Global Trends in Civil and Commercial Space
(Presentation)

Bhavya Lal
Emily J. Sylak-Glassman
Nayanee Gupta
The Institute for Defense Analyses is a non-profit corporation that operates three federally funded research and development centers to provide objective analyses of national security issues, particularly those requiring scientific and technical expertise, and conduct related research on other national challenges.
Global Trends in Civil and Commercial Space

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October 2015
# Outline – Global Trends in Space

<table>
<thead>
<tr>
<th>Drivers</th>
<th>Signposts</th>
<th>Near-Term Implications</th>
<th>Implications in the 10-15 year Time Frame</th>
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<tbody>
<tr>
<td>Improvements in and falling cost of technology</td>
<td>Accelerated space investment globally</td>
<td>Transition to a more globalized mainstream sector</td>
<td>Difficult to predict trajectories</td>
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<td>Newer and lower-cost space-based applications, products, and services</td>
<td>New users and suppliers</td>
<td>New challenges, in space and on the ground</td>
<td>Difficult for governments to manage sector</td>
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<td>Changing national policies</td>
<td>Diverse approaches to space development</td>
<td>New opportunities for governments</td>
<td>US control of the space sector wanes</td>
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<th>Wildcards</th>
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<td>Unanticipated technological developments</td>
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<td>Abrupt geopolitical changes</td>
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<td>Other unexpected developments</td>
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Process and Products

**Sources:** Literature, interviews with ~60 experts, primary data, purchased data/reports

**Analytic methods:**
Content analysis, social network analyses, bibliometric assessment, analogies with other industries

**Product:** Two publicly available volumes
(1) Overarching trends
(2) Trends within 7 sub-sectors, as well as trends in small satellites

[https://www.ida.org/~media/Corporate/Files/Publications/STPIPubs/2015/p5242v1.ashx](https://www.ida.org/~media/Corporate/Files/Publications/STPIPubs/2015/p5242v1.ashx)

[https://www.ida.org/~media/Corporate/Files/Publications/STPIPubs/2015/p5242v2.ashx](https://www.ida.org/~media/Corporate/Files/Publications/STPIPubs/2015/p5242v2.ashx)
Caveat
Space not a monolith

Global Trends in “Space”
Caveat

Space not a monolith – Some trends apply more to some sectors

- Communication
- Human Space Flight (HSF)
- Earth Observation
- Robotic Exploration
- Scientific Research
- Manufacturing (additive, assembly)
- Debris Removal, Sat Servicing
- On orbit repair, servicing
- Other Activities (Habitat, Tourism)
- Space Resources (Mining, Energy)
- Data Analytics, Storage, Services
- Ground Operations
- Spaceports/Other Infrastructure
- Satellite and Other Manufacturing
- Launch/Transport
- PNT
- SSA
SELECT DRIVERS
Improvements in Technology and its Falling Cost

- Advances in IT
  - COTS hardware - 40-60% improvements annually
  - Breakthroughs in image recognition/analysis software
  - Growing availability of cloud computing and big data analytics
  - COTS components can be made radiation hardened through software

- Breakthroughs in other technologies (e.g., power systems, miniaturization, advanced materials, 3DP)

- New technologies in the space sector (e.g., laser communications, metamaterial antennas, HTS)

- Result
  - A OneWeb satellite weighs 330 lbs compared with older Dish Network and HughesNet satellites — that weigh more than 13,000
  - Small satellites using COTS optical payloads improving (wrt ground sampling distance) more than 3x rate of larger satellites

Source: Adapted from Yah et al, 2014
Newer and Lower Cost Applications, Products and Services

- On-demand access to geospatial information available on smartphones
  - SkyNode allows customers to directly task a satellite and download imagery within 20 minutes
- Use of High Throughput Satellites in the Ka-band can provide high speed (20x vs normal satellites) data communications from MEO
  - Match data rates from terrestrial fiber optic networks
- Constellation-based broadband internet and telephony from LEO?
  - OneWeb plans a ~700-satellite constellation, 2017
  - SpaceX plans a 4000 satellite constellation
- Deep space missions relatively cheaply
  - MarCO, a cubesat for a Mars mission
  - Lunar IceCube
- SSTL (UK) developing three 1-meter resolution, 400 kg satellites for earth observation; cost including launch, insurance, and operations for seven years, around $160 million
- Dhruva Space (India) builds small satellites in the 10-100 kg range, within 18 months, and cost less

- Note: Lower costs result not just from technology but alternative approaches
  - Non-radiation-hardened microprocessors/memory chips cost two or three orders of magnitude less than radiation-hardened ones

Projected global market for satellite-sourced intelligence $5 B in 2019
SIGNPOSTS
Growing Global Public Expenditures


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<tr>
<th>Year</th>
<th>Average World Funding</th>
<th>CAGR</th>
<th># of Countries</th>
<th>Civil/Defense</th>
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Source: Euroconsult Government Space Programs: Forecast and Benchmarks 2014

Individual country trajectories vary from CAGR +60% to -100%
...Challenging U.S. Dominance

Source: STPI generated using data from McDowell 2015
Growing and Non-Traditional Private Investment

- Growing private (non-aerospace) and VC interest
- Crowdfunding (e.g. Ardusat)
- Investors not looking just for traditional ROI – “lost children of Apollo”

SpaceX Sat $1.2 B
Skybox acquired by Google, $500 M
OneWeb $500 M
Planet Lab $200 M
Kymeta $82 M
Spire $70 M
Mapbox $60 M
Urthecast $63.5 M

Source: http://www.hotstockmarket.com/t/274184/spacex-other-elon-musk-stuff,
Emerging Actors – Users, Brokers and Suppliers

