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Nanosatellite Launch Forecasts - Track Record and Latest Prediction

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ABSTRACT

After almost 300 CubeSats were sent to space in 2017, the following 3 years saw a continued decline. While 2021 set a new record of about 326 nanosatellites launched, most published forecasts and expectations from the last 10 years about the growth about CubeSats have not come to fruition. This paper attempts to answer the question why and make a new prediction based on scheduled missions and historic trends.

First part of the paper presents the latest nanosatellite and CubeSat launch statistics. Out of over 3400 entries in the database, 2068 nanosatellites or 1893 CubeSats have been launched as of August 1, 2022. Total estimated mass of launched CubeSats is only ∼7428 kg (4952U×1.5 kg), which is less than a batch of 60 Starlink spacecraft. Second part focuses on the subset of nanosatellites flying beyond the low Earth orbit and 79 missions with orbits from MEO to heliocentric have been listed with 15 of them launched to space.

Third part of the study collected small satellite launch forecasts from multiple organizations and compared them to historical results. Reasons for the divergence were discussed. Launch delays are one of the causes for some years, but most of the growth was supposed to come from commercial CubeSat constellations and nearly all of them have not yet happened at scale or are transitioning to larger satellites.

Last part of the work created a new CubeSat launch forecast for the next 6 years. This is an update to the previous predictions by the author in early 2018 and 2020. We predict that there will be 2080 nanosatellites launched from the beginning of 2022 to the end of 2027.

Some early excitement might have passed for universities and companies after launching their first nanosatellites and facing the challenges of space technology development and space business models. However, with only 4 interplanetary CubeSats in space, quickly expanding launch options, and numerous possible exciting technologies yet to be developed, the productive times of nanosatellites are still likely ahead.

INTRODUCTION

Nanosats Database (www.nanosats.eu) has been tracking CubeSats, pico- and nanosatellites since 2014. Over 3400 entries encompass 2068 launched spacecraft until August 1, 2022.[1] Uniquely to many other lists, largest amount of upcoming and cancelled missions are also included.

After 297 CubeSats were sent to space in 2017, the following 3 years experienced a continued decline. While 2021 set a new record of about 326 nanosatellites launched, most published forecasts and expectations from the last 10 years have not come to fruition. This paper attempts to explain the reasons behind it and make a new prediction.

CubeSats helped to kick off the NewSpace mentality and economy, but sustainable business models have been slower to emerge. Planet and Spire are still the largest CubeSats constellations and recently followed by Swarm (SpaceX). Others are far behind in quantities and many are transitioning to larger spacecraft. These largest constellations have also been built in-house compared to outsourcing.

First part of the paper presents the latest nanosatellite and CubeSat launch statistics. Picosatellites and PocketQubes have also seen rapid growth in the last year.

Second part of the work focuses in detail on the nanosatellites flying beyond LEO to fit with the conference theme and many of those spacecraft have also faced years of delays.

Third part of the study collects forecasts from multiple organizations and compares them to historical results. Reasons for the divergence will be analyzed and discussed. Launch delays are part of it, but after multiple consecutive years and available capacity on many rockets, it is not the whole answer.

Fourth part of the research includes creating a new forecast for the next 6 years. This will be an update to the previous predictions by the author in early 2018 and 2020. Various methodologies will be discussed and authors approach will be described. Entries for future missions and adjacent databases for commercial constellations and small launchers allow wider insights into the future when comparing solely to past launch trends.

NANOSATELLITE LAUNCH STATISTICS

First part of the paper presents the CubeSat and nanosatellite launch statistics and trends. Upcoming missions will be also plotted based on announced launch years, or when not available or delays have occurred, then educational guesses have been made. Cancelled are not shown. This is an update to the authors' work presented latest in April 2021.[2]

Survey Criteria

Included in the Nanosats Database:

- All CubeSats from 0.25U to 27U.
- Nanosatellites from 1 kg to 10 kg (in kilograms).
- Picosatellites from 100 g to 1 kg (in grams).
- PocketQubes, TubeSats and ThinSats.

Not included:

- Femtosatellites (10 g to 100 g), chipsats and suborbital launches.
- CubeSats bolted to upper stages and not meant to be separate flying objects.
- Deep space inspection cameras, like flown on IKAROS & Tianwen-1.
- Data is since 1998, whereas at least 21 nanosats were launched in the 1960s.
- Custom microsatellites in the 10-50 kg range.

By the previous criteria, the term "nanosatellite" in the wider context includes all CubeSats, custom nanosatellites, PocketQubes and picosatellites.

Most nanosatellites have some public information and are easy to enter into the database, but there are also many challenges. Photos of some CubeSats are impossible to find. Detailed and timely mission status is only rarely shared, though some do it well. Some CubeSat names are not unique making search more difficult. A source for an upcoming CubeSat could be a screenshot of a presentation, which is not easy for data mining. There are limited other sources with references. Proactive sharing of information or offers for help are also rare. Another challenge is separating CubeSat units (U-s) and kilograms because exact masses are rarely published.

Error of the cumulative satellite count is about ±5 spacecraft, due to a few unknown objects from military (e.g. X-37B? and USA 320-323) and some satellites from China. There is no information about the form factors of many launched spacecraft and it is possible some more could match the criteria.

Nanosatellite Statistics as of August 1, 2022

- Nanosats launched: 2068
- CubeSats launched: 1893
- PocketQubes launched: 52
- CubeSat 1U-sized units launched: 4952.1U
- CubeSats launched in mass: ∼7428.15 kg (assuming 1.5 kg per U)
- Interplanetary CubeSats: 4
- Nanosats destroyed on launch: 108
- Deployment failures and prohibitions: 16
- Most nanosats on a rocket: 120, Transporter-1
- Countries with launched nanosatellites: 77
- Companies in the database: 550

Total Nanosatellites

The total cumulative launched nanosatellites and CubeSats is plotted on Figure 1. As of 2022 August 1, the total nanosatellites launched is 2068 including launch failures. Total CubeSats launched on a rocket including launch failures is 1893, which adds up to ∼4952U and ∼7428 kg, when assuming 1.5 kg per U. The number of CubeSats which have made it to orbit and were successfully deployed is 1786. Thus, launch does not equal deployment in orbit, but the spacecraft was still built. Nanosatellites with propulsion modules is 134, but here more could be unknown.

The increase in nanosatellites over the last 20 years broadly divides into 3 phases. Relatively slow growth can be observed from 1999 to 2013. From 2013 to 2016, there is a noticeable increase as projects started in 2008-2010 began to be launched including the first demonstrations for constellations. From 2017 onwards, the growth became even more rapid.

Launches by Years

Yearly launches of nanosatellites is on Figure 2. After the record of 297 spacecraft launched in 2017 there were 3 years of continuous decline. One of the causes is that multiple new small launchers and large rideshare missions were delayed by 2-3 years. Launch delays are not the only cause, because many satellites are also built according to launch schedules. As a larger effect, most constellations have been much slower to scale up from the first demonstrations in 2017-2018.[3] Nevertheless, 2021 was a new record in nanosatellite launches with 326 spacecraft. 2022 may see another record, but it is very unlikely to be as high as the 646 as illustrated by the announced and listed missions on Figure 2.

