



**DoD Space S&T
Community of Interest
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DoD Space S&T Strategy



**DEPARTMENT OF DEFENSE
SPACE SCIENCE AND TECHNOLOGY
STRATEGY
2015**

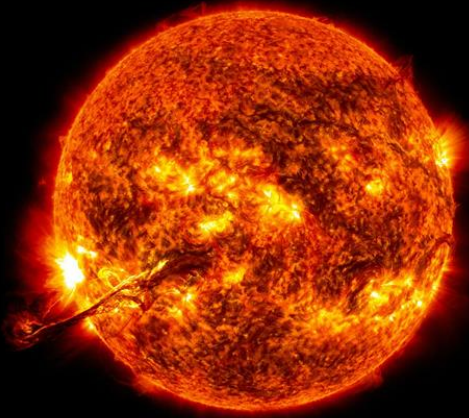


Photo: Coronal mass ejection as recorded by NASA, August 31, 2014

- Report to Congress – updated 2015
- Guides the development of the space-unique technologies that are essential to maintain existing U.S. conventional and asymmetric military advantages enabled by space systems at the strategic, operational, and tactical levels
- Looks across the entire DoD Space S&T Enterprise
- Prepared with the assistance of the DoD Space S&T Community of Interest



Space is no longer uncontested



Space Threats

Threat
RF Jamming
Low power laser dazzling
High Power Laser Kill
LEO ASAT
GEO ASAT
On-Orbit Jammers
Co-orbital kinetic ASAT
Adversary attachment
Cyber attack
Space nuclear detonation

Capabilities needed to deliver the Threats

Capability
Ground surveillance networks
World-wide ground SSA coverage
Precision Tracking capability

- In last 5 years, potential adversary threat capability has sharply increased.
- National Space Policy (2010): We will protect our Space Capability from adversary hostile actions.



Space S&T COI Portfolio Overview



- **COI Description**

- The goal of the Space COI is to 1) Facilitate collaboration and leveraging of complementary investments of the space S&T efforts across the community in support of the intent of the nation's Space interests; and 2) Identify gaps, establish and maintain a set of S&T roadmaps to guide Space Community research program investments, perform portfolio assessments, and provide future resource recommendations to leadership

- **COI Purpose**

- The Space S&T COI is a forum for sharing new ideas, technical directions and technology opportunities, jointly planning programs, measuring technical progress, and exchanging advances in space S&T

- **Portfolio Focus**

- DoD S&T investments in space-unique technologies that are essential to maintain and advance existing U.S. conventional and asymmetric military advantages enabled by space systems at the strategic, operational, and tactical levels

