Summary of Capabilities in Spacecraft and Mission Design

Presentation to
Steering Group
Planetary Decadal Survey
July 7, 2009

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Acting Space Department Head
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240 228 6242

APL
The Johns Hopkins University
APPLIED PHYSICS LABORATORY

Divisions & Neighbors of The Johns Hopkins University

School of Arts & Sciences

Whiting School of Engineering

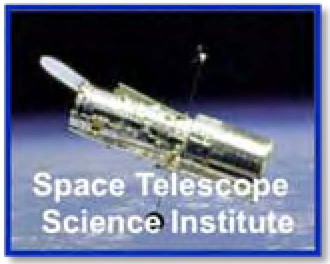
School of Professional Studies in Business & Education

School of Medicine

School of Hygiene & Public Health

School of Nursing

Applied Physics Laboratory



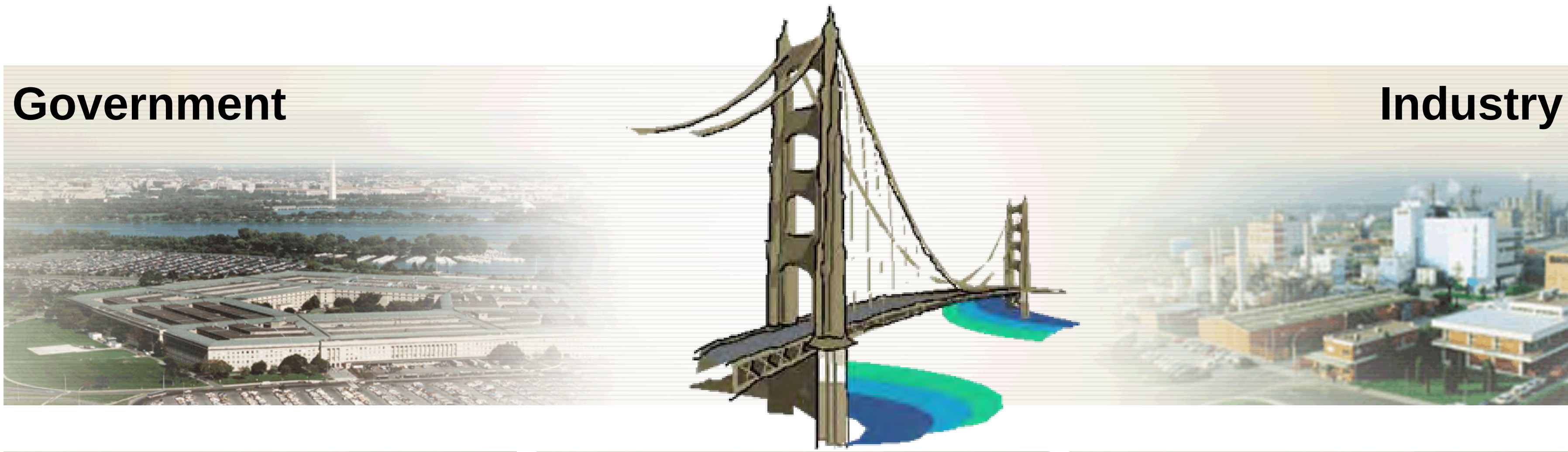
Nitze School of Advanced International Studies

Peabody Institute

Profile of the Applied Physics Laboratory

- **Not-for-profit university research & development laboratory**
- **Division of the Johns Hopkins University founded in 1942**
- **On-site graduate engineering program in 8 degree fields**
- **Staffing: 4,500 employees (69% scientists & engineers)**
- **Annual revenue ~ $ 950M**

What is Our Typical Role?



Concept Development

- Problem Definition
- System Concept
- Critical Technology Identification
- Demonstration, Validation, Prototyping

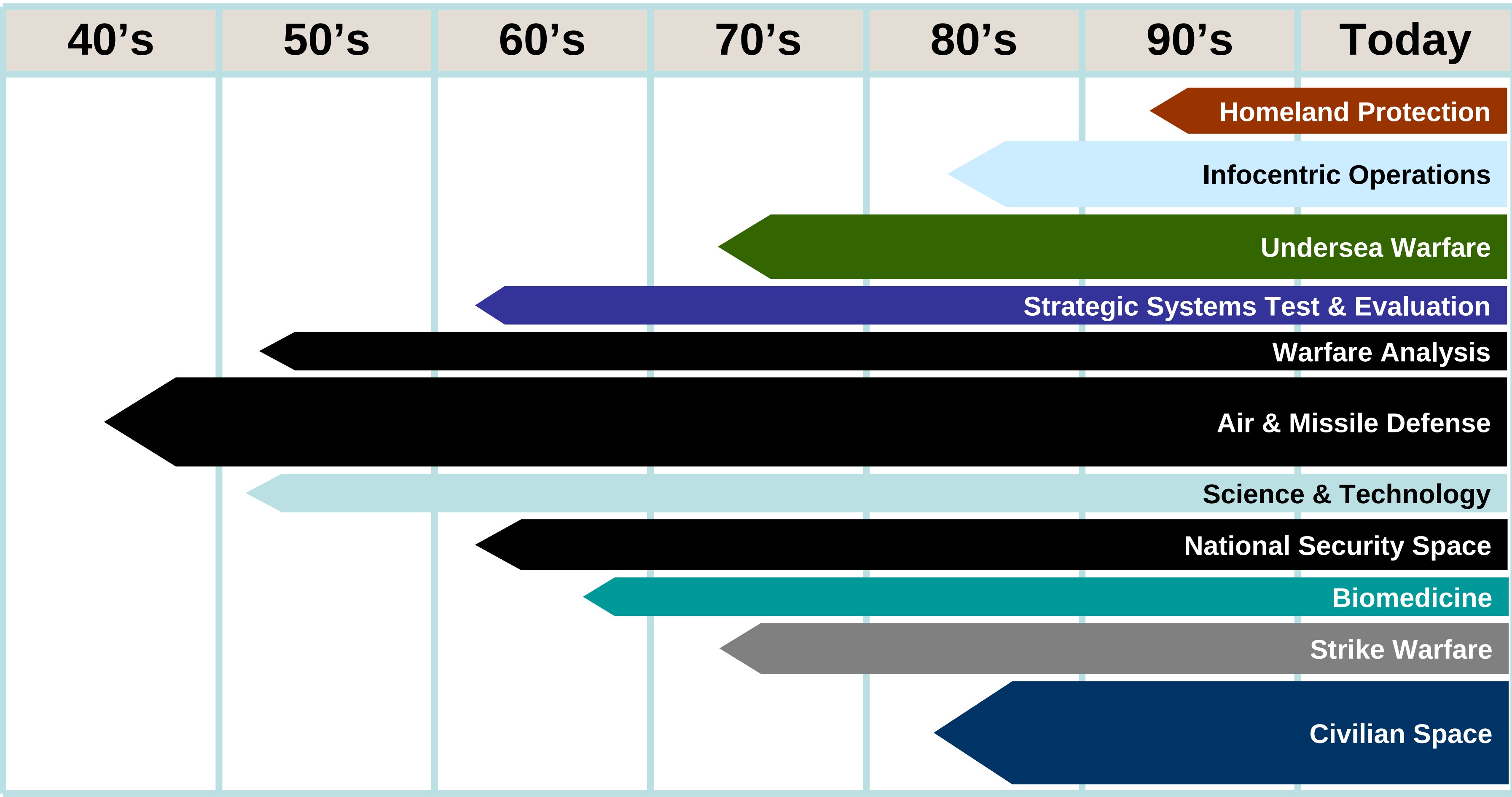
Requirements Definition

- System Design Requirements
- Design Development with Government & Industry
- Technical Evaluation
- Coordination of Integration Testing

