AVIATION WEEK
& SPACE TECHNOLOGY

SPECIAL TOPIC

SMALLSATS

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SPECIAL TOPIC

SMALLSATS

Small satellites were long considered the domain of educational projects and novel experiments. But a combination of technological advancements, manufacturing techniques and evolving military and business needs have driven dramatic change within the industry.

Similar to the creation of the smart phone, electronics are small enough now they can fit in a tinier box, and communications capabilities allow for terabytes of data to be easily sent from space to Earth at high rates of speed. Sensors have vastly improved. And as the price of launching satellites into space appears to be dropping, new industries are taking note and eager to tap into new opportunities that space may provide.

As such, the world is poised to launch thousands of satellites weighing 500 lb. or less over the next decade worth tens of billions of dollars – be they Earth observation satellites, ones designed to deliver communication to far corners of the globe or satellites that will enhance scientific knowledge.

Aviation Week & Space Technology has been covering the build-up of the industry, watching over the technological developments underpinning it and explaining the promise that may come from ancillary businesses.

The stories that follow look at some of the new roles for new satellites, where the next generation of space start-ups are headed, the risks and opportunities associated with the build-up in small satellites and how their entry into space is impacting the wider satellite market. The stories also delve more deeply into technologies for Earth observation and broadband communications.

Jen DiMascio
Managing Editor
Defense & Space

Eight Satellite Constellations Promising Internet Service From Space

Thierry Dubois

A number of in-development constellations of satellite telecommunications from low and medium Earth orbit (LEO and MEO) are set to pass milestones in 2018. Launches of clusters of production satellites and prototypes are planned, as is one entry into service. The space industry is eager to see if the promise of dramatic improvement in broadband performance and cost can crystallize into a successful business model.

Iridium Next

THALES ALENIA SPACE

Goal: Enhanced Iridium global mobile communications on land, at sea and in the skies
Number of satellites: 66 (plus 9 spares)
Satellite manufacturer: Thales Alenia Space, in partnership with Orbital ATK
Satellite weight: 860 kg (1,900 lb.)
Year announced: 2009
Planned service-entry year: 2018
Orbit altitude: 780 km (485 mi.)

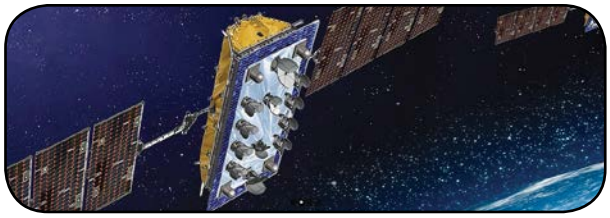
Description: Iridium Next is betting on established reputation for truly global communications and is increasing bandwidth—up to 1.4 Mbps. The company is thus targeting safety services for the cockpit but not passenger-cabin Wi-Fi. The interconnected satellites will operate in L band and Ka band. Each is carrying a secondary payload that provides satellite-based tracking of aircraft (under the Aireon brand) and ships. As of mid-November, 30 Iridium Next satellites were in orbit.

Boeing

Goal: Enhanced availability of broadband access in the U.S. and globally
Number of satellites: 2,956
Satellite manufacturer: Boeing
Satellite weight: N/A
Year announced: 2016
Planned service-entry year: Within six years after license is granted
Orbit altitude: 1,200 km (745 mi.)

Description: Boeing plans to deploy the first part of the system—1,396 satellites operating at an altitude of 1,200 km—within six years once the license is granted, and it aims to subsequently increase the constellation to a total of 2,956. It will use the V band, for which it promises efficient reuse, for fixed satellite service. The application was filed in June 2016.

LeoSat


LEOSAT

Goal: Global, enterprise-grade, high-speed and secure data network
Number of satellites: 78 to 108
Satellite manufacturer: Thales Alenia Space
Satellite weight: 1,250 kg (2,755 lb.)
Year announced: 2015
Planned service-entry year: 2022
Orbit altitude: 1,400 km (895 imi.)

Description: LeoSat aims to orbit a constellation of small, high-throughput Ka-band spacecraft to deliver internet services globally. It plans to have all of its satellites interconnected through laser links, creating "an optical backbone in space about 1.5 times faster than terrestrial fiber backbones" and without the need for any terrestrial touchpoint. The constellation will thus provide "instant infrastructure from anywhere to everywhere," it says. The first launch is scheduled for 2019.

OneWeb


ONEWEB

Goal: Internet service for all, to bridge the digital divide by 2027
Number of satellites: 900 (including 648 operational)
Satellite manufacturer: OneWeb Satellites, a joint venture with Airbus
Satellite weight: 150 kg (330 lb.)
Year announced: 2015
Planned service-entry year: 2019
Orbit altitude: 1,200 km (745 mi.)

Description: OneWeb hopes to use the low cost of its mass-produced satellites to offer internet links totaling 10 terabits per second to mobile operators and internet service providers. Ground terminals with embedded LTE, 3G, 2G and Wi-Fi will include simple rooftop terminals that can be installed on schools and other public buildings in the developing world. OneWeb plans to use both Ka and Ku bands.

SpaceX Starlink

Goal: Wide range of broadband and communications services for residential, commercial, institutional and governmental users worldwide
Number of satellites: 4,425 (plus in-orbit spares)
Satellite manufacturer: SpaceX
Satellite weight: N/A
Year announced: 2015
Planned service-entry year: 2024
Orbit altitude: 1,110-1,325 km (685-823 mi.)

Description: SpaceX intends to use Ku and Ka bands and an optical intersatellite link. As of May, SpaceX planned to launch a prototype by the end of 2017 and another early in 2018. An operational launch campaign to start the 4,425-satellite constellation would follow in 2019. SpaceX is pressing Congress for policies that would allow for spectrum sharing and incentives for companies that use "spectrally efficient" technologies.

Samsung

Goal: Monthly 200-GB capacity for 5 billion users worldwide
Number of satellites: 4,600
Satellite manufacturer: N/A
Satellite weight: N/A
Year announced: 2015
Planned service-entry year: 2028
Orbit altitude: 1,500 km (930 mi.)

Description: In a paper released in 2015, Farooq Khan, then president of Samsung Research America, outlined a vision "to make affordable internet services available to everyone in the world via low-cost micro-satellites." Those satellites would be interconnected and operate in the V band.

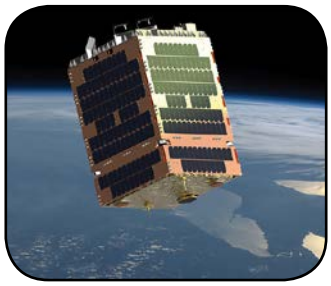
SES O3B

Goal: Fiber-optic-cable-like internet service
Number of satellites: 27
Satellite manufacturer: Thales Alenia Space (O3b), Boeing (O3b mPower)
Satellite weight: 700 kg (1,543 lb.) (O3b), N/A (O3b mPower)
Year announced: 2008 (O3b) and 2017 (O3b mPower)
Planned service-entry year: 2021 (O3b mPower); O3b has been in service since 2014
Orbit altitude: 8,000 km (4,970 mi.)


THALES ALENIA SPACE

Description: Founded to bridge the digital divide globally, O3b has evolved to a more business-to-business approach. A large cruise ship can now be followed and provided with 1 Gbps connectivity in Ka band. SES took over 100% of the company in 2016 and is now planning on synergies between its geosynchronous-Earth-oribit and MEO satellites, meaning the latter may partly replace the former. The constellation will have 20 current-standard satellites, after the launches scheduled for 2018-19. In addition, seven next-generation O3b mPower satellites will each feature 4,000 steerable beams for much greater capability at lower cost. Covered area spans 45 deg. S. Lat. and 45 deg. N. Lat.

Telesat LEO


TELESAT LEO

Goal: Universal and cost-effective fiber-optic-cable-like connectivity for business, government and individual users
Number of satellites: At least 117
Satellite manufacturer: Airbus' SSTL and Space Systems Loral (first two prototypes)
Satellite weight: N/A
Year announced: 2016
Planned service-entry year: 2021
Orbit altitude: 1,000 km (620 mi.) (polar orbits) and 1,248 km (inclined orbits)

Description: Telesat's LEO satellites will operate in Ka band and use optical intersatellite links. Targeted are "busy airports; military operations on land, sea and air; major shipping ports; large, remote communities; and other areas of concentrated demand," according to the company. Telesat says it will offer a cost per megabit per second equal to or lower than the lowest on the market or being developed. Two prototype satellites are scheduled for launch in 2018.

Tsunami Of Smallsats Creating Opportunities And Problems

Irene Klotz

On Feb. 22, U.S. Space Command logged two more satellites into the growing catalog of objects orbiting Earth. Items 43216 and 43217 hitched a ride aboard a SpaceX Falcon 9 rocket that blasted off from Vandenberg AFB, California, with the Paz radar-imaging spacecraft, owned by Hisdesat, the Spanish government satellite services company. The secondaries were then dispatched into orbits 311-321 mi. (500-517 km) above Earth and inclined 97.5 deg. north and south of the equator. SpaceX is using the birds, which they call Tintin A and B, to test technologies for a mega-constellation of small satellites that would provide high-speed internet and other communications services directly to consumers.

