Science of Advanced Materials on the Space Shuttle & the International Space Station – Spin off applications on Earth

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Experiments in Space
Combustion
USML-2
USML-2
Advanced Materials
zeolites
25 μm
Biomaterials, Plant growth
Human Life Sciences

Why Grow Advanced Material Crystals in Space?

SCIENTIFIC RATIONAL

Eliminate sedimentation

Diffusion limited growth

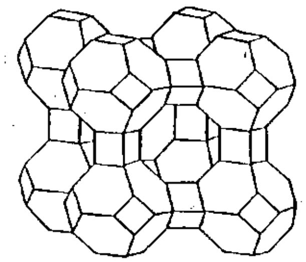
Secondary nucleation effects minimized

Overall effect : crystals with fewer defects

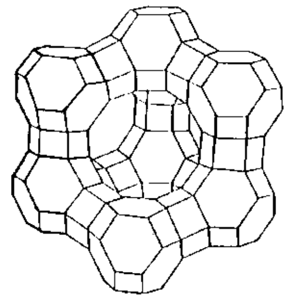
Economic Rational (Zeolites)

Chemical Process Industry's major catalytic material,
Wide range of applications,
Exotic use

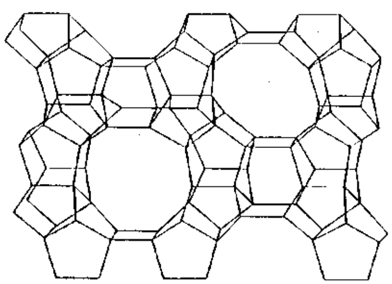
ZEOLITE- MOLECULAR SIEVE



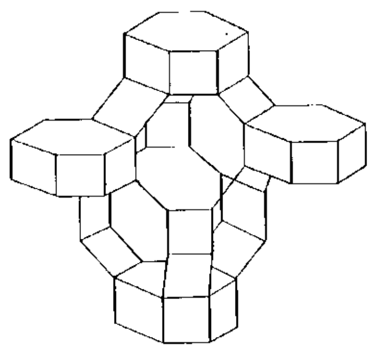
ZEOLITE A



FAUJASITE



PENTASIL LAYER



CHABAZITE

Zeolites (more than 50 types)

Alumino silicate crystals

$M_{2/n}$-Al_2O_3-$xSiO_2$-yH_2O

Nanoporous crystal structure.

Some areas of use: - Economic and social impact

- Cat. cracking in petroleum refineries (gasoline production)
- ion exchangers (water treatment , powdered detergents)
- gas or liquid separation processes, petrochem. catalysts
- nanocomposites , antibacterials, hosts for microencapsulation.

Worldwide market over 2.5 billion USD

Categories of Crystals Growth in Space

SOLUTION

Proteins

(Drug Design)

Zeolites

(petrochemicals
Fuel cells,
Antibacterial agents)

VAPOR Phase

Mercury Cadmium Telluride

$Hg_{1-x}Cd_xTe$

Electronics

From MELTS

Gallium Arsenide

GaAs (selenium doped)

Mercury Zinc Telluride

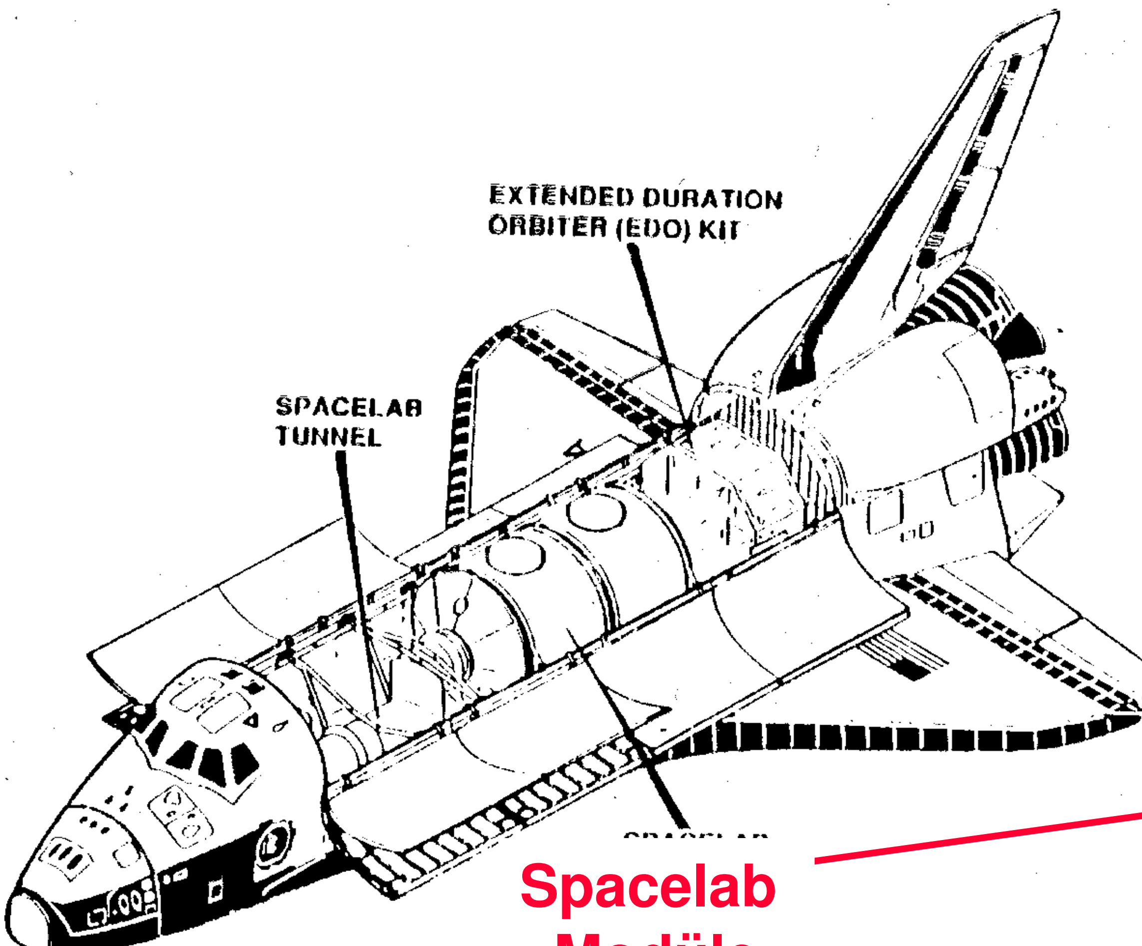
$Hg_{1-x}Zn_xTe$

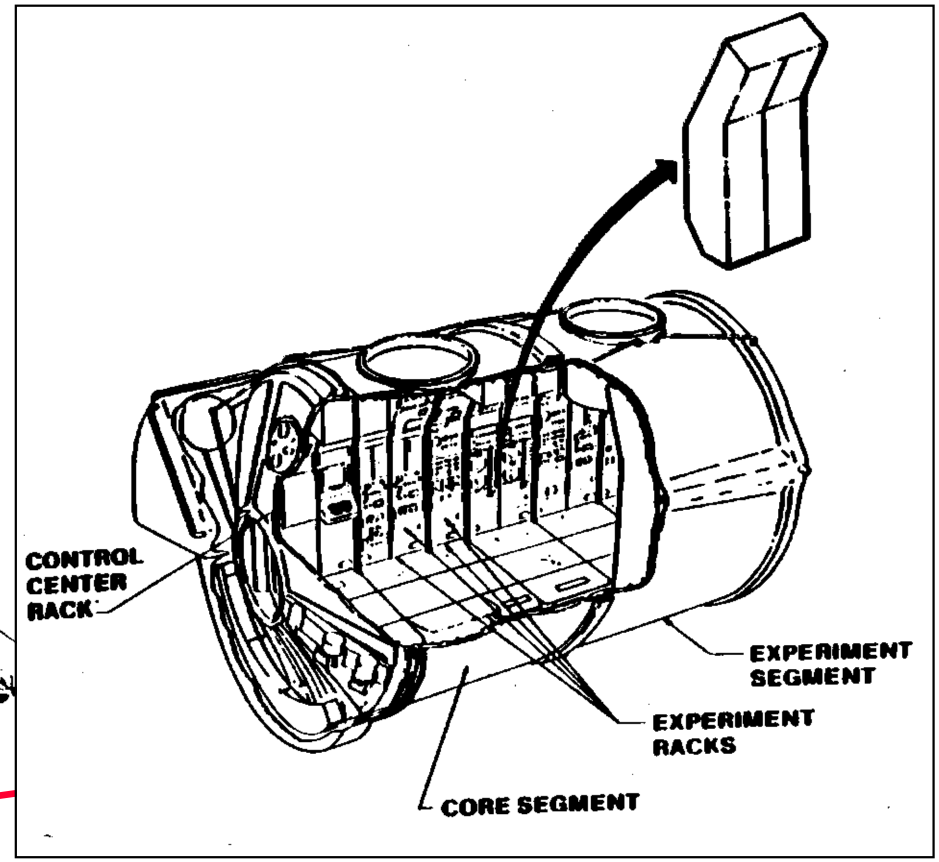
Cadmium Zinc Telluride

$Cd_{1-x}Zn_xTe$

Electronics

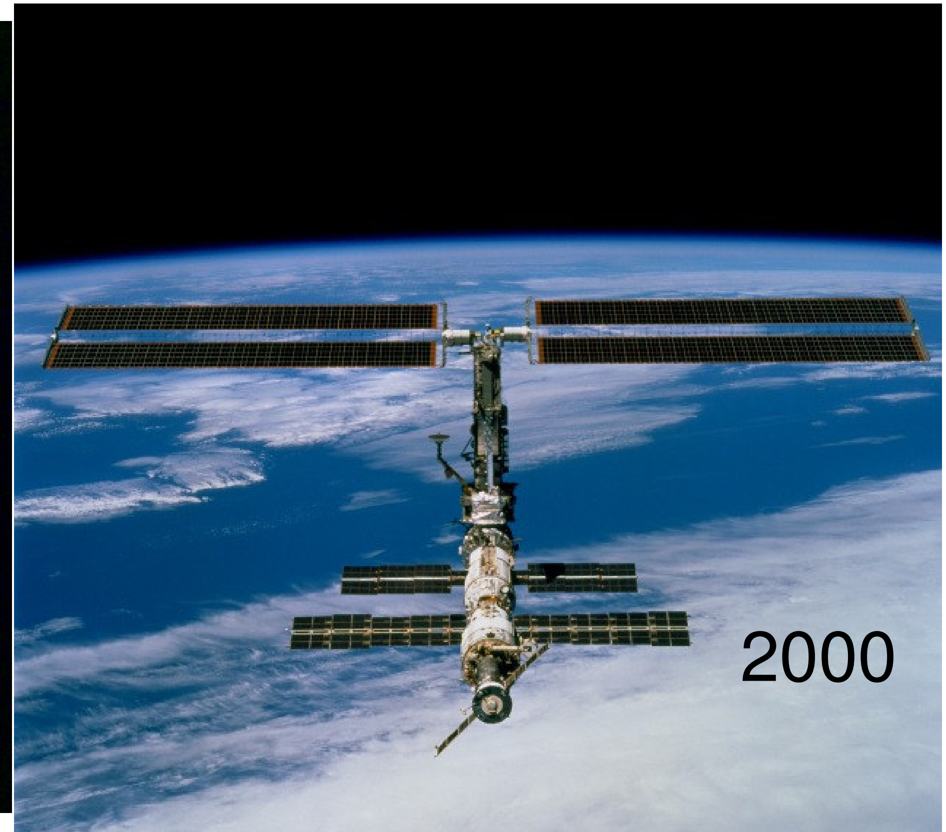
Where Were These Experiments Held ?
Columbia Space Shuttle STS-73
USML-2 (United States Microgravity Lab- 2)

