Goldman Sachs

A new Space Age is emerging. Rocket launches are being privatized, the most ambitious satellite constellation ever is being deployed, man is looking back to the Moon and to Mars, and militaries are vying for the ultimate high ground. In the latest in our **Profiles in Innovation** series, we examine where new industries are being created, and where others are being disrupted in the latest race to harness the cosmos. We show how technological advances and necessity are creating a wave of opportunity as business and governments invest in a new Space Economy.

INSIDE:

VENTURE CAPITAL HORIZONS

Private Company Ecosystem

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PROFILES IN INNOVATION

SPACE

The Next Investment Frontier

The Goldman Sachs Group, Inc.

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PROFILES IN INNOVATION

This is the eighth report in our *Profiles in Innovation* series analyzing how emerging technologies are creating profit pools and disrupting old ones. Access the entire series below and visit our portal to see related resources, including a video on the topic.

Virtual & Augmented Reality | Drones | Factory of the Future | Blockchain | Precision Farming | Advanced Materials | Artificial Intelligence

THE NEW SPACE AGE in numbers

START-UP SUPPORT

$13.3 BILLION

Total investment in space start-ups since 2000, heavily weighted toward the last 10 years. (p. 60)

WORLD WIDE WEB

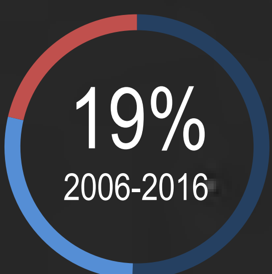
50%

The share of the world's population that satellite connectivity could bring online. (p. 36)

THE SPACE(X) RACE

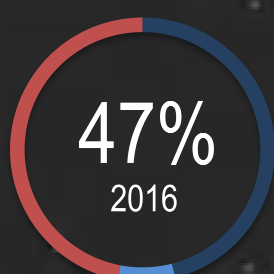
40%

The launch discount that SpaceX offers versus incumbents, though at lower success rates. (p. 25)



The US share of global commercial launch revenues, averaged over the last decade. Europe dominated with a 45% share over the same period, while Russia held 25%. (p. 23)

The US share of global commercial launch revenues in 2016, driven largely by SpaceX, creating a virtual duopoly between US (SpaceX) and European (Arianespace) launchers. (p. 23)



OUTGROWING THE BUDGET

6%

The CAGR we expect for the US defense and intelligence space budget over the next five years as the Pentagon seeks to defend half a trillion dollars worth of friendly assets in orbit. We believe many A&D investors underestimate the size of the government space budget. (p. 80)

SATEL-LITE

10cm x 10cm x 10cm

The size of a CubeSat, one of the smallest satellites and also the most common. A CubeSat weighs only 1 kg and has up to a 3-year lifespan vs. thousands of kilograms / 15 years for traditional commercial and government satellites. While CubeSats have to be replaced more frequently because of their shorter lifespan, the benefit is a newer and more technologically advanced fleet in orbit. (p. 10)

Satellite drawn to scale

STRIKE IT RICH

$25-50 BILLION

The value of platinum on an asteroid the size of a football field, according to Planetary Resources. Asteroids are also rich in water, which can be converted into rocket fuel (orbiting gas stations, anyone?). We believe space mining is still a long way from commercial viability, but it has the potential to further ease access to space and facilitate an in-space manufacturing economy. (p. 74)

FOR THE LONELY-PLANET TYPES

$35 MILLION / PERSON

$250,000 / PERSON

The historical price of a tourist seat on a Soyuz rocket vs. a tourist seat on Sir Richard Branson's new Virgin Galactic sub-orbital spacecraft. (p. 73)

Executive summary

The Second Space Age has begun, and the forces of innovation and disruption are overtaking formerly stagnant industries. New technology is emerging, as old assets fossilize and certain legacy industries wrestle with structural change. Space has always played an important role in our lives, a lynchpin in the modern era, with so many components of everyday life either due to, or reliant on, space and its players. But the space economy is also now inflecting, and we believe will become a multi-trillion dollar market within the next two decades.

The key driver of change today is the enabling power of major change in the commercial launch and satellite manufacturing industries. While relatively small markets today, rapidly falling costs are lowering the barrier to participate in the space economy, making new industries like space tourism, asteroid mining, and on-orbit manufacturing viable, and growing the existing flagship communications satellite services business while taking exploration deeper into space.

Space is becoming a military focal point as governments pivot off Earth and space becomes more congested. If conflict were to start between substantial powers, the opening salvos could be in space, where years of underinvestment have left key assets vulnerable. This looks set to drive an immediate resurgence in US military space investment.

We have broken this report in to 3 major sections:

(1) Creative disruption – where we assess which profit pools are being created and which disrupted in the space economy, and what is moving to private enterprise from government, with a particular focus on the launch and satellite industries.

- **Venture Capital Horizons:** As part of our VCH initiative, Heath Terry assesses the venture capital funding landscape in Space, finding that new funding in the sector has been growing rapidly in recent years.

For more on the Venture Capital Horizons initiative, see the team's inaugural report *Venture Capital Horizons: The Global Venture Landscape.*

(2) Exploration – where we assess whether or not NASA can resurge, and what it next explores, as well as look at new exploration industries including space tourism and asteroid mining.

(3) Militarization – where we assess the degree of criticality of space in military strategies, and look at the potential for increased investment in space by the US military, given both its significance and vulnerability.

Creative Disruption: profit pool creation and disruption in Space

Structural change is coming to space, as new entrants and new technologies displace the old guard, both public and private. This is most apparent in launch and satellites. New entrants and privates in launch are attempting to reinvent the process of getting to Space, including technologies like reusability and shared payloads. New satellite technology, including high throughput and constellations, is materially changing the supply source, disrupting the existing satellite OEM and services businesses. While these changes cause near-term disruptions, they could ultimately open up the Space economy and its positive impacts to a substantially larger set of industrial companies and the world's population.

3 key takeaways from this section:

1. **Launch**: There are several new or private players, including the likes of SpaceX (Elon Musk) and Blue Origin (Jeff Bezos), driving innovation in launch.

2. **Satellite**: Services end markets are seeing oversupply and therefore pricing is deteriorating rapidly. Planned growth in small satellites, satellite constellations, and high throughput satellites could exacerbate this situation.
3. **A new economy**: While new entrants pushing new boundaries can be harmful to some near-term, it is opening up an entire new space economy with substantial new opportunity, long term.

Creative Disruption: Exposures

Launch	Satellite Manufacturing	Satellite Services
SpaceX (Private) Large Geostationary Orbit market share (duopoly with Arianespace), competitive pricing, testing reusability, diversifying into large satellite constellation	**Boeing (BA)** Strong position in very large Geostationary Orbit satellites, but facing new competition for government business	**OneWeb (Private)** Preparing to launch 650+ satellite constellation in Low Earth Orbit, likely multiplying existing capacity by 10X
Arianespace (AIR.PA-SAF.PA JV) The other key player in the Geostationary Orbit commercial market alongside SpaceX; reliable systems with increasingly competitive pricing	**Lockheed Martin (LMT)** Government prime on many programs, but sunsetting its commercial business	**ViaSat (VSAT.O)** Pioneer in high-throughput satellites in Geostationary Orbit, where each can double the amount of available bandwidth
Blue Origin (Private) New entrant developing reusable orbital and suborbital vehicles for tourism and satellites. Stands to directly compete with SpaceX	**Airbus (AIR)** Key Geostationary Orbit OEM developing first mass production line for Low Earth Orbit satellites	**Inmarsat (ISA.L)** Mobility-levered satellite service provider likely to see growth
United Launch Alliance (LMT-BA JV) Government launch provider with high reliability though high costs, but limited commercial opportunity	**MacDonald Dettwiler (MDA.TO)** Large Geostationary Orbit commercial manufacturer attempting to grow government exposure	**Digital Globe (DGI)** High-definition Earth observation satellites with large government exposure
	Orbital ATK (OA) OEM for small-medium commercial satellites, which could become a key source for growing government exposure	**SpaceX (Private)** Planning deployment of 4,425-satellite Low Earth Orbit constellation

Exploration: many potential Earth solutions can be found in Space

GPS; memory foam; LEDs; artificial limbs; baby food; car tires – all owe something to NASA. Space research and investment in science, technology, and exploration are fundamental to the modern economy. Space was once the sole domain of governments, but that has steadily changed the last half century. NASA and private industry are pushing the boundaries of what is known and unknown, ushering in the 22nd century economy.

We believe a new space renaissance has started, where a positive feedback mechanism of exploration and budget allocation could fuel development of the space economy. With greater access to space, there could be a renewed interest in space exploration. Several industry participants are targeting Mars. Others believe traditional Earth-based manufacturing should be done on-orbit. Asteroid mining could crater the global price of platinum, and could also reduce the fuel requirement to send rockets to geostationary orbit, while potentially solving other major energy needs on Earth.

NASA and other civil agencies are undergoing a wave of privatization, shifting government responsibilities to private companies. Budgets for science & exploration are moving slowly, but a renewed political interest amid geopolitical competition could drive spending higher.

3 key takeaways from this section:

1. **NASA role**: The NASA budget is still indeterminate, but could substantially accelerate were its budget to reconnect with a prioritization of space. The Trump administration has discussed the potential to do this.
2. **Public to private**: Exploration used to be the domain of governments, but is increasingly being privatized, adding to the addressable opportunity.

3. **Entirely new industries**: New technologies are creating new industries (tourism, mining, manufacturing), which are important sources of growth and progress.

Exploration: Exposures

Civil Space	Emerging Space Markets
Science NOC is prime on the $9bn Webb telescope.	**Earth Observation** Established operators like DGI and AIR offer different imaging solutions than start-ups like Spire and Planet Labs, which focus on cheaper assets and big data plays.
Missions to the Int'l Space Station OA (**Thales** is a major subcontractor), SpaceX, and Sierra Nevada Corp. (on ULA rockets) ferry supplies to and from the ISS. SpaceX and Boeing will be transporting people there.	**Tourism** Blue Origin, Virgin Galactic, SpaceX, and XCOR vie to become the first tourism solution.
	Mining Planetary Resources and Deep Space Industries are working to develop and deploy probes as first step towards asteroid mining for water as well as rare and basic materials.
Human Exploration LMT, BA, OA, and AJRD are developing the SLS rocket and Orion capsule for exploration missions.	**On-Orbit Manufacturing** OA and MDA to deploy competing satellite servicing vehicles, a step toward space-based manufacturing economy (likely built around 3-D printers). Blue Origin also in the mix.

Militarization: US military infrastructure often runs through Space

Space represents the ultimate high ground for the US military, and other countries are starting to notice. Pentagon leaders are rethinking how to defend their billions of dollars of assets in orbit, even as other countries seek ways to narrow the gap: through both offensive capabilities and deploying more assets of their own.

We look at how protection of these assets is becoming a core pillar of US strategy, as well as what new assets are being added to national security constellations. The crowding in space has the potential to threaten both military and commercial assets. All told, we see both the unclassified and classified space portions of the US DoD budget growing faster than total spend in both the medium and long term.

3 key takeaways from this section:

1. **Substantial military infrastructure is in space**: Space is key to national security, as much of the US military's assets are in space and are increasingly vulnerable.
2. **It is crowded up there**: More countries and more commercial players moving in to space is causing congestion which adds risk.
3. **Space moves Defense numbers more than you might think**: Our assessment of the DoD budget shows that Space is a larger portion of US Defense, growing at a faster rate, than we think the average A&D investor realizes.

Military: Exposures

Northrop Grumman **(NOC)**: Classified payloads likely a large part of their overall business & government exposure	Lockheed Martin **(LMT)**: Large share of government business, particularly as prime member of United Launch Alliance (ULA), focused on space awareness	Boeing **(BA)**: Government satellite OEM, member of ULA
Harris Corp. **(HRS)**: Antenna and payload specialization, particularly on the government side	Raytheon **(RTN)**: Government-focused payload manufacturer, with exposure to ground stations and smallsats	SpaceX **(Private)**: New government-qualified rockets with compelling pricing

Venture Capital Horizons: substantial private investment in Space

Private investment in space has been growing quickly in recent years. When looking at number of investments or total size of investment, nearly 3/4 of activity in the sector since the year 2000 has occurred in the last 5 years, including an average of 8 start-ups in space per year. More than 50 venture capital firms invested in space in 2015, driving more venture capital dollars into space in 2015 alone than in the prior 15 years combined.

3 key takeaways from this section:

1. **Available capital**: Financing in space appears readily available, with several different investor categories making investment into space in recent years.
2. **Growth**: Recent years have seen substantially more space startup companies formed, and substantially more venture capital put into the sector, compared to any time in history.
3. **Who?**: A lot of investment has been from, or into, well known players in the sector – like Google and Fidelity investing in SpaceX, or Softbank investing in OneWeb. But dozens of smaller firms have put money into smaller privates as well.

Venture Capital: Exposures

Major Investors	Major Recipients
SoftBank: Invested in OneWeb, likely making it the largest space VC investor	**SpaceX**: Reusable launch provider with plans for large satellite Internet constellation
Bessemer: Invested in Rocket Lab, Skybox, Spire	**OneWeb**: Likely first major LEO communications constellation operator
Fidelity: Major investor in SpaceX	**Rocket Lab**: Raise reportedly implied value of >$1bn before first launch of its Electron ultralight rocket
Google: Major investor in SpaceX, Terra Bella	**Planet Labs**: Earth observation/big data entrant with growing smallsat constellation

5-Year Impact by Subsector

Subsector	Impact
Most Positive	
Internet Satellite Services	Growth in supply likely matched by demand growth at a large scale
Medium-Heavy Launch	Growth in demand from Internet satellite services creates new opportunity pools for select players, despite headwinds
Military Satellite OEMs	New wave of classified opportunities in the pipeline amid renewed focus on space and space asset protection
Mobility Satellite Services	Possible demand outgrowth in niche markets where pricing is more stable
Ultra-Light Launch	Opportunities abound for smallsat launch, but risks from larger rockets capturing share
Gov't Satellite Services	Military demand increasingly captured by commercial providers and pricing is more stable, but volumes are comparatively low
Earth Observation	Numerous new applications but the path to commercial profitability is unclear for capex-intensive operators
Satellite OEMs	Headwinds to capex spend and growing satellite capabilities at low cost dampen outlook for volume and pricing
Insurance	Continuing compression of rates amid heightened risk associated with new rockets
Video Satellite Services	Facing both space and terrestrial headwinds, leading to potential 50% decline in pricing over next five years
Most Negative	

The Ecosystem

Space - Key Players

Satellite Manufacturers

Boeing
Lockheed Martin
MacDonald Dettwiler & Associates
Northrop Grumman
Orbital ATK
Airbus
Harris Corp
Raytheon
Thales
ViaSat
SpaceX
L3 Technologies
Embraer
China Academy of Space Technology

Operators

OneWeb
ViaSat
Dish Network
AT&T
Intelsat
Sirius
Inmarsat
Eutelsat
SES
Airbus
DigitalGlobe
Planet Labs
Spire
Iridium
Planetary Resources
Deep Space Industries

Launch Providers

Lockheed Martin
Boeing
Airbus
Safran
Orbital ATK
SpaceX
Blue Origin
Mitsubishi Heavy Industries
International Launch Services
China Great Wall Industry Corp.
Virgin Galactic
Stratolaunch
Vector
Rocket Lab
XCOR Aerospace

Goldman Sachs

Rocket Science 101

Since the first satellite was placed in space in 1957, commercial and government scientists have pushed the boundaries of what is possible. We look at some key terminology and technology needed for discussing rockets and satellites in this section.

Rockets

Most payloads (i.e., satellites, scientific probes, human transport capsules, etc.) get to space on expendable rockets. Reusable systems, like the Space Shuttle, have been tried, but there are outstanding questions about reliability and refurbishment cost. While most of the weight of the rocket is fuel, the vast majority of the cost is in the hardware, driving Elon Musk's argument that returning a rocket for reuse can lead to substantial cost savings.

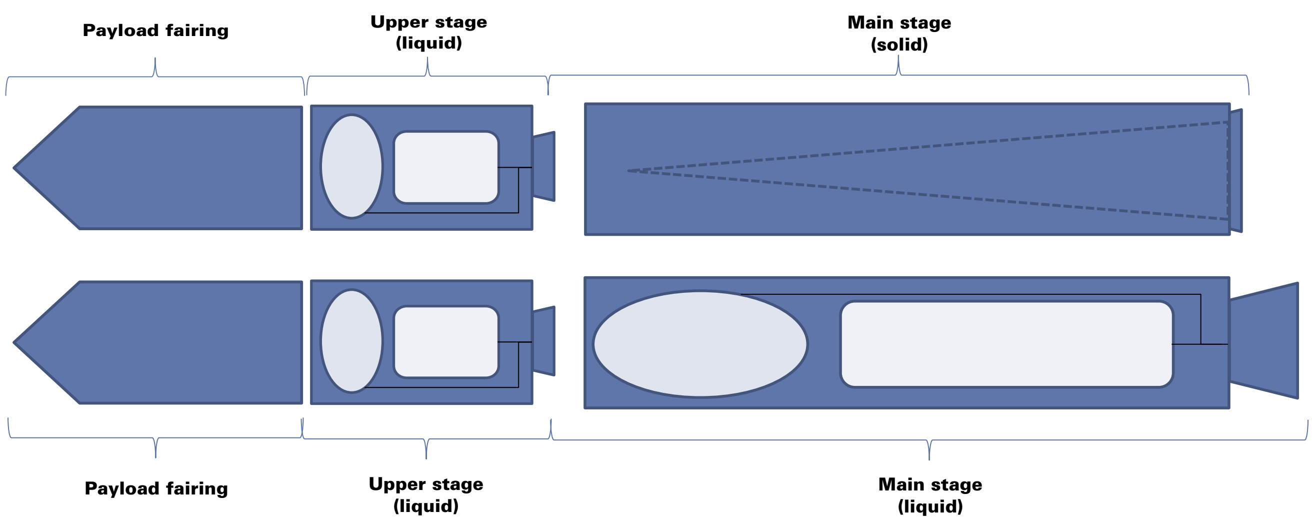
Staging

Rockets are built on a layered system, with the most powerful propulsion in the first (main) stage. That stage provides the initial lift as the rocket pushes past the thickest parts of the Earth's atmosphere. Strap-on boosters can be added to provide additional thrust. Typically, that main stage and the boosters are jettisoned as they run out of fuel, giving way to a smaller upper stage. This stage then lifts the now-lightened rocket and payload into space. It is not uncommon for there to be multiple upper stages (though usually no more than two). Some rockets deliver satellites directly to their final positions, but generally small thrusters on the satellite itself perform the final precise maneuvering.

Solid vs. liquid propellants

Until recently most rockets were designed around a liquid-fuel engine for the first stage, with the addition of solid-fuel boosters for additional power. That is beginning to change. Liquid-fueled rockets (bottom of Exhibit 1) burn a highly refined form of fuel and liquid oxygen whereas solid rockets (top of Exhibit 1) burn a highly flammable compressed explosive. Each has its pros and cons:

Exhibit 1: Solid vs. liquid rocket technology
Liquid-fueled main stage (bottom); solid-fueled main stage (top)



Source: Goldman Sachs Global Investment Research.

Liquid-fueled rockets… chemistry at thousands of miles per hour: These rockets store fuel and oxidizer in separate tanks before mixing them in the engine as part of the combustion reaction that provides lift. The rocket is only filled prior to launch due to the volatile nature of the fuel and oxidizer, so storage and fueling mean that these launches must be planned well in advance and conducted under highly controlled conditions. As examples, ULA's Atlas V and SpaceX's Falcon 9 both employ liquid-fueled first stages. Upper stages for most rockets are liquid-fueled as they enable more precise maneuvers.

Solid-fuel rockets…gunpowder in a tube: Solid rockets have the fuel and oxidizer premixed in a single shaped compartment. This technology is seen in ordinary fireworks and US Minuteman intercontinental ballistic missiles. These rockets are more stable than liquid-fueled peers, allowing them to be carefully stored and launched at short notice.

Once lit, solid rockets will burn until they run out of fuel, reducing precision to some degree. The historical drawback of these rockets is that the 'ride' tends to be a little rougher than liquid alternatives. Orbital ATK says they have been able to eliminate this problem, which may allow them to qualify for the most sensitive national security payloads.

Industrial base: Many A&D companies participate in rocketry, providing either integrated solutions or critical subsystems. Major manufacturers include ULA (Lockheed Martin-Boeing JV), Orbital ATK, Arianespace (Airbus-Safran JV), SpaceX, Blue Origin, International Launch Services (Russia SOE), and China Great Wall Industry Corporation (China SOE).

Exhibit 2: Large launch providers and their product offerings

Company	Rockets (current and next gen)
Arianespace	Ariane 5, Vega, Ariane 6
SpaceX	Falcon 9, Falcon Heavy
United Launch Alliance	Atlas V, Delta II, Delta IV, Vulcan
Orbital ATK	Antares, Next Generation Launcher, Pegasus, Minotaur
International Launch Services	Proton, Angara
China Great Wall Industry Corporation	Long March
Blue Origin	New Shepard, New Glenn
Antrix/India Space Research Organization	PSLV, GSLV, LVM3

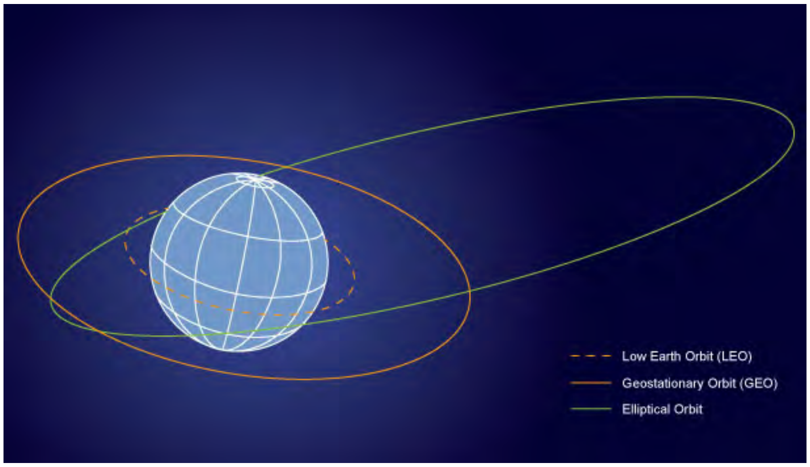
Source: Company data, FAA, Goldman Sachs Global Investment Research.

Satellites

There are about 1,500 satellites orbiting the Earth today, generally split between commercial, military, non-military government and civilian (mostly academic), though some satellites fly with dual payloads. While about a quarter of satellites are for primarily military applications, we think that military satellites draw roughly 3/4 of spending (based on our spending analysis).

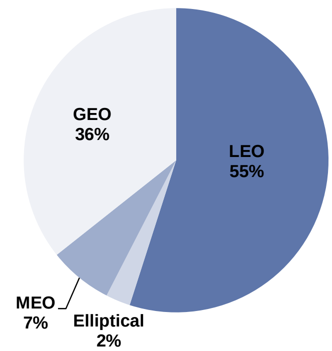
Most communications satellites weigh more than 1,000kg, but some space assets like the Hubble Telescope can be more than 10X that. Increasingly, small satellites, often referred to as "smallsats" are becoming more prevalent as miniaturization enables a more flexible platform. Some of the smallest are known as CubeSats—roughly measuring 10X10X10cm and weighing about 1kg. Standard commercial satellites normally have about 15 years of fuel onboard, with electronics rated for longer. Smallsat operators typically plan for just 1-3 years of operations. At the end of their lives, satellites are generally placed in graveyard orbits or de-orbited, but some operators leave them in place, creating dangerous space debris.

Exhibit 3: Map of key orbits
Each has its own value proposition and launch requirements



Source: Goldman Sachs Global Investment Research.

Exhibit 4: Orbital distribution of satellites
Most satellites are in LEO (in units), but the value of the assets is concentrated in GEO



Source: Union of Concerned Scientists (All instances use the 6.30.16 data set).

Active satellites are positioned in different orbits for different applications:

Low Earth Orbit (LEO) satellites orbit faster than the Earth rotates, allowing them to pass the same point as often as once every 1.5 hours. These satellites are often used for Earth observation, due to their proximity to the planet (~150km-800km). The International Space Station and Hubble Telescope are positioned in LEO, along with many Earth observation satellites. Operators are planning to use LEO for low-latency communications (such as Internet), but the proximity to the Earth and high velocities mean that hundreds of satellites would be needed for global coverage. A new class of light rockets catering to small satellites is emerging, offering solutions to LEO for payloads of ~50-500kg.

Geostationary Orbit (GEO) also known as geosynchronous equatorial orbit is a specific orbit 36,000 kilometers above the Earth's equator where satellites move at the same speed the Earth rotates. GEO is where most communications satellites are based, since they maintain their station over a given point on the surface. The downside is the distance creates latency that can limit 2-way communications, but works well for 1-way broadcasts like satellite TV and radio. Three satellites in GEO could provide coverage for the world. Medium-heavy lift rockets are primarily tasked with launch to GEO, given the large payloads (in the thousands of kg), and are facing a new generation of low-cost alternatives and potential for reusability.

Medium Earth Orbit (MEO) lies between GEO and LEO and represents a compromise between the two. Some two-way communications networks operate here, where tens of satellites can provide global coverage but latency is reduced. GPS flies in MEO with 32 satellites, providing global navigation services.

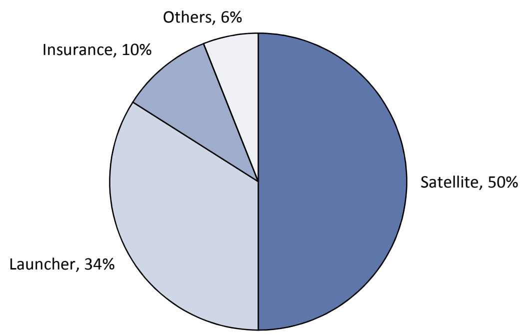
Elliptical Orbit can be any of several non-circular pathways. These orbits tend to have specialized applications, with one of the most common being polar coverage, which is normally not well-serviced by satellites aligned with the equator. A geostationary transfer orbit (GTO) is a special elliptical orbit that is used as an intermediate step to deliver satellites to GEO, before they eventually circularize at the far end of the ellipse.

While most satellites in terms of units are in LEO, the concentration of value is in GEO, where most large telecom satellites are positioned.

Space access is expensive but pays off

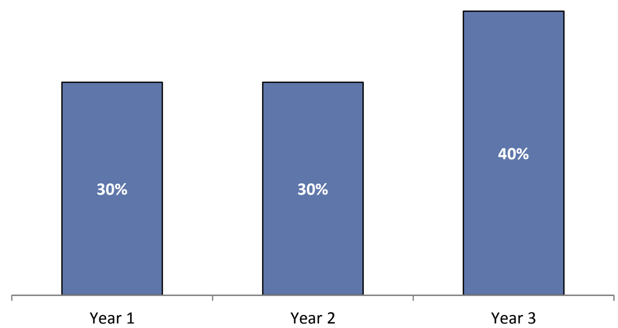
Satellites typically take 2-3 years to build and then generate strong cash flow for ~15 years. We estimate the average satellite plus launch is ~$300mn and generates ~$40mn-$60mn cash post interest annually.

Exhibit 5: A satellite represents only half of program costs
Typical satellite program capex profile



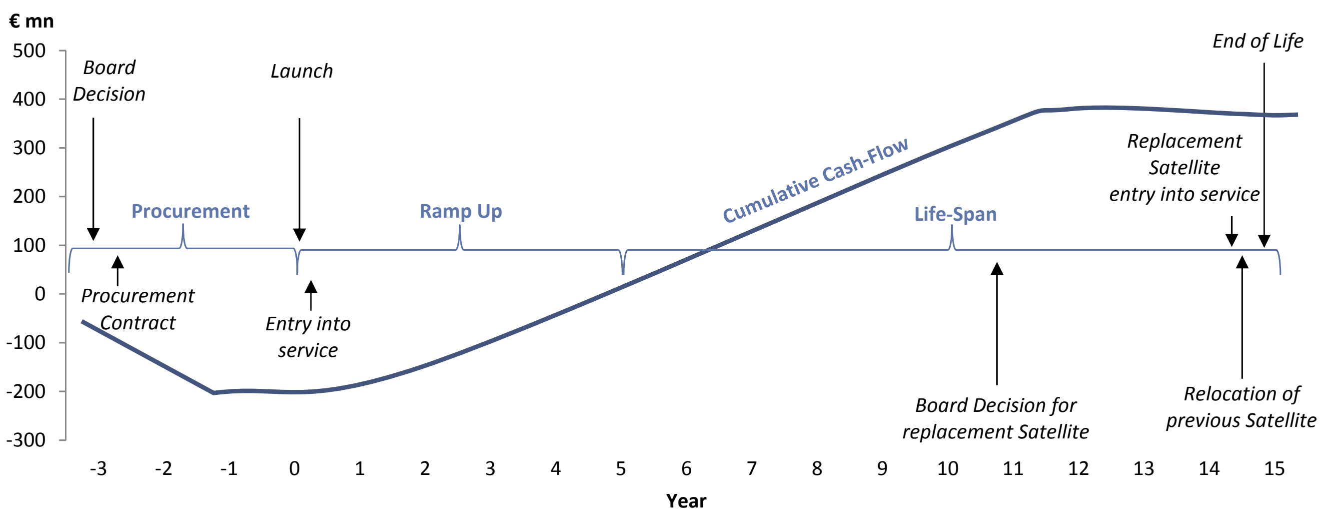
Source: Eutelsat.

Exhibit 6: The capex associated with a satellite is typically split over three years prior to launch
Typical timing of capex payments



Source: Eutelsat.

Exhibit 7: Typical GEO satellite cash flow
€ mn and years

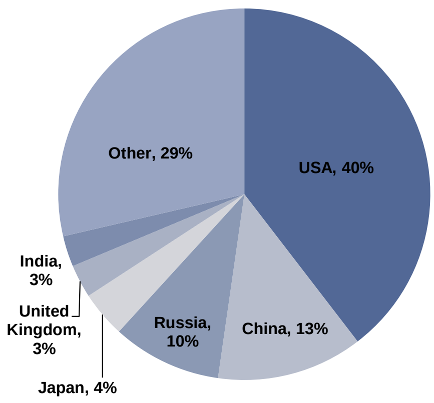


Source: Company data, Goldman Sachs Global Investment Research.

Satellites are disproportionately owned by the wealthiest countries

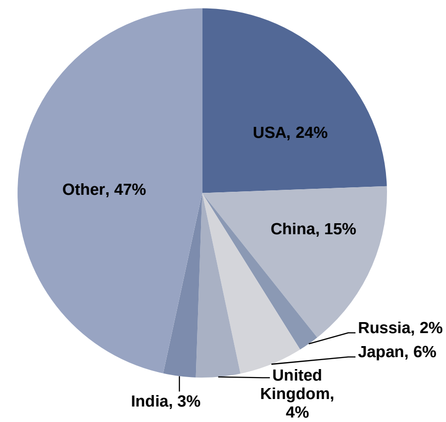
US operators fly about 40% of all satellites, far above its share of global GDP. Russia is also heavily exposed to space, largely due to its legacy Soviet space program. China's exposure to space is growing, and is now nearly in-line with its global GDP share. Smaller countries often pool resources for government space programs, or else contribute to military programs of large countries like the US for shared intelligence capabilities.

Exhibit 8: Share of satellites
Certain large countries have a share of satellites…



Source: Union of Concerned Scientists.

Exhibit 9: Share of world GDP
…disproportionate to the relative size of their economies



Source: Union of Concerned Scientists.

Industrial base: Most satellites are built in the US or Europe. In US military, Northrop, Lockheed, Boeing, Harris, Raytheon, and Orbital ATK compete. In Europe military, Airbus appears to have the largest share. State owned enterprises tend to be pervasive in other countries. Key commercial manufacturers listed below make ~3/4 of the commercial satellites.

Exhibit 10: Key commercial satellite manufacturers and core offerings

Manufacturer	Core Product	Sizes
Lockheed Martin	A-2100	Large
Boeing	BSS-702	Medium-Large
Orbital ATK	GEOStar	Small-Medium
MacDonald Dettwiler	SSL-1300	Large
Airbus	ES-3000	Small-Large
Thales	SB-4000	Medium-Large

Source: FAA.

Operator base: Satellite operators range from large-cap companies to startups and universities. Companies like Intelsat, Inmarsat, Eutelsat, SES, DISH, and SIRI fly GEO satellites. LEO constellations (some existing, some planned) include Iridium, OneWeb, SpaceX, Planet Labs, and Spire.

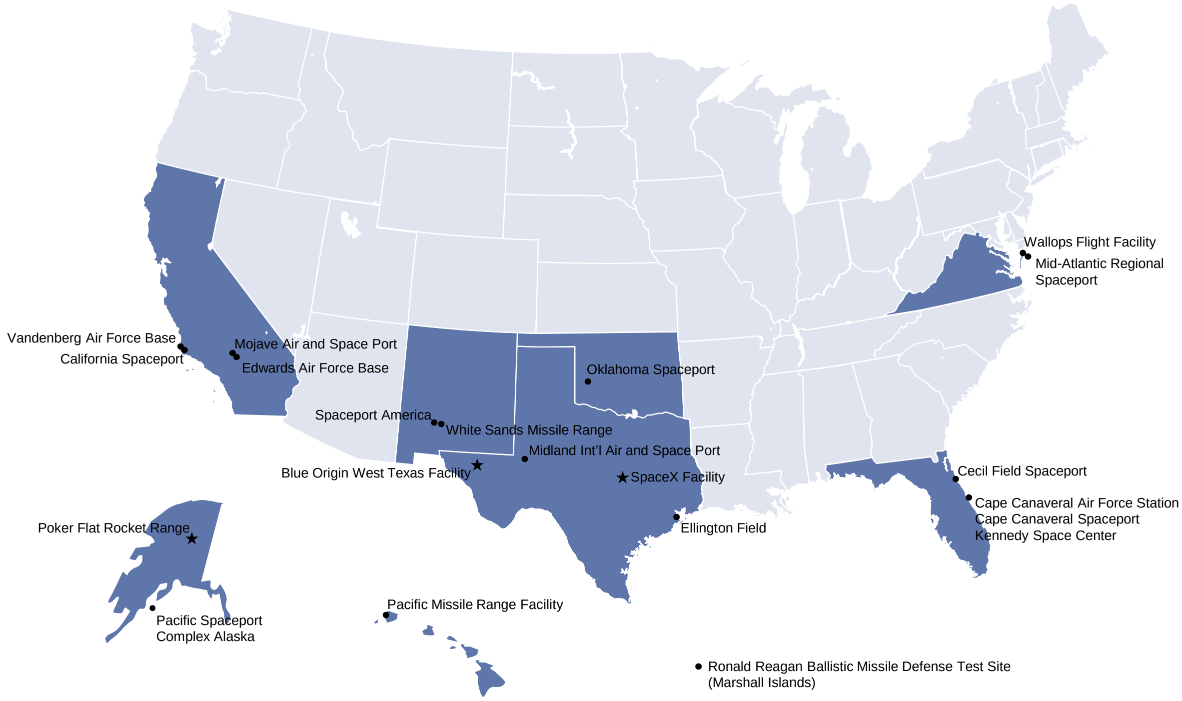
Ground infrastructure

Ground infrastructure enables satellite launches, tracking, and connectivity to end users. Access to space requires launch pads and rocket servicing facilities. Once satellites are up, there is need for continued fleet maintenance, data processing, and command and control of space assets, especially those operated by the government. Finally, space assets are tied into the terrestrial economy largely through consumer equipment– from satellite dishes used for TV to GPS receivers in smartphones.

Launch and Reentry sites: moving payloads to and from space

Building and licensing rocket launch pads is largely a governmental enterprise. Usually these places allow for launch vehicle component integration, payload and launcher integration and vehicle fueling and maintenance prior to the actual launch. Companies like Blue Origin are actively moving to co-locate production and launch facilities to reduce transport cost and risk. Launch sites closer to the Equator offer more efficient launches, allowing for larger payloads on the same rocket vs. those launched further north or south.

