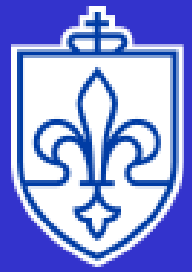
Smallsat Mission Assurance: Annual Checkup and New (?) Models

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

2022 NEPP Electronics Technology Workshop
15 June 2022

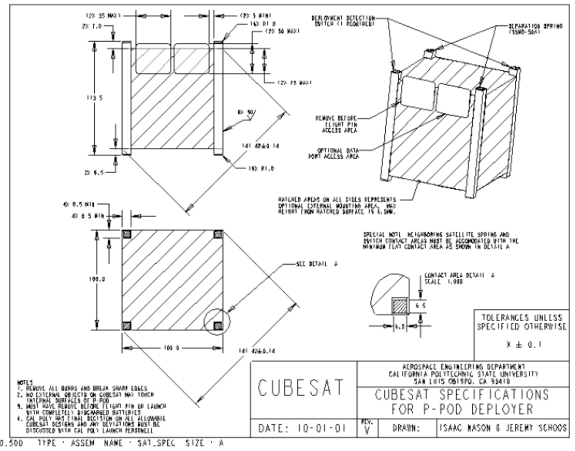


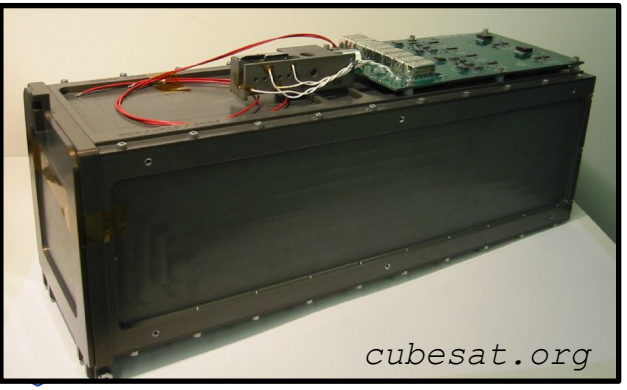
SAINT LOUIS UNIVERSITY
PARKS COLLEGE OF ENGINEERING,
AVIATION AND TECHNOLOGY

If You're Side-Screening This Talk

- Census Updates
  - More missions
    (1880, and 1750 in the last 10 years)
  - More constellations
  - More *more*, and I'm not sure what to do with it
- Mission assurance: R-GENTIC for structures
- Mission assurance: Complexity metric

One-Chart Short Course: CubeSats

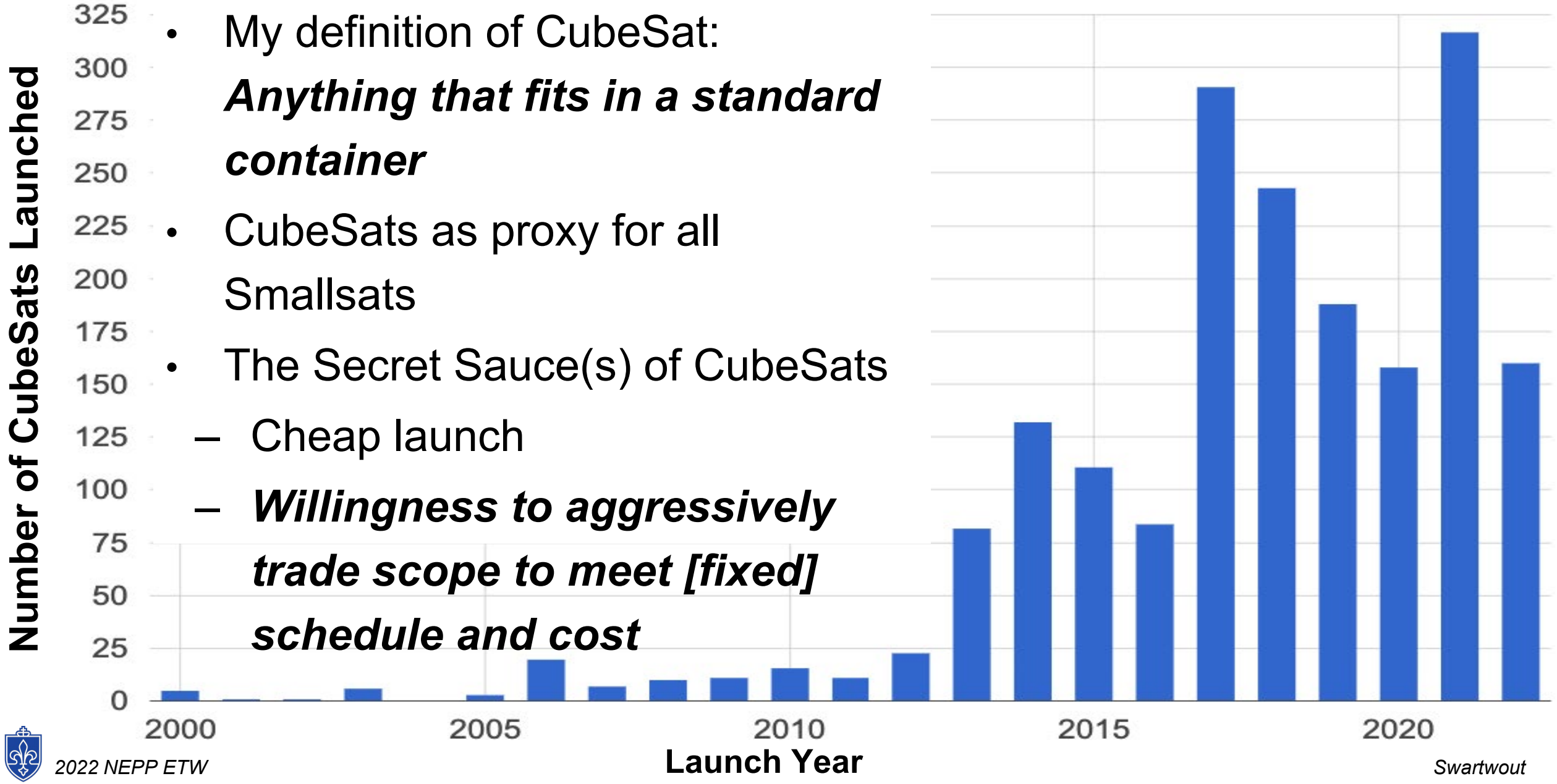




- Twiggs (Stanford) and Puig-Suari (Cal Poly) defined a standard for carrying 10 cm, 1 kg cubes into space ("1U")
- Goal: Give students easy access to spaceflight
- Unintended consequence: the P-POD makes launches cheap
- Timeline
  - **1999** Concept definition, flight validation
  - **2003** First 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
  - **2018** CubeSats go to Mars
  - **2021** 1500th flight, 300th builder