In a November 2016 application still pending before the Federal Communications Commission (FCC), SpaceX seeks authorization to operate a constellation of 4,425 broadband satellites in low Earth orbit, using Ka- and Ku-bandwidths, beginning in 2019. The company followed up with a second application last year for an additional 7,500-member network that would use spectrum in the V-band for a constellation to serve U.S. markets from very low Earth orbit.

They are not the not the only ones. In June, OneWeb, headquartered in Britain's Channel Islands, won the first FCC approval to operate a nongeostationary satellite orbit (NGSO) network in the U.S. The company, formerly known as WorldVu, is on schedule to launch the first 10 of an initial 720-member Ku-band constellation this year. The spacecraft were designed and built by Airbus Defense and Space in Toulouse, but future satellite production will shift to a OneWeb manufacturing facility adjacent to the Kennedy Space Center in Florida that will be operated in partnership with Airbus. The factory is due to open this spring.

6,200 smallsats on tap for launch by 2026

Growing population raises concerns of impacts, clouds of debris

OneWeb has an option to add another 1,980 satellites to its initial constellation and has filed a second application with the FCC for a second 2,560-member network using V-band frequencies from middle Earth orbit.

Also last year, the FCC approved applications from Canada-based Telesat to access U.S. markets with a 117-member NGSO network and from Space Norway to operate the experimental two-satellite Arctic Satellite Broadband Mission. The FCC is considering more than a dozen other applications to operate broadband satellite constellations from SpaceX, Boeing, ViaSat, LeoSat, O3b Networks, Theia Holdings and other companies.

The tsunami of satellites is not expected to peak anytime soon. More than 6,200 smallsats are expected to be launched in 2017-26, with a total market value of more than $30 billion, compared to $9 billion in the previous decade, according to a 2017 global market study by Euroconsult that focused on satellites weighing up to 1,100 lb. (including fuel).

About one-third of the 2,500 satellites launched in the past 20 years fall into this weight class, researcher Timo Wekerle, with the Brazilian Department

SpaceX prototype broadband satellites Tintin A and B were deployed from the upper stage of a Falcon 9 rocket on Feb. 22 for a trial run in orbit.

SPACEX

of Aerospace Science and Technology, and colleagues write in the September edition of Journal of Aerospace Technology and Management.

"The amount of smallsats launched in the last five years is nearly equivalent to the accumulated amount of the 15 years before," the researchers wrote. "What has begun as a research and development project has evolved and found commercial applications in areas like communications and remote sensing. It is not clear how far this miniaturization process will lead, but in many cases smallsats can already accomplish what only big satellites could do in the past."

A case in point is Planet, an Earth-observation and data analytics company based in San Francisco, which in 2017 became the operator of the world's largest constellation of satellites, with more than 180 Dove cubesats, five RapidEye smallsats and 13 SkySats smallsats, the latter acquired as part of the company's purchase of Google's Terra Bella.

Cubesats are satellites built in increments of 10-cm (3.9-in.) cubes, with one cube known as 1U, two unit cubes as 2U, etc. Planet's Doves are 3U cubesats. Another San Francisco company, Spire, operates a 60-member constellation of 3U-cubesats known as Lemur to provide high-frequency weather data, ship and airplane tracking and other data services.

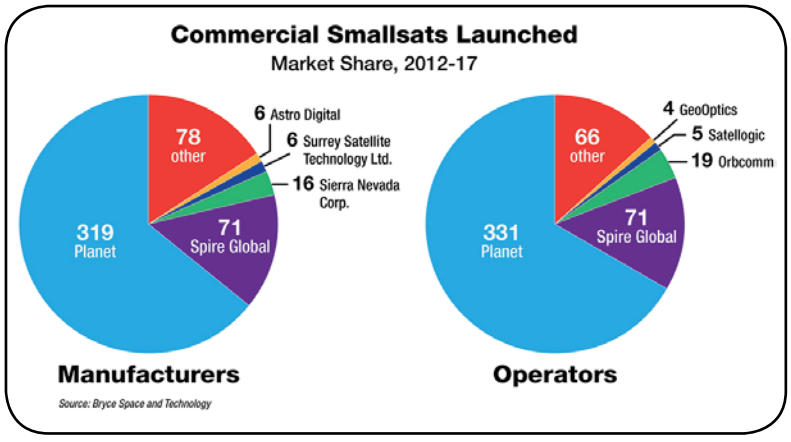
EUROPEAN SPACE AGENCY

Artist impression of satellites circling in low Earth orbit, which extends to about 1,200 mi. above the planet's surface.

Cubesats, which can be built with commercial, off-the-shelf components, began as educational projects, but quickly found their way into the marketplace. More than 2,600 satellites weighing up to 62 lb. will be heading into orbit over the next five years, SpaceWorks, an Atlanta-based consultancy, notes in its 2018 Nano/Microsatellite Market Forecast.

"Cubesats have been shown to share many characteristics of disruptive innovations, such as rapid improvement of capabilities and finding niche uses in research, commercial, and homeland and national security communities," the National Academy of Sciences' Space Studies Board wrote in a 2016 report.

The disruption applies not just to markets, but potentially to the space environment itself. "The biggest issue is that when satellites collide, it is not like cars colliding. You don't call a tow truck and say 'There's a little traffic jam' and then in 30 min. it's gone. You live with it forever," says OneWeb founder and CEO Greg Wyler.



BRYCE SPACE AND TECHNOLOGY

"Imagine if every car accident could not be moved or if every car accident has a ghost car that keeps slamming into everything else around it and you couldn't get rid of it. That is the fundamental problem. We will ruin space," he says.

Wyler supports a stronger regulatory environment to oversee the industry, including some minimum requirement of technical capability before a company is authorized to operate in space. "If you are going to build an aircraft you have a huge amount of regulatory oversight on the safety of that aircraft. Even if you were going to build an experimental aircraft you still have to go through safety and verification, and you can't fly in certain places and a certain way. If you build a

car, there's a bunch of certification. But you build a satellite and there is no certification. There is no oversight. None. So you could put up a bunch of satellites that may fail and crash into each other and destroy an orbit. There is no way to fix that."

The risk of a cubesat conjunction or collision is not insignificant, the Space Studies Board wrote in its report. "The cubesat community has an opportunity to avoid potential future problems by continuing to proactively engage in policy discussions and seek technological solutions, such as low-cost means for cubesats to be maneuverable, trackable and deorbited appropriately," the report said.

The National Space Council, which is headed by Vice President Mike Pence, is proposing to create a new office under the auspices of the Commerce Department to oversee and manage U.S. commercial space activities beyond licensing for space launches and atmospheric reentries, which is handled by the FAA.

"If regulators moved with reasonable expedience they would keep up and predict technology," says Wyler. "That's the challenge."

Satellite Industry Scrambles For New Footing

Irene Klotz, Jen DiMascio

It would be easy to overlook a pair of small satellites that rolled off an assembly line at Airbus' Toulouse manufacturing facility in March. For starters, they are pint-sized cousins of the flock of more than 200 satellites built by Airbus since 1961. Plus, they will never fly in space.

The birds are test articles for a joint venture with OneWeb, which plans to operate an initial constellation of 720 spacecraft in low Earth orbit (LEO) to provide worldwide high-speed internet and data services. The first 10 satellites are due to launch this year. The Airbus assembly line, as well as a second manufacturing facility in Florida that is set to open this spring, will be building satellites not just for OneWeb. Airbus already has sold the platform, which it calls Arrow, to the European Space Agency for an in-orbit technology testbed slated to fly in 2020.

Airbus, which logged nearly $82 billion (€67 billion) in revenues last year, is not the only giant company taking an interest in small satellites. Lockheed Martin is now offering nanosat platforms and services via a partnership with Tyvak Nano-Satellite Systems. "We are looking for cool new space companies in order to incorporate them into some of our mission areas," says Kay Sears, Lockheed vice president of strategy and business development. "We are not going to go create a nanosat platform—that is not what Lockheed does well. So we found a company called Tyvak, which is part of the Terran Orbital group, and we invested in them. They have a great small nanosat bus, and we have a bunch of payloads, so they are the bus provider and we are the payload provider."

Melding with 5G, terrestrial systems are on the horizon

Companies experiment with new business structures and partnerships

RICK MASTRACCHIO/NASA

Small satellites, such as these deployed from the International Space Station, are the fastest-growing segment of the global satellite industry.

Small satellites, generally defined as weighing less than 1,300 lb., comprise a tiny but fast-growing share of a global space economy worth about $350 billion in 2017, according to a recent report by Washington-based consultancy Bryce Space and Technology.

Morgan Stanley forecasts that global space industry revenues will reach $1.1 trillion or more by 2040. There was much arm-waving about that report at the Satellite 2018 conference in Washington March 12-15, but Bryce CEO Carissa Christensen notes that the industry already has been steadily growing at about 7% a year, which, if the trend continues, would put it within the Morgan Stanley ballpark. "It is basically saying if the industry continues along its present pace, and if we see in the future what we have seen in the past, we'll get there," Christensen says.