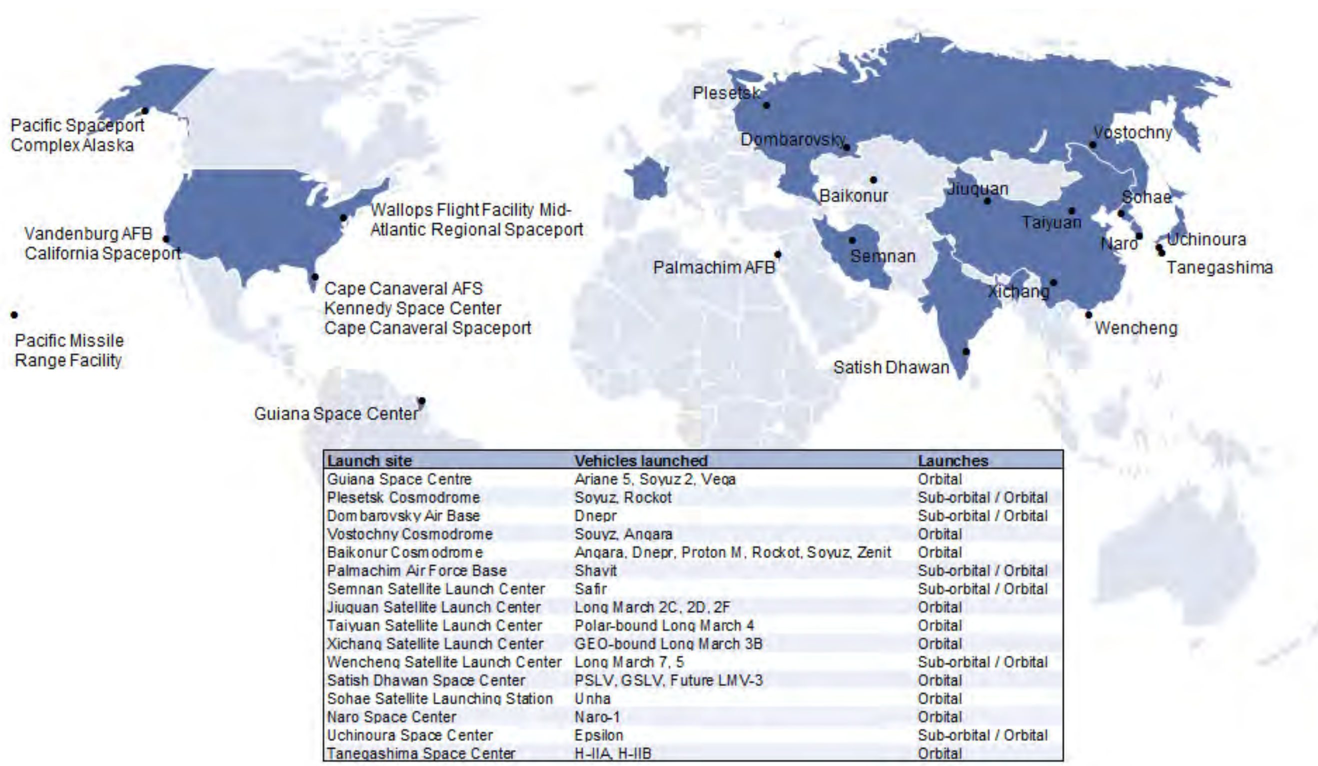
Exhibit 11: Map of active United States launch and reentry sites
Dots represent licensed or government sites; stars represent non-licensed sites



Source: FAA, Goldman Sachs Global Investment Research.

Globally, we highlight 10 countries that manage the most active launch and reentry sites.

Exhibit 12: Map of main active global launch and reentry sites
Russia, China, France, Japan, South Korea, North Korea, Israel, India, Kazakhstan and the US manage the most active facilities



Launch site	Vehicles launched	Launches
Guiana Space Centre	Ariane 5, Soyuz 2, Vega	Orbital
Plesetsk Cosmodrome	Soyuz, Rockot	Sub-orbital / Orbital
Dombarovsky Air Base	Dnepr	Sub-orbital / Orbital
Vostochny Cosmodrome	Souyz, Angara	Orbital
Baikonur Cosmodrome	Angara, Dnepr, Proton M, Rockot, Soyuz, Zenit	Orbital
Palmachim Air Force Base	Shavit	Sub-orbital / Orbital
Semnan Satellite Launch Center	Safir	Sub-orbital / Orbital
Jiuquan Satellite Launch Center	Long March 2C, 2D, 2F	Orbital
Taiyuan Satellite Launch Center	Polar-bound Long March 4	Orbital
Xichang Satellite Launch Center	GEO-bound Long March 3B	Orbital
Wencheng Satellite Launch Center	Long March 7, 5	Sub-orbital / Orbital
Satish Dhawan Space Center	PSLV, GSLV, Future LMV-3	Orbital
Sohae Satellite Launching Station	Unha	Orbital
Naro Space Center	Naro-1	Orbital
Uchinoura Space Center	Epsilon	Sub-orbital / Orbital
Tanegashima Space Center	H-IIA, H-IIB	Orbital

Source: FAA.

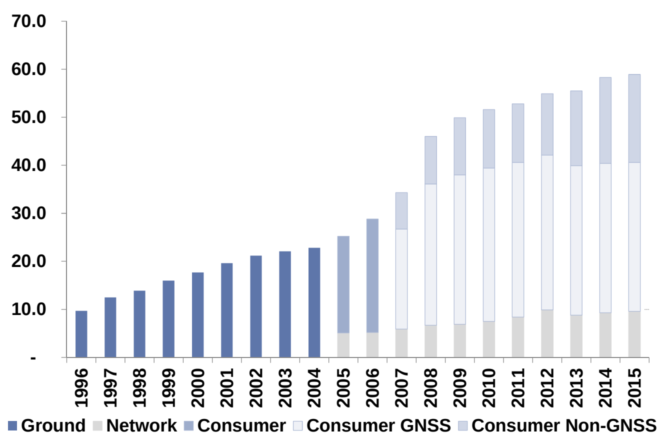
Ground Equipment: Network and Consumer applications

The space economy is inextricably linked to the terrestrial one, making the line between the two difficult to draw. The tethers that bind the two together are the ground stations, antennas, and associated hardware in everyday consumer products. Space ground equipment is a $59bn market, according to the Satellite Industry Association, split into network and consumer-related equipment. The European GNSS Agency uses a more comprehensive definition for its nearly $80bn estimate, adding segments like chipsets, traffic information systems, avionics, maritime, surveying, and rail.

Network equipment includes gateways, network operations centers, satellite news gathering equipment, and terminal equipment. In 2015, this market was estimated to be worth $10bn by the Satellite Industry Association. Growth has been strong but volatile in the last 10 years, driven by increased demand for satellite TV, radio and data applications and bundled services.

Consumer equipment, as defined by the Satellite Industry Association, includes global navigation satellite systems (GNSS) and other non-location-driven applications like satellite dishes, radios, phones, and other hardware, which we classify as non-GNSS. In 2015, the consumer hardware market was worth close to $50bn.

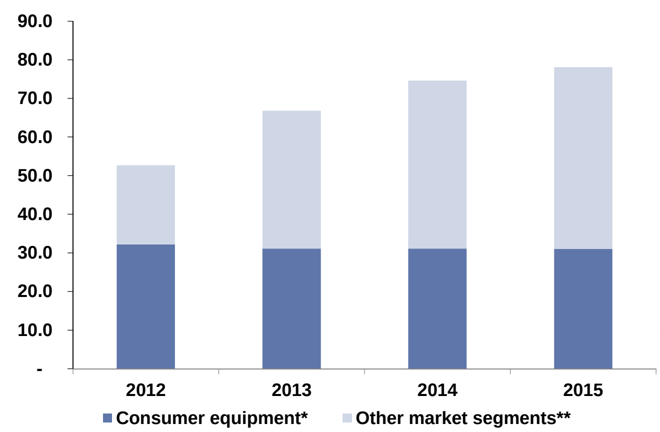
Exhibit 13: Ground equipment sales, SIA
A $59bn market



* From 1996 to 2004, only total sales values are available. In 2005-06, the network/consumer breakdown was provided. Since 2007, consumer applications are split between GNSS and non-GNSS applications.

Source: Satellite Industry Association (SIA).

Exhibit 14: Ground equipment sales, European GNSS
More comprehensive definition increases the market size



Source: Satellite Industry Association (SIA).

Connecting people: One of the greatest hurdles for proposed LEO fleets is the ground element, especially in developing countries where the cost could be prohibitive. Non-GNSS refers to the receiving end, on the consumer side, for content and data products.

Finding people: The European GSA estimates that over 90% of GNSS market revenues come from location-based services (53%) and road applications (38%). GNSS hardware communicates with satellites to provide geolocation anywhere on Earth. In the US, this is known as GPS.

Exhibit 15: Location based services supply chain

From component manufacturers to app stores

Component manufacturers (receivers and others)	Device vendors	Service and content providers	App developers / retailers	App Stores
Qualcomm **Broadcom** **CSR-SIRF** **Texas Instruments** **Mediatek** **STM** **U-Blox AG** **Fujitsu Ltd** **Skytraq** **Intel**	**Smartphone / Tablet:** Samsung, Apple, LG, Microsoft, ZTE, HTC, Xiaomi, Lenovo, Huawei, Blackberry **Cameras:** Canon, Nikon, Sony **Watches:** Garmin, Microsoft, Suunto, Timex **PCS:** Apple, Acer, Asus, Dell, HP, Lenovo **People tracking:** Garmin, Pocket finder, Spot Teltonika **OEMs:** Pegatron, Wistron	**Apple** **Garmin** **Google** **Tomtom** **Assistance data providers** **Mobile network operators**	**App developers:** Apple Electronic Arts Google Microsoft Tripadvisor Yelp Small app developers **Retailers:** Airlines, banks, general retailers, media companies, mobile network operators, transport providers, vehicle manufacturers	**Google Play** **Apple App Store** **Windows Phone Store** **Amazon App Store** **Blackberry World**

Source: European GSA.

Road applications of GNSS are part of a shift to smarter infrastructure, allowing for improvements in transport productivity, safety and monitoring and tracking capacities.

Exhibit 16: Road applications supply chain

GNSS improves transportation efficiency, safety, and monitoring capacity

	System integrators			
Component manufacturers (receivers and others)	Tier 1 Suppliers and Aftermarket Device Vendors	Vehicle manufacturers	Service providers	Users
CSR-SIRF **Qualcomm** **ST Microelectronics** **Japan Radio Co** **Laird** **Telit (NXP)** **Kathrein-Werke KG** **Mediatek** **Broadcom** **Furuno** **U-Blox** **Pulse Electronics** **Gemalto**	**Bosch** **Continental** **Denso** **Ficosa** **Garmin** **Octo Telematics** **Magneti Marelli** **Siemens** **TomTom** **Valeo**	**Toyota** **GM** **Volkswagen** **Hyundai-Kia** **Ford** **Renault-Nissan** **FCA** **Honda** **Suzuki** **Peugeot-Citroen** **BMW** **Daimler** **Geely** **Jaguar Land Rover**	**Fuel/fleet card issuing companies** **Mobile network operators:** Vodafone Telefonica T-mobile **Traffic information providers:** TomTom Garmin Google **Telematics service providers** **Toll operators:** Sky toll Toll collect	**Car owners, commercial vehicles drivers, fleet operators, insurance companies, road network operators**

Source: European GSA.

CREATIVE DISRUPTION

Launch: There are several interesting private players that are well funded, including the likes of SpaceX (Elon Musk) and Blue Origin (Jeff Bezos), particularly in launch.

Satellite: Services end markets are seeing oversupply and therefore pricing falling drastically. Planned growth in small satellites, satellite constellations, and high throughput satellites could exacerbate this situation.

A new economy: While new entrants pushing new boundaries can be harmful to some near-term, it is opening up an entire new space economy with substantial new opportunity, long term.

Major players: NewSpace: SpaceX, Blue Origin, OneWeb, Rocket Lab, Vector. OldSpace: ULA, Arianespace, Orbital ATK, MDA, Intelsat, Eutelsat, Inmarsat, SES, Dish Network.

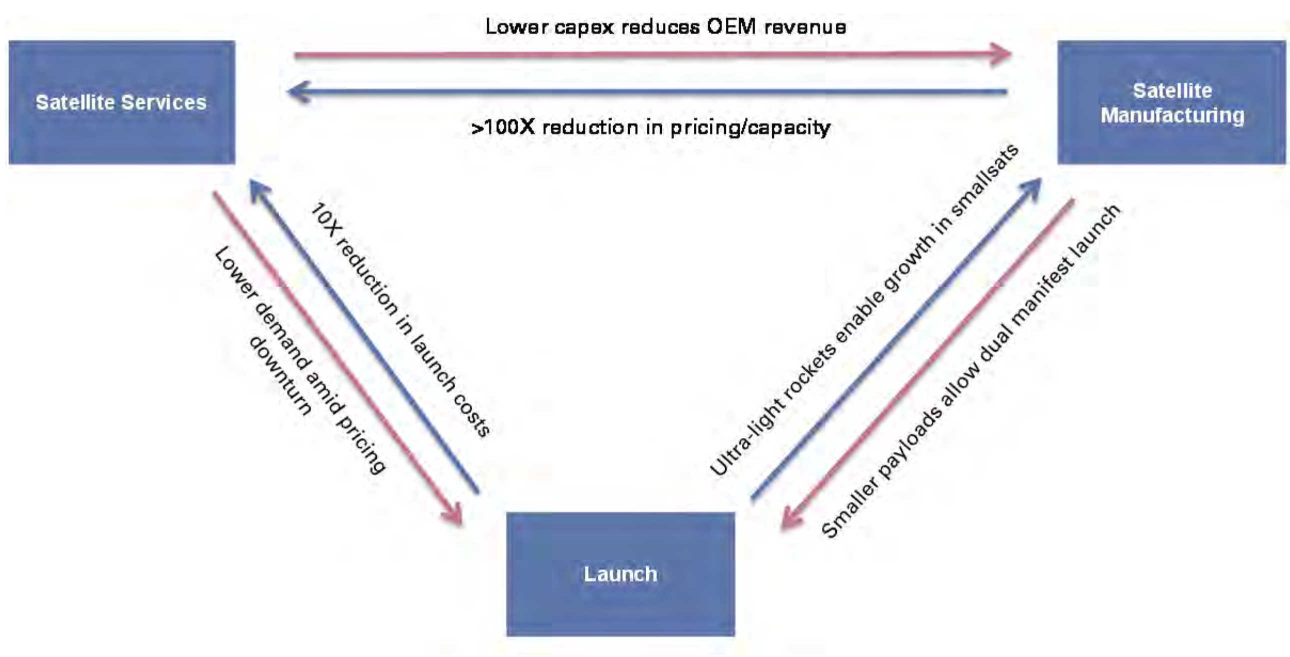
Creative Disruption: a market seeing significant change

The commercial space economy has stood nearly still for decades. More satellites have gone up and growth has been solid, but the fundamental commercial landscape has remained relatively stagnant. We are witnessing an inflection point in the significance of the space economy, where it becomes central in providing Internet access and basic services to more than half the world's population, compounding growth. The coming decade will be one of pruning, where only the strongest and most innovative survive the wave of new technology and business models, but that is necessary to propel the mainstay manufacturing and services industries forward.

The commercial satellite services industry is entering an arms race to acquire the most capacity as pricing collapses in end markets. A single satellite is now being built with more Internet bandwidth than everything launched into orbit, ever. A constellation of small satellites will likely grow the amount of bandwidth on orbit by a factor of at least 10X, at a rapidly falling cost. At the same time, pricing in the launch industry is plummeting. On a cost per kg to LEO basis, prices will soon have fallen by about 90% over the last decade. Decreased launch cost lowers the barrier to entry and helps incumbents that may take advantage of lower capex to flood the market with additional capacity.

We do not expect all existing players to survive the turbulence that is unfolding, but we also expect new companies to rise to the challenge to take the place of those that fail. The near term will present challenges, but in the back half of the next decade we see supply and demand balancing once prices have fallen sufficiently to fit the budgets of the rural populations of developing countries. Given our view on elasticity in the space economy, though with some stickiness, we expect lower prices to spur demand for launch, spacecraft, and satellite services.

Exhibit 17: Commercial sector changes ripple across markets
Blue arrows indicate positive impact of one segment to another, red indicates a negative



Source: Goldman Sachs Global Investment Research.

LAUNCH

Access to space is now cheaper and easier

- Center of Newspace activity
- Prices lower as new generation takes flight
- Jury still out on reusability

Exhibit 18: Creative disruption at work: Launch

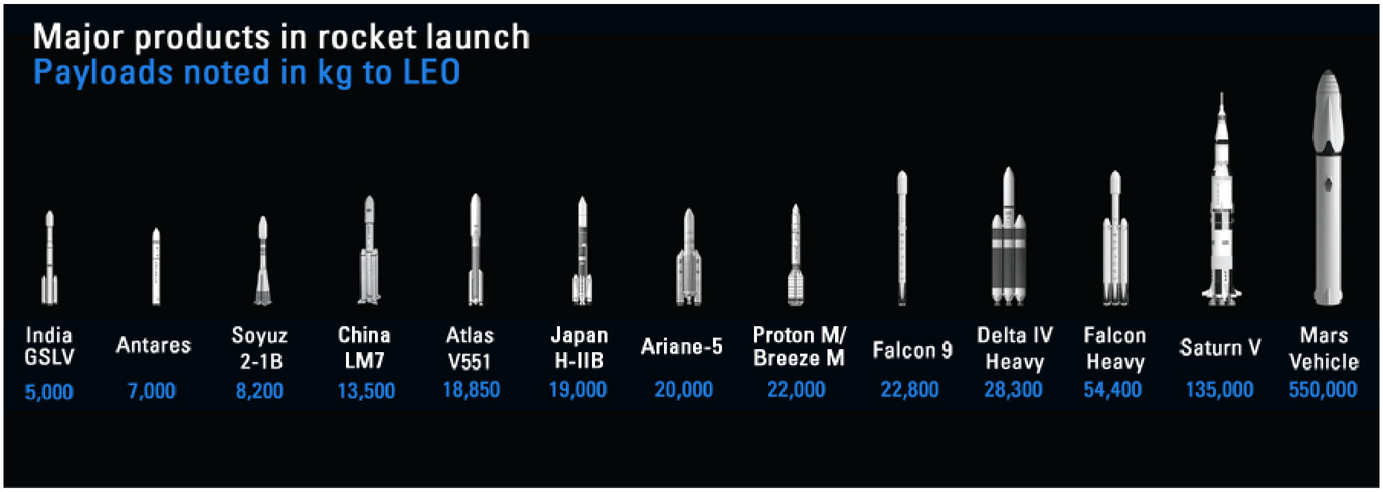
	Volume growth		Pricing changes		Comments
	Last 10 yrs	Next 3 yrs	Last 10 yrs	Next 3 yrs	
Launch	Light: Nearly nonexistant Med/Heavy: Flat @ 90/yr	Light: ~100 launches/yr Med/Heavy: Flat	Light: N/A Med/Heavy: -10X	Light: -10X Med/Heavy: -50%	New vehicles at lower price points vs predecessors; off low base SpaceX constellation could take rates higher; GEO launch in decline
Satellite OEMs	Flat-down on units, capacity +5-10%/yr	Units structurally lower/capacity oversupply	-20X	-20X	Rapid tech improvements push costs into free fall amid low volumes
Satellite Services	Video: +SD growth/yr Data: +10X	Video: Flat Data: +10X	Video: Stable Data: DD declines/yr	Video: Flat/slightly down Data: -30%	Flat outlook, with minor change from compression/formatting/pricing Oversupply lowers pricing, but builds the market
Insurance	+50% capacity growth	Underperform relative to total sat fleet growth	-50%	Decreasing	Rate decline likely to continue, but new rockets could support increase

Source: Company data, Goldman Sachs Global Investment Research.

Access to space is the greatest impediment to opening the space economy of the future. But by the end of this year, we expect launch costs to have compressed 10X over a decade, with improvements in capability and reductions in cost fundamentally changing the math for investment in space. Costs in launch have declined more in the last decade than during the entire prior period of space exploration. As this barrier to entry is lowered, new applications become feasible, fueling demand – key to keeping costs low.

A new generation of rockets is about to take flight. The next decade will pit three competing designs against each other in a negative pricing environment. Reusable liquid-fueled rockets, non-reusable liquid-fueled rockets, and solid-fueled rockets will vie to become the cheapest and most reliable rocket, in what will become a lean environment in the short-to-medium term, especially given the entrance of new competitors. Large bulk orders and intracompany purchase are likely to be key differentiators.

Lower launch costs may be just what saves the satellite services industry in the near term and catalyzes growth over the longer term. The risk of oversupply is putting increasing pressure on the satellite services providers, and low launch costs in a worsening pricing environment may be the only way to sustain sufficiently attractive IRRs for GEO operators. Ultimately, over the long term, we see the low launch costs fueling demand as new applications become possible with the lowered financial barriers to the space economy. In the words of Jeff Bezos, "the cost of admission to do something interesting in space is too high," despite recent decreases, and that prevents the dynamism necessary for developing the space economy. Low-cost operational reusability is likely the most efficient way to normalize access to the space economy long term, which is ultimately the future of the Earth economy in our view. Less than a week ago, SpaceX successfully re-launched a main stage as part of the SES-10 mission, marking the first time a commercial orbital class rocket has been re-flown. This event, coupled with the five suborbital launches conducted by Blue Origin's New Shepard, is a promising data point for the future of reusability.



* Based on industry data

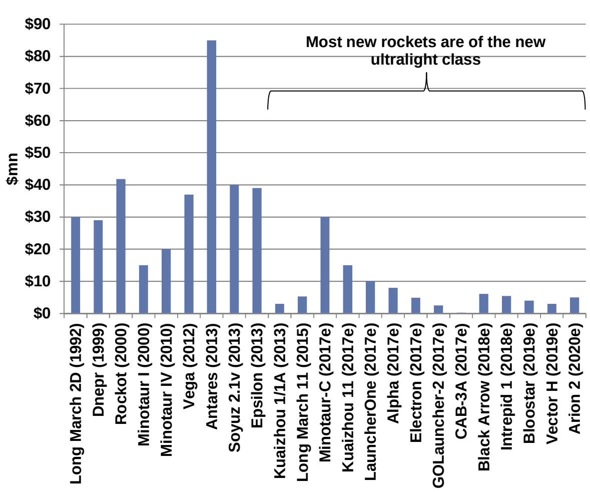
Launch costs are grinding lower

No two rocket launches are alike, but the data suggest the industry is rapidly extracting costs to lower the price. Although launch costs are difficult to quantify and depend on the payload, all signs point to rapidly falling costs (Exhibit 30), as legacy operators seek to remain competitive with recent offerings and the possibility of still-lower cost reusable rockets. New light rockets are creating customizable low-cost solutions in a market that previously did not exist. Larger medium-heavy rockets primarily for GEO launch are undergoing a wave of change, cutting costs per kg launched by about half as the industry unveils the next generation over the next 3-5 years. Industry is working through growing pains as it wrestles with the technological and economic implications of reusable rocketry. GEO launches over the next two years will likely be highly consolidated between SpaceX and Arianespace, but the market will become more competitive eventually. LEO constellations boost their share over the longer term.

Light rockets create optionality

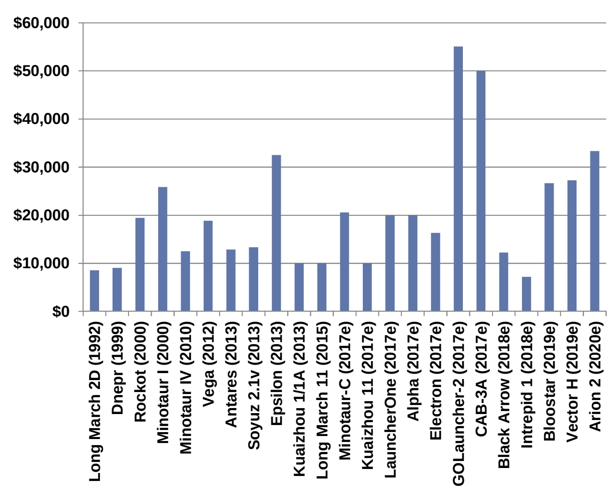
Catering to the smallest satellites, a new class of small rocket is emerging. Priced between ~$3mn and ~$10mn, the rockets offer solutions for payloads of 50-500kg. One, the CAB-3A (a CubeCab company rocket) targets individual CubeSat payloads (<5kg) at an estimated price of $100K for a single cube and $250K for a three-unit CubeSat. These assets were normally launched as secondary payloads on larger launch vehicles, but that left smallsat operators subject to the schedule and needs of the primary customer.

Exhibit 19: Light rocket pricing over time
New designs tend to focus on a new class of launcher



Source: Company data, FAA, Goldman Sachs Global Investment Research.

Exhibit 20: Light rocket pricing per kg to LEO
Smaller rockets tend to be more expensive per kg



Source: Company data, FAA, Goldman Sachs Global Investment Research.

The flexibility offered by the new light rockets comes at a price. On a per kg basis, the cost to launch to LEO is generally higher than existing solutions. Rockets like Arianespace's Soyuz have a payload capacity that makes them well suited to deploying a group of satellites along a single orbital flightpath, as demonstrated by its role in launching the OneWeb constellation of 650+ satellites, 32-36 at a time according to SpaceNews. Other rockets, like India's PSLV, are gaining note as dedicated CubeSat deployment vehicles. A single rocket deployed 104 satellites on February 15, 2017, a new record. Most of the payload were optical imaging CubeSats for Planet Labs. The capability to deliver volume will support launch on heavier end of the rockets typically tasked to LEO missions. Bundled smallsat payloads on these rockets, while lacking the flexibility of single-payload launches, continue to provide the most economical solutions. Some even larger rockets, primarily built for GEO missions, can be tasked with LEO payload delivery. Furthermore, these large rockets are a particular threat to the startups, since they are likely lower cost. As shown below, while the demand for light rocket launchers could be significant, prevalence of larger rockets (able to lift thousands of kg) could dramatically reduce the opportunity. ULA now offers free CubeSat launch slots as secondary payloads on some flights.

Exhibit 21: Smallsat units (StratSpace) and upmass (GSe) per year and projected rocket demand sensitivities (units)
Demand could be significant for ultralight launchers, but a handful of larger vehicles could limit opportunity

Smallsat (1-150kg) launch demand per year									
	2017	2018	2019	2020	2021	2022	2023	2024	2025
Satellites/yr	341	477	513	488	536	566	604	591	613
Implied kg/yr	6,540	15,903	20,225	19,963	22,123	23,765	26,698	27,268	28,555

Rocket lift to LEO capability (kg per rocket)

Annual lift demand (kg)	Sample rockets:	Vector-R	Vector-H	Arion 2	Electron	LauncherOne	Rockot/Vega	Soyuz/Dnepr/PSLV	Falcon 9/Ariane 5
		50	100	150	300	500	2,000	3,000	20,000
	3,000	60	30	20	10	6	2	1	0
	6,000	120	60	40	20	12	3	2	0
	9,000	180	90	60	30	18	5	3	0
	12,000	240	120	80	40	24	6	4	1
	15,000	300	150	100	50	30	8	5	1
	18,000	360	180	120	60	36	9	6	1
	21,000	420	210	140	70	42	11	7	1
	24,000	480	240	160	80	48	12	8	1
	27,000	540	270	180	90	54	14	9	1
	30,000	600	300	200	100	60	15	10	2

*Volume constraints and idiosyncratic needs likely add to the theoretical opportunity shown here, which is only driven by payload weight

Source: StratSpace, Goldman Sachs Global Investment Research.

Significant opportunity for smallsat launch, but larger vehicles could reduce it

LEO launch outlook: Given the rate and ease by which smallsats can be deployed, we are somewhat concerned about whether the market will be able to sustain the variety of new rockets that are poised to begin operations in the next two years, but the sheer volume of smallsats in backlog will create opportunity for a few providers. There has been a shift to smallsats as a share of total launches, and we believe that they will grow off a low base.

Our view on individual smallsat launch providers becomes more favorable if particular companies secure agreements with satellite operators or government bodies. For example, Virgin Galactic will provide a constellation-patching solution for OneWeb in the event of satellite failure. Other ultra-light launch providers could conceivably participate in the current US government push to establish a reactive rapid-launch capability whereby it could quickly replace satellite combat losses with emergency smallsats.

On the larger side of light rockets, we see a continued low rate of demand for launch—likely less growth than in the ultralight market, with the exception of the deployment of the OneWeb constellation by Soyuz. The manufacturers of the traditional light rockets typically provide other launch and manufacturing services, with that diversified revenue profile being key to our positive outlook on them.

Space Startups: Vector

The Problem: Smallsat operators face major launch delays, which can be particularly problematic because they are often working from seed or Series A financing. Delays can tie up a large portion of that early stage funding for potentially years. There are now ~1,500 smallsats planned for launch in 2018-2020, according to a StratSpace report. Many are likely to fly together on ultralight launchers.

The Solution: Vector has designed and flown a class of rapid-launch low cost rockets. The company plans to achieve cost efficiency by launching more than 100 rockets per year—and it already has at least that in backlog. The use of smaller rockets allows satellite operators better scheduling and orbital insertions. Critically, their pricing and payload capabilities are likely competitive with most paid-launches as secondary payloads on medium-heavy rockets, which are the current options for launch.

The Bottleneck: If launch tempos are going to increase to the level Vector and other ultralight launch companies have pointed to, ground infrastructure availability would become an issue. This is a good problem to have for an industry that made use of the same pads for decades. Within the last decade, the number of commercial launch sites has grown rapidly, with SpaceX, Orbital ATK, Blue Origin, Rocket Lab, and Vector taking steps to ensure regular launch capabilities.

Exhibit 22: Vector's rocket is highly mobile and can launch from numerous sites, creating optionality

Source: Vector.

Shifting demand sources, new competitors on supply side create uncertainty near term

Medium-heavy lift rockets reinventing themselves

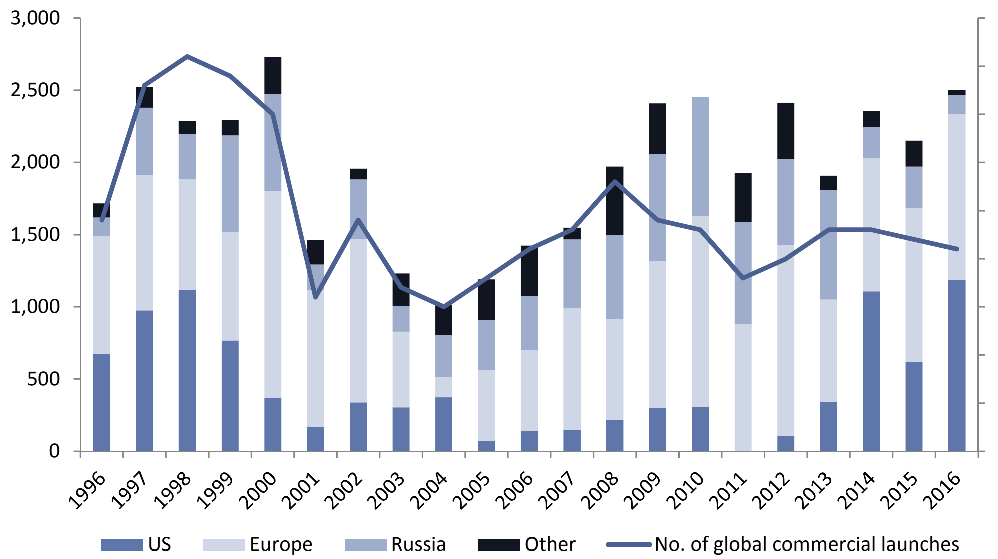
This segment is the hub of economic activity in launch, and it is in turmoil. For decades, little changed, but the arrival of SpaceX and the 'Silicon Valley-approach' to engineering is catalyzing change – the next generation of rockets could cost half as much as the current generation as the industry becomes more competitive and efficient. But moves to cut cost are testing the industry's safety records. The industry is reinventing itself, ushering in a new generation of rockets built around the debate of the economics of reusability.

We see risk to the achievement of planned launch rates medium term to GEO. Short term, launches are set to accelerate at SpaceX and Arianespace, as they launch the Iridium, OneWeb, and SpaceX constellations; however, current satellite order rates and a planned softening in capex among satellite service companies points to weakness on the horizon. Furthermore, the SpaceX-Arianespace commercial launch duopoly will be broken around that time by several new entrants, disrupting the GEO market. Together, these factors suggest challenges for launch providers.

Given the size of launch in capex of satellite service, lower prices can help sustain that industry short term before fueling growth in new applications and on-orbit capabilities.

Background on medium-heavy rockets:
Medium-heavy lift rockets are primarily tasked with launch to GEO, but they also ferry supplies to the International Space Station and increasingly LEO satellites. After the cost of the satellite itself, launch is the next most significant factor in the capex of satellite operators. According to the Satellite Industry Association, global spending on competitively-procured launches totaled $5.4bn (65 launches, including commercial and competed military launches) in 2015. We estimate that the total spending on medium-heavy lift launch is nearly triple that when factoring in classified spending and non-satellite payloads like cargo runs to the space station. In Exhibit 23, we outline commercial launches by geography over time.

Exhibit 23: Europe has been the largest commercial launch provider
Commercial launch revenues ($ mn) (LHS), and total commercial launches per year (RHS)



Source: FAA, Goldman Sachs Global Investment Research

Given Europe's relatively low-profile compared to the US and Russia in space, the scale of the European commercial launcher industry is significant (the major difference is Europe's low military and civil involvement). In 2016, the US carried out 22 total launches, Russia had 17, and China launched 19, while Europe launched 11. Rest of world launches brings the total orbital launch volume to 83, with 3 failures according to the Space Launch Report.

America rising: From 2006-16, Europe has accounted for 45% of global commercial launch revenues, compared with Russia at 25% and the USA at 19%. In the last few years, the emergence of SpaceX and failures of International Launch Services rockets have led to larger US share, creating a commercial launch duopoly between Europe's Arianespace and the American SpaceX/ULA. This can be seen in 2016, where the revenue split was broadly even at 46%/47%.

GEO is stagnating, while LEO takes flight

A tale of two orbits: Although GEO satellite orders have slowed, we expect launch activity to be strong the next two years driven by LEO. Satellites take 2+ years to build so weak orders take time to impact launch. Planned deployment of LEO constellations creates opportunity, most already committed to a launch provider (Arianespace or SpaceX). SpaceX will deploy its own constellation, so we do not factor that into the opportunity set but it is a significant uptick in total launch volume. These windfall years consolidate the market, and new entrants will largely be left with GEO commercial. However, the shift to LEO could open new opportunities, as satellites there are shorter-lived.

Exhibit 24: Medium-heavy commercial rocket launch estimates
Large schedule slips from 2016 into 2017; non-intracompany launches and representative sales

Mission	Provider	2016	2017E	2018E	2019E	2020E
LEOSAT Constellation	Unknown	0	0	0	1	3
OneWeb Constellation	Arianespace	0	0	7	7	7
Iridium Constellation	SpaceX	0	5	3	0	0
NASA (ISS transport)	SpaceX; Orbital ATK; Sierra Nevada	4	6	8	7	7
Roscosmos (ISS transport)	Roscosmos/Progress	7	5	5	5	5
Other LEO commercial	Mixed	2	2	2	2	2
GEO commercial launch	Mixed	12	25	20	18	18
Total		25	43	45	40	42
Growth			*72%*	*5%*	*-11%*	*5%*

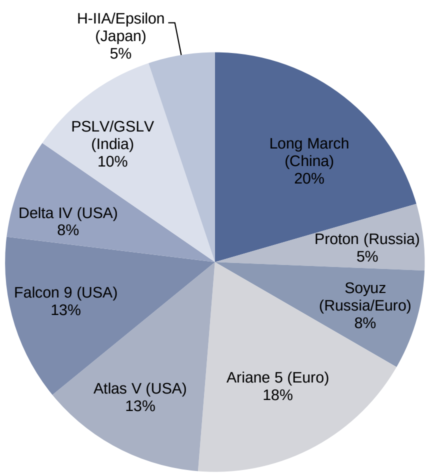
Mission	Provider	2016	2017E	2018E	2019E	2020E
LEOSAT Constellation	Unknown	0	0	0	80	240
OneWeb Constellation	Arianespace; Virgin Galactic	0	0	490	490	490
Iridium Constellation	SpaceX	0	300	180	0	0
NASA (ISS transport)	SpaceX; Orbital ATK; Sierra Nevada	320	480	640	700	700
Roscosmos (ISS transport)	Roscosmos/Progress	160	160	160	160	160
Other LEO commercial	Mixed	160	160	160	160	160
GEO commercial launch	Mixed	1,440	3,000	2,400	2,160	2,160
Total ($mn)		$2,080	$4,100	$4,030	$3,750	$3,910
Growth			*97%*	*-2%*	*-7%*	*4%*

Source: Company data, FAA, Gunter's Space Page, Goldman Sachs Global Investment Research.

