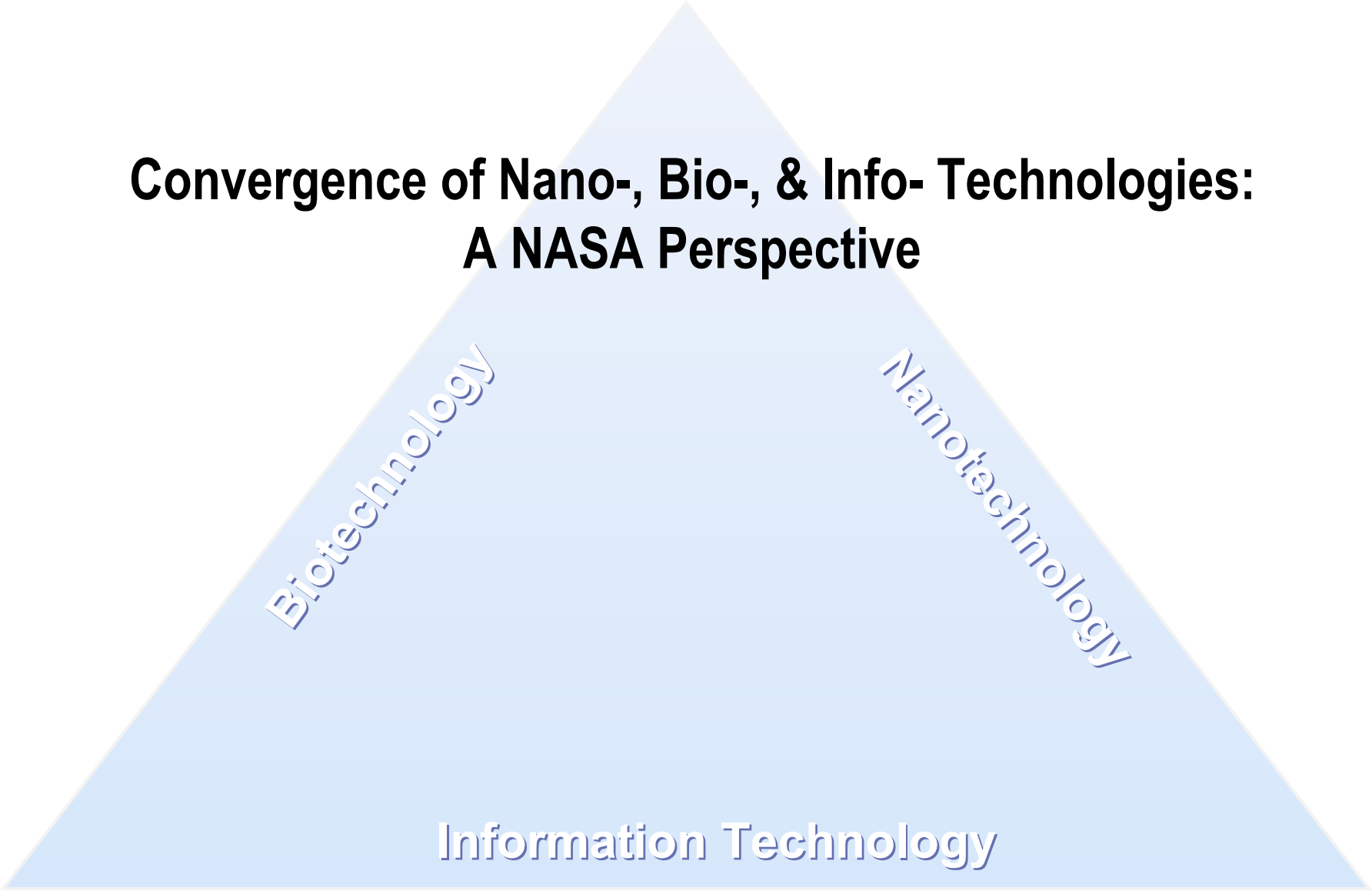
Convergence of Nano-, Bio-, & Info- Technologies: A NASA Perspective



Minoo N. Dastoor
Office of Aerospace Technology
NASA

NASA's Technology Landscape

Goals for Future NASA Space Systems

Autonomous

- Systems that think for themselves and understand uncertainty
- Create information and knowledge from data
- Greater productivity with less people

Resilient

- Highly durable and damage tolerant: ability to perform self-diagnosis and repair
- Long life in the harshest conditions

Ultra-Efficient

- Optimal use of mass, power and volume
- Travel about the Earth and the universe rapidly, safely and at low cost