COI Taxonomy

Technology Sub-Area 1

Satellite Communications

Technology Sub-Area 2

Missile Warning, Missile Defense, Kill Assessment and Attack Assessment

Technology Sub-Area 3

Positioning, Navigation and Timing

Technology Sub-Area 4

Intelligence, Surveillance and Reconnaissance

Technology Sub-Area 5

Space Situational Awareness

Technology Sub-Area 6

Space Access

Technology Sub-Area 7

Space and Terrestrial Environmental Monitoring

Technology Sub-Area 8

Command and Control; and Satellite Operations

Technology Sub-Area 9

Space Enablers

Technology Sub-Area 10

Space Control and Space Resilience



Space COI Sub-Areas

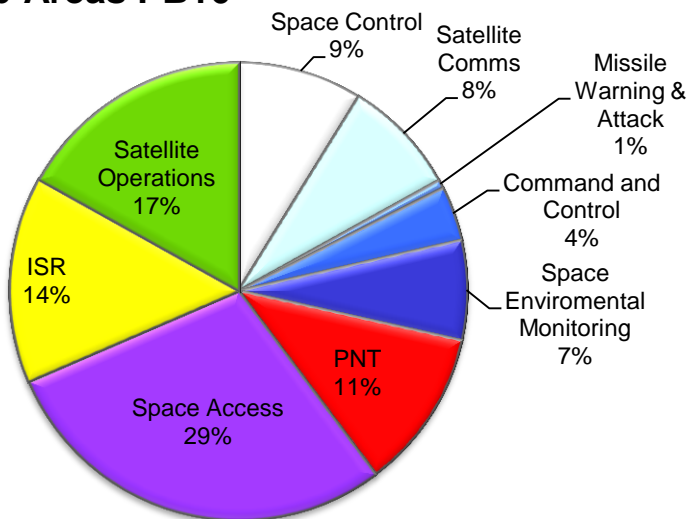
Satellite Communications <u>Technical Challenges</u> <ul style="list-style-type: none">• Reduce SWaP-C and improve thermal management• Develop V/W band RF and laser comms	Missile Warning, Missile Defense, and Attack Assessment <u>Technical Challenges</u> <ul style="list-style-type: none">• Improve sensors for whole-Earth staring• Improve data fusion algorithms	Positioning, Navigation and Timing <u>Technical Challenges</u> <ul style="list-style-type: none">• Improve anti-jam capability• Improve atomic clocks• Enhance orbital navigation technology	Intelligence Surveillance and Reconnaissance <u>Technical Challenges</u> <ul style="list-style-type: none">• Increase persistence of ISR• Improve data compression• Integrate space, air and ground based ISR	Space Situational Awareness <u>Technical Challenges</u> <ul style="list-style-type: none">• Improve space object detection and monitoring of potential threats
Space Access <u>Technical Challenges</u> <ul style="list-style-type: none">• Reduce cost and time cycle• Higher performance on-orbit propulsion• Enable fully reusable launch systems	Space and Terrestrial Environmental Monitoring <u>Technical Challenges</u> <ul style="list-style-type: none">• Improve awareness of Earth/Sun environment• Enable real-time threat warning due to weather• Enable marine Meteorology and ocean conditions	Command and Control; and Satellite Operations <u>Technical Challenges</u> <ul style="list-style-type: none">• Increase autonomy to reduce manning• Space robotic capabilities for servicing/repair	Space Enablers <u>Technical Challenges</u> <ul style="list-style-type: none">• Standardized and miniature components and interfaces• Carbon-based nanotechnology• Ultra-high efficiency power systems	Space Control and Space Resilience <u>Technical Challenges</u> <ul style="list-style-type: none">• On-board adaptive planning• Local area imaging sensors• Laser survivability



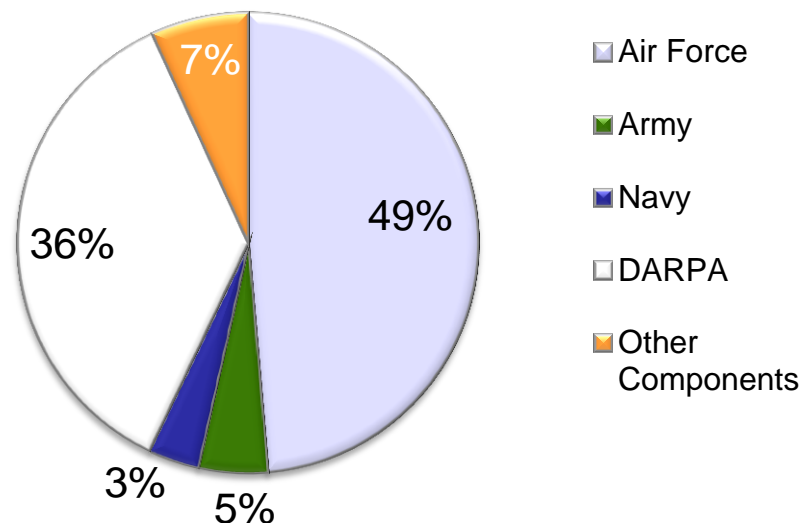
Space S&T COI Investment and Performers



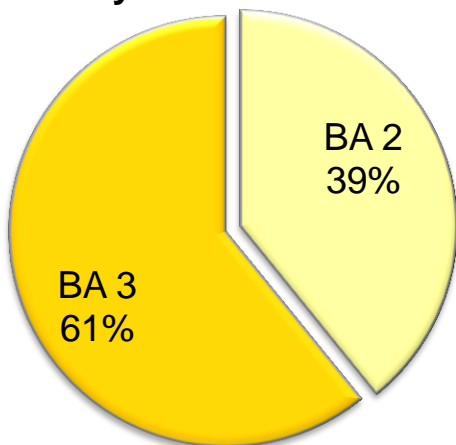
COI Sub-Areas PB16



Component Investment



Budget Activity



Intramural vs. Extramural split:

- Army - 6.2 47/53; 6.3 38/62
- Navy - 6.2 60/40; 6.3 40/60
- Air Force - 6.2 48/52; 6.3 20/80

Major Performers:

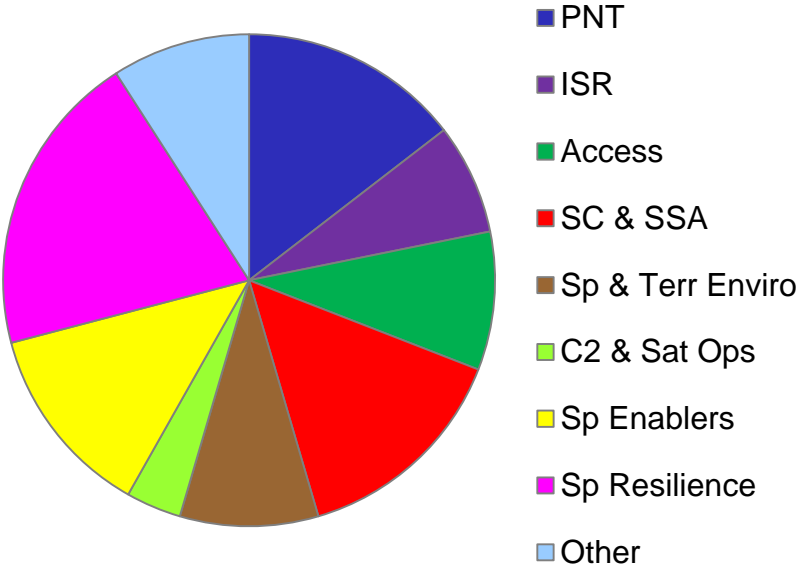
- Aerojet-Rocketdyne, APL, BAE Systems, Ball Aerospace, Boeing, Dynetics, Honeywell, Lockheed Martin, MIT-LL, Northrop Grumman, NRL, Orbital/ATK, Raytheon, Sandia National Laboratory, Teledyne Brown



