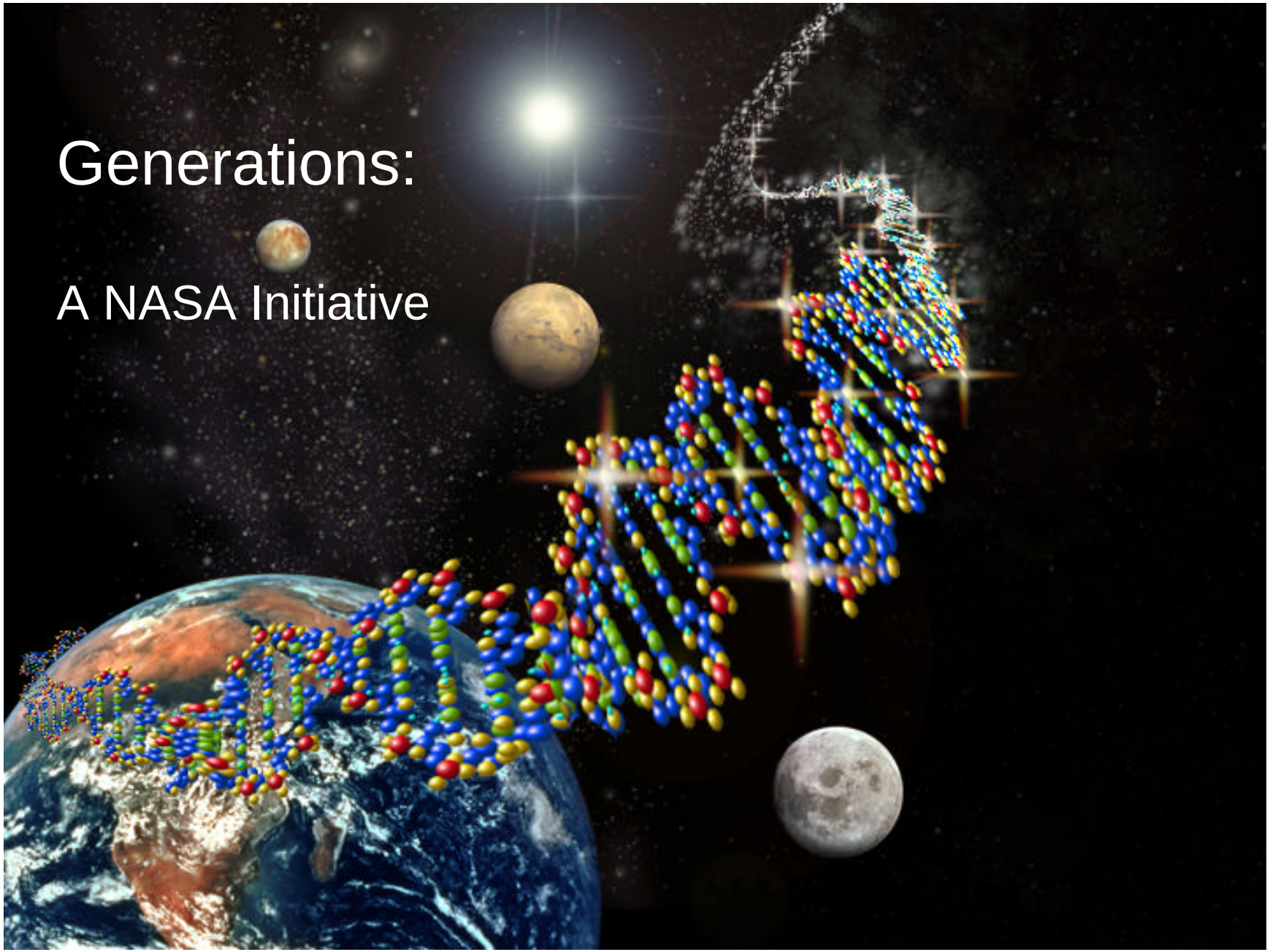
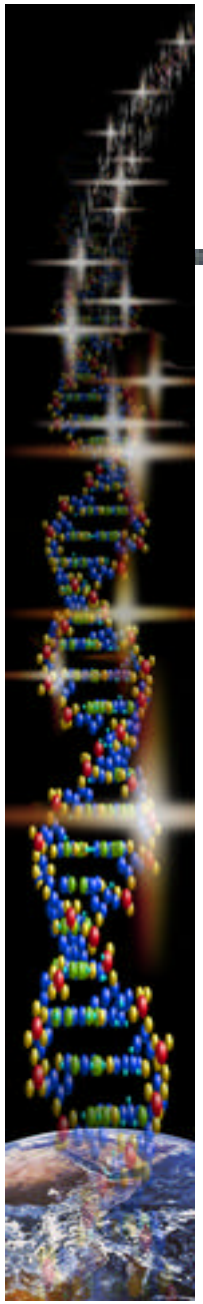
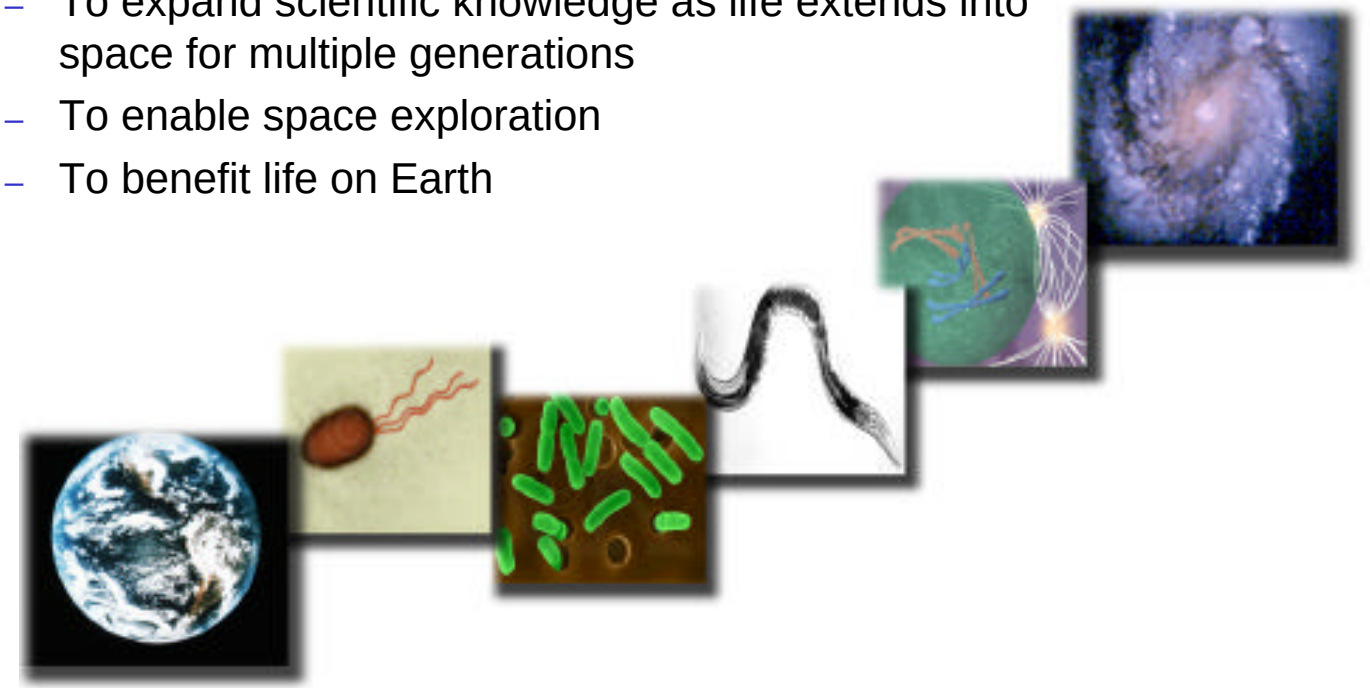
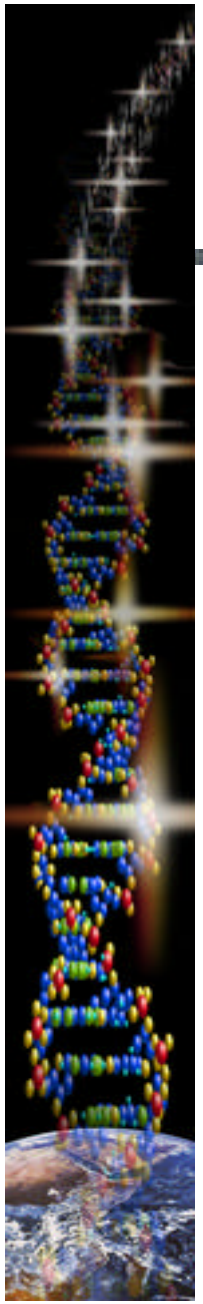

