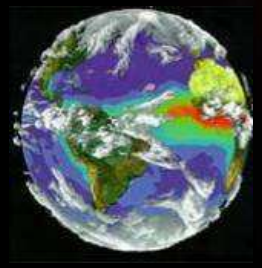
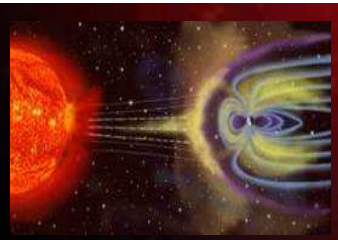






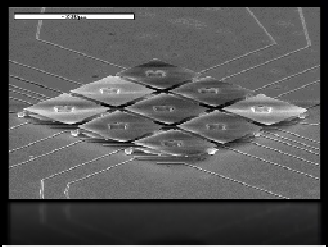
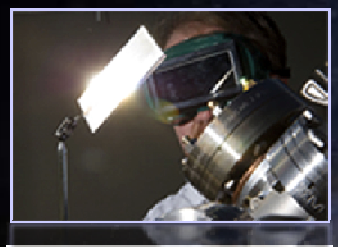
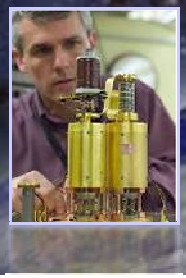
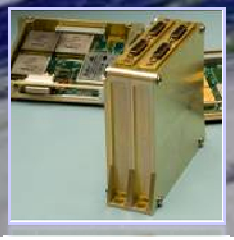
NASA Goddard Space Flight Center: *On the Cutting Edge*

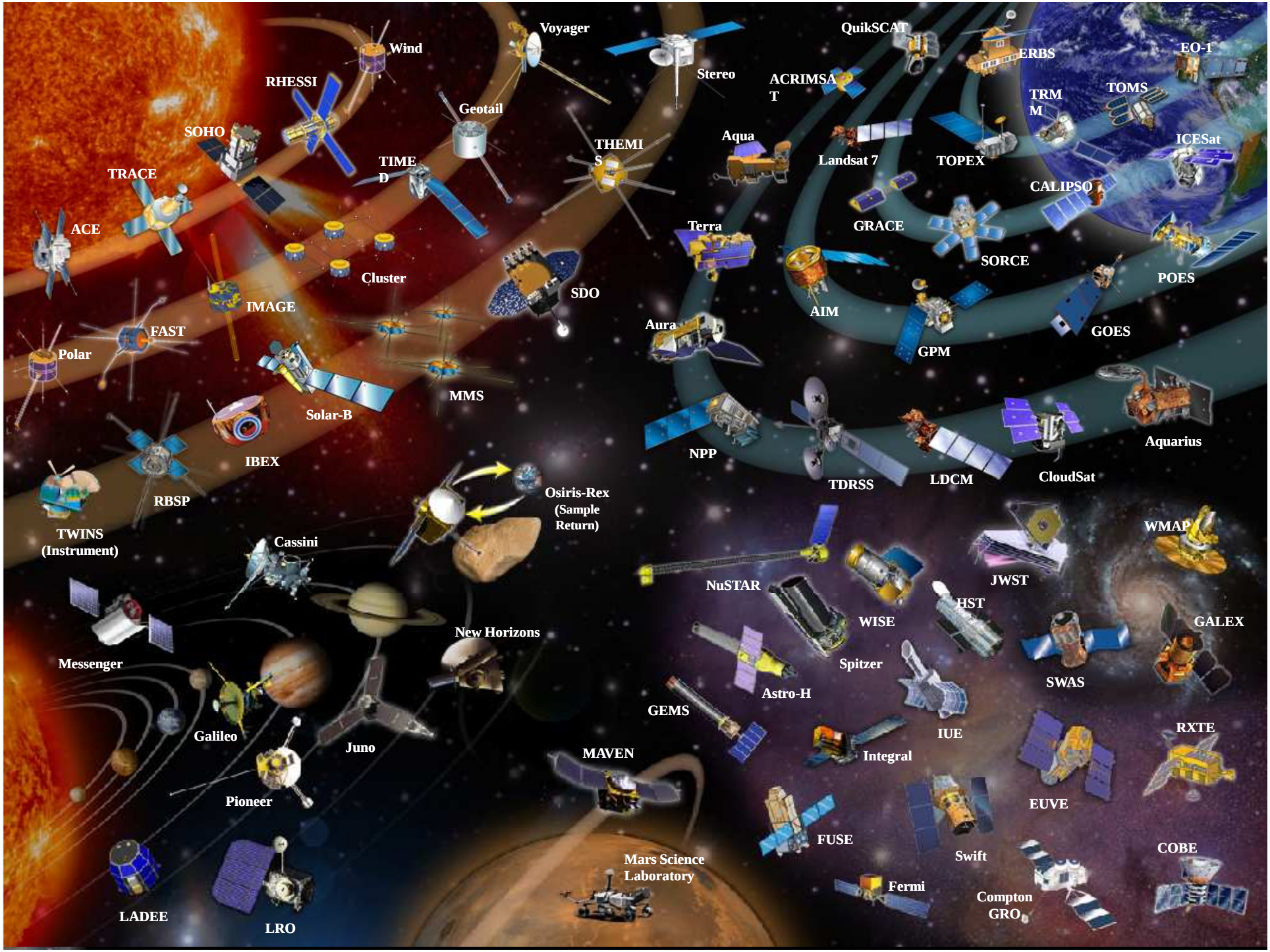
Presentation at

NAC Technology & Innovation Committee

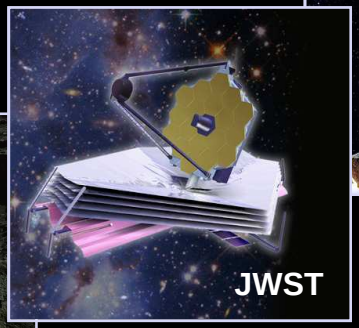
July 24, 2012

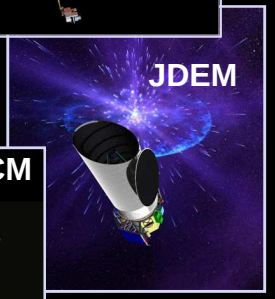
Peter Hughes
Chief Technologist, Goddard Space Flight Center
peter.m.hughes@nasa.gov

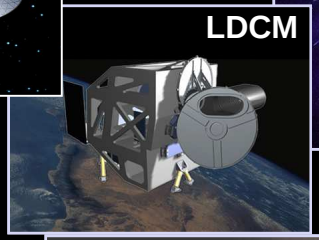





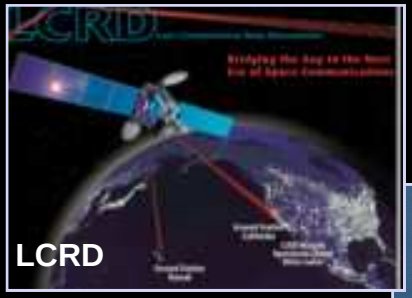


Wind
Voyager
Stereo
QuikSCAT
ERBS
EO-1
RHESSI
ACRIMSAT
TRMM
TOMS
Geotail
SOHO
THEMIS
Aqua
Landsat 7
TOPEX
ICESat
TRACE
TIMED
CALIPSO
ACE
Terra
GRACE
SORCE
Cluster
SDO
POES
IMAGE
AIM
Aura
GOES
FAST
Polar
GPM
MMS
Solar-B
Aquarius
IBEX
NPP
TDRSS
LDCM
CloudSat
RBSP
TWINS
(Instrument)
Osiris-Rex
(Sample
Return)
WMAP
Cassini
NuSTAR
JWST
HST
WISE
GALEX
Messenger
New Horizons
Spitzer
SWAS
Astro-H
GEMS
IUE
RXTE
Galileo
Juno
Integral
MAVEN
EUVE
Pioneer
FUSE
Swift
COBE
Mars Science
Laboratory
Fermi
Compton
GRO
LADEE
LRO

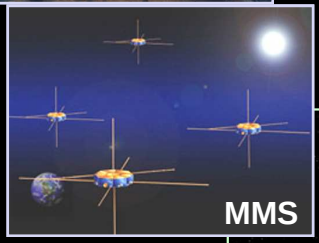
NASA GSFC Future Missions

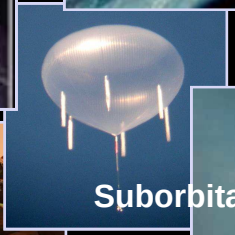


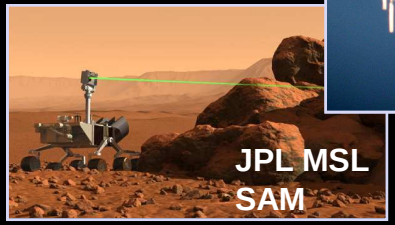


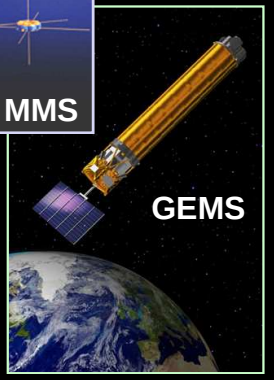












GSFC Lines of Business

Lines of Business

Heliophysics

Earth Science

Suborbital Platforms

Cross Cutting Technology and Capabilities

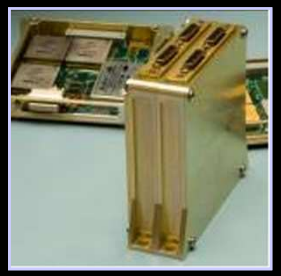
Astrophysics

Planetary & Lunar Science

Communications and Navigation

Enables and Enhances

GSFC's Advanced Research and Technology Development



Astrophysics

Questions

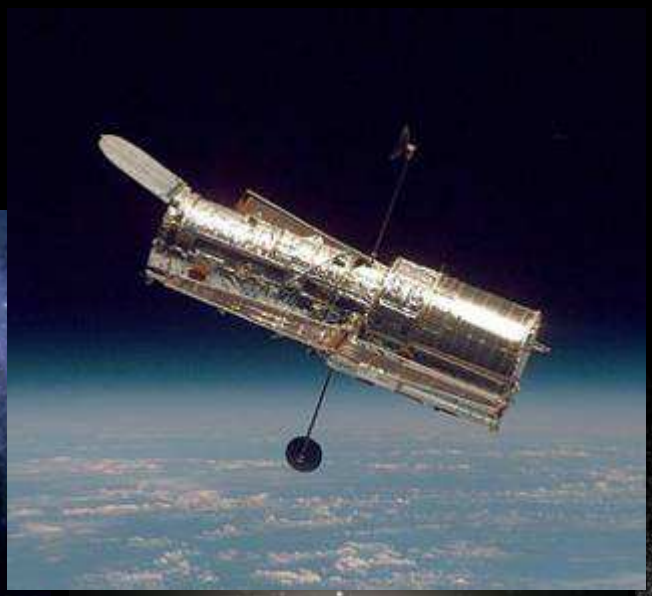
How do matter, energy, space and time behave under the extraordinary diverse conditions of the cosmos?

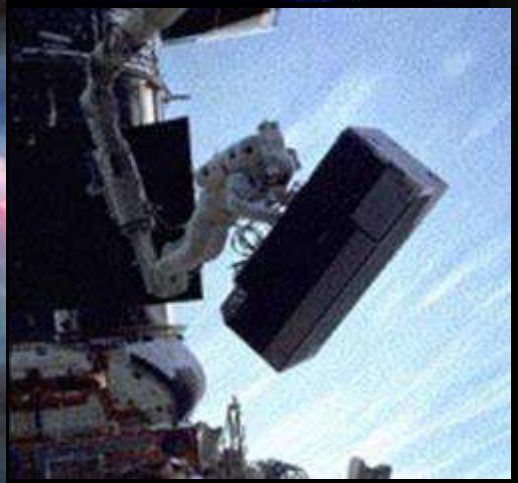
How did the universe originate and evolve to produce the galaxies, stars, and planets we see today?

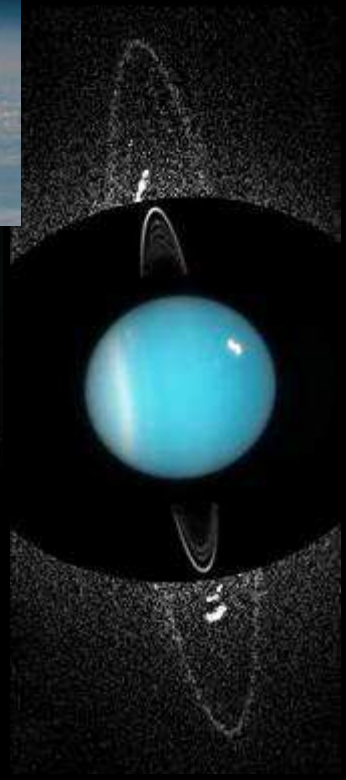
What are the characteristics of planetary systems orbiting other stars, and do they harbor life?