• New users
  – Nation states - ~80 countries have satellites; 170 have financial interest in satellites
  – Consumers - Growing demand and WTP for ubiquitous and real-time situational awareness

• New private suppliers and brokers
  – Investors and companies with an IT bent
    • Hardware (e.g., Canada’s NorStar Space Data, Singapore’s Astroscale)
    • Software (e.g., Mapbox - custom online maps)
    • Launch (e.g., New Zealand’s Rocket Lab)
  – Brokers – Launch and other services
  – Non-profits and citizens
United States Remains the Locus of Space Entrepreneurship

- Global supply chain
  - Rocket Lab launching from New Zealand
  - Spire based in UK with offices in the United States and Singapore
- Entrepreneurial activity growing in areas like small satellites, data analytics
Growing Functional Modularization

Example: Space Situational Awareness
New Entrants Bringing New Approaches

- Private sector focus on cost innovation (philosophy of “good enough,” prioritizing cost over performance/reliability)
  - Streamlined/simpler processes
  - Incorporation of systems from non space sectors (e.g., reaction wheels meant for dental tools, COTS software; use of the Cloud)
  - Agile manufacturing, “production” model
  - Open source hardware (microcontrollers, 3D printing) and software (android operating system, NASA’s PhoneSat bus)
  - Experimenting with higher-risk ideas (e.g., Sputnix using LEGO-ideology, low cost constellations)

- See space as just another place where data is collected; pitched as IT or media companies; investment viewed as being in data products and services not space

- New firms are takeover targets not of traditional aerospace but of tech giants like Google and Facebook

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Planet Labs’ Cubesats (Doves) have gone through 12 generations of design since the firm was established in 2010.

20% of the Doves can fail in orbit without losing a meaningful amount of imaging capacity
Diverse Approaches by Governments

• No longer starting with activities with low technical complexity to those with high technical complexity, or starting with the establishment of space agency

• Indigenous industrial base no longer a prerequisite for having sophisticated space capabilities; savings enable investments in other critical areas
  – India: Leveraging NASA’s DSN
  – Singapore: Purchasing launch as a commodity service from India and investing in emerging techniques in data analytics
  – Over half of governments using foreign contractors for their first satellite project

• Pursuing the parallel development of civilian-commercial and defense space activities enables organizational efficiencies
  – Japan, China, India

• Emerging alternatives to the United States government as a partner
  – Brazil, Europe (China), ITU filings – even US firms - through other countries

Shift from buying technology and products to buying services (United States leading)
Growing Integration of the Space Enterprise

Example: Collaborations in Publications

Scopus Database Co-Authorship
For publications with keyword “satellites”
NEAR-TERM IMPLICATIONS
Structural Changes Underway - Transition Into Mainstream Sectors

- **Bifurcation**
  - Government-driven specialized applications
  - A less capable but more widely utilized consumer/commercial set of sectors

- **Structural changes**
  - Globalization – integration of space value chains and markets
  - Commoditization – satellites, launch
  - Growing consumer power
  - Service model

### Diagram:

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<tr>
<th>Risk Taker</th>
<th>Private Entities/ Market Take Risk</th>
<th>Customer Base</th>
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<tbody>
<tr>
<td>Government Takes Risk</td>
<td>“Emerging” Private (Referred to as Commercial Space) [e.g., Orbital Sciences, Boeing Corporation, SpaceX, Bigelow Aerospace]</td>
<td>Government One of Many Customers</td>
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<td>“True” Private Space [e.g., Virgin Galactic, Bigelow (future), Iridium, Intelsat, Trimble (current)]</td>
<td>Government Only/Primary Customer</td>
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| Note: The porous boundaries imply the movement of firms within quadrants.
Growing Space Governance Challenges

- **Domestic**
  - Commercial Remote Control Licensing Regime
  - Export Controls
  - Other (e.g., space mining, on-orbit servicing)

- **Global**
  - Management of Space Debris
  - Management of Radio Frequencies
  - Exploitation of In-Situ Celestial Resources
  - STM/Management of On-Orbit Activities (e.g., debris removal)
  - Planetary Near-Earth Object (NEO) Defense
  - Other: private HSF and space stations, lunar habitats

- **Other**
  - Responding to disruptions (e.g., cyberattacks, space weather-related interferences)

JSpOC tracks ~23,000 pieces of debris 10 cm in diameter or larger. There are more than 500,000 objects larger than one centimeter and several million that are smaller.

IMPLICATIONS IN THE 10-15 YEAR TIME FRAME
Implications... assuming no wildcards come into play

• Given pace of innovation, its global spread, and diverse approaches to development, difficult to predict developments either in the private sector or within governments globally

• Given growing capabilities in the private sector, difficult for governments to manage these sectors

• Given global power and diversity of interests, waning asymmetric control by space faring nations including the US

➢ United States has the potential to guide the agenda for a long time to come
United States Will Remain a Major Force

- Today, US total space expenditures may exceed that of the entire world combined; Civilian expenditures higher than the next 19 countries combined
- Proportion would drop, but the United States will continue to dominate government budgets

Source: EuroConsult Profiles of Government Space Programs, 2014

![Graph showing average 5-year annual investment in US$ billion from 2009-2013, 2014-2018, and 2019-2023 for various countries including USA, Russia, Japan, and China.](Source: Euroconsult Government Space Programs: Forecast and Benchmarks 2014)
Wildcards
May Disrupt Global Trends

- **Technology-based Wildcards**
  - Dramatic reduction in the cost of launch
    - Advanced propulsion
    - Fully reusable rockets (SpaceX’s Falcon 9 rocket currently carries a list price of about $54 million. However, the cost of fuel for each flight is only around $200,000—about 0.4% of the total; cost of building the engine $16 million)
  - Technologies that reduce dependence on space
    - Quantum PNT and other technologies that may make GPS superfluous
    - Atmosphere-based platforms
  - Turnaround of the economics of using space-based resources
    - *In-situ* resource utilization (celestial mining)
    - Space based solar power

