Evolvable Hardware for Space Exploration

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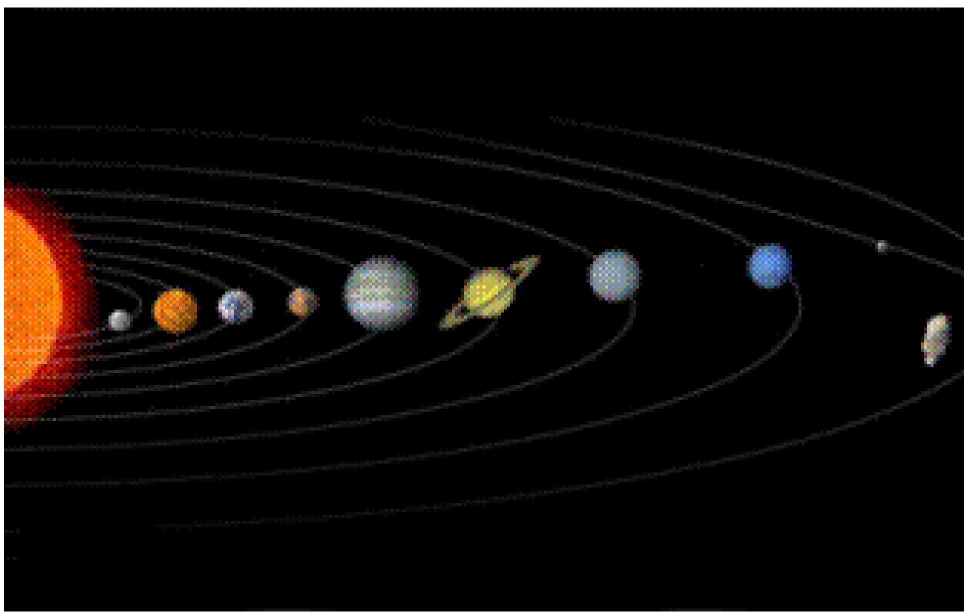
NASA Enterprises

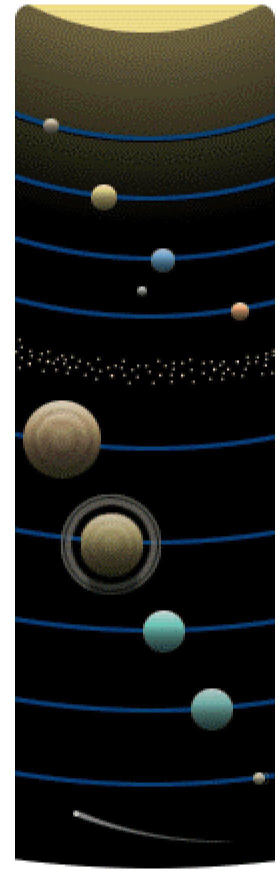
- Aerospace Technology
- Biological and Physical Research
- Earth Science
- Human Exploration and Development of Space
- Space Science
  - Search for Origins
  - Structure & Evolution of the Universe
  - Exploration of the Solar System
  - The Sun-Earth Connection

Solar System Exploration

Solar System Exploration Questions:

- Evolution and Destiny of our Solar System
- Evidence of life ?
- Evidence of pre-biotic chemistry ?
- Is life abundant in the Solar System ?
- Are there other habitable places in our Solar System ?





The Solar System Exploration Program Conducts Three Quests for Knowledge:

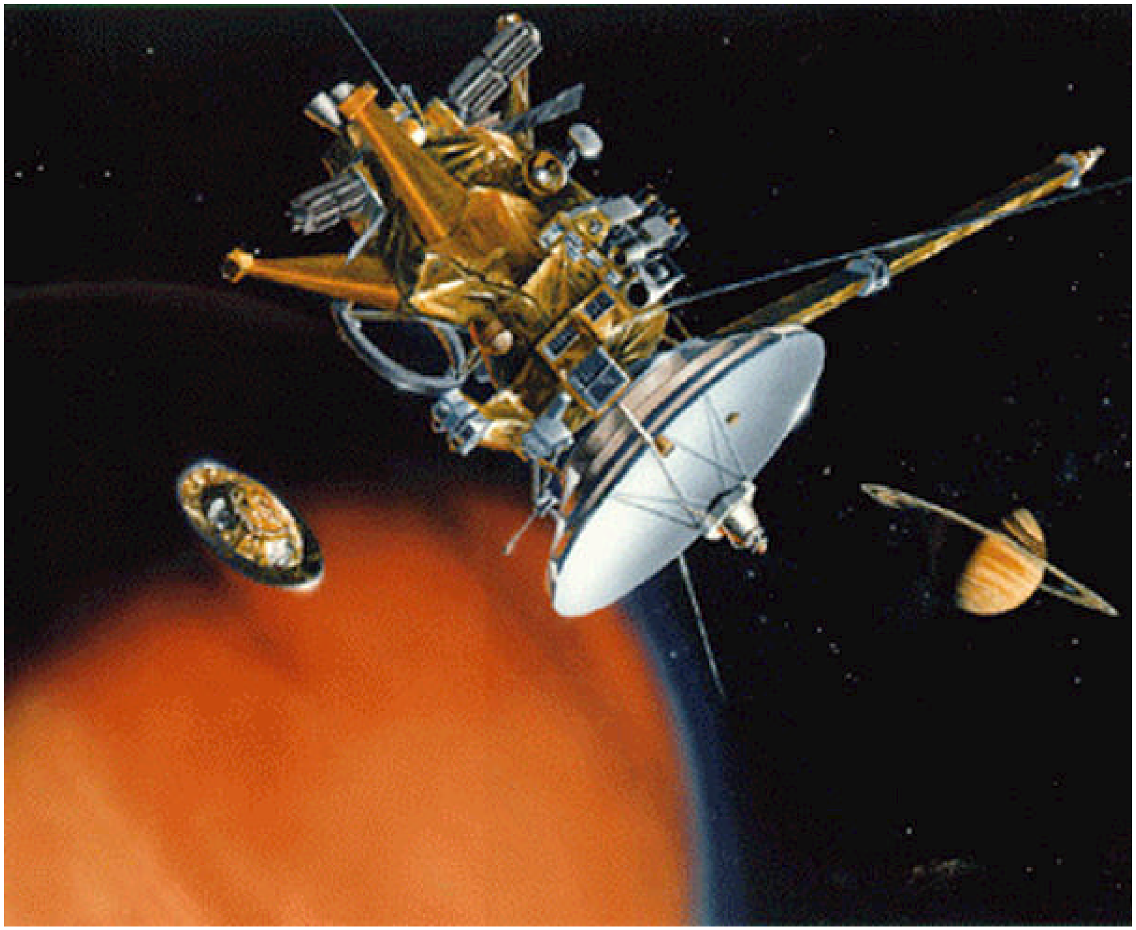
Quest 1:
To Explain the Formation and Evolution of the Solar system and the Earth Within It

