Technology Needs & Innovations for Space Exploration*

North Houston Space Society

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NASA Exceptional Service Medal Recipient

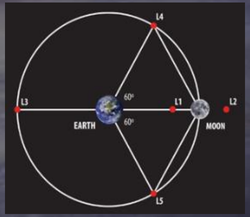
July 10, 2021

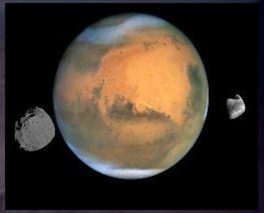
*The views expressed in this presentation are not necessarily those of NASA

Presentation Outline

- **Space Exploration & Utilization in Next few Decades**
- **Space Exploration & Utilization Challenges & Needs**
- **List of Technologies with High Pay-off**
- **New Technologies (Examples)**

Superconductors, Ionic Polymer Metallic Composites, Carbon Nano Technology, Variable Specific Impulse Magnetoplasma Rocket , Wavelet Technology

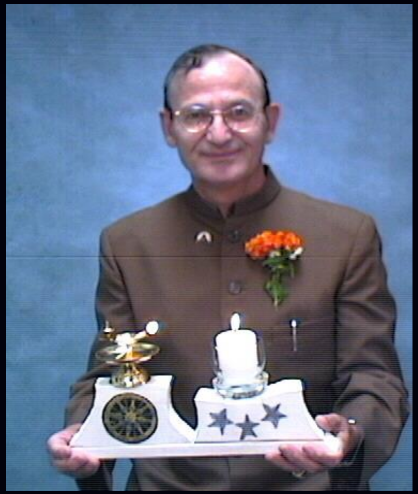




Towering genius disdains a beaten path. It seeks regions hitherto unexplored.

President Abraham Lincoln

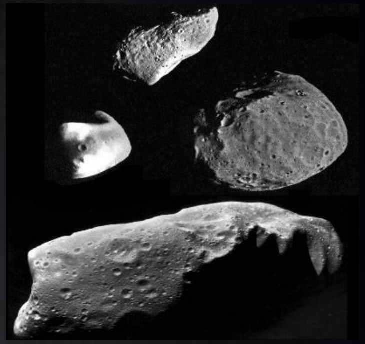
On Understanding Universe



Expanding the boundaries of our knowledge to understand the birth, existence, and extinction processes of the universe(s) presents one of the greatest challenges of all times. This includes the understanding of time, space, energy, matter, and life.

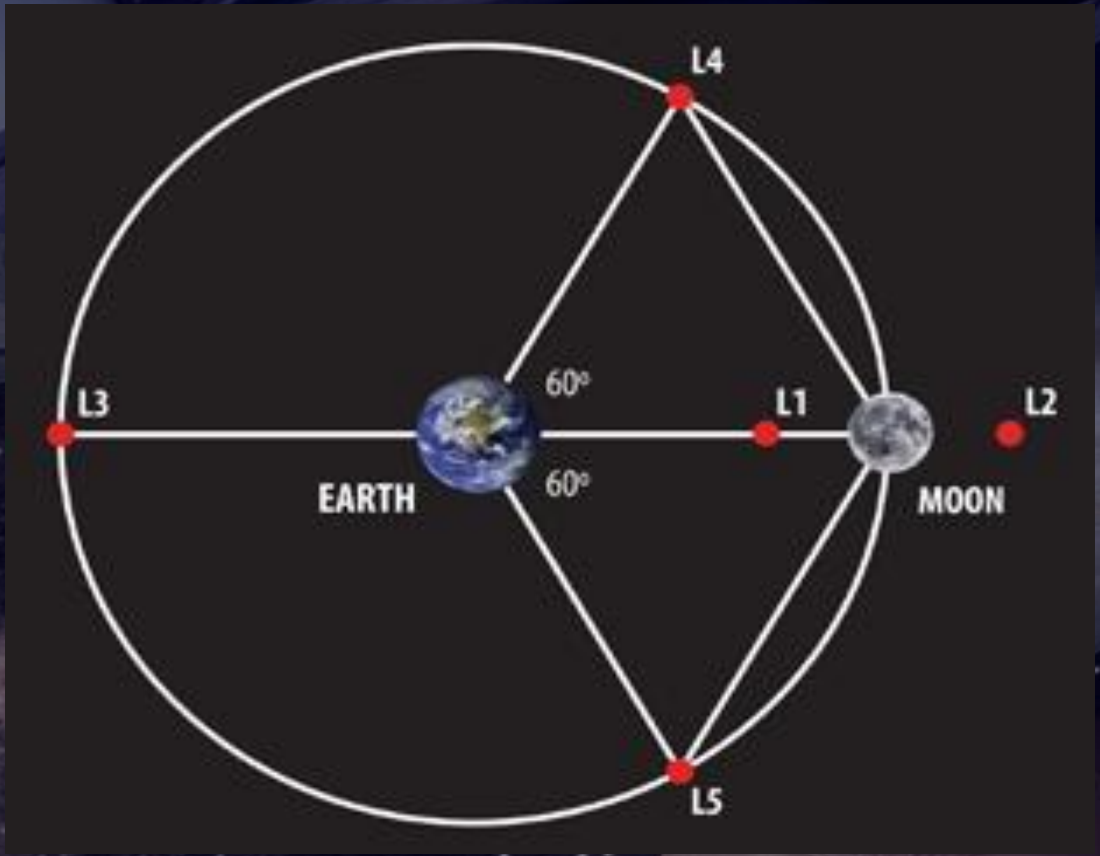






Exploration & Utilization Scenarios

Lagrange Points



There are five Lagrange Points in cis-lunar space. These points are five locations in space where the gravitational pull of the Earth and Moon are balanced. This means that a vehicle or facility stationed at a Lagrange point, such as EM L1 or L2, would require very little fuel to stay in place, making it a prime staging point for space exploration/utilization.

From NASA Voyages Report

Next Few Decades for Space Exploration

- Exploration of Solar System and Universe
  - Telescopes and Observatories
- Earth Orbit and Lagrange Points
  - Observation – Earth and Space
  - Storing/Assembly/Staging
  - Human Laboratories and Recreation/Tourism
  - Moon and Mars Mission Technology Development
  - Communication Infrastructure
  - GPS Infrastructure
  - Space Force

Next Few Decades for Space Exploration

- **Moon**
  - Telescopes and Observatories
  - Scientific and Technological Laboratories
  - Manufacturing, Mining, and Testing
  - Recycling of Resources
  - In-Situ Resource Utilization
  - Mars Human Mission Test Bed
- **Mars**
  - Exploration- Robotics and Automation
  - Human Mission(s)

Big Tech Seems Ready to Conquer Space

Lifewire-Allison Matyus, October 23, 2020

- **Microsoft and SpaceX's Partnership**
  - **Another Big Tech Company Entering Space Industry**
- **Google, Amazon, Microsoft, and Facebook Interested in Space Technology**
  - **Venturing into Satellite Communications**
    - **Estimated 42 million in USA have access to Broadband Internet**
    - **Launching a Network of 3,236 Satellites as Project Kuiper**
    - **PointView Tech Satellite uses 71-76 GHz for Downlinks, 81-86 GHz for Uplinks in E-band spectrum**
  - **Earth Observation Satellites**
  - **GPS Constellations**

Big Tech Seems Ready to Conquer Space

Lifewire-Allison Matyus, October 23, 2020

- **Big Tech Companies have Money and Resources to add Space to Portfolios**
- **Space Community Growing Rapidly**
  - **Innovation is lowering the barriers for Public and Private Sector**
  - **The Starlink Satellites SpaceX and Microsoft Working on**
    - **Will result in more than 40,000 spacecraft added to geostationary orbit, according to Space.com. Amazon's Project Kuiper promises 3,236 satellites to crowded satellite belt, about 22,236 miles above Earth**

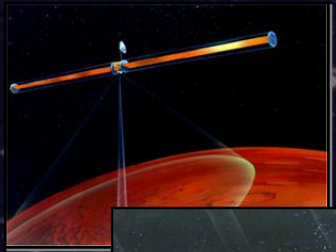
Overarching Technology Drivers for Exploration

- **Performance in Extreme Environments**
  - Gravity, Temperature, Radiation, Vacuum, Dust, Dust Storms
- **Mission Cost**
  - Mass, Size, Power Consumption, Long Life, Reusable, Recycling, In-Situ Resource Utilization
- **High Degree of Autonomy, Reliability, and Safety**
- **Human "Agents" and "Amplifiers"**

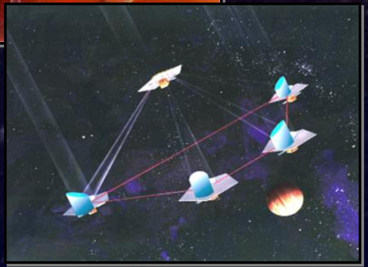
Future Challenges*

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

Size per Mass

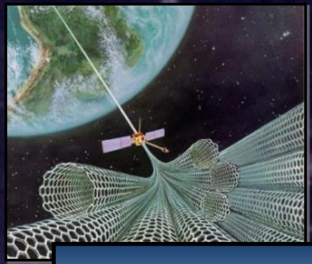


- Ultra-large apertures
- Solar sails
- Gossamer spacecraft



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

Strength per Mass

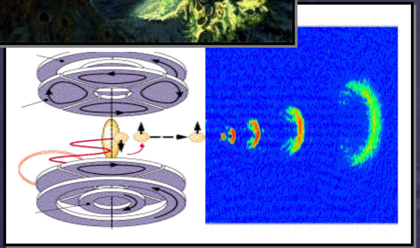


- Air/launch/space vehicles
- Human habitats in space
- Self-sensing& Healing systems

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

Capability per Mass & Power

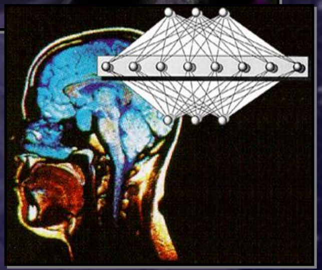
- Micro spacecraft
- Quantum-limited sensors
- Biochem lab-on-a-chip



Conventional device technologies cannot be pushed much farther

Intelligence per Mass & Power

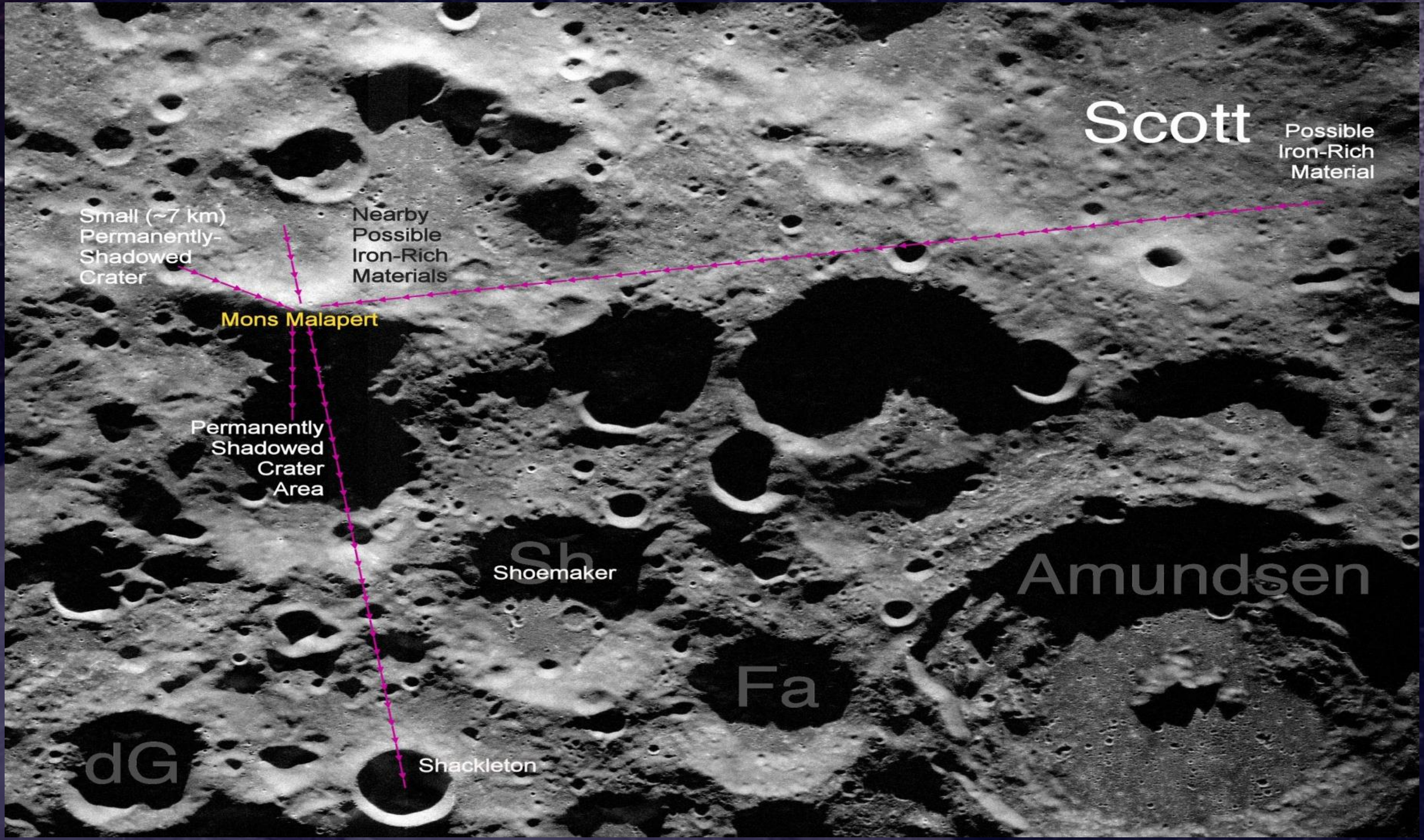
- Medical autonomy
- AI partners in space
- Evolvable space systems