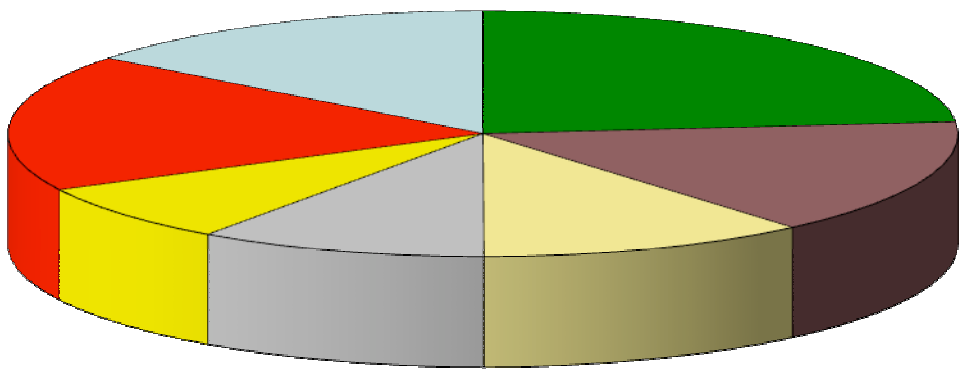
Production & Deployment

- Transition of Prototype Design
- Follow-on Review and Requirements

Business Area History



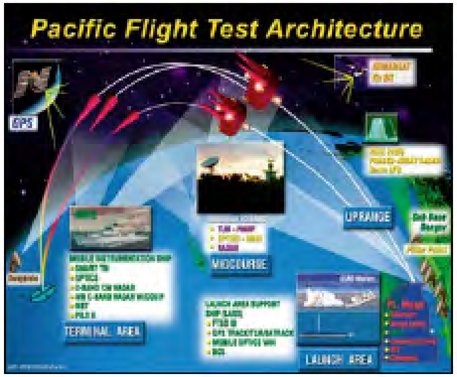
Principal Areas of Work – GFY2009



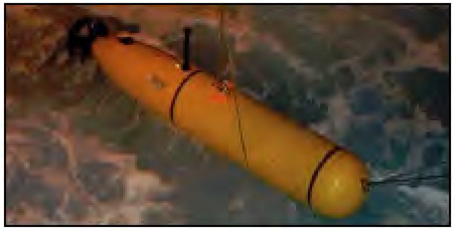
Example Programs
From the 2008 Annual Report









Space Department at a Glance

- Department hosts two APL Business Areas:
  - Civilian Space
  - National Security Space
- Three functional branches support these two business areas:
  - Software Engineering
  - Hardware Engineering
  - Science Research and Analysis
- Vital Statistics
  - Approx. 600 staff, plus 50 on-site contractors
    - Approximately 150 space scientists
  - $150-200M Funding
  - Sponsors: NASA, DoD, National Science Foundation, National Oceanic and Atmospheric Association (NOAA)

Current Operations

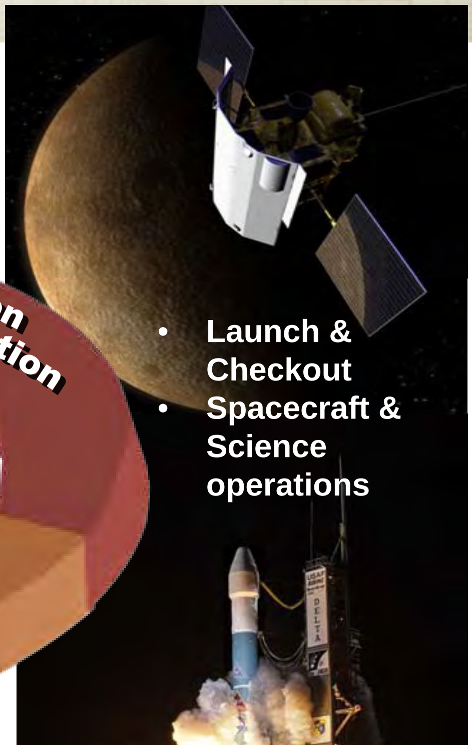
- **We are currently operating five spacecraft:**
  - ***MESSENGER* – Launched 2004, First spacecraft to orbit Mercury, 1st & 2nd Flyby 2008, Final Orbit 2011**
  - ***New Horizons* – Launched 2006, First Mission to Pluto, Jupiter Flyby Feb 28 2007; Pluto Flyby 2015**
  - ***TIMED* – Launched 2001, Earth Orbit, study Earth's upper atmosphere**
  - ***STEREO* – Launched Fall 2006, Twin spacecraft around the Sun to study coronal mass ejections**
- **Example Active Instruments**
  - **LECP on Voyager**
  - **CRISM on MRO**
  - **Mini-RF on ISRO Chandrayaan-1 (Mini-RF on LRO)**
  - **MIMI on Cassini**
  - **PEPPSI on New Horizons**
  - **GUVI/SSUSI on TIMED/DMSP**
- **Current Spacecraft Engineering**
  - **Radiation Belt Storm Probes, twin spacecraft to investigate Van Allen Belts, recently confirmed for Phase C**

End-To-End Capability

Space Science & Exploration

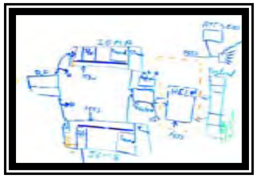
- Publish Scientific Advances
- Work with National Academy & NASA in developing roadmaps for future

Phase E:
- Operations & Sustainment
- Data Acquisition and Analysis
- Publication of results
- Revised investigations



- Launch & Checkout
- Spacecraft & Science operations

Pre Phase A:
- Mission Concept Studies
- Technology Development
- Mission Proposals



