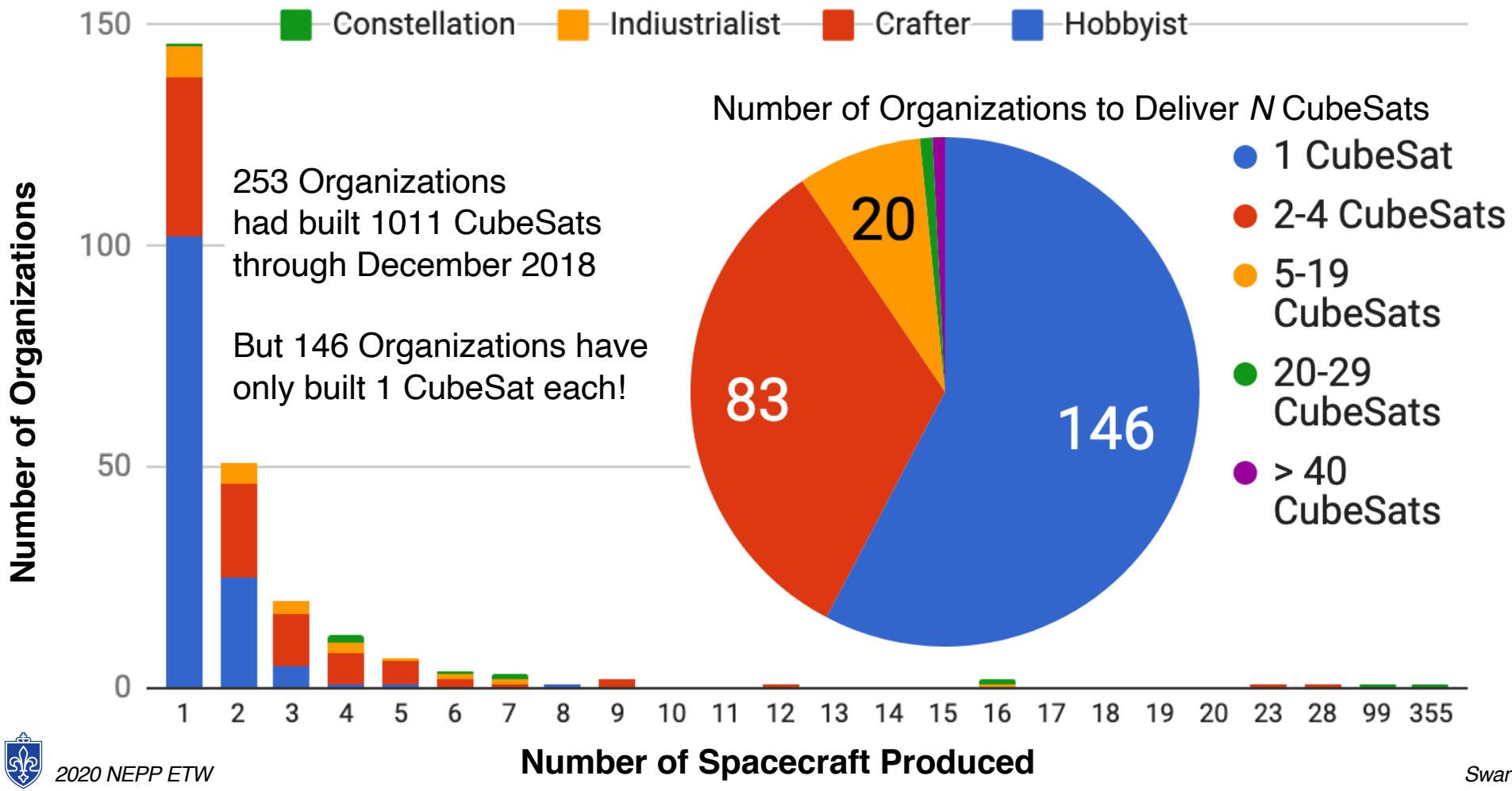


2010-2014
79 missions



2015-2018
86* missions

Hobbyists: It's Hard to Improve, When You Don't Repeat!



Correlation is Not Causation ...

