SCIENCE AND TECHNOLOGY POLICY INSTITUTE

Focus for STMD's Small Satellite Technology Investments – Interim Update

Bhavya Lal, Asha Balakrishnan, Ben Corbin
Alyssa Picard, Jonathan Behrens, Ellen Green
IDA Science and Technology Policy Institute

NAC Technology, Innovation and Engineering Committee Meeting
November 18, 2016

Preliminary Findings/Do Not Cite or Quote

Project Goal

Given investments outside STMD, and NASA's mission needs, what should be the focus for STMD's smallsat investments?

In March 2016, the NASA Advisory Council recommended that "STMD conduct an independent study of current small satellite technology developments to "determine the appropriate focus for NASA's small spacecraft technology investments…NASA is at risk for having STMD's small satellite technology investments duplicated in commoditized capabilities. (consequence of no action)." The committee asked NASA to consider the "the appropriate, discriminating role for STMD vis-à-vis all the other organizations that are developing small satellite technology."

Approach

- Examine smallsat developments
  - Ecosystem – players and activities in government and industry, domestically and globally
  - Historical and emerging trends in markets
  - Enablers – launch infrastructure, policies, public and private investment
  - State-of-the-art by technology area
- Analyze STMD's current and emerging smallsat portfolio
- Identify NASA's small spacecraft needs, both user driven (tech pull) and technology driven (tech push)
- Identify gaps
- Determine if STMD can or should fund these areas given its goals, scope, constraints and resources

➢ *Team includes consultants Malcolm MacDonald, Iain Boyd, and Roger Myers, and reviewers Brian Zuckerman and Mike Yarymovych*

Data Sources

Discussions with Stakeholders (~60 planned, 40 conducted)	
NASA	12 (9 conducted)
Other government	2 (2)
University/Non-Profit	16 (15)
Industry (suppliers and operators) – U.S.	21 (12)
Industry (suppliers) – International	9 (3)
Literature Review	
National Academy of Sciences CubeSat Report (2016)	
SSTP/Ames State of the Art Report (2015)	
Trade Association/Other Reports: EuroConsult smallsat Market Analysis, Satellite Industry Association Annual Reports, Space Works, Frost & Sullivan, NSR	
Other Literature – STPI Report on Microsatellites, journal articles	
Assembled a Database of smallsat Organizations	
Conferences	
Small Sat 2016, Hosted Payload and smallsats Summit, USGIF Small Satellite Workshop	
Considering use of Crowdsourcing and Prediction Markets to Assess Trends	

Scope/Definition

- Scope
  - Understanding STMD's Small Spacecraft Technology Program (SSTP) supplemented by other STMD efforts
  - Understanding portfolio content not its evaluation
- Definition of a smallsat
  - Considered several metrics – mass, cost, innovation approach ("lean satellite")
  - Settled on mass with upper limit ~200 kg
    - With exceptions up to 500 kg as needed

Today's Goal

- Interim Findings
  - Portfolio analysis
  - Technology needs *as articulated by stakeholders*
  - Gaps between articulated needs and portfolio
  - Preliminary assessment
- Feedback and Discussion

STMD’S SMALLSAT PORTFOLIO

SSTP Program

Goals

- "To develop and demonstrate new small spacecraft technologies and capabilities for NASA's missions in science, exploration and space operations"

- "To promote the small spacecraft approach as a paradigm shift for NASA and the larger space community"

Overall Statistics

- Program initiated - 2013
- $~80M allocated from 2013 to 2016
  - $73.6M to SSTP-funded awards
  - $6.1M to other awards in STMD for Small Spacecraft Tech
  - If including future committed funds - ~$125M
- Number of awards since inception - 63
  - 42 SSTP-funded awards
  - 21 other awards in STMD for Small Spacecraft Technology

>Nearly 70% of SSTP Funds to-date Allocated to Flight Demonstrations

	Number of Projects	2013 to 2016 Funding ($M)	Median Award Size
SSTP Funded	**42**	**$73.6M**	**$250K**
SSTP: Flight Demonstrations	7	$50.0M	$12,900K
SSTP: University Partnerships^	29	$13.9M^	$515K
Tipping Point	4	$3.8M	$2,050K
Early Career Initiatives (ECI)	2	$5.9M	$3,188K
Preliminary Totals	**63**	**$79.7M**	**$250K**

Funding data is preliminary for projects funded between 2013-2016. Project funding represents total funding of project regardless of the outlay year.

^includes assumed FTE funding to NASA Centers for each project

SSTP Not the Only smallsat Funding Program in STMD

	Number of Projects	2013 to 2016 Funding ($M)	Median Award Size
SSTP Funded	**42**	**$73.6M**	**$250K**
SSTP: Flight Demonstrations	7	$50.0M	$12,900K
SSTP: University Partnerships^	29	$13.9M^	$515K
Tipping Point	4	$3.8M	$2,050K
Early Career Initiatives (ECI)	2	$5.9M	$3,188K
Other STMD Programs	**21**	**$6.1M**	**$200K**
FOP: Flight Opportunities	6	$1.2M	$217K
SBIR: Phase I	12	$1.5M	$125K
SBIR: Phase II	3	$3.4M	$1,499K
Preliminary Totals	**63**	**$79.7M**	**$250K**

Funding data is preliminary for projects funded between 2013-2016. Project funding represents total funding of project regardless of the outlay year.