Phase A:
- Mission Concept Development
- Preliminary Mission Analysis

Phase B:
- Definition
- Preliminary Design

Phase C
- detailed design

Phase D
- fabrication, assembly, integration & test
- Hardware Implementation

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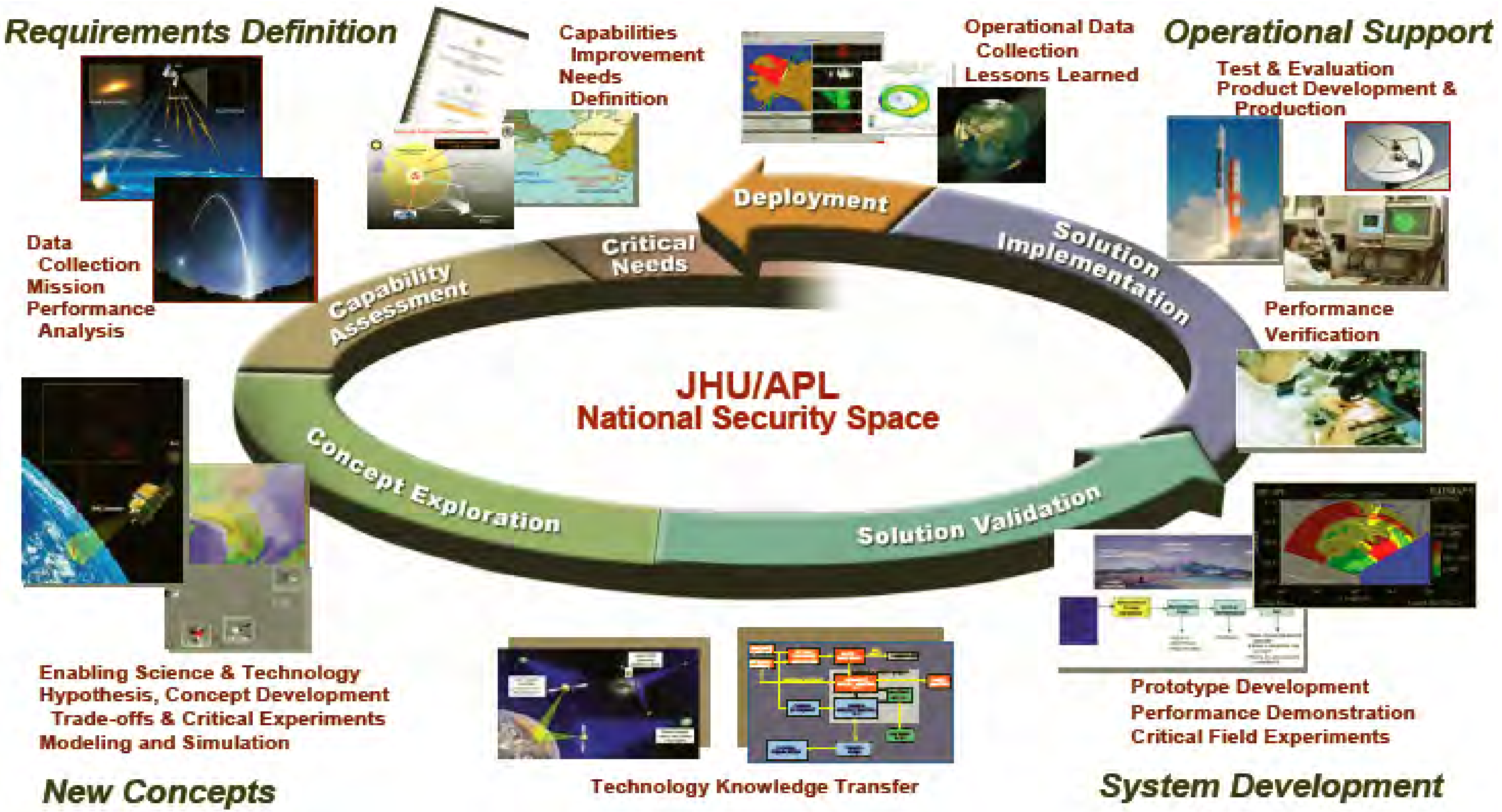
End-To-End Capability
Space-based Support of National Security

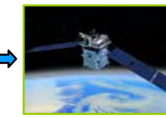


Civilian & National Security Space Synergy

CIVILIAN ← → NATIONAL SECURITY

GUVI - SSUSI	Adapted from DMSP
TIMED	GPS navigation, independent tasking processes
MESSENGER	Neural Network Anomaly Detection
Mini-RF (Chandrayaan & LRO)	Mini-RF technology
Lunar Nav/Com	Incorporates DARPA MiDSTEP study findings
ORS	Bus standards, plug & play technology
Lightweight optics	LEOSS adapted for AFRL
New Horizons	Autonomy, schedule, long-term ops processes
MDA work	Adapted for MESSENGER phased array





Other examples include Mars ATD low power converter for NSS programs, an NRO instrument adapted for RBSP, CS thermal switch used by USNA MidStar, CS FLAPS IRAD used on USAFA Falconsat

A Tradition of Firsts in Space

1958 Satellite Navigation System

1961 Nuclear-powered spacecraft

1963 Gravity gradient stabilization

1967 Color picture of the full Earth

1972 Drag-compensated satellite

1975 Pulsed plasma thrusters

1982 Autonomous satellite navigation with GPS

1984 Artificial Comet

1986 Intercept of a thrusting target in space

1988 Autonomous target acquisition and Track

1996 Near Earth Asteroid Rendezvous (NEAR)

1996 First Hyperspectral Imager in Space (MSX)

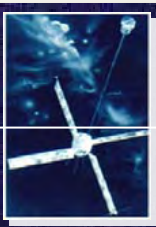
1996 Invention of Polymer Battery

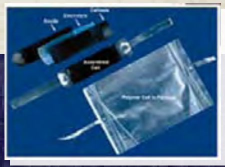
2001 Landing on an Asteroid (NEAR)

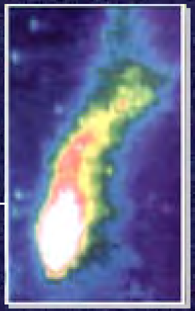
2002 Re-Configurable Self-Repairing Processor (on FEDSAT)

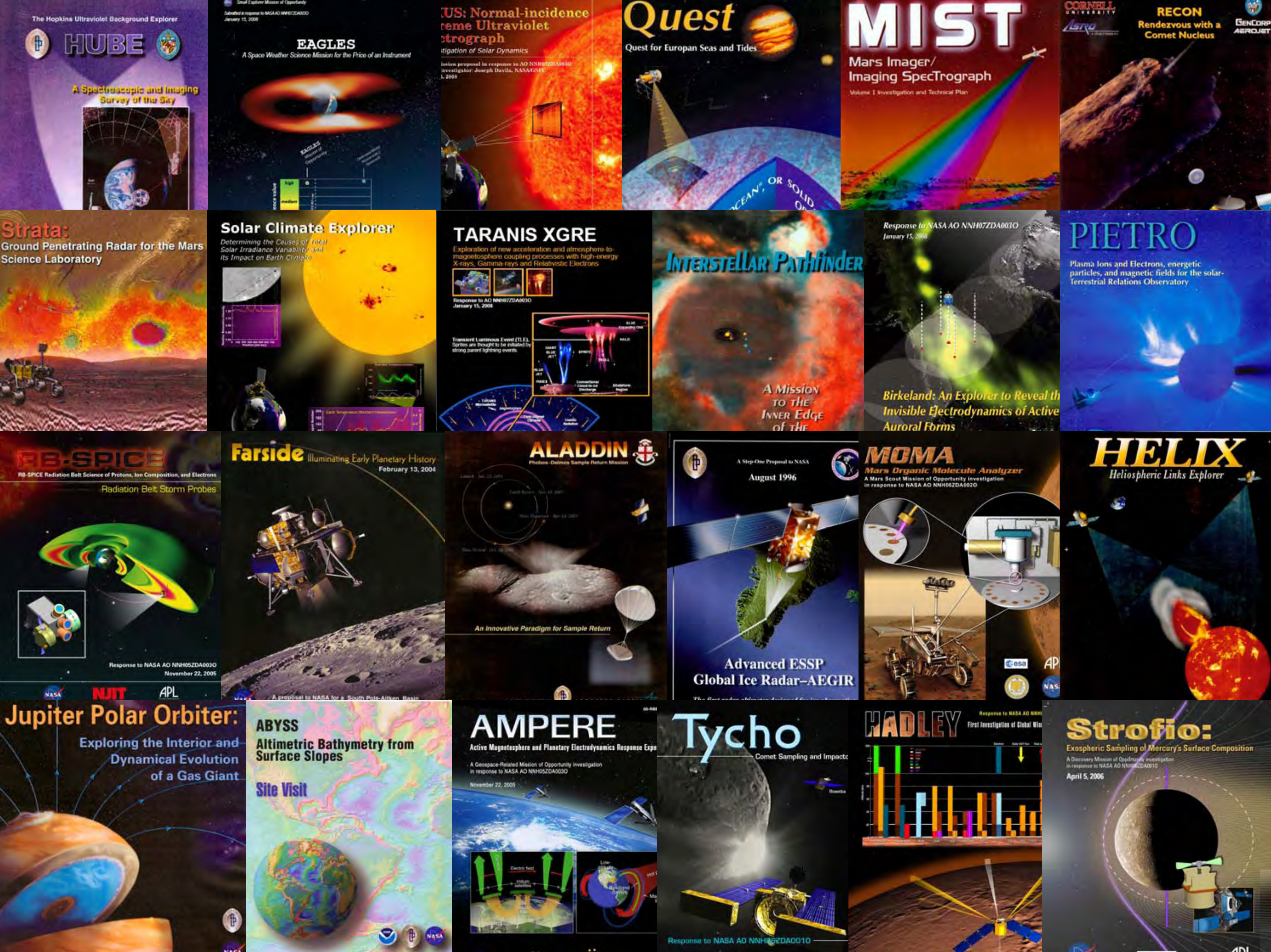
2003 First orbital Mercury exploration mission launched (MESSENGER)

