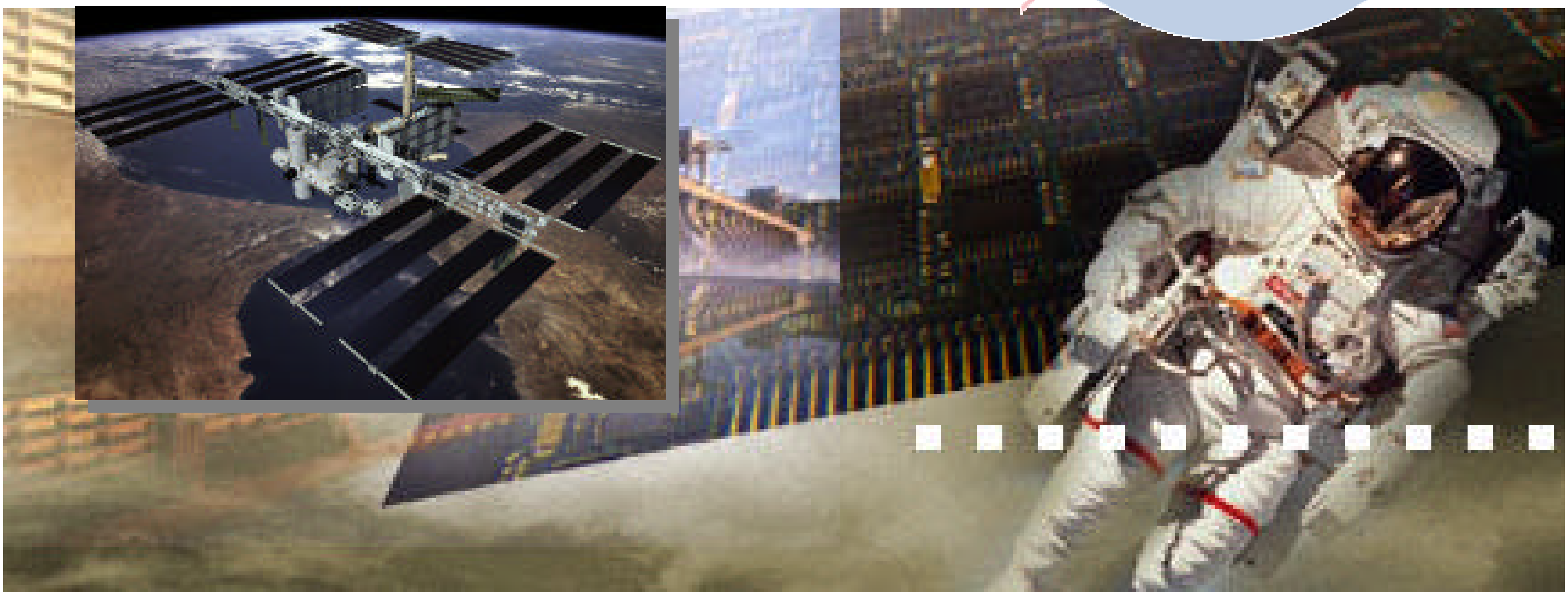
Office of Biological and Physical Research

International Space Station Research Plan

Assembly Sequence Rev. F, Aug. 2000



What are the GOALS for ISS Utilization?

ISS is an international cooperative research platform

To Provide…

…a state-of-the-art research facility on which to study gravity’s effects on physical, chemical, and biological systems

...an advanced testbed for technology and human exploration

…a commercial platform for space research and development

Use space environment…

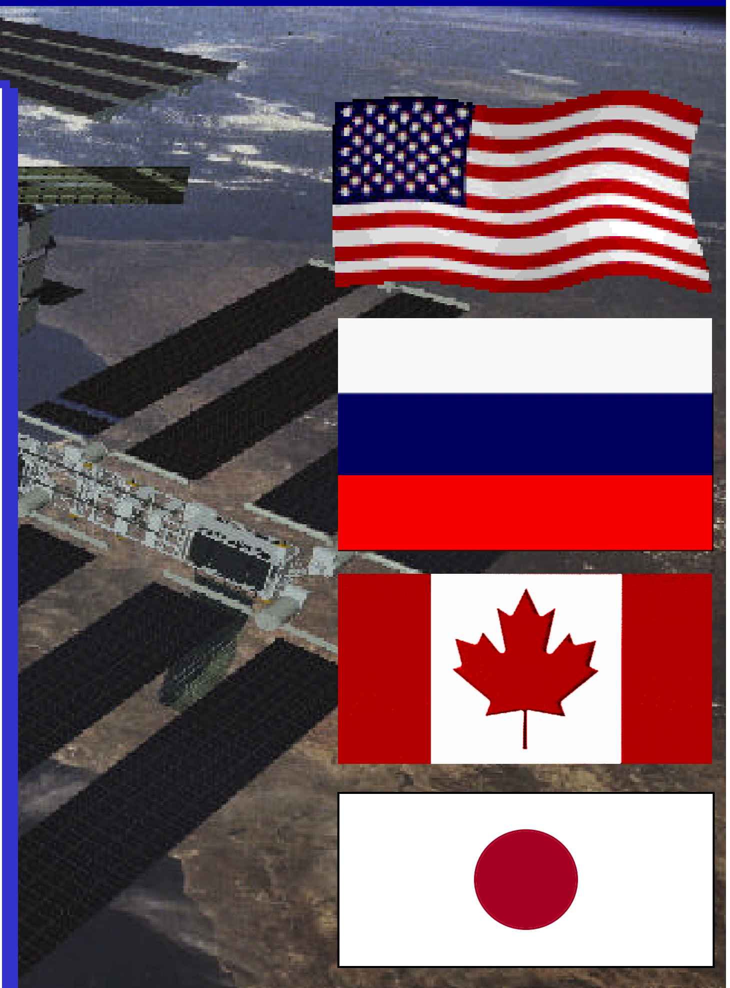
…to advance scientific knowledge

…to live, explore, and work productively in space

…to use the attributes of space to improve products and processes on Earth

What are the ISS Utilization Research Areas?

Linking research communities in space and on Earth

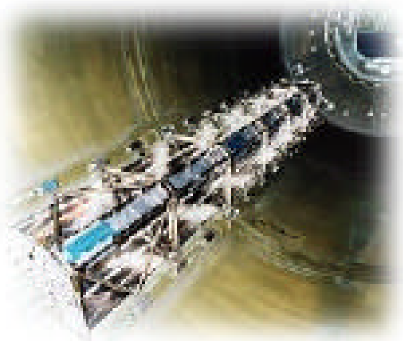


Major Research Areas

- Fundamental Biology
- Physical Science
  - Materials Science
  - Biotechnology
  - Fundamental Physics
  - Fluid Physics
  - Combustion
- Biomedical Research and Countermeasures
- Advanced Human Support Technology
- Earth Observation
- Space Science

What is our Approach to ISS Utilization?

- The ISS Flight Program arises from years of Earth based research and previous flight experience
- To ensure we communicate ISS research objectives, we are building themes around research associated with Utilization Flights (Increments 1-17)
- Each flight increment is assigned a research theme
  - ✓ The theme represents ~50% of the activity
- Initial research will validate research Facilities' performance and provide baseline data; later research will emphasize a synergistic approach



What Are Increments?

Increments unify integration, research, and crews under a single theme

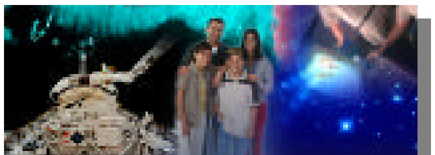
- Increments average about 4 months and are determined by crew rotations and flights to/from ISS
- Each increment has a theme that focuses on the primary science or activities performed
  - ✓ Increment 1: Bringing space to the public
  - ✓ Increment 2: Radiation
  - ✓ Increment 3: Bone and muscle research
  - ✓ Increment 4: Plants in space
  - ✓ Increment 5: From molecules to matter - *Using space to probe the forces that structure our world*

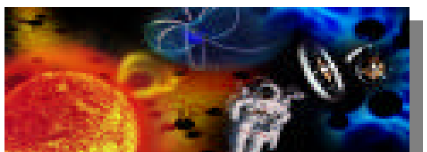
Increment 1 is here!

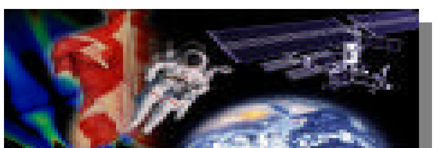
As of 11/2/2000

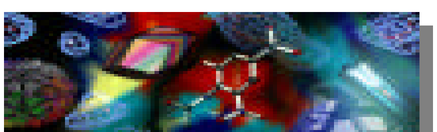
Increments and Manifesting

Manifesting assigns experiments to specific flights and crew members







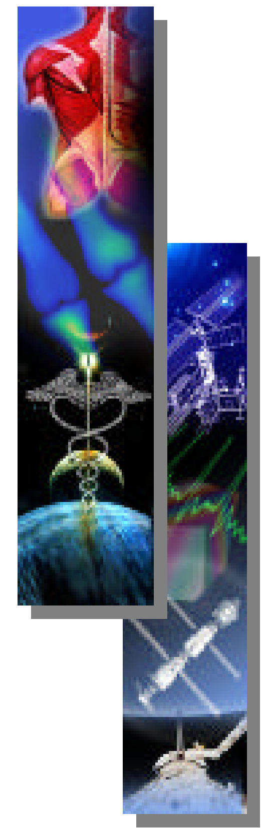


- Constraints on experiment manifesting
  - ✓ On-orbit crew time
  - ✓ Crew training and expertise
  - ✓ Residual acceleration environment
  - ✓ Upmass/downmass and stowage
  - ✓ Power
  - ✓ Refrigeration/freezer capability
- Theme development should serve as a negotiating tool in minimizing constraints

Benefits of the Increment Approach

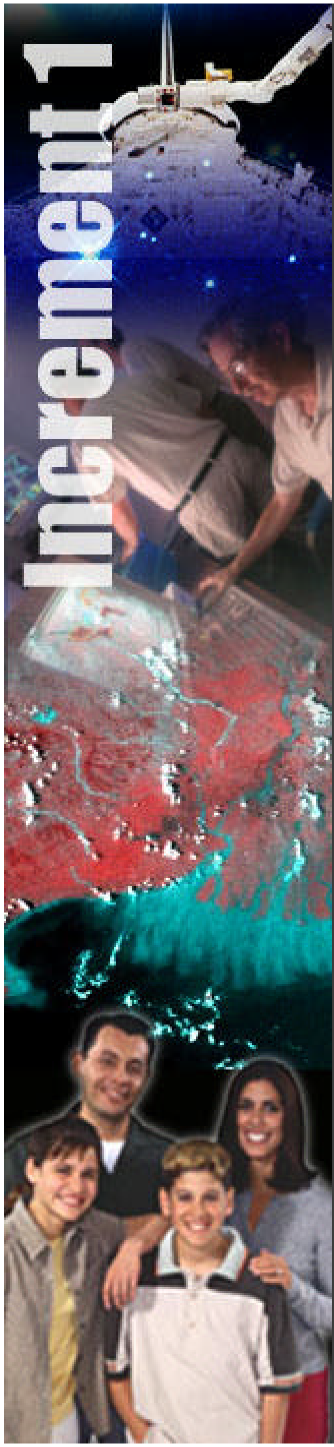
- Provides framework for long range planning and NRA development
- Better communicates our needs to the Office of Space Flight
- Explains our Research Plan to the outside community
- Supports external advocacy for resources