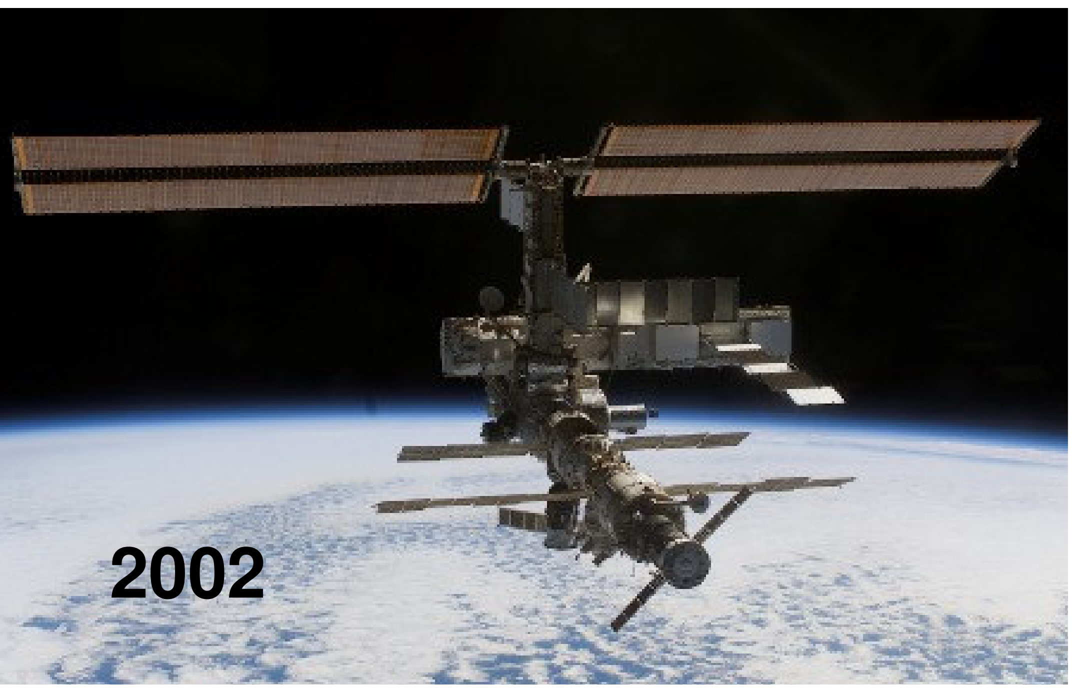




Spacelab
Modüle

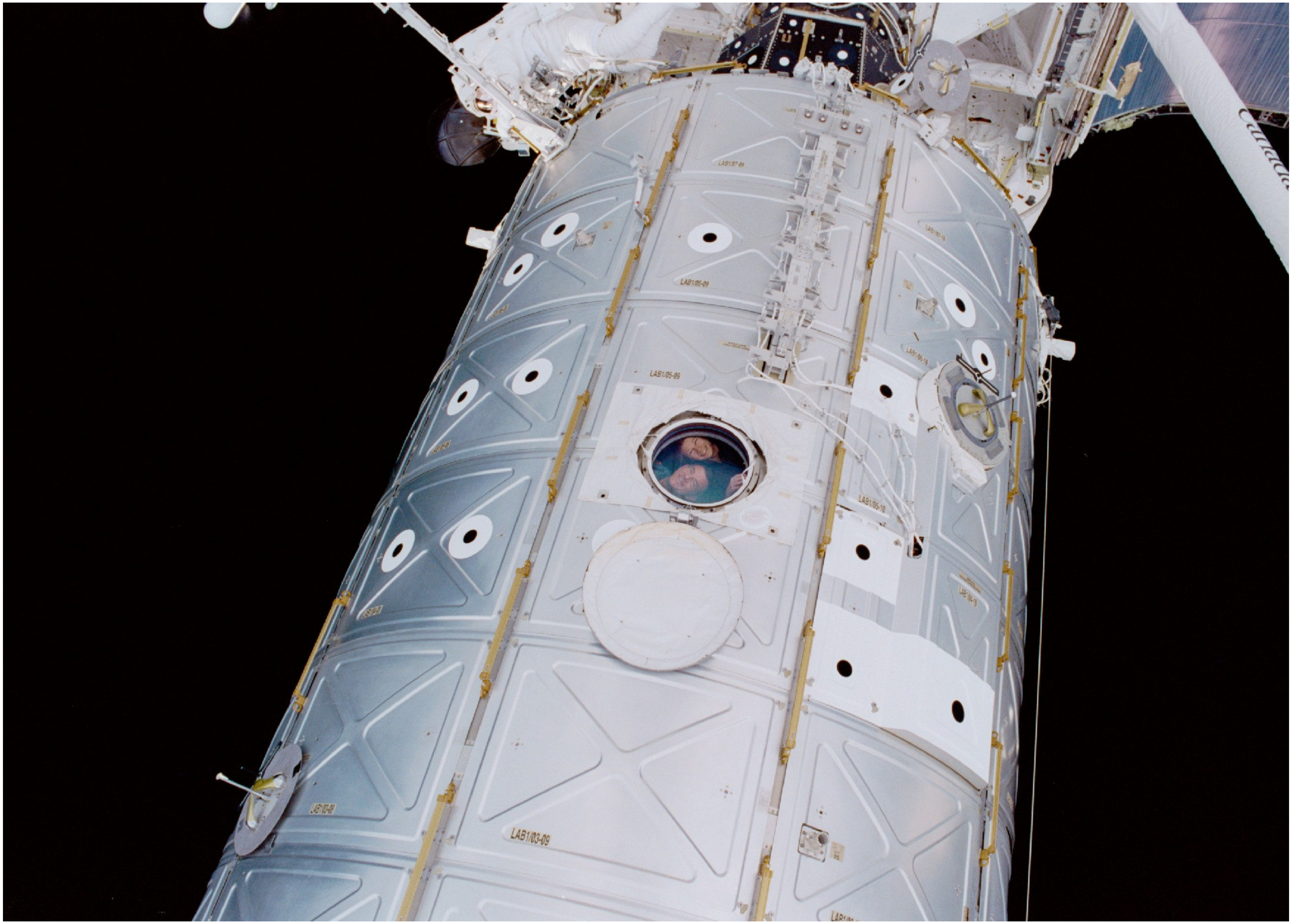

ISS ASSEMBLY
1998

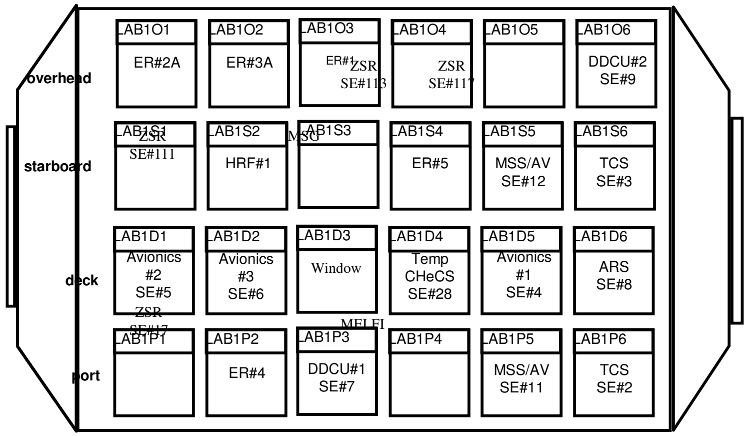

2000


2002


2008

ISS - US Lab (Destiny)





Iternational Space Station - US Lab

EXPRESS Rack

EXPRESS Rk 1

Locker1	Locker5
DCPCG-C (UG) (pwr)	**DCPCG-T (UG) (pwr)**
Locker2	Locker6
DCPCG-V (UG) (pwr)	
Locker3	Locker7
PCG-STES7 (UG) (pwr)	**CGBA4 (UX) (pwr)**
Locker4	Locker8
PCG-STES8 (UG) (pwr)	**CGBA5 (UX) (pwr)**
Drawer1	Drawer2
SAMS-II-RTS1 (Sys)	**SAMS-II-ICU (UG)**

EXPRESS Rk 2

Locker1	Locker5
ZCG-FU1 (UX)	
	Locker6
Locker3	Locker7
Locker4	Locker8
Drawer1	Drawer2

EXPRESS Rk 3

Locker1	Locker5
Locker2	Locker6
Locker3	Locker7
Locker4	Locker8
Drawer1	Drawer2

EXPRESS Rk 4

Locker1	Locker5
Locker2	Locker6
	MEPS1 (UX)
Locker3	Locker7
ADVASC-GC3 (UX)	**MAMS (Sys)**
Locker4	
ADVASC-SS1 (UX)	
Drawer1	Drawer2
KU-Rec (Sys)	**SAMS-II-RTS2 (Sys)**