but that sure looks like a learning curve

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- Early Loss
- Partial Mission
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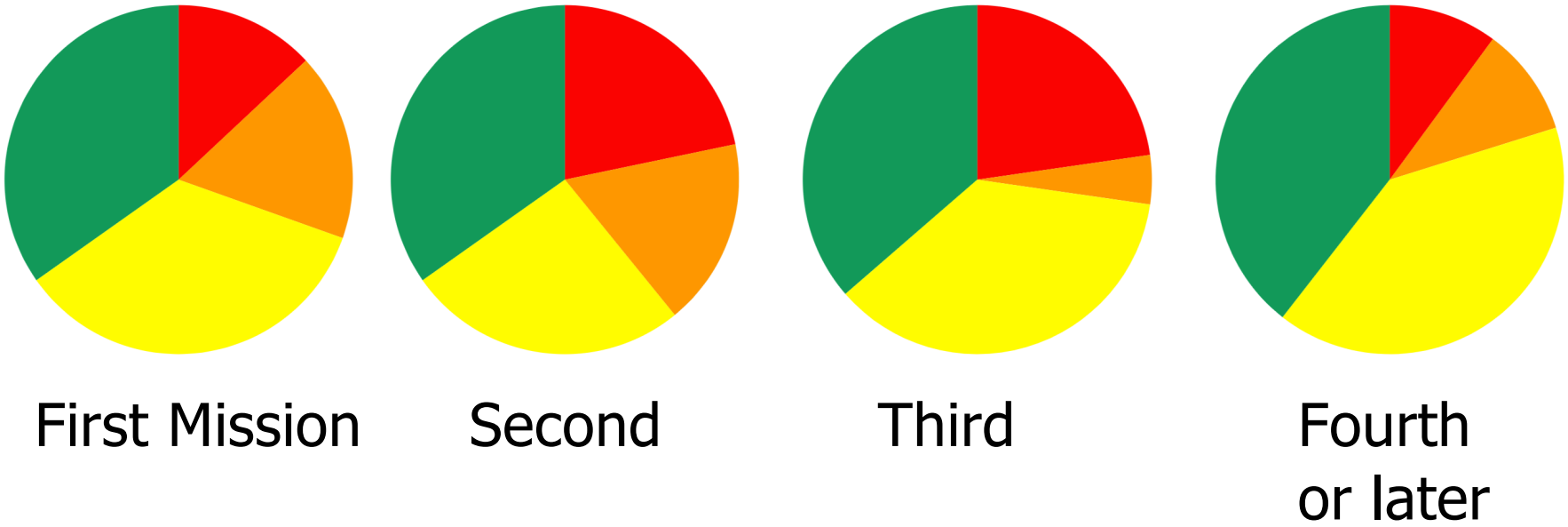
Mission Status, "Top 24" Crafters by Ordinal Flight

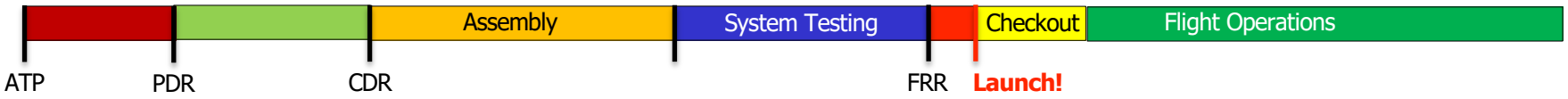


The Plural of “Anecdote” is not “Data”, but …

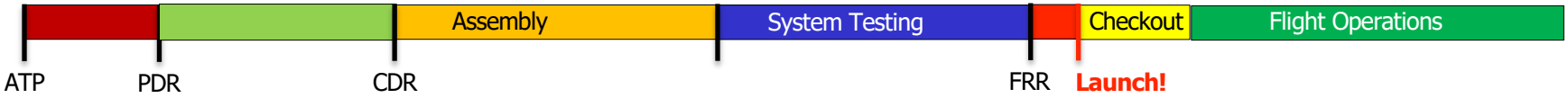
- Possible reasons for DOA
  - **Compressed development schedule leads to uncaught mistakes** (software errors, mechanisms binding, inadequate power budget, non-robust startup sequences)
  - Shock loads expose workmanship flaws (few hobbyists test for shock)
  - Underpowered RF system
  - Two or more recoverable errors “team up”
  - SEEs
- Sources of early failure
  - Environmental wear (thermal cycling, radiation effects)
  - Low margins (battery depth-of-discharge)
  - Long-term software instability

About That Compressed Schedule …

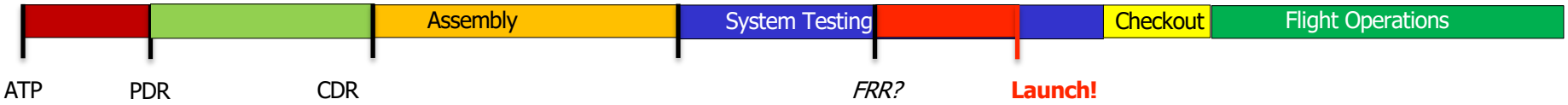
The Original Schedule



The Actual Schedule



The Smallsat Schedule



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It's Not All Bad News …

- Those that survive the first 90 days tend to stick around
  - PCSat (2001), XI-IV (2003), XI-V (2005)
  - Think of it as post-launch "burn-in" and end-to-end functional testing (!?!)
- Common characteristics of success
  - Process, process, process!
  - Development schedule with significant functional testing and margin
  - Organizational robustness to staff turnover and mission failure
- Common features for on-orbit success: operational robustness
  - "Bulletproof" power-rich safe mode
  - Hard reset from the ground (bypassing flight software)
  - Flight software uploads
  - Lack of time-critical operational events

Acknowledgements

- 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
- NASA NEPP (NNX17AJ46G and 80NSSC18K0637)
- Student research team: Samantha Carlowicz, Scott Elliott, Connor Highlander, Andie Kaess, Tinevimbo Ndlovu, Cody Powers, Patrick Sullivan, Adam Walker, Sean Walsh

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