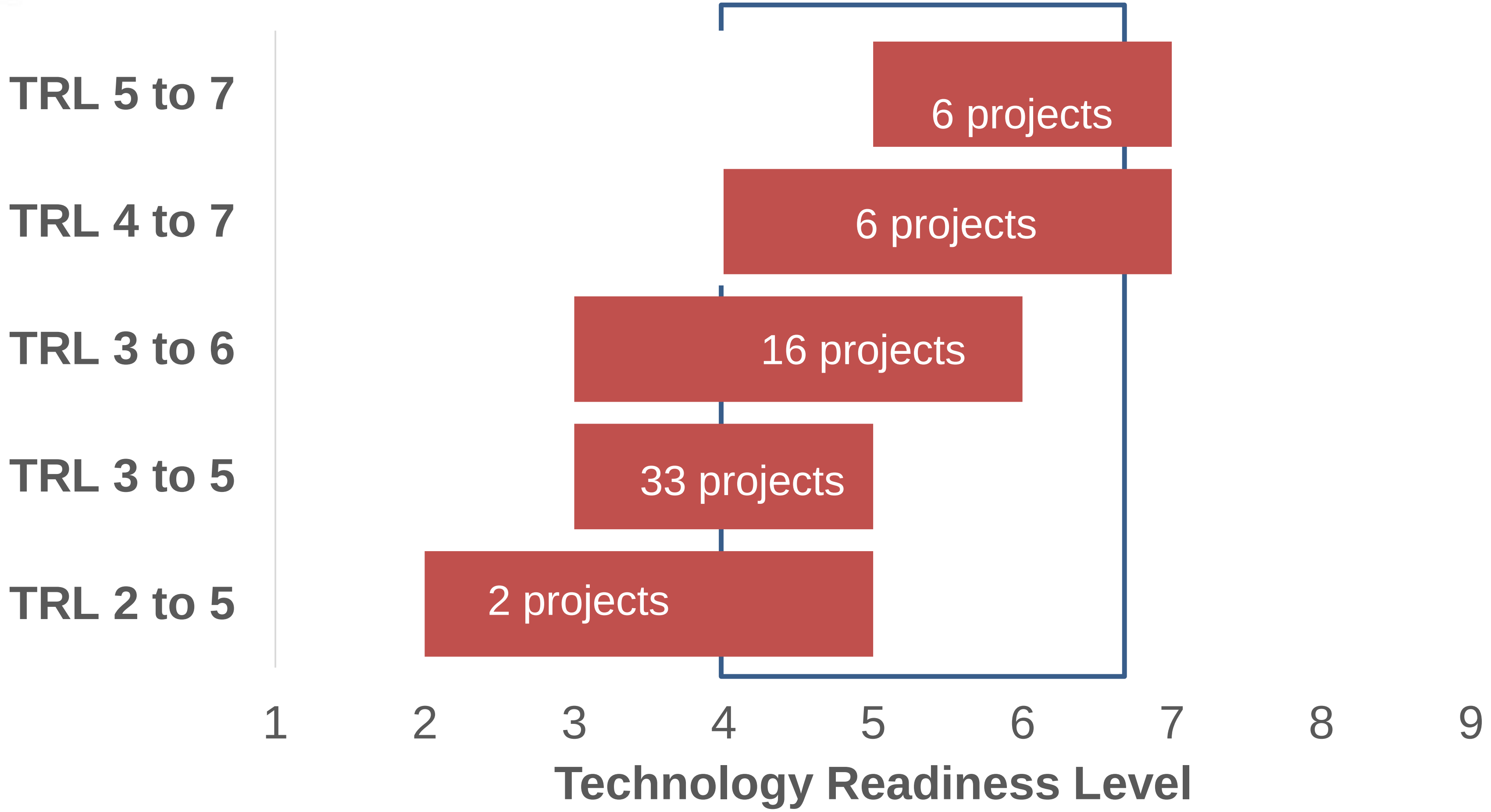
^includes assumed FTE funding to NASA Centers for each project