Hubble Space Telescope

An Amazing 22-Year Legacy

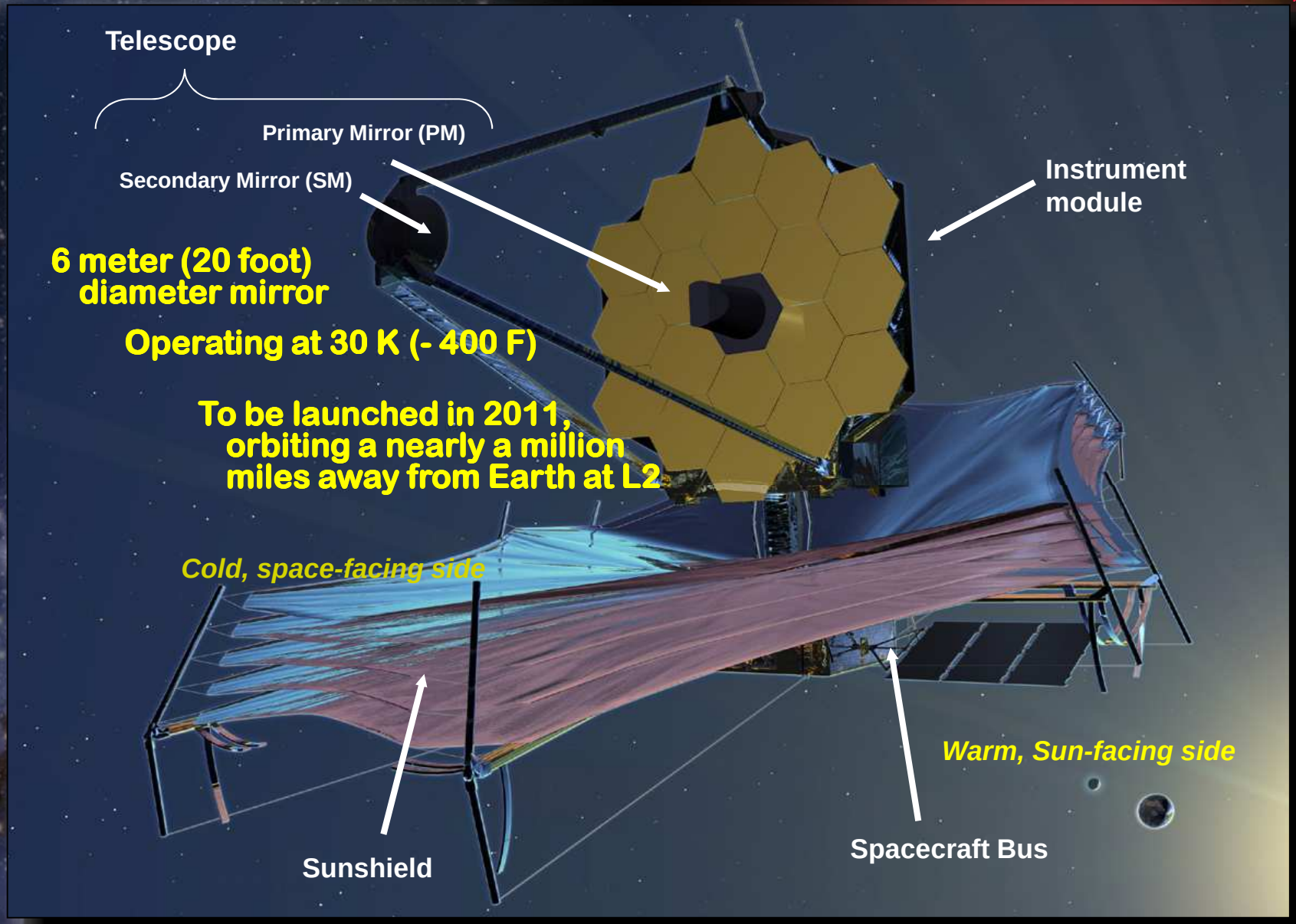




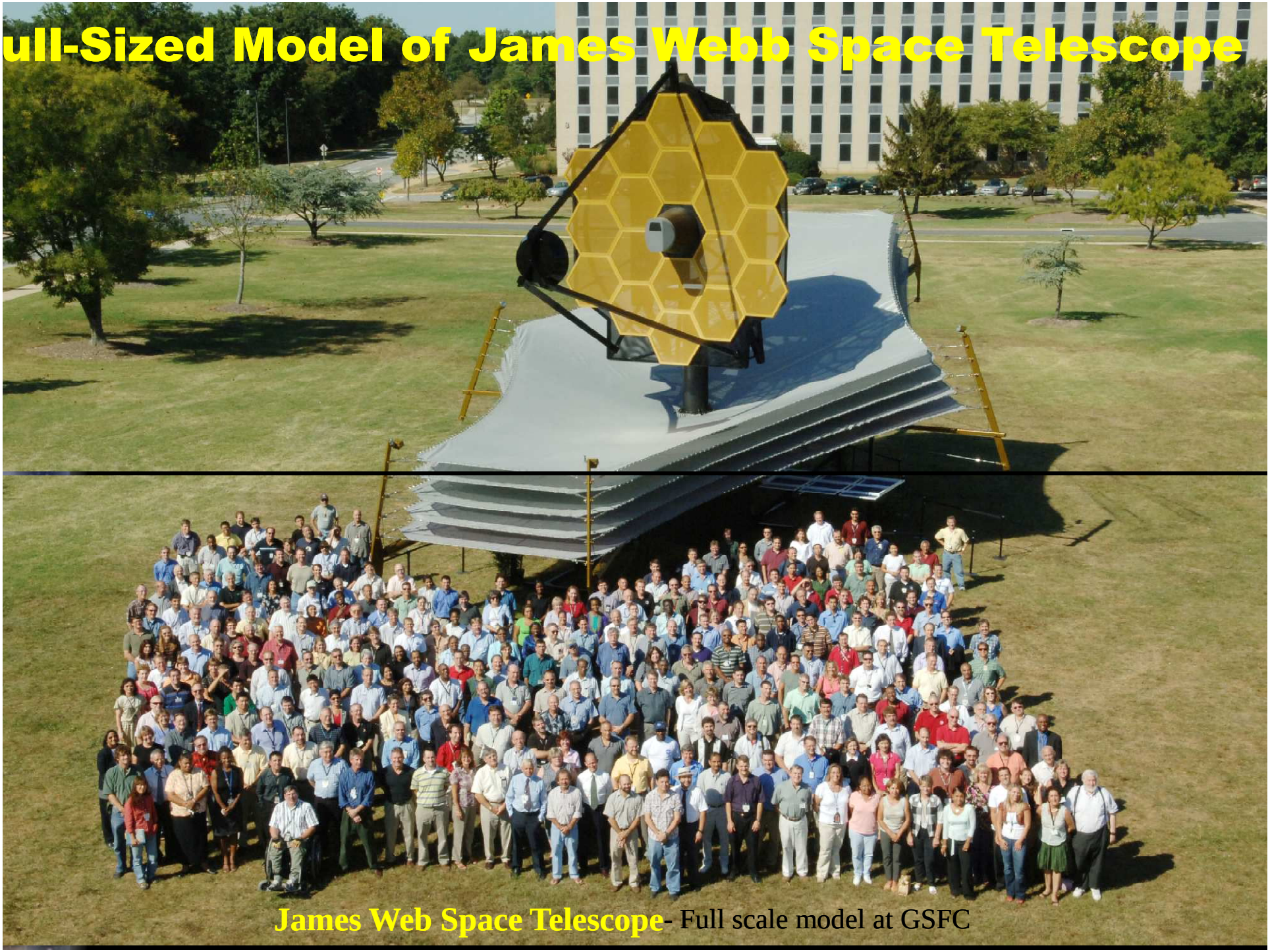


6

James Webb Space Telescope



First large-scale space application of deployable optics, wavefront control and passive cooling with tennis court-sized deployable structures.



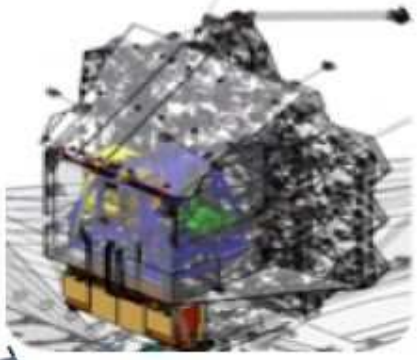
James Web Space Telescope- Full scale model at GSFC

JWST Technologies

Mirror Phasing Algorithms

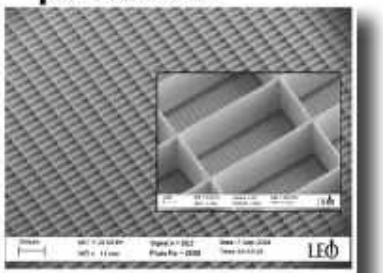
To be launched in 2011, orbiting a nearly a million miles away from Earth at L2

ISIM

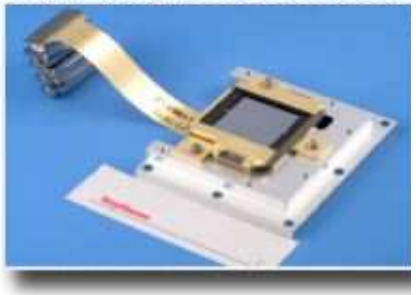


Near-Infrared Detector

µShutters

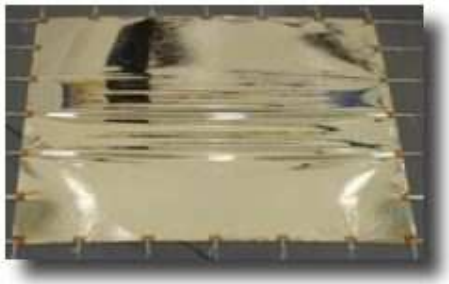


Mid-Infrared Detector



Beryllium Primary Mirror Segment

Sunshield Membrane



Cryocooler

Cryogenic ASICs

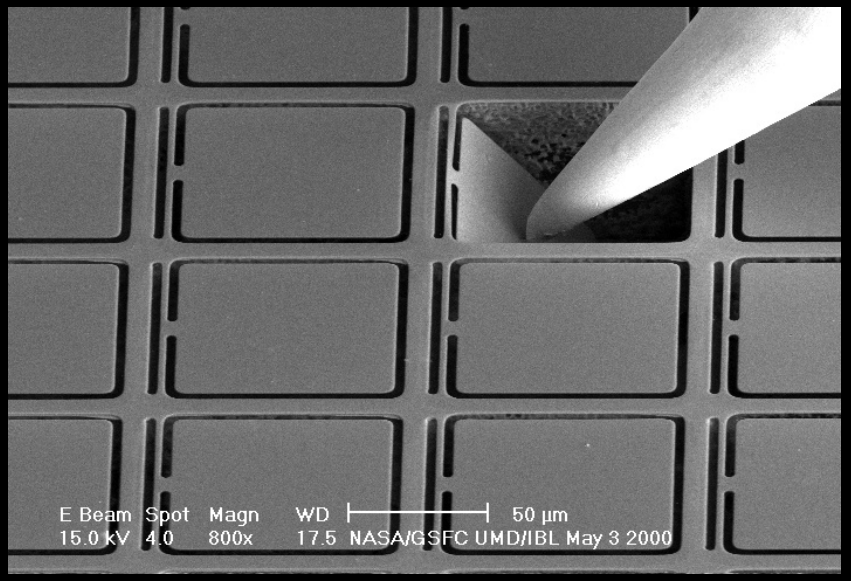
Microshutter Arrays for Space Application

The Problem: Current space telescopes unable to select specific objects within field of view for spectral analysis.

Our Solution: Apply MEMS technology to make a *programmable aperture mask* in the form of a *Microshutter Array (MSA).*

Space Application: To be flown on the James Webb Space Telescope (JWST) Near Infrared Spectrograph (NIRSpec)

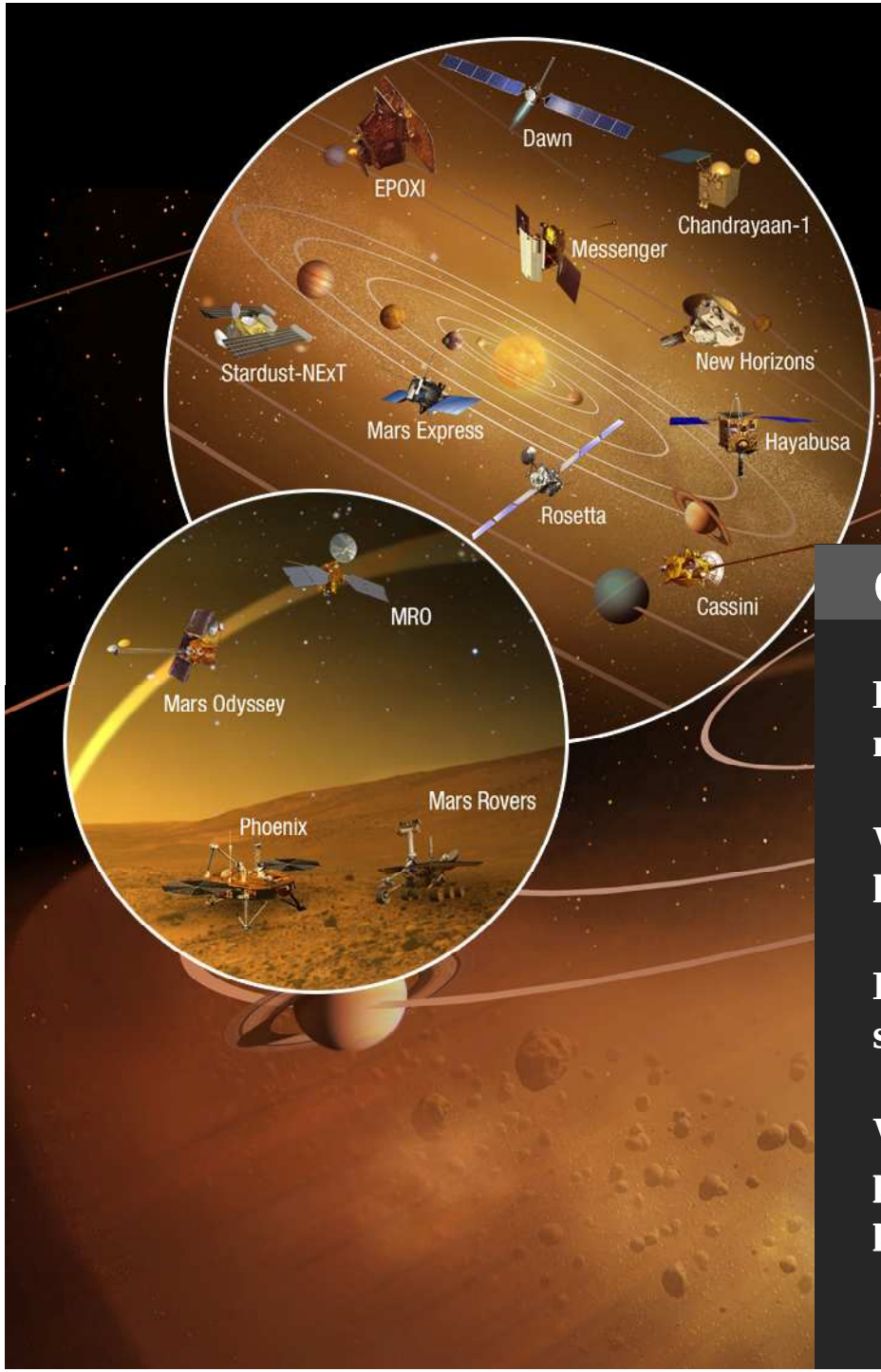
Hubble Ultra Deep Field
Hubble Space Telescope • Advanced Camera for Surveys



Microshutter Array

10

Planetary Science



Questions

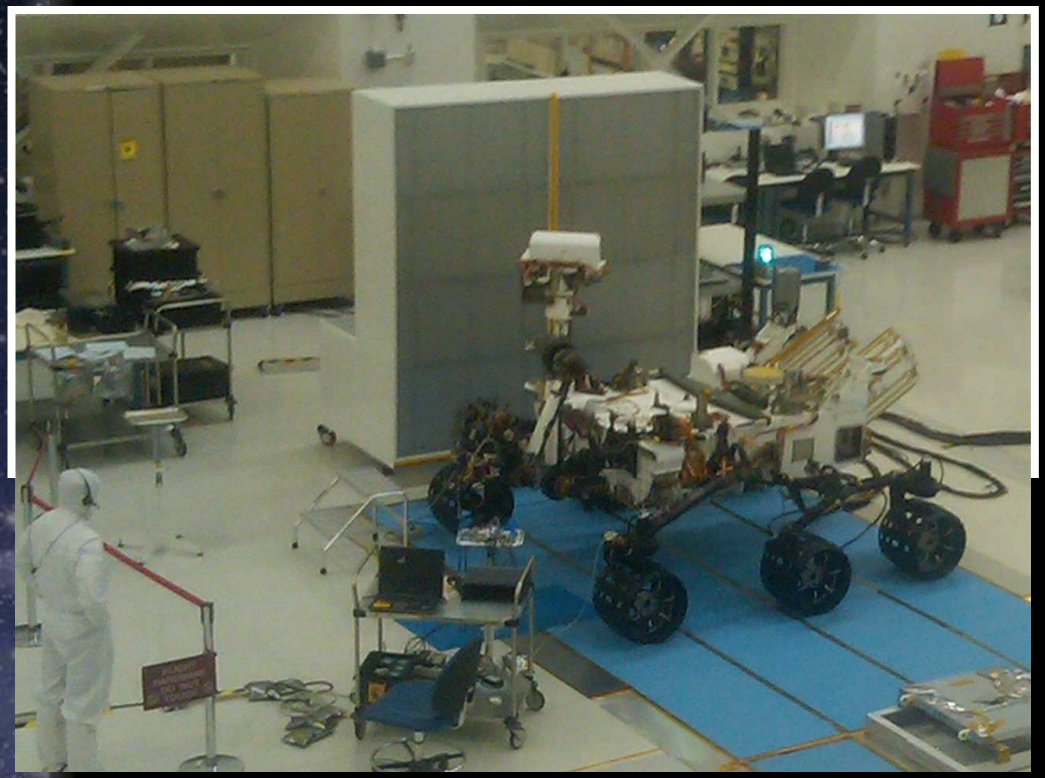
How did the Sun's family of planets, satellites, and minor bodies originate and evolve?