Two $100 billion markets currently dominate the industry—direct-to-home television and GPS navigation services—but what the future holds is anyone's guess. Traditionally, manufacturers have measured market share by tallying how many geostationary orbit (GEO) communication satellites were sold in a calendar year, but that yardstick may already be anachronistic. "It is probably an old metric," says Chris Johnson, vice president of Boeing Commercial

Satellite Services. "Looking at traditional GEO awards is not the right metric to judge the healthiness of the industry. We all probably wish there were a few more GEOs."

Last year, satellite manufacturers competed in open markets for a near-record-low seven GEO contracts. Maxar Technologies CEO Howard Lance says its satellite manufacturing company SSL is seeing its fastest growth in LEO satellites for commercial and government markets. "We are also seeing double-digit growth in imagery, commercial customers, international [customers] and double-digit growth in the Radiant services business," he says. "We see a big pipeline now in Canada. They have come out with their new budgets around defense and space, and we are very encouraged by that as well."

In addition to rolling out new satellite platforms and operational orbits, companies are experimenting with new business structures and partnerships. Maxar, for example, wants to keep its four companies—MDA, SSL, DigitalGlobe and Radiant Solutions — separate and distinct.

VIASAT

The Boeing-built ViaSat-2, the world's highest-capacity commercial communications satellite, entered service in March with connectivity pricing competitive with terrestrial services.

In February, Lockheed published previously closely held technical data about payload interfaces for its LM 2100, LM 400 and LM 50 satellite platforms. "We didn't come to that decision lightly," says Lockheed's Sears. "It was [something] like, 'Oh, no. We are releasing the crown jewels.' But we wanted to stimulate the creative juices that we know are happening all around the space community, so that was our way of saying, 'We will work with you.'"

Luxembourg-based SES, an early investor in O3b, an internet-via-satellite constellation, purchased the entire company in 2016, placed a seven-satellite order with Boeing to update the O3b network and now faces competition in medium Earth orbit (MEO) from, among others, Viasat, which provides broadband internet service only from GEO.

"We are not concerned about the dip in GEO orders," says Sears. "There is still a lot of power in GEO, and we believe that orbit will continue to thrive for certain types of applications. But overall, we are convinced it is going to be a mix of orbits that will solve most of our customers' needs, a blend of the agility and resiliency of LEO with the power and persistence of satellites in GEO."

Nicolas Chamussy, head of Airbus Space Systems, adds: "The main reason for the drop is because [operators are] still scratching their heads, thinking, 'Where am I going? Am I going to GEO? Am I going to LEO? Am I going to MEO? A combination of everything? Or am I simply not in the business anymore because of terrestrial operators?' This is the main driver."

To that end, manufacturers are trying to build as much flexibility as possible into their manufacturing processes and individual satellites. Lockheed and other satellite-makers are preparing for a future with fully digital, software-defined payloads that will be as customizable as a cell phone.

Johnson points out that Boeing has already produced generations of digital payloads, but the price needs to catch up with the technology. "As the affordability of digital payloads takes hold . . . you will start seeing that as the standard," he says. "Then you won't have to pay the premium you would have had to in the past."

DOMINIQUE ESKENAZ/ONEWEB

Airbus borrowed technologies and processes from its commercial aircraft division to pioneer a new way to manufacture the OneWeb—and future—satellites

One thing that is certain is more change. Hosted at the Satellite 2018 show this year were representatives from Ford, General Motors, Toyota, Tesla and Audi, as well as Amazon Web Services, a harbinger of potential future satellite applications driven by connected vehicles and data management.

"The mainstream trend in telecoms is wireless, and the good news is the satellite is wireless. We are a great wireless technology. We bring things to the table that are complementary to other wireless technologies: . . . ubiquity, reach, security, quality of service, point-to-multipoint services very efficiently, as well as broadcasting," says Intelsat CEO Stephen Spengler. "On top of that, with the massive investment and innovation that we have seen in our industry in recent years, we have made tremendous strides in terms of performance and economics of our services. You look at all that, and it says we are ready to participate in the broader market."

The harmonic convergence? Industry players think it will be fifth-generation wireless systems, with their promise of faster connectivity and no lag time. "We still have a lot of work to do in the standards area to make sure that we plug and play seamlessly in that future network," says Spengler. "We have to work on our terminals and our antennas and devices to make them smaller, more cost-effective and easier to deploy, but we are heading in the right direction."

Smallsat Space Companies Embracing Big Data Tech

Irene Klotz

When the U.S. Defense Innovation Unit Experimental (DIUx), a Silicon Valley-based agency that funds game-changing commercial technologies to solve military problems, was looking for its first investment in space, it bypassed satellites, launchers and ground terminals in favor of artificial intelligence (AI) and machine learning.

It's easy to see why. Last year, 345 commercially procured satellites were launched into orbit, a threefold increase over 2016. Of those, 212 were cubesats, mostly for Earth observation and meteorology.

At least 22 companies are operating or plan remote-sensing satellite networks

Venture capital is investing $2-3 billion annually in space startups

The satellite boom is just beginning. By the end of 2017, there were 1,738 operational satellites in orbit, compared to 1,167 in 2012, a 49% increase, the Satellite Industry Association (SIA) said in its 2018 State of the Satellite Industry report. Analysts estimate the number could climb to 27,000 operational satellites over the next 10 years.

"We have more access to and information about our planet and the activity upon it than at any time in history," says Robert Cardillo, director of the National Geospatial-Intelligence Agency. "We've moved from the world of pictures to pixels to today's big data environment."

To process the data and glean insights, the military is looking for technologies beyond its research labs and traditional contractor base. "The expenditure rates on data analytics outside the fence line far exceed spending inside [the Defense Department], so I've told my folks to get the hell off the base and go work outside of the line," says Col. Russell Teehan, director of the Air Force Research Laboratory Space Vehicles Directorate and commander of Phillips Research Site at Kirtland AFB, New Mexico.

"I've also told them to stop creating data repositories within fence lines. There's way more data out in the open. It's more abundant, more innovative and peer-reviewed," he says.

PLANET

Images Planet took of Peru's La Pampa gold mine in January 2016 (left) and January 2017 revealed illegal expansion of the mine into the Tambopata National Reserve surrounding it.

Much of that spending has come from venture capital, which has invested $18.4 billion in more than 180 startup space ventures since 2000, Bryce Space and Technology, a Virginia-based analytic consulting company, wrote in its 2018 Start-Up Space Report. The last three years have been particularly active, with $2-3 billion invested in 19 companies on average per year, it notes.

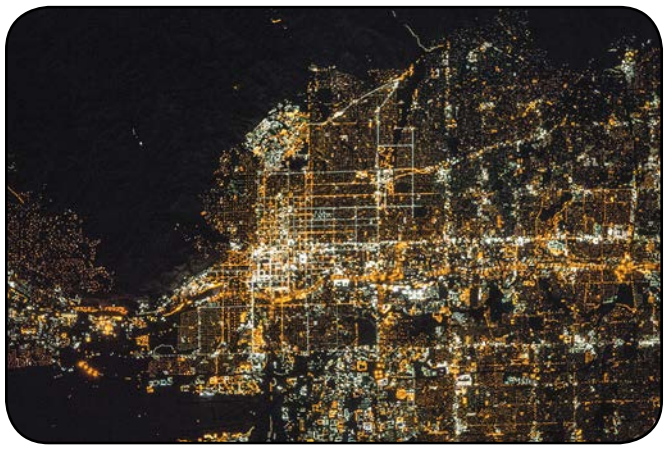
In separate reports in 2017, research arms of Goldman Sachs, Morgan Stanley and Bank of America Merrill Lynch all concluded that the global space industry, now worth about $350 billion annually, will reach at least $1 trillion in the 2040s. Bank of America was most optimistic, forecasting 25% growth in the industry, which could be valued at $2.7 trillion in the 2040s.

To put that in context, consider a 2013 study done for Google by the European consultancy Oxera that looked at the global economic value of geospatial services—everything from interactive digital mapping and location-based services to satellite imagery, satellite positioning signals and navigation devices. Its analysis determined that the geospatial services industry was generating global revenues of $150–270 billion per year. It also noted that the industry was growing rapidly, at a rate of 30% per year globally.

Sunil Nagaraj, managing partner at Ubiquity Ventures, a seed-stage venture capital company in Palo Alto, California, does not see the $1 trillion space industry happening by just doubling or tripling the number of satellites. "I think the direction is going to come from downstream applications," he says.

He points to Cape Analytics, a one-time space company based in Mountain View, California, that now sells AI-enabled property intelligence to insurance companies and other industries. "Ten years ago, if a space person went to a farmer and said, 'Hey look, I have satellites in low Earth orbit,' the farmer would say, 'I don't care about that.' Today, because space companies can outsource their satellite buses, sensor payloads and ground stations, they can actually go to the farmer and speak the farmer's language.

"Space CEOs can now spend more of their brains on customer needs and understanding the nuances of each vertical. It's a big shift," Nagaraj continues.



NASA

The color of the light in this nighttime image of Salt Lake City, taken from the International Space Station, is indicative of land use—gold for major roadways, bright white for commercial areas. Residential and suburban regions are relatively dim.