- **Geopolitical Wildcards**
  - Drastic changes to the Outer Space Treaty or other international rules governing space
  - Increased militarization or weaponization of space (e.g., military presence on the moon)

- **Space-related disasters**
  - Discovery of a large earthbound asteroid or comet
  - Large, debilitating space weather disaster or cyber-event that cripples space-based services for an extended period
  - Space debris cascading event
  - Unforeseen single or repeated mishaps (especially involving human spaceflight)
Global Trends in Space Data Slides

Bhavya Lal, Emily Sylak Glassman, Nayanee Gupta
Science and Technology Policy Institute

October 28, 2015
Synopsis of Global Trends in Space

Better and cheaper technology, especially in the commercial and IT sectors, has led to the development of newer and lower-cost space-based applications, products, and services which, in turn, have accelerated space investment globally and spawned new users and suppliers that are following diverse approaches to space development.

There are three primary consequences of these changes. First, portions of the space sector are transitioning from a monopsonic-oligopoly to a more globalized mainstream sector. Second, governments, especially in emerging countries, are leapfrogging traditional development and aiming to reach parity with the major space faring nations. Third, growing space-based activity is introducing new challenges for the global space community, both on the ground and in space.
Synopsis of Global Trends in Space

In the next few 10–15 years, these changes imply that it would be difficult to predict developments in the space sectors, difficult for governments to manage these sectors, and the United States would see its control of the space sector wane. These trends are likely to hold if no wildcards [technological, geopolitical, or other] come into play.
1. Expenditures and activities, 6–18
2. Launch, 20–24
3. Private sector, 26–44
4. Partnerships and collaborations, 46–52
5. Scientific Capabilities, 55–59
6. Scientific collaborations, 61–87
7. Small satellites, 80–97
8. Governance Issues, 98–105
9. Other, 107–115
EXPENDITURES AND ACTIVITIES
Space Activities—Current and Forecasted

2014 Budgets/Revenues
$330 Billion

- 37% Non-US Government Space Budgets
- 13% US Government Space Budgets
- 11% Commercial Infrastructure and Support Industries
- 39% Commercial Space Products and Services

Forecasted 2024 Budgets/Revenues
$600 Billion

- 44% Non-US Government Space Budgets
- 9% US Government Space Budgets
- 5% Commercial Infrastructure and Support Industries
- 42% Commercial Space Products and Services

Source: Space Foundation, 2015, and Unpublished
Civil Expenditures 2013

WORLD GOVERNMENT EXPENDITURES FOR CIVIL SPACE PROGRAMS (2013) * TOTAL $43.7 BILLION

Budgets indicated for European countries include their contributions to ESA and EUMETSAT.

* Includes only budgets over $10 Million

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IDA
SCIENCE AND TECHNOLOGY POLICY INSTITUTE
Civil Expenditures 2008–2013

Civil Space Budget in Current USD Millions (2008–2013)

Source: EuroConsult 2014
### Space expenditures 1994-2023

#### WORLD GOVERNMENT SPACE EXPENDITURES 1994-2023

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#### CIVIL AND DEFENSE 2004-2023

![Graph showing civil and defense expenditures](image)

### 3 DECADES OF GOVERNMENTS INVESTMENT IN SPACE PROGRAMS

Derived from *Government Space Programs: Forecast and Benchmarks 2014*
Expenditures in Countries of Interest

China

France

India

Russia
United States Expenditures
CAGR (2008–2013) for Space Expenditures in Select Countries

Source: EuroConsult 2014
Expenditures in Human Space Flight

Source: EuroConsult 2014
Planned Missions by Domain of the Major Space-Faring Powers

Country or space agency:
- Russia
- MLM: Multi-purpose laboratory module
- LUM: Node module (docking port)
- NEM: Science and power modules
- ShK: Airlock Module
- TM: Transformable Module
- EM: Power Module
- Japan
- ERG: Exploration of Energization and Radiation in Geospace
- SLIM: Smart Lander for Investigating Moon
- MELOS: Mars Exploration with a Lander Orbiter Synergy
- India
- China
- ESA
- France
- Germany
- Italy
- CHEOPS: Characterizing Exoplanet Satellite
- JUICE: Jupiter Icy moons Explorer
- PLATO: Planetary Transits and Oscillations of stars
- ATHENA: Advanced Telescope for High-Energy Astrophysics
- InSight: The Interior Exploration Using Seismic Investigations, Geodesy, and Health Transport
- DEOS: Deutsche Orbital Servicing

Firm Plans ▲
Soft Plans ●

Country Involvement in Space

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*Source: STPI analysis using data from Euroconsult (2014a).*
Country Involvement in Space

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Spaceports Globally
(all, including commercial, civil and military)
LAUNCH
Countries Developing LEO and GEO Payload Launchers

Does not include SLS or Long March 9 (130 tonnes capacity)

Source: http://blog.thomsonreuters.com/index.php/tag/space/
Growing Competition in the Commercial/Civil Launch Sector

Non-Defense (Civilian, Commercial, Other) Launches of Satellites from Other Countries

US start-up Spire to ride on Indian rocket to space with Astrosat

The ride on the PSLV would be the first of the 100 satellite constellation it plans to launch for weather monitoring and tracking ships across oceans.