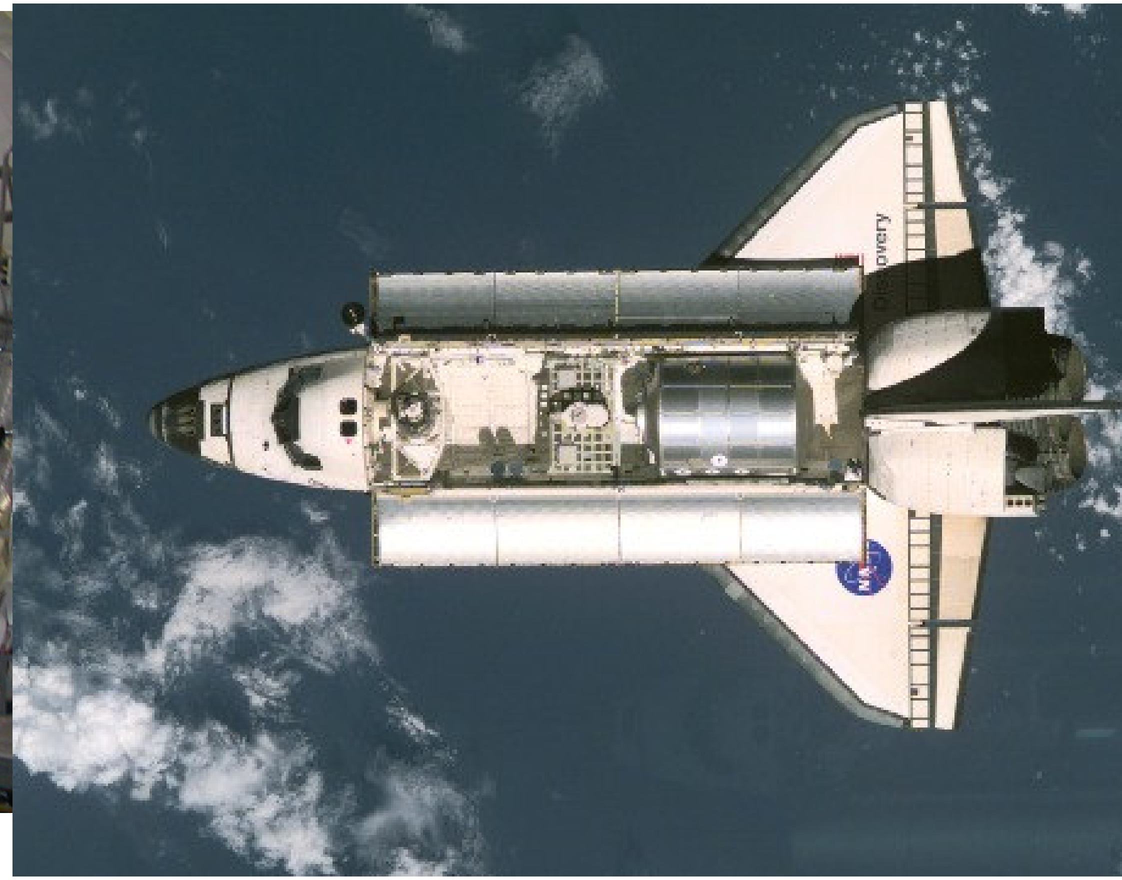
EXPRESS Rk 5

Locker1	Locker5
Space-DRUMS1 (UX)	**Space-DRUMS1 (UX)**
Locker2	Locker6
Space-DRUMS1 (UX)	**Space-DRUMS1 (UX)**
Locker3/4/7/8	
Space-DRUMS1 (UX)	
Drawer1	Drawer2
Space-DRUMS1 (UX)	**Space-DRUMS1 (UX)**

EXpedite **PR**ocessing **E**xperiments on **S**pace **S**tation

Experiments Are Transported to ISS

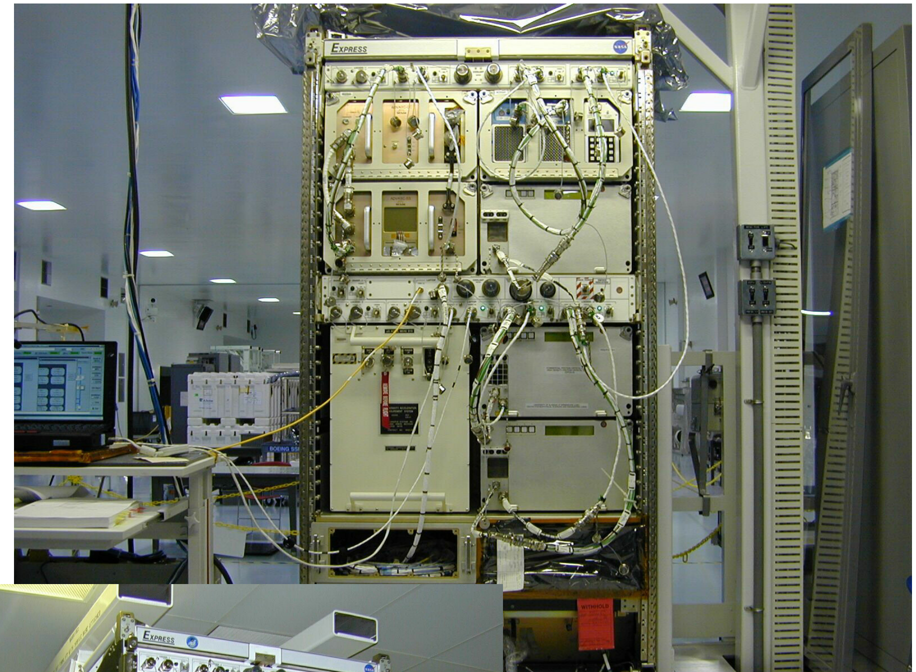
MPLM at Kennedy Space Center (KSC , Florida - 2002)



MPLM is being transported to ISS

MPLM=Multi Purpose Logistics Module

"Expedite the Processing of Experiments to Space Station Rack" (EXPRESS Rack)



FACILITY OBJECTIVE

Provides simple, standard interfaces to accommodate drawer-level, locker, and modular-type payloads.

The EXPRESS Rack concept provides the capability for a simple and shortened integration cycle.

FLIGHT OPERATIONS SUMMARY

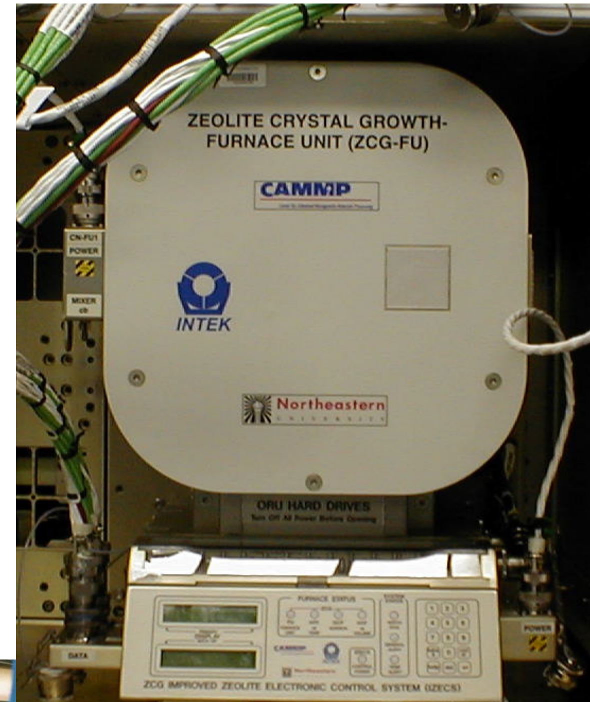
Transported in MPLM to Orbit with partial subrack payload complement

Rack transferred to Destiny and installation checkout performed

SPD

"Zeolite Crystal Growth Furnace" (ZCG)

Al Sacco, Ph.D.; Nurcan Bac, Ph.D. Center for Advanced Microgravity Materials Processing (CAMMP), Boston



RESEARCH OBJECTIVE

- Use the ISS Microgravity environment to grow larger crystals with improved defect structure for zeolites, or other materials to enhance their adsorption properties and catalytic performance in important chemical processes, electronic device manufacture, and other applications

FLIGHT OPERATIONS SUMMARY

- ZCG is mostly autonomous except crew interaction required for:
  - Start up
  - Shutdown
  - Sample change out (experiment runs last 10-20 days)
  - Monitoring: Photography and check temperatures at predetermined intervals
  - Packaging samples for return to Earth

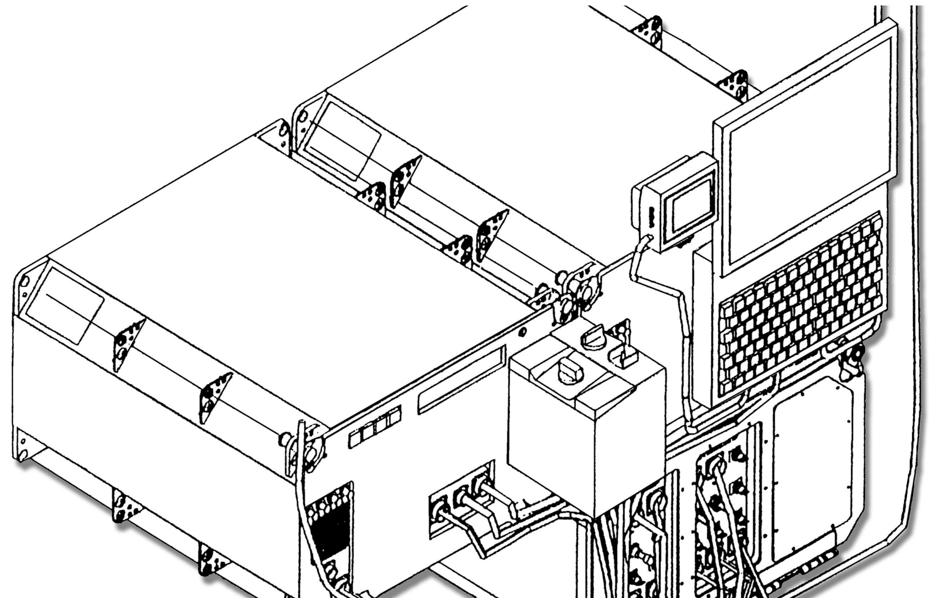
Microgravity

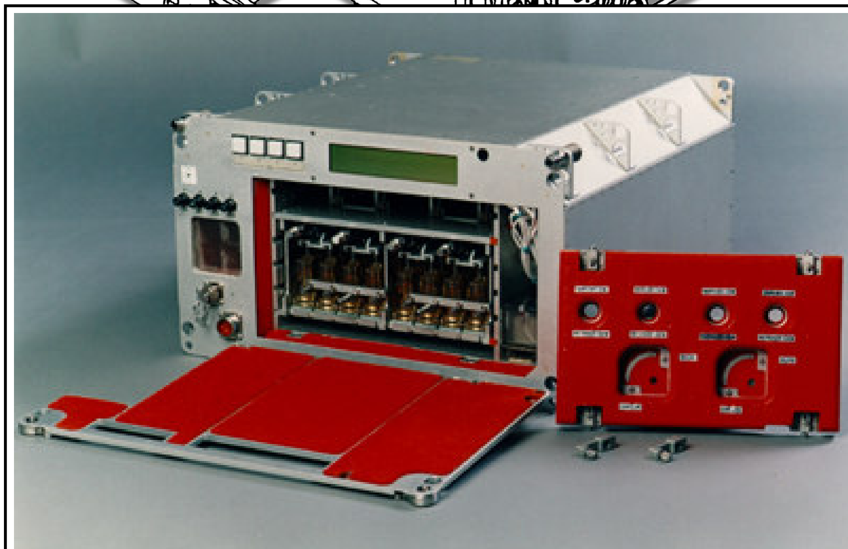
"Dynamically Controlled Protein Crystal Growth" (DCPCG-V/C)