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

*Source: **NASA**

Lunar South Polar region Showing Mons Malapert*



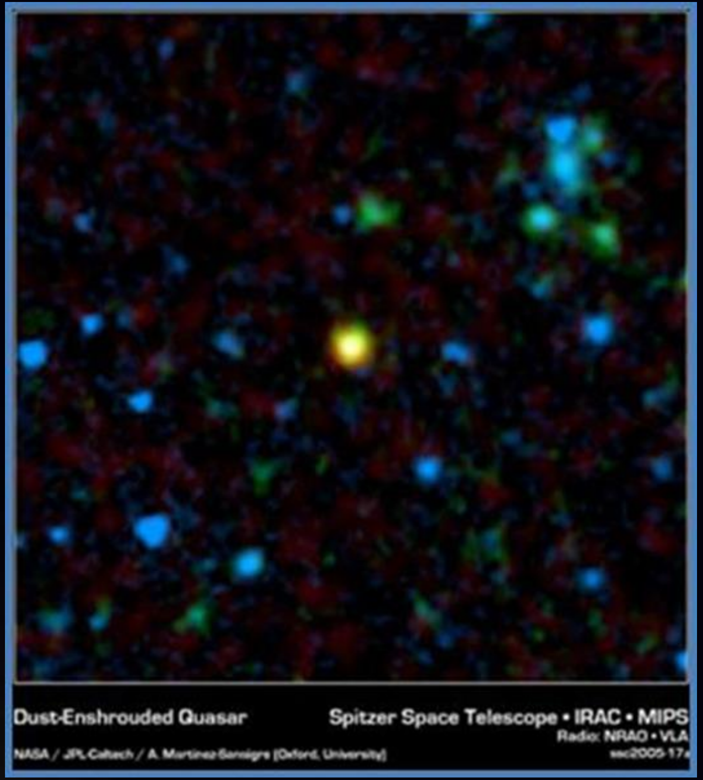
*Source **NASA**

Possible Iron Rich Material

Lunar dust covers the lower part of Astronaut Harrison Schmitt’s spacesuit during the Apollo 17 Mission

Galactic Cosmic Rays (GCR)

- Space radiation is composed of high-energy protons and heavy ions (HZEs) along with secondary protons, neutrons, and heavy ions produced via interaction with shielding materials
- Abundances and energies in space environment understood, but large biological uncertainties limit ability to accurately evaluate risks
- Heavy ions are not effectively shielded (break up into lighter, more penetrating fragments)



Space Radiation Environment

- **Space radiation environment poses both acute & chronic risks to crew health and safety, with clinically relevant implications for the lifetime of the crew**
  - Risk of Radiation Carcinogenesis from Space Radiation Exposure

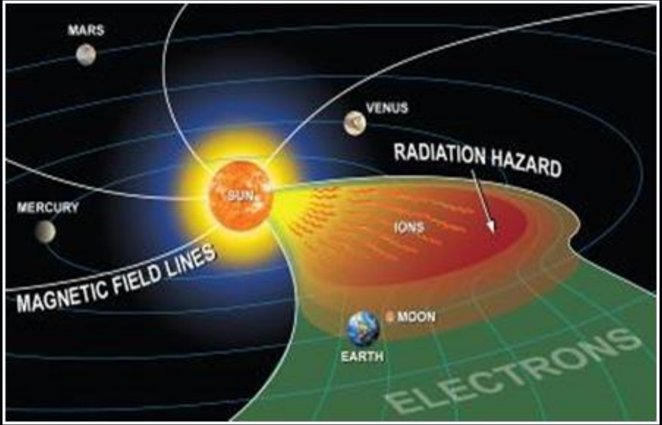
- **Risk of Acute or Late Central Nervous System Effects from Space Radiation – inflight cognitive or behavioral changes that impact mission success and late neurological disorders**

- **Risk of Cardiovascular Disease and other Degenerative Tissue Risks from Space Radiation**

- **Acute Radiation Risks from Solar Particle Event Exposure**
  - prodromal risks, immune system dysfunction and

  skin injury that jeopardize crew health

  and mission success



Thriving in Space

Aerospace America -November 2020

- **Communications**
  - Radiation Hardning for Hardware and Software
  - Low-cost Architecture
  - In-Space Connectivity
- **Food Production**
  - Growing Something Green Reminds Astronauts of Home
  - Water and Nutrient Solution to Roots
  - Large Scale Food Production
  - Hybrid Life Support System by Providing Supplemental Oxygen

Thriving in Space

Aerospace America -November 2020 (Continued)

- **Manufacturing**
  - Radiation-Resistant Enclosures
  - 3D Printing of Plastic, Metal, Ceramics, and Electronics
  - Challenge is Having Right Raw Materials
  - Make It: Don’t Take It!
  - Bio-Printed Human Tissue on Board ISS
- **Mining**
  - Need for Demand
  - Water Production
  - Mining Metals for Space and Earth Use

Thriving in Space

Aerospace America -November 2020 (Concluded)

- **Transportation**
  - **Reusable Vehicles**
  - **Need for propellant and other consumables**
  - **Lunar poles have water ice and other consumables**
    - **Harvest for Rocket Propellant**
    - **Sun Flower- Megawatts Low-Cost Power**
  - **Mars Atmosphere has Carbon Dioxide and Surface has Water**
    - **Make Liquid Oxygen, Liquid Hydrogen, and Methane**
  - **Harvest Asteroid Resources**

Farming on Mars [Science News]

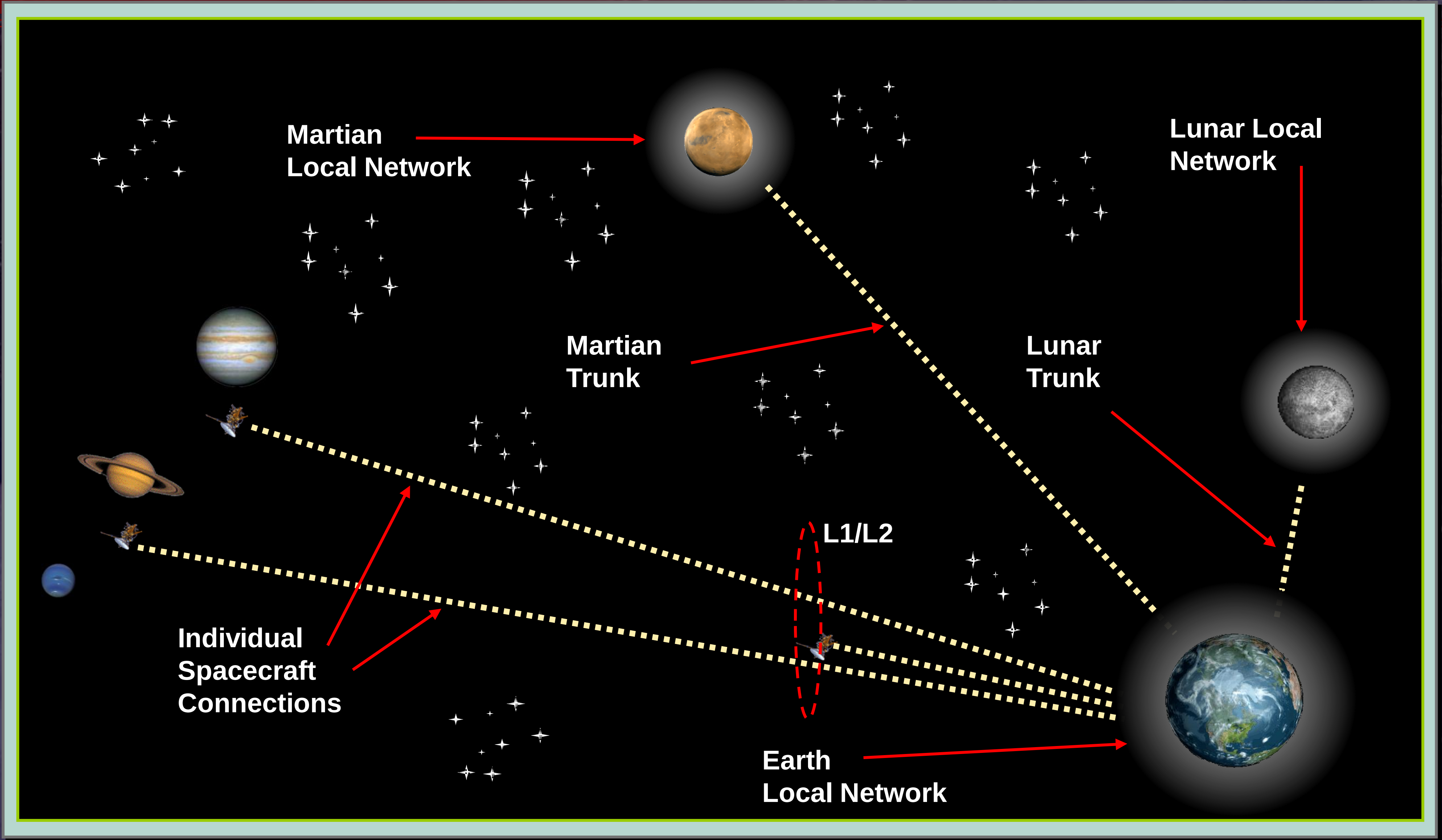
https://www.sciencenews.org/article/mars-farming-harder-martian-regolith-soil

- **In dirt closer to Mars**
  - **It gets harder and harder for plants to grow in it**

- We will Need to put in a lot of work to transform Mars dirt into something that plants can grow in
  - **Plants need to be fertilized with a mixture of nitrogen, potassium, calcium and other nutrients**
  - Under hydroponic-like conditions
- **Mars dirt high in pH**, about 9.5
  - Natural soils has pH level around 7
  - synthetic dirt treated with sulfuric acid to lower the pH to 7.2
- **About 2 percent Mars surface has calcium perchlorate, a toxic salt**
  - As the **microbes eat the salt**, they give off oxygen. If these bacteria were taken from Earth to Mars, Martian dirt could be used for farming
- **It's not quite as easy as it looks in The Martian**

By **Maria Temming**
NOVEMBER 18, 2020

Top Level Conceptual Communication Architecture



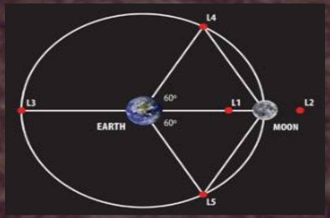
Source
NASA

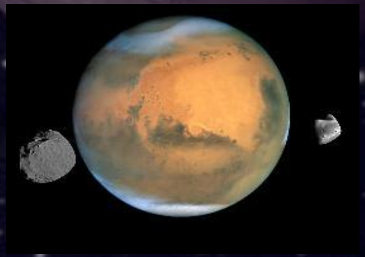
General Comments

There are systems many Nations have (will have) in the orbits of Moon/Mars or have left (will leave) on their surfaces. An admirable goal would be to collect and properly store these used systems. These would also provide valuable data regarding the environmental effects associated with being around or on Moon and Mars