Three Technology Areas Represent >80% of STMD Funds from 2013 to 2016

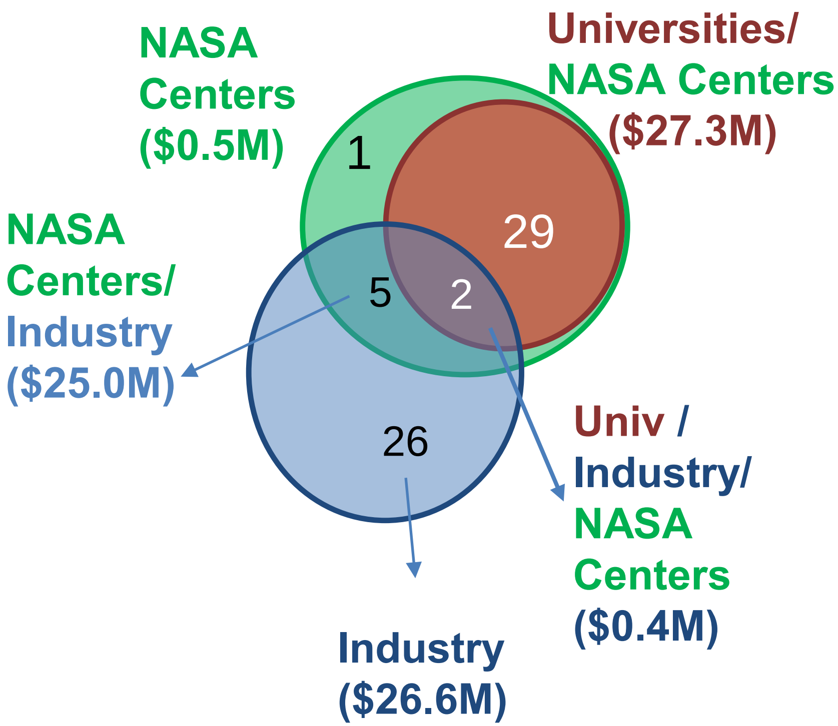
Technology Area	Number of Technology Areas^	2013 to 2016 Funding	Number of Flight Demo Projects	2013 to 2016 Funding for Flight Demo Projects
Mobility and Propulsion	20	$16.0M	9	$10.0M
Communications	16	$20.7M	5	$14.9M
Attitude and Orbit Determination and Control	8	$5.1M	2	$0.4M
Electrical Power Generation and Storage	10	$5.2M		
Payloads	5	$1.4M		
Systems and Constellations	5	$27.5M	2	$24.2M
Flight and Ground Systems Software	2	$0.8M		
Thermal control	2	$1.3M		
Data Handling, Processing, and Autonomy	2	$0.6M		
Systems Integration	2	$1.2M	1	$0.5M

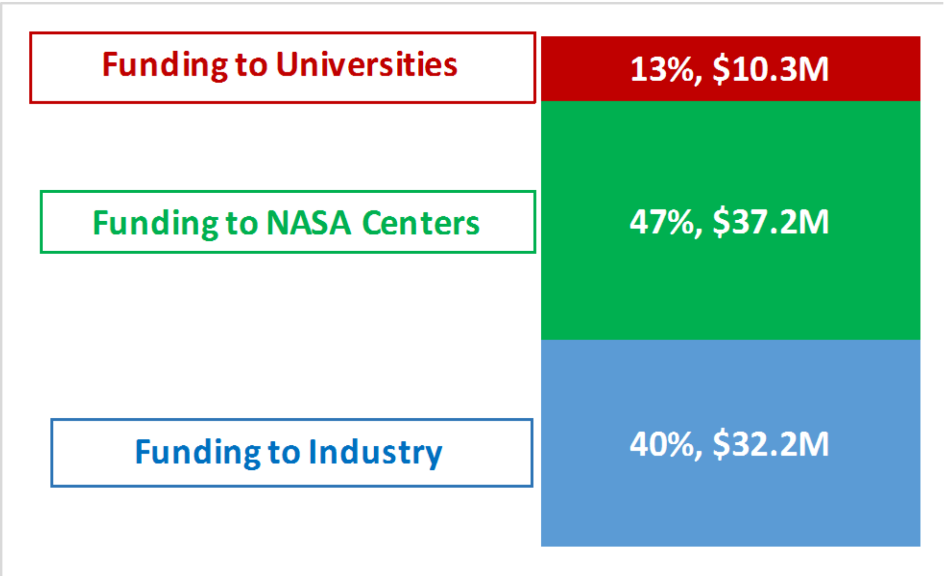
Note: ^We identified 73 technology areas for 63 projects. Some projects were coded to have 2 technology areas. The funding was assigned to each project's primary technology area with the exception of the Pathfinder Technology Demonstrator (PTD) Project. Funding for PTD was assigned 3/5 to Mobility and Propulsion, 1/5 to Attitude and Orbit Determination and Control and 1/5 to Communications.

