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

Biotechnology

Nanotechnology

Technologies Shaping the Future
UCLA
October 11, 2002

Information Technology

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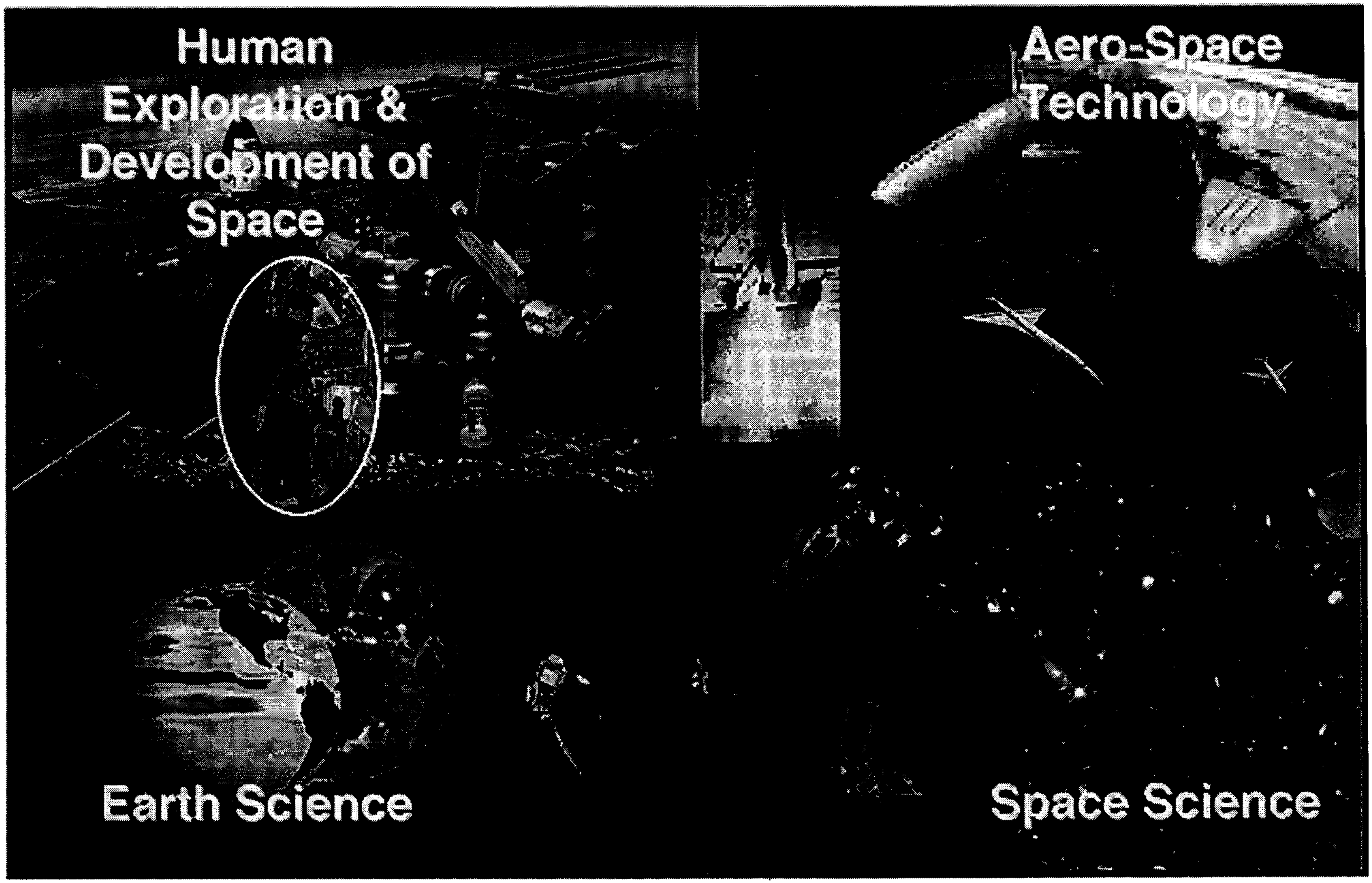
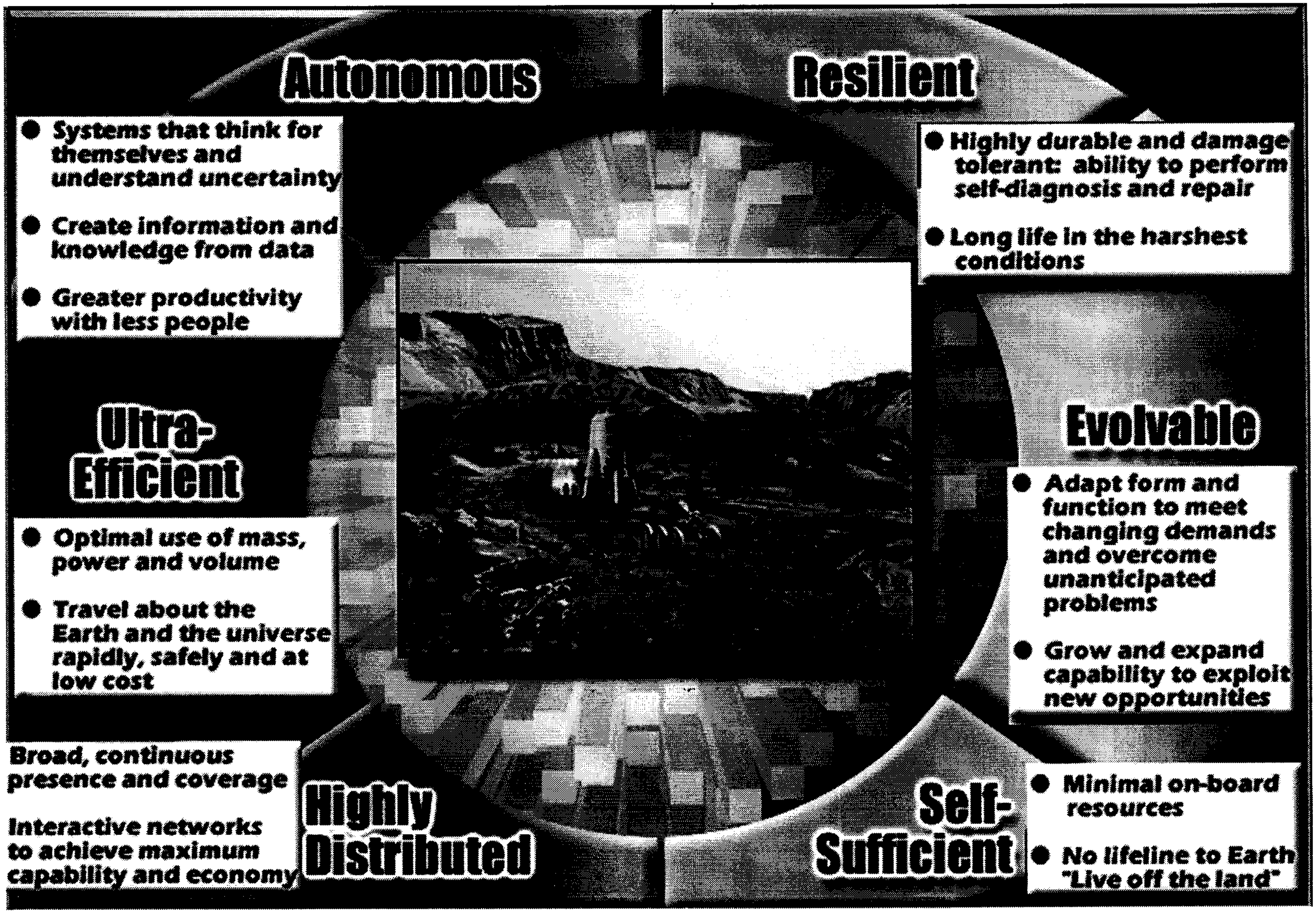
Office of Aerospace Technology
NASA