What are the characteristics of the solar system that lead to habitable environments?

How and where could life begin and evolve in the solar system?

What are the characteristics of small bodies and planetary environments that pose hazards or provide resources?

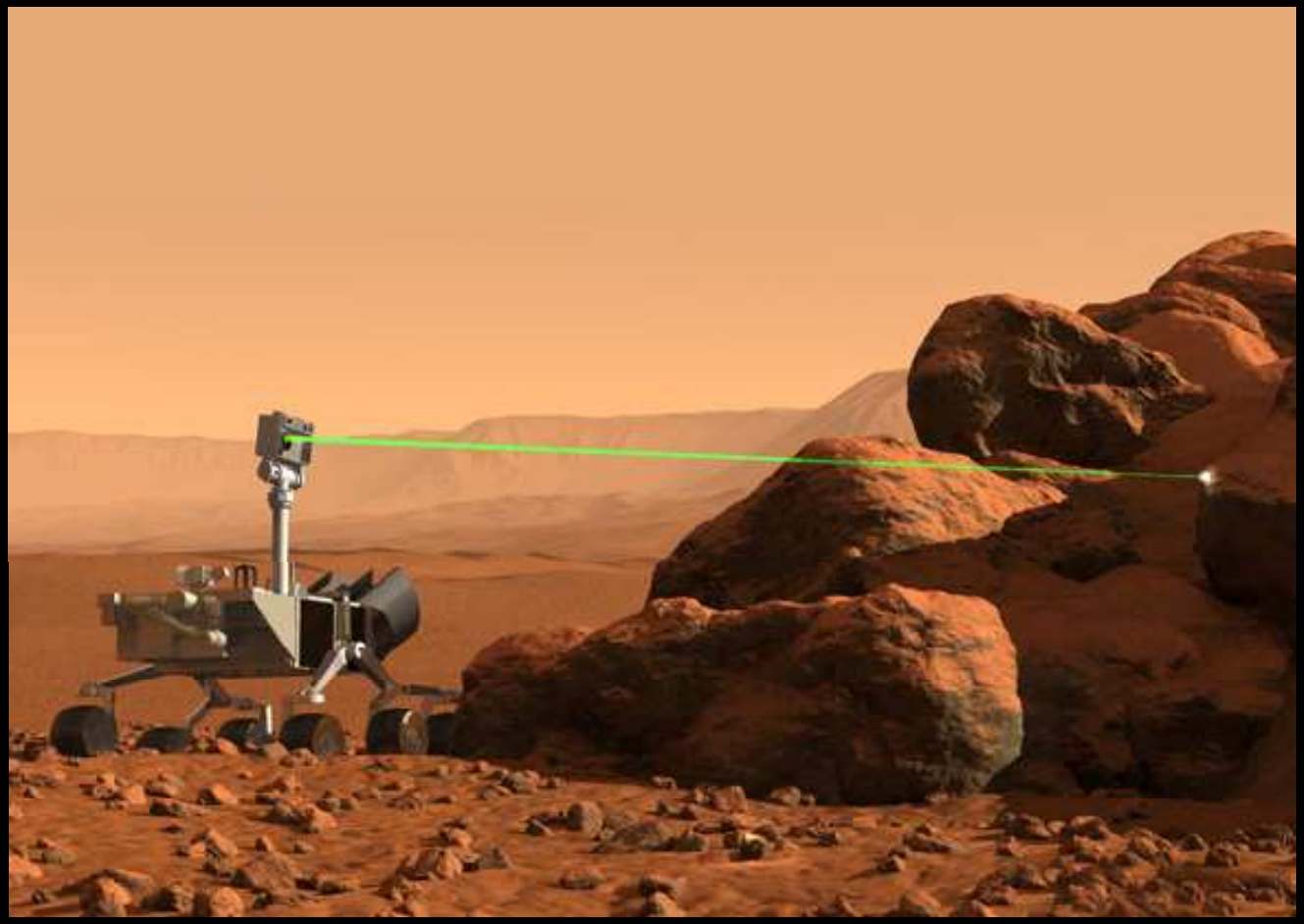
GSFC's SAM Instrument enroute to Mars on Curiosity Rover



Curiosity ready for Launch Vehicle

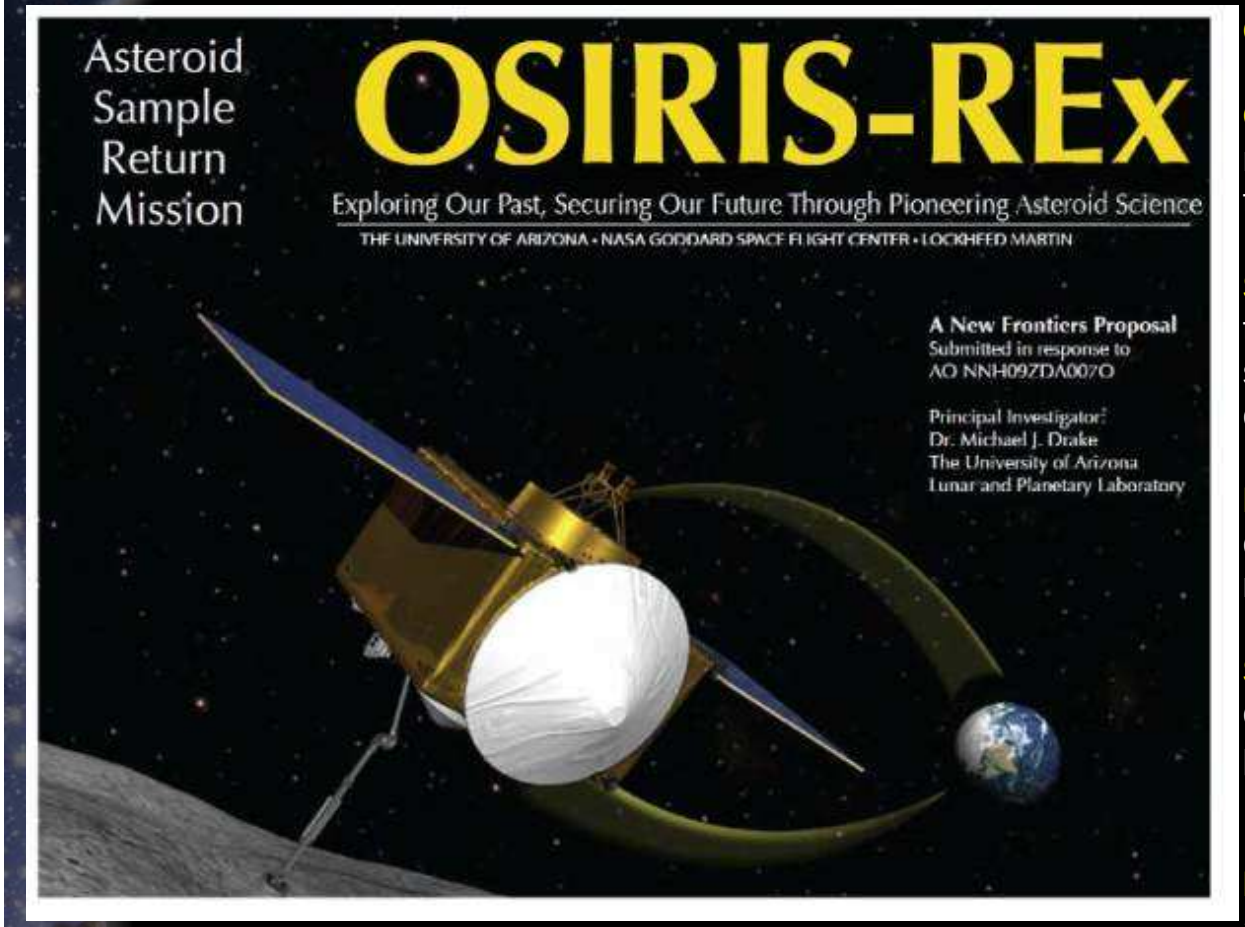
NASA Goddard developed the Sample Analysis at Mars (SAM) instrument for the Mars Science Laboratory mission successfully launched November 2011.

GSFC's Sample Analysis at Mars (SAM)



GSFC's Sample Analysis at Mars (SAM) is one of 10 Science Instruments on the Mars Science Laboratory mission to begin surface operations after August 5 Landing (7 min of terror!)

Objective- To answer: Did life exist on Mars?



OSIRIS REx is a sample return mission that returns at least 60 g (and as much as 2 kg) of pristine carbonaceous regolith from asteroid 1999 RQ36

OSIRIS REx is an acronym:

Origins - provide pristine sample to reveal the origin of volatiles and organics that led to life on Earth

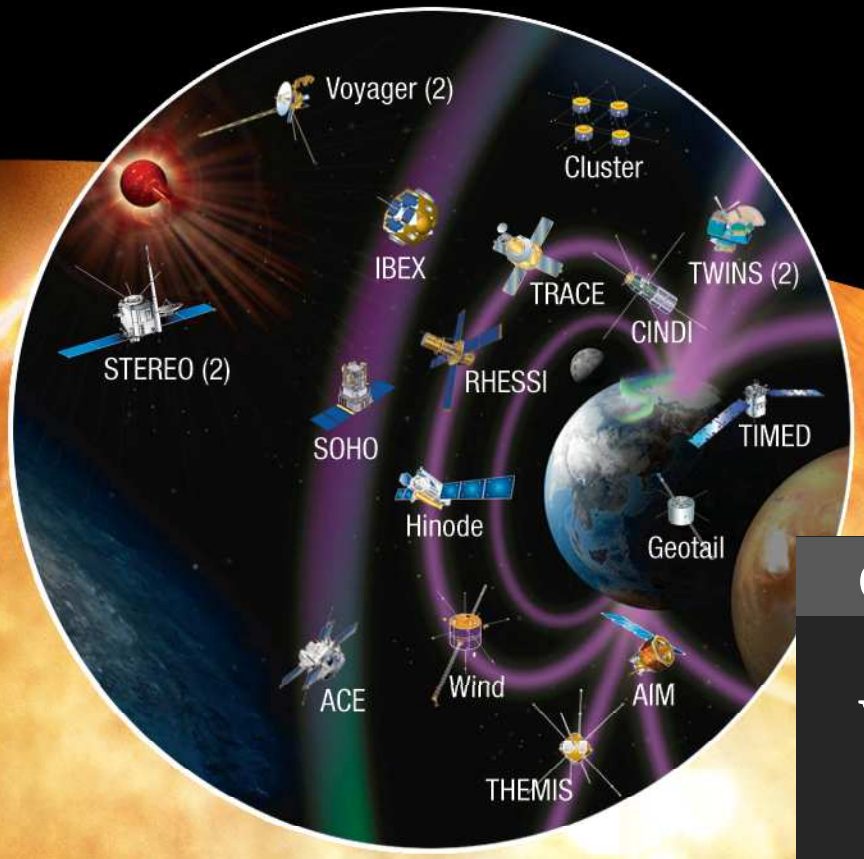
Spectral Interpretation - provide ground truth for ground-based and space based spectral observations of B-type carbonaceous asteroids

Resource Identification - identify carbonaceous asteroid resources that we might use in human exploration

Security - quantify the Yarkovsky Effect on a potentially hazardous asteroid, thus providing a tool to aid in securing the Earth from future asteroid impacts

Regolith Explorer- Explore the regolith at the sampling site *in situ at scales down to sub-millimeter*

Heliophysics



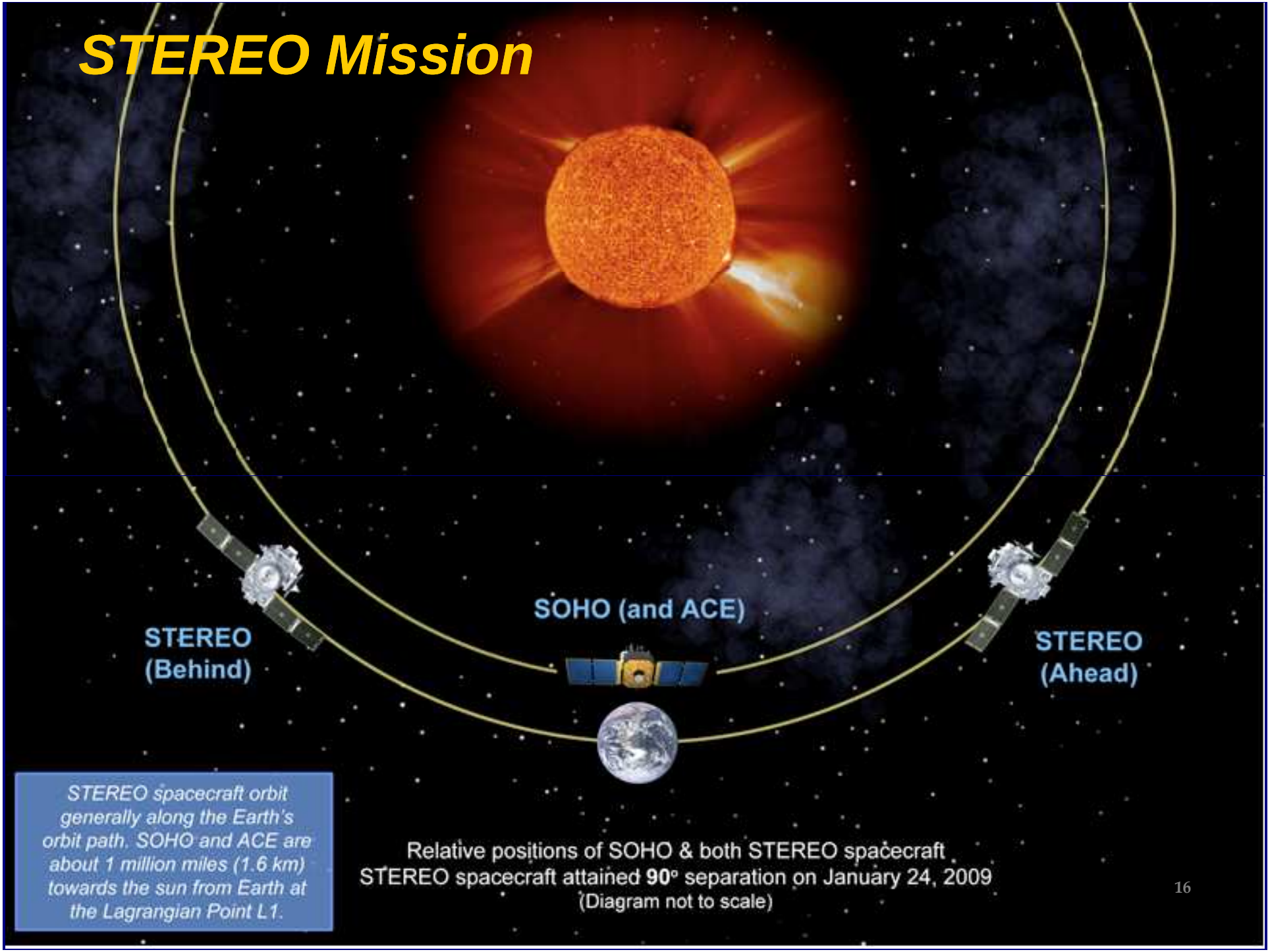
Questions

What causes the Sun to vary?