2004 First mission to Pluto launched (New Horizons)









The Hopkins Ultraviolet Background Explorer
HUBE
A Spectroscopic and Imaging Survey of the Sky
EAGLES
A Space Weather Science Mission for the Price of an Instrument
Quest
Quest for Europan Seas and Tides
MIST
Mars Imager/ Imaging SpecTrograph
Volume I Investigation and Technical Plan
RECON
Rendezvous with a Comet Nucleus
Strata:
Ground Penetrating Radar for the Mars Science Laboratory
Solar Climate Explorer
TARANIS XGRE
Response to AO NNH07ZDA003O
January 15, 2008
Interstellar Pathfinder
A Mission to the Inner Edge
Response to NASA AO NNH07ZDA003O
Invisible Electrodynamics of Active Auroral Forms
PIETRO
Plasma Ions and Electrons, energetic particles, and magnetic fields for the solar-Terrestrial Relations Observatory
RB-SPICE
Radiation Belt Storm Probes
Response to NASA AO NNH05ZDA003O
November 22, 2005
NJIT
APL
Farside Illuminating Early Planetary History
February 13, 2004
ALADDIN
Phobos-Deimos Sample Return Mission
An Innovative Paradigm for Sample Return
A Step-One Proposal to NASA
August 1996
Advanced ESSP Global Ice Radar–AEGIR
MOMA
Mars Organic Molecule Analyzer
HELIX
Heliospheric Links Explorer
Jupiter Polar Orbiter:
Exploring the Interior and Dynamical Evolution of a Gas Giant
ABYSS
Altimetric Bathymetry from Surface Slopes
Site Visit
AMPERE
November 22, 2005
Tycho
HADLEY
Strofio:
Exospheric Sampling of Mercury's Surface Composition
April 5, 2006

Study & Proposal Examples

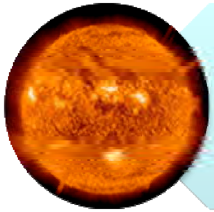
Planetary

Titan Saturn System Mission

Astrophysics
Interstellar Pathfinder → IBEX SwRI

Earth Science

AEGIR → CryoSat ESA

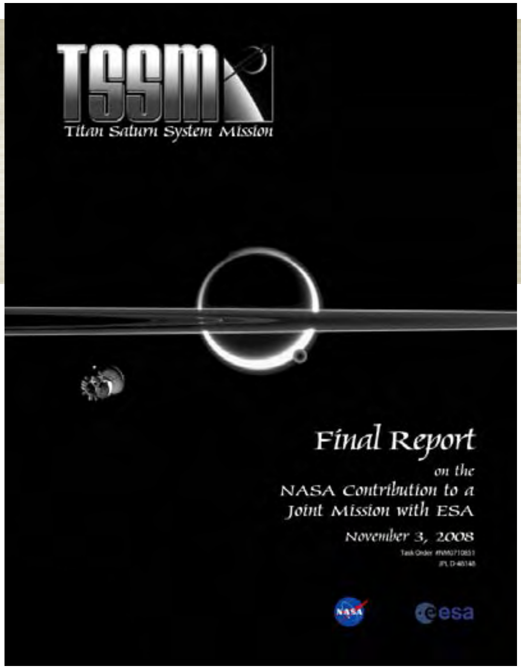


Heliophysics

HELIX → STEREO

Titan Saturn System Mission

An APL Led Outer Planet Flagship Mission Study



Goal A: Explore Titan, an Earth-like System

Goal B: Examine Titan's Organic Inventory – A Path to Prebiological Molecules

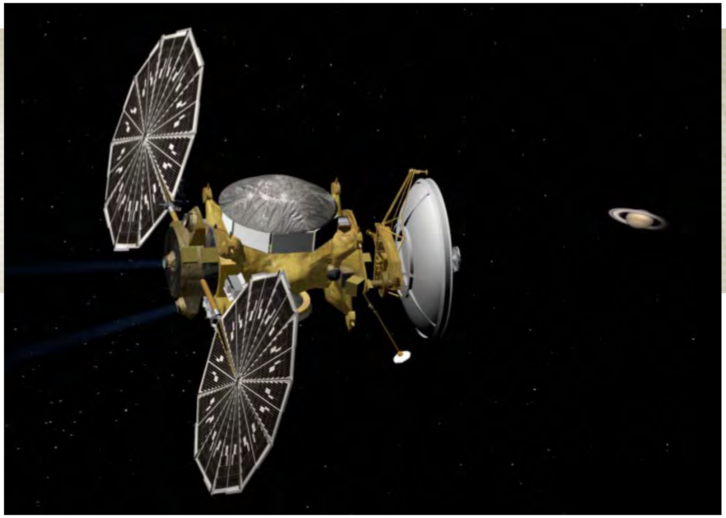
Goal C: Explore Enceladus and Saturn's Magnetosphere – Clues to Titan's Origin and Evolution

Science Team

Jonathan Lunine, Co-Chair (University of Arizona)
Jean-Pierre Lebreton, Co-Chair (ESA/ESTEC)
Athéna Coustenis, European Lead Scientist (Observatoire de Paris-Meudon)
Dennis Matson, NASA Study Scientist (JPL)
Lorenzo Bruzzone, University of Trento
Maria-Teresa Capria (Instituto di Astrofisica Spaziale, Rome)
Julie Castillo-Rogez (JPL)
Andrew Coates (Mullard Space Science Laboratory, Dorking)
Michele K. Dougherty (Imperial College London)
Candice Hansen (JPL)
Andy Ingersoll (Caltech)
Ralf Jaumann (DRL Institute of Planetary Research, Berlin)
William Kurth (University of Iowa)
Luisa M. Lara (Instituto de Astrofísica de Andalucía, Granada)
Rosaly Lopes (JPL)
Ralf Lorenz (JHU/APL)
Chris McKay (ARC)
Ingo Muller-Wodarg (Imperial College London)
Olga Prieto-Ballesteros (Laboratorio de Geologia Planetaria, Madrid)
François Raulin (LISA Universités Paris 12 & Paris 7)
Amy Simon-Miller (GSFC)
Ed Sittler (GSFC)
Jason Soderblom (University of Arizona)
Frank Sohl (DLR Institute of Planetary Research, Berlin)
Christophe Sotin (JPL)
Dave Stevenson (Caltech)
Ellen Stofan (Proxemy Research)
Gabriel Tobie (Université de Nantes)
Tetsuya Tokano (Universität zu Köln)
Paolo Tortora (Università di Bologna)
Elizabeth Turtle (JHU/APL)
Hunter Waite (SwRI)