NASA's Strategic Enterprises



Goals for Future NASA Space Systems



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

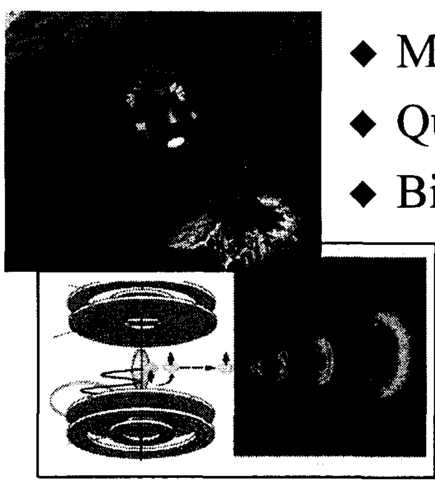
Diameters > 25-50 m are not achievable by extension of current materials technologies

◆ 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

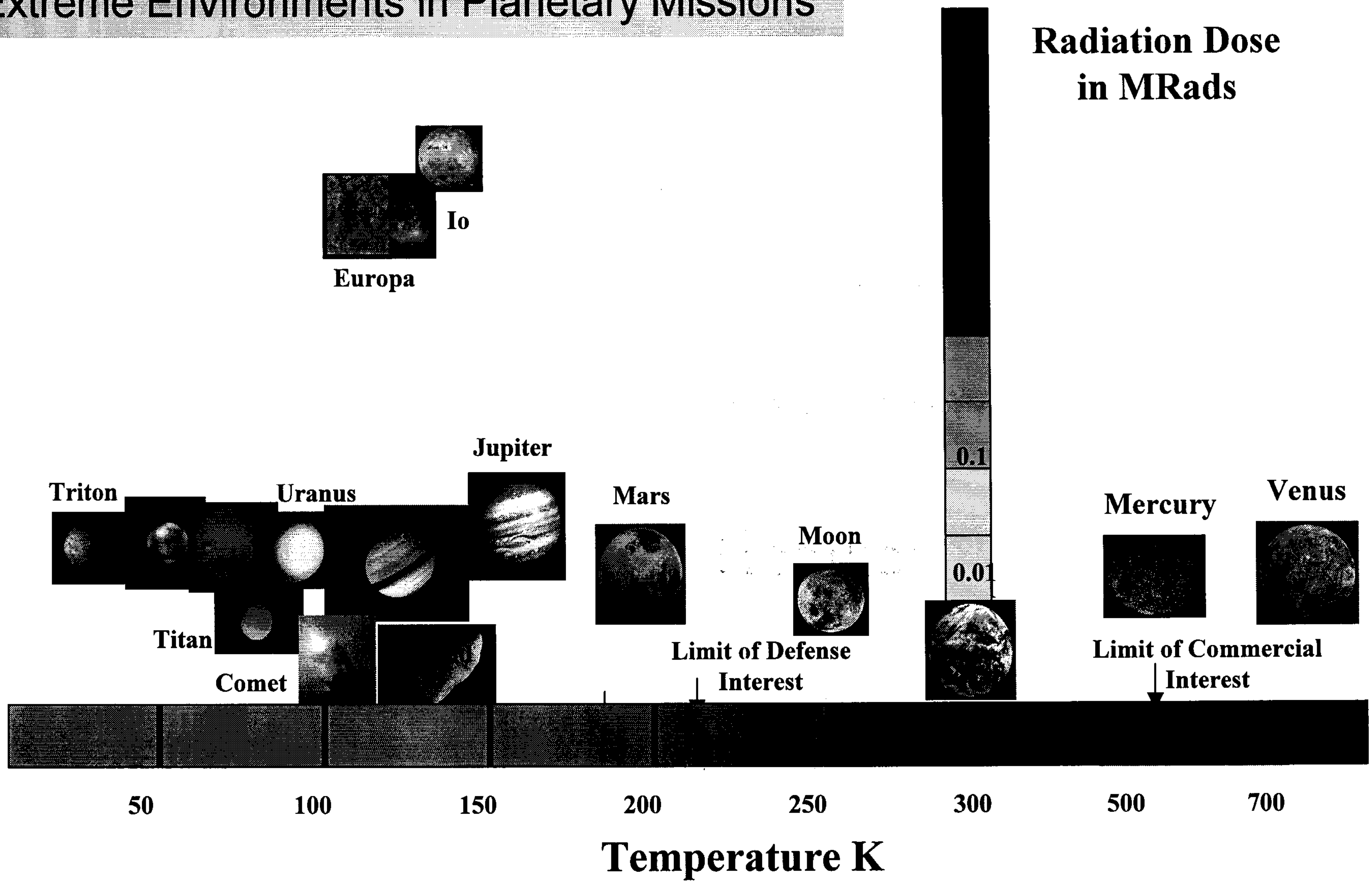
◆ Intelligence per Mass & Power

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

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

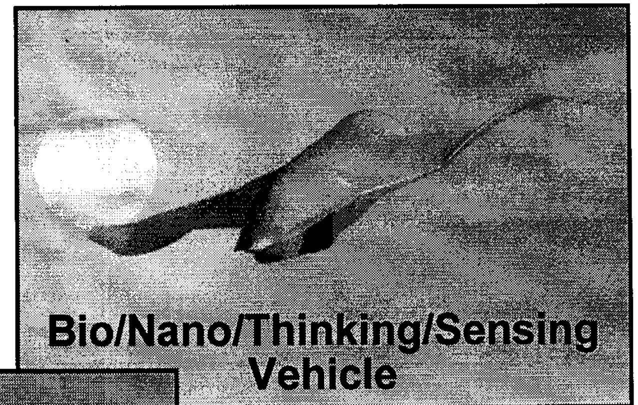
Challenges in Resiliency:
Exploring the Solar System