Source: STPI generated using data from McDowell 2015
Number of Total (and Commercial) Launches, 2014

Number of Countries with Launch Capability

Distribution of Orbital Launches by Decade and Country

Number of Countries that Have Satellites

Satellites by Owner Country -1950s-today

PRIVATE SECTOR
Transition from a Monospsonic Oligopoly to a Competitive Globalized Sector
## Emergence of the True Private Space Sector

<table>
<thead>
<tr>
<th>Risk Taker</th>
<th>Private Entities/Market Take Risk</th>
<th>Government Takes Risk</th>
<th>Customer Base</th>
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<tbody>
<tr>
<td></td>
<td>&quot;Emerging&quot; Private (Referred to as Commercial Space) [e.g., Orbital Sciences, Boeing Corporation, SpaceX, Bigelow Aerospace]</td>
<td>&quot;True&quot; Private Space [e.g., Virgin Galactic, Bigelow (future) Iridium, Intelsat, Trimble (current)]</td>
<td>&quot;Government Only/Primary Customer&quot;</td>
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<td>&quot;Traditional&quot; Space [e.g., Orbital Sciences, Boeing Corporation, Lockheed Martin]</td>
<td>[e.g., Roscomos, Arianespace]</td>
<td>&quot;Government One of Many Customers&quot;</td>
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### Note: The porous boundaries imply the movement of firms within quadrants.
Space Applications Incorporating Technology from Other Sectors

Evolution from space-only to space-led and space-also

Newer satellite manufacturing firms using:
- inertial measurement units from video games
- radio components from cellphones
- processors meant for automobiles and medical devices
- reaction wheels meant for dental tools
- cameras intended for professional photography and the movies
- open-source software available on the Internet

Changing Relationship and Relative Influence of the Main Stakeholders

Adapted From P. Ehrenfreund, N. Peter, “Toward a Paradigm Shift in Managing Future Global Space Exploration Endeavors,” 
Evolution of the Role of the Private Sector

Delegation
Government retains responsibility and oversight while using the private sector for service delivery (e.g., contracts with Boeing to produce the space shuttle)

Divestment
Government relinquishes responsibility (SAA with SpaceX to deliver cargo)

Displacement
Private sector grows and displaces ad government activity (future Bigelow space station)

Adapted from C. Anderson, Space Policy 29 (2013) 266–271
Governments Cost-Sharing with Private Sector—Primarily a “Western” Phenomenon

Source: Payson, IAC 2014
Increasing Private Investment

**Investing in Space**
Fundraising for 100 largest closely held companies

- **Spending in millions**
- **Years:** 1995 to 2015

**Source:** NewSpace Global

1995-2002 annual totals were $2.5 million or less except 1998. 2015 includes projected funding.

Source: http://www.hotstockmarket.com/t/274184/spacex-other-elon-musk-stuff
Scope of VC Funding

- Traditional space-related technology such as space travel and rocket propulsion
- More contemporary technologies like satellite imagery, asteroid mining, space debris cleanup

There’s this canonical thing about a startup needing to pitch a 10X improvement to be a worthwhile investment. You rarely see an entrepreneur pitch a 100X improvement. But in space we’ve seen 1,000X, and really we’ve seen 10,000X.”

- Steve Jurvetson
  Partner, Draper Fisher Jurvetson

Known investments

Major Investments
• Space X – 1.2 B
• Skybox – acquired by Google, $500 m
• OneWeb – $500 M
• Planet Labs – $200 M
• Kymeta – $82 M
• Spire – $70 M
• Mapbox – $60 M
• Urthecast – $63.5 M

Others – Investment levels unknown
• Rocket Labs (Smallsat launch)
• Spaceflight Industries (Small sats)
• Accion System (Micropropulsion)
• Astroscale (Space Debris)
• Orbital Insight (Imagery, utilize deep learning to analyze large datasets)
• Windward (Imagery)

Lux Capital, RRE Ventures, and Bessemer Venture Partners have been the 3 most active VCs in space startups since 2012. Other include Khosla Ventures, Promus Ventures and Founders Fund

Even Smaller Firms Are Global Enterprises

- Even if governments retain an omnipresent role in space affairs, as funders of major institutional R&D programs and as customers, the private industry supply chains are getting more complex, influenced by the global markets space companies.

Skybox Partners and Supply Chain

Source: https://www.zeemaps.com/map?group=1145582
Space Is a Global Activity
20 of 33 Team and 4 of 9 Winners of the Google Lunar X Prize Are Non-U.S. Entities

- Brazil
- Canada
- Chile
- China
- Germany (2)
- Hungary
- India
- International (4)
- Israel
- Italy
- Japan
- Malaysia (2)
- Romania
- Russia
- Spain
- United States (13)

Source: http://lunar.xprize.org/teams
Growth of a New Private Sector

- United States is the locus of NewSpace activity but there is entrepreneurship activity in Europe, Russia, Australia, Singapore, Israel, South Africa, Argentina and other countries
  - (Australia) Saber Astronautics develops spacecraft systems that can automatically repair themselves if damaged
  - (New Zealand) Rocket Lab designs and fabricates small satellite launch and propulsion systems.
  - (Singapore) Astroscale develops space debris removal technology
  - (Argentina) Satellogic is launching a network of hundreds of satellites in Low Earth orbit that will allow customers to get “an image of any place on Earth in high resolution and in real time.”
  - (India) Dhruva Space builds small satellites in the 10-100 kg range which have a much shorter turnaround time of around 18 months, and cost less adopting the model of frugal innovation

Identified ~150 NewSpace companies
And It IS New

Source: STPI Compilation Using Public Sources
Areas of NewSpace Firms (since 2000)

- Data Analytics
- Habitats and real Estate
- Human Spaceflight
- In-Space Services
- Launch and Transport
- Microgravity Research
- Other
- Satellites
- Space Energy
- Space Resources
Country of NewSpace Firms (since 2000)

Number of Companies

Year

United States
Foreign

India
France
Brazil
United Kingdom
Spain

United States $n = 86$
Functional Modularization in EO

- Instrument Development (example: Ball Aerospace)
- Platform Development (example: Surrey Satellite Technology)
- Satellite Operation and Data Collection (example: Planet Labs)
- Software Development (example: Esri)
- Data Processing (example: Google Earth)
- Data Storage (example: Amazon)
- Data Analysis (example: eLEAF)
- Data Visualization, Reports, and other EO Services to Customer (example: The Weather Channel)
SmallSats May Enable the Space Sector to Mirror Trends in Other Sectors

Evolution of computing devices.
~1 major form factor innovation every decade.