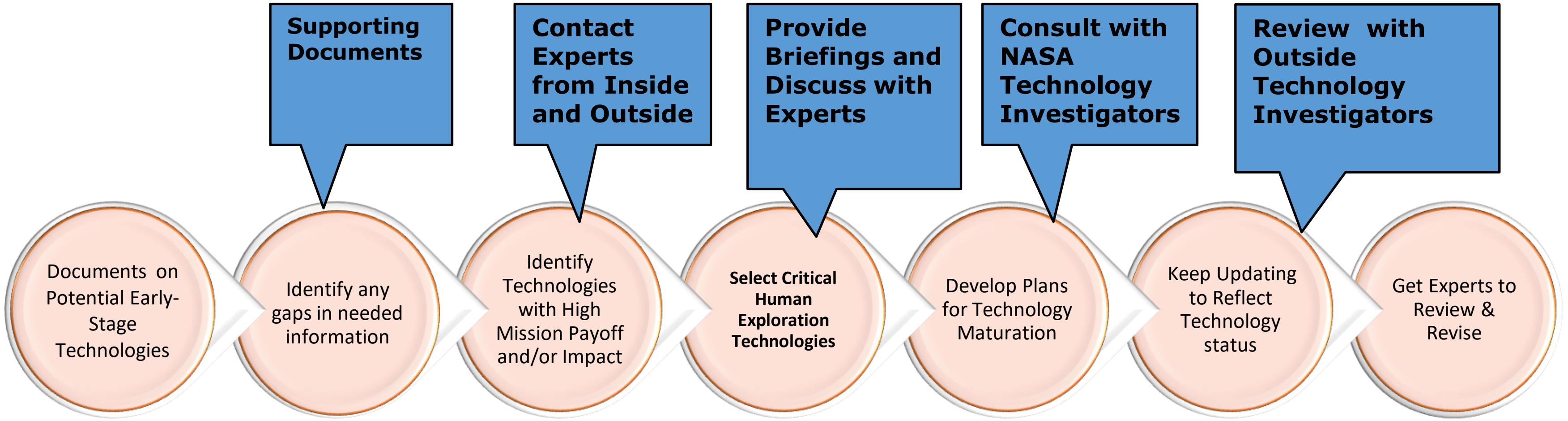
Leave Mars and Moon Pristine

Steps to Selecting New Technologies for Space Exploration





Provide recommendation and plan to mature early-stage technologies that will close critical human exploration technology gaps



Steps to Selecting New Technologies and Development of Plans

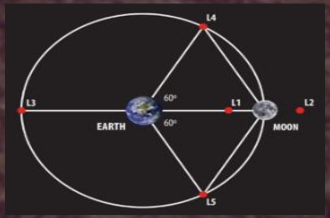
Dr. Kumar Krishen- Updated October 2017

New Technologies with Potential for Space Exploration

- **Quantum Vacuum Plasma Thruster (Q-Thruster) Technology**
- **Variable Specific Impulse Magnetoplasma Rocket (VASIMR®) Engine**
- **Habitation Wastewater Recovery Technology**
- **Biodigesters: Waste-to-Fertilizer Conversion Technology**
- **Laser Processed Heat Exchangers**
- **In-Situ Resource Utilization Technology**
  - **Methane Production**
  - **Water Processing**
  - **Oxygen Production**

New Technologies with Potential for Space Exploration

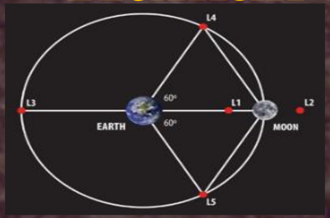
- Augmented Reality Environment for Human Mission Applications
- Expandable Structures/Habitats
- Shape-Morphing Adaptive Radiator Technology
- Effects of Dust and Dust Storm Alleviating/Reducing Technology/Systems





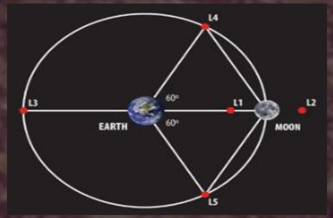

New Technologies with Potential for Space Exploration

- **Wavelet Technology**
- **Advanced Space Suit Technology**
- **New Sensor Technology**
  - **Temperature**
  - **Atmosphere**
  - **Gases**
  - **Biological**
  - **Human Health**

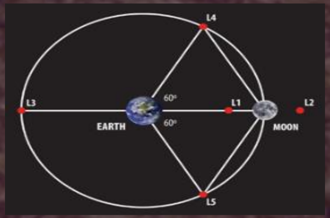


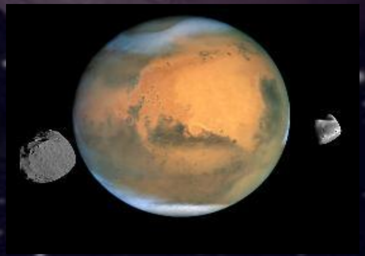
New Technologies with Potential for Space Exploration

- **Autonomous Systems (Fuzzy logic, Neural Networks)**
- **Carbon Nano Technology**
  - **Coatings**
  - **Composite structures**
- **IPMC - Intelligent/ Smart Materials (Actuators and sensors)**
- **Superconductor Technology**
- **Tera Hertz Technology**

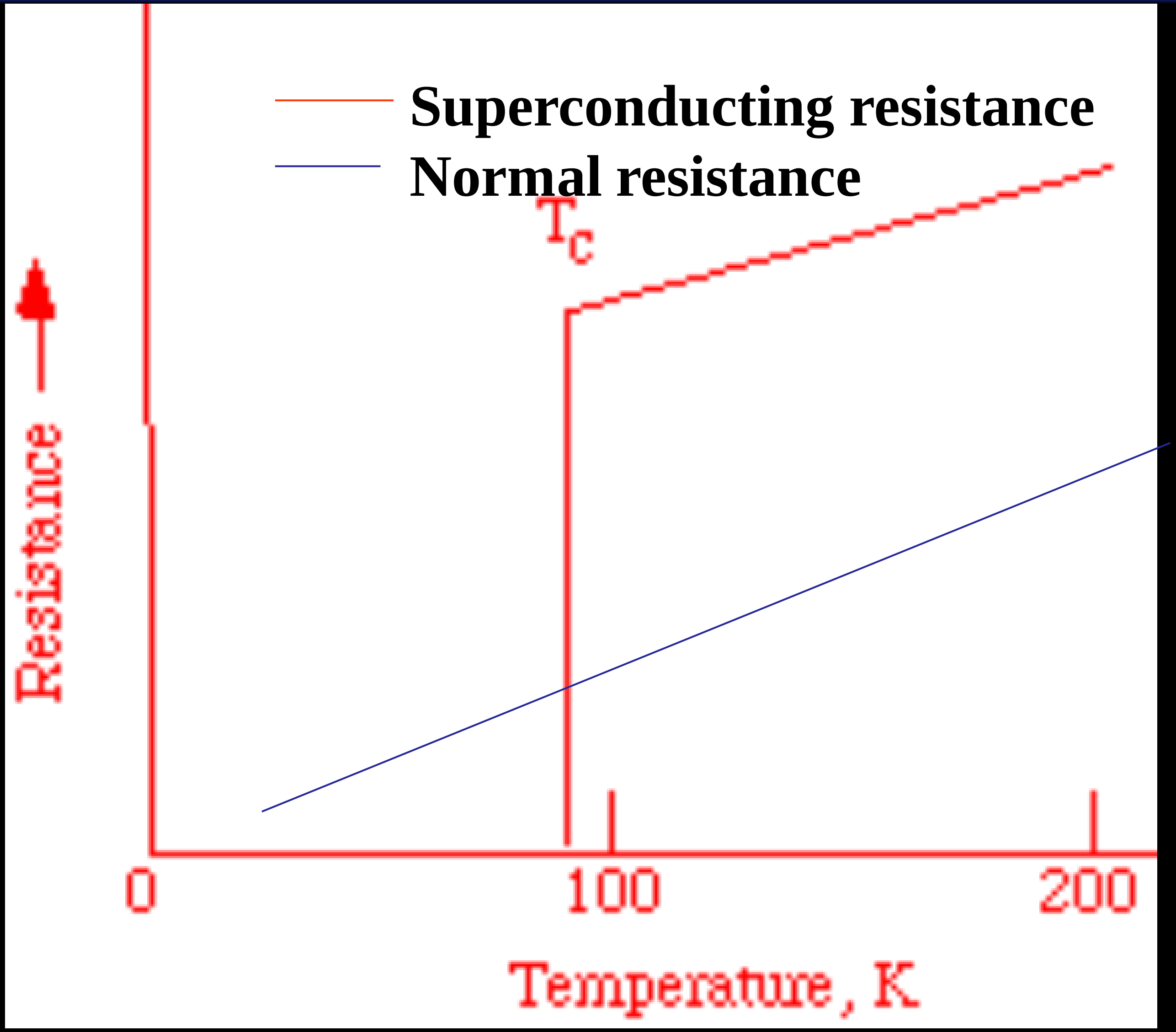


Superconductor Technology





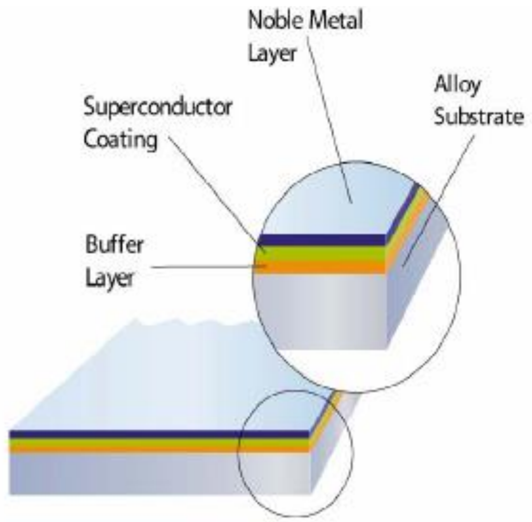
High Temperature Superconductors (HTS) Resistance

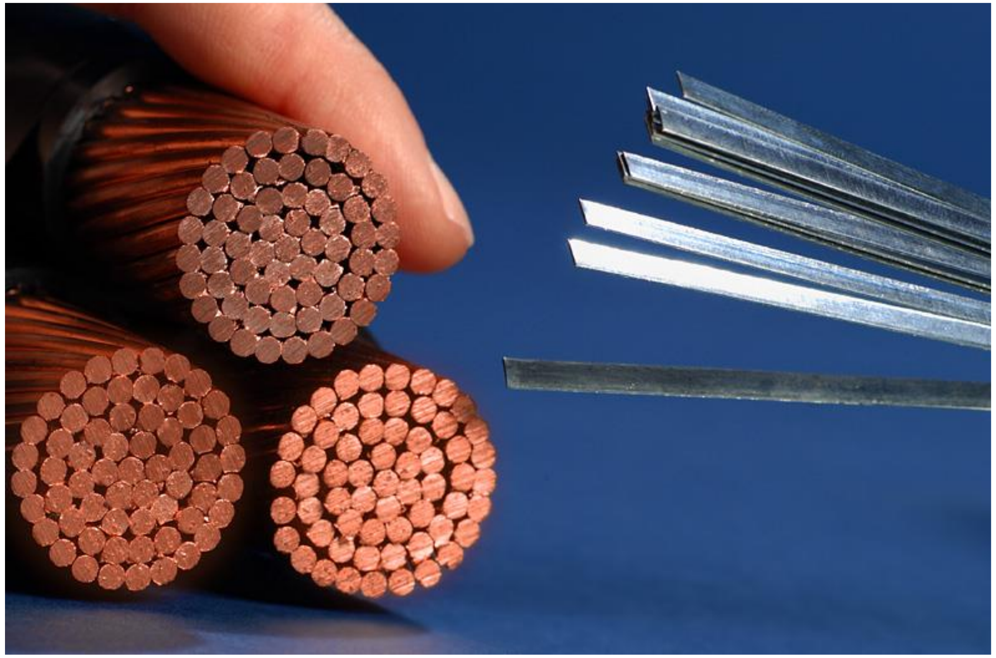


As Temperature decreases, resistance decreases.