- To facilitate Field Center /Headquarters Communication, OBPR Project Scientists have been assigned to work with the ISS Lead Increment Scientists
  - ✓ **Stephen Davison, Ph.D.** (Increments 1-4)
  - ✓ **Louis Ostrach, Ph.D.** (Increments 5-8)
  - ✓ **Brad Carpenter, Ph.D.** (Increments 9-12)



Increment 1
Bringing Space to the Public

November 2000 to February 2001



Increment Flight Info

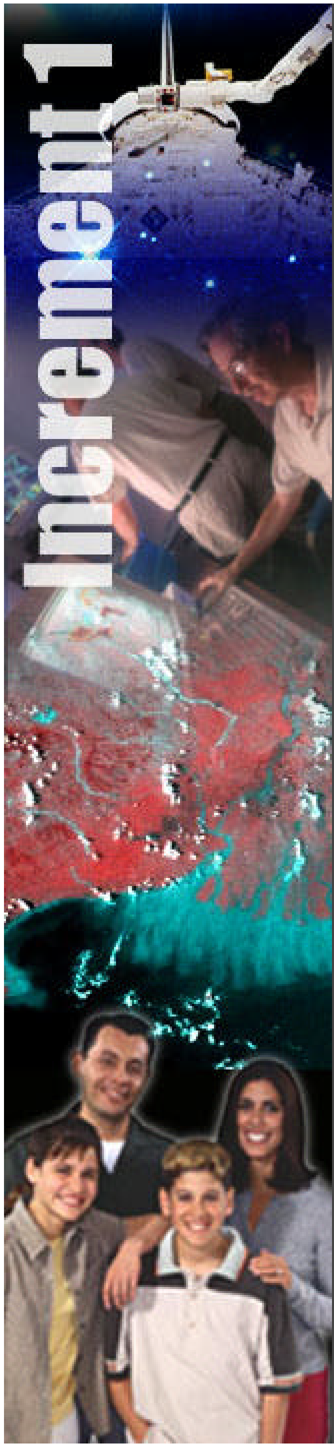
- November 2000-February 2001
- 4 Modules on-orbit
  - ✓ Unity (Node)
  - ✓ Zarya (Functional Cargo Block)
  - ✓ Zvezda (Service Module)
  - ✓ Destiny (U.S. Lab 01/01)
- 5 assembly and resupply flights
- Expedition 1 Crew arrived November 2, 2000 on *Soyuz*

ISS at end of Increment 1

Yuri Pavlovich Gidzenko

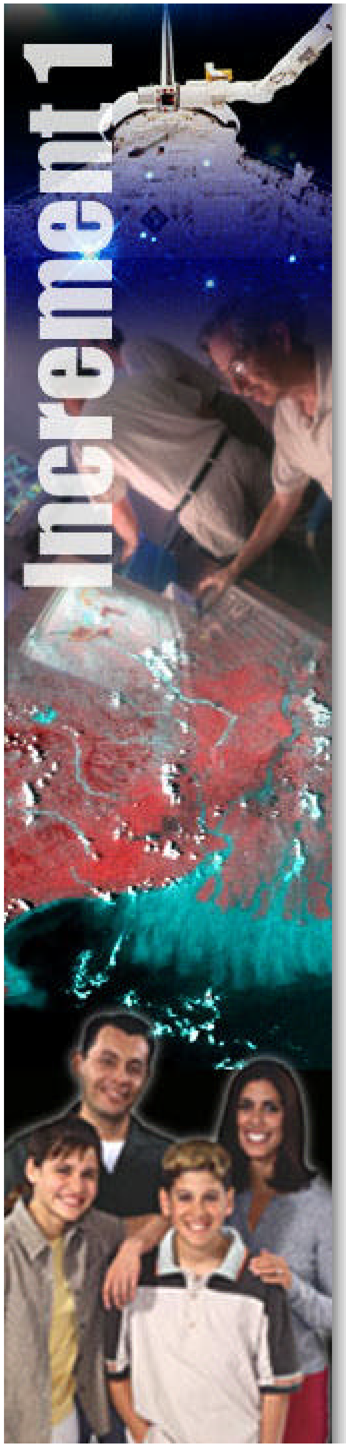
William (Bill) Shepherd
Commander

Sergei K. Krikalev



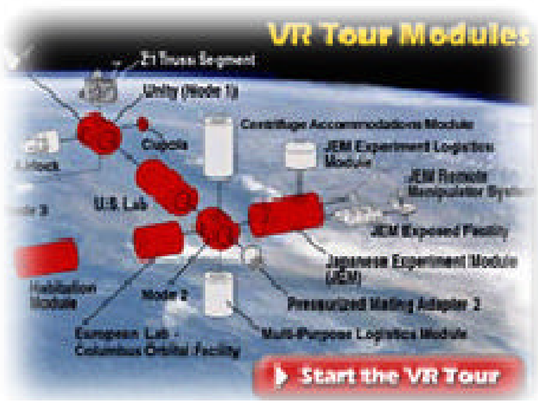
Why Bring Space to the Public?

- Space is an engaging topic that can be used inside and outside the classroom to interest students in mathematics and science
  - ✓ K-12 curriculum
  - ✓ Undergraduate & graduate research partnerships
  - ✓ Community outreach
- Space research generates technological applications & commercial products that affect lives on Earth
  - ✓ Technology transfer
  - ✓ Spin-offs
  - ✓ Space product development
  - ✓ Commercial space centers



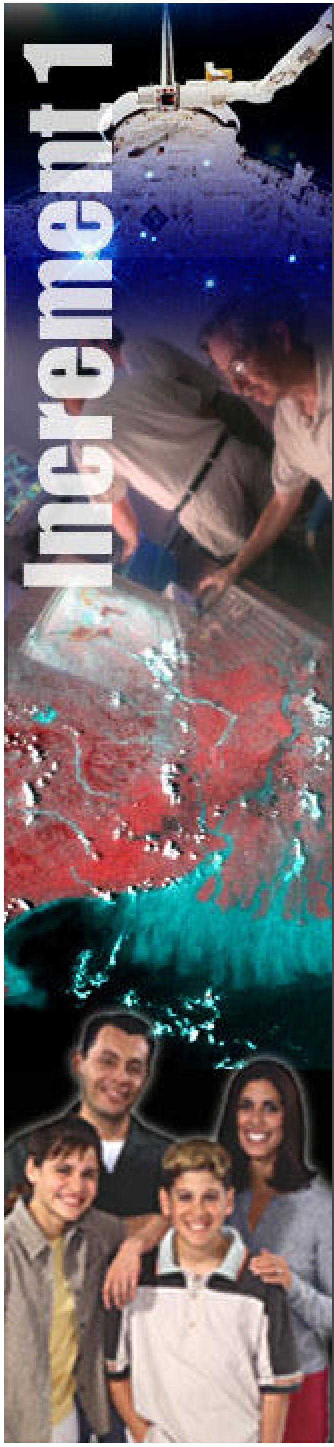
Bringing Space to the Public Through....

- Tele-education
  - ✓ Videoconferencing with ISS
  - ✓ Virtual reality tours of ISS
  - ✓ International exchange and collaboration



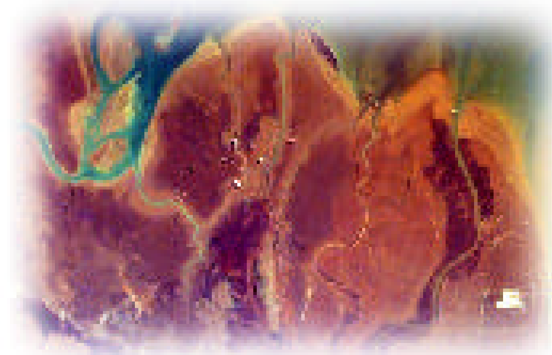
*EarthKAM, SEEDS, Earth Observations continue throughout ISS operations

- Curriculum development
  - ✓ EarthKAM (Earth Knowledge Acquired by Middle School): students conduct ISS remote sensing research
  - ✓ SEEDS (Space Exposed Experiment Developed for Students): students compare ISS-germinated seeds (ug) to seeds germinated in classrooms (1g); grades 4-9
  - ✓ Earth Observations

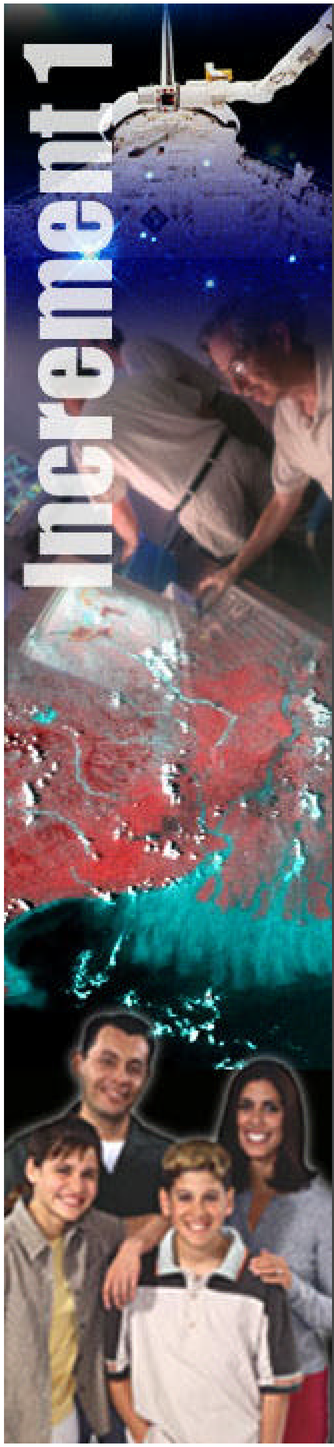


Education Activity: EarthKAM

- Began as pilot project, KidSat launched on STS-76 in March 1996 and again on STS-81 and STS-86
- KidSat evolved into EarthKAM & had its first official flight on STS-89 in January 1998
- On STS-99, the EarthKAM camera took 2,715 photographs of our planet
- Library of EarthKAM images found at http://www.earthkam.ucsd.edu/
- NASA has had requests from over 100 schools, universities, industrial, and foreign interests for images and information