SBIR Investment FY15 Phase I and II Awards

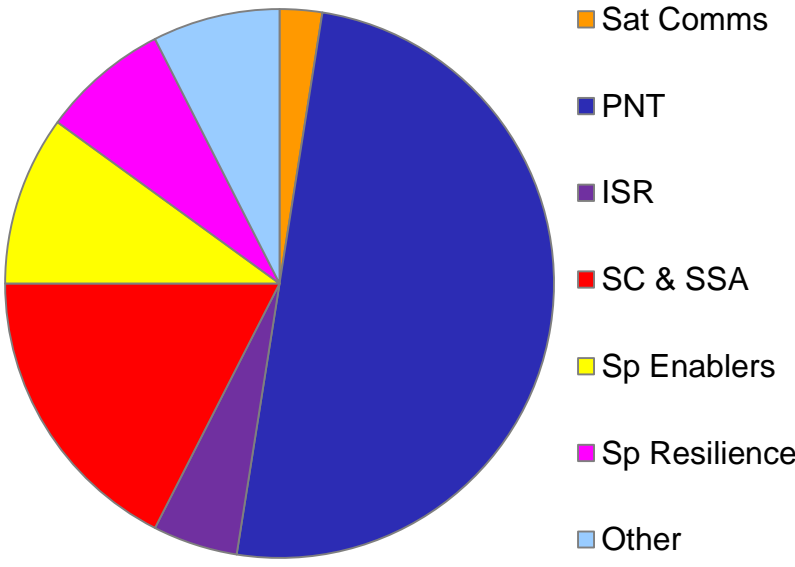


FY15 Phase I



55 Awards

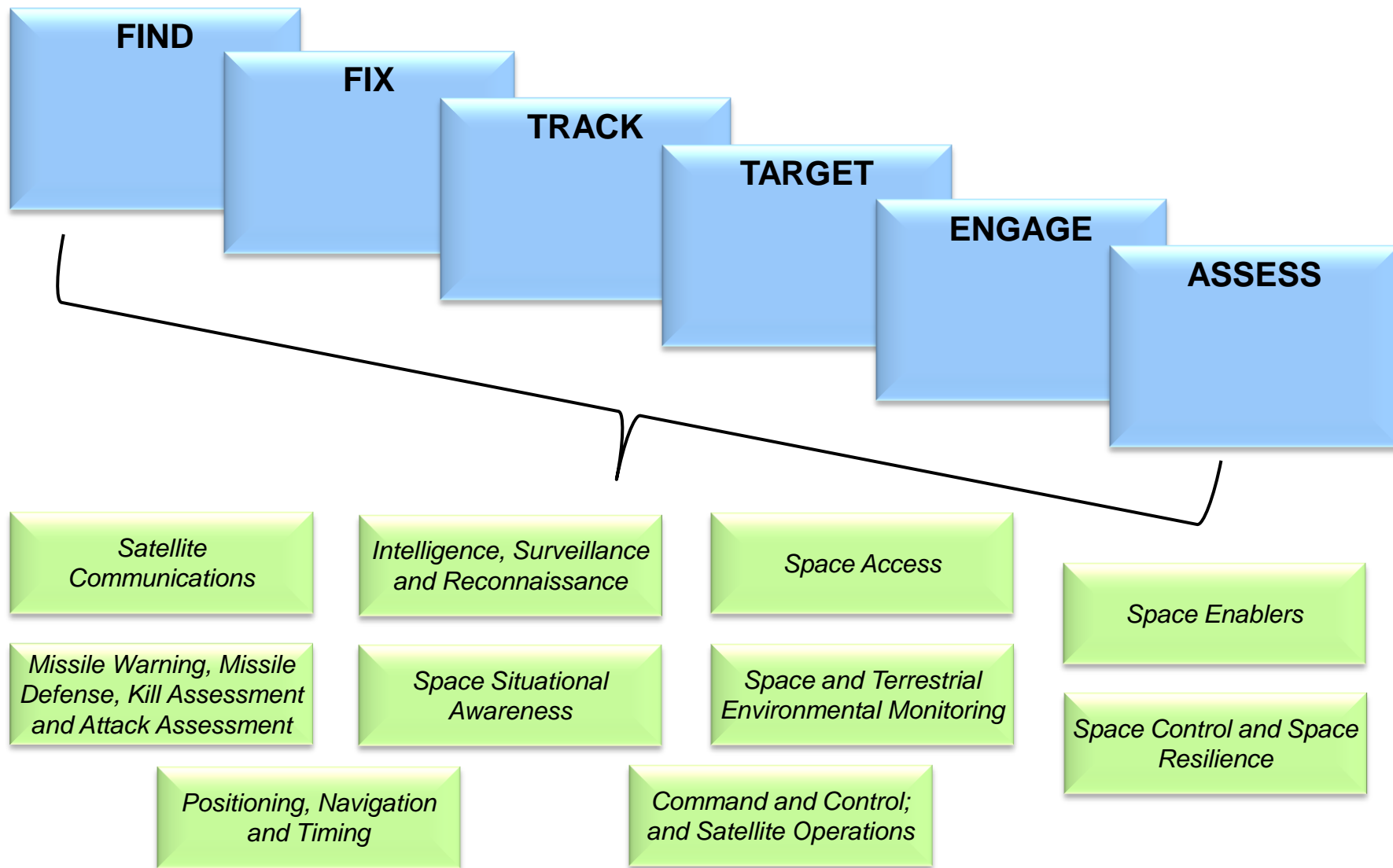
FY15 Phase II



40 Awards



Space COI Relationship to Kill Chain





Gaps



- **Understanding Allied Investments**
 - NATO countries
 - Long-term Allies & partners
 - Other cooperating nations
- **Understanding Investments of Potential Rivals**
 - Intent, Doctrine, ROEs & TTPs
 - Technical performance of systems
- **Understanding Benefits and Risks of Employing Commercial Systems**
 - Security, availability, responsiveness
 - Cost, limitations
- **On-Orbit Servicing & Repair**
 - What's next?
- **Trade-off: Cost v Schedule v Lifetime**
 - 10+ year on-orbit lifetime = high first cost but long replenishment schedule
 - Other paradigm – short life = low initial cost but short replenishment schedule
 - Which paradigm is the future?



Current Challenges Driving Space S&T Investments



- **Cost-effective manufacturing and acquisition of spacecraft**
 - Very few spacecraft (~3/year)
 - Highly specialized payloads required
- **Lower launch cost**
 - Reducing overall launch cost and cycle time
- **Adding protection and resiliency to our current space fleet**
 - Avoiding expensive block upgrades
- **Low data rate comms to dispersed units**
- **Cost-effective sustainment of existing constellations**
- **Improve ability to remotely measure sea-surface height and ocean surface vector winds to support navy oceanographic models**
- **Expanding LEO beyond experimentation to Warfighter capability**
- **Cyberspace awareness – threats and mitigation**
- **Smart leveraging and use of Commercial Space**
 - Can we match the Commercial Industry speed of business?



Risks for Space S&T



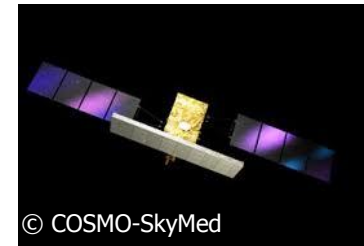
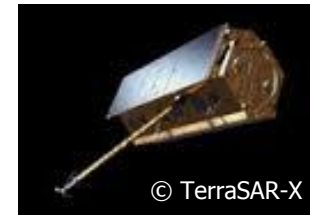
- **Investing ahead of others and converse**
 - Many nations now acquiring space-based capabilities including development of indigenous capabilities
 - Commercial systems offering ISR services
 - Cubesats are good – low cost test platforms and capabilities
 - Cubesats are bad – low cost enable many to test & develop space capabilities that were cost prohibitive in the past
 - Protecting existing operational satellites
- **International collaboration**
 - US space S&T collaboration with international partners continues to increase
- **Classifications**
 - US space S&T conducted at multiple security levels
- **No affordable responsive launch options exist today**



