IDA

SCIENCE & TECHNOLOGY POLICY INSTITUTE

Global Trends in Civil and Commercial Space (Presentation)

Bhavya Lal
Emily J. Sylak-Glassman
Nayanee Gupta

October 2015
Approved for public release;
distribution is unlimited.
IDA Document NS D-5682
Log: H 15-001221

IDA SCIENCE & TECHNOLOGY
POLICY INSTITUTE
1899 Pennsylvania Ave., Suite 520
Washington, DC 20006-3602

IDA | SCIENCE AND TECHNOLOGY POLICY INSTITUTE

Global Trends in Civil and Commercial Space

Bhavya Lal

Emily J. Sylak-Glassman, Nayanee Gupta

October 2015

1899 Pennsylvania Avenue NW, Suite 520
Washington, DC 20006 • 202.419.3720

Outline – Global Trends in Space

Drivers
- Improvements in and falling cost of technology
- Newer and lower-cost space-based applications, products, and services
- Changing national policies

Signposts
- Accelerated space investment globally
- New users and suppliers
- Diverse approaches to space development

Near-Term Implications
- Transition to a more globalized mainstream sector
- New challenges, in space and on the ground
- New opportunities for governments

Implications in the 10-15 year Time Frame
- Difficult to predict trajectories
- Difficult for governments to manage sector
- US control of the space sector wanes

Wildcards
- Unanticipated technological developments
- Abrupt geopolitical changes
- Other unexpected developments

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/p5242v2.ashx

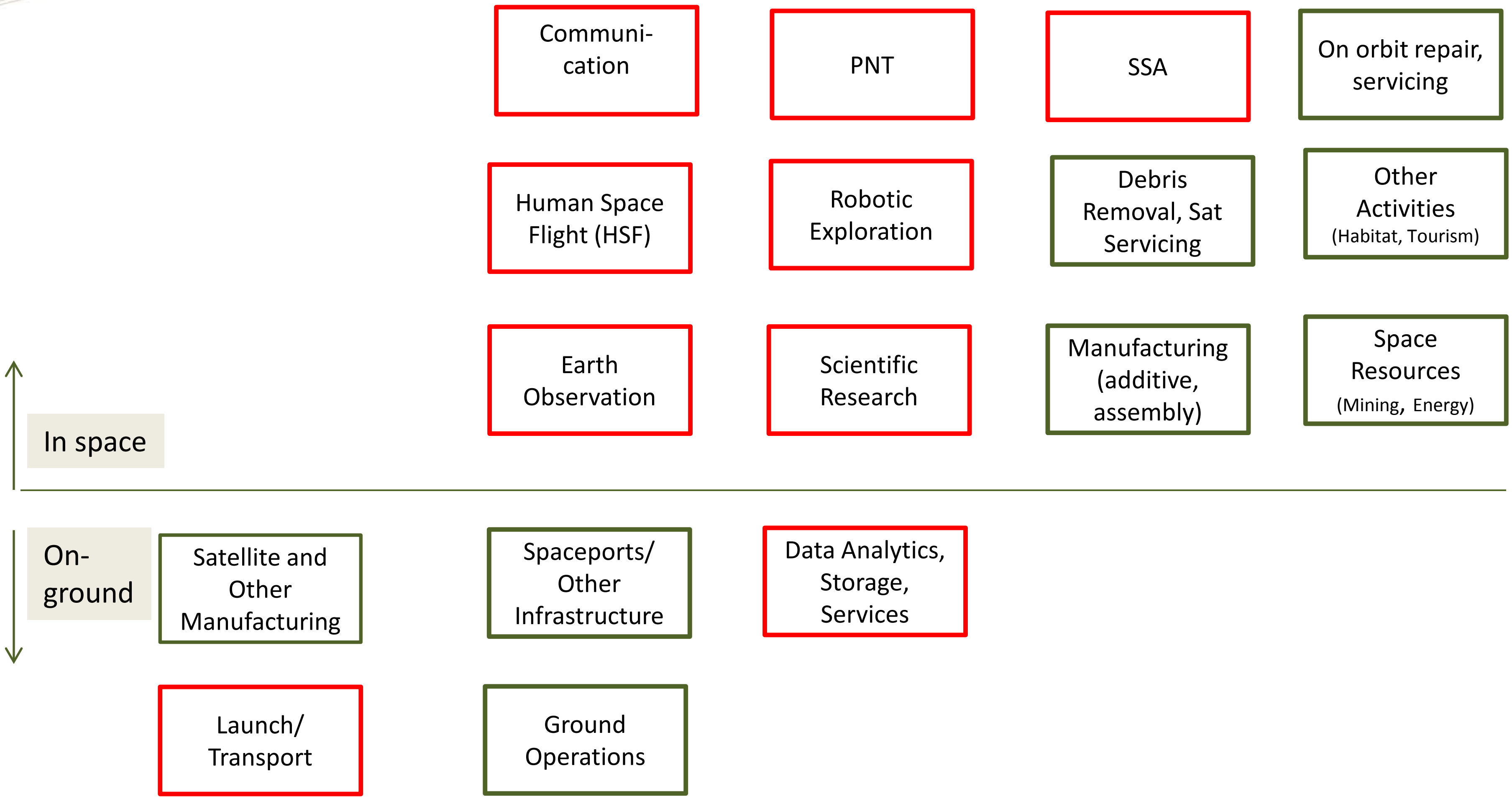
Caveat

Space not a monolith

Global Trends
in “Space”

Caveat

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

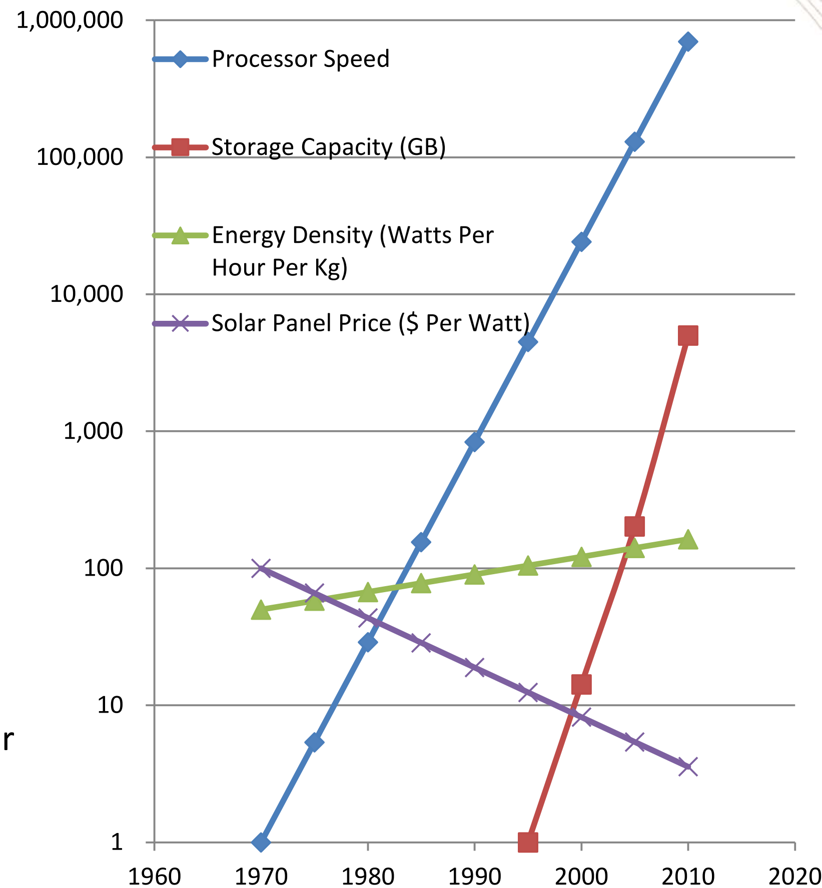


SELECT DRIVERS

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

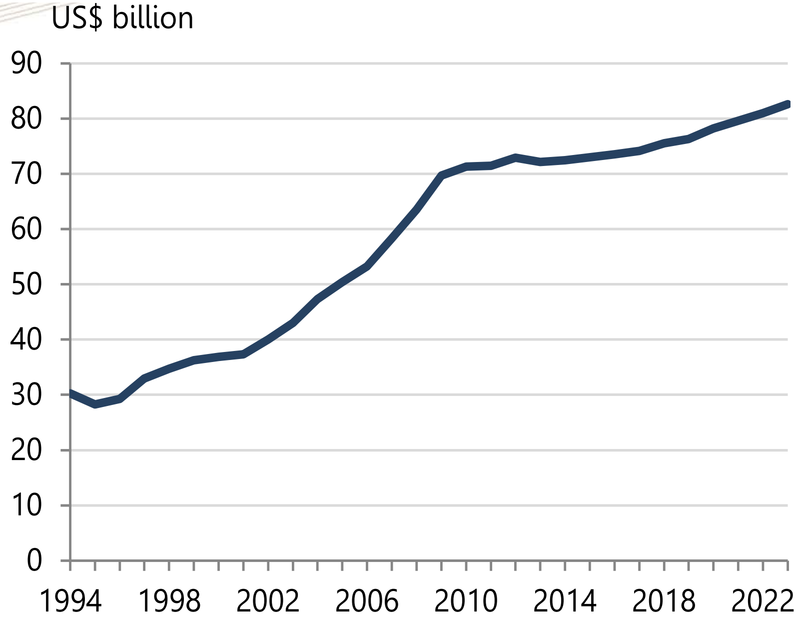
Projected global market for satellite-sourced intelligence $5 B in 2019

IDA SCIENCE AND TECHNOLOGY POLICY INSTITUTE

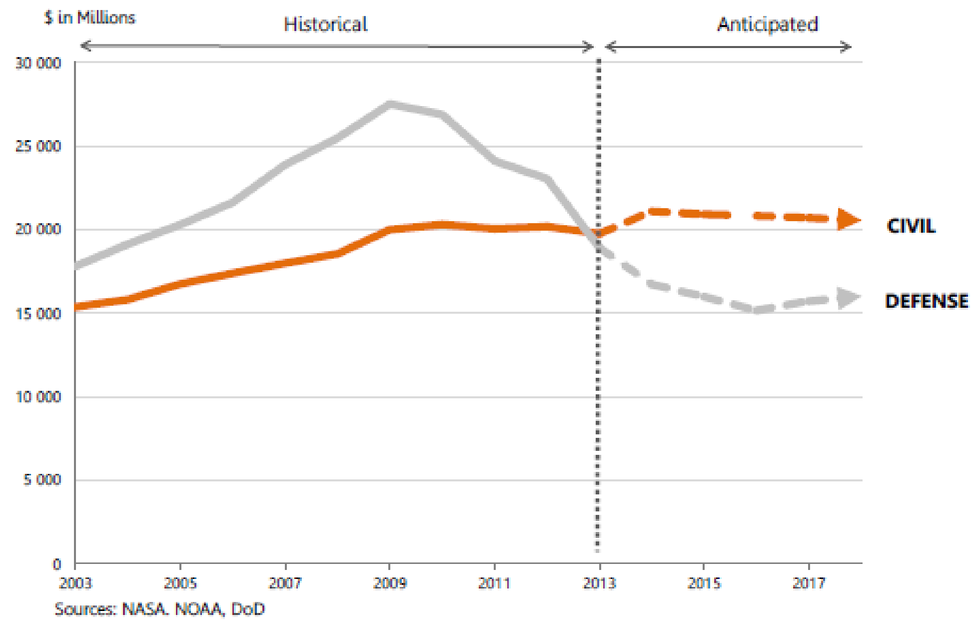
SIGNPOSTS

Growing Global Public Expenditures

World Government Space Expenditures 1994-2022



United States Space Expenditures 2003-2017

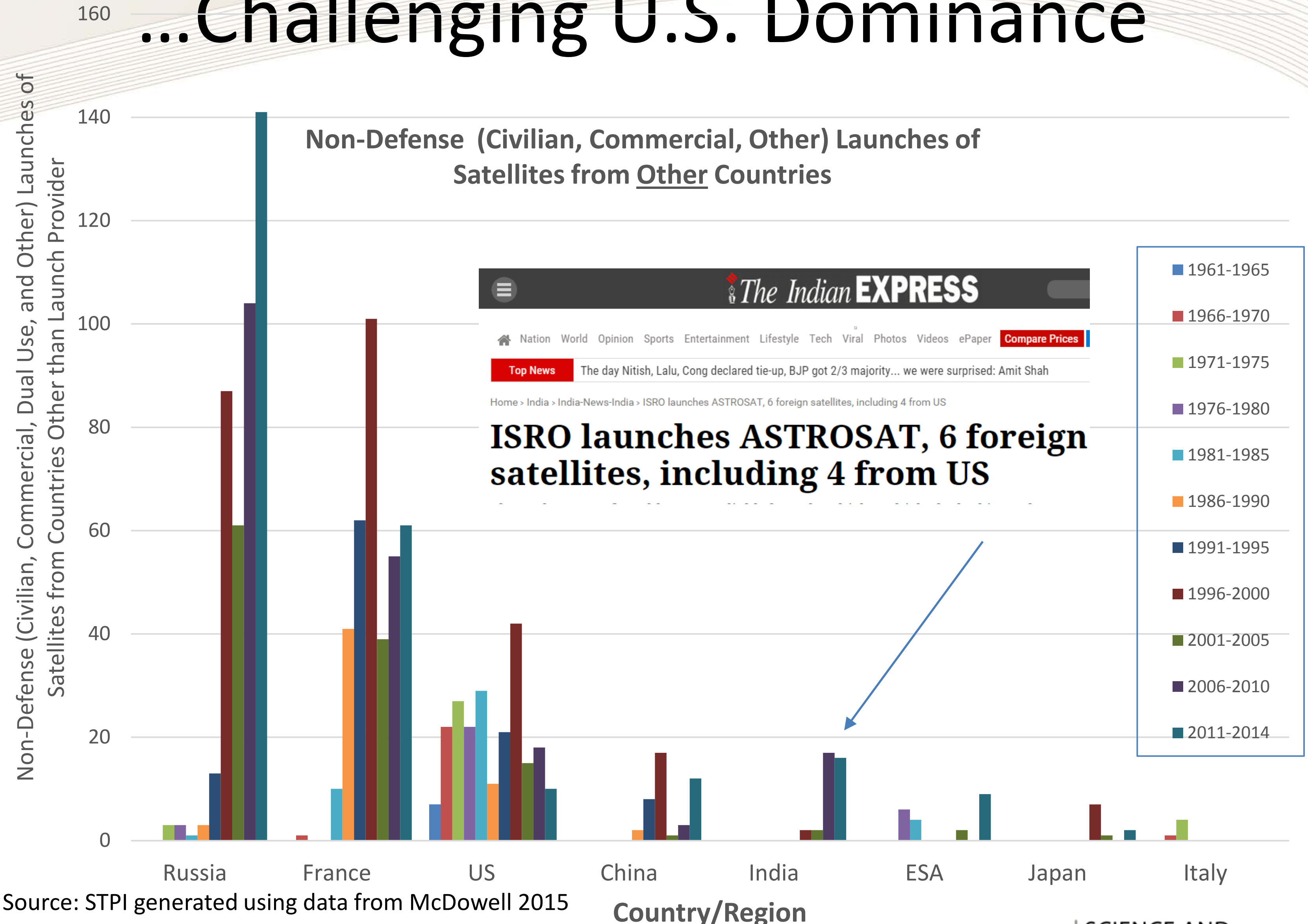


Individual country trajectories vary from CAGR +60% to -100%

	Average world funding	CAGR	# of countries	Civil/Defense
1994-2003	$33 billion	4.3%	33	61%/39%
2004-2013	$63 billion	4.8%	68	55%/45%
2014-2023	$77 billion	1.5%	86	62%/38%

Source: Euroconsult *Government Space Programs: Forecast and Benchmarks 2014*

...Challenging U.S. Dominance

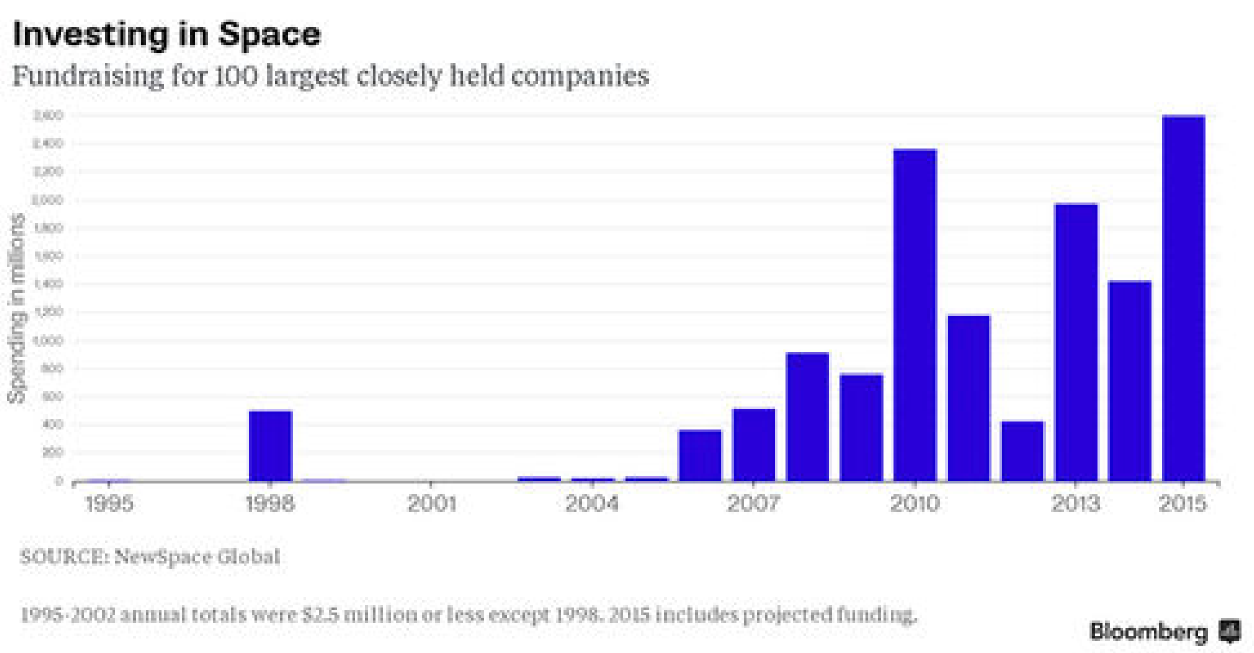


Source: STPI generated using data from McDowell 2015

UNCLASSIFIED//FOUO

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"

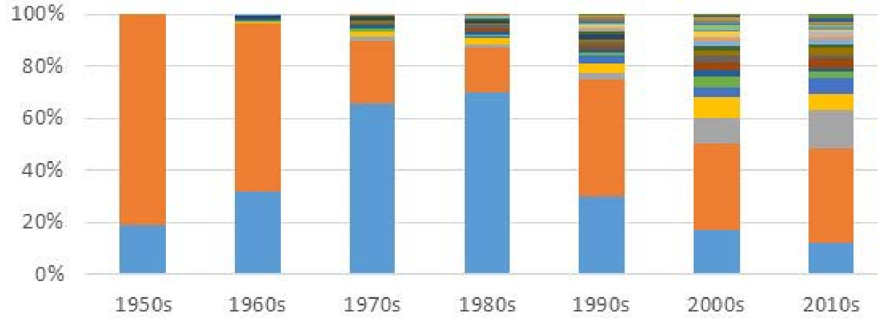


SpaceX Sat	$1.2 B
Skybox	acquired by Google, $500 M
OneWeb	$500 M
Planet Lab	$200 M
Kymeta	$82 M
Spire	$70 M
Mapbox	$60 M
Urthecast	$63.5 M

Source: http://www.hotstockmarket.com/t/274184/spacex-other-elon-musk-stuff,
CB Insights, The Future Of Frontier Tech, *Analyzing Trends In Drones, Space, And AR/VR, Technology,* August, 2015

Emerging Actors – Users, Brokers and Suppliers

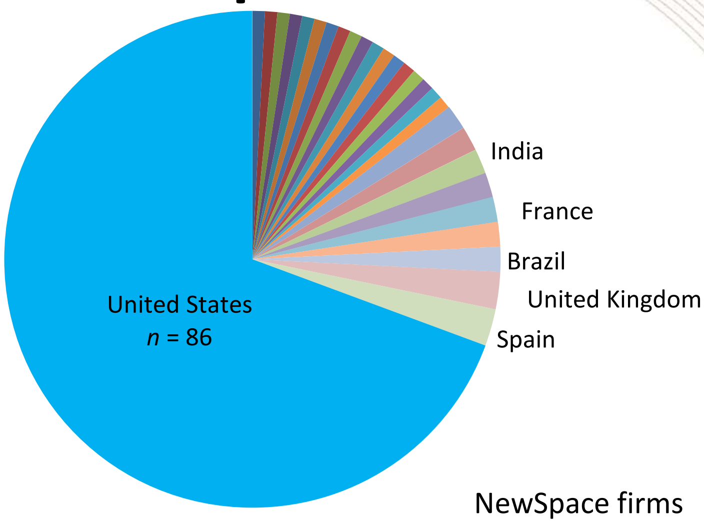
- New users
  - Nation states - ~80 countries have satellites; 170 have financial interest in satellites



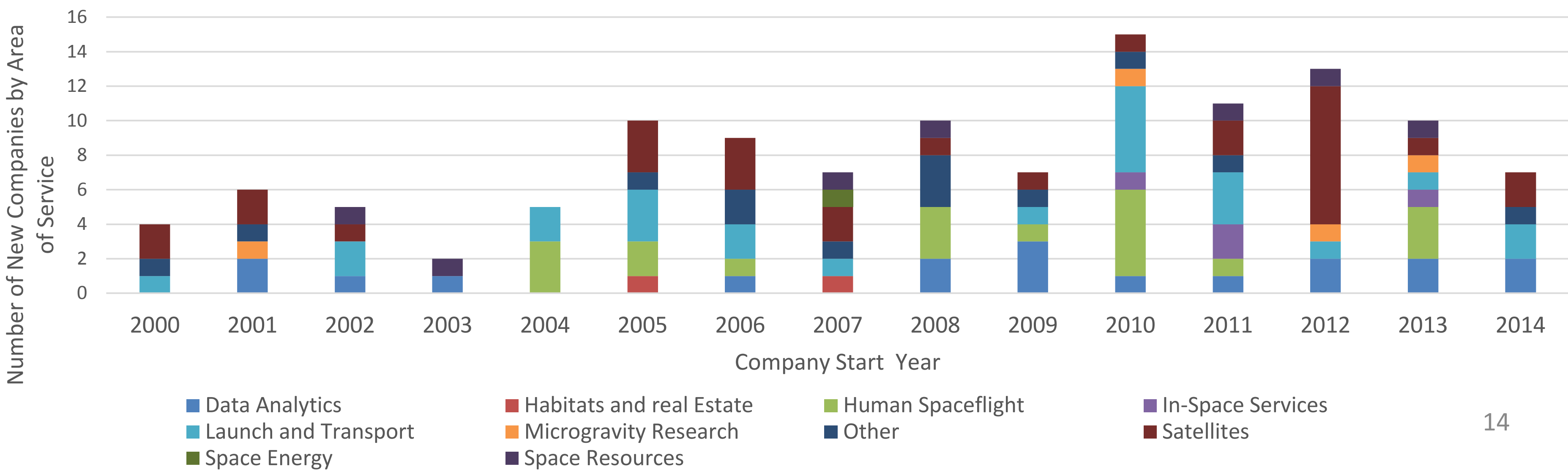
  - Consumers - Growing demand and WTP for ubiquitous and real-time situational awareness
- New private suppliers and brokers
  - Investors and companies with an IT bent
    - Hardware (e.g., Canada's NorStar Space Data, Singapore's Astroscale)
    - Software (e.g., Mapbox - custom online maps)
    - Launch (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

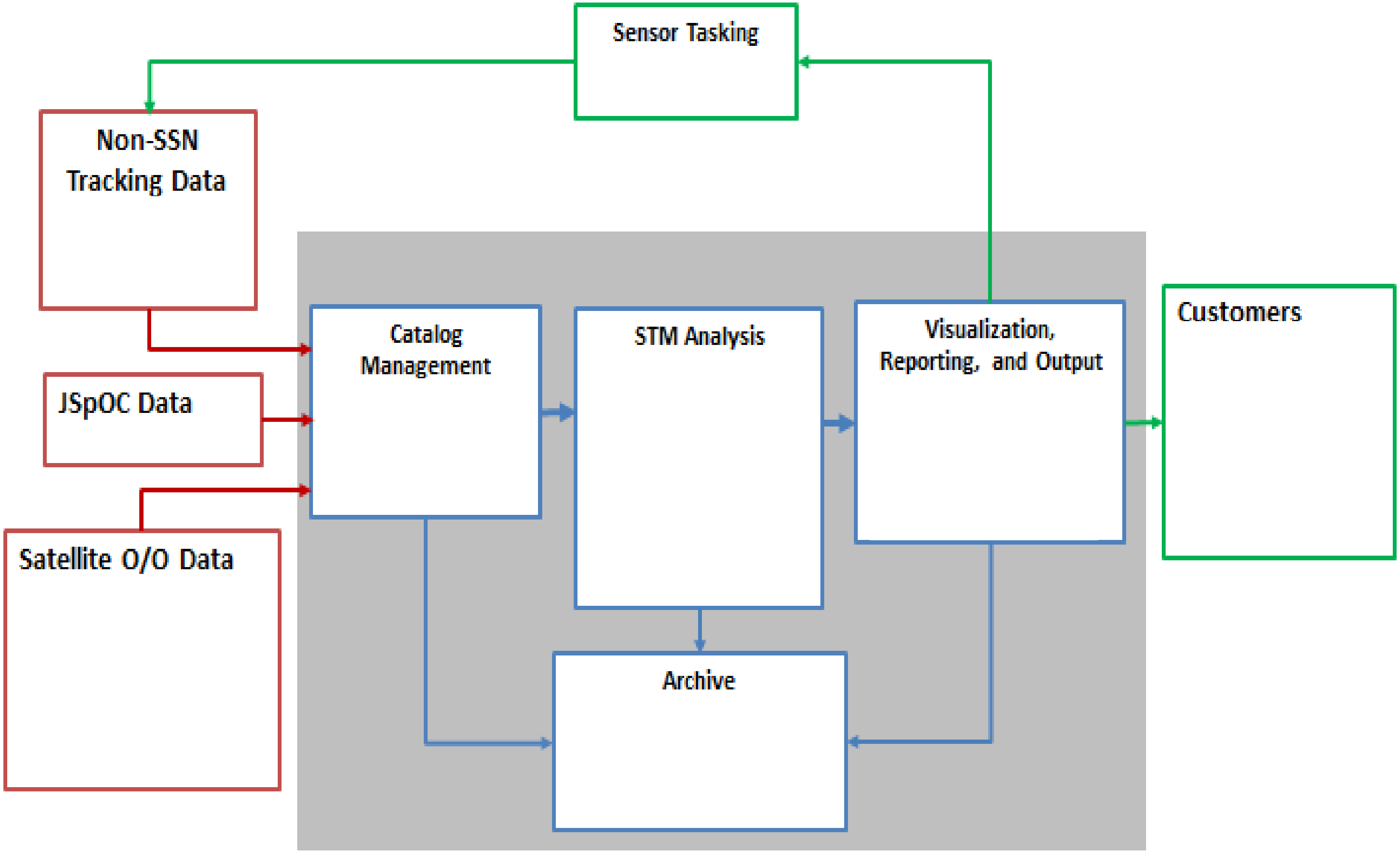


NewSpace firms
Since 2000 (n=124)



Growing Functional Modularization

Example: Space Situational Awareness



New Entrants Bringing New Approaches

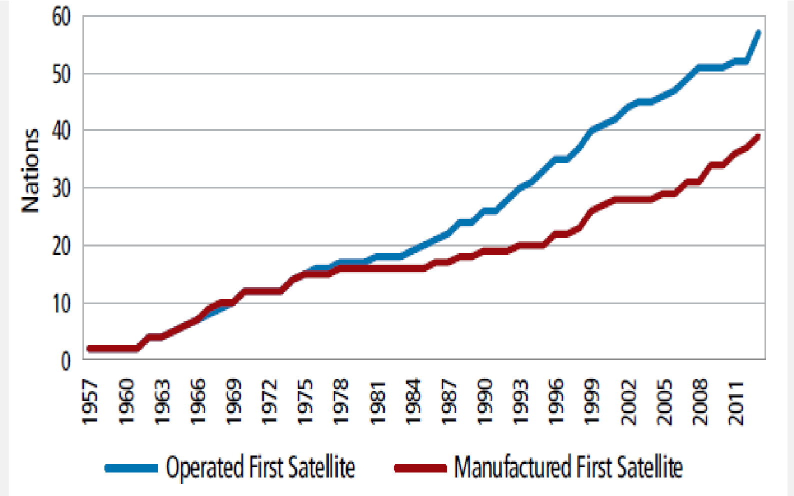
- Private sector focus on cost innovation (philosophy of "good enough," prioritizing cost over performance/reliability)
  - Streamlined/simpler processes
  - Incorporation of systems from non space sectors (e.g., reaction wheels meant for dental tools, COTS software; use of the Cloud)
  - Agile manufacturing, "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

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



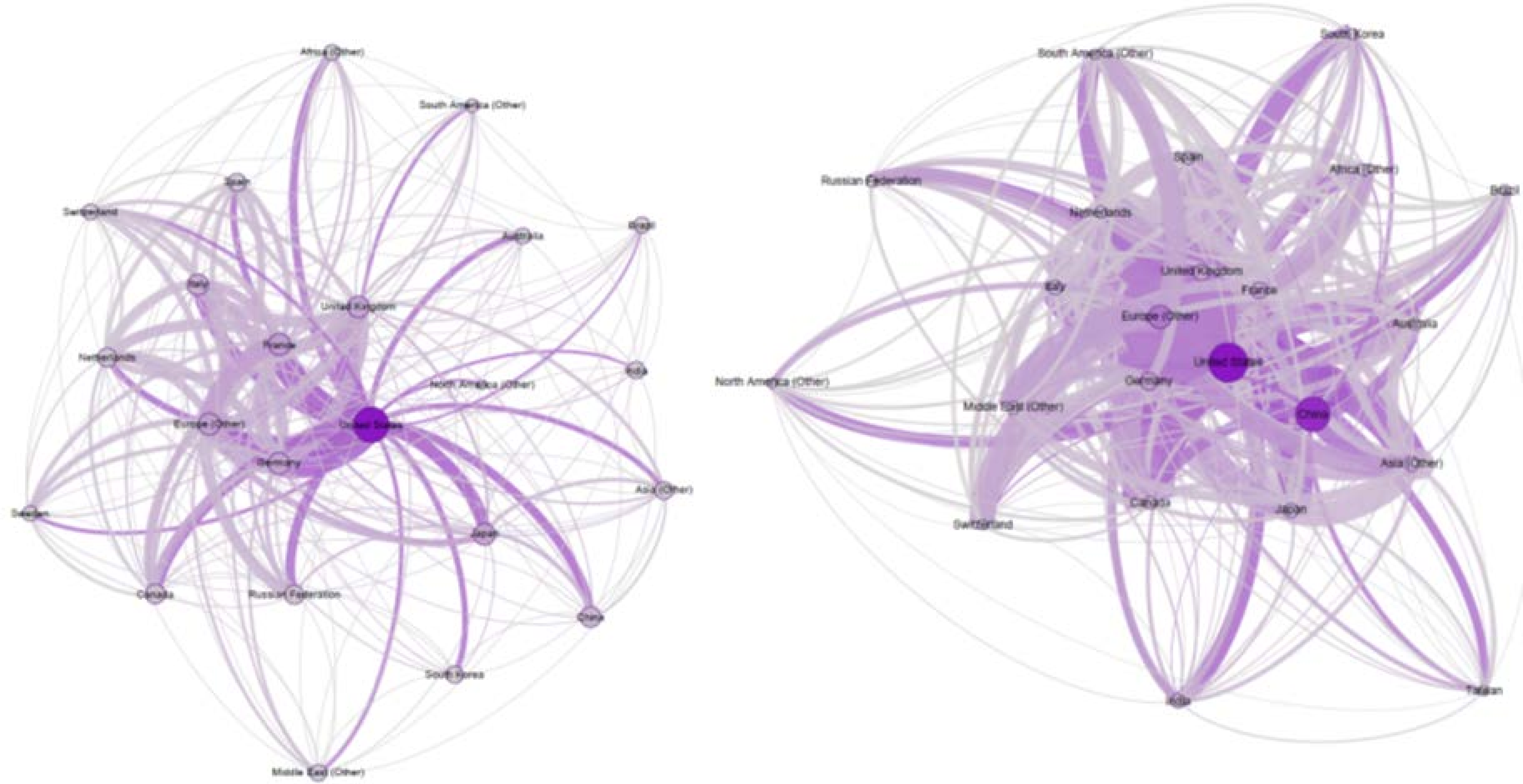
Source: The Space Report 2014

Shift from buying technology and products to buying services (United States leading)

IDA SCIENCE AND TECHNOLOGY POLICY INSTITUTE

Growing Integration of the Space Enterprise

Example: Collaborations in Publications

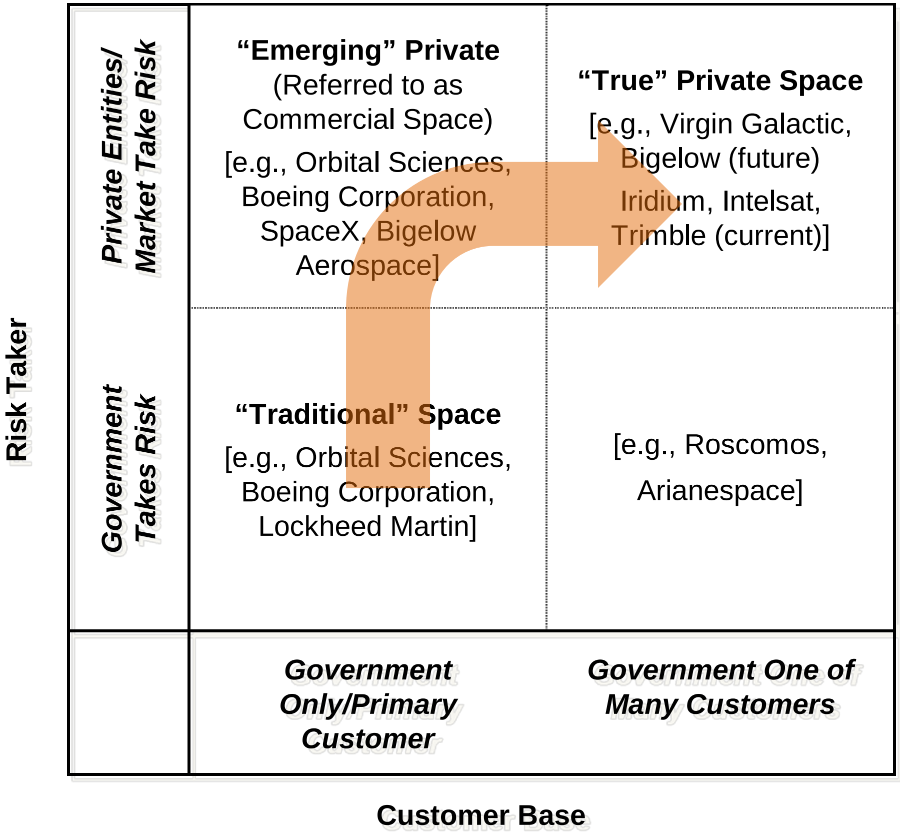


2003 Scopus Database Co-Authorship For publications with keyword "satellites" 2013

NEAR-TERM IMPLICATIONS

Structural Changes Underway - Transition Into Mainstream Sectors

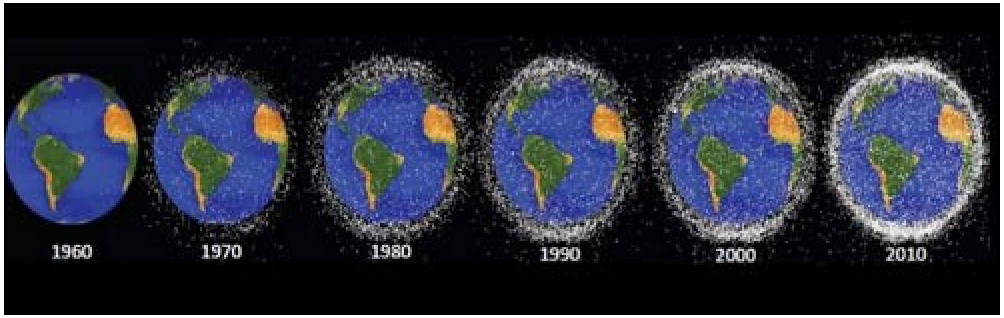
- Bifurcation
  - Government-driven specialized applications
  - A less capable but more widely utilized consumer/commercial set of sectors
- Structural changes
  - Globalization – integration of space value chains and markets
  - Commoditization – satellites, launch
  - Growing consumer power
  - Service model



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



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.

Source: http://spacesecurityindex.org/wp-content/uploads/2015/06/executive.summary.2015-electronic.pdf

  - 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)

IMPLICATIONS IN THE 10-15 YEAR TIME FRAME

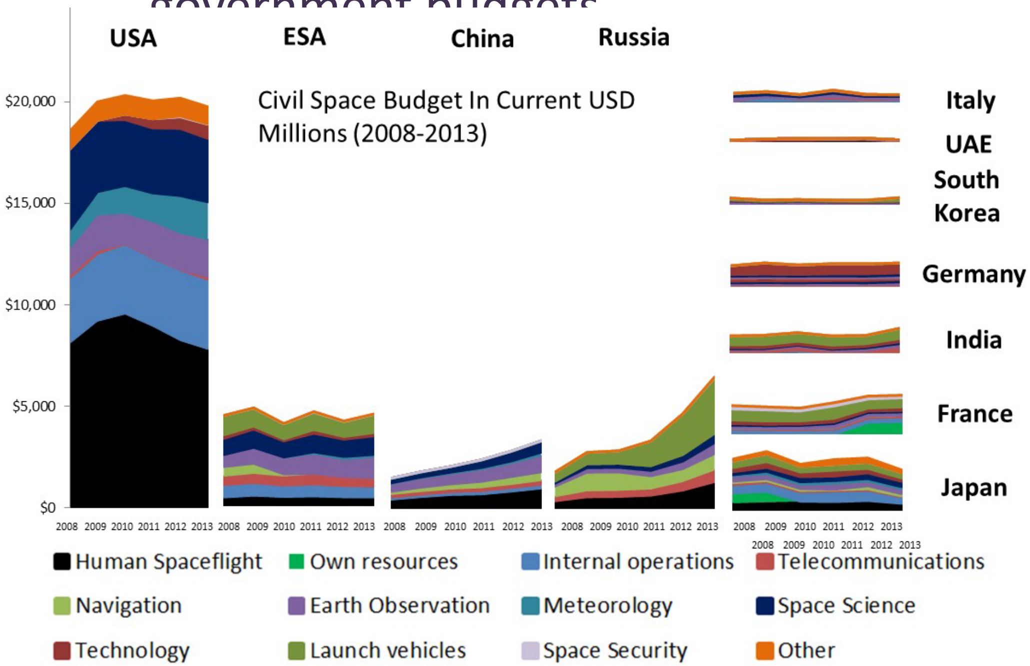
Implications…
assuming no wildcards come into play

- 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

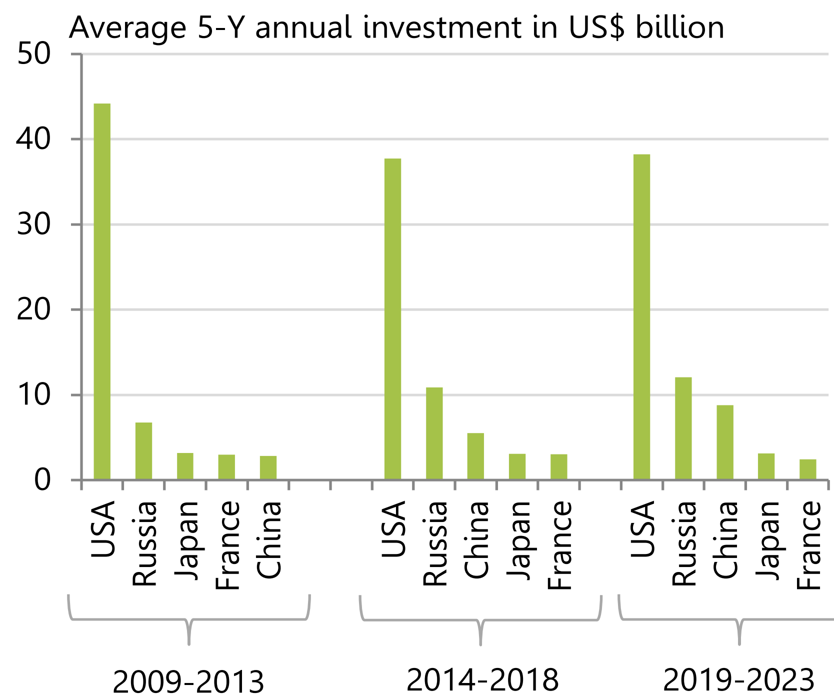
➢ United States has the potential to guide the agenda for a long time to come

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



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)

IDA | SCIENCE AND TECHNOLOGY POLICY INSTITUTE

Global Trends in Space Data Slides

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

October 28, 2015

1899 Pennsylvania Avenue NW, Suite 520
Washington, DC 20006 • 202.419.3720

Synopsis of Global Trends in Space

Better and cheaper[1] technology, especially in the commercial and IT sectors, has led to the development of newer and lower-cost[2] space-based applications, products, and services which, in turn, have accelerated space[3] investment globally and spawned new users[4] and suppliers that are following diverse approaches to[5] 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[6] sector. Second, governments, especially in emerging countries, are leapfrogging traditional[7] development and aiming to reach parity with the major space faring nations. Third, growing space-based activity is introducing new challenges[8] for the global space community, both on the ground and in space.

Synopsis of Global Trends in Space

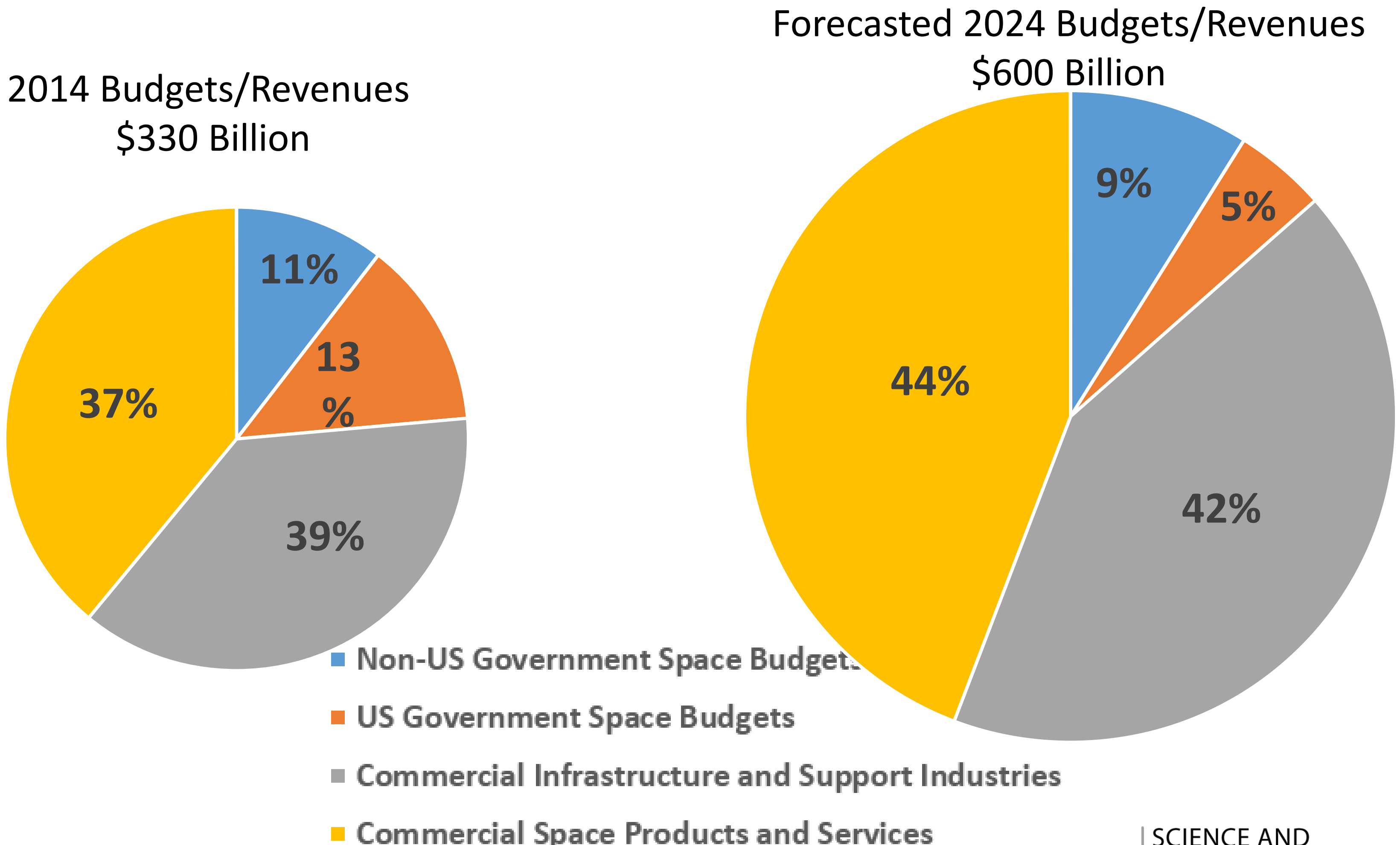
In the next few 10–15 years, these changes imply that it would be difficult to predict developments [9] in the space sectors, difficult for governments to manage these sectors [10], and the United States would see its control of the space sector wane [11].