Quest 2:
To Seek the Origin of Life and Its Existence Beyond Earth

Quest 3:
To Chart Our Destiny in the Solar System

Cassini S/C & Huygens Probe

Mission to Saturn and Titan



Objectives:
Detailed study of Saturn, its Rings, its Magnetosphere, its Icy Satellites, and Titan.

Cassini:

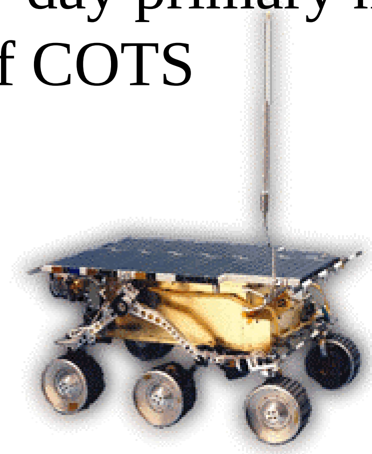
- Last of the Grand Spacecraft
- Launch: 1997
- Technology: early 80s
- Complex S/C
- Complex Operations

Mars Pathfinder Mission

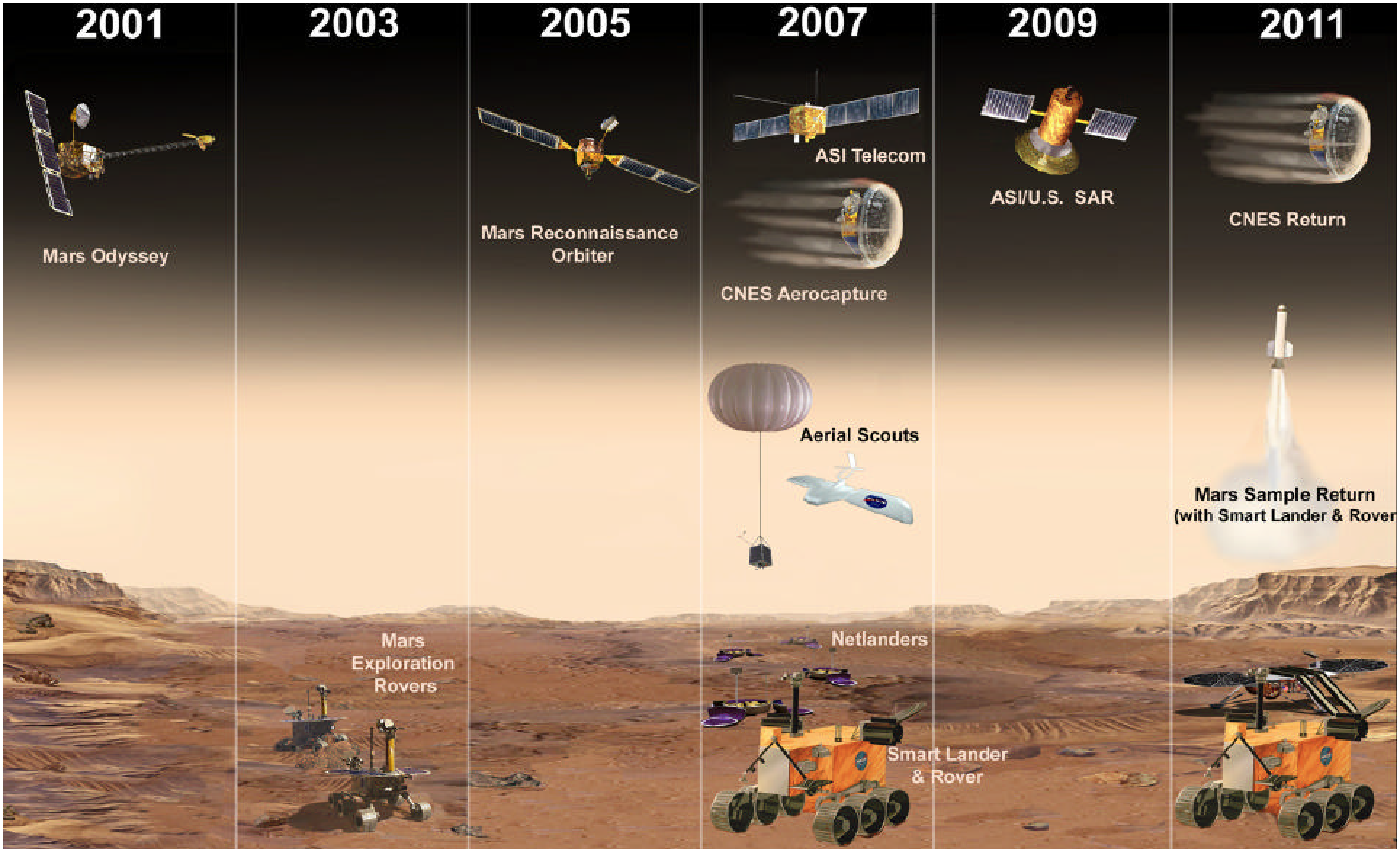
- Mission Launch: 1996
- Landing: July 4th 1997
- Tech. Freeze: 1992
- Total mission cost: 175 M$

Lander and Sojourner Rover

- Low cost Entry/Descent/Landing
- New ‘micro-rover’ technology
- Designed for 30-day primary mission
- Extensive use of COTS