Commercial is highly concentrated, whereas government launch is more diversified globally (though concentrated nationally)

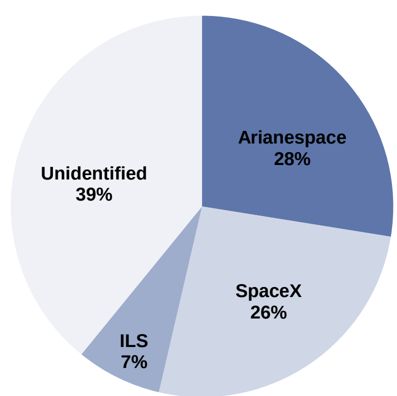
Defense industrial base requirements support diversification: Looking beyond commercial, launches have been fragmented; however, it is more concentrated than it first appears—most rockets compete in their own national markets with little serious competition. For idiosyncratic reasons, many are not very competitive for certain commercial applications. Some diversity of offerings is likely to be restored with the next generation of rockets, which could time with the commercial headwinds.

Exhibit 25: Defense market is fragmented thanks to national support…
2016 market breakdown for launch to GEO



Source: Space Launch Report.

Exhibit 26: …while commercial market is increasingly concentrated
2017-19 commercial GEO market breakdown



Source: FAA.

Related reading

In a companion note also published today, our European A&D analysts explore one of the byproducts of private competition in space: Airbus and Safran's decision to consolidate their Arianespace stakes into Airbus Space Launchers.

Read the note →

The new guy vs. the legacy guy - Falcon 9 vs. Ariane 5

The cost of access to space has come down more in the last decade than in the entire prior period of space travel. The arrival of companies like SpaceX, offering launch services at discounts as high as 40%, has shaken the market. Whether these changes post an existential threat to the 'old guard' of providers is so far unclear, and Arianespace has maintained its share of commercial launches despite the newcomer SpaceX and its Falcon 9. Eventually the question will be if expendable rockets can compete with reusable ones.

Exhibit 27: At first glance, the price difference is vast
Estimated payload and pricing for Arianespace's Ariane 5 vs. SpaceX's Falcon 9

	Current Generation	
	Ariane 5	Falcon 9***
Max Payload to GTO* (kg)	9,500	5,500
Price ($ mn)	178	62
$1,000/kg	18.7	11.3
First Launch	1996	2010
Successes/Total**	87/91	30/33
Success Rate	96%	91%

*GTO: Geosynchronous Transfer Orbit
**Partial failures classed as failures
***SpaceX pricing assumes return of first stage for later reuse by the company

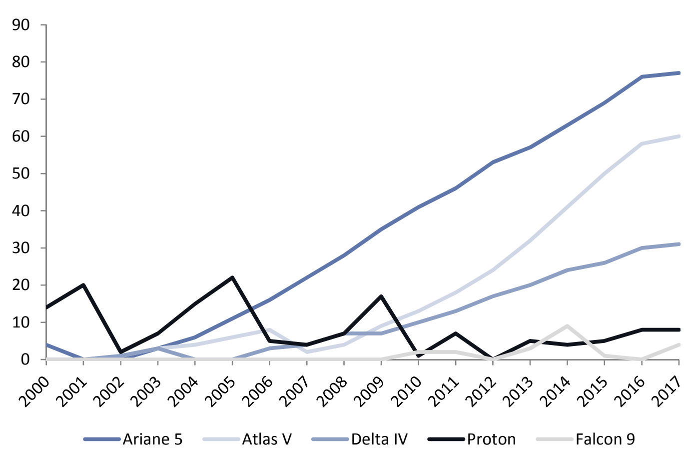
Source: FAA, Goldman Sachs Global Investment Research.

Pricing on a per kg basis is somewhat deceptive, since some rockets are more powerful than needed or else have volume restrictions on payloads. On a per launch basis, SpaceX's Falcon 9 is ostensibly still very competitive, but it does not take the commanding market share one would expect given its pricing on a per kg basis.

Ariane can carry two satellites at once, helping to balance the math: While the $/kg rates assume a max payload, that is unlikely to always be the case. Ariane 5 is able to better maximize it, regularly carrying two payloads per launch. It can also split costs between two different customers (though that is not always easy to find).

Safety matters: While difficult to get an apples-to-apples price comparison, it is likely that the Falcon 9 offers a less expensive service than Ariane 5 and other rockets. However, a key mitigating factor is success rate. The numbers suggest a similar level of reliability, with Ariane at 96% vs. Falcon 9 at 91%, but that gap is considerable in the launch community, and timing matters. Since 2002, Ariane 5 has been accident free, with 77 consecutive successful launches, while SpaceX has suffered two failures in the past two years.

Exhibit 28: Ariane 5's impressive safety record
Consecutive launches without incident at year end



Source: Company data, FAA, Goldman Sachs Global Investment Research.

Safety record justifies some pricing premium: A GEO satellite can be worth hundreds of millions of dollars, making the difference between a 90% and a 100% launch success rate substantial. According to some industry sources, the cost of insuring an Ariane 5 is 1/3 that of a Russian Proton launcher. The Proton has suffered 5 failures in 6 years, including an accident in 2015 that destroyed a MexSat payload insured for ~$390mn. Given rates of about 5% for an Ariane 5, a 3x insurance rate would essentially add nearly $40mn to the Proton's price relative to Ariane, without factoring in lost revenue. SpaceX's failed launches would imply that they are likely seeing higher insurance rates as well.

Failures jeopardize physical assets of satellite operators and their operational plans/cash. Failures can result in multi-month grounding for a family of rocket. ULA, another non-equatorial medium-heavy launch company, estimates the average delay from operational issues is 3-6 months, versus their average of 2-weeks.

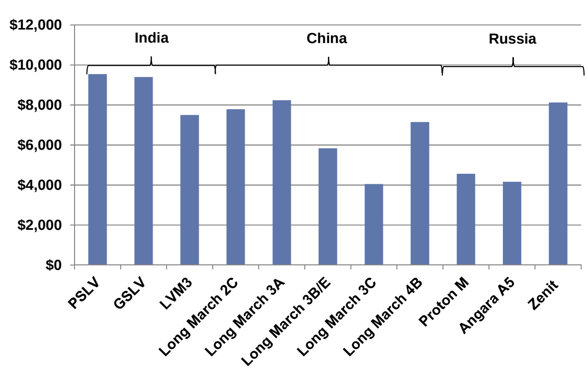
ULA's Atlas V has a perfect safety record, but its price is high. There are no scheduled commercial Atlas V launches in 2017 vs. 2 in 2016. The rocket remains a mainstay of the US government fleet, where launch demand is robust.

Location matters: Arianespace rockets launch from French Guiana, very close to the equator. This means the launch is much more efficient. NASA engineers estimated that the payload penalty associated with launching the Saturn V from Cape Canaveral vs. an equatorial launch would be at least 20% for GEO and 80% for LEO.

The GTO capabilities quoted by SpaceX are for an orbit with an inclination of 27 degrees - likely the most efficient GTO orbit given their less-equatorial launch sites, but not a generally desirable one. Conversely, the GTO capabilities of Arianespace when launching from the spaceport in French Guiana create nearly a direct route to GEO. Using the numbers from ULA: a max payload of 8,856kg to an inclined GTO on its Atlas V equals delivery of just 3,856kg to GEO. The gap between Arianespace's GTO and GEO capabilities should be nearly nonexistent. This essentially means that the Atlas V (and most rockets launched from higher latitudes) appears more price competitive than it actually is.

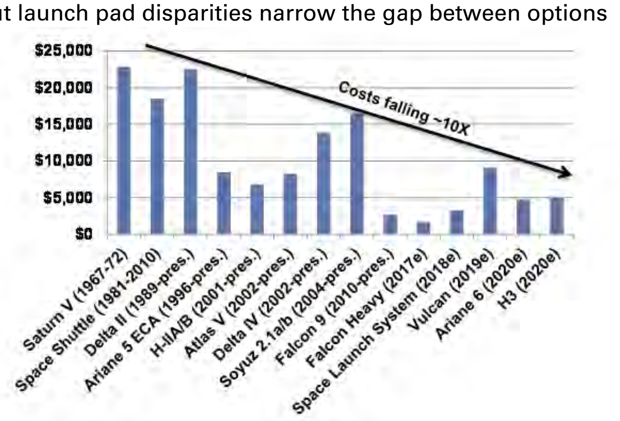
Certain LEO orbits are more desirable, but the capability gap associated with different launch sites is somewhat minimized. As such, we compare and analyze all rockets on a cost-to-LEO basis (incl. in deriving our 10X launch cost reduction estimate) because it helps neutralize the impact of the launch location, but it should be noted that the pricing advantages of less equatorial companies like SpaceX and ILS narrow when competing for launches to GEO, where most launch revenue is derived. This helps old-guard launch providers stay competitive, even if their rockets are not.

Exhibit 29: Low-cost country offerings
Cheaper than Western options from labor cost, state support



Source: Company data, FAA, Goldman Sachs Global Investment Research.

Exhibit 30: Launch costs have been falling (cost-to-LEO)
But launch pad disparities narrow the gap between options



Source: Company data, FAA, Goldman Sachs Global Investment Research.

Other competitors are catching up: With satellite operators heavily reliant on Arianespace and SpaceX in the near term, other launch providers are becoming more aggressive on price with current vehicles to stay competitive. Nearly all rocket models will be replaced within the next 3-5 years, with new clean sheets adding further optionality and pressure to the market. We think customers will reward diversification, even if some price gap remains. SES and Eutelsat have indicated a commitment to ensure that the launch industry does not become a duopoly between Arianespace and SpaceX due to concerns about long-term pricing and reliability, supporting the introduction of new models. We loosely divide the field into current and next generation rockets, finding that most platforms will likely reduce the cost per kg to LEO by about half in the new generation.

Exhibit 31: Changing costs ($/kg to LEO)
The first step function lower should decrease costs 38% on avg.

Prior generation		Next generation		Change
Rocket	$/kg to LEO	Rocket	$/kg to LEO	%
Proton	$4,565	Angara A5	$4,167	-9%
Ariane 5	$8,476	Ariane 6	$4,762	-44%
Falcon 9 *	$4,654	Falcon 9 FT*	$2,719	-42%
N/A	N/A	Falcon Heavy*	$1,654	N/A
H-IIA/B	$6,818	H3	$5,000	-27%
GSLV	$9,400	LVM3	$7,500	-20%
Saturn V	$22,857	SLS	$3,268	-86%
Atlas V/Delta IV	$11,093	Vulcan	$6,378	-43%

*Assumes no price increase if main stage not returned

Source: Company data, FAA, NASA, Goldman Sachs Global Investment Research.

Exhibit 32: Changing costs ($mn per launch)
Planned prices per launch fall about 31% on average

Prior generation		Next generation		Change
Rocket	Price ($mn)	Rocket	Price ($mn)	%
Proton	$105	Angara A5	$100	-5%
Ariane 5	$178	Ariane 6	$100	-44%
Falcon 9 *	$61	Falcon 9 FT*	$62	1%
N/A	N/A	Falcon Heavy*	$90	N/A
H-IIA/B	$113	H3	$50	-56%
GSLV	$47	LVM3	$60	28%
Saturn V	$3,200	SLS	$500	-84%
Atlas V/Delta IV	$200	Vulcan	$85	-58%

*Assumes no price increase if main stage not returned

Source: Company data, FAA, NASA, Goldman Sachs Global Investment Research.

Why launch costs are falling

Prices are falling as smaller, lighter, more powerful, and/or less expensive rockets enter the market. Most of this is healthy, where the industry is becoming more competitive and costs are coming out; however, there may be instances of concurrency, subsidies, moral hazard, and risk allocation that could be damaging to the industry. We explore the key drivers of lower costs, as well as the headwinds that support pricing near current levels:

Positive factors: David Quancard, COO of Airbus Safran Launchers, said 50% of the cost of a rocket propulsion system lies in its industrial procedures, according to SpaceNews, which is reflective of the operating leverage pervasive in the industry. The company won 21 launches for its Soyuz rocket over the next 2 years, an important uptick. SpaceX likely also benefits from higher volumes from constellation launches.

Ariane 6 will replace the Ariane 5 as the medium-heavy lift offering by Arianespace

Below we outline the 5 main ways that we believe costs can be stripped out of the Ariane 6 relative to the Ariane 5 with changes to production processes:

1) **Margin elimination through Airbus-Safran Launchers.** Previously, Safran (and other suppliers) sold parts to Airbus, who assembled the launcher as the prime contractor and then sold the completed product to Arianespace. Margin was therefore taken twice on many components—now it is just once.

2) **ASL synergies**. Alain Charmeau, head of operations for space systems at Airbus, said 80-90% of the cost of a rocket is manpower, making efficiency key. The supply chain is changing too: the structures of the Ariane 5 are built in five places across Europe. On the Ariane 6, the entire structure will be built in one factory.

3) **Industry-led design.** For the Ariane 6, the European Space Agency (ESA) has handed over design authority to Airbus-Safran Launchers, which should allow greater cost focus.

4) **Industrialization and new technology.** Commercial focus should also allow better adoption of new cost-saving technology, perhaps the most clear being additive manufacturing. Importantly, a large new hanger in French Guiana will allow horizontal assembly of the launcher (which is both faster and cheaper than vertical stacking), mimicking the style of SpaceX and the Russian Proton.

5) **Integration with Vega.** A slight but significant change is that the Ariane 6 will use the same P120 solid rocket strap-on boosters used on Arianespace's Vega C. This means shared development costs and benefits from larger production scale.

SpaceX has also leveraged higher production volumes to reduce cost. Most rockets have historically relied on one or two main stage engines—the Falcon 9 uses 9, plus a 10th in the second stage. More engines introduce more risk, a key reason the Soviet Union's 30-engine N1 rocket never made it to the Moon. But engineering and manufacturing have advanced, and making a large number of small engines brings an element of standardization and mass production to rocketry.

Negative factors: Competition and the ongoing price war could diminish quality, passing off risk short term to launch insurance providers. In February 2017, the Wall Street Journal reported that the US Government Accountability Office was preparing a report detailing that SpaceX's fuel pumping fans were prone to cracking.

While the failure rate and possible system defects impact SpaceX launches, this may be a factor of the corporate culture of iterative innovation rather than quality control or supply chain; nevertheless, it could put the aggressive launch rate proposed by the company at risk. While innovation is healthy in the long term, higher failure rates across the industry could signify some saved R&D costs at manufacturers but a greater financial burden on insurance providers and operators, plus a risk profile to launch that had not been there previously.

New innovative practices increase risk short term for customers/insurance, but may be justified long term

Companies like SpaceX and Blue Origin represent fundamentally different approaches to rocketry. To us, it appears the old guard, striving for reliability, kept to the adage, "if it ain't broke, don't fix it," since changing out a single mission-proven system introduced uncertainty to the next flight. The question now becomes whether the new companies' approach can improve their rockets faster than possible failure rates drive away customers.

To date, we have seen little pricing discipline in the market, with Arianespace selling below cost due to subsidies (according to the company) and SpaceX appearing to earn close to no profit on its commercial launches (based on company documents published by the Wall Street Journal; though NASA contracts are likely accretive). Over the last few years Arianespace has operated at around breakeven, but with an annual subsidy from the ESA near €100mn (this has halved over the last decade) while the ESA and CNES (the French national space agency) jointly provide the launch infrastructure in French Guiana. The ESA has stated that the Ariane 6 will need to succeed without an operating subsidy.

Pricing support: While costs are trending lower, there could be a reversal based on existing weakness in the satellite services and manufacturing markets.

Consolidation & Risk: If the industry remains consolidated between two primary launch providers, pricing could be stagnant if both are satisfied with share. We do not think limited competition would slow innovation at SpaceX, since new entrants are on the horizon and it has set ambitious long term goals (creating technologies and attempting missions that are unprecedented), but it could potentially hold onto pricing to grow margins.

Government: We do not expect the same level of price compression in the government market as we see in commercial because of the emphasis the government has placed on reliability, availability, capability, and expendability. Government demand is likely to remain strong, and the higher assurance required there will slow the downward pricing trend. Given recent supplier issues, we think the government is committed to maintaining a competitive environment. Government contracting vehicles may support better margins than commercial price shootouts over launches. The EELV block buy should support ULA pricing for several years. For the foreseeable future, government launches are likely to avoid reused rockets.

China and India are cheap, but less threatening because of trade barriers

Trade barriers: The Chinese Long March rockets are priced very competitively, and have low failure rates. US and European launch providers are largely able to ignore this competitive threat due to regulatory barriers that prevent US components flying on Chinese rockets (nearly all European satellites use US components too); however, it is unlikely that these companies will see much opportunity to grow in Chinese markets. This is because of retaliatory trade barriers, cost competitiveness of Chinese offerings, and the near non-existent Chinese commercial satellite industry. Foreign satellite operators are unlikely to employ Chinese satellites (which could create demand for Chinese launchers), because the nascent Chinese commercial satellite manufacturers have yet to prove their technology over a meaningful period of time. Their oldest satellite is 6 years old according to the Union of Concerned Scientists database as of June 2016. Rather, the Chinese market is likely to play out in relative isolation for the foreseeable future.

India is becoming a more common launch site for US and European payloads, though normally requires a waiver. India is developing increasingly large rockets, with its new LVM3 launcher a possible new competitor if regulatory patterns in smallsat launch are repeated for GEO, but we do not think that is likely given the wide availability and entrenchment of US competitors. Furthermore, expenses are rising as labor costs grow. Success rates are not high and there is significant government support, lessening the likelihood of international commercial use at the higher end of their capabilities.

Is there room for new entrants?

Given likely medium-term launch rates, there is little flexibility for additional offerings, but many are in the pipeline:

1. Arianespace is developing a replacement for the Ariane 5, the Ariane 6.
2. ILS is replacing its troubled Proton with the Angara rocket.
3. ULA has begun development on the Vulcan, primarily for government markets, but it will likely also compete for commercial launches like its predecessors.
4. SpaceX will likely continue development of its reusable Falcon 9, along with its untested Falcon Heavy.
5. Blue Origin is ostensibly targeting the industry with a reusable rocket built around its liquid-fueled BE-4 engine.
6. Orbital ATK is considering a clean sheet solid-fueled design pending an Air Force commitment to support development and purchase of the rocket.

We think the unique capabilities and likely price points of some of these platforms are sufficiently compelling to potentially compete with the current Falcon 9 and Ariane 5. But the market is likely not large enough to naturally support this many competitors.

1. Arianespace: Ariane 6

The challenge for Arianespace is what happens if/when the Falcon 9 becomes a reliable, proven reusable platform at a significant discount. The ESA and Arianespace have responded to the changing world via the Ariane 6 project, scheduled for its first launch in 2020. The plan is for a 62 (2 solid rocket boosters) and 64 (4 SRBs) version of the launcher, with the 62 model primarily launching single payloads to GTO and the 64 launching dual-manifested payloads.

Exhibit 33: Ariane 6 aims to narrow the gap to the Falcon 9 and Falcon Heavy
Estimated payload and pricing for Ariane 62 & 64 vs. Falcon 9 & Heavy

	Future Models			
	Ariane 6 A62	Ariane 6 A64	Falcon 9***	Falcon Heavy***
Max Payload to GTO* (kg)	7,000	10,000	5,500	8,000
Price ($ mn)	80	100	62	90
$1,000/kg	11.4	10.0	11.3	11.3
First Launch	2020E	2020E	2010	2017E
Successes/Total**	NA	NA	30/33	NA
Success Rate	NA	NA	91%	NA

*GTO: Geosynchronous Transfer Orbit
**Partial failures classed as failures
***SpaceX pricing assumes return of first stage for later reuse by the company

Source: Company data, FAA, Goldman Sachs Global Investment Research

Industry estimates for the targeted price-per-launch vary, but average around $80mn for an Ariane 62 and $100mn for a 64, but with a larger usable payload than Falcon Heavy. On these numbers the Ariane 6 looks very competitive – assuming similar reliability to the 5.

2. International Launch Services: Angara

Following a series of failures by its current generation Proton rocket, ILS has designed and launched the first in a new series of Angara rockets. Under development since 2004, there are currently two versions of the launcher: the heavy A5 which will replace the Proton rocket (estimated 7,500kg to GTO, with dual payload, according to the FAA), and the light A1.2 version (for LEO missions), which is due to replace the Rokot. The Angara family is built around the same push for volume that is at SpaceX and Arianespace, as they will both employ the same Universal Rocket Module (URM-1) which is designed to form the core first stage of every Angara vehicle. Currently the Angara 5 costs around $100mn, (vs. the Proton-M at around $65mn), but according to the program designers, the target is to be 20% cheaper by 2025. Should these savings materialize it would be at a very competitive price point ($9,600/kg vs. the Ariane 6 and Falcon 9 in the $10,000-12,000/kg range).

Hampered by Politics? There are two significant political hurdles for the Angara to overcome. First, part of the project's appeal lies in its strategic independence. The Russian government has spoken about the desire to have a fully-Russian and independently launched rocket, whereas current rockets have a reliance on foreign (mostly Ukrainian) component suppliers. The focus on cultivating an all-Russian supply chain, and using new and untested suppliers, may be at odds with keeping down costs.

The second issue is the launch site. The Proton currently launches form Baikonur, in Kazakhstan, leaving Russia exposed to expensive rent and lacking strategic independence. As a result, the Angara will launch from Plesetsk, a few hundred kilometers north of Moscow and near the Arctic circle. The result of this will be a negative payload impact to GTO, leaving the Angara with a similar capability to the Proton. Plans to build a new launch site in the far east of Russia have been put on hold as the government is prioritizing a new launch site for the Soyuz-2. The Angara is likely to be cheaper than its European competition, but the performance disadvantage from launching so far north will leave it less competitive on the international market.

3. United Launch Alliance: Vulcan

Developed for US government launch as a replacement for Atlas and certain Delta launches, the Vulcan will likely compete commercially too. Atlas and Delta launches have strong track records for success, but that has come at a less competitive price. Because the Vulcan is due to eventually replace the Delta as well as the Atlas, the rocket could be flown nearly 50% more than the current Atlas, which should help save on cost. The BE-4 engine by Blue Origin and OA's solid boosters provide thrust for the main stage. The company has stated that it will continue to employ the workhorse Centaur second stage before shifting to a new system.

The United Launch Alliance, a joint venture between Boeing and Lockheed Martin, was formed in 2006 as lower launch volumes, expanding costs and an ongoing legal battle threatened the survival of the industry. The mainstay for its government business is a block buy contract for Evolved Expendable Launch Vehicles (EELV). The current contract guarantees the purchase of 36 rocket cores from ULA through 2018. Additionally, the US government pays ULA as much as a billion dollars per year to maintain launch readiness.

4. SpaceX: Falcon 9, Falcon Heavy, ITS/BFR

SpaceX continues to invest in reusable rocketry, and it plans to have its reusable rockets ready when the next generation of competitors launch. Plus, the Falcon Heavy is planned to launch this year, with several launches planned over the next several years. Additionally, the company plans to invest in an even larger rocket, temporarily named the Interplanetary Transport System or BFR, which is intended as a platform for trips to Mars. Based on planned company specifications, it would be the largest rocket ever launched, would add scale that space transportation has never seen, and could support the transport of Mars infrastructure. The company suggests it will cost $230mn to manufacture the first stage booster, plus either $130mn for a tanker or $200mn for a human-rated ship, depending on the variant. The company suggests the Booster could perform as many as 1,000 launches, with an average maintenance cost of $200,000 per use. Combining the different costs required for a trip to Mars, SpaceX says they can reduce the cost to $140,000 per ton.

5. Blue Origin: New Glenn

Focusing on a reusable solution, Blue Origin is likely to fly a heavy-lift rocket that will directly compete with SpaceX. These two designs are likely the only rockets in the next generation that fully incorporate reusable technology. Depending on the success of the rockets, satellite operators may flock to these 'flight proven' rockets, which would be detrimental to the expendable rocket industry, or they might reject them. In that case, views on reusability might put those systems at a slight disadvantage to expendable options, particularly if those rockets have had high failure rates, though it would not likely to drive them out of the market.

Blue Origin's liquid-fueled engines are significant—only one other American company, Aerojet Rocketdyne, manufactures such systems today. Many current generation rockets like the Atlas V employ Russian-made engines, which have come under scrutiny in Washington as geopolitical tensions may compromise the supply of engines, and therefore access to space. ULA's Delta series, which has some overlapping capabilities with Atlas, could likely serve as an alternative if ultimately needed. So far, the company has successfully flown its BE-3 engine on its New Shepard suborbital vehicle—it appears to be a contender as the primary upper stage propulsion for several next-gen entrants.

The BE-4 engine is likely to power ULA's next-gen Vulcan rocket, as well as a proprietary Blue Origin rocket, called the New Glenn. The engine's capabilities likely place the New Glenn rocket firmly among other heavy rockets, providing the thrust to deliver most commercial satellites to geostationary orbit. The New Glenn rocket will employ 8 of these engines. As with SpaceX, it is likely the company becomes its own customer, using launch capabilities as a stepping stone to other economic drivers. Blue Origin recently booked Eutelsat as its first customer for the New Glenn, with that flight in 2021 or 2022, and 5 flights for OneWeb.

6. Orbital ATK: Next Generation Launcher

The next-generation launcher (NGL) proposed by OA attempts to break the US government launch ULA / SpaceX duopoly while offering a product with key new capabilities for the Air Force. The OA rocket has a solid-fueled main stage, allowing for storage and more rapid deployment—a potentially important consideration given the Pentagon's prioritization of rapid launch programs that could replace combat losses of satellites. Though first intended for government launch, the cost, capability, and reliability could lead to commercial as well.

We think the NGL's solid-fueled lower stages will offer more thrust early in the launch sequence than vehicles like the Falcon 9, but less than rockets like the Delta IV Heavy, which are much more expensive. This could create a Goldilocks scenario for OA, where its rocket could lift payloads too large for Atlas V or Falcon 9-size launchers but too small to fully justify a heavy launcher in both military and commercial markets. This rocket could also be down-sized and replace the likely higher-cost Antares or synergistically assure OA's low-cost access to space for other programs like a Mission Extension Vehicle.

We expect the solid-booster design could reduce failure risk, the costs of which are largely shouldered by the government, which essentially self-insures the launch and payload. NASA has estimated the likelihood of space shuttle solid rocket booster failure was 0.001% vs. the historical liquid failure rate of about 6%, though history suggests it is higher.

Cost competitiveness of solid fueled rockets. Low production volumes (there are fewer than 100 launches per year globally) mean that launchers rarely reach economies of scale and liquid-fueled vehicles are often over-engineered since testing opportunities are limited.

However, solid rockets are much more common, because of their military applications. This creates more opportunity for testing, development, and spreading out cost. ATK built solid rockets for the space shuttle, America's nuclear arsenal, and now the exploration-class SLS. ATK has more launches into space than SpaceX and ULA combined.

The comparatively high volume of solid rocket work, along with the experience gained in past decades of refining the technology, suggests that OA can reduce cost on a likely-cheaper system. If the company launches its MEV vehicles on this rocket, that would further increase the production volumes and support lower costs, all else being equal.

Solid rockets are inherently cheaper. They consist of a casing filled with solid fuel, without the same complicated propellant mixing and thrust vectoring associated with liquid fueled engines and main stages. In 2002, legacy ATK was awarded a $429mn contract extension for 70 reusable solid rocket boosters for the Space Shuttle. This implies a cost per booster of $8mn in 2016 dollars. Thiokol (acquired by OA) received a contract in 1999 that puts each booster at $34mn in 2016 dollars. A 1996 contract for 54 Pratt & Whitney space shuttle boosters implies a cost per booster of $14mn in 2016 dollars. These prices imply substantially lower cost/thrust ratios than liquid alternatives. We think a bottom-up cost analysis points to a roughly $50mn-$70mn launch vehicle. We use $70mn in our assumptions for commercial launch and $90mn for government launches, which tend to command a premium. A lower price is certainly possible. Plus these could be made reusable.

Thrust lowers cost per kg launched. We expect an NGL commercial launch price of approximately $70mn with the capability to deliver up to 25,000 kg to LEO. In Exhibit 34, we show the sensitivity of these estimates with shaded cells indicating a pricing discount relative to a commercial Falcon 9 launch, which is likely the closest competitor. At both Government and Commercial price points, we think OA could achieve a lower cost per kg delivered to LEO.

Exhibit 34: Cost per kg to LEO sensitivity table
Shaded cells indicate NGL possible pricing below Falcon 9 FT (output in $/kg)

Payload to LEO (kg) \ Launch Price ($mn)	$40	$50	$60	$70	$80	$90	$100
5,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000
10,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
15,000	2,667	3,333	4,000	4,667	5,333	6,000	6,667
20,000	2,000	2,500	3,000	3,500	4,000	4,500	5,000
25,000	1,600	2,000	2,400	2,800	3,200	3,600	4,000
30,000	1,333	1,667	2,000	2,333	2,667	3,000	3,333
35,000	1,143	1,429	1,714	2,000	2,286	2,571	2,857
40,000	1,000	1,250	1,500	1,750	2,000	2,250	2,500

Source: Company data, Goldman Sachs Global Investment Research.

Proven solid booster recovery

While rocket reuse efficacy is still debatable, the legacy ATK business has been recovering and reusing solid boosters for over a decade. OA indicates that reusing the solid-fueled stages is not currently planned, but we think the proven reusability of the Space Shuttle solid rocket boosters suggests OA could introduce reusable main stages to further lower launch costs in the future at minimal cost and risk if it gains sufficient market share.

The great debate: to reuse or not to reuse?

One of the key questions faced by the launch industry today is whether reusable rockets are the future. SpaceX and Blue Origin have been testing reusable rockets, arguing they are critical to keeping costs low. Elon Musk once famously compared expendable rockets to building disposable 747s and throwing them away after every flight.

The cost/feasibility of refurbishing engines is seen differently by industry participants

On the other side of the debate is the old guard - companies that have built rockets for half a century. They argue that the cost of refurbishment does not justify reusable rocketry, especially for current launch rates. They point to the Space Shuttle, which was largely reusable but never saw sufficient operating tempo to bring refurbishment costs down, keeping per launch costs at approximately half a billion dollars. Chief executive of Arianespace, Stephane Israel, has said that the company's initial assessment of reusability pointed to a breakeven launch tempo of 30 times per year—more than 4X their current Ariane 5 rate. Orbital ATK has stated the number could be greater than 100 launches per year. Still, that math may change, so the European Space Agency has begun its own reusable rocket engine development program called Prometheus and a first stage concept capable of horizontal landing called Adeline, built by Airbus. The Prometheus engine will likely first be tested in 2020 for possible use in beyond-next-generation rockets.

We see reusability as a key shift in the industry that is beneficial for its long-term health, enables missions like Mars landings, and improves the engineering knowledge base; however, we see only minor benefits in the short term as launch volumes are likely insufficient to support significant cost decreases and the current technology lacks refinement. We assess the impact of reusability in the near term (rockets launched within 2 years), finding that the technology would likely expand SpaceX margins given the 10% pricing discount the company suggests. We are bullish on the future of reusable rockets, but there will be challenges to bring economics and safety to acceptable levels.

Exhibit 35: Recycling the first stage to find savings
GSe of savings available through re-usable first stage

Re-usable Falcon 9	Falcon 9
Revenue per launch today ($mn)	62
Costs per launch today ($mn)	62
First stage as % of total costs	70%
First stage costs ($mn)	43
Second stage costs ($mn)	9
Vehicle/payload integration ($mn)	2
Program support/SG&A ($mn)	6
Contingency ($mn)	2
Number of uses for first stage ($mn)	10
Amortized reused first stage costs ($mn)	4
Reusable rocket direct costs ($mn)	23
Refurbishment costs of rocket ($mn)	8
First stage savings ($mn)	31
Cost of reusable launch ($mn)	31
Savings seen by second-use customers	10%
Pro-forma sales price ($mn)	56
SpaceX margin with reused rocket	44%

Source: Goldman Sachs Global Investment Research

If this 10% discount were applied to the first reused flight (subsequent flights may necessitate additional discounting and incrementally higher refurbishment costs), the reusable Falcon 9 would see an 11% discount to the Ariane 62 (on a per kg to GTO basis, disregarding launch site payload penalties) vs the current gap of about 40% vs the Ariane 5. We estimate reuse costs could be $8mn for SpaceX based on a 2-month refurbishment period, amortized first launch discounts, one Merlin engine replacement, and about 10% of the first stage's value replaced for missions ordered now for flights in ~2 years.

Should SpaceX succeed in manufacturing a commercially viable reusable rocket, it is not clear what savings might be passed through to operators. The company has changed its estimates from a 100X price reduction in 2011 to just 10% in 2016. Part of this may be related to the company obtaining a fuller picture of the costs associated with refurbishment identified as it moves forward in its development (its plans to reuse a first stage have slipped ~10 months), but it is also possible that the company is satisfied with its market share while capturing a higher margin on what it now labels 'flight proven' rockets.

We think it's likely SpaceX does not offer lower price than competitors to gain radically different market share than planned for 2017—a launch every other week. We think it could be difficult to achieve this rate, and challenging for the supply chain. But even if achieving this rate, it may prioritize margins over an even larger market share.

For the foreseeable future, US government launches will not fly reusable rockets, though if the safety record of these rockets becomes that of 'flight proven rockets' vs. 'second-hand rockets,' we expect the US DoD will revisit its stance.

What the launch industry looks like in the next decade

With the pending wave of new product offerings, we see the industry becoming more competitive. The next several years are likely to be an uncomfortable time for much of the launch industry as external demand decreases amid structural changes in satellite manufacturing. Launch costs are coming down alongside rates, compounding the effect.

We expect launch providers to struggle in this environment, but most are diversified outside this industry or have strong government backing, so they are unlikely to disappear.

Following this period of compression, we expect lower launch costs to eventually stimulate demand. Given the timing of launch payments and their significance for NPV calculations, lower launch costs would help keep satellite operators alive during their own period of turbulence near term and would enable a critical reduction of capex. Exhibit 36 shows that for a representative $250mn satellite (spread over 3 years), a $50mn change in launch costs changes the IRR 200 bp over the asset's 15 year life when the asset generates a fixed $50mn per year.

Exhibit 36: IRR of $250mn satellite services with different launch costs

Lower launch costs have significant impact on IRR

			Investment Period			Operational Period														
Launch Cost	**Satellite Cost**	**IRR**	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
$50mn	$250mn	12%	-100	-100	-100	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
$100mn	$250mn	10%	-100	-100	-150	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
$150mn	$250mn	8%	-100	-100	-200	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50

Source: Goldman Sachs Global Investment Research.

If costs continue to fall, they unlock new demand

Longer term, we believe rockets are gatekeeper technologies and that launch demand is elastic. Lower launch costs open new applications, fueling additional demand. A positive feedback mechanism is initiated as launch volumes pick up, further driving down cost. Eventually, access to space would likely become routine.

We are already seeing the change, and companies like SpaceX and Blue Origin that eventually seek to become their own customers with on-orbit businesses are planning for it. In the case of SpaceX's satellite internet constellation, costs have fallen by about 50% which could mean the launch of at least 50 rockets a year, which would likely more than triple the rate for the entire industry.

New businesses like tourism, asteroid mining, and space-based manufacturing are becoming possible. The latter two, though still a way out, would be economic game changers, while the former normalizes human spaceflight. With reusability a dominating theme for the next decade, the following decade of rocketry may well be defined by the impact of on-orbit fueling and manufacturing. Earth-to-GEO launch could become a thing of the past. Instead, a diversified LEO economy that includes fueling and manufacturing sectors could radically change the payload and power needs of the world's rocket fleets.

The reusability debate will likely be resolved within the next 5 years, as manufacturers attempt to prove out the technology's viability. While most commercial operators do not see the launch volumes sufficient to justify reusability, SpaceX is in the unique position of becoming its own customer, likely demanding launch capabilities for 4,425 satellites in a LEO constellation. If the constellation goes forward, reusability may as well.