For Those Who Just Joined Us …

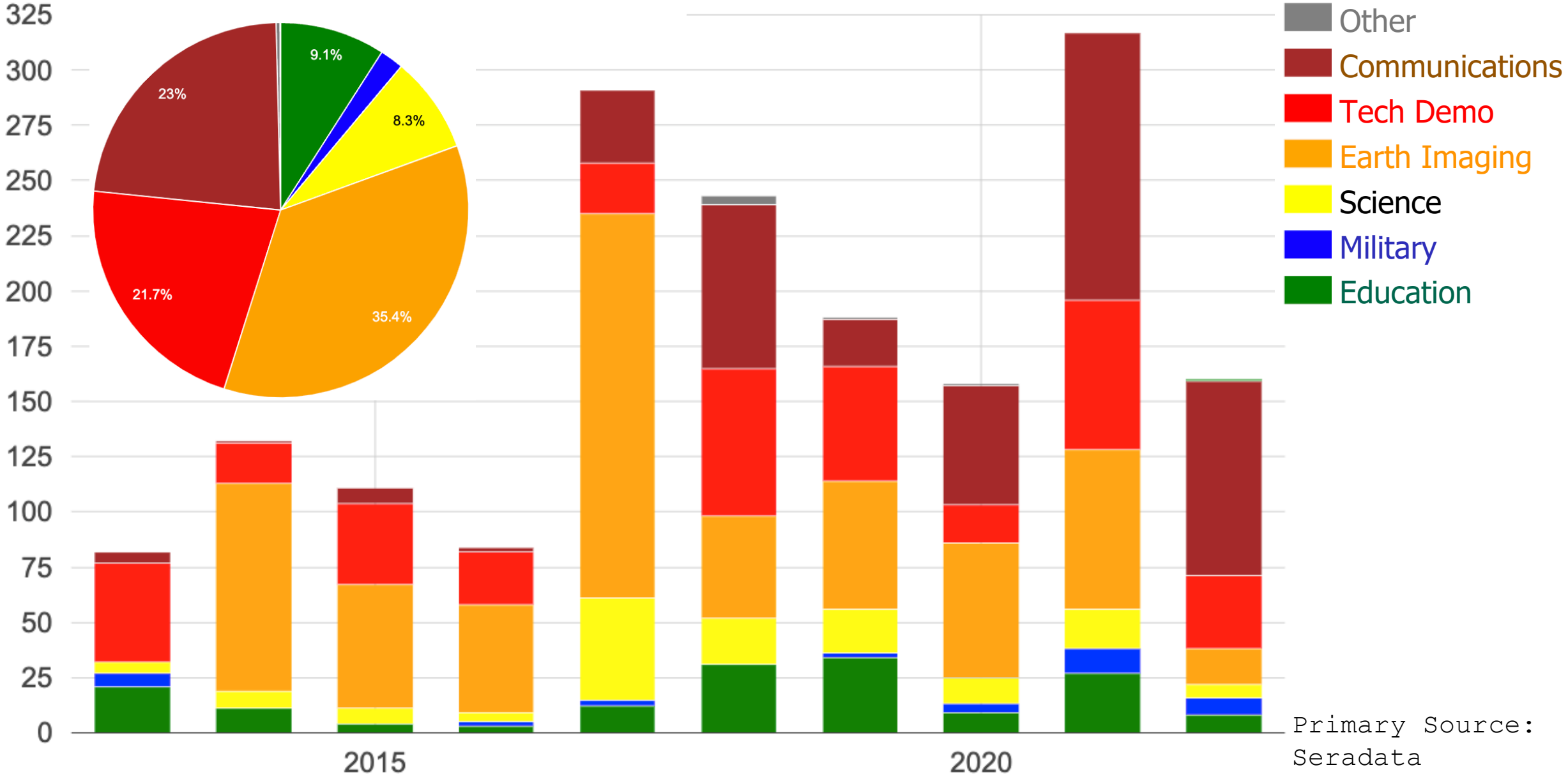
- My definition of CubeSat:
  Anything that fits in a standard container
- CubeSats as proxy for all Smallsats
- The Secret Sauce(s) of CubeSats
  - Cheap launch
  - ***Willingness to aggressively trade scope to meet [fixed] schedule and cost***



Why Fly CubeSats?

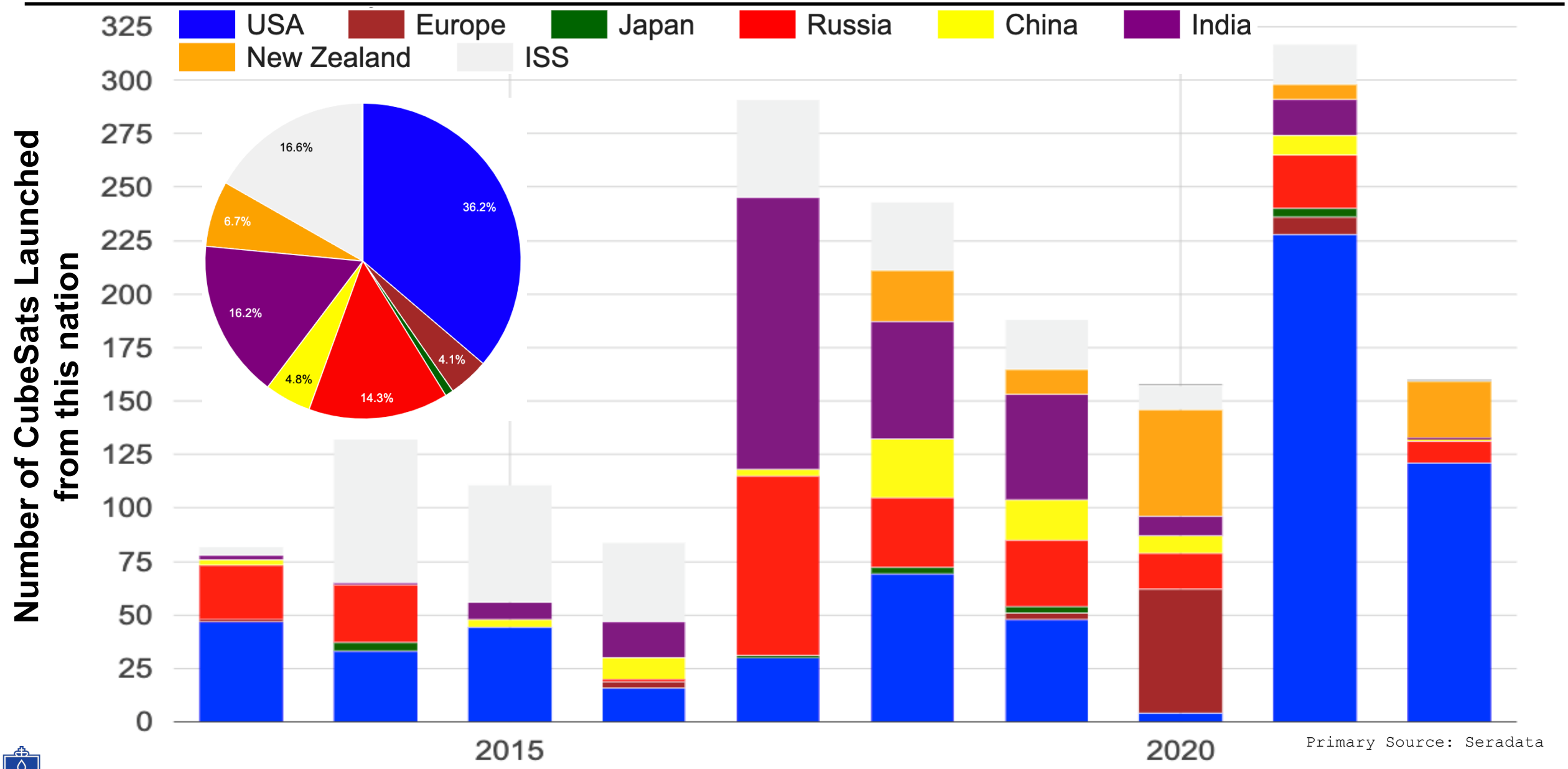
- Let's give the kids something to do
  - Nothing teaches systems engineering like … doing systems engineering
  - Let students (or new hires) burn their fingers on short, low-consequence missions
- Kick-start a space industry
  - 414 organizations from 65 nations
  - First flight in 2020: 26 organizations, 5* nations
  - First flight in 2021: 47 organizations, 3* nations
  - So far in 2022: 21 organizations
- 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)
  - ***Market entry without the need for 5 years and $50M***
  - Rapid(ish) turnaround on flights of many, many, many spacecraft

CubeSat by Mission Type (2013-2022)