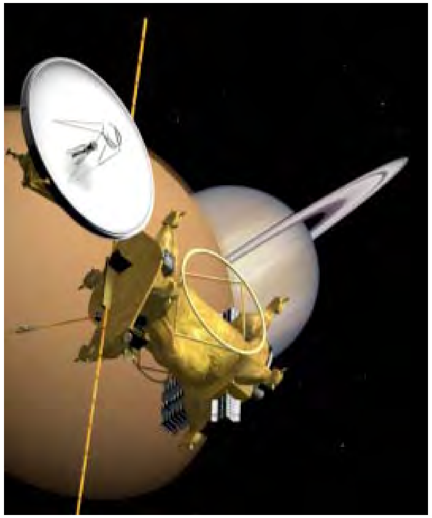
Titan Saturn System Mission

An APL Led Outer Planet Flagship Mission Study



- **2020 Launch, Gravity Assist, SEP**
  - 6203 kg total launch mass, Atlas V 551
- **9 yrs to Saturn, SEP release after 5 yrs**
- **Montgolfiere release 1st flyby, Lander 2nd**
- **4 yr prime, 2 yr Saturn tour, 20 mo TItan orbit**
- **Orbiter (NASA)**
  - 4m high gain antenna 35W Ka-band amplifier for high data downlink
  - 5 ASRG provide 540 W at EOM (MMRTG compatible)
  - Solar Electric Propulsion, 3 NEXT thrusters
  - Two 7.5kW Orion CEV Ultraflex solar arrays
  - 165 kg payload
- **Montgolfiere (ESA)**
  - US MMRTG buoyancy, 10km cruise alt, 6 mo mission
  - 600kg launch mass, telecom with orbiter via 0.5m HGA
- **Lander (ESA)**
  - 9 hour mission, battery operated, X-band omni, 190 kg launch mass

$2.5B (FY07)
$1B ESA



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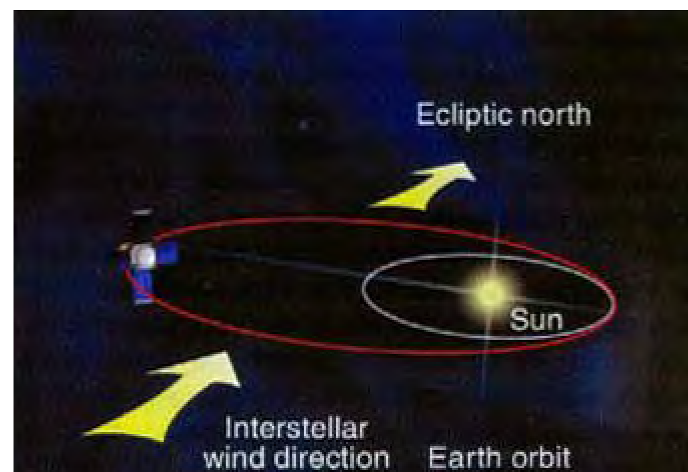
Interstellar Pathfinder

- **"…a mission to the inner edge of the interstellar medium."**
  - **Composition of local interstellar matter**
  - **Global images of heliosphere boundary region at 100 to 150 AU**
- **Submitted 1998 and 2001**
- **PI George Gloeckler, Univ of MIchigan**
- **'98 Spacecraft (Orbital Sciences Corp)**
  - July 2006 Launch, 2.3 yr mission
  - 854kg launch mass
  - Orbit 1 to 3 AU, 0° inclination
  - Sun oriented, spin stabilized
  - 1.5m fixed HGA, 10 m^2 solar array
- **'98 Payload (37kg, 29W)**
  - Ion Composition Spectrometer, Energetic Neutral Atom Imager, Helium Detector, Solar UV Monitor, Solar Wind Monitor



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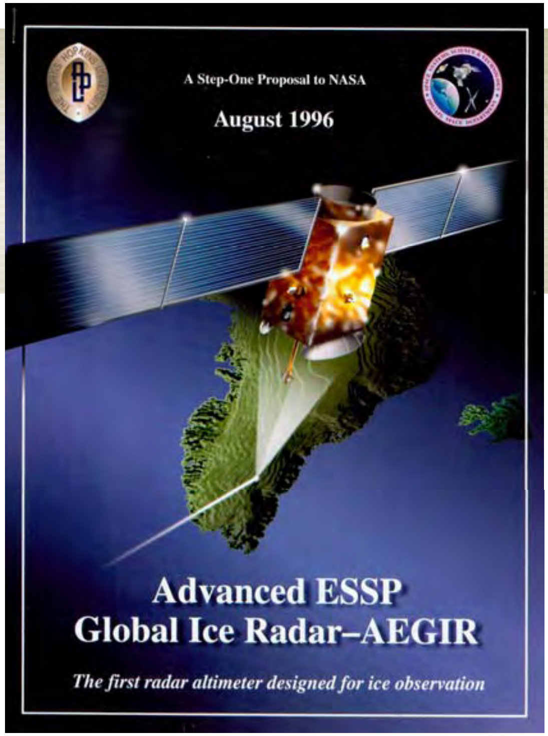
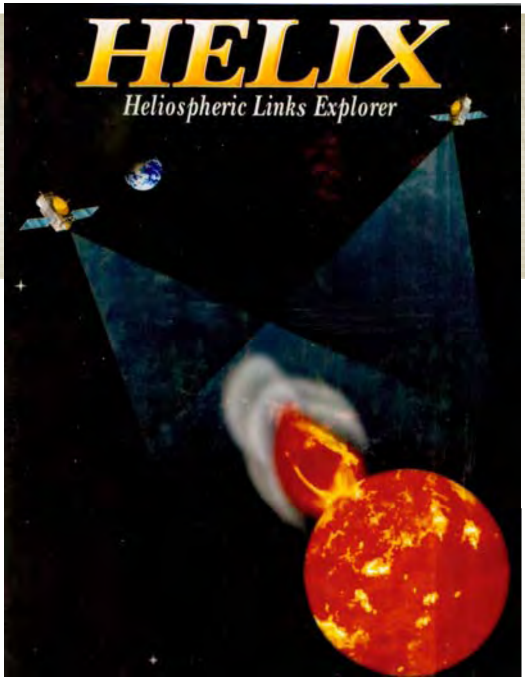
AEGIR
Advanced ESSP Global Ice Radar

- First radar altimeter designed to observe global ice
- Submitted 1996
- PI Keith Raney, JHU/APL
- Uses APL's patented Delay/Doppler technology at Ku-Band
- Builds on APL experience with Geosat, Seasat, and TOPEX
- Spacecraft
  - Sun Synchronous
  - 880 km altitude
  - 300 W
  - 2001 launch, 5 yr mission
- International Team Members take concept to ESA's CryoSat proposal



HELIX
Heliospheric Links Explorer



- "… provide stereoscopic images of solar mass ejections from their origins on the Sun to their arrival at Earth."
  - Track eruptions from Sun to Earth
  - Test magnetic helicity conservation
  - Develop geomagnetic storm forecast techniques
- Submitted 1995
- 2 identical spacecraft
  - Heliocentric orbits at 1 AU
  - HELIX-1 remains within 0.2 AU of Earth
  - HELIX-2 drifts away from Earth at 30° per year
- Payload
  - Interplanetary Disturbance Imager
  - Solar Ejection Telescope
  - Plasma and Magnetic Field Sensors