DIUx's portfolio includes AI-developer SparkCognition, Orbital Insight, which develops tools to analyze satellite imagery, and Capella Space, which operates microsatellites equipped with synthetic aperture radar that can see through clouds or at night. "Early on we learned that you don't just need a lot of data, you need the right types of data and the right temporal resolution or revisit rates," says DIUx Space Lead Steve Butow.

"If you want to look at a glacier in Alaska, you could image it every week or two and you'd be able to model its behavior quite well. But if you want to count cars in parking lots or count shipping containers, you need to be able to look at these things more frequently," he says. "The best way to really understand what's going on with the world is to image it several times a day."

The bellwether company doing just that is San Francisco-based Planet, but it is far from the only one. The SIA report lists 22 companies operating or planning constellations of satellites outfitted with optical, radar and other sensors to monitor Earth, with more on the way. "On a fundamental level, individuals and machines are getting more connected. We're having more sensors on us, and we are relying more on that sensory data," says OneWeb founder and CEO Greg Wyler.

OneWeb is nearing completion of the first 10 of more than 900 satellites designed to provide global, high-speed broadband. The company recently announced it is foregoing satellite-to-satellite communications links in favor of ground stations, to alleviate concerns about data integrity.

"If satellites end up providing in-country broadband like any other [internet service provider (ISP)], nations are concerned about whether the data that flows through it can be manipulated and whether the data is actually managed in a country like any other ISP. Or should satellite [service providers] get some kind of pass that the terrestrial operators don't have?" Wyler says. "Suppose data from your computer goes up to a satellite and runs through a ground station in North Korea and then goes out by fiber somewhere else. How comfortable do you think the U.S. would be

if 5 million of its citizens' data [passed] through North Korea?" he asks.

By using ground stations, OneWeb will mirror what a country's terrestrial-based internet companies already are doing. "We are identical to a local ISP. The countries will know where all of the traffic is going," Wyler says.

"With the data explosion, it's a societal concern, as we are making decisions based on the input of our sensors," he adds. "Fake news is not a sensor, but it's an example of inputs that our machines generated that can affect and modify societal behavior. These are challenging issues for society as we become more and more technically run by the machines."

Orbital Mapping Service Responds To LEO Constellation Growth

Graham Warwick

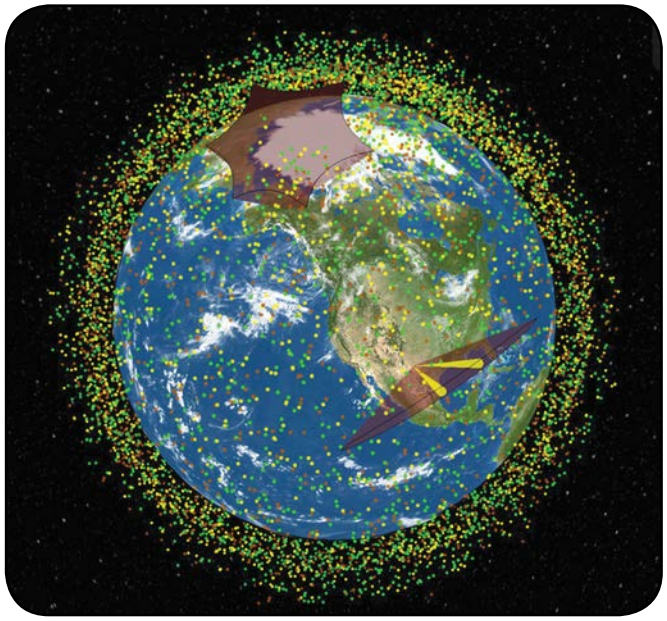
Commercial space situational awareness provider LeoLabs is to expand its ground-radar network to track smaller objects in low Earth orbit (LEO) after raising an additional $13 million in funding.

The Series A financing round was led by WERU Investment and Airbus Ventures, along with Space Angels and Horizons Ventures. Airbus, which is building more than 900 satellites for OneWeb's LEO constellation, invested in LeoLabs' $4 million initial investment round in February 2017.

With the projected growth in the number of commercial satellite mega-constellations in LEO expected to greatly increase the risk of collisions, LeoLabs was spun out of research organization SRI International in 2017 to provide low-Earth-orbit mapping services to operators, space agencies and regulators.

Four more radars to be added to Alaska and Texas sites

System will track LEO objects down to 2 cm in size



LEOLABS

Radars in Alaska and Texas are enabling LeoLabs to track almost 13,000 LEO objects down to 10 cm in size.

The new funding round will allow the Menlo Park, California-based startup to expand its software platform and network of radars, enabling it to track orbiting objects down to 2 cm (0.8 in.) in size. "So much of the collision risk—95%—is in untracked small debris," says CEO Dan Ceperley.

Approximately 250,000 pieces of orbital debris remain untracked in LEO and threaten satellite constellations, says LeoLabs. The company's two existing radars, near Fairbanks, Alaska, and in Midland, Texas, can track objects down to 10 cm, or 1U cubesat size.

LeoLabs will build four more radars, including its first outside the U.S. "That is a big step to a global radar network," Ceperley says. The new sites will be improved versions of the UHF-band Midland Space Radar, a one-dimensional phased array commissioned in February 2017.

"As we add more radars, the service level will go up," he says. "Four more radars will get us to small debris and allow us to check on new satellites with updates every couple of hours so that we can minimize the creation of new debris."

With the build-out of the planned network of six radars—which includes access to the Poker Flat Incoherent Scatter Radar built by SRI for the National Science Foundation and located near Fairbanks—"we will track 10 times more objects," he says.

With new operators often launching their smallsats at the same time as many others on larger rockets, LeoLabs' increased coverage and resolution will "let you know which one is yours and make sure you do not have collisions" as the spacecraft are deployed, Ceperley says.

LeoLabs also will use the new funding to grow the company and expand its software platform to provide more analytical applications for commercial customers. "This is a new business model, a subscription service providing access to information and analytics," he says.

"In the past, we delivered a radar to the government and they developed the software. Now operators can focus on flying their satellites and get the data as a service," says Ceperley.

"We are serving a number of satellite operators, in and outside the U.S.," he notes. "The development of LEO is really international. There are large constellation operators in Europe and Japan, all operating in the same space, with the same fundamental requirements."

LEOLABS

A phased-array radar in Midland, Texas, tracks orbital objects using electronically steerable beams.

With designation of the U.S. Commerce Department as the lead agency for commercial space and space traffic management, Ceperley expects the industry to grow rapidly. He also points to more countries creating civil space agencies, such as Australia and the UK.

"They are all asking themselves what platform they want to use to see what is going on in space. LeoLabs is well-positioned to be the foundational information source for LEO," he says. "We are building out a Google Maps platform for low Earth orbit. We are pulling together a huge amount of observation data and putting it into the cloud with our own analytics."

LeoLabs also intends to combine its service with data from other sources, such as business and weather information, to help operators know where best to position their satellites to provide services such as imaging or communications. "We can connect them together through our [application programming interfaces]," he says.

The scale of the data being acquired is also enabling LeoLabs to bring machine learning to bear to help with space operations. "The problem has been the lack of data. Machine learning needs a lot of data, and ours is the first commercial dataset of sufficient scale to do that," he says.

As the space industry comes to grips with the problem of mitigating space debris, Ceperley believes LeoLabs' dataset will prove critical. In addition to detecting and tracking debris, the system could be used to identify which is the most important and verify that it has been removed.

While a good statistical analysis of space debris is available annually, it is not real-time, and the growth in commercial operations will require rapid response to threats. Using LeoLabs' data, he says, "the ability to react in real-time will give rise to new satellite operations and fleet management procedures."

Startups Selling Services, Tech Far Beyond Satellites And Rockets

Irene Klotz

In 2011, Christopher Richins, vice president of business development for what was to become the asteroid-mining company Planetary Resources, had a problem. The company, then known as Arkyd Astronautics, needed to find a way for a prototype telescope in low Earth orbit (LEO) to communicate vast amounts of data back to Earth.

"We could not find a reasonable offering," says Richins. "There were no technically suitable systems available that were competitively priced, from a commercial business model."

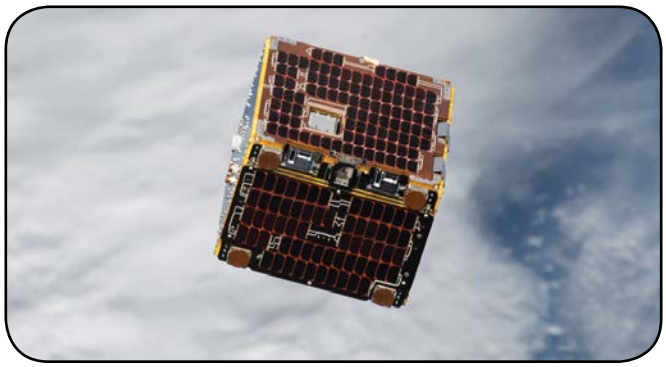
This was the genesis of the idea for RBC Signals, a Seattle-based company Richins founded in 2015 that brings the shared services business model to space-to-ground communications. The company leases excess capacity from antenna owners and operators worldwide, bundles it together and creates tailored, low-cost and easy-to-use communications services for the smallsat community and other customers.