The Mars Exploration Plan



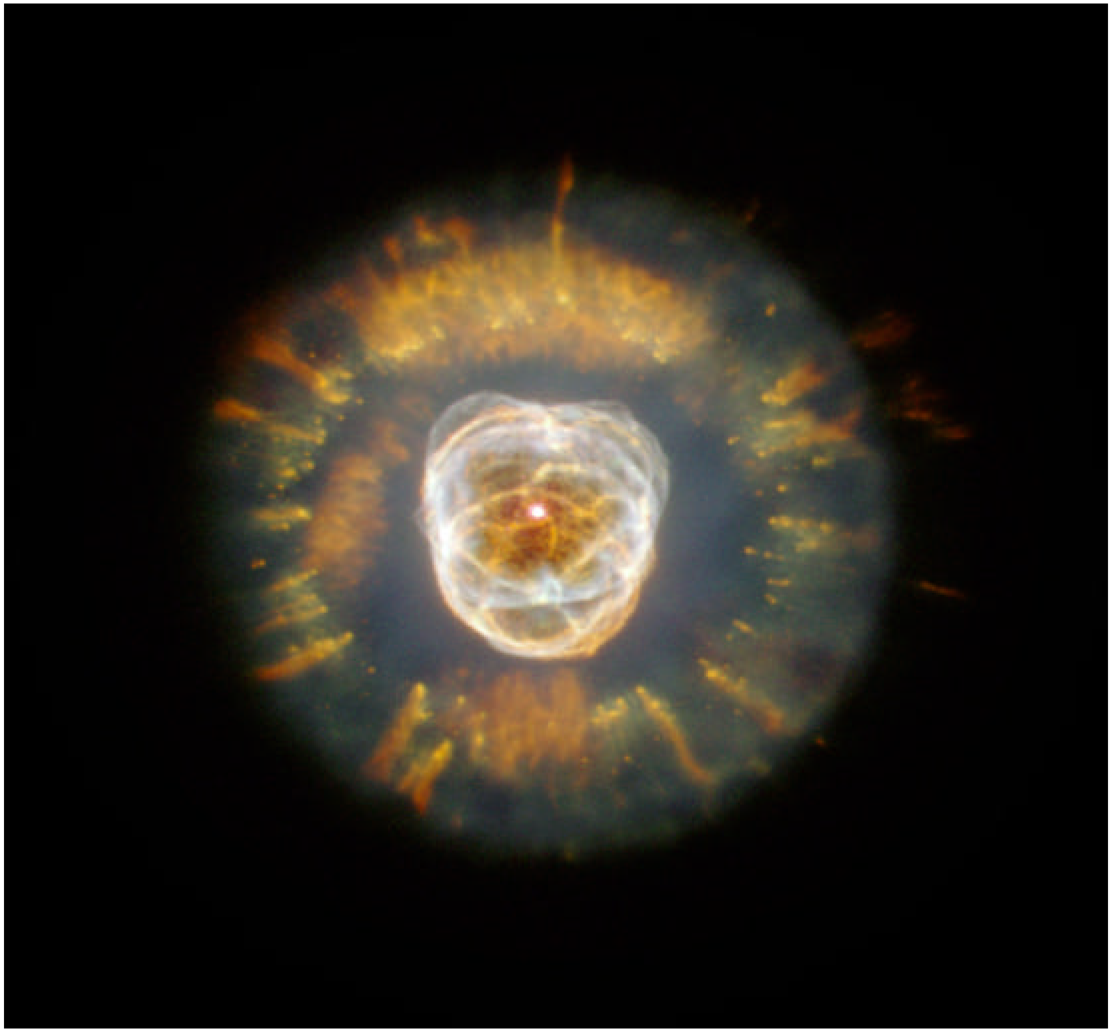
Europa Orbiter Mission

- Tremendous scientific opportunity
  - radar sounder, mapping
- Extreme Radiation Environment
- Extensive Shielding of electronics
- Extreme mass constraints
- Technology Freeze: 00-02
- Launch 08 time frame
- Technology Program:
  - X2000/CISM
- Follow-on missions:
  - Europa Lander
  - Europa penetrator/submarine
- Flight Time(Yrs), ~3

Europa Orbiter Mission Objectives

- Determine the presence or absence of a subsurface ocean;
- Characterize the three-dimensional distribution of any subsurface liquid water and its overlying ice layers;
- Understand the formation of surface features, including sites of recent or current activity, and identify candidate landing sites for future lander missions.