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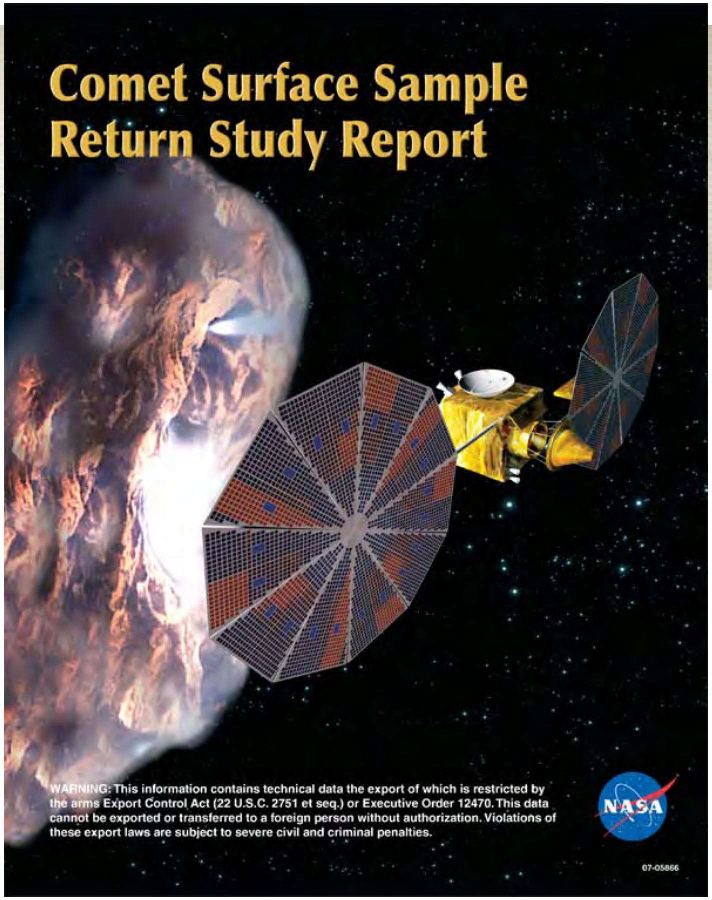
Comet Surface Sample Return

- **APL led study shows that a CSSR mission can fit a $820M (FY07) cost cap**
- **SDT of community comet experts set reqmts**
- **Acquire & return 500cc (or more) sample from surface of any comet nucleus**
- **Return material from a depth of at least 10cm**
- **Do not allow aqueous alteration**
- **Capture evolved gasses, maintaining elemental and molecular integrity**



Science Definition Team
- Mike A'Hearn (UMD): Co-chair
- Hal Weaver (JHU/APL): Co-chair
- Mike Combi (University of Michigan)
- Yan Fernández (University of Central Florida)
- Will Grundy (Lowell Observatory)
- Martha Hanner (University of Massachusetts)
- Casey Lisse (JHU/APL)
- Karen Meech (University of Hawaii)
- Joe Veverka (Cornell University)
- Paul Weissman (JPL)
- Mike Zolensky (NASA/JSC)

APL

ROSES DSMCE ASRG Study

ILION: AN ASRG-ENABLED TROJAN ASTEROID MISSION

Science Objectives: Ilion addresses critical questions about Trojan asteroids:

1. Did the Trojan asteroids originate near Jupiter's orbit, or further out in the solar system?
2. How much ice and organics are present on Trojan asteroids?
3. How do the geological processes which have occurred on the Trojans compare to those that have affected other small bodies?
4. What is the relationship between Trojan asteroids and comets, KBOs, and outer planet satellites?

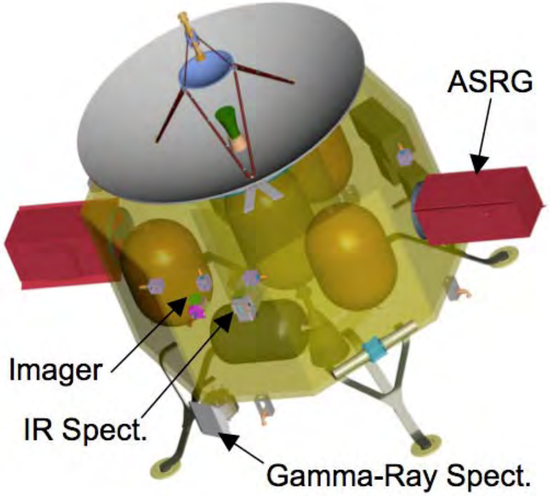
Mission Schedule:

Launch date depends on final target selection

Project Start	**August 2009**
Launch	**September 2013**
Jupiter Flyby	**May 2016**
Trojan Orbit Insertion	**August 2023**
Land on Trojan	**May 2024**
End of Mission	**September 2024**

	Instrument	Heritage/Analog
Remote Sensing	Wide/Narrow Field Imager	MESSENGER
	IR Spectrometer	MESSENGER
	Laser altimeter	NEAR
	Neutron Spectrometer	MESSENGER
	Gamma-Ray Spectrometer	MESSENGER
Surface Sensing	APXS	MER
	(LAMS? LIBS?)	
	Thermal Conductivity	Rosetta et al.
	Electrical Dissipation	

Strawman Payload

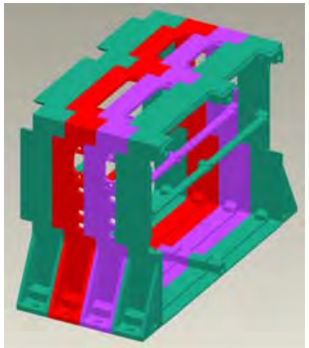


NASA SmallSat Study Summary

Study Lead: George Cancro, George.Cancro@jhuapl.edu; 443-778-3476

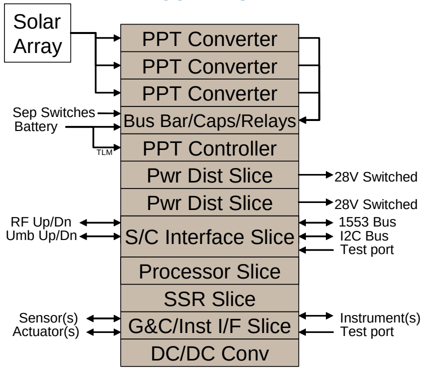
"The Explorers Program is initiating a study with the Applied Physics Laboratory with the purpose of invigorating the Small Explorer program by introducing innovating approaches to lower cost and improve performance of spacecraft and instrument platforms suitable for future small satellite (SmallSat) missions."

- **TASK 1 – Component and Spacecraft Catalog:**
  - Developed SmallSat Catalog of 300+ different space components,17 different spacecraft platforms, from 100+ different companies and organizations.
- **TASK 2 – Reliability, Parts, and Redundancy:**
  - Augmented failure databases (1962-1995) by adding recent data (1995-2007)
  - Based on results as categorized in the database, leads us to conclusion design issues have greater impact than parts and redundancy.
- **TASK 3 – DoD Dual-Use Technologies:**
  - Surveyed multiple DoD programs resulting in several lessons learned and a RFI to launch providers to guage near future secondary capabilities.
- **TASK 4 – NASA SmallSat Standards:**
  - Developed modular strategies for single box modular avionics (CDH+G&C+PwrDist+SolarArray control for ~8kg and ~30 W) and modular plug-n-play software applications.
  - **NASA RBSP, ILN, and Solar Probe Plus missions using elements of SmallSat Task 4 concepts**



Modular Stacking Slices

Sample SMEX BLOCK DIAGRAM



SCIF Board

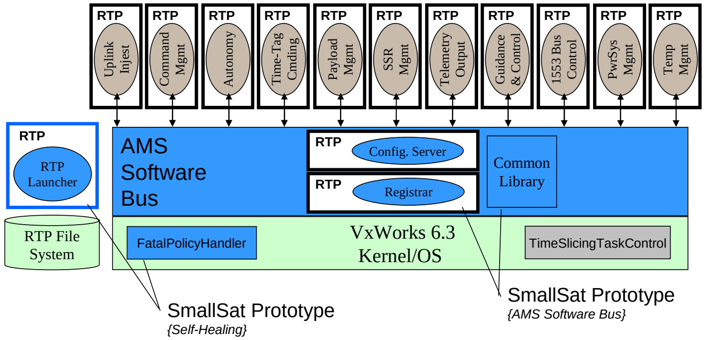
(H/W framer, RAM-based S/W I/F; Transitioned to RBSP)