These trends are likely to hold if no wildcards [12] [technological, geopolitical, or other] come into play.

Section and Page Number

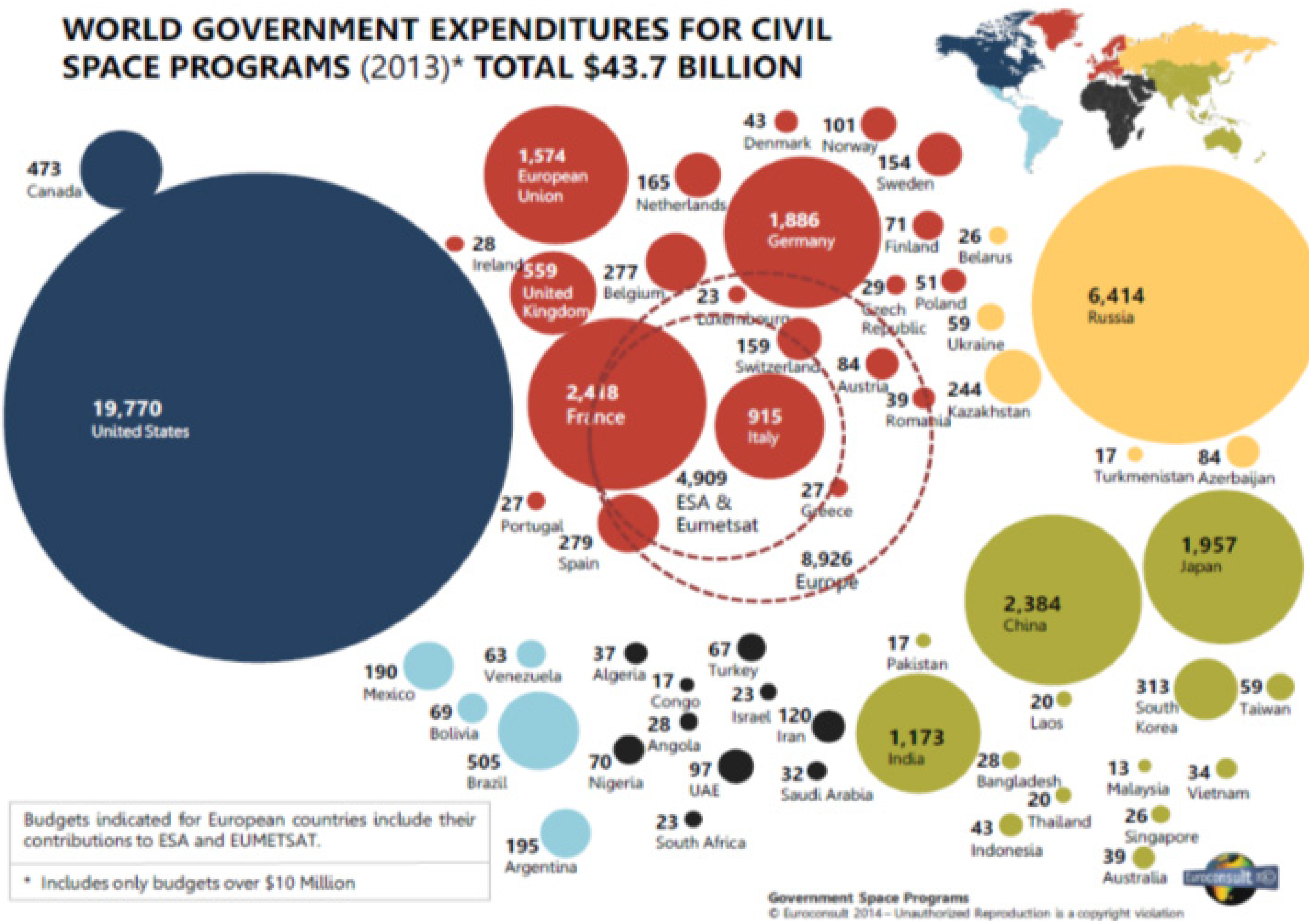
EXPENDITURES AND ACTIVITIES

Space Activities—Current and Forecasted

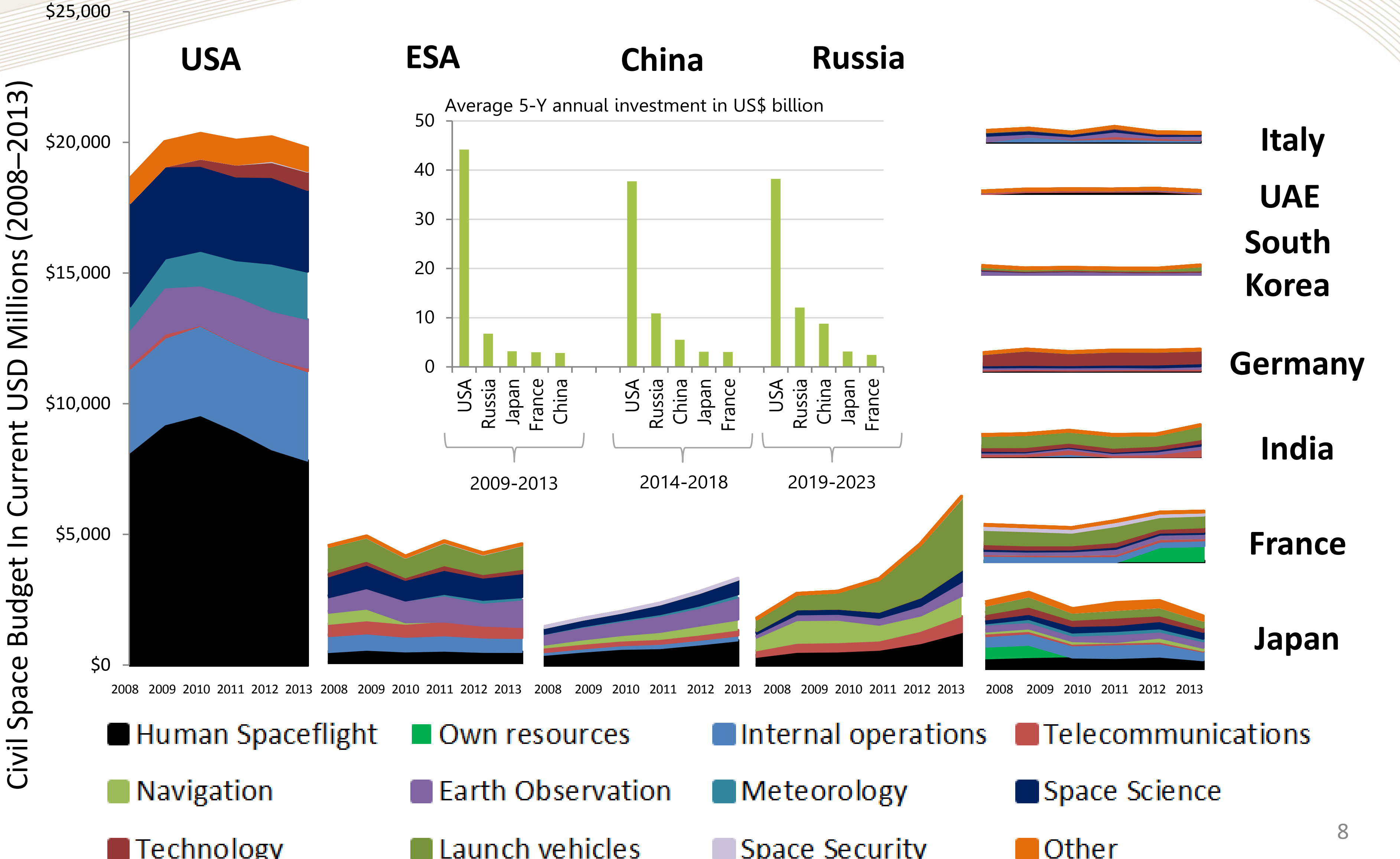


Source: Space Foundation, 2015, and Unpublished

Civil Expenditures 2013



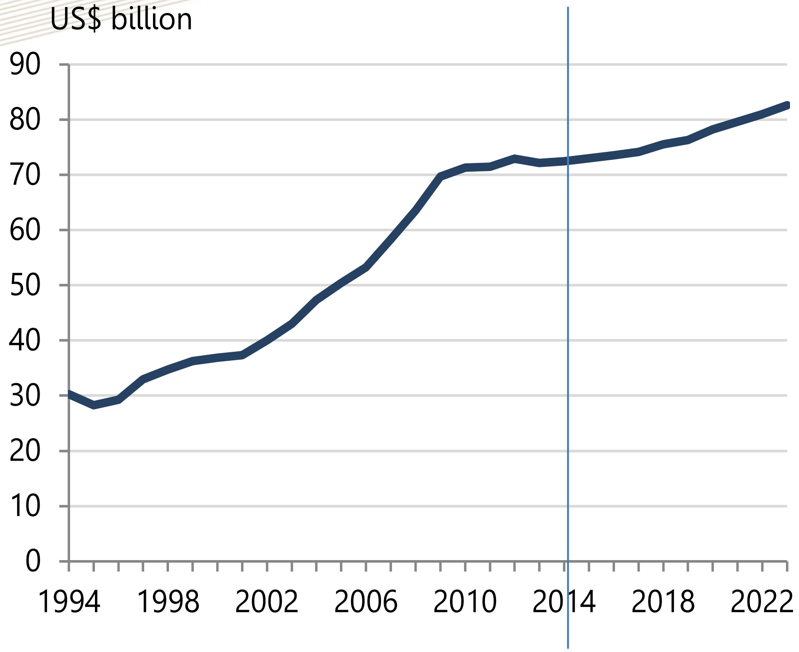
Civil Expenditures 2008–2013



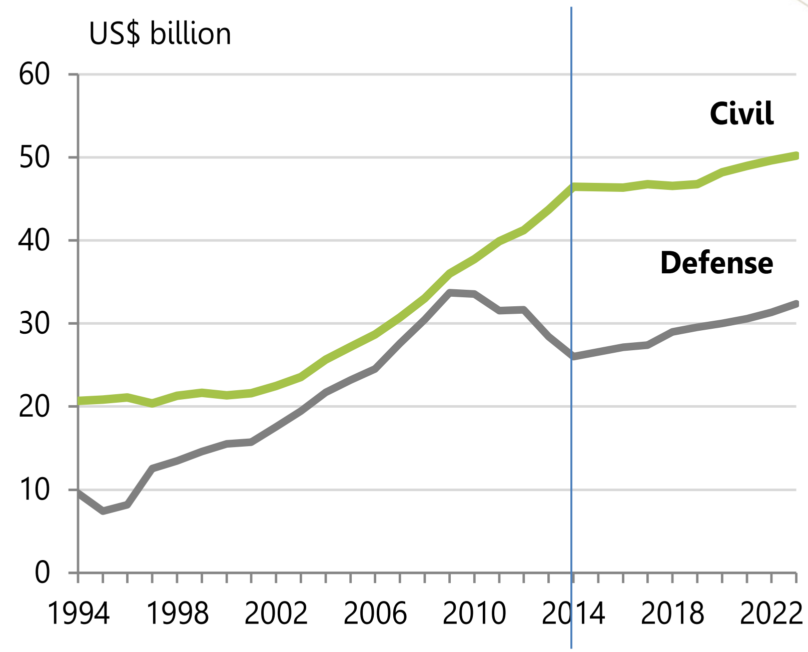
Source: EuroConsult 2014

Space expenditures 1994-2023

WORLD GOVERNMENT SPACE EXPENDITURES 1994-2023



CIVIL AND DEFENSE 2004-2023

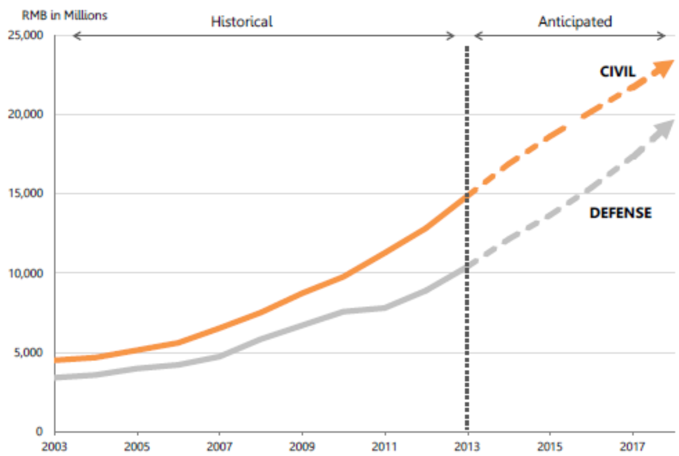


3 DECADES OF GOVERNMENTS INVESTMENT IN SPACE PROGRAMS

	Average world funding	CAGR	# of countries	Civil/Defense
1994-2003	$33 billion	4.3%	33	61%/39%
2004-2013	$63 billion	4.8%	68	55%/45%
2014-2023	$77 billion	1.5%	86	62%/38%

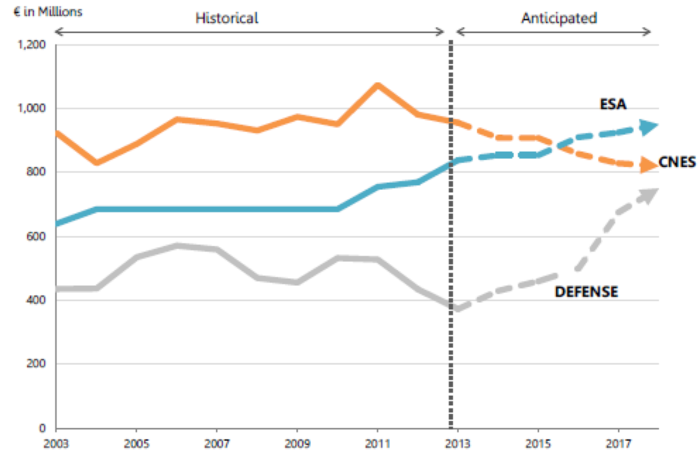
Derived from *Government Space Programs: Forecast and Benchmarks 2014*

Expenditures in Countries of Interest



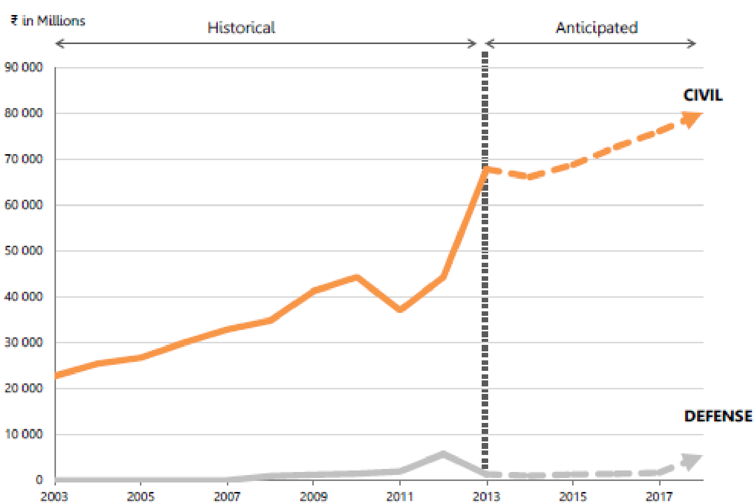
Sources: Euroconsult's estimates

China



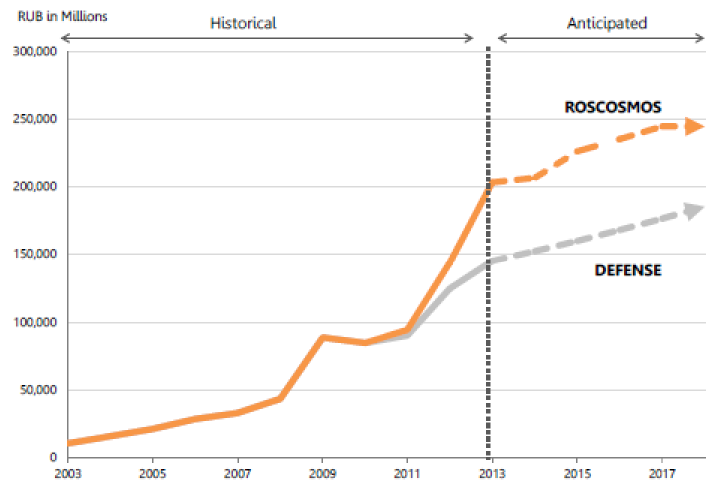
Sources: CNES, ESA, Euroconsult estimates

France



Sources: ISRO, Euroconsult's estimates

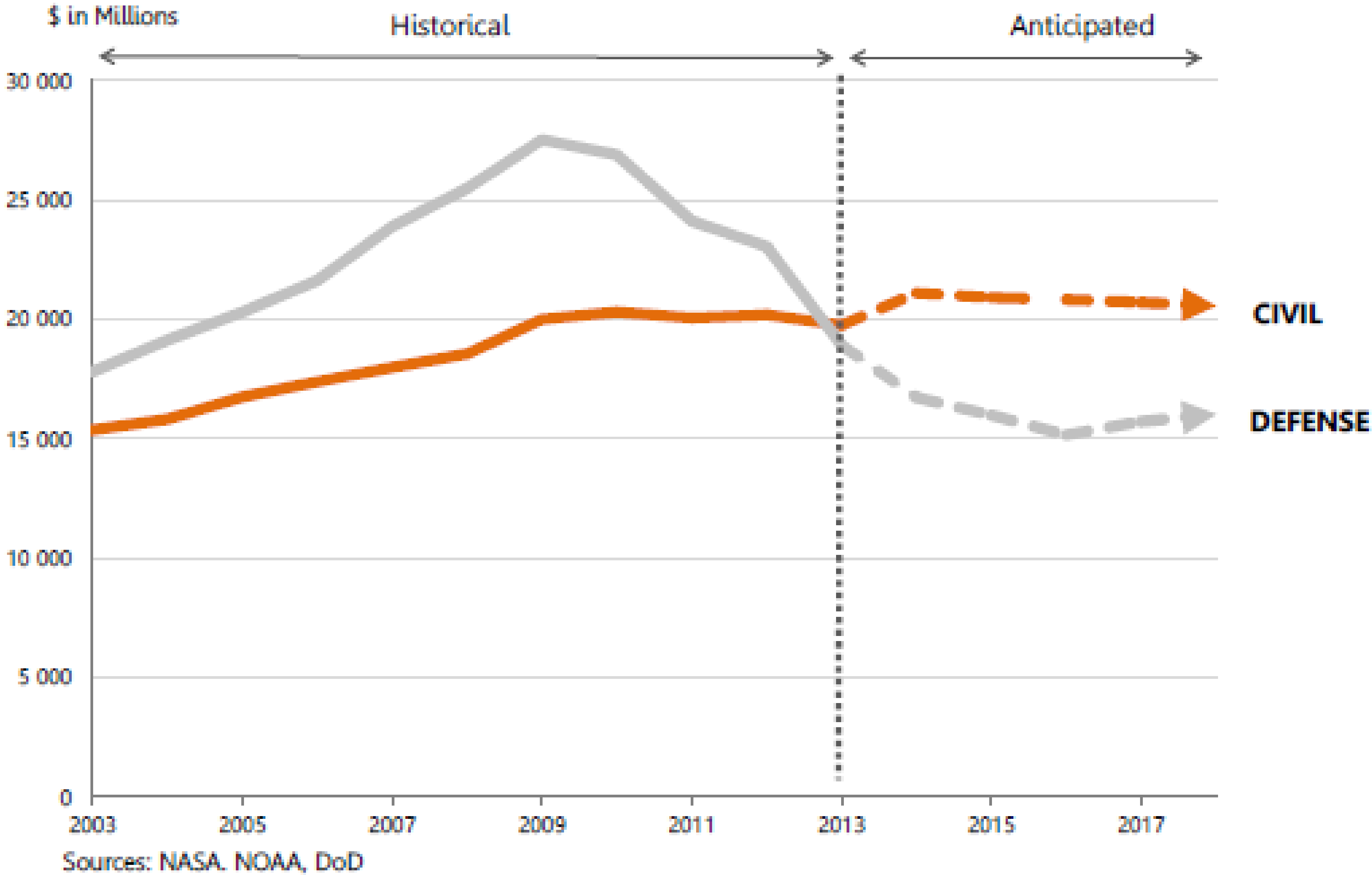
India



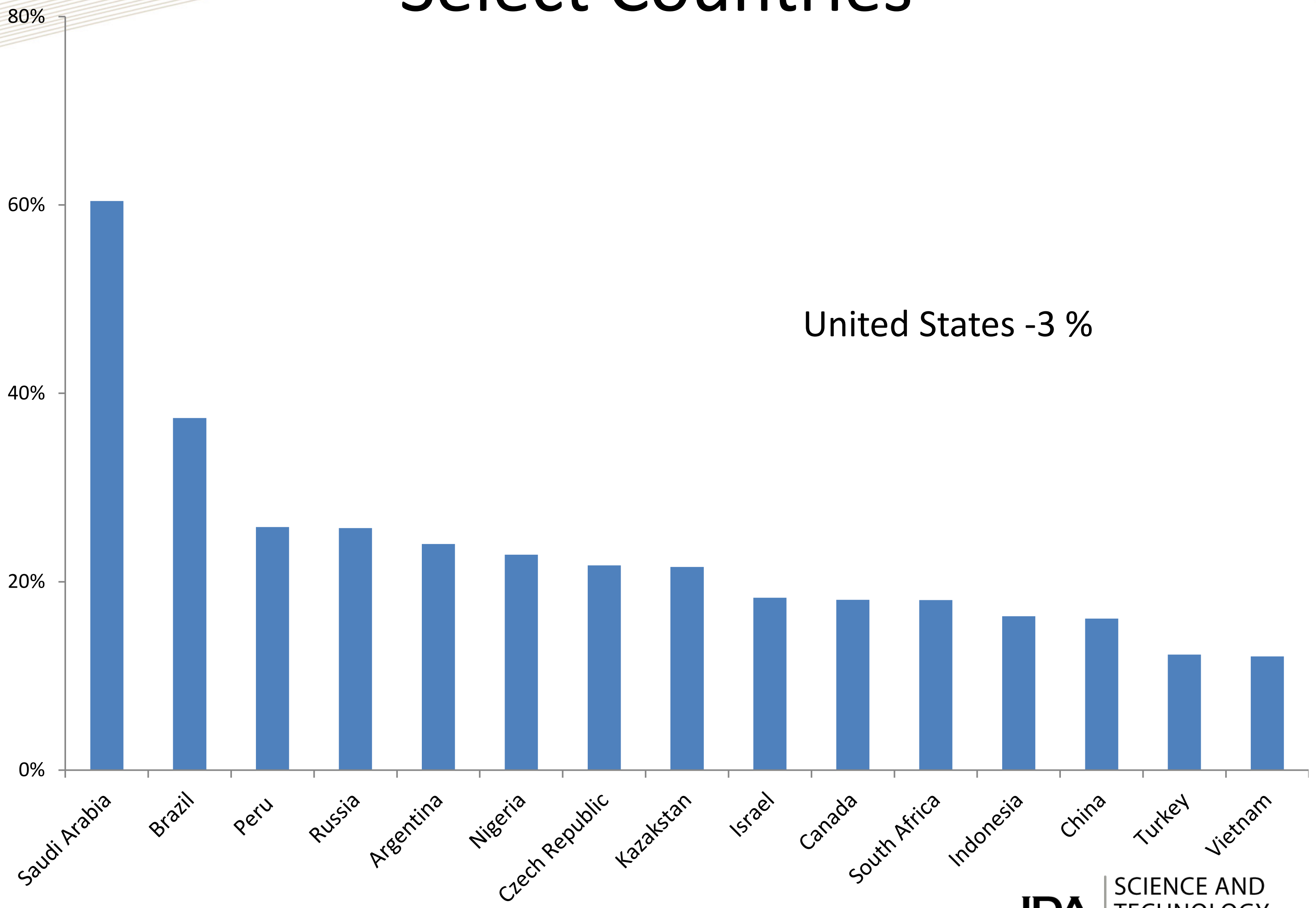
Sources: Roscosmos, Euroconsult estimates

Russia

United States Expenditures



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

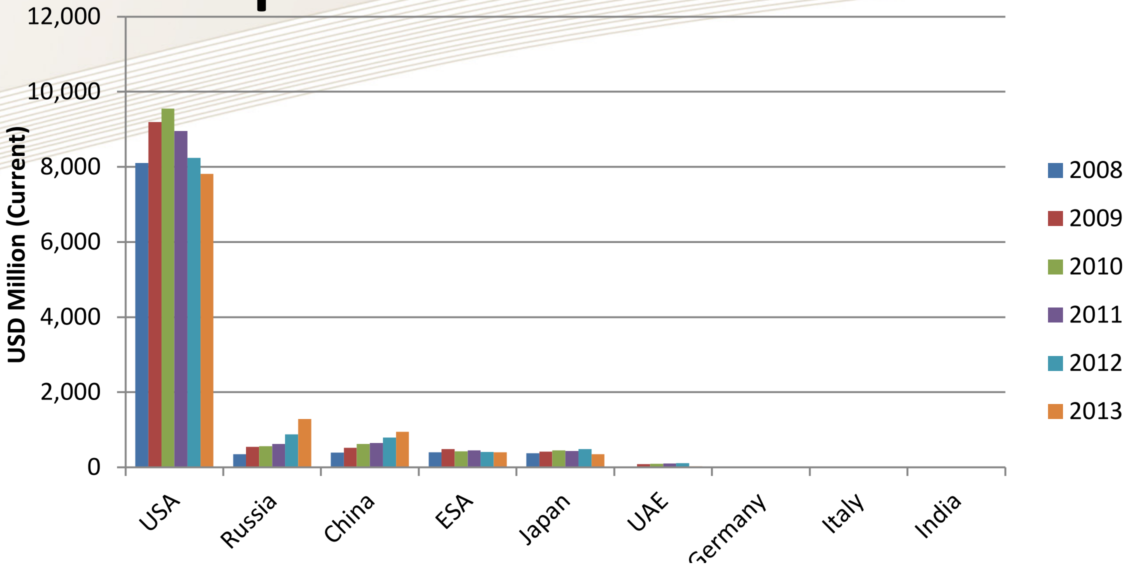


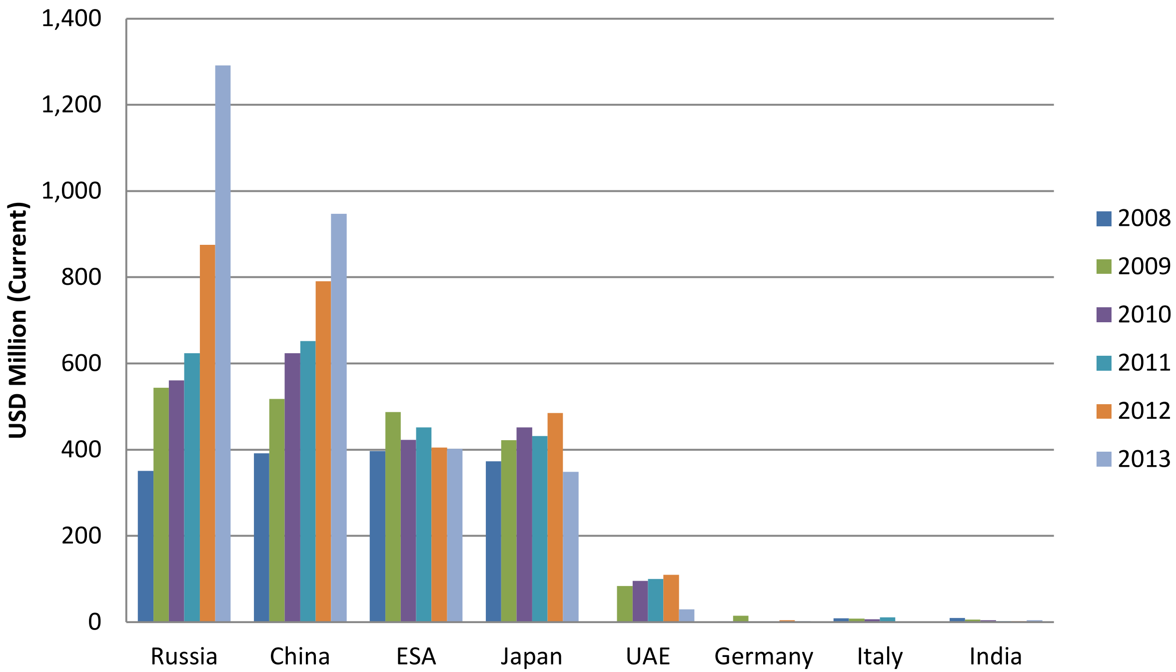
Source: EuroConsult 2014

IDA | SCIENCE AND TECHNOLOGY POLICY INSTITUTE

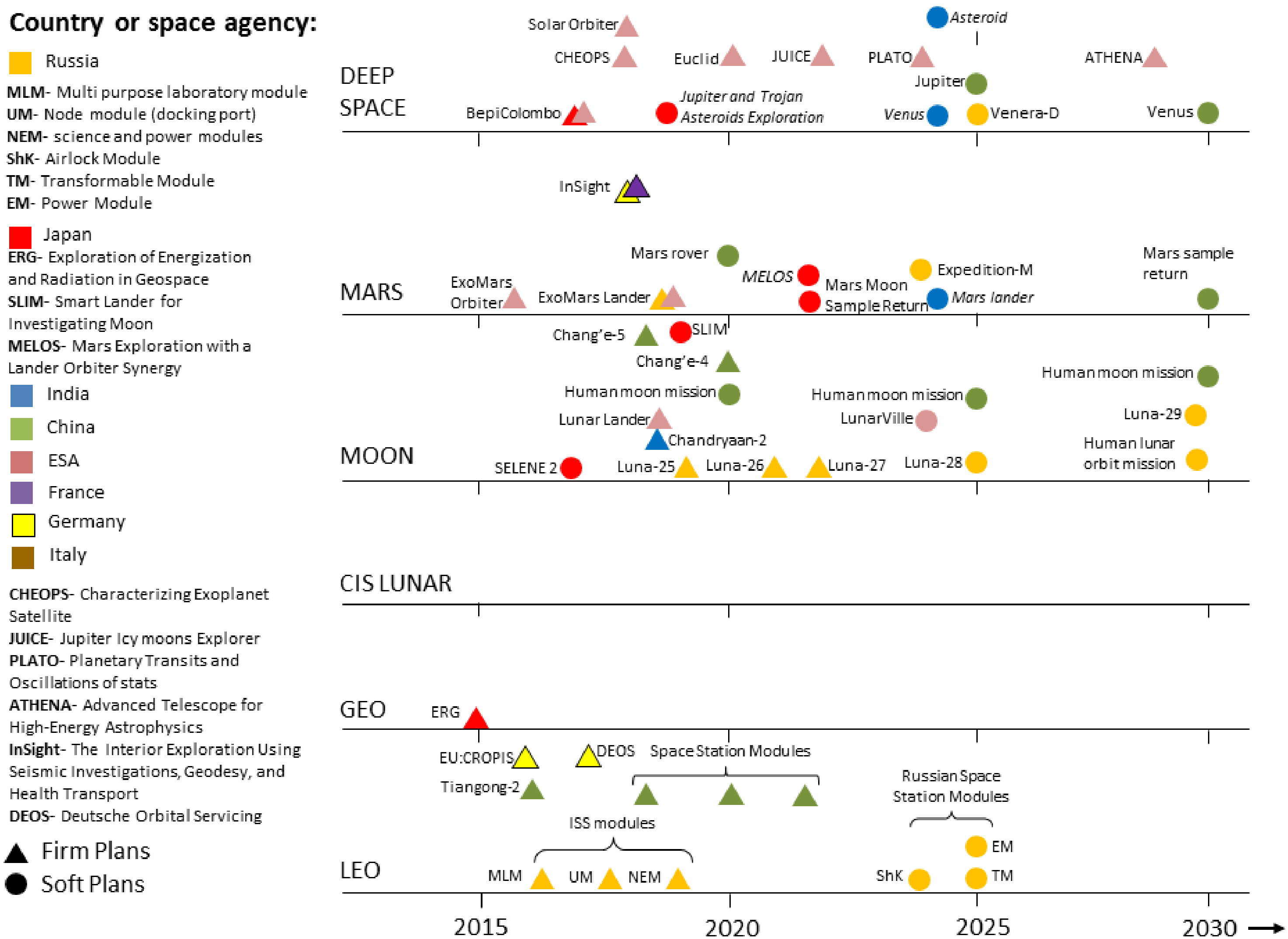
Source: EuroConsult 2014

Expenditures in Human Space Flight



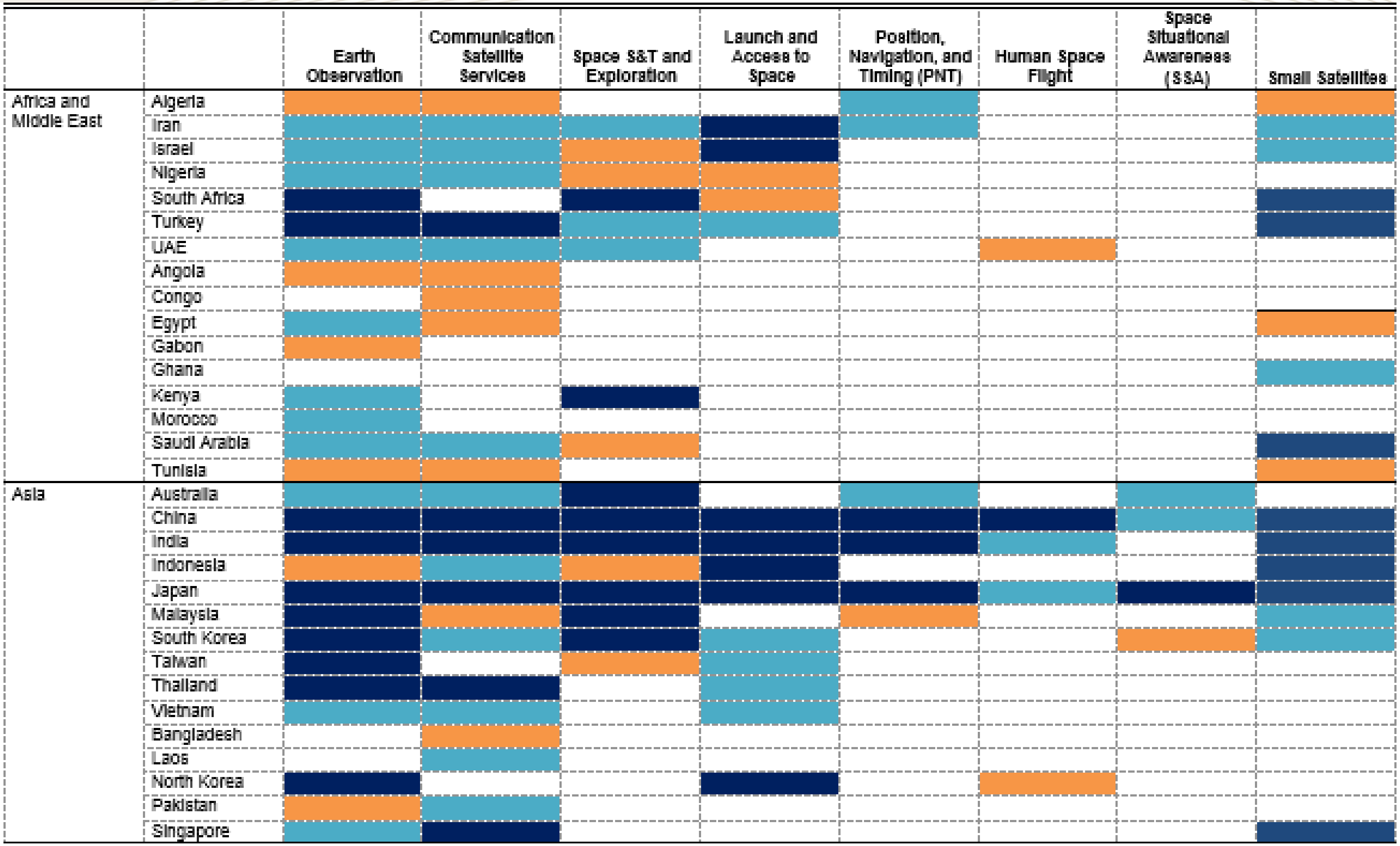


Planned Missions by Domain of the Major Space-Faring Powers



Source: Lal et al., *Global Trends in Space, Volume 3: Deep Dives of Five Space-Faring Powers*.

Country Involvement in Space



White	Orange	Turquoise	Blue
No interest or activity	Interest and minimal development	Operating or near-operating capability with international partnerships	Fully fledged and independent capability

Source: STPI analysis using data from Euroconsult (2014a).

Country Involvement in Space

		Earth Observation	Communication Satellite Services	Space S&T and Exploration	Launch and Access to Space	Position, Navigation, and Timing (PNT)	Human Space Flight	Space Situational Awareness (SSA)	Small Satellites
Europe, Western	Austria	Turquoise	Turquoise	Turquoise	Orange	Turquoise	White	White	White
	Belgium	Blue	Turquoise	White	Turquoise	White	White	White	Turquoise
	Czech Republic	Turquoise	Turquoise	Blue	White	White	Turquoise	White	White
	Denmark	Turquoise	Turquoise	Blue	White	White	White	White	Blue
	ESA	Blue	Blue	Blue	Blue	Blue	Turquoise	Orange	Blue
	Eumetsat	Blue	Blue	White	Blue	Blue	Turquoise	Orange	Blue
	EU	Blue	White	Blue	Blue	Blue	Turquoise	Orange	Blue
	Finland	Turquoise	Turquoise	Blue	White	Turquoise	White	White	Blue
	France	Turquoise	Blue	Blue	Blue	White	White	Turquoise	White
	Germany	Turquoise	Turquoise	Blue	Turquoise	Orange	Orange	White	White
	Italy	Turquoise	Turquoise	Blue	Turquoise	Turquoise	Turquoise	White	Orange
	Luxembourg	Orange	Turquoise	White	White	Orange	White	White	Blue
	Netherlands	Turquoise	White	Blue	Turquoise	White	White	White	White
	Norway	Turquoise	Turquoise	Turquoise	Turquoise	Turquoise	White	Orange	Turquoise
	Poland	Turquoise	White	Blue	Orange	Turquoise	White	White	Blue
	Spain	Turquoise	Turquoise	White	Orange	White	White	Orange	Blue
	Sweden	Turquoise	Turquoise	Blue	Turquoise	White	White	White	Blue
	Switzerland	Turquoise	Turquoise	Turquoise	Turquoise	White	Turquoise	White	Turquoise
	UK	Blue	Turquoise	Blue	Orange	Turquoise	Turquoise	White	Blue
Europe, Eastern	Bulgaria	Turquoise	Orange	Turquoise	White	White	White	White	White
	Cyprus	Orange	White	White	White	Turquoise	White	White	White
	Estonia	Orange	White	Turquoise	White	Orange	White	Orange	Turquoise
	Greece	Turquoise	Orange	Blue	White	Turquoise	White	White	White
	Hungary	Turquoise	White	Blue	White	Orange	White	White	Blue
	Ireland	Orange	Orange	Turquoise	Turquoise	Orange	White	White	White
	Latvia	Orange	White	White	White	Turquoise	White	White	White
	Lithuania	White	White	Orange	White	White	White	White	Blue
	Portugal	Turquoise	Turquoise	Turquoise	White	White	Orange	White	Orange
	Romania	Turquoise	White	Turquoise	White	White	White	Orange	Orange
	Slovakia	Orange	Orange	Turquoise	White	Orange	White	White	White
	Slovenia	Turquoise	Orange	Turquoise	White	White	Orange	White	Turquoise

White	Orange	Turquoise	Blue
No interest or activity	Interest and minimal development	Operating or near-operating capability with international partnerships	Fully fledged and independent capability

Source: STPI analysis using data from Euroconsult (2014a).

Country Involvement in Space

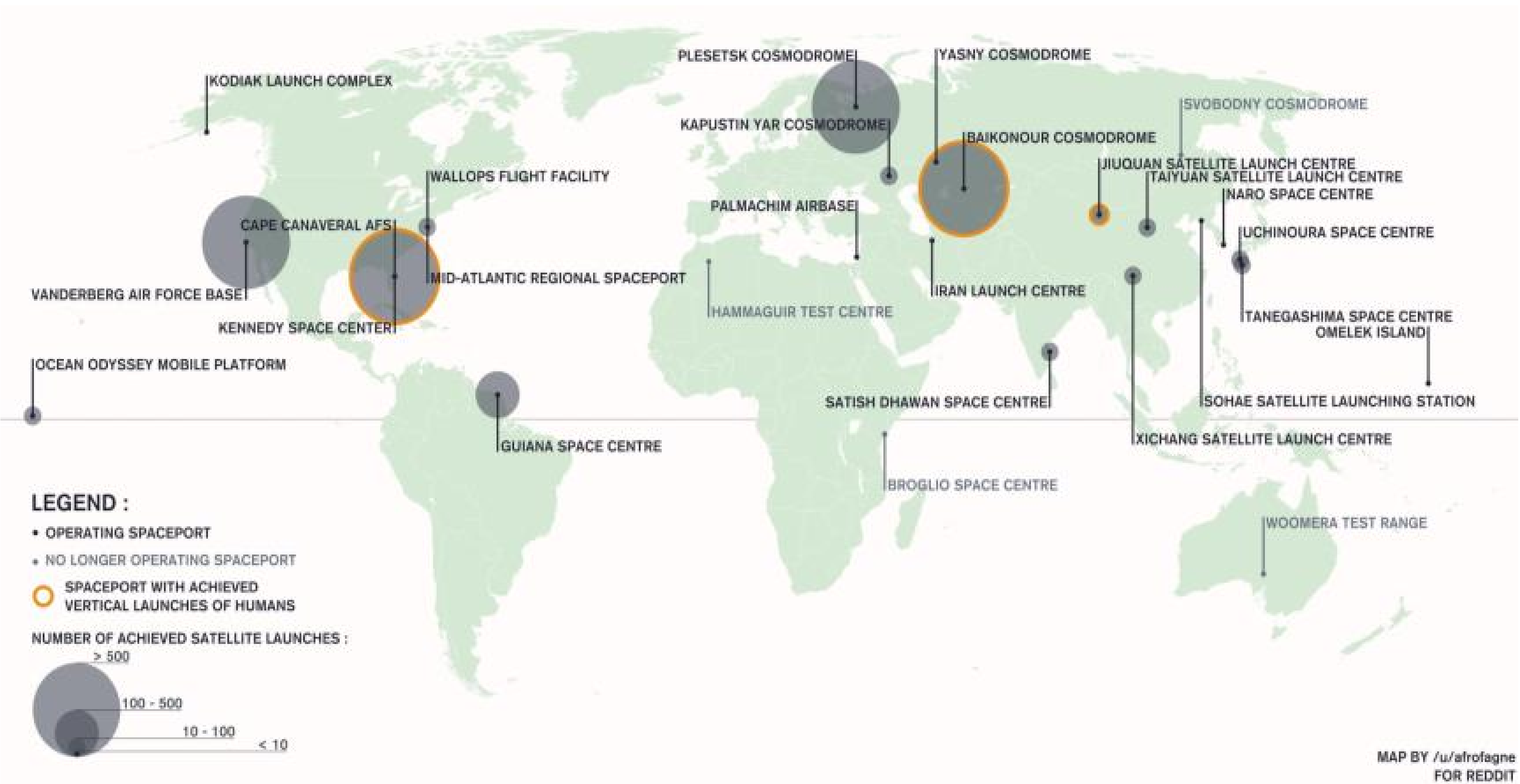
		Earth Observation	Communication Satellite Services	Space S&T and Exploration	Launch and Access to Space	Position, Navigation, and Timing (PNT)	Human Space Flight	Space Situational Awareness (SSA)	Small Satellites
Latin America	Argentina	Turquoise	Blue		Turquoise				
	Bolivia	Orange	Blue						
	Brazil	Turquoise	Turquoise	Turquoise	Turquoise		Orange		Blue
	Mexico	Orange	Turquoise						
	Venezuela	Turquoise	Blue	Turquoise	Orange				
	Chile	Turquoise							
	Colombia	Orange			Blue				Blue
	Ecuador	Blue		Orange					
	Nicaragua	Turquoise	Turquoise						
	Peru	Orange	Orange	Orange	Orange				Orange
North America	Canada	Blue	Blue	Turquoise			Turquoise		Orange
	United States	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
Russia and CIS	Belarus	Turquoise	Turquoise (-)						
	Kazakhstan	Turquoise	Turquoise	Turquoise	Blue				
	Russia	Blue	Blue	Blue	Blue	Blue	Blue		Blue
	Ukraine	Blue	Turquoise	Turquoise	Orange	Turquoise			Turquoise
	Armenia	Orange				Orange			
	Azerbaijan	Orange	Turquoise	Orange					
	Mongolia	Orange	Orange						
	Turkmenistan		Turquoise						

White	Orange	Turquoise	Blue
No interest or activity	Interest and minimal development	Operating or near-operating capability with international partnerships	Fully fledged and independent capability

Source: STPI analysis using data from Euroconsult (2014a).