Evolvable

- Adapt form and function to meet changing demands and overcome unanticipated problems
- Grow and expand capability to exploit new opportunities

Highly Distributed

- Broad, continuous presence and coverage
- Interactive networks to achieve maximum capability and economy

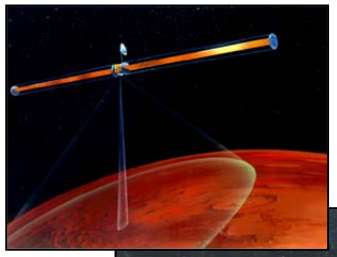
Self-Sufficient

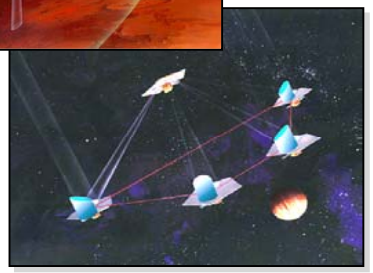
- Minimal on-board resources
- No lifeline to Earth "Live off the land"

NASA Challenges

Many of NASA's challenges are not achievable by extensions of current technology

◆ Size per Mass

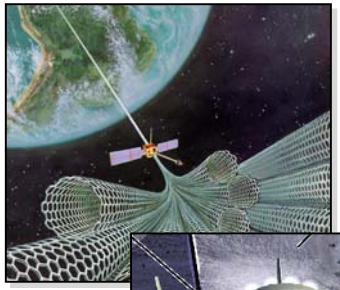


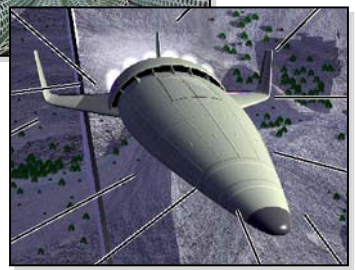


- Ultra-large apertures
- Solar sails
- Gossamer spacecraft

Diameters > 25-50 m are not achievable by extension of current materials technologies

◆ Strength per Mass

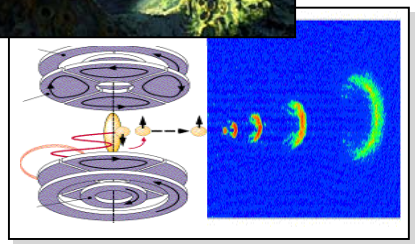




- Air/launch/space vehicles
- Human habitats in space
- Self-sensing systems

Factors of 10 - 100 are not achievable by current materials options

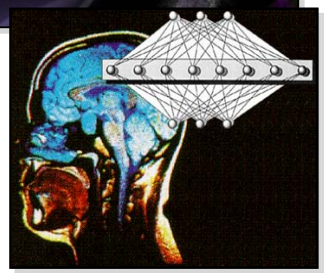
◆ Capability per Mass & Power



- Microspacecraft
- Quantum-limited sensors
- Biochem lab-on-a-chip

Conventional device technologies cannot be pushed much farther

◆ Intelligence per Mass & Power

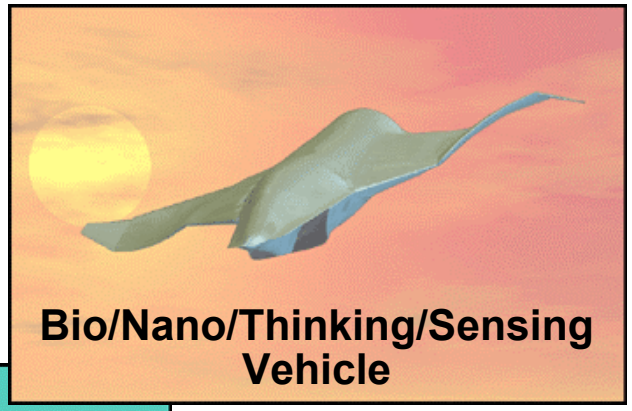


- Medical autonomy
- AI partners in space
- Evolvable space systems

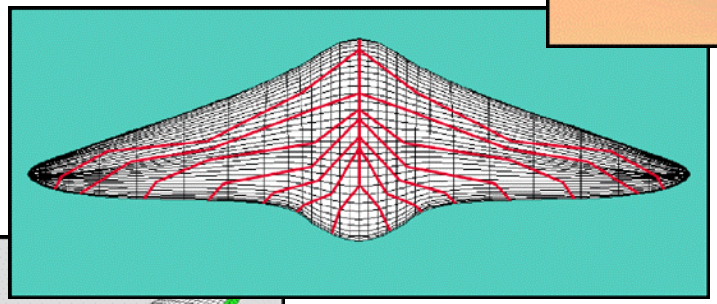
Current information processing technologies are approaching their limit, and cannot support truly autonomous space systems