S&T Opportunities



- **Exploiting expanding commercial space**
- **Ever growing and lucrative commercial satcom and ISR markets (GEO, MEO, and LEO)**
 - Digital Global Systems
 - TerraSAR-X
 - COSMO-SkyMed
- **Wealthy visionaries are investing in space tourism and transportation**
- **Commercial startups and international entrants are expanding micro and small sat capabilities**
 - Future large “micro” & “small sat” constellations
 - SpaceX
 - OneWeb
 - Planet Labs
 - SPIRE
 - Black Sky
 - Skybox
- **NASA investments are buoying new entrants for orbital and suborbital markets**

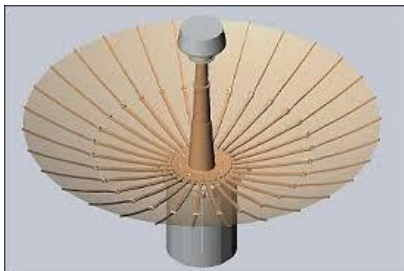




Army Space S&T Themes



Deployable Antennas



*Reliable, High Gain, CubeSat
Compatible*

Software Defined Radios



*Low Size, Weight and Power,
High Capacity, Flexible*

Encryption



High Throughput

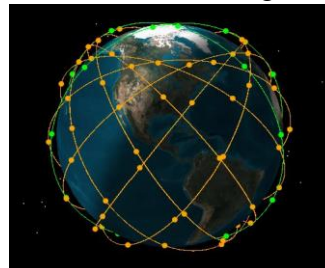
Communication For Forward Forces

Imagery



IR, Low Light, MSI

Constellation Management

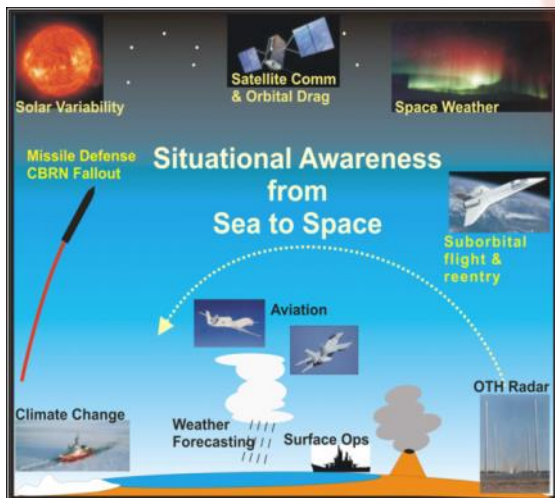


*Highly automated, common architecture,
optimized planning and tasking*

Innovative, Affordable Space Technologies Support Future Battlefield Dominance



Navy Space S&T Themes - Research



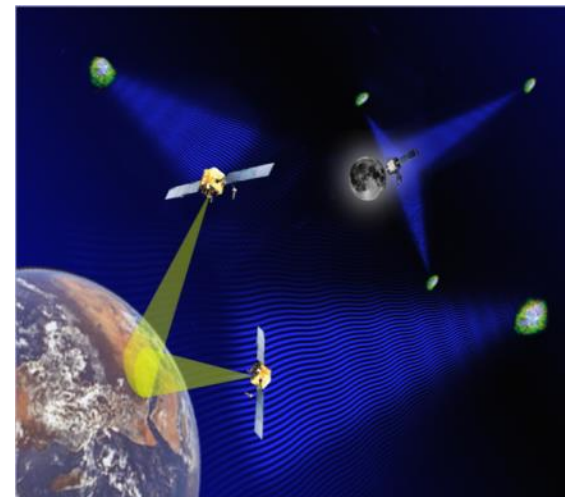
Geospace

Observe and forecast,
for enhanced
situational awareness



Heliospace

Develop improved
sensors, specification,
monitoring and
prediction tools for
operational impacts and
real-time threat warning



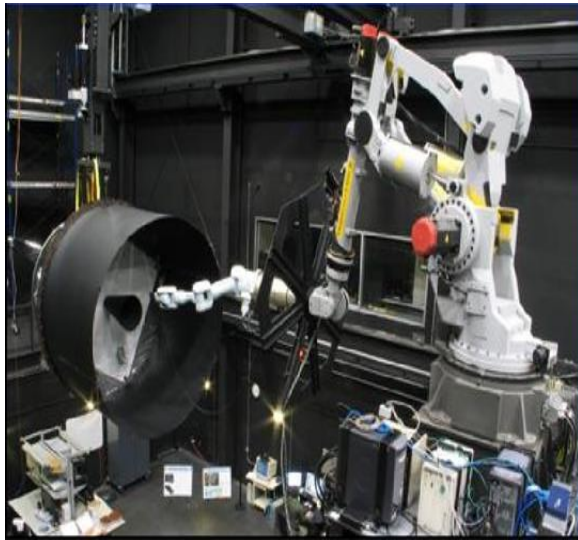
High Energy Space

Measure, simulate and
model natural and artificial
radiation and rad/nuke
signatures, for detection
and remediation