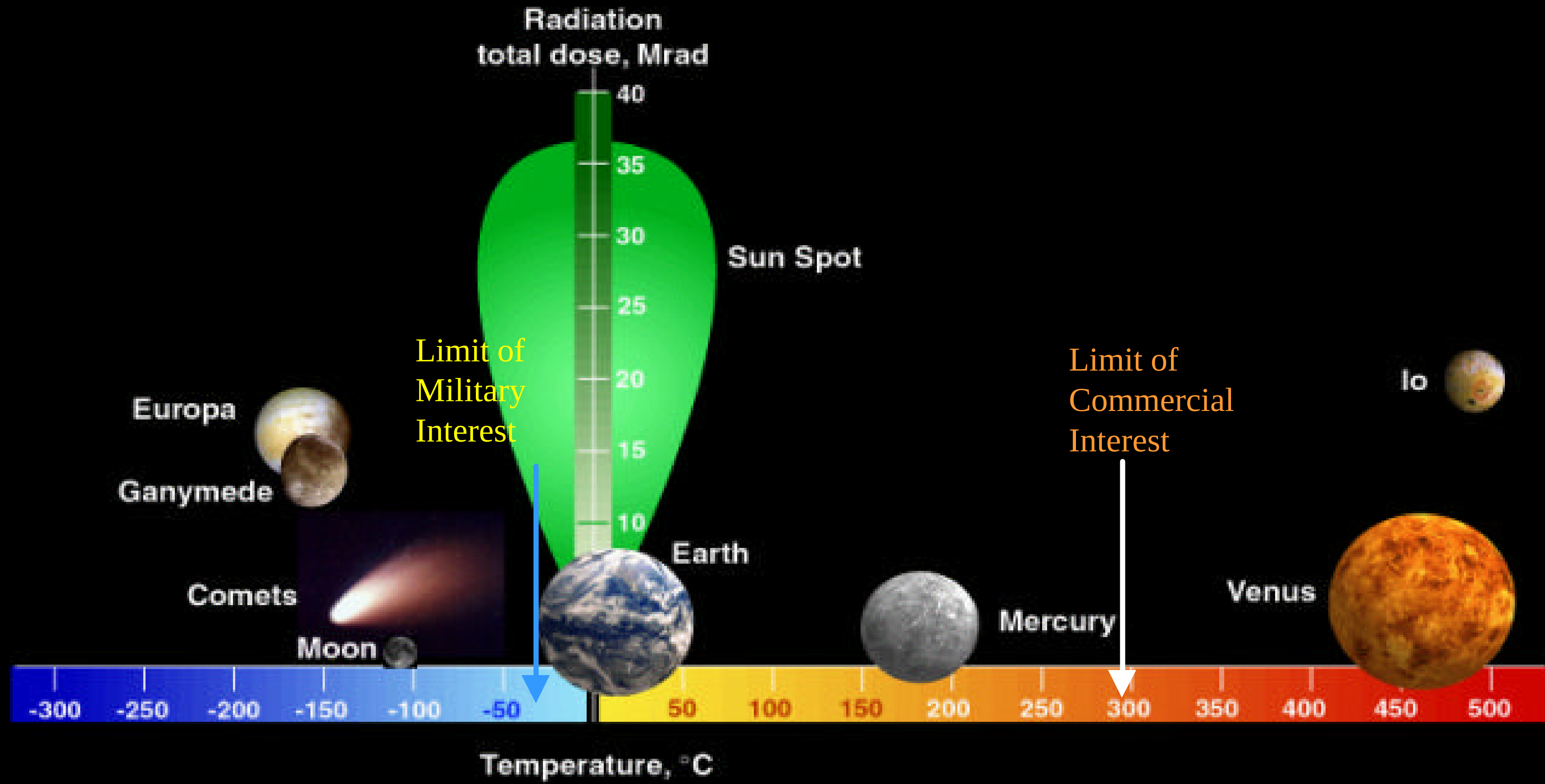
Inter-Stellar Explorations



Technology needs:

- Long Term Evolvable and Survivable Spacecraft
- Ultra Low Power Technology
- Autonomous Systems
- New Propulsion Techniques
- Solar Sail Technology
- Optical Communications
- On-Board Intelligence
- Harness the environment for energy

Planetary Extreme Environments



Revolutionary Computing for Deep Space Exploration

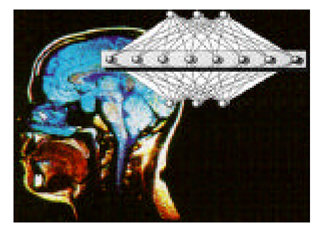
Goal:

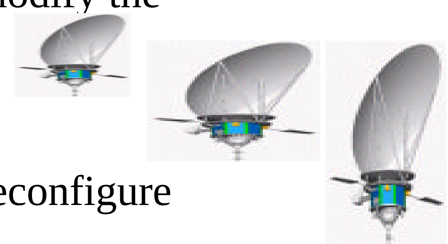
- Conduct basic research into ***Revolutionary Computing*** models and paradigms that will enable long-term, reliable, low-power, autonomous and intelligent deep-space exploration.

Survivable Autonomous Space Systems

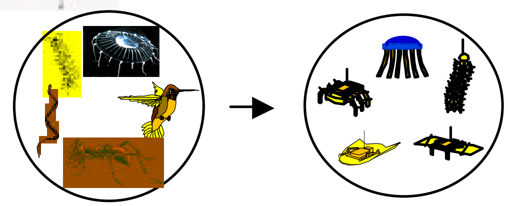
- Survivability today's exists only as physical redundancy, safeing, and limited software fault tolerance, which has been adequate for Voyager-class functionally limited spacecraft exposed to mostly predictable conditions (~20 yrs).
- In-situ space exploration will be characterized by sustained presence (50-100 yrs), harsher and uncertain conditions, and the need to respond usefully to unanticipated opportunities.

- Survivable autonomous space systems
  - Sense, respond and adapt to hazards and opportunities
  - Perform self-diagnosis and self-repair
  - Recover lost functions and develop new functions
  - Utilize revolutionary long-life materials and structures
- Onboard Awareness
  - Reasoning ability to perform, direct and modify the mission from a top-down viewpoint.





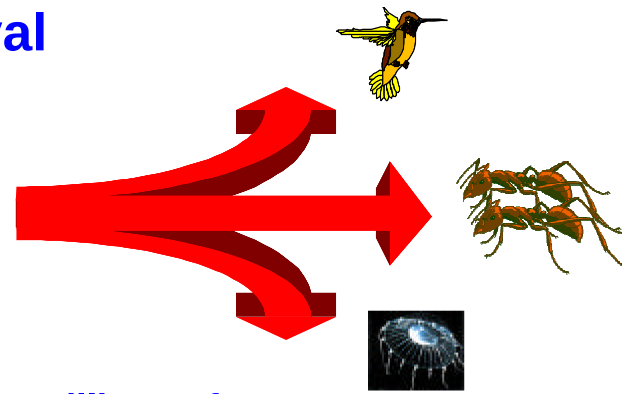
- Evolvable Hardware
  - Utilize principles of natural evolution to reconfigure the platform from a bottom-up viewpoint.
- Biomimetic Systems
  - Recreate unique functionalities of biological systems such as sensor fusion, emotion and immunity.



Smart Engineering System Design
Nature's way

"Design" goal: survival

Evolution in nature has lead to species highly adapted to their environment: ***adaptation ensured survival*.**

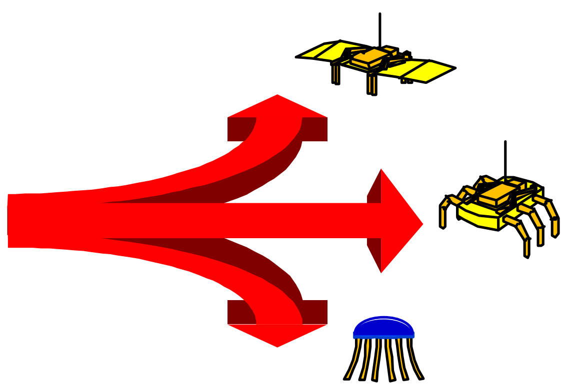


Millions of years

The most fit individuals survive becoming parents; children inherit parents characteristics, with some variations, and may perform better, increasing the level of adaptation.

Design goal: meet system specifications

Same evolutionary principles can be applied to machines.