Lawrence DeLucas, Ph.D.; University of Alabama, Birmingham

RESEARCH OBJECTIVE

- Develop an automated crystallization system that provides real-time control of the supersaturation levels and assess the usefulness of dynamic control for improving the success of space-based protein crystal growth experiments
- DCPCG-V uses nitrogen gas to influence the rate of evaporation of the protein solution to induce crystal growth
- Compare microgravity vs. 1-g results in crystal quality, growth rates, movement and distribution, and vapor diffusion equilibration



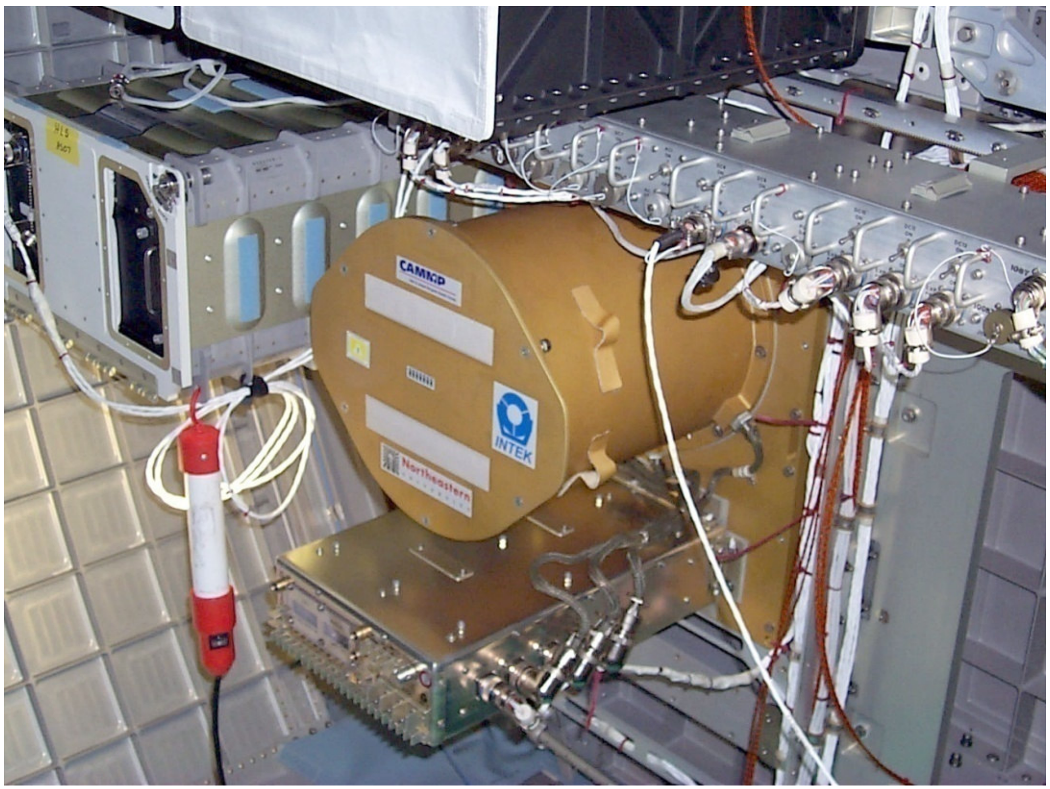


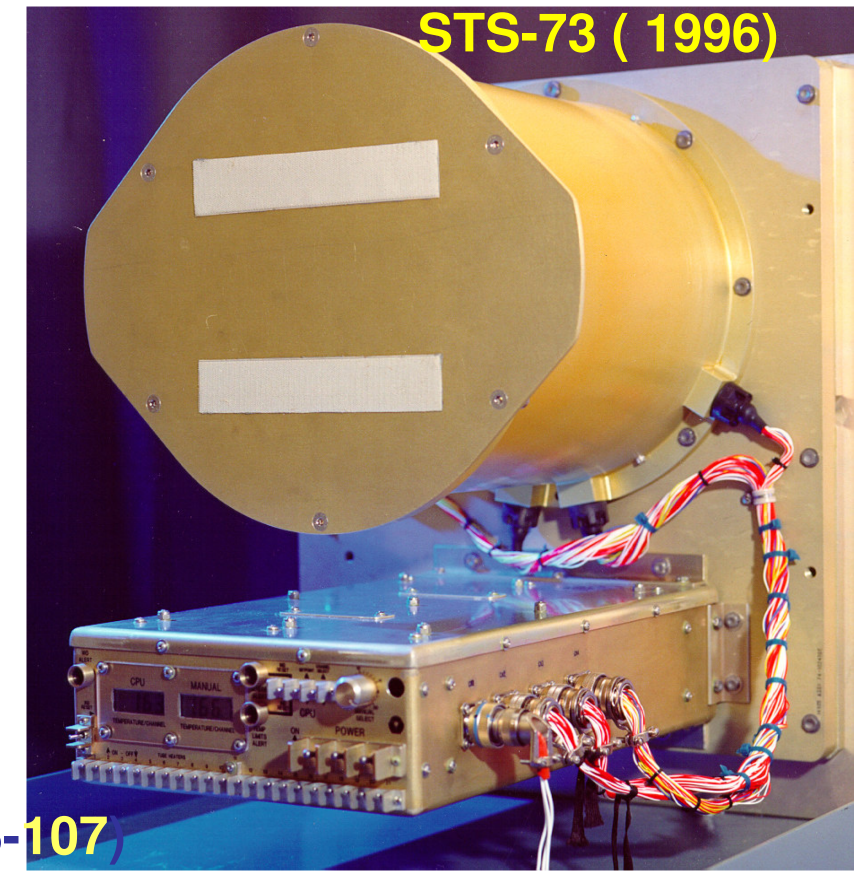
Pictured above is the Commercial Vapor Diffusion Apparatus inside the CRIM.

ZCG (Zeolite Crystal Growth) FURNACE ON THE SPACE SHUTTLE – Al Sacco Jr. and N. Bac

Specs

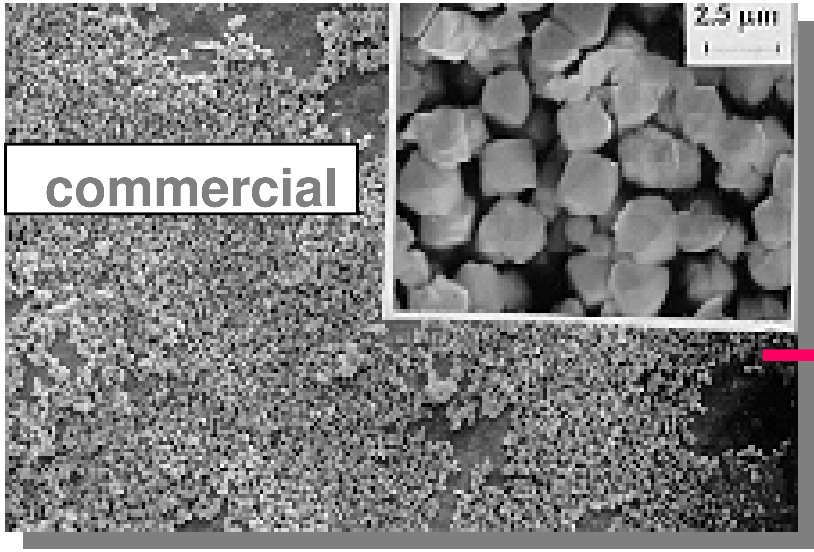
- Power (heat-up) :150 - 200 W
- Power (steady state) : 90 - 170 W
- Weight (loaded) : ~ 75 kg
- Temperature : 88 - 190 °C.
- Samples : 38 autoclaves