Most Projects Intend to Span "Valley of Death" (*not assessed*)



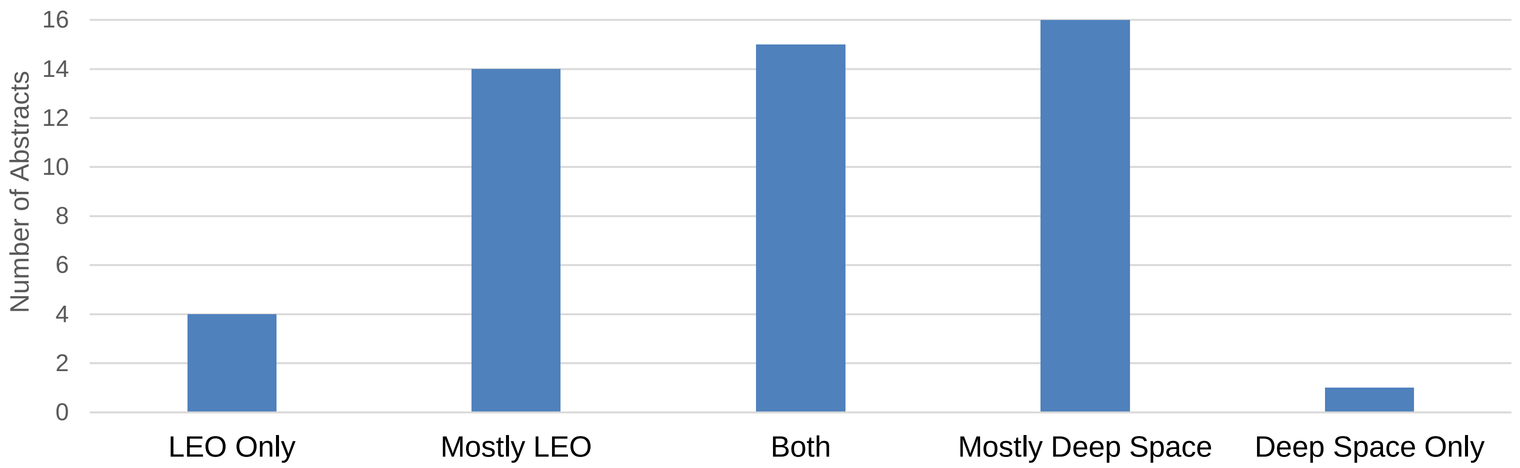
Over 50% of STMD's smallsat Funds to date Awarded to Universities and Industry (Suppliers)





NOTE: Project and funding data reflects both SSTP projects as well as other STMD programs that fund small spacecraft projects

Distribution of Applications: LEO versus Beyond



- STPI assessed that most projects in SSTP portfolio developing technology that has application to both LEO and beyond LEO missions
- Some were equally applicable to both, while others were designed to be more focused on one over the other

SMALLSAT TECHNOLOGY NEEDS (INTERVIEWEE FEEDBACK)

Stakeholder Discussions

- 40 interviews conducted to-date
- Stakeholders asked about
  - State-of-the-art in small spacecraft
  - Key technologies required to enable science, human exploration and industry missions
  - Bottlenecks/constraints that if removed could accelerate or improve the cost-effectiveness of discovery/commercialization
  - Outside activities and sources of funding, domestically and abroad
  - Other impediments in the smallsat ecosystem
  - Recommendations for SSTP
- Not a survey - questions differed by sector and affiliation

Mobility/Propulsion

- NASA/University users: Not at a high enough TRL level, no system clearly a frontrunner for development. Many see some form of electric propulsion as the most likely solution.

- Adequate for industry users (operators) for now, but will require attention as they move into new applications.

Systems and Constellations

- Constellations require advances in many different technology areas
  - Radar, passive optical, and active radiofrequency communication systems
  - Long-lasting batteries
  - High-frequency launch capabilities (enables use of multiple orbital planes)
  - Propulsion systems (small, cheap) that would enable maneuverability
  - Software: ground systems to manage, on-board to enable autonomous operations for weeks to months
  - For NASA/University users: rad-hard components for deep space missions

Communications

- All users want higher data rates. Two ways forward: move into higher frequency bands, or develop optical communication.
  - Optical communication requires development of ground stations, and precision pointing and power systems on-board
- Non-NASA users want systems that can be compatible with existing ground stations.
- Also of interest to all users: software defined radio, inter-satellite communication systems, and improved on-board data processing (to reduce how much information must be relayed).

Attitude and Orbit Determination and Control

- NASA/University users: Need under 0.5 arcsec precision pointing for 10 minutes to be competitive with on-ground telescopes. Access to GPS signal in GEO would also be helpful.
- Advancing well in industry (down to <10 arcsec pointing), but less precision needed than for science missions.

Technology Needs in Other Areas

- Electrical Power Generation and Storage
  - Higher density batteries, higher efficiency solar cells, larger deployable panels, better power budgeting tools
- System Integration
  - Better integration with sensors, plug-and-play connectivity
- Payloads
  - Miniaturized sensors, instruments, and deployable apertures
- Thermal control
  - Miniaturized heat exchangers, cryogenic coolers, deployable radiators, better thermal management tools
- Flight and Ground Systems Software
  - More streamlined options for downlinking through various networks
- Data Handling, Processing, and Autonomy
  - Better chips for onboard processing and reduced data transmission

Technology Needs of NASA Users

- SMD and HEO
  - High delta-V propulsion
  - Chip development for on-board image processing
  - Higher data rate communications
  - Increased reliability of components
- SMD
  - Smaller and greater variety of instruments and sensors
  - Instrument-enabling bus technologies*
  - Constellation-enabling technologies
- HEO
  - Rapid flight testing of key technologies
  - Sensor and instrument development and testing for human spaceflight