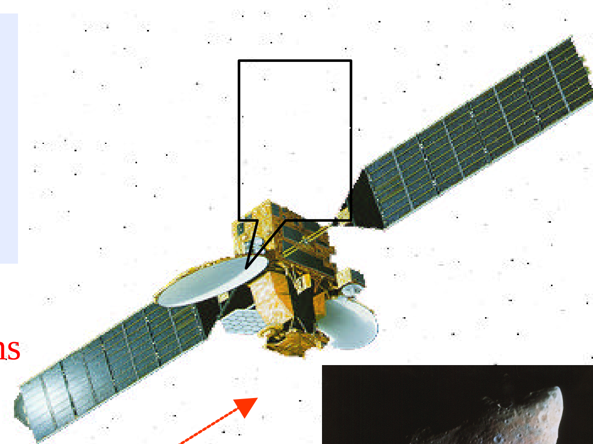
Potential designs compete; the best ones are slightly modified to search for even more suitable solutions.

Accelerated evolution, ~ seconds for electronics

EHW in Space:
Enable long-life (100+ years) survivable spacecraft

Dramatic changes in hardware/environment, e.g. in case of faults or need for new functions, may require in-situ synthesis of a totally new hardware configuration.

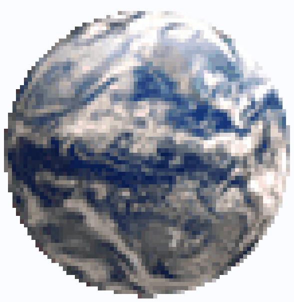
Survivability:
Maintain functionality coping with changes in HW characteristics



Versatility: Create new functionality required by changes in requirements or environment

- Radiation impacts
- Temperature variations
- Aging
- Malfunctions, etc.

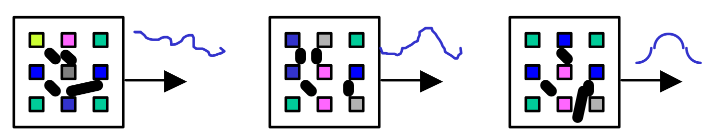
New functions required for new mission phase or opportunity



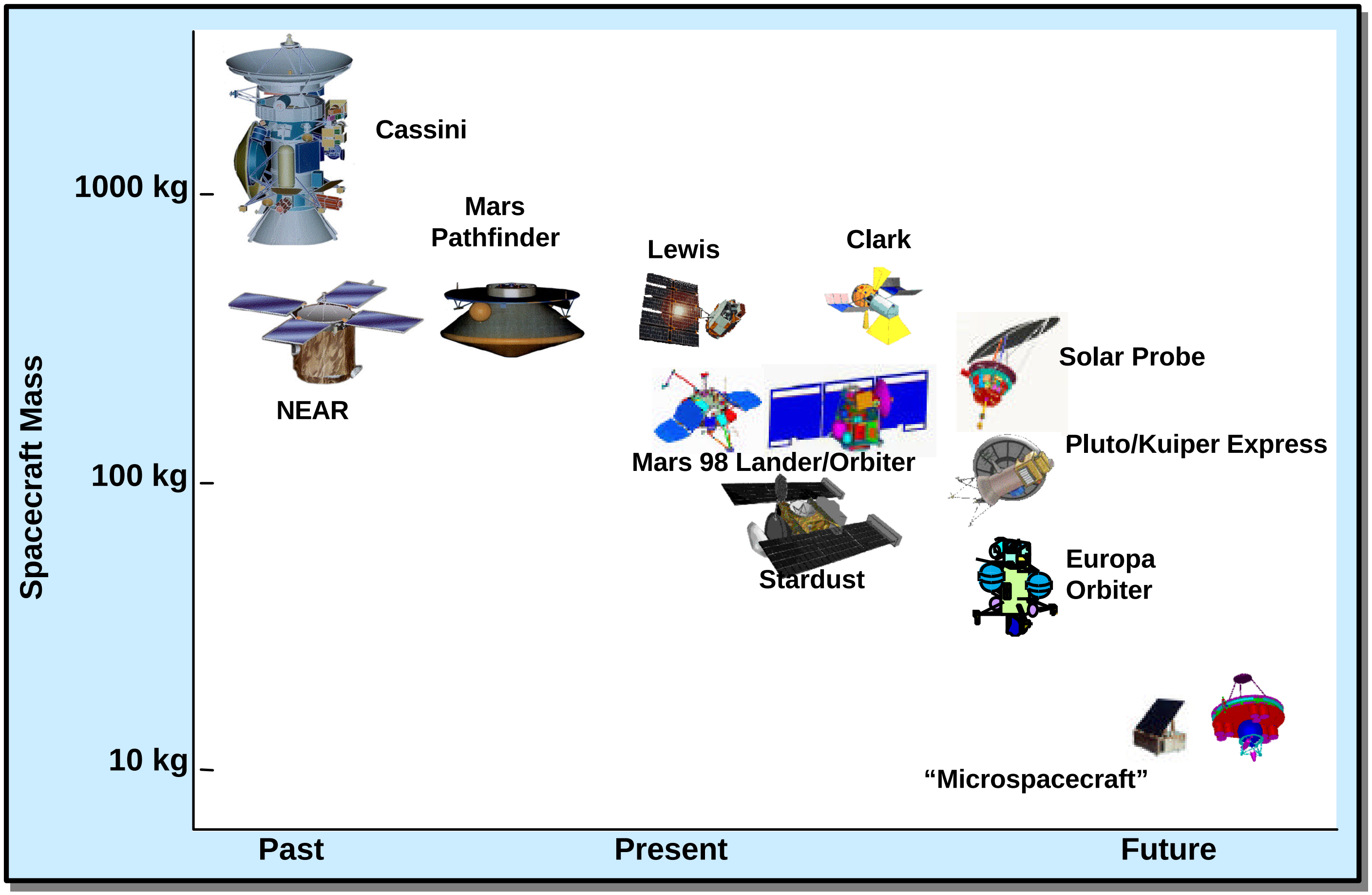
Up-link new functions for re-planned mission