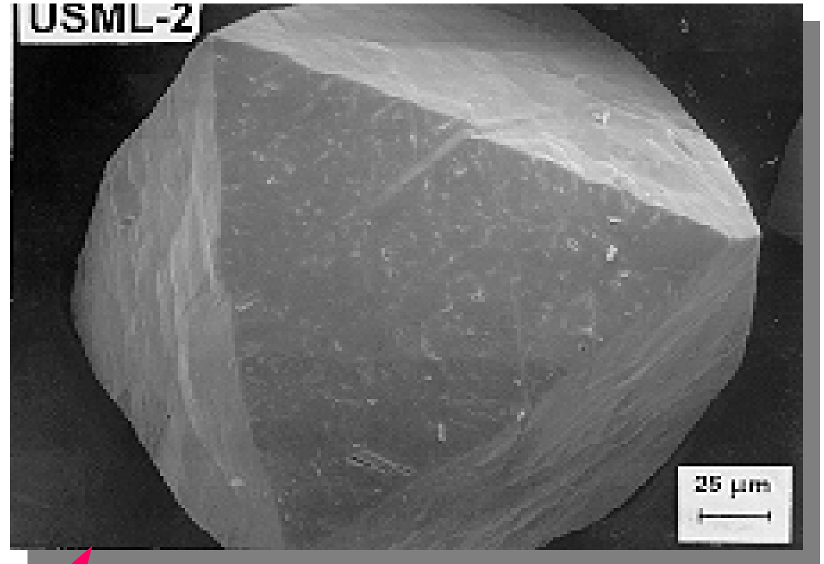


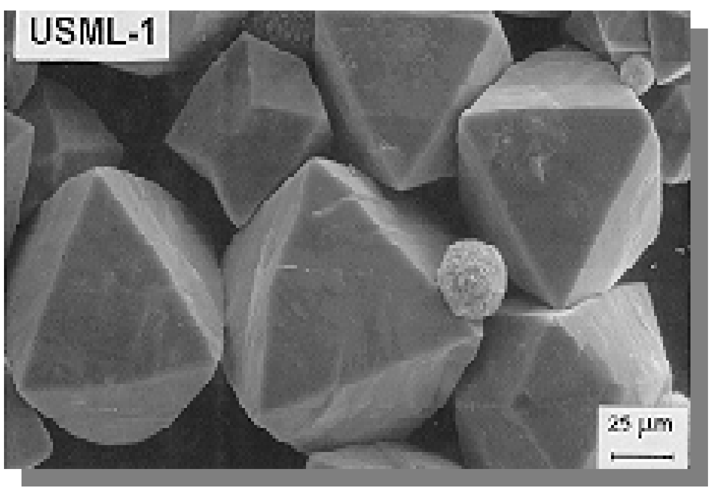


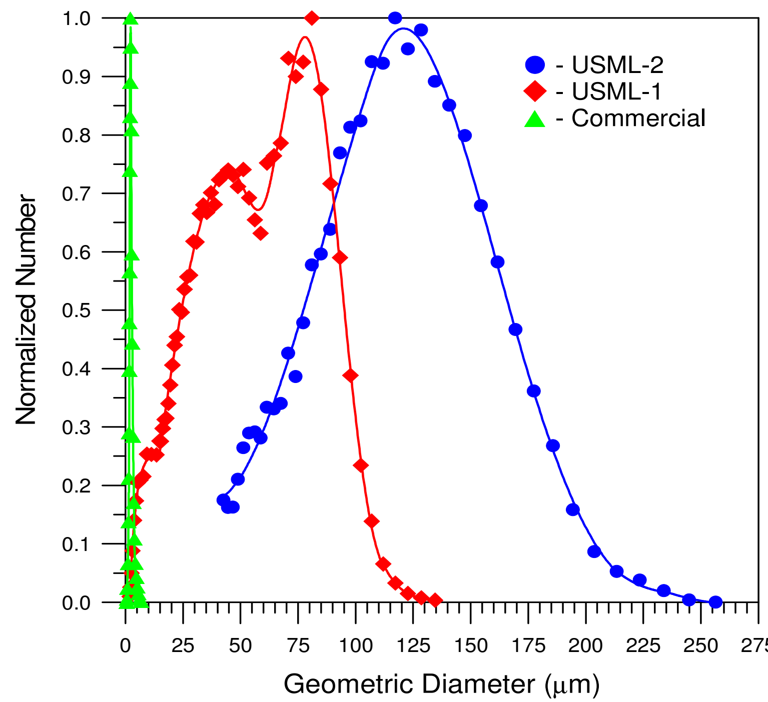
ZCG Furnace was lost when Columbia (STS-107) Shuttle burned as it entered the atmosphere 1/2/2003

