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Satellite Constellations - 2024 Survey, Trends and Economic Sustainability

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Abstract

The author's previous satellite constellations survey from 2021 has garnered over 13000 views, thus an update is well-justified. NewSpace Index has tracked commercial constellations since 2016 and is the largest known public database. There were 411 entries by September 2024, 160 more since the last manuscript.

While most of the constellations have been slower to scale-up than announced, new ones keep emerging. Listed and new companies have continued launching their first or early demonstration missions and, in some cases, small batches of satellites. SpaceX and OneWeb have completed their first-generation constellations. However, OneWeb has yet to start global consumer services. Many more constellations have gone bankrupt or become dormant. The largest constellations continue to be SpaceX's Starlink, OneWeb, Planet and Spire. For many constellations, it is unclear when the multitude of launches will start due to delays, a more challenging fundraising environment, and with new markets being slow to grow. Nevertheless, over 40 satellite constellations launched their first prototypes in 2023, an increase over the previous years.

The first part of the paper will present the updated industry survey of commercial satellite constellations thanks to contemporary data and by adding activity status to the figures. Trends will also be covered, for which there is now more information, for example on applications, masses, funding, delays and manufacturers. Delays and launch cadences are an important input to satellite manufacturing and launch market forecasts. Fundraising trends are a similar case with many companies now requiring later stage funding.

The second half of the paper will examine constellations by applications, selected by their popularity and relevance. Trends will also be discussed for each application. Furthermore, the economic sustainability of many applications will be researched and presented when information is available, based on public company financials, fundraising amounts, and market studies. Starlink and Unseenlabs have been stated to have achieved break-even, but for most others the profitability is far.

Satellite constellations count for the majority of satellites; thus, the field is important for the whole NewSpace ecosystem. However, it is also concluded that most commercial constellations are not happening at their announced scales and timelines, because of the market and unit economics challenges.

Keywords: constellations, Starlink, satellite constellations, megaconstellations

1. INTRODUCTION

NewSpace Index (www.newspace.im) has tracked commercial satellite constellations since 2016.[1] There are over 411 entries as of 2024 September 30, which is 160 more since 2021, and likely makes it the largest public database. For comparison, there were only 60 projects listed at the end of 2017.

Satellite constellations count for the majority of spacecraft built and launched, and often make revenue from non-space actors; thus, the health of field is important for the whole space economy.

Future work saw foresee studying application specific trends and development timelines in much more detail. Many new applications do not have existing markets, which will take years to emerge, and/or the revenue potential seems to be small.

2. CONSTELLATIONS SINCE 2021

This section is a non-comprehensive overview of publications and news since August 2021. Application- and company-specific updates are in Section 5. A more complete literature review can be found in the 2021 manuscript.[2] Most of the sections and figures there should be directly comparable.

2021 Foust wrote a piece on "Space SPACs struggle to lift off,"[3] which has remained largely true, with the exception of recent AST stock price increase. Virgin Orbit invested in customers such as Hypersat and SatRev to expand markets,[4] but itself went bankrupt in 2023.[5] Lynn wrote a piece on "The LEO Satellite Broadband Market Outlook for 2022,"[6] when Starlink only had 90,000 subscribers.

2022 Bordalo Monteiro published "A review of small satellite constellations for IoT connectivity" in 2022.[7] De Selding published an article "Smallsat builders York Space Systems & GomSpace agree: Volume production isn't key to cost reduction."[8]

2023 Around 2022-2023, IoT hype came back as Direct-to-Cell (DTC) or Direct-to-Device (D2D). However, terminals are now (unmodified) cellular or bluetooth devices, instead of dedicated equipment.

McKinsey & Company published "Expectations versus reality: Commercial-satellite constellation" in 2023 using some NewSpace Index data.[9] Congressional Budget Office published an overview of large LEO constellations in May 2023.[10]

Quilty Space tracked 350 current and planned constellations to estimate satellite launch activity through 2030 and concluded that demand for satellites is rising but not skyrocketing.[11]

Byers and Boley's book "Who Owns Outer Space?" includes a section on mega-constellations.[12]

Rainbow discussed how "big constellations no longer necessarily mean small satellites".[13]

Euroconsult (now Novaspace) published "Satellites to be Built and Launched," and forecasted an average of over 2800 satellites launched annually – and 4 tons per day – between 2023 and 2032, with demand concentrated in a handful of players[14]

2024 Seraphim Space's SpaceTech Map 2024 includes many of the constellations.[15]

There has been more discourse on the environmental impact of rocket launches and also satellites burning up in the atmosphere in recent years.[16]

World Economic Forum report "Space: The $1.8 trillion opportunity for global economic growth" predicted that the space economy will be worth $1.8 trillion by 2035, up from $630 billion in 2023.[17] However, author does not consider most of that as space.

OECD published report "Space economy investment trends: OECD insights for attracting high-quality funding."[18]

PwC published report "Main Trends & Challenges in the Space Sector - 4th Edition."[19]

Novaspace latest forecast for the number of satellites to be launched over the next decade is smaller than previously, explained by heavier spacecraft.[20]

Summary Starlnk has launched over 7 thousand satellites and OneWeb completed deployment, but no other commercial high-cadence launches have started yets. Non-commercially, many tranches of spacecraft have been launched for the US Space Development Agency.

3. MARKET SURVEY

3.1 Survey Criteria

- Satellite constellation - Number of similar satellites, of a similar type and function, designed to be in similar, complementary, orbits for a shared purpose, under shared control.[21] Sometimes defined as a set of satellites working together in order to provide a service or a group of satellites with a common purpose.[22,23] Different from satellite programs and fleets.
- 3 or more spacecraft - Minimum required for a continuous coverage in geostationary or Molniya orbits. Literature review revealed minimum satellite counts of 2^{24} and official definition has not been found, but 3 appropriately filters out many satellite pairs.
- Commercial focus - Primarily owned, financed and managed by commercial entities for the purpose of providing a commercial service. Excluding government, military, academic, scientific and non-profit constellations. Likely to be expanded in the future, because all constellations will have an impact to the space economy, including launch and manufacturing services.
- Announced or launched after 2002 - Filtering out the first-generation constellations for Iridium, Globalstar and Orbcomm as of now, in addition to other projects from the 1990s.

3.2 Applications Classification

Constellations can have multiple applications. The following list of keywords, applications and fields is not exhaustive. In no specific order:

- Optical Earth Observation (EO) - VNIR (Visible and Near-Infrared), Multispectral - Earth Observation and remote sensing are very broad terms, but here defining optical EO as using passive silicon CCD/CMOS image sensors to collect imagery of Earth in visible and near-infra-red wavelengths.[25] Most multispectral instruments have 3 to 20 spectral bands and there is overlap with VNIR constellations.[26]
- Infrared EO - Divides into SWIR (Short-Wave Infrared), MWIR (Mid-Wave Infrared) and LWIR (Long-Wave Infrared) and often also known as thermal imaging. Commonly used for weather and climate monitoring, and for example for forest fire detection.[27]

- Hyperspectral EO - More than 20 spectral bands and typically hundreds of narrow spectral bands, which enables new applications in agriculture, vegetation, geology and water resources to identify specific organic matter.[28]
- SAR (Synthetic Aperture Radar) - Emits microwave radiation and collects the reflected radiation to form an image. Synthetic aperture is used to synthesize a long antenna by combining reflected signals as the satellite moves along orbit. Spaceborne radar satellites, for example in X, C or L radio bands, see through clouds and are not dependent on sunlight.[29,30]
- VR/AR (Virtual Reality, Augmented Reality) - Subset of EO with stereo or 360 degree cameras for 3D pictures and videos.
- Video - Subset of EO for high-resolution video capture and possibly real-time transmission.[31]
- Emissions Monitoring - Remote sensing, quantifying and locating greenhouse gas emissions, for example CO_2 and methane, using spaceborne imaging spectrometers.[32,33]
- Internet (Broadband) - Wideband high-speed satellite communications offering real-time Internet or data backhaul service.[34]
- IoT / M2M - Using satellites to extend the coverage of IoT (Internet of Things) and M2M (Machine-to-Machine) communications for remote areas. Often one-way or two-way messages and low data rates in narrowband.[35,36]
- Store-and-Forward - Subset of satellite communications, both narrowband and wideband, which is not real-time and data is stored on the spacecraft until a ground station pass.[37]
- 5G - Subset of satellite communications and IoT / M2M using 5G standards including NB-IoT, that may be compatible with common terrestrial equipment including smartphones.[38,39]
- Direct-to-Cell (Satellite-to-Cellphone) - Subset of satellite communications, which is capable of sending and/or receiving text messages, voice calls or even real-time broadband data from unmodified mobile phones.[40]
- Orbital Data Relay (Internet in Space, Space Data Relay) - Providing telemetry & telecommand and ground station service to other satellites. Aim is to connect space assets to mission control centres in real-time and to increase the amount of downlinked data.[41] Can use laser communications or RF.
- QKD (Quantum Key Distribution) - Satellite-based QKD uses laser communications between two users to produce a common random secret key at a distance, which is then used to encrypt messages sent over a standard communication channel. Any eavesdropper on the quantum channel will introduce disturbance to the system that is in superposition state, which can then be detected by the two users.[42,43]
- ADS-B (Automatic Dependent Surveillance–Broadcast) - Every aircraft transmits its identification, position, altitude, speed and other information, which is relayed to air traffic controls for more accurate situational awareness.[44] Space-based ADS-B is used for tracking aircraft beyond the reach of land-based receivers, but it could be expanded to space-based air traffic services to provide more information to pilots.[45]
- AIS (Automatic Identification System) - Space-based AIS is used to track ships beyond the reach of land-based receivers by listening to the VHF radio transmissions of ships identity, position, speed and heading.[46] Now also known as AIS 2.0.
- VDES (VHF Data Exchange System) - In some ways the next generation of AIS, which is starting to enter operation as of 2021. VDES encompasses AIS and adds a higher rate two-way data communications system, which also foresees a special satellite link. At the same time, new dedicated channels will solve AIS overloading problems in crowded waters.[47]
- Asteroid Prospecting - Mapping composition of asteroids for asteroid mining purposes. Here envisioned as rendezvous or flyby spacecraft for fine measurements, sometimes with MWIR sensors. Could be also asteroid discovery, characterization and cataloguing constellation in LEO to increase the known population.[48]
- On-Orbit Inspection - Satellites intended to maneuver nearby to other spacecraft for identification and to physically inspect deployables and malfunctions in case of problems.[49] Subfield of On-Orbit Satellite Servicing. Related to Non-Earth Imaging.
- In-Orbit Computing - Dedicated orbital servers for processing data from other satellites in space, before sending to ground or back to the satellites.[50,51] Can be related to In-Orbit Computing and Orbital Data Relay. Not the same as orbital edge computing, which in-

cludes payload data processing boards and machine learning software.[52]

- In-Orbit Data Storage - Space-based cloud data storage service on-board satellites or inside laser beams, which could be highly secure when using narrow radio or laser beams. Could be related to In-Orbit Computing and Orbital Data Relay applications.[53]
- Constellation-As-A-Service - Full end-to-end service to build and operate a constellation for a customer. Sometimes called Satellite-Data-As-A-Service and can include payload development. Related to hosted payloads when sharing the same spacecraft. Many more commercial entities are offering or planning to offer this solution than shown in Figure 1.
- Hosted Payloads - Could be one-off or numerous in-orbit demonstration & verification missions for payloads and subsystems, or alternatively scientific or commercial microgravity experiments. Piggybacked on individual satellites or on another constellation.[54,55] Sometimes related to Constellation-As-A-Service and also called rent-a-satellite.
- GNSS (Global Navigation Satellite System) and PNT (Positioning, Navigation and Timing) - Commercial satellite navigation systems. Often envisioned to be based in LEO to provide better performance, much stronger signals, encryption and 3-D location when compared to free GPS, Galileo, GLONASS and BeiDou.[56,57] Possible that existing GNSS constellations signals will be used as inputs.[58]
- Orbital Display - Using formation flying satellites to compose a message or advertisement visible to the naked eye on Earth by using large deployable sails that reflect Sunlight.[59]
- RF Spectrum Monitoring and Geolocation - Listening for radio emissions with formation-flying spacecraft to identify and triangulate the sources. Common application is ships or vehicles that do not have AIS enabled.[60]
- Weather Monitoring - Measuring vertical atmosphere profiles of various parameters e.g. pressure, temperature, humidity and wind speed for weather and climate forecasting. Common technologies are GNSS-RO,[56] GNSS-R,[61] microwave radiometry and others.[62]
- Wireless Energy Supply - Providing satellites with extra electrical power from other spacecraft using microwave or laser power transmission.[63] Sub-field of Space-Based Solar Power.
- SSA (Space Situational Awareness) - Space-based SSA for detecting, monitoring and determining the orbits other satellites and space debris. To enable higher revisit and consecutive observations of objects.[64,65] Often performed with infra-red space telescopes, which could also be used for asteroid astronomy.
- Space Weather - Monitoring the effects of space weather to the ionosphere and magnetosphere by measuring energetic charged particles to help improve space weather forecasting models.[66,67] Satellites sometimes conceived to be located in Earth-Sun Lagrange-points to increase warning time for solar flares.[68]

3.3 Form Factors Classification

Constellations can consist of spacecraft with different masses and form factors. The database aims to capture and publicize all of the used or announced size classes.