Experimentally-led sensing R&D integrated across three environmental areas that underpin, connect, and inform successful operations, with metrics to increase TRL from 0-1 to 2 and to identify transition potential



Navy Space S&T Themes - Technology



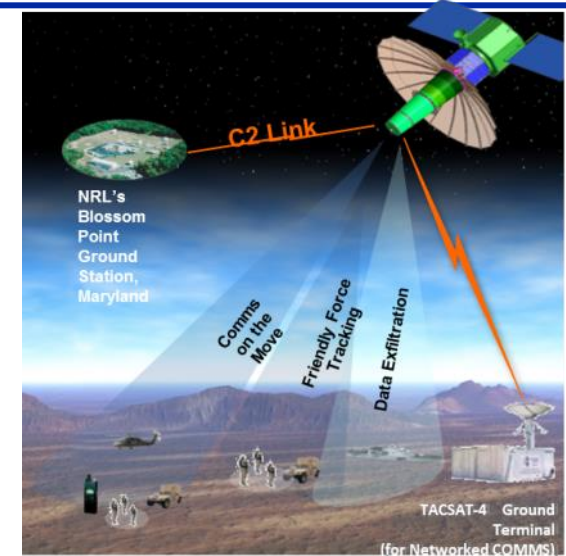
Advanced Spacecraft Technologies

Sub-systems, for new and prototype building-blocks; propulsion & control, towards precision maneuvering while minimizing fuel; materials resiliency characterization



Payloads & Sensing

Next-generation, to improve monitoring for threats



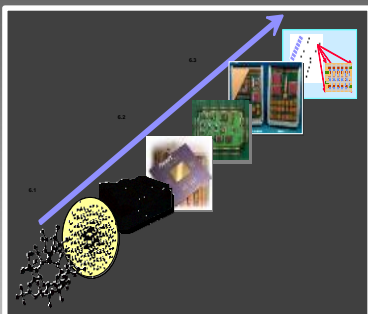
Connectivity

High-bandwidth, space-based, for disadvantaged users

Spacecraft R&D in three strategic areas that lead to the fielding of systems that perform functions critically important to operations, with metrics to increase TRL from 1-2 to 3 and to develop transition pathways

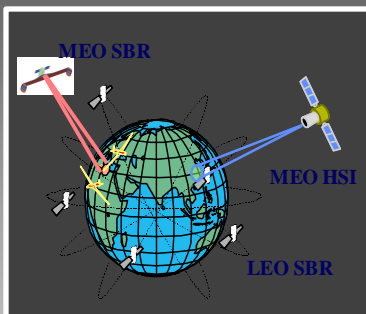


Air Force Space S&T Themes



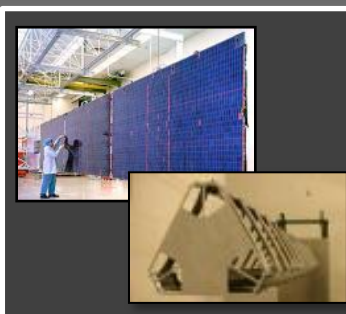
Space Electronics

- Space electronics physics to understand failure modes and improve reliability
- New space processors, solid-state amplifiers for GPS/Comm, A-D converters, memory



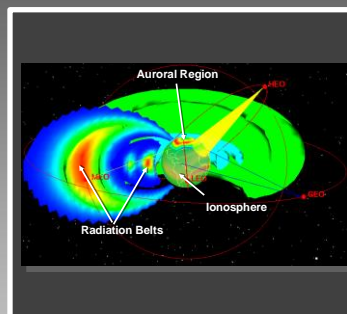
Space Remote Sensing

- Exploitation of collected photons (temporal, spectral, polarimetric)
- New sensors and components for missile warning
- Detectors, algorithms, optics
- Nuclear explosion monitoring



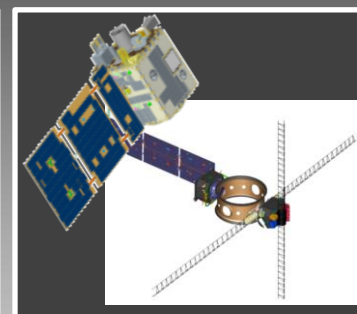
Space Platform & Ops Tech

- New technology to support AF-specific missions
- Solar arrays with 8X lower volume
- High-capacity thermal control
- Guidance, navigation
- Autonomous systems



