Why Invest in Space Technology?

- Enables a **new class of NASA missions** beyond low Earth Orbit.
- **Delivers innovative solutions** that dramatically improve technological capabilities for NASA and the Nation.
- Develops technologies and capabilities that make NASA’s missions **more affordable and more reliable**.
- Invests in the economy by **creating markets and spurring innovation** for traditional and emerging aerospace business.
- **Engages the brightest minds** from academia in solving NASA’s tough technological challenges.

**Value to NASA**

**Value to the Nation**

Addresses National Needs

A generation of studies and reports (40+ since 1980) document the need for regular investment in new, transformative space technologies.

**Who:**

- The NASA Workforce
- Academia
- Industry & Small Businesses
- Other Government Agencies
- The Broader Aerospace Enterprise
Challenges for Deep Space Exploration

- Communication
- Environment Control & Life Supporting Systems
- Navigation
- Manufacturing In Space & For Space
- Propulsion
- Power Generation & Storage
- Logistics
- Entry, Descent & Landing
- Radiation Mitigation
Space Technology Programs

• **Adheres to a Stakeholder Based Investment Strategy:** NASA Strategic Plan, NASA Space Technology Roadmaps / NRC Report and Strategic Space Technology Investment Plan

• **Invests in a Comprehensive Portfolio:** Covers low to high TRL, student fellowships, grants, prize competitions, prototype developments, and technology demonstrations

• **Advances Transformative and Crosscutting Technologies:** Enabling or broadly applicable technologies with direct infusion into future missions

• **Selects Using Merit Based Competition:** Research, innovation and technology maturation open to academia, industry, NASA centers and other government agencies

• **Executes with Structured Projects:** Clear start and end dates, defined budgets and schedules, established milestones, and project authority and accountability

• **Infuses Rapidly or Fails Fast:** Rapid cadence of technology maturation and infusion, informed risk tolerance to infuse as quickly as possible

• **Positions NASA at the cutting edge of technology:** Results in new inventions, enables new capabilities and creates a pipeline of innovators for National needs
Evaluating current STMD investments as recommended by the Strategic Space Technology Investment Plan (SSTIP, NRC, other Stakeholders)

- Initial evaluation is consistent with the SSTIP Core, Adjacent, and Complementary recommendations
- Approximately 72% of investments are in Core areas
- STMD has investments in all 14 Technology Areas
- Approximately 10% of investments are low TRL (1-3) consistent with the recommendation by the National Research Council (NRC) Final Report on Space Technology Roadmaps and Priorities

STMD investments are consistent with the Strategic Space Technology Investment Plan (SSTIP)
STMD Technology Investments within NRC’s Top 16 Priorities

**Electric Propulsion**
- Solar Electric Propulsion
  - Solar Arrays
  - Thruster & Power Processing Unit
  - Propellant Feed System & Storage Tanks
  - High Power Electric Propulsion Systems (SBIR)
  - Hall Thruster & Erosion (Lifetime) Measurements (STRG)

**Solar Power Generation**
- Advanced Batteries
- Regenerative Fuel Cells
- Advance Photovoltaic Systems (SBIR)
- Nanostructured Photovoltaics for Space Power (STRG)
- "SPS-Alpha" Space Solar architecture (NIAC)

**Environmental Control and Life Support System**
- CO2 to O2 recovery
- Water Processing
- Air Regulators
- Biocomposites
- Crew Accommodations and Water Recovery for Long Duration Missions (SBIR)
- New Technology for Gas Absorption (STRG)
- Solid State Air Purification System (NIAC)

**Entry, Descent and Landing**
- Woven Thermal Protection
- Deployable Aeroshell Concepts
- Hypersonic Entry Systems
- Supersonic Descent Systems
- Ablative Thermal Protection Systems (SBIR)
- Quantitative Measurements of Ablation-Products Transport for Turbulence Model Validation (STRG)

**Active Thermal Control of Cryogenic Systems**
- Cryogenic Propellant Storage and Transfer
- Integrated Multilayer Insulation
- Cryogenic Systems for Sensors and Detectors (SBIR)
- Two-Stage, 20 K Pulse Tube Cryocooler for Space Studies (STRG)

**Extreme Terrain Mobility**
- Human Robotic Systems
- Robotic Satellite Servicing
- Autonomous Systems
- Robotic Mobility, Manipulation and Sampling (SBIR)
- Exploration of Under-Ice Regions with Ocean Profiling Agents (EUROPA) (NIAC)
STMD Technology Investments within NRC’s Top 16 Priorities