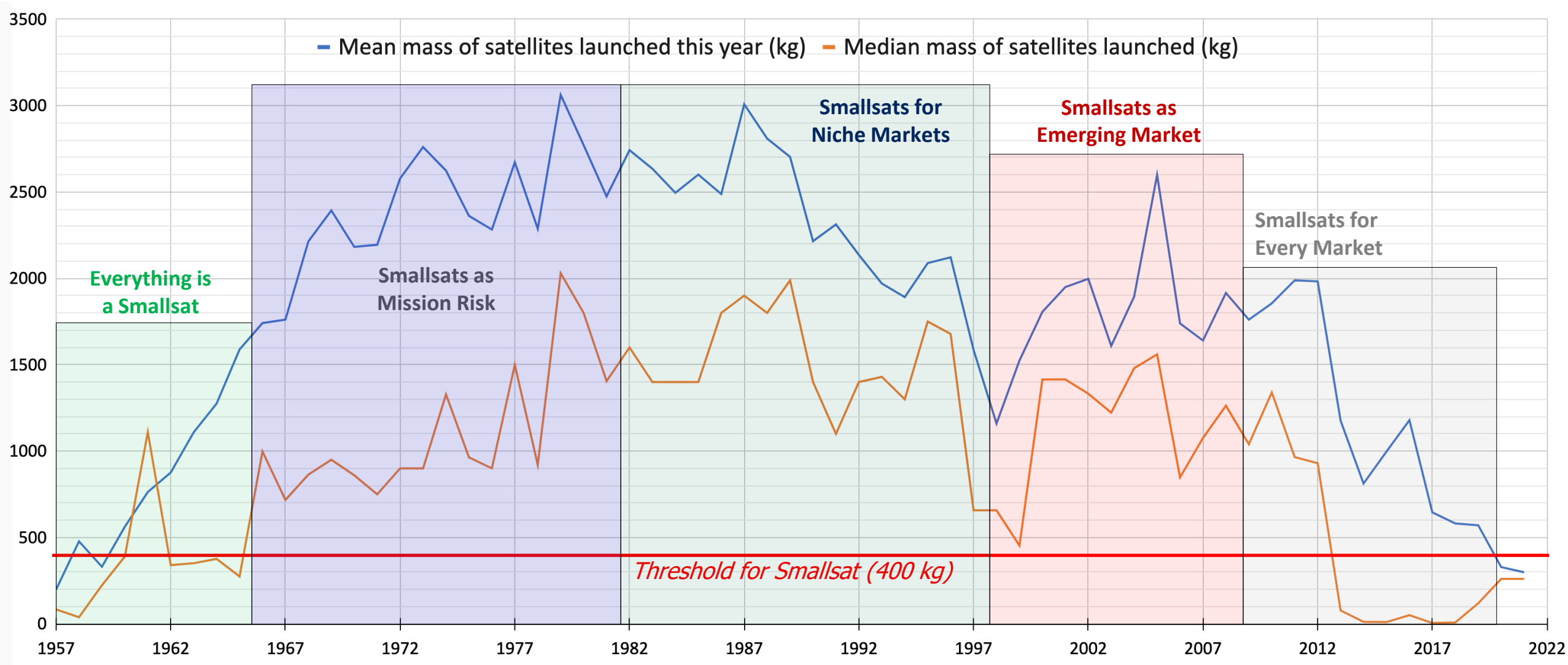


Primary Source: Seradata

Worldwide Launches of CubeSats (2013-2022)