Extreme Environments in Planetary Missions

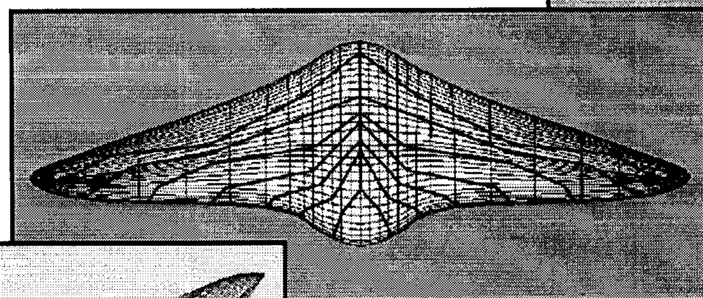


Towards Advanced Aerospace Vehicles: "Nature's Way"

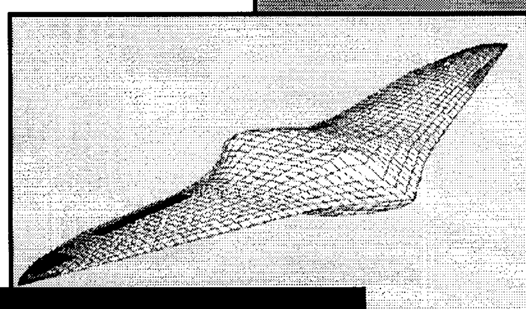
- Distributed self-assessment and repair
- Adaptive shape control
- Highly efficient propulsion
- Exploits Bio-Nano-Info technology revolution



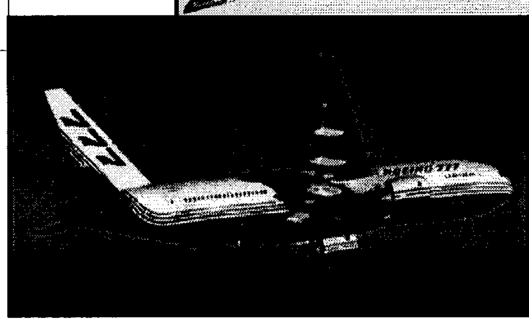
Bio/Nano/Thinking/Sensing Vehicle



Self-Healing Structure with "Central Nervous System"



Smart Structure with Active Flow Control



Modern Advanced Metal Aircraft

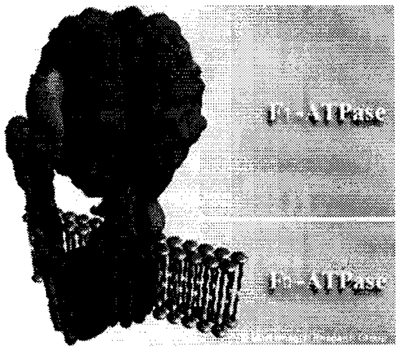
- Ultra Safe
- Whisper Quiet
- "Zero" Emissions
- Extreme Maneuverability
- High Survivability
- Ultra Low Fuel Burn

Advanced Technology Development

Time

NANOBIOTECHNOLOGY

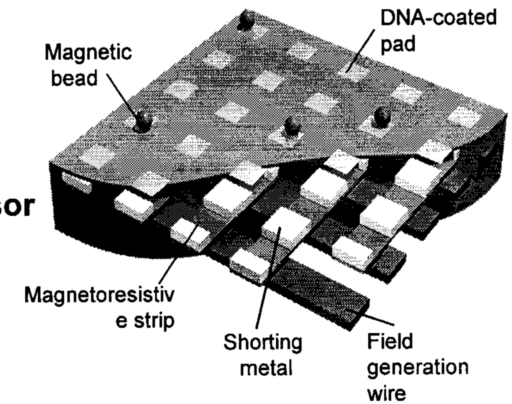
Chemistry/Physics of Biological Nanostructure



Molecular Motor (Montemagno, Cornell)