Early Stage Innovation:
GCD, CIF, NIAC, STRG, SBIR/STTR

- (Nuclear) Thermal Propulsion
- Fission (Power)
- Long-Duration (Crew) Health
- Detectors & Focal Planes
- (Instrument and Sensor) Optical Systems
- High-Contrast Imaging and Spectroscopy Technologies
- In Situ (Instruments and Sensor)
- Radiation Mitigation for Human Spaceflight
- Lightweight and Multifunctional Materials and Structures
- Guidance, Navigation, and Control
Creating Markets & Growing Innovation Economy

Pioneering Concepts/Developing Innovation Community

Transformative & Crosscutting Technology Breakthroughs

Game Changing Development (ETD/CSTD)

Technology Demonstration Missions (ETD/CSTD)

Small Spacecraft Technologies (CSTD)

Space Technology Research Grant (CSTD)

NASA Innovative Advanced Concepts (NIAC) (CSTD)

Center Innovation Fund (CSTD)

Centennial Challenges (CSTD)

Small Business Innovation Research & Small Business Technology Transfer (SBIR/STTR)

Flight Opportunities Program (CSTD)
Portfolio Approach

**Technology Areas**

- **ETD: TDM**
  - Human Exploration Telerobotics (HET)
  - Cryogenic Propellant Storage and Transfer (CPST)
  - Materials ISS Experiment X (MISSE-X)
  - Green Propellant Infusion Mission

- **CSTD: TDM**
  - Low Density Supersonic Decelerators (LDSD)
  - Laser Communications Relay Demonstration (LCRD)
  - Deep Space Atomic Clock (DSAC)
  - Solar Sail Demonstration (SSD)

**Technology Areas**

- **CSTD: Small Spacecraft Technologies**
  - Integrated Solar Array and Reflectarray Antenna for High Bandwidth CubSats
  - Integrated Optical Communications and Proximity Sensors for Cubesats
  - Proximity Operations Nano-Satellite Flight Demonstration
  - Edison Demonstration of SmallSat Networks (EDSN)
  - PhoneSat

**GEO**

- In-Space Propulsion
- Space Power Generation and Storage
- Lightweight Materials and Structures
- Nuclear Systems
- Autonomous Systems
- Next-Generation Life Support
- Deployable Aeroshell Concepts & Flexible TPS
- In-Situ Resource Utilization (ISRU)
- Composite Cryogenic Propellant Tanks
- Hypersonic Inflatable Aerodynamic Decelerator (HIAD)
- Advanced Radiation Protection

**Technology Demonstration Missions**
- Flight Opportunities
- Centennial Challenges
- Game Changing Development

**TRL Ranges of Programs**
- Technology Requirements Levels - Technology Maturity
FY2014 Big Nine

Increases space-based broadband, delivering data rates 10-to-100 times faster than today’s systems, addressing the demands of future missions.

Better fuel handling technology will improve spacecraft fuel economy. Required for Cryogenic Propulsion Stage (Space Launch System - SLS - upper-stage).

This tiny atomic clock is 10-times more accurate than today’s ground-based navigation systems, enabling precise, in-space navigation.

This solar sail has an area 7 times larger than ever flown in space, enabling propellant free propulsion and next generation space weather systems.

Develops and demonstrates green propellants, thus provides an alternative to highly corrosive and toxic hydrazine; consequently expanding the capabilities of small spacecraft systems.

Developing advanced systems capable of remotely operating robots to assist in future exploration; maturing new robots capable of assisting humans in routine and tedious work.

Develops large-scale solar array panels and deployment mechanisms. Critical step on the development path to a high-power solar electric propulsion system.

Demonstrating large composite, light weight fuel tanks that can reduce the mass and cost of the next generation SLS.

TDM Laser Communications
TDM Cryogenic Propellant Storage & Transfer
TDM Deep Space Atomic Clock
TDM Large-Scale Solar Sail
TDM Low Density Supersonic Decelarators
TDM Green Propellants
TDM & GCD Human Exploration Telerobotics & Human-Robotic Systems
TDM & GCD Solar Electric Propulsion
GCD Composite Cryotank

NASA Space Technology
The L’ Garde Sail is a unique design well suited to very large (high performance) solar sails.