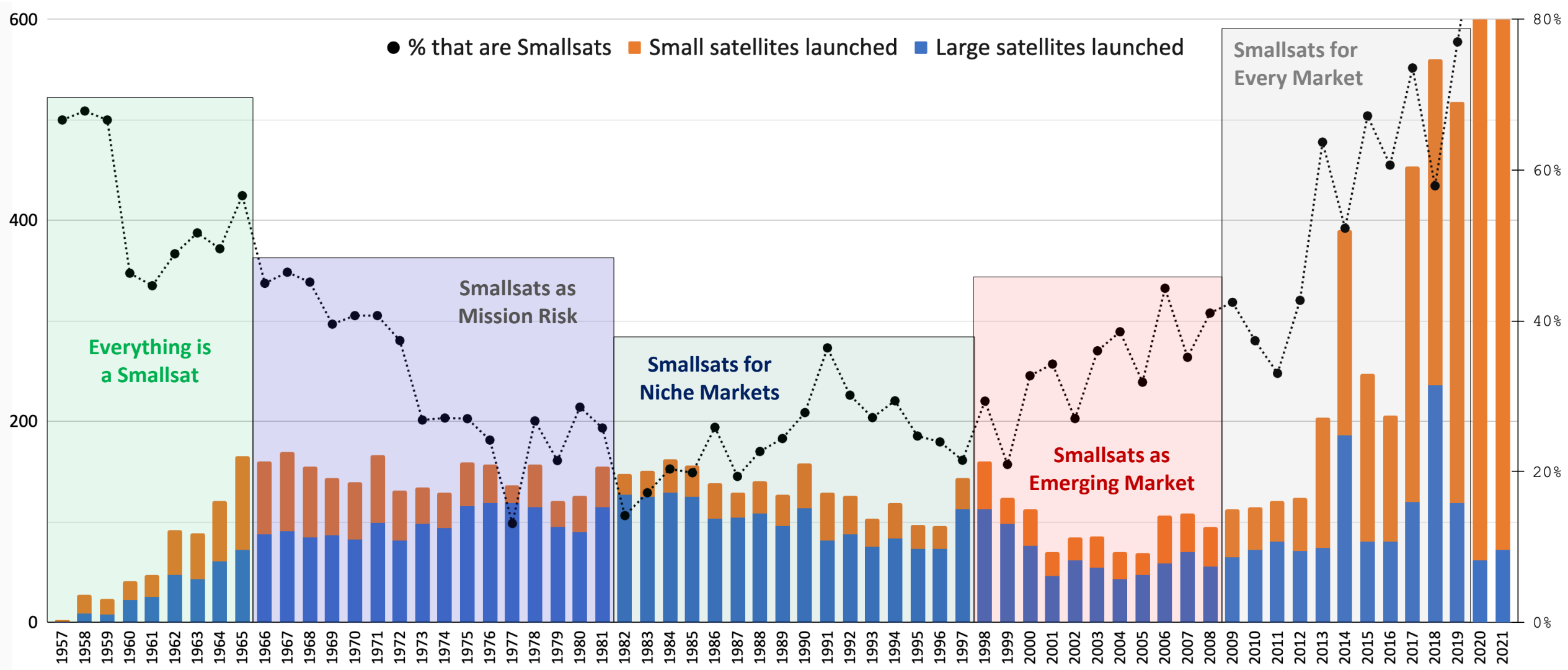


Observations: Today. Interpretations: TBD



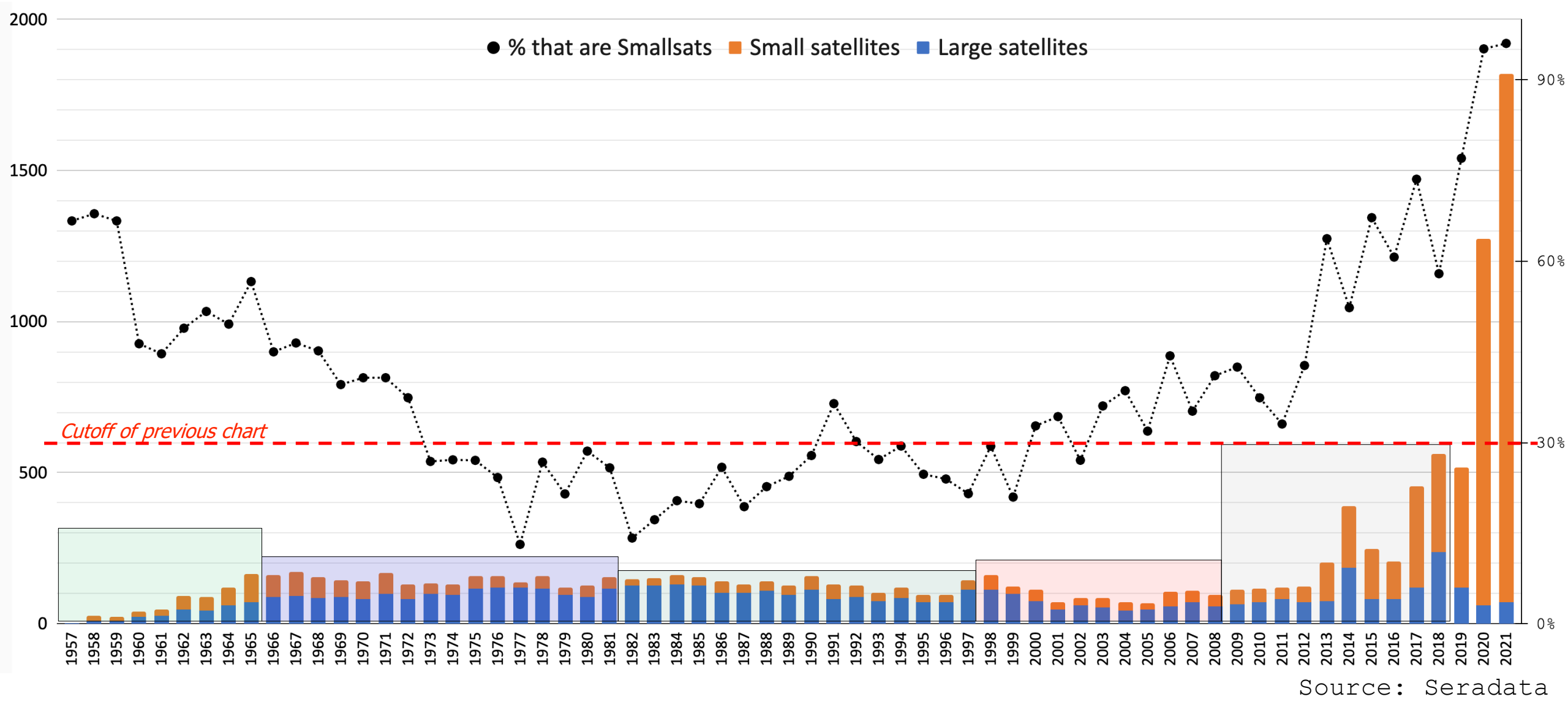
Source: Seradata

Observations: Today. Interpretations: TBD



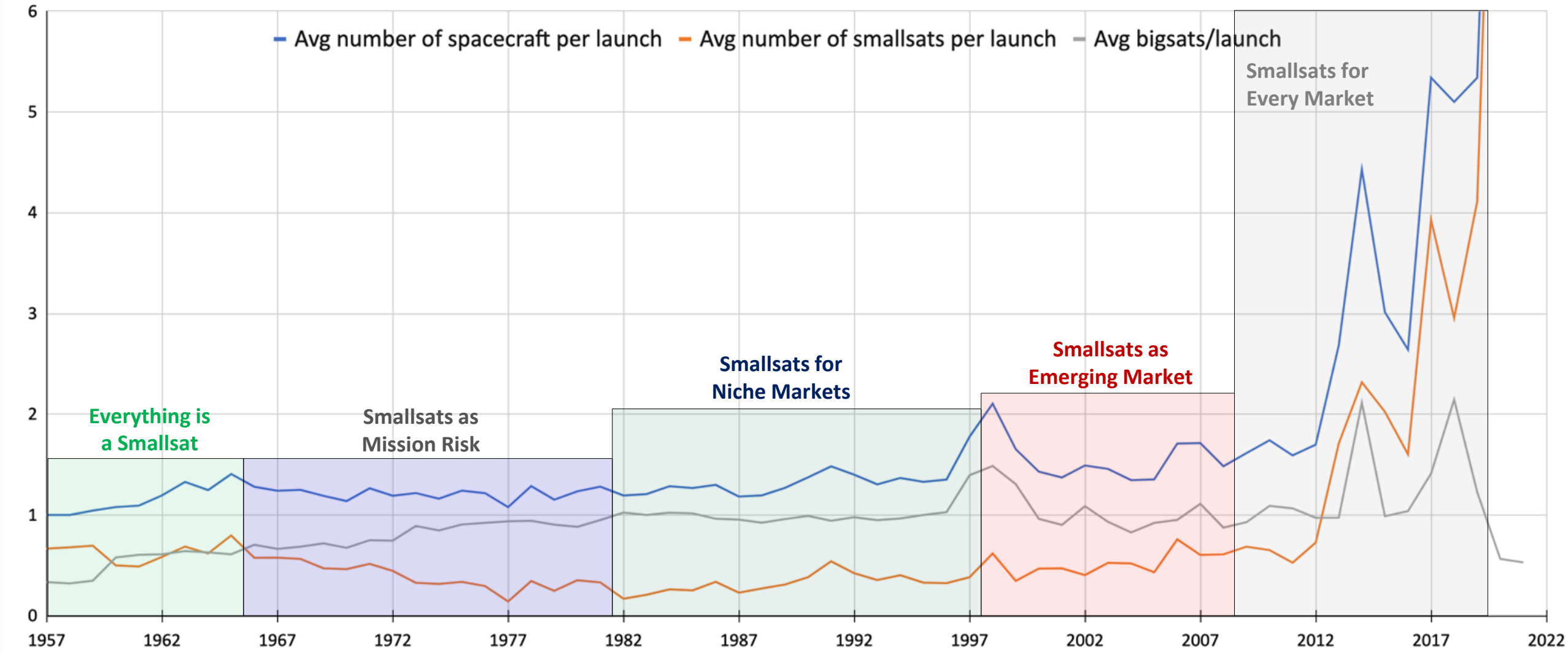
Source: Seradata

“This Means Something”