As the cost-to-orbit falls, the connection between the terrestrial economy and the space economy would strengthen. SpaceX caught the industry with its guard down over the last decade. Companies that developed successful rockets did little and moved slowly to change their platforms, leaning heavily on the reliability premium associated with proven designs. If nothing else, the new Silicon Valley tech approach brings a new form of energy to the sector, striving to continually improve existing designs. We see this as positive for the overall industry over the long term.

SATELLITE MANUFACTURERS

Rapidly changing capabilities

- Manufacturing costs down ~100X in a decade
- Headwinds likely to impact commercial
- Government demand to remain robust

Exhibit 37: Creative disruption at work: Satellite Manufacturers

	Volume growth		Pricing changes		Comments
	Last 10 yrs	Next 3 yrs	Last 10 yrs	Next 3 yrs	
Launch	Light: Nearly nonexistant Med/Heavy: Flat @ 90/yr	Light: ~100 launches/yr Med/Heavy: Flat	Light: N/A Med/Heavy: -10X	Light: -10X Med/Heavy: -50%	New vehicles at lower price points vs predecessors; off low base SpaceX constellation could take rates higher; GEO launch in decline
Satellite OEMs	Flat-down on units, capacity +5-10%/yr	Units structurally lower/capacity oversupply	-20X	-20X	Rapid tech improvements push costs into free fall amid low volumes
Satellite Services	Video: +SD growth/yr Data: +10X	Video: Flat Data: +10X	Video: Stable Data: DD declines/yr	Video: Flat/slightly down Data: -30%	Flat outlook, with minor change from compression/formatting/pricing Oversupply lowers pricing, but builds the market
Insurance	+50% capacity growth	Underperform relative to total sat fleet growth	-50%	Decreasing	Rate decline likely to continue, but new rockets could support increase

Source: Company data, Goldman Sachs Global Investment Research.

The legacy commercial satellite manufacturing business is challenged. The landscape is changing, and many OEMs have unclear strategies. Demand has recently slowed, in what is historically a cyclical business, but we see today's change as more structural. New technologies on the largest and smallest satellites threaten to fossilize existing assets. On the large side, high throughput satellites are driving growth in capacity, with each successive satellite capable of doubling the current on-orbit capacity. At the other end, small cheap constellations leverage miniaturization and volume to potentially increase the current supply by a factor of 10 over the next 3 years. Even cheaper CubeSats are still immature, but they will likely see rapid improvements that may create a new challenge to traditional players. Together, these new satellites deliver this capability at a price that poses an existential threat to the typical order rates of ~20 commercial GEO satellites per year. Government satellite businesses are likely to remain strong during this period.

As satellites become less expensive, they become more viable communications conduits and data gathering tools for new applications and customers. While the next several years could be challenging for existing OEMs, as replacement demand and imbalances in their end markets become headwinds, the use of satellites to provide global Internet access changes the industry long term. What is a relatively small industry today is poised to bring the space economy into the lives of half the planet on a near constant basis through deployment of large Internet-providing fleets to the population currently without Internet. We see this part of the industry as highly elastic, where lower-cost installed hardware capacity can radically increase supply, driving down prices and fueling demand growth in end markets. This in turn would be supportive of OEMs as more capacity would be subsequently demanded.

The market as it is today

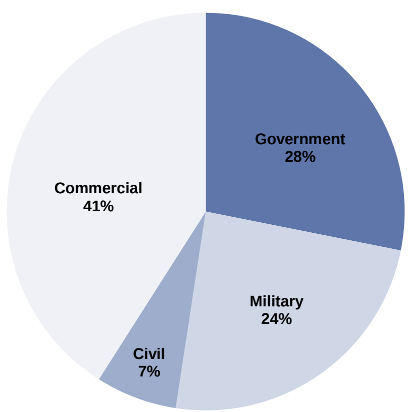
Pricing pressure in end markets plus cost reductions through building better satellites are risks to satellite OEM revenues

The satellite services industry is under pressure, forcing structural change in the demand for new assets. Historically, the business model was simple: issue debt and spend capex on a satellite and rocket, then enjoy 15 years of strong free cash flow. But that is now changing as there is substantial pricing pressure in many of the end markets those satellites serve. Satellites are launching with just 40-50% of capacity filled, versus the prior average of ~70% utilization, per our GS Telco team estimate, and this oversupply plus terrestrial factors that reduce demand are generating a more competitive environment, especially in video. Plus, multiple threats are increasingly apparent on the horizon. This tough outlook has led to our expectation of normalized capex cuts of about 20% industry-wide for the next several years, a relative headwind to commercial satellite OEM revenue as growth is achieved with less investment. Eutelsat, a major satellite operator, is exhibiting capacity discipline by cutting all new data investment in their own fleet. Demand profiles are changing as operators increasingly deploy shorter-lived cheaper assets that better keep pace with technological change.

Relief from military demand will support most satellite manufacturers, given the military satellite budget likely eclipses commercial spending. Civil should also remain strong medium-term despite possible near-term headwinds to Earth sciences program at NASA. Defense companies including Northrop, Raytheon and Harris are effectively 100% exposed to government and predominantly commercial companies like MDA are trying to pivot more towards government exposure, especially in the US.

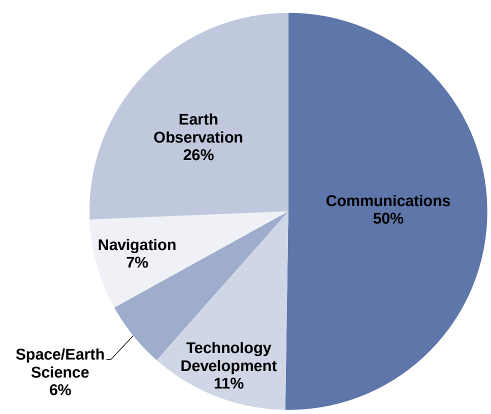
There are about 1,500 satellites orbiting the Earth today, generally split between commercial, military, government and civil (mostly academic). While about 1/4 of satellites are for primarily military applications, we estimate that military assets draw roughly 3/4 of spending. Satellite applications are extremely varied, but can be largely broken into communications, observation, science, and technology development testbeds, regardless of whether their purpose is military, commercial, civil, or government.

Exhibit 38: Share of operators
Majority commercial



Source: Union of Concerned Scientists.

Exhibit 39: Share of applications
Majority communications



Source: Union of Concerned Scientists.

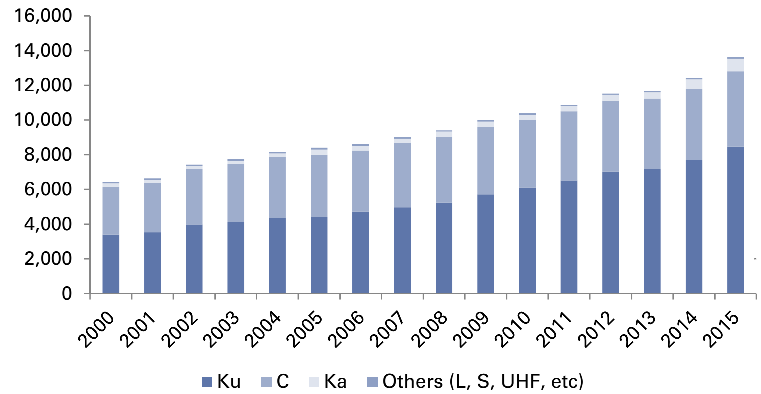
Changes for satellite manufacturers

OEMs face headwinds we expect to continue for several years: (1) Added capacity is likely to outpace demand growth, which would lead to imbalances short term; (2) Satellites are becoming larger and more capable, reducing the replacement rate; (3) Satellite installed capacity is increasingly cheap. Together, these reduce demand for satellites (while increasing capacity), as well as pricing as technology and scale allow manufacturers to reduce the cost of capacity to orbit. OEMs do not have large backlogs, with satellites ordered when needed and with about a 2-3 year build time.

We expect growth in Internet, government, and mobility (maritime and aviation) demand, but markets like video and legacy data are seeing significant pressure, and those are much larger end markets today. Most LEO satellites that do not network with each other can only provide service where ground terminals are available, meaning that maritime and aviation markets are somewhat isolated from this supply growth.

Although capacity (below) has grown steadily, pricing and demand cycles in the end markets have compromised order rates (Exhibit 42). Operators seeking to fill that capacity can oversupply the market by cutting price—this lack of discipline is apparent today as operators respond to an already tough pricing environment to meet debt payments associated with their older space assets, which can have lower earnings potential.

Exhibit 40: Satellite transponder capacity growth by frequency
Growing at 5% CAGR, but improvements accelerate capacity, making this the minimum



Source: The Space Foundation.

(1) Supply-demand imbalances

Satellite transponders have historically grown at about a 5% CAGR (power and data compression improvements make actual capacity growth higher, likely more than double). New demand for services like maritime and aviation connectivity can drive satellite growth. But we do not think satellite OEM sales growth will match the growth of capacity, where a single satellite can now double existing bandwidth. Newer markets are commonly cited as the primary drivers for growth, but we are less certain they will justify the total wave of supply that satellite manufacturers are bringing to market near term. Instead, we have some optimism about the ability of LEO fleets to bring satellite Internet to under-developed parts of the world (but this will happen over the longer term).

Growth is poised to accelerate in mobility markets, to a mid double digit CAGR (Exhibit 41), but we expect on-orbit supply to outpace it by a factor of ~10X if all planned LEO constellations are deployed, though much of that capacity will be over land providing Internet to rural areas and not target mobility markets, which are generally better served by high throughput satellites. Inmarsat expects high throughput capacity to be ~3,000 gbps in 2020, with total demand not exceeding ~1,000 gbps. We are more bullish, seeing demand at ~2,800 gbps for maritime and aero markets, in line with demand growth for mobility (but capacity on several LEO constellations could provide superfluous supply).

Exhibit 41: Mobility demand is growing, but a handful of new satellites can meet the need
~3tbps on demand side by 2020

	Scenario 1			Scenario 2			Scenario 3		
	2016	**2020**	**2035**	**2016**	**2020**	**2035**	**2016**	**2020**	**2035**
Large Commercial Aircraft									
Total fleet size	21,500	24,198	37,700	21,500	26,133	54,329	21,500	28,182	77,755
Enabled aircraft	3,229	3,630	5,655	3,229	5,227	13,582	3,229	7,046	27,214
Penetration	15%	15%	15%	15%	20%	25%	15%	25%	35%
Speed (mbps)	40	80	240	40	120	480	40	160	800
Total bandwidth (gbps)	**129**	**290**	**1,357**	**129**	**627**	**6,520**	**129**	**1,127**	**21,771**
Business Jets									
Total fleet size	20,000	21,649	29,136	20,000	22,510	35,070	20,000	23,397	42,137
Enabled aircraft	5,500	6,495	9,324	5,500	7,203	12,625	5,500	8,189	16,855
Penetration	28%	30%	32%	28%	32%	36%	28%	35%	40%
Speed (mbps)	40	80	240	40	100	400	40	120	600
Total bandwidth (gbps)	**219**	**520**	**2,238**	**219**	**720**	**5,050**	**219**	**983**	**10,113**
Cruise Ships									
Total fleet size	312	326	377	312	362	455	312	398	547
Enabled vessels	312	326	377	312	362	455	312	398	547
Penetration	100%	100%	100%	100%	100%	100%	100%	100%	100%
Speed (mbps)	250	800	2,400	250	1,000	3,000	250	1,200	3,600
Total bandwidth (gbps)	**78**	**261**	**905**	**78**	**362**	**1,364**	**78**	**478**	**1,970**
Other Maritime Vessels*									
Total fleet size	72,720	75,673	87,854	72,720	79,494	105,939	72,720	83,468	127,515
Enabled vessels	21,000	37,836	87,854	21,000	43,722	105,939	21,000	50,081	127,515
Penetration	29%	50%	100%	29%	55%	100%	29%	60%	100%
Speed (mbps)	10	20	60	10	25	75	10	30	90
Total bandwidth (gbps)	**210**	**757**	**5,271**	**210**	**1,093**	**7,945**	**210**	**1,502**	**11,476**
Total bandwidth (gbps)	**635**	**1,827**	**9,771**	**635**	**2,803**	**20,879**	**635**	**4,090**	**45,330**
Total growth vs 2016		188%	1438%		341%	3186%		544%	7034%
CAGR vs 2016		30%	15%		45%	20%		59%	25%

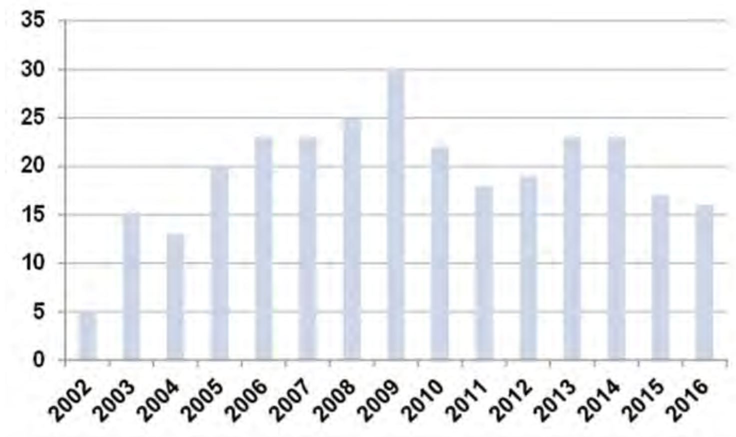
**Includes commercial freighters, fishing trawlers, and yachts*

Source: Ascend, Goldman Sachs Global Investment Research.

Video markets are unlikely to see much growth, and less likely to pass that growth along to OEMs. Furthermore, capabilities are improving such that operators can do more with less, allowing them to buy smaller GEO satellites as they replace 15-year-old technology.

The order rates for satellites are low, so the decision to delay or cancel just a few can make a large difference in industry volume. If the services industry cannot absorb the capacity of high throughput satellites, order rates at OEMs could be lower at cycle peak. Because satellites are typically built over 2-3 years, orders are similar to launch rates, and most have available capacity to begin work relatively soon after the order is placed.

Exhibit 42: Annual commercial satellite orders
Orders have been weak, suggesting lower revenue near term

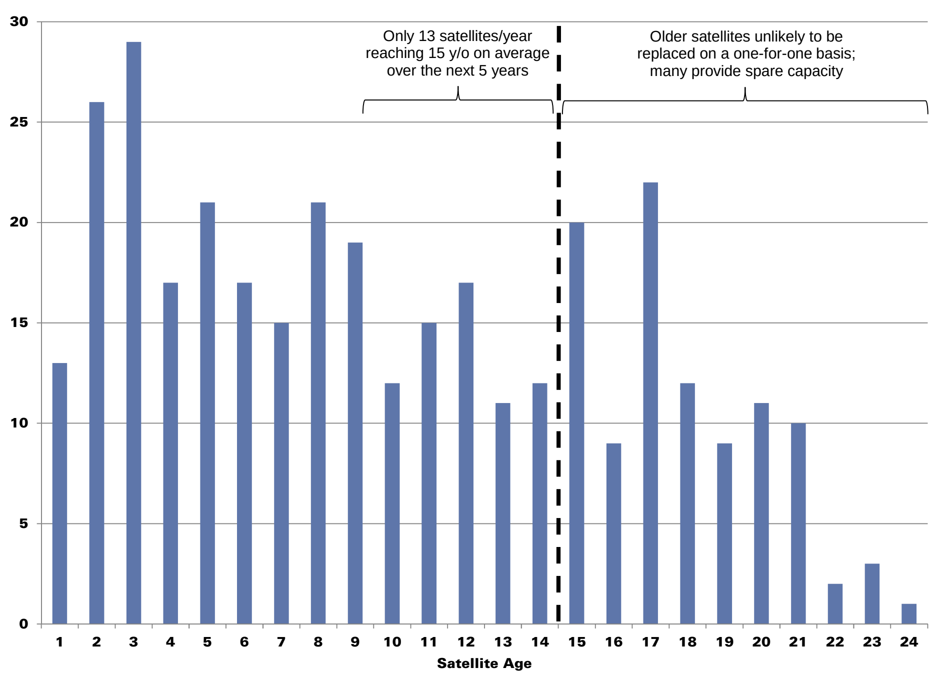


Source: Company data.

(2) Replacement demand decreasing

A new satellite is far more capable than one being retired, which is employing technology from 15 years prior. A substantial capability increase means one for one replacement may not be necessary. Furthermore, satellites reaching their scheduled end of lives are likely to remain low over the next 5 years relative to recent launch rates, based on visible likely retirements (Exhibit 43).

Exhibit 43: Satellites reaching end of life
Satellite retirements likely to be low over next 5 years



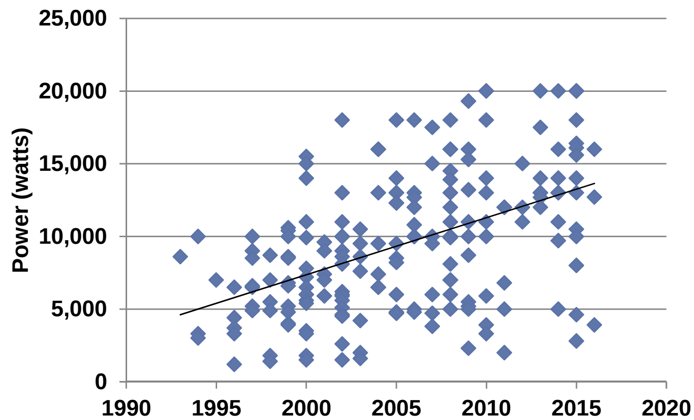
Note: Age 1 only captures a half year

Source: Union of Concerned Scientists, Goldman Sachs Global Investment Research.

Those beyond their expected lives are even less likely to be replaced on a one-for-one basis, and many have already been formally replaced and now serve as reserve capacity.

While not a perfect proxy, the power of satellites is positively correlated to transponders, and satellites launched today are about twice as powerful as the satellites reaching retirement age. Transponders can also now do more with less power.

Exhibit 44: Satellites are now more powerful, reducing unit-for-unit replacement need
This accelerates transponder growth and points to split in market, reducing the middle of it



Source: Union of Concerned Scientists.

As capacity of new satellites grows, we expect satellite operators to face negative pricing. We are concerned that satellites were ordered and launched in recent years with optimistic end-market pricing outlooks. Older technology creates a higher cost basis for operators, and with relatively new entrants with young fleets adding supply, existing operators are forced to chase pricing lower, likely needing new satellites to lower their cost basis and cover the financing costs of the existing fleet given the capability gap. Short term, this actually could cause orders to pick up, but would not be due to healthy demand and it would further pressure pricing in the end markets.

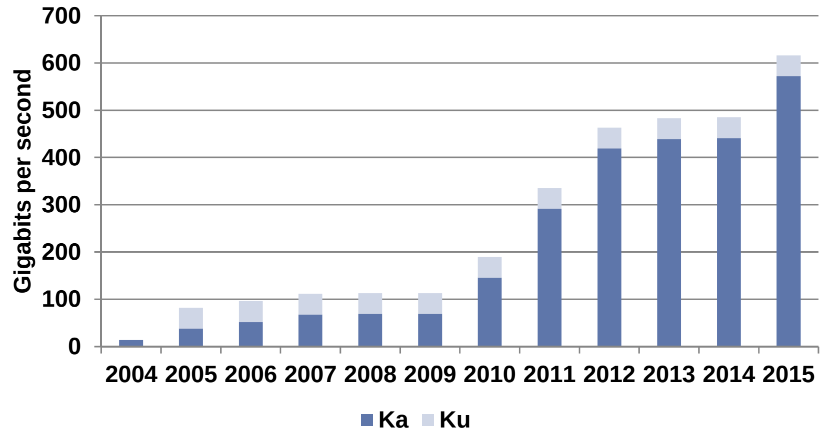
Video markets are likely to see continued replacement of old satellites at a fairly regular pace, though it is likely that improved technology would allow operators to purchase fewer and smaller satellites. That is also incentivized short term by the deficit of small satellites to fill one of the positions on Ariane 5 launches, where lower launch costs meaningfully change the ROI.

(3) Cheaper capacity

The price per capacity built is falling rapidly, which means that volume is now the new mantra for the industry. Mass production of satellites and capacity densification in high throughput satellites are highly disruptive. For satellite manufacturers, they mean revenue headwinds, and for operators they mean lower operating costs with sufficient volume to flood the market with oversupply.

When ViaSat launched ViaSat-1 in 2011 it was estimated to cost $500mn and deliver 140 gbps of bandwidth. At the time it effectively doubled the amount of bandwidth on orbit. ViaSat-2 is set to launch this month and with 350 gbps of capacity at an approximate cost of $625mn (including launch). It will represent more than a 50% increase in comparable capacity.

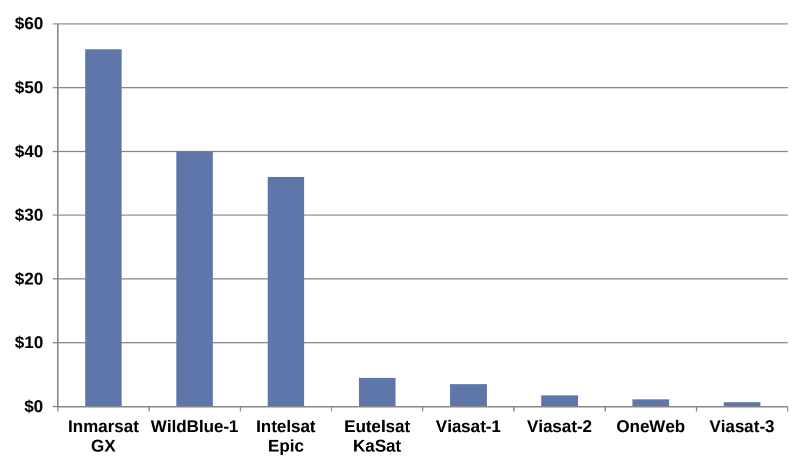
Exhibit 45: High throughput satellite capacity
Bandwidth on orbit has grown quickly, at a 41% CAGR thanks to large capacity additions



Source: The Space Foundation.

In the five and a half years between ViaSat-1 and 2, the cost fell from $3.5mn/gbps to $1.8mn/gbps, a 50% reduction. The ViaSat-1 price point per capacity was already a significant decline from prior models. ViaSat-2 is likely to generate about $45mn per month of revenue according to its CEO, about 10X the amount from ViaSat1.

Exhibit 46: Estimated cost per installed gbps including satellite, launch, and insurance
Satellites are rapidly lowering their cost basis over today's most advanced systems



Source: Company data, Goldman Sachs Global Investment Research.

The second of three future ViaSat-3's is expected to cost $650mn, according to Eutelsat, a partner. With more than 1 tbps, this implies the price per gbps would fall below $0.8mn in the next 5 years. Although high throughputs align with the core competencies of OEMs, they may not capture all of the manufacturing dollars. ViaSat purchased a Boeing satellite bus for ViaSat-3, but is manufacturing the payload itself; and buses are increasingly commoditized.

Military demand highly supportive: The same cost compression is not occurring on the military side, primarily due to encryption and resiliency requirements. These satellites, like some of the higher value commercial counterparts like Inmarsat GX have steerable antennas, which allow the satellite to track priority ships or aircraft.

Costs for satellites themselves are down ~100X with mass production, causing launch to become the most significant cost

From hand-crafted to mass production: The first mass production line for satellites is starting, likely driving costs even lower and becoming key to the future of Internet for half the world's population. The two most significant constellations in LEO are OneWeb (~650 satellites initially, plus possibly 2,000 more) and SpaceX (approximately 4,500 satellites). With approximately 10 terabits per second of capacity for the initial deployment of 650 at OneWeb, these satellites could radically change the market. Airbus is targeting a price of half a million dollars per satellite in OneWeb's constellation, and with a plan for 10 terabits per second, the implied cost per installed gbps is $45,000. However, that number is just for the satellite—unlike GEO satellites, launch is likely to be the largest cost associated with LEO fleets. In this case, we think it brings the total cost per installed gbps over $1mn. LEO fleets are unlikely to be insured. LeoSat is moving toward launching 78-108 satellites made by Thales. Importantly, LEO constellations allow for low latency communications, whereas GEO satellites, which are situated further from Earth, have higher latency and are therefore most suited to broadcast communications like satellite TV and radio. LEO enables everyday two-way internet usage like VOIP where latency matters. For this reason, we see them better able to serve everyday internet markets in hard-to-reach places.

The CubeSat revolution

The next step toward low-cost communications could be CubeSats. Today they provide a low cost alternative for basic technology testing and science experimentation vs. traditional satellites and are being used for an increasing number of commercial applications. Low cost comes at a price—longevity; and CubeSats operate for less than 3 years. Shorter lives means more stable capex on the assets, but also implies a more flexible architecture that can be updated 5X as often as traditional satellites to keep pace with technology changes.

There are no CubeSat constellations like those proposed by SpaceX and OneWeb, but we think the throughput viability of the CubeSat as a communications platform is reaching roughly breakeven, though power capabilities are likely still too low. Safety, reliability, and fleet management are key factors holding the market back, but with the largest CubeSat communications transponders now capable of generating more than 100 mbps at a likely cost of ~$200,000, CubeSats could theoretically double 2015 on-orbit bandwidth through asset capex of about $1.2bn ex launch, less than 10% the cost associated with all competitively-procured satellites deployed in 2015. We expect that currently deployed assets may eventually compete as transponder capabilities improve and costs come down and technological hurdles are resolved. The ability of OEMs to build at increasingly low cost is a greater headwind to sales than any existing demand weaknesses. As more companies share the ambitions and capitalization for developing high capacity satellites and constellations, the revenues attributable to manufacturers could be impacted.

A new dawn

While the commercial headwinds in the short term are strong (with low order rates <20 GEO satellites likely for several years), the importance of government and civil cannot be overstated, and they will be highly supportive of the industry. We are not convinced that the combination of unit price and the unit volume trends of satellites are going to be sufficient to maintain revenue near current levels. The industry is fundamentally changing, but we expect that when end-market pricing for data reaches something close to terrestrial solutions, growth will return to satellite manufacturing, and that growth will be very strong as pent-up elasticity is released. However, it is somewhat less clear how much of that growth is in LEO or GEO fleets.

SATELLITE SERVICES

Structural changes in supply & demand

- Substantial growth in capacity
- Negative pricing pressuring operators
- Capex-lite environment challenges OEMs

Exhibit 47: Creative disruption at work: Satellite Service Providers

	Volume growth		Pricing changes		Comments
	Last 10 yrs	Next 3 yrs	Last 10 yrs	Next 3 yrs	
Launch	Light: Nearly nonexistant Med/Heavy: Flat @ 90/yr	Light: ~100 launches/yr Med/Heavy: Flat	Light: N/A Med/Heavy: -10X	Light: -10X Med/Heavy: -50%	New vehicles at lower price points vs predecessors; off low base SpaceX constellation could take rates higher; GEO launch in decline
Satellite OEMs	Flat-down on units, capacity +5-10%/yr	Units structurally lower/capacity oversupply	-20X	-20X	Rapid tech improvements push costs into free fall amid low volumes
Satellite Services	Video: +SD growth/yr Data: +10X	Video: Flat Data: +10X	Video: Stable Data: DD declines/yr	Video: Flat/slightly down Data: -30%	Flat outlook, with minor change from compression/formatting/pricing Oversupply lowers pricing, but builds the market
Insurance	+50% capacity growth	Underperform relative to total sat fleet growth	-50%	Decreasing	Rate decline likely to continue, but new rockets could support increase

Source: Company data, Goldman Sachs Global Investment Research.

There is a growing disconnect in supply vs. demand near term for satellite services: TV, radio, communications, and Internet. Certain markets are bright spots, but the threat from new space-based capacity, plus changes in consumer behavior and technology on Earth, are disrupting the equilibrium. Satellite operators with legacy assets and significant debt are at risk, and likely add to a growing wave of oversupply as they aim to stay competitive amid near term market weakness. Eventually, prices should fall low enough to stimulate new sources of demand. Internet in sub-Saharan Africa can cost more than 100X as much as in the US, but the average income is 35X lower. We see this, plus the price elasticity of demand and limitations of terrestrial technology, as a large source of untapped demand that will eventually propel the space economy forward to new highs over the long term.

Related reading

In a companion note also published today, our European satellite analysts revisit their thesis on European satellite operators, preferring those more exposed to growth areas such as Inmarsat.

Read the note →

Video risk to persist, operators seeking growth in mobility and data

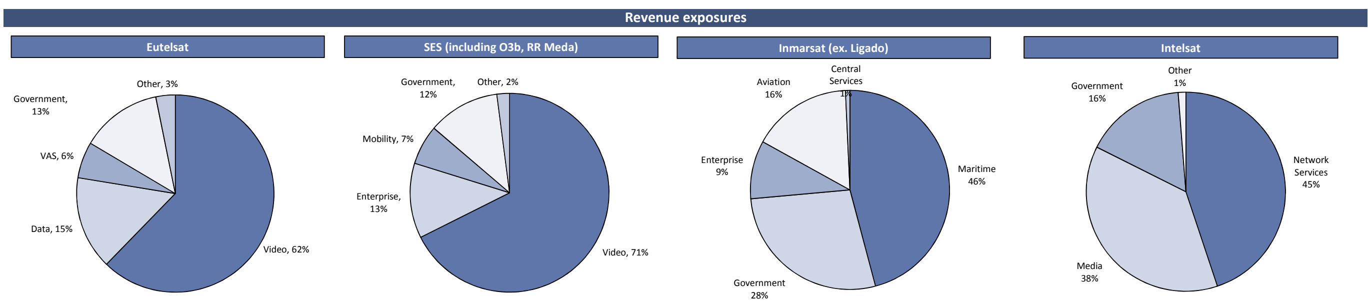
Video markets are currently challenged: European end markets are struggling with structural changes associated with fleet technology, and American providers are contending with terrestrial alternatives. The two listed satellite operators largely exposed to European Video are SES and Eutelsat (~60% of revenues, Exhibit 48). Overall, we expect continued pressure on European Video revenues as over-the-top (OTT) substitution impacts capacity (usually measured by number of transponders) pricing and ongoing compression (the number of channels per unit of capacity) advances largely offset improving image quality growth (the higher the image quality, the lower the number of channels per unit of capacity, all else equal). As the Video market matures, focus is increasingly switching to data-centric offerings (including mobility services) as an area of growth. Operators are employing differing strategies to access higher growth data markets across a range of verticals, including Maritime, Aerospace and consumer broadband. We highlight below the varying operator strategies to capture growth across new data verticals such as Aerospace, Consumer broadband and broader data (including government).

- **SES**– SES is increasingly seeking to diversify its business and increase exposure to mobility and growing data in part through the recent acquisition of O3b (MEO satellite fleet) and new HTS satellite launches. This appears to be aimed at compensating for declining core video revenues and deflation in widebeam data caused by increasing supply across the industry.
- **Eutelsat**– Eutelsat is taking what we view as a pragmatic approach to what it refers to as 'low visibility around industry economics for data'. It has stopped all

data launches and is partnering with ViaSat (in EMEA) to pursue the mobility and data opportunity.

- **Inmarsat**– Inmarsat does not have any video exposure and is focused on mobility (Maritime in particular). It is pursuing a largely organic strategy with its own HTS ka band fleet (Global Express) completing existing L-Band satellites. In addition it is partnering with Deutsche Telekom to build out a European Aviation network to access the underpenetrated Inflight Wi-Fi market in Europe.
- **Intelsat**– On February 28, Intelsat announced an agreement to combine with OneWeb in a transaction that will be accompanied by an investment by SoftBank and a proposed debt exchange. The merger will combine Intelsat's global scale, terrestrial infrastructure and GEO satellite network with OneWeb's LEO satellite constellation with the goal of providing affordable broadband anywhere in the world.

Exhibit 48: SES/Eutelsat primarily exposed to video, while Inmarsat is focused on mobility and Intelsat on a mix
Revenue breakdown by segment, 2016E (%)



Source: Company data, Goldman Sachs Global Investment Research.

Video – Structural challenges ahead

We see limited growth within European video. We expect structural pressure in video to be realized from high relative existing capacity pricing, increasing OTT threat and continued advances in compression largely offsetting higher capacity demands from HD/UHD.

Ubiquitous coverage has always been a key driver for TV operators using satellite as a means of transmission. We believe this will remain a key selling point, given the likes of Sky are nationwide operators and this is important particularly for live events such as sport. However, the underlying overall demand for transponder capacity is more unclear and pricing is clearly higher than in other mature markets such as the US with limited fundamental reasons aside from the lack of FTA broadcasters.

Exhibit 49: Long-terms drivers of video

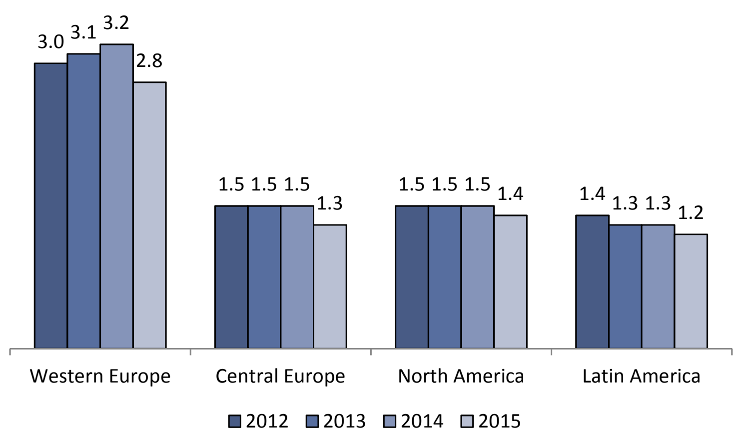
Drivers of Video	
Positive Drivers	**Negative Drivers**
Ubiquitous coverage	*Increasing OTT and fibre*
Non-user based pricing	*Increasing IPTV competition taking share from DTH*
CPE a barrier to switching	*Pricing high versus more mature US market*
Long term contracts/backlogs	*Compression*
Concentrated supply due to orbital slots	*Falling channel counts*
Increasing definition of channels (HD/UHD)	*Large DTH providers as end users*
Low latency important for live sports etc	*Limited channels reliant on low latency*

Source: Goldman Sachs Global Investment Research.

Transponder pricing remains relatively high in Europe vs. other regions

European transponder pricing remains high on a per transponder basis vs. other regions today. In Exhibit 50, we highlight the difference between European transponder pricing (at c.€3 mn/year) compared to North America, Central Europe and LatAm, which are all around half of the levels in Europe. Within Europe, we estimate pricing is higher in Germany/UK at c.€4-6 mn/TPE compared to as low as €1 mn/TPE in Eastern Europe. We see structural pressures posing predominantly downside risks to long term European pricing and therefore growth.

Exhibit 50: Core European transponder pricing remains high vs. other markets
Industry average revenue per transponder (US$ mn)



Source: Eutelsat CMD, 2015

Technological drivers – Higher definition versus better compression

Technology plays a crucial part in framing the investment opportunity for satellites. Below we consider some of the key determinants as to how much capacity is required for a certain number of channels. Each new compression format doubles the number of channels per unit of capacity (per transponder). With reference to the table below, a movement from left to right in the table from MPEG-2 to MPEG-4 to HEVC shows that an increasing number of channels can be held per transponder, all else equal, as compression formats improve.

As better image quality is demanded, the number of channels per transponder decreases, helping to offset the improvement in compression. HD channels require around five times the capacity of SD channels, while UHD is four times HD. As fewer are transponders are needed, satellites can become smaller and cheaper or larger and fewer. Old satellite can receive software updates to support new formats, so this doesn't necessitate new assets.

Exhibit 51: Determining the number of channels per unit of capacity; improving image quality vs. compression format
Number of channels per transponder by modulation, format, and compression

Increasing compression →

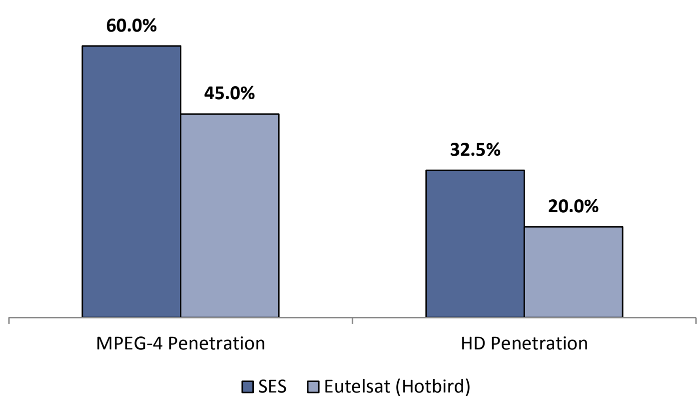
Better picture; more intensive needs ↓

Format	Period	Modulation	# channels by compression format		
			MPEG-2	MPEG-4	HEVC
SD	1990s-2000s	DVB-S	12	20	
		DVB-S2		26	
HD	2000s-2010s	DVB-S	2-3	5	
		DVB-S2	3-4	6-8	12-15
UHD	2020s	DVB-S2		1-2	3-4

Source: Eutelsat.