Generations:
A NASA Initiative



Initiative Goal

- Investigate the potential for life to transition into space:
  - To expand scientific knowledge as life extends into space for multiple generations
  - To enable space exploration
  - To benefit life on Earth

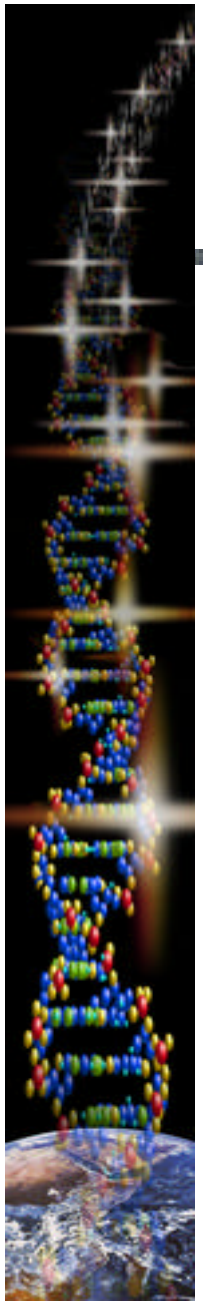




Why?

- Life's history on Earth is the story of major transitions:
  - *Life without oxygen to life that requires it,*
  - *Life in water to life on land,*
  - *Life on land to life in the air*.
- We are poised at the frontier of a new transition:
  - *From life on Earth to life in Space.*
  - This major transition, as previous ones, will result in enormous consequences to the future of life.
  - We can use this unprecedented opportunity to obtain unique knowledge about living systems through study of multiple generations in space.

This initiative lays a foundation for life's future expansion into the solar system

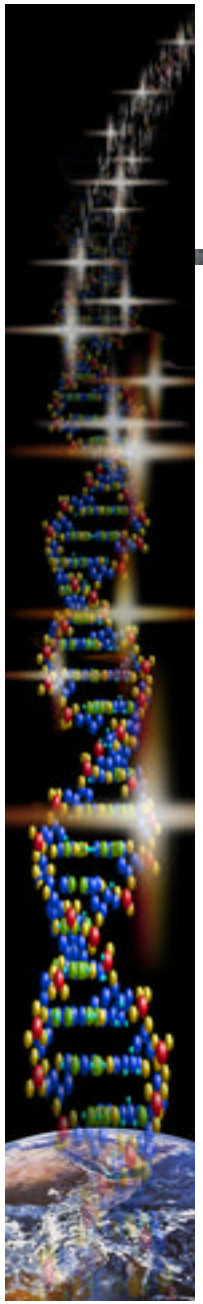


Why now?

Confluence of Critical Factors

- *Opportunity:*
  The International Space Station and free-flying missions in low Earth orbit will enable the first opportunity to expose life to space across multiple generations.
- *Tools:*
  Powerful new advances in genomics and molecular, biotechnological and informational tools enable profound new insights.
- *Results:*
  Enabling solutions for NASA's major strategic goals of exploration and scientific knowledge will come from the study of life's adaptation to space.

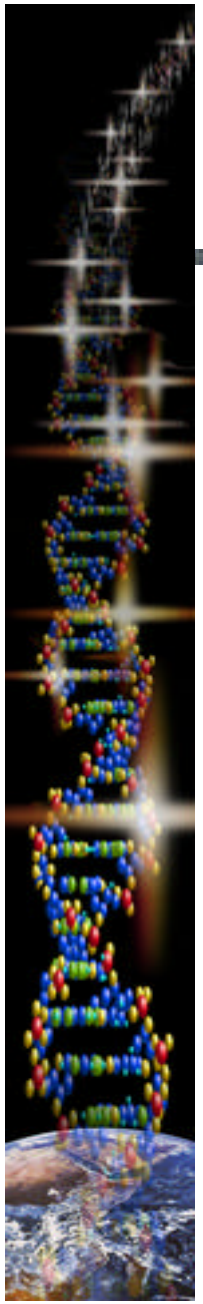
Science within this initiative will generate new knowledge to help enable NASA's primary strategic goals in the 21st century



Education and Public Engagement

- Biology is the science of the 21st century
  - The study of life's transition into space offers a unique opportunity to excite and engage the public
- *Generations* proposes an innovative and aggressive education and outreach program including
  - Web-based curricula for elementary and secondary students
  - Real-time mission-based biology laboratory curriculum partnerships
  - Private sector partnerships to identify medical and technology products
  - Regional forums and town hall meetings to encourage public participation in space biology and exploration
- A critical long-term goal: training the next generation of scientists

NASA has a unique responsibility to enable a greater understanding of biology through public interest in space



Generations - the central theme

DNA → Mutations → Changes in genotype & genotype expression

↓

Changes in Phenotype

↓

Variability in populations (adaptations)