Second Generation (2G) Coated Conductor Wire based on YBCO is now being manufactured

- Uses Thin Film Technology
  - Ni –W Metallic Foil Substrate
  - Textured buffer layer
  - Flexible YBCO Thin Film (~1-2 μm)



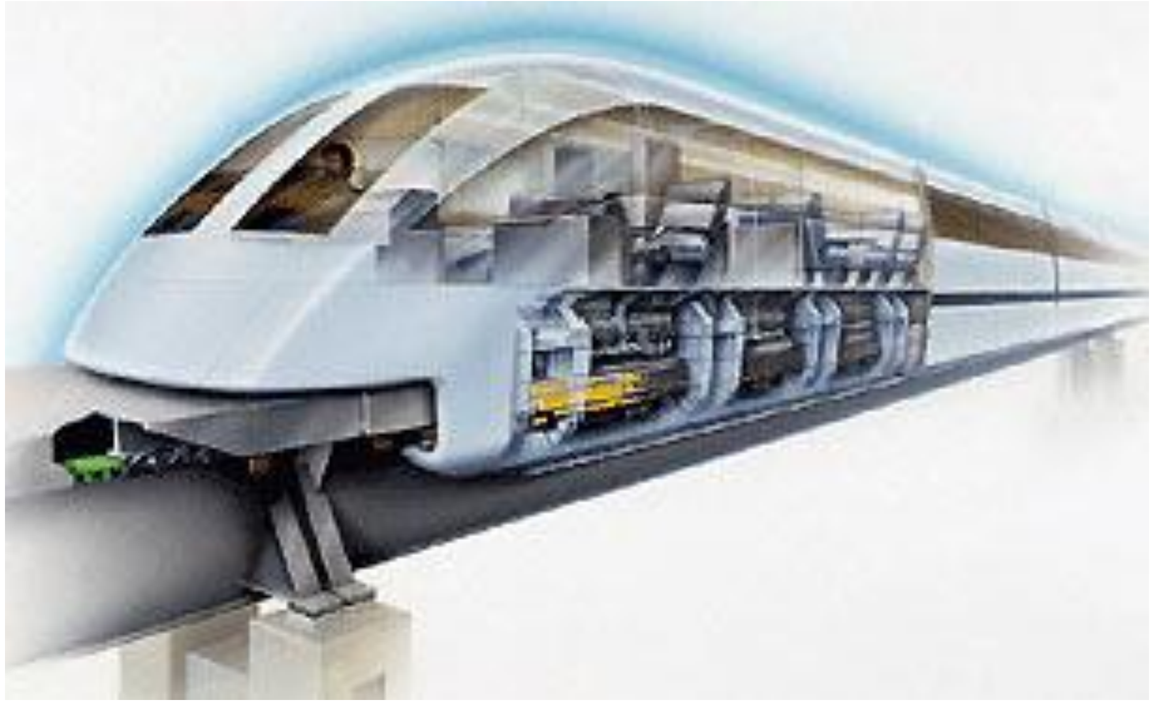


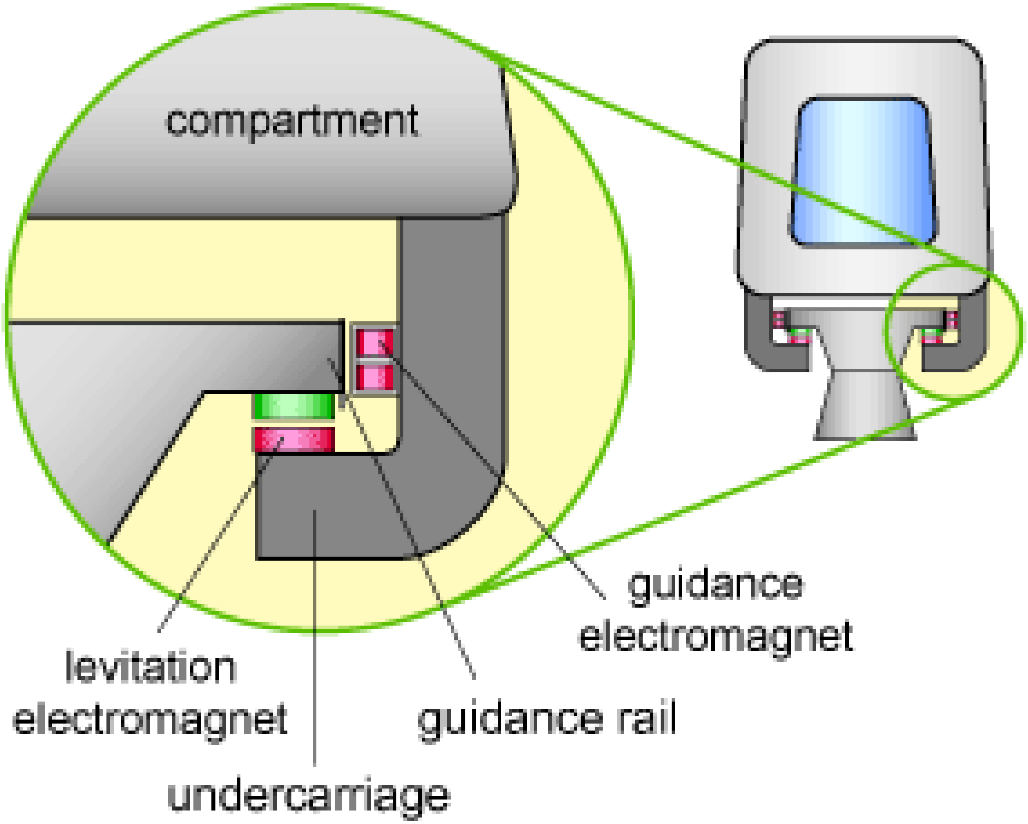
American Superconductor
REVOLUTIONIZING THE WAY THE WORLD USES ELECTRICITY

TcSUH HTS Levitation

The Meissner Effect

(University of Houston)




compartment
guidance
electromagnet
levitation
electromagnet
guidance rail
undercarriage

SQUIDs: The most sensitive detectors of magnetic fields

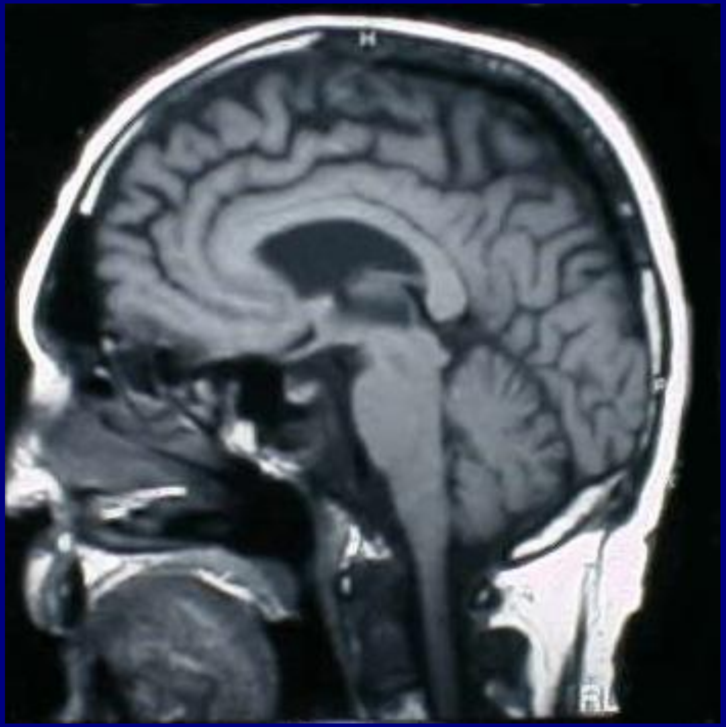
Superconducting

Quantum

Interference

Devices

Superconducting MRI system in operation



Example of an MRI brain scan

SentiMAG Technology Transfer

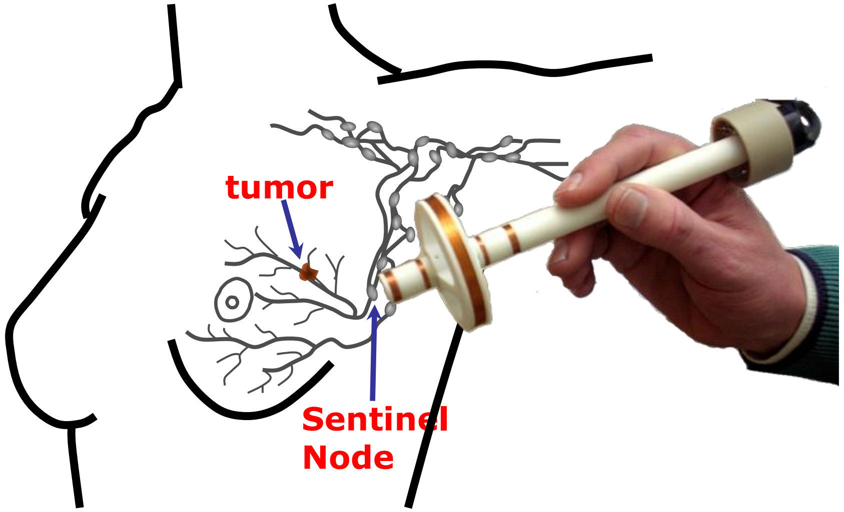
Endomagnetics Inc.

Endomagnetics Inc. was founded to solve a range of important surgical and healthcare diagnostic problems through the application of novel advances in bio-magnetics, nanotechnology and magnetic sensing technology based on high-temperature superconductors.

SentiMAG™ is an innovative handheld probe that can detect tiny magnetic fields – one millionth of the Earth's field.

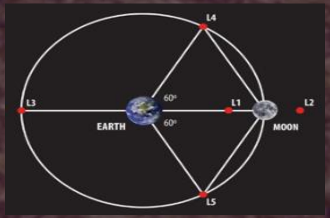
It has a unique, patented design with state of the art noise rejection so that it can be used in harsh clinical environments.

It overcomes the logistical, cost, compliance and regulatory problems that users dislike when using radioactive tracers.

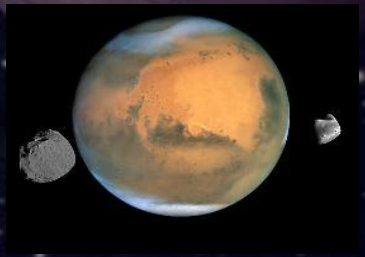


A University of Houston and University College London spinout.

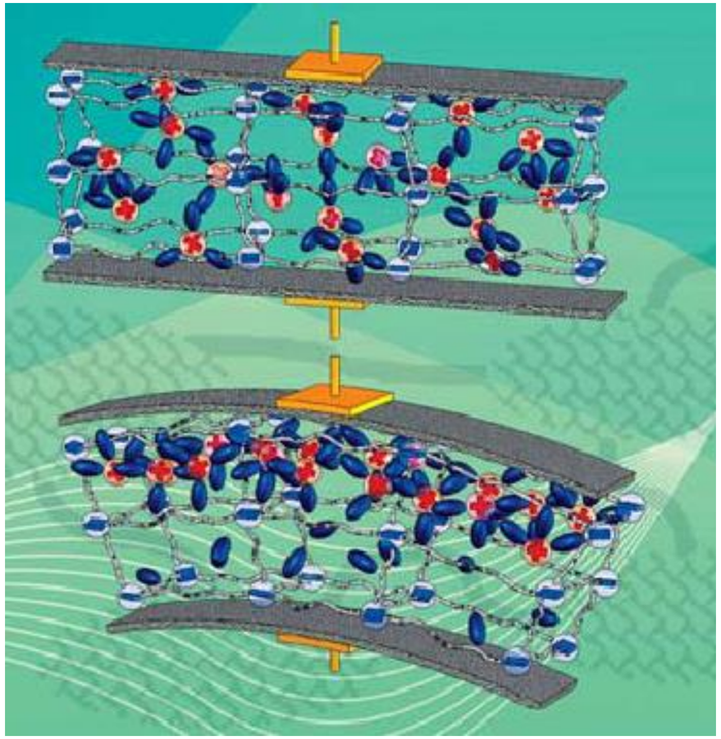
Ionic Polymer Metallic Composites
Intelligent / Smart Materials