In Exhibit 52, we show the relative MPEG-4 penetration at SES and Eutelsat compared to HD. Eutelsat management have highlighted the opportunity they have to accelerate HD penetration across their video capacity (Hotbird) to the peer levels.

Exhibit 52: SES typically has a more advanced end-user vs. Eutelsat
MPEG-4 and HD penetration (%)



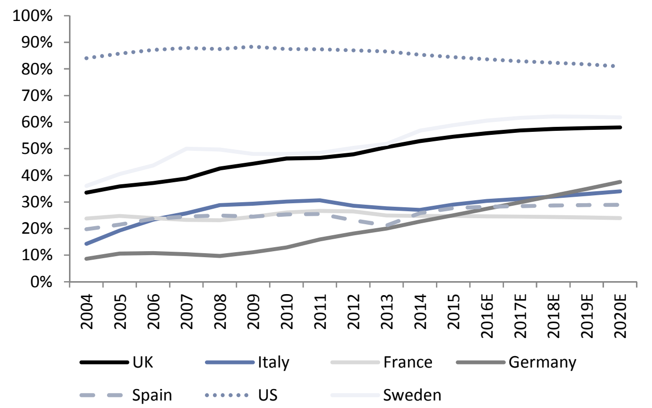
Source: Company data.

OTT risk increasing

Satellite TV is being disrupted by new space-based technologies and terrestrial Internet-based video services. Over-the-top distribution allows for the delivery of content via the Internet, which shifts the opportunity from video to data. We continue to see increasing OTT substitution across key European markets, with the UK in particular seeing a sharp increase, including traditional direct-to-home (DTH) operators increasingly looking to broaden the distribution routes to end users.

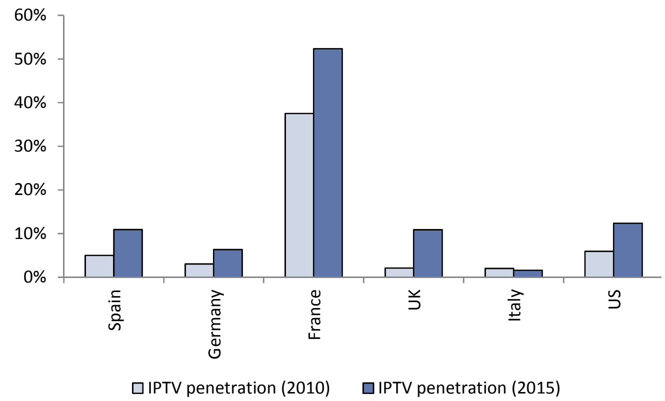
As the exhibits below show, in a number of regions Internet Protocol TV (IPTV) penetration is growing, with investment in fixed networks (by both incumbents and cable operators). Fixed network operators are able to offer higher speeds such that they are increasingly positioned to offer more advanced OTT services. We believe this shifting pattern of viewership moves the balance of power more towards fixed network operators as opposed to satellite operators given the availability of other distribution mechanisms and ability to reduce DTH channel counts.

Exhibit 53: Europe pay TV penetration continues to grow
Pay TV penetration by markets, % of TV homes



Source: SNL Kagan, Goldman Sachs Global Investment Research.

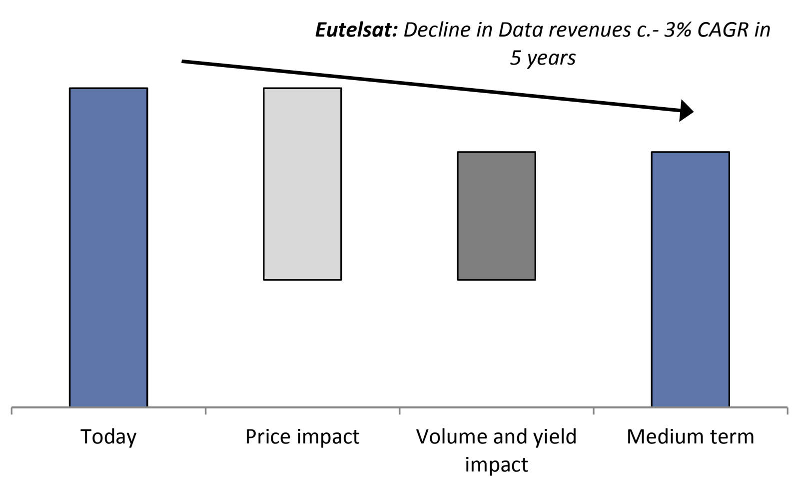
Exhibit 54: IPTV increasing in all the big EU countries
Internet Protocol TV (penetration by market (2015 vs. 2010)



Source: SNL Kagan, Goldman Sachs Global Investment Research.

Data – Pressure in existing data businesses – Seeking growth in mobility and Aero
Operators are continuing to see the impact of wider pressure on satellite data pricing (per MHz), in particular existing widebeam data revenues given the continued increase in industry supply driven by High Throughput Satellite (HTS) launches. HTS satellites represent the new frontier in the satellite industry, offering more data at a far lower implied cost compared to traditional wide beam satellites. We expect the continued increase in industry supply to continue, and highlight Eutelsat's estimation for a further 50% decline in pricing in the next five years. However, there remain a number of relatively nascent markets in Europe in both Aero (lack of inflight Wi-Fi), rural consumer broadband (lack of fiber) and elements of maritime/mobility which operators are targeting for growth.

Exhibit 55: Eutelsat has guided that data pricing will decline by 50% in five years, with some compensation from higher volumes
Eutelsat guided evolution of data revenue (data guided to shrink to 10% of total revenue)



Source: Eutelsat.

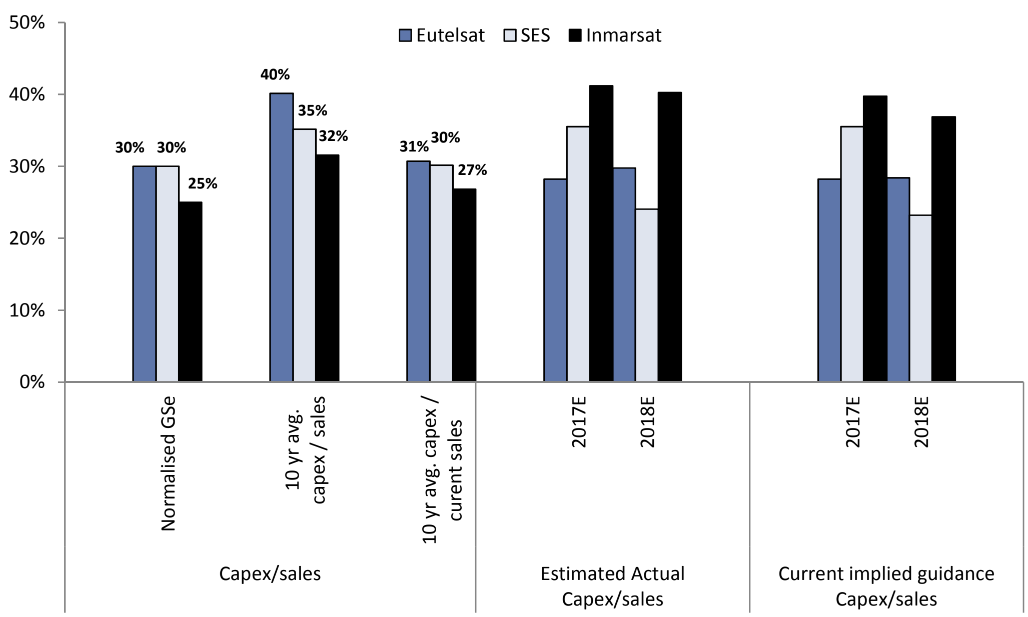
Improving capital efficiency: Implications of decreasing the cost of space access
Decreasing the cost of launching capacity in the long term presents an opportunity for satellite operators to protect or increase returns. Specifically we examine existing guidance on the scope for satellite operators to reduce their normalized capex requirements.

We believe that relatively high barriers to entry for global satellite operators' domains will remain, noting the nature of their global offering and large fleet size, orbital slot access, long-duration contracts and the current use of the satellites (satellites themselves suited particularly to their current use – not easy to replicate).

- SES is aiming for a **15-20% reduction in normalized Capex from 2018-2022** due to fleet scale, design and cope synergies. We note SES has cited four key areas: Fully digitized payloads, modular satellites, satellite life extensions and access to space.
- Eutelsat has launched a 'design-to-cost' program to reduce future capex and has recently cited >30% savings on Eutelsat 5WB citing lower cost of the payload, smaller platform and lower launch and insurance costs
- Inmarsat also hopes to benefit from lower capex and recently agreed to a shared launch with regards to its European S-Band satellite, reducing cost significantly versus a stand-alone launch.

We note historic volatility, and differences, between the capex levels of satellite operators over recent years. Accordingly, we consider valuation using normalized capex/sales for the listed European satellite operators.

Exhibit 56: Normalized and 10-year average, GSe and company guidance capex/sales (%)



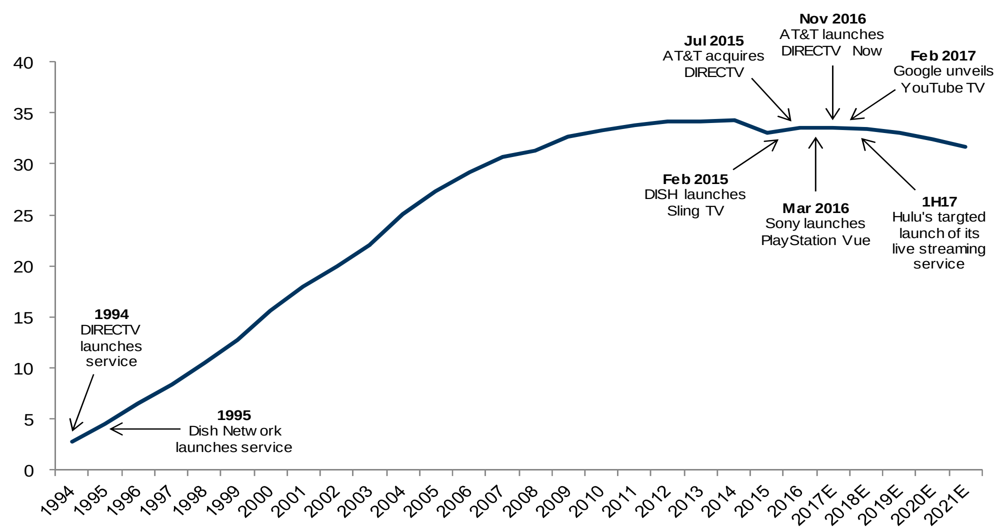
Source: Company data, Goldman Sachs Global Investment Research.

US TV comes back to Earth

In the US pay-TV sector, the space race began in the mid-1990s. That is when a handful of direct broadcast satellite (DBS) TV operators – led by Hughes Electronics' DIRECTV and EchoStar's Dish Network – launched satellites that could deliver over 100 channels of premium programming to households nationwide. Over the next two decades, satellite

TV's rise was meteoric with the number of DBS subscribers growing at a CAGR of 13%, eclipsing the 2% annual growth of the overall pay-TV sector in the US. The initial appeal of satellite TV vs. cable and free 'over-the-air' television was simple: more channels. DBS operators were also leaders in innovation, being among the first pay-TV providers to offer high-definition channels and digital video recorders. Over the last two years, however, the number of DBS subscribers has started to come back to Earth, declining by about 1% annually, a trend we expect to continue through the end of the decade.

Exhibit 57: Direct broadcast satellite TV subscribers in the US
Subscribers in millions



Source: Company data, SNL Kagan, Goldman Sachs Global Investment Research

Satellite TV is not just being disrupted by new space-based technologies, it is being disrupted by terrestrial Internet-based video services

The space race gives way to a flood of streaming services back on Earth

The key driver of the decline in satellite TV subscribers, as well as an overall decline in pay-TV subscribers, is the rise of streaming video delivered over the Internet. As of year-end 2016, nearly 90% of consumers with a postpaid wireless plan had a smartphone, and as of year-end 2014, 94% of households had access to a broadband service offering download speeds of at least 10 Mbps, according to the FCC. Based on this growing connectivity, consumers can increasingly watch whatever they want, whenever they want, wherever they are without a pay-TV subscription.

This is driving 'cord-cutting' (i.e., consumers disconnecting from traditional pay-TV service), but perhaps more significantly a generation of 'cord-nevers' (i.e. consumers who have never subscribed to a traditional pay-TV service). For example, According to a survey from Magid Associates, 34% of millennials that don't subscribe to pay TV are cord-nevers, which is 10 percentage points higher than the total population (24%). So, traditional satellite TV is not just being disrupted by new space-based technologies, it is being disrupted by terrestrial Internet-based video services.

Adoption of streaming video services is likely to accelerate as options proliferate. As we show in Exhibit 57, over the last two years Dish, Sony and AT&T have launched their own streaming services and we expect Google (YouTube) and Hulu to enter the market in early 2017, based on their public statements. The growing number of streaming options is likely to cause sustained declines in traditional pay-TV services, but we see DBS as being more vulnerable to Internet-based competitors than cable companies. The key reason is that cable companies are the largest providers of fixed-line broadband services. This positions them to benefit from the rise of streaming video by providing the broadband access, even if it cannibalizes their video services. It also provides a hook into the consumer that they can leverage to sell bundles, perhaps including their own streaming video options.

DBS operators, by contrast, have difficulty leveraging their satellite TV networks to deliver competitive broadband speeds. This has caused the two providers of nationwide satellite TV services – Dish Network and DIRECTV – to pursue diverging strategies. Dish has ramped up its investment in its own streaming service (Sling TV) while also looking to position itself for continued growth in wireless data usage by investing in mobile spectrum licenses. AT&T, DIRECTV's parent, has pursued a strategy of vertical integration as it looks to provide bundles of wireless, broadband and video (satellite and streaming) to households.

Extra Space?

With AT&T making DIRECTV the focus of its residential video strategy, the overall decline in satellite TV subscribers should be moderate for at the least the next few years. But, as AT&T upgrades its wireline network to fiber and its wireless network to 5G, we expect the company to increasingly embrace streaming video as a core service.

This raises an interesting question as to what will happen to the infrastructure supporting DBS services in the US as customers migrate away from these platforms. With Dish focusing more on rural markets vs. DIRECTV, the two companies are less in competition with each other than with other traditional pay-TV providers (e.g., cable) and streaming services. This has caused management of Dish to suggest that perhaps the two companies, which had attempted a merger in 2001 that was ultimately blocked by regulators, should consider sharing infrastructure. For example, during the company's 2Q16 conference call, Charlie Ergen, Dish's CEO, suggested that Dish and DIRECTV could achieve a "fair amount of synergy" by combining their use of backhaul connectivity into the broadcasters and perhaps combine their advertising resources.

Whatever the outcome, DBS providers – the shooting stars of TV's space age – no longer seem to have the "right stuff" as video enters the Internet age.

Where Say's law becomes space law: build it and they will come

Supply is the source of demand according to Say's law. We think availability of low-cost satellite Internet, especially, will usher in a new era of relevancy for the space economy. Longer term, the key disruptor for satellite data services would likely come from ultra-high throughput satellite fleets and LEO/MEO. OneWeb, SpaceX, LeoSat, Google and others are all potentially involved in launching new LEO fleets with hundreds of satellites and overall throughput towards 10tbps per fleet. Clearly the launch of such fleets would see overall global satellite capacity multiply significantly. The launch of such fleets given the LEO nature will not be without regulatory challenges, but unlike previous launches (such as Teledesic) the financial stability of the sponsors is generally better.

Such constellations target a variety of applications, e.g. OneWeb aims to provide connectivity that is able to serve cellular backhaul applications, connected cars and other vehicles (e.g. planes, trains). Intelsat recently reached an agreement with OneWeb to form one company, the two companies citing the complementarity between the Intelsat GEO fleet and OneWeb LEO fleet.

We think ultimately prices will fall enough to tap new sources of demand. As demand for Internet in developing parts of the world is elastic, this becomes a long-term growth area for space companies as the half of the world's population without Internet access could access Internet via Space, creating high growth opportunities for satellite operators and OEMs when pricing falls.

INSURANCE

For when things go boom

- Continued compression of rates likely
- Tailwind for new entrants/riskier rockets
- Success rates justify pricier launch, esp. for gov't.

Exhibit 58: Creative disruption at work: Insurance

	Volume growth		Pricing changes		Comments
	Last 10 yrs	Next 3 yrs	Last 10 yrs	Next 3 yrs	
Launch	Light: Nearly nonexistant Med/Heavy: Flat @ 90/yr	Light: ~100 launches/yr Med/Heavy: Flat	Light: N/A Med/Heavy: -10X	Light: -10X Med/Heavy: -50%	New vehicles at lower price points vs predecessors; off low base SpaceX constellation could take rates higher; GEO launch in decline
Satellite OEMs	Flat-down on units, capacity +5-10%/yr	Units structurally lower/capacity oversupply	-20X	-20X	Rapid tech improvements push costs into free fall amid low volumes
Satellite Services	Video: +SD growth/yr Data: +10X	Video: Flat Data: +10X	Video: Stable Data: DD declines/yr	Video: Flat/slightly down Data: -30%	Flat outlook, with minor change from compression/formatting/pricing Oversupply lowers pricing, but builds the market
Insurance	+50% capacity growth	Underperform relative to total sat fleet growth	-50%	Decreasing	Rate decline likely to continue, but new rockets could support increase

Source: Company data, Goldman Sachs Global Investment Research.

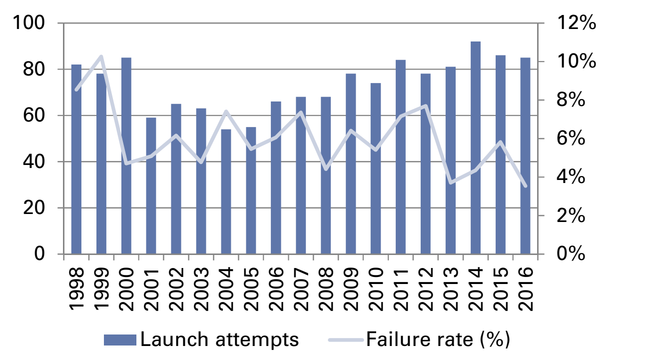
Chemistry at thousands of miles, gunpowder in a tube, and untested delicate payloads exposed to an ever growing debris field – there are risks in Space. Insurance rates are compressing, even though risk remains. High capitalization and competition forces rates lower. Rocket and satellites are fairly unique in the insurance world. There are only a handful of commercial launches per year, with relatively low certainty on the outcomes.

We see the current negative trend in insurance rates as supportive of GEO satellite services, and therefore traditional OEMs, relative to those operating in LEO, since GEO operators more frequently insure their assets. As overall rates compress, we think this is supportive of lower quality launch and satellite systems, as the difference between premiums for launchers is also likely to compress. This lowers the barrier to entry for new designs.

Competitive dynamics:

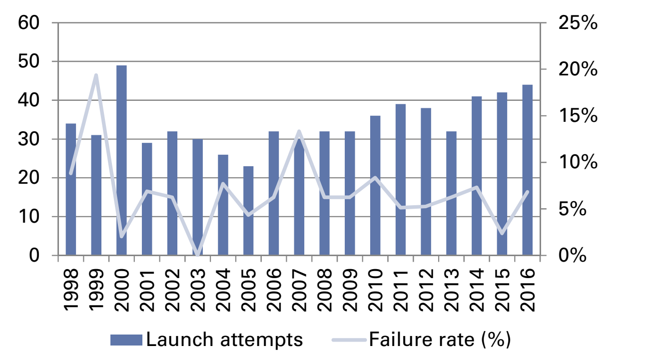
There is a large spread between the peak value at risk for the largest commercial launches and the average insured commercial launch. According to XL Catlin, top-value satellites plus launch are about $750mn while the average is ~$250mn per launch. This means that the industry needs at least $750mn available to cover large satellite launches, but typically the market only requires $250mn, creating additional competition and driving down insurance rates as risk periods are largely sequential. The difference between the high end and average has exerted pressure on the prices paid for coverage, more than halving them over the last 15 years to between 5% and 10%, in line with historical failure rates.

Exhibit 59: Total launch and failure rates of rockets
Rockets appear to be getting safer…



Source: Space Launch Report.

Exhibit 60: GEO launch and failure rates of rockets
…but failure rates among the largest rockets remain at 7%



Source: Space Launch Report.

As the insured values of the largest satellites continue to climb, and average values remaining relatively constant, the gap is widening. The number of GEO satellites launched to orbit will likely be low for the next few years given the current order outlook. According to XL Catlin, large constellations typically do not pay for insurance, or else have a high deductible, due to differences in their business model. As such, we see little incremental opportunity from the pending deployment of OneWeb and SpaceX constellations.

While insurance rates are generally trending lower, new rockets and satellite technology can introduce more risks. During the first launch, XL Catlin sees about 1/3 of rockets fail. By the third launch, the probability of failure decreases to just over 20% and by the 12th, the probability falls to about 10%. Commercial launches are normally insured, limiting the burden of a failed launch for the operator, but the lost revenue is not covered. Rockets like the Ariane 5 and the Falcon 9 carry premiums of approximately 6% and O3b reportedly paid an 8.6% premium for launch and first year coverage of 4 satellites launched on a European Soyuz spacecraft according to SpaceNews.

Solid rocket failure rate estimated at 0.001% vs. historical liquid rate at 6%

The US government self-insures its launches, meaning that failure rates are a key consideration in pricing. NASA has estimated that the likelihood of space shuttle solid rocket booster failure was 1 in 100,000 vs. liquid rockets at about 1 in 20. Solid rockets are far simpler than liquid alternatives, meaning less risk. De-risked launch enables pricing premiums, contributing to our positive view on solid-fueled systems. Defense payloads can cost billions of dollars and are vital to national security. Reduction in the likelihood of failure is often worth far more than the theoretical breakeven math based on risk and payload plus launch costs. As such, in Exhibit 61, we show just the theoretical minimum accepted pricing delta between two rockets of different risk profiles.

Exhibit 61: Illustrative sensitivity table for launch risk vs. premium ($mn)
Implied de-risking premium for government launches of assorted payloads

		Payload + launch cost value					
		$100	**$300**	**$500**	**$800**	**$1,000**	**$2,000**
Relative failure risk differential	**0%**	$0	$0	$0	$0	$0	$0
	1%	$1	$3	$5	$8	$10	$20
	3%	$3	$9	$15	$24	$30	$60
	5%	$5	$15	$25	$40	$50	$100
	10%	$10	$30	$50	$80	$100	$200
	20%	$20	$60	$100	$160	$200	$400

Source: Goldman Sachs Global Investment Research.

We think a representative payload plus launch cost for a national security launch on an NGL, Atlas V, or Falcon 9 would be between $500mn and $1bn. Both the Atlas V and Falcon 9 have good records, with the Atlas V claiming a ~10% better success rate. If the payload plus launch were valued at $800mn, this would imply a financial breakeven decision when the Atlas V costs $80mn more than a Falcon 9 due to the lower risk profile of the Atlas.

Transferring innovation risk to the customers and insurance companies:
With two failures in as many years, SpaceX innovation is in some ways costing customers, insurance companies, and itself at a level that raises questions about its strategy vs. the more step function path adopted by its competitors. While such practices may be acceptable for unmanned flights, we think that the premiums associated with manned flight for tourism or government purposes would likely be required and possibly prohibitively expensive if rates do not converge with ULA's offerings.

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VENTURE CAPITAL HORIZONS

Available capital: Financing in space appears readily available, with several different investor categories making several different investment types into space in recent years.

Growth: Recent years have seen substantially more space startup companies formed and substantially more venture capital put into the sector compared to any time in history.

Who?: A lot of investment has been from or into well-known players in the sector – like Google and Fidelity investing in SpaceX or SoftBank investing in OneWeb. But there have been dozens of smaller investment firms putting money into smaller privates, as well.

Major players: Investors: Bessemer, DFJ, SoftBank, Fidelity, Google; Recipients: SpaceX, OneWeb, Planet Labs, Rocket Lab.

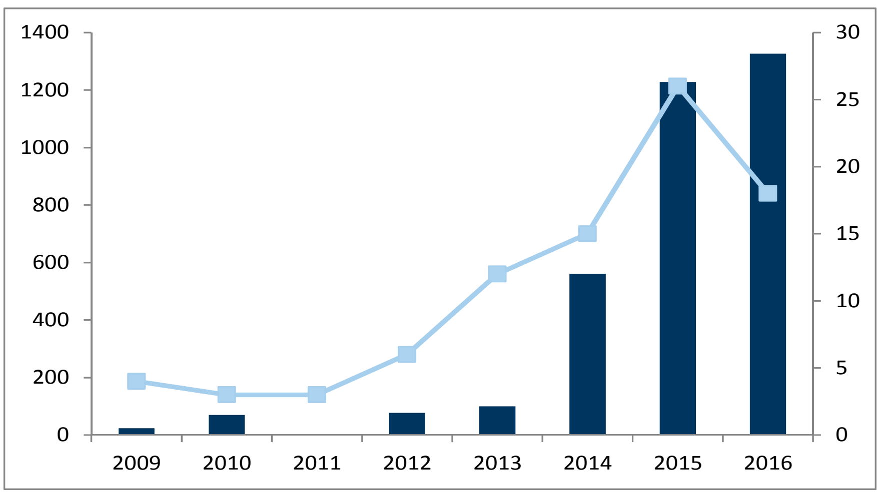
VCH Inside: Space: The Global Venture Landscape

Venture in Space

As a category, Space generated nearly $1.4bn in venture investment in 2016, having never reached over $125mn in venture investment annually prior to 2014. We've seen this trend being primarily driven by large, consolidated funding rounds that have created new applications for Space technology that range beyond building rockets, from launch vehicle platforms to data collection and service providers.

Over the last 3 years, Space VC funding has increased on average 195% to over $1bn yearly, driven by larger one-off VC rounds and higher relative density of rounds >$10mn. If anything, this growth is likely understated given the direct founder-led investment in high profile efforts, like Jeff Bezos's Blue Origin and Richard Branson's Virgin Galactic, may not be fully captured in public figures.

Exhibit 62: The Global Venture Landscape: Space
$mn (lt. axis), # of deals (rt. axis)



Source: CB Insights, Goldman Sachs Global Investment Research

Given the high barriers to entry and capital costs required to enter the space market, as well as the early stage relative to other innovative categories in realizing positive returns on business operation costs, we are not surprised that deal count has remained low relative to a rapidly growing capital investment base.

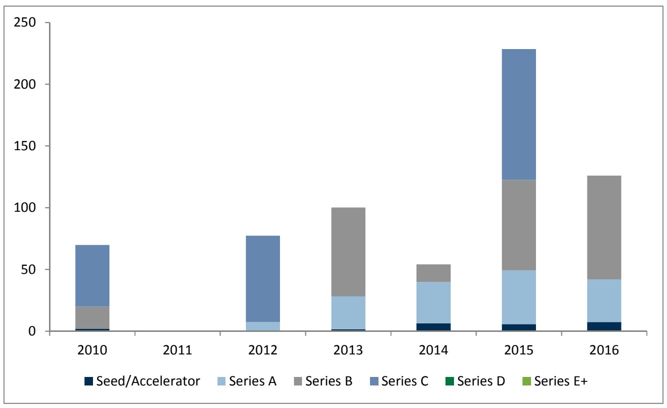
Characteristics of an early-growth VC vertical

In the venture world, the Space category is marked by a small number of large dollar capital investment rounds. These high profile rounds and the recent successes of their companies have sparked broadening venture interest in the category and related technologies and services.

As early stage as the category is, there has not been substantial large scale M&A activity. No large cap public company has acquired more than one Space company in the last 5 years, according to CB Insights. Take Google's acquisition of Terra Bella in 2014, for instance, a company that focuses on opening up the world's data through micro-satellite imagery and video. In 2017, Planet Labs, one of the larger private players in the space, announced the acquisition of Terra Bella from Google, highlighting the current private consolidation of a market that has slowly expanded beyond building rockets for space exploration.

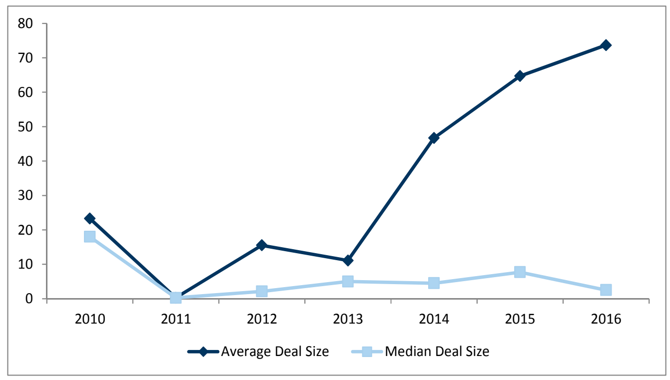
This is an early vertical both on a capital investment and deal count basis, with large spikes in each of the last three years highlighted by the Blue Origin, SpaceX, and OneWeb VC rounds ($500mn, $1bn and $1.2bn, respectively) driving investment growth. As this vertical matures and applicable technology allows companies to better gauge future returns on investment, we believe corporates, particularly in the Aerospace & Defense sector, may take more interest in private Space companies.

Exhibit 63: VC Funding in Space Startups by Investment Stage
Funding amount in $mn; excludes SpaceX, OneWeb and Blue Origin funding deals



Source: CB Insights, Goldman Sachs Global Investment Research.

Exhibit 64: Average and median deal size of VC investments in Space startups
Deal size in $mn



Source: CB Insights, Goldman Sachs Global Investment Research.

Nuance within Space: Sub-verticals in focus

In the venture world, investments are not limited to advanced spacecraft manufacturers and other **hardware** companies such as SpaceX. Planet Labs and Spire, for instance, focus on providing the space hardware necessary to collect image and video **data** that has long been unattainable and unusable for various applications in geopolitical, scientific, and even market analysis. We see companies like Planet Labs partnering with data analytics companies like Orbital Insights to make data more accessible and usable for entities in a variety of sectors and disciplines.

SpaceFlight Industries is a **services** company that connects interested parties with launch vehicle providers, making Space more attainable than years past to those who have the means and interest of getting there. Companies like Rocket Lab aim to provide the launch vehicle themselves. Finally, there are companies, like Moon Express and Planetary Resources, aiming to use technology to harness extra-terrestrial **resources** for the benefit of the planet (exhibit 65).

Exhibit 65: The Space Ecosystem: VC rounds >$15mn
Funding in $mn

	Company	Company Description	Round	Date	Amount	Total Funding	Country	City
Data	Spire	Satellite-powered data collection company	Series B	Jun-15	$40	$70	United States	San Francisco
	Planet Labs	Data collection through differentiated quality in satellite imagery	Series C - II	Apr-15	$23	$196	United States	San Francisco
	Planet Labs	Data collection through differentiated quality in satellite imagery	Series C	Jan-15	$70	$196	United States	San Francisco
Resources	Moon Express	Focus on harnessing lunar resources for the benefit of life on earth	Series B - II	Jan-17	$20	$48	United States	Cape Canaveral
	Planetary Resources	Robotic space exploration for resource retrieval	Series A - II	Nov-16	$15	$49	United States	Redmond
	Planetary Resources	Robotic space exploration for resource retrieval	Series A	Oct-15	$21	$49	United States	Redmond
Services	Rocket Lab	Rapid delivery of small satellites into orbit through it's Electron launch vehicle	Series D	Mar-17	$75	$75	United States	Los Angeles
	Spaceflight Industries	Space services and solutions, including launch coordination for satellites	Series B - II	Jun-16	$25	$45	United States	Seattle
	FireFly Space Systems	Launch company for small satellites	Series B	Jun-16	$19	$22	United States	Cedar Park
	Astroscale	Space Debris removal technologies	Series B	Mar-16	$35	$43	Singapore	
	Spaceflight Industries	Space services and solutions, including launch coordination for satellites	Series B	Mar-15	$20	$45	United States	Seattle
Hardware	OneWeb	Plans to put >600 satellites in orbit for low-cost global Internet access	Unatt.	Dec-16	$1,200	$1,719	United States	Arlington
	Axelspace	Micro-satellite company with applications in weather monitoring	Series A	Sep-15	$15	$15	Japan	Tokyo
	SpaceX	Manufacture and launch of advanced spacecrafts	Series D	Jan-15	$1,000	$1,185	United States	Hawthorne
	Blue Origin	Aerospace developer / manufacturer	Unatt.	Aug-14	$500	$526	United States	Kent

Source: CB Insights, Goldman Sachs Global Investment Research.

Exhibit 66 shows the VC investors that have funded Space companies, recently.

Exhibit 66: Investors in top 15 VC rounds >$15mn

Company	Latest Funding Round Investors
Rocket Lab	Bessemer Venture Partners, Data Collective, K1W1, Khosla Ventures, Promus Ventures
Moon Express	Autodesk, Collaborative Fund, Founders Fund, Undisclosed Investors
OneWeb	Airbus Group Ventures, Bharti Enterprises, Hughes Network Systems, Qualcomm Ventures, SoftBank Group, The Coca-Cola Company, Totalplay,Virgin Group
Planetary Resources	Societe Nationale de Credit et d'Investissement
Spaceflight Industries	Mithril Capital Management, Razors Edge Ventures, RRE Ventures, Vulcan Capital
FireFly Space Systems	Undisclosed Investors
Astroscale	Innovation Network Corporation of Japan, JAFCO Asia
Planetary Resources	Bold Capital Partners, Bryan Johnson, Conversion Capital, Grishin Robotics, Larry Page, OS Fund, Seraph Group, Sinovation Ventures, Space Angels Network, Vast Ventures
Axelspace	Energy & Environment Investment, Global Brain Corporation, Japan Science and Technology Agency, Mitsui & Co., SBI Investment, Seibu Shinkin Capital, SKY Perfect JSAT Corporation, SMBC Venture Capital
Spire	Bessemer Venture Partners, Jump Capital, Lemnos Labs, Promus Ventures, RRE Ventures
Planet Labs	International Finance Corporation
Spaceflight Industries	Razors Edge Ventures, RRE Ventures, Vulcan Capital
Planet Labs	AME Cloud Ventures, Capricorn Investment Group, Data Collective, Draper Fisher Jurvetson, Felicis Ventures, First Round Capital, Founders Fund, Frontier Tech VC, Industry Ventures, Innovation Endeavors, Lux Capital, O'Reilly AlphaTech Ventures, Obvious Ventures, Ray Rothrock, Space Angels Network, Yuri Milner
SpaceX	Fidelity Investments, Google
Blue Origin	Bezos Expeditions

Source: CB Insights, compiled by Goldman Sachs Global Investment Research.

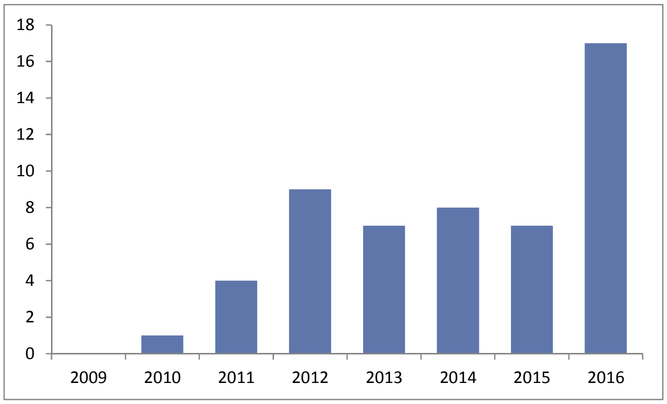
Expect VC funding in Space startups to accelerate

In the last few years, the space industry has witnessed an increase in interest from entrepreneurs and engineers, driven by the public successes in lower launch vehicle costs, as well as increased democratization of the industry for commercial activity once Congress updated the SPACE Act in November 2015 to allow private companies to own, transport and sell on Earth any asteroid resource or space resource.