Fittest individuals pass on their genes

Selective Pressures

Changes in allele frequency in the gene pool

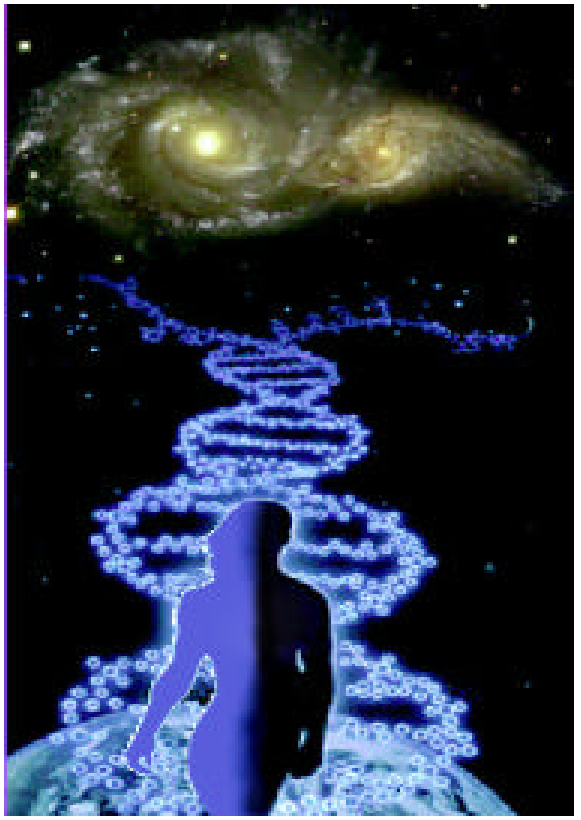
Selective Pressures

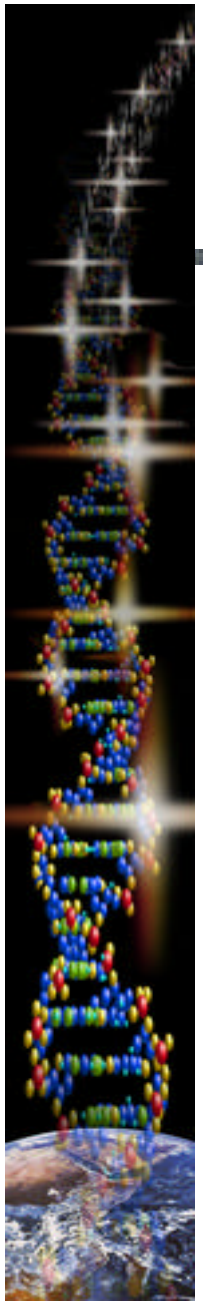
Many Generations

New Species?

Overwhelmed by environmental pressures → Extinction

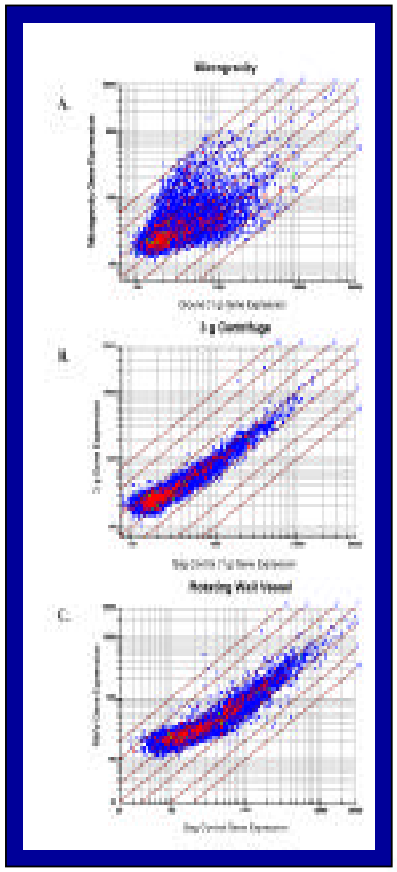
Continued Success in the environment → **Evolution**



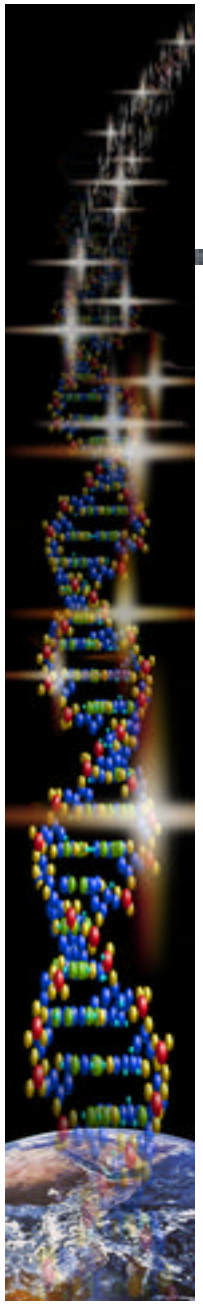


Novel Environments Reveal Novel Biological Insights

- Space is a profoundly different environment for biology than anything encountered in 3.8 billion years of evolutionary history
- Life survives beyond Earth via still undiscovered mechanisms
  - This offers a vast new realm for biological exploration.
- We now know how to explore the most fundamental aspects of life in the most novel evolutionary environments ever encountered to provide unique knowledge on:
  - How cells function
  - How body systems interact
  - How evolution works
  - How life will thrive beyond the planet of origin



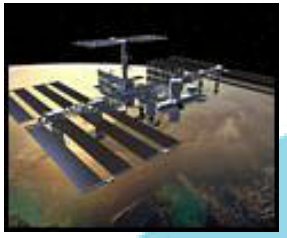
Knowledge gained from the new space biology will reveal insights on life's fundamental processes on Earth



Research Strategy: From Earth to Deep Space

Multigenerational research beyond the Van Allen belts:

- Studies on living systems subjected to the full radiation spectrum of deep space
- Long-term space adaptation and evolution studies
- Studies on selected organisms for exploration

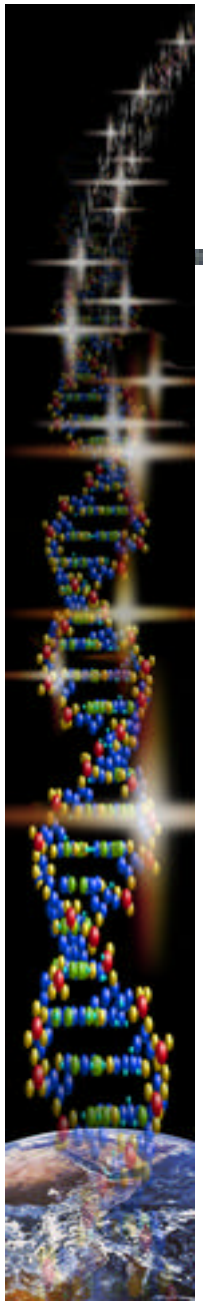


Single and Multigenerational research in Low Earth Orbit:

- Evolutionary studies on ISS and Free-Flyers
- System and technology validation

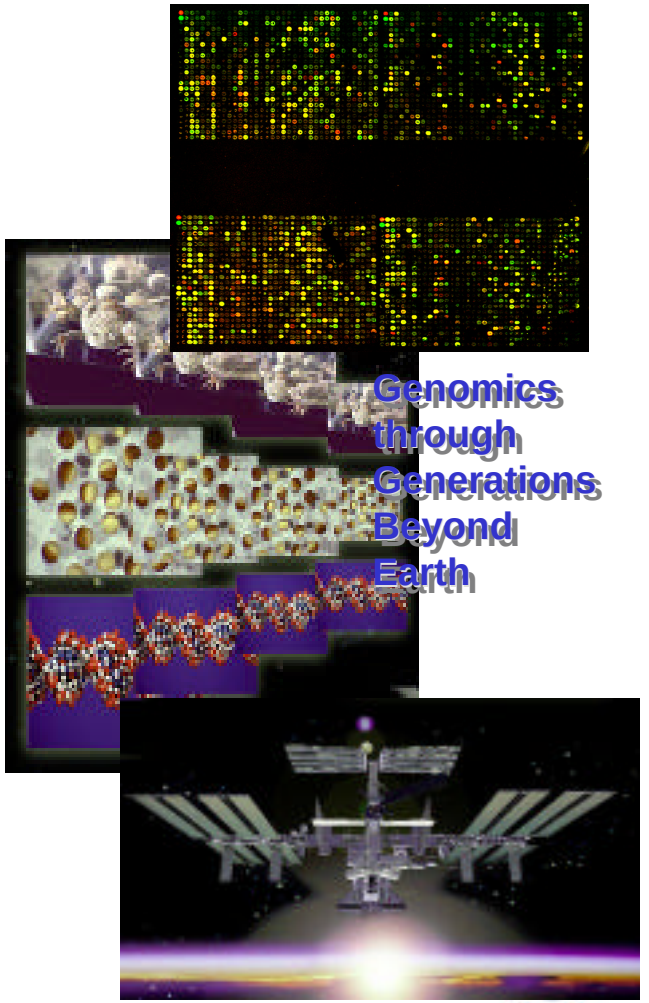
Single and Multigenerational research on Earth:

- Evolutionary studies on model organisms
- Single spectrum radiation biology
- Extreme environment evolution



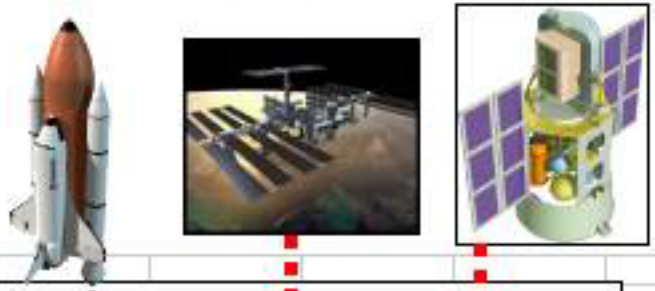
Space Genetics

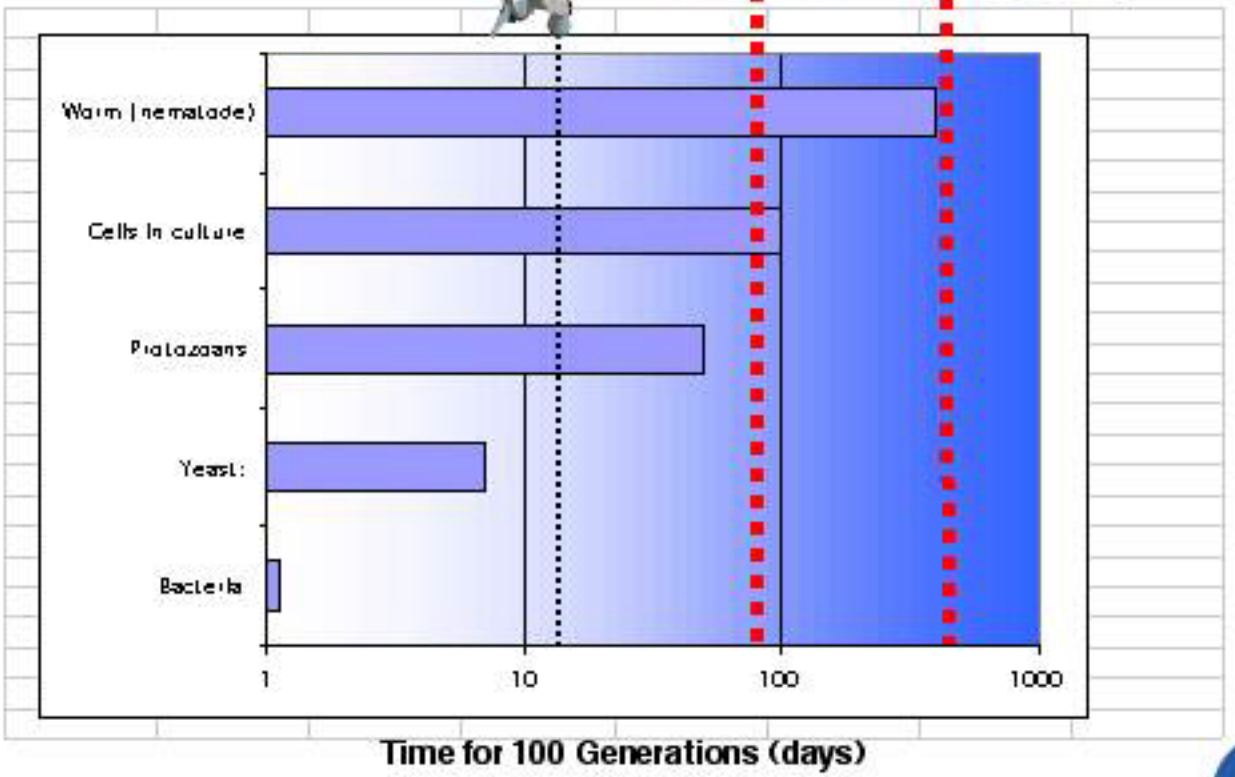
- **Goals:**
  - Correlate genomic, physiological, and metabolic responses of Terran life in space.
  - Determine the potential for Terran life to evolve beyond Earth.
  - Transfer knowledge and technology products for public benefit.
- **Technologies:**
  - Autonomous integrated measurements on multiple species over multiple generations
  - Bioinformatics
  - Functional Genomics, Proteomics
  - cDNA libraries and sample archives
- **Applications:**
  - Space Station and Free Flyers
  - Planetary Exploration
  - Earth and Space Medicine