Towards Advanced Aerospace Vehicles: "Nature's Way"

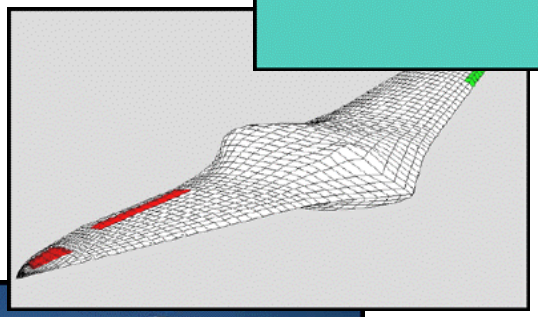
- Distributed self-assessment and repair
- Adaptive shape control
- Highly efficient propulsion
- Exploits Bio-Nano-Info technology revolution



Bio/Nano/Thinking/Sensing Vehicle



Self-Healing Structure with "Central Nervous System"



Smart Structure with Active Flow Control

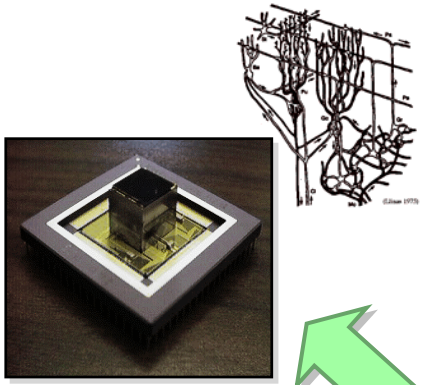
Modern Advanced Metal Aircraft

- Ultra Safe
- Whisper Quiet
- "Zero" Emissions
- Extreme Maneuverability
- High Survivability
- Ultra Low Fuel Burn

Advanced Technology Development

Time

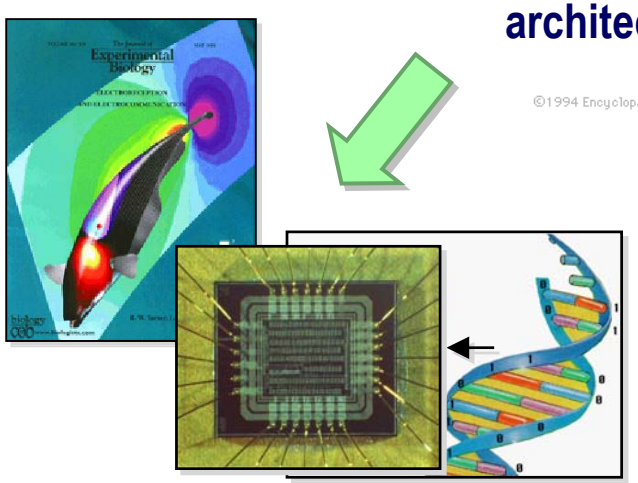
Features of Biology



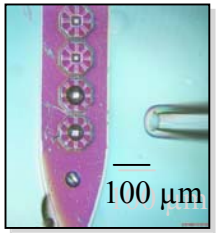
3-D neural net processor

- Distributed and networked sensing and decision making
- Homeostasis via feedback (forward) control
- Information processing: Massively parallel, analogue and extremely low power consumption
- Capacity to adapt and evolve
- Fault tolerance through redundancy and architecture