In this survey, only the latest known and most likely form factors for the majority of the satellites in a constellation have been presented for clarity.

No official standard for mass definitions exists and the FAA mass classes[69] are too exhaustive so henceforth using the following reduced categories:

- PocketQubes (Femtosatellites) - Sizes from 1p to 3p, where 1p is $\approx$ 5 cm $\times$ 5 cm $\times$ 5 cm.[70]
- CubeSats (Nanosatellites) - Satellites following the CubeSat Design Specification from 0.25U to 16U, where 1U is 10 cm $\times$ 10 cm $\times$ 11.35 cm.[71] The general category is for constellations that will use CubeSats based on available information, but the exact type has not been made public.
- Hosted - Constellations hosting payloads on other multi-use satellites or constellations, where spacecraft resources are shared and spacecraft mass has lower correlation to the payload performance and specifications.
- Microsats - 10 kg to 100 kg, except larger CubeSats which can be up to 25 kg, because those masses are rarely shared publicly.
- Smallsats - 100 kg to 500 kg. Small satellites term is often used broadly for any satellite below 500 kg.
- Satellites - 500 kg and above.

3.4 Status Classification

Categories to indicate the current status of satellite constellations by consolidating various publicly accessible information. In some cases, an educated guess has been made.

- Launched - Constellation fully launched with no replenishments foreseen due to long expected lifetime and already existing orbital spares. Iridium is a fitting example.
- Launched and replenishing - Most of the planned constellation has been launched and the expected size has been achieved. New iterations are being sent to orbit every 1-3 years as satellites retire or deorbit. Planet and Spire fit well here.
- Launches ongoing - Constellation deployment of identical or similar satellites actively in progress or ramping up. Starlink and OneWeb are best examples.
- Prototype(s) launched - One or more first satellites or hosted payloads launched, which serve as prototypes or pathfinders.
- Prototype development - First payload or spacecraft is being actively worked on. Company seems to be growing and likely has announced one or more rounds of funding.
- Early stage / Concept - A few announcements, presentations and pitches for a constellation idea, but likely in the stages of starting development, looking for funding and gaining traction with a very small team.
- Dormant / Unknown - Early signs towards to the development has slowed down or stopped, but in rare cases can be explained with stealth mode or temporary setbacks.
- Cancelled - Company is bankrupt, website and social media channels have been quiet for more than 1-2 years, lack of funding announcements, team seems to have been disbanded and/or the idea never entered implementation phase.
- Retired - Constellation, which has been removed from active service, but satellites could still be in orbit and even operational.

3.5 Orbit Classification

ITU and FCC primarily differentiate non-geostationary (NGSO) and geostationary (GSO) orbits, but in the database large majority are NGSO.

- VLEO (Very Low Earth Orbit) - Here defined as sustained orbits with altitudes in the 250-350 km range.[72] Earth Observant's Stringray spacecraft will be designed to fly at 250 km altitude. Albedo Space[73] is expected to use similar orbit range. SpaceX V-band constellation between 336-346 km is also called VLEO.[74] Literature defines VLEO below 450-500 km altitude and Super Low Earth Orbit (SLEO) with perigee below 300 km, but both definitions seem to be rarely used in practice.[75]
- LEO (Low Earth Orbit) - Up to 2000 km from the Earth's surface, excluding the previous VLEO definition.
- MEO (Medium Earth Orbit) - Altitudes between 2000 km and 35786 km.
- GEO (Geosynchronous Earth Orbit) - Altitude of 35786 km.
- HEO (Highly Elliptical Orbit) - Low perigee (1000 km) and high apogee (35786 km). Includes Geostationary Transfer Orbit (GTO), Tundra orbit and Molniya orbit, where the latter two are special cases of Highly Inclined Elliptical Orbit (HIEO).
- Lunar - Constellations intended to orbit around the Moon. Sub-fields such as Low Lunar Orbit (LLO) will be created as applicable. Likewise with other Solar System bodies.

3.6 Delay Classification

Comparing launches and upcoming manifests to statements about launch cadences and deployment intentions. Plans change and not all delays should be taken as a bad sign, but nevertheless gives some indication about the company and state of industry.

- Cancelled - Cancelled and dormant constellations where no more launches are expected.
- Generally on-time - Up to 6 months of delays, some of which can be due to launch delays.
- Partially behind - Approximately 6-12 months of delays.
- Year behind - More than 1 year of delays.
- Years behind - More than 2-3 years of delays.
- Unknown - No public announcements found and unable to make a comparison.

4. 2024 STATISTICAL OVERVIEW

This sections cover the statistical overview of the 411 entries included in this commercial satellite constellations survey.

4.1 Applications and Fields

Many constellations perform multiple functions with identical or similar satellites. Figure 1 counts services independent of multi-usage spacecraft. In other words, applications and fields have been counted separately and the sum of applications does not equal the number of constellation entries or companies covered by this survey. Figure only shows a selection.

As seen on Figure 1, IoT/M2M is the most popular application followed by Broadband Internet, Optical Earth Observation, Orbital Data Relay, SAR, Hyperspectral Earth Observation, SSA and AIS.

In 2021, the popularity order was IoT/M2M, Optical Earth Observation, Broadband Internet, SAR and AIS. They have also grown the most.

In the last 3 years, Direct-to-Cell, Orbital Data Relays, Hyperspectral EO and SSA have been favorite new constellation ideas.

4.2 Current Status

Figure 2 shows the current activity and development status of the commercial constellations. Only about 5% (17+3+2 of 411) are considered launched. 14% (60 of 411) are being launched but most of these deployments are relatively slow.

Approximately 21% (86 of 411) have launched only one or more prototypes while 30% (87+36 of 411) are in development phase. About 29% (52+68 of 411) have canceled or dormant status and this could be larger. Retired are RapidEye and Swarm.

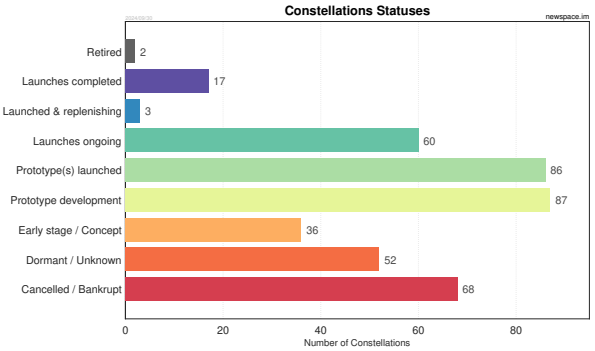

Figure 2: Constellations Current Status

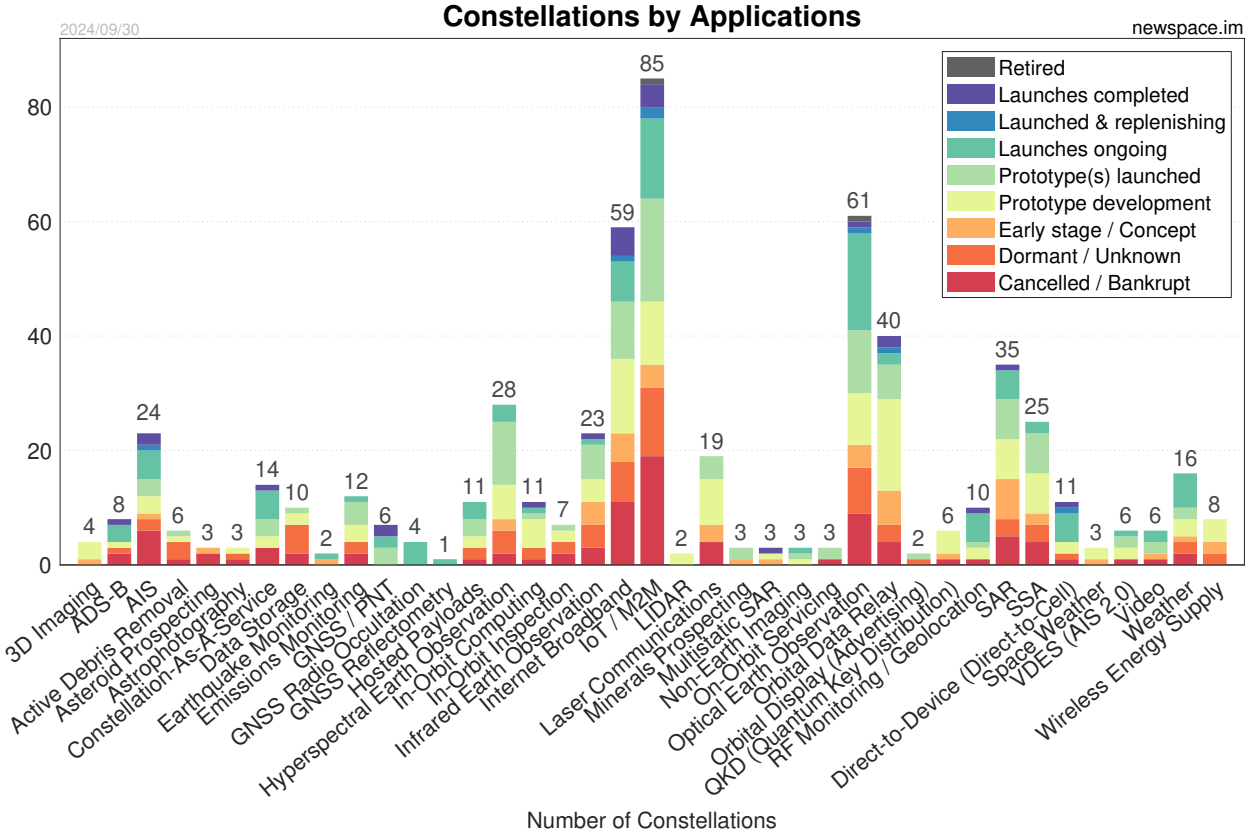

Figure 1: Constellations Applications

4.3 Form Factors

The distribution of spacecraft size and type classes is visualized on Figure 3. CubeSats are the most popular segment with a combined 39% (159 of 411), including the 16% (64 of 411) which are likely to be CubeSats, but specific form factor is currently unknown. Followed by microsatellites with 17% (70 of 411) and small satellites with 16% (65 of 411). Mass classes for about 16% (66 of 411) of the constellations have not been made public yet.

Among CubeSats, 3U was the most popular in 2021, but now 6U is, followed by 3U and 16U and 12U. Swarm went into the opposite direction by using 0.25U CubeSats. Now, Apogeo Space has started launching and GUMUSH is planning similar types.

PocketQubes have been slower to become widely deployed. Fossa Systems has developed a new satellite format usable with CubeSat deployers.

Many entities are moving towards larger satellites due to stacking, appendage, power and thermal limitations of CubeSats and microsatellites. Larger satellites allow for better performance and efficiency. For example Kepler, Fleet, Unseenlabs, SpaceX.