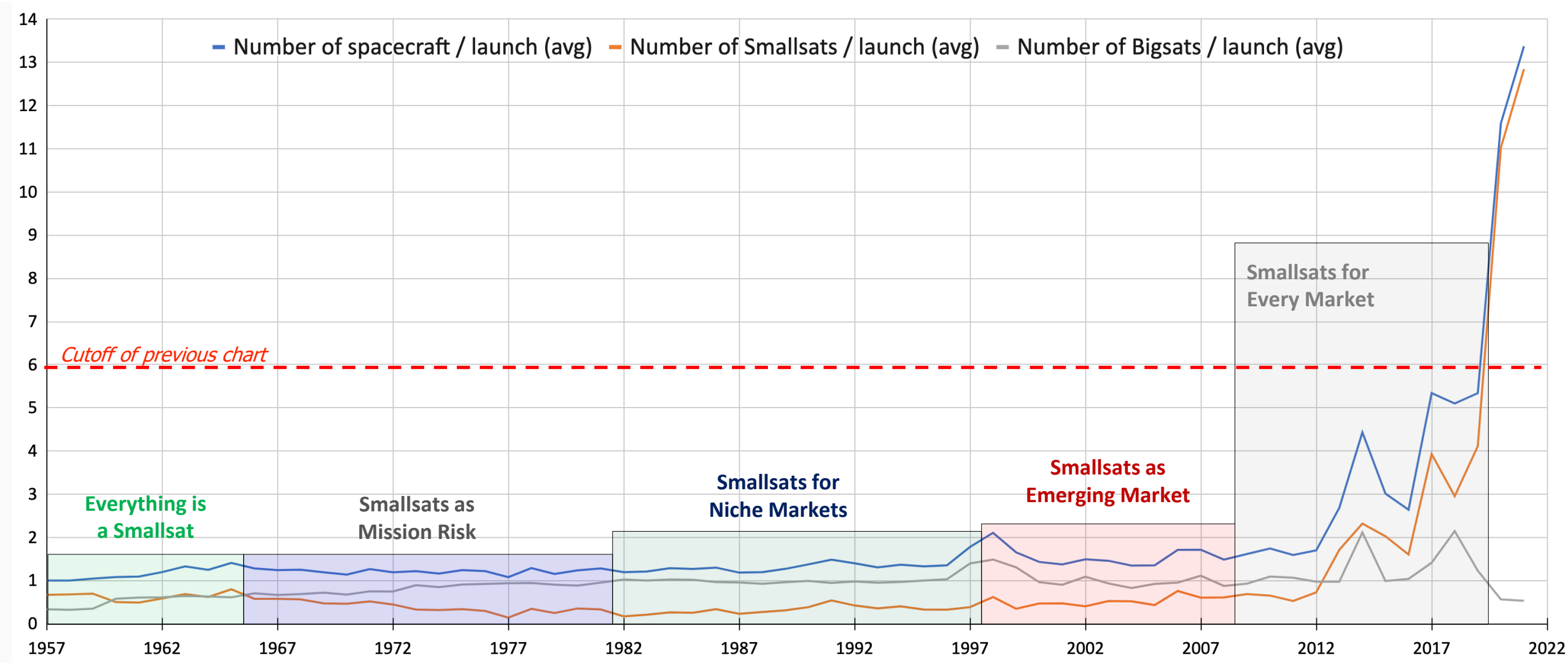
Source: Seradata

Not Your Father's Launch Market



Source: Seradata

I Don't Know What to Do With Starlink

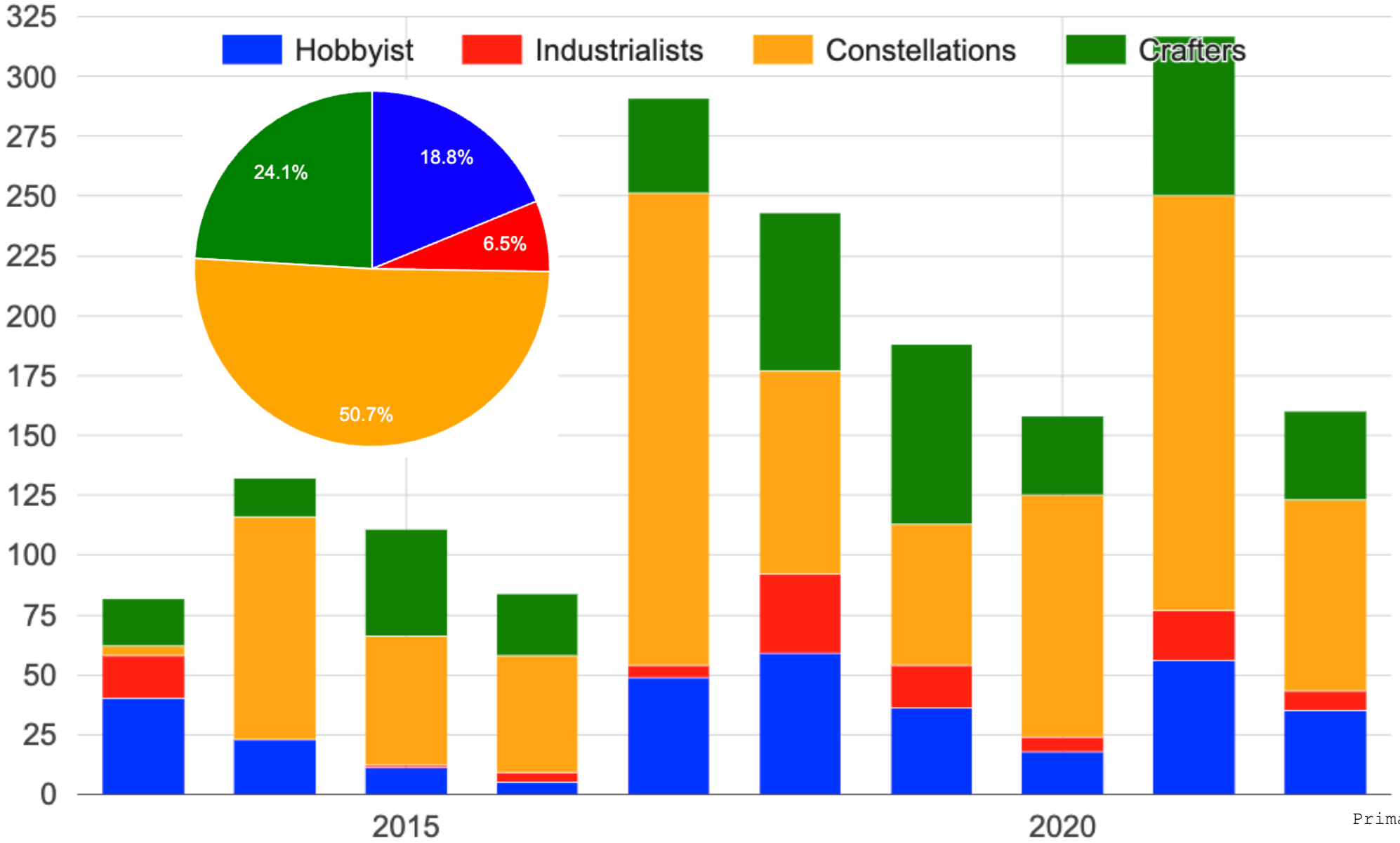


Source: Seradata

None of These Things are Quite Like the Others …

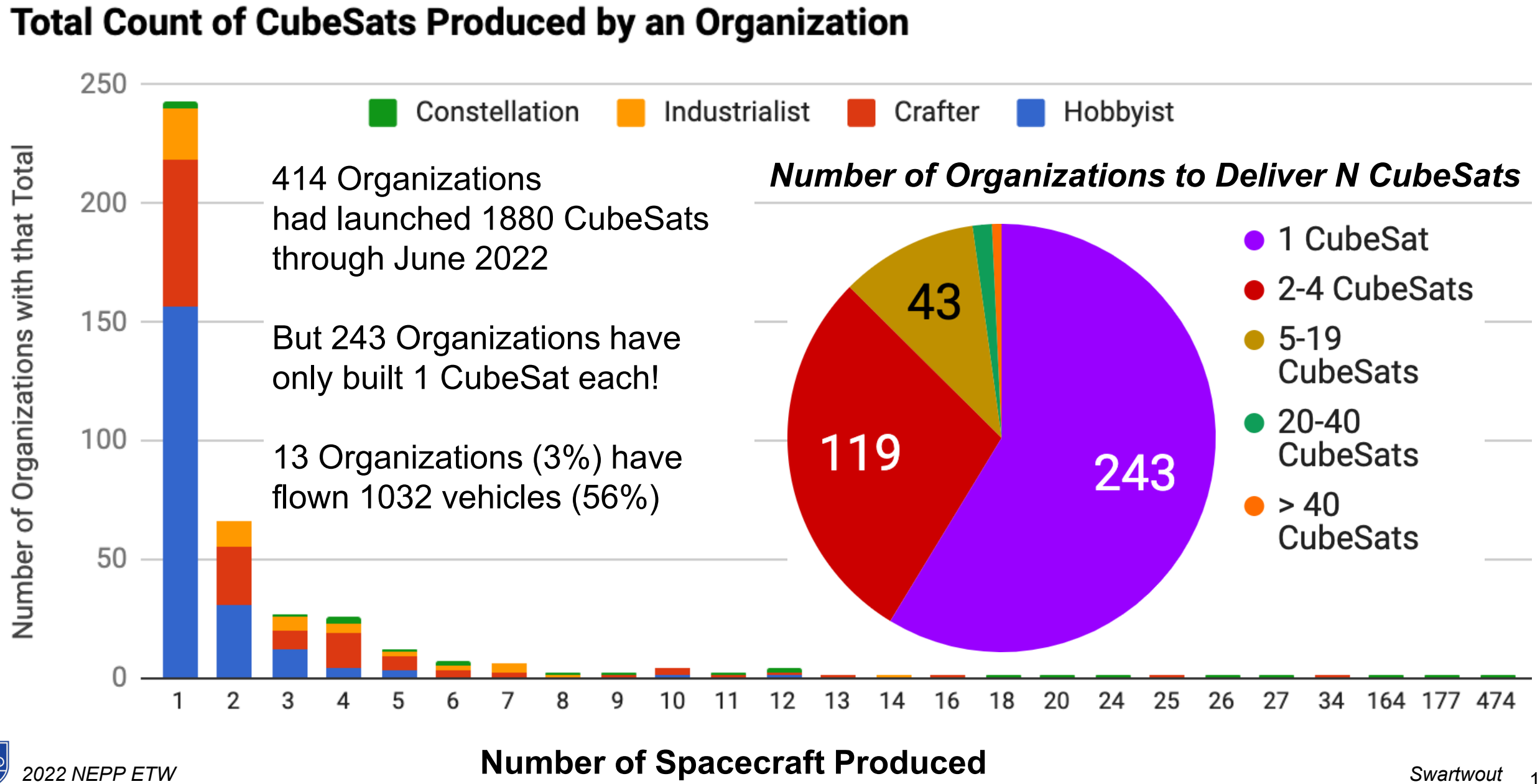
- **Hobbyist**
  - No real experience in the field
  - Building for fun & future profit
  - **Ad hoc practices**
  - **< 4 missions**
- **Industrialist**
  - Experienced builders of big spacecraft
  - Building under gov't contract
  - **Standard space system practices, with some truncation**
  - **Smallsats are not the main business line**
- **Crafter**
  - Experienced builders of small spacecraft
  - Working under contract
  - **Streamlined practices, experientially developed**
  - **4+ missions, smallsats are main business line**
- **(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