Space startups attracting $2-3 billion per year in venture capital

RBC Signals and LeoLabs eye growing smallsat community

In July, RBC signed a partnership agreement with India's Antrix Corp. Ltd., the commercial arm of the Indian Space Research Organization, adding 11 ground stations to a network that now numbers 62. The deal, which was RBC's first with a national space agency, also expands the company's reach beyond LEO. "Because of the quality of the infrastructure, we can support lunar- and deep-space capabilities," Richins says.

RBC is part of a small but growing cadre of companies jockeying to serve the expected tsunami of smallsats, the fastest growing segment of a global satellite industry worth $269 billion in 2017, according to the Satellite Industry Association. While spacecraft manufacturers and launch companies garner most of the attention and investment dollars, ventures such as RBC and LeoLabs, which sells satellite-tracking and mapping services, are diversifying the ecosystem of the New Space economy.



NANORACKS

RemoveDebris technology demonstrator is being deployed from the International Space Station.

"I think that investing in the space sector and the growth of the space economy now is a massive opportunity to make a lot of money," said Joe Landon, chairman of the venture capital firm Space Angels, at the NewSpace conference in Seattle in June.

In the last three years, startup space ventures have attracted $2-3 billion per year, excluding debt financing, according to Bryce Space and Technology's 2018 Startup Space report.

In 2017, 73 startup space companies reported receiving new funding, one-third more than in 2016, with the average deal worth $36.3 million, the report found. Those investments were made by 87 venture capital firms.

With several megadeals pending, "2018 has the potential to outpace 2017 investment," the report notes. "The next few years have the potential to transform the startup space ecosystem. . . . We are now in a proving period, as many services and products that attracted investment are deploying or planning deployment shortly, and investors are seeking indications they will realize returns," the report states.

Richins' RBC Signals, which so far has raised just over $2.5 million in seed funds, plans a Series A round later this year. "I feel like the services we are providing are really incubating the industry as a whole," he says. "You can't make a dime in space without being able to transmit data back to Earth."

LEO is particularly challenging for communications because the satellites are moving so fast that ground stations must have tracking antennas to point at the spacecraft as they fly overhead. "That can be difficult equipment to build, maintain and operate, and the licensing and regulatory challenges are significant," says Richins. "We are able to manage all of those complexities for our customers and give them a very simple, subscription-based service. They don't ever really even see the complexity of what's going on behind," he notes.

RBC's network of 62 ground stations—which include everything from small, simple dishes to giant, 32-m (105-ft.) antennas—handles a wide range of frequencies, including VHF, UHF and S-, C-, X-, Ku and Ka bands. The company plans to add its first optical ground station later this year to support a customer wanting to test a satellite with an optical laser communication system. It also is looking at leasing excess capacity on satellites, such as the Iridium constellation, to provide space-to-space communications.

"We are technology-agnostic," says Richins. "We just make it easy to move data between space and the ground, whether that means using our radio frequency ground stations or an optical ground station or satellite links. It's just about being really efficient at moving data and making it really flexible and simple."

LEOLABS

LeoLabs' phased array radar in Midland, Texas, is one of two used to provide commercial LEO tracking services.

In the future, RBC could use its network to tap into the growing market for satellite tracking and space situational awareness—the focus of another startup, LeoLabs, which in July closed a $13 million Series A round of financing.

Combined with a $4 million initial investment, LeoLabs, a spinoff of Stanford University's nonprofit research arm SRI International, plans to expand its network of ground radars to track objects in LEO as small as 2 cm (0.8 in.). The company's current two radars, located in Poker Flat, Alaska, and Midland, Texas, can track orbiting objects as small as 10 cm, the size of a 1U cubesat.

With the addition of four new ground radars, including its first outside the U.S., LeoLabs expects its roster of trackable objects to skyrocket to 750,000 by 2020 from 13,000 today, says co-founder and Chief Technology Officer Michael Nicolls. The data will feed an expanding line of services available from LeoLabs, including collision avoidance, orbit determination, space situational awareness and other analytics for commercial LEO constellation operators, government regulators and the risk-management industry.

Not all new space startups are focused on LEO. Seattle-based Off Planet Research hopes to parlay NASA, international and commercial interest in the Moon into a viable business developing regolith simulants that closely match the mechanical properties of the lunar soil. "If you increase the moisture content, you can test really well for cohesive properties, and if you lower the moisture content, you can test for dust mitigation and that sort of thing," says co-founder Vince Roux.

"The survival rate of equipment that goes to the Moon is notoriously low," he adds. "Most spacecraft only survive a matter of days on the surface. We need equipment that's going to survive months or years."

Like RBC Signals, the impetus for Off Planet Research started with an insolvable problem. Roux and co-founder Melissa Roth wanted to compete in the Google Lunar X Prize, a now-mothballed competition to land and operate privately funded spacecraft on the Moon.

"Investors didn't want to put in money unless we could demonstrate that the technology would work when it got there," Roux says. "We had to find a way to test this technology so we could get investors and compete."

RBC SIGNALS

This ground station is part of RBC Signals' 62-member network for commercial space-to-ground communications.

What Roux and Roth found, however, was a lack of lunar soil simulants, and what was available was of questionable quality since it had been around for a long time. "We realized we had to make our own simulants and testing labs to just get to the point where we could get investors," Roux says. After that, it was clear that developing and selling regolith simulant to the lunar exploration community was "where we needed to go."

As a mother of invention, nothing has been more inspiring than the proliferation of cubesats, a standard 10-cm, cube-shaped, off-the-shelf satellite kit, several of which can be cobbled together to form larger satellites. Oxford Space Systems, for example, has discovered how to pack a 4-m deployable boom system into less than a 1U (one-unit) cubesat. Airbus contracted with Oxford to manufacture the boom for a technology demonstration satellite that will test techniques for removing debris from orbit. The spacecraft, known as RemoveDebris, was deployed from the International Space Station in June for a series of tests.

Founded in 2013, Oxford Space, based in the UK, also is developing deployable antennas and power arrays. "We have developed some proprietary materials and we quite often use origami engineering techniques," says Oxford founder and CEO Mike Lawton.

That kind of innovation has caught the eye of investors. After winning prize funds, seed funds and early venture capital worth about $2.5 million, Oxford expects to close a Series A round of financing worth up to $10.5 million in September.

"Antennas don't sound exciting, but when you think about antennas that are two-thirds cheaper, three times more powerful and twice as small, suddenly it becomes very interesting," says Bogdan Gogulan, CEO and managing partner of NewSpace Capital, a Luxembourg-based private equity firm. " It enables completely different business models and opens new markets.

"What we're really doing is growing an economy in space, not an industry," adds Space Angels' Landon. "There are going to be lots of industries that do business in space. . . . We are looking for companies that are contributing to the growth and development of the economy in space."

Satellite Makers Buy Low, Maybe Sell High

Michael Bruno Washington

Legacy satellite makers are beginning to reshape their portfolios to reflect a dramatic market shift away from large-bus satellites flying in geosynchronous orbits to small satellites that will populate low Earth orbit.

Boeing announced Aug. 16 it is buying small-satellite specialist Millennium Space Systems and will organize the company under the leader of its Phantom Works unit. Days earlier, Lockheed Martin revealed it had doubled down on its investment in smallsat startup Terran Orbital.

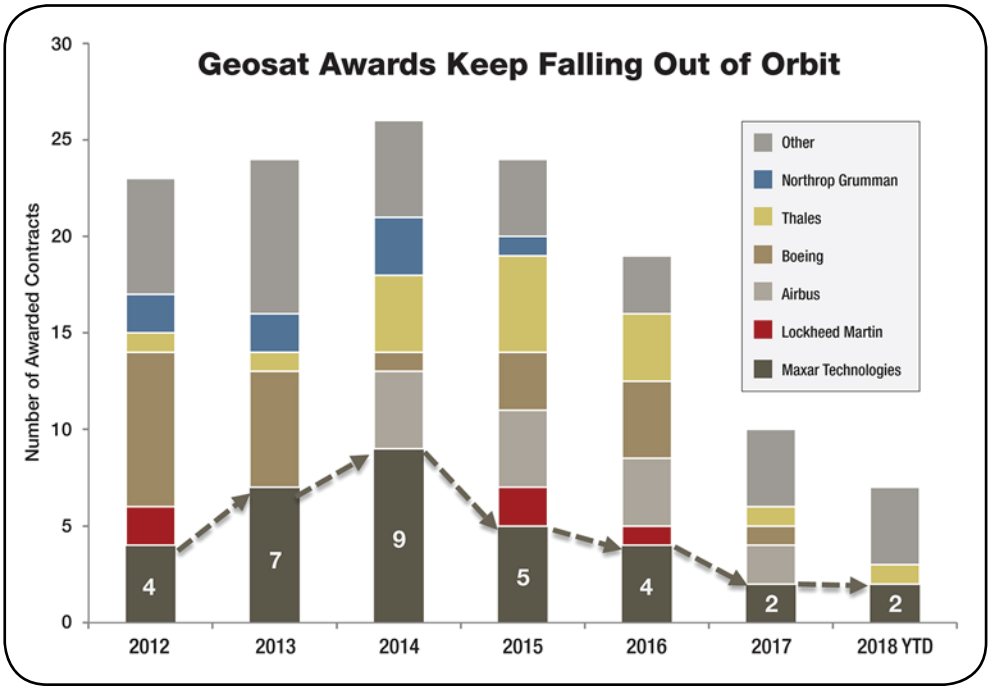
By comparison, Maxar Technologies announced in late July that it was weighing strategic options for its geosat manufacturing business, as the market for high-flying birds appears likely to remain mired in a multiyear slump.