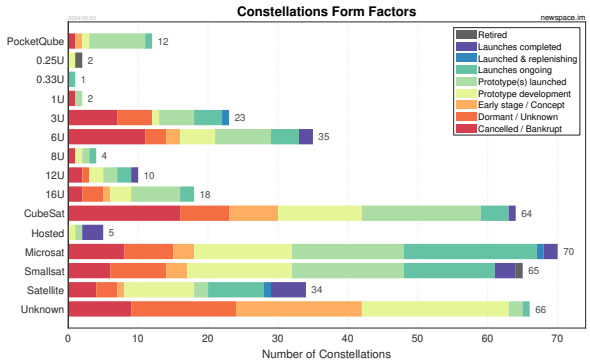

Figure 3: Constellation Form Factors

4.4 Orbits

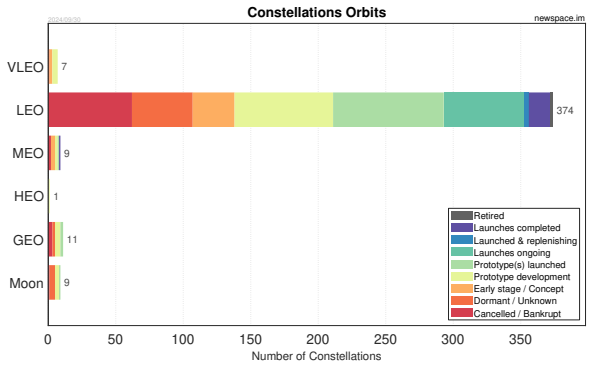

Figure 4: Constellation Orbits

Figure 4 divides the NewSpace constellations by orbit types. LEO is by far the most popular with 91%, 374 of 411. Very-high resolution Earth Observation constellations in VLEO have been announced, but demonstrations have not yet launched. MEO orbits are often used for Internet and Space Data Relay services. GEO orbit will see satellites primarily for Internet, Non-Earth Imaging and SSA. With new startups looking for niches, non-LEO orbits have started to be proposed more often.

4.5 Delays and Launch Cadences

Announced launch cadences were compared with the current launch status to create Figure 5. Most companies have not announced their plans and delays are very common. Only a small number are on-time and delayed less than 6-12 months from plans.

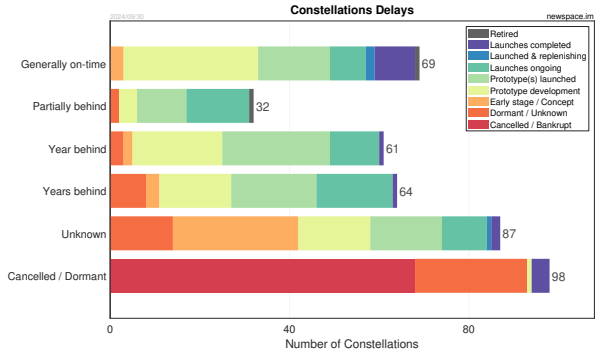

Figure 5: Constellation Delays

4.6 Companies Founded

Founding dates since 2000 are on Figure 6. Some have been filtered out with the earliest from 1895. There is an increase after 2009 with major peaks in 2015-2016. Second peak in 2020-2021. Decrease could still be a sign of waiting to see how existing entities will perform economically.

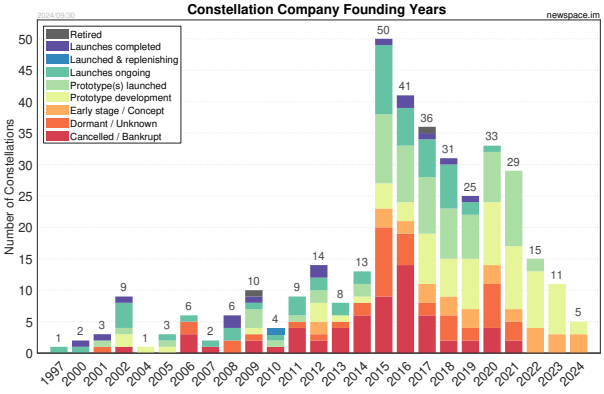

Figure 6: Constellation Companies Founded

4.7 Manufacturers

Subcontracting the first or more spacecraft to a satellite manufacturer does not ensure a constellation order. Some have used the services of multiple integrators. Many have later switched to building the spacecraft in-house. The database lists multiple manufacturers when applicable. In this survey, only the latest used or announced satellite producer has been presented on Figure 7.

About 37% (154 of 411) are building spacecraft in-house and 34% (139 of 411) of constellations are currently unknown. Rest divide between a large number of manufacturers. Few manufactures have full contracts and only a small number of constellations have been fully funded. Going further, it is likely that most constellations will not be continued.

NanoAvionics is followed by Spire, Terran Orbital, GomSpace and AAC Clyde Space. However, Spire has been launching more regularly and larger batches. GomSpace has been launching UnseenLabs satellites regularly and now started development of microsatellites. SFL has been launching HawkEye 360 satellites regularly. Thus, the amount of constellations should not be the primary metric.

4.8 Funding and Investments

Funding amounts, which have been made public, or estimated internal investments, have been summarized on Figure 8. Several dozen companies have considerable funding enough for demonstrations and first small batches. However, capital does not always convert into tangible results or high number of launched satellites. Many other entities have extensive investments based on activities, but the exact sums have not been announced. Approximately 18% (72 of 411) have likely received no funding.

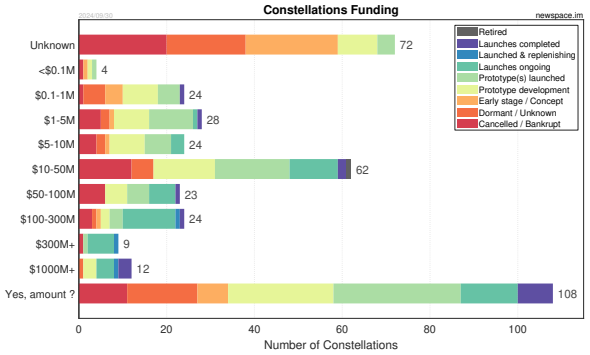

Figure 8: Constellations Funding

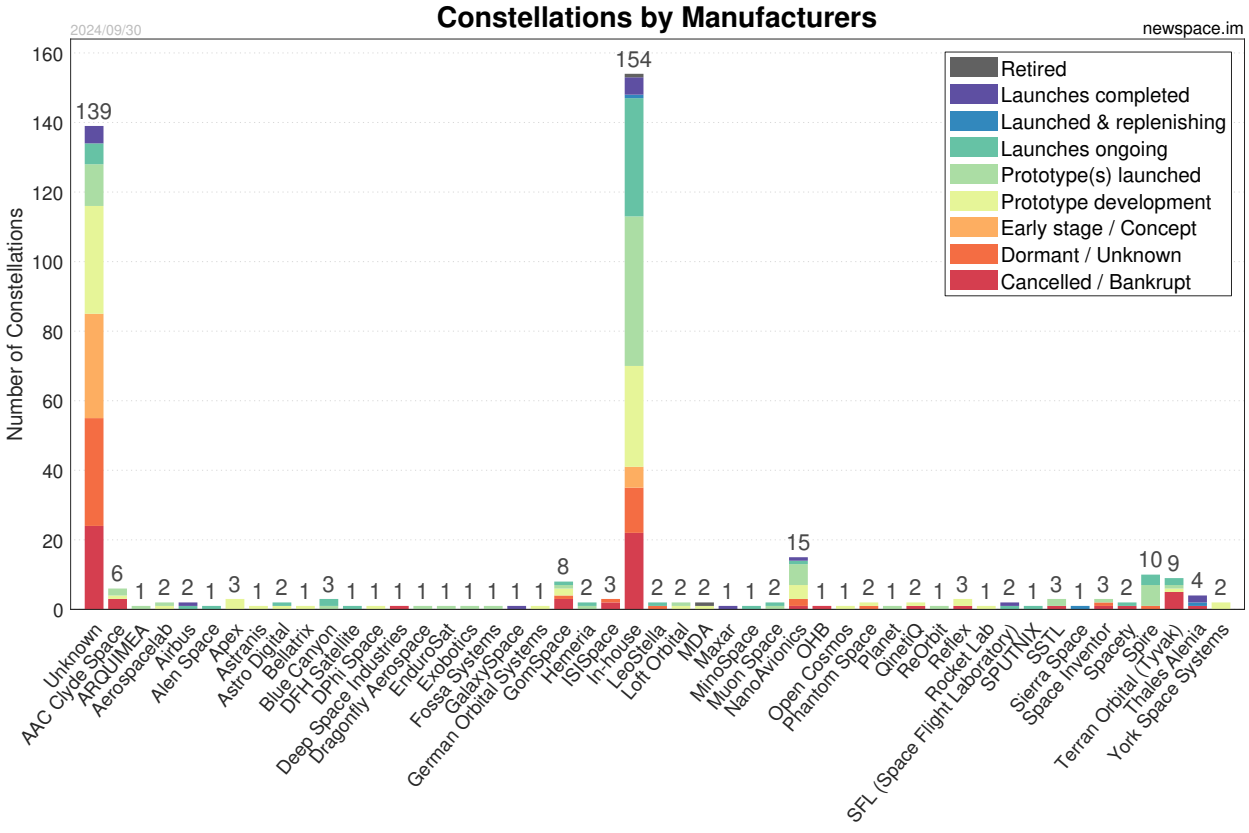

Figure 7: Constellation Subcontractors

4.9 First Launches

First satellite launches of constellation companies are depicted on Figure 9. First launch is defined as the direct prototype or the first operational satellite of a constellation. In many cases, the form factor, payload, performance or even application of a pathfinder can be very different from the operational spacecraft. This requirement has been tightened to better track satellites with relevant missions.

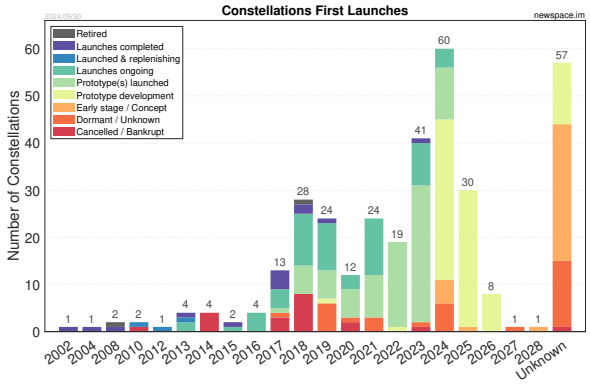

Figure 9: Constellation First Launches

2023 was a new record with 41 constellations launching their first satellites or payloads to space. 60 is currently scheduled for 2024, but most of them will happen. As of September 2024, 17 constellations have launched in 2024 and Transporter-12 flight is still to come. Delays have been very common and will likely continue to be so.

4.10 World Map

Distribution of the constellation companies by headquarters locations is on Figure 10. The map has 45 marked countries. The most notable case, where the headquarters does not match the manufacturing location, is Spire, whose satellites are assembled and tested in Glasgow, UK.

Generally, the US is far ahead with 39% of constellations being located there, followed by China with 10%, UK with 8%, Canada with 5% and France with 4%. While Russia, India and Japan with domestic launch capability do not stand out among Spain, Italy and Australia for example.

These numbers likely show a mix of entrepreneurial activity and funding availability. However, more important than the count is an economically sustainable company, and then it could be the only one.

In 2023, Amini raised $4 million to launch first remote sensing satellite in early 2025 and is based in Kenya. Gemini Space from Nigeria is not active anymore. ONDO Space is based in Mongolia. DeepSat is based in Armenia and is planning a VLEO Earth observation constellation. EOS Orbit is based in Thailand and launched first IoT CubeSat in 2023. Telnet from Tunisia launched a 3U CubeSat for IoT in 2021 and was planning a constellation but no further news have been found recently.

Compared to 2021, the US has grown the most in absolute terms (99 to 160), followed by China (23 to 41) and UK (19 to 34).