Spaceports Globally

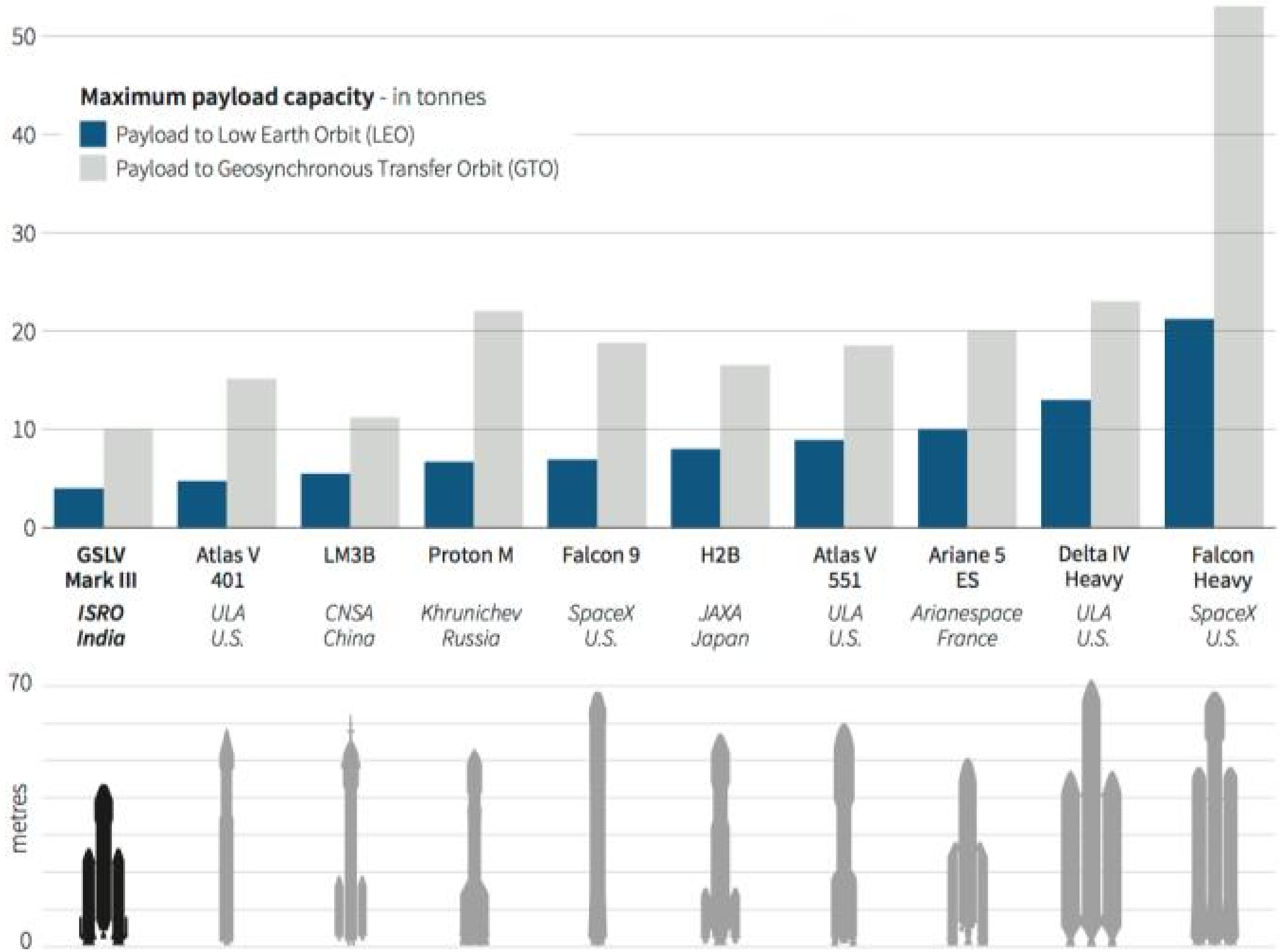
(all, including commercial, civil and military)



Source: http://i.imgur.com/Ggl0Yys.jpg

LAUNCH

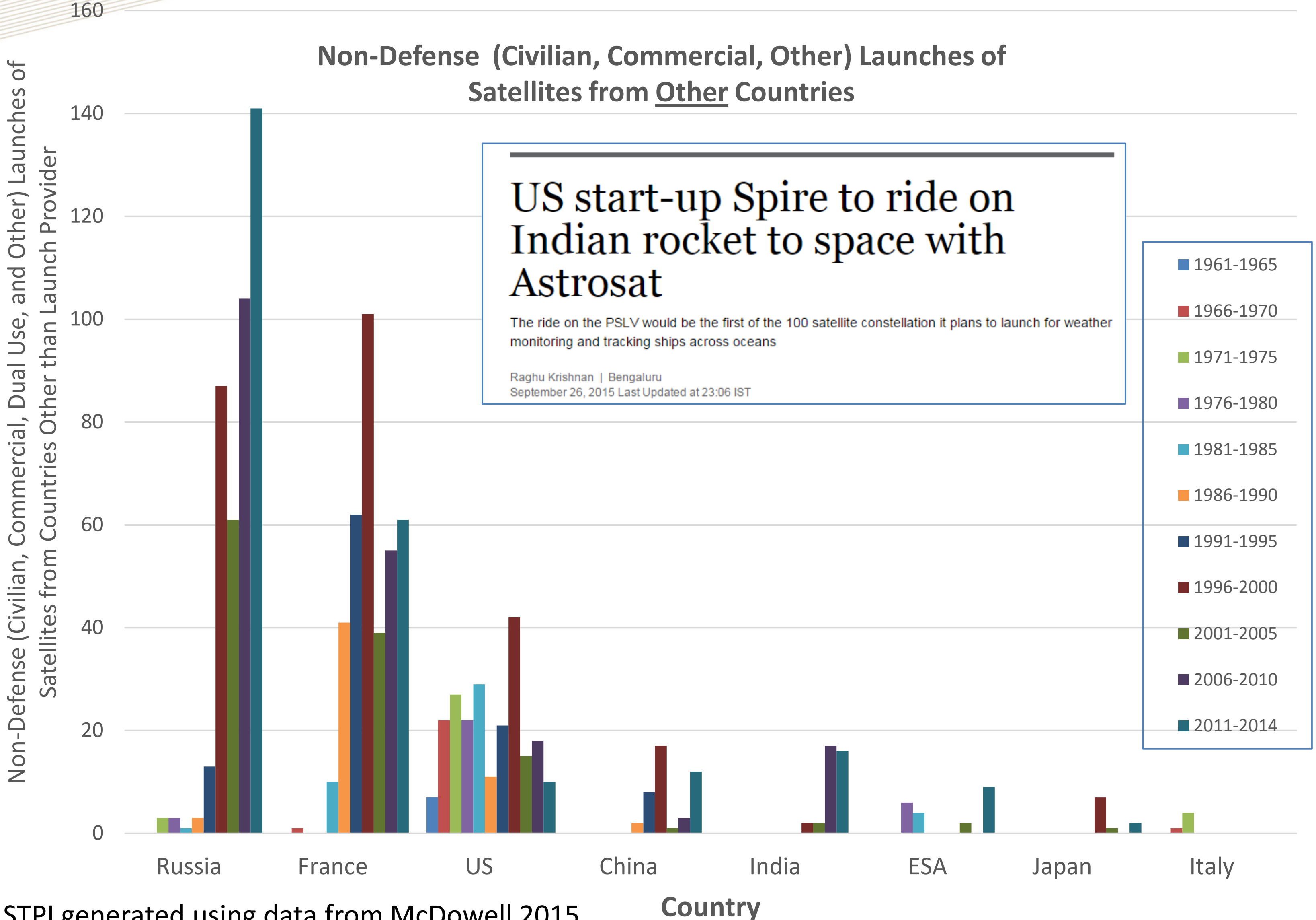
Countries Developing LEO and GEO Payload Launchers



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

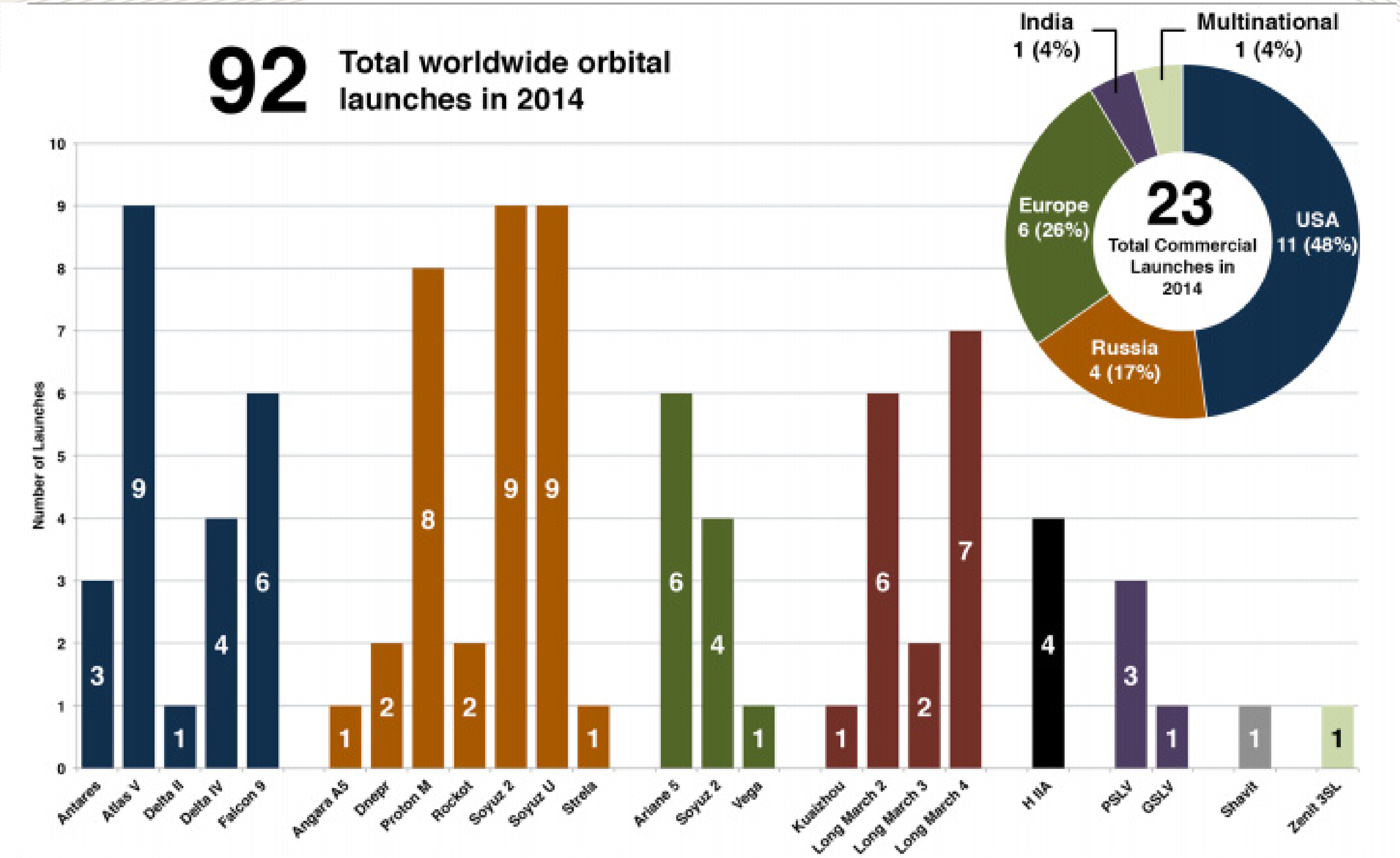
Source: http://blog.thomsonreuters.com/index.php/tag/space/

Growing Competition in the Commercial/Civil Launch Sector



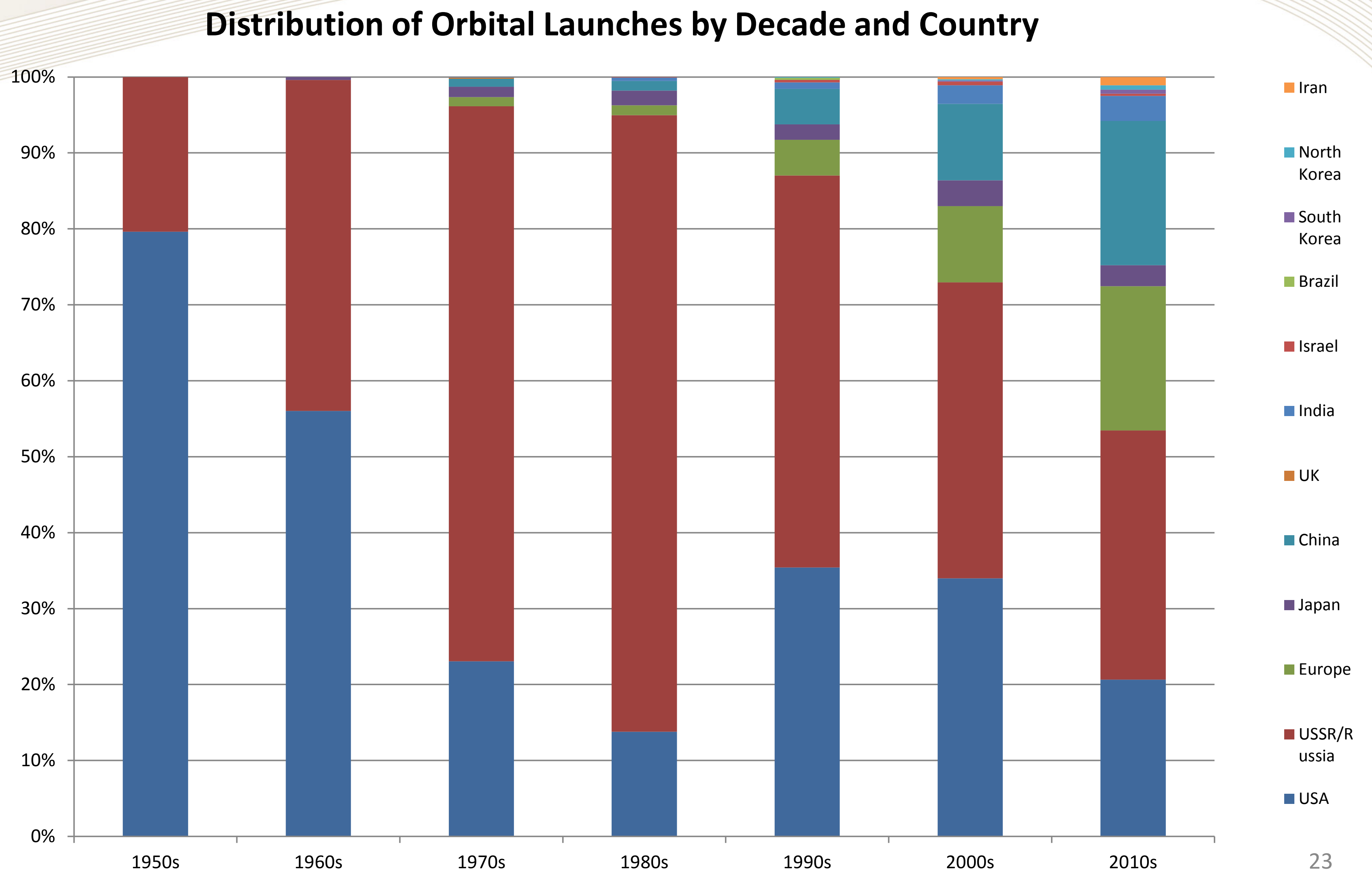
Source: STPI generated using data from McDowell 2015

Number of Total (and Commercial) Launches, 2014



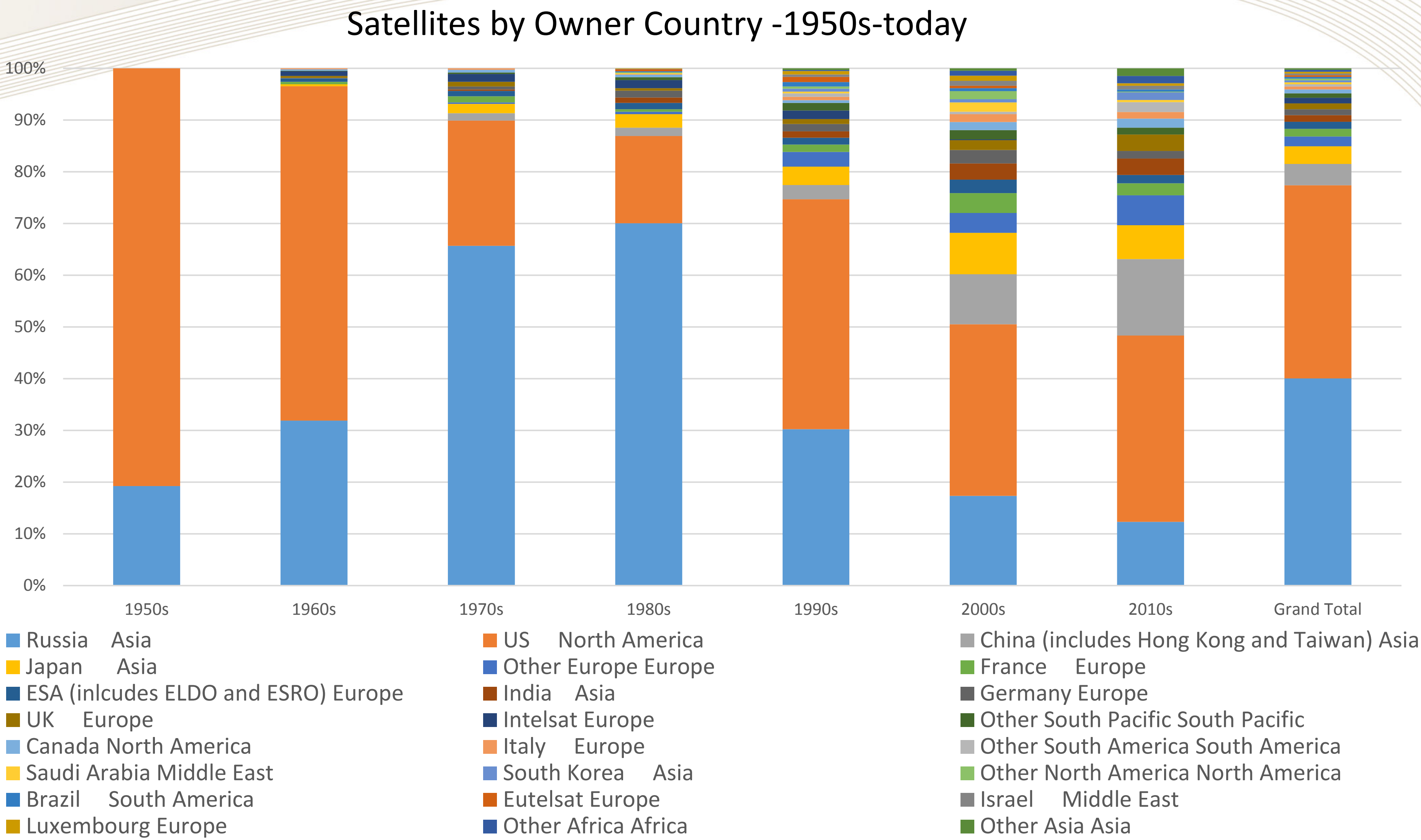
Source: FAA 2015, http://space.taurigroup.com/reports/FAA_Annual_Compendium_2014.pdf

Number of Countries with Launch Capability



Source: McDowell, Jonathan C, 2015— Satellite Statistics, http://planet4589.org/space/log/stats.html

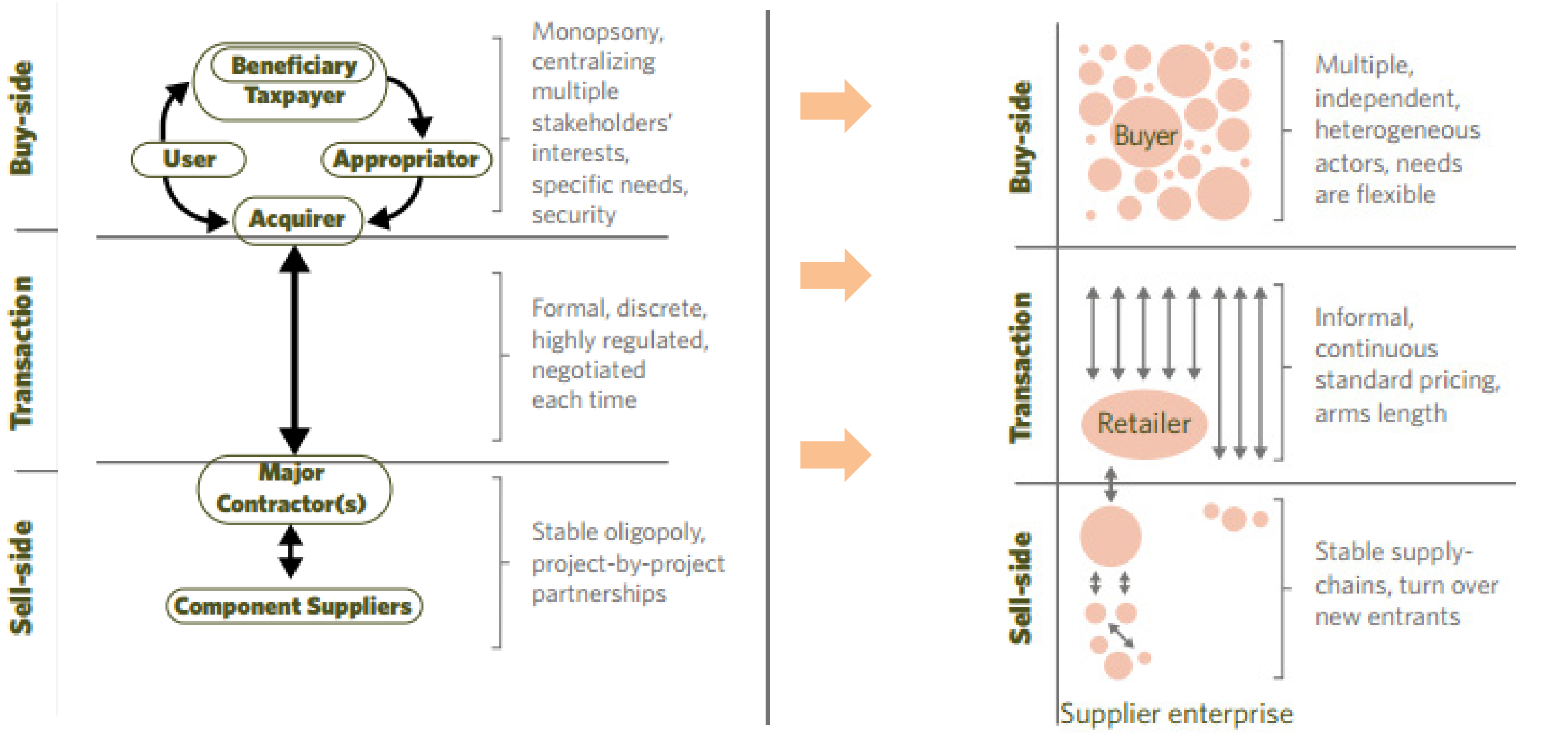
Number of Countries that Have Satellites



Source: McDowell, Jonathan C, 2015—Satellite Statistics, http://planet4589.org/space/log/stats.html

PRIVATE SECTOR

Transition from a Monospsonic Oligopoloy to a Competitive Globalized Sector



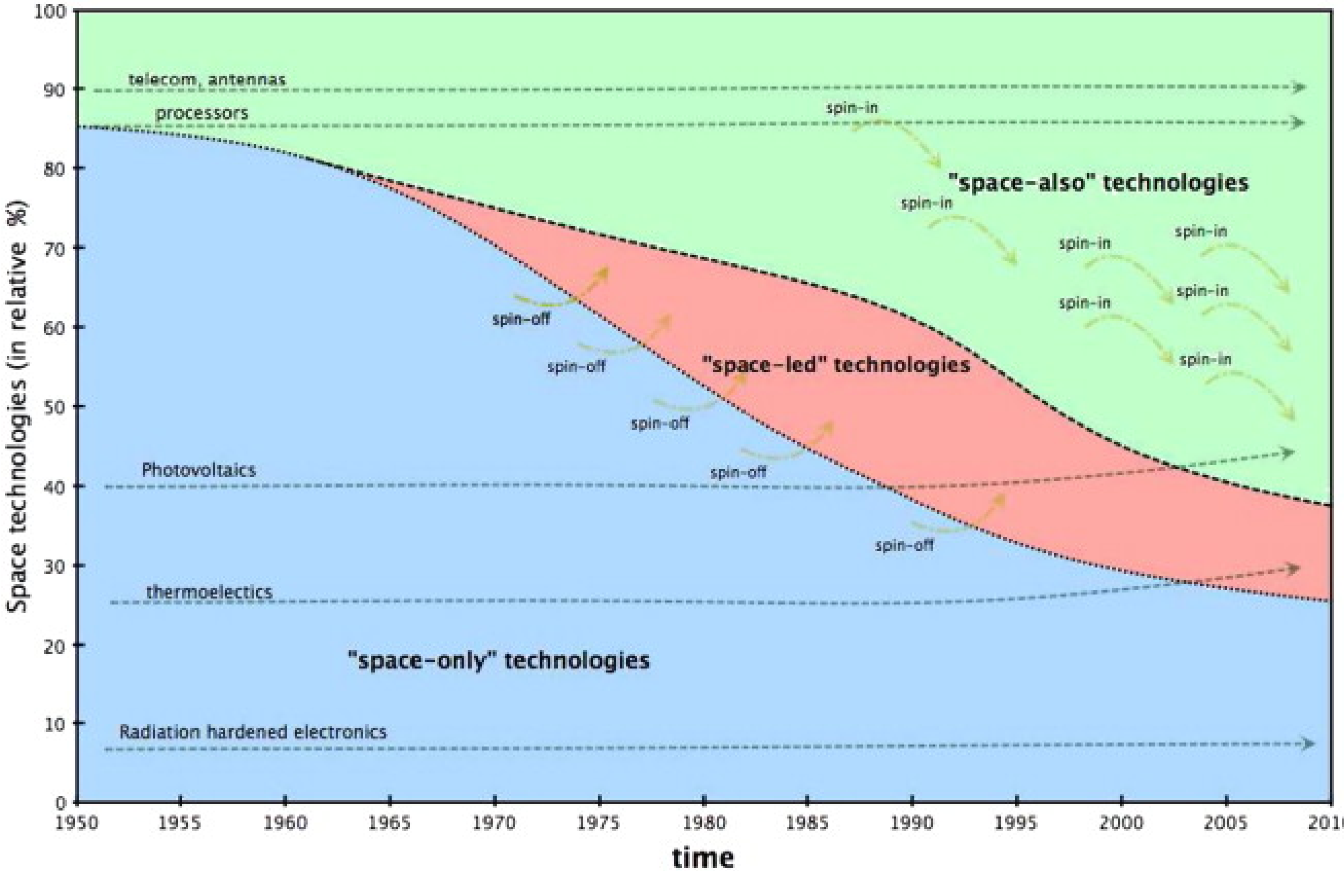
Emergence of the True Private Space Sector

Risk Taker		Customer Base: ***Government Only/Primary Customer***	Customer Base: ***Government One of Many Customers***
Risk Taker	***Private Entities/ Market Take Risk***	**“Emerging” Private** (Referred to as Commercial Space) [e.g., Orbital Sciences, Boeing Corporation, SpaceX, Bigelow Aerospace]	**“True” Private Space** [e.g., Virgin Galactic, Bigelow (future) Iridium, Intelsat, Trimble (current)]
Risk Taker	***Government Takes Risk***	**“Traditional” Space** [e.g., Orbital Sciences, Boeing Corporation, Lockheed Martin]	[e.g., Roscomos, Arianespace]

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

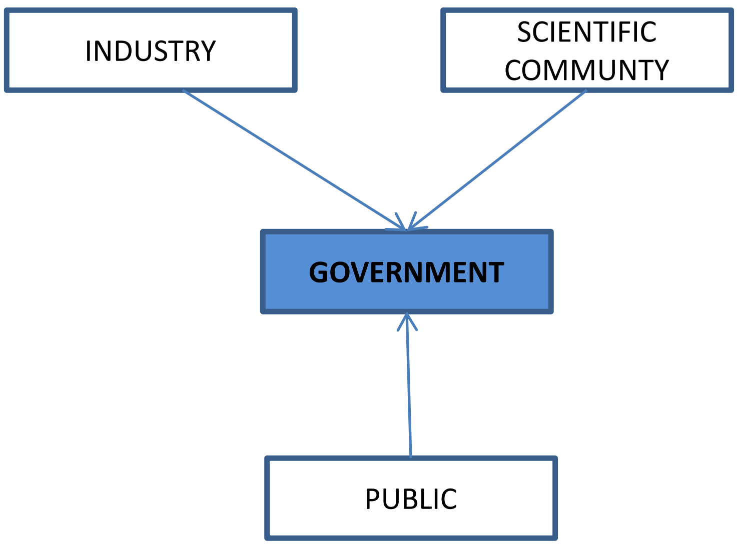


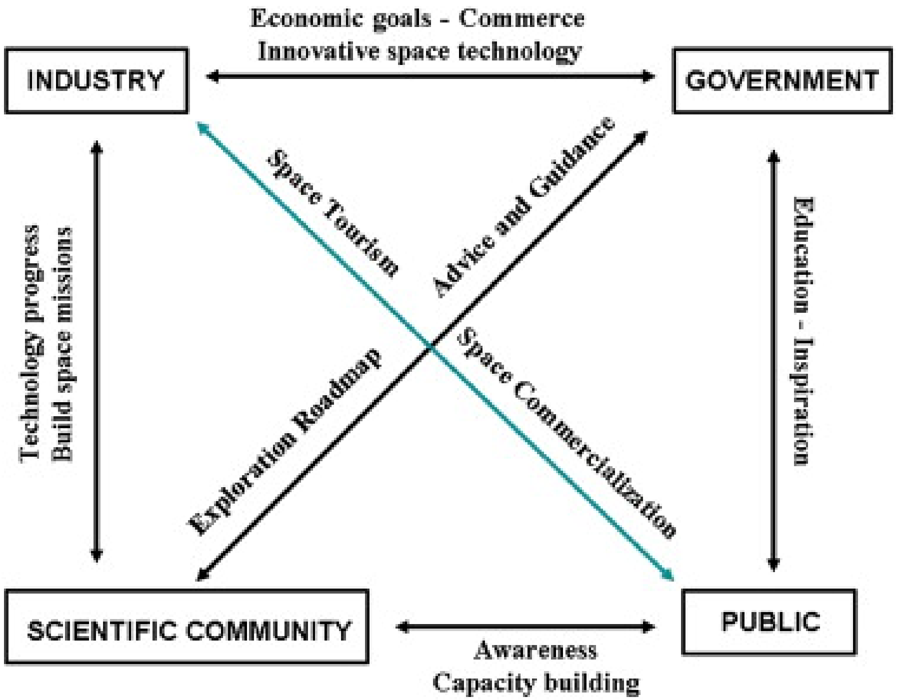
Newer satellite manufacturing firms using:

- 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

Source: L. Summerer, Evaluating research for disruptive innovation in the space sector, Acta Astronautica, Volume 81, Issue 2, 2012, 484–498

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,” *Space Policy*, Volume 25, Issue 4, 2009, 244–256, http://dx.doi.org/10.1016/j.spacepol.2009.09.004

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

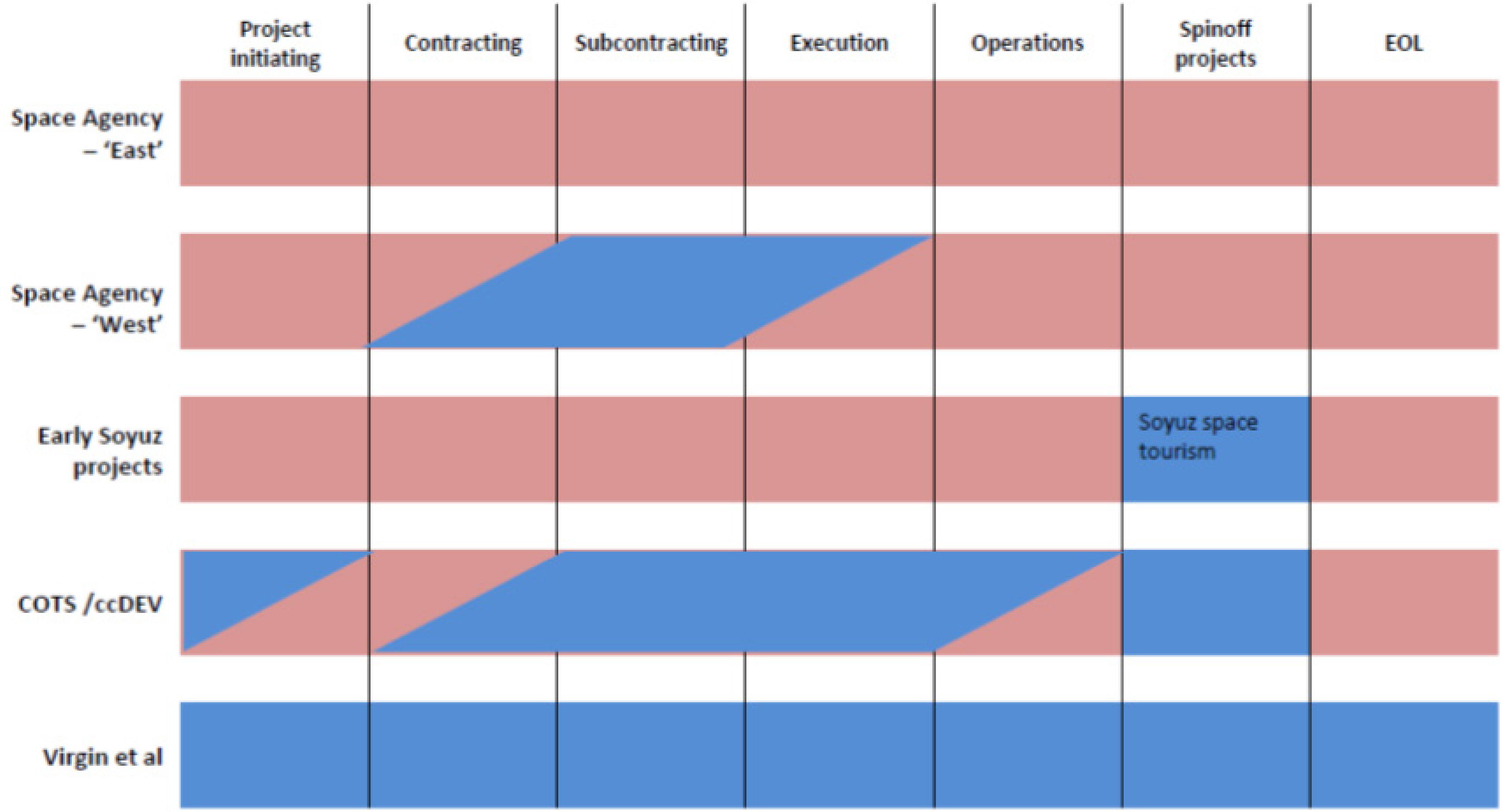
Government relinquishes responsibility (SAA with SpaceX to deliver cargo)

Displacement

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

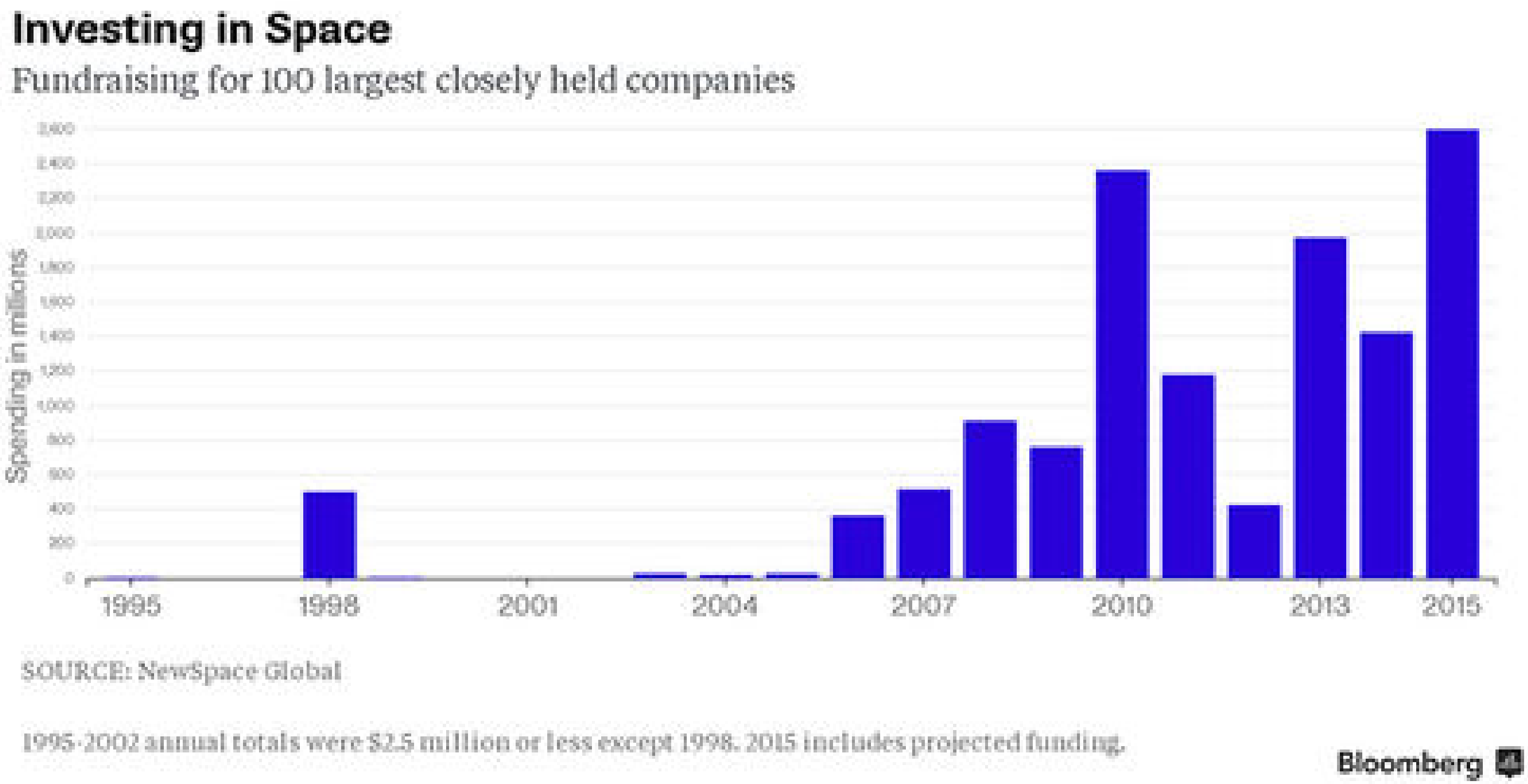
Adapted from C. Anderson, Space Policy 29 (2013) 266–271

Governments Cost-Sharing with Private Sector—Primarily a "Western" Phenomenon



Source: Payson, IAC 2014

Increasing Private Investment



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

SATELLITES

OneWeb
Planet Labs
Kymeta
Spire
Firefly Space Systems
Dauria Aerospace
Spaceflight

SPACE SERVICES/ROCKET TECH

SpaceX
Planetary Resources
XCOR Aerospace
Astroscale
Bagaveev
Masten
Accion Systems

IMAGERY

Mapbox
Orbital Insight
Windward
GSi
HydroBio Advanced Remote Sensing

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

Source: Fortune

Source: CB Insights, The Future Of Frontier Tech, *Analyzing Trends In Drones, Space, and AR/VR, Technology,* August 28, 2015

Known investments

$5B

Projected global commercial satellite imagery market in 2019

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)

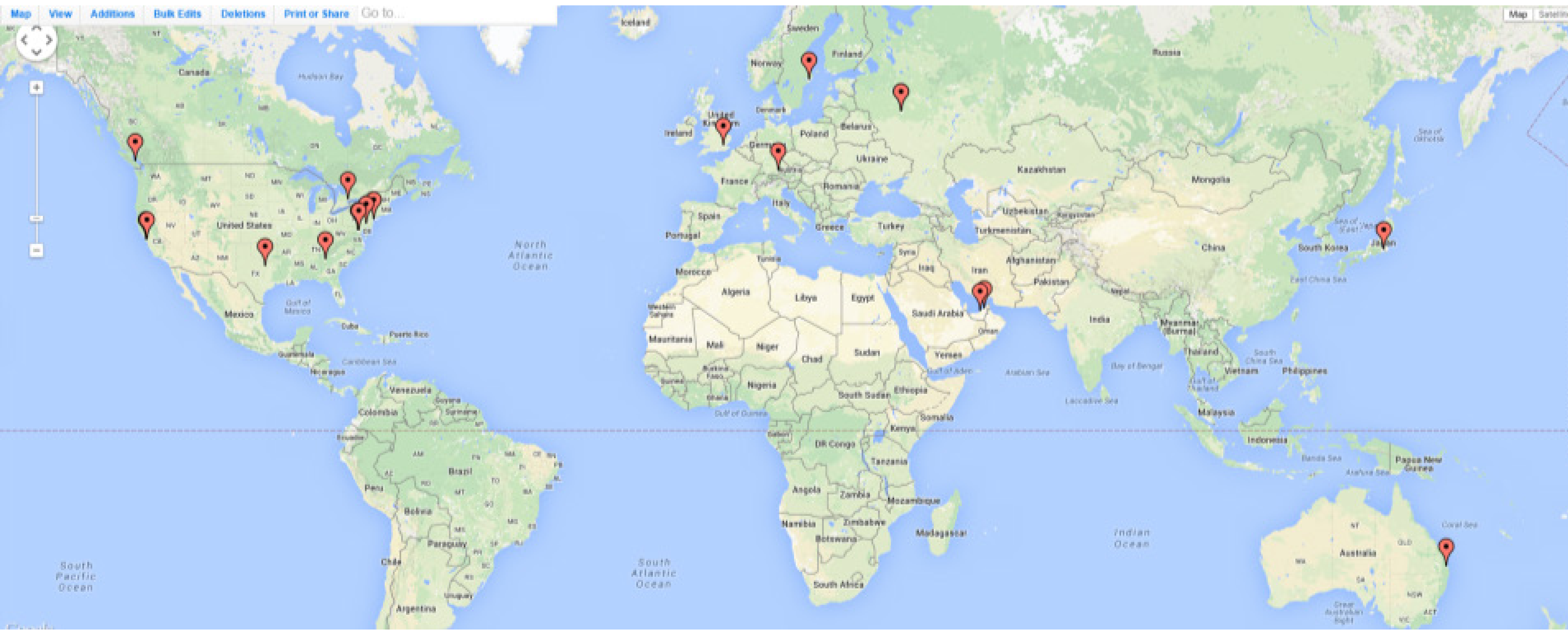
Lux Capital, RRE Ventures, and Bessemer Venture Partners have been the 3 most active VCs in space startups since 2012. Other include Khosla Ventures, Promus Ventures and Founders Fund

Source: CB Insights, The Future Of Frontier Tech, *Analyzing Trends In Drones, Space, And AR/VR, Technology,* August 28, 2015

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)

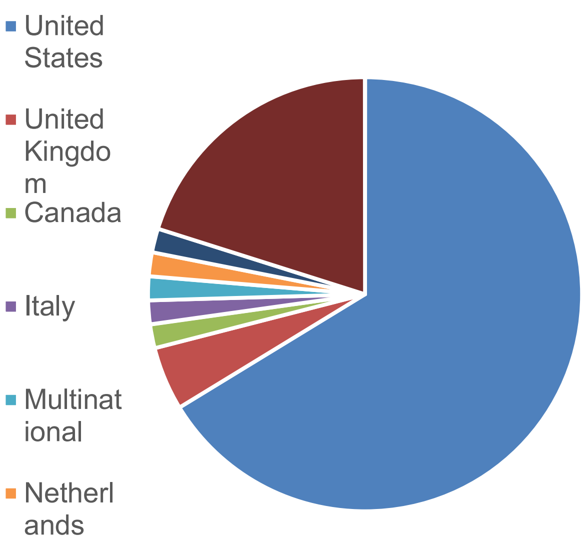
Google LUNAR X PRIZE

Landing ($1 Million each)	Mobility ($500,000 each)	Imaging ($250,000 each)
Astrobotic (US)	Astrobotic (US)	Astrobotic (US)
Team Indus (India)	Hakuto (Japan)	Moon Express (US)
Moon Express (US)	Part-Time Scientists (Germany)	Part-Time Scientists (Germany)