How do the Earth and Heliosphere respond?

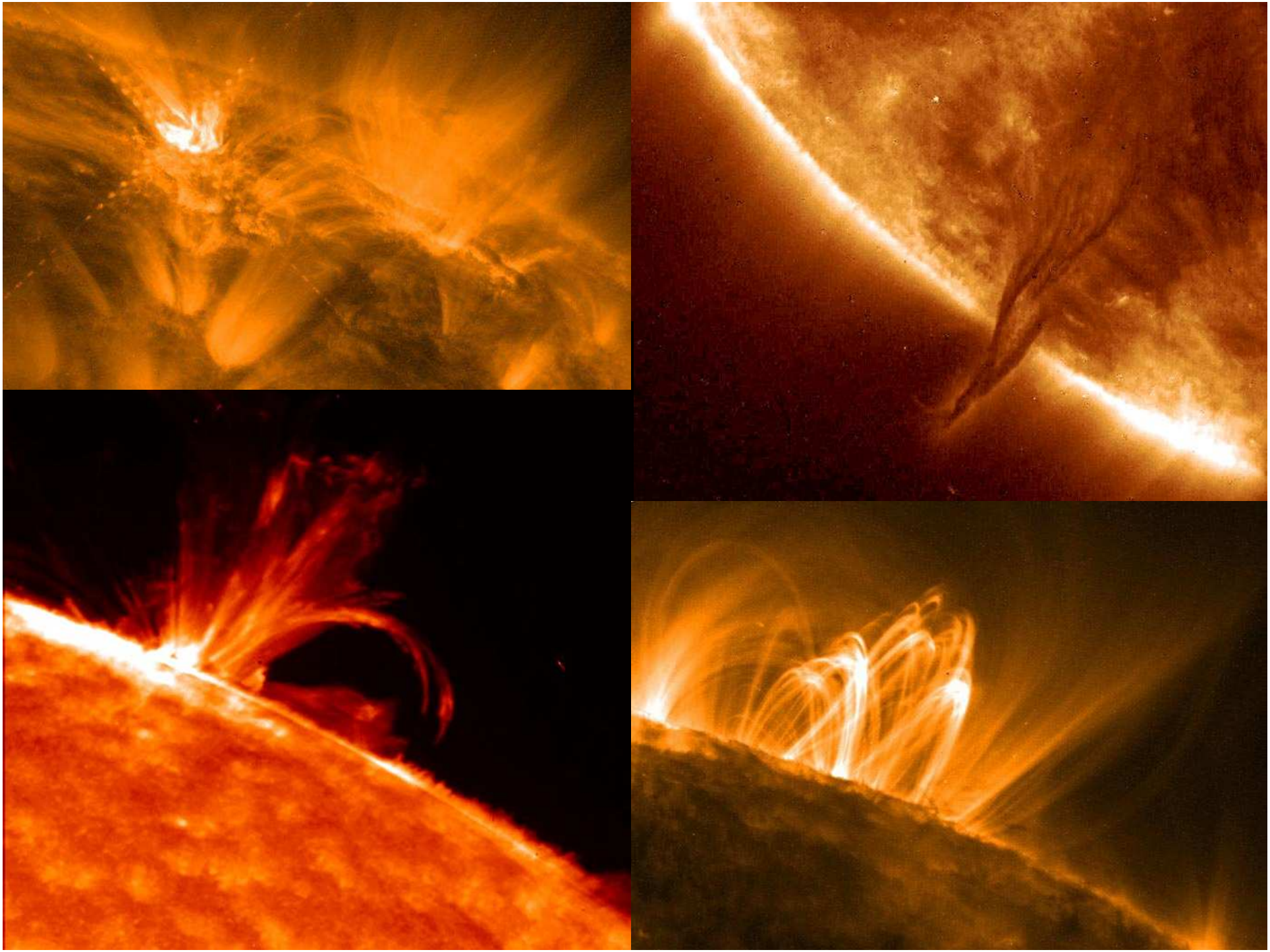
What are the impacts of space weather on humanity?

STEREO Mission

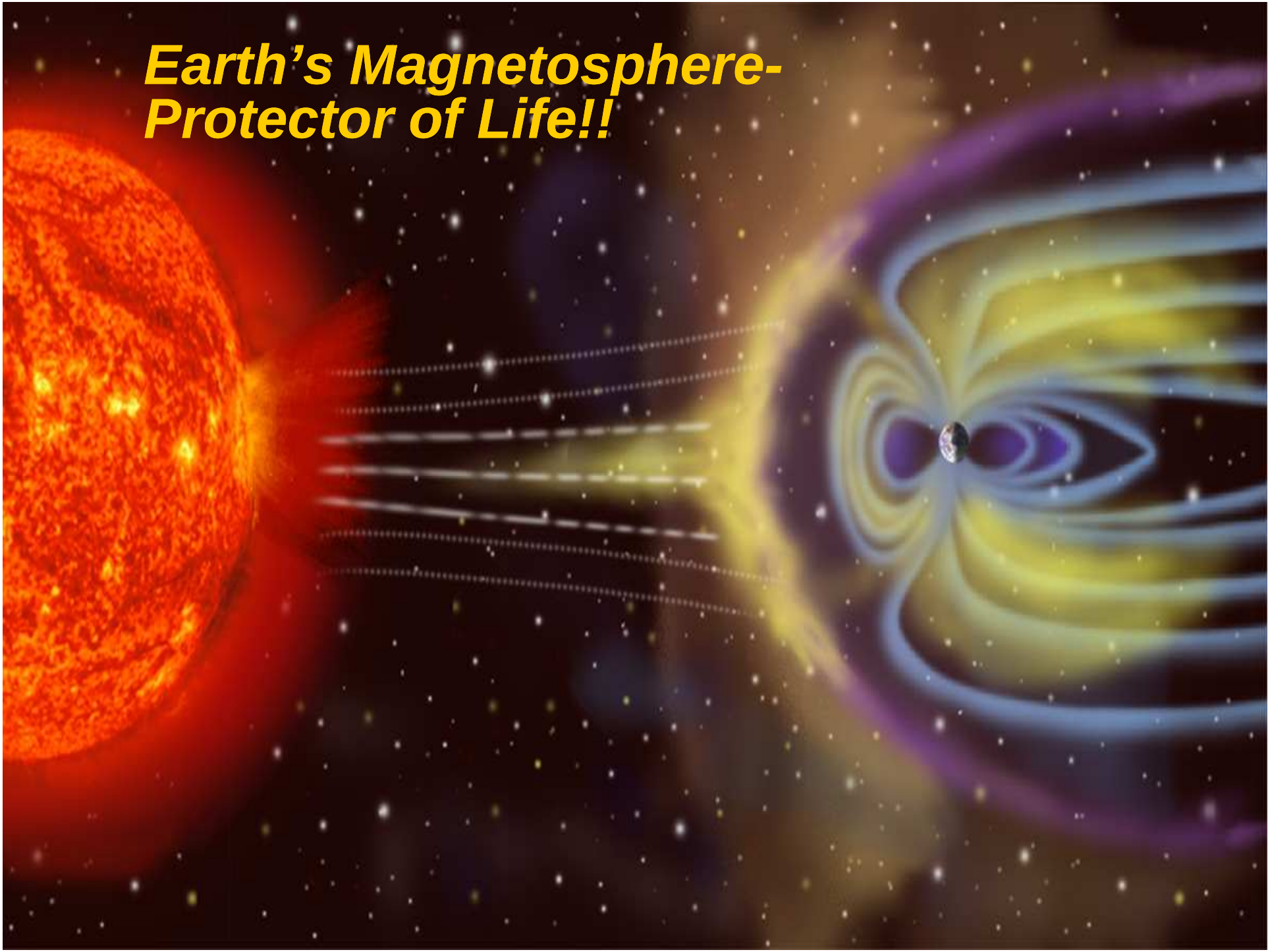


STEREO spacecraft orbit generally along the Earth's orbit path. SOHO and ACE are about 1 million miles (1.6 km) towards the sun from Earth at the Lagrangian Point L1.

Relative positions of SOHO & both STEREO spacecraft
STEREO spacecraft attained **90°** separation on January 24, 2009
(Diagram not to scale)

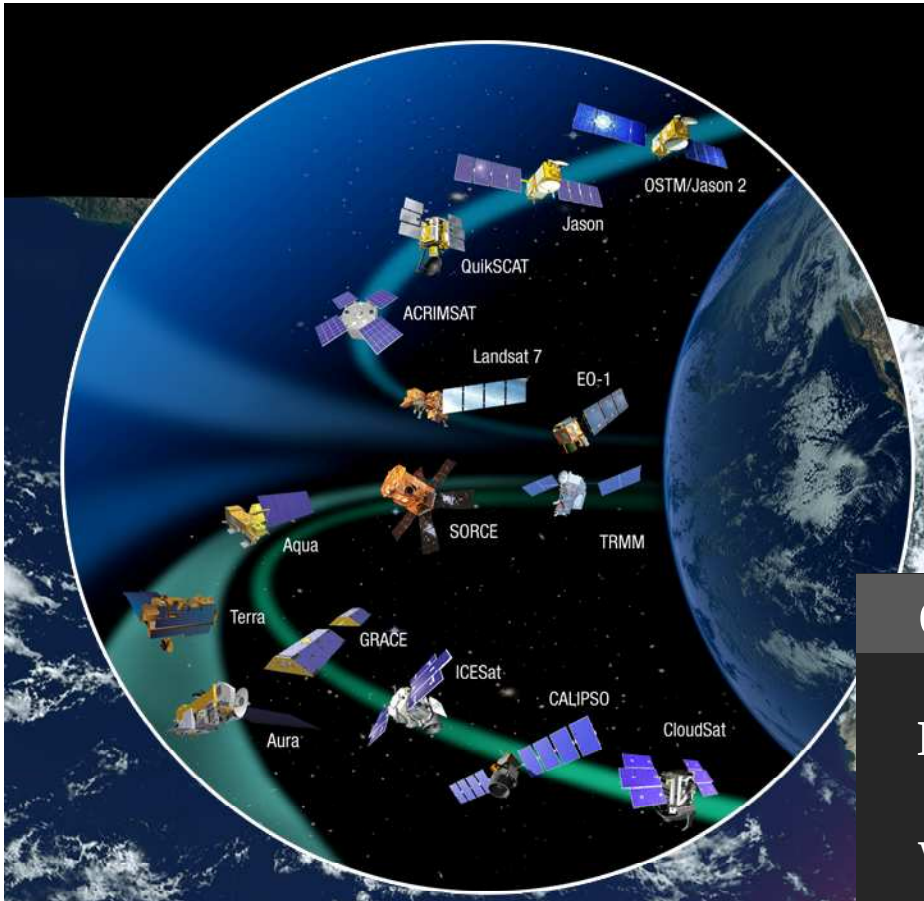



Approximate size
of earth for
comparison


Earth's Magnetosphere-
Protector of Life!!


MAGNETOSPHERIC MULTISCALE
A SOLAR-TERRESTRIAL PROBE
Launch October 2014
UNLOCKING THE MYSTERIES OF
MAGNETIC RECONNECTION

Earth Science



Questions

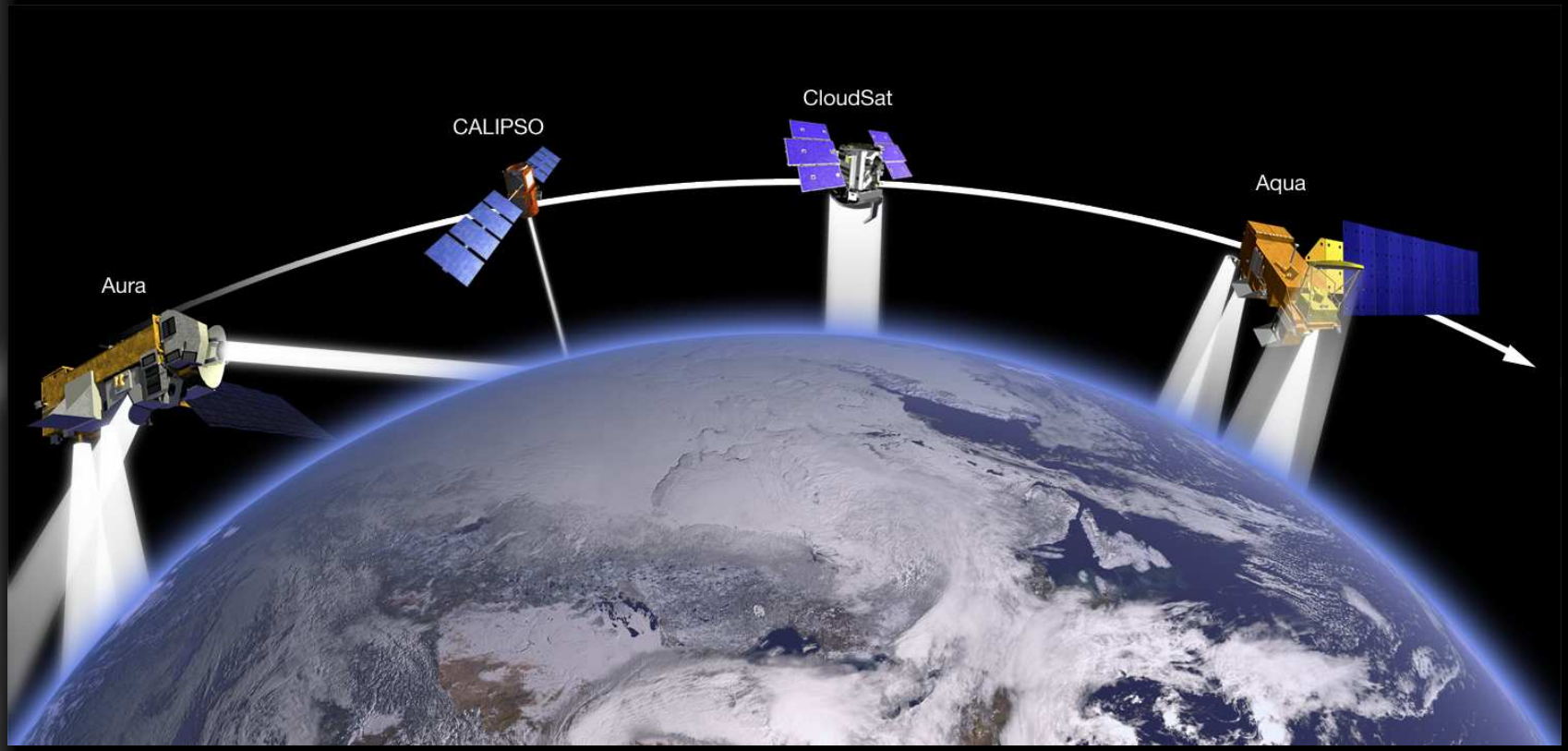
How is the global Earth system changing?

What are the sources of change in the Earth system and their magnitude and trends?