Space Development - Zeolite X

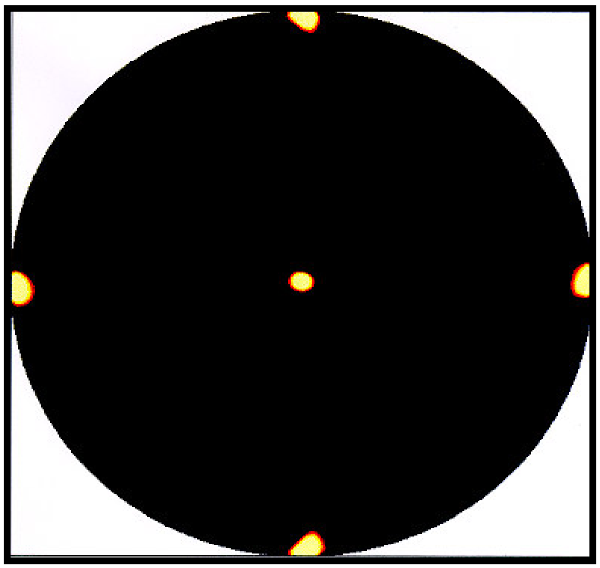


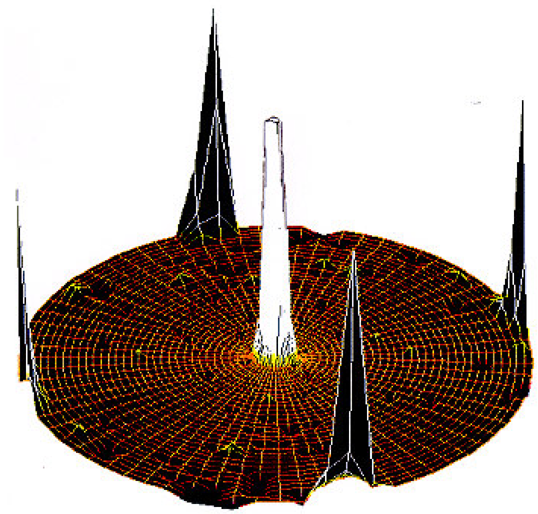




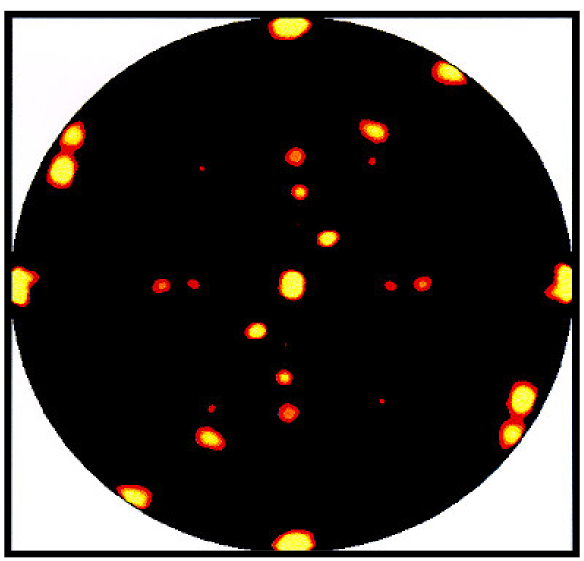


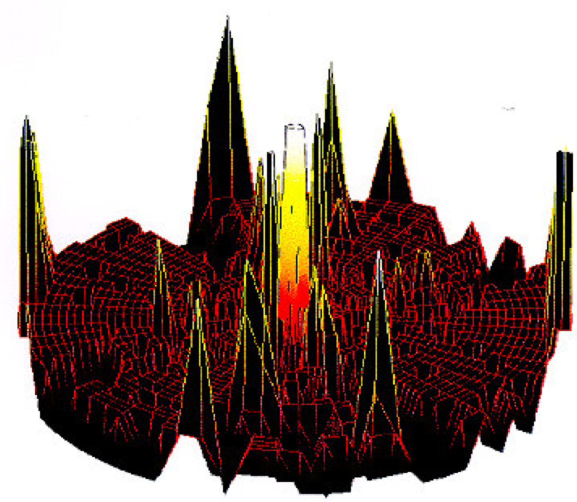
Single Crystal X-Ray - Zeolite A





SPACE

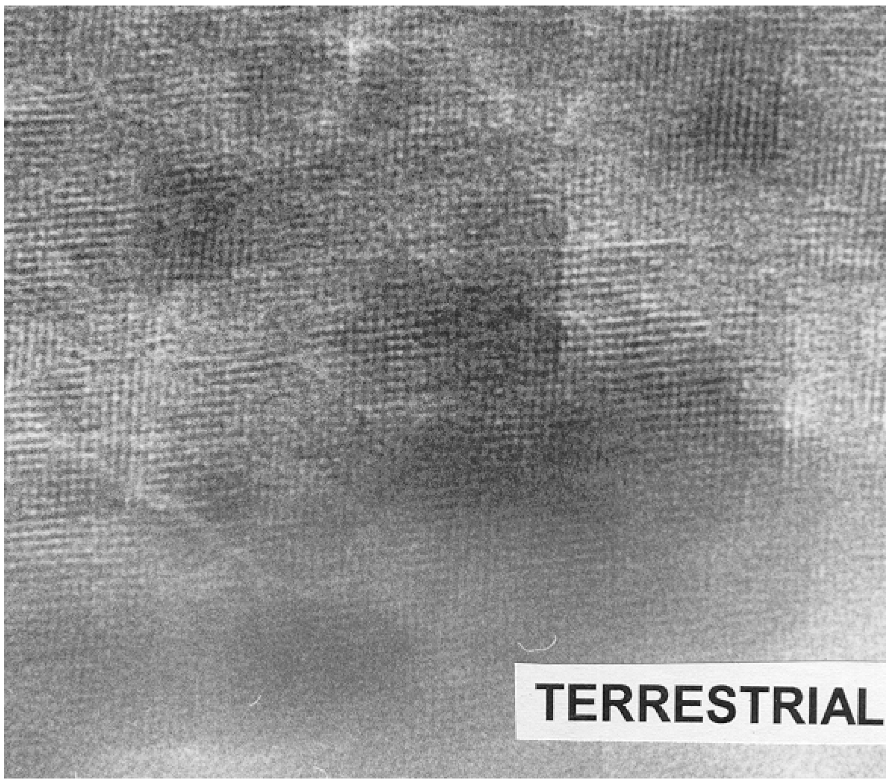




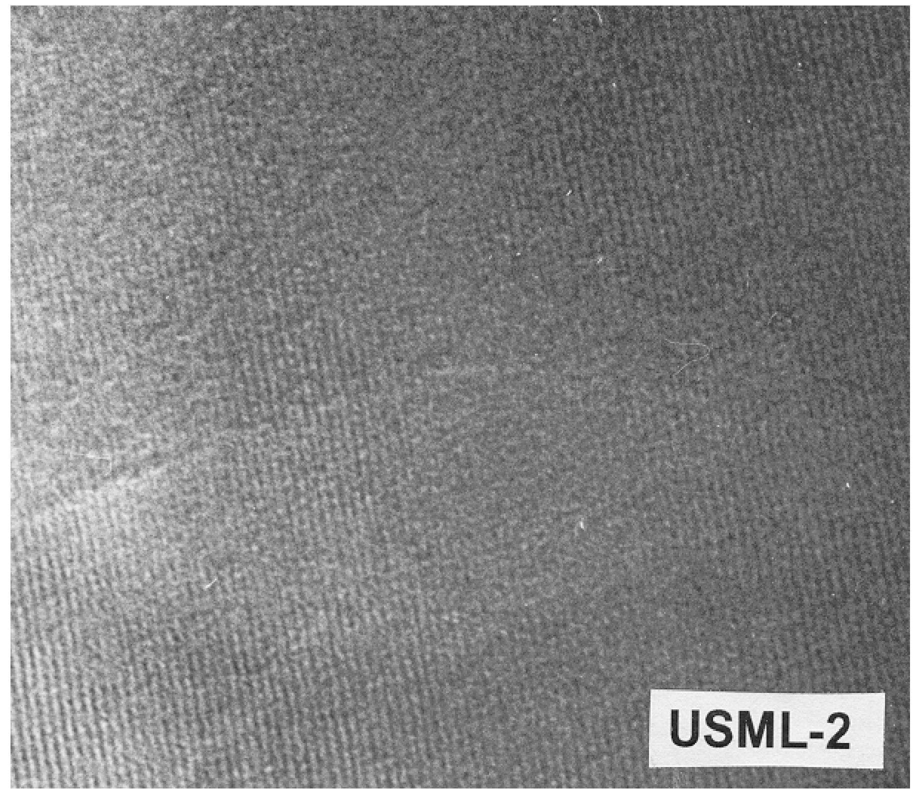
TERRESTRIAL

Transmission Electron Microscope (TEM)

Zeolite Beta- Defect-Free Crystal



Ground



Space

PROTEIN CRYSTAL GROWTH

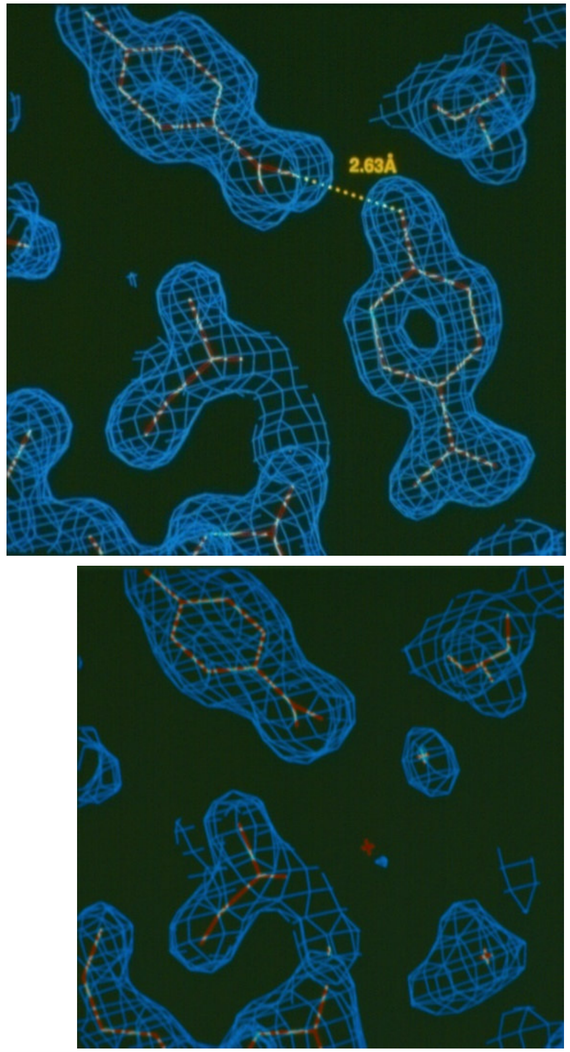
Commercial Protein Crystal Growth.

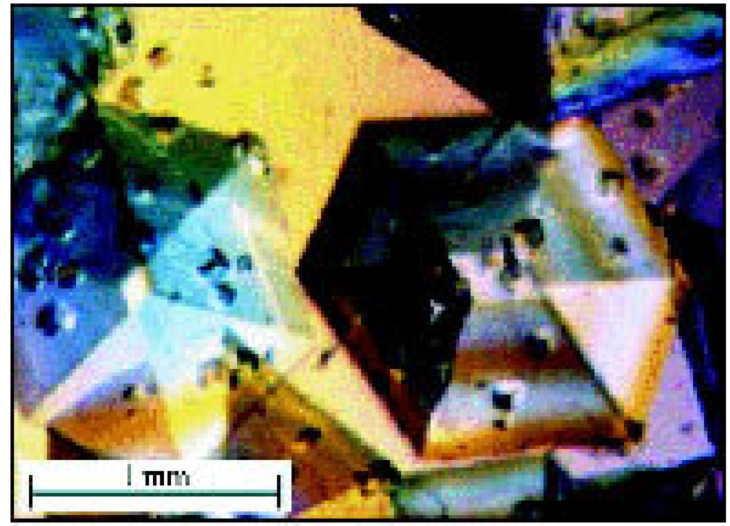
Space grown crystals become Benchmarks.

Structures are better defined

Impact :

DESIGN OF NEW ANTIVIRAL DRUGS





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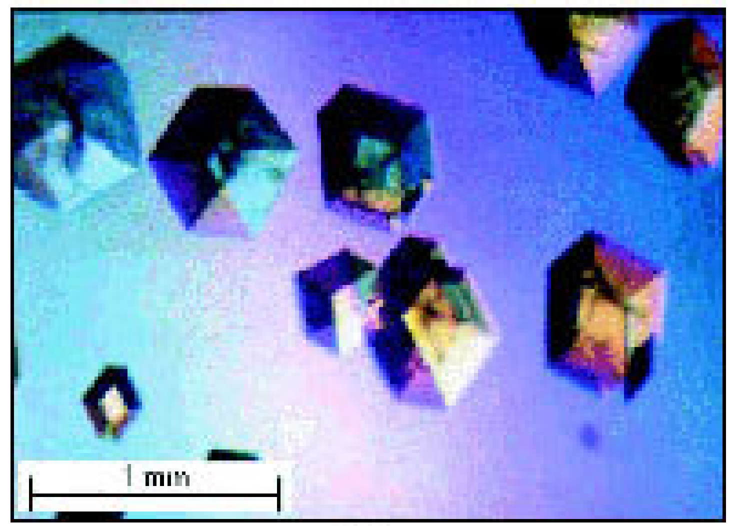


(b)

a) Space   b) Terrestrial

Courtesy of Prof. Larry Delucas , UAB
The Center for Biophysical Sciences and Engineering (CBSE)

CONCLUSION –Space Results

STS-73 Columbia Crew

- *Large and structurally defect-free zeolites and proteins* are grown in space.

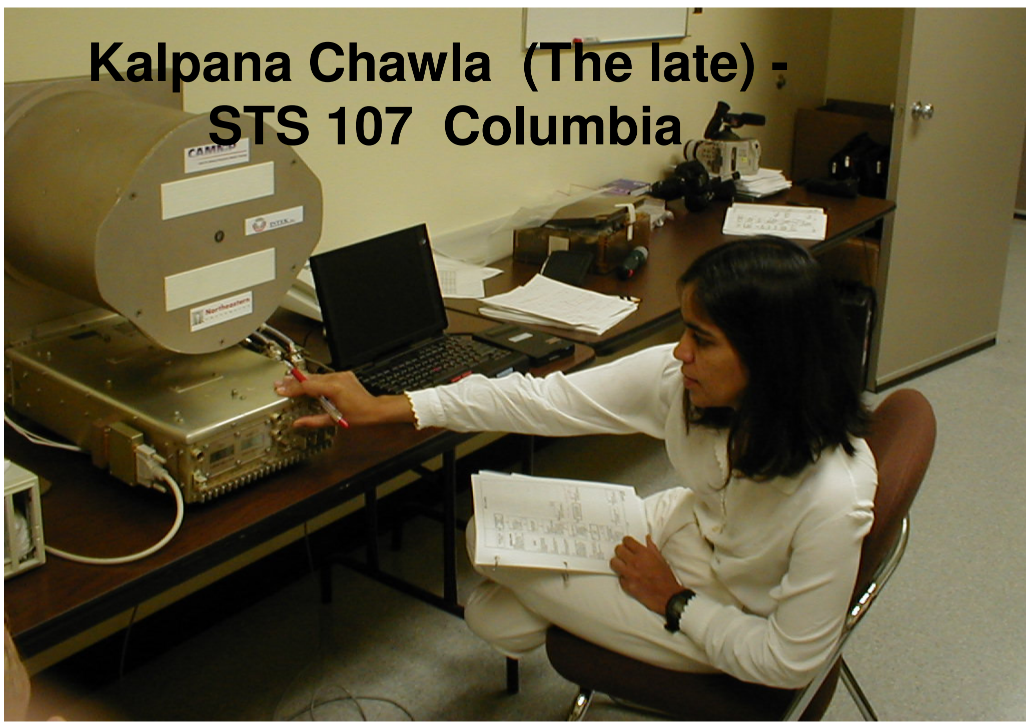
  These become benchmark crystals.