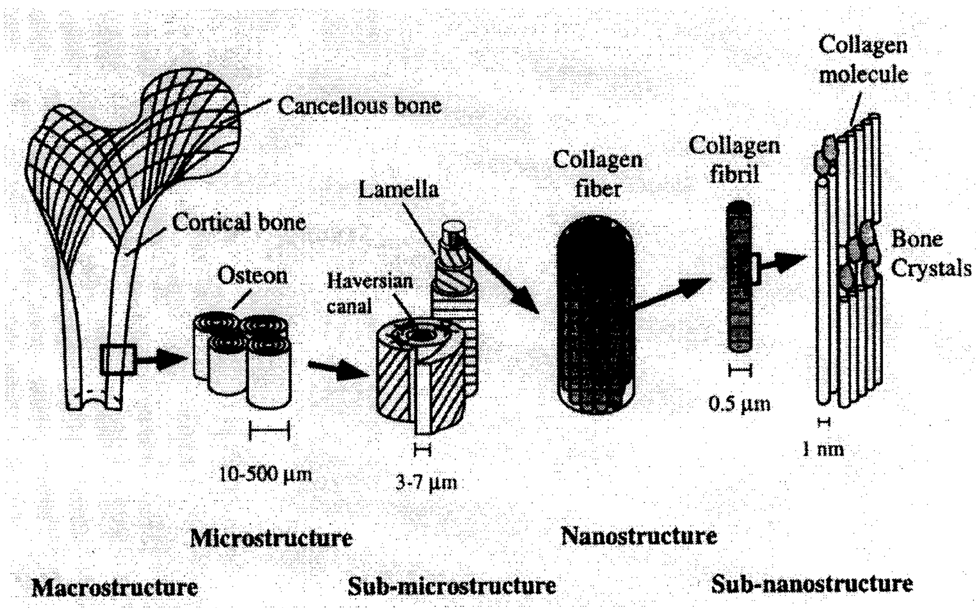
Earlier Detection and Treatment of Disease

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



BARC Sensor
(Colton, NRL)

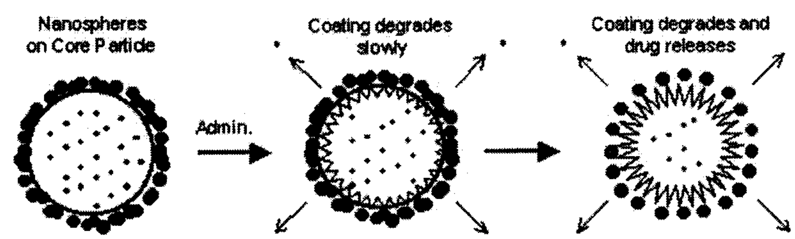
Improved Implants



Bone Structure (Siegel, RPI)