For example, according to the Federal Aviation Administration, there was a 55% yoy increase in the number of launch applications filed by private companies in FY16, which include a wide range of space vehicles including small-payload rockets and space vehicle carrier aircraft. VC investors are attracted to the space industry financially as startups focus on areas that had previously been protected from competition and are not yet fully explored.

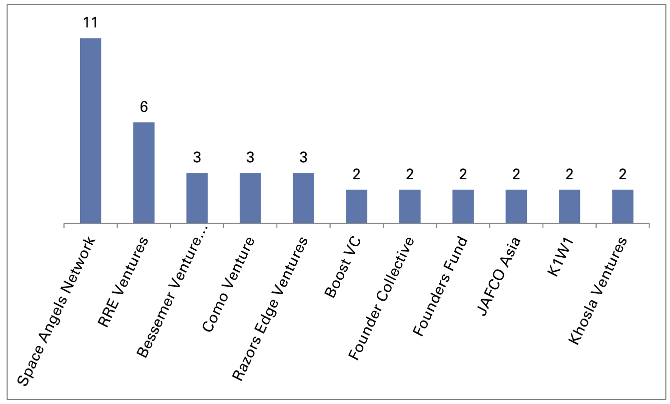
Investors are not just funding startups in relatively well established industries within space such as development of satellites and launchers, but also less established space ventures such as space mining and tourism. As we have seen in other sectors, large incumbents in the space industry could start looking outside their internal R&D teams and at space startups for innovative solutions. Therefore, many exits in the space industry could come from acquisitions rather than IPOs.

Exhibit 67: Space M&A & IPO Exits
# of exits



Source: CB Insights, Goldman Sachs Global Investment Research

Exhibit 68: Top Investors in Space Startups
# of participated deals in 2014-to date

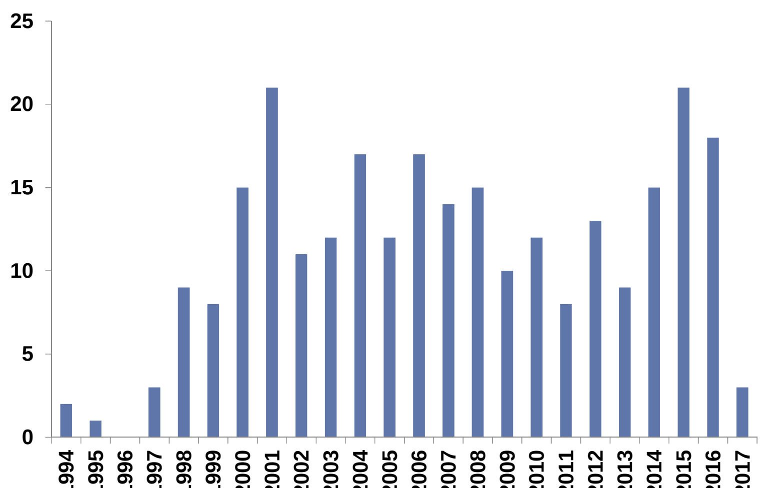


Source: CB Insights, Goldman Sachs Global Investment Research

Beyond VC

Capital markets, beyond venture capital, have been active to support space-related companies. According to Bloomberg, over 260 deals have been announced in the industry since 1994, including transactions among space hardware manufacturers, satellite operators and technology companies.

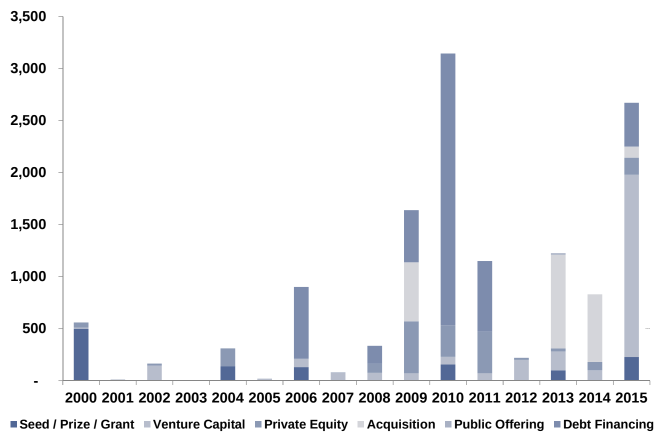
Exhibit 69: M&A deals involving space-related companies
Total deals announced



Source: Bloomberg.

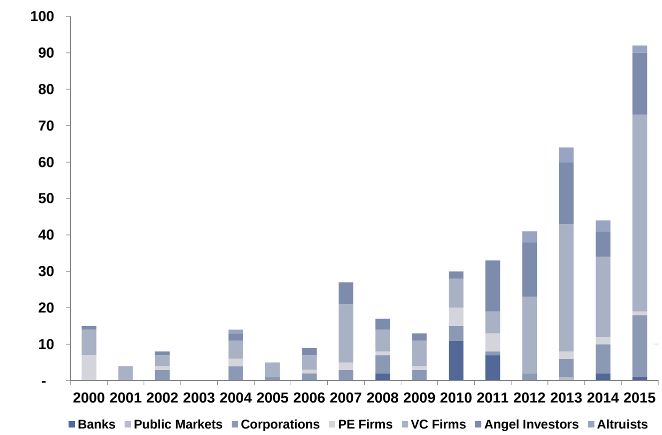
There has also been increasing support for Space startups, defined as space companies that started as angel- and venture capital-backed startups. According to Bryce Space and Technology, these companies have received support from multiple sources of capital, from angel investors to bank debt financing, as shown in exhibits 70 and 71.

Exhibit 70: Investment in Startup Space companies
$ mn



Source: Bryce Space and Technology.

Exhibit 71: Investment in Startup Space companies
Number of investors



Source: Bryce Space and Technology.

One important source of funding for satellite launches has been the United States Export Import Bank (ExIm). Historically, ExIm has provided over $5.7bn in loans and guarantees for satellite launches, services and insurance.

Exhibit 72: United States Export-Import Bank support for Space items
In US$

Country	Authorization Date	Obligor	Supplier	Product	Interest rate	Loans	Guarantees
Russia	1/8/1998	Vnesheconombank	Hughes Space & Communications International Inc.	Delta II Launch Vehicle	n/a	n/a	122,829,547
Brazil	7/20/1999	Empresa Brasileira De Telecomunicacoes	Hughes Space Communications Co.	Satellite / Integration	n/a	65,051,988	n/a
Thailand	2/28/2002	Shin Satellite Public Co. Ltd.	Space Systems/Loral Inc.	Satellite	n/a	n/a	184,511,149
Mexico	4/17/2003	Satelites Mexicanos S.A. de C.V.	Space Systems/Loral Inc.	Satellite and Related Equipment / Ground station	n/a	n/a	149,799,409
Malaysia	11/23/2004	Binariang Satellite Systems SDN BHD	Boeing Satellite Systems	Communications Satellite System	n/a	n/a	137,718,019
Malaysia	6/2/2006	Binariang Satellite Systems SDN BHD	Boeing Satellite Systems	Satellite Communications (Capital Increase)	n/a	n/a	8,321,051
Malaysia	6/8/2006	Measat Satellite Systems SDN BHD	Orbital Sciences Corp.	Satellite Communications	n/a	n/a	102,537,321
Spain	12/10/2009	HISPASAT S.A.	Space Systems/Loral Inc.	HISPASAT 1E Geostationery Satellite (Launch Insurance)	n/a	n/a	160,560,390
United Kingdom	12/3/2009	Avanti Communications Group PLC	Marsh & McLennan Companies	Geostationery Satellite	3.37%	215,621,649	n/a
Azerbaijan	4/27/2011	Azercosmos OJSCO	Orbital Sciences Corp.	Satellite	n/a	n/a	116,615,338
Luxembourg	11/18/2010	SES S.A.	Space Systems/Loral Inc.	Satellite	2.47%	158,004,263	n/a
Spain	12/9/2010	Hispasat Canarias S.L.U.	Space Systems/Loral Inc.	Satellite	n/a	n/a	228,286,420
United Kingdom	12/16/2010	Inmarsat Investment Ltd.	Boeing Satellite Systems Inc.	Satellite	3.11%	700,000,000	n/a
Australia	7/19/2012	Jabiru Satellite Ltd.	Lockheed Martin Space Science Systems Co.	Satellite	n/a	281,110,000	n/a
France	11/3/2011	Eutelsat Communications S.A.	Space Systems/Loral Inc.	Satellite	n/a	66,243,347	n/a
Mexico	7/12/2012	Government of Mexico	Boeing Space and Intelligence Systems Orbital Sciences Corp	Satellites	n/a	921,830,504	n/a
Vietnam	9/27/2012	Government of Vietnam	Lockheed Martin Space Science Systems Co.	Satellite	n/a	118,081,740	n/a
Australia	1/17/2013	Jabiru Satellite Ltd.	Lockheed Martin Space Science Systems Co.	Satellite and Launch Insurance (Amendment)	n/a	13,220,000	n/a
Hong Kong	11/15/2012	Kingsbridge Ltd.	Space Systems/Loral LLC (SSL), et. al.	Satellite and Launch Insurance	n/a	179,609,546	n/a
Hong Kong	11/15/2012	Kingsbridge Ltd.	Boeing Satellite Systems Inc., Space Exploration Technologies Corp. (SpaceEx), et, al.	Satellite, Launch Services and Launch Insurance	n/a	291,060,659	n/a
Hong Kong	5/30/2013	Asia Satellite Telecommunications Co. Ltd., et. al.	Space Systems/Loral LLC (SSL), Space Exploration Technologies Corp. (SpaceEx), et. al.	Satellite, Launch Services and Launch Insurance	n/a	343,292,904	n/a
Israel	8/23/2013	Space Communication Ltd.	Space Exploration Technologies Corp. (SpaceEx)	Satellite, Launch Vehicles and Launch Insurance	n/a	105,436,551	n/a
Spain	1/17/2013	Hispasat Canarias S.L.	Orbital Sciences Corp.	Satellite and Launch Insurance	n/a	n/a	87,149,423
United Kingdom	11/28/2012	Avanti Communications Group PLC	Orbital Sciences Corp.	Satellite (Amendment)	n/a	6,657,868	n/a
Australia	2/10/2014	Jabiru Satellite Ltd.	Lockheed Martin Corp.	Communications Satellite	n/a	9,869,000	n/a
Bulgaria	12/12/2013	Bulgaria Sat AD	Space Systems/Loral LLC (SSL) Space Exploration Technologies Corp. (SpaceX)	Communications Satellite and Launch Services	n/a	150,542,286	n/a
Hong Kong	11/26/2013	Asia Satellite Telecommunications Co. Ltd.	Space Systems/Loral LLC (SSL)	Communications Satellite and Launch (Credit Amendment)	n/a	2,231,470	n/a
Israel	11/1/2013	Space Communication Ltd.	Space Exploration Technologies Corp. (SpaceEx)	Geosynchronous Satellite Launch Services	n/a	618,751	n/a
Mexico	2/20/2014	Innova S.A. de R.L. de C.V.	Orbital Sciences Corp.	Communication Satellite	n/a	79,583,800	n/a
United Kingdom	7/14/2014	Inmarsat Investment Ltd.	Boeing Satellite Systems Inc.	Communications Satellite	n/a	185,907,209	n/a
United Kingdom	9/29/2014	Viasat Technologies Ltd.	Boeing Satellite Systems Inc.	Communications Satellite	n/a	524,929,198	n/a
Bulgaria	5/14/2015	Bulgaria Sat AD	Space Systems/Loral LLC (SSL)	Satellite (Credit Amendment)	n/a	4,547,714	n/a
TOTAL						**4,423,450,447**	**1,298,328,067**

Source: United Stated Export Import Bank.

The beginnings of European space Venture Capital

In general, Europe lags the US in terms of venture capital funding. In recent years European venture capital funds have raised on average around 1/5th of the total funds of their US counterparts.

EC 'Fund of Funds': The EU has begun to make efforts to improve this situation, with 2016 proving to be a significant year for European venture capital. The EU Commission launched the Venture Capital 'Fund of Funds' in 2016, committing to funding up to 25% of the total investment, capped at €400mn. This suggests that the total potential fund could reach as high as €1.6bn, potentially benefitting technology and engineering firms in the space sector.

Seraphim Space Fund: Also in 2016, the London-based Seraphim Capital launched the Space Fund, the largest space-focused European VC fund to date. The fund is aiming to raise £80mn for space technology investing, and has already received £50mn from the British Business Bank and a range of other global investors. The ESA is supporting the fund, acting as a facilitator and suggesting investments in return for some compensation. These developments indicate some early steps towards bridging the funding gap with the US.

ESA Initiatives: The ESA's Advanced Research in Telecommunications Systems (ARTES) is set up to help turn R&D investment in satellite communication products into successful commercial ventures. With €67mn of ESA funding to date, 61 ARTES downstream projects have generated €210mn in revenue. The ESA also runs Business Incubation Centres (BICs) which offer support to startups that attempt to apply space technology to non-space commercial fields. The aim is to make these businesses more investible, and in 2014 the BIC companies received 5 times the investment they had received in 2012.

Challenges in Space funding

Space startups in markets such as satellites and launchers could face challenges as there are already a large number of small startups in those markets doing similar things and targeting the same funding pool. This could lead to some consolidation, as we have seen in the case of Planet Labs' acquisition of Terra Bella from Google.

In addition, the privatization of space technology is driving the restructuring of the current regulatory framework for regulating new business models, licensing emerging ventures, and managing conflicts when companies from various geographies are involved in space working on similar missions. Also, areas within the space industry such as space tourism or asteroid mining are in very early stages and it is difficult to easily estimate the returns on investments in startups targeting these areas.

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EXPLORATION

NASA role: The NASA budget is still undecided, but could substantially accelerate were it to reconnect with a prioritization of space. The Trump administration has discussed the potential to do this.

Public to private: Exploration used to be the domain of governments, but is increasingly being privatized, adding to the addressable opportunity.

Entirely new industries: New technologies are creating new industries (on-orbit data plays, tourism, mining, on-orbit manufacturing), which are important sources of growth and progress.

Major players: Northrop Grumman, Lockheed Martin, Planet Labs, Spire, Orbital ATK, SpaceX, Blue Origin, Boeing, Bigelow, Sierra Nevada, Planetary Resources, Deep Space Industries, Virgin Galactic.

Exploration: new markets, new technologies, new places

Budget hawks often ask, "What can space do for me?" Quite a lot it turns out. For the A&D investor, NASA's nearly $20bn annual budget is hard to ignore. For generalists, space exploration has paved the way for entire industries in the S&P. For taxpayers, it is a source of national pride, but also key to everyday services and technologies.

We believe a new space renaissance is starting, where a positive feedback mechanism of exploration and budget allocation could fuel development of the space economy. Beyond growth, the market is also shifting towards the private sector, where corporations are replacing government agencies, enabling the later to venture further out while pushing boundaries of their own to create new businesses like space tourism, asteroid mining, and on-orbit manufacturing and satellite services. Scientists and Silicon Valley entrepreneurs claim the conquest of space is the next step for human civilization, but exploration leads the way and we believe a thriving space economy is the primary path to realizing it.

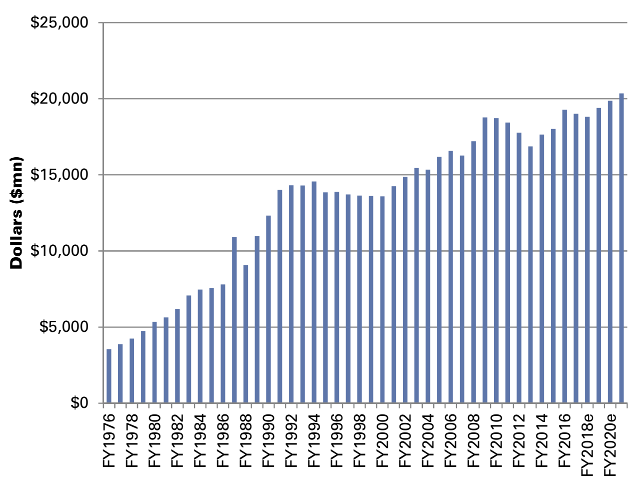
CIVIL SPACE

Wrestling with the value of exploration

- Flat is best scenario near term
- Privatization underway creates opportunity
- Resumption of manned exploration key to future

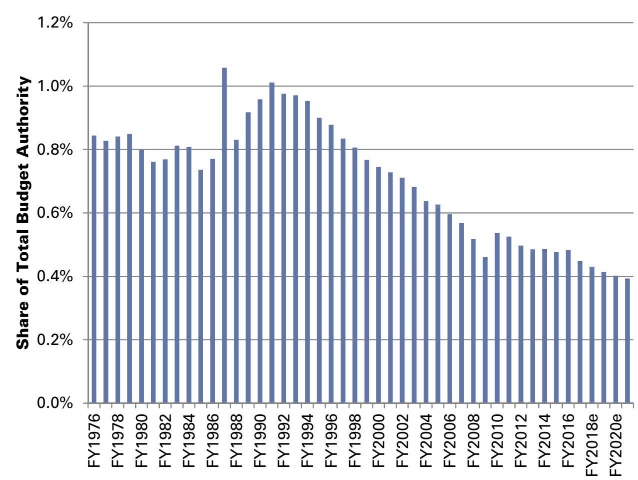
The greatest headwind to more exploration dollars is political will. NASA now accounts for less than 0.5% of federal discretionary spending after half a century of decline. The agency remains the most popular government agency according to the Pew Research Center (on a basis of favorable minus unfavorable ratings), with more than 2/3 of participants citing a favorable view. While it may require realized or potential scientific achievement strengthening the relationship between public and political support in order to drive a higher NASA budget, a return to Bush-era spending levels would increase the NASA budget 50% and to Clinton-era levels, 100%.

Exhibit 73: NASA budget ($mn)
The budget is growing...



Source: White House.

Exhibit 74: NASA budget as % of federal discretionary
...but less than the federal budget



Source: White House.

Rising competition with Russia and China geopolitically may spread to space. While cooperation is likely to continue, competition towards scientific achievement may fuel a civil space race not unlike during the Cold War. This dynamic would also strengthen political will to support NASA. The Space Foundation speculates that China's spending may already surpass US space spending.

Commentary from the new Trump administration suggests that it has set its sights on new national achievements in space, opening the possibility that space spending could outpace budget growth or that dollars may shift from Earth-science work to more private sector-accessible procurement for deep space exploration.

While civil space has not surpassed the growth of the overall US budget, it remains a $19bn line item and significant source of opportunity for federal contractors. More importantly, the operations, exploration and technology development funded and conducted by civil agencies are foundational to human progress, a smoothly operating economy, and the growth of new industries and products.

Exhibit 75: Main NASA and NOAA sample programs
Programs represent significant opportunity for OEMs

NASA program	Description	Manufacturer	Program cost
Rosetta Space Probe	Space probe launched in March 2004, sent to explore comets and asteroids. The probe ended its mission in September 2016.	Spacecraft: Astrium (airbus subsidiary) Launcher: Arianespace	$1.8bn
Lunar Reconnaissance Orbiter	Robotic spacecraft launched in June 2009, currently orbiting the Moon and collecting data for future NASA missions.	Spacecraft: NASA Launcher: ULA (Atlas V)	$583mn
Dawn	Space probe launched by NASA in September 2007 to study Vesta and Ceres, two protoplanets of the asteriod belt. Dawn is expected to remain in orbit indefinitely.	Spacecraft: Orbital ATK Launcher: ULA (Delta II)	$446mn
OSIRIS-REx	The OSIRIS-REx spacecraft will travel to a near-Earth asteroid, study it in detail, and bring back a sample to Earth.	Spacecraft: Lockheed Martin Launcher: ULA (Atlas V)	~$800mn excluding Atlas V
Juno	Launched in August 2011, a probe orbiting Jupiter to measure its chemical and physical properties. To be de-orbited into Jupiter's atmosphere when mission is complete.	Spacecraft: Lockheed Martin Launcher: ULA (Atlas V)	~$1.1bn
JuIcE	A joint NASA-ESA mission to investigate 3 ocean worlds in the Jupiter system: Europa, Ganymede and Callisto. Launch planned in 2022, arrival in 2030.	Spacecraft: Airbus Launcher: Arianespace (Ariane 5)	~$59mn until 2021
Hubble Telescope	A still-active space telescope launched into low Earth orbit in 1990. It played an important role in determining the rate of expansion of the universe.	Spacecraft: Lockheed Martin Launcher: Rockwell International (Space Shuttle Discovery)	~$10bn
James Webb Space Telescope	Next-generation space telescope. Expected to be launched in late 2018, to observe the formation of galaxies, stars and planets, including exoplanets.	Spacecraft: Northrop Grumman / Ball Aerospace Launcher: Arianespace (Ariane 5)	$9bn
Voyager Program	A program involving two probes, Voyager 1 and Voyager 2, to explore the outer Solar System. Launched in 1977, are now exploring the interstellar space - the furthest that a man-made object ever reached. Shutdown expected to start in 2020.	Spacecraft: Jet Propulsion Laboratory Launcher: NASA	$3.7bn until 2012
Solar Probe Plus (SPP)	Robotic spacecraft to explore the outer corona of the Sun, will orbit the Sun at a distance of less than five times its diameter, the closest any spacecraft has ever reached. Launch expected in August 2018.	Spacecraft: Applied Physics Laboratory Launcher: ULA (Delta IV Heavy)	$1.4bn
Van Allen Probes	Two spacecraft launched in August 2012 to study the radiation belts around Earth, which can disrupt satellites and cause power grid failures. The program has important practical applications.	Spacecraft: Applied Physics Laboratory Launcher: ULA (Atlas V)	~$670mn
Space Launch System	The first launch system capable of reaching deep space carrying a crew and support systems. The SLS will carry Orion, and is designed to support missions towards asteroids and other planets, like Mars.	Boeing	$10bn through 2017
Orion Spacecraft	Spacecraft designed to enable deep space human exploration missions, and potentially supporting a crew on longer duration missions.	Lockheed Martin	$6bn through 2017
NOAA Program	**Description**	**Manufacturer**	**Program cost**
GOES-R Series	Geostationary Operational Environmental Satellite (GOES) spacecraft deliver weather forecasts and provide short-term advance weather warning products to the commercial, educational, and public sectors.	Lockheed Martin	$10.2bn
Jason-3	International earth observation satellite that provides ocean surface measurement.	Thales Alenia Space	~$200mn
JPSS	Joint Polar Satellite System is a constellation of polar-orbiting, non-geosynchronous, environmental satellites designed to provide data used in weather forecast models and climate monitoring.	Ball Aerospace, Orbital ATK, Raytheon, Exelis, Northrop Grumman	$11.3bn
Polar Follow On	Follow on to JPSS.		$2.9bn until 2021
DSCOVR	Earth observation and weather satellite launched in 2015, orbits a sun-earth lagrangian point.	SpaceX	~$140mn
Space Weather Follow On	Follow on to DSCOVR.		~$760mn

Source: NASA, NOAA.

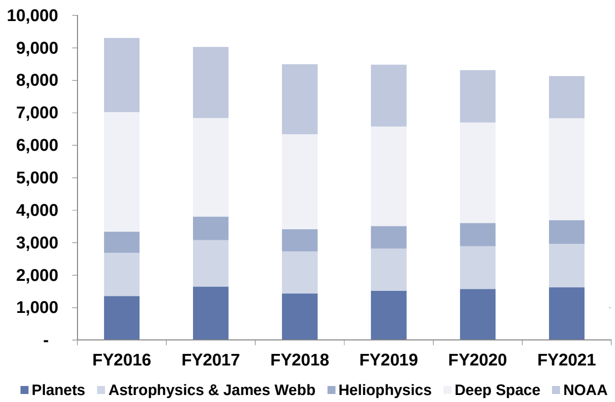
While the immediate dollar impact is not always clearly definable when conducting research and exploration missions like those to Mars, these missions could yield species-steering discoveries in energy, health, and climate change that could have profound economic implications. We look at some of the more immediate relationships between space agencies and the top lines of exposed companies.

Exploration of the weather, planets, asteroids, the Sun, and beyond

A significant share of NASA's budget is committed to exploration, and much of it is addressable by the private sector. In this section, we explore what the agency plans to do in the next few years on those fronts – and what companies are involved. We also include in this section NOAA weather satellites, which are an important addressable market for satellite launchers and manufacturers.

Exhibit 76: US Space exploration budget FY2017

Over $8bn a year committed to exploring the space



Source: NASA, NOAA.

How's the weather today?

The National Oceanic and Atmospheric Association (NOAA) conducts Earth observation and weather monitoring using satellites and other space based instruments. Programs like the GOES-R, the Jason-3, the JPSS and DSCOVR are included in the agency's budget. Several large programs are wrapping up, causing budget compression; however, the aging fleet of US government satellites are in need of replacement as they approach the end of their useful life, opening the possibility of additions.

Exhibit 77: NOAA FY 2017 budget ($mn)

$1.9bn each year for weather and climate satellite monitoring

FY2017 NOAA Presidential Budget Request	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021
NOAA addressable market	**2,286**	**2,187**	**2,153**	**1,906**	**1,617**	**1,295**
National Weather Service	127	134	125	115	113	109
National Environmental Satellite, Data & Information Service	2,159	2,053	2,028	1,792	1,504	1,186

Source: NOAA.

Beyond the blue

NASA's Planetary Science division conducts the agency's ventures towards other planets, comets, and natural satellites using probes like the Rosetta, Dawn, OSIRIS-Rex, Juno spacecraft. NASA plans to spend $1.5bn a year in planetary science initiatives, and some defense companies like LMT, AIR, and OA are beneficiaries.

Exhibit 78: Planetary Science Budget FY2017 ($mn)

$1.5bn each year are committed to NASA's planetary exploration initiatives

FY2017 NASA Presidential Budget Request	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021
Planetary Science	**1,361**	**1,647**	**1,440**	**1,520**	**1,576**	**1,626**
Planetary Science Research	276	301	272	286	282	287
Discovery	156	203	277	337	345	405
New Frontiers	259	184	82	91	143	234
Mars Exploration	412	614	589	565	498	280
Outer Planets and Ocean Worlds	116	170	56	78	128	247
Technology	142	176	164	164	180	172

Source: NASA.

Through the looking glass

Exploration and observation of the cosmos are funded under the Astrophysics and James Webb Space Telescope divisions. NASA's telescopes, including the $10bn Hubble, $9bn James Webb, Spitzer and Fermi are funded under these divisions. A month ago, Spitzer discovered 4 planets likely inhabitable (per NASA) near our solar system. The agency spends roughly $1.3bn a year on these initiatives, and companies such as NOC, LMT, GD, and BLL have won large contracts.

Exhibit 79: Astrophysics and James Webb Telescope Budget FY2017 ($mn)
$1.3bn each year committed to NASA's celestial observation ventures

FY2017 NASA Presidential Budget Request	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021
Astrophysics and James Webb Telescope	**1,329**	**1,436**	**1,295**	**1,297**	**1,316**	**1,342**
Astrophysics Research	188	229	236	236	249	252
Cosmic Origins	199	199	198	197	196	210
Physics of the Cosmos	108	100	88	94	98	94
Exoplanet Exploration	64	210	148	309	373	451
Astrophysics Explorer	150	129	91	156	204	186
James Webb Telescope	620	569	534	305	197	150

Source: NASA.

Here comes the Sun

Programs studying heliophysics and the impact of the sun in our solar system like the Voyager are funded at this budget line. Companies such as Lockheed Martin, and Boeing are involved in some of these programs.

Exhibit 80: Heliophysics Budget FY2017 ($mn)
$700mn each year committed to NASA's sunny endeavors

FY2017 NASA Presidential Budget Request	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021
Heliophysics	**651**	**724**	**684**	**698**	**715**	**724**
Heliophysics Research	159	195	192	210	216	214
Living with a Star	343	384	399	245	136	127
Solar Terrestrial Probes	51	40	39	127	179	198
Heliophysics Explorer Program	99	105	55	116	184	184

Source: NASA.

Another giant leap for mankind

We are going to Mars, taking the next great step for man, but it is unclear who will be first: NASA or a private company. With increased privatization, the line between them is blurring, but NASA is continuing to lead the way with the first exploration-class rocket built in half a century. For some commercial players, achievement has a more narrow definition, which may allow them to beat NASA to Mars, which could challenge NASA's role in space exploration and affect its budget.

NASA's Exploration Systems Development Division develops programs that will enable deep space exploration. This division coordinates three programs to procure the spacecraft, the rocket, and the ground systems that will enable human flight beyond the Moon, into asteroids and Mars: Space Launch Systems (SLS), Orion Multi-Purpose Crew Vehicle (scheduled to fly primarily on SLS), and Ground Systems Development & Operations.

The SLS is scheduled to launch in 2018 without a crew in its first launch, but there is now a NASA study looking at the feasibility of adding crew to that launch. We see this move as potentially aiming to accelerate NASA's relevancy as a valued exploratory agency in the eyes of Washington. The first crewed flight was scheduled for 2021. With that timeline, it would be possible for a commercial operator to make a significant enough achievement to potentially challenge NASA's position. Regardless of that outcome, we maintain a view that NASA will be critical in governing, regulating, and advancing the new space economy.

We maintain that the agency plays an important role in exploration and see the potential value of SLS/Orion launches as a substantial economic opportunity, especially if launch tempos pick up alongside political will for exploration, which the Trump administration has indicated. The agency has a more nuanced view of the tasks, risks, and steps associated with exploration that ensure it is conducted in the most responsible manner. While it may not be the first, it is important to note that innovators like SpaceX are made possible by NASA and the billions they have spent helping the company develop its systems and commercial viability. For NASA, Mars is not the only goal or worthwhile step forward. It is a big one, but there are intermediate steps it will take that are nearly as significant from both an economic and an achievement standpoint.

Exhibit 81: Exploration Systems Development Budget FY2017 ($mn)
Roughly $3bn annually to be spent in these programs

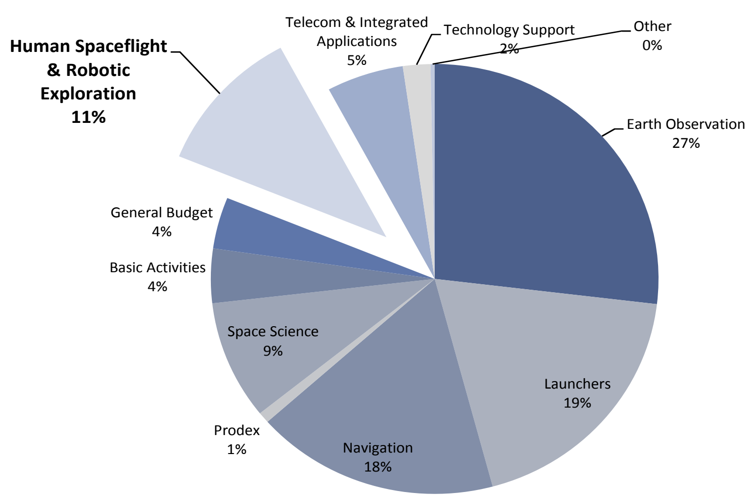
FY2017 NASA Presidential Budget Request	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021
Exploration Systems Development	**3,680**	**3,033**	**2,923**	**3,062**	**3,092**	**3,142**
Orion Program	**1,270**	**1,186**	**1,120**	**1,124**	**1,135**	**1,153**
Crew Vehicle Development	1,252	1,176	1,109	1,113	1,125	1,143
Orion Program Integration and Support	19	11	11	11	11	11
Space Launch System (SLS)	**2,000**	**1,391**	**1,362**	**1,485**	**1,500**	**1,524**
Launch Vehicle Development	1,950	1,343	1,295	1,420	1,432	1,455
SLS Program Integration and Support	50	48	67	65	68	70
Exploration Ground Systems	**410**	**456**	**441**	**453**	**458**	**465**
EGS Development	391	440	426	438	442	449
EGS Program Integration and Support	19	15	15	15	15	16

Source: NASA.

European Exploration

Compared to NASA's near $20bn budget, the ESA's 2017 spending of €5.7bn (c.$5.4bn) is modest, but a relatively large chunk (11%) is allocated to exploration (~$600mn vs NASA's ~$9bn; Exhibit 82). Much of this is covered by Aurora, the long-term plan for European exploration of the solar system. So far this has included ExoMars, launched in 2016, which put a research satellite into orbit around Mars, though its experimental lander crashed on the planet's surface. Next in 2020 is a planned Mars rover, followed by a robotic sample-collection mission in the 2020s and finally a human mission in the mid-2030s. Alongside Aurora are proposals for a lunar mission and even a base on the Moon by 2030.

Exhibit 82: ESA to spend €633mn of the €5.7bn budget on exploration
ESA budget allocation by domain, 2017



Source: ESA, Goldman Sachs Global Investment Research

Privatization: changing of the guard

Space was once the sole domain of governments, but that has steadily changed over the last half century. Today, we are witnessing a new wave of privatization as not only the size of the private sector space economy accelerates, but also its complexity. Traditional contractor-accessible programs continue, but private companies like OA, BA, SpaceX and Sierra Nevada Corp. are beginning to take over regular US government operations as NASA ventures further out.

Cargo and commercial crew transportation

Since the early 2000s, NASA has been partnering with private companies to design and develop cargo and crew transportation capabilities to support its missions. According to the FAA, almost 80 commercial cargo and crew launches are projected from 2017 to 2026.

Exhibit 83: NASA commercial crew and cargo launch projections
76 crew and cargo missions from 2010 to 2024

2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
COTS 1		COTS 2 / 3	Orb D1	Spx 3	Spx 5	Spx 8	Spx 10	Spx 13	Spx 16	Spx 19	Spx 22	Spx 25	Spx 28	Spx 31
		Spx 1	Spx 2	Spx 4	Spx 6	Spx 9	Spx 11	Spx 14	Spx 17	Spx 20	Spx 23	Spx 26	Spx 29	Spx 32
			A ONE	~~Spx 5~~	~~Spx 7~~	OA 5	Spx 12	Spx 15	Spx 18	Spx 21	Spx 24	Spx 27	Spx 30	Spx 33
				Orb 1	OA 4	OA 6	OA 7	Orb 9E	Orb 11	Orb 12	Orb 13	Orb 14	Orb 15	Orb 16
				Orb 2			OA 8	Orb 10E	SNC 1	SNC 2	SNC 3	SNC 4	SNC 5	SNC 6
				~~Orb 3~~			Spx DM1	Spx DM2	USCV 1	USCV 3	USCV 5	USCV 7	USCV 9	USCV 11
								OFT	USCV 2	USCV 4	USCV 6	USCV 8	USCV 10	USCV 12
								CFT						

COTS	Commercial Orbital Transportation Services: Development of commercial cargo transportation systems
CRS 1	Commercial Resupply Services: cargo transportation for the International Space Station
CRS 1E	Commercial Resupply Services Extension
CRS 2	Commercial Resupply Services 2
CRS 3 ?	Commercial Resupply Services 3?
Antares	Antares test flight
CCtCap	Commercial Crew Transportation Capability: commercial development of a crew transportation capability
CTS	Crew Transportation System: intended to conduct regular flights to the International Space Station

Rescheduled
Unsuccessful

Source: FAA Compendium 2017, NASA.

Exhibit 84: Space transportation budget FY2017 ($mn)
Over $2bn each year are committed to NASA's Commercial Crew and ISS Cargo initiatives

FY2017 NASA Presidential Budget Request	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021
Space Transportation	**2,849**	**2,758**	**2,475**	**2,119**	**2,144**	**2,214**
Commercial crew	1,243	1,185	732	173	36	36
Crew and Cargo - including CRS	1,606	1,573	1,743	1,946	2,109	2,178

Source: NASA.

(1) Cargo resupply contracts

In 2006, NASA unveiled the Commercial Orbital Transportation Services (COTS) program, which aimed to develop and demonstrate commercial cargo transportation capabilities. Under the COTS, SpaceX and Orbital ATK developed launch vehicles and spacecraft that demonstrated the ability to take cargo into the space station. NASA then awarded two Commercial Resupply Services contracts to SpaceX and Orbital to take cargo to the ISS from 2012 through 2015. These CRS contracts were afterwards extended to include further missions in 2017 and 2018. In early 2016, NASA awarded the second CRS contract, CRS-2, where SpaceX, Orbital ATK and Sierra Nevada Corporation were awarded contracts to resupply the space station until the mid-2020s, with each guaranteed at least 6 missions.