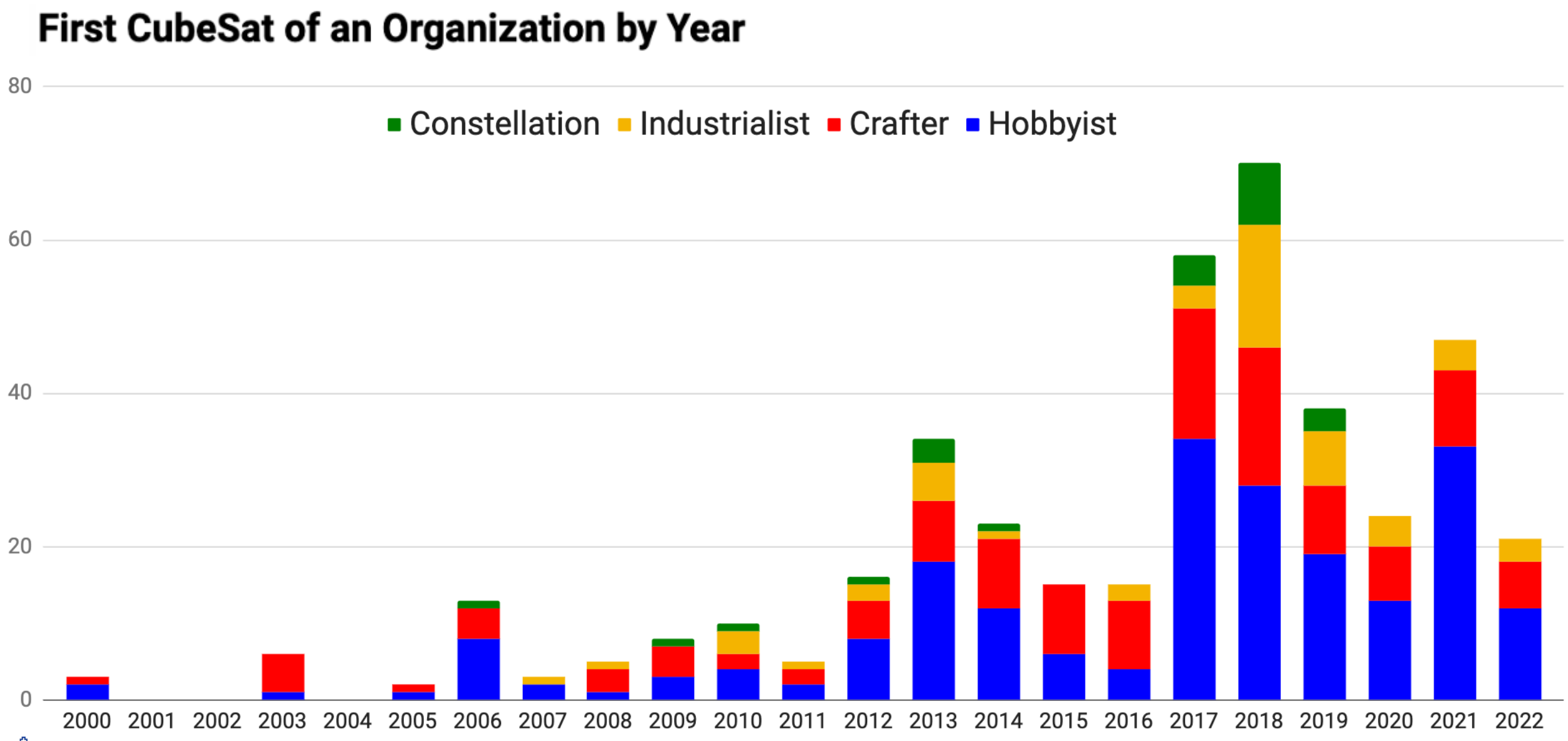


Primary Source: Seradata

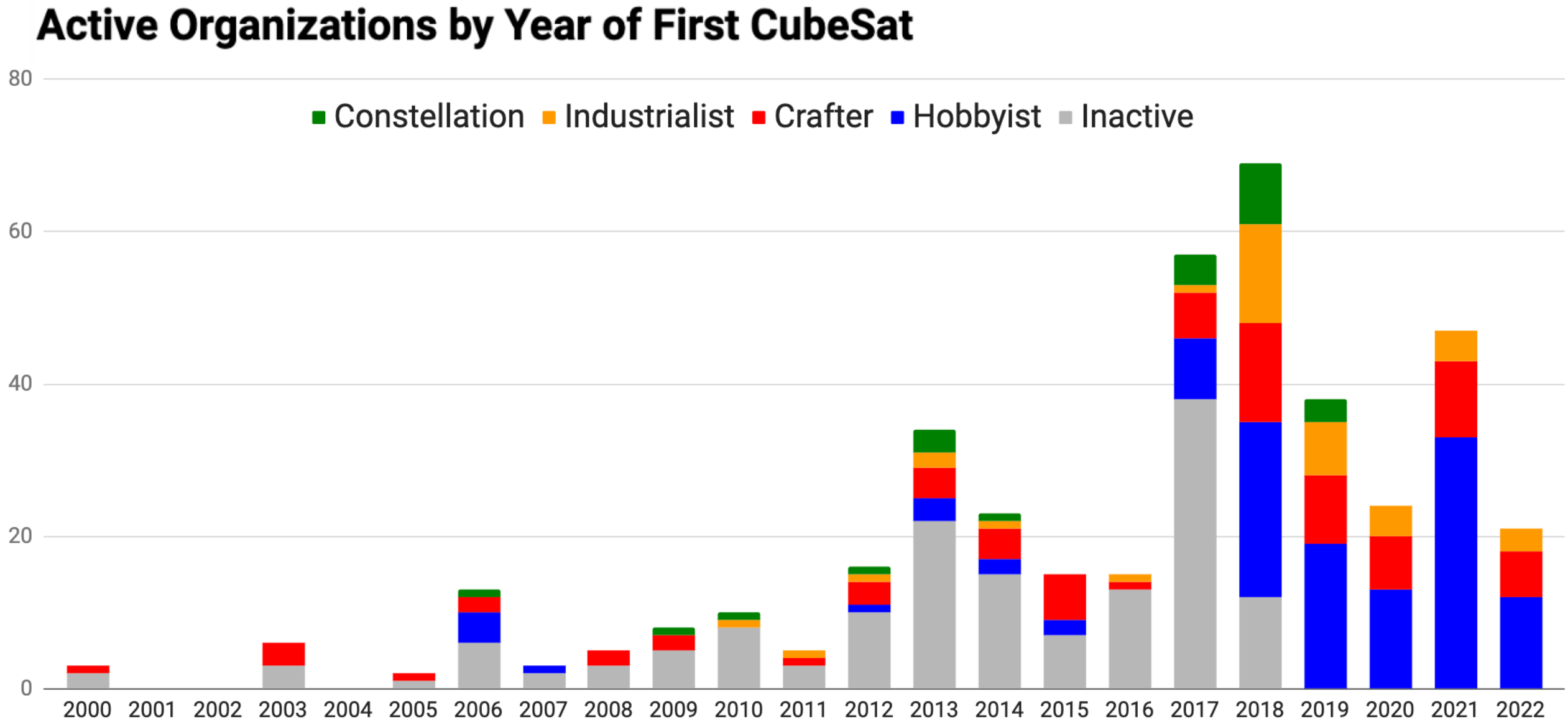
Hobbyists: It's Hard to Improve, When You Don't Repeat!