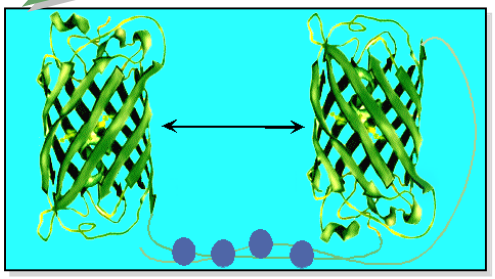
Electronic Nose



Revolutionary & Evolvable computing



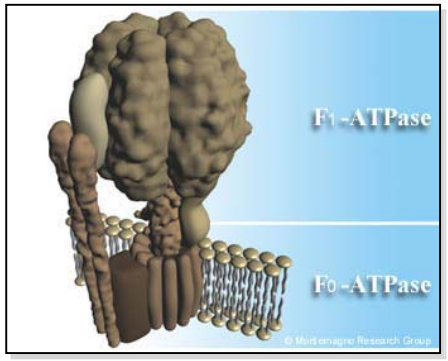
Neuron-silicon interfacing



Biomolecular sensors

NanoBioTechnology

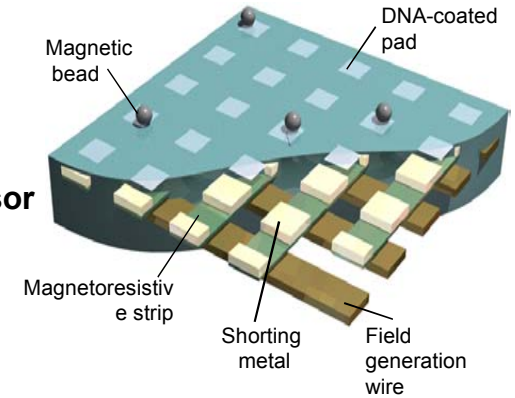
Chemistry/Physics of Biological Nanostructure



Molecular Motor (Montemagno, Cornell)

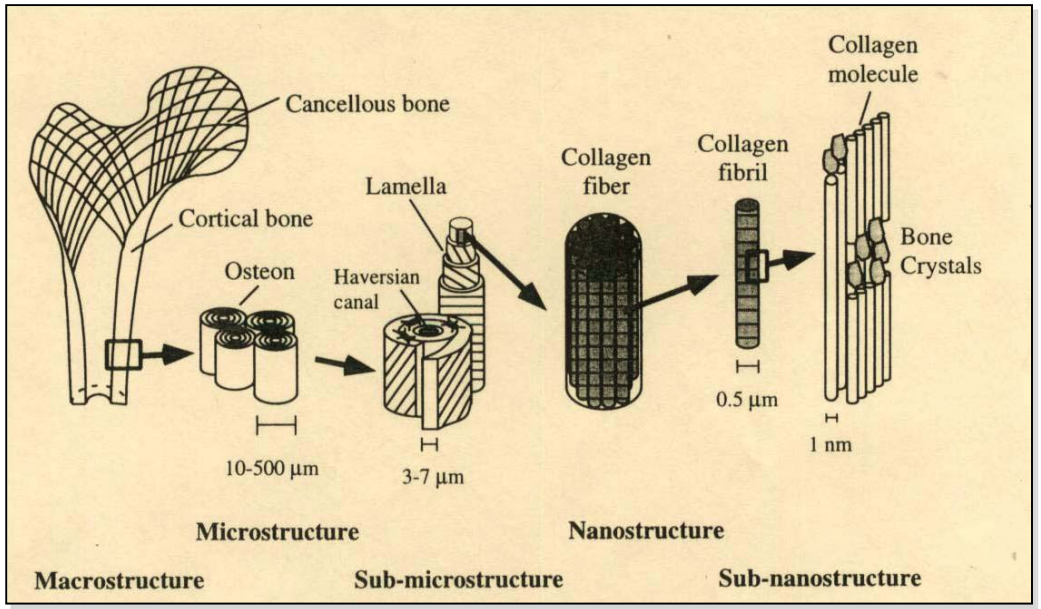
Earlier Detection and Treatment of Disease

Contrast Agents for Imaging
Sensors
Susceptibility Testing (DNA/RNA)



BARC Sensor
(Colton, NRL)

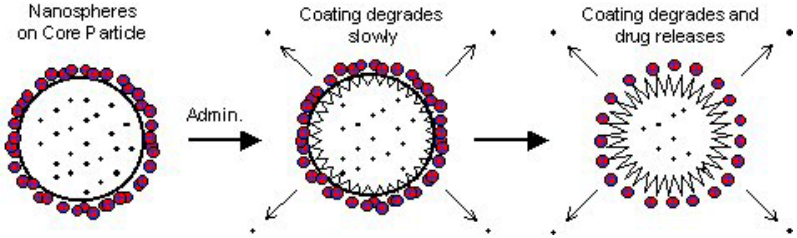
Improved Implants



Bone Structure (Siegel, RPI)