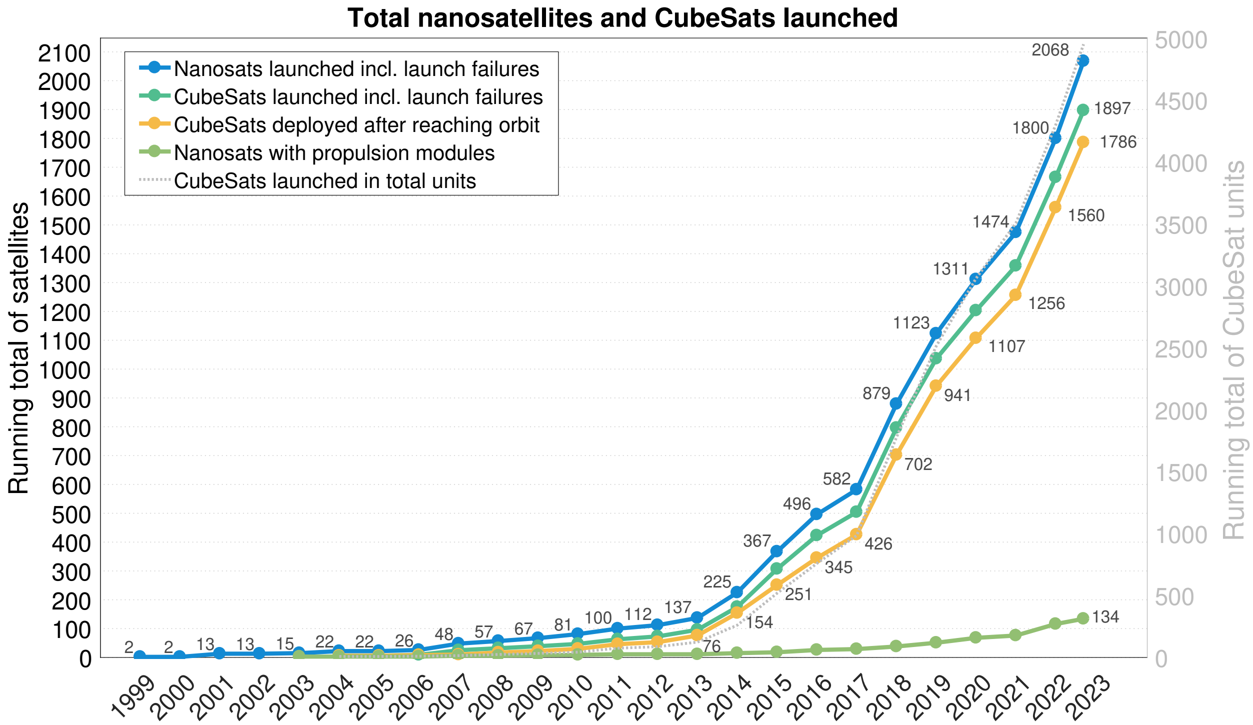

Figure 1: Total Nanosatellites

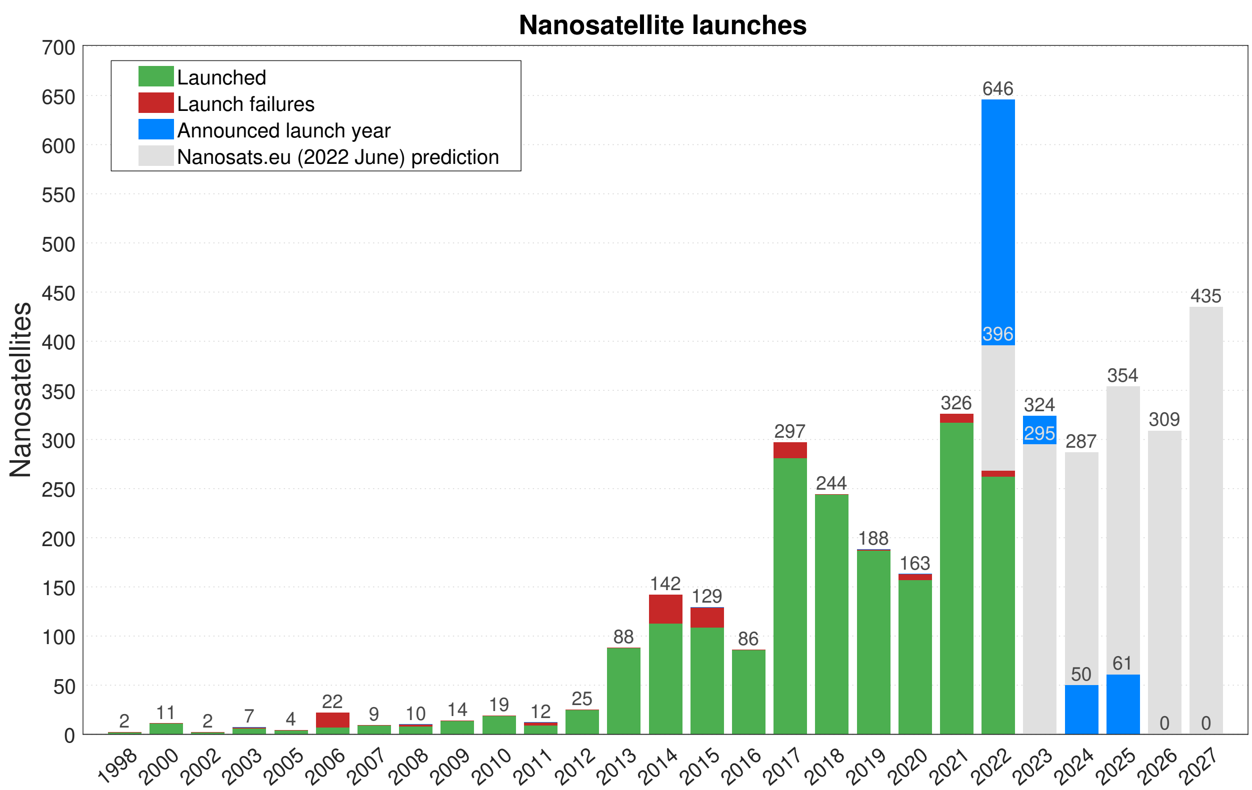

Figure 2: Launches by Years

Status

The current status of all launched nanosatellites including rocket and deployment failures as of 2022 Aug 1 is on Figure 3. Mission status is challenging to collect and the true operational count is likely lower than the 1192 shown on the plot because constellation retirements or statuses are not announced. This operational status also includes semi-operational. Operational does not imply that the mission has been completed, but at least a beacon with working telemetry should be sent regularly. CubeSats never heard from with "no signal" status is about 6%, 132 of 2068. A single status criterion can be subjective, because partially failed complicated missions can achieve more results and impact than simple CubeSats.

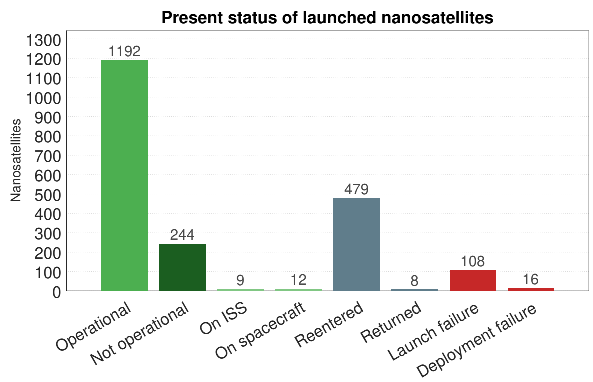

Figure 3: Nanosatellites Status

Form Factors

Figure 4 shows the form factors of all nanosatellites in the database and separates them by "launched" and "not launched" criteria. 3U continues to be the most popular size and it also makes up the bulk of Planet's Flock and Spire's Lemur-2 constellations. 0.25U increased rapidly in numbers thanks to Swarm. 6U is being used by multiple newer constellations. Largest launched is 16U. PocketQubes and other nanosatellites make up a relatively small amount.

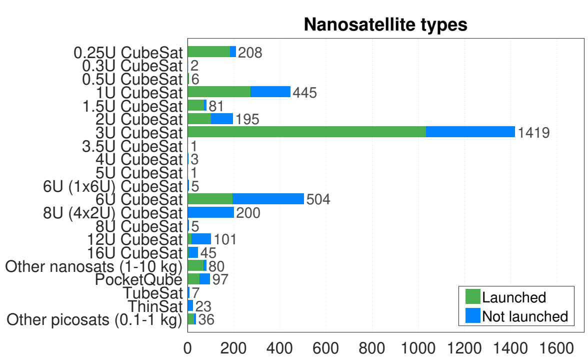

Figure 4: Nanosatellites Form Factors

Constellations

Figure 5 lists selected CubeSats constellations. Planet and Spire continue to be some of the largest CubeSat constellations. Swarm has recently taken 2nd place from Spire and while their 0.25U form factor makes it faster, it is still an achievement. Kepler is now at 4th place with 19 satellites on orbit and 16 of them are 6U XL, which is the largest constellation in that form factor. Kleos Space, Astrocast, GeoOptics, UnseenLabs and Fleet Space all have about 10 CubeSats in space. Many other startups are still at 0-2 demonstration missions and approximately over 2 years behind compared to their announcements.[3]

Map

Figure 6 plots launched nanosatellites by the leading organization headquarters location. The United States is very far ahead in launches with 1375 spacecraft, thanks to many constellation companies' headquarters and NASA's ELaNa program. Followed by China (80), Japan (64), Germany (50), UK (40), Russia (39), Spain and Canada. It has been great to see the map filling up and currently 77 countries have put at least one nanosatellite on a rocket.

Orbits

Figure 7 collects the approximate orbits of deployed nanosatellites. Categorization has been prioritized here over exact apogee, perigee and inclination values. The trend into lower altitude orbits with 1-10 year lifetimes is continuing. Limited number of CubeSats are above 600 km altitude, where orbital lifetimes reach ∼25 years, and these used to be more common due to the primary payloads of early SSO rideshare missions. Interesting to note the 8 MEO, 2 GTO, 1 GEO and 4 deep space CubeSats.

Yearly Launches by Organizations

Figure 8 shows the nanosatellite yearly launches by organizations types, which will be a valuable input for the forecasting step. CubeSats from academia are increasing, but growth has stayed relatively stable and linear. Similar case is with governmental and non-profit spacecraft. Some fluctuations can be attributed to launch delays because such missions are often aiming for lowest launch costs or are manifested on the early launches of new rockets. Commercial satellites are now the most popular segment by quantity, and they also vary the most, which makes predictions highly dependent on announced constellations coming to fruition.