Source: http://www.slideshare.net/scapecast/accenture-bubble-over-barcelona-2013-mwc-mobility-trends
Parallel: Computing

- Transition from large, expensive, and exquisite “mainframe” supercomputer capability to the distribution of smaller, more standardized microcomputer systems with less processing power.
  - Similar to early satellites, a primary motivation for early computing systems was critical national defense purposes—encryption/decryption and nuclear simulation.
  - Each computer, like a traditional satellite, was a large project, and maximizing performance and reliability of each component was essential. These custom systems would be produced by governments and contractors (including IBM, CDC, Cray, and others) with primarily government and large business customers that could afford to purchase them and employ trained individuals to use them effectively.
  - In time, consumer grade COTS processors and computers became available, finally reaching a price point and degree of usefulness (through miniaturization and improved performance via Moore’s Laws) that they became progressively more attractive for personal and business use.
  - Eventually, these processors were produced for the mass market in such quantity that using many of these processors (described as “killer micros”) in parallel became a more cost-effective architecture to improve performance and reach wider use of the supercomputers of exquisite capability, with innovations in the consumer and microprocessor sector feeding back into high performance systems.
PARTNERSHIPS AND COLLABORATIONS
Korea Has a Different Pathway than India (OECD Space at a Glance)
Country-Country “Partnerships”

- Countries in the EU generally fall into a single group (blue).
- Countries collaborating with the U.S. compose another group (green).
- Developing countries often collaborating with China as a third group (red).
- There is significant cross-over between the blue (EU-centric) and green (U.S.-centric) groups.

Note: China isn't just partnering with resource rich countries in Asia, Africa, and Latin America.

Colors indicate grouping using a community detection algorithm. Data from manual mining of Euroconsult’s Profile of 80 Countries.
China’s “Partnerships”
Europe’s “Partnerships”

India’s “Partnerships”
Japan’s “Partnerships”

Russia’s “Partnerships”

Brazil Forges Space Cooperation Agreements Everywhere Except Washington

The Brazilian government is looking to join the front ranks of spacefaring nations and has struck multiple agreements with other nations for cooperation on launch vehicles (Ukraine and Germany), satellite telecommunications (France), Earth observation (China), small-satellite development (Argentina and Japan) and space technology development (Canada and France).

Notably absent is the United States, where 16 years of classifying satellite exports as armaments has had a chilling effect in foreign capitals. Recent moves by the U.S. government to reverse some of the effects of the policy have yet to be felt in Brazil.

CAPABILITIES
Significant Number of Publications from China in Chinese, Compared with Others; but Fraction Falling

Publications from China with Keyword "Satellite"

Source: Scopus
Key Word: Satellites
Data until end of 2013
Country: China
Language: as specified
China Is the Country with the Fastest Rate of Growth of Satellite-Related Publications

Source: Scopus
Key Word: Satellites
Data until end of 2013
Emerging Countries Have a Faster Rate of Publication Growth Compared to Most Established Countries

Source: Scopus
Key Word: Satellites
Data until end of 2013
While the U.S. Far and Away Leads the Way in Astronomy, Other Nations Increasing Their Publication Count Tenfold in <10 Years
The Publication Trend Varies Strongly Depending on the Subject Area

Publications with Keyword "Satellites" from Top 5 non-U.S. countries

Number of Publications with Term "Astronomy" by Top 5 Non-U.S. Countries

- United Kingdom
- Germany
- France
- Italy
- China
SCIENTIFIC COLLABORATIONS
Growing Collaborations in Research

Scopus Database Co-Authorship
For publications with keyword “satellites”
Case Study of Emerging Country: Brazil has had an increase in collaborations and an increasing number of collaborations with China, in particular.

2003 Brazil 2013
Russia Has Had a Small Increase in the Number of Publications with Foreign Collaborators in “Satellites”
From 2003–2013, a net total of 10 additional countries were collaborated with on publications regarding “satellites”
China Publishes with the United States More Than with Any Other Country

2003 China 2013
China, 2003–2013


Collaborative Country

Amount of Publications
U.S. Collaborations with a Country Are Roughly Proportional to the Number of Publications by that Country
From 2003–2013, a net 42 additional countries were collaborated with on publications regarding “satellites” (gain of 52 loss of 10)
France Publication in “Satellites”

2003 2013
From 2003–2013, a net total of 39 additional countries were collaborated with on publications regarding “satellites” (7 lost and 46 gained).
Brazil: France Collaborations in 2013 by Subject Area and Secondary Keywords

The Secondary Keywords are:
Remote sensing (11)
Satellite imagery (9)
Satellite data (8)
.....
India Publication in “Satellites”

2003

2013
India, 2003–2013

The main sub-keywords of the 19 articles regarding satellites are:
Satellite imagery (11)
Satellite data (8)
Remote sensing (7)

...
China: U.S. Collaborations in 2013 by Subject Area and Secondary Keywords

The Secondary Keywords are:

- Satellite imagery (98)
- Remote sensing (72)
- Satellite data (68)
- Algorithm(s) (68)
- Radiometers (32)

......
Japan Publication in “Satellites”

2003

2013
Japan, 2003–2013

The main sub-keywords of the 47 articles regarding satellites are:

- Satellite data (11)
- Satellite imagery (110)
- Atmospheric chemistry (7)
Japan: Germany Collaborations in 2013 by Subject Area and Secondary Keywords

The Secondary Keywords are:

Satellite data (11)
Satellite imagery (11)
Atmospheric chemistry (7)
Carbon dioxide (7)
Data set (7)
Comparative study (6)
Algorithm (5)
Climatology (5)

.....
SMALL SATELLITES
SmallSats—Disruptive Technology

Initially the performance satellites was poor and it improves slowly. As experience with technology grew, performance improved rapidly. Eventually performance plateaus. The next wave of technology (SmallSats) is initially not as good. However, it is improving rapidly and firms jump to the new S curve and dramatically improve performance.