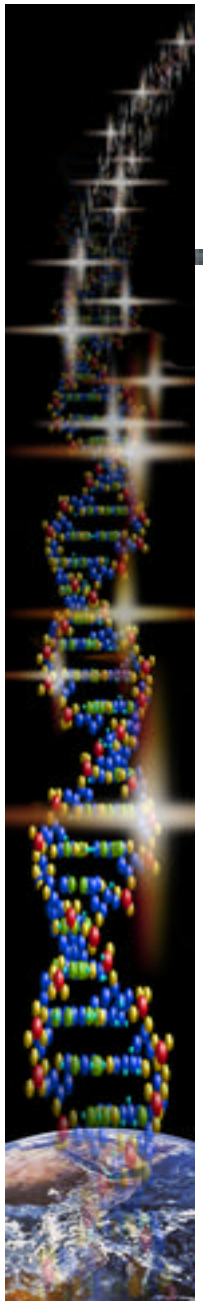


Multigenerational studies

- The International Space Station and free-flyers enable the study of higher organisms over more generations.







Science Drivers

Can life's transition to Space provide information on how life has evolved on Earth?

Do simple living systems evolve in the unique environment of Space?

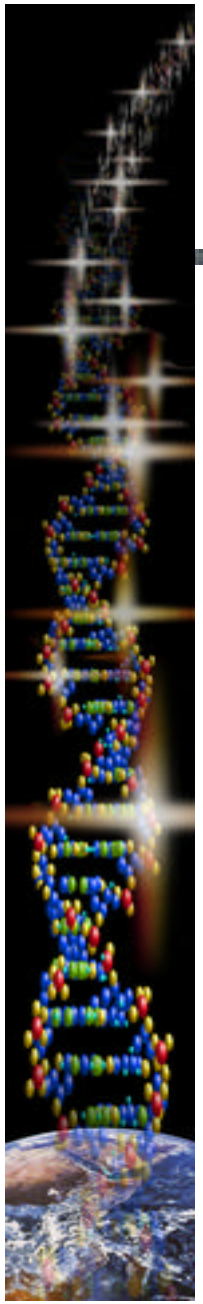
What is the whole genome response of a variety of cells and tissues to the space environment?

What is the flow of information from cellular receptors through genomic responses to physiological adaptation?

Can the study of the transition of life to Space assist in the search for life in the Cosmos and Planetary Protection?

Can the biological knowledge gained from multigenerational experiments be used to provide a foundation for new technologies?

Can lessons learned from life's adaptation to extreme environments be applied to adaptation to space?



Initiative Approach

Science: From biomolecules to living systems

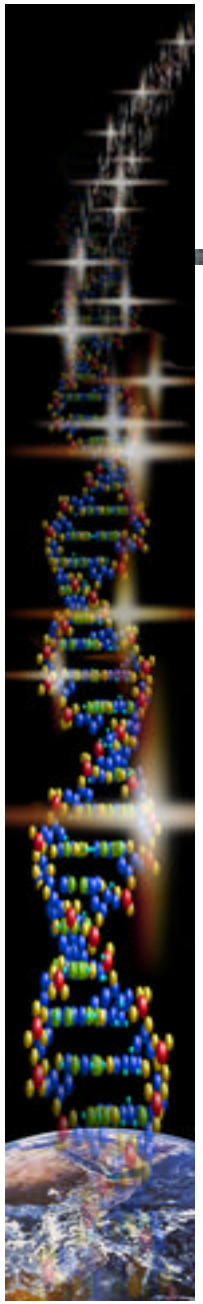
- Study the effects of the space environment on survival, replication and repair, variation, and selection and speciation of living systems
  - *Utilize scientific and technological advances in genomics, advanced instrumentation and informational technology for an unprecedented understanding of evolution*

Enabling Technologies

- Integrated, highly autonomous, miniaturized biological laboratories for flight research
  - *Developed through highly-leveraged partnerships with industry, academia and other government agencies, including NASA Space Station facilities*

Missions: Low Earth Orbit Free-Flyers and Bioexplorers

- Competed, peer-reviewed payloads and missions modeled after NASA's Discovery program
- Payloads with increasing autonomy and biological measurement capabilities
- Initial science and testing on Shuttle and Space Station, leveraging Space Station habitat development
- Bioreturn probes orbiting above Van Allen belts for study of radiation and microgravity on returned samples
- Free-flyers for long-term, autonomous studies



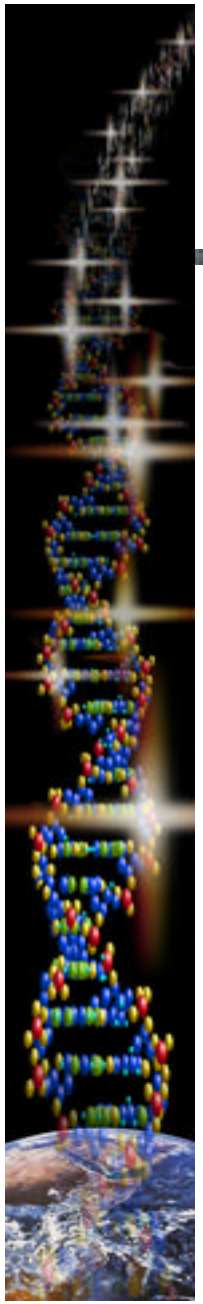
Science program elements

Gene Function: *The effect of the space environment*

- Bring the objectives and processes of the Human Genome Project to space
- Characterize the genomics of model organisms in space
- Correlate changes in gene expression in space with protein and metabolic effects (proteomics)
- Determine flow of information from cellular receptor through genomic response to physiological adaptation..

