DoD Space S&T Community of Interest Presentation to NDIA S&T Conference 13 April 2016

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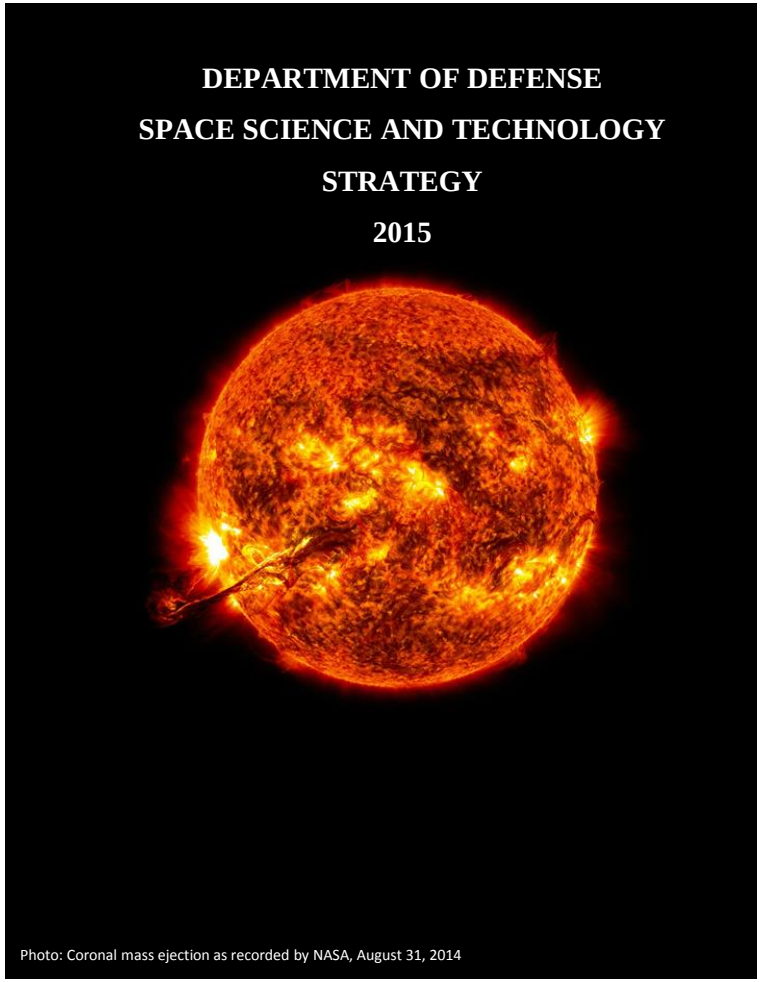
DoD Space S&T Strategy



- 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

Technical Challenges
- Reduce SWaP-C and improve thermal management
- Develop V/W band RF and laser comms

Missile Warning, Missile Defense, and Attack Assessment

Technical Challenges
- Improve sensors for whole-Earth staring
- Improve data fusion algorithms

Positioning, Navigation and Timing

Technical Challenges
- Improve anti-jam capability
- Improve atomic clocks
- Enhance orbital navigation technology

Intelligence Surveillance and Reconnaissance

Technical Challenges
- Increase persistence of ISR
- Improve data compression
- Integrate space, air and ground based ISR

Space Situational Awareness

Technical Challenges
- Improve space object detection and monitoring of potential threats

Space Access

Technical Challenges
- Reduce cost and time cycle
- Higher performance on-orbit propulsion
- Enable fully reusable launch systems

Space and Terrestrial Environmental Monitoring

Technical Challenges
- 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

Technical Challenges
- Increase autonomy to reduce manning
- Space robotic capabilities for servicing/repair