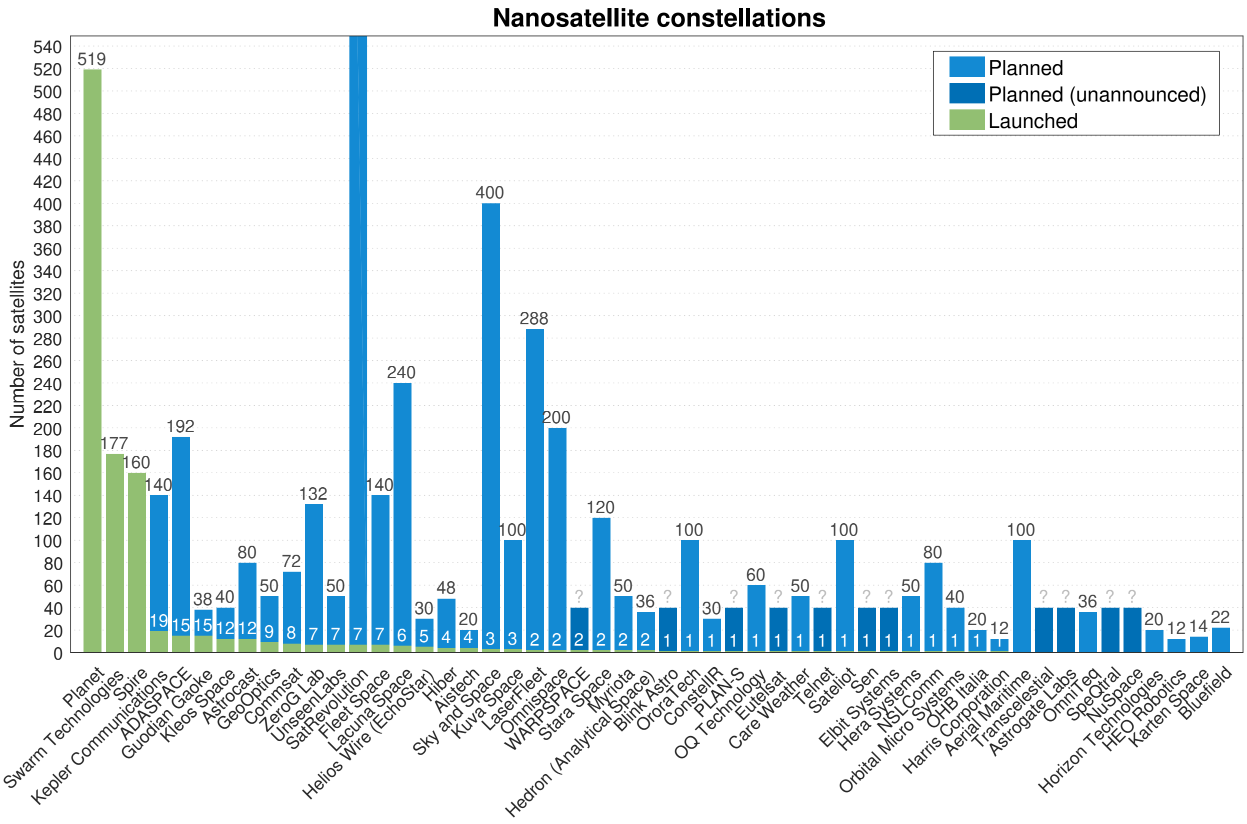

Figure 5: Nanosatellites Constellations

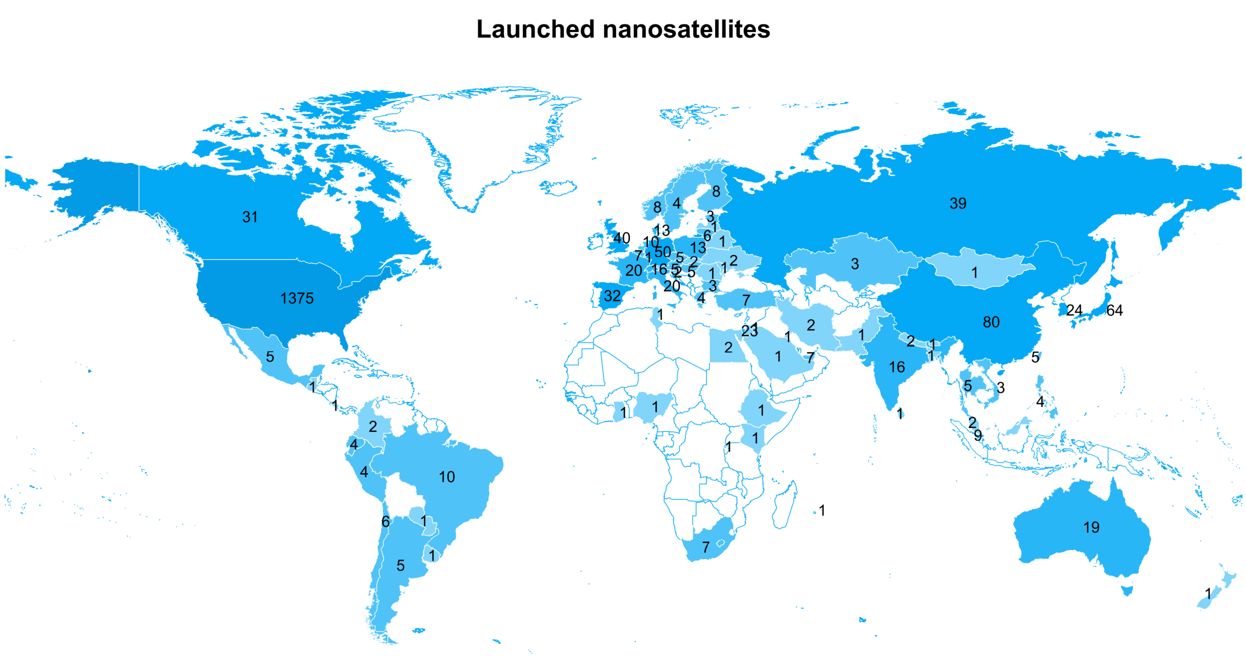

Figure 6: Nanosatellites Map

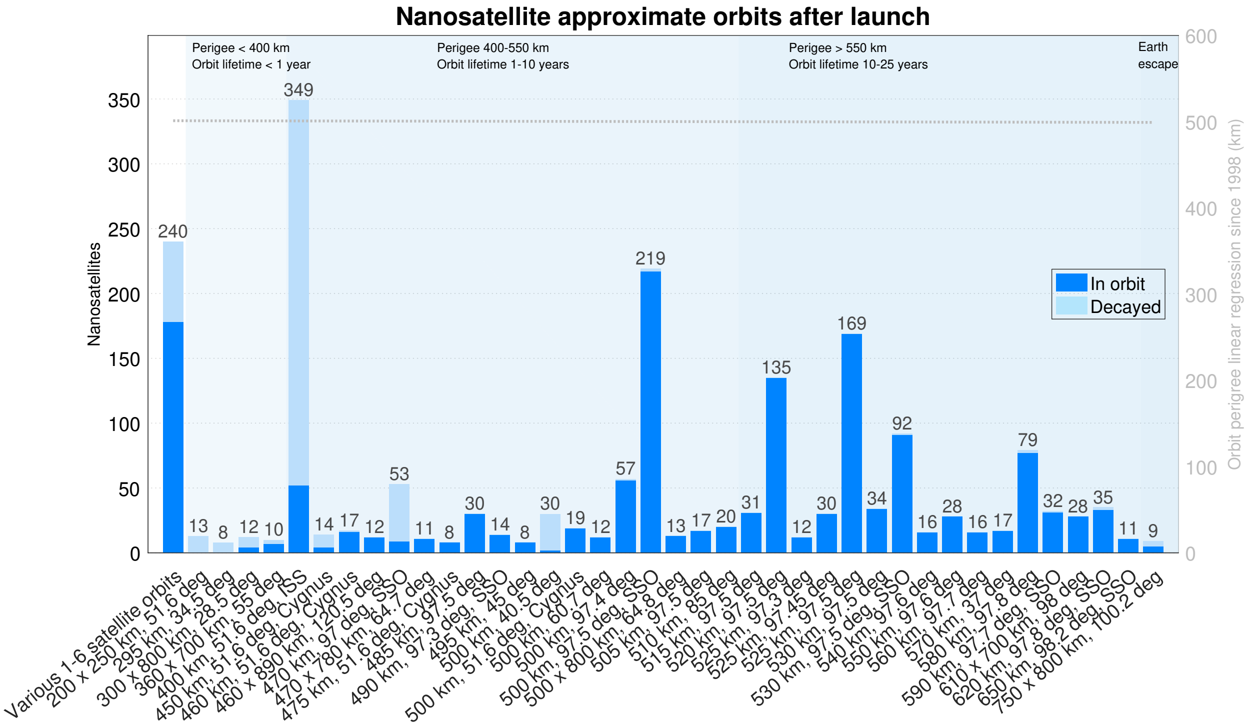

Figure 7: Nanosatellites Orbits

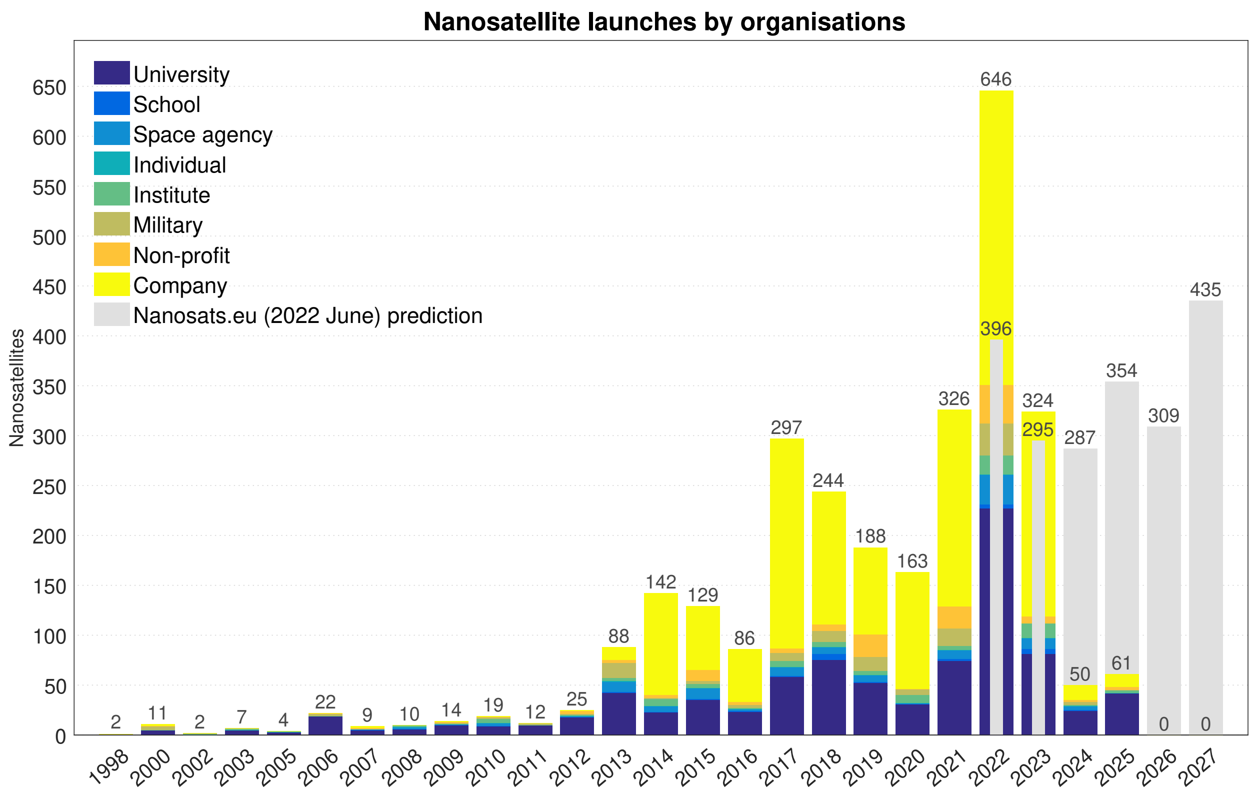

Figure 8: Nanosatellites Launches by Organizations

Yearly Launches by Launchers

Figure 9 collects the yearly nanosatellite launches by launch vehicle families. Initially, Dnepr, Delta-II and Minotaur used to be the most common CubeSat rideshare launchers. Then most CubeSats were launched on PSLV, Antares (ISS, Cygnus) and Soyuz. Now Falcon 9, Rocket Lab, Vega, many other small launchers, and numerous Long March variations compromise the majority thanks to price, availability, and regularity. Space tugs (Spaceflight, D-Orbit, Momentus, Launcher and more) have also entered the launch broker market, but they are most often still flying to orbit on Falcon 9.

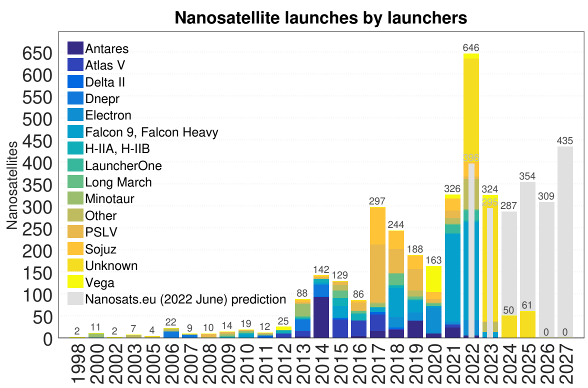

Figure 9: Nanosats Launches by Launchers

Yearly Launches by Form Factors

Figure 10 shows the yearly nanosatellite launches by form factors. For the first 10 years, 1U size used to be most common, but then 3U became more popular thanks to higher capabilities and commercial missions. Over 1000 3U's have been launched. Recent years have seen the rise of 6U, 12U and 16U from factors. 2U CubeSats had a temporary increase due to the QB50 project around 2016-2017, but are more difficult to launch. Thanks to Swarm, 0.25U size has also gained in popularity in the last 2 years.

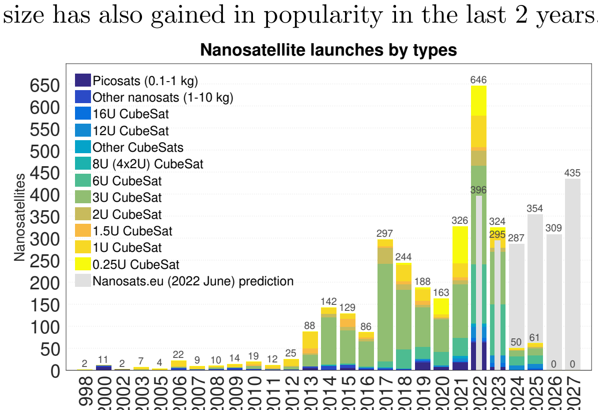

Figure 10: Nanosats Launches by Sizes

Yearly Launches by Deployers