Replication and repair: *The role of radiation and gravity on evolution*

- Identify mechanisms and extent of environmentally-induced damage and repair
- Identify environmental effects on replication
- Determine the association between replication and repair strategies on Earth and in space



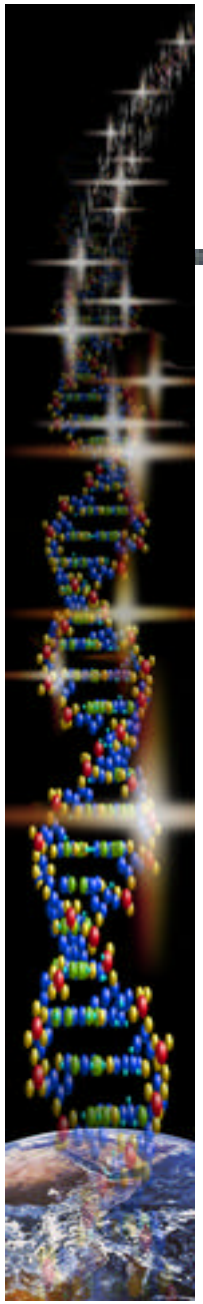
Science program elements (cont'd)

Variation: *Changes in gene networks in space fuel natural selection*

- Analyze changes in known gene networks
- Identify new gene regulatory pathways
- Determine effects of the space environment on gene networks

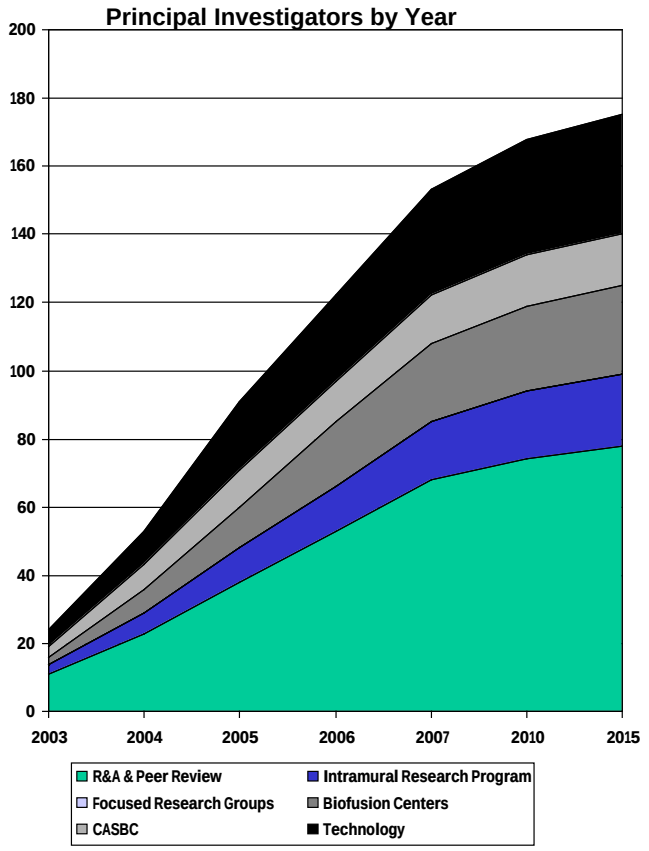
Selection and speciation: *Evolution in space*

- Determine the effects of the space environment on models and rates of selection and speciation
- Characterize the coevolution of competing species and opportunistic organisms on Earth and in space
- Apply evolutionary principles obtained from studies on Earth to space-based studies
- Utilize this knowledge for biologically-inspired technologies