- *AFM, results indicate smooth surface for space grown zeolite crystals with distinct growth planes.*
- *Knowledge base from space grown products enable us to synthesize them better on earth.*

ASTRONAUTS AND COSMONAUTS TRAINED ON THE ZCG EXPERIMENT

Bonnie Dunbar - STS-50 (1992)
Albert Sacco Jr. - STS-73 (1995)
Vladimir Dezhurov - ISS Inc. 3 (2000)
Yuri Oniferenko - ISS Inc. 4 (2001)
Carl Walz - ISS Inc. 4 (2001)
Peggy Whitson - ISS Inc. 5 (2001)
Ken Bowersox - ISS Inc. 6 (2002)

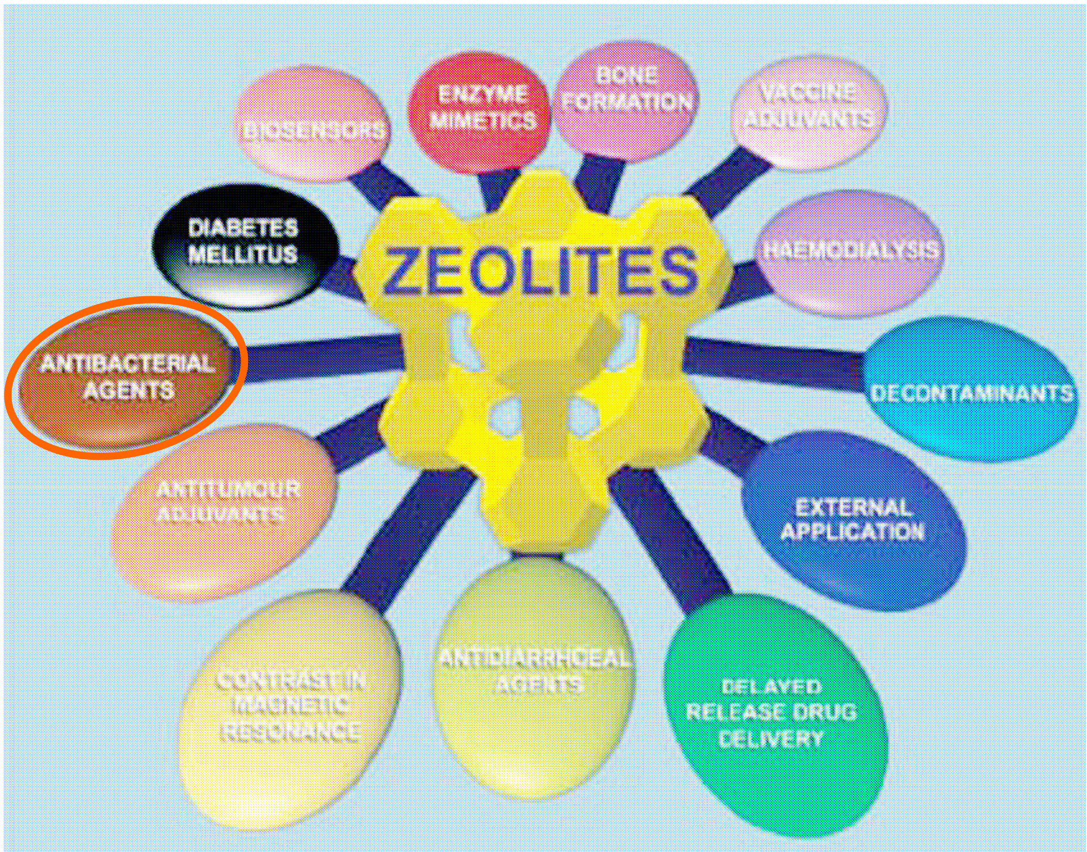
STS – Space Shuttle Columbia flight crew
ISS – International Space Station Crew
Inc = Increment # on orbit



Kalpana Chawla (The late) - STS 107 Columbia

Laurel Clark (The Late) - STS 107 Columbia

Applications - Zeolites in Medicine



- Known biological properties
- Long term stability
- Ability to reversibly bind to small molecules
- Size and shape selectivity
- Low cost

Auerbach et. al., "*Handbook of Zeolite Science and Technology*", New York: M. Dekker, 1–2, **2003**.

Silver Ion, Ag^+

- Antibacterial effect known since the ancient times
- Strong antibacterial activity
- High stability
- Very broad spectrum
- Exerts its effect through binding to bacterial DNA and inhibiting the most important metabolic activities of the cell such as transport processes and respiration.
- Metallic silver has only slight antibacterial effect when compared to Ag^+.

Inoue, Y. et. al., J. of Inor. Biochem., 92, 37-42, 2002.
Schierholz, J. M. Et. al., J. of Hosp. Inf., 40, 257-262, 1998.

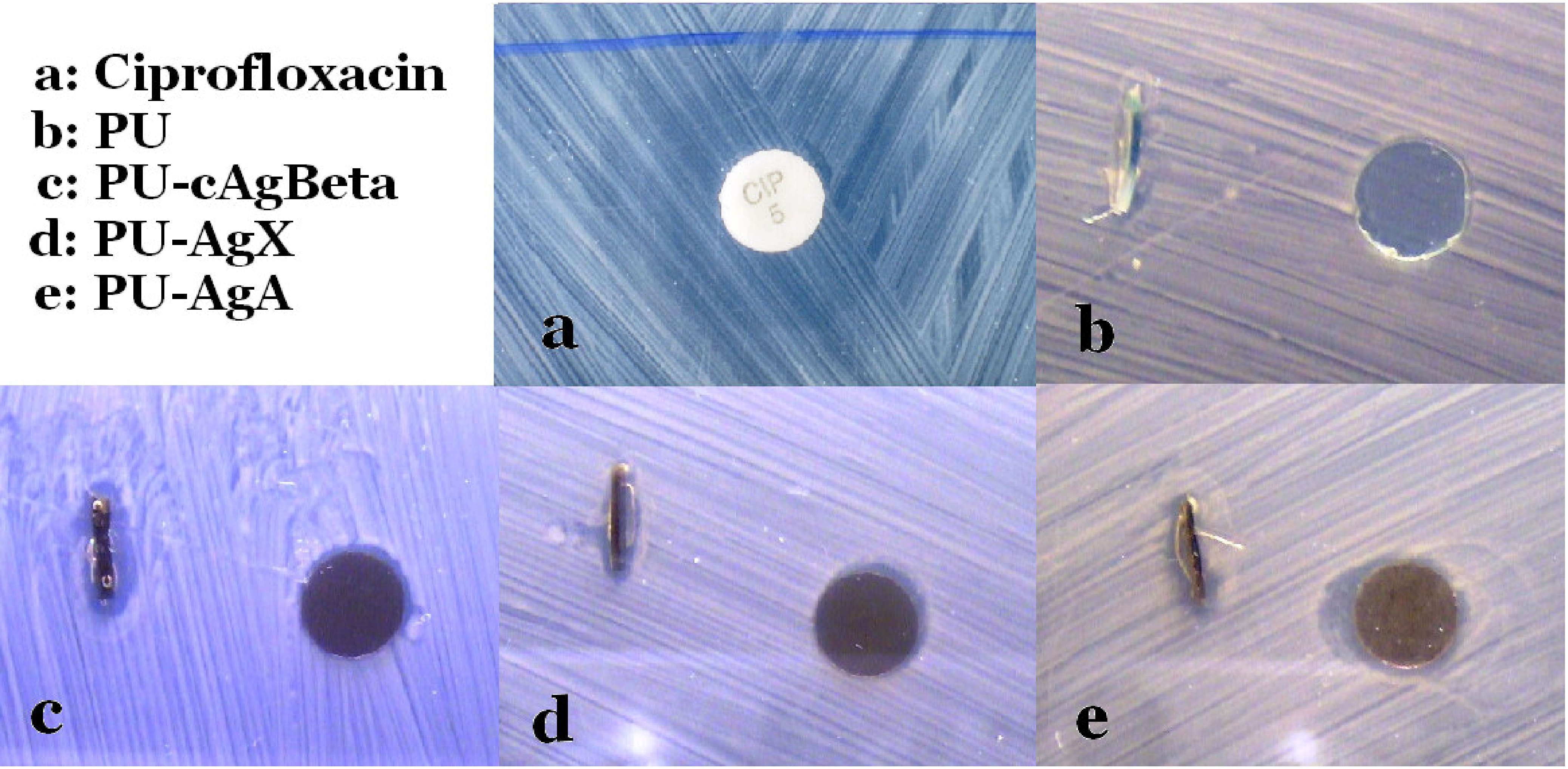
PU-Zeolite Nanocomposites

- Powder form of zeolites limit their use especially in manufacturing field.
- Zeolites can be incorporated into medical grade polyurethanes (PU)
- Antibacterial effect of Ag^{+}-zeolites may contribute to the efficacy of PU in biomedical applications.

Aksoy, E.A.; Akata, B.; Baç, N.; Hasırcı N., *J. of Appl. Polym. Sci.*, 104, 3378-3387 , 2007.

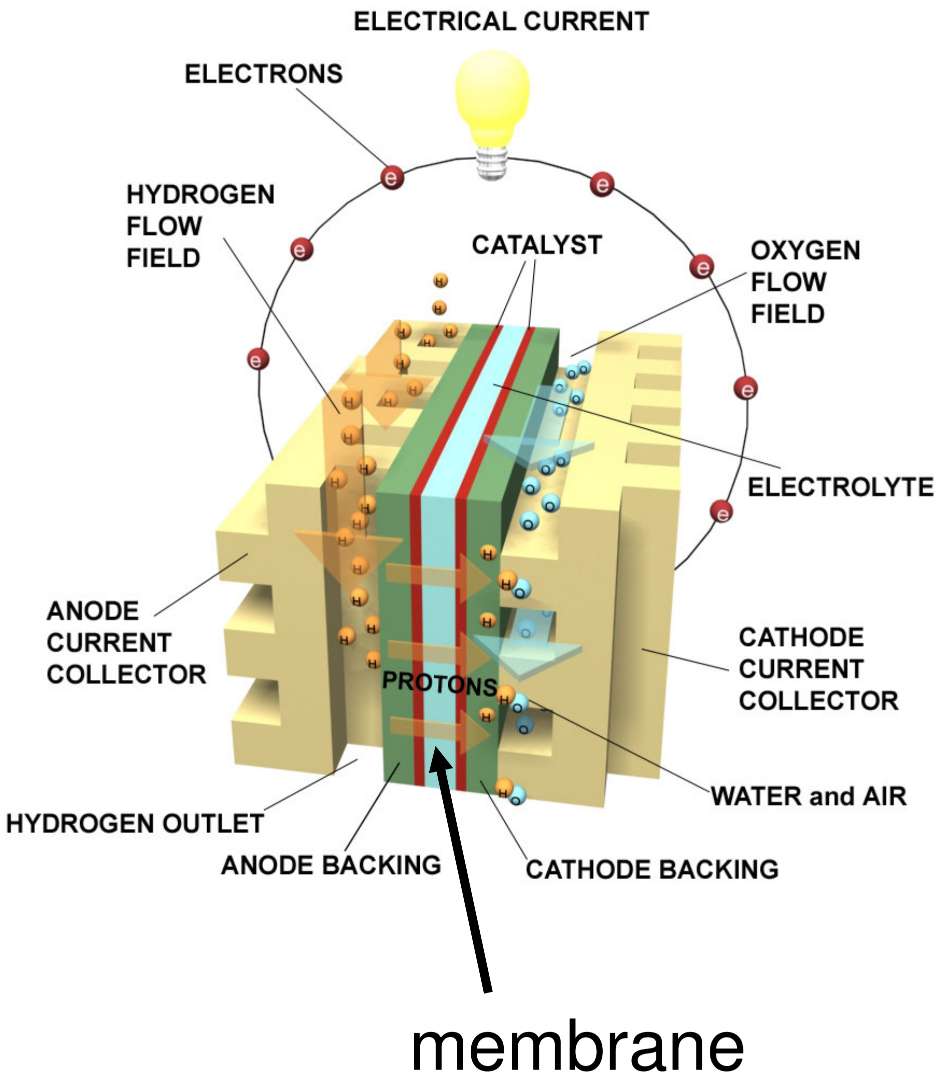
Results – Microbiology

- Antibacterial effect of composites



Kamışoğlu, K., Aksoy, E.A.; Akata, B., Hasırcı N., Baç, N. *J. of Appl. Polym. Sci.*, 110, 2854-2861, 2008.

