A survey of nanosatellites by The Economist below. A big GEO satellite can weigh > 5,000 kg. The goal with GOOG's WorldVu is 100 kg about the same as Skybox.

Many things like Oculus Rift VR headsets benefit from the peace dividend which is low cost electronics manufactured at scale for handsets.

http://www.economist.com/news/technology-quarterly/21603240-small-satellites-taking-advantage-smartphones-and-other-consumer-technologies

Small satellites: Taking advantage of smartphones and other consumer technologies, tiny satellites are changing the space business

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ALTHOUGH widely used, satellites are expensive to build and to launch. That began to change last year. On November 19th Orbital Sciences, an American company, launched a rocket from the Wallops Flight Facility in Virginia. It carried 29 satellites aloft and released them into low-Earth orbit, a record for a single mission. Thirty hours later, Kosmotras, a Russian joint-venture, carried 32 satellites into a similar orbit. Then, in January 2014, Orbital Sciences carried 33 satellites up to the International Space Station (ISS), where they were cast off a month later.

Many of these 94 satellites were built in a standard format known as a CubeSat, a 10cm (4 inch) cube weighing 1.3kg (2.9lb) or less. Some comprised units of two or three cubes. After a decade of fits and starts, during which some 75 CubeSats were launched, satellites of this scale and other small satellites are moving from being experimental kit to delivering useful scientific data and commercial services.

In the next five years or so some 1,000 nanosats, as small satellites of 1-10kg are called, are expected to be launched. Some will be smaller than a CubeSat; others bigger and heavier. Some are like a *matryoshka* doll: the Russian launch included a satellite that launched eight smaller ones, including four PocketQubes (a 5cm cube format). One of these smaller satellites, developed in Peru, released its own tiny bird.

There will be upsets along the way. In April, as part of a mission by SpaceX, an American company, to resupply the ISS, a small mothership was placed in orbit carrying 104 "sprites" (pictured below). Not much larger than a postage stamp, these contain all the basic elements of a satellite, such as a radio, aerials, a solar cell and instruments. Developed as part of a crowd-funded project called KickSat at Cornell University, each sprite cost just $25 in parts. Their launch was free, courtesy of NASA, the American space agency. The sprites were designed to remain in orbit for a few weeks collecting data before burning up on re-entry. Unfortunately, due to a fault with a timer, the mothership failed to release them before it burned up on re-entry. A second mission is now being planned.

Despite that setback, the way ahead for satellite technology is clear. "You can now, with a single chip, create most of the capabilities that you would have found in ***Sputnik***, but, of course, orders of magnitude faster," says Mason Peck, a former chief technologist at NASA and now a professor at Cornell University.

The most ambitious project to date is a flock of 28 nanosats, each one three CubeSats in size (ie, 30cm long). These were carried to the ISS in January and released in batches (pictured at the beginning of this article) through a sort of satellite shooter developed by NanoRacks, an American company. These nanosats came from Planet Labs, a firm based in San Francisco. The satellites now take pictures as they scan the Earth more frequently than traditional ones and at a fraction of the cost, albeit at a lower resolution.

Planet Labs, funded modestly with $65m of private investment, says its nanosats provide much of the performance of a conventional satellite for a fraction of the cost. That reflects a lot of antiquated technology in the space business, much of which can be bettered by the latest off-the-shelf equipment, says Will Marshall, Planet Labs' boss. There are other cost-saving measures. Satellites are usually built in elaborate clean rooms, but Planet Labs assembles its nanosats in "clean-enough" rooms in its downtown offices. The company expects to put another 100 nanosats into orbit in the next 12 to 18 months.