Figure 11 illustrates the yearly launches by deployers and dispensers. The initially used P-POD was overtaken by ISIPOD and QuadPack starting from around 2013 and they were soon followed by EXOpod from Exolaunch. At the same time, NRCSD and NRCSD-E became common thanks to Nanoracks deployments from the ISS. Rocket Lab developed their own Maxwell series of deployers. The options keep expanding because many space hardware startups, multiple small launcher and space tug companies develop their own deployers to improve unit cost margins or are searching for extra revenue sources.

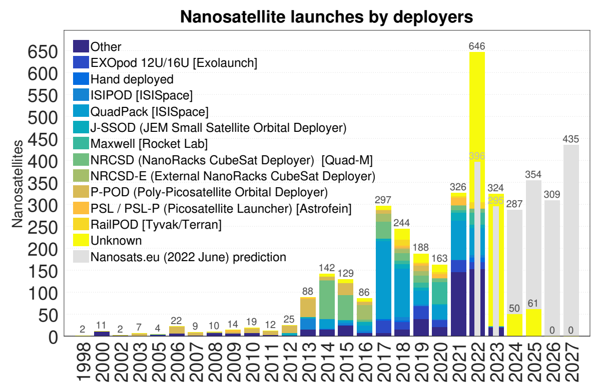

Figure 11: Nanosats Launches by Deployers

Companies Founded

The founding years of companies active in the CubeSat ecosystem is on Figure 12. It includes constellations that use CubeSats, various end-to-end manufacturers, product offerings and supporting service providers. For example, Planet Labs was founded in 2010 and Spire in 2012. The peak in 2016-2018 and subsequent decline could be a sign of a boom phase and the CubeSat ecosystem entering a more economically sustainable phase afterwards.

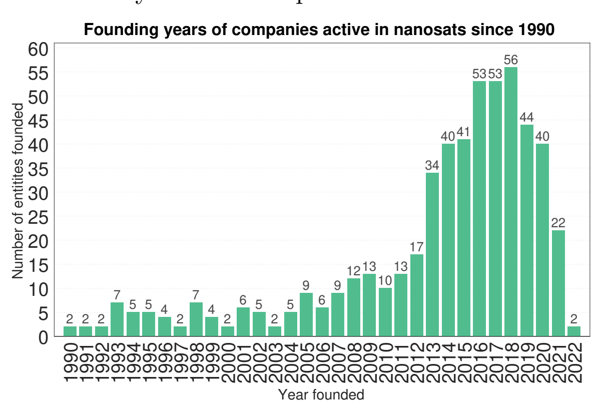

Figure 12: Nanosatellite Companies Founded

BEYOND-LEO CUBESATS

This section of the work focuses on the nanosatellites flying beyond low Earth orbit (LEO) to fit with the conference theme and many of those spacecraft have also experienced launch and development delays. This is an update to a presentation from 2021.[4]

Interplanetary, MEO, GTO, GEO and other "beyond LEO" CubeSats are still in the early days but have recently started to increase in quantity and mission types. Table 1 lists selected examples.