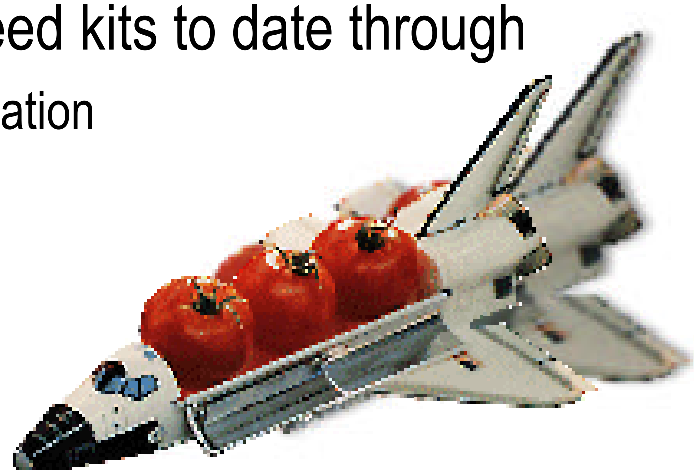


STS-99 EarthKam photo of Persian Gulf



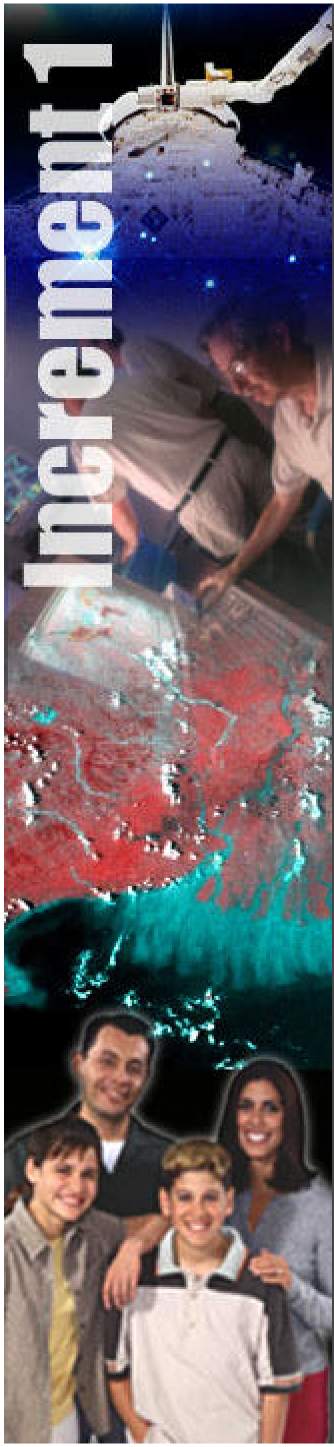
Education Activity: SEEDS

- Space Exposed Experiment Developed for Students (SEEDS) begun 1989-1990 school year by NASA HQ Education Division
- Life Sciences Outreach continued SEEDS on STS-86 and has distributed 60,000 tomato seed kits to date through
  - ✓ National Science Teacher's Association
  - ✓ Challenger Centers
  - ✓ Star Station One
  - ✓ Museums
  - ✓ Life Sciences Educator Network
  - ✓ Via channels in Ukraine and Russia



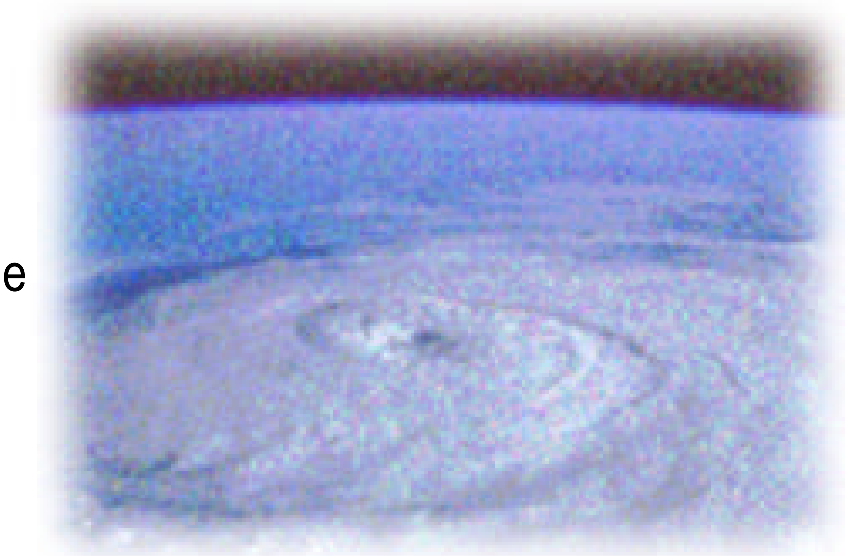
http://www.parkseed.com/framenasa.htm

- Collaboration with the JASON Project
  - ✓ Soybeans and corn grown in orbit will be compared with seeds grown in the classroom on Earth

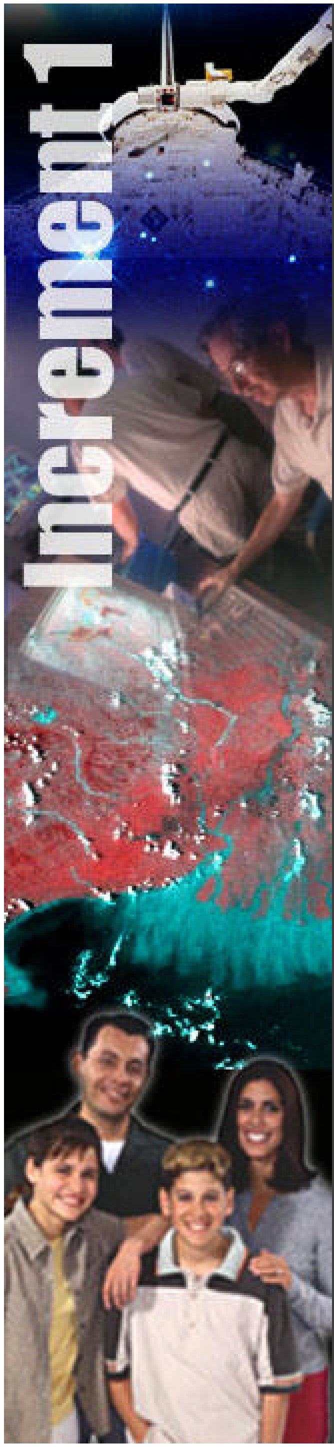


Activity: Crew Earth Observations

- Record observable Earth surface changes and image events (hurricanes, plankton blooms, volcanic eruptions)
  - ✓ Hand-held photography downlinked of selected sites
  - ✓ Add to historical data base started in 1961
- Long-term applications
  - ✓ Weather modeling
  - ✓ Environmental monitoring
  - ✓ Urban planning
  - ✓ Epidemiology (vector-borne disease tracking)

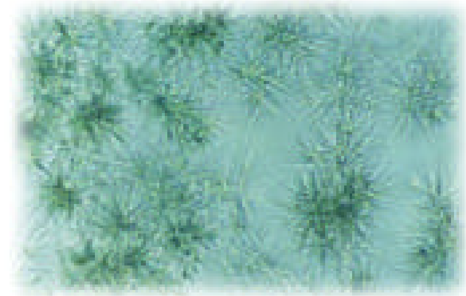


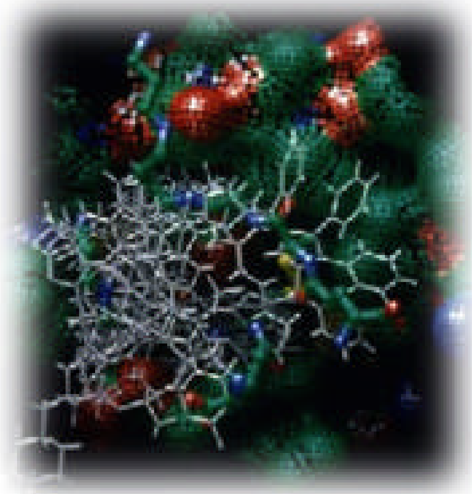
Earth Observation photos:
http://images.jsc.nasa.gov/iams/html/earth.htm



Other Increment 1 Research

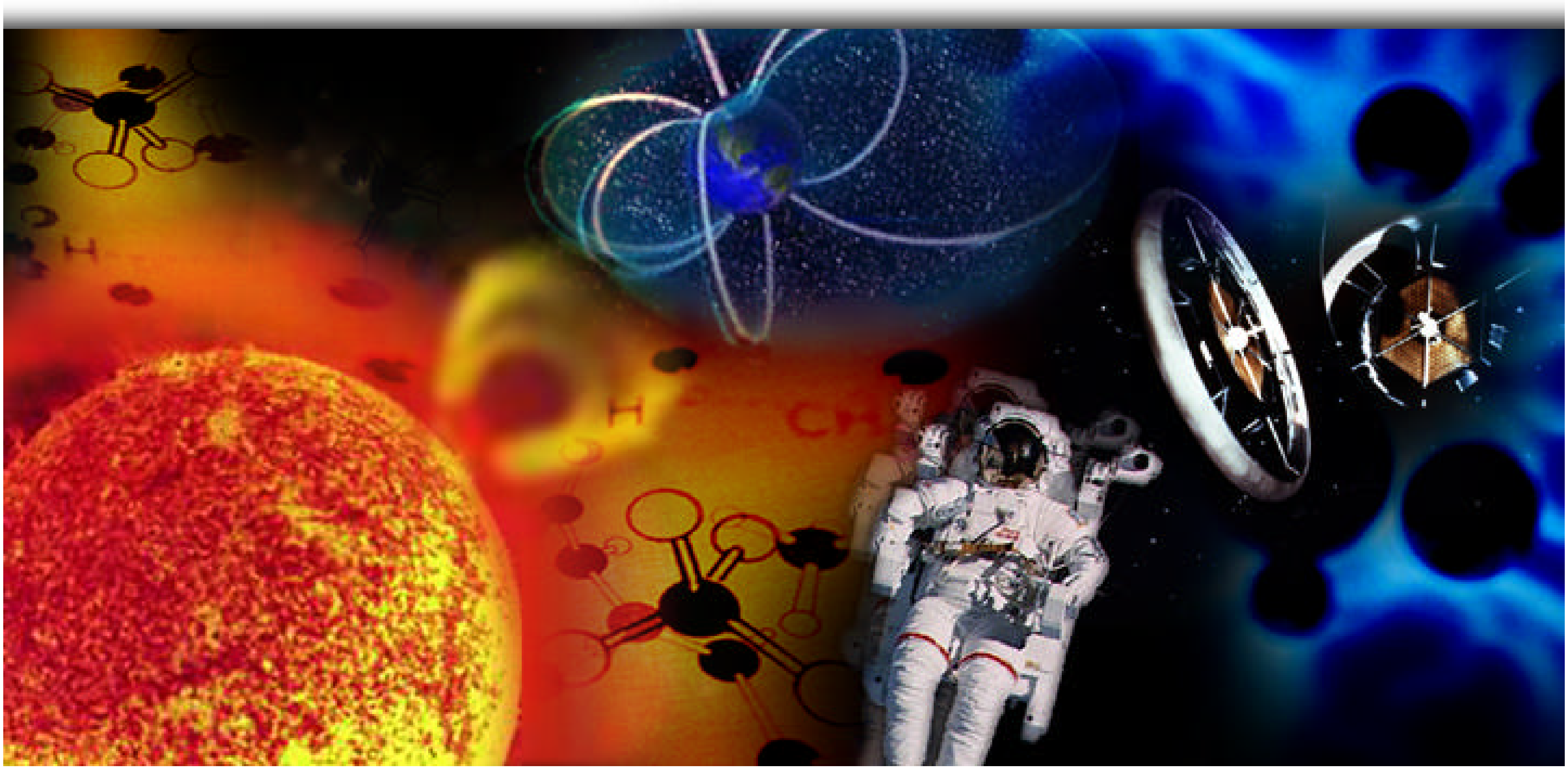
- Macromolecular crystallization
  - ✓ Protein Crystal Growth-Enhanced Gaseous Nitrogen (PCG-EGN): implementation of high-throughput biological crystal growth experiments in microgravity
    - Refining an alternate on-orbit process for crystallization
    - Extensive educational outreach effort (1000 high school teachers and ~25,000 students in 4 states: FL, TN, AL, CA)
- Space Technology
  - ✓ Middeck Active Control Experiment (MACE II): measurements of motion and vibration in advanced structures that “self adjust” to changes
    - Evaluation of autonomous satellite control algorithms
    - USAF/DOD/NASA collaboration
    - University and Small Business partners