Boeing, Lockheed buy Into LEO, while Maxar looks to hive off Geo

7,000 smallsats worth $38 billion Forecast To Be launched over next decade

"Larger-scale satellites continue to fall out of favor relative to more flexible, less complex smallsat constellations," according to Credit Suisse analyst Rob Spingarn. "From a national security perspective, smallsats are more resilient, presenting smaller, dispersed targets for highly sophisticated opponents. From a commercial standpoint, smaller low-Earth orbit (LEO) satellites have greater refresh rates, lower latency and are less expensive than their exquisite geostationary cousins."

Maxar is feeling that difference now. "The company continues to review strategic alternatives for its geostationary communications satellite business to improve its financial performance," representatives said July 31, while announcing their latest quarterly results. Those results included a net loss of $18.6 million for the latest three-month period, compared with a $19.3 million gain a year before.



SPACE.SKYROCKET.DE; NATIONAL BANK OF CANADA FINANCIAL MARKETS

"No final decision has been made," Maxar said about the geosat business. "At the same time, the company continues to see strong growth in its U.S. government and low-Earth-orbit communications and Earth-observation businesses and remains encouraged regarding the potential in these markets."

Still, Maxar's strategic review comes as satellite operators in the communications industry continue to defer new large satellite construction awards while they evaluate geostationary

and other competing satellite system architectures as well as market factors such as a wave of expected LEO smallsats. Maxar has been pivoting toward space services and away from traditional big-bird manufacturing. Formerly known as MDA, it acquired DigitalGlobe last October and proceeded to rebrand itself and relocate to the U.S. But the geosat slump has affected earnings and forced workforce cuts and cost-cutting.

To that effect, Maxar—which in August became a public target of short-selling activist investor Spruce Point Capital Management—continues to exit leased buildings and consolidate its footprint on its Palo Alto, California, campus. Concurrently, it is forming a separate organization to target U.S. government and commercial smallsat-based services growth opportunities, for which it is hiring and promoting new executives. Also, a new facility is being built in nearby San Jose.

Maxar CEO and President Howard Lance is focused on redirecting the company to capitalize on space services, whether to provide big data analytics or in-orbit satellite servicing, as well as efforts to ride the LEO trend. To that end, Maxar and Thales Alenia Space, a joint venture of Thales and Leonardo, on July 30 announced a pact to pursue development and manufacture of Telesat's advanced global LEO satellite constellation and end-to-end system. Also, the consortium, led by Thales Alenia Space, has been awarded a nine-month contract by Telesat for a system-design and risk-management project for the constellation.

As for GEOsats, the outlook remains grim. "As we've discussed at length in the past, industry orders fell significantly in 2015 and have remained at those low levels ever since," Lance says. "At this point, we do not expect a significant recovery for this market, with industry orders likely to be at the low end of the 8-12-awards range this year. From our perspective, industry growth clearly is moving in the direction of LEO and NEO consolidations, with demand for GEO primarily driven by their replacement needs for the existing satellites."

Lance believes there is "a healthy pipeline" of smallsat and government business opportunities, and that other companies see enough growth to merit spending, too.

Boeing's acquisition of 17-year-old privately held, employee-owned Millennium represents a rare addition to its Boeing Defense, Space & Security (BDS) division, which otherwise has been streamlining its assets to the new Boeing Global Services in recent years.

Millennium focuses on satellites ranging from 50-6,000 kg (110-13,228 lb.) or more, for military and intelligence customers. It has grown its fleet, operations and manufacturing capability in El Segundo, California, in recent years. On May 17, its mostly automated cubesat-class Althair Pathfinder demonstrator surpassed a full year of LEO operations. The first operational Althair is scheduled to launch this fall for an unidentified government customer, the company said July 24.

"Millennium Space Systems' expertise in vertically integrated small-satellite solutions perfectly complements Boeing's existing satellite portfolio, and will allow us to meet the needs of a diverse customer set," says BDS Chief executive Leanne Caret.

Likewise, the head of Lockheed Martin Ventures, Chris Moran, has touted Terran as an ideal investment for the Pentagon's leading contractor by sales. Terran's smallsat focus complements Lockheed's large-bus heritage, he says.

Terran has raised $36 million from investors, starting with two tranches from Lockheed, and will use proceeds of its recent Series B round to expand its manufacturing footprint and workforce, the company said Aug. 6. Moran's group first invested last summer.

"With the added capacity of our new facility, Terran Orbital is well-positioned [for the huge] demand from our government, military and commercial customers to gain access to our nano- and microsatellite technology," says Terran CEO and co-founder Tony Previte. "Our ability to cost-effectively design, build and launch our small satellites within 6-12 months puts us in an enviable, competitively advantaged position."

According to a new Euroconsult report, a "significant" expansion is underway in the smallsat market, both in terms of demand and systems' capabilities. About 7,000 smallsats worth around $38 billion are due to be launched over the

next decade, a sixfold increase from the 1,200 units launched over the past decade. About 50 constellations, two of which are "mega constellations," account for more than 80% of the total smallsat count.

Maxime Puteaux, a senior consultant at Euroconsult and editor of the report, says this means an average of 580 smallsats will be launched every year by 2022 and then jump to 850 each year through 2027. This compares with an annual average of 190 satellites launched over the past five years.

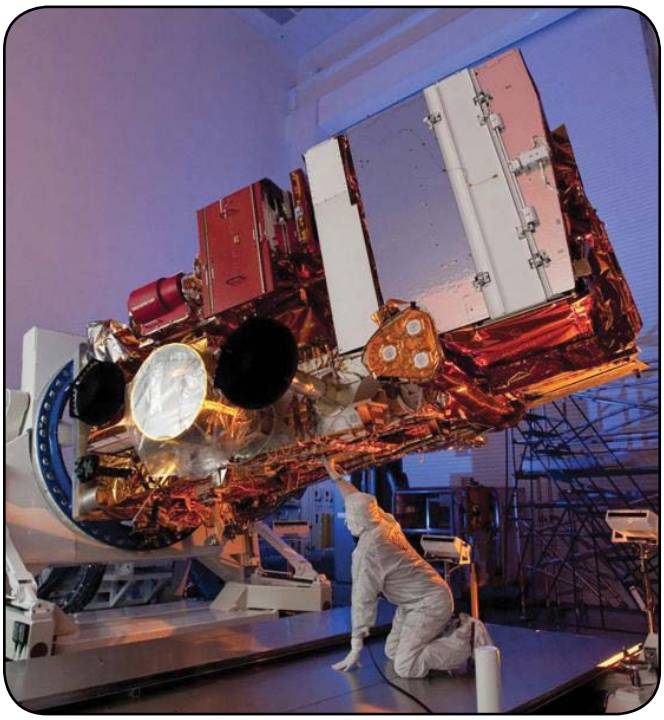
Not surprisingly, venture capital funding also is flowing "liberally" to space startups, with more than $7.9 billion invested since 2015, notes Spingarn. Lower barriers to entry are attracting new players, such as Planet Labs, Spire and Satellogic.

Says Spingarn, "As the tide turns toward LEO, incumbents including Northrop Grumman, Boeing, Lockheed and Maxar need to contend with greater competition in an increasingly commoditized market."

The Big Shrink: Small Satellites Take On Big Missions

Irene Klotz

From 2012-17, more than 1,000 small satellites were launched into orbit, including about 725 cubesats, which are standardized platforms consisting of 4 X 4 X 4-in. (10 X 10 X 10-cm) units (U) that can be scaled up to create 3U, 6U, 12U and larger cubesats. Currently, the spacecraft primarily are used for Earth observations, but that business is expected to be eclipsed in the next few years as broadband operators roll out megaconstellations to provide high-speed internet services via satellites. Already, the Federal Communications Commission has approved the deployment of 5,264 small satellites from four companies—OneWeb, Space Norway, Telesat and SpaceX—to provide broadband communications services from Earth orbit. Proposals from eight other companies are pending. And that is just the beginning. Here is a sampling of some of the other major satellite missions being taken on by smallsats.