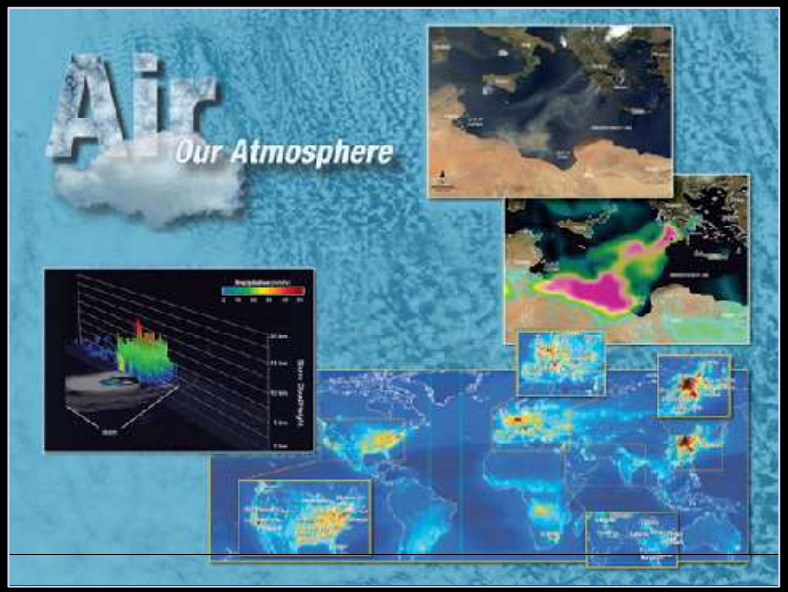
How will the Earth system change in the future?

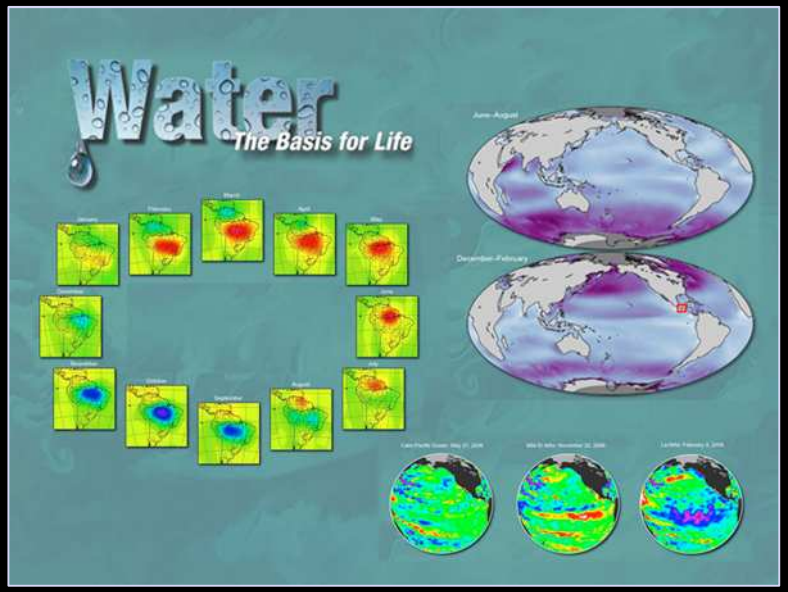
How can Earth system science improve mitigation of and adaptation to global change?

Earth Observing System A-Train (2009)

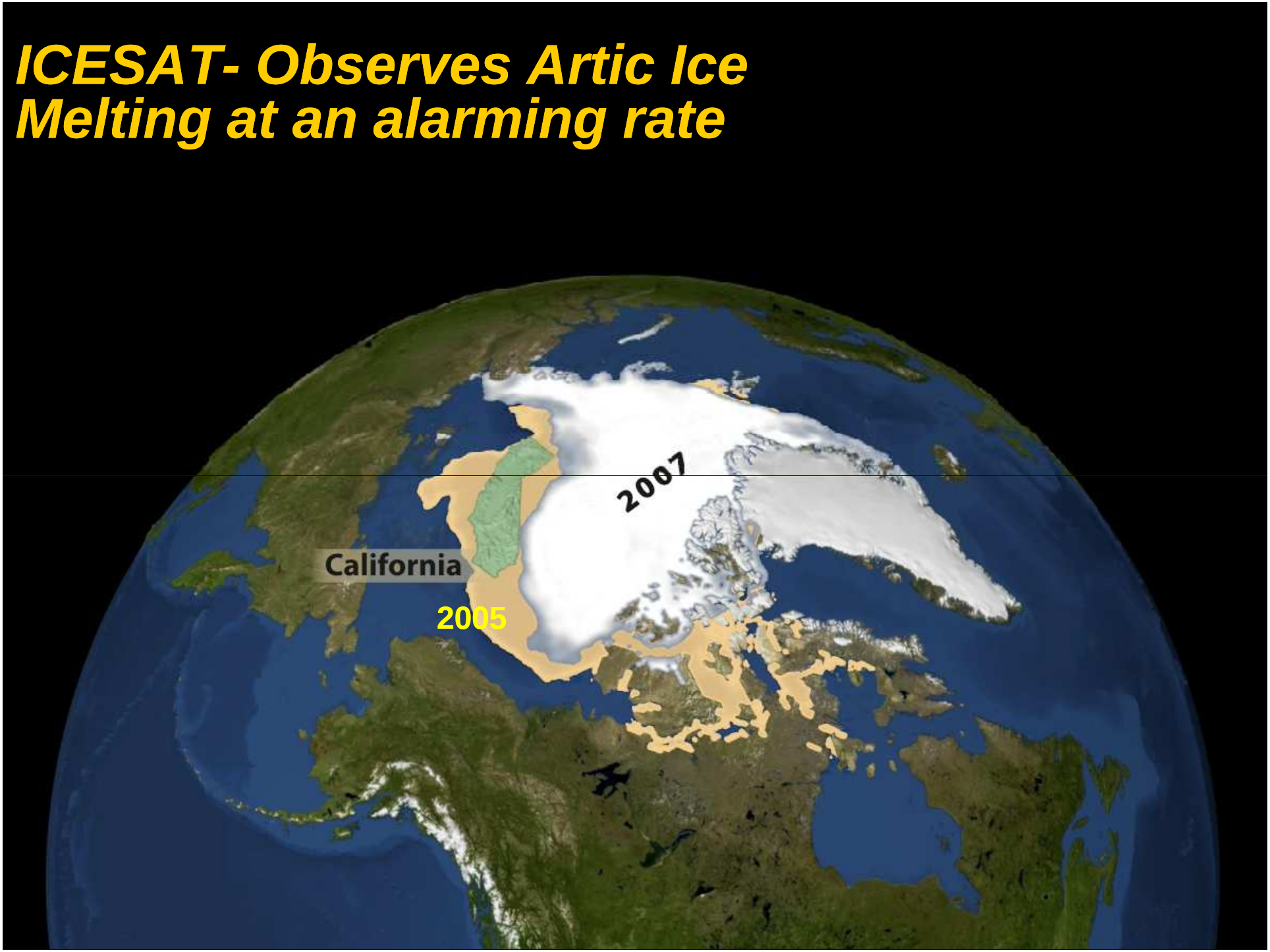


Earth Science Focii





ICESAT- Observes Artic Ice Melting at an alarming rate



GSFC Internal Research & Development (IRAD) Overview

IRAD provides "seed funding" to develop concepts, reduce technology risk, and advance human capital and technological capabilities *(predominantly Civil Servant!)*

Purpose-to enable future missions and increase our probability of award of external technology and mission funding - ultimately facilitate breakthrough scientific discoveries

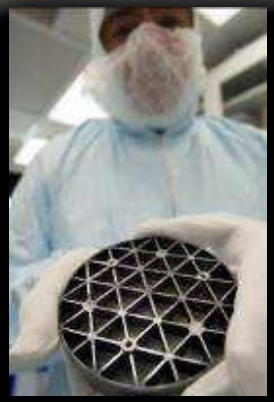
It is a highly competitive, opportunity-driven program that is *100% strategically aligned*

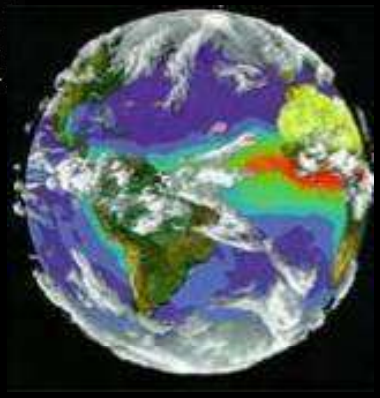
It is not bridge funding; nor does it provide coverage for individuals "available for new work"; it does not fund "blue sky"* initiatives, but rather out-of-the-blue ideas

IRAD portfolio formulation is cyclical and Center Line of Business-focused

- Award decisions made on a yearly basis with opportunity for spontaneous investments
- Address emerging needs, new capabilities, strategic direction and re-direction, and creating new opportunities
- Closely coordinated with New Opportunities Office/B&P

FY12 GSFC Internal Research and Development



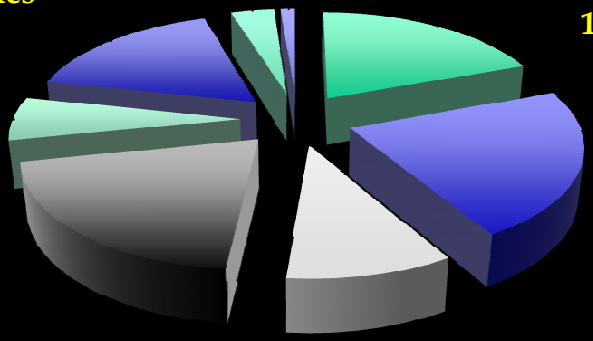


Suborbital Platforms & Range Services 4%

Education 1%

Cross Cutting Capabilities 17%

Astrophysics 19%

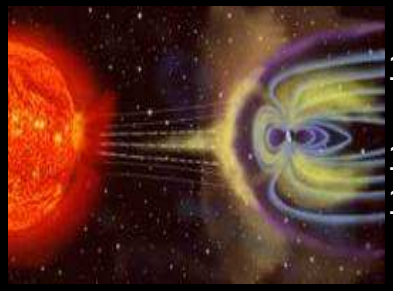


Communication and Navigation 7%

Earth Science 22%

Planetary and Lunar Science 20%

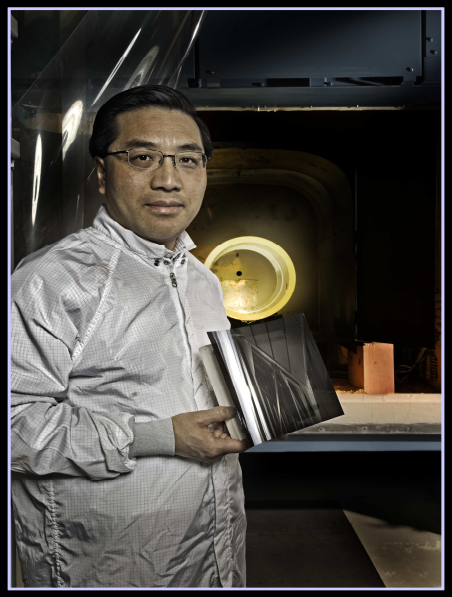
Heliophysics 10%

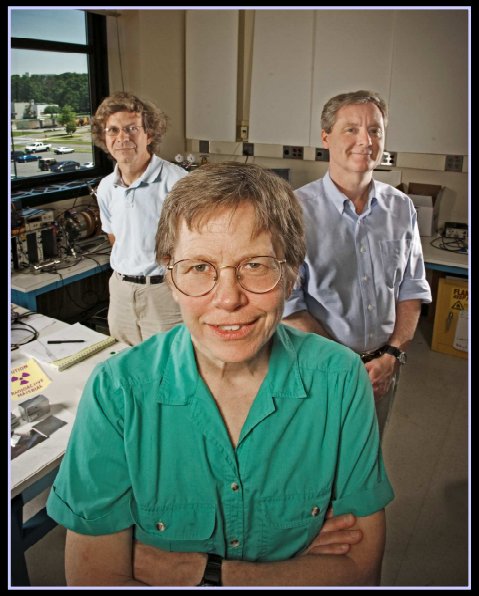


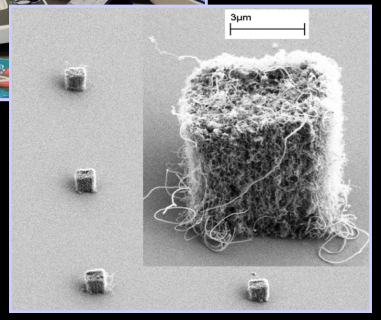
10% - detector technologies
24% - instrumentation
26% - instrument component technologies
11% - analysis tools or algorithm development
17% - platform component technologies
12% - mission and instrument concept development

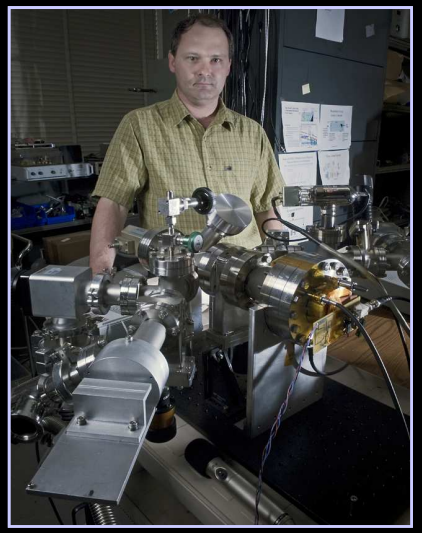
25% of IRAD efforts are led by Early Career technologists
45% of tasks are Early Stage Innovations

Advanced Technology: Broad Portfolio to meet Science, Exploration and National Needs



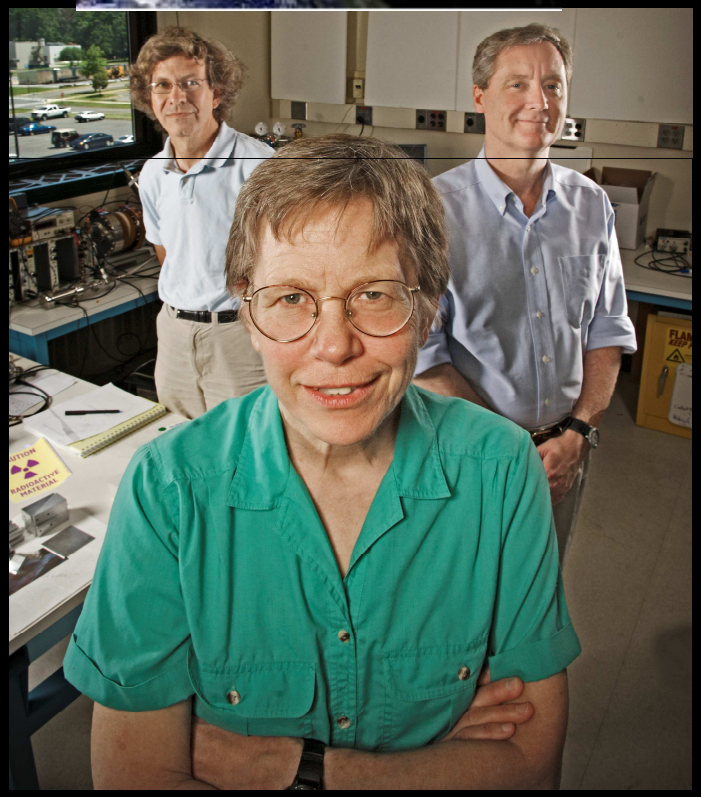






Example GSFC Mission:
Gravity and Extreme Magnetism SMEX (GEMS)

The GEMS team is developing the world's first **time-projection chamber polarimeter** to open a new window on the universe through X-ray polarimetry.