Increment 2
Radiation Research

February 2001 to June 2001



Increment Flight Info

- February 2001-June 2001
- 4 Modules on-orbit
  - ✓ Unity (Node)
  - ✓ Zarya (Functional Cargo Block)
  - ✓ Zvezda (Service Module)
  - ✓ Destiny (U.S. Lab)

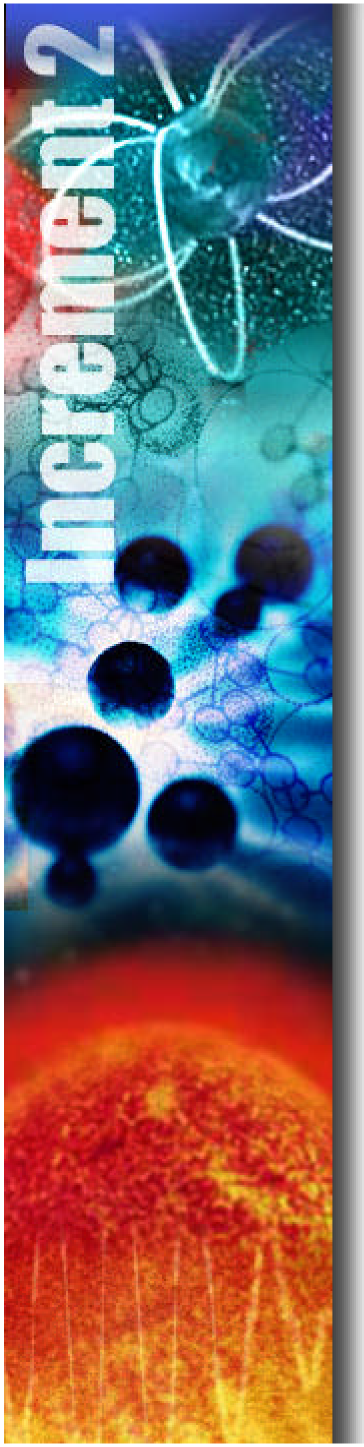
ISS at end of Increment 2

- 6 assembly and resupply flights
  - ✓ Lab outfitting 2/01(includes Human Research Facility)
  - ✓ Remote manipulator arm 4/01
- Expedition 2 Crew arrives February 2001 on Shuttle

James Voss

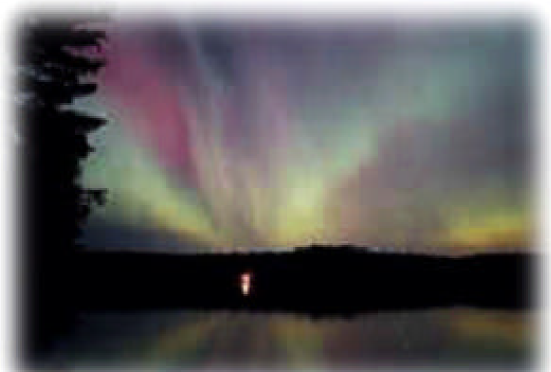
Yuri Usachev
Commander

Susan Helms



Why Study Radiation?

- On Earth, we are protected from radiation by the magnetosphere. Beyond the atmosphere, astronauts experience a steady dose of cosmic radiation
- Prolonged exposure to high radiation doses (e.g. during missions to Mars) adversely affects human health
  - ✓ Cancer
  - ✓ Genetic defects
  - ✓ Cataracts
  - ✓ Central nervous system damage
- Learn how life is affected by radiation
- Protection of ISS crews, interpretation of ISS experiments, & plans for Mars missions, require an understanding of the space radiation environment
  - ✓ Space-based research
  - ✓ Ground-based research and modeling (accelerator facilities)



Aurora borealis

Radiation Research

- Continuous monitoring of the radiation environment with dedicated equipment
  - ✓ The Phantom Torso (**TORSO**): monitors radiation absorption at brain, heart, stomach, thyroid, colon (2 month study)
  - ✓ Dosimetric mapping (**DOSMAP**): document nature and distribution of radiation inside ISS and around crew-members' bodies - German investigator, periodic data download (4 month study)
  - ✓ Bonner Ball Neutron Detector (**BBND**): monitors neutron radiation that may affect blood-forming bone marrow
    - NASDA provided hardware
    - Increments 2 and 3 (ongoing 8 months)
- Medical research and care
  - ✓ Data base of personal annual and lifetime exposure limits for crew members with regular medical examinations (ongoing)

Phantom Torso

Bonner Ball

Other Increment 2 Research

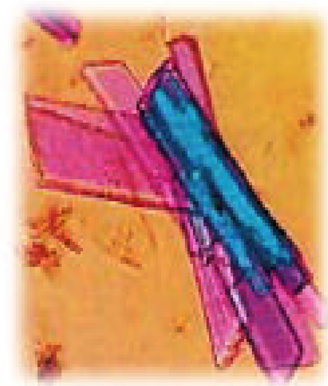
- Environmental studies
  - ✓ Space Acceleration Measurement System (**SAMS II**) & Microgravity Acceleration Measurement System (**MAMS**): measurements of ISS vibration and gravitational levels (continuous throughout ISS operation)
- Bone & muscle studies
  - ✓ **Subregional Bone**: monitors the magnitude and distribution of bone loss during space flight (Increments 2-6, pre/post flight measurements)
  - ✓ **H-REFLEX**: confirm decrease in spinal cord reaction in µg; inflight measurements (Increments 2-5)

Crewmember completing a questionnaire

- Psychosocial studies
  - ✓ **Interactions**: identify and define interpersonal factors that may affect flight and ground crew (done during flight throughout 7 Increments)

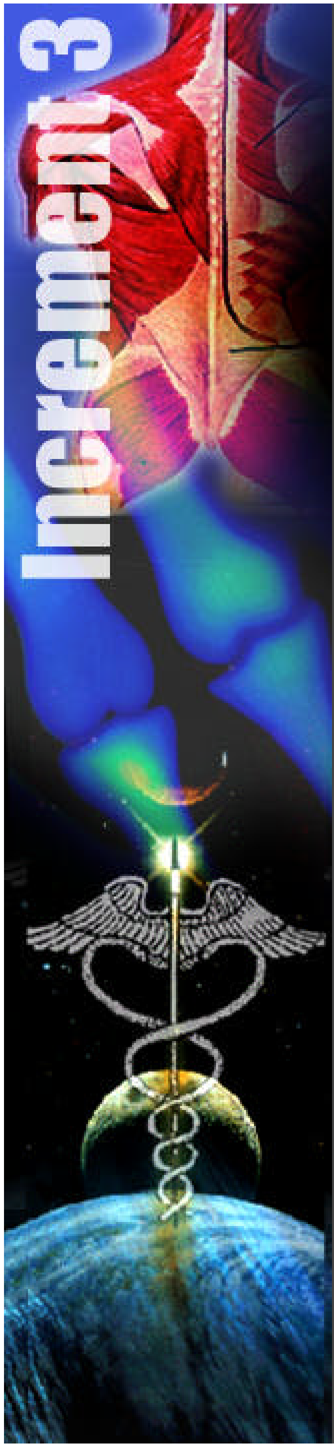
Other Increment 2 Research

- Fluids science
  - ✓ Physics of Colloids in Space (PCS): study of the formation and structure of colloids in space to further understanding of self-assembly mechanism of complex systems (continues through 3 increments)
- Commercial research & development
  - ✓ Advanced Astroculture: initial capability for growing commercially valuable crop specimens (2-month study with new system brought up to ISS on subsequent Increments)
  - ✓ Commercial Protein Crystal Growth: growth of large high-quality crystals for structural studies (2-month study)
- Protein crystallization
  - ✓ Biotechnology Ambient Generic Protein Crystal
  - ✓ Growth-(PCG-BAG): on-orbit diffusion controlled crystallization of large protein crystals (1 Increment)
  - ✓ PCG-Single Locker Thermal Enclosure System (STES): 1-4^{o}C controlled temperature studies (ongoing starting with Increment 2)



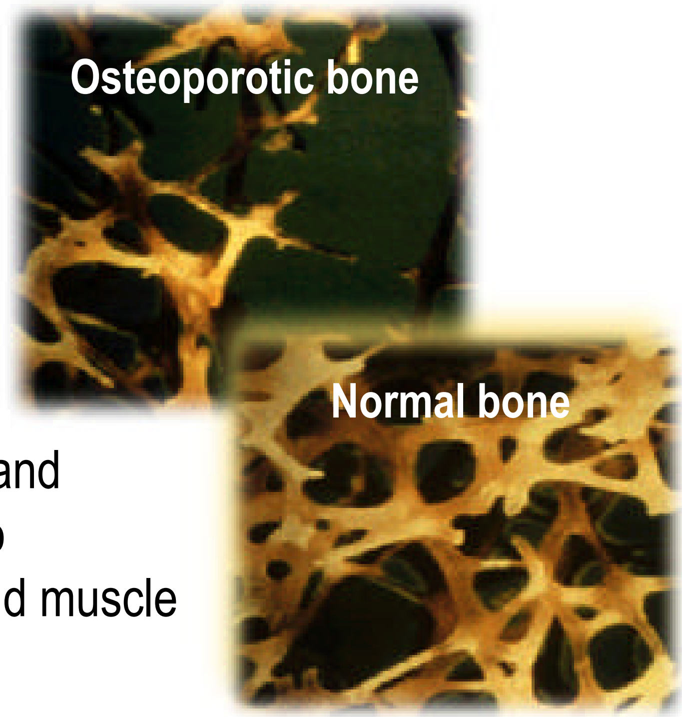
Increment 3
Bone and Muscle Health

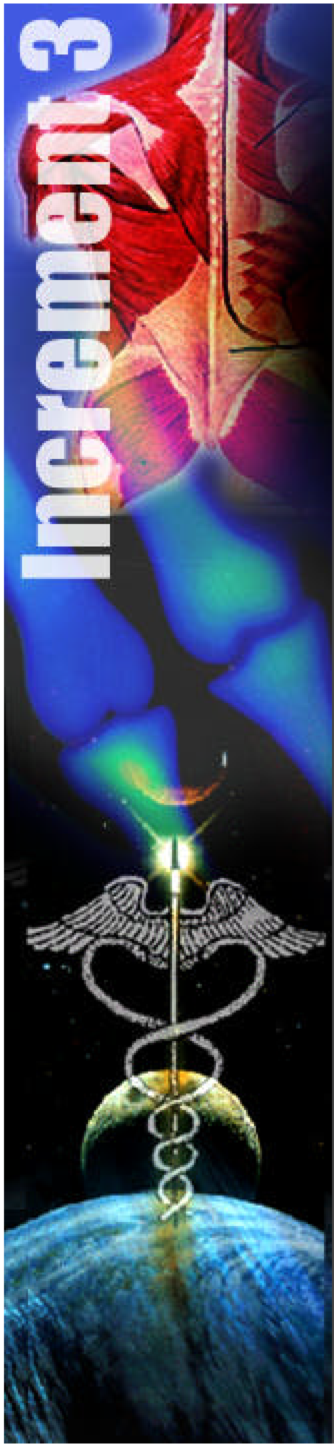
June 2001 to October 2001



Why Study Bone and Muscle?