Exhibit 85: Cargo resupply awards
OA, SpaceX, and SNC are likely to see more opportunity in the next decade

Contract	Year	Amount	Company	Remarks
COTS	2006	$396mn	SpaceX	Dragon
COTS	2006	$207mn	Kistler*	K-1
COTS	2008	$288mn	Orbital	Cygnus
CRS-1	2008	$1.6bn	SpaceX	Dragon (12 flights)
CRS-1	2008	$1.9bn	Orbital	Cygnus (8 flights)
CRS-1E	2015	$1.2bn	SpaceX	Extension of five missions from 2017 to 2018
CRS-1E	2015	$475mn	Orbital ATK	Extension of one mission from 2017 to 2018
CRS-2	2016	$900mn	SpaceX	Six missions from 2019 to 2024
CRS-2	2016	$1.4bn	Orbital ATK	Six missions from 2019 to 2024
CRS-2	2016	Undisclosed	Sierra Nevada Corp.	Six missions from 2019 to 2024

Source: NASA, FAA.

(2) Commercial crew transportation contracts

NASA took transport one step further to include a human-rated capability, starting the Commercial Crew Development program in 2010 for concept work. NASA awarded parts of the contract to Blue Origin, Boeing, Paragon, Sierra Nevada Corporation, ULA and SpaceX. After other maturation programs and downselects, NASA awarded Boeing and SpaceX contracts under the Commercial Crew Transportation Capability, which focused on the final design, testing, and evaluation of the spacecraft CST-100 Starliner and Crewed Dragon as potentially certifiable for human spaceflight, with first flights in 2017 and 2018.

Exhibit 86: Commercial Crew awards
Boeing and SpaceX are racing to be first commercial human launch provider

Contract	Year	Amount	Company	Remarks
CCDev	2010	$20mn	Sierra Nevada Corp.	Dream Chaser
CCDev	2010	$18mn	Boeing	CST-100 Starliner
CCDev	2010	$6.7mn	United Launch Alliance (ULA)	Atlas V human rating
CCDev	2010	$3.7mn	Blue Origin	Launch abort systems
CCDev	2010	$1.4mn	Paragon	Space life support
CCDev2	2011	$112.9mn	Boeing	CST-100 design maturation
CCDev2	2011	$105.6mn	Sierra Nevada Corp.	Dream Chaser design maturation
CCDev2	2011	$75mn	SpaceX	Crewed Dragon development
CCDev2	2011	$22mn	Blue Origin	Launch abort systems
CCiCAP	2012	$460mn	Boeing	CST-100 Starliner crewed maturation
CCiCAP	2012	$440mn	SpaceX	Crewed Dragon maturation
CCiCAP	2012	$212.5mn	Sierra Nevada Corp.	Dream Chaser crewed maturation
CCtCap	2014	$4.2bn	Boeing	Final development phase of CST-100 Starliner
CCtCap	2014	$2.6bn	SpaceX	Final development phase of Dragon V2

Source: NASA, FAA.

NEW SPACE EXPLORERS

Emerging markets in space

- Earth Observation: Eyes in the sky
- Tourism: Normalizing human spaceflight
- Space Mining: Unlimited resources?
- On-orbit OEMs: The backbone of the future

The space economy is reigniting as new technologies and markets emerge. We explore exciting growth areas outside traditional core businesses.

Earth Observation: Eyes in the sky

Earth observation is gaining traction in the big data world. The implications and end uses are significant, though it is unclear whether the commercial industry is ready to stand on its own. Companies are forced to differentiate themselves from free services provided by the US government, usually through higher resolution imaging and frequency of revisits, which means high capex. Fortunately for operators, government demand growth is strong, growing at about 8% per year in the US. This has supported some of the higher resolution operators, but we worry the commercial space is crowded, especially on the private side where VC funding has been an enabler of businesses that are likely not profitable yet. Consolidation may be necessary for some to be viable, and those who find the broadest use cases are most likely to succeed.

Cars: The Road Ahead

For more on our autos team forecast that autonomous driving will spur a $100bn parts market by 2025, see *Cars 2025: Vol. 3: Monetizing the Rise of Autonomous Vehicles.*

Applications

Data from imaging satellites helps underlie autonomous vehicle systems (for HD mapping), 5G deployment, ship tracking, and agricultural assessments, but these systems have a long way to go before they become serious revenue generators. Our Autos research team sees autonomous vehicles as commercially available by 2025, tower placement planning for 5G could leverage other existing methods, legally-operating ships are already tracked, and farmers have access to free data from government sources.

Operators and users are typically forced to choose between imaging quality and frequency of revisits. Some companies are attempting to develop a joint architecture whereby lower cost assets can make a binary observation – whether change has occurred in an image--and then communicate that to a larger satellite which would take a closer look. While both satellites and drones are riding a new wave of imaging and data demand, they do not necessarily compete with each other. Unmanned aerial vehicles obtain far more detailed imaging, with resolutions providing survey-grade imaging. Satellites can build a better macro picture faster, but sacrifice resolution. As such, we expect the two industries to develop in a complementary fashion.

Government customers continue to demand more data. The US government operates a fleet of classified Keyhole Earth-imaging satellites. While their capabilities are far greater than any commercially operated platform, they cannot look everywhere at once, so more eyes in the sky are likely desired.

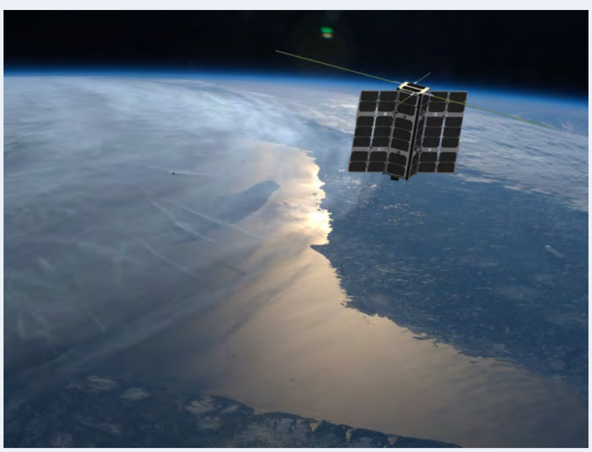
Space Startups: Spire

The Problem: We spoke to big-data startup Spire, which operates a fleet of satellites for maritime and aviation tracking, as well as precision meteorology. There are large swathes of ocean and sky that are beyond terrestrial tracking systems, leaving a door open to potentially illegal activities. Sequestration in Washington has delayed the next generation of weather satellites to a critical point, according to the GAO and industry participants.

The Solution: While there are existing services for tracking and meteorology, and many of them are free, Spire brings new levels of precision and competitive solutions for both public sector and private customers. The company is able to detect ships that have turned off their transponders, often a sign of illegal activity, pinpoint responsibility for insurance providers, and gather better data that meaningfully improves weather models. It also sells data to hedge funds seeking better data in these markets. The company has deployed a sophisticated constellation of smallsats the size of a shoebox that bounce signals off the ionosphere as a detection method and study distortions in GPS signals to better forecast weather.

The Bottleneck: Launch of smallsats is a challenge, particularly when the target fleet size is in the hundreds of satellites and replaced every few years. Schedule delays at launch providers are common, typically resulting in year-long delays. The company is forced to plan for delays, spreading launches across rockets and launch sites, and hedge on orders and scheduling.

Exhibit 87: Spire's Lemur 2 in orbit



Source: Spire.

Exhibit 88: Spire's Lemur 2 on a table during testing

Source: Spire.

Tourism: Normalizing human spaceflight

In the first step towards opening Space to anyone, entrepreneurs are developing vehicles designed to bring tourists to the edge of space. This end market will stress the launch industry, testing its ability to build and launch people safely, cheaply, and quickly. While we view the industry as critical to normalizing human spaceflight, we see it struggling to take flight amid safety concerns in the near-term. Tourism may catalyze further investment in space, clean energy, and climate science. Astronauts often speak about the impact of seeing the Earth from space on their life and perspectives. Adding more people to those ranks would only help fund programs, organizations, and businesses devoted to exploration and Earth preservation.

Background

A tourist seat on a Soyuz rocket costs about $35mn, but Sir Richard Branson believes he can lower that cost 140X—to $250,000 a person—for sub-orbital travel. Jeff Bezos's Blue Origin will likely compete at a similar price point for sub-orbital flights. In the orbital market, SpaceX and Boeing are possible entrants, using their NASA-funded commercial crew capsules for tourism. Bigelow Aerospace has proposed an inflatable space station as a destination—a space hotel per se.

Most ventures focus on sub-orbital flight, just beyond the Karman Line, 100km from the surface of the Earth and the conventional edge of space. That is about 10X the altitude flown by most commercial aircraft.

The math is challenging

The five Space Shuttles launched 135 times, with two catastrophic failures. At about $500mn per launch and with a 98% success rate, the Shuttles are some of the most successful launch vehicles ever developed. But they only flew 27 times each on average, and two failed. We have concerns about the implications of flying lower-cost rockets repeatedly and frequently. We believe the industry will "live or die" by the launch record of all participants. A few failures could rapidly diminish demand. Customer perception of risk in an industry with relatively few launches could harm even those with perfect records.

The fly away cost of most of these launch vehicles is not public. As seen through NASA's commercial crew program, the cost of developing an orbital crew capsule capable of space travel is in the billions. Developing even a small rocket or aircraft to launch it can cost hundreds of millions. Amortizing that cost across rockets that generate less than a million per flight seems unrealistic. Suborbital rockets are advantaged because they do not reach the same speeds as orbital systems, and therefore do not need to endure the same heat damage. Although this makes suborbital rockets better candidates for low cost reusability, that cost is still not insignificant.

Regulations

The US government proposed a set of rules in December 2015 to regulate space tourism, including screening procedures and emergency training requirements. Any company offering to launch paying passengers from American territory on a suborbital rocket needs to be licensed by the FAA. This process focuses on public and property safety, and is regulated under the Code of Federal Regulations, Title 14, Chapter III.

Space Startups: XCOR Aerospace

The Problem: If the average person is going to space, rocket reliability is going to have to improve. A few failures could jeopardize the industry. Additionally, the FAA will be needed to maintain a degree of safety assurance for participants and third parties.

The Solution: We spoke with XCOR Aerospace, a rocket propulsion company that is expanding towards being a launch solutions provider, with a particular focus towards tourism. Reusability is a natural way to prove reliability—an engine that has been flown before is one less likely to fail, so long as no part is less reusable than the number of times it has been used and the quality control associated with refurbishment and part testing is just as rigorous as for the first launch. The FAA appears to be heavily embedded with launch providers and actively engaged with ensuring a supportive yet responsible regulatory environment for human spaceflight.

The Bottleneck: The challenge with rockets traditionally is that they are very difficult and expensive to test—this means that a $500mn launcher like SLS may never fly before it is human rated. How many *launches* with what *success rate* need to happen before the general public lines up to fly? We think both numbers need to be very high. The only viable way to achieve this is with a very simple clean-burning reusable engine, enabling fast turnaround and low maintenance. XCOR believes they have developed such an engine. It is capable of flying 7-8X per day at very low cost. This would enable to company to run hundreds of test launches in the time a more traditional light rocket system could do a dozen.

Space Mining: Unlimited resources?

Space mining could be more realistic than perceived. Water and platinum group metals that are abundant on asteroids are highly disruptive from a technological and economic standpoint. Water is easily converted into rocket fuel, and can even be used unaltered as a propellant. Ultimately being able to stockpile the fuel in LEO would be a game changer for how we access space. And platinum is platinum. According to a 2012 Reuters interview with Planetary Resources, a single asteroid the size of a football field could contain $25bn-$50bn worth of platinum.

Water

The Space Shuttle's fuel supply was essentially water with its atoms rearranged. And space is full of it. Deep Space Industries has even developed a thruster that simply heats water into steam as a propellant, making it safe to fly as a secondary payload when other propellants cannot. According to Planetary Resources, it takes 54 liters of water (fuel) to lift one kg to LEO. Lifting that same kg to GEO requires just 4 liters, but each of those requires 54, compounding the size of rocket required. This means that an orbiting 'gas station,' using water from asteroids, could radically change the way we interact with space and cut launch costs significantly.

Metals

Successful asteroid mining would likely crater the global price of platinum, with a single 500-meter-wide asteroid containing nearly 175X the global output, according to MIT's Mission 2016. Furthermore, the less valuable metals from asteroids can be ground into a powder and used in a 3-D printer. Asteroid mining could very quickly supply an emerging on-orbit manufacturing economy with nearly all the raw materials needed.

Capex

While the psychological barrier to mining asteroids is high, the actual financial and technological barriers are far lower. Prospecting probes can likely be built for tens of millions of dollars each and Caltech has suggested an asteroid-grabbing spacecraft could cost $2.6bn. We expect that systems could be built for less than that given trends in the cost of manufacturing spacecraft and improvements in technology. Given the capex of mining operations on Earth, we think that financing a space mission is not outside the realm of possibility.

Regulations

The exploration and extraction of resources from celestial bodies – like minerals found on the Moon – are generally regulated by the Outer Space Treaty of 1967, which limits claims on celestial bodies but allows for resource extraction. In the US, former President Obama signed Commercial Space Launch Competitiveness Act, which opened the door for US companies to explore, extract, and recover space resources.

Space Startups: Deep Space Industries

The Problem: Dreams of colonizing other worlds are likely not attainable without industrial infrastructure in space. Extracting raw materials from asteroids is just the first part—the space economy ultimately needs people.

Little research has been conducted to study the minimum gravity needed for people to survive long term in space. Zero gravity can be devastating on the human body, but what is the tipping point between the Earth's gravity and zero that triggers health problems? Astronauts are carefully selected for physically intense, relatively short, missions on the ISS, but as plans are developed for everyday people to dwell in space, the issue of gravity comes front and center.

The Solution: After acquiring the raw materials from asteroids, Deep Space Industries intends to process the metals into a powder and employ additive manufacturing technology to print a rotating space station capable of simulating different gravities. This station would be key to determining the biological limitations of life on Mars or the Moon. Furthermore, it would likely become a hub for the economy off Earth. As an intermediate step the company may seek to become the first orbiting 'gas' station, extract high value minerals, or supply a potential early-stage on-orbit manufacturing base.

The Bottleneck: Low launch costs are an enduring theme in the future of the space economy. Launching a handful of people per launch at a cost of tens of millions of dollars will never be economically viable. Deep Space Industries suggests that launch costs need to come down by at least 2 orders of magnitude to normalize space travel and the space economy. Tourism is a good first step, but scale will matter. Low launch cost primes the on-orbit economy, but ultimately the expansion of the on-orbit economy will reduce the need for missions from Earth.

On-orbit OEMs: The backbone of the future

Satellites break. They run out of fuel. They can be placed in improper orbits. Until now, little could be done to repair them. Critical space assets like the International Space Station and the Hubble Telescope can be serviced by astronaut spacewalks or, previously, shuttle missions. But when something happens to a satellite, it is usually the end of the asset. Competing on-orbit servicing solutions from OA and MDA are emerging, investable fore-runners of a space-based manufacturing economy.

> *"The ability to safely and cooperatively interact with satellites in GEO would immediately revolutionize military and commercial space operations alike, lowering satellite construction and deployment costs and improving satellite lifespan, resilience, and reliability."*
>
> *-Defense Advanced Research Projects Agency*

Looking forward, we do not dismiss the idea of space-based manufacturing, assuming that the development of asteroid mining ventures is successful and capable of supplying the raw materials. For now, access to and from LEO is expensive, but efforts to normalize space travel through reusable rocketry are underway and may eventually succeed in lowering launch costs enough for an orbiting manufacturing sector to develop.

Orbital ATK's Mission Extension Vehicle (MEV)

Though some investments in space are almost literally moonshots, OA's plans for a satellite servicing system are far closer to Earth. Orbital ATK is developing an MEV, a jetpack for satellites, which will connect with satellites out of fuel to enable station keeping beyond their typical 15-year life expectancies, largely using proven technology. We see this investment as a tangible step towards a space-based manufacturing and repair economy, with immediate ROI while maturing key technology. We believe what is at stake is not just higher free cash flow to satellite operators and OA but the coming decades of how man operates in space. OA is getting a clear head start through this investment.

The opportunity

Geostationary satellites cost hundreds of millions of dollars. They carry enough fuel to operate for about 15 years and are built with electronics rated for about 20 years, creating an opportunity to extend mission life. Extending a satellite's life by a third would change the return profile for satellite operators in a highly competitive environment, especially as end market pricing pressures their financials amid structural changes in the industry (as discussed in the satellite services section).

The solution

Orbital's solution attaches to host satellites running low on propellant and uses its own fuel and propulsion system to keep the host satellite at its station. At present, the technology does not involve a transfer of fuel or mechanical repairs; however, these are logical next steps, which would open new opportunities for subsequent platform development.

How an MEV could change investment returns on satellites

OA's MEV, planned to begin operations in about 2 years, will target the roughly 300 commercial satellites in Geostationary Orbit. About 20 of those reach the end of their service lives each year (in service divided by useful life), and government satellites would add to the opportunity set. Operators choosing to extend will likely face a breakeven decision when costs for the MEV reach about 40% of revenue, the high end of current D&A.

Operators may be willing to accept slightly higher MEV costs since it eliminates uncertainty of filling capacity in an already oversupplied market while further paying down debt.

We model the operator breakeven based on satellite size, location, pricing, and fill rate, as well as OA MEV annual pricing.

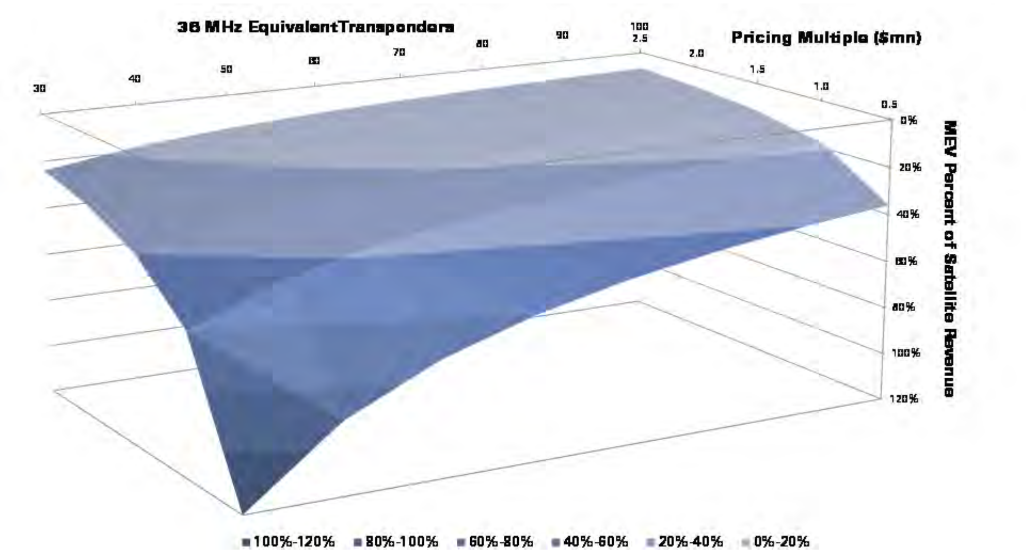
- **Size:** Satellite size is based on the number of 36 MHz equivalent transponders. Transponders in today's fleets can reach over 100 per satellite with the smallest numbering less than 20. We see 60 transponders as sufficiently large to justify mission extension under almost every situation with fewer in key orbital positions.
- **Location & Returns:** Satellite returns vary by location, with those positioned over key geographies like Europe seeing better pricing than those over North America.
- **Fill rate:** Older satellites tend to have a higher fill rate than new. Newer satellites have as much as 40-50% unused capacity. A high utilization rate is 80-90%.
- **OA MEV price:** OA pricing will likely depend heavily on contract term length and customer. We expect a $13mn annual rate (based on press reports) for its anchor customer/satellite (Intelsat) with positive pricing for subsequent vehicles. Follow on contracts during the initial 5-year performance period could range between $15-20mn per annum (assuming 40% of revenue per satellite and assumption of pricing increase above initial rate).

Our model employs an interaction term 'pricing multiple' that is the fill rate multiplied by the annual revenue for each given satellite terminal at a 100% fill rate. It estimates the average revenue per transponder for a satellite. High value locations with a high fill rate see a higher pricing variable. Low value locations with low fill rates have values less than 1.

That value is multiplied by the number of transponders for estimated satellite revenue and divided by $18mn per satellite (mid point of $15-20mn) for mission extension services. The resulting opportunity surface is shown in Exhibit 89. Dark blue shading shows areas of increasingly lower return compatibility for the MEV and satellites of a given profile.

Exhibit 89: Indicative opportunity surface for an MEV

Pricing at $18mn/yr would be reasonable for most satellites (Darker blue = less suitable)



Source: Goldman Sachs Global Investment Research.

Which satellites to extend?

Conventional thought on the MEV is the vehicle will be deployed to give additional life to assets close to retirement. And that is logical, because it reduces capex from replacement demand. These satellites are well established and often have higher utilization than newer assets, which have spare capacity. However, the oldest satellites tend to be smaller with less return potential. Operators could use the MEV to extend new satellites with greater capability. As operators come under pressure to maintain returns amid the current pricing/capex environment, the MEV would be a critical offset and competitive advantage. This implies the MEV is well placed to benefit during what we see as the ongoing supply ramp and downward trend in pricing. Exhibit 90 compares the cash returns associated with a typical geostationary satellite with and without the MEV. Our European Telecom research team estimates that the representative satellite plus launch is about $300mn and generates about $40mn-$60mn cash post interest. It is likely that OA's servicing vehicle will target similar or larger satellites. If this were to materialize, the MEV could improve the returns of a particular investment by ~100 bp, as well as postpone capex, expand margins, de-risk, and improve interest coverage—key considerations for operators today, particularly those that are distressed.

Exhibit 90: Traditional satellite operator returns vs. returns using MEV

MEVs can drive higher returns and margins, while reducing capex

Satellite operations without MEV

		Investment Period			Operational Period														
Launch + Satellite Cost	**IRR**	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
$300mn	12%	-100	-100	-100	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50

Satellite operations with MEV

		Investment Period			Operational Period															MEV Period				
Launch + Satellite Cost	**IRR**	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
$300mn	13%	-100	-100	-100	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	32	32	32	32	32

Source: Goldman Sachs Global Investment Research.

The MDA response

OA is likely to have an effective monopoly on commercial satellite life extension in the near term, but MacDonald, Dettwiler and Associates is developing refueling technology with Defense Advanced Research Projects Agency (DARPA). Although MDA's prior efforts to develop a commercial satellite life extension system did not materialize, the company may now succeed given DARPA support. MDA's Space Infrastructure Servicing (SIS) vehicle would ostensibly be more capable than OA's MEV, able to actually refuel satellites and deploy a greater array of servicing sensors and technologies from day one. Many of the considerations associated with the MEV would apply to the SIS, though the more varied capabilities of the SIS would allow shorter-term servicing operations, which could improve the NPV associated with the vehicle.

Space-based industry

It is still a long way off, but satellite servicing technologies developed by OA, MDA and civil space agencies, along with advances in 3D printing, are paving the way for on-orbit manufacturing. In conjunction with the emergence of asteroid mining companies that could supply the raw materials, production capabilities in space would radically change the math of the space economy and open new possibilities. Just as SpaceX's launchers appear to be a means to a goal of a large LEO communications network, Blue Origin's New Glenn rocket may be the same for an eventual LEO manufacturing economy.

Manufacturing in space would allow others in the space economy to bypass launch to LEO, fundamentally changing the capabilities of the assets in space. Products like large antennae that would not otherwise fit in a rocket capsule could be assembled in orbit and joined to more sophisticated parts built on Earth. On-orbit gas stations could fuel newly assembled rockets, which could be built with negligible concern for weight and propellant. High pollution industries could be relocated to orbit to avoid harmful effects on the environment, though the environmental impacts are likely not well understood. These systems will be critical to eventually colonizing Mars if and when possible. We are decades out from seeing classic industry, but the building blocks are being assembled today.

MILITARIZATION

Substantial military infrastructure is in space: Space is key to national security, as much of the US military's assets are in space and are increasingly vulnerable to adversaries.

It is crowded up there: More countries and more commercial players moving into space is causing congestion which adds risk.

Space moves Defense numbers more than you might think: Space is a larger portion of the US Defense budget, growing at a faster rate, than we think the average A&D investor realizes.

Major players: Northrop Grumman, Lockheed Martin, Boeing, Raytheon, Harris Corp., and SpaceX.

Militarization: the battle for the highest ground

PROFILES IN INNOVATION

For more on the growing military market for drones, see *Drones: Flying into the Mainstream*, also from our Profiles in Innovation series.

As more critical assets are placed in orbit, and terrestrial assets increasingly rely on their connections to Space-based infrastructure, world militaries are rethinking how Space fits into battle plans. Nearly every facet of the US military is reliant on space—everything from drones, weapon guidance units, and communications, to its nuclear forces.

In 2016 the Deputy Secretary for Defense commented that the Pentagon did not have tactics and doctrine in space until recently. As space becomes a renewed national priority, investable themes will emerge. The US defense and intelligence budget for space is broadly classified, but we estimate there is $22bn in addressable annual spending, growing at a 6% CAGR over the next 5 years based on our bottom-up analysis. Because most of the budget is classified, we think investors overlook the importance of this sector, and the changes that are unfolding.

We look at how the US military and its allies are responding to varied threats with $350bn-$400bn of friendly defense, civil, and commercial assets. With a size beginning to rival the US Marine Corps, the space warriors of the US military are becoming an increasingly important line item on Capitol Hill and within the Pentagon.

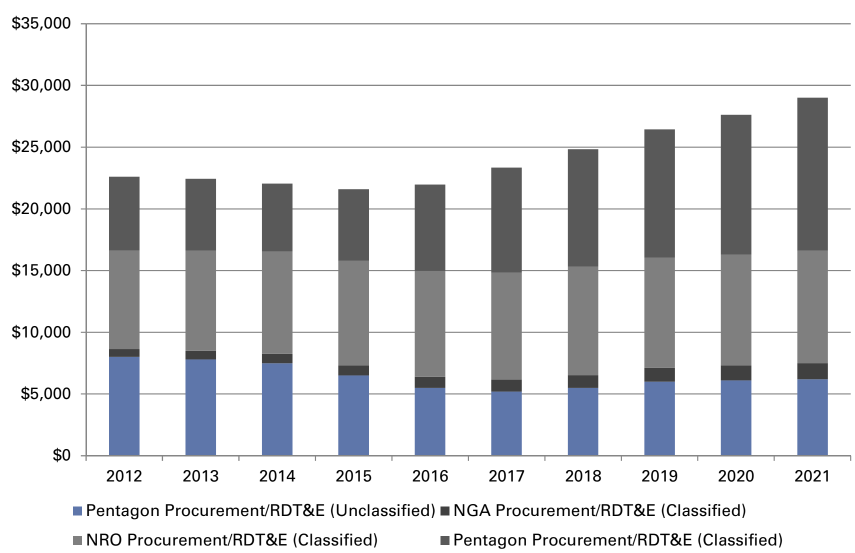
Behind the curtain

The Pentagon ostensibly spends ~$5bn on major unclassified space programs, but that is only the tip of the iceberg. We estimate total addressable national security spending on space was $22bn in FY2016. These accounts have been growing, and based on commentary from senior military and political leaders, that growth is poised to accelerate.

There are 5 key budgets for Space in the US defense budget:

1. Pentagon (Unclassified)
2. Pentagon (Classified)
3. National Reconnaissance Office (Classified)
4. National Geospatial-Intelligence Program (Classified)
5. Military & National Intelligence Programs (Classified)

Exhibit 91: Addressable US defense spending on space ($mn)
Unclassified spending (blue) is just the tip of the iceberg vs. Classified (gray shades)



Source: Department of Defense, Goldman Sachs Global Investment Research.

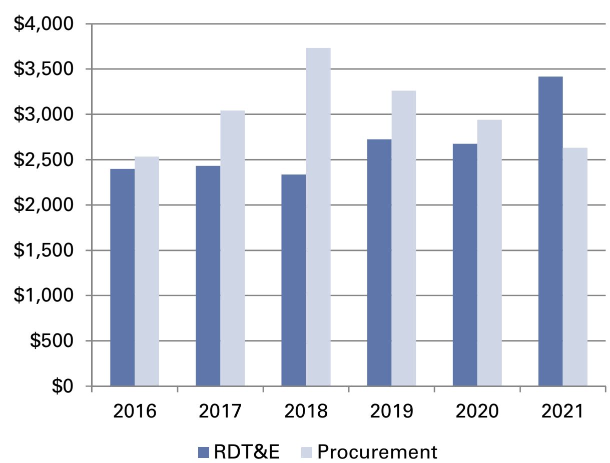
Pentagon (Unclassified)

Officially, the Air Force, Navy, DARPA, and the Missile Defense Agency will spend $6bn on Space in 2017. Of the $3bn in procurement, most is spent on four headline programs:

- **Evolved Expendable Launch Vehicle:** The EELV program assures the US national security apparatus access to Space for medium-to-heavy launches. *Beneficiaries: SpaceX, LMT, BA. Opportunity: $1.8bn in 2017.*
- **Advanced Extremely High Frequency system:** The AEHF program builds a 4-satellite communications constellation in GEO that expands secure capacity and data rate capabilities beyond the current system. Canada, the UK, and the Netherlands are participating partners. *Beneficiaries: LMT. Opportunity: $905mn in 2017.*
- **GPS III**: The Global Positioning System provides continuous navigation for military and civil users globally. The new satellites expand current military and civil capabilities. *Beneficiaries: LMT, RTN, LLL, COL. Opportunity: $569mn in 2017.*
- **Space-Based Infrared System:** SBIRS is comprised of four GEO satellites and two elliptical orbit satellites used to provide initial warning of ballistic missile launches, as well as other ISR capabilities. *Beneficiaries: LMT. Opportunity: $544mn in 2017.*

Procurement budget authority ramps steeply FY2016-FY2018 (Exhibit 92), which likely supports margin expansion amid a growing top line through at least 2020. Within classified, we think the line is blurred with Research, Development, Test & Evaluation (RDT&E) and margins converge.

Exhibit 92: Unclassified Air Force spending on Space ($mn)
Growth driven by higher-margin procurement budget



Source: Department of Defense.

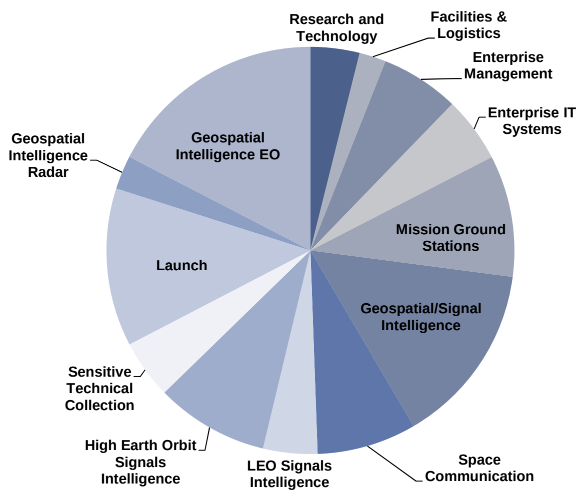
Pentagon (Classified)

The Air Force official classified budget in the FY2017 request was $33.4bn. That is more than 2X the Air Force spend on unclassified aircraft ($14.8bn). Not all is spent on Space, but we believe a large portion is (~$10bn). Classified dollars are everywhere, and can be outside the line items that describe them. As such, we believe there could be considerable upside beyond the most-visible numbers. We estimate go-forward numbers for the classified budget based on bottom-up analysis and historical growth rates, estimating that about a third of the Air Force classified budget is spent on Space. While a commercial satellite generally costs in the hundreds of millions of dollars, America's most expensive spy satellites are known to cost in the billions of dollars. Launch costs on heavy-lift rockets like the Delta IV can reach mid-single-digit hundreds of millions of dollars.

National Reconnaissance Office (Classified)

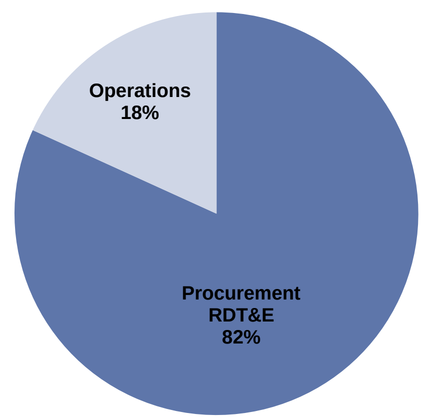
Develop. Acquire. Launch. Operate. That is what the NRO says it does, but its work is highly classified. The NRO is the eyes and ears of the US government. Analysis of budget documents, news reports, and declassified information under the Freedom of Information Act suggests an NRO investment budget of about $9bn and operational spending of $2bn. While development and launches are accomplished through this budget, we expect the Air Force classified budget is leveraged for supplemental capex on new satellites.

Exhibit 93: National Reconnaissance Office
$10.9bn estimated in FY2017



Source: Washington Post, FAS, Goldman Sachs Global Investment Research.

Exhibit 94: Estimated addressable share of NRO budget
The majority is likely addressable to Defense contractors

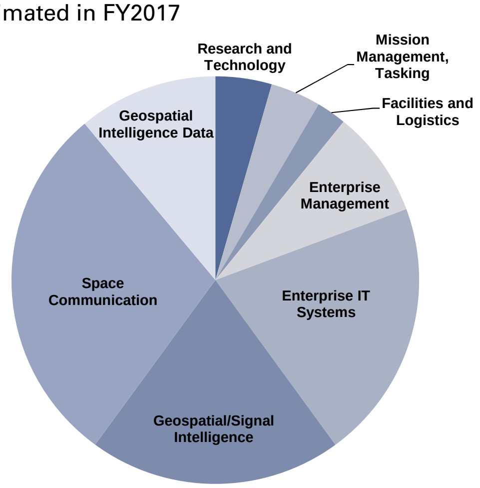


Source: Washington Post, FAS, Goldman Sachs Global Investment Research.

National Geospatial-Intelligence Agency (Classified)

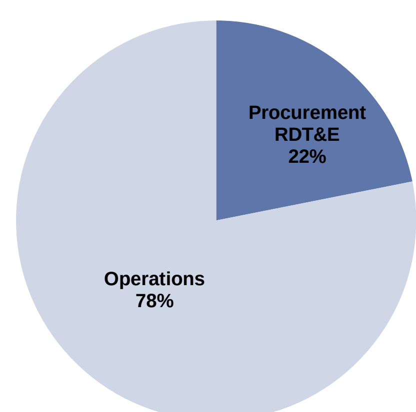
The NGA is tasked with providing geospatial imagery for defense, intelligence, and public safety personnel. Although its budget is classified, we estimate the addressable portion of its FY2017 request is approximately $1bn with an additional $4bn in operational expense. Based on these budget estimates, we do not think the NGA is directly procuring many large satellites, though it likely leverages the intelligence, assets, and budget of the Air Force and NRO. The NGA also buys data from commercial satellite operators like Digital Globe.

Exhibit 95: National Geospatial-Intelligence Agency
$4.8bn estimated in FY2017



Source: Washington Post, FAS, Goldman Sachs Global Investment Research.

Exhibit 96: Estimated addressable share of NGA budget
Data analysis priorities limit opportunities for contractors



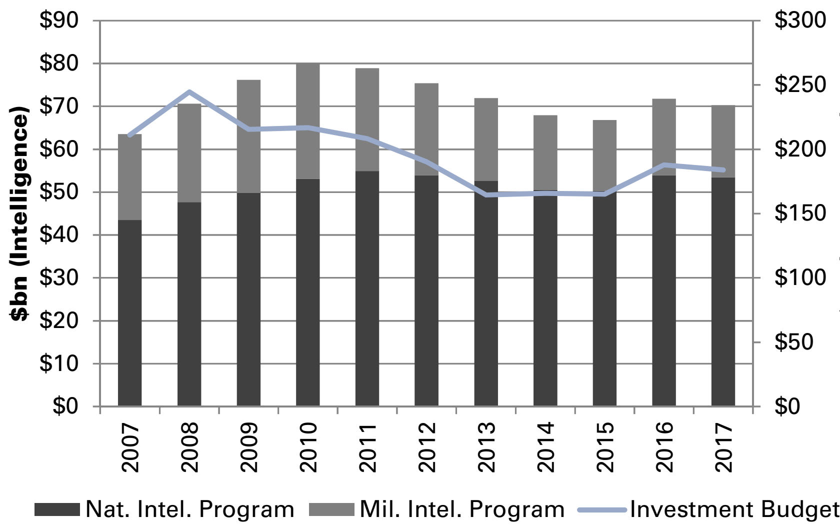
Source: Washington Post, FAS, Goldman Sachs Global Investment Research.