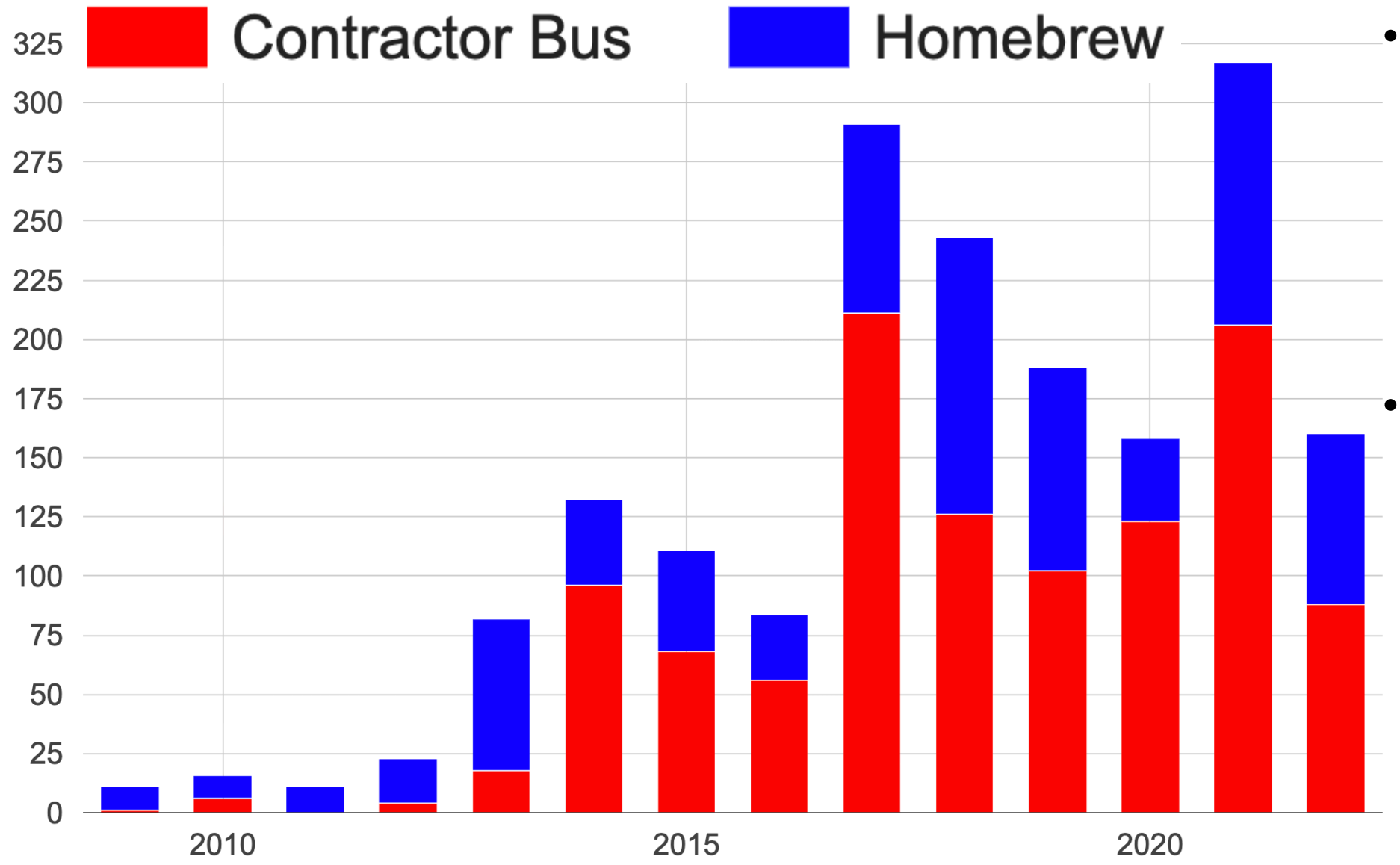
Indirect Measures of Success



Indirect Measures of … Not-Success?



While We Were Away … The Market Took Care of Business



- Professional programs buy an integrated bus (or they mass-produce their own
- Suspicion (not ready to claim): hobbyist/ homebrew are mostly where the mission losses happen

Primary Source: Seradata

Showing Wasn't Easy; I'll Try Telling

- We're in a 6th (!?!) era of small satellites
- CubeSats started it, but the spacecraft mass is creeping upwards
- Unprecedented (or at least, new)
  - Cheap access to space worldwide
  - Commercially-driven development
  - Massive numbers of heterogeneous spacecraft on one launch
  - Ad hoc "constellations"
  - Quiet consolidation around a dozen-ish integrated bus providers
  - Five providers (Starlink, OneWeb, Planet, Spire, Swarm) are skewing my numbers and everyone's perception

R-GENTIC for Deployable Systems

- **Question**: Can an automated (web-based) guided interview help untrained designers make reliable deployable-system design decisions?
- **Approach**:
  - Taxonomy of deployable systems
  - Mapping of deployables to risks/testing strategies
  - Guided interview process
- **Goals**:
  - Near term: taxonomy and lists of risks/testing strategies
  - Medium-term: associated map between configurations and previous missions
  - Long-term: model-based system to prioritize mission assurance strategies based on risk
- **Sources**:
  - S. Carlowicz, *Development of a Guided-Interview Risk Assessment for Small Satellite Deployable Systems*, SLU MS Thesis, July 2022
  - Sauder, J. and Gebara, C. and Arya, M., *A Survey of CubeSat Deployable Structures: The First Decade*, AIAA SciTech 2021 Forum.
  - Rivera, A. and Stewart, A. *Study of Spacecraft Deployable Failures,* 19th European Space Mechanisms and Tribology Symposium, 2021.

"R-GENTIC for Deployables": Status

Launch Restraint	Dispenser	Held in place by container in which the spacecraft travels; deployed when released from container.
	Burn Wire	Held in place by wires; deployed when wires burned.
	Shape Memory Alloy	Held in place by Shape Memory Alloy (SMA); deployed when SMA is displaced through heating.
	Motor	Held in place by motor power (electrical current converted to mechanical force); deployed when motor actuated.
	Wax Actuator	Held in place by a pin; deployed when heat applied to wax causes expansion of the wax, acting as a linear actuator device.
	Another Deployable	Held in place by another deployable; deployed when first deployable deploys.
	Latch / Tight Fit	Held in place by a preloaded cover; deployed when actuator pushes cover / latch open.