GEMS will provide first-of-a-kind measurements of **how fast black holes spin** and **how their spin rates affect the curvature of space-time**

GEMS will also study what powers pulsars and magnetars, and how cosmic rays accelerate in supernova remnants

Enabling the Next Level in Sample Processing

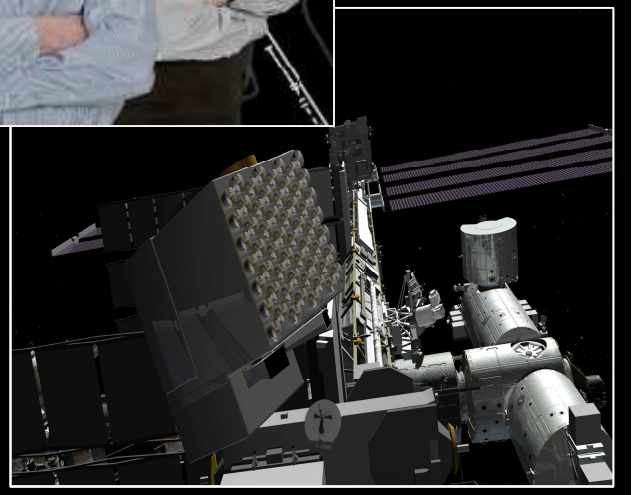
Sample Analysis at Mars (SAM) will use extreme heat to process samples

Heat, however, breaks carbon bonds, resulting in the loss of certain chemical information

Challenge is to offers the capabilities and flexibility of an Earth-based organic geochemistry lab

An IRAD-funded principal investigator, Dr. Jennifer Eigenbrode enhanced the original SAM design to enable the potential identification of a much larger variety of compounds and get a more complete picture of how life evolved over time

NICER and SEXTANT: Three-in-One Payload



- Keith Gendreau awarded Phase-A study for the proposed **Neutron Star Interior Composition Explorer (NICER)** and **12 FTE** from the HQ Office of Chief Technologist for **X-Nav**

- The instrument, designed to fly on ISS, would consist of 56 X-ray telescopes, advanced detectors, and other technologies to explore the exotic states of matter within **neutron stars** and reveal their interior and surface conditions

- NICER also advances technology. The payload also will demonstrate **pulsar-based navigation** & the world's first **X-ray communication** system

The three-in-one instrument concept represents the quintessential crosscutting experiment and earned Dr. Gendreau and team Goddard's FY11 "IRAD Innovator of the Year" award

Micro-scale ElectroHydroDynamic (EHD) Thermal control

What is EHD?

- Thermal control device that uses electric fields to pump coolant through tiny ducts inside a cold plate
- No mechanical pumps and other moving parts

EHD's Significance

- Mitigates overheating and power needs of advanced electronics by removing heat from small spaces
- Can be directly integrated as modular devices
- Scalable: macro to micro to lab-on-chip devices

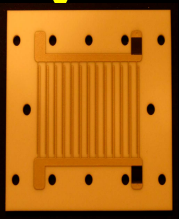
Demo unit for Sounding Rocket

Sounding Rocket Prototype Pump

GSFC EHD Target Applications

- Highly efficient space-based thermal control systems
- Lab-on-a-chip Fluid Management
- MEMS and Nano-Scale Applications

Critical Next Step: In-space Demonstration on ISS



EHD Micro-scale Proof of Concept

GSFC Nanotechnology

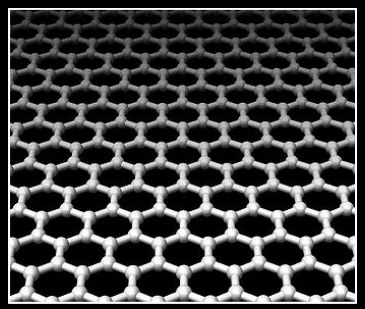
Nanotechnology Development

- The manipulation of matter on an atomic and molecular scale

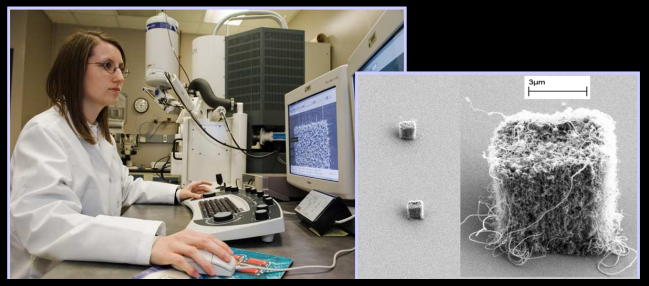
Current Nanotechnology Activities

- Conducted through in-house activities, competitively-selected research with industry and universities and other government agencies. Activities include:
  - Graphene based sensor development
  - Si-nanowire for next-gen particle physics instruments
  - Nano-materials for stray-light suppression
  - Nano-enhanced materials for enhanced structures
  - Nano-structured optics
  - Carbon-nanotube emission sources

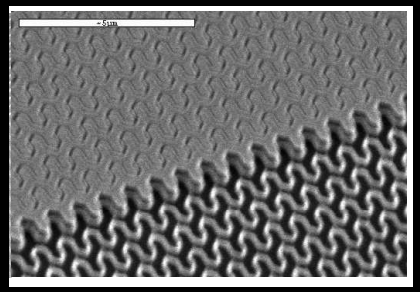
"Superblack" for stray-light suppression



Graphene Research



Next-gen Electron-gun for miniaturized Mass Spectrometer

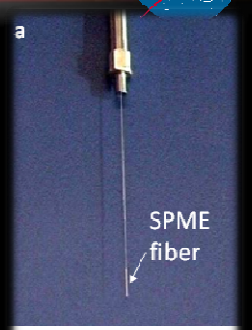


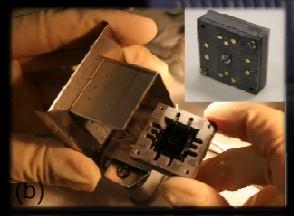
Nanostructured Mirrors

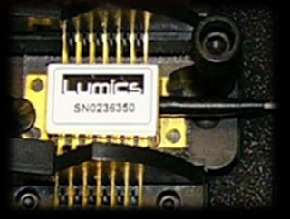
Early Stage Innovations

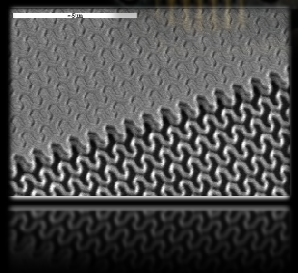
High-risk, strategically aligned, **potentially high-payoff technologies** that are longer-term. Address a long-term and/or latent need, create an opportunity, and/or provide significant advancements to replace existing capabilities.

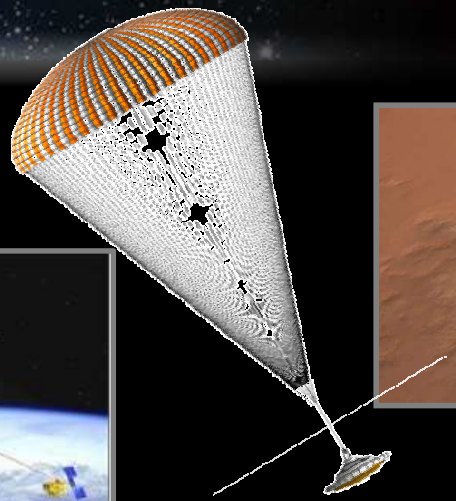
- Approximately 40% of IRAD portfolio is early stage innovation
  - Instrument Miniaturization
  - Advanced laser technologies
  - X-ray diffractive optics
  - Subcooling cryogenic propellants
  - Nanotechnologies, such as structures for stray light and diffraction suppression
  - Advanced electronics for extreme environments

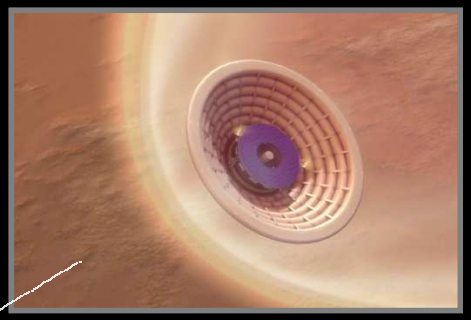




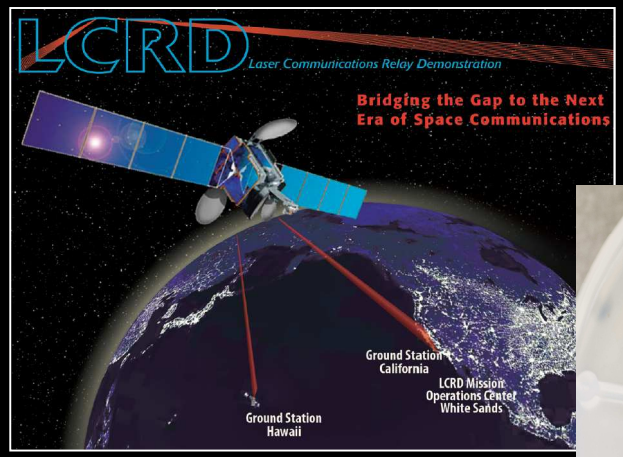


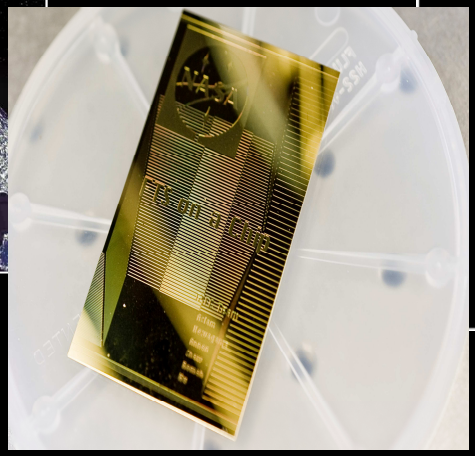


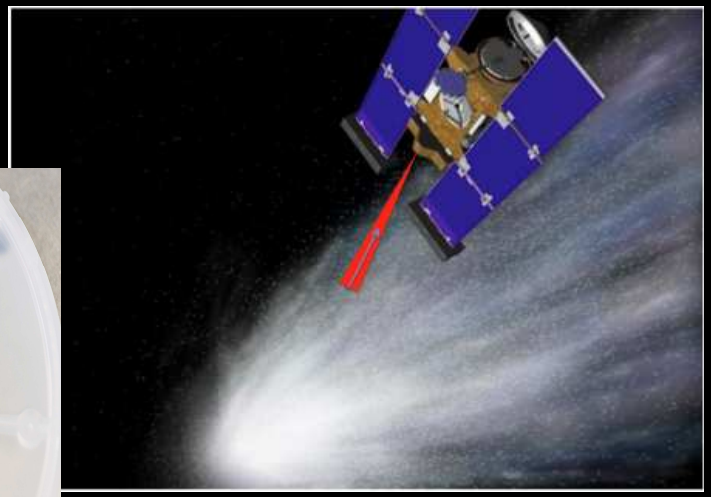




Goddard's Role in the new NASA Space Technology Program







The 16 Highest Priority Technologies Identified by the NRC (as part of ST Roadmap Review)

Objective A Extend and sustain human activities beyond low Earth orbit	Objective B Explore the evolution of the solar system and the potential for life elsewhere	Objective C Expand understanding of Earth and the universe
Radiation Mitigation for Human Spaceflight	**Guidance, Navigation, and Control**	Optical Systems (Instruments and Sensors)
Long-Duration Crew Health	Solar Power Generation (Photovoltaic and Thermal)	High-Contrast Imaging and Spectroscopy Technologies
Environmental Control and Life Support Systems	Electric Propulsion	Detectors and Focal Planes
Guidance, Navigation, and Control	Fission Power Generation	**Lightweight and Multifunctional Materials and Structures**
(Nuclear) Thermal Propulsion	Entry, Descent and Landing Thermal Protection Systems	Active Thermal Control of Cryogenic Systems
Lightweight and Multifunctional Materials and Structures	In-Situ Instruments and Sensors	Electric Propulsion
Fission Power Generation	**Lightweight and Multifunctional Materials and Structures**	Solar Power Generation (Photovoltaic and Thermal)
Entry, Descent, and Landing Thermal Protection Systems	Extreme Terrain Mobility	

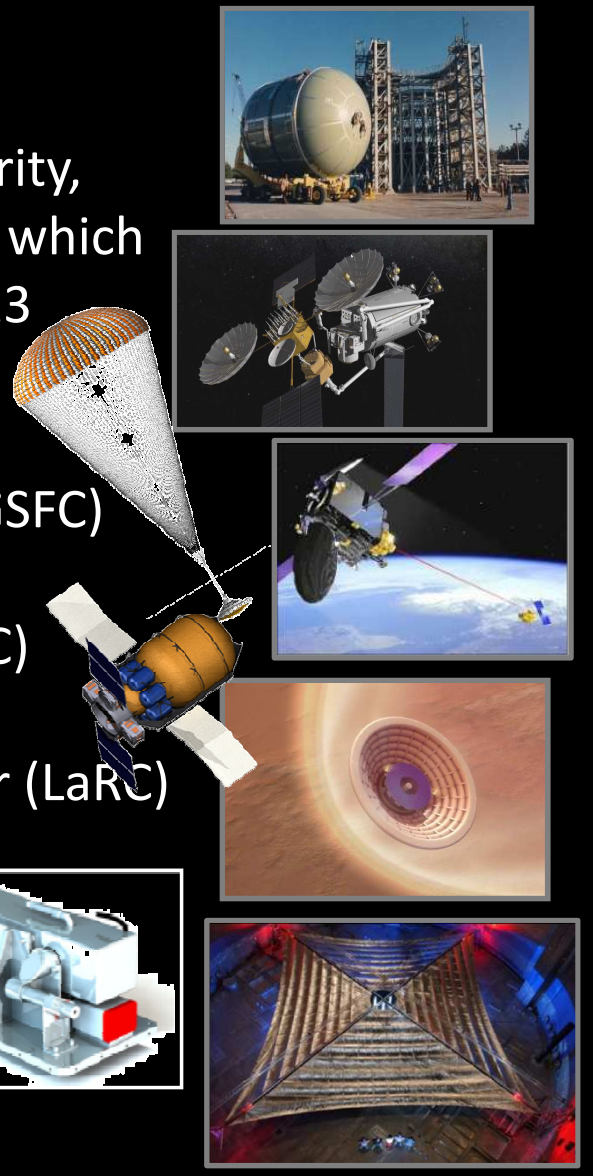
Yellow = GSFC area of strength

FY12: The Big Nine

- Space Technology consists of hundreds of small projects distributed across the country.
- These projects include the following nine high-priority, high-visibility, broadly-applicable activities, each of which has major testing milestones in FY 2012 and FY 2013

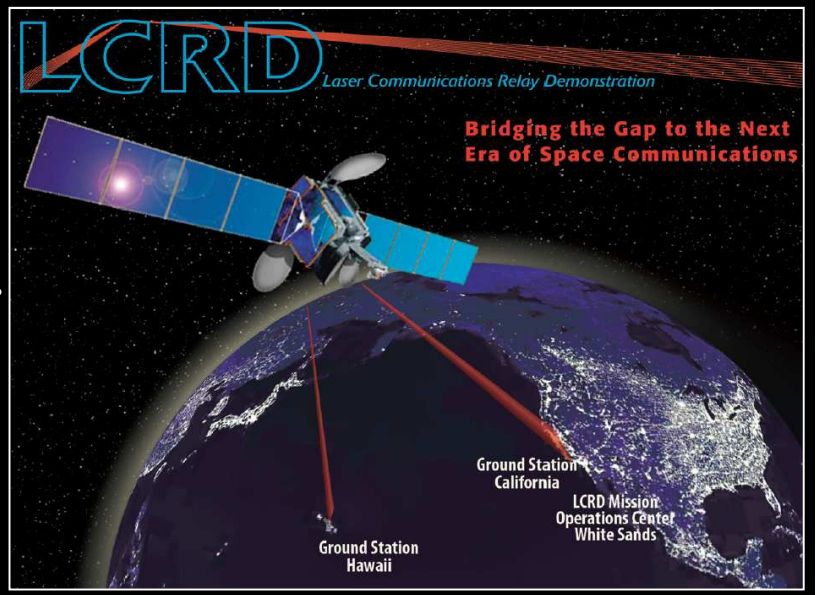
The Big Nine:

- Laser Communications Relay Demonstration (GSFC)
- Low Density Supersonic Decelerators (JPL)
- Cryogenic Propellant Storage and Transfer (GRC)
- Deep Space Atomic Clock (JPL)
- Hypersonic Inflatable Aerodynamic Decelerator (LaRC)
- Composite Cryotanks (MSFC)
- Robotic Satellite Servicing (GSFC)
- Solar Sail (L'Garde)
- Human-Robotic Systems (JSC)



Laser Comm Relay Demonstration (LCRD)

• NASA OCT has awarded GSFC more than $160M to develop the Laser Communications Relay Demonstration (LCRD) mission



• LCRD will launch NET 2016 &will operate 2-3 years to demonstrate and evaluate coding, link layer and network layer options.