Source: http://lunar.xprize.org/teams

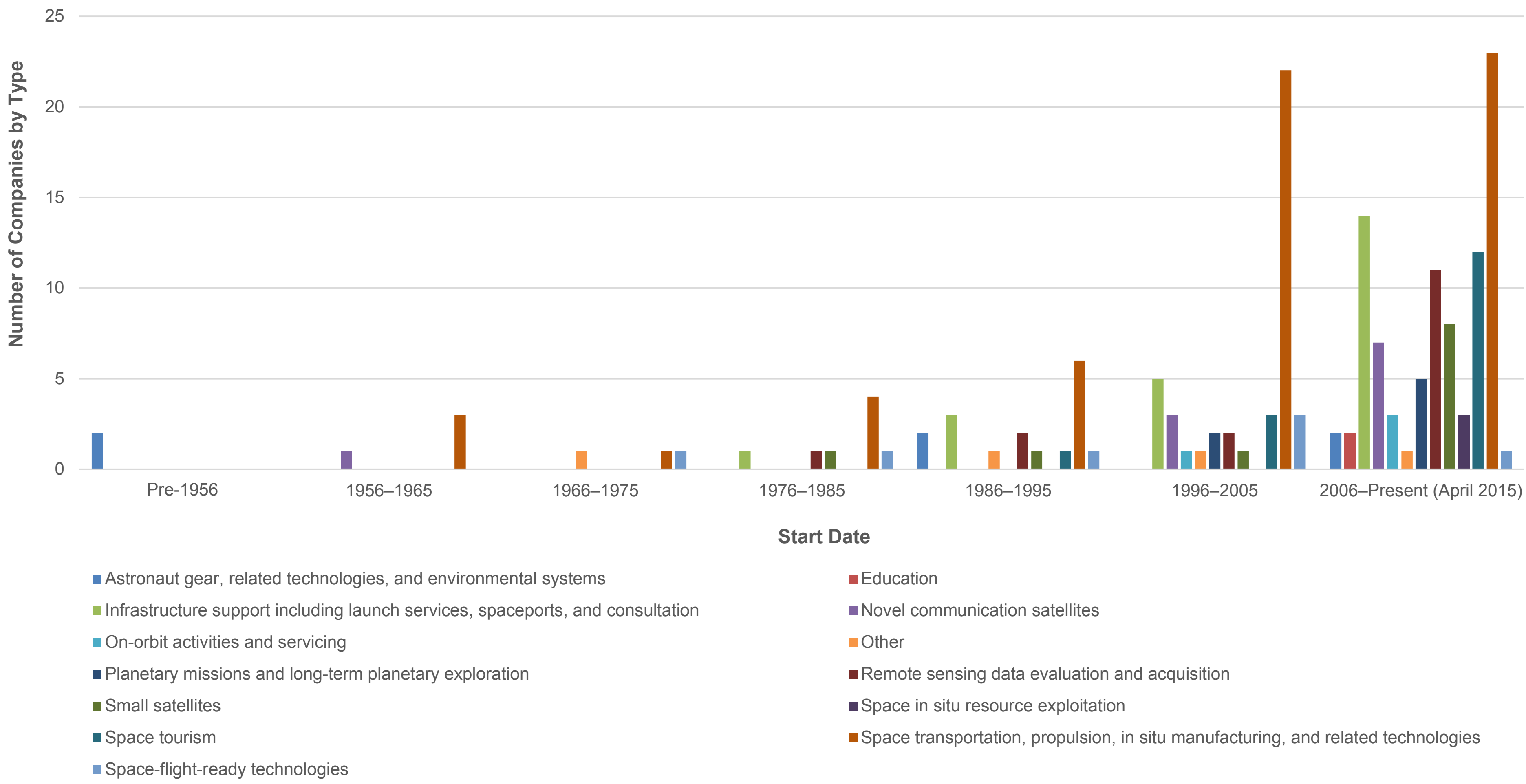
Growth of a New Private Sector

- 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

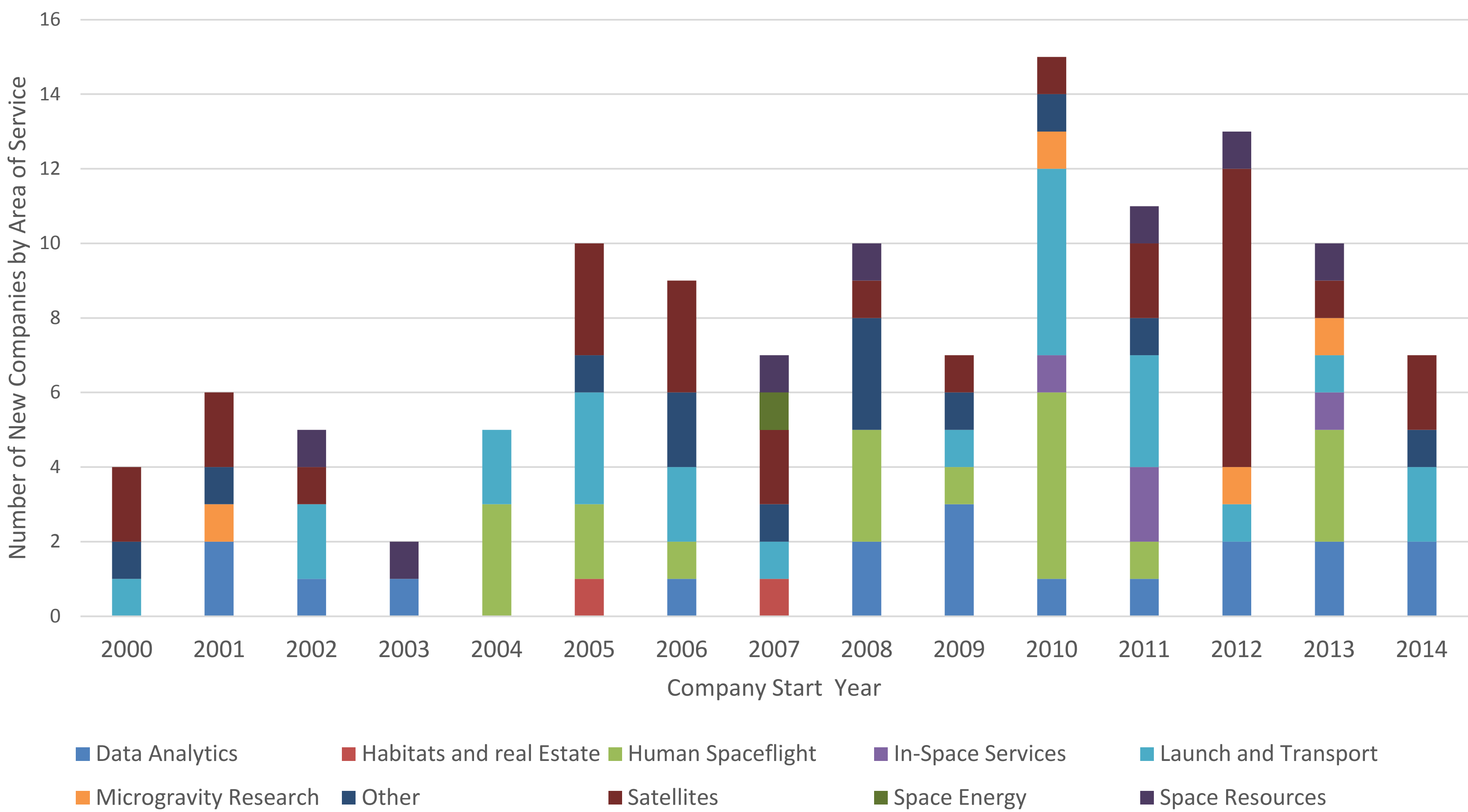
And It IS New



Source: STPI Compilation Using Public Sources

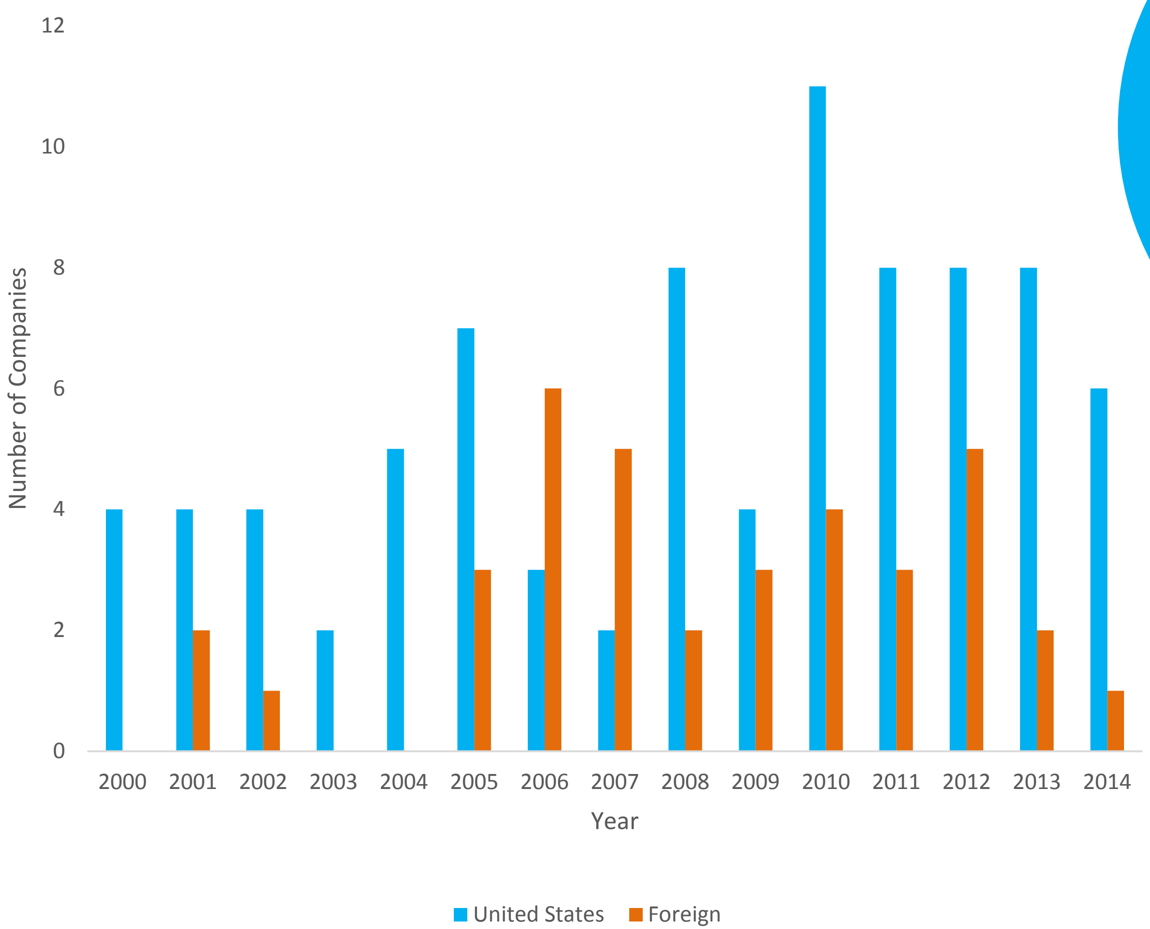
IDA SCIENCE AND TECHNOLOGY POLICY INSTITUTE

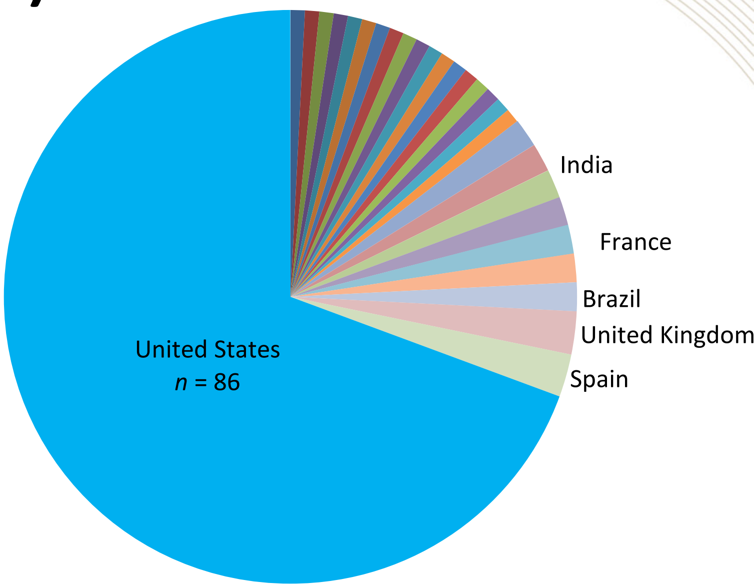
Areas of NewSpace Firms (since 2000)



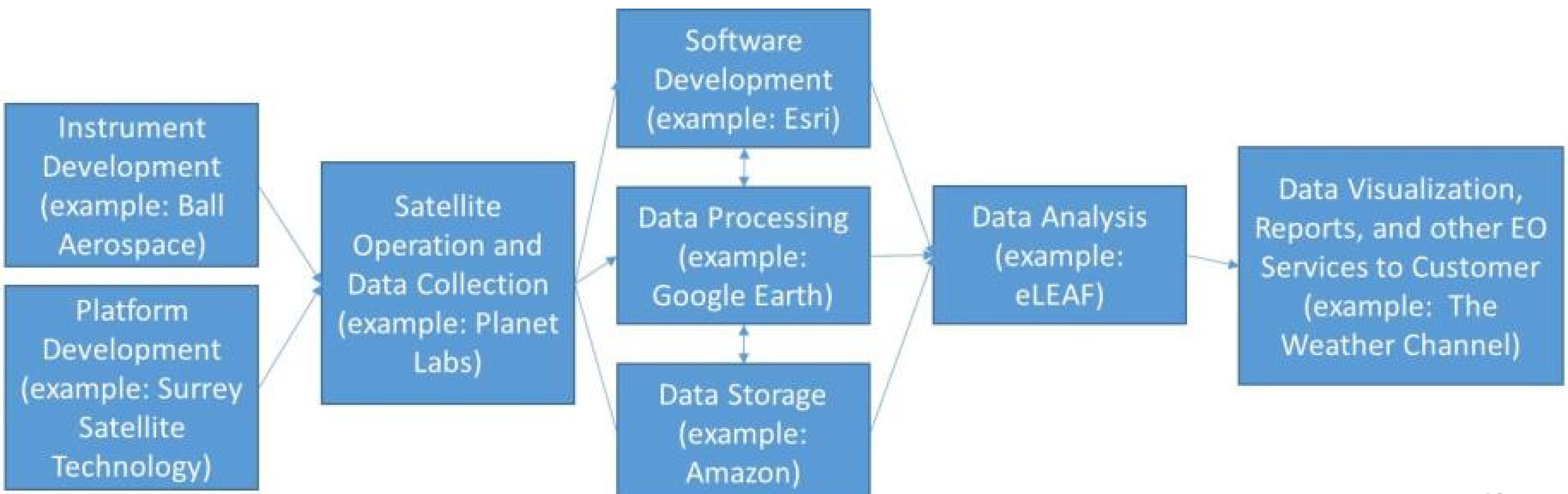
IDA SCIENCE AND TECHNOLOGY POLICY INSTITUTE

Country of NewSpace Firms (since 2000)

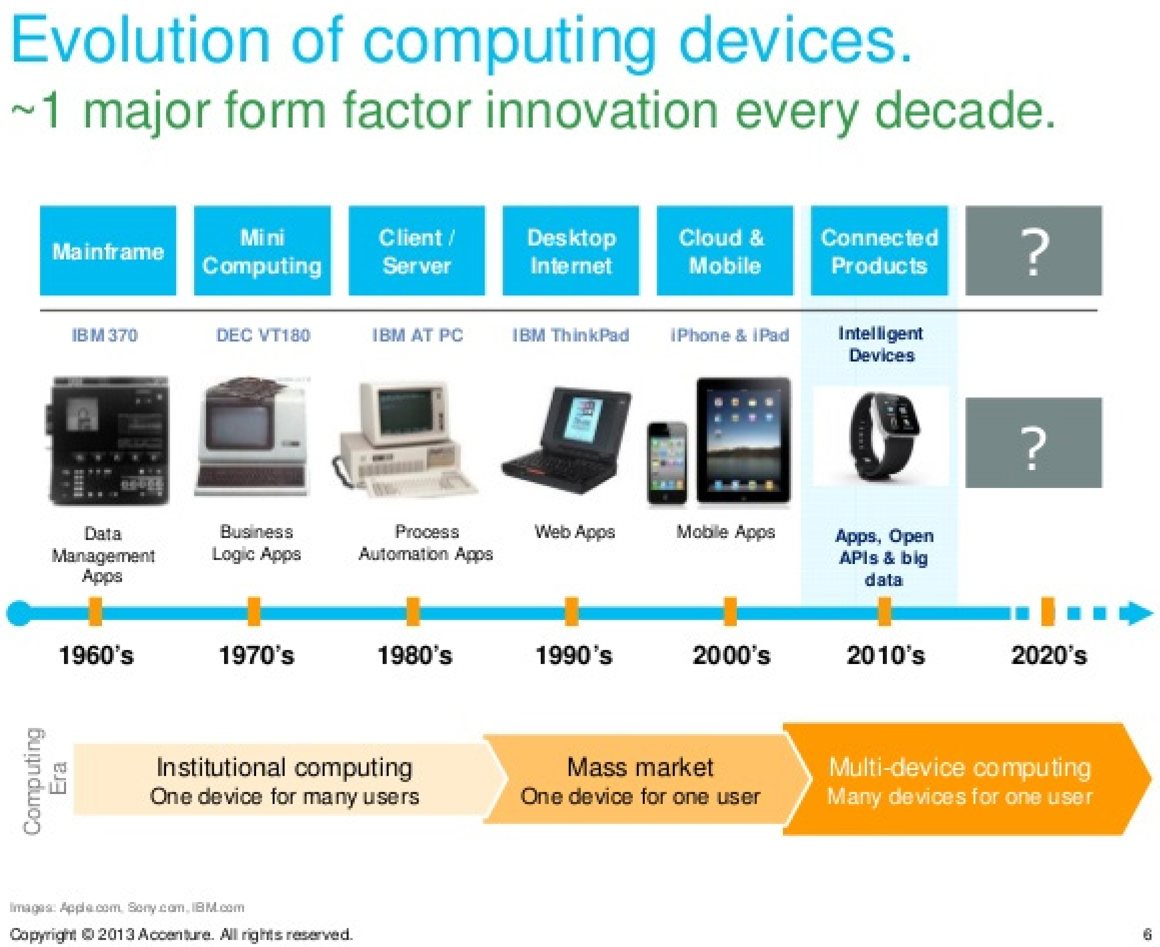




Functional Modularization in EO



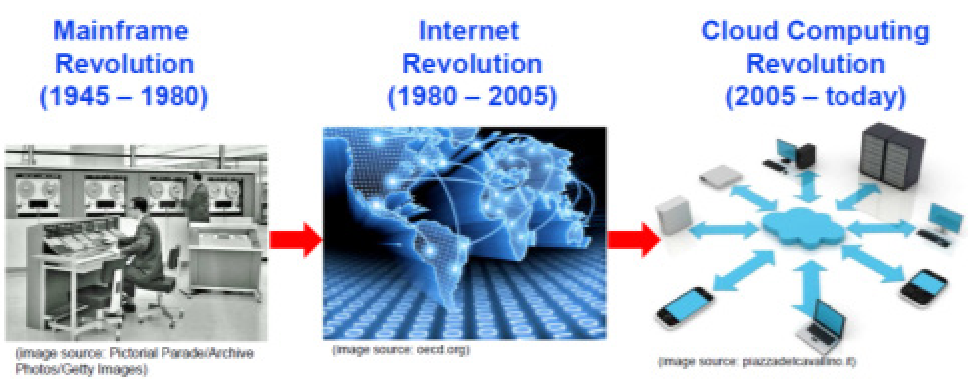
SmallSats May Enable the Space Sector to Mirror Trends in Other Sectors



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)

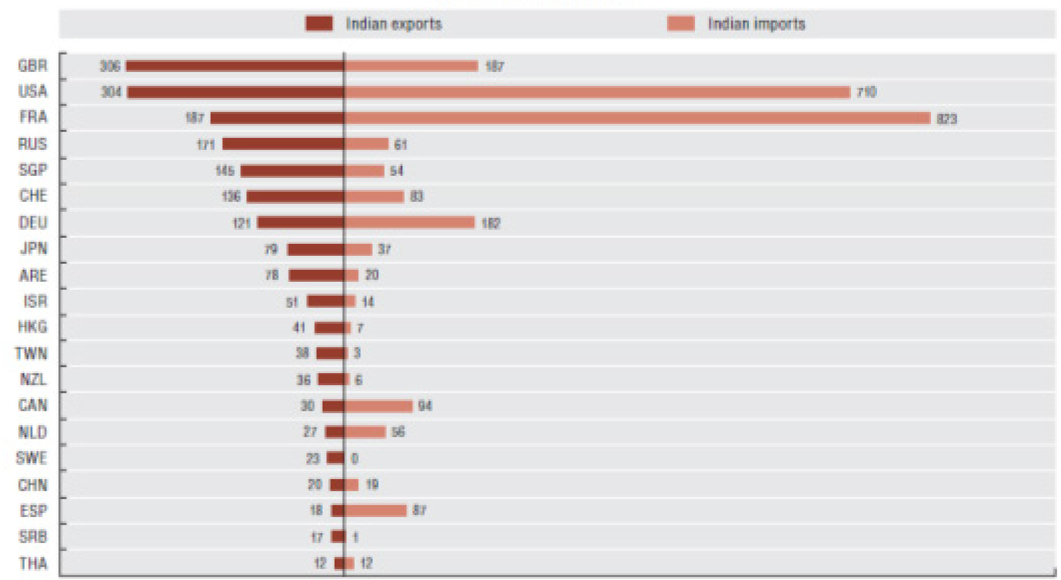
32.5. Korea's main aerospace trade partners

In million USD (current), 2012

Source: OECD STAN Database, 2014, *www.oecd.org/sti/btd.*

30.5. India's main aerospace trade partners

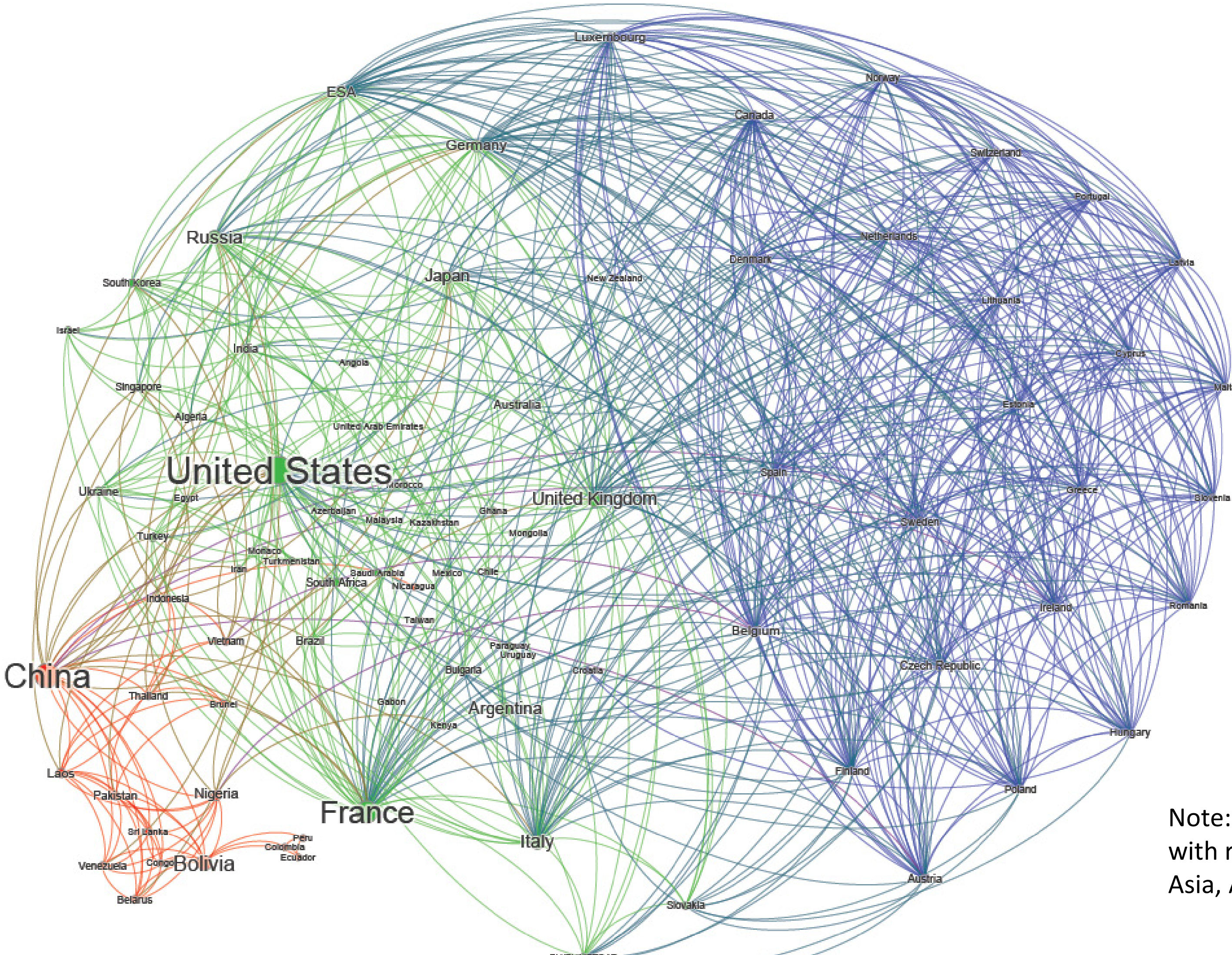
Million USD (current), 2012



Source: OECD STAN Database, 2014,*www.oecd.org/sti/btd.*

StatLink http://dx.doi.org/10.1787/888933142102

Country-Country "Partnerships"

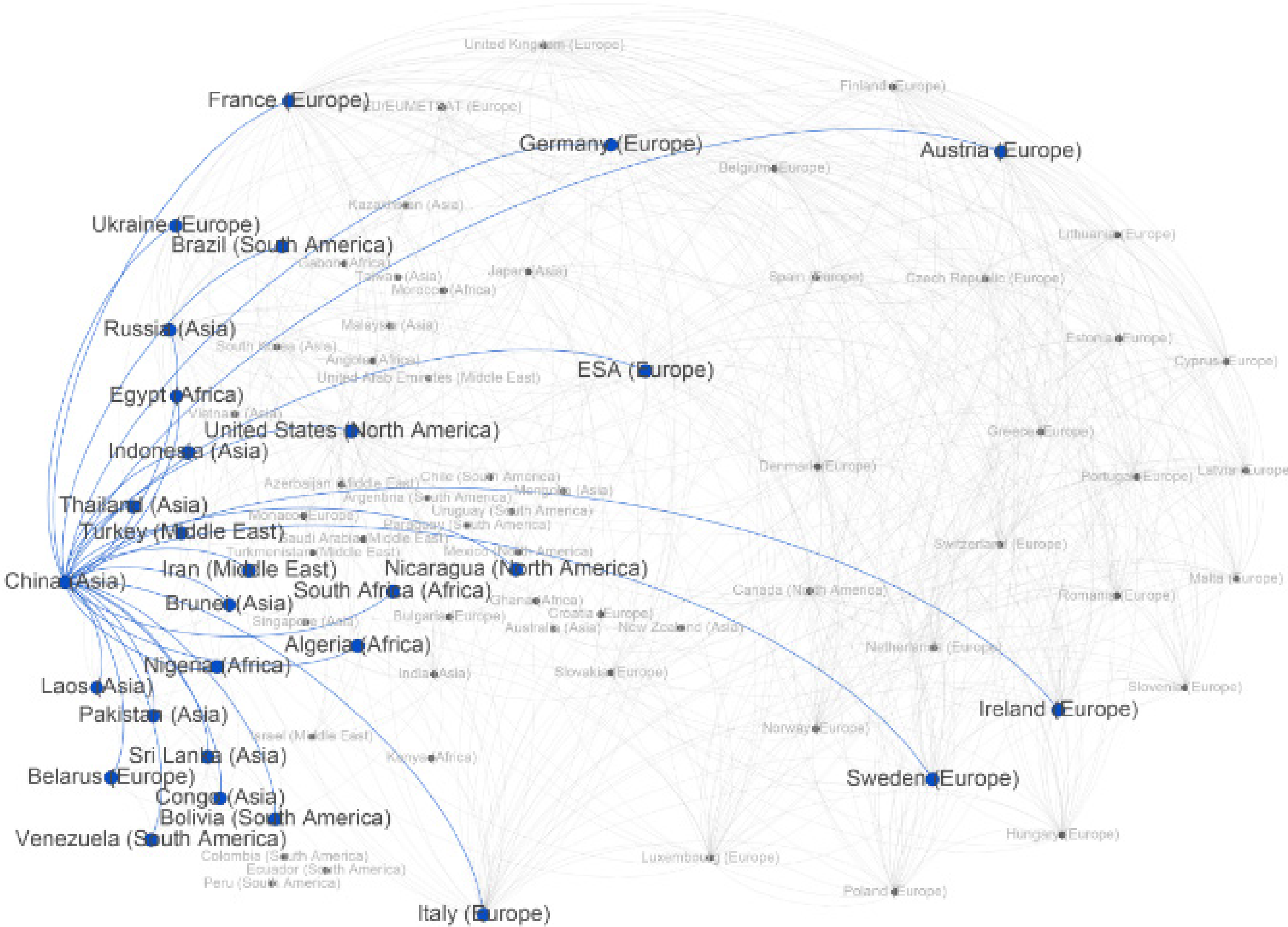


- Countries in the EU generally fall into a single group (blue)
- Countries collaborating with the U.S. compose another group (green)
- Developing countries often collaborating with China as a third group (red).
- There is significant cross-over between the blue (EU-centric) and green (U.S.-centric)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

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

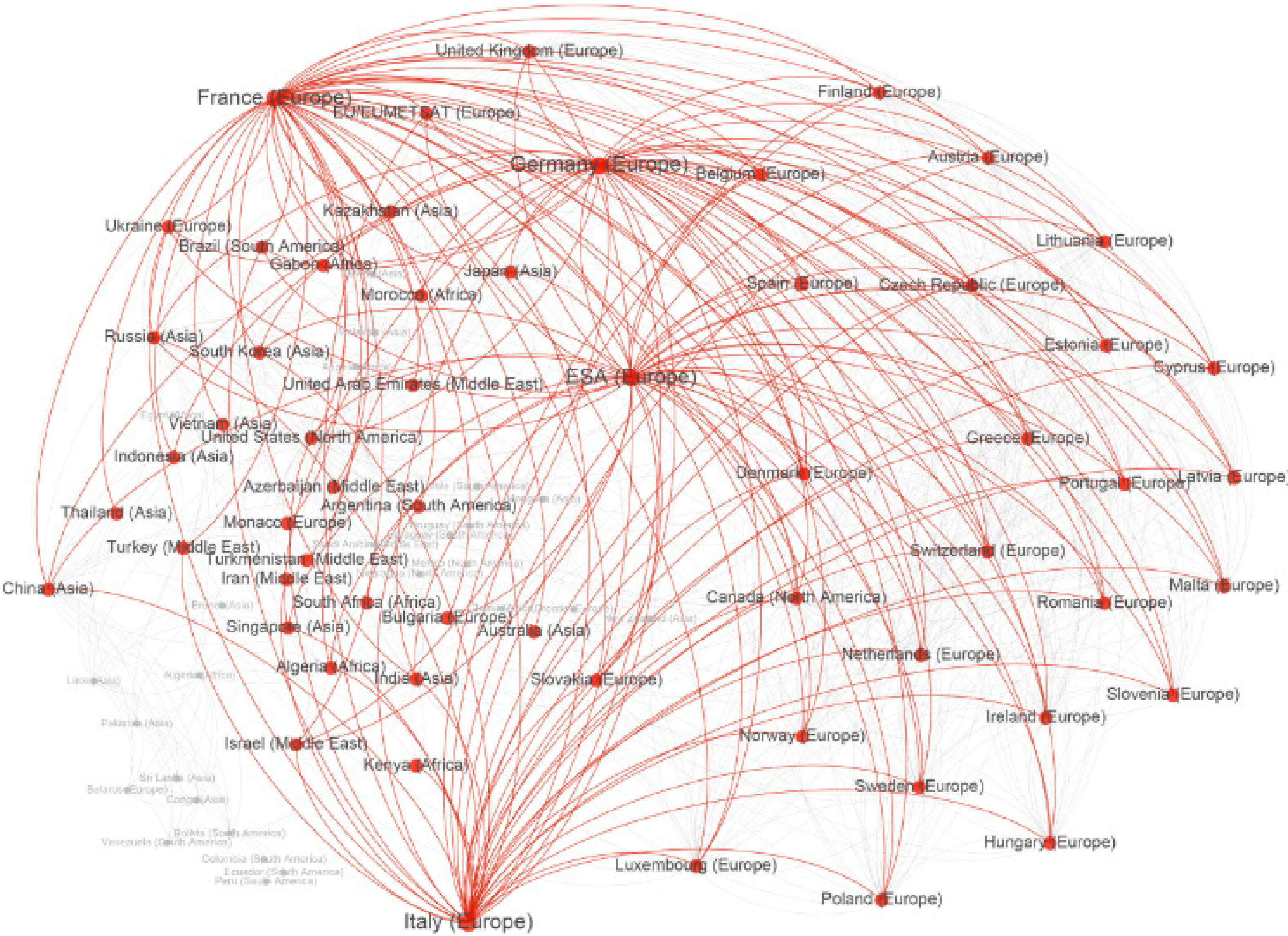
Colors indicate grouping using a community detection algorithm
Data from manual mining of Euroconsult's *Profile of 80 Countries*

China’s “Partnerships”



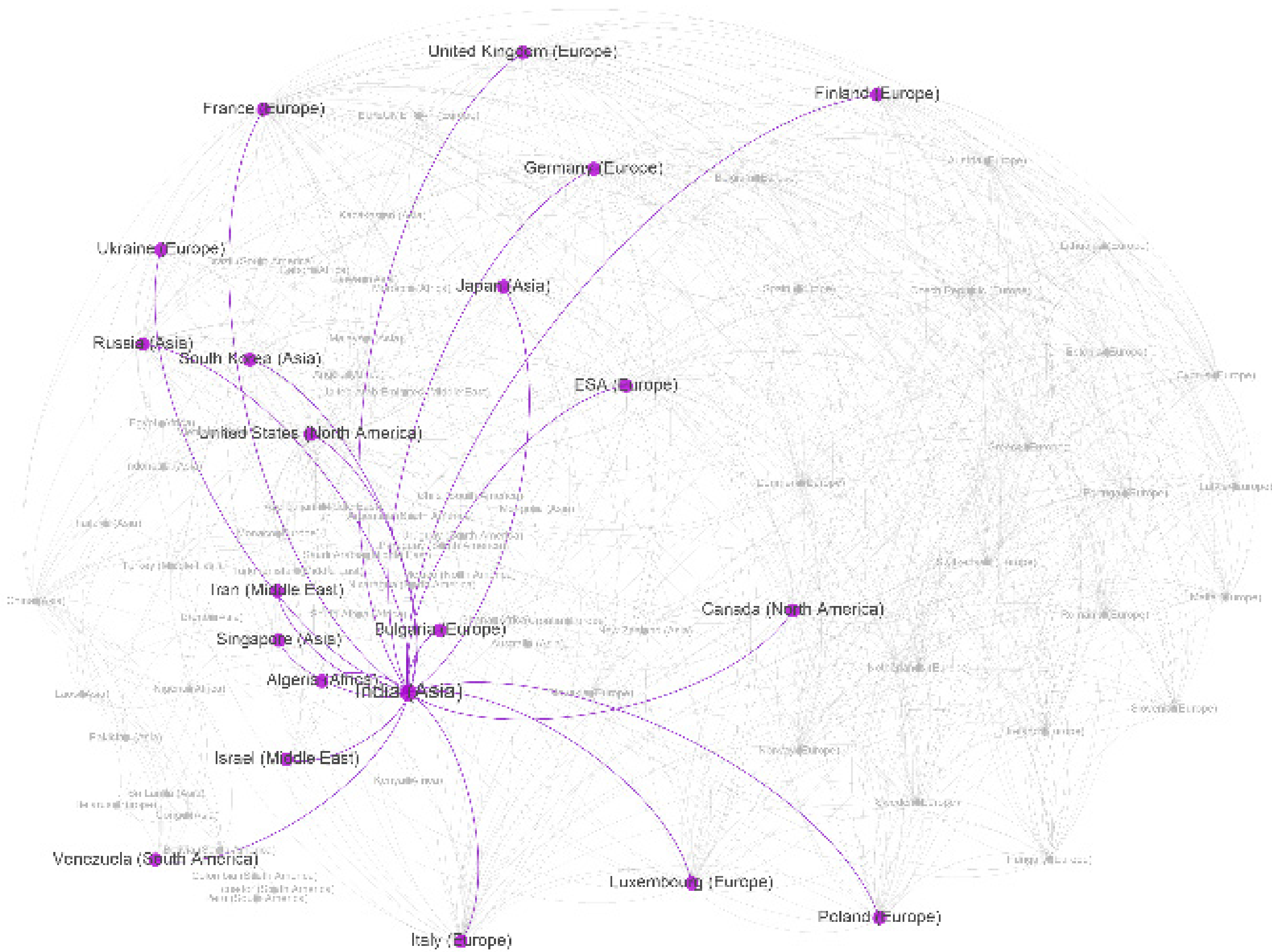
Source: Euroconsult (2014a).

Europe's "Partnerships"



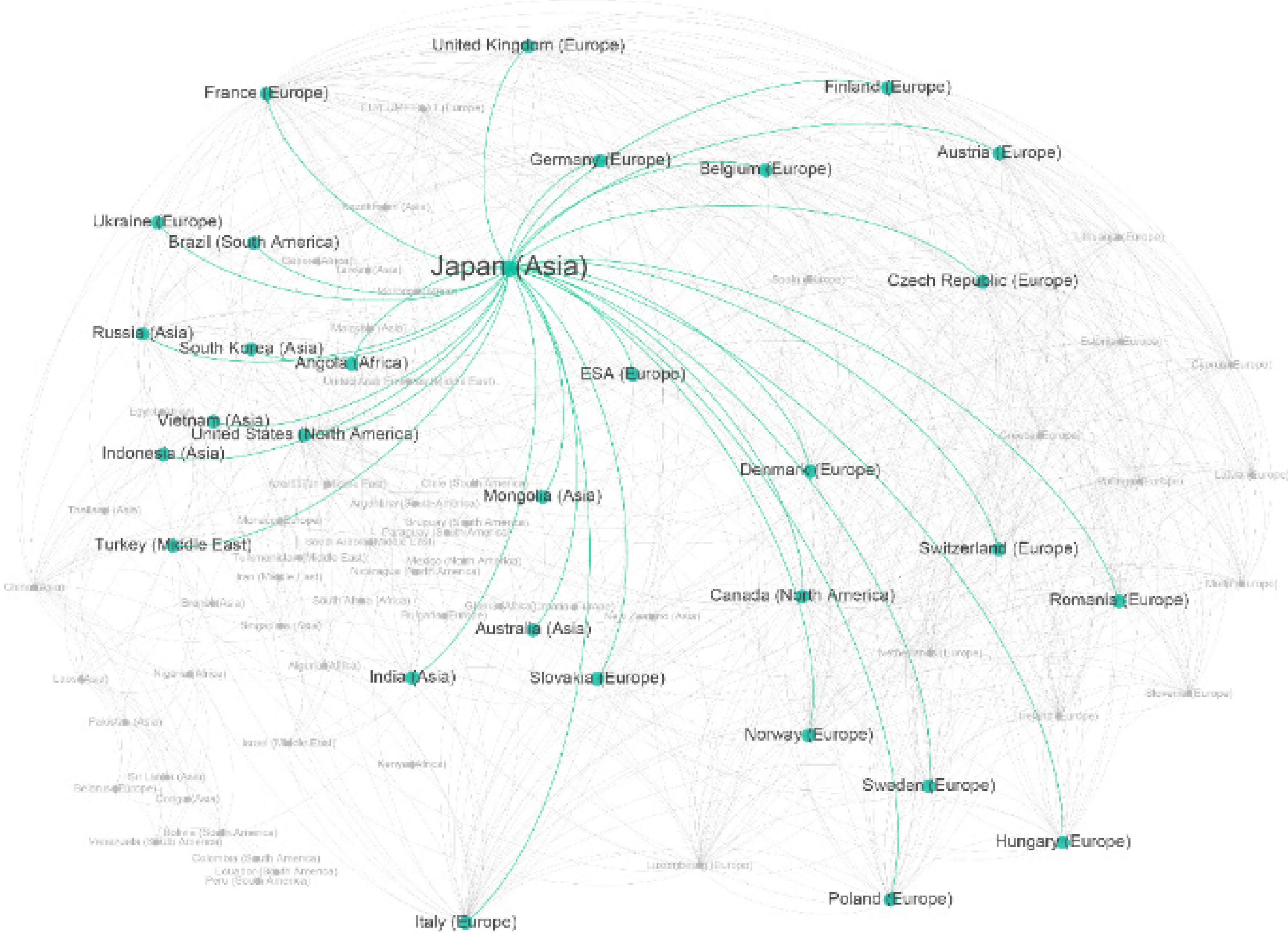
Source: Euroconsult (2014a).

India's "Partnerships"



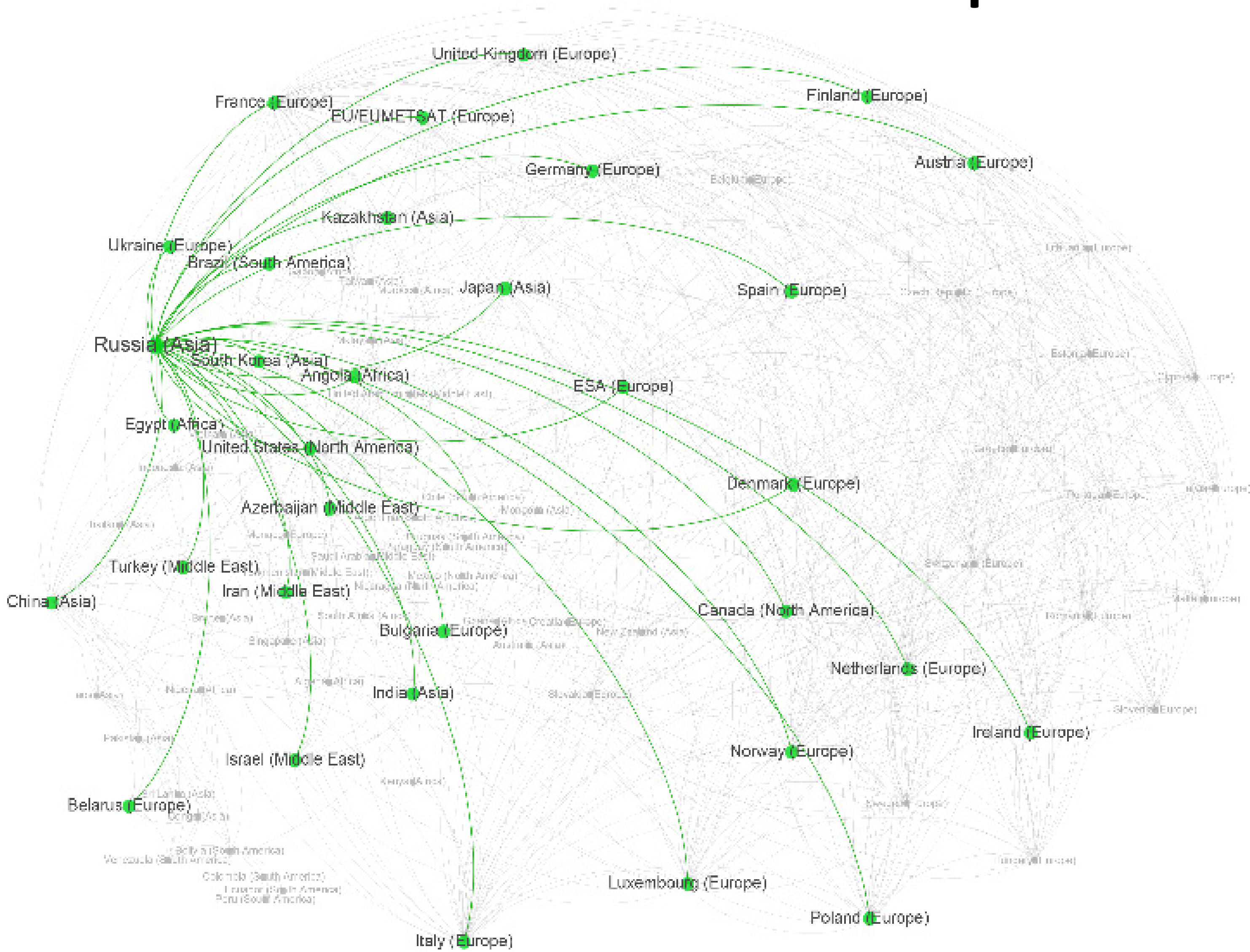
Source: Euroconsult (2014a).

Japan's "Partnerships"



Source: Euroconsult (2014a).

Russia's "Partnerships"



Source: Euroconsult (2014a).