Beyond LEO CubeSat statistics:

- Beyond-LEO CubeSats in database: 79
- Beyond-LEO CubeSats launched: 15
- Interplanetary CubeSats launched: 4
- Lunar CubeSats launched: 1
- GTO CubeSats launched: 2
- GEO CubeSats launched: 1
- MEO CubeSats launched: 8

The database includes 79 nanosats marked with the keyword "beyond LEO", which includes MEO, GTO, GEO, lunar, interplanetary or deep space missions. There are 15 of such CubeSats launched, up from 4 at the start of 2021. 8 are from the USA, 4 from Italy, 2 from France and 1 from Slovenia.

Also 9 of the 79 have a cancelled status and that count may be larger. There are many concepts for deep-space CubeSats, but they are of too early development stage to be considered for admittance into the database. Nevertheless, adding them for completeness and historical archive is one of the future goals. The database also does not yet include deep space inspection camera probes flown on missions like IKAROS and Tianwen-1 but maybe should.

CubeSats Yearly Launches Beyond LEO

Figure 13 illustrates the launched and planned CubeSats sent to orbits further than LEO.

Two MarCO launched in 2018 and successfully performed Mars flyby mission.[5] Two CubeSats called TDO were sent to GTO in 2019 and 2020, but only a few details are available and may have been passive.

ASCENT launched to geostationary orbit (GEO) in 2021. LICIACube launched in 2021 piggybacked on DART and will perform asteroid flyby mission in 2022.[6] Two more TDO's were launched to MEO in 2021. CAPSTONE launched in June 2022.[7]

13 spacecraft out of the 79 were scheduled to fly on the Artemis-1 mission on SLS (Space Launch System) as announced in early 2016 with the launch planned for 2018, but it has been delayed for many years. Three CubeSats missed the deadline thus 10 have been integrated to the rocket[8] and the launch is scheduled for late August or September 2022.[9]

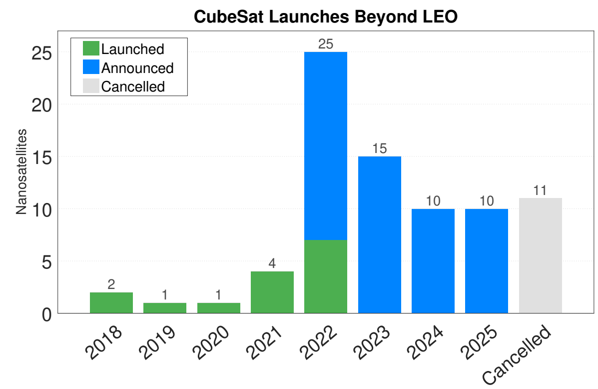

Figure 13: Beyond LEO CubeSats by Years

Form Factors of Beyond LEO CubeSats

Figure 14 collects the form factors of beyond LEO CubeSats. Most missions planning to fly beyond Earth are 6U or 12U. Out of the launched missions, two MarCO's and LICIACube are 6U, while the four TDO's and ASCENT are 12U. All 10 CubeSats on Artemis-1 are 6U. CAPSTONE is listed in the database for completeness, because its main structure is based on a 12U CubeSat but by strict specification it is not a standard CubeSat or nanosatellite.

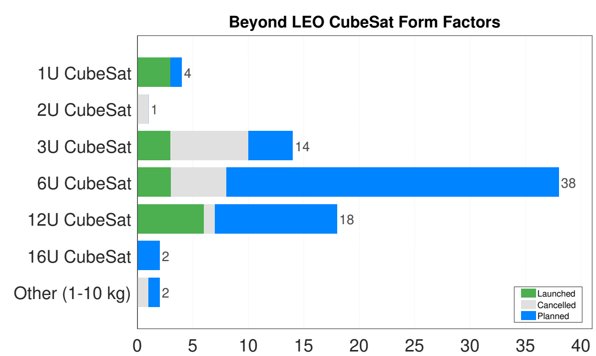

Figure 14: Beyond LEO CubeSats by Sizes

Orbits of CubeSat Launches Beyond LEO

Figure 15 shows the large variety of orbits and destinations where the beyond-LEO CubeSats are planning to fly. GEO, GTO and lunar orbit are the most popular, likely due to accessibility and more immediate use cases. The first SLS launch will expand this figure considerably and some of those spacecraft will enter new orbits for nanosatellites.

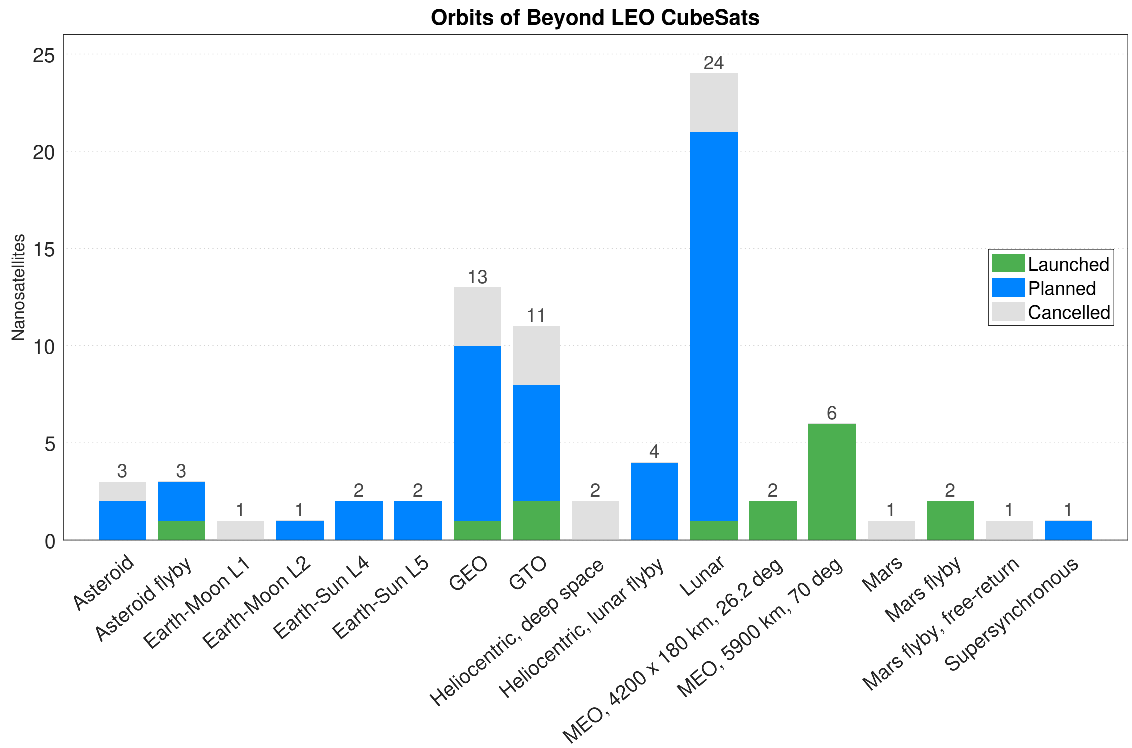

Figure 15: Beyond LEO Launches by Orbits or Destinations

Organizations of Beyond LEO CubeSats

Figure 16 shows the types of organizations that are developing CubeSat missions, which will fly to higher altitudes than 2000 km. Governmental missions from space agencies and military (MarCO's and TDO's) first launched into those new destinations. Academic and commercial missions followed starting from 2022. For example, G-Space 1 CubeSat from Gravity Space is planned to fly to GEO in 2022.[10] First Vega-C mission launched 6 CubeSats to 5900 km MEO orbit in July 2022.[11]

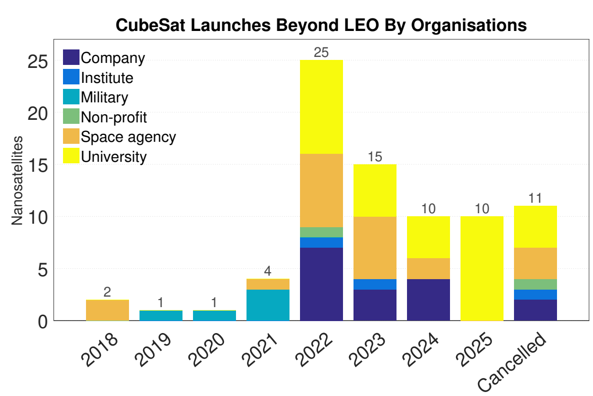

Figure 16: Beyond LEO CubeSats by Organization Types

Missions of CubeSat Launches Beyond LEO

Figure 17 divides the beyond-LEO CubeSats by simplified mission types. At such an early stage, technology demonstration and scientific purposes are common and expected. For example, MarCO had a primary mission to relay communications during Mars landing, but they were also successful technology demonstrations.[5] TDO's have been set as scientific. Some possible first commercial applications for CubeSats in such orbits could be in-orbit inspection in GEO and lunar communications relay.