Other Feedback from Science/NASA Interviews

- Have more cost-sharing agreements with private companies
  - Helps relieve financial burden from SSTP while giving a private company the reward for being first to market of an important technology
- Have a roadmap that links the needs of SMD and HEO
  - Understand *why* these technologies are being developed, and how those technologies cascade to further development, both for NASA's goals and commercial companies
  - "SSTP operating in isolation greatly limits their potential impact – especially given their low budget for smallsats. An intentionally designed consortium (i.e. centers and academia) would leverage small sat work and investment throughout NASA"
- Make sure there are clear science applications, not just new applications of better technology

Technology Needs of Industry Suppliers and Operators

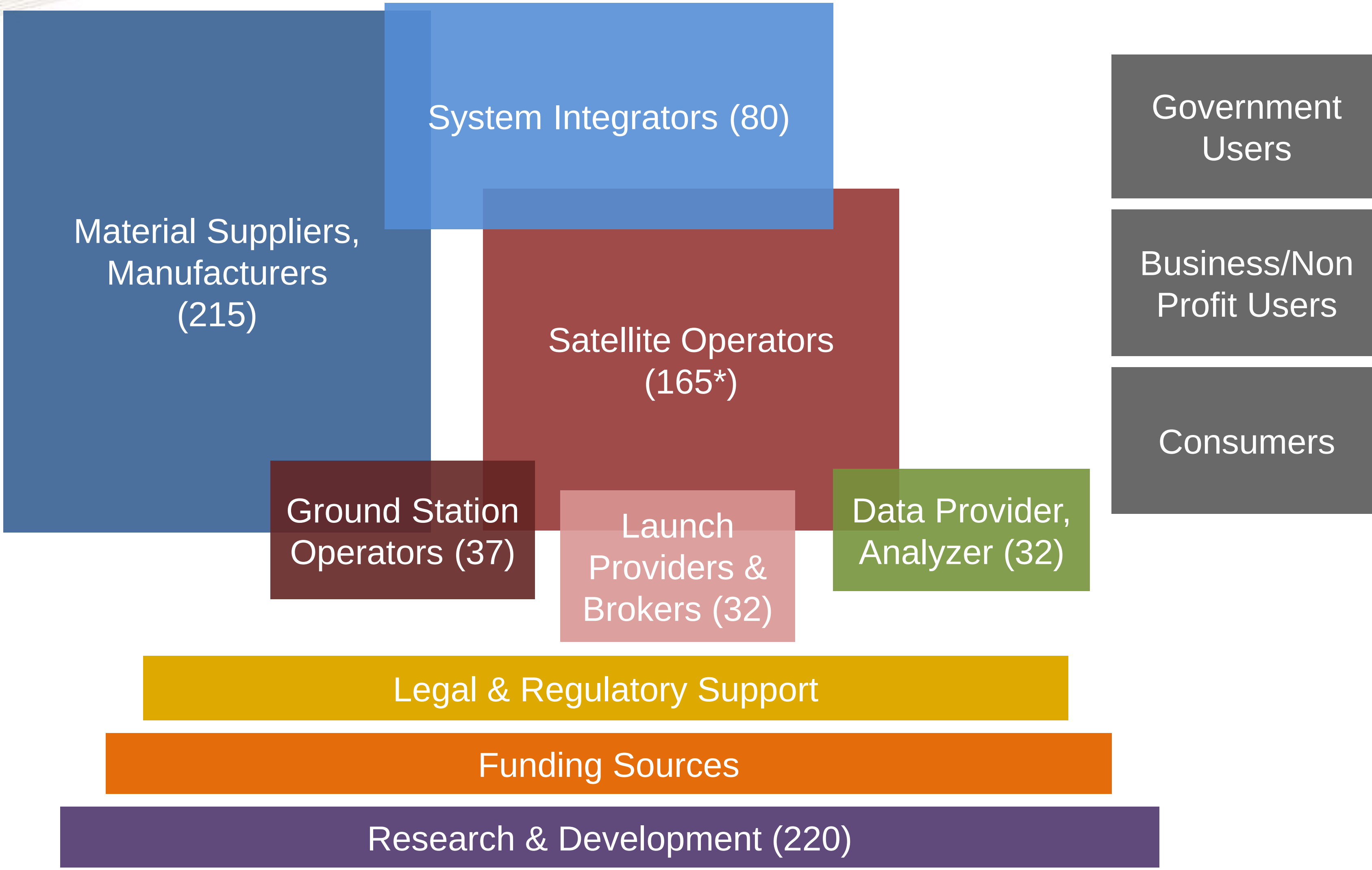
- Few respondents identified specific technology breakthroughs in the near-term
  - Current "state of the art" appears to meet or exceed most commercial application needs **today**
  - Advances needed in automating manufacture of satellites, lowering cost by fundamental redesign of satellite buses
  - Operators would prefer to have government as a customer (e.g., less interest in the R&D end)
  - Government role in regulations, ITAR, spectrum allocation, streamlining licensing process, etc.
  - Other bottlenecks include launch, bringing products to market, and securing customers