- Taxonomy
- Risk list
- Verification (?) via subject-matter experts

		Stowing Methods									
2	**Failure Mode**	Single Fold	Multiple Folds	Origami Folds	Telescopic	Spooled	Coiled	Stuffed	Dispenser	Burn Wires	Shape Memo
3	**Did Not Deploy**										
4	Not Enough Force in Deployment Direction (1)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5	Sticking / Jamming - Internal (1.1)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
6	Cold-Weld (1.1.1)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
7	Corrosion (1.1.2)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
8	Incompatible materials chosen (1.1.2.1-F)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
9	Incorrect modeling of the environment (1.1.2.2-M)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
10	Undesired thermal deformation (1.1.3)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
11	Unexpected environment (1.1.3.1-H)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
12	Incorrect design of dimensional tolerances - thermal (1.1.3.2-F)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Cost [*Risk*] Modeling Using Countable Metrics

- **Question**: Can we predict the complexity (cost/risk) of a small-satellite mission using design-time information?
- **Approach**:
  - Adapt CoBRA factors for small missions (countable metrics)
  - Gather data on real (NASA) missions
  - Generate normalized complexity score: 0 (PhoneSat) to 100 (MarCO)
  - Assess and expand
- **Goals**:
  - Near term: convert to online tool (plots and comparisons)
  - Medium-term: include reliability/risk assessments, add missions
  - Long-term: build a “capability metric” to accompany the complexity metric
- **Sources**:
  - A. Wagner, *Spacecraft Complexity Metric Analysis for CubeSats*, SLU MS Thesis, August 2021
  - D. A. Bearden, *A Complexity-Based Risk Assessment of Low-Cost Planetary Missions: When is a Mission Too Fast and Too Cheap?* International Conference on Low-Cost Planetary Missions, Laurel, MD, May 2000.

Complexity Modeling: Status

CubeSat Complexity Index Parameters		CoBRA Parameters (2018)	
Factor	**Unit**	**Factor**	**Unit**
Development Cost	FY$20M	Development Cost	FY$12M
Development Time	months	Development Time	months
Payload Mass	kg	Payload Mass	kg
Payload Avg Power	W	Payload Avg Power	W
Number of Payloads	#	Number of Payloads	
		Payload Type	
Data Volume	MB/day	Data Volume	MB/day
Stakeholders	#	Foreign Partnership	
Design Life	months	Design Life	months
Satellite Mass (dry)	kg	Satellite Mass (dry)	kg
Orbit Regime		Orbit Regime	
Orbit Avg Power	W	Orbit Avg Power	W
Solar Array Area	m^2	Solar Array Area	m^2
		Solar Cell Type	
		Battery Type	

- First-cut data (28 NASA CubeSats)
- Need to review weighting to fit cost/schedule plots
- Need more missions

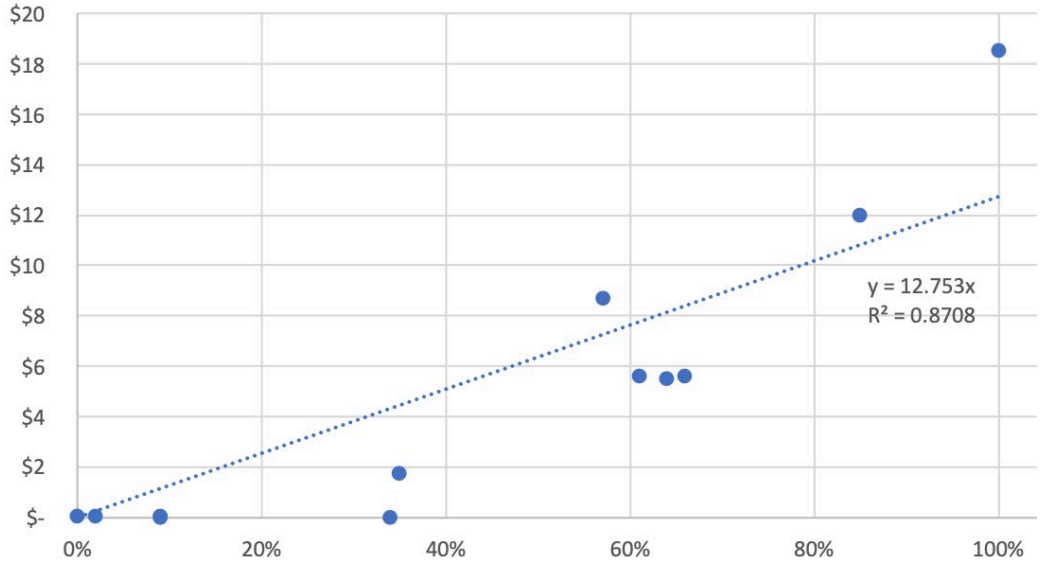


Figure 5: Development Cost ($M) vs. NCI

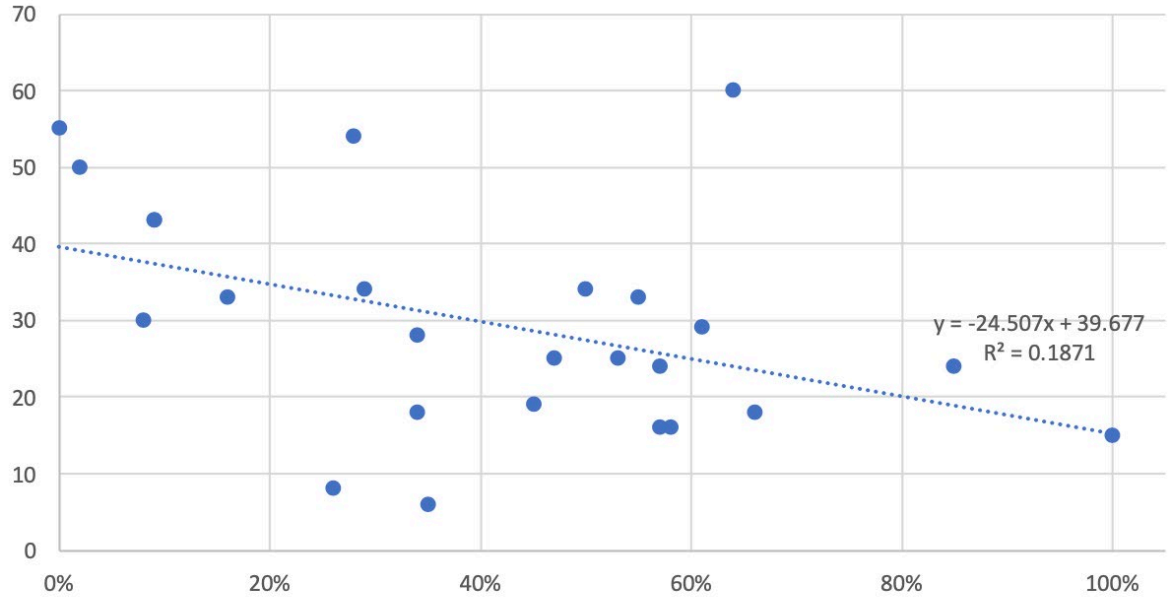


Figure 6: Development Time (mos) vs. NCI

Acknowledgements

- Data Sources
  - Private: Ascend SpaceTrak
  - 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)
  - Public: SatNOGS (operational status)
  - Private: Personal communications
- NASA NEPP (80NSSC20K1230)
  - Andrew Wagner (MSAE 2021)
  - Samantha Carlowicz (MSAE 2022)