Space Environment Impacts & Mitigation

- Models for spacecraft shielding and lifetime
- Anomaly resolution
- Astrodynamics for collision avoidance
- Reentry environment
- Space plasma physics & chemistry



Space Flight Experiments

- Space system & payload development
- Integration, test, & flight
- Modeling & simulation
- Space system engineering

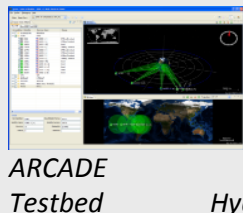


Air Force Space S&T Snapshot

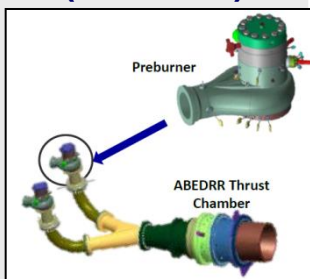


Near Term

- SSA: Local GEO SSA using ANGELS. Proving close object detection using Ground SSA
- JSpOC: ARCADE Testbed accelerating 10 new Apps
- Protection: Space testing of new tech-insert options.
- Launch: Combustion modeling tools to Industry; Preburners transitioned to NASA Adv Booster Program (ABDERR)



ARCADE
Testbed



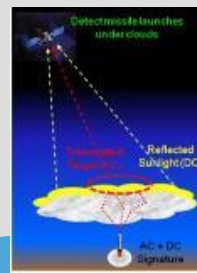
Hydrocarbon Boost pre-burners

- WGS and Commercial Comm
- JMS Increment 3
- Commercial Launch options

Mid Term

- SSA: ARCADE testbed integrated with JICSpOC for Battlespace management (BMC2)
- Comm: Increase frequency trade-space into the W/V band
- GPS: All-digital, High-power GPS payloads increases anti-jam
- Missile Warning: Detect difficult theater missiles under clouds
- Launch: Ox-rich Staged Combustion engine technology

V/W Band Transmitter



- Protected Nuclear Comm (NC3)
- GPS III SV 9+
- RD-180 replacement option

Far Term

- SSA: Resolved ISAL imaging of GEO satellites using ground telescopes
- GPS: Cold Atom (Quantum) Inertial Navigation and clocks
- ISR: Networked tactical sensing between Space & Air domains
- Launch: Low cost, manufacturable rocket engines

Cold Atom Inertial Nav



ISAL GEO image
(Simulated)