LEON3FT Eval. Board

(Rad-Hard, SpW, High MIPS / Watts ratio)

Envisioned S/W System Concept

(Memory & Time protected apps, S/W Bus, Self-Healing)



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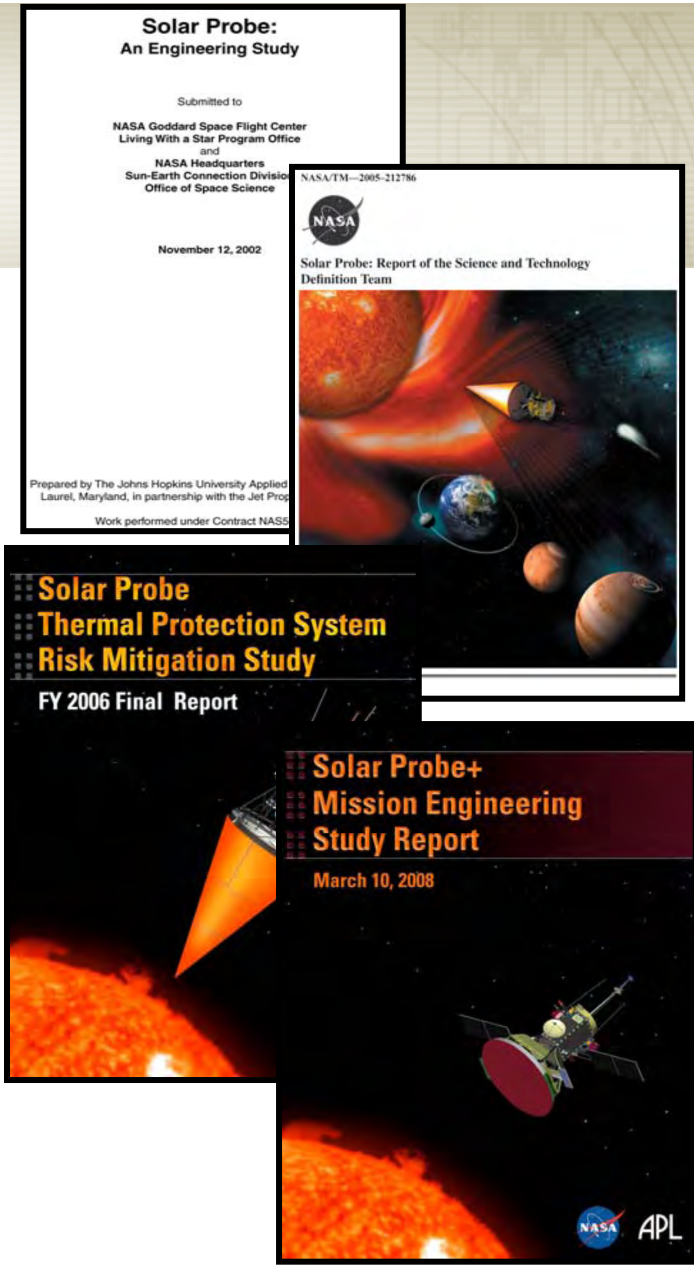
Solar Probe

- 2002 Engineering Study
- 2005 Science & Technology Definition Team Report
- 2006 Thermal Protection System Risk Mitigation Study
- 2008 Solar Probe+ Mission Engineering Study



Solar Probe

was:

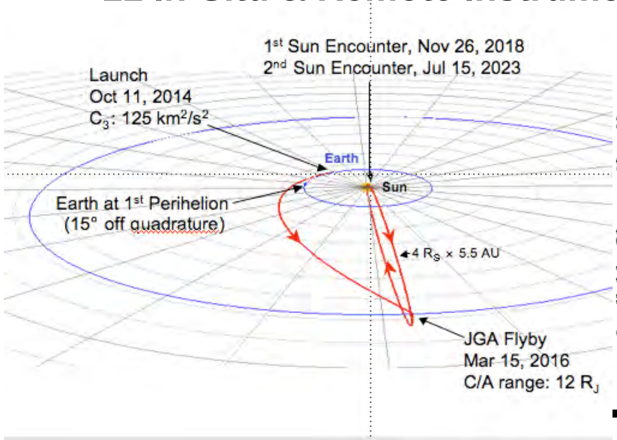
2005 STDT

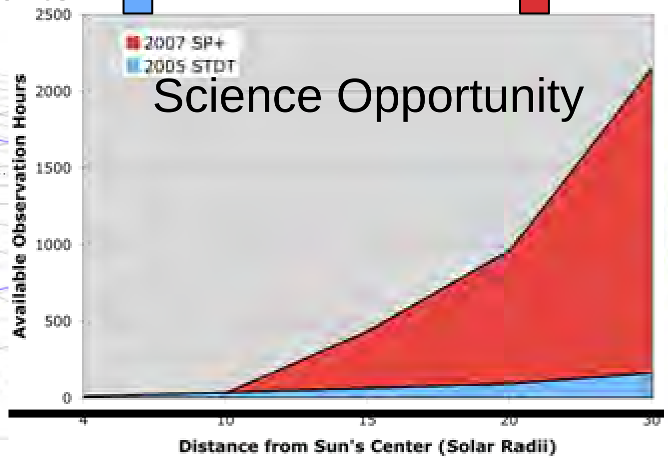
- $1.2B (FY05 $'s)
- Launch Oct 2014
- Atlas V 551, STAR-48, 672 kg (wet)
- Nuclear Power 375 W
- Closest Approach 4 R_{Sun} (0.02 AU)
  - 3000 Earth Suns
  - CC Heat Shield 2870 °F
- Radiation 44 krad (100 mils Al)
- 2 Polar Orbits in 8.8 years
- Science (121 Gbits returned)
  - Solar Wind source, Energy flow, Acceleration mechanisms, Dusty Plasma phenomena
  - 11 In-Situ & Remote Instruments

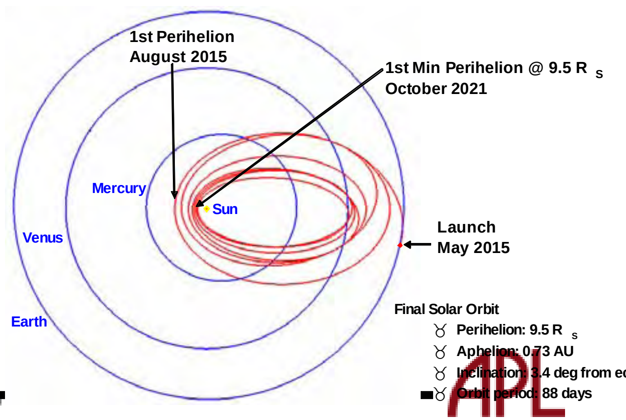
is now:

2007 SP+

- $739M (FY07 $'s)
- Launch May 2015(?)
- Atlas V 551, STAR-48BV, 481 kg (wet)
- Solar Power 482 W
- Closest Approach 9.5 R_{Sun} (0.044 AU)
  - 510 Earth Suns
  - CC Heat Shield 2600 °F
- Radiation 30 krad (100 mils Al)
- 24 Equatorial Orbits in 6.9 years
- Science (2765 Gbits returned)
  - Goals same as SP 2005
  - Only the Polar Imager is deleted from the 2005 payload - 10 Instruments