TIPPING POINT

*Breakthrough based on falling costs and dramatic improvements especially in processing power, data storage, camera technology, compression, solar array efficiency and propulsion*
The Satellite Size Spectrum

As space applications have grown, so has satellite diversity. The spacecraft shown here are all too large to effectively use planetary magnetic fields or solar pressure for propulsion. Sprites, if they could be made to weigh less than 50 milligrams, could do both.

1957
**SPUTNIK 1**
*First artificial satellite*
**Mass:** 83.6 kilograms
**Size:** 58-centimeter-diameter sphere, with whisker-like antennas measuring 2.4 and 2.9 meters

1971
**INTELSAT 4 F-3**
*International communications satellite*
**Mass:** 1410 kg
**Size:** 5.3 meters long, with antenna

1990
**HUBBLE SPACE TELESCOPE**
*World's most massive space telescope*
**Mass:** 11,110 kg
**Size:** 13.2 meters long

1998
**ZARYA**
*First International Space Station module*
**Mass:** 19,323 kg
**Size:** 12.6 meters long

2003
**CUTE-1**
*One of the first standardized miniature CubeSats*
**Mass:** 1 kg
**Size:** 10-cm-wide cube

2005
**XM-3**
*Commercial radio satellite*
**Mass:** 2800 kg
**Size:** 47.9 meters from the end of one solar panel to the other

2011
**SPRITE PROTOTYPES**
*Test chips attached to International Space Station*
**Mass:** 10 grams
**Size:** 3.8- by 3.8-cm boards
A microcosm (SmallSats)
Attendance at SmallSat Utah conference has tripled
Attendance at SmallSat Utah Conference
Industry Has Been the Major Participant
Attendance at SmallSat Utah Conference

Within industry, the United States Remains the Dominant Player

- ~600 companies represented at SmallSat 2015
- Most are American, followed by the UK and Japan
United States Dominates but Growing International Participation (Attendees)

- United States dominates
  - 85% of attendees and exhibitors have U.S. affiliations
    (slight increase from 14 to 15)

- Interest in SmallSats growing
  - 46% increase in attendance at the annual Logan UT SmallSat meeting (938 to 1374 registered attendees)
    - U.S. participation up 44%
    - Non-U.S. participation up 64%

- Among global participants, a small number of countries dominates
  - 13 new countries attended in 2015

New Attendees in 2015
- Estonia (1)
- Finland (1)
- India (1)
- Ireland (1)
- Italy (1)
- Lithuania (3)
- Luxembourg (1)
- Oman (1)
- Pakistan (3)
- Russia (7)
- Spain (2)
- Taiwan (1)
- Turkey (1)
United States Dominates but Growing International Participation (Exhibitors)

- United States dominates
  - 85% of attendees and exhibitors have U.S. affiliations (slight increase from 14-15)
- Interest in SmallSats growing
  - 46% increase in attendance at the annual Logan UT SmallSat meeting (938 to 1374 registered attendees)
    - U.S. participation up 44%
    - Non-U.S. participation up 64%
- Among global exhibitors (proxy: tech capability), small fraction dominates
  - France, Denmark, Sweden, Germany increased >50%

New Exhibitors in 2015
- Argentina (5)
- Lithuania (3)
- New Zealand (4)
United States Dominates but Growing International Participation

New Attendees in 2015
- Estonia (1)
- Finland (1)
- India (1)
- Ireland (1)
- Italy (1)
- Lithuania (3)
- Luxembourg (1)
- Oman (1)
- Pakistan (3)
- Russia (7)
- Spain (2)
- Taiwan (1)
- Turkey (1)
*Belgium (1), Colombia (2) and Kazakhstan (4) participated in 2014 but not 2015

New Exhibitors in 2015
- Argentina (5)
- Lithuania (3)
- New Zealand (4)
*Norway (1) participated in 2014 but not 2015
Small, light and cheap satellites could transform Earth observation. How they measure up to their larger brethren:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Dove</th>
<th>Skysat</th>
<th>LandSat 8</th>
<th>WorldView-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Satellites</td>
<td>Planet Labs</td>
<td>Skybox Imaging</td>
<td>NASA</td>
<td>DigitalGlobe</td>
</tr>
<tr>
<td>32</td>
<td>24</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Weight</td>
<td>~5 kg</td>
<td>~100 kg</td>
<td>~2,000 kg (without instruments)</td>
<td>~2,800 kg</td>
</tr>
<tr>
<td>Instruments</td>
<td>Optical and near-infrared spectral bands</td>
<td>Optical and near-infrared spectral bands</td>
<td>Multiple spectral bands</td>
<td>Multiple spectral bands</td>
</tr>
<tr>
<td>Spatial Resolution</td>
<td>3-5 m</td>
<td>~1 m</td>
<td>15-100 m</td>
<td>0.3-30 m</td>
</tr>
<tr>
<td>Cost</td>
<td>$60,000</td>
<td>$50 million</td>
<td>$850 m (including launch)</td>
<td>$400m (including launch $750 m)</td>
</tr>
<tr>
<td>Time to Build</td>
<td>Days-weeks</td>
<td>4 years</td>
<td>-</td>
<td>8 years</td>
</tr>
</tbody>
</table>

Decreasing Percentage of Small Satellites Will Be from the Government and Civil Sector

Nano/Microsatellite Trends by Sector (1 – 50 kg)

The civil sector remains strong, contributing over one third of future nano/microsatellites, but it will see reductions compared to 2009-2013 when the sector contributed 63%
Growing Role of Nano/Microsats in the Near Future

Global Satellite Launches by Mass

Source: NSR

http://www.nsr.com/news-resources/the-bottom-line/mass-challenge-for-cubesats/
Projections based on announced and future plans of developers and programs indicate between 2,000 and 2,750 nano/microsatellites will require a launch from 2014 through 2020.