Application of Zeolites in PEM Fuel Cells



Reactions:

PEMFC

Anode: $H^2 \rightarrow 2H^+ + 2e^-$

Cathode: $\frac{1}{2}O_2 + 2e^- + 2H^+ \rightarrow H_2O$

$\frac{1}{2}O_2 + H_2 \rightarrow H_2O$

DMFC

Anode: $CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^-$

Cathode: $3/2\ O_2 + 6H^+ + 6e^- \rightarrow 3\ H_2O$

$CH_3OH + 3/2\ O_2 \rightarrow CO_2 + 2\ H_2O$

Polymer Electrolyte Fuel Cells (PEMFC) Applications- Anode, Polymer Electrolyte, Cathode

Limitations with current perfluorosulfonic acid membranes (Nafion):

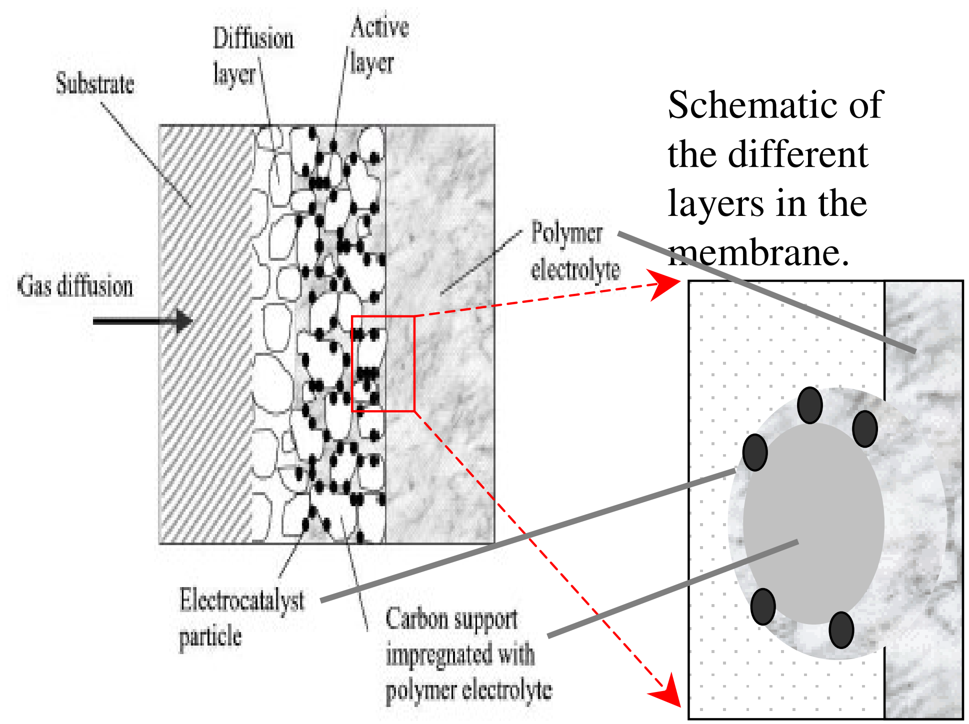
-Loss of conductivity when dehydrated
-Low operating temp. (80 C)
-High cost

Motivation for Elevated Temperature (100℃-200℃) PEM Fuel Cell Operation:

- Enhanced kinetic rates
- Lower CO poisoning
- Improved water and thermal management
- Alleviate system integration issues

Requirement of New Polymer Electrolyte Membrane for High Performance PEMFC

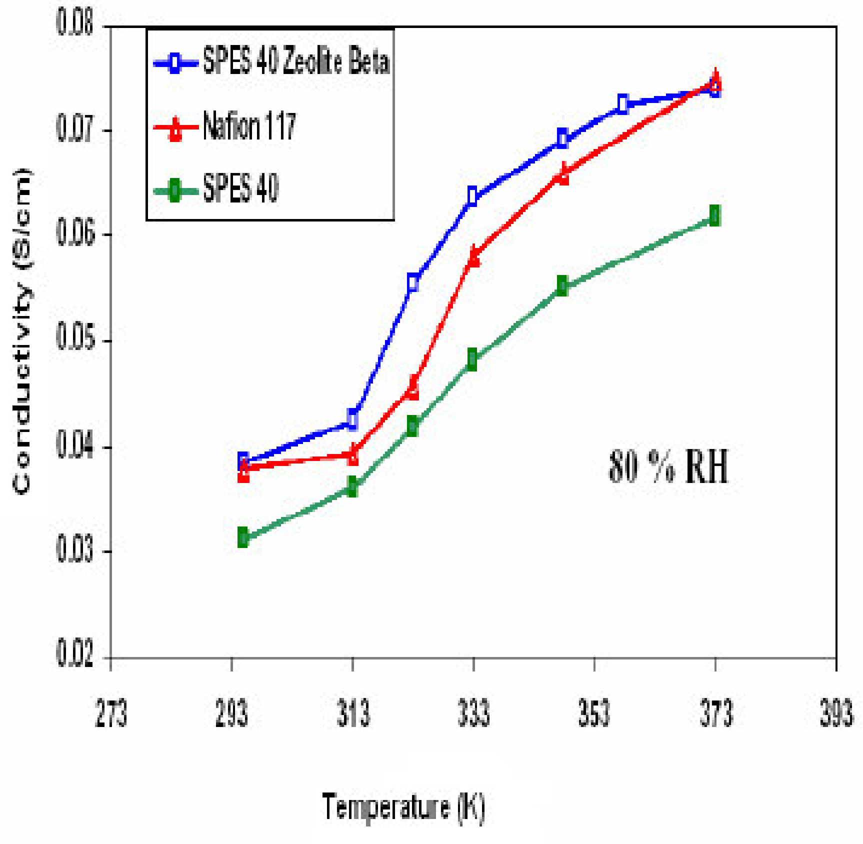
- Cheap, high Tg temperature and long durability
- High proton conductivity at elevated temperature and lower relative humidity



Schematic of the different layers in the membrane.

P. Costamagna, S. Srinivasan, *J. Power Sources*, 102 (2001) 242

Effect of inorganic additives on proton conductivity



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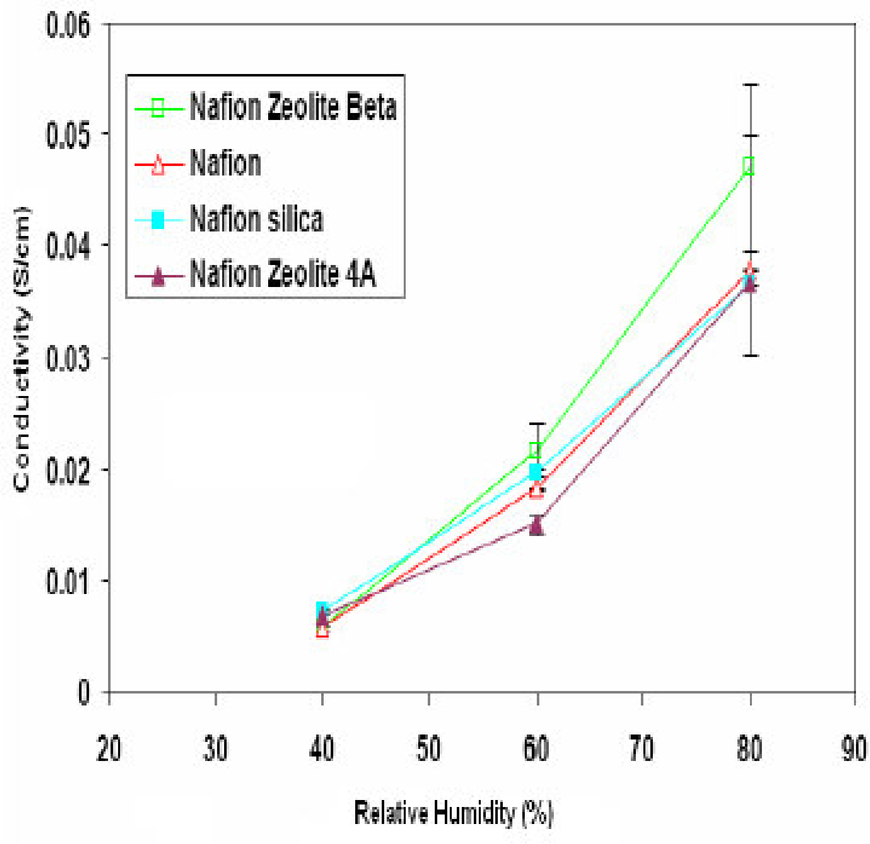

(b)

Bac N. et al. International Hydrogen Energy Conference Istanbul, 13- 15 July 2005

SUMMARY

Knowledge base from space grown advanced materials (zeolites and protein) results in spin-offs for new products for the society. Some of these are:

Antibacterial Zeolites -

New Antiviral drug design (Proteins)

Nanocomposite zeolite-polymer fuel cell membranes. Portable power, or utilization of hydrogen energy in the future

Microencapsulation of fragrance in zeolites for extended release in detergents / softeners

Thank you for the opportunity

ACKNOWLEDGEMENTS

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Hülya Erdener
Kübra Kamışoğlu
Erce Sengul
Berker Fıçıcıllar