Other Feedback from Industry/University Interviews

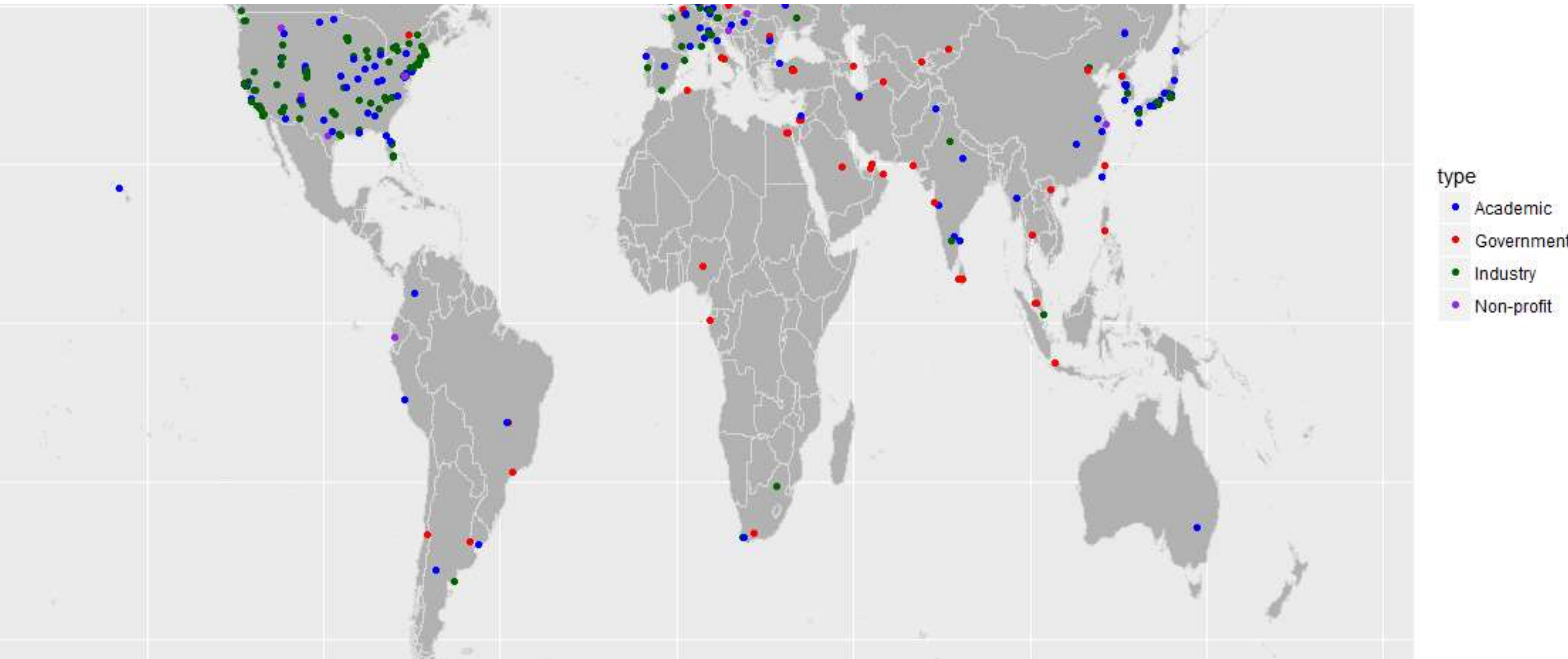
- Database of testing results for COTS parts
  - Comprehensive testing
  - Curate database of known failures across the entire small satellite sector
- Work with commercial ground systems
  - Help solve oversubscription problems with the DSN and NEN
- Do not ignore new systems engineering methods
  - Choosing the "best" design of a constellation for space science missions is much more difficult compared to monolithic systems
  - Developing concept exploration tools can be just as important as spaceflight hardware in the grand scheme

PRELIMINARY FINDINGS

SSTP is One Organization in a Large smallsat Ecosystem (n>500)