Space Enablers

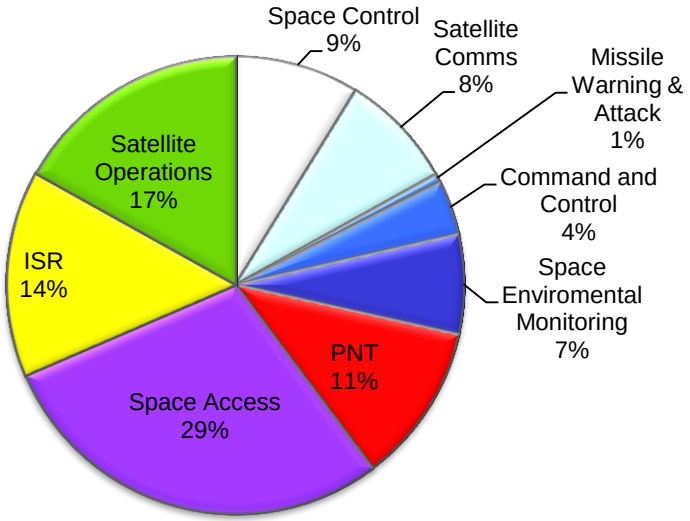
Technical Challenges
- Standardized and miniature components and interfaces
- Carbon-based nanotechnology
- Ultra-high efficiency power systems

Space Control and Space Resilience

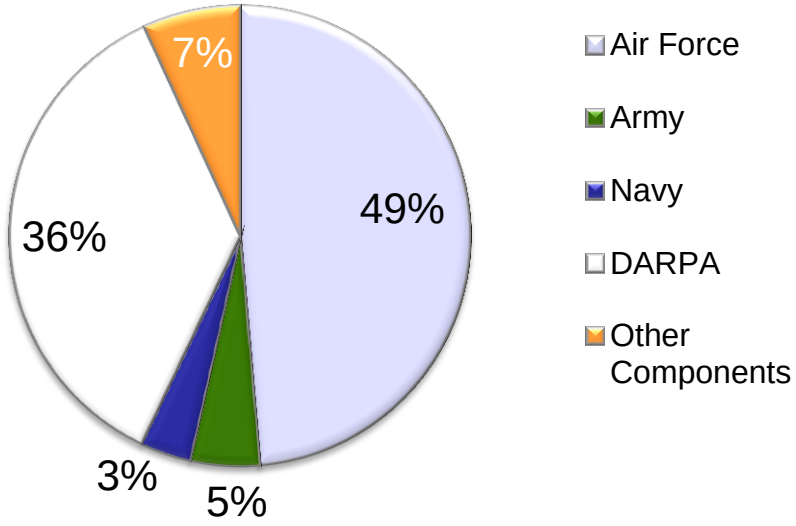
Technical Challenges
- On-board adaptive planning
- Local area imaging sensors
- Laser survivability

Space S&T COI Investment and Performers

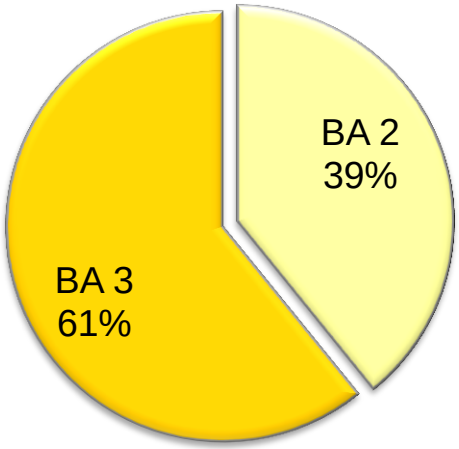
COI Sub-Areas PB16



Component Investment



Budget Activity



Intramural vs. Extramural split:

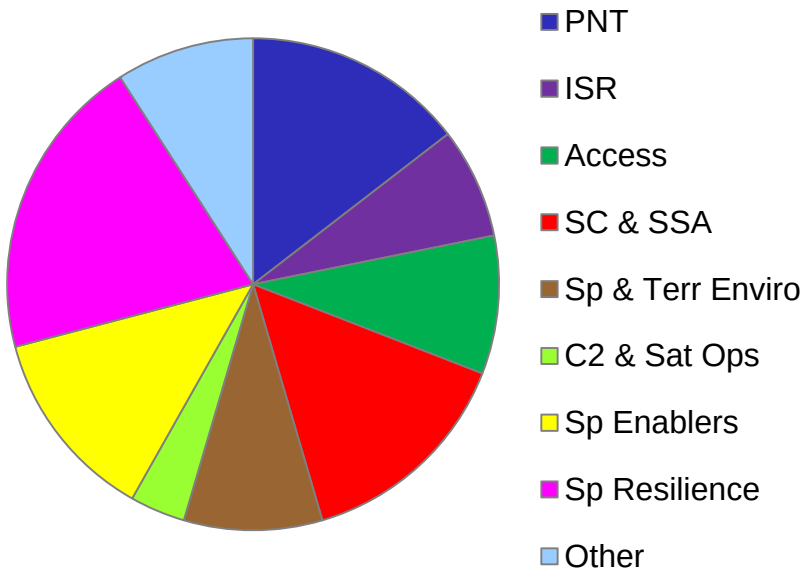
- **Army - 6.2 47/53; 6.3 38/62**
- **Navy - 6.2 60/40; 6.3 40/60**
- **Air Force - 6.2 48/52; 6.3 20/80**

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**

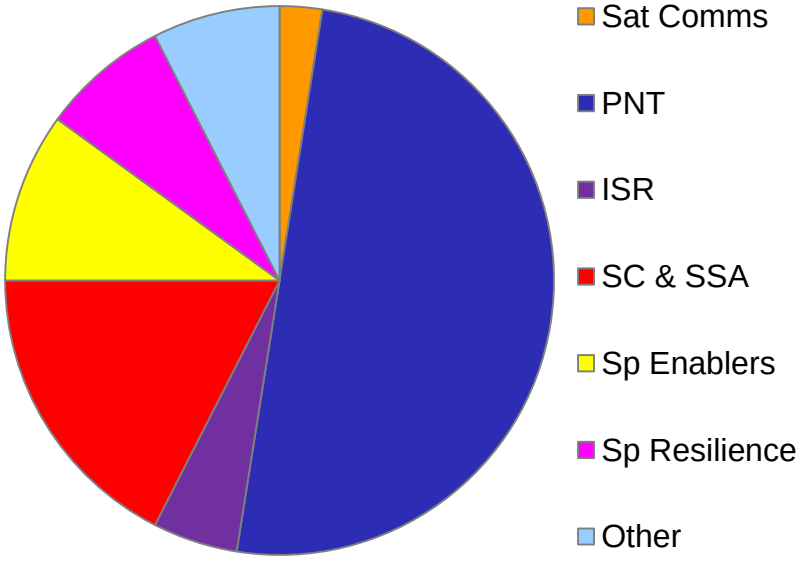
SBIR Investment
FY15 Phase I and II Awards