The Full Market Potential dataset is a combination of publicly announced launch intentions, market research, and qualitative/quantitative assessments to account for future activities and programs. The SpaceWorks Projection dataset reflects SpaceWorks' expert value judgment on the likely market outcome.

*Please see End Notes 1, 2, 4, 5, and 6.*

## Nano/Microsatellite Future Program Summary (1 – 50 kg)

### Large Program Breakdown for Announced Future Satellites

<table>
<thead>
<tr>
<th>Name of Program/Satellite Constellation</th>
<th>Timeframe</th>
<th>Organization</th>
<th>Country</th>
<th>Mass (kg)</th>
<th>Launched to Date</th>
<th>Total Planned</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSF Geospace &amp; Atmospheric CubeSat</td>
<td>2010-2015</td>
<td>NSF</td>
<td>USA</td>
<td>1-3</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>NASA EDSN</td>
<td>2013-2014</td>
<td>NASA ARC</td>
<td>USA</td>
<td>3</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>NASA CubeSat Launch Initiative</td>
<td>2011-2017</td>
<td>NASA</td>
<td>USA</td>
<td>1-12</td>
<td>24</td>
<td>115</td>
</tr>
<tr>
<td>SeeMe Payloads</td>
<td>2016</td>
<td>DARPA</td>
<td>USA</td>
<td>12</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>QB50</td>
<td>2015</td>
<td>Von Karman Institute / Various</td>
<td>Various</td>
<td>2</td>
<td>0</td>
<td>52</td>
</tr>
<tr>
<td>HUMSAT</td>
<td>2013-2014</td>
<td>University of Vigo / Various</td>
<td>Various</td>
<td>1</td>
<td>0</td>
<td>9</td>
</tr>
</tbody>
</table>

Existing large programs will comprise only 25% of future nano/microsatellites (compared to 65% in 2013) due to worldwide growth in the civil and commercial sectors.

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http://www.slideshare.net/prateepbasu/nano-and-microsatellite-market-assessment2014
Projections based on the announced plans of nano/microsatellite developers and programs indicate a range of 121 to 188 nano/microsatellites requiring launch by 2020.
Cubesat Launches Growing Dramatically

Source: https://sites.google.com/a/slu.edu/swartwout/home/cubesat-database
Earth Observation Is the Fastest Growing Application of Cubesats

CubeSats Each Year by Mission Type

[Chart created on Sun Sep 06 2015 using data from M. Swartwout]

Key Players in the Cubesat Community Are in the Private Sector
(8) CHALLENGES THAT COME WITH GROWING PARTICIPATION AND DEPENDENCE ON SPACE
Orbital Debris and SSA

Today the U.S. Department of Defense (DoD) is using the Space Surveillance Network to track some 23,000 pieces of debris 10 centimeters (cm) in diameter or larger. Experts estimate that there are more than 500,000 objects with a diameter larger than one centimeter and several million that are smaller.


https://upload.wikimedia.org/wikipedia/commons/8/82/Orbitalaltitudes.jpg
Number of Companies Submitting SmallSat APIs to the ITU

Source: ITU via SpaceNews March 2015
Sources of Debris by Weight (LHS) and Number (RHS) of Objects

Physical and Electromagnetic Environment

• Projections for Increases in Space Debris

![Graph showing the increase in space debris over time.](image-url)
Countries with Members in the International Astronautical Federation

Source: STPI synthesis of IAF data.
Number of Treaties, National Space Laws, and Regulations per Year

Source: OECD calculations based on United Nations data (OECD 2014, 45).
Increasingly Complex Global Governance Landscape

Source: MIKE
We’ve seen this rodeo before!

WHAT IS DIFFERENT THIS TIME?
Space-Based Internet Gold Rush
Have the 1990s Returned?

• Back then, all the talk was the development of constellations of satellites to provide telephone and data services.
• Globalstar, Iridium, and ORBCOMM got far enough to actually deploy their systems, but there were many more concepts being discussed in the 1990s.
• Best known of those was Teledesic, which in its early planning proposed launching nearly 1,000 satellites for high-speed data services.
• But there were many more in various stages of development, like Celestri, Ellipso, Final Analysis, and SkyBridge, among others.
• Beyond a couple of demonstration satellites, none of these systems got off the drawing boards, killed by the telecom bust at the end of the 1990s that also sent Globalstar, Iridium, and ORBCOMM into Chapter 11 bankruptcy protection and reorganization.
More Companies Died than Are Alive

**2013**

**STILL WITH US (15):**

- Armadillo Aerospace
- Blue Origin
- Canadian Arrow/PlanetSpace
- Inter Orbital Systems
- Kelly Space and Technology¹
- Masten Space Systems
- Microcosm Inc²
- Micro-Space Inc
- Orbital¹
- Reaction Engines Limited
- SpaceDev²
- Space Exploration Technologies¹
- Starchaser Industries PLC
- TGV Rockets²
- XCOR Aerospace