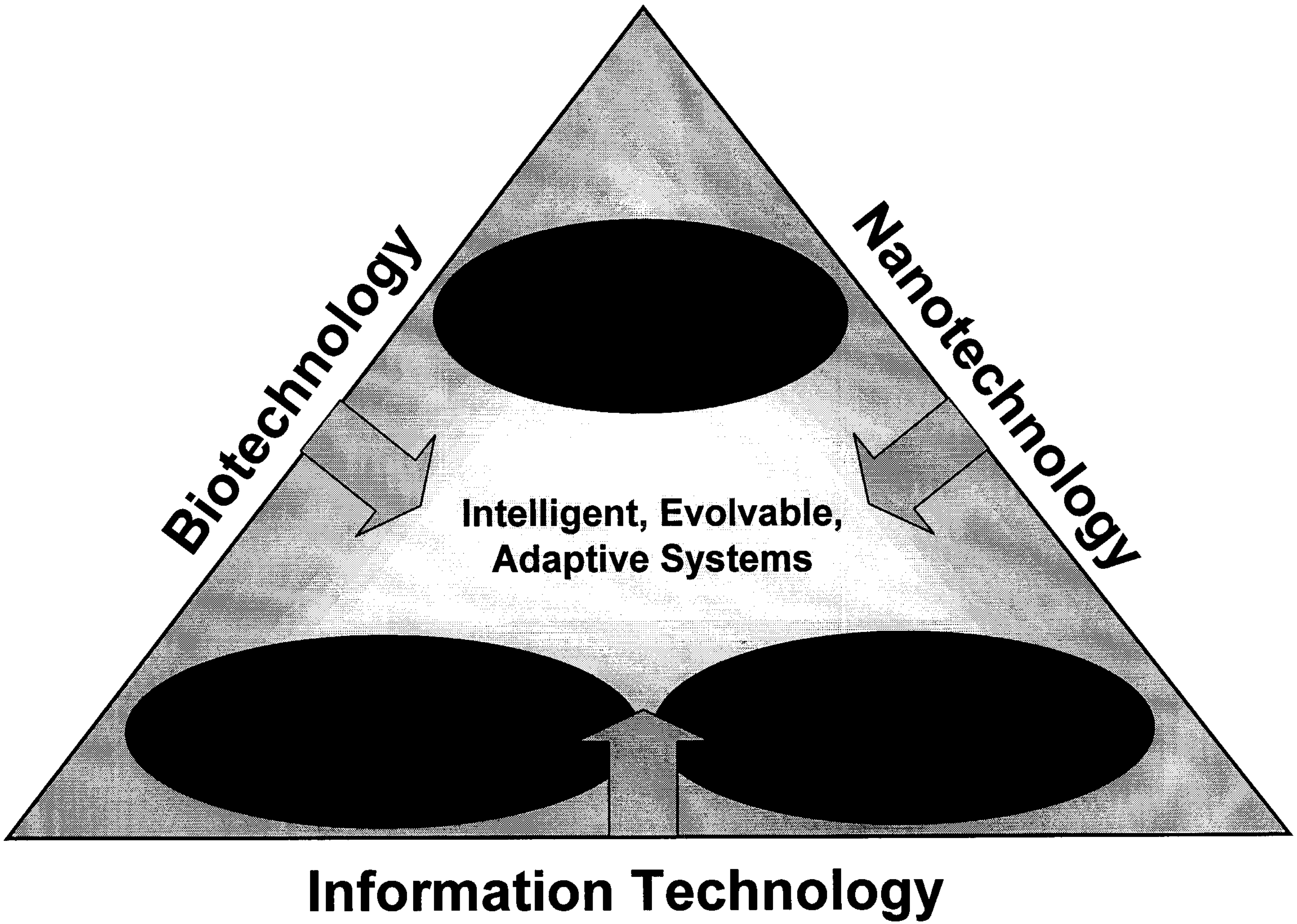
Therapeutic Delivery

Enhanced Solubility
Targeted, Local Delivery



Nanosphere enhanced drug solubility
(Nanosphere)

Revolutionary Technology Vision: The "Zone of Convergence"