FY15 Phase I



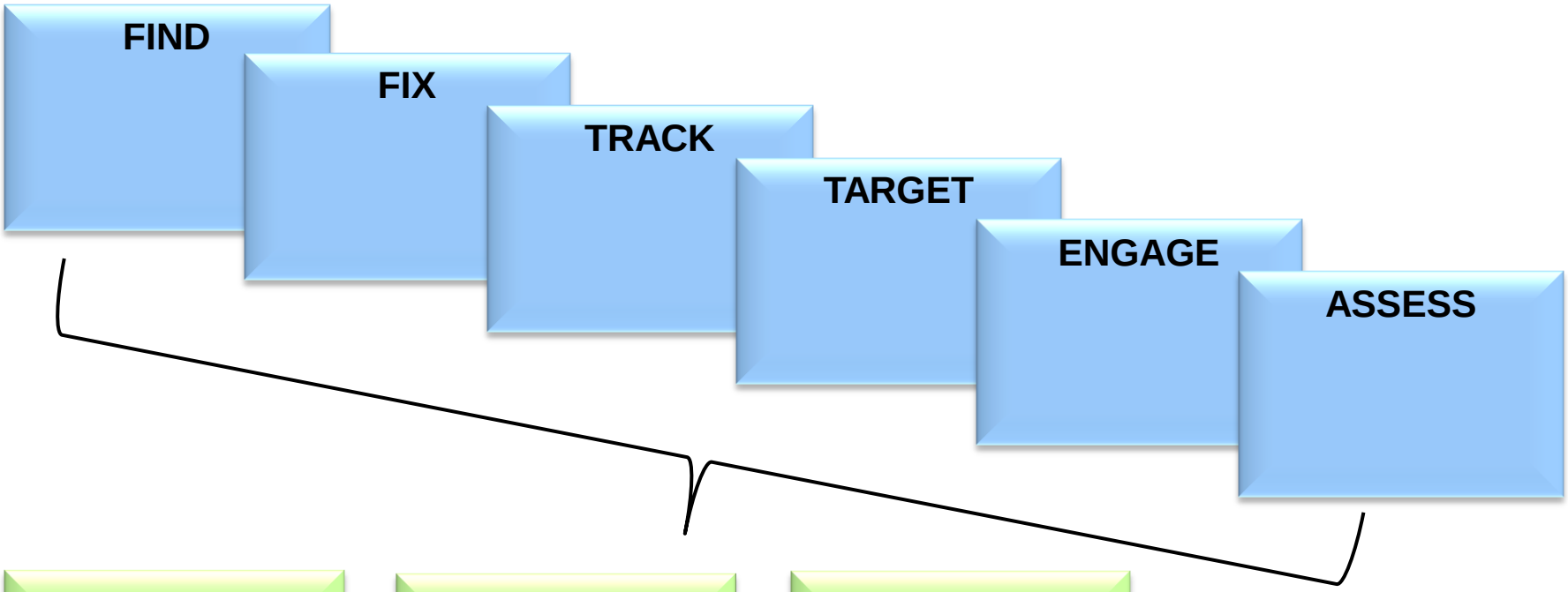
55 Awards

FY15 Phase II



40 Awards

Space COI Relationship to Kill Chain



Satellite Communications

Intelligence, Surveillance and Reconnaissance

Space Access

Space Enablers

Missile Warning, Missile Defense, Kill Assessment and Attack Assessment

Space Situational Awareness

Space and Terrestrial Environmental Monitoring

Space Control and Space Resilience

Positioning, Navigation and Timing

Command and Control; and Satellite Operations

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

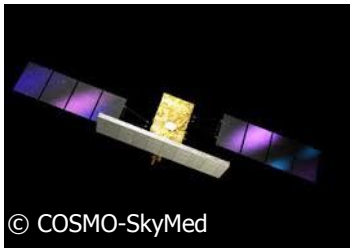
- **Cost-effective manufacturing and acquisition of spacecraft**
  - Very few spacecraft (~3/year)
  - Highly specialized payloads required
- **Lower launch cost**
  - Reducing overall launch cost and cycle time
- **Adding protection and resiliency to our current space fleet**
  - Avoiding expensive 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?

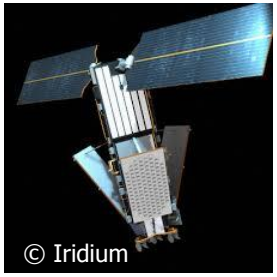
Risks for Space S&T

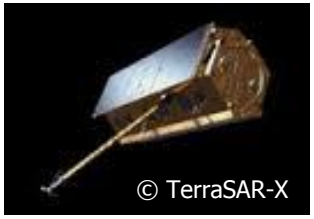
- **Investing ahead of others and converse**
  - Many nations now acquiring space-based capabilities including development of indigenous capabilities
  - Commercial systems offering ISR services
  - Cubesats are good – low cost test platforms and capabilities
  - Cubesats are bad – low cost enable many 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