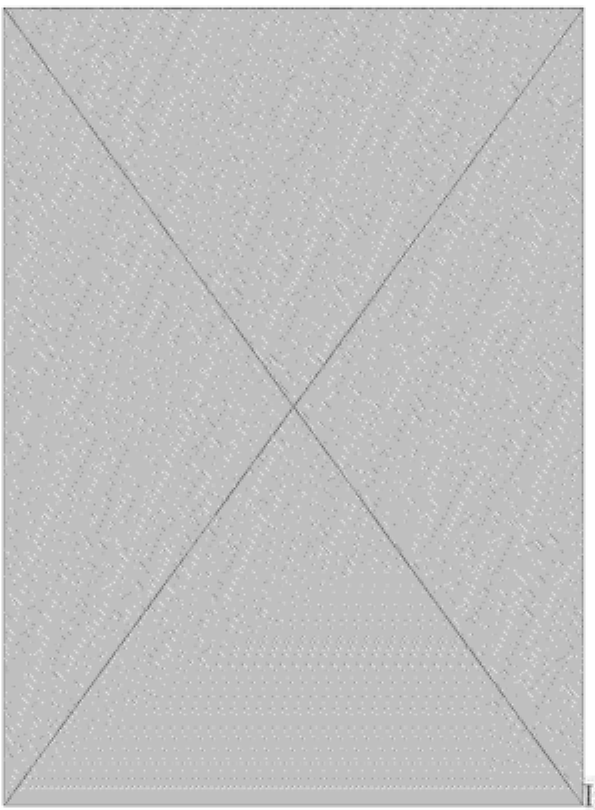
A few miles away, in another modest San Francisco office, Nanosatisfi is working on its ArduSats. These are open-source platforms and two have already gone up. They will contain an array of sensors and can carry out various missions, such as locating things. More than 250,000 ships, for instance, now broadcast an automatic identification signal than carries about 50 nautical miles. A fleet of small satellites in low orbit could pick up these signals and provide frequent updates about the ships' positions without the vessels having to use costly dedicated satellite uplinks. Such a system might have been able to track Malaysian Airlines flight MH370, which went missing in March.

Farther south in Mountain View, Skybox captures high-resolution imaging data from its first satellite in orbit as it prepares another 23 to launch in the coming years. Some things, though, can be shrunk only so far and larger satellites are needed for a telescope to obtain the higher resolutions required for the firm's analysis. While Skybox's minisatellites weigh around 100kg, a fairly common size for small satellites, the firm proved its concept to investors using CubeSats. "Being able to put something in space at very low cost allows you to demonstrate the technology to get more money," says Dan Berkenstock, one of the company's founders.

The CubeSat specification came out of the academic world in the late 1990s. Bob Twiggs, then at Stanford University and now at Morehead State University, was frustrated by long delays on a large-satellite programme and set about thinking how much satellite capability might be crammed into a much smaller craft that could be launched cheaply. Space launches usually comprise one or more primary payloads and require ballast to balance the rocket. CubeSats, reasoned Mr Twiggs, could take the place of some of this ballast, so long as they did not jeopardise the main mission. The optimum size Mr Twiggs came up with was based on a box used to display Beanie Babies. Later, with Jordi Puig-Suari of California Polytechnic State University, it was turned into a full specification. Mr Twiggs also developed the 5cm PocketQube, which has a maximum weight of 180 grammes.

Small satellites benefit from the constant improvements in price and performance being achieved by the consumer-electronics industry, particularly in smartphones. A typical phone is now likely to contain an accelerometer to measure how fast it is moving, a magnetometer to detect magnetic fields and provide a compass reading, a GPS receiver to pick up satellite data, multiple radios, a gyroscope to measure its position, a barometer to detect pressure, two cameras and much more.

Last year the world's first "phonesat" went into orbit. It was a Google Nexus One smartphone incorporated into a three-unit CubeSat called STRaND-1. This was built by Surrey Satellite Technology, a British firm that specialises in small satellites and which is part of the European Airbus group. The idea was to test the components of the smartphone in a space environment. The phone was loaded with a number of experimental apps for such things as taking photographs and recording magnetic fields during orbit.


Is my smartphone in there?

Smartphones and other consumer electronics provide a wealth of ready-made technologies that can enable a CubeSat to perform many of the functions of a satellite a hundred times heavier and much larger, but at substantially less cost. Including the launch, a nanosat of CubeSat dimensions might cost $150,000-1m, rather than $200m-1 billion for a full-sized one.

Low cost and a tolerance of less-stringent standards allow multiple nanosats to be built faster. This allows for a higher risk of failure. Nanosats have a relatively short life, which might be no more than a year or two in low-Earth orbit before re-entering the atmosphere and burning up. Planet Labs, for one, expects to replace some of its nanosats with new versions every year.

Into space in a flash

In an industry in which preparing some missions has taken decades, the speed at which nanosats can be developed and put into orbit makes the biggest in the space business take notice. NASA has also found ways to leverage the consumer-electronics industry, says Bruce Yost of the space agency's Ames Research Centre in California. His group (some former members of which founded Planet Labs) has launched five phonesats and is now planning a small fleet of them to experiment with communications between satellites.