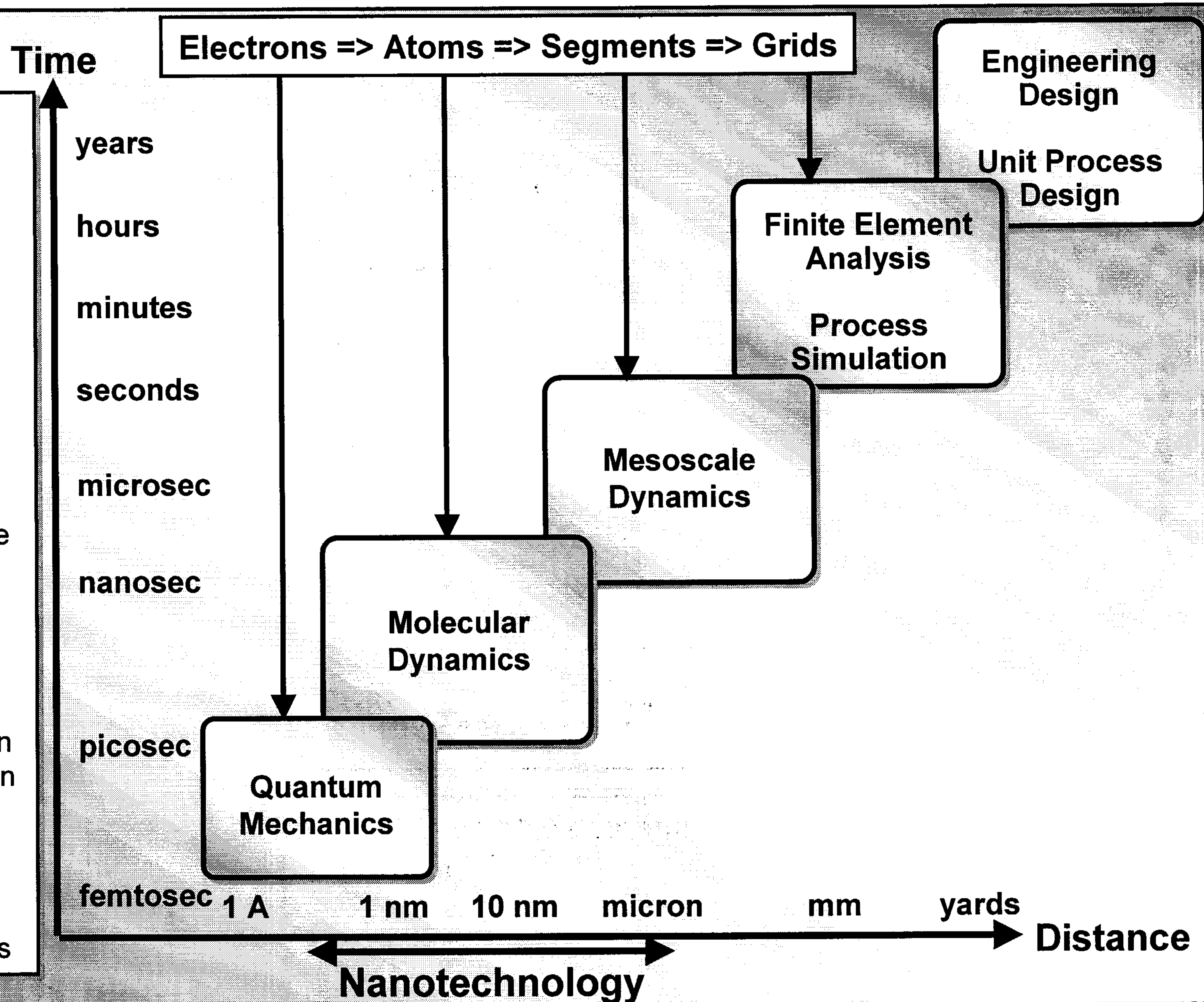


Critical Nanotechnology Investment Areas

- **Nanostructured Materials ($10 M)**
  - 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 ($9 M)**
  - 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 ($8 M)**
  - 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 ($12 M)**
  - 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 ($15 M)**
  - Biomolecular self-assembly and processing in space
  - Non-invasive diagnostic tools
  - Molecular signature for early detection
  - Tools for study of space-induced health effects

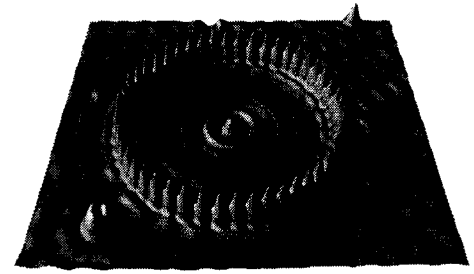
Multi-Scale Simulation Hierarchy

- ***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



ASSEMBLY

ATOMIC/MOLECULAR MANIPULATION

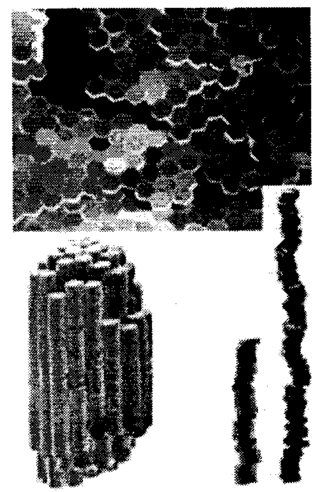


Quantum Corral
(D. Eigler, IBM)

SELF ASSEMBLY

DEFECT MINIMIZATION

DIRECTED HEIRARCHICAL

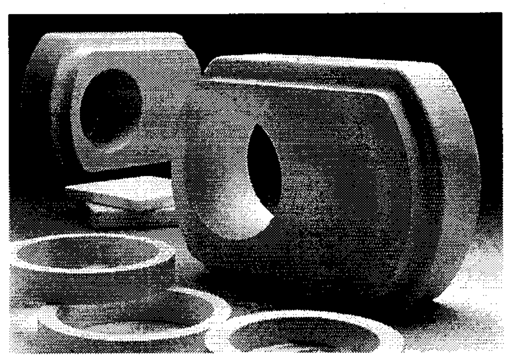


Self Assembled A*u*
(Whitesides, Harvard)

MATRIX EMBEDDED (COMPOSITE)

COMPACTION

COATING



Net Shape Forming via Consolidated Titania and Alumina Nanoparticles

(R. Siegel and Nanophase Technology Corp.)

NASA Research in Nanotechnology

Aerospace Vehicle Materials and Structures

Program Elements

- Nanotube Fiber Development
- Composite Matrix Development
- Multifunctional Structures

11 Participating Universities

Nano-Electronics and Computing

Program Elements

- Computational Modeling
- Computing Architectures
- Bio-Nano Synergy

11 Participating Universities

High Temperature Materials

Program Elements

- CNT / Polymer & Ceramic Matrix Comp
- High Temperature Nanotubes (e.g. BN)
- Nanostructured Alloys & Coating

7 Participating Universities

Sensors and Components for Microspacecraft

12 Participating Universities

US: National Nanotechnology Initiative (NNI) Program ($M)

		FY00	FY01	FY02	FY03
KNOWLEDGE GENERATION		87	140	212	~225
GRAND CHALLENGES		71	125	235	~265
Nanostructured Materials by Design	NSF				
Nanoelec, Photonic, Magnetic	DOD				
Advanced Healthcare/Therapeutics	NIH				
Environmental Improvement	EPA				
Energy Conversion/Storage	DOE				
Microcraft & Robotics	NASA				
CBRE Protection/Detection	DOD				
Instrumentation & Metrology	NIST				
Manufacturing Science	NSF				
CENTERS/NETWORKS		47	66	89	~110
INFRASTRUCTURE		50	77	52	~90
ETHICAL/SOCIAL IMPLICATIONS		15	21	16	~16
	TOTALS	270	422	604	~700