Brazil Forges Space Cooperation Agreements Everywhere Except Washington

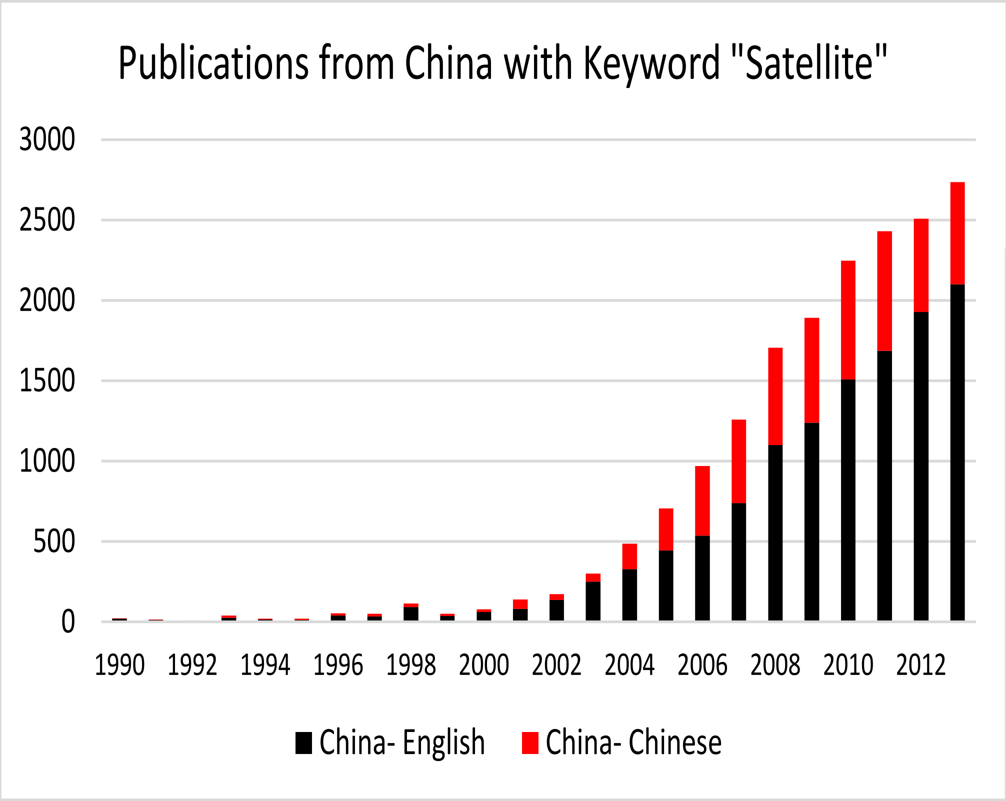
The Brazilian government is looking to join the front ranks of spacefaring nations and has struck multiple agreements with other nations for cooperation on launch vehicles (Ukraine and Germany), satellite telecommunications (France), Earth observation (China), small-satellite development (Argentina and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

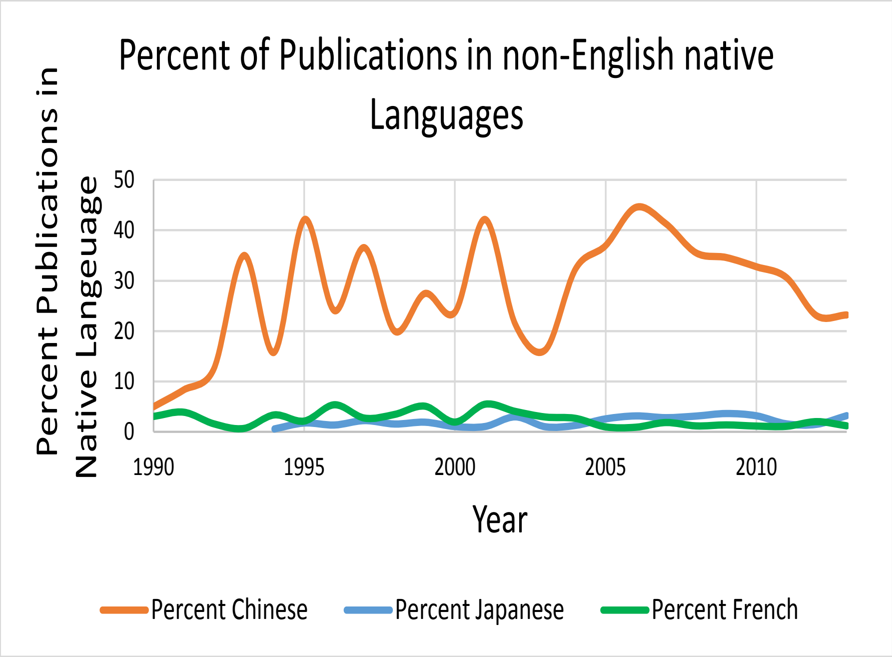
Notably absent is the United States, where 16 years of classifying satellite exports as armaments has had a chilling effect in foreign capitals. Recent moves by the U.S. government to reverse some of the effects of the policy have yet to be felt in Brazil.

http://spacenews.com/brazil-bypassing-the-us-as-it-builds-out-a-space-sector/

CAPABILITIES

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

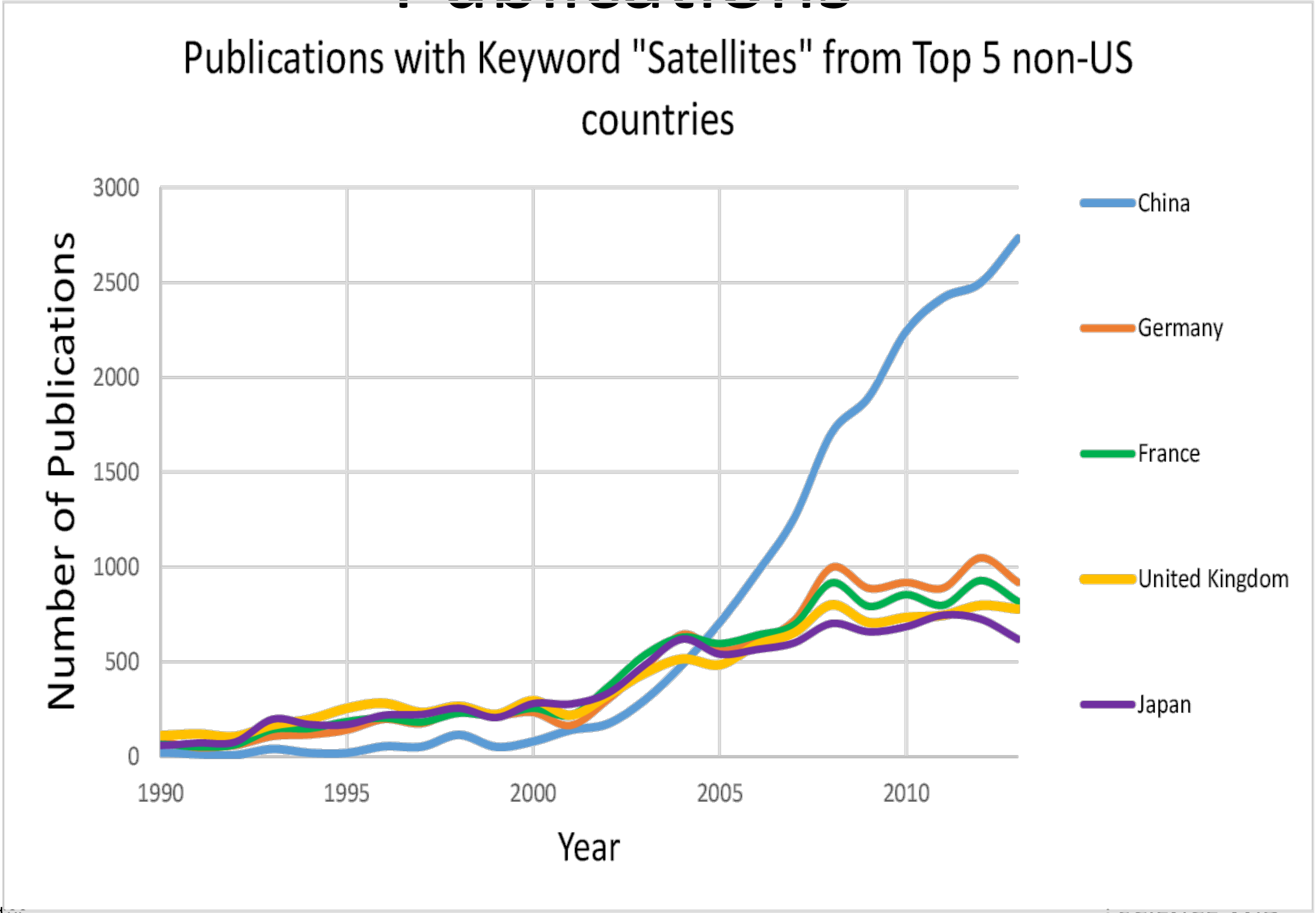




Source: Scopus
Key Word: Satellites
Data until end of 2013
Country: China
Language: as specified

IDA SCIENCE AND TECHNOLOGY POLICY INSTITUTE

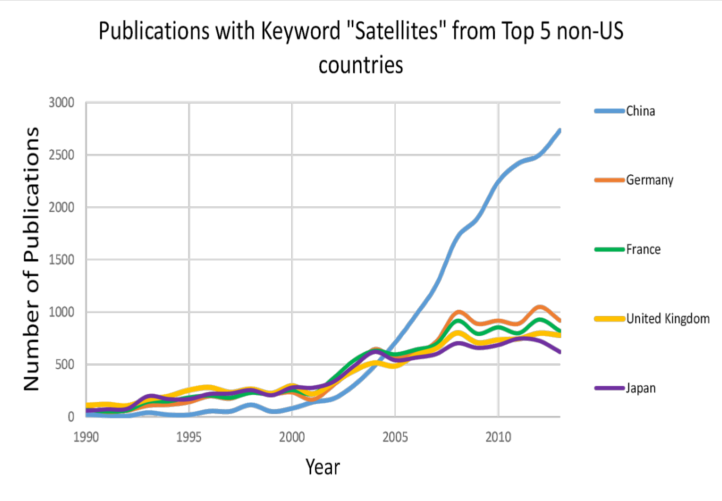
China Is the Country with the Fastest Rate of Growth of Satellite-Related Publications

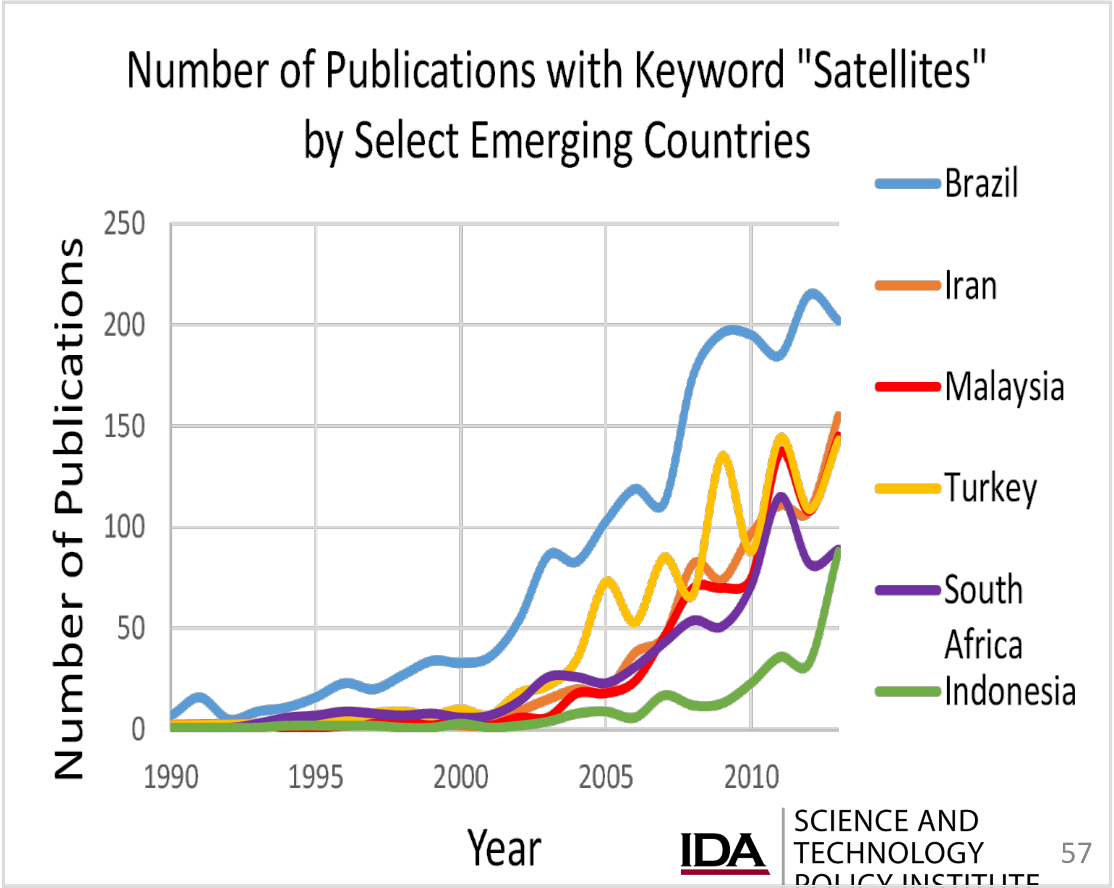


Source: Scopus
Key Word: Satellites
Data until end of 2013

IDA SCIENCE AND TECHNOLOGY POLICY INSTITUTE

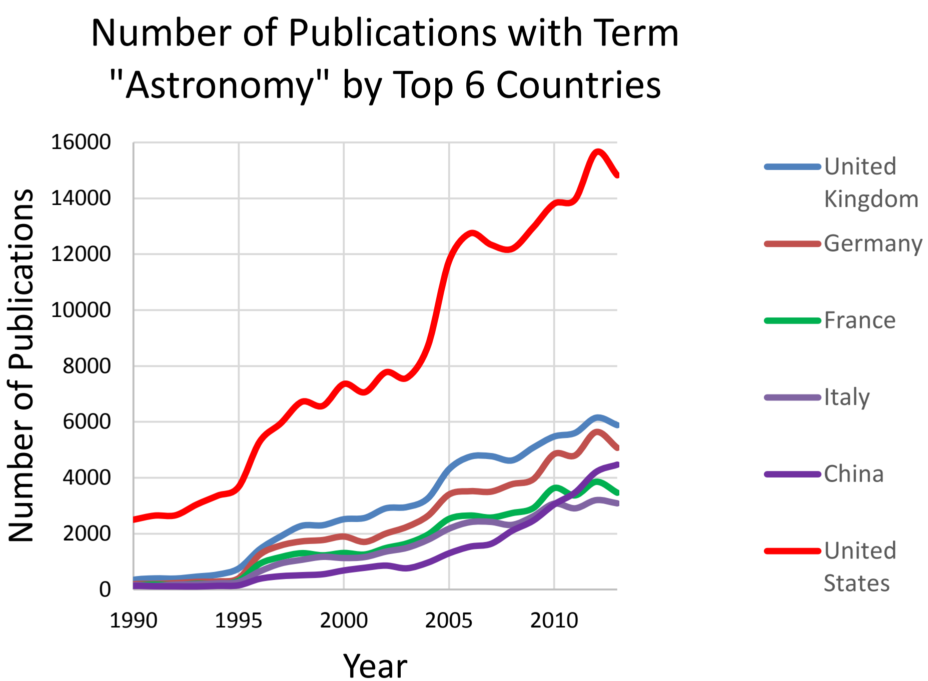
Emerging Countries Have a Faster Rate of Publication Growth Compared to Most Established Countries

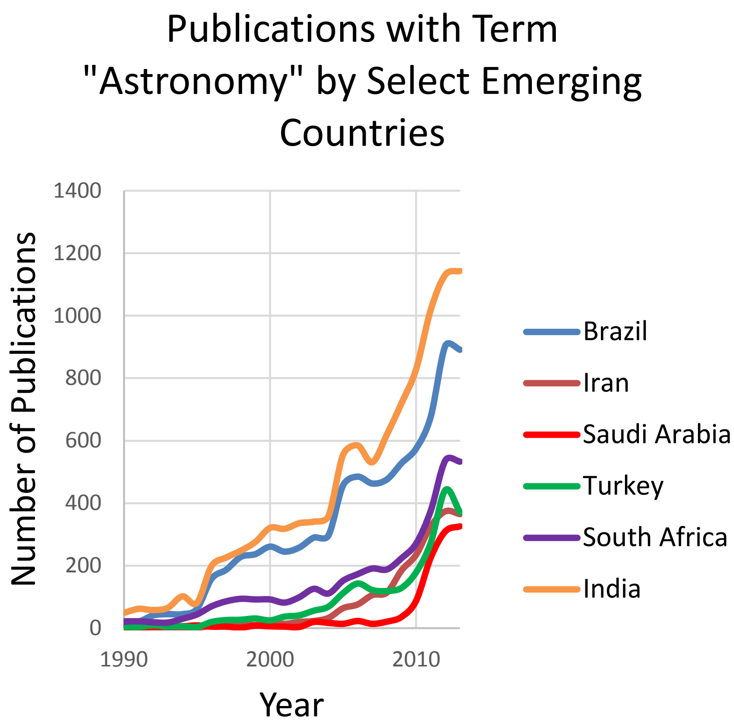




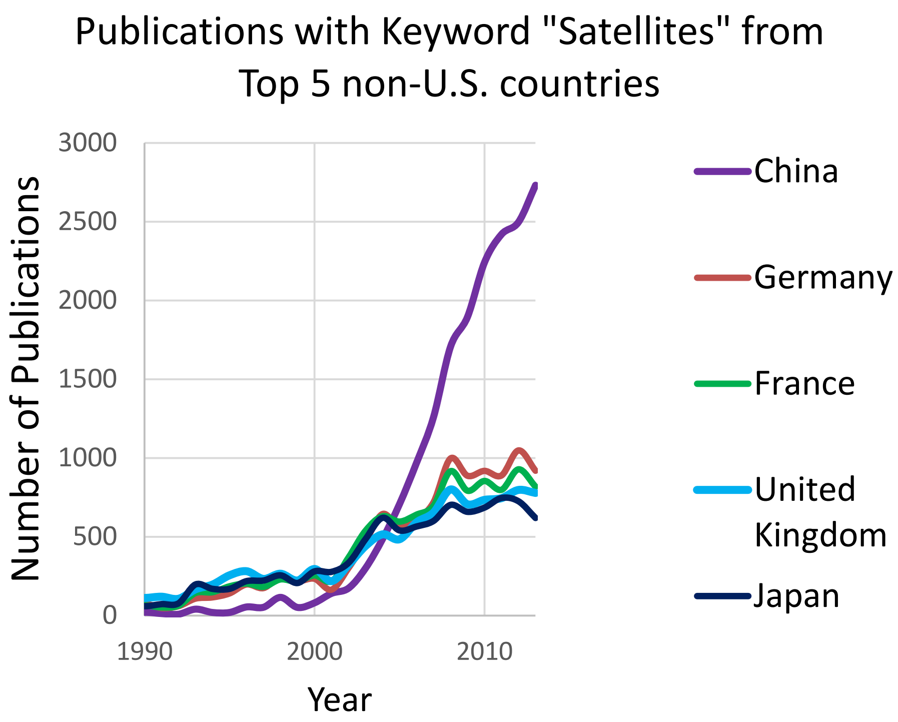
Source: Scopus
Key Word: Satellites
Data until end of 2013

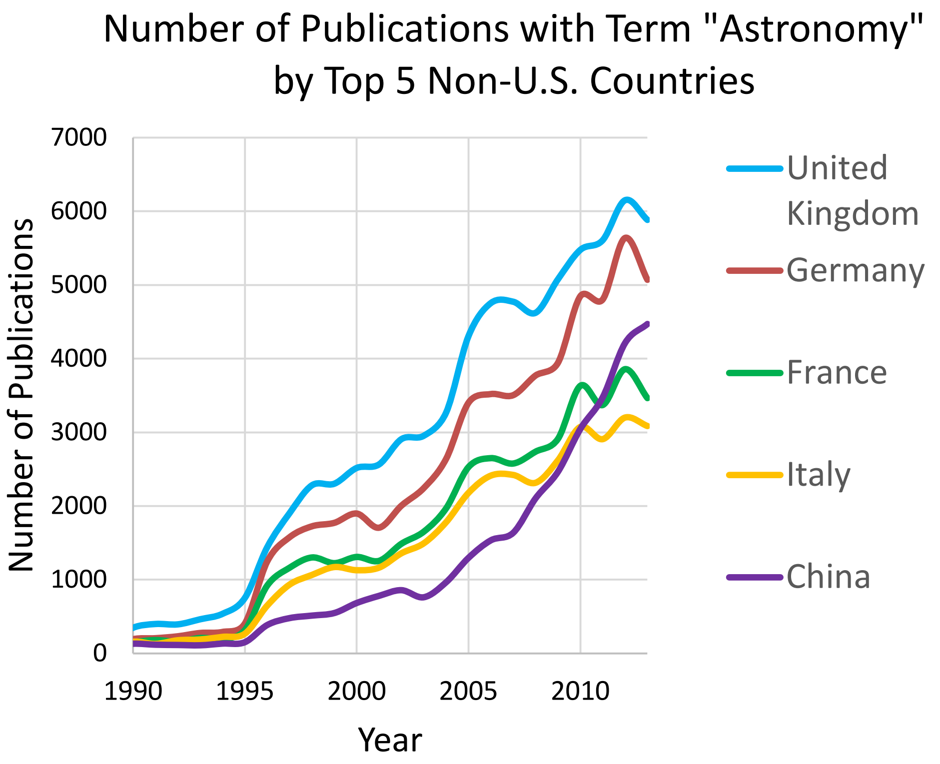
While the U.S. Far and Away Leads the Way in Astronomy, Other Nations Increasing Their Publication Count Tenfold in <10 Years

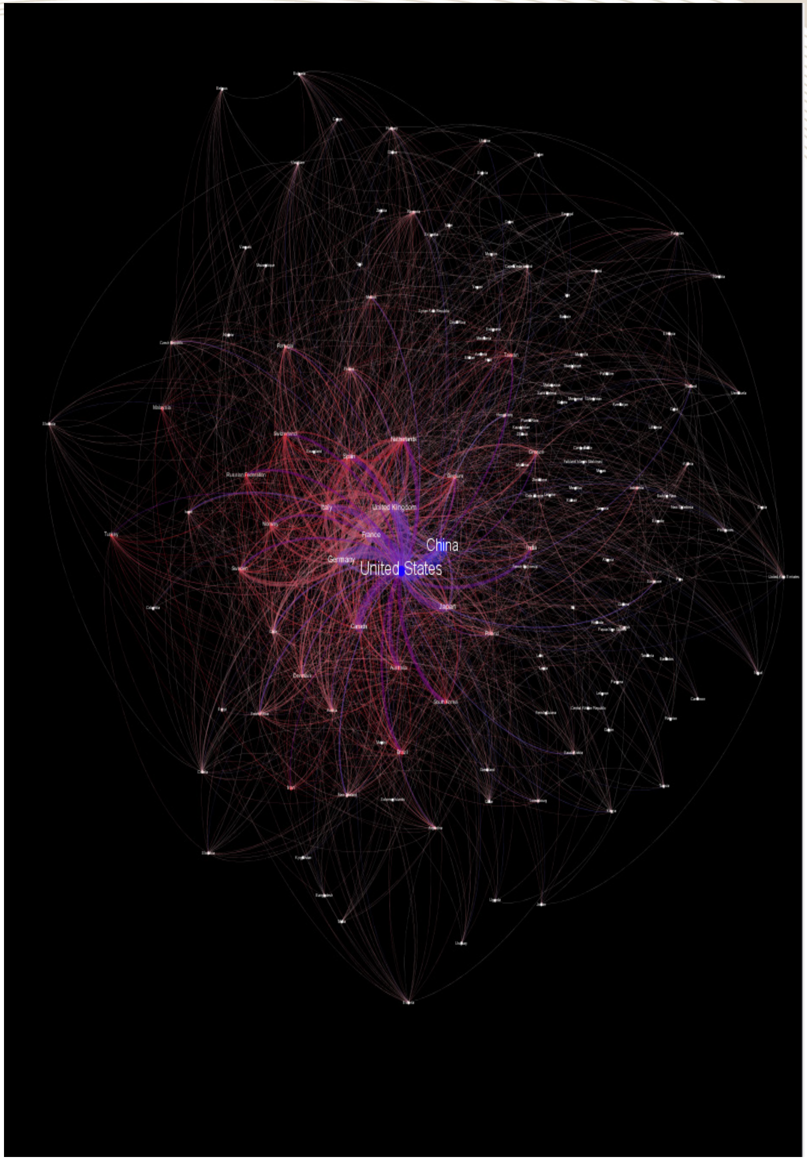




The Publication Trend Varies Strongly Depending on the Subject Area



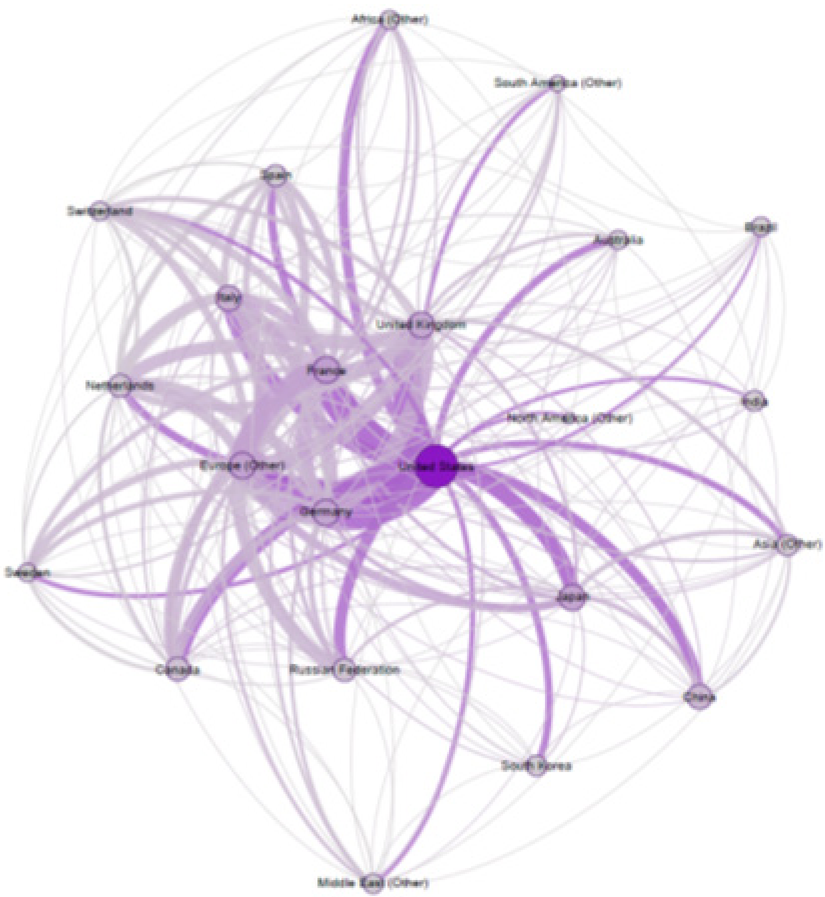




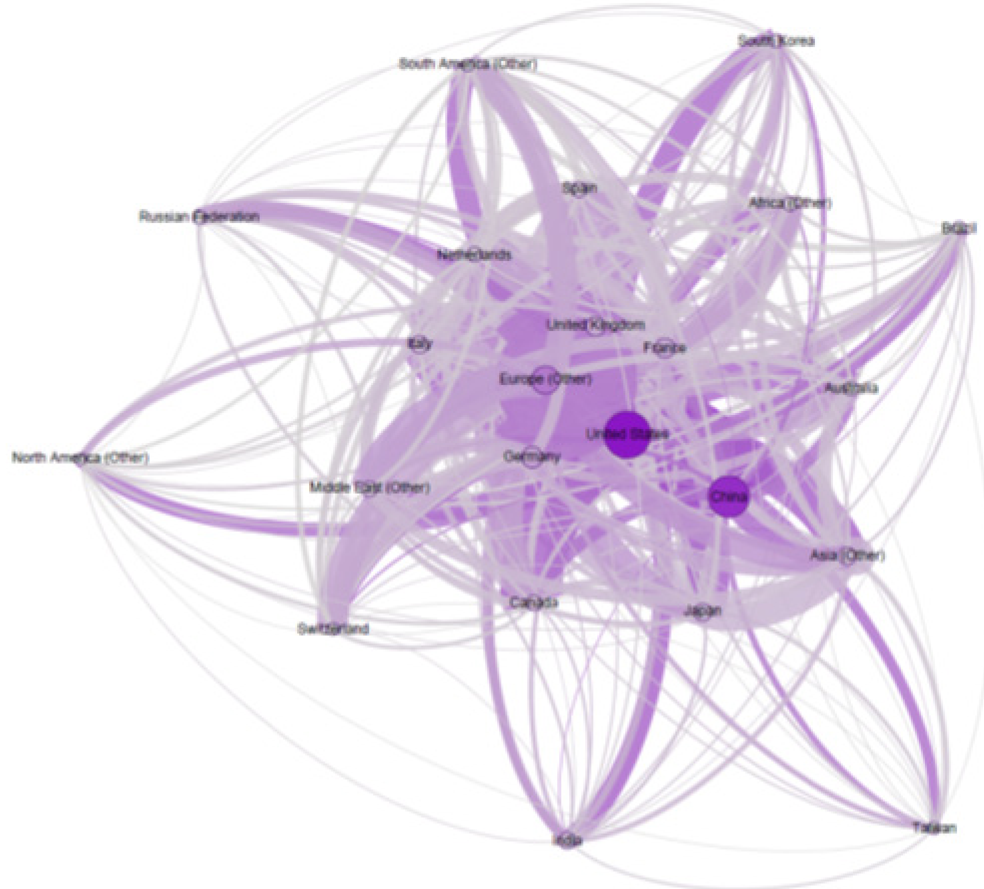
SCIENTIFIC COLLABORATIONS

Growing Collaborations in Research

Scopus Database Co-Authorship
For publications with keyword “satellites”



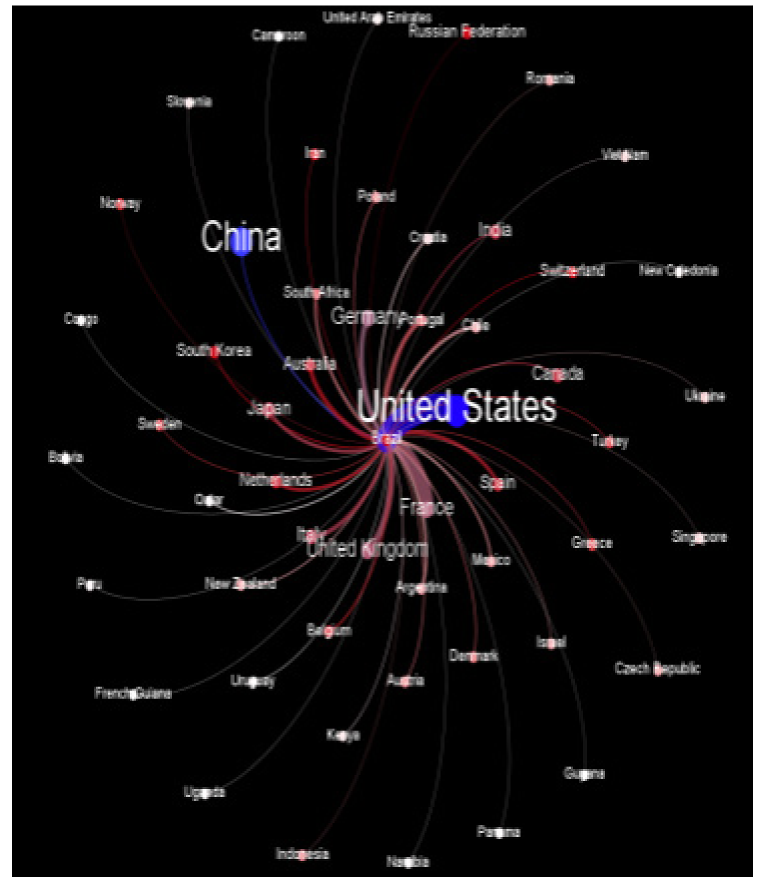
2003



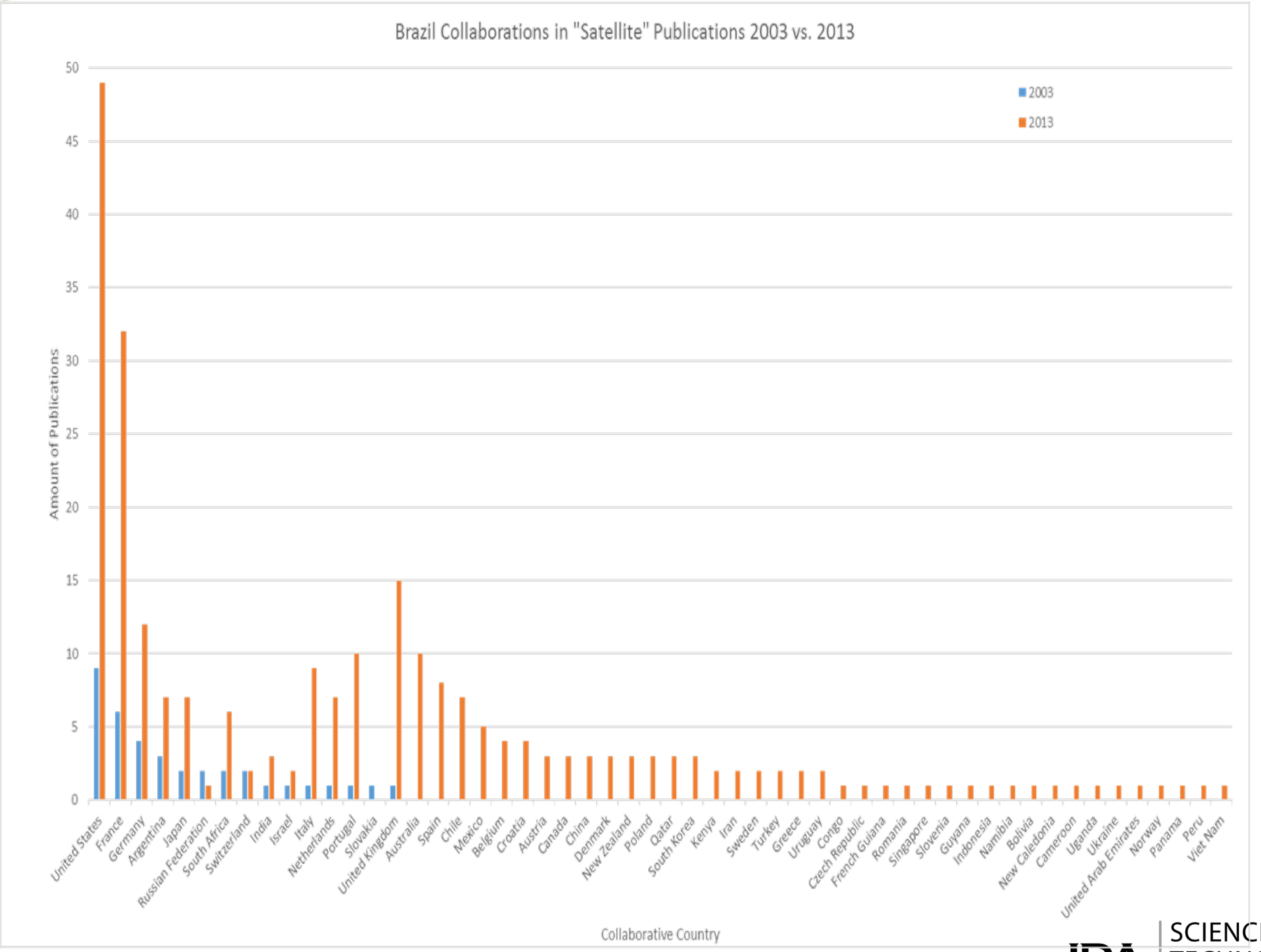
2013

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



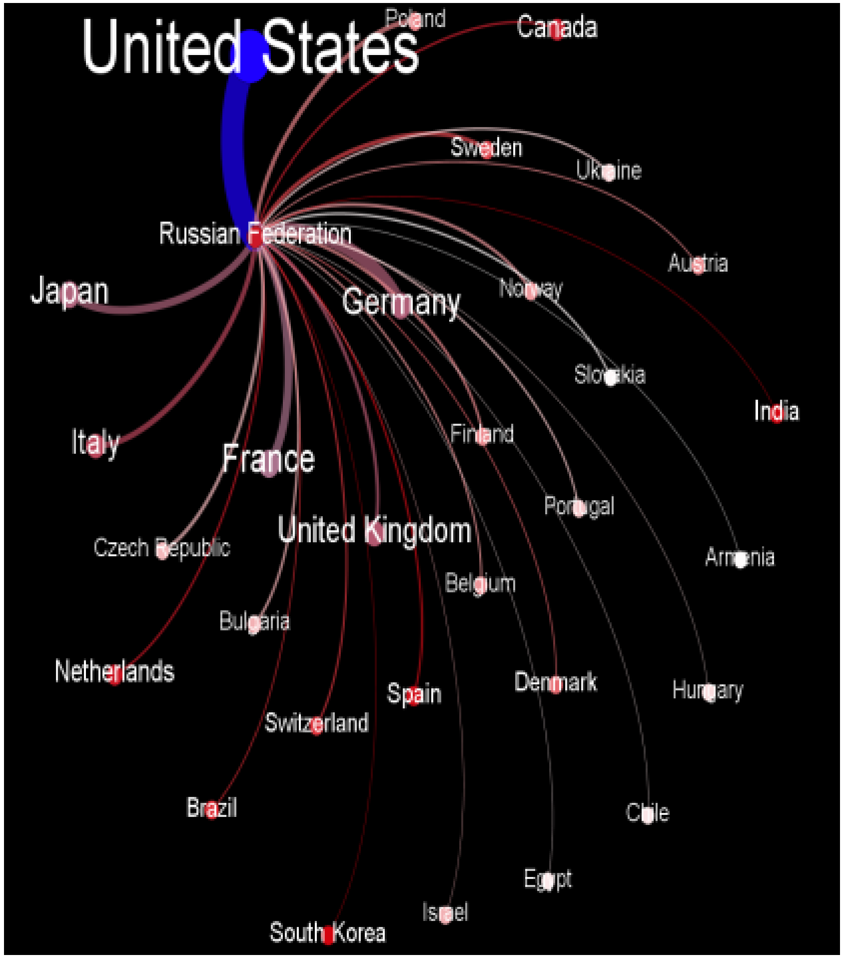
Brazil, 2003–2013

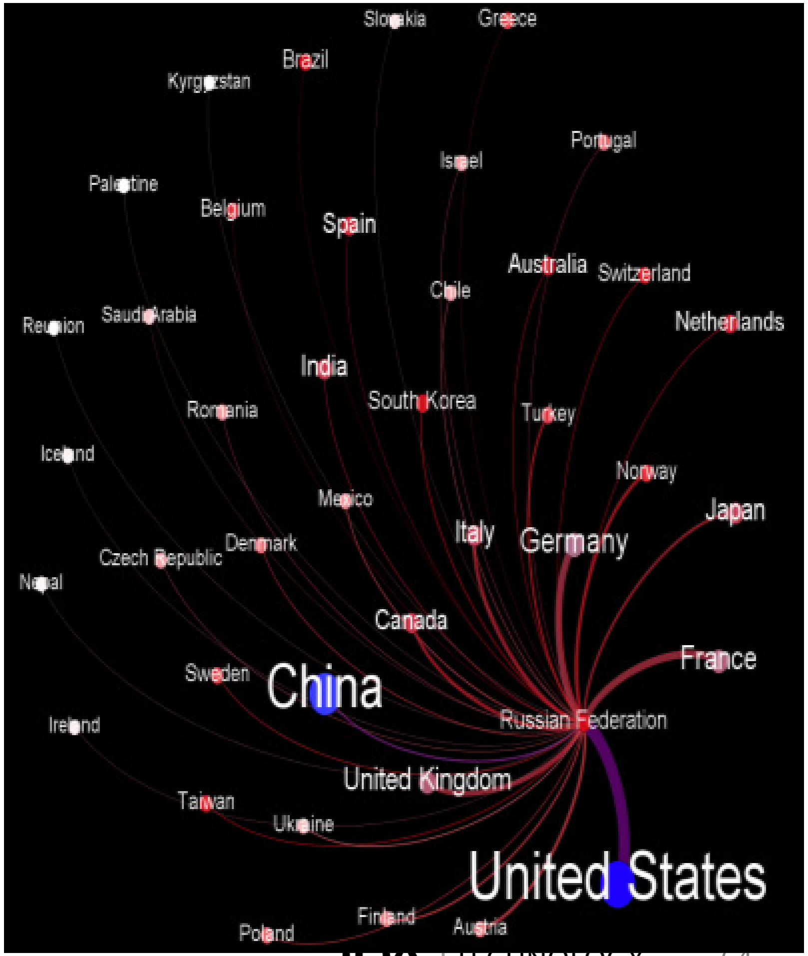


IDA SCIENCE AND TECHNOLOGY POLICY INSTITUTE

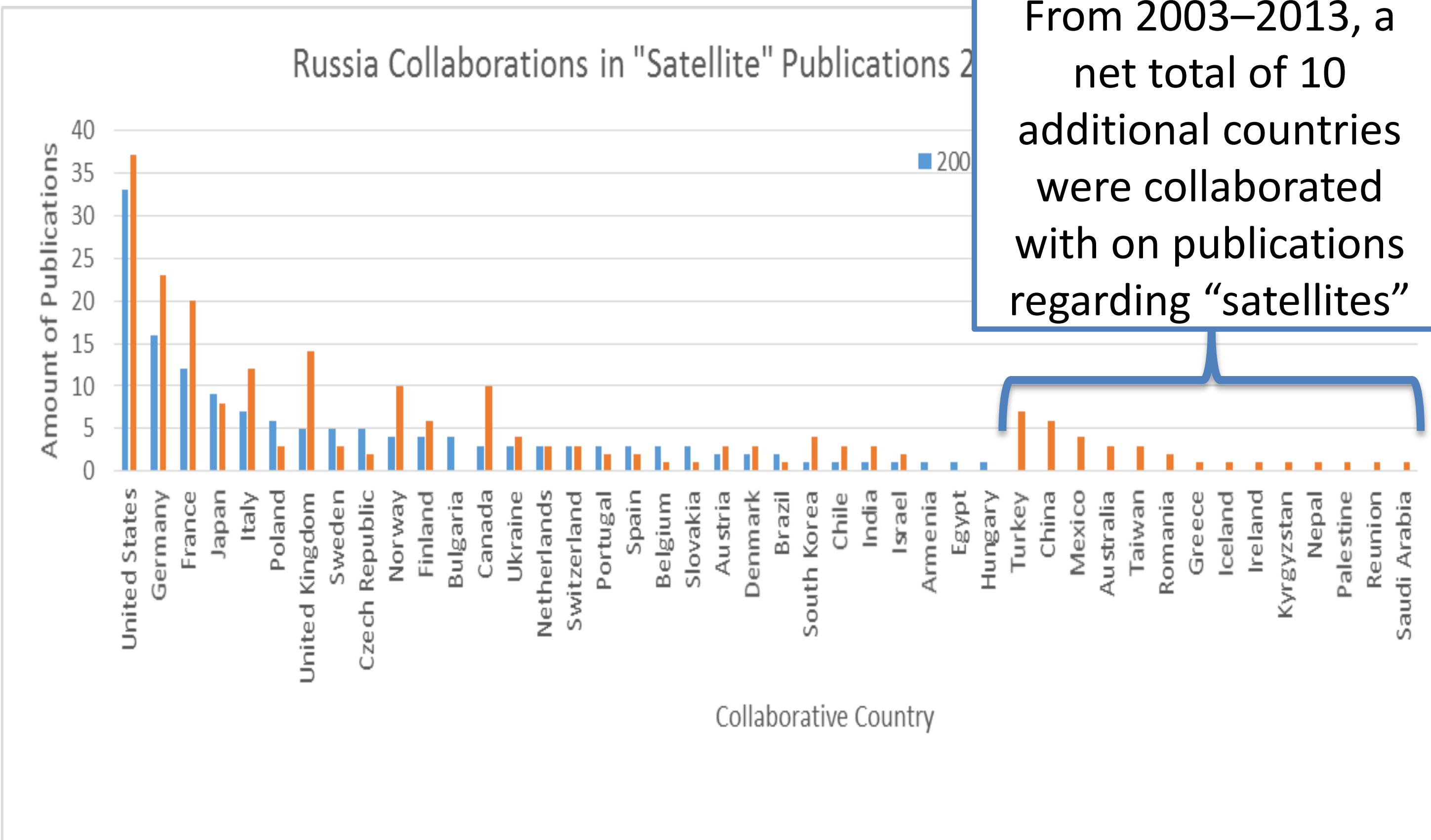
Russia Has Had a Small Increase in the Number of Publications with Foreign Collaborators in "Satellites"

2003 Russia 2013





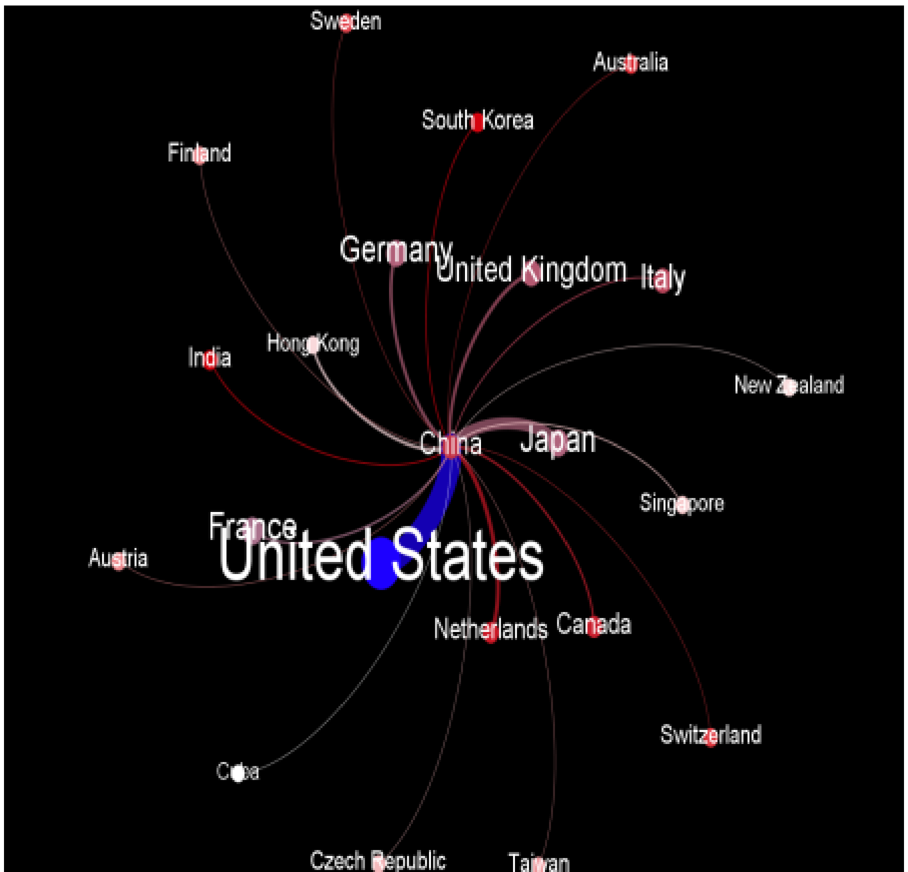
Russia, 2003–2013

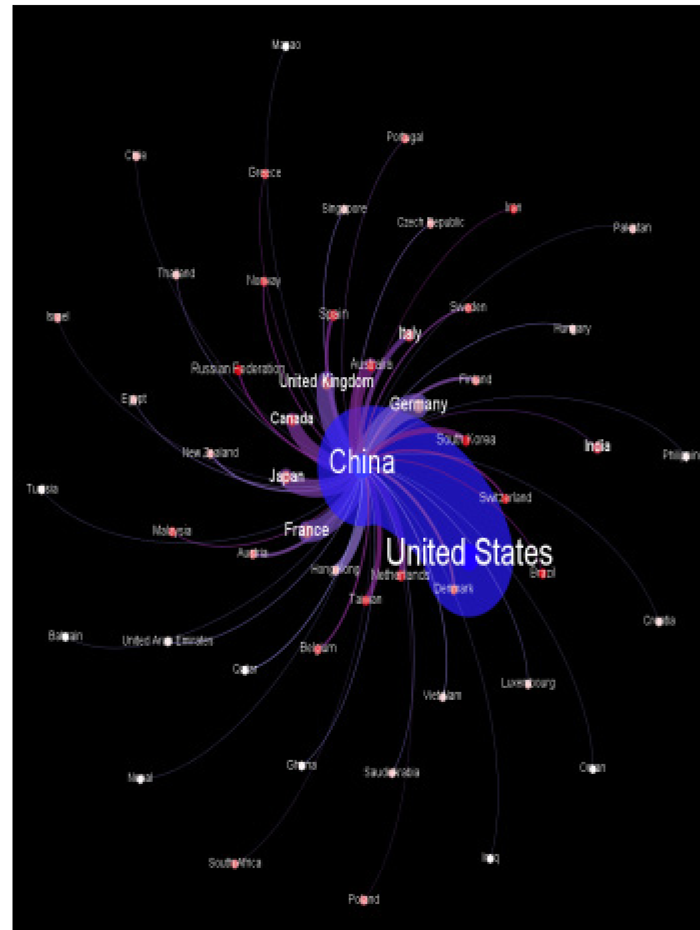


From 2003–2013, a net total of 10 additional countries were collaborated with on publications regarding "satellites"