APL's Role in Exploration of the Solar System

Sun
Ulysses
ACE
STEREO
SOLAR PROBE Plus
Solar Orbiter

Mercury
MESSENGER

Venus

Earth
MagSat
Geosat
PolarBear
Hilat
GEOSs
Grace
TIMED
MSX
DELTAs
SASs
IMP
AEs
DMSP
MMS/EPD

Moon

Apollo 17
Chandrayaan 1
LRO
ILN

Mars
MRO/
CRISM
ExoMars/
MOMA

Asteroid and Comet
NEAR

Jupiter
Voyager
Galileo
New-
Horizons
JUNO
Europa Flagship

Saturn
Voyager
Cassini

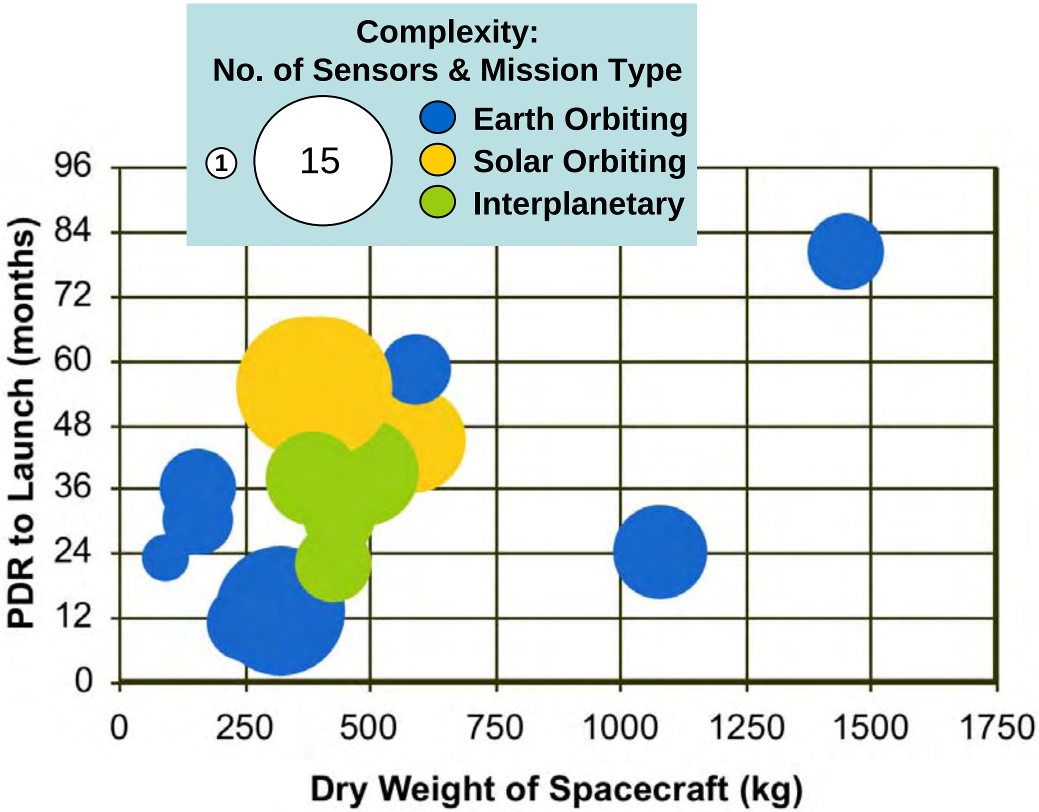
Uranus
Voyager

Neptune
Voyager

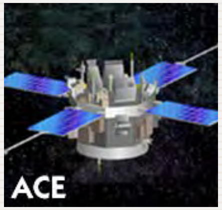
Pluto
New
Horizons

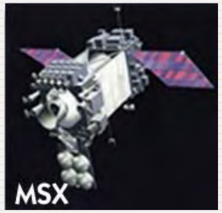
APL Track Record in Space

Innovative, Cost-Effective, End-to-End Space Missions



Recent Examples:





- **60+ Spacecraft**
- **150+ Sensors & Payloads**
- **Short time to space**
  - **Modest-sized missions**
  - **Tight requirements process**
  - **Disciplined development**

AS 9100 Registration

- **JHU/APL is AS 9100 certified as of February 18, 2009.**
- **Scope of certification includes: Space and Earth science, analysis, research, technology development, program management, mission systems engineering, engineering, design, development, production, integration and test, and operation of spacecraft and instruments for both Civilian and National Security purposes.**
- **Continual monitoring of our Quality Management System will assure JHU/APL meets rigorous standards.**

Certificate of Registration

nqa. global assurance

This is to certify that the Quality Management System of:

The Johns Hopkins University - Applied Physics Laboratory
11100 Johns Hopkins Road
Laurel, MD 20723-6099

applicable to:

Space and Earth science, mission system engineering, analysis, research, and technology development, including program management, systems engineering, design, development, production, integration, test, and operation of spacecraft and instruments, to make critical contributions to our Nation's Civilian and National Security Space challenges.

has been assessed and approved by
National Quality Assurance, U.S.A., against the provisions of:

ISO 9001: 2000 and AS9100 Revision B
and in accordance with the requirements of AS9104A.

For and on behalf
of NQA, USA, Acton, MA 01720

Certificate Number:	12883
EAC Code:	34
First Issued:	February 18, 2009
Valid Until:	February 18, 2012

ANAB ACCREDITED

This approval is subject to the company maintaining its system to the required standard, which will be monitored by NQA, USA, an accredited organization under the Aerospace Registrar Management Program.

APL Space Mission Cost/Schedule History

Program	Sponsor	Launch Year	Bus Cost (FY05 $M)	Weight of Bus (kg) Dry Mass	Cost Growth* (%)	Start to PDR (months)	PDR to Launch (months)	Schedule Growth** (months)	Mission Success
MAGSAT	NASA/GSFC	1979	30	158	8	3	30		Fully Successful
AMPTE	NASA/GSFC	1984	31	156	0	36			Fully Successful
GEOSAT-A	Navy	1985	38	543	7	3	37		Fully Successful
POLAR BEAR	USAF	1986	21	94	-5	5	23		Fully Successful
Delta 180	SDIO	1986	24	323	-3	3	13		Fully Successful
Delta 181	SDIO	1988	133	1081	-1	24			Fully Successful
Delta 183	SDIO	1989	25	253	8	3	11		Fully Successful
NEAR	NASA	1996	83	429	-7	30	22	0	Fully Successful
MSX	BMDO	1996	130	1449	13	10	38/80	0/42	Fully Successful
ACE	NASA/GSFC	1997	57	590	-10	30	45	0	Fully Successful
FUSE	NASA/GSFC	1999	22	264	3	43		0	Fully Successful
TIMED	NASA/GSFC	2001	85	591	10	30	37 / 58	0 / 21	Fully Successful
CONTOUR	NASA	2002	50	443	1	11	30	0	S/C lost during SRM burn
MESSENGER	NASA	2004	138	494	15	18	39	2 / 3	Successful To Date
New Horizons	NASA	2006	147	385	22	13	38	0	Successful To Date
STEREO	NASA/GSFC	2006	173	558/591	16	29	58	0/11	Successful To Date

Last updated 4/3/09

*** Growth from cost estimate as of PDR**

**** # / #: First number shows slip attributable to APL; second number shows slip attributable to external factors (LV, scope change, etc.)**

JOHNS HOPKINS
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