•Ultimate objective- to reduce future risk of what NASA has long needed: High-speed data rates 10 to 100 faster than current capabilities and the potential streaming of high-definition video from distances beyond the Moon

Unique In-space demonstration of:

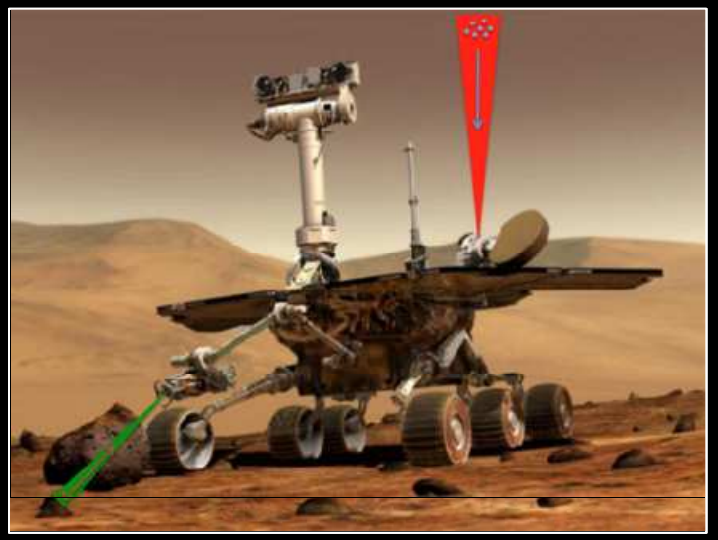
- Pulse Position Modulation (PPM) and Differential Phase Shift Keying (DPSK) Modulation
- Optical link to optical link real-time and store and forward in space relay
- Delay Tolerant Networking (DTN) flight and ground systems

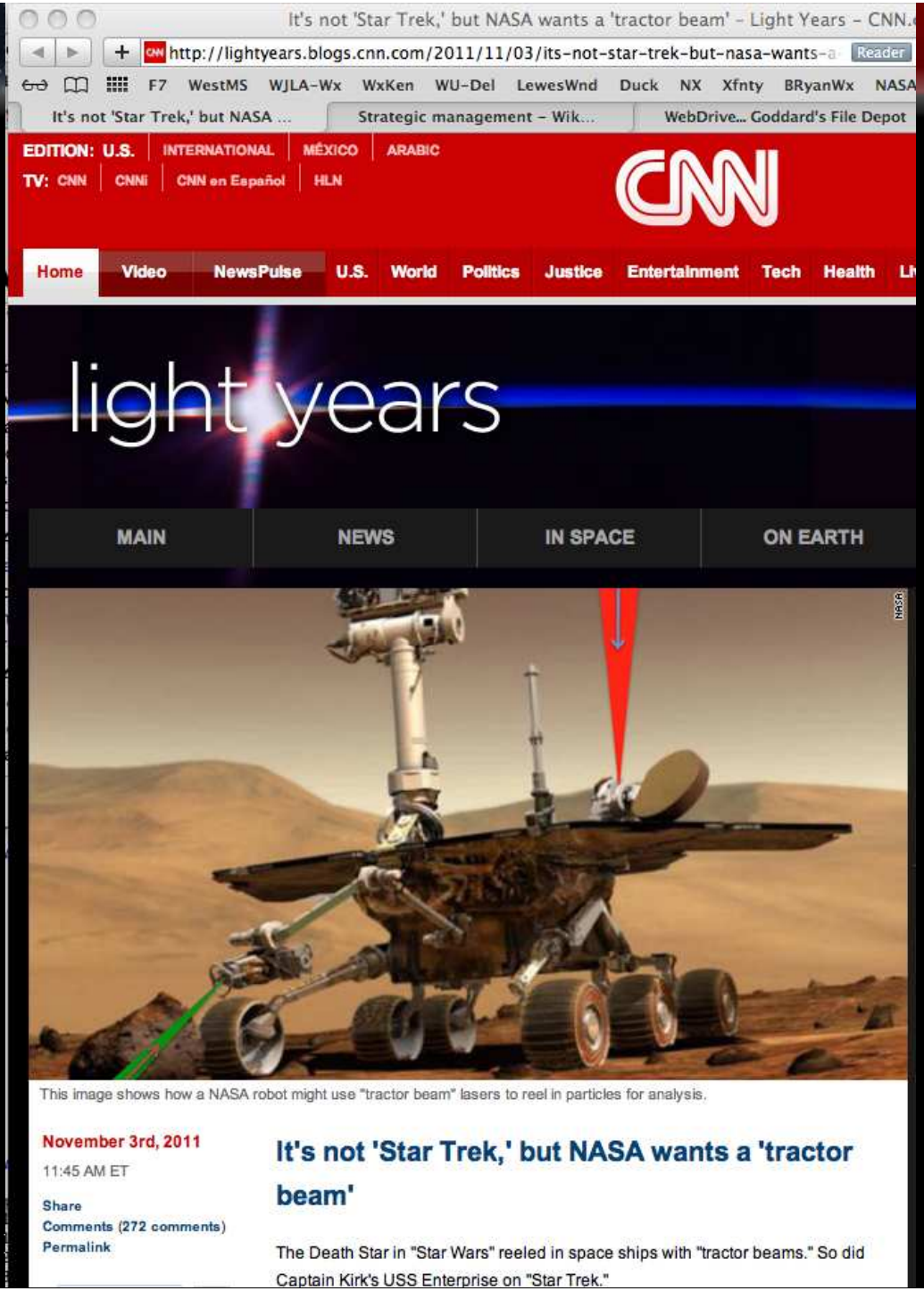
37

Technologists Turn Science Fiction into Reality

Goddard engineers have won **NASA Innovative Advanced Concepts (NIAC)** funding to investigate three techniques for **trapping and moving objects using laser light**

- The team is eyeing the technology as a potential technique **for gathering particles and transporting them via laser to a scientific instruments** for analysis
- If developed, the **technique could replace NASA's current sample-collection methods**, including aerogels and robotic rovers that drill and scoop samples
- An **optical-trapping system** could grab desired molecules from the upper atmosphere on an orbiting spacecraft or trap them from the ground or lower atmosphere from a lander — continuously and remotely




It's not 'Star Trek,' but NASA wants a 'tractor beam' - Light Years - CNN.
http://lightyears.blogs.cnn.com/2011/11/03/its-not-star-trek-but-nasa-wants-a
Reader
F7 WestMS WJLA-Wx WxKen WU-Del LewesWnd Duck NX Xfnty BRyanWx NASA
It's not 'Star Trek,' but NASA ...
Strategic management - Wik...
WebDrive... Goddard's File Depot
EDITION: U.S. INTERNATIONAL MÉXICO ARABIC
TV: CNN CNNi CNN en Español HLN
CNN
Home Video NewsPulse U.S. World Politics Justice Entertainment Tech Health
light years
MAIN NEWS IN SPACE ON EARTH
This image shows how a NASA robot might use "tractor beam" lasers to reel in particles for analysis.
November 3rd, 2011
11:45 AM ET
Share
Comments (272 comments)
Permalink
It's not 'Star Trek,' but NASA wants a 'tractor beam'
The Death Star in "Star Wars" reeled in space ships with "tractor beams." So did Captain Kirk's USS Enterprise on "Star Trek."

FY12 Allocation of CIF Resources

CIF Task Title	Principal Investigator	FY12 Resources (FTE/$K)
Miniaturized Waveguide Fourier Transform Spectrometer	Shahid Aslam	0.72 / -
Innovative Application of Lobster-Eye X-Ray Transient Detector to ISS Hydrogen Leak Detection	Jordan Camp	0.26 / 75.5
Decomposing Nitrous Oxide Thruster using Dielectric Barrier Discharge	Eric Cardif	- / 15
Atomic Layer Deposition to Enable the Production, Optimization and Protection of Spaceflight Hardware	Vivek Dwivedi	0.49 / 15
Nonlinear Adaptive Filter for MEMS Gyro Error Cancellation	Joe Galante	0.63 / -
Micro Thruster Development with Green Propellant at mN and microN levels	Dan Ramspache	0.1 / -
Micro Pulse Detonation Rocket Engine for Nano-Satellite Propulsion	Dan Ramspache	0.1 / -
Laser Source for Atomic Gravity Wave Detector	Babak Saif	0.93 / 90
Graphene-GaN Schottky Photodiodes	Mahmooda Sultana	0.41 / -

FY12 Allocation of CIF Resources - Continued -

CIF Task Title	Principal Investigator	FY12 Resources (FTE/$K)
A Range Resolved CO2 Backscattering Profile Measurement Technique for Ground Calibration	John Burris	0.75 / -
Particle Filter Simulation and Analysis Enabling Non-Traditional Navigation	Russell Carpenter	0.44 / -
Science-Enabling Atmospheric Entry at Venus	Lori Glaze	0.55 / 15
Scotch-Tape Mirror for Hard X-rays	Maxim Markevitch	0.39 / -
Approximation Assisted Robust Design Optimization of Aerospace Systems	Gary Mosier	0.09 / -
Polarimetric and Interferometric Synthetic Aperture Radar (Pol-InSAR): a new way to quantify three-dimensional structure of Earth and planetary surfaces	Jon Ranson	0.78 / 22.65
Developing New Testing Methods for Nanosatellites	Stephen Rinehart	0.48 / -
Solar ENA imaging coronagraph	Albert Shih	0.7 / -
NavDev- Next Generation Navigation Capabilities	Jason Mitchell	0.0 / 300
Larger scale Cleaning Telescope Mirrors with Electron Beams	Fred Minetto	0.50 / -

GSFC CIF: Atom Interferometry

- Goddard has teamed with Stanford University to advance an emerging, highly precise measurement technology — atom optics to leverage extensive DARPA investments.
- Atom optics — heralded by some as a technological panacea for many things from measuring gravitational fields to navigating ships and planes — works like optical interferometry, but with far greater precision
- The Goddard-Stanford team is applying the technology to develop a space-based atom interferometer that would detect theoretical gravitational waves
- Proving their existence would revolutionize astrophysics, giving scientists a new tool for studying everything from black holes to the early cosmos
- Other applications include navigational sensors, highly precise gravimeters and highly precise clocks —any application demanding exacting measurements

Stanford University drop tower, which is being used to test a Goddard-designed laser system critical in atom-optics technology.

Cataclysmic events, such as this artist's rendition of a binary-star merger, are believed to create gravitational waves that cause ripples in space-time.

Cleaning Telescope Mirrors with E-Beams

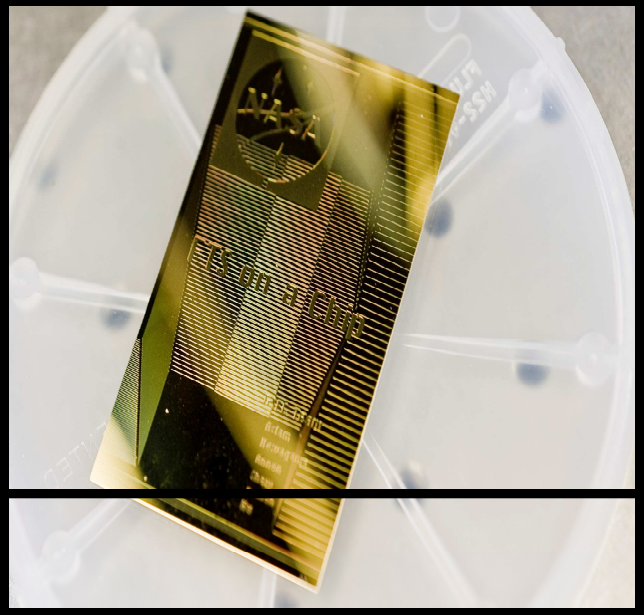
Fred Minetto developed proof-of-concept instrument that would clean contaminants from mirror surfaces or sensors in space

Innovation: combined an electron gun with a "fractal Penning discharge pin" to create a "fractal wand" that would pass over a mirror and simply wave off dust

Utility: Use of low powered electron beam electrically charging dust particles to allow gentle cleaning of lenses and mirror surfaces in space.

Spectrometer on a Chip

- Goddard team is developing a new spectrometer whose components fit onto a silicon wafer and do not require moving parts to operate
- Payoff could be significant for NASA science and commercial spinoffs because of its potential to dramatically reduce the size of instruments
- The team is replacing mirrors used in traditional spectrometers with a photonic system featuring 60 hollow waveguides, or tunnel-like circuits 10 times thinner than a human hair



- Etched inside a silicon chip, these tiny circuits carry out the job of more traditional Michelson-type spectrometers
- Technology is being developed to gather spectra of outer planets and moons

Space-Age Materials One Atomic Layer at a Time

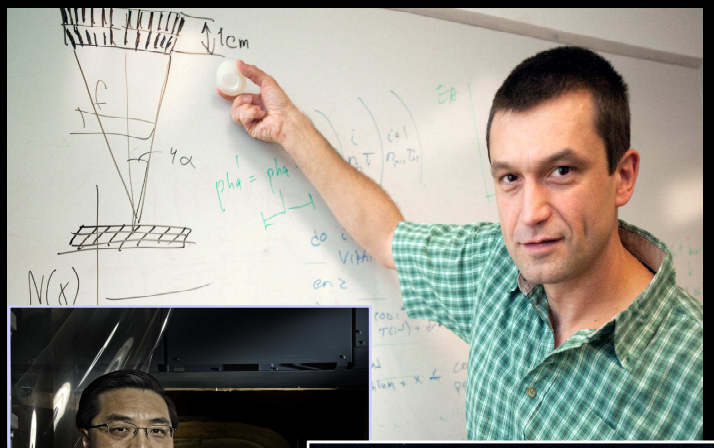
- Goddard technologists are collaborating with U of MD to experiment with a new technology to coat smart radiators and X-ray mirrors and create nano-scale coatings to strengthen spacecraft components

- Atomic Layer Deposition, like chemical vapor deposition, involves placing a substrate inside a chamber and sequentially pulsing different precursor gases to create ultra-thin films

- The advantage of ALD is that it coats 3D objects. Furthermore, it creates these thin films at much lower temperatures, providing a more robust and less expensive way to coat mirrors and radiators

Inspiration from a Roll of Scotch® Tape

- GSFC Scientist Maxim Markevitch wants to study cosmic rays, but would need an X-ray observatory with 30 times the collecting area of NuSTAR, requiring an even larger number of X-ray mirror segments
- X-ray mirrors, which are curved and nested inside optical assemblies, are difficult and expensive to produce.
- Dr. Markevitch has begun investigating the feasibility of fashioning an X-ray mirror from specially coated plastic rolled like adhesive tape.