China Publishes with the United States More Than with Any Other Country

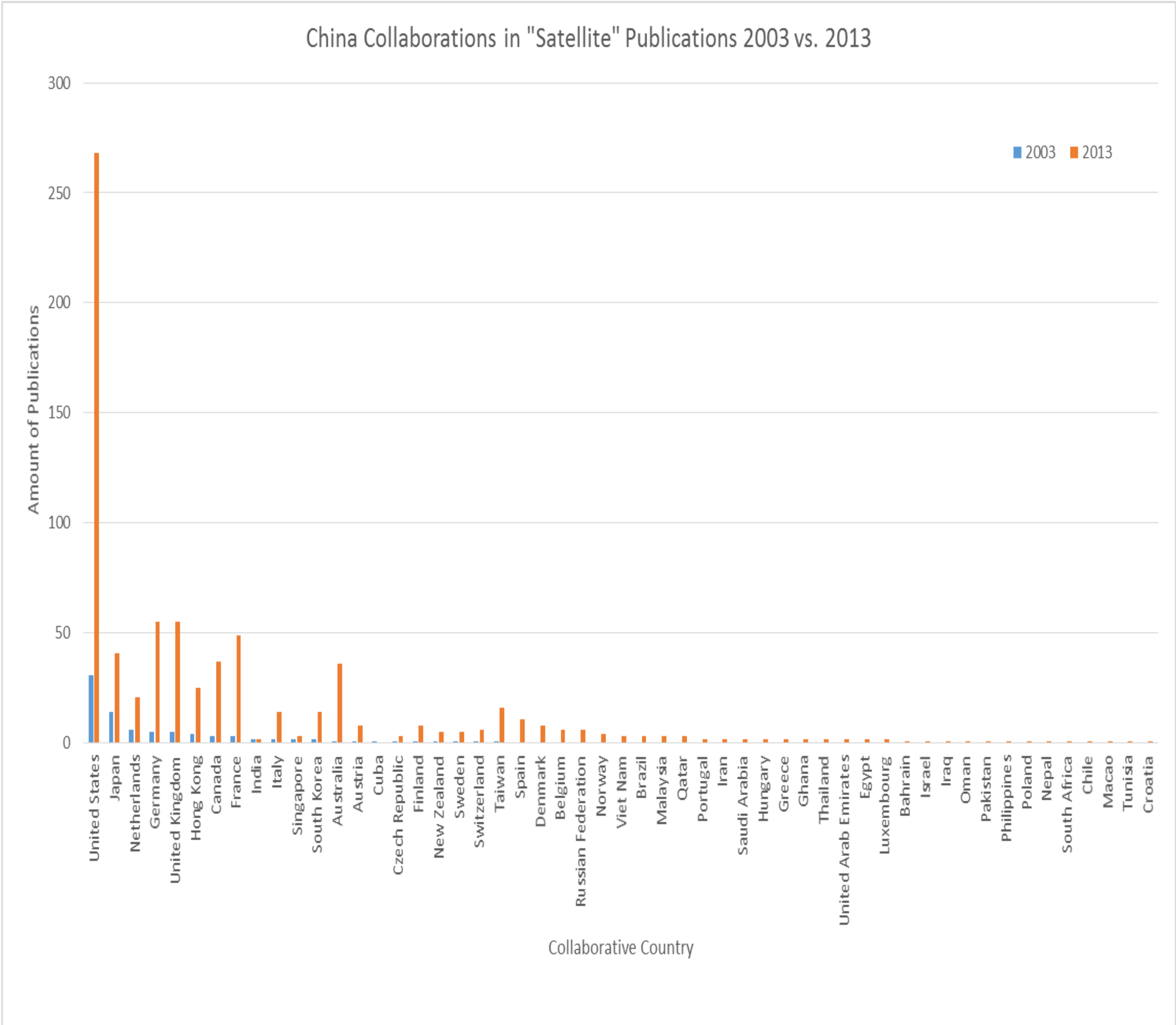
2003 China 2013





POLICY INSTITUTE

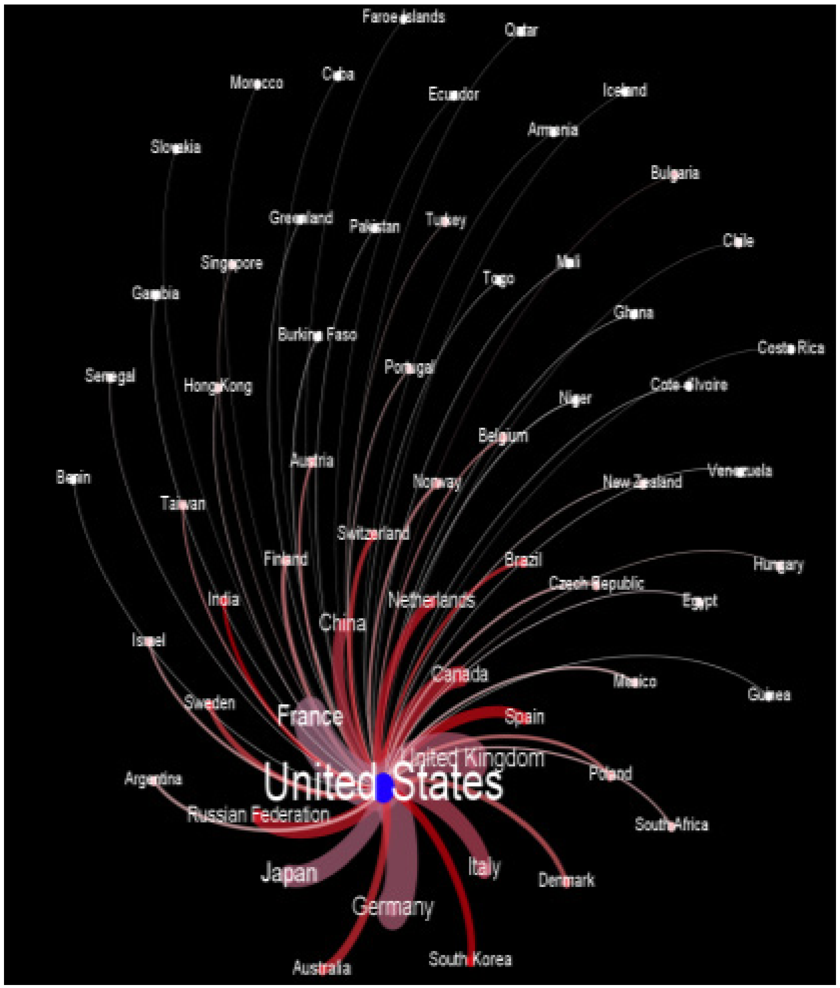
China, 2003–2013

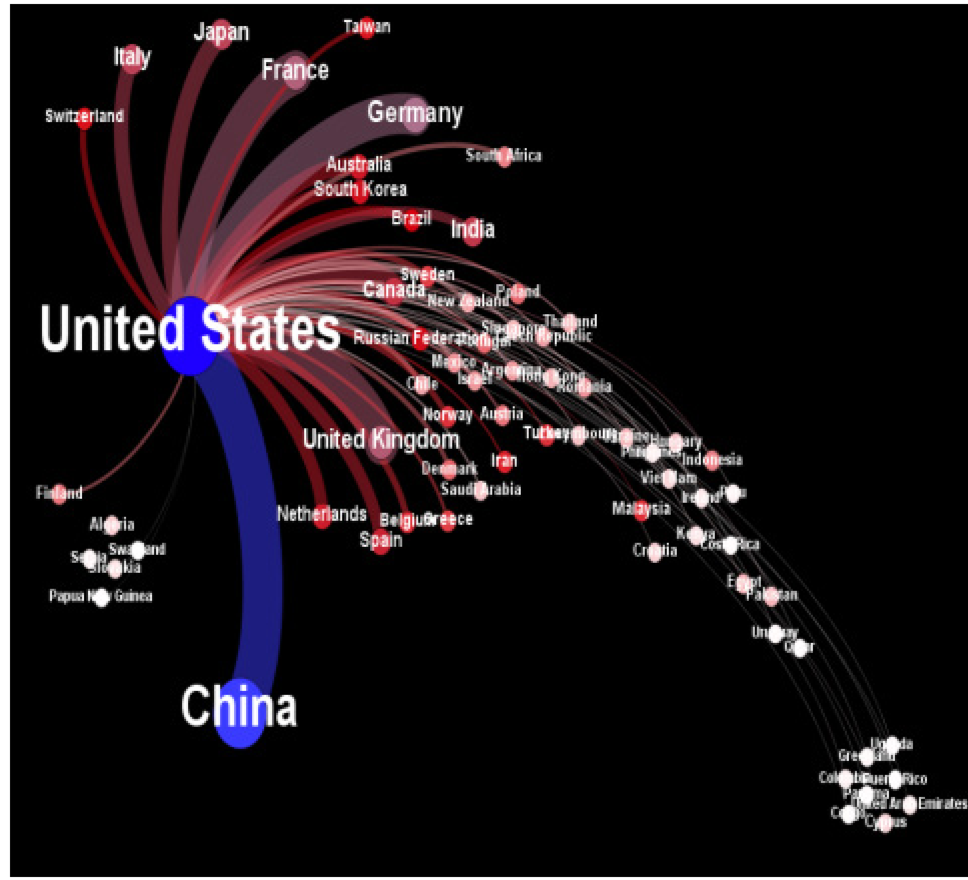


CE AND
IOLOGY
Y INSTITUTE

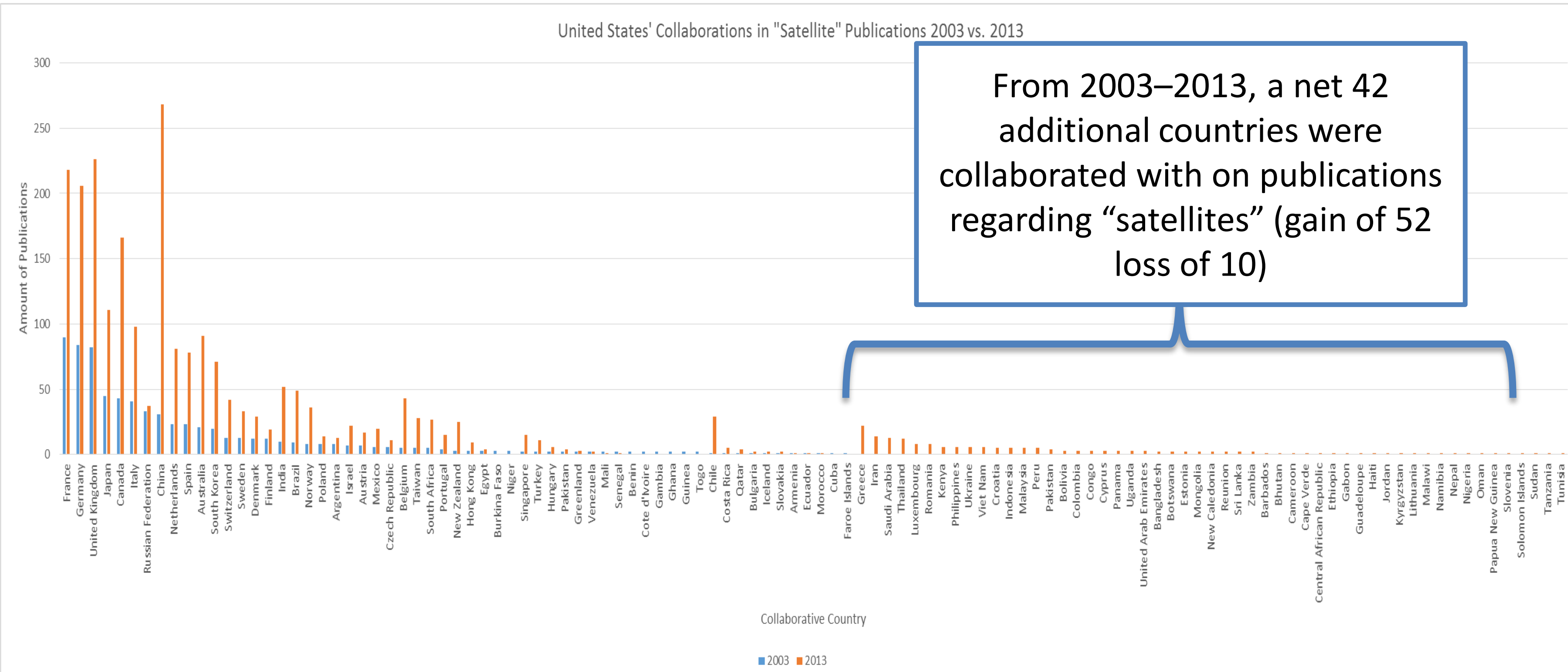
U.S. Collaborations with a Country Are Roughly Proportional to the Number of Publications by that Country

2003 United States 2013





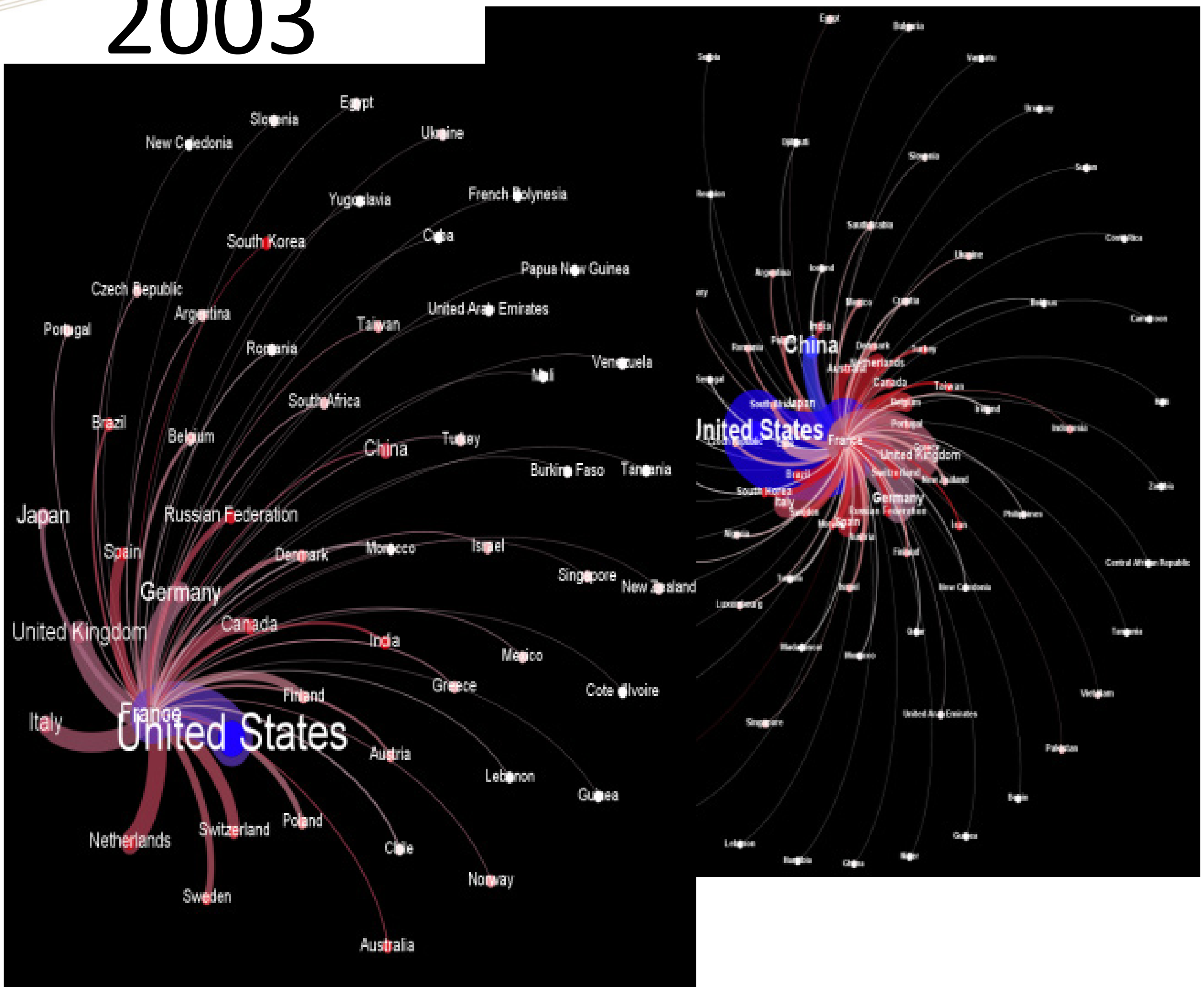
United States, 2003–2013



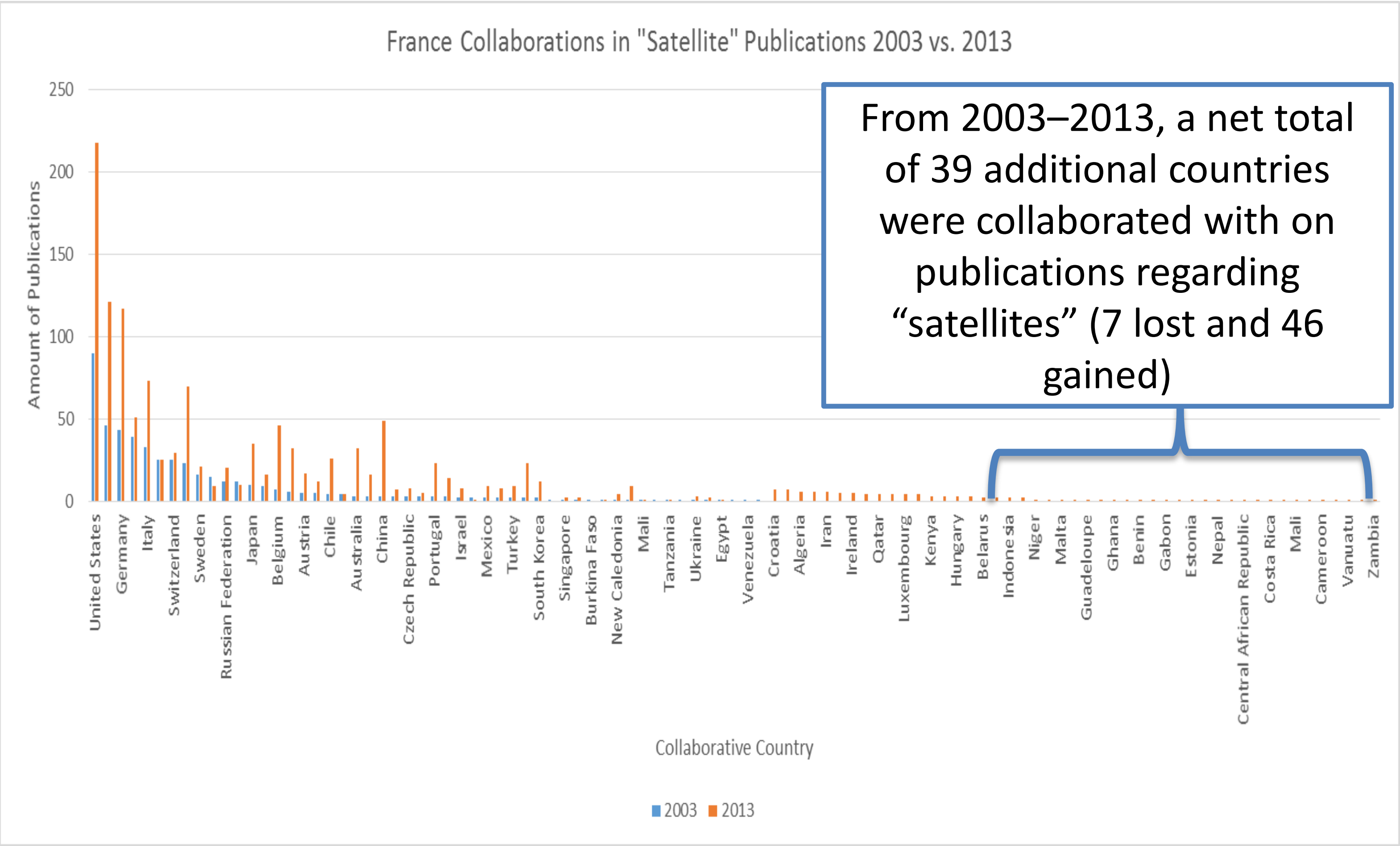
France Publication in “Satellites”

2003

2013

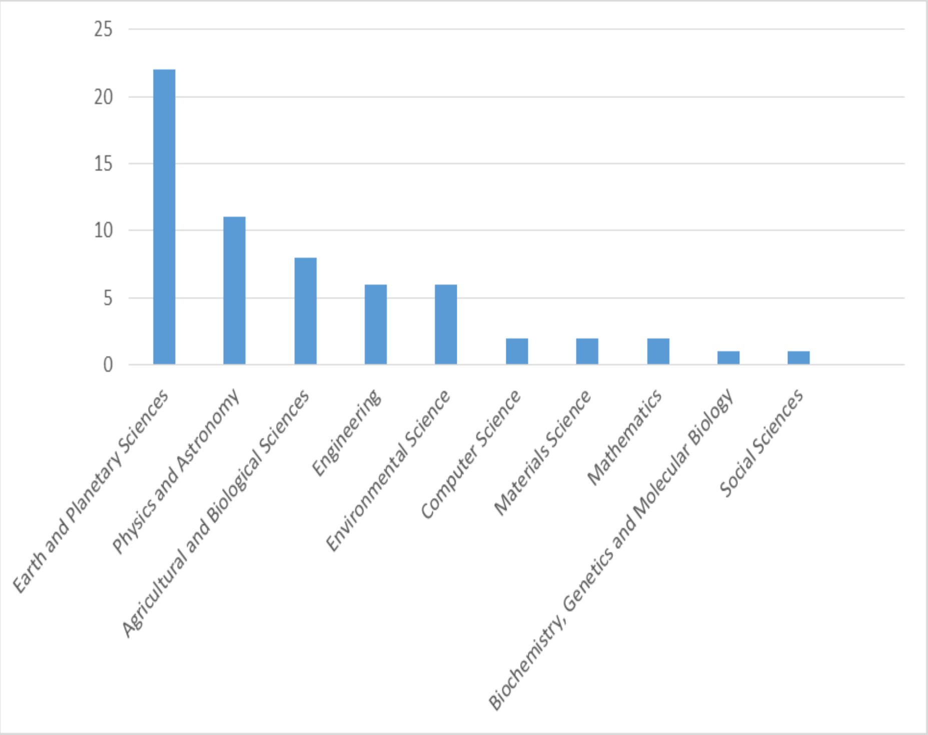


France, 2003–2013



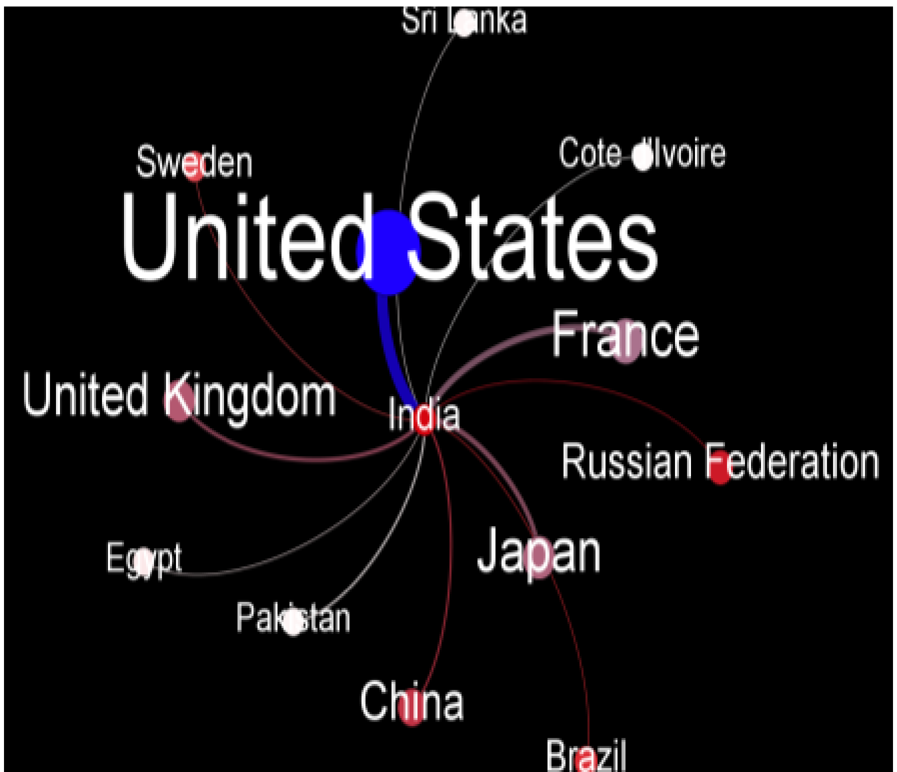
Brazil: France Collaborations in 2013 by Subject Area and Secondary Keywords

The Secondary Keywords are:
Remote sensing (11)
Satellite imagery (9)
Satellite data (8)
.....

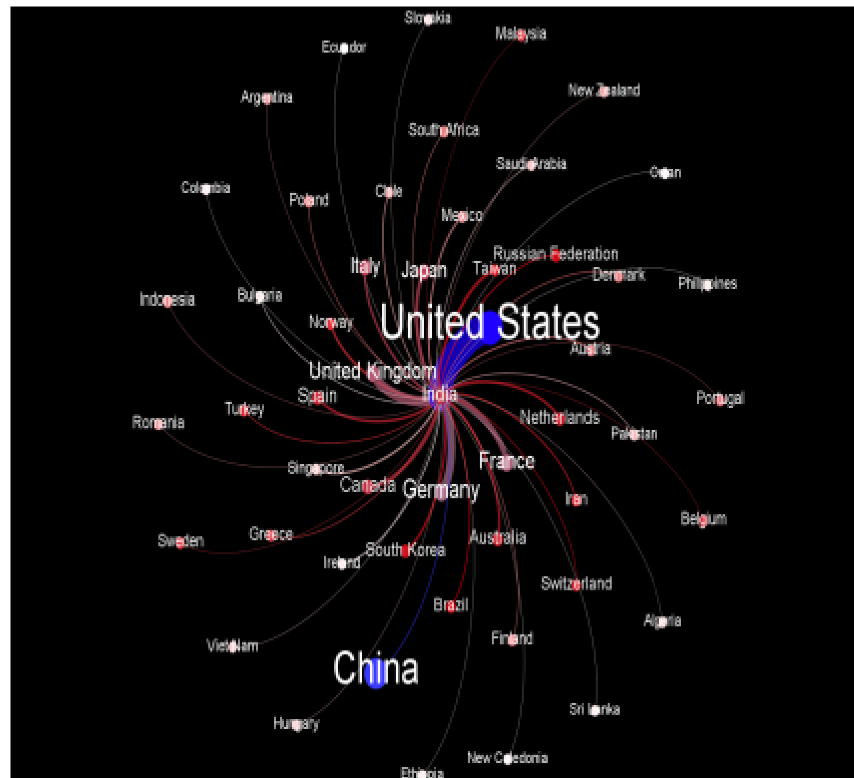


India Publication in “Satellites”

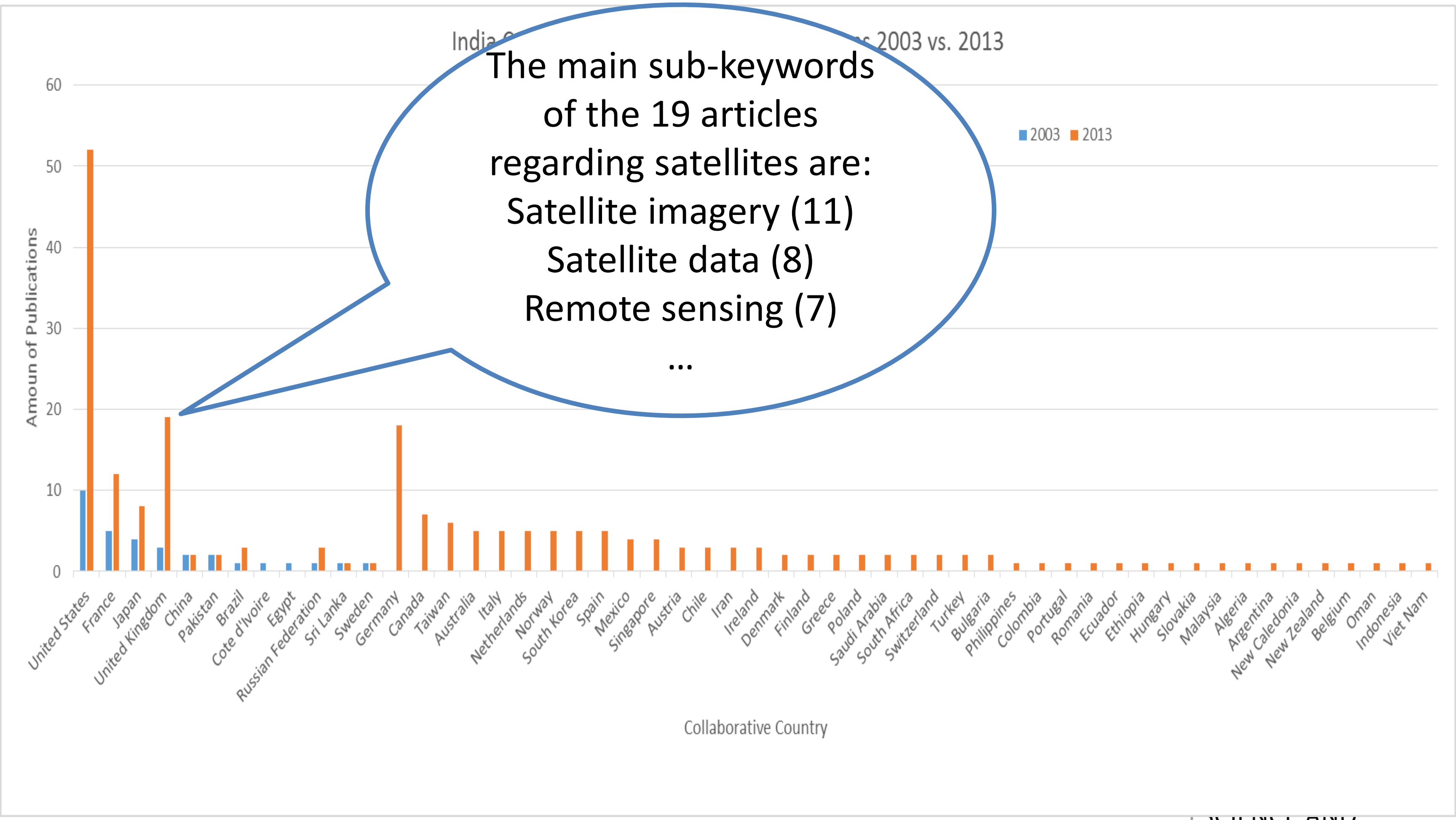
2003



2013



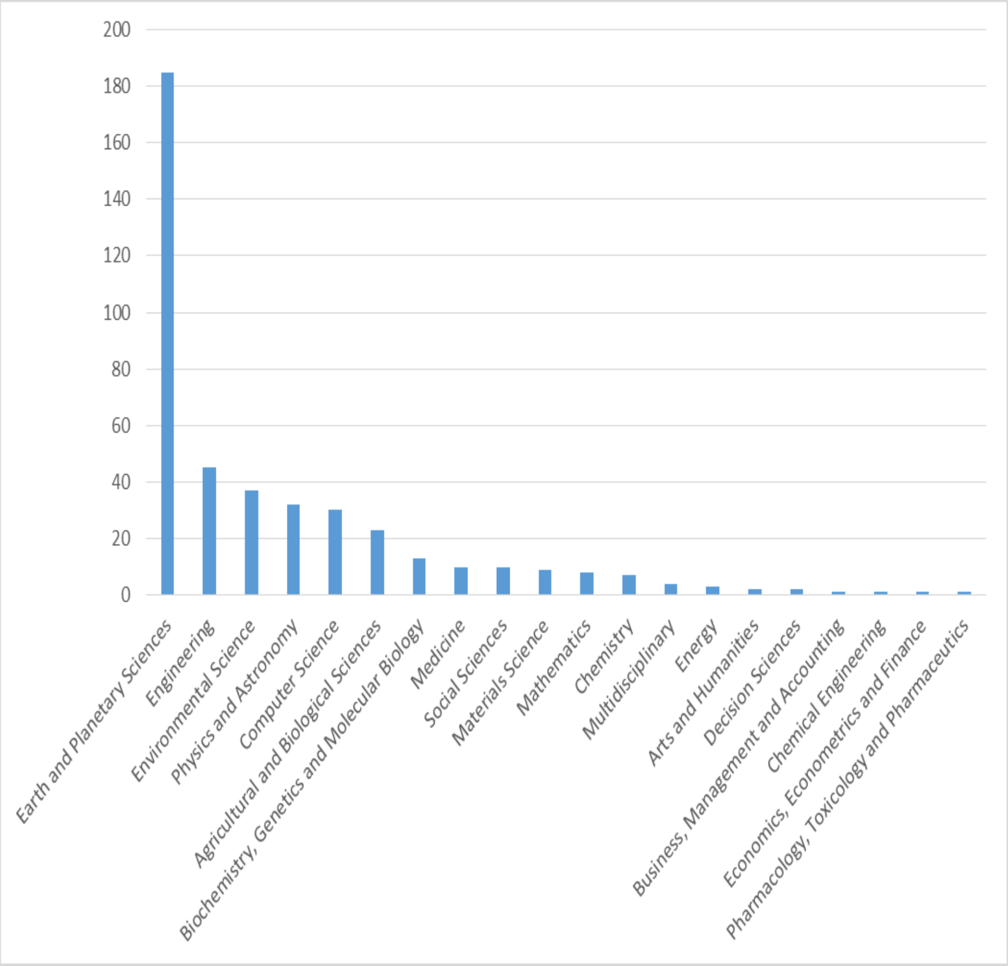
India, 2003–2013



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

The Secondary Keywords are:

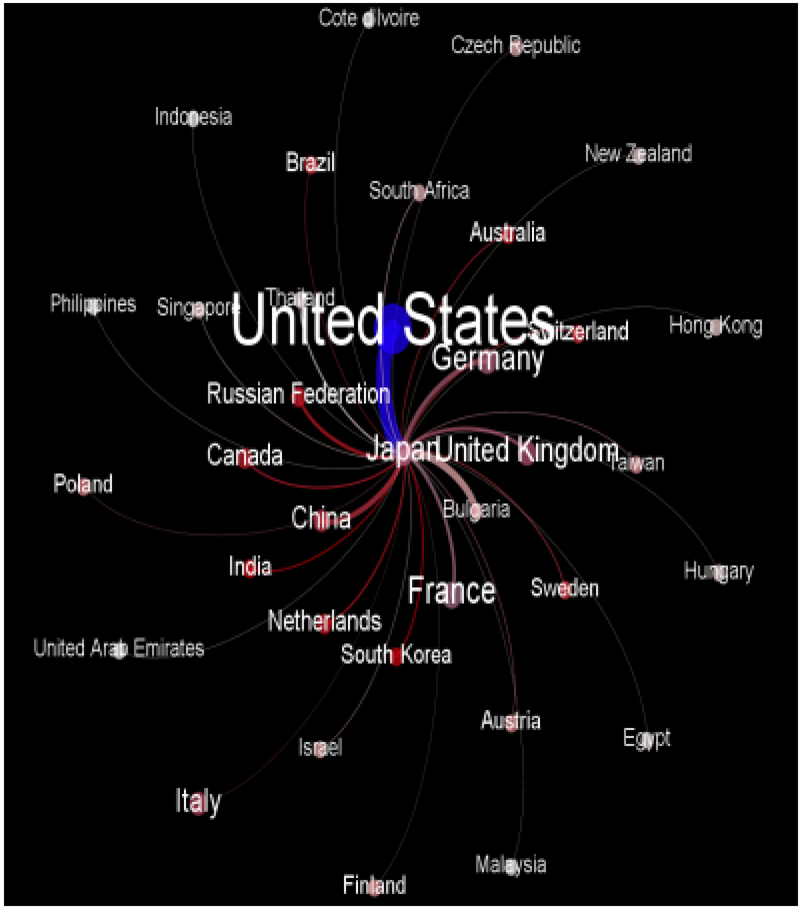
Satellite imagery (98)
Remote sensing (72)
Satellite data (68)
Algorithm(s) (68)
Radiometers (32)
…..

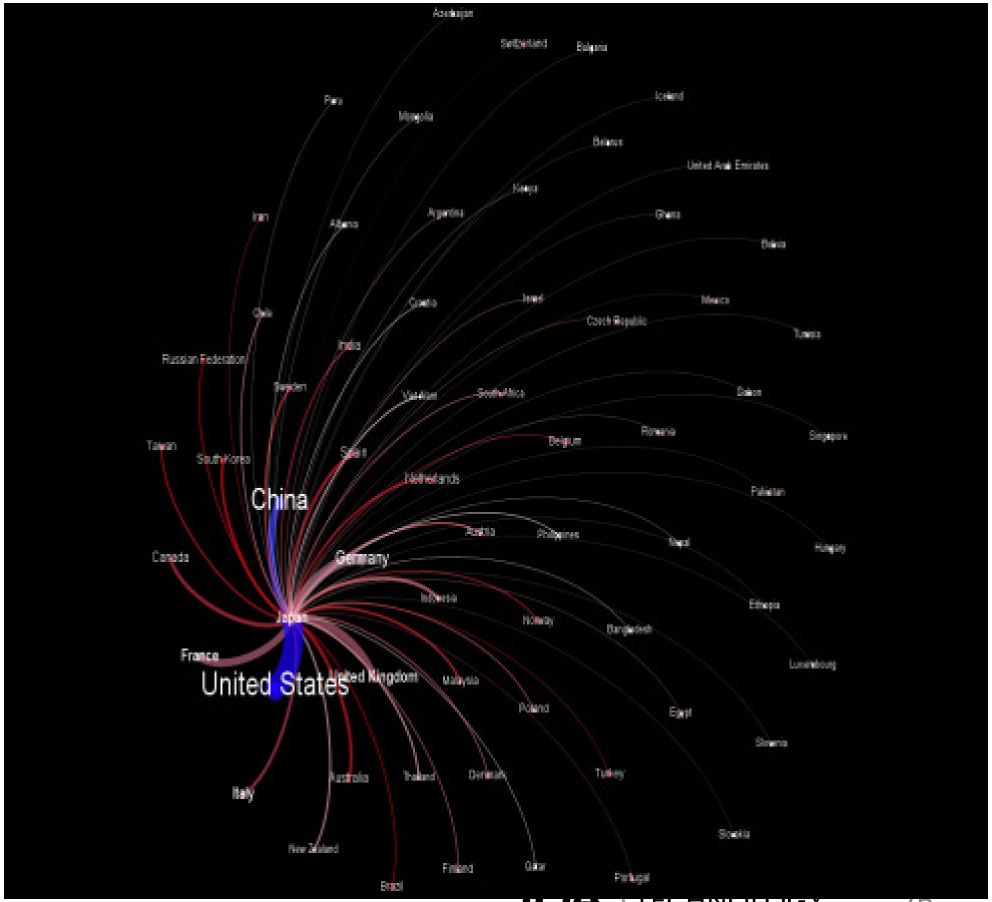


IDA SCIENCE AND TECHNOLOGY POLICY INSTITUTE

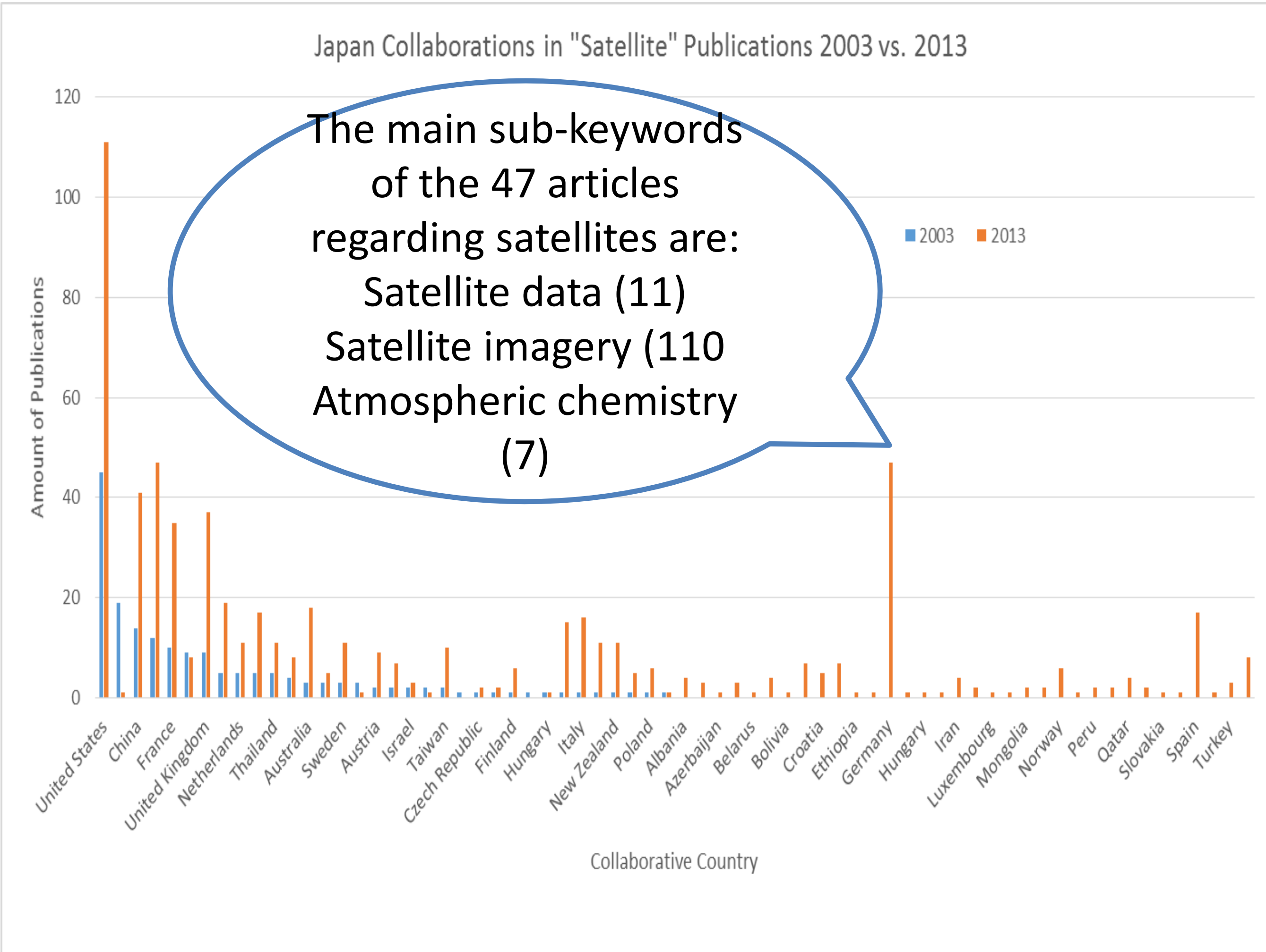
Japan Publication in "Satellites"

2003 2013





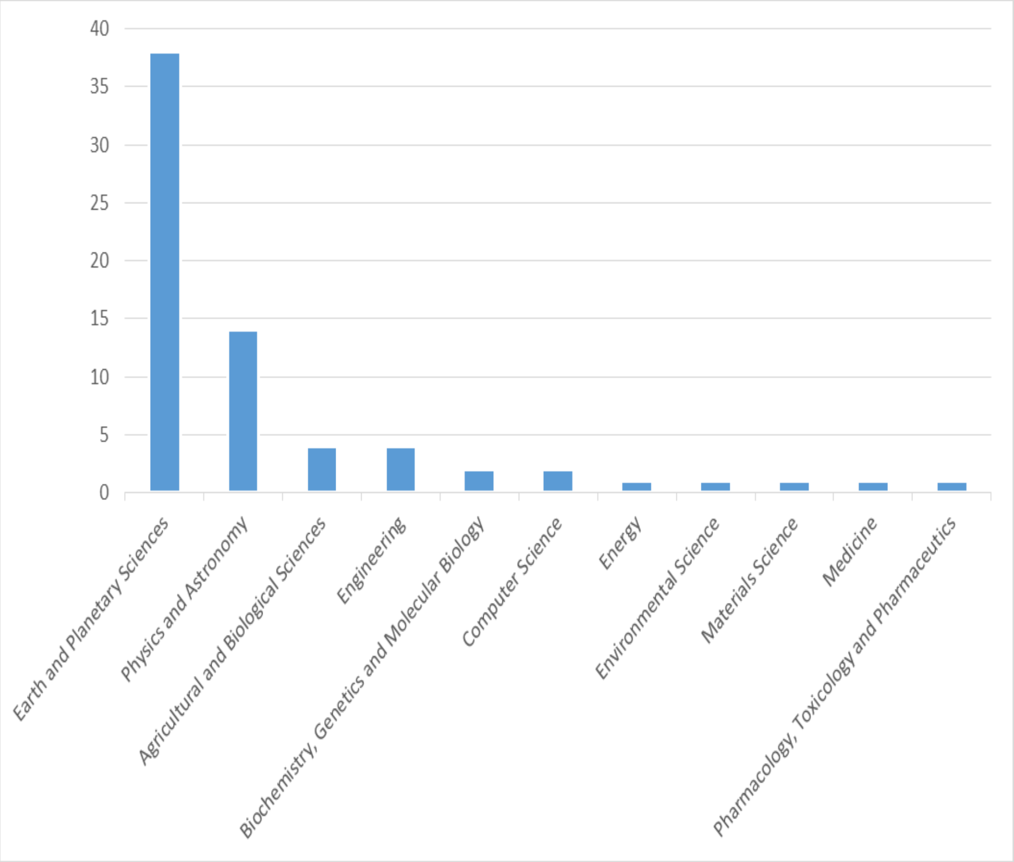
Japan, 2003–2013



Japan: Germany Collaborations in 2013 by Subject Area and Secondary Keywords

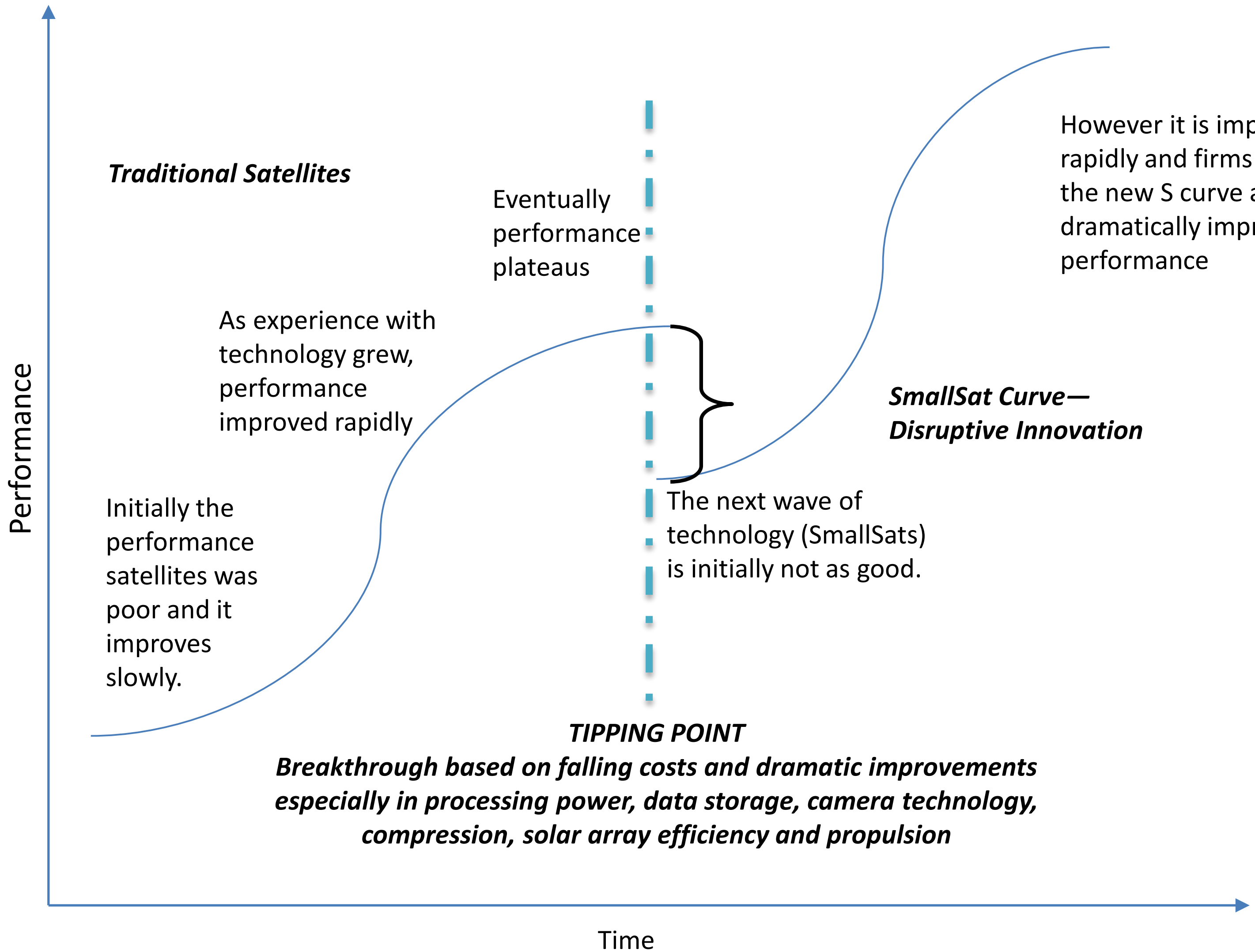
The Secondary Keywords are:

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



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.