Nanosat parts are readily available to researchers. One supplier, Pumpkin, operates from a residential San Francisco neighbourhood. Andrew Kalman, its founder, started in 2000 selling standard components that Mr Twiggs and his colleagues at Stanford needed. Pumpkin now sells items ranging from brackets for a few hundred dollars up to complete systems for hundreds of thousands of dollars. The company has also supplied America's National Reconnaissance Office with 12 three-unit CubeSats to help the agency demonstrate the technology.

Although many satellites already circle the globe taking pictures, some of the images may not be updated for days, months or even years. Commercial services can provide relatively rapid satellite images on demand, a number of them taking pictures down to a resolution of 50cm (ie, 50cm x 50cm per pixel, the legal limit in America for commercial satellites, although military ones can peer closer). But such satellites may cover only part of the globe each day. Once their fleets are complete, Planet Labs will offer images with resolutions of between 500cm to 300cm and Skybox, with its bigger minisatellites, 90cm. The companies will provide pictures that can be updated in hours for a variety of scientific and commercial applications.

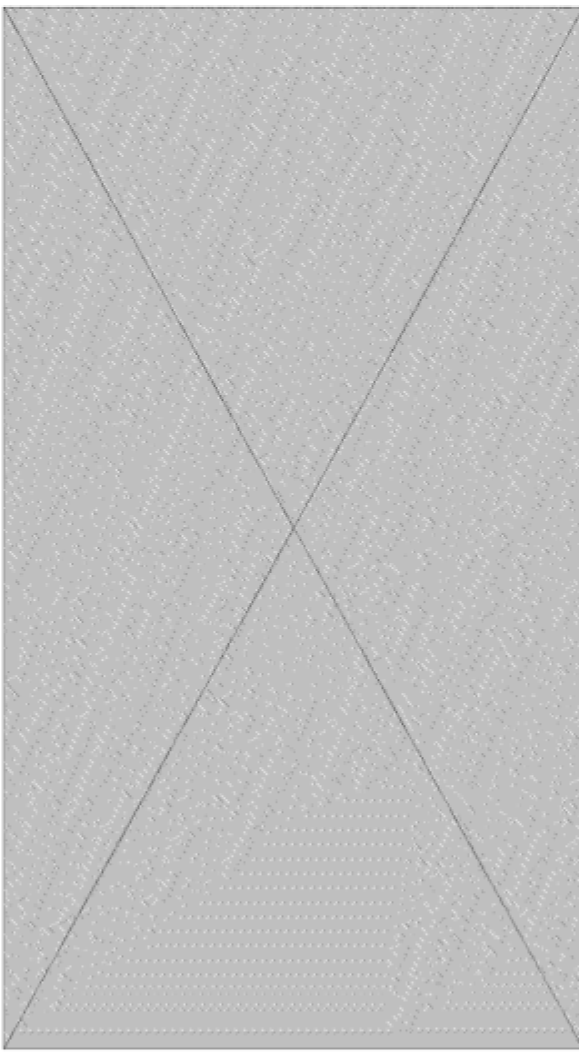
They could, for instance, be used to track environmental conditions, illegal tree-felling or changes in the course of rivers—which, even in their initial deployment, Planet Labs has discovered happen surprisingly often. The frequency of satellite passes opens up many new possibilities, says Skybox's Mr Berkenstock. His firm can offer a stream of analysis, such as the number of trees in a forest or the number of cars at various times of the day in parking lots across America. Transport patterns can be followed, infrastructure monitored, the planting of fields, plumes from smokestacks and ships in ports can all be observed. Overlaying more and more data will provide much richer visualisation, adds Mr Berkenstock.

Nor will all the nanosats be looking downwards. Sensors facing sideways and upwards from low-Earth orbit will allow researchers to carry out a large number of experiments and to take measurements that have previously been too costly to consider. This includes detecting solar and cosmic radiation, interactions between magnetic fields and other forces which together make up what is called space weather. Measuring and predicting space weather could be used to protect billion-dollar satellites and prevent astronauts from receiving high doses of radiation. Many satellites measure aspects of space weather, but they tend to do so only in certain directions. Part of the failed KickSat experiment was to use the sprites to see if arrays of inexpensive devices could constantly monitor such forces.

Nanosats may be inexpensive, but resisting gravity's inexorable pull comes with a price tag. Although there is no standard price list for a launch, a CubeSat costs roughly $100,000 to put each 1.3kg unit into low-Earth orbit. A three-unit CubeSat might cost as much as $400,000. Jeff

Foust, an analyst at Futron, a consultancy, studies launch costs and says he has heard of charges as low as $30,000 for a single CubeSat launched on a Russian rocket.