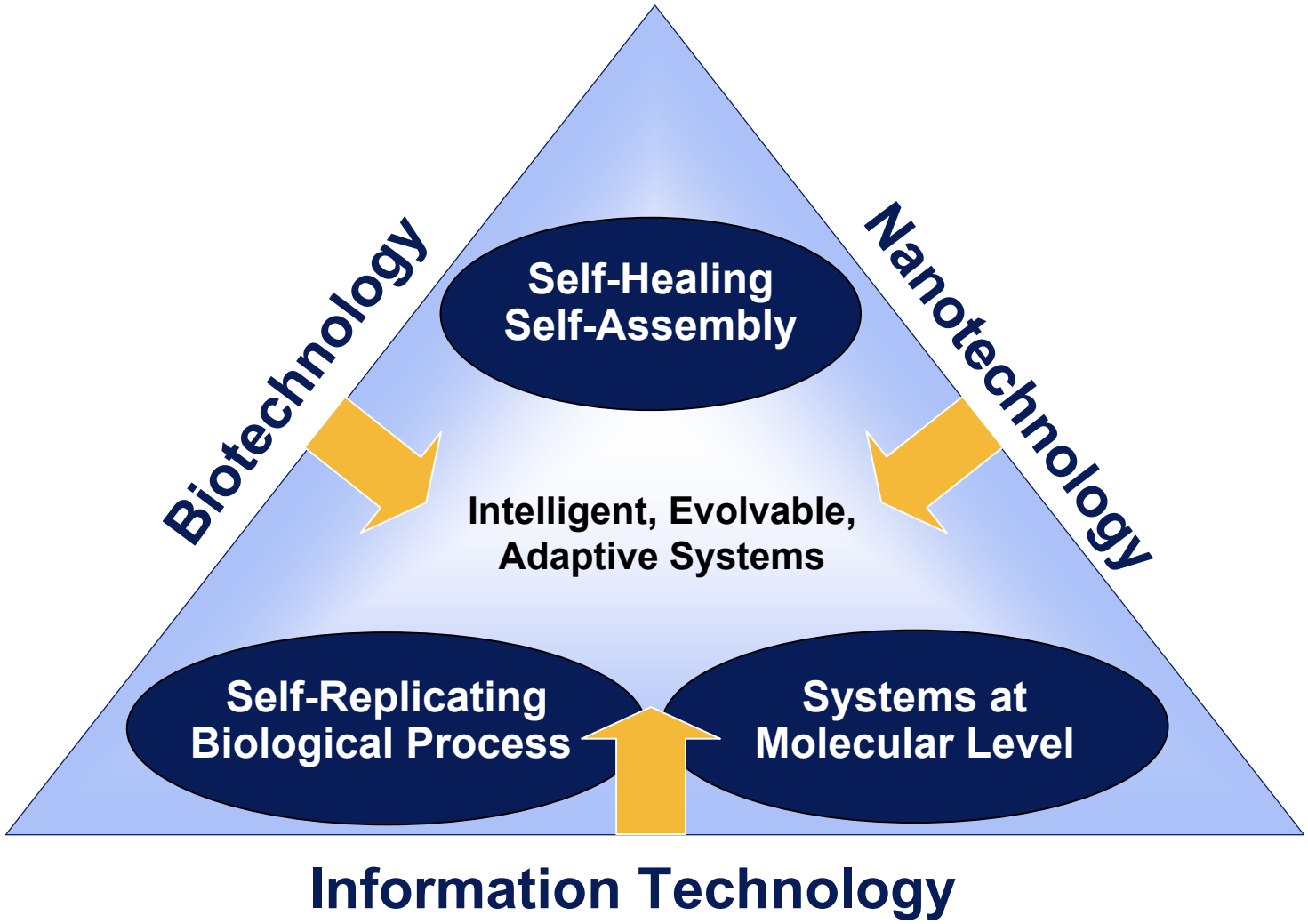
Therapeutic Delivery

Enhanced Solubility
Targeted, Local Delivery



Nanosphere enhanced drug solubility
(Nanosphere)

Revolutionary Technology Vision: The "Zone of Convergence"



Impact of Nanotechnology on NASA Missions

- **New and Powerful computing technologies**
  - Onboard computing systems for future autonomous intelligent vehicles; powerful, compact, low power consumption, radiation hard
  - High performance computing (Tera- and Peta-flops) processing satellite data
    - integrated space vehicle design tools
    - climate modeling

- **Smart, compact devices and sensors**
  - Ultimate sensitivity to analytes
  - Discrimination against varying and unknown backgrounds
  - Ultrasmall probes for harsh environments
  - Advanced miniaturization of all systems

- **Microspacecraft/Micro-Nanorovers**
  - “Thinking” Spacecraft with nanoelectronics/nanosensors
  - Size reduction through multifunctional, smart nanomaterials