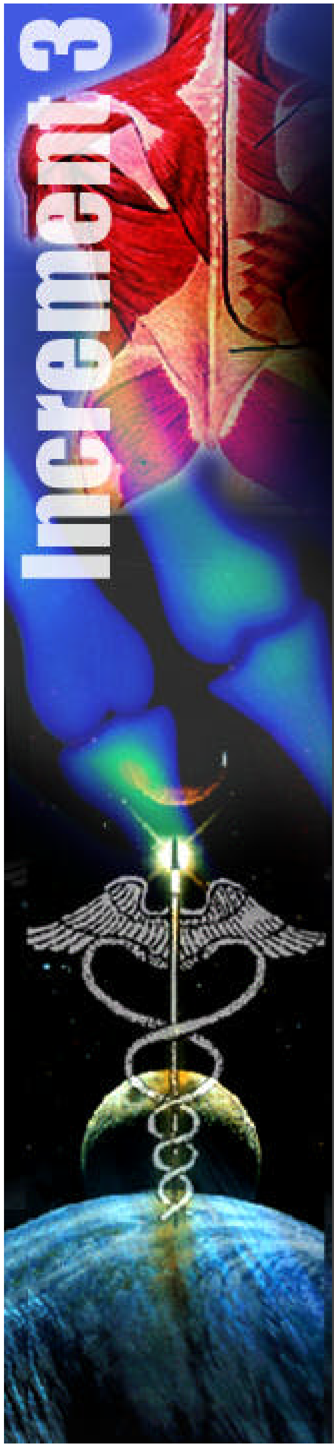
- Prolonged exposure to microgravity causes loss of bone mass (similar to osteoporosis) and atrophy of muscles
  - ✓ Higher risk for bone fracture upon return to Earth
  - ✓ Potential for "slipped discs"
  - ✓ Diminished ability to quickly respond to emergencies
- Astronaut recovery to pre-flight levels of bone and muscle mass may take several years
  - ✓ In-flight countermeasures (aerobic and resistive exercise) are insufficient to maintain pre-flight levels of bone and muscle





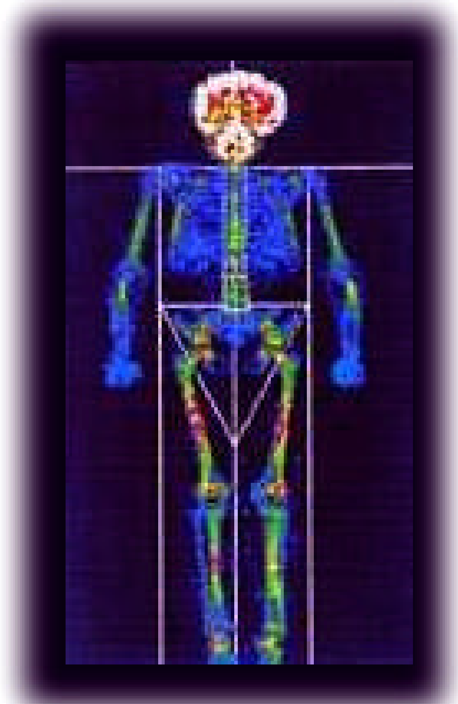
Space Studies & Earth Correlation

- Bone and muscle mass loss in space resemble some forms of bone loss on Earth (osteoporosis), but is reversible
- The treatment of bone and muscle mass loss in space may hold clues as to how to treat similar conditions on Earth, while research on how to treat terrestrial bone and muscle conditions may aid NASA in its search for bone and muscle countermeasures



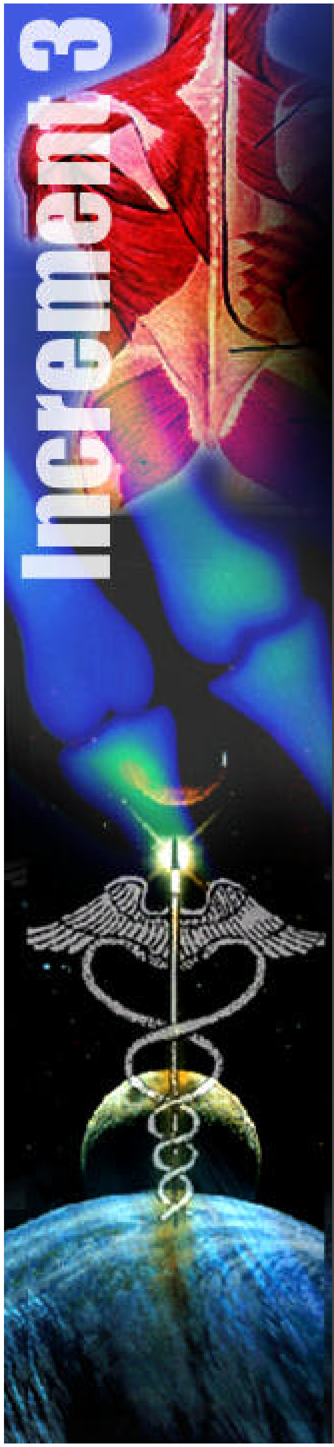
Space Studies & Osteoporosis on Earth

- Men and women of all ethnicity are at risk of developing osteoporosis
- 10 million Americans currently suffer from osteoporosis*
  - ✓ 8 million women
  - ✓ 2 million men
- 28 more million Americans are currently at risk of developing osteoporosis*
- Osteoporosis causes over 1 million injuries annually*
  - ✓ 300,000 hip fractures
  - ✓ 700,000 vertebral fractures
  - ✓ 250,000 wrist fractures
- Osteoporosis and osteoarthritis cost the United States at least $50 billion a year in treatment and lost wages



Bone Mineral Density (BMD) scans identify people at risk for osteoporosis

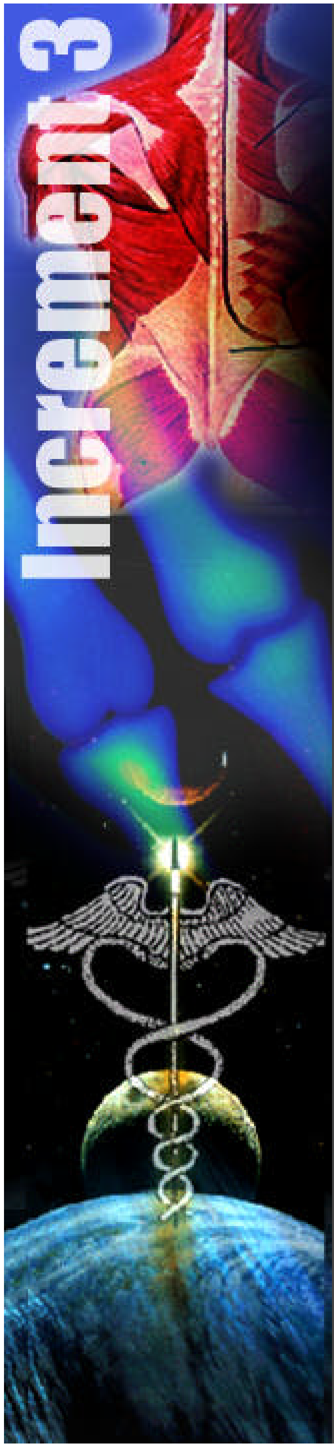
**Source*: National Osteoporosis Foundation*



Space Studies and Muscle on Earth

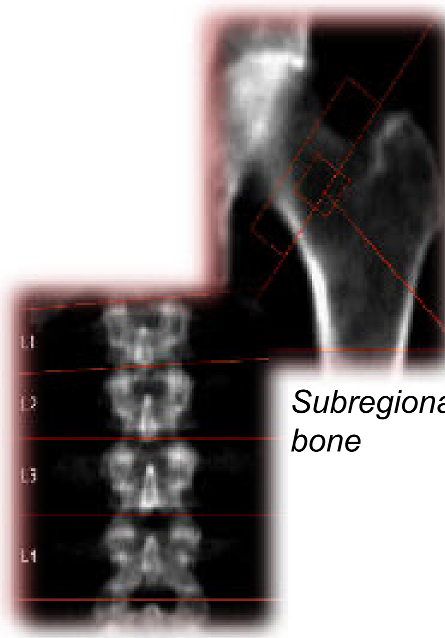
- Muscle atrophy occurs as a result of the aging process, disuse (following illness or injury), or disease.
  - ✓ Aging: a healthy person at age 70 has about 30% less skeletal muscle mass than at age 25 or 30
  - ✓ Disuse: spinal cord injury (occur in 12,000-15,000 people annually; 10,000 are permanently paralyzed)
  - ✓ Disuse: stroke (affects 1 in 250 people)
  - ✓ May be aggravated by or exacerbate osteoporosis

- Currently, physicians have few options to prescribe for patients with muscle atrophy. Space research designed to counteract space flight-induced muscle atrophy may contribute to a better understanding of and treatments for muscle atrophy on Earth.
  - ✓ Resistive exercise has allowed previously sedentary 60-to-72-year-old men to double their strength and significantly increase muscle size