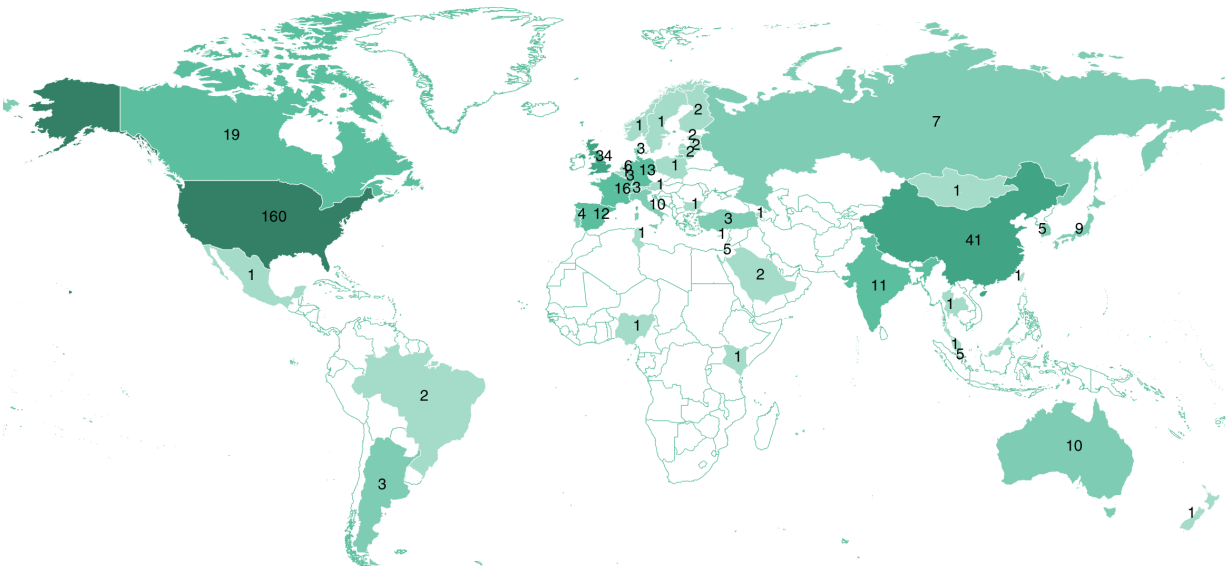

Figure 10: Constellations Headquarters Map

5. 2024 SURVEY BY APPLICATIONS

This section presents commercial satellite constellations by selected applications in no specific order. Some discussions on trends have been included. Each figure for an application includes the names of companies, status, launched and planned number of satellites. Prototypes and hosted payloads are usually added to the launched count, except in cases of established space companies, where the number of unrelated satellites is too large.

In other words, not all are independent satellites and some are hosted payloads. Launch failures are included in the launched count, because the spacecraft were built and contracted to launch. Such aspects are proof of activity and gives better insight into the status of company. The launched count also does not show the number of satellites which are still in orbit or operational.

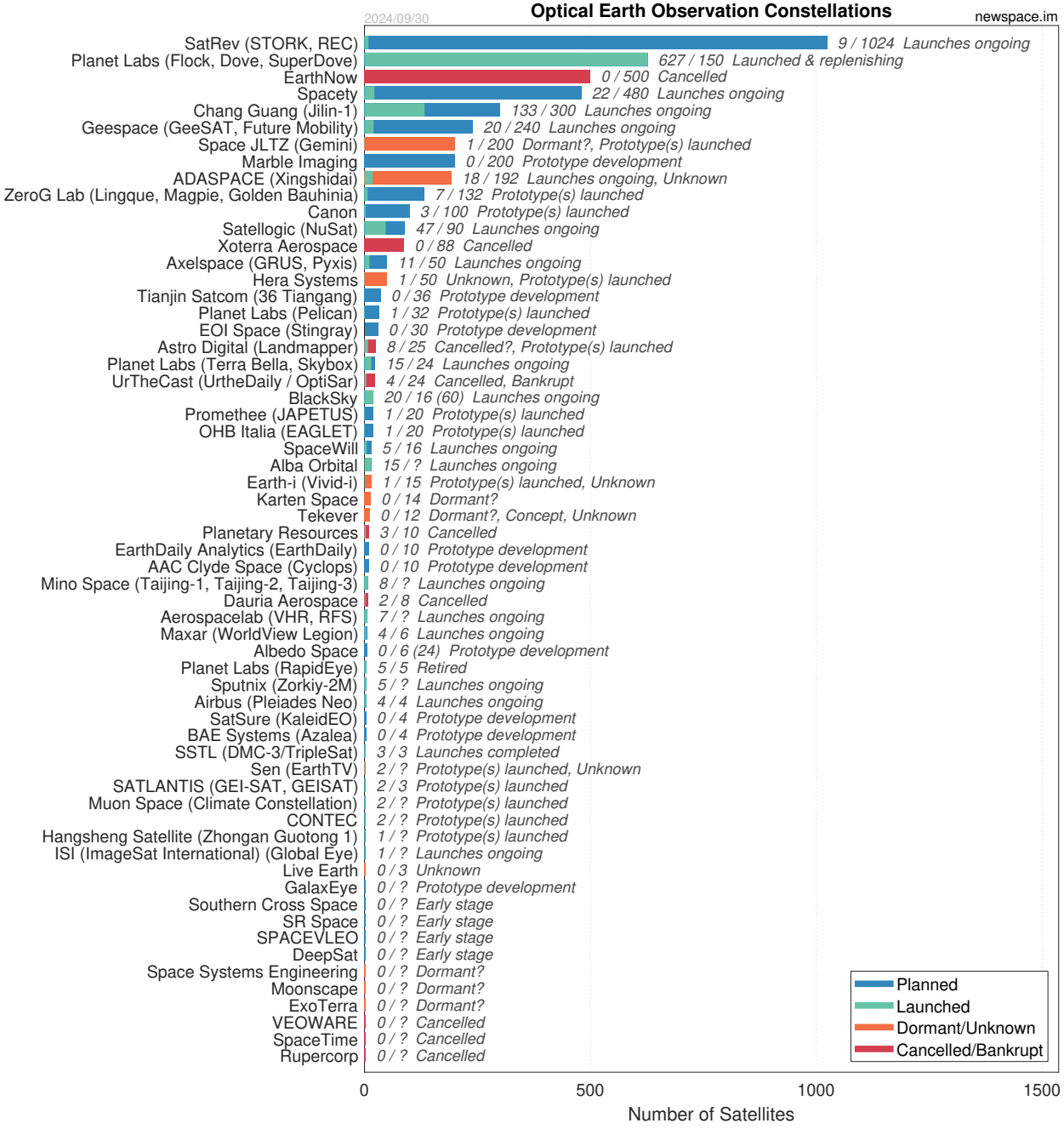

Figure 11: Optical (VNIR) Launched and Planned Spacecraft

5.1 Application: Optical EO (VNIR)

Figure 11 gathers Earth Observation constellations in the visible and near-infrared (VNIR) range and multispectral.

Planet's Dove (SuperDove) and Skybox constellations together with BlackSky and Jilin-1 are being actively used and expanded.

In 2021, a trend was very-high resolution satellites pursued for example by Albedo Space[73] and Earth Observant,[72] both aiming for approximately 10-cm per pixel resolution, comparable to the capabilities of best military spacecraft. The first launches have not yet happened. Since then, different wavelengths such as infrared and hyperspectral seem to have been more popular as new constellation ideas.

Satellogic went public in early 2022 and has launched 47 satellites, but does not seem to be doing financially well as of September 2024.[76,77]

Starshield is likely to have significant impact on Earth observation field also, with an estimated 73 spacecraft launched and a $1.8B contract from NRO.[78–80]

Hera Systems was acquired by Redwire in 2024. They had been relatively quiet since launching their first satellite in 2019. However, they achieved profitable growth and had $15M in revenue in 2023.[81]

AAC Clyde Space secured its first customer for Cyclops Earth Observation constellation. It will be made up of four satellites manufactured under the xSPANCION project.[82]

5.2 Application: Infrared EO

Infrared Earth observation constellations have started or are close to launching first demonstrations. Figure 12 shows Earth Observation constellations in the infrared (IR) and thermal range. Here excluding Near-Infrared (NIR), but including Mid-Wave Infrared (MWIR) and Long-Wave Infrared (LWIR).

OroraTech has launched 2 satellites since 2022 with Spire, but the third satellite launching soon has been developed in-house.[83]

Albedo Space will also have a thermal imager in the LWIR range to capture 2-m resolution photos from VLEO.[73] Albedo raised $35M Series A1 in early 2024 for a total funding of $97M and is planning first launch in 2025.[84]

Aistech Space pivoted from AIS and ADS-B to infrared and launched first hosted payload in 2022.[85]

ConstelIr launched payload to the ISS in 2022 and first commercial satellite will launch in 2024.[86,87]

SatVu (previously SatelliteVu) launched in 2023, but the payload stopped working 6 months later.[88]

Skysight (China) launched first batch of 3 in 2023.[89]

Hydrosat launched first payload in 2024 on Loft Orbital's YAM-7 spacecraft.[90]

Muon Space in partnership with Earth Fire Alliance announced the FireSat Constellation. First phase will launch in 2026 and consist of 3 spacecraft with potentially up to 50+ satellites in future.[91]

5.3 Application: Hyperspectral EO

Several hyperspectral Earth observation constellations have started or are close to launching first demonstrations. Figure 13 plots Earth Observation constellations with hyperspectral imagers.

Planet's and Carbon Mapper's Tanager-1 was launched in 2024.[92]

Satellogic's hyperspectral product has 32 bands.[93]

Wyvern has used 3 satellites from AAC Clyde Space launched in 2023 under a space-data-as-a-service contract and plans to also use data from sensors on Loft Orbital spacecraft.[94,95]

Zhuhai Orbita's constellation includes 4 satellites with 32-band hyperspectral imager.[96,97]

Kuva Space launched first satellite in their constellation in 2024.[98]

Pixxel has launched 2 prototype spacecraft since and plans for 6 more in 2024.[99]

Absolut Sensing will fly on Transporter-12 and has hyperspectral instrument for methane sensing.[100]

Orbital Sidekick shared imagery in 2024.[101]

Esper launched a hosted hyperspectral payload in 2024, but contact was not established with the Space Machines satellite.[102]