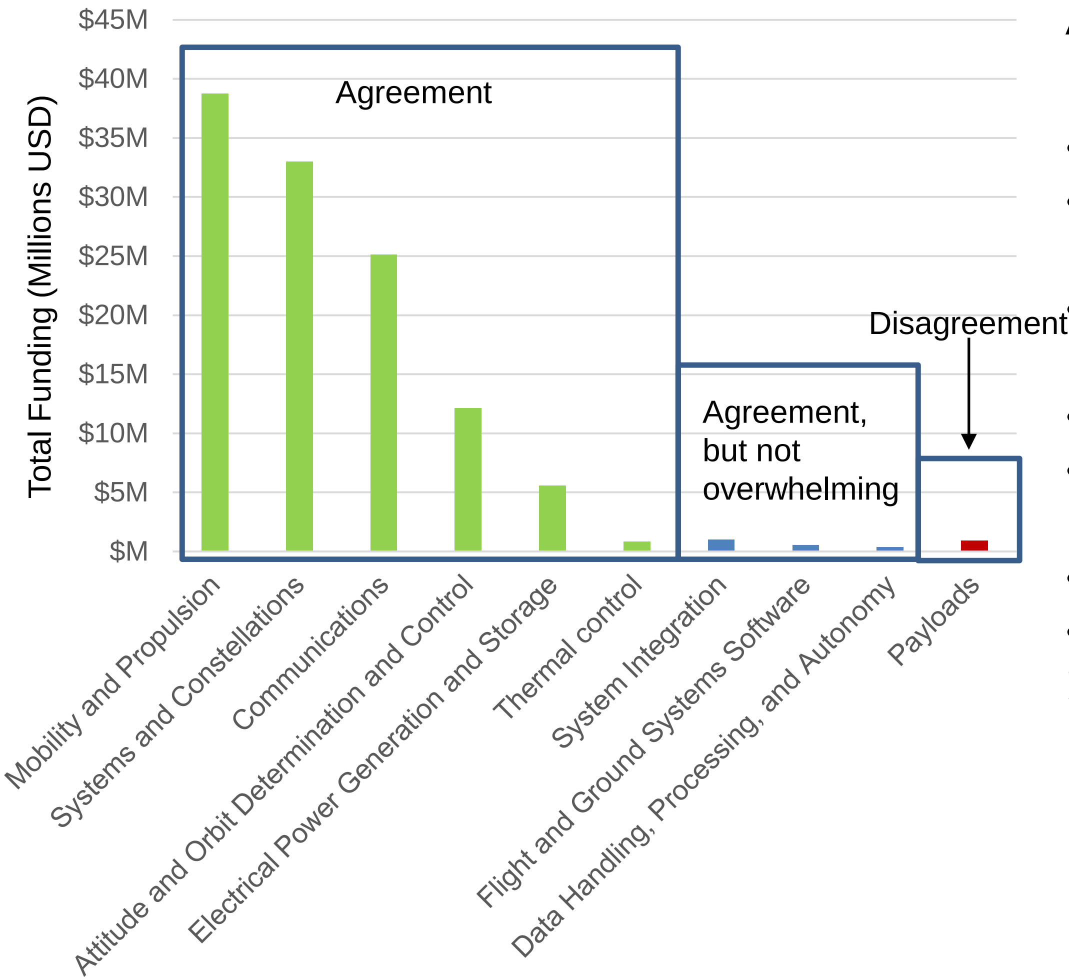
Global Ecosystem - smallsat Organizations Span >70 Countries



- United States - 263 organizations (47%)
- Europe - 129 (23%) includes Russia 25 (4.4%)
- 33 countries have only one organization – mostly government or academic

Preliminary Findings/Do Not Cite or Quote

Preliminary Finding: STMD Investments are Generally in the Right Areas



Areas SSTP Currently Not Funding (but stated as valuable)

- Reliability testing
- Development of "plug and play" universal platform
- Miniaturized calibration sources for science payloads
- Deployable systems for science needs
- Development of radiation hardened systems
- Ground station systems/software
- Clearinghouse for testing and parts data
- ➢ *Dedicated smallsat launch*

Note: Chart includes current and future allocations

Preliminary Finding: Need for a Portfolio Evaluation

- Understanding barriers to effective transition from development to operational use can help guide questions about the balance of the investments across the portfolio
  - How many technologies have transition plans (from development to operation) with mission users lined up?
  - How many technologies have transitioned out of SSTP programs into operational missions or over to suppliers or operators?
  - Have any start-up companies been formed to market SSTP-developed technologies?

Preliminary Finding: Lack of Communication [of Strategy] to Users/Stakeholders

- There appears to be communication and awareness [especially with users at NASA] but no formal coordination or collaboration
- Outside NASA, little understanding of SSTP thrusts
- STMD has not communicated how its smallsat portfolio relates to specific missions, user needs, or overarching NASA goals
  - Projects seem to be a list of one-offs. There appears to be no stated "theory of change" or metrics to guide investment

Discussion

- An "opportunistic" approach may have worked to-date
- Going forward, SSTP could
  - Continue to be opportunistic
  - Begin to focus on its "comparative advantage"
    - Formally connect development plans with user plans
    - Push on a small number of important goals

Discussion (cont.)