- BMC2 JICSpOC
- Air-Space integration



DARPA S&T Theme GEO Servicing

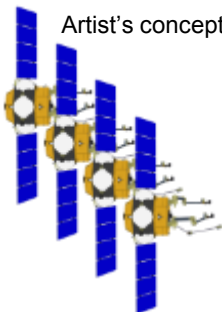


SERVICING



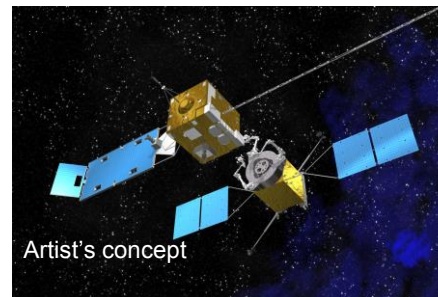
Artist's concept

First robotic
capability in
GEO



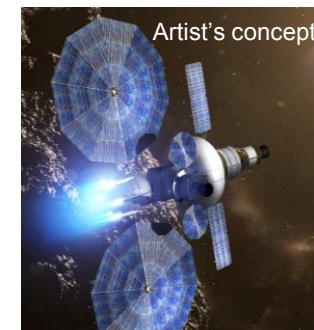
Artist's concept

Commercial
providers expand
coverage



Artist's concept

Automated,
scheduled
refueling



Artist's concept

LEO-to-
GEO space
tug

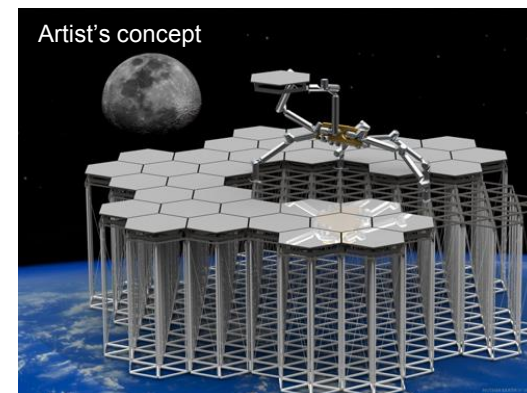
Technology development and investment

- On-orbit replaceable units
 - Modular spacecraft



- Reduced redundancy
- Lightly fueled at launch
- Assembly experiments

Large apertures,
structures and bases



Artist's concept

Space robotics = national-level growth potential

NEW ARCHITECTURES



Overarching Space S&T COI Subarea Roadmap



Space S&T Subareas

- Satellite Communications

- Missile Defense and Attack Assessment

- Positioning, Navigation and Timing

- Intelligence, Surveillance and Reconnaissance

- Space Control and Space Situational Awareness

- Space Access

- Space and Terrestrial Environmental Monitoring

- Command and Control & Satellite Operations

- Space Enablers



15	16	17	18	19	20	21	22	23	24-27
	Comms for Disadvantaged Platforms & Users		UHF / Ka band comms			V/V and Ka-Band Comms			
	6	6	6	6	6	6			
	Post Intercept Assessment Capability	OPIR Enterprise Tasking Capability							
	6	6	6	6					
	Improved/New MD Applications	Improved Future Space Sensors	Next Gen GPS Space User Equipment		Space Systems				
			6		6				
	On-Demand EO Imagery	Improve Utilization of Space Assets			Comprehensive Knowledge of Man-made Orbital Objects			Increase Persistence	
		7	6		6	6		6	
	Environmental Monitoring Technologies		Ground-based Optical Systems		Fully Integrated Space-, Air-, and Ground-based				
	7		8	9					
	Operational Spacecraft Systems	Threat I&W Software Technologies	EELV Space Access						
	6	6	6						
	Space Environment Sensors and Earth-to-Sun Understanding	Ionospheric Prediction for Sensor Optimization and Performance	Entrepreneurial Space Access						
	6	5	5						
	Space Environment Prediction for Spacecraft and Terrestrial Impacts								
					Robotic Capabilities				
		6		8			7		
		Efficient On-orbit Maneuvering and Life Extension				Autonomous Systems			
	Structural Components					Thermal Management			
	6	6	5		5	7	6		
	Power and Power Management	Innovation			Modeling and Simulation	Space Electronics			



Army Future Space S&T Trends and Opportunities



- The Space Operational Environment will become increasingly complex over time (both in capacity and capability). Friendly, Coalition, and Threat forces will vie for Space capabilities and seek to deny others
- The future Army Operational Environment (Asymmetric warfare, Mega Cities, non-state operators, etc.) will be increasingly more dependent on tactical Space capabilities in multiple Mission Areas.



Navy Future Space Trends/ S&T Opportunities



- Multi-scale whole-atmosphere prediction of ionospheric effects, emphasis on Arctic and Tropical regions
- Terrestrial gamma-ray flashes observation base and background events modeling
- Characterize celestial pulsar sources for space-based GPS-stressed timing and navigation
- Investigate x-ray space-based communications
- Specification and prediction of geospace, heliospace, and high energy environmental effects for improved HF propagation, geolocation, SATCOM, orbital analysis, geomagnetic ULF resonance, and rad/nuke maritime detection and interdiction
- Imaging of GEO satellites from earth
- Cooperative, automatic space robotic capabilities
- Low-mass and novel active technologies for spacecraft propulsion systems
- Space sensor and analysis tools integrating on-orbit observations with modeling for improved SSA
- Lightweight articulation and sensing integrated space robotics architectures
- Spacecraft propulsion and control capabilities for precision maneuvering while minimizing fuel
- Low Earth Orbit radiation environment characterization payloads



Air Force Future Space S&T Trends



- **Space Comm:**
 - S&T to reduce risk on LEO constellation technology to support Air Dominance
 - Alternatives needed to AFSCN TT&C
- **Launch detection**
 - Near-term AFSPC/SMC focus is on low-cost disaggregation approaches.
 - Long-term DoD focus is on tactical missiles. AFRL Hyper-temporal is a major contribution, but gaps still exist.
- **PNT**
 - Resiliency needed for GPS space and control segments
 - PNT user equipment
- **SSA**
 - Leveraging commercial observations (ground and space) crucial to improve persistence
 - Key challenges are data trust, fusion, and interoperability with AF operational systems
 - Space-based, GEO focused SSA
- **Space Access**
 - On orbit propulsion
- **Space C2 & Ops**
 - Leverage commercial systems.
- **Pervasives**
 - Protection and Resilience technology
 - S&T approaches to accelerate spacecraft manufacturing



DARPA Future Space S&T Trends



- **Launch:**
 - Flexible, affordable access
 - Affordable, routine and reliable access to space
 - Aircraft-like space access to lower cost and increase capabilities
- **Satellite:**
 - Changing the paradigm of satellite operations
 - New satellite architectures for speed and robustness
 - GEO space robotics to repair and assemble very large satellites that could not be launched
- **Space Domain Awareness (SDA):**
 - Real-time space domain awareness
 - Real-time detection and tracking versus catalog maintenance and days to weeks of forensics