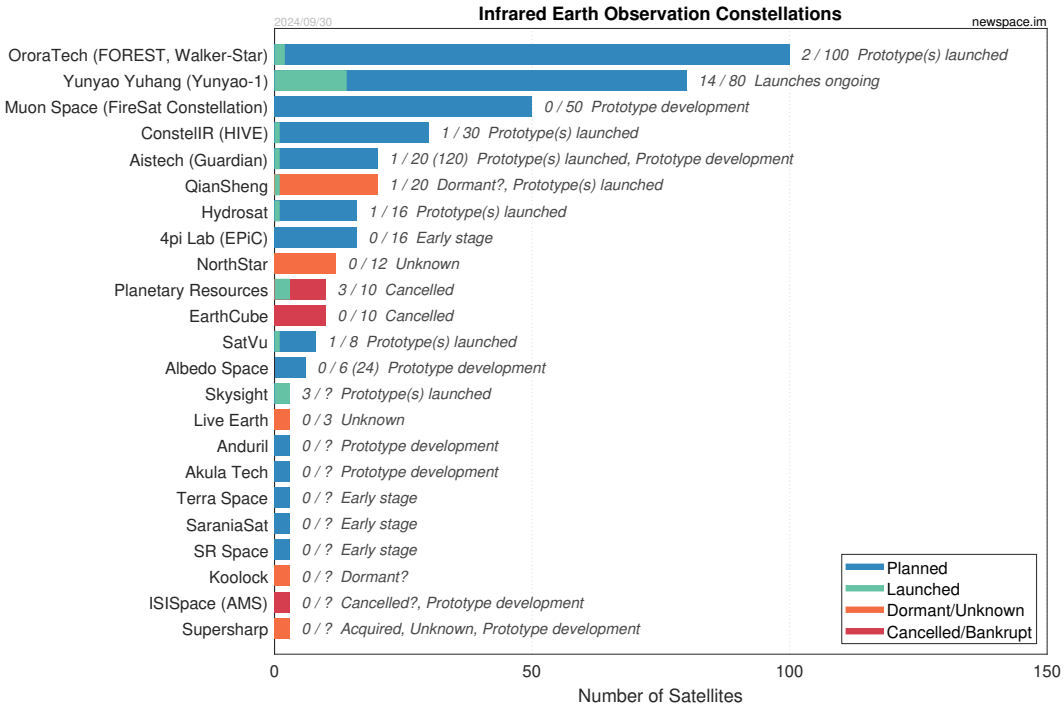

Figure 12: Infrared EO Launched and Planned Spacecraft

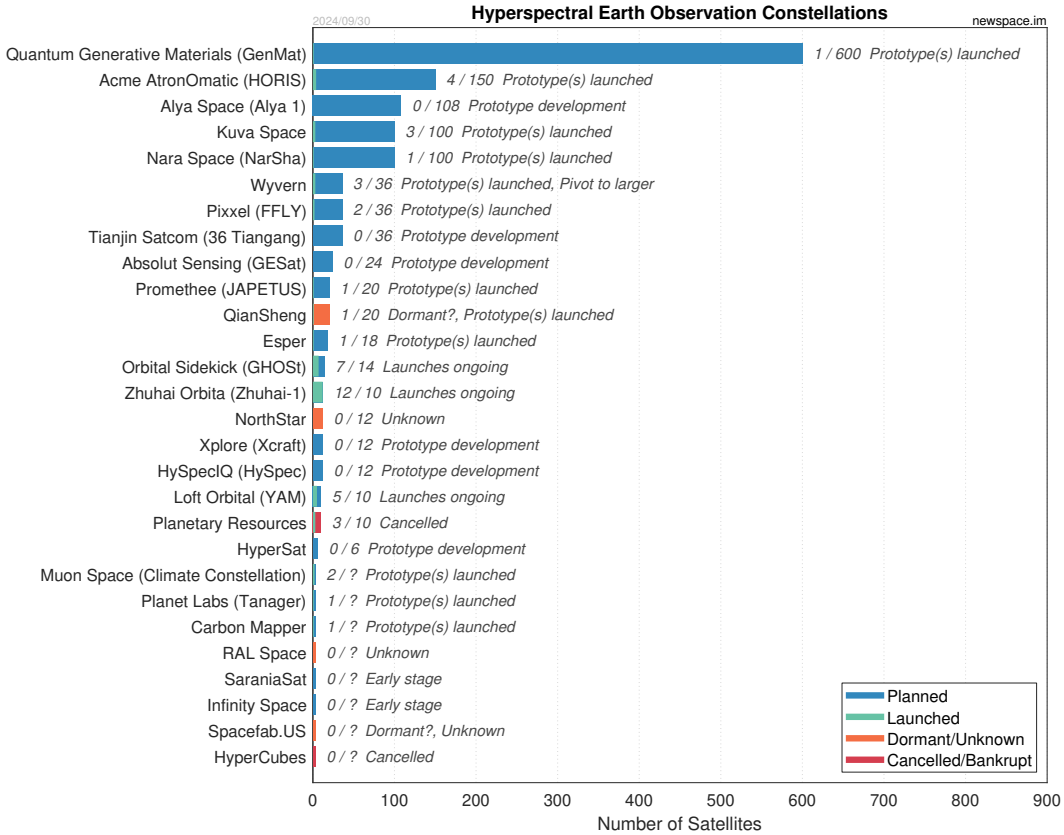

Figure 13: Hyperspectral EO Launched and Planned Spacecraft

5.4 Application: SAR

Figure 14 illustrates SAR (Synthetic Aperture Radar) constellations. Companies have continued launching SAR satellites. For example, ICEYE has now launched 39 spacecraft, Capella has 15, iQPS has 8, Umbra has 10 and Synspective has 5. Demand for SAR data for defense applications is growing.[103]

Terran Orbital canceled own PredaSAR constellation in 2022 to focus on selling SAR spacecraft.[104]

Synspective raised $47M Series C in June 2024.[105] GalaxEye secured $6.5M Series A in 2024 and will have SAR payload plus multispectral imager.[106]

Sisir Radar is planning a commercial two-band (L and P) SAR constellation.[107]

Multistatic SAR Bistatic and multistatic is a recent SAR constellation trend to produce 3D imagery for measuring the height of objects. At least 2 spacecraft flying in formation are required and many configurations have been proposed.[108]

ICEYE proposed bistatic mission with SATLANTIS in 2022.[109] Capella demonstrated bistatic collection in 2023.[110] Umbra shared example bistatic data in early 2024 and plans to offer it to customers.[111]

Array Labs raised $5M in 2022 for 3D radar imaging.[112] KappaZeta is planning a 3D-SAR mission.[113] PIESAT launched 4 SAR satellites in 2023 flying in a cartwheel configuration.[114] Italian Space Agency is funding the SATURN mission.[115]

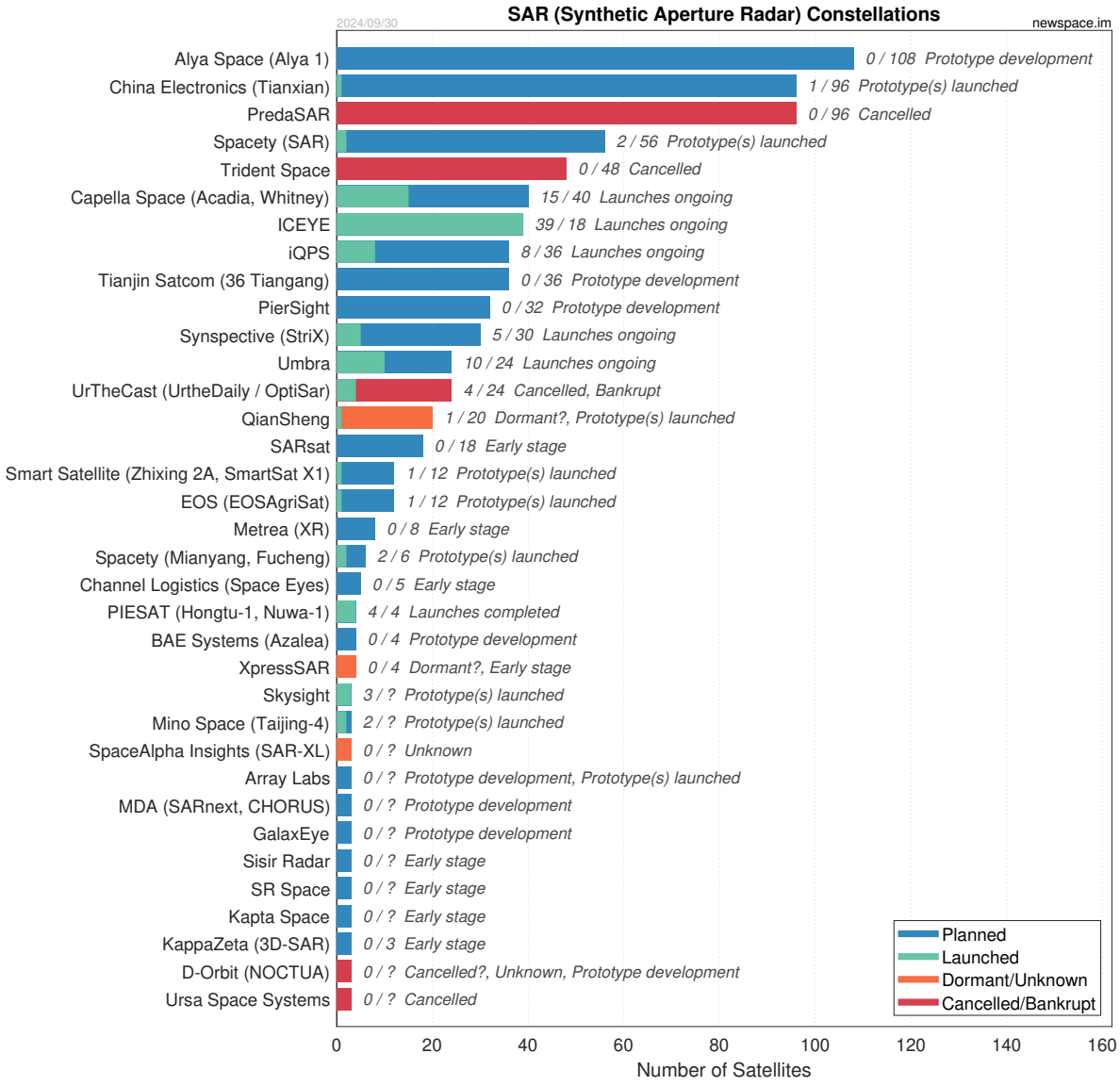

Figure 14: SAR Launched and Planned Spacecraft

5.5 Application: ADS-B

Figure 15 illustrates ADS-B constellations of which Spire and Aireon (hosted payloads on Iridium-NEXT) are currently offering service.

Skykraft launched two batches of 4 spacecraft for air traffic management in 2023.[116]

Indra created Space NewCo, which will include the Startical constellation.[117]

Spire-led group won $18M ESA project Eurialo in 2023 to design the system and launch a demonstrator.[118] Thales, Spire and the European Satellite Services Provider announced a MoU in 2024 to develop a constellation dedicated to air traffic surveillance with services starting in 2027.[119]

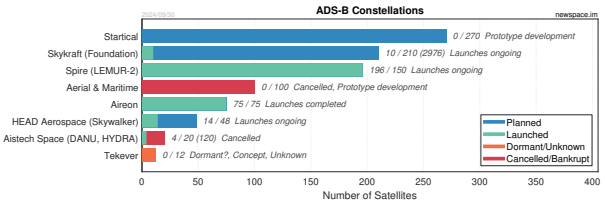

Figure 15: ADS-B Launched & Planned Spacecraft

5.6 Application: VDES

Figure 16 gathers VDES (AIS 2.0) constellations. It remains a nascent field with Saab and Sternula having launched 1 spacecraft. HEAD Aerospace has launched 14 satellites, but it is unclear whether they have VDES payload onboard.

LusoSpace is a recent addition and plans first launch in 2024 and a constellation of 12 CubeSats.[120]

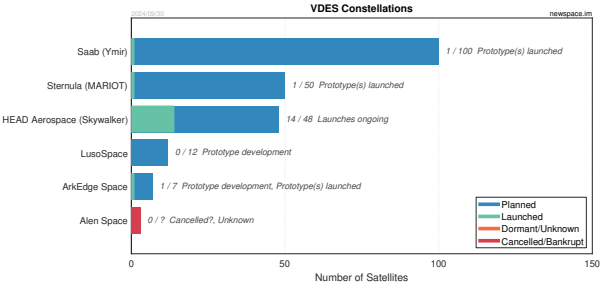

Figure 16: VDES Launched and Planned Spacecraft

5.7 Application: RF Spectrum Monitoring

Figure 17 hows constellations detecting radio emissions from objects and likely also performing geolocation. Space-based monitoring of electronic signals is a popular field and capabilities are being extend beyond ship tracking.[121]

Unseenlabs and HawkEye 360 have continued launching satellites regularly. However, Kleos Space went bankrupt in 2023 after launching 16 satellites.[122]

Maxar announced the acquisition of Aurora Insight in early 2023 and sold them to HawkEye 360 at the end of 2023.[123]

Sierra Nevada Corporation (SNC, Sierra Space) entered this market with the launch of 4 CubeSats in 2023.[124] Next, Muon Space will deliver three larger satellites for SNC's Vindler constellation.[125]

Aerospacelab launched 3 spacecraft with radio frequency sensing payloads in 2024.[126]

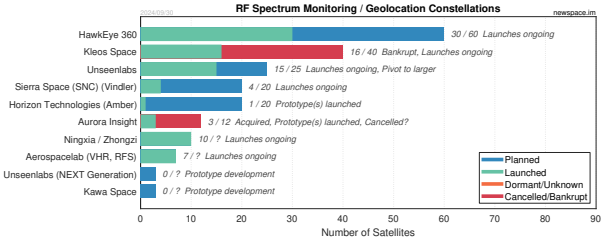

Figure 17: RF Spectrum Monitoring Constellations

5.8 Application: Emissions Monitoring

Figure 18 shows companies monitoring greenhouse gas emissions. GHGSat has 12 satellites in orbit. Absolut Sensing will launch a spacecraft in autumn of 2024. AIRMO and Grasp are recent additions.