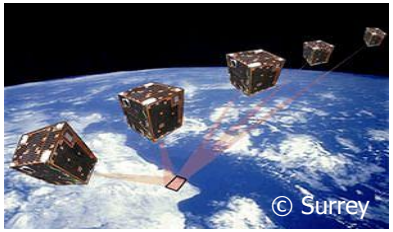
- **Exploiting expanding commercial space**
- **Ever growing and lucrative commercial satcom and ISR markets (GEO, MEO, and LEO)**
  - Digital Global Systems
  - TerraSAR-X
  - COSMO-SkyMed







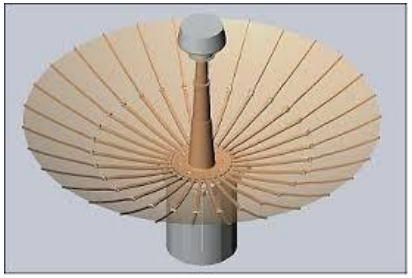
- **Wealthy visionaries are investing in space tourism and transportation**
- **Commercial startups and international entrants are expanding micro and small sat capabilities**
  - Future large “micro” & “small sat” constellations
    - SpaceX
    - OneWeb
    - Planet Labs
    - SPIRE
    - Black Sky
    - 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

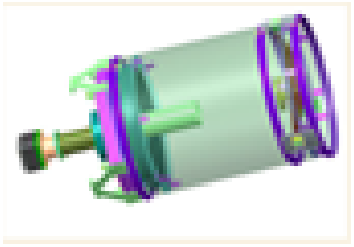
Low Size, Weight and Power, High Capacity, Flexible