Bio/Nanotechnology

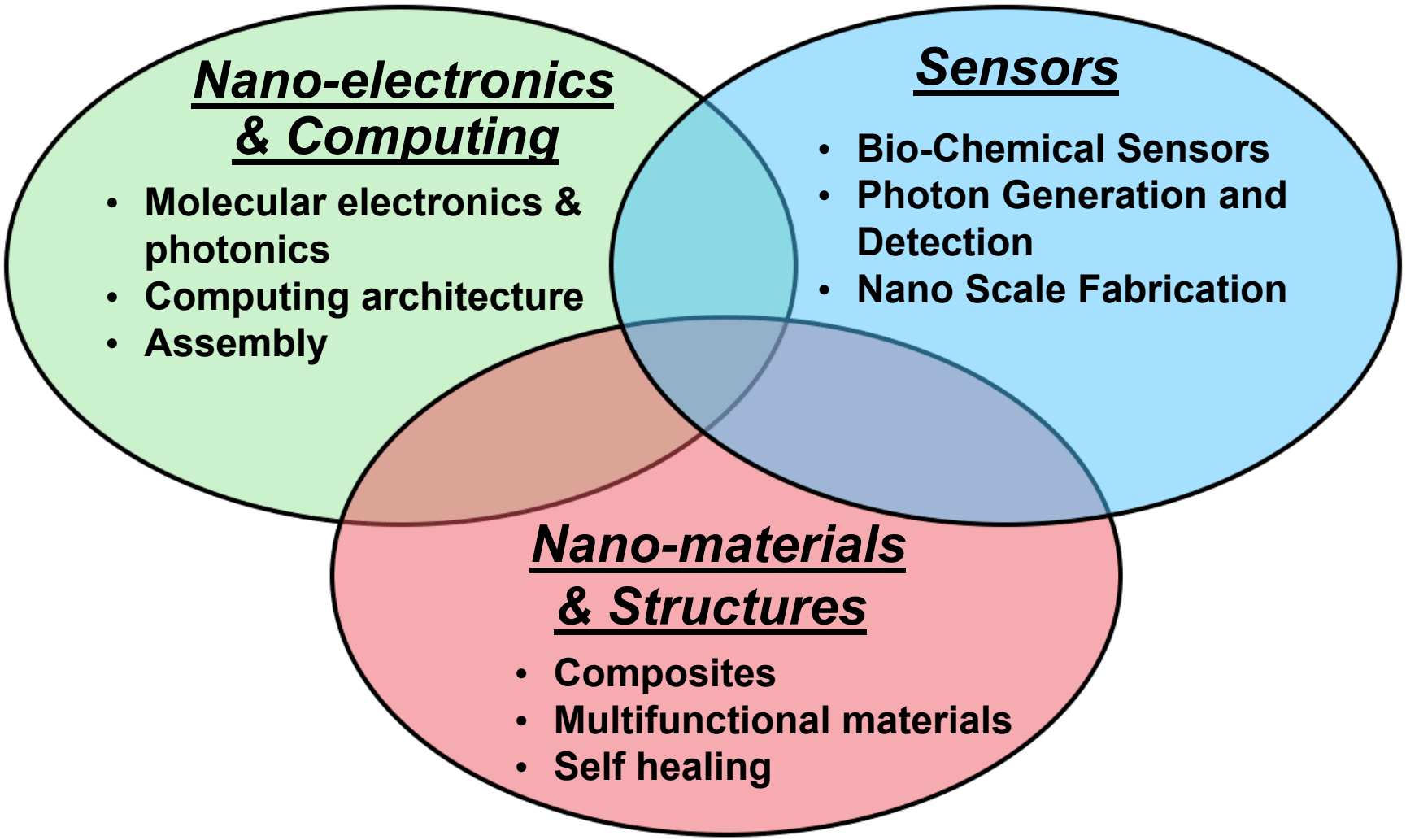
Goal:

Leverage emerging capabilities in the fields of nano-science, information science, and biology into a nanotechnology program focused on unique NASA needs that will revolutionize the way the agency conducts its aerospace missions within a decade.

Nanotechnology **is the science of creating functional materials, devices and systems through control of matter on the nanometer (atomic) scale and the exploitation of novel phenomena and properties at that length scale.**

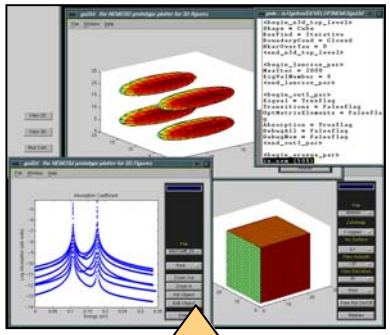
Technology Development	• Nanoscale, chemical, biological, and physical sensors • Nanopore for gene sequencing • Imaging • Self-assembly	• Nanoelectronics and Computing • Molecular electronics • Quantum and molecular computing • Artificial quantum structures	• Nanomaterials and structures • Multifunctional materials • Lightweight shielding materials • Carbon nanotube composites
Capabilities	Integrated Nanosensor Systems Sensor Arrays	Nanoelectronic brain for space exploration Autonomous spacecraft	Bio-inspired materials and processes Adaptive self-repairing space missions
Target Impact	• Orders of magnitude improvement in sensor sensitivity and coverage • In-situ life detection • Astronaut health monitoring	• Radical new approaches to size reduction and extraordinary speed • Fault tolerant, radiation tolerant electronic devices	• Ultra high strength composites • Smart skin materials • Integral thermal control