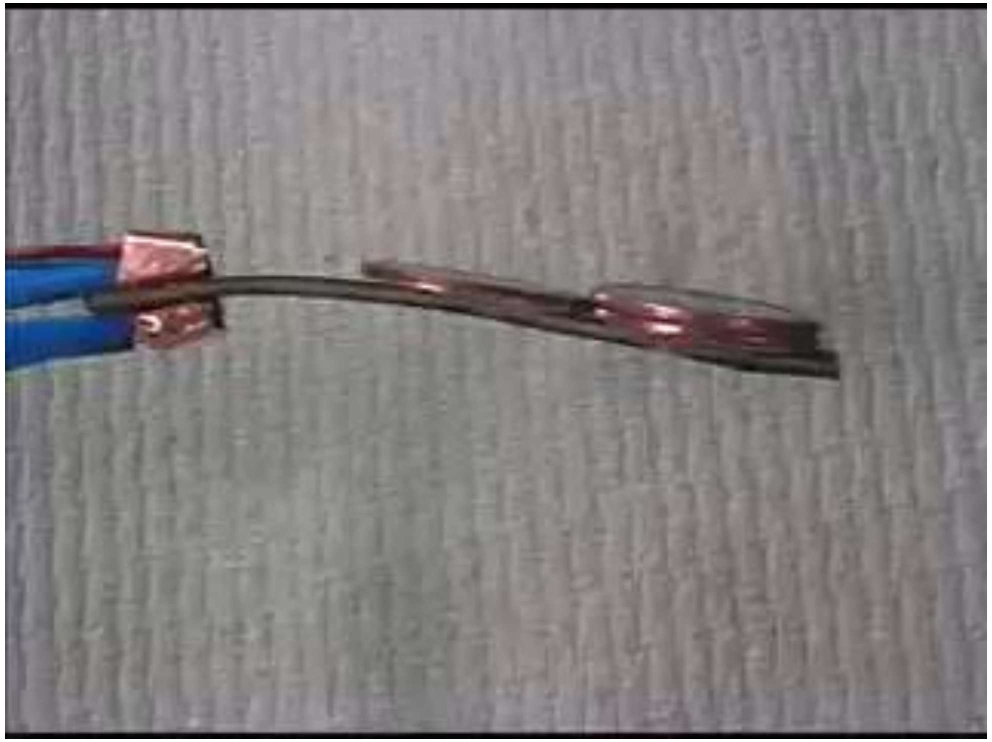




Structure/Properties of IPMC

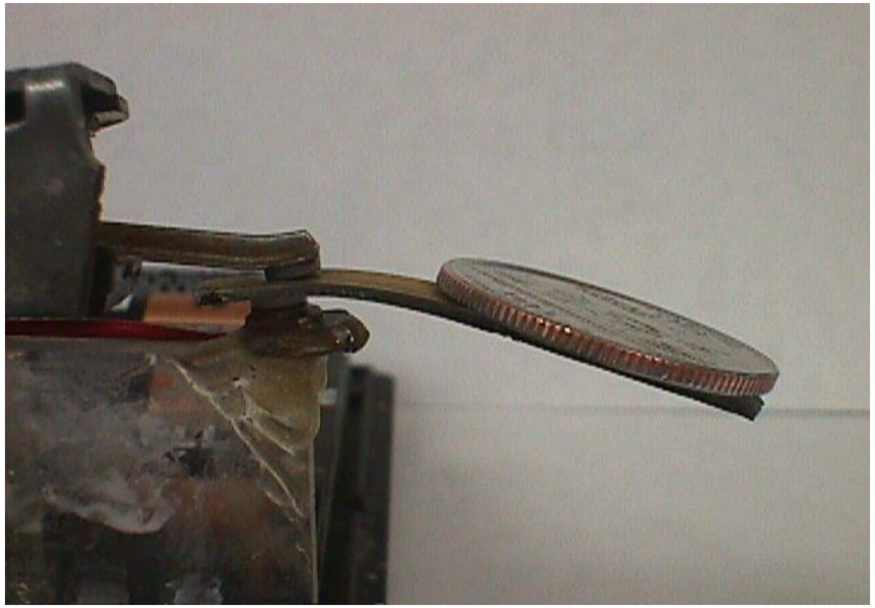


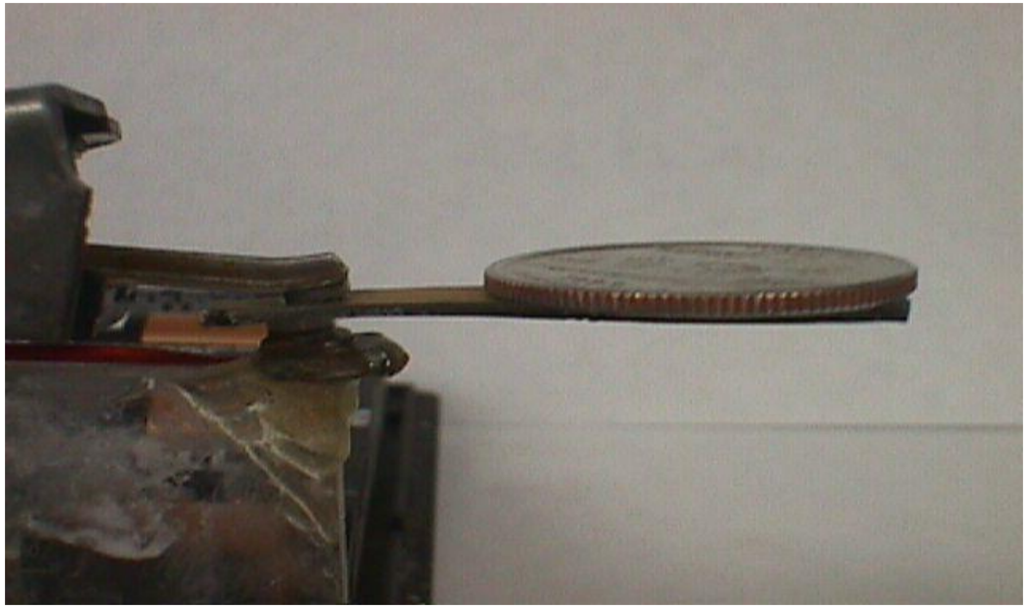


When a voltage is applied to an IPMC, the two metal strips become charged. The cations will all shift to one side of the polymer, making one edge bulge and the other crumple. To change direction of the movement, the voltage flows in the opposite direction. This is how the polymer actuates.

IPMC lifting ~20x its weight

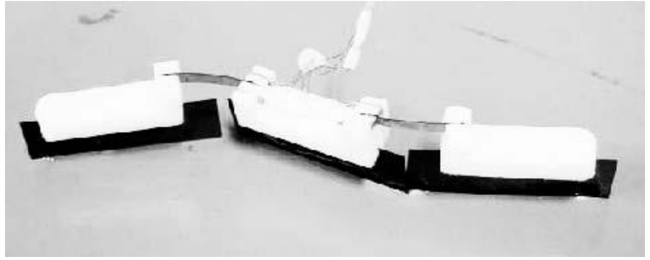
Quarter lifted with IPMC



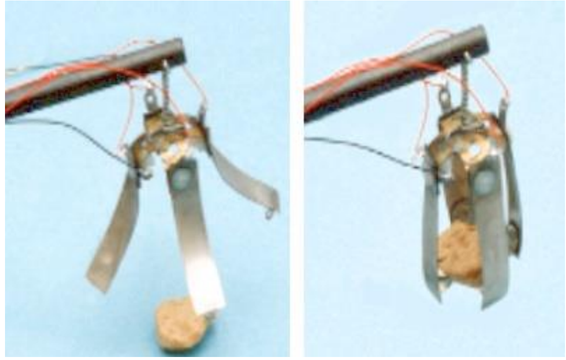


Quarter lifted by an IPMC by the application of a step voltage of 2.8 volts (E=1.4 V/mm). The time internal between the frames is approximately 1 sec (with permission from Dr. K. J. Kim)

Current Research of IPMC



A snake like swimming robot using IPMC

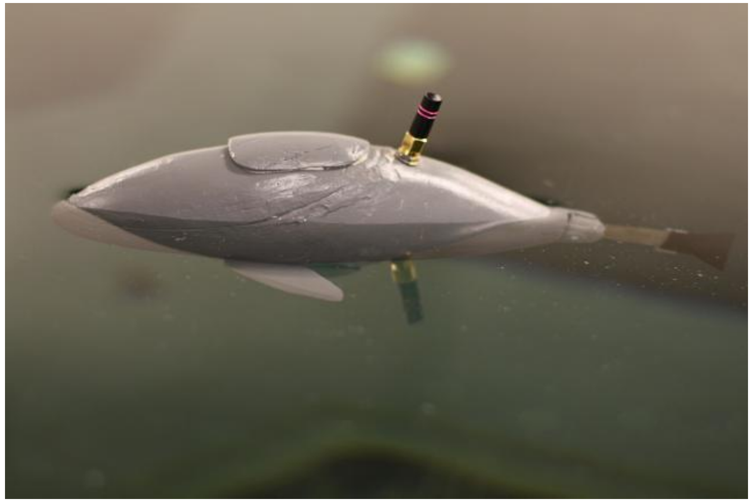


Small grabbing device lifting two times it’s weight

Muscular assistance

(with permission from Dr. K. J. Kim)

Current Research of IPMC



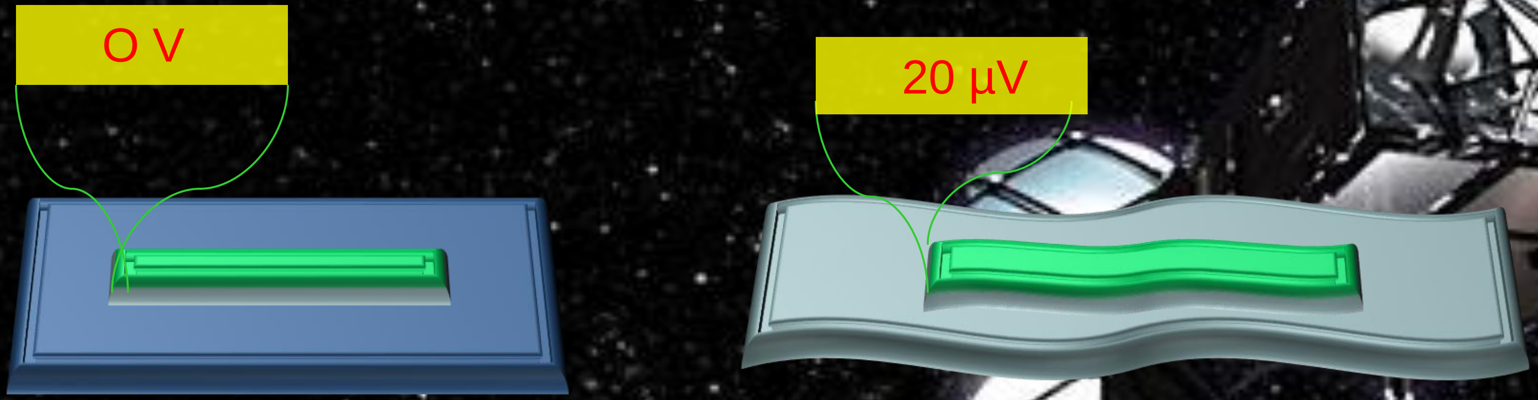
Using IPMC as means of propulsion

(with permission from Dr. K. J. Kim)

Used as a shield or lens cleaning device

Example of robotic hand built using IPMC

IPMC as Sensors



Zero Voltage

Voltage Builds up due to object vibrations

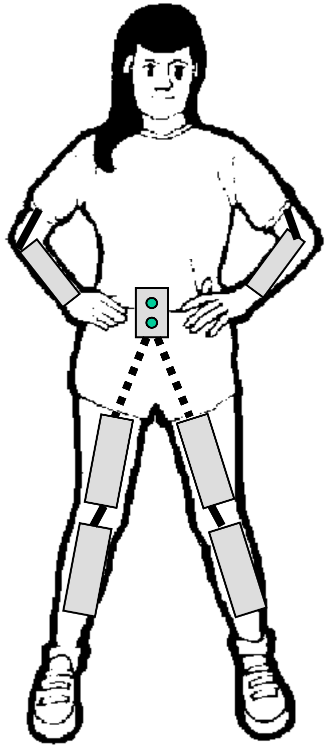
The movement of anions and cations causes a voltage to build up. This voltage can be measured and used to determine movement of an object (with permission from Dr. K. J. Kim)

IPMC Applications for Space

- **Provide muscular resistance to counter the effects of muscle atrophy or assist when atrophy occurs**
- **By vibrating bones, bone mass can be maintained in presence of microgravity or partial gravity**
- **Have application for robotic missions to decrease energy consumption significantly**
- **Sense and correct vibrations caused from daily movement and activities inside a space module**

Tightly Worn Suit with IPMC Devices In It

Recent NASA research has suggested that **loss of bone** mass can be **minimized by vibrating body bones**.



A team of researchers discovered that normally active **animals exposed to 10 minutes per day** of **low-magnitude (.25 g), high frequency (90 Hz) vibrations** experienced **increased bone formation** when compared to the control group.

A system with several configurations, providing such an oscillatory activation can be developed using IPMC materials.

These systems **tightly worn around bone joints and backbone, and neck areas** are possible and can be used while astronauts are working either inside or outside of spacecrafts for **muscle exercise** .