Encryption

High Throughput

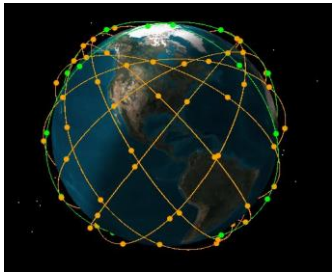
Communication For Forward Forces

Imagery



IR, Low Light, MSI

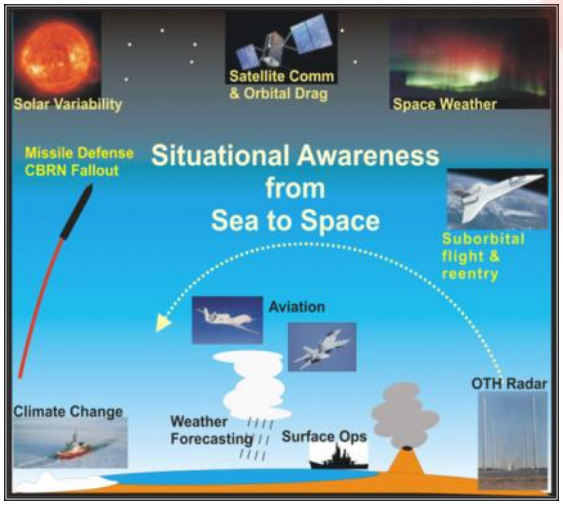
Constellation Management

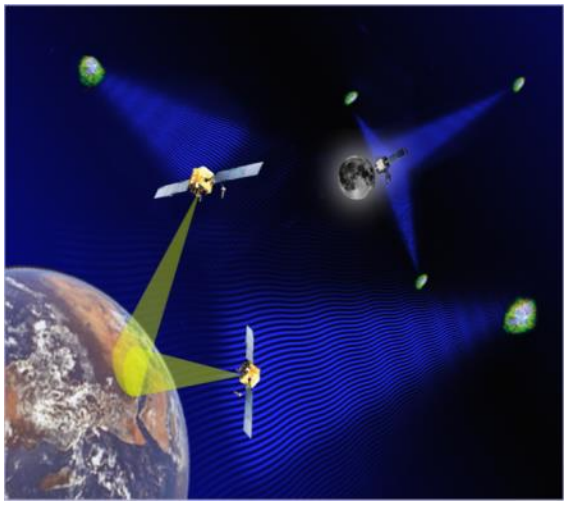


Highly automated, common architecture, optimized planning and tasking

Innovative, Affordable Space Technologies Support Future Battlefield Dominance

Navy Space S&T Themes - Research





Geospace

Observe and forecast, for enhanced situational awareness

Heliospace

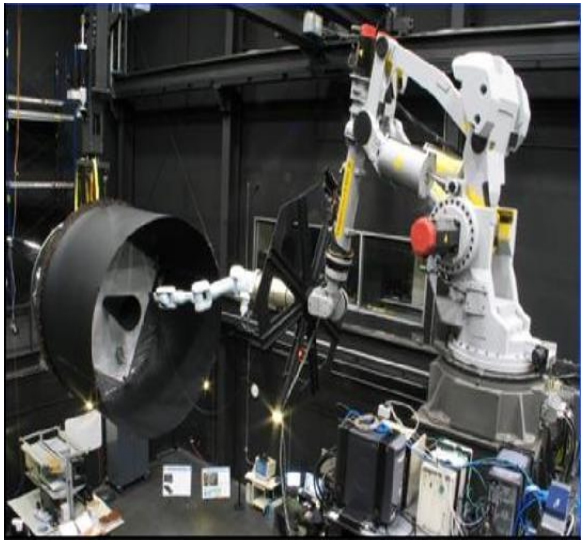
Develop improved sensors, specification, monitoring and prediction tools for operational impacts and real-time threat warning

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

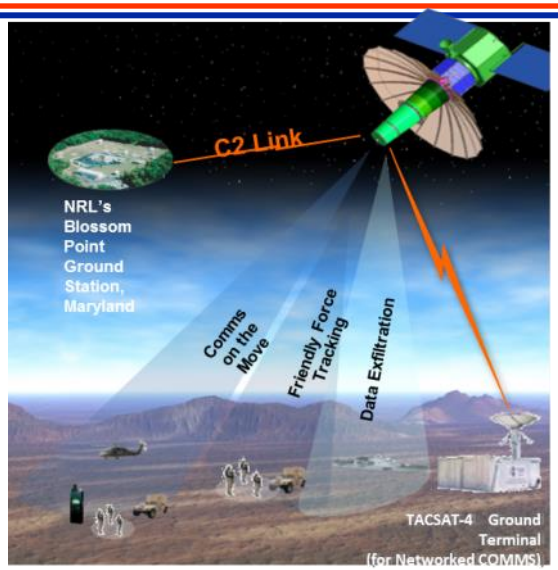


Advanced Spacecraft Technologies

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

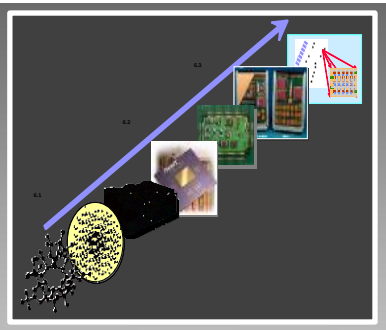


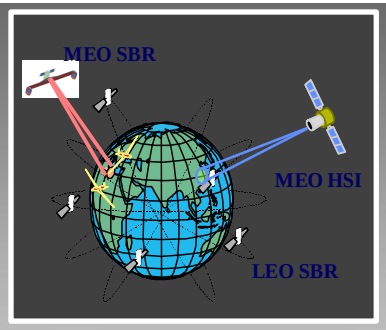
Connectivity

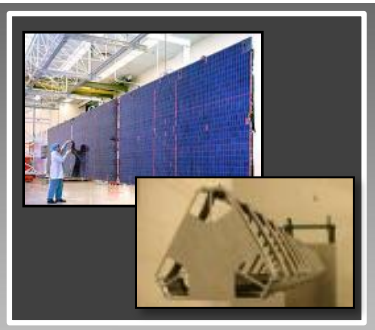
High-bandwidth, space-based, for disadvantaged users