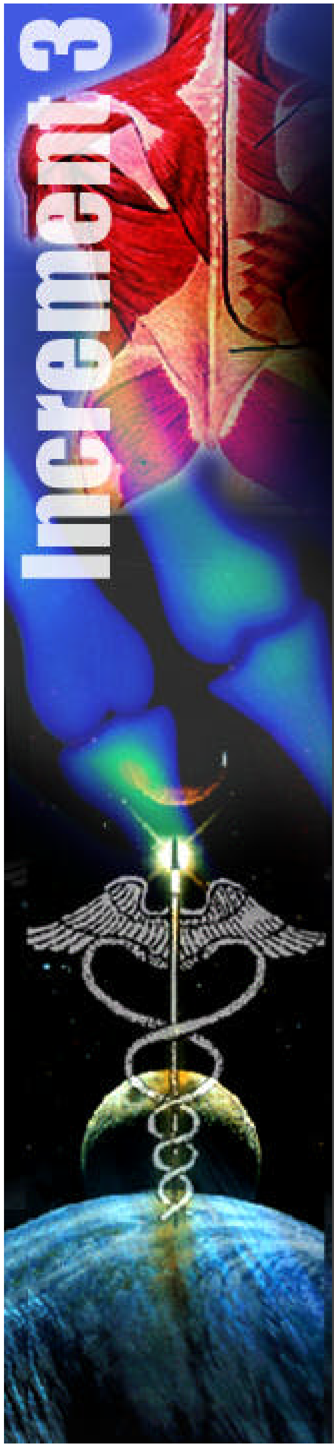


Increment 3 Research: Bone & Muscle

- Effects of space flight on muscle
  - ✓ Effect of Prolonged Space Flight on Human Skeletal Muscle (**BIOPSY**): effects of microgravity on muscle structure and function (pre/post flight measurements over 3 alternating Increments)
  - ✓ **H-REFLEX**: confirm decrease in spinal cord reaction in microG (inflight measurements from Increments 2-4)
  - ✓ **Xenon 1**: effects of microG on blood flow to leg and resultant muscle activity (pre/post flight measurements, Increments 3-6)
- Effects of space flight on bone
  - ✓ **Subregional Bone**: magnitude and distribution of bone loss during long-duration space flight; recovery of bone mass post-flight (pre/post flight measurements, Increments 2-7)

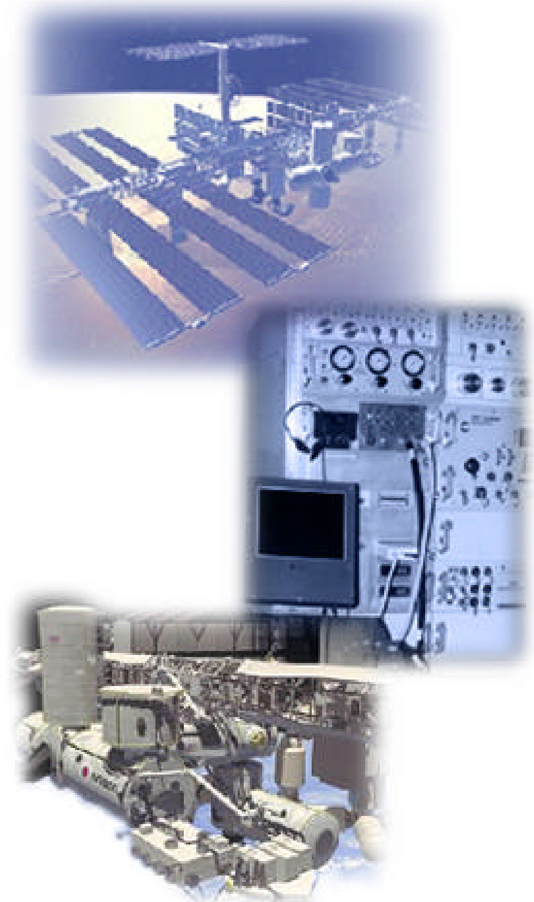


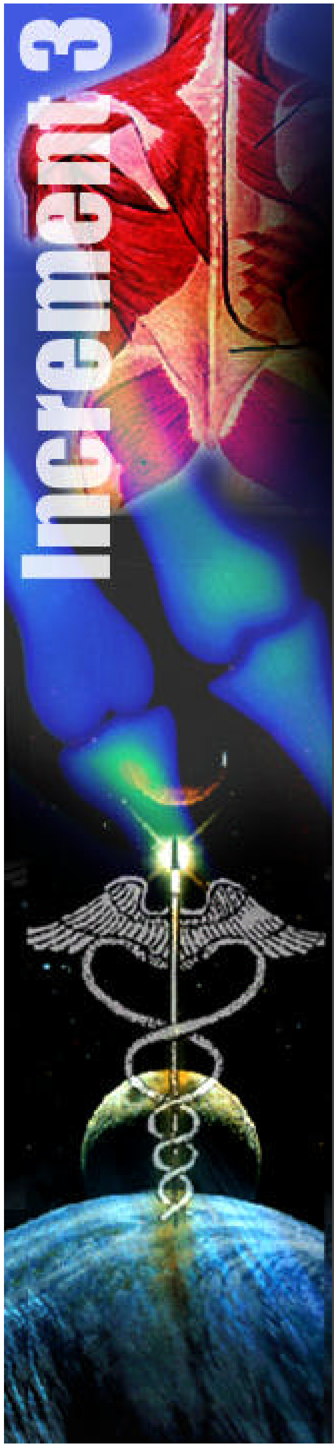
Subregional bone



Other Increment 3 Research

- Crystal growth
  - ✓ Dynamically Controlled Protein Crystal Growth (DCPCG-V/C): development automated system and procedures for vapor-diffusion approach to crystal growth
  - ✓ Zeolite Crystal Growth: develop a nucleation and growth data base to improve the process leading to enhanced catalytic performance of zeolites
  - ✓ Advanced Protein Crystallization Facility (APCF): on-orbit crystallization of large protein crystals providing undisturbed nucleation; provided by Italian Space Agency (Code M activity)





Other Increment 3 Research

- Cell biology
  - ✓ Biotechnology Specimen Temperature Controller & Biotechnology Refrigerator (BSTC/BTR): examination of cell to cell interactions in quiescent cell culture environment and their role in cell aggregates; cell types include: ovarian cancer, colon cancer, renal normal, rat PC-12 (increment 3 into 4 (6 months))
- Human physiology
  - ✓ PuFF: effects of μg and EVA on pulmonary function (inflight activities, increments 3-6)
  - ✓ Renal Stone: examination of in-flight susceptibility of astronauts to renal stone formation (in flight increments 3-12)

Increment 4
Plants in Space

October 2001 to February 2002

Studying Plants in Space

- Increment 4 is the first increment with multiple plant experiments and multiple plant facilities
- By full up utilization, several plant facilities will be on ISS.
The Plant Research Unit (PRU) will have the capability to be mated with the centrifuge.

Why Study Plants?

- *Plant* development is influenced by gravity
  - ✓ ISS experiments may shed light on plant development processes that aid researchers on Earth
  - ✓ Long-duration human space missions will require biomass production for food sources, environmental control, and perhaps even systems operations
  - ✓ Mir experiments by Musgrave, demonstrating seed to seed germination, paved the way for continuing studies.

Brassica rapa

Plants in Space

Biomass Production System (BPS) will have the following research objectives:

- Performance of peer reviewed science protocol studying the effects of μg on wheat photosynthesis and metabolism
- Technology validation of BPS subsystems and their ability to support plant growth (wheat and Brassica) in μg (increment 4 only)
- Risk reduction to development of dedicated ISS Plant Research Unit (which will interface to the centrifuge as a permanent facility)

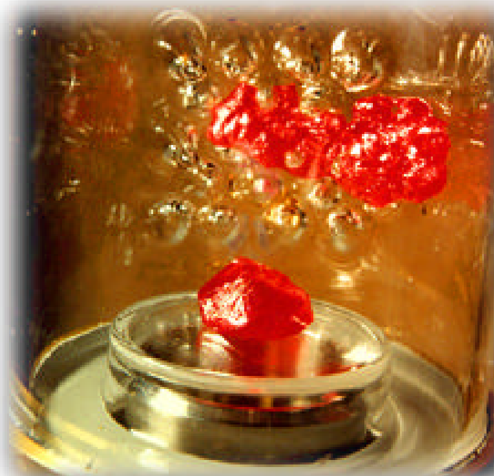
Biomass Production System

Plants in Space

- Advanced Astroculture (ADVASC)
  - ✓ Provide initial capability to grow commercially valuable crop specimens (soybeans, wheat, miniature tuber potatoes) from seed to maturity
    - One set of experiments on Increment 4 - 4 months
    - Second set of experiments started spanning increments 4 and 5
- Commercial Generic Bioprocessing Apparatus (CGBA)
  - ✓ Applications toward agricultural plants
    - Duration& plant types TBD

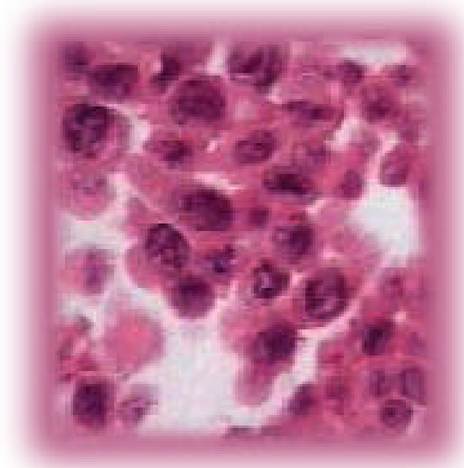
Other Increment 4 Research: Crystals, Cells, & Environment

- Crystallization and Cell Biology Experiments
  - ✓ Protein Crystal Growth-Single Thermal Enclosure System (PCG-STES): new technology for macromolecular structural biology; controlled temperature from 1-40^{o}C (4 months)
  - ✓ Zeolite CGF: growth of larger, more pure zeolite crystals (ongoing during multiple Increments to 2002)
  - ✓ Commercial Protein Crystal Growth (CPCG): growth of large high-quality crystals for structural studies leading to pharmaceutical design (1 month during Increment 4, 2nd set of multi-increment experiments started increment 5)



Other Increment 4 Research: Crystals, Cells, & Environment

- Protein Crystal and Cells Experiments (cont.)
  - ✓ Microencapsulation Electrostatic Processing System (MEPS): process for production of large quantities of drugs
  - ✓ Rotating Wall Perfusion System (RWPS): continuation of growth of carcinoma cells in bioreactor (started as Increment 3 experiments)