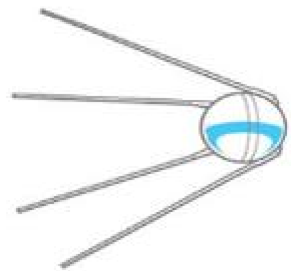
1957

SPUTNIK 1

First artificial satellite

MASS: 83.6 kilograms

SIZE: 58-centimeter-diameter sphere, with whiskerlike antennas measuring 2.4 and 2.9 meters



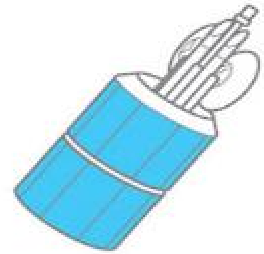
1971

INTELSAT 4 F-3

International communications satellite

MASS: 1410 kg

SIZE: 5.3 meters long, with antenna



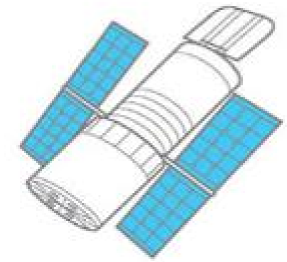
1990

HUBBLE SPACE TELESCOPE

World's most massive space telescope

MASS: 11 110 kg

SIZE: 13.2 meters long



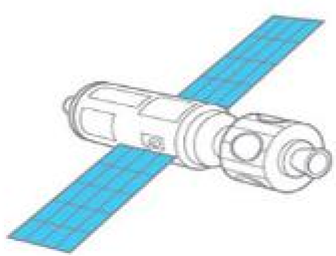
1998

ZARYA

First International Space Station module

MASS: 19 323 kg

SIZE: 12.6 meters long



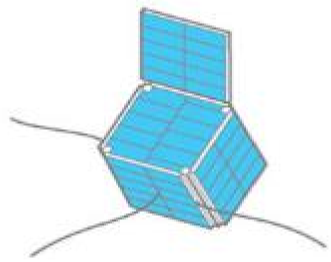
2003

CUTE-1

One of the first standardized miniature CubeSats

MASS: 1 kg

SIZE: 10-cm-wide cube



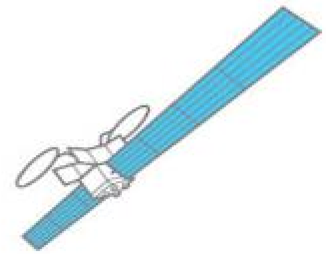
2005

XM-3

Commercial radio satellite

MASS: 2800 kg

SIZE: 47.9 meters from the end of one solar panel to the other



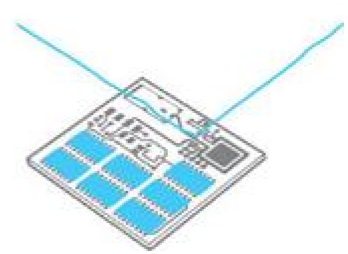
2011

SPRITE PROTOTYPES

Test chips attached to International Space Station

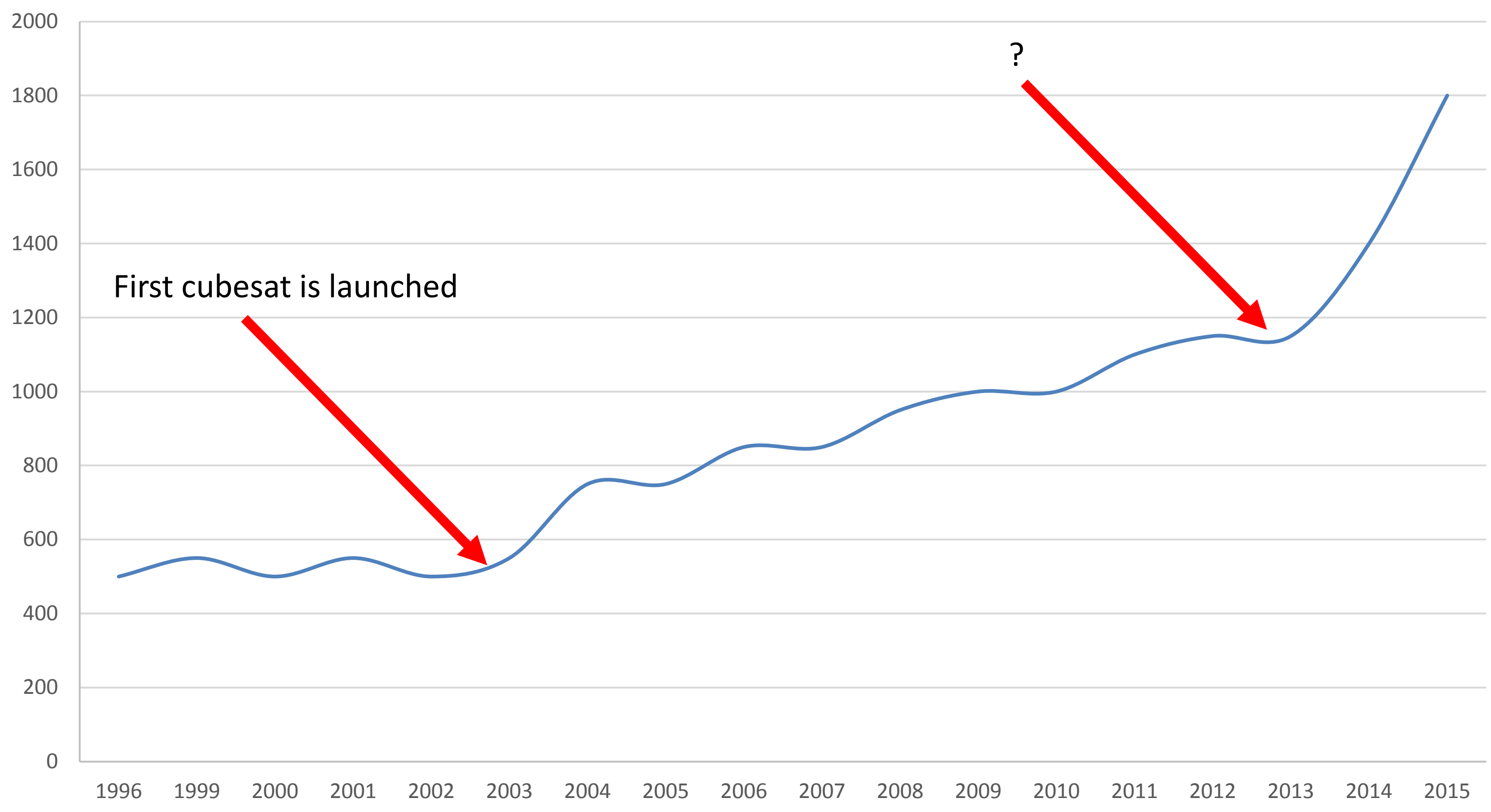
MASS: 10 grams

SIZE: 3.8- by 3.8-cm boards



A microcosm (SmallSats)

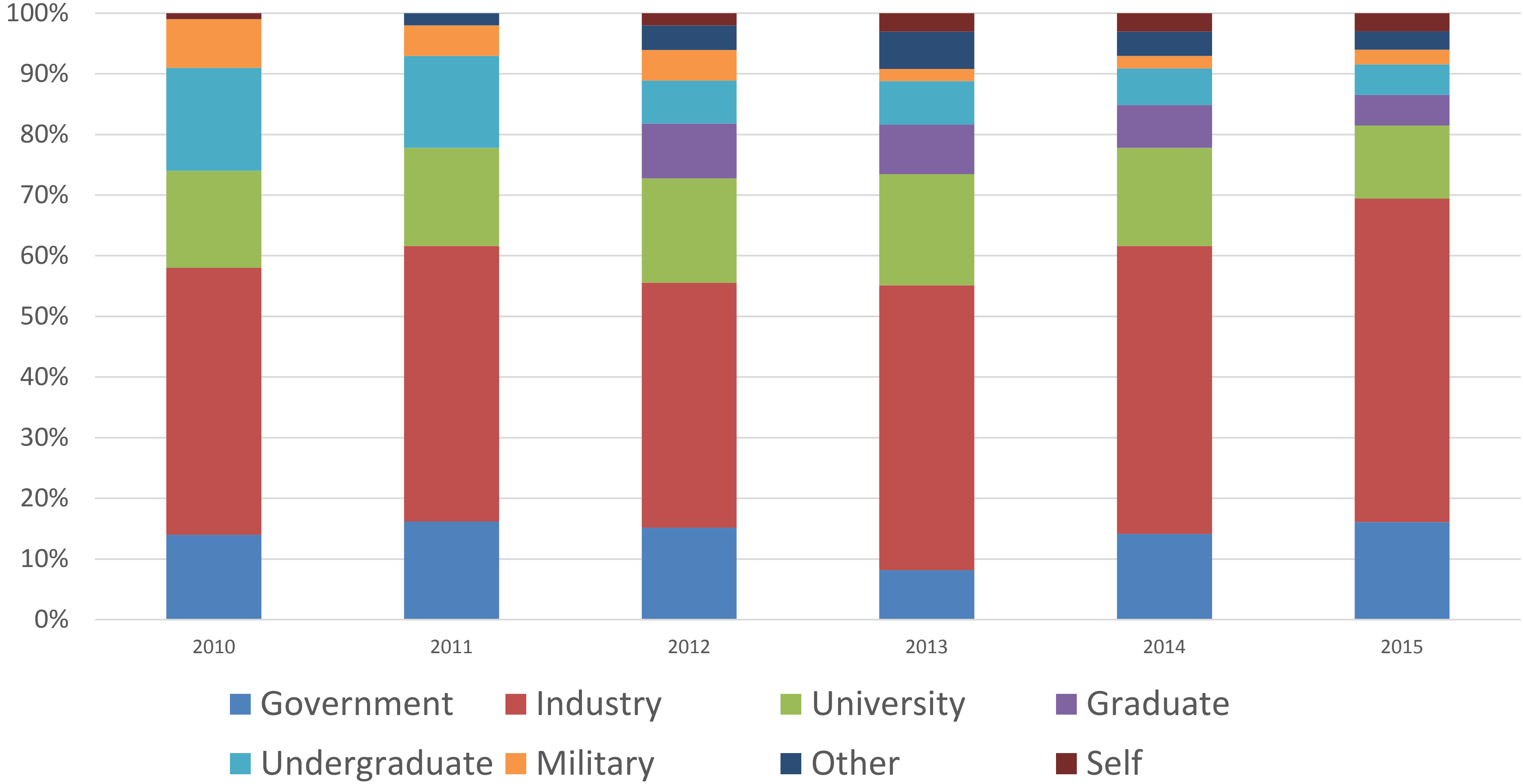
Attendance at SmallSat Utah conference



Attendance at SmallSat Utah conference has tripled

Attendance at SmallSat Utah Conference

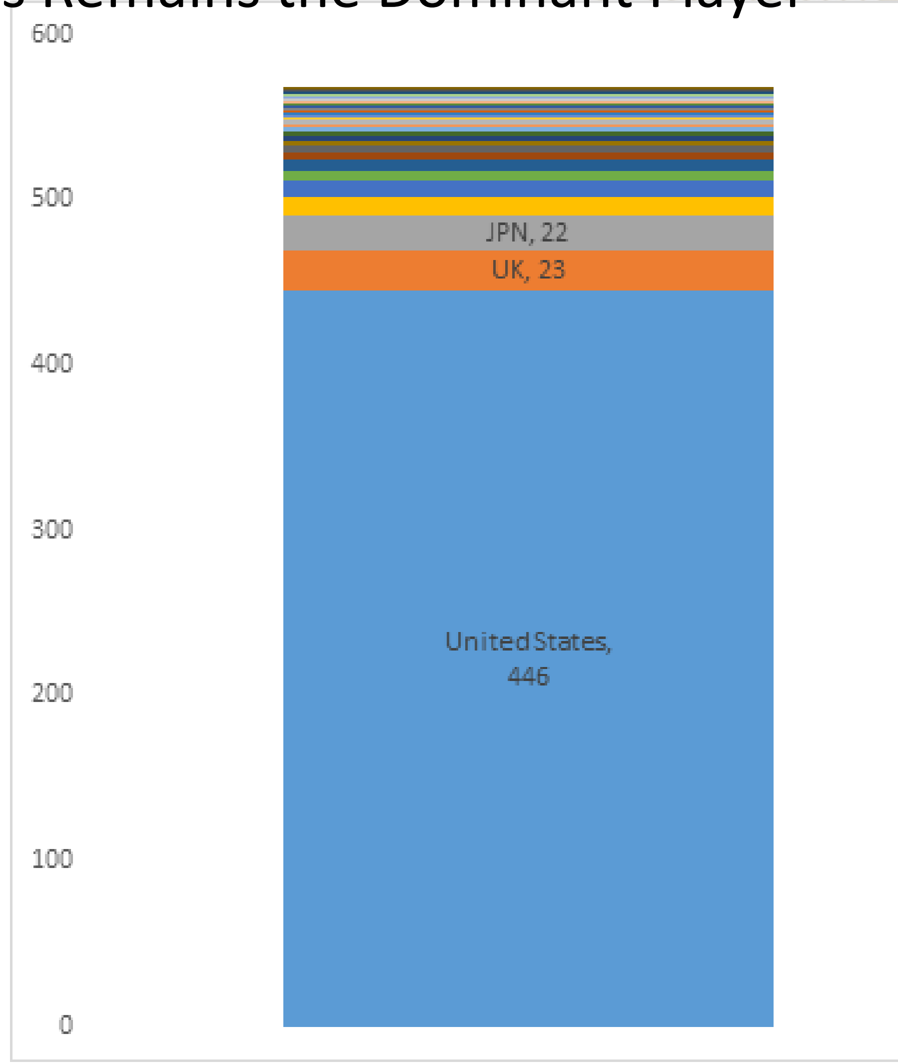
Industry Has Been the Major Participant



Attendance at SmallSat Utah Conference

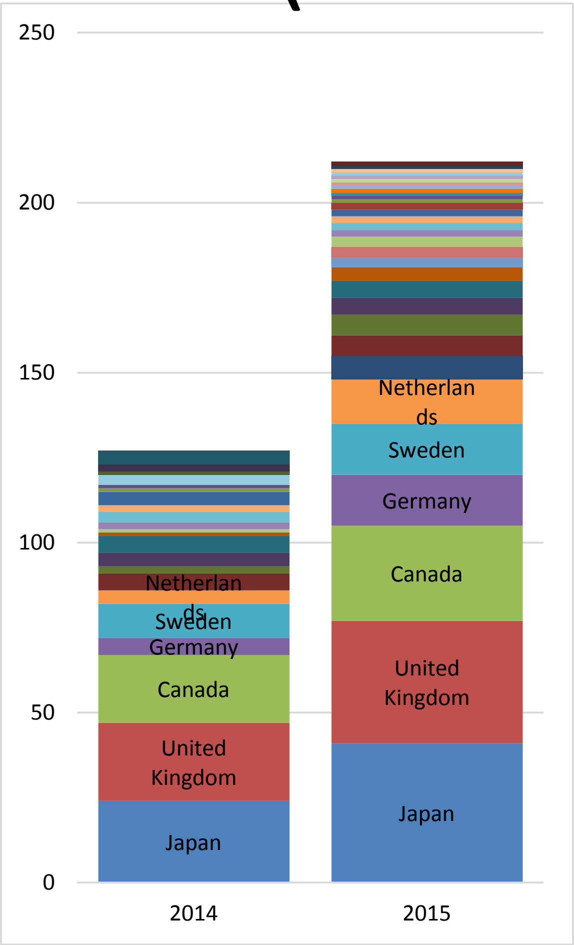
Within industry, the United States Remains the Dominant Player

- ~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*

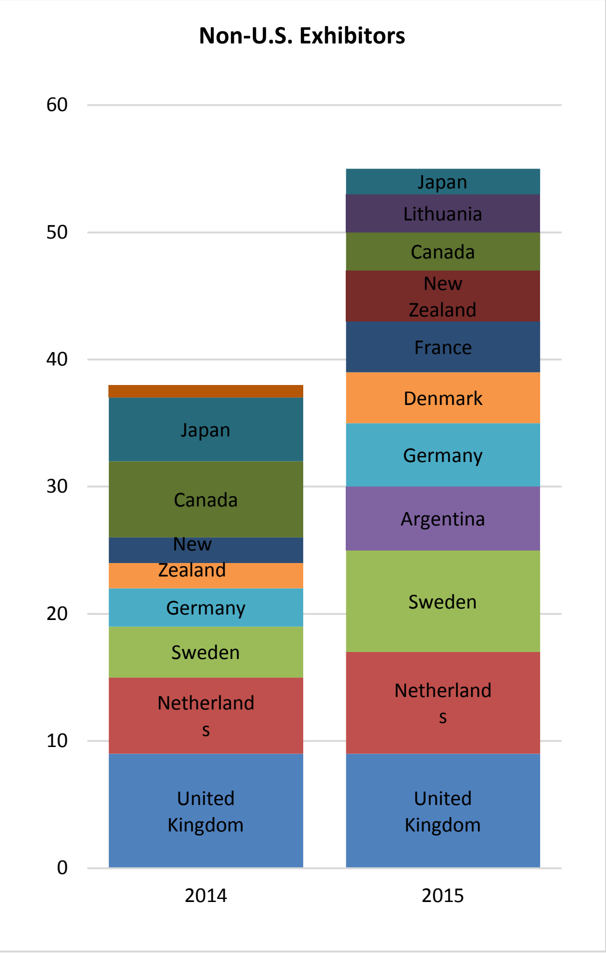


New Attendees in 2015

- 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)

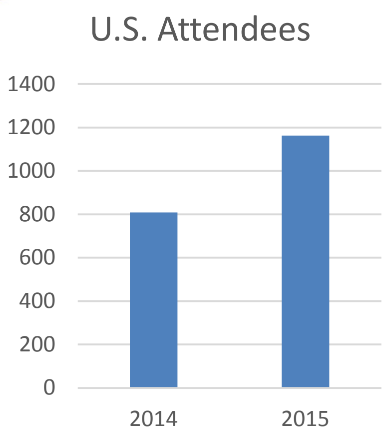
- United States dominates
  - 85% of attendees and exhibitors have U.S. affiliations (slight increase from 14-15)
- Interest in SmallSats growing
  - 46% increase in attendance at the annual Logan UT SmallSat meeting (938 to 1374 registered attendees)
    - U.S. participation up 44%
    - Non-U.S. participation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

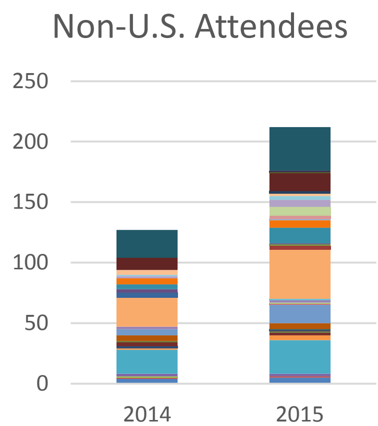


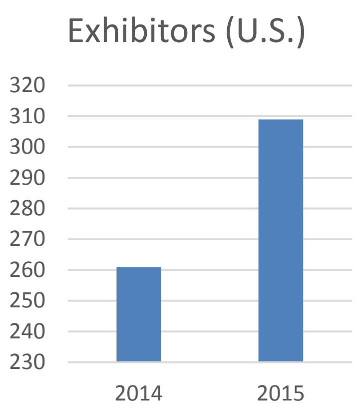
New Exhibitors in 2015

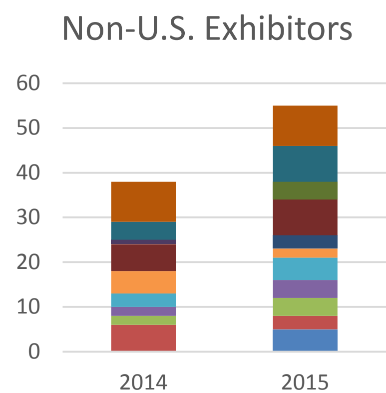
- Argentina (5)
- Lithuania (3)
- New Zealand (4)

United States Dominates but Growing International Participation









<u>New Attendees in 2015</u>

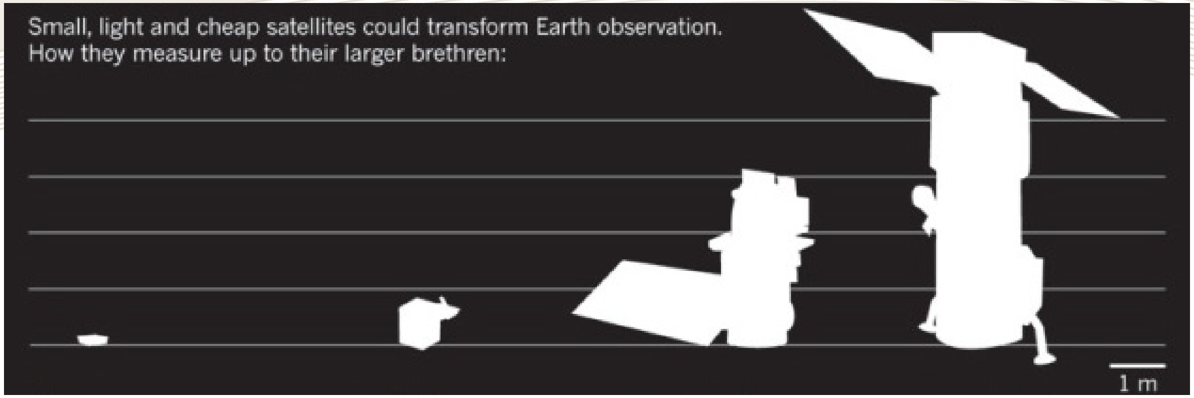
- Estonia (1)
- Finland (1)
- India (1)
- Ireland (1)
- Italy (1)
- Lithuania (3)
- Luxembourg (1)
- Oman (1)
- Pakistan (3)
- Russia (7)
- Spain (2)
- Taiwan (1)
- Turkey (1)

*Belgium (1), Colombia (2) and Kazakhstan (4) participated in 2014 but not 2015

<u>New Exhibitors in 2015</u>

- Argentina (5)
- Lithuania (3)
- New Zealand (4)
- *Norway (1) participated in 2014 but not 2015

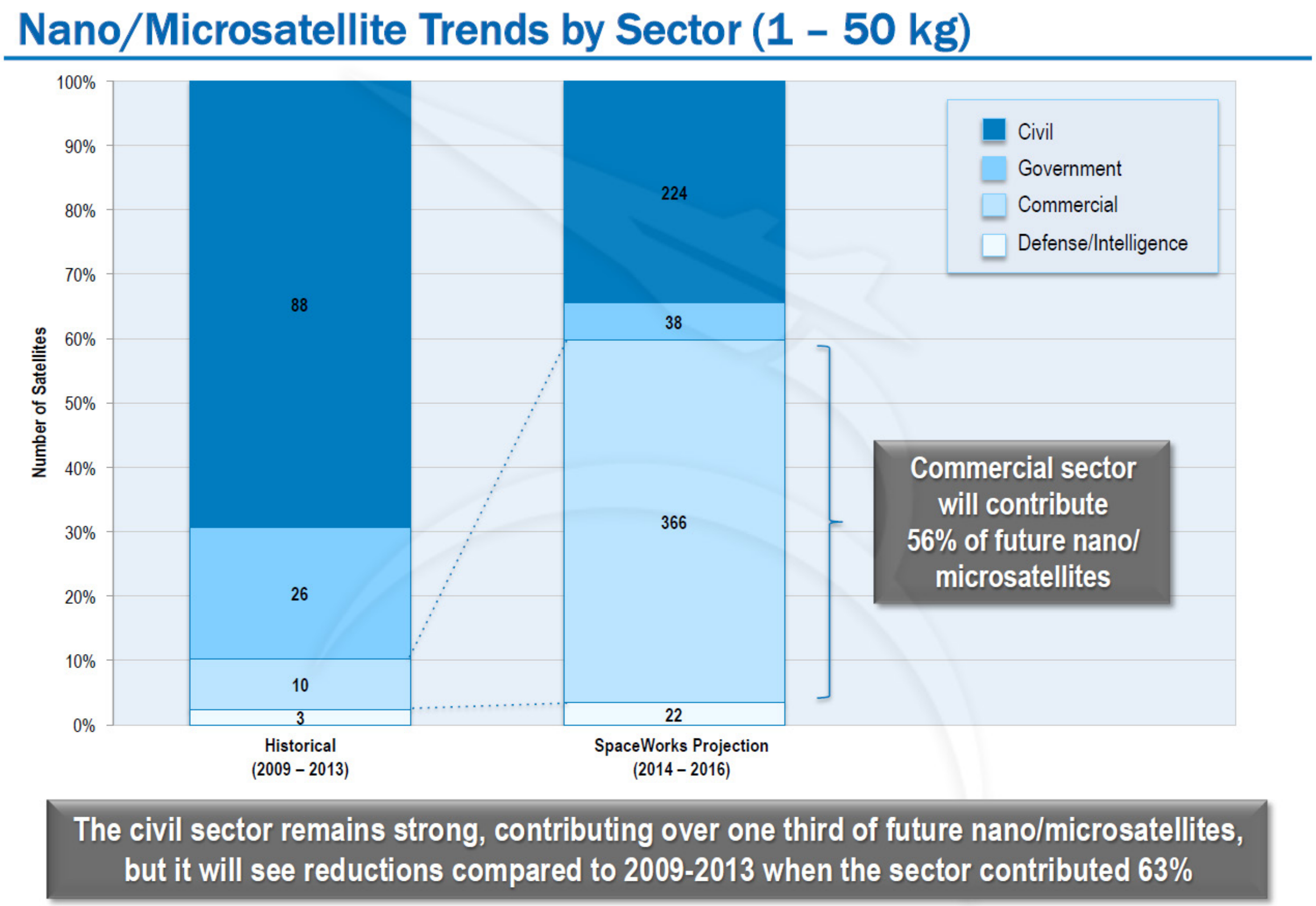
Data from the 29th Annual AIAA/USU Conference on Small Satellites



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

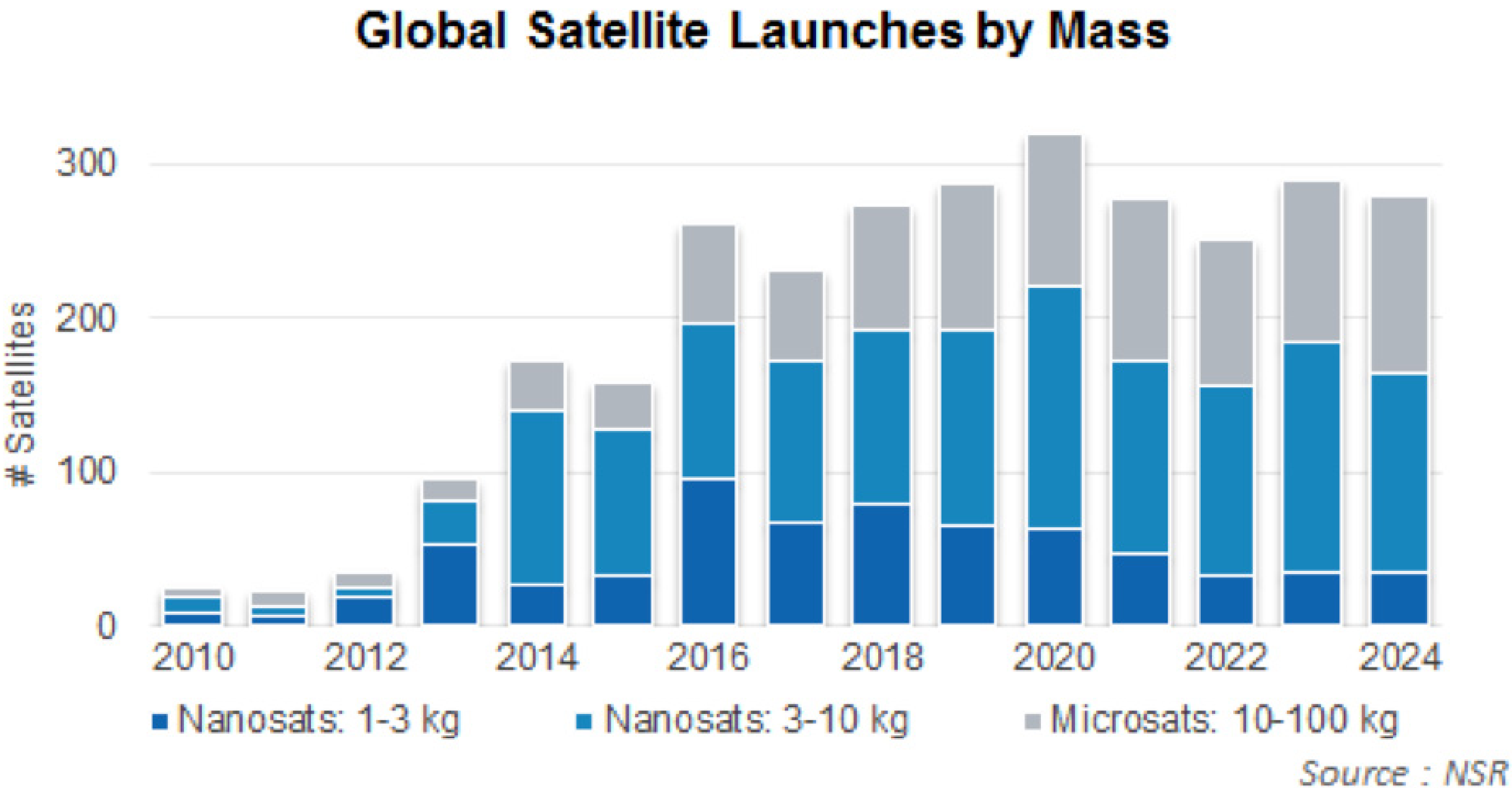
Source: Adams (2014), 1 Harwood (2013), 2 de Selding (2015f).

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



2014 Nano / Microsatellite Market Assessment
Copyright 2014, SpaceWorks Enterprises, Inc. (SEI)

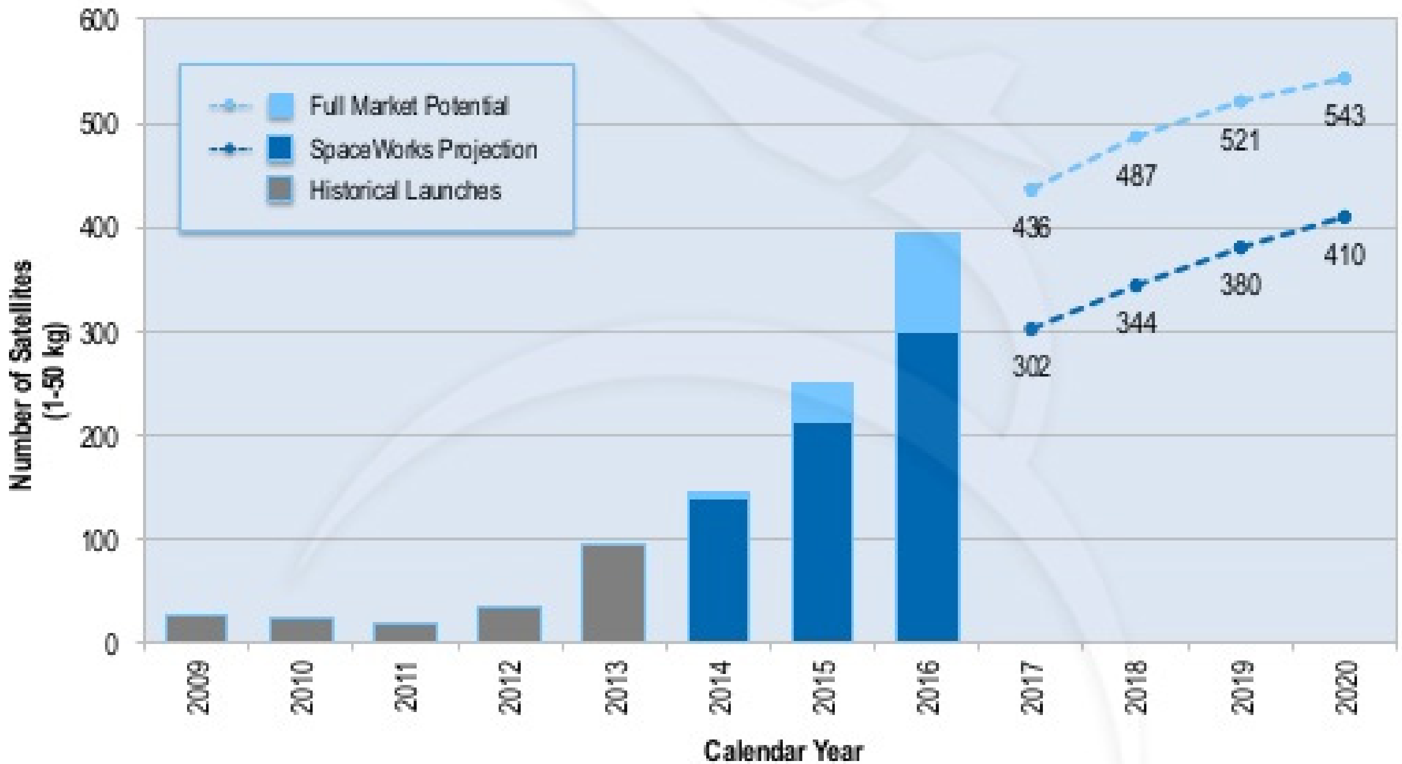
Growing Role of Nano/Microsats in the Near Future



http://www.nsr.com/news-resources/the-bottom-line/mass-challenge-for-cubesats/

Nano/Microsatellite Launch History and Projection (1 - 50 kg)

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 publically 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.

SpaceWorks

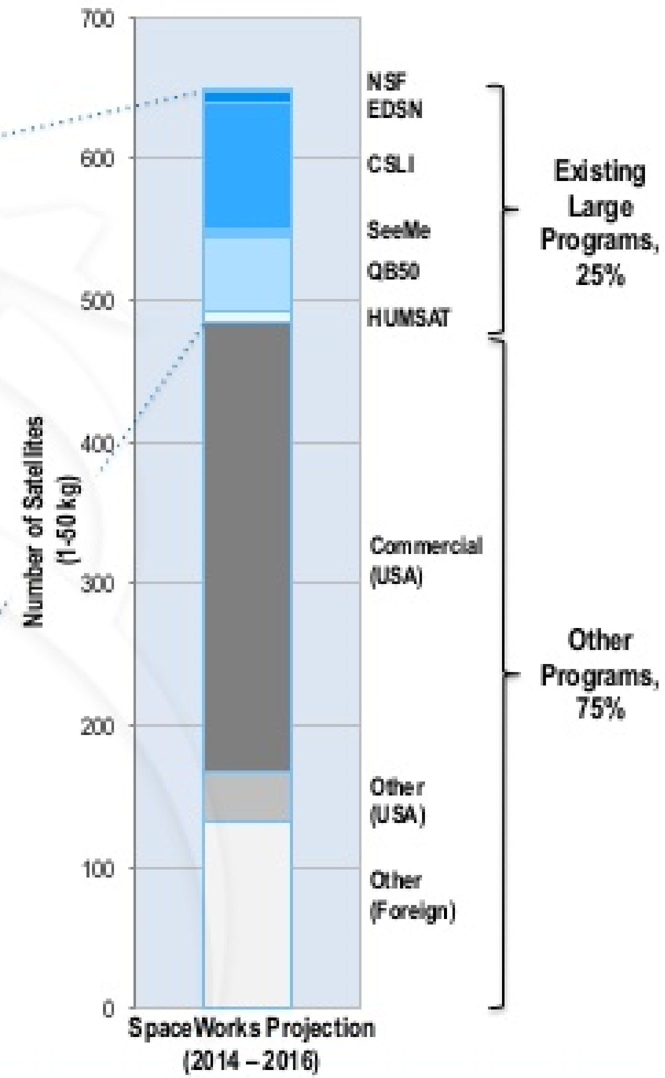
Source:: 2014 Nano / Microsatellite Market Assessment, 2014, SpaceWorks Enterprises, Inc.
http://www.slideshare.net/prateepbasu/nano-and-microsatellite-market-assessment2014

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

Large Program Breakdown for Announced Future Satellites

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

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

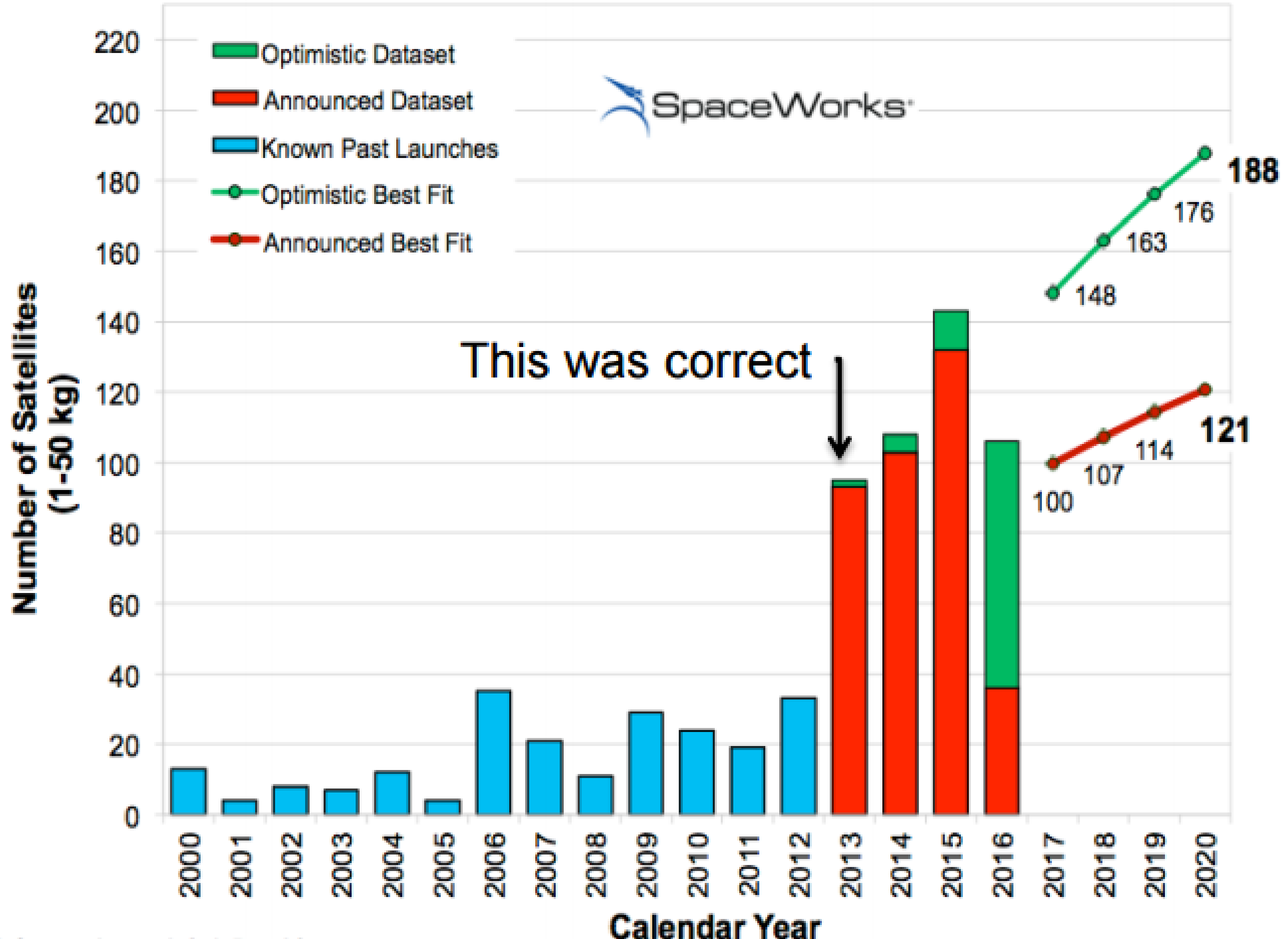


* Assumes two NSF Geospace & Atmospheric CubeSat satellites selected in 2014. NASA CubeSat Launch Initiative total includes the sixteen missions chosen in February 2014 (in response to August 2013 Announcement of Opportunity) and the timeframe listed is based on when the already selected CubeSats are scheduled to launch. QB50 total includes two precursor satellites.
Please see EndNotes 2, 3, 4, 6, and 7.