NASA's Nanotechnology Investments

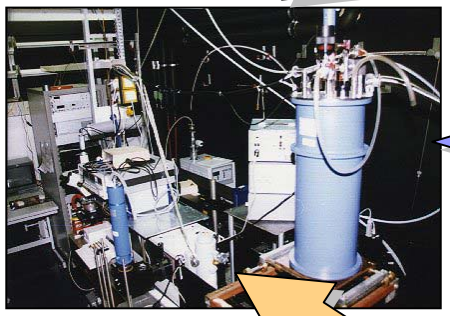


- *Emphasis on 'bio-inspired' approach*
- *Guidance from modeling and simulation*

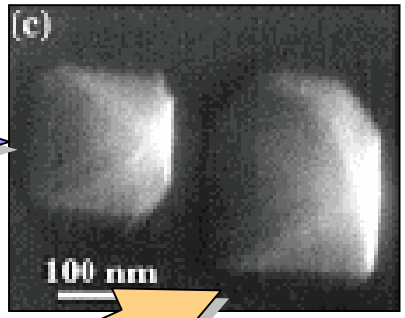
Modeling, Characterization and Fabrication are inseparable for nanoscale devices



Simulation



Characterization



Fabrication

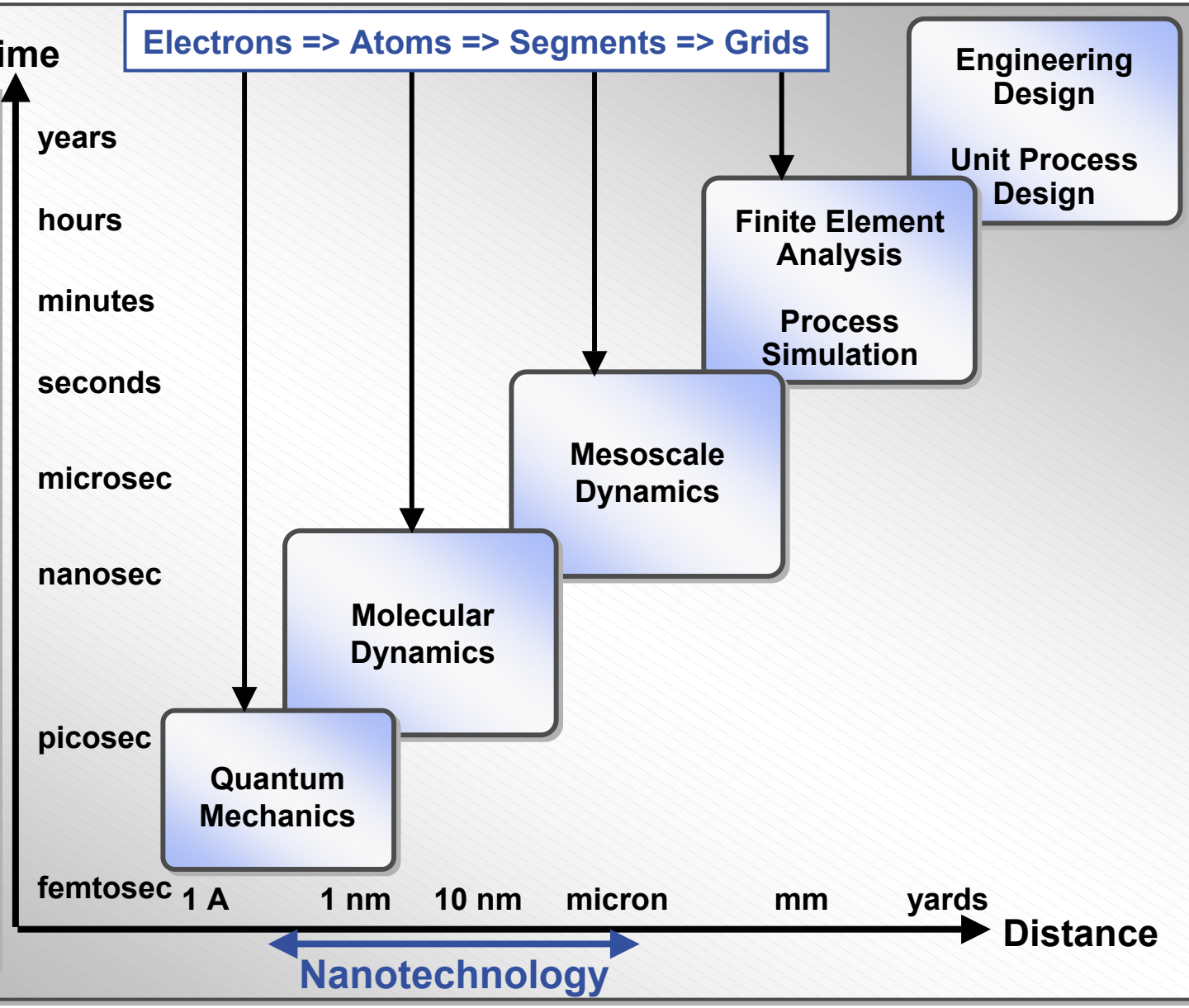
Applications

Critical Nanotechnology Investment Areas

- **Nanostructured Materials**
  - High strength/mass, smart materials for aerospace vehicles and large space structures
  - Materials with programmable optical/thermal/mechanical/other properties
  - Materials for high-efficiency energy conversion and for low temperature coolers
  - Materials with embedded sensing/compensating systems for reliability and safety
- **Nano Electronics and Computing**
  - Devices for ultra high-capability, low-power computing & communication systems
  - Space qualified data storage
  - Novel IT architecture for fault and radiation tolerance
  - Bio-inspired adaptable, self-healing systems for extended missions
- **Sensors and Microspacecraft Components**
  - Low-power, integrable nano devices for miniature space systems
  - Quantum devices and systems for ultrasensitive detection, analysis and communication
  - NEMS flight system @ 1μW
  - Bio-geo-chem lab-on-a-chip for in situ science and life detection
- **University Research Engineering and Technology Institutes**
  - Bio-nano-information technology fusion (UCLA)
  - Bio-nanotechnology materials and structures (Princeton)
  - Bio-nanotechnology materials and structures (Texas A&M)
  - Nanoelectronics computing (Purdue)
- **Basic Nanoscience**
  - Biomolecular self-assembly and processing in space
  - Non-invasive diagnostic tools
  - Molecular signature for early detection
  - Tools for study of space-induced health effects

Multi-Scale Simulation Hierarchy

- ***An essential ingredient in the dream of nanotechnology is to*** design new nanoscale devices and test their performance ***before*** experimental prototyping and manufacturing