Key features include:
- **Stripped-Net Sail Architecture**
- **Unstressed Sail Material**
- **1200 m² Sail Area**
- **~40m on a Side**
- **5um Kapton Film (8.5kg)**

**L’ Garde Patented Sub-Tg Conical Deployable Booms**

**Total Cost of Project ~ $25M**
Solar Sail Mission Overview

Demonstration Objectives

1. Demonstrate segmented deployment of a solar sail
2. Demonstrate attitude control plus passive stability and trim using beam-tip vanes.
3. Execute a navigation sequence with mission-capable accuracy.
4. Fly to and Possibly Maintain Position at sub-L1 and/or Pole Sitter Positions

Access to Space:
Manifested as Secondary on DSCOVR Launch to L1 (F9 1.1 in Q4 2014)
STMD support for SMD Astrophysics

- NIAC
- STRG
- Game Changing
  - NICER/SEXTANT
  - Adjustable Grazing Incidence X-ray Optics with 0.5 arc second resolution
  - Advanced laser frequency stabilization using molecular gases
- Future Collaborations
  - Exo-planet spectroscopy Internal coronagraphs and external occulters
  - Atomic Interferometer
• **OCCAMS Advanced Membrane Active Mirrors**
  
  **Goal:** Develop membrane mirrors able to deform at a molecular level, allowing huge, self-focusing mirrors
  
  – Low cost of manufacture, exceptionally light,
  
  – Active at the molecular level, back side of polymer chain expands when hit with a certain wavelength of LASER light, allowing on-orbit tuning of shape
  
  – 1 Lb. Mass for 2.4M (Hubble-sized) primary, could go much larger
  
  – $10k in materials cost for 2.4M primary

• **HOMES: Holographic Optical Method for Exoplanet Spectroscopy**
  
  **Goal:** Develop a preliminary architecture of a thin-film Holographic telescope able to analyze Exoplanet Spectroscopy
  
  - Replaces large heavy mirror optics with gossamer holograms
  
  - Holographic dispersion allows multiple spectrometer sensors, each tuned to a different wavelength, allowing faint signals to be readable
  
  - Potentially enables detection of habitable planets up to 30 light years away
• **Recent (January 2013) *Early Stage Innovations* Awards:**

- **Wavefront Control for High Performance Coronagraphy on Segmented and Centrally Obscured Telescopes:** Olivier Guyon, University of Arizona
  
  **Goal:** To develop and demonstrate an accurate and efficient approach to measure fine cophasing errors in support of future high contrast imaging missions. This work is critical to understand how future large space telescopes can directly image and study habitable planets around nearby stars.

- **Integrated Control Electronics for Adjustable X-Ray Optics:** Susan Trolier-Mckinstry, Pennsylvania State University
  
  **Goal:** To enable increased angular resolution and collection areas for future major X-ray observatories by incorporating improved figure control of the mirror surfaces. This project will utilize thin film electro-mechanical actuators that allow the mirror surfaces to be adjusted after fabrication.

• **NASA Space Technology Research Fellowship Awards**

  - NSTRF11: 6
  - NSTRF12: 6
  - NSTRF13: 9

  **Significance of an NSTRF11 Award**

  The detector array will observe the Cosmic Microwave Background (CMB) polarization with unprecedented sensitivity on arcminute angular scales. This research is pushing the state of the art for far-infrared background limited detectors and will enable an improved understanding of how to use these devices in practical environments, which can potentially lower the risk of use in planned space- and balloon-borne scientific applications by NASA.

• **Astrophysics subtopic included in 2013 *Early Stage Innovations* solicitation**

NICER / SEXTANT

- NICER/SEXTANT – explorer class ISS demo (2017)
  Joint Science and Technology Demo Mission on ISS

  - NICER: X-ray optical telescope demonstration
    Neutron star Interior Composition ExploreR (NICER), would observe (in the X-ray band) the thermal, magnetic, and rotational traits of neutron stars

  - SEXTANT: X-ray navigation (XNAV) demonstration
    Station Experiment for X-ray Timing and Navigation Technology (SEXTANT) mission, would detect X-ray photons from known steady pulsars to demonstrate spacecraft navigation using these naturally-occurring cosmic beacons

- STMD-SMD collaboration
  - NICER by SMD / SEXTANT by STMD
  - Shared hardware, ConOps, Data archive, Ops Center; ISS Platform, and target pulsars
• **Adjustable Grazing Incidence X-ray Optics**
  