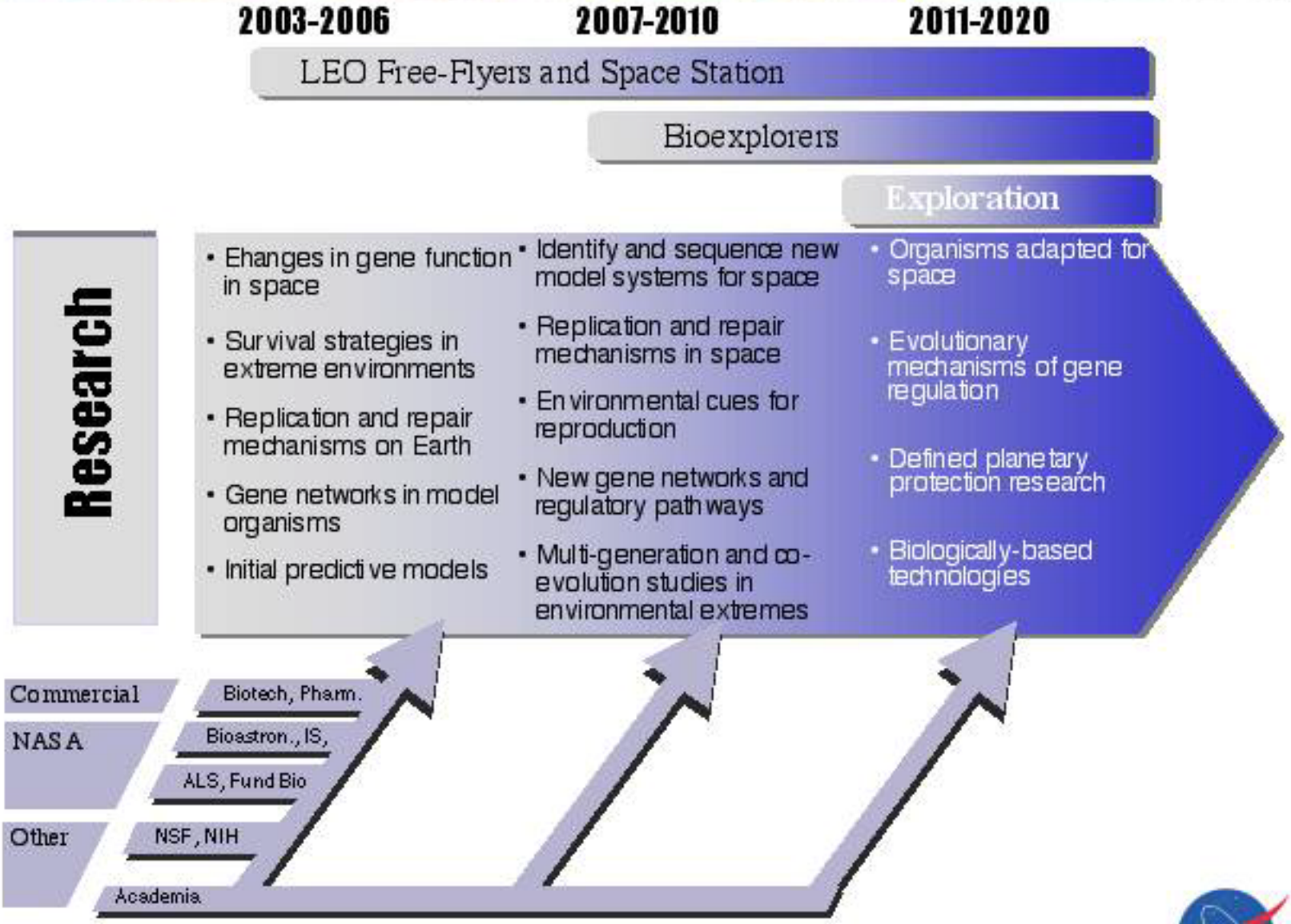
Science Implementation

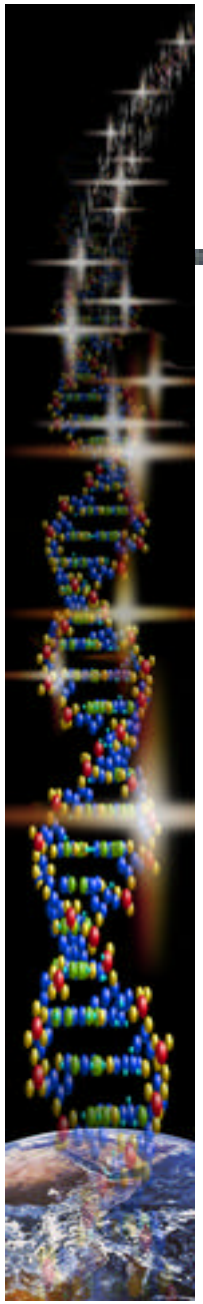
- **Research and Analysis**
  - Peer-reviewed grants programs open to broad scientific community
  - Focus: science program elements and cross-cutting research areas
- **Intramural Research**
  - Peer-reviewed research projects in exploratory areas
- **Focused Research Groups**
  - Peer-reviewed research groups in emerging, cross-disciplinary focus areas
- **Biofusion Centers**
  - Peer-reviewed research centers focused on multidisciplinary research problems and development of biologically-based technology concepts
- **Center for Advanced Space Biology Concepts**
  - Think tank of eminent scientists focused on problems in space biology
- **Technology**
  - Peer-reviewed research and development on enabling technologies



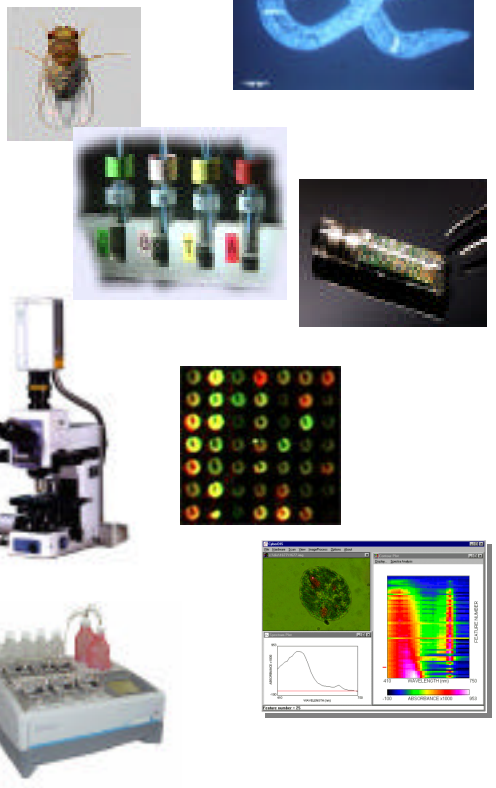
Long-term Targets

Science Roadmap





Technology Drivers



- GROW - Autonomous, multigenerational Habitats

  In-flight systems and modules will permit growth and nurturing of cells, tissues, and higher organisms

- SENSE - *in-situ* Biosensors

  Development of biosensors, DNA chips and automated sample management and handling systems will permit in-situ measurement and analysis of biological processes

- OBSERVE - Microscopy and Advanced Imaging Systems

  Incorporation of new advances in optical, nano- and information technologies will allow in-situ imaging systems to visualize changes in cell shape and configuration

- ANALYZE - Information Systems and Technologies

  Revolutionary developments in bioinformatics, modeling, simulation, and adaptive - autonomous bioanalytical systems will enable rapid conversion of raw data to information/knowledge

Target Technologies

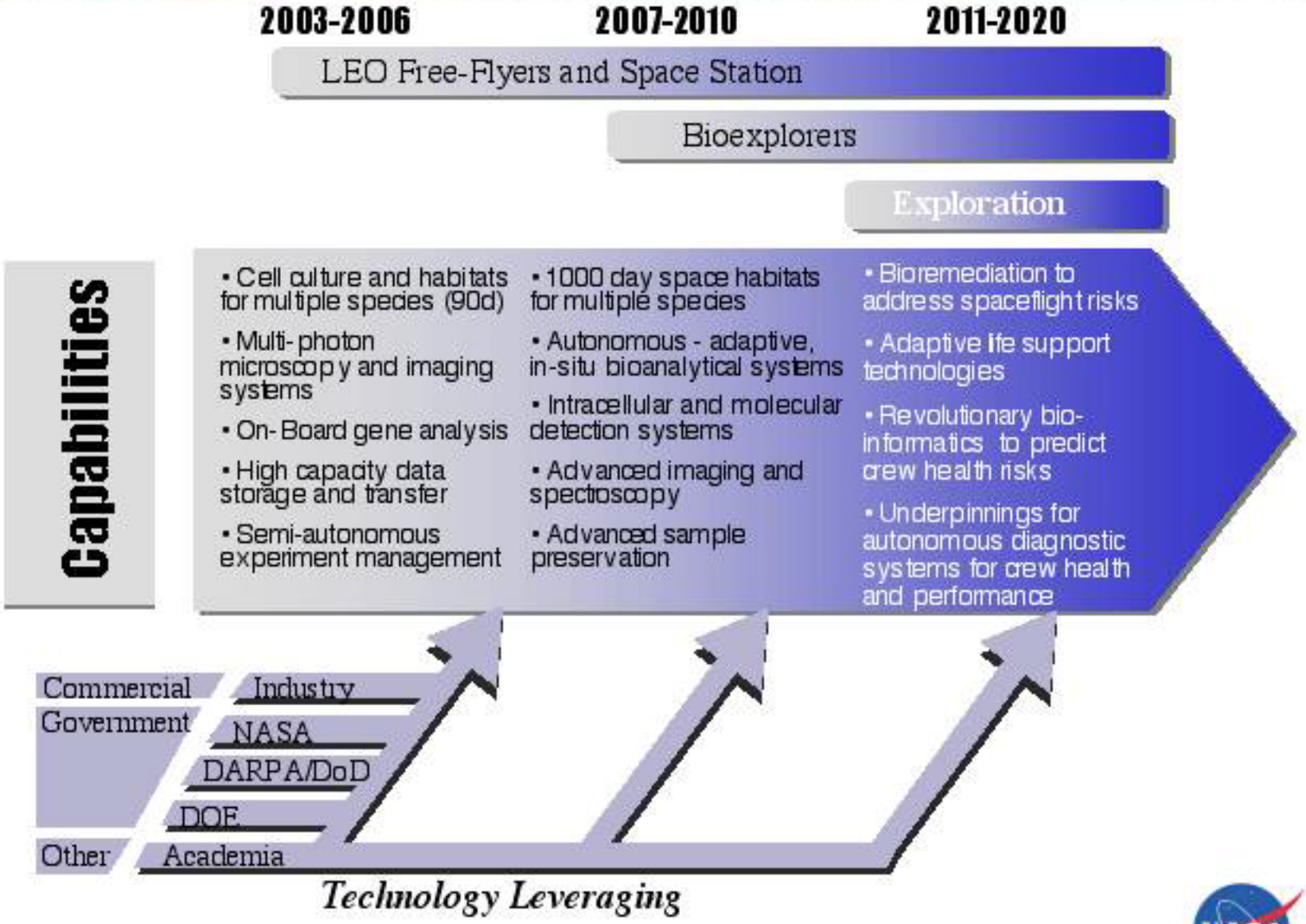
Grow
- Autonomous, multigenerational habitats
- Specimen handling and management