Source:: 2014 Nano / Microsatellite Market Assessment, 2014, SpaceWorks Enterprises, Inc.
http://www.slideshare.net/prateepbasu/nano-and-microsatellite-market-assessment2014

Nano/Microsatellite Launch History and Projections

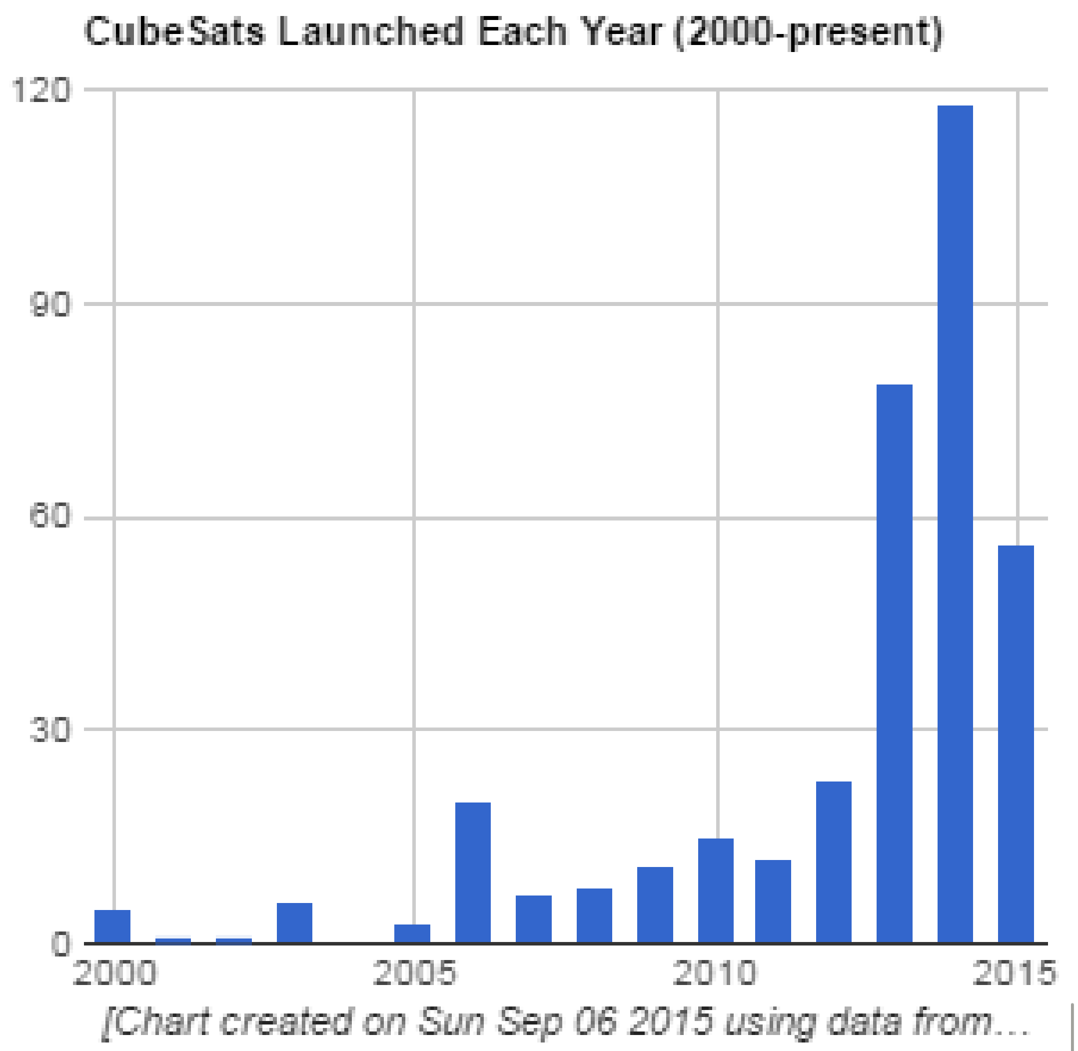
Projections based on the announced plans of nano/microsatellite developers and programs indicate a range of 121 to 188 nano/microsatellites requiring launch by 2020



Notes: Refer to end notes 1, 2, 4, 5, and 6.

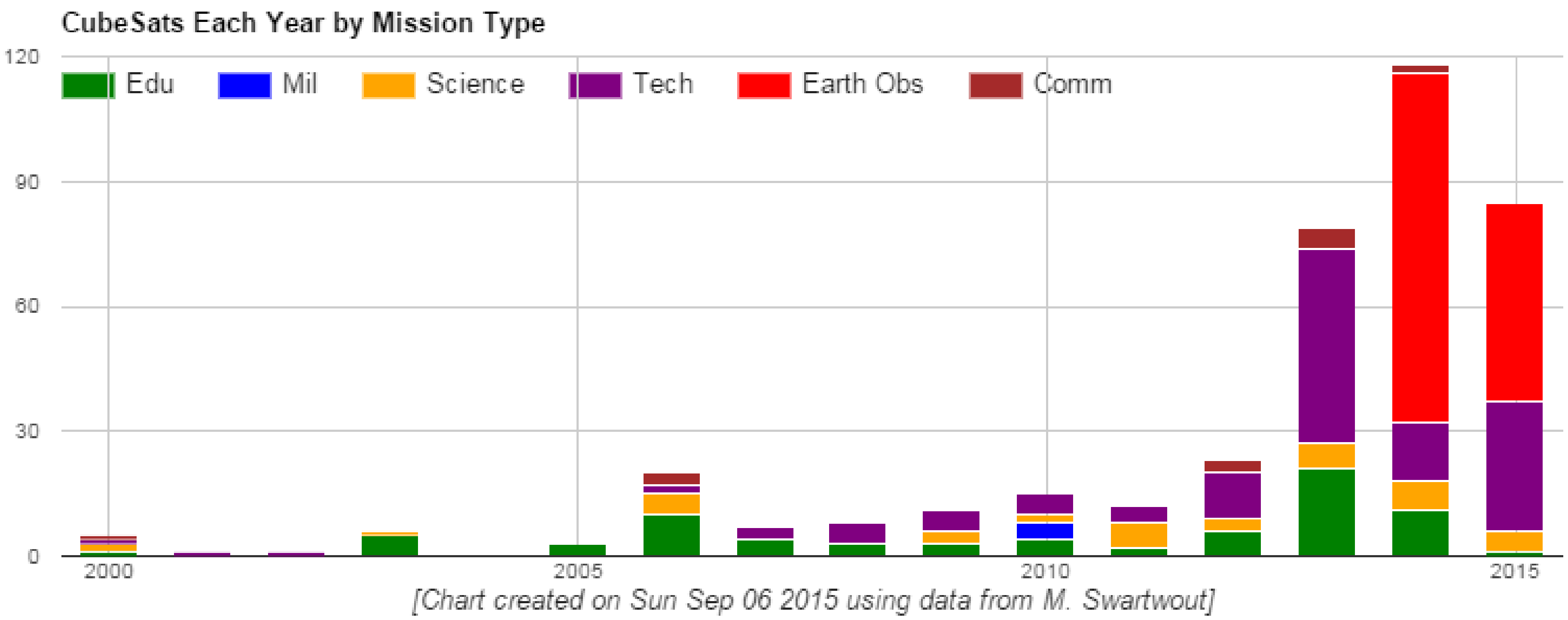
Source: file:///U:/A%20-%20STPI/NRC/NRC%20CubeSats/Industry/Jordi-ITU_prague_2015.pdf

Cubesat Launches Growing Dramatically



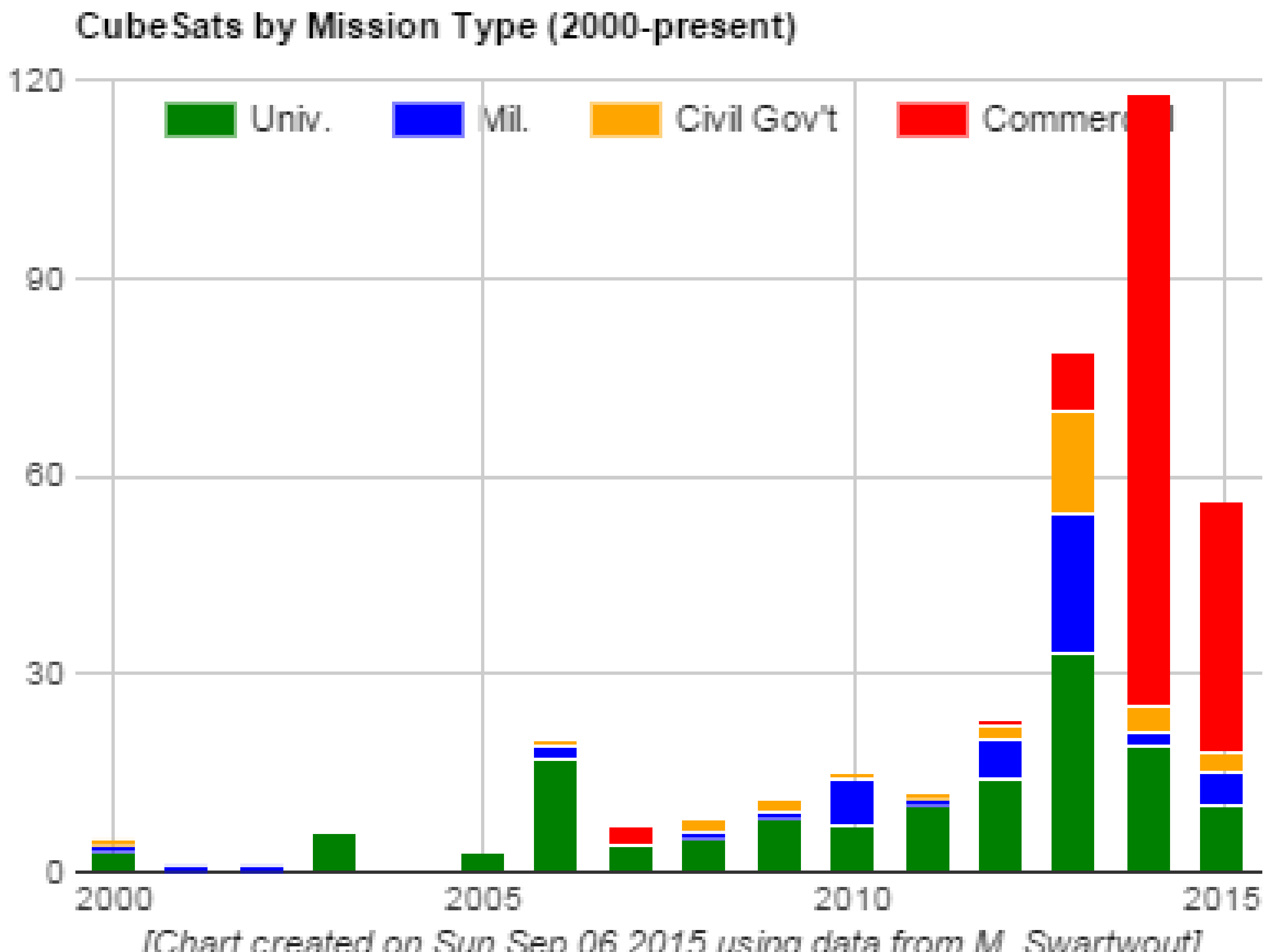
Source: https://sites.google.com/a/slu.edu/swartwout/home/cubesat-database

Earth Observation Is the Fastest Growing Application of Cubesats



Source: http://nepp.nasa.gov/workshops/eeesmallmissions/talks/11%20-%20THUR/1300%20-%20swartwout%20eee%20201409%20v2.pdf

Key Players in the Cubesat Community Are in the Private Sector



https://sites.google.com/a/slu.edu/swartwout/home/cubesat-database

(8) CHALLENGES THAT COME WITH GROWING PARTICIPATION AND DEPENDENCE ON SPACE

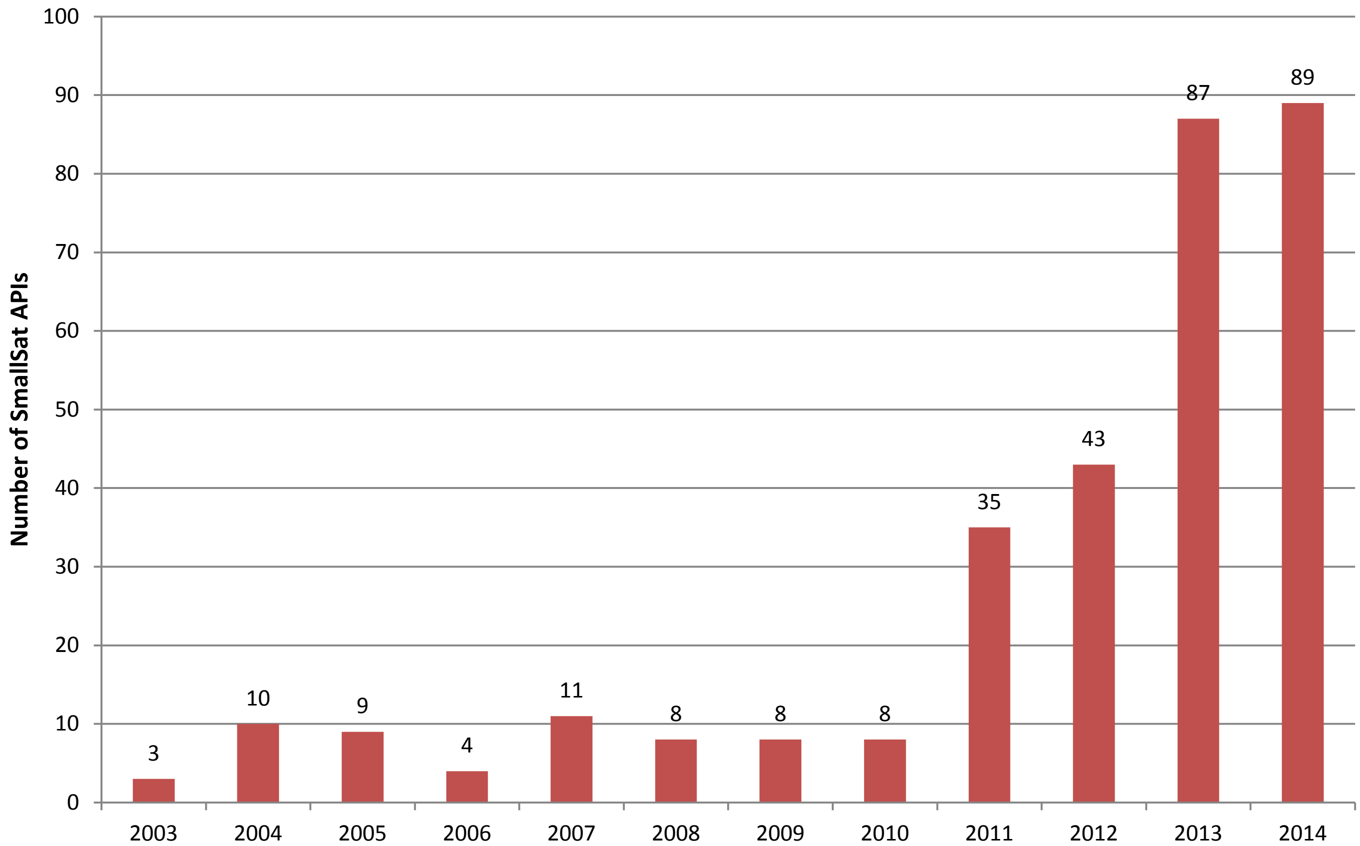
Orbital Debris and SSA

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.

http://spacesecurityindex.org/wp-content/uploads/2015/06/executive.summary.2015-electronic.pdf

https://upload.wikimedia.org/wikipedia/commons/8/82/Orbitalaltitudes.jpg

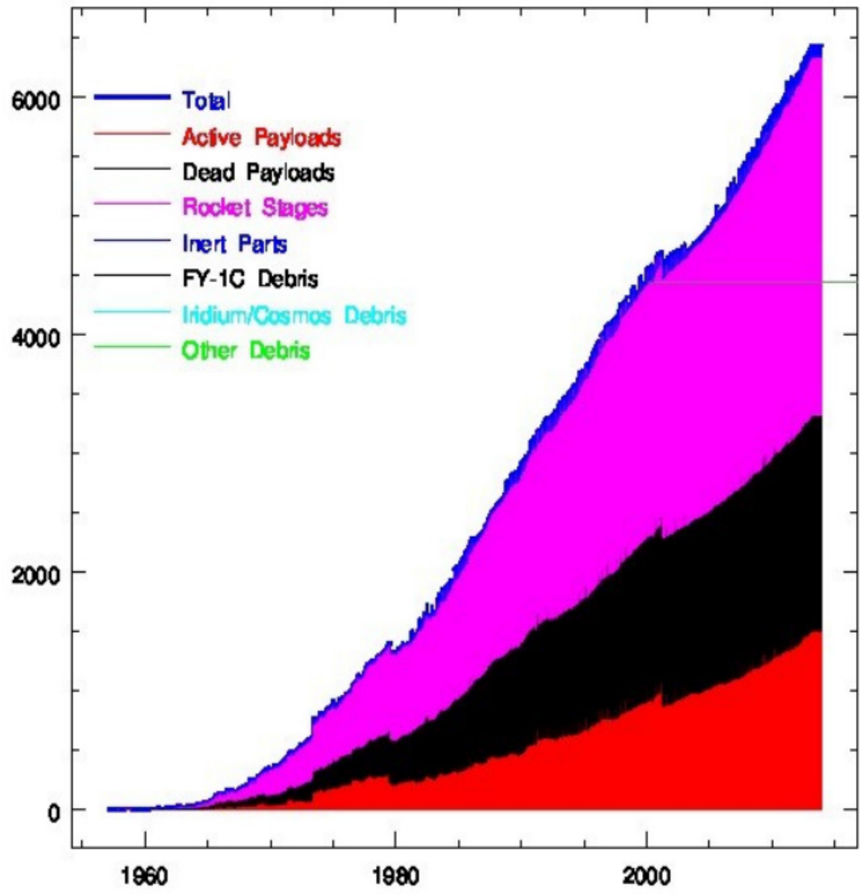
Number of Companies Submitting SmallSat APIs to the ITU

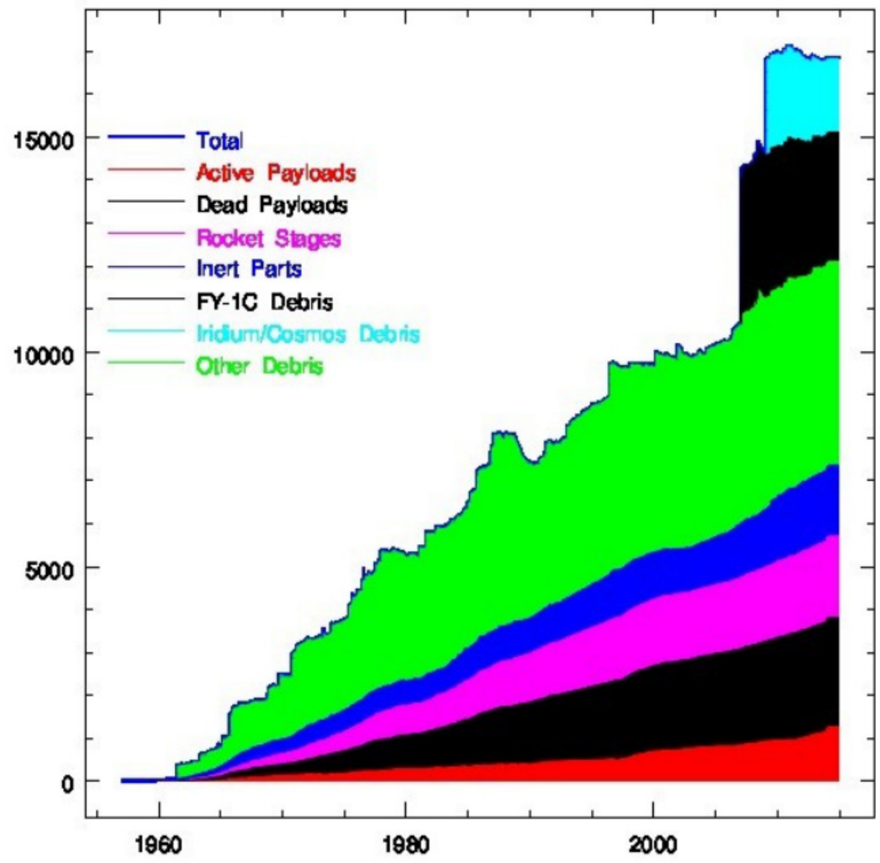


Source: ITU via SpaceNews March 2015

IDA SCIENCE AND TECHNOLOGY POLICY INSTITUTE

Sources of Debris by Weight (LHS) and Number (RHS) of Objects

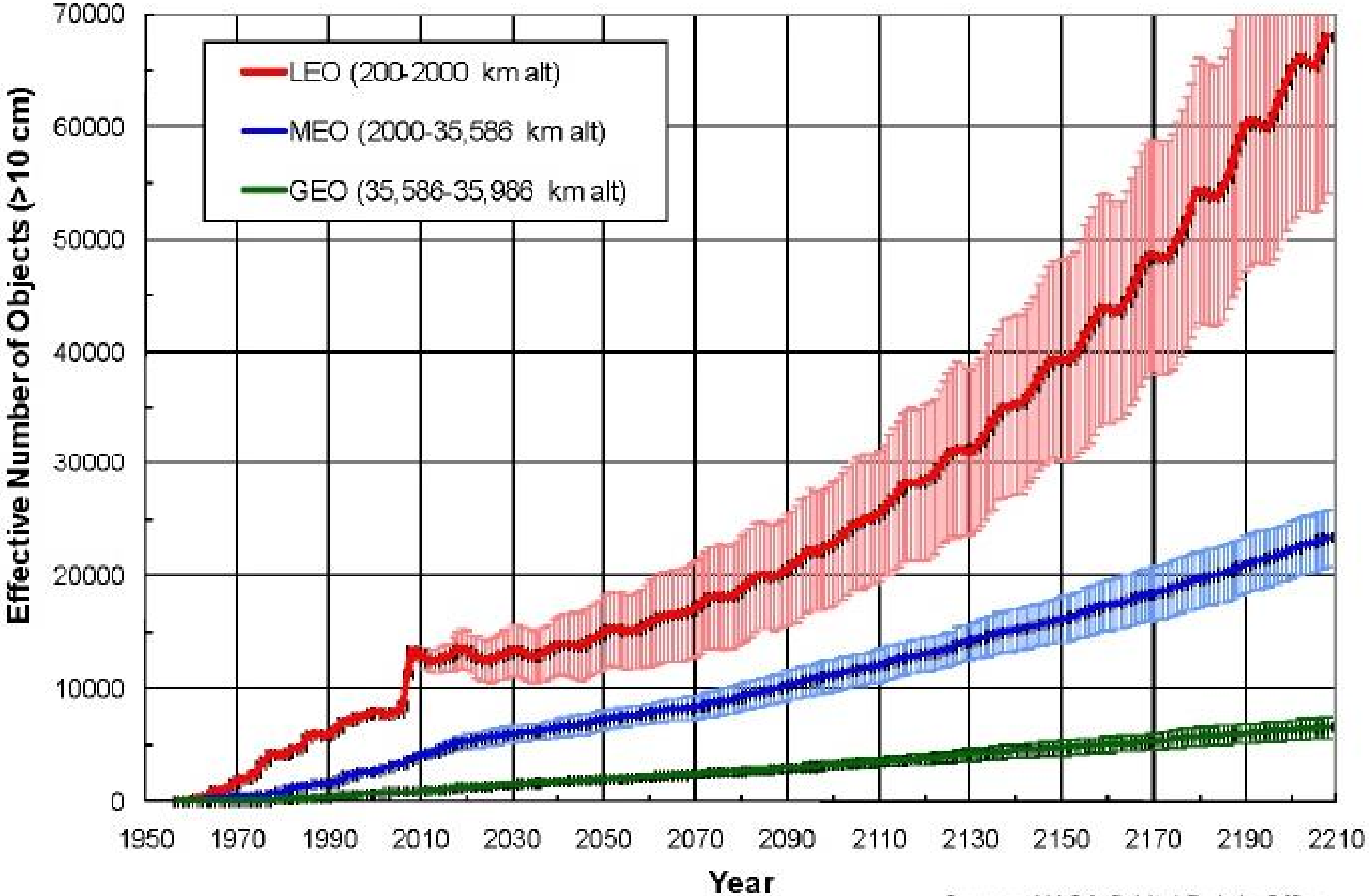




Source: J. McDowell's Space Website http://planet4589.org/talks/global/global5.pdf.
Note: The *y* axis represents weight in metric tons.

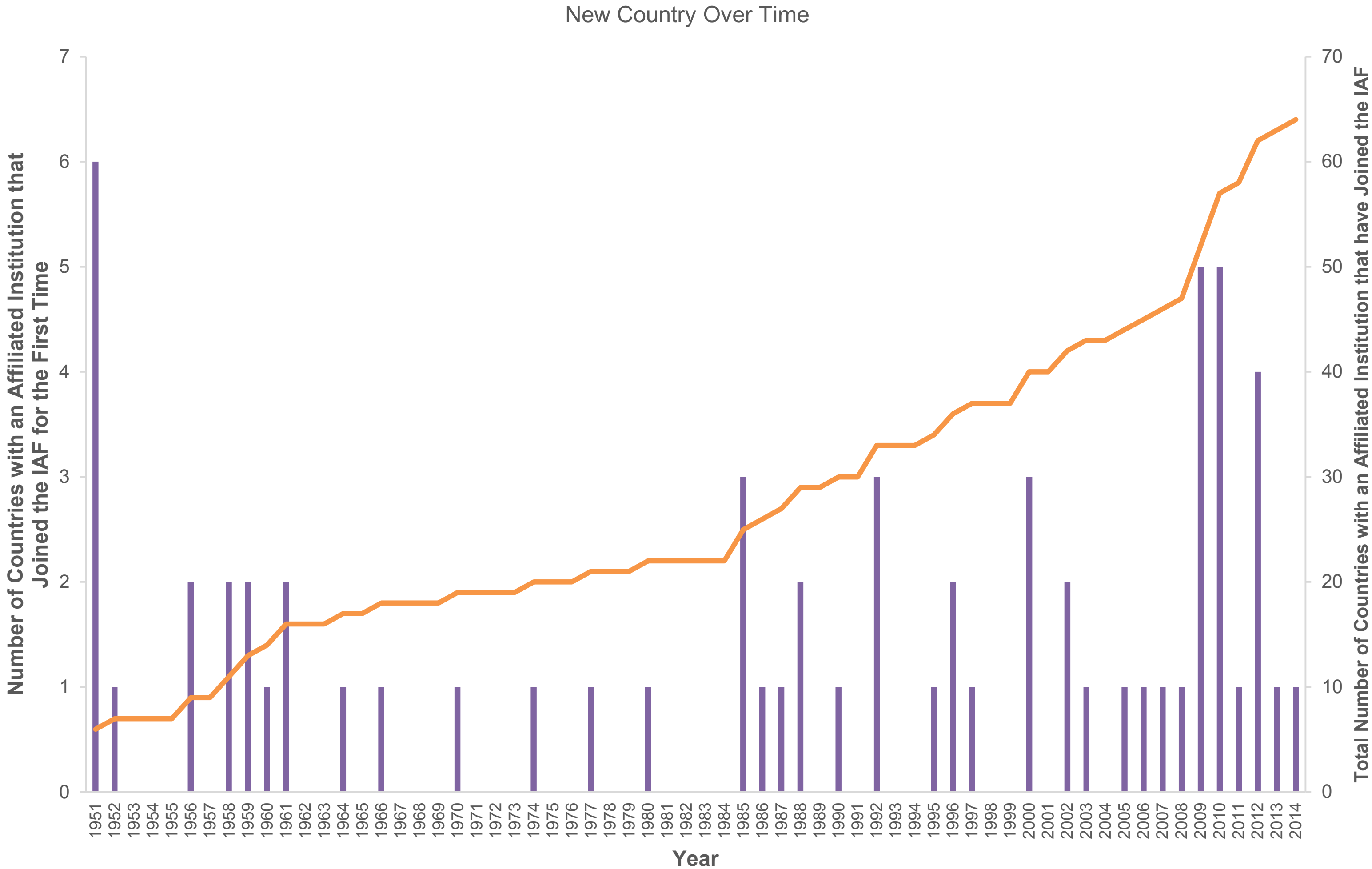
Physical and Electromagnetic Environment

- Projections for Increases in Space Debris



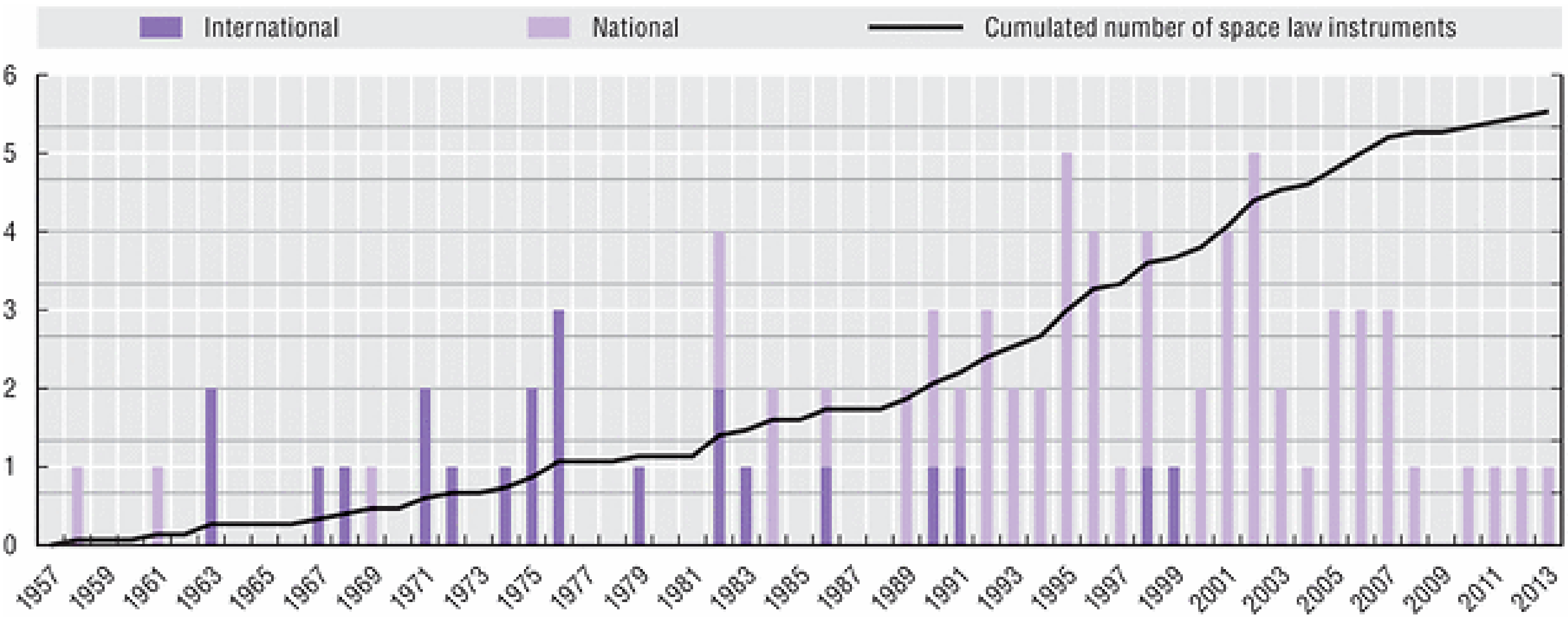
Source: NASA Orbital Debris Office

Countries with Members in the International Astronautical Federation



Source: STPI synthesis of IAF data.

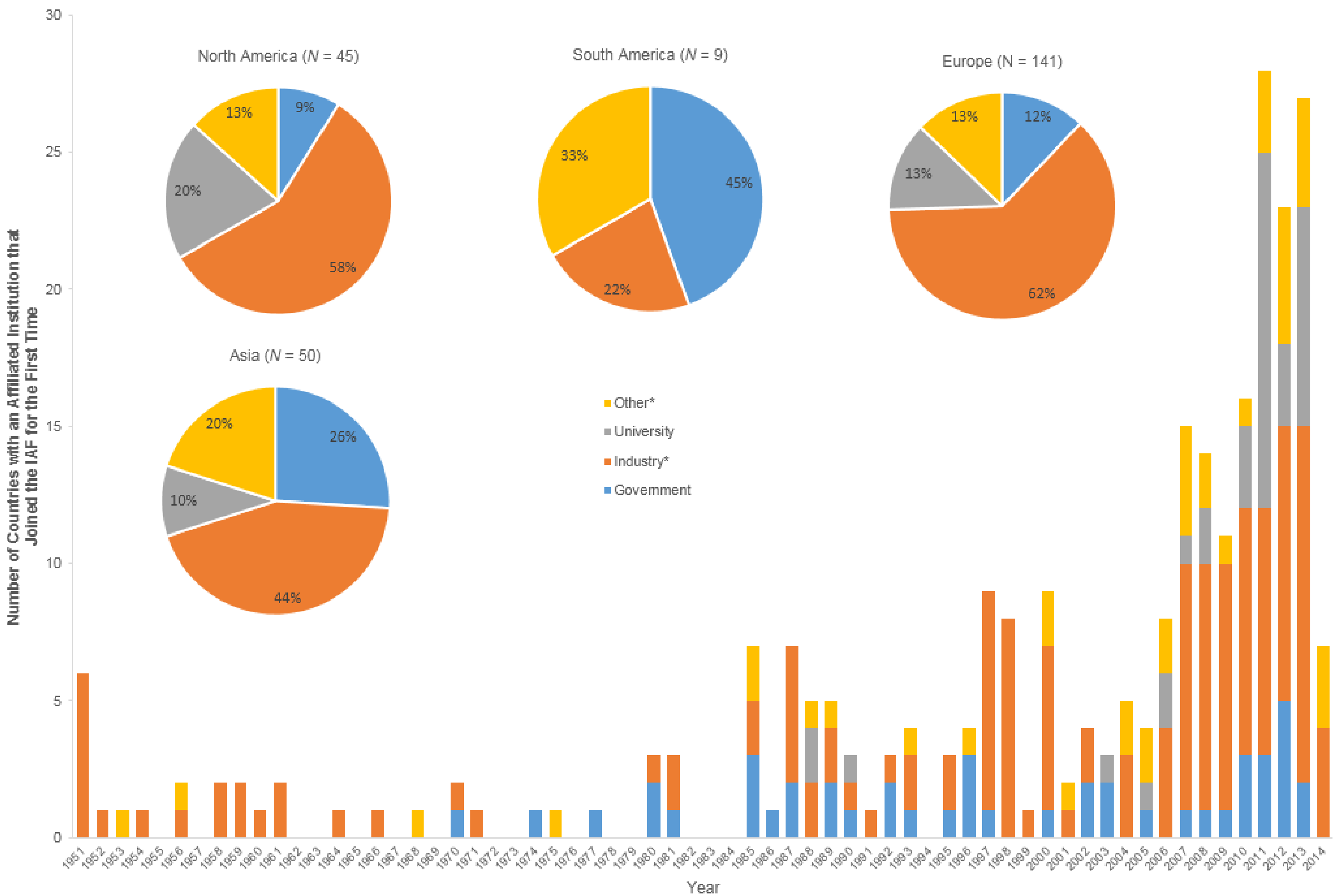
Number of Treaties, National Space Laws, and Regulations per Year



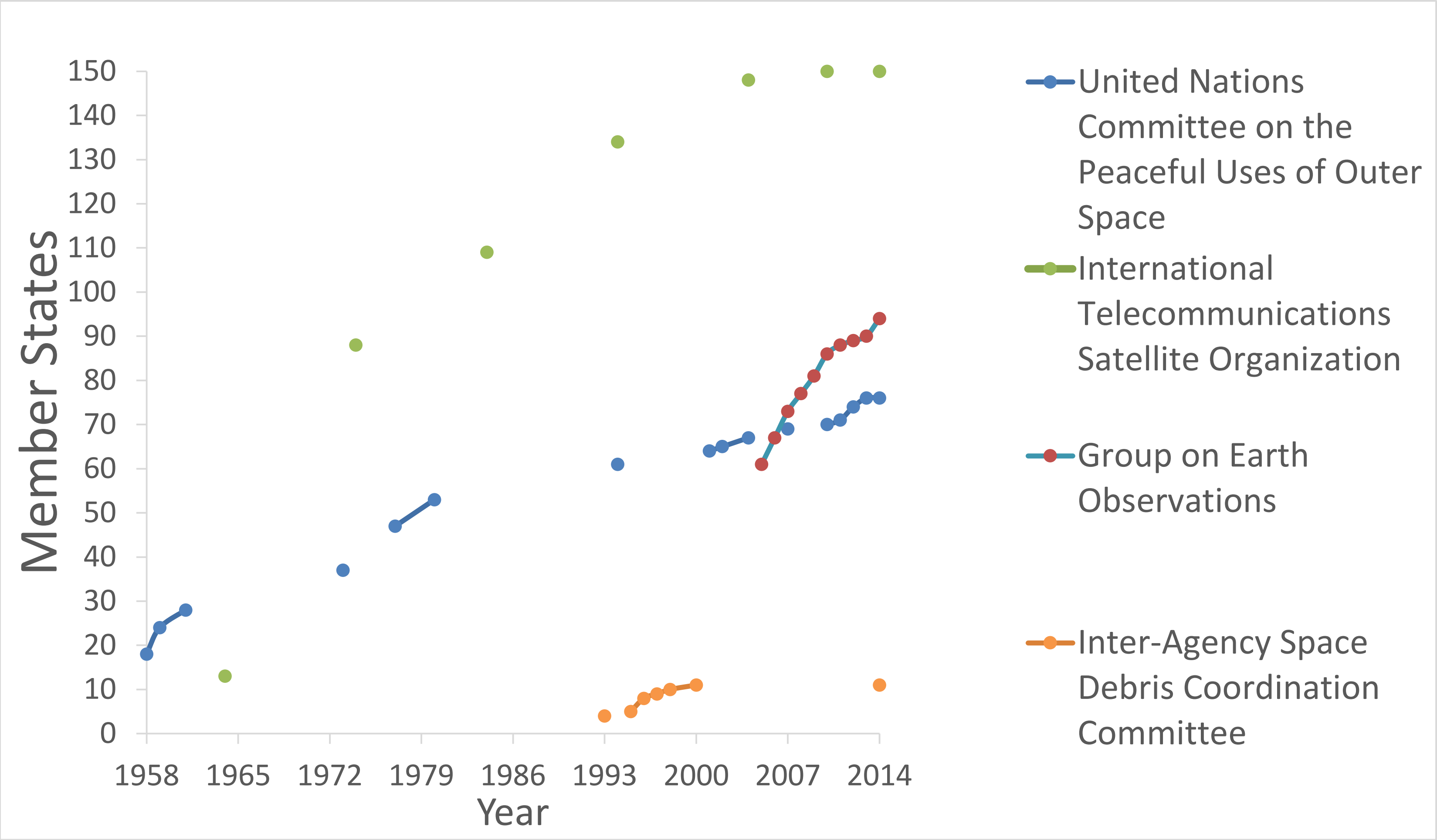
Source: OECD calculations based on United Nations data (OECD 2014, 45).

Membership of International Organizations

IAF Institutional Membership



Increasingly Complex Global Governance Landscape



Source: MIKE

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 Technology[2]
Masten Space Systems
Microcosm Inc[2]
Micro-Space Inc
Orbital[1]
Reaction Engines Limited
SpaceDev[2]
Space Exploration Technologies[1]
Starchaser Industries PLC
TGV Rockets[2]
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
AMROC
Advent Launch Services
AeroAstro LLC
Angara
Aquarius
Athena (a.k.a. LLV)*
Ausroc
Beal Aerospace Technologies
Capricornio
Cerulean Freight Forwarding Co.
Conestoga
CTA Launch Services
DC-X
E-Prime Aerospace Eagle
Fundamental Technology Systems
International Micro Space
Iterorbital Systems
Kistler Aerospace
KittyHawk Technology
Lone Star Space Access
ORBEX
PacAstro
Pacific Americal Launch Systems
Panaero, Inc.
Platforms International
RASCAL
Rocketplane Limited
Rotary Rocket
Seagull
SEALAR
Space Access Inc.
Space America Inc.
Star-Raker Accosiates
Starcraft Boosters Inc.
Third Millenium Aerospace Inc.
Truax Engineering, Inc.
Vela Technology Development, Inc.
VentureStar
VLS
World Aerospace

* 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

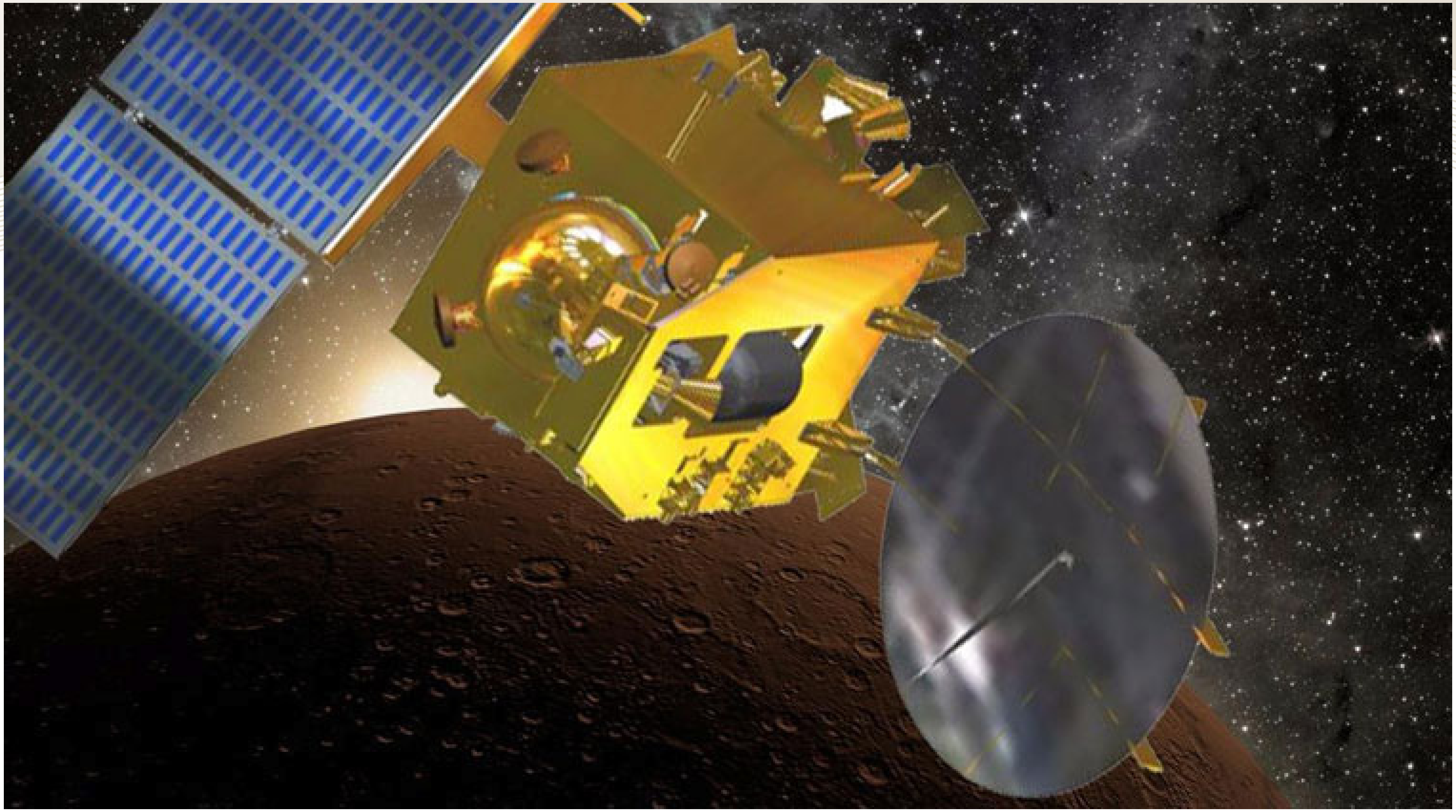
- Google's satellites could cost up to 20 times more than their low-end estimate—more like $20 billion than $1 billion.
  - "This is exactly the kind of pipe dream we have seen before…the landscape is littered with failed satellite projects like the one being proposed by Google."

- 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 capitally 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

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
10-XX-2015	Final	Aug 2015 - Oct 2015

4. TITLE AND SUBTITLE
Global Trends in Civil and Commercial Space

5a. CONTRACT NUMBER
NSFOIA0408601/NNH14CM08601

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Lal, Bhavya
Sylak-Glassman, Emily J.
Gupta, Nayanee

5d. PROJECT NUMBER

5e. TASK NUMBER
ED-20-3909

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
IDA Science and Technology Policy Institute
1899 Pennsylvania Avenue, NW, Suite 520
Washington, DC 20006-3602

8. PERFORMING ORGANIZATION REPORT NUMBER
IDA Document NS D-5682

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Strategy and Policy
National Astronautics and Space Administration
300 E Street, SW
Washington, DC 20546

10. SPONSOR/MONITOR'S ACRONYM(S)
NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited (25 November 2015).

13. SUPPLEMENTARY NOTES

14. ABSTRACT
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.

15. SUBJECT TERMS
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

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Patrick Besha
Unclassified	Unclassified	Unclassified	Same as Report	140	19b. TELEPHONE NUMBER *(Include area code)* 202-358-2636