"Nanotechnology" Research Programs in the World

Main Government Sponsored Research Programs

	2001	2002 (est.)
USA	$420M	~$600M
Japan	$500M	~$800M
Western Europe	$250M	~$300M
Other Countries (FSU, China, Canada, Australia, others)	$200M	~$400M
Total	**~$1400M**	**>$2000M**

Fiscal year start/stop varies from country to country

Barriers and Challenges for Nanotechnology

- **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
- **Applications Development**
  - Tools and techniques for applications of nanotechnology
  - Verification of predicted behavior/performance in actual environments
  - Systems Analysis to guide technology development

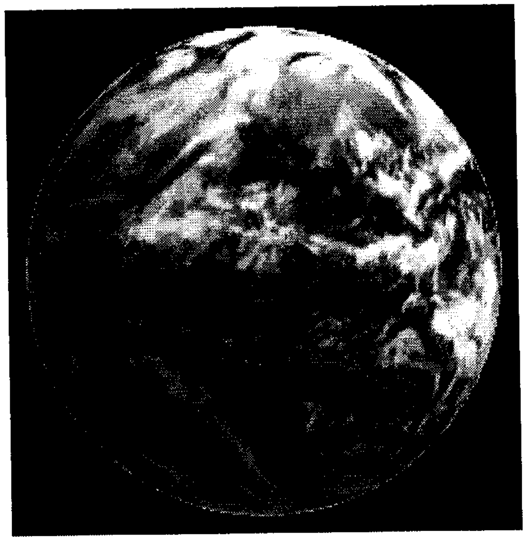
Summary

- NASA's nanotechnology initiative is part of a national effort to stay in the race for the 21st century technological leadership

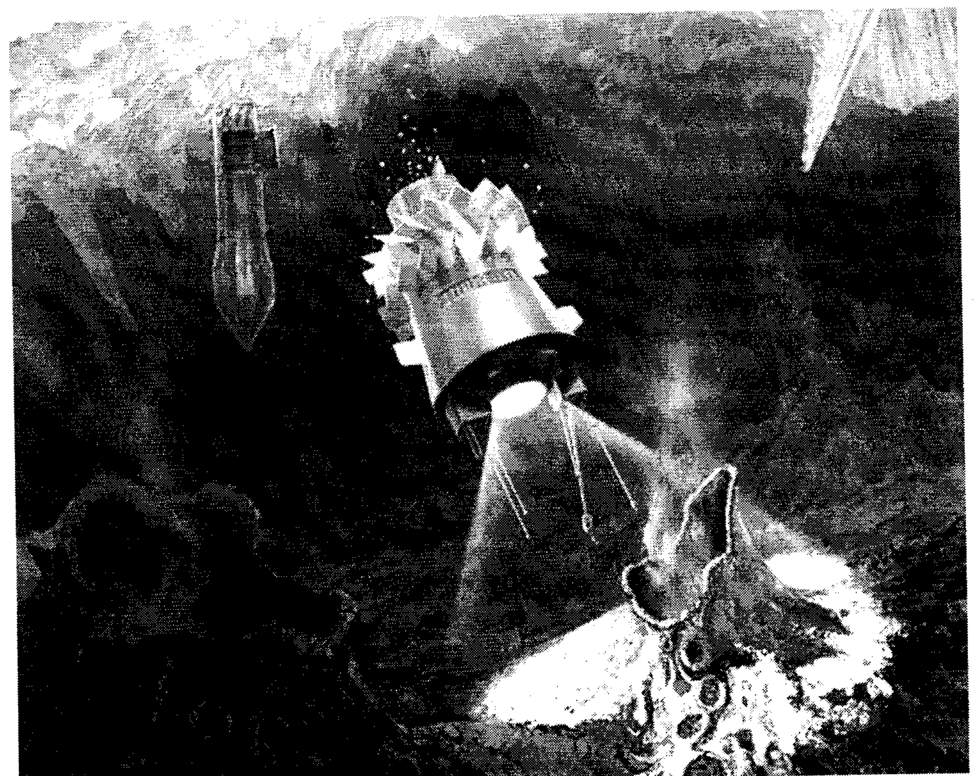
- NASA faces unique challenges in the coming decades that cannot be achieved with existing technologies

- Emerging nanotechnology-based capabilities in nano engineered materials, nano electronics and biomolecular nanotechnology offer possible solutions for these challenges

Summary



The most direct path from the Earth to the depths of Europa's ocean....



Will be the path enabled by advances in info-, nano, and bio - based technologies