ISS-33 EVA 01

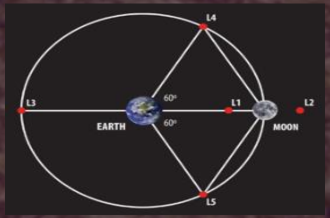
Sunita Williams

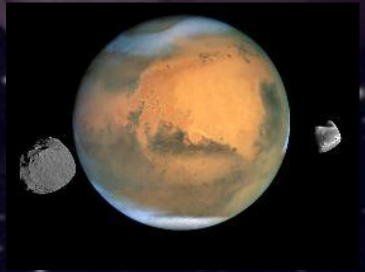
Docking with ISS

Docking also
contributes
to higher vibration
environment
with possibility of
damaging the structure

SpaceX's Crew
Dragon spaceship
autonomously dock
4 astronauts to
International Space Station

Carbon Nano Technology

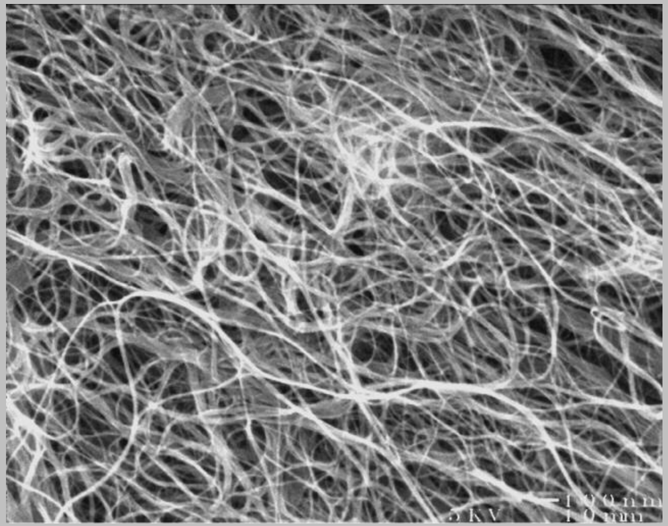


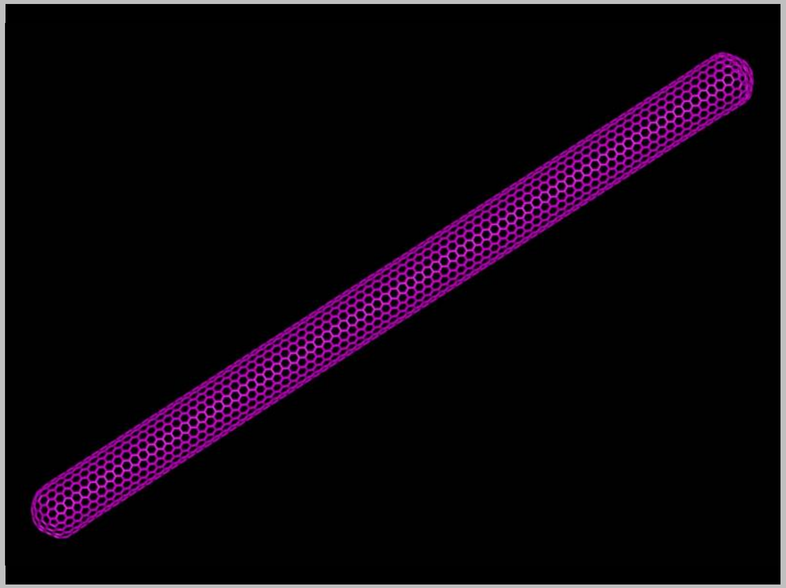


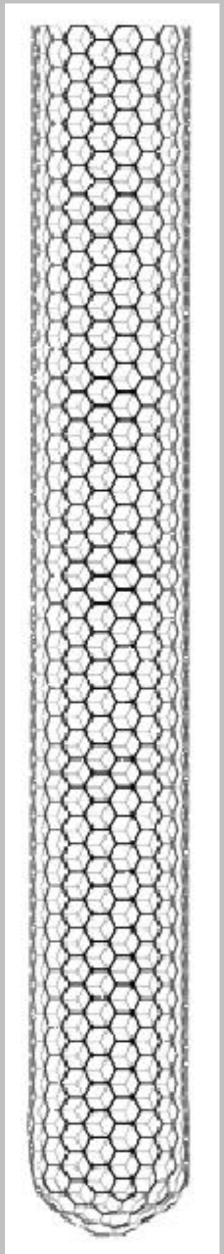
Why NANOTECHNOLOGY?

MOLECULAR PERFECTION & EXTREME PERFORMANCE

- The Strongest Fiber Possible.
- Electrical Conductor, Semi Conductor, and Superconductor.
- Thermal Conductivity of Diamond.
- The Unique Chemistry of Carbon.
- The Scale and Perfection of DNA – The Fullerene Ideal
- The Ultimately Versatile Engineering Material



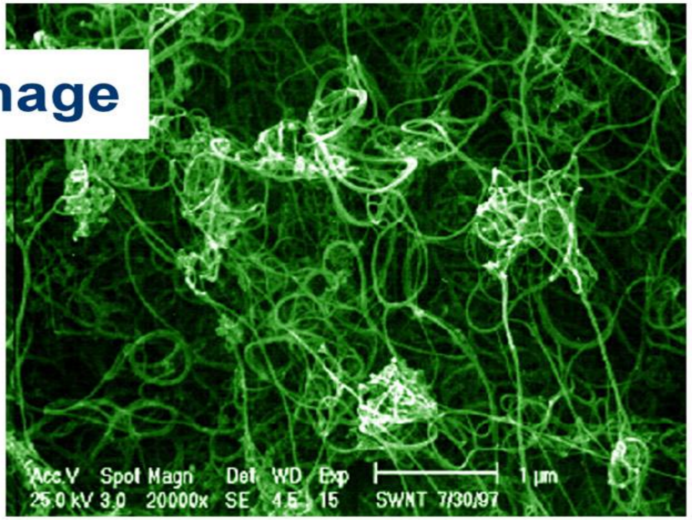




Explore. Discover. Understand.