- This requires that we base simulations of nanoscale systems on First Principles
- This requires a multiscale strategy in which the information from quantum mechanics is captured in coarser levels to define the essential parameters



NASA's Nanotechnology Program is a Key Element of the Larger *National Nanotechnology Initiative*

NSF
Focus: Promote Science
Nanostructured metal alloys
Nanomaterials for electronic applications
Hybrid materials
Bioinspired materials

NASA
Focus: Aerospace Applications
Nanoscale & bioinspired material development
Modeling & simulation
Optical & biosensors/devices
Power sources/batteries
Data storage and molecular devices

NIH
Focus: Biomaterials
Material-tissue interfaces
Biocompatible materials
Biosensors and research tools
Drug and genetic material delivery
Social, ethical, and legal aspects

DoE
Focus: National Security
Sensors for biomedical applications
Sensors for air or water-borne molecules
MEMS
Computational biosciences
Embedded computing design
Imaging
Pattern recognition
Biomechanics
Robotics

DoC
Focus: Economic Health
Lithium polymer batteries
Tissue engineering
Artificial muscle
Nanocomposites
Sensor development
Adaptive Learning
Catalysis and biocatalysis
Microelectronics manufacturing

DoD
Focus: National Defense
Ship antifouling
Bioadhesion
Cooling technologies
Energetic materials
Self-assembling mesostructures
Integrated multifunctional sensing
MEMS
Rapid prototyping
Neural networks

Barriers and Challenges for Nanotechnology

- **Science at the nanoscale**
  - The Physics of the behavior of molecules/atoms at the mesoscale is poorly understood. The full potential of nanotechnology will be realized when such “new” laws are established.

- **Production of nanomaterials**
  - Quantity, quality, control of properties & production in specified forms

- **Characterization at both atomic and bulk scale**
  - Fundamental mechanical, electrical and optical properties

- **Modeling & Simulation**
  - Prediction of physical/chemical properties and behavior from nanoscale to macroscale as well as models for material production