  *Goal: Develop thin, lightweight mirrors with angular resolution of 0.5 arc sec, comparable to the Chandra X-ray Observatory*
  
  – Low cost; and 30x more densely nested than Chandra
  
  – New design with thin segments of a Wolter-I grazing incidence mirror
  
  – Piezo-electric material deposited directly on the back surface
  
  – Localized mirror deformation by energized PZT cells; no need for reaction structure
  
  – Co-funded 3-years development between GCD & Astrophysics/PCOS

• **Advanced laser frequency stabilization using molecular gases**
  
  *Goal: Develop a laser stabilization scheme approaching the performance of ultra-cold neutral atom clocks*
  
  - Simpler, lighter, and cheaper packaging, and operates at lower power levels
  
  - Operates near 1568 nm using low pressure CO gas as a molecular reference, with the possibility of migrating to near 1064 nm at a later date
  
  - Ultra-stable lasers are a corner stone of a future gravitational wave mission
  
  - Co-funded 3-years development between GCD & Astrophysics/PCOS
Potential Joint SMD & STMD Initiative:

Develop a coronagraph for AFTA-WFIRST mission

- **SoA Space based observatories:**
  - NASA’s Kepler (2009) (Photometry);
  - NASA Hubble & Spitzer (Transit technique);
  - TESS (2017 launch planned) (transit spectroscopy)

- **Goal:** Develop an advanced high contrast coronagraph + occulter for AFTA-WFIRST
  - Observe fainter planets using advanced direct imaging (10x Earth mass or better)
  - High contrast, high sensitivity, & high optical throughput
  - Small inner working angle (close to star), large discovery space
  - AFTA-WFIRST concept: using a donated 2.4-m telescope;
    - First opportunity for an in-space high contrast coronagraph.
    - Pathfinder mission for future telescopes to characterize Earth-like planets.

1000+ exoplanets discovered to date; Milky Way has 50B+ potentially habitable rocky-planets.
New Hardware in Advancing Space Technology

- **Green Propellant 22N Thruster**
- **Low Density Supersonic Decelerator Proof Test**
- **MSL Heat Shield with Instrumentation**
- **Deep Space Atomic Clock**
- **Additive Manufacturing**
- **PhoneSat**
- **Woven TPS**
- **BIRD Focal Plane Arrays**
- **NICER/SEXTANT**
- **Solar Sail and Boom Fab**
- **Inflatable Re-entry Vehicle Experiment**
Game Changing Technology

Arrival and testing of 2.4m precursor tank, the largest out-of-autoclave tank fabricated in the world

Launch of IRVE-3 – successful suborbital test of 3m HIAD

Space Power Systems
First build of flight-like fuel cells

DSOC: Vibration Isolation Platform

SWORDS model for wind tunnel testing at NASA MSFC

Nuclear Systems delivered the Fission Power System Technology Demonstration Unit (TDU) Reactor Simulator
Technology Demonstration and Testing

- Reduced Liquid Hydrogen boil off test
- Laser Communication Relay Demonstration
- ARC Jet Testing
- Low Density Supersonic Decelerator Sled Test
- Deep Space Atomic Clock
- Mike Fossum with Smart SPHERES checkout
- K10 rover deploying polyimide film
- LCAT Stagnation Test (50 W/cm²)
- MSL Launch and MEDLI measurements successfully completed
Collaborations with Other Government Agencies

Currently, significant engagements include:

- Green Propellant Infusion Mission partnership with Air Force Research Laboratory, propellant and rideshare with DoD’s Space Test Program (STP)
- Solar Sail Demonstration partnership with NOAA, and rideshare with Air Force
- Soldier-Warfighter Operationally Responsive Deployer for Space (SWORDs) low-cost nano-launch system with Army
- UAS Airspace Operations Prize Challenge coordinated with FAA
- Working with the USAF Operationally Responsive Space Office (ORS) for launch accommodations for the Edison Demonstration of Smallsat Networks (EDSN) mission.
- Partnership for Ohio’s first hydrogen generating fueling station with Greater Cleveland Regional Transit Authority to power city bus
- Partnership with DARPA on “Next Generation Humanoid for Disaster Response”
- In discussion with Department of Veteran Affairs for a collaborative project with “Exoskeleton” from our Human Robotics Systems Program
Working Together to Innovate