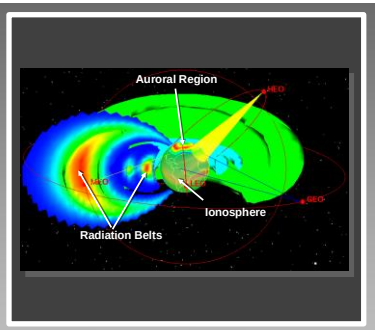
Spacecraft R&D in three strategic areas that lead to the fielding of systems that perform functions critically important to operations, with metrics to increase TRL from 1-2 to 3 and to develop transition pathways

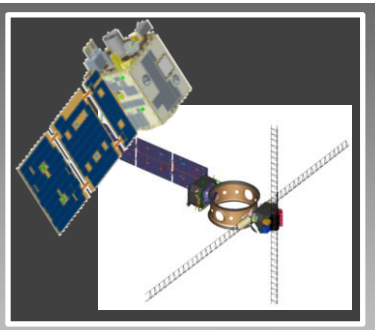
Air Force Space S&T Themes











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

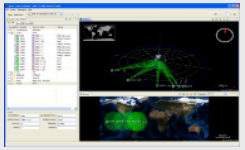
Space Flight Experiments

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

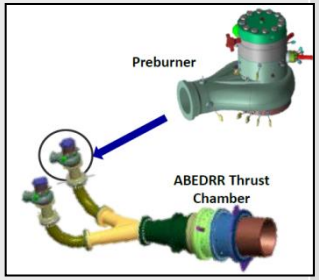
Air Force Space S&T Snapshot

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



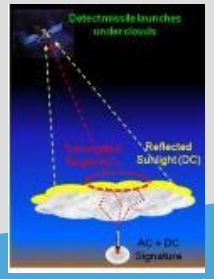
Hydrocarbon Boost pre-burners

- 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

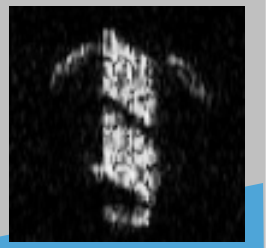


- Protected Nuclear Comm (NC3)
- GPS III SV 9+
- RD-180 replacement option

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



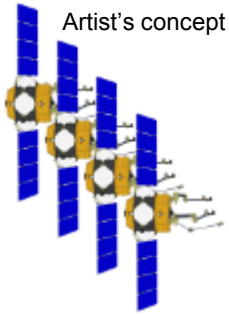
ISAL GEO image (Simulated)