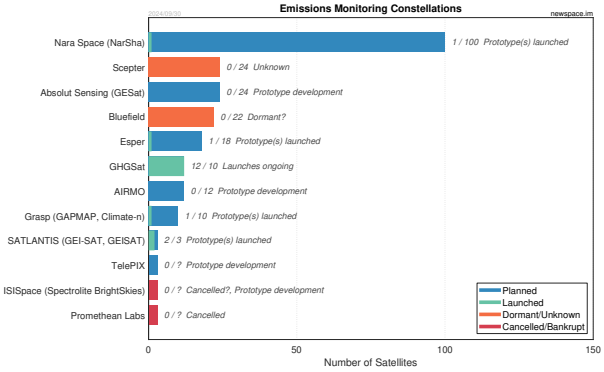

Figure 18: Emissions Monitoring Constellations

5.9 Application: GNSS and PNT

Figure 19 represents constellations offering commercial positioning, navigation and timing services. It has been a relatively popular field with recent articles such as "Can "AltPNT" Really Replace GPS?"[127] and "Why GPS Is Under Attack".[128]

Satelles has hosted payloads on 66 Iridium-NEXT spacecraft and it was acquired by Iridium in 2024 and renamed to Iridium's PNT Division.[129]

Xona Space System raised $19 million Series A in May 2024.[130] ESA funded two LEO-PNT demonstrations.[131,132] Thales Alenia Space won one of those projects.[133]

TrustPoint raised $2M in late 2021 for about 300 satellite constellation,[134] has performed two tech demos in orbit and won $3.8M in grants in 2024.[135]

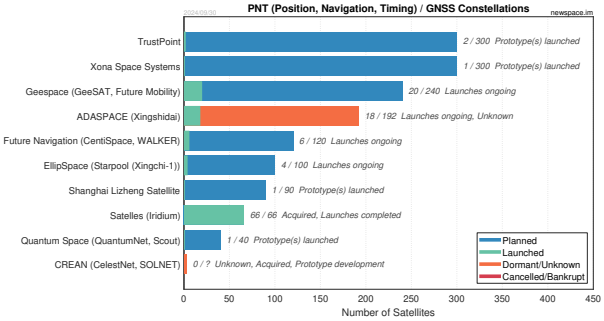

Figure 19: GNSS and PNT Constellations

Geeky's Geespace launched 9 satellites in 2022 and 11 more in 2024. First phase focuses on data communication services, but in the second phase the network will expand to 168 satellites and deliver global centimeter-level positioning services.[136]

Future Navigation launched a batch of 4 CentiSpace satellites in 2022 to provide GNSS augmentation services.[137,138] Quantum Space envisions a fleet on spacecraft around the Moon with a variety of payloads including navigation.[139] Sierra Space won a contract in 2024 to design smaller and more resilient GPS satellites.[140]

5.10 Application: Weather

Figure 20 shows constellations generating data uniquely suited for weather prediction models.

Spire has been the most active with over 196 Lemur-2's launched since 2014 (52 more since previous paper) and is offering both GNSS-R and GNSS-RO data.

GeoOptics has launched 9 satellites for GNSS-RO measurements, but none since 2022.

Orbital Micro Systems has been relatively quiet since launching first and only satellite in 2019. More satellites were planned to be launched by now.[141] However, they received $1.7M order in 2023 from US Space Development Agency.[142]

Tomorrow.io planned to go public via SPAC but it was called off in 2022.[143] They launched two satellites with Ka-band radar in 2023 and two more with passive microwave sounders in 2024.[144,145]

PlanetiQ has been launching one GNOMES satellite per year since 2020 and recently received a $6.5M NOAA contract.[146,147]

Care Weather has launched early prototypes and is now developing Veery radar microsatellites with first launch planned for 2026.[148]

Acme/MyRadar plans 250 satellite weather constellation.[149] Has launched PocketQubes before but pathfinder satellites will start from 2024.[150]

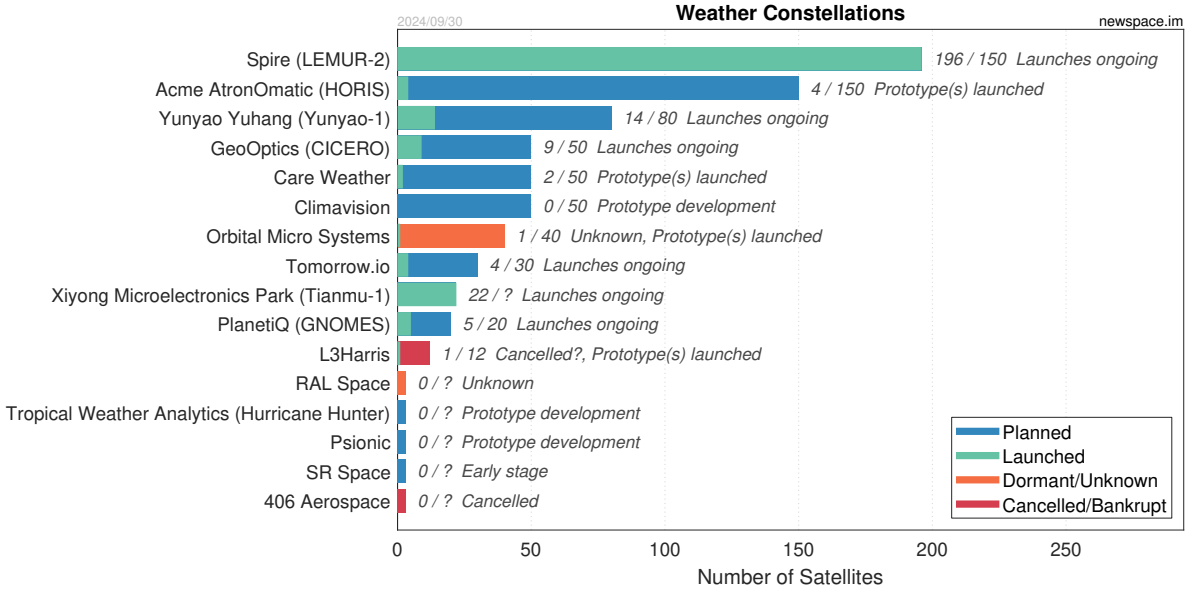

Figure 20: Weather Launched and Planned Spacecraft

5.11 Application: Orbital Data Relay

Figure 21 displays constellations that provide data communications service to other satellites or assets in space using inter-satellite links (ISL).

Laser communication has been merged here, because many of them use lasers. "A Survey on Laser Space Network: Terminals, Links, and Architectures" was published by Li et al. in 2022.[151] A Chinese commercial firm completed high-speed laser transmission test to Earth in 2023.[152] "On the Use of Mega Constellation Services in Space" was published by Capez et al. in 2022.[153] Urban discussed the state of the optical communications market in 2023.[154]

Addvalue's IDRS service using Viasat/Inmarsat satellites is currently one of the leading operational commercial real-time ISL services.[155] Globalstar and Iridium are also being used for orbital data relays.

Analytical Space was renamed to Hedron and raised $17.8M in 2021,[156] but now seems bankrupt.

Kepler launched first microsatellites in late 2023, announced successful test of optical inter-satellite links, and plans to launch 10 satellites in 2025.[157]

NASA has contracted at least 6 in-orbit relay demonstrations for 2025-2026.[158] Kepler recently joined the program.[159]

Polaris Dawn mission tested SpaceX's Plug and Plaser lasercom terminal with Starlink satellites.[160]

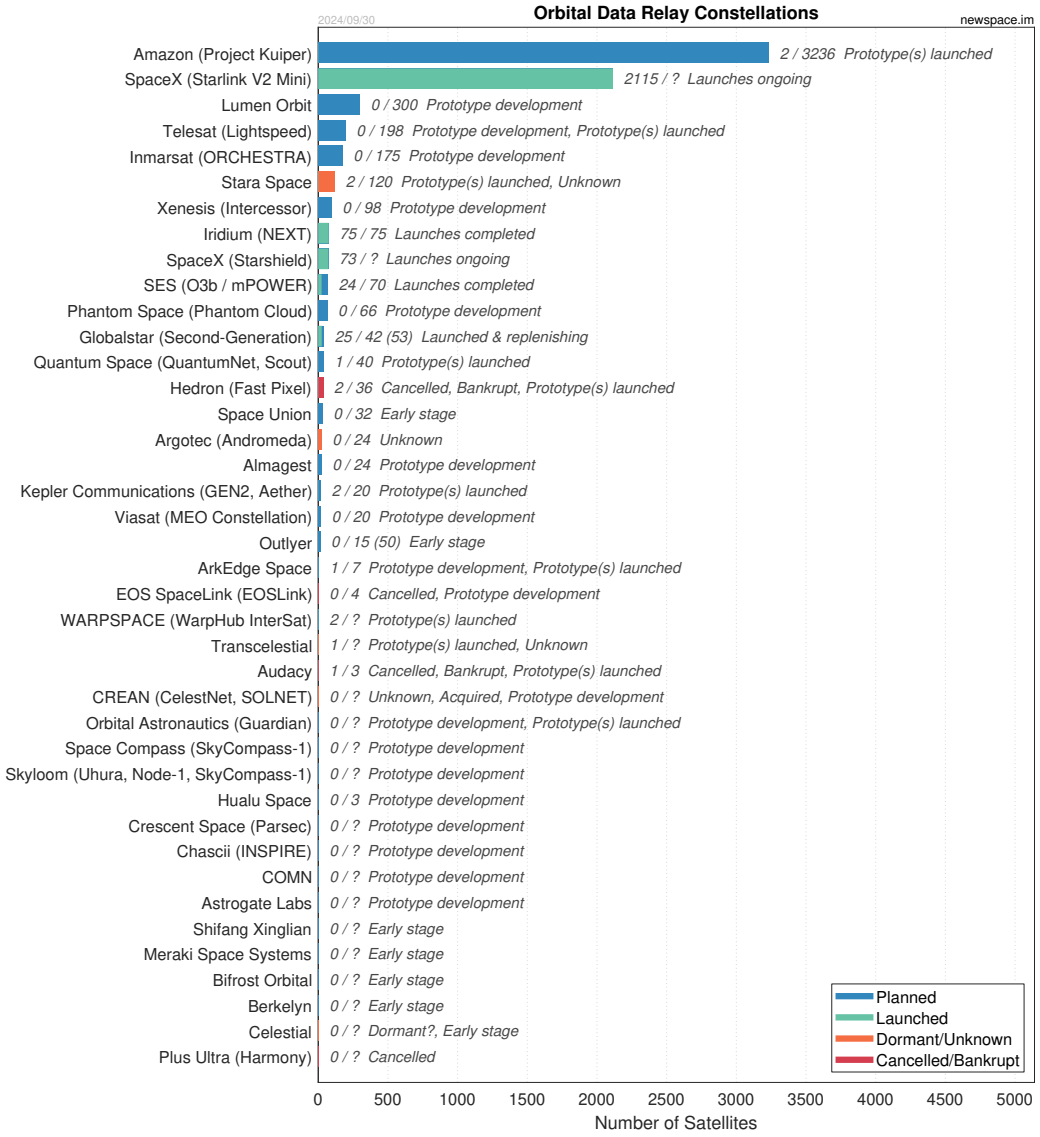

Figure 21: Orbital Data Relay Constellations

5.12 Application: Constellation-As-A-Service and Hosted Payloads

Figure 22 indicates constellations that host multiple payloads concurrently or are outsourced as a full end-to-end service. In some cases called Satellite-Data-As-A-Service. The number of launched satellites does not always match the number of satellites with hosted payloads. The line between satellite manufacturers and constellation-as-a-service can be very narrow and possibly missing several entities.

Sidus Space launched first satellite in 2024 and the next satellite is ready.[161] Satellogic and Axelspace have started to offer this service according to the websites but such spacecraft have not yet launched. Wyvern will use data from sensors on Loft Orbital satellites to expand its constellation of AAC Clyde Space supplied data.[95, 162]

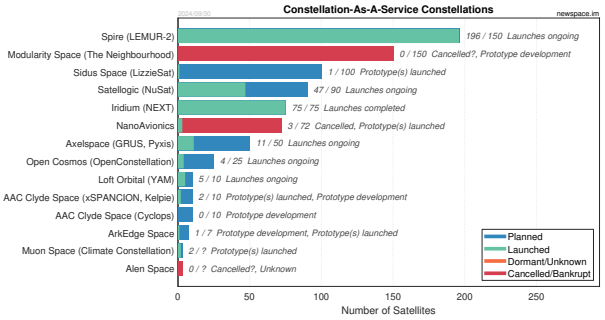

Figure 22: Constellation-As-A-Service and Hosted Payloads Launched and Planned Spacecraft

5.13 Application: SSA and Non-Earth Imaging

Figure 23 plots SSA (Space Situational Awareness) constellations aiming to detect and track other satellites and objects in space for orbit determination or in-space inspection. The latter is also known as Non-Earth Imaging (NEI). Space Domain Awareness (SDA) is considered to be another synonym.

SSA has been a popular theme in the recent years with numerous companies receiving private funding, either for satellites or non-satellite solutions.