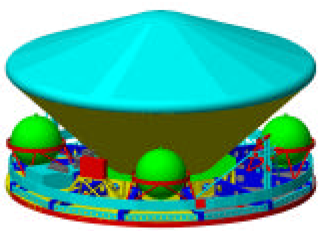
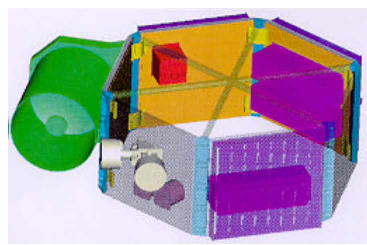
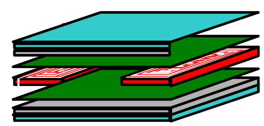
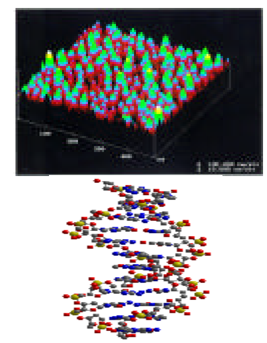
Accurate model of hardware is not available after launch

Develop space HW that can evolve



Progressive spacecraft miniaturization



Vol..: 50,000cc Mass: 80kg (ss) Power: 300 watts	Vol.: 10,000cc Mass: 40kg (ss) Power: 150 watts	Vol.: 1,000cc Mass: 1 kg (ss) Power: 30 watts	Vol.: 10cc Mass: 10gr Power: 5 watts
			
Mars Pathfinder	Europa Mission	System on a chip	Future RC
State of the Art	**2003**	**2010**	**2020**

Nano-Bio-Technology and Space Exploration

- ***Nanotube-based sensors and systems*** **enable** **miniaturization**, **survivability**, **and** **new capabilities**

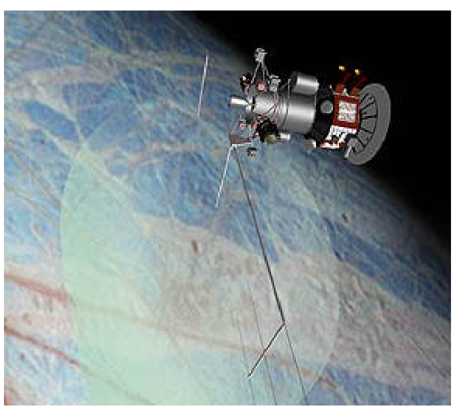
Miniaturization:
- Nanoscale mechanical systems offer dramatic reductions in size, power, and mass
- Long term: in situ nanoscale manufacturing

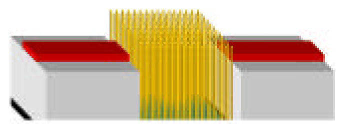
Survivability:
- Exceptional radiation tolerance due to strong C-C bonds and insensitivity of mechanical systems to radiation damage

New Capabilities:
- High-Q RF signal processing
- Single molecule sensing and manipulation
- Acoustic life detection
- On-chip biomolecular analysis

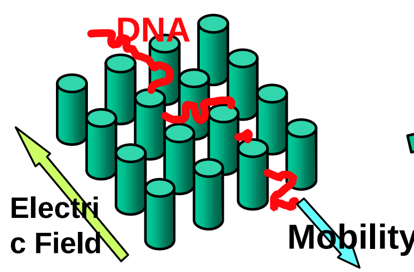
For example:

Europa & other Orbiters



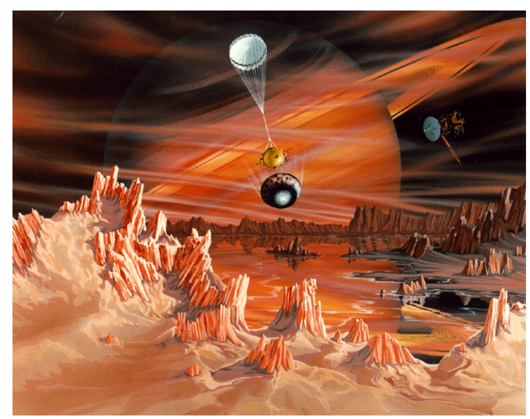


RF signal processing



Biomolecular analysis

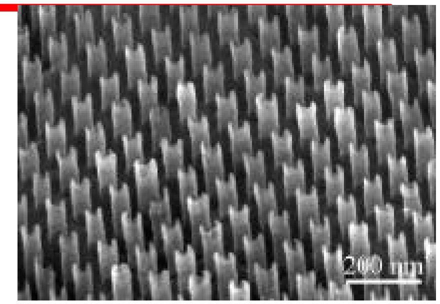
Europa, Titan Landers



and other in situ missions

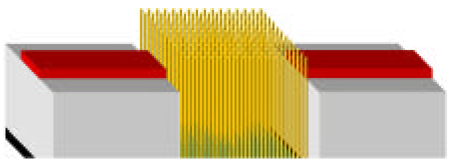
Nanomechanical Systems for Signal Processing, Sensing, and Biomolecular Analysis

- *Nanoscale mechanical structures provide basis for ultra-low power mechanical signal processing and single molecule sensing and manipulation*
- **Carbon nanotubes combine nanoscale dimensions with unique properties: e.g. direct electro-mechanical conversion to enable nanoscale force sensors and actuators**



Carbon nanotube array, J.Xu

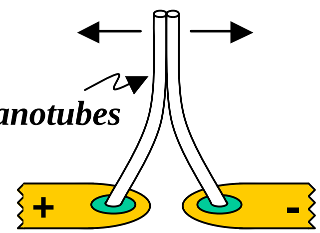
Nanotube Array RF Filter



Mechanical signal processing at MHz to GHz frequencies

- Individual and arrayed nanotubes provide very high Q mechanical oscillators in the GHz range
- Rad-hard and ultra-low-power signal processing for radar, communications, and computation

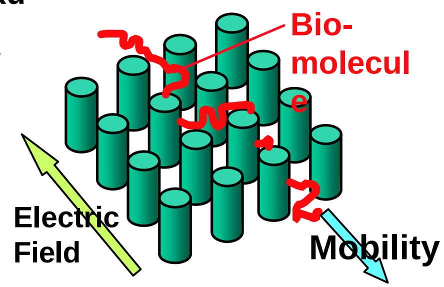
NT bimorph sensor & actuator



Single molecule sensing and manipulation

- Nanotube bimorph device functions as:
  - Nanoscale force sensor
  - Actuator and molecular manipulator
  - Single molecule chemical sensor