¹ Currently Manufactures and Operates Orbital Launch Vehicles
² Currently Produces Space Components or Services

**Requiescat In Pacem (42):**

- Acceleration Engineering
- Advent launch Systems
- AMROCS
- Advent Launch Services
- AeroAstro LLC
- Angara
- Aquanar
- Athena (a.k.a. LLV)²
- Ausroc
- Beal Aerospace Technologies
- Capistrano
- Cerulean Freight Forwarding Co.
- Conestoga
- CTA Launch Services
- DC-X
- E-Prime Aerospace Eagle
- Fundamental Technology Systems
- International Micro Space
- Ikeroribital Systems
- Kistler Aerospace
- KittyHawk Technology
- Lone Star Space Access
- ORBEX
- PacAstro
- Pacific American Launch Systems
- Panavao, Inc.
- Platforms International
- RASCAL
- Rocketplane Limited
- Rotary Rocket
- Sagan
- SEALAR
- Space Access Inc.
- Space America Inc.
- Star-Raker Accessories
- Starcraft Boosters Inc.
- Third Millennium Aerospace Inc.
- Triax Engineering, Inc.
- Vela Technology Development, Inc.
- VentureStar
- VLS
- World Aerospace

² Only One to have Successfully Launched to Orbit
Prior Failures—that prevented predictions from coming true

Type 1: Inadequate investment into a promising technology
- Space shuttle
  - NASA had to compromise on the original fully reusable design
    - Designed with a stage and a half with boosters
    - Wanted to choose liquid engines for boosters because at that time people were not placed on vehicles with solid engines
    - But solid engines were cheaper so they chose that
    - Decided to have an external tank instead of a fully reusable winged first stage
    - Crew compartment should be above external tank but was not

Type 2: Promising/worthwhile technology but political issues not addressed
- Nuclear Thermal Engines
  - Nuclear Engine for Rocket Vehicle Application (NERVA) for 3rd stage (in-space propulsion) began in 1961
  - Although there were no real safety issues, the political tension around the use of nuclear engines resulted in the canceling of NERVA
  - Protests around nuclear material in space continued because people were nervous about accidents

Type 3: Investment in poor technology
- Roton rotary rocket
  - Goes up like a rocket and comes down like a helicopter
  - Funded privately, not through the government
- DARPA AirLaunch
  - Emerged out of desire to build a hypersonic cruise vehicle (HCV) but with FALCON connected it to common aero vehicle (CAV)
  - DARPA and the Air Force had a Memorandum of Agreement (MOA), signed in May 2003, where DARPA was in charge of the FALCON small vehicle launch (SLV) program and the Air Force was funding the program
  - CAV renamed the hypersonic test vehicle (HTV) program once congress said no weapons in space
  - In 2007 the HTV-3X Blackswift resurrected the FALCON program as a demonstrator to the SR-72. Canceled in October 2008.

Type 4: Technology overcome by events
- Space-based telecom Iridum) good idea but could not compete with cell towers
Staying Away from Hype

• Google’s satellites could cost up to 20 times more than their low-end estimate—more like $20 billion than $1 billion.
  
  – “This is exactly the kind of pipe dream we have seen before...the landscape is littered with failed satellite projects like the one being proposed by Google.”

• Source: http://amigobulls.com/articles/googles-skybox-acquisition-can-drive-revenue-growth
Tipping Point

• Growing demand for ubiquitous Internet access and situational awareness
  – Connexion by Boeing failed before because not enough people had PDAs on flights; demand is now there

• Better and cheaper hardware and software, software as service
  – Lease cloud space at Amazon, couldn’t do that 15 years ago
  – Mars Curiosity Rover has a 2 MPixel camera because design frozen 10 years ago

• More value for the investment
  – Before: money into a long-term, capital-intensive, monolithic industry dominated by government contracts, legacy fixed satellite services and big-iron hardware
  – Now: less capital-intensive investments

• Different motivations
  – Wyler of OneWeb motivated by altruism and a heartfelt desire to deliver Internet to the unwashed masses
  – Musk driven by a desire to generate cash to fund Mars colonization
  – Virgin Galactic motivated by the opportunity to use their launch platform

➢ Wall Street has indeed forgotten Teledesic/Iridium
LOW-COST INNOVATION—INDIAN MOM
Mangalyaan Mission

- Of the 51 Mars missions attempted across the world so far, only 21 have succeeded; Mangalyaan succeeded on 1st try
- Solo effort—ESA’s Mars express involved 17 nations
- Cost $ 74 million (NASA Maven $671 million)
- Took 15 months to complete (NASA Maven took 5 years)
Triumph of Low-Cost Engineering

- Proven technology used
  - PSLV rocket rather than the more uncertain GSLV rocket
- Use of homegrown and proven equipment—gyros, attitude control, sensor, star trackers
- No expensive ground testing, fewer models built
- No spares—went straight to flight model which flew to Mars
- Low personnel cost

BL view

- Not as capable as MAVEN—comparisons are unreasonable
- Leveraged NASA—nearly 250 staff at the 3 NASA Deep Space Networks had been earmarked specially to monitor MOM insertion
This presentation summarizes findings from a series of projects on global trends in space. Space activities, previously the exclusive realm of the United States and the Soviet Union, now include many more actors, both governmental and commercial. This growth is not new—the number of countries involved in space activities has been growing continually since the early 1960s. While there has been commercial activity in space for decades, recent years have seen growth both in the number and variety of space-related technologies and services available for purchase. STPI explored these recent changes in the space sector to understand the factors that are driving them and to identify trends.

Global Trends in Space, Civilian Space, Commercial Space, Private Sector Space, NewSpace, International Space Activities, China, India, Europe, Japan, Russia, Space Strategy, Small satellites, CubeSats, Innovation, Innovation in the Space Sector