These prices put nanosats in the reach not just of small firms, but also of start-ups and researchers relying on academic grants. Some schools are also planning nanosat experiments. Bulk-buying launches for heavier combined payloads can work out, per kilo, even cheaper. And these costs could come down, too. Elon Musk, SpaceX's boss, has consistently predicted substantial price drops in launch costs, even to as little as $200 per kilo. The firm's Falcon 9 rocket recently demonstrated a successful controlled descent of its booster stage, which would allow it to be reused.



Interorbital's nano rocket

There is plenty of innovation in putting smaller payloads into space. Interorbital Systems, a Californian company, recently carried out a successful suborbital test flight of a small rocket (pictured right) designed to carry a 145kg payload. The company has presold berths for dozens of CubeSats at $13,000-38,000 per unit, as well as its own TubeSat format, which it offers to academia as kit and launch for $8,000.

NASA will test an air-launched system in 2016 with Generation Orbit, an Atlanta company. It uses a Gulfstream G-IV executive jet to carry aloft a rocket which it fires off to put 45-50kg payloads into low-Earth orbit. NASA is also working with Virgin Galactic, a private space venture led by Richard Branson. Virgin Galactic has developed its LauncherOne, another air-launched rocket. It can be flown to a higher altitude and carry payloads up to 225kg.

Neither Generation Orbit or Virgin Galactic may come down much on price, as both see a profit to be made in offering regular launches, even weekly ones. Operators whose nanosats ride shotgun as ballast in other missions do not have much control over when they launch or the orbits they reach, says William Pomerantz, the head of special projects at Virgin Galactic. John Olds, boss of Generation Orbit, says that as constellations of nanosats increase, placing them in a precise orbit will be critical in keeping small-satellite networks operating.

The nanosat wars

Nanosats also face two other limiting factors: communications and propulsion. Those used for academic work principally rely on amateur-radio frequencies, with basic equipment squeezed into the CubeSat form. Transmission and reception are further hindered by the size of antennae or dishes, both on the ground and on the satellites. Many academic projects set up their own listening stations and recruit space buffs who can use inexpensive kit, but these work on an informal basis. Companies tend to use licensed frequencies and plump for more expensive radio gear to handle their data flows. More development in communications equipment and investment in ground stations would improve things.

The other bugbear, propulsion, is harder to solve. Currently, launch operators can prevent nanosats carrying hazardous propellants that might be used to power them to another orbit. Nor have engineers had a reason to design tiny spaceship engines using safer fuel. But they do now. Even a basic capability to push in one direction would allow nanosats to remain in orbit longer, or allow a satellite that has been placed into low-Earth orbit, using an inexpensive launch provider, to nudge itself to a higher geostationary orbit. And some might travel far beyond Earth.

Benjamin Longmier of the University of Michigan and founder of Aether Industries, which makes equipment for high-altitude research, has begun production of a nanosat propulsion system based on his previous work at the Johnson Space Centre in Texas. This is a rocket that uses ionised propellants accelerated by magnetic fields. He has been able to scale this down to CubeSat size, using liquid water or solid iodine as the propellant. Dr Longmier says the system could allow a constellation of satellites to remain in the correct position relative to one another, move satellites to polar orbit from less-expensive launch insertions or increase an orbit.

Surrey Satellite Technology's STRaND-1 also contained a couple of experimental propulsion systems. One is a re-entry device that ejects a mixture of water and alcohol to tip the nanosat out of orbit at the end of its useful life. The other is an array of pulsed-plasma thrusters which heat and evaporate a material to produce a charged gas to push the satellite along.

NASA has plans to offer a $5m prize using a six-unit CubeSat for groups to demonstrate ways both to communicate across large distances and display the effective use of unconventional propellants. Jennifer Gustetic, in charge of NASA's prizes, says the winner will have to show that their systems are survivable and can be operated far out into space. The programme is still at an early stage, but it could involve transporting the CubeSats for release into orbit around the Moon. But NASA has competition. Dr Longmier believes his technology can beat NASA to the Moon without the use of an additional spacecraft to carry the CubeSats there. And James Cutler, a satellite-propulsion expert now also at the University of Michigan, thinks he can propel small birds even deeper into space. Let the nanosat wars begin.