Sense
- *In-situ* measurement
- Genomics and Proteomics
- Biosensing

Observe
- Optics: space microscopy, spectroscopy
- Dual-photon, hyperspectral imaging
- Multi-dimensional fluorescent microscopy

Analyze
- Explorative Bioinformatics
- Intelligent modeling and simulation
- Autonomous - adaptive bioanalytical systems

Technology Roadmap

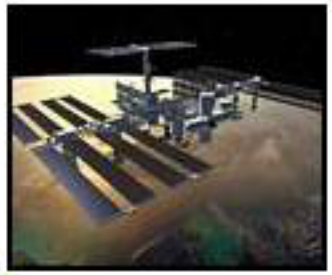


Missions: BioExplorers

Payload Development
- Autonomous, multigenerational habitats
- Advanced in-situ analytical technologies

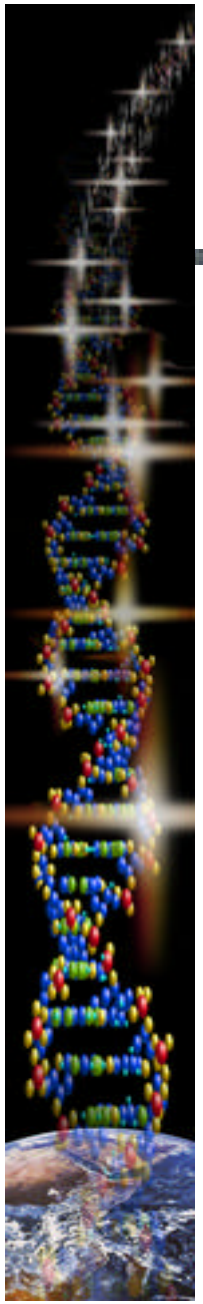
LEO Free-Flyers
- Technology validation
- Initial multigenerational studies

Space Station/LEO Free-flyers
- Studies of evolution in microgravity
- Payload and technology validation



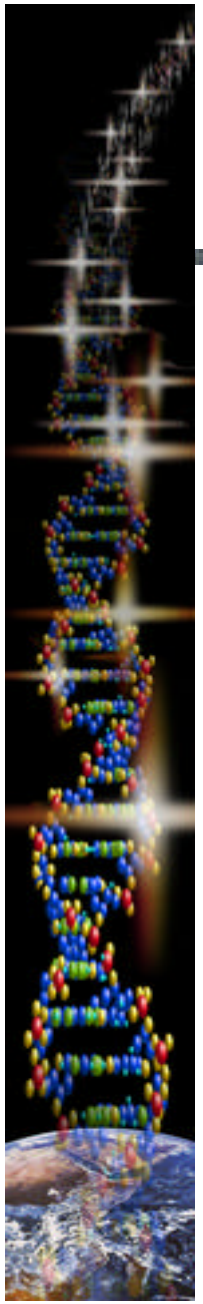
Bioexplorers: Return Probes
- Small, adaptable-configuration probes
- Microgravity/radiation study, return analysis

Bioexplorers: Free Flyers
- Autonomous, integrated laboratories
- Long-term multigenerational studies



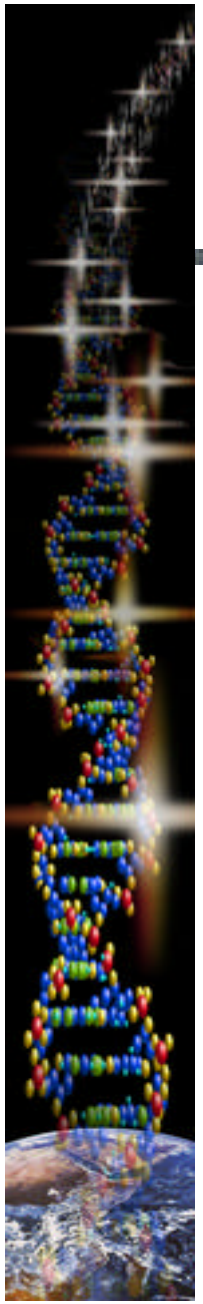
Leveraging

- **Science**
  - Further development of established relationships with NSF, NIH
  - Development of partnerships with industry in focused research areas
  - Community enhancement through existing relationship with Universities Space Research Association
    - Workshop in planning for summer 2001
  - Active international participation through International Space Station Life Sciences Working Group
- **Technologies**
  - Significant investment exists in key technologies, e.g.,
    - DARPA: over $50M/year in developing technologies from biosensors to DNA analysis
    - Industry: hundreds of $M in DNA-related technologies from DNA chips and detectors to bioinformatics
    - Intelligent systems: NASA investments in intelligent data understanding and autonomous systems
  - Initiative strategy:
    - Integration of government, industry and other technologies through existing and new partnerships
    - Development of key technologies in gap areas
- **Unique space platform and other assets**
  - Maximum use of existing Space Station facilities (e.g., Space Station Biological Research Program) in cooperation with international partners
  - Use of Bion and Photon in cooperation with Russians, potential use of ESA free-flyer
  - Use of existing ground radiation facilities and ground centrifuges for evolution research
  - Identification and use of opportunistic space flights



Outcomes

- Understanding the effects of extreme environments (e.g., gravity and radiation) on gene function and evolution
- Novel and enhanced space platforms for the study of evolution in space
- Capability to predict multigenerational biological response to space
- Selection of organisms for targeted needs, e.g., radiation resistance and life support
- Underpinnings for biologically-based technologies
- Strategies to ensure protection against biological cross contamination of other worlds
- Advanced, integrated and autonomous bio-laboratories for space and extreme environments
- Advanced tools for biological modeling, simulation and prediction



Conclusions

- Biological questions are amongst the formidable challenges of space exploration. This initiative provides the biological foundations for:
  - Understanding the effects of microgravity and radiation on the evolution of living systems
  - Selecting organisms uniquely suited for the environment of space to enable future exploration
- The convergence of mission opportunities with technological advances enables breakthrough opportunities in space biological research
- This initiative will engage and leverage the broad scientific and technology communities to revolutionize space biology missions
- Earth benefits will extend from new insights in biology and biotechnologies to increased opportunities for public engagement

This initiative provides a biological foundation for NASA's primary strategic goals of the 21st century