Cancer cells cultured in bioreactor

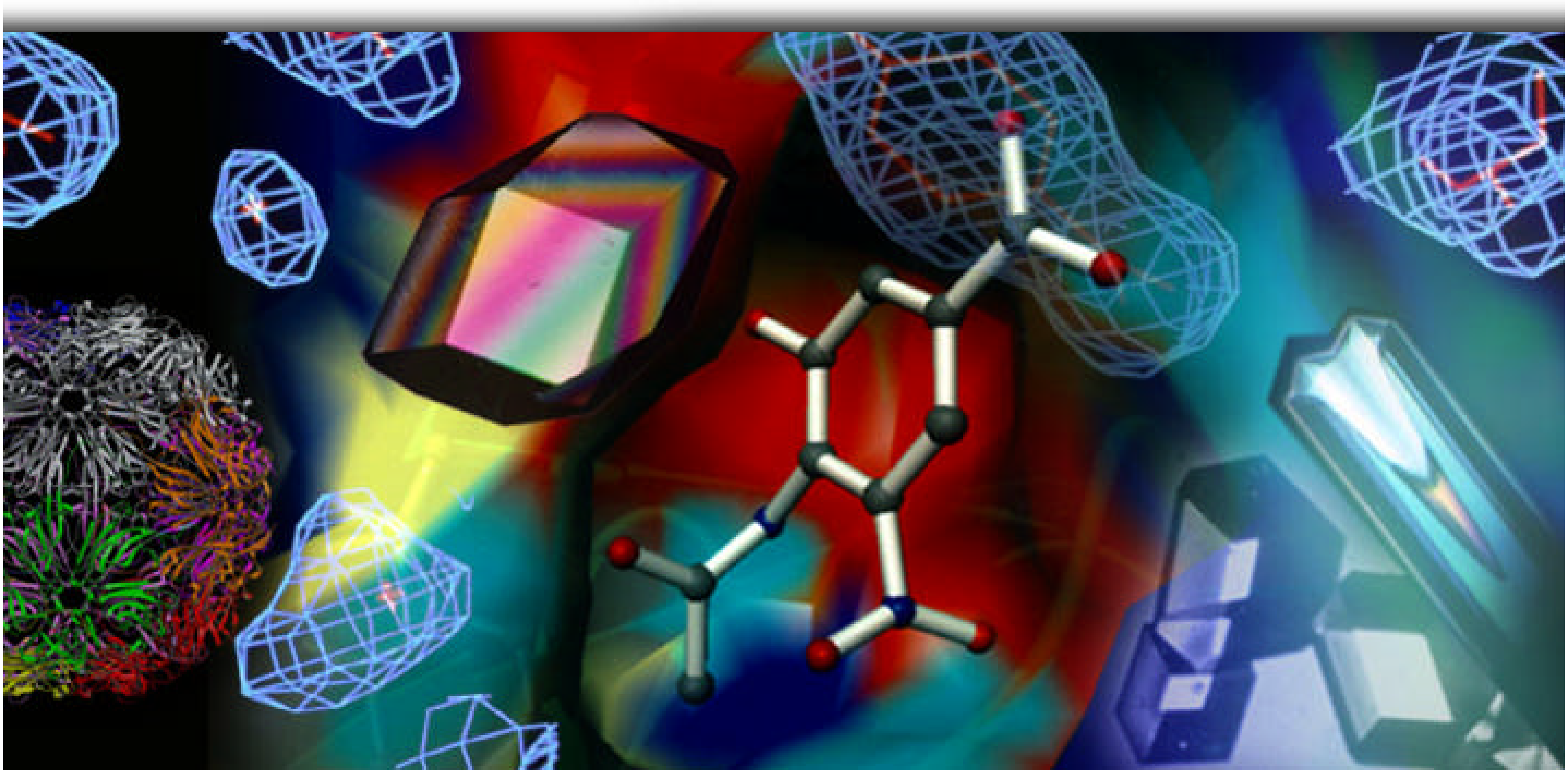
- Microgravity Glove Box (**MSG**) brought to US Lab
- Environmental Studies
  - ✓ g-LIMIT: vibration isolation system for glove box facility; functionally tested to become part of the MSG

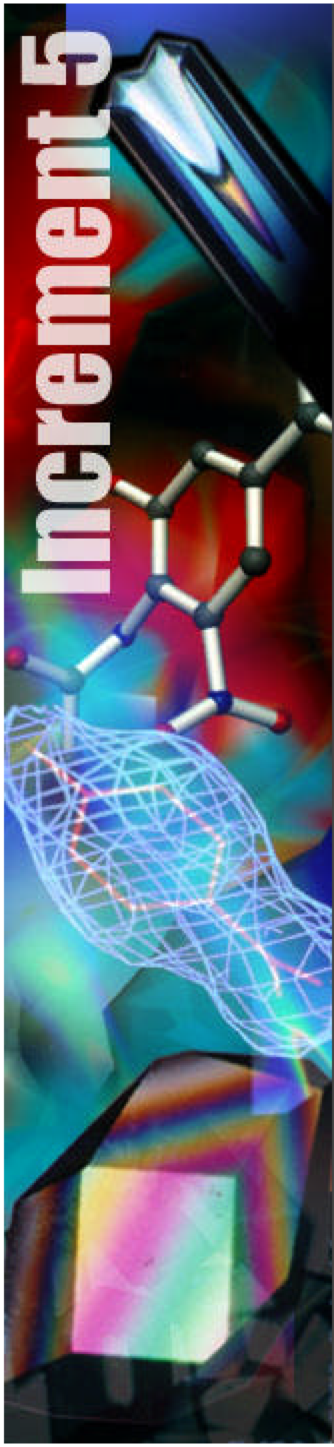
Increment 5

From Molecules to Matter

Using Space to Probe the Forces that Structure Our World

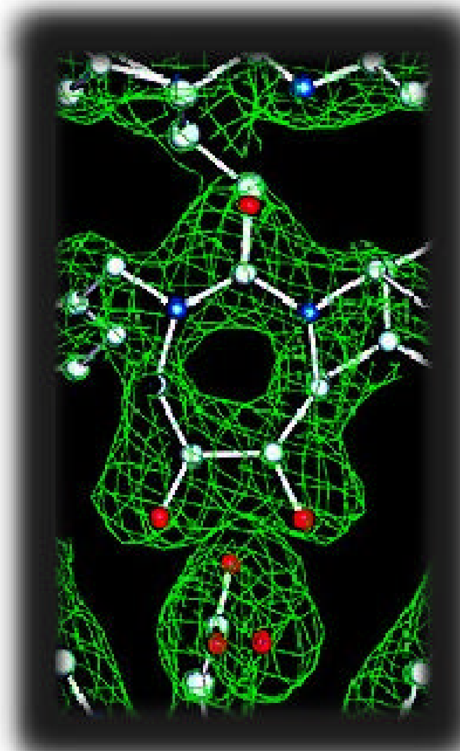
October 2001 to February 2002

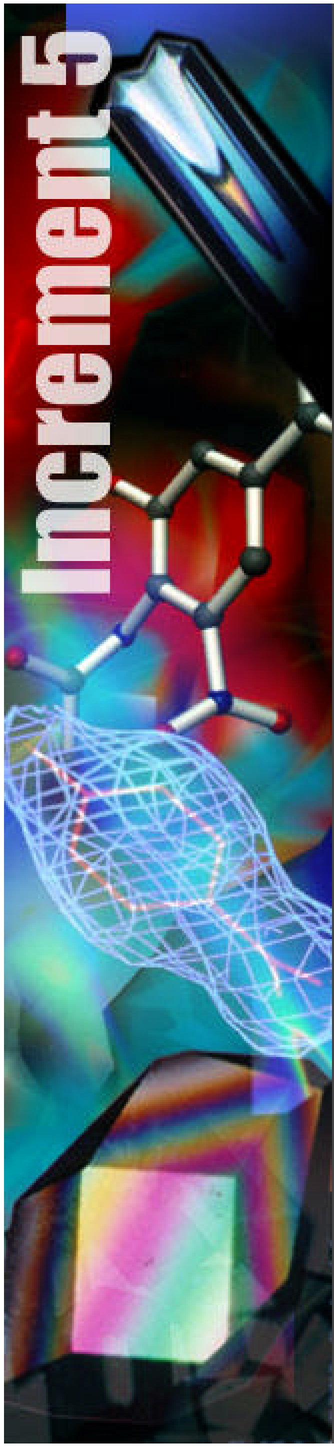




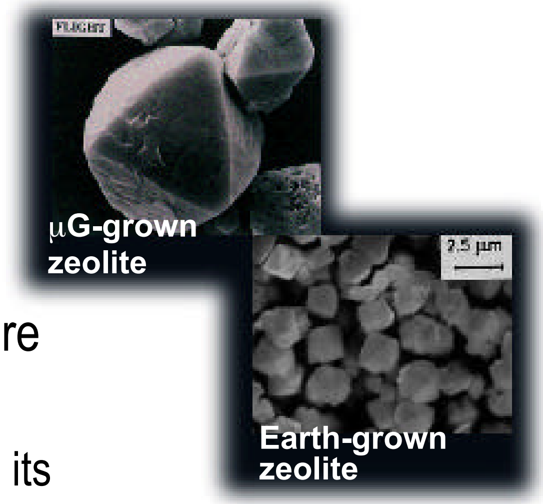
Why Study Matter in Space?

- On Earth, the forces that give rise to structure in matter are often overlaid by the gravity-driven forces of buoyancy / sedimentation, convection, and hydrostatic pressure
- Under certain conditions, there may be differentiation in materials such as:
  - ✓ Organic macromolecules (proteins, viruses, RNA, carbohydrates, etc.)
  - ✓ Zeolites
  - ✓ Detector crystals
- Crystals are mapped and structurally analyzed using crystallography on the ground



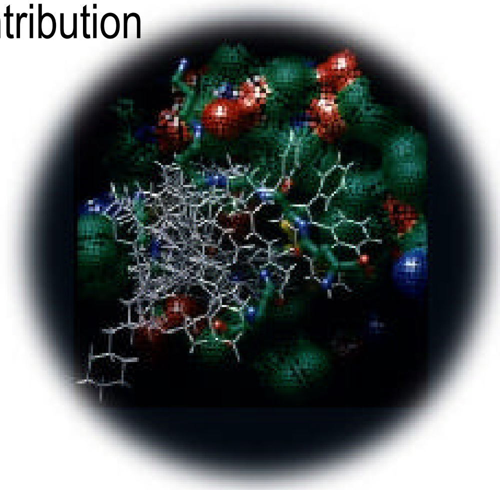


Matter Research & Earth Benefits

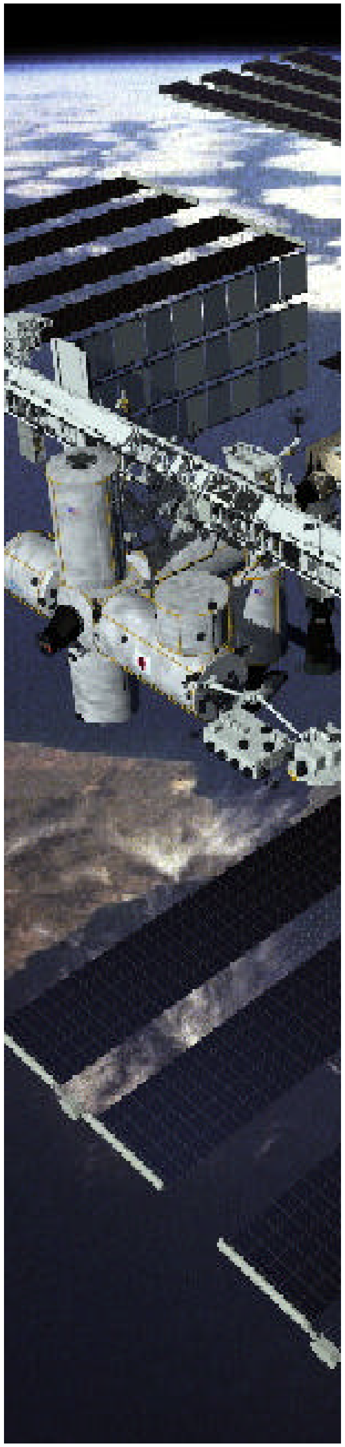


- Space-grown protein crystals enhance the ability of scientists to study the intricate structure of a protein
  - ✓ Greater understanding of the human body and its normal and diseased states through proteomics
  - ✓ Ability to develop improved drugs for through a contribution to structural biology

- Zeolite crystals, important components of the chemical process industry, may be more easily analyzed and understood with microgravity-grown chemically purer specimens with reduced defect density
  - ✓ Cleaner, more efficient chemical processes
  - ✓ New products (fuel, semiconductors, detergents, filters)