First demonstrations have been launched in 2023 by Turion Space[163] and in 2024 by NorthStar and Quantum Space.[164] However, NorthStar has reported challenges with data quality.[165]

Privateer acquired Orbital Insight, a geospatial data analysis company, and raised $56.5M.[166] Aravind tweeted "Privateer's CEO openly acknowledged that the revenue prospects for SSA are limited."[167]

BlackSky was recently awarded two 7-figure contracts to deliver non-Earth Imagery, including from Australian company HEO[168, 169]

Atomos Space and Katalyst Space are collaborating to retrofit geostationary satellites with space domain awareness sensors and Katalyst estimates that there is about a billion dollars in the SDA hosted payload market in the next five years.[170]

The US Space Security and Defense Program is doing market research on advanced space domain awareness technologies available in the 2030-2040 timeframe.[171]

Vyoma has raised over €16M and plans first satellite launch in 2025.[172]

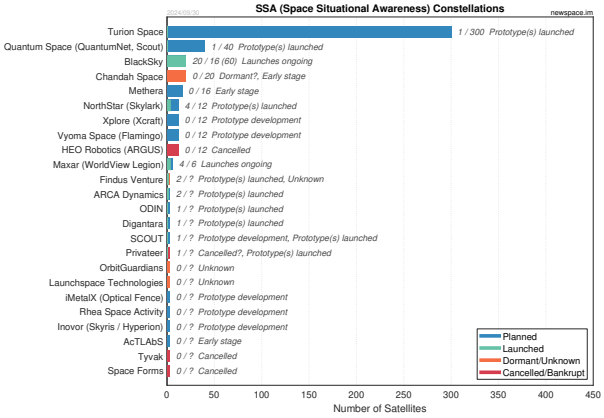

Figure 23: SSA and NEI Constellations

5.14 Application: QKD (Quantum Key Distribution)

Figure 24 details QKD (Quantum Key Distribution) constellations for unhackable communications. It has the potential to be a large future industry.

Arqit canceled plans to operate satellites in late 2022 after going public via SPAC in 2021.[173]

Eagle-1 is developed by ESA, European Commission, SES and other companies, and is scheduled for launch in 2025 or 2026 (previously 2024) to test quantum key distribution.[174] Boeing plans to test quantum networking satellite in 2026 using internal funding.[175] SpeQtral presented their QKD plans in 2024.[176] China plans QKD demonstration from MEO orbit for a longer ground station contact.[177]

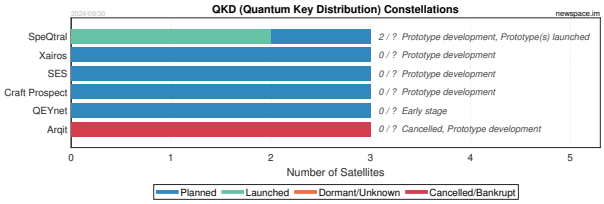

Figure 24: QKD Launched and Planned Spacecraft

5.15 Application: AIS

Figure 25 displays AIS constellations, which was one of the first commercial constellation applications. Spire entered the market in 2014 and has the largest constellation. ExactEarth has 58 hosted AIS receiver payloads on Iridium-NEXT and was acquired by Spire in 2021.[178]

Many countries have dedicated satellites to receive AIS messages, for example Norway has a series of AISSat and NorSat spacecraft.

As a newcomer, Sitronics with subsidiary Sputnix started launching 3U and 6U CubeSats for AIS message collection in 2023 and have launched 28 satellites named SITRO-AIS and 5 as Zorkiy-2M.[179]

5.16 Application: Wireless Power

Figure 26 details Wireless Power Beaming and Space Solar Power constellations.[180] Many are likely missing from this figure (e.g. Overview Energy?) because it is not yet public whether there will be a constellation of satellites or large space structures.

Reflect Orbital is planning a constellation of satellites with large mirrors and first orbital launch is planned for 2025.[181] Star Catcher aims to develop a space power grid to wirelessly power other spacecraft and first mission in 2025.[182] Aetherflux plans to develop a constellation of satellites in LEO that will collect solar power and beam it to Earth using infrared lasers. First demonstration is planned for early 2026.[183]

Volta is planning a constellation of laser power beaming satellites for the Moon with the first LEO demonstration in 2026 and initial lunar network projected for 2028.[184, 185]

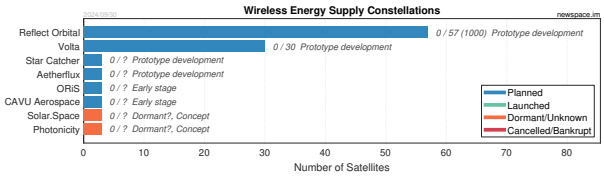

Figure 26: Wireless Energy Supply Launched and Planned Spacecraft

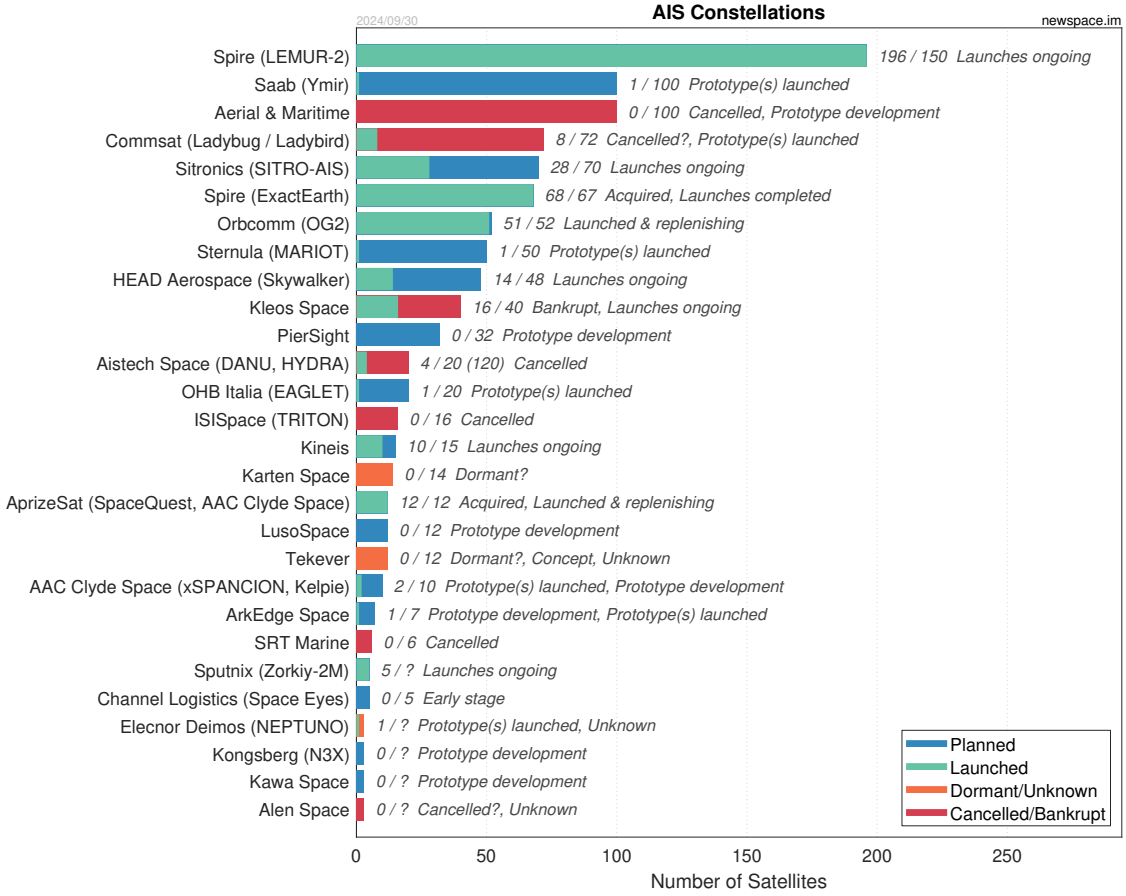

Figure 25: AIS Launched and Planned Spacecraft

5.17 Application: Broadband Internet

Figure 27 shows Broadband Internet constellations. These include the largest planned constellations and the most launched satellites up to now.

In 2021, SpaceX expected to achieve uninterrupted service coverage by autumn of 2021 and OneWeb by the end of 2022.

The Chinese G60 constellation "Qianfan" launched the first 18 satellites in 2024.[186]

Starlink has launched over 7000 spacecraft, including V2-Mini and V2-MiniDTC.[187]

Starlink achieved cash-even in late 2023.[188] Quilty Space estimates Starlink will make $6.6 billion in revenue in 2024.[189] In September 2024, Starlink reached 4 million subscribers.[190]

Eutelsat OneWeb completed deployment but has not yet started providing worldwide services due to ground delays.[191] Next generation spacecraft are expected to be in the 500 kg range and likely not more than a thousand satellites.[192] A prototype (JoeySat) for the next generation was launched in 2023.[193]