NT array electro-phoresis system



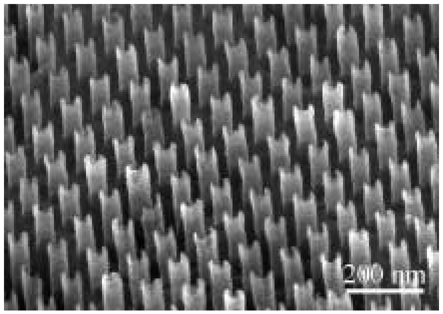
Biomolecular analysis

- Electrophoresis is essential biomolecular analysis tool
- Rad-hard NT-array molecular sieve offers small size, high speed electrophoresis
- Wrist-watch size instrument for rapid DNA, protein, and chiral analysis

N.B. Toomarian, 7/12/2001

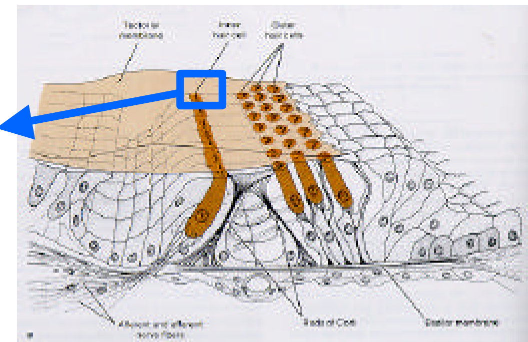
Nanoscale Bio-Inspired Acoustic Sensors: Artificial Stereocilia

Combining biology and nanotechnology to achieve breakthroughs in sensitivity and miniaturization:



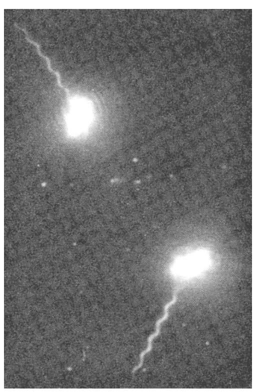
Carbon nanotube arrays (Xu et al.)

Stereocilia bundle in the cochlea

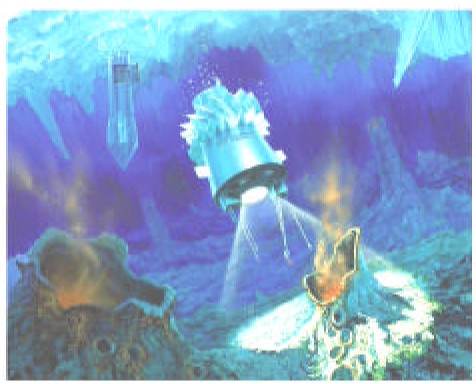


Cross-section of human cochlea

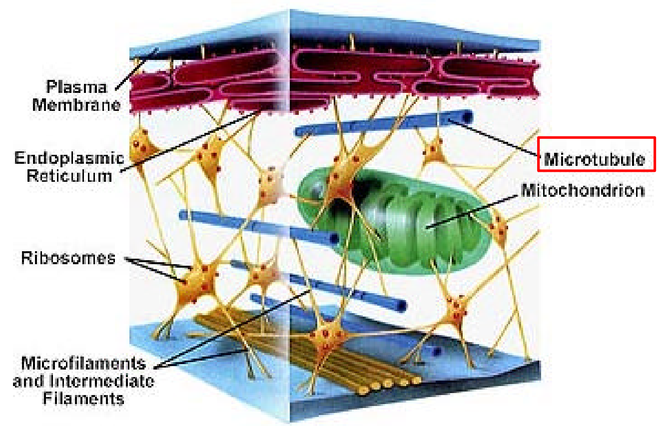
- **Applications**



Listening to the Sounds of Life



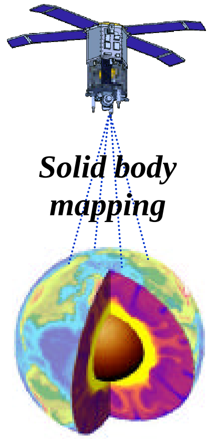
Acoustic sounding in planetary atmospheres and oceans



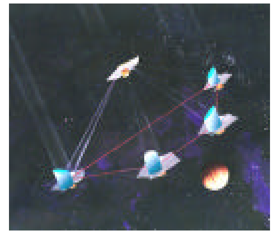
Active or passive monitoring of cellular processes

Roadmap: Sensors and Spacecraft Components

In space nanoprobes



Solid body mapping



Ultrasensitive detection & precision metrology

Nanosensor based bio explorer

NEMS flight system @ 1 uW

High-temp, radiation tolerant nano components

Quantum navigation sensors: 1E3 improvement in gyros, accelerometers & timing

High performance Nano Sensors

Nano flight system components
- **Precision actuators: sub Å**
- **Propulsion: nano emitters**
- **Power: 40% efficiency**