NASA's NuSTAR Mission

- Currently testing candidate tape that he plans to coat on one side with a reflective coating
- The tape then would be rolled, forming a large number of densely packed nested shells that are spaced by the varying thickness of the tape.
- Target form: a rolled, self-supporting, already-aligned mirror assembly

Concluding Remarks

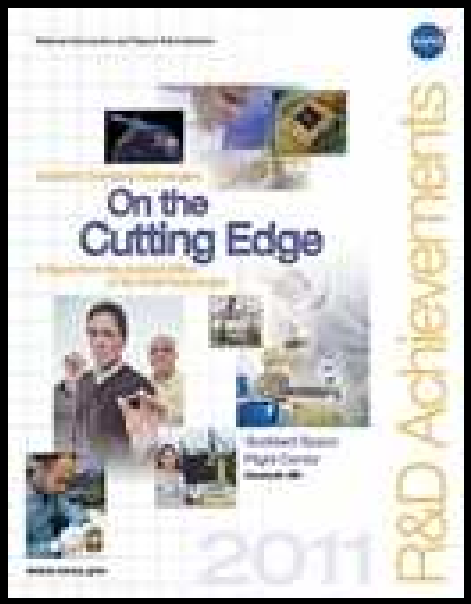
- Advanced Technology Development is an exciting and critical part of the work we do at GSFC. It is truly an enabler of future work and funding.

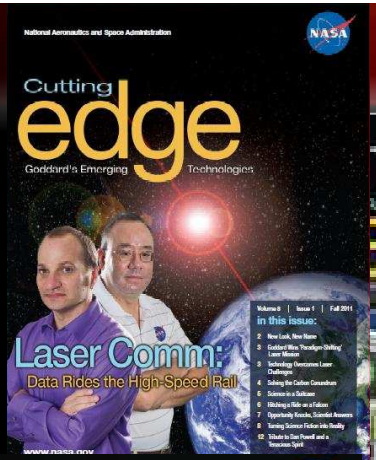
- Through strategic technology investments, we create new opportunities, improve our existing missions, and develop wholly new capabilities for science & exploration.

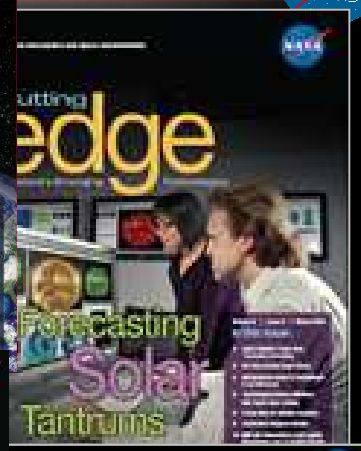
- These strategic investment have potential applications that not only meet National needs, but can foster economic growth and foster collaborations with other OGAs.

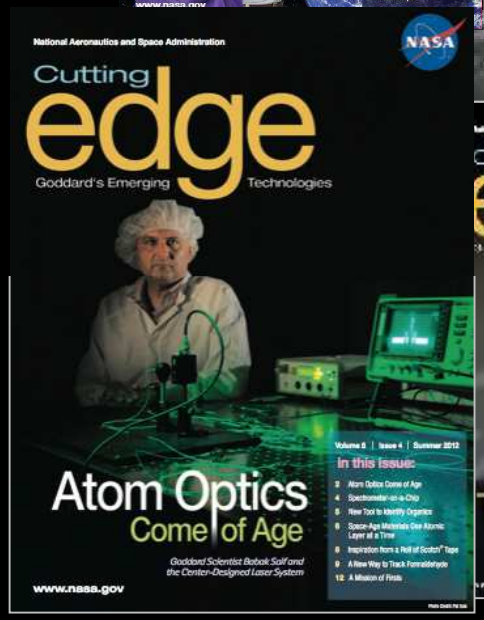
Thank you!

For more information:









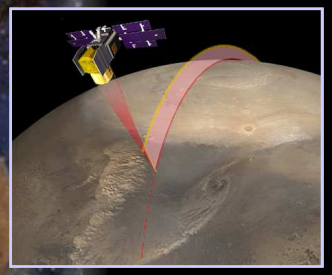
Goddard 'Cutting Edge' and the annual R&D Achievements report are just two vehicles used to inform stakeholders of strategic technology investments. For these documents and more information on GSFC's technologies:
Visit http://gsfctechnology.gsfc.nasa.gov

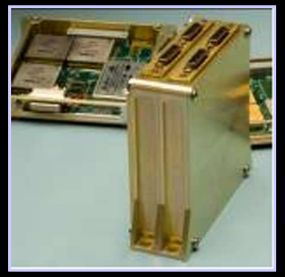

It is difficult to say what is impossible...
for the dream of YESTERDAY
is the hope of TODAY
and the reality of
TOMORROW.
- Robert H. Goddard (1882 - 1945)

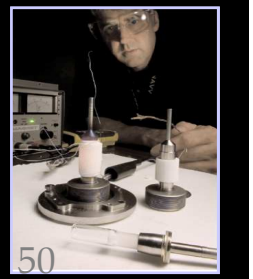
Why GSFC Invests in Technology

- Technology investments are made for one or more of these reasons:
  - **Prepare ourselves** to take on new technological and scientific challenges
  - **Make GSFC more competitive** in securing new instrument and mission development projects (aka targeted opportunities)
  - Significantly **reduce mission risk or costs**
  - Significantly **increase or optimize scientific return**
  - Provide a **unique, differentiating technology capability** for science or exploration
  - To **win external funding** for technology or mission development

- Strategic impact and realism of external funding capture are key criteria for internal investments





NASA's Earth Science Missions

- How is the global earth system changing?
- What are the primary forcings of the Earth system?
- How does the earth system respond to natural and human-induced changes?
- What are the consequences of change in the earth system for human civilization?
- How will the Earth system change in the future?

Graphene Technology Development at GSFC

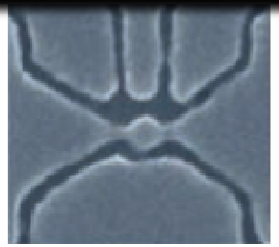
Current Graphene Efforts at Goddard

- Transparent conductive electrodes (TCE)
- Single molecule chemical detectors
- Ultrafast laser and ultra wide bandwidth detectors

Other applications:

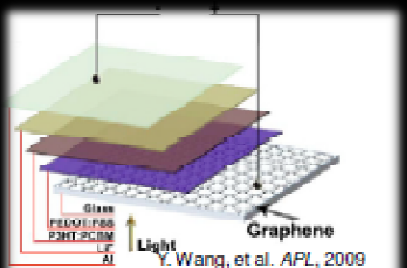
Integrated circuit interconnects
Frequency multipliers for data transmission
Field emission transistors
Ultra capacitors
Graphene bio devices

Flexible/transparent Electronics


Molecular Transistor

National Benefit

- Flexible/transparent Electronics
- Molecular Transistor
- Solar Cells

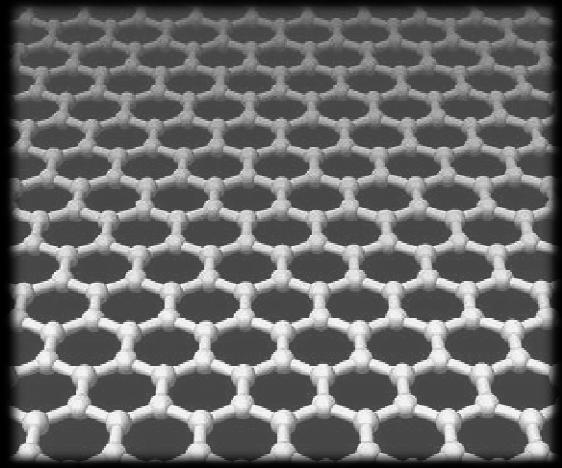


Solar Cells

Graphene – Quick Overview

What is Graphene

- New class of carbon crystal one-atom-thick
- Crystalline or “flake” form of graphite consists of many graphene sheets stacked together
- Formed by “exfoliating” sheets from graphite flakes or by Chemical Vapor Deposition (CVD)

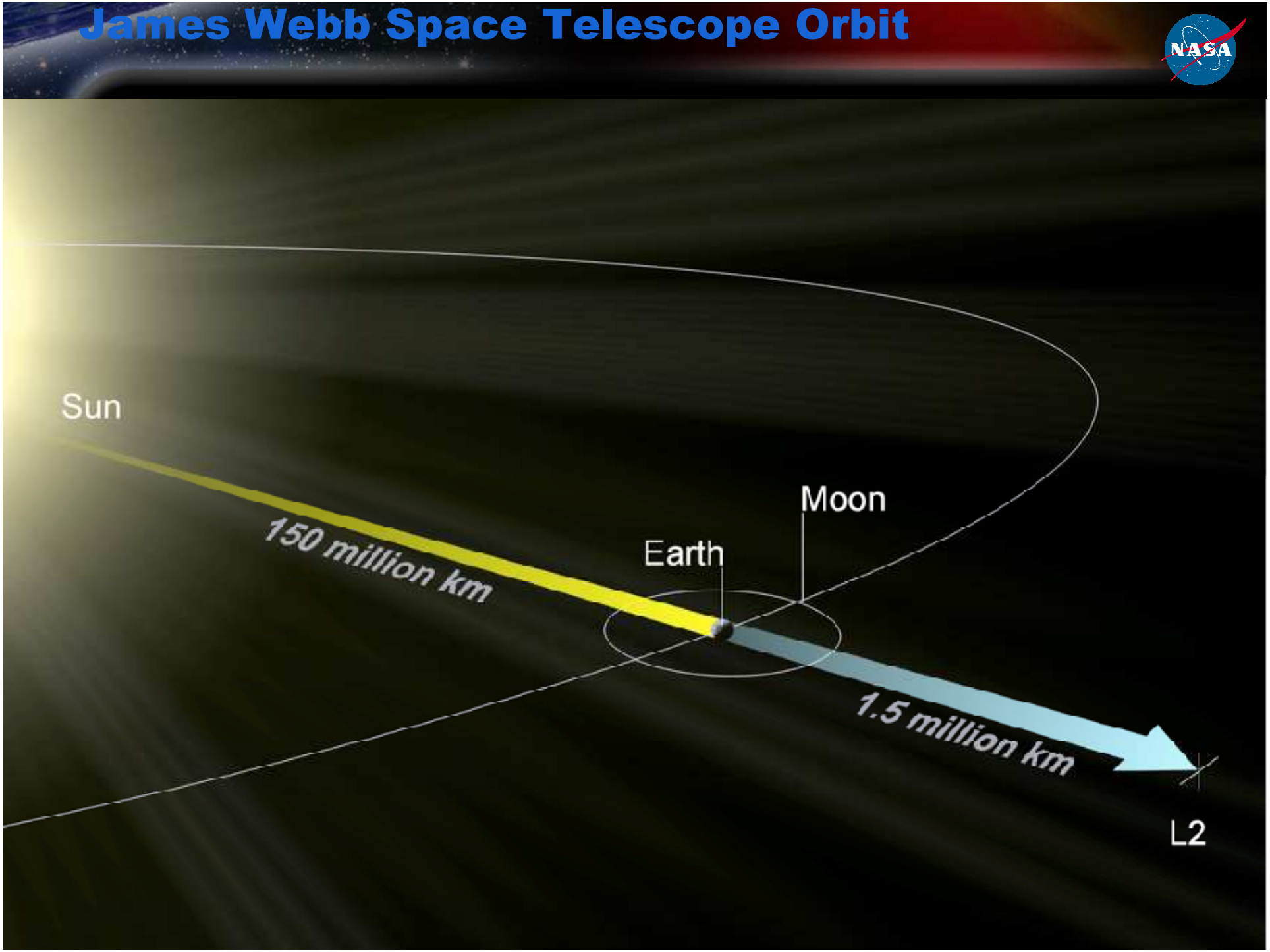


Graphene’s Exceptional properties

- Ultrahigh optical transparency: 98% for a single layer graphene – double transparency of the best transparent metal known with wider bandwidth of optical transparency compatible with infrared
- Extraordinary chemical sensitivity enabled detection of single molecules
- Ultrahigh electron mobility – theoretical conductivity twice that of silver the most conductive metal known
- Strongest material measured to date – able to stand up to rigors of flexible circuits

GSFC researchers are developing a method for the fabrication of high purity large area graphene films

James Webb Space Telescope Orbit



X-ray Navigation (XNAV): A Galactic Positioning System

What is X-NAV

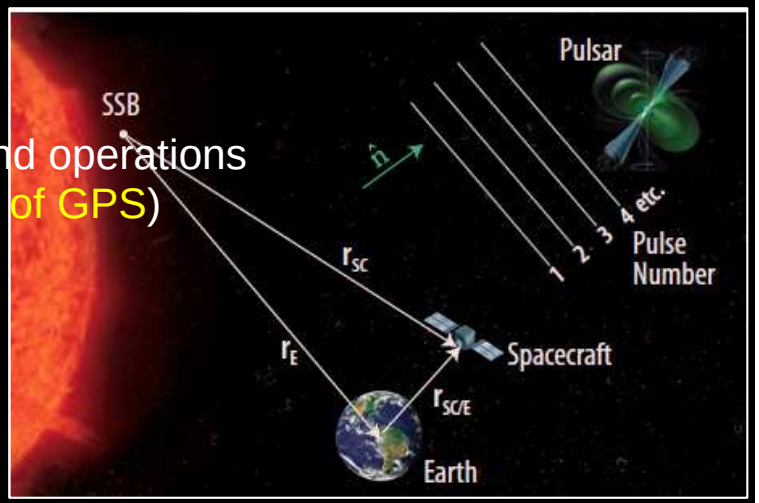
- Autonomous space navigation and timing using cosmic "clocks"
- NASA-developed X-ray sensor and onboard navigation software

X-NAV's Significance

- Exploits X-rays emitted by *pulsars* – "natural celestial lighthouses" - to derive position and time onboard
- Autonomous, real-time, 3-dimensional spacecraft navigation throughout the Solar System

National Benefit

- Enables independent synchronization of assets and operations anywhere, anytime (e.g. for increased robustness of GPS)
- Permanent Architecture immune to tampering
- Game-changer for both civilian and military space



Full Family of MARS Rovers
Pathfinder, Spirit and Curiosity

FY11 IRAD Successes: Key Messages

IRAD has consistently generated measurable and increased returns on investment

IRAD is highly competitive, opportunity driven, and 100 percent aligned to Goddard's Lines of Business

Program continues to fund technology development and risk reduction for nearer-term opportunities

- **however, larger share of resources invested in early-stage innovations, new ideas, and early-career innovators**
  - **Investment in early-stage innovation has increased 300% since FY07**

Early Career Innovators*		**24.8%** (vs 23% in'10)
Early Stage Innovations		**45%** (vs 35% in '09)

** Early Career Innovators defined as <= 7 years as professional*

FY11 IRAD Successes: ROI Highlights

Disciplined investment strategy paid off in FY11:

- **Return on investment totaled over $40 million**
- **Five principal investigators won new mission and instrument-development opportunities or demonstrated technologies on high-altitude aircraft, sounding rockets, Cubesats, and scientific balloons**
- **Technologists also received funding under two high-profile OCT technology-development projects**
- **Twenty-four principal investigators won follow-on funding from non-IRAD sources to further advance their technologies**
- **Eight technology-development teams received funding for or completed technological capabilities needed by others to advance instruments or help interpret data needed by the public**