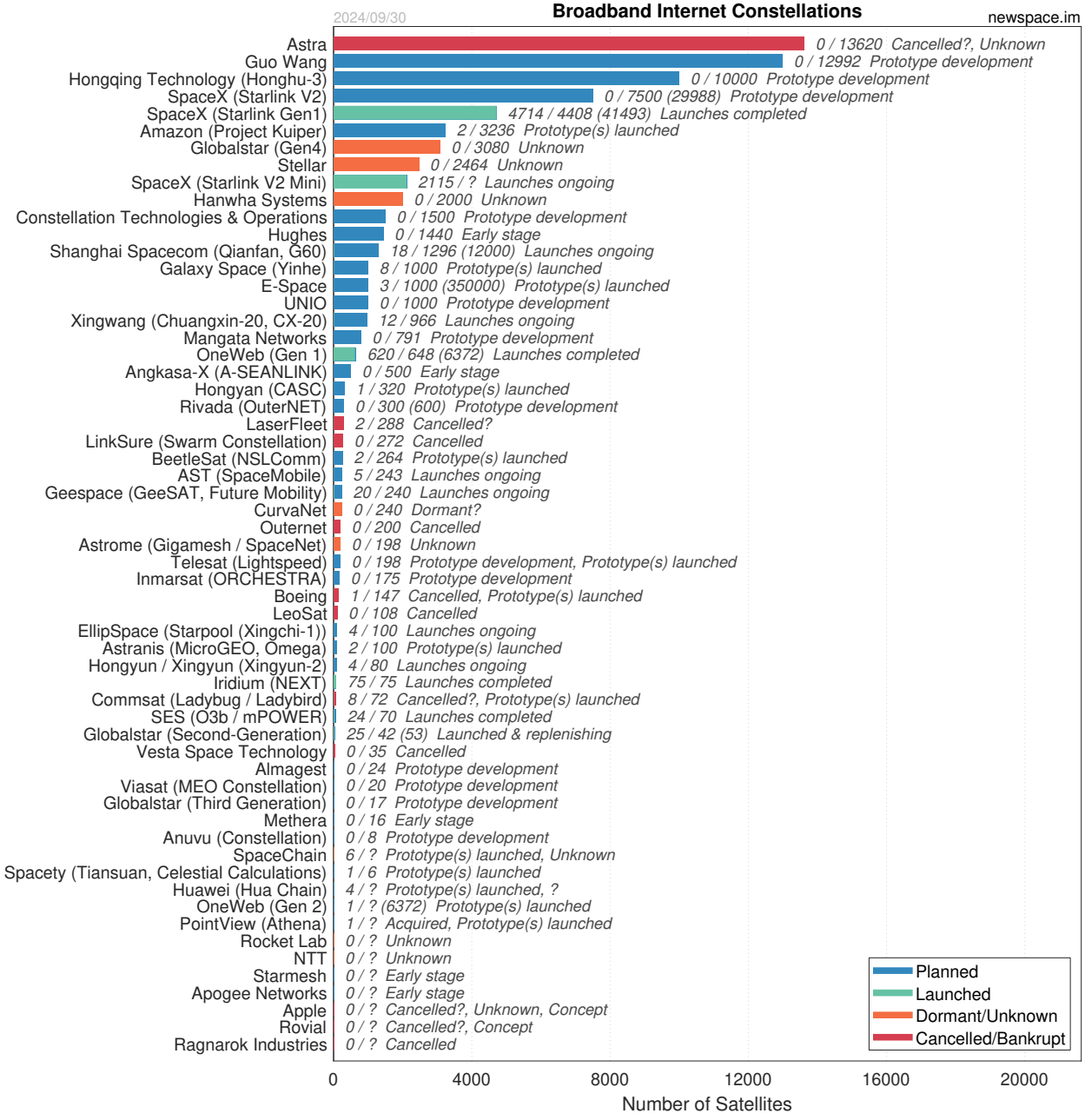

Figure 27: Internet Launched and Planned Spacecraft

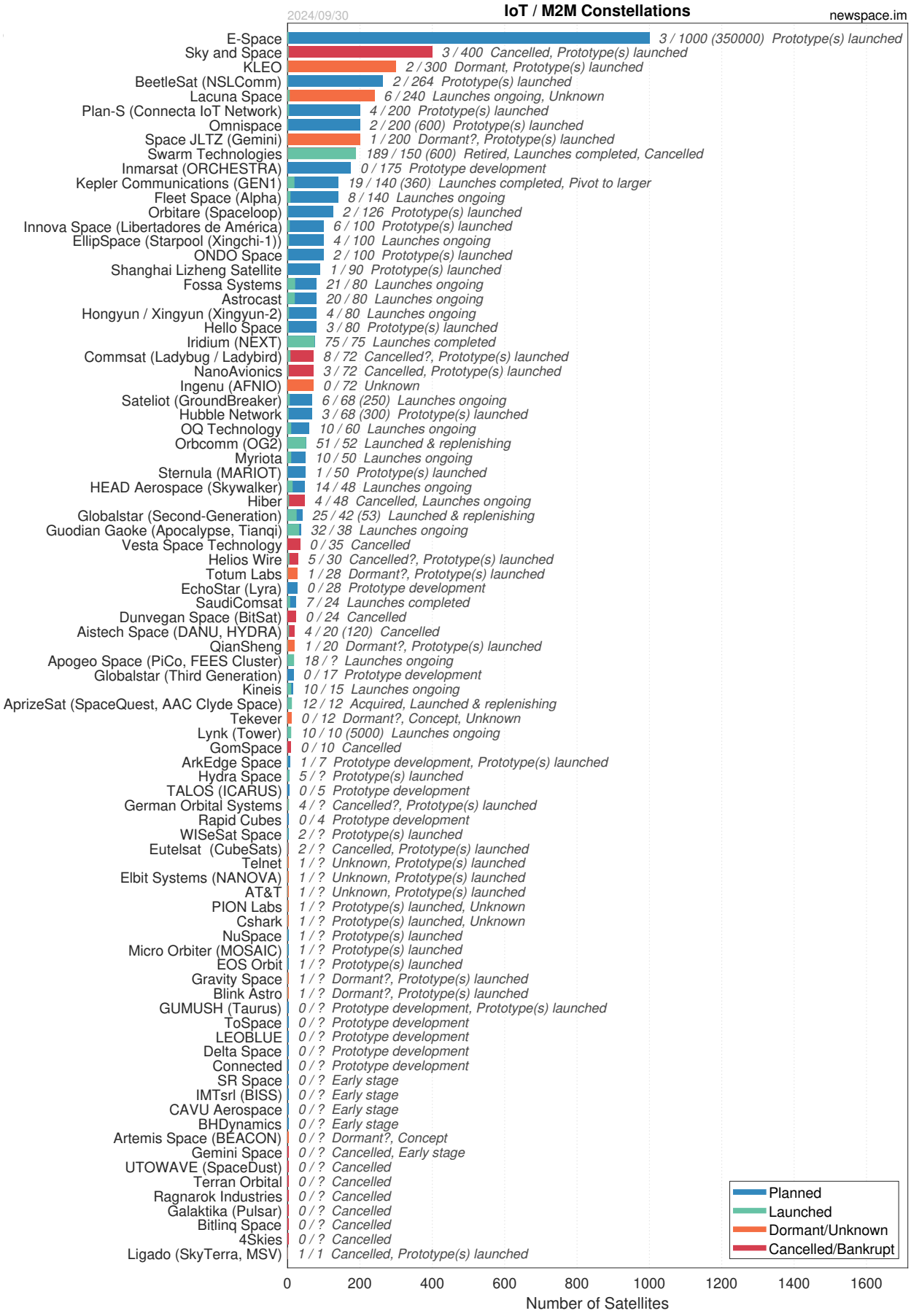

Figure 28: IoT / M2M Launched and Planned Spacecraft

Astranis raised $200 million Series D for larger Omega satellite development, for a total $750M raised. Aims to launch 100 MicroGEO satellites by 2030 and connect millions to affordable internet.[194]

Telesat secured $1.9 billion government funding for Lightspeed constellation, which is more than half of the cost, and plans to start launches in 2026.[195]

Rivada's financials have been uncertain and Terran Orbital removed them from backlog in 2024.[131]

Kuiper launched first prototypes in 2023 and the first batch of operational satellites should launch in 2024.[196] Quilty Space estimates that Amazon is spending up to $20B on Project Kuiper. They also forecast that revenue could amount to tens of billions of dollars yearly, but launch cadence would have to be very rapid to meet FCC's 2026 deadline.[197]

5.18 Application: IoT / M2M

Figure 28 details IoT / M2M constellations and is the largest table with 85 entries. This was one of the first commercial markets pursued by Globalstar, Iridium, Orbcomm and AprizeSat before CubeSats.

In late 2021, Hiber canceled plans for satellite constellation.[198]

Swarm's service will be shut down in March 2025.[199] Apogeo Space has launched 18 similarly sized CubeSats since 2023.[200]

Fleet Space raised $50M Series C in 2024.[201] Fossa Systems raised €6.3M Series A in June 2024.[202]

Astrocast went public in 2021 and became a private company again in 2024. In 2021, they predicted $164M revenue for 2025.[203,204]

E-Space launched 3 satellites in 2022 and raised $50M but the news since have been limited.[205]

Hubble has launched 2 satellites to connect Bluetooth devices directly to satellites.[206,207]

Kineis has launched two sets of satellites in 2024 on dedicated Electron launches.[208]

Sateliot and Plan-S both launched a batch of 4 satellites in 2024.[209,210]

5.19 Application: Direct-to-Cell (DTC)

Direct-To-Cell (DTC), also known as Direct-to-Device (D2D) and Direct-To-Cellphone, constellations can be found on Figure 29.

IoT hype came back as D2D around 2022. Devices are now cellular or bluetooth devices, instead of dedicated units. Being able to use existing devices should mean a larger market. However, the market size estimates have been mixed and varied.

There has been a large number of publications and opinion pieces on DTC in recent years. A selection is below:

- "Sizing Up the Satellite-to-Cell Opportunity," Wainscott-Sargent (2022).[211]
- "Satellite executives spar over direct-to-device evolution," Rainbow (2023).[212]
- "Game Changer: The Great Convergence and the Future of Satellite-Enabled Direct-to-Device," Jones and Allison (2023).[213]
- "Space 5G Changes Course Cellular industry predictions for 2023 fell short, as satellite technology branched into IoT," Laursen (2023).[214]
- "The satellite industry cannot ignore the huge potential of D2D services," Ottolini (2024).[215]
- "Calling all space stewards: could direct-to-smartphone elevate space sustainability?" (2024).[216]
- "New direct-to-cell satellite tech could disrupt billion-dollar military satcom programs," Erwin (2024).[217]
- "Satellite operators join forces to chase direct-to-smartphone opportunity," Rainbow (2024)[218]
- "The promise of direct-to-device," Rainbow (2024).[212]
- "Satellite direct-to-device technology needs to evolve through four phases before reaching its full potential," Palerm and Zhang (2024).[219]
- "Is satellite direct to handset really dead? Here are the real opportunities for 5G NTN," Hill and Kibutu (2024).[220]

SpaceX has launched 233 DTC-dedicated satellites. T-Mobile performed the first emergency alert via Starlink in 2024.[221]

AST SpaceMobile launched first 5 production direct-to-cell satellites in September 2024.[222]

Lynk is providing intermittent texting for unmodified phones in more than 7 countries, including the Solomon Islands, Cook Islands and Palau. However, the SPAC funding plans are still ongoing.[223]

Iridium plans a new standards-based service called NTN Direct, a global, 5G NB-IoT service operating on its existing satellite network.[224]

EchoStar also plans direct-to-device satellites after selling Dish and reducing debt. They think "it is one of the greatest, if not the single greatest, opportunity left in the space right now".[225]

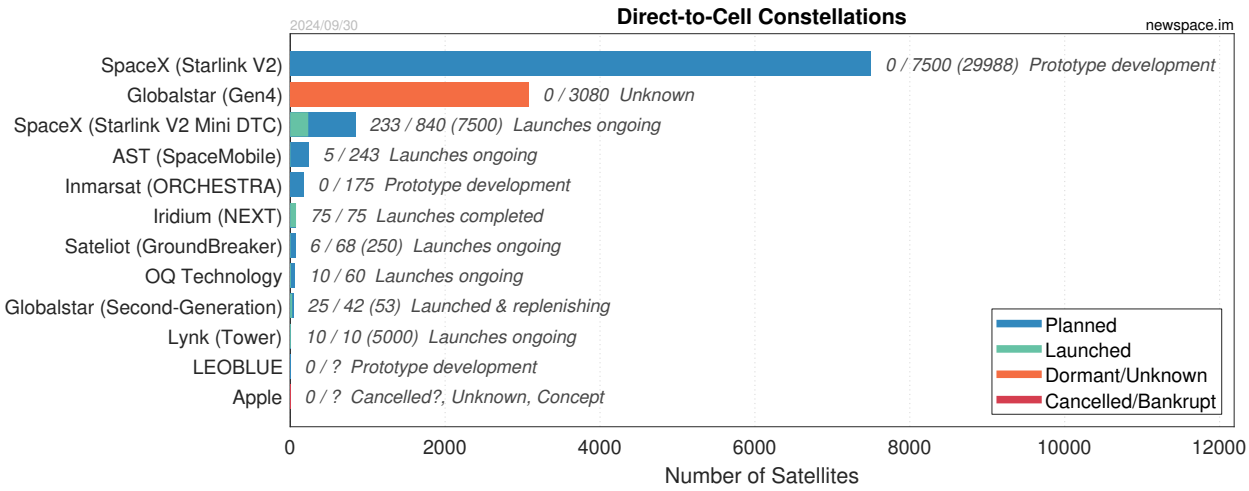

Figure 29: Direct-To-Cell Launched and Planned Spacecraft

6. CONCLUSIONS

A comprehensive statistical overview of 411 commercial satellite constellations has been presented. This is an update to the previous paper by the author from 2021. In addition, the most popular applications were shown in detail and relevant trends were discussed.

Only about 5% are considered launched with 14% being actively launched. However, for most of them the growth has been slow or stagnant. Approximately 21% have launched one or more prototypes. For many, the launch may have happened years ago already and future steps are unclear. 30% are in the prototype development phase.

About 29% have canceled or dormant status and this is likely considerably larger with many of the prototyped and development-phase constellations not expected to move forward.

Broadband Internet constellations continue to the largest planned satellite networks by size and also have the most spacecraft launched, led by Starlink. OneWeb has been deployed also. Constellations from China have launched first batches of satellites.

Next in popularity are Optical Earth Observation, SAR, Infrared EO and IoT/M2M. The historically proven applications of Earth Observation, SAR and communications are favored and doing better thanks to existing value chains and markets. AIS has been a commercial market since early 2000s, now followed by ADS-B and slowly VDES.

Three years ago, latest trends were considered to be RF Spectrum Monitoring with Geolocation, Orbital Data Relays, and Emissions Monitoring. In addition, very recent and without prior governmental or commercial satellites were considered to be QKD (Quantum Key Distribution), SSA (Space Situational Awareness), commercial GNSS / PNT, VDES, In-orbit Inspection and Constellation-As-A-Service among others. These have largely remained unchanged.

RF Spectrum Monitoring is doing well based on HawkEye 360 and Unseenlabs, but Kleos Space also went bankrupt. Dedicated Orbital Data Relays have not yet been deployed at scale, but demonstrations have been performed or scheduled for the next 1-2 years and Starlink should enter this market soon with Plug-and-Plaser. Commercial GNSS and PNT has seen first early demonstration launched or projects awarded. SSA and Non-Earth Imaging have been trending, but market size has yet to be proven.

For future readers, the latest database and figures can be found on the NewSpace Index website (www.newspace.im) and they will be updated 3-4 times per year.

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