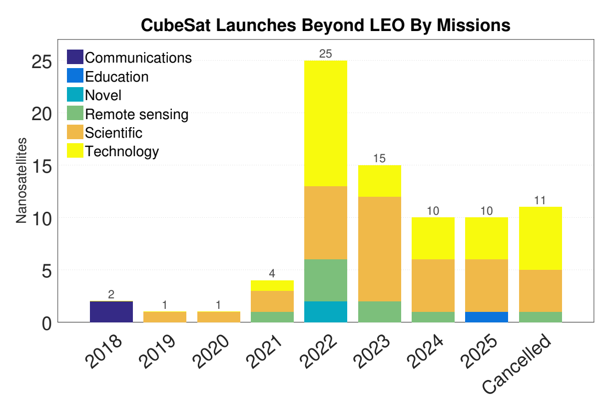

Figure 17: Beyond LEO CubeSat Missions

Table 1: Selected Examples of Beyond LEO CubeSats

Satellite name	Leading Organization	Nation	Type	Year	Orbit / Destination
MarCO A & B	NASA	US	2×6U	2018	Mars flyby
TDO $ TDO-2	Air Force Research Laboratory	US	2×12U	2019	GTO
TDO-3 & TDO-4	Air Force Research Laboratory	US	2×12U	2021	MEO, 4200x180 km
LICIACube	Italian Space Agency	Italy	6U	2021	Asteroid flyby
ASCENT	Air Force Research Laboratory	US	12U	2021	GEO
CAPSTONE	NASA Ames Research Center	US	12U	2022	Lunar
ALPHA	ARCA Dynamics	Italy	1U	2022	MEO, 5900 km
Astrobio Cubesat	Sapienza University of Rome	Italy	3U	2022	MEO, 5900 km
TRISAT-R	University of Maribor	Slovenia	3U	2022	MEO, 5900 km
NEA-Scout	NASA Marshall Space Flight Center	US	6U	2022	Asteroid flyby
EQUULEUS	JAXA	Japan	6U	2022	Earth-Moon L2
BioSentinel	NASA Ames Research Center	US	6U	2022	Heliocentric, lunar flyby
CuSP	Southwest Research Institute	US	6U	2022	Heliocentric, lunar flyby
LunIR	Lockheed Martin	US	6U	2022	Heliocentric, lunar flyby
ArgoMoon	Argotec	Italy	6U	2022	Lunar
LunaH-Map	Arizona State University	US	6U	2022	Lunar
Lunar IceCube	Morehead State University	US	6U	2022	Lunar
Miles	Team Miles / Tampa Hackerspace	US	6U	2022	Lunar
OMOTENASHI	University of Tokyo	Japan	6U	2022	Lunar
GS-1	Gravity Space	Ukraine	16U	2022	GEO
Linus	Lockheed Martin	US	2×12U	2022	GEO
GTOSat	NASA Goddard Space Flight Center	US	6U	2022	GTO
SpectroCube	ESA (European Space Agency)	France	3U	2022	GTO
DOGE-1	Geometric Energy Corporation	Canada	12U	2022	Lunar
Garatea-L	Airvantis	Brazil	6U	2022	Lunar
SunRISE	NASA JPL	US	6×6U	2023	GEO
SWIMSat	Arizona State University	US	6U	2023	GEO
LACCE	University of Louisiana at Lafayette	US	3U	2023	GTO
Foresail-2	Finnish Sustainable Space CoE	Finland	6U	2023	GTO
CU-E3	University of Colorado	US	6U	2023	Heliocentric, lunar flyby
RADMIA	Northwestern Polytechnical University	China	16U	2023	Lunar
Seven Sisters 1	Seven Sisters (Fleet Space)	Australia	6U	2023	Lunar
Cislunar Explorer	Cornell University	US	6U	2023	Lunar
Lunar Flashlight	NASA Jet Propulsion Laboratory	US	6U	2023	Lunar
M-ARGO	ESA (European Space Agency)	France	12U	2024	Asteroid
Juventas	ESA (European Space Agency)	France	6U	2024	Asteroid
Milani	Politecnico di Milano	Italy	6U	2024	Asteroid flyby
Orbital Factory 4	The University of Texas at El Paso	US	3U	2024	GTO
Jervis-1	Rhea Space Activity	US	12U	2024	Lunar
LUMIO	Politecnico di Milano	Italy	12U	2024	Lunar
VMMO	MPB Communications	Canada	12U	2024	Lunar
Zeus-MS	Qosmosys	Singapore	2×3U	2024	Lunar
OSC	New Mexico State University	US	6U	2024	Supersynchronous
SULIS-A	Northumbria University	UK	2×12U	2025	Earth-Sun L4
SULIS-B	Northumbria University	UK	2×12U	2025	Earth-Sun L5
mDOT	Stanford University	US	6U	2025	GEO
Cape IV-GTO	University of Louisiana Lafayette	US	0.2 kg	2025	GTO
Binar Prospector	Curtin University	Australia	2×6U	2025	Lunar
DRACO	ISAE-Supaero University of Toulouse	France	2 ×6U	2025	Lunar

LITERATURE REVIEW OF SATELLITE LAUNCH PREDICTIONS

Third part of the study gathers forecasts from other authors, compares them to historical results, and discusses possible reasons for the divergence.

Nanosats Database

Figure 18 collects most of the here-forth referenced forecasts. Nanosats Database' predictions have been very optimistic with the previous from 2020 January estimating that 2500 nanosatellites would launch in the next 6 years (2020-2026). The prediction from 2018 January was even more optimistic as see on the figure. The year 2018 was close to reality, but 2019, 2020 and 2021 have been under-performing 2-3 times by the number of nanosatellites launched. The method used has been kept the same and will be described in a later section.

> 1000 CubeSats have been launched! It only took 15 years from 2003. Not all of them made it to orbit and handful are unknown, but certainly over 1000 have been on a rocket. Next thousand in 3 years? - Nanosats Database, Dec 30, 2018

As of August 1, 2022, there have now been 2068 nanosats and 1893 CubeSats on a rocket as seen on Figure 1 and may surpass 2000 CubeSats this year.

At the end of 2018, the author predicted (see the quote before) that the second thousand of CubeSats would be launched in the next 3 years, but instead it will take about 4 years and the last half a year has seen 3 SpaceX Transporter rideshare missions, which had a large number of nanosatellites on-board.

SpaceWorks

SpaceWorks started publishing the widely referenced "Nano/Microsatellite Market Forecast" in 2011 and continued for 10 years ending with the last edition in 2020.[12] Forecasts from 2014 to 2020 have been collected on Figure 18. Their projections in 2020 indicated that as many as 2400 nano/microsatellites will require launch in the next five years.

Their method uses SpaceWorks' Launch Demand Database (LDDB) which includes future missions together with Probabilistic Forecast Model (PFM) and then the analysts interpret and refine the PFM results to create final forecasts.[12]

While their research includes all spacecraft from 1-50 kg, the quantity of satellites below the 1 kilo-