Military & National Intelligence Programs (Classified)

We see the Military and National Intelligence Programs under the Office of the Director of National Intelligence as primarily an O&M line item, making them largely inaccessible to defense contractors; however, we view them as indicators of ongoing government demand for satellite intelligence. The budget grew at a 1% CAGR over the available period of 2007 to 2017. While this growth rate is not substantial, it eclipses the investment budget trajectory, which declined at a (1)% CAGR. Additionally, it did not experience the same (24)% peak-to-trough decline during the budget downturn, exhibiting a much shallower (17)% decline.

Exhibit 97: Military and National Intelligence budget vs. DoD Investment ($bn)

The Intelligence budget has outperformed the Investment budget over the last decade



Source: US Government, Goldman Sachs Global Investment Research.

Why Space is poised to outgrow the budget

Reprioritization and historic underinvestment in asset protection create opportunity

Companies exposed to Space are well-positioned to outgrow the budget. The US warfighting doctrine is more reliant on space than that of any other country, but little has been done to protect and develop those assets in recent decades. According to testimony of the former commander of Air Force Space Command at a House hearing, R&D spending on space is at a 30-year low. That is changing. As protection becomes a greater focus, it creates a secondary source of growth beyond that of the core intelligence-gathering assets. Space assets are in constant need of replacement, where accessibility challenges create a uniquely lucrative opportunity, creating a higher replacement cycle rate, which we think accelerates growth as new payloads justify new deployments, especially as near-peer adversaries build out their own space infrastructure.

"The Department of Defense has finally awoken to the reality that we must invest in the next generation of space capabilities, and recent budgets have begun to arrest the decline in those investments. Over the next five years, space must be a priority for additional funding to ensure that the United States maintains its space superiority and has the capabilities and capacity to deter and defend our critical space assets in future conflicts."

-Senator John McCain, Chairman of the Senate Committee on Armed Services

A clear priority area

Nearly every part of every modern military touches space. Drones are controlled via satellite data links. Almost all communications get routed through space. GPS satellites guide ships, aircraft, personnel, and munitions. Space assets are central to missile defense.

A rising tide floats all spaceships

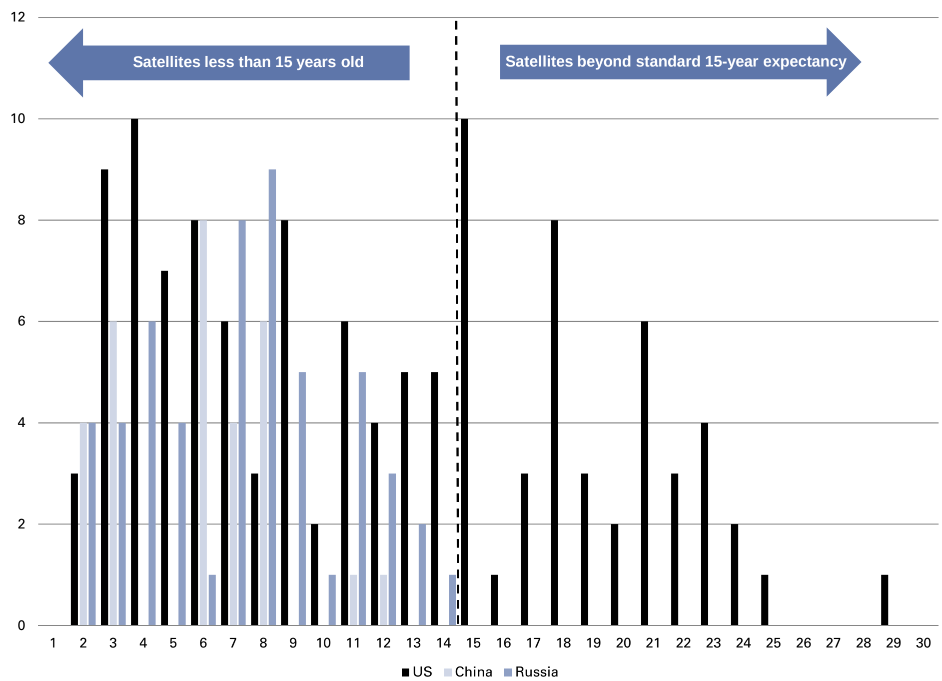
Space is the intersection between three of the most significant growth areas we see in Defense: nuclear recapitalization; intelligence, surveillance, and reconnaissance (ISR); and offset strategies. First, space infrastructure is considered part of the US nuclear deterrent. Second, ISR capabilities have been identified as a priority area for military leaders (Drones a key example). Finally, the military is investing in a new wave of 'offset' technologies; which have become critical to US military doctrines after World War II.

With Space a vulnerable and important part of US strategy, satellites become a prime target for adversary countries with larger militaries, or ones simply less reliant on advanced technologies.

Military replacement demand likely to accelerate

Given the likely growth in overall military investment topline and growing intelligence demand, we expect Space to grow independent of, and relative to, the Pentagon investment budget, but we also see an additional source of opportunity as satellites reach the maximum expected lifespan of 15 years, suggesting the fleet needs recapitalization.

Exhibit 98: Active large military satellites by age in 2018
Only American satellites remain active beyond 15 year retirement



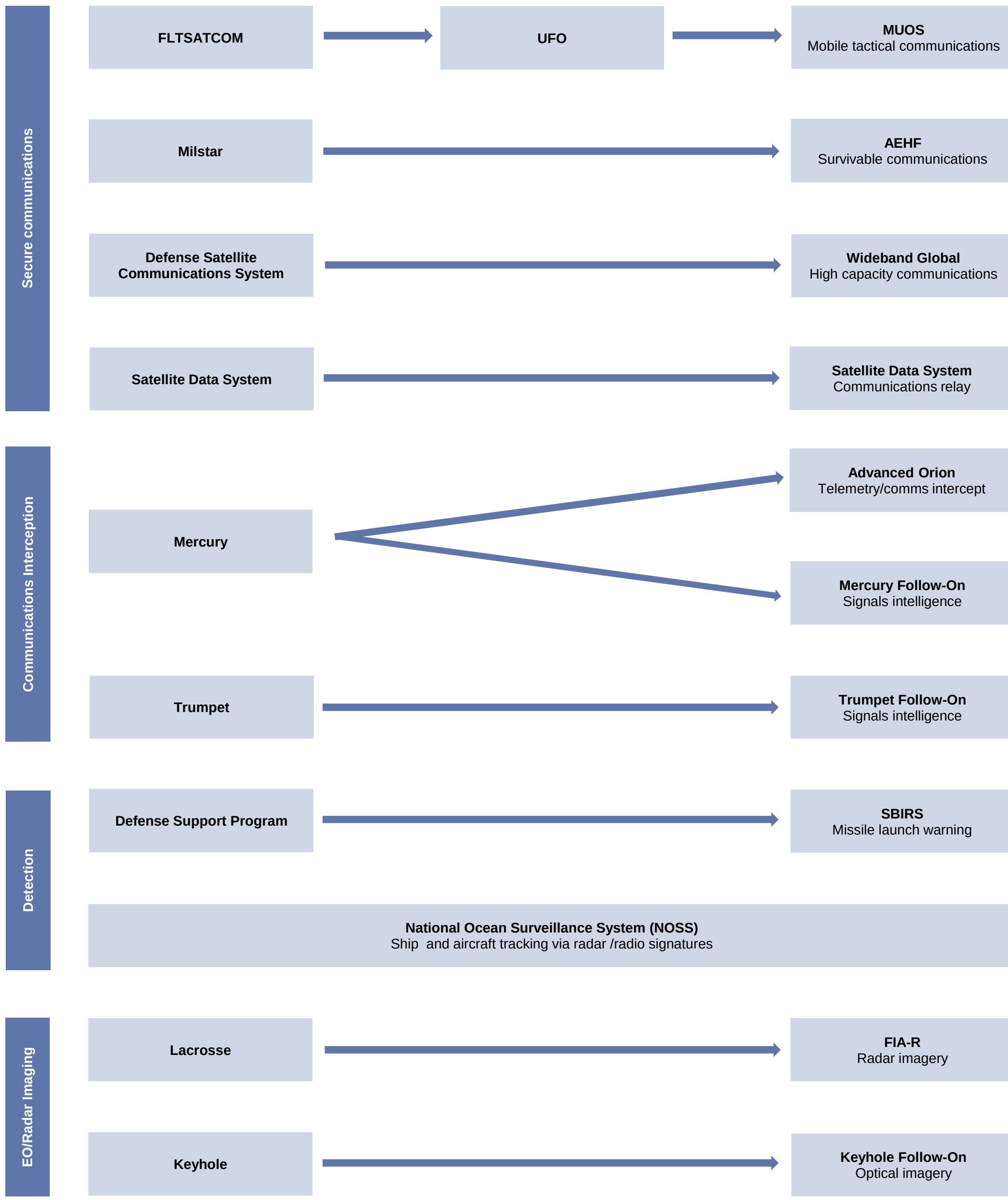
Source: Union of Concerned Scientists, Goldman Sachs Global Investment Research.

There are 35 known active large satellites that are operational beyond the end of the usual <15 year lives (29% of all large US defense satellites) and another 18 will reach their end of life in the next 5 years. Most of these satellites are scheduled for replacement or have already been replaced and merely serve as supplemental reserve systems; however, some are likely still in operation due to sequestration and may be relieved.

Given the pace of retirements as technology accelerates, many military satellites have shorter expected lives than the usual 15 years seen in commercial markets. This assures a fairly continuous replacement cycle—new satellites are always in either active production/

deployment or are in development. Certain satellites and capabilities are in a near constant state of replacement, with only small incremental upgrades rather than larger changes.

Exhibit 99: New generations are broadly replacing the current fleet
Classified sats like Keyhole, Advanced Orion, Mercury, and Trumpet starting replacement cycles



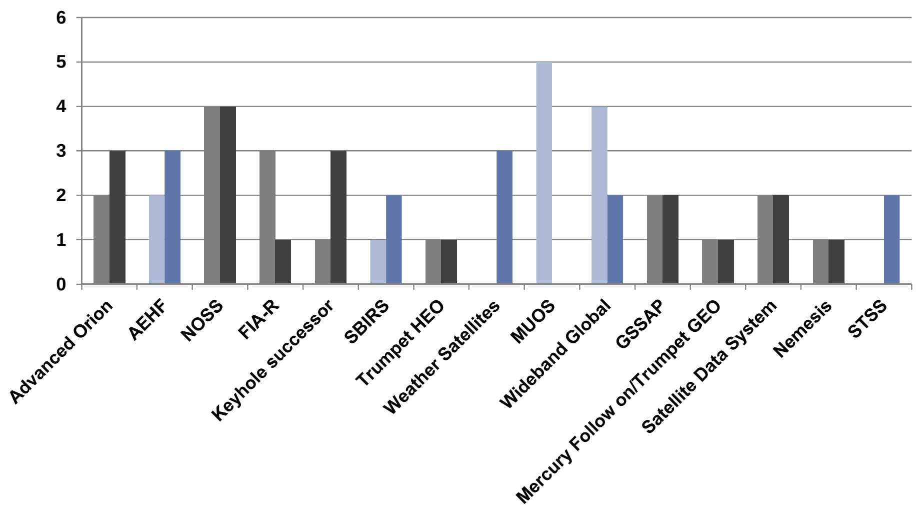
Source: Union of Concerned Scientists, New York Times, Gunter's Space Page, Goldman Sachs Global investment Research.

Failed recon program creates new growth opportunity

Some satellite programs fail, most notably the NRO's planned replacement for its Keyhole satellites. According to the NY Times, the agency spent $13bn on the Boeing Keyhole replacement program before cancelling it amid cost overruns and schedule slippage, when it became clear a further $5bn was required to possibly complete it. Boeing stopped competing on optical reconnaissance satellites, but it continued to build the sister radar-imaging FIA satellites, and Lockheed was apparently awarded a stopgap extension of the Keyhole program according to industry observers. This gap created an air pocket of capability and RDT&E, which we believe could be ramping at Northrop.

The major programs of the next 5 years will look similar to those of the last 5 years, with greater capability per platform and better mix more than offsetting a slight decline in the total number of platforms, primarily driven by the tail end of MUOS (but that will enter a new R&D phase most likely).

Exhibit 100: Units launched in last 5 years vs. next 5 years
Dark colors denote next 5 years, light last five years, gray are classified, blue are unclassified



Source: Department of Defense, Gunter's Space Page, Goldman Sachs Global Investment Research.

SBIRS, AEHF and Advanced Orion are likely to offset potential weakness in the unclassified communications satellites. Programs like a Trumpet update may be extended beyond HEO to GEO, which could add meaningful upside. However, the possibility of the Keyhole replacements creates the most significant upside. Each satellite could cost several billion dollars, with additional MSD billions in RDT&E. It is possible there is also some follow-on to the highly secretive 'Misty' program launched at the end of the 20th century, which could compound the upside from an optical surveillance system. We also expect that the STSS demonstrator may turn into a procurement program, as threats to space assets become more apparent. NOC was the prime on the demonstrator. OA's GSSAP satellites may become more prevalent as a 'neighborhood watch' spacecraft.

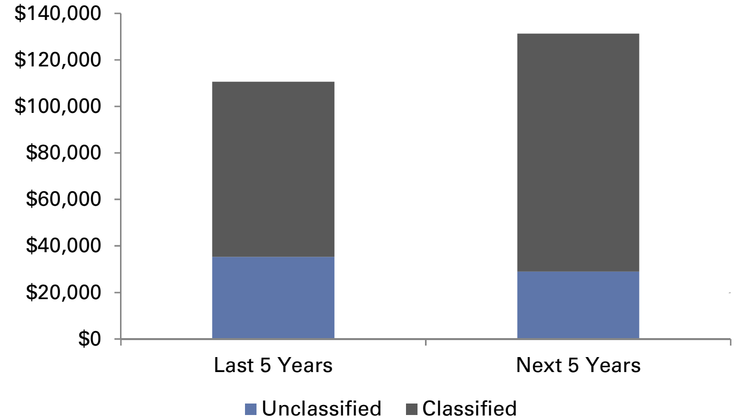
The military is deciding between a communications network built on large geostationary and elliptical orbit satellites or a larger array of smaller satellites, possibly in LEO. An award for that program may happen within the next year or two. This may further offset the end of MUOS on the communications side.

The satellite programs described above are only the largest—fleets of small CubeSats are increasingly attracting attention at DARPA and the space agencies. Although these tend to be low cost today, a distributed space architecture could come to rely on them more, and miniaturization could compress higher value payloads into these smaller buses.

Addressable US military space spending likely up 19% next 5 years over last 5 years

The unclassified budget is 18% lower in the next 5 years vs. the last 5 years, mostly due to the inclusion of pre-sequestration spending, meaning that we expect a total addressable Defense space budget increase of 19%, including Classified.

Exhibit 101: Total military space spending 5-year block forecast ($mn)
Unclassified -18%, Classified +36%, Total +19%



Source: Department of Defense, Goldman Sachs Global Investment Research.

Lack of ability to incrementally upgrade hardware drives constant generational upgrades and spending growth

Tech changes drive constant growth

Space assets are uniquely positioned to absorb more budget dollars. The simple reality is that these assets cannot benefit from hardware upgrades like ground-based assets, which likely necessitates fairly frequent clean sheet design, launch, and deployment relative to other military equipment. As such, successive, increasingly expensive, generations of satellite will likely be launched with far higher frequency than the current generations of fighter aircraft or ships.

In 1987, the Congressional Budget Office published a report that suggested the cost of each successive generation of fighter jet increases by more than 150%. Like with jets, each generation of military satellites is likely significantly more expensive than the current generation as the government pushes the bounds of science and technology with its most capable flagship platforms. Space is unique because the generations are necessarily closer together, precipitating better growth. As an example, during the lifespan of 4th Gen fighters, there will be at least 3 distinct generations of GPS satellites deployed.

As near-peer rivals challenge US capabilities in space through development of their own programs, the US will face increased competitive pressure, likely accelerating the replacement cycle, which would drive spending higher.

The US isn't alone in prioritizing space

Big 3 vie for space dominance

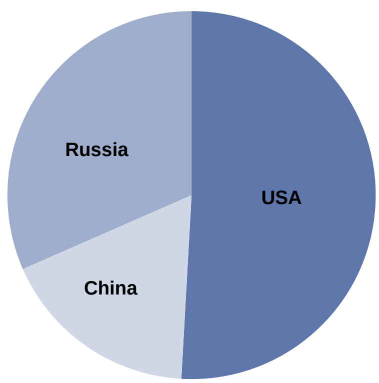
While the US could afford to field somewhat aged equipment when it was the dominant spacefaring nation, upward pressures by competitor states could compress replacement cycles. China is growing its military and scientific presence in space rapidly, likely sparking a race for space-based capabilities. Although the US has had a head start, its interest in space waned after the Cold War, as budget cuts at NASA, ground wars in the Middle East, and the absence of a clear rival relegated its geostrategic significance.

Russia and China are currently the only countries with the ability to send people to space. China's space program has been rapidly launching new assets to orbit. The capability gap between China and the US still exists, and that makes China a threat in that they have less to lose in terms of space assets. On the basis of GDP, Russia is even more exposed to the security of space than the US, and it has a half century of experience coexisting peacefully there, realizing the importance of that domain in nuclear deterrence and human progress.

China routinely launches satellites where the use is unknown. China is looking to build out a space architecture, similar to that of the United States, with advanced and broad capabilities. For example, China appears to fly a similar constellation of NOSS-like satellites for tracking ships. China is testing QUESS, a quantum communications system that could have substantial cyber defense walls.

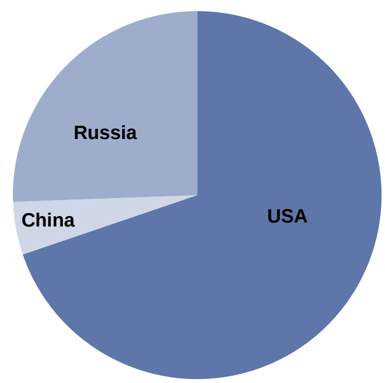
Russia's space presence is in decline, for now, but its legacy infrastructure is formidable. The country is pivoting from Baikonur to Vostochny, and is reinvesting in its space supply chain. Construction is delayed due to a multitude of issues. The site is likely less ideal than Baikonur, but it is illustrative of Russia's continued interest in space. US and Russian commercial space economies are intertwined with both countries edging away from shared technology and resources, which could increase tensions and volatility in space, though the International Space Station will remain a symbol of cooperation.

Exhibit 102: Current share of milsats launched (0-5 y/o)…
US share of most recent 5 yrs launches vs. Russia and China



Source: Union of Concerned Scientists.

Exhibit 103: …vs. prior share (11-15 y/o satellites)
US share of 2002-2006 launches vs. Russia and China



Source: Union of Concerned Scientists.

European Militarization

European co-operation to militarize space has so far been limited. In fact, the ESA's charter stipulates that it should pursue space programs for 'peaceful purposes' only, and there is no military section in the budget. Since 2015, the USA, China and Russia have launched 15, 11 and 10 military-class payloads into orbit respectively, while Europe has launched one according to the FAA and Union of Concerned Scientists. There is some potential friction here between the European Union and the ESA (formed separately in 1973), as while the EU wants more cooperation on space security, member states are reluctant to allow the EU to usurp control over space matters potentially due to questions over allocation of work. As a result, programs like Copernicus (the ESA's world observation system) have remained commercial, and member states like France, Italy, Germany, Spain and the UK have obtained their own individual military satellite communications systems. More recently though, there have been indications of change. The new Galileo positioning and navigation system has a non-military label, but will allow secure signals for military use. Meanwhile, a consortium working for the European Defence Agency (which includes Airbus) has proposed a govsatcom system which would be entirely owned by the EU, to address border surveillance, civil protection and other governmental needs. These appear to be early steps towards more cooperation on European space security and a move away from reliance on the US.

International collaboration in Space

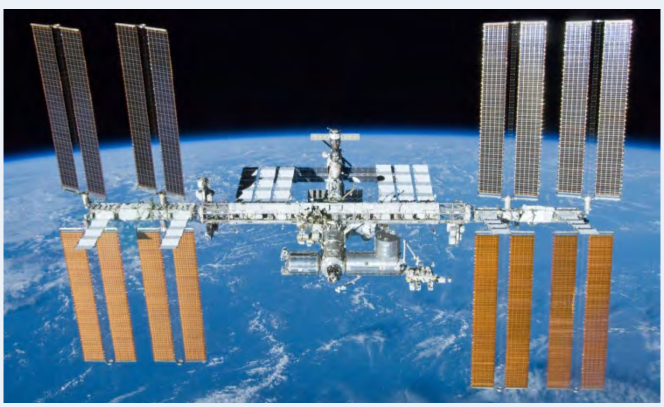
Space Fence, LMT's space object tracking system, like several other programs, is the product of substantial cooperation between countries. In this case, Space Fence will be shared by at least 8 countries (US, Australia, Japan, Italy, Canada, France, Republic of Korea, and the UK), as well as the ESA. Shared resources are force-multipliers for countries that would not be able to afford their own platforms.

According to a SpaceNews article, General Raymond, now Commander of US Space Command, wrote a memo calling for increased collaboration, saying "When we operated in benign environments, these partnerships were important; in contested domains they are critical."

Infrastructure in space is expensive, so much so that asset-sharing has become common among allies, and even adversaries. The International Space Station is a prime example of countries cooperating for the benefit of everyone. The US GPS satellites provide precision navigation for everyone globally, though alternatives are emerging.

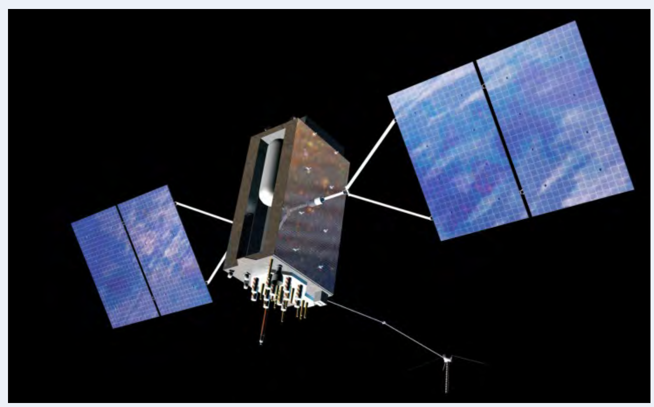
Beyond cost, the fundamentals of geography often necessitate collaboration. Tracking stations are positioned around the world to maintain continued telemetry with spacecraft. With Space Fence, tracking in the southern hemisphere is conducted by a station in Australia. On the civilian side, telescopes are positioned globally—each hemisphere will never see certain parts of the night sky—and are shared by the scientific community.

Exhibit 104: International Space Station
$160bn shared asset on orbit



Source: Washington Post, Wikimedia.

Exhibit 105: Global Positioning System
Everyone, including America's adversaries, can use it



Source: Wikimedia.

America's soft underbelly

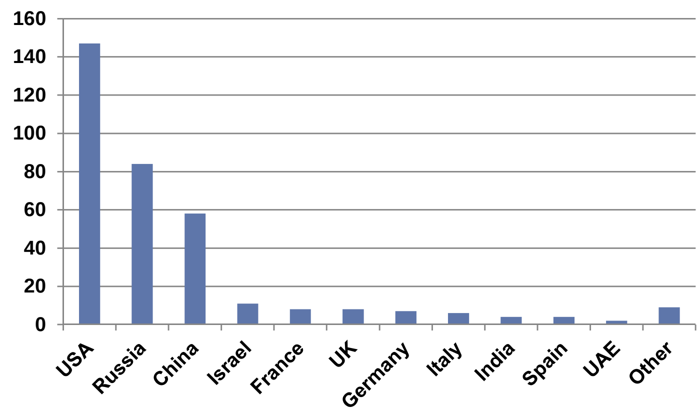
Maybe space assets aren't as safe as the US government thought

There is little real-estate more critical to the national security of the United States than a narrow band occupied by its intelligence satellites in geostationary orbit, 42,164 kilometers from the Earth's core directly over the equator. For decades these space assets were considered relatively safe. This led to underinvestment in their defenses and few contingency plans for war in space. The military is refocusing by spending $9bn over the next 5 years on protecting these assets based on our estimates. The DoD has nearly doubled this line item in revisions over the last few years.

Other countries have demonstrated an ability to destroy satellites through missile strikes (eg, China since 2007 and Russia for half a century), suggesting that space assets may not be all that secure from potential threats. US Strategic Command has stated that every US spacecraft could soon be vulnerable to threats.

With much of the US competitive military edge derived from on-orbit technology, the US could be disproportionately disadvantaged from potential space conflict. Mobilizing for space conflict readiness is going to be expensive.

Exhibit 106: Military satellites by country
US is most exposed to military space, but China is expanding quickly



Source: Union of Concerned Scientists.

What does the greater threat imply for investment?

We explore the key growth focus areas through the framework of how satellites are attacked and defended. These themes will likely drive the direction the spacecraft and launch industries take for the foreseeable future.

How to kill a satellite, and how to protect one: a practical guide for investors

Satellites are very fragile, and travel at thousands of miles per hour. It does not take much to render one inoperable. Cyber attacks, lasers, missiles, parasitic satellites, radio jamming could all do it. Satellites now require broad-spectrum defenses. While highly secretive about plans to protect space assets, governments appear to be committing substantial resources to their defense, as well as offensive capabilities to disable adversaries' satellites.

Offensive capabilities

The three major space powers have demonstrated capabilities to destroy orbiting satellites. When a satellite is hit, its shards spread throughout its orbit and into nearby flightpaths, creating the potential for collateral damage. Alternative methods—lasers, cyber-attacks, jamming, and parasite satellite attacks—are cleaner and more temporary, but those systems are still in their infancy.

Defensive capabilities

If hitting an object moving thousands of miles per hour is difficult, protecting those objects is even harder. Countermeasures might work some of the time, but missiles would likely not be fooled and the shrapnel from a successful missile detonation in the vicinity of a satellite could be just as deadly as a direct hit. We outline key steps that are likely being taken to better protect space assets.

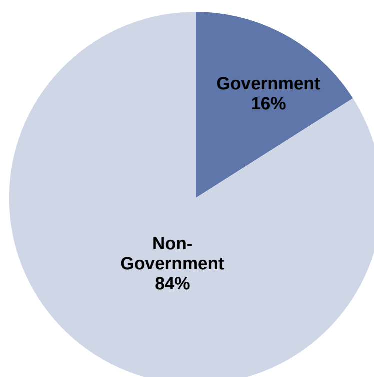
Step 1: Identify: Identifying risks to US space infrastructure is a top priority. This requires systems both on the ground, like Space Fence built by Lockheed, and those on orbit, like the Geosynchronous Space Situational Awareness Program built by Orbital ATK and the Space Tracking and Surveillance System Demonstrator built by Northrop Grumman.

Step 2: Disguise: Most satellites are visible at night to the naked eye or a pair of binoculars—this means that it is broadly known where they are and they are readily apparent on radar. Hobbyist trackers report that the US military is adding optical/radar stealth systems to their satellites. These are likely to have a minimal radar cross section and be among the most expensive platforms flying today.

Step 3: Dodge: The advantage of moving 17,000 miles an hour is that a small change in velocity leaves the object in a radically different place than it was moments before and a fairly small amount of energy can quickly accomplish that. However, satellites do not carry much fuel, so parallel efforts are underway to extend their lives. Systems like OA's MEV and MDA's SIS system could stretch the fuel further.

Step 4: Disaggregate: By distributing space-based capabilities across an expansive architecture, the military eliminates its reliance on a handful of key assets; instead, it relies on a network of commercial and government platforms. For many commercial satellite operators, a commitment from the government to buy a certain share of bandwidth is a welcome way to fill capacity on communications satellites. This trend supports demand on the commercial side, but is likely a small headwind for the less sophisticated government satellite manufacturers.

Exhibit 107: Chart of share of government use on commercial satellites
Government is approximately 16% of commercial satellite operator revenue



Source: Company data, Goldman Sachs Global Investment Research.

Step 5: Replace: If satellites are destroyed, they must be rapidly replaced to restore critical warfighting capabilities. Navigation, communications, bomb guidance, and intelligence all heavily rely on them. This could mean that satellites, and the rockets to launch them, would be stockpiled as the likelihood of space conflict increases, though many of these are likely to be less capable smallsats. Several GPS satellites are known to be currently orbiting, deactivated but ready for use. It is actually standard practice to classify certain satellites launched to space as debris as a form of deception. Still, the military is exploring new vehicles that can launch repeatedly in short periods of time at low cost.

The secretive XS-1 program is designed to test cheap reusable technologies. Another program, Operationally Responsive Space is developing expendable rockets capable of launching constellations quickly. We see reusability being a key theme tested by the government, as it seeks a high volume of launches in a short period of time at low cost.

Securing access to space

Assured access to space is a key pillar of US strategy. The national security launch industry is undergoing significant change as the US government-sanctioned monopoly ULA cedes share to SpaceX, Orbital ATK prepares to develop a competitive rocket, and questions arise about whether the US industry can provide surety around access to space.

From one monopoly to another?

The certification of SpaceX for government launches creates the possibility of large pricing gaps with the incumbent ULA monopoly. However, nuances in government procurement realities may change the math to create a healthy equilibrium. Furthermore, new contender Orbital ATK may offer a rocket of its own, with a differentiated capability profile.

Only specially certified launch vehicles are eligible for national security launches, and before 2015, only ULA's Atlas V and Delta IV were qualified. Critically, the Atlas V flies using the Russian-made RD-180 engine. Following US sanctions on Russia, the availability of the engine has come into question, but ULA indicate these issues are behind them.

In 2014, SpaceX successfully sued the US government for the right to compete in EELV launches with its Falcon 9 rocket. In 2016, SpaceX won its first EELV mission, an $82.7mn contract to launch a GPS satellite in 2018. Given the large differential in price, there is concern in the industry that the Pentagon will swap one monopoly for another. We think EELV requirements for price, reliability, and availability will naturally combine to prevent a monopoly by ULA or SpaceX.

Whereas commercial launches are insured, government launches are generally self-insured—i.e., the government still pays for a loss. And because most EELV launches are national security related, delays can have a big impact for the Pentagon. Diversification to the Falcon 9 helps, and the presumptive certification of the Falcon Heavy will create a full spectrum alternative to the ULA offerings, but those programs have had schedule issues.

While the Falcon 9 is cheaper than an Atlas V, the rocket's failure rate is concerning, and it has been grounded nearly 50% of the time between its June 2015 failure and present. The failure rate, while relatively low, means that government officials take substantial risk in a given launch. The current 91% success rate implies that the risk-adjusted cost for Falcon 9 is $187mn ($90mn higher than its most recent government GPS launch award value) if the EELV payload + rocket cost is ~$1bn. An Atlas V would likely have cost ~$150mn with its 100% success rate. Large national security and science launches, which might be lifted on the Falcon Heavy, can likely reach ~$10bn+. We do not think there will be much pressure in the ultra-heavy space occupied by the Delta IV. The payloads on those launches prioritize reliability above all else, so the addition of the alternative possibly cheaper Falcon Heavy is unlikely to be a serious threat given the entrenched record held by the Delta IV.

Ground Equipment: managing military satellite fleets

Military satellite ground control and data management are very different than those of commercial operations. Oftentimes ground control stations are worth more than the satellite assets, given the need for hardened command and control, as well as superior data processing and protection. Systems are purposefully redundant and often operate in isolation from parallel systems. Beyond ground infrastructure itself – satellite operations centers, remote tracking stations, and their supporting infrastructure – significant resources are devoted to the perpetually increasing amount of data collected by satellites, making data analytics central to military ground architecture and opening the space economy to government IT companies. Below we present the budget for the key government space program ground elements from the unclassified budget, over the next 5 years. We expect the classified numbers add significantly to the opportunity.

Exhibit 108: Space ground-based infrastructure unclassified budget: NASA, USAF, Navy and Army
Ground infrastructure to support military fleets moves ~$8bn a year. FYDP for Navy, AF and Army; Notional budget for NASA

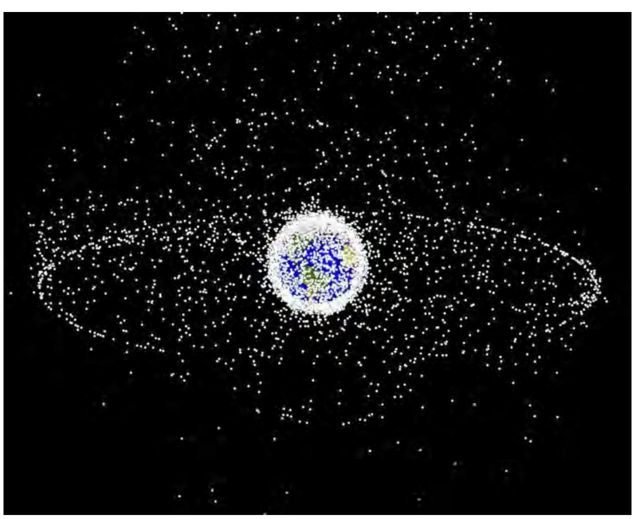
	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021
US Air Force Programs	**1,080**	**1,140**	**801**	**694**	**530**	**547**
GPS Operational Control Segment (OCX)	349	393	253	233	125	127
JSPOC Mission System	81	73	63	65	67	69
Space Fence	241	168	50	5	-	-
Space and Missile Center - Civil Workforce	176	177	189	192	196	197
Other programs	233	329	247	198	143	153
US Navy Programs	**54**	**44**	**57**	**57**	**52**	**32**
US Army Programs	**952**	**676**	**930**	**977**	**1,087**	**1,017**
WIN-T - Ground Forces Tactical Network	695	437	705	686	784	748
Defense Enterprise Wideband Satcom Systems	172	144	134	178	170	140
Other programs	85	95	91	112	132	129
NASA Programs	**5,978**	**6,015**	**6,160**	**6,271**	**6,411**	**6,603**
Exploration Systems Development (Orion, SLS, EGS)	410	455	441	453	458	465
Space Operations: Ground infrastructure support	1,871	1,909	2,040	1,981	1,959	2,040
Safety, Security and Mission Services	2,769	2,837	2,894	2,952	3,010	3,071
Construction and Environmental Compliance and Restoration	389	420	390	398	406	414
Other programs	539	394	395	487	579	614
TOTAL	**8,064**	**7,876**	**7,947**	**7,998**	**8,080**	**8,199**

Source: NASA, USAF, Navy, Army, DoD.

What happens as space gets more crowded

When space gets more crowded, in some ways it is safer, and in others it is less safe. In the near-to-medium term, we see it as less safe as new entrants launch untested technologies at high rates, but eventually, we see it becoming more safe as technologies mature. Short term, the US/EU military and commercial presence in space dwarfs all other countries. This lopsided exposure implies that potential adversaries have disproportionate risk/reward when it comes to fighting in space. From a military side, that means US/EU assets might be targeted in a first-strike scenario, making space less safe, particularly now that they are less associated with the nuclear deterrent. From the commercial side, new spacecraft built by relatively unproven space powers may experience a higher failure rate, or improper orbital retention that endangers other assets. A 2015 GAO report indicated that the Air Force Joint Space Operations Center provided 671,727 collision warnings during 2014. This comes out to more than one warning per day for every satellite in orbit. As new entrants to space mature their technology and practices, it is likely the balance restores a lower risk state.

Exhibit 109: Tracking space objects



Source: NASA.

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Reg AC

We, Noah Poponak, CFA, Matthew Porat, Michael Bishop, Chris Hallam, Brett Feldman, Heath P. Terry, CFA, Andrew Lee, Sam Wood, Peter Lapthorn, Tais Correa, Gavin Parsons, Adam Hotchkiss and David Tamberrino, CFA, hereby certify that all of the views expressed in this report accurately reflect our personal views about the subject company or companies and its or their securities. We also certify that no part of our compensation was, is or will be, directly or indirectly, related to the specific recommendations or views expressed in this report.

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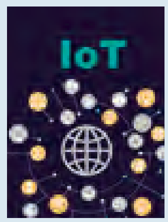

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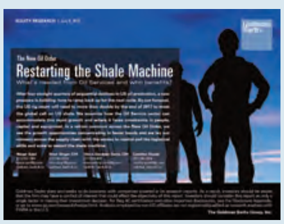

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