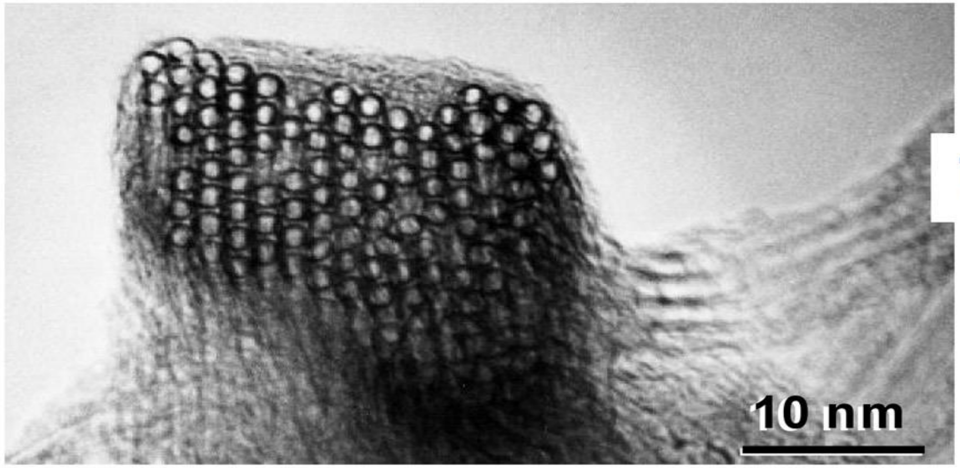
Carbon Nanotubes

SEM Image

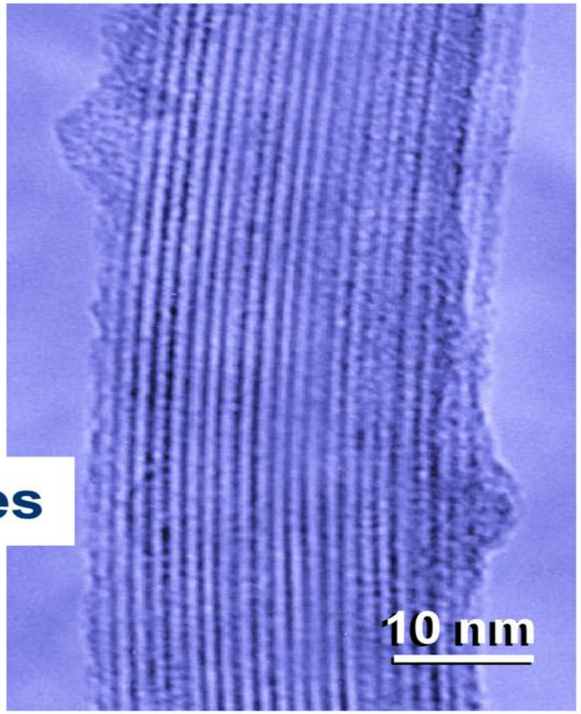


Randomly oriented tangles of nanotube bundles

TEM Images



Cross-section of a nanotube bundle

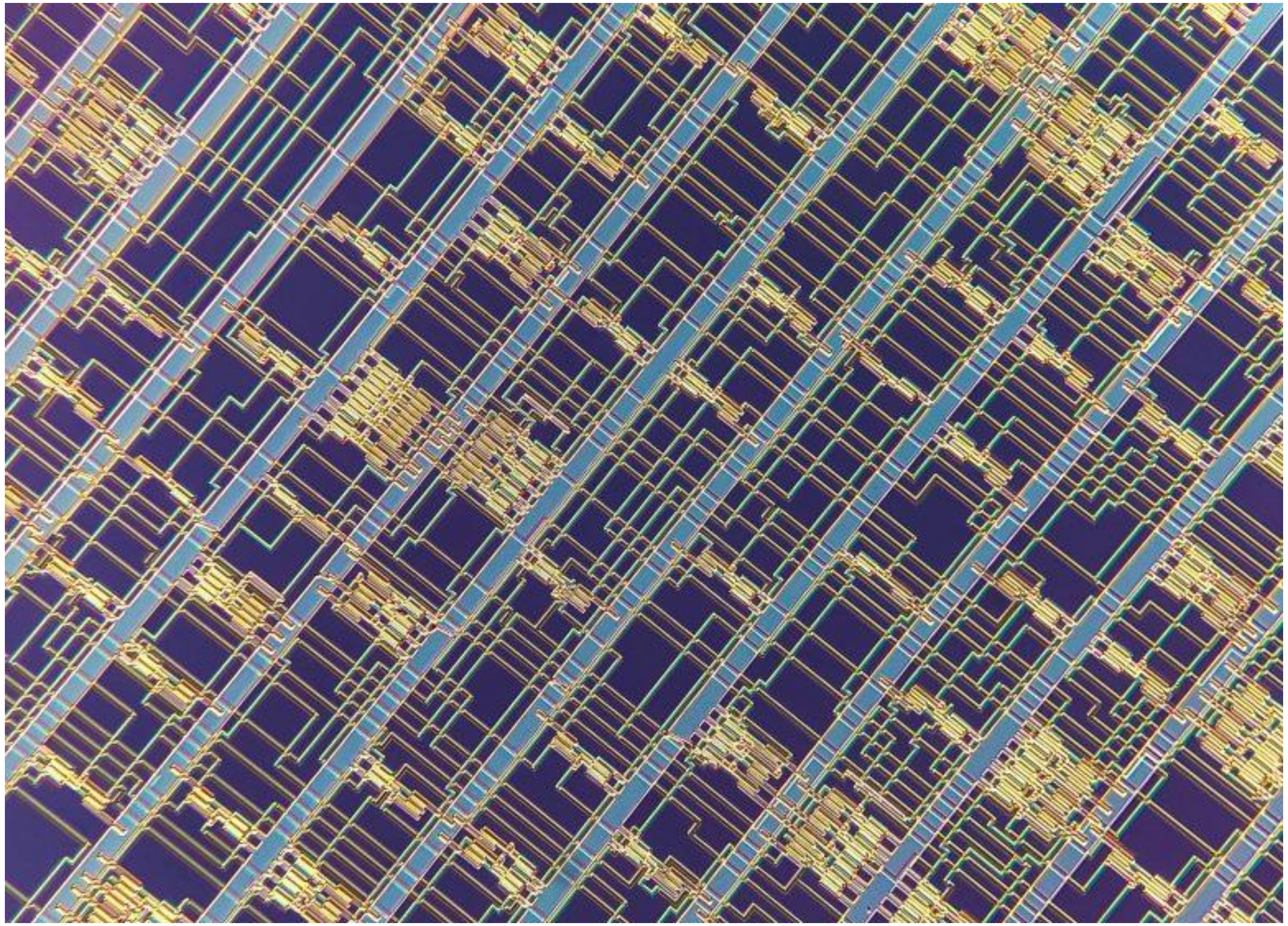


Length-wise view of a nanotube bundle

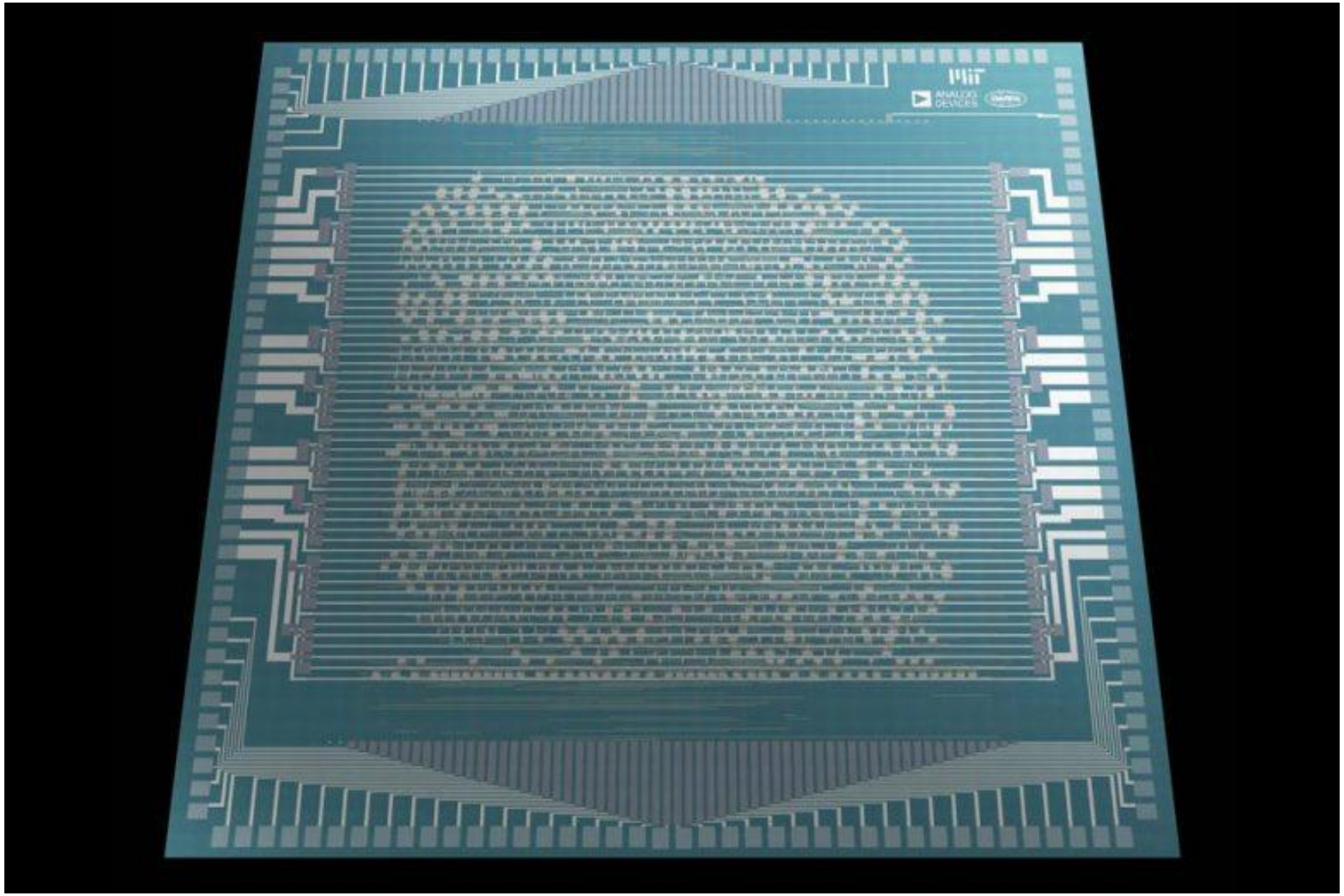
Advanced Microprocessor Built with Carbon Nanotubes

https://scitechdaily.com/advanced-microprocessor-built-out-of-carbon-nanotubes/

By Rob Matheson, Massachusetts Institute of Technology **August 30, 2019**



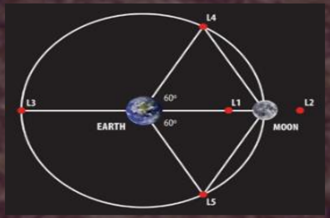
Advanced Microprocessor Built with Carbon Nanotubes

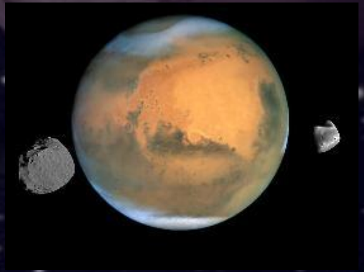


Advanced Microprocessor Built with Carbon Nanotubes

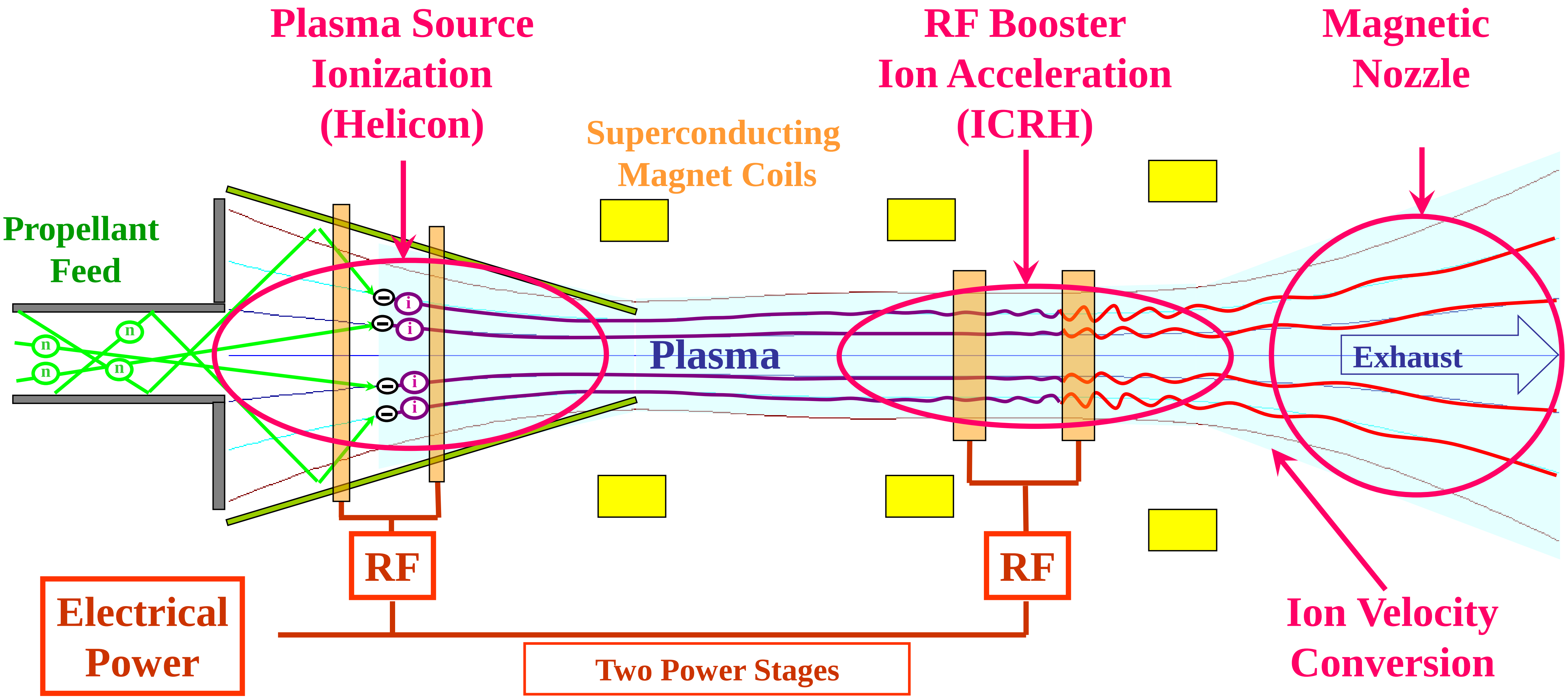
- MIT engineers have built a modern microprocessor from carbon nanotube field-effect transistors
- The new approach uses the same fabrication processes used for silicon chips
- They demonstrated a 16-bit microprocessor with more than 14,000 CNFETs that performs the same tasks as commercial microprocessors
- The researchers’ microprocessor was able to execute the full set of instructions accurately

Propulsion Technology





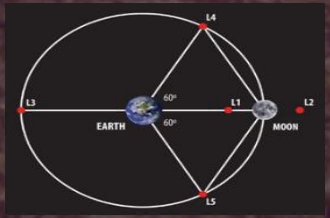
VASIMR Diagram

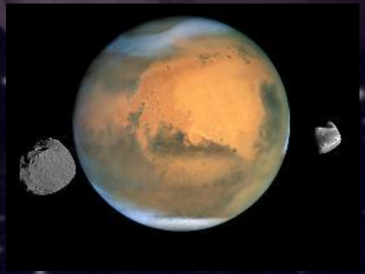


Description of VASIMR Diagram

- The Variable Specific Impulse Magnetoplasma Rocket (VASIMR) system encompasses **three linked magnetic cells**
  - The **"Plasma Source"** cell involves the main injection of neutral gas (argon or lighter gasses) to be turned into plasma and the ionization subsystem.
  - The **"RF Booster"** cell acts as an amplifier to further accelerate the plasma ions to the desired energy using electromagnetic waves and ion cyclotron resonance
  - The **"Magnetic Nozzle"** cell converts the energy of the plasma into directed motion and ultimately useful thrust

Wavelet Technology





What are Wavelets?

- Functions that satisfy certain mathematical requirements and are used in representing data or other functions
- Wavelet offer opportunity to choose a wavelet series according to the application
- Modern wavelet family founded by Ingrid Daubechies in 1988
  - Developed Orthonormal Bases of Wavelets

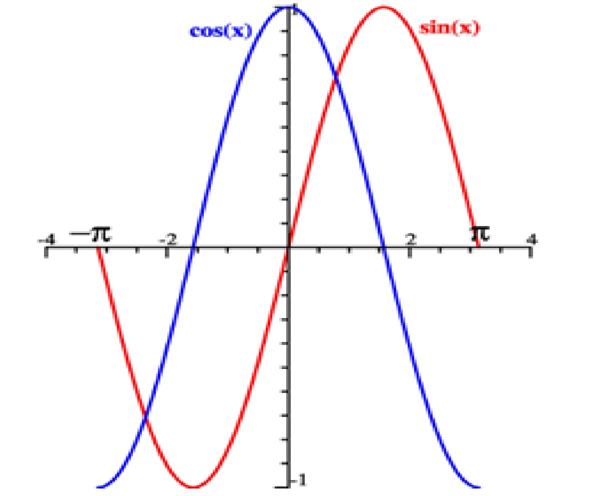


Figure 1. Plotted Sine and Cosine Wave. *The translation between the sine and cosine wave causes the two functions to be an orthogonal set. Courtesy of Google Images.*

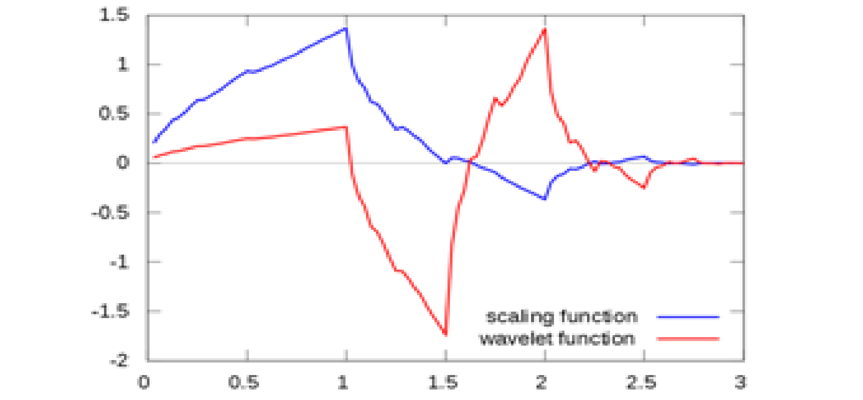


Figure 2. Daubechies Wavelet Function. *The graph shows a plotted Daubechies wavelet set consisting of the wavelet function and its scaling function. This wavelet set is an orthogonal wavelet set. Courtesy of Google Images.*