- Role of government in an area that has large outside investment and is moving fast in the private sector
  - Plan on necessary duplication
  - Strategic choices
    - LEO vs. deep space
    - Focus on high risk high reward areas/market failure
    - Alignment with "customer" needs
      - Need for articulation of strategic intent at the Agency level
      - Need for clarification wrt role of centers, WHICH centers for WHAT activity
      - In industry – supplier needs different than operators
    - ➢ Models and lessons in other sectors (SEMATECH)
- Alignment of program organization and management with goals
  - Lay out goals and objectives more explicitly than "nurture smallsat paradigm"
  - Metrics to guide decision-making and evaluation

Next Steps

- Complete interviews (Nov 2016)
- Consider brief survey of performers (Dec 2016)
- Discuss preliminary findings (Nov-Dec 2016)
- Finalize findings and recommendations (Dec 2016)
- Finalize draft report and have external experts provide feedback (Dec-Jan 2017)
- Deliver report to NASA (Feb 2017)

BACKUP SLIDES

Guiding Principle
Principle of Comparative Advantage

Just because STMD-funded smallsat research is
(a) high quality, or (b) important
does not mean SSTP should support it

STMD should only support research where it has a unique advantage over other actors in the ecosystem especially because non STMD funding is likely 10x or higher

STMD's Comparative Advantage

Correct for Market Failures

- Non-appropriability of investing in R&D
- Non-appropriability of investing in "industrial commons"
- Uncertainty of outcome and time horizons

Correct for Systemic Failures

- Coordination within and outside NASA
- Maintaining international competitiveness of U.S. smallsat sector
- Driving disruptive technology innovation

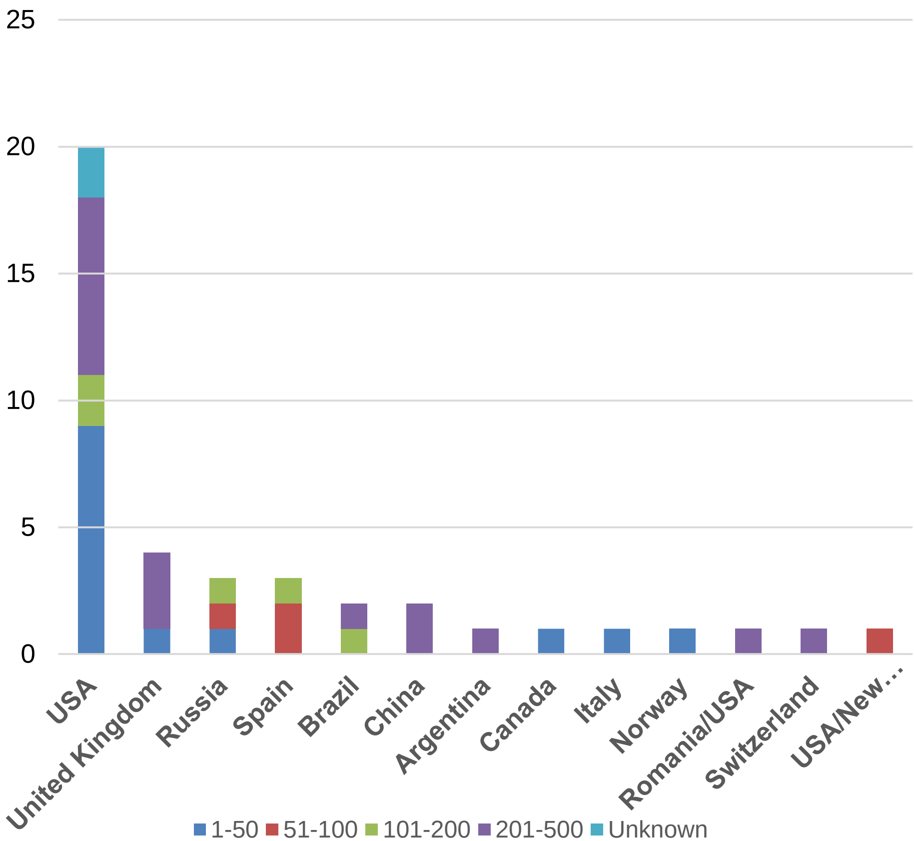
- Where investment is non-appropriable
  - Early TRL research
  - Training and workforce development
  - Industrial commons
- Where there is uncertainty of outcome
- Where time horizon to fruition is too long
- Where there needs to be coordination across the system
- Maintaining international competitiveness of the United States in critical sectors
- Where innovation will disrupt mainstream players

Areas Other than Technology that Require Support Not under STMD Purview

- Infrastructure
  - Databases
  - Voluntary parts certification programs
  - Ground network interface to reduce operations costs
  - Testing facilities
  - Access to affordable, timely launch
  - Ground Stations
- Policy Areas
  - Make process for obtaining launch, observation, and transmission licenses more streamlined
  - Reduce the burdens of ITAR
  - Address issues related to debris mitigation

Smallsat Launchers

(Acknowledgement: Laurie Dacus)



- United States leads with respect to the number of smallsat launchers under development
- Of the 41 launchers we know of, 37 are under development
- All 41 focus on LEO, 16 categorized as serving sun-synchronous markets
- Most focus on cubesats (14) or 201-500 kg smallsats (16) with very few in the 51-100 (4) 101-200 (5) categories

Sources: D. Lim, “Small launcher market survey – where are we and where are we going?” Room, October 2016, and D. Messier, “A Plethora of Small Satellite Launchers” www.parabolicarc.com, October 2016