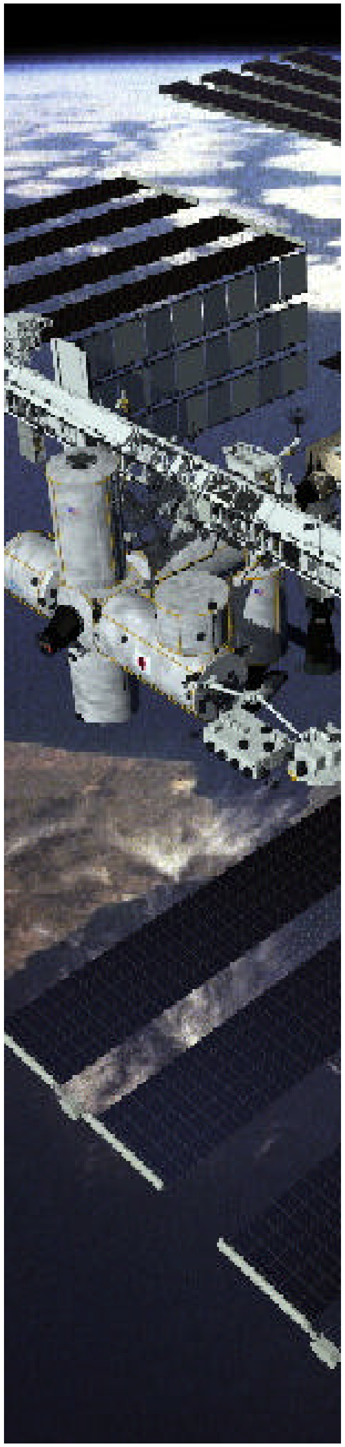
Model of protein based on analysis of space-grown crystal



ISS Biology Research Facilities @ Assembly Complete

- Human Research Facility (HRF) containing multiple pieces of equipment to support medical monitoring equipment* (2/01 and 2/02)
- Life sciences glove box (9/04)
- Biology habitats
  - ✓ Cells (9/04 and 2/05)
  - ✓ Insects (9/04)
  - ✓ Rodents (rats, eventually mice - 10/05)
  - ✓ Plants (07)
  - ✓ Fish (fresh water and marine-07)
  - ✓ Egg Incubator (07)
- Centrifuge for biology habitats (5/06)

*Elements of the Crew Health Care System may be used in research activities as required and available



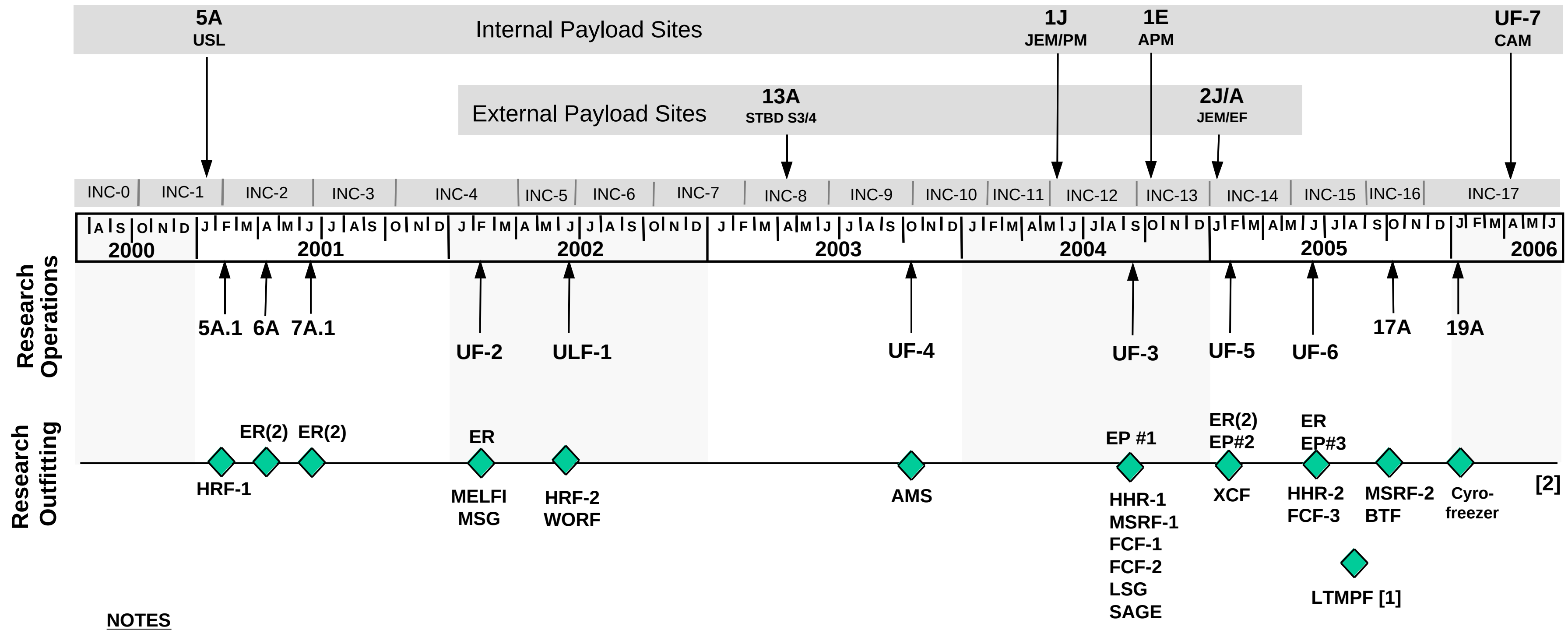
ISS Physical Sciences Research Facilities @ Assembly Complete

- Microgravity Sciences Glove Box (10/01)
- Alpha Magnetic Spectrometer (10/03)
- Materials Science Research Facility (9/04)
- Fluids and Combustion Facility (9/04)
- Biotechnology Facility (10/05)
- Low Temperature Microgravity Physics Facility (9/05)
- Laser Cooling and Atomic Physics Facility (05)

Note: Commercial research facilities will be interchanged within EXPRESS Racks as required and scheduled. Commercial researchers may also have access to both biology and physical sciences research facilities aboard the ISS as research plans permit and as agreed upon between NASA and the commercial researcher.

Utilization Sequence for ISS Research

Based on the
Rev F Assembly Sequence (8/24/00) and
Draft Multilateral Payload Outfitting Model (8/10/00)



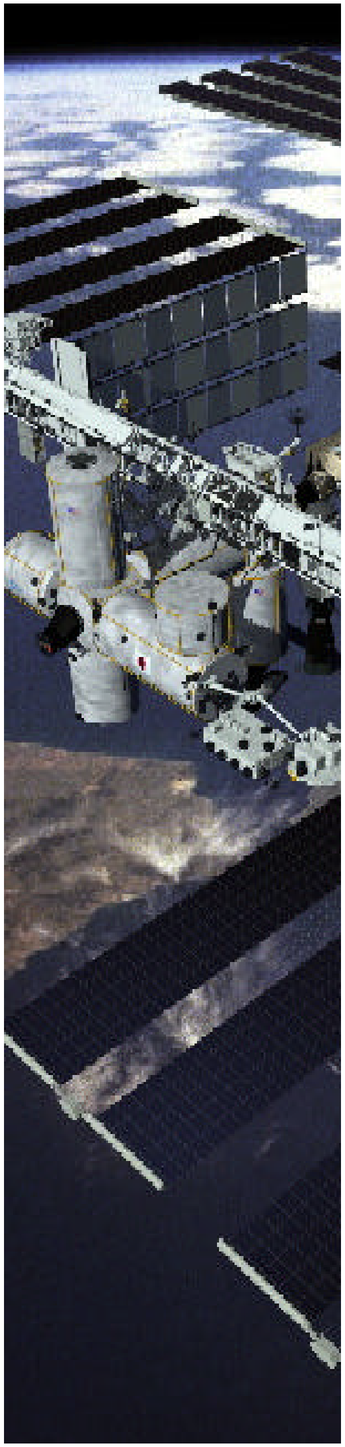
NOTES

[1] LTMPF delivery TBD; carrier under review (originally on HTV2).

[2] Racks deferred to 2006+: MSRF-3, AHST, Comm. Materials

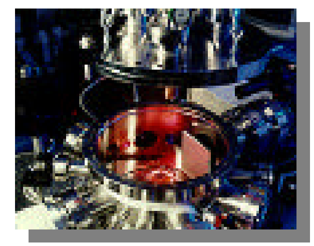
ACRONYMS

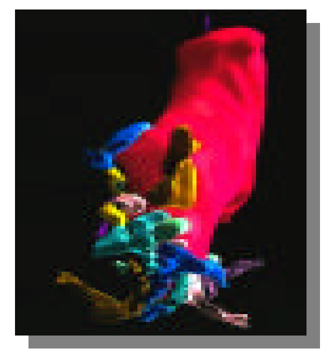
AHST: Advanced Human Support Technology
AMS: Alpha Magnetic Spectrometer
APM: Attached Pressurized Module
BTF Biotechnology Facility
CAM: Centrifuge Accommodation Module
EP: EXPRESS Pallet
ER: EXPRESS Rack
FCF: Fluids and Combustion Facility
JEM/PM: Japanese Experiment Module / Pressurized Module
JEM/EF: Japanese Experiment Module / Exposed Facility
HHR: Habitat Holding Rack
HRF: Human Research Facility
INC: Increment
LSG: Life Sciences Glovebox
LTMPF: Low Temperature Microgravity Physics Facility
MSRF: Materials Science Research Facility
MSG: Microgravity Sciences Glovebox
MELFI: Minus Eighty Degree Life Sciences Freezer
SAGE: Stratospheric Aerosol & Gas Experiment
STBD S3/4: Starboard Truss Segment 3/4
USL: US Lab
WORF: Window Observational Facility
XCF: X-ray Crystallography Diffraction System

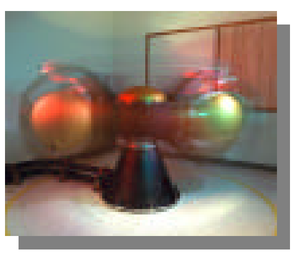


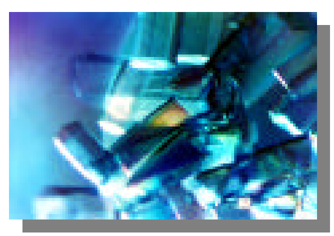
ISS Research Plan: What Needs to be Done?

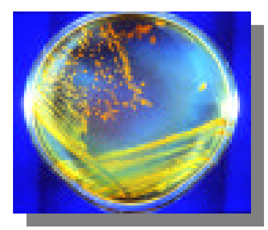
- Define themes for Increments 6-12 for existing experiment manifest and expand on manifest where needed
- Develop targeted research needs for Increments after 13 (2004) with NRA solicitations starting 2001
- Request Science Community to advocate for resources to support a ground:flight ratio of 4-6:1











The Final Result--

Full up outfitted International Space Station supporting the research requirements of the science community!