ADVANTAGES OF WAVELETS

- Can approximate data with sharp jumps, discontinuities, and abrupt changes
- Localized in time/distance and frequency
- Infinite set of possible basis functions
  - Provides immediate access to information that can be obscured by methods such as Fourier

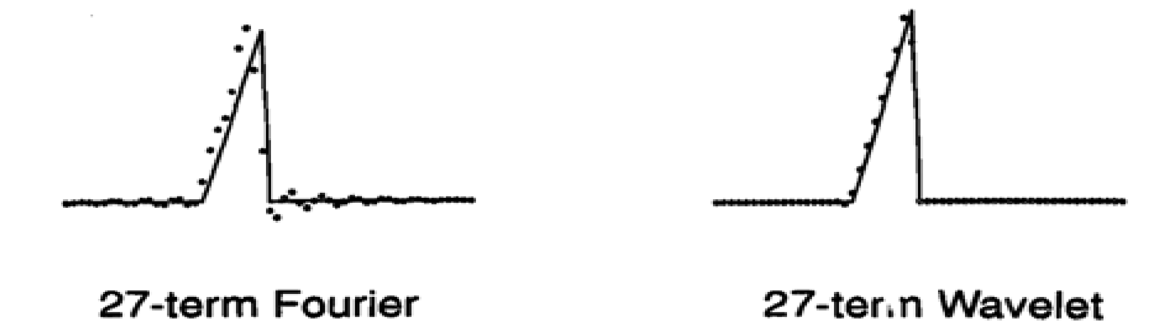
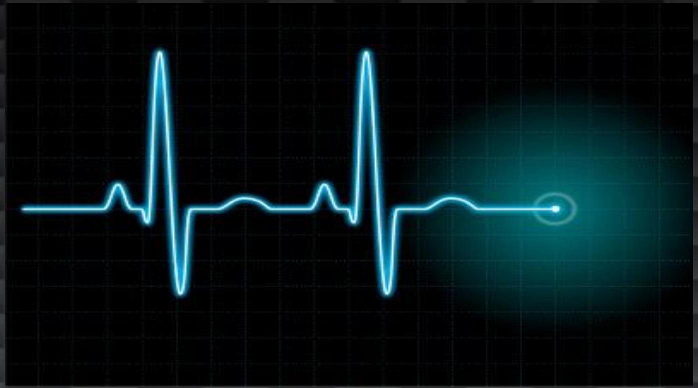


Figure 3 [5]. Comparison of a Fourier and wavelet representation of a transient signal. *The wavelet function represents the signal smoothly, as it only displays the necessary components.*



EKG

100daysofrealfood.com

Current Applications/ Research

Identification
Compressive Sensing
Data Compression

FBI

Figure 7 [1]. Comparison of Fingerprint Images. *The one on the left is the original image and the one on the right is the wavelet compressed image (26 to 1 data compression).*

BAE SYSTEMS

Target Detection

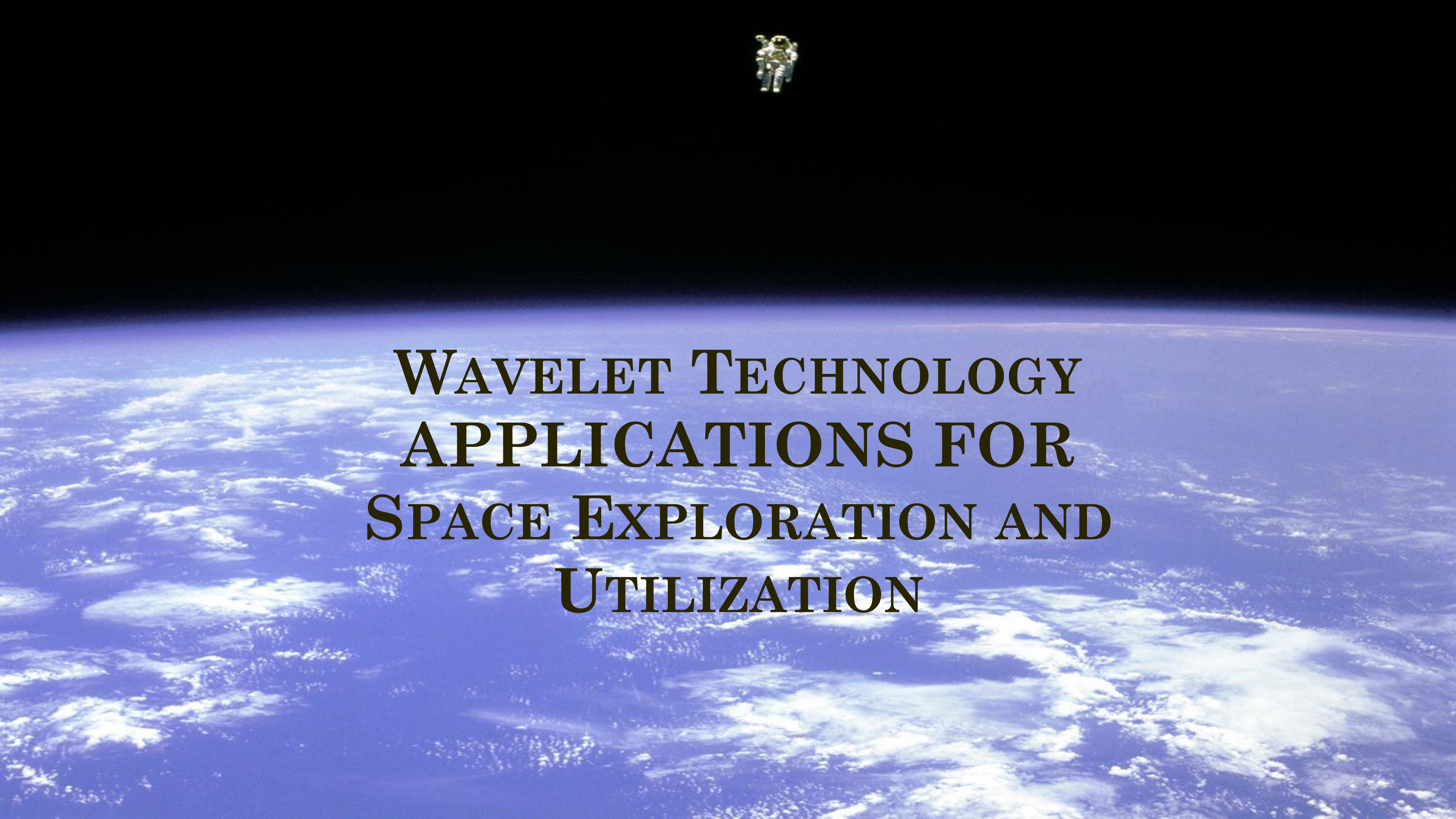
VERINT
VIDEO INTELLIGENCE SOLUTIONS™

Wavelet IDR Center

Consortium of 9 institutions conducting wavelet research

RICE

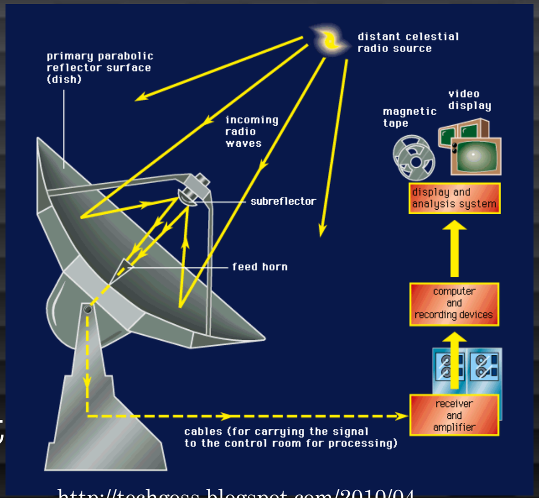
Dr. Sidney Burrus
Dr. Richard Baraniuk



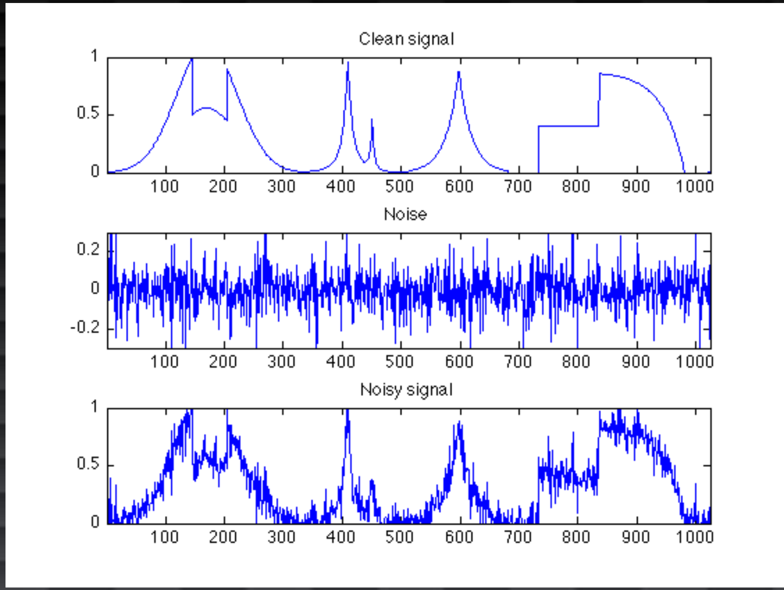
Wavelet Technology APPLICATIONS FOR Space Exploration and Utilization

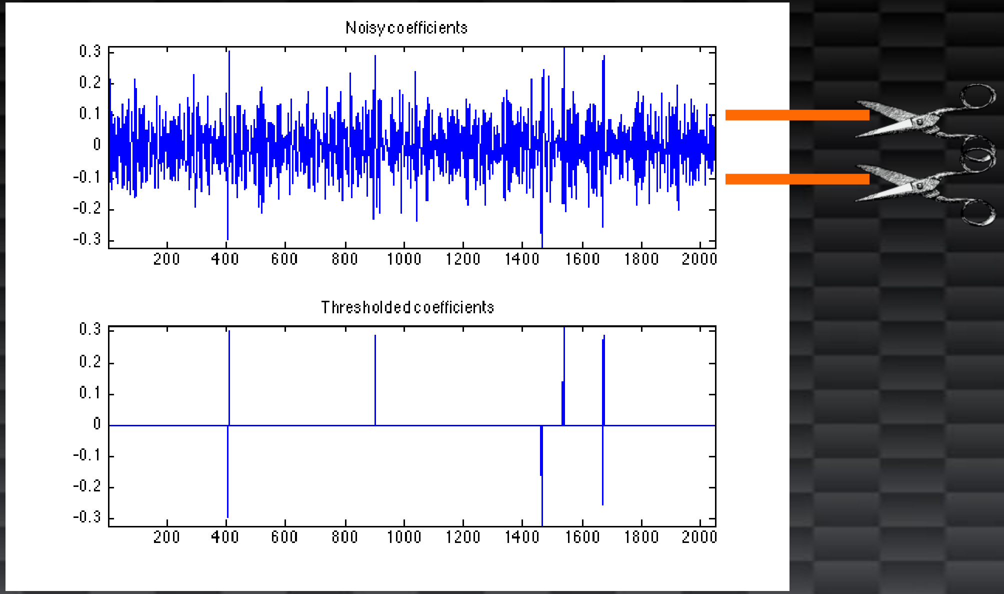
DENOISING

- Wavelet's way of "filtering" the noise out of a signal. Magic of wavelets- Stores importance in largest coefficients
- Set threshold for signal and delete the parts that don't make the "cut"
- A new signal is reconstructed with little to no noise.
- Denoise all Earth Observation and Space Exploration data



http://techgoss.blogspot.com/2010/04/evoulation-of-radio-astronomy.html





Courtesy of MathWorks

Data Processing/ Compression

- Audio- 8:1 Images- 100:1 Video- 140:1
- Space Agencies will continue to document what we see on Moon, Mars, Asteroids and Space
- We are running out of data storage space (disk space and physical space)
- Recent report shows that the amount of data being generated is growing 58%/yr but the amount of storage is growing 31% slower.
- Today, we produce several times more as much data than can be stored!

Photo from Hubble Space Telescope.
Courtesy of NASA.

Figure 10. Spirit Rover on Martian Surface. *Spirit is a rover that functions as a robotic geologis on Mars relaying mass amounts of critical data. Courtesy of NASA.*

Discrete Cosine Transform (Fourier)

Wavelet Transform

TOO BIG!

LOSSY

LOSSLESS

Thank You!

Dedicated to

President Abraham Lincoln