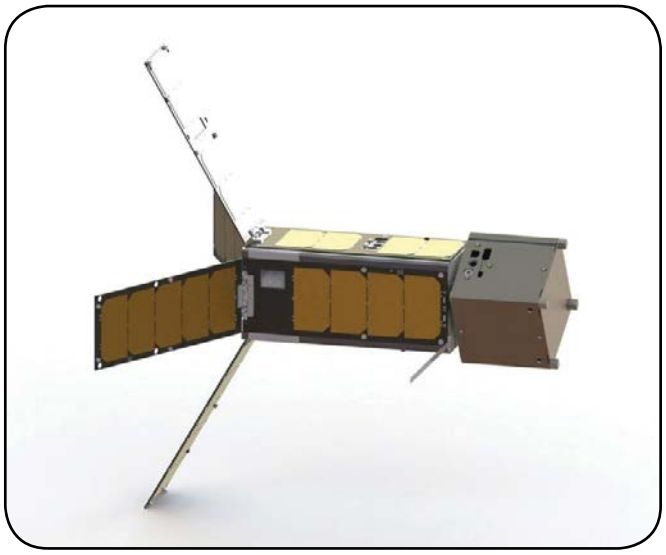
NASA

Bigsat: Suomi National Polar-orbiting Partnership.

Technology: Microwave sounding

Application: Weather forecasting

Among the measurements that feed meteorologists' weather models, satellite data reigns king. Geostationary satellites stare down and take images at very high revisit rates, but they can't obtain vertical profile data. That task falls to low-Earth-orbiting satellites, but these pass over a particular region only about once every 12 hr. To bridge the gap, a team of researchers headed by William Blackwell at MIT's Lincoln Laboratory has been testing the Microsize Microwave Atmospheric Satellite (MicroMas), a dual-spinning, 3U cubesat equipped with a passive microwave spectrometer to collect temperature and humidity profiles regardless of cloud cover. "The hard part is miniaturizing the electronics, but we can do that, even in a 3U cubesat," says Blackwell.



NASA

Smallsat: MicroMas tech demos, Tropics cubesat constellation.

MicroMas-2a, which operated from January-April 2018, will be followed by another MicroMas technology demonstration mission, 2b, scheduled to launch this year. In 2020, a six-member MicroMas constellation called the Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats, or Tropics, is expected to become NASA's first operational science mission implemented with cubesats.

Each Tropics cubesat will host a high-performance radiometer to provide temperature profiles using seven channels near the 118.75-GHz oxygen absorption line, water vapor profiles using three channels near the 183-GHz water vapor absorption line, imagery in a single channel near 90 GHz for precipitation measurements (when combined with higher-resolution water vapor channels), and a single channel at 206 GHz that is more sensitive to precipitation-size ice particles. With six satellites flying in three, low-Earth-orbital planes, Tropics data should be collected about every 30-40 min. so that researchers can track features of tropical cyclones as they are evolving.

Blackwell and colleagues are also developing a scanning 22-channel, high-resolution microwave spectrometer housed aboard a 12U cubesat to augment data from polar-orbiting weather satellites.

Technology: Precision photometry

Application: Extrasolar planet detection using transit method

Like NASA's Tess and Kepler space telescopes, Asteria measures the brightness of stars so researchers can look for dips in the amount of light caused by any orbiting planets passing by, or transiting, the face of the star, relative to the telescope's line of sight. Unlike Tess and Kepler, however, the 6U cubesat Asteria weighs just 22 lb. With its two solar panels unfurled, the satellite is about as long as a skateboard.

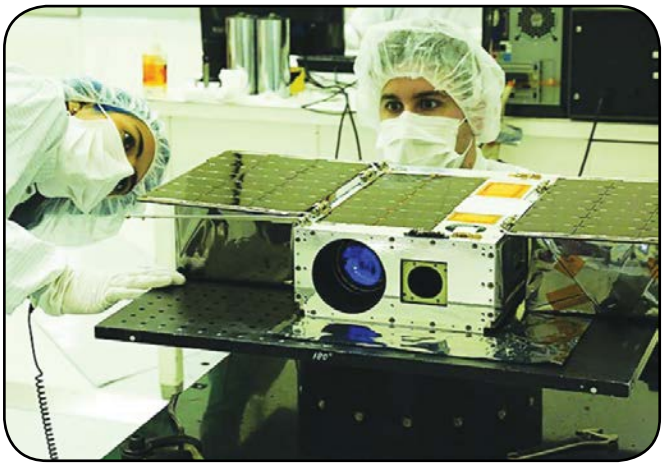
Asteria was deployed from the International Space Station in November for a demonstration run, and to assess nanosatellite technology for astrophysical observations. By the end of its 90-day primary mission, it had achieved a pointing stability of 0.5 arcseconds root mean square, which refers to the degree to which the payload wobbles away from its intended target over a 20-min. observation period. "Holding steady on a faraway star is difficult because there are many things that subtly push and pull on the satellite, such as Earth's atmosphere and magnetic field," NASA wrote in a mission status report in April.

The pointing stability was repeated over multiple orbits, with the stars positioned on the same pixels on each orbit, akin to hitting a quarter with a laser pointer from about a mile away, notes Christopher Pong, Asteria attitude and pointing control engineer at NASA's Jet Propulsion Laboratory. "The laser beam has to stay inside the edge of the quarter, and then the satellite has to be able to hit that exact same quarter—or star—over multiple orbits around the Earth, so what we've accomplished is both stability and repeatability," he adds.

Asteria also demonstrated a control system to reduce noise in the data caused by temperature fluctuations in the satellite. During observations, the temperature of the

NASA

Bigsat: Kepler Space Telescope, Transiting Exoplanet Survey Satellite (Tess).



NASA

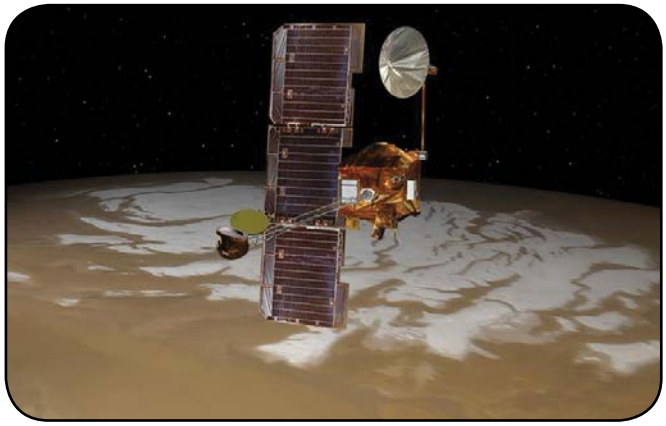
SmallSat: Arcsecond Space Telescope Enabling Research in Astrophysics (Asteria).

controlled section of the detector fluctuated by less than 0.02F (0.01K/0.01C). The spacecraft is now in an extended mission, looking at bright nearby stars for transiting exoplanets. It may serve as a pathfinder for a fleet of low-cost space telescopes.

Technology: Miniature transponder compatible with NASA's Deep Space Network communications system

Application: Relay entry, descent and landing data from NASA InSight spacecraft

When an Atlas V rocket lifted off in May to send NASA's InSight spacecraft on its way to Mars, a pair of 6U cubesats hitched a ride. About 90 min. after launch, the pair, collectively known as Mars Cube One, or Marco, separated from the rocket's Centaur upper stage to begin independent journeys to Mars. The hope is that the cubesats will fly by Mars at the right position and time to listen to InSight's signals during its Nov. 26 entry, descent and landing (EDL) and relay the data back to Earth. Though not required for InSight's mission success, Marco operations should allow for near-real time telemetry downlink and health monitoring of the EDL process.



NASA

BigSat: Mars Odyssey.

Each 31-lb. Marco satellite contains a Vacco cold gas propulsion system with R-236FA propellant for trajectory correction maneuvers and to desaturate the reaction wheels; a Jet Propulsion Laboratory-developed Iris X-band transponder with UHF reception capability; AstroDev command and data-handling and electrical power system; MMA Design deployable solar panels; Blue Canyon Technologies XACT attitude control system; Jet Propulsion Laboratory antennas, including a high-gain reflective array; and two Gumstix boards and cameras.

"At its heart, Marco is a technology demonstration. It's the first time a lot of this technology has flown in a deep space environment," says Jet Propulsion Laboratory systems engineer Anne Marinan.

"As a technology demonstration mission, the Marco spacecraft are proving the capability of a low-cost mission to survive and thrive in the deep-space environment, and training scientists and engineers in the sometimes difficult world of operations," Marinan and colleagues write in a paper presented at the 32nd Annual Small Satellite Conference in Logan, Utah, in August.

If successful, Marco will demonstrate a new "carry-your-own-relay" concept for critical operations.

NASA

SmallSat: Mars Cube One (Marco).

Technology: Software-defined radio, custom radio frequency front end, band-specific antennas

Applications: Signals intelligence, including spectrum mapping, communication interference detection, emergency response, transportation activity tracking, other geolocation, tracking and identification services.

ULA

BigSat: Classified spacecraft, launching on the nation's biggest rockets, including United Launch Alliance's Delta IV Heavy.

Herndon, Virginia-based HawkEye 360 has a long list of potential applications for its innovative cubesat constellation, which is designed to map and analyze wireless signals. A prototype system consisting of three cubesats is due to launch in November to demonstrate how the network can monitor and track aircraft, ships, ground transportation, and provide data for emergency responders and other services by combining geolocation algorithms to pinpoint terrestrial and aerial radio frequency (RF) emitters.