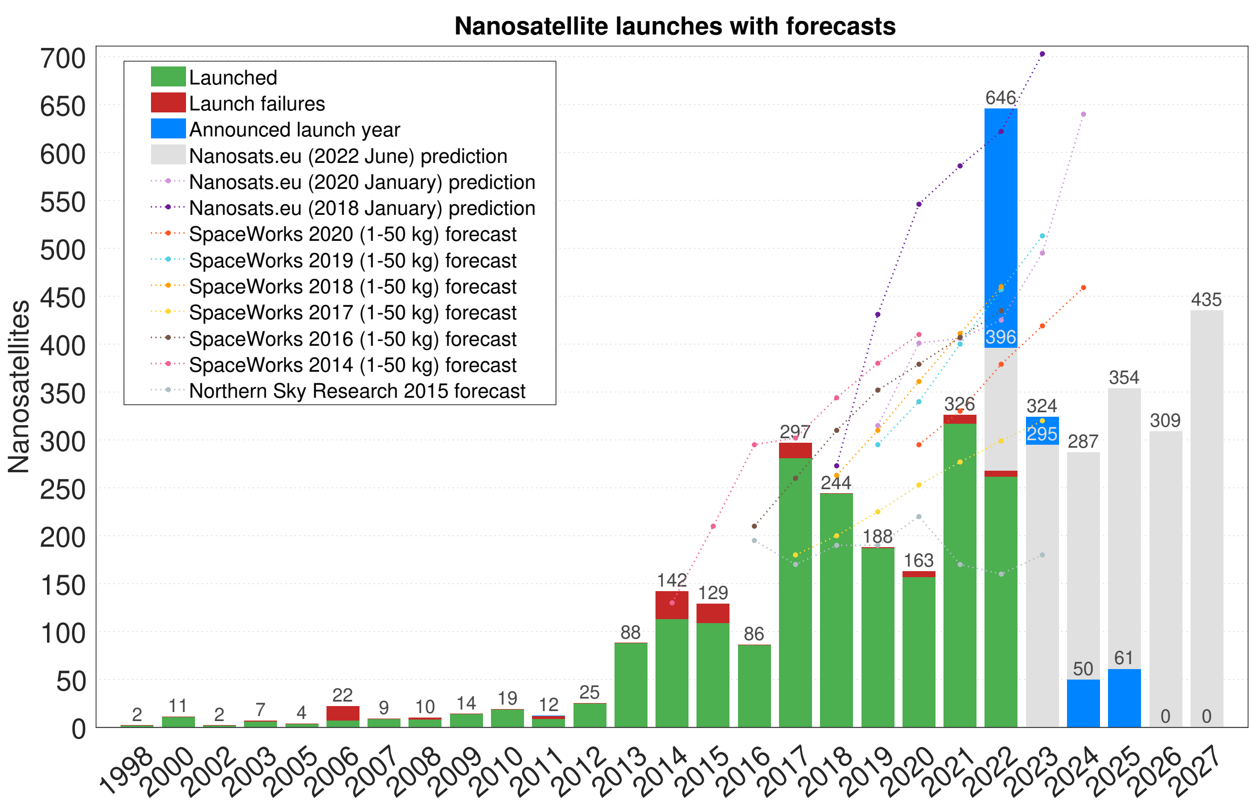

Figure 18: Nanosats.eu Launch Forecast showing previous, SpaceWorks and NSR

gram range and also non-CubeSat microsatellites below 50 kg have been relatively small up to about the year 2020. Thus, the author here considers the predictions comparable up to that time. Since 2020, Swarm has launched over 170 of 0.25U CubeSats and smaller custom microsatellites have increased in popularity[3] and the forecasts would be less compatible now about 2.5 years later.

Northern Sky Research

Northern Sky Research has published numerous "Nano and Microsatellite Market" and "Small Satellite Market" reports. A report from early 2015 is notable because the nanosatellite market is forecast to be largely stable. There is no exponential growth predicted based on the Figure 18 up to 2024 and some years have a decline in quantities.[13] Only the year 2020 surpassed more than 200 nanosatellites per year in their study. Years of 2019 and 2020 matched relatively well with actual events.

Small Satellite Markets 5th Edition from 2019 forecasts that nanosatellites in the 1-10 kg range will stay relatively stable at about 250 nanosatellites per year until 2027. Spacecraft from 10-50 kg are forecast to see larger growth, but neither are predicted to pass a total of 450 yearly satellites by 2027.[14]

Satellite Applications Catapult

Satellite Applications Catapult published quarterly Small Satellite Market Intelligence Report from Q2 2017 to Q4 2021. Each report has a figure about the historical and projected numbers for small satellites using a mathematical model.[15] Their definition of small satellite was 500 kg and thus it is nowadays largely incompatible with CubeSat studies. Nevertheless, before OneWeb and Starlink, the yearly number of smallsats was relatively low and the statistics was largely dominated by CubeSats.

Author interprets that they missed to predict the very rapid increase of Starlink and OneWeb satellites, which shows the limitations of mathematical models using purely or primarily historical data. Past trends are not a great predictor for future during the times when new technologies, new approaches and large funding opportunities enable unforeseen quantities of satellites and launch rates.

Miscellaneous Launch Studies

A paper by C. A. Costa et al made a forecast for CubeSat launches in the mid-2018.[16] Using a logistic model and historical data from CGEE CubeSat Database,[17] they predicted that in 2021 one thousand CubeSats would be launched every year.

This forecast has not come true and actual yearly quantities of nanosatellites have been 3-4 times lower and with a larger year-on-year variability. First half of 2018 was an optimistic time of many CubeSats constellation announcements, the record year of 2017, and 2018 was looking like another record based on then planned missions in the Nanosats Database. Overall, this is another example of the limitations of performing forecasting based on primarily historical data during times when the ecosystem is experiencing a rapid change and growth.

Market Size Studies

According to Grand View Research's report released in March 2020, the global nanosatellite and microsatellite market size was estimated at $1.28 billion in 2018 and is expected to reach $4.95B by 2025 developing at a 22.2% CAGR from 2019 to 2025.[18]

The global CubeSat market was valued at $210.1 million in 2019, and is projected to reach $491.3 million by 2027, registering a CAGR of 15.1%, according to Allied Market Research.[19]

Markets and Markets report from December 2018 estimates that the global CubeSat market is projected to grow from $152 million in 2018 to $375M by 2023, at a CAGR of 19.87% from 2018 to 2023.[20]

Having participated in a number of interviews for similar reports, these market studies seem to broadly based on the estimated number of yearly satellites and with each nanosatellite costing on the order of $1 million as quoted by some public contracts. This overall does not seem to be a very accurate method when most of the serially produced constellation and educational CubeSats cost much less.

Discussion & Conclusion

Looking back, most forecasts including Nanosats Database have been too optimistic and they have also not accounted for the up-and-down reality. Historical data is not a good predictor for future, when new companies like Planet, SpaceX and Swarm with new approaches and large funding are able to achieve what most experts in the industry would have considered to be impossible or impractical.

Launch delays are part of the forecast failures, but after multiple consecutive years and available capacity on many rockets, it is not the whole answer. Development delays and especially the commercial constellations, which would have been the majority, have been much slower to happen.

NANOSATELLITE LAUNCH FORECAST

Last part of the work entails creating a new forecast for the next 6 years. This will be an update to the previous predictions by the author in early 2018 and 2020. Methodologies will be discussed and author's approach will be described.

Adjacent databases for commercial constellations and small launchers allow wider insights into the future when comparing solely to past launch trends.

Methodology

Forecasting launch demand is a challenging and time-consuming problem. No mathematical model or market expertise predicted the rise of Starlink constellation 10 years ago, but they already launch the most spacecraft by far. As SpaceX launches only on their own rockets, that launch market will also not be accessible for others.

Simple mathematical models based on historical trends do not show the failures of commercial constellations, which can range from not meeting the fundraising and revenue goals or alternatively transitions to larger satellites. Both of which can have a large effect on the quantity of spacecraft.

Here the problem is broken into smaller parts:

1. Historic trends together with all announced missions are a good starting point for satellites initiated by academia and governments.

2. Each constellation company is analyzed one-by-one to forecast their yearly number of satellites. Based on market field & knowledge, public statements, fundraising status, launch delays, technology competitiveness, competitors, team size & growth path and more. Most of the announced companies will not succeed and then their demise has been estimated, but some of their places will be taken by future constellations. A single company such as SpaceX or Planet can heavily skew the results.

Non-Commercial CubeSats - Historical Trends and Planned Launches

The academic, non-profit and governmental spacecraft have been relatively stable or growing slowly as seen on Figure 19. Some variations can be caused by projects like QB50, which aimed to launch 50 CubeSats. Second cause for variation is that many such missions look for cheaper rides to orbit and there can be and have been long delays with rideshare and space tug missions. NASA's ELaNa program has also used new small launchers, which have experienced their own delays. Development challenges starting from people resources to funding are also common reasons for delays and cancellations.

It is unlikely that 351 non-commercial nanosats will launch in 2022, because many of them will keep getting delayed due to development challenges and launch delays. It is thought that many of the listed missions for 2022 have been cancelled, but due to the lack of public information and statements, the launch dates have been rolled over year by year. After over 2-3 years with no updates and signs of life they will be changed into a cancelled state.

Overall, a slow stable growth can be deducted from the Figure 19 for non-commercial CubeSats and that is likely to continue into the future.

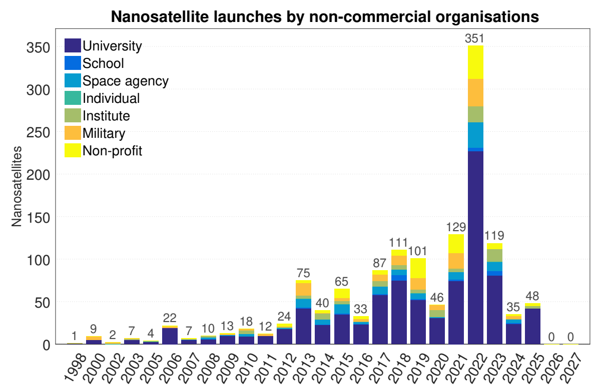

Figure 19: Launched and Not Launched Non-Commercial Nanosatellites in Database

Commercial CubeSats - Historical Trends and Planned Launches

Largest yearly variation is among the commercial nanospacecraft, especially constellations. Figure 20 illustrates the launched and not launched nanosatellites, which are listed in the database.