Integrated smart nano sensor systems

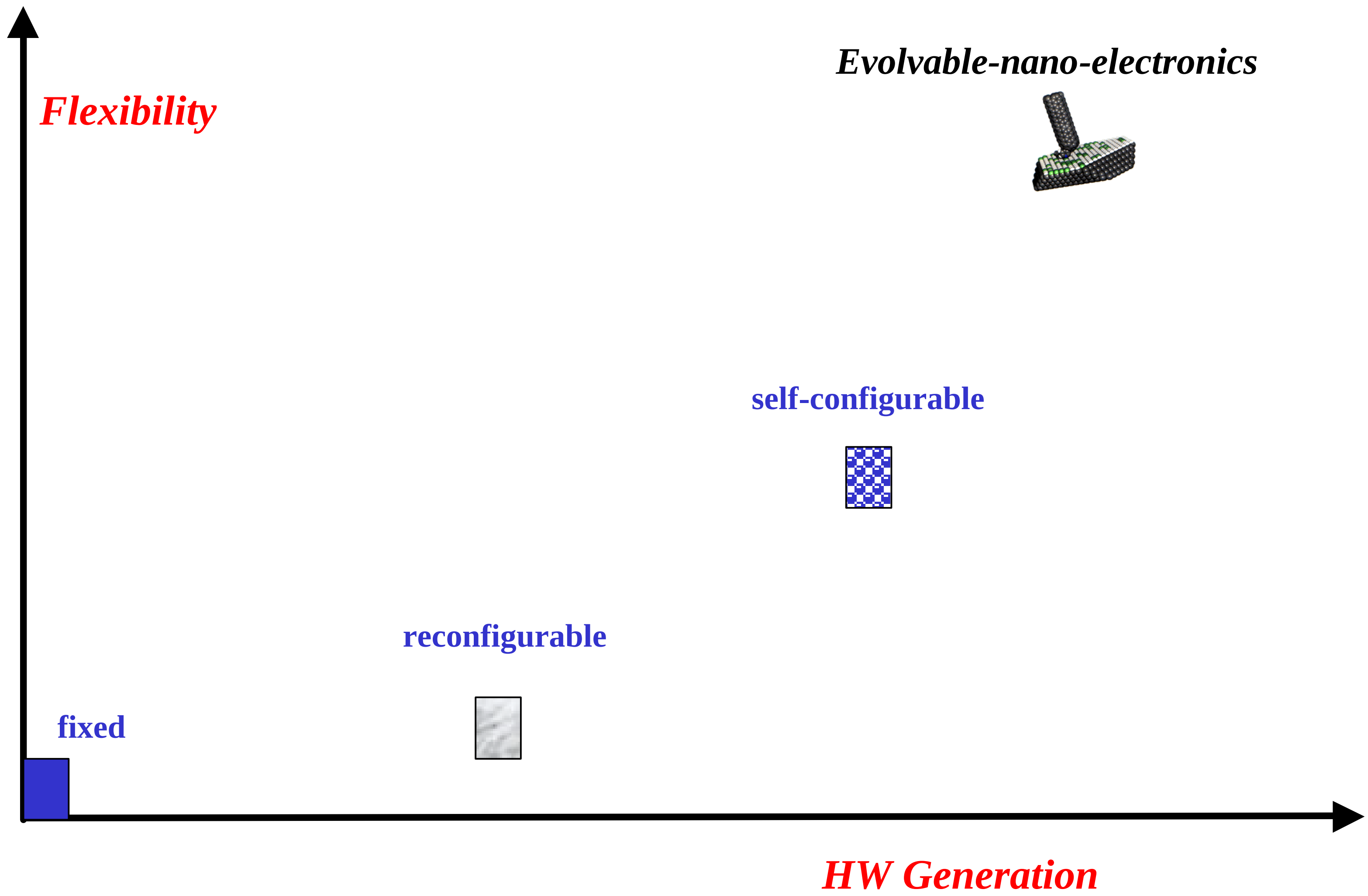
Microspacecraft for Harsh Environments

Quantum limited EM detector: microwave to Gamma Ray

Quantum-atomic gravity gradiometer: 1E3 higher sensitivity

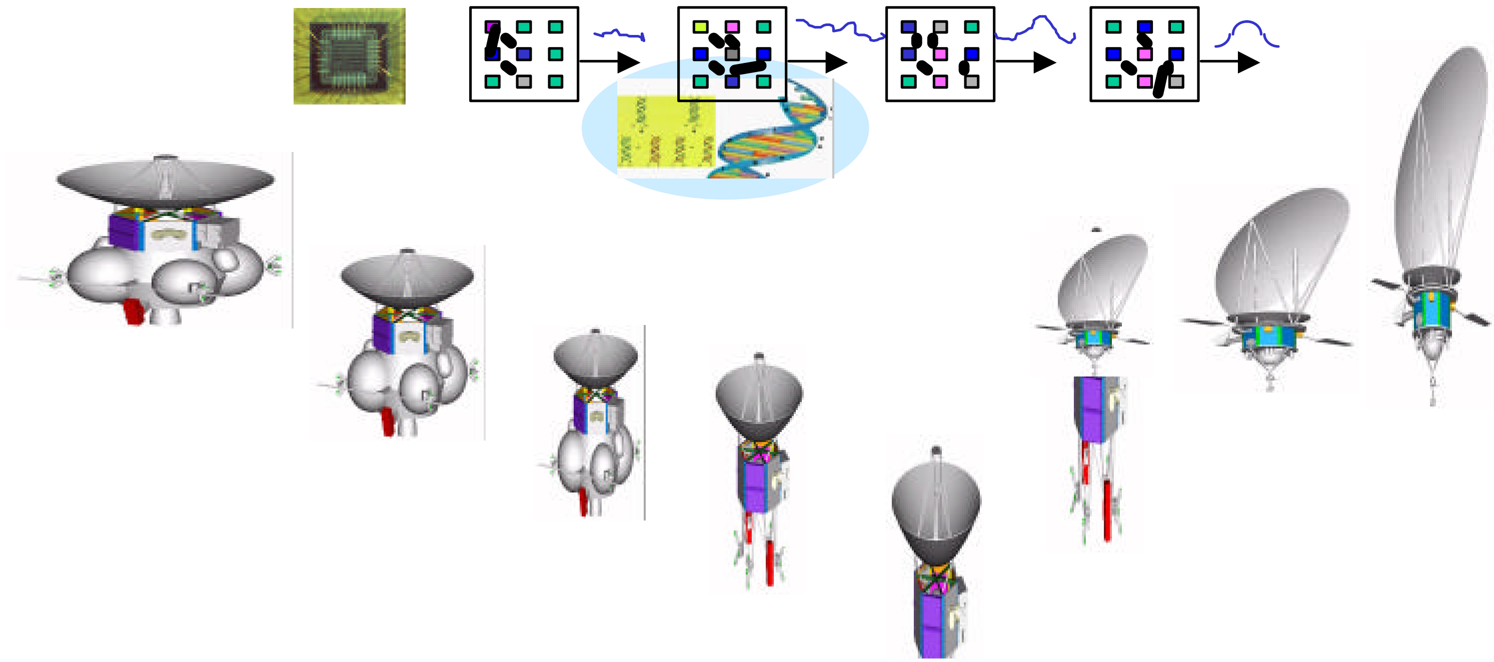
Carbon nanotube based chemical probes

HW Flexibility



Toward fully evolvable space systems

- Morphing/plasticity can expand gradually from electronic subsystems to entire space systems.



EHW has the potential to be the underlying technology behind the avionics infrastructure (not only the electronics but also smart optical/structural/ thermal subsystems through reconfigurable/morphing/adaptive MEMS/ materials) of the space systems for 2020 and beyond.

Evolvable hardware for long duration missions in harsh environments

Develop evolvable nano-systems that autonomously adapt to environments, self-heal and self -repair