- BMC2 JICSpOC
- Air-Space integration

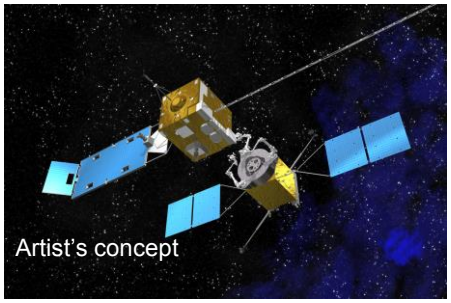
DARPA S&T Theme
GEO Servicing

SERVICING

First robotic capability in GEO



Commercial providers expand coverage



Automated, scheduled refueling

LEO-to-GEO space tug

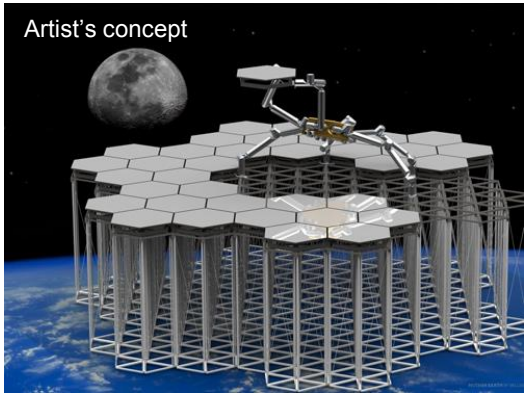
Technology development and investment

NEW ARCHITECTURES

- On-orbit replaceable units
  - Modular spacecraft

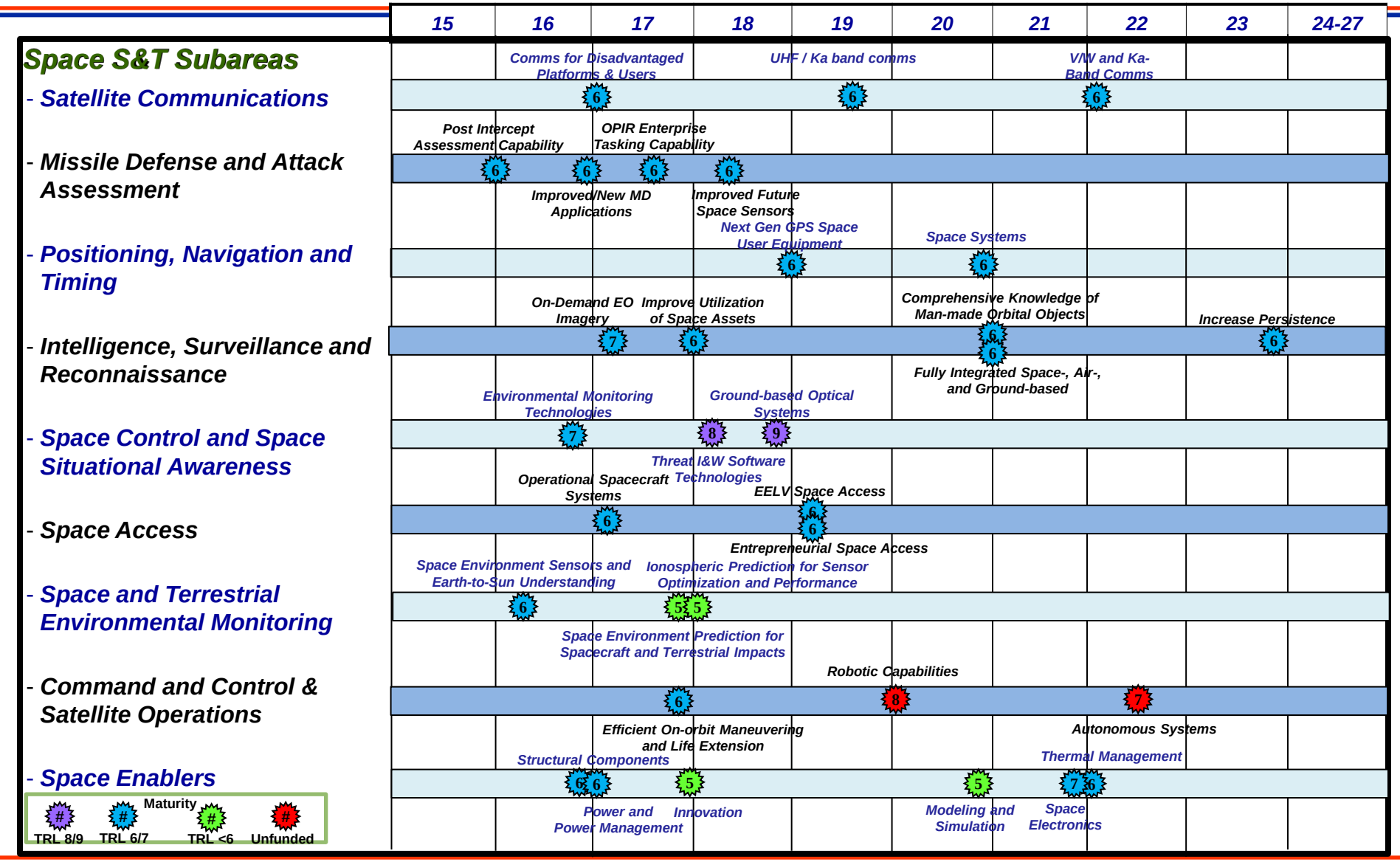
- Reduced redundancy
- Lightly fueled at launch
- Assembly experiments

Large apertures, structures and bases



Space robotics = national-level growth potential

Overarching Space S&T COI Subarea Roadmap



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