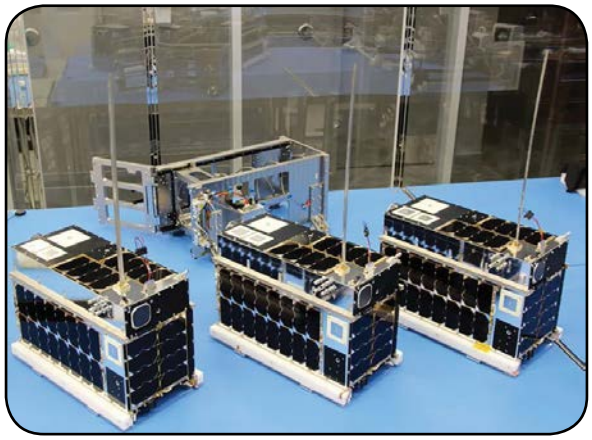
"The mission is filling a void by bringing a level of visualization to a domain that has historically only been understood by governments. For example, the ability to locate and characterize RF signals across many bands from space will allow regulators, telecommunications companies and broadcasters to monitor spectrum usage and to identify areas of interference," Dan CaJacob, director of space systems at HawkEye, and colleagues write in a paper presented at the Smallsat conference.

The three prototypes will be placed into a sun-synchronous orbit at a 357-mi. altitude and will fly in formation, within line-of-sight of multiple terrestrial emitters. Signals will arrive at the three receivers at separate times, corresponding to different slant ranges between the satellite and the RF emitter. Signals also will arrive at different apparent center frequencies due to Doppler effects.

By comparing the time-of-arrival and frequency-of-arrival measurements between pairs of receivers, the system will be able to pinpoint the position of the transmitter. The final piece of the puzzle—the position and velocity of the receivers—is provided by GPS receivers.

Following the Pathfinder demonstration, HawkEye plans to launch a constellation with 18 satellites, arranged in six clusters of three, though the final constellation size and geometry will depend on market factors and the results of the pathfinder mission.

Contractors for the prototypes include Deep Space Industries, which among other systems is providing a novel water-fueled, electro-thermal propulsion system that will fly on each spacecraft. Space Flight Laboratory designed and manufactured the spacecraft platforms.

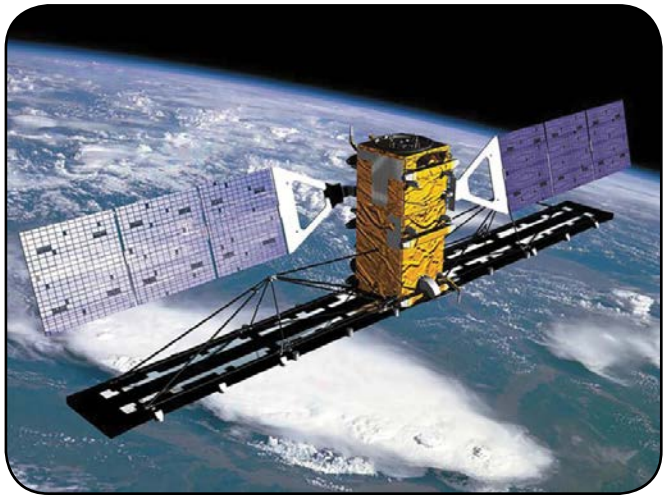


HAWKEYE 360

SmallSat: HawkEye 360.

Technology: Synthetic aperture radar

Applications: Imagery through clouds and in darkness



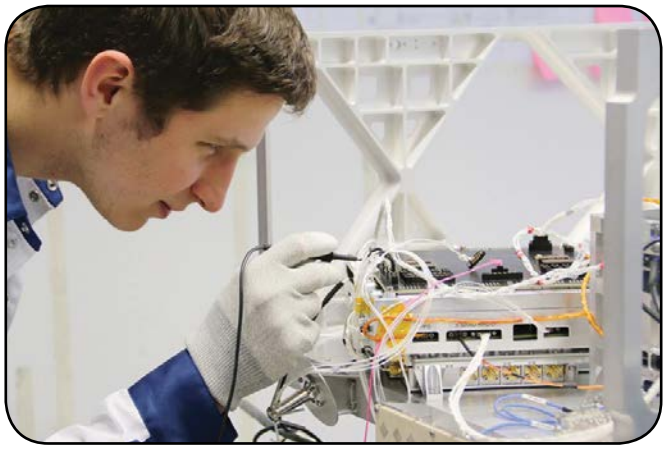
MAXAR TECHNOLOGIES

BigSat: RadarSat-2.

Planet's fleet of Dove satellites have revolutionized the Earth-imaging business, providing daily pictures of nearly every part of the planet. But the satellites' optical telescopes cannot penetrate cloud cover, or image during nighttime passes. Enter synthetic aperture radar, or SAR, which takes advantage of the long-range propagation characteristics of radar signals and the complex information-processing capability of modern digital electronics to provide high-resolution imagery. SAR data is used in a wide variety of fields, such as mineral exploration, environmental monitoring and military reconnaissance and targeting.

Taking advantage of smaller, lower-cost electronics, Finland-based Iceye launched the first commercial SAR cubesat in January and aims to have an 18-member constellation in orbit by the end of 2020 that will be capable of providing imagery of any place on Earth every 3 hr. "We started with ice-monitoring in the beginning . . . and now we're aiming at developing a more comprehensive service, which we refer to as global change detection, based on an information stream provided by our satellite constellation," says founder and CEO Rafal Modrzewski.

They are not alone. San Francisco-based Capella Space plans to launch its first SAR satellite, based on a 12U cubesat, this year. Eventually, the Capella constellation will consist of 30 satellites that can relay hourly global SAR images with 1-m (3-ft.) resolution. Combined, the companies have raised more than $75 million in venture capital and development funding. A European Space Agency study, presented at the Federated and Fractionated Satellite Systems Workshop in Toulouse in November 2017, found nine other SAR satellite constellations in development. "With the SAR market benefiting from the growing demand for Earth-observation data . . . the SAR market is expected to grow at a rate of 10.3% per year until 2024," the report concludes.



ICEYE

SmallSat: Capella, Iceye.

Technology: Quantum entanglement

Applications: Unbreakable encryption keys

Last year, Chinese physicists published a landmark paper in the journal Science detailing how they had sent intertwined quantum particles from the Micius satellite in low Earth orbit to two ground stations located 750 mi. apart, setting a new distance record for what Albert Einstein once lampooned as "spooky action at a distance."

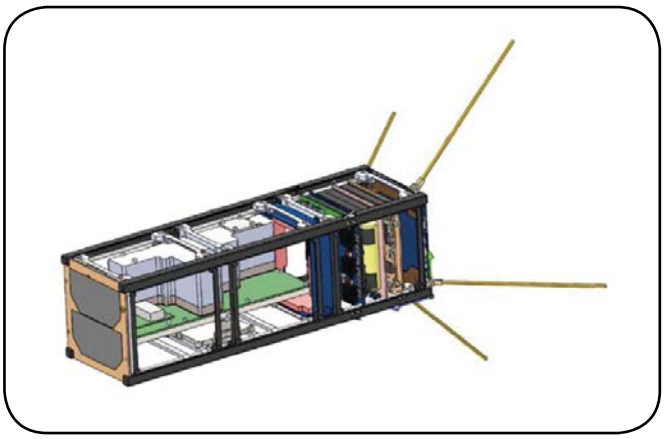
Aside from demonstrating China's growing skill in quantum physics, the technology has potential practical applications, including hackproof communications networks. "Long strings of entangled photons, shared between distant locations, can be 'quantum keys' that secure communications," the Science paper said. "Anyone trying to eavesdrop on a quantum-encrypted message would disrupt the shared key, alerting everyone to a compromised channel," it stated.

Distributing quantum keys via satellite bypasses attenuation and other issues with ground-based optical fiber systems.

Distributing quantum keys via satellite bypasses attenuation and other issues with ground-based optical fiber systems. For the Micius experiment, a laser beam was directed onto a light-altering crystal aboard the satellite, resulting in pairs of entangled photons that would have opposite polarization states when one was measured. The pairs were split and relayed to receiving stations in Delingha and Lijiang, located in the mountains of Tibet. Scientists then simultaneously measured more than 1,000 photon pairs and found they had opposite polarizations more often than sheer chance would warrant, confirming the spooky action over a record distance.

XINHUA

BigSat: China National Space Agency's Micius 630 kg.



NATIONAL UNIVERSITY OF SINGAPORE

SmallSat: SpookQy-1, Qube.

Experiments with Micius continue, but already quantum key distribution technology via cubesat is in development. The National University of Singapore conducted a quantum light source demonstration in 2016 on Galassia, a 2U cubesat. Next up: SpooQy-1 a 3U cubesat that will attempt to validate a next-generation entangled photon light source and demonstrate a radio beacon of quantum random numbers. The university also is working on miniaturizing entangled photon light sources and combining them with a high-precision pointing, acquisition and tracking system and optical communication links to enable a global quantum key distribution network with small satellites. The research already has resulted a commercial spinoff, S15 Space Systems.

Another quantum cubesat project is in development at the Center for Telematics in Wurzburg, Germany.