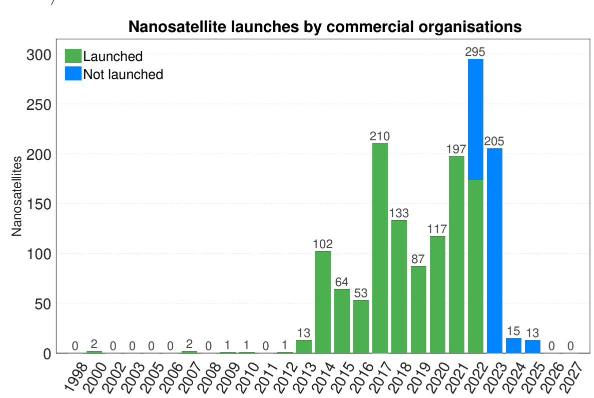

Figure 20: Launched and Not Launched Commercial Nanosatellites in Nanosats Database

Constellation Additions & Corrections

Separately made one-by-one estimates of CubeSat constellation launches, which are not included in the database as satellite entries, have been summarized and added to the previous commercial and non-commercial counts. Keeping them private to avoid controversies. In addition, corrections have been made to account for the likely unannounced delays, cancellations and yet to be announced missions. Year 2027 is a long time away and plans often change or new ideas emerge as seen with most constellations in the past.

Results

Figure 21 illustrates the latest Nanosats Database's prediction made in June 2022 for nanosatellite launches from the start of 2022 to the end of 2027.

Author forecasts that 396 nanosatellites will launch in the year 2022 followed by 295 in 2023, 287 in 2024, 354 in 2025, 309 in 2026 and 435 in 2027.

While many existing constellations actively in development are switching to larger spacecraft, there are also new companies emerging and launching their first demonstrations soon, which should fill the gap and possibly increase the overall ecosystem.

Discussions and Trends

Multiple well-funded constellations have recently announced transition from CubeSats to microsatellites or small satellites for their future constellations e.g., Fleet Space[21] and Kepler Communications.[22] Astrocast also recently stated that later models beyond the first twenty 3U could be 6U CubeSats.[23] Spire launched their first 6U CubeSats in early 2022 and has announced larger missions.[24] NanoAvionics flew its first modular microsatellite MP42 in 2022.[25] These examples together with statistics[3] show that the initial plans about the quantity and form factors of constellation spacecraft rarely become reality. Higher mass allows higher absolute performance and often better performance per cost.

Planet remains the largest nanosatellite constellation with 519 CubeSats launched in total. Second place has recently been taken by Swarm (SpaceX) with 177 CubeSats, while Spire has launched 160. 0.25U CubeSats from Swarm are easier to build and launch in quantity compared to 3U or 6U, thus only looking at quantity has limitations.

Most other CubeSat constellations are way behind schedule compared to statements from 2-3 years ago or not happening at that announced scale.[3]

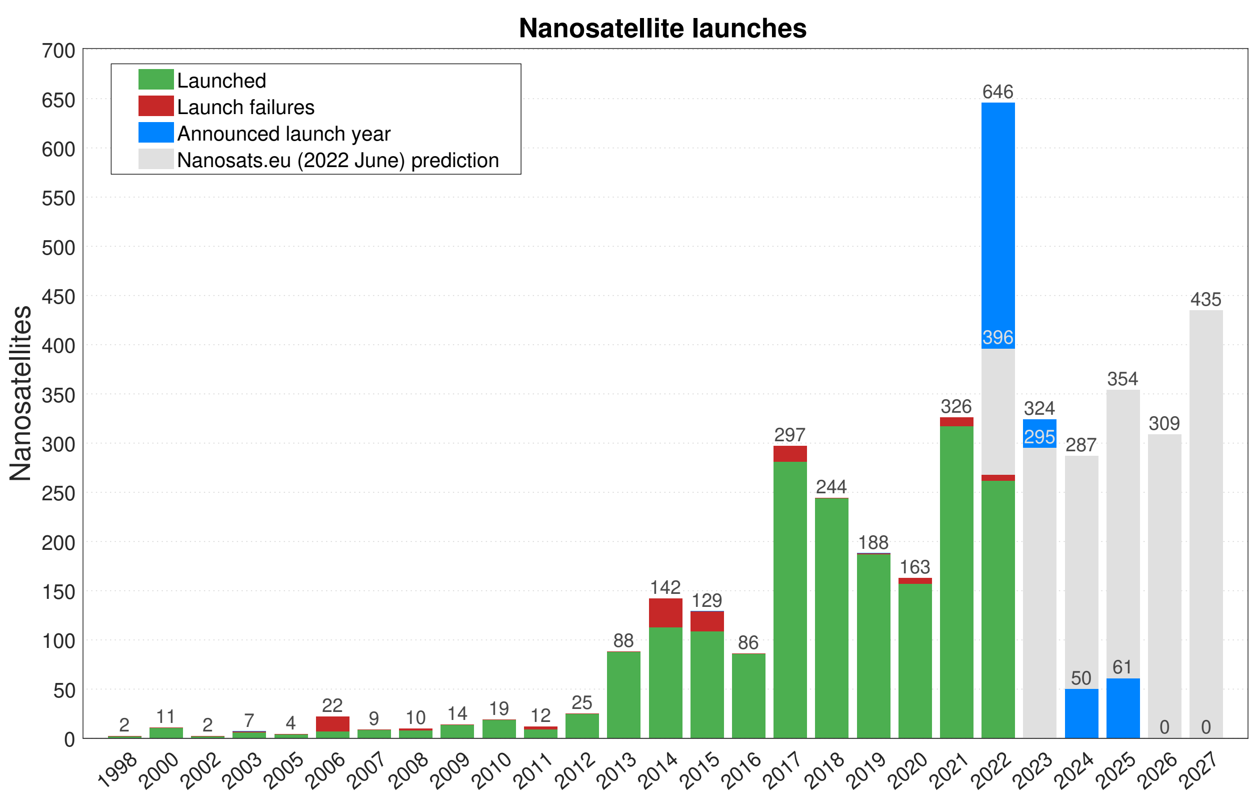

Figure 21: Nanosats.eu New Launch Forecast from June 2022

CONCLUSIONS

Some early excitement might have passed after many universities and companies launched their first satellites and faced the challenges of space technology development and space business models. However, with only 4 interplanetary CubeSats in space, expanding launch options, and numerous technologies yet to be developed, we believe the productive times of nanosatellites are still ahead.

First part of the paper presented the latest CubeSat and nanosatellite launch statistics and trends. Out of over 3400 entries in the database, 2068 nanosats and 1893 CubeSats have been launched as of August 1, 2022. Total estimated mass of launched CubeSats is only approximately ~7428 kg (4952U ×1.5 kg), which is less than a batch of 60 Starlink spacecraft. 2022 will likely set a new record of launches after previous in 2021 and 2017. Second thousand CubeSats will launch in about 4 years (2019-2022) compared to the first 1000 taking 15 years for the first 1000 (2003–2018). Sizes are both getting larger and smaller. Educational missions could move into smaller form factors. Decreasing launch costs on the other hand favor larger commercial satellites to save development cost on miniaturization and to improve cost per performance and per mass efficiency.

Second part focused on the subset of nanosatellites flying beyond the low Earth orbit and 79 of such missions with orbits from MEO to heliocentric have been listed with 15 of them launched.

Third part of the study collected small satellite launch forecasts and compared them to historical results. Most predictions have been overestimated. Launch delays can have relatively large impact due to rideshare missions but are only one aspect of it. Large part of the growth was supposed to come from commercial constellations, but most of them have not yet happened at scale and some already have or will be transitioning to larger satellites.

Fourth part of the work created an updated CubeSat launch forecast for the next 6 years. We predict that there will be 2080 nanosatellites launched from the start of 2022 to the end of 2027. Long-term economic sustainability of most CubeSat constellations remains to be proven, making market and launch forecasting challenging. There is a large difference in launch mass and volume whether CubeSats are 0.25U or 6U from factor. Many even well funded constellations have not yet happened at the planned scale they were announced some years ago.

Latest versions of the database and figures can be found on the Nanosats Database website and they will be updated 3-4 times per year.

Acknowledgments

- Launch schedules and manifests such as Gunter's Space Page.[26]
- Jonathan McDowell's[27] Space Reports and Master Satellite List.
- Websites such as IARU,[28] Space-Track,[29] NASA Spaceflight Forums.[30]
- Official websites, news articles and social media posts.
- Presentations and proceedings from conferences.
- Radio amateurs such as DK3WN,[31] JA0CAW,[32] SatNOGS,[33] TinyGS.[34]
- Other databases such as M. A. Swartwout[35] for some cross-checking.
- Databases SPOON[36] (parts on orbit) and PMPedia[37] (radiation tested parts).
- Occasional emails and self-additions.

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